Department for Environment Food & Rural Affairs

Department for Business, Energy & Industrial Strategy

Met Office Hadley Centre

Environment Agency

UKCP18 Factsheet: UKCP Local (2.2km) Projections

For the first time internationally, a climate model at a spatial resolution on a par with operational weather forecast models, is being used for national climate scenarios. The 2.2km model allows you to examine the risk of extreme weather events in local areas for the coming decades. The local projections are expected to be the primary source of information for users interested in daily rainfall extremes in summer or changes on hourly timescales.

We recommend that you read the non-technical summary in the UKCP18 Convection-permitting model projections: Science report (Kendon et al, 2019) which summarises what the local projections are, the key results and the situations where you may wish to use them. This factsheet supplements this by:

- Introducing "convection-permitting" climate models which underpin the local projections.
- Providing additional advice on how to use the local projections alongside other UKCP products.
- Highlighting useful information from Kendon et al (2019) and other sources which could inform your use of the data.

Contents

1. What are convection-permitting climate models?

Figure 1 Schematic of the spatial resolution of UKCP18 climate models and the implications for being able to model important climatic processes that lead to the weather we experience in the UK.

Global Climate Models (GCMs) and Regional Climate Models (RCMs) have typical resolutions of 60-300km and 10-50km respectively. These models are able to simulate physical climate processes, average climate and variability at daily and longer time scales, at national or larger spatial scales. RCMs are also useful at administrative-region or large-catchment scales (see Figure 1). However, for many, local-scale information and extreme weather are of particular interest. This includes the intense (convective) storms that we typically see in UK summers and that are not well simulated by GCM and RCM due to their coarser resolutions.

The new 2.2km "Convection-Permitting*" Model (CPM) used in the local projections, represents a step forward in our ability to simulate small-scale behaviour seen in the real atmosphere. In particular this includes atmospheric convection, which can lead to intense storm events, 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. You can find further information on CPMs in Kendon et al (2017) and Prein et al (2015).

* The term "convection-permitting" is used for models with grid spacing of less than about 5km. At this resolution convective storms are represented explicitly ("permitted") on the model grid. At coarser resolution, traditional climate models rely on a parameterisation scheme to represent the average effects of convection (which occurs at scales smaller than the grid scale of the model) and this simplification is a known source of model error.

1. Local (2.2km) gives better understanding of flooding risk by providing a more realistic representation of hourly rainfall, including intensity and rainfall duration. This is due to the ability of Local (2.2km) to better represent small-scale atmospheric processes, such as convection*.

* Motion caused by the tendency of hotter, less dense fluid (liquid or gas) to rise, and cooler, more dense fluid to sink, under the influence of gravity. In the atmosphere, convection leads to vertical transfer of heat and moisture, driving the development of showers and thunderstorms.

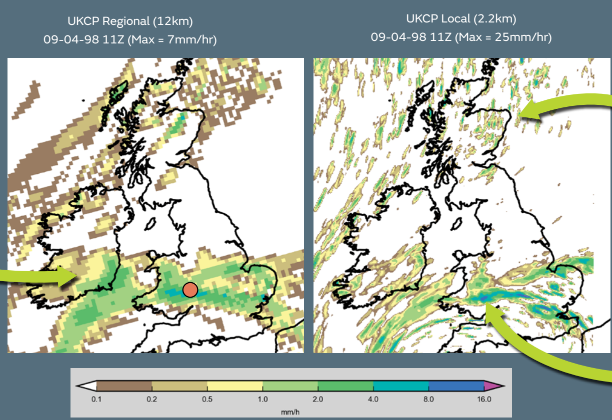
EASTER FLOODS 9-10 APRIL 1998

Event observation

Observed 12hr accumulation total: 61.6mm near Worcester
Observed peak rainfall rate: 10mm/hr

Worcester ●

Good agreement between Regional (12km) and Local (2.2km) for overall position of the frontal system in the south



Local (2.2km) better captures the spatial structure of rainfall, including local showers

Local (2.2km) provides a more realistic representation of rainfall, shown here by the embedded convective elements within the frontal system

2. Local (2.2km) provides a better representation of flash flooding as for the first time it can simulate hourly rainfall extremes.

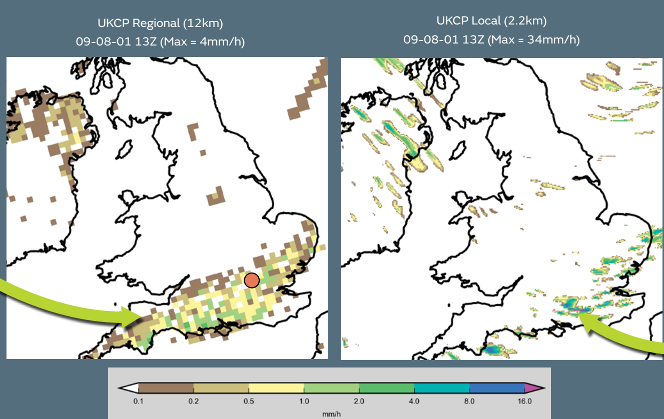
SUMMER STORMS 9 AUGUST 2001

Event observation

Northolt 09-08-01
12 hr accumulation total = 57mm
peak hourly rainfall rate: 34mm/hr

Northolt ●

Coarser spatial scale of the Regional (12km) underestimates rainfall intensity



Local (2.2km) captures heavy nature of showers, showing rainfall intensities above 30 mm/h

Figure 2 Improvements in modelling capability when using the convection-permitting model at 2.2km spatial resolution compared to the regional climate model at 12km spatial resolution.

The CPM is based on the Met Office operational UK weather forecast model (UKV), which has been extensively tested for use in weather forecasting. The CPM shares many of the same physical components as the 12km RCM in the regional projections (Murphy et al 2018), but with some notable differences particularly in how atmospheric convection is represented. Further descriptions of the different projections can be found in table 3 on page 12.

In the UKCP Convection-Permitting Model Projections: Science report (Kendon et al, 2019), we show that the CPM better simulates several aspects of present-day climate, which is verified by comparing the model results with observations of the real world (see Section 3 of Kendon et al, 2019). This leads to improved confidence in its ability to project the effects of future changes to our weather for extreme events at local and hourly scales. For example, for rainfall:

In the RCM: it rains much more frequently, leading to an excessive occurrence of wet days

In the CPM: it does not rain as frequently, in better agreement with observations, although when it does, it does so with greater intensity (see Figure 2)

Improvements in the simulation of other climate processes are also seen when using the CPM and are described in detail in Section 3 of Kendon et al (2019).

2. When should you use the Local (2.2km) projections?

2.1 The Local (2.2km) projections in the UKCP18 context

The UK Climate Projections comprise:

- Probabilistic projections that combine climate model data, observations and advanced statistical methods to simulate a wide range of climate outcomes for five emissions scenarios (RCP2.6†, RCP4.5, RCP6.0, RCP8.5 and SRESA1B).
- Global (60km) projections - a set of 28 climate futures at 60km grid resolution, showing how the 21st Century climate could evolve under the highest emission scenario, RCP8.5. They assess the uncertainty across different models from different modelling centres as well as the parameter uncertainty. They incorporate 15 members of the Met Office Hadley Centre model, HadGEM3-GC3.05 (PPE-15), and 13 other climate models selected from the climate models that informed the Intergovernmental Panel on Climate Change's 5th Assessment Report (CMIP5-13).
- Regional (12km) projections - a set of 12 high resolution projections at 12km (RCM-PPE), downscaled from the PPE-15 over the UK and Europe. They assess the uncertainty in the regional model parameters, as well as uncertainty in the large-scale conditions from the driving global model.
- Local (2.2km) projections - a set of 12 high resolution projections at 12km (RCM-PPE), downscaled from the PPE-15 over the UK and Europe. They assess the uncertainty in the regional model parameters, as well as uncertainty in the large-scale conditions from the driving global model.

† Note that the "RCPs" are not strictly emission scenarios but the term is used here for brevity - further information on emissions scenarios and RCPs can be found in UKCP18 Guidance: Representative Concentration Pathways.

- Derived projections - a set of climate futures for the UK at 60km grid resolution for a low emissions scenario, RCP2.6 and a global warming level of 2°C and 4°C. These have been derived from the global projections using statistical techniques.

2.2 When are the Local (2.2km) projections the most appropriate dataset?

For guidance on which set of projections to use, you should first consult UKCP18 Guidance: How to use the land projections (Fung et al, 2018). You may also find Figure B.1 (Appendix B) helpful. In summary:

- Use the probabilistic projections if you wish to assess the broadest range of future outcomes from UKCP18. They are the primary tool for assessments of the ranges of uncertainties in UKCP18.
- The global, regional and local projections provide flexible datasets derived directly from climate model output. These have full spatial and temporal coherence and offer information on a wider set of variables (that are physically consistent), metrics and time scales than is available from the probabilistic projections. However, only RCP8.5 is available for the global, regional and local projections.
- The global projections include results from the Met Office's global climate model (HadGEM3-GC3.05) as well as a set of international climate models (CMIP5) used in the Intergovernmental Panel on Climate Change's (IPCC) 5th Assessment Report.
- The regional and local projections explore a narrower range of future outcomes than the probabilistic or global projections as they only consider results from Met Office climate models. Note that the regional projections explore (to a limited degree) the impacts of modelling uncertainties at regional scales, whereas the local projections do not. In applications where consideration of uncertainties is more important than spatial detail, you should use the probabilistic or global projections.
- The derived projections provide (1) outcomes under a lower emissions scenario, RCP2.6, without running a climate model and using pattern-scaling and time-shifting techniques (2) the UK climate response to global temperature increases of 2°C and 4°C above pre-industrial levels.

The set of projections that you decide to use will be dependent on the variable of interest, the required temporal/spatial resolution, your data processing capability and the processes influencing the local climate in your location of interest. We summarise our latest understanding in Table 1 and Table 2 to support your decision on which set of physically-modelled spatially-coherent projections (i.e. global, regional and local) to use.

		Global (60km)	Regional (12km)	Local (2.2km)
General usage considerations		Use where exploration of a wider range of future outcomes is more important than spatial detail (some exceptions, e.g. winter mean precipitation)	Use where improved representation of extremes or spatial detail is more important than exploring a wider range of future outcomes.	Use where improved representation of extremes or spatial detail is more important than exploring a wider range of future outcomes. • Enhanced local resolution but needs to be balanced against larger data processing overheads • Hourly and 3-hourly data • Generally better agreement with observations
Temperature Metrics	Winter mean temperature	✔	✔	✔ Smaller increase over Scotland than RCM
	Summer mean temperature	✔	✔ But only samples warm outcomes	✔ But only samples warm outcomes
	Cold winter days	✔ But better representation of daily extremes in RCM/CPM	✔	✔ Smaller increase in temperature in the north than RCM
	Hot summer days	✔ But better representation of daily extremes in RCM/CPM	✔	✔ Greater increase in southern England than RCM
	Cold spells	✔ But better representation of daily extremes in RCM/CPM	✔	✔ Smaller decrease in frequency of intense cold spells in the north than RCM
	Hot spells	✔ But better representation of daily extremes in RCM/CPM	✔	✔
Precipitation Metrics	Winter mean precipitation	✔ But may underestimate “upper-end” response	✔ But may underestimate “upper-end” response	✔ Greater increase in precipitation than RCM. Samples “upper-end” responses outside range of GCM and RCM outcomes
	Summer mean precipitation	✔	✔ But only samples dry outcomes	✔ But only samples dry outcomes
	Heavy daily events in winter		✔	✔ Better agreement with observations than RCM over mountains
	Heavy daily events in summer			✔
	Hourly precipitation variability (all seasons)			✔
	Hourly precipitation extremes (all seasons)			✔

Table 1 Advice on which set of projections to use for temperature and precipitation metrics based on capabilities of Global Climate Model (GCM), Regional Climate Model (RCM) and Convection-Permitting Model (CPM) to simulate present climate and their similarities in projected future changes. Further details on the reasons for the differences between the regional and local projections are available in Kendon et al (2019).

		Global (60km)	Regional (12km)	Local (2.2km)
	General usage considerations	Use where exploration of a wider range of future outcomes is more important than spatial detail (some exceptions, e.g. winter mean precipitation)	Use where improved representation of extremes or spatial detail is more important than exploring a wider range of future outcomes.	
				• Enhanced local resolution but needs to be balanced against larger data processing overheads • Hourly and 3-hourly data • Generally better agreement with observations
Other Metrics	Humidity (relative and specific)	Available but not evaluated against observations		
	Radiation (net long/short wave)	Available but not evaluated against observations		
	Lightning			Not available Further evaluation required before use
	Snow		Use with caution	Use with caution Less sophisticated treatment of lying snow than RCM
	Soil moisture	Use with caution	Use with caution	Use with caution Better agreement with proxy for observed soil moisture
	Total cloud cover	✔	✔	✔ Better agreement with observations than RCM
	Wind (direction, speed, gust)	Available but not evaluated		

Table 2 Advice on which set of projections to use for metrics other than precipitation and temperature, based on capabilities of GCM, RCM and CPM to simulate present climate and their similarities in projected future changes. Further details on the reasons for the differences between the regional and local projections are available in Kendon et al (2019).

Not all the variables mentioned in Table 1 and Table 2 are available through the UKCP User Interface and Centre for Environmental Data Analysis (CEDA) Data Catalogue as some were produced only to understand the benefits of using the CPM over the RCM.

3. What do you need to be aware of before using the Local (2.2km) projections?

As with the regional projections, before using the local projections, you need to be aware of the following:

- The local projections sample a narrower range of potential future outcomes compared to the full set of global projections. In particular, the regional climate models only downscale 12 members of the PPE-15 (and are in turn downscaled using the CPM) and none of the CMIP5-13. If you would like to explore other potential futures, consider using the EURO-CORDEX multi-model regional climate model simulations (see www.euro-cordex.net).
- Unlike the regional projections (as well as global and probabilistic projections), the local projections do not sample the uncertainties in which the climate model represents climate processes (i.e. parameter uncertainties). So, the local projections generally provide a narrower range of future outcomes than the regional projections, although there are exceptions (e.g. for winter rainfall – see Kendon et al (2019)).
- While the finer resolution adds spatial detail, the benefit comes from being able to simulate smaller scale atmospheric processes as well as the effects on the climate of geographical features such as coastlines and orography (i.e. hills and mountains).
- For information on convective events (which includes both intense storm events that we typically experience in the UK summer and winter time convective showers) and associated hourly variability, you should use the local projections, which provide a better representation of convective processes. However, there will be biases in the climate models even when moving to kilometre-scale resolutions (see Kendon et al, 2017). Further guidance on correcting these biases is available at UKCP18 guidance: Bias Correction (Fung, 2018).
- We have evaluated the convection-permitting model underpinning the local projections for a number of variables and metrics (see Kendon et al, 2019) but work is continuing to understand the climate model further.
- It is important to evaluate the model's ability to downscale the variables and metrics of interest compared to observations, particularly if the core evaluation work described in Kendon et al (2019) does not cover them. This informs the level of credibility for the projected changes at local scales.
- A set of variants of the Met Office Hadley Centre Model, HadGEM3-GC3.05 (PPE-15), is used to drive the regional climate models. It is clear that the these models tend to sample the warmer end of the future response range projected by the probabilistic projections. The global projections also include climate models that fed into the IPCC's 5th assessment report (CMIP5-13) and these sample the mid-range and colder end – with some limited overlap in the middle. This is consistent with recent research into a HADGEM3 model version (GC3.1), to which the UKCP18 GC3.05 versions of the model are closely related, having an equilibrium climate sensitivity (ECS) above the likely end of the current IPCC range, and higher than the CMIP5 set of models. In the IPCC's 5th Assessment, ECS was judged to have a "likely" range of 1.5-4.5°C (Collins et al, 2013), and that there is a small probability (of up to 10%) that ECS exceeds 6°C.
- While high-resolution downscaling adds value to climate projections provided by their driving models, the regional and convection-permitting models do not, in general, correct large-scale biases inherited from global simulations.

‡ ECS is an important characteristic of climate models. It is the amount of warming that can be expected in response to the concentration of carbon dioxide in the atmosphere reaching double the level observed in pre-industrial times. However, potential users should note that the projected response over the UK has a wider spread in both GC3.05 and CMIP5 projection sets and the degree of overlap of the sets.

4. What data are available and where can you find them?

The local projections are additional datasets that sits alongside the UKCP18 suite of information available through the UKCP website, UKCP User Interface (UI) and CEDA Data Catalogue. Note that the latter requires the technical skill to analyse large datasets.

Table 3 and Table 4 summarise the UKCP18 datasets available over land and you can find technical details in UKCP18 Guidance: availability, access and formats. Similar datasets are available as the regional projections but the local projections provide:

- Sub-daily information (temperature and precipitation at hourly intervals and wind variables at 3-hourly intervals)
- Additional variables – snowfall amount, lying snow amount and wind gusts
- 20-year-long continuous time series only (1981-2000, 2021-2040 and 2061-2080) rather than a time series from 1981-2080[§].

All climate model datasets from the UKCP18 projections are available as raw model output on the original grid used in the simulations through the CEDA Data Catalogue. Regridded data on the Ordnance Survey's British National Grid (OSGB) are available through the UKCP User Interface and the CEDA Data Catalogue.

For the local projections, the original grid climate model gridded data at 2.2km spatial resolution has been regridded to 5km resolution for the OSGB grid (see UKCP18 Guidance: Data Availability, Access and Formats for further details of regridding method). This slightly coarser resolution was chosen as

- the regridded product is designed for those who are less familiar with using climate model information and the associated large datasets.
- the 5km OSGB grid is consistent with the observational datasets with which users are already familiar.
- the 5km resolution is a more robust way to view the output from the 2.2km model, i.e. a single 2.2km grid square should not be used in isolation.
- there were time constraints - providing data at the 2.2km resolution would have lengthened the regridding by about four times.

UKCP Local (2.2km) provides the most spatially detailed picture of future climate for the mainland UK. However, due to the proximity of the Shetland Isles to the northern boundary of the model domain used for these projections, data produced here is not reliable and should not be used. This is because at the edge of the model domain the projections are influenced by the techniques required to drive the model at its boundaries, which prevent Local (2.2km) from developing its own climatology over Shetland.

UKCP Local (2.2km) is just one of the tools available in the UKCP suite that provide national climate change information. We advise using the alternate tools to access future climate data over the Shetland Islands. For example, the Regional (12km) projections use a much larger European model domain which places the northern boundaries much further north. Shetland is represented at a 12km resolution and is free from any boundary issues.

[§] There are plans to update the dataset such that it becomes a continuous time series

We do not provide lightning data. Initial results suggests that the CPM overestimates lightning in winter but performs better in summer in terms of representing the UK-average occurrence rate, but with potential deficiencies in the spatial distribution of lightning. Before we can recommend use of this output, further work is needed to evaluate the lightning output from the CPM and understand the causes of any deficiencies. See Kendon et al (2019) for further information.

Observed datasets are available from the CEDA Data Catalogue. Further details can be found at https://www.metoffice.gov.uk/research/climate/maps-and-data/data/haduk-grid/datasets.

Although not produced in time to contribute to the UKCP18 project, you can find hourly rainfall datasets (CEH-GEAR1hr) from the Environmental Information Platform at https://catalogue.ceh.ac.uk/documents/d4ddc781-25f3-423a-bba0-747cc82dc6fa.

Dataset	Emissions scenarios	Time period	Geographical domain
Probabilistic projections	RCP2.6, RCP4.5, RCP6.0 RCP8.5, SRESA1B	1961-2100	UK
Global (60km) projections	RCP8.5	1900-2100	UK, Global
Regional (12km) projections	RCP8.5	1981-2080	Europe, UK
Local (2.2km) projections*	RCP8.5	1981-2000, 2021-2040 2061-2080	UK
Derived (60km) projections	RCP2.6, 2°C world, 4°C world	1900-2100	UK

Table 3 Summary of UKCP18 climate models and scenarios for projections over land.

Variable at the surface (short name in data file)	Units	Probabilistic	‡ Global (60km)	Regional (12km)	Local (2.2km)	Derived
Cloud cover (clt)	%	✔	✔	✔	✔	
Precipitation (pr)	mm/day, mm/hour	✔	✔	✔	✔ hourly	✔+
Radiation, total downward short wave flux (rsds)	W/m²	✔				
Radiation, net long wave (rls)	W/m²	✔	✔	✔	✔	
Radiation, net short wave (rss)	W/m²	✔	✔	✔	✔	
Relative humidity (hurs)	%		✔	✔	✔	✔
Snow: snowfall amount	mm/day			✔	✔	
Snow: lying snow amount	mm/day			✔	✔	
Specific humidity (huss)		✔	✔	✔	✔	
Temperature, maximum (tasmax)	°C	✔	✔	✔	✔	
Temperature, mean (tas)	°C	✔	✔	✔	✔ hourly	✔+
Temperature, minimum (tasmin)	°C	✔	✔	✔	✔	
Wind gust	m/s				✔ 3-hourly	
Wind speed (sfcWind)	m/s		✔	✔	✔ 3-hourly	✔
Wind speed eastwards (uas)	m/s		✔	✔	✔	✔
Wind speed northwards (vas)	m/s		✔	✔	✔	✔
Time steps *		Monthly, Seasonal, Annual, 20/30-year means	Daily, Monthly, Seasonal, Annual, 20/30-year means (and subdaily for some variables)			

Table 4 Available UKCP18 variables for the projections over land on the UKCP User Interface (UK-only) and CEDA Catalogue.
* Seasonal, annual, 20 and 30-year (not for Local (2.2km)) means are available over the UK only.
+ Only daily precipitation and temperature are available for the derived projections.
‡ Not all variables are available for CMIP-13 (see UKCP18 Guidance: Data Availability, Access and Formats).

5. What examples are there for using the results of convection-permitting models?

Examples of the use of convection-permitting models include

- Using the input to calculate your design drainage uplifts (e.g. UKWIR (2017) that looked at using a similar climate model at the 1.5km spatial resolution to calculate uplifts for sewer drainage).
- Using more realistic, climate model variables that reflect the diurnal cycle to feed into your weather files (e.g. demonstration project by Eames et al, 2018).
- Analysing the urban heat island effect, e.g. Argüeso et al (2014) used a convection-permitting model to look at the effect of future urban expansion on local near-surface temperature for Sydney, Australia.
- Calculating future river flows and groundwater levels at the catchment scale for the UK, e.g. Rudd et al (2019), Kay et al (2015) who used a similar climate model at the 1.5km spatial resolution to simulate peak flows.
- Understanding projected land use changes (Ritchie et al, 2019) and the suitability of habitat for forest management in mountainous areas in Scotland (e.g. demonstration project by Petr et al, 2018).
- Investigating the impact of summer heat extremes in the future (e.g. Kershaw et al, 2010).
- Combining with the global, regional and local projections to understand the effects of large-scale drivers at the local scale (e.g. Palin et al, 2016).

6. How will this affect climate allowances issued by regulatory bodies?

We understand that many UKCP18 users will be interested in how the local projections (and wider UKCP18 products) may affect the climate allowances such as peak rainfall and peak flood issued by regulatory bodies (Environment Agency, Scottish Environment Protection Agency, Natural Resources Wales and Northern Ireland Environment Agency). These have not been calculated as part of UKCP18 but work is underway by the Environment Agency to investigate the implications of the local projections as well as the wider UKCP18 suite of data. The research community, in collaboration with the Met Office, is also investigating the use of UKCP18 products to revise guidance on uplifts for drainage design, e.g. the UK-Research-and-Innovation-funded FUTURE-DRAINAGE project.

Potential applications of the local projections are explored in the demonstration project leaflets that set out pathways to arrive at information required for urban drainage design and surface water flood assessment (Norman et al, 2018 and Old and McLay, 2018). The pathways require significant additional work and evaluation. An example of such a study using the results of one simulation of a Met Office 1.5km convection-permitting model is set out in UKWIR (2017).

7. Is there substitute information available for the UKCP09 weather generator?

A weather generator has not been provided in UKCP18. If you are interested in the effects of sequences of events and multiple variables, daily data is available from the regional, local projections and the derived projections. In UKCP18, we have chosen to provide data from a physically-based modelling system that is capable of accounting for potential changes in the relationship between changes in basic characteristics of climate (such as the long-term average) and changes in daily or sub-daily extremes.

For example, the weather generator provided hourly information, but this was based on application of basic climate change factors to observational data, thus neglecting potential effects of changes in the characteristics of sub-daily variability (Jones et al, 2010). In UKCP18, we provide hourly data (for temperature and precipitation) based on physically-based models which provide more realistic data on how weather changes through the day.

The UKCP09 weather generator also provided stochastic information as long time series that supported applications where annual exceedance probabilities were required. While it generated time series of 10,000 years that enabled calculation of 100 year return periods, users were warned that return periods longer than 10 years should be used with caution as they would be predicated on a stationary climate (Jones et al, 2010). Should you require stochastic information, the global and regional projections provide climate metrics (e.g. mean sea level pressure to calculate North Atlantic Oscillation index) that you could use to build a weather generator for your location and metric of interest.

8. What if you need information for other emissions scenarios?

If you need information for emission scenarios other than RCP8.5[**], then you need to use the probabilistic projections (available for RCP2.6, RCP4.5, RCP6.0 and SRESA1B) or the derived projections (available for RCP2.6 and global warming levels of 2°C and 4°C).

Higher resolution datasets for emissions scenarios other than RCP8.5 are not available in the UKCP18 dataset. If you require information for additional emissions scenarios, there are methods that exist in the literature that scale the patterns of future change for different emissions scenarios as a function of global mean temperature. Similar to the derived projections, strong assumptions are made and you need to consider these before applying these methods. Some studies have found that large scale, annual to seasonal temperature and precipitation can be characterised robustly but the method could be limited when applying to finer resolution (spatial and temporal) as well as for extremes and for locations where the change in climate can be non-linear (Tebaldi and Arblaster, 2015).

[**] Note that the "RCPs" are not strictly emission scenarios but the term is used here for brevity - further information on emissions scenarios and RCPs can be found in UKCP18 Guidance: Representative Concentration Pathways.

9. Where can you find more information?

As well as the non-technical summary in the UKCP18 Convection-permitting model projections: Science report (Kendon et al, 2019), we recommend that you read the UKCP18 Science Overview (Lowe et al, 2018) to understand the different components of the projections.

For a comprehensive description of the underpinning science, evaluation and results for the other strands of the UKCP18 suite of information, see the UKCP18 Land Science Projections Report (Murphy et al, 2018).

Further information and guidance is available at the UK Climate Projections website.

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Appendix A
Comparing the Convection and Regional Climate Models

Phenomenon	CPM improved present-day biases?	CPM different future changes?	Understanding of CPM-RCM projection differences and implications for reliability
	✓ (improved) or ✗ (made worse) or ~ (similar) compared to RCM-PPE	+ (enhanced) − (weakened) or ~ (equivalent) compared to RCM-PPE	Where projections differ, key processes represented differently in CPM, and implications for reliability (✓, ✗ or ■ unknown) - denotes similar projections
Temperature			
Winter mean temperature	✓ Reduced cold bias in north and reduced warm bias in south in CPM.	− Smaller increase in CPM over Scotland. ~ Similar increases elsewhere.	Differences in N likely related to missing graupel in the snowpack and different snow scheme in CPM, which lead to much less lying snow in the present-day and a smaller decrease in lying snow in the future in the CPM. ■ Reduced temperature biases in present-day, but treatment of lying snow less sophisticated in CPM. Both CPM and RCM projections plausible, but deficiencies in both cases.
Summer mean temperature	✓ CPM is warmer, with reduced biases except in S.	~ Similar increases	- Reduced biases in present-day likely related to less cloud in CPM, but future changes driven by large-scale warming seen by both models.
Cold winter days	✓ Reduction of cold bias in N in CPM.	− Smaller increase in temperature in CPM in N.	(See above for winter mean temperature) ■ Reduced temperature biases in N in present-day, but treatment of lying snow less sophisticated in CPM. Both CPM and RCM projections plausible, but deficiencies in both cases.
Hot summer days	✓ Biases reduced in N in CPM ✗ CPM too hot in S.	~ Similar increases in temperature	- Models have different present-day biases, but future changes dominated by large-scale warming seen by both models.
Cold spells	✓ Reduced biases in the number of intense cold spells in N in CPM (with too many in RCM).	− Smaller decrease in frequency of intense cold spells in N in CPM	(See above for winter mean temperature) ■ Reduced biases in present-day, but treatment of lying snow less sophisticated in CPM. Both CPM and RCM projections plausible, but deficiencies in both cases.
Hot spells	✓ Reduced biases in the number of hot spells in S in CPM (with too few in RCM).	~ Similar increase in frequency of hot spells	- Models have different present-day biases possibly related to drier soils in CPM, but future changes dominated by large-scale warming seen by both models.

Phenomenon	CPM improved present-day biases?	CPM different future changes?	Understanding of CPM-RCM projection differences and implications for reliability
	✓ (improved) or ✗ (made worse) or ~ (similar) compared to RCM-PPE	+ (enhanced) − (weakened) or ~ (equivalent) compared to RCM-PPE	Where projections differ, key processes represented differently in CPM, and implications for reliability (✓, ✗ or ■ unknown) − denotes similar projections
Precipitation			
Winter mean precipitation	✓ Reduced wet bias in CPM.	+ Substantially greater increase in CPM	Improved representation of daily precipitation occurrence in explicit convection model, with greater increase in precipitation occurrence in the future. Large-scale processes common to both models also driving increases in mean precipitation. ✓ Increased confidence in CPM projections due to improved representation of daily variability, but more work needed to understand present-day biases and the relevance of these for future changes.
Summer mean precipitation	✓ Reduced wet bias in CPM, except in S.	~ Similar decreases in mean + Enhanced changes in underlying frequency and intensity in CPM	− Similar changes in mean precipitation. Improved representation of daily rainfall occurrence in CPM, linked to better representation of convective processes, so increased confidence in CPM projections of changes in frequency/intensity components.
Heavy daily events in winter	✓ Improved biases over mountains in CPM (where RCM underestimates heavy events).	~ Similar increases in intensity of heavy events.	− Higher resolution and explicit convection in CPM improves precipitation intensity, especially over mountains. However future changes in daily precipitation intensity are driven by large-scale changes captured by both models.
Heavy daily events in summer	~ CPM overestimates and RCM underestimates intensity of heavy events	+ Greater tendency for increase in summertime rainfall intensity in CPM	CPMs give better representation of convection, but tendency for heavy events to be too intense is known bias in CPMs due to convection not being fully resolved. RCM tends to underestimate heavy events due to deficiencies in convection parameterisation. ✓ CPM better represents convective processes, but further research is needed to establish the importance of known biases in the heaviest events for future projections.
Hourly precipitation variability (all seasons)	✓ RCM rainfall is too frequent and low intensity, with biases improved in CPM. ✓ CPM better captures afternoon peak in convection.	+ Enhanced changes in hourly rainfall occurrence in CPM + Greater increase in summer rainfall intensity in CPM ~ Similar increase in intensity in winter and autumn	Improved representation of hourly rainfall characteristics in explicit convection model; although convection not fully resolved resulting in heaviest events being too intense. ✓ Improved realism of hourly rainfall in the CPM gives us greater confidence in CPM changes. RCM projections of hourly precipitation change considered unreliable.
Hourly precipitation extremes (all seasons)	~ CPM overestimates the intensity of hourly extremes, but better represents the rate at which extremes increase with increasing return period.	~ Similar increases in 2yr return level − Smaller increases in CPM for 10yr (and longer) return level in autumn and winter	Convection-parameterised model underestimates intensity of moderate extremes, and has unphysical grid point storms leading to high values >100mm/h in the far extreme tail. Explicit convection gives more realistic extremes, but overestimates intensity due to convection not being fully resolved. ✓ CPM projections plausible, but further work needed to understand the importance of known biases for future projections. RCM projections for hourly precipitation extremes considered unreliable.

Table B Summary of present-day biases and future changes in CPM-12 compared to RCM-PPE, and our understanding of the model differences (after Table 5.1 in Kendon et al, 2019).

Appendix B
Figures from UKCP18 Guidance: How to use the Land Projections

How to choose the most appropriate land projection

New to climate projections?

See What do you want to do? on UKCP18 website

Looking for headline messages?

See Key results on UKCP18 website

Carrying out detailed analysis?

Select strand(s) of land projections based on task

Task	Probabilistic	Global (60km)	Regional (12km)	Local (2.2km)	Derived
Assess broadest range of future outcomes from UKCP18	●				
Stress-test results		●	●	●	●
UK-Focus					
Compare UKCP09 with UKCP18	●				
Scenario: Assess across all RCPs in AR5	●				
Scenario: Assess across high and low emissions	●	●+			●+
Scenario: Assess for high emissions only	●	●	●	●	
Scenario: Assess 2°C or 4°C world					●
Time: Analyse monthly and longer time-steps	●	●	●	●	●
Time: Analyse daily and longer time steps		●	●	●	●
Time: Analyse sub-daily and longer time steps				●	
International-Focus					
Assess (imported) risks across Europe		●	●		
Assess (imported) risks across the globe		●	●		
Assess at multiple locations where spatial coherence is important		●	●	●	●
Analyse large scale drivers of climate and weather		●	●		
Assessments where local-scale effects important for climate			●	●	
Assess daily rainfall extremes in the summer				●	
Assessments where sub-daily information is required				●	
Develop storylines of climate drivers to local impact		●	●	●	●
Assess daily rainfall extremes in the summer				●	
Assessments where subdaily information is required				●	

+ To assess RCP8.5 and RCP2.6 both Global and Derived Projections are required.

Consider bias-correction. See How to Bias Correct.

Carry out your analysis. See demonstration projects.

Place in context of probabilistic

Consider evaluating model output for your application

Figure B.1 Schematic for choosing the most appropriate UKCP18 land projections data for the task (based on Figure 3 of UKCP18 Guidance: How to use the UKCP18 land projections)

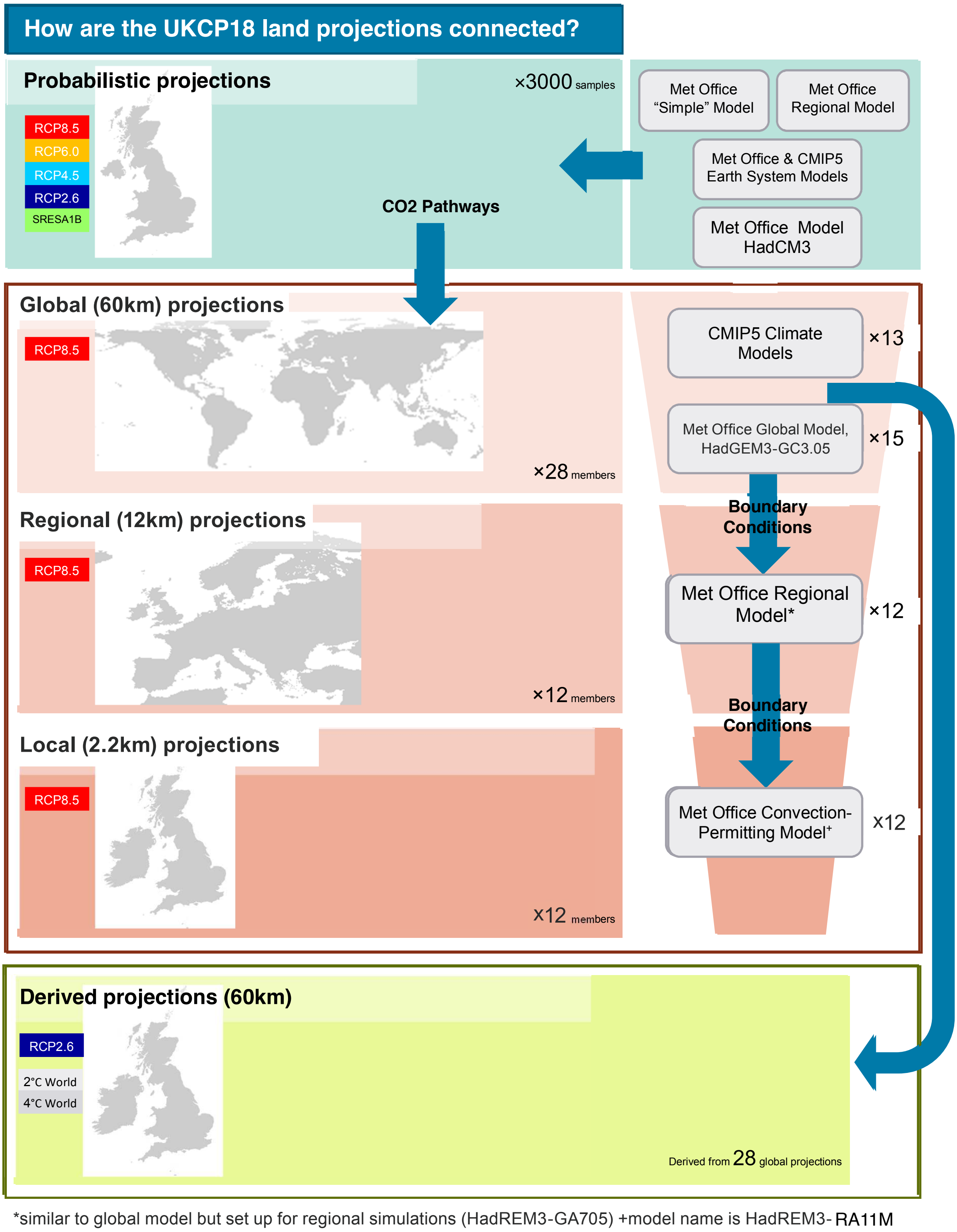

Figure B.2 Schematic showing how the different components of the land projections are connected based on Figure 2 of UKCP18 Guidance: How to use the UKCP18 land projection

