Department for Environment Food & Rural Affairs
Department for Business, Energy & Industrial Strategy
Met Office Hadley Centre
Environment Agency

UKCP18 Guidance: How to use the UKCP18 land projections

This document places the use of climate projections in the context of risk analysis and aims to help you navigate the different components of the UKCP18 land projection with examples of how you can use them. It covers:

1. Using climate model projections
2. Why are there multiple strands of information?
3. What should you be aware of before using the land projections?
4. What is the relationship between the sets of land projections?
5. How do you choose the appropriate UKCP18 projections?
    - 5.1 When should you use the probabilistic projections?
    - 5.2 When should you use the global (60km) projections?
    - 5.3 When should you use the regional (12km) and local (2.2km) projections?
    - 5.4 When should you use the derived projections?
6. How do the UKCP18 land projections relate to UKCP09?
7. How do you access the data and get further information?

1. Using climate model projections

- Together with observations, projections can be used as one source of information when planning for the future or as a communication tool.
- When planning for the future, you may wish to carry out a climate change risk assessment. This needs to takes into account the hazard, exposure, vulnerability and how they interact with each other (see Figure 1). Climate model projections and observations only inform one aspect of this interaction, i.e. the climate component of the hazard.
- Your approach to climate change risk assessment and how it informs decision-making informs whether, how and which climate model projections that you use.
- This document assumes that you have already established your approach and wish to better understand the information that the UKCP18 land projections could potentially offer to inform the climate-related hazard.

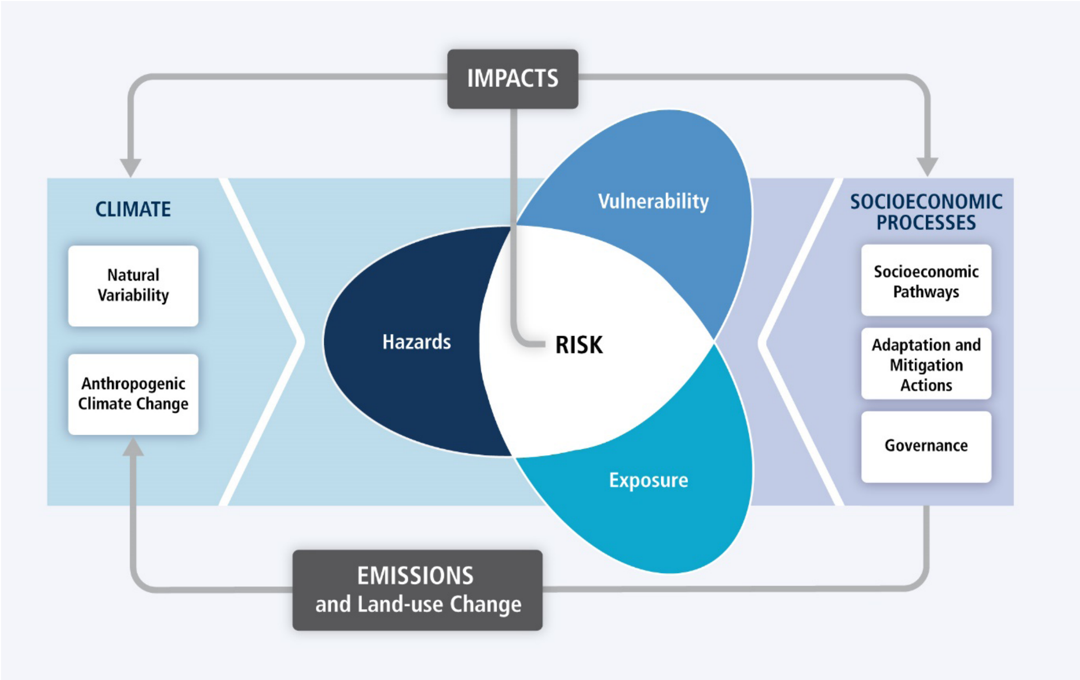


Figure 1. Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems (from Figure 19-1 of IPCC, 2014).

The latest Working Group II report from the Intergovernmental Panel on Climate Change states that "climate-related risks arise from the interaction of the evolving exposure and vulnerability of human, socio-economic, and biological systems with changing physical characteristics of the climate system" (IPCC, 2014). In UKCP18, we provide our understanding on how the climate system may evolve in the future based on current observations and modelling. We focus on providing information to help characterise the climate-related hazard, which only contributes to one part of multi-faceted climate-related risk assessment or decision making.

The uncertainty in how future socioeconomic processes will evolve also exist for future climate and can present a challenge when making long-term investment decisions. A number of resources have been developed to assist organisations in their adaptation planning (e.g. UKCIP, 2013) and you are advised to consult these resources before embarking on using the UKCP18 suite of data, guidance and reports. As part of your adaptation strategy, you will have chosen an approach to making your decision or "decision making framework" which will inform how you treat the uncertainty and the use of climate model projections.

There are a number of possible approaches to decision making robust to future climate (and other) changes and inherent uncertainty which are summarised by Hallegate et al, (2012) as follows:

- **Cost-benefit analysis** under uncertainty where expected benefits are based on the beliefs on the likelihood of different future climates. Although Hallegatte et al, (2012) warns that that this may be difficult with large uncertainties.
- **Real options** which considers when to invest rather than whether to invest and values flexible strategies that can adapt to future new information. For example, Woodward et al, (2014) who use the UKCP09 probabilistic projections (as well as the sea level rise data) to inform flood risk management in the Thames Estuary. Note that as with the cost-benefit analysis, this method relies on beliefs of likelihood of different future climates.

- **Climate informed-decision analysis** (or "scenario-neutral approach" or "decision scaling") where the focus is on understanding the vulnerabilities of a system by carrying out a sensitivity analysis, exploring scenarios that may not be sampled by model projections. Note that climate projections are not ignored but are only considered where they may add value to the analysis. See Prudhomme et al, (2010) for an example on UK river flooding and the UKCP18 demonstration project on water resources and drought (Counsell et al, 2018).
- **Robust decision-making** which evaluates adaptation options by analysing multiple uncertainties in parallel (e.g. climate, economic technological). See Matrosov et al, (2013) for an example on robust decision making and Info-Gap for a water supply system.

In this document, we do not recommend any particular decision-making framework but present information on UKCP18 land projections data to support your analysis. We present a decision-tree to help you navigate through the information in the document, a table of the available data and how to access it, examples of how others have used similar information in other studies and also what you should be aware of before using the data.

2. Why are there multiple strands of information?

The suite of information available in UKCP18 reflect current advances in climate science and address the information needs of different audiences. In short, the characteristics of the land strands are as follows (Table 1 provides a more detailed summary of the characteristics of each land strand):

<table>
<tr><th colspan="4">UKCP18 Projections over land</th></tr>
<tr><th>Probabilistic projections</th><th>Global (60km) projections</th><th>Regional (12km) projections</th><th>Local (2.2km) projections</th></tr>
<tr><td rowspan="3">probabilistic uncertainty assessments
similar set of variables as in UKCP09
presented at seasonal timescales</td><td colspan="3">wide range of daily variables and metrics
analysis at different geographical locations simultaneously</td></tr>
<tr><td rowspan="2">large scale extremes information
analysis back to 1900
information on international risks that could impact on the UK
analysis of drivers of climate change at the global scale
Derived projections available for lower emissions scenario and global warming levels for a limited number of variables and metrics over the UK</td><td colspan="2">enhanced spatial detail
improved simulation of extremes on daily and shorter timescales</td></tr>
<tr><td>analysis of drivers of climate change at the European scale</td><td>sub-daily information
information on high-intensity (convective) rainfall processes</td></tr>
</table>

	Probabilistic projections	Global (60km) projections	Regional (12km) and Local (2.2km) projections	Derived projections
Description	Probabilistic changes in future climate based on a assessment of model uncertainties	A set of 28 climate futures with detailed data on how it may evolve in the 21st century ▪ 15 x Hadley Centre Model variants HadGEM3-GC3.05 (PPE-15)‡ ▪ 13 x Other climate models (CMIP5-13)‡	Two sets of 12 climate futures at high resolution: ▪ 12km over Europe, downscaled from the global projections (PPE-15) using Hadley Centre model HadREM3-GA705 ▪ 2.2km for the UK, providing further downscaling from the 12km simulations using HadREM3-RA11M	A set of climate futures derived from the global projections for a lower emissions scenario and global warming levels
Period	1961-2100	1900-2100	1981-2080 for 12km 1981-2000, 2021-2040, 2061-2080 for 2.2km	1900-2100
Temporal resolution	Monthly Seasonal Annual	Daily Monthly Seasonal Annual	Subdaily for 2.2km Daily Monthly Seasonal Annual	Daily Monthly Seasonal Annual
Spatial resolution	25km	60km	12km 2.2km	60km
Geographical extent	UK & regions	UK & regions Global	UK & regions Europe for 12km	UK
Emissions scenarios	RCP2.6 RCP4.5 RCP6.0 RCP8.5 SRES A1B	RCP8.5	RCP8.5	RCP2.6 2°C world 4°C world
Why should you use it?	▪ Explores emissions scenario uncertainty ▪ Explores uncertainty in key processes in climate models ▪ Helps characterise future extremes in risk assessment	▪ Long time series ▪ Spatially and temporally coherent* ▪ Direct access to 'raw' climate model data ▪ Met Office Hadley Centre global climate model HadGEM3-GC3.05	▪ Enhanced spatial detail ▪ Spatially and temporally coherent* ▪ Improved extremes ▪ Direct access to 'raw' climate model data ▪ CPM projections uses climate model featuring explicit dynamical representation of large convective storms	▪ Long time series ▪ Spatially and temporally coherent* ▪ Explore emissions scenario uncertainty when used with global projections ▪ Explore global warming levels

Table 1. A summary of the key characteristics of each of the three strands of information for the UKCP18 land projections. *spatial coherence is important when analysing climate risks at different geographical locations at the same time and if there is physical connection between the climate characteristics at these locations, e.g. national assessments. ‡ Go to https://ukclimateprojections.metoffice.gov.uk for further detail on the PPE-15 and CMIP5-13.

3. What should you be aware of before using the land projections?

The probabilistic, global and regional projections that comprise the UKCP18 land projections are derived from climate models which approximate the real climate system. Hence there are systematic differences between climate model results and observations (i.e. biases). In addition, climate models neglect unknown effects of missing earth system processes. While the combined evidence of UKCP18 covers a broad range of potential future climate pathways, it remains possible that observed future changes could lie outside the envelope of these. Future generations of climate models will be developed that reflect improved scientific capabilities and understanding, potentially leading to a requirement to update the UKCP18 projections resulting in new, and potentially different, advice.

The probabilistic projections

We have designed the probabilistic projections to provide the primary tool for assessments of the ranges of uncertainties in UKCP18. For a given emissions scenario, they provide information on known uncertainties in future climate changes. In particular, the aim is to represent uncertainties consistent with the knowledge incorporated in existing ensembles of climate model projections, plus the effects of internal climate variability. They are derived from a statistical framework that supports the formal application of observational constraints and estimation of the relative likelihood of specific outcomes. However, we emphasise that they are conditional on the knowledge, data, methods and subjective choices used to construct them. As such, they should not be confused with (for example) probabilistic weather forecasts, which can be assessed in a frequentist sense through repeated trial and verification (e.g. Hamill, 1997). Other researchers could arrive at different results if they made different choices. For a more detailed discussion see Section 2.1 of the Land Projections Science Report, (Murphy et al, 2018).

The probabilistic projections typically show broader ranges of outcomes than the global and regional projections. This enables assessments across a larger set of climate futures than relying on a small set of future outcomes, e.g. only using the climate models from the Climate Model Intercomparison Project (CMIP5) that fed into the 5th Assessment Report from the Intergovernmental Panel on Climate Change.

The probabilistic format should not be misinterpreted as an indication of high confidence in the weight of evidence behind specific outcomes. That is, future developments in our physical understanding of climate change drivers and improvements in climate modelling capability could lead in the future to revised projections giving different probabilities for changes in UK variables. The probabilistic projections should be seen as a source of broad guidance that forms a useful starting point for risk assessments.

The global, regional, local and derived projections

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. These projections provide storylines of climate futures that you can use to develop case studies, stress-test your system and decision options. You can also use the global and regional projections to build confidence in your use of the data, by providing opportunities to explain the future outcomes that they represent. For example, the global model provides information on large-scale drivers that affect the patterns of weather that we experience in the UK. Drivers include the Atlantic meridional overturning circulation, a large system of ocean currents that carries warm water from the tropics northwards into the North Atlantic.

Due to computational expense, only RCP8.5 is available for the global and regional projections using Met Office models. The derived projections provide:

- A lower emissions scenario, RCP2.6, without running a climate model and using pattern-scaling and time-shifting techniques.
- The UK climate response to global temperature increases of 2°C and 4°C above pre-industrial levels.

These are derived from both the Met Office Hadley Centre's global climate model (HadGEM3-GC3.05) and CMIP5 model members. The approach is described in more detail in the UKCP18 Derived Projections Report, (Gohar et al, 2018). Note that a smaller number of variables are available. The derived projections introduces additional uncertainties and assumptions and should be considered as having a lower confidence than the actual, unscaled, climate model outputs. See the guidance on the Caveats and Limitations and the Derived Projections report.

We recommend that you place any analysis using the global, regional and derived projections in the broader uncertainty context of the probabilistic projections, where the information is available. As mentioned above, common to all climate models, the results will contain biases and you may wish to adjust the data for these (i.e. carry out bias correction). You can find guidance on how to bias correct at the UKCP18 website.

For UKCP18, we aim to provide not only results for future climate changes but also evaluation and deeper understanding of the behaviour of the climate models. This provides information on how well the UKCP18 suite of models capture past and present climate as well as the possible causes for the modelled future outcomes. We have captured our understanding so far in the Science Overview, Land Projections and factsheets. However, we continue to analyse the climate models to further our understanding and will be publishing results in forthcoming peer-reviewed papers. These will be highlighted on the UKCP18 website and we encourage you to contribute to the increasing understanding.

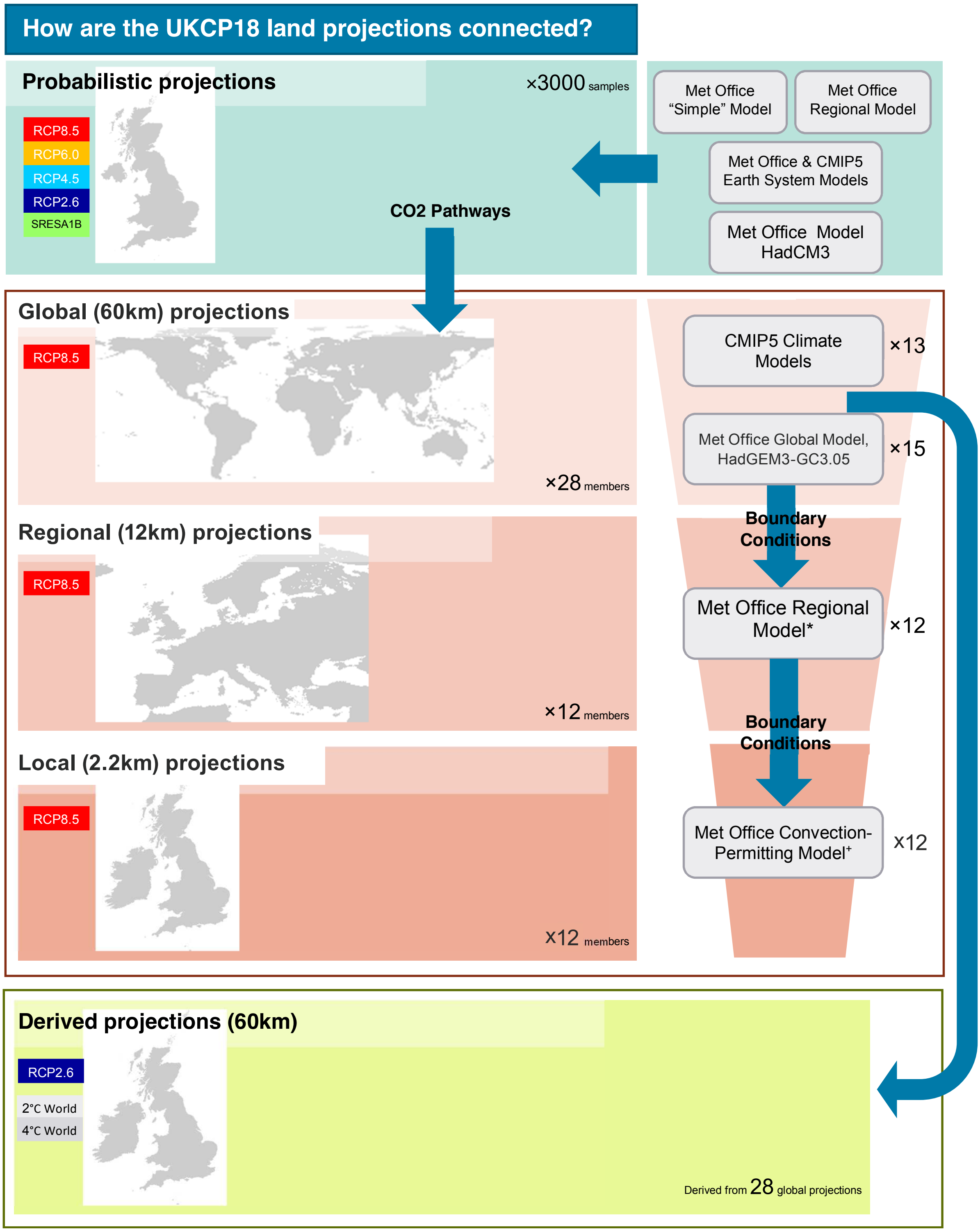
4. What is the relationship between the sets of land projections?

Each of the sets of land projections address different user requirements and many may wish to use multiple products. The probabilistic, global and regional projections are linked through (i) their use of observations (ii) their use of CMIP5 models and (iii) the probabilistic projections that provide the CO_2 concentrations for the PPE-15 global modelling (see Figure 2). The derived projections are calculated from the global projections.

Of the strands of information, the probabilistic projections provide information on the largest range of future emissions scenarios (RCP2.6, RCP4.5, RCP6.0, RCP8.5 and SRESA1B) and generally provide the broadest range of future climate outcomes in the suite of UKCP18 land projections.

The global projections provide a set of future climate outcomes for RCP8.5 only. The range of results cover a large fraction of the range from the probabilistic projections. Do note that they sometimes show results outside of this range (see Murphy et al, 2018). 15 of the 28 global projections use CO_2 pathways from the probabilistic projections. This subset, PPE-15, uses one of the Met Office Hadley Centre's (MOHC) global climate models, HadGEM3-GC3.05. 13 of the 28 (CMIP5-13) have been selected from the climate model simulations that informed the IPCC 5th assessment (CMIP5). These two subsets evolve into two semi-distinct clusters, during the second half of the 21st century. Out of the global projections, the PPE-15 provides most of the warmest future outcomes for the UK particularly after 2050. The PPE-15 also provides the strongest reductions in precipitation for England and Wales. This clustering doesn't occur for winter precipitation changes with both subsets showing a gradual increase.

The global projections are used as input into the MOHC's latest regional climate model to provide the twelve regional projections at 12km. Only 12 of the PPE-15 are available due to factors including the availability of High Performance Computing resources and model performance in the historical period (see section 4.3 of Murphy et al, 2018). The regional projections are used as input into a very high resolution (convection-permitting) climate model at 2.2km resolution.



*similar to global model but set up for regional simulations (HadREM3-GA705) +model name is HadREM3-GARA11M

Figure 2. Schematic showing how the different components of the land projections are connected.

The UKCP18 probabilistic projections are an update to those in UKCP09 and address the continued requirement for a product exploring uncertainties. They are intended to support future climate risk assessments and context for applications reliant on output from projection systems containing more limited sampling of uncertainties (such as the global and regional projections).

The global, regional and derived projections are more flexible datasets than the probabilistic projections and offer data for those who prefer to work directly with climate model output. They can support a wide range of impacts studies and provide data with full spatial and temporal coherence and a wider range of variables (that are physically consistent) and time resolutions. These are important for applications requiring assessment of multiple drivers of changing hazards. As stated above you may wish to adjust the data for the systematic differences between climate model results and observations (i.e. carry out bias correction) before conducting an impacts study.

For further details about the science underpinning the projections please see the UKCP18 Science Overview (Lowe et al, 2018) and UKCP18 Land Projections (Murphy et al, 2018).

5. How do you choose the appropriate UKCP18 projections?

This will depend on your application (see Figure 3) and you should consider:

- If your primary need is access to estimates of uncertainty in climate variables, the probabilistic projections should be your main source of information. They provide an estimate of the probability associated with a given level of climate change, subject to the caveats listed in this document. They also provide a percentile range that covers a given level of risk aversion. These levels or "ranges" can be compared qualitatively against various vulnerabilities in your system of interest. As stated earlier, if your decision is sensitive to relative likelihood or focused heavily on specific probability levels, you should test the sensitivity of your results.
- If you are carrying out an impacts study and interested in looking at weather events that have length of days rather than months that affect different geographical locations simultaneously then use the global and regional projections.
- If you are interested in exploring futures that are outside of the 10^{th}-90^{th} percentiles of the probabilistic projections, there may be some global, regional or CPM projections that exhibit this behaviour for certain variables that you could use. You may also consider searching for an alternative source, such as other climate model projections not included in UKCP18.
- Whether the variables and time frequency (e.g. daily) that you are interested is available in a particular strand of information. For example, wind direction is only available for the global and regional projections and hourly to 3-hourly information is only available from the CPM projections.
- Whether you wish to use a combination of more than one set of projections for some applications. For example, you may require a more complete understanding of uncertainty (from the probabilistic projections) to provide a probability context for impacts derived from the global or regional projections. Alternatively, a case study may require selection and understanding of a specific large-scale circulation event from the global projections. You can then combine this with the regional projections to derive local impacts such as flood risk at the river-basin scale.

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 3. Schematic for choosing the most appropriate UKCP18 land projections data for the task.

5.1 When should you use the probabilistic projections?

You should use the probabilistic projections if you are interested in:

- Exploring a broad set of future outcomes within the 10^{th}-90^{th} percentile range provided by the UKCP18 probabilistic projections.
- Exploring the four emissions scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5.*
- Future changes at one geographical location, i.e. not multiple geographical locations simultaneously.
- Carrying out a comparison study with UKCP09 using the SRES A1B emissions.
- Placing the global and regional projections in context of the broader set of possible outcomes available from the probabilistic projections.

For example, you may wish to...

- Carry out a robust risk assessment for your system (e.g. CCC, 2017).
- Construct weather files for input into your building simulation models (e.g. demonstration project by Eames and Mylona, 2018).
- Overlay the probabilistic projections on response surfaces that show the vulnerabilities of specific systems or sectors to climate change (e.g. demonstration project by Counsell et al, 2018; Kay et al, 2013).
- Downscale the probabilistic projections for impacts studies (e.g. change in fluvial flood risk (Kay and Jones, 2012 – note that they suggest assessing more than one of the UKCP09 products: probabilistic projections, weather generator and regional climate models), perhaps in conjunction with direct use of the climate model output from the global or regional projections.
- Construct your own weather generator (e.g. Jones et al, 2010).

In addition to the points outlined in section 3, before using the probabilistic projections you need to be aware of the following:

- The probabilities are estimates based on climate models, expert judgement, observational evidence and the statistical methodology used to produce them.
- They are conditional upon the inputs outlined above.
- They are not estimates of the likelihood of real world outcomes.
- They may not capture all possible future outcomes.
- If your decision is sensitive to relative likelihood or focused heavily on specific probability levels, you should test the sensitivity of your results, i.e. explore the consequences of using values above and below the probability level interest.

* 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.

- When using the data you should bear in mind that:
  - They are location specific and lack the full spatial coherence available from raw climate model output.
  - There is no daily data. The shortest averaging period is monthly.
  - The pre-prepared visualisations have a fixed baseline of 1981-2000. However, you have the option of creating alternative baselines for use in their applications.

5.2 When should you use the global projections?

You should use the global projections if you are interested in:

- Analysing climate at multiple geographical locations at the same time should there be a physical connection between the climate characteristics at these locations, e.g. assessing climate change impacts on the rail network across the whole of the UK (note that some may prefer the enhanced spatial detail offered by the regional projections). Note that the global projections may not sample a broad a range of outcomes as the probabilistic projections and do not enable estimates of relative likelihood.
- Using daily data and being able to calculate a larger set of metrics than that available in the probabilistic projections.
- Analysing drivers and impacts of year-to-year variability. The probabilistic, global, regional and local projections all include information on interannual variability. In addition, the global projections support analysis of physical and dynamical processes (e.g. conditions in the North Atlantic and the state of the Arctic) that give rise to the climate variability experienced over the UK. The global and regional projections also support investigation of the resulting high-impact events.
- Exploring future outcomes across MOHC's (PPE-15) and other models from international climate modelling centres (CMIP5-13). Note that we do not prefer any particular set of projections and treat both similarly.
- Combining with the probabilistic projections to look at projections that explore the extremes of the distribution, e.g. you could use the PPE-15 to explore unlikely but plausible heat-related impacts in summer climate or the CMIP5-13 for unusually cool future seasons.
- Geographical regions outside of the UK and Europe. Note that the regional projections also includes Europe.
- Providing large scale or historical context for regional changes (note that the regional projections cover the North Atlantic and Europe only, the local projections cover the UK only and both start in 1981). For example, see UKCP Factsheet on Weather Types or consult section 3.4b of the UKCP18 Land Projections Science Report on weather types.
- Exploring the impacts over the UK of the RCP8.5 emissions scenario. However, some may prefer the enhanced spatial detail offered by the regional projections. If you are interested only in the UK, then you may wish to consider the derived projections that provide the RCP2.6 emissions scenario and changes projected at two specific global warming levels (2°C and 4°C) – see section 5.4.

For example, you may wish to use them for:

- Stress-testing your system and decision options as some members of the global projections explore ranges outside of the probabilistic projections for some variables.
- Large-scale impact studies across the whole of the UK and where very fine spatial detail may not be important, e.g. large-scale spatial patterns of droughts by Rahiz and New (2013).
- Impacts studies in other parts of the world such as developing weather files for buildings simulations as discussed in demonstration project by Eames and Mylona (2018).
- Developing statistical models such as a weather generator to support stochastic analyses as discussed in demonstration project (Counsell et al, 2018).
- Developing narratives of alternative climate evolutions that reference the large-scale drivers of climate change, as reported by (Hazeleger et al, 2015) in the Netherlands.
- Combining with the regional projections to understand the effects of large-scale drivers such as relating the North Atlantic Oscillation to winter disruption of transport systems (see Palin et al, 2016).

Before using the global projections, you need to be aware of the following in addition to those outlined in section 3:

- The combined set of 28 projections is not designed to support estimates of the relative likelihood of alternative future climate pathways. They cover a broad range of outcomes but do not provide as broad an assessment of uncertainties as the probabilistic projections.
- We use two sets of model projections: 15 variants of the MOHC's HadGEM3-GC3.05 model (PPE-15) and a selection of the CMIP5 models (CMIP5-13). The global projections explore process uncertainties through parameter perturbations for PPE-15 and through variations in structural choices for model components for CMIP5-13.
- To analyse future outcomes that are indicated by the probabilistic projections but not available in the global projections, you may consider a number of approaches. These include sourcing additional climate model simulations form the wider CMIP5 dataset (subject to further evaluation), or use of statistical techniques or impacts models driven by climate changes sampled from the probability distributions.
- If you choose to sub-select from the 28-member set for your analysis, do this with caution, ensuring that you are able to justify your selection.
- If evaluation of the variable or metric of interest is not available in the UKCP18 reports and guidance, ensure that you carry out your own evaluation against observations before using the data.
- There are systematic differences between model results and observations (biases) common to all climate models. You may wish to adjust the data for the differences between climate model results and observations (i.e. carry out bias correction). You can find guidance on how to bias correct at the UKCP18 website.
- We recommend that you place them in the context of the probabilistic projections where the variables or metrics are available.

- An important characteristic of climate models 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, also known as the equilibrium climate sensitivity (ECS). The 21st century warming levels from the global projections for RCP8.5 using HadGEM3-GC3.05 suggest that they are likely to have ECS values above 4.5°C. 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.
- The UKCP18 factsheets on the available variables provide additional information on specific caveats and limitations as well as information on how confident we are with the results available on the UKCP18 website.

5.3 When should you use the regional and local projections?

In addition to the benefits outlined in section 5.2, you should use the regional and/or local projections if you are interested in:

- Applications where local scales are essential, as the regional and/or local projections better represent local effects due to land elevation, coastlines and surface characteristics, as well as providing improved resolution of dynamical features such as mesoscale circulations and frontal systems.
- Improved simulation of extremes with higher temporal variability (e.g. daily, subdaily).
- Extremes that explore future outcomes outside of the 90th percentile of the probabilistic projections (e.g. changes in long-term average precipitation showing large increases in winter in some western coastal regions).

For example, you may wish to:

- Calculate future river flows and groundwater levels at the catchment scale for the UK (e.g. Prudhomme et al, 2013).
- Understand the suitability of habitat for forest management in mountainous areas in Scotland (e.g. demonstration project by Petr et al, 2018).
- Investigate the impact of summer heat extremes in the future (e.g. Kershaw et al, 2010).
- Combine with the global projections to understand the effects of large-scale drivers at the local scale (e.g. Palin et al, 2016).

Before using the regional projections, you need to be aware of the following in addition to those outlined in sections 3 and 5.2:

- The regional and/or local projections sample a narrower range of potential future outcomes compared to the full set of global projections. In particular, they only downscale 12 members of the PPE-15 and none of the CMIP5-13. If you would like to explore other potential futures, consider using the EURO-CORDEX (https://euro-cordex.net/) multi-model Regional Climate Model simulations.
- You need to weigh the benefits of fuller range of sampling available from the probabilistic projections, or the global projections, against the benefits of finer resolution available from the regional climate model.

- While the finer resolution adds spatial detail, the benefit comes from the being able to simulate smaller-scale atmospheric processes as well as the effects on the climate of geographical features such as coastlines and orography.
- For information on summer convective storms (intense storm events that we typically experience in the UK summer) and the associated short-term precipitation events, you should use the local projections, which provide a better representation of convective processes. As mentioned previously, there will be biases in the climate models even when moving to kilometre-scale resolutions (see Kendon et al, 2017).
- We have evaluated the regional model underpinning the regional projections for a number of variables and metrics (see Murphy et al, 2018 and UKCP18 Factsheets) but work is continuing to understand the climate models further.
- It is important to evaluate the level of downscaling skill for variables and metrics of interest, particularly if the core evaluation work does not cover them (see UKCP18 Land Science Report or Factsheets). 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 is used to drive the regional climate models. The levels of warming in these (PPE-15) simulations suggest that most members possess values of climate sensitivity (the equilibrium response to a doubling of CO2) above 4.5ºC, lying outside the IPCC likely range of 1.5-4.5ºC, but below the IPCC unlikely level of 6ºC.
- While high-resolution downscaling adds value to climate projections provided by their driving models, the regional models do not, in general, correct large-scale biases inherited from global simulations.
- For further information on the Local (2.2km) projections and how they compare to the Regional (12km) projections, see UKCP Factsheet: Local (2.2km) Projections.

5.4 When should you use the derived projections?

You should use the derived projections if you are interested in:

- Exploring the impacts over the UK of the RCP2.6 emissions scenario and/or changes projected at two specific global warming levels (2°C and 4°C).
- The reasons for using the global projections (see Section 5.2).

However, the derived projections:

- support analyses over the UK only.
- do not provide information on large scale drivers.
- have a smaller number of monthly and daily variables available (see guidance on Data Availability, Access and Formats).
- involve using statistical methods based on the global projections, and therefore involve additional caveats (see UKCP18 Derived Projections Report (Gohar et al, 2018) and guidance on Caveats and Limitations (Fung et al, 2018).

6. How do the UKCP18 land projections relate to UKCP09?

The UK Climate Projections published in 2009 (UKCP09) provided the following products for land areas:

- Probabilistic projections over land at 25km grid resolution.
- 11-member perturbed physics regional climate model set at 25km grid resolution.
- 11 "Spatially Coherent Projections" derived from the 11-member regional climate model ensemble and scaled to achieve a better representation of the wider set of outcomes included in the UKCP09 probabilistic projections.
- Weather generator (and associated threshold detector).

We have updated the probabilistic projections and provided a new set of regional climate model projections. See Table 2 for a summary of the key differences between UKCP09 and UKCP18.

UKCP09 provided a Weather Generator which is a tool for generating long synthetic series of daily climate variables. This was used for risk analysis of impacts that depend upon the sequence of weather conditions (e.g. river flows and plant growth). It also provided a convenient tool for statistical analysis of the joint effects of multiple climate variables. A Weather Generator has not been provided in UKCP18. If you are interested in the effects sequences of events and multiple variables will be able to use outputs from the regional, local and the derived projections.

Note that the methods used to produce the probabilistic projections are similar to those used in UKCP09. We have updated them using additional climate models (e.g. Met Office Hadley Centre and CMIP5 earth system models) as well as more recent observations. The probabilistic projections in UKCP18 are presented at the monthly, seasonal and annual time steps, whereas their UKCP09 counterparts were only available for 30-year average changes. You can find a detailed description of the method in section 2.2 of the Land Projections Science Report.

Product	UKCP09	UKCP18
Probabilistic projections	25km in rotated pole grid* Administrative regions and river basins	25km in Ordnance Survey's British National Grid+ Countries, administrative regions and river basins
	Monthly, seasonal, annual	Same
	30-year averages	30-year averages and monthly time series
	SRESB2 (low) SRESA1B (medium) SRESA1FI (high)	SRESA1B RCP2.6, RCP4.5, RCP6.0, RCP8.5
	10,000 samples	3,000 samples
Regional climate models	25km in rotated pole grid* Daily time series	60km global projections 12km regional projections over Europe 2.2km local projections over UK
Spatially coherent projections	25km in rotated pole grid* 30-year averages	No longer available. Replaced by spatially coherent ▪ 60km global projections ▪ 12km regional projections over Europe ▪ 2.2km local projections over UK
Weather generator	Daily and hourly	No longer available. Replaced by ▪ Daily from global and regional climate models ▪ Hourly from regional 2.2km climate model

Table 2. Summary of characteristics of UKCP09 and UKCP18 products. Key updates are in bold. *The rotated pole grid is the same coordinate system used in UKCP09 + See Ordnance Survey (2018) for further details.

7. How do you access the data and get further information?

You can find key messages, maps and graphs for the land projections on the UKCP18 website. Factsheets are also available that summarise the key findings for the available variables.

Further details about the results, methods, evaluation and limitations are available in the UKCP18 Science Overview (Lowe et al, 2018), UKCP18 Land Projections (Murphy et al, 2018), UKCP18 Derived Projections (Gohar et al, 2018), and CPM Projections (Kendon et al, 2019) reports.

You can download and view the land projections data over the UK on the UKCP18 User Interface. The full dataset over the whole globe (for the 60km model), Europe (for the 12km model) and the UK (for the 2.2km model) at the CEDA Data Catalogue: note that this requires familiarity with handling large datasets. Note that the UKCP18 Marine Projections are also available through these data portals.

Observational datasets are also available for use alongside the land projections (see State of the UK Climate Report (Kendon et al, 2018) and UKCP18 guidance on Data Access, Availability and Formats guidance for further information). As described in earlier sections, climate model results contain systematic differences from observations (i.e. biases). More information on these are in the UKCP18 factsheets as well as the science reports (Murphy et al, 2018; Palmer et al, 2018). You may wish to adjust for these differences before using the data and can find an introduction to this in the UKCP18 guidance "How to Bias Correct".

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