



Climate change projections for Greater Manchester

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EcoCities is a joint initiative between the School of Environment and Development at the University of Manchester and commercial property company Bruntwood. The project looks at the impacts of climate change and at how we can adapt our cities and urban areas to the challenges and potential opportunities that a changing climate presents.

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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. Continued 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. 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 and aerosols. The UKCP09 projections are therefore more complex, but respond to demands from users for this level of detail (Murphy et al 2009).

The weather generator, available through UKCP09, generates daily outputs of climate for a specific location on a 5x5 km grid scale. When combined with the UK Climate Projections, it is able to generate future daily weather series. The EcoCities research project required customised climate projections information for the conurbation of Greater Manchester. However, the resolution of the weather generator was too fine for this scale of analysis. Therefore, a climate zone analysis was undertaken for Greater Manchester, and the weather generator was run for each of the resulting zones. In addition, a separate analysis of central Manchester was undertaken of some key future daily weather thresholds.

This document summarises the climate projections information for Greater Manchester in tables, graphs, maps and descriptions. Specifically, it focuses on information for the 2050s (2040–2069) for the low and high emissions scenarios, and for three probability levels. In addition, outputs from the weather generator for central Manchester report all time periods and emissions scenarios. As in the report for the North West region,¹ 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. It then outlines the climate zone analysis undertaken for Greater Manchester,

¹ The report for the North West region is available to download from: http://www.sed.manchester.ac.uk/architecture/research/ecocities/library/documents/ThefutureclimateofNorthWestEngland_000.pdf

provides an introduction to the weather generator, and presents the future daily weather generator outputs for the Greater Manchester conurbation and central Manchester area.

The information on the future climate of the Greater Manchester is particularly valuable to a wide range of stakeholder groups within the conurbation wishing to learn more about this subject. The analysis provided here is specific to Greater Manchester: it is not available for any other conurbation at this level and refines the most recent climate projections.

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 occurred. Global warming rates have increased to $0.17 \pm 0.05^{\circ}\text{C}$ 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

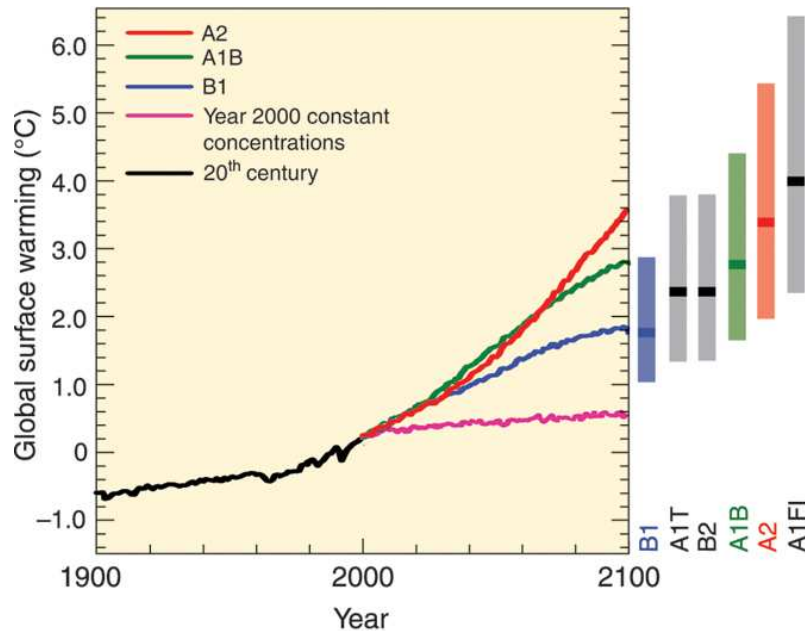
In order to construct projections of climate change in the UK over the next century, it is necessary to make some assumptions about future emissions of greenhouse gases (and other pollutants) from human activities (Murphy et al 2009).

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 to differing interpretations of future social, economic and technical forces and their implications for greenhouse gas emissions.

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.

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).



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.

Recent estimates of global carbon dioxide emissions indicate that CO² emissions increased by more than 3% per year between 2000–2004, compared to 1.1% per year between 1990–1999 (Raupach et al 2007). This rate of 3% per year is faster than that projected in any of the emissions scenarios. Therefore, even the high emissions scenario used in UKCP09 may be an underestimate of future emissions and future climate change. However, due caution should be applied

when basing conclusions about emissions over future decades on estimates over a short time period.

This report focuses on outputs for the low and high emissions scenarios at the Greater Manchester conurbation level. In addition, outputs from the weather generator are provided for central Manchester, which includes threshold information for all three emissions scenarios.

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.²

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°C 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°C 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°C 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 EcoCities' 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.

² 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/>

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. This report focuses on outputs for the 2050s (2040-2069) as this is the time-frame of the EcoCities project.

Figure 2: The seven 30-year future time periods over which projections are averaged, relative to the baseline period (Murphy et al 2009: 18). The 2050s (2040-2069) is the focus of outputs in this report.



1.5 The weather generator

The weather generator provides a high resolution time series of weather variables at a 5x5km grid square resolution for user-specified future periods up to 2100 (Jones et al 2009). It is based around a stochastic rainfall model that simulates future rainfall sequences, and other weather variables, which are generated according to the rainfall state (wet or dry). The weather generator is calibrated from observed daily rainfall data, as well as data from a number of other weather variables. Then, monthly change factors from the UKCP09 probabilistic projections are applied to each grid square to define the range of possible climate change futures. The rainfall model is then refitted using the perturbed future daily rainfall statistics, and other weather variables for the future are then generated (Jones et al 2009).

The weather generator provides hourly and daily weather data for rainfall, temperature, humidity and sunshine.³ Thus, it provides extra detail for weather data at a specific location, on the timescale of an hour or day, rather than the monthly or seasonal averages for a 25km grid square (as provided by the probabilistic projections). This type of information can be further analysed in terms of exceedances of thresholds or accumulations/deficits, such as a drought. The threshold detector tool is particularly useful for analysing thresholds of different climate variables and associated vulnerabilities.

³ A second version of the weather generator was released in Spring 2011. The analysis in section 3 of this report was undertaken with version 1 of the weather generator. This second version of the weather generator provides a better representation of extremes. The analysis of thresholds in Manchester City Centre was therefore updated using version 2.

2 Climate zone analysis for Greater Manchester

The weather generator, available through UKCP09, generates daily outputs of weather for a specific location on a 5x5 km grid scale. Thus, when combined with the UK Climate Projections, it is able to generate future daily weather series. However, due to the complex nature of the probabilistic projections, the weather generator outputs are extremely large (e.g. for each 5x5km grid square and for each emissions scenario, 100 simulations of 30 years of a number of daily weather variables are produced). Producing results on a 5km grid across the conurbation was therefore not possible due to time and resource constraints. It was therefore necessary to reduce the output from the weather generator to a realistic amount of data to analyse at the conurbation scale.

Determining spatial variations in climate, through analyses of climate zones across Greater Manchester, provided a method that respected the spatial patterns in climate across the conurbation, whilst also providing a compromise between the standard UKCP09 25 x 25 km gridded output that is not representative of the climate of the area, and the unrealistic goal of producing detailed information at 5 x 5 km across the whole conurbation. Defining climate zones across GM also ensured that homogenous regions (in terms of climate) are chosen for the weather generator analysis, an important pre-requisite when analysing larger regions up to 1000 km² (Jones et al 2009).

Statistical analysis⁴ resulted in the identification of three climate zones across Greater Manchester: Mersey Basin; Pennine Fringe; and Pennine Upland. The Pennine Fringe climate zone is an intermediary climate zone sitting between the mountainous, wet and cold Pennine uplands, and the lower, drier and warmer plains of the Mersey basin (figure 3 and table 1).

⁴ A full description of the methods used to generate the climate zones is provided in the Appendix.

Figure 3: The three climate zones across Greater Manchester

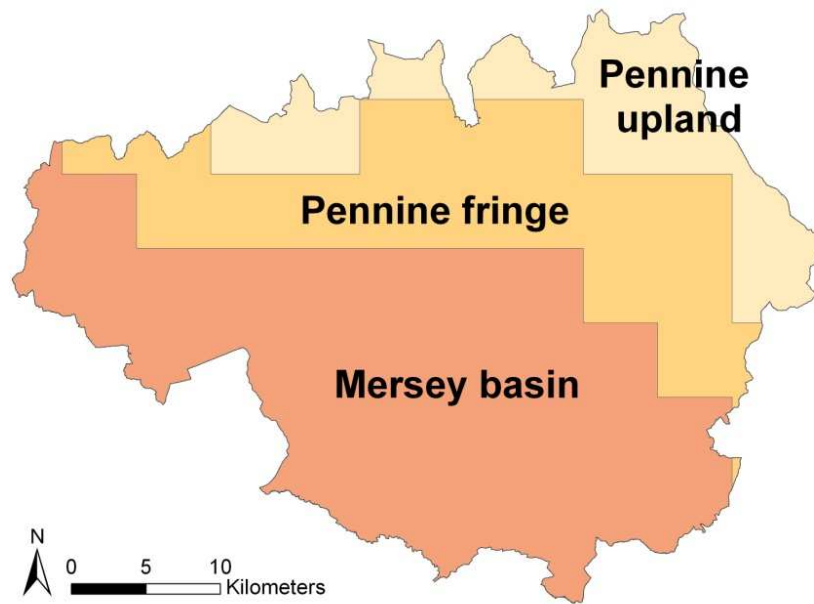
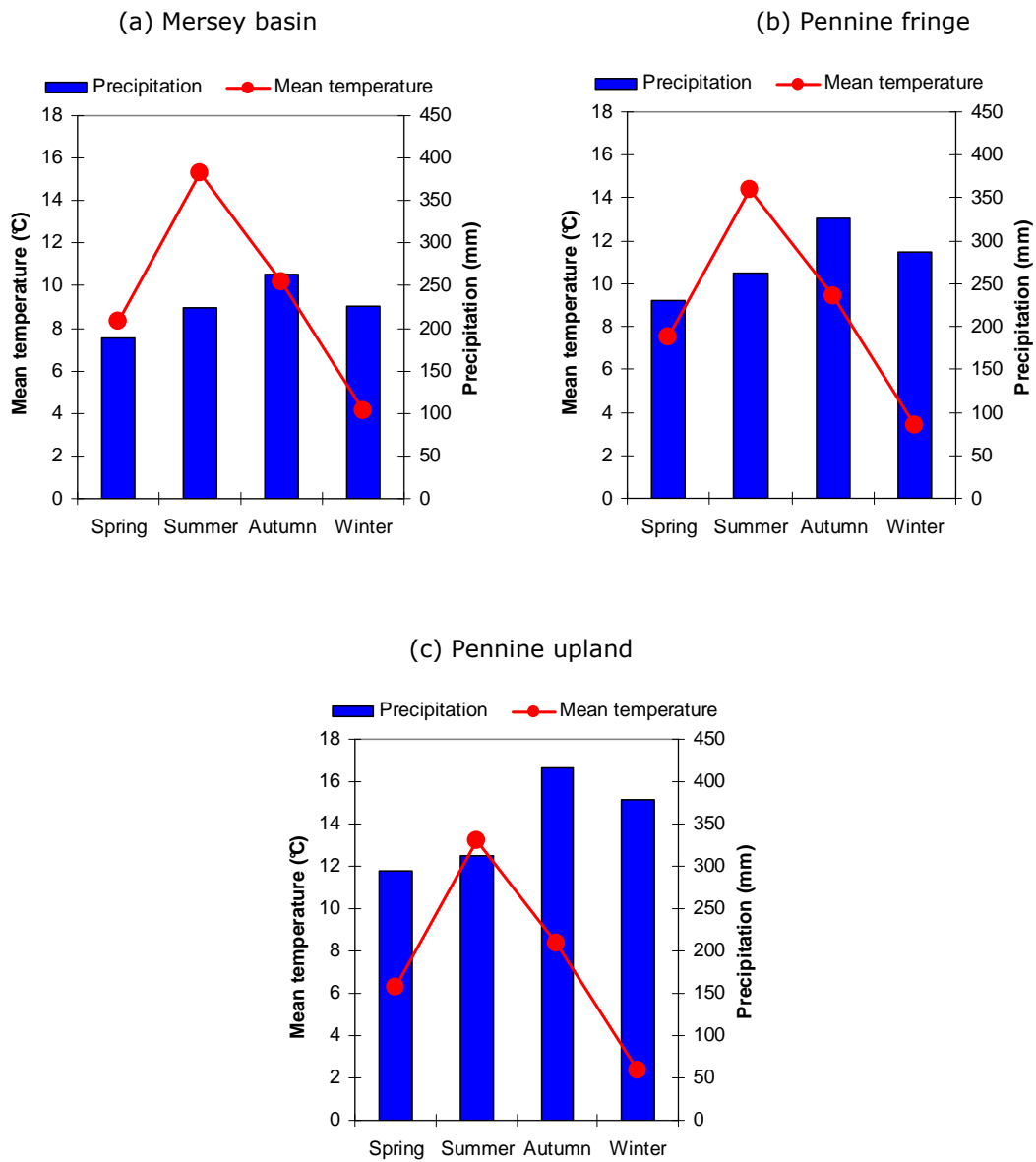


Table 1: Key characteristics of each climate zone

Key characteristics	Climate zone		
	Mersey Basin	Pennine Fringe	Pennine Upland
Area	688.3 km ²	376.1km ²	211.61km ²
Mean elevation	62 m	159 m	318 m
Mean annual temperature	9.4°C	8.7°C	7.5°C
Mean annual precipitation	902 mm	1104 mm	1401 mm

Seasonal rainfall and temperature characteristics for each climate zone are provided in figure 4.

Figure 4: Seasonal rainfall and mean temperature characteristics for each climate zone



The weather generator was then run for each of the three climate zones. Outputs are provided and discussed in the next section.

3 Climate change projections for Greater Manchester

This section presents some mapped outputs of the UKCP09 weather generator (incorporating the probabilistic projections) of changes in key climate variables for the future time period of the 2050s (2040-2069) and for the high emissions scenario. For information, outputs for the low emissions scenario are also provided in the tables.

Absolute values of each climate variable are mapped for each climate zone for each climatic variable. In addition, changes from the baseline period, 1961–1990 are provided on top of the map in black.

Summer is defined as the three month period including June, July and August. Winter is the period including December, January, and February.

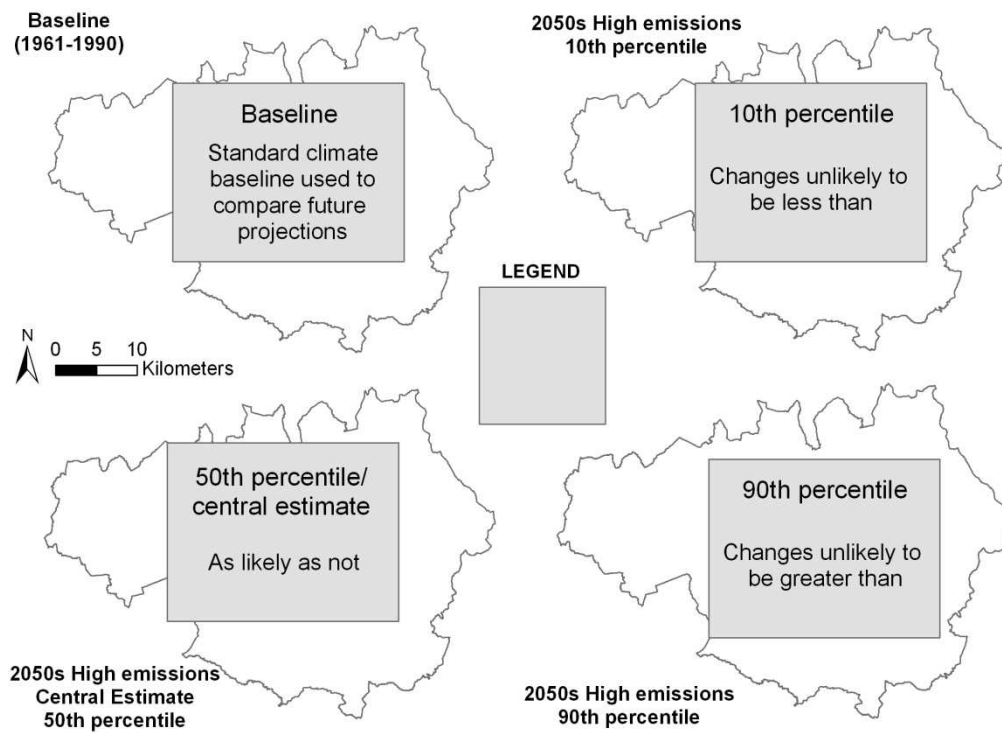
The 10%, 50% and 90% probability levels can be interpreted as:

- 10% probability level - unlikely to be less than;
- 50% probability level - as likely as not; and,
- 90% probability level - unlikely to be greater than.

The baseline data used in all of the outputs is the 50th percentile. The baseline is also a simulated output from the weather generator, rather than 'real' past observations of climate. Therefore, the weather generator also produces 100 variations of the baseline time period. Only the 50th percentile value is used for each climate variable, to produce a less confusing output. However, it is very important to note that there is much less variance in statistics for the baseline time period.

The following data presented in spatial maps of the Greater Manchester conurbation follow a standard format in order to aid interpretation of the probabilistic projections (figure 5).

Figure 5: Standard format of the Greater Manchester climate projections



This section includes projections information about the following climate variables:

- Temperature
- Annual mean temperature
- Summer mean daily maximum temperature
- Warmest day in Summer
- Summer mean daily minimum temperature
- Warmest night in Summer
- Winter mean daily minimum temperature
- Coldest night in winter
- Precipitation
- Annual mean precipitation
- Winter mean precipitation
- Wettest day in Winter
- Summer mean precipitation
- Wettest day in Summer

Table 2 provides a summary of changes in key climate variables in Greater Manchester for the low and high emissions scenarios for the 2050s (2041-2070). Thus, the full range of projected changes generated by the UKCP09 weather generator for the climate zones across Greater Manchester can be obtained by taking the 10th percentile of the low emissions scenario together with the 90th percentile of the high emissions scenario. 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) shows an enhanced seasonal variation, with summer precipitation decreasing, whilst winter precipitation is increasing. The direction of change for annual mean precipitation is more uncertain, with the central estimate (50% probability level) for both low and high emissions scenario suggesting little change (e.g. 0-2% increase in the Mersey basin).

Table 2: Summary of changes from the baseline (1961-1990) for key climate variables under the high and low emissions scenarios for the 2050s

Climate variable (changes from the baseline)	Zone *	Low emissions scenario			High emissions scenario		
		Probability level			Probability level		
		10th	50th	90th	10th	50th	90th
Annual mean temperature (°C)	MB	1.4	1.9	2.9	1.8	2.4	3.6
	PF	1.4	1.9	2.9	1.8	2.5	3.6
	PU	1.4	1.9	2.9	1.8	2.4	3.6
Summer mean daily maximum temperature (°C)	MB	1.1	2.5	4.3	1.4	2.9	5.6
	PF	0.9	2.4	4.1	1.4	3.0	5.5
	PU	1.1	2.5	4.2	1.5	3.0	5.7
Warmest day in summer (°C)	MB	1.3	2.6	4.6	1.5	3.1	6.0
	PF	1.1	2.6	4.3	1.6	3.4	6.0
	PU	1.2	3.0	4.7	1.6	3.4	5.9
Summer mean daily minimum temperature (°C)	MB	0.9	1.7	2.9	1.3	2.1	4.0
	PF	1.0	1.8	3.0	1.2	2.3	4.0
	PU	1.1	1.8	3.0	1.2	2.3	4.0
Warmest night in summer (°C)	MB	0.9	1.8	3.6	1.3	2.6	4.4
	PF	1.1	2.0	3.4	1.3	2.6	4.6
	PU	1.0	2.0	3.5	1.4	2.6	4.4
Winter mean daily minimum temperature (°C)	MB	0.9	1.9	3.3	1.7	2.4	3.9
	PF	1.0	1.9	3.2	1.8	2.5	3.9
	PU	0.9	1.9	3.4	1.7	2.4	3.9
Coldest night in winter (°C)	MB	0.6	1.9	3.3	1.3	2.4	3.5
	PF	1.2	2.0	3.3	1.7	2.4	3.8
	PU	0.8	2.0	3.7	1.4	2.6	3.7
Annual mean precipitation (%)	MB	-6	0	9	-5	2	9
	PF	-5	3	12	-4	5	13
	PU	-4	3	13	-3	4	12
Summer mean precipitation (%)	MB	5	-15	-29	-5	-20	-36
	PF	15	-12	-26	0	-20	-36
	PU	13	-13	-27	-2	-21	-36
Wettest day in summer (%)	MB	-13	1	18	-15	0	19
	PF	-12	7	31	-17	2	25
	PU	-14	5	27	-20	-3	20
Winter mean precipitation (%)	MB	-3	9	23	0	14	28
	PF	-2	10	23	1	16	36
	PU	-4	9	22	3	16	33
Wettest day in winter (%)	MB	-6	7	18	1	11	31
	PF	-1	11	22	2	15	38
	PU	-1	10	25	2	14	31

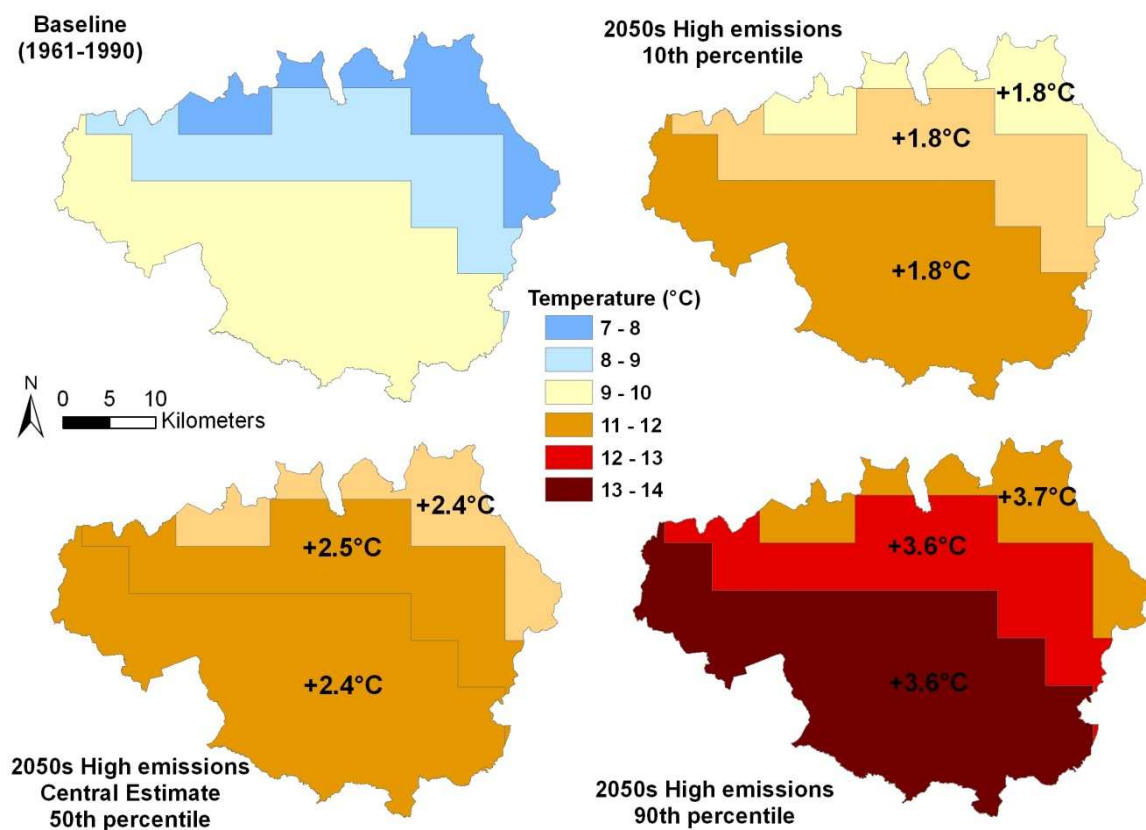
*MB=Mersey basin; PF=Pennine Fringe; PU=Pennine Upland

3.1 Change in temperature

3.1.1 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 6 shows the annual mean temperature for the baseline (1961-1990) and under the high emissions scenario for the 2050s. This indicates that under the high emissions scenario for the 2050s, the central estimate of increase in annual mean temperature across Greater Manchester is 2.4–2.5°C; it is very unlikely to be less than 1.8°C and is very unlikely to be more than 3.6–3.7°C.

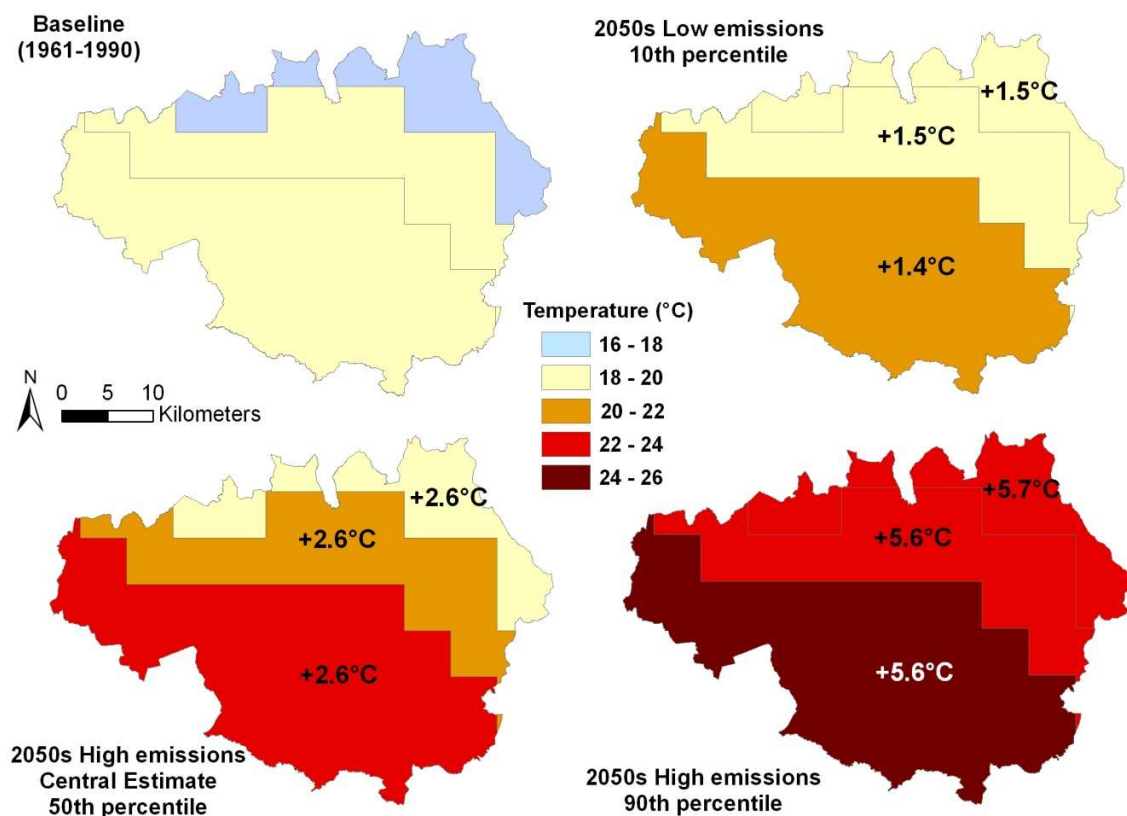
Figure 6: Annual mean temperature across Greater Manchester for the baseline and 2050s high emissions scenario



3.1.2 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). Figure 7 indicates that the baseline summer mean daily maximum temperature is 18–20°C across the Mersey basin and Pennine fringe, and a slightly cooler 16–18°C across the Pennine upland climate zone. Under the high emissions scenario for the 2050s, the central estimate of increase in summer mean daily maximum temperature across Greater Manchester is 2.6°C; it is very unlikely to be less than 1.4–1.5°C and is very unlikely to be more than 5.6–5.7°C (figure 7).

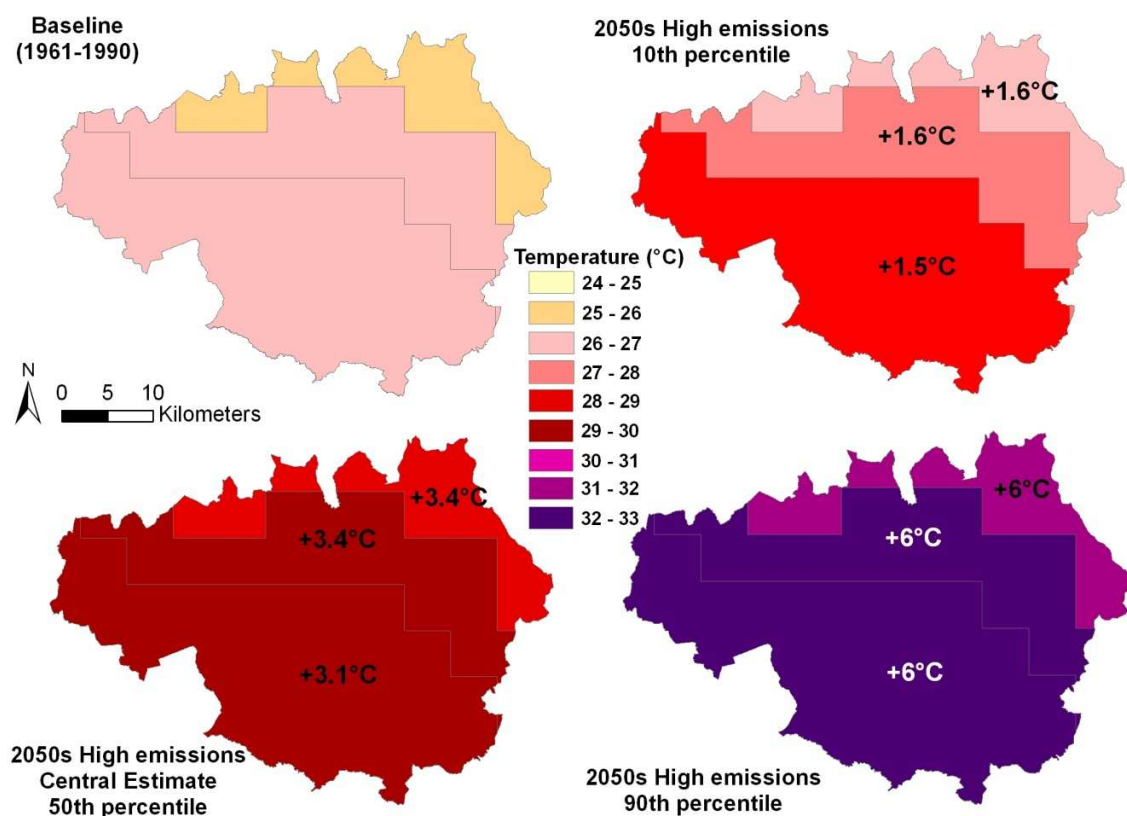
Figure 7: Summer mean daily maximum temperature across Greater Manchester for the baseline and 2050s high emissions scenario



3.1.3 Warmest day in 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, and is likely to occur on one day per summer every year. Figure 8 indicates that under the high emissions scenario by the 2050s, the central estimate of change in the warmest day in summer across Greater Manchester is 3.1–3.4°C; it is very unlikely to be less than 1.5–1.6°C and is very unlikely to be more than 6°C (figure 8). Thus, the warmest day in summer across Greater Manchester under the 2050s high emissions scenario is very unlikely to be higher than 33°C (90th percentile).

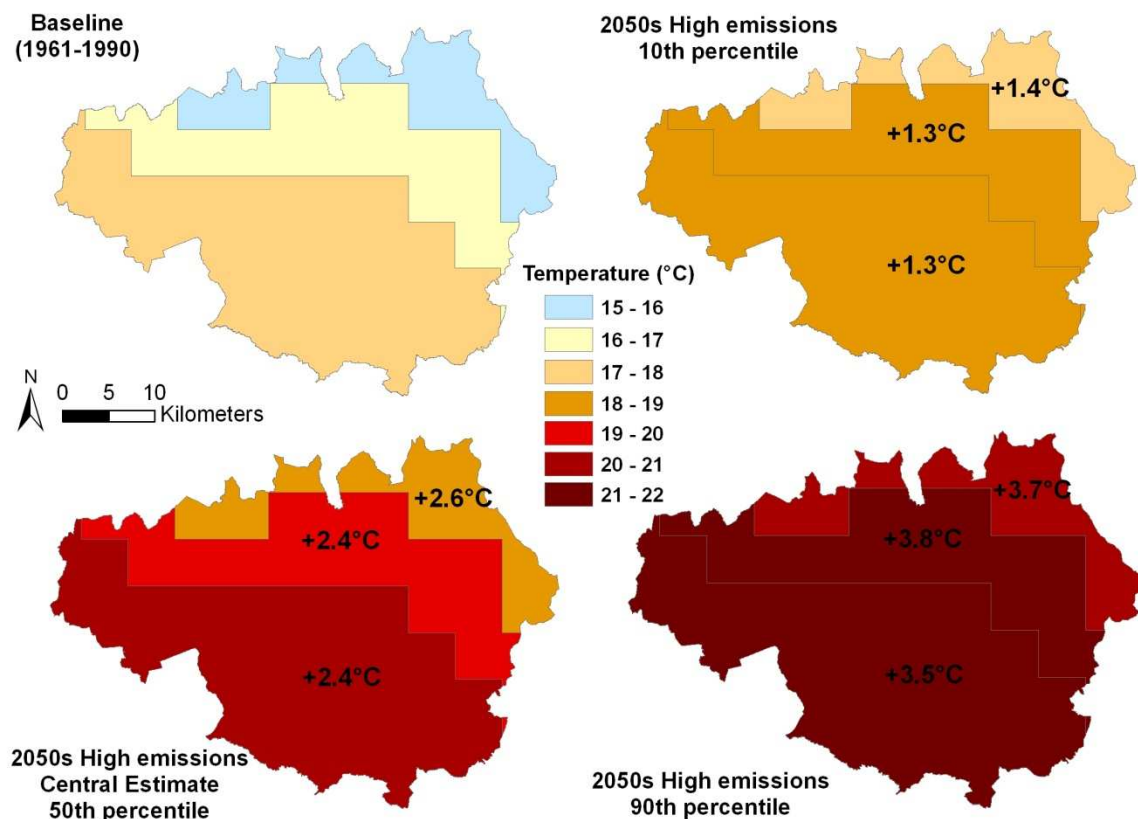
Figure 8: Temperature of the warmest day in summer across Greater Manchester for the baseline and 2050s high emissions scenario



3.1.4 Warmest night in 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 summer. Figure 9 shows that under the high emissions scenario by the 2050s, temperature change in the warmest summer night across Greater Manchester is likely to be greater than 1.3–1.4°C. There is a 10% likelihood that temperatures will be greater than 3.5–3.8°C warmer than the baseline period, when the conurbation could experience night-time temperatures of 20–22°C. The built environment stores heat during the day and re-radiates it at night (causing the Urban Heat Island effect), thus enhancing night-time temperatures further. High night-time temperatures in summer cause a great risk to human health, particularly for vulnerable groups such as the very young, old, or infirm, and particularly when in combination with high day-time temperatures.

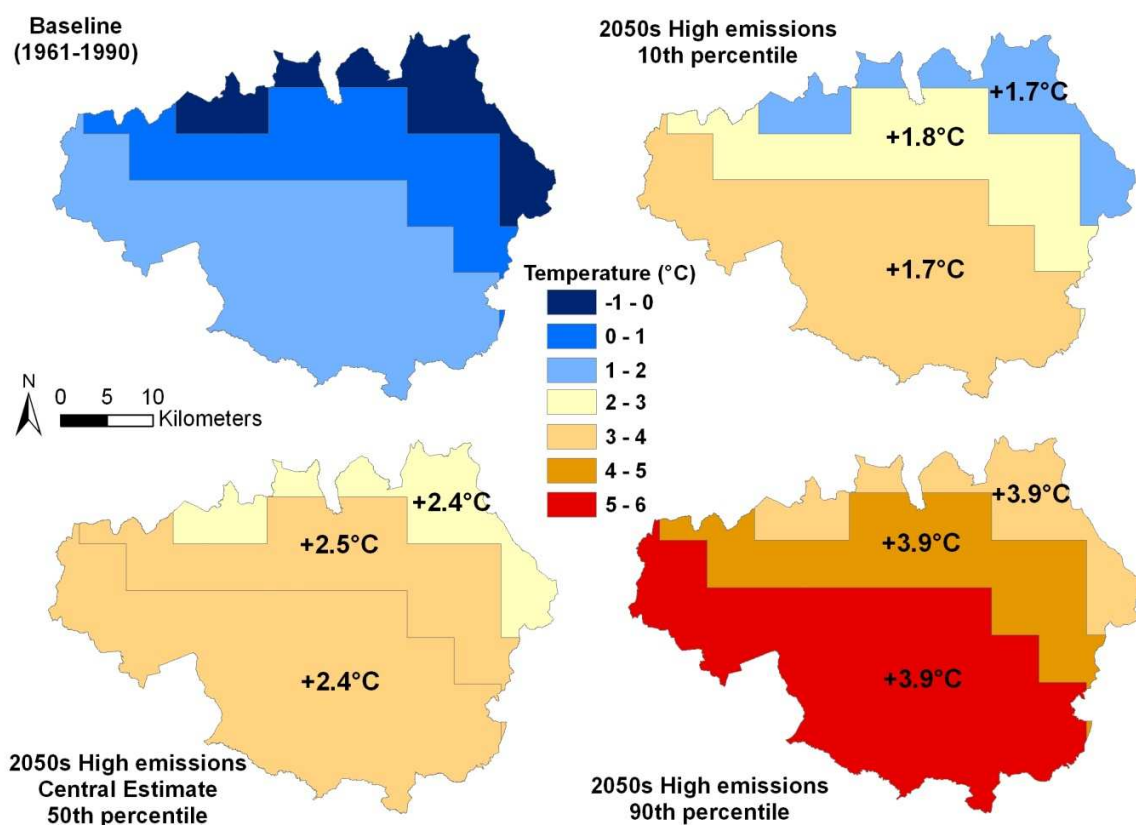
Figure 9: Temperature of the warmest night in summer across Greater Manchester for the baseline and 2050s high emissions scenario



3.1.5 Winter minimum temperature

The baseline 1961–1990 winter minimum (night-time) temperature ranges from -1°C to 1°C across Greater Manchester, with coldest temperatures occurring in the Pennine upland zone. Under the high emissions scenario for the 2050s, the central estimate of increase in the winter mean temperature is $2.4\text{--}2.5^{\circ}\text{C}$; it is unlikely to be less than $1.7\text{--}1.8^{\circ}\text{C}$ and is very unlikely to be more than 3.9°C (figure 10). Such an increase in the mean night-time temperature in winter is likely to mean fewer winter mortalities and lower space heating costs.

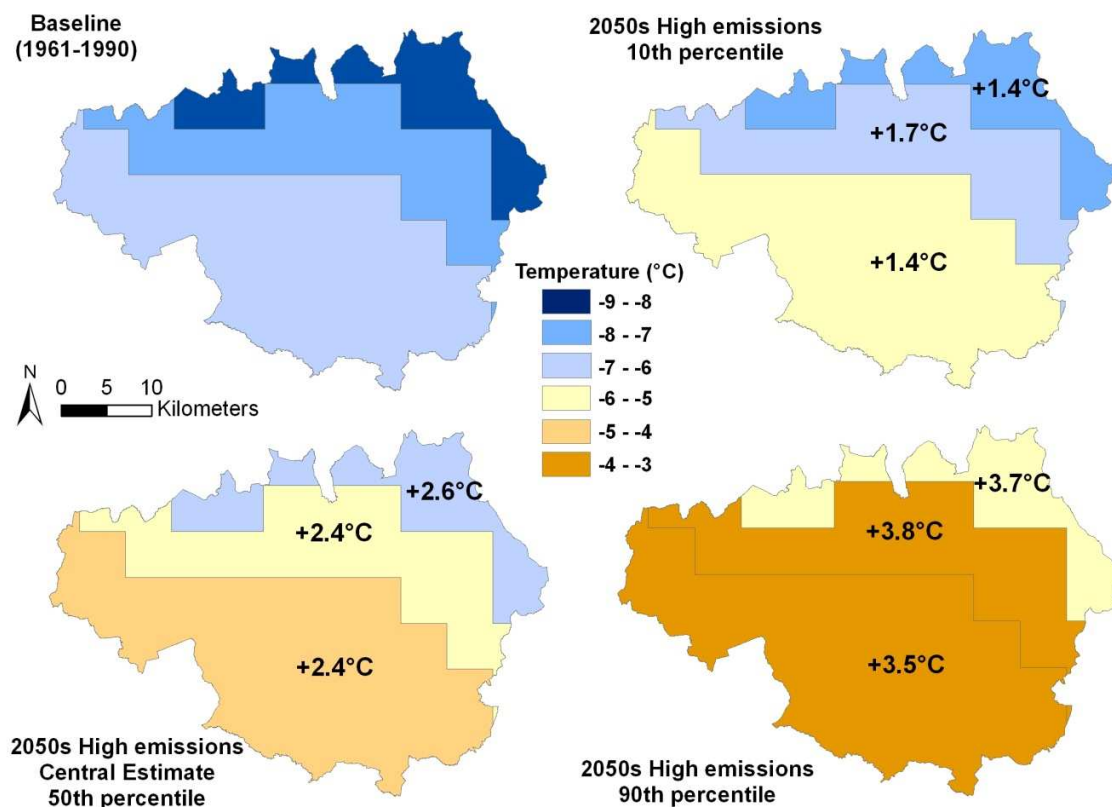
Figure 10: Mean winter minimum (night-time) temperature across Greater Manchester for the baseline and 2050s high emissions scenario



3.1.6 Coldest night in winter

The change in temperature of the coldest night in winter is the change in the 1st percentile of the daily minimum temperature of the winter season. This represents the extreme minimum (night-time) temperature in winter, likely to occur about once per season. For the baseline 1961–1990 period, the coldest night in winter is up to -9°C in the Pennine Fringe area. Climate projections indicate that the coldest night in winter will increase by around 2.4–2.6°C under the central estimate for the 2050s high emissions scenario, across Greater Manchester (figure 11).

Figure 11: Temperature of the coldest night in winter across Greater Manchester for the baseline and 2050s high emissions scenario

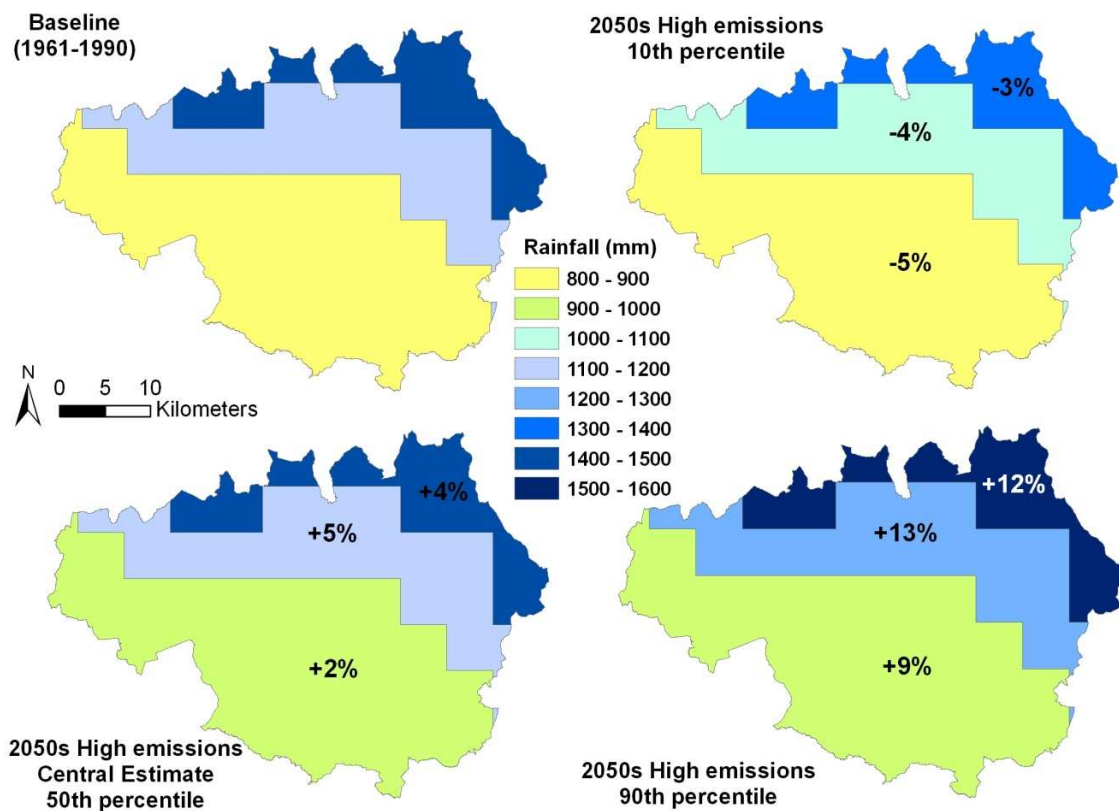


3.2 Changes in precipitation

3.2.1 Annual mean precipitation

The annual mean precipitation is the total amount of rain, snow and hail received over January to December. The annual rainfall received across Greater Manchester varies greatly, with the high Pennine upland area receiving up to 1500mm a year, in comparison to the Mersey basin area, receiving up to 900mm annually. Climate projections indicate little change in annual mean precipitation, with around 2–5% increase under the central estimate for the 2050s high emissions scenario across Greater Manchester (figure 12). However, the direction of change in annual mean precipitation is more uncertain, with the 10th percentile indicating a slight reduction and the 90th percentile indicating an increase in annual mean rainfall.

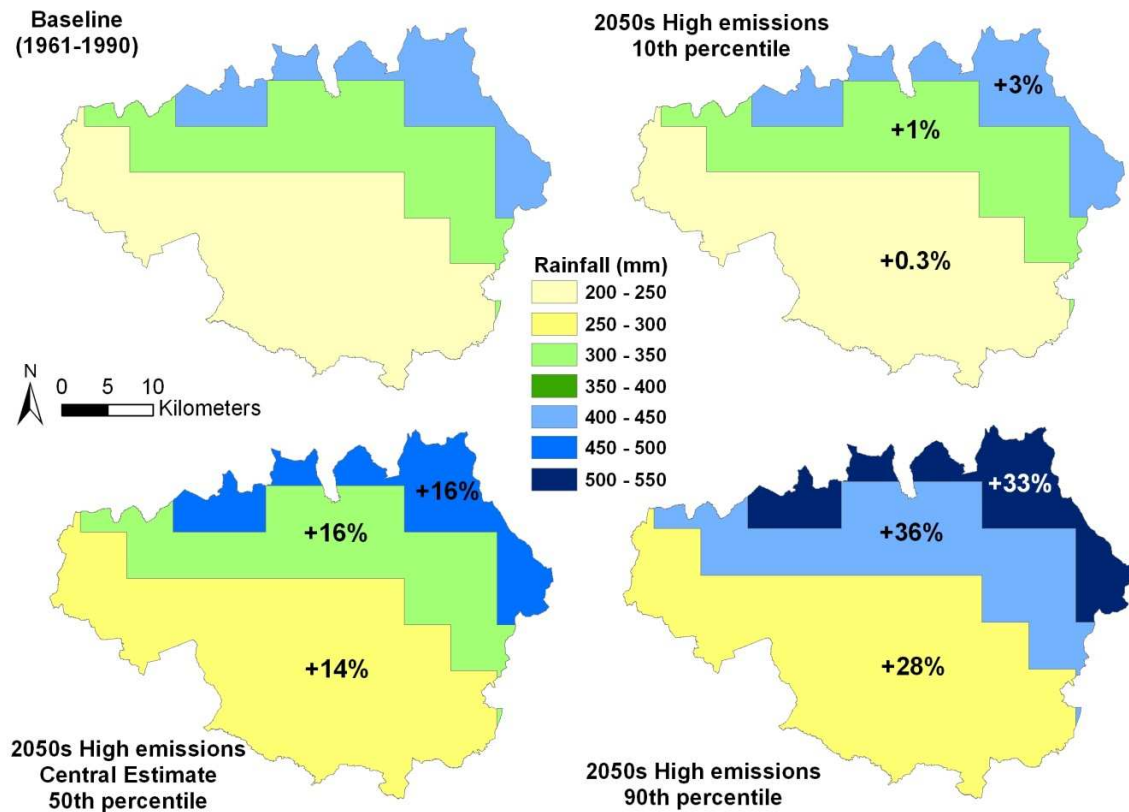
Figure 12: Annual mean precipitation across Greater Manchester for the baseline and 2050s high emissions scenario



3.2.2 Winter mean precipitation

The winter mean precipitation is the total amount of rain, snow and hail received in December, January and February. Climate projections for winter rainfall suggest that winter rainfall will increase across Greater Manchester. Whilst the 10th percentile for the 2050s high emissions scenario shows only very slight increases, under the 90th percentile, increases in winter rainfall could be up to 28–36% across Greater Manchester (figure 13).

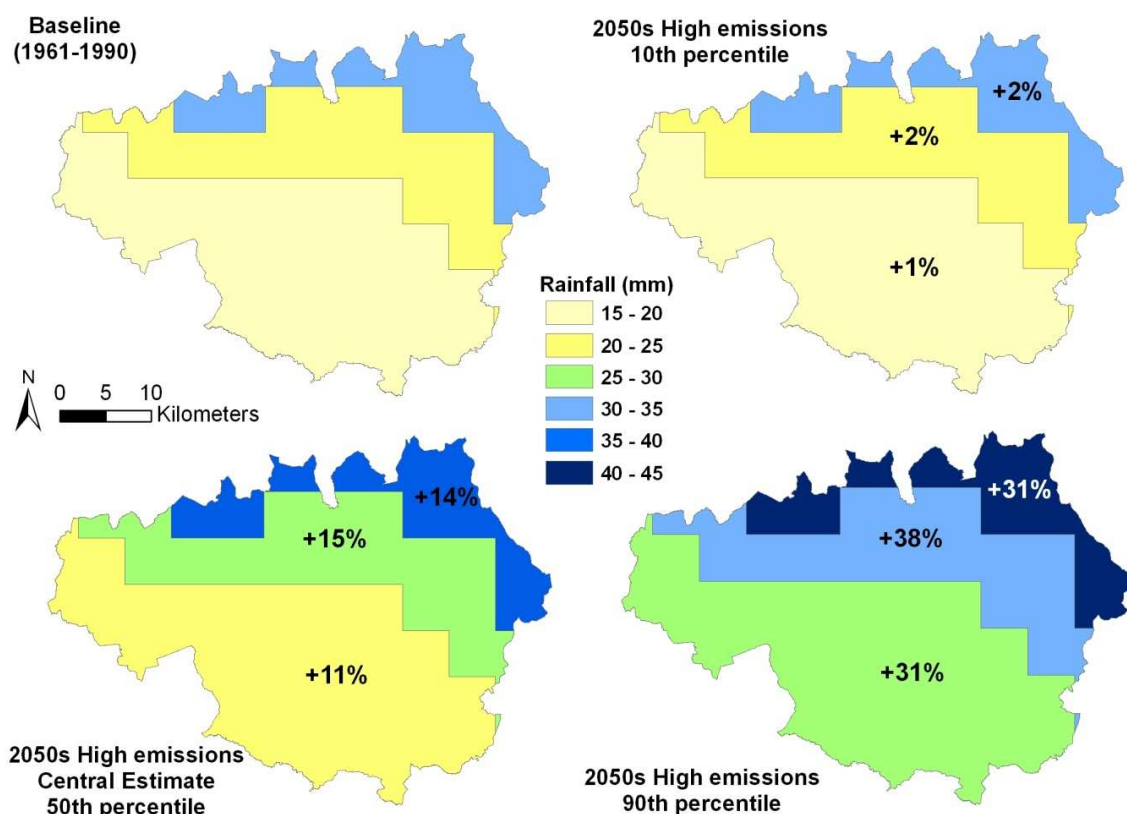
Figure 13: Winter mean precipitation across Greater Manchester for the baseline and 2050s high emissions scenario



3.2.3 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). Together with an increase in the amount of winter rainfall, the wettest day in winter is also likely to increase. Under the central estimate for the 2050s high emissions scenario, the wettest day is projected to be 11–15% wetter. The wettest day is very unlikely to be greater than 31% wetter than the baseline period (90th percentile), which could mean over 40mm of rainfall is received in the Pennine upland area (figure 14). This increase in heavy rainfall events is likely to cause an increase in the incidence of flooding, in particular, surface water flooding. Section 4 presents an analysis of specific climate thresholds for central Manchester.

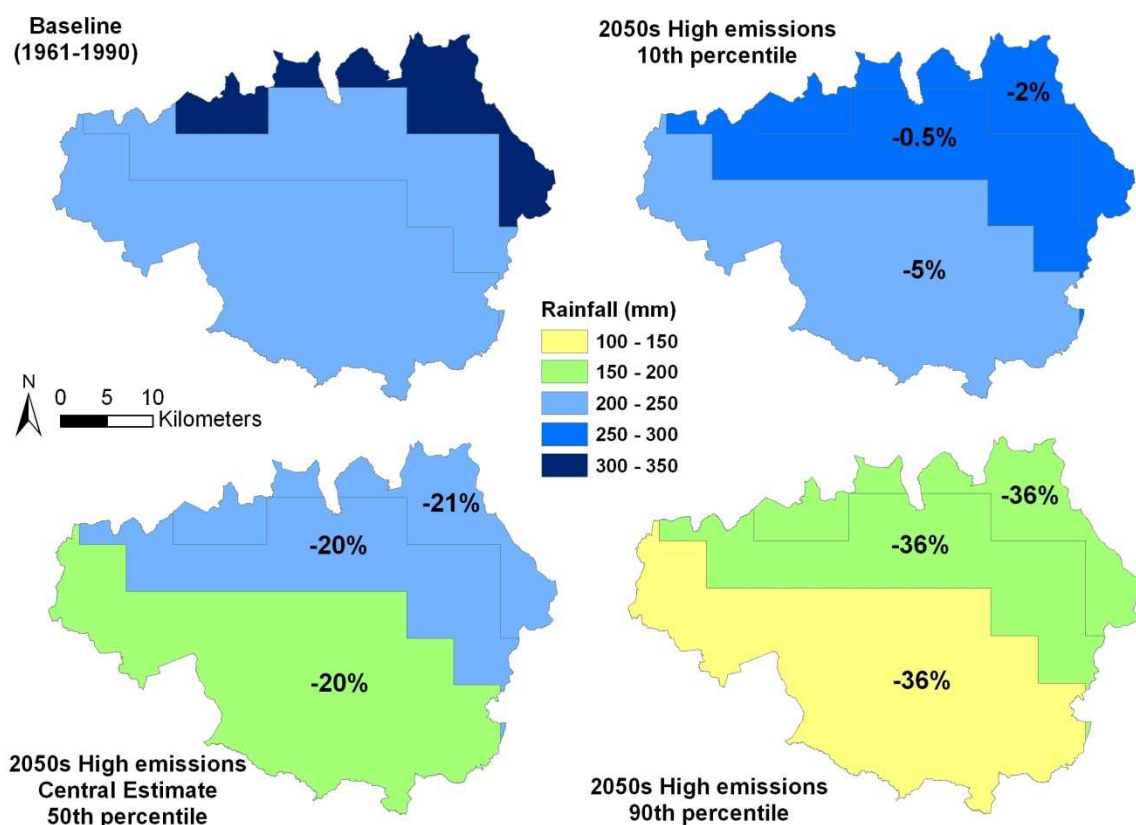
Figure 14: Wettest day in winter across Greater Manchester under the baseline and 2050s medium emissions scenario



3.2.4 Summer mean precipitation

The summer mean precipitation is the total amount of rain, snow and hail received in June, July and August. The Mersey basin and Pennine fringe climate zones received around 200–250mm of rainfall in summer between 1961–1990. The Pennine uplands receive more rainfall, around 300–350mm on average in summer. Climate projections indicate that rainfall in summer across Greater Manchester is projected to decrease. Figure 15 indicates that the central estimate for summer rainfall is a decrease of 20% under the high emissions scenario for the 2050s. Additionally, summers are very unlikely to receive more than 36% less rainfall across Greater Manchester than in the baseline period (90th percentile).

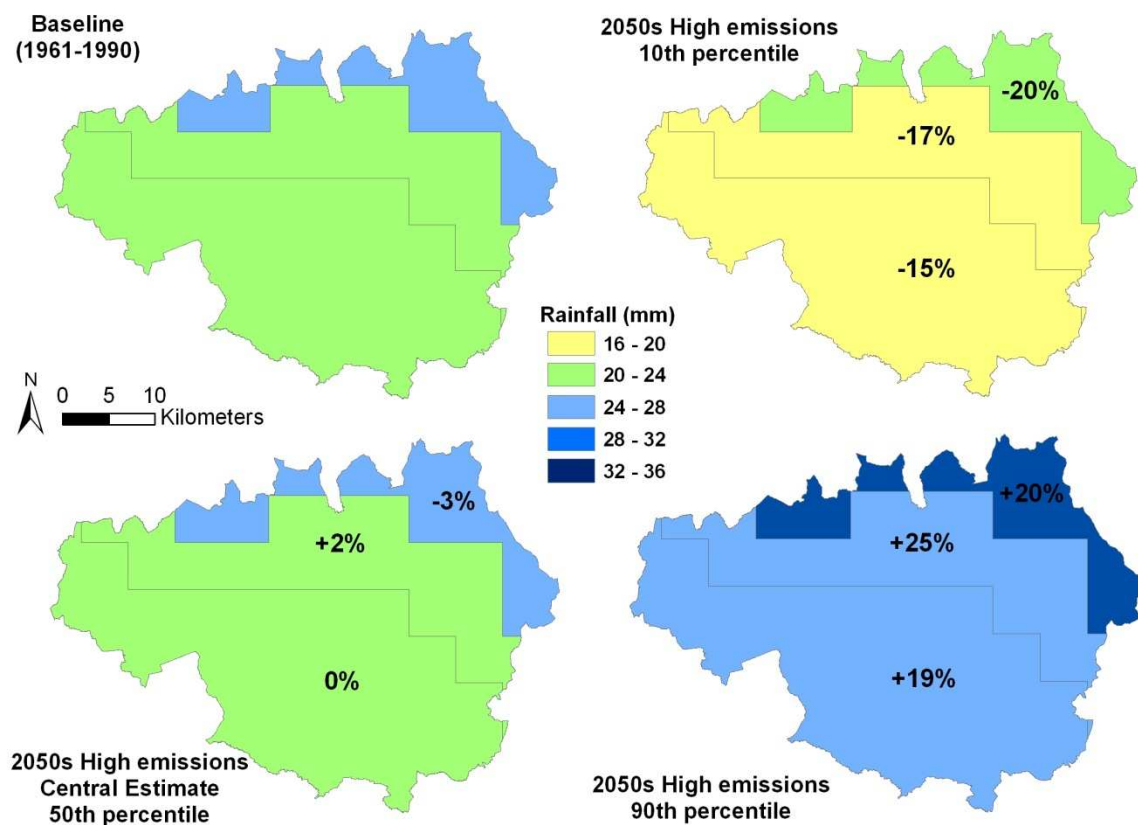
Figure 15: Summer mean precipitation across Greater Manchester for the baseline and 2050s high emissions scenario



3.2.5 Wettest day in summer

The wettest day in summer is 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 16 indicates that under the central estimate for the wettest day in summer for the 2050s high emissions scenario climate projections indicate very little change from the baseline period. Differences between the direction of change for the 10th and 90th percentiles highlight the uncertainty about whether the wettest day in summer will get wetter or not.

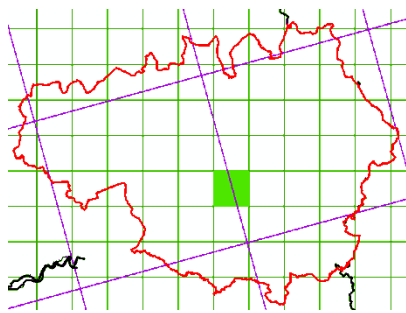
Figure 16: Wettest day in summer across Greater Manchester for the baseline and 2050s high emissions scenario



4 Climate thresholds for central Manchester

To provide location-specific climate data required for the EcoCities neighbourhood scale case study, which focussed on the Oxford Road Corridor,⁵ the UKCP09 weather generator⁶ was run for a single 5x5km grid square. This 5x5km grid square is the most built-up area in Greater Manchester, with around 57% built-up urban areas, and contains most of Manchester and Salford city centres (figure 17).

Figure 17: The UKCP09 weather generator 5x5km grid of Greater Manchester and the single grid chosen for the neighbourhood scale case study focussed on the Oxford Road Corridor



UKCP09 weather generator grid



5x5km grid covering Oxford Road corridor area, GM

⁵ The EcoCities case study results focussing on the analysis of impacts of development and greening scenarios on the Oxford Road corridor can be found at www.manchester.ac.uk/ecocities

⁶ Version 2 of the weather generator was utilised in this analysis as it provide a better representation of extremes (though only very minor differences were observed between the outputs of v1 and v2), for more information on the revised weather generator, see report at http://ukclimateprojections.defra.gov.uk/images/stories/Tech_notes/UKCP09_WGen2_technote.pdf.

Analysis of the following key thresholds was undertaken for the Oxford Road Corridor area in Manchester, using the UKCP09 weather generator and threshold detector:

- Number of days with maximum temperature over 30°C;
- Number of heatwave events;
- Heating degree days;
- Cooling degree days;
- Heavy rainfall days;
- Drought events;
- Frost days; and,
- Extremely hot days (number of days with maximum temperature $\geq 35^{\circ}\text{C}$).

Due caution should be taken when interpreting the results in this section, due to the difficulty in generating extreme weather series.⁷

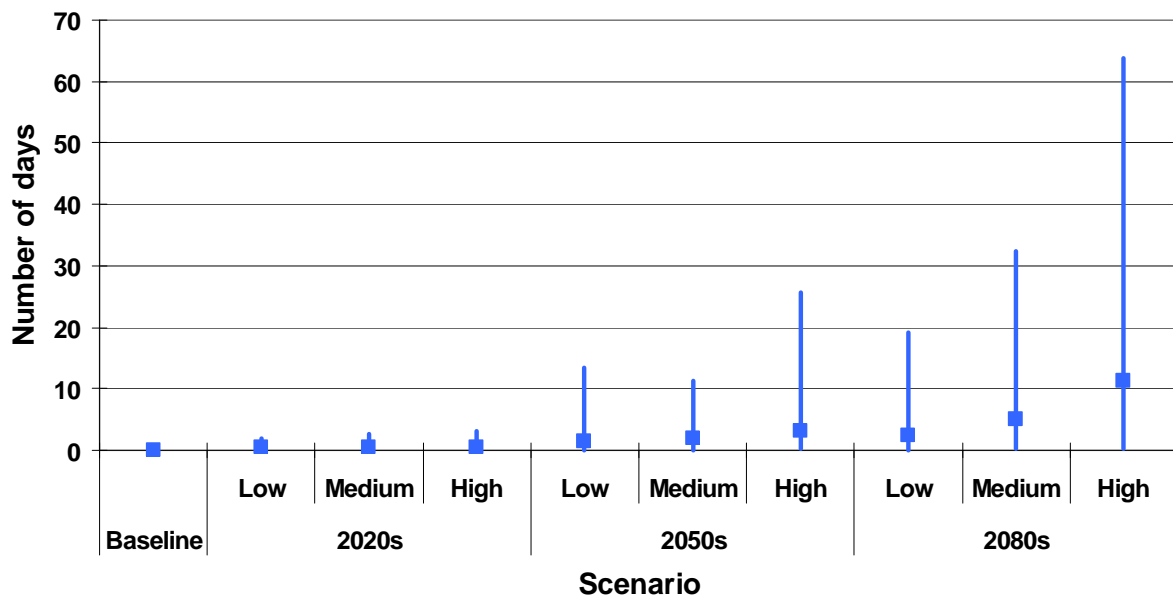
Results are presented in Figures 18-25, and include the number of days per year (or number of events per year) that the threshold is likely to be exceeded, under the low, medium and high emissions scenarios, for the 2020s, 2050s and 2080s time-slices. In the figures, the square indicates the mean of all of the 100-generated series, and the tail ends represent the minimum and maximum (or 1st and 99th percentiles).

⁷ For more information regarding the difficulty in generating extreme weather series, see: <http://ukclimateprojections.defra.gov.uk/content/view/1169/500/>.

4.1 Hot days (maximum temperature over 30°C)

Figure 18 presents the results of the number of days per year with a maximum temperature exceeding 30°C. This indicates that, under the high emissions scenario by the 2050s, the mean number of days per year over 30°C is 3 days. It is very unlikely that there will be less than 1 day with a temperature over 30°C, and very unlikely that there will be more than 25 days (1st and 99th percentiles).

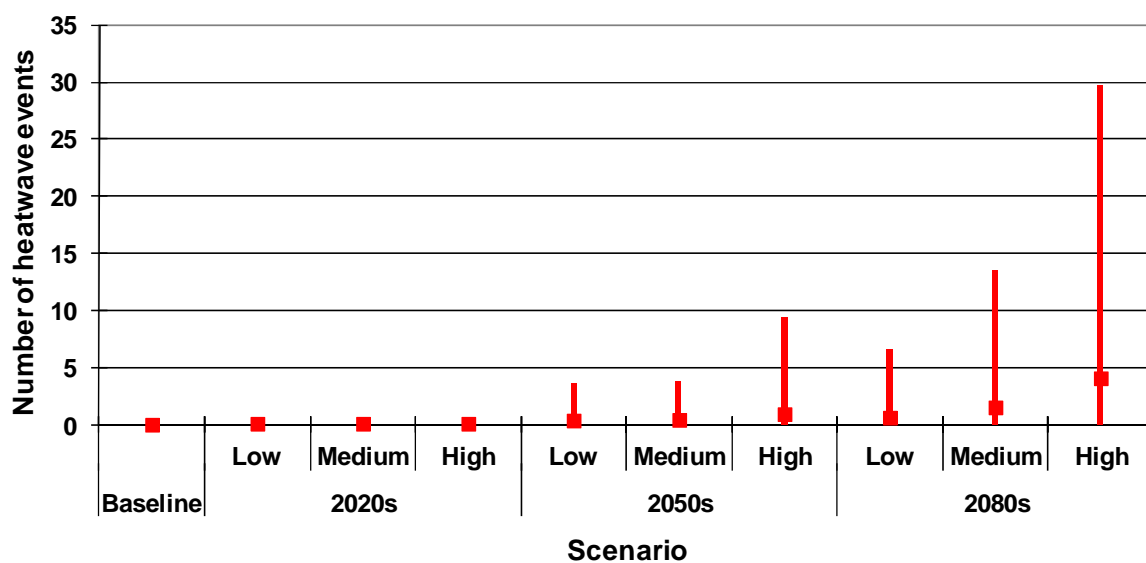
Figure 18: Number of days per year with a maximum temperature exceeding 30°C in central Manchester



4.2 Heatwave events

Figure 19 presents the number of heatwave events per year. A heatwave is defined using the UK Met Office Heat-Health threshold of a maximum temperature exceeding 30°C for two days and a minimum temperature exceeding 15°C on the intervening night. Such a heatwave event causes significant issues for human health, particularly for vulnerable groups such as elderly, infirm or young people. Climate projections indicate that under the high emissions scenario for the 2050s, it is unlikely that there will be fewer than zero heatwave events per year, and it is very unlikely that there will be more than 9 heatwave events per year (mean <1 event).

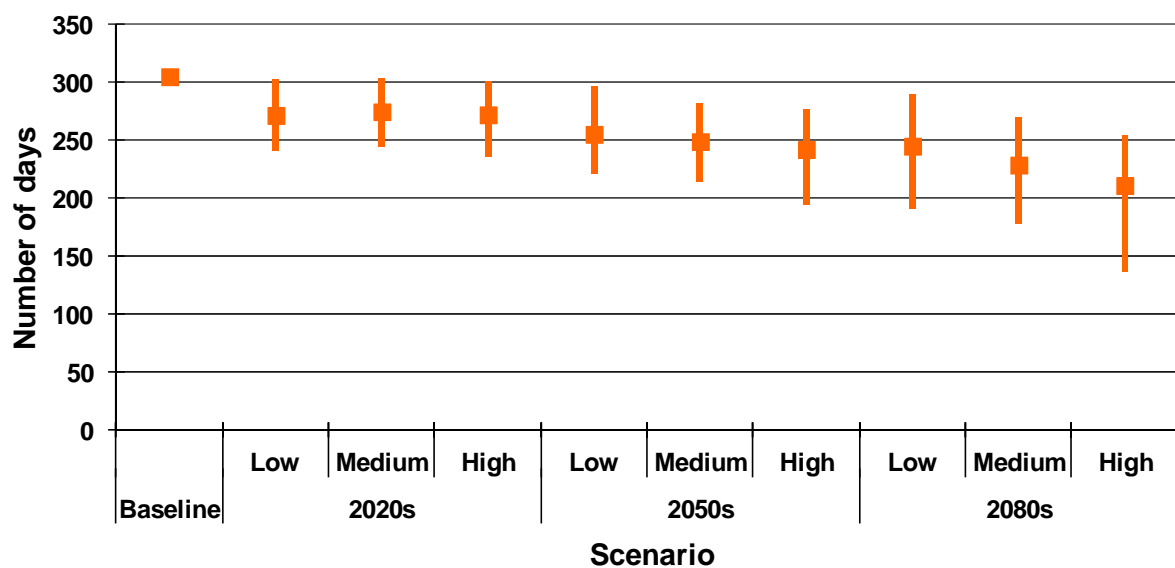
Figure 19: Number of heatwave events per year in central Manchester



4.3 Heating degree days

Figure 20 presents the number of heating degree days per year. A heating degree day is when some form of space heating is required in buildings, defined as days with a mean temperature less than 15.5°C. Climate projections indicate a reduction in heating degree days. Under the baseline period, there were around 305 heating degree days in central Manchester. The number of days when heating of buildings is required reduces considerably throughout the 21st century. Under the high emissions scenario for the 2050s, the mean number of heating degree days is 242 days – a reduction of 21% from the baseline period. This could result in significant cost savings from heating in winter.

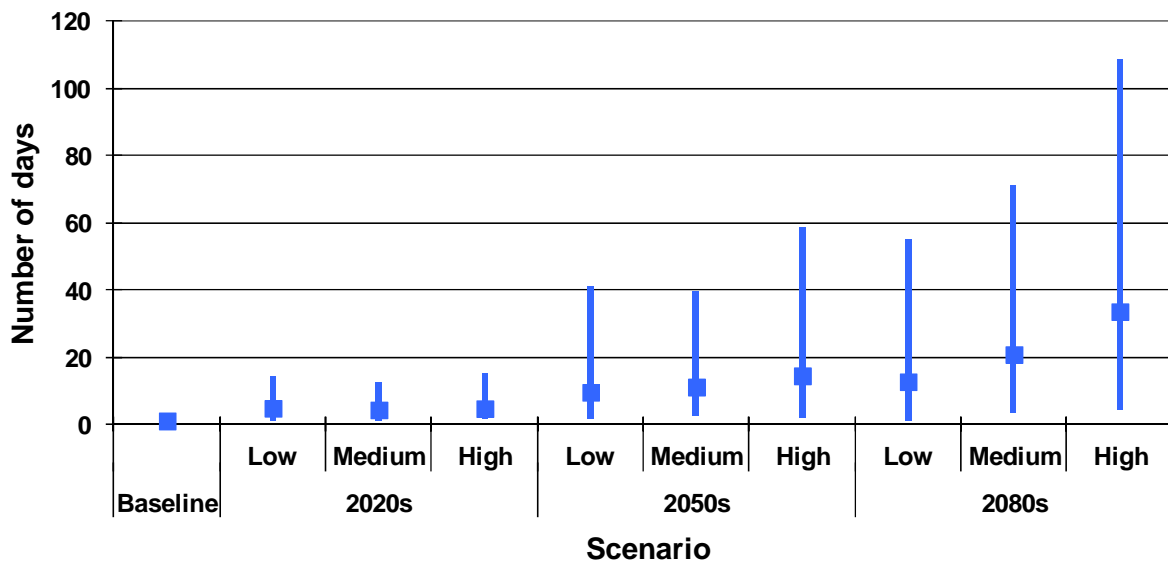
Figure 20: Number of heating degree days per year in central Manchester



4.4 Cooling degree days

Figure 21 presents the number of cooling degree days per year in central Manchester. A cooling degree day is when some form of cooling or air conditioning is required in buildings, defined as days with a mean temperature exceeding 22°C. Climate projections indicate an increase in cooling degree days. Under the baseline period, there were no days on which cooling of buildings was required in central Manchester. The number of days when cooling of buildings is required increases quite significantly throughout the 21st century. Under the high emissions scenario for the 2050s, the mean number of cooling degree days is 14.5 days – there is unlikely to be fewer than 2 days requiring cooling and unlikely to be more than 60 days per year when cooling of buildings is required. The climate projections for cooling degree days show a high range of uncertainty, indicated by the large range between the 1st and 99th percentiles. However, the trend indicates that the need for cooling of buildings is likely to increase in the future.

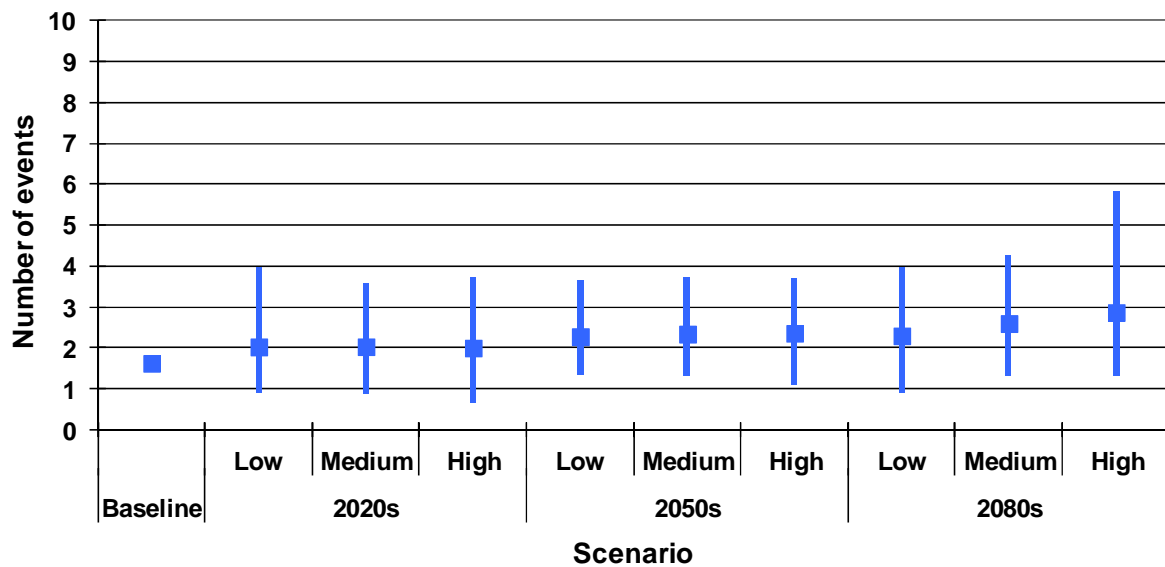
Figure 21: Number of cooling degree days per year in central Manchester



4.5 Heavy rainfall events

Analysis of rainfall and flooding records indicated that in south Manchester, flooding is likely to occur when rainfall is greater than or equal to 25mm per day (Smith and Lawson 2010). Figure 22 shows the number of days of heavy rainfall per year that are likely to cause flooding in Manchester. For the baseline 1961–1990 period, there were around 1–2 days per year with heavy rainfall. Under the high emissions scenario for the 2050s, the mean number of rainfall events likely to result in flooding increases to 2.4 days, and is very unlikely to be greater than 3.7 events per year on average.

Figure 22: Number of days with heavy rainfall per year in central Manchester

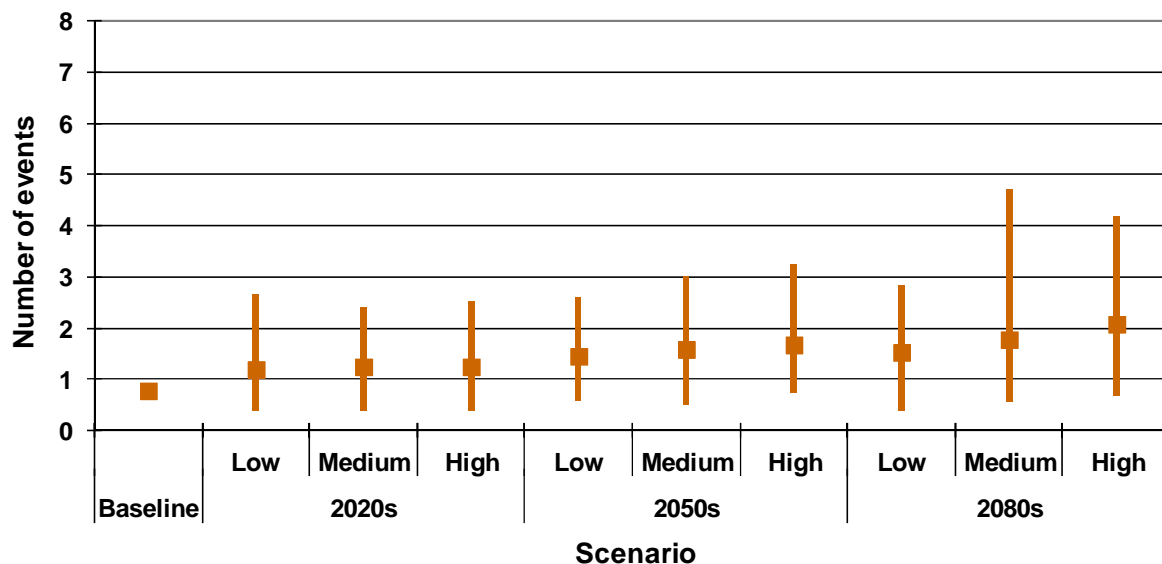


4.6 Drought events

Drought can be defined in a few different ways, since it depends on who or what is being affected. There are three main types of drought: meteorological, agricultural or hydrological drought. Drought can be calculated from metrics based on rainfall and evaporation or soil moisture. However, a more simple definition was used here (in order to fulfil requirements of the weather generator threshold detector), where a drought was defined as a period of 10 days or more with each day receiving less than 0.3 mm of rainfall.

Figure 23 presents the number of drought events per year in central Manchester. Climate projections indicate a very slight increase in drought events. Under the high emissions scenario for the 2050s, the mean number of droughts is around 1.7 events per year. However, persistence of specific weather types leading to events such as droughts are particularly difficult for the weather generator and climate models to reproduce,⁸ and therefore, such values should be treated with caution.

Figure 23: Number of drought events per year in central Manchester

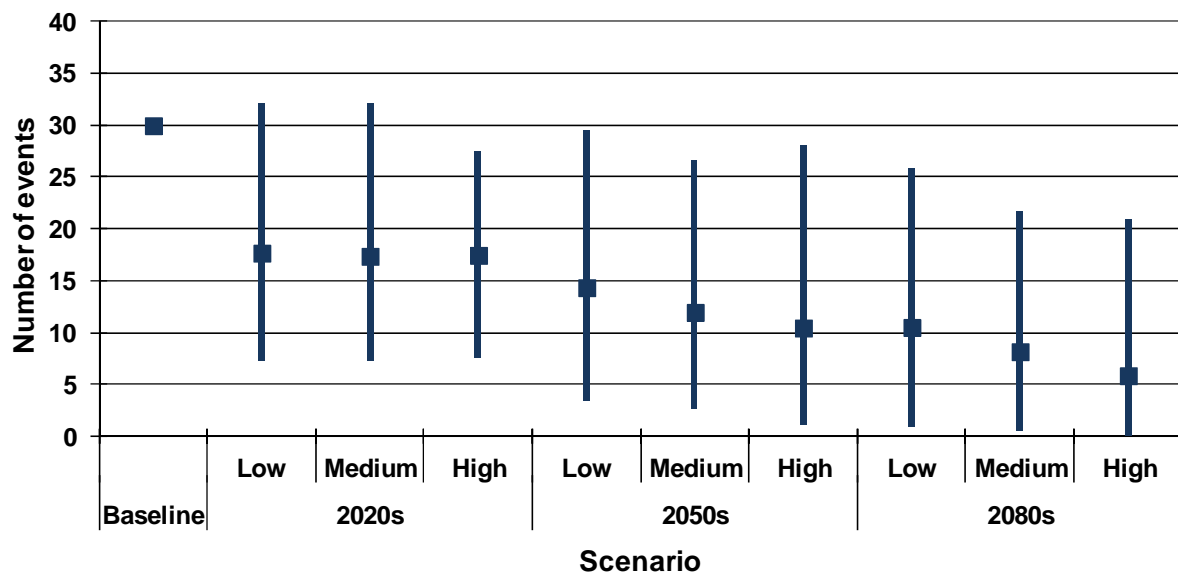


⁸ For more information regarding the difficulty in generating extreme weather series, see: <http://ukclimateprojections.defra.gov.uk/content/view/1169/500/>.

4.7 Frost

Figure 24 presents the number of days of air frost per year in central Manchester. Air frost is assumed to occur on days which fall below 0°C. Due to the urban heat island, temperatures in Manchester city centre are warmer than surrounding rural areas, and therefore, under the baseline period, around 30 frosts per year occurred. Analysis of the climate projections indicates quite a significant decrease in the annual number of frosts. Under the high emissions scenario for the 2050s, the mean number of frosts reduces by 65% to just 10 per year.

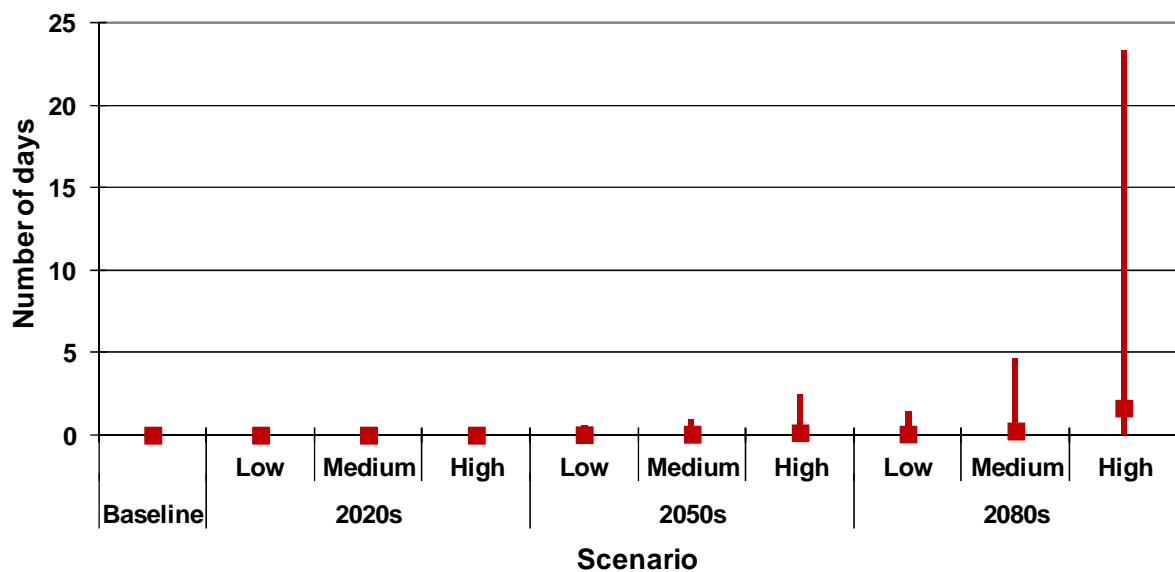
Figure 24: Number of days of air frost per year in central Manchester



4.8 Very hot days (maximum temperature 35°C or greater)

Finally, thresholds for extremely hot days were analysed to enable investigation of impacts of high temperatures on transport infrastructure. In particular, a threshold of 35°C was found to cause asphalt on roads to melt and rails to buckle. Figure 25 presents the number of days per year in central Manchester with a maximum daytime temperature of 35°C or over. The climate projections indicate that such an extreme temperature is unlikely to be experienced until the 2080s. Under the 2080s high emissions scenario, a high amount of uncertainty is evident, but climate projections suggest that between 2–23 days per year (1st and 99th percentiles) could have maximum temperatures that exceed 35°C.

Figure 25: Number of days per year with a maximum temperature exceeding 35°C in central Manchester



5 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. Although much research and policy has focussed 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 the 2040s, at least, 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 the likelihood of maladaptation (measures which prevent or reduce the 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 the north west of 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, to respond 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' 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. Spatial maps presented in this report will be available to users to view in more detail in the online Blueprint.

Further information on the likely impacts of climate change for Greater Manchester can be found in the LCLIP report, and other EcoCities outputs available to download from the website, www.manchester.ac.uk/ecocities.

Acknowledgements

All data presented in this report is from the UK Climate Projections (© Crown Copyright 2009). Thanks to Christopher Kenny and Thomas Jones for help with processing the weather generator data, and to Anna Steynor at UKCIP for advice.

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7 Appendix: Methods used to generate the climate zones

Multivariate statistics have been widely applied to determine climate zones, particularly Principal Components Analysis (PCA) and cluster analysis (CA) (e.g. Patterson et al 1978; Goossens 1995; DeGaetano 1996; Comrie and Glenn 1998; Malmgren and Winter 1999; Host et al 1995; Astrada et al 2009). These techniques were used to determine the climate zones across Greater Manchester.

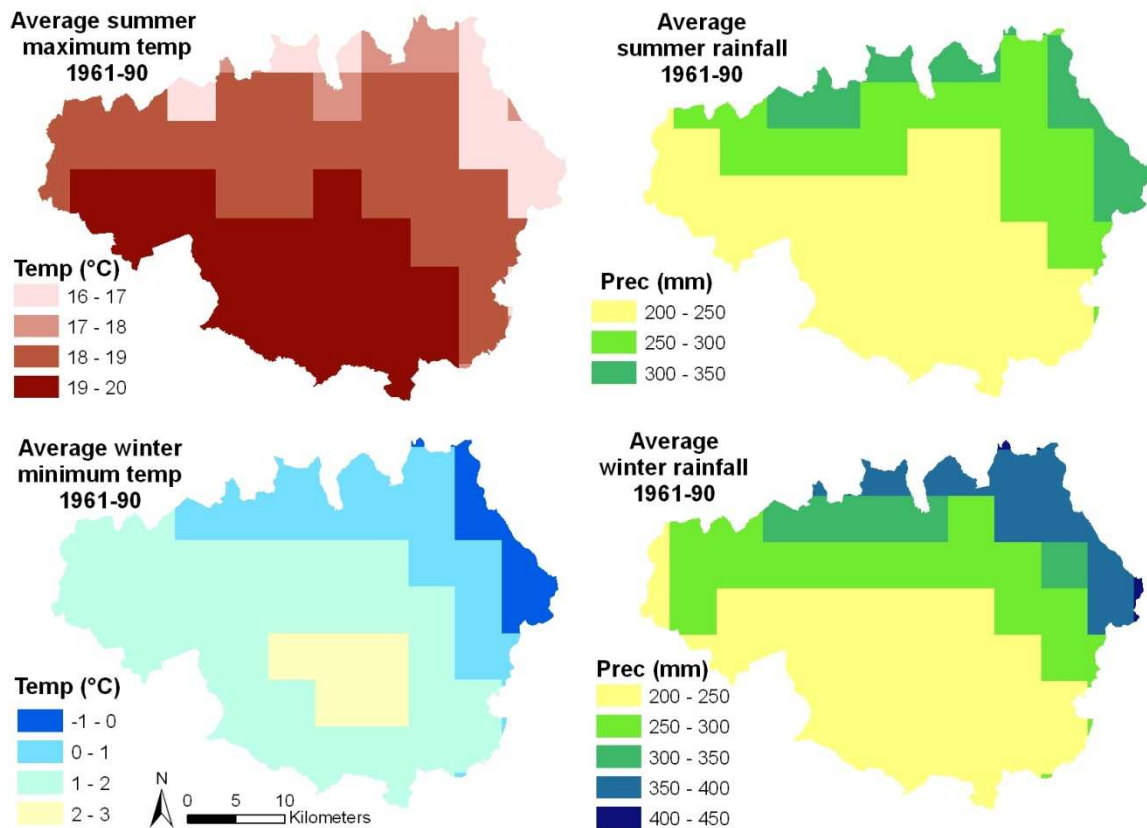
Climate zones in Greater Manchester were identified based on a climate database consisting of a number of climate variables, interpolated over a 5 km² grid across the study region. The monthly gridded data is provided by the UK Meteorological Office. The 5km x 5km gridded data is generated using observed data from a historical database of weather observations from a network of meteorological stations across the UK. This set of observed station data is interpolated to a grid using multiple regression and inverse-distance weighted interpolation (Perry and Hollis 1995). Local variations in geographic and topographic factors, including easting and northing, terrain height and shape (topography), and urban and coastal effects are incorporated into the interpolation process, either through normalisation with regard to the 1961–90 average climate, or as independent variables in the regression (Perry and Hollis 1995). Therefore, the 5km gridded datasets of climatic variables incorporate the local effects of topography, land use type and latitude.

Statistical analysis was undertaken using SPSS v10. Analysis of the correlation between the climate variables from the UK Met Office 5x5 km gridded observed dataset (annual and seasonal mean, maximum, minimum temperatures and precipitation) and environmental data (elevation, slope and land use) revealed that there was very high correlation (>0.90) between the variables, due to the interpolation process outlined above. A principal component analysis resulted in only one principle component being retained, thus, PCA is not appropriate for the data. Instead, a smaller number of variables could be extracted to represent all climatic and driving environmental factors in a cluster analysis. The key variables considered to be important for this analysis (which incorporate the key variables and seasons in which climatic extremes will occur, requiring adaptation responses) are:

- Winter precipitation;
- Summer precipitation;
- Summer maximum temperature; and,
- Winter minimum temperature.

Figure A1 shows the spatial distribution of these key variables across Greater Manchester.

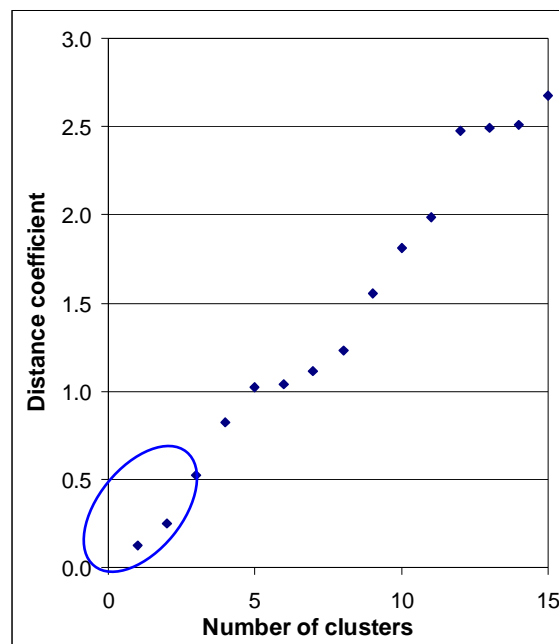
Figure A1: Climatic variables used in the cluster analysis (Data: © Crown copyright 2010, Published by the Met Office)



Three different hierarchical cluster analysis methods were investigated with the squared Euclidean distance linking method: Ward's, average linkage and centroid.⁹ The centroid method produced the best result, as it identified 3 clear zones (figure A2).

Descriptive statistics of each climate zone was then undertaken, and each 5x5km grid square across the Greater Manchester conurbation was assigned to the appropriate cluster or climate zone.

Figure A2: Scree plot of eigenvalues for the Centroid method, revealing 3 clusters



⁹ For further information on cluster methods, see, for example; Yarnal (1993) or DeGaetano (1996).