The future climate of North West England

THE BRUNTWOOD INITIATIVE FOR SUSTAINABLE CITIES
AT THE UNIVERSITY OF MANCHESTER

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Cavan, G.
Carter, J. and Kazmierczak, A.

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1 Introduction

The UK Climate Projections (UKCP09) provided through the UK Climate Impacts Programme (UKCIP) is the latest and most comprehensive package of information on the potential future climate for the UK. Continuing improvements in modelling and understanding of the climate system allow climate projections to be periodically reviewed and refined. This latest set of projections is an improvement on the last suite of UKCIP02 scenarios as they are downscaled to a 25km grid and provide a probabilistic element. Thus, for the first time, it provides information on the relative degree to which each projected climate outcome is supported by current evidence. Changes in the Gulf Stream are taken into account, as are carbon feedbacks are aerosols. The UKCP09 projections are therefore more complex, but respond to demands from users for this level of detail (Murphy *et al*., 2009).

The UKCP09 website provides a range of readily-available information for the future climate of the North West region. This includes text, graphs and mapped outputs[1]. This report compiles some of this readily-available information to summarise the key future changes to the North West region. In addition, it includes some customised information that was created in the UKCP09 user interface[2].

This document summarises climate projections information for the North West region in tables, graphs, maps and descriptions. It provides information for a range of climate variables, time periods, emissions scenarios and probability levels. It begins by providing a brief background to climate change, the emissions scenarios used in UKCP09, an introduction to the probability levels including an explanation of how probability should be interpreted in the climate projections, and a note on time periods.

The information on the future climate of the North West region is of potential value for a wide range of stakeholder groups wishing to learn more about this subject. Although the UKCP09 website provides access to some of this information, and offers the potential to obtain more through the user interface, this report brings together a summary of the relevant climate change projections data for North West England in an easily accessible format.

1.1 Background to climate change

The Earth's climate has continually changed throughout history, influenced by natural factors such as volcanic activity, changes in solar output, changes in the Earth's orbit and oscillations in the climate system such as the North Atlantic Oscillation (NAO) and El Nino Southern Oscillation (ENSO). The difference between these natural cycles and the recent changes in climate we have experienced is the rate that change has

[1] UKCP09 pre-prepared maps and graphs for North West England are available at: http://ukclimateprojections.defra.gov.uk/content/view/292/499/
[2] UK Climate Projections User Interface can be accessed at: http://ukclimateprojections-ui.defra.gov.uk/

occurred. Global warming rates have increased to 0.17 ± 0.05°C per decade – likely to exceed any 100-year rate of warming during the past 1000 years (EEA, 2004).

These recent changes to the climate cannot be explained by natural causes (Stott *et al.*, 2000; Hulme *et al.*, 2002). In fact, we can now state that it is *very likely* (>90% probability) that this warming of the observed global average temperature is due to anthropogenic emissions of greenhouse gases (Jenkins *et al.*, 2007). In other words, humans are contributing to warming through emissions of greenhouse gases from burning fossil fuels, causing the climate to change beyond its natural variability. These human-induced emissions include carbon dioxide, one of the main greenhouse gases, the atmospheric concentrations of which have increased by 34% compared with pre-industrial levels, and an accelerated rise has occurred since 1950 (EEA, 2004). Changes to land use and natural systems on a global scale, including the loss of rainforest and changes in agricultural practices, also contributes to the increased emissions of greenhouse gases. Some degree of climate change is now inevitable due to the impact of historical emissions, and the amount of future warming will greatly depend on the future emissions of greenhouse gases (Section 1.2), the extent of land use change, and the associated response of natural systems.

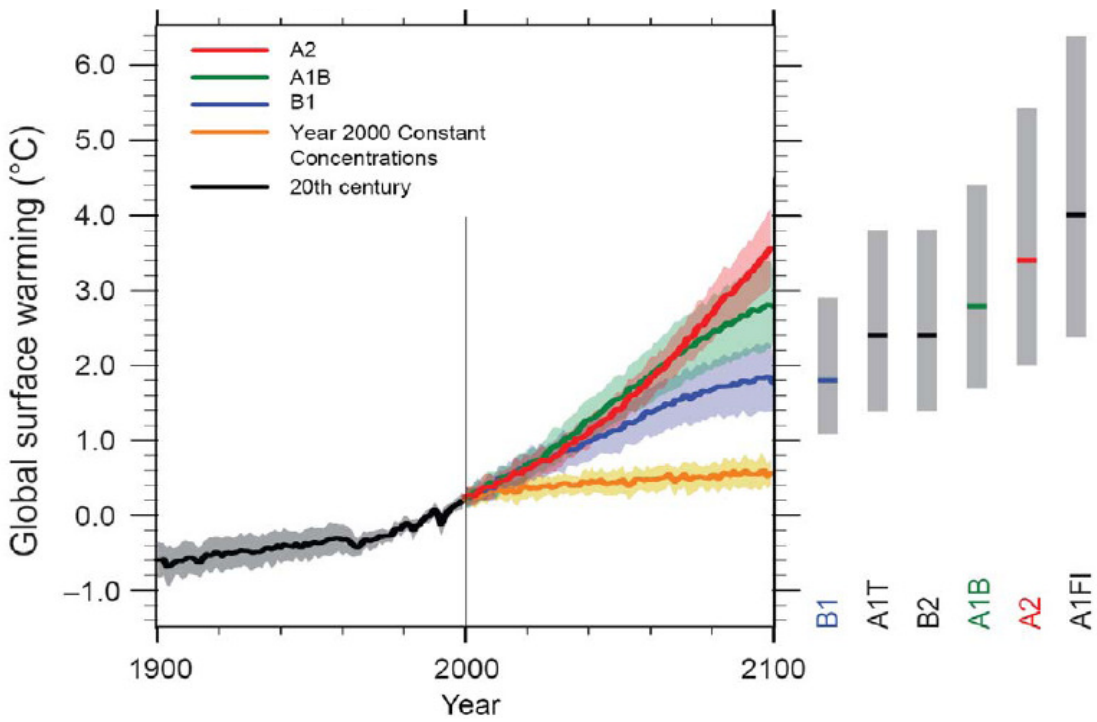
1.2 Emissions scenarios

In order to make projections of climate change in the UK over the next century, it is necessary to make some assumptions about future emissions of greenhouse gases (and other pollutants) from human activities (Murphy *et al.*, 2009).

The IPCC Special Report on Emissions Scenarios (SRES) (Nakićenović and Swart, 2000) defined different future emissions pathways based on potential storylines for the future. These representations of the future development of emissions are based on a coherent and internally consistent set of assumptions about factors such as demographic changes, socio-economic development and technological change. Six storylines for future emissions were developed, each resulting in different estimates of greenhouse gas emissions and the associated increase in global average surface temperatures (Figure 1).

The inertia in the climate system means that the degree of climate change over the next two or three decades is relatively insensitive to future emissions scenarios. However, this situation changes after the 2040s, as projections based on different emissions scenarios increasingly diverge due differing interpretations of future social, economic and technical forces and their implications for greenhouse gas emissions.

Figure 1: Global averages of surface warming (relative to 1980-1999) for the emissions scenarios (SRES), shown as continuations of the 20th Century simulations. The bars indicate the best estimate and likely range for the six SRES scenarios (Source: IPCC, 2007: 46).



In UKCP09, projections are developed under three different emissions scenarios, providing a wide range of the full SRES emissions scenarios. The emissions scenarios used in UKCP09 do not include the effects of planned mitigation policies, but do assume changes in technology and economic growth, including a move to renewable sources of energy.

The three emissions scenarios used in UKCP09 are labelled based on their relative greenhouse gas emissions level, and can be summarised as:

- Low (B1) – this scenario envisions a more integrated and ecologically friendly world with a high uptake of low carbon technologies.
- Med (A1B) – within this scenario, strong economic growth and convergent societies and economies are accompanied by a balanced approach to energy generation featuring fossil fuels and renewable energy technologies.
- High (A1FI) – within this scenario economic growth is strong, and societies and economies are increasingly integrated, yet the emphasis is on fossil fuel energy sources.

1.3 Probability levels

A major advancement of the new UK climate projections is the inclusion of probability. Probability given in UKCP09 can be seen as the relative degree to which each possible climate outcome is supported by the evidence available, taking into account the current understanding of climate science and observations, as generated by the UKCP09 methodology (Murphy *et al.*, 2009). If the evidence changes in the future, so will the probabilities[3].

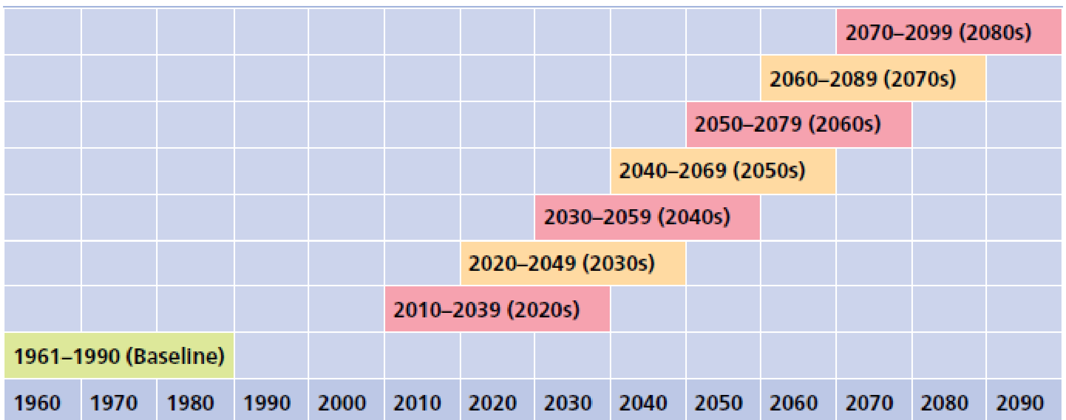
Probability levels associated with a given change should be interpreted as indicating the relative likelihood of the projected change being at or less than the given change. For example, if a projected temperature change of +4.5℃ is associated with the 90% probability level at a particular location in the 2080s for the UKCP09 medium emission scenario, this should be interpreted as "it is projected that there is a 90% likelihood that temperatures at that location will be equal to or less than 4.5℃ warmer than temperatures in the 1961–1990 baseline period". Additionally, it can be stated that "there is a 10% likelihood that those temperatures will be greater than 4.5℃ warmer than the baseline period" (Murphy *et al.*, 2009).

There are a number of probability levels provided in the UKCP09 projections. The 10th, 50th and 90th probability levels were chosen to report in the key findings following consultation from stakeholders, recognising that these represented a good spread of results. It is possible to get changes associated with other probability levels from the UKCP09 user interface.

1.4 Time periods

UKCP09 projections are provided averaged over seven 30-year future overlapping time periods (Figure 2). These are referred to by their middle decade, from 2020s (2010-2039) to 2080s (2070-2099). Changes are expressed relative to the baseline period.

Figure 2: The seven 30-year future time periods over which projections are averaged, relative to the baseline period (Murphy *et al.*, 2009: 18)



[3] More information on 'subjective' probability on which the UKCP09 projections are based can be found at http://ukclimateprojections.defra.gov.uk/content/view/1118/690/

2 Climate change projections for North West England

This section presents some maps of the UKCP09 probabilistic projections of changes in key climate variables, for the future time period of the 2050s (2040-2069) and for the medium emissions scenario. In addition, it includes tables which show projections for additional time periods (2020s and 2080s) for these key climate variables and graphs (or plume plots) showing the full range of change projected over all time periods and for all probability levels. All projected changes are relative to the baseline period, 1961-1990.

The 10th, 50th and 90th probability levels are reported in the projections tables, together with the wider range. The wider is defined as the range from the lowest to highest value of change for all emissions scenarios and all three (10, 50, and 90%) probability levels for each 30-year time period. Summer is defined as the three month period including June, July and August. Winter is the period including December, January, and February.

The 10%, 50% and 90% probability levels can also be interpreted as:

- 10% probability level - very likely to be exceeded every nine out of ten years;
- 50% probability level - likely to be exceeded every one out of two years (i.e. as likely to be exceeded as not); and,
- 90% probability level - only likely to be exceeded every one out of ten years.

This report includes Information about the following climate variables:

- Temperature
    - Annual mean temperature
    - Winter mean temperature
    - Summer mean temperature
    - Summer mean daily maximum temperature
    - Change in temperature of the warmest day in Summer
    - Summer mean daily minimum temperature
    - Change in temperature of the warmest night in Summer
- Precipitation
    - Annual mean precipitation
    - Winter mean precipitation
    - Wettest day in Winter
    - Summer mean precipitation
    - Wettest day in Summer
- Other variables
    - Summer mean relative humidity
    - Winter mean relative humidity
    - Summer cloud cover
    - Winter cloud cover

Table 1 provides a summary of changes in key climate variables in North West England for the medium emissions scenario for the 2050s. The climate projections indicate a robust pattern of warming of annual and seasonal temperatures, both during the day and night. Rainfall patterns are more uncertain indicated by their wider ranges, but the central estimate of change (50% probability level) indicates that summer precipitation will decrease, whilst winter precipitation will increase. The direction of change for annual mean precipitation is more uncertain, with the central estimate suggesting no change (50% probability level).

Table 1: Summary of changes for key climate variables under the medium emissions scenario for the 2050s

Climate variable	Probability level				
	10%	50%	90%	Wider range	
Annual mean temperature	1.4	2.3	3.3	0.8	4.4
Winter mean temperature	1.1	1.9	3.0	0.8	3.3
Summer mean temperature	1.2	2.6	4.1	1.1	4.7
Summer mean daily maximum temperature	1.0	3.3	5.8	1.0	6.5
Summer mean daily minimum temperature	1.0	2.5	4.4	0.9	4.9
Annual mean precipitation	-6	0	6	-8	8
Winter mean precipitation	+3	+13	+26	-1	+27
Summer mean precipitation	-36	-18	+1	-37	+8

2.1 Changes in temperature

2.1.1 Annual mean temperature

Mean daily temperature (or mean temperature) is the average of the daily maximum and daily minimum temperatures. The mean annual temperature is the average over the whole year, January-December. Figure 3 shows the change in annual mean temperature under the medium emissions scenario for the 2050s. This indicates that under the medium emissions scenario for the 2050s, the central estimate of increase in annual mean temperature is 2.3℃; it is very unlikely to be less than 1.4℃ and is very unlikely to be more than 3.3℃. A wider range of uncertainty is from 0.8℃ to 4.4℃ (Table 2). Figure 4 shows a plume plot of changes in annual mean temperature for all seven 30-year time periods and the full range of all probability levels. This illustrates the increasing uncertainty with time as the projected changes increasingly diverge throughout the century. However, although the projected changes diverge with time, a robust pattern of warming is evident.

Figure 3: Change in annual mean temperature under the medium emissions scenario for the 2050s

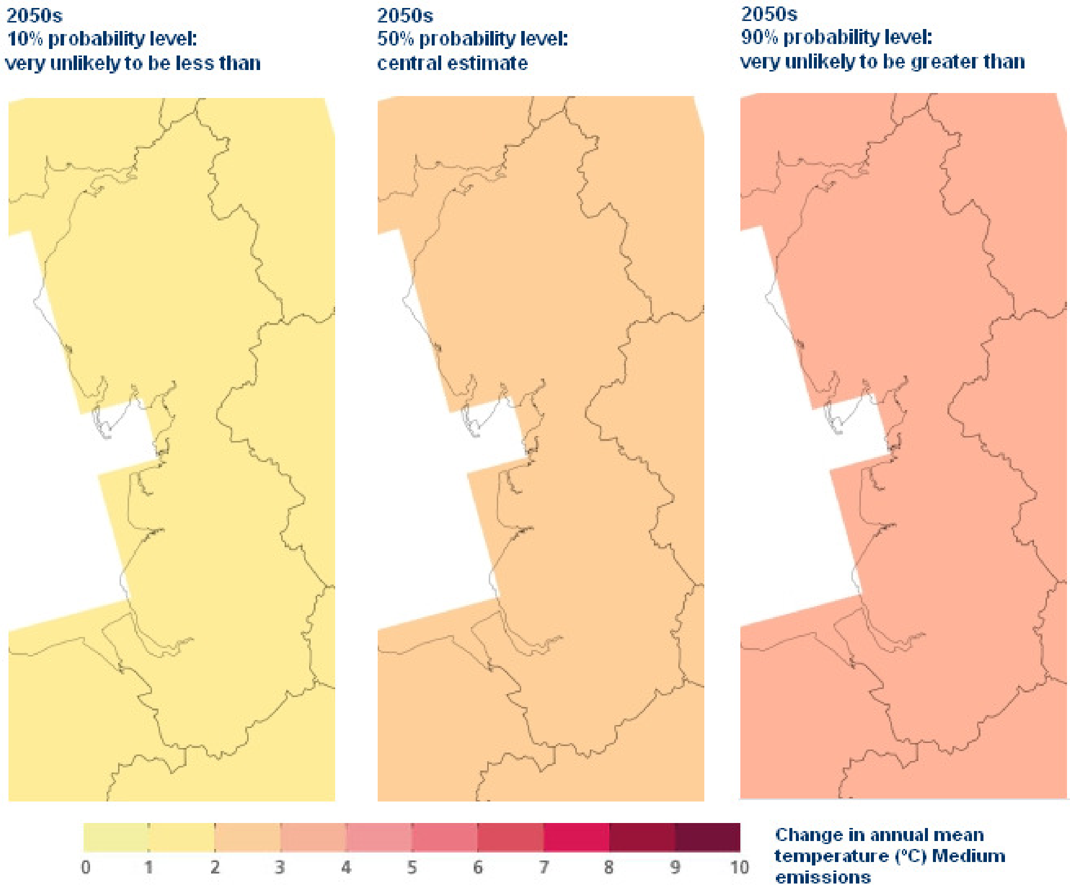
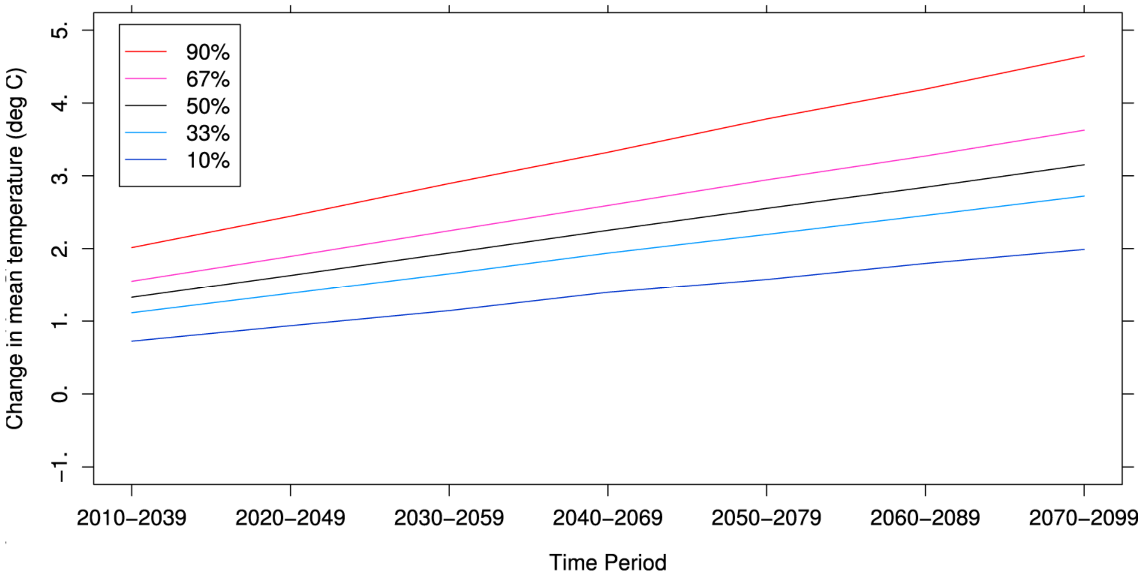


Table 2: Changes in annual mean temperature (°C)

Timeslice	Emissions scenario	Probability level				
		10%	50%	90%	Wider range	
2020s	Low	0.8	1.4	2.0	0.3	2.7
	Medium	0.7	1.3	2.0	0.2	2.7
	High	0.7	1.3	2.0	0.3	2.6
2050s	Low	1.2	2.0	3.0	0.6	4.0
	Medium	1.4	2.3	3.3	0.8	4.4
	High	1.6	2.5	3.7	0.9	4.9
2080s	Low	1.6	2.6	3.8	0.8	5.2
	Medium	2.0	3.2	4.6	1.2	6.2
	High	2.5	3.9	5.7	1.7	7.6

Figure 4: Plume plot showing changes in annual mean temperature for all 30-year time-slices and the full range of probability levels



2.1.2 Winter mean temperature

Under the medium emissions scenario for the 2050s, the central estimate of increase in winter mean temperature is 1.9℃; it is very unlikely to be less than 1.1℃ and is very unlikely to be more than 3℃ (Table 3). A wider range of uncertainty is from 0.8℃ to 3.3℃.

Table 3: Changes in winter mean temperature (℃)

Timeslice	Emissions scenario	Probability level				
		10%	50%	90%	Wider range	
2020s	Low	0.4	1.2	2.0	0.3	2.0
	Medium	0.5	1.2	2.0	0.3	2.0
	High	0.3	1.2	2.0	0.3	2.0
2050s	Low	0.8	1.8	2.8	0.8	3.3
	Medium	1.1	1.9	3.0	0.8	3.3
	High	1.2	2.1	3.3	0.8	3.3
2080s	Low	1.3	2.3	3.5	1.3	4.8
	Medium	1.4	2.6	4.0	1.3	4.8
	High	1.9	3.1	4.8	1.3	4.8

2.1.3 Summer mean temperature

Under the medium emissions scenario for the 2050s, the central estimate of increase in summer mean temperature is 2.6℃; it is very unlikely to be less than 1.2℃ and is very unlikely to be more than 4.1℃ (Table 4). A wider range of uncertainty is from 1.1℃ to 4.7℃.

Table 4: Changes in summer mean temperature (°C)

Timeslice	Emissions scenario	Probability level				
		10%	50%	90%	Wider range	
2020s	Low	0.8	1.6	2.5	0.6	2.5
	Medium	0.6	1.5	2.5	0.6	2.5
	High	0.6	1.5	2.5	0.6	2.5
2050s	Low	1.1	2.4	3.8	1.1	4.7
	Medium	1.2	2.6	4.1	1.1	4.7
	High	1.5	3.0	4.7	1.1	4.7
2080s	Low	1.3	2.8	4.6	1.3	7.3
	Medium	2.0	3.7	5.9	1.3	7.3
	High	2.5	4.7	7.3	1.3	7.3

2.1.4 Summer mean daily maximum (daytime) temperature

Summer mean daily maximum temperature is the average of the daily maximum temperatures over the summer period (June, July, August). Under the medium emissions scenario for the 2050s, the central estimate of increase in summer mean daily maximum temperature is 3.3ºC; it is very unlikely to be less than 1ºC and is very unlikely to be more than 5.8ºC (Table 5). A wider range of uncertainty is from 1ºC to 6.5ºC.

Table 5: Changes in summer mean daily maximum temperature (°C)

Timeslice	Emissions scenario	Probability level				
		10%	50%	90%	Wider range	
2020s	Low	0.6	2.0	3.5	0.4	3.5
	Medium	0.4	1.9	3.5	0.4	3.5
	High	1.0	3.1	5.3	1.0	6.5
2050s	Low	1.0	3.1	5.3	1.0	6.5
	Medium	1.0	3.3	5.8	1.0	6.5
	High	1.3	3.8	6.5	1.0	6.5
2080s	Low	1.0	3.6	6.6	1.0	10.1
	Medium	1.6	4.8	8.3	1.0	10.1
	High	2.3	6.0	10.1	1.0	10.1

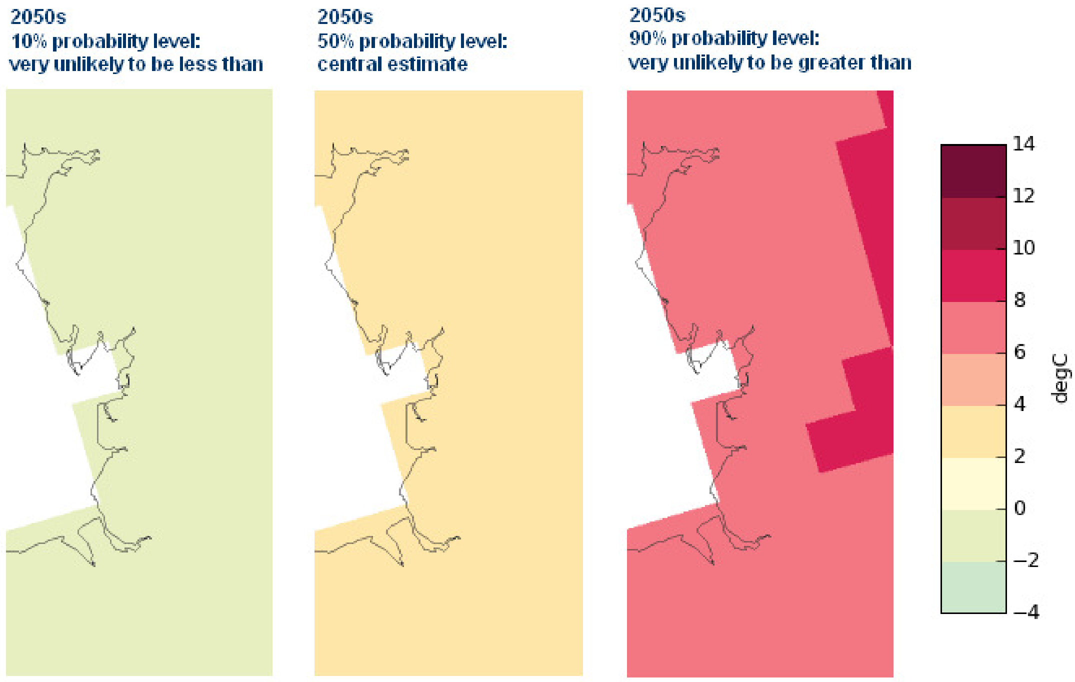
Figure 5 illustrates the absolute (or actual) summer maximum daily temperature for North West England under the medium emissions scenario for the 2050s. This indicates that summer maximum daily temperatures are very unlikely to be greater than 21-24°C across most of North West England by the 2050s under the medium emissions scenario (90% probability level).

Figure 5: Future absolute summer maximum daily temperature under the medium emissions scenario for the 2050s

2.1.5 Change in temperature of the warmest day of the summer

The change in temperature of the warmest day of the summer is the change in the 99th percentile of the daily maximum temperature of the summer season. This represents the extreme maximum (daytime) temperature in the summer. Figure 6 indicates that under the medium emissions scenario by the 2050s, the warmest day in summer is very unlikely to be greater than 6℃ increase from the baseline period (90% probability level). Alternatively, it could be stated that by the 2050s (under the medium emissions scenario), 1 in 10 years are very unlikely to have a warmest day in summer of over 6℃ greater than the baseline period.

Figure 6: Change in temperature of the warmest day in summer under the medium emissions scenario for the 2050s



2.1.6 Summer mean daily minimum (night-time) temperature

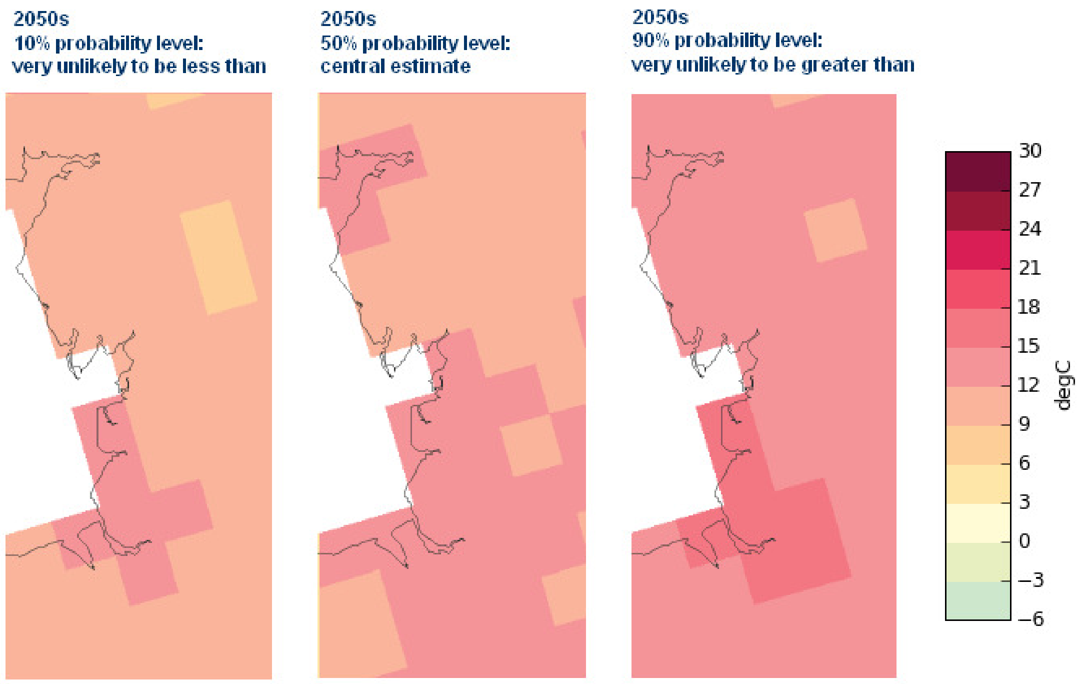
Summer mean daily minimum temperature is the average of the daily minimum temperatures over the summer period, June-August. Under the medium emissions scenario for the 2050s, the central estimate of increase in summer mean daily minimum temperature is 2.5℃; it is very unlikely to be less than 1℃ and is very unlikely to be more than 4.4℃ (Table 6). A wider range of uncertainty is from 0.9℃ to 4.9℃.

Table 6: Changes in summer mean daily minimum (night-time) temperature (℃)

Timeslice	Emissions scenario	Probability level				
		10%	50%	90%	Wider range	
2020s	Low	0.6	1.5	2.6	0.5	2.6
	Medium	0.5	1.5	2.6	0.5	2.6
	High	0.9	2.3	3.9	0.9	4.9
2050s	Low	0.9	2.3	3.9	0.9	4.9
	Medium	1.0	2.5	4.4	0.9	4.9
	High	1.3	2.9	4.9	0.9	4.9
2080s	Low	1.1	2.8	4.9	1.1	7.8
	Medium	1.6	3.7	6.4	1.1	7.8
	High	2.2	4.6	7.8	1.1	7.8

Absolute (or actual) summer minimum daily temperatures are very unlikely to be greater than 12-15℃ across most of North West England by the 2050s under the medium emissions scenario (90% probability level) (Figure 7).

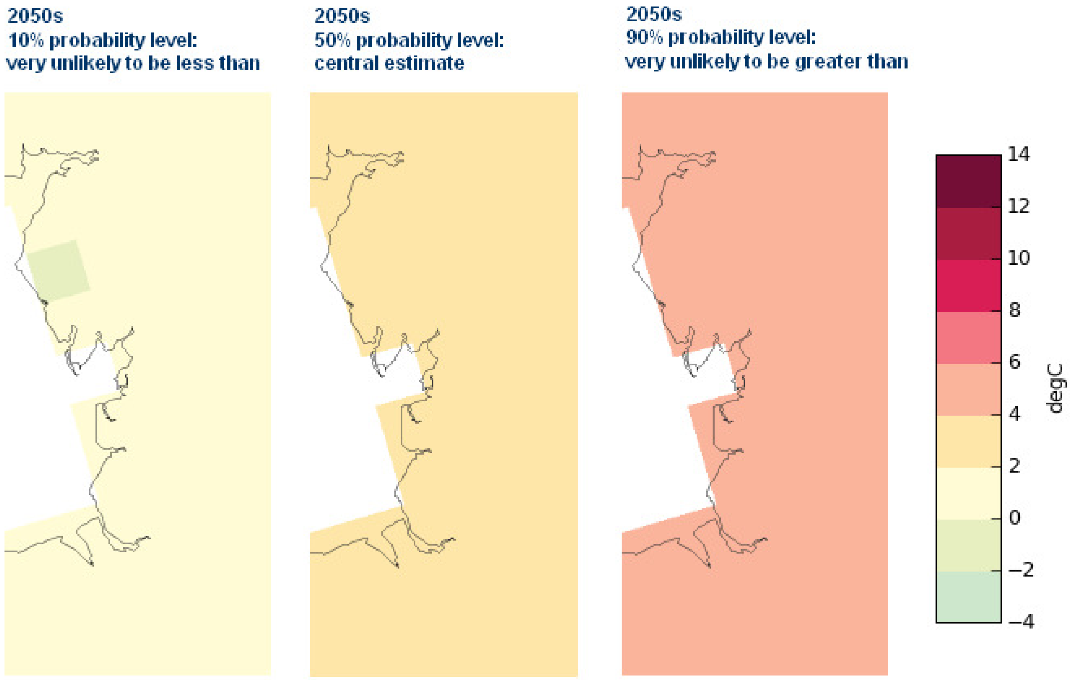
Figure 7: Future absolute summer mean daily minimum (night-time) temperature for the 2050s under the medium emissions scenario



2.1.7 Change in temperature of the warmest night of the summer

The change in temperature of the warmest night of the summer is the change in the 99th percentile of the daily minimum temperature of the summer season. This represents the extreme minimum (night-time) temperature in the summer. Figure 8 shows that under the medium emissions scenario by the 2050s, the warmest night in summer is very unlikely to be greater than 4℃ increase from the baseline (90% probability level). Alternatively, it could be stated that by the 2050s (under the medium emissions scenario), 1 in 10 years are very unlikely to have a warmest night in summer of over 4℃ greater than the baseline period.

Figure 8: Change in temperature of the warmest night in summer for the 2050s under the medium emissions scenario



2.2 Changes in precipitation

2.2.1 Annual mean precipitation

The annual mean precipitation is the total amount of rain, snow and hail received over January to December. Table 6 shows the percentage changes in annual mean precipitation for three time periods, all three emissions scenarios, and key probability levels. Under the medium emissions scenario for the 2050s, the central estimate of change in annual mean precipitation is 0% or no change; it is very unlikely to be less than –6% and is very unlikely to be more than 6% (Table 7). A wider range of uncertainty is from –8% to 8%. The direction of change of the annual mean precipitation is therefore quite uncertain in the climate projections.

Table 7: Changes in annual mean precipitation (%)

Timeslice	Emissions scenario	Probability level				
		10%	50%	90%	Wider range	
2020s	Low	-5	1	7	-6	7
	Medium	-5	0	6	-6	7
	High	-6	0	6	-6	7
2050s	Low	-8	-1	6	-8	8
	Medium	-6	0	6	-8	8
	High	-7	0	8	-8	8
2080s	Low	-6	0	8	-10	12
	Medium	-8	0	8	-10	12
	High	-10	1	12	-10	12

2.2.2 Winter mean precipitation

The winter mean precipitation is the total amount of rain, snow and hail received in December, January and February. Climate projections indicate that under the medium emissions scenario for the 2050s, the central estimate of change in winter mean precipitation is +13%; it is very unlikely to be less than +3% and is very unlikely to be more than +26% (Table 8). A wider range of uncertainty is from –1% to +27%. Figure 10 shows a plume plot of changes in winter mean precipitation for all seven 30-year time periods and the full range of all probability levels.

Figure 9: Change in winter mean precipitation under the medium emissions scenario for the 2050s

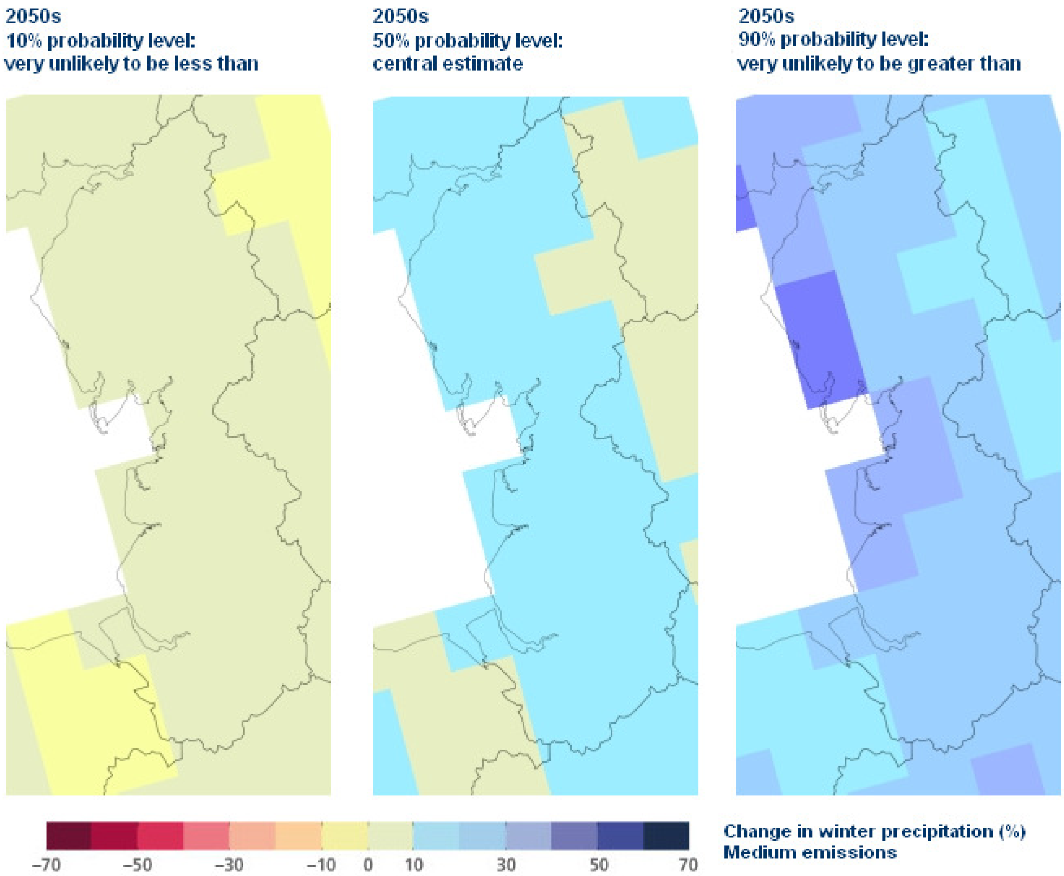
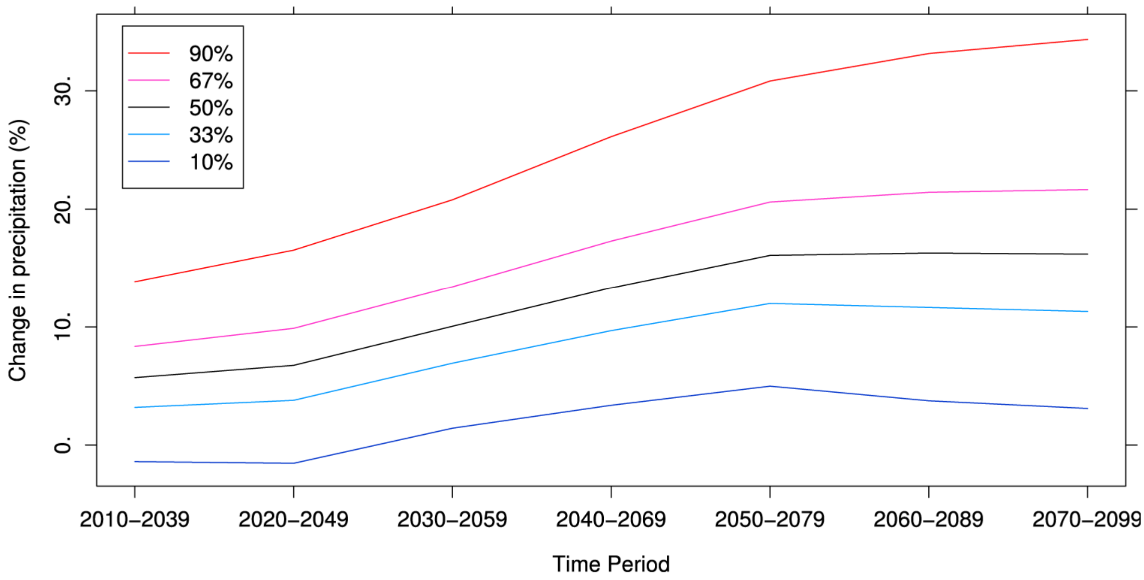


Table 8: Changes in winter mean precipitation (%)

Timeslice	Emissions Scenario	Probability level				
		10%	50%	90%	Wider range	
2020s	Low	-4	+4	+14	-4	+14
	Medium	-1	+6	+14	-4	+14
	High	-4	+4	+13	-4	+14
2050s	Low	-1	+9	+20	-1	+26
	Medium	+3	+13	+26	-1	+27
	High	+3	+13	+27	-1	+27
2080s	Low	+5	+15	+30	+3	+50
	Medium	+3	+16	+34	+3	+50
	High	+9	+26	+50	+3	+50

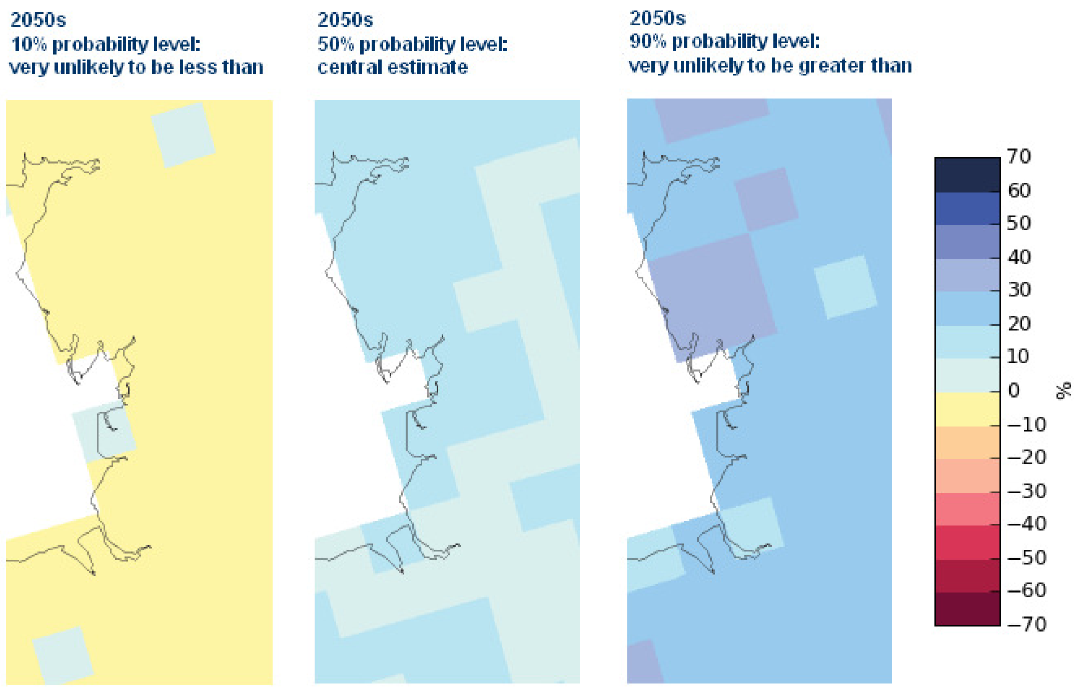
Figure 10: Plume plot showing changes in winter mean precipitation for all 30-year time-slices and the full range of probability levels



2.2.3 Wettest day in winter

The change in the wettest day in winter is the change in the 99th percentile of daily precipitation of the winter season (December, January, February). Figure 11 indicates that under the medium emissions scenario by the 2050s, the wettest day in winter is very unlikely to be greater than 10-20% increase from the baseline period (90% probability level).

Figure 11: Change in the wettest day in winter under the medium emissions scenario for the 2050s



2.2.4 Summer mean precipitation

The summer mean precipitation is the total amount of rain, snow and hail received in June, July and August. Figure 12 shows the spatial distribution of summer mean precipitation across North West England. Under the medium emissions scenario for the 2050s, the central estimate of change in summer mean precipitation is –18%; it is very unlikely to be less than –36% and is very unlikely to be more than +1% (Table 9). A wider range of uncertainty is from –37% to +8%.

Figure 12: Change in the summer mean precipitation under the medium emissions scenario for the 2050s

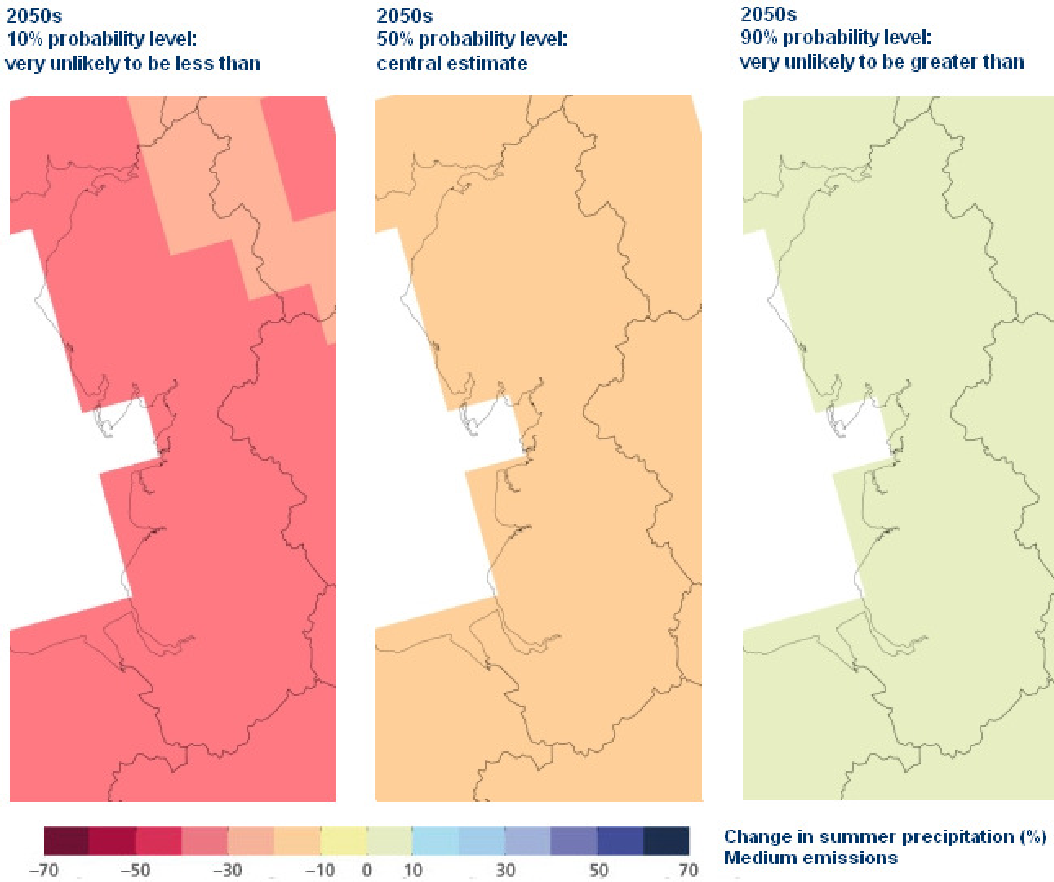
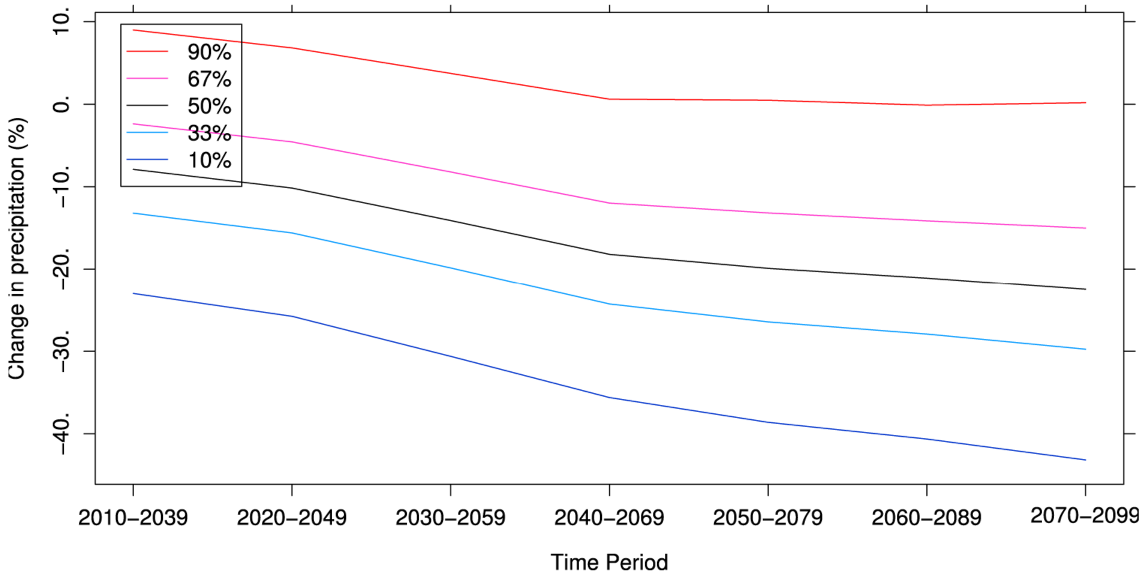


Table 9: Changes in summer mean precipitation (%)

Timeslice	Emissions scenario	Probability level				
		10%	50%	90%	Wider range	
2020s	Low	-20	-6	+8	-23	+10
	Medium	-23	-8	+9	-23	+10
	High	-19	-5	+10	-23	+10
2050s	Low	-34	-14	+8	-37	+8
	Medium	-36	-18	+1	-37	+8
	High	-37	-18	+2	-37	+8
2080s	Low	-35	-17	+3	-51	+3
	Medium	-43	-22	0	-51	+3
	High	-51	-28	-2	-51	+4

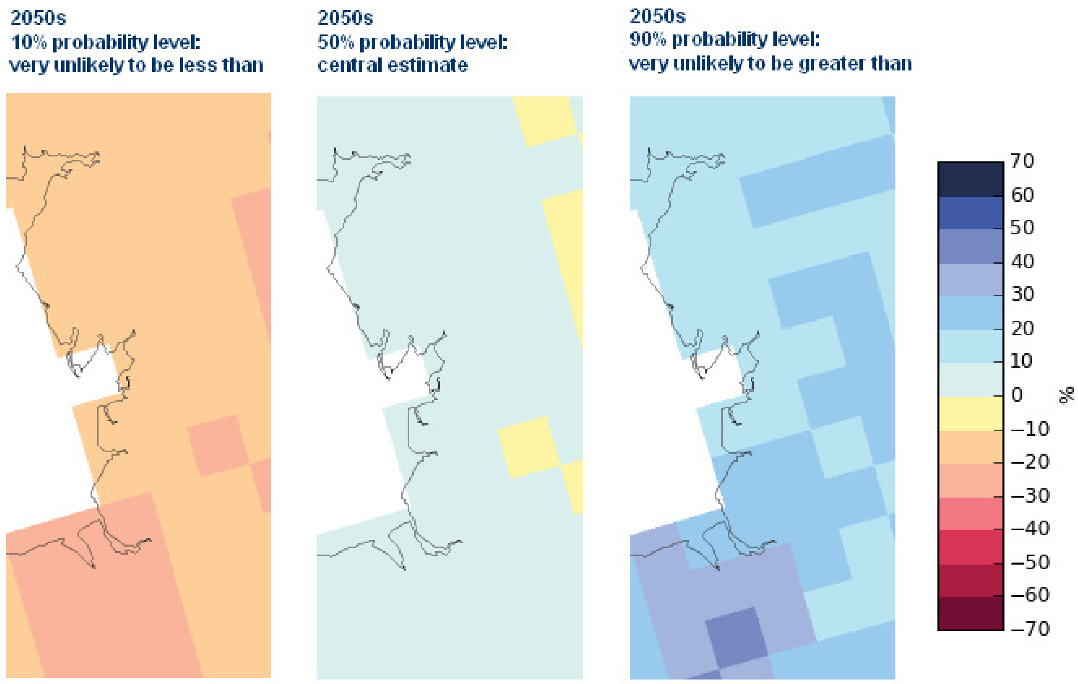
Figure 13: Plume plot showing changes in summer mean precipitation for all 30-year time-slices and the full range of probability levels



2.2.5 Wettest day in summer

The change in the wettest day in summer is the change in the 99th percentile of daily precipitation of the summer season (June, July, August). This extreme amount of rainfall will occur about once per summer. Figure 14 indicates that under the medium emissions scenario by the 2050s, the central estimate of change is 0-10% increase from the baseline period (50% probability level).

Figure 14: Change in the wettest day in summer under the medium emissions scenario for the 2050s

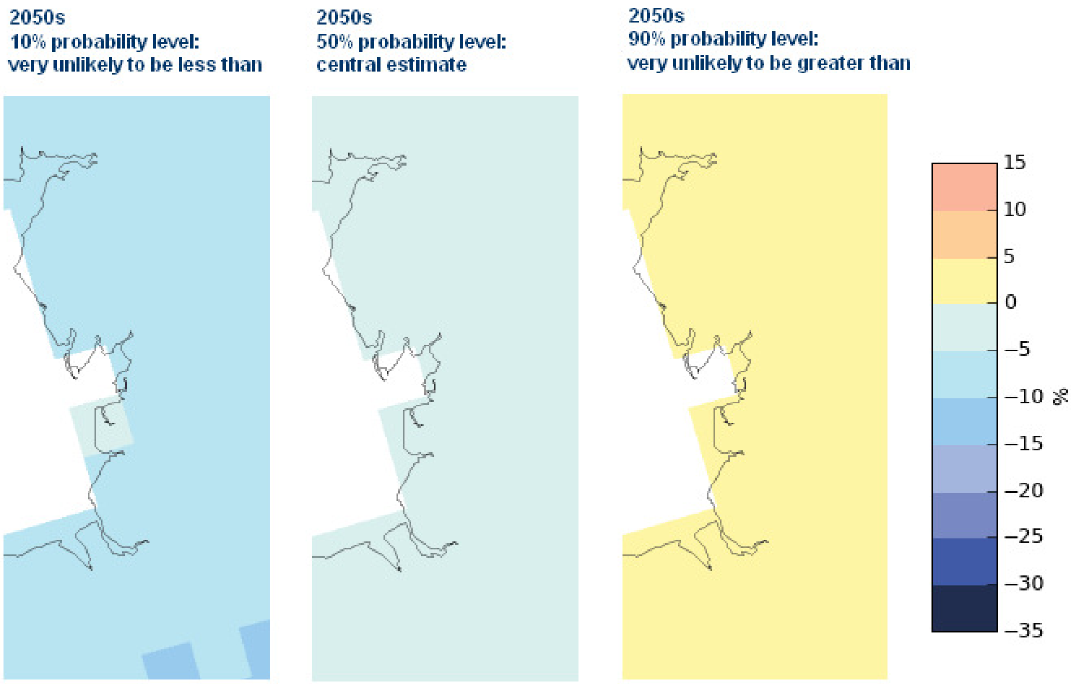


2.3 Changes in relative humidity

2.3.1 Summer mean relative humidity

The central estimate for change in summer mean relative humidity across North West England under the medium emissions scenario for the 2050s is between no change to a -5% decrease (50% probability level) (Figure 15).

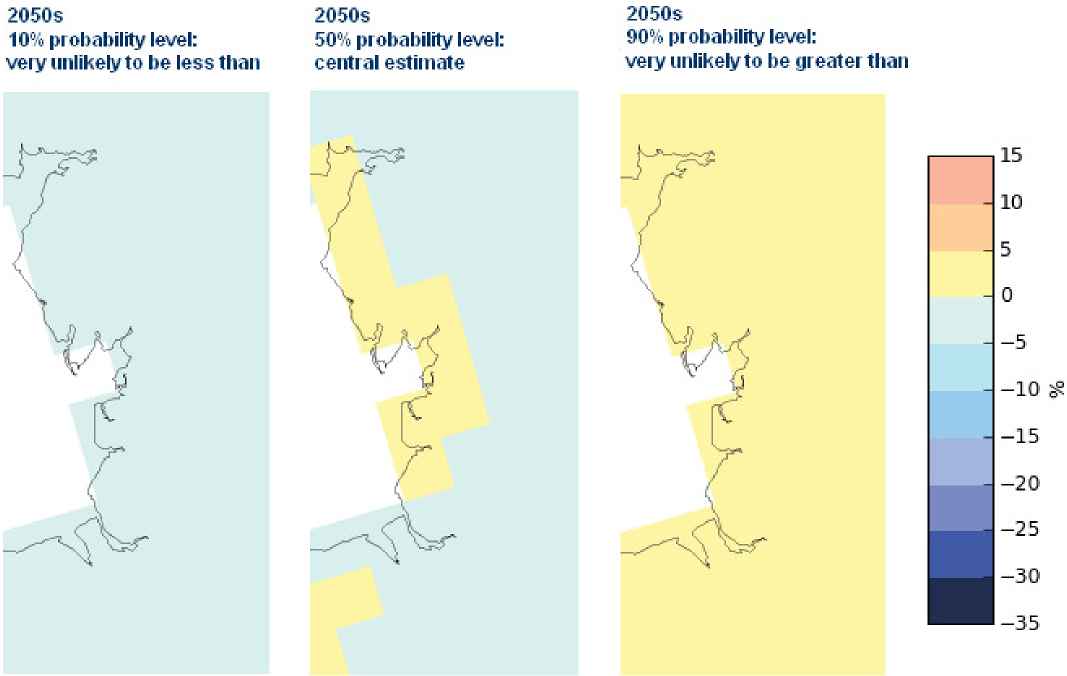
Figure 15: Change in summer mean relative humidity under the medium emissions scenario for the 2050s



2.3.2 Winter mean relative humidity

Under the medium emissions scenario for the 2050s, the change in winter mean relative humidity from the baseline 1961-1990 period is very unlikely to be greater than 0-5% increase (90% probability level) (Figure 16).

Figure 16: Change in winter mean relative humidity under the medium emissions scenario for the 2050s

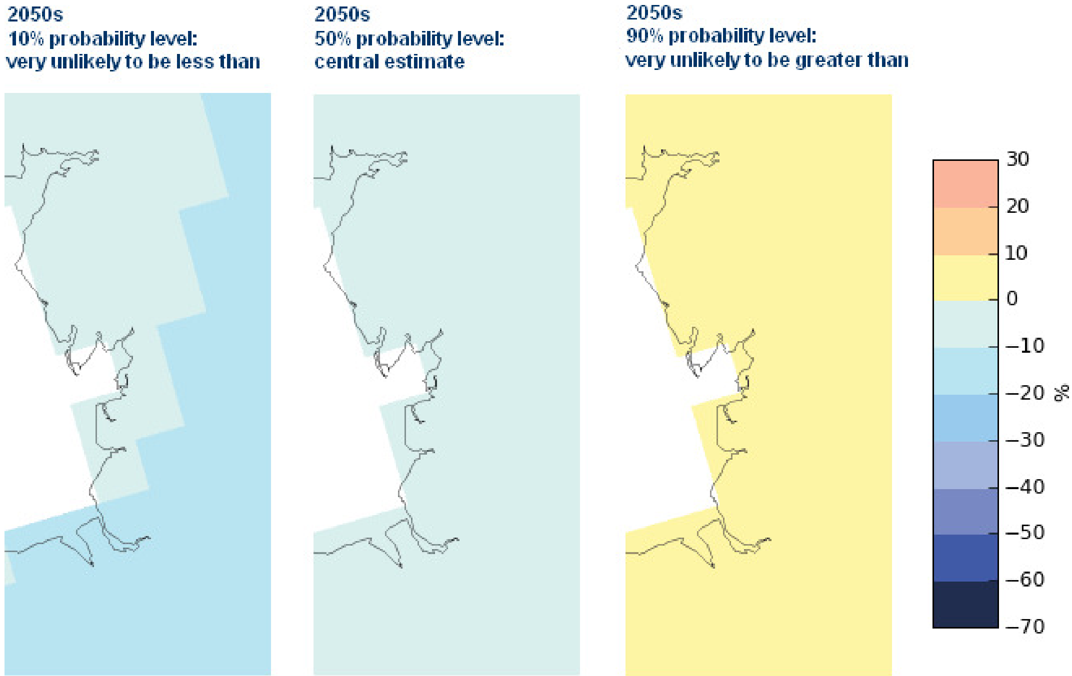


2.4 Changes in cloud cover

2.4.1 Summer cloud cover

The central estimate for change in summer cloud cover across North West England under the medium emissions scenario for the 2050s is no change to a -10% decrease (50% probability level) (Figure 17).

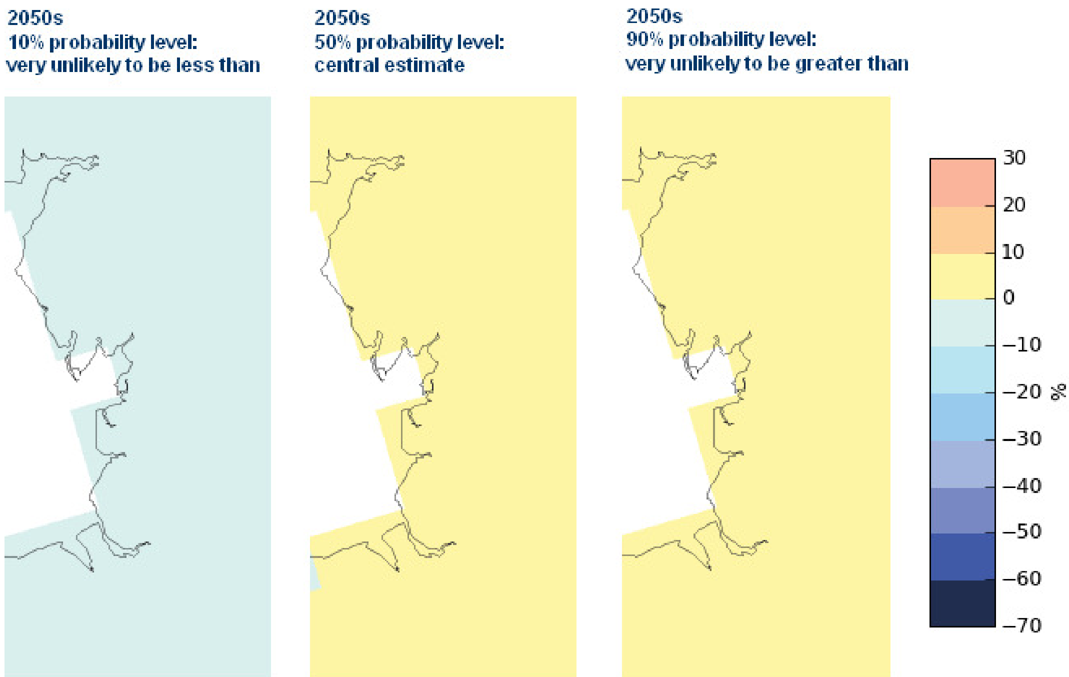
Figure 17: Change in summer cloud cover under the medium emissions scenario for the 2050s



2.4.2 Winter cloud cover

The central estimate for change in winter cloud cover across North West England under the medium emissions scenario for the 2050s is no change to a 10% increase (50% probability level) (Figure 18).

Figure 18: Change in winter cloud cover under the medium emissions scenario for the 2050s



3 Impacts of climate change

Although climate change is a global phenomenon, different parts of the world are expected to experience a wide and varying range and intensity of impacts. The previous section provided an insight into changes to the climate of North West England that are projected for the coming decades. Broadly, temperatures are projected to increase, particularly over the summer months when the mean temperature could increase by 2.6°C (2050s medium emissions scenario, 50% probability level). Another key change is the intensification of a seasonal variation in rainfall patterns. The winter months are projected to become wetter with 13% more rainfall (2050s medium emissions scenario, 50% probability level), whilst summers are projected to become 18% drier under the same scenario and probability level. In addition to this seasonal variation, the intensity of rainfall events is also anticipated to increase, with the amount of precipitation falling on the wettest days in both winter and summer increasing (2050s medium emissions scenario, central estimate). The projections also suggest small changes in relative humidity in summer and winter, a reduction in summer cloud cover and an increase in winter cloud cover.

The future changes in climate may have significant impacts across a range of sectors in North West England including health, infrastructure, economy and biodiversity. These include:

- Cold related illnesses and mortality are likely to decrease due to milder winters. However, the number of incidents of food poisoning, heat stress and heat related deaths may increase in summer;
- Domestic energy use may decrease in winter due to higher temperatures. However, it may increase during summer months as refrigeration and air conditioning demand increases;
- Wetter winters and more intense rainfall events throughout the year may result in a higher risk of flooding from rivers;
- More intense rainstorms may in some locations result in the amount of surface water runoff exceeding the capacity of drainage systems, consequently leading to more frequent and severe localised flash flooding;
- Whilst insurance claims associated with freezing temperatures are likely to decrease, more frequent storms and floods may cause increased damage to property and infrastructure, resulting in significant economic costs;
- Periods of drought in summer could lead to soil shrinking and subsidence, causing damage to buildings and transport networks. Drought may also impact negatively on agriculture, industry and biodiversity;
- Warmer and drier summers may benefit the recreation and tourism economy, yet they are also likely to affect the quantity and quality of water supply, which will need careful management; and,
- The changing climate will impact on the behaviour and distribution of species, and may encourage the spread of invasive species.

A North West England perspective to climate change and the potential impacts that this may bring is an important consideration for cities such as Manchester. Cities rely on their hinterlands for a number of essential services including water supplies, transport networks and opportunities for leisure and tourism, all of which are likely to be impacted by climate change. Improving understanding of climate change impacts at a regional scale can help cities to appreciate such issues and inform the development of appropriate adaptation responses. It must also be acknowledged that climate change at a global scale will affect regions such as North West England. For example, migration patterns, agricultural markets and tourism will all be significantly affected by climate change, which could bring knock-on impacts for the region. However, such issues are beyond the scope of this report.

4 The adaptation imperative and EcoCities

The climate of the second half of the 21st Century will be influenced by the greenhouse gases emitted over the next few decades, and therefore, the human contribution to climate change will become increasingly important (Hulme *et al.*, 2002). Mitigation (the reduction of greenhouse gas emissions) is needed to limit the extent of further changes in climate. However, mitigation alone will not arrest changes completely, and although much of the focus of research and policy has been on mitigation and investigation of impacts (McEvoy, 2007), there is growing acceptance that a twin-response to climate change is needed incorporating both mitigation and adaptation.

Due to the long memory of the climate system and inertia in energy systems, much of the change in climate over the next 30 to 40 years has been pre-determined by past and present emissions of greenhouse gases. Therefore climate impacts through to at least the 2040s are unavoidable. Adaptation is necessary to address impacts resulting from the warming which is already unavoidable due to past emissions (IPCC, 2007). Adaptation is action to minimise the adverse impacts of climate change and to take advantage of opportunities it might present. There is a pressing need for society to adapt to climate change now (Hulme *et al.*, 2002).

The case for climate change adaptation is highlighted by the following points (adapted from Willows and Connell, 2003):

- Climate change cannot be avoided;
- Climate change may be experienced more rapidly than scenarios suggest;
- Planned adaptation is more cost effective than emergency measures and retrofitting;
- Planned adaptation reduces likelihood of maladaptation (measures which prevent or reduce ability to adapt to climate change);
- Immediate improvement gives protection from climate extremes and other benefits;

- Planned adaptation captures benefits of climate change where these are applicable; and
- Planned climate change adaptation develops a receptive policy environment.

There is a clear need to develop adaptation responses to climate change both to reduce the extent of negative impacts and to realise potential benefits associated with positive impacts. The extent of the climate change impacts experienced in North West England will depend on the success of adaptation strategies implemented to respond to these impacts. Indeed, adaptation interventions may significantly reduce the exposure to impacts such as the threat of flooding or heat stress. In the same way that climate change impacts will differ across the globe, so will the capacity of different locations, such as cities, in responding to the challenges and opportunities associated with a changing climate. The success of initiatives to develop adaptation responses will be influenced by a wide range of factors such as political motivation, the existence of supportive legislation and guidance, and the availability of resources.

EcoCities is a joint initiative between the University of Manchester and property company Bruntwood, drawing on the expertise of the Manchester Architecture Research Centre, Centre for Urban Regional Ecology and Brooks World Poverty Institute. The project focuses on the response of urban areas to the impacts of climate change, looking particularly at how we can adapt our cities to the challenges and opportunities that a changing climate presents.

EcoCities is creating an adaptation 'Blueprint' is for Greater Manchester. This aims to support and inform climate change adaptation responses in Greater Manchester by providing insights into issues including climate change impacts and possible adaptation responses to these impacts. It is hoped that the blueprint will enable a longer term view to climate change adaptation to be taken which is planned rather than reactive.

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