RMetS
Royal Meteorological Society

Volume 39 Number S1 July 2019

International Journal of Climatology

The Royal Meteorological Society Journal of Climate Science

Editor
Radan Huth

State of the UK Climate 2018

WILEY

wileyonlinelibrary.com/journal/joc

ISSN-0899-8418

INTERNATIONAL JOURNAL OF CLIMATOLOGY

The Royal Meteorological Society Journal of Climate Science

AIMS AND SCOPE

The *International Journal of Climatology* aims to span the well established but rapidly growing field of climatology, through the publication of research papers, major reviews of progress and reviews of new books and reports in the area of climate science. The Journal's main role is to stimulate and report research in climatology, from the expansive fields of the atmospheric, biophysical, engineering and social sciences. Coverage includes:

- Climate system science
- Local to global scale climate observations and modelling
- Seasonal to interannual climate prediction
- Climatic variability and climate change
- Synoptic, dynamic and urban climatology, hydroclimatology, human bioclimatology, ecoclimatology, dendroclimatology and palaeoclimatology
- Application of climatological knowledge to environmental assessment and management and economic production
- Climate and society interactions

INTERNATIONAL JOURNAL OF CLIMATOLOGY

The Royal Meteorological Society Journal of Climate Science

Information for Subscribers

International Journal of Climatology is published in 15 issues per year: one per month, with an additional issue in March, June and November. Institutional subscription prices for 2019 are:
Print & Online: US$5181 (US and Rest of World), €3344 (Europe), £2646 (UK). Prices are exclusive of tax. Asia-Pacific GST, Canadian GST/HST and European VAT will be applied at the appropriate rates. For more information on current tax rates, please go to www.wileyonlinelibrary.com/tax-vat. The price includes online access to the current and all online backfiles to January 1st 2015, where available. For other pricing options, including access information and terms and conditions, please visit www.wileyonlinelibrary.com/access.

Delivery Terms and Legal Title

Where the subscription price includes print issues and delivery is to the recipient's address, delivery terms are **Delivered at Place (DAP)**; the recipient is responsible for paying any import duty or taxes. Title to all issues transfers FOB our shipping point, freight prepaid. We will endeavour to fulfil claims for missing or damaged copies within six months of publication, within our reasonable discretion and subject to availability.

Sample Copies

If you are interested in subscribing, you may obtain a free sample copy by contacting John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK.

Back Issues

Single issues from current and recent volumes are available at the current single issue price from cs-journals@wiley.com. Earlier issues may be obtained from Periodicals Service Company, 351 Fairview Avenue – Ste 300, Hudson, NY 12534, USA. Tel: +1 518 822-9300, Fax: +1 518 822-9305, Email: psc@periodicals.com.

Publisher

International Journal of Climatology
ISSN 0899-8418 (Print)
ISSN 1097-0088 (Online)
is published by John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK.

For submission instructions, subscription and all other information visit: wileyonlinelibrary.com/journal/joc.

Production Editor: Janelle Mae Eusebio (email: jmeusebio@wiley.com)

Advertising: Email: adsales@wiley.co.uk

Author Reprints Order online: (50–300 copies) www.sheridan.com/wiley/eoc

Journal Customer Services: For ordering information, claims and any enquiry concerning your journal subscription please go to www.wileycustomerhelp.com/ask or contact your nearest office.

Americas: Email: cs-journals@wiley.com; Tel: +1 781 388 8598 or +1 800 835 6770 (toll free in the USA & Canada).

Europe, Middle East and Africa: Email: cs-journals@wiley.com; Tel: +44 (0) 1865 778315.

Asia Pacific: Email: cs-journals@wiley.com; Tel: +65 6511 8000.

Japan: For Japanese speaking support, Email: cs-japan@wiley.com; Tel: +65 6511 8010 or Tel (toll free): 005 316 50 480.

Visit our Online Customer Help available in 7 languages at www.wileycustomerhelp.com/ask.

Online Open

International Journal of Climatology accepts articles for Open Access publication. Please visit http://olabout.wiley.com/WileyCDA/Section/id-828081.html for further information about OnlineOpen.

Production Details

Typeset in India by Laserwords Private Ltd, Chennai.

Printed in Singapore by C.O.S. Printers Pte Ltd.

Abstracting and Indexing

International Journal of Climatology is indexed by: Abstracts on Hygiene and Communicable Diseases (CABI), Add FRANCIS (CNRS), Agricultural Engineering Abstracts (CABI), Agroforestry Abstracts (CABI), Animal Breeding Abstracts (CABI), ASFA: Aquatic Sciences & Fisheries Abstracts (CSA/CIG), Bibliography & Index of Geology/GeoRef (AGI), CAB Abstracts® (CABI), CAB HEALTH (CABI), CABDirect (CABI), Cambridge Scientific Abstracts (CSA/CIG), COMPENDEX (Elsevier), Crop Physiology Abstracts (CABI), CSA Environmental Sciences & Pollution Management Database (CSA/CIG), CSA Sustainability Science Abstracts (CSA/CIG), Current Contents: Physical, Chemical & Earth Sciences (Thomson Reuters), Current Geographical Publications (AGS), Current Index to Statistics (ASA/IMS), Environment Abstracts (LexisNexis), Environment Index (EBSCO), Field Crop Abstracts (CABI), Forestry Abstracts (CABI), GeoArchive (Geosystems), GEOBASE/Geographical & Geological Abstracts (Elsevier), GeoRef Geotitles (Geosystems), Global Health (CABI), Grasslands and Forage Abstracts (CABI), Groundwater & Soil Contamination Database (AGI), Horticultural Science Abstracts (CABI), IBIDS: International Bibliographic Information on Dietary Supplements (NIH), IBR & IBZ: International Bibliographies of Periodical Literature (KG Saur), INSPEC (IET), Irrigation & Drainage Abstracts (CABI), Journal Citation Reports/Science Edition (Thomson Reuters), Leisure Tourism Database (CABI), Leisure, Recreation and Tourism Abstracts (CABI), Maize Abstracts (CABI), Meteorological & Geoastrophysical Abstracts (CSA/CIG), Oceanic Abstracts (CSA/CIG), Ornamental Horticulture (CABI), PASCAL Database (INIST/CNRS), Plant Genetic Resources Abstracts (CABI), Review of Medical and Veterinary Entomology (CABI), Review of Plant Pathology (CABI), Rice Abstracts (CABI), Rural Development Abstracts (CABI), Science Citation Index (Thomson Reuters), Science Citation Index Expanded™ (Thomson Reuters), SCOPUS (Elsevier), Soils and Fertilizer Abstracts (CABI), Soybean Abstracts Online (CABI), Sugar Industry Abstracts (CABI), Tropical Diseases Bulletin (CABI), VINITI (All-Russian Institute of Science & Technological Information), WATERLIT (NISC), Web of Science (Thomson Reuters), Wheat, Barley & Triticale Abstracts (CABI), World Agricultural Economics and Rural Sociology Abstracts (CABI).

Access to this journal is available free online within institutions in the developing world through the AGORA initiative with the FAO and the OARE initiative with UNEP. For information, visit www.aginternetwork.org, www.oaresciences.org.

Identification Statement

INTERNATIONAL JOURNAL OF CLIMATOLOGY, (Print ISSN: 0899-8418; Online ISSN: 1097-0088), is published monthly with additional issues in March, June and November, total 15 issues. US mailing agent: Mercury Media Processing LLC, 1850 Elizabeth Avenue, Suite #C, Rahway, NJ 07065 USA. Periodical postage paid at Rahway, NJ.

Postmaster: Send all address changes to INTERNATIONAL JOURNAL OF CLIMATOLOGY, John Wiley & Sons Inc., C/O The Sheridan Press, PO Box 465, Hanover, PA 17331 USA.

INTERNATIONAL JOURNAL OF CLIMATOLOGY

wileyonlinelibrary.com/journal/joc

Contents

Volume 39 Number S1 July 2019

Cover Images:

(Left) Lying snow on a residential street in Exeter on 18 March 2018. Image courtesy Mike Kendon, Met Office.

(Right) Visible satellite image of the UK swathed in cloud from fronts associated with storm Callum on 12 October 2018; up to 200mm of rain fell across the Brecon Beacons in South Wales. Image copyright Met Office / NOAA / NASA.

DOI: 10.1002/joc.6213

SPECIAL ISSUE ARTICLE

International Journal of Climatology RMetS

State of the UK climate 2018

Mike Kendon[1] | **Mark McCarthy**[1] | **Svetlana Jevrejeva**[2] | **Andrew Matthews**[2] | **Tim Legg**[1]

[1]Met Office National Climate Information Centre, Exeter, UK

[2]National Oceanography Centre, Liverpool, UK

INTRODUCTION

This report provides a summary of the UK weather and climate through the calendar year 2018, alongside the historical context for a number of essential climate variables. This is the fifth in a series of annual "State of the UK climate" publications and an update to the 2017 report (Kendon *et al*., 2018). 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. In addition, time series of near-coast sea-surface temperature (SST) and sea-level rise are also presented. The process for generating national and regional statistics from these observations has been updated since Kendon *et al*., 2018. This report makes use of a new dataset, HadUK-Grid, which provides improved quality and traceability for these national statistics along with temperature and rainfall series that extend back into the 19th Century. Differences with previous data are described in the relevant sections and appendices.

The report presents summary statistics for year 2018 and the most recent decade (2009–2018) against 1961–1990 and 1981–2010 averages. Year 2009–2018 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 2009 and 2018 and the baseline reference averages may reflect shorter-term decadal variations as well as long-term trends. These data are presented to show what has happened in recent years, not necessarily what is expected to happen in a changing climate.

This article is published with the permission of the Controller of HMSO and the Queen's Printer for Scotland.

The majority of maps in this report show year 2018 against the 1981–2010 baseline reference averaging 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.

Throughout the report's text the terms "above normal" and "above average," etc. refer to the 1981–2010 baseline reference averaging period unless otherwise stated.

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

FEEDBACK

We would welcome suggestions or recommendations for future 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

Land temperature

- 2018 was the seventh warmest year for the UK in a series from 1884, and fourth warmest year for Central England in a series from 1659.
- Summer 2018 was the equal-warmest summer for the UK in a series from 1884, and the warmest in the series for England.
- All the top 10 warmest years for the UK in the series from 1884 have occurred since 2002.
- The most recent decade (2009–2018) has been on average 0.3°C warmer than the 1981–2010 average and 0.9°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

- The number of air frosts in 2018 was slightly below average for the year overall. The number of ground frosts was equal-11th lowest in a series from 1961.
- The most recent decade (2009–2018) has had 5% fewer days of air frost and 9% fewer days of ground frost compared to the 1981–2010 average, and both 15% fewer compared to 1961–1990.

Energy demand and growing conditions indices

- Heating degree days in 2018 were below average, and cooling and growing degree days (GDDs) were each third-highest in series from 1960.
- The most recent decade (2009–2018) has had 4% fewer heating degree days per year on average compared to 1981–2010 and 9% fewer compared to 1961–1990.
- The most recent decade (2009–2018) has had 5% more GDDs per year on average compared to 1981–2010 and 15% more compared to 1961–1990.

Near-coast SST

- Year 2018 was the equal-11th warmest year for UK near-coastal SST in a series from 1870.
- The most recent decade (2009–2018) has been on average 0.3°C warmer than the 1981–2010 average and 0.6°C warmer than 1961–1990.
- Eight of the 10 warmest years for near-coast SST for the UK have occurred since 2002.

Precipitation

- Year 2018 rainfall for the UK overall was 92% of the 1981–2010 average and 96% of the 1961–1990 average.
- June 2018 was the driest June for England since 1925.
- Six of the 10 wettest years for the UK in a series from 1862 have occurred since 1998.
- The most recent decade (2009–2018) has been on average 1% wetter than 1981–2010 and 5% wetter than 1961–1990 for the UK overall.
- For the most recent decade (2009–2018) UK summers have been on average 11% wetter than 1981–2010 and 13% wetter than 1961–1990. UK winters have been 5% wetter than 1981–2010 and 12% wetter than 1961–1990.

Snow

- From late February to early March the UK experienced the most significant spell of widespread snow since December 2010.
- Year 2018 was a relatively snowy year in the context of the last two decades, but near average compared to the last 60- years.
- 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

- Year 2018 sunshine for the UK overall was 114% of the 1981–2010 average and the third sunniest year in a series from 1929.
- The 3-month period May–July 2018 was the sunniest 3-month period for the UK on record.
- The most recent decade (2009–2018) has had for the UK on average 4% more hours of bright sunshine than the 1981–2010 average and 7% more than the 1961–1990 average.
- Winter and spring for the most recent decade (2009–2018) have had for the UK on average 3/9% more sunshine than the 1981–2010 average and 11/14% more than 1961–1990.

Wind

- Ten named storms affected the UK in year 2018 (including storms David and Emma, named by Meteo France and the Portuguese Met Service, respectively). The overall number and severity of these storms were not unusual 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

- The UK mean sea level index for 2018 was equal-highest (with 2015) in the series from 1901, although uncertainties in the series mean caution is needed when comparing individual years.
- Mean sea level around the UK has risen by approximately 1.4 mm/year from the start of the 20th century, when excluding the effect of vertical land movement.
- The 99th percentile water level (exceeded 1% of the time) at Newlyn, Cornwall for year 2018 was the second highest in the series from 1916. Year 2014 was highest in this series.

Significant weather

- A spell of snow and low temperatures from late February to early March 2018 was the most significant severe winter weather to affect the UK since December 2010.
- Summer 2018 was among the most warm, dry and sunny summers experienced by the UK for over 100 years.
- Storm Callum on October 11–12, 2018 was one of the most notable extreme rainfall events across South Wales in the last 50 years.

1 | SYNOPTIC SITUATION

Figure 1 shows seasonal mean sea-level pressure anomalies for the four seasons of 2018 relative to the 1981–2010 average, using the NCEP/NCAR reanalysis (Kalnay *et al*., 1996). This provides an indication of atmospheric circulation patterns for each season overall. Sea-level pressure was slightly lower than normal across the UK and central Europe in winter 2017/2018, and to a greater extent spring, whereas it was above normal for UK and northern Europe in summer and autumn.

December 2017 and January 2018 saw a mix of weather types. In January, a changeable westerly weather type brought Atlantic low-pressure systems including four of the named storms of the year and the windiest days of the year. In February, high pressure over Scandinavia often extended its influence to the UK, with low pressure over the Mediterranean. The weather was relatively dry, cold and sunny, and a bitterly cold east wind established in late February extending into early March. During March, low pressure again tended to dominate the UK's weather bringing often cold, wet and dull conditions, particularly outside the north-west. By April, the low-pressure anomaly moved to the west of the UK. The weather remained often relatively dull and unsettled, but warmer with a more southerly flow and a brief hot spell from 18th to 22nd.

May, June and July were dominated by high pressure near or over the UK, bringing plenty of warm, dry, sunny weather, hot at times, with an airflow from the near continent. However, by August, the high pressure slipped to the south allowing low-pressure systems to influence more northerly areas with a cooler and more unsettled regime after the first week. In September and October, the UK was again influenced by high pressure, but with unsettled spells in mid-September (coinciding with storms Ali and Bronagh) and October (storm Callum). In November and to a lesser extent December, the low-pressure anomaly was to the west of the UK, with high pressure over Scandinavia in November and Iberia in December, bringing mostly milder but sometimes unsettled weather and a mainly south-east or south-westerly flow.

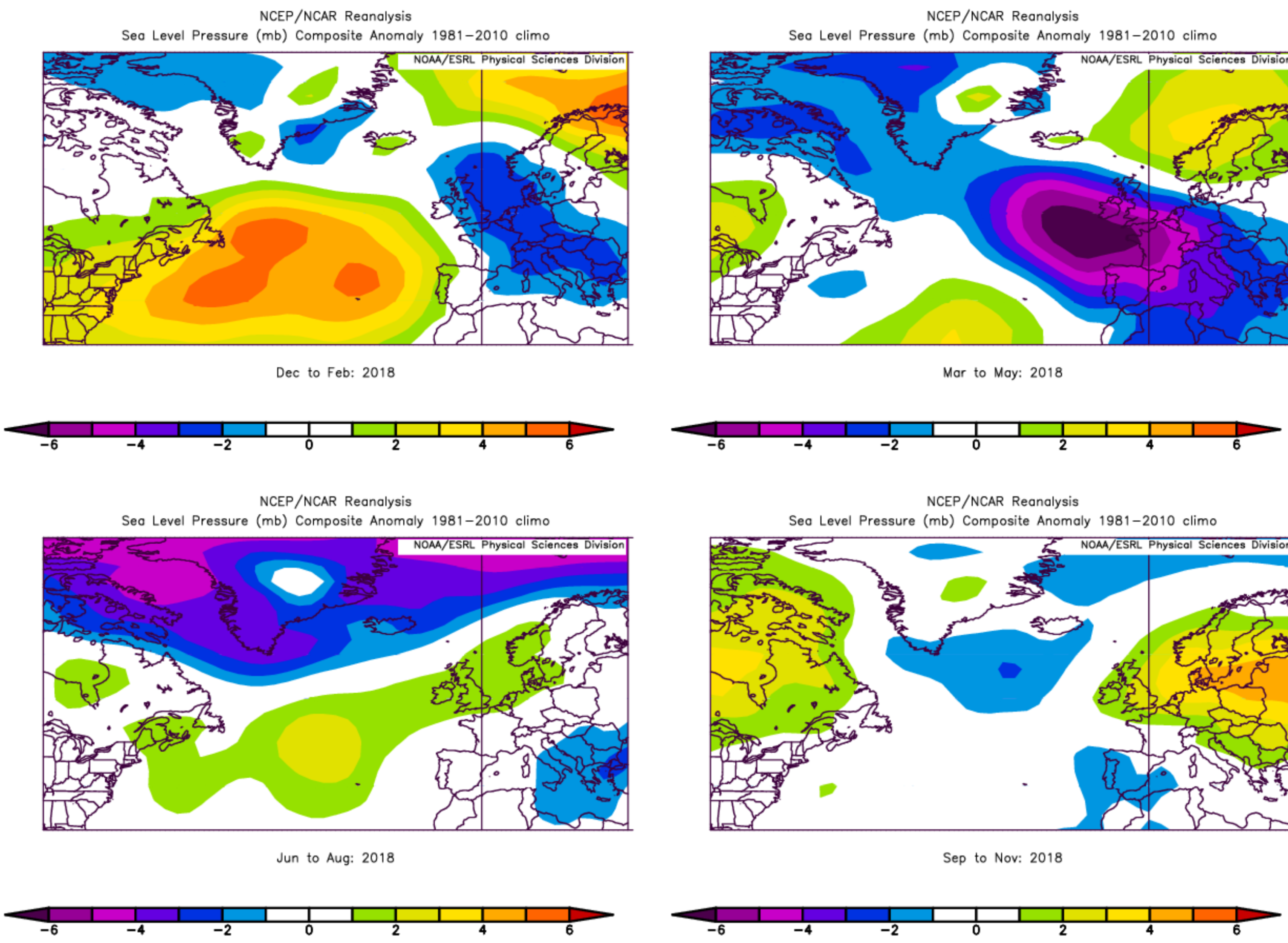


FIGURE 1 Year 2018 seasonal mean sea-level pressure anomalies (hPa, relative to 1981–2010 average). Winter refers to the period December 2017 to February 2018. Note that winter 2019 (December 2018 to February 2019) will appear in State of the UK Climate 2019. Images provided by the NOAA-ESRL Physical Sciences Division, Boulder, Colorado from their web site at http://www.esrl.noaa.gov/psd/

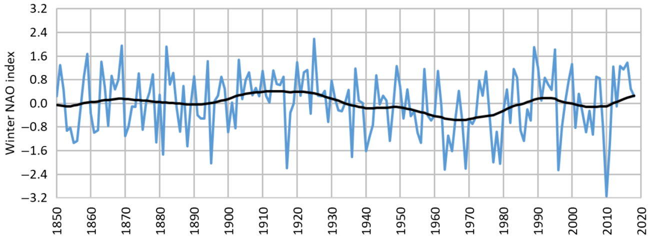


FIGURE 2 Winter NAO index based on standardized monthly mean pressure difference. Winter 2018 refers to the period December 2017 to February 2018. Note that winter 2019 (December 2018 to February 2019) will appear in State of the UK Climate 2019

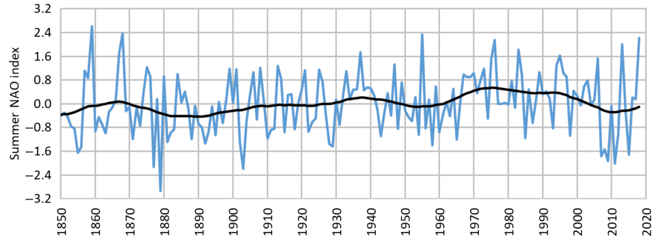


FIGURE 3 Summer NAO index based on standardized monthly mean pressure difference. Summer 2018 refers to the period June to August 2018

1.1 | NAO index

Figure 2 shows the winter North Atlantic Oscillation (WNAO) index from 1850 to 2018 inclusive. (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 Iceland and the Azores, which determines the strength of westerly winds across the Atlantic, and is thus 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 2018 was near-zero, and the winter overall was fairly near average for both temperature and rainfall. 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 recent changes in the NAO index and notes an increase in variability of WNAO within the last two decades. The most negative winter in the index is 2010 which was characterized by prolonged periods of blocked weather patterns and this was the UK's coldest winter since 1979.

Figure 3 shows the summer North Atlantic Oscillation (SNAO) index from 1850 to 2018 inclusive. 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.

The UK's summer in 2018 was much warmer, drier and sunnier than average. The 2018 SNAO index was the highest since 1955 and fourth highest in the series.

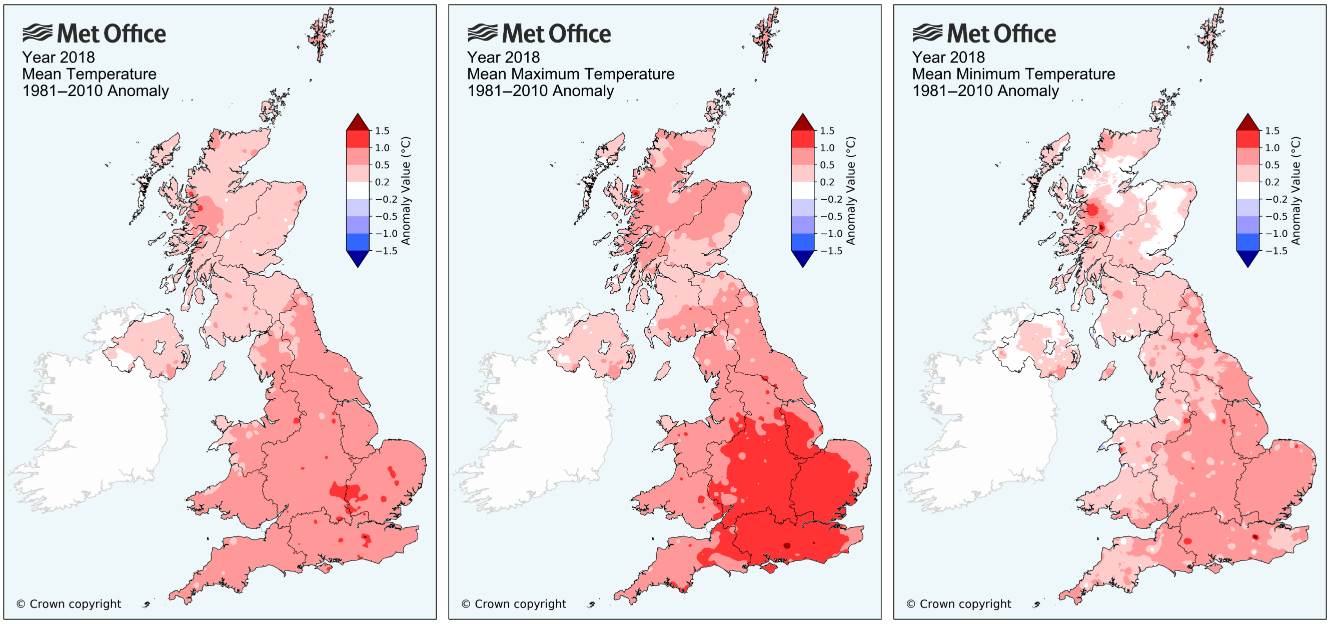


FIGURE 4 Year 2018 annual average temperature anomalies (°C) relative to 1981–2010 average for mean, maximum and minimum temperature. Bulls-eye features present in the T_{min} map are likely to be due to localized micro-climate features, such as frost hollow effects, at individual weather stations which the gridding process is unable to fully represent

Other summers in the second half of the series with a high SNAO index include 2013, 2006, 1995, 1983, 1976, 1975 and 1955, and these were all warm, dry and sunny summers for the UK overall. 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 striking recent decrease in SNAO since the 1990s, which includes the run of recent wet summers from 2007 to 2012. The summers of 2013 and 2018 are in marked contrast to this recent sequence.

2 | TEMPERATURE

The UK mean temperature (T_{mean}) for 2018 was 9.5°C, which is 0.6°C above the 1981–2010 long-term average, making this the seventh warmest year in the UK series from 1884. Year 2018 was ranked fourth warmest in the Central England temperature (CET) series from 1659. The annual mean temperature was around 0.5–1.0°C above normal across England and Wales, with anomalies exceeding 1.0°C for a few locations in England, whereas anomalies across Scotland and Northern Ireland were generally less than 0.5°C (Figure 4, Table 1).

The UK annual mean maximum temperature (T_{max}) for 2018 was 13.2°C, which is 0.8°C above average. The highest T_{max} anomalies of over 1.0°C were across central southern England, whereas anomalies were lower across the northern half of the UK—particularly Northern Ireland and Scotland's Central Belt. The UK annual mean minimum temperature (T_{min}) for 2018 was 5.7°C, which is 0.4°C above average, with T_{min} anomalies generally lower than

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 2018. Colour coding relates to the relative ranking in the full series which spans 1884–2018 for all series except CET which is 1659–2018

	UK		England		Wales		Scotland		Northern Ireland		CET	
	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly
January	4.0	0.4	5.1	1.0	4.8	0.7	2.1	−0.5	4.0	−0.3	5.3	0.9
February	2.3	−1.3	2.6	−1.5	2.7	−1.2	1.6	−1.1	2.9	−1.4	2.9	−1.5
March	3.8	−1.7	4.6	−1.6	4.0	−1.7	2.4	−1.8	4.0	−1.9	4.9	−1.7
April	8.4	1.0	9.5	1.4	8.6	1.0	6.6	0.5	8.0	0.4	9.8	1.3
May	12.0	1.7	12.9	1.7	11.8	1.2	10.7	1.8	11.9	1.7	13.2	1.5
June	14.8	1.8	15.8	1.7	15.3	2.2	13.0	1.7	14.9	2.1	16.1	1.6
July	17.2	2.1	18.8	2.5	17.2	2.0	14.9	1.6	15.7	1.2	19.1	2.4
August	15.2	0.3	16.7	0.6	15.2	0.2	12.9	−0.2	14.4	0.1	16.6	0.2
September	12.4	−0.3	13.6	−0.1	12.5	−0.4	10.5	−0.4	11.5	−0.9	13.7	−0.3
October	9.6	0.1	10.5	0.2	9.5	−0.3	8.0	0.1	9.2	−0.2	10.6	−0.1
November	7.3	1.1	7.9	1.1	7.5	0.8	6.2	1.3	7.2	0.7	8.3	1.2
December	5.8	1.9	6.5	2.2	6.9	2.4	4.2	1.4	6.5	2.0	6.9	2.3
Winter	3.5	−0.2	4.2	0.0	4.2	0.0	2.2	−0.5	3.9	−0.5	4.3	−0.2
Spring	8.1	0.3	9.0	0.5	8.2	0.2	6.6	0.2	8.0	0.1	9.3	0.4
Summer	15.8	1.4	17.1	1.6	15.9	1.5	13.6	1.1	15.0	1.1	17.3	1.4
Autumn	9.7	0.3	10.7	0.4	9.8	0.0	8.2	0.3	9.3	−0.1	10.9	0.3
Annual	9.5	0.6	10.4	0.8	9.7	0.6	7.8	0.4	9.2	0.3	10.7	0.7

Key: Warmest on record | Top ten 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 ten cold | Coldest on record

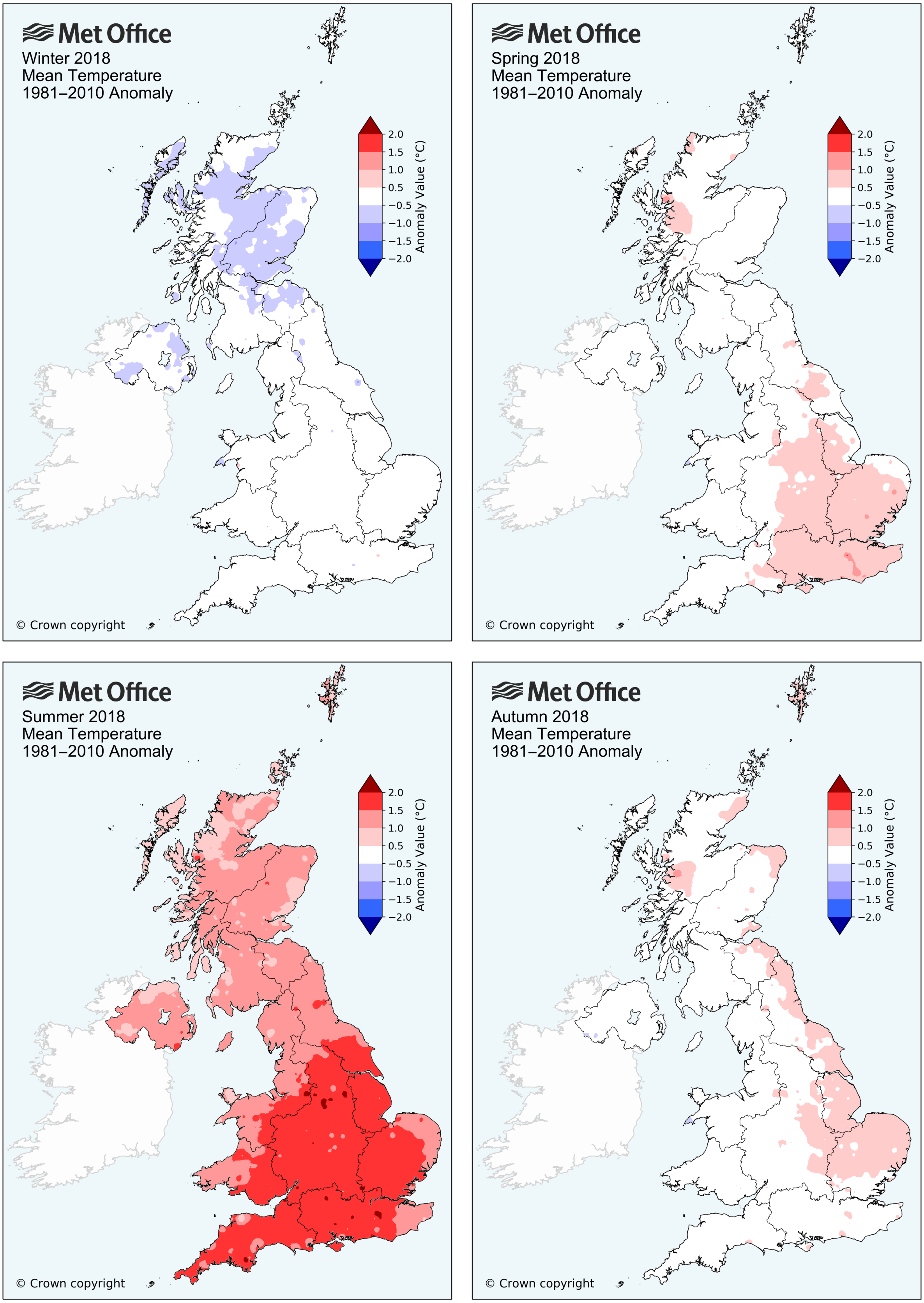


FIGURE 5 Year 2018 seasonal average temperature anomalies (°C relative to 1981–2010 average). Winter refers to the period December 2017 to February 2018. Note that winter 2019 (December 2018 to February 2019) will appear in State of the UK Climate 2019

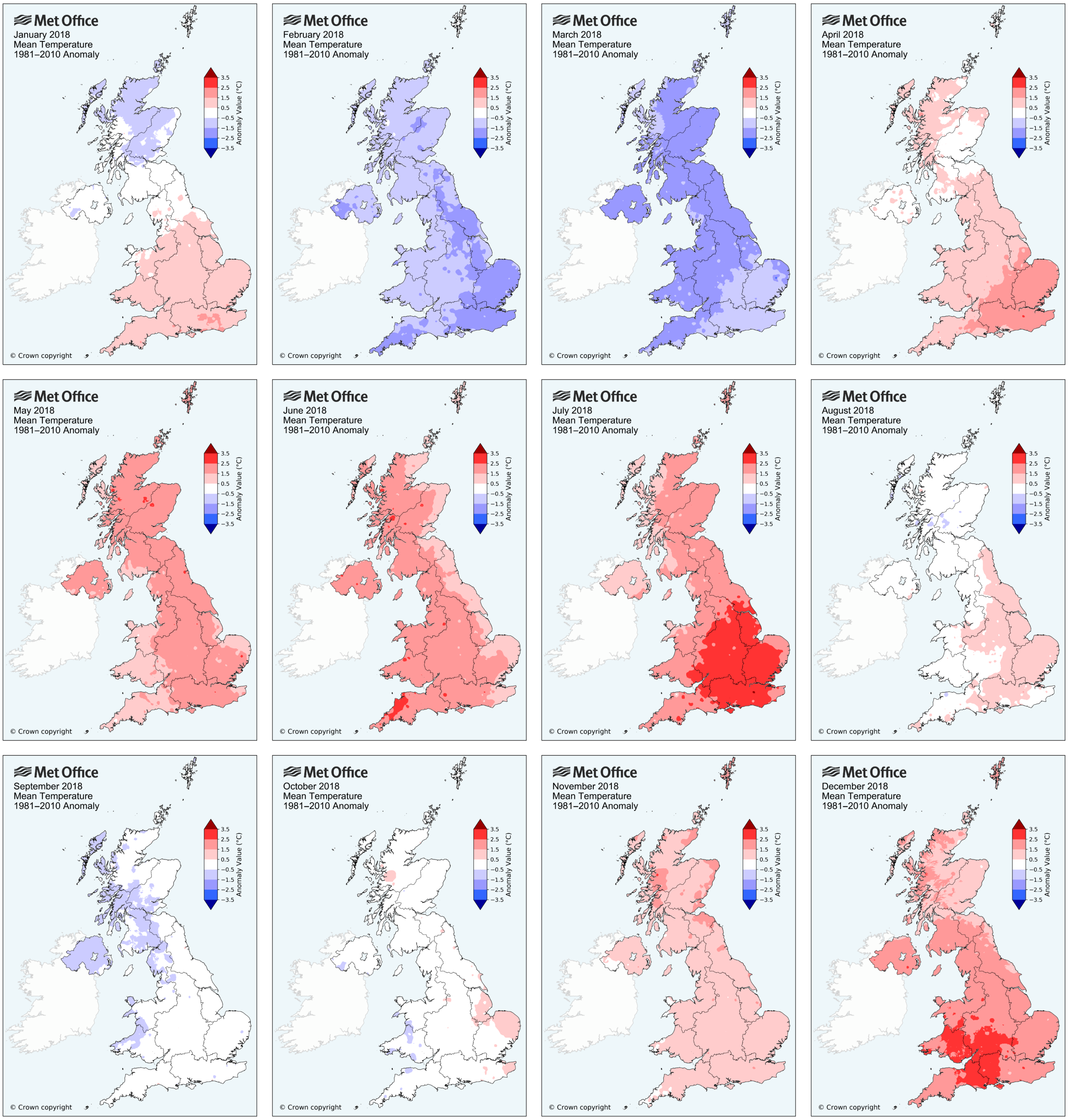


FIGURE 6 Year 2018 monthly average temperature anomalies (°C) relative to 1981–2010 average

T_{max} anomalies across the UK, and near-zero across parts of Northern Ireland and northern Scotland (Figure 4, Table 1).

The UK seasonal T_{mean} for winter 2018 (December 2017 to February 2018) was 3.5°C, which is 0.2°C below the 1981–2010 average and this was the coldest winter for the UK since 2013. For the UK overall, temperatures were near-normal in December 2017 and January 2018, but 1.3°C below normal in February (Figures 5 and 6, Table 1). A spell of severe winter weather with easterly winds became established across the UK from late-February to early March, with temperatures as much as 10°C below average for the time of year (for more details see the significant weather events section).

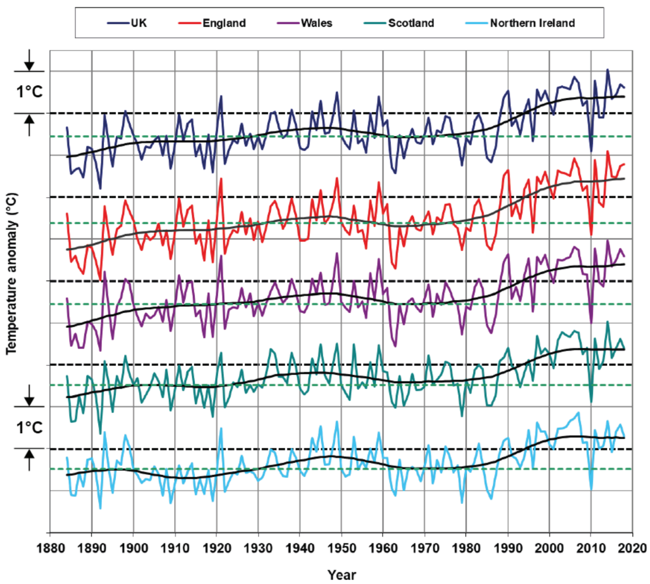
The UK seasonal T_{mean} for spring was 8.1°C, which is 0.3°C above the 1981–2010 average. Temperature anomalies were 1.7°C below normal in March and on the first Tredegar, Blaenau Gwent recorded a daily maximum temperature of −4.7°C, the lowest March maximum on record for the UK at a low-level station. Even so, March 2018 was not as cold as March 2013 overall. In contrast, temperatures were 1.7°C above normal in May. It was the third-warmest May for the UK in a series from 1884 (although not quite as warm as the previous May of 2017) and for T_{max} the warmest May in the series. Remarkably, both the early and late May bank holidays were dominated by dry, warm, settled weather across most of the UK. There was also a significant warm spell in mid-April; temperatures reached 25–27°C widely across central and eastern England on the 19th, with 29.1°C at London St James's Park the UK's highest April temperature since 1949 (see the significant weather events section).

The UK seasonal T_{mean} for summer was 15.8°C, 1.4°C above normal, largely due to fine, warm weather in June and July. For the UK, this was the equal-warmest summer in a series from 1884, with 2006, and marginally warmer than the summers of 2003 and 1976, while England had its warmest summer in the series. Temperatures were widely more than 2.0°C above normal in June (for Wales the warmest June in the series from 1884) and more than 2.5°C above normal across central southern England in July. Temperatures exceeded 30°C across parts of Highland Scotland, North Wales and Northern Ireland on 28th June, and fairly widely across England on 15 days during July and early August, although T_{mean} for August was near normal overall (for more details see the significant weather events section).

The UK seasonal T_{mean} for autumn was 9.7°C, 0.3°C above normal, with anomalies near-normal in September and October but somewhat above in November. December 2018 was another mild month overall. In summary, for year 2018 overall, temperatures in February and March were well below average, with May, June, July and December well above (Figure 6, Table 1).

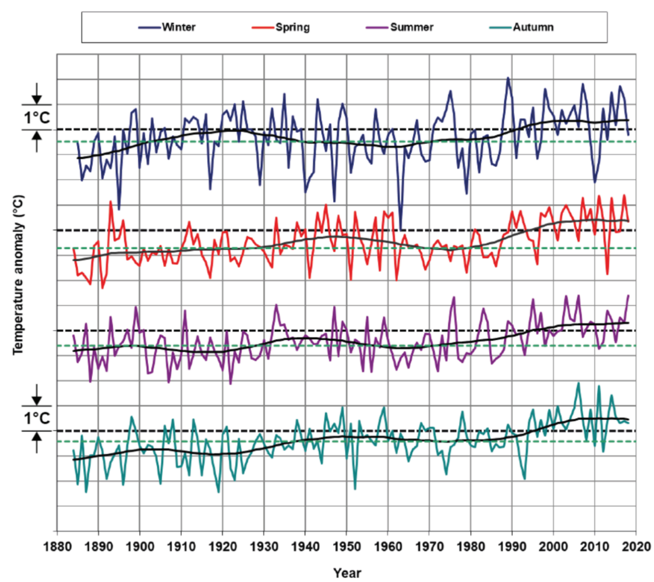
Figure 7 shows time series of annual T_{mean} anomalies for the UK and countries from 1884 to 2018 inclusive, and Figure 8 the seasonal UK T_{mean} anomaly series. There has been an increase in temperature from 1970s to 2000s with the most recent decade (2009–2018) being on average 0.9°C warmer than the 1961–1990 average and 0.3°C above 1981–2010. All the top 10 warmest years in the UK T_{mean} series have occurred since 2002, and year 2018 is ranked seventh (Figure 7). Year 2018 was warmer than any year in the series from 1884 to 2002. In contrast, none of the top 10 coldest years in the UK T_{mean} series have occurred this century. The coldest year this century (2010) is ranked 22nd coldest in the UK series.

All four seasons have seen 2009–2018 warmer than 1961–1990, with the largest change for spring at 1.1°C and



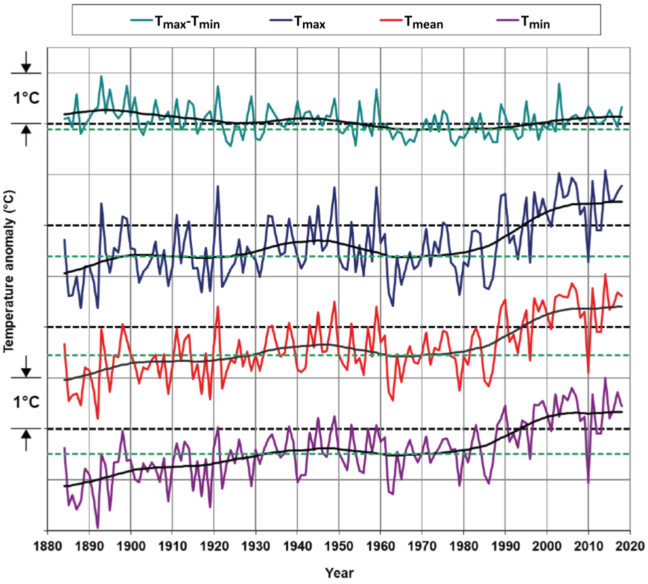
Area	1961-1990 average	1981-2010 average	2009-2018 average	2018
UK	8.3	8.8	9.2	9.5
England	9.0	9.7	10.0	10.4
Wales	8.6	9.1	9.4	9.7
Scotland	6.9	7.4	7.7	7.8
Northern Ireland	8.4	8.9	9.1	9.2

FIGURE 7 Annual T_{mean} for the UK and countries, 1884–2018, 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 values (°C). Smoothed trend lines used here and throughout the report are described in Annex 2



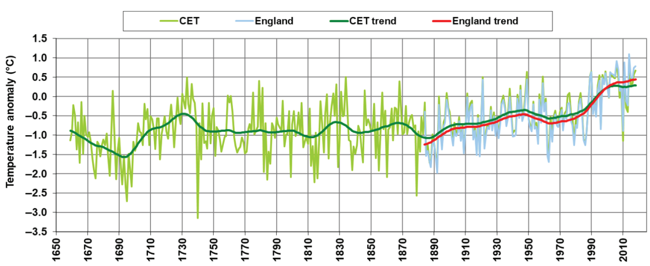
Season	1961-1990 average	1981-2010 average	2009-2018 average	2018
Winter	3.3	3.7	3.8	3.5
Spring	7.0	7.7	8.1	8.1
Summer	13.8	14.4	14.6	15.8
Autumn	9.0	9.4	9.9	9.7

FIGURE 8 Seasonal T_{mean} for the UK, 1884–2018 (note winter from 1885 to 2018; year is that in which January and February fall. Winter 2019—which includes December 2018—will appear in next year''s publication). Light grey grid-lines represent anomalies of ±1°C. The table provides average values (°C)



Variable	1961-1990 average	1981-2010 average	2009-2018 average	2018
Tmax	11.8	12.5	12.8	13.2
Tmean	8.3	8.8	9.2	9.5
Tmin	4.8	5.3	5.5	5.7
Tmax minus Tmin	7.1	7.2	7.3	7.5

FIGURE 9 Annual T_{max}, T_{mean} and T_{min} for the UK, and T_{max} minus T_{min}, 1884–2018, expressed as anomalies relative to the 1981–2010 average. Light grey grid-lines represent anomalies of ±1°C. The table provides average values (°C)



Variable	1961-1990 average	1981-2010 average	2009-2018 average	2018
CET	9.5	10.0	10.2	10.7
England	9.0	9.7	10.0	10.4

FIGURE 10 Annual T_{mean} for CET series, 1659–2018, and England temperature series, 1884–2018, expressed as anomalies relative to the 1981–2010 average. The table provides average values (°C)

the smallest for winter at 0.6°C (Figure 8). As with the annual series, the seasonal series show large inter-annual variability and some decadal variability, with an increase in temperature across all four seasons from 1970s to 2000s. Warming has been slightly greater for T_{max} than T_{min} (Figure 9) resulting in a small increase in the average daily temperature range but to levels similar to those observed prior to the mid 20th century.

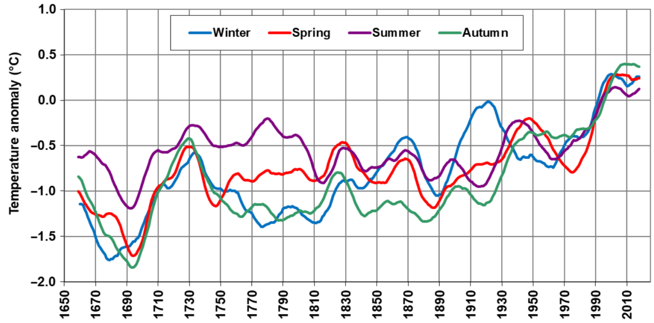


FIGURE 11 Seasonal CET series, 1659–2018, expressed as anomalies relative to 1981–2010 average. The figure shows a smoothed trend for each series using a weighted kernel filter described in Annex 2

TABLE 2 Centennial averages for CET series 1659–2018 (winter from 1660 to 2018)

Season	1659–1700	1701–1800	1801–1900	1901–2000	2001–2018
Year	8.7	9.2	9.1	9.5	10.3
Winter	3.0	3.5	3.7	4.2	4.8
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

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 this uncertainty is less than 0.1°C and consequently 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 T_{mean} for England from 1884 to 2018 and CET series from 1659. The series are highly correlated for the period of overlap (R^2 value 0.98) 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 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 (2001–2018) 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 the greatest difference in autumn and the least in summer (Table 2).

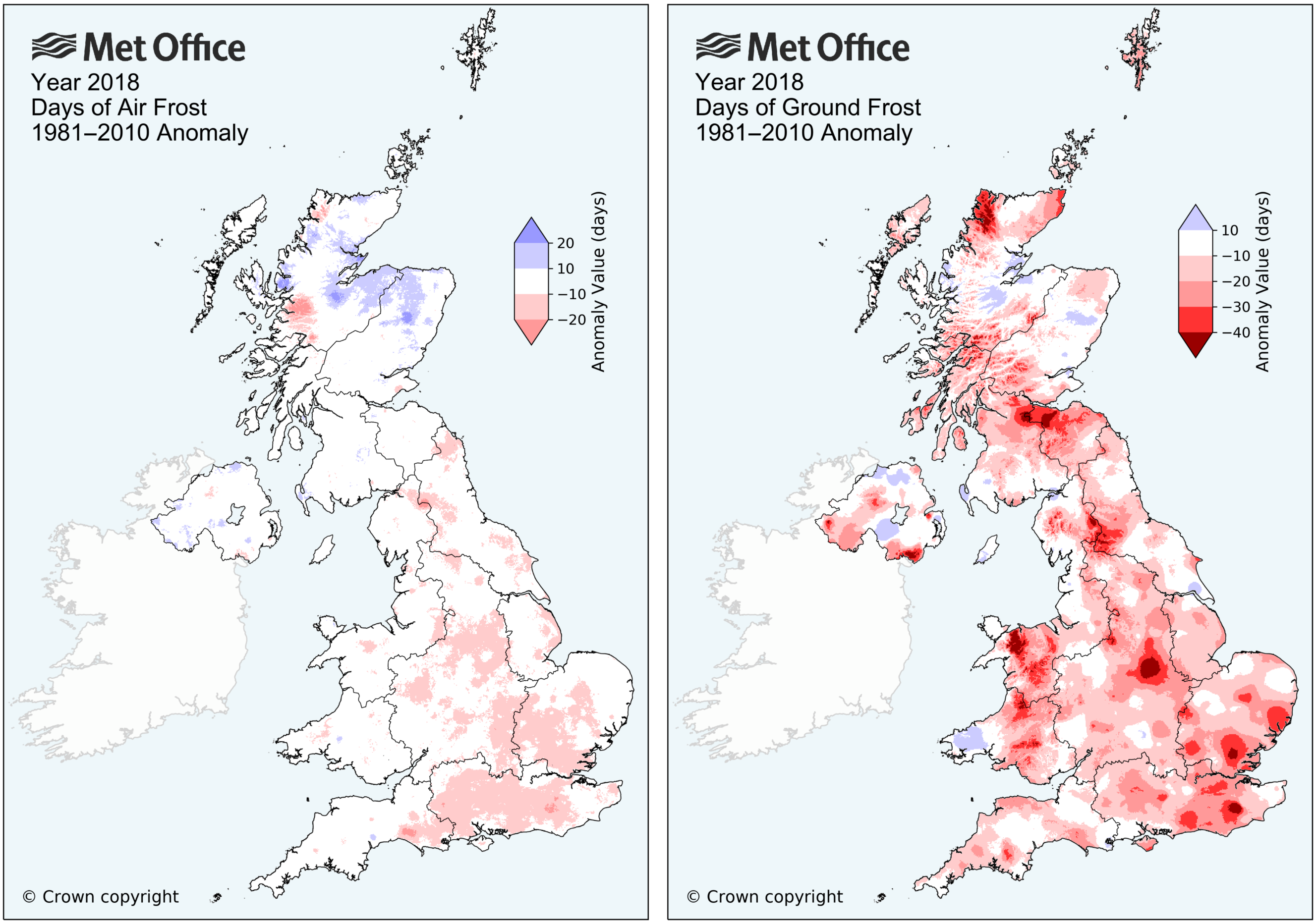
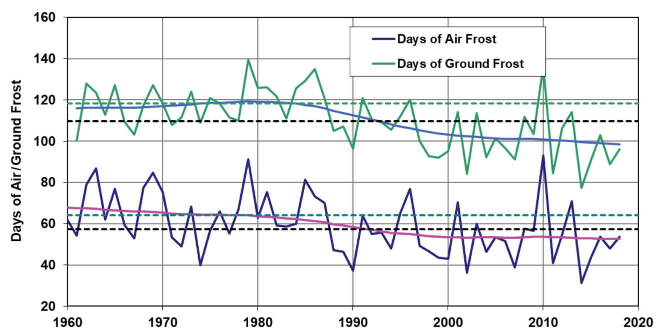


FIGURE 12 Days of air frost and days of ground frost anomaly for year 2018 relative to 1981–2010. See Annex 1 for definitions. Bulls-eye features in these and the T_{min} maps are likely to be due to localized factors such as frost hollow effects at individual weather stations (present in the actual or long-term average grids) which the gridding process is unable to fully represent, particularly for ground frost

2.1 | Days of air and ground frost

The average number of days of air frost for the UK for 2018 was 54 days, which is 3 days below the 1981–2010 average. The number of air frosts was near average across much of the UK, but below normal across central and south-east England and above normal across parts of north-east Scotland. The number of days of ground frost for 2018 was 96 days, 14 days below the 1981–2010 average and equal-11th lowest in a series from 1961. Some locations recorded at least 30 fewer days of ground frost for the year overall compared to normal but with considerable spatial variation across the UK (Figure 12). The number of air and ground frosts was well below average in January (except across Scotland), April, November and December but above in February, March and October.

The annual numbers of days of air and ground frost for the UK overall for 2018 was close to or slightly below the average for the most recent decade, with the series showing a reduction through the 1980s and 1990s. The most



Variable	1961-1990 average	1981-2010 average	2009-2018 average	2018
Days of Air Frost	64	57	55	54
Days of Ground Frost	118	110	100	96

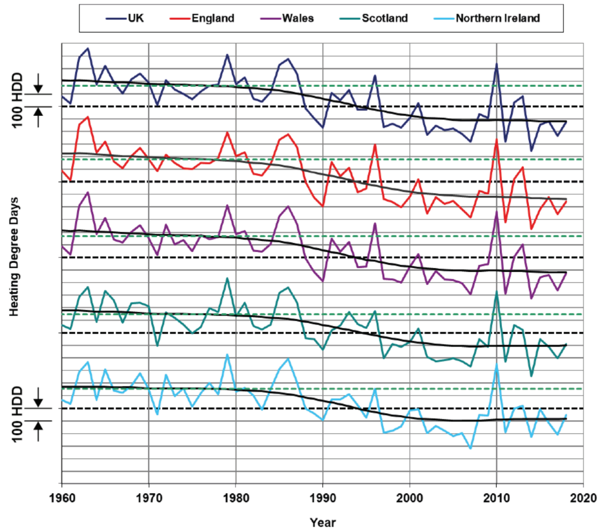
FIGURE 13 Annual number of days of air frost and ground frost for the UK, 1961–2018. The hatched black line is the 1981–2010 long-term average. The hatched green line is the 1961–1990 long-term average. The table provides average values (days)

recent decade, 2009–2018, has recorded 15/16% fewer annual days of air frost and ground frost per year than the average for 1961–1990, and 5/9% fewer than 1981–2010 (Figure 13). 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 GDDss 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 definitions and thresholds used are described in Annex 1.

Heating degree days (HDD) for 2018 were between 90 and 95% of average across most of England but near average across much of Wales, Scotland and Northern Ireland (Figure 14). Averaged across the UK, HDD for 2018 were 95% of the 1981–2010 average. The lowest 10 HDD



Area	1961-1990 average	1981-2010 average	2009-2018 average	2018
UK	2737	2571	2480	2446
England	2521	2342	2236	2187
Wales	2616	2448	2359	2325
Scotland	3142	2995	2923	2908
Northern Ireland	2650	2496	2447	2444

FIGURE 15 Heating degree days for the UK and countries, 1960–2018, 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 values (HDD)

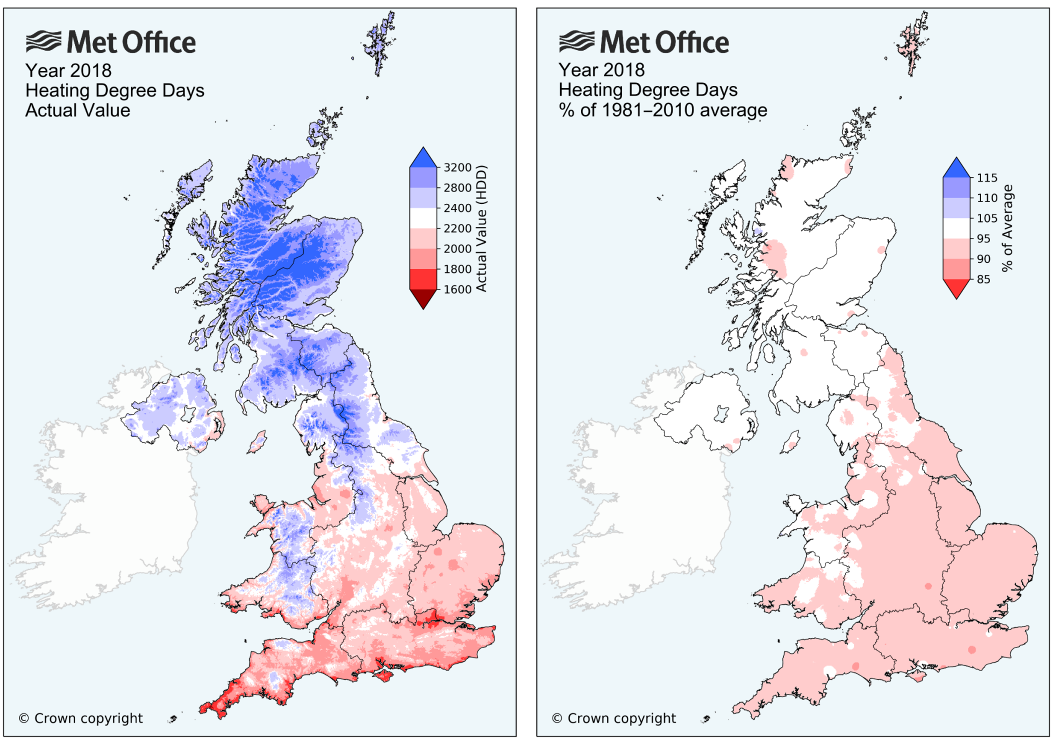
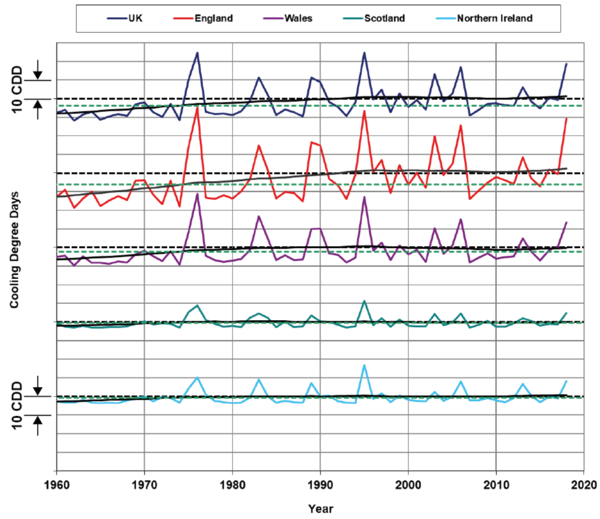


FIGURE 14 Heating degree days for 2018 (left) actual and (right) % of 1981–2010 average

years for the UK in a series from 1960 have all occurred since 1990, with the lowest eight since 2002 (Figure 15). For the UK, the most recent decade has had an annual average HDD 9% lower than 1961–1990 and 4% 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.

The UK experienced a fine, warm summer, with daily maximum temperatures widely exceeding 28°C (at 20 or more observing stations) on 28 days from late June to early August across England. As a result, cooling degree days (CDD) were well above average, with the highest values across the east Midlands, East Anglia and Greater London (the latter due in part to the urban heat island effect). In these areas, there were between 60 and 80 CDD widely, compared with a 1981–2010 average of around 30–40 CDD in these areas, and in some locations more than 50 CDD above average (Figure 16). The UK recorded 32 CDD compared to a 1981–2010 long-term average of 13 CDD, and all countries recorded between two and three times the long-term average.

The years with high CDD in the time-series across England and Wales are those when major summer heatwaves occurred. This sequence of years—1976, 1995, 2003 and 2006—now also includes 2018. For both the UK and England, CDD in 2018 were the third highest in the series



Area	1961-1990 average	1981-2010 average	2009-2018 average	2018
UK	9	13	14	32
England	14	20	22	50
Wales	8	10	9	24
Scotland	3	3	3	8
Northern Ireland	3	4	4	12

FIGURE 17 Cooling degree days for the UK and countries, 1960–2018, 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 values (CDD)

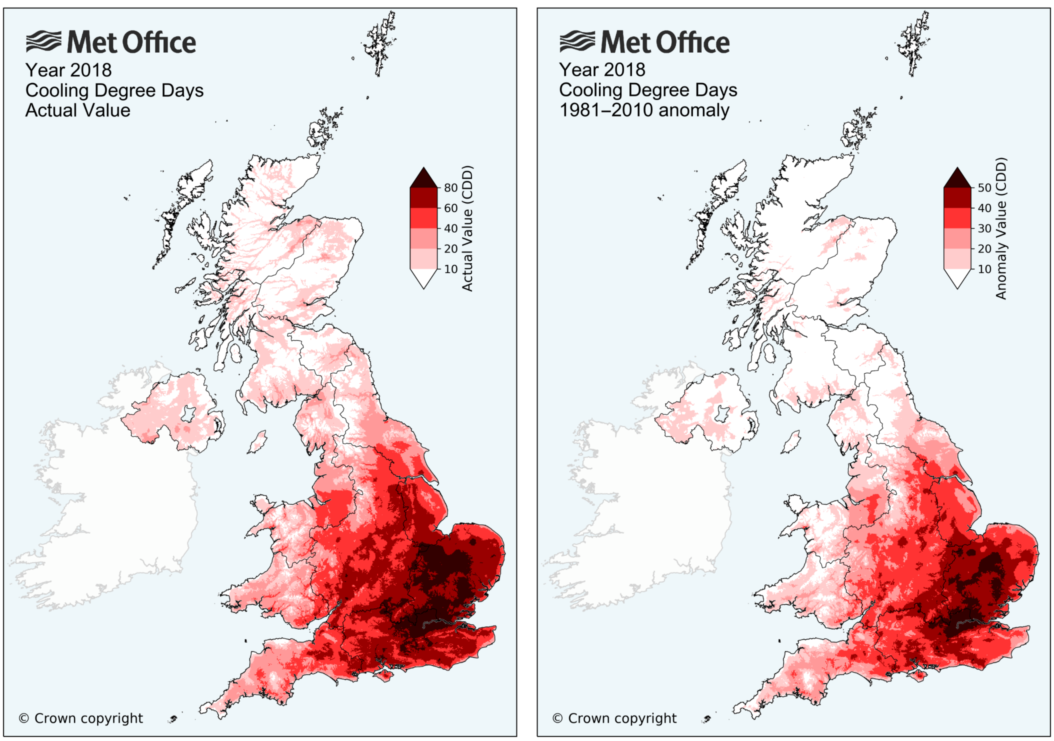
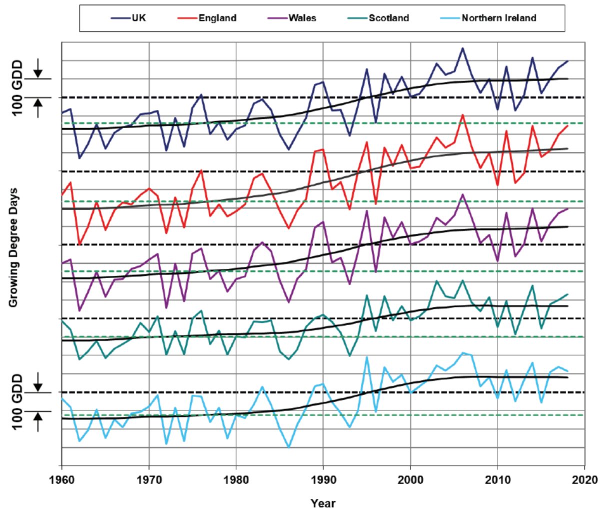


FIGURE 16 Cooling degree days for 2018, (left) actual and (right) anomaly. The anomaly is presented as a difference from, rather than percentage of, average. This is because CDD are close to zero over much of Highland Scotland

behind 1995 and 1976, and for Wales fifth highest. The cooler climate of Scotland and Northern Ireland means that CDD are much lower, each with long-term averages of less than 5 CDD, but nevertheless CDD in 2018 were equal-fourth highest on record for each country. Although there has been a general increase in CDD across England, significant peaks are dependent on when major heat-waves happen to occur. Prior to 2018, the most recent major summer heatwave for the UK affecting CDD was in July 2006, with a run of notably cool summers with low CDD from 2007 to 2012 (Figure 17). CDD for the most recent decade are comparable with 1981–2010, largely because 2013 and 2018 are the only years with well above-average CDD in the period 2009–2018.

GDD for 2018 were between 110 and 115% of average across most of the UK, but higher than this for some areas (Figure 18). UK GDD overall were 112% of the 1981–2010 average, the third highest in a series from 1960, behind 2006 and 2014. GDD for 2018 were also above the average for the most recent decade across all regions.

The most recent decade has had an annual GDD 15% higher than 1961–1990 and 5% higher than 1981–2010, and the similar (downward) trend in HDD and (upward) trend in GDD from 1960 to date each reflect the underlying warming of the UK's climate (Figure 19). The recent cold years of 2010 and 2013 still recorded GDD above the 1961–1990 average.



Area	1961-1990 average	1981-2010 average	2009-2018 average	2018
UK	1472	1610	1695	1807
England	1677	1841	1946	2088
Wales	1520	1663	1741	1857
Scotland	1128	1225	1282	1356
Northern Ireland	1426	1552	1617	1668

FIGURE 19 Growing degree days for the UK and countries, 1960–2018, 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 values (GDD)

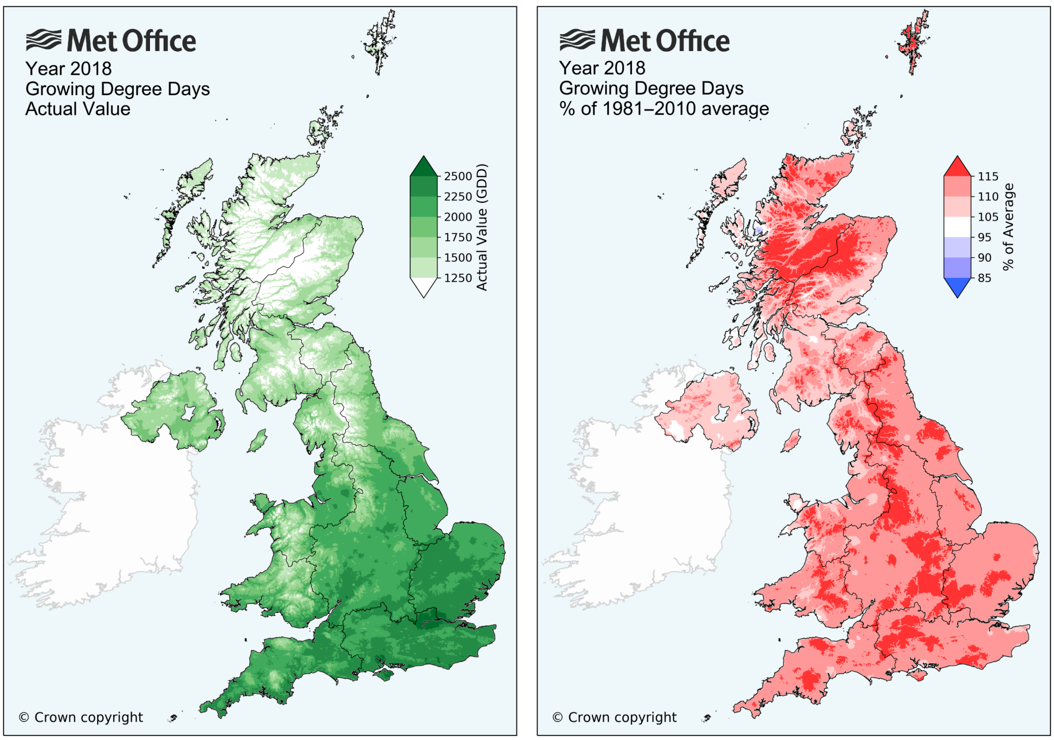
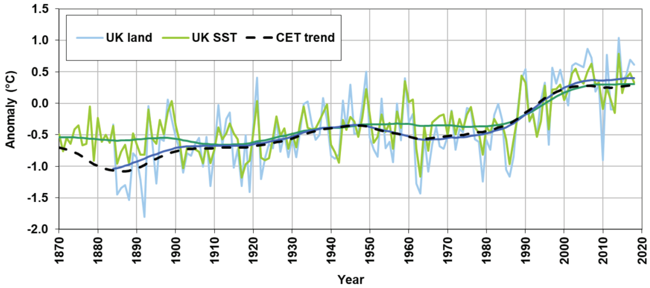


FIGURE 18 Growing degree days for 2018 (left) actual and (right) % of 1981–2010 average



Area	1961-1990 average	1981-2010 average	2009-2018 average	2018
UK land	8.3	8.8	9.2	9.5
UK near-coast SST	11.1	11.5	11.7	11.8

FIGURE 20 UK annual mean temperature over land 1884–2018, Central England temperature trend and UK annual mean sea surface temperature across near-coastal waters around the UK 1870–2018, expressed as anomalies relative to the 1981–2010 long-term average. The table provides average values (°C)

2.3 | Coastal waters

The annual mean SST for 2018 for near-coast waters around the UK was 11.8°C, 0.3°C above the 1981–2010 long-term average. This ranked equal-11th warmest in the series from 1870 and warmer than any year in the series before 1959 (Figure 20).

Near-coast SST data is highly correlated with the land observations (R^2 value 0.82, 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 Central England temperature series, also shown in Figure 20, 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. For UK near-coast SST, the most recent decade, 2009–2018, is 0.6°C warmer than the 1961–1990 average and 0.3°C above 1981–2010. Eight of the 10 warmest years in the series have occurred since 2002. Every year this century has fallen within the warmest third of the series.

3 | PRECIPITATION

The UK rainfall total for 2018 was 1,056 mm, 92% of the 1981–2010 average and the driest year for the UK since 2010. Most of the country was drier than average—especially parts of north-east Scotland which recorded less than 75% of normal. In contrast, some coastal fringes—particularly west Wales and much of the south coast—had above average rainfall (Figure 21).

The wettest and driest observed locations for the year generally reflected the long-term climatology. Several rain-gauges across the Lake District and West Highlands recorded over 3,000 mm (with the highest annual total 4,972 mm at Styhead, Cumbria)—although totals in these areas were more typically 2000–3000 mm. In contrast, the driest locations in parts of Essex, Suffolk Cambridgeshire and Moray recorded less than 500 mm—with a few locations less than 450 mm. Overall this represents a fairly typical range for the UK.

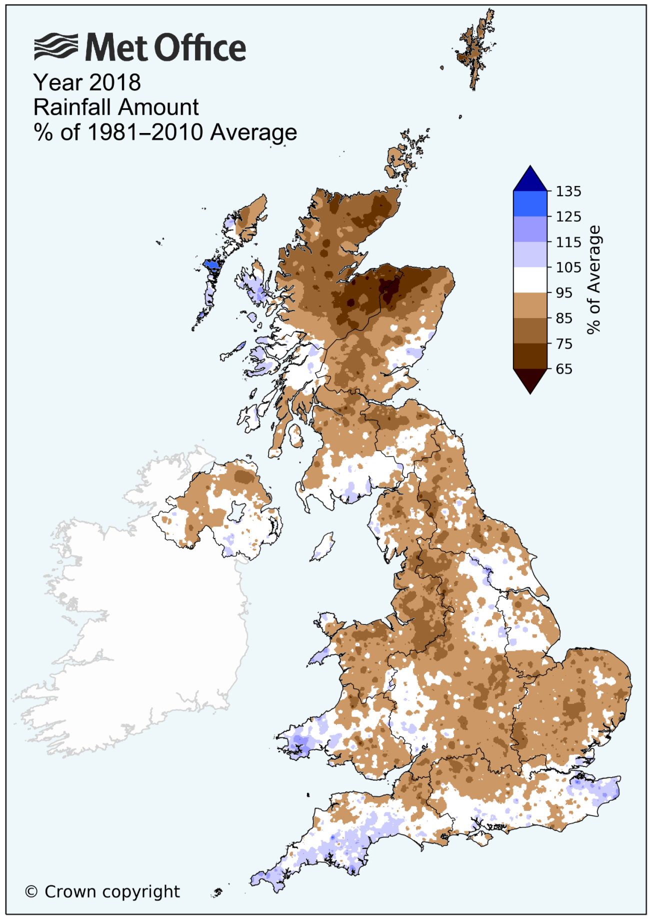


FIGURE 21 Rainfall anomalies (%) for year 2018

Figures 22 and 23 and Table 3 show seasonal and monthly rainfall anomalies across the UK for 2018. Inevitably, as is always the case, the annual map conceals the detail behind significant monthly and seasonal variations which occurred in rainfall patterns over the course of the year.

The UK rainfall anomalies for winter (98%), spring (99%) and autumn (96%) were near-normal overall but with large spatial variation, while summer was relatively dry (72%). The winter rainfall pattern was variable but it was notably wet across parts of East Anglia and Northern Ireland, and dry across much of central and eastern Scotland. December 2017 was rather drier than average in some north-eastern areas, but central and south-east England, especially East Anglia, were rather wet (not shown, see Kendon *et al.*, 2018). January 2018 was wet in

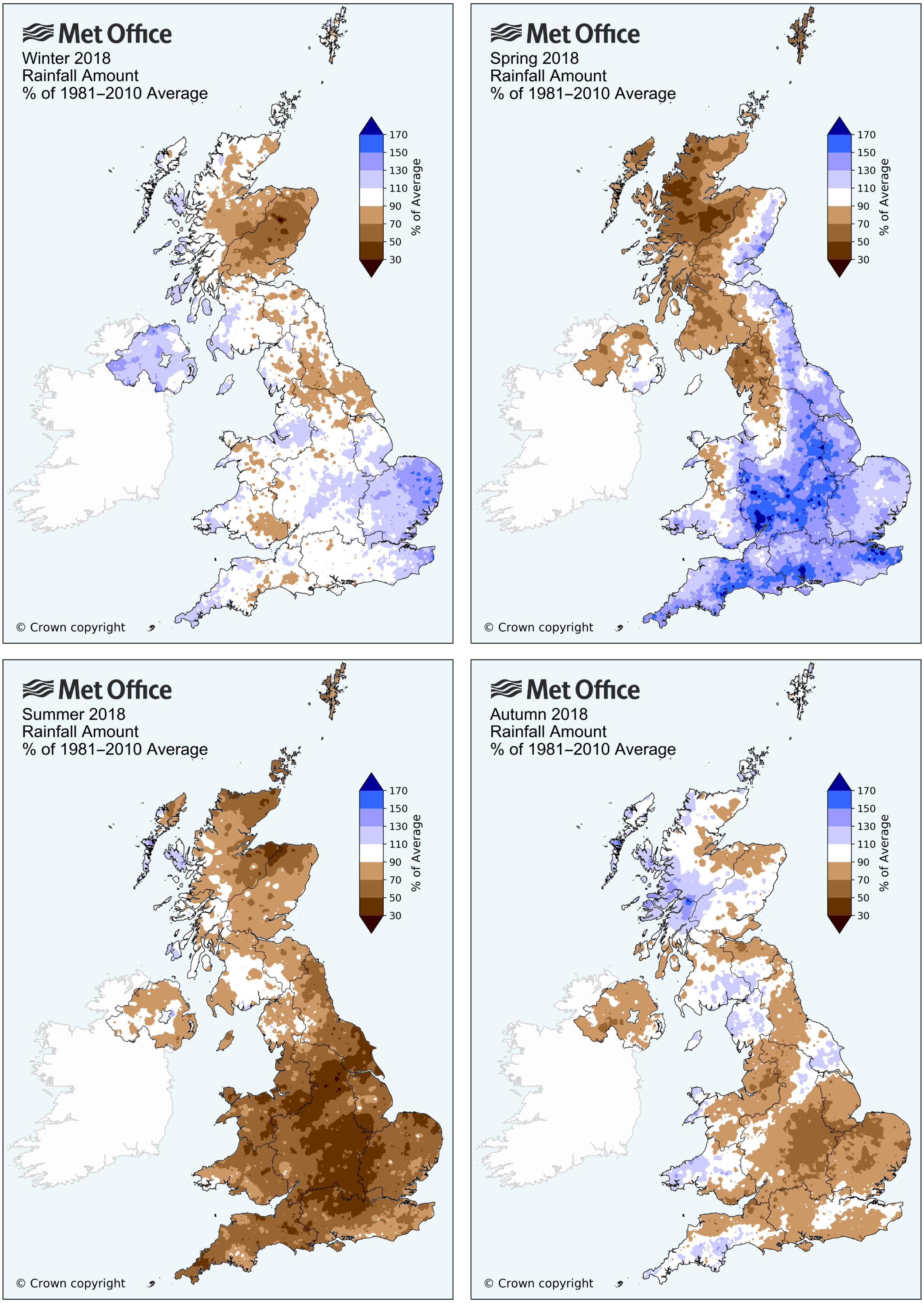


FIGURE 22 Rainfall anomalies (%) for seasons of 2018. Winter refers to the period December 2017 to February 2018. Note that winter 2019 (December 2018 to February 2019) will appear in State of the UK Climate 2019

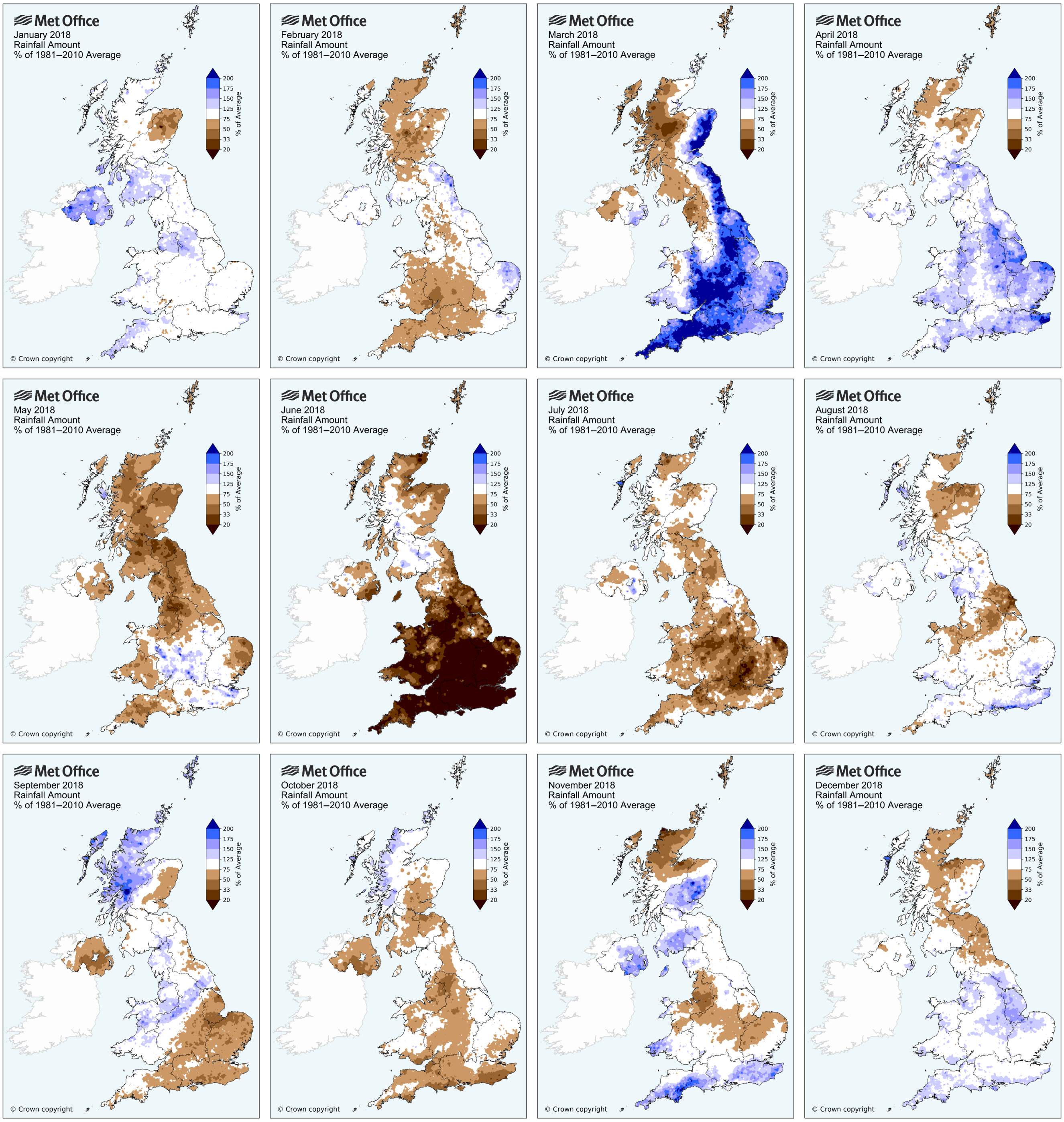


FIGURE 23 Rainfall anomalies (%) for months of 2018

some western areas, dry in Aberdeenshire, but totals were near-normal across much of the UK. February was relatively dry across all areas.

Spring 2018 was relatively wet across much of England, Wales and eastern Scotland with more than 150% of average fairly widely—but in contrast dry across north-west England, Northern Ireland and western Scotland with less than 50% in a few locations. This north-west/south-east gradient is a relatively frequent feature of UK spring rainfall, with a similar pattern seen in spring 2012, and a reversed wet north-west/dry south-east gradient during springs 2011 and 2015. More than 200% of average rainfall fell in a swathe from Cornwall to Aberdeenshire during March 2018, while much of western Scotland received less than 50% of average. April was somewhat wetter than average across most of the UK, while May was relatively dry for most of

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 2018

	UK		England		Wales		Scotland		Northern Ireland		EWP	
	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly
January	133	110	90	109	170	108	184	105	179	154	105	112
February	69	78	49	81	78	70	97	75	83	99	53	79
March	104	110	103	162	141	121	99	71	81	85	115	161
April	84	116	78	134	115	129	85	94	80	107	91	141
May	48	69	45	77	61	71	48	57	53	73	52	82
June	35	48	15	24	21	24	69	78	50	66	17	25
July	54	70	36	58	62	67	79	80	73	90	40	59
August	83	93	66	96	99	92	104	89	99	102	77	102
September	102	106	59	86	134	115	172	127	55	61	67	87
October	105	83	65	71	133	78	169	97	70	59	76	73
November	122	101	90	102	164	101	159	96	144	129	105	104
December	118	98	99	114	189	114	131	81	108	95	116	119
Winter	322	98	237	103	418	96	427	91	377	120	271	105
Spring	236	99	227	125	317	108	233	74	214	88	258	129
Summer	173	72	117	61	182	64	252	83	222	87	133	63
Autumn	328	96	214	86	431	96	500	105	270	84	248	88
Annual	1,056	92	796	93	1,366	94	1,398	90	1,076	95	912	96

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 1862–2018 for all series except EWP which is 1766–2018 the UK except central southern England where showers, thunderstorms and longer spells of rain broke out toward the end of the month in the wake of the hot weather.

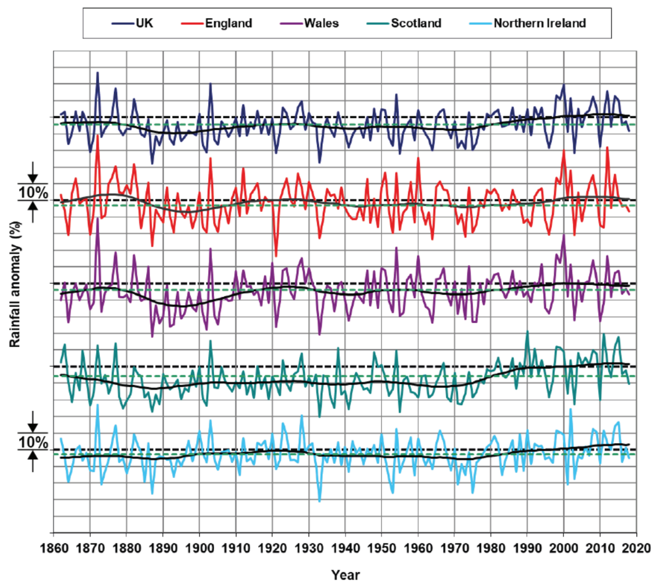
Summer 2018 was relatively dry across the UK (the driest summer since 1995). It was particualry dry across central England with less than 50% of normal rainfall widely—for England this was the eighth driest summer in a series from 1862—although not as dry as the other notable heatwave summers of 1995 and 1976. High pressure brought dry, settled conditions through much of May, June and July and some locations across southern England recorded a run of over 50 dry days from the end of May until late July. June was exceptionally dry across parts of central and southern England with less than 5 mm of rain widely—for southern England only June 1925 was drier in a series from 1862. July was also much drier than average until the last few days of the month—especially toward the south-east. August rainfall totals were broadly near-average across the UK overall.

The autumn rainfall pattern was variable but rather dry across central England. September was wetter than average across many western and northern areas but drier elsewhere; rainfall in October was near or slightly below average across many areas, especially the south coast of England; rainfall totals in November and December were above average in certain areas but below in others; northern Scotland was notably dry during both months.

Various flood events occurred during 2018. Some flooding was reported in south-east England, Wales and southern Scotland in early January, associated with heavy rainfall from storm Eleanor. Further localized flooding from heavy rain and snowmelt affected parts of west Wales, south-west England and southern Scotland late in the month. In mid-February, flooding affected roads in the south-west including the M5, causing two serious accidents. In mid-March, a low-pressure system to the west brought flooding to parts of the south-west, the West Midlands and Northern Ireland. There was further flooding in parts of Derbyshire and Yorkshire on first and second April due to heavy rain; the Foss Barrier in York was activated as levels rose on the River Ouse. Heavy rain also affected parts of Devon and north-east England on 9–10th April, while thunderstorms and heavy rain caused flash flooding in the Southampton area on 1–2ndand across south-east England on 2 9–30th. In early May, there was further localized flooding in Kent, Norfolk and south Wales.

Heavy showers and thunderstorms associated with a breakdown of the hot weather at the end of May caused further flooding problem, with the M5 shut in the Birmingham area and there was widespread flooding in Wales. Toward the end of the month, localized flooding affected parts of Kent and the Southampton area. In early June, further heavy rainfall caused widespread flooding problems across Scotland, Northern Ireland, Norfolk, Lincolnshire and Nottinghamshire. Thunderstorms again caused surface water flooding problems in Kent on 5th July and more widely in the London area, parts of eastern England and North Wales around mid-month. Parts of Lincolnshire, Northern Ireland and Gloucestershire were affected by flooding late in the month. Torrential rain affected Merseyside, Lancashire and parts of south-east England in mid-August.

Storms Ali and Bronagh brought some heavy rain to Scotland, northern England and Wales in mid-September, and there was localized flooding in the West Highlands in early October. A very significant flood event for the year resulted from persistent rain from Storm Callum on 12th October, causing significant flooding problems across parts of south Wales and south-west England. The wettest area was south Wales, with much of the Brecon Beacons National Park recording 100–150 mm of rainfall over a 2-day period, and up to 200 mm across the higher ground (for more details see the significant weather events section). Further flooding affected Northern Ireland and south-west England in early November, and parts of Wales late in the month, and Storm Deirdre caused some flooding in Northern Ireland and south-west England in mid-December. However,



Area	1961-1990 average	1981-2010 average	2009-2018 average	2018
UK	1100	1150	1158	1056
England	827	853	855	796
Wales	1402	1459	1421	1366
Scotland	1470	1562	1585	1398
Northern Ireland	1099	1133	1176	1076

FIGURE 24 Annual rainfall, 1862–2018, 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 values (mm)

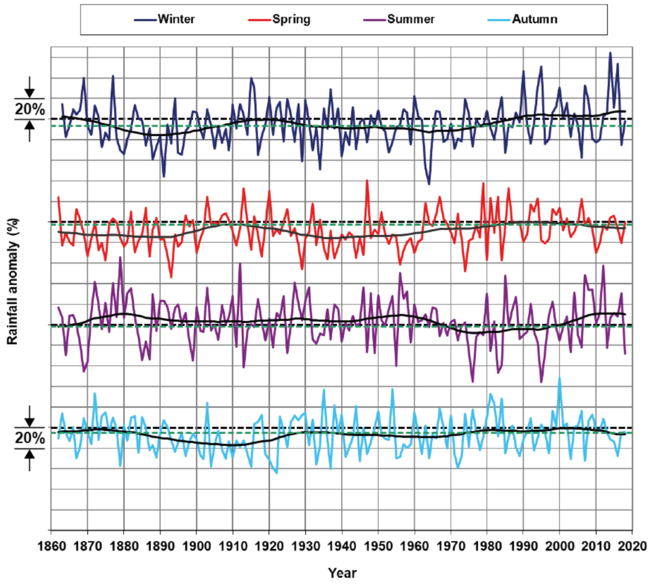
in comparison with storms Ali, Bronagh and Callum, the remainder of the year was mainly relatively quiet.

The precipitation data show large annual variability, with a slight increase from the 1970s onwards (Figure 24). The most recent decade (2009–2018) has been on average 5% wetter than 1961–1990 although only 1% wetter than 1981–2010; this increase is most pronounced for Scotland being 8% wetter than 1961–1990. The wettest year for the UK overall is 1872 (127% of average) and the driest 1887 (72%). Year 2018 was ranked in the middle third of the UK series from 1862. Six of the 10 wettest years in the UK series from 1862 have occurred since 1998, including 2014, 2012 and 2008.

Figure 25 shows seasonal rainfall series for the UK from 1862 to 2018 (for winter 1863–2018). The two recent winters of 2013–2014 and 2015–2016 stand out, each with over 150% of the 1981–2010 average UK rainfall overall. As with the annual series, the seasonal series typically show a large inter-annual variability about a relatively stable long-term mean, although with some decadal variability.

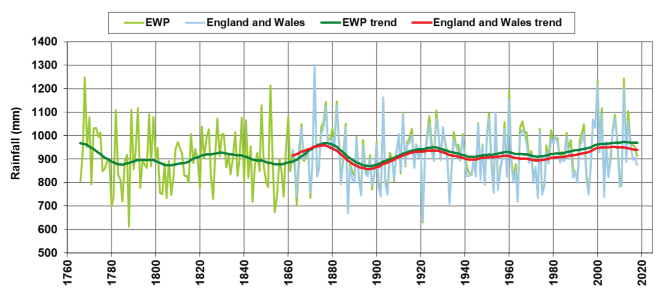
The annual rainfall total for 2018 in the long running England and Wales precipitation (EWP) series was 912 mm (Figure 26), which is 96% of the 1981–2010 average, making this an unremarkable year in the EWP series overall. Figure 26 shows there are some notable decadal fluctuations in the series such as a wet period through the 1870s, and the "Long Drought" from 1890–1910 (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 2% wetter than 1981–2010 and 5% 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 0.98 and root mean square difference of 1.9%. 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 27 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.*, submitted).



Season	1961-1990 average	1981-2010 average	2009-2018 average	2018
Winter	307	329	345	322
Spring	231	237	217	236
Summer	236	240	267	173
Autumn	326	343	326	328

FIGURE 25 Seasonal rainfall for the UK, 1862–2018 (note winter from 1863–2018; year is that in which January and February fall. Winter 2019—which includes December 2018 – will appear in State of the UK Climate 2019). Light grey grid-lines represent anomalies of ±20%. The table provides average values (mm)



Area	1961-1990 average	1981-2010 average	2009-2018 average	2018
EWP	915	948	965	912
England and Wales	906	936	933	875

FIGURE 26 Annual rainfall for EWP series, 1766–2018, and England and Wales areal series, 1862–2018 (mm). The table provides average values (mm)

The increasing winter rainfall has been offset by a slightly smaller reduction in summer rainfall, although a run of recent wet summers from 2007 to 2012 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

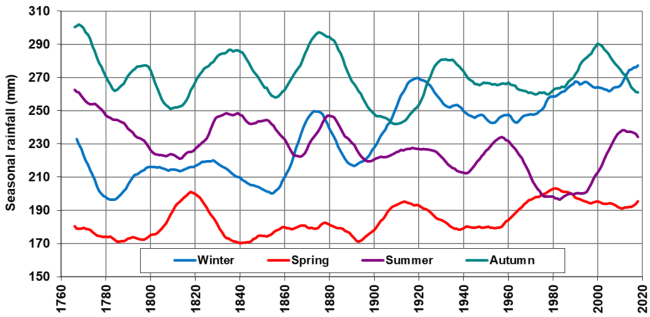


FIGURE 27 Seasonal rainfall trends for EWP series in mm, 1766–2018 (note winter from 1767). The figure shows a smoothing trend for each series using a weighted filter (see Annex 2)

over estimated (Murphy *et al*., 2019). 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 over time can approach 1–4% depending on region in early decades, but less than 1 or 2% 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) during 2018 was mostly within 5 days of the long-term average, with a variable spatial pattern across the UK, but notably below normal across northern Scotland (Figure 28). In general, the monthly variation was comparable to the rainfall anomaly pattern (Figure 23), with fewer days of rain than average in May, June, July and October but more in January and March—although with some regional variation. The number of days of rain greater than or equal to 10 mm (RR10) was near-normal across much of the UK, but below normal across upland areas of the west and north—and again particularly western and northern Scotland (Figure 28), with February, March, November and December all having much fewer than normal RR10 in this

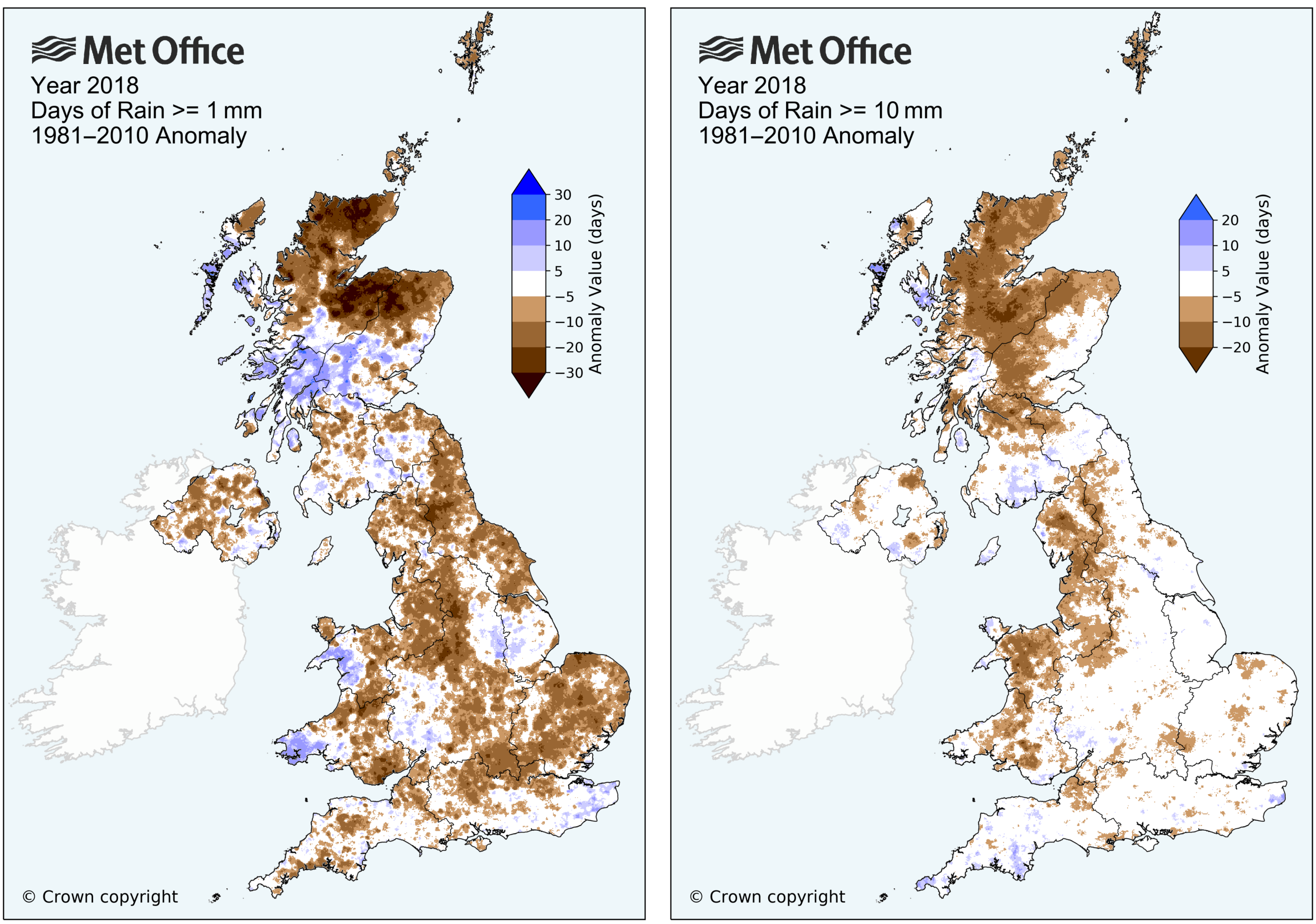
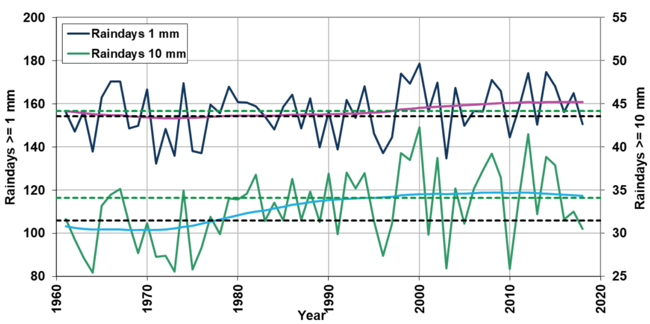


FIGURE 28 Days of rain ≥1 mm (RR1) and 10 mm (RR10) for 2018, difference from 1981–2010 average

area—these being climatologically among the wettest months of the year.

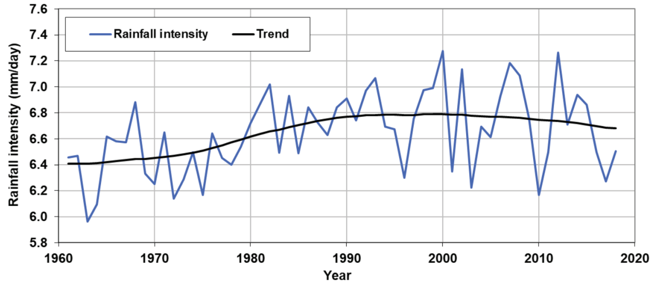
Figure 29 shows the annual area-average RR1 and RR10 for the UK for 1961–2018. Overall, 2018 was below the 1981–2010 average for both RR1 and RR10. For both RR1 and RR10 the year with the most days was 2000, and this year was also the third-wettest in the UK series from 1862, with only 1872 and 1903 wetter. While the RR1 series is broadly flat, the RR10 series shows a slight increase from around 31 days for 1961–1990 to 34 days for the period 1981–2010, an increase of around 10%. 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 30 shows an estimate of the areal-average rainfall intensity (see Annex 1 for definition) across the UK for each year from 1961 to 2018. 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, 2018 was also below the 1981–2010 average for this metric, and consistent with RR1 and RR10 also being below average. The 2 years with highest rainfall intensity in the series (2000 and 2012) also correspond to the wettest years in the UK series since 1961. There is a slight upward increase of 0.2–0.3 mm (approximately 3–5%), but again this is a short time-series dominated by year-to-year variability. The rainfall intensity series is well correlated with the RR10 series (R^2 value 0.70), as would be expected because in years with a large number of very wet days the average rainfall intensity on wet days is higher.



Climate variable	1961-1990 average	1981-2010 average	2009-2018 average	2018
Raindays >= 1mm	154	157	161	151
Raindays >= 10mm	31	34	34	30

FIGURE 29 Annual average number of days of rain ≥ 1 mm and 10 mm for the UK, 1961–2018. 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 values (days)



	1961-1990 average	1981-2010 average	2009-2018 average	2018
UK rainfall intensity	6.5	6.8	6.6	6.5

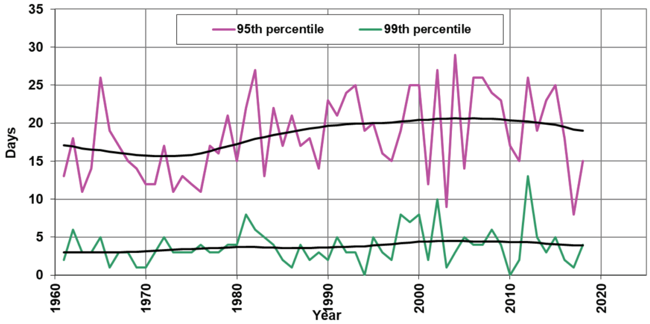
FIGURE 30 Annual average rainfall intensity for the UK on days of rain > = 1 mm, 1961–2018. The table provides average values (mm/day)

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.

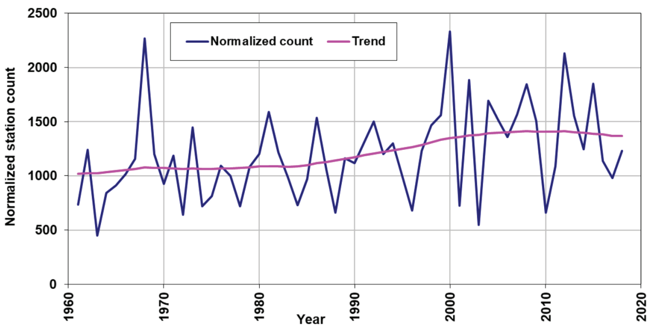
The 95th and 99th percentiles of UK daily areal-average rainfall based on the 50-year period 1961–2010 inclusive are 9.4 and 13.9 mm, respectively. Figure 31 plots the number of days each year in the series from 1961 to 2018 when this percentile was exceeded (by definition we would expect on average 18 days and 3–4 days, respectively). As with rainfall intensity, this neither includes a seasonal break-down, nor does it distinguish between orographically enhanced frontal rain and convective rain. The climatologically wetter parts of the UK in the north and west will tend to have a greater influence on this metric than the drier parts in the south and east, but rainfall would need to be fairly widespread across the UK to exceed these percentiles, so this metric gives some indication of trends in widespread heavy rain events.

Fifteen days in 2018 exceeded the fifth percentile, and 4 days exceeded the ninth percentile. The 4 days were 20 September (storm Bronagh), 12 and 13 October (storm Callum) and 15 December (storm Deirdre)—see the wind section of this report. They, therefore, corresponded to heavy and widespread frontal rainfall events associated with major autumn and winter Atlantic storm systems affecting the UK. Both series show large annual variability, with some decadal variability and a slight rising trend from around 17/3 days for 1961–1990 to 20/4 days for 1981–2010 for the fifth and 99th percentiles, respectively



Percentile	1961-1990 average	1981-2010 average	2009-2018 average	2018
99th	3	4	4	4
95th	17	20	19	15

FIGURE 31 The number of days per year with UK areal-average daily rainfall exceeding 95th percentile (9.5 mm) and 99th percentile (13.9 mm) from 2016 to 2018. Percentiles are calculated from the period 1961–2010. The table provides average values (days)



	1961-1990 average	1981-2010 average	2009-2018 average	2018
Number of station-days	1056	1263	1338	1231

FIGURE 32 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 2018, adjusted for station network size and excluding stations above 500 m asl. The table provides average 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 (1062, 1271). This is mainly because the adjustment for station network size has altered as a result of inclusion of year 2018. 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

(although with a subsequent small reduction for the most recent years)—that is again some evidence for a slight increase in widespread heavy rain events.

Figure 32 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 thousands 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.

3.3 | Snow

The UK experienced a spell of wintry weather in mid-January 2018, although not exceptional for the time of year. Snow depths from 16th to 22nd exceeded 20 cm across parts of Highland Scotland and the east of Northern Ireland, with up to 40 cm across southern Scotland and 53 cm at Leadhills, Lanarkshire on 20th and 21st. There were numerous road traffic accidents including two fatalities in Northern Ireland, and schools were closed across Northern Ireland, northern England and Scotland. Severe transport disruption affected Scotland on the 16–17th, with a 7-mile traffic jam on the M74 due to jack-knifed lorries. Further disruption affected the east of England and the Midlands on the 21st from snow as frontal systems pushed into the colder air from the south-west; East Midlands airport was closed for a time. There was further disruption from snow across western and central parts of England, North Wales, Northern Ireland, the Highlands and Scotland's Central Belt in mid-February.

The most significant snow event of the year occurred from late February to early March. High pressure dominating Scandinavia and Northern Europe blocked milder Atlantic weather, with a bitterly cold easterly airflow affecting the UK. Initially, eastern England and eastern Scotland were affected by snow showers from the North Sea, with convergence lines running through the English Channel and other areas such as eastern Scotland. There was further heavy snow across southern and south-west England and South Wales on first March as storm Emma in the Bay of Biscay pushed mild, moist air north across the UK. Strong winds caused significant drifting of lying snow and this lay un-melted for several days. The greatest snow depths were across Scotland's Central Belt with 49 cm at Drumalbin, Lanarkshire, 46 cm at Glasgow, Bishopton and 41 cm at Spadeadam, Cumbria on second March. The Met Office issued two Red Warnings for snow and this was the most significant spell of snow and low temperatures across the UK since December 2010 (for more details see the weather events section).

This event caused major disruption to road, rail and air travel. In the worst affected areas, numerous major roads were impassable or experienced severe delays, there were large numbers of road traffic accidents and in several cases vehicles stranded overnight. Hundreds of trains and flights were cancelled or delayed widely across the UK. Thousands of schools were closed for several days, while tens of thousands of homes lost electricity supplies. There were reported to be at least 10 weather-related deaths, and in early March Chinook helicopters were used to drop supplies to some isolated communities in east Cumbria.

A brief return of cold easterly winds on 17–18th March led to further snow, with southern coastal counties and southwest England particularly affected by significant lying snow. There was further widespread transport disruption (with flights cancelled at Heathrow, Gatwick and London City Airports) although overall the extent and severity of this snow event was less than at the start of the month. Northern parts of the UK were affected by snowfalls at the start of April, and there was further freezing rain, snow and ice across the north of the UK in mid-December, associated with storm Deirdre.

The late February to early March 2018 event saw significant and widespread lying snow across lowland areas of the UK. The last time this occurred in the UK was in January and March 2013 and before that there were major snow episodes in January and December 2010. Year 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 33 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. Year 2018 was a relatively snowy year in the context of the last two decades, but not as snowy overall as 2013, 2010 and 2009 and would be regarded as near-average for the first half of the series (with the 2018 network size roughly half that of the 1960–1990s, see Annex 1).

4 | SUNSHINE

The UK sunshine total for 2018 was 1,560 hours, 114% of the 1981–2010 average. This was the third sunniest year for the UK in a series from 1929, with only 2003 and 1995 sunnier. Sunshine totals were above normal across the majority of the UK, with more than 20% above average across parts of eastern and northern England, and especially northern

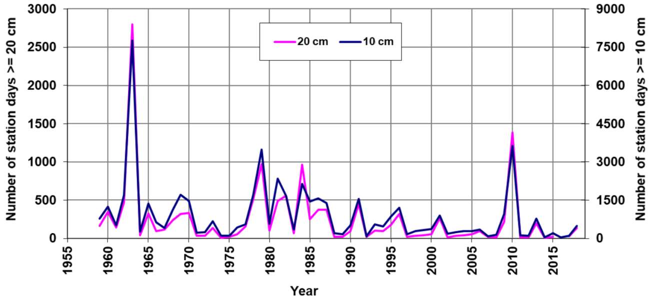


FIGURE 33 Count of number of station-days per year in the UK with recorded snow depths exceeding 10 and 20 cm, excluding stations above 500 m asl. This series has not been adjusted for network size. The 2018 values are 493 (10 cm) and 133 (20 cm)

Scotland and the Northern Isles. Northern Scotland recorded its second-sunniest year on record. The highest sunshine anomalies were at Kinloss, Moray (134% of average), Shoeburyness, Essex (127%) and Lerwick, Shetland (126%) but the majority of stations recorded sunshine anomalies of between 110 and 120% (Figure 34). Note however the possibility that imperfect exposure at individual stations and the relatively sparse density of stations are likely to have had

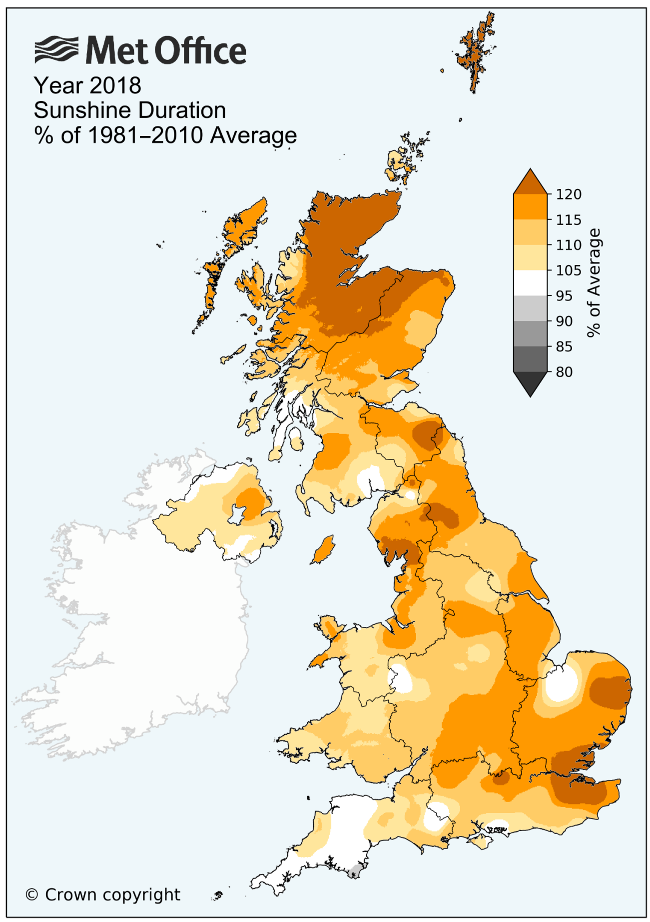


FIGURE 34 Sunshine anomalies (%) for year 2018 relative to 1981–2010

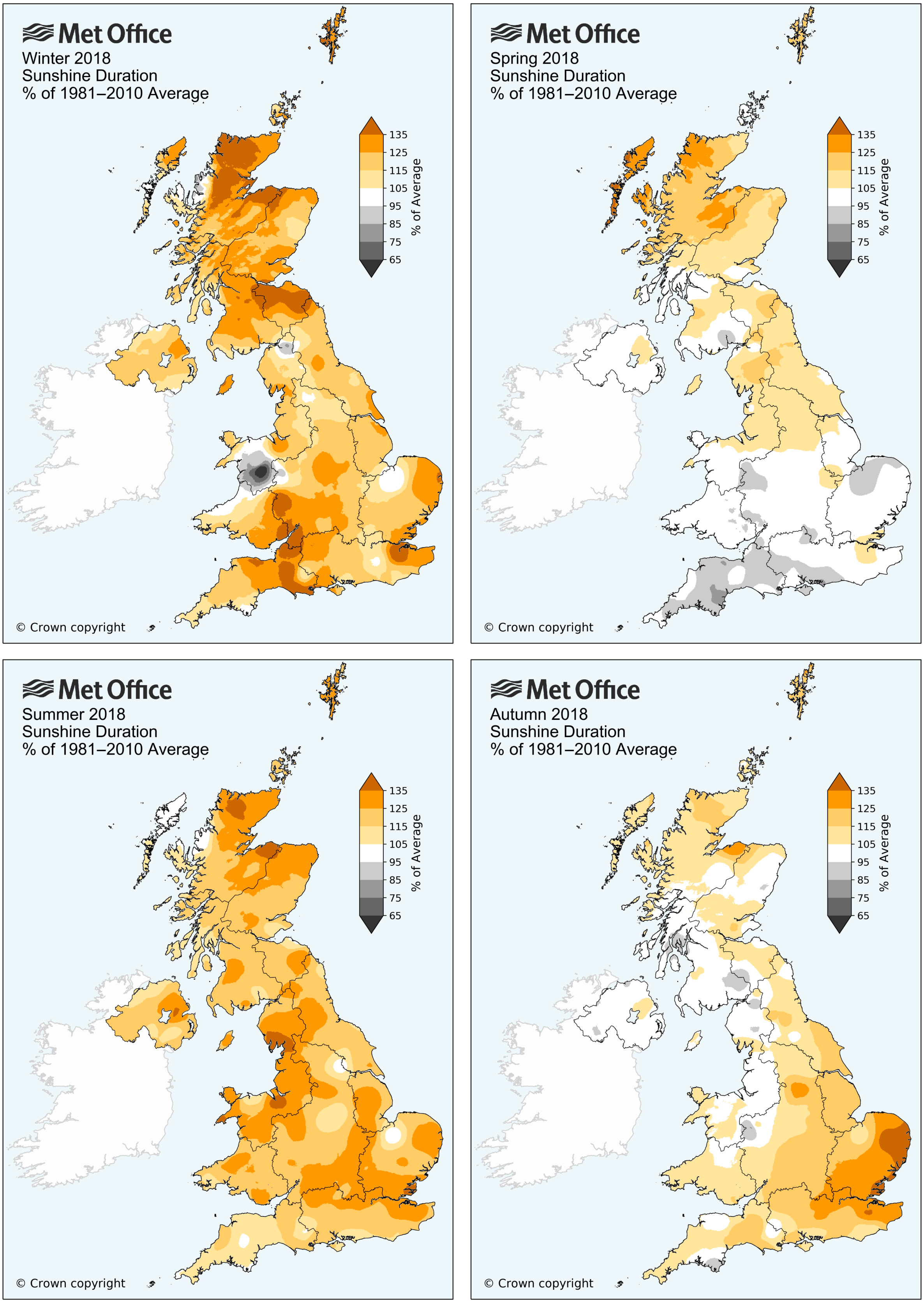


FIGURE 35 Sunshine anomalies (%) for seasons of 2018. Winter 2018 refers to the period December 2017 to February 2018

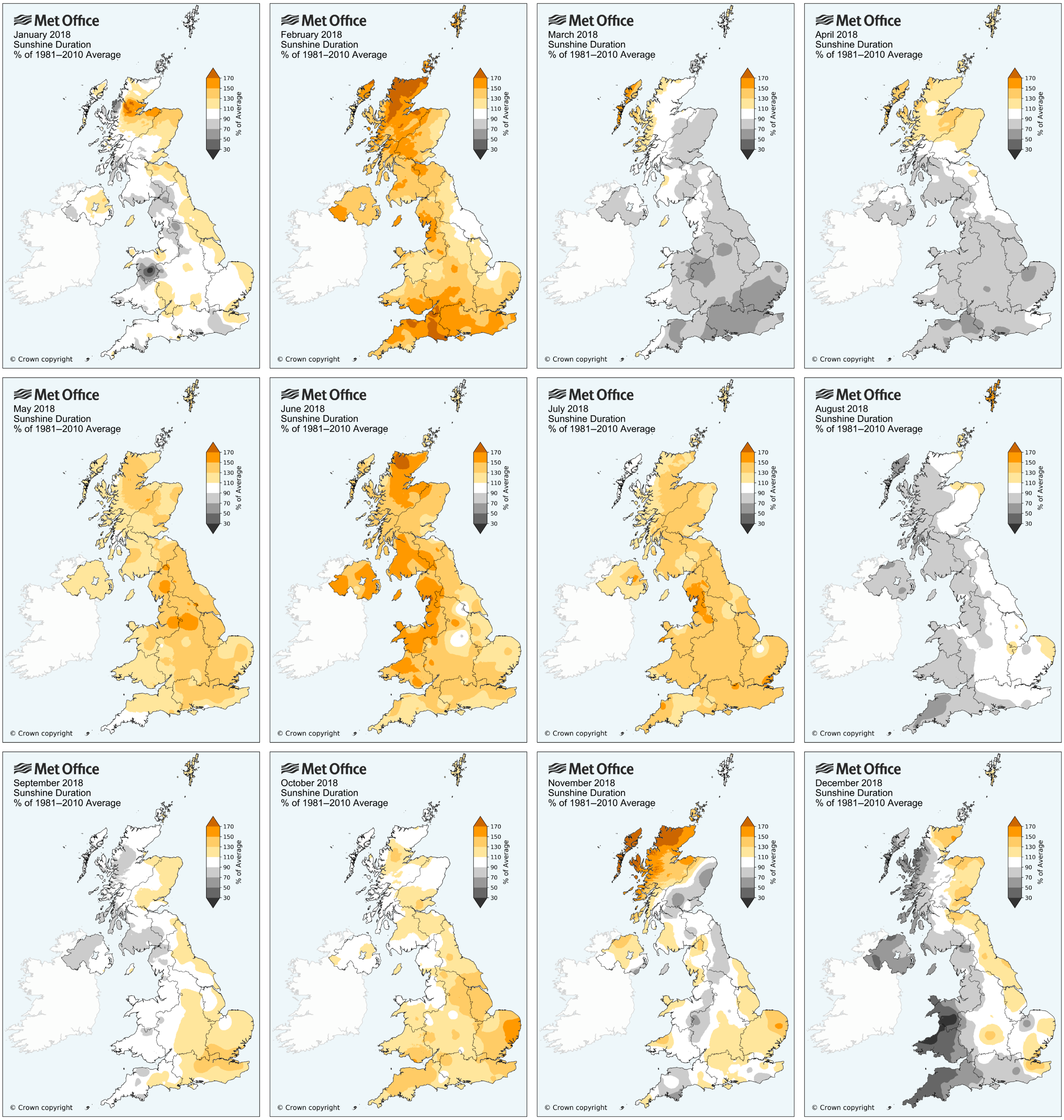


FIGURE 36 Sunshine anomalies (%) for months of 2018

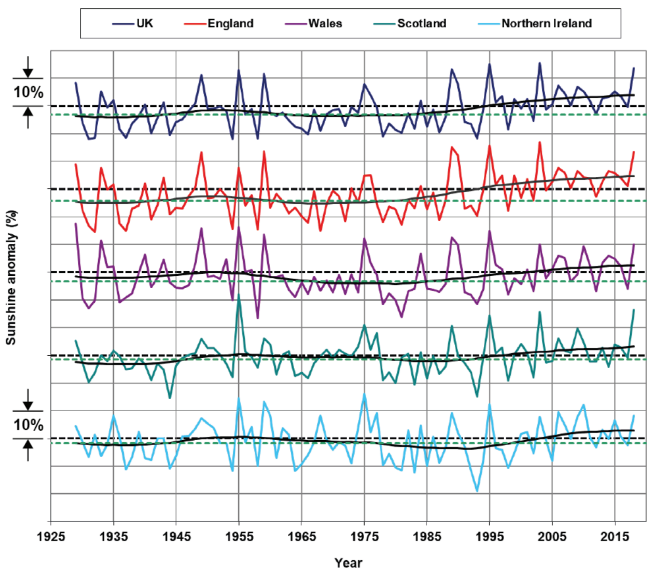
some influence on the detail in the sunshine anomaly pattern. The UK's highest annual sunshine total was 2,171 hours at Shoeburyness, but several other stations in Dorset, East and West Sussex and Kent also recorded more than 1900 hours. The lowest total was at Loch Glascarnoch, Ross-shire with 1,177 hours (still well above average in this location).

Winter 2018 (December 2017 to February 2018) was sunny overall across most of the UK. December and January sunshine totals were near normal across the UK, but with significant regional variation. February was sunnier than average almost everywhere, with a sunshine total exceeding December and January combined. It was the second-sunniest February in the UK series from 1929.

March and April were relatively dull across much of the UK, except for some northern areas. In contrast, May was sunny across the UK—it was the second-sunniest May in the UK series from 1929. June and July were also each sixth-sunniest in the series, and the UK's 3-month sunshine total for May–July of 709 hours (7.8 hours per day and 134% of the 1981–2010 average) represented the sunniest 3-month period for the UK in the series from 1929 by a margin of 11 hours. August was rather dull in western areas but even so the UK's summer sunshine total was fifth highest in the series from 1929 and the sunniest summer since 1995.

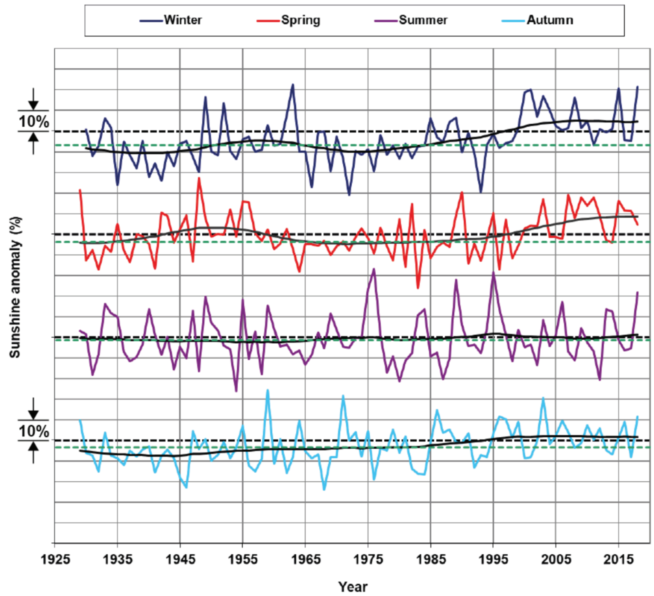
Southern and eastern areas, particularly East Anglia, were relatively sunny through the autumn, while November was a sunny month across the far north-west of the UK. December 2018 was bright in eastern areas but very dull in parts of the south-west; Wales had its dullest December and calendar month on record with only 18 hours of bright sunshine (Figures 35 and 36).

Figures 37 and 38 show annual sunshine anomalies for the UK and countries, and seasonal sunshine anomalies for the UK, from 1929 to 2018 inclusive. The smoothed trend shows a slight increase in sunshine from a low during the 1960–1980s to a sunnier period from 2000 onwards. The most recent decade (2009–2018) has had for the UK on average 7% 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 11 and 14% higher than 1961–1990, respectively. Of note is the run of sunny springs for the UK since 2007 (with the exception of 2013 and 2014).



Area	1961-1990 average	1981-2010 average	2009-2018 average	2018
UK	1328	1373	1426	1560
England	1430	1493	1561	1693
Wales	1355	1402	1437	1545
Scotland	1167	1184	1221	1378
Northern Ireland	1240	1260	1302	1364

FIGURE 37 Annual sunshine duration (hours) for UK and countries, 1929–2018, 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 values (hours)



Season	1961-1990 average	1981-2010 average	2009-2018 average	2018
Winter	147	158	163	191
Spring	419	436	477	456
Summer	498	505	510	615
Autumn	264	274	278	306

FIGURE 38 Seasonal sunshine duration for the UK, 1929–2018 (note winter from 1930 to 2018; year is that in which January and February fall). Light grey grid-lines represent anomalies of ± 10%. The table provides average values (hours)

The sunshine network is relatively sparse, with the 2018 network comprising around 110 stations (Figure A1.4). This means that some parts of the UK such as Highland Scotland and central Wales have 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%. More details can be found in Annex 2.

5 | WIND

The windiest days of 2018 are listed in Table 4. Storms are named as part of an initiative between the Met Office and Met Eireann, and similar schemes by other European national meteorological agencies. The naming of storms was aimed at improving the communication of approaching severe weather through the media and government agencies by using a single authoritative system. This scheme was introduced in autumn 2015 with storms named if they had the potential to cause medium or high impacts from wind on the UK and/or Ireland. The naming system was subsequently adjusted to take into account other weather types, so storms could be named on the basis of impacts from wind but also include impacts of rain and snow. The change in convention means that the number of named storms from year-to-year should not be used as a climate index in its own right.

Storm Eleanor brought strong winds across Northern Ireland and most of England and Wales on 2 to January 3, 2018. Winds were widely 50–60 Kt (58–69 mph) around exposed coastlines but some inland locations also recorded gusts well over 50 Kt, with 63 Kt (72 mph) at Northolt, Greater London—it is fairly unusual for winds as strong as this in the London area. Storm Fionn on 16 January was named by Met Eireann and brought strong winds across much of Ireland although impacts were limited in the UK.

Storm David was named by Meteo France and tracked rapidly eastward across the southern half of the UK overnight 17–18 January. The strongest gusts were in a swathe from North Wales, through the south Pennines to Lincolnshire and Norfolk, exceeding 60 Kt even in some inland locations. Capel Curig, Conwy recorded a gust of 81 Kt (93 mph), the UK's highest gust of the year at a low-level station, and Tibenham, Norfolk recorded a gust of 72 Kt (83 mph), the highest gust in East Anglia since October 27, 2002. The storm brought significant disruption with over 100,000 properties without power, reports of fallen trees and rail services affected. The storm continued to intensify as it moved in to the North Sea—causing further disruption across Holland and Germany (where it was named Friederike) (Table 5).

Storm Georgina on 24 January was a fairly typical winter storm tracking across the north of Scotland. The strongest winds were near the centre of the low with a gust of 74 Kt (85 mph) at South Uist, Western Isles. Storm Emma on 2 March was named by the Portuguese Met Service. The main impact for the UK was related to snowfall initiated by the milder moist air pushing north.

TABLE 4 The windiest days of year 2018

Date	England (96)	Wales (15)	Scotland (35)	N Ireland (11)	Total	Named storm
02 January, 2018	22	8	2	6	38	Eleanor
03 January, 2018	41	7	1		49	Eleanor
04 January, 2018	22	8			30	
14 January, 2018		1	9		10	
16 January, 2018	8	3	3		14	Fionn
17 January, 2018	10	7	2		19	David
18 January, 2018	52	11			63	David
24 January, 2018	16	9	18	2	45	Georgina
27, January, 2018		1	14		15	
10, January, 2018	5	4	2		11	
14, January, 2018	1	4	15	1	21	
02 March, 2018	10	4	2	1	17	Emma
14 June, 2018	8	3	14	6	31	Hector
19 September, 2018	17	9	29	9	64	Ali
20 September, 2018	7	3	3		13	Bronagh
12 October, 2018	19	8	13	3	43	Callum
09 November, 2018	9	3	9	4	25	
28 November, 2018	16	13	16	3	48	
29 November, 2018	19	8	2		29	
07 December, 2018	5	4	4	1	14	
08 December, 2018	11	4			15	
15 December, 2018	10	10	14	3	37	Deirdre
18 December, -2018	5	2	12	6	25	

Note: The table lists dates where 10 or more stations across the UK recorded a maximum wind gust greater than or equal to 50 Knots (58 mph) on that day. The table also gives a count of affected stations by country. The number of wind observing sites in 2018 for each country (based on data availability) is also given in brackets

However wind gusts reached 73 Kt (84 mph) at Warcop Range (Cumbria).

The last named storm of the 2017/2018 season was storm Hector on June 14, 2018, bringing unseasonably strong winds to the UK in contrast to a spell of largely fine, settled weather over the previous few weeks. Hector brought widespread disruption to Northern Ireland and Scotland, where winds gusted at over 50 Kt in exposed locations. Gusts of 64 Kt at Orlock Head, County Down and 62 Kt (71 mph) at Capel Curig were close to record values for June for Northern Ireland and Wales, respectively. Historical examples of previous stormy June days include June 1, 2015, June 22, 2008 and June 23, 2004.

The first storms of the 2018/2019 season arrived in close succession in mid-September, marking an emphatic transition from the fine summer of 2018 to autumn. Storm Ali brought widespread gusts in excess of 60 Kt (69 mph) across the north of the UK on 19 September and this was one of the most notable storms at this time of year in recent decades. Two people died in County Armagh and County Galway (Irish Republic) and there was extensive travel disruption and power outages (for more details see the weather events section). Storm Bronagh on 20–21 September brought strong winds across southern England and Wales but impacts were mainly flood-related from heavy rain. Storm Callum on 12 October brought wind gusts of 50–60 Kt across exposed locations in the north and west of the UK but this storm was also much more significant for heavy rain across south Wales (for more details see the weather events section). Storm Deirdre brought strong winds to western and northern parts of the UK in mid-December but impacts were mainly related to freezing rain.

As a measure of storminess Figure 39 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

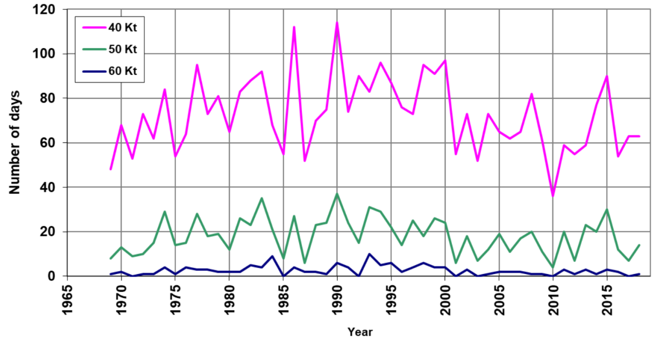


FIGURE 39 Count of the number of individual days each year during which a max gust speed ≥40, 50 and 60 Kt (46, 58, 69 mph; 74, 93, 111 kph) has been recorded by at least 20 or more UK stations, from 1969 to 2018. Stations above 500 m above sea level are excluded

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 max 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.

The most significant storms of 2018 were David and Ali—in mid-January and mid-September, respectively. The latter was a very significant September storm with over 30 stations recording a maximum gust speed of 60 Kt (69 mph) or higher, but this was the only day of the year where at least 20 stations reached this threshold. Overall 2018 was an unexceptional year for storminess when compared to previous decades and does not stand out in terms of the 40, 50 or 60 Kt metrics. There were many windier years than 2018, particularly in the 1980s and 1990s.

Note that the 40 Kt counts as shown in Figure 35 broadly track the 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 January 25, 1990, the "Boxing Day Storm" of December 26, 1998 and the "Great Storm" of October 16, 1987. In the last decade, the most significant major winter storms have been on December 5, 2013, January 3, 2012 and December 8, 2011, and none of the storms of 2018 compared with these 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 39 is based comprises around 130 stations in

TABLE 5 UK Named storms of 2018

Name	Date of impact on UK and/or Ireland
Eleanor	2–3 January
Fionn	16 January
David	17–18 January
Georgina	24 January
Emma	1–2 March
Hector	14 June
Ali	19 September
Bronagh	20–21 September
Callum	12–13 October
Deirdre	15–16 December

the 1970s, 150 in the 1980s, 190 in the 1990s and 2000s and 160 in the 2010s. Figure 39 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.

6 | SEA LEVEL

A UK sea level index (Figure 40) for the period since 1901 provides a best-estimate trend of 1.4 ± 0.2 mm/year for sea level rise, when excluding the effect of vertical land movement (Woodworth *et al.*, 2009). This is close to the estimate of 1.7 ± 0.2 mm/year estimated for the global sea-level rise suggested by the Fifth Assessment Report of Intergovernmental Panel on Climate Change (Church *et al.*, 2013). However, UK sea level change is not a simple linear increase, but also includes variations on annual and decadal timescales. A number of large-scale atmospheric and ocean processes contribute to non-uniform sea-level rise around the coast of the UK.

The UK sea level index for 2018 was the equal-highest on record (with 2015) in this series. However, the 2018 value is based on one station only (Newlyn) due to missing data for the other stations at various times during the year. The error bars indicate uncertainty (1 *SD*) in values for individual years; the method for calculating uncertainties does not currently taken into account missing stations. Unfortunately, the 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. Years 2010 and 2018 values are based on only one gauge so error bars are not available.

Figure 41 presents a 100-year record of sea level at Newlyn, Cornwall showing time-series of the annual 99th percentile water level and annual maximum water levels, relative to the long-term mean for the 99th percentile. The 99th percentile is the level which is exceeded 1% of the time, or for about 88 hours in any given year. Any periods of high tides and storm surges in the year are likely to be in the 88 hours above the 99th percentile. The annual maximum water level shows greater annual variability than the 99th percentile series. Consequently, the 99th percentile time-series is sometimes preferred because it provides a description of change in high and low water characteristics without the greater year-to-year variability inherent in the true extremes.

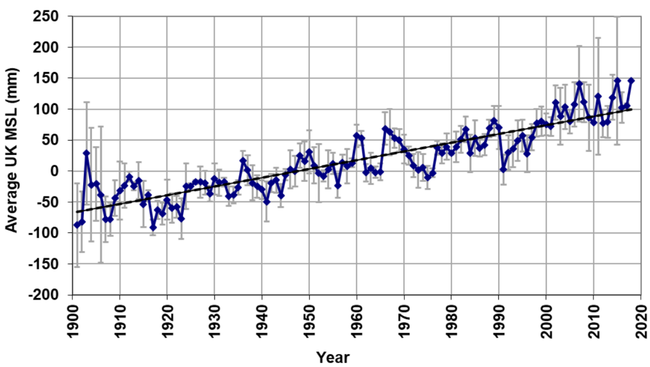


FIGURE 40 UK sea level index for the period since 1901 computed from sea level data from five stations (Aberdeen, North Shields, Sheerness, Newlyn and Liverpool) from Woodworth *et al.* (2009). The linear trend-line has a gradient of 1.4 mm/year

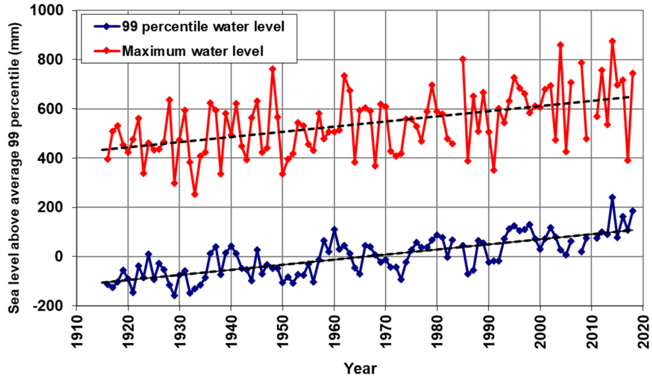


FIGURE 41 Extreme sea levels at Newlyn, Cornwall (1916–2018), in mm. The blue and red time-series are annual 99 percentiles and maximum water levels respectively. Levels are relative to the long-term average for the 99 percentile, computed for the whole period 1916–2018. The linear trend-lines for the 99th percentile and maximum water levels each have gradients of 2.1 mm/year

The 99th percentile water level at Newlyn for year 2018 was the second highest in the series, with year 2014 highest. The highest maximum water level during 2018 was seventh highest. The long-term trends in 99 percentile level and highest maximum water levels are both 2.1 mm/year for the period 1916–2018.

7 | EXTREMES FOR YEAR 2018

Table 6 shows the UK weather extremes for year 2018. The highest temperature of the year, 35.6°C at Felsham, Suffolk on 27th July was the UK's highest temperature since 36.7°C at Heathrow Airport on July 1, 2015. Temperatures also reached 35.3°C on 26th July. In the last 50 years, 35°C has been reached in 2018, 2015, 2006, 2003, 1995, 1990 and 1976, but only widely (10 or more stations) on 4 days—July 19, 2006, August 6 and 10, 2003 and August 3, 1990.

The lowest minimum of −14.2°C at Faversham, Kent occurred on the last day of the meteorological winter at the

TABLE 6 Annual extremes for the UK for year 2018, excluding stations above 500 m above mean sea level (masl)

Extreme	Observation	Date	Station
Highest daily maximum temperature (09–09 GMT)	35.6°C	27 Jul	Felsham, Suffolk 92 masl
Lowest daily minimum temperature (09–09 GMT)	−14.2°C	28 Feb	Faversham, Kent 46 masl
Lowest daily maximum temperature (09–09 GMT)	−5.3°C	28 Feb	Malham Tarn, North Yorkshire 381 masl
Highest daily minimum temperature (09–09 GMT)	21.5°C	27 Jul	Hastings, East Sussex 45 masl
Lowest grass minimum temperature (09–09 GMT)	−16.8°C	28 Feb 28 Feb	Odiham, Hampshire 118 masl Benson, Oxfordshire 57 masl
Highest daily rainfall (09–09 GMT)	183.4 mm	12 Oct	Trecastle, Powys 260 masl
Greatest snow depth (09 GMT)	57 cm	4 mar	Little Rissington, Gloucestershire 210 masl
Highest daily sunshine	17.0 hr	25 Jun	Kinloss, Moray 5 masl
Highest gust speed	81 Kt 93 mph	17 Jan	Capel Curig, Conwy 216 masl
Highest gust speed (mountain)	116 Kt 133 mph	15 Dec	Cairngorm summit, Inverness-shire 1,237 masl

Note: Stations above 500 masl are considered as mountain stations and therefore not representative of low-level areas. Channel Island values are also quoted if these exceed UK values

start of the spell of severe winter weather; temperatures fell widely below −10°C across Kent and Surrey. It is comparatively unusual for the UK's lowest minimum to occur outside Scotland, and this was the only day of the year where more than 10 stations fell below −10°C. During this spell, the strong easterly wind substantially reduced the normal diurnal temperature variation, with the relatively mild influence of the North Sea preventing overnight temperatures falling further. The greatest snow depth of 57 cm at Little Rissington, Gloucestershire on fourth March also occurred during this spell but is likely to have been significantly influenced by drifting.

The highest daily rainfall total of 183.4 mm occurred during storm Callum and this was a major rainfall event across South Wales. This total is only 28 mm below the Wales daily rainfall record. The highest gust speed of 81 Kt at Capel Curig occurred during storm David and is fairly typical for the UK. This station, although not at a particularly high elevation, is often the windiest in the UK, being located in an exposed position in a west–east orientated valley in Snowdonia where local topography is likely to have a significant influence on gust speeds.

8 | SIGNIFICANT WEATHER EVENTS OF 2018

This section describes notable weather events which occurred during 2018. 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. A discussion of notable and named storms for 2018 is also included in the wind section of this report.

8.1 | Snow and low temperatures late February to early March

The UK experienced a spell of severe winter weather with very low temperatures and significant snowfalls from late February to early March 2018. In terms of weather impacts, this was the most significant weather event of the year. There was severe travel disruption with roads closed, numerous road traffic collisions and cars were stranded overnight on many roads in both Scotland and England, for example, the A31 in Hampshire and M80 in Scotland. Rail series were cancelled and air transport was severely disrupted, for example, Glasgow airport closed on 28 February. Thousands of schools across England, Wales and Scotland were closed, and many areas suffered power cuts. Isolated communities and farms across the North Pennines received supplies by helicopter.

Figure 42 shows analysis charts for 28 February and March 2, 2018. A large area of high pressure dominated Scandinavia and northern Europe with an easterly airflow drawing bitterly cold air originating from Finland, northwest Russia and the Barents Sea, extending across much of Europe and well out into the Atlantic. The squeeze in the isobars provides an indication of the strength of the easterly wind, leading to a wind-chill at times widely below −10°C

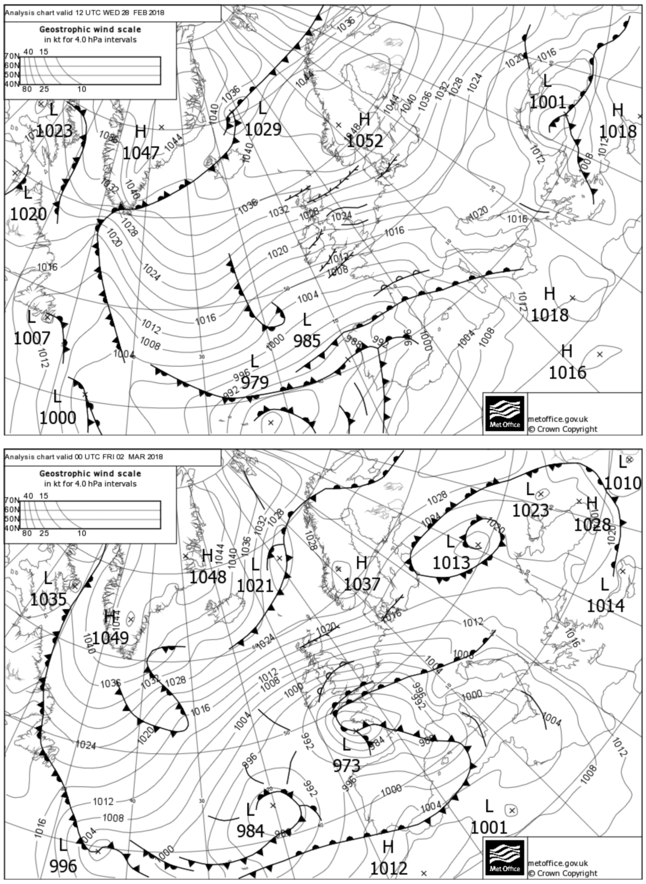


FIGURE 42 Analysis charts at (a) 1200 UTC February 28, 2018 and (b) 0000 UTC March 2, 2018

even at low-level. This situation was associated with a stratospheric warming event over the previous few days, blocking the Jet Stream and milder air associated with Atlantic weather systems. A discussion of the contributing factors which may have led up to this event, including the sudden stratospheric warming, is given in Greening and Hodgson, 2019.

Figure 43 shows rain-radar images during this event, with the majority of this precipitation falling as snow. Initially, the main areas affected by snow were across eastern England and eastern Scotland, from persistent snow showers as the easterly airflow picked up moisture from the North Sea. These snow showers tended form in convergence lines resulting in some locations receiving relatively little snow whereas others nearby very large amounts. Examples of these convergence lines run through the English Channel and other parts of the UK such as eastern Scotland; due to persistent heavy snow a Met Office Red Warning was issued for Scotland's Central Belt for 28 February (Figure 43a).

During the afternoon of 1 March, a low-pressure system in the Bay of Biscay (named as Storm Emma by the Portuguese Met Service) pushed north, bringing mild, moist air into the colder air resulting in further heavy snow, particularly across southern and south-west England and south Wales; the Met Office issued a second Red Warning for this event (Figure 43b). Subsequently as this milder, moist air moved north, much of the UK received further snow. Behind this weather system southern areas also experienced freezing rain (on contact with cold surfaces).

Figure 44 shows daily maximum temperatures from 27 February to March 3, 2018 relative to the 1981–2010 February and March long-term averages. On 28 February, maximum temperatures were typically below −2°C across central and eastern England and eastern Scotland, and below −4°C across upland areas in the north. Sheltered locations in the west and south remained nearer or above freezing, but all areas were exposed to the strong east wind, typically gusting at 20–30 Kt (23–35 mph); such conditions resulting in a “feels like” temperature of around −10°C. Even St Mary's Airport, Isles of Scilly, recorded a daily maximimum of only 0.8°C. These temperatures were widely between 8 and 10°C below the February average.

On March 1, 2018 (the first day of meteorological spring), daily maximum temperatures again remained widely below freezing. Parts of the west Midlands and south Wales recorded daily maximum temperatures more than 12°C below the March average (around −2°C compared to a March average of around 10°C). In these areas, some new records were set: −4.7°C at Tredegar, Blaenau Gwent was the lowest March daily maximum temperature for the UK and Wales; −3.7°C at Pennerley, Shropshire and Little Rissington, Gloucestershire was also the lowest March daily maximum temperature for England. A large number of long-running weather stations recorded their lowest March daily maximum temperature on record.

Figure 45 shows hourly air temperature and hourly maximum gust speed for Heathrow, Greater London, and Edinburgh, Gogarbank from 22 February to 8 March showing temperatures hovering around freezing or falling to around −5°C from 26 February to 3 March. The wind speeds picked up notably during this period, particularly on 1 and 2 March, contributing to the significant wind-chill. For example, on the morning of March 1, 2018 the air temperature at Heathrow was around −4°C with wind gusting at around 25 Kt, and by the morning of March 2, 2018 the temperature was around −1°C with wind gusting at around 40 Kt. The strong easterly wind suppressed the normal diurnal temperature cycle.

Conditions were particularly severe across upland areas. On 28 February, Cairngorm Summit recorded an air temperature of around −14°C with a wind speed gusting at around 50 Kt. By 1st March, the temperature had risen slightly to

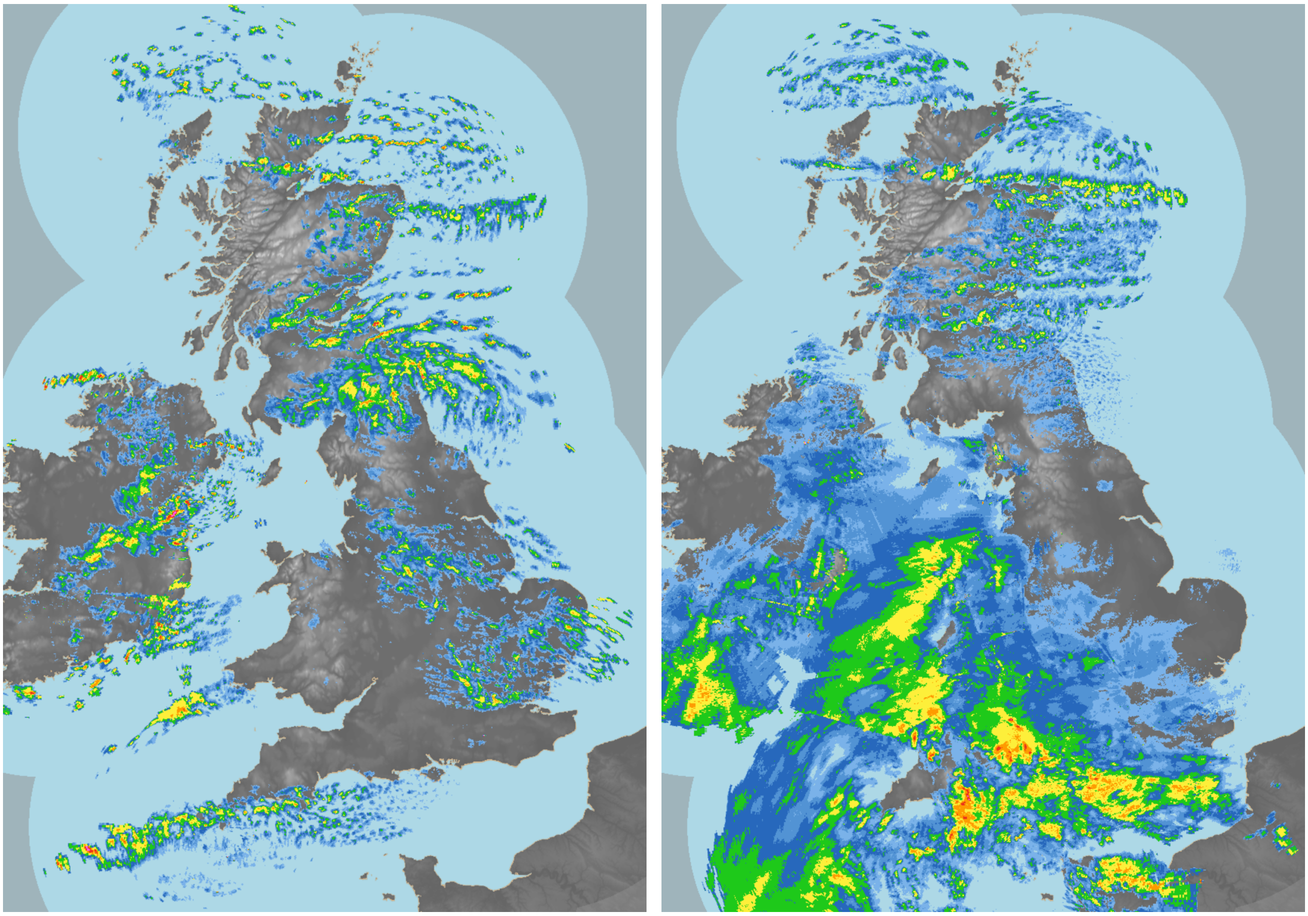


FIGURE 43 Rain-radar images at (a) 1200 UTC February 28, 2018 and (b) 2100 UTC March 1, 2018

around −10°C and wind gusting at up to 87 Kt (100 mph). The wind chill temperature approached −30°C and this arguably represented some of the most severe winter weather conditions experienced anywhere in the UK in the last 25 years (Kendon and Diggins, 2019).

Figure 46 shows snow depths at 09:00 UTC on March 2, 2018, with peak snow depths for this event. While almost all areas of the UK experienced some lying snow, the greatest depths were across upland areas of northern and eastern England and eastern Scotland, and subsequently to parts of south-west England and south Wales. Across northern England and southern Scotland depths were recorded of over 40 cm (49 cm at Drumalbin, Lanarkshire, 46 cm at Glasgow, Bishopton and 41 cm at Spadeadam, Cumbria), but depths were more typically 10–20 cm. Southern England and South Wales also received significant snow with 49 cm at St Athan, South Glamorgan, 25 cm at Hereford and 16 cm at Yeovilton (Somerset). Note the St Athan value is likely to have been significantly influenced by drifting.

Figure 47 shows time-series of snow depth measurements at these stations. Across northern areas snow accumulated steadily from 27 February to 2 March with depths subsequently reducing steadily but slowly due to the continuing low temperatures; by 7 March (a week after the event) significant lying snow was still present in many locations. The snow event across south-west England and South Wales occurred mainly on the afternoon and evening of 1 March. Strong winds resulted in significant drifting; for example, the A39 in North Devon was blocked due to wind effects on hedges at the side of the road while adjacent fields were stripped bare.

The last time the UK experienced a flow of bitterly cold air from Siberia, with significant snowfalls, was in March 2013, but the 2018 event was more severe in terms of extent, duration and severity and this was the most significant spell of severe winter weather since December 2010. In terms of atmospheric patterns, an analysis of the areal-extent and duration of the "cold pool" based on the NCEP reanalysis suggests that this was the second most severe cold pool event affecting the UK in the last 70 years, with only January 1987 more severe (Graham and Webb, 2019). It also demonstrated once again the potential for severe winter weather to still affect the UK, even in the context of a warming climate. In 2010, there were two

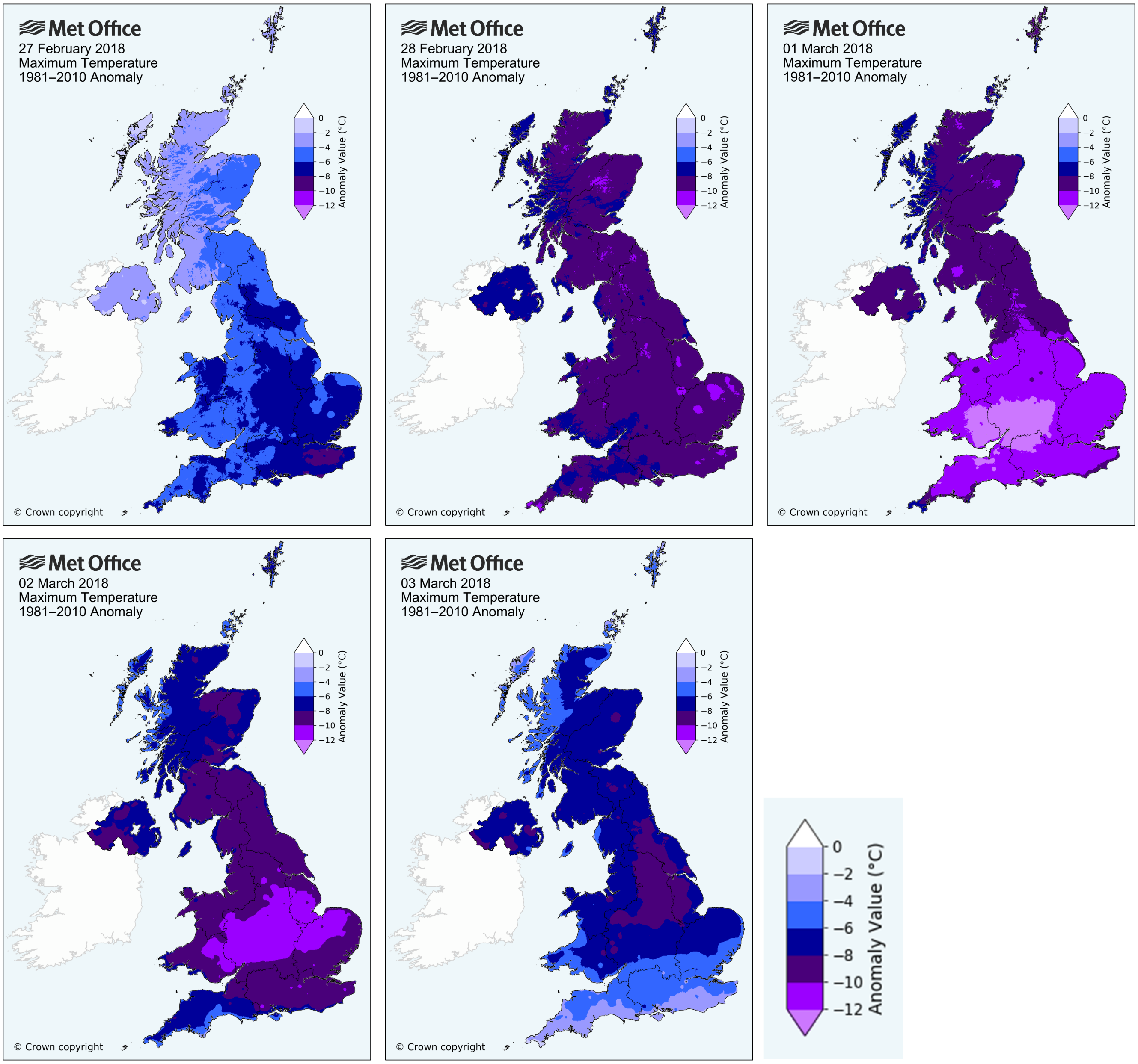


FIGURE 44 Daily maximum temperature relative to 1981–2010 monthly long-term average from 27 February to March 3, 2018

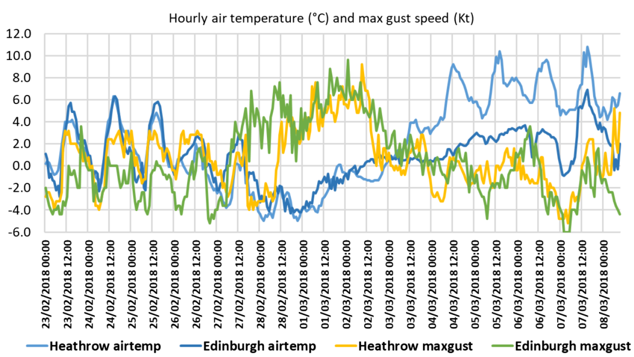


FIGURE 45 Time-series of hourly air temperature and maximum gust speeds at Heathrow and Edinburgh, Gogarbank from 23 February to March 8, 2018

spells of snow and freezing temperatures from late-November to early December, and from mid-December to Christmas. December 2010 was the coldest December for the UK in a series from 1884 and, remarkably, the second-coldest December for Central England in a series from 1659. Snow depths accumulated to 50 cm or more across upland areas of northern and eastern England and eastern Scotland with the temperature falling below −20°C in the far north (Prior and Kendon, 2011).

From 17 to March 19, 2018 the UK experienced a further spell of snow and low temperatures as easterly winds briefly returned. This was not as severe as the earlier spell but nevertheless still represented a significant event with parts of

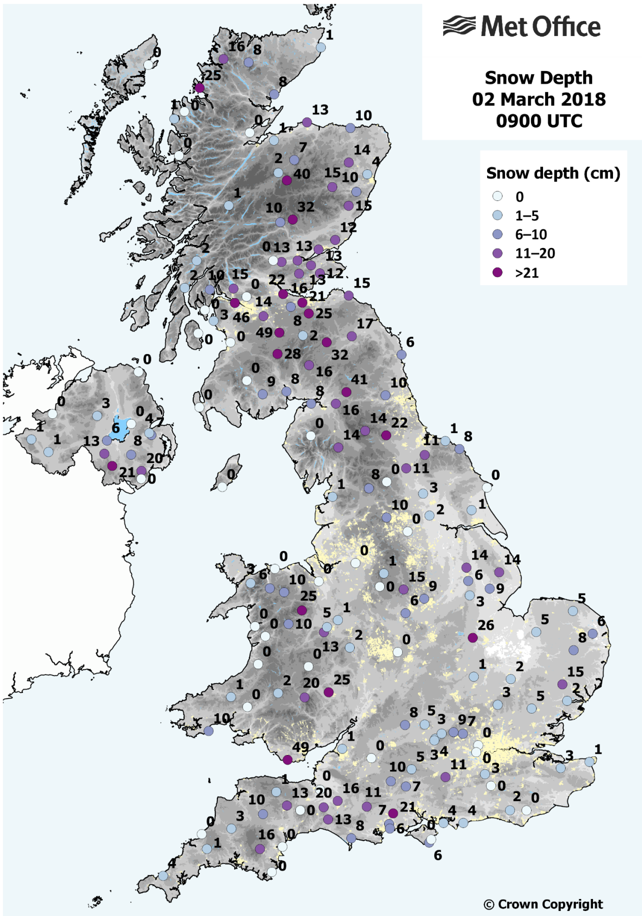


FIGURE 46 Snow depths at 0900 UTC March 2, 2018

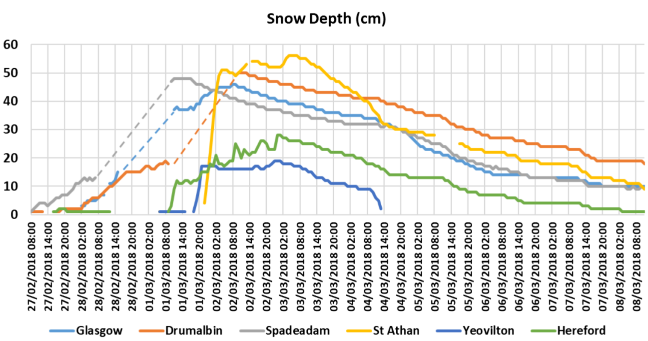


FIGURE 47 Hourly snow depth at Glasgow Bishopton, Drumalbin (Lanarkshire), Spadeadam (Cumbria), St Athan (South Glamorgan), Yeovilton (Somerset) and Hereford from 27 February to March 8, 2018. The hatched lines are periods of no data but have been included to provide an indication of the timing and overall rates of accumulation at these stations. These stations have been selected as showing the greatest snow depths and are likely to be significantly influenced by drifting, the large spatial variation in depths across the UK means that a 'representative' snow depth cannot realistically be defined

the south-west (for example Exeter) recording the second period of significant lying snow in just over 2 weeks. See also the cover image of this report.

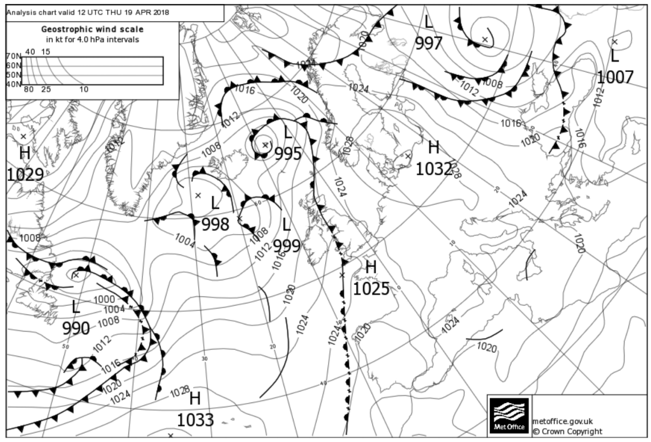


FIGURE 48 Analysis chart at 1200 UTC April 19, 2018 showing high pressure across the near continent drawing a hot southerly flow of air across central and eastern parts of the UK

8.2 | Exceptional warmth, April

The UK experienced some unusually high temperatures for the time of year from 18 to 22 April, with high pressure over the near continent drawing very warm air from the south (Figure 48). The hottest day was 19 April with temperatures across south-east England widely above 26°C and locally above 28°C - in places more than 14°C above the long-term average for the time of year (Figure 49). St James's Park (London) recorded a maximum temperature of 29.1°C making this the UK's warmest April day since 1949. A large number of long-running stations recorded their highest April on record (Table 7).

On April 19, 2018 Kenley Airfield (Greater London) recorded a daily minimum temperature of 15.9°C, a new April record for the UK, breaking the previous record of 15.2°C at Inverailort, Highland on April 15, 2007 and at Eastbourne, East Sussex on 23 April 2011. The spell of hot weather was in marked contrast to much colder conditions earlier in the month; daily maximum temperatures on April 12, 2018 across much of central England reached only 6 to 7°C. This difference of almost 20°C in little over a week nicely illustrates the highly variable nature of the UK's spring weather.

8.3 | Warm, dry and sunny summer

Summer 2018 brought plenty of warm, dry, sunny weather with the UK often under the influence of high pressure, particularly during June and July. This was the UK's warmest summer since 2006, and the driest and sunniest since 1995. Any short, unsettled spells brought rainfall mostly of a showery and sometimes thundery nature. Temperatures were often well above average with 30°C exceeded fairly widely on 15 days during July and early August. The summer mean

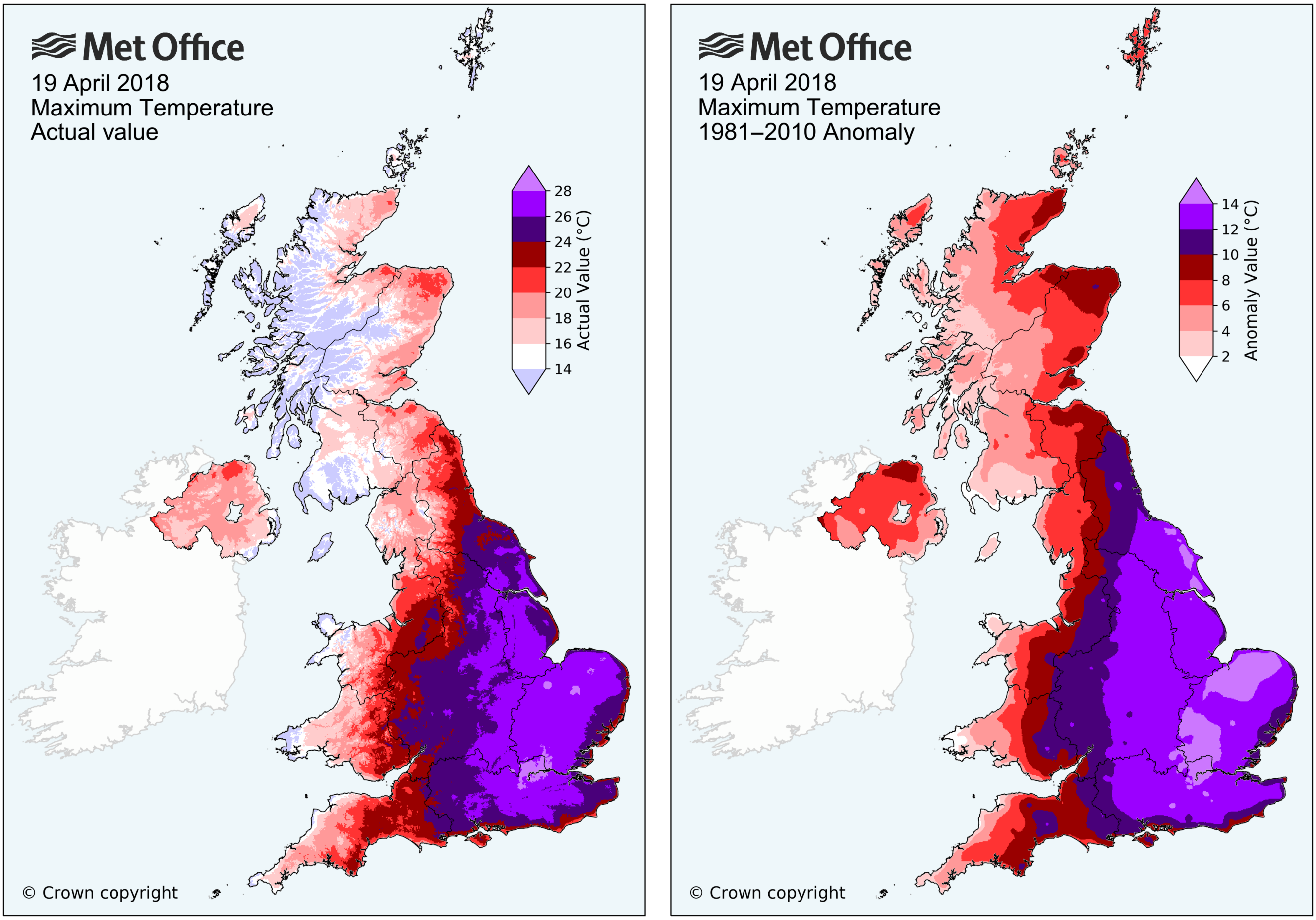


FIGURE 49 Daily maximum temperatures on April 19, 2018 as (a) actual values and (b) relative to 1981–2010 April long-term average

TABLE 7 April temperature records at long-running stations

Location	Max temp	Previous record	Previous date	Record length (years)
Sheffield, South Yorkshire	26.4	24.8	April 16, 2003	135
Bradford, West Yorkshire	24.3	23.9	April 15, 1949	109
Rothamsted, Hertfordshire	26.8	26.1	April 16, 1949	104
Woburn, Bedfordshire	27.1	26.1	April 16, 1949	103
Wisley, Surrey	28.3	27.8	April 23, 2011	103
Cranwell, Lincolnshire	26.3	25.3	April 23, 2011	102

temperature was around 2.0°C above average across much of England and Wales, largely as a result of warmth in June and July, whereas temperatures for August overall were nearer the long-term average (Figures 5 and 6). Most of England and Wales recorded less than 75% of average rainfall, with large areas of central England less than 50% (Figure 22). Summer sunshine totals were widely 125% of average or more across the UK (Figure 35).

While for the UK, this was the equal-warmest summer for the UK in a series from 1884, England had its warmest summer in the series (Figure 50) and it was also the equal-

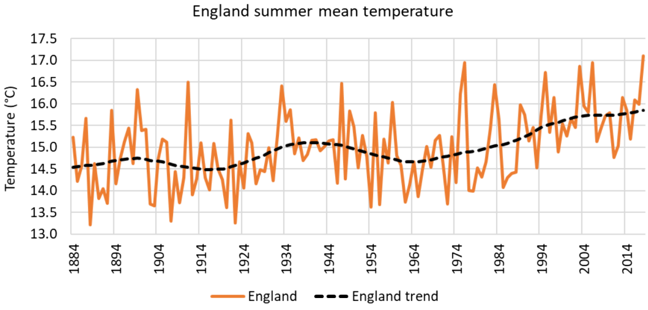


FIGURE 50 Summer mean temperature for England, 1884–2018

fourth warmest summer in the Central England Temperature (CET) series from 1659, with summer 1976 warmest in this series.

As is a feature of all the warmest summers in the UK series, mean maximum temperature anomalies relative to the long-term average were generally much higher than mean minimum temperature anomalies, as a result of generally dry air, low humidity and cloud-free skies resulting in a large diurnal cycle with long sunny days and an absence of cloud-cover at night. The UK mean maximum and minimum temperature anomalies for summer 2018 were + 2.3°C and + 0.8°C, respectively, but nevertheless in both cases this was the third-warmest summer in the series, for maxtemp behind 1976 and 1995 and for mintemp behind 2003 and 2006. The highest maxtemp anomalies were across central England, but in general significantly lower than summer

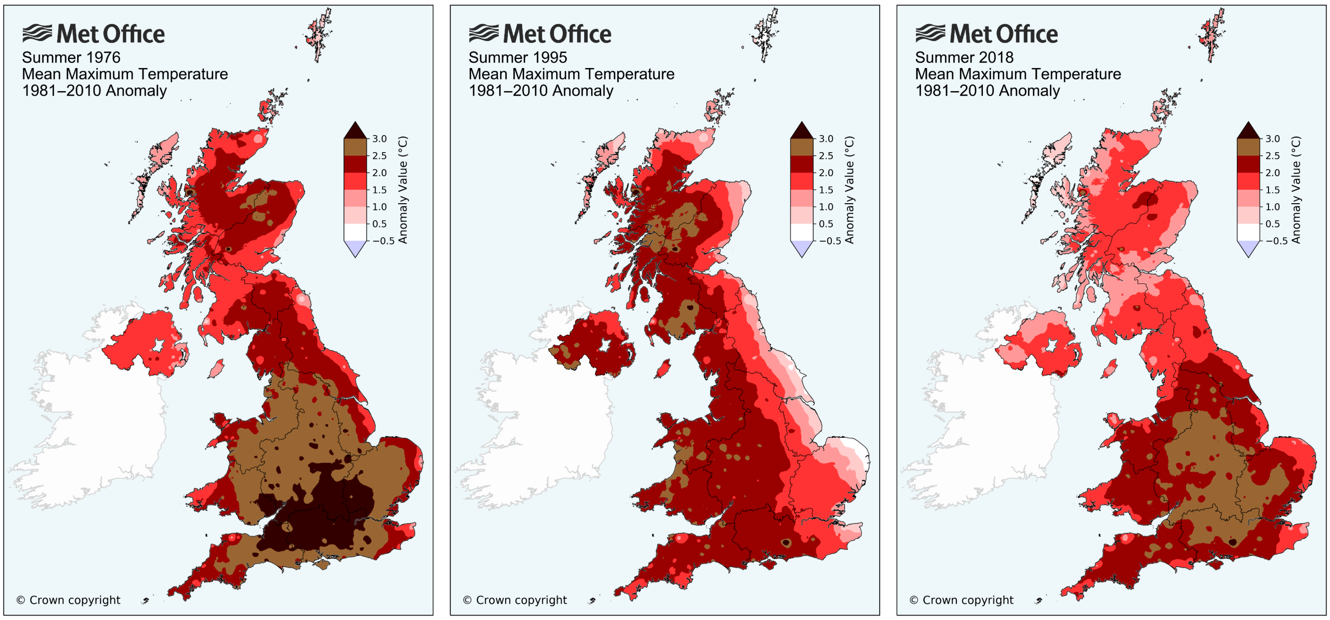


FIGURE 51 The three warmest summers for UK mean maximum temperature in a series from 1884:1976, 1995 and 2018, relative to the 1981–2010 long-term average

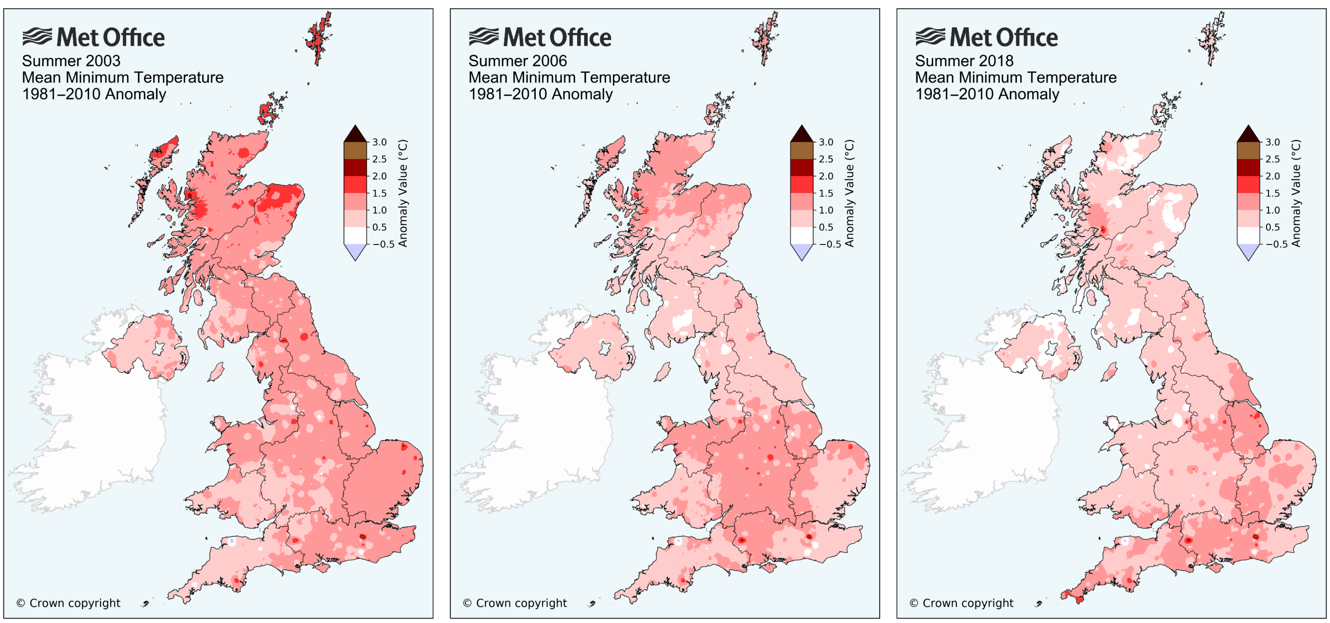


FIGURE 52 The three warmest summers for UK mean minimum temperature in a series from 1884:2003, 2006 and 2018, relative to the 1981–2010 long-term average

1976. The highest mintemp anomalies were also mainly across the southern half of the UK (Figures 51 and 52).

Figure 53 shows a count of the number of stations across the UK and England on each day during the summer with a daily maximum temperature exceeding 25°C. This shows a prolonged spell of widespread warmth from late-June to early August, with only brief interludes of cooler conditions around 11th, 17th and 29th July. The hottest weather was mostly focussed across England (particularly south-east England and East Anglia), but extended at times to north-western parts of the UK, particularly in late June and early July.

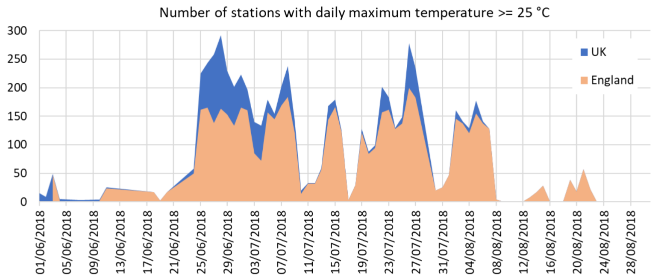


FIGURE 53 Count of the number of stations for England and the UK overall during summer with a daily maximum temperature exceeding 25°C

The hottest day across north-western parts of the UK was 28 June, with 30°C exceeded across north-west England, Scotland's Central Belt, and parts of the Highlands, Northern Ireland and North Wales. In some locations, maximum temperatures were more than 14°C above the monthly average, and most of the UK except coastal areas of Yorkshire, Lincolnshire and Norfolk exceeded 25°C. Maximum temperatures on 28 June of 31.9°C at Glasgow Bishopton and 30.5°C at three stations in Northern Ireland fell within 1°C of the all-time Scotland and Northern Ireland records, while in Wales 33.0°C at Porthmadog (Gwynedd) on 28 June was part of a sequence of 6 out of 7 days more than 30°C at this station. Numerous stations recorded their hottest June day on record including Armagh—152 years, Balmoral (Aberdeenshire)—104 years and Eskdalemuir (Dumfriesshire)—also 104 years (Figure 54).

The UK's hottest day of the summer was on 27 July, with 35.6°C recorded at Felsham (Suffolk); 32°C was exceeded

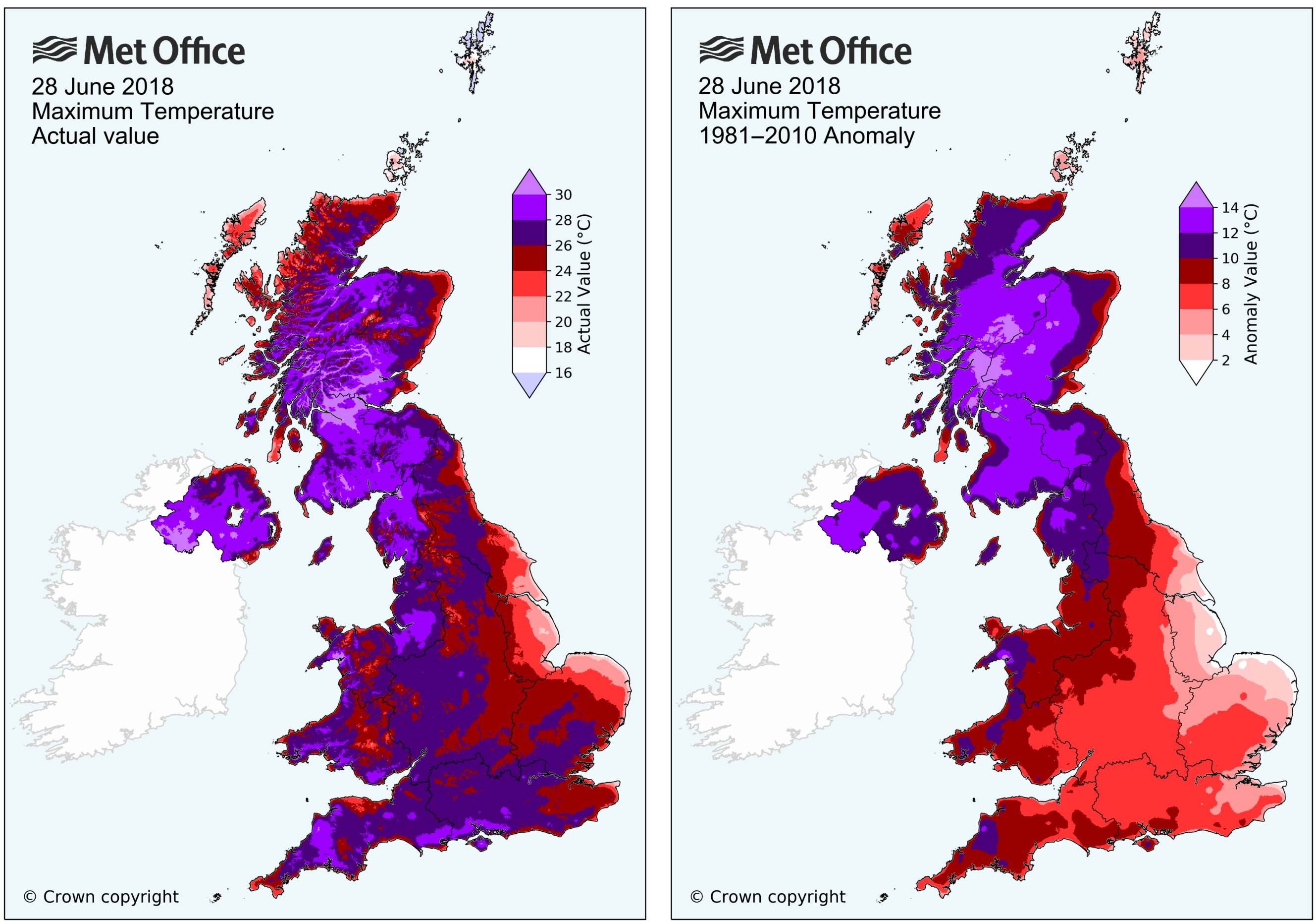


FIGURE 54 Daily maximum temperatures on June 28, 2018 as (a) actual values and (b) relative to 1981–2010 long-term average

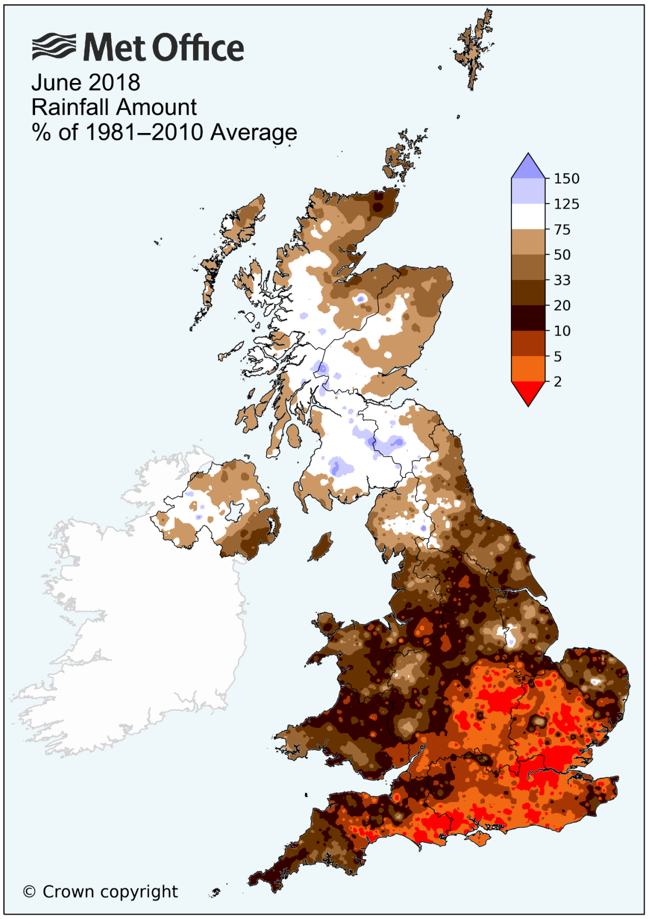


FIGURE 55 June 2018 rainfall relative to 1981–2010 long-term average

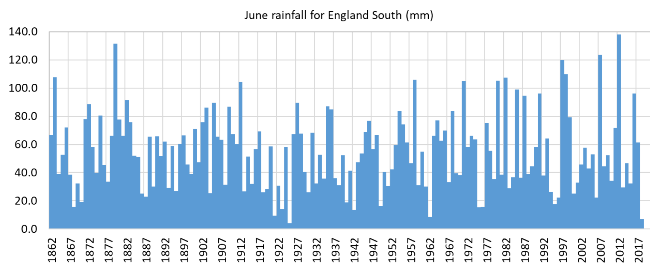


FIGURE 56 June rainfall for England South, 1862–2018 based on the same monthly gridded data as the national series. This region covers includes England south of a line from North Wales to the Wash

widely across East Anglia and south-east England on both 26 and 27 July and temperatures reached 35°C on both dates in parts of East Anglia, Kent and central London.

June was exceptionally dry across parts of southern England with a run of over 50 dry days at some stations in the south-east lasting until late July. June rainfall totals across parts of central and southern England were widely less than 5 mm, and some areas (for example, parts of Hampshire, London and Cambridgeshire) less than 1 mm—that is, essentially no appreciable rain. The June rainfall map below shows large parts of southern England recording less than 5% of the June average rainfall, with some places less than 2% (Figure 55). Southern England recorded its driest June since 1925 (Figure 56).

In contrast to the summers of 2006 and 2003, there were no extended spells of exceptonal heat during summer 2018 (despite the fact that temperatures reached 35°C on 2 days). Nevertheless, while summer 1976 will remain as the benchmark summer for the UK in terms of exceptional and prolonged hot and dry conditions, the summer of 2018 stands out as among the most notable fine, warm, dry, sunny summers in 100+ years. In terms of global-scale atmospheric circulation patterns, the warm, dry summer, associated with high pressure established near the UK during June and July cannot be viewed in isolation, but may have been linked with other severe weather events across the northern hemisphere, both heatwaves and extreme rainfall (Kornhuber *et al.*, 2019).

8.4 | Strong winds from storm Ali

Storm Ali brought very strong winds and heavy rain to Scotland and Northern Ireland on September 19, 2018, with widespread gusts in excess of 60 Kt (69 mph) across the north of the UK. There were extensive power outages and travel disruption in Northern Ireland and Scotland, with rail cancellations due to fallen trees on the line. Some damage to buildings and vehicles was reported alongside many fallen trees across the northwest of the UK. Five hundred cruise passengers and crew were stranded in Greenock after severe weather broke their ship's mooring lines.

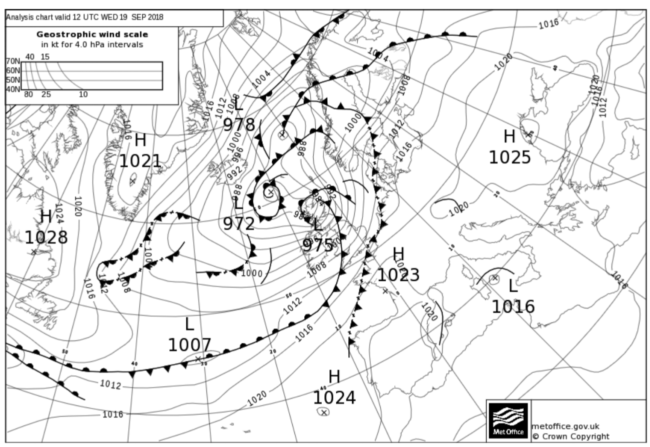


FIGURE 57 Analysis chart at 12 UTC September 19, 2018 showing storm Ali and associated fronts tracking eastward across the UK. The low's centre continued to deepen as it moved toward Shetland and Norway

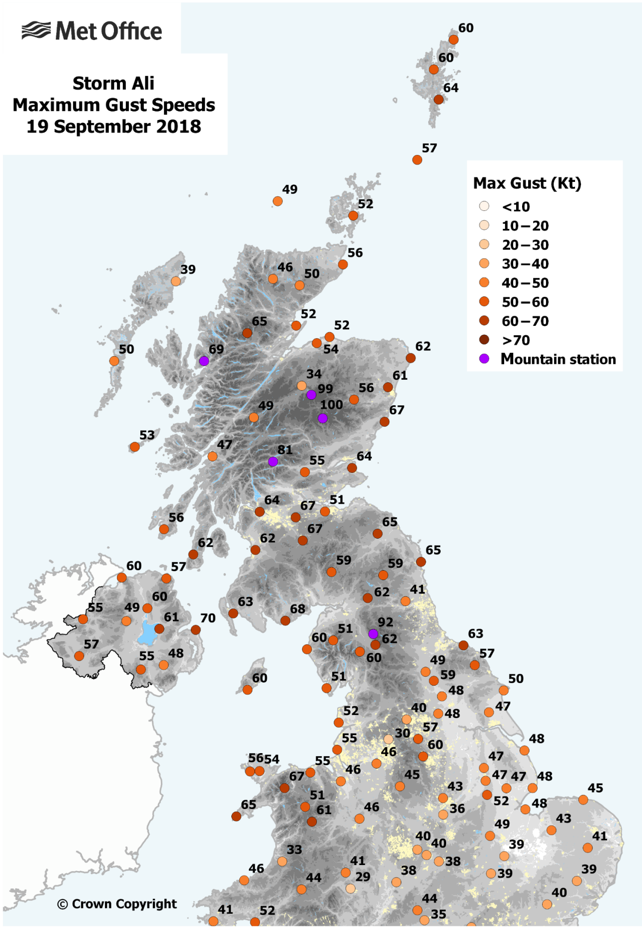


FIGURE 58 Maximum gust speeds (Kt) on September 19, 2018

Figure 57 shows the surface pressure chart and Figure 58 maximum gust speeds from storm Ali. The strongest winds in excess of 60 Kt were in a swathe across Northern Ireland, southern, central and eastern Scotland. Killowen (County Down) recorded 79 Kt (91 mph) and gusts across Scotland's Central Belt were typically around 65 Kt (75 mph). Maximum gusts were 50–60 Kt (58–69 mph) across northern England and Wales with 67 Kt (77 mph) at Capel Curig (Conwy) and 63 Kt (72 mph) at Loftus (Cleveland). Across the mountain summits of Scotland and northern England, winds gusted at over 87 Kt (100 mph).

Deep areas of low pressure are to be expected at this time of year. However, the most powerful Atlantic storms tend to be later in autumn—more typically October than September. Figure 59 provides a count of the number of stations in the wind network which recorded gusts ≥60 Kt for the UK in either September or October. Thirty stations across the UK, and 15 in Scotland (around 20% and over 40% of the network in these areas, respectively) reached 60 Kt. This was therefore one of the most notable storms to affect the UK in recent decades, particularly in September in the context of

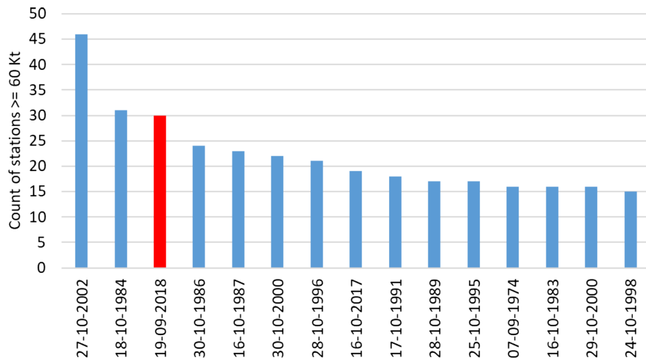


FIGURE 59 Count of the number of stations in the UK wind network which have recorded gusts ≥60 Kt in either September or October, based on data from 1970. Note that if all months are included the most significant storms are in December, January and February, with October 27, 2002 ranked 11th by this metric

the area affected by gusts exceeding this threshold. One of the most notable autumn storms of recent decades was October 27, 2002 (mainly affecting the south of the UK) while ex-hurricane Ophelia on October 16, 2017 also brought some very strong winds to western parts of the UK and Ireland (Kendon *et al.*, 2018). However, other storms, while less extensive, were much more severe—for example, October 16, 1987.

8.5 | Heavy rain across South Wales from storm Callum

Storm Callum brought persistent heavy rain across western upland areas of the UK on October 11–12,, 2018. The wettest area was South Wales, with much of the Brecon Beacons National Park recording 100–150 mm of rainfall over a 2-day period, and up to 200 mm across the higher ground. The frontal system also led to a dramatic

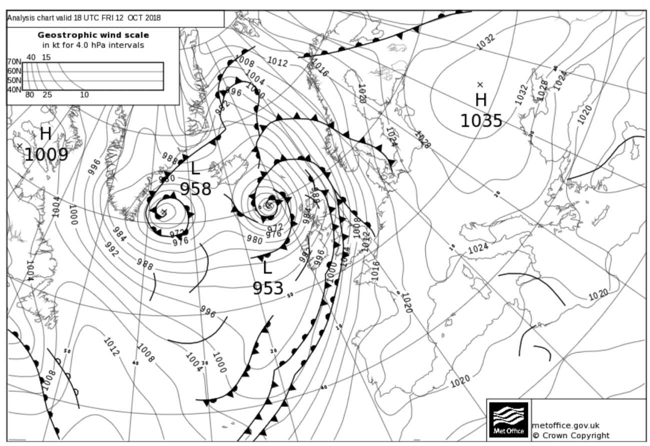


FIGURE 60 Analysis chart at 1800 UTC October 12, 2018 showing storm Callum centred to the north-west of the UK with associated fronts trailing across northern England and Wales

temperature contrast of more than 10°C and unseasonably high temperatures across parts of eastern England. Figure 60 shows the surface pressure chart and Figure 61

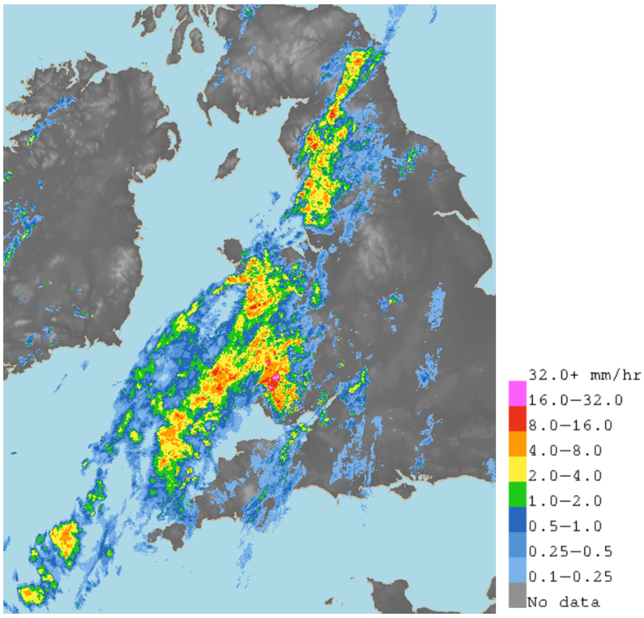


FIGURE 61 Rain-radar image at 1800 UTC Friday October 12, 2018 showing fronts bringing heavy rain to Wales and northern England, with the heaviest rainfall across the hills of South Wales

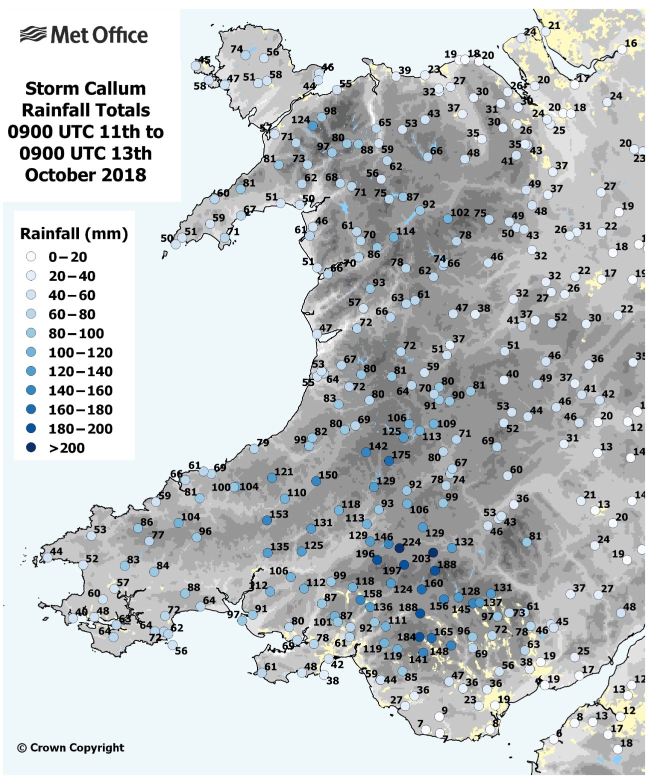


FIGURE 62 Rainfall accumulations across Wales for the two consecutive rain-days 11 and October 12, 2018

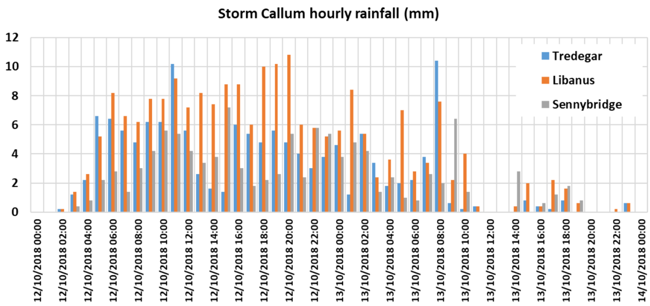


FIGURE 63 Hourly rainfall for three stations located in or near the Brecon Beacons: Sennybridge and Libanus (Powys) and Tredegar (Blaenau Gwent)

a rain-radar image from storm Callum. See also the cover image of this report.

Storm Callum brought widespread travel disruption from strong winds and flooding. Large waves battered exposed coastlines in the south and west. Power cuts affected thousands of homes and there were flight cancellations, travel disruption on roads and rail cancellations due to landslips. The most severe impacts were across south Wales. Homes and businesses were flooded in Carmarthenshire, Ceredigion and Powys. Around 100 sheep were swept away by floodwater in west Wales. Rail services were delayed or cancelled across Wales, south-west England and between Preston and Scotland.

There was very significant orographic enhancement of the rainfall across South Wales, so that upland areas recorded 3 or 4 times as much rainfall as coastal locations around Swansea, or locations to the north-east in the rain-shadow—such as the Black Mountains (Figure 62). This very pronounced contrast in the spatial pattern of rainfall is very typical of such extreme rainfall events, for example, November 19, 2009 or December 5, 2015. The extreme nature of the rainfall was due to duration rather than intensity. For example, at Libanus, Powys, the rain-rate averaged around 6 mm per hour for 34 hours (Figure 63), with a total of 202.4 mm over this duration, 115% of the October whole-month average rainfall (and October being one of the wettest months of the year on average).

Historically, events with 2-day rainfall accumulations across upland areas of Wales widely 100–150 mm or more have occurred in 1994, 1981, 1980, 1979, 1973, 1965, 1964 and 1963. Of these, the stand-out event in terms of rainfall totals across south Wales was that of 17 to December 18, 1965 with 10 raingauges recording a 2-day total of over 200 mm and two of these over 250 mm. Figure 64 compares rainfall totals of 11 to October 12, 2018 against 17 to December 18, 1965. In terms of historical context, 11 to October 12, 2018 was undoubtedly one of the most notable

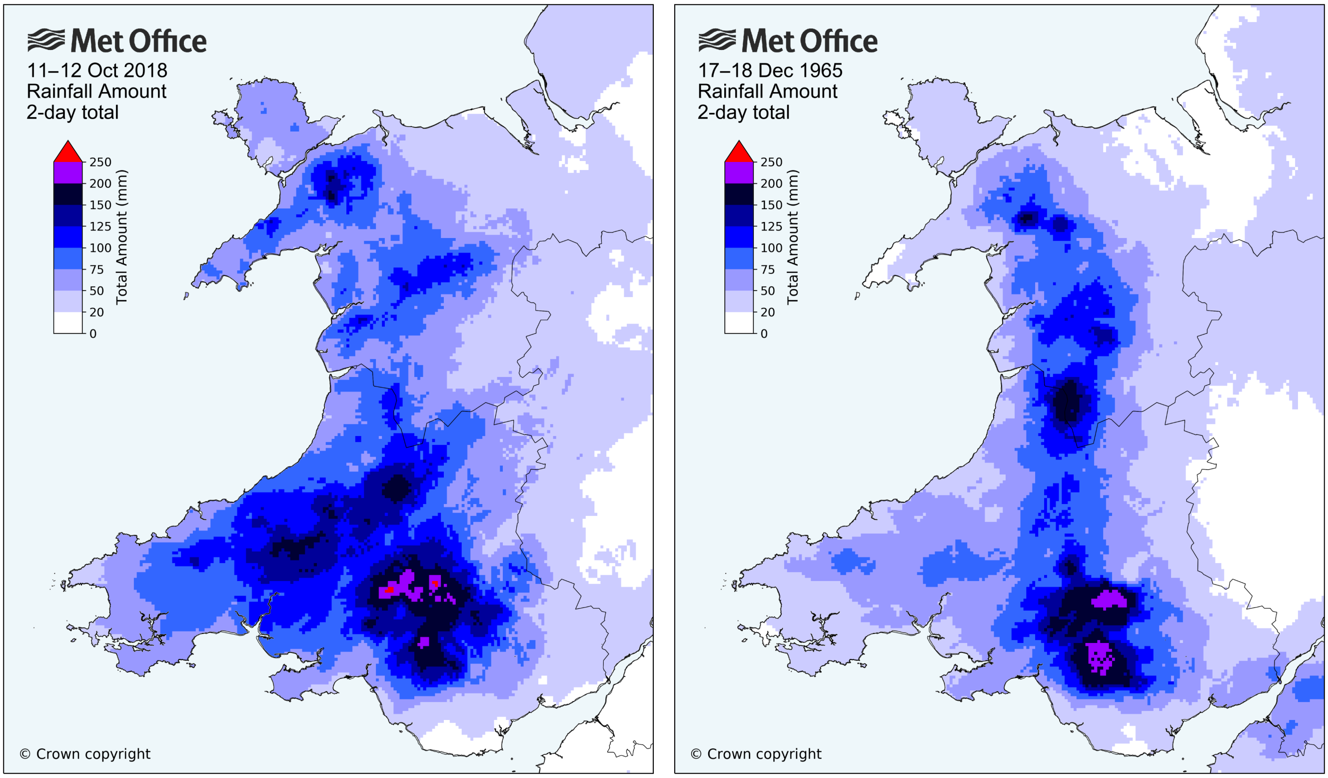


FIGURE 64 Two-day rainfall totals for 11 to October 12, 2018 compared against 17 to December 18, 1965

extreme rainfall/flood events across South Wales in the last 50 years.

State of the UK Climate 2018—Appendices.

ACKNOWLEDGEMENTS

This report would not have been possible without the help of colleagues in the Met Office National Climate Information Centre, in particular Dan Hollis, for developing the underlying ClimateGrid software. Thanks to John Kennedy (Met Office) for providing UK near-coast SST and NAO index data. Thanks to reviewers Gerard van der Schrier (KNMI), Ian Jolliffe (University of Exeter) and one anonymous reviewer for providing helpful comments and feedback.

REFERENCES

Alexander, L.V. and Jones, P.D. (2001) Updated precipitation series for the U.K. and discussion of recent extremes. *Atmospheric Science Letters*, 1. https://doi.org/10.1006/asle.2001.0025.

Allan, R. and Ansell, T. (2006) A new globally complete monthly historical gridded mean sea level pressure dataset (HadSLP2): 1850–2004. *Journal of Climate*, 19(5), 816–5842. https://doi.org/10.1175/JCLI3937.1.

Araujo, I.B. and Pugh, D.T. (2008) Sea levels at Newlyn 1915–2005: analysis of trends for future flooding risks. *Journal of Coastal Research*, 44, 203–212. https://doi.org/10.2112/06-0785.1.

Bradley, S., Milne, G., Shennan, I. and Edwards, R.J. (2011) An improved glacial isostatic adjustment model for the British Isles. *Journal of Quaternary Science*, 26(5), p541–p552. https://doi.org/10.1111/j.1365-246X.2008.04033.x.

Church, J.A., Clark, P.U., Cazenave, A., Gregory, J.M., Jevrejeva, S., Levermann, A., Merrifield, M.A., Milne, G.A., Nerem, R.S., Nunn, P.D., Payne, A.J., Pfeffer, W.T., Stammer, D. and Unnikrishnan, A.S. (2013) Sea level change. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (Eds.) *Climate Change 2013. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Folland, C.K., Knight, J., Linderholm, H.W., Fereday, D., Ineson, S. and Hurrell, J.W. (2009) The Summer North Atlantic Oscillation: Past, Present, and Future. *Journal of Climate*, 22(1), 082–1,103. https://doi.org/10.1175/2008JCLI2459.1.

Graham, E. and Webb, J.D. (2019) The very deep cold pool of 27 February–1 March 2018 – historical precedents and perspective. *Weather*, 74, 85–91. https://doi.org/10.1002/wea.3471.

Greening, K. and Hodgson, A. (2019) Atmospheric analysis of the cold late February and early March 2018 over the UK. *Weather*, 74, 79–85. https://doi.org/10.1002/wea.3467.

Hall, R.J. and Hanna, E. (2018) North Atlantic circulation indices: links with summer and winter UK temperature and precipitation and implications for seasonal forecasting. *International Journal of Climatology*, 38, e660–e677. https://doi.org/10.1002/joc.5398.

Hanna, E., Cropper, T.E., Jones, P.D., Scaife, A. and Allan, R. (2015) Recent seasonal asymmetric changes in the NAO (a marked summer decline and increased winter variability) and associated changes in the AO and Greenland blocking index. *International Journal of Climatology*, 35(9), 2540–2,554. https://doi.org/10.1002/joc.4157.

Hollis, D., McCarthy, M., Kendon, M., Legg, T. and Simpson, I. (2019) HadUK-Grid – A new UK dataset of gridded climate observations. *Geoscience Data Journal* submitted.

Jenkins, G.J., Perry, M.C. and Prior, M.J. (2008) *The Climate of the United Kingdom and Recent Trends*. Met Office: Exeter, UK.

Jones, P.D., Jónsson, T. and Wheeler, D. (1997) Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. *International Journal of Climatology*, 17, 1433–1450. https://doi.org/10.1002/(SICI)1,097-0088(19971115)17:13 < 1,433::AID-JOC203 > 3.0.CO;2-P.

Kalnay, E., Kanamitsu, M., Kistler, R., et al. (1996) The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.*, 77, 437–471.

Kendon, M. and Hollis, D. (2014) How are UK rainfall-anomaly statistics calculated and does it matter? *Weather*, 69, 37–39. https://doi.org/10.1002/wea.2249.

Kendon, M., McCarthy, M., Jevrejeva, S., Matthews, A. and Legg, T. (2018) 2018. State of the UK climate 2017. *International Journal of Climatology*, 38(Suppl. 2), 1–35 10.1002/joc.5798.

Kendon, M. and Diggins, M. (2019) Severe weather and snow conditions on Cairngorm summit in February to March 2018. *Weather*, 74, 98–103. https://doi.org/10.1002/wea.3390.

Kornhuber, K., Osprey, S., Coumou, D., Petri, S., Petoukhov, V., Rahmstorf, S. and Grey, L. (2019) Extreme weather events in early summer 2018 connected by a recurrent hemispheric wave-7 pattern. *Environmental Research Letters*, 14(5), 054002. https://doi.org/10.1088/1748-9326/ab13bf.

Legg, T.P. (2011) Determining the accuracy of gridded climate data and how this varies with observing-network density. *Adv. Sci. Res.*, 6, 195–198. https://doi.org/10.5194/asr-6-195-2011.

Legg, T.P. (2014) Comparison of daily sunshine duration recorded by Campbell-Stokes and Kipp and Zonen sensors. *Weather*, 69, 264–267. https://doi.org/10.1002/wea.2288.

Legg, T.P. (2015) Uncertainties in gridded area-average monthly temperature, precipitation and sunshine for the United Kingdom. *International Journal of Climatology*, 35, 1367–1378. https://doi.org/10.1002/joc.4062.

Manley, G. (1974) Central England temperatures: monthly means 1659 to 1973. *Quartely Journal of Royal Meteorological Society*, 100, 389–405. https://doi.org/10.1002/qj.49710042511.

Marsh, T., Cole, G. and Wilby, R. (2007) Major droughts in England and Wales, 1800–2006. *Weather*, 62, 87–93. https://doi.org/10.1002/wea.67.

Murphy, C., Wilby, R.L., Matthews, T.K.R., Thorne, P., Broderick, C., Fealy, R., Hall, J., Harrigan, S., Jones, P.D., McCarthy, G., Macdonald, N., Noone, S. and Ryan, C. (2019) Wetter winters and drier summers in England and Wales precipitation explained by observational and sampling bias in early records. *International Journal of Climatology* accepted.

Parker, D.E., Legg, T.P. and Folland, C.K. (1992) A new daily central England temperature series, 1772–1991. *International Journal of Climatology*, 12, 317–342. https://doi.org/10.1002/joc.3370120402.

Parker, D.E. and Horton, E.B. (2005) Uncertainties in the Central England Temperature series since 1878 and some changes to the maximum and minimum series. *International J. Climatol.*, 25, 1173–1188. https://doi.org/10.1002/joc.1190.

Parker, D.E. (2010) Uncertainties in early Central England temperatures. *International Journal of Climatology*, 30, 1105–1,113. https://doi.org/10.1002/joc.1967.

Perry, M. and Hollis, D. (2005a) The development of a new set of long-term climate averages for the UK. *International Journal of Climatology*, 25, 1023–1039. https://doi.org/10.1002/joc.1160.

Perry, M. and Hollis, D. (2005b) The generation of monthly gridded datasets for a range of climatic variables over the UK. *International Journal of Climatology*, 25, 1041–1054. https://doi.org/10.1002/joc.1161.

Perry, M.C., Hollis, D.M., and Elms, M.I., 2009. The generation of daily gridded data sets of temperature and rainfall for the UK, NCIC Climate Memorandum No. 24. Met Office: Exeter, UK.

Prior, J. and Kendon, M. (2011) The disruptive snowfalls and very low temperatures of late 2010. *Weather*, 66, 315–321. https://doi.org/10.1002/wea.874.

Prior, J. and Perry, M.C. (2014) *Analyses of trends in air temperature in the United Kingdom using gridded data series from 1910 to 2011, NCIC Climate Memorandum No. 24*. Exeter, UK: Met Office 10.1002/joc.3944.

Rayner, N.A., Parker, D.E., Horton, E.B., Folland, C.K., Alexander, L. V., Rowell, D.P., Kent, E.C. and Kaplan, A. (2003) Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *Journal of Geophysical Research*, 108(D14), 4407. https://doi.org/10.1029/2002JD002670.

Simpson, I.R. and Jones, P.D. (2012) Updated precipitation series for the UK derived from Met Office gridded data. *International Journal of Climatology*, 32, 2271–2282. https://doi.org/10.1002/joc.3397.

West, H., Quinn, N. and Horswell, M. (2018) *Regionalising the influence of the North Atlantic Oscillation on seasonal hydrological extremes in Great Britain*. European Geosciences Union General Assembly, Vienna, Austria: Available at: http://eprints.uwe.ac.uk/35800.

Wigley, T.M.L., Lough, J.M. and Jones, P.D. (1984) Spatial patterns of precipitation in England and Wales and a revised, homogeneous England and Wales precipitation series. *Journal of Climatology*, 4, 1–25. https://doi.org/10.1002/joc.3370040102.

Woodworth, P.L., Teferle, F.N., Bingley, R.M., Shennan, I. and Williams, S.D.P. (2009) Trends in UK Mean Sea Level Revisited. *Geophysical Journal International*, 176, 19–30. https://doi.org/10.1111/j.1365-246X.2008.03942.x.

How to cite this article: Kendon M, McCarthy M, Jevrejeva S, Matthews A, Legg T. State of the UK climate 2018. *Int J Climatol*. 2019;39 (Suppl. 1):1–55. https://doi.org/10.1002/joc.6213

ANNEX 1: DATASETS

NAO index

The Winter North Atlantic Oscillation (WNAO) index is traditionally defined as the normalized pressure difference between Iceland and the Azores. 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 south-west Iceland and Gibraltar (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 0.55 for winter mean temperature and 0.31 for winter rainfall based on years 1885–2018 and 1863–2018, respectively, see Annex 2). This means that just 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, Folland *et al*., 2009) correspond to grid-point pairs 60°N, 5°E and 80°N, 50°W—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 Atlantic storm track (Folland *et al*., 2009). Unfortunately, due to the location of these points a station-based SNAO series cannot be used. Instead, the SNAO index was calculated from the Met Office Hadley Centre's sea-level pressure dataset, HadSLP2 (Allan and Ansell, 2006) as the difference in seasonal mean sea-level pressure between these grid-point pairs for each year from 1850 to 2018 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 0.30 for summer mean temperature and 0.45 for summer rainfall based on years 1884–2018 and 1862–2018, respectively).

HadSLP2 is a global dataset of monthly mean sea-level pressure on a 5° latitude–longitude grid from 1850 to date (Allan and Ansell, 2006). 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 sources of data in this report are monthly and daily gridded datasets covering the UK, released as HadUK-Grid for the Met Office UK Climate Projections (UKCP18) in November 2018 (Hollis *et al*., 2019). The primary purpose of these data is to facilitate monitoring of UK climate and research into climate change, impacts and adaptation.

All gridded data are at 1 km resolution. The method used for gridding follows that used for the previous set of UK gridded datasets released as part of the Met Office UK Climate Projections (UKCP09) in 2009 (Perry and Hollis, 2005b and Perry *et al*., 2009) which were at 5 km resolution. The 5 km gridded dataset was used for the previous State of the UK Climate 2017 report (Kendon *et al*., 2018), earlier State of UK Climate reports, and UK climate statistics published on the Met Office website, but these are now superseded by the HadUK-Grid dataset. The grids are based on the GB national grid, extended to cover Northern Ireland and the Isle of Man, but excluding the Channel Islands.

Table A1.1 shows the monthly and daily grids from HadUK-Grid used for this report, including the year from which variables are available. Derived annual grids are also included. A key improvement in the dataset is the improved resolution (1 km rather than 5 km). This increases the level of detail, and allows the grids to better 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

TABLE A1.1 List of monthly and daily variables presented in this report, gridded over the UK at 1 km resolution. The table also includes monthly and annual grids derived from daily grids

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	1929	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

[a]Monthly grids derived from daily grids.
[b]Annual grids derived from daily grids.

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

Climate variable	Number of years	Number of grids	Average number of stations per grid	Total number of station values
Monthly maxtemp	135	1,620	360	580,000
Monthly rainfall	157	1884	1,790	3,400,000
Monthly groundfrost	58	696	400	280,000
Monthly sunshine	90	1,080	260	280,000
Daily maxtemp	59	21,550	520	11,000,000
Daily rainfall	128	46,750	1880	88,000,000

may not necessarily be improved. The higher resolution can also be used to better explore uncertainties in the gridding methods, and facilitates re-gridding to new high-resolution climate model resolutions.

In addition, the dataset makes use of new data sources, allowing the grids to extend significantly further back in time. The principal source of data is the Met Office Integrated Data Archive System Land and Marine Surface Stations (MIDAS) Database containing UK station data, but this has been supplemented by further recently digitized 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 rainfall and temperature from up to 190 stations for the period 1862–1958. The additional historical data has allowed monthly temperature to extend back to 1884 (previously

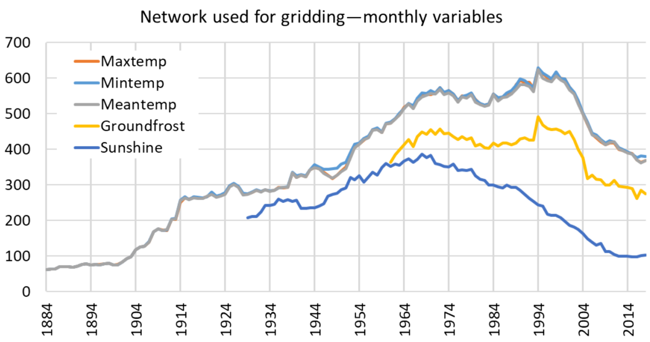


FIGURE A1.1 Number of stations used for gridding – monthly maxtemp, mintemp, meantemp (1884–2018), days of ground frost (1961–2018) and monthly sunshine (1929–2018)

1910), monthly rainfall back to 1862 (previously 1910) and daily rainfall back to 1891 (previously 1958). 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.

A further advantage of the new dataset is that the data extraction and gridding process has been carried out in a single batch process, whereas the previous 5 km dataset was processed in a series of batches covering 1961–2000, 1914–1960, 1910–1913 and subsequent monthly updates from 2001 to 2018. Generating the entire dataset in 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.

The 1 km resolution daily maxtemp, mintemp and rainfall grids of the UK have also been generated using a similar method to that for the 5 km grids (Perry *et al*., 2009). Daily temperature has been gridded back to 1960, covering the same period as previously, 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. 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.

One difference from the previous 5 km gridded datasets is that 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 otherwise not be the case). 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.

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. A description of the gridding process is also given in Jenkins *et al*. (2008) and Prior and Perry (2014).

Figures A1.1 to 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 to 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. The number of

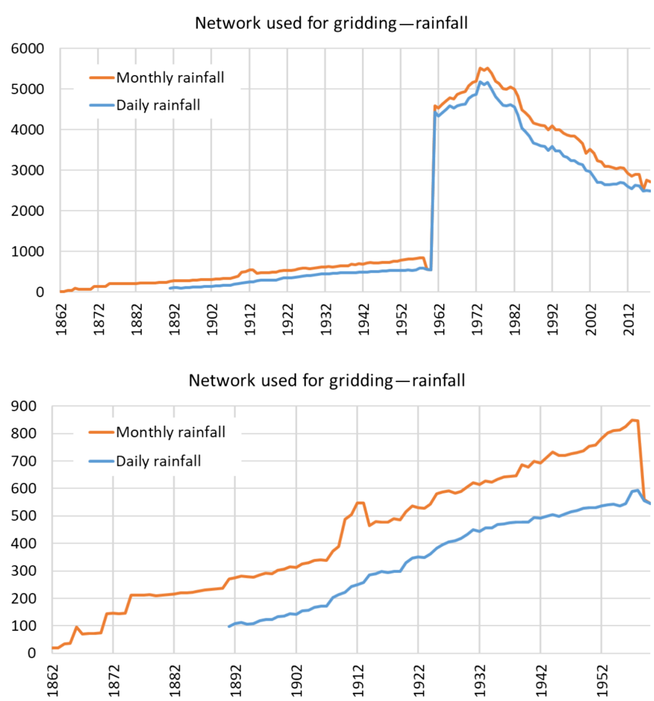


FIGURE A1.2 Number of stations used for monthly/daily rainfall (a) 1862/1891–2018 and (b) 1862/1891–1960, with the step change from <1,000 stations to >4,000 stations occurring in 1961

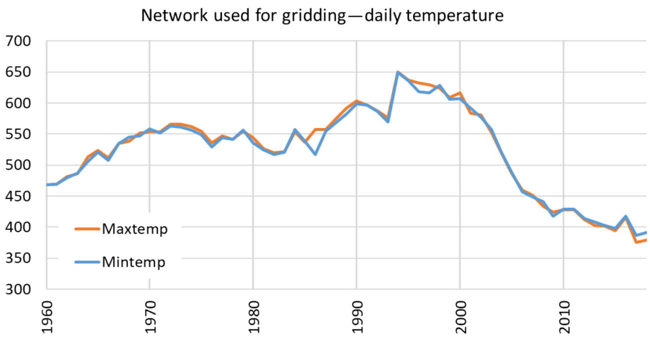


FIGURE A1.3 Number of stations used for daily temperature 1960–2018. The number of stations is very similar to monthly maxtemp and monthly mintemp as shown in Figure A1.1

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 200 to almost 400 from the 1930s to 1970, followed by a steady decline to around 100 stations in the 2010s (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 2010s (Figure A1.2b).

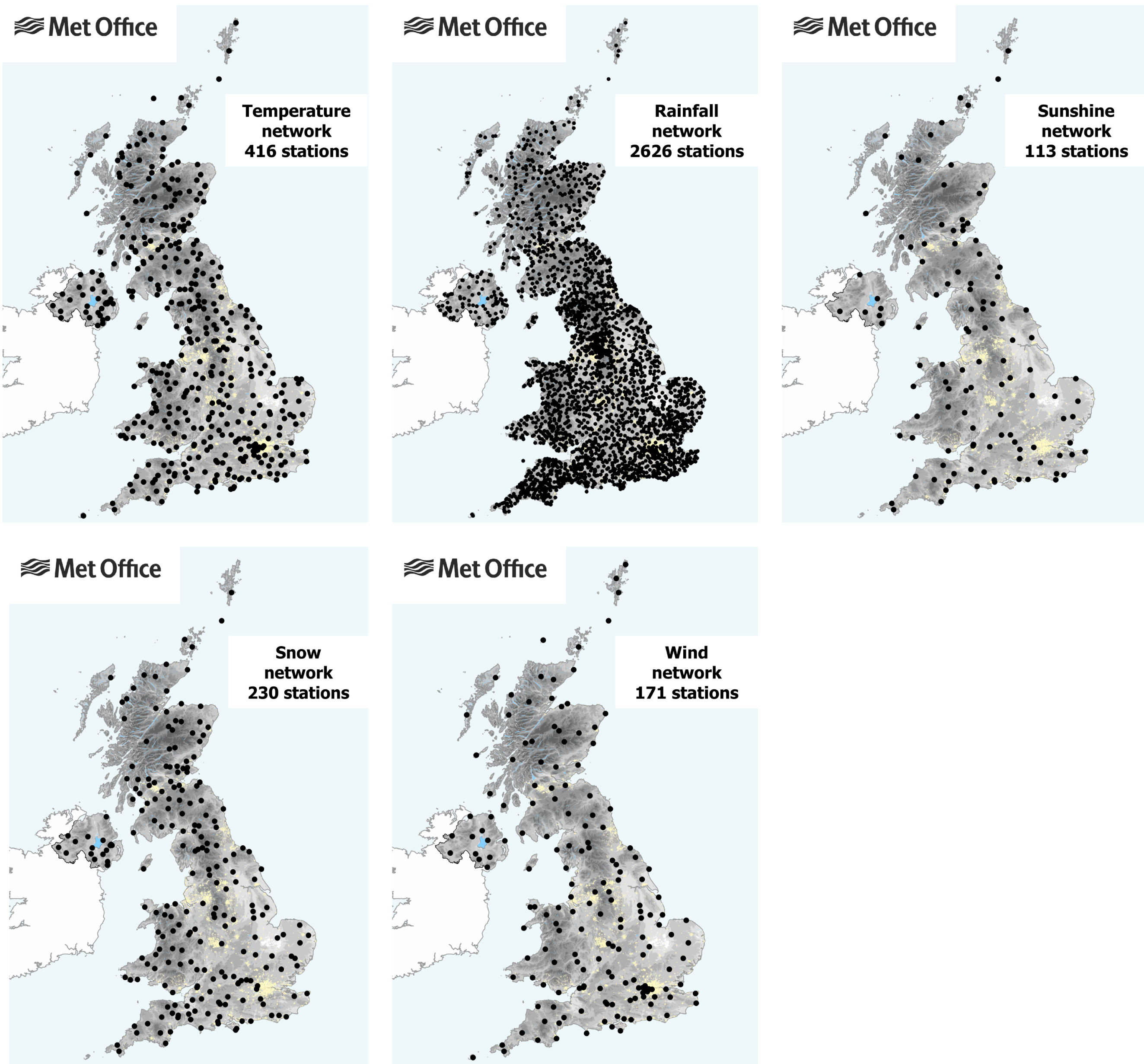


FIGURE A1.4 State of the UK observing network in 2018. The number of observations is indicative as these may vary on a daily basis due to data availability

As would be expected the number of stations for daily temperature over the period 1960–2018 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 (for example 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).

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.

The approximate total number of station values used to generate the grids for each variable is given in Table A1.2. In total over 100 million station values have been used to generate the HadUKGrid_v1, with more than 90% of these accounted for by daily temperature and daily rainfall. Note however that for monthly variables (for example monthly maxtemp), the majority of the monthly station values will have themselves been derived from daily station values (daily maxtemp). 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 2018. 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 number of stations in the 2010s may be fewer than in earlier decades (for example the 1970s), the spatial distribution of station 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. These gridded datasets were produced for HadUK-Grid following the same general method as the previous long-term average gridded datasets used previously (Perry and Hollis, 2005a) but modified as described in more detail by 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 (Hollis *et al*., 2019).

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

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

Climate variable	Average 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	1,203	545
Rainfall	9,547	3,857
Sunshine	611	226

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. Differences are calculated from unrounded values

Area	Temperature – Long- term average (degC)	Temperature – Long-term average derived from monthly grids	Difference (degC)	Rainfall – Long-term average (mm)	Rainfall – Long-term average derived from monthly grids	Difference (%)
UK	8.85	8.86	−0.02	1,150	1,144	0.5
England	9.66	9.65	0.01	853	850	0.3
Wales	9.13	9.15	−0.02	1,459	1,443	1.1
Scotland	7.41	7.47	−0.06	1,562	1,552	0.6
Northern Ireland	8.92	8.92	0.00	1,133	1,130	0.3

the order of the calculation differs, and because 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 A1.3 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.

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 of 0.5% 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 much smaller than those seen when comparing 1 km long-term averages and those derived from 5 km monthly grids presented in previous State of UK Climate reports (see Kendon *et al*., 2018, Table A1.3), largely because for the HadUK-Grid dataset the long-term average and individual monthly grids are at the same resolution (both 1 km). Overall this therefore represents a marked improvement in self-consistency of the dataset.

Annual degree days

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

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

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

TABLE A1.5B 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
$T_{min} \geq T_{threshold}$	0
$T_{max} \leq T_{threshold}$	$T_{threshold}$ - T_{mean}
$T_{mean} \leq T_{threshold}$ & $T_{max} > T_{threshold}$	$0.5\ (T_{threshold} - T_{min}) - 0.25\ (T_{max} - T_{threshold})$
$T_{mean} > T_{threshold}$ & $T_{min} < T_{threshold}$	$0.25\ (T_{threshold} - T_{min})$

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. The previous 5 km UK gridded datasets have been manually quality controlled since 2001, and the HadUK-Grid processing chain included a step to ensure these QC decisions were transferred by comparing the HadUK-Grid 1 km resolution grids and the associated 5 km resolution grids. Further details are beyond the scope of this report.

The dataset has adopted new and open-source ancillary files for terrain elevation, proximity to coast and urban land use that are used within the interpolation scheme. This provides a more traceable dataset. The HadUK-Grid dataset is also version controlled – including a version-controlled numbering system, so this and future State of the UK Climate publications can all be linked to a specific version of the dataset. This report uses version 1.0.1.0 of the HadUK-Grid dataset. Details 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 (for example 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 varation 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 1,772 (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 1960 the data have been adjusted to allow for any effects of warming due to the expansion of local built up areas. Parker and Horton (2005) and Parker (2010) have investigated uncertainties in the CET series.

Sea-surface temperature data

The Met Office Hadley Centre's sea ice and 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 fell within this area (Figure A1.5).

England and wales precipitation series

The England and Wales precipitation series (EWP) has monthly data back to 1,766, 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 (for example: the number of stations used historically to compile the EWP

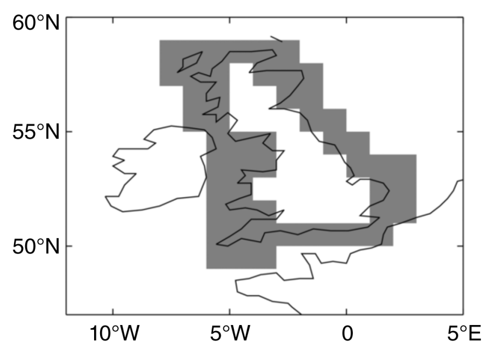


FIGURE A1.5 1° Grid cells from HadISST1 used to calculate UK near-coast sea-surface temperature series, how well the network has historically captured orographically enhanced rainfall across high ground, how well the network has historically captured precipitation which has fallen as snow) remains an area of investigation – see for example Murphy et al (submitted). Various papers detail the development of the EWP series (Wigley, 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 just under 200 stations in 2018.

Sunshine data

The UK's sunshine network in 2018 comprises two instrument types: just under half the network comprises Campbell-Stokes (CS) sunshine recorders which are read manually; the remainder comprising Kipp & Zonen CSD-1 (KZ) automatic sunshine recorders. An upward 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 (2014) and references therein provide further details.

Sea level data

Sea-level changes around the British Isles are monitored by the UK national network of tide gauges; for 2018 this network comprises 44 sites. For more than 100 years tide gauges provide 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 sites (Aberdeen, North Shields, Sheerness, Newlyn and Liverpool) provides the best estimate for UK sea level rise, excluding the effect of this vertical land movement. The records from each site 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/yr is reintroduced (Woodworth *et al*., 2009, Bradley *et al*., 2011).

As mentioned in Woodworth (2009), the network of 44 sites falls under the responsibility of the Environment Agency (although it is no longer operated by the Proudman Oceanographic Laboratory), but only five date back to the beginning of the 20th century: the other sites 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 (2009), 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 onward, there have been more gaps in observations for the five stations. More information about reasons for the issues can be found in the UK Coastal Monitoring and Forecasting annual reports, which are available from https://www.bodc.ac.uk/data/hosted_data_systems/sea_level/uk_tide_gauge_network/reports/

Newlyn, Cornwall has a century of hourly (or, since 1993, 15-minute) sea-level data from float and pressure tide gauges that have been maintained better than most around the UK. It also has a more open ocean location than stations around North or Irish Sea coasts (Araujo and Pugh, 2008).

ANNEX 2: TIME-SERIES, TRENDS AND UNCERTAINTY

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. At the ends of the time series, only the 14 points to one side of the target point are used, increasing to the full 29-year bandwidth by the 15th point from each end. Similar smoothing filters were used for the earlier trend reports and State of UK Climate reports (Jenkins *et al*., 2008, Prior and Perry, 2014, Kendon *et al*., 2018).

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. 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 Central England Temperature 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 previous discussion on long-term averages), although in practice any differences are small. Annex 1 Table A1.4 provides further details. We use the 1 km resolution 1961–1990 and 1981–2010 averages because these datasets contain the most comprehensive set of stations, and thus represent our best estimate of these climatologies.

Uncertainty estimates

Recent studies have considered uncertainties in the gridded data and areal-averages (Legg, 2011, Legg, 2015), based on the previous 5 km gridded dataset. The HadUKGrid_v1 1km 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 – i.e., 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 the 5 km gridded dataset. The uncertainty estimates in these studies have been adjusted upward 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 ranges for annual mean temperature, rainfall and sunshine for different periods in the 5 km gridded dataset. Indicative date periods are presented here. These correspond to: the earliest years in the 5 km

TABLE A2.1 1σ Uncertainty ranges for annual T_{mean}, rainfall and sunshine

Year range	UK	England	Wales	Scotland	Northern Ireland
Temperature (°C)					
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 (%)					
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 (%)					
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

dataset where the availability of station data is 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 recent period in the 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 $\sqrt{2}$ 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). Uncertainties in the CET and EWP series have also been investigated elsewhere (Parker and Horton, 2005, Parker, 2010, Simpson and Jones, 2012).

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 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 area 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.

Comparison of areal averages with 5 km gridded dataset

Table A2.2 provides a summary of grid-point differences between the HadUK-Grid and 5 km gridded dataset. The net impact of changes based on mean and root-mean-square difference across all grid points in all grids for each variable are well within the expected uncertainty range of the interpolation and overall relatively small.

TABLE A2.2 Mean and root mean square difference between 1 km and 5 km grid points

Variable	Mean difference	Root mean square difference
Daily rainfall	−0.1 mm	0.3 mm
Daily maximum temperature	0.01°C	0.21°C
Daily minimum temperature	−0.02°C	0.23°C
Monthly rainfall	0.8 mm	9.3 mm
Monthly maximum temperature	0.01°C	0.22°C
Monthly minimum temperature	−0.02°C	0.24°C

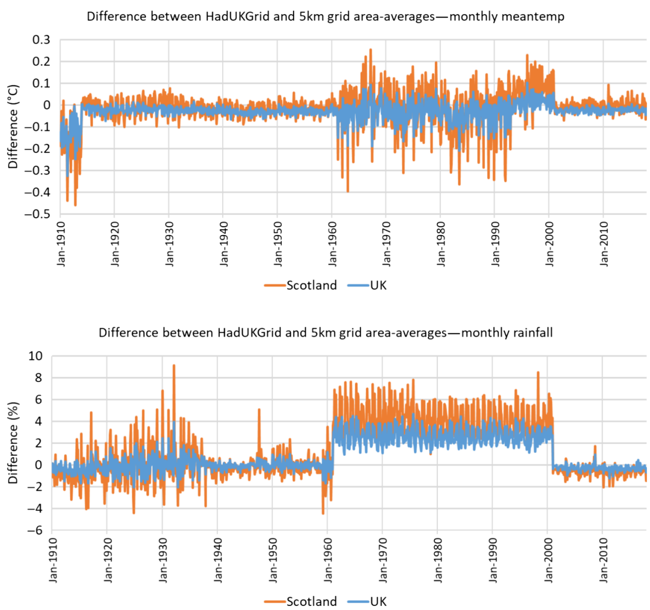


FIGURE A2.1 Difference in area-average monthly mean temperature (°C) (a), and rainfall (%) (b) from 1910 to 2017 inclusive, between the HadUKGrid_v1 1km resolution gridded datasets and the previous 5 km gridded dataset for the UK and Scotland

Figure A2.1 compares the difference in area-average monthly mean temperature (a), and rainfall (b) from 1910 to 2017 inclusive (finalized 2018 data were not available at the time of comparison), between the HadUK-Grid and 5 km gridded datasets for the UK and Scotland. A full comparison between these datasets is beyond the scope of this report, but the figure provides an indication of the size of any differences and time-periods over which they occur. Scotland is included because it contains a large proportion of mountainous terrain, so any changes in topographic factors are likely to have a greater effect here than elsewhere in the UK.

The differences for UK monthly mean temperature are generally less than 0.1°C except for the period 1961–2000 where they are up to 0.2°C, and for Scotland occasionally over 0.3°C. The difference in rainfall for the UK is generally less than 2%, except for this same period 1961–2000 in which the UK monthly totals are typically around 2% wetter from September to March and 3% wetter from April to August. This is most apparent for Scotland where these differences are typically around 3% from September to March and 5 to 6% wetter from April to August.

The differences in UK and Scotland monthly mean temperature and rainfall values from 1961 to 2000 relate to historical changes in the processing chain of the 5 km dataset and therefore reflect structural uncertainties within this 5 km dataset. These structural uncertainties have been eliminated in HadUK-Grid due to this being processed as a single batch – a significant benefit of HadUK-Grid as noted in Annex 1. Although the differences are overall relatively small, they highlight an inhomogeneity in the 5 km gridded dataset – in particular a dry bias over the period 1961–2000, mainly affecting upland areas of the UK. Most differences in the earlier decades are likely to relate to changes in the underlying station data. These differences are in some instances significantly larger than the uncertainties presented in Table A2.1. The focus of Legg, 2015 was primarily uncertainties associated with spatial sampling, and although upward adjustments were made to acknowledge the potential for other sources of error (such as structural uncertainty) these were not examined explicitly in this paper. The generation of the HadUK-Grid dataset and comparison with the 5 km dataset has allowed these structural uncertainties to be better understood. The key statistics and headline messages in this report based on the HadUK-Grid dataset remain consistent with earlier State of the UK Climate reports using the 5 km dataset (e.g., Kendon *et al*., 2018).

Coefficient of determination

The coefficient of determination, R^2, is the square of the correlation coefficient, r, between an independent 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 independent variable. An R^2 value of 1 would indicate a perfect correlation, in which the dependent variable can be predicted without error from the independent variable. An R^2 value of 0 would mean the dependent variable cannot be predicted from the independent variable. An R^2 value of 0.5 would mean that 50% of the variance in the dependent variable can be explained by variations in the independent variable. For example, in this report R^2 values which exceed 0.9 would indicate time-series 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 (for example comparing the most recent decade with 1981–2010), this difference is calculated from the original unrounded values.

ANNEX 3: USEFUL RESOURCES

Met office

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

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

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

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/

UKCP09 gridded observation datasets https://www.metoffice.gov.uk/climate/uk/data/ukcp09

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

Met Office UK Storm Centre Name our Storms project http://www.metoffice.gov.uk/uk-storm-centre

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

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

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/guidance-and-advice/environmental-topics/water-management-and-quality/resources/water-situation-report-2018/?lang=en

NOAA-ESRL Physical Sciences Division, monthly and seasonal composites from NCEP reanalysis https://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl

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/