UK CLIMATE PROJECTIONS

The climate of the UK and recent trends

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Met Office Hadley Centre

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The climate of the United Kingdom and recent trends

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Summary

- Warming of the global climate system is unequivocal, with global average temperatures having risen by nearly 0.8 °C since the late 19th century, and rising at about 0.2 °C/decade over the past 25 years.
- It is very likely* that man-made greenhouse gas emissions caused most of the observed temperature rise since the mid 20th century.
- Global sea-level rise has accelerated between mid-19th century and mid-20th century, and is now about 3mm per year. It is likely* that human activities have contributed between a quarter and a half of the rise in the last half of the 20th century.
- Central England Temperature has risen by about a degree Celsius since the 1970s, with 2006 being the warmest on record. It is likely that there has been a significant influence from human activity on the recent warming.
- Temperatures in Scotland and Northern Ireland have risen by about 0.8 °C since about 1980, but this rise has not been attributed to specific causes.
- Annual mean precipitation over England and Wales has not changed significantly since records began in 1766. Seasonal rainfall is highly variable, but appears to have decreased in summer and increased in winter, although with little change in the latter over the last 50 years.
- All regions of the UK have experienced an increase over the past 45 years in the contribution to winter rainfall from heavy precipitation events; in summer all regions except NE England and N Scotland show decreases.
- There has been considerable variability in the North Atlantic Oscillation, but with no significant trend over the past few decades.
- Severe windstorms around the UK have become more frequent in the past few decades, though not above that seen in the 1920s.
- Sea-surface temperatures around the UK coast have risen over the past three decades by about 0.7 °C.
- Sea level around the UK rose by about 1mm/yr in the 20th century, corrected for land movement. The rate for the 1990s and 2000s has been higher than this.

*These findings of IPCC AR4-WG1, discussed in this report, use IPCC terminology to express likelihoods: very likely = >90% probability, likely = >66% probability.

Introduction

Scenarios of climate change for the UK have been published by the United Kingdom Climate Impacts Programme (UKCIP) in 1998 (Hulme & Jenkins, 1998) and 2002 (Hulme et al., 2002), and in each case the accompanying Scientific Reports have contained an early chapter which discussed observations of global and UK climate trends, to provide an historical context for the future climate change projections. These have been welcomed by users, who have requested a similar feature as part of the report accompanying the next set of scenarios, UKCP09, planned for launch in late 2008, and these are shown in Section 1 of this report.

In addition, following the success of *A handbook of climate trends across Scotland* published by SNIFFER (Barnett et al., 2006), its was suggested that similar detailed graphics of climatology and trends be included over the whole of the UK, selected to show as many as possible of the same variables as those to appear in the UKCP09 future projections. The addition of these extra maps and graphs would have led to the historical climate chapter dominating the content of UKCP09 Science Report, and hence it was decided that the information should be presented in a separate report; this is the genesis of the present volume. Section 2 of this report shows maps of the baseline 1961-90 UK climate for a number of variables; similar maps for the period 1971-2000; maps of the difference between these two 30-year periods; maps of changes between 1961-2006; graphs showing smoothed trends of each variable, for each of 14 regions of the UK (those over which future projections will be given in the UKCP09 scenarios) and, finally, a table of seasonal and annual changes over the period 1961-2006 over the same areas.

Section 1: Changes in UK climate indicators

1.1 The global context

Although the majority of this report is concerned with UK climate and changes, it is useful, where possible, to put these in the context of changes at the global scale. This is done here for temperature and sea level, based on the most recent, fourth, assessment from Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007, referred to hereafter as IPCC AR4-WG1. This can also be seen at http://ipcc-wg1.ucar.edu/wg1/wg1-report.html).

1.1a Global temperature trends

- Warming of the global climate system is unequivocal, with global average temperatures having risen by nearly 0.8 °C since the late 19th century, and rising at about 0.2 °C/decade over the past 25 years.

The most widely used indicator of climate change is that of global-mean, annual-average, near-surface air temperature – commonly referred to as simply global temperature. There are a few different data sets of this quantity, but successive IPCC assessments since the first in 1990 have used that produced by the Met Office Hadley Centre (MOHC) and the Climatic Research Unit (CRU) of the University of East Anglia (UEA). The most recent version of this data set, known as HadCRUT3, blends land-surface air temperatures from over 4,000 stations with sea-surface temperatures from 185 million observations from ships and buoys over the past 157 years (Rayner et al., 2006). This dataset is used to plot Figure 1.1, showing individual annual average differences from the 1961-1990 baseline period*, together with the estimated error in each value (Brohan et al., 2006). It is also used in IPCC AR4-WG1.

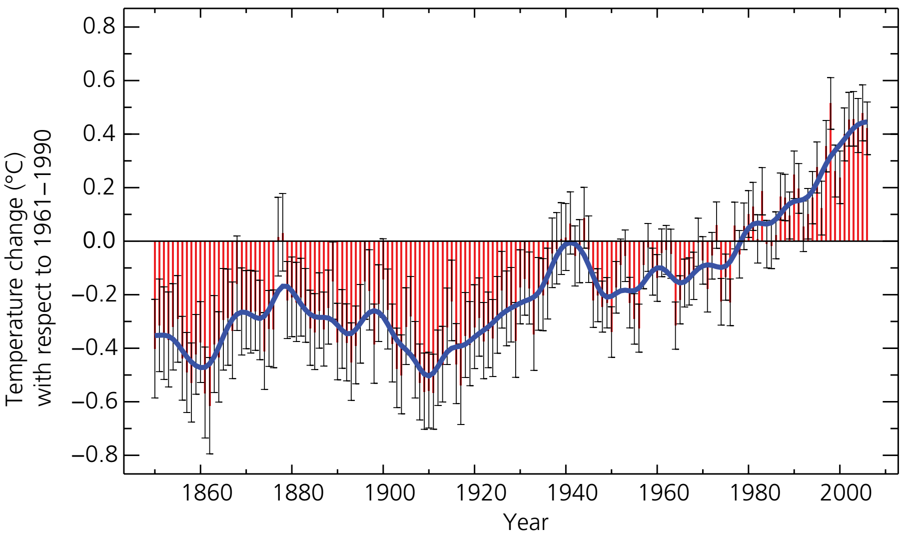


Figure 1.1: Annual-average global-mean near-surface temperature (red bars) from 1850-2006, as an anomaly from the average over the 1961-1990 baseline period (almost exactly 14 °C, Jones et al. (1999)). The error bars shown for each year indicate the 5% to 95% confidence range; the true value is more likely to be towards the middle of the error bar. The blue curve shows the data smoothed to emphasise decadal variations. (Source: MOHC/UEA)

*Climate averages in this report are generally given over 30 year periods as recommended by the World Meteorological Organization; the period 1961-1990 is the latest WMO baseline period.

As can be seen from Figure 1.1, global temperature has increased by about 0.8 °C (0.76 ± 0.19 °C) between the last half of the 19th century and the period 2001-2005; trends over the past 25 years (1981-2005) have been much greater than that over the whole period at about 0.2 °C/decade (0.18 ± 0.05 °C/decade). The warmest year so far has been 1998, caused in part by the global effects of the strongest El Niño ocean warming event observed in at least the last century. The ten warmest years so far are, in order of rank: 1998, 2005, 2003, 2002, 2004, 2006, 2001, 1997, 1995 and 1999. However, the full size of uncertainties in individual annual values (in recent years about 0.17 °C) is such that the most recent complete year, 2006, is statistically indistinguishable from any of the eight warmest years.

A more detailed description of observed changes to the global climate system can be found in Chapter 3 of IPCC AR4-WG1. Taken together, they allowed the IPCC to say that warming of the climate system is unequivocal, as it is now evident from observations of increasing global average air and ocean temperatures, widespread melting of snow and ice and rising average sea level (IPCC 2007).

Further detail on global surface temperatures can be found on the Met Office website at:

www.metoffice.gov.uk/research/hadleycentre/obsdata/HadCRUT3.html and
www.metoffice.gov.uk/research/hadleycentre/obsdata/climateindicators.html

A much wider range of observations, in addition to temperature, can be seen at: www.metoffice.gov.uk/research/hadleycentre/obsdata/index.html

1.1b The causes of recent changes in global temperature

- It is very likely (>90% probability) that man-made greenhouse gas emissions caused most of the observed global average temperature rise since the mid 20th century.

The changes in global temperature seen in Figure 1.1 could be due to a number of causes, both natural and man-made. Under the heading of natural we include the internal (chaotic) variability of the earth's climate system and also naturally-forced changes such as cooling due to aerosol from energetic volcanic eruptions and changes in the output of the sun. In UKCIP02 we showed results from experiments (Stott et al., 2000) which indicated clearly that recent temperature rises could not be explained by natural causes. In that paper, the Met Office Hadley Centre climate model was driven over the period 1860-2000 firstly with only changes in natural agents (solar output, volcanic aerosol); the modelled temperature rise was in poor agreement with that actually observed, especially over the last few decades. Only when changes in forcing from human activities (greenhouse gases and sulphate aerosols) were added could the temperature rise over the last few decades be replicated by the climate model.

Since then, many other modelling centres have repeated these experiments with their own models, and found similar results. IPCC AR4-WG1 combined these results to give the comparison shown in Figure 1.2, illustrating the inability of models to simulate observations over the past few decades when driven by natural factors only, but their relative success at simulating observations when human-made factors were included, thus confirming and strengthening the conclusions from the original MOHC work*.

*Schwartz et al. (2007) claim that the model error has been underestimated, and should be twice that shown (in pink) in Figure 2, thus weakening the attribution to human activities. This claim has subsequently been challenged in Forster et al. (2007).

In the above simulations the direct effect of changes in radiation from the sun has been included, but there have been hypotheses in the past that the sun's influence may also be via its geomagnetic activity, influencing cloud-producing cosmic rays, for example. However Lockwood and Frohlich (2007) have investigated recent trends in a number of solar activity indices and shown that over the last 20 years none of them is consistent with the observed increase in global temperatures. The internal variability of climate can be important on decadal timescales; for example Knight et al. (2005) claim that the warming event around 1940 may be caused by the northern hemispheric effects of a temporary strengthening of the North Atlantic thermohaline circulation.

Comparisons between observed and modelled changes in patterns of temperature, both across the earth's surface and through the atmosphere, and of other climate variables, provide more powerful evidence of the effect of human activities on climate, and enabled IPCC AR4-WG1 to say that "it is very likely (>90% probability) that anthropogenic greenhouse gas increases caused most of the observed increase in global average temperatures since the mid-20th century."

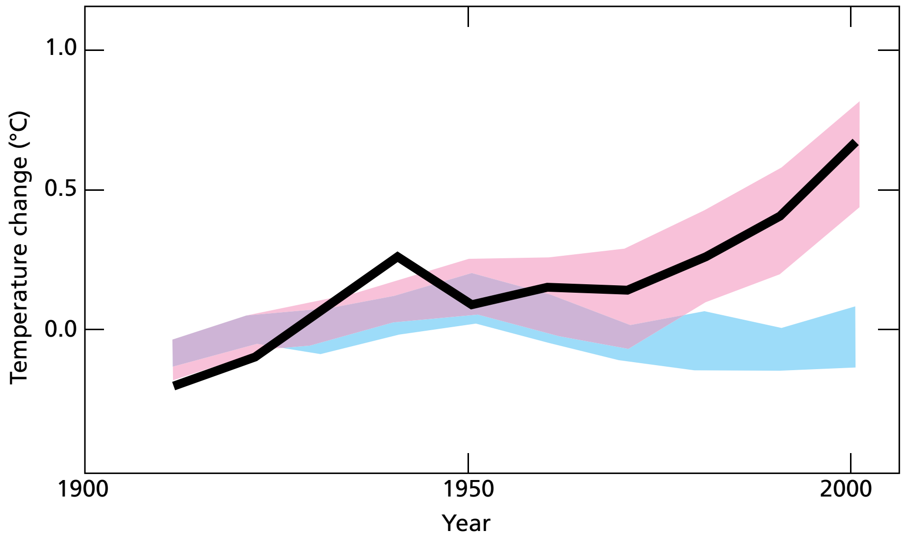


Figure 1.2: Comparison of observed (black line) change in global average surface temperature with results simulated by climate models using only natural (blue) and natural + man-made (pink) forcings. Decadal averages of observations are shown for the period 1906-2005, plotted against the centre of the decade and relative to the average for 1901-1950. Blue bands show the 5-95% range for 19 simulations from five climate models (including HadCM3) using only natural forcings due to solar activity and volcanoes. Pink bands show the 5-95% range for 58 simulations from 14 climate models (including HadCM3) using both natural and man-made forcings (greenhouse gases and aerosols). © IPCC 2007: WG1-AR4

1.1c Continental-scale changes

IPCC AR4-WG1 includes diagrams similar to Figure 1.2 but for continental areas, demonstrating that it is likely (>66% probability) that there has been significant man-made warming over the past 50 years over almost all these areas, including Europe. In addition to the attribution of long-term changes, research has begun to focus on specific types of continental-scale events, such as the summer of 2003 which was probably the hottest in Europe since at least 1500AD (IPCC, 2007). Using a threshold for mean summer temperature that was exceeded in 2003, but in no other year since the start of the instrumental record in 1851, Stott et al. (2004) estimated that it is very likely that human influence has at least doubled the risk of a heatwave exceeding this threshold magnitude. This work studied an area of Europe south of 50 °N, however a subsequent similar analysis for a European area north of 50 °N, including the UK, has reached the same conclusion (Peter Stott, Pers Comm).

For a more detailed discussion of the attribution of climate change to human activities, see Chapter 9 of IPCC AR4-WG1.

1.1d Global sea level

- Global sea-level rise has accelerated between mid-19th century and mid-20th century, and is now about 3mm per year. It is likely that human activities have contributed between a quarter and a half of the rise in the last half of the 20th century.

IPCC AR4-WG1 presented tide gauge and satellite measurements of global-mean sea level; this is reproduced as Figure 1.3. There is a high confidence that the rate of sea-level rise (SLR) has accelerated between the mid-19th and mid-20th centuries. For the period of satellite altimetry observations,1993-2003, the estimates of sea-level rise contributions from thermal expansion (the biggest contributor), glaciers and ice caps, and the Greenland and Antarctic Ice Sheets, sum up to be in good agreement with that actually observed (3.1 ±0.7mm/yr), although this is not true of the longer period 1961-2003. IPCC AR4-WG1 also says that it is very likely that human activities have contributed to sea-level rise during the later half of the 20th century, and this contribution is likely to amount to one-quarter to one-half of the total over that period, the rest being due to natural causes.

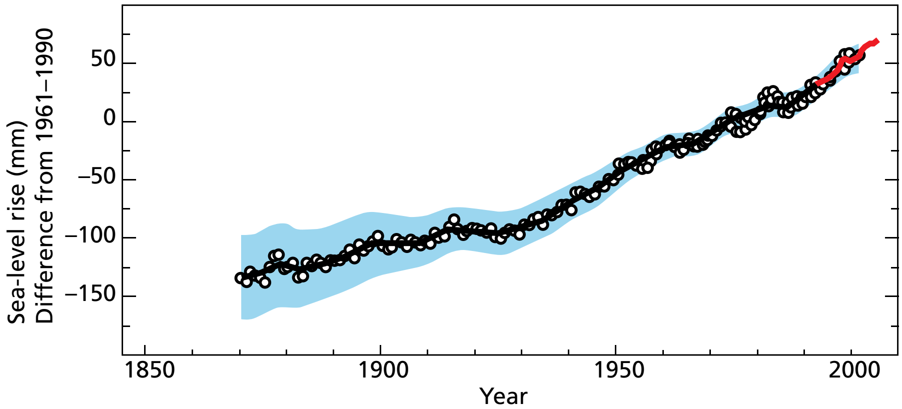


Figure 1.3: Observed changes in global sea level from tide gauge (blue) and satellite (red) data, relative to averages for the period 1961-1990. The circles show yearly values, the smoothed curves emphasise decadal variations. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties. © IPCC 2007: WG1-AR4

1.2 Central England Temperature

- Central England Temperature has risen by about a degree Celsius since 1980, with 2006 being the warmest on record.

The Central England Temperature (CET) monthly series, beginning in 1659, is the longest continuous temperature record in existence (Manley, 1974). The observing stations used to compile CET are currently Rothamsted (Hertfordshire), Pershore (Worcestershire) and Stonyhurst (Lancashire). However, the stations used have changed over the years. Following each change the data is adjusted to ensure consistency with the historical series. Recent work (Parker and Horton, 2005) has enabled error bars to be attached to annual averages since 1877, and hence this is the start date of the data shown in Figure 1.4. Since 1960, the data have been adjusted to allow for any effects of warming due to the expansion of local built-up areas.

Croxton et al. (2006) compare monthly temperatures from stations distributed across the UK and find they are highly correlated with the corresponding CET, so its applicability extends beyond central England.

Figure 1.4 shows that after a period of relative long-term stability for most of the 20th century, CET has increased by about a degree Celsius since the 1980s. This is a more rapid rise than that of the global average land-surface temperature over the same period, and considerably faster than that of the global mean temperature (shown in Figure 1.1). The annual mean CET of 10.82 °C in 2006 was 1.35 ± 0.18 °C above the 1961-90 average, and was the warmest in the 348-year series. The fifteen warmest calendar years in the series are, in order: 2006, 1990/1999, 1949, 2002, 1997, 1995, 1989/2003, 1959/2004, 1733/1834/1921 and 2005. Several of these high ranking years are too long ago to have had any significant contribution from man-made warming. This reflects the large natural variability of climate over a small area such as that of the CET.

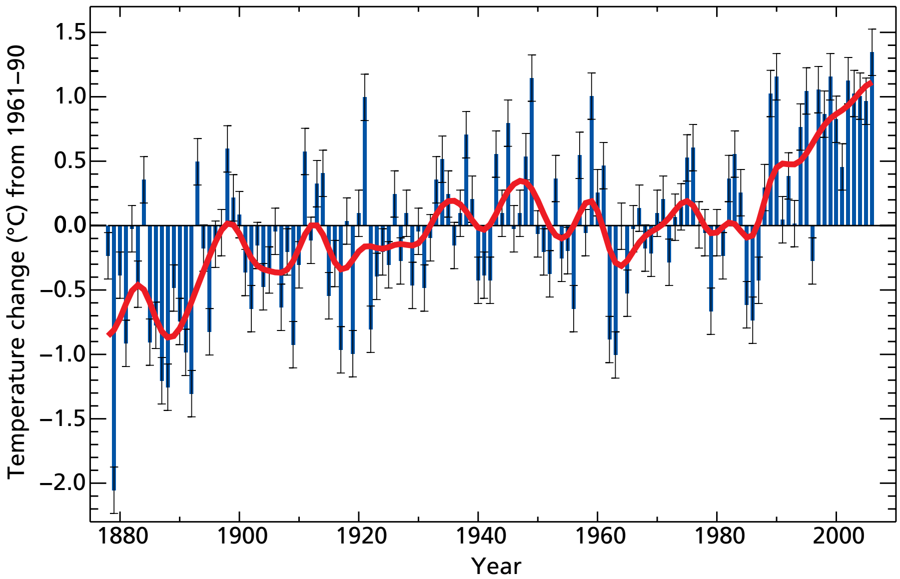


Figure 1.4: Changes in CET annual values (blue bars) from 1877 to 2006 relative to the average over the 1961-90 baseline period (about 9.5 °C). Error bars enclose the 95% confidence range. The red line emphasises decadal variations. (Source: MOHC)

The years 2006 and 2007 have seen a number of records in the CET monthly series broken. July 2006 was the warmest month since observations began, with a mean temperature of 19.7 °C; September 2006 was the warmest September; Autumn 2006 was the warmest Autumn; and April 2007 was the warmest April. In addition to calendar-year averages, as shown above, the monthly CET data set is also organised into successive 12-month rolling averages. As a consequence of some of these recent, particularly warm, individual months, the 12-month period ending in April 2007 was the warmest such period on record (Figure 1.5).

In Section 2 of this report, trends in several temperature quantities are presented for 14 regions of the UK. In terms of record warm individual days, 10 August 2003 saw the hottest ever maximum temperature in the UK; 38.5 °C at Faversham, Kent, exceeding the previous record in 1990 by 1.4 °C.

The CET dataset, known as HadCET, is maintained by the MOHC (Parker et al., 1992) and consists of daily (from 1772), monthly and seasonal averages temperatures and their anomalies with respect to 1961-90. It can be downloaded at www.metoffice.gov.uk/research/hadleycentre/obsdata/cet.html

1.2a The causes of recent changes in Central England Temperature

- It is likely that there has been a significant influence from human activity on the recent warming of CET.

Increasingly confident statements have been made about the attribution of global temperature change to specific causes, and in the past few years the same has been done for most continental-scale changes. Sexton et al. (2004) showed,

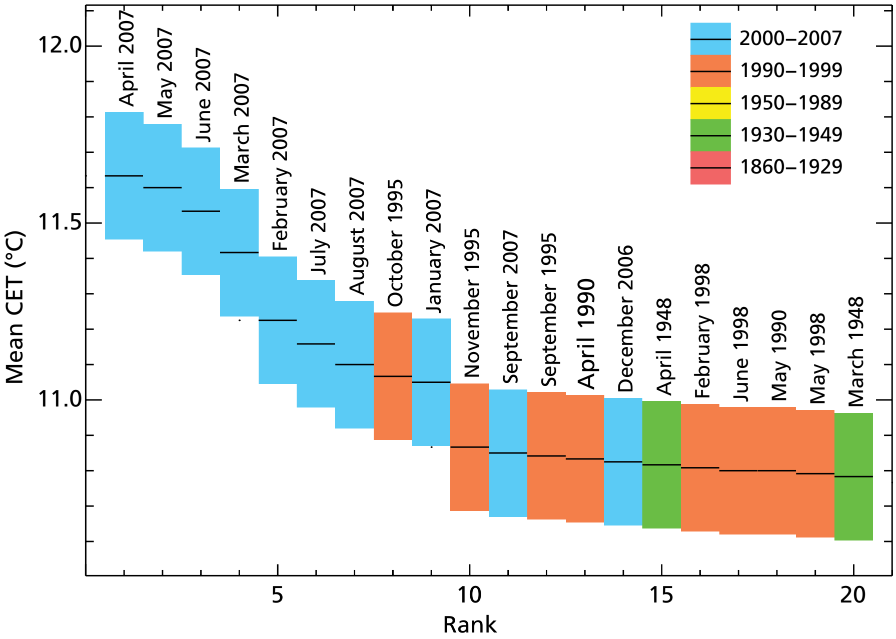


Figure 1.5: The value of the top 20 highest ranks of the 12-month CET, i.e. the average temperature (black bar) for any 12 successive months in the record, ending in the month shown. The estimated error is shown as a box, coloured to represent the period in which the year lies. It can be seen that many of the top ranks end in months in 2007, with that to April 2007 being warmest of all. Observations up to September 2007 are included. The average value of CET for the baseline period 1961-1990 is 9.5 °C. (Source: MOHC)

using comparisons between observations and atmospheric climate models, that the long-term warming of CET cannot be fully explained by atmospheric circulation changes, natural forcings and rising SST alone. Their analysis suggested a significant influence from man-made greenhouse gases on CET.

Karoly and Stott (2006) undertook a similar comparison, but using coupled-ocean atmosphere model simulations. They found, firstly, that there is good agreement between the simulated variability of CET by the HadCM3 model and its observed variability over the period 1700-1900. They also found that the observed warming in annual-mean CET of about 1.0 °C since 1950 cannot be explained by natural climate factors (which would have led to a cooling in recent decades) but is consistent with the model response to increasing greenhouse gases and aerosols. They conclude that it is likely that there has been a significant human influence in the recent warming of Central England Temperature, associated with man-made increases of greenhouse gases in the atmosphere and including the cooling effect of man-made sulphate aerosols. They also noted that there is less confidence in the attribution of winter warming since the climate model cannot simulate the observed increase in North Atlantic Oscillation (NAO) over the period 1965-1995 (see below).

The growing of grapes in the medieval period has been used to imply that current warm temperatures in England have been experienced before. However, Jones and Mann (2004) note that "past vine growing in England reflects little, if any, on the relative climate changes in the region since medieval times".

A further influence on interdecadal variations in CET may come from natural variations in the North Atlantic ocean thermohaline circulation, as North Atlantic SST is currently warming substantially faster than the global average. This influence may be contributing to the current sharp increase in CET (Parker et al., 2008, in press). Baines and Folland (2007) ascribe the faster North Atlantic warming, particularly evident in the extratropics, to a combination of this natural effect and a recovery from man-made surface cooling in the 1960s to 1980s caused by increased regional man-made aerosol forcing at that time, which has since decreased.

1.3 Temperature in Scotland and Northern Ireland

- Temperatures in Scotland and Northern Ireland have risen by about 0.8 °C since about 1980, but this rise has not been attributed to specific causes.

The Met Office updates time series of monthly mean maximum and minimum temperatures for the Scottish mainland and for Northern Ireland, based on the original construction by Jones & Lister (2004). Annual means of temperature constructed from these data sets are shown as Figure 1.6 and Figure 1.7, respectively. Both temperature series have exhibited an increase of about 0.8 °C over the past two or three decades, somewhat less than that in CET. Although no similarly long time series is available for Wales, the trends in the gridded data over Wales since 1914, shown in Section 2 of this report, are broadly similar to those for CET. No attempt to attribute recent trends to specific causes has been made for regions other than Central England. It is unlikely that these would be robust due to the smaller length of the time series compared to that for CET (for example, since 1800 in the case of Scotland).

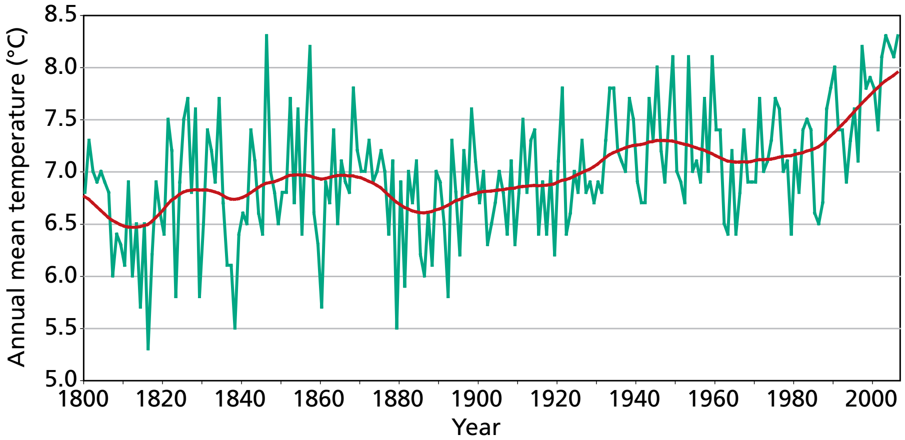


Figure 1.6: Annual mean temperature averaged over the Scottish Mainland, 1800-2006. The red line emphasises decadal variations. (Source: Met Office, after P. Jones)

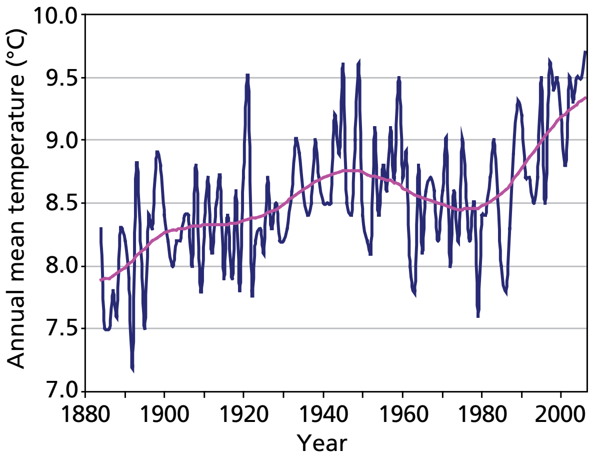


Figure 1.7: As Figure 1.6 but for Armagh, 1884-2006, representing Northern Ireland. (Source: Met Office, after P. Jones)

1.4 Precipitation in the UK

- Annual mean precipitation over England and Wales has not changed significantly since records began in 1766. Seasonal rainfall is highly variable, but appears to have decreased in summer and increased in winter, although with little change in the latter over the last 50 years.

- All regions of the UK have experienced an increase in the contribution to winter rainfall from heavy precipitation events. In summer all regions except NE England and N Scotland show decreases.

The longest-running UK observational data set is that of England and Wales Precipitation (EWP), which for monthly means starts in January 1766. Croxton et al. (2006) compare monthly mean precipitation records for individual stations widely spread across the UK with the corresponding EWP, and find that, for the most part, there are highly significant correlations; exceptions occurring increasingly in the most northerly stations. Hence the use of EWP in a range of studies across the UK appears to be justified.

Figures 1.8 and 1.9 show variability and trends of winter (Dec-Feb) and summer (Jun-Aug) total precipitation. The first characteristic to note is that of large year-to-year variability in both seasons; over the past two centuries winter totals have varied between 88.9mm (1964) and 423mm (1915), and those in summer between 66.9mm (1995) and 409.7mm (1912). Despite this variability, a general trend can be seen of decreasing precipitation in summer, although this is difficult to quantify robustly as it depends on the period used. In winter, an increasing trend can be observed, although there has been little change over the past 50 years. There is no discernable trend in annual mean England & Wales precipitation.

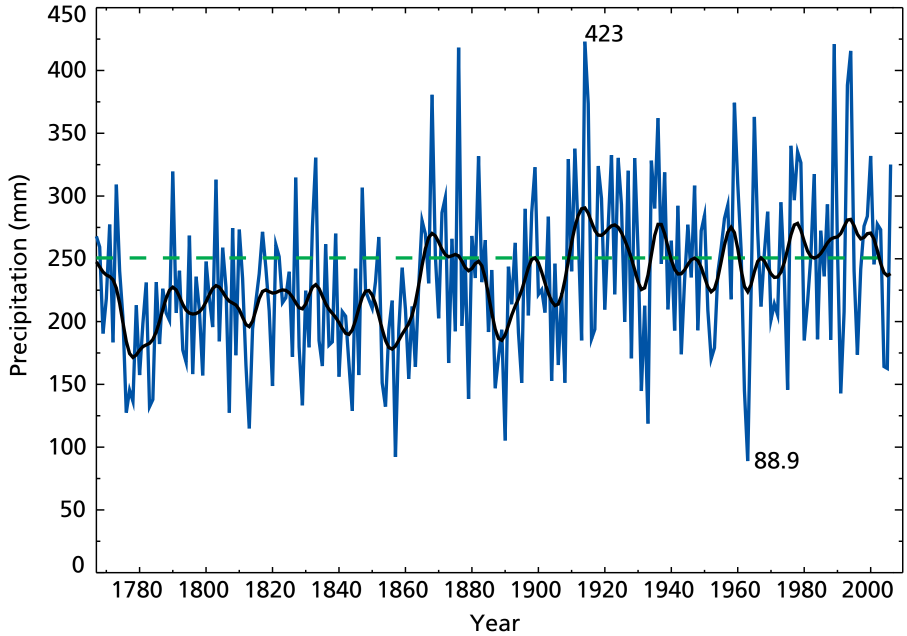


Figure 1.8: England and Wales Precipitation 1766-2006 averaged over the three winter months (Dec-Feb). Individual winters are shown by the blue line; the black line emphasises decadal variations. Highest and lowest seasonal totals (mm) are indicated. The winter is shown by the year of its December. The 1961-90 average seasonal precipitation is shown by the green dotted line

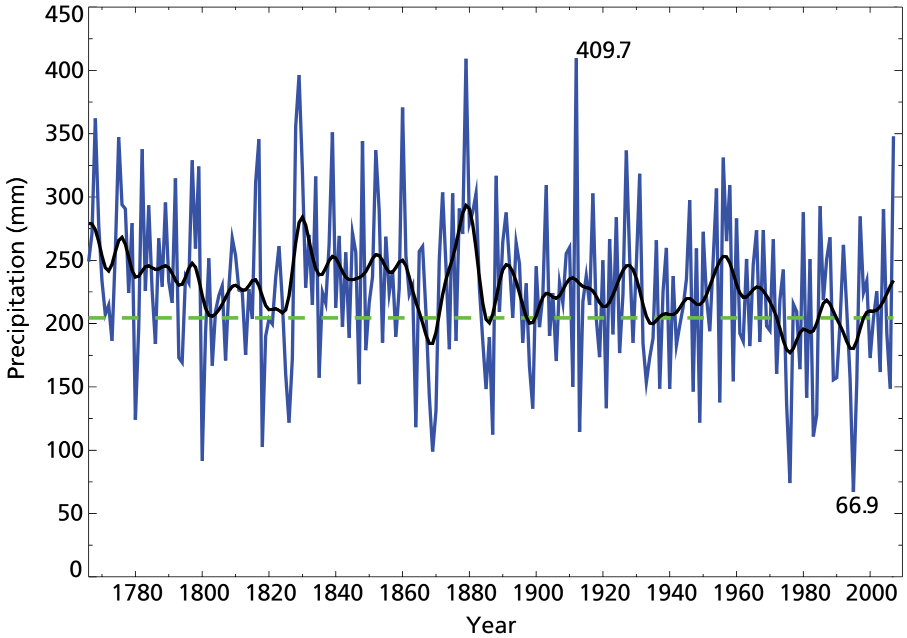


Figure 1.9: As for Figure 1.8 but averaged over the three summer months (Jun-Aug) 1766-2007. (Source: MOHC)

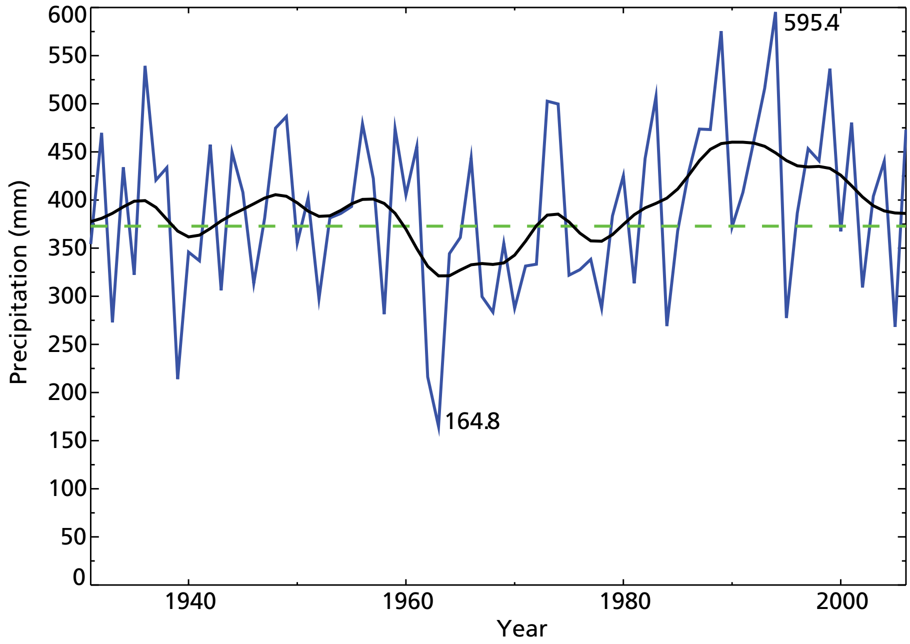


Figure 1.10: Precipitation over Scotland 1931-2006 averaged over the three winter months (Dec-Feb). Individual winters are shown by the blue line; the black line emphasises decadal variations. Highest and lowest seasonal totals (mm) are indicated. The winter is shown by the year of its December. The 1961-90 average seasonal precipitation is shown by the green dotted line

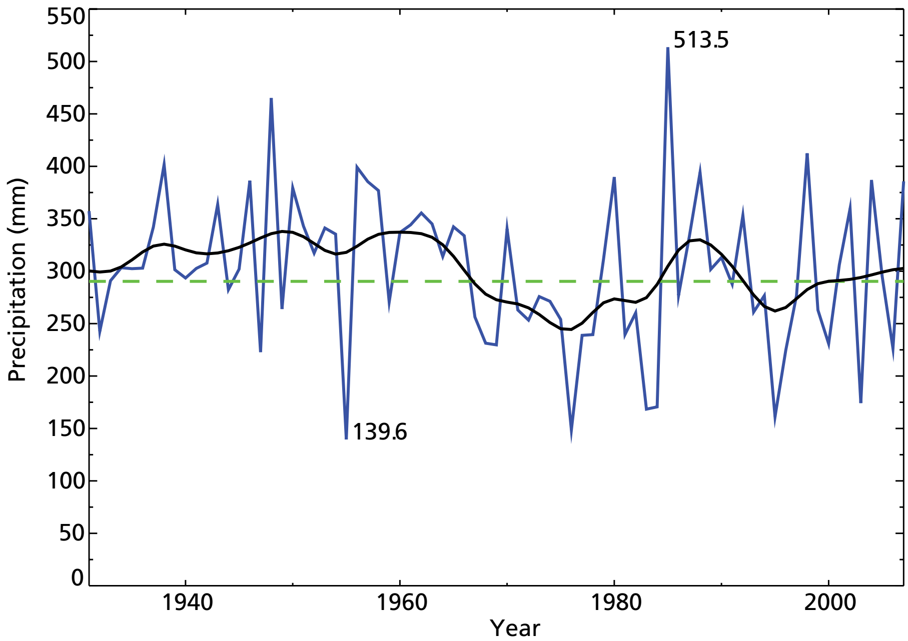


Figure 1.11: As for Figure 1.10 but averaged over the three summer months (Jun-Aug). (Source: MOHC)

IPCC AR4-WG1 commented that significantly increased precipitation has been observed over northern Europe (an area which includes the UK) between 1900 and 2005; particularly noticeable since about 1979. Recent work by Zhang et al. (2007) has shown that man-made factors have had a detectable influence on observed changes in precipitation within latitudinal bands over land, which cannot be explained by natural internal climate variability or natural forcing. They estimate that man-made forcing has contributed between 50% and 85% (5-95% uncertainty levels) of the increase in precipitation between 40 °N and 70 °N observed over the period 1925-1999. This conclusion may seem inconsistent with the lack of any trend over the UK, which lies between these latitudes, but is a reflection of the difficulty of detecting small trends within the natural variability seen at small scales such as that of England & Wales.

Seasonal precipitation over Scotland, from 1931, in a similar format to that for England and Wales, is shown in Figures 1.10 and 1.11.

In Section 2 of this report we also present trends in precipitation amount and days of rain (>= 1mm) averaged over 14 UK regions. Other regional precipitation data is available at: http://hadobs.metoffice.com/hadukp/data/download.html

In addition to changes in the seasonality of precipitation, there have also been changes to its characteristics. Figure 1.12 shows changes from 1961-2006 in the contribution from heavy precipitation to winter and summer precipitation in the nine Met Office climatological regions of the UK (Maraun et al., 2007). A change of 5% in the contribution of heavy events (evident in most regions during winter) implies a change from a contribution of, say, 7.5% in the 1960s to a contribution of, say, 12.5% in the recent decade. It can be seen that all regions have seen an increase in the contribution in winter, albeit marginally in Northern Ireland and NW England. In summer, all regions show decreases except NE England, which has a positive trend, and N Scotland which has little change.

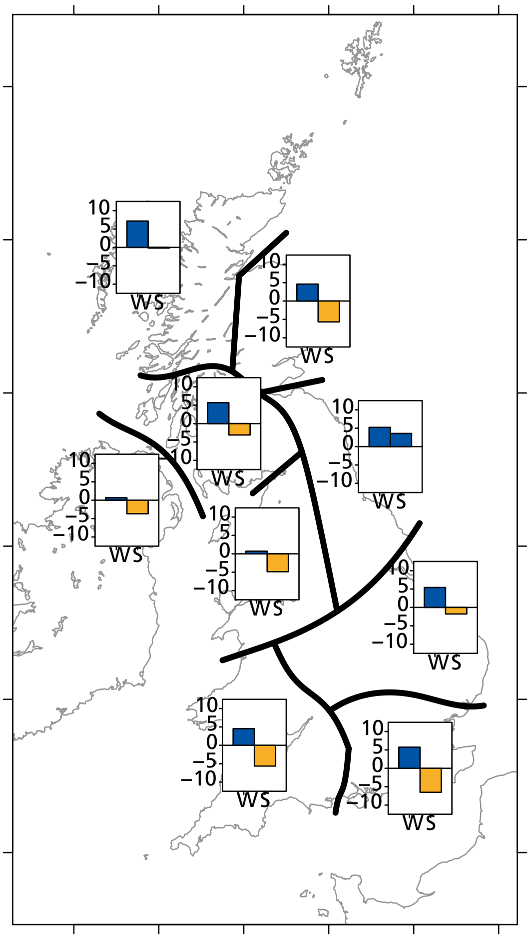


Figure 1.12: Trends over the period 1961-2006 in the contribution (%) made by heavy precipitation events to total winter (left-hand bars labelled "W") and summer (right-hand bars labelled "S") precipitation. For clarity, positive trends are shown in blue, negative in orange. (Source: Tim Osborn, CRU, UEA)

Finally, on the question of droughts, Marsh et al. (2007) find that the frequency of drought episodes in England and Wales, as indexed by exceptional 12-month non-overlapping rainfall deficiencies, shows no clear trend over the period 1776-2006.

1.5 The North Atlantic Oscillation

- There has been considerable variability in the North Atlantic Oscillation, but with no significant trend over the past few decades.

The average atmospheric pressure over the North Atlantic in winter* is less than that over the Atlantic sub-tropics; this pressure gradient is consistent with the winter climate of the UK being dominated by westerly winds. However, the pressure gradient (usually defined by the sea-level pressure difference between the Azores and Iceland) changes from winter to winter, part of a pattern of atmospheric variability known as the North Atlantic Oscillation (NAO). In some winters the gradient will be larger (that is, a greater average pressure difference, defined as a positive phase of the NAO), giving westerly winds which are stronger or more persistent than average, leading to northern Europe being warmer and wetter than average and southern Europe colder and drier. In the opposite, negative, phase of the NAO, the pressure gradient is smaller, giving weaker or less persistent westerly winds, northern Europe is colder and drier than average and southern Europe warmer and wetter.

Figure 1.13 shows changes in the winter NAO, in standardised units**, derived from the Azores-Iceland pressure difference. The strength of the winter NAO has varied considerably in sign and magnitude from 1867-2006. Year-to-year changes are very evident, as are multidecadal variations, where the winter NAO index remains in a predominantly positive or negative mode. Thus there was a considerable increase in the NAO index from the 1960s to the1990s which has been partially reversed since then, giving little overall trend over the last 50 years. Climate models tend not to pick up these multidecadal variations for reasons that are not understood (IPCC, 2007) though the stratosphere may play a role. Hence it is not possible to attribute such changes in the NAO to specific causes.

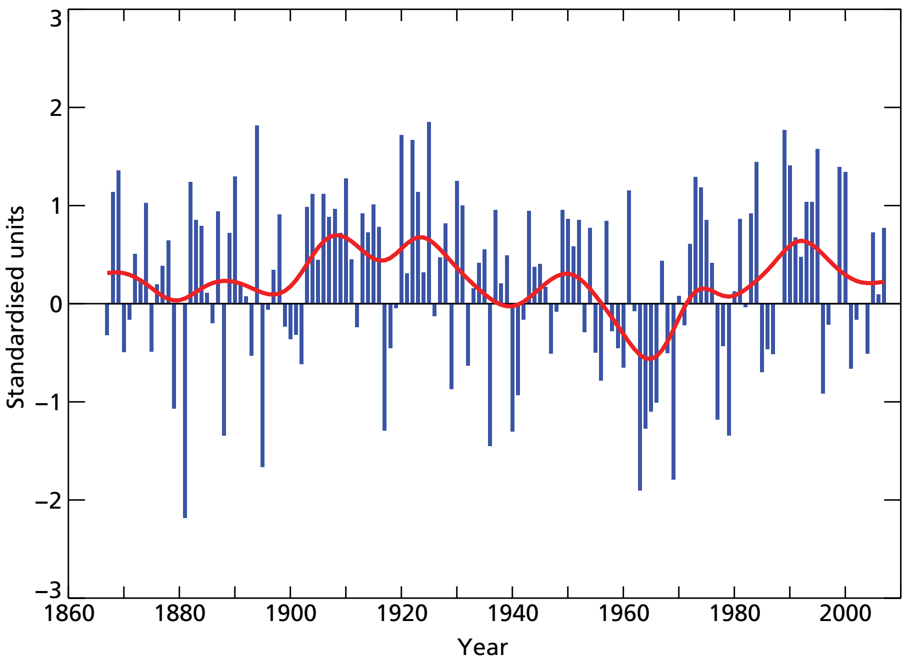


Figure 1.13: The North Atlantic Oscillation Standardised Index, winter (December – February) 1867-2006. The year shown is that of the December. Individual winters are shown by blue bars; the red line emphasises multi-decadal variations. (Source: MOHC)

*The NAO has been most commonly studied in winter, and we limit ourselves to discussing this season here, although it also exists in summer, and indeed throughout the year, but on a smaller scale.

**Standardised units are derived by removing the 1961-90 winter average Azores-Iceland pressure difference from each data point and dividing it by the standard deviation of the 1961-90 period. This ensures that the series has mean of zero and standard deviation of one over the 1961-90 period (based on Jones et al., 1997).

1.6 Storminess

- Severe windstorms around the UK have become more frequent in the past few decades, although not above that seen in the 1920s.

There is considerable interest in possible trends in severe wind storms around the UK, but these are difficult to identify, due to low numbers of such storms, their decadal variability, and by the unreliability and lack of representativity of direct wind speed observations. In UKCIP02, we showed how the frequency of severe gales over the past century, although showing an increase over the past decade or so, did not support any relationship with man-made warming. Alexander et al. (2005) presented an analysis whereby a severe storm event is characterised by a rapid change in mean sea-level pressure (MSLP) (specifically ±10hPa in a 3h period); this is different from the severe gales in UKCIP02. They found a significant increase in the number of severe storms over the UK as a whole since the 1950s. This analysis is being extended back in time using newly-digitised MSLP data from as many as possible long-period observing sites in the UK and Ireland, and some preliminary results are shown in Figure 1.14 (Allan et al., in preparation). It appears that an equally stormy period to those in the most recent full decade (1990s) was experienced in the 1920s. Similar conclusions are drawn in IPCC AR4 (Chapter 3, para 3.8.4.1 and Fig. 3.41).

Whereas it is not our purpose here to discuss detailed links between the NAO and storminess, it will be immediately apparent that the two stormiest periods in Figure 1.14, in the 1920s and 1990s, coincide with decades of sustained positive NAO index, whereas the least stormy decade, the 1960s, is a time when the smoothed NAO index was most negative (see Figure 1.13). Although work by Gillett et al. (2003) has shown that man-made factors have had a detectable influence on sea-level pressure distributions (and hence atmospheric circulation patterns) over the second half of the 20th century, there continues to be little evidence that the recent increase in storminess over the UK is related to man-made climate change.

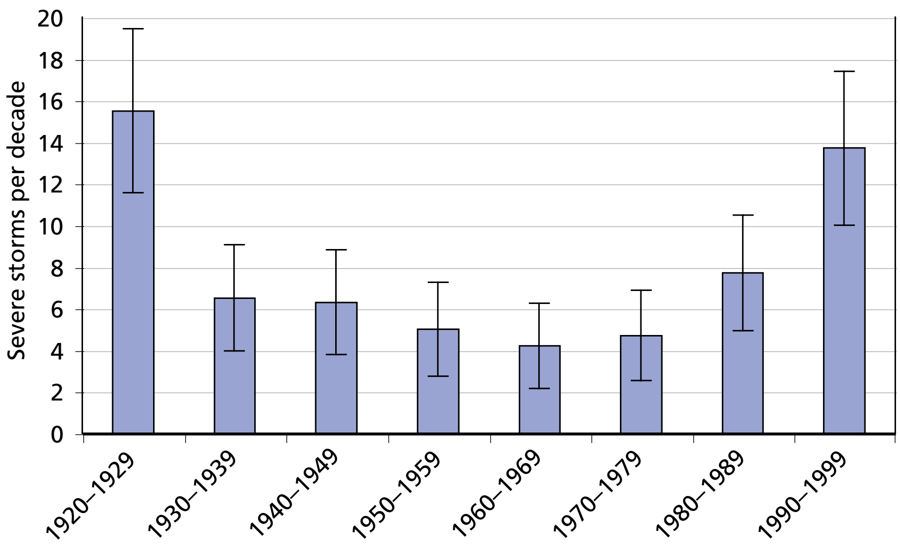


Figure 1.14: The total number of severe storms per decade over the UK and Ireland during the half year period October to March, from the 1920s to the 1990s. Error bars show ± one standard deviation. (Source: Rob Allan, MOHC)

1.7 Coastal sea-surface temperature

- Sea-surface temperatures around the UK coast have risen over the past three decades by about 0.7 °C.

Long observational data sets of the temperature of the coastal sea are available from a few point locations around the UK (see references to useful websites at the end of this paragraph). However, a more representative picture of trends can be gathered by using global gridded data sets of sea-surface temperature (SST, typical of the first few metres below the sea surface) and selecting all the grid squares which border the UK coastline. This is done in Figure 1.15, using a global data set of observations (Rayner et al., 2003). Also shown in this figure are the decadal variations and trends over a similar area in the night marine air temperature (NMAT, Rayner et al. (2003)), the air temperature measured over sea at night when it is unaffected by possible errors due to solar radiation. These show good agreement over the last century with the SST and hence act to corroborate the latter. Despite considerable year-to-year and even decade-to-decade variability, a clear coastal SST increase of about 0.7 °C over the past three decades is evident. Comparison with Figure 1.4 shows that coastal SST has warmed more slowly than CET, partly because SST temperatures generally lag behind air temperatures over land, but also because of a much smaller warming off northern Scotland, possibly due to local natural variability.

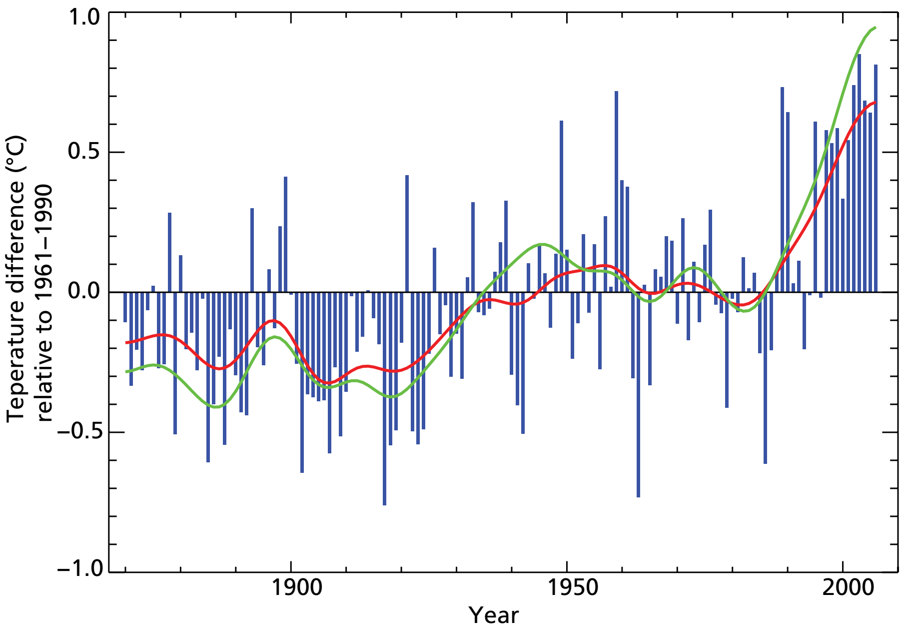


Figure 1.15: Annual-mean sea-surface temperature averaged around the UK coastline, for the period 1870-2006 (blue bars extending from the 1961-90 average of 11.3 °C); the smoothed red line emphasises decadal variations. The green curve shows night marine air temperature over roughly the same area, with the same smoothing. (Source: MOHC HadISST1.1)

Details of the HadISST1.1 SST dataset used for this analysis, with a resolution of 1° latitude x 1° longitude, can be seen at www.metoffice.gov.uk/research/hadleycentre/obsdata/HadISST.html

SST observations at coastal sites around the UK can be seen at: www.marlab.ac.uk/Delivery/Information_Resources/information_resources_view_document.aspx?contentid=2174 (Scotland) and www.cefas.co.uk/data/sea-temperature-and-salinity-trends.aspx (England and Wales).

1.8 Sea level around the UK

- Sea level around the UK rose by about 1mm/yr in the 20th century, corrected for land movement. The rate for the 1990s and 2000s has been higher than this.

Sea level around the UK, relative to land, is changing for two reasons; firstly because the volume of the oceans is changing and secondly because land is moving in response to the melting of the ice-sheet following the end of the last ice age – the latter is causing a general upward land movement in northern Britain and downward movement in southern England. The UK national network of tide gauges, the instruments by which sea level is monitored, is maintained by the Proudman Oceanographic Laboratory, Liverpool. Figure 1.16 shows observations of change in sea level from five locations around the coast of the UK which have particularly long records, with the last data point being for 2006. These changes are of absolute sea level, that is, not corrected for any land movement, as this cannot be done at individual stations with useful accuracy. However, such estimates as are available suggest that over the 20th century the effect of land movement will have been quite small at Liverpool and Aberdeen, and about 1mm/yr at Newlyn and Sheerness.

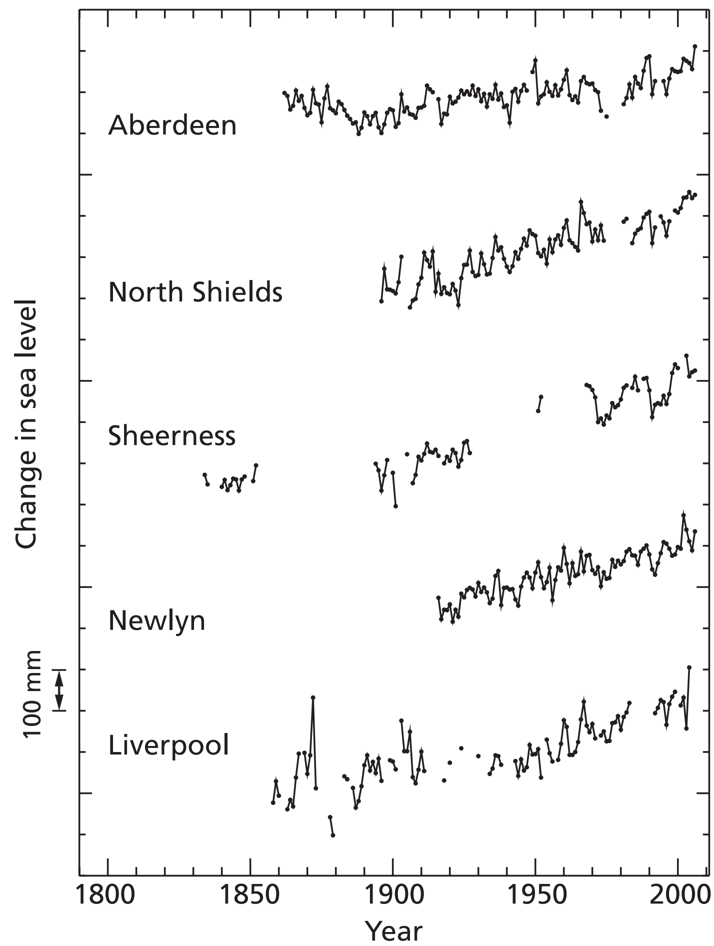


Figure 1.16: Change in annual-mean absolute sea level recorded by tide gauges at UK stations with particularly long records: Aberdeen, North Shields (Tyne and Wear), Sheerness (Kent), Newlyn (Cornwall) and Liverpool. (Source: Phil Woodworth, POL)

The rate of relative sea-level rise (i.e. corrected for land movement) around the UK in the 1990s and 2000s is higher than that for the 20th century overall; the latter being about 1mm/yr. Extreme high sea levels (storm surges) are also of interest; changes in these are determined by changes in sea level and storminess in combination with tides. There is evidence that annual extreme high (99%) and low (1%) sea levels at Newlyn (since 1916) and Aberdeen (since 1946), have changed at roughly the same rate as the mean sea level – 2.1mm/yr and 1.3mm/yr respectively – although with high extremes increasing slightly faster than low extremes. (Subsection 1.8: P. Woodworth, Pers Comm).

Further details of tide gauge measurements by POL, including extremes, can be seen at www.pol.ac.uk/ntslf/products.php. Changes to many other marine quantities, such as salinity and waves, can be seen on the website of the Marine Climate Change Impacts Partnership (www.mccip.org.uk). In addition, the websites of the Marine Environmental Change Network (www.mba.ac.uk/MECN/index.htm) and the Inter-agency Committee on Marine Science and Technology (www.marine.gov.uk/) are useful resources.

Section 2: United Kingdom climatologies and recent regional trends

2.1 Description of the maps, graphs and tables

This section presents – in graphical form – climatological information for the whole of the UK, including long-term average climates and changes and trends. It was suggested as an extension to the whole of the UK of the sort of information presented for Scotland in the recent SNIFFER report (Barnett et al., 2006), and hence we have followed the methods used in that report. We have modified the list of variables and derived quantities shown (Table 2.1) to be more in line with those planned to be available in the UKCP09 projections, where possible. Similar information on some additional climate variables is given in Perry (2006).

The climatological information shown in this section for the whole of the UK is as follows:

- Maps of the long-term averages (LTA) for the 30-year period 1961-1990 (the UKCP09 baseline period), by season and for the whole year.

- Maps of the long-term averages for the 30-year period 1971-2000, by season and for the whole year.

- Maps showing the differences (or percentage changes) between the above two long-term averages, that is (1971-2000) minus (1961-1990), by season and for the whole year.

- Maps showing the change between 1961 and 2006, based on a linear trend over that period, for each season and the whole year.

- Graphs of the smoothed time-series for 14 regions, from 1961-2006 (and from1914-2006 for temperature and precipitation) presented by season and for the whole year, smoothed to show decadal variations.

- Tables of changes (based on trends) for 14 regions from 1961-2006 (and from 1914-2006 for temperature and precipitation) presented by season and for the whole year. Linear regression was used to calculate the trend in each variable.

Eleven variables are considered in this report and the climatological information given for each is shown in Table 2.1. Standard meteorological seasons are used: December, January and February (Winter); March, April and May (Spring); June, July and August (Summer); and September, October and November (Autumn).

Most of the variables are self-explanatory; the definitions of the two quantities which are derived from temperature are given in Table A1.2. The degree day quantities are weighted temperature summations and include Heating Degree Days (HDD) and Cooling Degree Days (CDD). A detailed explanation of how HDD and CDD are calcuated is given in Annex 2.

For most of the variables all the information is given. The inhomogeneous nature of station data for wind speed, together with a relatively sparse (and changing) observational network, result in estimates of change and trends which are not robust, and so only the latest long-term average is shown. HDD, CDD and days of air frost, being annual totals, have no seasonal information.

2.2 Data sources and limitations

All the information in this section is constructed from gridded datasets. The Met Office has a UK data archive containing hourly and daily observations of many different weather elements. These observations come from a network of meteorological stations that has changed over the years. From this information a consistent series of climate statistics has been produced which allows comparisons across space and time. In order to do this, methods were developed to create monthly gridded datasets from the information gathered at each station. Values of climate variables between observing stations can be estimated with a good degree of accuracy, producing detailed and representative maps of the UK climate.

Changes in spatial patterns over time, as well as trends in climate, can be investigated using gridded data at a resolution of 5km x 5km, which is available month-by-month (see Annex 1). Most studies of climate trends for other countries have been made using series of data from a small number of long-period stations. The use of gridded datasets and area-averaged series to analyse trends has the advantage of not being reliant on individual stations, which are vulnerable to missing data and inhomogeneities and, most importantly, provide a limited spatial representativity. However, the accuracy depends on the nature of the variable and how many stations there are providing information for an area. Inaccuracies occur most often in areas where there are few stations, particularly in complex upland terrain. The process used to provide gridded datasets does

Table 2.1: Variables and climatological information presented in this report

	1961-90 LTA maps	1971-2000 LTA maps	Differences between LTA maps	Change maps 1961-2006	Regional decadal changes graph	Regional linear trends table
Mean temperature	✓	✓	✓	✓	✓	✓
Daily maximum temp	✓	✓	✓	✓	✓	✓
Daily minimum temp	✓	✓	✓	✓	✓	✓
Days of air frost	✓	✓	✓	✓	✓	✓
Heating Degree Days	✓	✓	✓	✓	✓	✓
Cooling Degree Days	✓	✓	✓	✓	✓	✓
Total precipitation	✓	✓	✓	✓	✓	✓
Days of rain ≥ 1mm	✓	✓	✓	✓	✓	✓
Sea-level pressure	✓	✓	✓	✓	✓	✓
Relative humidity	✓	✓	✓	✓	✓	✓
Windspeed at 10m		✓				

not take account of localised effects on climate such as frost hollows, and effects caused by soil type and vegetation. For some variables, inhomogeneities caused by changes in observing practice across the station network may also affect the quality of the results. For the reasons above, care must be taken not to over-interpret high resolution spatial detail.

The start date of 1961 was chosen for most variables because there is a significant increase in the availability of digitised information from that year; it is also the start year of the UKCP09 baseline period. Temperature and rainfall data has been digitised back to 1914, so this has enabled trends for these variables to also start from that year. However precipitation trends for periods before 1961 are less accurate, because less data is available.

2.3 Long-term averages

The maps of the climate averages for the two 30-year periods, 1961-1990 and 1971-2000, were produced from a 1km gridded dataset, using the methods described in Perry and Hollis (2005b). The maps showing differences between the two long-term averages give some indication of the variability over the same time-averaging periods typically used as baselines for climate change scenarios, although the large overlap between the two (1971-1990) means that the full measure of this variability is not reflected.

The colour scales in maps have been chosen to make the information as easily assimilated as possible; this means that not all the scales are the same. The highest scale interval is sometimes wider than the others to allow the inclusion of a few higher value points which do not warrant a new colour bar.

2.4 Changes and trends

Recent changes and trends are illustrated in a number of different ways. Firstly, and most simply, we show maps of the difference between the two 30-year averages, at 1km resolution. For most variables this is given as a simple arithmetic difference, but for precipitation and HDD, the change is given as a percentage of the 1961-1990 long-term average.

Secondly, we show maps of changes over the period 1961-2006, using the month-by-month 5km x 5km resolution data set described in Annex 1. The change shown for each grid square was based on a linear trend at that square, for each season and the whole year. These give an indication of recent trends, but the value of derived trends is sensitive to the period over which it was taken and in particular any extremes at either end of this period. Quite different trends (and hence quite different maps of changes) could have resulted if we had used, say, the period 1971-2000. For example, the data shows some very large increases in winter precipitation over NW Scotland from 1961-2006 - over 200% in some grid squares. For this reason the trends and changes must be treated as indicative, and useful for geographical patterns, but their exact values should be treated with caution.

Thirdly, we show graphs of trends calculated over 14 regions of the UK. They comprise the 12 UK administrative regions with Scotland being subdivided into three using the Met Office climatological regions. They are illustrated in Figure 2.1, and are the same as will be used in the UKCP09 projections of future changes. The time series data for each of the regions were smoothed to show decadal variations. Smoothing* was done so that the trend lines for all the regions could be presented on one graph; individual years could have been shown (see example in Figure 2.2) but this would have made the graphs too complicated to see the essential information, that is, the trends themselves.

Lastly, we show tables of changes, for each of the 14 regions, over the period 1961-2006 by season and for the whole year. In addition, changes over the period 1914-2006 are given for temperature and precipitation. Linear regression was used to calculate the trend in each variable, and then the average rate of change from the linear regression multiplied by the length of the data period was used to provide a measure of change since the start of the period. Bold type indicates a 95% confidence level that trends are statistically significant**. Note that this significance refers to the trend itself, and not to the question of the origin of such trends, that is, man-made or natural.

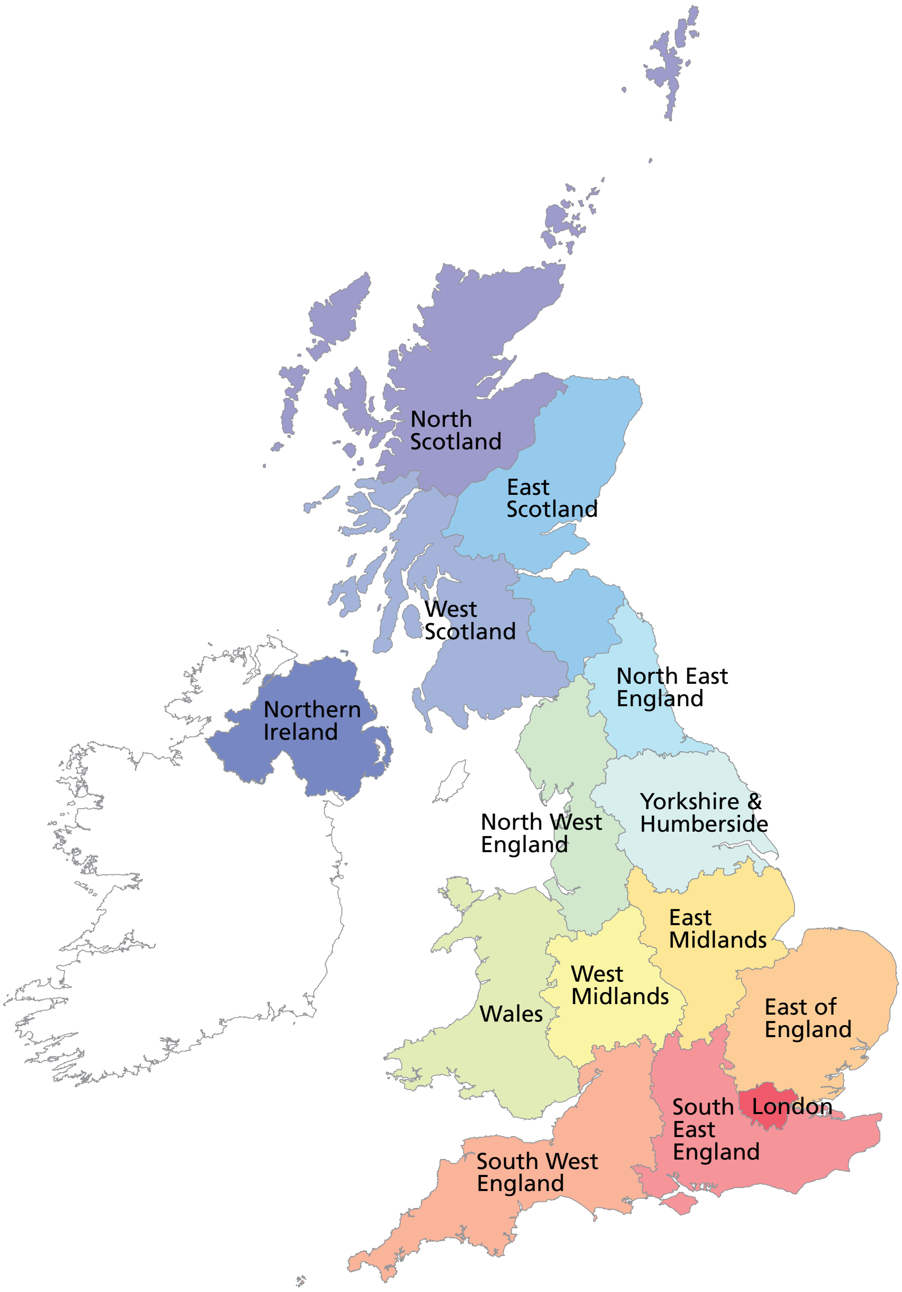


Figure 2.1: The 14 UKCP09 regions over which trends have been calculated

*The smoothing used a weighted kernel filter, with 15 terms either side of each target point. At the ends of the time series, only the 15 points to one side of the target point were used, increasing to the full 31 year bandwidth by the 16th year from each end. This non-parametric filter enables the long-term fluctuations in the climate to be clearly seen without assuming that the trend follows a stated model.

No comment is made about the reason for the trends and changes in this Section. The attribution of change in one regional indicator, Central England Temperature, is discussed in Section 1 of this report, but no such analyses have been done of any other time series. Very few of the trends reported in the tables in this Section - apart from those related to temperature - are statistically significant. This does not necessarily contradict expectations from model projections of climate change. Studies that have evaluated the likely time at which climate-change induced trends might be detectable at the scale of the UK (for example, Wilby, 2006) show that, because of high natural variability and short observational datasets, unambiguous trends are unlikely to emerge in some variables for several decades to come.

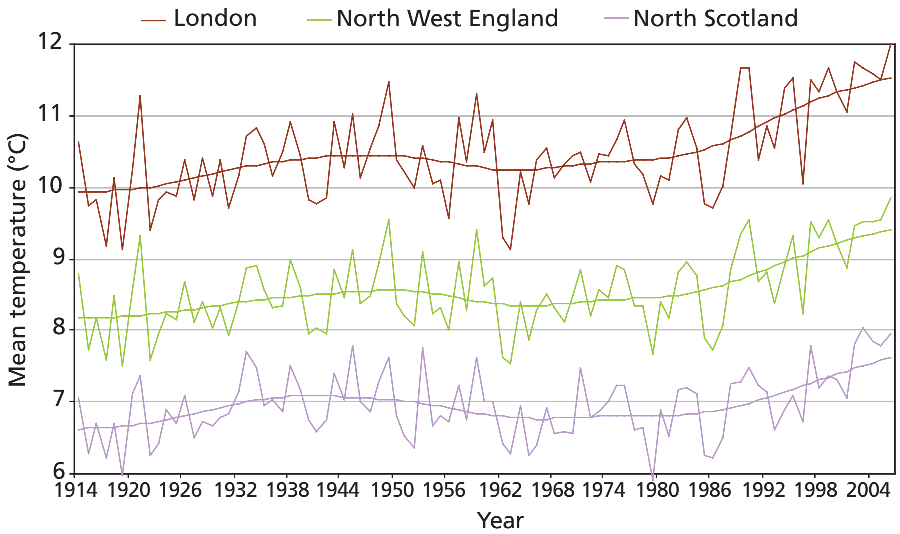


Figure 2.2: Annual time series of mean temperature for three of the regions, together with their smoothed decadal trend lines

**The Mann-Kendall statistical test was used to show whether significant changes had taken place. This is a rank-based non-parametric test (Sneyers, 1990).

2.1 Mean temperature

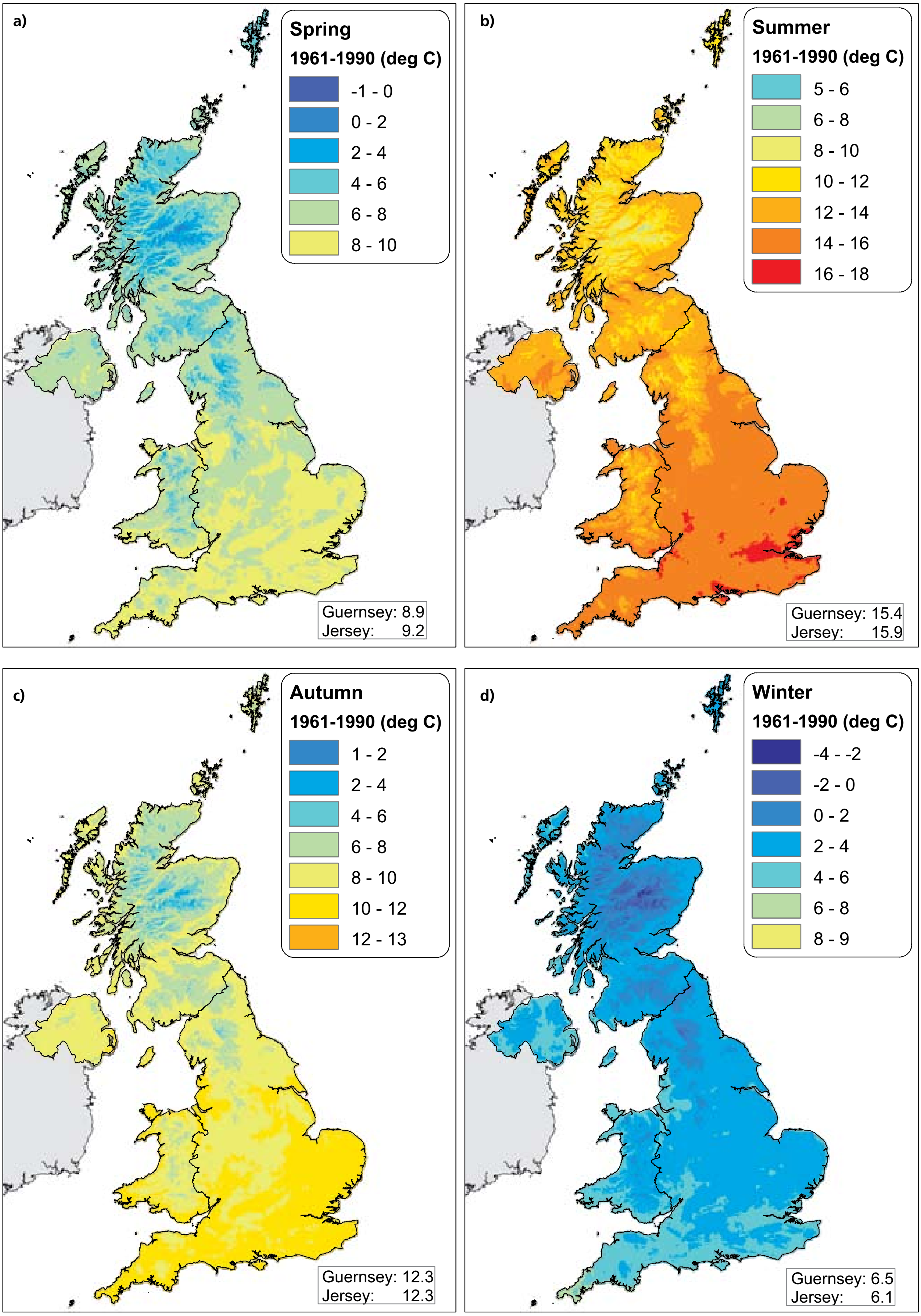


Figure 2.3: 1961-1990 average daily mean temperature (°C) for a) spring, b) summer, c) autumn and d) winter

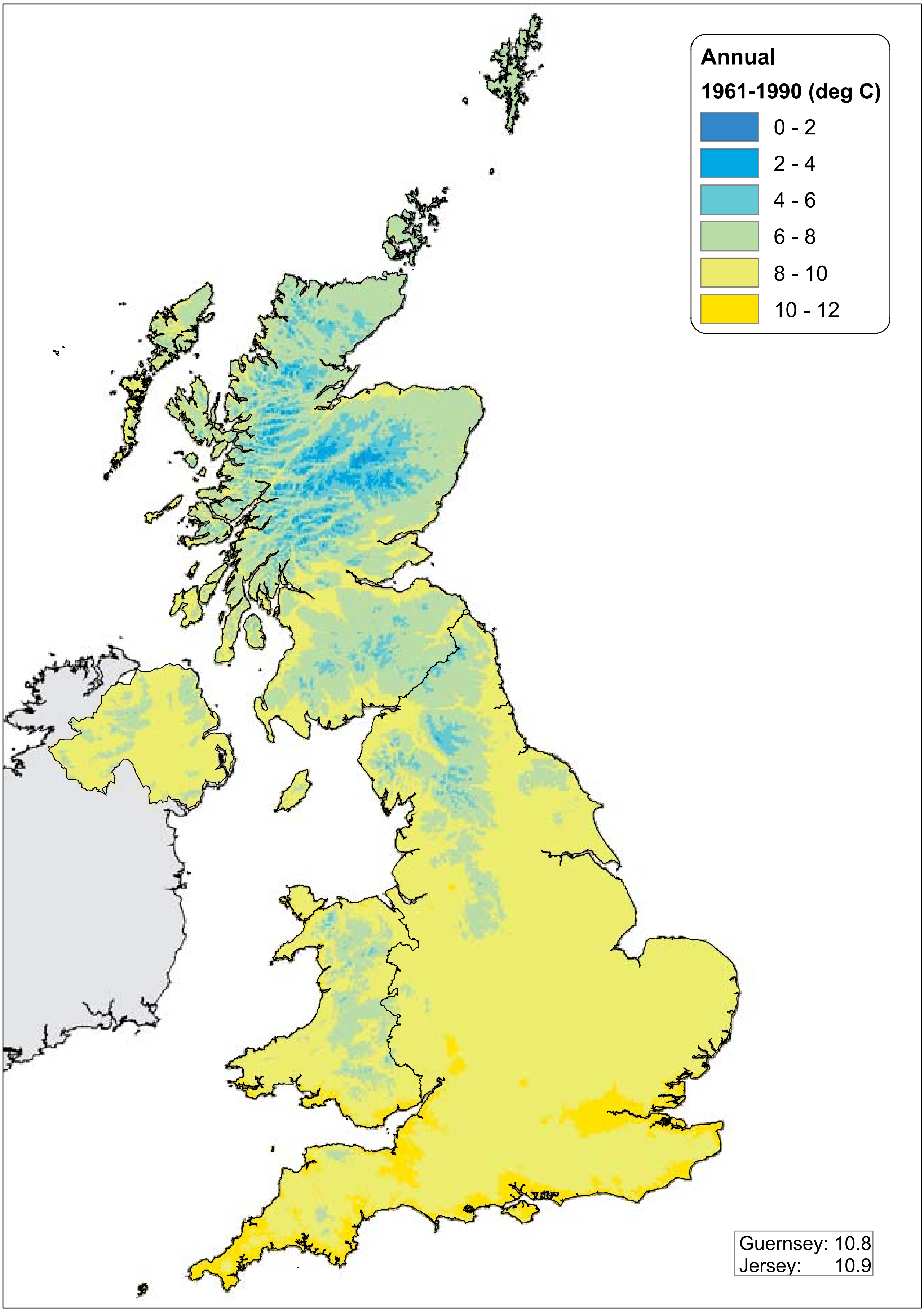


Figure 2.4: Annual average daily mean temperature (°C) for 1961-1990

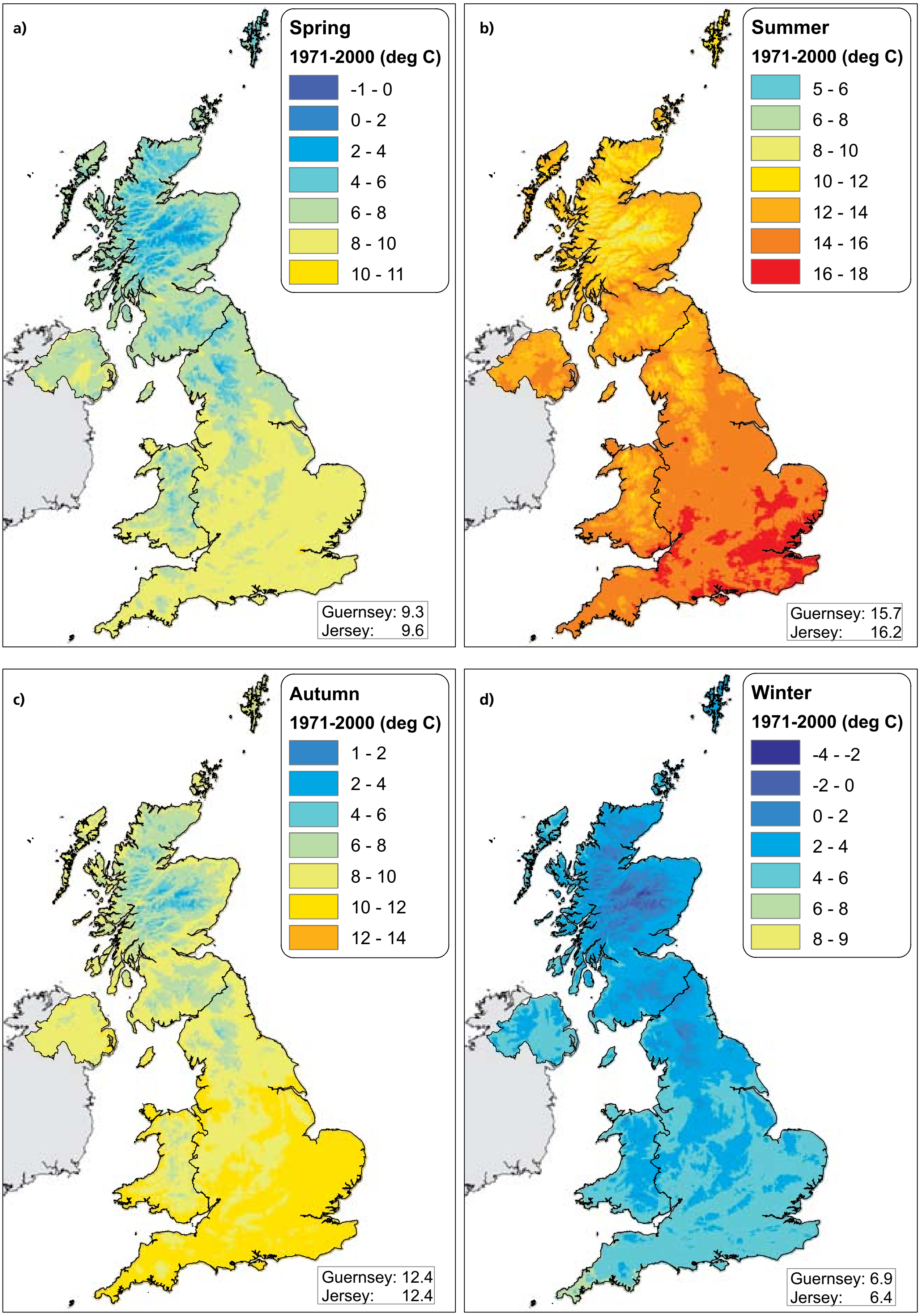


Figure 2.5: 1971-2000 average daily mean temperature (°C) for a) spring, b) summer, c) autumn and d) winter

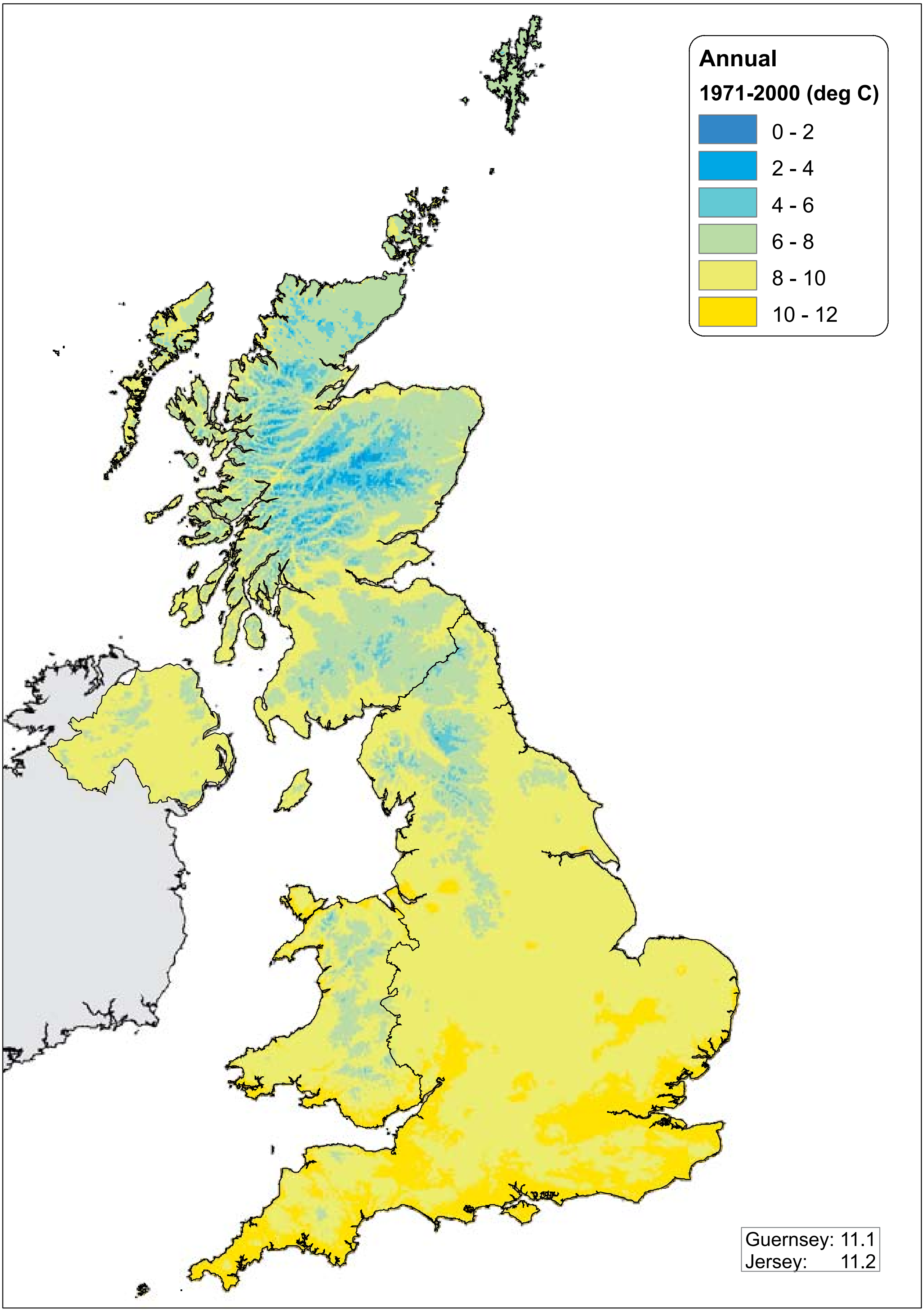


Figure 2.6: Annual average daily mean temperature (°C) for 1971-2000

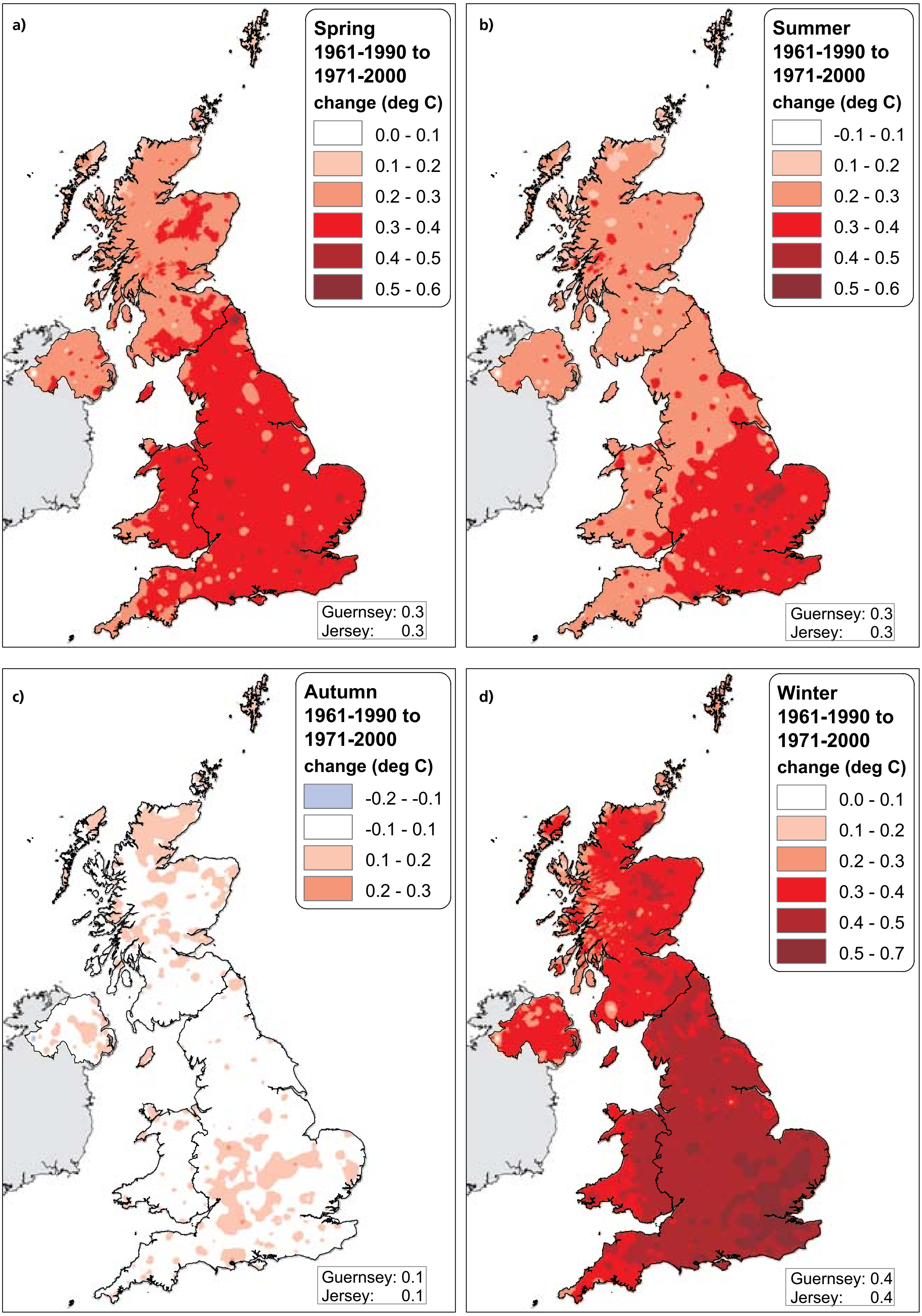


Figure 2.7: Change in daily mean temperature (°C) from 1961-1990 to 1971-2000 for a) spring, b) summer, c) autumn, d) winter

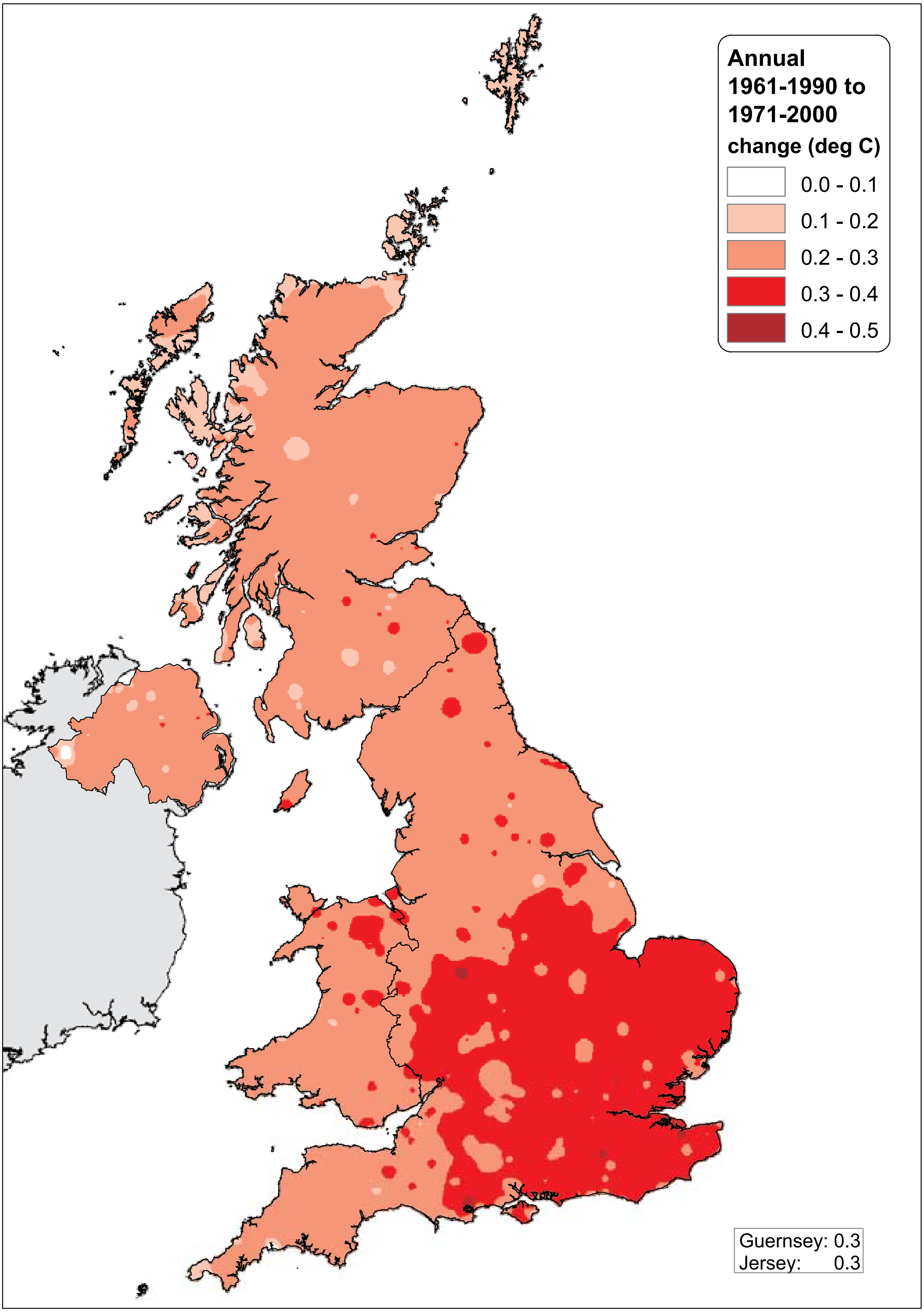


Figure 2.8: Change in annual average daily mean temperature (°C); between 1961-1990 and 1971-2000

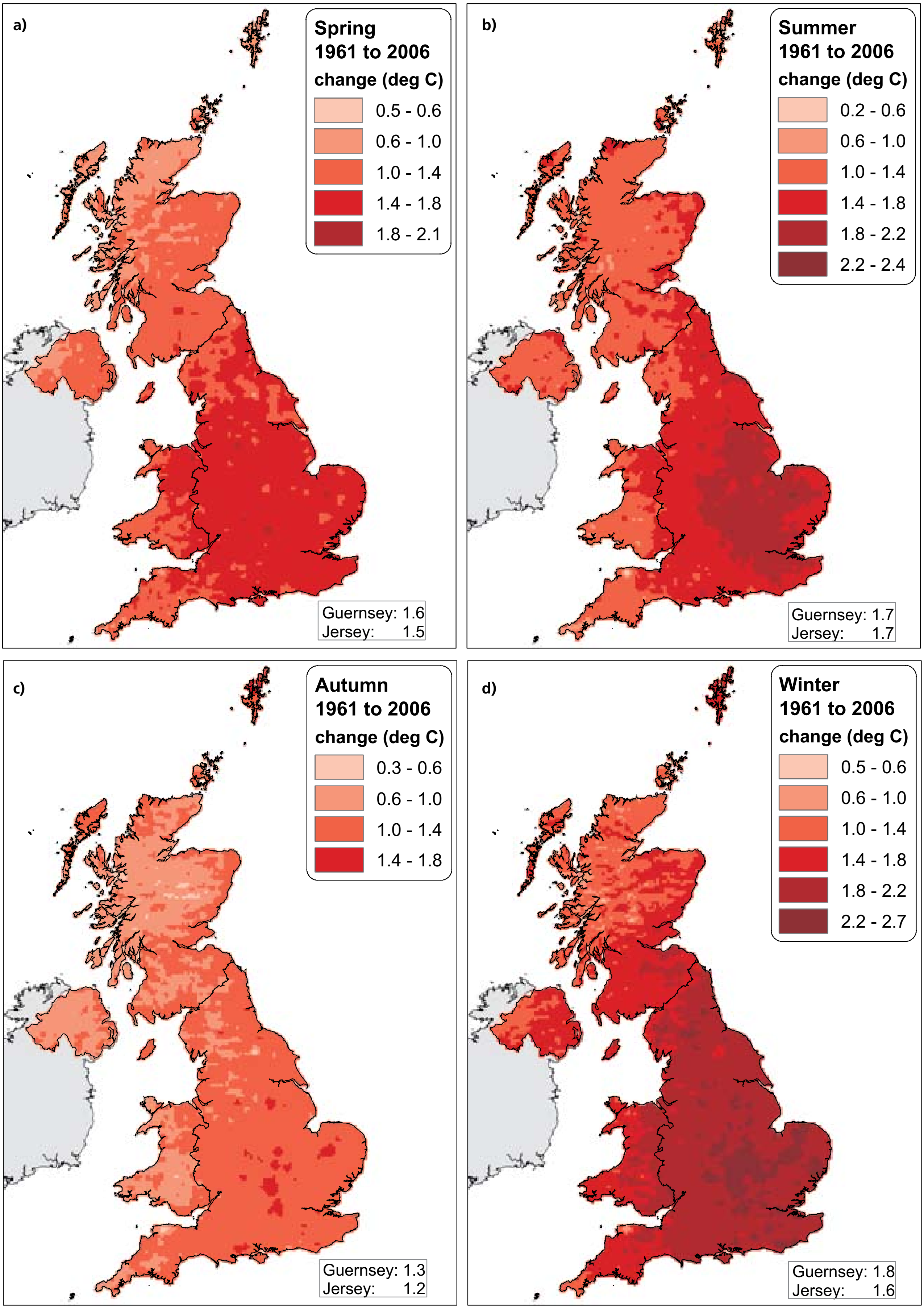


Figure 2.9: Change in daily mean temperature (°C) from 1961 to 2006 based on a linear trend for a) spring, b) summer, c) autumn, d) winter

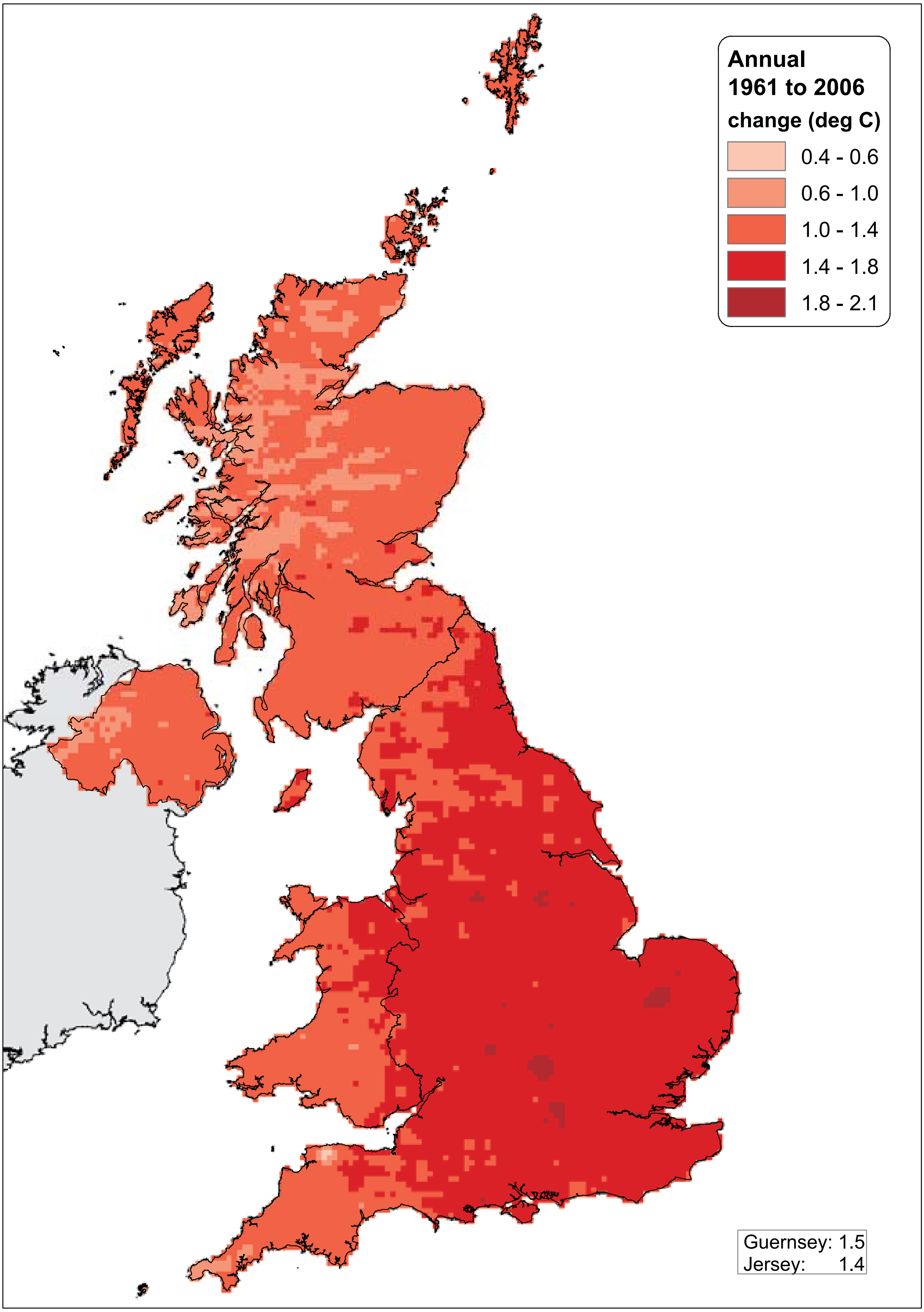
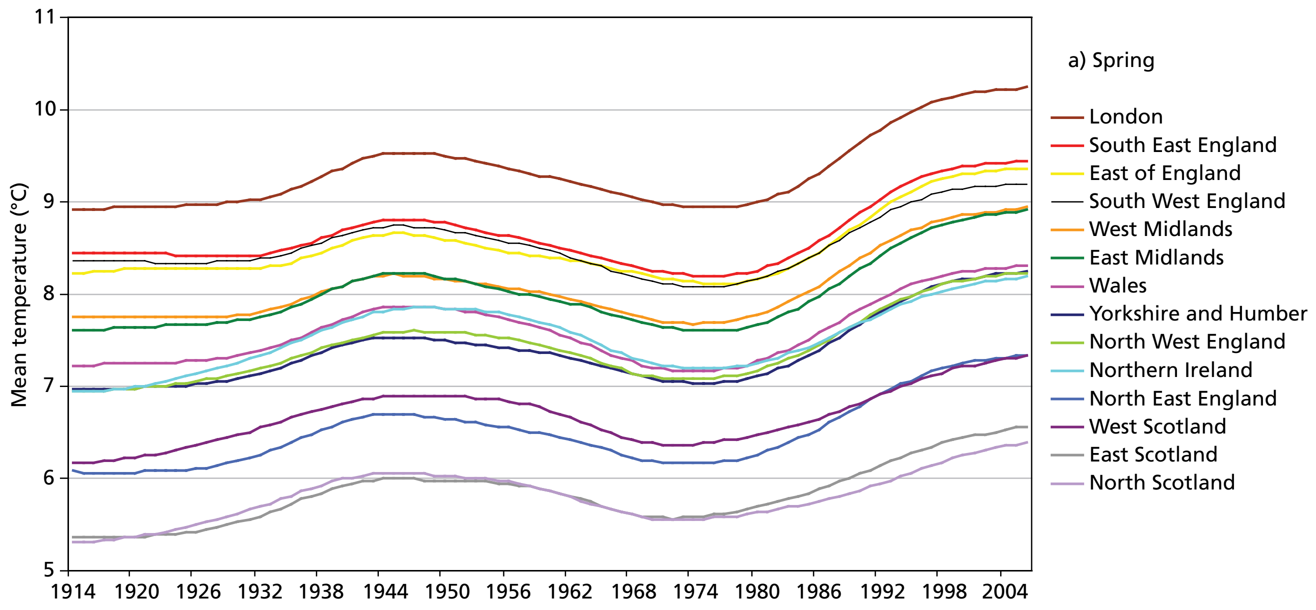
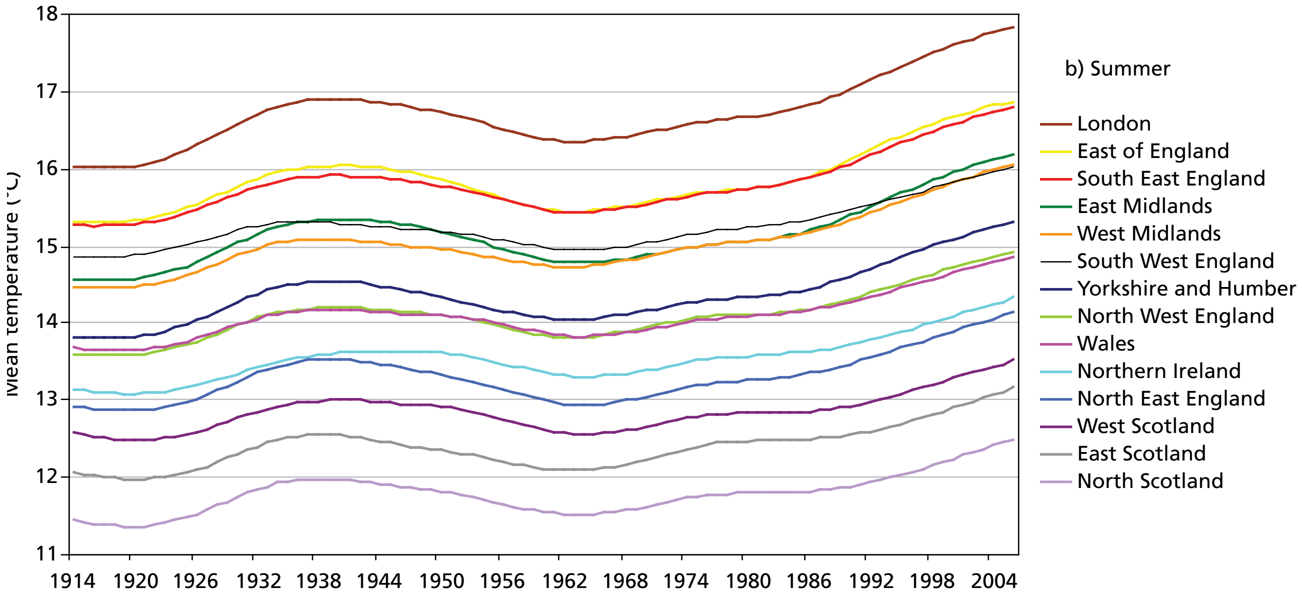
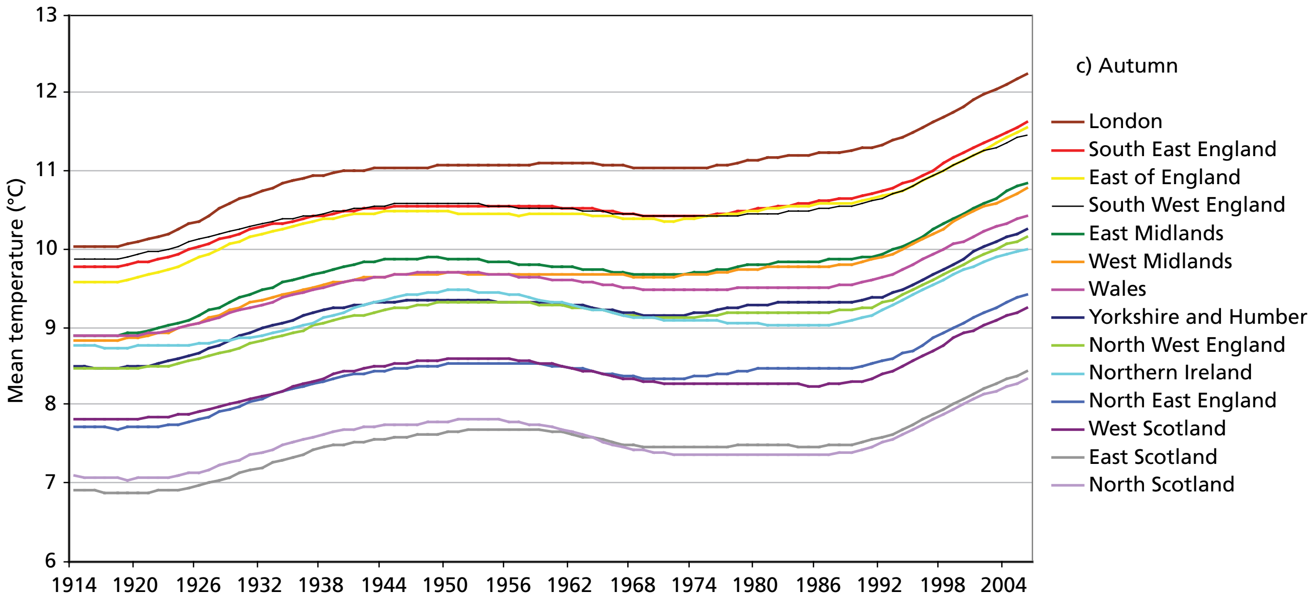


Figure 2.10: Change in annual average daily mean temperature (°C); between 1961 and 2006 based on a linear trend


a) Spring
Mean temperature (°C)
11
10
9
8
7
6
5
1914 1920 1926 1932 1938 1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
London
South East England
East of England
South West England
West Midlands
East Midlands
Wales
Yorkshire and Humber
North West England
Northern Ireland
North East England
West Scotland
East Scotland
North Scotland


b) Summer
18
17
16
15
14
13
12
11
1914 1920 1926 1932 1938 1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
London
East of England
South East England
East Midlands
West Midlands
South West England
Yorkshire and Humber
North West England
Wales
Northern Ireland
North East England
West Scotland
East Scotland
North Scotland


c) Autumn
Mean temperature (°C)
13
12
11
10
9
8
7
6
1914 1920 1926 1932 1938 1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
London
South East England
East of England
South West England
East Midlands
West Midlands
Wales
Yorkshire and Humber
North West England
Northern Ireland
North East England
West Scotland
East Scotland
North Scotland

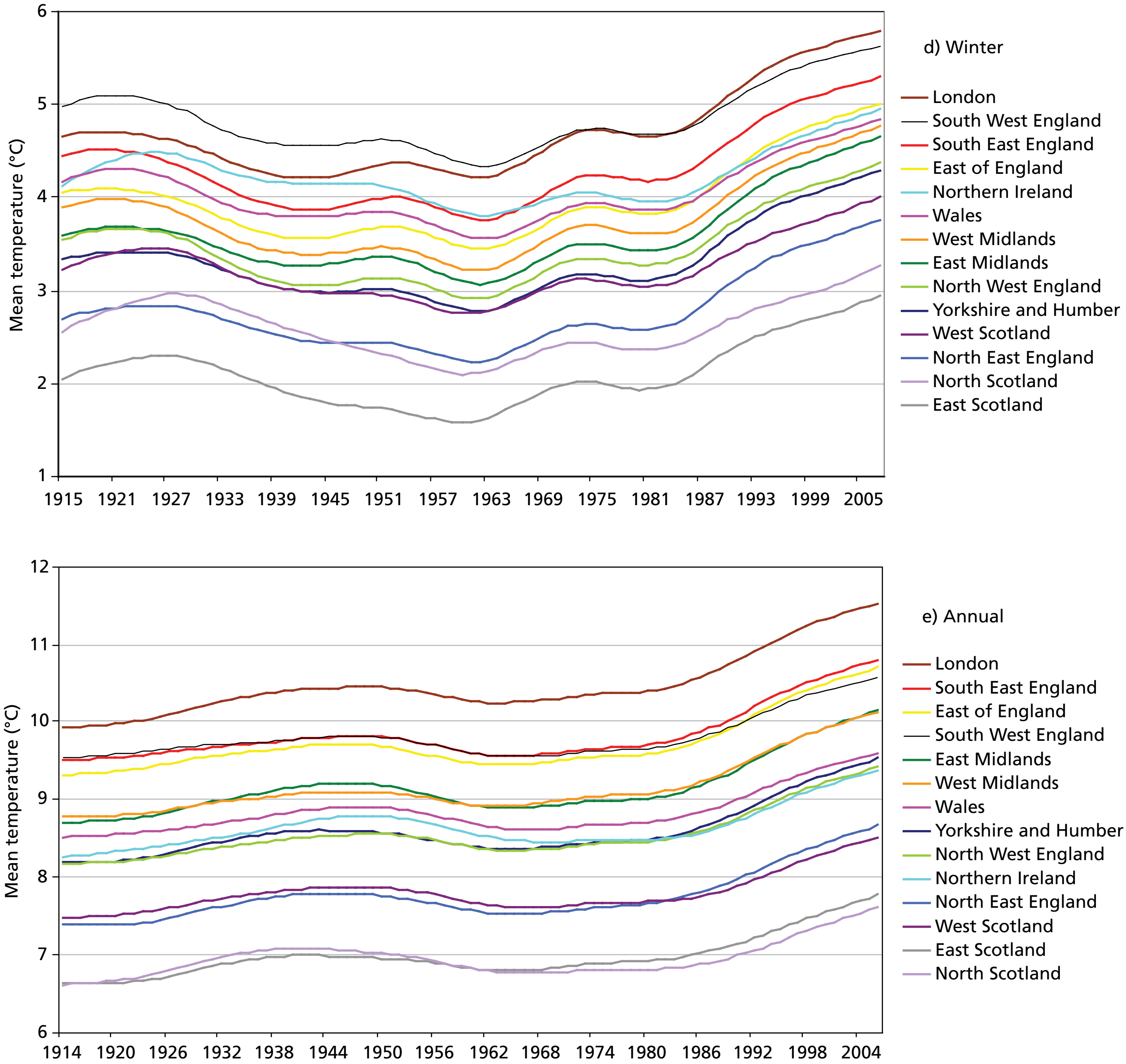


Figure 2.11: Filtered daily mean temperature (°C) by area, 1914-2006 for a) spring, b) summer, c) autumn, d) winter, e) annual

Area	Spring	Summer	Autumn	Winter	Annual
South West England	0.48	**0.78**	**1.02**	0.50	**0.66**
South East England	**0.65**	**1.02**	**1.25**	0.79	0.89
London	**0.93**	**1.20**	**1.60**	**1.13**	**1.18**
Wales	**0.67**	**0.79**	**0.99**	0.47	**0.70**
East of England	**0.76**	**0.97**	**1.35**	0.85	**0.95**
West Midlands	**0.86**	**1.14**	**1.41**	0.74	**1.00**
East Midlands	**0.86**	**1.01**	**1.33**	0.84	**0.97**
Northern Ireland	**0.74**	**0.84**	**0.75**	0.31	**0.64**
Yorkshire and Humberside	**0.90**	**0.97**	**1.20**	0.75	**0.92**
North West England	**0.89**	**0.91**	**1.19**	0.66	**0.88**
North East England	**0.89**	**0.73**	**1.20**	0.81	**0.87**
West Scotland	**0.67**	0.55	**0.85**	0.47	**0.61**
East Scotland	**0.83**	**0.74**	**1.02**	0.59	**0.76**
North Scotland	**0.57**	**0.62**	**0.63**	0.18	**0.47**

Table 2.2: Change in daily mean temperature (°C) from 1914 to 2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Area	Spring	Summer	Autumn	Winter	Annual
South West England	**1.40**	**1.41**	**1.15**	**1.72**	**1.37**
South East England	**1.56**	**1.77**	**1.32**	**2.00**	**1.62**
London	**1.60**	**1.90**	**1.31**	**2.02**	**1.67**
Wales	**1.44**	**1.36**	**1.00**	**1.70**	**1.33**
East of England	**1.52**	**1.86**	**1.27**	**2.02**	**1.63**
West Midlands	**1.57**	**1.70**	**1.21**	**1.95**	**1.56**
East Midlands	**1.57**	**1.87**	**1.27**	**2.01**	**1.64**
Northern Ireland	**1.13**	**1.32**	**0.97**	**1.43**	**1.18**
Yorkshire and Humberside	**1.45**	**1.66**	**1.15**	**1.90**	**1.50**
North West England	**1.44**	**1.45**	**1.07**	**1.81**	**1.40**
North East England	**1.43**	**1.57**	**1.13**	**1.86**	**1.46**
West Scotland	**1.15**	**1.25**	**0.98**	**1.44**	**1.16**
East Scotland	**1.17**	**1.34**	**1.00**	**1.49**	**1.20**
North Scotland	**0.95**	**1.24**	**0.96**	**1.22**	**1.05**

Table 2.3: Change in daily mean temperature (°C) from 1961 to 2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Maximum Temperature

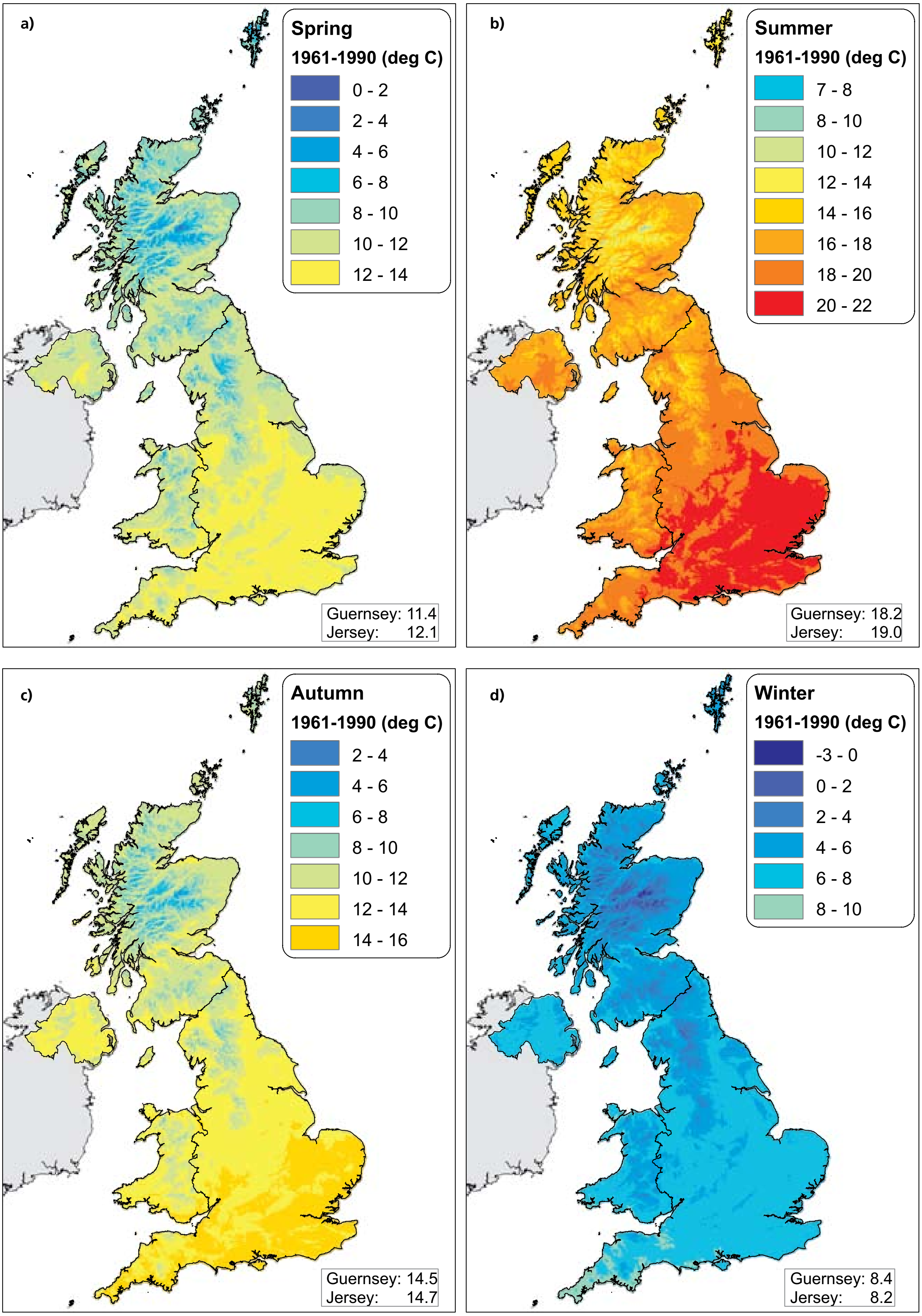


Figure 2.12: 1961-1990 average daily maximum temperature (°C) for a) spring, b) summer, c) autumn and d) winter

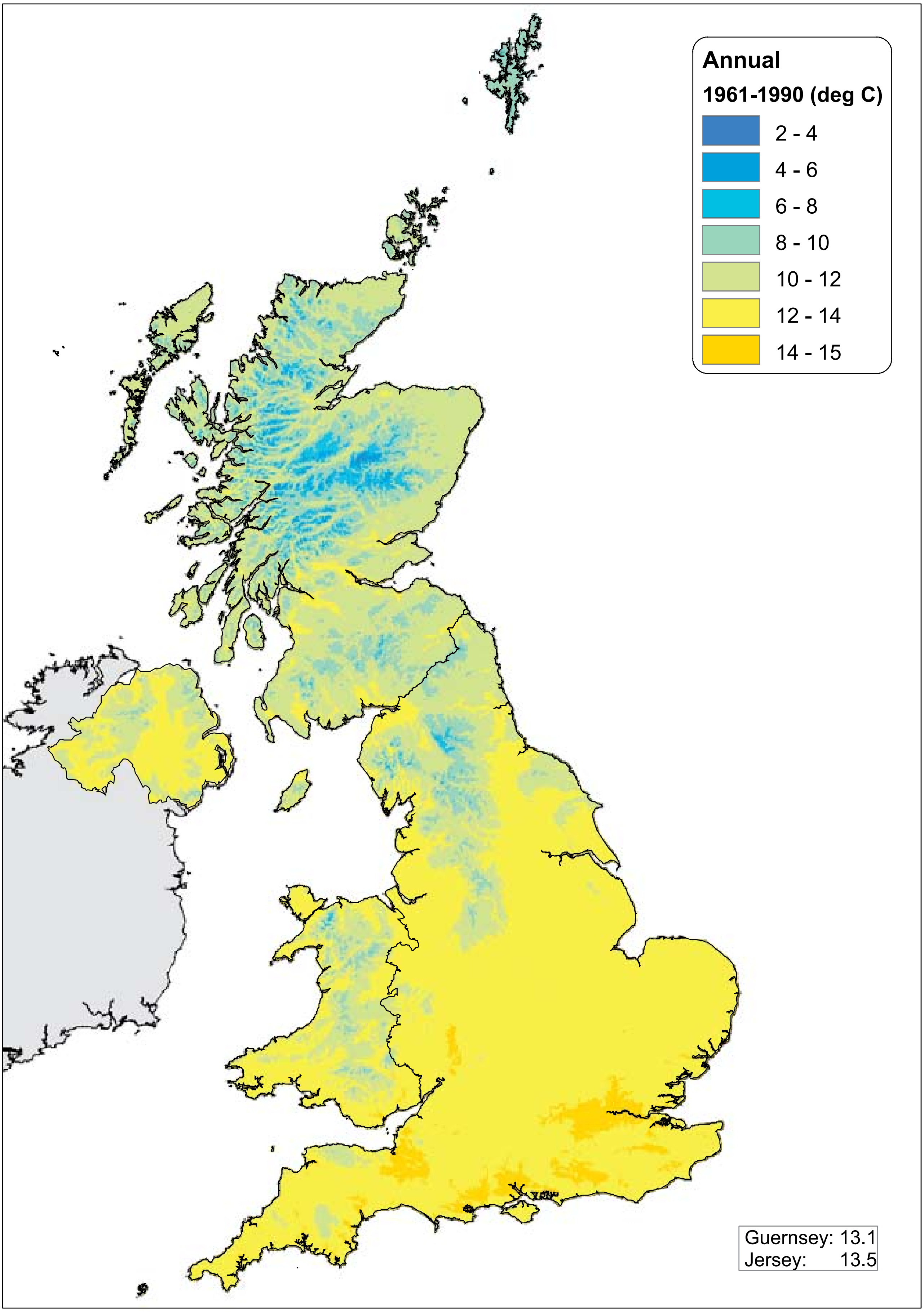


Figure 2.13: Annual average daily maximum temperature (°C) for 1961-1990

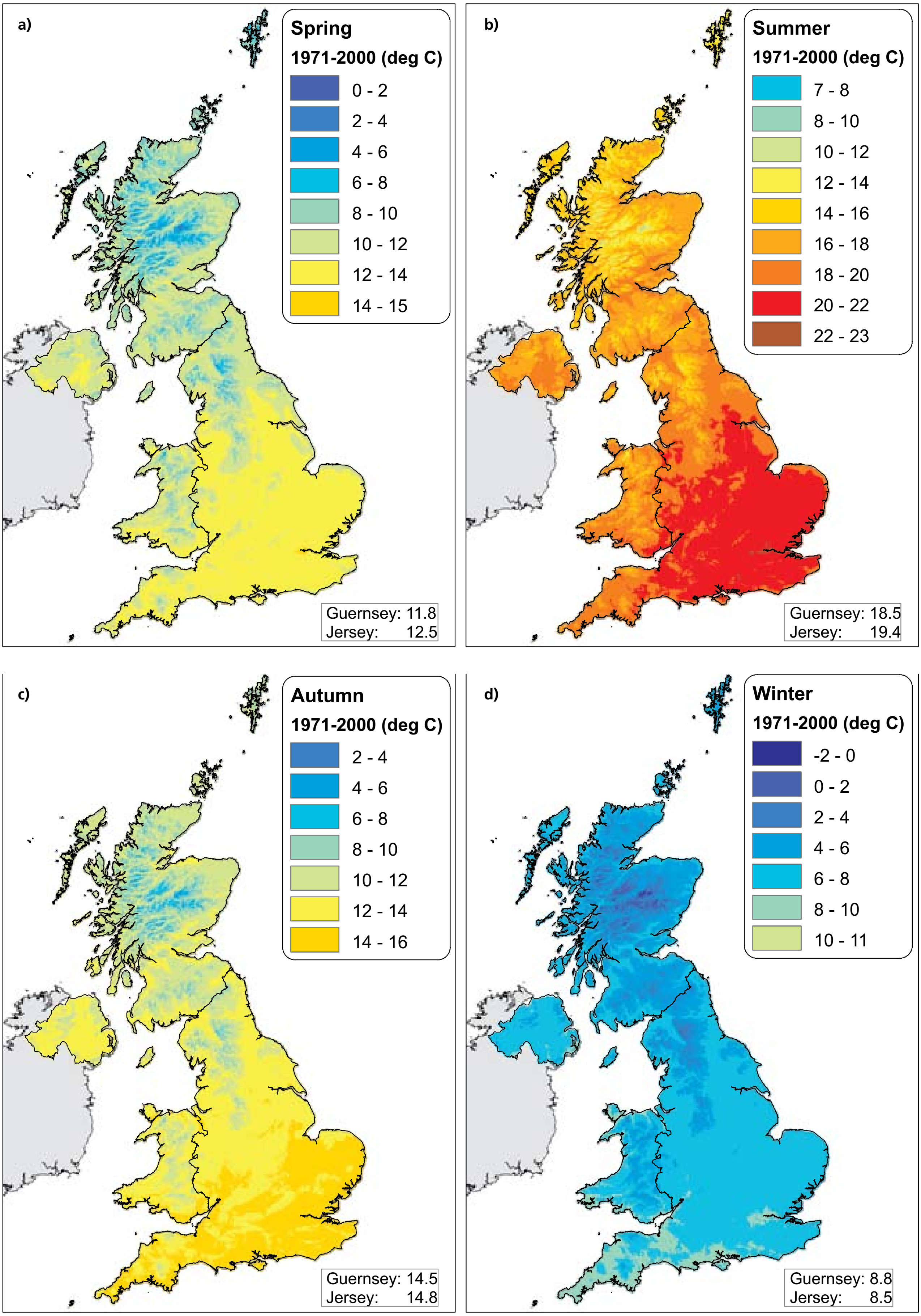


Figure 2.14: 1971-2000 average daily maximum temperature (°C) for a) spring, b) summer, c) autumn and d) winter

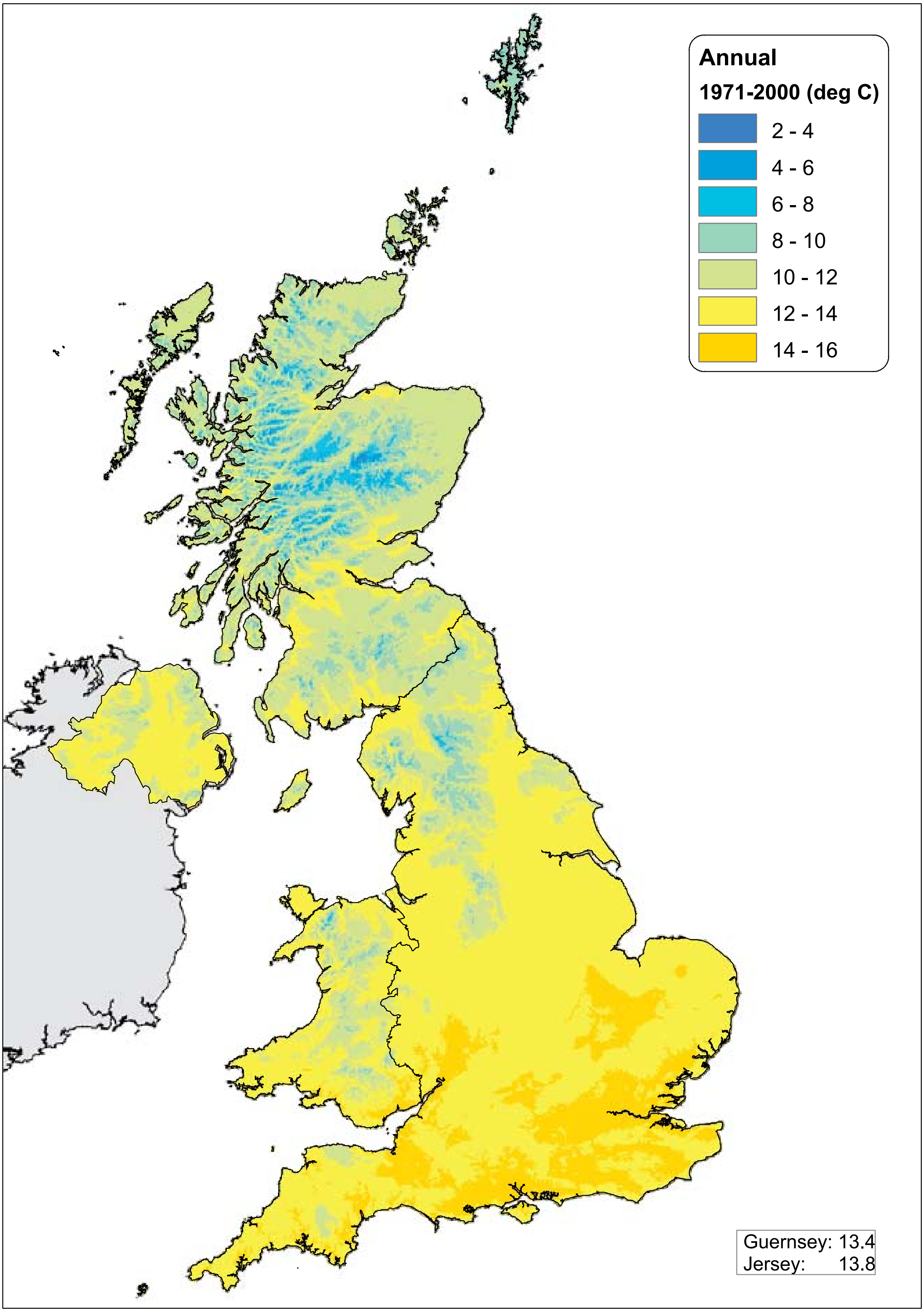


Figure 2.15: Annual average daily maximum temperature (°C) for 1971-2000

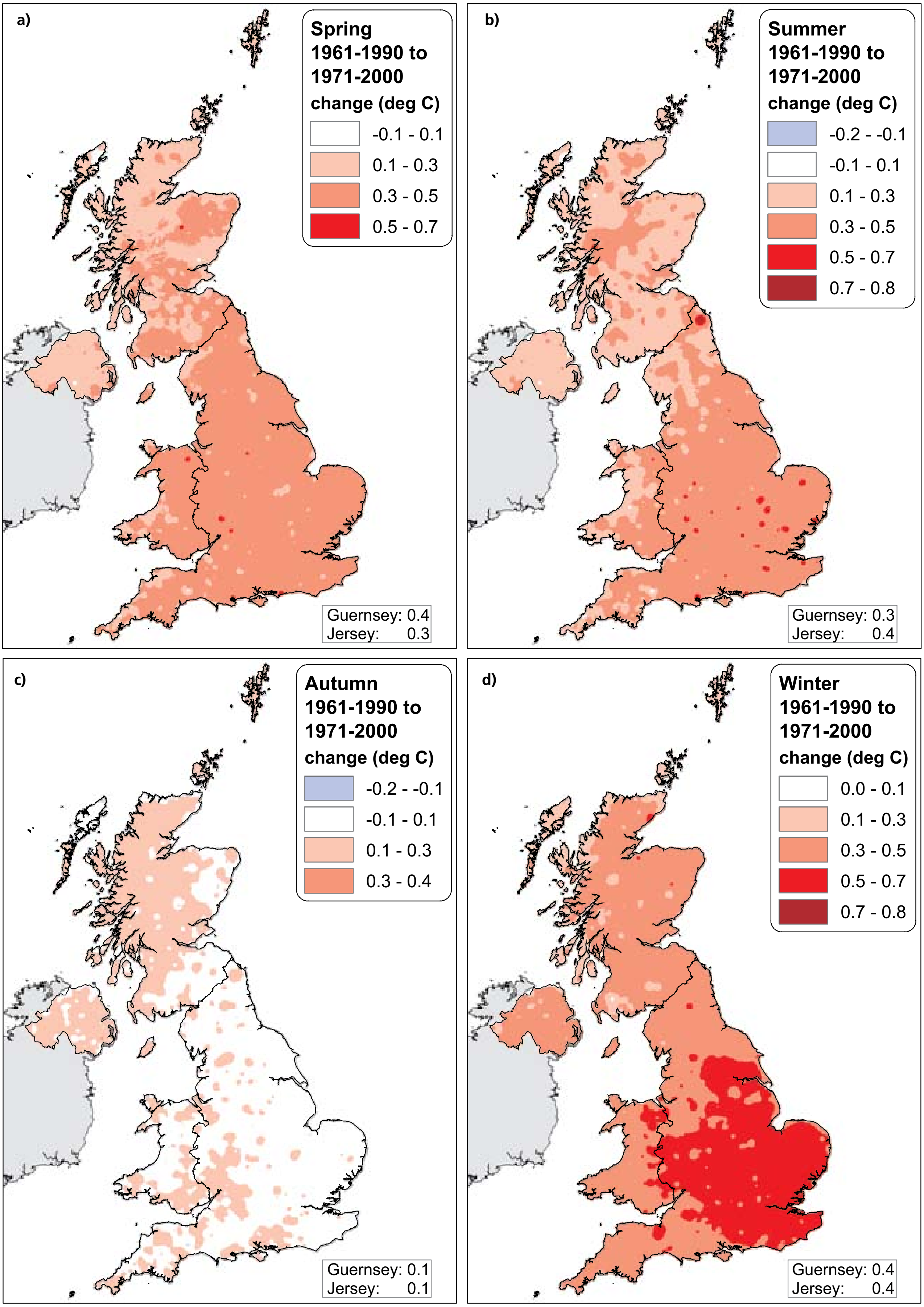


Figure 2.16: Change in daily average daily maximum temperature (°C) from 1961-1990 to 1971-2000 for a) spring, b) summer, c) autumn, d) winter

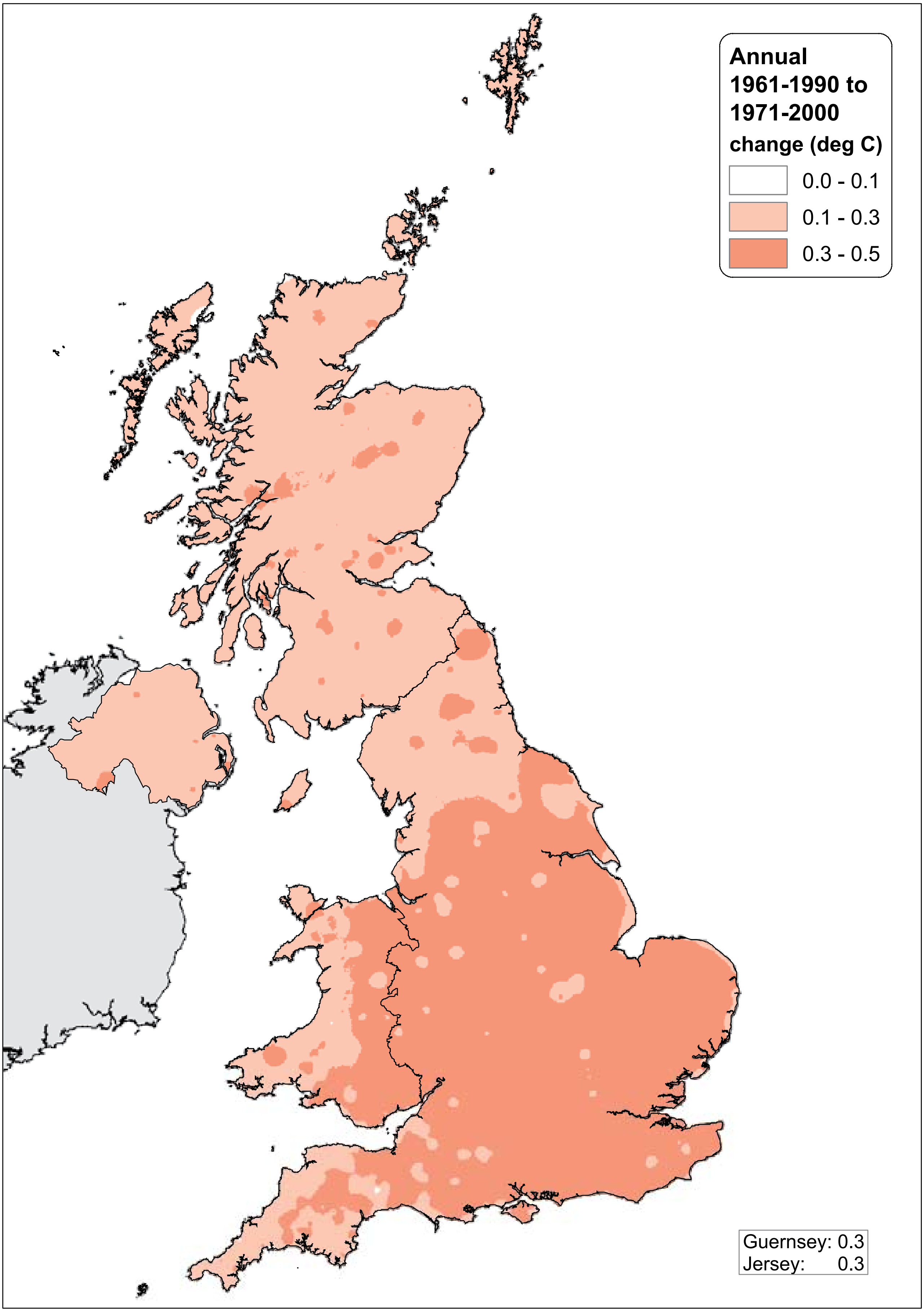


Figure 2.17: Change in annual average daily maximum temperature (°C) between 1961-1990 and 1971-2000

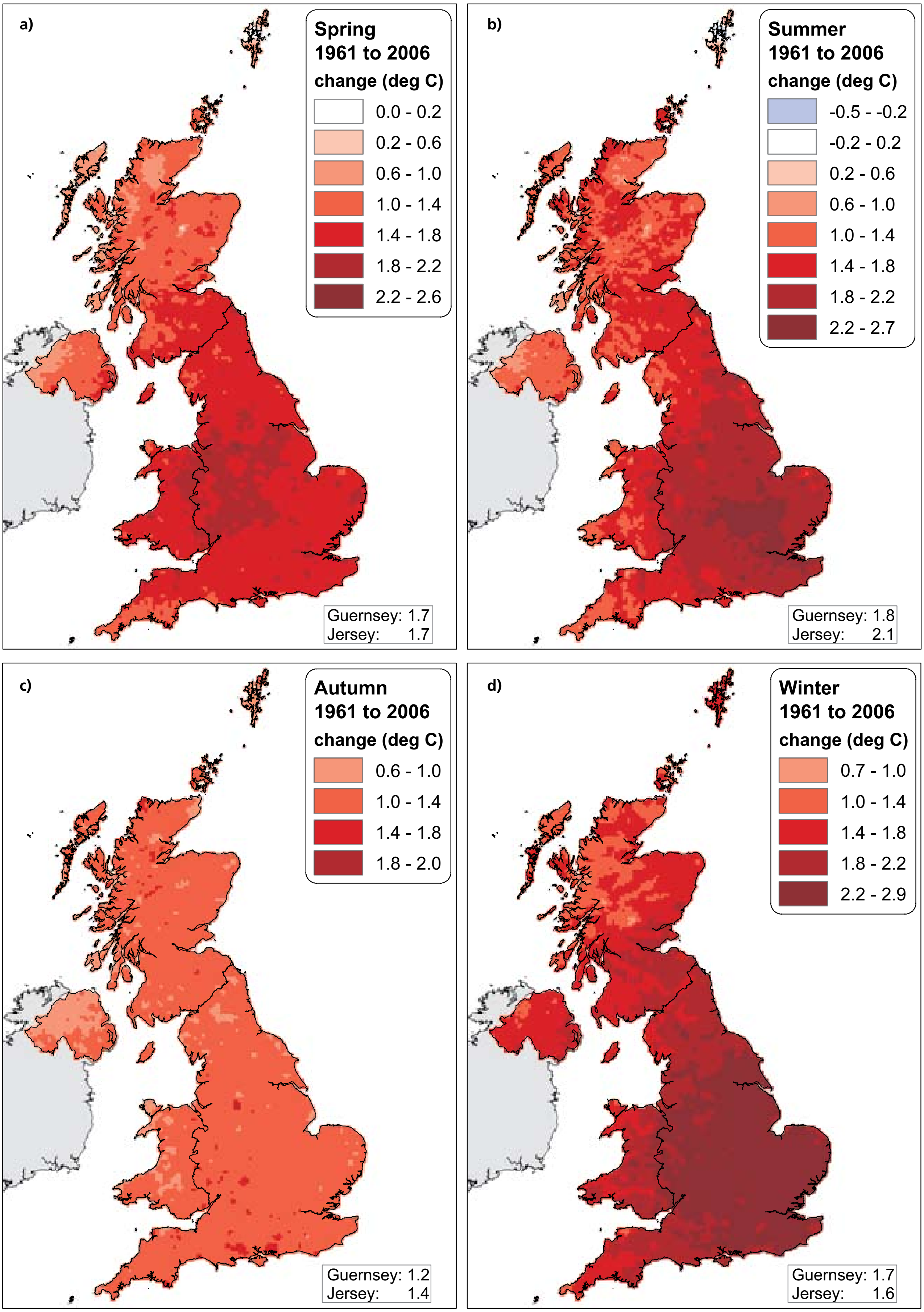


Figure 2.18: Change in average daily maximum temperature (°C) from 1961 to 2006 based on a linear trend for a) spring, b) summer, c) autumn, d) winter

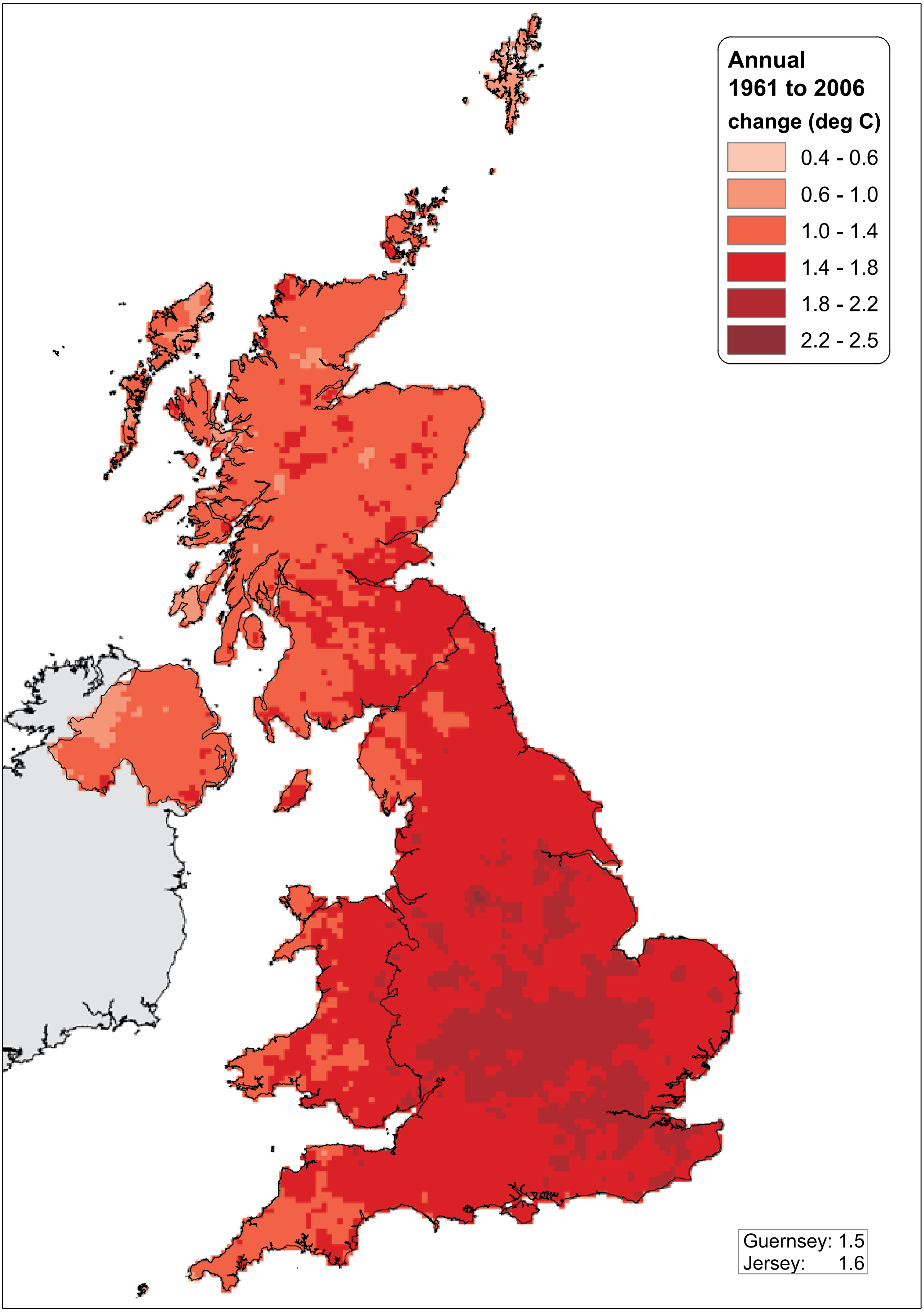
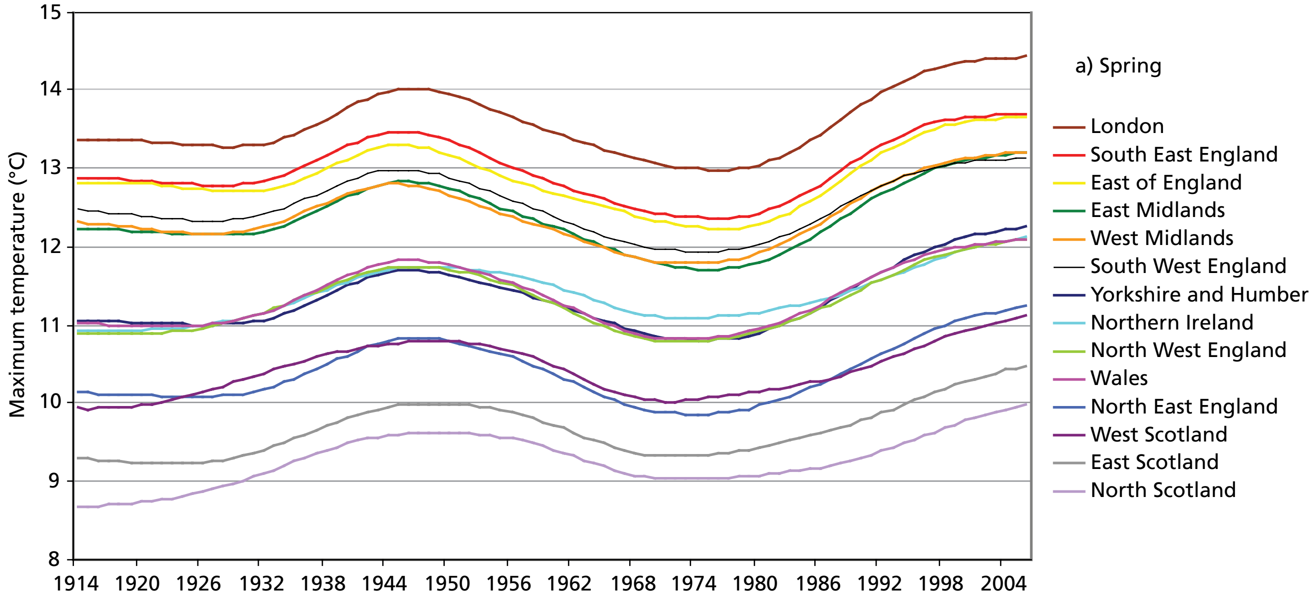
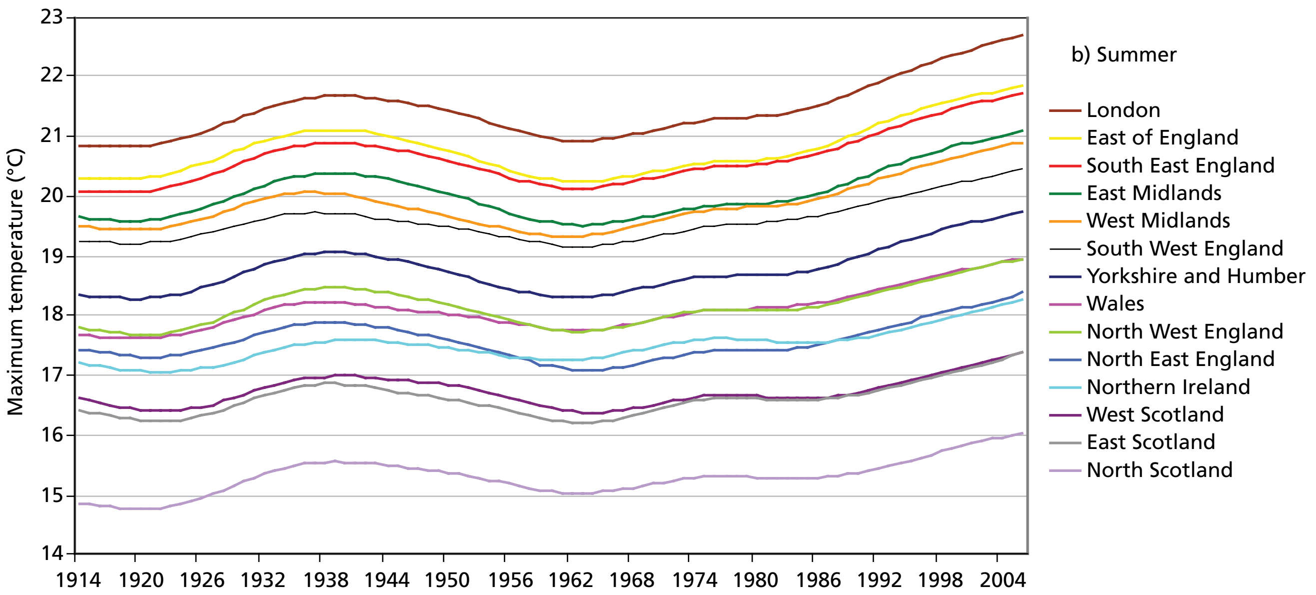
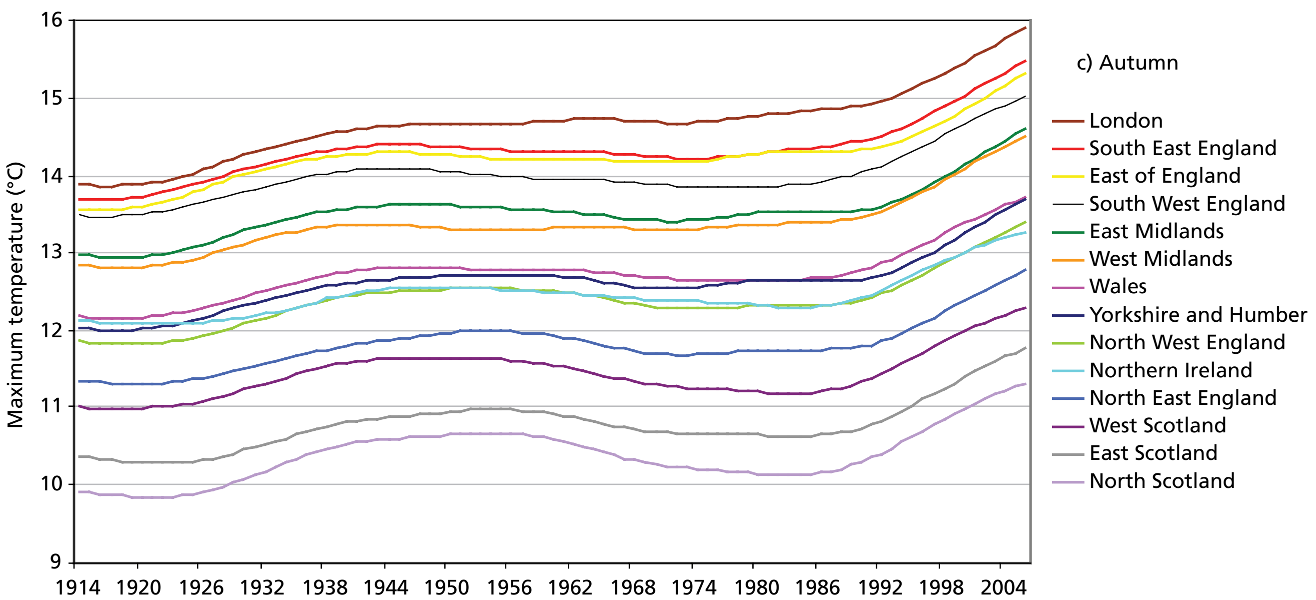


Figure 2.19: Change in annual average daily maximum temperature (°C) between 1961 and 2006 based on a linear trend


a) Spring
Maximum temperature (°C)
15
14
13
12
11
10
9
8
1914 1920 1926 1932 1938 1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
London
South East England
East of England
East Midlands
West Midlands
South West England
Yorkshire and Humber
Northern Ireland
North West England
Wales
North East England
West Scotland
East Scotland
North Scotland


b) Summer
Maximum temperature (°C)
23
22
21
20
19
18
17
16
15
14
1914 1920 1926 1932 1938 1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
London
East of England
South East England
East Midlands
West Midlands
South West England
Yorkshire and Humber
Wales
North West England
North East England
Northern Ireland
West Scotland
East Scotland
North Scotland


c) Autumn
Maximum temperature (°C)
16
15
14
13
12
11
10
9
1914 1920 1926 1932 1938 1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
London
South East England
East of England
South West England
East Midlands
West Midlands
Wales
Yorkshire and Humber
North West England
Northern Ireland
North East England
West Scotland
East Scotland
North Scotland

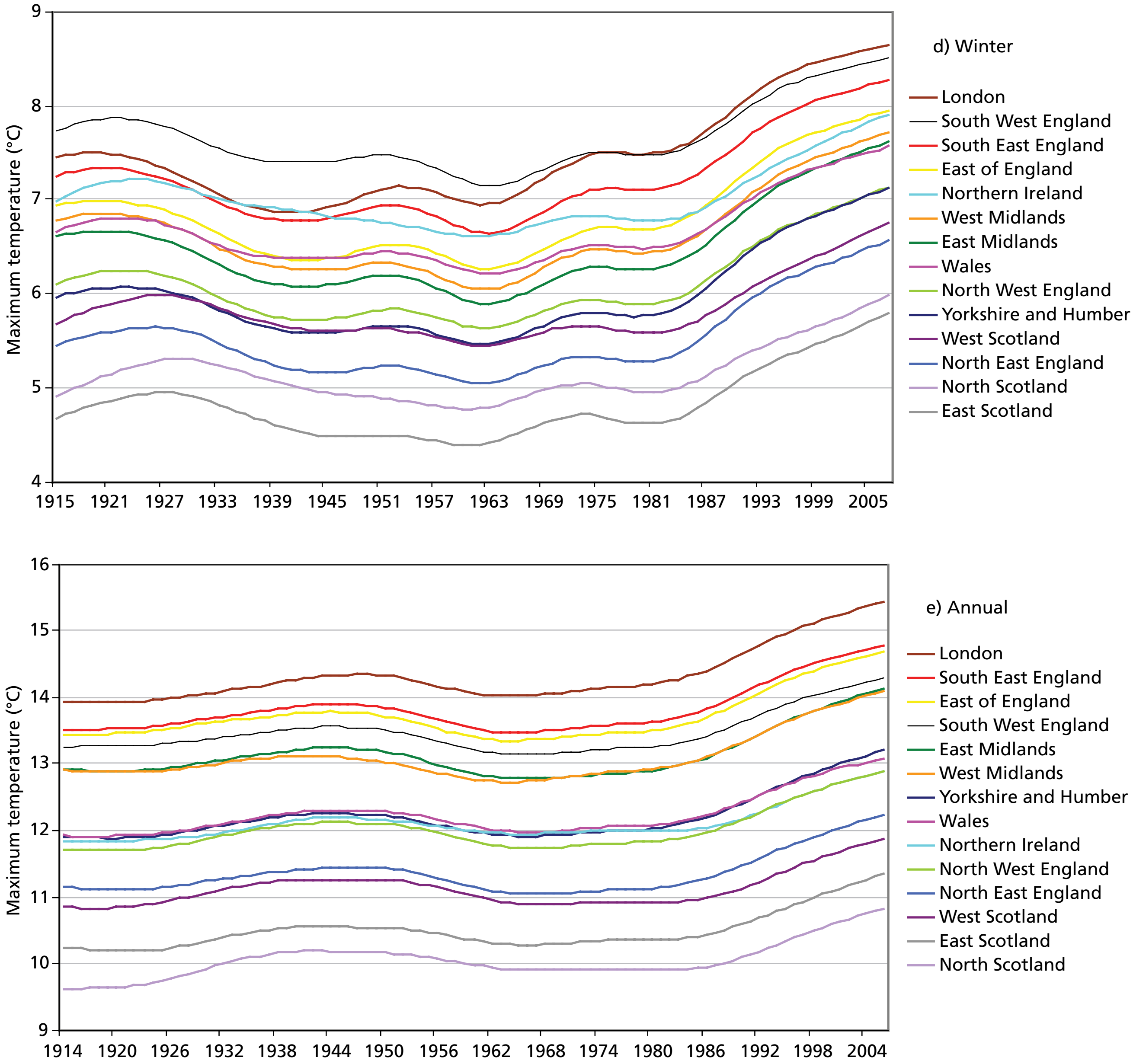


Figure 2.20: Filtered daily maximum temperature (°C) by area, 1914-2006 for a) spring, b) summer, c) autumn, d) winter, e) annual

Area	Spring	Summer	Autumn	Winter	Annual
South West England	0.21	0.80	**0.89**	0.58	**0.59**
South East England	0.31	**1.03**	**1.12**	0.94	**0.81**
London	0.58	**1.17**	**1.50**	**1.32**	**1.11**
Wales	0.56	**0.92**	**0.99**	0.68	**0.76**
East of England	0.33	**0.87**	**1.10**	0.93	**0.76**
West Midlands	0.44	0.94	**1.09**	0.77	**0.77**
East Midlands	0.41	0.81	**0.98**	0.83	**0.71**
Northern Ireland	**0.68**	**0.82**	**0.72**	0.48	**0.65**
Yorkshire and Humberside	0.68	0.85	**1.07**	0.93	**0.84**
North West England	**0.59**	0.67	**0.95**	0.77	**0.71**
North East England	**0.53**	0.44	**0.88**	0.79	**0.62**
West Scotland	0.49	0.36	**0.63**	0.57	**0.48**
East Scotland	**0.71**	0.57	**0.85**	0.73	**0.68**
North Scotland	**0.67**	**0.70**	**0.76**	0.57	**0.65**

Table 2.4: Change in daily maximum temperature (°C) from 1914 to 2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Area	Spring	Summer	Autumn	Winter	Annual
South West England	**1.55**	**1.65**	**1.26**	**1.89**	**1.54**
South East England	**1.67**	**2.03**	**1.32**	**2.17**	**1.75**
London	**1.78**	**2.23**	**1.31**	**2.22**	**1.84**
Wales	**1.66**	**1.59**	**1.12**	**1.84**	**1.52**
East of England	**1.70**	**2.09**	**1.18**	**2.24**	**1.76**
West Midlands	**1.83**	**2.01**	**1.26**	**2.16**	**1.77**
East Midlands	**1.79**	**2.10**	**1.20**	**2.24**	**1.79**
Northern Ireland	**1.16**	**1.20**	**1.01**	**1.59**	**1.20**
Yorkshire and Humberside	**1.72**	**1.88**	**1.14**	**2.13**	**1.68**
North West England	**1.67**	**1.63**	**1.13**	**1.93**	**1.55**
North East England	**1.63**	**1.72**	**1.11**	**1.92**	**1.55**
West Scotland	**1.31**	**1.37**	**1.11**	**1.57**	**1.30**
East Scotland	**1.34**	**1.47**	**1.17**	**1.62**	**1.36**
North Scotland	**1.06**	**1.30**	**1.17**	**1.33**	**1.18**

Table 2.5: Change in daily maximum temperature (°C) from 1961 to 2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Minimum Temperature

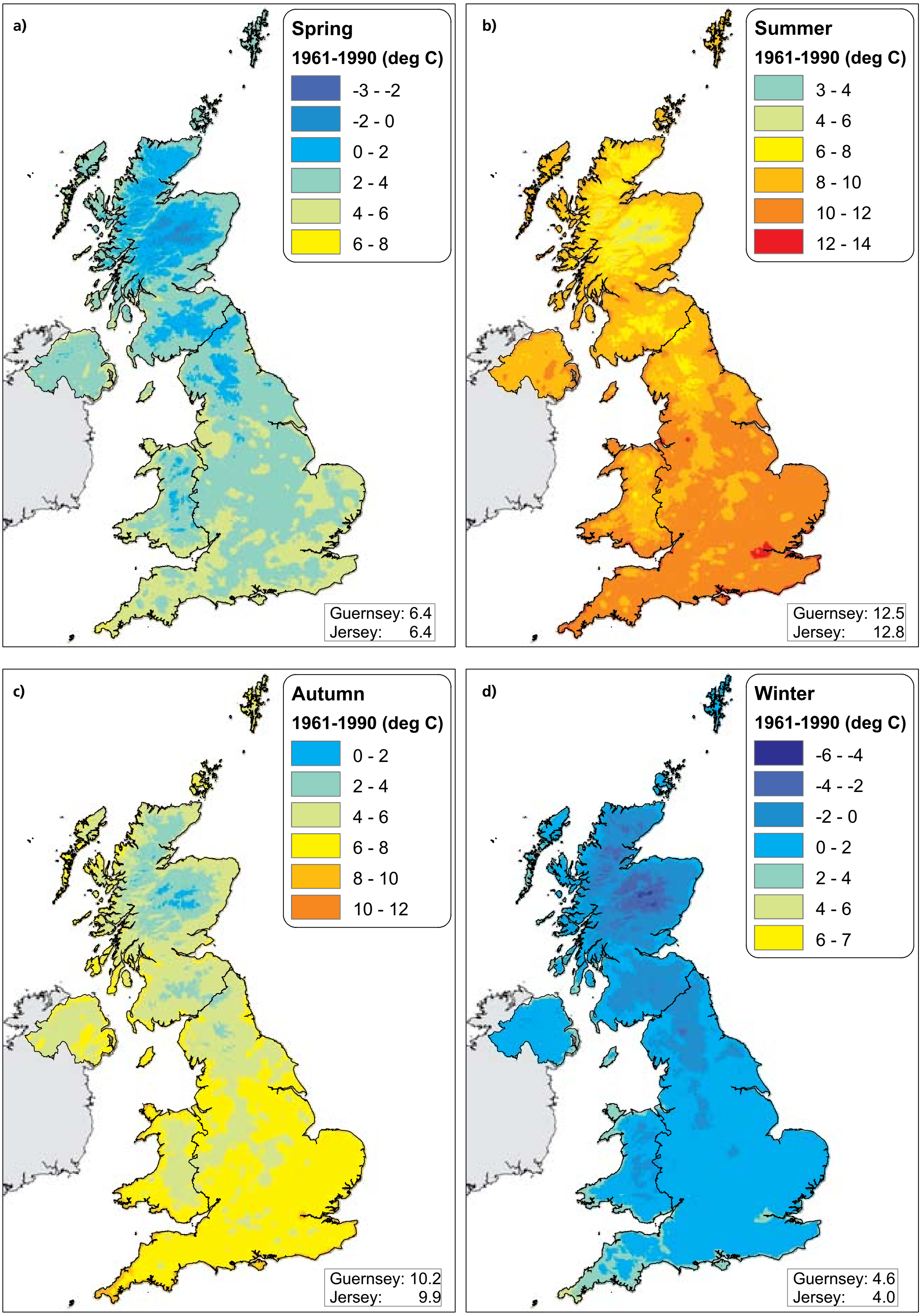


Figure 2.21: 1961-1990 average daily minimum temperature (°C) for a) spring, b) summer, c) autumn and d) winter

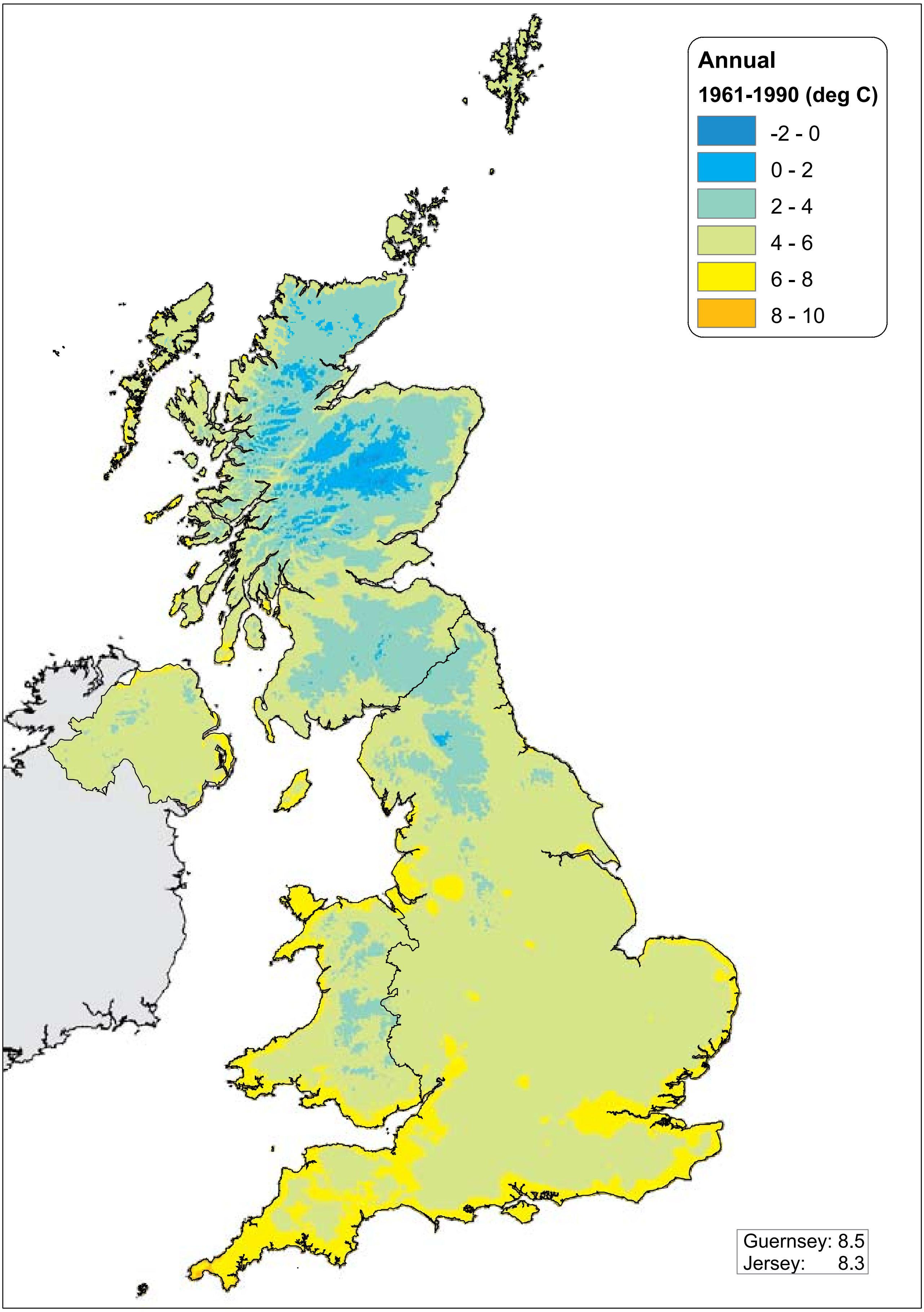


Figure 2.22: Annual average daily minimum temperature (°C) for 1961-1990

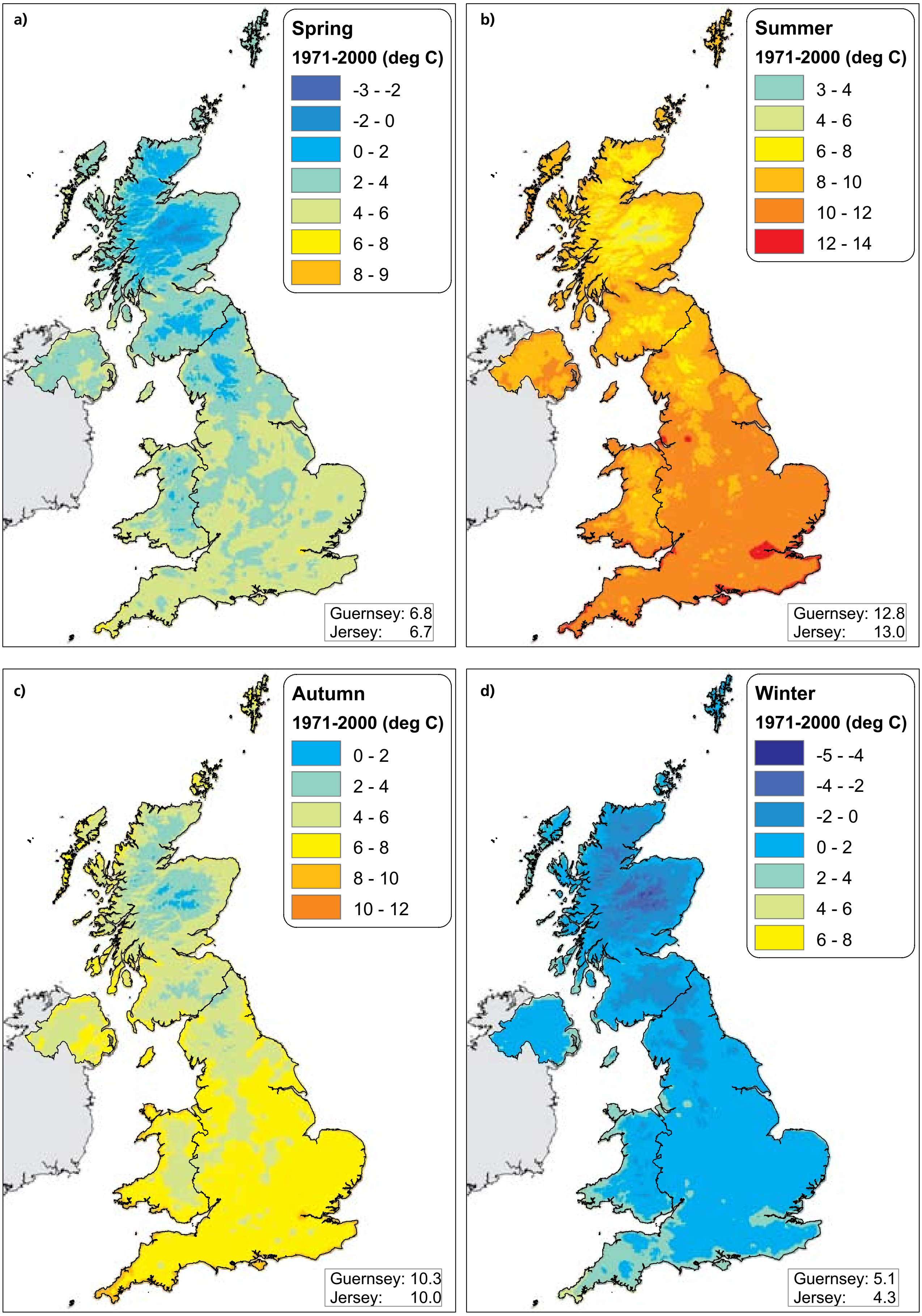


Figure 2.23: 1971-2000 average daily minimum temperature (°C) for a) spring, b) summer, c) autumn and d) winter

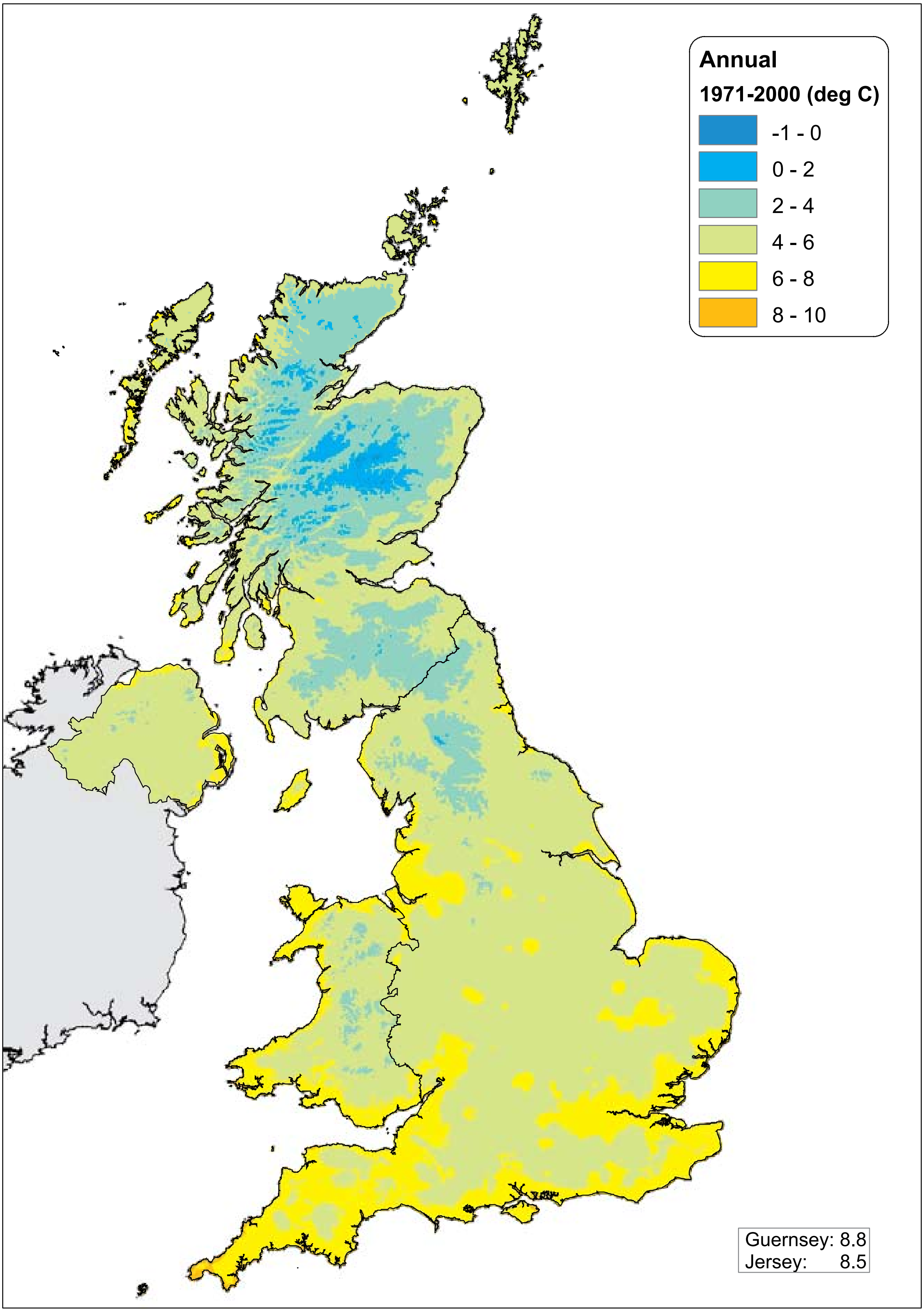


Figure 2.24: Annual average daily minimum temperature (°C) for 1971-2000

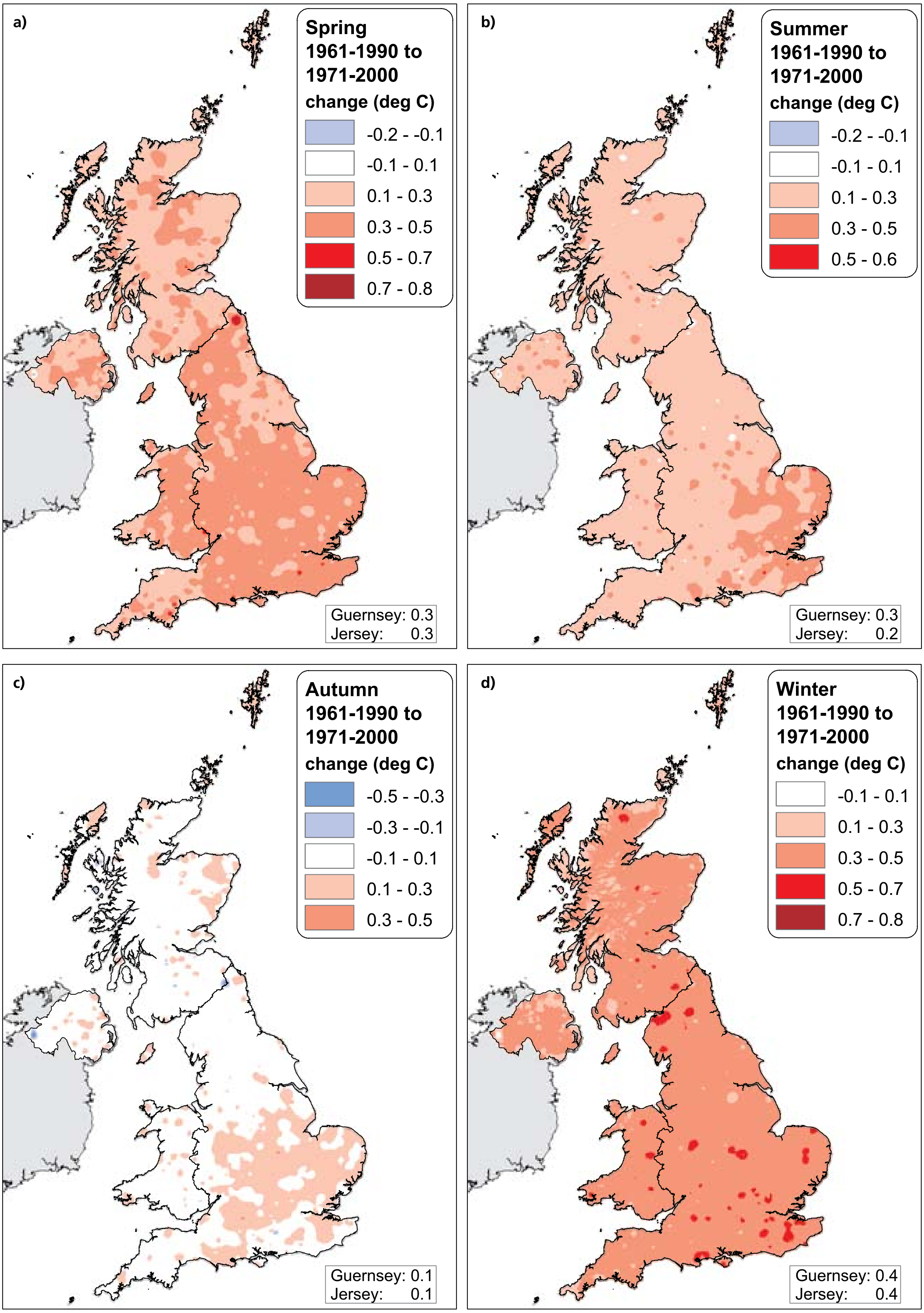


Figure 2.25: Change in daily average daily minimum temperature (°C) from 1961-1990 to 1971-2000 for a) spring, b) summer, c) autumn, d) winter

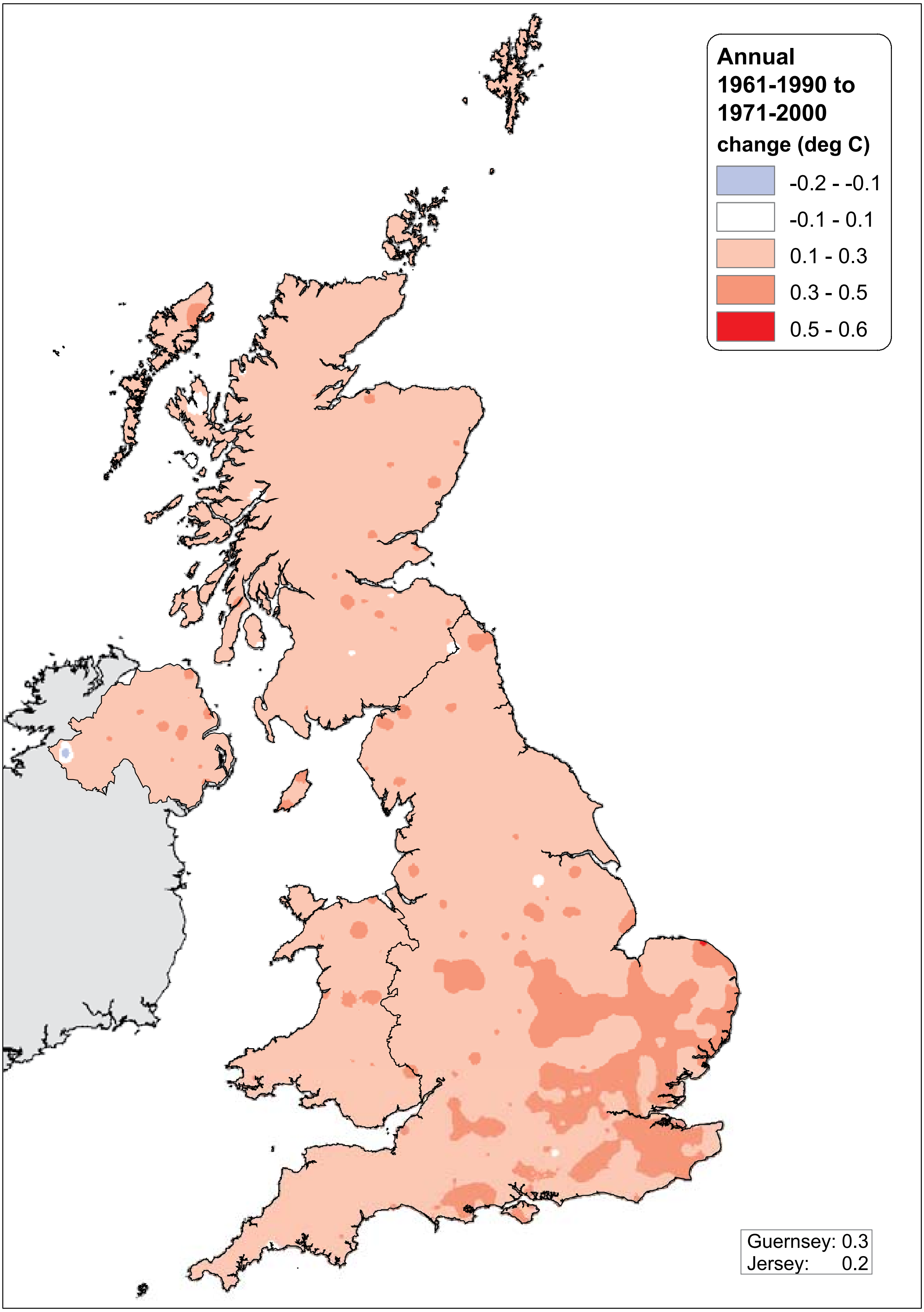


Figure 2.26: Change in annual average daily minimum temperature (°C) between 1961-1990 and 1971-2000

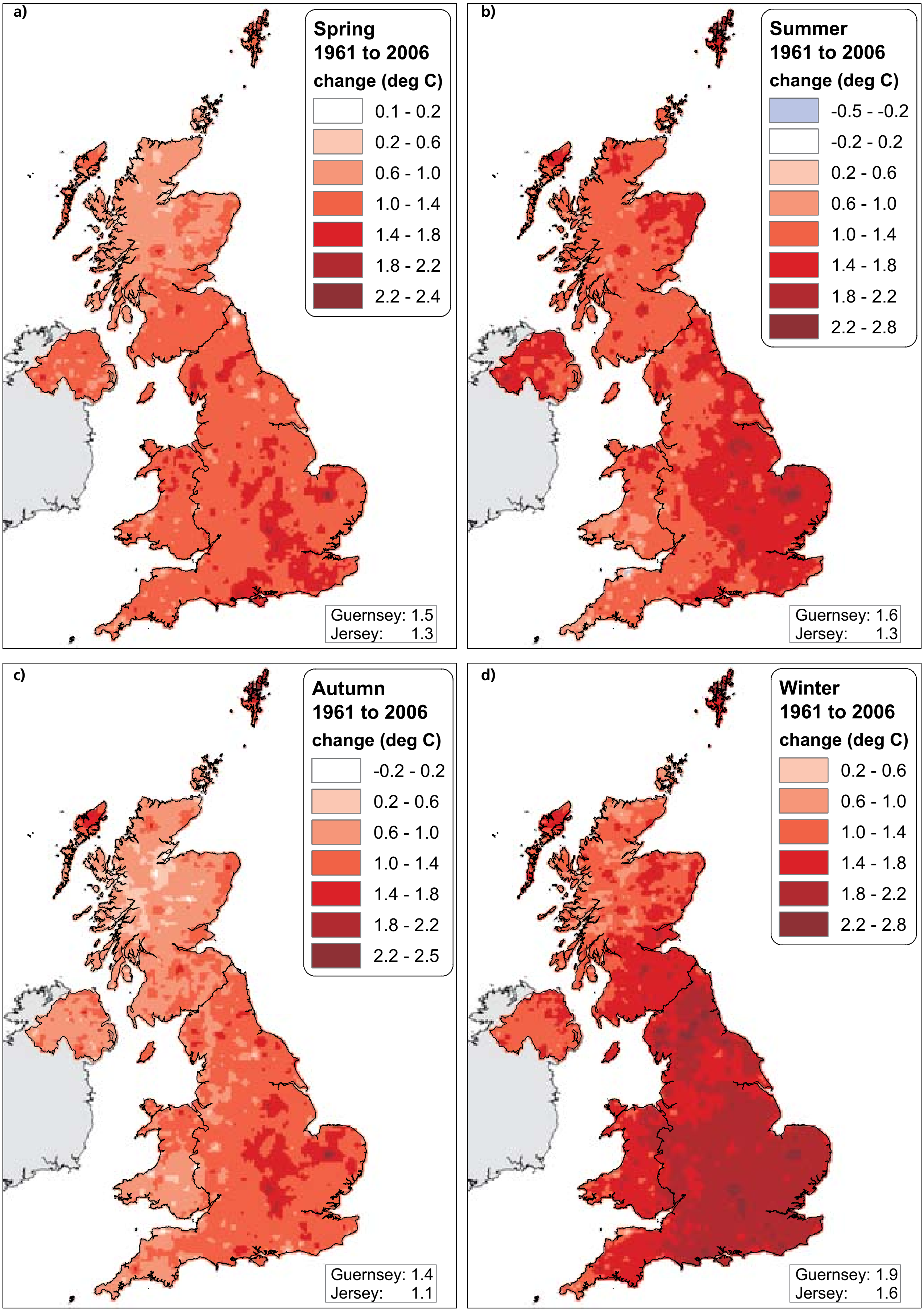


Figure 2.27: Change in average daily minimum temperature (°C) from 1961-2006 based on a linear trend for a) spring, b) summer, c) autumn, d) winter

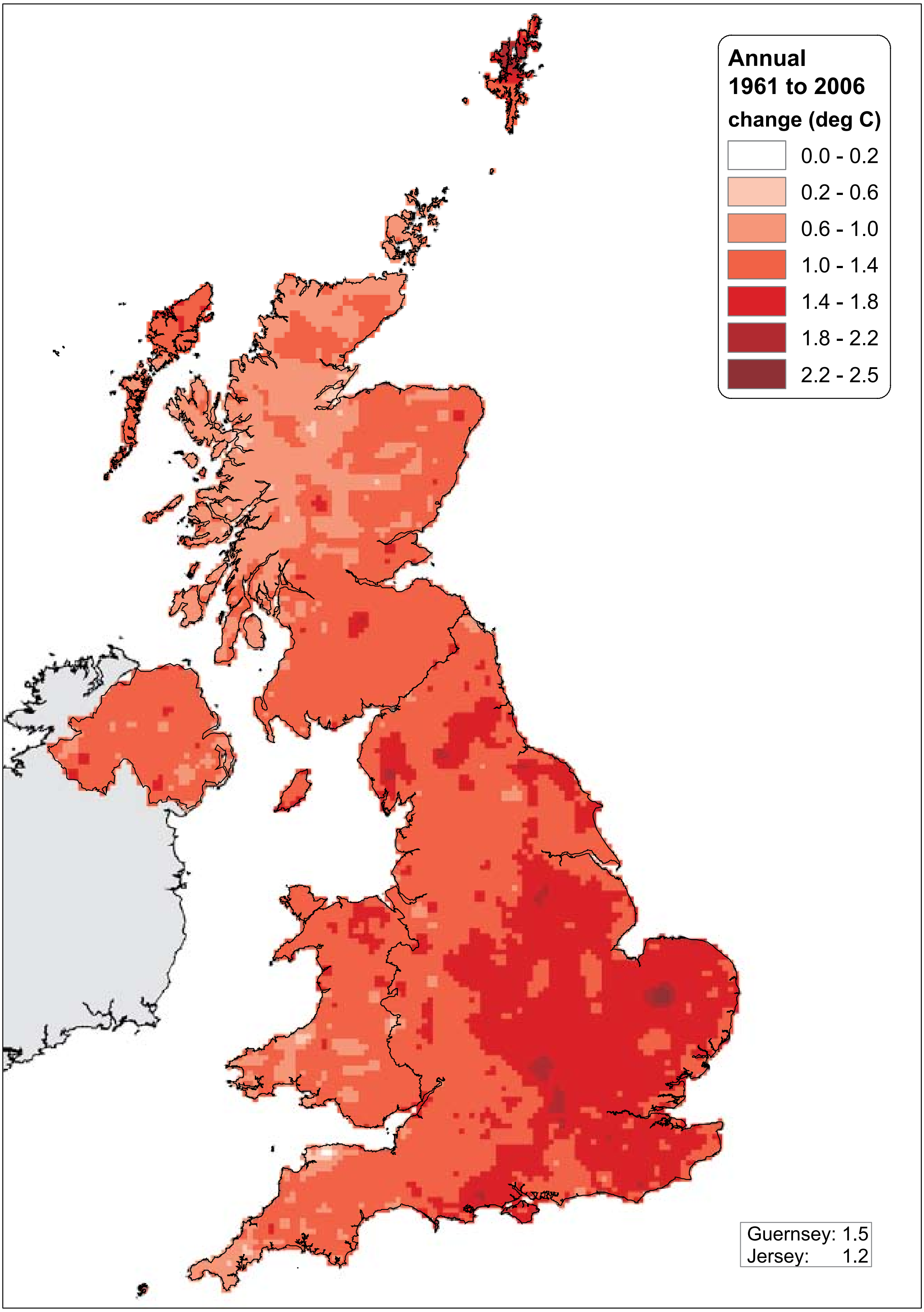
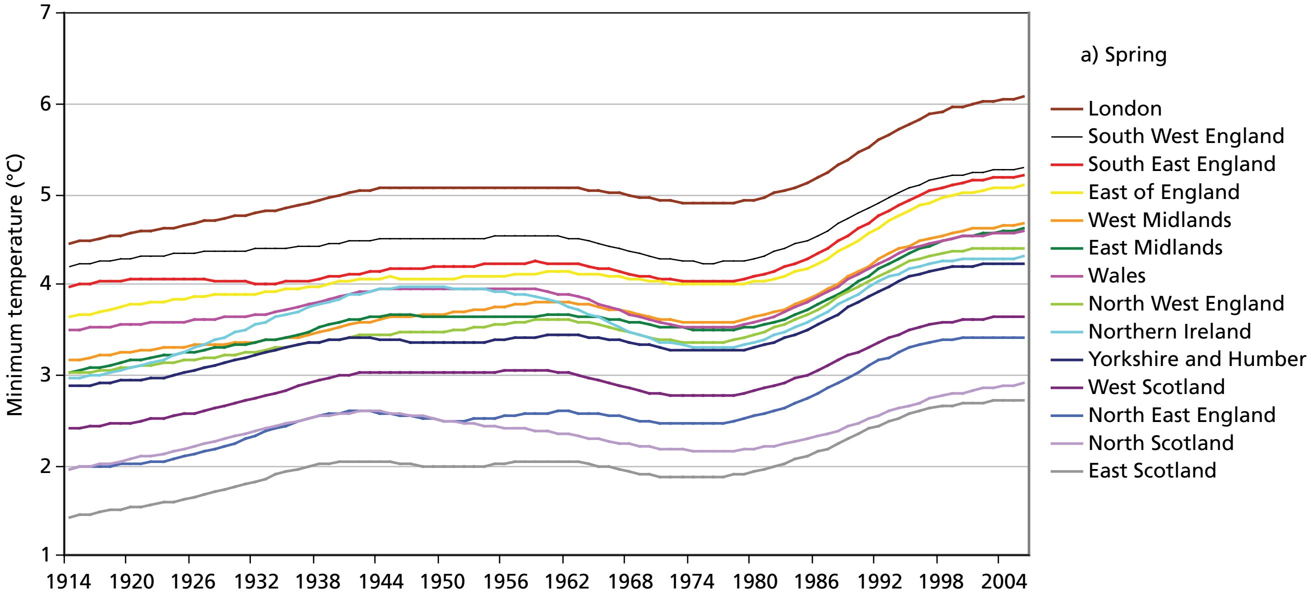
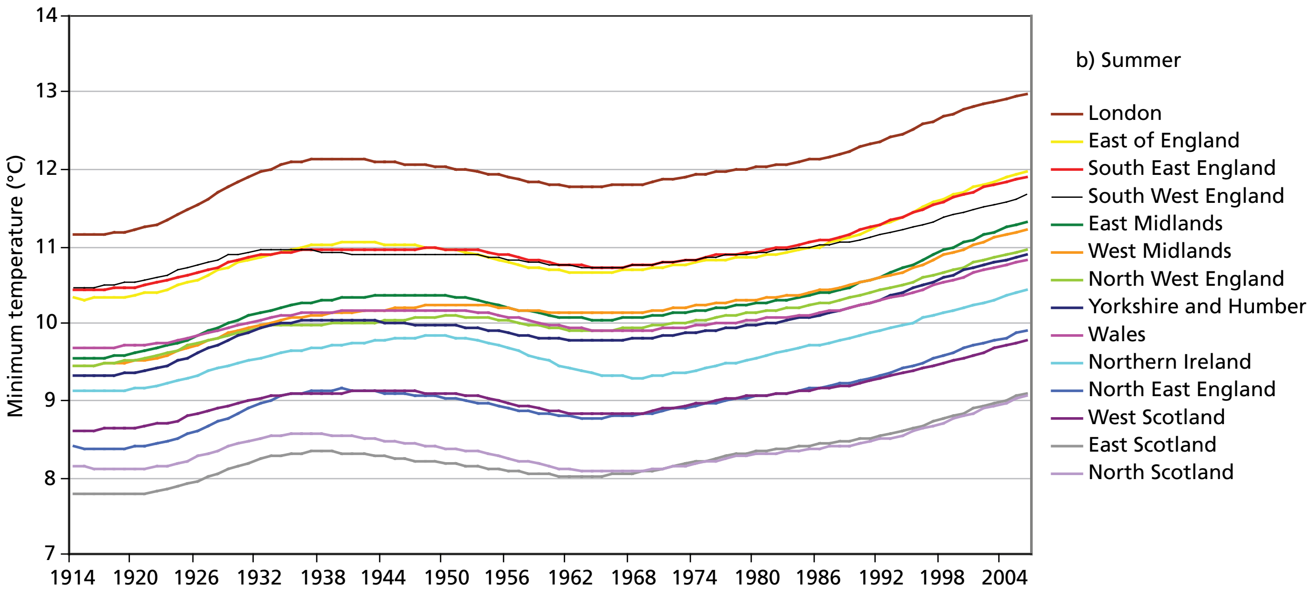


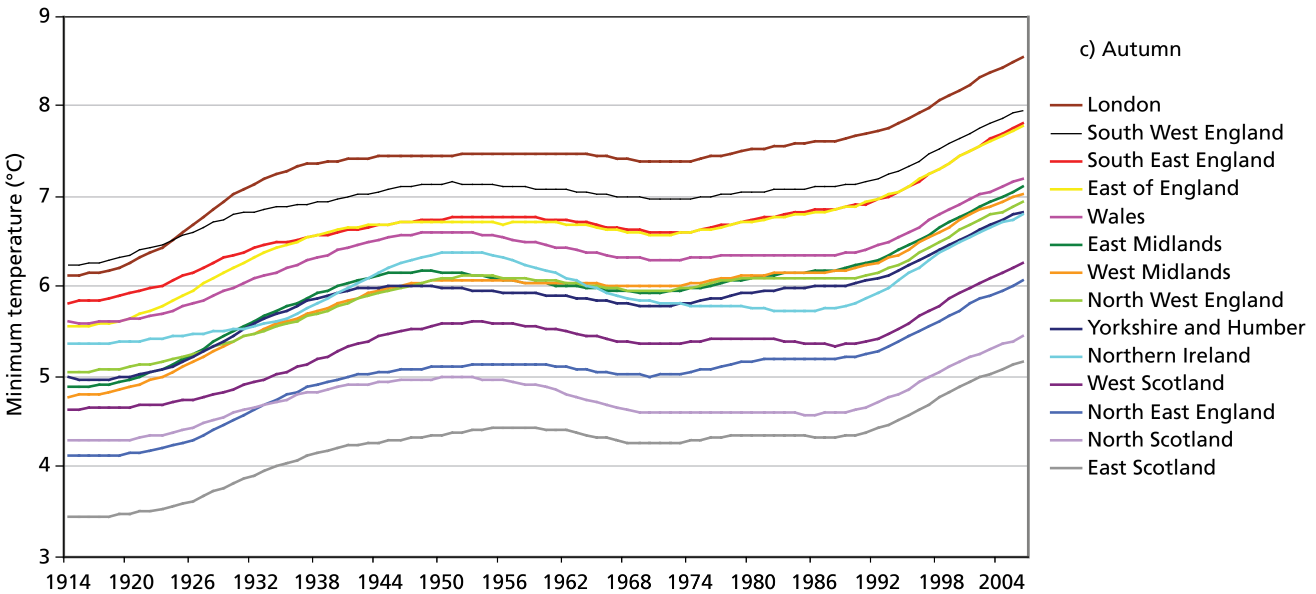
Figure 2.28: Change in annual average daily minimum temperature (°C) between 1961 and 2006 based on a linear trend



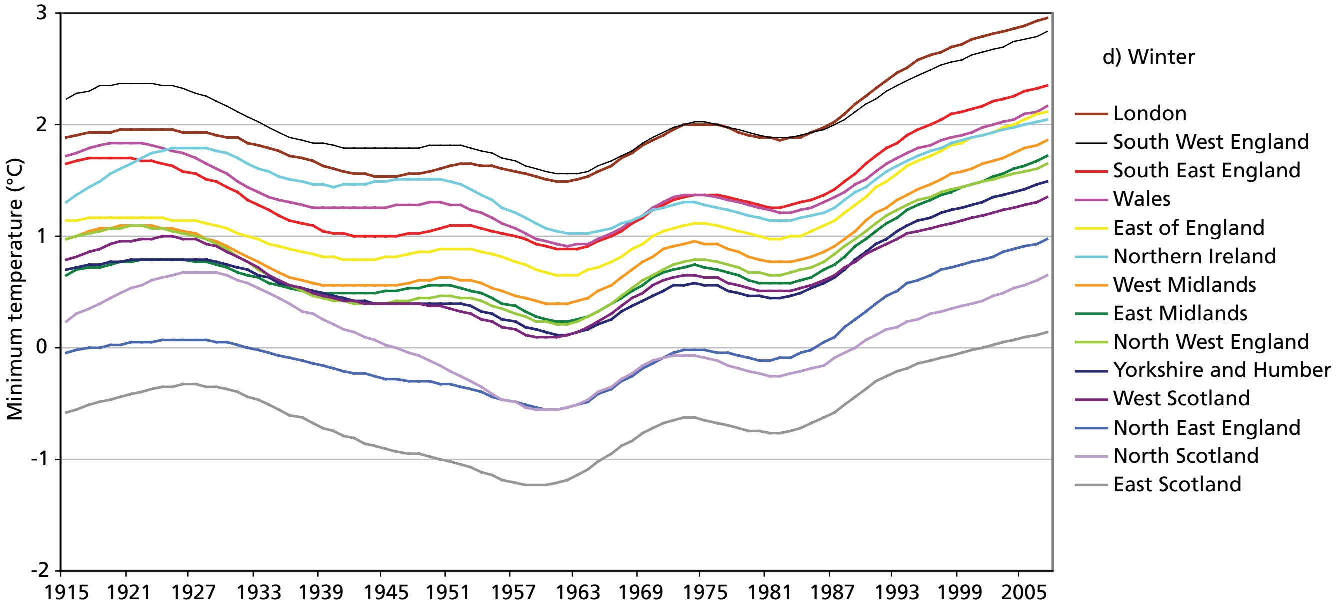
Minimum temperature (°C)
7
6
5
4
3
2
1
1914 1920 1926 1932 1938 1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
a) Spring
London
South West England
South East England
East of England
West Midlands
East Midlands
Wales
North West England
Northern Ireland
Yorkshire and Humber
West Scotland
North East England
North Scotland
East Scotland



Minimum temperature (°C)
14
13
12
11
10
9
8
7
1914 1920 1926 1932 1938 1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
b) Summer
London
East of England
South East England
South West England
East Midlands
West Midlands
North West England
Yorkshire and Humber
Wales
Northern Ireland
North East England
West Scotland
East Scotland
North Scotland



Minimum temperature (°C)
9
8
7
6
5
4
3
1914 1920 1926 1932 1938 1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
c) Autumn
London
South West England
South East England
East of England
Wales
East Midlands
West Midlands
North West England
Yorkshire and Humber
Northern Ireland
West Scotland
North East England
North Scotland
East Scotland



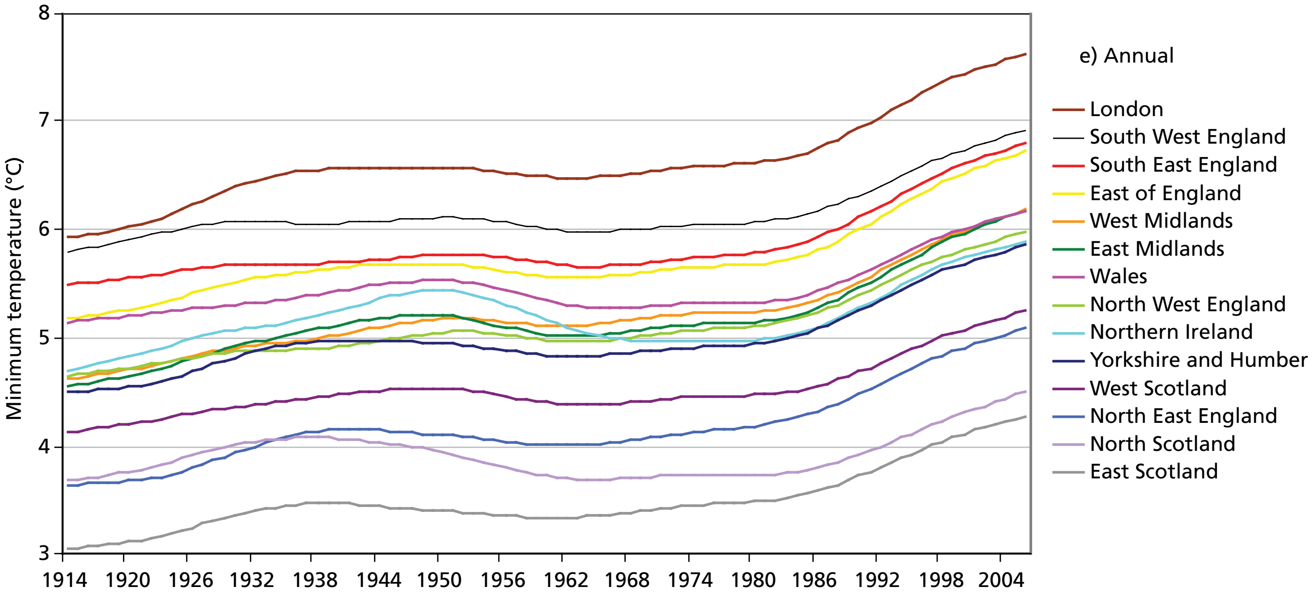


Figure 2.29: Filtered daily minimum temperature (°C) by area, 1914-2006 for a) spring, b) summer, c) autumn, d) winter, e) annual

Area	Spring	Summer	Autumn	Winter	Annual
South West England	**0.75**	**0.75**	1.13	0.39	**0.72**
South East England	**0.98**	**0.99**	1.39	0.63	**0.97**
London	**1.25**	**1.23**	1.70	**0.94**	**1.25**
Wales	**0.75**	**0.70**	1.04	0.24	**0.65**
East of England	**1.12**	**1.05**	1.60	0.81	**1.11**
West Midlands	**1.29**	**1.34**	1.75	0.73	**1.25**
East Midlands	**1.24**	**1.19**	1.61	0.79	**1.17**
Northern Ireland	**0.79**	**0.80**	0.83	0.15	**0.63**
Yorkshire and Humberside	**1.10**	**1.07**	1.32	0.55	**0.98**
North West England	**1.19**	**1.10**	1.47	0.60	**1.06**
North East England	**1.25**	**1.03**	1.49	**0.81**	**1.11**
West Scotland	**0.94**	**0.73**	1.16	0.35	**0.77**
East Scotland	**1.00**	**0.90**	1.28	0.48	**0.88**
North Scotland	0.45	0.41	0.54	-0.20	0.28

Table 2.6: Change in daily minimum temperature (°C) from 1914-2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Area	Spring	Summer	Autumn	Winter	Annual
South West England	**1.23**	**1.18**	**1.07**	**1.58**	**1.21**
South East England	**1.45**	**1.52**	**1.33**	**1.85**	**1.50**
London	**1.43**	**1.57**	**1.28**	**1.80**	**1.48**
Wales	**1.23**	**1.18**	**0.95**	**1.56**	**1.19**
East of England	**1.34**	**1.65**	**1.36**	**1.81**	**1.51**
West Midlands	**1.31**	**1.38**	**1.15**	**1.74**	**1.36**
East Midlands	**1.35**	**1.62**	**1.35**	**1.79**	**1.49**
Northern Ireland	**1.14**	**1.50**	**0.98**	**1.32**	**1.20**
Yorkshire and Humberside	**1.17**	**1.43**	**1.16**	**1.67**	**1.33**
North West England	**1.25**	**1.31**	**1.03**	**1.70**	**1.29**
North East England	**1.19**	**1.42**	**1.13**	**1.78**	**1.35**
West Scotland	**1.02**	**1.23**	**0.86**	**1.34**	**1.07**
East Scotland	**1.03**	**1.33**	**0.91**	**1.41**	**1.13**
North Scotland	**0.82**	**1.25**	**0.82**	**1.17**	**0.97**

Table 2.7: Change in daily minimum temperature (°C) from 1961-2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Days of air frost

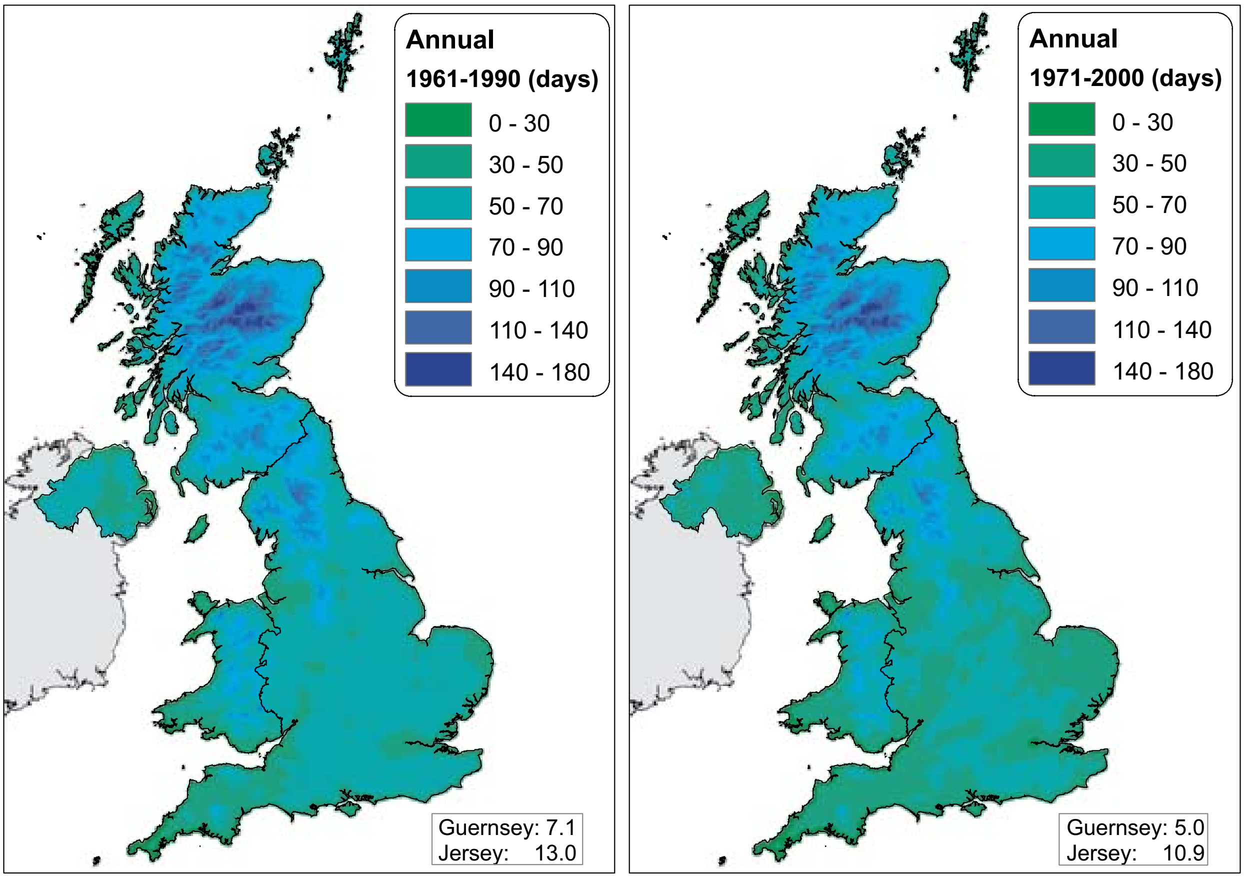


Figure 2.30: Annual average days of air frost for a) 1961-1990, b) 1971-2000

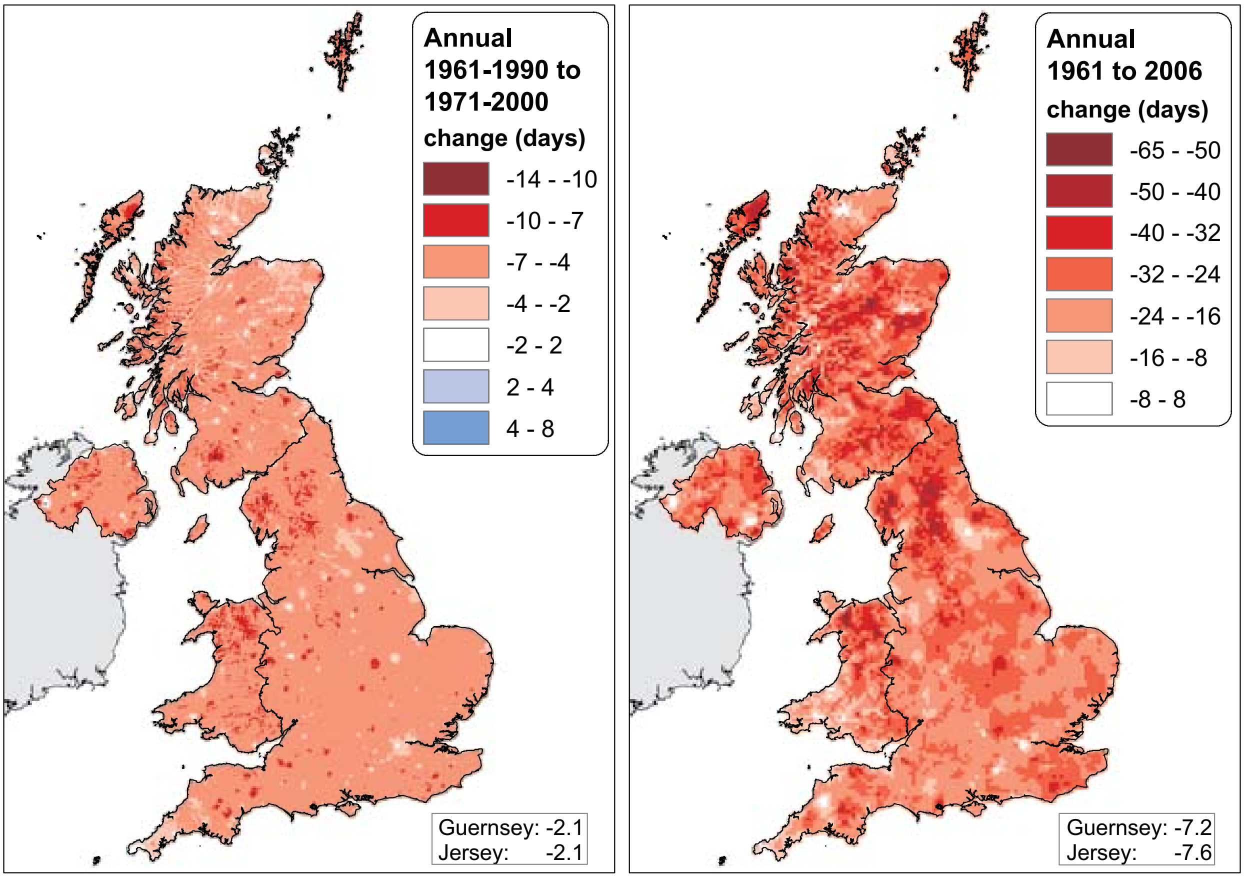


Figure 2.31: Change in annual days of air frost; a) between 1961-1990 and 1971-2000, b) between 1961 and 2006 based on a linear trend

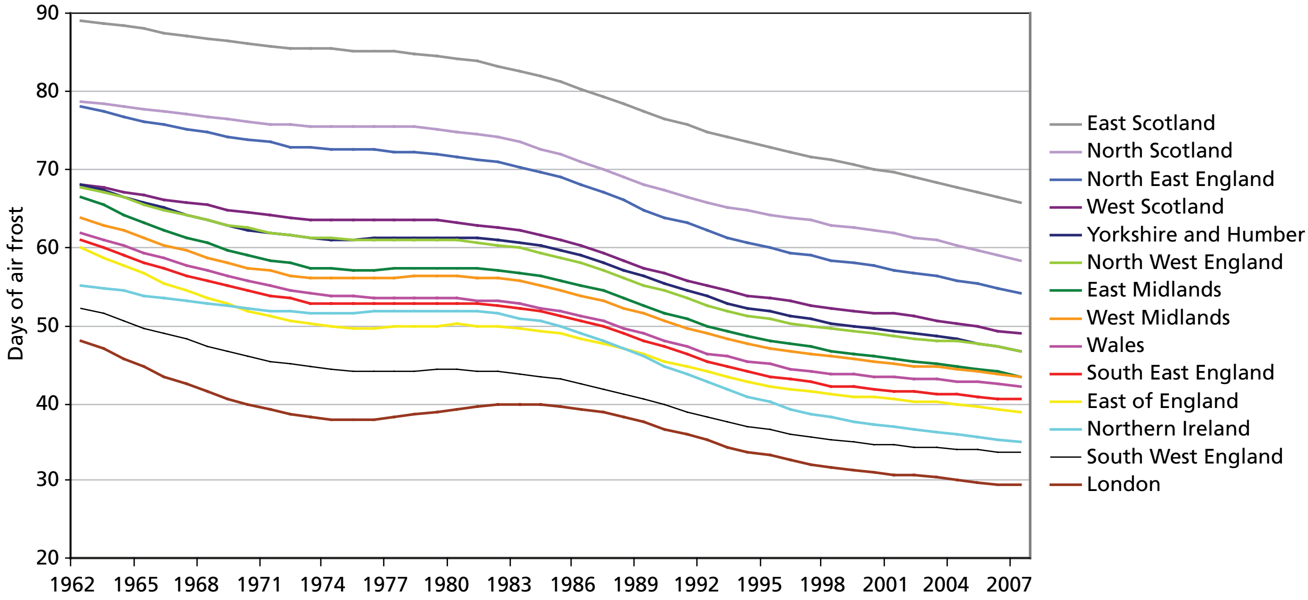


Figure 2.32: Filtered annual days of air frost by area, 1961/62 – 2006/07

Area	Spring	Summer	Autumn	Winter	Annual
South West England	**-5.1**	**-0.04**	-1.7	**-12.9**	**-20.9**
South East England	**-5.1**	**-0.1**	-2.1	**-14.8**	**-23.4**
London	-3.6	**-0.1**	-0.5	**-13.5**	**-18.7**
Wales	**-6.0**	**-0.2**	-2.0	-12.6	**-22.4**
East of England	-4.0	**-0.1**	-2.3	**-14.7**	**-22.6**
West Midlands	**-5.7**	**-0.1**	-2.2	-13.4	**-23.2**
East Midlands	-5.2	-0.1	**-3.1**	**-15.0**	**-25.3**
Northern Ireland	**-5.9**	-0.1	**-3.7**	**-13.6**	**-24.8**
Yorkshire and Humberside	-4.3	**-0.1**	**-3.3**	**-14.2**	**-24.1**
North West England	**-5.9**	**-0.1**	**-3.2**	**-13.1**	**-24.4**
North East England	-5.3	**-0.2**	**-5.0**	**-15.2**	**-28.2**
West Scotland	-4.8	**-0.1**	**-4.1**	**-11.7**	**-22.8**
East Scotland	**-6.5**	-0.2	**-5.5**	**-12.9**	**-27.6**
North Scotland	-6.4	-0.1	**-4.9**	**-11.5**	**-24.6**

Table 2.8: Change in days of air frost from 1961-2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Heating Degree Days *(See Annex 2 for a definition)*

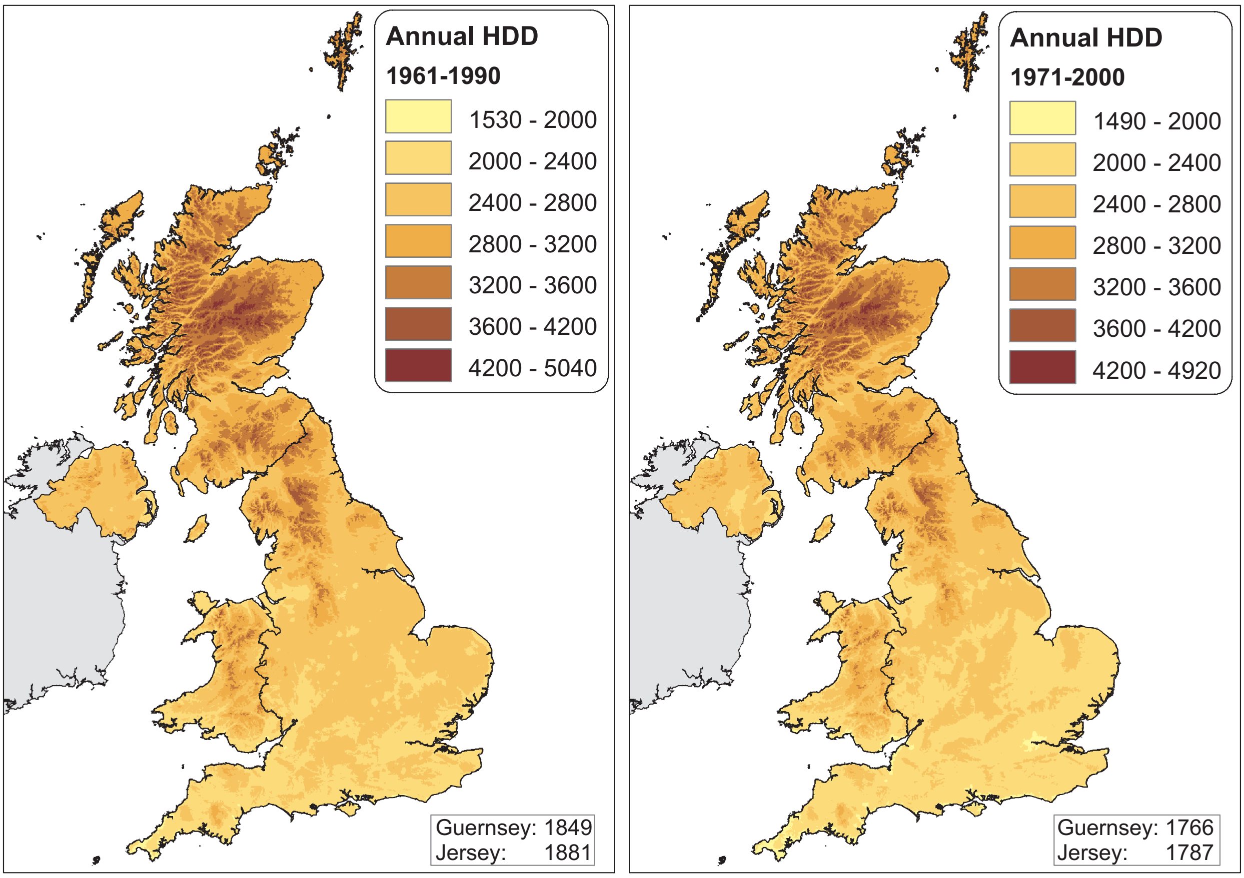


Figure 2.33: Average annual heating degree days (HDD) for a) 1961-1990, b) 1971-2000

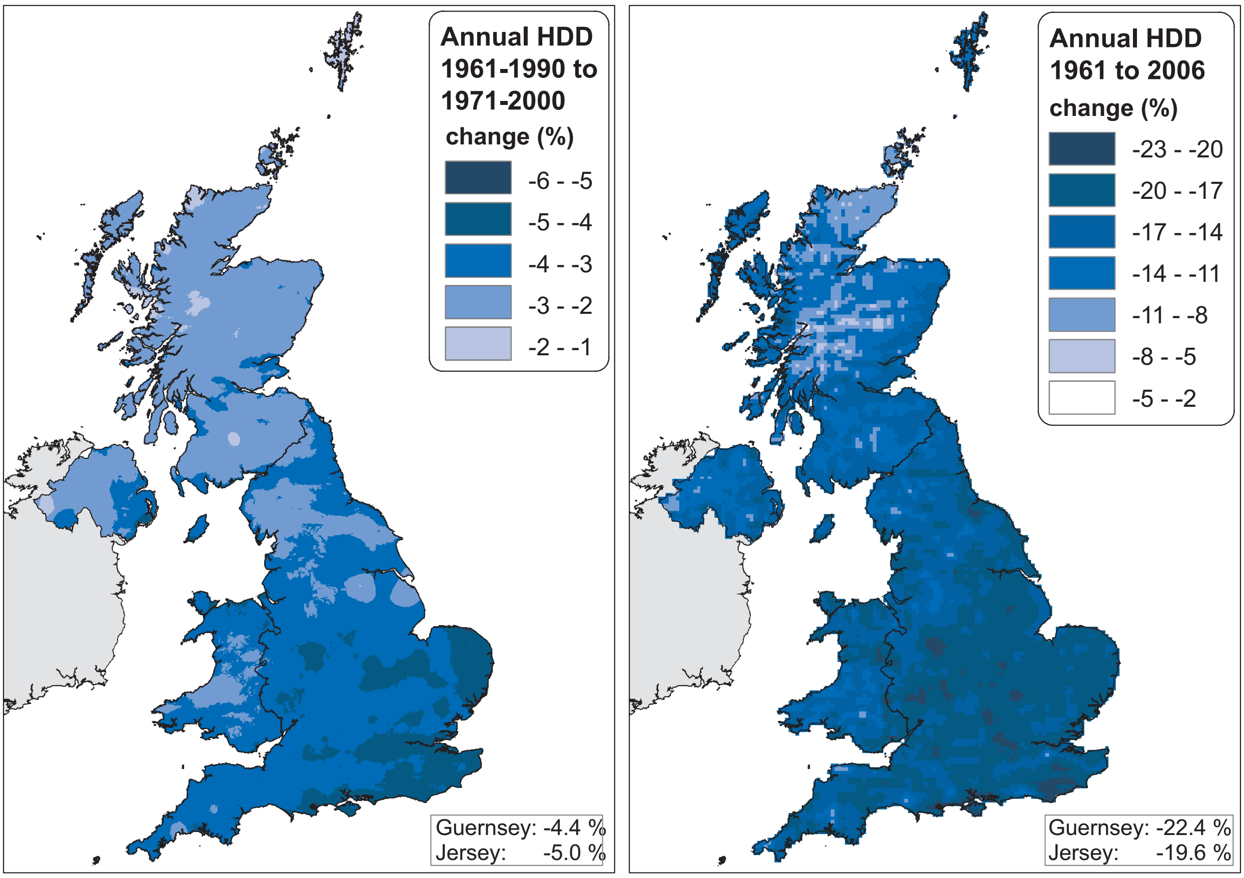


Figure 2.34: Percentage change in annual heating degree days (HDD) a) between 1961-1990 and 1971-2000; b) from 1961 to 2006 based on a linear trend

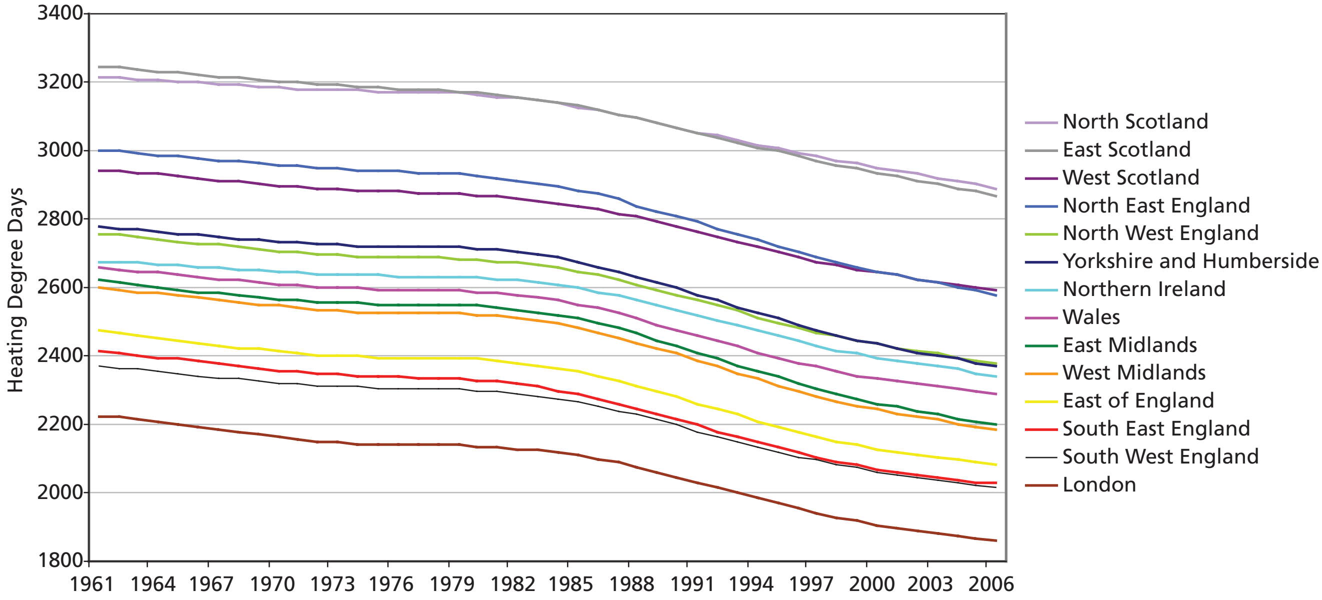


Figure 2.35: Filtered annual heating degree days by area, 1961–2006. See Annex 2 for a definition of HDD.

Cooling Degree Days *(See Annex 2 for a definition)*

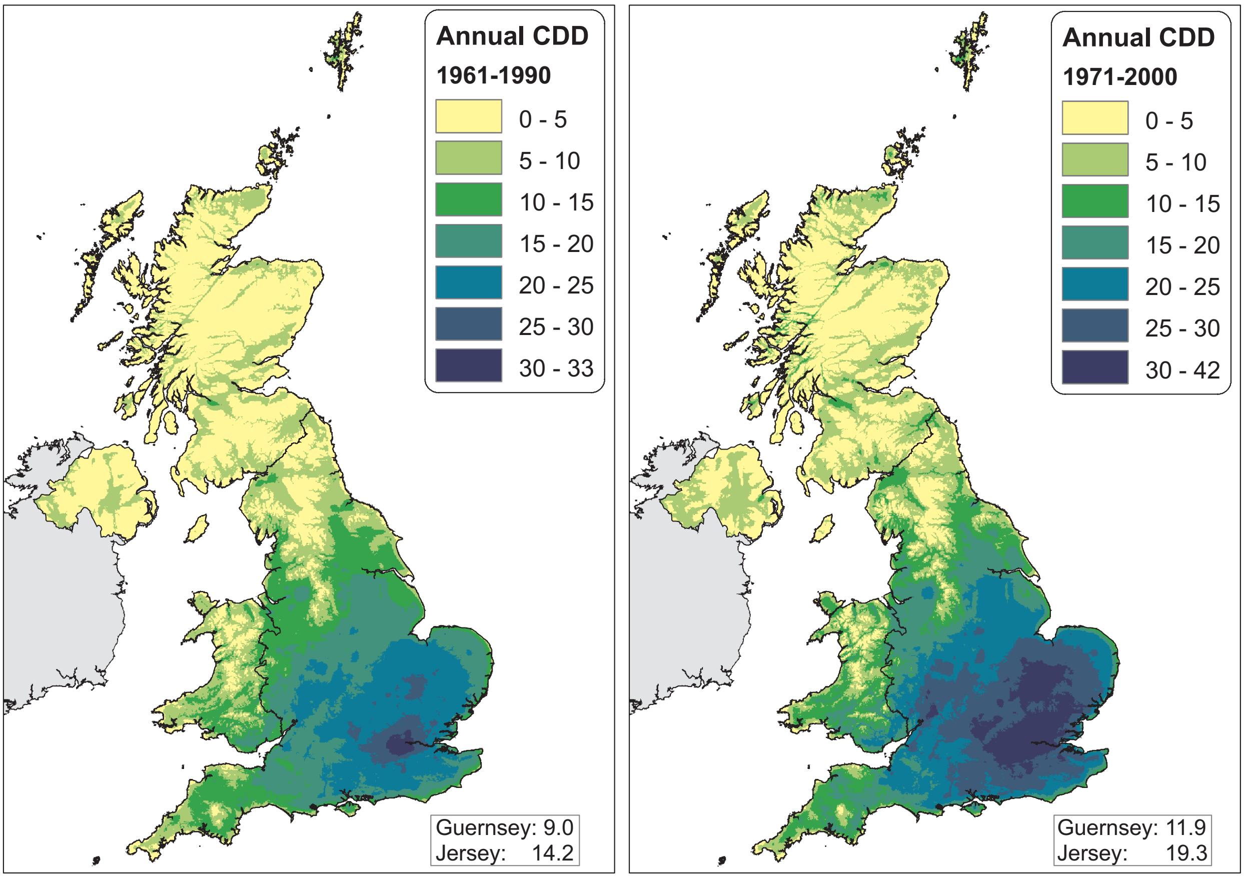


Figure 2.36: Average annual cooling degree days (CDD) for a) 1961-1990, b) 1971-2000

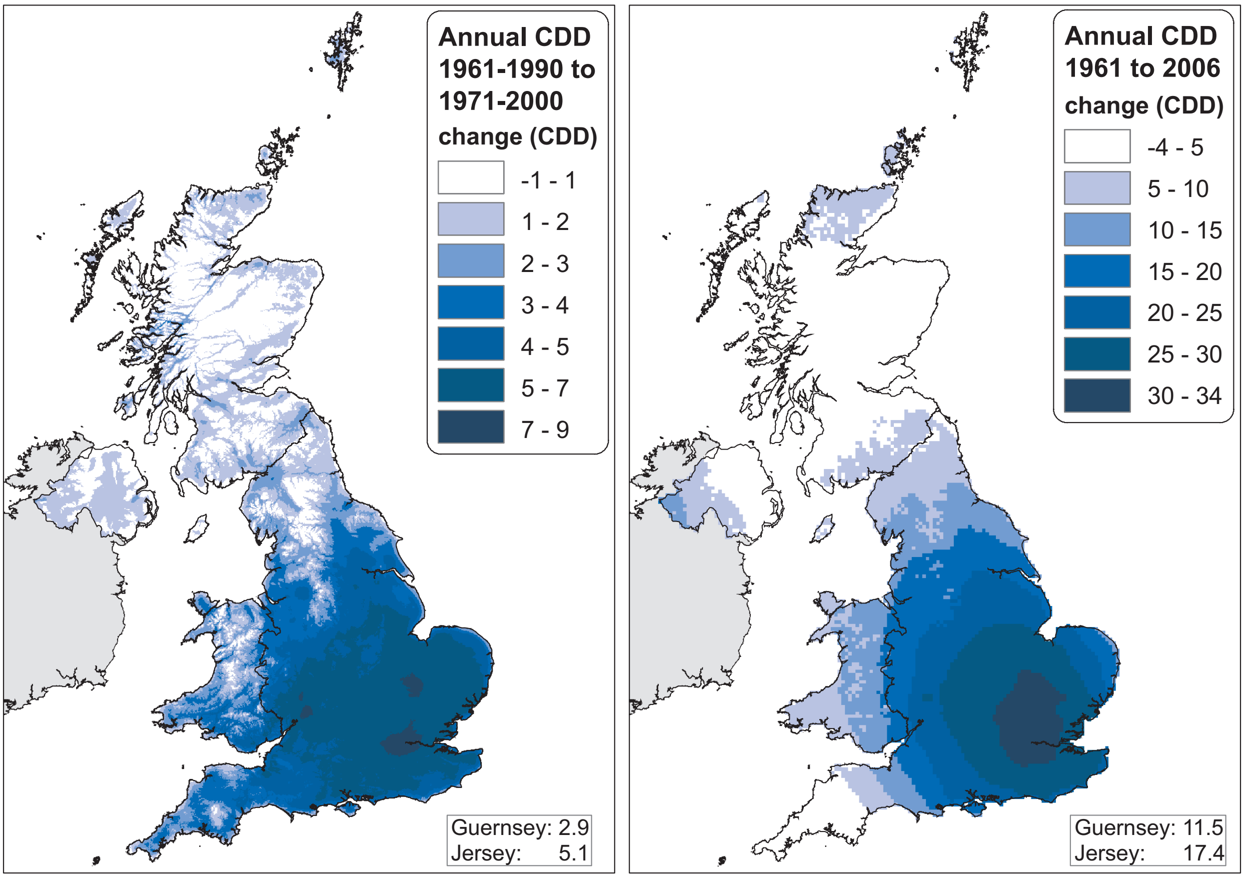


Figure 2.37: Change in annual cooling degree days (CDD) a) between 1961-1990 and 1971-2000; b) from 1961-2006 based on a linear trend

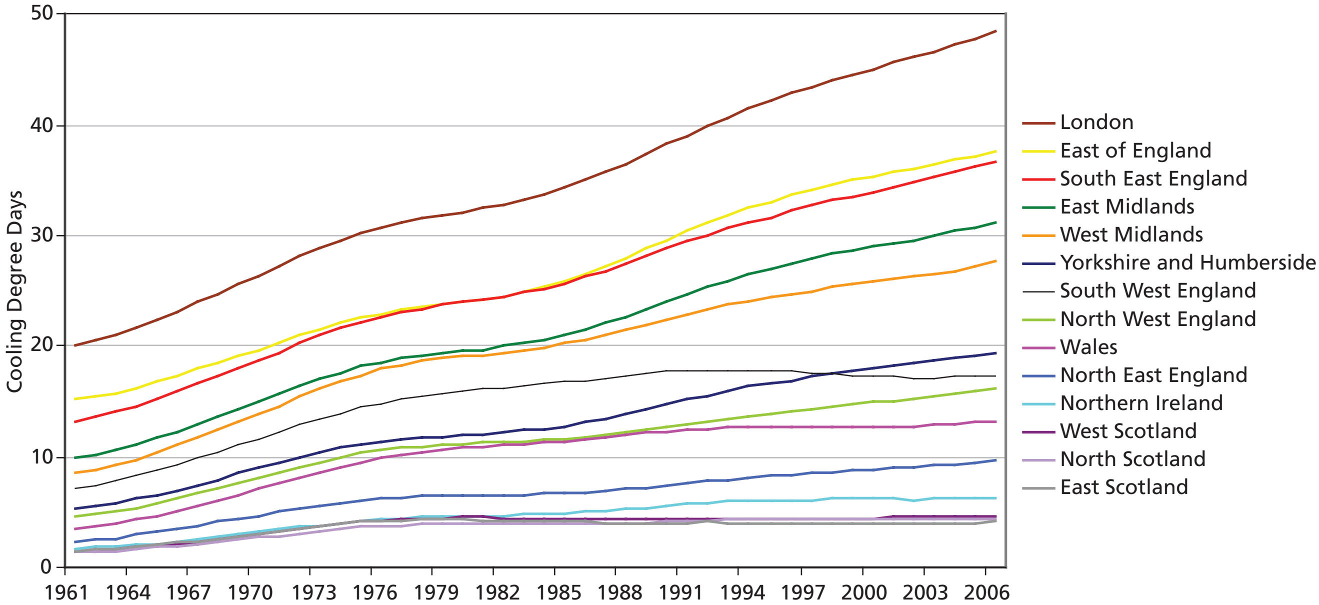


Figure 2.38: Filtered annual cooling degree days by area, 1961 – 2006. See Annex 2 for a definition of CDD.

Area	HDD	CDD
South West England	**-16.9**	**11.6**
South East England	**-18.3**	**26.9**
London	**-18.1**	**32.3**
Wales	**-16.0**	**11.1**
East of England	**-17.9**	**26.5**
West Midlands	**-17.9**	**21.6**
East Midlands	**-17.9**	**24.4**
Northern Ireland	**-14.1**	**5.3**
Yorkshire and Humberside	**-16.5**	**16.2**
North West England	**-15.4**	**12.8**
North East England	**-15.8**	**8.0**
West Scotland	**-13.4**	**3.3**
East Scotland	**-13.0**	2.5
North Scotland	**-11.5**	**3.4**

Table 2.9: Percentage change in annual heating degree days and absolute change in cooling degree days from 1961-2006 by area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Precipitation

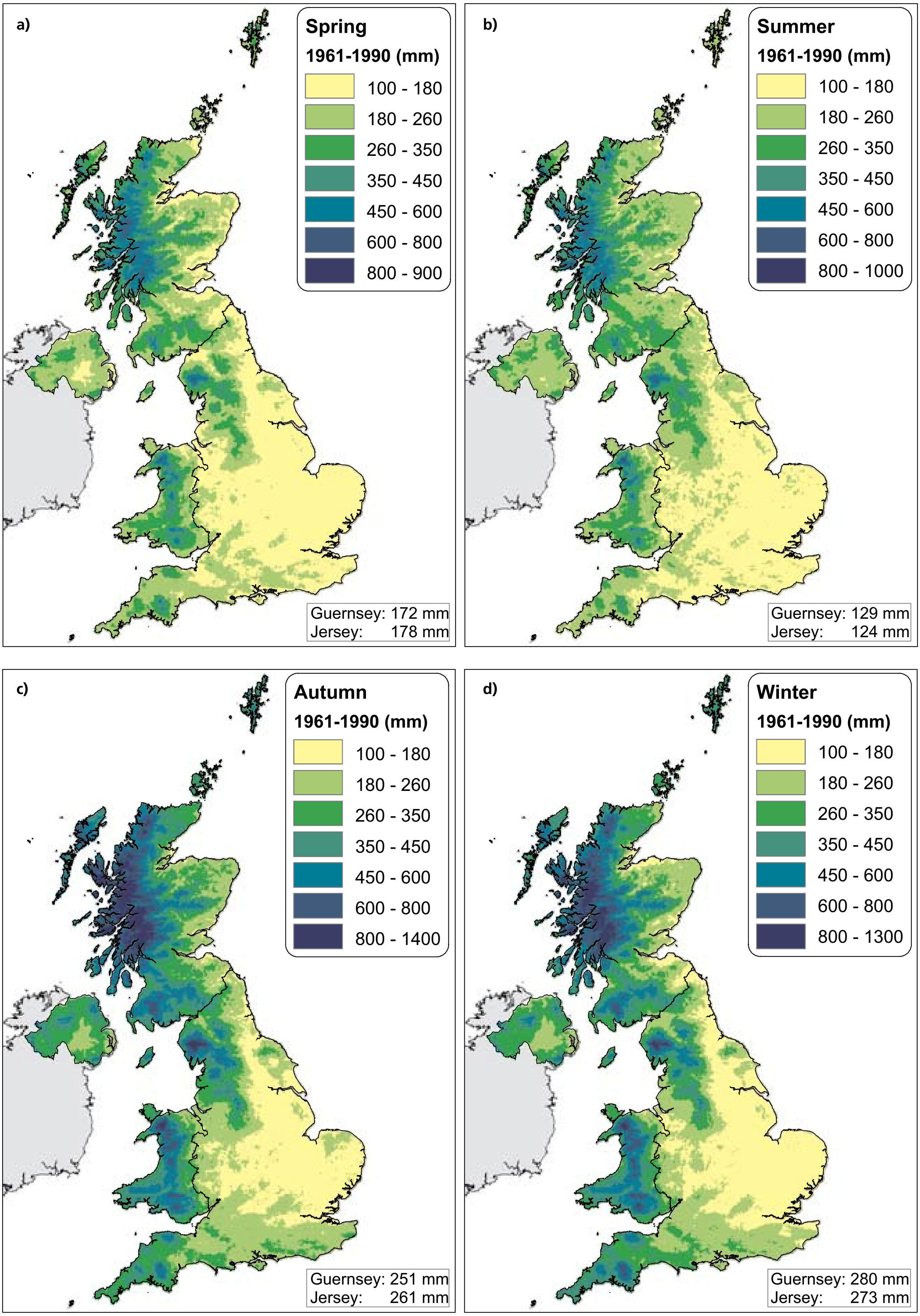


Figure 2.39: 1961-1990 average total precipitation amount (mm) for a) spring, b) summer, c) autumn and d) winter

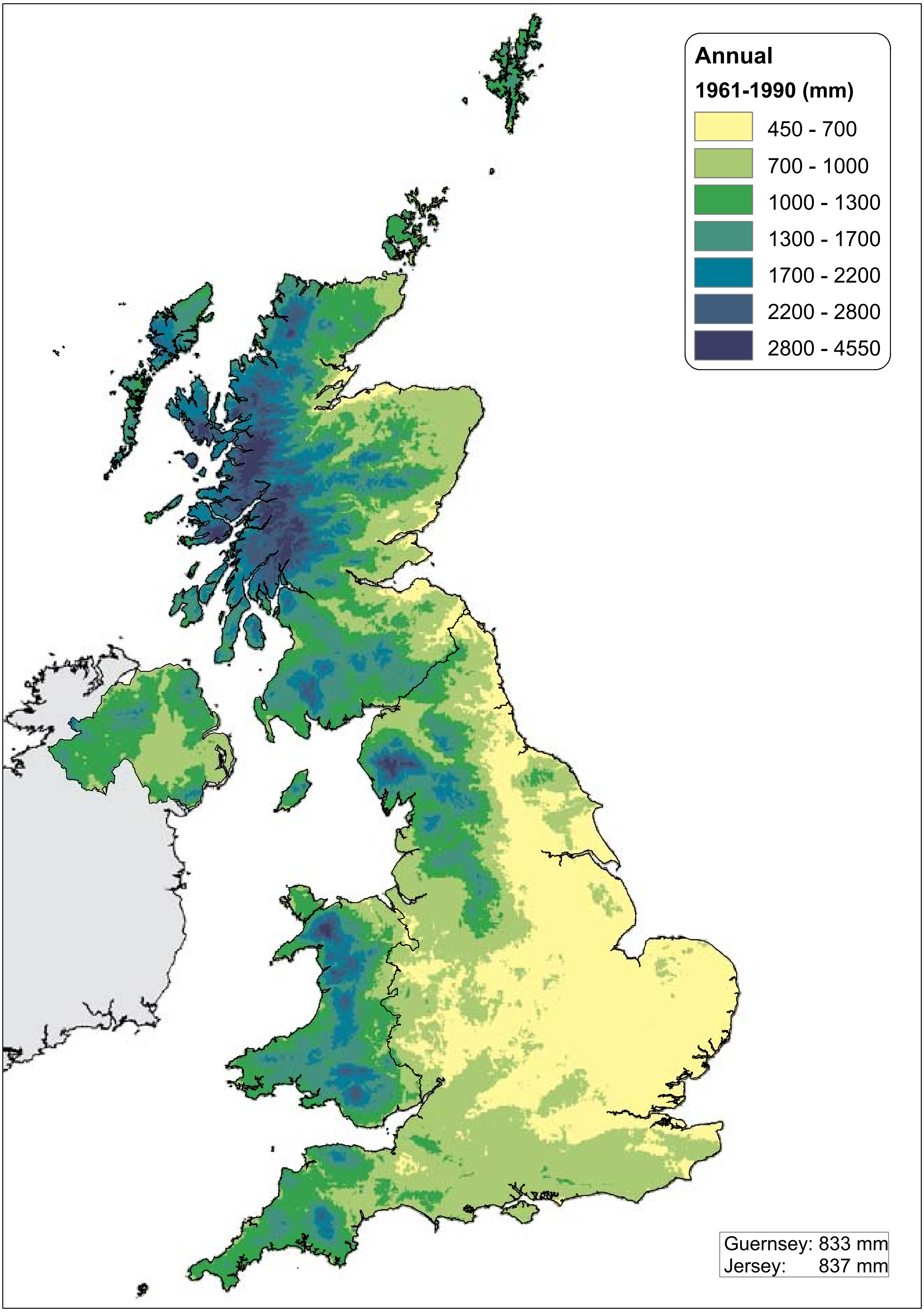


Figure 2.40: Annual average total precipitation amount (mm) for 1961-1990

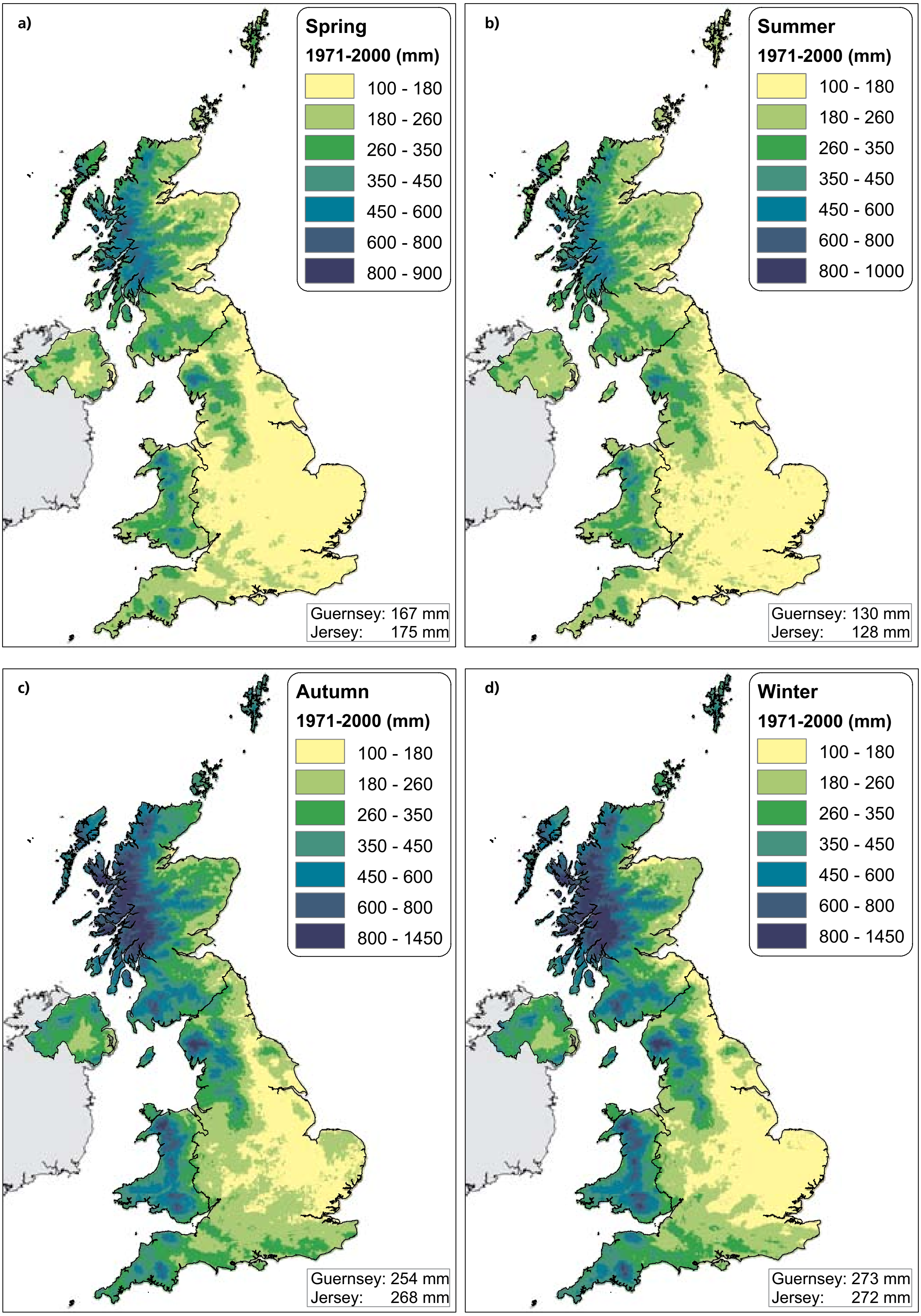


Figure 2.41: 1971-2000 average total precipitation amount (mm) for a) spring, b) summer, c) autumn and d) winter

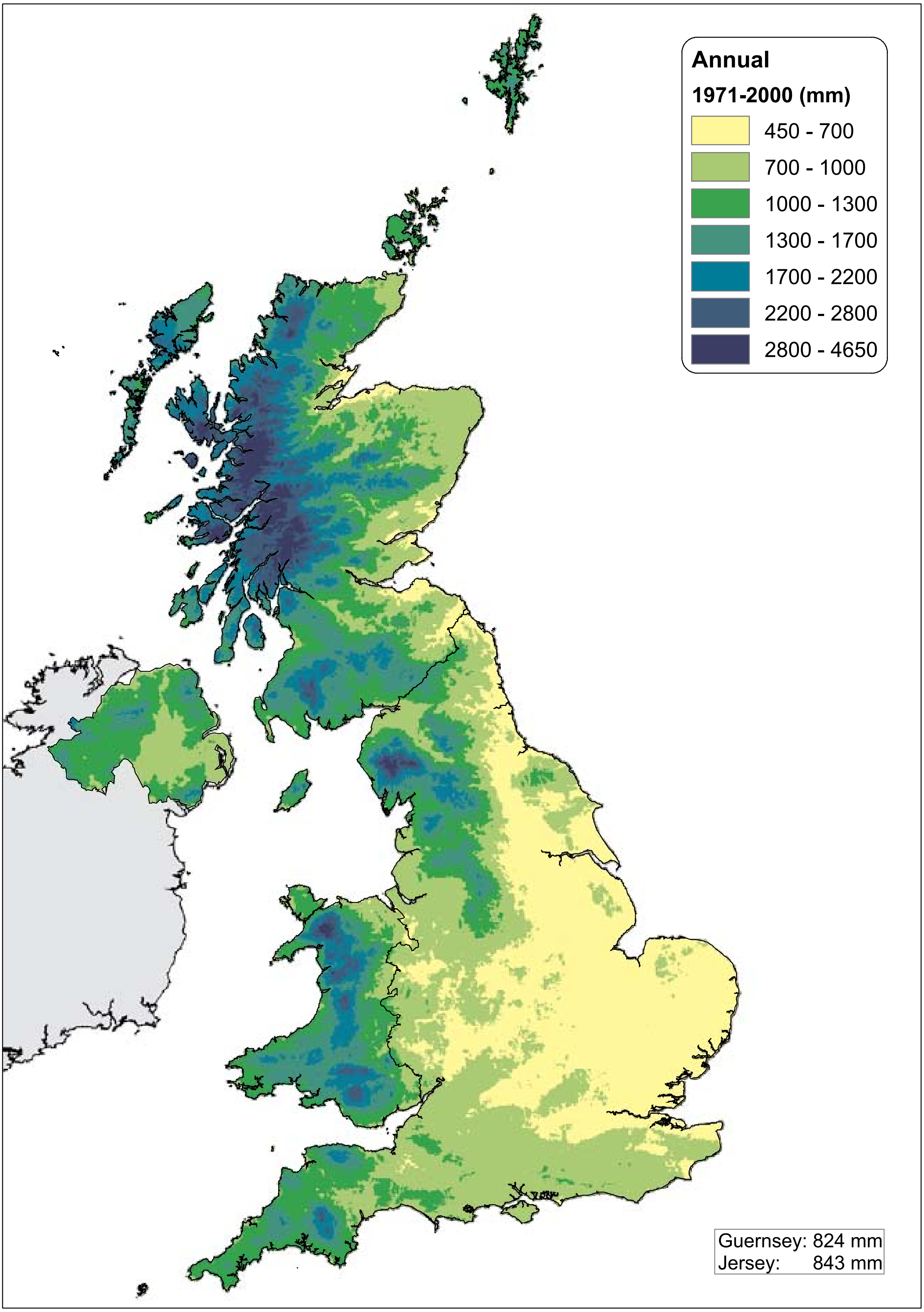


Figure 2.42: Average annual total precipitation amount (mm) for 1971-2000

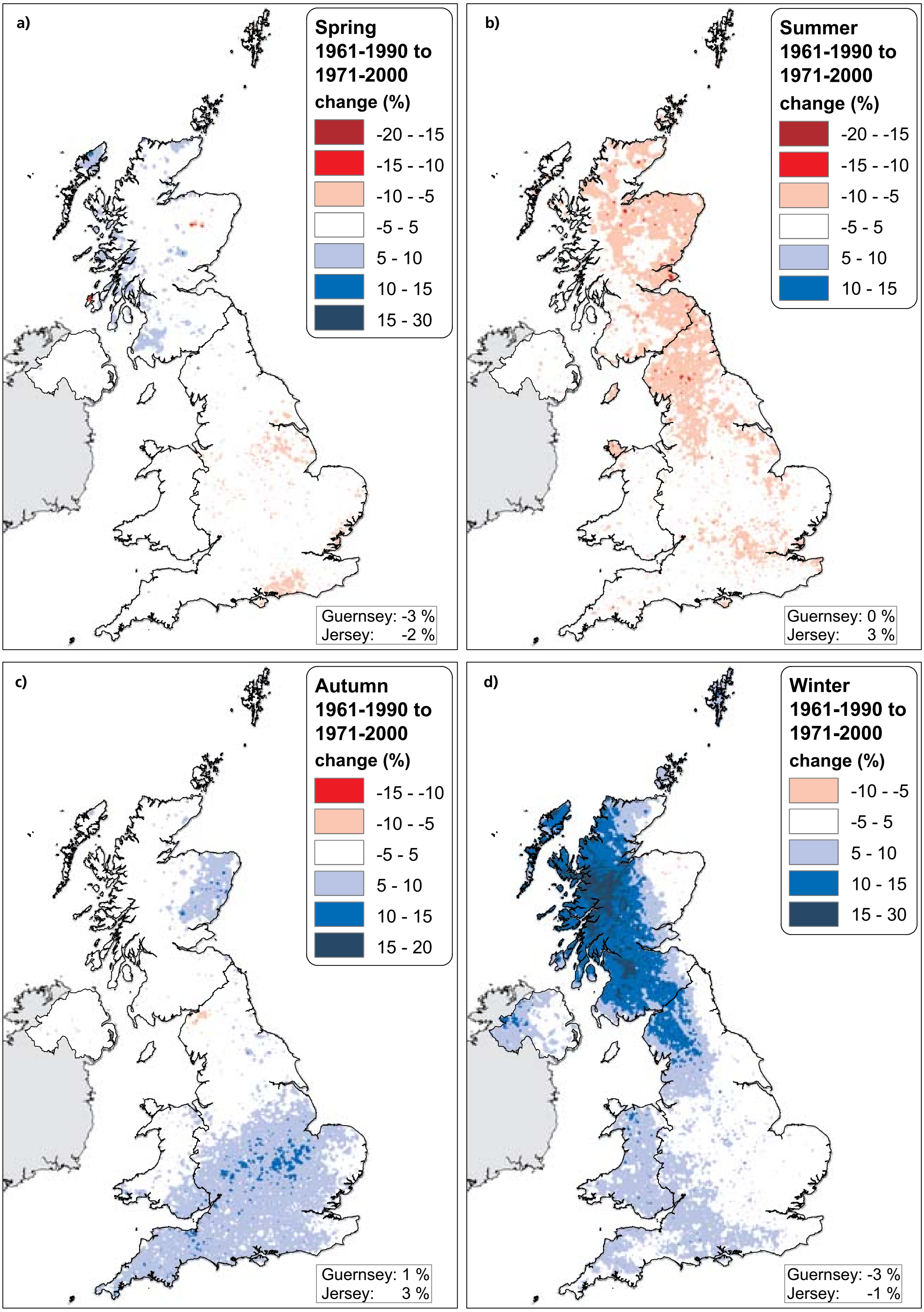


Figure 2.43: Percentage change in total average precipitation amount between 1961-1990 and 1971-2000 for a) spring, b) summer, c) autumn and d) winter

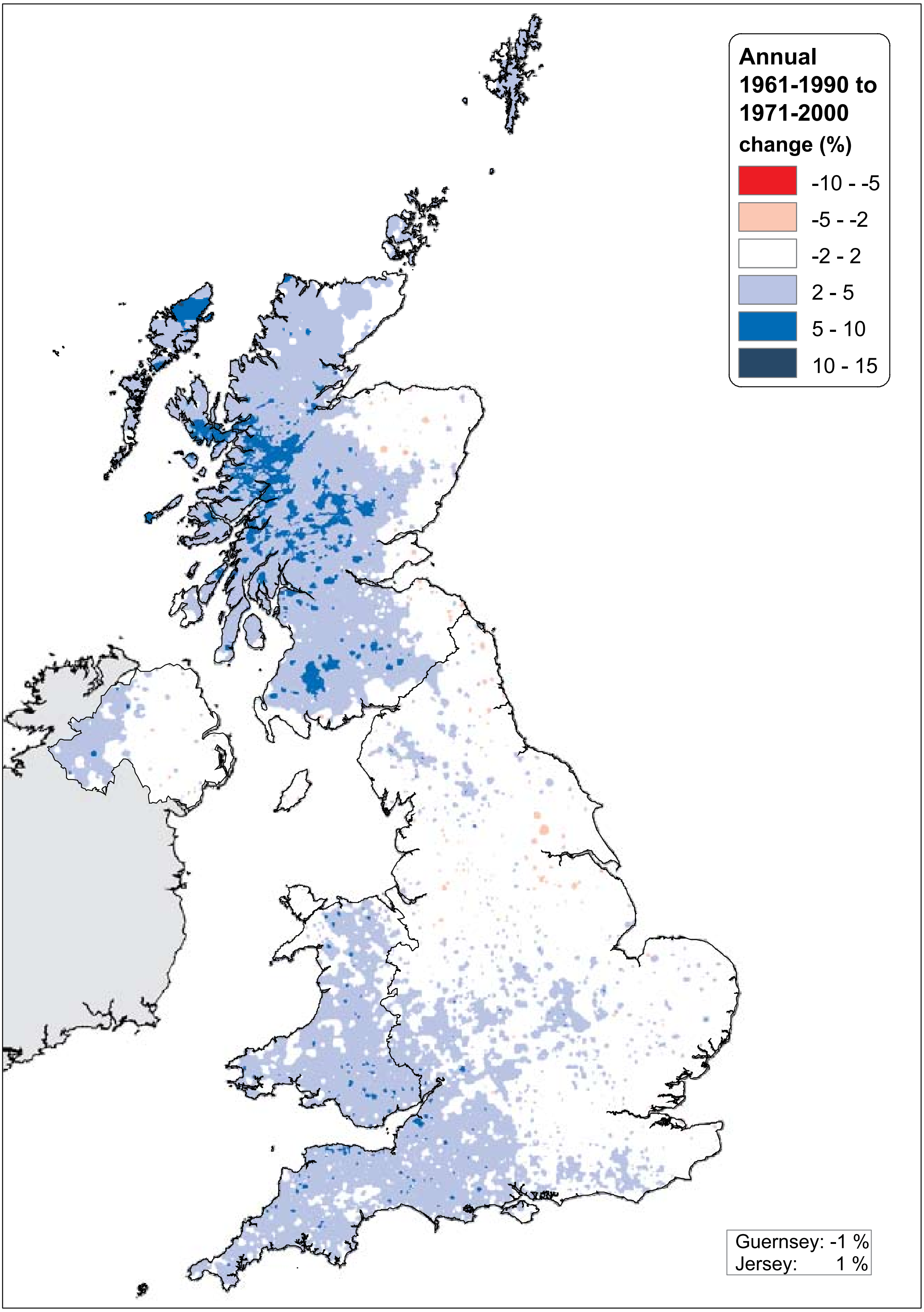


Figure 2.44: Percentage change in annual total average precipitation amount between 1961-1990 and 1971-2000

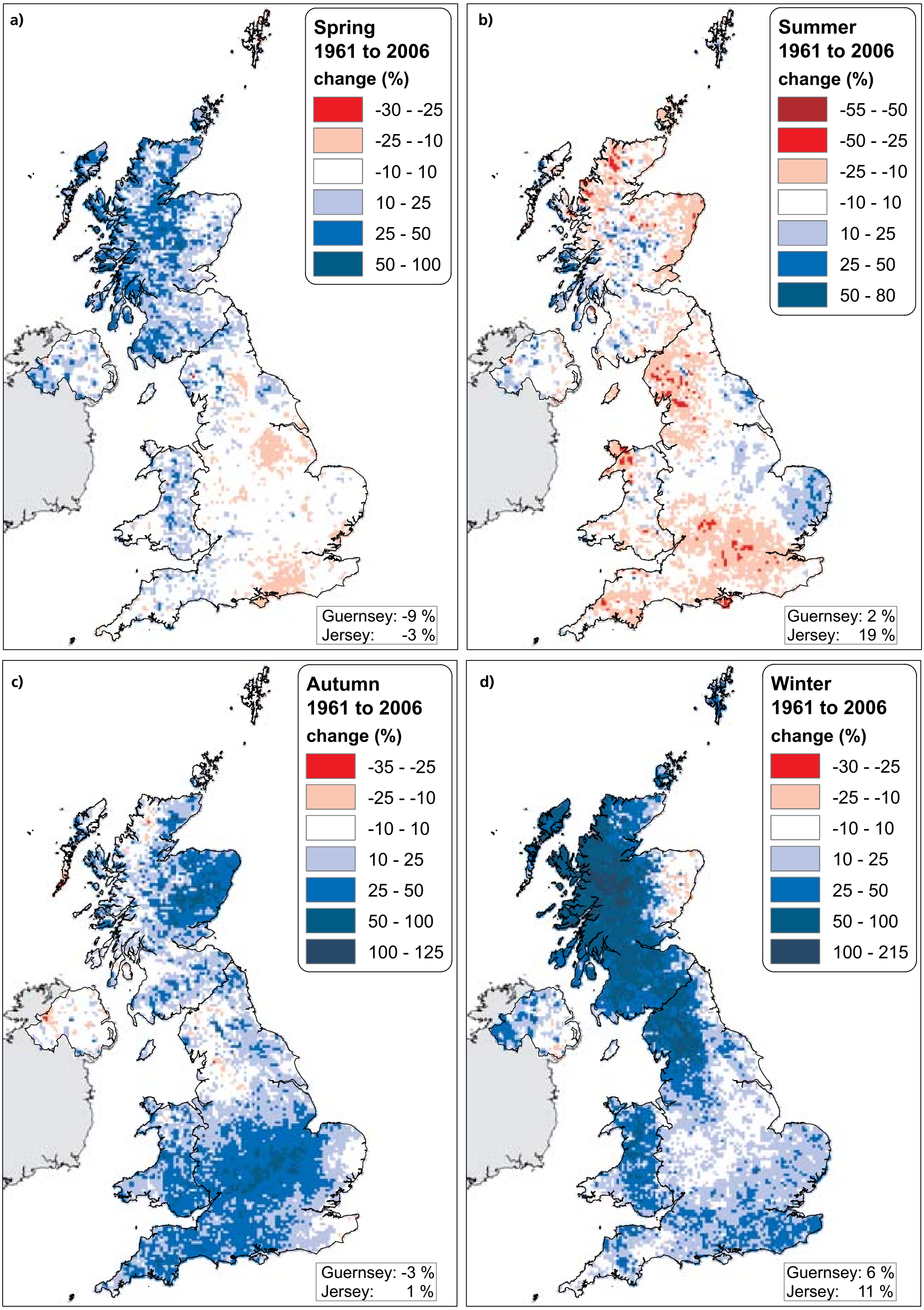


Figure 2.45: Percentage change in total precipitation amount from 1961-2006 based on a linear trend for a) spring, b) summer, c) autumn and d) winter

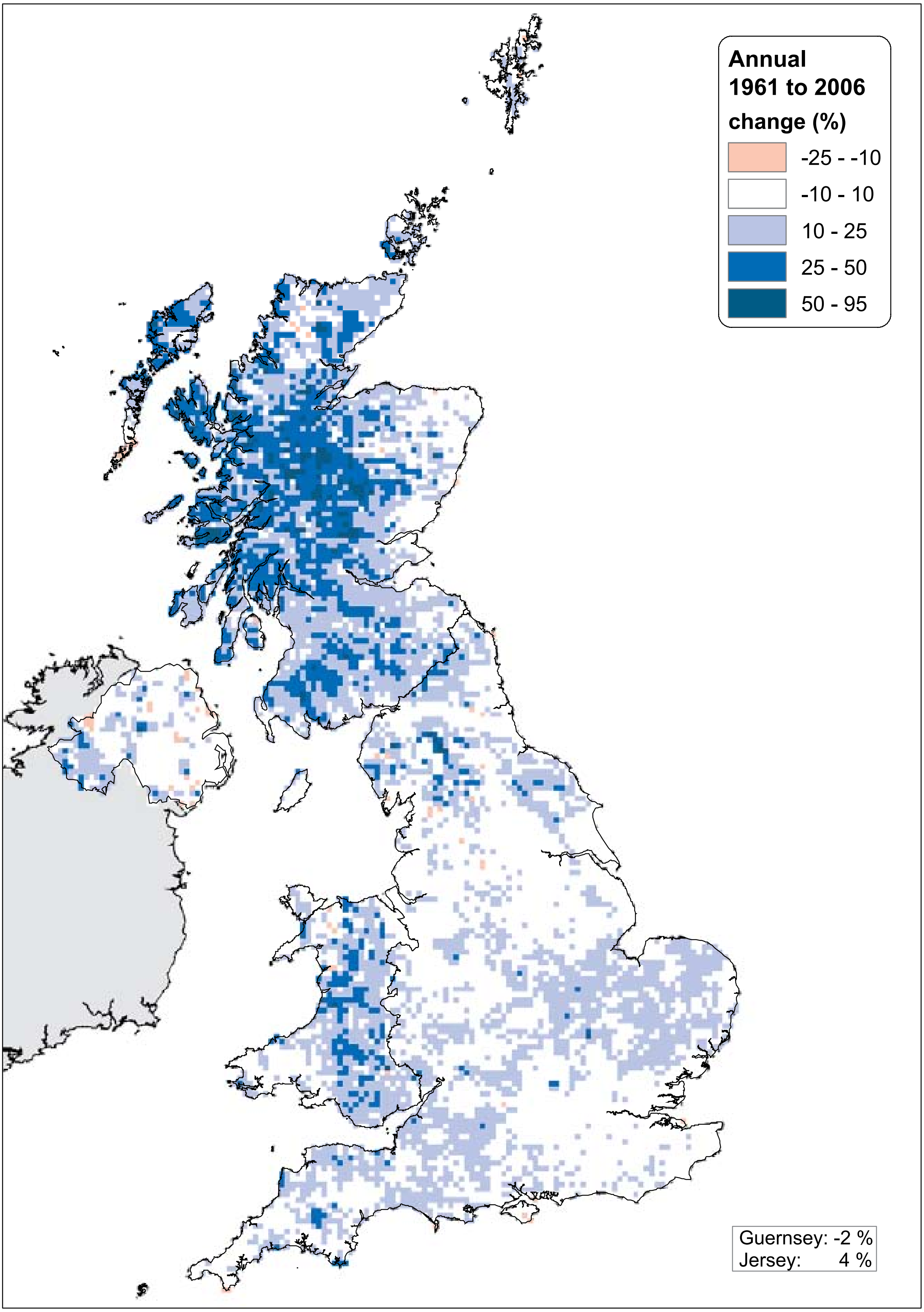
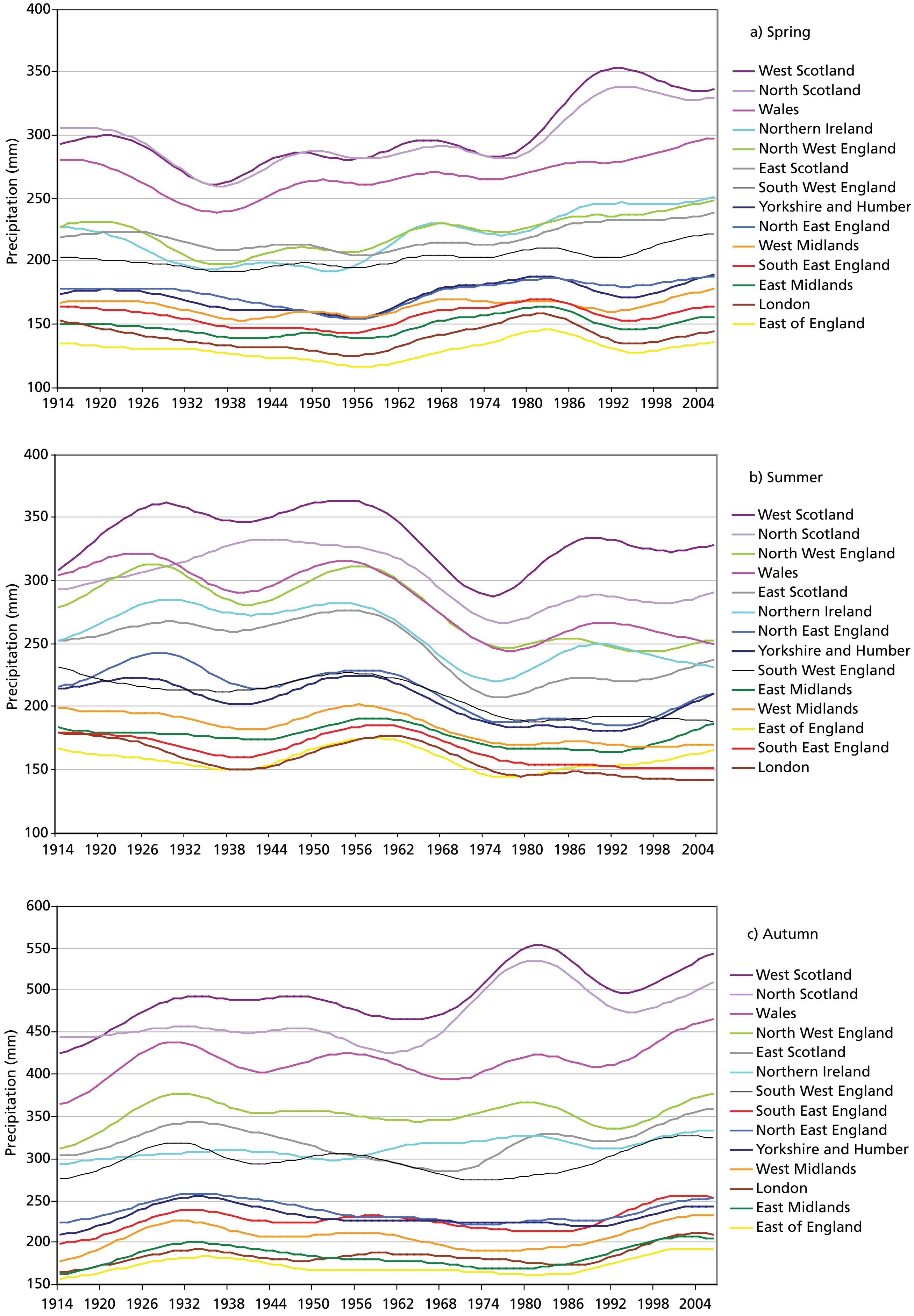
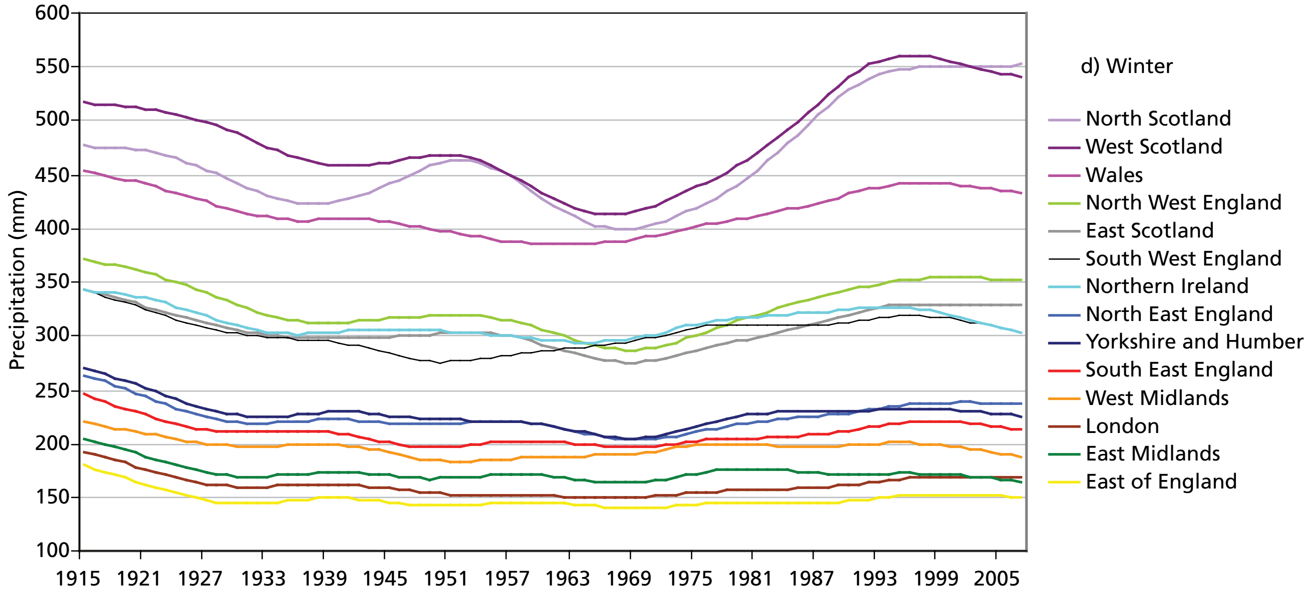


Figure 2.46: Percentage change in annual total average precipitation amount between 1961 and 2006 based on a linear trend


a) Spring
West Scotland
North Scotland
Wales
Northern Ireland
North West England
East Scotland
South West England
Yorkshire and Humber
North East England
West Midlands
South East England
East Midlands
London
East of England
Precipitation (mm)
400
350
300
250
200
150
100
1914 1920 1926 1932 1938 1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
b) Summer
West Scotland
North Scotland
North West England
Wales
East Scotland
Northern Ireland
North East England
Yorkshire and Humber
South West England
East Midlands
West Midlands
East of England
South East England
London
c) Autumn
West Scotland
North Scotland
Wales
North West England
East Scotland
Northern Ireland
South West England
South East England
North East England
Yorkshire and Humber
West Midlands
London
East Midlands
East of England
600
550
500
450
400
350
300
250
200
150



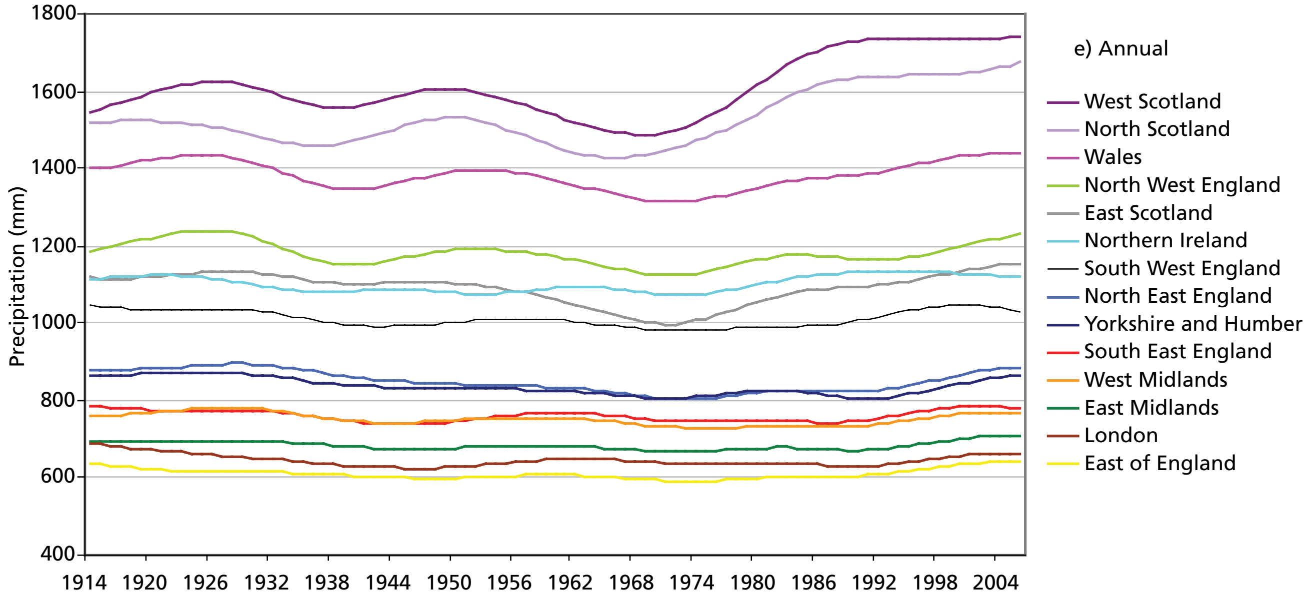


Figure 2.47: Filtered total precipitation (mm) by area, 1914-2006 for a) spring, b) summer, c) autumn, d) winter, e) annual

Area	Spring	Summer	Autumn	Winter	Annual
South West England	9.6	-18.9	2.6	-0.9	-2.3
South East England	4.7	-15.3	9.3	-6.2	-2.1
London	3.0	-18.4	10.1	-7.0	-3.7
Wales	12.8	**-24.0**	9.1	0.5	-0.9
East of England	5.5	-4.0	5.8	-8.2	-0.6
West Midlands	5.4	-17.2	4.7	-6.0	-3.8
East Midlands	8.8	-5.8	5.0	-9.7	-0.9
Northern Ireland	**25.2**	**-18.3**	10.7	-2.0	1.9
Yorkshire and Humberside	10.6	-15.9	-2.0	-8.9	-5.2
North West England	**15.7**	**-21.6**	3.5	-0.5	-2.4
North East England	8.7	**-20.7**	-3.6	-3.5	-6.0
West Scotland	**26.1**	-8.7	**18.7**	10.0	10.3
East Scotland	9.0	**-20.5**	3.9	0.1	-2.7
North Scotland	18.0	-12.1	**17.1**	21.9	**11.4**

Table 2.10: Percentage change in total precipitation amount from 1914 to 2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Area	Spring	Summer	Autumn	Winter	Annual
South West England	4.0	-8.8	28.6	15.9	9.7
South East England	-6.5	-13.1	20.6	23.3	5.4
London	-7.0	-16.7	19.4	22.7	2.5
Wales	8.4	-5.6	22.3	27.0	13.6
East of England	-1.7	4.9	21.6	17.7	9.3
West Midlands	-1.4	-5.2	29.8	10.9	7.6
East Midlands	-4.6	2.6	28.7	11.0	8.1
Northern Ireland	9.5	2.5	-0.7	12.5	5.2
Yorkshire and Humberside	-0.3	-1.1	10.2	24.3	7.1
North West England	6.3	-13.2	5.6	**43.0**	8.8
North East England	4.6	-6.9	12.4	**29.6**	8.7
West Scotland	23.2	4.3	11.0	**58.6**	**23.2**
East Scotland	14.3	-3.6	28.0	**35.9**	**18.7**
North Scotland	22.6	-5.0	11.1	**65.8**	**23.0**

Table 2.11: Percentage change in total precipitation amount from 1961-2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Days of rain ≥ 1mm

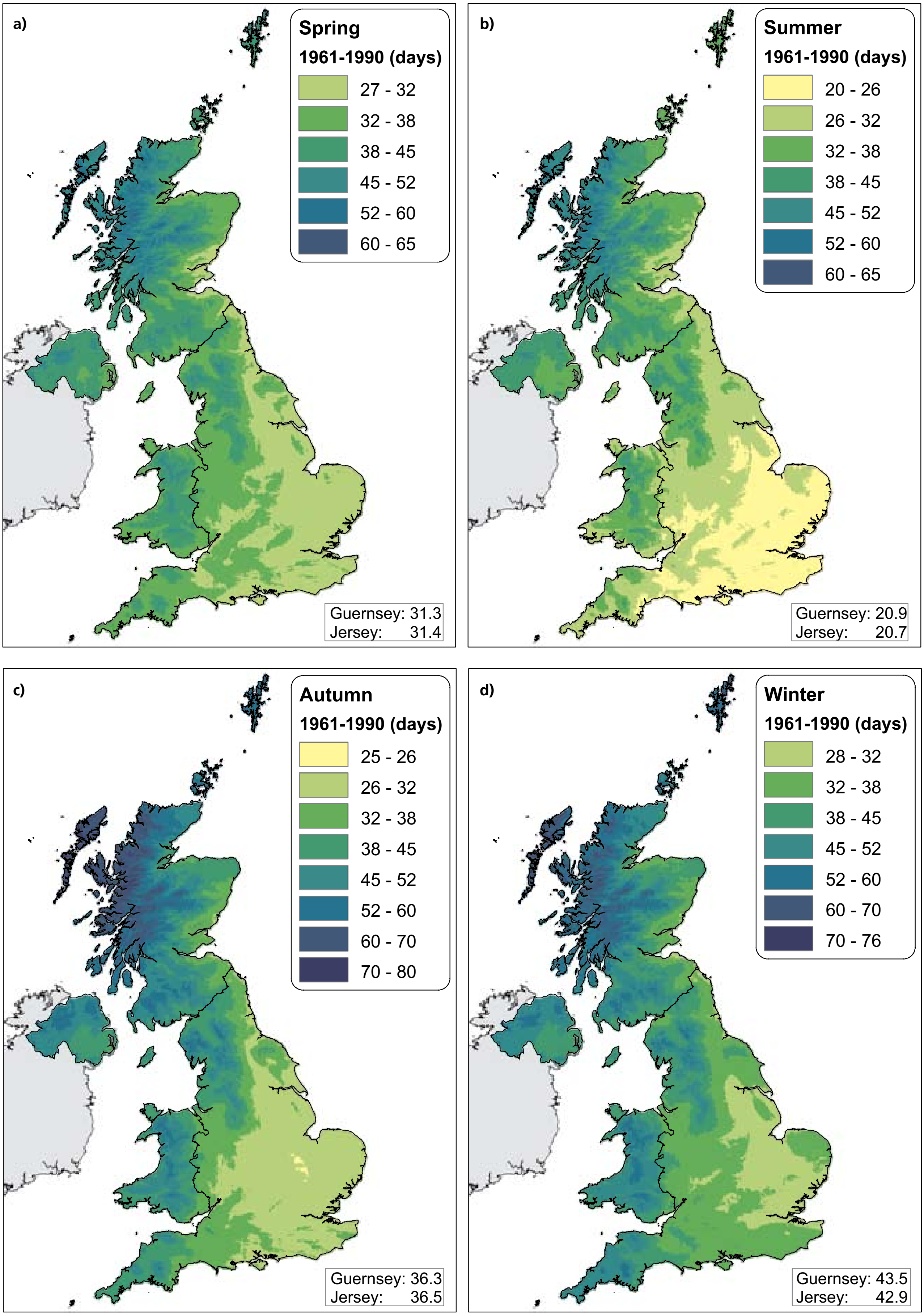


Figure 2.48: 1961-1990 average days of rain ≥ 1mm for a) spring, b) summer, c) autumn and d) winter

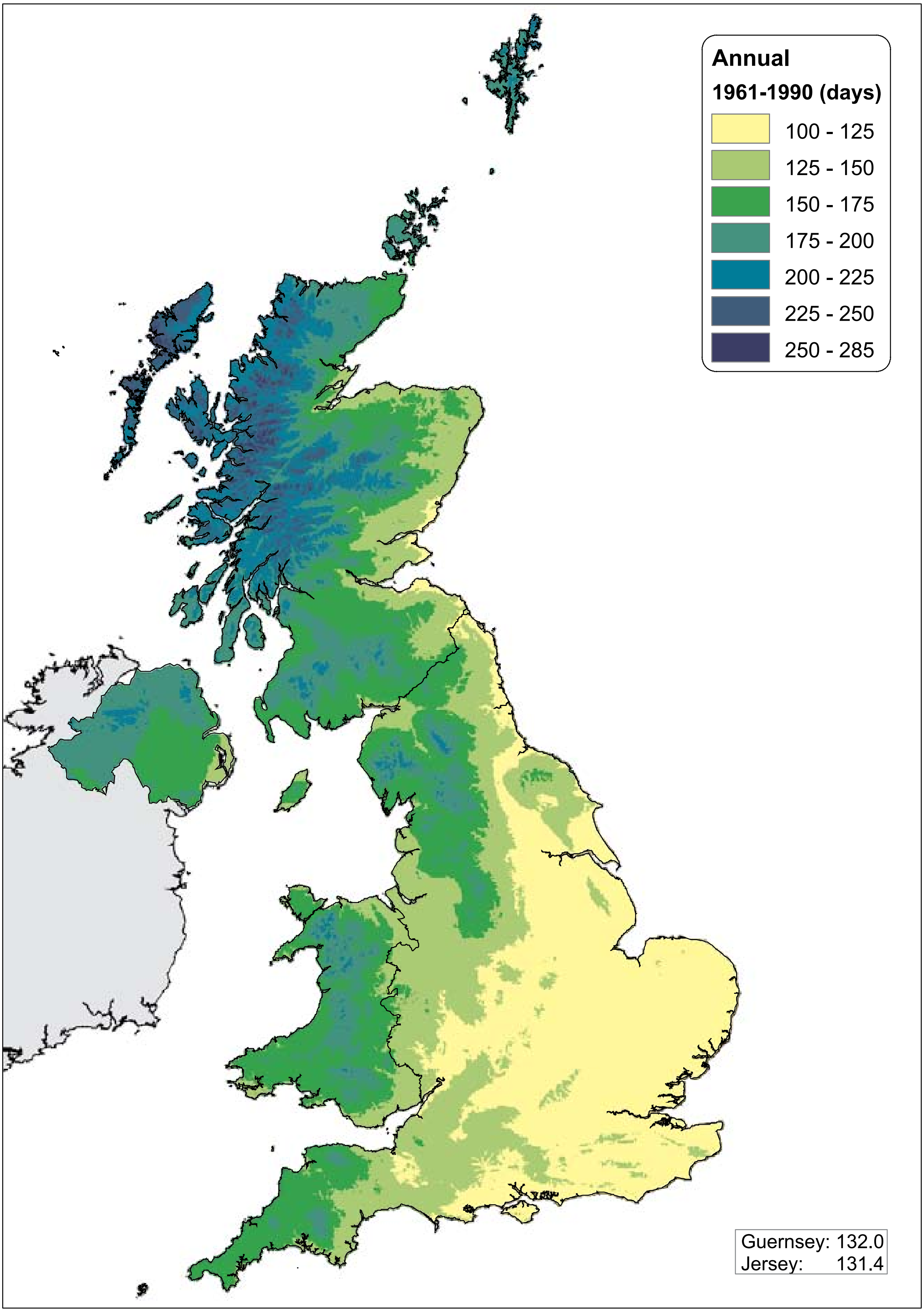


Figure 2.49: Average annual days of rain ≥ 1mm for 1961-1990

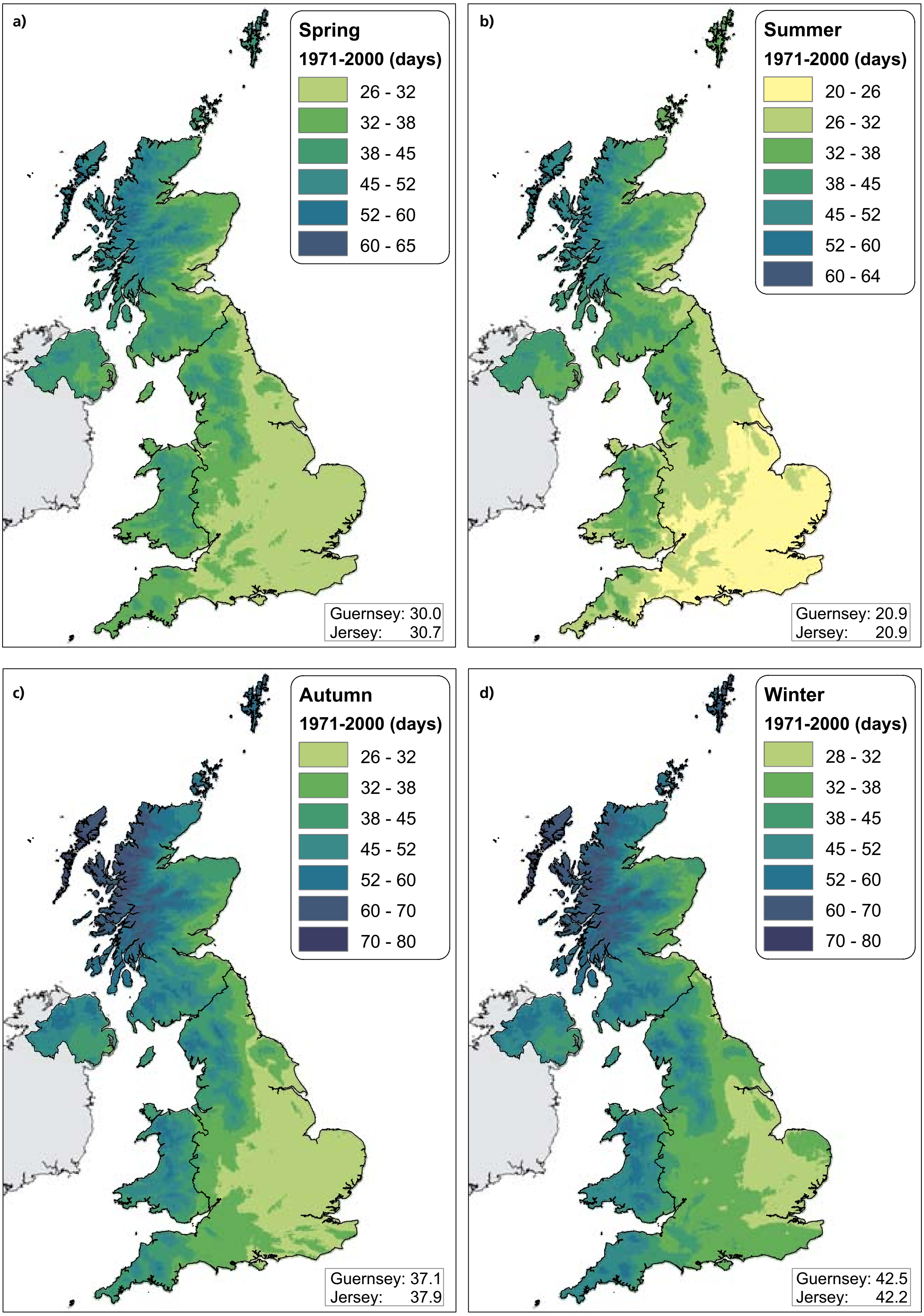


Figure 2.50: 1971-2000 average days of rain ≥ 1mm for a) spring, b) summer, c) autumn and d) winter

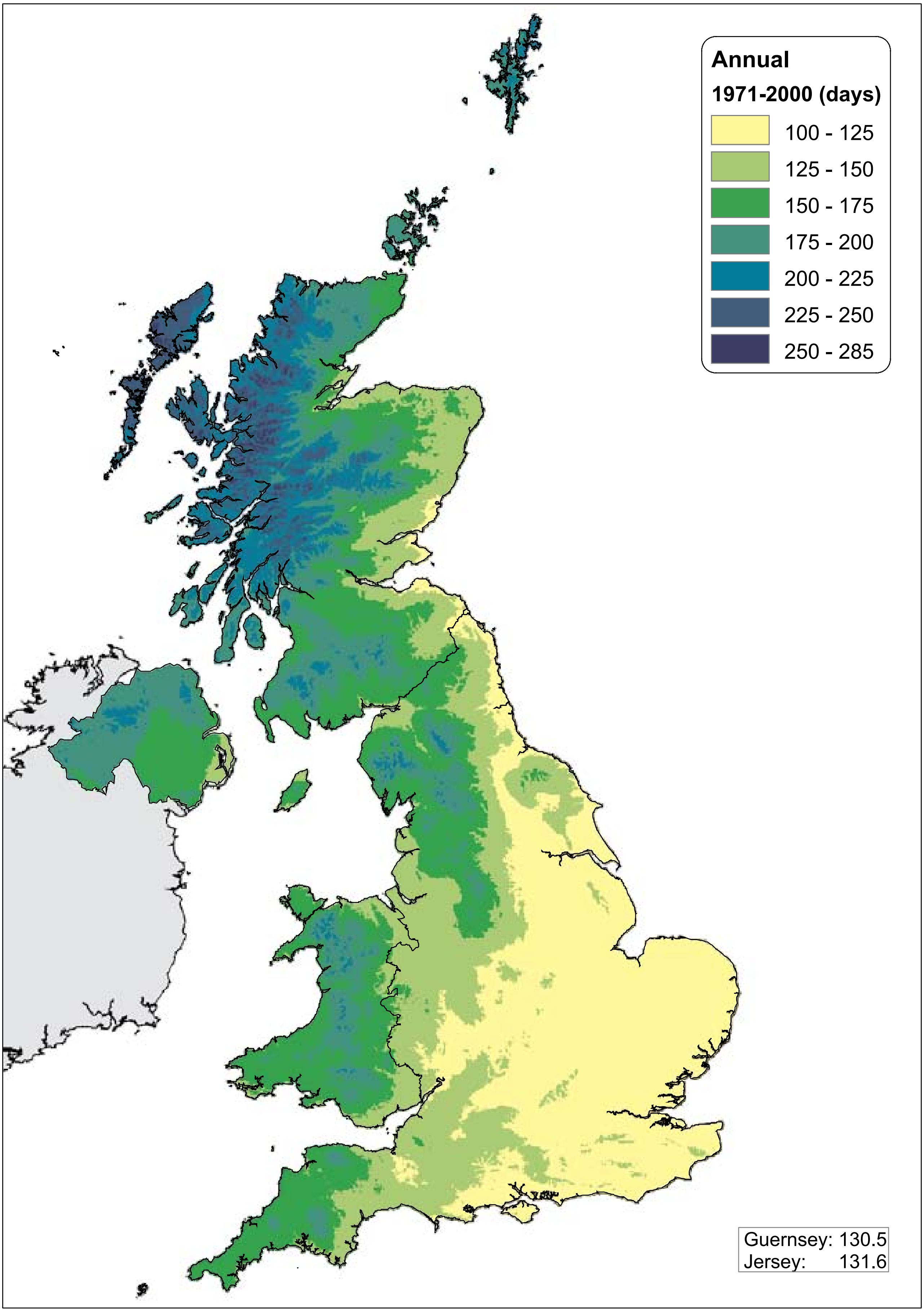


Figure 2.51: Average annual days of rain ≥ 1mm for 1971-2000

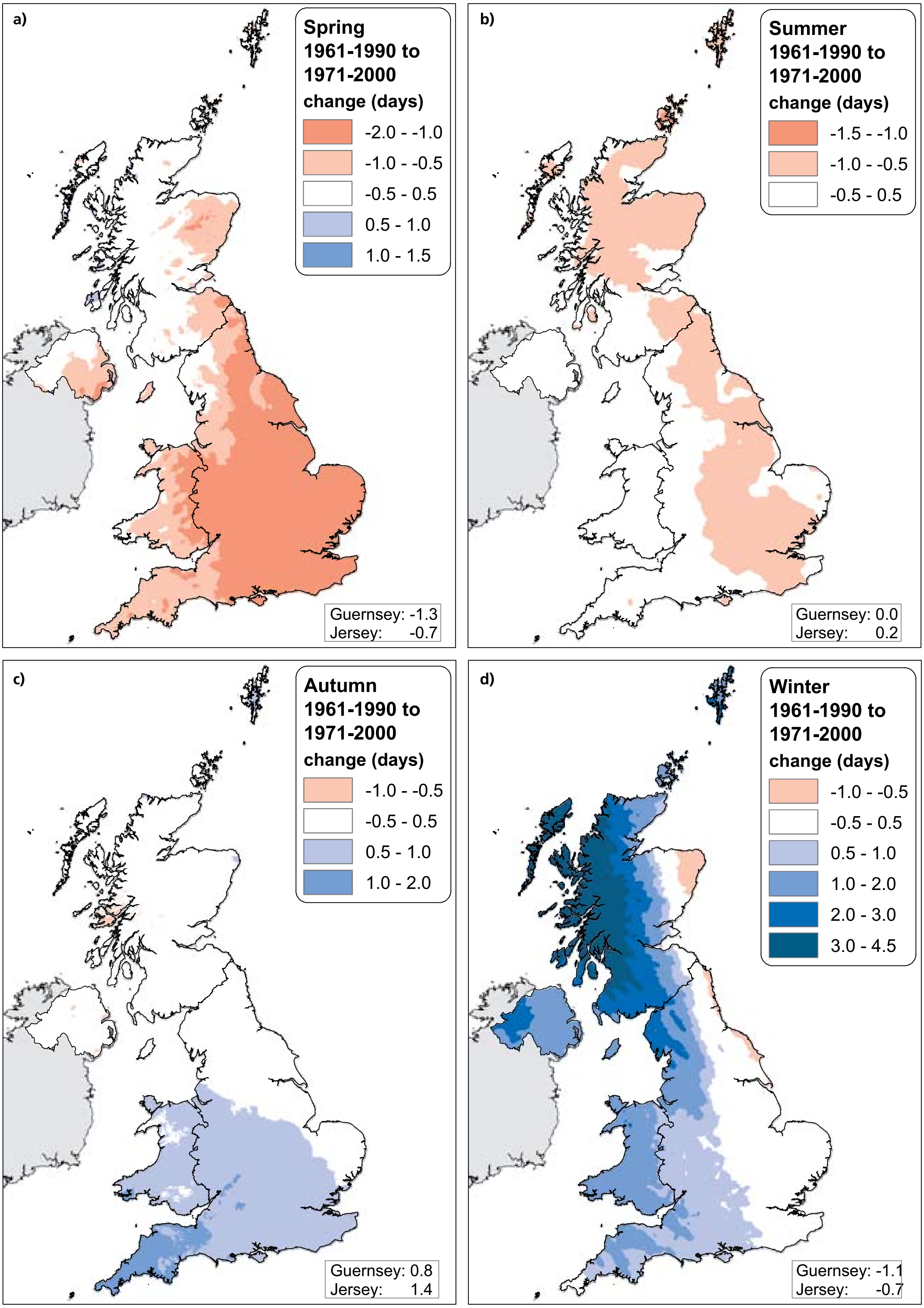


Figure 2.52: Change (days) in average days of rain ≥ 1mm between 1961-1990 and 1971-2000 for a) spring, b) summer, c) autumn and d) winter

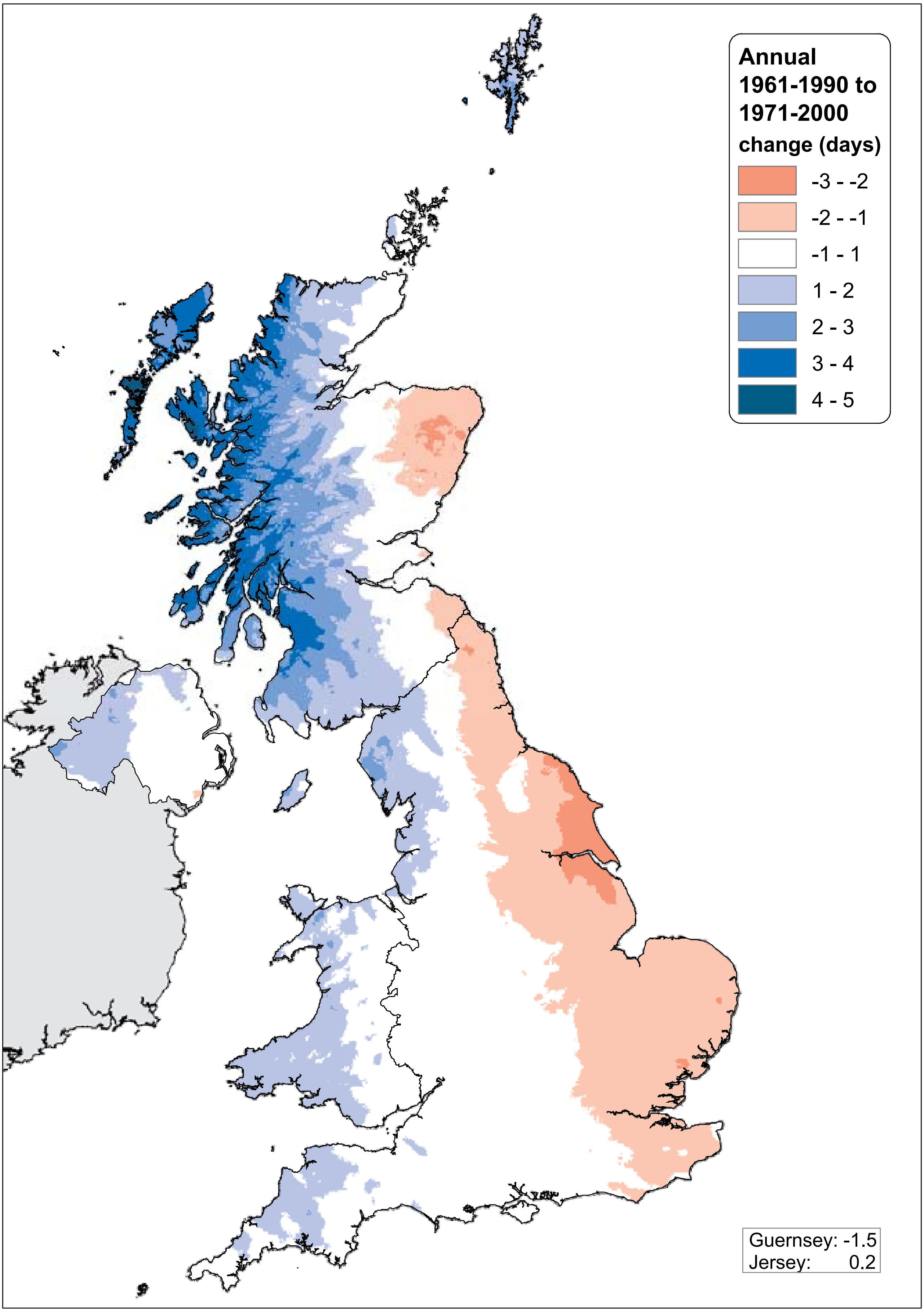


Figure 2.53: Change in annual days of rain ≥ 1mm between 1961-1990 and 1971-2000

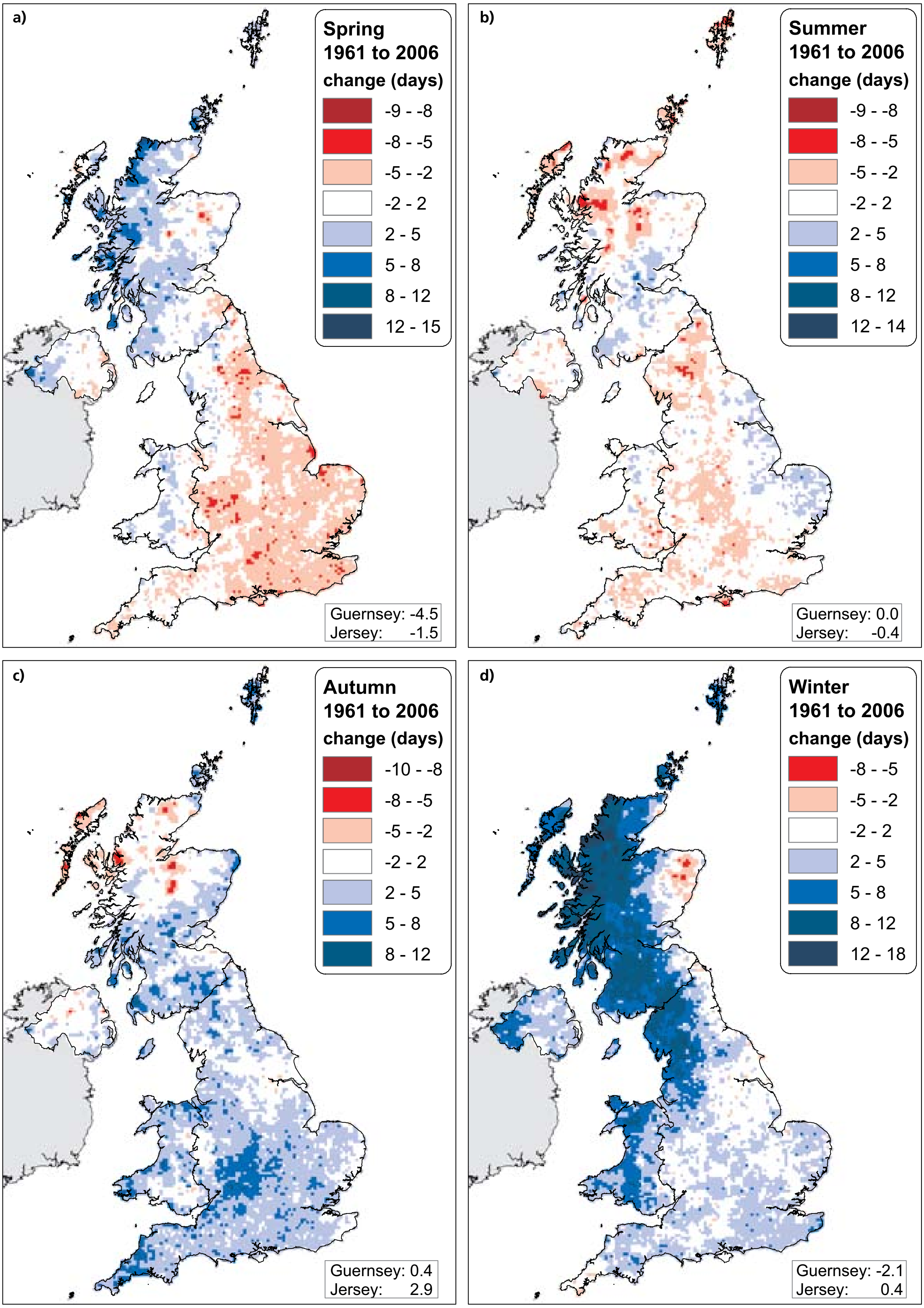


Figure 2.54: Change in days of rain ≥ 1mm from 1961 to 2006 based on a linear trend for a) spring, b) summer, c) autumn and d) winter

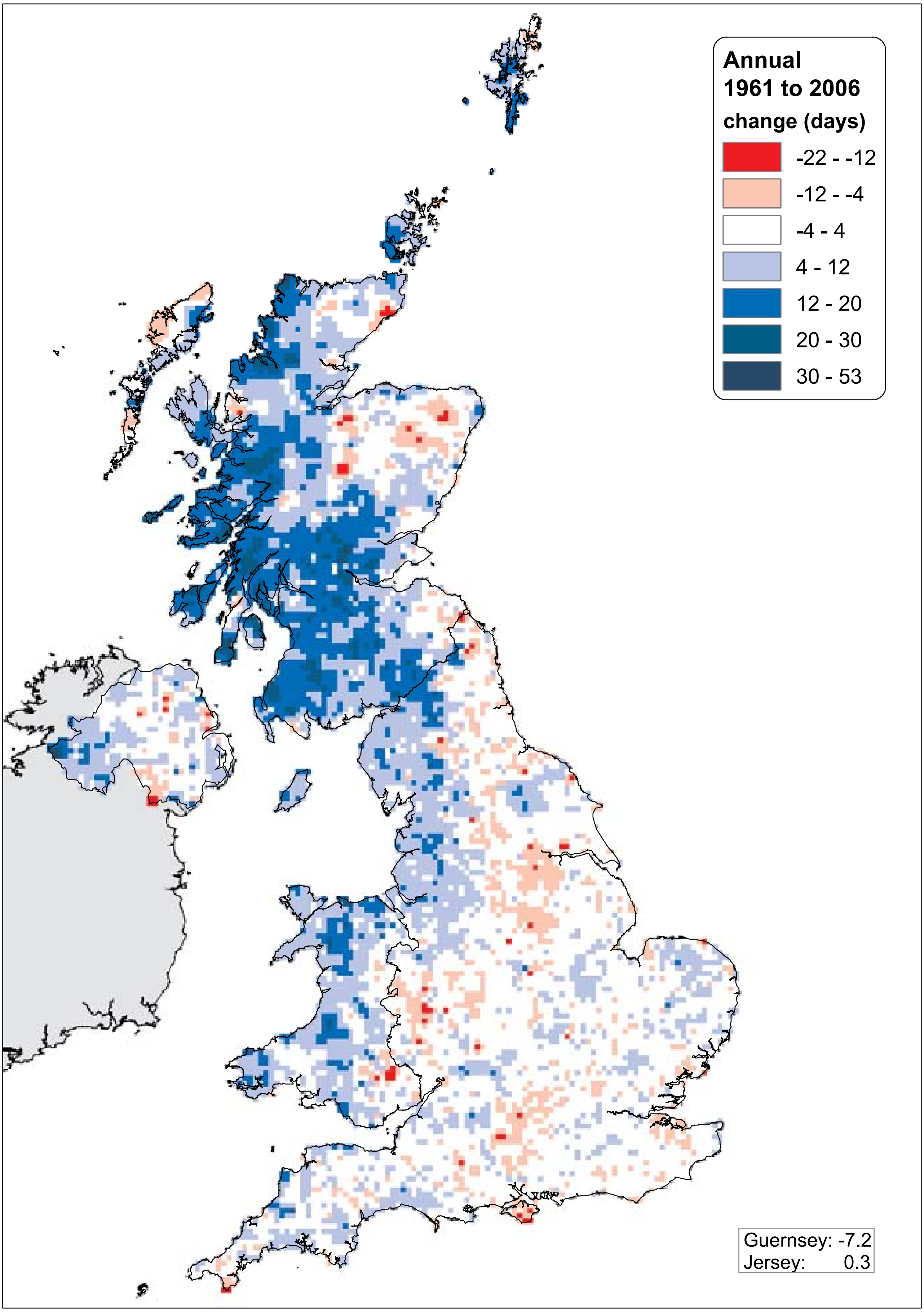
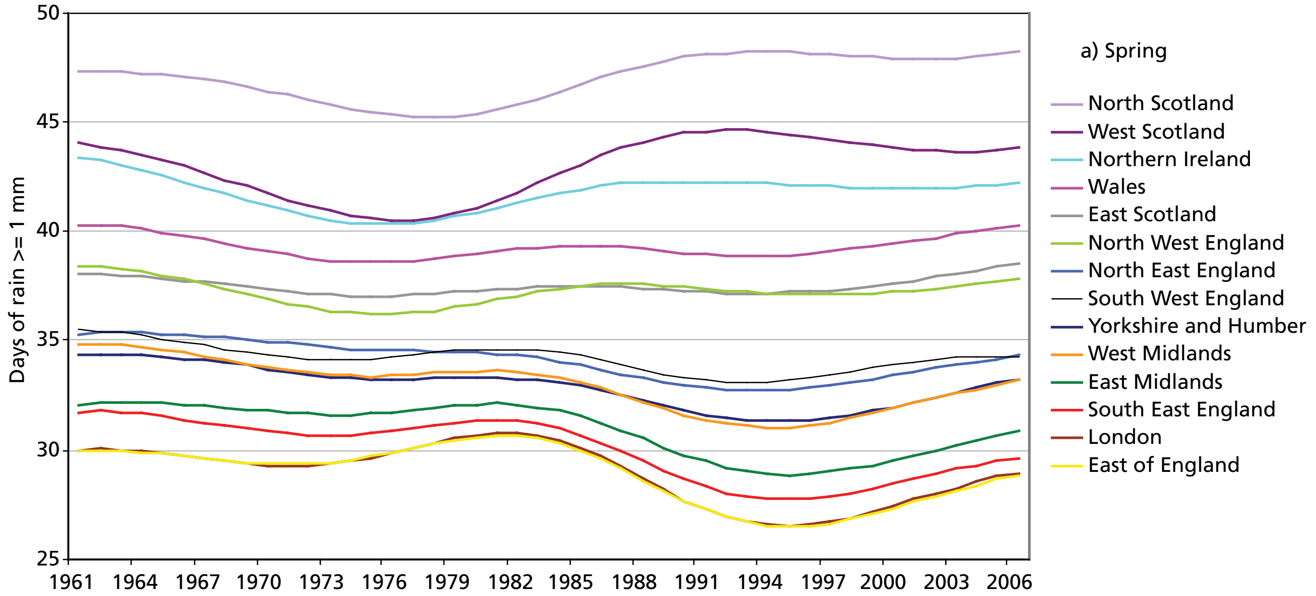
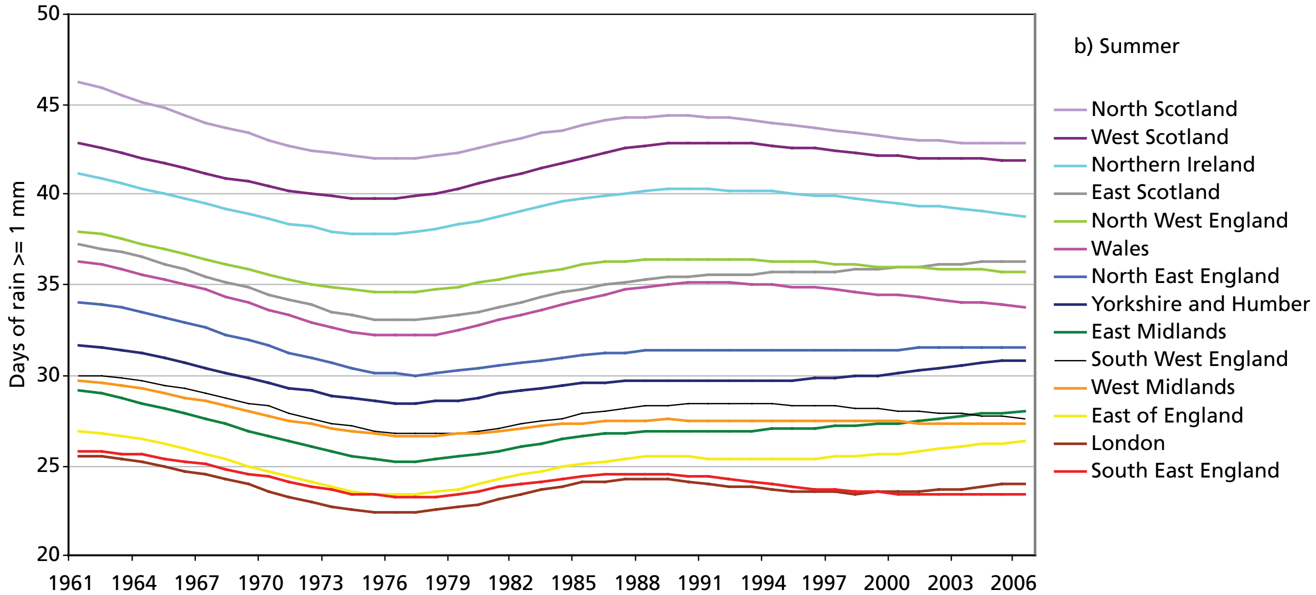


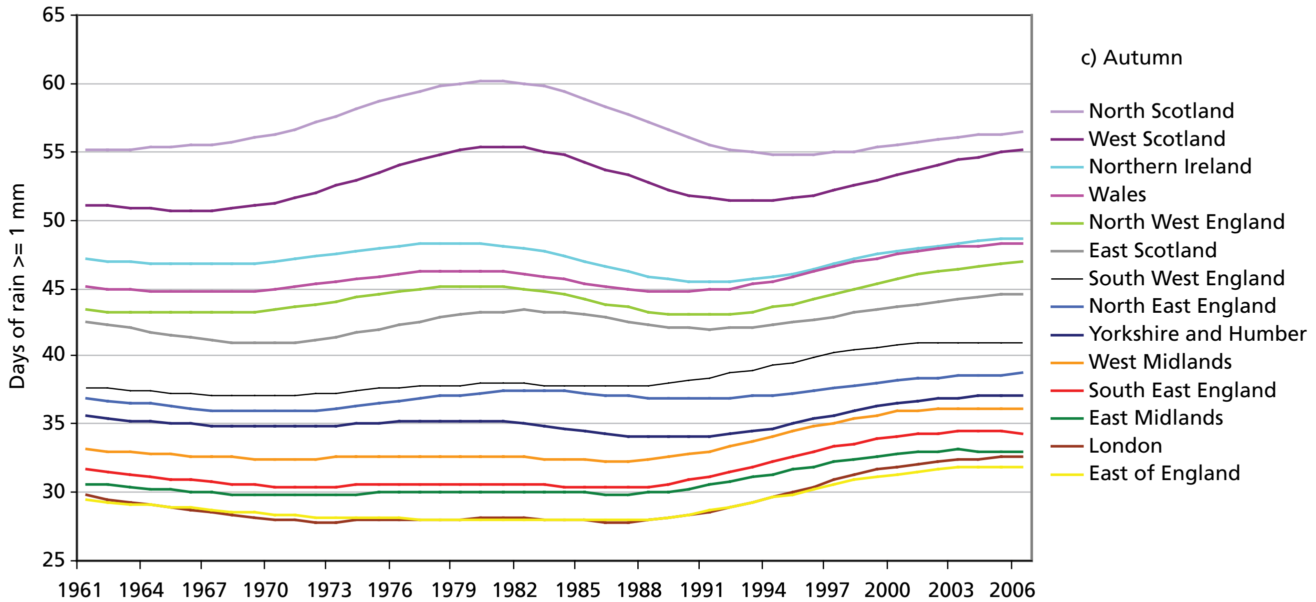
Figure 2.55: Change in annual days of rain ≥ 1mm between 1961 and 2006 based on a linear trend



50
45
40
35
30
25
Days of rain >= 1 mm
1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006
a) Spring
North Scotland
West Scotland
Northern Ireland
Wales
East Scotland
North West England
North East England
South West England
Yorkshire and Humber
West Midlands
East Midlands
South East England
London
East of England



50
45
40
35
30
25
20
Days of rain >= 1 mm
1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006
b) Summer
North Scotland
West Scotland
Northern Ireland
East Scotland
North West England
Wales
North East England
Yorkshire and Humber
East Midlands
South West England
West Midlands
East of England
London
South East England



65
60
55
50
45
40
35
30
25
Days of rain >= 1 mm
1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006
c) Autumn
North Scotland
West Scotland
Northern Ireland
Wales
North West England
East Scotland
South West England
North East England
Yorkshire and Humber
West Midlands
South East England
East Midlands
London
East of England

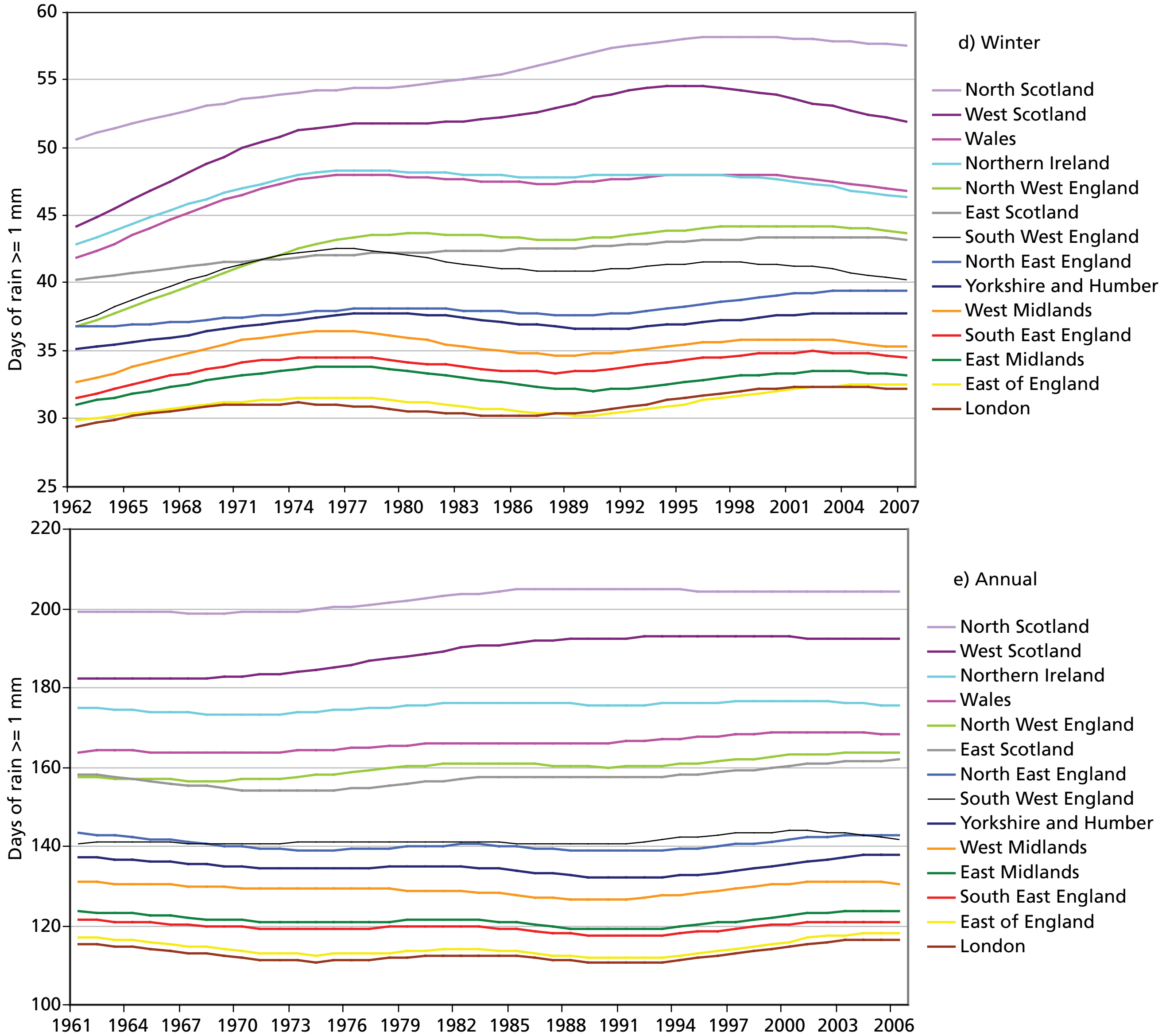


Figure 2.56: Filtered days of rain ≥ 1mm by area, 1961-2006 for a) spring; b) summer; c) autumn; d) winter; e) annual

Area	Spring	Summer	Autumn	Winter	Annual
South West England	-1.4	-1.3	4.1	2.2	1.9
South East England	-3.4	-1.8	3.4	2.6	-0.9
London	-2.5	-0.7	3.5	2.6	1.3
Wales	0.5	-0.7	2.9	4.6	5.7
East of England	-2.8	0.6	2.9	2.1	0.9
West Midlands	-2.7	-1.8	3.6	1.9	-0.7
East Midlands	-2.6	-0.2	3.0	1.4	-0.2
Northern Ireland	0.5	-0.7	0.5	3.2	2.5
Yorkshire and Humberside	-2.0	-0.2	1.4	2.2	-0.1
North West England	0.4	-1.1	2.9	6.8	7.5
North East England	-1.9	-1.8	2.4	2.7	0.1
West Scotland	2.6	0.8	2.9	8.6	14.1
East Scotland	0.8	0.4	2.4	3.4	5.8
North Scotland	2.8	-1.9	-0.6	8.4	7.7

Table 2.12: Change (days) in days of rain ≥ 1mm from 1961 to 2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Mean sea-level pressure

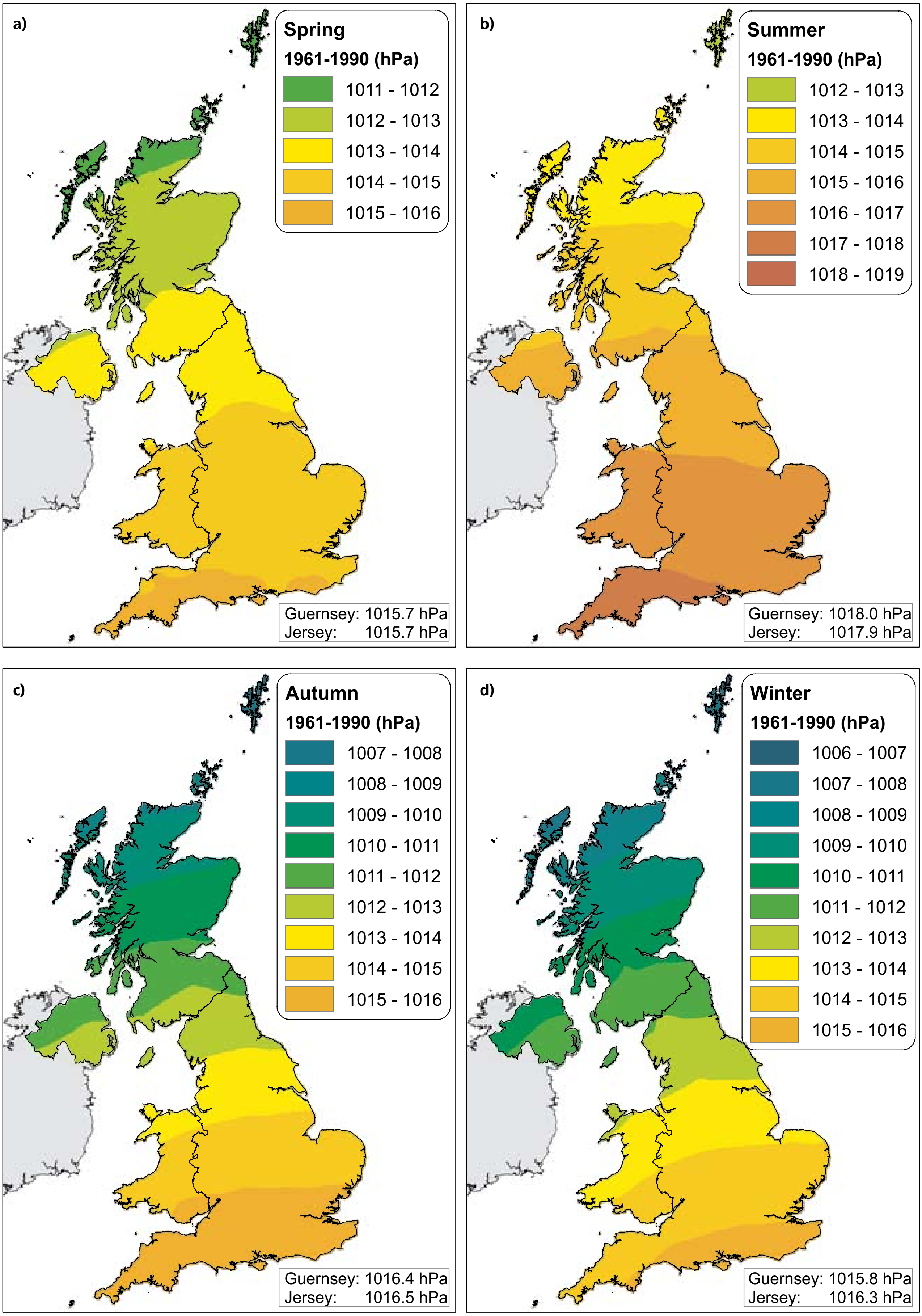


Figure 2.57: 1961-1990 average mean-sea level pressure (hPa) for a) spring, b) summer, c) autumn and d) winter

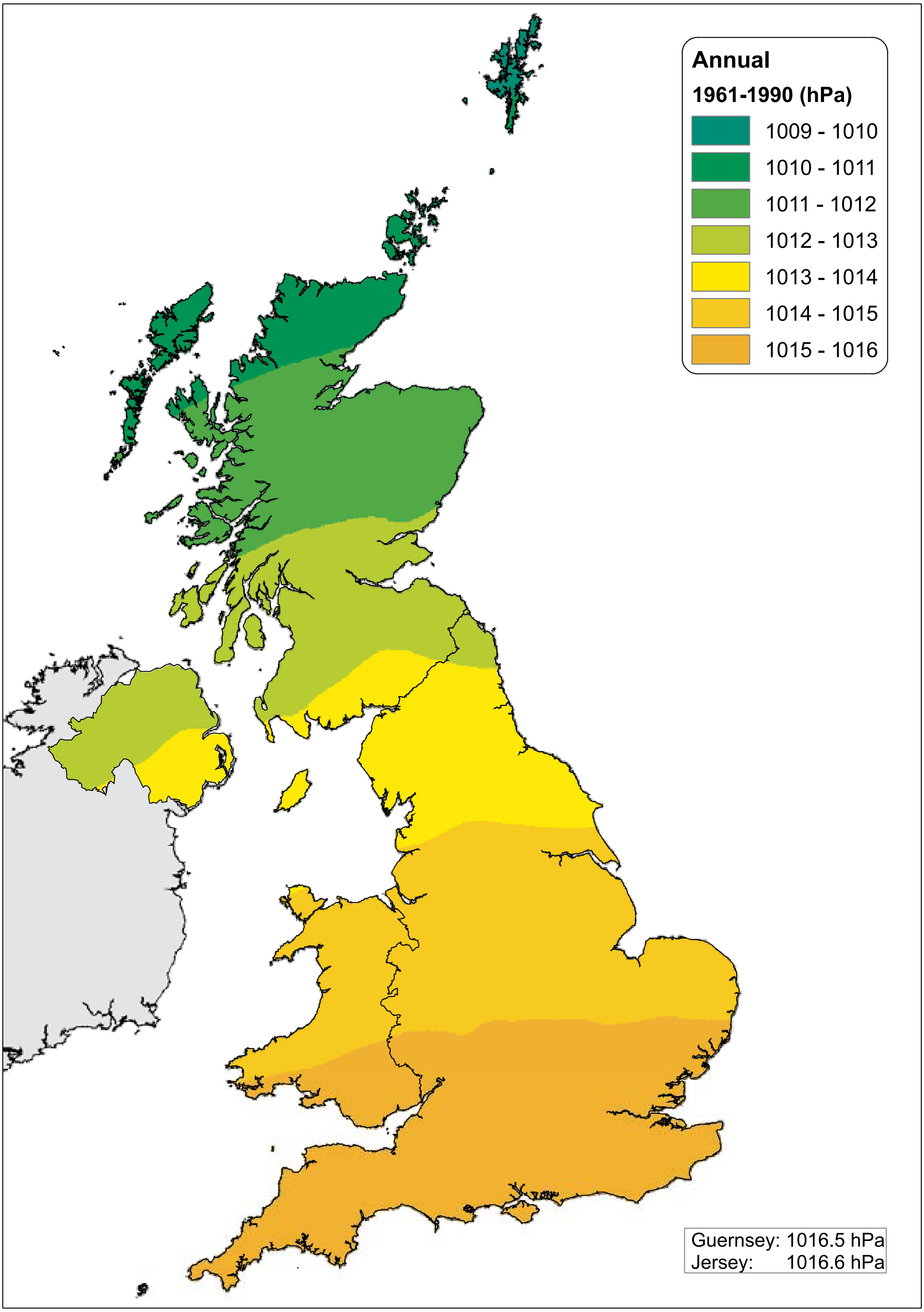


Figure 2.58: Annual average mean sea-level pressure (hPa) for 1961-1990

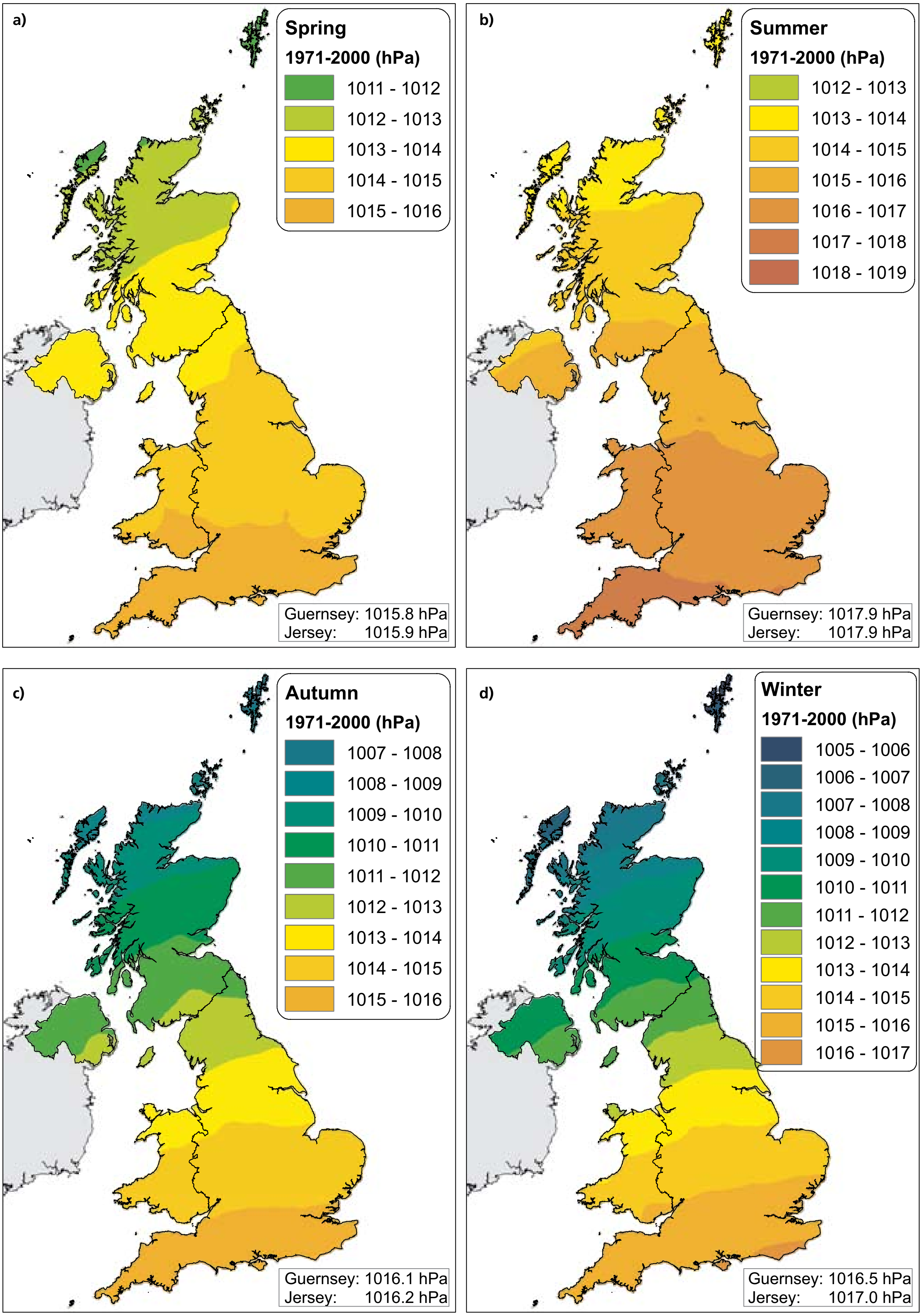


Figure 2.59: 1971-2000 average mean sea-level pressure (hPa) for a) spring, b) summer, c) autumn and d) winter

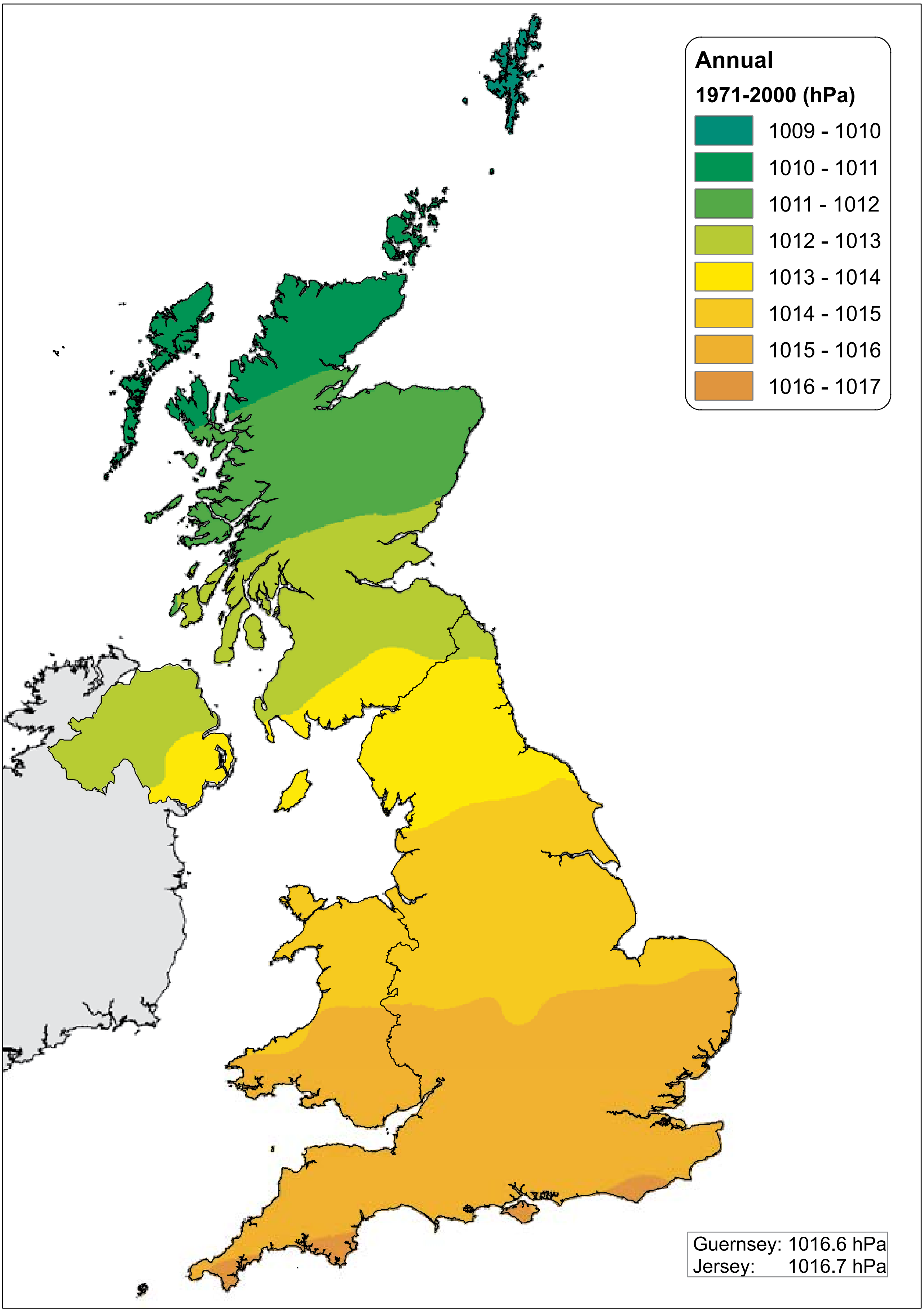


Figure 2.60: Annual average mean-sea level pressure (hPa) for b) 1971-2000

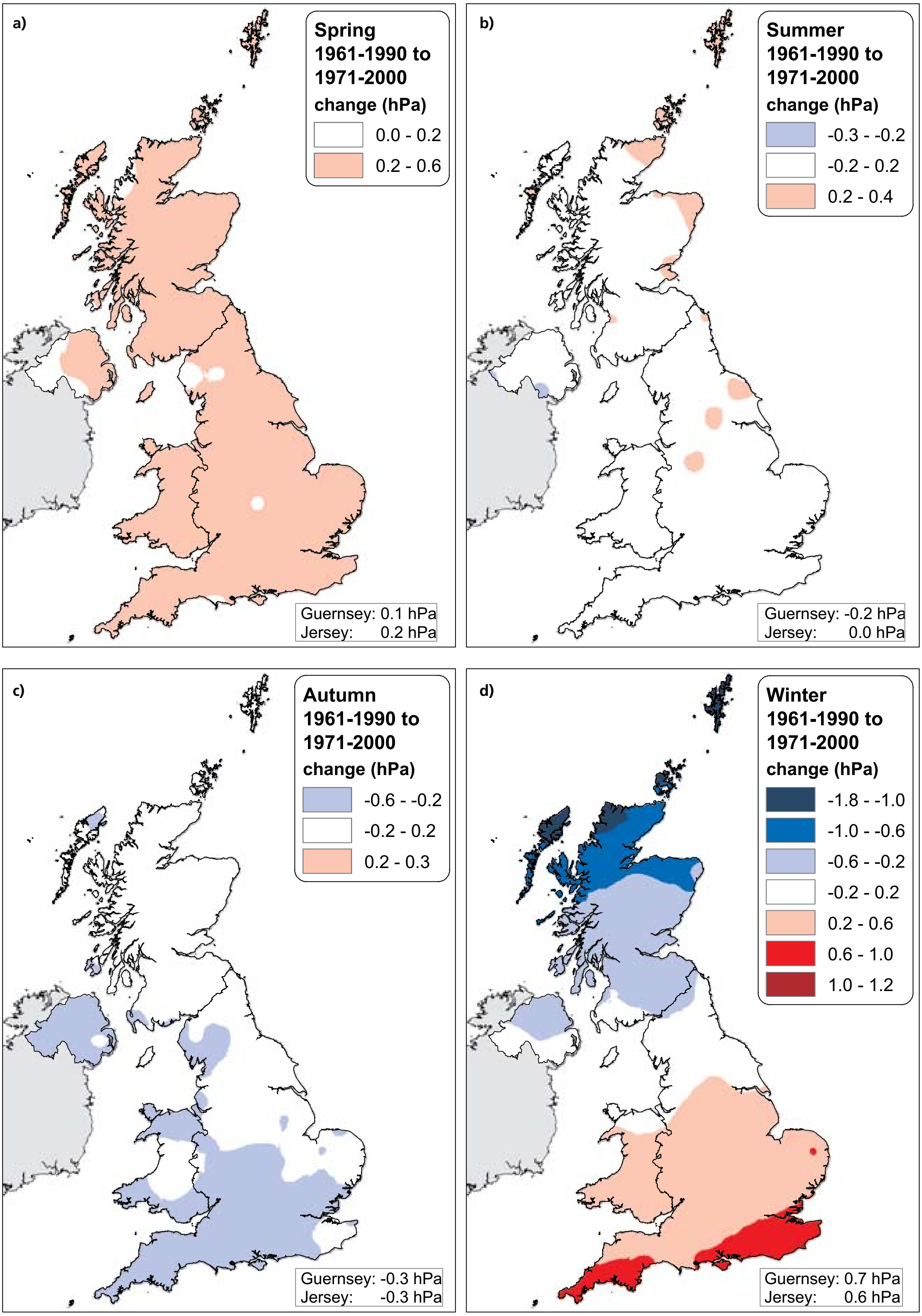


Figure 2.61: Change in mean sea-level pressure (hPa) from 1961-1990 to 1971-2000 for a) spring, b) summer, c) autumn, d) winter

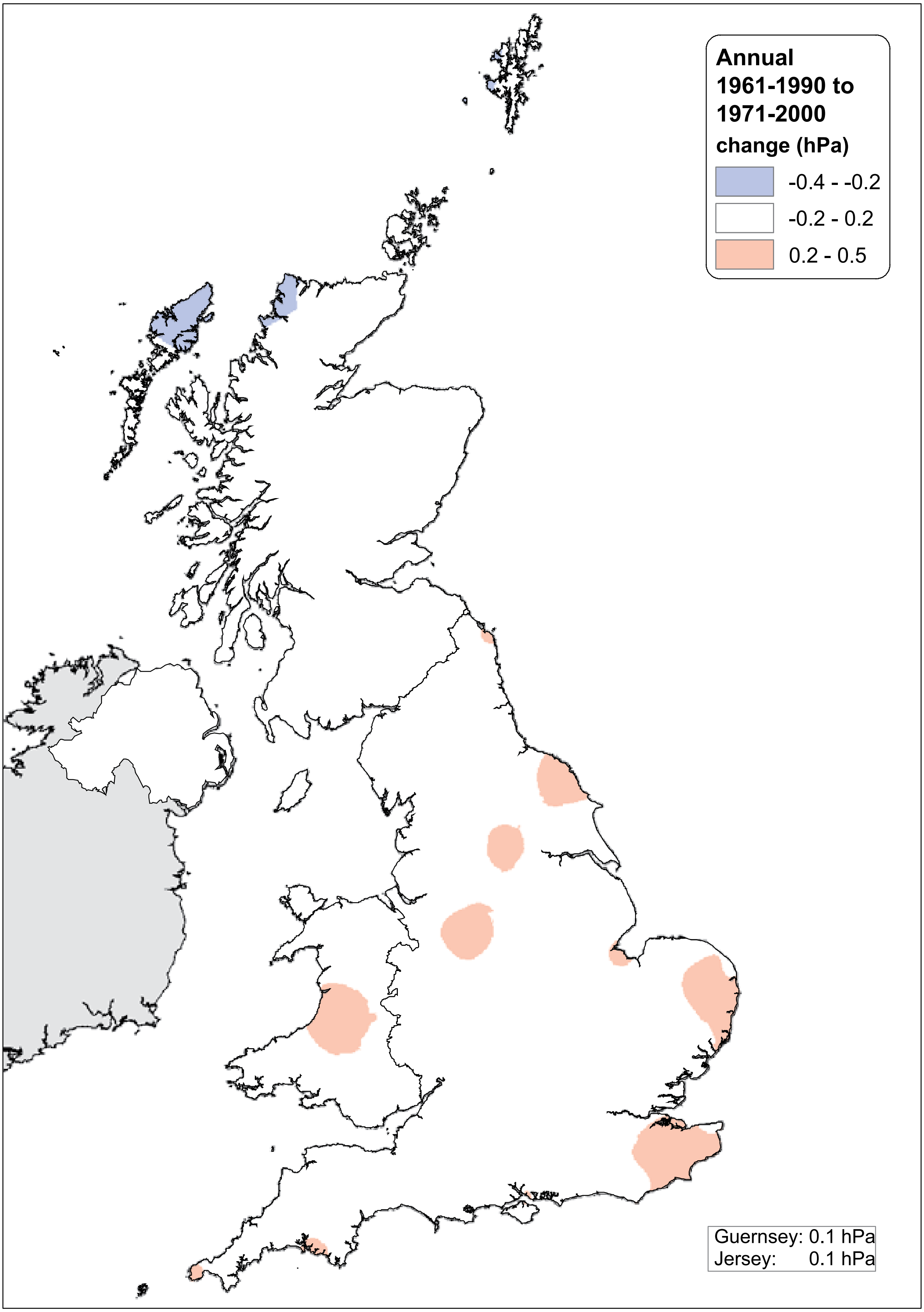


Figure 2.62: Change in mean sea-level pressure (hPa) between 1961-1990 and 1971-2000

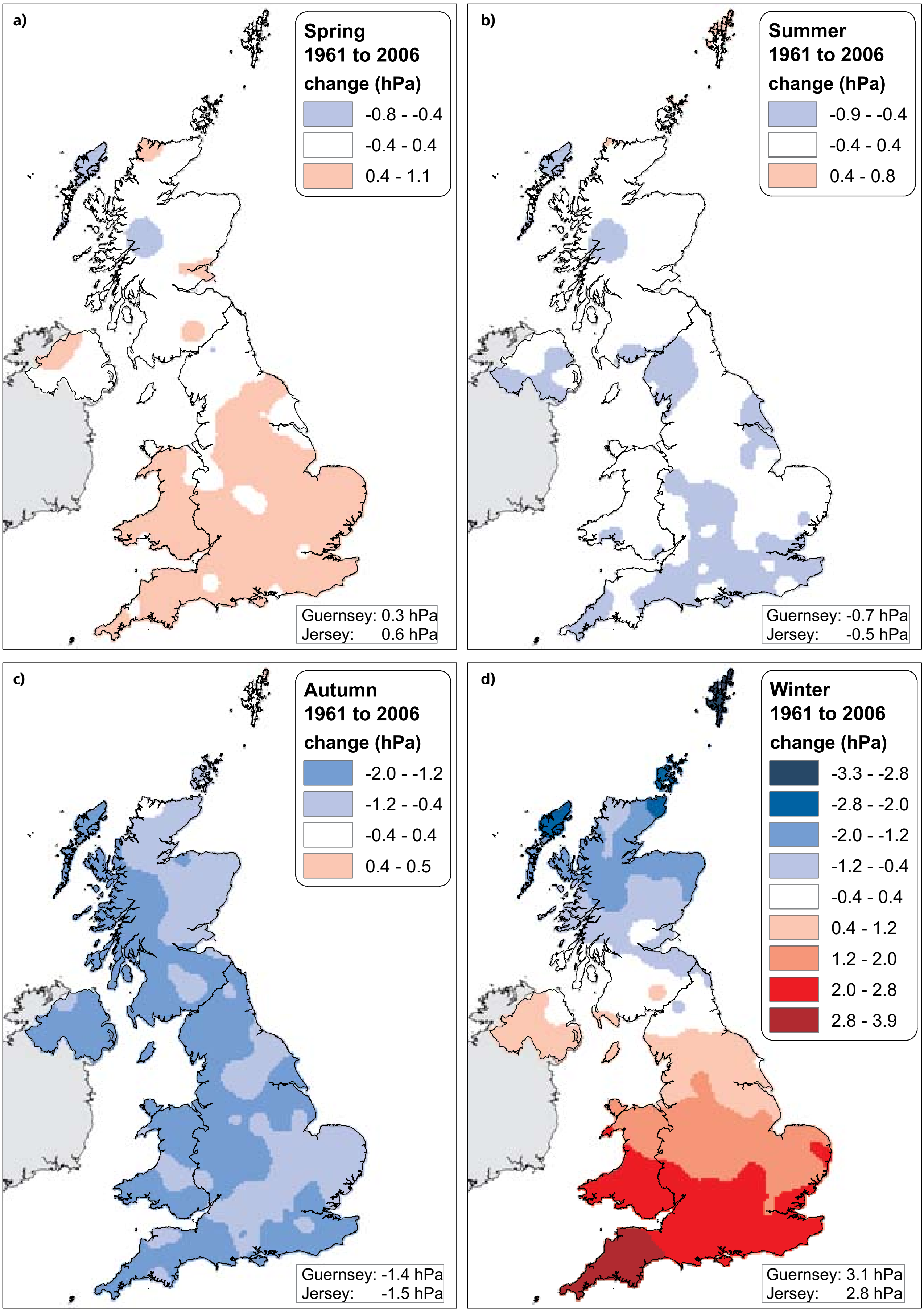


Figure 2.63: Change in mean sea-level pressure (hPa) from 1961-2006 based on a linear trend for a) spring, b) summer, c) autumn, d) winter

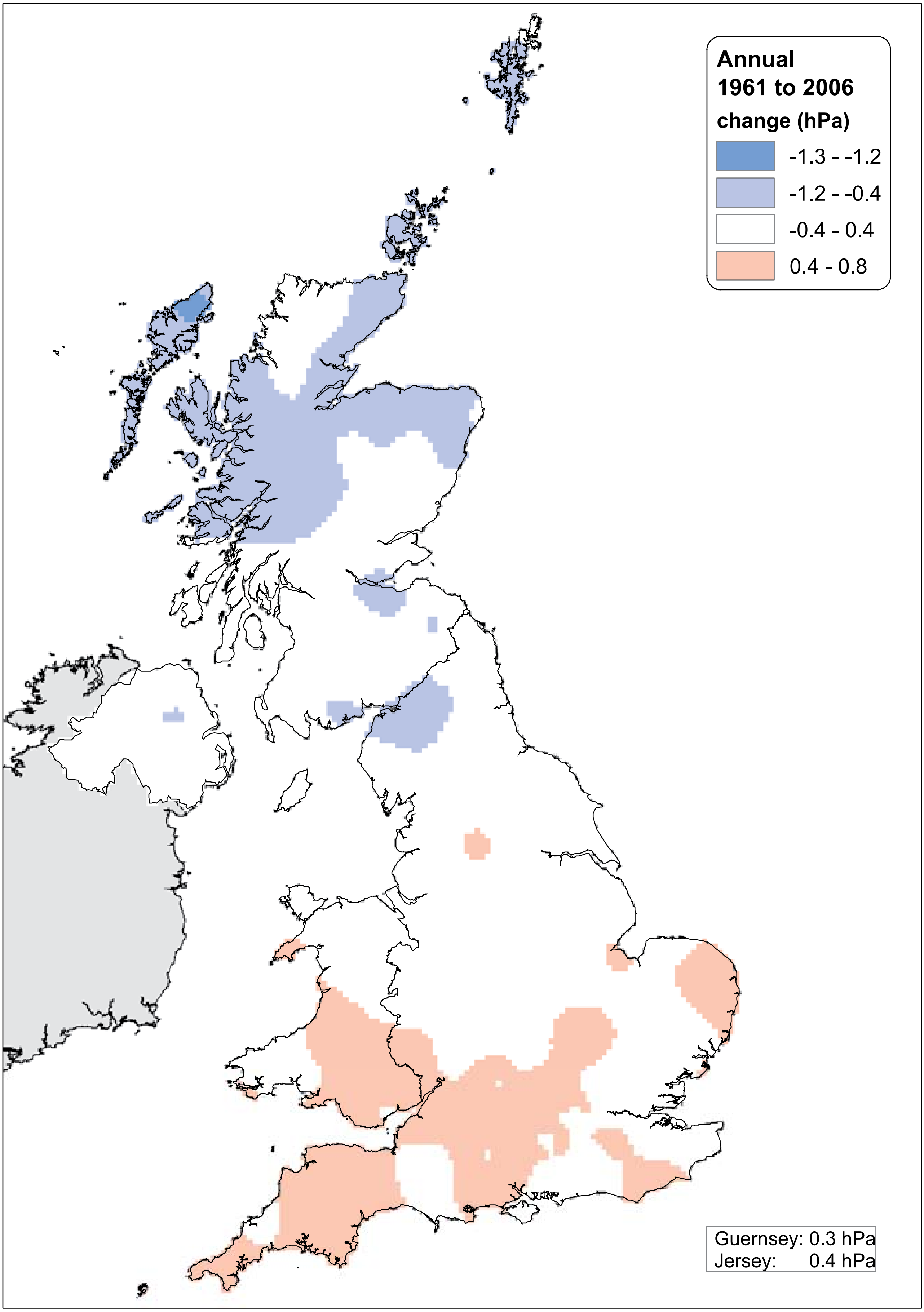
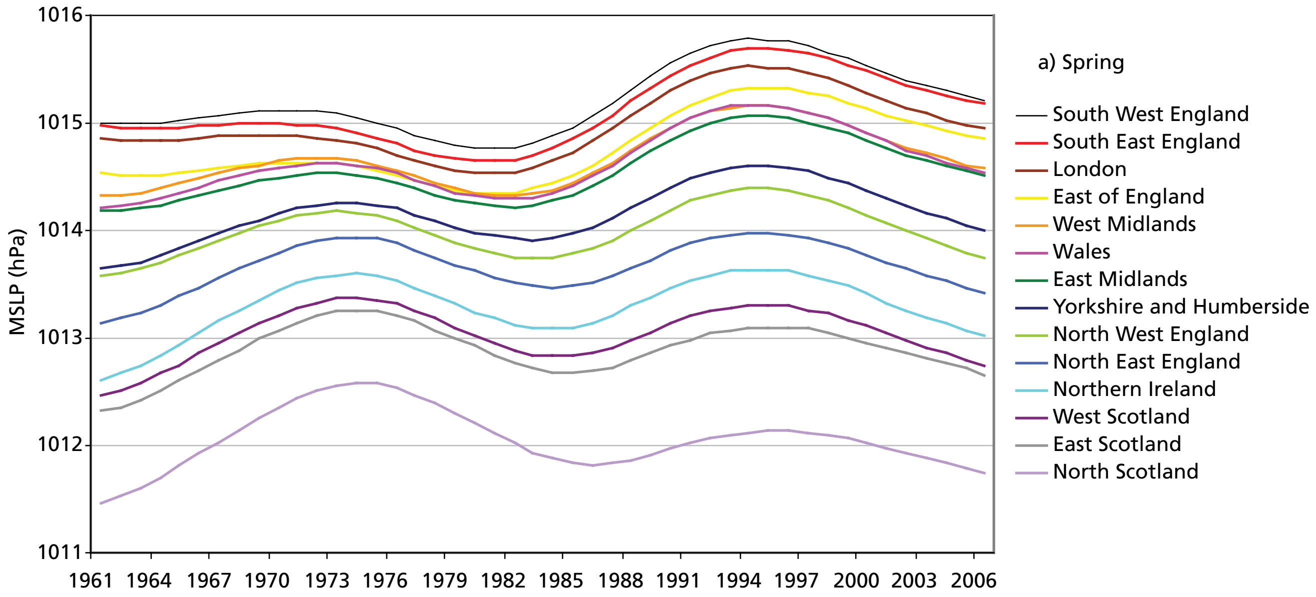
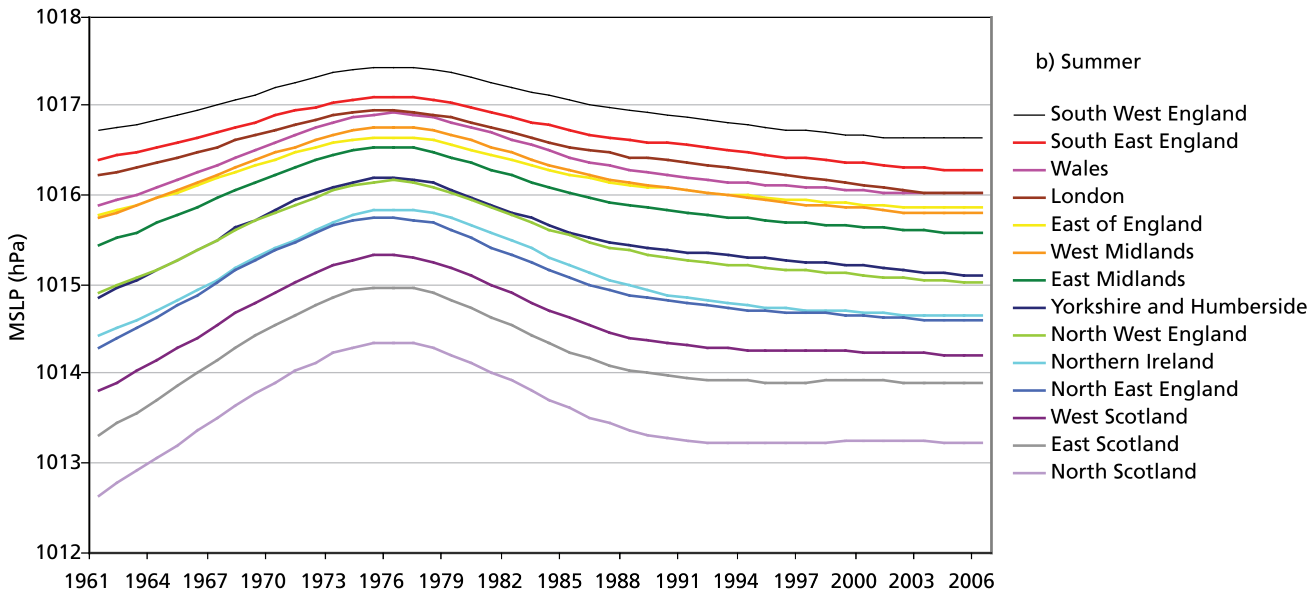
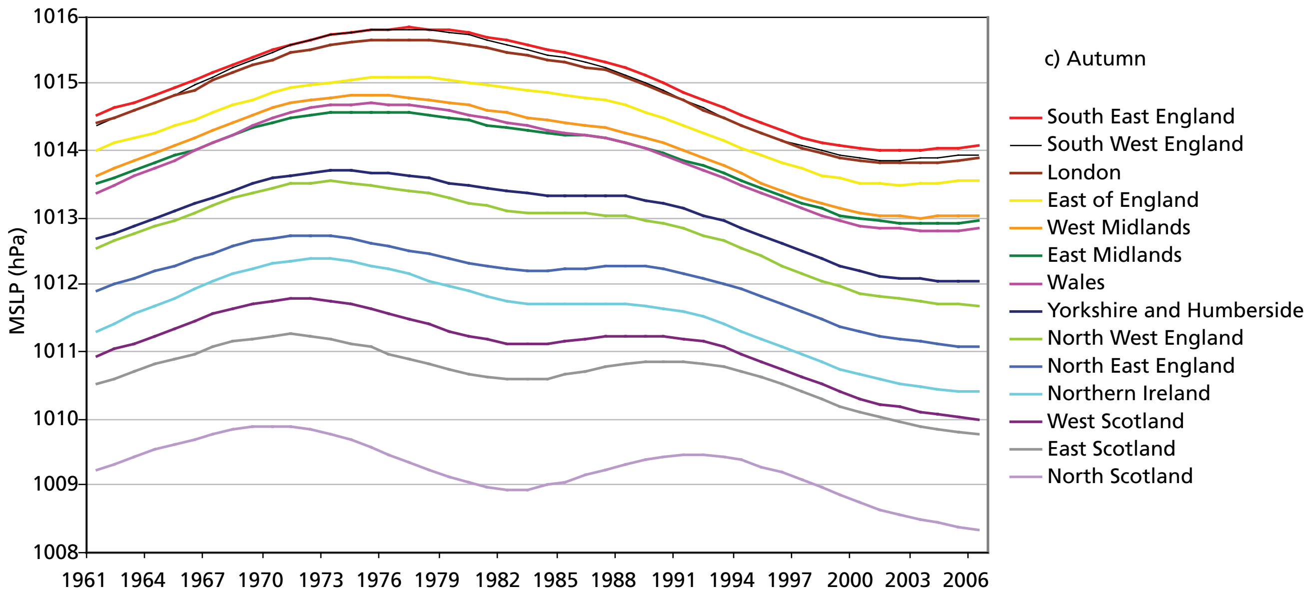
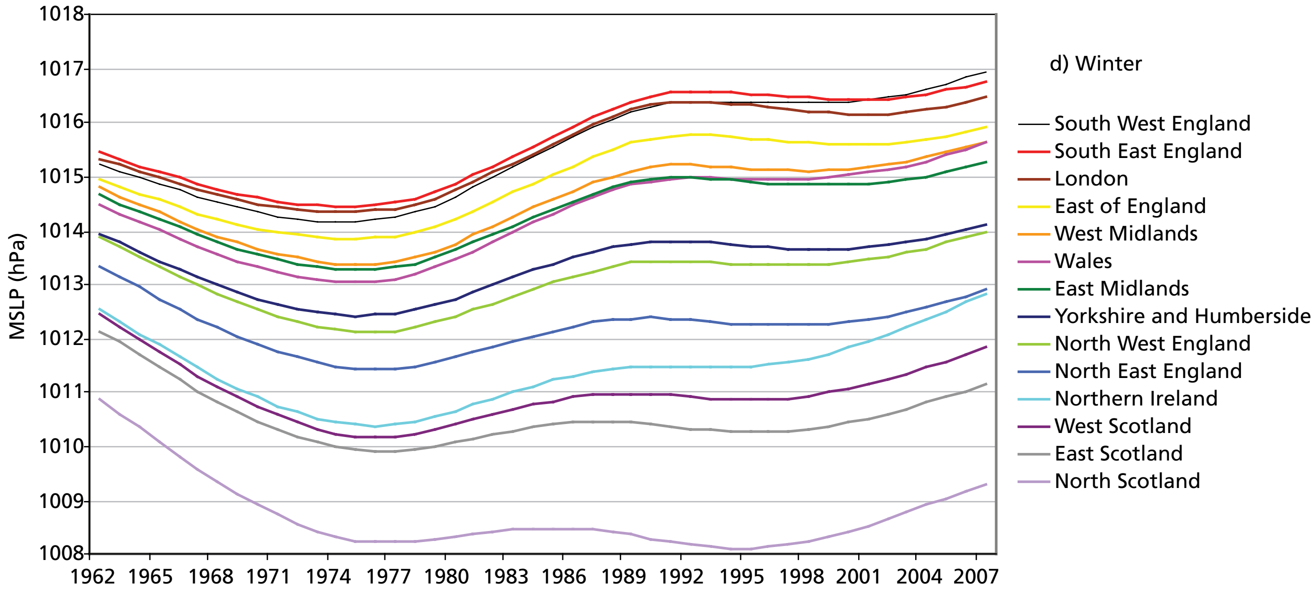


Figure 2.64: Change in annual average mean sea-level pressure (hPa) between 1961-1990 and 1991-2006


a) Spring
MSLP (hPa)
1016
1015
1014
1013
1012
1011
1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006
South West England
South East England
London
East of England
West Midlands
Wales
East Midlands
Yorkshire and Humberside
North West England
North East England
Northern Ireland
West Scotland
East Scotland
North Scotland


b) Summer
MSLP (hPa)
1018
1017
1016
1015
1014
1013
1012
1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006
South West England
South East England
Wales
London
East of England
West Midlands
East Midlands
Yorkshire and Humberside
North West England
Northern Ireland
North East England
West Scotland
East Scotland
North Scotland


c) Autumn
MSLP (hPa)
1016
1015
1014
1013
1012
1011
1010
1009
1008
1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006
South East England
South West England
London
East of England
West Midlands
East Midlands
Wales
Yorkshire and Humberside
North West England
North East England
Northern Ireland
West Scotland
East Scotland
North Scotland



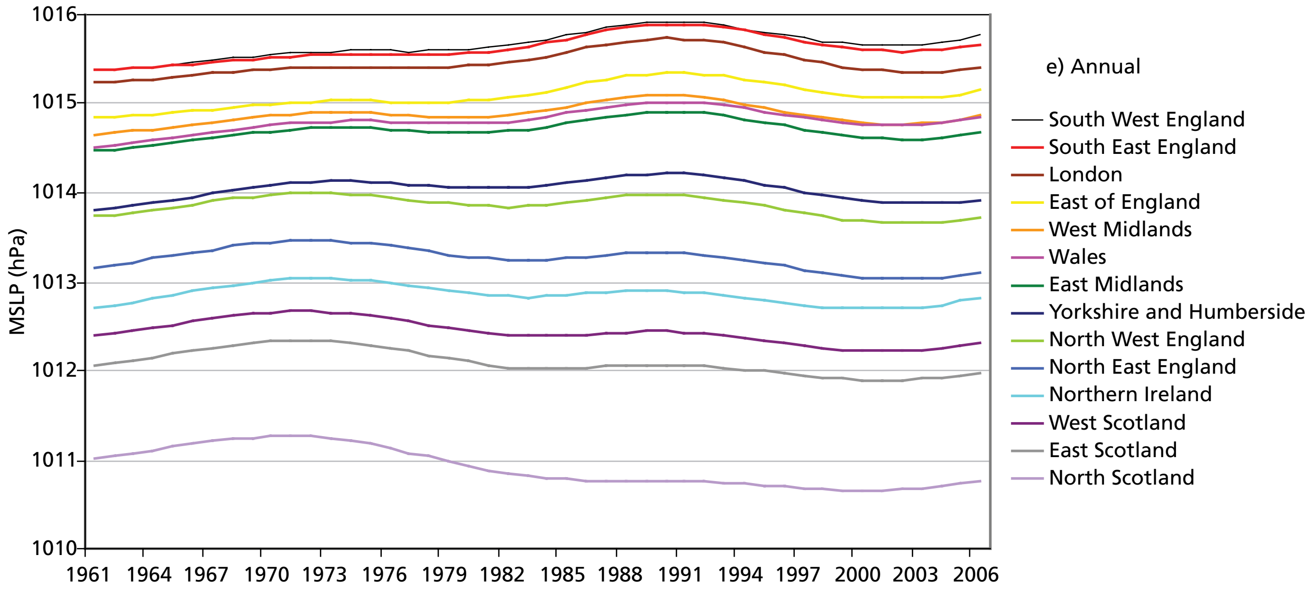


Figure 2.65: Filtered mean sea-level pressure (hPa) by area, 1961-2006 for a) spring, b) summer, c) autumn, d) winter, e) annual

Area	Spring	Summer	Autumn	Winter	Annual
South West England	0.6	-0.4	-1.3	2.8	0.5
South East England	0.6	-0.4	-1.2	2.4	0.4
London	0.5	-0.6	-1.3	2.1	0.3
Wales	0.6	-0.3	-1.3	2.1	0.3
East of England	0.7	-0.3	-1.1	1.9	0.4
West Midlands	0.5	-0.4	-1.3	1.7	0.2
East Midlands	0.5	-0.3	-1.2	1.5	0.2
Northern Ireland	0.3	-0.4	-1.5	0.8	-0.1
Yorkshire and Humberside	0.4	-0.3	-1.2	0.9	0.1
North West England	0.2	-0.4	-1.4	0.7	-0.1
North East England	0.2	-0.3	-1.3	0.0	-0.2
West Scotland	0.1	-0.2	-1.4	-0.2	-0.3
East Scotland	0.1	-0.1	-1.0	-0.8	-0.3
North Scotland	-0.1	-0.1	-1.1	-1.6	-0.6

Table 2.13: Change in mean sea-level pressure (hPa) from 1961-2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

Mean wind speed

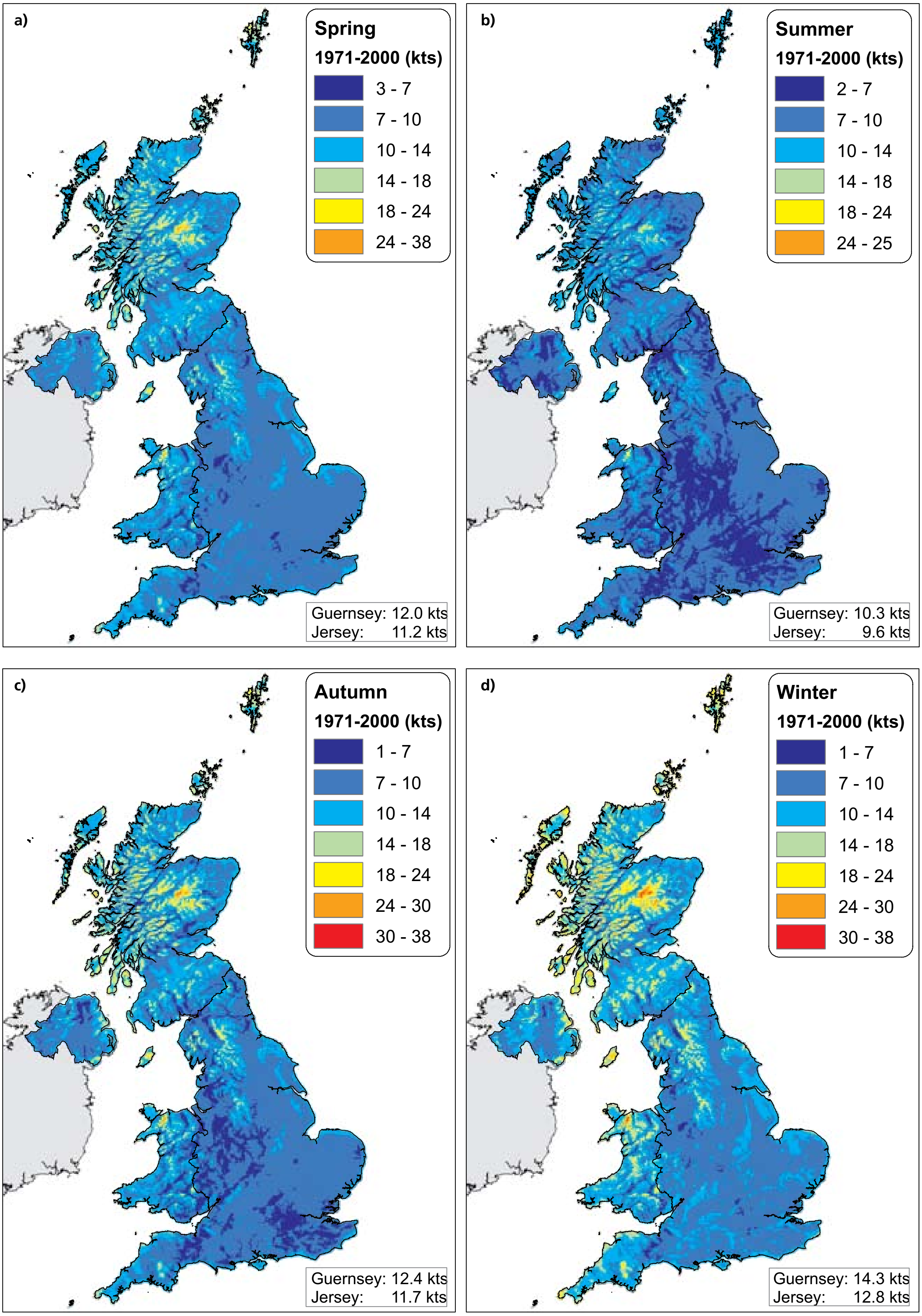


Figure 2.66: 1971-2000 average 10m mean wind speed (knots) for a) spring, b) summer, c) autumn and d) winter

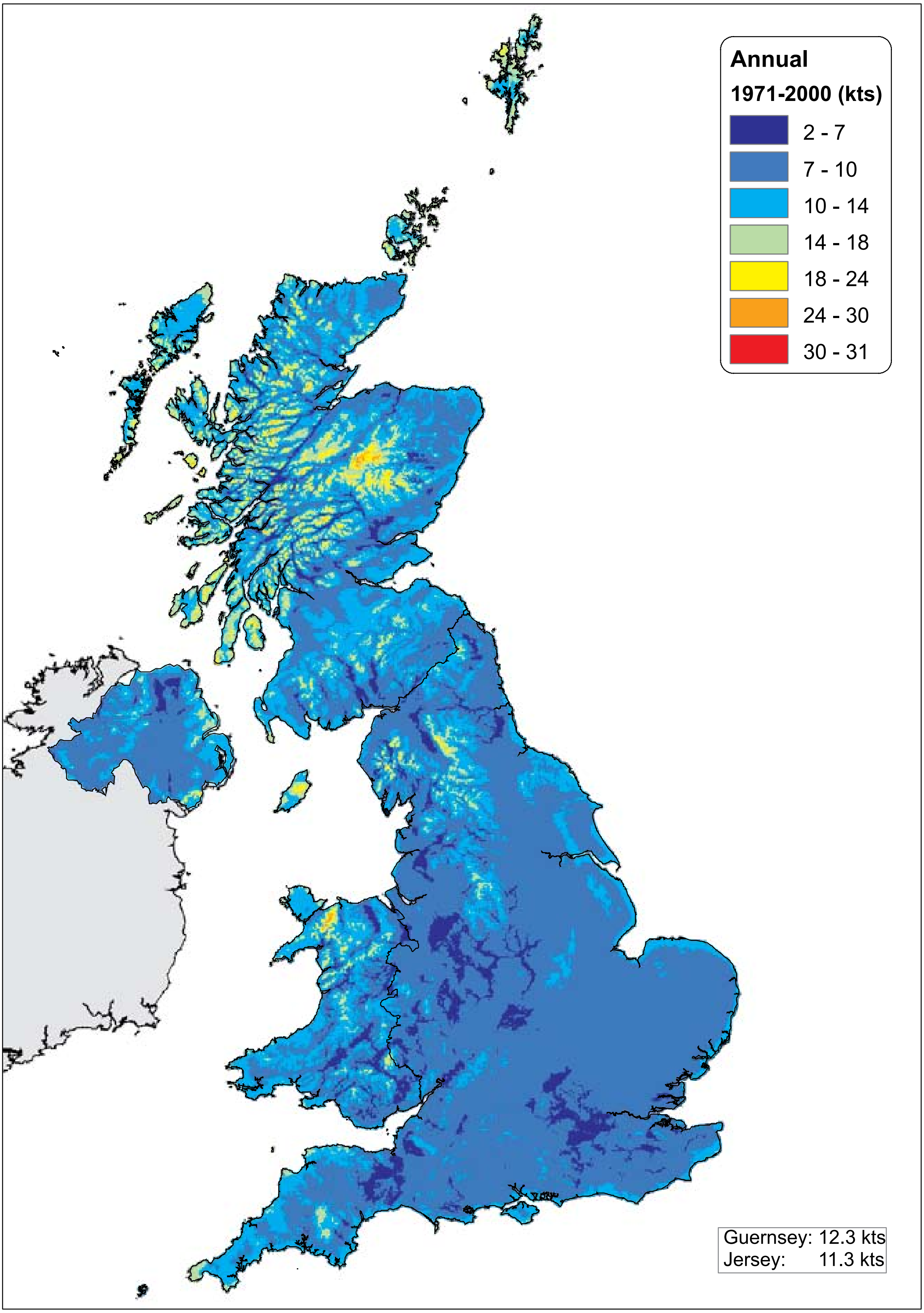


Figure 2.67: Annual average 10m mean wind speed (knots) for 1971-2000

Relative humidity

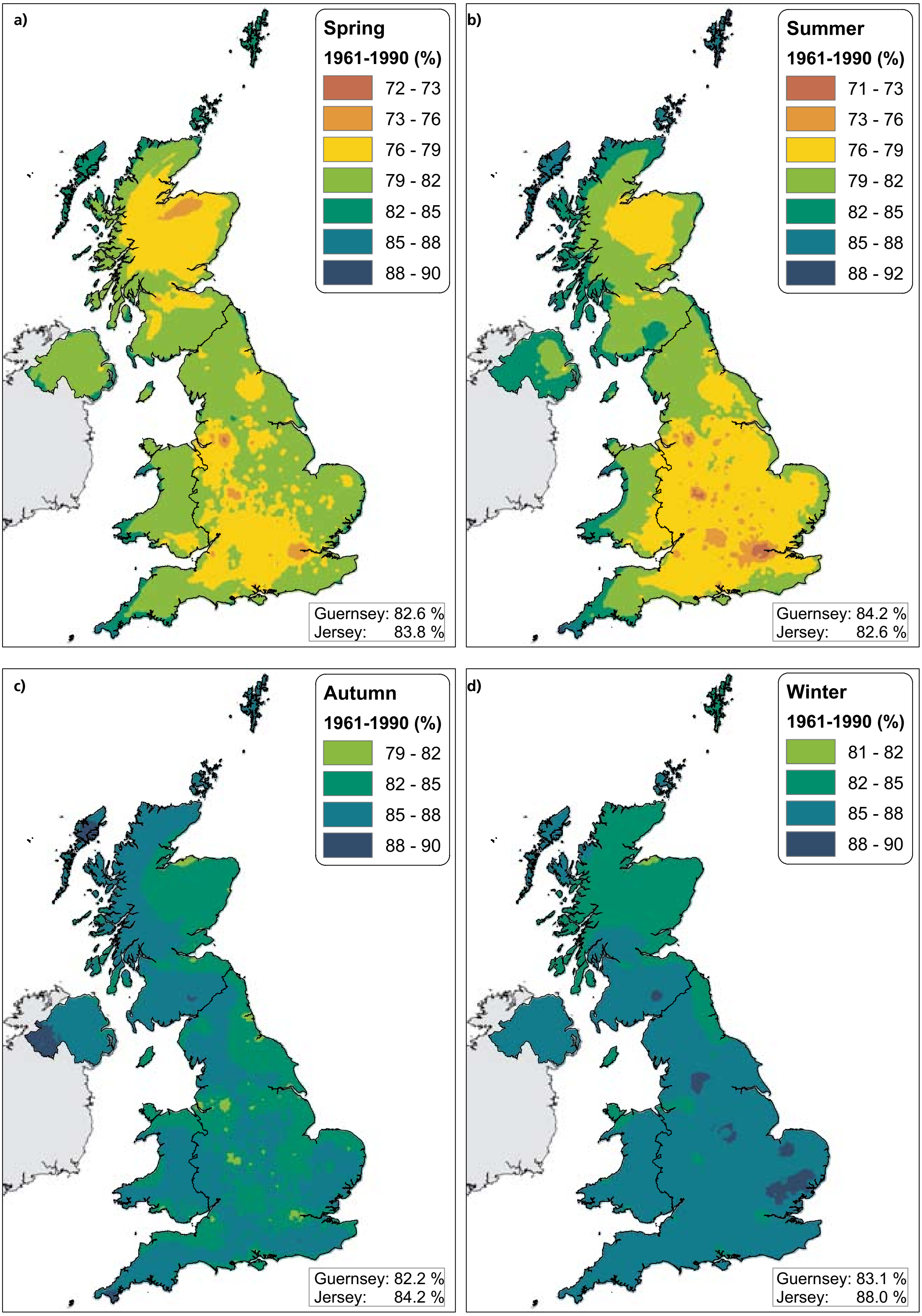


Figure 2.68: 1961-1990 average relative humidity (%) for a) spring, b) summer, c) autumn and d) winter

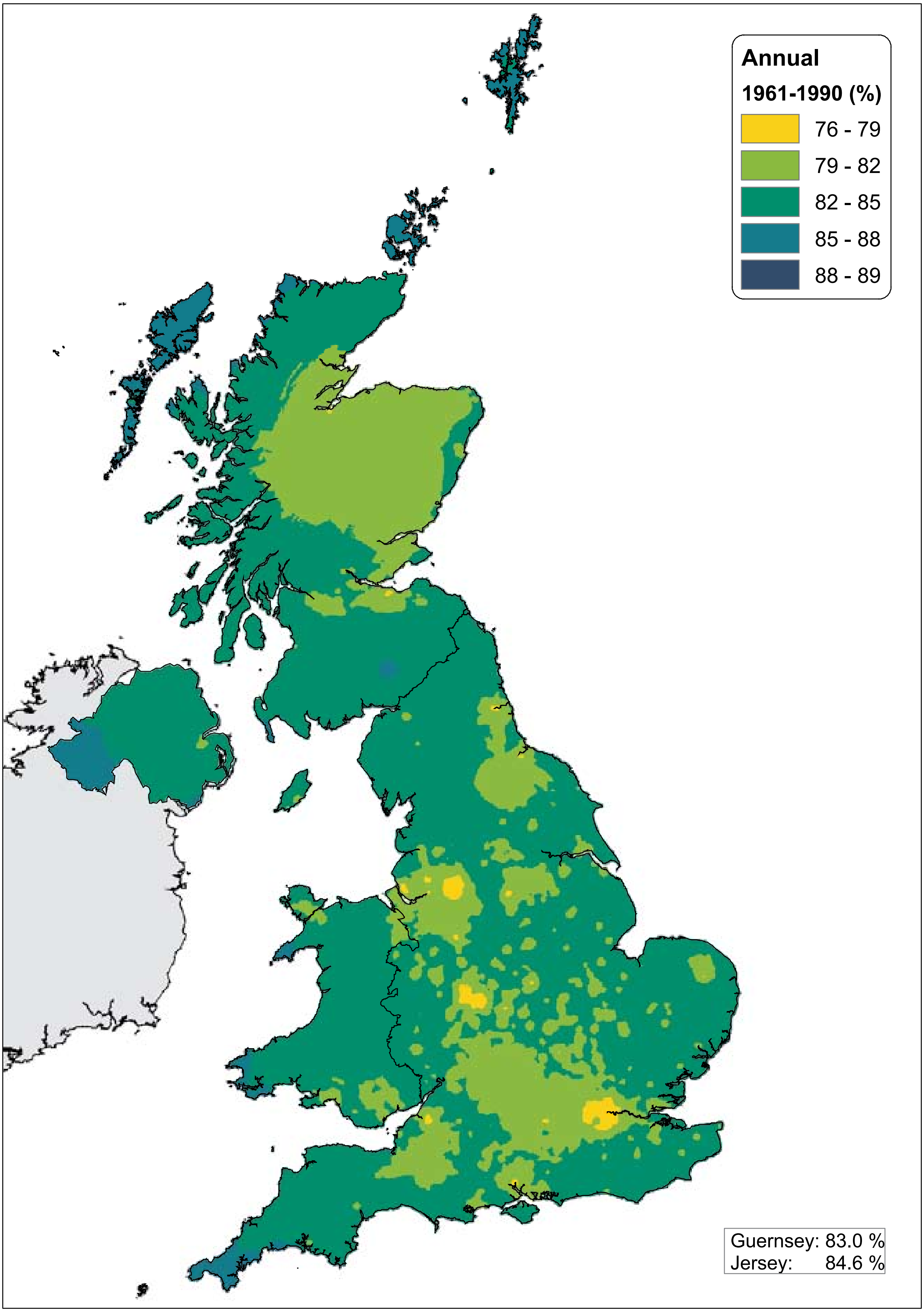


Figure 2.69: Annual average relative humidity (%) for 1961-1990

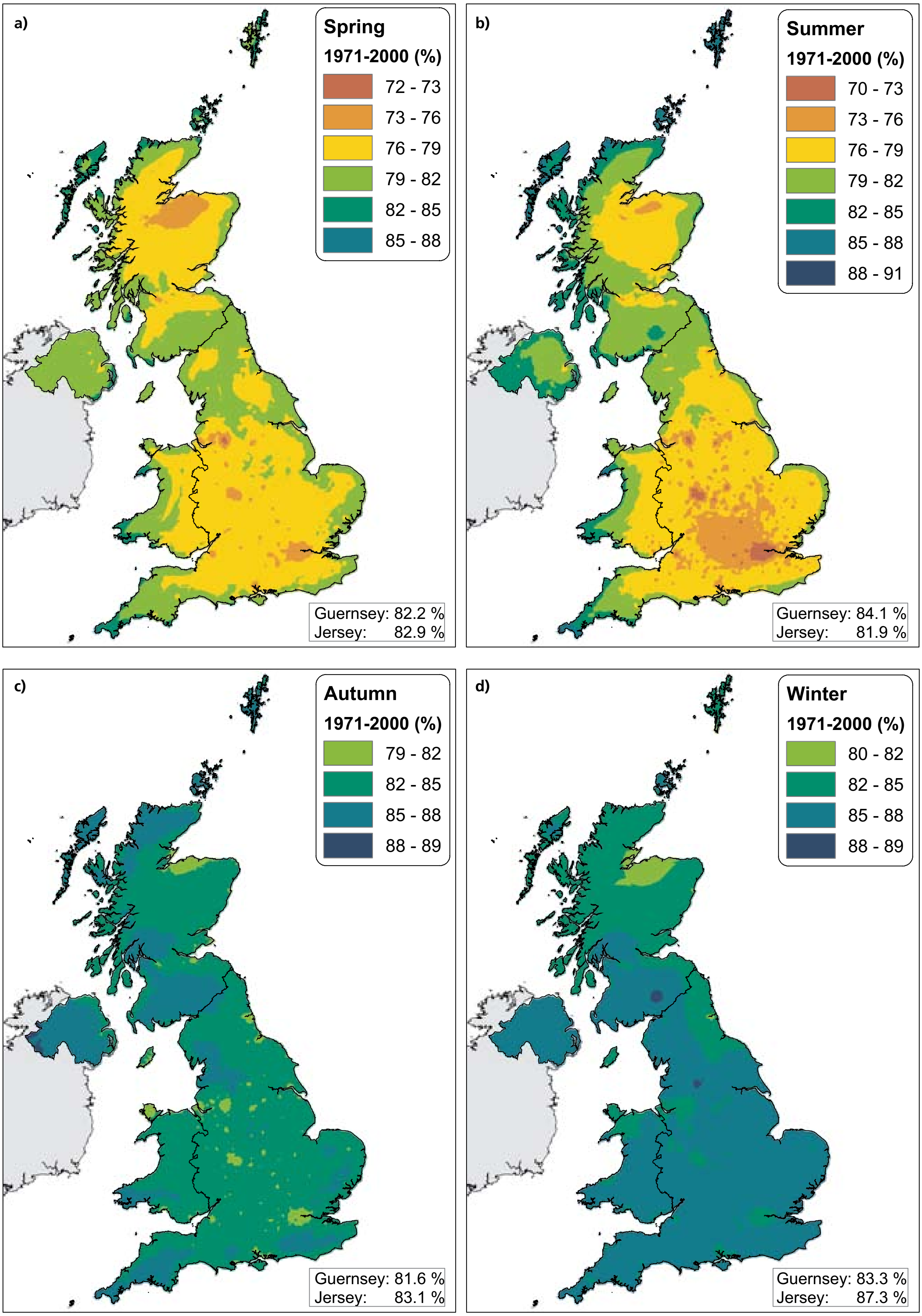


Figure 2.70: 1971-2000 average relative humidity (%) for a) spring, b) summer, c) autumn and d) winter

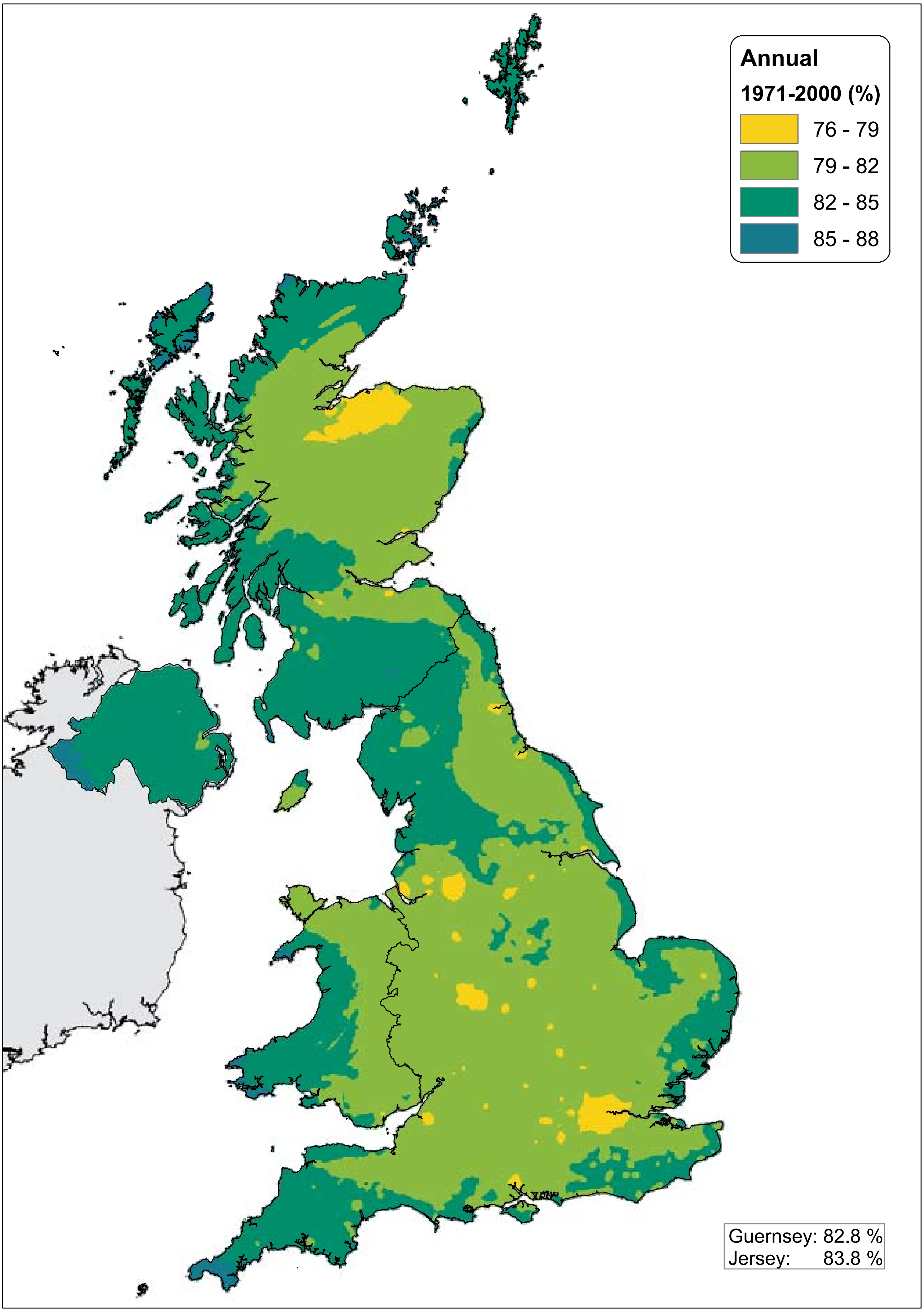


Figure 2.71: Annual average relative humidity (%) for 1971-2000

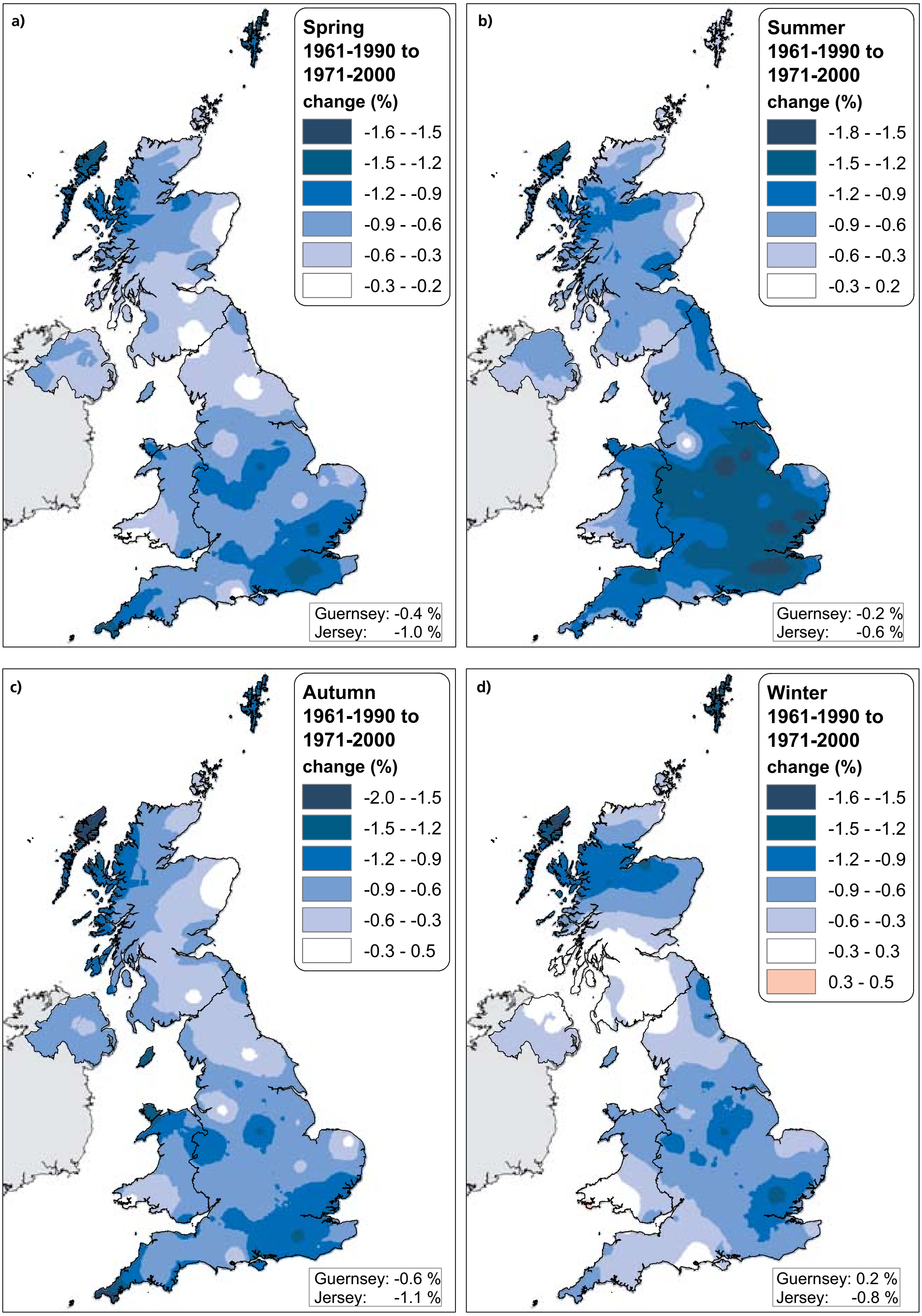


Figure 2.72: Change in relative humidity (%) from 1961-1990 to 1971-2000 for a) spring, b) summer, c) autumn, d) winter

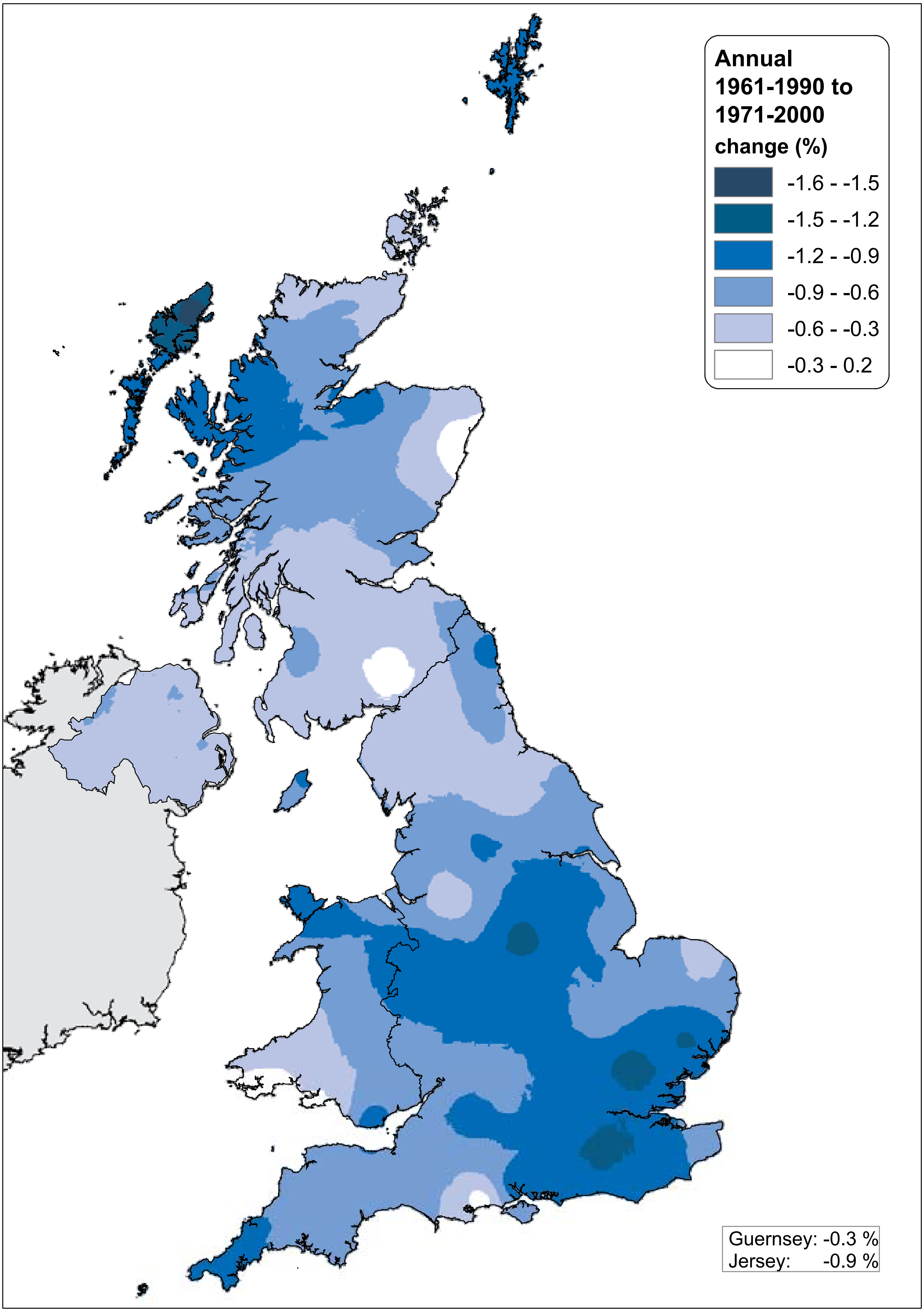


Figure 2.73: Change in annual average relative humidity (%) between 1961-1990 and 1971-2000

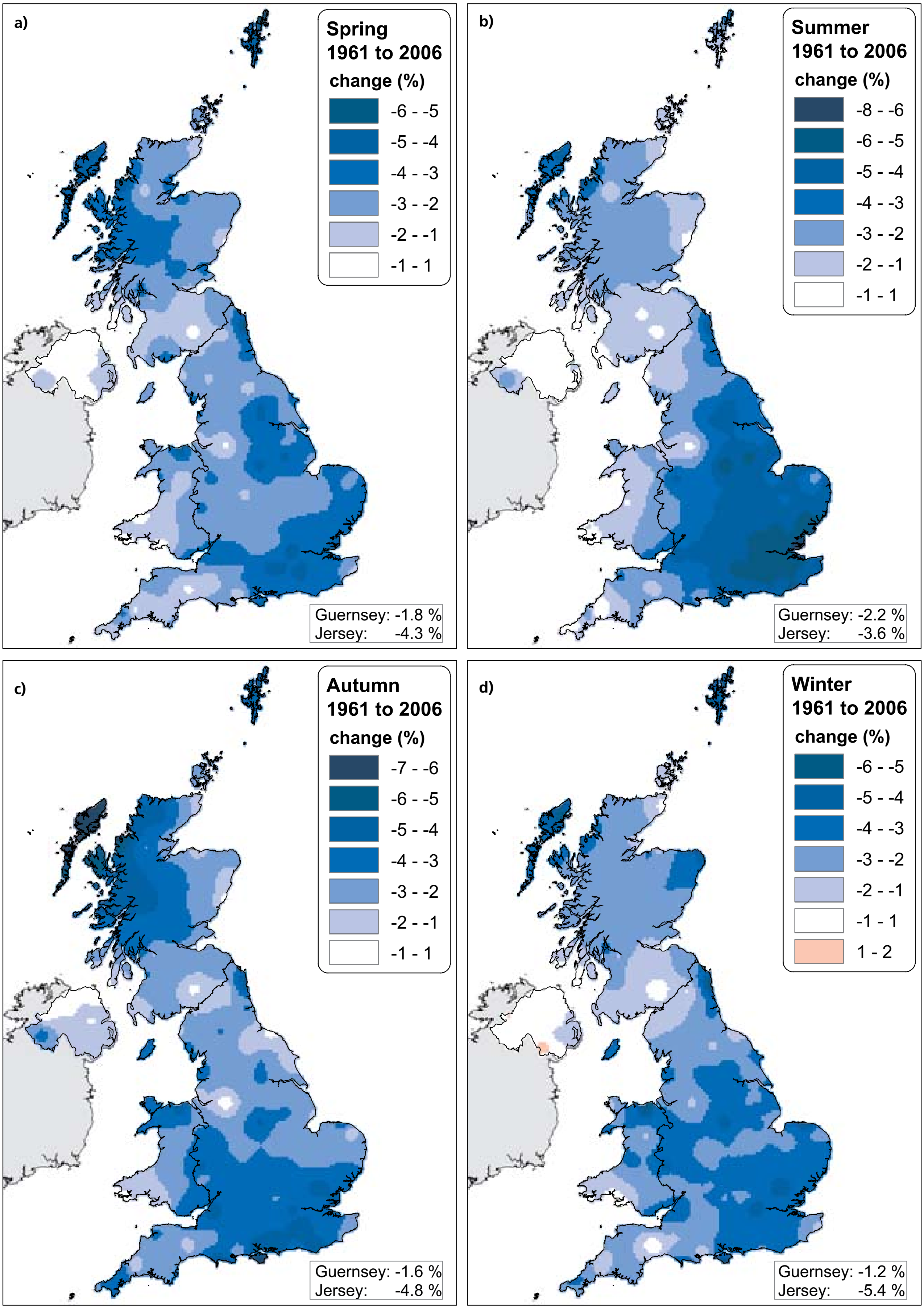


Figure 2.74: Change in relative humidity (%) from 1961-2006 based on a linear trend for a) spring, b) summer, c) autumn, d) winter

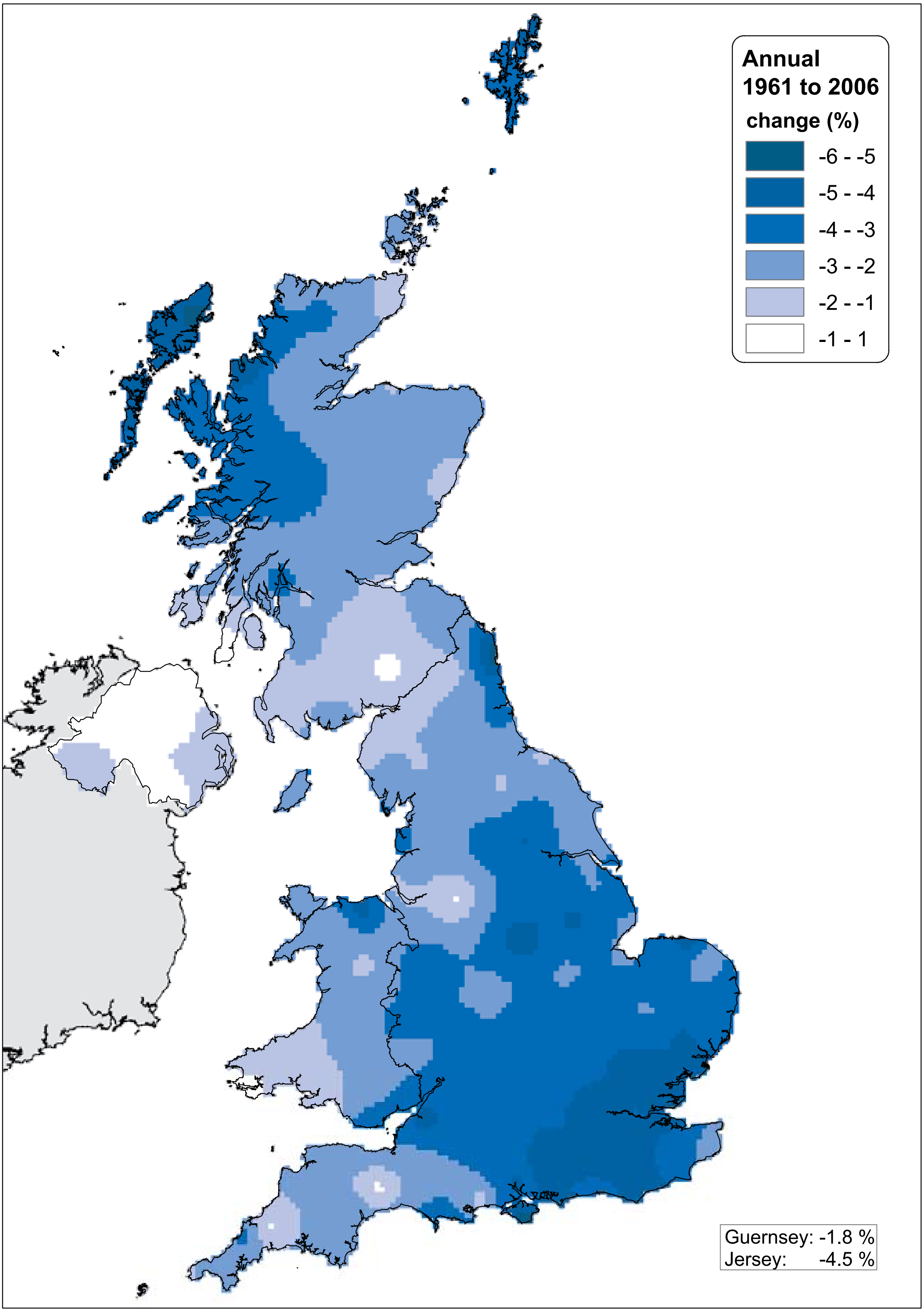
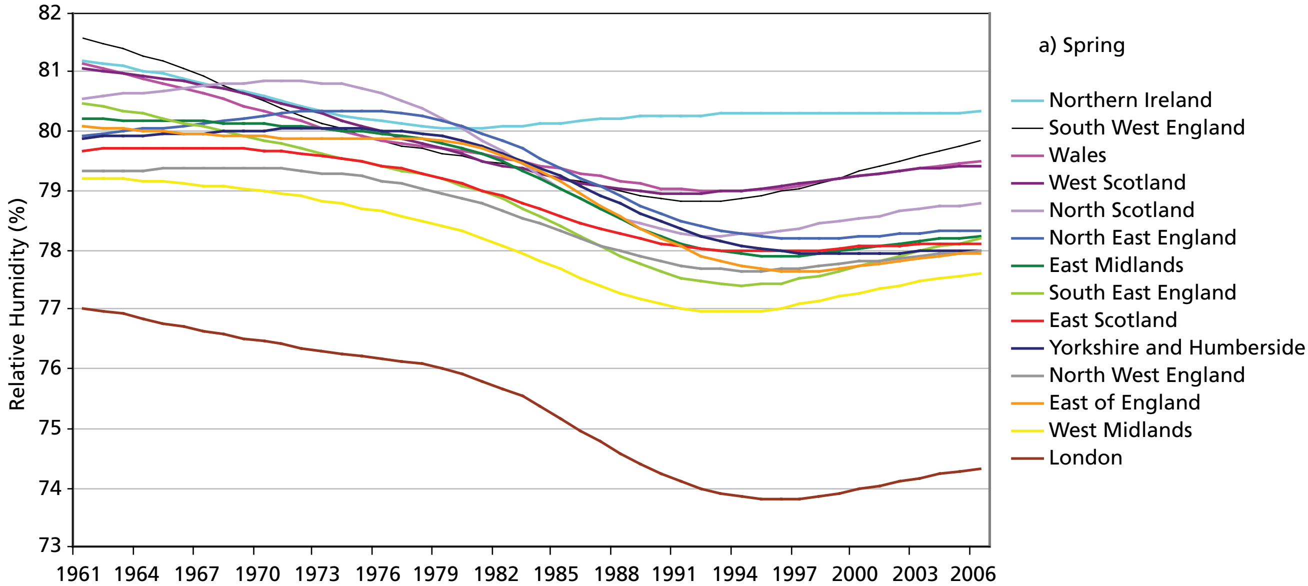
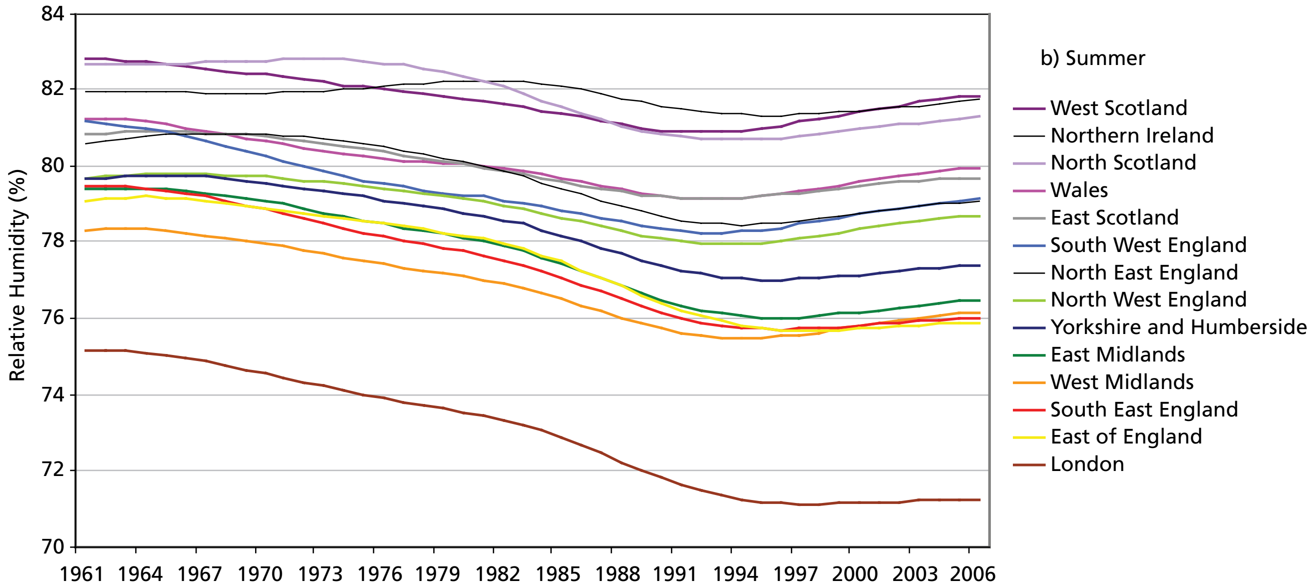


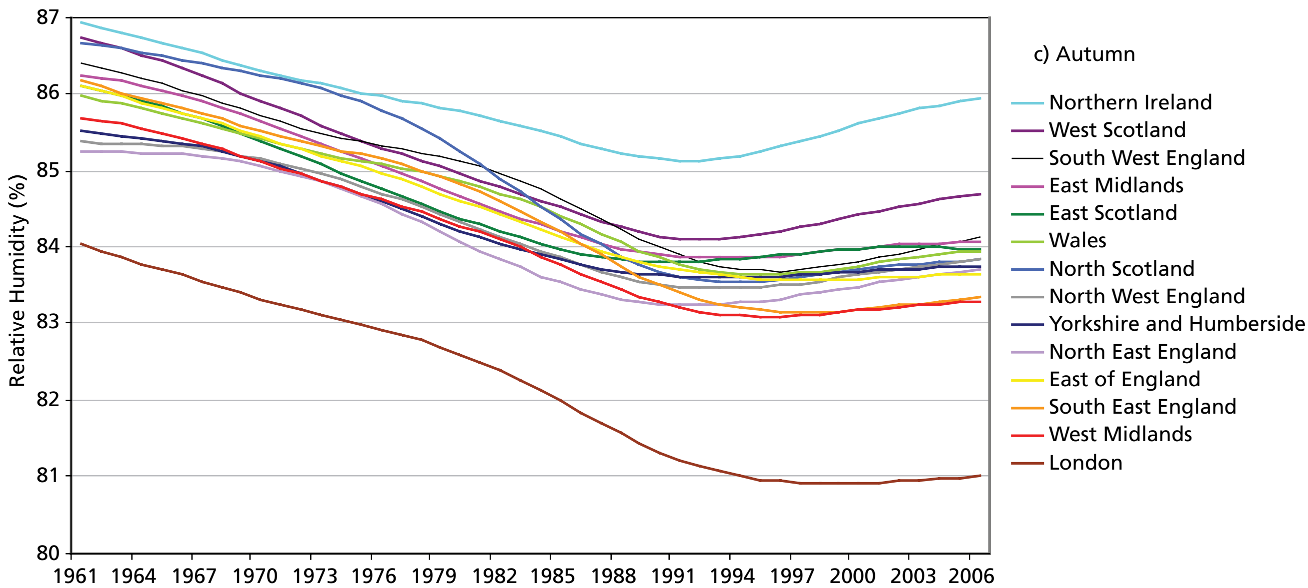
Figure 2.75: Change in annual average relative humidity (%) from 1961-2006 based on a linear trend



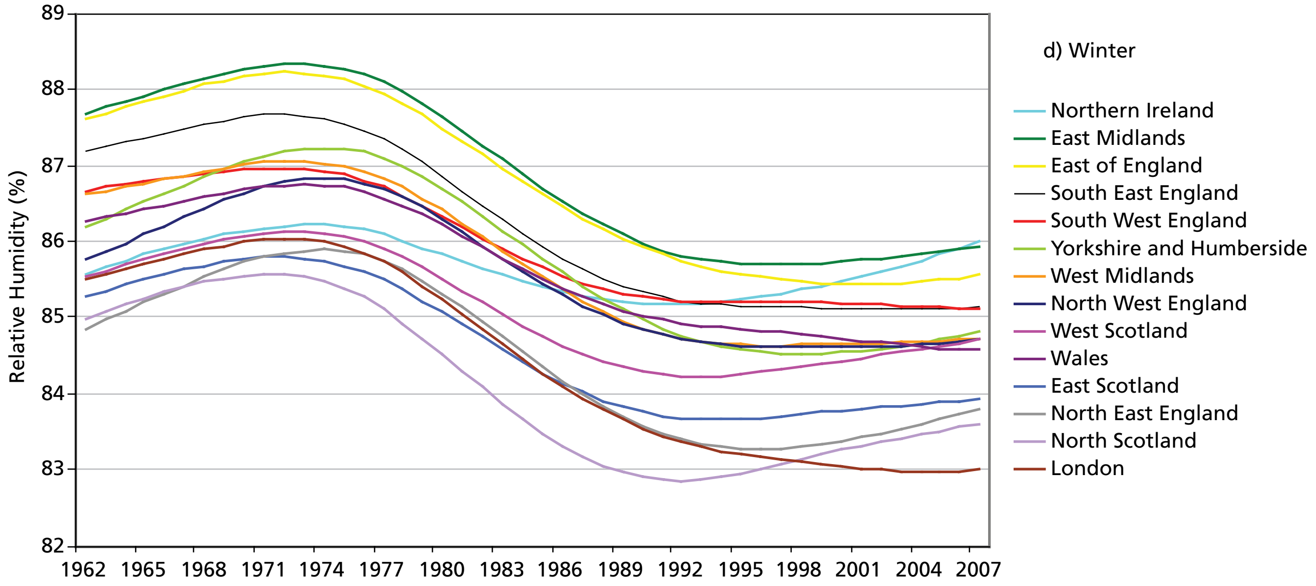
82
81
80
79
78
77
76
75
74
73
Relative Humidity (%)
1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006
a) Spring
Northern Ireland
South West England
Wales
West Scotland
North Scotland
North East England
East Midlands
South East England
East Scotland
Yorkshire and Humberside
North West England
East of England
West Midlands
London



84
82
80
78
76
74
72
70
Relative Humidity (%)
1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006
b) Summer
West Scotland
Northern Ireland
North Scotland
Wales
East Scotland
South West England
North East England
North West England
Yorkshire and Humberside
East Midlands
West Midlands
South East England
East of England
London



87
86
85
84
83
82
81
80
Relative Humidity (%)
1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006
c) Autumn
Northern Ireland
West Scotland
South West England
East Midlands
East Scotland
Wales
North Scotland
North West England
Yorkshire and Humberside
North East England
East of England
South East England
West Midlands
London



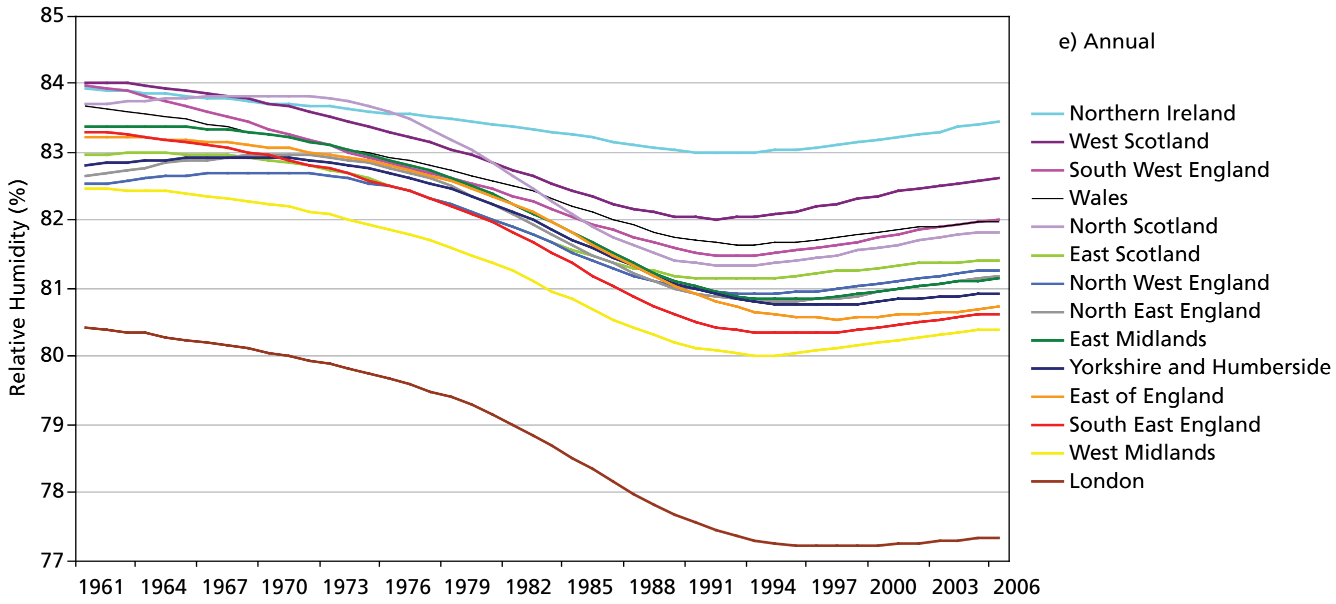


Figure 2.76: Filtered relative humidity (%) by area, 1961-2006 for a) spring, b) summer, c) autumn, d) winter, e) annual

Area	Spring	Summer	Autumn	Winter	Annual
South West England	**-2.3**	**-2.7**	**-3.0**	**-2.4**	**-2.7**
South East England	**-3.4**	**-4.7**	**-3.7**	**-3.3**	**-3.8**
London	**-3.9**	**-5.2**	**-3.9**	**-3.9**	**-4.3**
Wales	**-2.1**	**-1.9**	**-2.7**	**-2.6**	**-2.4**
East of England	**-3.2**	**-4.5**	**-3.1**	**-3.4**	**-3.6**
West Midlands	**-2.6**	**-3.3**	**-3.1**	**-3.1**	**-3.1**
East Midlands	**-3.1**	**-4.2**	**-2.8**	**-3.1**	**-3.3**
Northern Ireland	-0.7	-0.6	-1.4	-0.2	-0.8
Yorkshire and Humberside	**-2.9**	**-3.4**	**-2.3**	**-2.9**	**-2.9**
North West England	**-2.3**	**-1.9**	**-2.3**	**-2.3**	**-2.2**
North East England	**-2.8**	**-2.8**	**-2.3**	**-2.6**	**-2.7**
West Scotland	**-2.2**	**-1.6**	**-2.7**	**-1.9**	**-2.1**
East Scotland	**-2.4**	**-1.9**	**-2.6**	**-2.5**	**-2.4**
North Scotland	**-3.2**	**-2.5**	**-4.0**	**-2.8**	**-3.2**

Table 2.14: Change in relative humidity (%) from 1961 to 2006 by season and area, based on a linear trend (bold type indicates significance of the trend at the 95% level)

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Annex 1: The observed UK climate data set

A1.1 Monthly and annual data

The UK climate data set is presented as a grid of 5km by 5km cells containing month-by-month and year-by-year statistics for 28 climate variables or their derivatives. The grids are based on the GB national grid, extended to cover Northern Ireland and the Isle of Man. Data for the Channel Islands are not currently available. Table A1.1 shows the variables available at a monthly resolution and Table A1.2 those available at an annual resolution. The tables also include further details of each of the available variables and their derivatives, including the year from which values are available. Currently the data set includes variables updated to the end of 2005 with subsequent years expected to be periodically added.

The Met Office archive of UK observations has been used as the source of data for this climate data set. The network of stations for which data has been digitised, and is therefore available for the gridding calculations, changes slightly each

Table A1.1: The monthly variables included in the observed UK climate data set

Climate variable	Definition	First year available
Maximum air temperature	Average of the daily highest air temperatures (°C)	1914
Minimum air temperature	Average of the daily lowest air temperatures (°C)	1914
Mean air temperature	Average of mean daily maximum and mean daily minimum temperatures (°C)	1914
Days of air frost	Count of days when the air minimum temperature is below 0 °C	1961
Days of ground frost	Count of days when the grass minimum temperature is below 0 °C	1961
Mean vapour pressure	Hourly (or 3 hourly) vapour pressure (hPa) averaged over the month	1961
Mean relative humidity	As above but in units of %	1961
Mean wind speed at 10m	Hourly mean wind speed (knots) at a height of 10m above ground level averaged over the month	1969
Mean sea-level pressure	Hourly (or 3 hourly) mean sea-level pressure (hPa) averaged over the month	1961
Total hours of sunshine	Total hours of bright sunshine during the month, based on the Campbell-Stokes recorder	1929
Total precipitation	Total precipitation amount (mm) during the month	1914
Days of rain ≥ 1mm	Number of days with ≥ 1mm precipitation	1961
Days of rain ≥ 10mm	Number of days with ≥ 10mm precipitation	1961
Days of sleet or snow falling	Number of days with sleet or snow falling	1971
Days of snow cover	Number of days with greater than 50% of the ground covered by snow at 0900	1971
Mean cloud cover	Hourly (or 3 hourly) cloud cover (%) averaged over the month	1961

Climate variable	Definition	First year available
Heating Degree Days	∑(15.5 – daily mean temperature) whenever mean temperature <15.5 °C. This assumes both the daily Tmax and Tmin are < 15.5 °C and in other cases weighted increments are used (See Annex 2)	1961
Cooling Degree Days	∑(daily mean temperature – 22) for Tmean > 22 °C. This assumes both the daily Tmax and Tmin are > 22 °C and in other cases weighted increments are used (See Annex 2)	1961
Extreme temperature range	Annual maximum temperature minus annual minimum temperature	1961
Growing season length	Period bounded by daily mean temperature >5 °C for >5 consecutive days and daily mean temperature <5 °C for >5 consecutive days	1961
Summer 'heatwave' duration	∑days with daily maximum >3 °C above 1961-90 daily normal for ≥5 consecutive days (May-Oct)	1961
Winter 'heatwave' duration	As summer heatwave but for Nov-Apr	1961
Summer 'cold wave' duration	∑days with daily minimum >3 °C below 1961-90 daily normal for ≥5 consecutive days (May-Oct)	1961
Winter 'cold wave' duration	As summer cold wave, but for Nov-Apr	1961
Maximum number of consecutive dry days	Longest spell of consecutive days with precipitation ≤ 0.2mm during the year	1961
Greatest 5-day precipitation total	Greatest total precipitation amount (mm) for 5 consecutive days during the year	1961
Rainfall intensity	Total precipitation on days with ≥1mm divided by count of days with ≥1mm during the year	1961

Table A1.2: The annual variables included in the observed UK climate data set

month, and the methods used are designed to reduce the effect of these changes on the consistency of the datasets through time. Table A1.3 shows, by variable, the average number of stations used before and after 1961. For precipitation, the number of stations digitised rises from about 450 in 1914 to about 850 by the late 1950s. It then jumps to about 4,500 in 1961, rises to 5,500 in the mid-1970s, and falls back to about 3,000 at the end of the period. For temperature, numbers of digitised stations rise gradually from about 270 in 1914 to about 600 in the mid-1990s and fall to about 450 in 2006. For sunshine, numbers rose from 200 in 1929 to about 400 by 1970 before falling gradually to 150 by 2006.

Table A1.3: Approximate average number of stations used to create the gridded datasets

Climate variable	Before 1961	1961 onwards
Total precipitation	650	4400
Days of rain, annual precipitation indices	n/a	4000
Air temperature (max, min, mean)	320	550
Day of ground frost	n/a	420
Degree days, growing season length	n/a	440
Heat and cold wave duration	n/a	200
Snow (from 1971)	n/a	420
Humidity, pressure, wind speed, cloud	n/a	100
Sunshine	270	300

A challenge in the gridding process is to remove the effects of the constantly varying pool of stations. This could be overcome by only using stations with a complete record but the sparseness of the network that this would lead to would introduce much greater uncertainty due to the spatial interpolation required. Instead, all stations believed to have a good record in any month are used, and every effort made to compensate for missing stations during the gridding process.

The gridding process is accomplished in several stages. Firstly, for most parameters, the monthly average or total values are turned into differences from or percentages of the 1961-1990 long period average (termed anomalies). This generally produces a field that is smoother than the raw observations (termed actuals) and is therefore easier to interpolate. This assumes that a grid of the 1961-1990 average has already been generated. For most parameters, this has been done on a 1km x 1km grid. To do this, gaps in the monthly or annual station data are first filled in with estimates generated using relationships with well-correlated neighbour stations. The resulting station averages are then gridded using a combination of multiple regression and spatial interpolation of the regression residuals.

The regression equation is fitted to the station averages using a range of different factors. These include latitude, longitude, altitude, terrain shape, coastal and urban effects. Different combinations of factors are used for different parameters. It is not appropriate to use all geographic factors for all parameters, as there may not be a plausible reason for such a relationship, leading to the possibility of generating spurious correlations that only add noise to the regression surface. The fit of the regression surface to station values will not be perfect, the differences being known as regression residuals. At stations where the residuals are large they tend to be indicative of spurious values and so the residuals are used to help with quality control checks.

The same process is used to generate the monthly and annual gridded datasets. The same range of factors is available for the regression fitting, but since the data being analysed are usually anomalies most of the factors are already accounted for. Often, only a cross-polynomial of latitude and longitude is required to account for broad spatial patterns in the anomalies.

The regression residuals are then interpolated on to a 5km x 5km grid using inverse-distance weighting (IDW). This ensures that local variations in the climate are incorporated into the final grid, which is produced when the regression and interpolated residual surfaces are added together. If anomalies were analysed the long term average field is added back on to produce a field of the original parameter.

Testing of different regression models and interpolation methods and settings is carried out by leaving out a set of 10% of the station data. Error statistics of the actual values at these stations compared with values estimated by the grid are calculated and compared. Different settings of the IDW interpolation have been tested, for example varying the power and radius parameters. Spline surfaces have also been tested but were not found to give as good a result. The full method is described in Perry and Hollis (2005a).

A1.2 Daily data

Daily values of mean, maximum and minimum air temperature have been calculated for the grid of 5km by 5km cells for the period December 1960 to December 2005.

Although not part of the observed UK climate data set, daily values of precipitation have also been calculated for the same grid cells and time period. Further information about gridded precipitation data may be obtained by contacting the Met Office Customer Centre (details at www.metoffice.gov.uk/corporate/contact/contact.html).

A similar method is used to generate the daily gridded datasets as that described above for the monthly and annual datasets. However, with daily data there is often a less strong link between the data and the geographical factors which shape the average over a longer timescale. Consequently, at least one of the stages of converting to anomalies and regression may be omitted.

The monthly, annual and daily data files summarised above are available from the Met Office at: http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcip.html.

Annex 2: Glossary of some terms used in this report

Cooling Degree Days (CDD)

An annual measure of the extent to which temperatures suggest that buildings may require some form of cooling (e.g. air conditioning), based on the daily temperature being above a specified threshold of 22°C. To derive CDD, the number of degrees celsius and weighted increments using the criteria in Box 2.1 are summed for all days of the year.

Coupled Ocean-Atmosphere Model

A climate model which couples a numerical representation of the atmosphere with that of the ocean, and is thus able to project transient changes in climate.

Extratropics

The latitudes between the tropics and the polar regions, in which the UK sits.

Heating Degree Days (HDD)

An annual measure of the extent to which daily temperatures suggest that buildings may require some form of space heating, based on the daily temperature being below a threshold of 15.5°C. To derive HDD, the number of degrees Celsius and weighted increments using the criteria in Box 2.1 are summed for all days of the year.

Box 2.1: How Heating Degree Days and Cooling Degree Days are calculated.

Cooling Degree Days	
Daily situation	**CDD daily increment**
Tmax ≤ 22°C	0
Tmin > 22°C	Tmean – 22°C
Tmean > 22°C and Tmin ≤ 22°C	0.5 (Tmax – 22°C) – 0.25 (22°C – Tmin)
Tmean ≤ 22°C and Tmax > 22°C	0.25 (Tmax – 22°C)
Heating Degree Days	
Daily situation	**HDD increment**
Tmin ≥ 15.5°C	0
Tmax < 15.5°C	15.5°C – Tmean
Tmean < 15.5°C and Tmax ≥ 15.5°C	0.5 (15.5°C – Tmin) – 0.25 (Tmax – 15.5°C)
Tmean > 15.5°C and Tmin < 15.5°C	0.25 (15.5°C – Tmin)
Tmin = minimum daily temperature Tmax = maximum daily temperature Tmean = mean daily temperature = 0.5 (Tmean + Tmax)	

hPa

Abbreviation for a hectopascal, equal to 100 Pascals, used as the meteorological unit of atmospheric pressure. Previously known as a millibar.

Indicator

A variable or quantity commonly used to illustrate trends in climate, not necessarily caused by human activity.

Latitudinal band

A band circling the earth in an east-west direction bounded by two latitudes.

Likely

The IPCC definition of the likelihood of an outcome or result being greater than 66% probable. If not referring to IPCC conclusions, the meaning is not specified in terms of a probability.

Mean

The mean of a series of numbers (usually taken to refer to the arithmetic mean) is the sum of the values of all the members of a series divided by the number of items in the series; also referred to as the average.

North Atlantic Oscillation (NAO)

The year-to-year variation in the relative strength of the pressure gradient between the permanent low-pressure system near Iceland and the permanent high pressure system near the Azores. It corresponds to fluctuations in the strength of the main westerly winds across the Atlantic into Europe.

Series (time series)

A sequence of values of a particular climate variable. Ordered by time if it is a time series; for example the annual mean global temperature anomalies from 1850-2006.

Sea-surface temperature (SST)

The temperature of the sea typical of the first few metres below its surface.

Smoothing

A process of time (or space) averaging of data to supress short-period (or local) variations. A ten-year running mean, for example, averages values in an annual time series over each successive ten-year period.

Standard deviation

A statistical measure of the spread of values in a dataset about their mean. If there are N values x_i in a dataset, and the average of all the values is $\overline{x}$, the standard deviation is defined by:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

Storm surge

The temporary increase, at a particular place, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.

Stratosphere

The region of the earth's atmosphere extending above about 10km in mid-latitudes, up to about 50km, where temperature does not decrease with height.

Trend

A long-term change in a time series which extends outside the normal range of variability.

Thermohaline Circulation (THC)

Large-scale circulation in the ocean that transforms low-density upper ocean waters to higher-density intermediate and deep waters and returns those waters back to the upper ocean. The THC is driven by high densities at or near the surface, caused by cold temperatures and/or high salinities, but despite its suggestive though common name, is also driven by mechanical forces such as wind or tides.

Very likely

The IPCC definition of the likelihood of an outcome or result being greater than 90% probable. If not referring to IPCC conclusions, the meaning is not specified in terms of a probability.

UK Climate Projections

This report on observed climate sets the scene for the new UK Climate Projections (UKCP09), to be launched in spring 2009. UKCP09 has been developed in response to consultation with users and also to advances in climate science.

Climate change scenarios for the UK published in 1998 and 2002 acknowledged the many uncertainties in climate projections. UKCP09 will, for the first time, explore the major known uncertainties, and allow users to factor these into their own risk assessments. UKCP09 will give the probability of different future changes (for example, of a local temperature rise exceeding 5 °C by the 2080s), rather than relying on single estimate, which hides the uncertainty. The probabilities will reflect our current knowledge of climate and the choice of methodology used to calculate them.

While based mainly on projections from the Met Office Hadley Centre climate models, UKCP09 will also include projections from models run at other climate centres, a requirement from users. Although representing a major advance, the new probabilistic projections will have limitations of their own, and these will be explored and explained to prospective users.

Key features

- Changes in climate over land; temperature, precipitation, snowfall, windspeed, humidity, cloud cover, solar radiation and soil moisture content.
- Maps and information available at 25km resolution.
- Details of monthly, seasonal and annual averages.
- Information in seven overlapping 30-year time slices, covering the 21st century.
- A dedicated website to give users access to the full range of UKCP09 information and data. This includes a dynamic user interface, allowing users to generate the output they need, e.g. data to use in impacts models, or maps for specific variables, future periods and locations.
- The user interface includes a specially-developed weather generator that will allow statistically-derived expressions of the future daily and hourly weather conditions, consistent with probabilistic climate projections.
- Changes in the marine environment, including: sea level, climate over the oceans, storm surges, and changes in temperature, salinity and currents at several depths in sea areas around the UK, although these will not be probabilistic.

The UKCP09 family of products

- Headline messages – for high-level use, focussing on the most commonly-used climate variables.
- Published material – written reports, maps and graphs prepared for general use, also available online.
- Customisable output – information created by the user from the UKCP09 user interface.

The projections in UKCP09 will be available for three possible future scenarios of man-made greenhouse gas emissions, labelled Low, Medium and High. These are from the same family of emissions scenarios as those used in UKCIP02 and UKCIP98.

The projections in UKCP09 are not simply drop-in replacements for previous ones. To help users to make the most of UKCP09, a training programme is planned and user guidance will be available online.

www.ukcp09.org.uk

The climate of the United Kingdom and recent trends

This report on observed climate sets the scene for the new UK Climate Projections, to be launched in spring of 2009, which have been developed in response to expressed users' needs and to advances in climate science.

Department for Environment, Food and Rural Affairs (Defra)

www.defra.gov.uk

The Department for Environment, Food and Rural Affairs' core purpose is to improve the current and future quality of life. The Department brings together the interests of the environment and the rural economy; farmers and the countryside; the food we eat, the air we breathe and the water we drink. Defra's first Departmental Strategic Objective is "A society that is adapting to the effects of climate change, through a national programme of action and a contribution to international action". To help us meet this goal, Defra has funded the UK Climate Projections programme on behalf of the UK Government and Devolved Administrations to provide updated climate information for the UK from 1961-2099.

Contact: helpline@defra.gsi.gov.uk

Met Office Hadley Centre

www.metoffice.gov.uk/research/hadleycentre

The Met Office Hadley Centre is the UK government centre for research into the science of climate change and its impacts. It was opened in 1990, building on the previous 20 years of research into climate change. Its Integrated Climate Change Programme is funded jointly by the Department for Energy & Climate Change (DECC), the Department for Environment, Food & Rural Affairs (Defra) and the Ministry of Defence (MoD). Its main roles are to:

- Improve our understanding of climate and use this to develop better climate models.
- Monitor climate variability and change at global and national scales, and use models to attribute recent changes to specific factors such as human activity.
- Quantify and reduce uncertainty in projections of climate change, particularly at a local scale and of extremes, and use this information to inform adaptation strategies.
- Define and assess the risk of dangerous climate change, whether gradual, abrupt or irreversible.
- Assess scientific aspects of options for mitigating climate change and its impacts.
- To advise government, business, the media and other stakeholders.

Contact: enquiries@metoffice.gov.uk

UK Climate Impacts Programme

www.ukcip.org.uk

The UK Climate Impacts Programme works at the boundary between research and society on the impacts of climate change and on adapting to those impacts. UKCIP works by promoting stakeholder-led research, and by developing tools and datasets to help organisations adapt to unavoidable climate change. UKCIP supports the users of UKCIP02 and UK Climate Projections.

UKCIP was established in 1997, and based at the University of Oxford Centre for the Environment. Defra funds UKCIP for the UK Government, Scottish Government, the Welsh Assembly Government and Department of the Environment Northern Ireland.

Contact: enquiries@ukcip.org.uk

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