UK shallow ground temperatures for ground coupled heat exchangers

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Abstract

Accurate estimations of shallow ground temperatures are required when sizing the horizontal closed loops and air supply culverts of ground coupled heating and cooling systems. These collector loops and culverts are within the zone affected by the seasonal swing in temperatures. Soil temperatures from 106 Met Office weather stations, located across the UK, have been analysed from which mean annual, seasonal minimum and maximum and daily minimum and maximum temperatures have been calculated. Mean annual temperatures at 1 m depth, reduced to sea level, range from 12.7 °C in southern England to 8.8 °C in northern Scotland, with corresponding seasonal ranges in temperature of 10.3 °C and 7.9 °C respectively. An average Urban Heat Island (UHI) effect at 1 m depth of 0.55 °C has been observed at localities adjacent to urban green spaces, from which it can be assumed that the UHI effect will be greater in densely developed city and town centres. A linear relation has been derived for the mean annual temperature at any non-urban UK locality, at 1 m depth. The seasonal temperature cycle has been extrapolated accurately to several metres depth with site specific thermal properties derived from the soil temperature measurements.

When designing closed-loop horizontal and vertical ground heat exchangers the temperature of the ground is a crucial parameter for correctly sizing the loops, whether the system is to be used for heating and/or cooling. Accurate ground temperatures are also required for passive heating and cooling systems, which temper ventilation air by introducing it through a large, buried air supply culvert, and this requires accurate knowledge of the seasonal temperature variations in the top 5 m of the ground (Orme & Isanska-Cwiek 2012). The temperature in the ground at around 15 m depth is equal to the mean annual air temperature (Rybach & Sanner 2000). At sea level for mainland UK, mean annual air temperature varies from north to south from about 8 to 12 °C (Perry & Hollis 2005). Air temperatures are mainly affected by position and elevation. The decrease of air temperature with increasing altitude is given by the Environmental Lapse Rate which has an average value of 0.65 °C per 100 m (ICAO 1993). Temperatures in the ground beneath the zone affected by seasonal fluctuations (i.e., > 15 m depth) will increase with depth depending on the local heat flow and the thermal conductivity of the ground. The average increase, referred to as the geothermal gradient, for the UK is 2.6 °C per 100 m. Assuming that heat transfer is only by conduction, Busby *et al*. (2009) generated temperatures for Great Britain at 100 m depth that showed a range of 4 to 17 °C. Within hydraulically transmissive rocks, heat can also be transferred by advection. Headon *et al*. (2009) report temperatures ranging from 11-15 °C at constant depths below ground level of 80 and 100 m within the Chalk aquifer below London. The higher temperatures in the SW of their study area are compatible with the geothermal gradient, but the lower temperatures in the east were speculatively attributed to recharge of cooler water. Pike *et al*. (2011) report a more extensive set of temperature measurements in the Chalk aquifer of the western London Basin syncline. At 100 m below ground level, temperatures varied from 9-9.5 °C to 14.5-15 °C. This range in temperatures was partly attributed to ground surface elevation, but the higher temperatures were not fully explained; one possibility being that the Tertiary sequence overlying the Chalk may have a lower bulk thermal conductivity, and hence insulating effect, than would be expected.

Horizontal ground loop collectors are buried either in a trench of sufficient width to allow the pipe to be looped horizontally along its base or looped vertically in a slit trench. Suggested depths of the trenches vary, for instance, Banks (2008) indicates 1.2-2 m, the IGSHPA (1996) rule of thumb is 1.2-1.8 m and VDI (2001) suggest 1.2-1.5 m. The trenches are within ground that is affected by the daily and seasonal temperature fluctuations, although the daily fluctuation only penetrates a few tens of centimetres (Banks 2008). It is a requirement (MIS 3005 2013) for the swing of ground temperatures through the year to be incorporated in ground source heat pump design so that base load and peak load requirements are met. The amplitude of the seasonal temperature swing decreases, and is offset in time, with depth (Banks 2008).

Maps of average soil temperatures at 30 cm depth are available from the Met Office based on monthly, seasonal or annual averages (http://www.metoffice.gov.uk/public/weather/climate/). There are also online agricultural services that will generate a soil temperature at 10 cm depth for a UK postcode based on the average of the 5 closest Met Office weather stations (e.g. https://www.kws-uk.com/go/id/fnbz) or apps that will give a monthly or annual average soil temperature (e.g. http://www.bgs.ac.uk/mySoil/). However, none of these services give temperatures for 100 cm depth, the average depth of a horizontal ground loop collector.

It has been widely reported that urban areas, especially large towns and cities, have raised mean annual air temperatures when compared to rural areas (e.g., Pollack *et al*. 1998; Magee *et al*. 1999; Perrier *et al* 2005; Taniguchi *et al.* 2007). This is due to a variety of factors including, large tarmacadam/paved areas that preferentially absorb solar energy compared to vegetation, re-radiation of thermal energy at night from buildings warmed during the day and heat leakage from poorly insulated buildings (Linacre & Geerts 1997). Higher mean air temperatures will also affect sub-surface temperatures that will also be enhanced by heat leakage from the floors and basements of buildings (Ferguson & Woodbury 2004; Ferguson & Woodbury 2007) and heat discharged from underground services, especially water and sewage pipes (Banks *et al*. 2009). This thermal anomaly is known as the urban heat island (UHI) effect (Oke 1973). It represents an increased sub-surface thermal resource that can be exploited by thermal ground coupling technology (Zhu *et al*. 2010), but can create problems for those designing ground coupled passive heating and cooling systems where accurate ground temperatures are required.

Most urban sub-surface temperature measurements have been made in boreholes. Banks *et al*. (2009) report an increase of around 2-3 °C at 20 m depth in two closed loop boreholes in Gateshead, Tyne and Wear, UK. Ferguson & Woodbury (2007) measured temperatures in 40 water wells in Winnipeg, Manitoba, Canada, from which they constructed a groundwater contour map at 20 m depth. This showed a general increase of 2-3 °C in the city centre compared to agricultural areas, but subsurface temperatures beneath green spaces in the city were lower than beneath business districts in the city centre. Menberg *et al*. (2013) examined shallow groundwater temperatures under six German cities and found regional differences in elevated temperatures between urban and rural areas of 3-7 °C. In Berlin, Munich and Cologne, the highest temperatures were close to or in the city centre, whilst in Karlsruhe and Darmstadt they were found in industrial areas and close to landfill sites. In three investigated cities in Finland, Arola & Korkka-Niemi (2014) found the average groundwater temperatures, below the seasonal fluctuation zone, were 1.3–2.0 °C higher in the urban area and 3.0–4.0 °C higher in the city centre than in the rural area around them.

There is very little in the literature on the UHI effect in the top 5 m of the ground. At these shallow depths, temperatures are affected by the seasonal swing in air temperature. The location of the site (i.e. proximity to green space) is likely to have an increased influence compared to temperatures at greater depths and the UHI effect may itself have a seasonal component.

This Technical Note presents soil temperature data from Met Office stations across the UK to a depth of 100 cm. The data is intended to assist those who require accurate shallow temperature data. Predictive trends are identified and some initial indications of the UHI effect in the top 5 m of the ground are investigated.

Methodology

Soil temperature data are collected and archived by the UK Met Office at several hundred weather stations and are made available for academic purposes via the British Atmospheric Data Centre (http://badc.nerc.ac.uk/home). The data are recorded at 09:00 each day at depths of 5, 10, 20, 30, 50 and 100 cm, although not all depths are covered at each station and some temperature depth records may be discontinuous. The data are recorded to the nearest 0.1 ºC. In general, these sites are on level ground with no trees, buildings or steep ground nearby (Met Office 2010). A typical soil temperature record for 5 years from the Met Office weather station at Eastbourne with daily temperature readings at 30 cm depth (black lines) and 100 cm depth (grey lines) is shown in Figure 1. There is considerable daily temperature fluctuation and hence a function of the form;

$$Y = a0 + a1\cos(wX) + b1\sin(wX) \tag{1}$$

has been fitted to the data (see the bold lines in Figure 1) in order to identify seasonal trends.

From these daily data the following temperatures are derived:

Mean annual –	The mean temperature over several continuous full years between 2000-2010 at depths of 30, 50 and 100 cm.
Seasonal minimum –	The minimum temperature of the fitted function at depths of 30, 50 and 100 cm.
Seasonal maximum –	The maximum temperature of the fitted function at depths of 30, 50 and 100 cm.
Daily minimum –	The minimum daily temperature recorded over the period from which the mean was calculated, at depths of 30, 50 and 100 cm.
Daily maximum –	The maximum daily temperature recorded over the period from which the mean was calculated, at depths of 30, 50 and 100 cm.

If heat transfer into the ground is solely by conduction then the mean temperatures at two depths should be equal (since the contribution from the geothermal gradient is negligible at 0.02-0.04 °C/m). Differences indicate the influence from other heat transfer processes such as evapotranspiration and advection. If taken over several full years, the mean should not be too affected by exceptionally cold or warm years. The seasonal minimum and maximum temperatures represent average cold and warm conditions that can assist in designing a ground loop for peak load conditions. Extreme temperatures are given by the daily minimum and maximum temperatures and these will be more dependent on the time period considered. Extreme temperatures in the UK usually only last for a few days, although in exceptional conditions they can last for weeks or even months. These daily extremes may need to be considered when designing for peak load conditions for a vertically looped horizontal collector, but should have dissipated to low levels at the depth of a horizontally coiled collector. As discussed above, the seasonal temperature fluctuation in the ground decreases in amplitude and increases in phase shift (time offset) with depth. This can be seen clearly in the fitted curves in Figure 1. For two vertically separated soil temperature measurements resulting from a periodic heating cycle (e.g. the yearly cycle), the amplitude and phase changes can be used to derive the thermal diffusivity of the soil (Kappelmeyer & Haenel 1974; Adams *et al*. 1976; Horton *et al*. 1983). This is not included here, but a full account is given in Busby (2015).

Soil temperature data from 106 UK Met Office weather stations have been analysed and their distribution is shown in Figure 2. Geographical information on these 106 stations is presented in Table A1 in the Appendix. They cover the full geographical extent of the UK and include coastal and urban settings. Datasets for the period 2000-2010 have been analysed with an emphasis on temperatures from 100 cm depth (the average depth of a horizontal loop trench), although data are also presented from depths of 30 and 50 cm. Only continuous yearly sequences were used to determine the derived temperatures.

Results

Tabulated results for each Met Office weather station are presented for England, Scotland, Wales and Northern Ireland in Tables A2-A5 in the appendix. In England, mean temperatures at 100 cm depth decrease from around 12 °C in the south to 10 °C in the north with a minimum of 9 °C at Shap and a maximum of 13 °C at St James' Park, London. Although Shap is at an altitude of 255 m, Buxton is higher at 307 m, but the corresponding temperature is 9.8°C and is due to the urbanised setting at Buxton and the exposed location at Shap. The lowest seasonal minimum at 100 cm depth of 3.8 °C occurs at Shap and the largest maximum of 18.6°C occurs at both Littlehampton and St James' Park (both urban settings). A seasonal maximum of 18.5 °C occurs at Westleton, a non-urban setting on the East Anglian coast. The seasonal minimums at 30 cm depth occur between 24th January-3rd February and the maximums between 25th July-4th August. At 100 cm depth, these minimum and maximum temperatures are delayed to 30th January-22nd February and 31st July-22nd August, respectively. The daily minimum at 100 cm depth is 1.5 °C at Warcop Range, 19 km from Shap and the maximum is 21.6 °C at both St James' Park and Oxford (both urban settings).

For Scotland, the range in mean temperatures at 100 cm depth is from around 10 °C in the south to 9°C in the north with a minimum of 8.2°C at Braemar (at an altitude of 339 m) and a maximum of 11.1 °C at Paisley (an urban setting). The lowest seasonal minimum at 100 cm depth of 3°C occurs at Aviemore and the largest maximum of 15.9°C occurs at Paisley. The seasonal minimums at 30 cm depth occur between 23rd January-7th February and the maximums between 24th July-7th August. At 100 cm depth, these minimum and maximum temperatures are delayed to 7th-23rd February and 7th-23rd August, respectively. The daily minimum at 100 cm depth is 1.2°C at Aviemore and the maximum is 18 °C at Paisley.

There are fewer data for Wales and these show a range in mean temperatures at 100 cm depth from around 12 °C in the south to 10.5 °C in the north with a minimum of 10.4 °C at Loggerheads and a maximum of 12.3 °C at Penmaen. The lowest seasonal minimum at 100 cm depth of 5.4 °C occurs at Loggerheads and the largest maximum of 17.6 °C at Penmaen. The seasonal minimums at 30 cm depth occur between 30th January-2nd February and the maximums between 30th July-3rd August. At 100 cm depth, these minimum and maximum temperatures are delayed to 11th-15th February and 12th-15th August, respectively. The daily minimum at 100 cm depth is 3.3 °C at Bala and the maximum is 18.9 °C at Penmaen.

In Northern Ireland, the minimum mean temperature at 100 cm depth is 10.3 °C at Coleraine and the maximum is 11.2°C at Annaghmore. The lowest seasonal minimum and largest maximum at 100 cm depth of 5.7 °C and 16.4 °C, respectively, both occur at St Angelo. The seasonal minimums and maximums at 100 cm depth occur between 8th-19th February and 9th-

20th August, respectively. The daily minimum and maximum temperatures at 100 cm depth of 3.8 °C and 17.4 °C, respectively, also both occur at St Angelo.

To facilitate comparison, the means and seasonal minimums and maximums at 100 cm depth have been reduced to sea level with a correction of 0.65 °C per 100 m and are shown in Table 1. Between southern and northern England, the range in mean temperature at 100 cm depth is 2.1 °C, whilst the range in seasonal minimums and maximums is 2.5 °C and 3.1 °C, respectively. The seasonal range in temperature in southern England is 10.3 °C and in northern England 10.2 °C. It should be noted that for central England there is no difference in mean temperatures between east and west, at a corrected to sea level mean value of 11.5 °C. Between southern and northern Scotland, the corresponding range in sea level corrected mean temperature is 2.4 °C and the range in seasonal minimums and maximums is 1.7 °C and 4.0 °C, respectively. The seasonal range in temperature in southern Scotland is 9.7 °C and in northern Scotland 7.9 °C. For Wales, the seasonal range in 100 cm sea level corrected temperatures is 9.9 °C and for Northern Ireland it is 8.8°C.

Some initial indications of the UHI effect have been investigated here by comparing mean annual temperatures at 100 cm depth between urban locations and, near-by, rural locations. For the comparisons, temperatures have only been considered over the same time period at the urban and rural sites and the temperature at the rural location has been corrected for the elevation difference to the urban site using the Environmental Lapse Rate of 0.65 °C per 100 m. The results are shown in Table 2. For the 10 comparisons considered, there is a measurable UHI effect at eight of them, with only one site showing a cooler temperature at the urban location. The maximum UHI effect measured, at Bournemouth, is 1.0 °C, and the average is 0.55 °C. Met Office weather stations in the urban environment are located on the edges of green spaces (parks, school playing fields, etc.). Hence, from the evidence cited above from borehole temperature measurements, it must be assumed that an increased UHI effect would be expected in the city/town centres. The highest mean annual temperatures were recorded at St James' Park, a green space in the centre of London. Unfortunately there is no near-by rural location with temperature data at 100 cm depth, but a comparison can be made with Aldenham School for 30 cm depth data, resulting in an UHI effect at St James' Park of 2.2 °C.

In Table 3, the same analysis has been applied to the seasonal minimums and maximums with comparisons between urban and elevation-corrected rural temperatures. For six of the eight urban locations that showed an UHI effect, the seasonal maximum has a greater UHI effect than the seasonal minimum, suggesting the effect is more dominant at very shallow depths in the summer. However, for two of the locations showing an UHI effect (Bradford and Paisley) this is reversed, as it is also for the two locations (Reading and Cambridge) that did not show an UHI effect.

Discussion

These data provide some insights into the variation of sub-surface temperatures within the top one metre of the ground, across the UK. Latitude and elevation are the main parameters that influence temperature. Mean annual temperatures corrected to sea level at 100 cm depth, vary from 12.7 °C in the south of the UK to 8.8 °C in the north, although higher temperatures can occur in towns and cities. The range in average seasonal temperatures, i.e. the difference between warm summer and cold winter, corrected to sea level at 100 cm depth, varies from 10.3 °C in southern England to 7.9 °C in northern Scotland. At a metre depth, for the UK, the coldest time of year is February and the warmest is August. The Met Office weather stations are not ideally placed to measure an UHI effect as, within urban areas, they are located adjacent to green spaces. However, where an effect was recognised, there is an average increase in temperature at 1 metre depth of 0.55 °C. By comparisons with other studies at greater depth, it must be assumed that the UHI effect will be higher in highly urbanised city and town centres.

For 12 of the stations located across the UK, the mean annual air temperature has been calculated for the same time periods used to calculate the temperatures at 100 cm depth. These are shown in Table 4, along with the mean annual temperatures at 100 cm depth. In all cases the soil temperature is greater than the mean annual air temperature and the range is 0.5-2.0 °C. The average of these 12 comparisons is 0.9 °C, which is in agreement with accepted practice that mean annual soil temperatures are slightly higher than mean annual air temperatures (e.g. Banks 2008).

In Figure 3 the mean annual temperatures at 100 cm depth for non-urban locations, corrected to sea level, are plotted against northing. There is a clear, linear trend, but with some scatter that will be due to other factors that affect the soil temperature, e.g. local topography and aspect. A linear trend has been fitted to these data that is also shown on Figure 3. From this fit it is possible to predict the mean temperature for non-urban locations at 100 cm depth as;

$$temp = (-3.539 \times 10^{-6} \times northing) + 12.8 - (elevation \times 0.0065) \pm 0.3, \qquad (2)$$

where *temp* is the predicted temperature in °C, at a location with a *northing* in m, at an *elevation* above OD in m. The quoted error of ± 0.3 °C is the standard deviation of the linear fit. For the Met Office stations used here, the maximum deviation between measured and predicted temperatures is 0.8 °C.

With these data it is also possible to generate accurate ground temperatures within the upper few metres of the ground and this is illustrated with data from the Wallingford Met Office weather station. The extrapolation of temperature with depth due to periodic surface heating is given by Beardsmore & Cull (2001) as,

$$T_\theta = T_0 \exp(-\varepsilon z) \sin(\omega t - \varepsilon z) \qquad (3)$$

where T_θ is the departure from a mean value of temperature at a particular depth, z, and time, t, due to a heating cycle with amplitude T_0 and frequency ω. For Wallingford, the heating cycle is taken as the seasonally fitted temperature curve at 50 cm depth. The thermal properties of the medium are included in the ε term where $\varepsilon = (\pi/P\kappa)^{1/2}$, where P is the period of the heating cycle and κ is the thermal diffusivity of the ground. As mentioned above, thermal diffusivity can be estimated from two vertically separated temperature measurements and for Wallingford, utilising the temperatures at 50 and 100 cm depths, the value for κ is 6.754×10^{-7} m^2 s^{-1} (Busby 2015). The amplitude of the heating cycle at 50 cm depth, T_0, is equal to 5.47 °C and the mean value of temperature at 50 cm depth is equal to 11.71 °C (see Table A2 in the Appendix). The resulting extrapolated temperatures from 0 to 5 m depths are shown in Figure 4. The phase offset was aligned from the known offset between the 50 and 100 cm depth seasonally fitted temperature curves. It should also be noted that the extrapolated curve at 1 m depth fits the 100 cm depth seasonally fitted curve to within ±0.1 °C. Hence, at Wallingford, the seasonal range in temperature is 13.3 °C at 0 cm depth, which is dampened to 4.2 °C at 3 m depth and 1.9 °C at 5 m depth. The time offset in the peaks and troughs of the seasonal temperature cycle, compared to the temperature at 0 cm depth, is 67 days at 3 m depth and 112 days at 5 m depth. Beardsmore & Cull (2001) define the effective wavelength ($z_{wl} = (4\pi P\kappa)^{1/2}$) as the depth at which the temperature fluctuation is in phase with that at 0 cm depth with a temperature perturbation equal to 0.0019 of that at 0 cm depth. This depth is considered to be the maximum depth to which seasonal temperature fluctuations need to be considered. At Wallingford, the effective wavelength is 16.4 m with a temperature perturbation of 0.03 °C.

Conclusions

The UK Government is committed to carbon emission reductions and a substantial increase in heat provided by renewables, including ground source heat (DECC 2013). The EU requires that Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings and the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources (EU 2010). It is therefore expected that there will be a substantial increase in the number of ground coupled heating systems installed in the UK over the next decade. Those planning or designing such systems require information and tools to assist them. For instance, Abesser et al. (2014) have produced an on-line tool for an initial assessment of the suitability of a site for open loop GSHP at the scale of a commercial building. Knowledge of shallow ground temperatures is also important in contaminated land studies since temperature is an important determinant in the rate of biodegradation (e.g. Leahy & Colwell 1990; Benoit et al. 2007; Yadav & Hassanizadeh 2011)

The data presented here are primarily intended to assist in the design of very shallow ground coupled heating systems where the seasonal swing of ground temperatures has to be taken into consideration. Soil temperatures from 106 Met Office stations have been analysed and tabulated data have been presented of the mean annual and seasonal temperatures, and the expected daily minimum and maximum temperatures, within the top one metre of the ground across the UK. Mean annual soil temperatures are, on average, 1 °C higher than mean annual air temperatures. Mean annual temperatures at 1 m depth, reduced to sea level, range from 12.7 °C in southern England to 8.8 °C in northern Scotland, with corresponding seasonal ranges in temperature of 10.3 °C and 7.9 °C, respectively. An average UHI effect at 1 m depth of 0.55 °C has been observed at localities adjacent to urban green spaces, from which it can be assumed that the UHI effect will be greater in densely developed city and town centres.

A linear relation has been derived from which the mean annual temperature for any non-urban UK locality, at 1 m depth, can be calculated. Accurate temperatures to several metres depth are also sometimes required and this has been demonstrated, on a site specific basis, by extrapolating the seasonal temperature cycle to depth.

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Figure and Table captions

Figure 1. Five year temperature record (from the 1st January 2000) from the Met Office weather station at Eastbourne. The black record is the temperature at 30 cm depth and the grey record from 100 cm depth. The rapidly fluctuating records are the daily measurements and the smooth records are the best fit through the data of an appropriate periodic function.

Figure 2. The locations of the 106 Met Office weather stations from which soil temperature data have been utilised. The stations are numbered from 1 to 106 based on their northing. Geographical information for the stations is presented in Table A1 in the Appendix.

Figure 3. Plot of the mean annual temperatures at 100 cm depth, for non-urban locations corrected to sea level, plotted against northing. The best linear fit through the data is shown by the solid line, which had a coefficient of determination of 0.9.

Figure 4. Seasonal soil temperature cycles at the Wallingford Met Office weather station. The seasonally fitted temperatures at 50 cm depth have been extrapolated to depths 0-5 m based on the periodic nature of the cycle. Site specific values of thermal diffusivity, mean value of temperature at 50 cm depth and amplitude of the heating cycle at 50 cm depth are given in the text.

Table 1. Mean annual and seasonal minimum and maximum temperatures at 100 cm depth reduced to sea level.

Table 2. Estimation of the urban heat island (UHI) effect based on comparisons of mean annual temperatures at 100 cm depth between urban and, near-by, rural locations. Temperatures are over the same time period for each comparison and the temperature at the rural location has been corrected for the elevation difference to the urban site using the Environmental Lapse Rate of 0.65 °C per 100 m.

Table 3. Estimation of a seasonal UHI effect based on comparisons of seasonal temperatures at 100 cm depth between urban and, near-by, rural locations. Temperatures are over the same time period for each comparison and the temperature at the rural location has been corrected for the elevation difference to the urban site using the Environmental Lapse Rate of 0.65 °C per 100 m.

Table 4. Comparisons between mean annual air temperatures and mean annual temperatures at 100 cm depth, calculated over the same time period for each comparison.

Appendix Tables

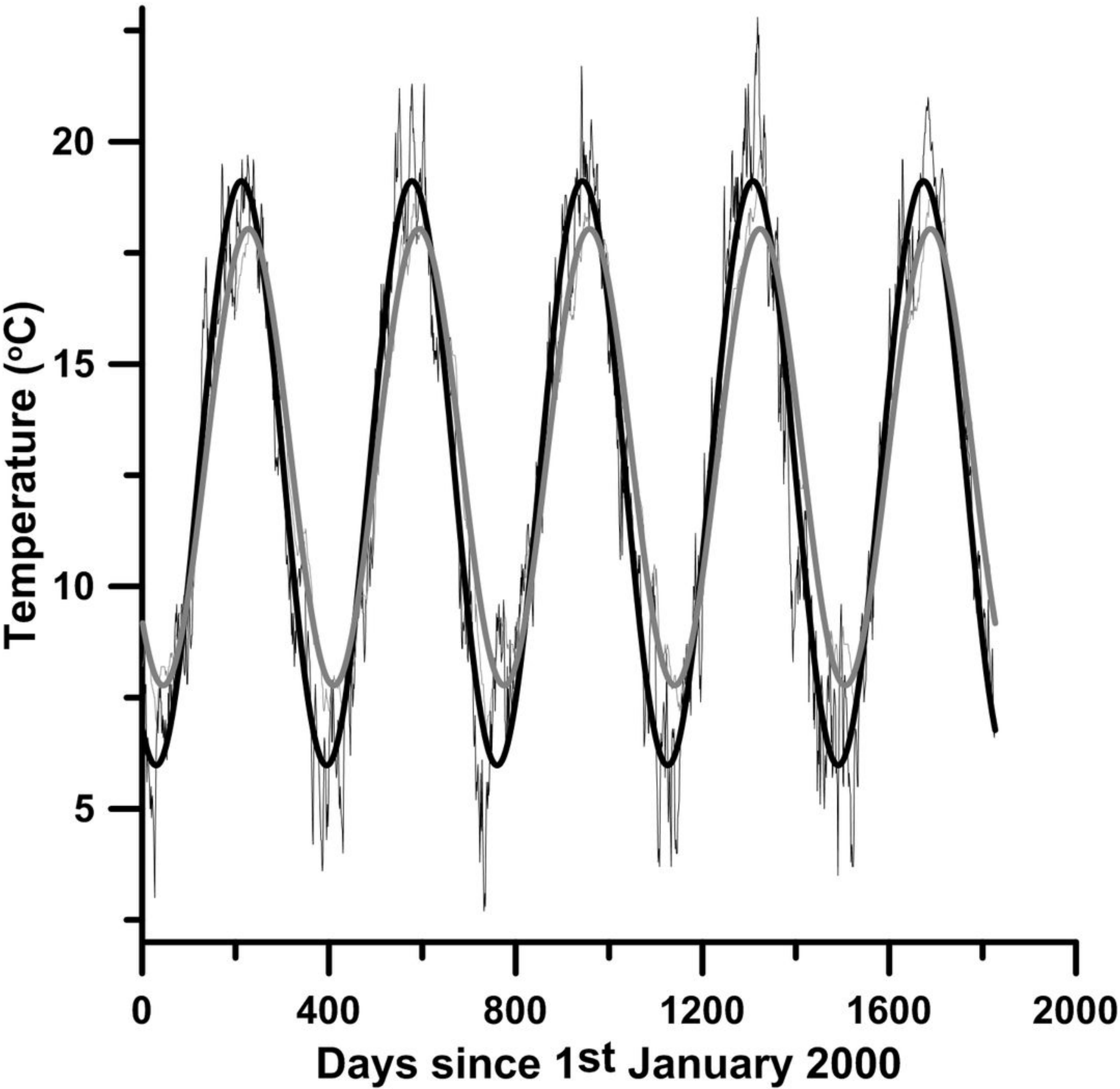
Table A1. Geographical information for the Met Office weather stations referred to in this paper. The record number (Rec) orders the stations based on northing and is used as the station identifier in Figure 2. The unique source identifier (src_id) is the Met Office station number. Eastings and northings are British National Grid and elevation is relative to OD (Ordnance Datum).

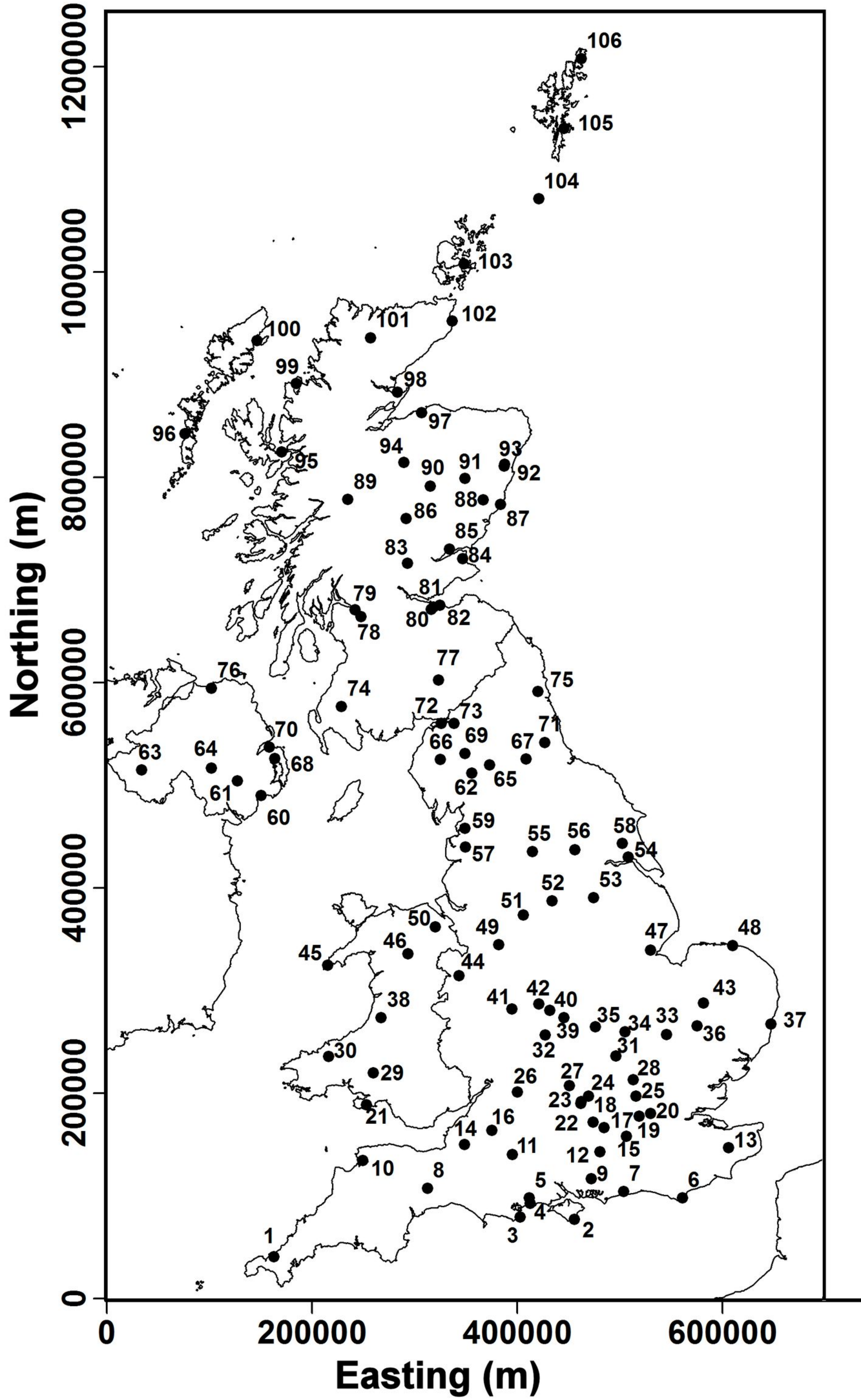
Table A2. Tabulated results of the mean annual (Mean), seasonal minimum (S_{min}) and maximum (S_{max}), and daily minimum (D_{min}) and maximum (D_{max}) temperatures for Met Office weather stations in England. The time period (in complete years) is the time over which the temperatures were calculated and the depth (in brackets to the right of the time period) is the depth of the temperature measurements.

Table A3. Tabulated results of the mean annual (Mean), seasonal minimum (S_{min}) and maximum (S_{max}), and daily minimum (D_{min}) and maximum (D_{max}) temperatures for Met Office weather stations in Scotland. Time period and depth are as described for Table A2.

Table A4. Tabulated results of the mean annual (Mean), seasonal minimum (S_{min}) and maximum (S_{max}), and daily minimum (D_{min}) and maximum (D_{max}) temperatures for Met Office weather stations in Wales. Time period and depth are as described for Table A2.

Table A5. Tabulated results of the mean annual (Mean), seasonal minimum (S_{min}) and maximum (S_{max}), and daily minimum (D_{min}) and maximum (D_{max}) temperatures for Met Office weather stations in Northern Island. Time period and depth are as described for Table A2.


20
15
10
5
Temperature (°C)
0
400
800
1200
1600
2000
Days since 1st January 2000


Northing (m)
Easting (m)
0
2000000
4000000
6000000
8000000
10000000
12000000
0
200000
400000
600000
1
2
3
4
5
6
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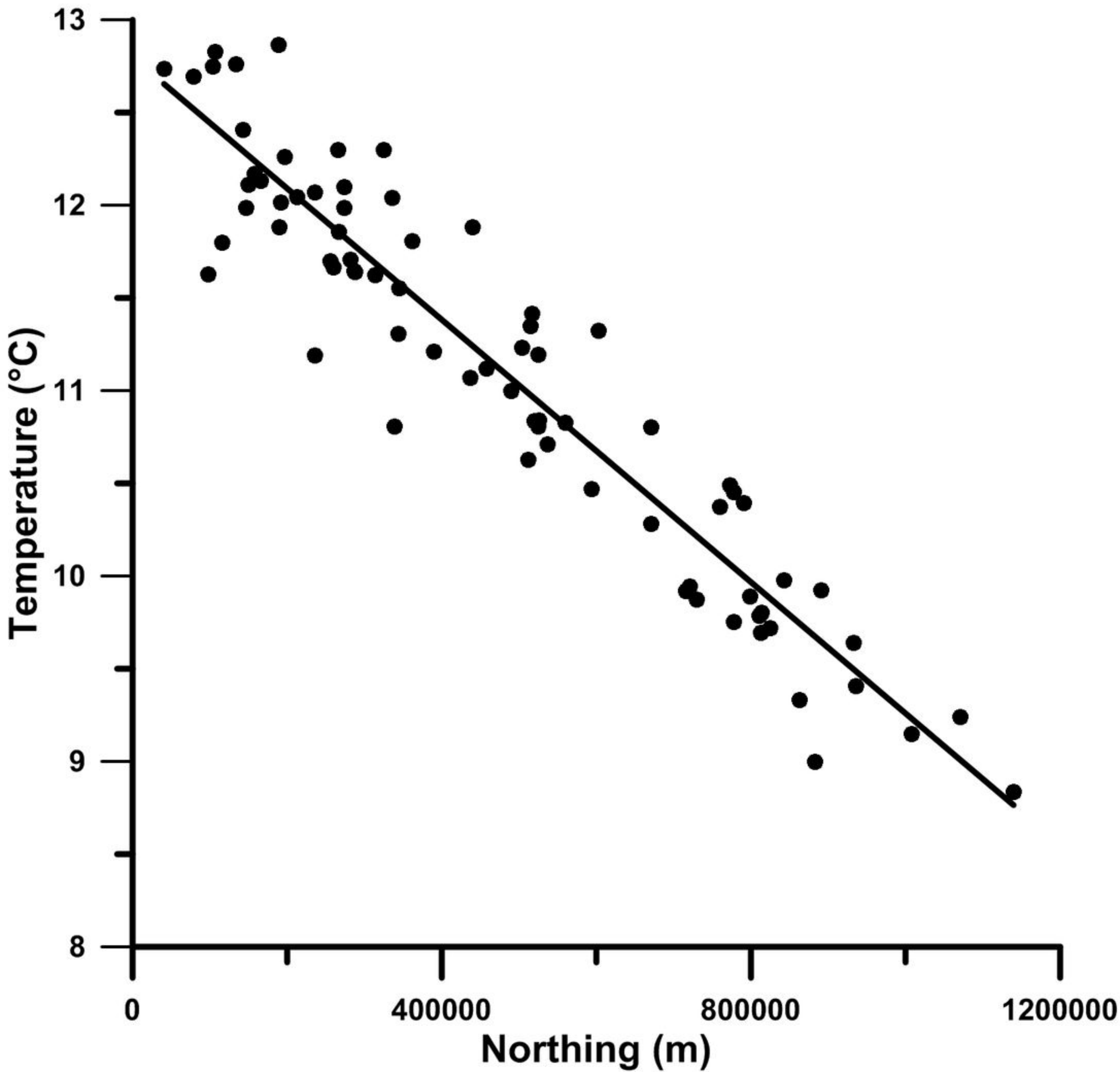
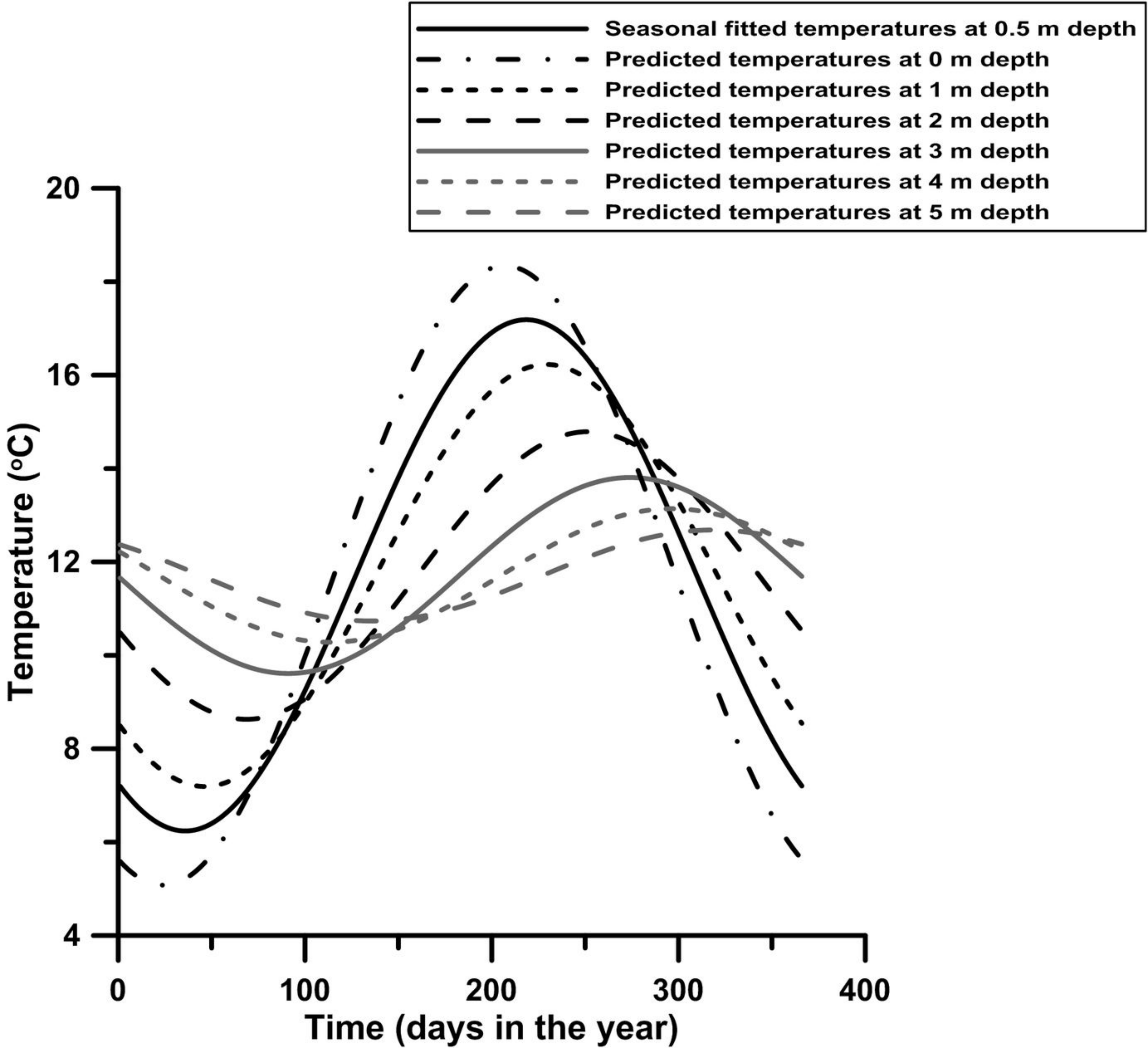

13
12
11
10
9
8
Temperature (°C)
0
400000
800000
1200000
Northing (m)



Seasonal fitted temperatures at 0.5 m depth
Predicted temperatures at 0 m depth
Predicted temperatures at 1 m depth
Predicted temperatures at 2 m depth
Predicted temperatures at 3 m depth
Predicted temperatures at 4 m depth
Predicted temperatures at 5 m depth
20
16
12
8
4
Temperature (°C)
0
100
200
300
400
Time (days in the year)

Met station id		Abbreviated station name	Sea level 100 cm temps. (°C)		
Rec	Src_id		Mean	S_{min}	S_{max}
ENGLAND 1	1395	Camborne	12.7	8.0	17.5
3	1326	Swanage	12.7	8.1	17.3
4	843	Bournemouth	12.7	7.2	18.3
5	842	Hurn	11.6	6.5	16.7
6	808	Eastbourne	12.9	7.8	18.1
7	16608	Littlehampton	12.7	6.9	18.6
8	1383	Dunkeswell Aerodrome	12.8	7.5	18.2
9	865	Butser, Windmill Hill	11.8	6.8	16.8
10	1346	Chivenor	12.8	7.7	17.8
12	868	Alice Holt Lodge	12.4	7.3	17.5
13	760	Wye	12.0	6.7	17.3
14	1304	Rodney Stoke	12.1	7.0	17.2
15	719	Wisley	12.2	7.0	17.3
17	838	Bracknell	12.1	6.9	17.4
18	830	Reading University	12.2	7.2	17.2
20	697	St James Park	13.0	7.4	18.7
22	825	Wallingford	11.9	7.4	16.4
23	613	Benson	12.0	7.0	17.0
24	609	Shirburn	12.3	6.6	18.0
27	606	Oxford	12.4	6.5	18.3
28	471	Rothamsted	12.0	6.7	17.4
31	458	Woburn	11.2	6.7	15.7
32	596	Wellesbourne	11.7	5.6	17.8
33	454	Cambridge Botanical Gardens	11.7	6.2	17.2
34	461	Bedford	11.7	6.9	16.4
35	578	Northampton, Moulton Park	12.4	7.1	17.8
36	435	Brooms Barn	12.3	6.2	18.4
37	445	Westleton	11.9	5.2	18.5
39	595	Church Lawford	12.0	6.1	17.9
40	24102	Coventry, Coundon	12.0	6.3	17.7
41	663	Halesowen	11.7	6.9	16.5
42	19187	Coleshill	11.6	6.3	17.0
43	413	Santon Downham	11.6	6.0	17.3
44	638	Preston Montford	11.6	5.8	17.5
47	392	Kirton Horticulture	10.8	5.5	16.1
48	421	Weybourne	11.3	5.4	17.3
49	622	Keele	11.6	6.6	16.5
51	539	Buxton	11.8	6.2	17.4
52	525	Sheffield	12.0	6.4	17.6
53	19204	Gringley-on-the-hill	11.2	6.0	16.4
55	516	Bradford	11.7	6.4	17.0
56	535	Cawood	11.1	4.7	17.5
57	1112	Myerscough	11.9	5.7	18.0
59	1105	Hazelrigg	11.1	6.6	15.7
62	1083	Shap	10.6	5.5	15.8
65	1074	Warcop Range	10.8	5.8	15.9
66	1060	Keswick	10.8	5.7	15.9
67	17182	Copley	11.2	6.1	16.3
71	326	Durham	11.5	6.1	16.9
72	1066	Drumburgh	10.8	6.1	15.5
73	1070	Carlisle	10.7	5.5	15.9
SCOTLAND 77	1023	Eskdalemuir	11.3	6.6	16.0
78	968	Paisley	11.3	6.4	16.1
79	24125	Glasgow Bishopton	10.8	5.8	15.8
80	19260	Edinburgh Gogarbank	10.3	5.5	15.1

83	212	Strathallan airfield	9.9	4.5	15.4
84	235	Leuchars	9.9	5.1	14.8
85	181	Mylnefield	9.9	5.5	14.3
86	214	Faskally	10.4	4.6	16.2
87	177	Inverbervie No 2	10.5	5.8	15.2
88	17310	Fettercairn, Glensaugh No 2	9.8	4.7	14.8
89	105	Tulloch Bridge	10.5	4.7	16.2
90	147	Braemar	10.4	5.3	15.5
91	150	Aboyne No 2	9.9	4.6	15.2
92	160	Craibstone	9.8	4.7	14.9
93	161	Dyce	9.7	5.2	14.2
94	113	Aviemore	9.8	4.5	15.2
95	19172	Skye: Lusa	9.7	5.2	14.2
96	18903	South Uist range	10.0	5.6	14.3
97	132	Kinloss	9.3	4.8	13.9
98	79	Tain Range	9.0	4.7	13.3
99	52	Aultbea No 2	9.9	5.0	14.8
100	54	Stornoway Airport	9.6	5.2	14.1
101	44	Altnaharra No 2	9.4	4.7	14.1
103	23	Kirkwall	9.1	4.9	13.4
104	3	Fair Isle	9.2	5.8	12.7
105	9	Lerwick	8.8	5.5	12.1
WALES 21	1256	Penmaen	12.9	7.5	18.2
30	1223	Whitechurch	12.1	8.0	16.2
38	1209	Trawsgoed	12.1	7.3	16.9
45	1161	Aberdaron	12.3	7.6	17.0
46	1180	Bala	12.0	6.5	17.6
50	1154	Loggerheads	11.8	6.7	16.9
N. IRELAND 60	1502	Murlough	11.0	6.3	15.7
61	1509	Magherally	11.2	7.0	15.5
63	1568	St Angelo	11.3	6.0	16.7
64	1532	Annaghmore	11.4	7.3	15.5
68	1517	Ballywatticock	10.8	6.7	15.0
70	1523	Helens Bay	10.7	6.3	15.1
76	1437	Coleraine University	10.5	6.5	14.5

Table 1

Table 2

Urban mean temp. (°C)		Rural mean temp. (°C)		Elevation diff. (m)	Elevation corrected rural mean temp. (°C)	UHI effect at urban location (°C)
Bournemouth	12.5	Hurn	11.6	17	11.5	1.0
Reading	11.7	Bracknell	11.7	-8	11.7	0.0
Oxford	12.0	Benson	11.6	-4	11.6	0.4
Cambridge	11.6	Brooms Barn	11.8	-63	12.2	-0.6
Northampton	11.6	Bedford	11.1	42	10.8	0.8
Coventry	11.2	Coleshill	11.0	12	10.9	0.3
Sheffield	11.1	Gringley-on-the-Hill	10.8	63	10.4	0.7
Bradford	10.8	Cawood	11.2	128	10.4	0.4
Durham	10.8	Copley	9.6	-151	10.5	0.3
Paisley	11.1	Glasgow Bishopton	10.4	-27	10.6	0.5

Table 3

Urban seasonal temp. (°C)			Rural corrected seasonal temp. (°C)			Seasonal UHI effect at urban location (°C)	
Met station	S_{min}	S_{max}	Met station	S_{min}	S_{max}	S_{min}	S_{max}
Bournemouth	7.0	18.1	Hurn	6.3	16.6	0.7	1.5
Reading	6.8	16.8	Bracknell	6.4	17.0	0.4	-0.2
Oxford	6.1	17.9	Benson	6.6	16.6	-0.5	1.3
Cambridge	6.1	17.1	Brooms Barn	6.1	18.3	0.0	-1.2
Northampton	6.3	17.0	Bedford	6.1	15.6	0.2	1.4
Coventry	5.5	17.0	Coleshill	5.6	16.2	-0.1	0.8
Sheffield	5.5	16.8	Gringley-on-the-Hill	5.2	15.6	0.3	1.2
Bradford	5.5	16.1	Cawood	4.3	16.5	1.2	-0.4
Durham	5.4	16.2	Copley	5.4	15.7	0.0	0.5
Paisley	6.2	15.9	Glasgow Bishopton	5.6	15.6	0.6	0.3

Table 4

Met Office station	Mean annual temp. at 100 cm depth (°C)	Mean annual air temp. (°C)	Difference of soil to air temp. (°C)
Camborne	12.2	11.1	1.1
Hurn	11.6	10.7	0.9
Eastbourne	12.9	11.7	1.2
Wallingford	11.6	10.9	0.7
Oxford	12.0	11.1	0.9
Cambridge	11.6	10.8	0.8
Sheffield	11.1	10.6	0.5
Durham	10.8	9.6	1.2
Eskdalemuir	9.8	7.8	2.0
Braemar	8.2	7.3	0.9
Stornoway airport	9.5	9.0	0.5
Lerwick	8.3	7.8	0.5

Rec	src_id	Met Office Weather Station name	Easting (m)	Northing (m)	Elevation (m)
1	1395	Camborne	162700	40700	87
2	877	Isle of Wight, Ventnor	455700	77300	60
3	1326	Swanage	403016	79332	10
4	843	Bournemouth	412500	92772	27
5	842	Hurn	411644	97778	10
6	808	Eastbourne	561100	98000	7
7	16608	Littlehampton, Toddington Lane	503700	104100	3
8	1383	Dunkeswell Aerodrome	312815	107480	252
9	865	Butser, Windmill Hill	472000	116500	92
10	1346	Chivenor	249600	134400	6
11	7786	Boyton	395209	140259	87
12	868	Alice Holt Lodge	480500	142700	115
13	760	Wye	605890	147010	56
14	1304	Rodney Stoke	348849	150155	40
15	719	Wisley	506300	157900	38
16	1311	Bath	375131	163725	114
17	838	Bracknell	484600	166400	74
18	830	Reading University, Whiteknights No 3	473900	171900	66
19	723	Kew	518680	177380	6
20	697	St James' Park, London	529800	180000	5
21	1256	Penmaen	253100	188800	87
22	825	Wallingford	461800	189800	48
23	613	Benson	462500	191669	67
24	609	Shirburn	469500	197100	108
25	469	Aldenham School	515741	197284	91
26	688	Cirencester	400300	201100	133
27	606	Oxford	450900	207200	63
28	471	Rothamsted	513156	213280	128
29	1231	Llandeilo	259700	219900	80
30	1223	Whitechurch	216200	235600	129
31	458	Woburn	496400	236000	89
32	596	Wellesbourne	427100	256500	47
33	454	Cambridge Botanical Gardens	545600	257200	12
34	461	Bedford	504900	259700	85
35	578	Northampton, Moulton Park	476400	264500	127
36	435	Brooms Barn	575300	265600	75
37	445	Westleton	647300	267200	10
38	1209	Trawsgoed	267395	273590	63
39	595	Church Lawford	445600	273600	107
40	24102	Coventry, Coundon	431600	280800	119
41	663	Halesowen	394900	282200	153
42	19187	Coleshill	421090	286940	96
43	413	Santon Downham	581600	287900	6
44	638	Preston Montford	343200	314400	71
45	1161	Aberdaron	215200	324800	95
46	1180	Bala	293500	335600	163
47	392	Kirton Horticulture	529920	339450	4
48	421	Weybourne	609900	343700	21
49	622	Keele	381900	344600	179
50	1154	Loggerheads, Colomendy Centre	320030	362160	210
51	539	Buxton	405800	373400	307
52	525	Sheffield	433930	387280	131
53	19204	Gringley-on-the-hill	474260	390500	68
54	369	Hull	508350	430130	2
55	516	Bradford	414900	435200	134

56	535	Cawood	456100	437200	6
57	1112	Myerscough	349500	440000	14
58	370	Leconfield	502545	443169	7
59	1105	Hazelrigg	349300	457820	95
60	1502	Murlough	150486	490209	12
61	1509	Magherally	127475	504236	97
62	1083	Shap	355700	512000	255
63	1568	St Angelo	33740	514703	47
64	1532	Annaghmore	101838	516887	27
65	1074	Warcop Range	373300	519700	227
66	1060	Keswick	325300	524900	81
67	17182	Copley	408500	525400	253
68	1517	Ballywatticock	163835	525962	6
69	1073	Newton Rigg	349300	530800	169
70	1523	Helens Bay	158462	536950	43
71	326	Durham	426700	541500	102
72	1066	Drumburgh	325900	560200	7
73	1070	Carlisle	338300	560300	28
74	24790	Drumlamford House	228800	576900	132
75	310	Morpeth, Cockle Park	420000	591200	95
76	1437	Coleraine University	102081	594462	23
77	1023	Eskdalemuir	323500	602600	242
78	968	Paisley	247895	664032	32
79	24125	Glasgow Bishopton	241788	671073	59
80	19260	Edinburgh Gogarbank	316100	671400	57
81	247	Edinburgh, East Craigs	318500	673500	61
82	253	Edinburgh Botanic Gardens	324500	675500	26
83	212	Strathallan airfield	293100	716200	35
84	235	Leuchars	346800	720900	10
85	181	Mylnefield	333900	730100	31
86	214	Faskally	291800	759900	94
87	177	Inverbervie No 2	383884	773425	134
88	17310	Fettercairn, Glensaugh No 2	366900	778200	171
89	105	Tulloch Bridge	235030	778298	237
90	147	Braemar	315200	791400	339
91	150	Aboyne No 2	349300	798700	140
92	160	Craibstone	387100	810700	102
93	161	Dyce	387810	812800	65
94	113	Aviemore	289652	814315	228
95	19172	Skye: Lusa	170593	824888	18
96	18903	South Uist range	76312	842502	4
97	132	Kinloss	306774	862804	5
98	79	Tain Range	283272	882720	4
99	52	Aultbea No 2	184575	891274	11
100	54	Stornoway Airport	146443	933104	15
101	44	Altnaharra No 2	256908	935830	81
102	32	Wick Airport	336490	952230	36
103	23	Kirkwall	348236	1007709	26
104	3	Fair Isle	421046	1071185	57
105	9	Lerwick	445392	1139664	82
106	12	Baltasound No 2	462488	1207786	15

Appendix Table A1

Rec	Src_id	Abbreviated station name	Time period & Depth (cm)	Mean (°C)	S_{min} (°C)	S_{max} (°C)	D_{min} (°C)	D_{max} (°C)
1	1395	Camborne	2000-2010 (30)	12.1	6.7	17.5	3.0	20.0
			2000-2010 (100)	12.2	7.4	16.9	5.5	18.3
2	877	Isle of Wight	2000-2003 (30)	12.7	5.9	19.4	3.0	22.9
3	1326	Swanage	2000-2003 (100)	12.6	8.1	17.2	7.2	18.7
4	843	Bournemouth	2000-2003 (30)	12.4	5.6	19.3	2.5	22.8
			2000-2003 (100)	12.5	7.0	18.1	5.7	20.0
5	842	Hurn	2000-2010 (30)	11.9	5.1	18.7	1.6	22.8
			2000-2010 (100)	11.6	6.3	16.9	4.1	19.2
6	808	Eastbourne	2000-2004 (30)	12.5	6.0	19.1	2.7	22.8
			2000-2004 (100)	12.9	7.8	18.0	6.7	19.7
7	16608	Littlehampton	2000-2002 (50)	12.6	6	19.2	3.3	21.7
			2000-2002 (100)	12.7	6.9	18.6	5.1	20.3
8	1383	Dunkeswell	2001-2010 (30)	11.5	4.5	18.5	-0.1	21.9
			2001-2010 (100)	11.2	5.9	16.5	2.2	18.8
9	865	Butser	2000-2004 (50)	11.4	5.4	17.4	3	19.4
			2000-2004 (100)	11.2	6.2	16.2	4.5	17.0
10	1346	Chivenor	2001-2010 (30)	12.4	6.3	18.5	2.0	21.2
			2001-2010 (100)	12.7	7.7	17.8	5.8	19.5
11	7786	Boyton	2000-2004 (30)	11.4	5.4	17.3	2.6	20.8
12	868	Alice Holt Lodge	2000-2006 (50)	11.7	5.4	18.1	3.2	20.0
			2000-2006 (100)	11.7	6.6	16.8	5.5	17.5
13	760	Wye	2000-2004 (50)	11.7	5.5	17.8	3	20.7
			2000-2004 (100)	11.6	6.3	16.9	5.2	18.9
14	1304	Rodney Stoke	2000-2004 (50)	12.0	5.8	18.3	4.0	21.5
			2000-2004 (100)	11.9	6.8	17.0	6.0	18.5
15	719	Wisley	2000-2000 (50)	12.0	5.9	18.2	3.3	19.3
			2000-2000 (100)	11.9	6.8	17.1	5.6	17.7
16	1311	Bath	2000-2004 (30)	12.2	5.6	18.9	3.0	23.0
17	838	Bracknell	2000-2002 (100)	11.7	6.4	16.9	4.8	17.9
18	830	Reading Univ.	2000-2006 (50)	11.8	5.9	17.7	3.4	20.5
			2000-2006 (100)	11.8	6.8	16.8	5.6	18.2
19	723	Kew	2000-2004 (30)	11.9	4.7	19.0	2.1	23.6
20	697	St James Park	2000-2004 (30)	13.6	6.5	20.7	4.3	24.0
			2000-2004 (100)	13.0	7.4	18.6	6.3	21.6
22	825	Wallingford	2000-2006 (50)	11.7	6.2	17.2	4.0	20.2
			2000-2006 (100)	11.6	7.1	16.1	6.0	17.8
23	613	Benson	2007-2008 (30)	11.4	5.5	17.4	3.7	18.9
			2007-2008 (100)	11.6	6.6	16.6	5.9	17.4
24	609	Shirburn	2000-2004 (30)	11.4	4.4	18.5	1.5	21.7
			2000-2004 (100)	11.6	5.9	17.3	4.7	19.1
25	469	Aldenham School	2000-2004 (30)	10.8	4.2	17.4	1.5	20.5
26	688	Cirencester	2000-2004 (30)	11.1	4.2	17.9	0.2	22.0
			2000-2004 (50)	11.3	4.8	17.9	2.6	21.3
27	606	Oxford	2000-2004 (30)	11.8	4.4	19.3	4.3	24.0
			2000-2004 (100)	12.0	6.1	17.9	6.3	21.6
28	471	Rothamsted	2001-2010 (30)	11.1	4.1	18.0	1.8	21.7
			2001-2010 (100)	11.2	5.8	16.6	4.2	18.0
31	458	Woburn	2001-2003 (30)	10.8	4.6	17.0	2.0	19.3
			2001-2003 (100)	10.6	6.1	15.1	5.2	16.0
32	596	Wellesbourne	2000-2004 (50)	11.3	4.5	18.1	2.2	21.3
			2000-2004 (100)	11.4	5.3	17.5	3.8	20.0
33	454	Cambridge	2000-2004 (30)	11.4	4.4	18.4	1.8	21.8
			2000-2004 (100)	11.6	6.1	17.1	4.9	18.9
34	461	Bedford	2000-2008 (30)	11.3	5.0	17.6	2.9	21.3
			2000-2008 (100)	11.1	6.4	15.9	5.3	17.7
35	578	Northampton	2000-2006 (50)	11.8	5.2	18.5	3.5	21.2
			2000-2006 (100)	11.6	6.3	17.0	5.1	18.8
36	435	Brooms Barn	2000-2006 (50)	11.8	4.8	18.9	2.7	21.3

			2000-2006 (100)	11.8	5.7	17.9	4.7	19.7
37	445	Westleton	2000-2004 (50)	11.8	4.3	19.2	1.7	23.0
			2000-2004 (100)	11.8	5.1	18.5	3.7	21.0
39	595	Church Lawford	2000-2010 (30)	11.3	4.5	18.1	2.0	21.5
			2000-2010 (100)	11.3	5.4	17.2	3.4	19.4
40	24102	Coventry	2000-2010 (30)	11.0	3.9	18.1	1.4	23.1
			2000-2010 (100)	11.2	5.5	17.0	4.4	19.4
41	663	Halesowen	2000-2003 (50)	10.7	4.8	16.7	3.2	19.0
			2000-2003 (100)	10.7	6.0	15.5	5.0	17.0
42	19187	Coleshill	2000-2010 (30)	11.1	4.7	17.4	2.4	21.1
			2000-2010 (100)	11.0	5.7	16.3	4.3	18.5
43	413	Santon Downham	2000-2004 (30)	11.4	4.3	18.4	1.8	21.6
			2000-2004 (100)	11.6	5.9	17.3	4.7	19.1
44	638	Preston Montford	2001-2006 (30)	11.1	4.2	18.0	1.2	21.3
			2001-2006 (100)	11.2	5.3	17.0	3.5	18.8
47	392	Kirton Horticulture	2000-2004 (50)	10.9	4.6	17.2	2.8	21.1
			2000-2004 (100)	10.8	5.5	16.1	4.6	18.4
48	421	Weybourne	2000-2003 (30)	10.8	3.7	17.9	-1.5	21.4
			2000-2003 (100)	11.2	5.2	17.1	3.8	19.4
49	622	Keele	2001-2005 (50)	10.6	4.5	16.6	3.0	18.4
			2001-2005 (100)	10.4	5.5	15.3	4.8	16.3
51	539	Buxton	2000-2006 (50)	10.0	3.4	16.6	1.5	19.7
			2000-2006 (100)	9.8	4.2	15.4	2.9	17.9
52	525	Sheffield	2002-2004 (30)	11.0	4.1	18.0	2.1	20.3
			2002-2004 (100)	11.1	5.5	16.8	4.4	18.1
53	19204	Gringley-on-the-hill	2002-2004 (30)	10.8	4.6	17.0	2.1	19.5
			2002-2004 (100)	10.8	5.6	16.0	4.4	17.2
54	369	Hull	2008-2009 (30)	10.8	3.6	18.1	1.0	20.0
55	516	Bradford	2004-2004 (30)	10.6	4.2	17.0	2.9	18.6
			2004-2004 (100)	10.8	5.5	16.1	5.1	17.0
56	535	Cawood	2001-2004 (50)	11.0	3.8	18.2	1.4	20.9
			2001-2004 (100)	11.0	4.6	17.4	3.3	19.5
57	1112	Myerscough	2001-2004 (50)	11.9	4.6	19.2	2.5	21.0
			2001-2004 (100)	11.8	5.7	17.9	4.7	19.1
58	370	Leconfield	2008-2009 (30)	10.8	4.2	17.5	2.1	19.6
59	1105	Hazelrigg	2000-2006 (50)	10.4	4.8	16.0	2.2	18.5
			2000-2006 (100)	10.5	6.0	15.1	4.3	16.5
62	1083	Shap	2005-2010 (30)	9.2	2.6	15.7	1.1	17.5
			2005-2010 (100)	9.0	3.8	14.1	2.7	14.9
65	1074	Warcop Range	2000-2010 (30)	9.5	3.4	15.6	1.2	18.0
			2000-2010 (100)	9.4	4.3	14.4	1.5	16.3
66	1060	Keswick	2000-2001 (30)	11.0	4.1	17.9	2.0	19.5
			2000-2001 (100)	10.3	5.2	15.4	4.5	16.3
67	17182	Copley	2000-2004 (30)	9.7	3.2	16.1	1.9	19.2
			2000-2004 (100)	9.6	4.4	14.7	3.4	16.5
69	1073	Newton Rigg	2000-2006 (30)	10.0	3.4	16.7	0.9	20.4
			2000-2006 (50)	10.2	3.9	16.5	1.8	20.0
71	326	Durham	2000-2004 (30)	10.4	3.5	17.4	1.4	20.3
			2000-2004 (100)	10.8	5.4	16.2	4.7	17.5
72	1066	Drumburgh	2006-2010 (100)	10.8	6.1	15.5	4.9	15.9
73	1070	Carlisle	2006-2010 (100)	10.5	5.3	15.8	3.9	17.5
75	310	Morpeth	2001-2006 (30)	9.51	3.4	15.6	1.4	18.4
			2001-2006 (50)	9.6	3.9	15.3	1.9	17.8

Appendix Table A2

Rec	Src_id	Abbreviated station name	Time period & Depth (cm)	Mean (°C)	S_{min} (°C)	S_{max} (°C)	D_{min} (°C)	D_{max} (°C)
74	24790	Drumlamford House	2000-2004 (30)	9.9	4.2	15.7	2.1	18.4
77	1023	Eskdalemuir	2000-2010 (30)	9.9	3.9	15.9	2.3	18.0
			2000-2010 (100)	9.8	5.0	14.5	3.7	15.9
78	968	Paisley	2000-2007 (50)	11.0	4.9	17.0	2.8	19.1
			2000-2007 (100)	11.1	6.2	15.9	5.0	18.0
79	24125	Glasgow, Bishopton	2000-2007 (30)	10.5	4.0	17.1	1.4	19.9
			2000-2007 (100)	10.4	5.5	15.4	4.1	16.7
80	19260	Edinburgh, Gogarbank	2000-2004 (30)	10.1	3.9	16.2	2.0	18.5
			2000-2004 (100)	9.9	5.1	14.7	4.0	15.8
81	247	Edinburgh, East Craigs	2000-2004 (30)	9.7	3.3	16.2	0.7	19.1
			2000-2004 (50)	10.0	4.0	15.9	2.0	18.2
82	253	Edinburgh, Botanic Gardens	2000-2010 (30)	9.8	3.5	16.2	0.9	20.2
83	212	Strathallan airfield	2000-2010 (30)	10.0	3.4	16.7	0.8	19.6
			2000-2010 (100)	9.7	4.2	15.1	2.4	16.5
84	235	Leuchars	2002-2010 (30)	9.8	4.1	15.5	1.4	17.8
			2002-2010 (100)	9.9	5.0	14.7	3.4	16.1
85	181	Mylnefield	2004-2010 (30)	9.6	3.0	16.2	0.0	19.3
			2004-2010 (100)	9.7	5.3	14.1	3.7	15.5
86	214	Faskally	2000-2009 (30)	9.8	2.1	17.5	0.5	20.6
			2000-2009 (100)	9.8	4.0	15.5	2.9	17.0
87	177	Inverbervie No 2	2003-2009 (30)	9.5	3.6	15.5	1.4	18.4
			2003-2009 (100)	9.6	4.9	14.3	3.7	15.4
88	17310	Fettercairn, Glensaugh No 2	2000-2004 (30)	8.7	1.9	15.4	0.5	17.9
			2000-2004 (100)	8.6	3.6	13.7	1.5	14.9
89	105	Tulloch Bridge	2001-2010 (30)	9.1	2.3	15.9	0.8	19.0
			2001-2010 (100)	8.9	3.1	14.7	1.8	16.4
90	147	Braemar	2000-2004 (50)	8.2	2.3	14.1	1.3	15.9
			2000-2004 (100)	8.2	3.1	13.3	2.2	14.6
91	150	Aboyne No 2	2002-2008 (30)	9.2	2.7	15.7	1.8	17.7
			2002-2008 (100)	9.0	3.7	14.3	3.1	15.8
92	160	Craibstone	2000-2004 (30)	9.1	2.9	15.4	1.4	17.3
			2000-2004 (100)	9.1	4.0	14.2	3.0	15.4
93	161	Dyce	2000-2010 (30)	9.3	3.4	15.3	1.6	18.4
			2000-2010 (100)	9.3	4.7	13.8	3.4	14.8
94	113	Aviemore	2000-2010 (30)	8.4	1.7	15.2	0.3	17.5
			2000-2010 (100)	8.3	3.0	13.7	1.2	14.7
95	19172	Skye	2000-2010 (30)	9.8	4.0	15.6	1.4	18.5
			2000-2010 (100)	9.6	5.1	14.1	3.5	15.7
96	18903	South Uist range	2001-2006 (30)	10.1	4.7	15.4	2.0	18.4
			2001-2006 (100)	10.0	5.6	14.3	3.9	16.1
97	132	Kinloss	2000-2010 (30)	9.5	3.7	15.3	0.9	17.6
			2000-2010 (100)	9.3	4.8	13.8	2.6	15.0
98	79	Tain Range	2000-2005 (30)	9.1	3.4	14.7	0.9	16.4
			2000-2005 (100)	9.0	4.7	13.3	2.8	14.3
99	52	Aultbea No 2	2000-2010 (30)	9.8	3.4	16.1	0.0	19.7
			2000-2010 (100)	9.9	5.0	14.7	3.4	16.6
100	54	Stornoway Airport	2004-2010 (30)	9.7	4.2	15.2	1.5	18.0
			2004-2010 (100)	9.5	5.1	14.0	3.7	14.7
101	44	Altnaharra No 2	2000-2010 (30)	8.9	3.0	14.8	1.1	18.5
			2000-2010 (100)	8.9	4.2	13.6	2.9	15.6
102	32	Wick Airport	2002-2010 (30)	8.4	3.3	13.4	1.5	16.5
103	23	Kirkwall	2003-2010 (30)	9.0	3.5	14.5	1.7	17.6
			2003-2010 (100)	9.0	4.7	13.3	3.6	14.7
104	3	Fair Isle	2000-2010 (30)	9.0	4.5	13.4	2.7	16.3
			2000-2010 (100)	8.9	5.4	12.4	4.0	13.4
105	9	Lerwick	2000-2010 (30)	8.4	3.2	13.6	1.3	16.9
			2000-2010 (100)	8.3	5.0	11.6	4.0	13.1
106	12	Baltasound No 2	2002-2009 (30)	8.6	3.1	14.1	1.8	18.0

Appendix Table A3

Appendix Table A4

Rec	Src_id	Abbreviated station name	Time period & Depth (cm)	Mean (°C)	S_{min} (°C)	S_{max} (°C)	D_{min} (°C)	D_{max} (°C)
21	1256	Penmaen	2000-2004 (50)	12.3	6.4	18.1	4.7	19.9
			2000-2004 (100)	12.3	7.0	17.6	5.6	18.9
29	1231	Llandeilo	2000-2004 (30)	11.4	5.7	17.1	3.2	19.5
30	1223	Whitechurch	2002-2004 (50)	11.5	6.2	16.8	3.6	17.8
			2002-2004 (100)	11.2	7.2	15.3	5.6	16.1
38	1209	Trawsgoed	2000-2004 (30)	11.8	5.7	18.0	2.7	20.5
			2000-2004 (100)	11.7	6.9	16.5	5.8	17.5
45	1161	Aberdaron	2000-2007 (30)	11.7	6.1	17.2	3.4	19.4
			2000-2007 (100)	11.7	7.0	16.4	5.5	17.5
46	1180	Bala	2000-2001 (50)	11.1	4.9	17.2	2.4	18.1
			2000-2001 (100)	11.0	5.5	16.5	3.3	16.8
50	1154	Loggerheads	2000-2003 (50)	10.3	4.4	16.2	2.5	17.9
			2000-2003 (100)	10.4	5.4	15.5	4.0	17.0

Appendix Table A5

Rec	Src_id	Abbreviated station name	Time period & Depth (cm)	Mean (°C)	S_{min} (°C)	S_{max} (°C)	D_{min} (°C)	D_{max} (°C)
60	1502	Murlough	2002-2005 (50)	10.9	5.1	16.7	3.3	18.8
			2002-2005 (100)	10.9	6.2	15.6	5.3	16.8
61	1509	Magherally	2000-2004 (50)	10.5	5.0	16.0	3.3	17.9
			2000-2004 (100)	10.6	6.3	14.9	5.3	15.9
63	1568	St Angelo	2002-2010 (30)	10.8	4.1	17.5	1.1	20.5
			2002-2010 (100)	11.0	5.7	16.4	3.8	17.4
64	1532	Annaghmore	2000-2004 (50)	11.2	6.1	16.3	4.4	18.2
			2000-2004 (100)	11.2	7.2	15.3	6.0	16.5
68	1517	Ballywatticock	2000-2004 (50)	10.9	5.5	16.2	3.5	18.5
			2000-2004 (100)	10.8	6.6	15.0	5.2	16.1
70	1523	Helens Bay	2000-2001 (50)	10.7	5.2	16.2	3.3	17.2
			2000-2001 (100)	10.4	6.1	14.8	4.8	15.0
76	1437	Coleraine University	2000-2000 (30)	10.4	4.8	15.9	3.1	17.8
			2000-2000 (100)	10.3	6.4	14.3	6.6	15.0