Non-technical summary

This report describes a new addition to the UKCP18 climate projections. For the first time internationally, a climate model at a resolution on a par with operational weather forecast models, is being used for national climate scenarios. This model allows us to examine the risk of extreme weather events in local areas for the coming decades.

> **We are able to describe how climate change will impact the types and extremes of weather for your local area.**

Global and regional climate models have typical resolutions of 60-300km and 10-50km, respectively. The new 2.2km "convection-permitting" model (CPM), by comparison, represents a step forward in our ability to simulate small scale behaviour seen in the real atmosphere, in particular atmospheric convection, and the influence of mountains, coastlines and urban areas. As a result, the CPM provides access to credible climate information on hourly timescales, important for small-scale weather features that affect flooding in summer, and also on local (kilometre) scales, improving our understanding of climate change in cities. Although the new data can provide information on small-scale weather events in the future, it should not be confused with an operational weather forecast, which provides information on weather that is likely to be experienced in the next few days. Instead the CPM provides a set of plausible projections of climate change for the UK if we follow a high emission pathway. In particular, it provides information on the local effects of changes in the types of weather that may be experienced in the future.

The new CPM projections are an addition to the UKCP18 toolkit, the land component of which consists of three Strands of information. Strand 1 provides updates to the UKCP09 probabilistic predictions, Strand 2 provides a new set of global model projections and Strand 3 provides downscaled regional climate model (RCM) projections. Projections from Strands 1, 2 and the 12km RCM projections from Strand 3 were released in November 2018 (Murphy et al., 2018). The 2.2km CPM projections are a new addition, which should be used in combination with these other Strands of information. In particular, the wider sampling of uncertainties in Strands 1 and 2 should be considered. Taken together the UKCP18 projections replace the previous UKCP09 scenarios. The CPM provides information at similar frequencies (daily and hourly) and spatial resolution as the UKCP09 weather generator. However, the CPM is based on a realistic physical representation of relevant climate processes, rather than relying on statistical relationships based on past observations. The UKCP18 website (https://www.metoffice.gov.uk/research/collaboration/ukcp) contains links to general advice on how to use the UKCP18 projections (Fung et al., 2018), and specific advice for previous users of UKCP09 (Fung and Gawith, 2018).

The new projections build on previous studies, which have shown that CPMs are able to represent hourly rainfall characteristics, including extremes, much more realistically than conventional climate models run at coarser spatial scales (Kendon et al 2014). However, the high cost of the simulations means that until now CPM results were based only on a single model projection of future climate change. Therefore, it has not been possible to assess uncertainties in the climate change signal at these scales. UKCP18 is the first time an ensemble of climate simulations has been carried out at convection-permitting resolution. The ensemble consists of 12 projections, run at 2.2km resolution. Each projection represents a plausible realisation of the future climate assuming no curbs on greenhouse gas emissions, with the ensemble members differing due

to natural climate variability and uncertainty in the global model physics. The CPM ensemble therefore gives an indication of uncertainties in future changes on kilometre and hourly scales for use in risk assessments, providing locally relevant information to inform decision making. However, we note that uncertainty in the convection-permitting model physics itself has not been sampled nor has information from other international climate models. The CPM ensemble therefore underestimates uncertainties.

The CPM projections provide data for the UK, for three 20-year periods (1981-2000, 2021-2040 and 2061-2080) under a high emission scenario RCP8.5. The 12 ensemble members are driven by the Strand 3 12km RCM ensemble. The CPM is based on the Met Office operational UK weather forecast model (UKV), which has been extensively tested for use in that context. The CPM shares many of the same model physics settings as the 12km RCM, but with some notable differences particularly in how convection is represented. Details on the model are provided in Section 2. Results presented here focus on temperature and precipitation, but some other variables including soil moisture, snow, cloud and lightning have also been considered.

Summary findings

Present-day model performance

- The CPM better simulates several aspects of present-day climate, which is verified by comparing the model results with observations of the real world. This leads to improved confidence in its ability to project the effects of future changes to aspects of our weather relating to extreme events at local and hourly scales. Here we examine how well the CPM represents the present-day climate compared to the driving 12km RCM (Section 3). We mainly consider temperature and precipitation, including extremes such as hot summer days and heavy downpours.
- In winter, the RCM is too cold in the north of the UK and too warm in the south, whilst the CPM gives better agreement with observations. The CPM also better represents cold winter days and the number of intense cold spells in the north UK in the present-day. In summer, the CPM is warmer than the RCM, giving better agreement with observations in the north but not in the south where it has a tendency for hot days to be too hot. These model differences are likely due to differences in the representation of snow (less lying snow in the CPM in winter), cloud (less cloud in the CPM) and the tendency for soil to be drier in the CPM.
- The CPM gives a significantly better representation of how rainfall varies day-to-day and hour-to-hour. In particular, rainfall is too persistent in the RCM, which leads to too much overall rainfall. There are fewer wet days in the CPM in better agreement with observations, although the CPM has too few wet days in the far south in summer. The CPM better simulates heavy rainfall in winter and over mountains. In summer, away from mountains, there is a tendency for heavy events to be too heavy in the CPM, resulting in poorer agreement with observations than the RCM. In common with climate models more generally, the RCM is unable to capture short intense downpours that can lead to flash flooding. Such events are more realistically captured in the CPM, although again they tend to be too heavy. These improvements in the CPM are due to the better representation of convection, and also of mountains and coastlines.

Climate change projections

- The CPM results do not change the UKCP18 headline message of a greater chance of warmer wetter winters and hotter drier summers across the UK in future (Lowe et al, 2018). For 2061-80, under a high emission scenario (RCP8.5), the CPM ensemble suggests winters will be warmer by 1.8-3.3ºC[1] and wetter by 16-42%, whilst summers will be hotter by 3.6-5.0ºC and drier by 16-46%. In general the CPM reinforces the results from the 12km RCM, projecting similar overall changes to UK climate. However the CPM results do provide new information in terms of winter mean precipitation changes, changes in extremes and changes at local scales (Section 4, Table 5.1).
- Mean temperature increases everywhere and in all seasons in future, with the greatest increases occurring in the south. The CPM ensemble shows increases in hot summer days (3.7-6.8ºC[1] increase by the 2070s under RCP8.5) and the frequency of hot spells, reinforcing the results of the RCM. In winter, there is a smaller increase in temperature over Scotland in the CPM compared to the RCM, with a smaller increase in the temperature of cold winter days and a smaller decrease in the frequency of intense cold spells. These differences are likely related to differences in lying snow, with a greater decrease in lying snow in the future in the RCM.
- Average winter precipitation increases in future, with the possible exception of northern Scotland where decreases are possible. We find that the CPM shows much greater increases than the RCM (27% compared to 16% increase[2]), due to greater increases in the number of wet days. This may be because it rains so often in the present-day in the RCM that there is little scope for this to increase further, although more research is needed to investigate this. Also the better representation of convective showers and their movement inland in the CPM may be a factor.
- Average summer precipitation decreases in future in the CPM ensemble, again with the possible exception of northern Scotland. The average changes are broadly consistent between the CPM and RCM ensembles, but the underlying changes in rainfall on a day-to-day and hour-to-hour basis are quite different. In particular, it rains less often in the future, but the rain is heavier when it does – and this shift to more intense rainfall in summer is more pronounced in the CPM projections. These changes in rainfall are primarily driven by increased moisture in the atmosphere with warming, leading to heavier rainfall, which is captured by both the CPM and RCM. However, local processes within the storms themselves can amplify increases, and these are only represented in the CPM projections.
- Hourly precipitation extremes increase in future. The CPM shows increases of 25%[3] in the precipitation associated with an event that occurs typically once every 2 years. RCM projections for hourly extremes are considered unreliable.

Use of projections

- The release of the CPM projections provides further capability to the UKCP18 suite of climate projection tools. The CPM provides information on changes in hourly rainfall and for local areas that can be used in local decision making, for example information on urban flooding for contingency planners. However, the CPM and RCM ensembles sample a narrower range of uncertainty than the UKCP18 Strand 1

[1] The range quoted corresponds to the UK-average of the 2nd lowest to 2nd highest responses across the 12-member CPM ensemble.
[2] UK-average of the central response across the 12-member ensemble
[3] UK-average of the central estimate across the 12-member CPM ensemble

(probabilistic) or Strand 2 (global model) projections. This is because they are driven exclusively by variants of a recent configuration of the Met Office Hadley Centre global model, and currently lack information from other international climate models, in contrast to Strands 1 and 2. Users need to balance the improvements the CPM offers against the fact that not all uncertainties are sampled. Where possible, users should use the new CPM projections in combination with other UKCP18 products that provide a wider sampling of uncertainty.

- The CPM results largely reinforce results from the RCM in terms of UK seasonal mean changes. One possible exception is for changes in winter precipitation where the CPM suggests greater increases compared to the RCM. Research is ongoing to understand the complex drivers behind this, but initial analysis suggests that projections based on conventional coarser resolution climate models may underestimate "upper-end" responses in winter mean precipitation (Section 5), although studies with other CPMs are needed to confirm this.
- For temperature, there is no evidence to suggest that the CPM projections are more or less plausible than those from the RCM. In some cases there are differences in the projections between the models, notably for temperature changes over Scotland in winter. In this case, although the CPM gives better agreement with observations, it has a less sophisticated treatment of lying snow, and so we do not have greater confidence in its projections. Thus for temperature changes, we recommend usage of information from Strand 1 and 2 given the more comprehensive view of uncertainties, except where fine spatial detail is required.
- The CPM projections are expected to be the primary source of information for users interested in daily rainfall extremes in summer or changes on hourly timescales. For these the CPM projections are considered more plausible, due to the better representation of convection and local processes in storms in the CPM. However, there are still deficiencies, as many convective storms occur on scales smaller than 2.2km in reality. Further research is needed to assess the importance of these deficiencies for future projections. Projections of hourly rainfall change from conventional climate models are unreliable. Coarser resolution models also likely underestimate increases in summer rainfall intensity, with implications for flood risk assessment.
- The CPM is expected to better represent changes over cities, due to the higher spatial resolution and use of a more sophisticated urban scheme, although more work is needed to confirm this. Also over mountains and coastlines, the added spatial detail provided by the CPM may be important for some users.
- We have confidence that the UKCP18 projections provide significant improvements on UKCP09, and additions of new capability. Nevertheless, there are still limitations in our ability to project 21st century weather and climate. For example, although the CPM provides a big step forward in representing small scale behaviour in the real atmosphere, there are still deficiencies. Also all projections are conditioned on the chosen scenario of future greenhouse gas emissions (RCP8.5) and the particular models and methodologies we employ in UKCP18. Supporting guidance documentation is being developed with the purpose to guide users through the new projections.

