A temperature of 20°C in the UK winter: a sign of the future?

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Introduction
In late February 2019, the UK experienced a spell of exceptional warmth for the time of year. For the first time, temperatures in excess of 20°C were recorded in the UK in a winter month in London, parts of west and north Wales and Manchester. Temperature records tend to be broken by narrow margins, but on 26 February the previous winter record was exceeded by 1.5 degC. Was this event a sign of the future as the UK’s climate warms? This article discusses the historical context of the heatwave based on observational data and model simulations of the UK climate for the twentieth century, and uses projections of plausible future UK climate to look forward to the latter half of the twenty-first century.

February 2019 – historical context
In late February 2019, the UK experienced an influx of exceptionally mild Tropical Maritime and Tropical Continental air from the Canary Islands and North Africa (Figure 1). Daily maximum temperatures responded to clear skies and long spells of late winter sunshine, with 18°C reached somewhere in the UK on every day from 21 to 27 February, and it was exceeded widely on the 25th to the 27th. Young and Galvin (2020) describe the detailed meteorological mechanism of this event including back-trajectories of the airmasses at different elevations in the atmosphere and contribution from continental air for south-east England. They note that the initial influx of air was further warmed by subsidence of air from higher altitudes, with high stability meaning that solar heating occurred within a relatively shallow layer near the surface, contributing to the exceptional warmth. These multiple atmospheric processes were required to coincide to generate a record-breaking spell of this type.

On 25 and 26 February, 20°C was exceeded in Greater London and west Wales, and also in the Manchester area on the 26th. This was the first time 20°C had been recorded in the UK in a winter month. The highest recorded station temperature was 21.2°C at Kew Gardens on 26 February, setting a new February and winter UK temperature record, while more than 20 stations also broke previous national records. New temperature records were set for the UK, England, Wales, and Scotland based on digitized station records from the second half of the nineteenth century – while the Welsh record was broken by a margin of 2.2 degC (Table 1). New February temperature records were also set in the Channel Islands and the Netherlands, and a new all-France mean daily maximum temperature record for February (Young and Galvin, 2020).

Figure 1. Met Office analysis chart at 1200 UTC Tuesday 26 February 2019.

Table 1
National highest maximum and minimum temperature records set in February 2019.

| Station               | Value | Date       | National record                      | Previous station          | Previous value | Previous date |
|-----------------------|-------|------------|--------------------------------------|---------------------------|----------------|---------------|
| Kew Gardens (London)  | 21.2°C| 26 Feb 2019| Feb and winter max. temp. record for UK and England | Greenwich Observatory (London) | 19.7°C         | 13 Feb 1998   |
| Porthmadog (Gwynedd)  | 20.8°C| 26 Feb 2019| Feb max. temp. record for Wales      | Velindre (Powys)          | 18.6°C         | 23 Feb 1990   |
| Aboyne (Aberdeenshire)| 18.3°C| 21 Feb 2019| Feb max. temp. record for Scotland  | Aberdeen                   | 17.9°C         | 22 Feb 1897   |
| Achnagart (Highland) | 13.9°C| 23 Feb 2019| Feb min. temp. record for UK and Scotland | Aboyne (Aberdeenshire)    | 13.7°C         | 13 Feb 1998   |
How unusual was this spell? Figure 2 compares daily maximum temperatures from the warmest day, 26 February 2019, against the previous warmest winter days for the UK based on temperatures widely reaching 18°C: 23 February 1990 and 13 February 1998. On these previous dates, temperatures reached this threshold across parts of central and eastern England, with 19.4°C at Santon Downham, Suffolk and 19.7°C at Greenwich Observatory, London the highest maxima, respectively. In comparison, on 26 February 2019, 18°C was recorded much more widely across England and Wales.

Figure 3 compares the 500hPa geopotential height anomaly over Europe relative to the 1981–2010 long-term average for these three dates, based on the NCEP/ NCAR reanalysis (Kalnay et al., 1996). Since warm air is less dense than cold air, in a warm air mass the 500hPa pressure surface will be higher in the atmosphere due to the increased thickness of the atmosphere below this level. On all three dates, the 500hPa geopotential height anomalies were well above average. However, the largest height anomalies were on 26 February 2019 with the anomaly centred closer to the UK, corresponding to actual 500hPa geopotential heights across England and Wales exceeding 5800 m. All three dates saw high pressure established across the near-continent drawing exceptionally mild air from the far south-west, but see Young and Galvin (2020) for more detailed analysis of the air trajectory.

Figure 4 and Table 2 show temperature anomalies relative to the February 1981–2010 long-term average on this date. Across much of England, Wales, and eastern Scotland, anomalies were at least +10°C, and across mainly northwestern parts of England and Wales +12 to +14°C. The geopotential height of the 500 hPa pressure surface above mean sea-level is adjusted for differences in gravity but closely approximates the true height.
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England: temperature anomalies as high as this are very likely to set new records for the UK.

In order to assess the historical context of the 21.2°C daily maximum value at Kew Gardens, we have extracted the highest daily maximum temperature recorded by a station anywhere in the UK on each date from 1960 to 2019, based on station data used for the HadUK-Grid dataset (Hollis et al., 2019). The station recording the UK’s highest maximum will vary day-to-day but tends to occur most frequently across the south-east.

The highest daily maximum temperatures for each winter season (December, January and February) are plotted from 1 January 1960 to 28 February 2019 in Figure 5. The linear trend-line has gradient +0.19 degC per decade equivalent to +1.2 degC across this 60-year period. Table 3 provides some summary statistics based on this series. The highest daily winter maximum temperature anywhere in the UK is typically 16°C to 17°C, with the lowest 6°C to 7°C (i.e. the maximum being below this value everywhere in the UK). The highest maximum temperature values occurred in 1999, 1998, and 1990 and the lowest in 1987 and 2018. The 2018 value of 2.3°C occurred on 28 February 2018 – the much publicised ‘Beast from the East’ indicating the spatial extent of this cold spell affecting the whole UK.

The time series has been split into two constituent histograms covering the 30-year periods 1960 to 1989, and 1990 to 2019 in Figure 6, with a right-ward shift in the distribution between the two periods clearly reflecting the warming of the climate over this period. The 21.2°C value on 26 February 2019 is 4.0σ (standard deviations) from the mean of the full distribution, indicating the extreme nature of the event, even in the context of the most recent climatological period. The distributions are skewed with a longer low temperature tail.

A time series of the UK’s highest winter temperature (i.e. the seasonal maximum temperature) shows the 21.2°C value as an extreme outlier to the series at 3.3σ (Figure 7). If a simple linear trend of +0.19 degC per decade is removed, the 2019 value is adjusted to 20.7°C at 3.0σ. This analysis suggests that this would have been a record-breaking event due to the exceptional synoptic conditions, even without the influence of a warming climate, with temperatures still reaching 20°C (although this is a simplistic approach). The previous heatwaves that included 13 February 1998 and 23 February 1990 saw a similar synoptic pattern; however, the 1998 spell occurred a few days later in the meteorological winter. As the sun’s strength increases on a daily basis at this time of year, this may have made a difference to the daily maxima observed, especially compared with 1998 which occurred nearly 2 weeks earlier in the calendar year.

Table 3

| Value (°C) | Year |
|-----------|------|
| Highest seasonal value – highest (orange squares in Figure 5) | 21.2 | 2019 |
| Highest seasonal value – average 1960–2019 (orange squares in Figure 5) | 16.6 | – |
| Highest seasonal value – lowest (orange squares in Figure 5) | 13.5 | 1977 |
| Lowest seasonal value – highest (grey squares in Figure 5) | 9.7 | 1990 |
| Lowest seasonal value – average 1960–2019 (grey squares in Figure 5) | 6.5 | – |
| Lowest seasonal value – lowest (grey squares in Figure 5) | 1.9 | 1987 |
| Average of full series | 11.7 | – |
| Average 1960–1989 | 11.4 | – |
| Average 1990–2019 | 12.1 | – |
UKCP Global projections are used rather than the higher resolution products (UKCP Regional at 12km and UKCP Local at 2.2km) as they are provided for the longest historical period and have a greater number of simulations. The 28 simulations come from two sources. The first subset consists of 15 simulations based on variants of a single climate model from the Met Office Hadley Centre (MOHC). Each variant has different values assigned to the settings in the climate model that control the strength of small-scale physical processes, which in turn affect the climate projection. The second subset (members 16–28) are 13 projections from the 5th Coupled Model Intercomparisons Project (CMIP5) generated for the 5th assessment of the Intergovernmental Panel on Climate Change (IPCC). This subset explores how differences between climate models can affect climate projections.

To examine the record breakers in the 28 simulations and the observations, we use the highest daily maximum temperature in any of the 64 UK land grid boxes and on any day in each winter (DJF). This is a practical way to use model simulations to replicate the analysis in the previous section. Figure 8 shows the 28 simulated time series of these annual highest winter temperatures. The simulations differ in their historical long-term climatology, in their slowly changing responses to anthropogenic forcing (the climate change signal), and in their variability from year to year and decade to decade. A perfect model with perfect knowledge of human emissions would reproduce the true climate change signal, and the long-term statistics of the average and variability would be consistent with the real world. However, even a perfect climate model would not be expected to reproduce the exact timings of record-breaking events which arise from a combination of extreme variability and the climate change signal. But climate models are imperfect, so we choose here to consider statistics across a set of different climate models and interpret the overall ensemble to explain the nature of the records of winter temperatures.

The historical record of highest daily winter temperatures is shown in Figure 8 (dashed line). Due to differences across the simulations in long-term climatology, variability, and warming trend, the record-breaking values vary between 15 and 21°C. Figure 8 shows that the warmest winter day, prior to 2019, is warmer than the third warmest by +1.5 degC in seven of the 28 projections (01, 04, 07, 17, 19, 25, 27) and by +1.0 degC in an additional four simulations (03, 08, 11, 13). This demonstrates that many of the projections illustrate the exceptional nature of the warmest winter days relative to those in other years. Indeed,

Figure 6. Histogram of highest UK daily maximum temperature (degC) for each winter season (DJF) splitting the dataset into two 30-year periods 1960 to 1989, and 1990 to 2019. The x-axis values refer to the lower limit of each bin. The number of observations in each bin in the tails for the period 1990 to 2019 is labelled for clarity.

Figure 7. Winter UK seasonal maximum temperature (DJF) showing actual and detrended series (based on a fitted linear trend of +0.19 degC per decade). The detrended value on 26 February 2019 is 20.7°C.

Figure 8. Winter UK seasonal maximum temperature (DJF) splitting the dataset into two 30-year periods 1960 to 1989, and 1990 to 2019. The x-axis values refer to the lower limit of each bin. The number of observations in each bin in the tails for the period 1990 to 2019 is labelled for clarity.

What do climate model projections tell us about warm UK winter days in the future?

To understand how often future winter days might exceed the current record, we analyse the official UK Government projections, UKCP (Murphy et al., 2018). Here, we use the UKCP Global projections covering the period 1900–2100. Data are provided for every grid box across the globe (roughly 60km x 60km around the UK). UKCP adopts a precautionary approach, so the projections are designed to simulate plausible outcomes in a world where emissions from 2005 onwards remain high with no specified climate change mitigation target.

The simple linear de-trending of UK seasonal maximum temperature series shown in Figure 7 is consistent with the fact that the UK’s winter climate has warmed by approximately +0.5 degC relative to a 1961–1990 baseline (Kendon et al., 2019). The exceptional nature of the warmest winter ever on record during a UK winter, although this particular analysis does not provide a formal quantification of the increased risk.

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1https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index.
in members 07 and 17, the warmest winter day exceeds the second warmest by +1.5 degC or more whilst in member 01 the difference between the top two is +1.1 degC.

Figures 8 and 9 (top panel) show that the record-breaking events occur in any decade in this period, with an increased frequency in decades since 2000. This suggests that the simulated winter records events are largely due to naturally occurring but exceptional synoptic conditions, but their value can be raised further by cli-
The result of how the weather regimes relate to the simulations only. Figure 10 (bottom panel) shows that in the future projections there are about 2900 days with the highest winter daily maximum temperature. This remains true in terms of very warm winter days (see Figure S2). As most of the record-breaking days come from the MOHC subset of the projections, and these have more credible representations of the weather regimes, we focus on these simulations only. Figure 10 (top panel) shows that it is possible for a number of weather regimes to result in a record-breaking warmest winter day in the simulations, though regimes 18 (anticyclonic south westerly, high over northern France, 20 and 21 (cyclonic south westerly, intense low over or south of Iceland), and 29 (cyclonic south-south-westerly, low west of Ireland) result in this more frequently than any others. Of the top 1% highest maximum temperature from observations these most frequently occurred under regimes 18 and 15 (south westerly, low over Iceland, not shown). Figure 10 (bottom panel) shows that in the future projections there are about 2900 days that exceed the historical record, and that these can occur under nearly all the weather regimes. However, weather regimes 3, 4, 7, 15, 20, 21, 23, 26 and 30 all feature more than would be expected by chance when highest winter daily maximum temperatures occur in historical climate statistics (see Figure 2), suggesting that they are conducive to producing record temperatures. Indeed, these eight circulation patterns represent a range of the synoptic situations: anticyclonic, west erlies, and south-west erlies over the UK, and cover about 75% of the cases. Overall, this suggests that there is not one distinct type of circulation pattern that can cause these records, and that in the future, the circulation patterns that are historically likely to set records remain so in the future (compare top and bottom panels of Figure 10).

**Summary**

The observational data show that in the context of the current climate, 20°C in winter can only be produced by exceptional synoptic conditions such as occurred in late February 2019. The margin by which the record was broken may have been increased by human-induced climate change, but see Neal *et al.* (2016) for details.
Figure 10. (Top panel) Frequency of each weather regime producing a top two daily maximum winter temperature across the 15 Met Office UKCP projections 1900–2018. (Bottom panel) Frequency of each weather regime producing a day where the highest temperature anywhere in the UK after 2018 beats the historical record from 1900–2018.

even without this it would still likely have been a record-breaking event.

Model simulations for 1900–2018 and projections of the UK's future climate show that, should emissions remain high, by the late twenty-first century we may regularly see winters that have at least 1–2 days hotter than the historical record, with less rare synoptic conditions having the potential to produce temperatures as high as this. Correspondingly, daily maximum temperatures similar to 26 February 2019 when compared with a future climatology reference period might then be considered much less unusual. The shift in likely frequency of such extremes (from exceptional, to fairly routine) is therefore a stark reminder of how human-induced climate change is projected to affect the UK, and our perception of what is ‘normal,’ in the future.

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Supporting Information
Figure S1. Distribution of the daily weather regimes for each member of the 28 UKCP Global projections. Blue lines show distributions from each member (labelled top left corner). Orange lines show observed distributions (the same in all plots). Members 01 to 15 are MOHC simulations, members 16 to 28 are from CMIP5.

Figure S2. (a) Distribution of the highest daily maximum temperature (°C) recorded by any UK weather station for each day of the winter by weather regime. Weather regimes are ordered by their highest daily maximum temperature. (b) As in (a) but for any of the 64 UK grid boxes from the first member of UKCP Global projections. The ordering is set to be the same as the top panel. Note the difference in y-axis values.