



# Making probabilistic climate projections for the UK

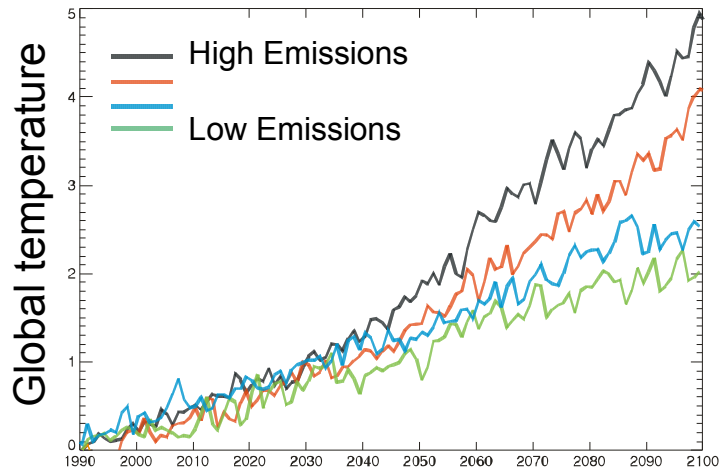
## Exeter University

David Sexton, James Murphy, Geoff Jenkins, Penny Boorman, Ben Booth, Kate Brown, Robin Clark, Mat Collins, Glen Harris, Lizzie Kendon

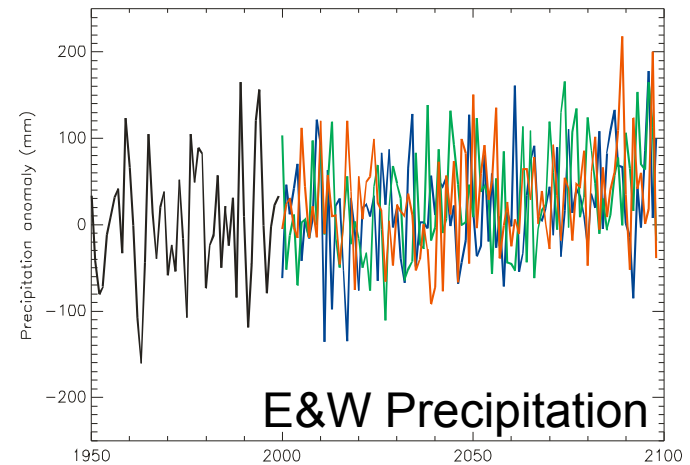
Met Office Hadley Centre  
2<sup>nd</sup> Feb 2010

# Cannot be certain about future climate because...

## 1 Emissions uncertainty

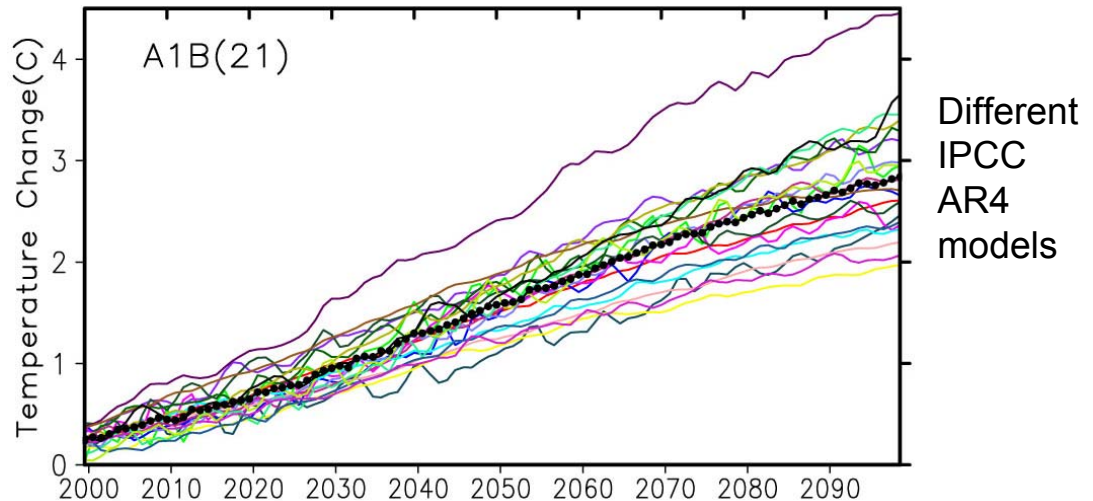


## 2 Natural variability



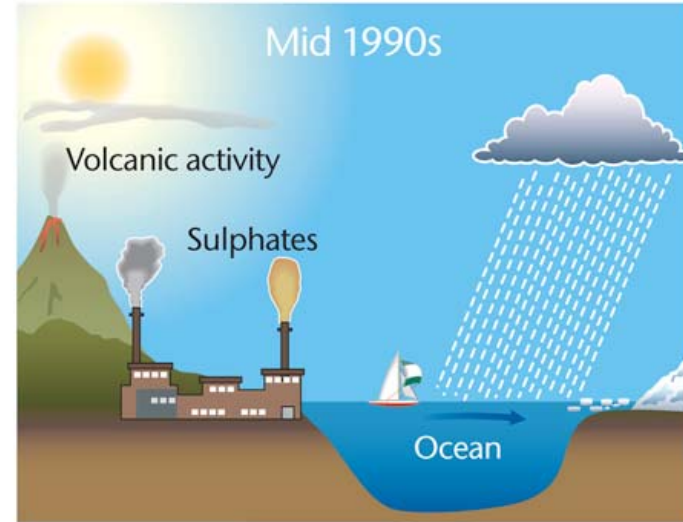
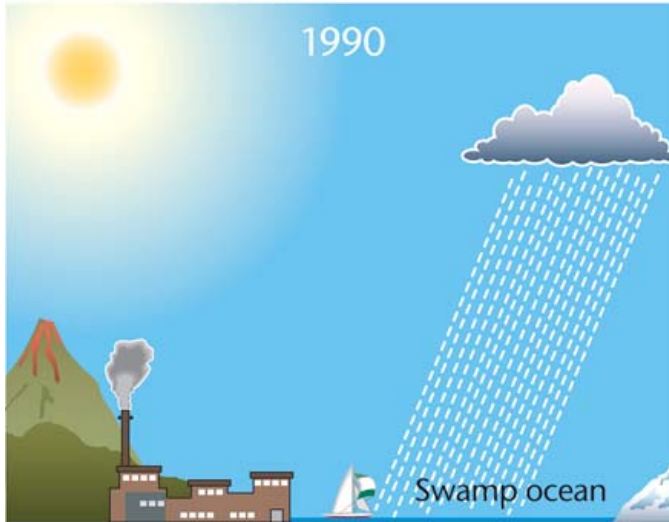
## 3 Modelling uncertainty

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

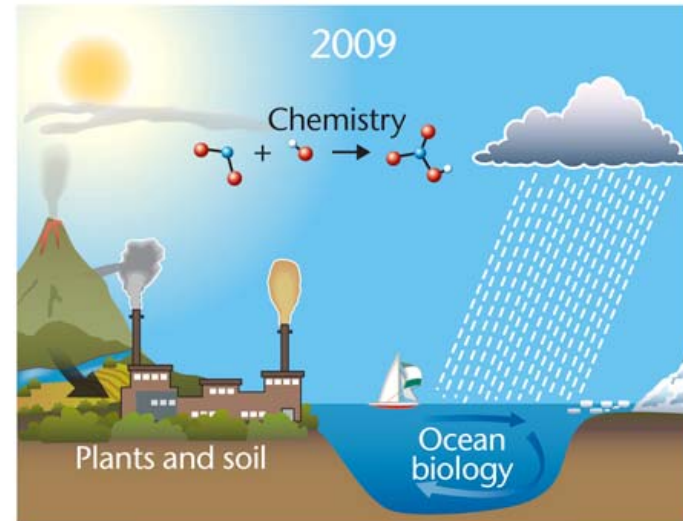
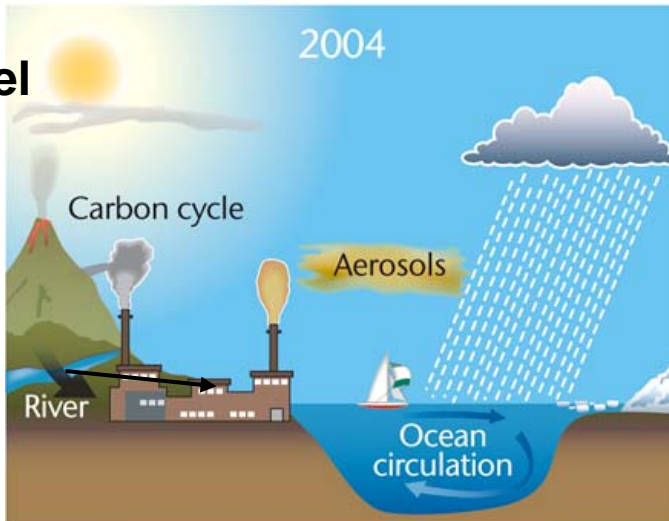


# Climate models

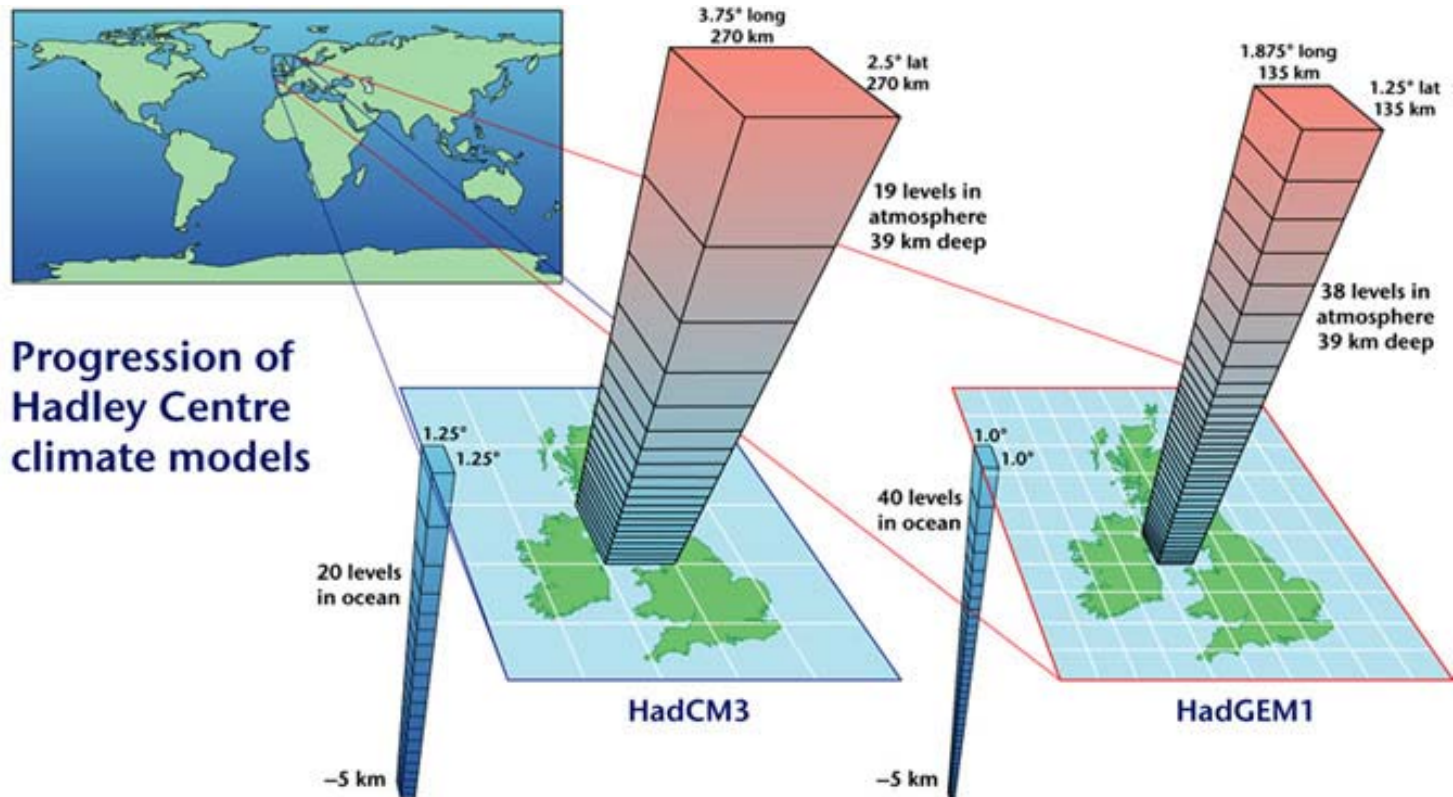
Slab ocean



Coupled model



# Climate modelling



Progression of Hadley Centre climate models

# Sub grid-scale processes

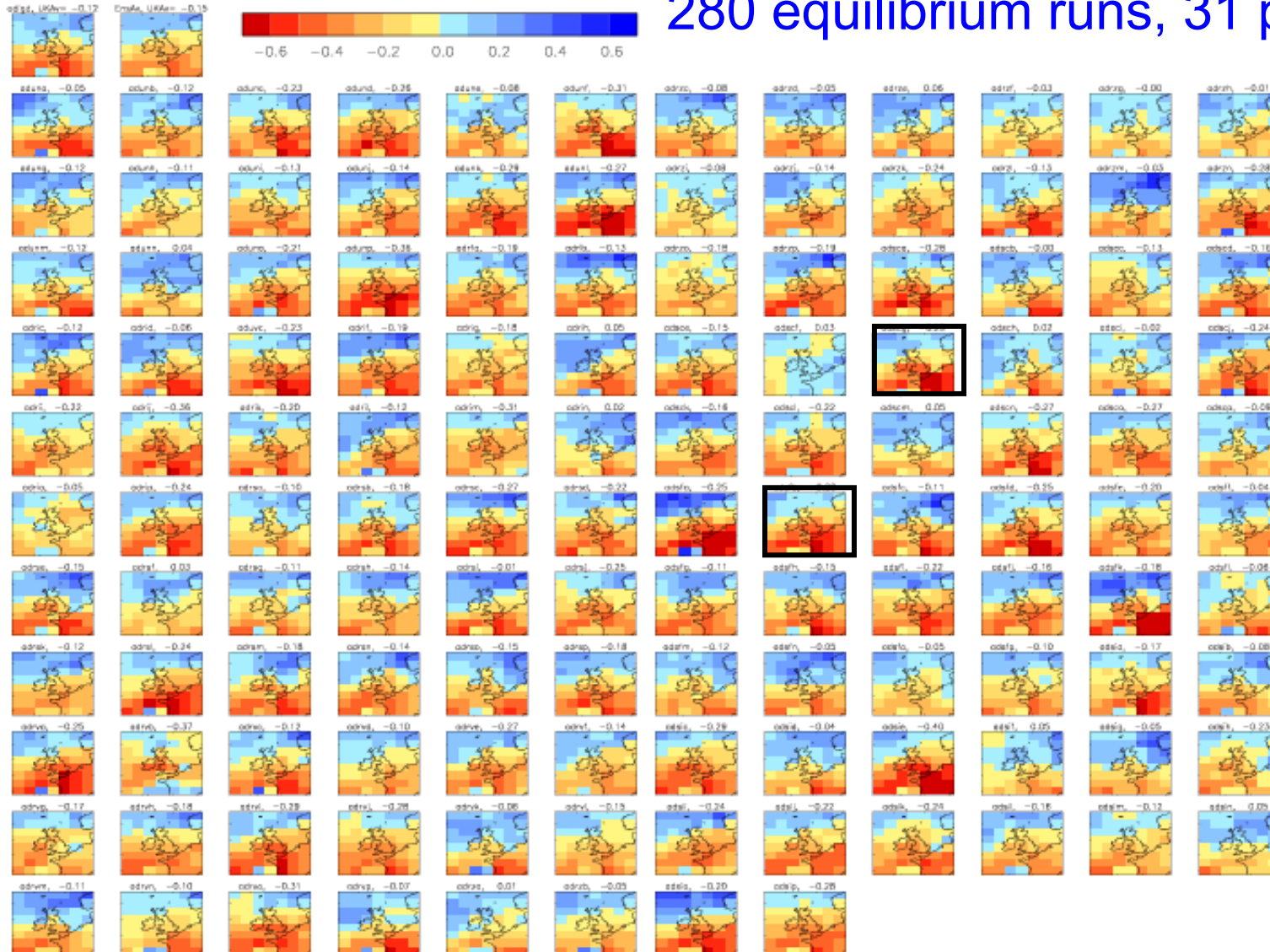
- “Parameterization” refers to the method of using a simplified process to replace processes that take place at scales below the gridbox scale
- Simplified processes are calculated as functions of the grid-scale variables and some controlling numbers called “parameters”
- These parameters are uncertain

# Perturbed physics ensemble

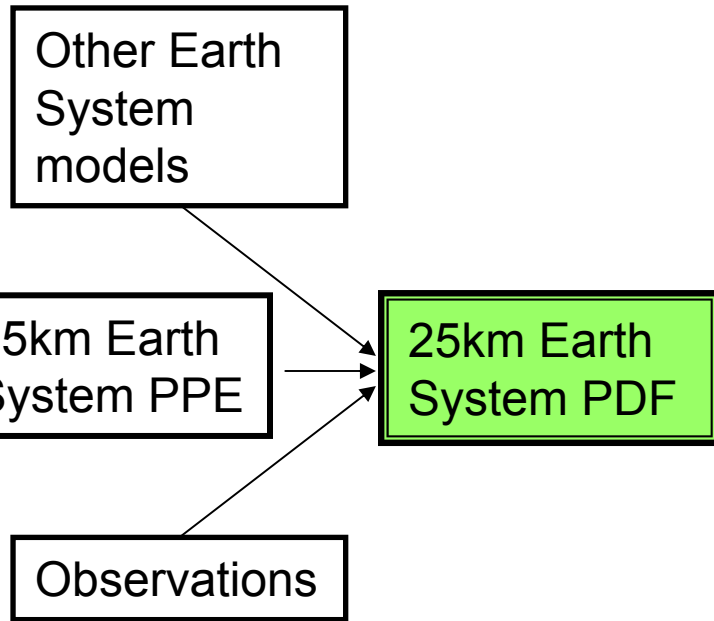
- There are plenty of different variants of the climate model that are as good if not better than the standard tuned version
- But their response can be different to the standard version
- Cast the net wide, explore parameter space with view to finding pockets of good quality parts of parameter space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

# Perturbed physics ensemble

280 equilibrium runs, 31 parameters

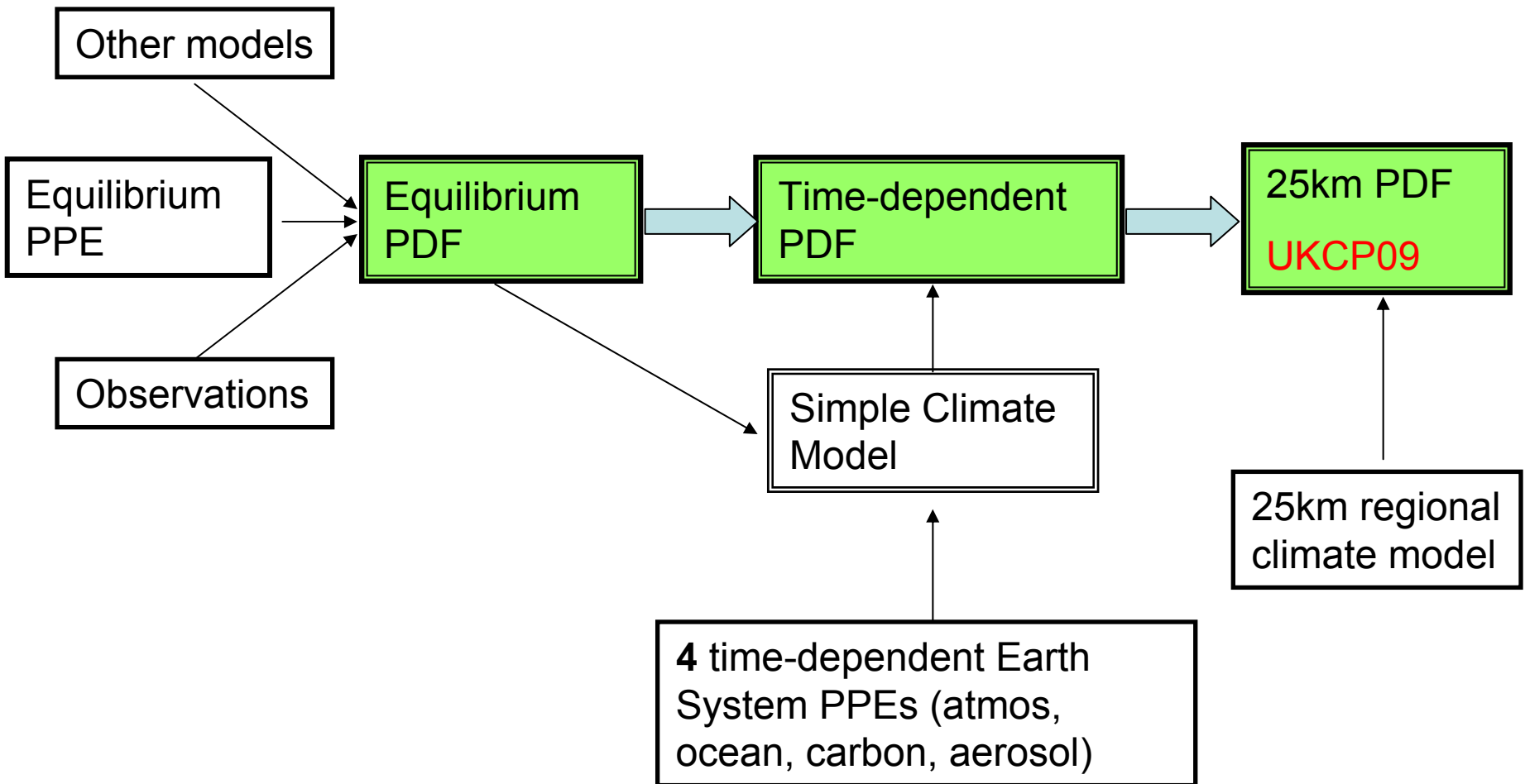


# Ideal experimental design

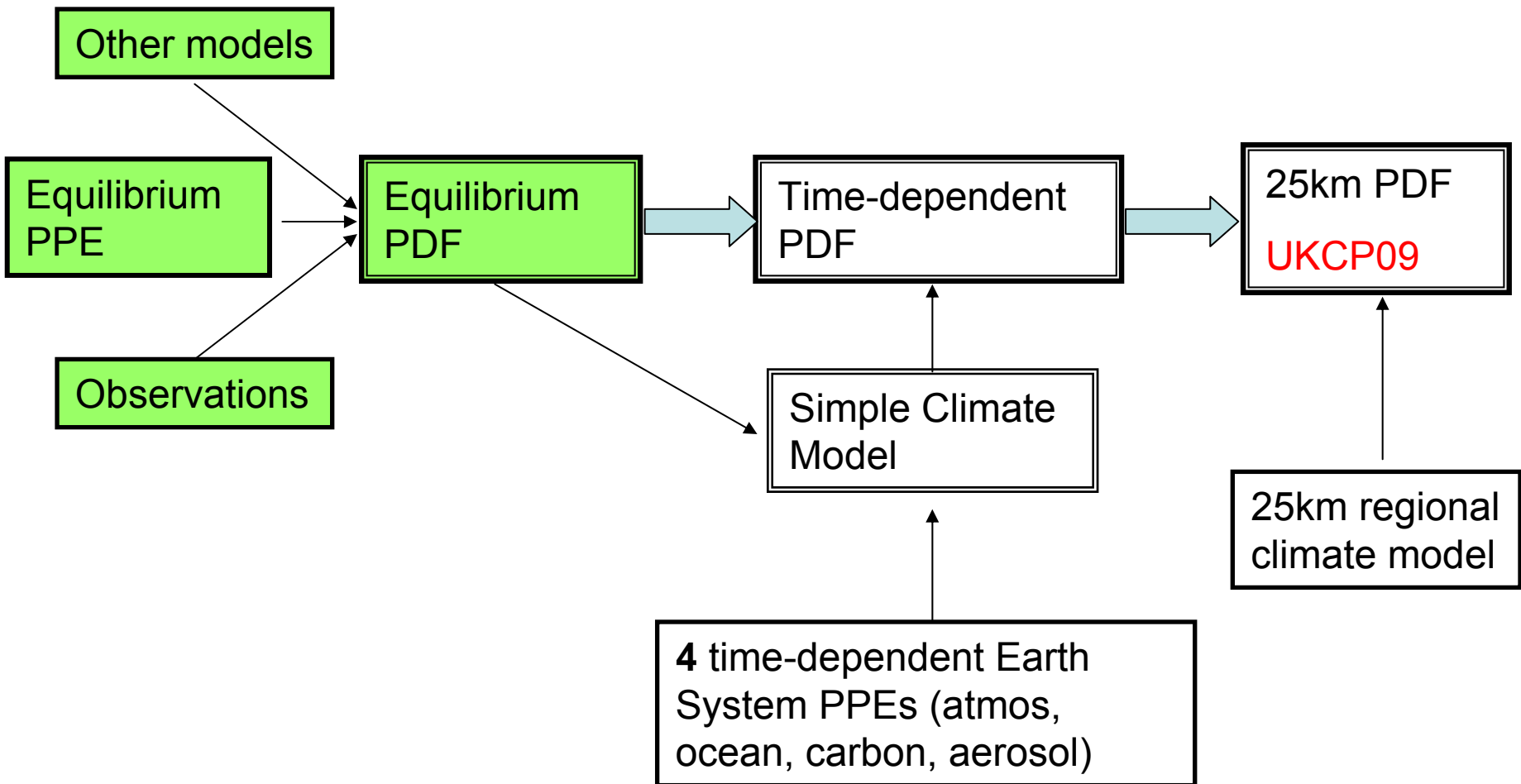




# Production of UKCP09 predictions



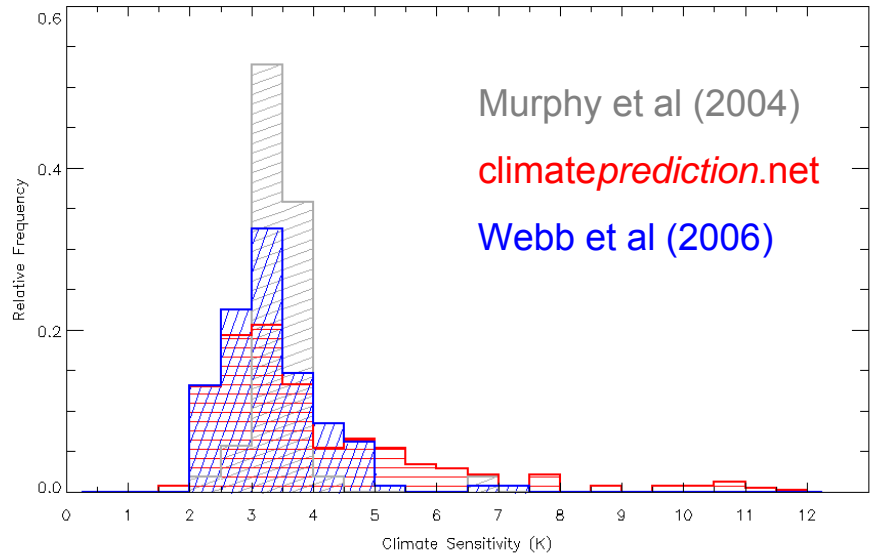
# Stage 1: Uncertainty in equilibrium response



# 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)

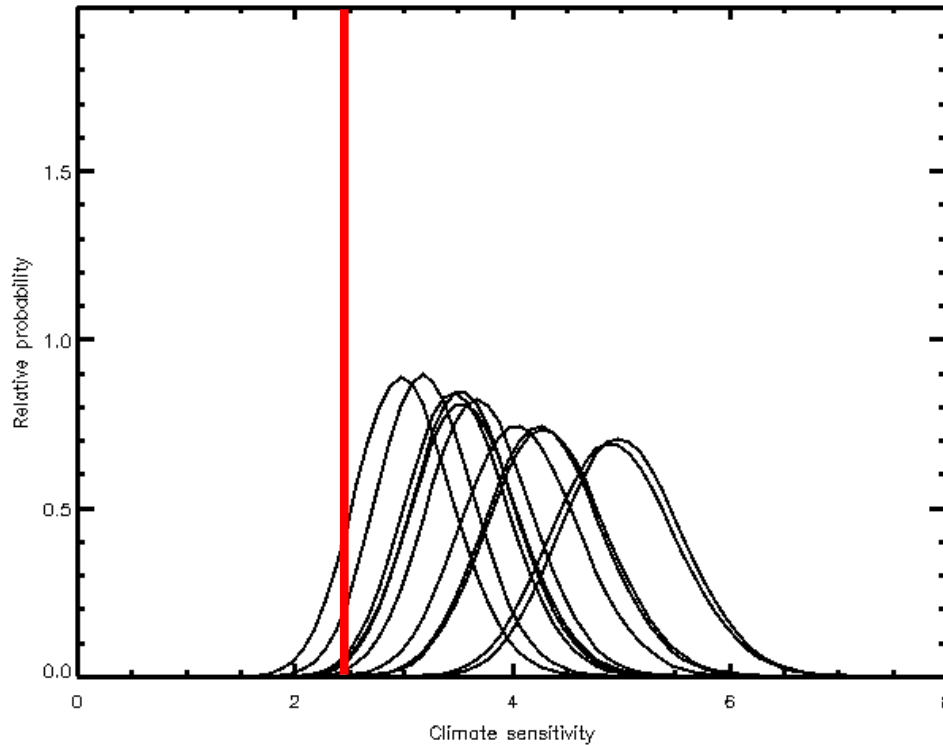
# Emulators



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

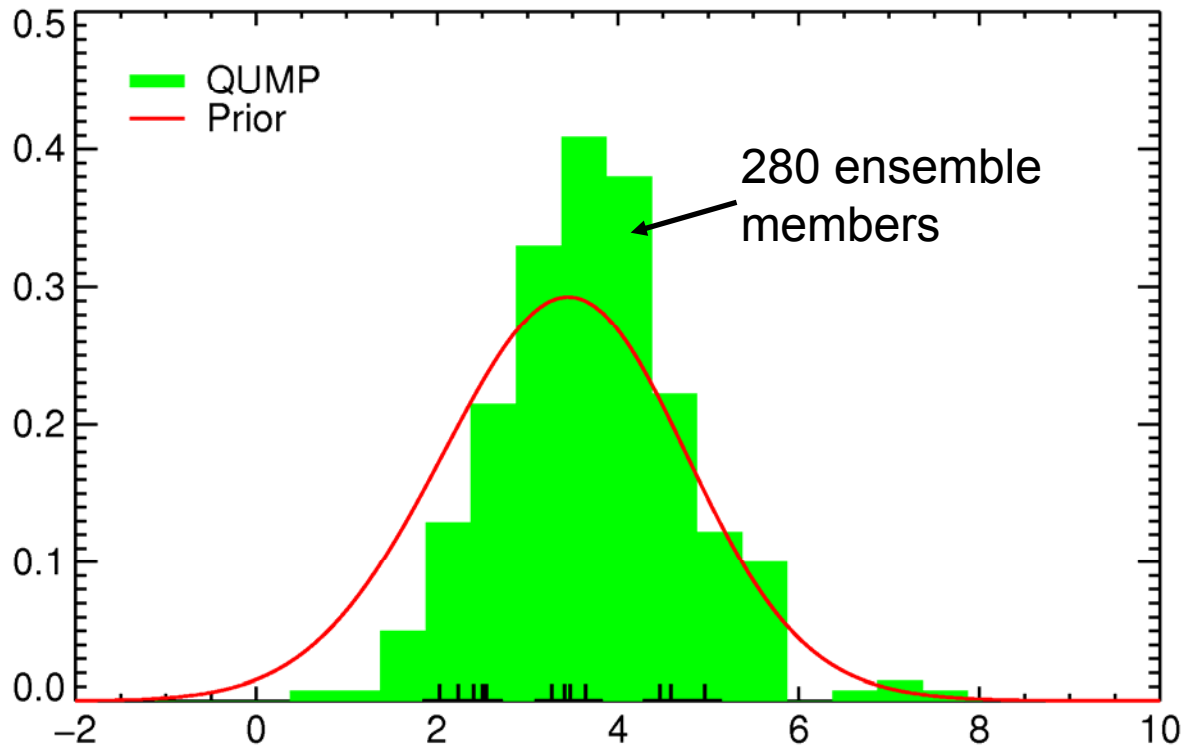
# Emulators



**Emulated  
distributions for  
10 different  
samples of  
combinations  
of parameter  
values**

# Prior PDF

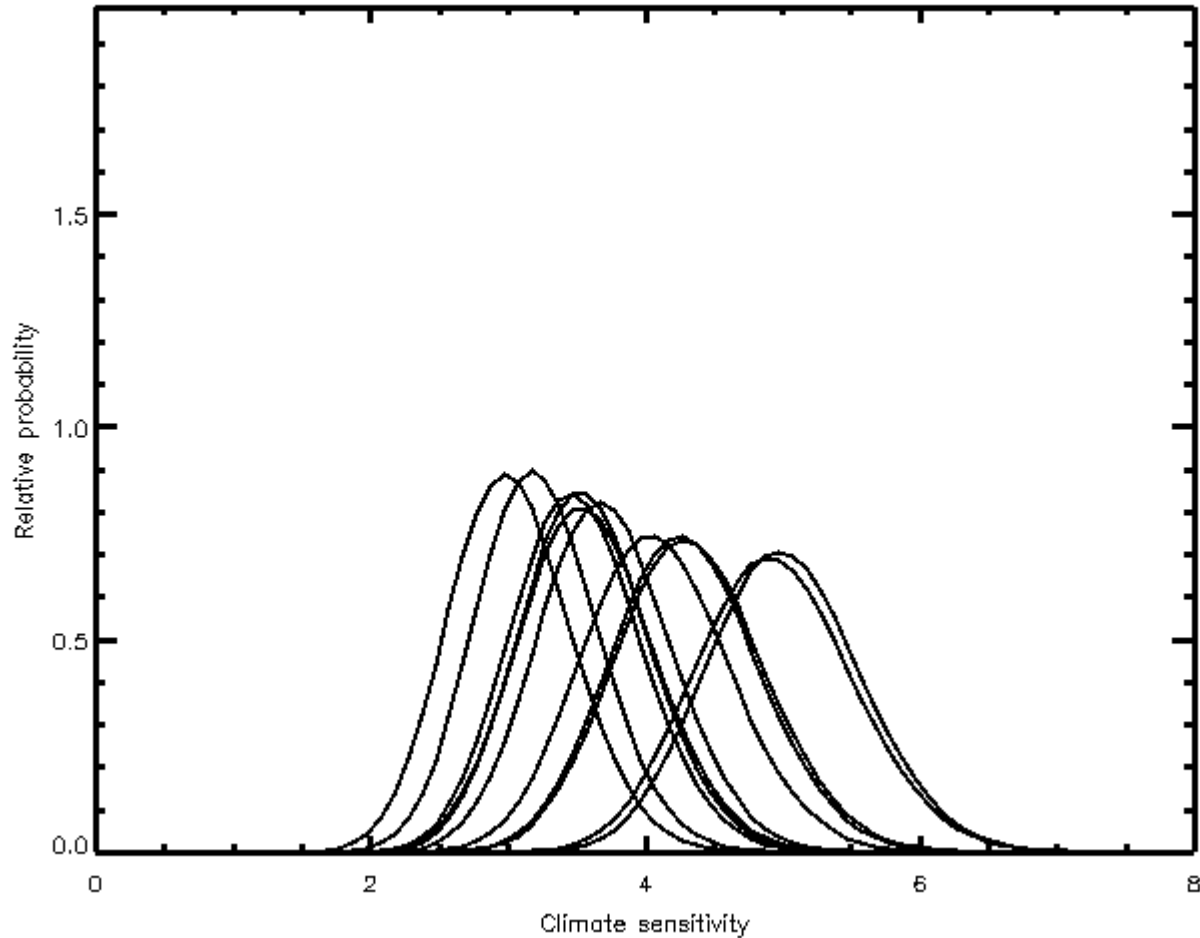
March mean TEMPERATURE AT 1.5M  
North England



# Constraining predictions with observations

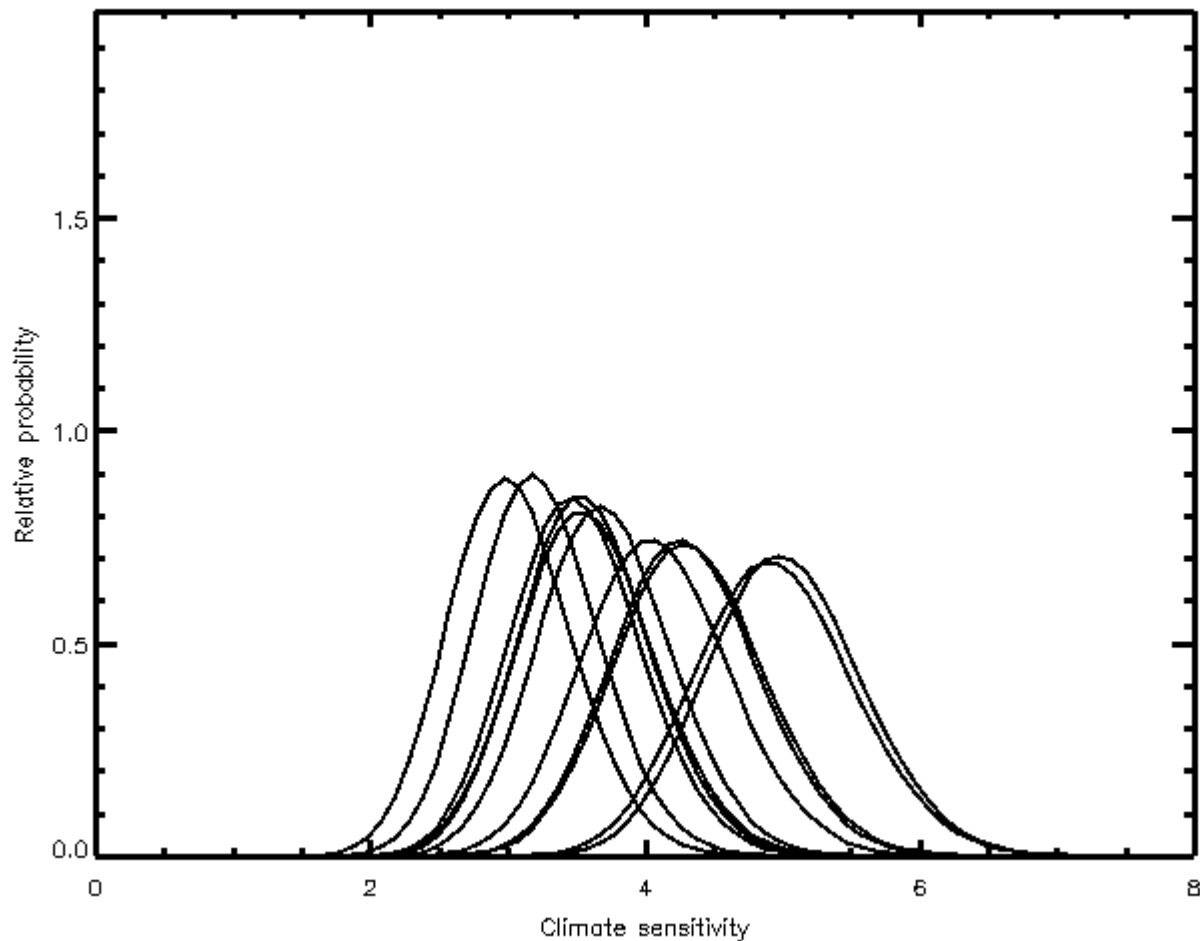
- Weight prediction towards higher quality parts of parameter space
- No verification or hindcasting possible so we are limited to this use of the observations
- Use 6 metrics for how well emulated variants are capturing important simultaneous variations in several climate mean variables. This reduces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

# Weighting different model variants



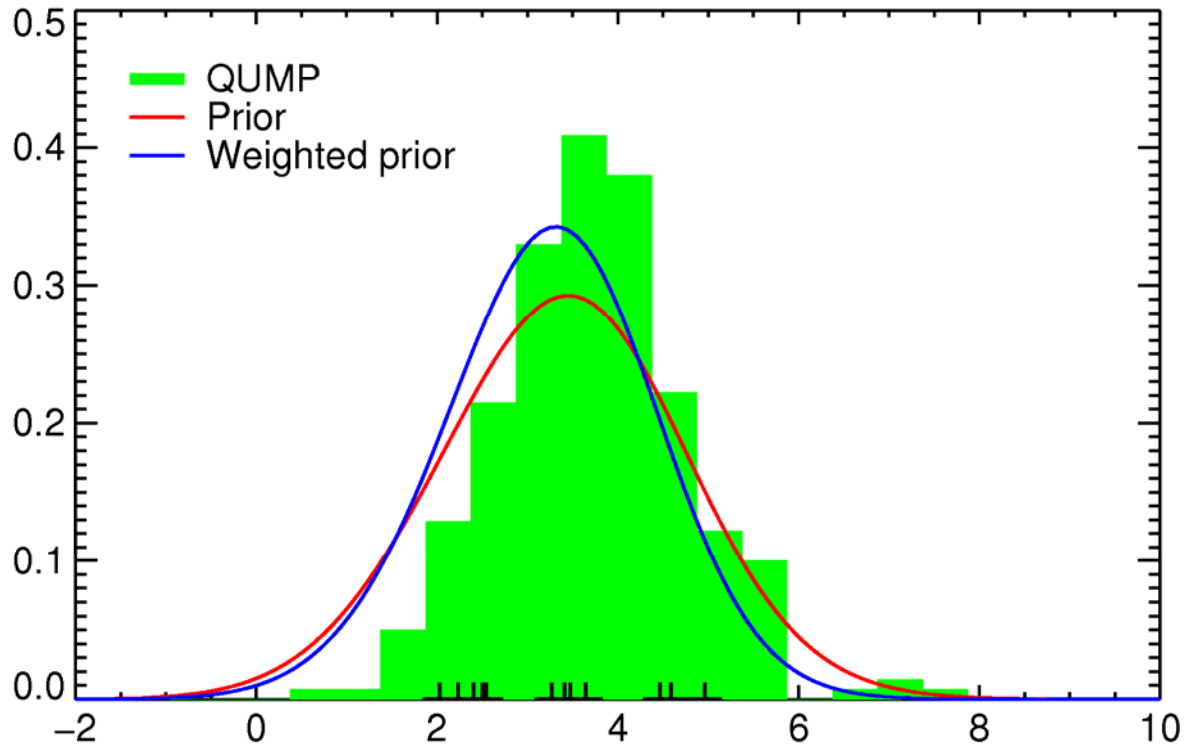


# Weighting different model variants

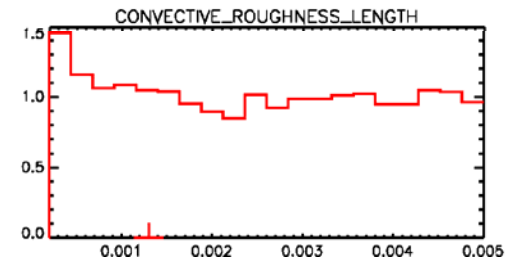
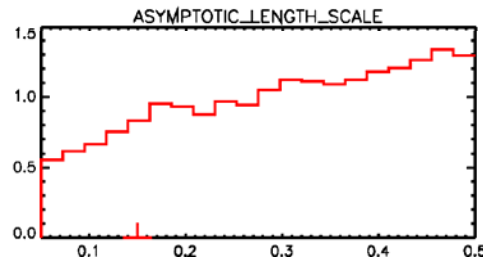
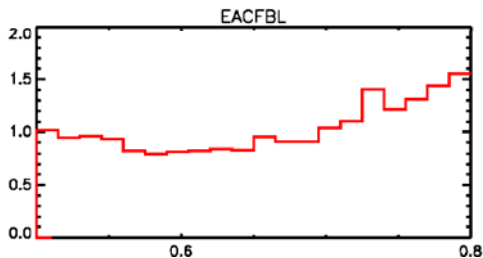
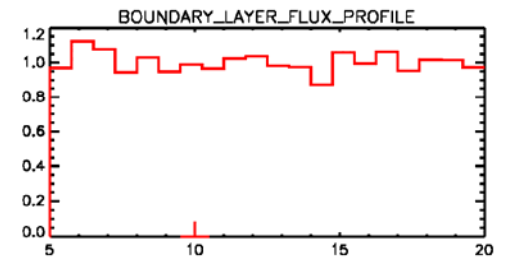
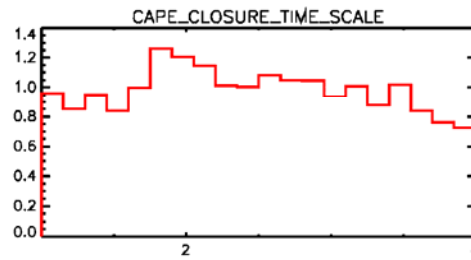
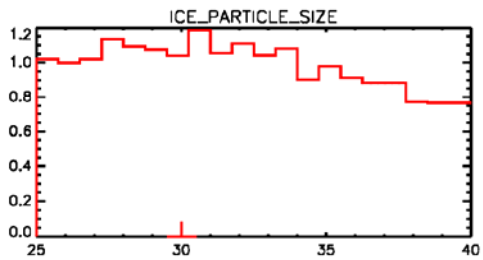
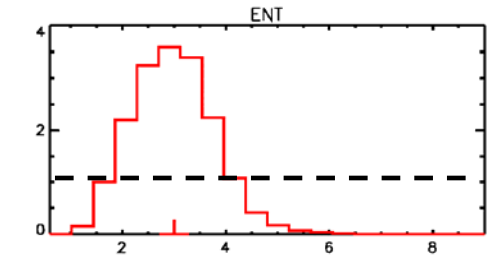
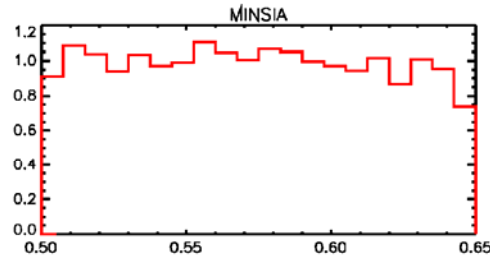
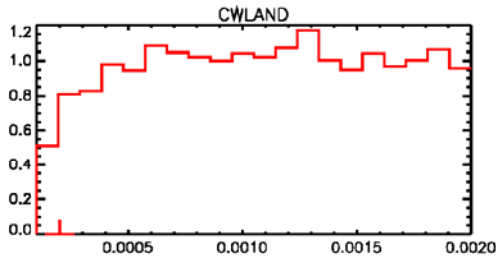
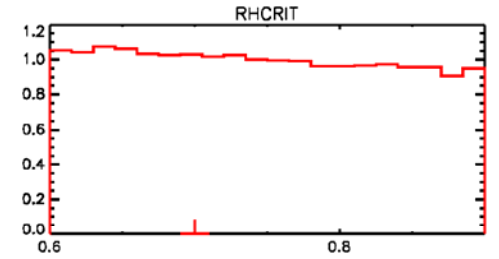
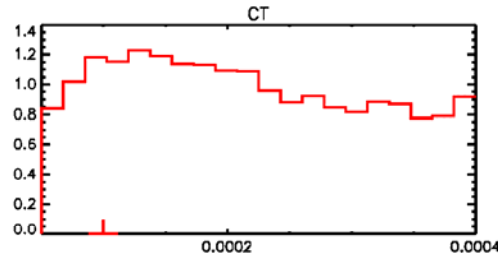
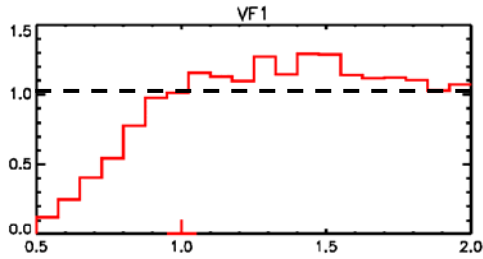


# Weighted PDF

March mean TEMPERATURE AT 1.5M  
North England



# Constraining parameters

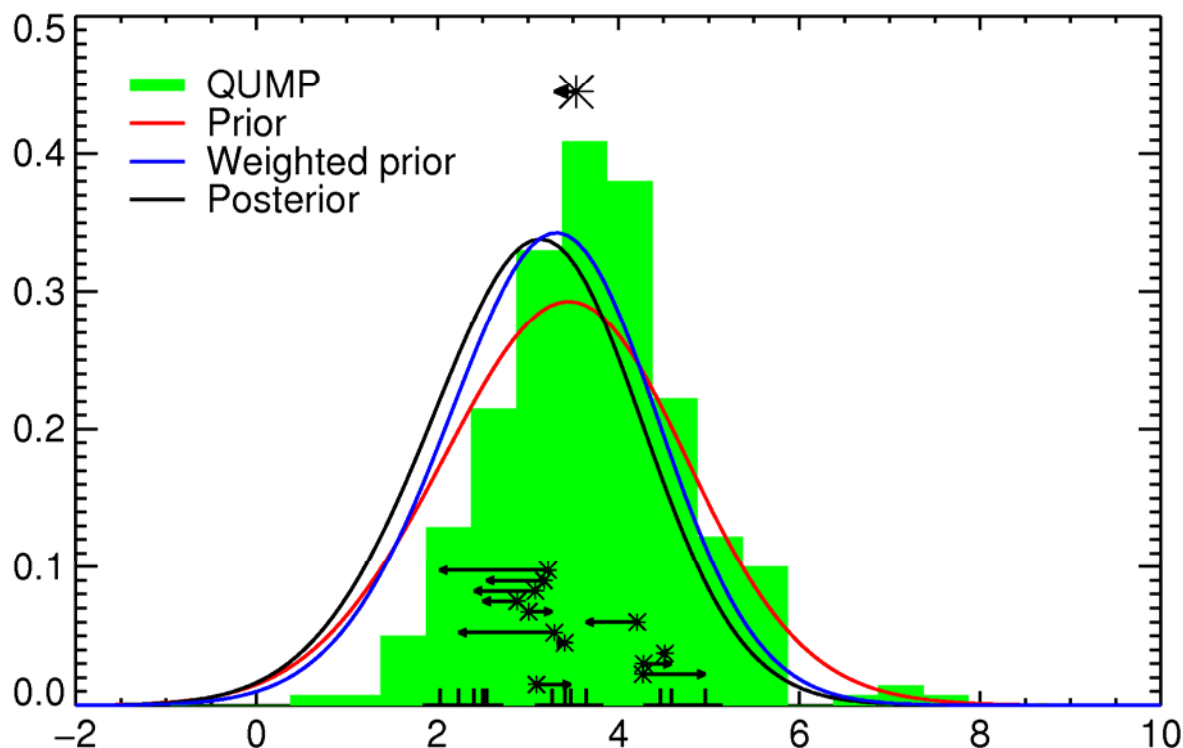


# Model imperfections

- 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

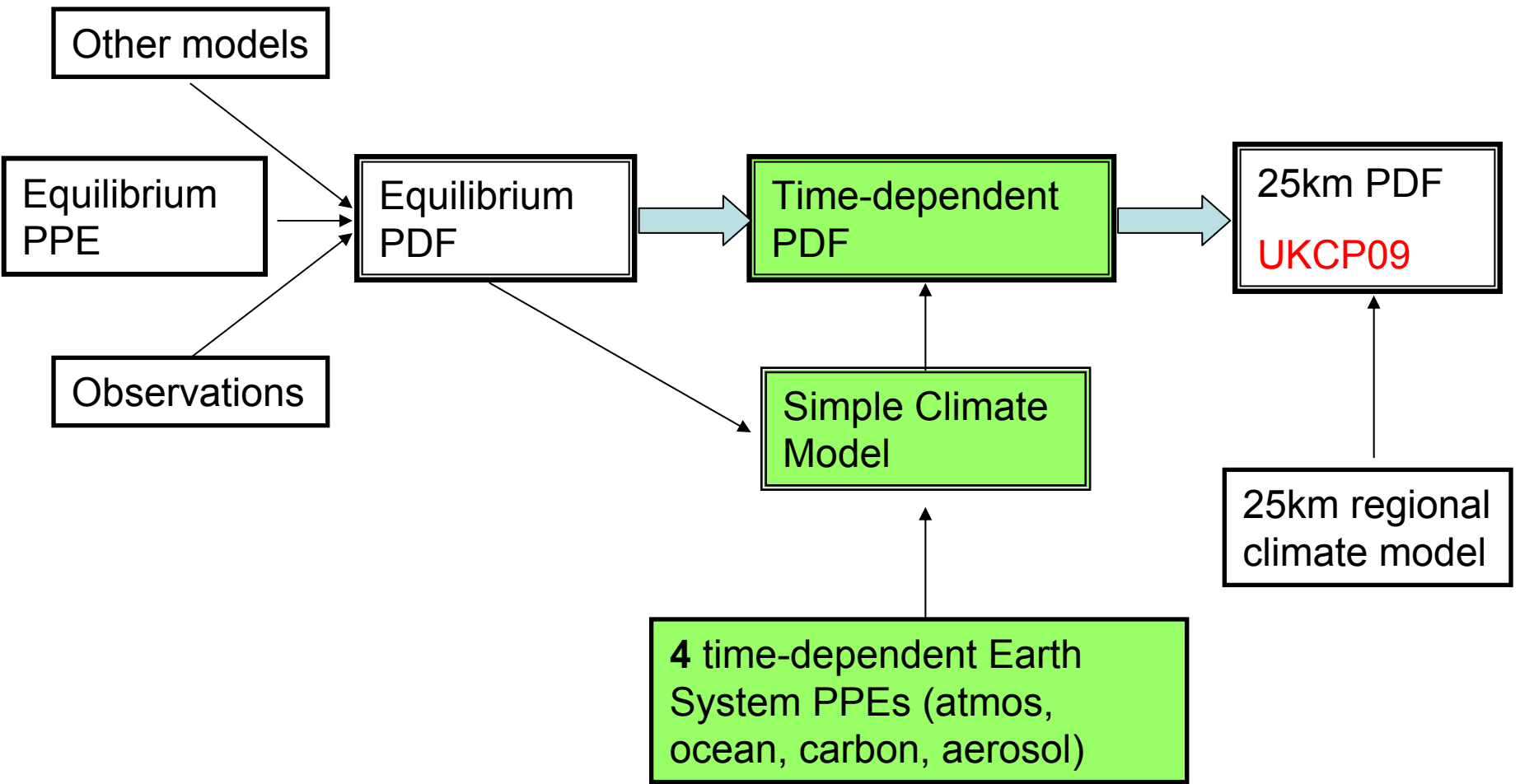
March mean TEMPERATURE AT 1.5M  
North England



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

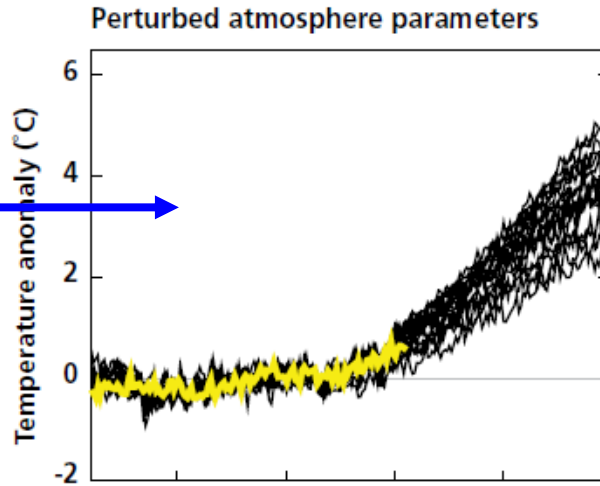
# Stage 2: Time Scaling

(Glen Harris and Penny Boorman)



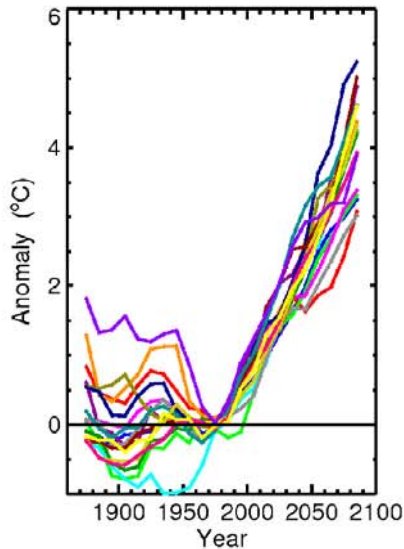
# Ensembles of coupled ocean-atmosphere runs

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

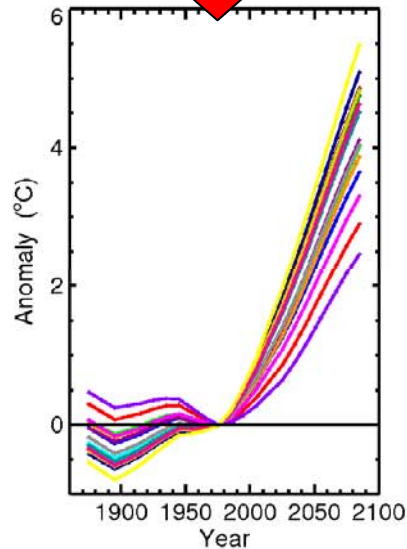


# Time-scaling diagnosis: Northern England summer surface temperature response

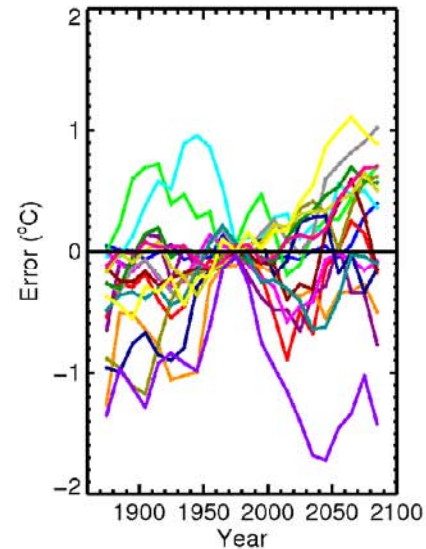
Scaled output =  $\Delta\text{SCM global temp}(t) \times \text{equilibrium response} / \Delta\text{eqm global temp}$



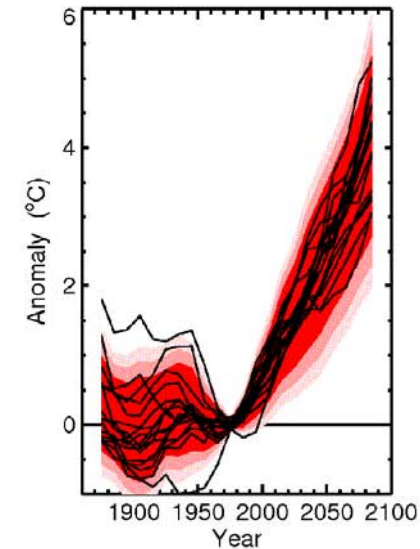
Raw GCM data



Scaled output from Simple Climate Model



Scaled output minus raw GCM data



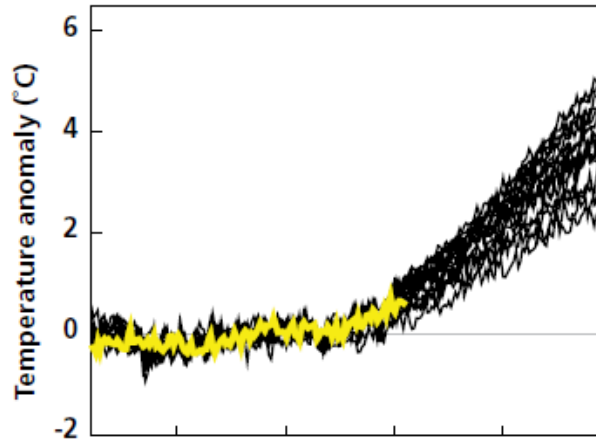
Plume for the 17 runs

**NOTE: this is not UKCP09**

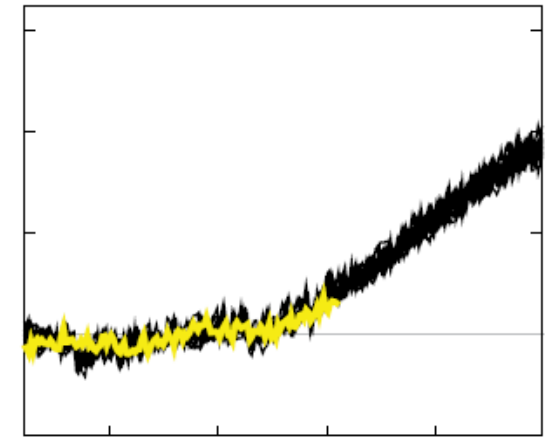


# Ensembles for other Earth System components

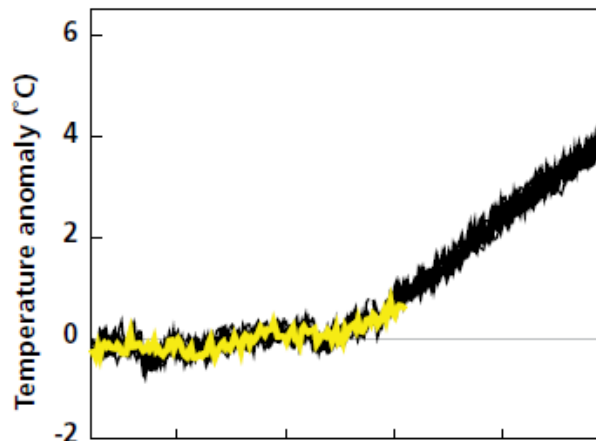
Perturbed atmosphere parameters



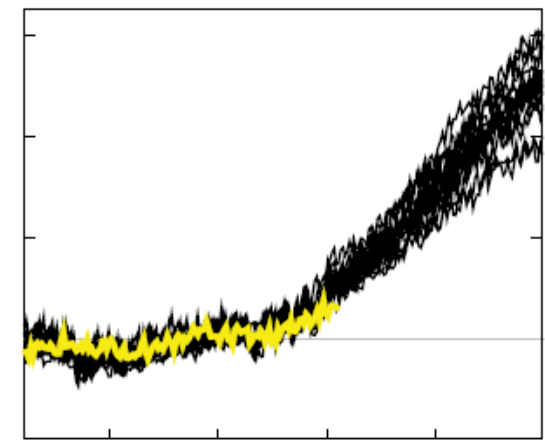
Perturbed ocean parameters



Perturbed sulphur cycle parameters



Perturbed carbon cycle parameters



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

1900 1950 2000 2050

Year

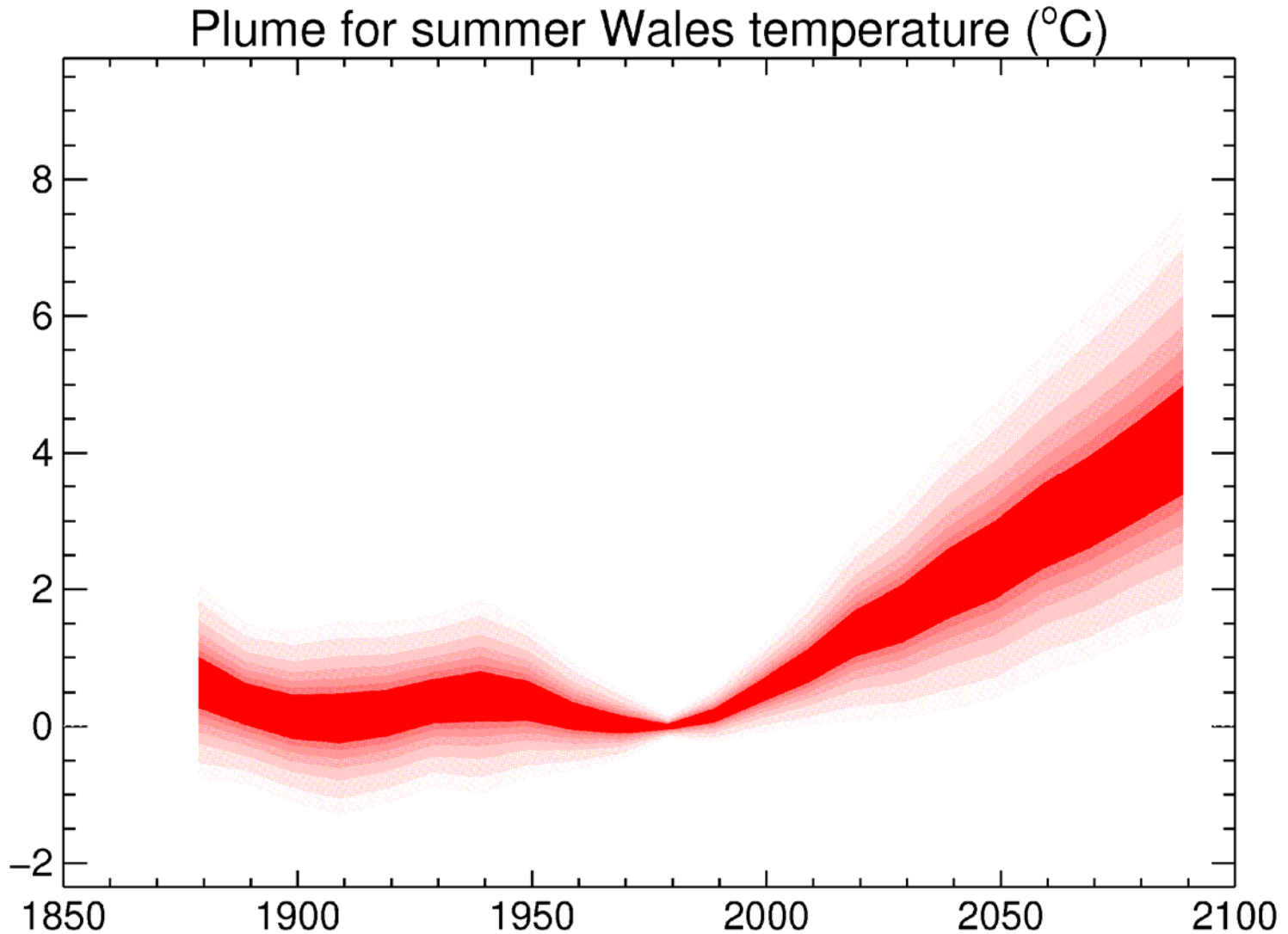
1900 1950 2000 2050

Year

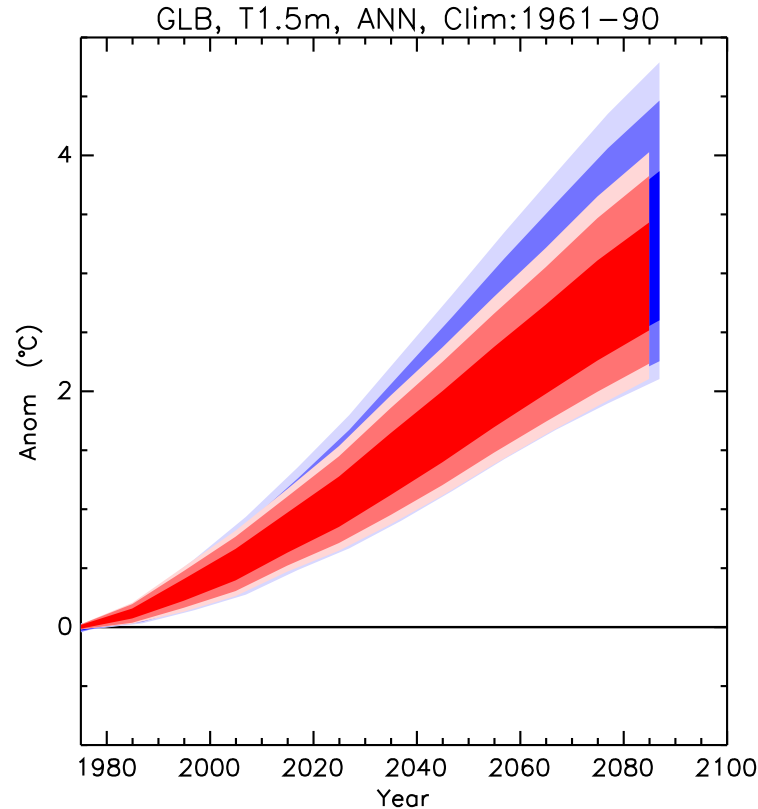
# Making time-dependent PDFs

- 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



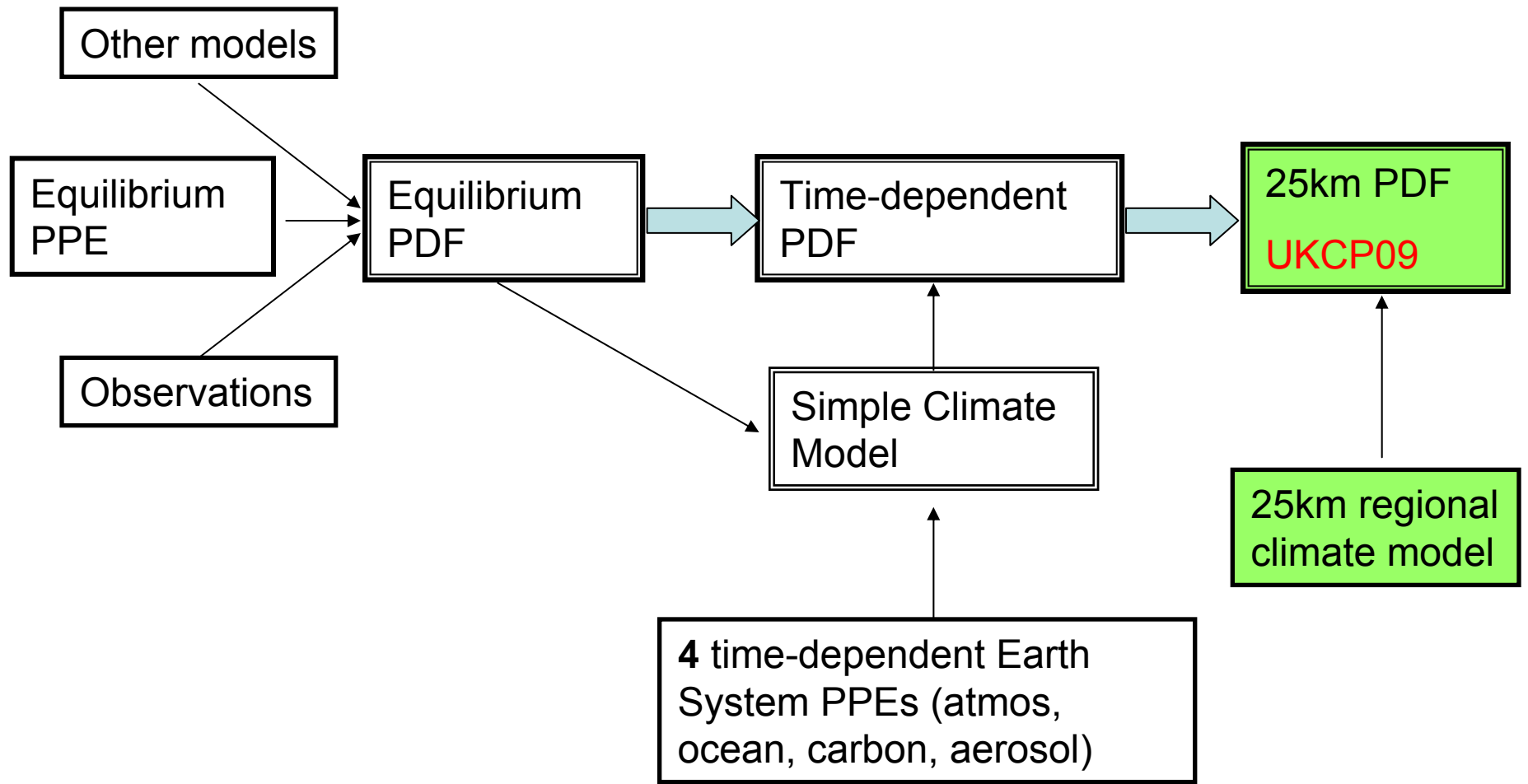
# Carbon cycle uncertainty compared with atmospheric feedback uncertainty



Sampling of carbon cycle feedbacks  
**included /**  
**not included**

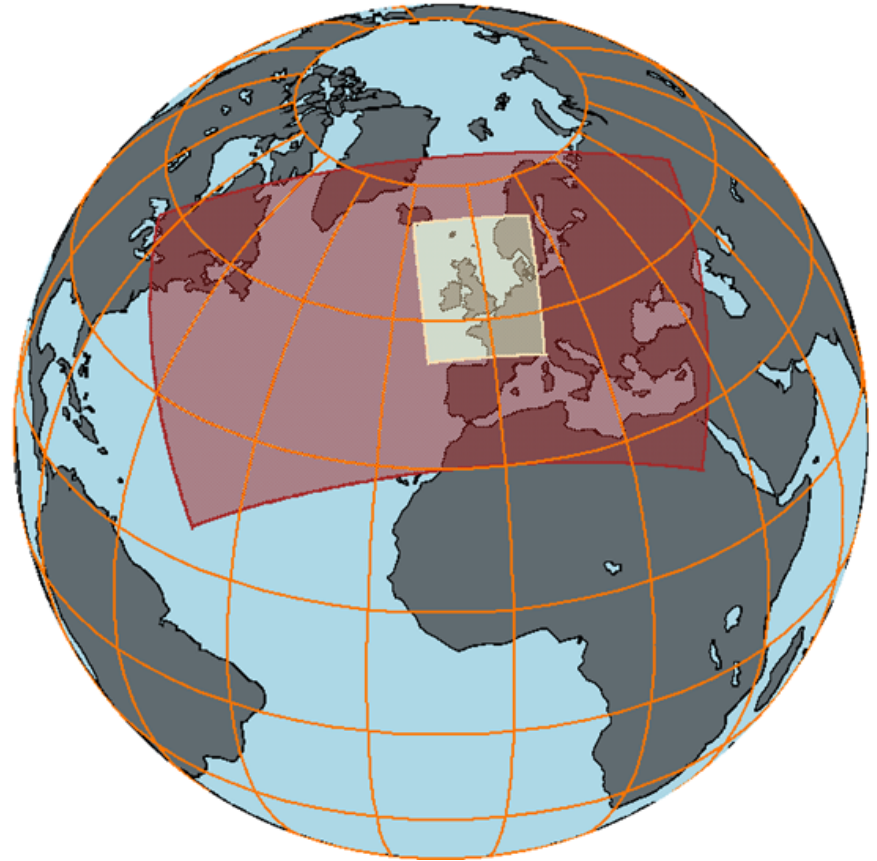
- By including carbon cycle, spread increased by ~40%, median increases by 0.23 °C.
- Corroborated by C4MIP analysis (Huntingford et al., 2009, Tellus).

# Stage 3: Downscaling (Kate Brown)



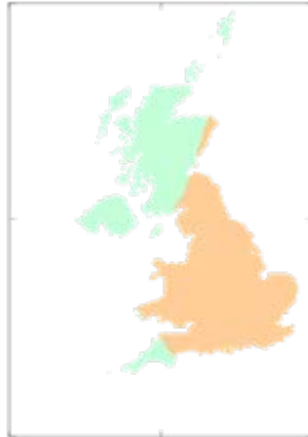
# Dynamical downscaling

- 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

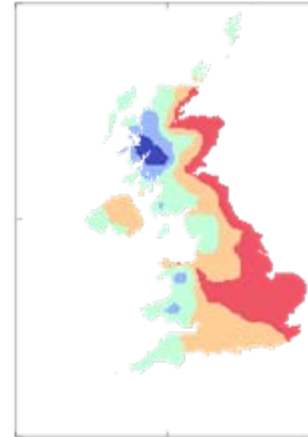


# Dynamical downscaling

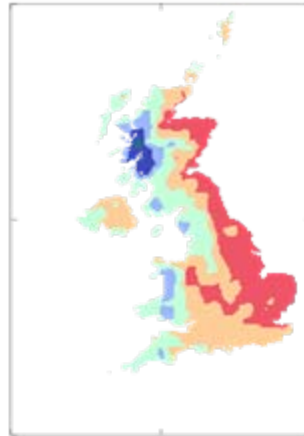
300km Global Model



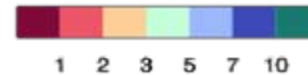
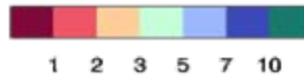
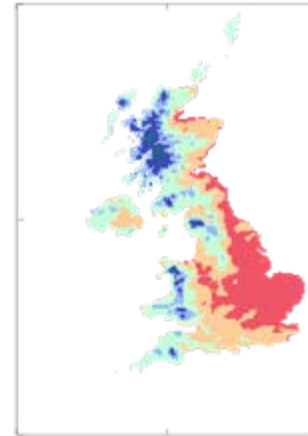
50km Regional Model



25km Regional Model



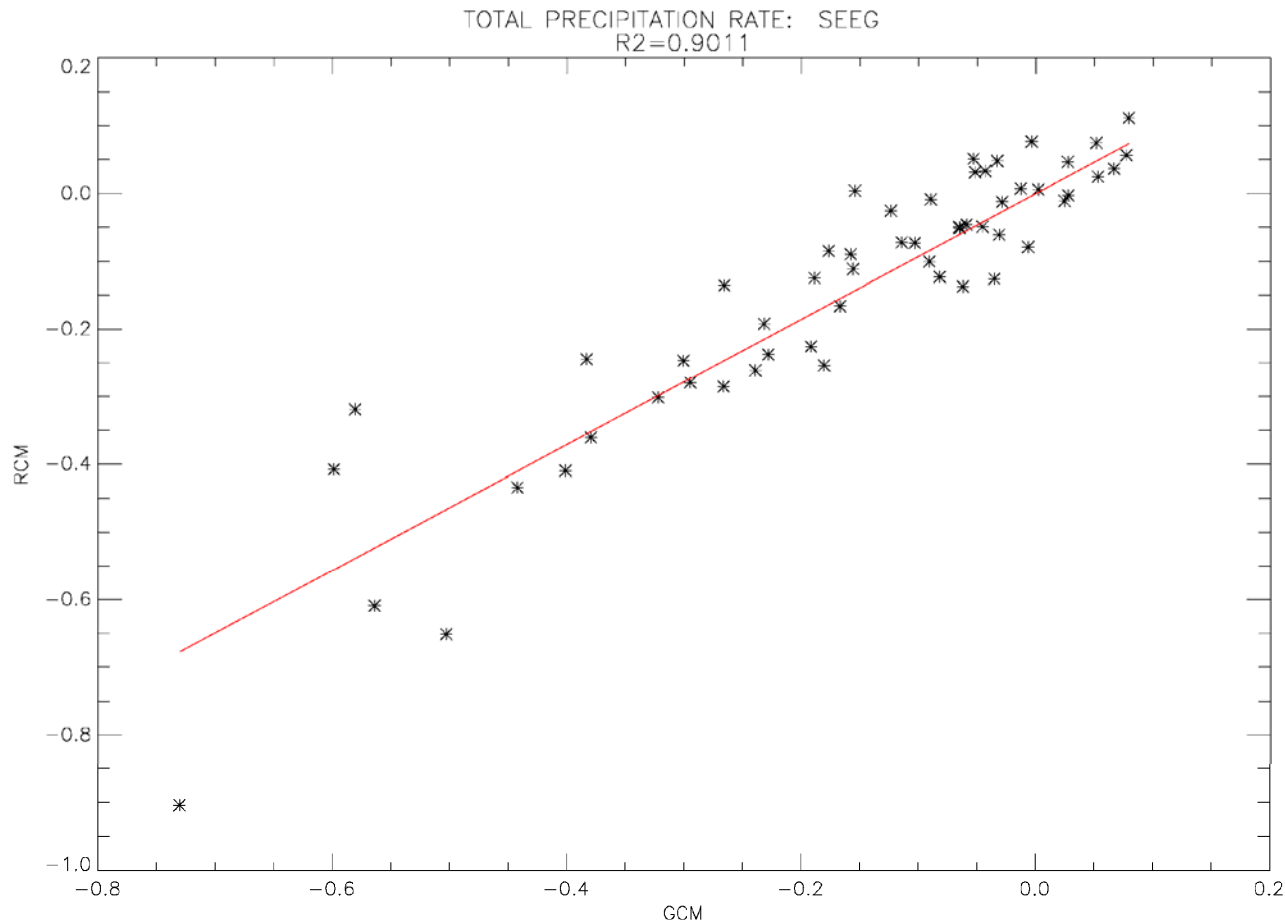
5km Observed



Winter precipitation for 1961-2000

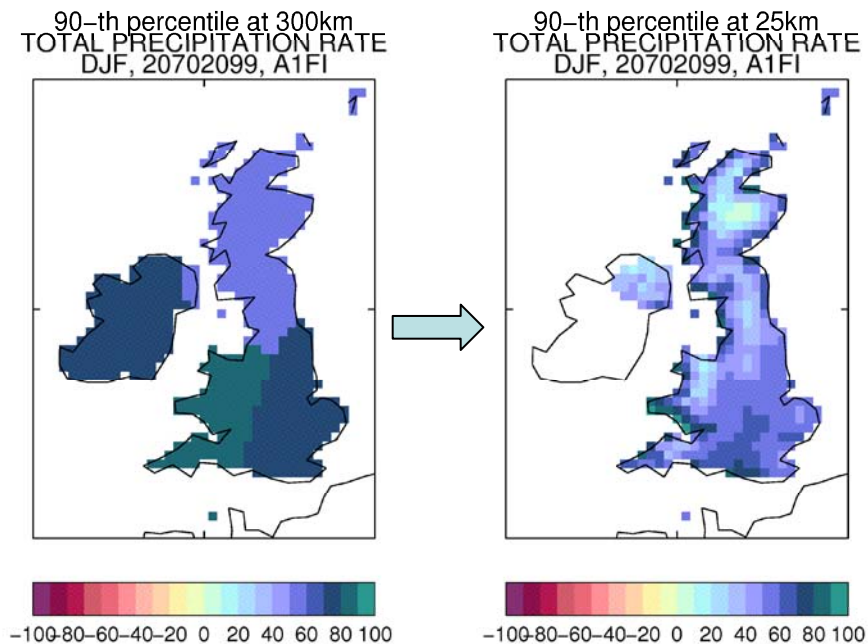
# Change in log(summer precipitation) over SE England

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





# Adding information at 25km scale

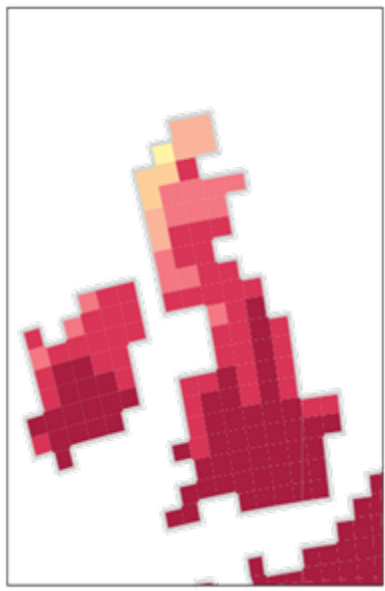


- High resolution regional climate model projections are used to account for the local effects of coastlines, mountains, and other regional influences.
- They add skilful detail to large scale projections from global climate model projections, but also inherit errors from them.

# Moving from uncertainty to probability

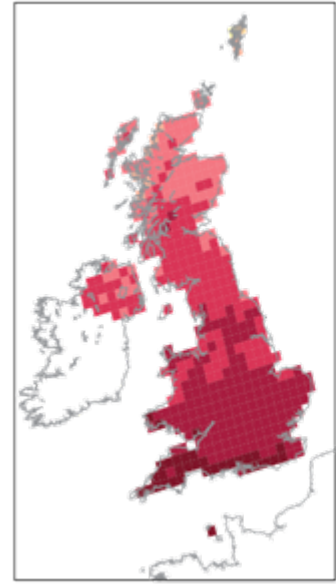
**UKCIP02**

**UKCP09**

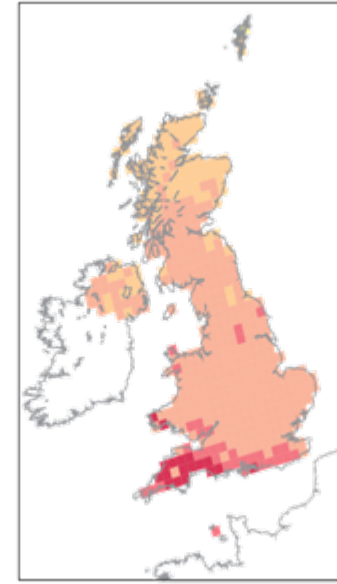


Summer Rainfall 2080's

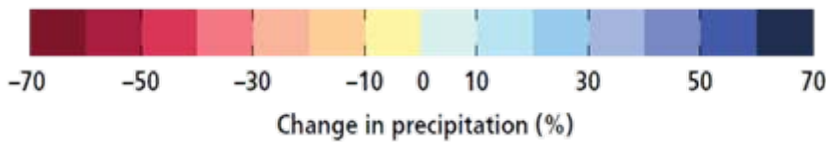
10%



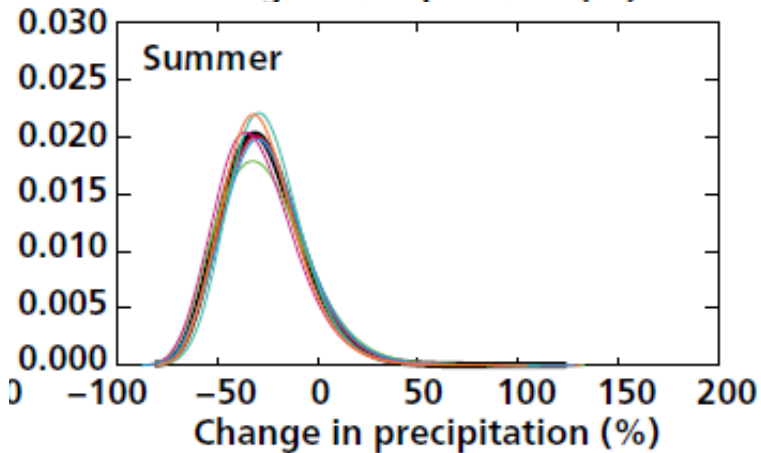
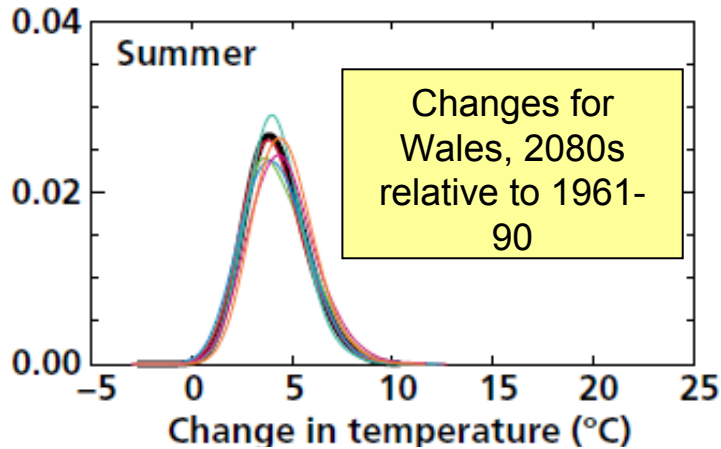
50%



90%



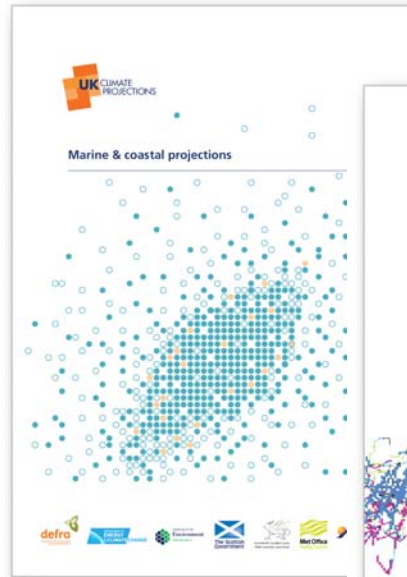
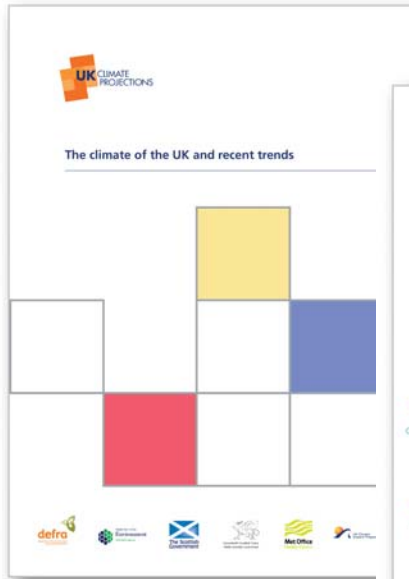
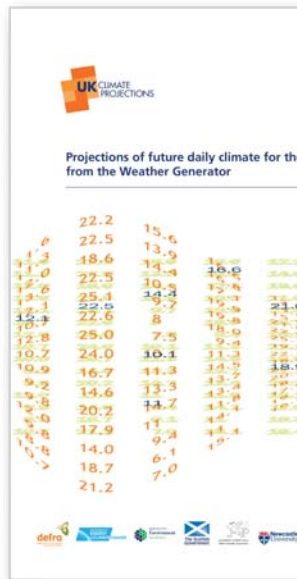
# Testing robustness



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

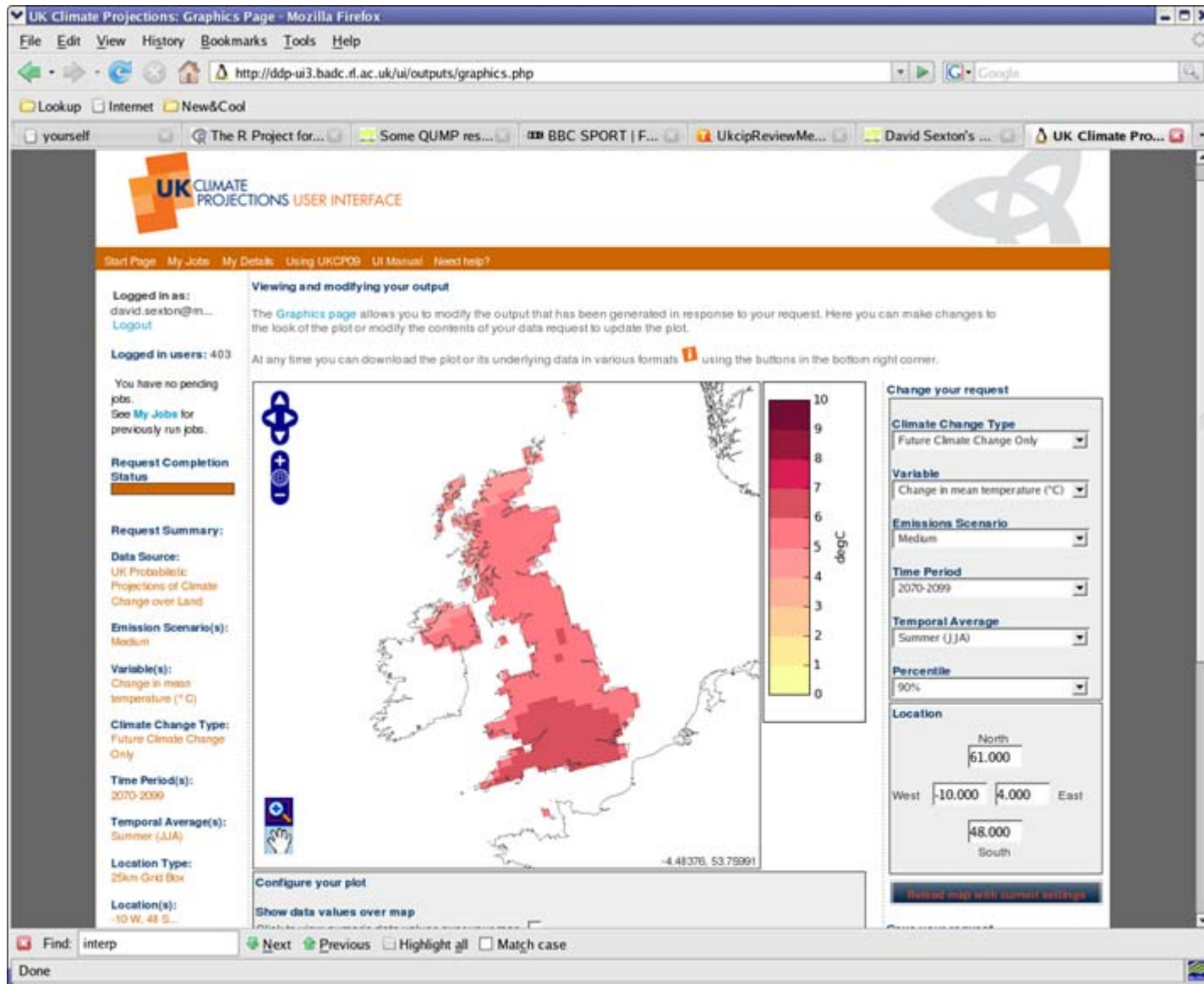
- |  |  |
|--|--|
|  UKCP09                       |  x2 discrepancy         |
|  Uniform prior                |  Inflated uniform prior |
|  x0.5 discrepancy             |  Five eigenvectors      |
|  No low resolution multimodel |  |

# UKCP09 Products



# User Interface

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



The screenshot shows the 'UK Climate Projections USER INTERFACE' in a Mozilla Firefox browser window. The page title is 'UK Climate Projections: Graphics Page - Mozilla Firefox'. The address bar shows the URL: <http://ddp-ui3.badc.rl.ac.uk/ui/outputs/graphics.php>. The browser tabs include 'yourself', 'The R. Project for...', 'Some QUMP res...', 'BBC SPORT | F...', 'UkcipReviewMe...', 'David Sexton's ...', and 'UK Climate Pro...'. The page content includes a navigation bar with links: 'Start Page', 'My Jobs', 'My Details', 'Using UKCPO9', 'UI Manual', and 'Need help?'. The main content area is titled 'Viewing and modifying your output' and contains the following sections:

- Logged in as:** david.sexton@im... [Logout](#)
- Logged in users:** 403
- Request Completion Status**
- Request Summary:**
  - Data Source:** UK Probabilistic Projections of Climate Change over Land
  - Emission Scenario(s):** Medium
  - Variable(s):** Change in mean temperature (°C)
  - Climate Change Type:** Future Climate Change Only
  - Time Period(s):** 2070-2099
  - Temporal Average(s):** Summer (JJA)
  - Location Type:** 25km Grid Box
  - Location(s):** -10 W, 48 S...
- Change your request**
  - Climate Change Type:** Future Climate Change Only
  - Variable:** Change in mean temperature (°C)
  - Emissions Scenario:** Medium
  - Time Period:** 2070-2099
  - Temporal Average:** Summer (JJA)
  - Percentile:** 90%
  - Location:** North: 61.000, West: -10.000, East: 4.000, South: 48.000
- Map:** A map of the United Kingdom showing a color-coded overlay representing temperature change. A legend on the right indicates values from 0 to 10 degC. The map shows a color gradient from yellow (0) to dark red (10) across the UK.
- Configure your plot:**
  - Show data values over map

The browser's search bar at the bottom contains the text 'Find: interp'. The status bar at the bottom left shows 'Done'.

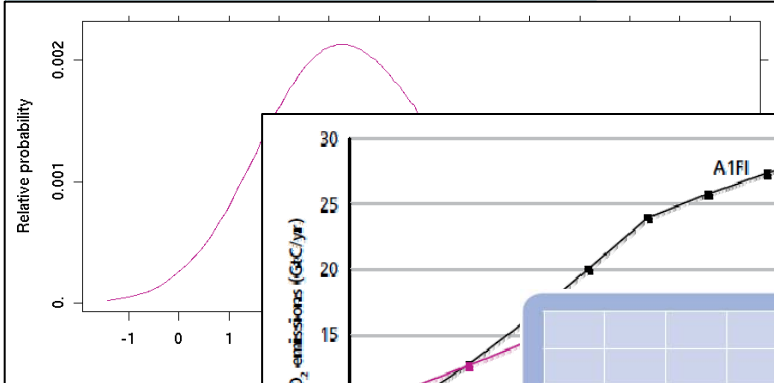
# 5-dimensional problem

Variables and months

Variables over land areas

Mean temperature
Mean daily maximum temperature
Mean daily minimum temperature

Uncertainty



Three different emission scenarios

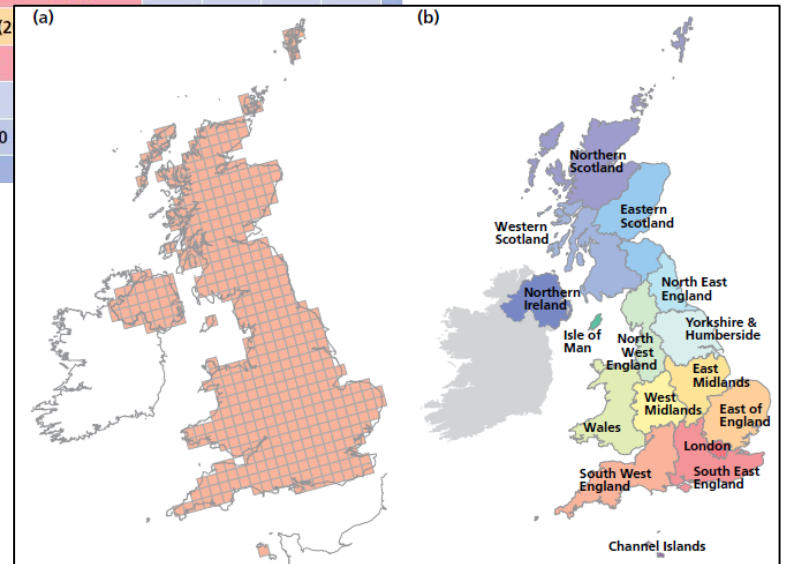
Seven different timeframes

relative humidity

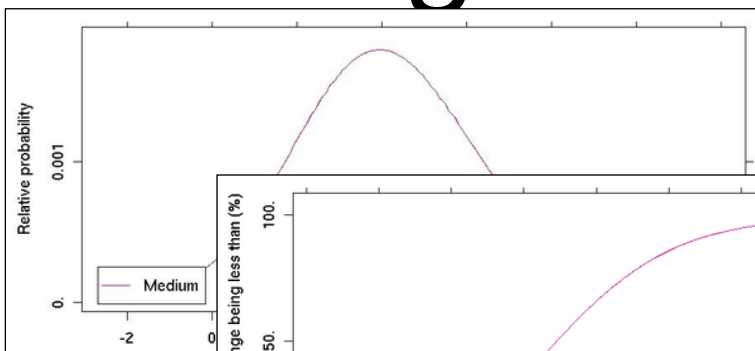
Total cloud
Net surface long wave flux
Net surface short wave flux
Total downward short wave flux
Mean sea level pressure



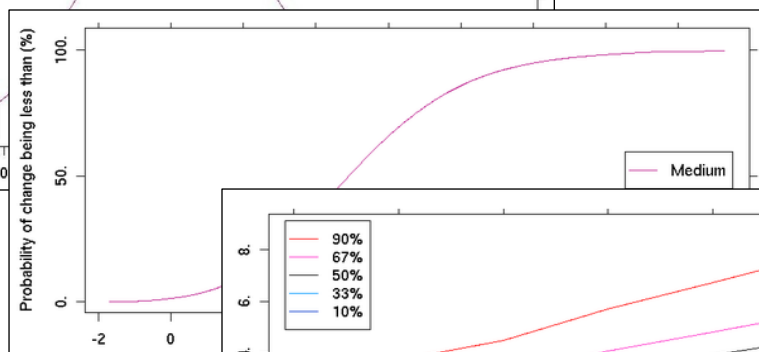
25km grid, 16 admin regions, 23 river-basins and 9 marine regions



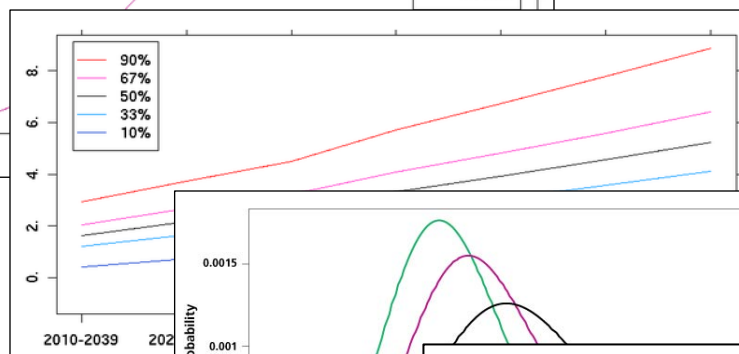
# Providing probabilities in a range of formats



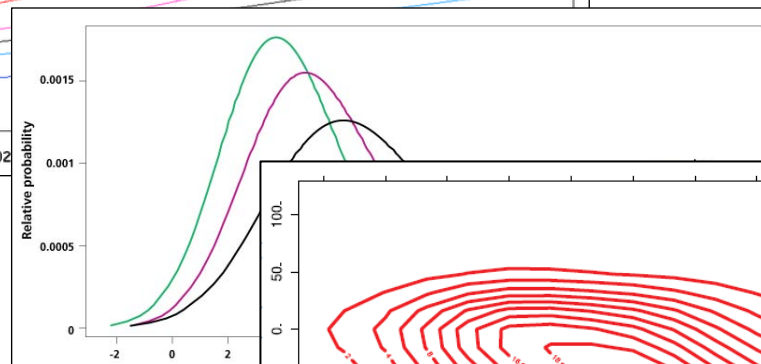
Probability density Functions



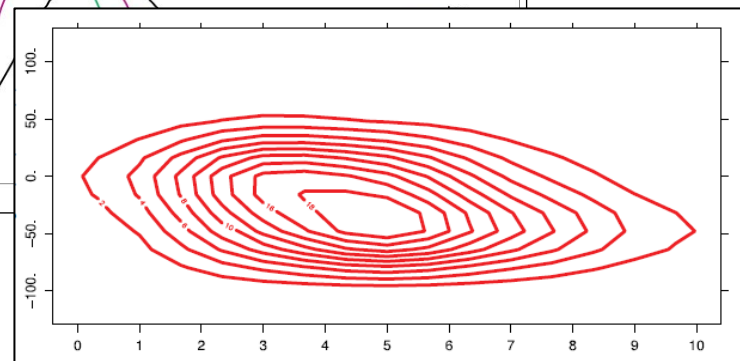
Cumulative distribution Functions



Plume plots over time



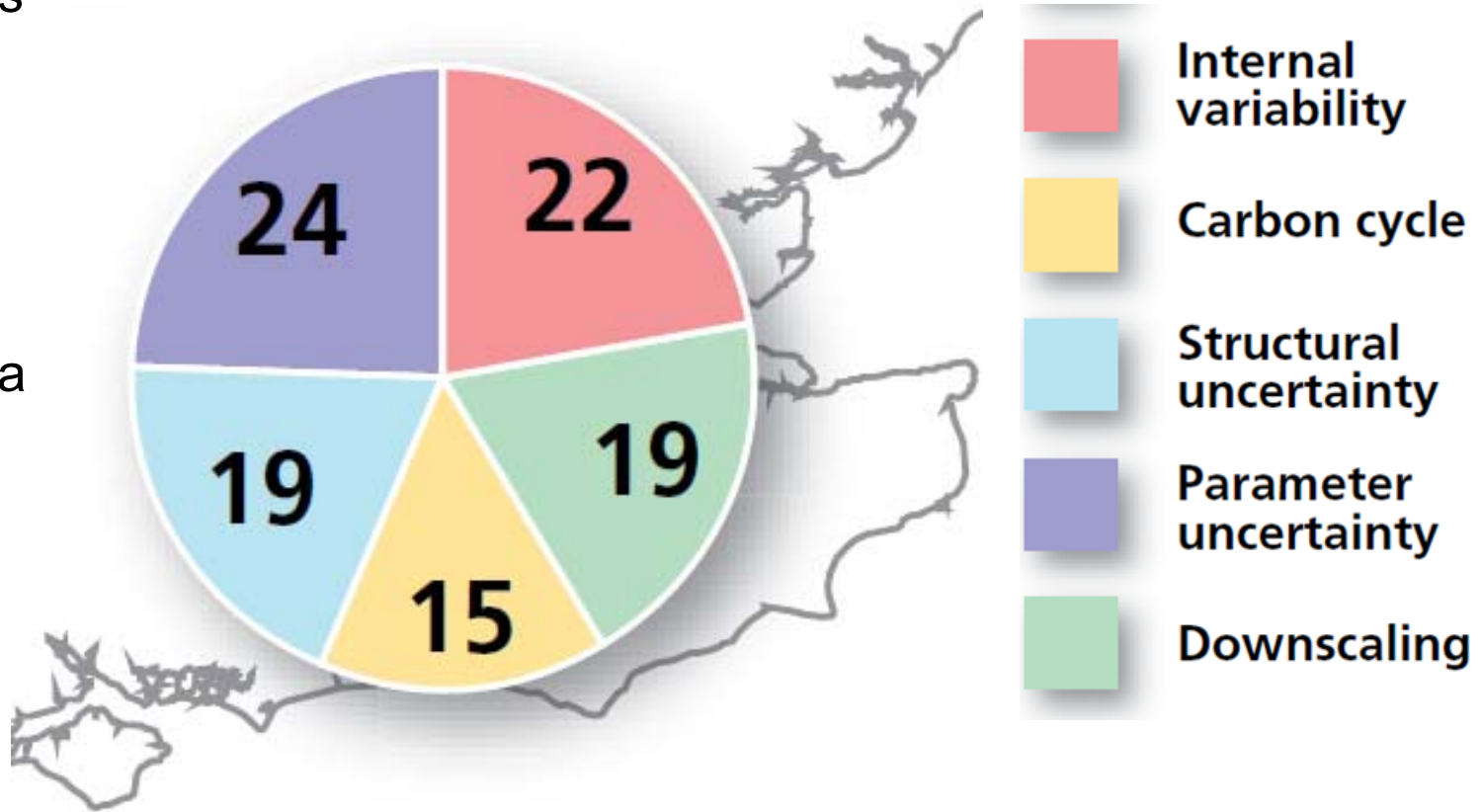
PDFs for range of emission scenarios



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

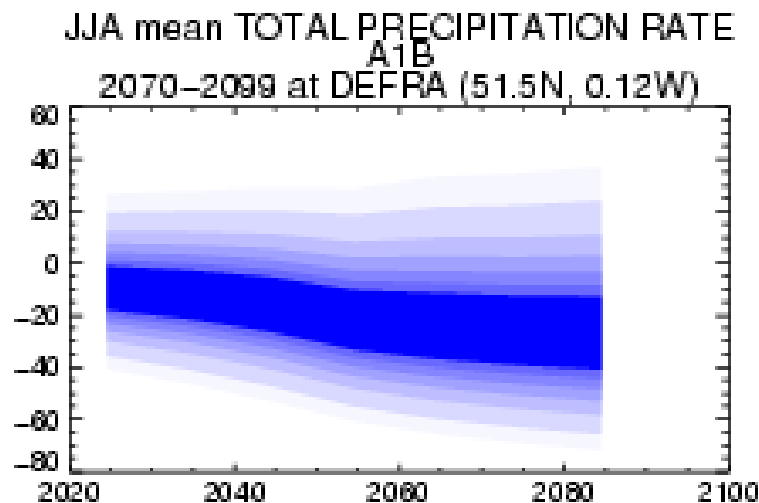
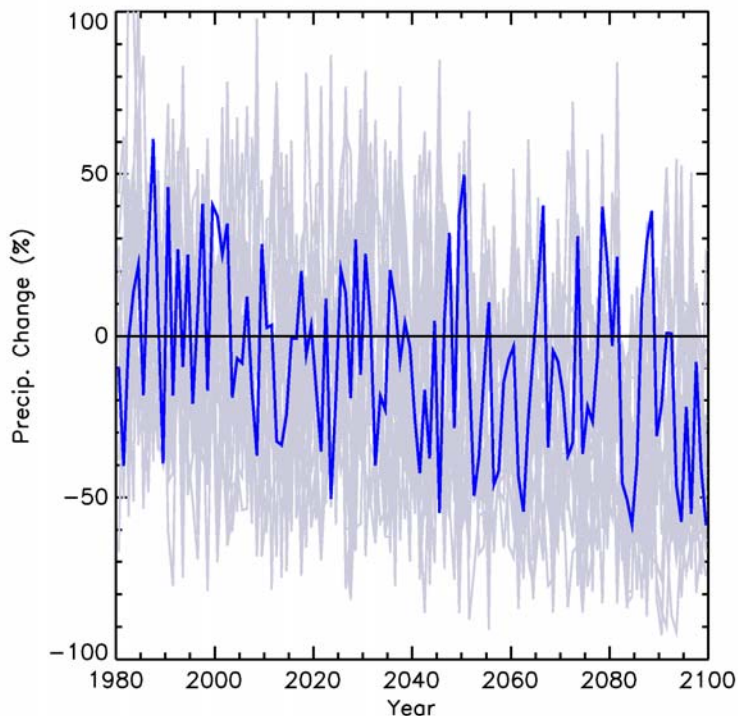


New information, methods, experimental design can reduce uncertainty so projections will change in future and decision makers need to consider this



# 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?