Making probabilistic climate projections for the UK

Exeter University

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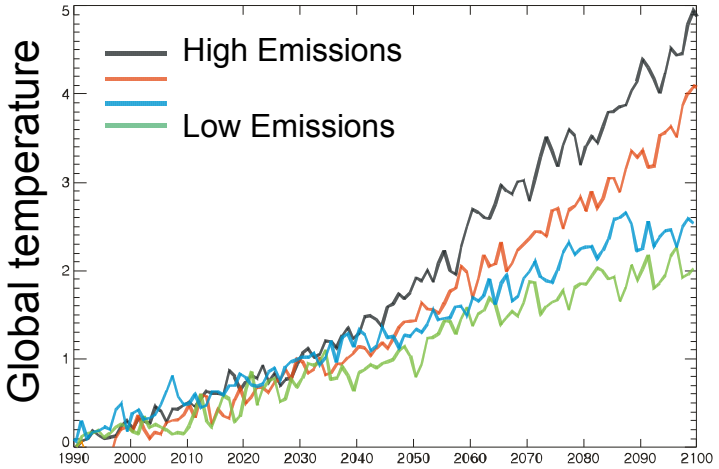
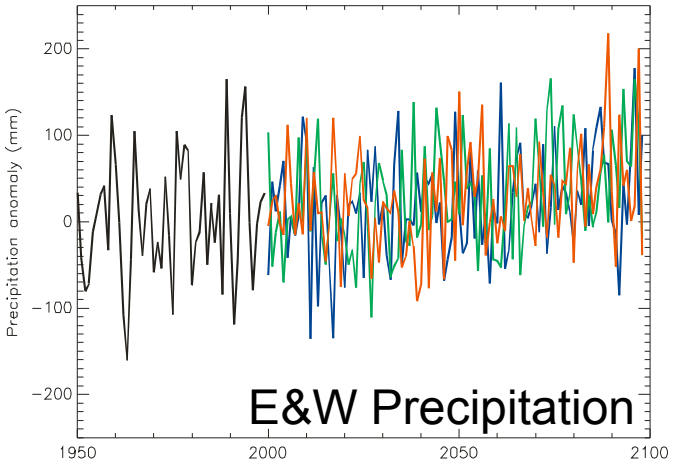
Met Office Hadley Centre
2nd Feb 2010

Cannot be certain about future climate because…

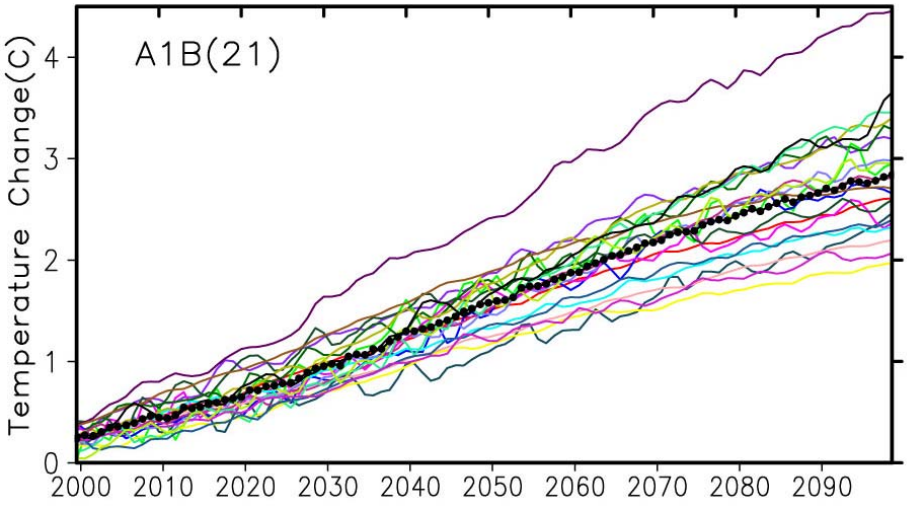
1 Emissions uncertainty



2 Natural variability



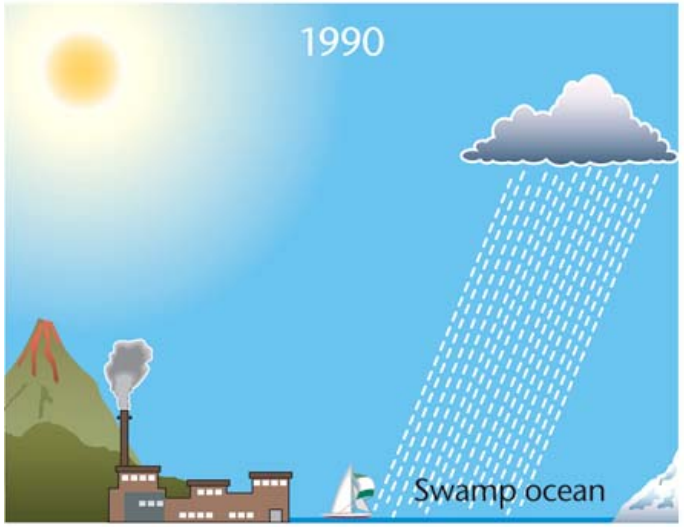
3 Modelling uncertainty – due to our incomplete understanding of climate processes and inability to model them perfectly.

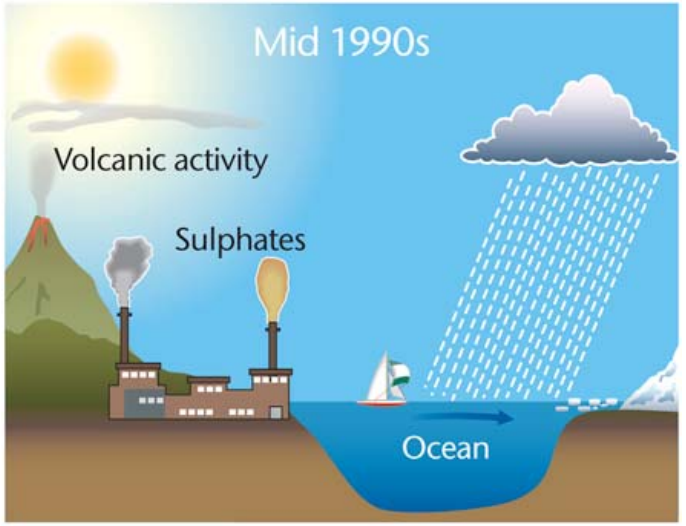


Different IPCC AR4 models

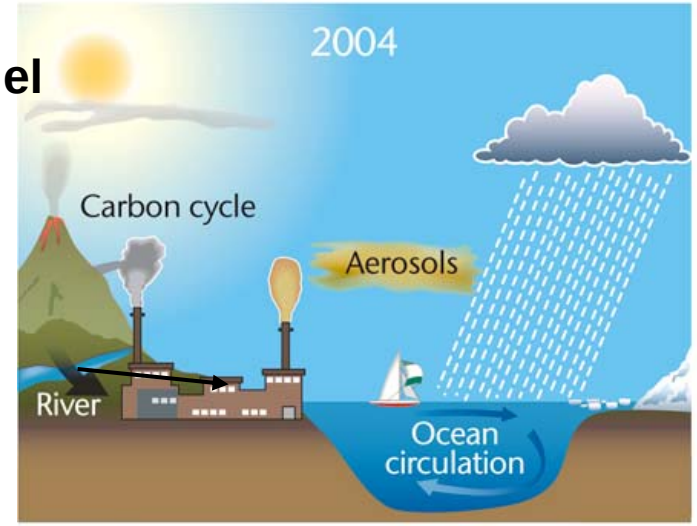
Climate models

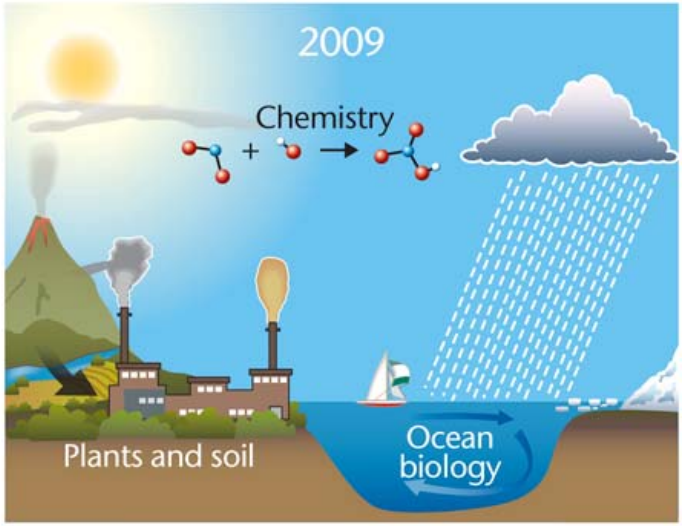
Slab ocean





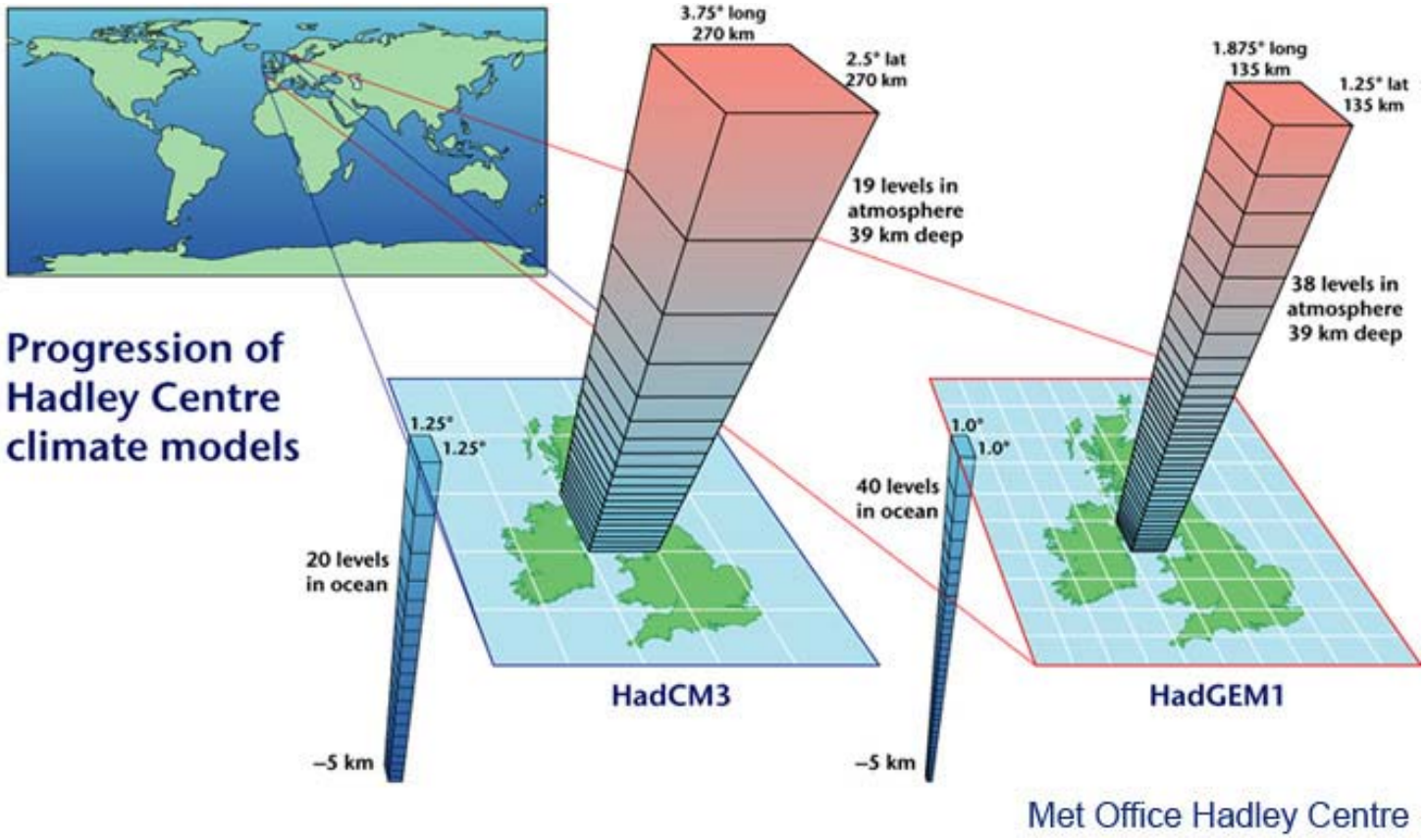
Coupled model





Met Office Hadley Centre adapted from IPCC

Climate modelling



Sub grid-scale processes

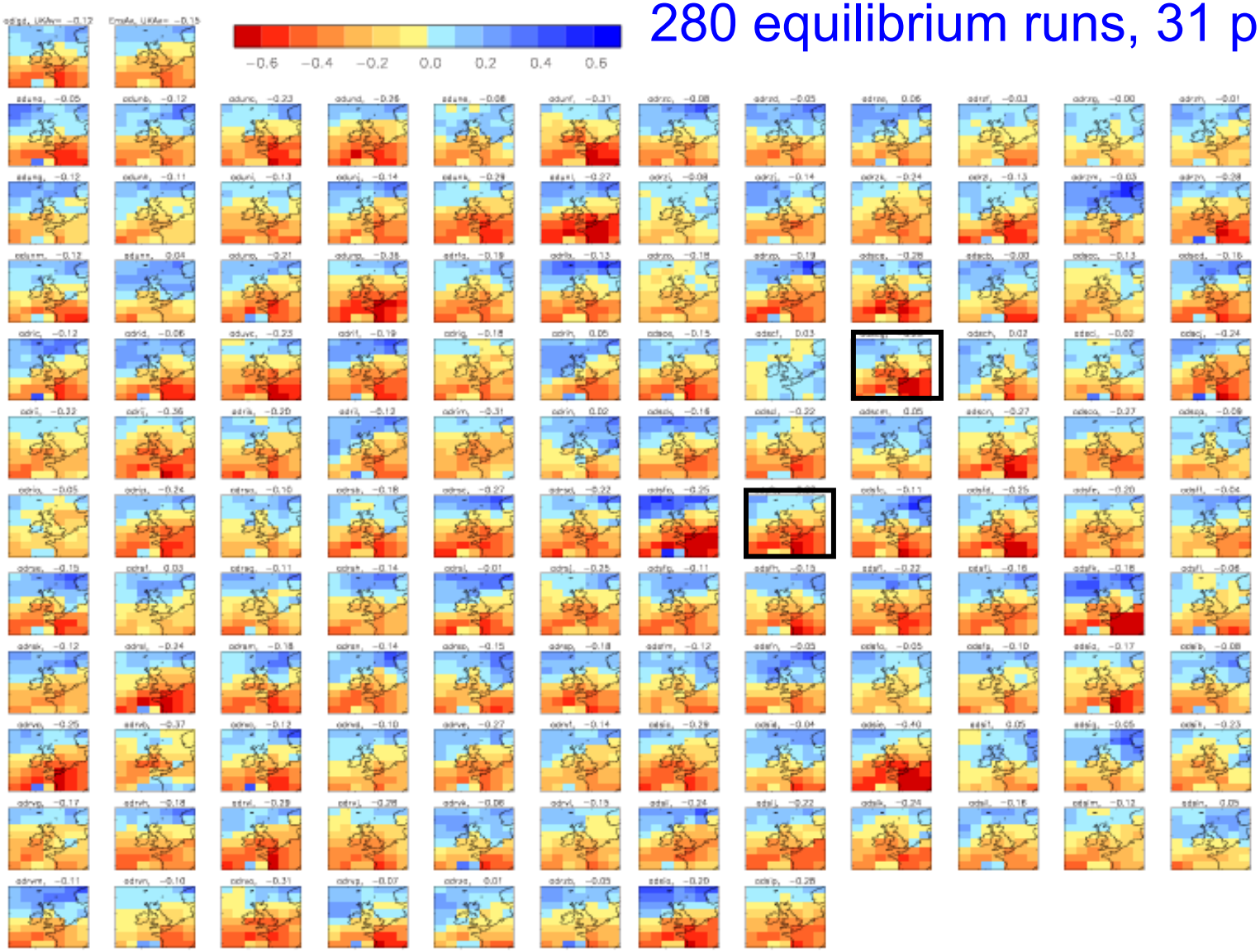
- “Parameterization” refers to the method of using a simplified process to replace processes that take place at scales below the gridbox scale
- Simplified processes are calculated as functions of the grid-scale variables and some controlling numbers called “parameters”
- These parameters are uncertain

Perturbed physics ensemble

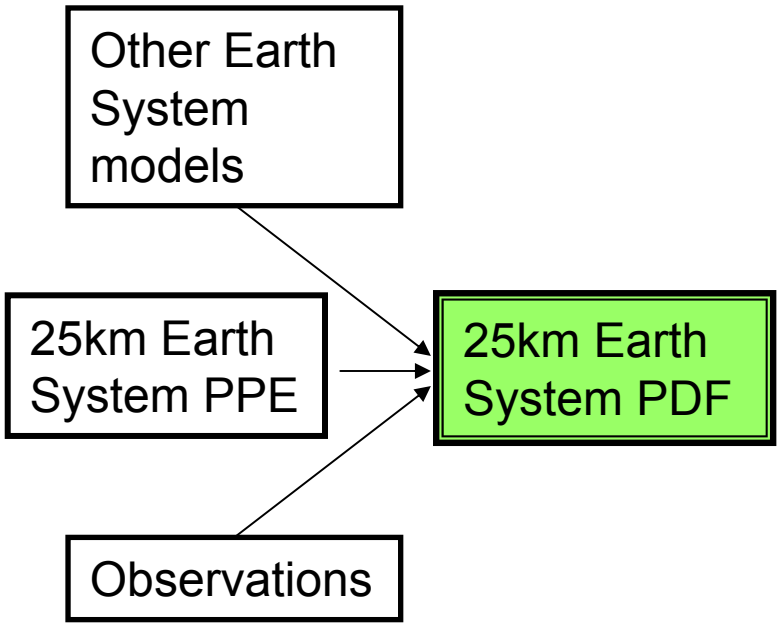
- There are plenty of different variants of the climate model that are as good if not better than the standard tuned version
- But their response can be different to the standard version
- Cast the net wide, explore parameter space with view to finding pockets of good quality parts of parameter space and see what that implies for uncertainty

Perturbed physics ensemble

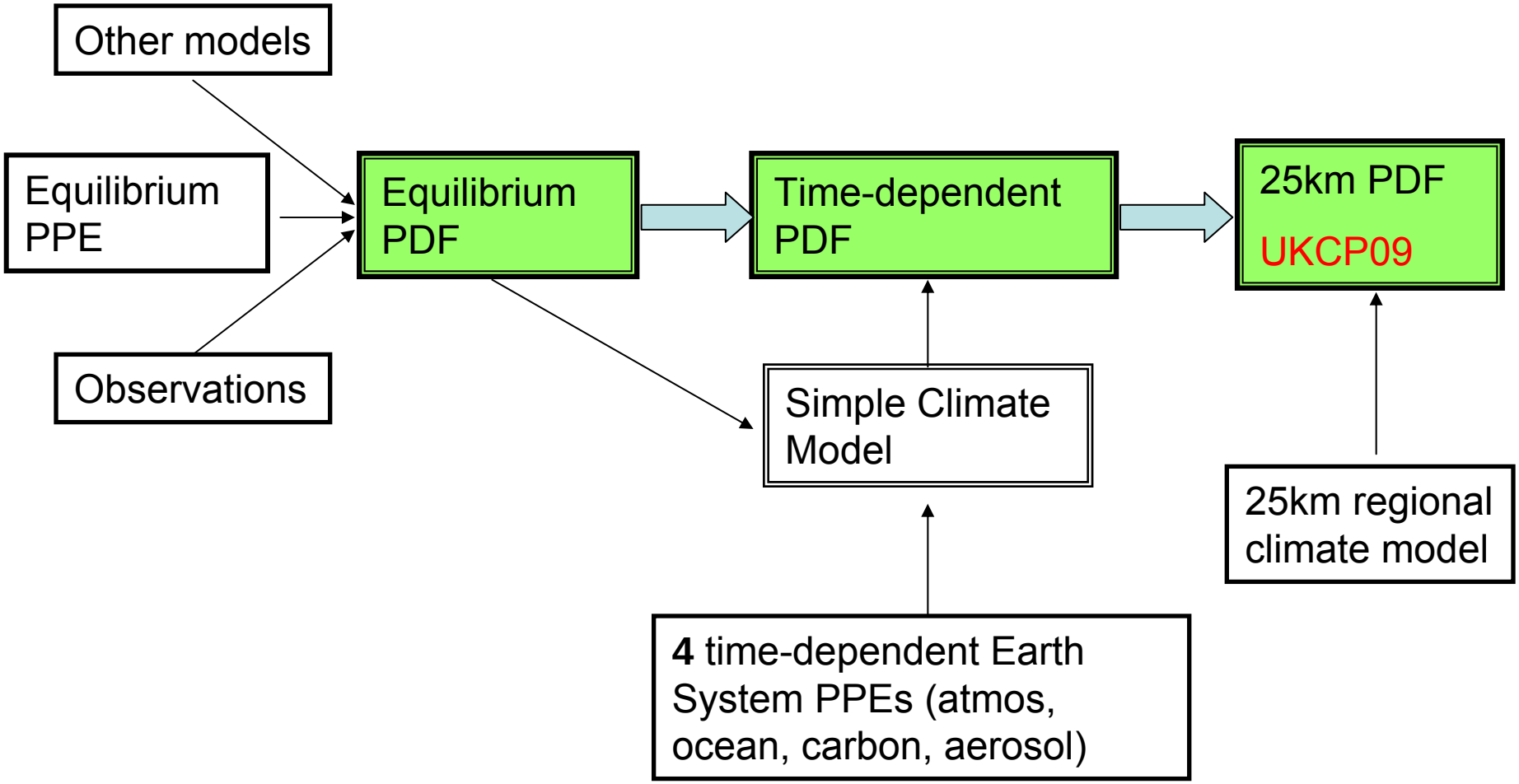
280 equilibrium runs, 31 parameters



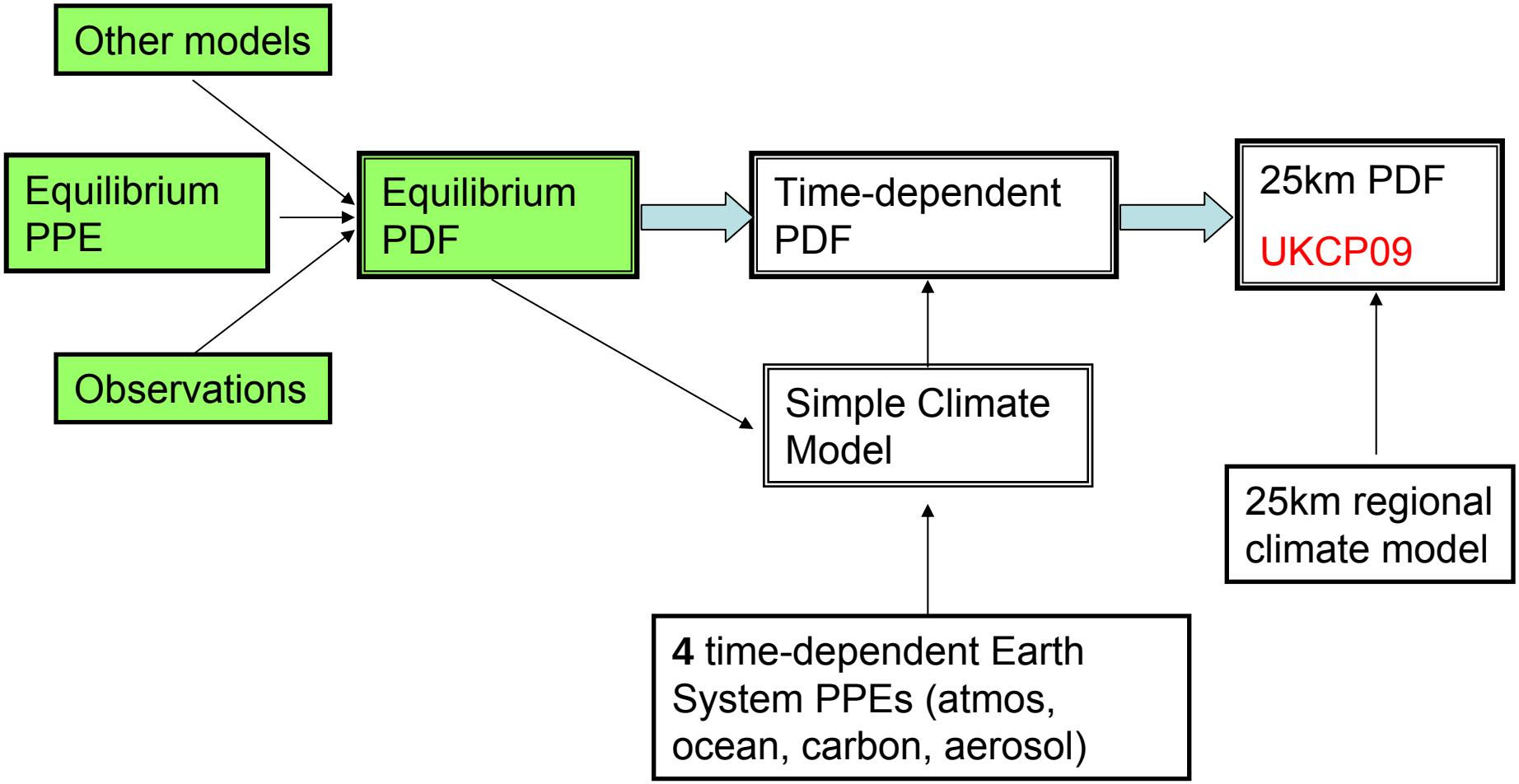
Ideal experimental design



Production of UKCP09 predictions



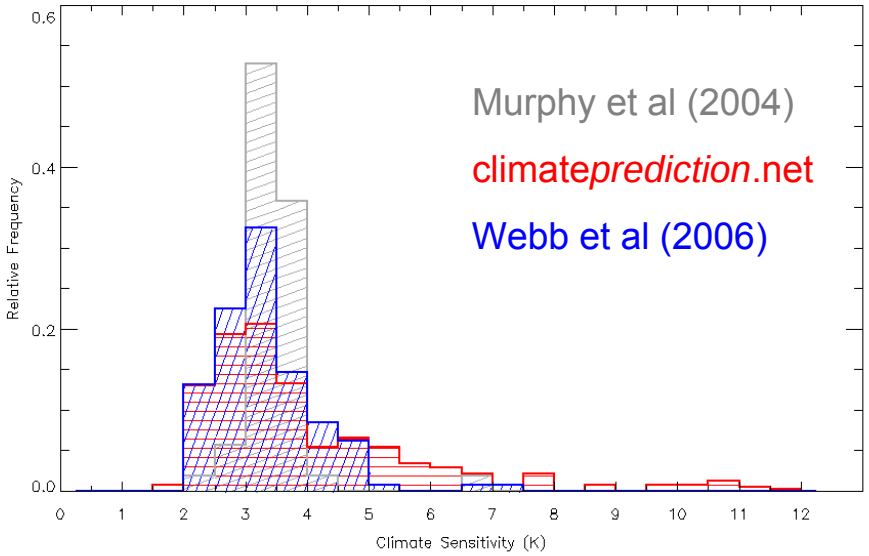
Stage 1: Uncertainty in equilibrium response



Bayesian prediction – Goldstein and Rougier

- Aim is to construct joint probability distribution p(X, m_h , m_f ,y,o,d) of all uncertain objects in problem.
    - Input parameters (X)
    - Historical and future model output (m_h,m_f)
    - True climate (y_h,y_f)
    - Observations (o)
    - Model imperfections (d)
- Probability here is a measure of how strongly a given value of climate change is supported by the evidence (model projections, observations, expert judgements informed by understanding)

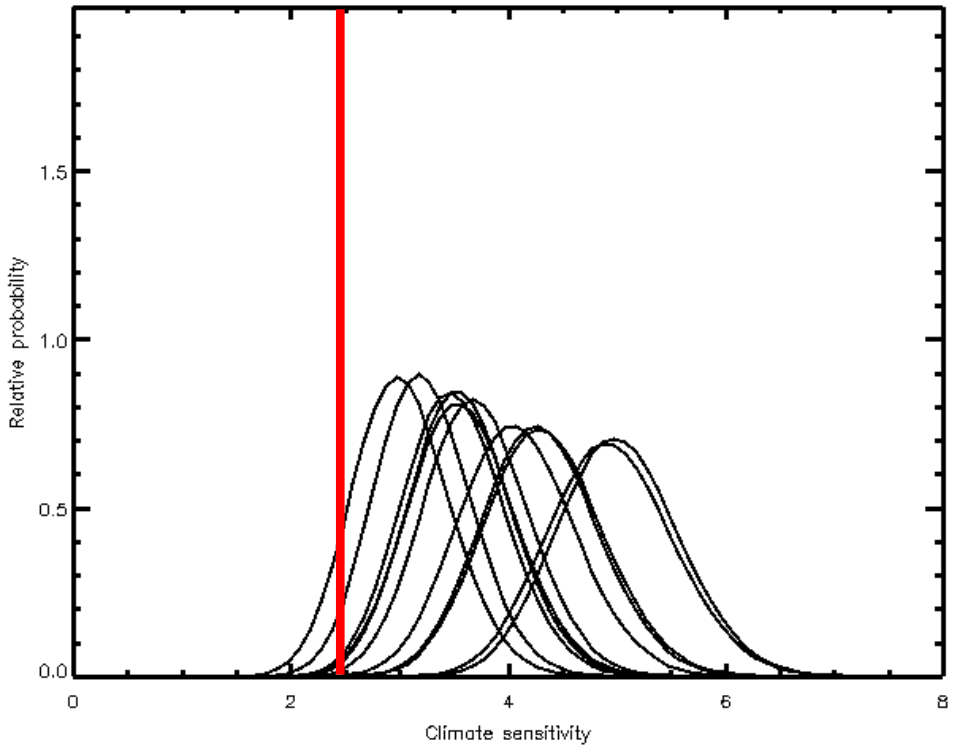
Emulators



Different sampling strategies can produce different histograms

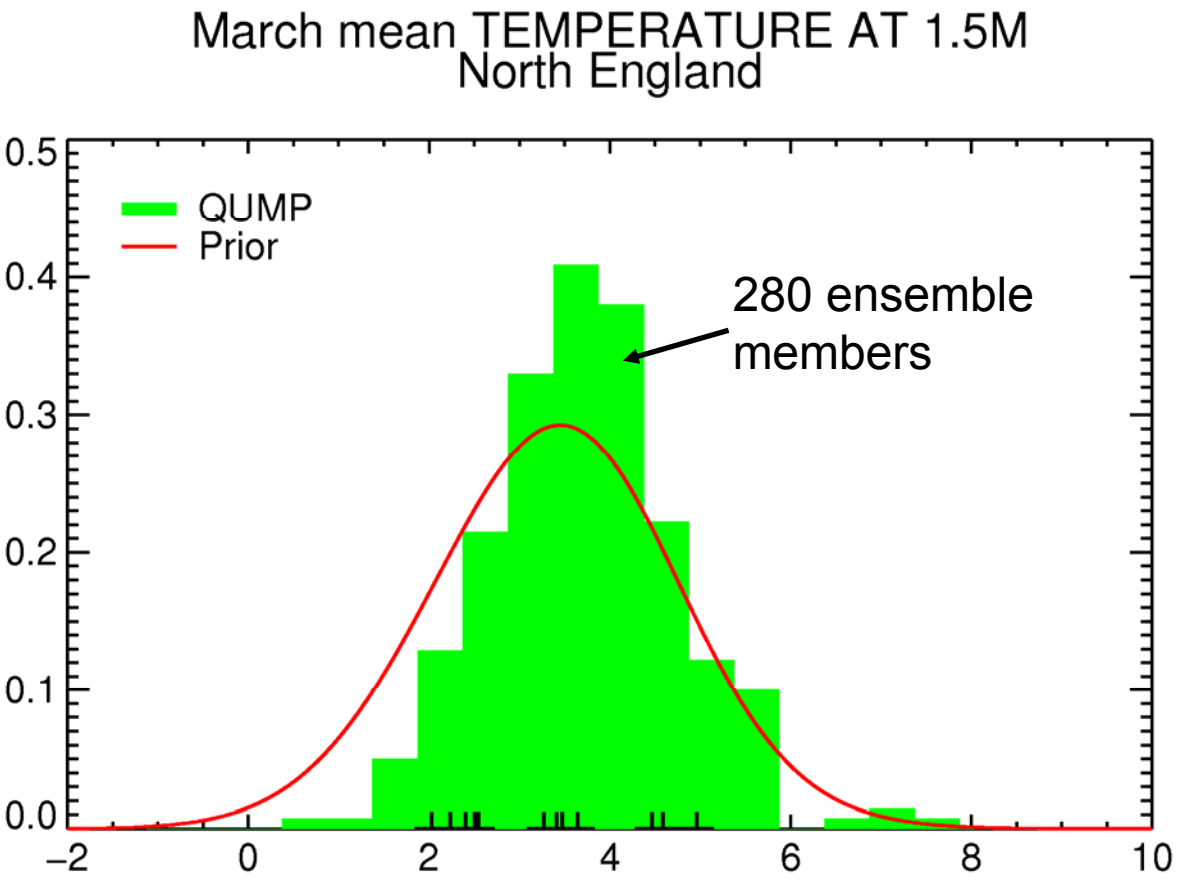
- Want to sample parameters according to the prior beliefs about where good parts of parameter space are
- Emulators are statistical models, trained on ensemble runs, designed to predict model output at untried parameter combinations

Emulators



Emulated distributions for 10 different samples of combinations of parameter values

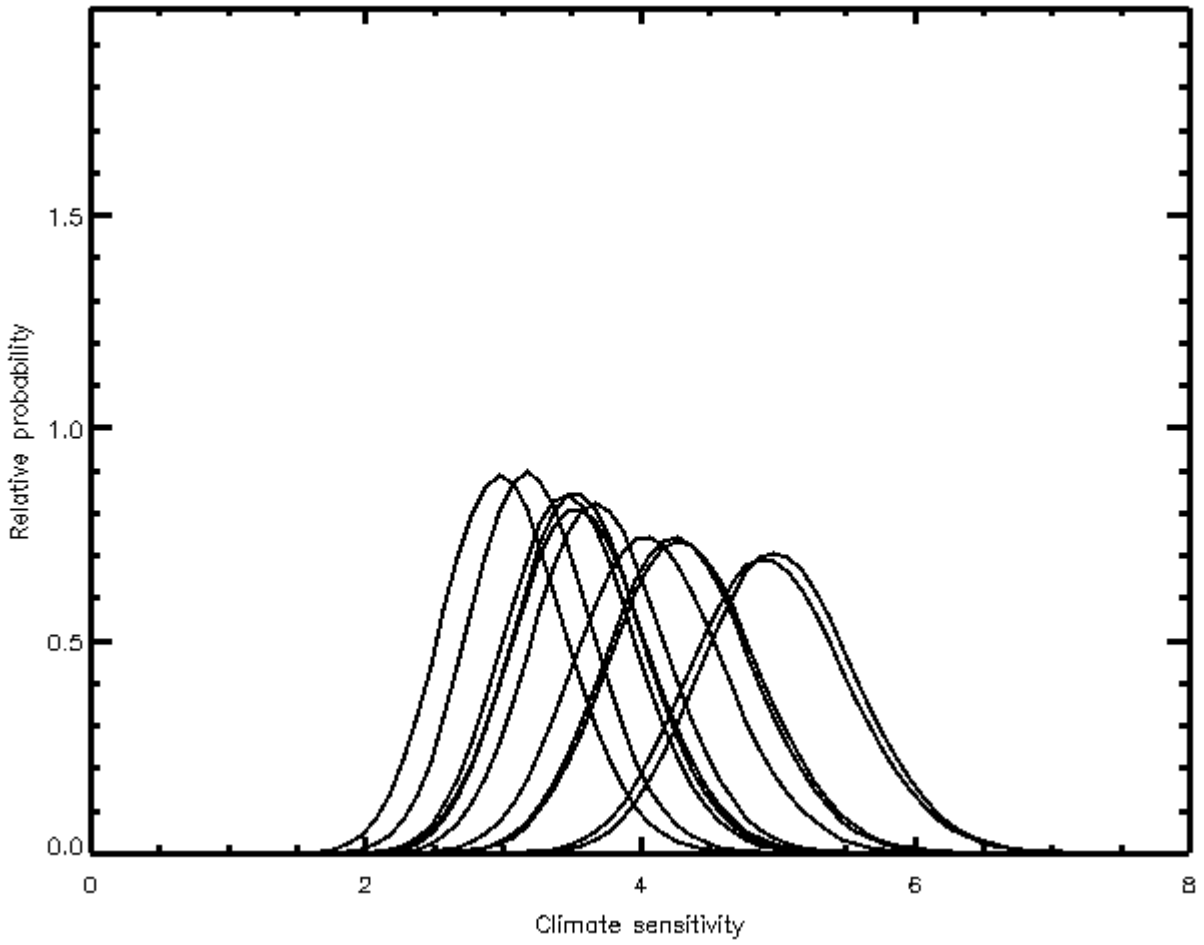
Prior PDF


March mean TEMPERATURE AT 1.5M
North England
QUMP
Prior
280 ensemble members
0.5
0.4
0.3
0.2
0.1
0.0
–2
0
2
4
6
8
10

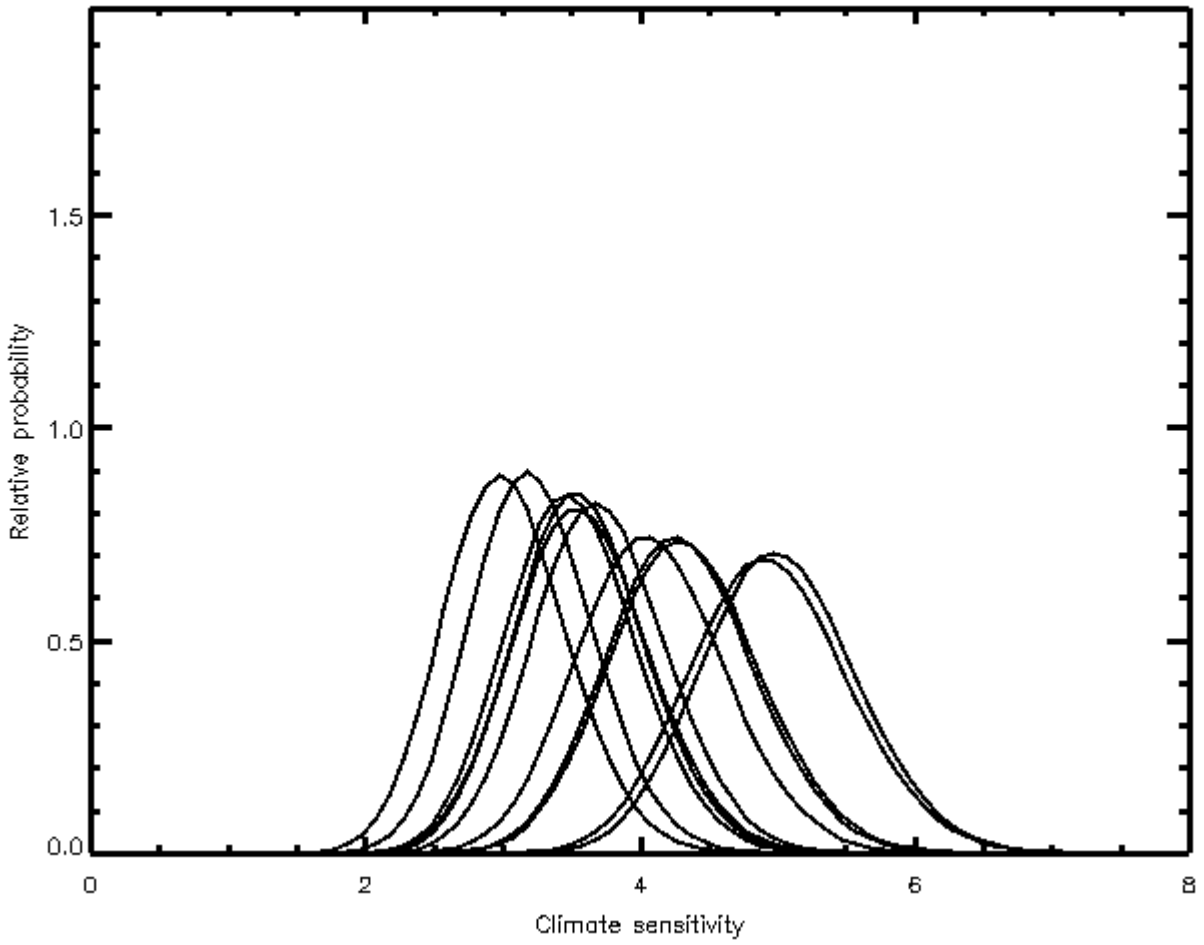
Constraining predictions with observations

- Weight prediction towards higher quality parts of parameter space
- No verification or hindcasting possible so we are limited to this use of the observations
- Use 6 metrics for how well emulated variants are capturing important simultaneous variations in several climate mean variables. This reduces risk of rewarding models for wrong reasons e.g. fortuitous compensation of errors

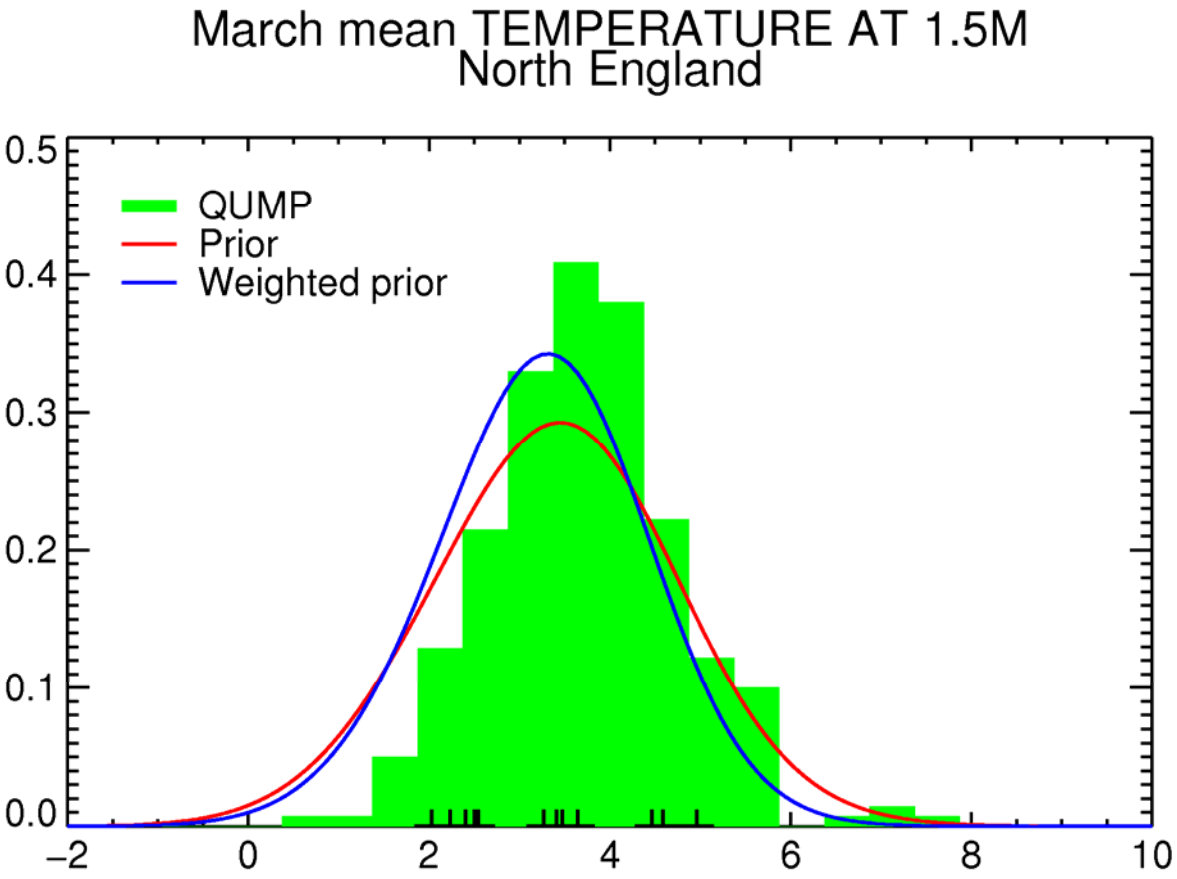
Weighting different model variants



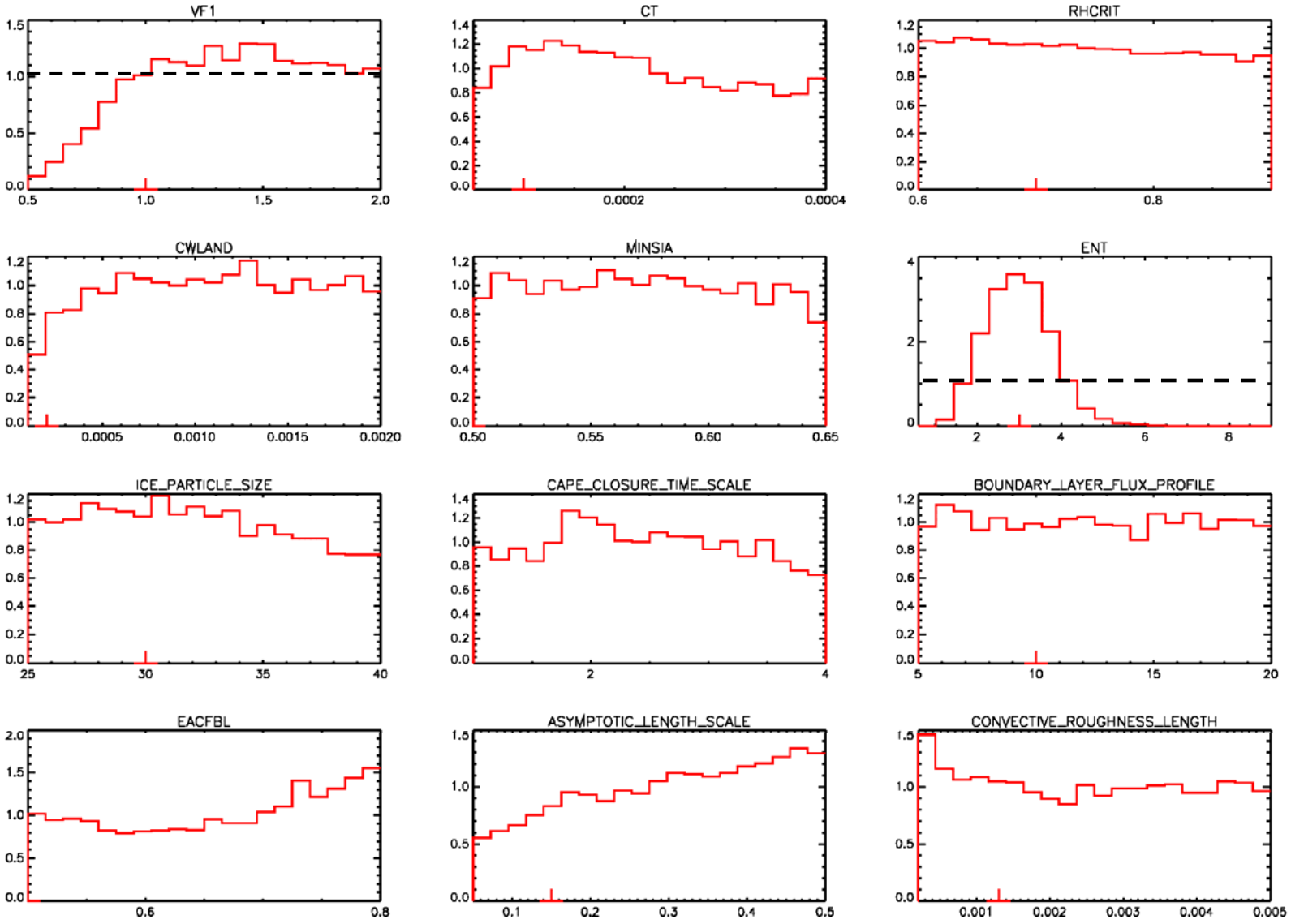
Weighting different model variants



Weighted PDF



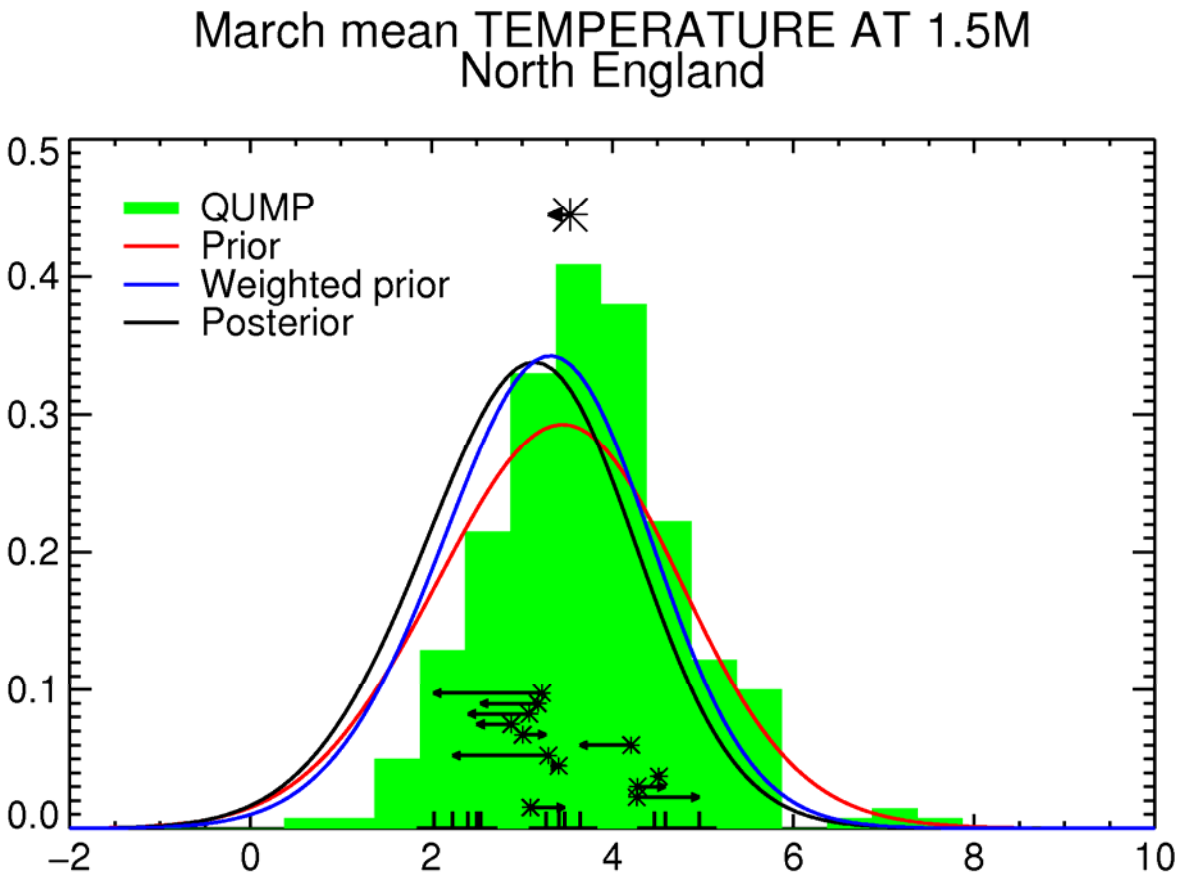
Constraining parameters



Model imperfections

- Define discrepancy as a measure of the extent to which model imperfections could affect the response.
- Assumes there exists a best choice of parameter values
- Discrepancy is a variance and it measures how informative the climate model is. A perfect model has zero discrepancy.
- Discrepancy inflates the PDFs of the prediction variables
- Discrepancy makes it more difficult to discern a good quality model from a poor quality model and so avoids over-confidence in weighting out poor parts of parameter space

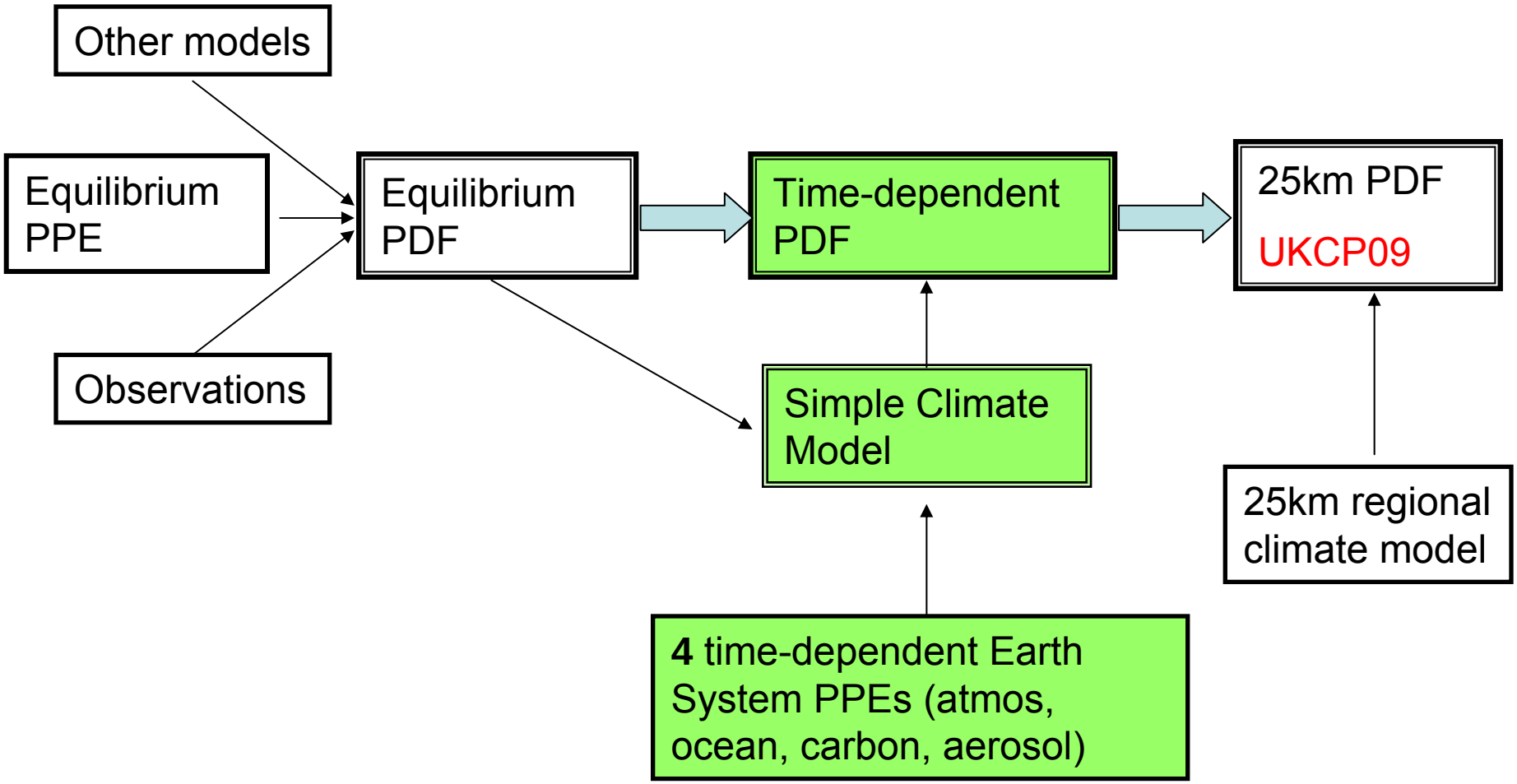
Probabilistic prediction of equilibrium response to double CO2



Method does not capture systematic errors that are common to all state-of-the-art climate models

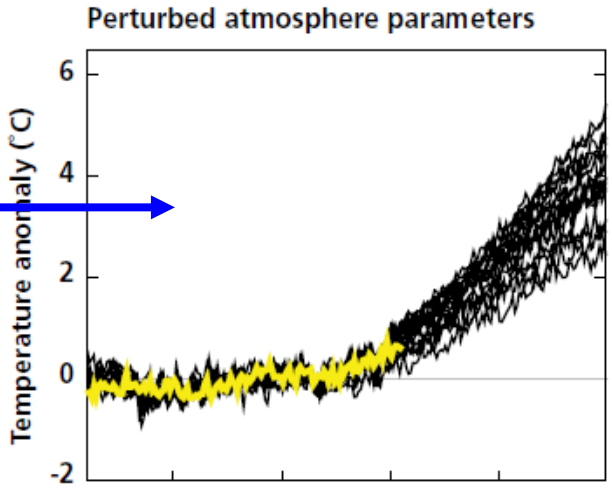
Stage 2: Time Scaling

(Glen Harris and Penny Boorman)



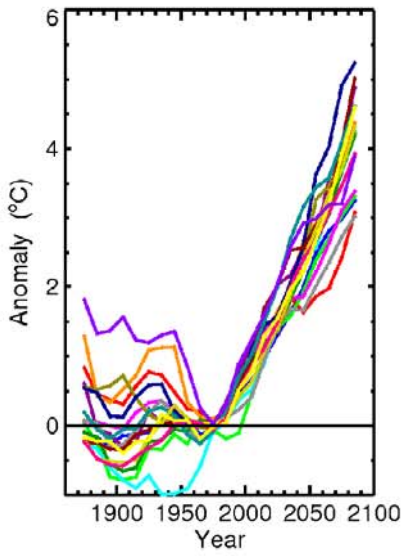
Ensembles of coupled ocean-atmosphere runs

17 members of Atmosphere Perturbed Physics Ensemble repeated with a full coupling between atmosphere and dynamic ocean

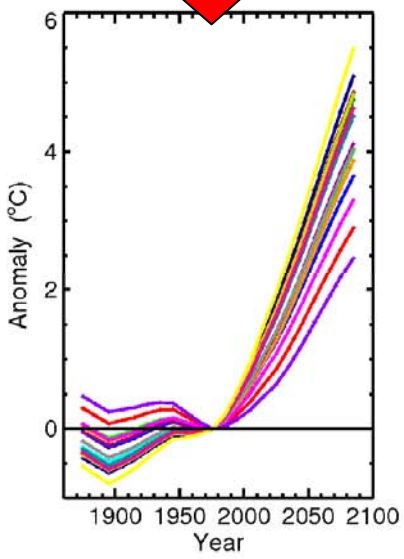


Time-scaling diagnosis: Northern England summer surface temperature response

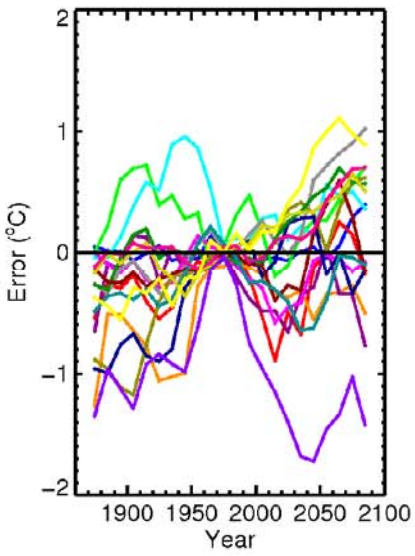
Scaled output = ΔSCM global temp(t) x equilibrium response / Δeqm global temp



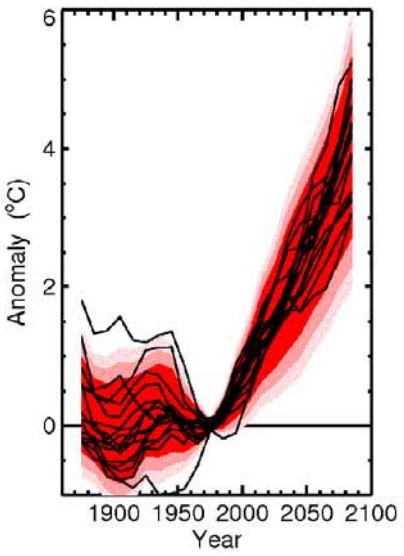
Raw GCM data



Scaled output from Simple Climate Model



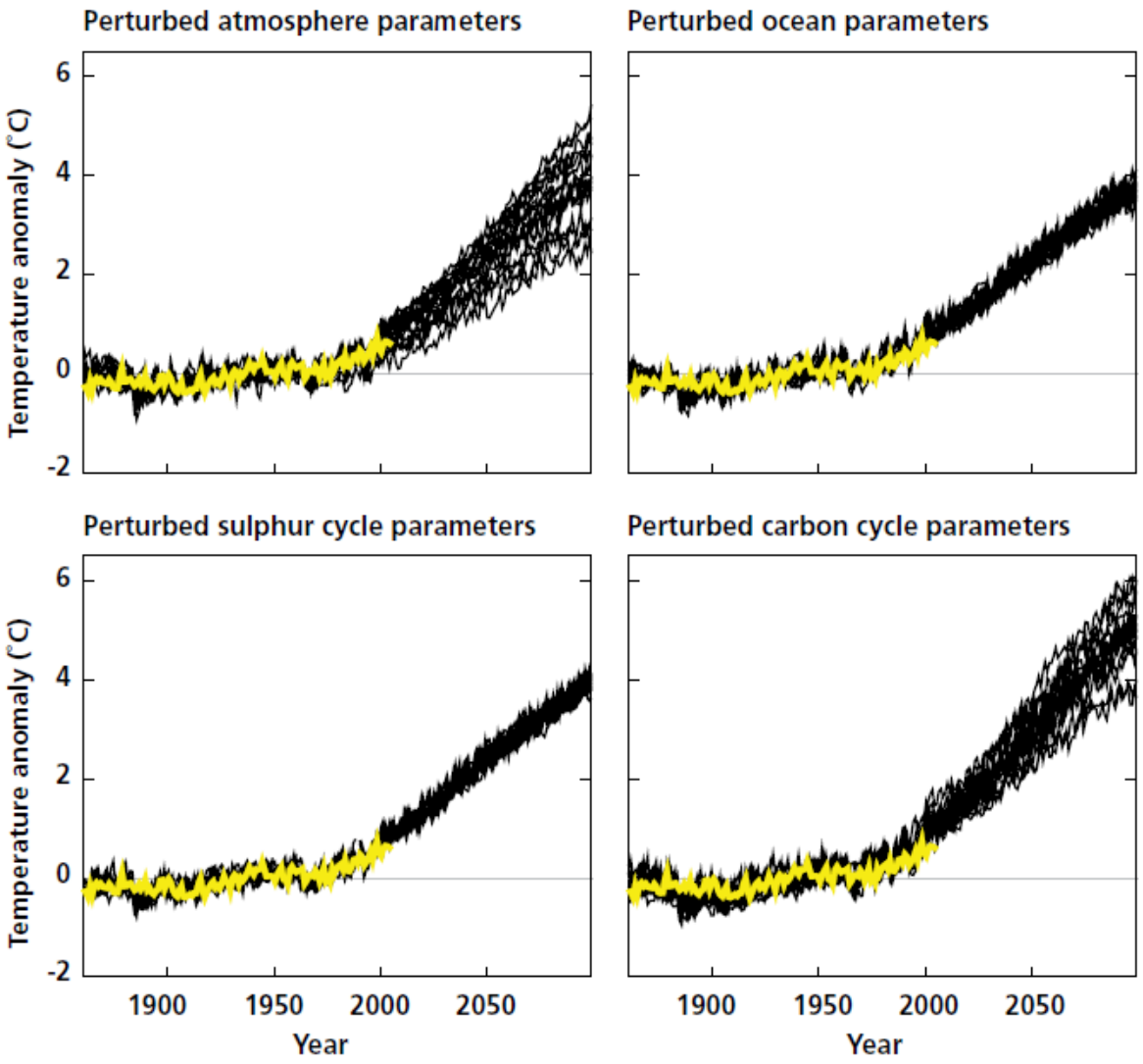
Scaled output minus raw GCM data



Plume for the 17 runs

NOTE: this is not UKCP09

Ensembles for other Earth System components

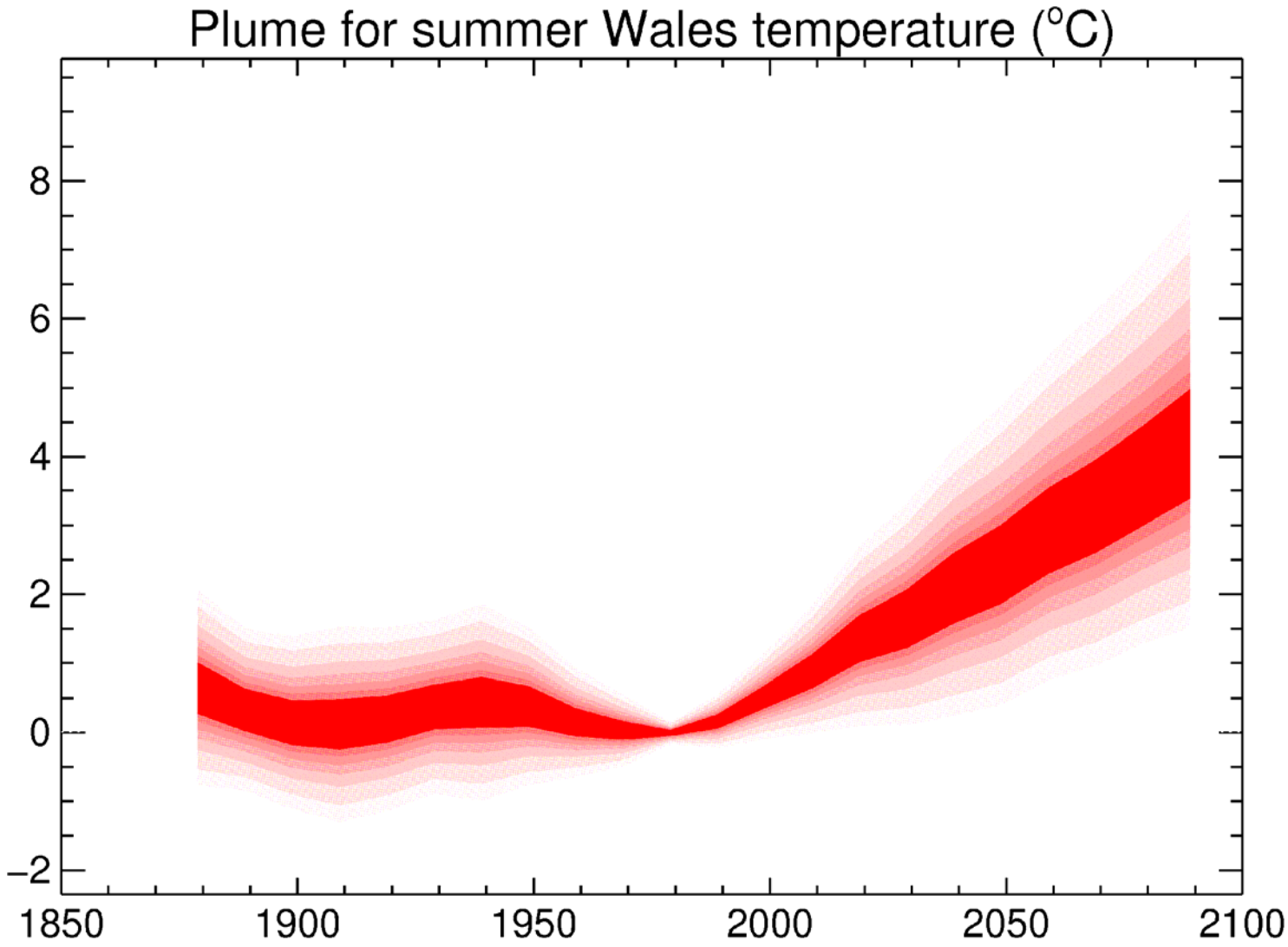


Use ocean, sulphur cycle, carbon cycle PPEs and multimodel ensembles to tune different configurations of the Simple Climate Model

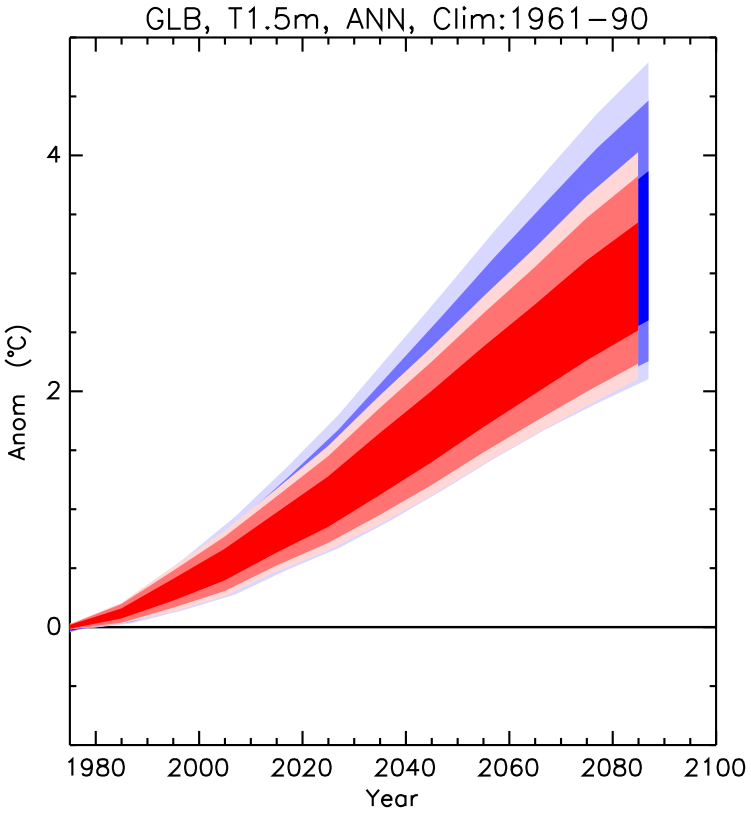
Making time-dependent PDFs

- Sample point in atmosphere parameter space
- Emulate equilibrium response in climate sensitivity and prediction variables and calculate weights
- Sample ocean, aerosol and carbon cycle configurations of Simple Climate Model
- Time scale the prediction variables
- And repeat sampling…

Plume for GCM grid box over Wales



Carbon cycle uncertainty compared with atmospheric feedback uncertainty

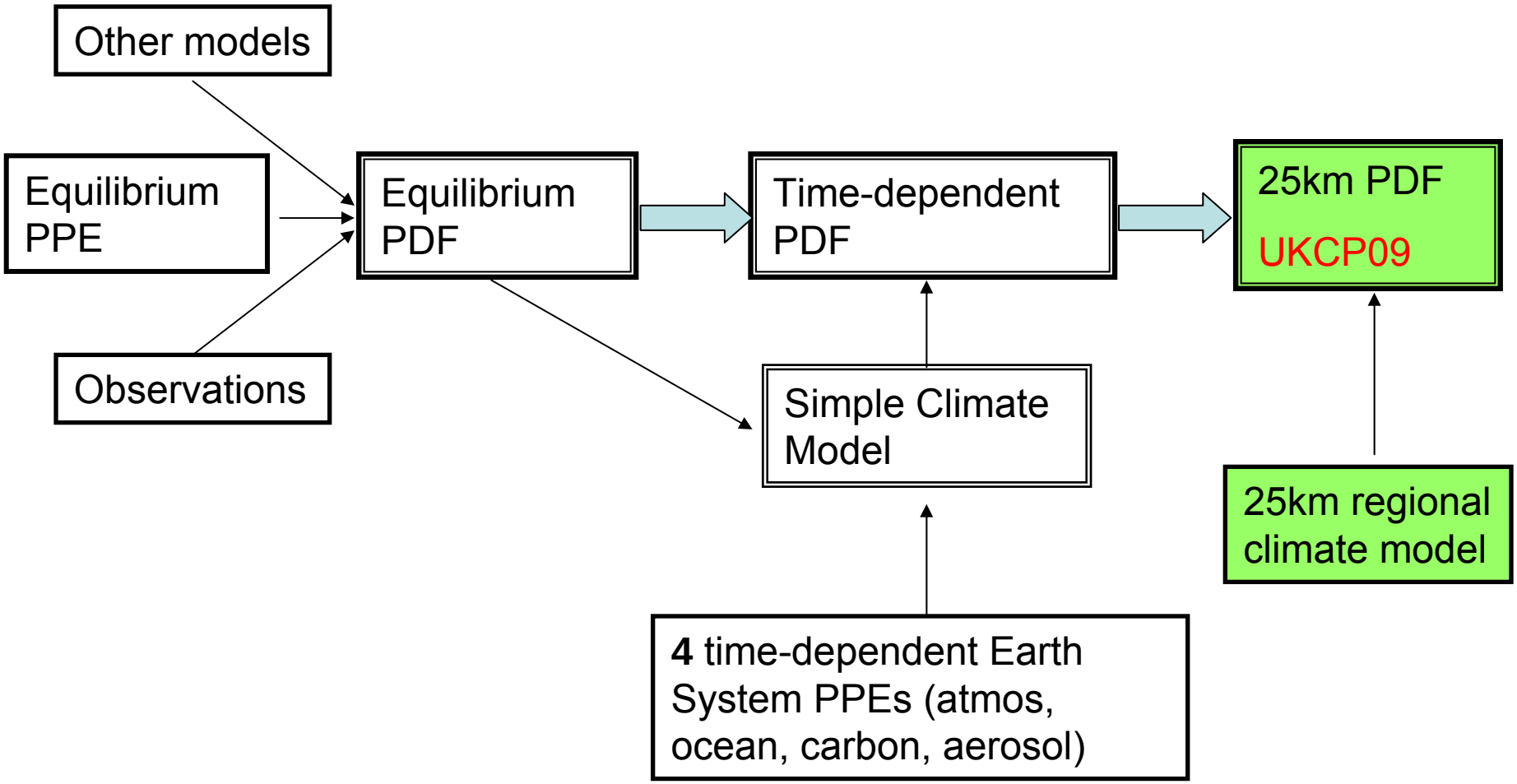


Sampling of carbon cycle feedbacks included / not included

- By including carbon cycle, spread increased by ~40%, median increases by 0.23 °C.
- Corroborated by C4MIP analysis (Huntingford et al., 2009, Tellus).

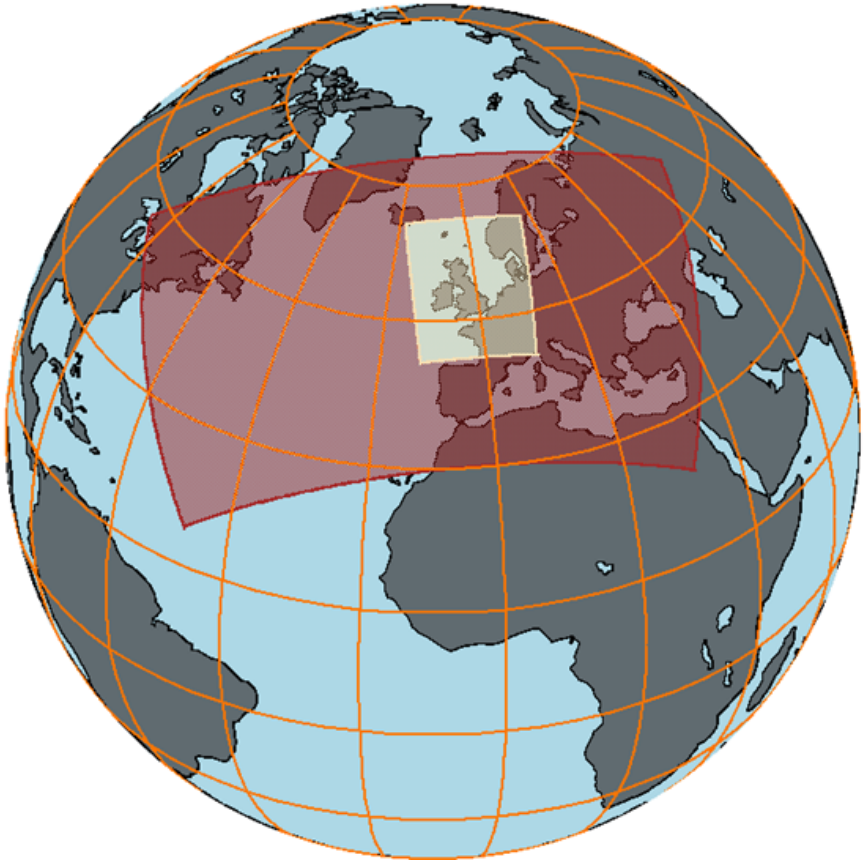
Stage 3: Downscaling

(Kate Brown)



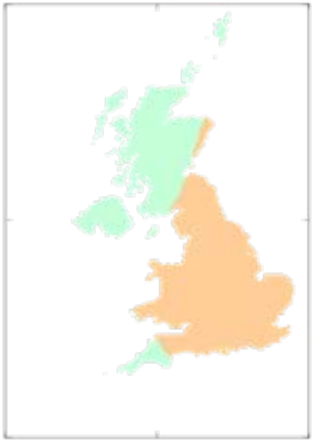
Dynamical downscaling

- For 11 of the 17 atmosphere fully coupled ocean-atmosphere runs, use 6-hourly boundary conditions to drive 25km regional climate mode for 1950-2100

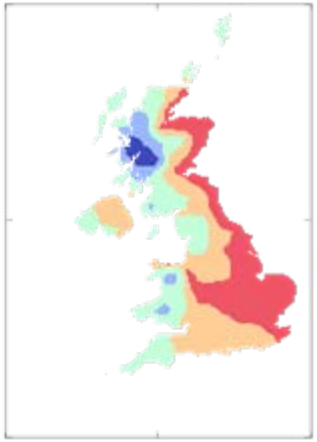


Dynamical downscaling

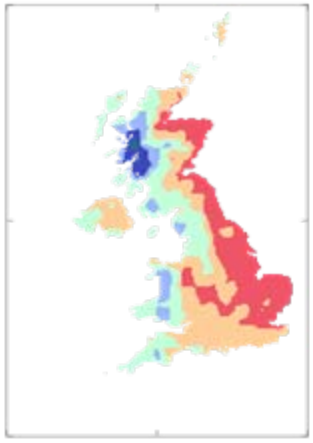
300km Global Model



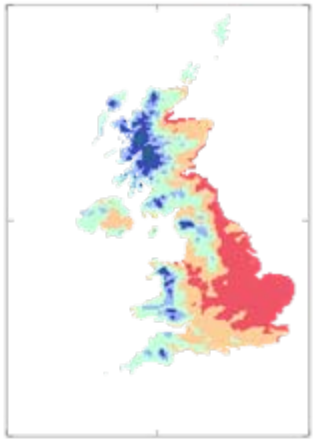
50km Regional Model



25km Regional Model



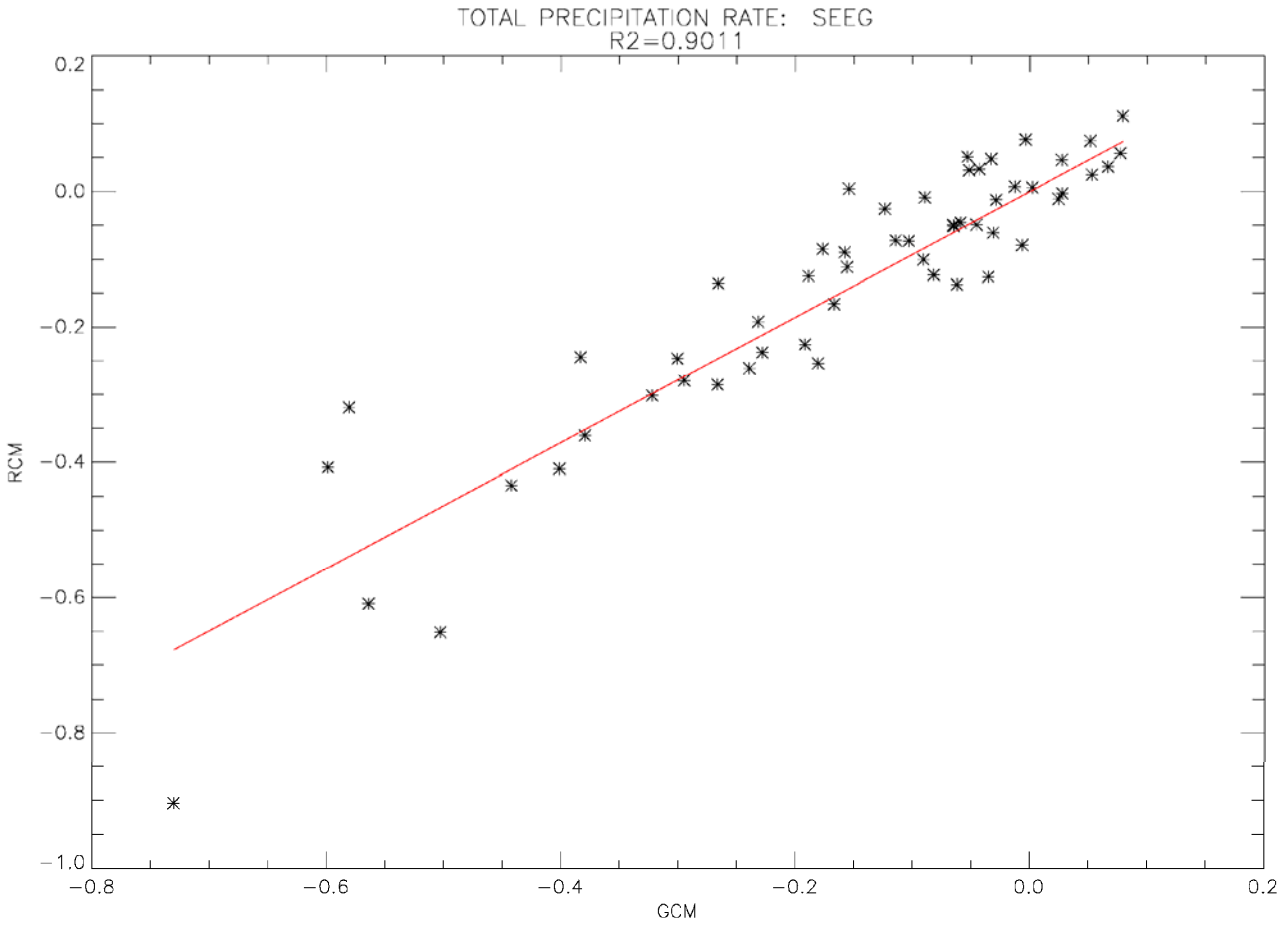
5km Observed



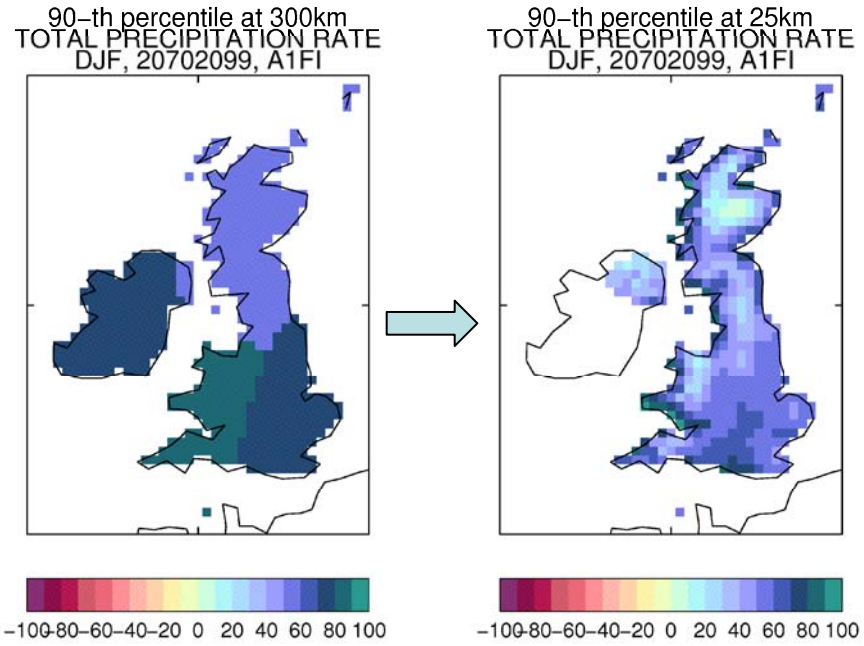
Winter precipitation for 1961-2000

Change in log(summer precipitation) over SE England

Quite strong relationships generally found for summer precip, as for winter (we showed winter in the UKCP report).



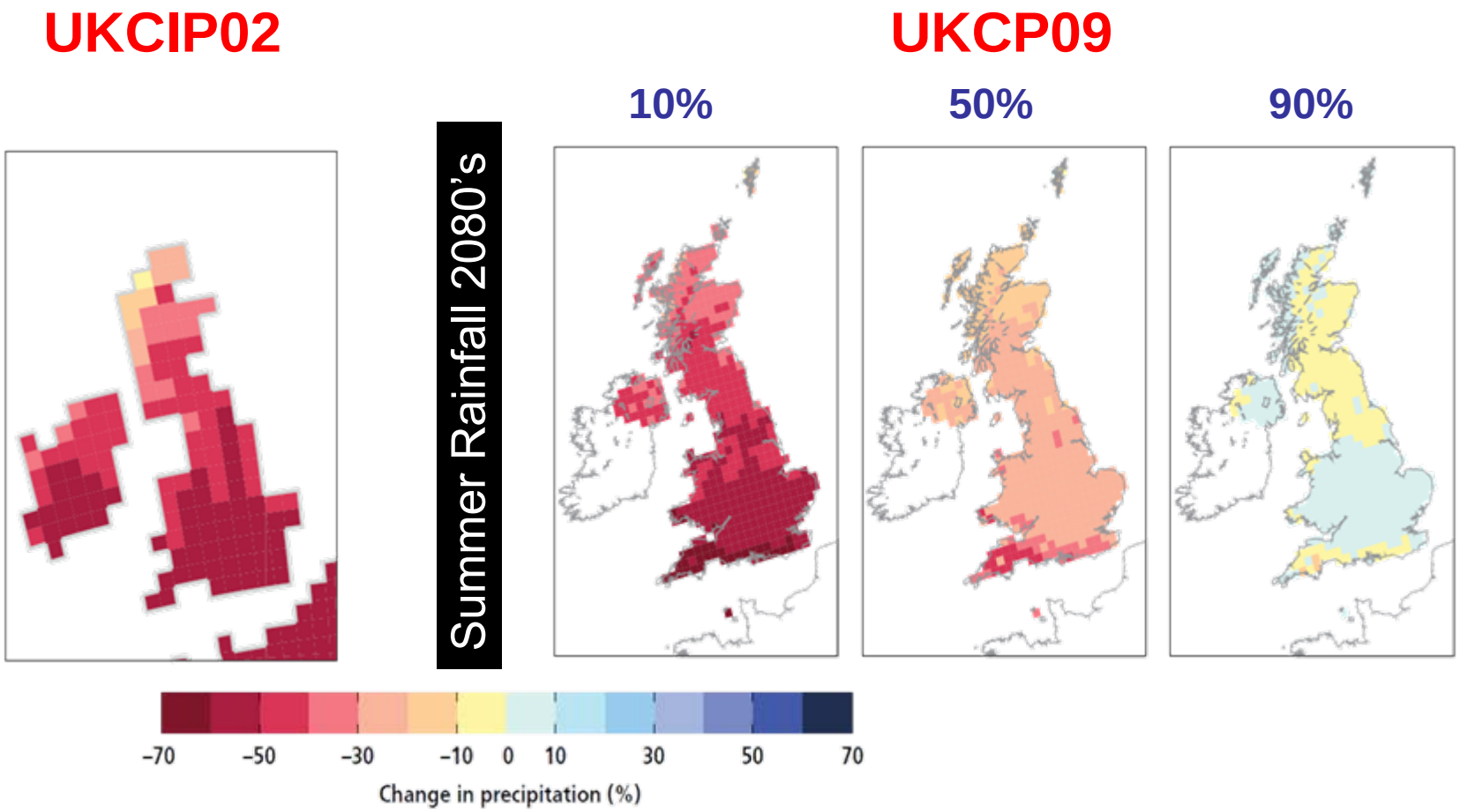
Adding information at 25km scale



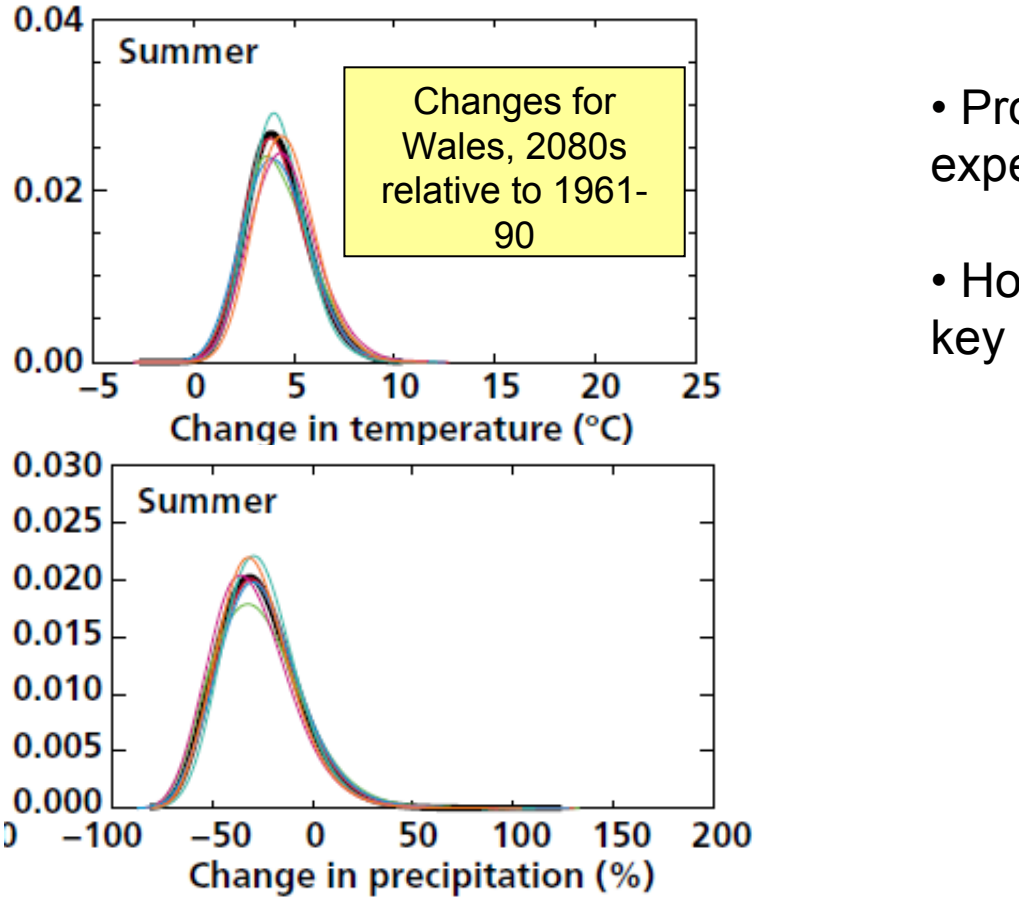
- High resolution regional climate model projections are used to account for the local effects of coastlines, mountains, and other regional influences.

- They add skilful detail to large scale projections from global climate model projections, but also inherit errors from them.

Moving from uncertainty to probability



Testing robustness

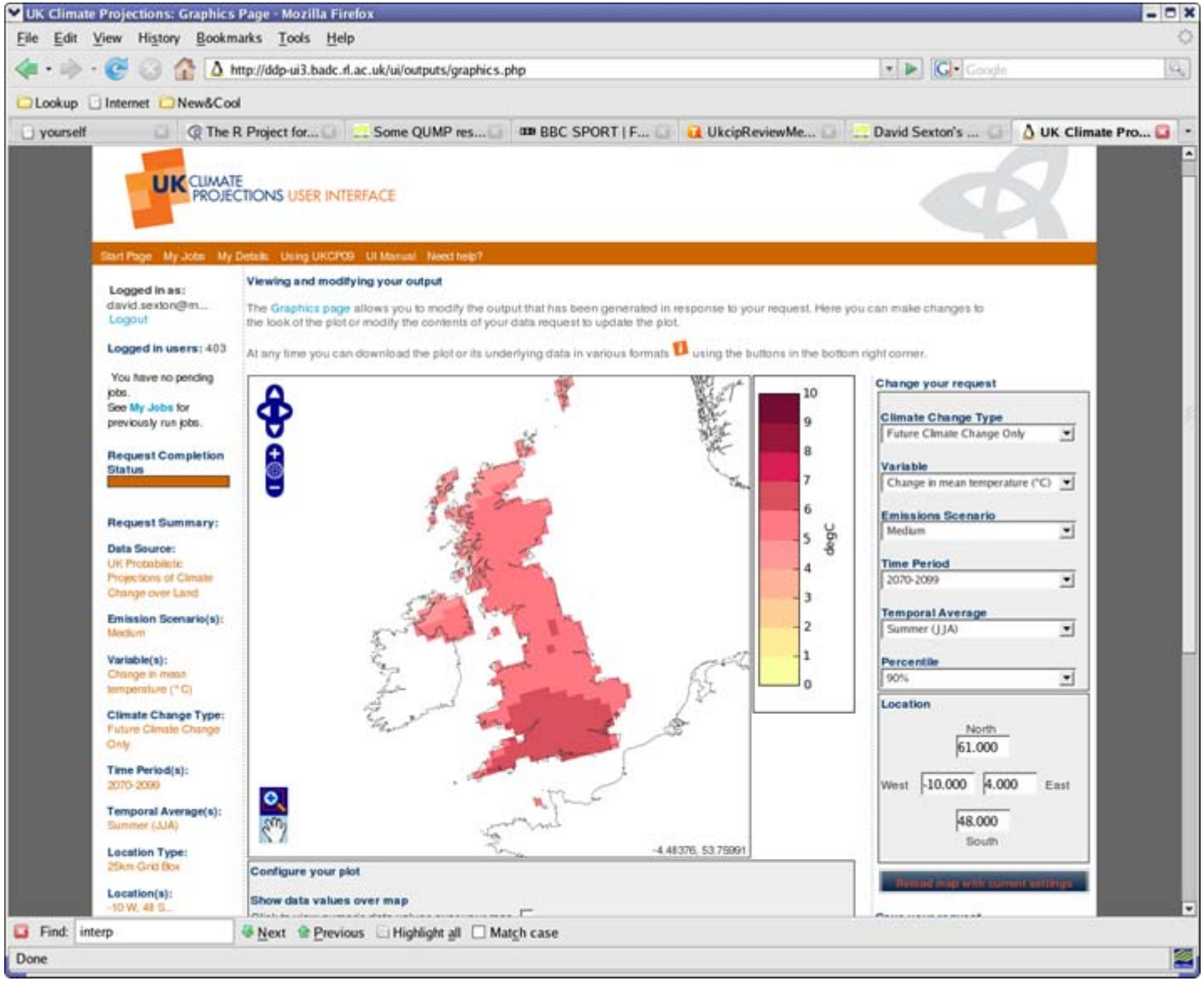


- Projections inevitably depend on expert assumptions and choices
- However, sensitivities to some key choices can be tested

UKCP09 Products

User Interface

http://ukclimateprojections-ui.defra.gov.uk/ui/admin/login.php



5-dimensional problem

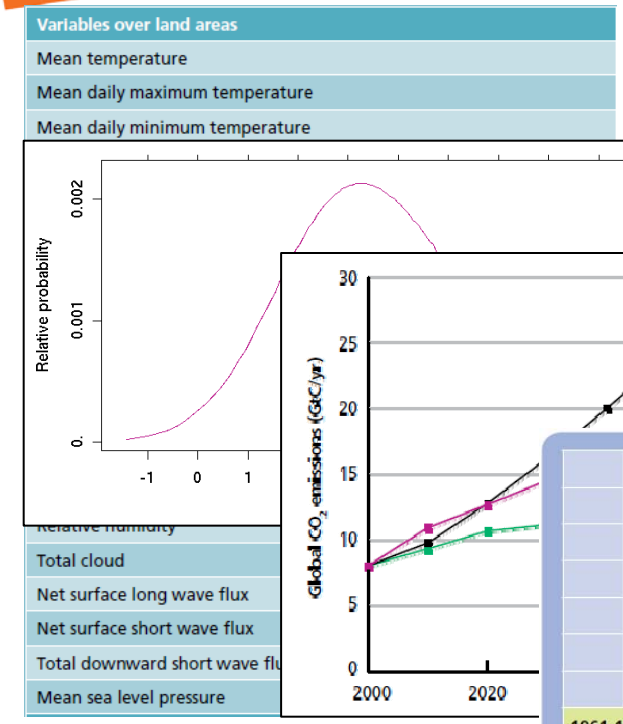
Variables and months

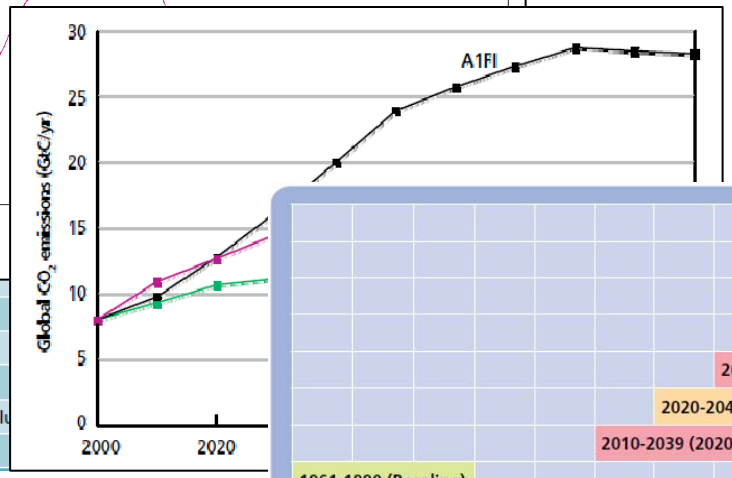
Uncertainty

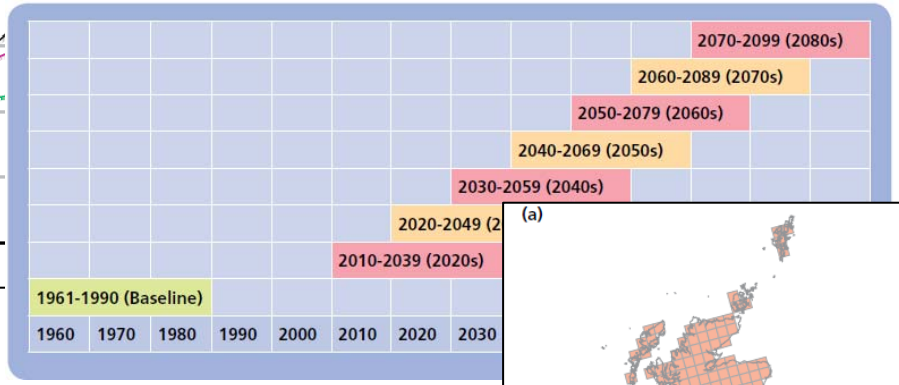
Three different emission scenarios

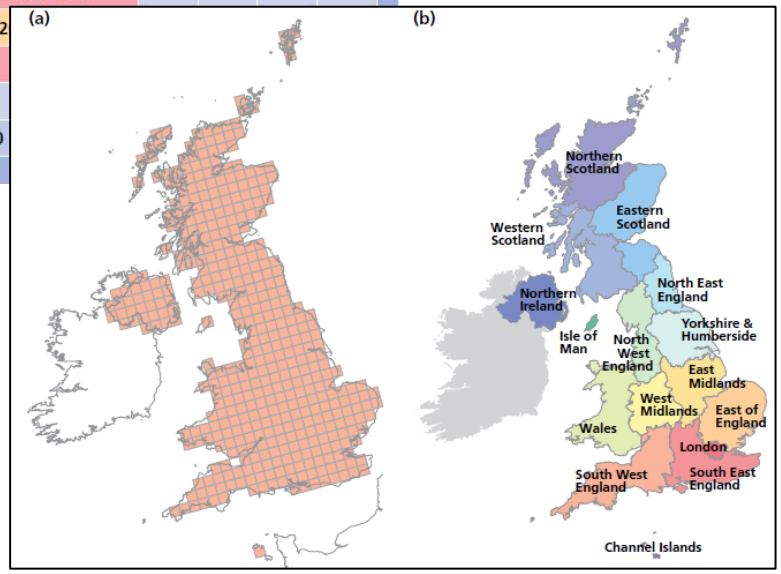
Seven different timeframes

25km grid, 16 admin regions, 23 river-basins and 9 marine regions

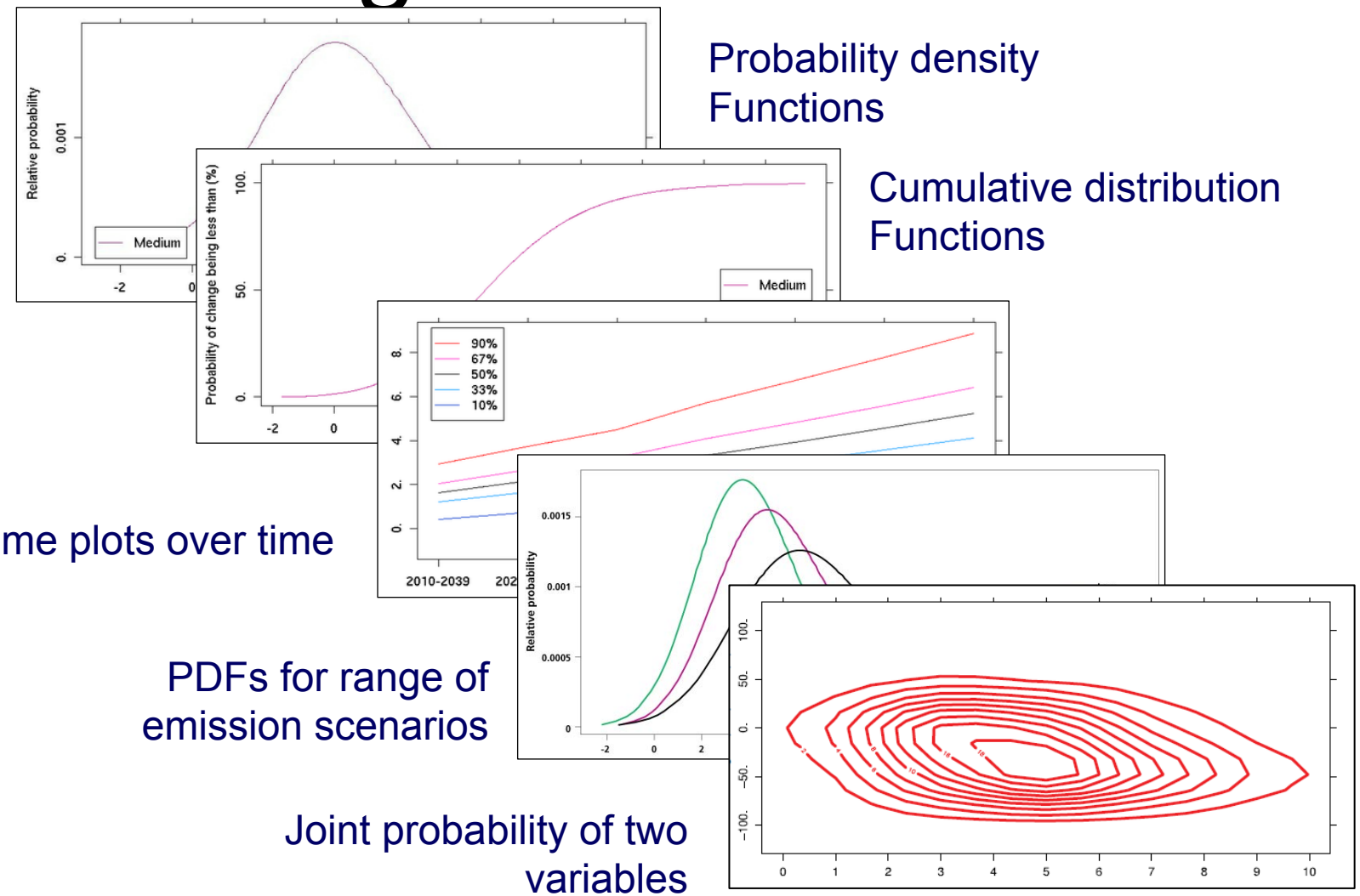








Providing probabilities in a range of formats



Probability density Functions

Cumulative distribution Functions

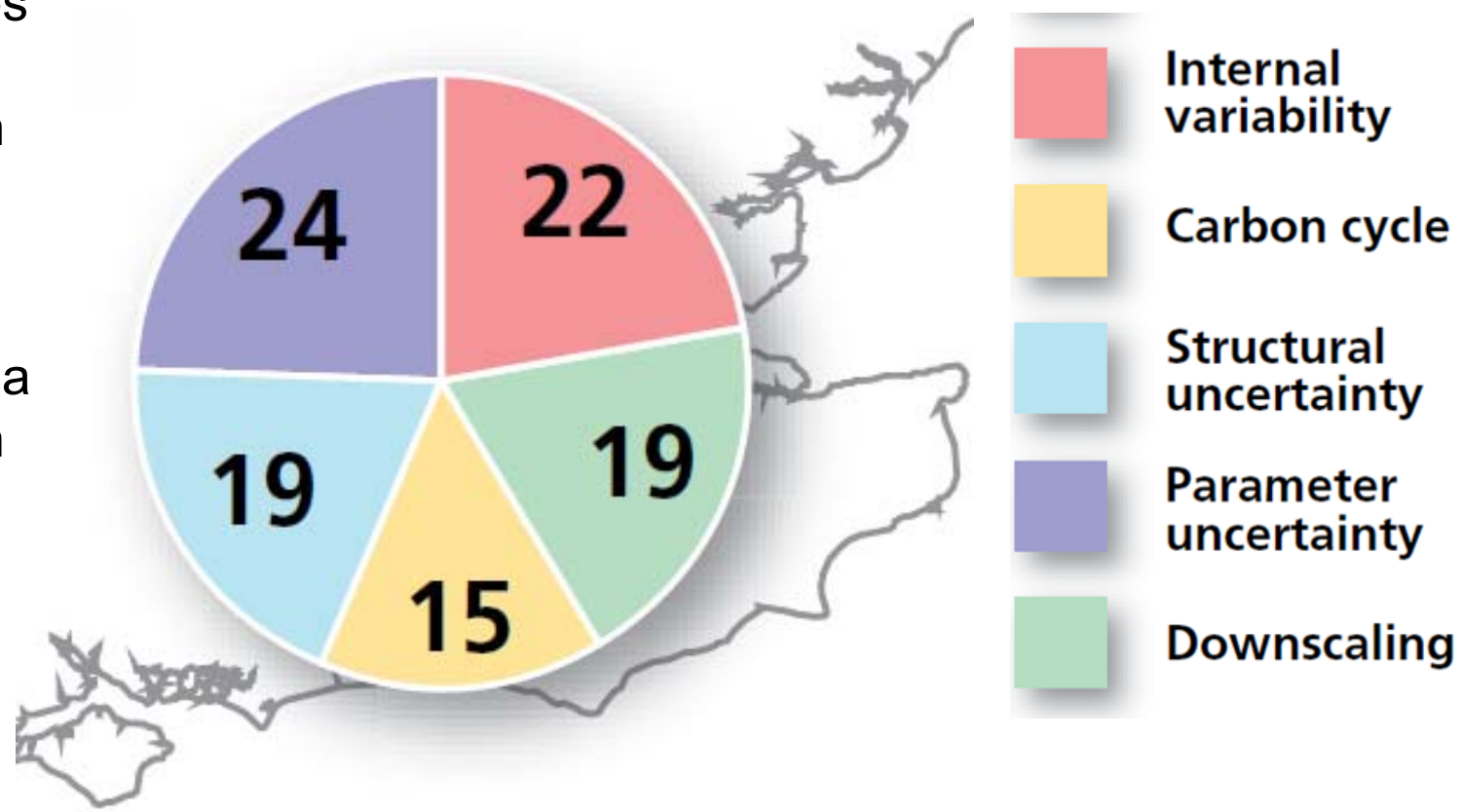
Plume plots over time

PDFs for range of emission scenarios

Joint probability of two variables

Reducing different sources of uncertainty?

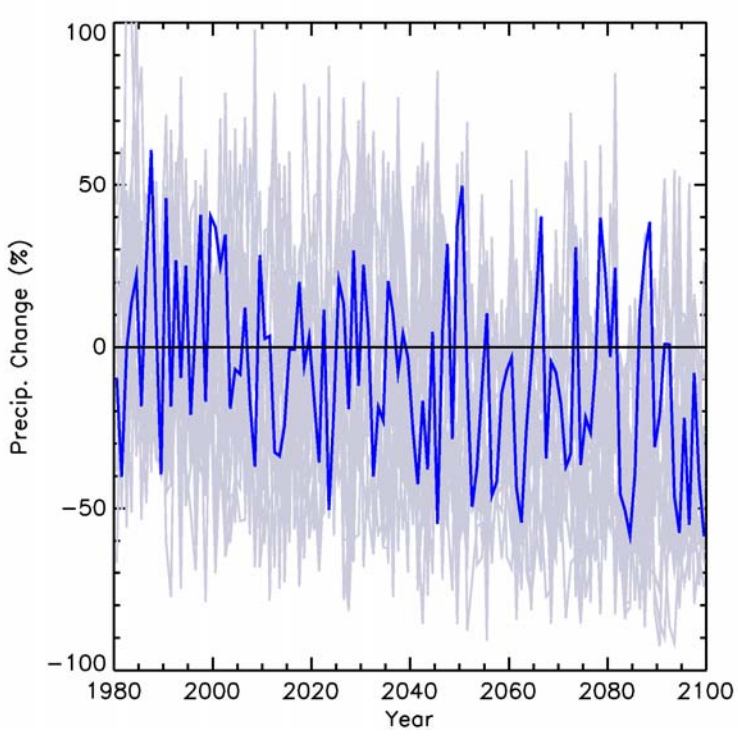
Uncertainties in winter precipitation changes for the 2080s relative to 1961-90, at a 25km box in SE England

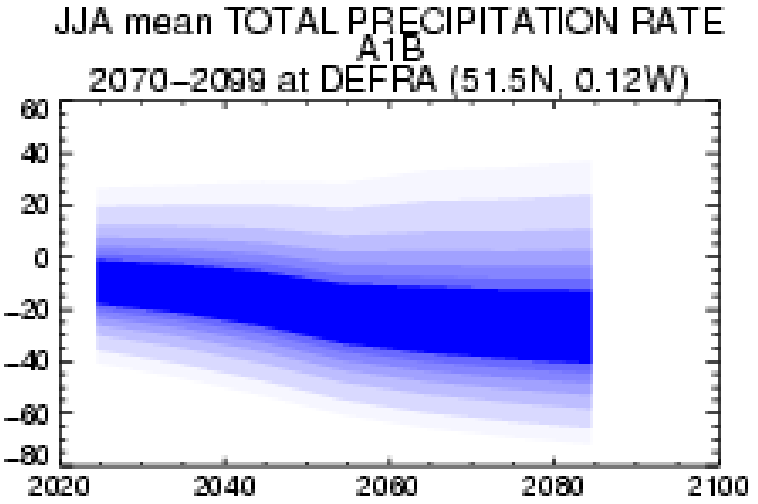


New information, methods, experimental design can reduce uncertainty so projections will change in future and decision makers need to consider this

Interannual results v. 30-year mean results

Predictions are for 30-year means, so should not be compared to annual climate anomalies.





Summer % rainfall change: a) interannual over SE England from 17 runs
b) time-dependent percentiles of 30-year mean at DEFRA

Royal Society Meeting, October 2009

- Good open discussion of the issues surrounding UKCP09
- Biggest weakness is perceived to be systematic errors common to all models but nobody really has handle on the extent of this problem
- I think best we can do next time is to offer to put the PDFs in context of model performance in form of some basic model validation
- Rob Wilby discussed how it was a good tool but not the only tool…

User feedback after UKCP09…

- Reasonable uptake
- Good use of UKCIP and Met Office helpdesks
- UKCIP have run a few workshops with users and scientists and collated feedback
- Wide spectrum of users ranging from some who are embracing the probabilities to others who are not. Some of their issues can be addressed by UKCP09 Extras

UKCP09 Extras

- Storylines:
  - Very useful ways to help users understand their climate vulnerability
  - Nationwide assessments
- Probability maps consistent with specific change in global mean temperature
- New functionality in User Interface
- Windspeed PDFs
- Ftp site so that users can do batch processing

- Lack of spatial coherence other than in RCM will remain an issue

Any questions?