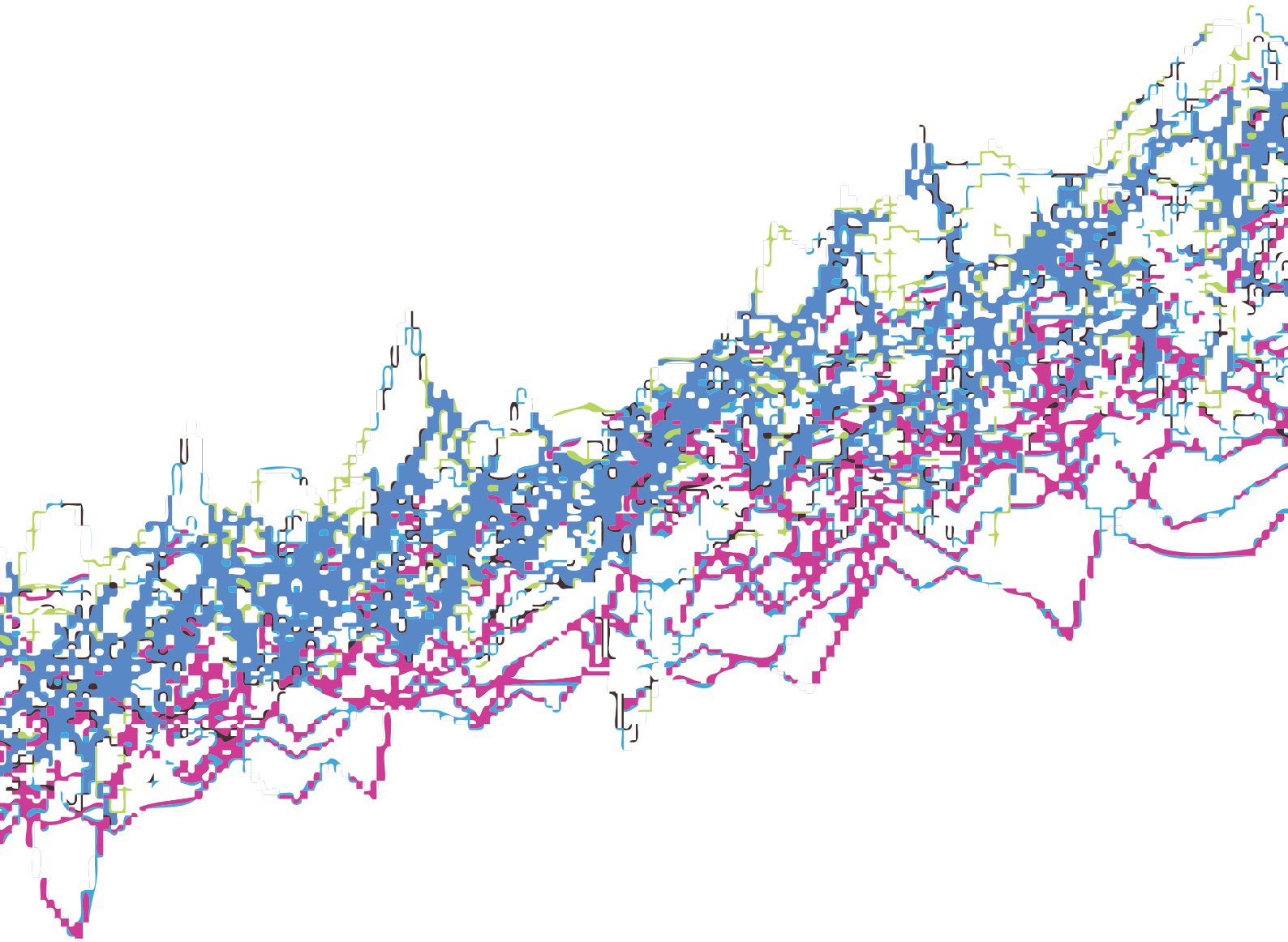
UK CLIMATE PROJECTIONS

Climate change projections



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ISBN 978-1-906360-04-7

This report is the second of the UKCP09 scientific reports, and should be referenced as:

Murphy, J.M., Sexton, D.M.H., Jenkins, G.J., Boorman, P.M., Booth, B.B.B., Brown, C.C., Clark, R.T., Collins, M., Harris, G.R., Kendon, E.J., Betts, R.A., Brown, S.J., Howard, T. P., Humphrey, K. A., McCarthy, M. P., McDonald, R. E., Stephens, A., Wallace, C., Warren, R., Wilby, R., Wood, R. A. (2009), *UK Climate Projections Science Report: Climate change projections*. Met Office Hadley Centre, Exeter.

Copies available to order or download from:
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ISBN 978-1-906360-02-3

UK Climate Projections science report: Climate change projections

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Version 3, updated December 2010

Acknowledgements

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Dr Rachel Capon, Arup, London
Dr Vic Crisp, Chartered Institution of Building Services Engineers, London
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Reviewers' comments have been extremely valuable in improving the final draft of this report. However, not all changes requested by all reviewers have been accepted by the authors, and the final report remains the responsibility of the authors.

The authors would like to acknowledge the original suggestion from Professor Alan Thorpe (when Director of the Met Office Hadley Centre) for a project to quantify uncertainty using large climate model ensembles, without which the UKCP09 probabilistic projections would not have been possible.

Discussions with Prof. Jonathan Rougier, University of Bristol, have encouraged us to adopt the methodology for the UKCP09 Probabilistic Projections.

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Summary

The UK Climate Projections (UKCP09) provide projections of climate change for the UK, giving greater spatial and temporal detail, and more information on uncertainty, than previous UK climate scenarios.

This report is designed for those who wish to find out more about the purpose and design of the UKCP09 methodology for producing the probabilistic projections of climate change, and is drafted to suit a range of levels of expertise. It shows some examples of projections; the full set of results is available through the User Interface and the pre-prepared maps and graphs, with key findings presented in the Briefing Report.

Purpose and design of UKCP09

- Over land, UKCP09 gives projections of changes for a number of climate variables, averaged over seven overlapping 30-yr time periods, at 25 km resolution and for administrative regions and river basins. Similar projections are given for a smaller number of variables averaged over marine regions around the UK (Chapter 1).

- UKCP09 is the first set of UKCIP projections to attach probabilities to different levels of future climate change. The probabilities given in UKCP09 represent the relative degree to which each climate outcome is supported by the evidence currently available, taking into account our understanding of climate science and observations, and using expert judgement (Chapter 1).

- The Met Office Hadley Centre has designed a methodology to provide probabilistic projections for UKCP09, based on ensembles of climate model projections consisting of multiple variants of the Met Office climate model, as well as climate models from other centres. These ensembles sample major known uncertainties in relevant climate system processes (Chapters 2 and 3).

- UKCP09 gives projections for each of three of the IPCC's Special Report on Emissions Scenarios (SRES) scenarios (A1FI (called High in UKCP09), A1B (Medium) and B1 (Low)) to show how different emissions pathways affect future climate (Chapter 2 and Annex 1). Each of the emissions scenarios suggests a different pathway of economic and social change over the course of the 21st Century; it is not possible to assign probabilities to each scenario. They do not include planned mitigation measures directly.

- For a given emissions scenario, the UKCP09 probabilistic projections account for uncertainties arising from the representation of climate processes, and the effects of natural internal variability of the climate system (Chapter 2).

- Changes to external factors such as solar activity and volcanic eruptions cannot be predicted, and are not considered (Chapter 2).

- UKCP09 projections explicitly include the climate carbon cycle feedback for the first time, and uncertainties in the feedback from the land carbon cycle. They also include the direct and first indirect effects of sulphate aerosol and uncertainties in these. Some feedbacks, such as those from the methane cycle, are not well enough understood to be included (Chapter 2).

- The UKCP09 methodology uses the Met Office regional climate model (RCM) to downscale global climate projections to a 25 km scale; uncertainties in this downscaling are also included in the probabilistic projections (Chapter 3).

- Continuous daily time series from 1950 to 2099 for 11 variants of the Met Office RCM are available via a separate project called LINK. These time series are spatially coherent between grid squares and are available over land and sea. However, being based only on Met Office models, they do not take as much uncertainty into account (Chapter 5)

- It has not been possible to produce probabilistic projections of changes in snowfall rate, and users are recommended to take these from the 11-member RCM ensemble (Chapter 4)

- The current observed strength of the Urban Heat Island effect is included in the projections of future climate, but possible changes in the strength of the Urban Heat Island in the future cannot yet be included (Annex 7).

- It is unlikely that an abrupt change in the Atlantic Ocean Circulation will occur this century. The effects of a gradual weakening of the circulation over time are included in the UKCP09 climate projections (Annex 5).

- Models will never be able to exactly reproduce the real climate system; nevertheless there is enough similarity between current climate models and the real world to give us confidence that they provide plausible projections of future changes in climate (Annex 3).

- There is a cascade of confidence in climate projections, with moderate confidence in those at continental scale; those at 25 km resolution are indicative to the extent that they reflect large-scale changes modified by local conditions such as mountains and coasts. The level of confidence is different for different variables.

- Errors in global climate model projections cannot be compensated by statistical procedures no matter how complex, and will be reflected in uncertainties at all scales.

Some examples of projected seasonal and annual changes

We summarise in the box below some changes by the 2080s with Medium emissions, but stress that projections can be very different for other time periods and other emissions scenarios. Users should look at the time period appropriate for their decisions, and examine projections for all three emissions scenarios, to gain a full appreciation of changes to which they might have to adapt.

Summer, winter and annual mean changes by the 2080s (relative to a 1961–1990 baseline) under the Medium emissions scenario. Central estimates of change (those at the 50% probability level) followed, in brackets, by changes which are very likely to be exceeded, and very likely not to be exceeded (10 and 90% probability levels, respectively).

- All areas of the UK warm, more so in summer than in winter. Changes in summer **mean temperatures** are greatest in parts of southern England (up to 4.2°C (2.2 to 6.8°C)) and least in the Scottish islands (just over 2.5°C (1.2 to 4.1°C)).

- **Mean daily maximum temperatures** increase everywhere. Increases in the summer average are up to 5.4°C (2.2 to 9.5°C) in parts of southern England and 2.8°C (1 to 5°C) in parts of northern Britain. Increases in winter are 1.5°C (0.7 to 2.7°C) to 2.5°C (1.3 to 4.4°C) across the country.

- Changes in the **warmest day of summer** range from +2.4°C (–2.4 to +6.8°C) to +4.8°C (+0.2 to +12.3°C), depending on location, but with no simple geographical pattern.

- **Mean daily minimum temperature** increases on average in winter by about 2.1°C (0.6 to 3.7°C) to 3.5°C (1.5 to 5.9°C) depending on location. In summer it increases by 2.7°C (1.3 to 4.5°C) to 4.1°C (2.0 to 7.1°C), with the biggest increases in southern Britain and the smallest in northern Scotland.

- Central estimates of **annual precipitation** amounts show very little change everywhere at the 50% probability level. Changes range from –16% in some places at the 10% probability level, to +14% in some places at the 90% probability level, with no simple pattern.

- The biggest changes in **precipitation in winter**, increases up to +33% (+9 to +70%), are seen along the western side of the UK. Decreases of a few percent (–11 to +7%) are seen over parts of the Scottish highlands.

- The biggest changes in **precipitation in summer**, down to about –40% (–65 to –6%), are seen in parts of the far south of England. Changes close to zero (–8 to +10%) are seen over parts of northern Scotland.

- Changes in the **wettest day of the winter** range from zero (–12 to +13%) in parts of Scotland to +25% (+7 to +56%) in parts of England.
- Changes in the **wettest day of the summer** range from –12% (–38 to +9%) in parts of southern England to +12% (–1 to +51%) in parts of Scotland.
- **Relative humidity** decreases by around –9% (–20 to 0%) in summer in parts of southern England — by less elsewhere. In winter changes are a few percent or less everywhere.
- **Summer-mean cloud amount** decreases, by up to –18% (–33 to –2%) in parts of southern England (giving up to an extra +20 Wm^{-2} (–1% to +45 Wm^{-2}) of downward shortwave radiation) but increase by up to +5% (zero to +11%) in parts of northern Scotland. Changes in cloud amount are small (–10 to +10%) in winter.

- Projected changes in **storms** are very different in different climate models. Future changes in anticyclonic weather are equally unclear (Annex 6).
- We have been unable to provide probabilistic projections of changes in **snow**. The Met Office Hadley Centre regional climate model projects changes in winter mean snowfall of typically –65% to –80% over mountain areas and –80% to –95% elsewhere.
- We make no assessment of how the **Urban Heat Island** effect may change (Annex 7).
- It is very unlikely that an abrupt change to the Atlantic Ocean Circulation (**Gulf Stream**) will occur this century (Annex 5).

- UKCP09 provides a state-of-the-art basis for assessing the risk of different outcomes consistent with current climate modelling capability and understanding. As our understanding, and our modelling and statistical capabilities, improve in future, the projections are very likely to change (Chapter 3 and Annex 2).
- UKCP09 projections are appropriate for decisions on adapting to long-term climate change which need to be taken on the basis of current knowledge (Chapter 2).

1 Introduction and overview

This report provides background information on, and key findings from, the new projections of UK climate change in the 21st century, known as UKCP09. It is designed for anyone who wants to know about the projections themselves, ranging from general awareness to their application in impacts and adaptation assessments. In particular, the projections have been designed as input to the difficult choices that decision makers will need to make, in sectors such as transport, healthcare, water resources and coastal defences, to ensure the UK is adapting well to the changes in climate that have already begun and are likely to grow in future.

This report has a rather different purpose to its predecessor in UKCIP02; it is not designed to give a comprehensive description, in graphics or text, of the changes that are projected. Many of these can be seen on the UKCP09 website, and custom products can be generated from the User Interface. Because the UKCP09 projections are more informative, but also more complex, than previous UKCIP scenarios, the report discusses at some length why and how they have been developed, and how they are presented, so that users can get the most out of them.

This report has been reviewed, firstly by the project Steering Group and User Panel, and secondly by a smaller international panel of experts, who also reviewed the methodology used to generate the probabilistic projections. Reviewers' comments have been taken into account in improving the reports.

Chapter 1 discusses briefly why the UKCP09 projections are needed, what information they provide, the uncertainties that they have been designed to treat and how this is done. Chapter 2 discusses causes of uncertainty in climate change projections, and gives a simplified description of the method used to derive the UKCP09 projections, with Chapter 3 going into much more detail on the methodology. Chapter 4 summarises the key findings based on the monthly and seasonal projections for regions of the UK, and displays maps and graphs of

changes for some temperature and precipitation variables. Chapter 5 deals with daily time series of recent and future climate from the Met Office Hadley Centre (Met Office) regional climate model. Finally, there are a number of annexes which allow the user to go into greater depth; in particular Annex 2 identifies some of the uncertainties in the UKCP09 projections themselves.

The components of UKCP09 are shown diagrammatically in Figure 1.1; they are supported by a number of publications, both hard copy and on line.

1.1 Why are climate change projections needed? Why new ones?

That global climate is changing is unequivocal. Although the extent to which human activities are contributing is still a matter of research, compelling evidence allowed the fourth science assessment* (AR4) from the Intergovernmental Panel on Climate Change in 2007 to say that "Most of the observed increase in global average temperatures since the mid-20th century is very likely (>90% probability) due to the observed increase in anthropogenic greenhouse gas concentrations". Even since the publication of the 2007 IPCC report, new research attributing changes in precipitation and water vapour to human activity strengthen our confidence in this statement.

Although there are many uncertainties about how climate will change in the future, changes projected by climate models are likely to result in significant impacts on business, infrastructure and the natural environment in the UK. Furthermore, we know that the combined effect of the long effective lifetime of the most influential man-made greenhouse gas, carbon dioxide, and the large thermal inertia of the oceans, causes any change in climate to lag behind the man-made greenhouse gas emissions that drive them. By the same token, current emissions, and those over the past few decades, have already built into

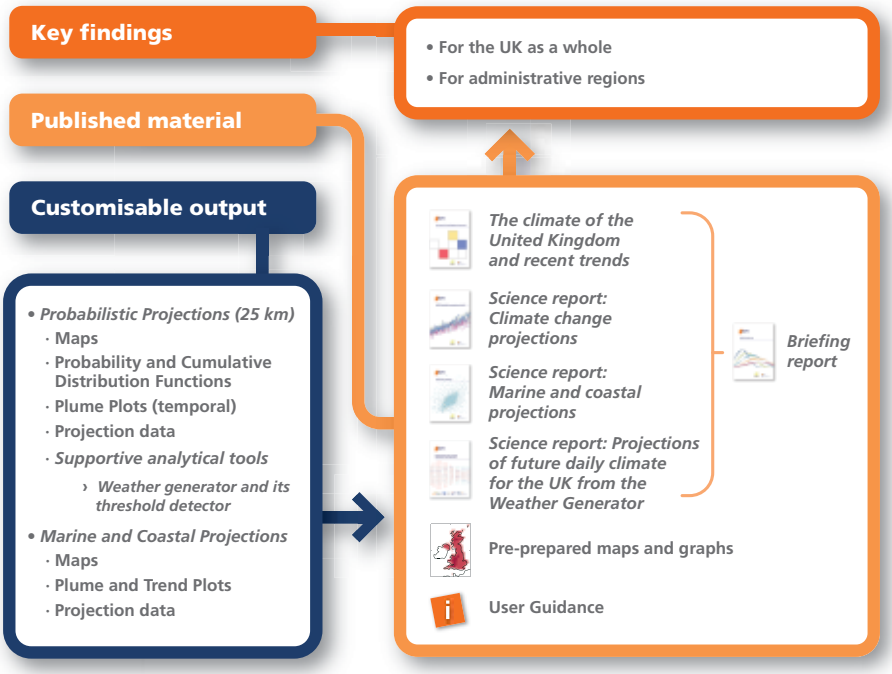

Figure 1.1: Information and publications supporting the UKCP09 projections.

* http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

the climate system a commitment to future climate change which cannot now, in any practical sense, be avoided. If there were to be reductions, even quite stringent ones, in global man-made greenhouse gas emissions, then this would be followed by a corresponding reduction in the rate of climate change, but the full effect would take decades or even centuries.

These three factors: the high likelihood that mankind has already begun to change the earth's climate, the projections of significant impacts in the future, and the commitment to further change over the next few decades irrespective of any emissions reductions in the short term, argue very strongly for a strategy of adaptation to minimise the consequences, and maximise the opportunities, of climate change. To adapt effectively, planners and decision-makers need as much information as possible on how climate will evolve, and this has been the purpose of the successive publications of climate change scenarios for the UK, firstly by the UK Climate Change Impacts Review Group in 1991 and 1996, and then by the UK Climate Impacts Programme (UKCIP) in 1998 and in 2002. Research has shown that most recent trends in observed climate fall broadly within the range of projections shown in these scenarios.

Why are new projections needed at this time? Continuing improvements in our understanding of the climate system and in modelling allows us to periodically update projections, which also helps to meet increasingly sophisticated user requirements. One example of the former is the growing recognition of how significant changes in the carbon cycle can act to exacerbate climate change; this factor is explicitly included for the first time in the UKCP09 projections. A more complex example concerns uncertainties; reports accompanying previous projections have mentioned the lack of a credible approach for handling these. The development of new techniques, together with increased computing power enabling them to be exploited, has allowed us to quantify the spread of future projections consistent with major known sources of uncertainty, by presenting projections which are probabilistic in nature. This sort of presentation is more complicated than the single projections (for each emission scenario) in UKCIP02, but more comprehensively reflects the state of the science; this is why probabilistic projections were adopted by IPCC for the first time in AR4. The UKCP09 projections respond to demands from a wide range of users for this level of detail.

1.1.1 What do we mean by probability in UKCP09?

It is important to point out early in this report that a probability given in UKCP09 (or indeed IPCC) is not the same as the probability of a given number arising in a game of chance, such as rolling a dice. It can be seen as the relative degree to which each possible climate outcome is supported by the evidence available, taking into account our current understanding of climate science and observations, as generated by the UKCP09 methodology. If the evidence changes in future, so will the probabilities. It is hoped that the constant quest to improve models, and make better use of observations to constrain their projections, will allow uncertainties to be reduced in the future. However, this cannot be guaranteed as the introduction of processes not yet included (for example, feedbacks from the methane cycle), or as yet unknown, could have the opposite effect. However, using a methodology developed by Met Office, UKCP09 provides state-of-the-art projections consistent with what we know now, together with an assessment of their limitations.