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Is UKCP09 still an appropriate tool for adaptation planning?
Land Projections

April 2016

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Executive Summary

This technical note assesses the extent to which advice from UKCP09 remains an appropriate tool for adaptation planning in the light of recent improvements in climate science. In order to do this, the results from climate models that underpinned UKCP09 are compared with those from the 5th Coupled Model Intercomparison Project (CMIP5) archive. These informed the most recent Intergovernmental Panel on Climate Change assessment (IPCC AR5), which was published during 2013 and 2014. This note focuses on one core component of the UKCP09 product, the probabilistic projections over the land. It doesn't consider the spatially coherent projections developed using the UKCP09 regional climate model ensemble, or the marine scenarios.

In summary, this note concludes that UKCP09 continues to provide a valid assessment of future UK climate over land, and it can still be used for adaptation planning. In particular, it demonstrates that UKCP09 gives results consistent with CMIP5 for future changes to summer and winter temperature, and winter rainfall in the UK.

However, some differences were found for future summer rainfall changes. When considering decisions that are sensitive to projected future changes in summer rainfall, CMIP5 results should therefore be used to inform interpretation of results derived from UKCP09, bearing the following points in mind:

- CMIP5 and UKCP09 results agree that a future reduction in long-term average summer rainfall is more likely than an increase.
- However, CMIP5 suggests a somewhat larger chance of an increase, and a smaller risk of substantial future reductions in summer rainfall, especially for England and Wales.
- The full range of summer rainfall outcomes from UKCP09 remains valid for consideration in planning decisions, however users are advised to assess the sensitivity of their applications to reasonable variations in the UKCP09 advice, informed by CMIP5 evidence.
- In most cases, qualitative consideration of CMIP5 evidence should be sufficient in such sensitivity testing.
- Quantitative analysis of CMIP5 data as an alternative to UKCP09 should not generally be necessary when considering summer rainfall, but users wishing to do this are strongly advised to seek expert help from specialists in their technical discipline.

1. Introduction

The most recent national projections of climate change are provided through the UK Climate Projections (UKCP09) and they currently form the UK Government's official scientific basis for planning climate change adaptation activities.

The UKCP09 land scenarios (Murphy et al., 2009) took the form of probabilistic projections representing uncertainties due to internal climate variability and the modelling of key earth system processes. They were constructed from several ensembles (groups of models) of variants of a single climate model (HadCM3), designed to represent modelling uncertainties by adjusting model parameters within expert-specified ranges in order to provide alternative plausible versions of the climate model. These are known as perturbed parameter ensembles, or PPEs. These model simulations were combined with results from the 4th IPCC assessment of international climate models (known as the CMIP3 ensemble) and a set of observational metrics of historical model performance. The approach is described in detail by Sexton et al. (2012) and Harris et al. (2013).

Since UKCP09 was released there have been improvements in the physical understanding of the climate system, as well as refined estimates of how emissions and concentrations of greenhouse gases and aerosols will evolve over the 21st century. This, combined with increases in supercomputing power, has facilitated the development of new climate models, such as those that form the IPCC 5th assessment (known as the CMIP5 ensemble).

Within the IPCC 5th assessment, Flato et al. (2013) evaluated the CMIP5 climate models, finding a general improvement compared to CMIP3. Areas of progress included better simulation of surface temperature at regional scales and rainfall at large (continental to global) scales, although rainfall at regional scales is simulated less well. There was also improvement in the simulation of rainfall extremes, partly due to a shift towards higher horizontal resolution in CMIP5 models. However both CMIP3 (the generation of models used in UKCP09) and CMIP5 exhibit a number of common systematic errors: The simulation of clouds remains a challenge, for example, despite the modest improvements found in CMIP5.

The general improvement of climate models since CMIP3/UKCP09 has prompted the question of whether UKCP09 land scenarios remains a suitable tool for informing planning of climate adaptation activities. This note addresses this issue. There is a more detailed technical note.

2. Comparing the model simulations with observations

Historical evaluation of climate models involves comparing their simulations of the recent past with climate observations. It is an important method of demonstrating the credibility of the models. A key aspect of assessing the continued credibility of UKCP09 is therefore to compare the quality of its underpinning model simulations against more recent models from CMIP5. The historical evaluation focused on a perturbed parameter ensemble (PPE) of 17 coupled ocean-atmosphere variants of HadCM3 (Collins et al., 2011), which is a core modelling component of the probabilistic scenarios in UKCP09. The PPE was found to be competitive with CMIP5 in its simulation of worldwide climate averages, across a range of standard model assessment variables. This reflected the status of HadCM3 as one of the best of the CMIP3 models (Reichler and Kim, 2008).

The analysis considered deviations in long-term climatological averages of several key simulated climate variables from the observational values. The differences between alternative models are influenced by a range of physical processes. The key finding is that the results for the PPE are competitive with those of CMIP5: for most variables the scores for the best PPE members rank amongst the top CMIP5 models, while for surface air temperature and precipitation several CMIP5 models score much worse than the least skilful PPE members.

The results also demonstrate that all contemporary models still contain significant systematic biases, since the best performing models (or model variants) almost always give larger deviations from the observations than those obtained from the differences between two alternative observational datasets.

In addition to the assessment of climatological averages summarised above, the PPE was found to compare well against CMIP5 models in its simulation of the winter and summer versions of the North Atlantic Oscillation, a key driver of UK climate variability on annual to decadal time scales.

3. Comparing the UKCP09 projections with recent IPCC simulations of the future climate

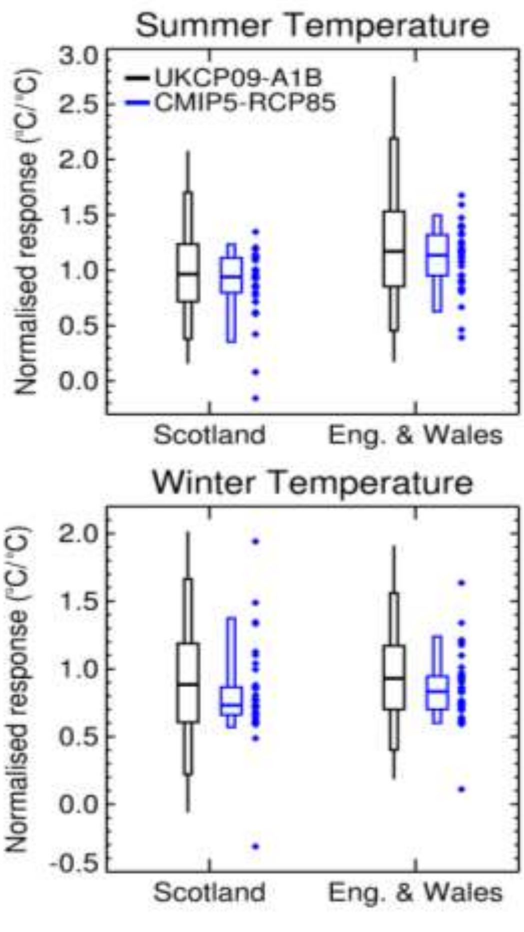
The IPCC 5th assessment reports on the ability of the latest global climate models to simulate the future. Here we place the climate models used in UKCP09 into the context of these recent IPCC simulations in order to establish how their future projections compare with those of the latest IPCC projections. We focus on temperature and rainfall changes, which are both drivers of a wide range of potential impacts. It is important to emphasise that the conclusions of this comparison inevitably rely on expert judgement, as we would not expect the CMIP5 and UKCP09 distributions to be identical. This arises not just from the use of different ensembles of climate model simulations, but also from differences in the methods of construction of the two products. For example:

- The UKCP09 distributions are influenced by the formal application of a set of observational constraints designed to weight alternative outcomes according to model credibility, whereas the CMIP5 results are presented on a simple "one model one vote" basis, without accounting for variations in model quality.
- The CMIP5 ensemble is limited in size - a few tens of members (the precise number is dependent on which future emissions scenario is considered), whereas UKCP09 was derived from more than 400 model simulations.

- Also, the CMIP5 results are not screened to account for the sharing of components (and hence errors) between the different models that contributed to the multimodel archive (Masson and Knutti, 2011). Therefore, analyses of its projected changes are potentially sensitive to outliers, or results from two or more closely-related configurations of the same climate model.

Looking first at the range of long-term global temperature changes in response to increased greenhouse gas concentrations in CMIP5 models and UKCP09, we find them to be consistent. This was based, in particular, on a comparison between CMIP5 and UKCP09 distributions of equilibrium climate sensitivity, a standard metric of climate model response defined as the steady-state response to a doubling of atmospheric carbon dioxide concentration.

For the UK (and other worldwide regions), the degree of consistency depends on how well spatial patterns of projected future change compare between CMIP5 and UKCP09, as well as on the globally averaged climate response. Figure 1 shows an example for surface air temperatures averaged over England & Wales, and Scotland. Here, patterns of changes are assessed by considering projected UK changes per degree of global temperature response. This enables us to compare different emission scenarios and is important because CMIP3 and CMIP5 used a different, but comparable set of future emissions. The results show reasonable consistency between UKCP09 and CMIP5 for both summer and winter: For example, the 5-95 percentile ranges of the CMIP5 distribution invariably lie within their UKCP09 counterparts, while the median CMIP5 response always lies well within the central portion (25-75 percentile range) of the UKCP09 distribution. Therefore, we conclude that the advice from the latest climate models are consistent with that from UKCP09.



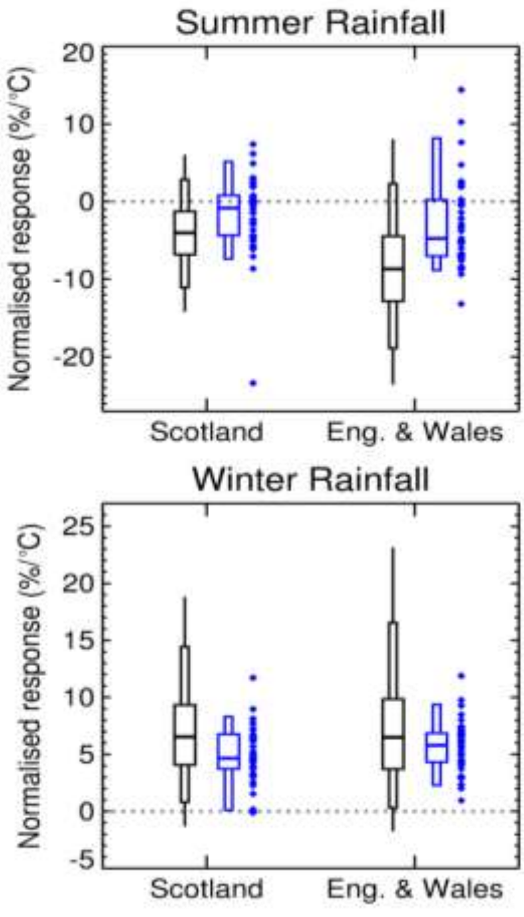
Surface air temperature in England & Wales and Scotland:

Figure 1. Future changes in summer and winter surface temperature, per degree of global mean warming. The black plots show the range of changes from UKCP09, relative to a 1961-90 baseline under the medium (A1B) emissions scenario. Blue diamonds show changes from individual CMIP5 models, taken from the RCP8.5 scenario. Boxes, horizontal lines and whiskers show the 5th, 25th, 50th, 75th and 95th percentiles of the CMIP5 and UKCP09 distributions of change, vertical lines showing the 1st and 99th percentiles in the case of UKCP09. CMIP5 is judged to show acceptable correspondence with UKCP09 where: (a) the 5th-95th percentile ranges of CMIP5 lie close to or within their UKCP09 counterparts, and (b) several CMIP5 simulations support outcomes both above and below the UKCP09 central estimate.

Focusing next on rainfall changes to the UK over coming decades, Figure 2 shows that there is a good overlap between UKCP09 and CMIP5 for winter rainfall changes per degree of global temperature rise. Therefore the advice from CMIP5 is consistent with the advice from UKCP09: The expectation of a long term trend towards wetter winters is confirmed, and the 5-95 percentile ranges of the CMIP5 results lie close to or within the UKCP09 ranges.

However, there are some differences between the projected summer rainfall changes. In this case, UKCP09 and CMIP5 agree to the extent that projected reductions are more likely than increases in the future. However, CMIP5 suggests smaller reductions, and contains few simulations projecting a drying response beyond the 50% probability level given by UKCP09 for England and Wales.

The results imply that there is a benefit to considering the implications of CMIP5 results when using UKCP09 to assess summer rainfall changes, in particular that CMIP5 implies a smaller risk of substantial future reductions for England and Wales. The change in risk cannot currently be quantified, because there is no formal method available to combine the lines of evidence available from UKCP09 and CMIP5. It is intended to provide this via new probabilistic projections as one of the products of the UKCP18 project, a forthcoming update to the UKCP09 scenarios (see http://ukclimateprojections.metoffice.gov.uk/24125). For users wishing to assess summer rainfall changes ahead of publication of UKCP18, it should in most cases be sufficient to test the robustness of their application or decision by applying reasonable sensitivity tests to the UKCP09 results, informed by the alternative CMIP5 projections. This would apply, for example, to applications dependent only on identifying a plausible range of outcomes for future summer rainfall. However, a minority of users may wish to go further, and analyse CMIP5 results themselves, for example to understand more precisely how CMIP5 and UKCP09 differ in projections of exceedance of some specific thresholds of future change. We recommend that expert help is sought in these cases. To illustrate the challenges involved, one major issue in interpreting the CMIP5 ensemble is that it may be biased by a few poorly performing models. In Figure 2, for example, the CMIP5 ensemble suggests a larger probability of future increases in summer rainfall over England and Wales than does UKCP09. However, the two models giving the largest increases are two closely-related variants of the MIROC earth system model, which do not provide independent realisations of future change. In addition, McSweeney et al. (2015) suggest that these simulations are not suitable for use in regional projections for Europe, due to biases in their historical simulations of storms. Advice on how to treat summer rainfall changes ahead of UKCP18 is provided in section 5.



Rainfall changes in England & Wales and Scotland:
Figure 2. As Figure 1 but for summer and winter rainfall.

Finally, changes in near-surface wind speed from CMIP5 models were also assessed, and revealed no clear signal for increases or reductions, consistent with UKCP09 advice (Sexton and Murphy, 2010).

4. How well do models simulate key drivers of UK climate?

This section explores a selection of large-scale features of the climate system that affect climate variability over the UK and Europe, comparing historical simulations and projected future changes in these phenomena from CMIP5 and UKCP09. This qualitative assessment augments the quantitative comparisons summarised in sections 2 and 3. The new Met Office Hadley Centre climate model, which will be used to update parts of UKCP09 in the UKCP18 project, aims to improve on several of these aspects. Understanding and reporting the degree of improvement will be an important part of producing the next generation of projections.

Atlantic Meridional Overturning Circulation (AMOC):
The AMOC provides a substantial northward transport of heat in the North Atlantic Ocean, which exerts a major influence on the atmosphere through transfer of heat at higher latitudes. Natural variability or externally-forced changes in the strength of the circulation affect surface temperatures, precipitation amounts and storm track characteristics over the North Atlantic and Europe, including the UK (Srokosz et al., 2012).

UKCP09 projections suggested that the AMOC would weaken by 10-30% with a doubling of CO_2 concentrations. Although some CMIP5 models show some improvements in simulating the AMOC, there is little difference in projected future changes in its strength compared to UKCP09. For example, the best estimate weakening by 2100 is 20-30% for the RCP4.5 scenario and 36-44% for RCP8.5, similar to the spread from UKCP09 (Sexton et al., 2016).

Storm tracks:
There is some evidence of improvement since the 4th IPCC assessment (CMIP3) in the ability of climate models to simulate the general characteristics of storm tracks and extra-tropical cyclones. For example, storm track biases in the North Atlantic have improved slightly. However, the number of storms that pass over the UK are still overestimated, due to a continued southward displacement in the simulated North Atlantic storm track compared to observations.

In terms of future response, there is still significant overlap between CMIP3 and CMIP5 projections for the end of the 21st century. For example, both CMIP3 and CMIP5 suggest a slight increase in wintertime storm activity over North Western Europe (Harvey et al., 2012; Harvey et al., 2013; Chang et al., 2012; Zappa et al., 2013b).

Blocking:
Blocking anticyclones occur when a high pressure system persists for several days or more, disrupting the prevailing mid-latitude westerly winds and storm track, causing a local reversal of zonal flow and in some locations a greater component of the wind in a north-south direction. Such systems are important for the UK as they are often associated with more extreme weather, such as very cold winters or heatwaves and droughts in the summer. Climate models in the past have universally underestimated the occurrence of blocking, in particular in the Euro-Atlantic sector (Scaife et al, 2011).

CMIP5 models have improved their simulation of blocking due in part to increases in horizontal (Matsueda, 2009) and vertical resolution (Anstey et al., 2012). However, in common with the climate models that underpinned UKCP09, they still significantly underestimate the frequency of winter Euro-Atlantic blocking (Anstey et al., 2012; Masato et al., 2012; Dunn-Sigouin and Son., 2013). For example, the UKCP09 results (Murphy et al., 2009) estimated blocking frequency using the Pelly and Hoskins (2003) variable-latitude index and found that the underestimation of the frequency of blocking over the UK in winter was about 30% on average (50 to 0% for individual models). Anstey et al (2012) concluded that CMIP5 models continue to underestimate the observed blocking frequency over Europe, and that deficits of approximately 50% are common, suggesting a similar distribution of biases to those that were used for UKCP09. The CMIP3 and CMIP5 generation simulate qualitatively similar future changes in blocking frequency - a reduction in future winter blocking frequency over the European/North Atlantic sector in response to increases in greenhouse gas emissions (Barnes et al., 2012; Masato et al., 2012).

5. Conclusions and implications

This note concludes that UKCP09 continues to provide a valid assessment of future UK climate over land. In particular, it demonstrates that UKCP09 is competitive with results from the most recent IPCC assessment, based on a comparison of simulations of historical climate from UKCP09 against CMIP5, the most recent set of international models which contributed to IPCC. Additionally, projected future changes from UKCP09 and CMIP5 are found to be consistent in future changes to summer and winter temperature in the UK. UKCP09 and CMIP5 also provide consistent results when comparing future winter rainfall changes. However some differences were found for future summer rainfall changes. In light of this, users whose applications depend on summer rainfall changes should bear the following points in mind:

- UKCP09 and CMIP5 projections agree that long term averages of summer rainfall are more likely to reduce than increase during the 21st century.
- However, CMIP5 suggests a larger chance of an increase in summer rainfall, and less risk of a substantial future reduction, compared to UKCP09.
- It is not surprising that CMIP5 and UKCP09 show some differences, because different ensembles of climate models rarely give identical ranges of projected outcomes. For example, results from previous generation of international climate models (CMIP3) also showed some differences from the UKCP09 probabilistic projections, despite being one of their constituents. This is because UKCP09 considered other lines of evidence, including projections from perturbed variants of a single climate model, in order to provide a more comprehensive view of uncertainties in future change.
- Therefore, users should continue to regard the full range of UKCP09 results as plausible outcomes for summer rainfall, to consider in planning decisions.

Work to update UKCP09 to provide new probabilistic projections incorporating CMIP5 results is planned for the forthcoming updated scenarios UKCP18 (see below). In the meantime, qualitative advice on the implications of CMIP5 for interpreting UKCP09 results on summer rainfall is as follows:

    - For applications sensitive to potential future increases in long-term average summer rainfall, users should consider the implications of a modestly higher probability for an increase than advised by UKCP09, subject to the constraint that the balance of probabilities favours lower rainfall in both CMIP5 and UKCP09.
    - Users interested in some threshold of choice representing the chance of a substantial reduction in average future summer rainfall, say a reduction of 10% or more compared to 1961-90, should regard the UKCP09 results as an upper limit on the chance of that threshold being crossed. They should test the sensitivity of their application to reducing the probability of crossing the relevant threshold.

For a decision dependent on considering a likely or very likely range of summer rainfall outcomes, for example, it remains acceptable to use UKCP09, with the addition of tests designed to explore the sensitivity of the user application to reasonable variations in the lower or upper end of the range. If a particular application is strongly dependent on the precise probability of exceeding a threshold, or of an extreme outcome occurring, then CMIP5 data could be used to derive an alternative probability to consider alongside UKCP09. Users wishing to analyse CMIP5 results are strongly advised to seek expert help from specialists in their technical discipline. The CMIP5 models and experiments are described in Flato et. al (2013) and the CMIP5 data is available for download from https://esgf-index1.ceda.ac.uk/projects/esgf-ceda/.

A new project has begun to update the UK's climate projections called UKCP18 (http://ukclimateprojections.metoffice.gov.uk/24125). This will build on recent improvements in scientific understanding and modelling capability, and will also seek to improve usability of the projections. One of the planned updates is new probabilistic projections which incorporate CMIP5 information, in combination with other lines of evidence included in UKCP09. This will allow the qualitative advice of summer rainfall above to be updated with improved quantitative advice on the implications of current modelling capability and understanding for future changes in this variable. Until this and other UKCP18 updates are ready, this note demonstrates that all aspects of the existing product still remain a useful tool for informing adaptation planning.

Two further related information notes are planned. One will look at the continued efficacy of the marine simulations. The other will provide advice to users on transitioning between UKCP09 and UKCP18 results.

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