Climate Change Scenarios for the United Kingdom

Summary Report

UK Climate Impacts Programme
Technical Report No.1

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Synopsis

This summary of a parallel Technical Report presents new scenarios of how the climate of the UK may change over the next 100 years. The scenarios, called the UKCIP98 scenarios, have been prepared for the UK Climate Impacts Programme (UKCIP). The range of possible future climates will assist stakeholders to carry out integrated assessments of climate change impacts and responses.

- The UKCIP presents four scenarios that span a range of possible future UK climates. These should be used to evaluate the sensitivity of different sectors and regions to climate change (pages 2-4).
- Analysis of historic climate data in the UK confirms a warming of 0.5°C during the twentieth century, with decreasing numbers of cold days and increasing numbers of hot days. Trends in precipitation and gale frequencies are less clear (pages 4-5).
- The four climate change scenarios span a range of future global warming rates from 0.1° to 0.3°C per decade, with associated increases in average sea-level and carbon dioxide concentrations (pages 5-6).
- Warming over the UK will be more rapid in the southeast compared to the northwest and wetter winters are likely for all scenarios (pages 6-9).
- Changes in climate variability and extreme events are likely to be more important for many impacts than simple changes in average climate and some examples of such changes are provided (pages 10-11).
- For some specific impact studies, these national climate scenarios may need to be supplemented with more detailed regional scenarios constructed using a regional climate model or statistical downscaling techniques (pages 11-12).
- The scenarios enable an evaluation to be made of the magnitude of climate change relative to natural climate variations and of differences between the UKCIP98 and other IPCC scenarios (pages 12-13).
- Major uncertainties about future climate prediction remain, including the rate of greenhouse gas emissions growth, the overall sensitivity of the climate system to human influence and the potential for rapid climate change (pages 13-15).

A full Technical Report of the UKCIP98 climate scenarios, a CD-Rom containing the data files, and further information about climate scenarios, are available from the UK Climate Impacts Programme and the Climate Impacts LINK Project (page 16).

An Introduction to Climate Change Scenarios

The UKCIP Climate Scenario Report

This brochure summarises the content of a new report prepared for the UK Climate Impacts Programme (UKCIP) and published by the Climatic Research Unit at the University of East Anglia and the Hadley Centre at the Met. Office. The report describes how the climate of the United Kingdom may change during the next 100 years. In this description, we take into account natural climate variations as well as a range of future greenhouse gas emissions scenarios and different assumed sensitivities of the climate system to these emissions. The resulting climate scenarios are referred to as the UKCIP98 climate scenarios and follow from earlier studies that were published in 1991 and 1996 by the Climate Change Impacts Review Group of the, then, Department of the Environment. These earlier CCIRG91 and CCIRG96 climate scenarios for the UK have been widely used in climate impacts assessments in the UK. The scenarios described here replace these earlier efforts.

Why Do We Need Climate Change Scenarios?

Climate is changing. We no longer have confidence that the climatic statistics of the recent past will provide us with an adequate description of the climate of the future. The industrial economy through its reliance on carbon-intensive energy has substantially altered the properties of the Earth's atmosphere. Atmospheric concentrations of greenhouse gases have risen by some fifty per cent in less than two hundred years and there is increasing evidence that a human influence on global climate has been detected. Given the inertia in our energy systems and the long memory exhibited by the climate system, this human-induced climate change will continue during the century to come. The implementation of the Kyoto Protocol, may slow the rate of change, but will not reverse it.

The major source of greenhouse gas emissions is from the combustion of fossil fuels. Future emissions levels depend on whether carbon fuels continue to dominate our energy economy.

Climate also varies naturally. The causes of natural climate variations - whether they stem from volcanic eruptions, changes in the sun's output or natural oscillations in the climate system such as El Niño - are now much better understood than they were, say, thirty years ago. Our ability to simulate, using advanced computer models, the full range of factors that influence global climate has also made dramatic advances in recent years.

It is for these two reasons - human-induced climate change and natural climate variability - that a thirty-year sequence of past weather data is no longer sufficient to define the probabilities of certain weather extremes occurring in the future. As we move into the next millennium, we are becoming increasingly aware of the need to predict as accurately as we can not only the seasonal climate anomalies to be experienced next year, but also the broad sweep of climate change to be encountered over the decades to come. Predicting the weather for next week is no longer sufficient to inform the choices our commercial and governmental institutions need to make.

Past and future changes in global climate are summarised in Figure 1. Variations in temperature occur from decade-to-decade for reasons that are probably natural in origin. The graph also shows, however, the warming trend of recent decades, a warming that is unlikely to be solely due to natural climate variations. Figure 1 also plots two sets of curves describing possible future temperature changes. These two sets of curves assume two different rates of expansion of the global carbon energy-economy - a high emissions scenario (red) and a low emissions scenario (blue). Within each scenario, natural climate variations alter slightly the rate of warming - hence the cluster of curves - but the overall message is clear: the warming trend that we already see in the observed data will continue into the next century and will probably accelerate.

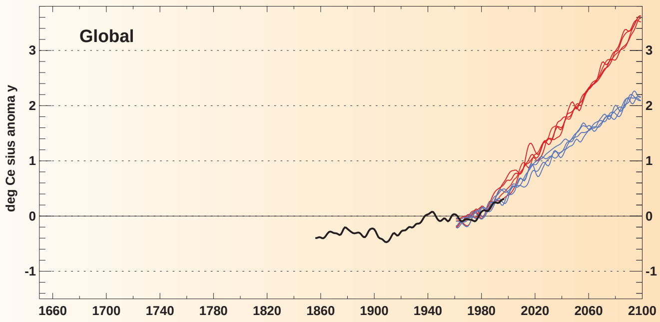

Figure 1: The observed global temperature trend from 1856 to 1997 (black curve) temperature trends from 1960 to 2100. The red curves result from a high greenhouse gas emissions scenario and the blue curves from a low emissions scenario. These curves are smoothed to emphasise decadal variations in temperature.

These changes in climate are not only apparent at the global-scale. Figure 2 shows a similar set of curves, but this time describing the climate of the United Kingdom. Although the natural variations in UK temperature are larger than those that occur for the global average, we again see the observed warming of recent decades and the cluster of curves leading to a further rise in temperature of between 2° and 3°C by 2100.

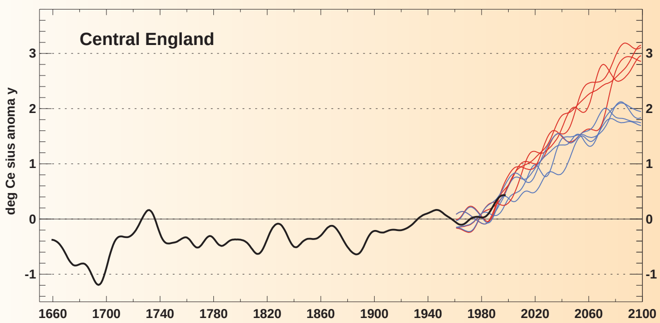

Figure 2: The observed temperature trend from 1659 to 1997 for the United Kingdom (black curve), smoothed to emphasise variations on thirty-year time-scales, and simulated temperature trends for the UK from 1960 to 2100. The red curves result from a high greenhouse gas emissions scenario and the blue curves from a low emissions scenario. These curves are smoothed to emphasise decadal variations in temperature.

Why Climate Change Scenarios and Not Climate Change Predictions?

Climate change scenarios present coherent, systematic and internally-consistent descriptions of changing climates. These scenarios will be typically used as an input into climate change vulnerability, impact or adaptation assessments. Climate change scenarios are most commonly constructed using results from global climate model (GCM) experiments. The UKCIP98 scenarios rely on one such set of experiments completed by the Hadley Centre during 1995 and 1996 and undertaken using a climate model called HadCM2. This model has been extensively analysed and validated and is one of the leading global climate models in the world.

The main modelling uncertainties in future climate change predictions stem from the contrasting behaviour of different climate models in their simulation of global and regional climate change. These differences are largely a function of the different schemes employed to represent important processes in the atmosphere and ocean and the relatively coarse resolutions of the models. In HadCM2, for example, the UK land area is represented by just four gridboxes making it impossible to differentiate between the climate of, say, the Lake District and Merseyside.

Another important uncertainty in describing future climate, however, is unrelated to the difficulties of climate modelling and stems from the unknown world future. How will global greenhouse gas emissions change in the future? Will we continue to be dominated by a carbon-intensive energy system? What environmental regulation may be introduced to control such emissions? Different answers to these questions lead to a wide range of emissions scenarios being created. Since all climate change experiments need to choose an emissions scenario, different choices can lead to quite different climate outcomes. We showed the results of two such choices in Figures 1 and 2.

For all these reasons it is preferable to talk about future climate change scenarios rather than future climate predictions. Predictions, in the sense of being able to attach specific probabilities to different climate changes, are not yet possible.

The UKCIP Approach

The UKCIP approach to this problem of climate change prediction is to present four alternative scenarios of climate change for the UK spanning a reasonable range of possible future climates. These scenarios are labelled **Low, Medium-low, Medium-high** and **High,** the labels referring to their respective global warming rates. In our analysis we work from the global-scale to the scale of the UK, and then from broad mean seasonal changes in climate for a range of scenarios to a more detailed set of variables for one of these scenarios - the **Medium-high.** We list the key assumptions we have made in the accompanying Box.

The UKCIP98 Climate Scenario Assumptions

Since no single climate change scenario can adequately capture the range of possible climate futures, we present a range of generalised climate scenarios for the UK.

This range of generalised scenarios depends on different values for the climate sensitivity, different levels of future anthropogenic forcing of the climate system, and on different global climate models.

Our scenarios result from future changes in greenhouse gas concentrations alone. We do not consider changes in natural forcing factors such as volcanoes or solar variability, nor in the concentration or distribution of sulphate aerosols created by human emissions of sulphur dioxide. The effects of sulphate aerosols on climate are highly uncertain, in addition to which their effects are likely to be transitory.

We base our more detailed scenario on experiments completed using the HadCM2 model. This more detailed scenario assumes a future increase of 1 per cent per annum in greenhouse gas concentrations. This is regarded as a convenient assumption regarding future anthropogenic emissions rather than as a best-guess outcome.

We assume that global climate model results have meaning at the scale of individual gridboxes (typically 300-400 km), but we do not attempt to interpret these results on smaller scales.

Recent Trends in UK Climate

Before we describe the range of future climates for the UK, it is instructive to examine the level of climate variability that the UK has been subject to over recent generations. This involves us in examining year-to-year, decade-to-decade and even century-to-century variations in relevant climate indices. The UK is fortunate in possessing some of the longest instrumental climate time series in the world, the longest being the Central England Temperature series that extends back to 1659.

The UK possesses some of the longest instrumental climate series in the world. Measurements made at the Radcliffe Observatory in Oxford contribute to the Central England Temperature series. [Photo; Bodleian Library].

These series present a unique opportunity to examine climate variability in the UK on long time-scales based on observational data. It is within this history of past climate variability that the British environment, economy and society has evolved and to which it has in some measure adapted. Just as future climate change can only be sensibly interpreted against a background of observed climate variability, so too the impacts of future climate change for the UK can only be properly evaluated in the context of the environmental and social adaptation that has occurred in response to past climate variability.

Long-term Trends in Temperature

From the Central England Temperature series, a smoothed version of which was plotted in Figure 2, we may deduce three things. First, there has been a warming of UK climate of about 0.7°C since the seventeenth century of which about 0.5°C has occurred during the twentieth century. Second, this warming has been greater in winter than in summer (not shown). Third, the cluster of warm years at the end of the series means that the last decade - 1988 to 1997 - has been the warmest in the entire series, with four of the five warmest years since 1659 occurring in this short period - 1989, 1990, 1995 and 1997.

The Central England Temperature series can also be used to examine changes in daily temperature extremes, although in this case only since 1772. Figure 3 shows the annual numbers of 'hot' and 'cold' days in Central England over this period. There has been a marked reduction in the number of cold days since the eighteenth century, these numbers falling from between 15 and 20 per year to around 10 per year during the present century. There has been a less perceptible rise in the number of hot days, although several recent years (1976, 1983, 1995 and 1997) have recorded among the highest numbers of such days. As with annual temperature, the last decade has seen the highest number of hot days in the entire series, averaging nearly eight hot days per year, about twice the long-term average.

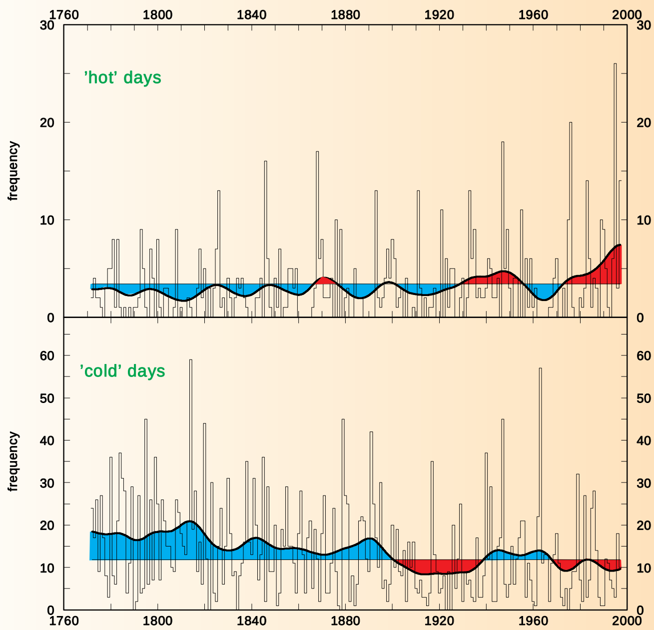

Figure 3: The annual number of 'hot' and 'cold' days extracted from the Central England Temperature series for the period 1772 to 1997. 'Hot' days are those with mean daily temperature above 20°C; 'cold' days are those with mean daily temperature below freezing.

Long-Term Trends in Precipitation and Gales

There are no comparable long-term trends in annual precipitation, whether over England and Wales or over Scotland (Figure 4). Substantial variations in precipitation have nevertheless occurred. For example, winter precipitation in Scotland has increased in recent decades, while summer rainfall in England and Wales has been falling (not shown). Many, if not most, of these fluctuations in precipitation are probably natural in origin, although we cannot deny the possibility of some human influence.

An index of gale activity over the UK (not shown) extends back to 1881. This series also shows no long-term trend, although gale activity is highly variable from year-to-year, with a minimum of two gales occurring in 1985 and a maximum of 29 gales in 1887. The most recent decade - 1988 to 1997 has recorded the highest frequency of severe gales since the series began in 1881.

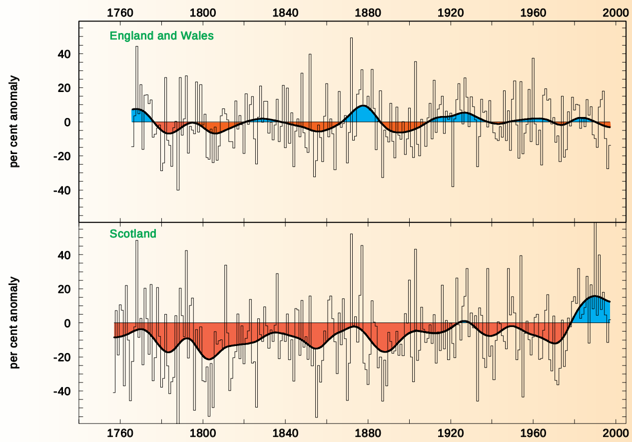

Figure 4: The annual precipitation for England and Wales (top) and for Scotland (bottom) for the periods 1766 to 1997 and 1757 to 1997. Both series are shown as per cent differences from the 1961-90 average. The smooth curves emphasise variations on time-scales of thirty years or more.

Future Changes in Global Climate

The four UKCIP98 scenarios contain a range of future global warming rates that spans many of the uncertainties in future global climate prediction.

Two of these scenarios are derived directly from experiments performed with the HadCM2 global climate model. The other two scenarios are selected from the range presented by the Intergovernmental Panel on Climate Change in their 1995 Second Assessment Report. None of the scenarios includes the modest cooling effect on climate of sulphate aerosols. The four scenarios are referred to as **Low, Medium-low, Medium-high** and **High** and the global warming rates associated with each scenario are shown in Figure 5.

The rate of warming of these scenarios ranges from about 0.1°C to 0.3°C per decade over the course of the twenty-first century. This compares with the observed rate of global warming for the last two decades of about 0.14°C per decade, a rate quite consistent with these UKCIP98 scenarios.

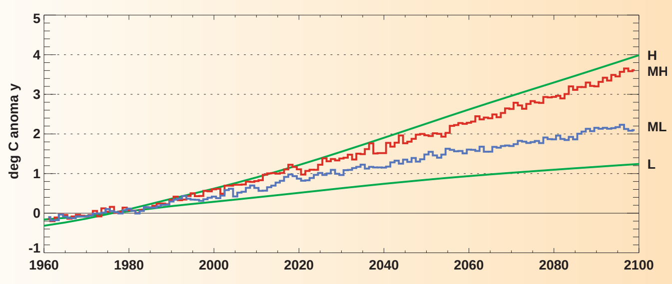

Figure 5: Global warming curves for the four UKCIP98 scenarios, identified by the letters. The temperature increases are shown with respect to the 1961-90 average.

The global sea-level changes and carbon dioxide concentrations associated with the scenarios are shown in Table 1 for the middle decade of next century. The pre-industrial carbon dioxide concentration of ~275 ppmv doubles by the 2050s under the **Medium-high** scenario, although this represents only about a fifty per cent increase over current 1990s concentrations (~360 ppmv). Concentrations of other greenhouse gases also increase. Global sea-level rises throughout each scenario, but the rate of increase varies from about 2 cm per decade for the **Low** scenario to about 9 cm per decade for the **High** scenario.

	Temperature Increase (degC)	*Sea-level Rise (cms)*	*CO_2 Concentration (ppmv)*
Low	*0.9*	*12*	*467*
Medium-low	*1.5*	*18*	*443*
Medium-high	*2.1*	*25*	*554*
High	*2.4*	*67*	*528*

Table 1: Global climate change estimates for the period centred around the 2050s for the four UKCIP98 scenarios. Changes in global temperature and sea-level are calculated with respect to the 1961-90 average.

Future Changes in UK Climate

What do these changes in global climate mean for the United Kingdom? Warming rates in the UK are very similar to the global warming rates described earlier and vary from about 0.1°C per decade for the **Low** scenario to about 0.3°C per decade for the **High** scenario. In all seasons and for all scenarios there is a southeast to northwest gradient across the UK in the overall magnitude of the climate warming, with the southeast warming more rapidly than the northwest. In general, the warming is slightly greater in winter than in summer.

The patterns of precipitation change are less consistent between seasons, scenarios and periods than are patterns of temperature change. Annual and winter precipitation increases for all periods and under all scenarios, although the annual increases for the **Low** and **Medium-low** scenarios, even by the 2080s, are very modest at only a few per cent. Winter precipitation increases are larger and reach 20 per cent or more by the 2080s in the **High** scenario. Such winter precipitation increases exceed what may reasonably be expected to occur due to natural variability. For summer, there is a general tendency for drying in the south of the UK and for wetting in the north. These summer rainfall changes are quite modest, however, and probably only exceed the range of natural variability in the southeast of the country for the 2080s period in the **Medium-high** and **High** scenarios.

Figures 6 and 7 summarise these changes for each of the four UKCIP98 scenarios and for three different periods in the twenty-first century by showing maps of average annual temperature and precipitation change.

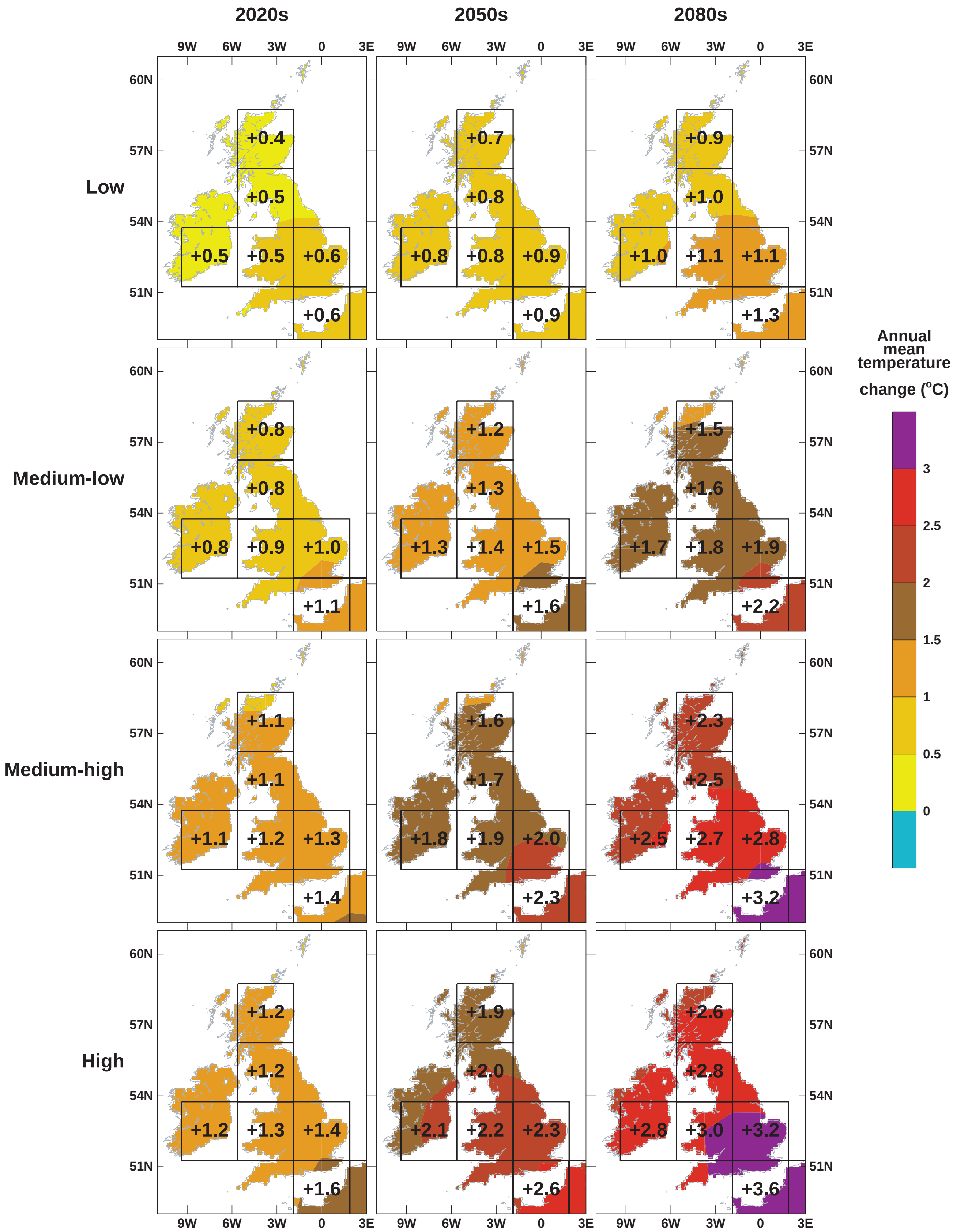

Figure 6: Change in average annual temperature (deg Celsius with respect to the 1961-90 average) for thirty-year periods centred on the 2020s, 2050s and 2080s and for the four UKCIP98 scenarios. The highlighted numbers show the change for each model land gridbox over the UK.

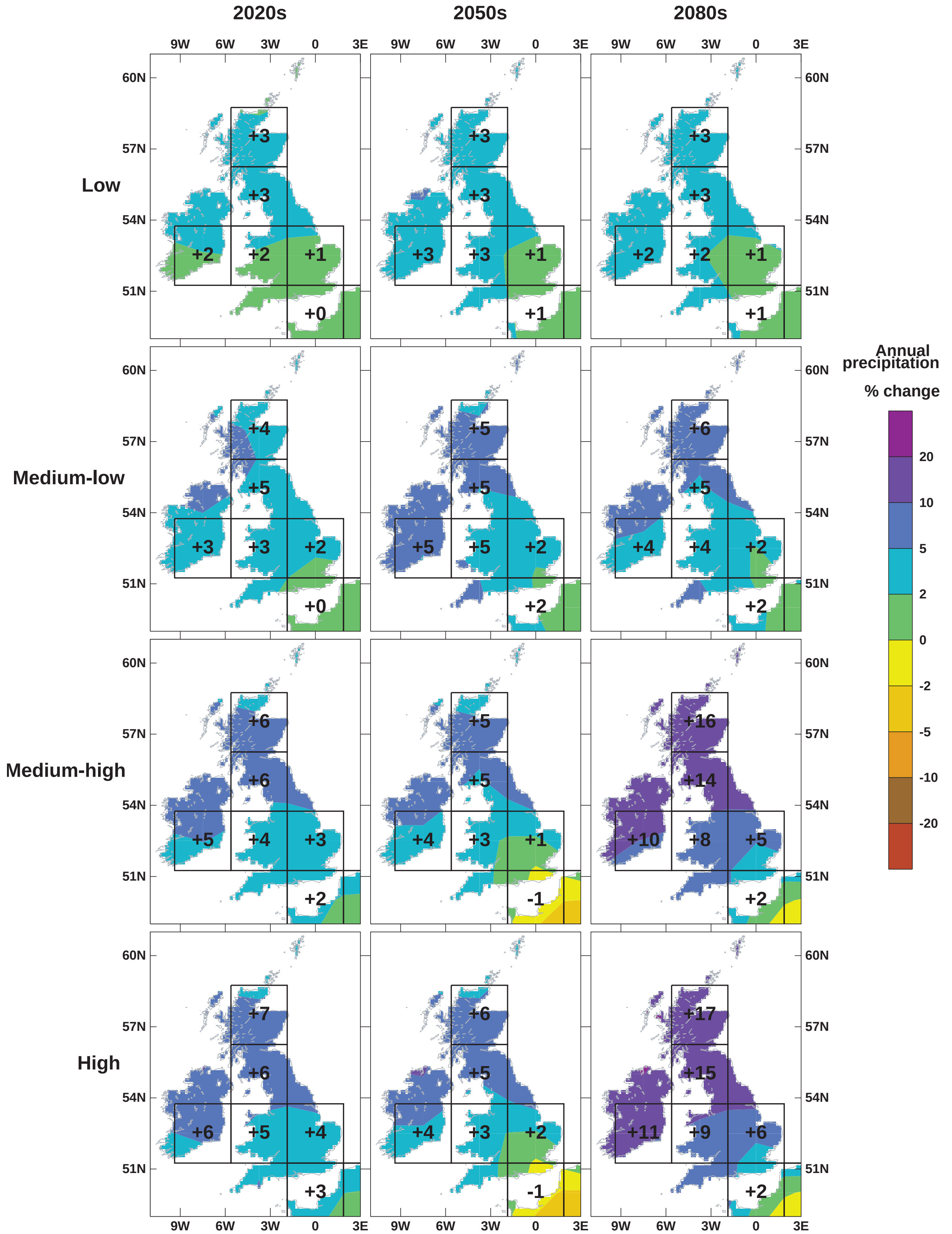

Figure 7: Change in average annual precipitation (per cent with respect to the 1961-90 average) for thirty-year periods centred on the 2020s, 2050s and 2080s and for the four UKCIP98 scenarios. The highlighted numbers show the change for each model land gridbox over the UK.

The maps in Figures 6 and 7 show changes in average climate. For many purposes, however, it is changes in the frequency of extreme events that will be more important. We can illustrate this by looking at how often a very warm year like 1997 occurs in the future. 1997 was the third warmest year ever recorded in the UK, nearly 1.1°C warmer than the average 1961-90 temperature. Years such as 1997 will become increasingly frequent in the future (Table 2). By the 2020s, more than half the years in the **Medium-high** and **High** scenarios are warmer than 1997 and by the 2080s nearly all the years, except for the **Low** scenario, exceed the warmth of 1997.

	Present	*2020s*	*2050s*	*2080s*
Low	6	13	26	56
Medium-low	6	47	74	88
Medium-high	6	59	85	99
High	6	67	89	100

Table 2: Percentage of years with annual temperature exceeding the warmth of 1997 for the four UKCIP98 scenarios. The present frequency is calculated from model results and not from observations.

The increases in average sea-level around the UK coast will be very similar to the global increase shown in Table 1. Although there will be regional differences in the rate of sea-level rise due to climate change, for the UK region the differences are generally within 2 or 3 cm of the global-average. It is also important to consider the role of vertical land movements when assessing impacts on coastal environments. These are the rates at which the coastline is rising or falling as a result of isostatic adjustments from the last glaciation 15,000 years ago. Much of the southern UK is sinking and much

Parts of the UK coastline are already vulnerable to coastal erosion. Rising sea-levels and more frequent storms would increase this vulnerability. [Photo: Mike Hulme].

of the northern UK is rising. The two most extreme regions in this respect are East Anglia - sinking by about 9cm by the 2050s - and western Scotland - rising by about 11cm by this period. These natural changes in relative sea-level compare with the range of sea-level rise caused by climate change by the 2050s of between 12 and 67cm (Table 1). Under the less extreme climate scenarios these natural land movements can therefore be quite significant in accelerating or offsetting the climate-induced change in average sea-level around the UK coast.

	Winter	***Spring***	***Summer***	***Autumn***
Diurnal temperature range	*Small decrease*	*Decreases, more in N than S*	*Decreases, except in SE*	*Large increases*
Precipitation	*Large increases*	*Little change*	*Decreases in S, slight increase in N*	*Large increases*
Vapour pressure	*Increases, more in S than N*	*Small increase*	*Increases*	*Increases*
Relative humidity	*Stable*	*Stable*	*Variable, with decreases in S*	*Small decrease in S*
Radiation	*Decreases*	*Increase in SE, decrease in NW*	*Increase in SE, decrease in NW*	*Increase*
Wind speed	*Variable changes*	*Slight decrease*	*Slight increase*	*Increases, especially in N*
Potential evapotranspiration	*Increases*	*Increases, especially in SE*	*Increases in S, stable in N*	*Large increases*

Table 3: A summary of seasonal changes for some selected climate variables for the ***Medium-high*** *scenario.*

More Detail for the Medium-High Scenario

The four UKCIP98 climate scenarios have been deliberately chosen to span a range of possible future climate changes for the UK. Attaching relative probabilities to these scenarios is difficult. There are perhaps some grounds for considering the **Medium-low** and **Medium-high** scenarios to be somewhat more likely than the **Low** and the **High** scenarios, although how much more likely cannot be said. We show more details for the **Medium-high** scenario not because it necessarily represents our best-guess at the future, but because more modelling results are available for this scenario and because it is helpful to analyse a wider sample of climate indices for at least one of the UKCIP98 scenarios.

Changes in Climate Variability

The seasonal changes in climate for a selection of climate variables are summarised in Table 3. Changes in climate variability will also be very important for determining the likely impacts of climate change and the subsequent adaptation adjustments. Changes in year-to-year temperature variability differ by season. Winter temperatures become less variable while summer temperatures become more variable, especially over the southern UK. This can be seen in the graphs plotted in Figure 8. Precipitation, however, becomes less reliable from year-to-year nearly everywhere and in every season despite the fact that precipitation increases in winter and autumn and decreases in spring and summer.

Partly related to these changes in the year-to-year variability of climate are the changing probabilities of certain seasonal climate extremes. Table 4 shows the changing likelihood of four different climate anomalies occurring in the southern UK. For example, an August as hot as that observed in 1997 - the second hottest August on record - occurs on average four times a decade by the 2080s. The probability of summers experiencing rainfall deficits 50 per cent or more below current levels increases very substantially and occurs once per decade in the future compared to once a century under present climate. In contrast, the probability of successive dry years - defined as a two-year precipitation deficit of 10 per cent or more - changes little in the future and by the 2080 actually becomes rarer. This is because summer rainfall deficits are more than compensated by increased precipitation in other seasons.

	Present	*2020s*	*2050s*	*2080s*
Mean temperature				
A hot '1997-type' August	2	15	32	40
A warm '1997-type' year	6	59	85	99
Precipitation				
Summer rainfall below 50% of average	1	7	12	10
A two-year precipitation below 90% of average	12	11	14	6

Table 4: Percentage of years experiencing certain climate extremes across England and Wales for the ***Medium-high*** *scenario. The present frequency is calculated from model results and not from observations.*

Changes in Extreme Events

Changes in the overall amount of precipitation will be accompanied by changes in the number and intensity of precipitation events. Over the northern UK, precipitation intensities will increase in both winter and summer, the most intense events becoming perhaps several times more frequent than at present. This is likely to lead to greater risk of flooding. Over the southern UK, intensities increase only in winter. In summer in the south, because there is a reduction in the overall amount of precipitation there are fewer high intensity rainfall events compared to the present climate. Annual lightning frequencies over the UK may increase by the 2080s by up to 20 per cent.

Changes in accumulated degree days above or below specified temperature thresholds will also change as the temperature regime changes. For example, degree days with minimum temperature below freezing decrease by between 70 and 80 per cent across the UK by the 2080s, while degree days with maximum temperature above 25°C more than treble by the 2080s.

Changes in extreme wind events are also of importance for considering the impact of climate change. Over the northern UK, the **Medium-high** scenario suggests more frequent days with high summer wind speeds, but little change in winter daily wind extremes. Over the southern UK there is little consistent change in the extreme daily wind regime in either summer or winter. In winter, overall gale frequencies decline in the future, although very severe winter gales increase in number. Summer gales are much less frequent than winter gales and consequently any changes in summer gale frequencies are likely to be small. Nevertheless, by the 2080s there is a modest (10 per cent) increase in the number of summer gales affecting the UK.

The Evolution of Climate

So far we have shown changes in average climate for discrete periods of the next century. Climate will change gradually, however, rather than jump from one average state to another, although this change will often be masked by the natural variability of climate. Figure 8 illustrates one possible evolution of winter and summer temperatures for England and Wales. The large variation in temperature from year-to-year and from decade-to-decade occurs as natural variations in climate are combined with the underlying warming trends caused by greenhouse gas accumulation in the atmosphere. Because of this natural variability, the establishment of new temperature records will be fairly sporadic. New temperature records will not be established every year or even every few years and there may be quite long periods when no temperature records are broken.

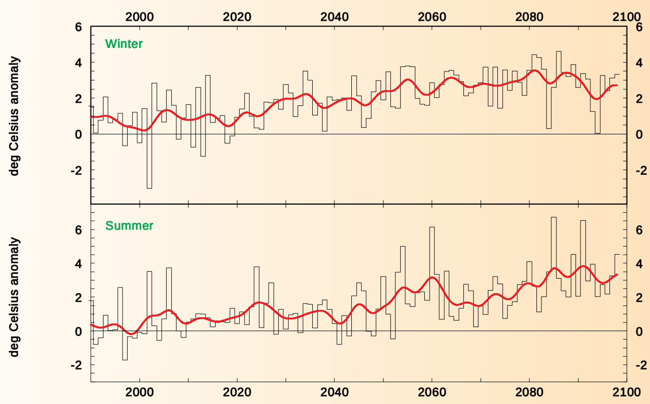

*Figure 8: A possible evolution of winter and summer temperature from 1990 to 2099 for England and Wales under the **Medium-high** scenario. The zero line is the average present-day climate. The smooth curves emphasise decadal variations in temperature.*

Obtaining Regional Scenario Information

The information provided by the UKCIP98 climate scenarios is presented at the same geographic scale that is resolved by the HadCM2 climate model. This model identifies only four discrete regions within the UK (see the boxes in Figures 6 and 7). Each of these four model gridboxes represents tens of thousands of square kilometers, within which there are large spatial differences in climate that are unresolved by the model. For this reason the UKCIP98 climate scenarios should be regarded as mainly national in scale.

This coarse resolution of GCM-based scenarios is at first sight a major limitation for their application to a wide range of impacts assessments. These assessments may either be quite localised - around a single river catchment or urban area - or may operate on a national scale, but with a spatial resolution of kilometers or tens of kilometers rather than hundreds of kilometers - for example a national land use classification assessment. How can the scenario information portrayed here be made useful in such impacts assessments? The answer to this question requires some consideration of the problem of 'downscaling' climate change information.

There are three main approaches for downscaling results from global climate models:

- Simple interpolation from coarse grids to fine grids
- Using high resolution regional climate models
- Using a variety of statistical methods

A full downscaling analysis for the UK is beyond the scope of this report, although it may be dealt with in subsequent UKCIP reports in this series. In this summary brochure, we show just one example of downscaling using the Hadley Centre regional climate model (RCM) with a resolution over the UK of 50 km compared to the resolution of the global model of about 350 km. Figure 9 shows two patterns of summer precipitation change across the UK taken from the global and regional models.

This comparison shows how the regional model provides more detail in the pattern of climate change than the global model, particularly around the coasts and over mountainous areas.

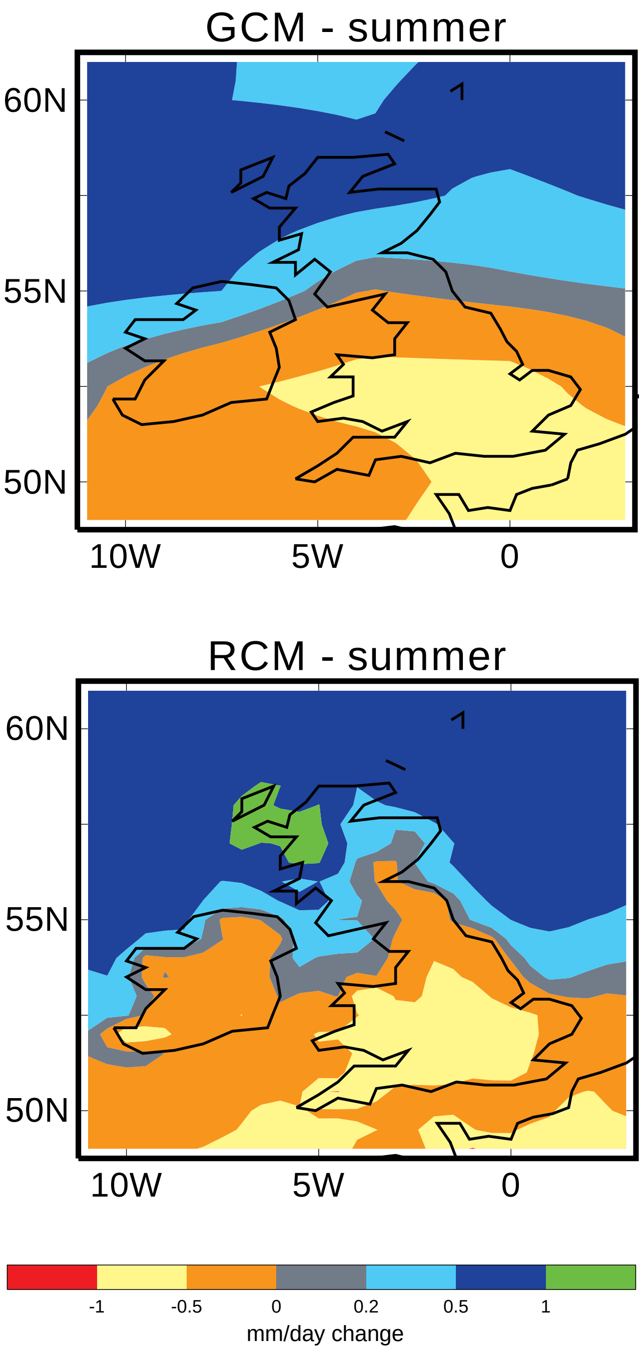

Figure 9: Change in average summer rainfall (mm/day) over the British Isles for the period centred on 2090 as simulated by the global climate model (top) and the regional climate model (bottom). The scenario is similar to the ***Medium-high*** *UKCIP98 scenario.*

Just because results from RCM experiments show greater spatial detail than GCMs does not automatically qualify them as more 'accurate'. There are several acknowledged limitations to the regional climate modelling approach. The most important of these is that the RCM is completely dependent upon the boundary conditions extracted from GCM experiments. In one sense, therefore, RCM output can only be as good as the global climate model that drives it. It is also worth noting that RCM output even at 50 km resolution is still not adequate for some impacts assessments. In such cases as a small river catchment or simulating agriculture or land use at 1 km or 10 km scales there will still be a need for some other form of downscaling. Nevertheless, the RCM holds much promise for providing high resolution climate scenarios at the regional scale.

The UKCIP98 Scenarios in Wider Context

Natural Climate Variability

We have mentioned earlier the importance of natural climate variability. Some of the climate change shown here will be caused by natural variations in climate rather than by human influence on climate. It is important that we give some consideration to separating these two effects. We can use the HadCM2 series of experiments to help us.

By examining results from a 1,400 year simulation of global climate in which there are no changes in greenhouse gas concentrations we identify by how much thirty-year climates in the UK may vary naturally. Average temperature on these time-scales varies by about ±0.6ºC in winter and by about ±0.4ºC in summer, and average precipitation varies by about ±10 per cent in both summer and winter. These natural ranges are plotted as ellipses centred on zero in the graphs in Figure 10 and tell us by how much the climate of the 2050s may differ from that of today without any human influence on climate at all.

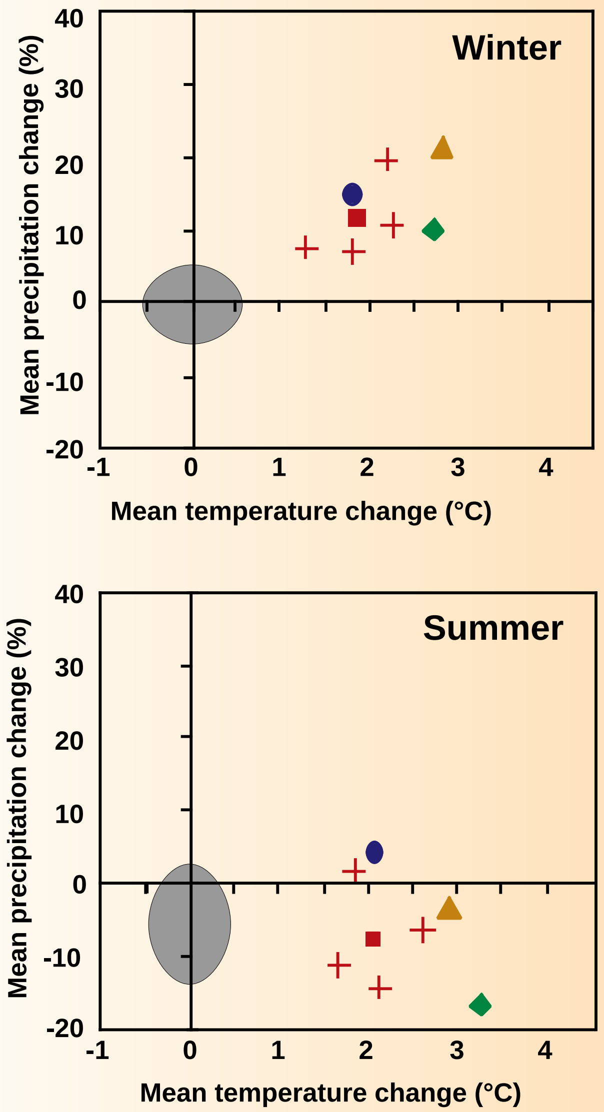

Figure 10: Changes in average winter (top) and summer (bottom) temperature and precipitation over the UK with respect to average 1961-90 climate. The ellipses centred on the origin define the natural variability of UK climate, while the coloured symbols show the changes in average UK climate for the 2050s for the ***Medium-high*** *scenario (red crosses and square) and for three other IPCC climate models (blue, green and orange symbols).*

Natural climate variability will therefore affect the future human-induced climate change we are simulating. We can use the results from four identical HadCM2 experiments in which greenhouse gas concentrations are increased to quantify this effect. We might expect that identical experiments using the same model would yield identical results. They don't and the reason for this is that in each experiment the natural variability of climate is slightly different, even though the human-induced change may be the same. Such identical experiments are called 'ensembles' and the results are summarised in Figure 10 for the winter and summer seasons for the 2050s and for the **Medium-high** scenario. The red crosses in these plots show the results from the four ensemble members, while the red square shows the ensemble average. The temperature changes can vary by up to 1°C or more in winter or summer, while the precipitation changes vary by more than 10 per cent. Indeed, in summer, one ensemble member simulates an increase in rainfall while the other three simulate decreases.

This analysis of natural climate variability alongside human-induced climate change is important when it comes to using climate scenarios for impacts assessments. Failure to appreciate the relative magnitudes involved may cause us to attribute the effects on social or environmental indicators of both human-induced climate change and natural climate variability as if they were the effects of human-induced climate change alone.

Climate Model Differences

There are several climate laboratories around the world that perform similar climate experiments to the Hadley Centre experiments used here. We have assessed for UK climate some of the differences between the results of these experiments. Figure 10, therefore, also plots the changes in UK climate for the 2050s defined by three other leading global climate models used by the Intergovernmental Panel on Climate Change. The blue, green and orange symbols on these graphs show a broad similarity in the temperature and precipitation changes for the UK defined by the **Medium-high** scenario. Winter precipitation always increases and summer rainfall usually decreases, but not by much.

Possible Rapid Climate Change

The UKCIP98 climate scenarios have been derived from climate models that include the best possible representation of processes in the atmosphere, ocean and land that will determine climate change. However, we do not understand the climate system well enough to be able to rule out other outcomes. It has been suggested, for example, that relatively rapid climate changes could occur if the climate system shows a non-linear response to increased greenhouse gas concentrations.

The most likely example of this is the thermohaline circulation (THC) of the world's oceans, a circulation that is driven by changes in water density related to temperature and salinity. Associated strong ocean currents transport large amounts of heat around the world. The THC brings warm subtropical water into the North Atlantic and this water warms the atmosphere, keeping northwest Europe, and particularly the British Isles, much warmer than they would otherwise be. Climate models show that increased greenhouse gas concentrations are likely to reduce the formation of dense cold water at high latitudes in the North Atlantic ocean. Under these conditions the THC would weaken and could eventually, if it collapsed, reduce the surface warming over western Europe by up to several degrees Celsius. A sudden, complete collapse of the THC has not yet been seen in any experiment using comprehensive climate models. Nonetheless, we must take the possibility seriously because of the potential major impact of such an event.

Another area for concern lies in the behaviour of the West Antarctic Ice Sheet (WAIS). It is possible that a more rapid rise in sea-level than suggested in our scenarios could occur should the WAIS begin to disintegrate. The WAIS is grounded below sea-level and is therefore potentially unstable. If it were to disintegrate completely, global sea-level would rise by about five metres. Due to the complexity of processes determining the stability of the WAIS predictions are difficult and uncertain. The most likely scenario appears to be one in which the WAIS contributes relatively little to sea-level rise in the twenty-first century, but over following centuries higher discharge rates from the ice sheet increase its contribution to sea-level rise to between 50 and 100 cm per century.

The contribution of changes in Antarctic ice sheets to global sea-level is uncertain. A disintegration of the West Antarctic Ice Sheet could greatly accelerate the rise in average sea-level. [Photo: Karen Heywood].

Further Scenario Characteristics

Uncertainties and Levels of Confidence

The future climates of the UK illustrated in this brochure are scenarios. They are plausible and self-consistent descriptions of future UK climate based on different assumptions about future emissions of greenhouse gases. The transformation of these emissions into future climate change estimates is itself beset with uncertainty due to the role of other climate agents and poorly represented processes in the climate models. Other factors that are not predictable will almost certainly affect climate, in particular cooling due to volcanic dust and both warming and cooling due to the changing energy output of the sun. We believe that these effects on climate are likely to be small when averaged over many decades. Lastly, there is the possibility that we may be ignorant of other effects or feedbacks on climate that could cause much greater, or much smaller, changes in future climate than are shown here. By definition, the risk associated with such surprises cannot be quantified.

There are some aspects of future climate change in which we have greater confidence than others. For example, we are more confident about increases in carbon dioxide concentrations and rises in sea-level than we are about increases in storminess or intense precipitation events. Such a relative evaluation of confidence may be useful in an impacts assessment when trying to interpret the effects of different sources of uncertainty on the range of impact outcomes.

Choice of Scenarios

The difference between the **High/Medium-high** and **Medium-low/Low** scenarios relates to different levels of future greenhouse gas concentrations. The 1 per cent per annum growth in concentrations upon which the **High/Medium-high** scenarios are based, approximates the IS92a emissions scenario which has been widely used as a 'best guess' emissions profile. The **Medium-low/Low** scenarios are based on a concentration growth of about 0.5 per cent per annum and therefore reflect an emissions profile more similar to IS92d.

The difference between the **High, Medium-high/ Medium-low** and **Low** UKCIP98 scenarios stems from the sensitivity of the climate system to changing concentrations of greenhouse gases. The **High** scenario assumes the highest likely sensitivity and the **Low** scenario the lowest likely sensitivity. The **Medium-high** and **Medium-low** scenarios both use the climate sensitivity of the HadCM2 model which falls someway between the two extremes.

The outcome of an impact assessment will depend to a significant extent on the climate change scenario that is chosen. Since we cannot attach probabilities to the different emission profiles and climate sensitivities that create the UKCIP98 scenarios, the full range of scenarios should ideally be evaluated to identify the potential risks of climate change and the effectiveness of different adaptive strategies. Where only a single scenario is used, say the **Medium-high** scenario, caution should be exercised when interpreting the results of the assessment.

Different climate change scenarios will lead to different impacts on the UK landscape. And different impacts will trigger different adaptations to climate change.

Future Modelling and Scenario Developments

Since compiling this report, the third version of the Hadley Centre climate model, HadCM3, has been developed. Many of the representations of processes in the atmosphere, in the ocean and on land, have been improved and the ocean resolution in the new model is more than doubled. This gives the model a much better representation of ocean currents such as the Gulf Stream. To date, only a single simulation has been made with HadCM3. The broad-scale global climate changes simulated by HadCM3 are similar to those used in the UKCIP98 scenarios. There are some differences, however, over the UK. The reduction in summer rainfall is greater than that seen in the **Medium-high** scenario and the increases in average wind speed are significantly greater than the small changes simulated by HadCM2. Future reports from UKCIP will assess the significance of these differences.

Until recently, it was thought that the variability of the climate system over a period of a decade was random and unpredictable. Recent research, however, has shown the possibility of predicting climate over this time period using the slowly changing patterns of sea surface temperatures. If these patterns can be adequately simulated in climate models, then they may be predictable up to a decade ahead. This research offers the possibility that short-term variations in climate, such as the run of warm winters in the late 1980s/early 1990s, are predictable several years ahead. The availability of this sort of forecast could be of considerable benefit to industry and commerce, not only in its own right, but also as an aid to planning for larger changes in the future due to human-induced climate change. Research at the Hadley Centre and at UK universities is aimed at demonstrating this potential and realising it on an operational basis, although several more years work will be needed to reach this goal.

This Summary Report was prepared from the full science report published as:

Climate Change Scenarios for the United Kingdom
UKCIP Technical Report No.1

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Obtaining the UKCIP98 Climate Scenario report

The full Scientific Report of the UKCIP98 Climate Scenarios and the CD-ROM containing the data can be obtained from one of the following two places. These products are free, although users of the CD-ROM will need to complete a Registration Form and abide by the terms and conditions of use.

Data Manager
UK Climate Impacts Programme
Enviromental Change Unit
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Further Internet Sources of Information on Climate Data and Scenarios

The Climate Impacts LINK Project:
http://www.cru.uea.ac.uk/link/

The Hadley Centre for Climate Prediction and Research:
http://www.met-office.gov.uk/sec5/sec5pg1.html

The UK Climate Impacts Programme:
http://www.ecu.ox.ac.uk/ukcip.html

The British Atmospheric Data Centre (BADC):
http://tornado.badc.rl.ac.uk/

The Inter-governmental Panel on Climate Change (IPCC):
http://www.ipcc.ch/

The IPCC Data Distribution Centre (DDC):
http://ipcc-ddc.cru.uea.ac.uk/

The IPCC Special Report on Emissions Scenarios (SRES):
http://sres.ciesin.org/index.html