Geoscience Data Journal

WILEY

Geoscience Data Journal RMetS

DATA ARTICLE OPEN ACCESS

An Update to the Central England Temperature Series—HadCET v2.1

Tim Legg[1] | Stephen Packman[1] | Thomas Caton Harrison[2] | Mark McCarthy[1]

[1]Met Office, Exeter, UK | [2]British Antarctic Survey, Cambridge, UK

Correspondence: Mark McCarthy (mark.mccarthy@metoffice.gov.uk)

Received: 24 July 2024 | **Revised:** 31 October 2024 | **Accepted:** 18 November 2024

Funding: This study was supported by Department for Science, Innovation & Technology.

Keywords: climate | observations | temperature

ABSTRACT

The Central England Temperature (CET) series is one of the longest instrumental climate records in the world. The CET record from 1659 represents a roughly triangular area of England extending from the Lancashire plain in the north, to London in the south-east and south-west of the Midlands of England. HadCET is a composite series produced by the Met Office Hadley Centre, using data from a succession of observing sites for which the data have been adjusted to remove inhomogeneities to be consistent with the original long running series and be updated in near real time. This paper documents a technical update to the HadCET which is referred to as HadCET version 2 (v2), and at time of publication v2.1.0.0 is the latest available version.

1 | Introduction

Although HadCET is geographically limited to central England, it is representative of the variability of temperature across the United Kingdom (Croxton et al. 2006), and as one of a small number of instrumental climate records that span multiple centuries, it is of global importance for climate studies. The series has been used to show, amongst other things, that for the United Kingdom the observed warming trend can be attributed to anthropogenic climate change (Karoly and Stott 2006) and an increased likelihood of experiencing extreme warm years (King et al. 2015).

The origins of 'Central England' are discussed in the original Central England Temperature (CET) work of noted British climatologist Gordon Manley (1902–1980), for example see Lamb et al. (1981) and Manley (1953), who for the period from 1815 represented 'Central England' as an average of Oxford and a weighted average of 4–7 stations in north west England, reduced to a common standard. For earlier periods, Manley (1953, 1974) made use of a range of stations from across the United Kingdom (and an early series from Utrecht, Netherlands) by calculating departures from local averages (anomalies) rather than absolute temperatures, to produce a series of monthly data spanning from 1659 to 1974. Manley had previously studied temperatures in Lancashire (Manley 1946), obtaining a series based on readings from several stations, and he also studied the long temperature record from Radcliffe Observatory in Oxford. Numerous sites representative of the English Midlands were carefully reviewed, and further corroborated against London sites in the earlier years. Knowing the painstaking way in which Manley 'reduced' series of station observations, as described in several of his published works, gives us the motivation to continue extending the CET series in a manner consistent with this important earlier work. Numerous subsequent works extended and developed the CET series, notably Jenkinson (1985); while the creation of multiple versions of the series caused some concern, Jones (1987) pointed out that differences of a few tenths of a degree between different reconstructions were not meaningful. The next substantial extension to the CET series was published by Parker, Legg, and Folland (1992) and Parker and Horton (2005) who developed a series of daily mean temperature (T_{mean}) from 1772, homogenised in order to be consistent with the monthly Manley series. Parker and Horton (2005) also described a series of daily maximum and minimum temperature (T_{max} and T_{min}, respectively) from 1878. This Parker & Horton version of the data set is referred to as the HadCET series and has been maintained and published by the Met Office since. Parker & Horton used many of the same observational sources as Manley, such as the meticulous records maintained by the country squire Thomas Barker and described by Manley (1952).

The current paper sets out a number of further improvements to the Parker & Horton version of HadCET as maintained by Met Office. This includes technical developments to improve the traceability and reproducibility of the series and its metadata and a description of every step of its generation, including all daily temperature readings for contributing stations used for the period from 1853. The methodology is unchanged from that described by Parker, Legg, and Folland (1992) but each step in the processing chain has been recalculated for the period from 1853 to present from the source data, which has resulted in some small numerical changes. Locations referenced within this paper are shown in Figure 1. Some input station choices have also been updated in order to reduce the overall number of station changes through time. The key elements of the approach are summarised in this paper, but readers are directed to the earlier literature for further detail. The data set is called HadCET, and in what follows, we will refer to the original version of CET as the 'legacy HadCET' and the new version is 'HadCET v2'.

2 | Source Data

The following section describes source data used. It should be noted that the original monthly series produced by Manley (1659–1973) is taken as a reference point. The daily HadCET series developed by Parker, Legg, and Folland (1992) was adjusted to ensure consistency with the longer running monthly series up to 1973. For the period post 1974, the monthly series is derived from the daily series. This is described in more detail in the methodology section. The Radcliffe Observatory site in Oxford, today the Radcliffe meteorological station, is referenced throughout this document and is referred to as Oxford or Oxford (Radcliffe).

2.1 | Monthly Mean Temperature Series, 1659–1973

For the period 1659–1973, the monthly mean temperature series are unchanged from the series originally published by Manley (1974) with the exception of February 1898 which Parker, Legg, and Folland (1992) noted as an error and reverted to the earlier published value from Manley (1953).

2.2 | Daily Temperature Series, 1772–1852

For the period 1772–1852, the series is unchanged from Parker, Legg, and Folland (1992) and Table 1 from that publication is reproduced in Table 1 below. First daily maximum, minimum or fixed hour data at individual stations were averaged into daily values, second where multiple stations were used for a given day, these were combined to a single composite daily value, finally the daily values were adjusted so that their

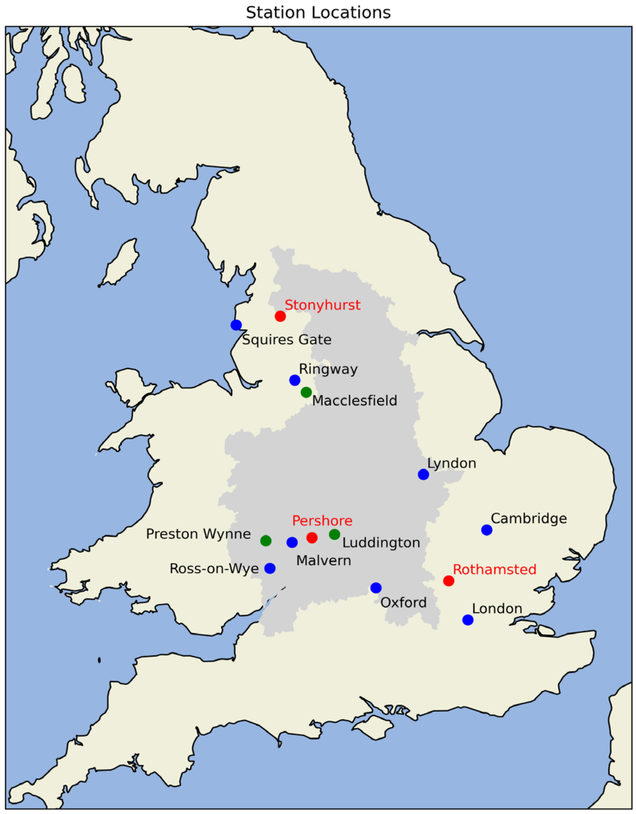

FIGURE 1 | Locations used or referenced in the generation of HadCET. Red dots are the stations comprising the current network since 2004. The blue stations are those used during earlier periods, and the green locations are those sites used in the generation of a rural reference series. The greyed-out region is the area used to define the HadUK-Grid Midlands series.

TABLE 1 | Stations used for HadCET 1772–1852.

Period	Station
1772–1773	London (Kennington) (Hoy's record)
1774–1776	London (Royal Society, Crane Court)
January 1777–June 1789 (except December 1786)	Lyndon Hall, Rutland (Barker's record)
December 1786	London (Syon House, Kew) (Hoy's record)
July 1789–December 1811	London (Royal Society, Somerset House)
1812–1825	Greenwich Observatory (London)
1826–1852	London (Royal Horticultural Society, Chiswick)

monthly means matched those of Manley (1974). However, the daily series from the contributing stations for this earlier work are not all available in digital form, and therefore we cannot

TABLE 2 | Station series used for the period 1853–present.

	HadCET legacy version	HadCET v2
1853–1877	Oxford (Radcliffe) only	Oxford (Radcliffe) only
1878–1930	Cambridge, Ross-on-Wye, Stonyhurst	Rothamsted, Ross-on-Wye, Stonyhurst
1931–1958	Rothamsted, Ross-on-Wye, Stonyhurst	
1959–Oct 2004	Rothamsted, Malvern, 0.5 (Squires Gate + Ringway)	Rothamsted, Malvern, 0.5 (Squires Gate + Ringway)
November 2004–December 2005	Rothamsted, Malvern, Stonyhurst	Rothamsted, Pershore College, Stonyhurst
2006 to date	Rothamsted, Pershore College, Stonyhurst	

Note: From 1878 onwards, stations representing three regions (Lancashire, Hertfordshire and Worcestershire) are averaged (see text).

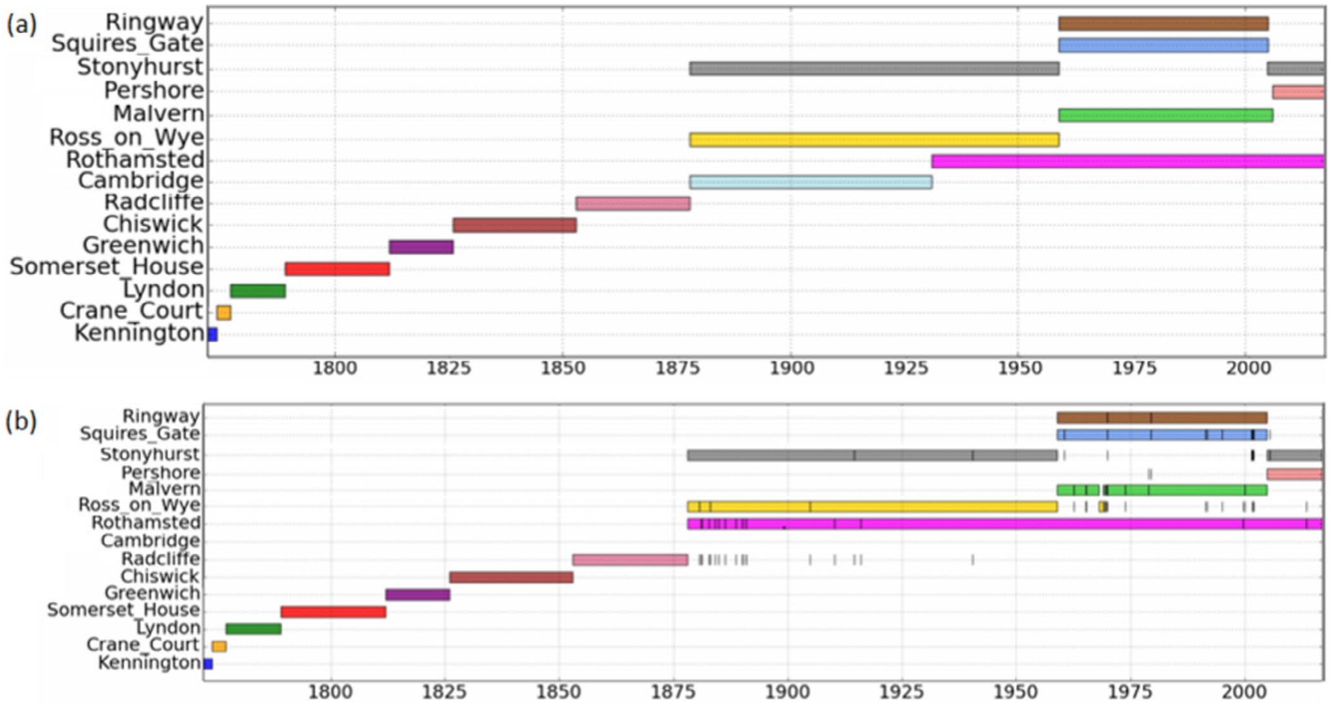

FIGURE 2 | Representation of station usage through time comparing (a) Parker et al. (1992) and Parker and Horton (2005) and (b) HadCETv2.0.0.0. Radcliffe refers to Oxford (Radcliffe).

reproduce the adjustments that have been conducted on this portion of the series, so for most of this period, the HadCET v2 is unchanged from the legacy version. An exception is for the daily values for December 1786. At some point in the past, within the legacy version each day's value for this month had been replaced with the associated monthly mean value. The daily adjusted Syon House series are available and have been restored for this month so that the series is again consistent with Table 1. Further work is required to recover all the original daily series as listed in Table 1, and the associated adjustments made to them.

2.3 | Daily Temperature Series, 1853–Present

For the period from 1853, some amendments to the source stations used have been made, and these are summarised in Table 2 and Figure 1. The locations of stations are shown in Figure 1, and their use through time represented in Figure 2. To reduce the number of station selection changes in the historical period two changes to the stations have been implemented in this version of HadCET, with Rothamsted replacing Cambridge for 1878–1930, which also has the additional benefit of improving consistency of the daily mean with the daily min and max series (Parker and Horton 2005). Second, Pershore College replaces Malvern from November 2004 to December 2005. The number of changes since 1878 has therefore reduced from five to three.

2.4 | Missing Data

For the period from 1878 to present, where a contributing station is missing a value on a given day, Table 3 lists the substitute stations (in order of preference) that are used. A substitute station cannot be used for more than one station on a given day.

TABLE 3 | Contributing CET stations and substitutes.

Station, time period used	Percentage of missing values (%)	Substitute Stations
Rothamsted, 1931 to date	0.04	Oxford, Pershore College, Malvern, Ross-on-Wye
Ross-on-Wye, 1878–1958	0.03	Oxford, Rothamsted
Stonyhurst, 1878–1958 & November 2004 to date	0.007	Squires Gate, Ringway
Malvern, 1959–2005	2.8	Ross-on-Wye, Pershore College, Oxford
Squires Gate, 1959 to October 2004	0.3	Stonyhurst
Ringway, 1959 to October 2004	0.03	Stonyhurst
Pershore College, 2006 to date	0	Malvern, Ross-on-Wye, Oxford, Rothamsted

The total proportion of substituted values is small, accounting for 0.3% of all values used in the generation of the CET from 1878 to date (roughly 1 day per year on average), with Malvern having the largest proportion of missing data. The use of stations through time is summarised in Figure 2, with vertical bars showing where some of the most prominent substitutions occur. For example, Oxford replaces Rothamsted, and to a lesser extent, Ross-on-Wye for dates in the late nineteenth and early twentieth century, and Ross-on-Wye replaces Malvern for some periods in the 1960s, 1990s and early 2000s.

2.5 | Additional Station Series

A number of additional station records are used within the HadCET process for the estimation of the urbanisation adjustment, but are not otherwise used. These are stations at Luddington, Preston Wynne and Macclesfield as shown in Figure 1.

2.6 | Evaluation Data

Regional averages calculated from the 1 km gridded data set HadUK-Grid (Hollis et al. 2019) have been used to provide some evaluation of the HadCET series. The HadUK-Grid monthly temperature series spans 1884–present, and the daily temperature series 1960–present. The HadUK-Grid data set also makes use of the stations in Table 2 so is not truly independent. However, while HadCET uses at most 4 stations, the HadUK-Grid makes use of the full network of observations across the United Kingdom: ranging from around 60–70 stations in 1884 to over 600 stations at its peak in the early 1990s, and its method of construction is completely different. Therefore, for comparison purposes, we will consider them almost independent series and use the HadUK-Grid 'Midlands' area average shown in Figure 1. It is acknowledged that the Manley (1974) and Parker, Legg, and Folland (1992) definition of 'central England' is not strictly a representation of the Midlands, and therefore the comparisons are to be seen as an evaluation of the broad consistency and homogeneity between these two alternative UK-based climate series to highlight any areas for further investigation.

3 | Methodology

Parker, Legg, and Folland (1992) and Parker and Horton (2005) outline how a daily series was constructed from temperature readings collected electronically in the modern era, and manually by both professional and amateur observers back to 1772. They built their series from individual station records within the CET region prior to 1878, when a switch to three averaged constituent stations is introduced. This approach, which is retained for the version 2, is summarised below, but further details are available in the referenced literature.

The series prior to 1853 has not been changed for this version, except for the replacement of December 1786. Therefore, in the sections that follow the changes to method and their impacts will focus on the period from 1853 onwards. For the period 1853–1877, the input Oxford series is unchanged, however the estimation of the variance adjustment applied to this period of the series is affected, so there are some small differences to note.

3.1 | Step 1: Calculate the Average of the Constituent Station Data

For the period 1853–1877, the Oxford Radcliffe series is used. For the period from 1878 onwards, equal weighting is given to three locations approximating to Lancashire, Hertfordshire and Worcestershire. From 1959 to 2004, two stations (Squires Gate and Ringway) are averaged to provide the Lancashire component and then averaged with stations from Hertfordshire and Worcestershire. The simple average of the constituent stations is referred to hereafter as the 'unadjusted' HadCET.

3.2 | Step 2: Adjust to Correct T_{max} Bias at Ross-on-Wye Up to 1921

Parker and Horton (2005) identified a significant warm bias in the T_{max} series for Ross-on-Wye for the period from 1878 to the early 1920s and estimated adjustments to compensate for this. These adjustments are applied for the period 1878–1921 and derived relative to a baseline period 1941–1970 due to the availability of Ross-on-Wye data. The adjustment is estimated by calculating the average of the monthly anomalies relative to a 1941–1970 baseline and taking the difference between the Ross-on-Wye station series and the unadjusted HadCET series. For consistency with Parker and Horton (2005), the adjustment is made to the unadjusted HadCET series, rather than to the Ross-on-Wye series. It is calculated separately for each calendar month. The adjustments are close to −0.2°C for T_{max} and +0.2°C for T_{min} for the months of April to September, and −0.1°C/+0.1°C or below for other months of the year. The adjustment is negative for T_{max} and positive for T_{min}, reducing the diurnal temperature range compared to the unadjusted series. The version of the daily series with this adjustment applied to the period 1878–1921 is referenced as the A0 series of HadCET. The calculation and application of adjustments are applied by the code directly without rounding, but the higher precision of values here do not imply greater accuracy; however, the seasonality of the adjustment is more apparent when using greater precision, peaking in May–June and lowest in October, December and January. The adjustments in v2.1.0.0 are compared to the Parker & Horton adjustments in Table 4.

3.3 | Step 3: Anchoring the Monthly Means to the Manley Series, 1772–1973

The monthly mean temperature series of Manley (1974) is taken as a reference series for HadCET. The HadCET daily temperature series are adjusted so that the equivalent monthly means match the Manley series for the period 1772–1973 on the assumption that the careful work of Manley has produced a homogeneous series through this period and that the daily series is itself consistent with the longer running Manley series. Adjustments are calculated to remove the difference between the monthly means of the A0 series and the original Manley monthly CET series for the period 1772–1973. The monthly adjustment is applied to each day of the month in the daily series. For the period from 1878, the same adjustment is then also applied to T_{max} and T_{min}. The magnitudes of the adjustments are shown in Figure 3 with the average adjustment for 1853–1877, when the series is based solely on Oxford Oxford, being −0.54°C reflecting that Oxford is on average warmer than the Central England Temperature series. For 1878–1958, the average adjustment is +0.23°C reflecting that the Manley series is on average warmer than the selected set of stations for HadCET v 2. There is a change of stations in HadCET in 1959 (Table 2) which results in a reduction in the adjustment to Manley. However, it is notable that there is a trend in the adjustment from approximately 1940 to 1970, irrespective of the station change in 1959. This would indicate that the unadjusted series exhibits a warming trend relative to the Manley CET record through this period that is not attributable to the change in constituent stations in 1959. To provide a cross-reference, we compare the series before and after adjustment, with the HadUK-Grid Midland series, and this is shown in Figure 4. The unadjusted series for T_{mean} in the upper panel of Figure 4 has a warming trend relative to the Midlands series from roughly the 1930s–1970s, this relative trend is removed in the adjusted series suggesting that the homogenisation work undertaken by Manley for his T_{mean} series results in improved consistency with the HadUK-Grid Midlands series. However, there is a relative cooling trend in the adjusted HadCET relative to Midlands for T_{min} and a warming trend for T_{max}. Future investigations may therefore wish to scrutinise more closely the representation of trends in the diurnal temperature range through this period. The resulting series is referenced A1.

TABLE 4 | Adjustments applied to correct Ross-on-Wye bias.

Month	HadCET v2.1.0.0 (°C)	Parker and Horton (2005) (°C)
January	0.069	0.1
February	0.107	0.1
March	0.103	0.1
April	0.153	0.2
May	0.203	0.2
June	0.200	0.2
July	0.165	0.2
August	0.173	0.2
September	0.140	0.2
October	0.065	0.1
November	0.078	0.1
December	0.060	0.1

Note: The adjustment is applied as a negative value to daily T_{max} and positive value to daily T_{min}.

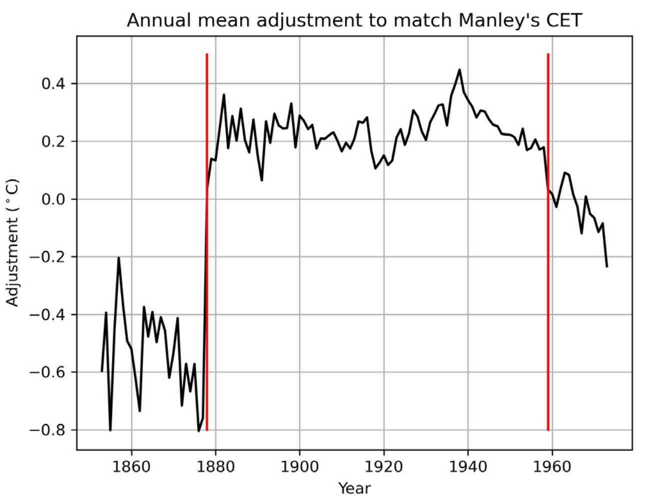

FIGURE 3 | Adjustments applied to the A0 series (see text) to correct to Manley. Positive adjustments increase the temperature of the A0 series and negative adjustments decrease it. Vertical bars highlight when there is a change in stations used in 1878 and 1959.

3.4 | Step 4: Extending the Homogenisation to the Manley Series, 1974–Present

The next step extends the homogenisation beyond the end of the Manley series. Average adjustments for the HadCET v2.1.0.0 station selection relative to the Manley series are calculated for each calendar month for the period 1959–1973, and these adjustments are then applied to all days from 1974 onward. The resulting series is referenced A2. The adjustments are shown in Table 5 alongside the equivalent estimates from table II of Parker, Legg, and Folland (1992). Although we use the same station combination in the adjustment period as the legacy HadCET, there are some differences in the estimated adjustment compared to

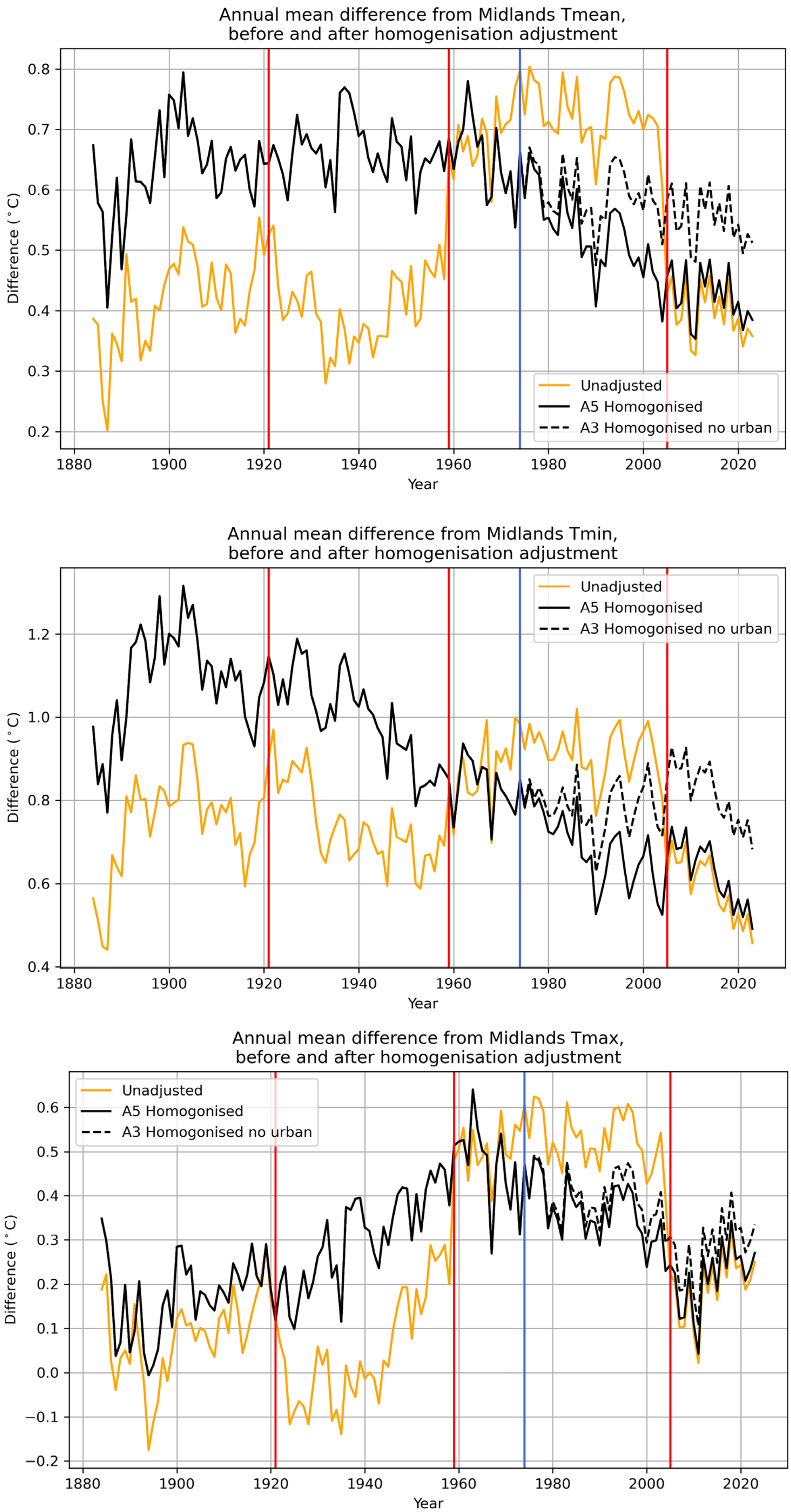

FIGURE 4 | Legend on next page.

FIGURE 4 | Annual mean difference (HadCET minus Midlands) of the HadCET (orange) A0 unadjusted, (dashed black) A3 homogenised and (black solid) A5 homogenised including urbanisation adjustments relative to the HadUK-Grid Midlands series for the period 1884–2020 for (top) T_{mean} (middle) T_{min} and (bottom) T_{max}. Dashed line reflects the difference after station homogenisation but before urbanisation adjustment. The vertical red lines mark change points in 1921, 1959, and 2005 (see text), and the blue line marks 1974 and the end of adjustments to the Manley series.

TABLE 5 | Homogenisation adjustments applied 1974–present.

Month	HadCET v2.1.0.0 (°C)	Parker, Legg, and Folland (1992) (°C)
1	0.1	0.1
2	0.0	0.0
3	−0.1	0.0
4	−0.1	−0.1
5	−0.2	−0.1
6	−0.2	−0.1
7	−0.2	−0.1
8	−0.2	−0.2
9	−0.2	−0.1
10	−0.2	0
11	−0.2	0.1
12	−0.1	0.1

TABLE 6 | Homogenisation adjustments applied 2004–present.

Month	T_{min} adjustment (°C)	T_{mean} adjustment (°C)	T_{max} adjustment (°C)
1	0.244	0.237	0.216
2	0.375	0.294	0.216
3	0.333	0.276	0.220
4	0.384	0.304	0.223
5	0.435	0.316	0.197
6	0.399	0.271	0.143
7	0.526	0.452	0.383
8	0.508	0.370	0.216
9	0.352	0.282	0.219
10	0.213	0.178	0.155
11	0.295	0.250	0.210
12	0.247	0.233	0.219

Parker, Legg, and Folland (1992): the largest discrepancy being in the months of October to December. This is a systematic adjustment applied to all data after 1973, and therefore will have an impact on the magnitude of the long-term warming trend in the series, with the net impact being that the period after 1973 is cooled in the HadCET v2.1.0.0 by −0.1°C relative to the legacy HadCET.

3.5 | Step 5: Homogenisation for Station Changes, Post-1974

In HadCET v.2.1.0.0, there is only a single station change to contend with post-1974 which occurs in November 2004. Contrary to common practice in some homogenisation efforts when the recent series is taken as the reference, the HadCET series is anchored to the Manley series up to 1973, so the present is homogenised to the past. In this instance, the impact of the station change is calculated as the mean difference between the calendar monthly average T_{mean} for the unadjusted new station combination and that for the unadjusted previous station combination over periods in which the two station combinations overlap. In this case, this overlap periods are the period 1959–1978, up to the closure of Stonyhurst, and 2002–2005 following the re-opening of Stonyhurst and before the closure of Malvern. The resulting adjustments for the period from November 2004 onwards are shown in Table 6. The adjustments are positive, indicating that the average for the current station selection is slightly cooler than for the previous selection. The adjustments are slightly larger for T_{min} than for T_{max} and slightly larger in summer than winter. The station changes in November 2004 have been modified compared to the legacy HadCET, so there is not a direct comparison to be made regarding the contents of Table 6 with the legacy version. The series including this station adjustment is referred to as the A3 series.

Equivalent homogenisation adjustments are also estimated for ad-hoc station substitutions that are applied to the data. The same process is undertaken in identifying overlap periods for each unique station combination and determining the mean difference for each calendar month with the prevailing station combination for the period of time that the substitution is required. As shown in Table 3, these constitute a small fraction of days but act to reduce spurious outliers resulting from these substitutions. The net impact of these homogenisation steps can be seen in how they affect the comparison with the HadUK-Midlands series as shown in Figure 4 comparing the orange (A0—unadjusted) and (A3—dashed black). There are trends in the difference between the A3 series and the HadUK-Midlands series, in particular for the period from 1920 to 1959, which indicates that the HadCET v2 T_{min} series cools over this period relative to the HadUK-Grid Midlands series by around 0.3°C, and that the HadCET T_{max} warms relatively by a similar amount, but the T_{mean} is more consistent between the two data sets.

3.6 | Step 6: Adjusting the Variance of the Daily Series From a Single Station (1853–1877)

For the period 1772–1877, HadCET is based on a single station series, and after that point is based on three (or four) stations. In

TABLE 7 | Variance scaling factor *b*.

Month	HadCETv2.0.0.0	Parker, Legg, and Folland (1992)
1	0.88	0.90
2	0.89	0.90
3	0.88	0.90
4	0.87	0.89
5	0.87	0.88
6	0.84	0.86
7	0.86	0.86
8	0.85	0.86
9	0.86	0.89
10	0.87	0.89
11	0.87	0.89
12	0.88	0.90

TABLE 8 | Comparison of maximum urbanisation adjustment for T_{mean}.

Month	HadCETv2.1.0.0 (°C)	Parker, Legg, and Folland (1992) (°C)
1	−0.186	−0.2
2	−0.124	−0.2
3	−0.062	−0.2
4	−0.126	−0.2
5	−0.152	−0.2
6	−0.217	−0.2
7	−0.267	−0.2
8	−0.171	−0.2
9	−0.079	−0.2
10	−0.039	−0.2
11	−0.020	−0.2
12	−0.086	−0.2

order to ensure homoscedasticity of the HadCET series, i.e. consistent variance through time, it is therefore important to adjust the variance accordingly. In HadCET v2, the period 1772–1852 is unchanged and includes the variance adjustments applied in Parker, Legg, and Folland (1992). For the period 1853–1877, the variance scaling factor (*b*) values and adjustments have been recalculated following the same method as Parker, Legg, and Folland (1992), although in this case the stations in operation during the three station reference period for 1878–1907 have changed with Rothamsted replacing Cambridge (Table 2). The adjusted HadCET (*Ta*) for any given day (*i*) is the daily temperature anomaly ($T_i - T_m$) scaled by *b*

$$Ta_i = b\left(T_i - \overline{T_m}\right) + \overline{T_m}$$

where T_m is the mean value for that calendar month. Table 7 compares the variance scaling factor *b* in v2 with that of Parker, Legg, and Folland (1992). Both versions have lower values in summer than winter, but in v2 the scaling factor is slightly lower than the previous estimate by 0.02 on average. This means that HadCET v2 will slightly reduce the magnitude of some extreme daily temperatures compared to the previous version. The impact on daily CET for the period 1853–1877 is that 53% of days are unchanged, over 95% are within 0.1°C and 99.5% within 0.2°C, showing that the impact of this update is small compared to the standard deviation in daily mean temperature anomaly of 2.5°C. The resulting series is referred to as A4.

3.7 | Step 7: Adjust the Series to Correct for Urbanisation, 1974–2004

This step addresses the need for adjustment to ensure that the HadCET series is not overly representing local influence of urbanisation around the stations of interest. The approach adopted is described in Parker, Legg, and Folland (1992) which identified that the series for Malvern and Ringway were likely to have been adversely impacted by urbanisation. A rural version of the series was constructed with 0.5×(Luddington + Preston Wynne) in place of Malvern, and Macclesfield in place of Ringway for the period 1959–1986, see Figure 1. The series was not extended beyond 1986 due to the closure of Luddington. An urban adjustment coefficient is determined for each calendar month from a linear regression of the difference in mean temperature between the HadCET and 'rural' series for the period indicated. The adjustment is multiplied by 1.5 for application to T_{min} and by 0.5 for application to T_{max}, following the recommended 75%/25% split advocated by Parker and Horton (2005). The adjustment scales from zero in 1974 to a maximum in 2004. The modern site selection of Rothamsted, Pershore College and Stonyhurst are not adversely impacted by urbanisation trends so the urbanisation adjustment is fixed from that point, but is retained for consistency of homogenisation, because the modern station selection has already undergone homogeneity adjustment.

Although the same reference rural stations are used, because some other elements of the data set construction have been altered, the recalculated urbanisation adjustments are not expected to match exactly with those of Parker, Legg, and Folland (1992). A comparison is shown for T_{mean} adjustments in Table 8 with slightly higher values in June and July and lower values elsewhere. The overall annual average urban adjustment reaches almost −0.2°C for T_{mean}, −0.3°C for T_{min} and −0.1°C for T_{max}. The largest changes are to summer T_{min} reaching −0.4°C. Figure 5 shows the impact of the urban adjustment over time as an annual mean adjustment, and Figure 6 shows the seasonality in the maximum adjustments applied that have the largest impact in the summer months. This particular adjustment has a strong dependence on the behaviour of regional and local climate series over the 1960s–1980s and has a relatively rudimentary linear application and therefore warrants further critical inspection for any future iteration of the HadCET data set. The introduction of the urban adjustment introduces a trend in the difference with the Midland series, shown in Figure 4.

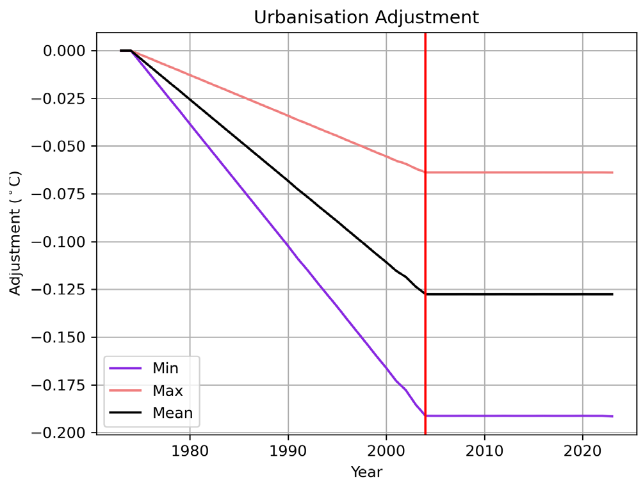

FIGURE 5 | Magnitude of average annual urbanisation adjustment 1974–2020. The vertical red line is located at 2005.

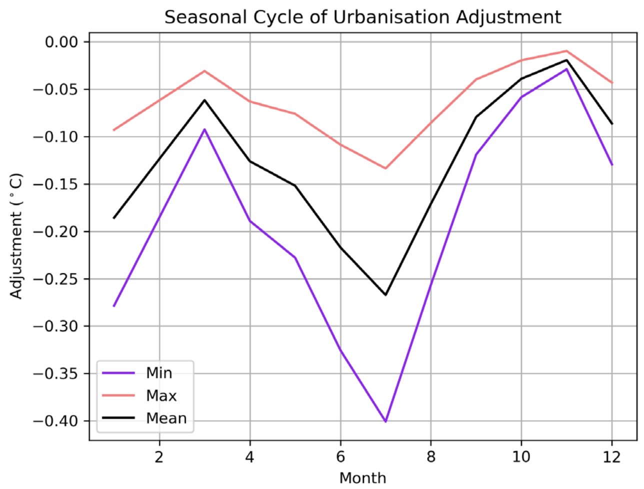

FIGURE 6 | Seasonal cycle of the maximum urbanisation adjustments applied for (black) mean (red) maximum and (purple) minimum temperature.

This implies that either (a) the Midlands series is itself adversely impacted by urbanisation over this period, (b) the urbanisation adjustment applied to the HadCET series is too large or (c) some combination of these two factors. The resulting series is referred to as A5.

4 | Revised Data Set and Concluding Remarks

The annual mean series for HadCET legacy, v2 and the Midlands series are shown in Figure 7 which puts the discrepancies highlighted in Figure 4 into the context of the long-term inter-annual variability and trend. The amendments implemented in version HadCET v2 have minimal net impact on the series relative to the legacy version with summary statistics for daily and monthly data supplied at https://doi.org/10.5281/zenodo.12732046. In Figure 8, we compare extreme values as the lowest minimum temperature and highest maximum temperature of the year for each data set, as anomalies relative to the 1961–1990 average annual lowest minimum and highest maximum temperature. There is very close agreement in the magnitude of the annual extremes in these data sets, allowing for the HadCET and HadUK-Grid not representing the same regional sampling. The HadCET v.2 series is highly correlated with the HadUK-Grid derived Midlands series, but as documented previously, there are some discrepancies in relation to the long-term trends.

This current activity yielding v2 was intended to improve the traceability of the data set to the source station series and reduce the number of station changes within the modern era but the methods applied follow those of the previously published data. It highlights a number of areas for further scrutiny and review, particularly:

1. The early era reconstructions for the 17th–19th centuries should be revisited to improve the traceability to source material used by Manley and Parker in the construction of these series, and modern resources could help improve the quantification of uncertainties, including recent developments of the early Oxford series (Burt and Burt 2019).
2. The relative trends between HadCET and HadUK-Grid for maximum and minimum temperature for the period from 1880s to 1974.
3. The role of the urban adjustment to diverging trends between HadCET and HadUK-Grid for the period from 1974 to present.

In order to facilitate better tracking of corrections or amendments subsequently made to this data set, a version numbering system has been adopted, consistent with other Met Office Hadley Centre observational data sets. The version numbering for the data set follows a pattern X.Y.Z.θ where:

1. X reflects a major update to the whole data set.
2. Y reflects a minor update to components of the data set.
3. Z reflects an incremental change.
4. θ is reserved for identifying provisional data or versions of the data set under development.

At time of publication, two versions have been made available. v2.0.0.0 includes amendments as described above. V2.0.1.0 additionally includes minor corrections:

1. A bug fix in the handling of substitute stations to ensure that the same substitute station was not used on the same date for two different CET stations with missing data.
2. Correcting an erroneous value for Ross-on-Wye on 23 December 1884 from −15.7°C to +5.4°C.
3. Precision of input station temperature values changed from floats to decimals.
4. All intermediate values retained internally to five decimal places through all calculations.

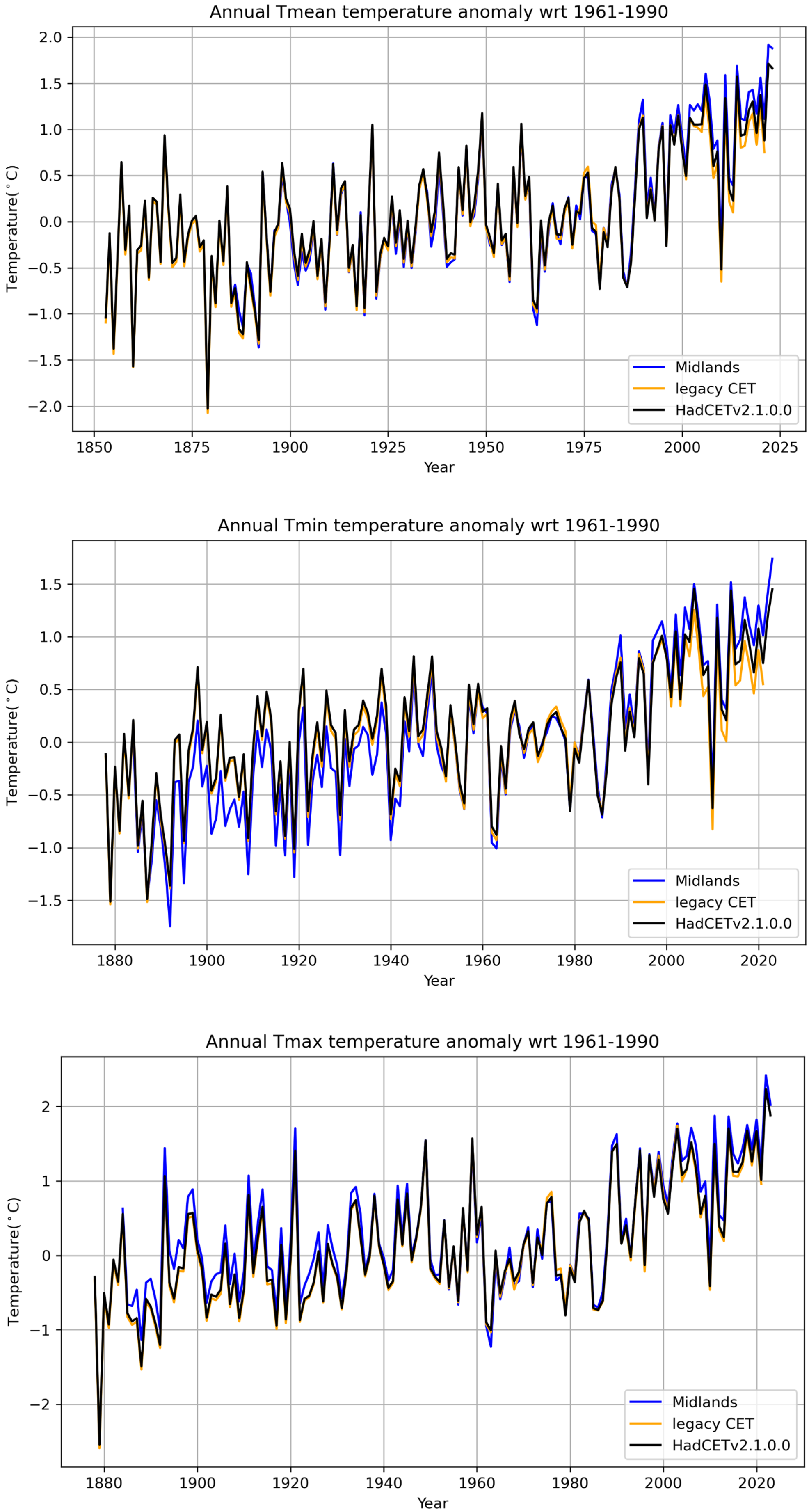

FIGURE 7 | Legend on next page.

FIGURE 7 | Annual mean time series for (top) mean, (middle) minimum and (bottom) maximum temperature. HadCET mean temperature is shown from 1853, and maximum and minimum temperature from 1878. The Midlands series commences in 1884 in all cases.

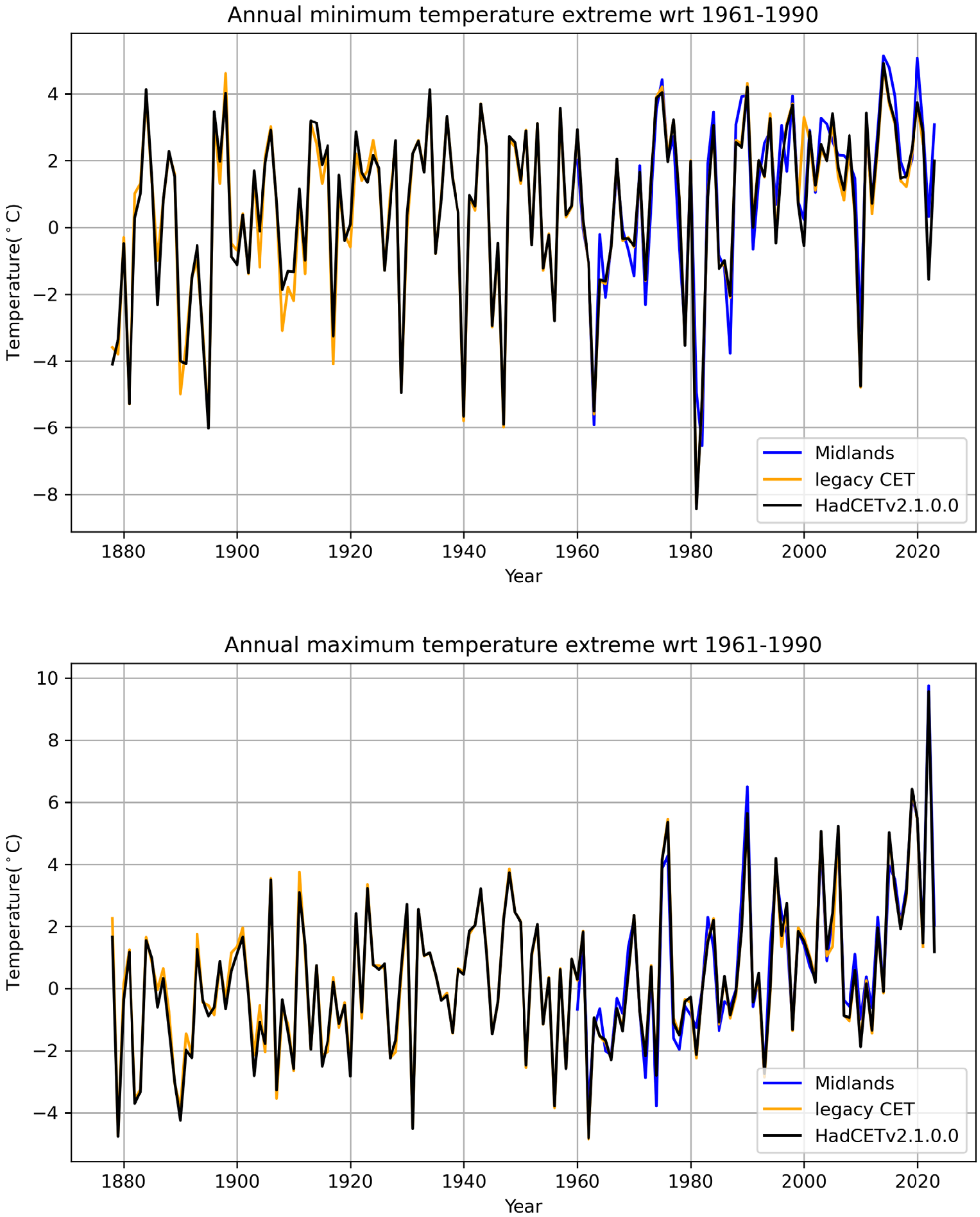

FIGURE 8 | Timeseries of annual (top) lowest minimum and (bottom) highest maximum temperature expressed as an anomaly relative to the average annual extreme temperature. Daily temperatures for the midlands series from which to derive the annual extremes are only available from 1960.

V2.1.0.0 additionally includes amendments to:

1. A correction to station data input files where values had incorrectly truncated the second decimal for mean temperatures.

All figures and tables presented in this manuscript are derived from v2.1.0.0.

5 | Using the Data

At time of publication, HadCET temperature series are available from https://www.metoffice.gov.uk/hadobs/hadcet/ including documentation and release notes for each version. In addition, a collection of files containing input station series, full set of adjustments and resulting temperature time series are provided from https://doi.org/10.5281/zenodo.12732046. These latter data files are in csv format adopting the BADC-CSV metadata convention (https://help.ceda.ac.uk/article/105-badc-csv) and README files to describe the contents of each folder and file.

Acknowledgements

This work was supported by the Met Office Hadley Centre Climate Programme funded by the UK Government Department for Science, Innovation and Technology (DSIT).

Data Availability Statement

The data that support the findings of this study are openly available in HadCET v2.1.0.0 at https://zenodo.org/records/12732046.

References

Burt, S., and T. Burt. 2019. *Oxford Weather and Climate Since 1767*. Oxford, UK: Oxford University Press. https://doi.org/10.1093/oso/9780198834632.001.0001.

Croxton, P. J., K. Huber, N. Collinson, and T. H. Sparks. 2006. "How Well Do the Central England Temperature and the England and Wales Precipitation Series Represent the Climate of the UK?" *International Journal of Climatology* 26, no. 15: 2287–2292. https://doi.org/10.1002/joc.1378.

Hollis, D., M. McCarthy, M. Kendon, T. Legg, and I. Simpson. 2019. "HadUK-Grid—A New UK Dataset of Gridded Climate Observations." *Geoscience Data Journal* 6, no. 2: 151–159. https://doi.org/10.1002/gdj3.78.

Jenkinson, A. F. 1985. "Hot Spells in Central England." *Weather* 40, no. 4: 127–128. https://doi.org/10.1002/j.1477-8696.1985.tb07496.x.

Jones, D. E. 1987. "Daily Central England Temperature: Recently Constructed Series." *Weather* 42, no. 5: 130–133. https://doi.org/10.1002/j.1477-8696.1987.tb06949.x.

Karoly, D. J., and P. A. Stott. 2006. "Anthropogenic Warming of Central England Temperature." *Atmospheric Science Letters* 7, no. 4: 81–85. https://doi.org/10.1002/asl.136.

King, A. D., G. Jan van Oldenborgh, D. J. Karoly, S. C. Lewis, and H. Cullen. 2015. "Attribution of the Record High Central England Temperature of 2014 to Anthropogenic Influences." *Environmental Research Letters* 10, no. 5: 054002. https://doi.org/10.1088/1748-9326/10/5/054002.

Lamb, H. H., J. M. Craddock, J. M. Grove, F. Oldfield, and M. J. Tooley. 1981. "The Life and Work of Professor Gordon Manley (1902–1980)." *Weather* 36, no. 8: 220–231. https://doi.org/10.1002/j.1477-8696.1981.tb05407.x.

Manley, G. 1946. "Temperature Trend in Lancashire, 1753–1945." *Quarterly Journal of the Royal Meteorological Society* 72, no. 311: 1–31. https://doi.org/10.1002/qj.49707231102.

Manley, G. 1952. "Thomas Barker's Meteorological Journals, 1748–1763 and 1777–1789." *Quarterly Journal of the Royal Meteorological Society* 78, no. 336: 255–259. https://doi.org/10.1002/qj.49707833612.

Manley, G. 1953. "The Mean Temperature of Central England, 1698–1952." *Quarterly Journal of the Royal Meteorological Society* 79, no. 340: 242–261. https://doi.org/10.1002/qj.49707934006.

Manley, G. 1974. "Central England Temperatures: Monthly Means 1659–1973." *Quarterly Journal of the Royal Meteorological Society* 100, no. 425: 389–405. https://doi.org/10.1002/qj.49710042511.

Parker, D., and B. Horton. 2005. "Uncertainties in Central England Temperature 1878–2003 and Some Improvements to the Maximum and Minimum Series." *International Journal of Climatology* 25, no. 9: 1173–1188. https://doi.org/10.1002/joc.1190.

Parker, D. E., T. P. Legg, and C. K. Folland. 1992. "A New Daily Central England Temperature Series, 1772–1991." *International Journal of Climatology* 12, no. 4: 317–342. https://doi.org/10.1002/joc.3370120402.