The UK Climate Projections 2009 (UKCP09)

David Sexton

IMAGe TOY Integrated Uncertainty Workshop

8th August 2012

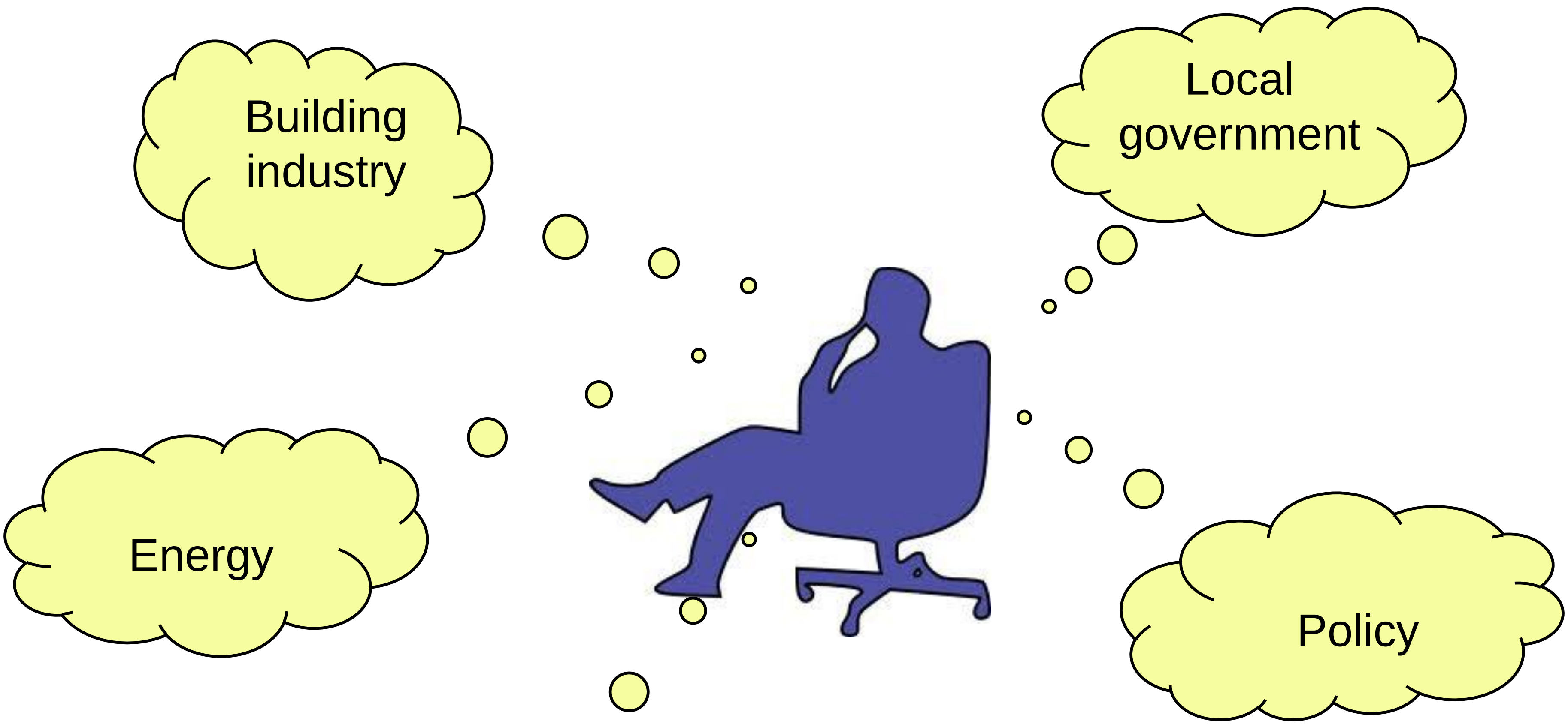
Contents

Met Office
Hadley Centre

- Introduction to UKCP09
- How was UKCP09 made
- Why UKCP09 is probabilistic and how should it be used
- Ways to improve UKCP09
- Does UKCP09 need updating yet?

Introduction to UKCP09

Users, decision makers, policy makers



To make a robust decision users need **multiple lines of evidence**

Met Office
Hadley Centre

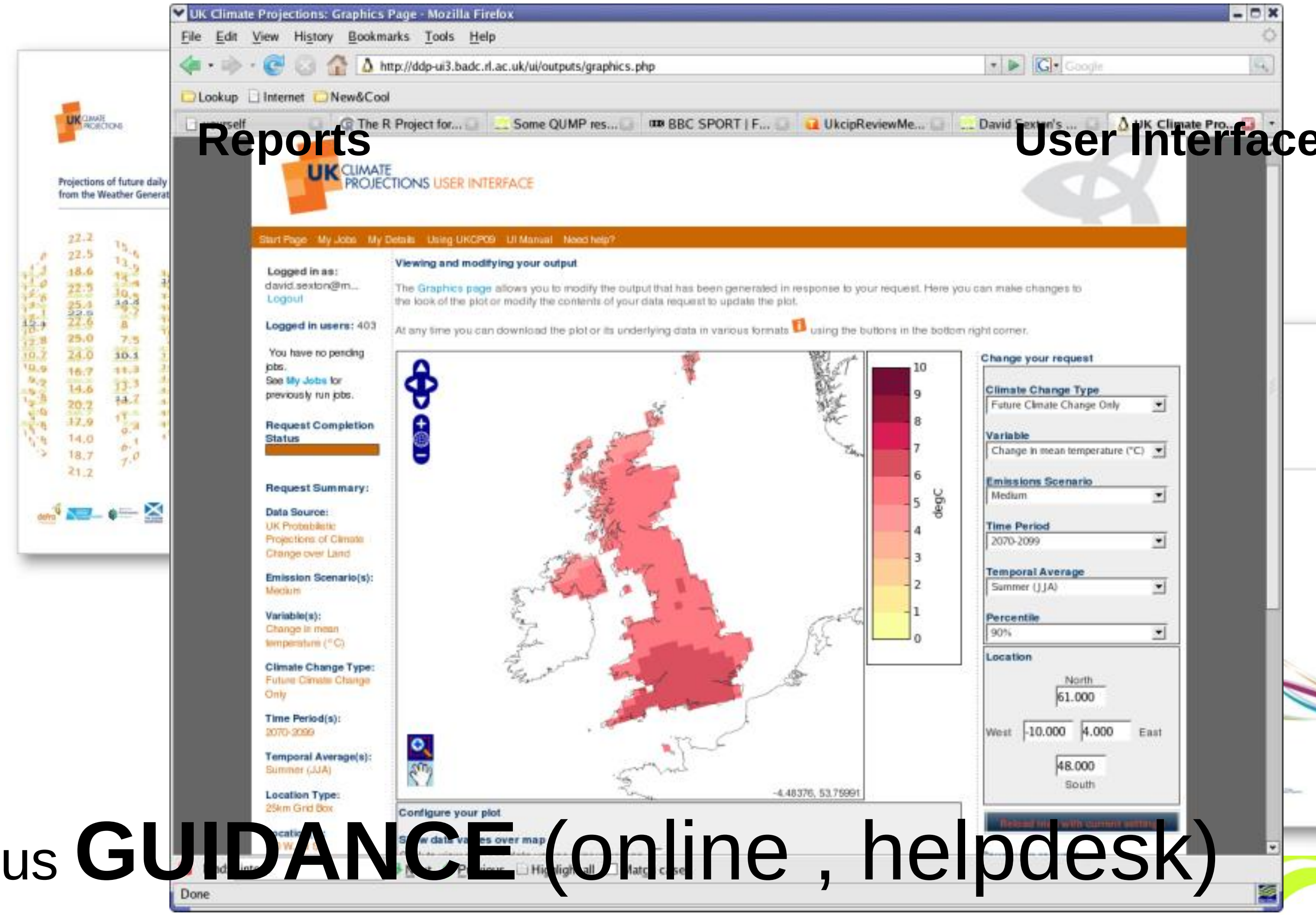
User requirements

- Wide range of sectors to cover so so a wide range of variables and time scales of interest
- Impacts are felt locally. Impacts models e.g. crop models or river flow, often need inputs at high spatial or temporal resolution, and/or spatially and temporally coherent data.
- There is a wide range of users and a wide range of sophistication in way which projections are used:
  - Impacts modellers
  - Climate consultants
  - Local government worker

Met Office
Hadley Centre

UKCP09 – the product

Reports **User Interface**



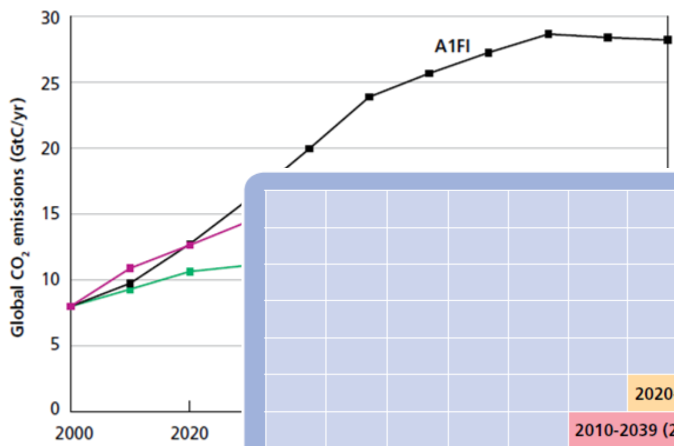
plus **GUIDANCE** (online , helpdesk)

Plus link to raw model data

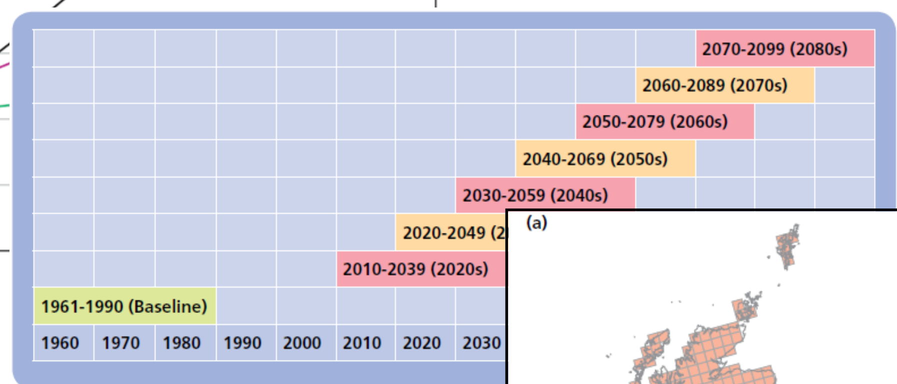
Met Office
Hadley Centre

Giving a range of information (from User Interface)

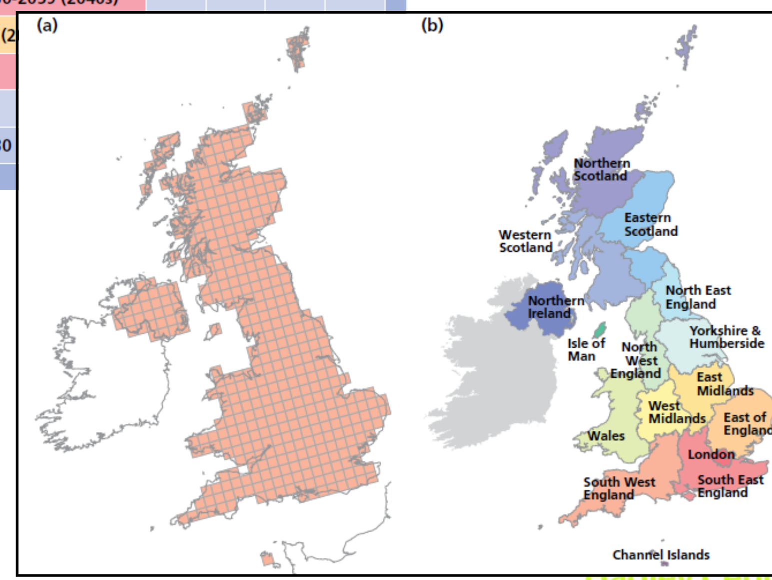
Several variables available for…



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

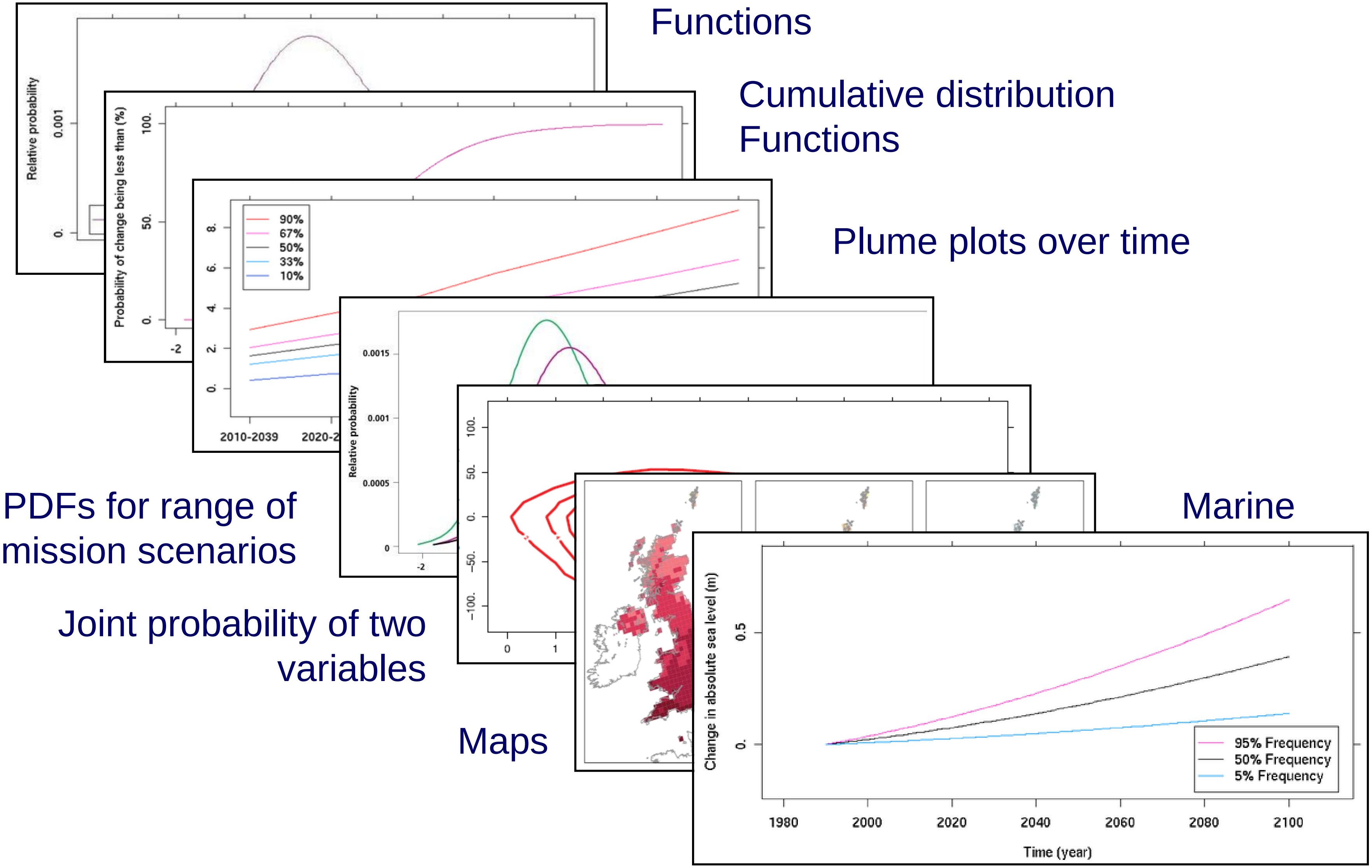
Plume plots over time

PDFs for range of emission scenarios

Joint probability of two variables

Maps

Marine

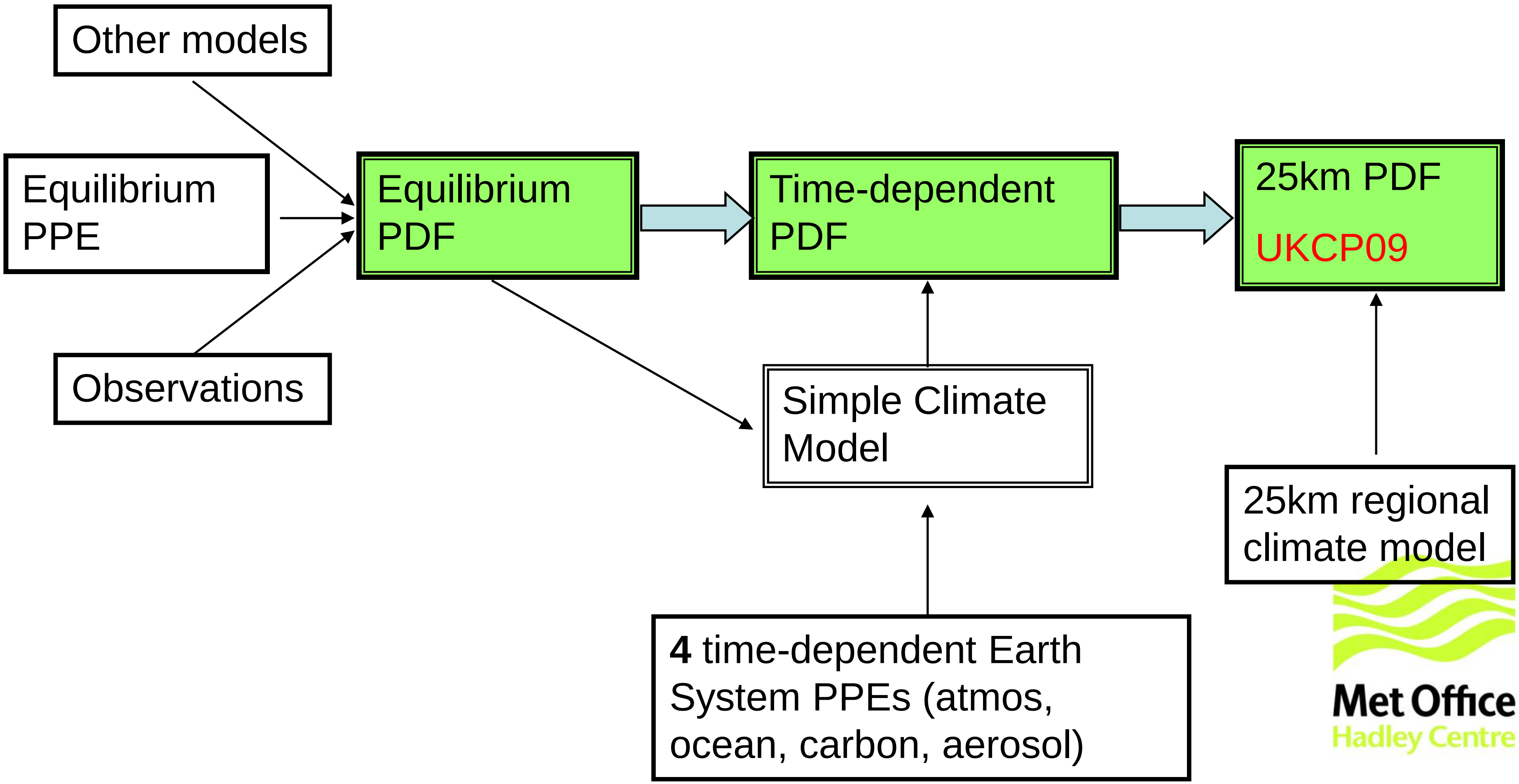


How UKCP09 was made

Uncertainties to quantify in UKCP09

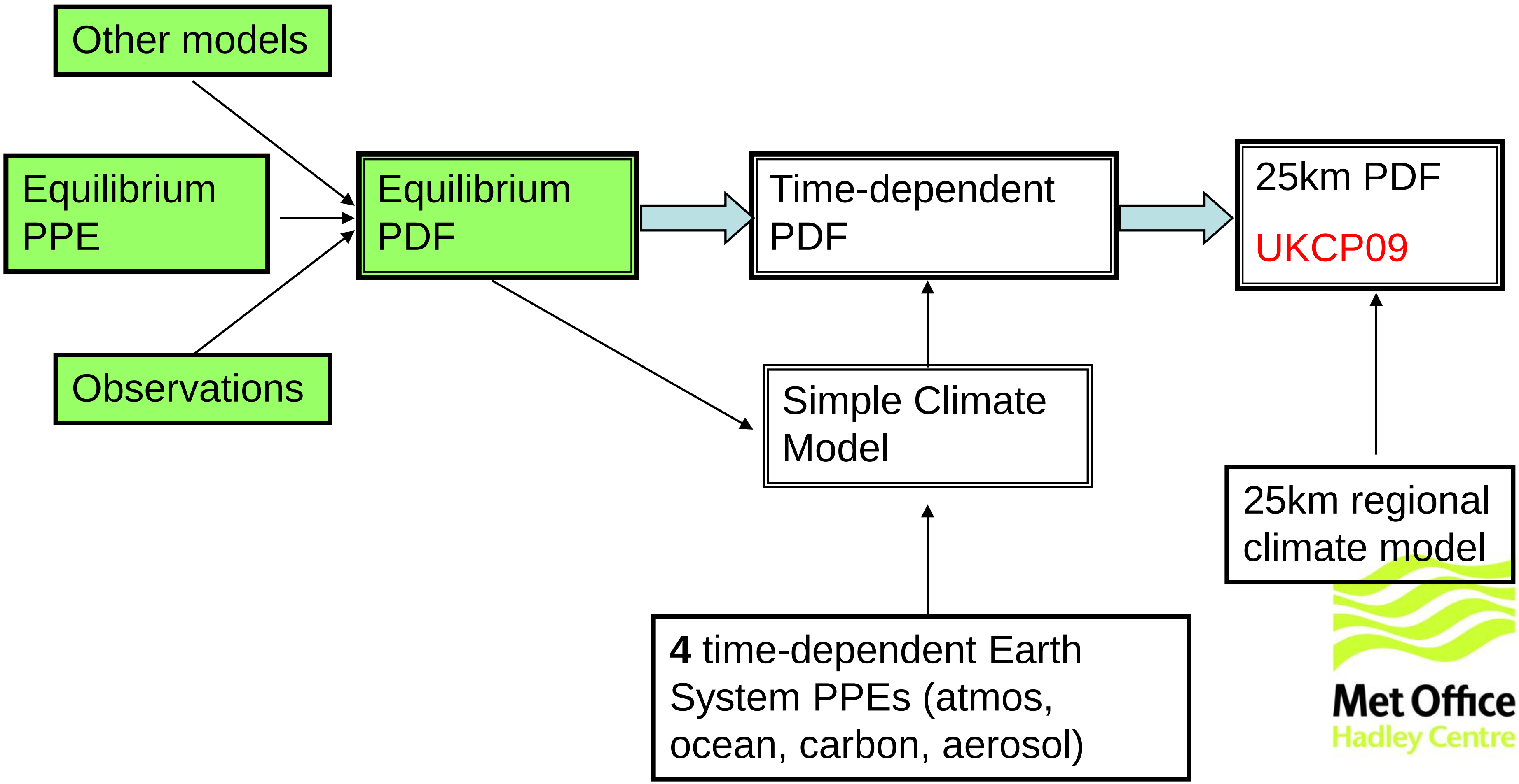
- 3 Emissions scenario (probabilities not attached to these)
- For a given emission scenario, there is uncertainty in the forcing that the climate system will experience
- For a given forcing, there is uncertainty in the climate response due to climate feedbacks and ocean heat uptake
- And there is always natural climate variability to include
- And then there is uncertainty in turning the large scale projections into projections at the local scale (here 25km).

Production of UKCP09 predictions



Met Office
Hadley Centre

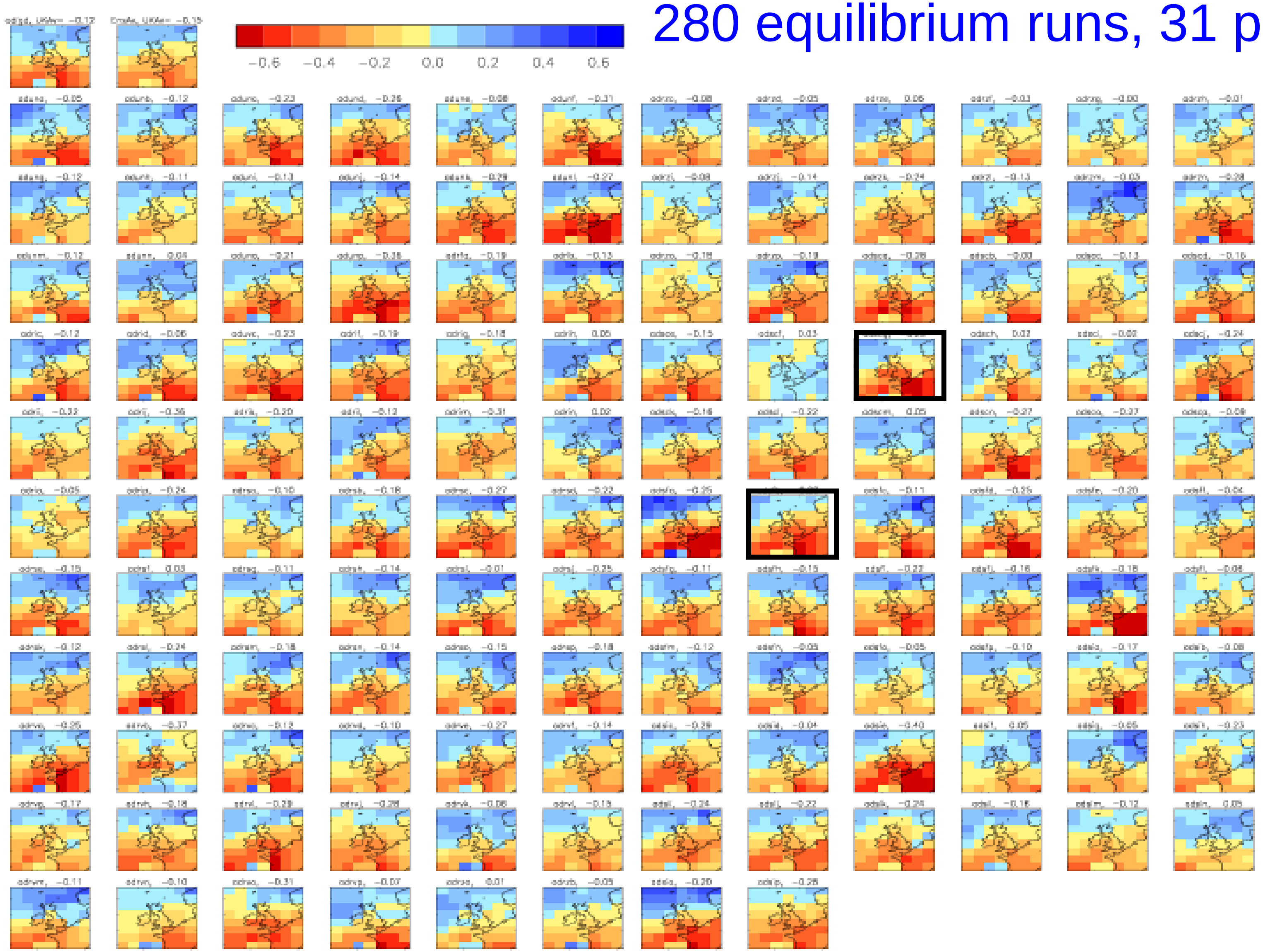
Stage 1: Uncertainty in equilibrium response



Met Office
Hadley Centre

Perturbed physics ensemble

280 equilibrium runs, 31 parameters



Met Office
Hadley Centre

Bayesian prediction (Goldstein and Rougier 2004)

- Mathematically rigorous synthesis of multiple lines of evidence from climate models and observations
- Aim is to construct joint probability distribution $p(X, m_h, m_f, y, o, d)$ of all uncertain objects in problem.
  - Model parameters (X)
  - Historical and future model output (m_h,m_f)
  - True climate (y_h,y_f)
  - Observations (o)
  - Model imperfections = discrepancy (d)

Met Office
Hadley Centre

Best-input assumption
(Goldstein and Rougier 2004)

- Model not perfect so there are processes in real system but not in our model that could alter model response by an uncertain amount.
- We assume that one choice of these values, x*, is better than all others
- Any point in parameter space has a probability of being x* so we need to sample parameter space

$$y = f(x^*) + d$$

True climate

Model output of best choice of parameter values x*

Discrepancy

d=0 for perfect model

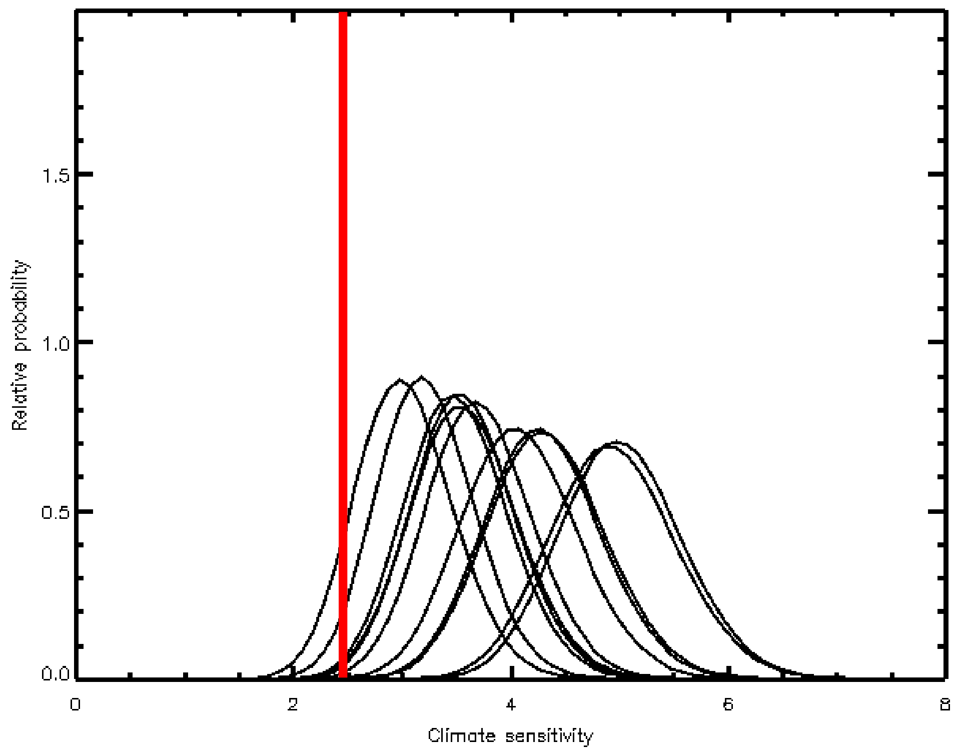
Met Office
Hadley Centre

Three things we need in this Bayesian problem

- Will sample parameter space 1 million times and derive a probability distribution of what the climate response is to doubling CO_2 concentrations. So we need…
- … a way to predict climate response for parameter combinations that are not sampled by the 280-member PPE
- … to choose some observations to evaluate each model variant to give more probability of being the best input to the better models.
- To specify this model imperfections

Met Office
Hadley Centre

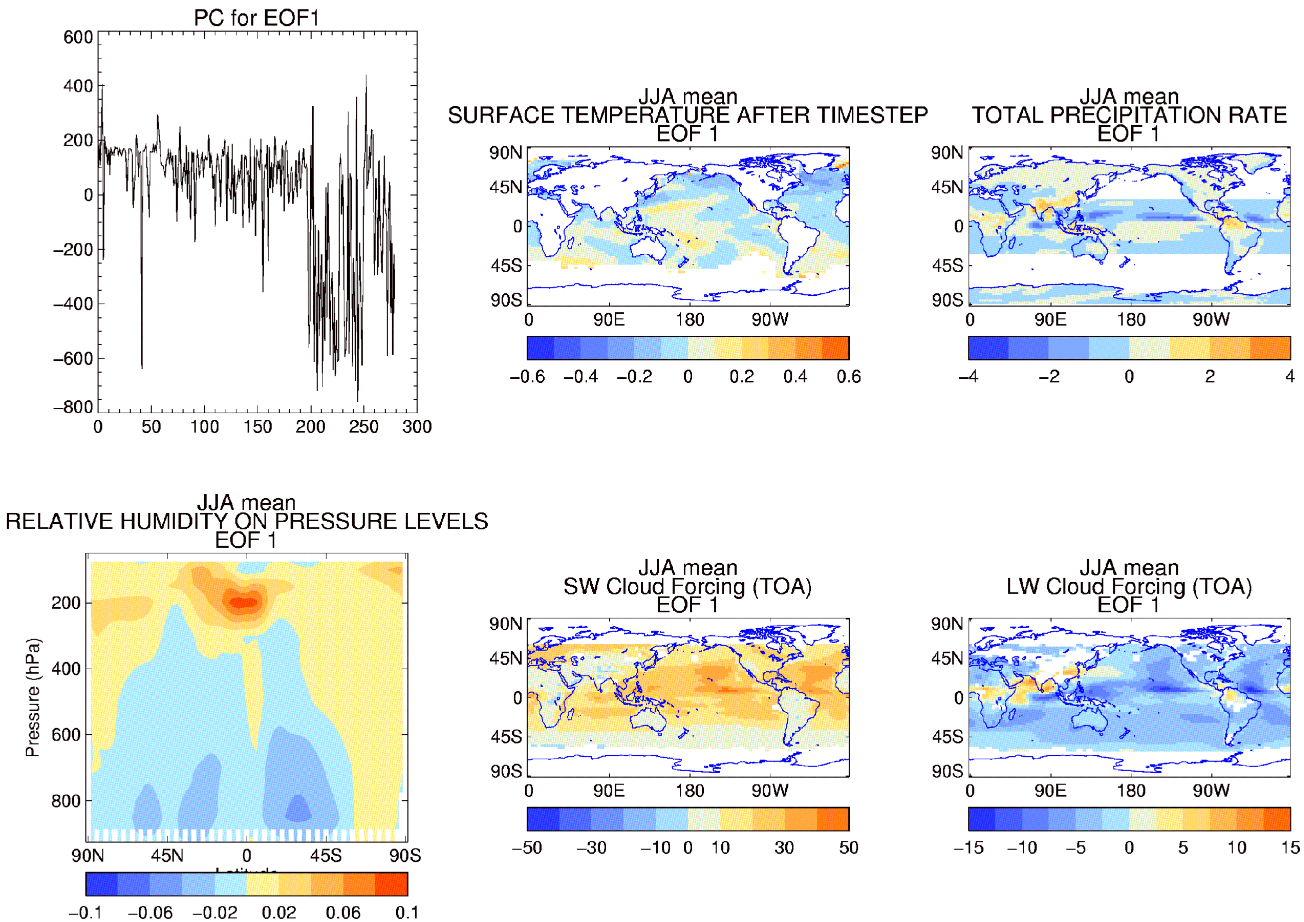
(1) Emulators – estimation of climate response at untried parameter combinations



Emulated distributions for 10 different samples of combinations of parameter values

- Emulators are statistical models, trained on ensemble runs, designed to predict model output at untried parameter combinations

(2) Choose observations carefully

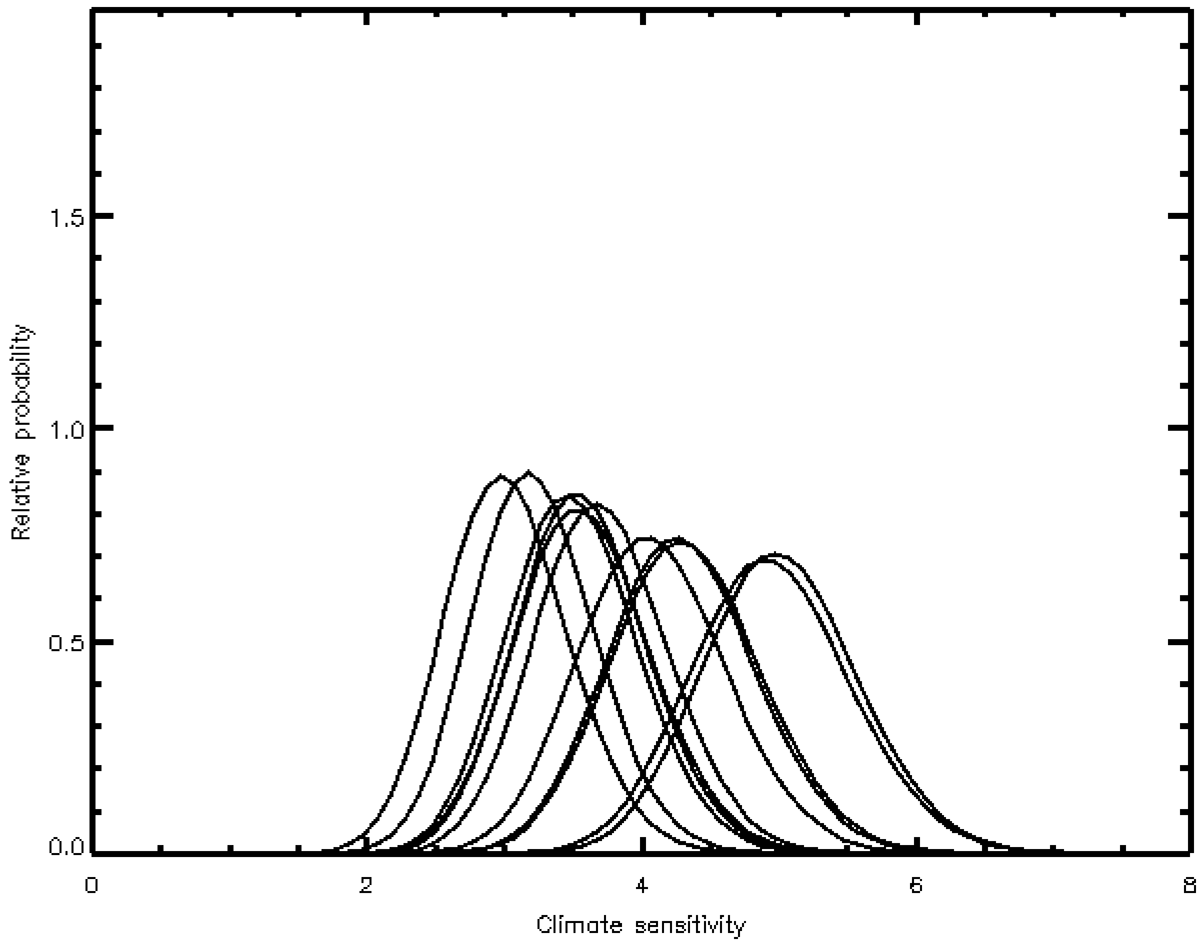


A small subset of climate variables are shown

Met Office
Hadley Centre

Weighting different model variants

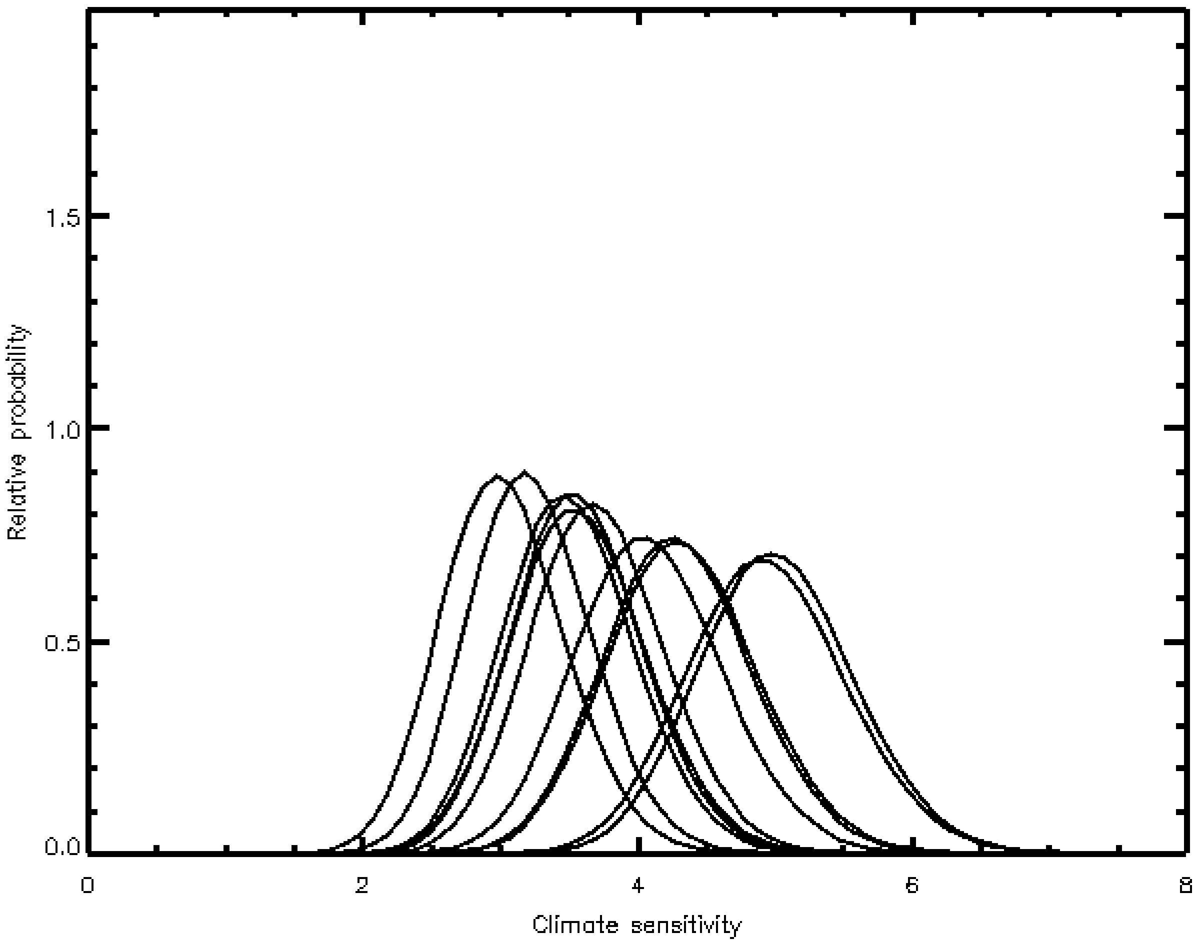
- Weight prediction towards higher quality parts of parameter space



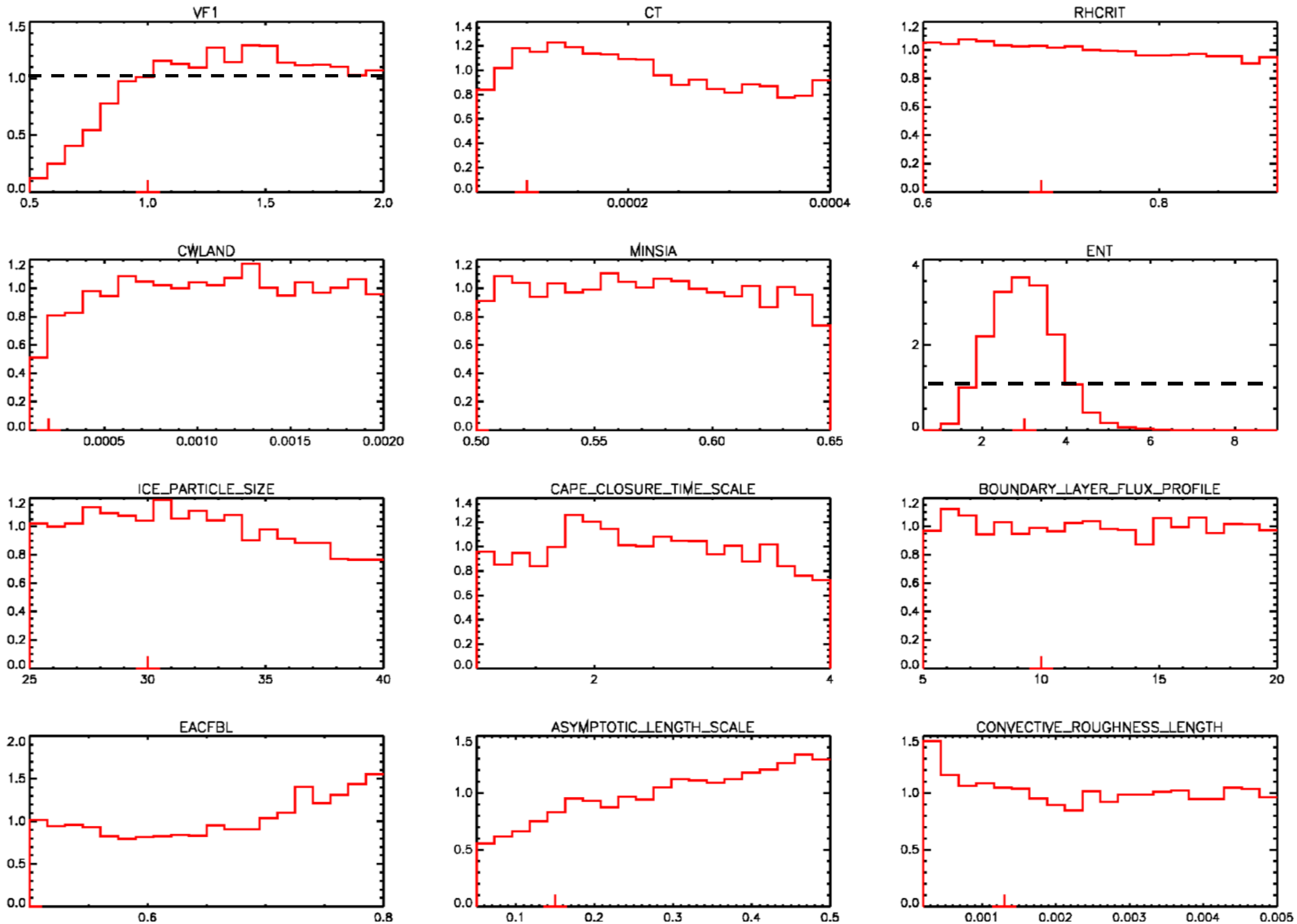
Met Office
Hadley Centre

Weighting different model variants

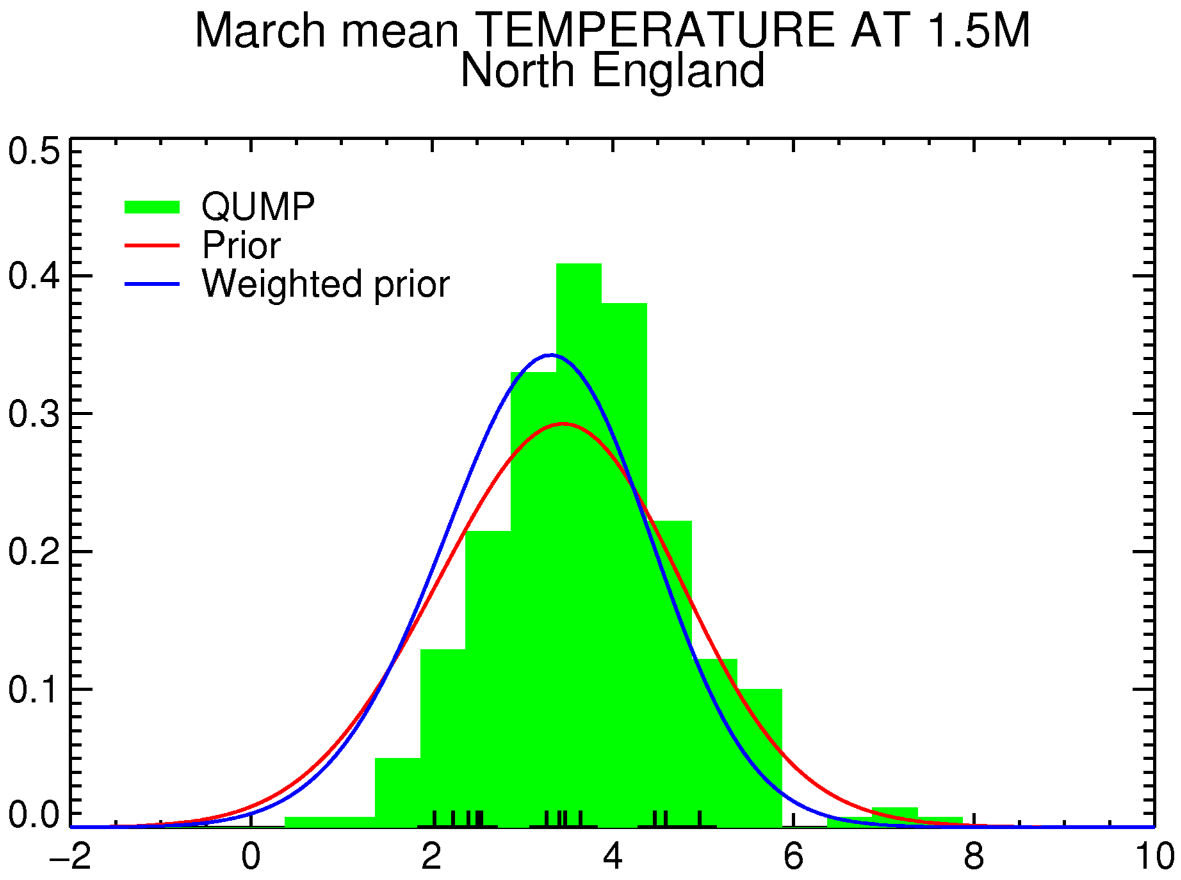
- Weight prediction towards higher quality parts of parameter space



Constraining parameters



Weighted PDF



Met Office
Hadley Centre

(3) Specifying discrepancy

- Cannot use observations to both weight PDF and specify discrepancy. That is “double-counting”
- Use multimodel ensemble from IPCC AR4 and CFMIP
- For each multimodel ensemble member, find the **best analogue** using the emulator of our (MOHC) ensemble
- There is a distance between climates of this multimodel ensemble member and this emulated “best analogue” i.e. effect of processes not explored by MOHC model variants.
- Pool these distances over all multimodel ensemble members

Comparing models with observations

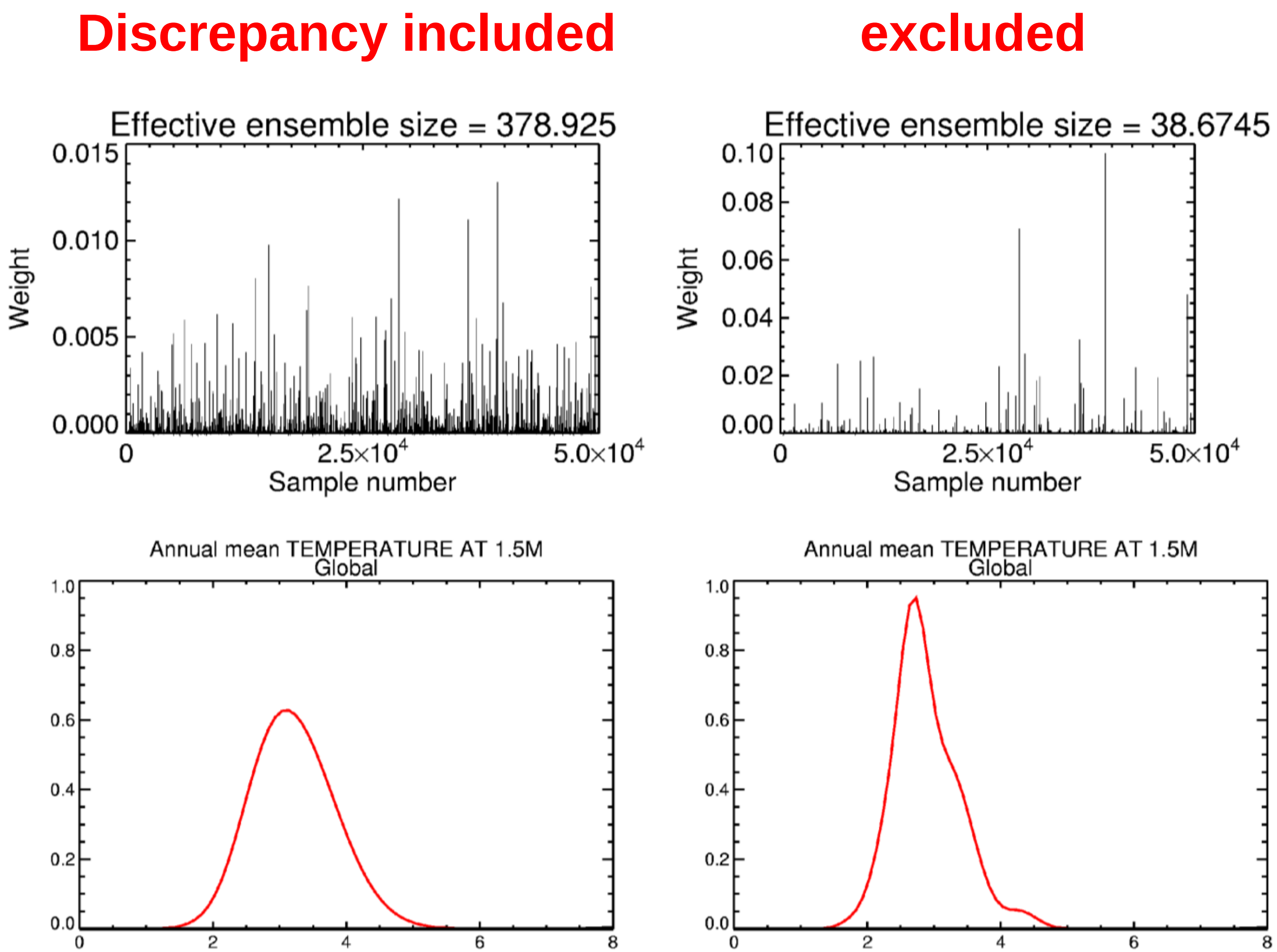
- "Posterior PDF = prior PDF x likelihood"
- Skill of model is likelihood of model data given some observations

$$\log L_o(\mathbf{m}) = -c - \frac{n}{2}\log|\mathbf{V}| - \frac{1}{2}(\mathbf{m}-\mathbf{o})^T \mathbf{V}^{-1}(\mathbf{m}-\mathbf{o})$$

V = obs uncertainty + emulator error + discrepancy

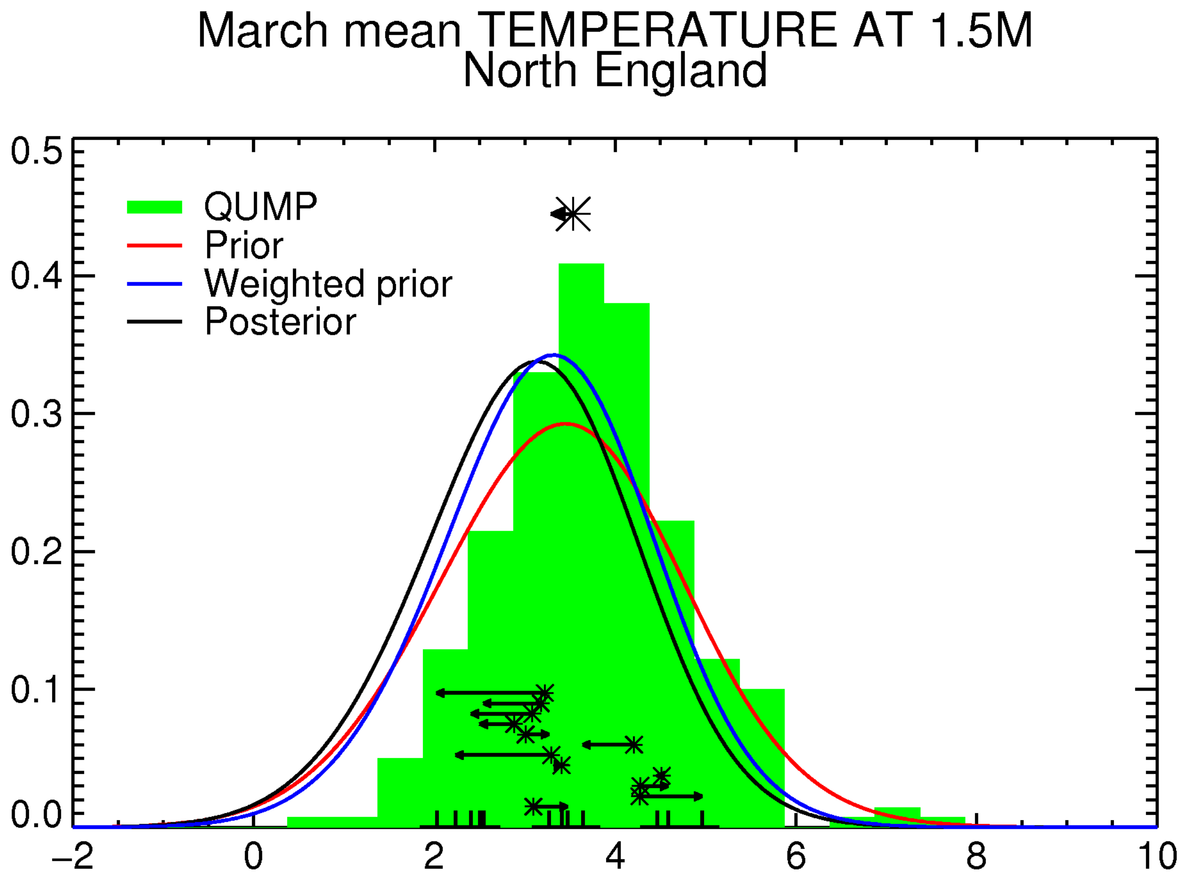
Discrepancy is 'distance' between real system and 'best' choice of input parameters

Effect of historical discrepancy on weighting



Estimated from sample size of 50000

Probabilistic prediction of equilibrium response to double CO2

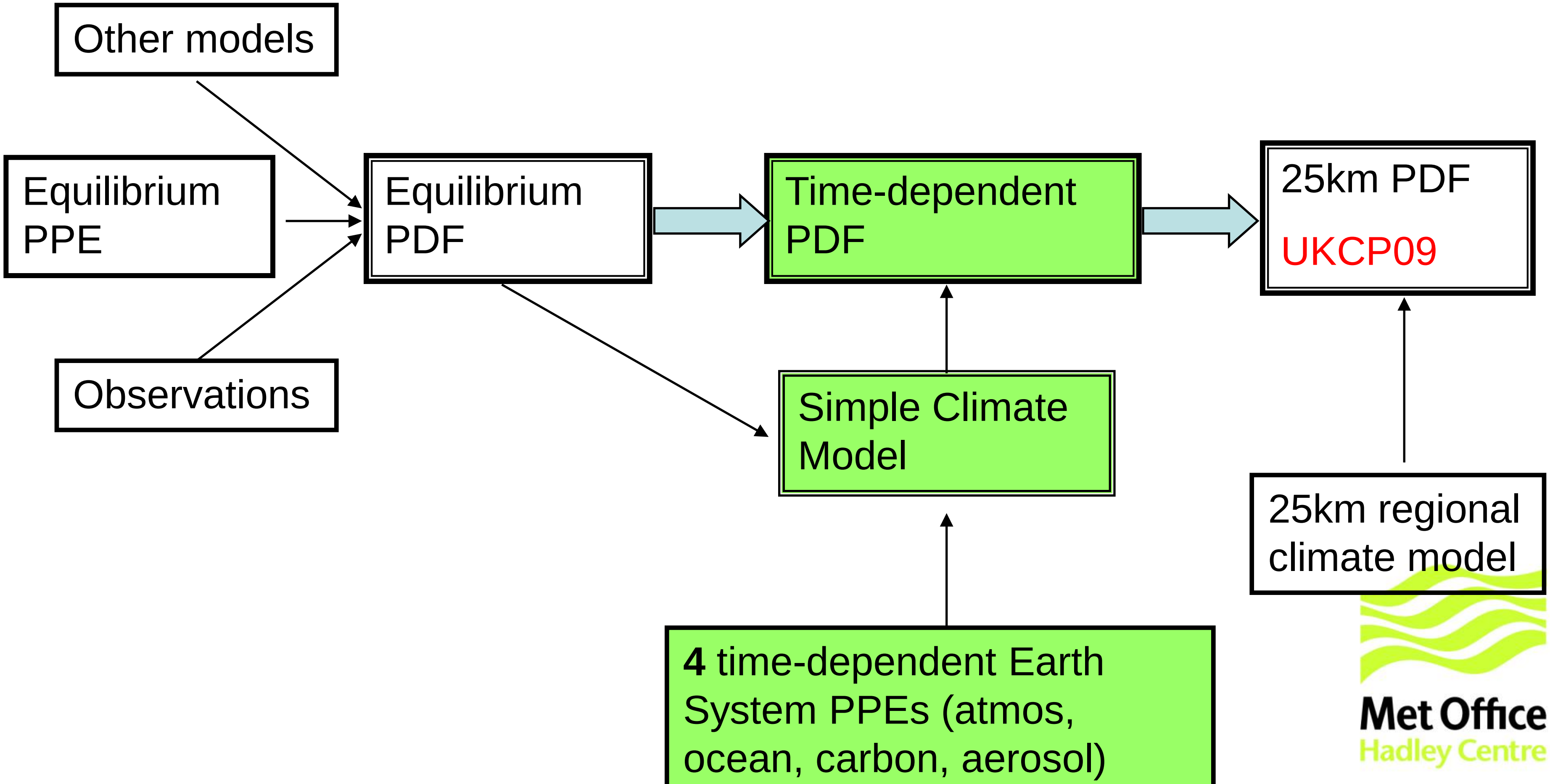


Met Office Hadley Centre

Model imperfections(d)

- True climate = “best” model climate + discrepancy
- Requires model to be informative
- This and the weighting make prediction relevant to real world
- We assume that structural differences between our model and other climate models is a good proxy for the discrepancy with reality
- Caveat is that there are systematic errors common to all climate models used here and they are not accounted for.

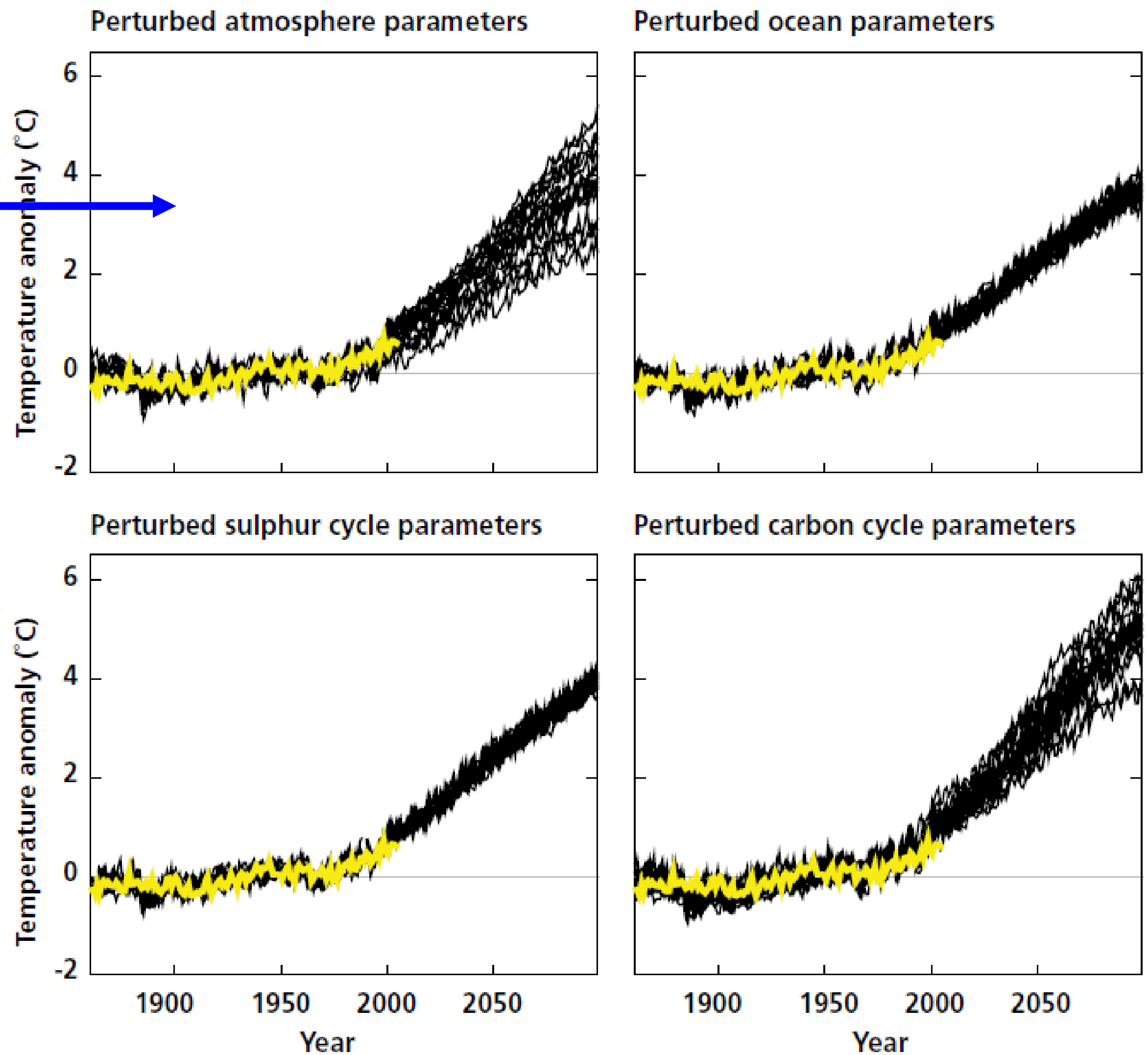
Stage 2: Time Scaling
(Glen Harris and Penny Boorman)



Met Office
Hadley Centre

4 Perturbed physics ensembles

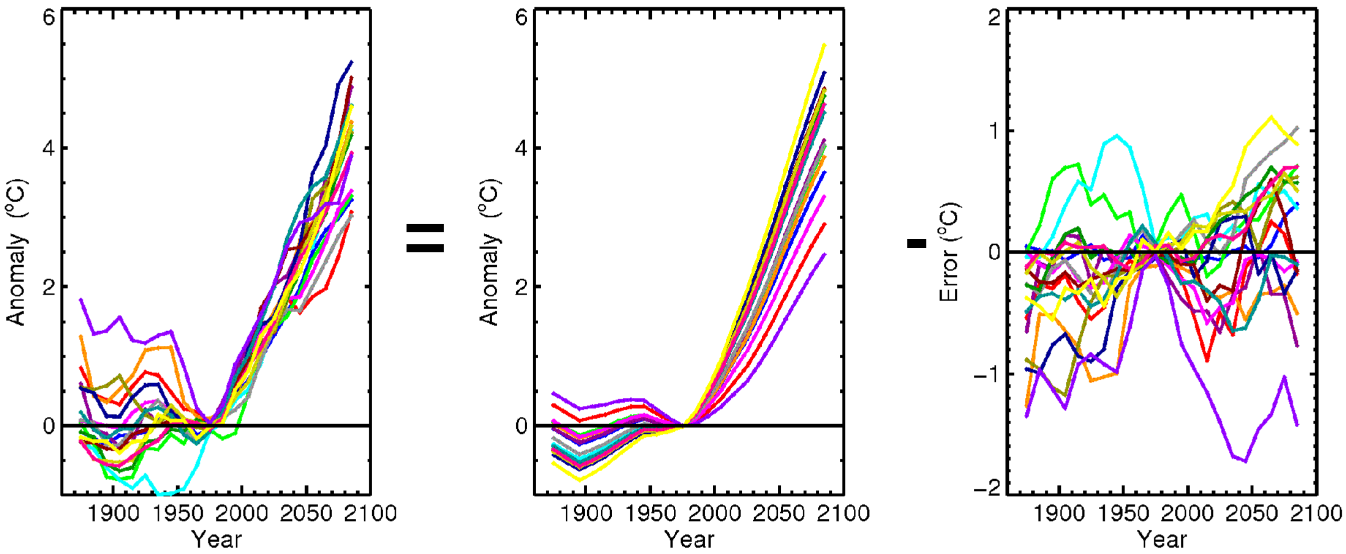
Atmosphere PPE samples 17 of the 280 model variants for the cheaper slab runs



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

Time-scaling diagnosis: Northern England summer surface temperature response

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



Raw GCM data

Scaled output from Simple Climate Model

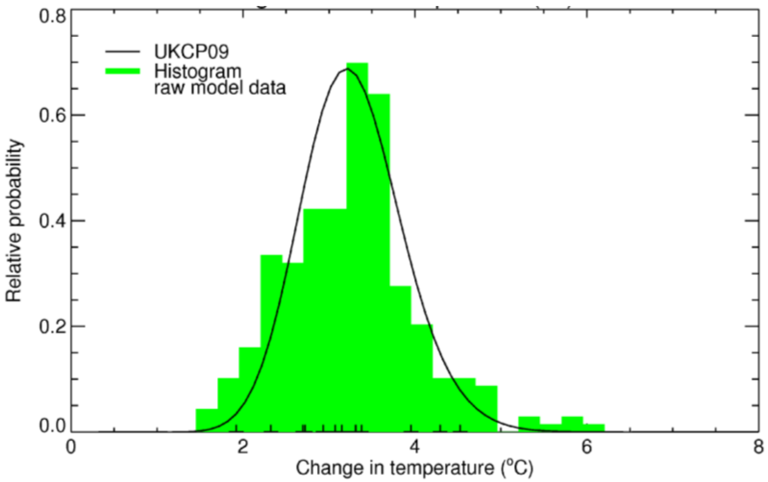
Scaled output minus raw GCM data

Met Office Hadley Centre

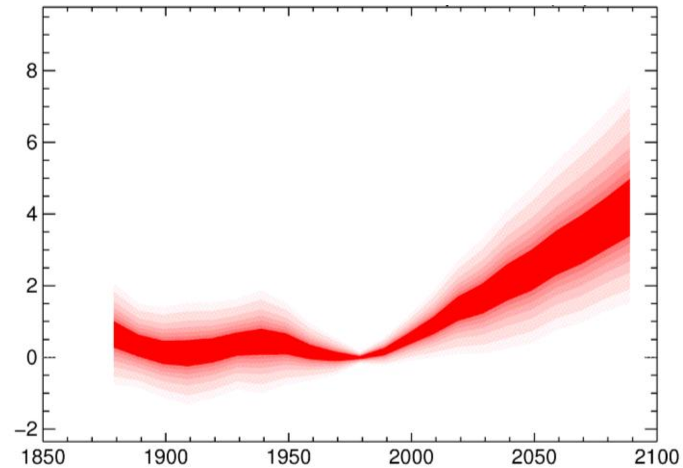
Making time-dependent PDFs

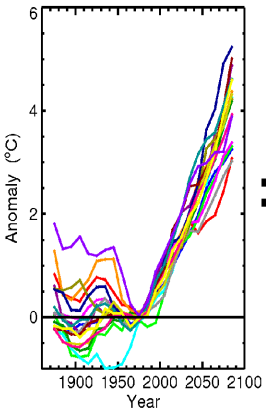
- Sample point in atmosphere parameter space
- Emulate equilibrium response in climate sensitivity and prediction variables and calculate weights
- Sample ocean, aerosol and carbon cycle configurations of Simple Climate Model
- Time scale the prediction variables
- Use observed historical changes in four large scale temperature indices to tweak the weight
- And repeat sampling…

Time Scaling

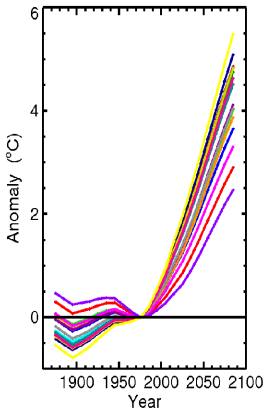


Time Scaling

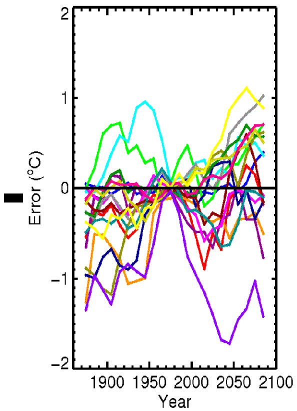




=



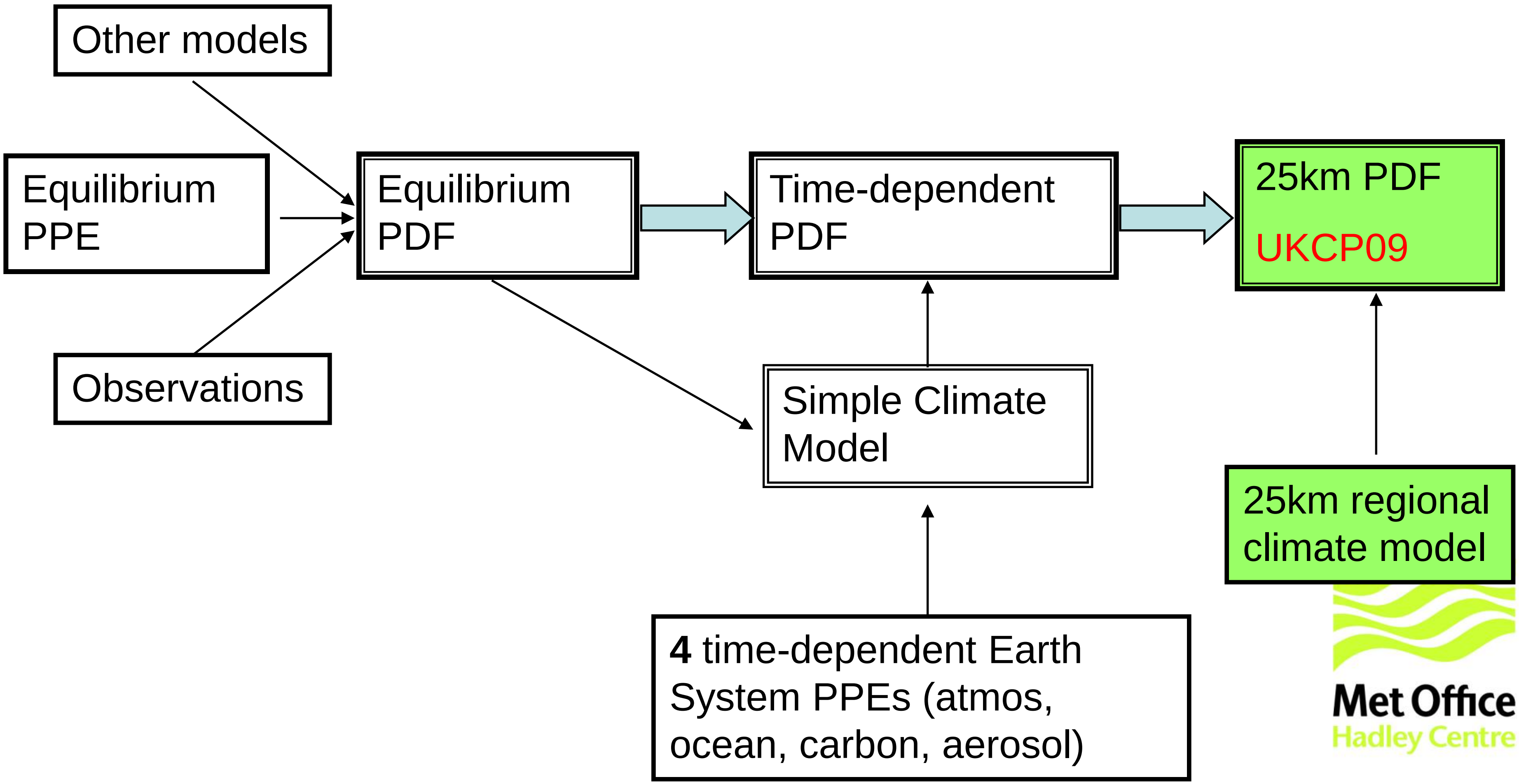
-



Plume at GCM resolution

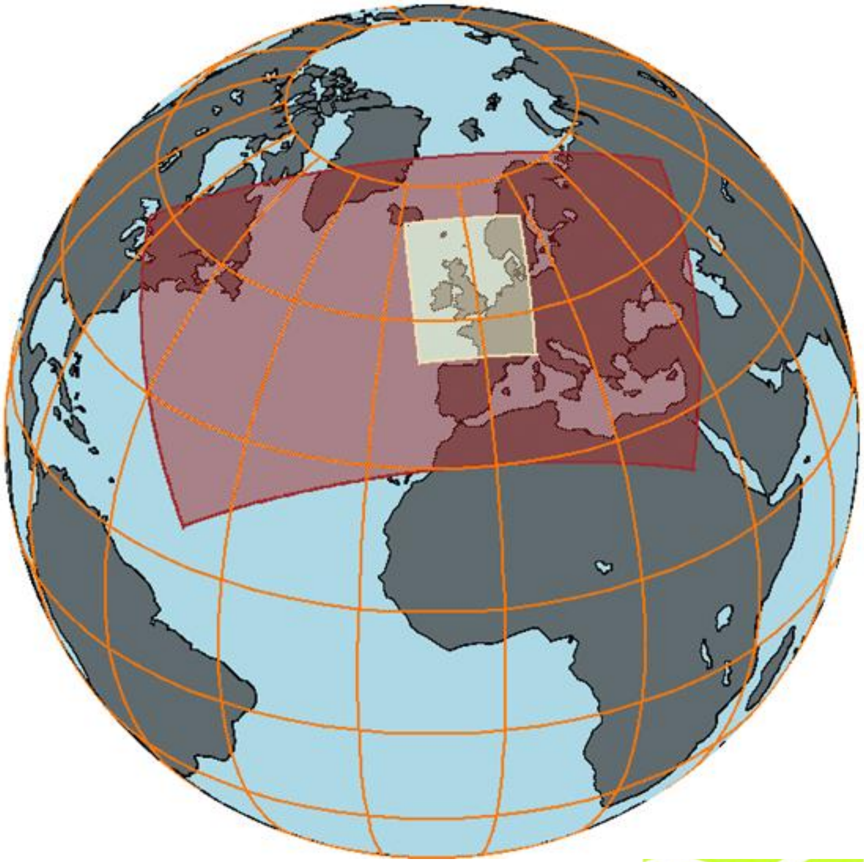
Met Office
Hadley Centre

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

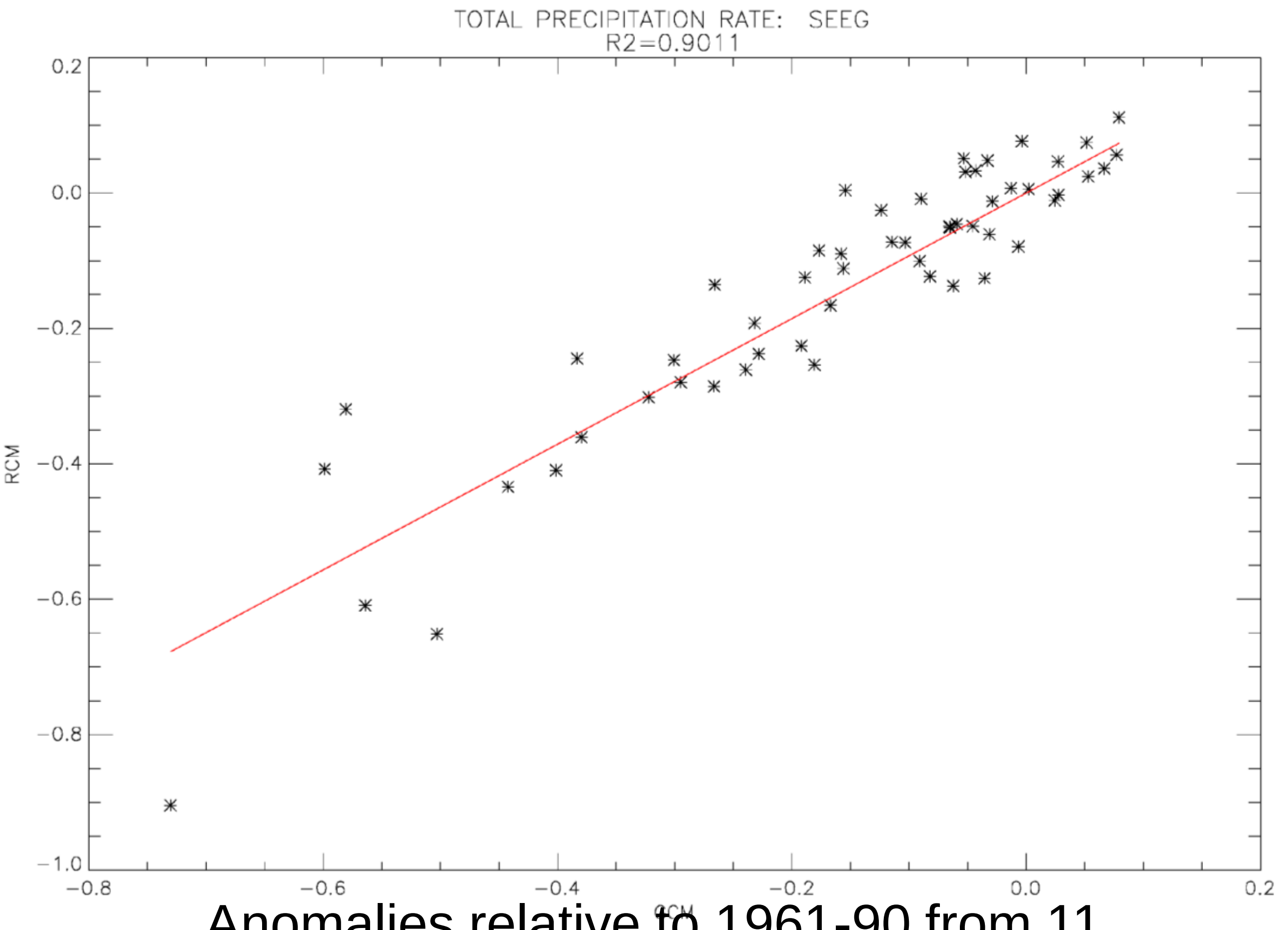


Met Office
Hadley Centre

E.g. Change in log(summer precipitation) over SE England

Quite strong relationships generally found for summer precipation

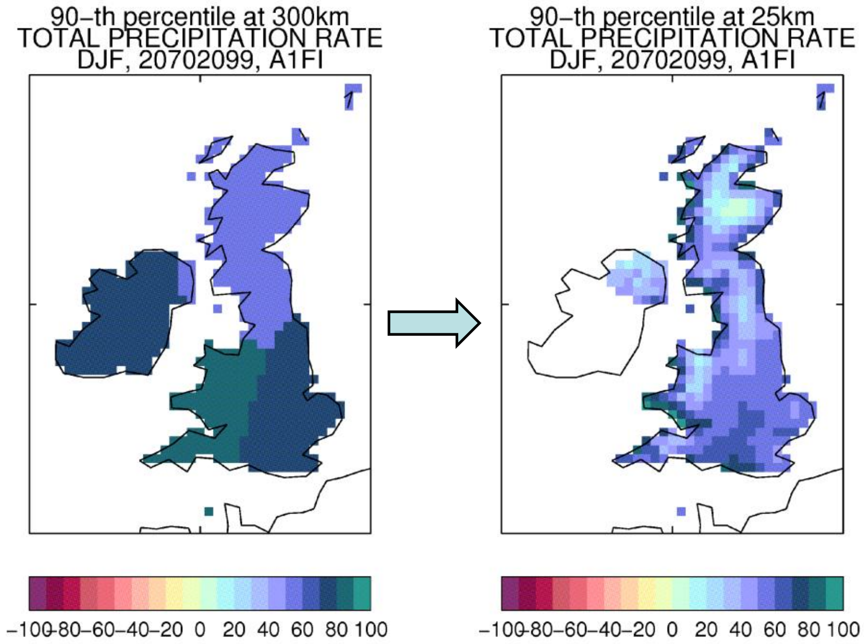
Anomalies relative to 1961-90 from 11 RCM runs



Anomalies relative to 1961-90 from 11 driving GCM runs

Met Office Hadley Centre

Adding information at 25km scale



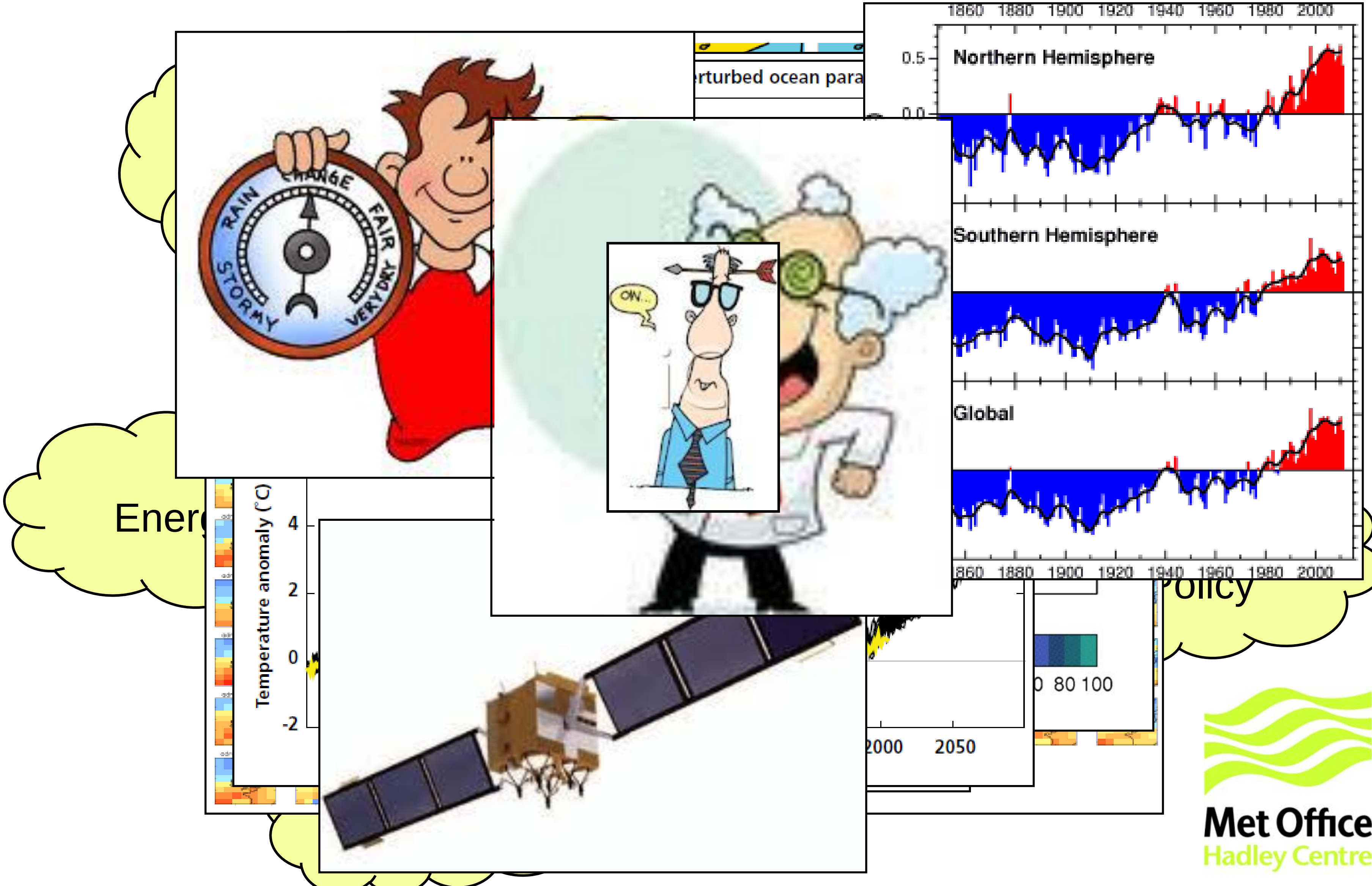
- High resolution regional climate model projections are used to account for the local effects of coastlines, mountains, and other regional influences.

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

Met Office
Hadley Centre

Why is UKCP09 probabilistic and how should it be used

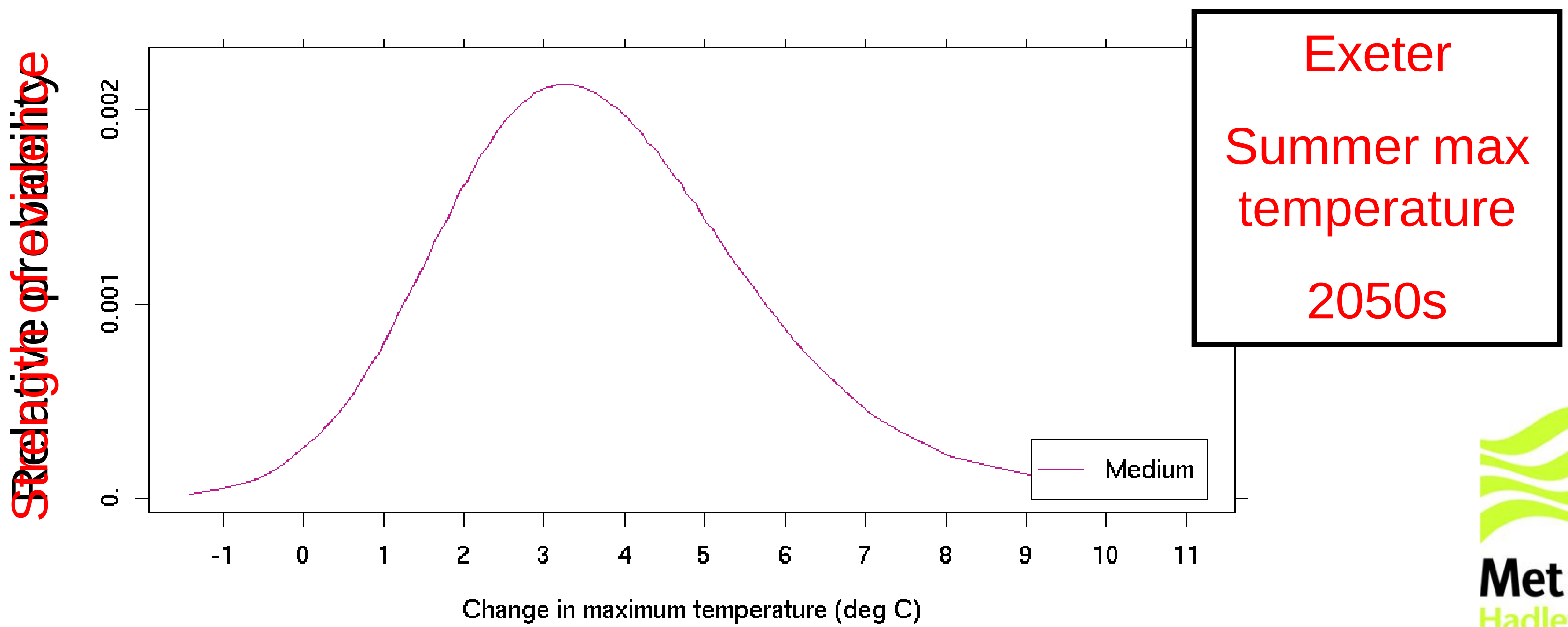
Multiple lines of evidence



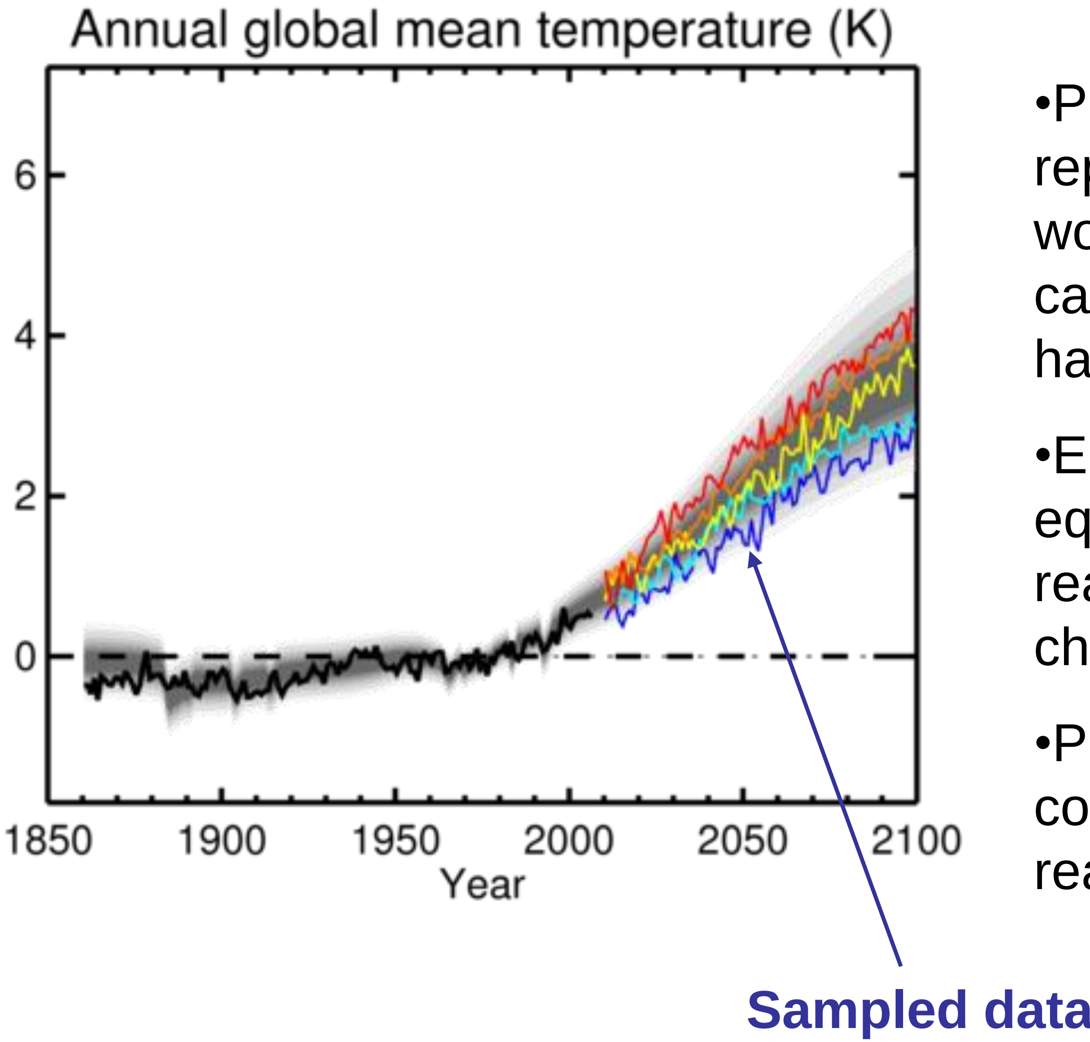
Met Office
Hadley Centre

UKCP09 probabilistic projections…

- UKCP09 probabilities represented “strength of evidence” where the aim is to provide a transparent synthesis of multiple lines of evidence (range of model output, observations, expert judgement)
- Based on statistical method developed by world-leading UK statisticians
- Provide information that can be used in decision making with aim of reducing risk of making a poor decision



Probabilistic projections are…



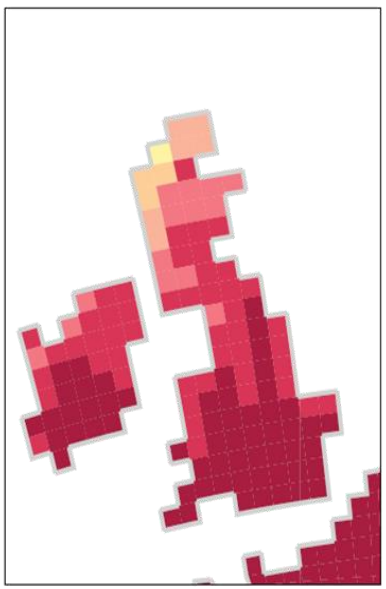
- Probability distributions are not representative of what the real world will do, but of what we can say about what might happen based on the evidence
- Each coloured line is an equally likely plausible realisation of future climate change
- Probability distribution shows concentration of these plausible realisations

Met Office
Hadley Centre

Moving from uncertainty to probability

UKCIP02

Single projection



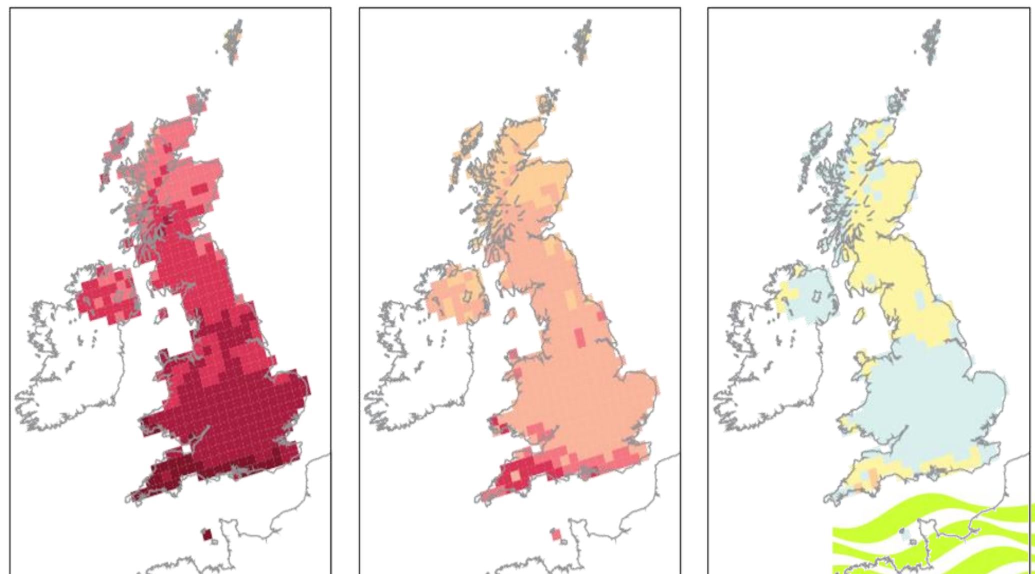
Summer Rainfall 2080's

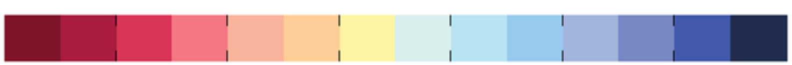
UKCP09

Very unlikely to be less than (10%)

Central estimate (50%)

Very unlikely to be more than (90%)

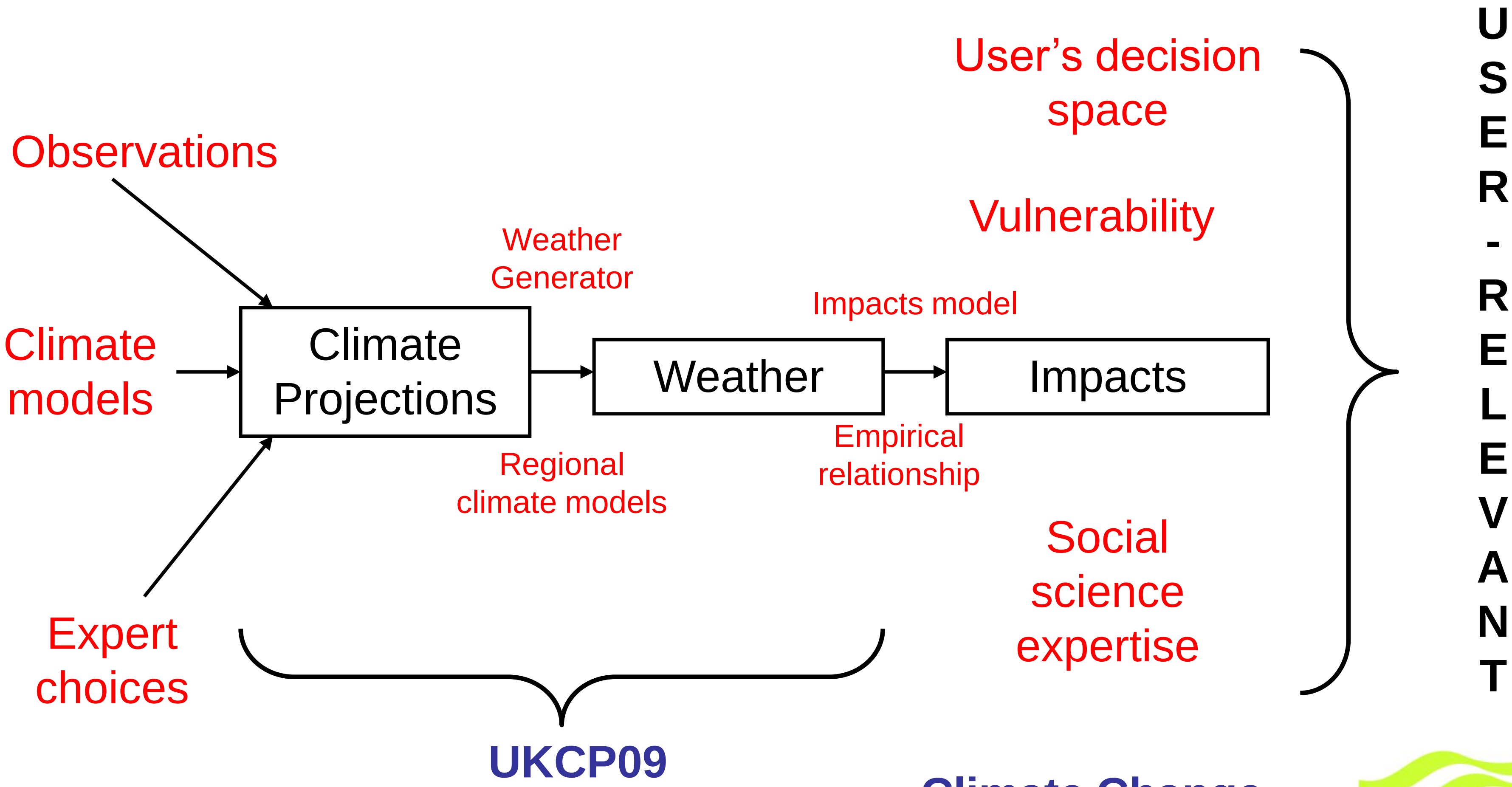




Met Office
Hadley Centre

End-to-end adaptation planning

National Adaptation Plan



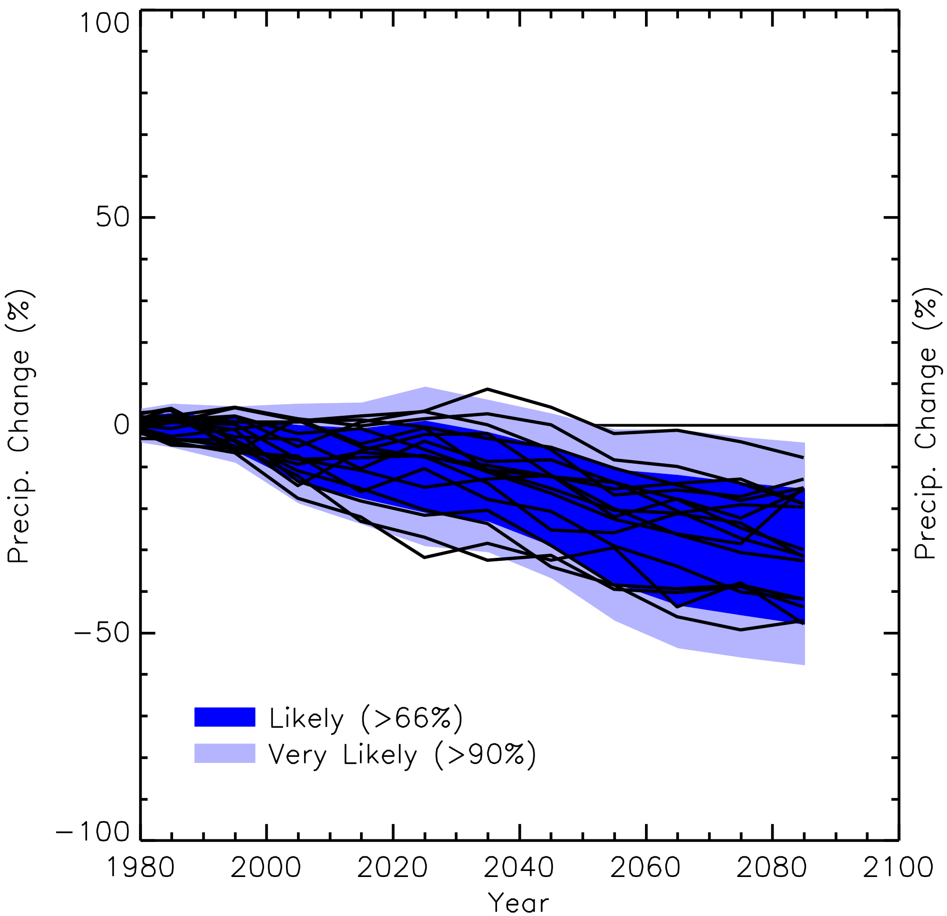
Red text shows "lines of evidence"

Climate Change Risk Assessment (CCRA) or Consultants

Met Office
Hadley Centre

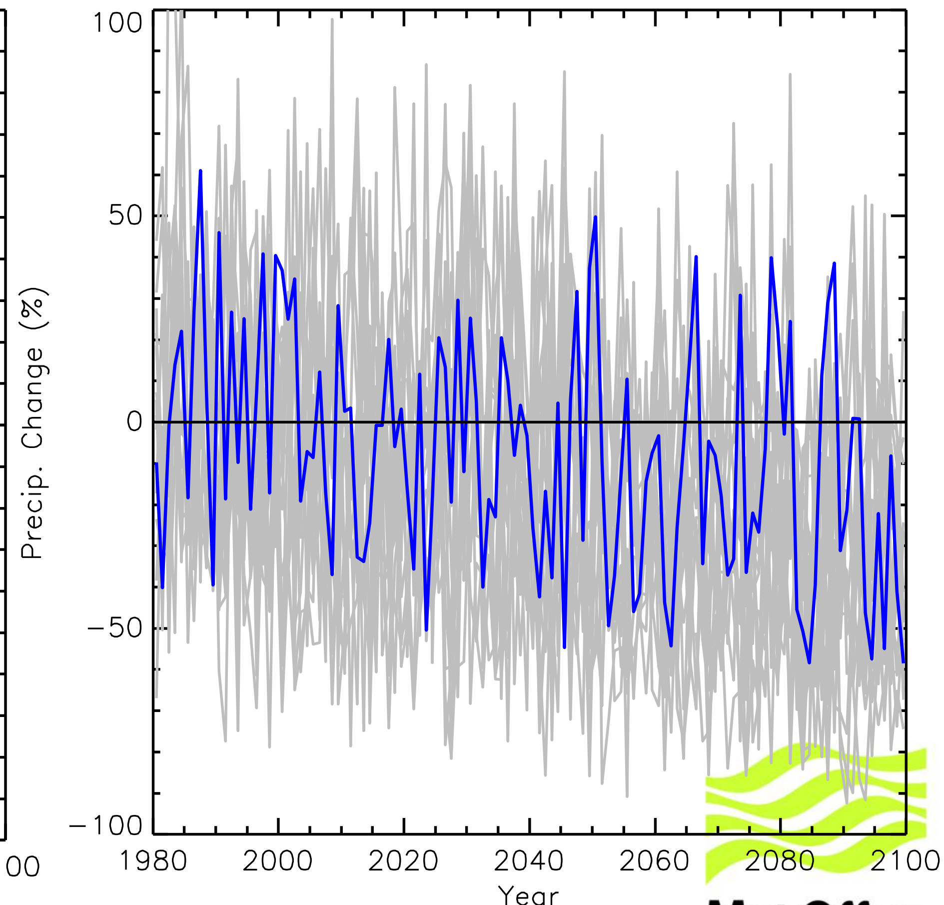
Climate and weather (i)

30-year summer mean change



England & Wales summertime rainfall change (%)

Year-to-year summertime change



Unperturbed model
16 x perturbed models

Met Office Hadley Centre

Climate and weather (ii)

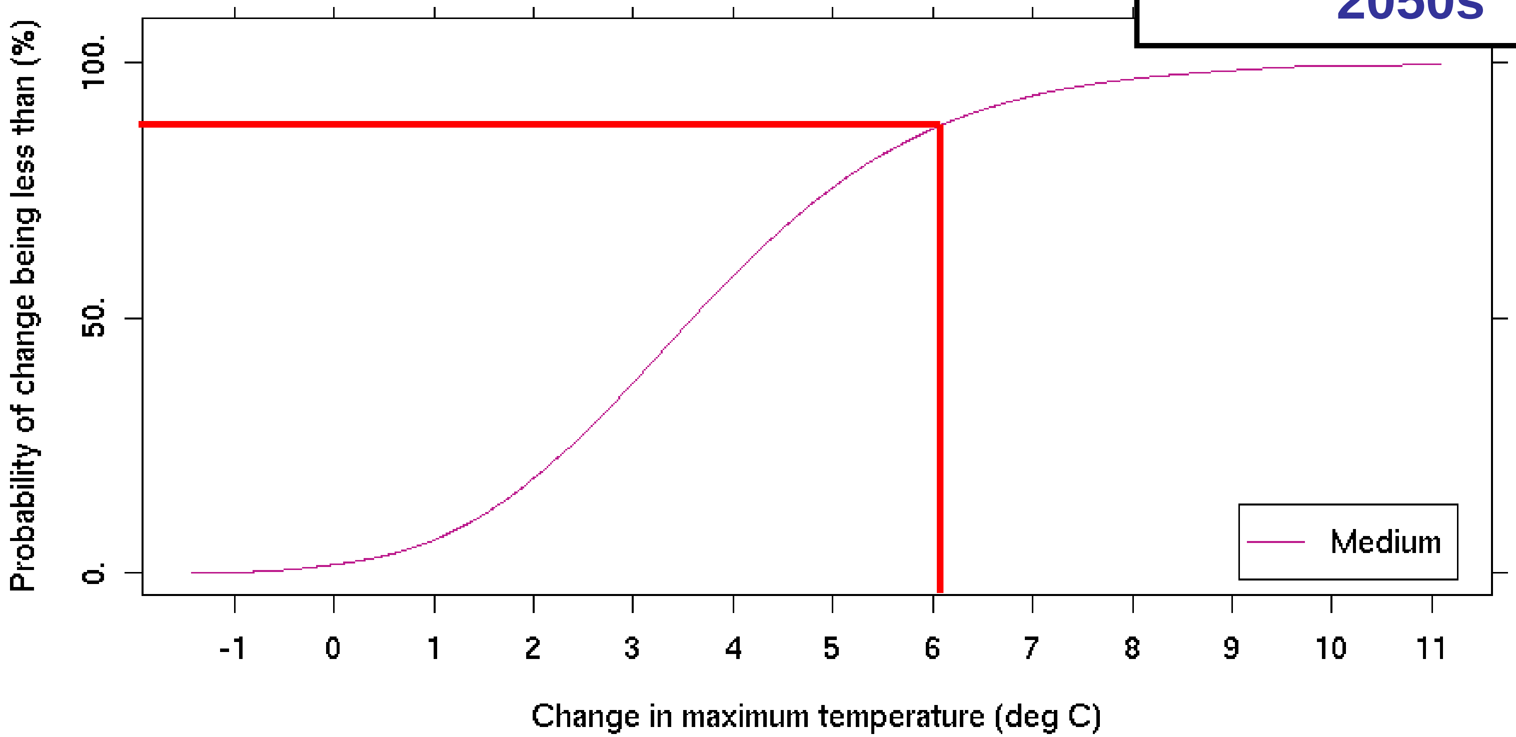
- In UKCP09, to produce daily time series that can be used to
  - drive impacts models
  - show change in frequency of exceeding a vulnerability threshold
- **Weather Generator**
  - Statistical generation of **a set of plausible daily time series** that are designed to reproduce the climate statistics for present day or for a future from UKCP09 probabilistic projections
  - Site specific
  - Don't go for return periods beyond 20 years
- **Regional Climate Model output**
  - Fully coherent across space and time
  - More variables e.g. reports on snow, fog and lightning
  - Explore smaller range of climate responses

Met Office
Hadley Centre

Cumulative distribution functions (CDFs)

Product that can cope with a spectrum of people with different levels of risk aversity

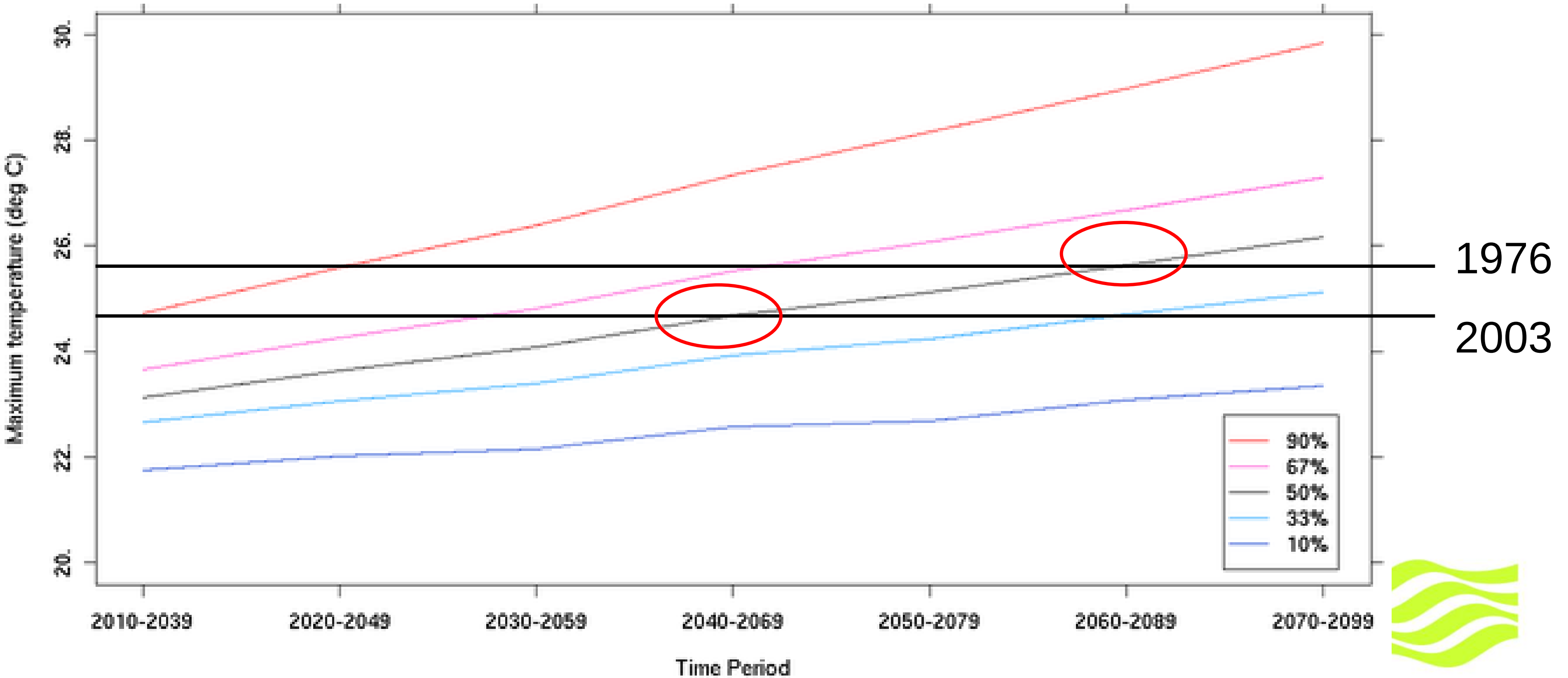
Changes in daily max temperature Exeter, summer, Medium Emissions, 2050s



Office
y Centre

When to adapt?

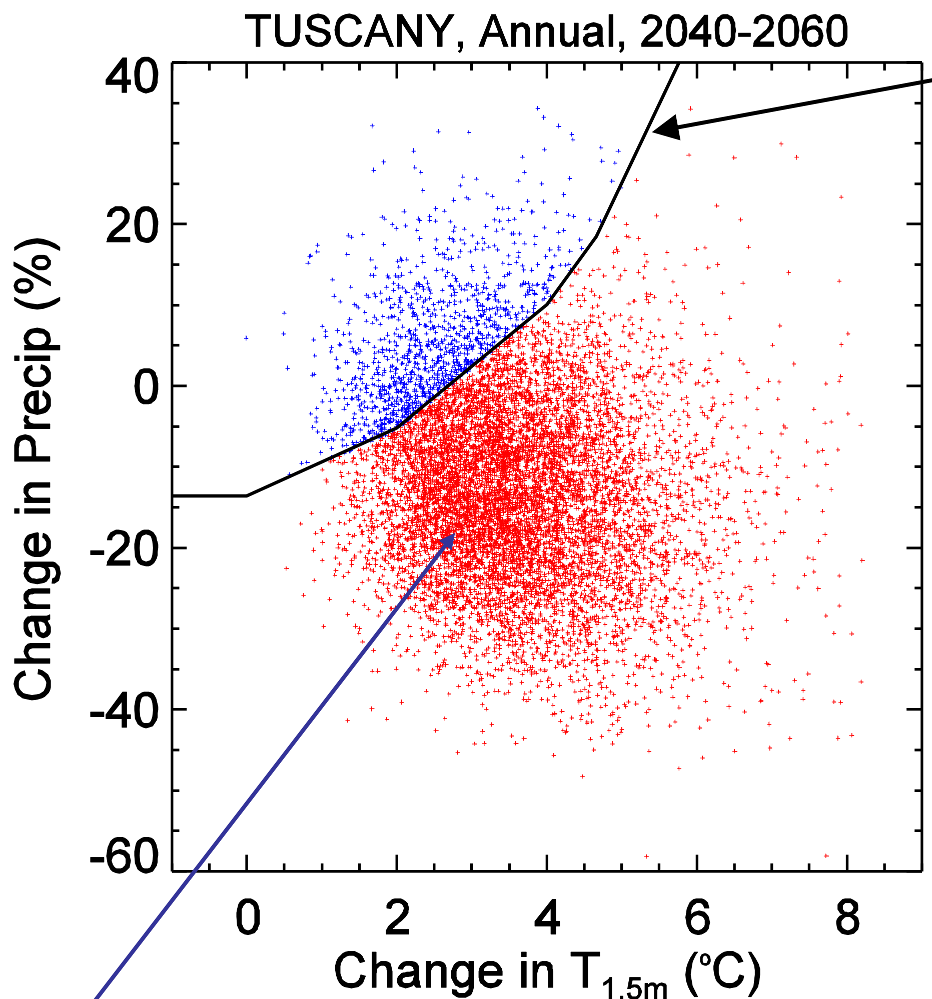
- Use plumes to assess whether planner can defer their decision until more information is available



In 2003, 16% increase in number of deaths in London from heatwave 4-13th August

Met Office
Hadley Centre

Societal impact illustration: durum wheat (pasta) yield in Tuscany 2040-2060



Response surface for current yield, including CO_2 fertilization

⇒ 86% risk of a reduction in yield

Sampled data

Thanks to:

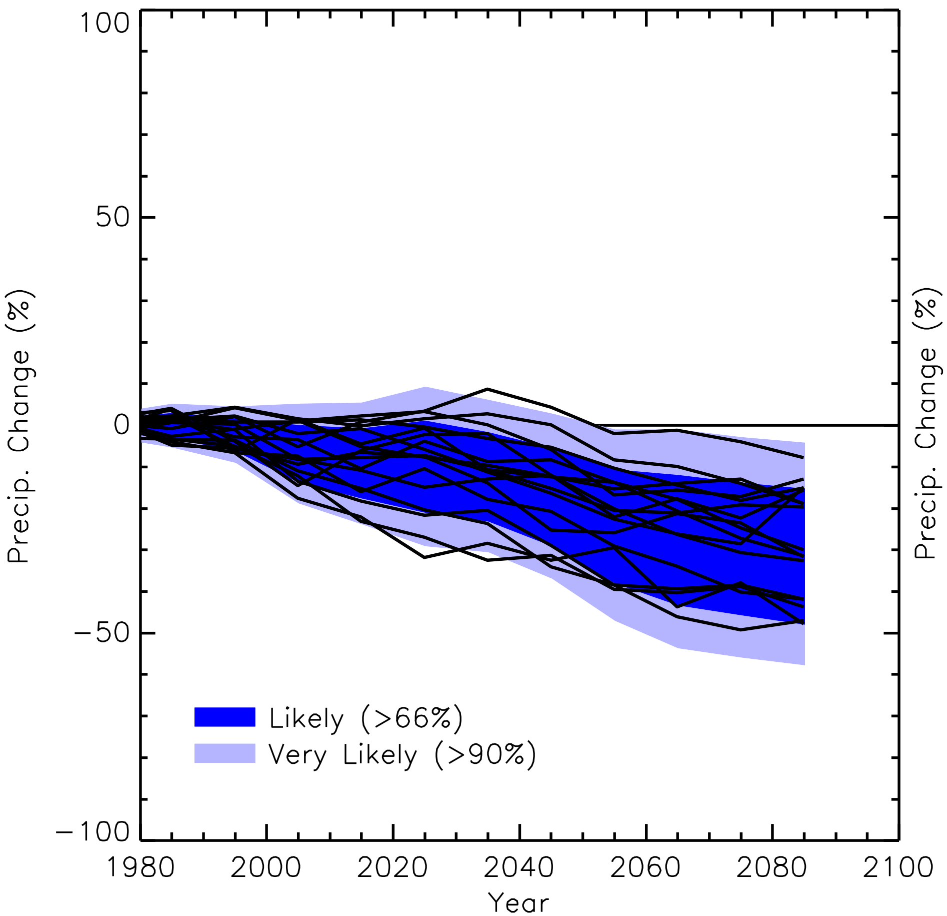
Roberto Ferrise, Marco Moriondo, Marco Bindi
Department of Agronomy and Land Management
University of Florence

Ways to improve UKCP09

Met Office
Hadley Centre

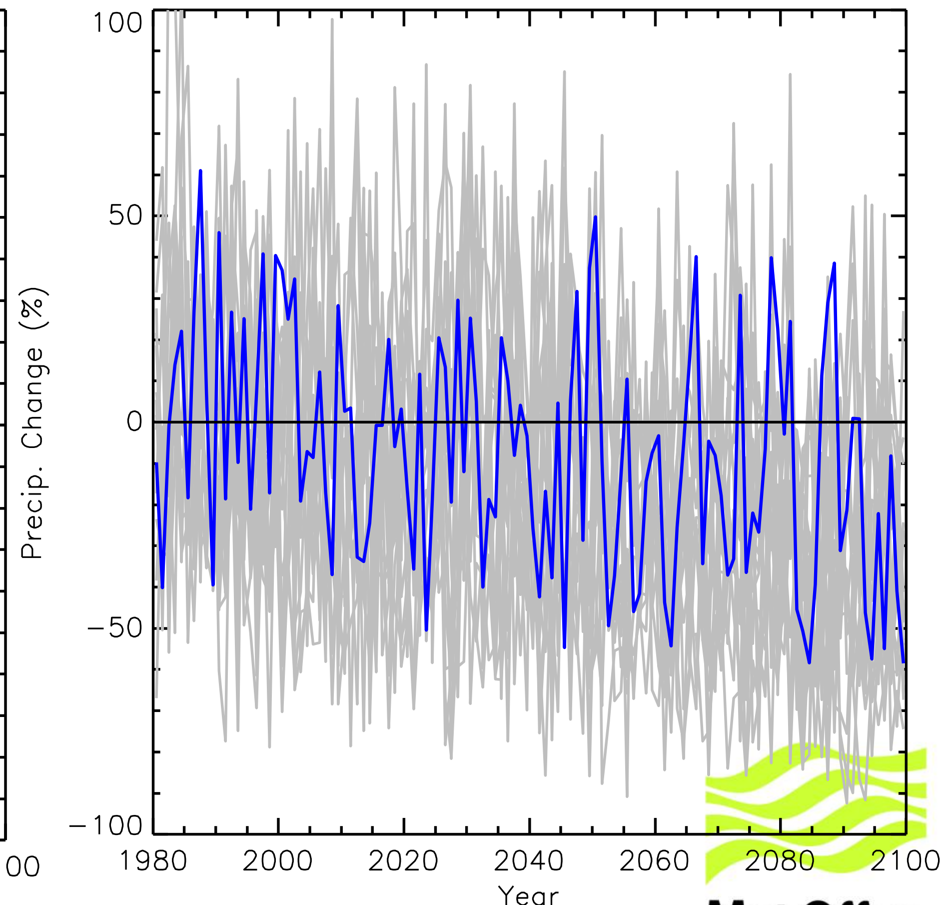
Climate and weather (i)

30-year summer mean change



England & Wales summertime rainfall change (%)

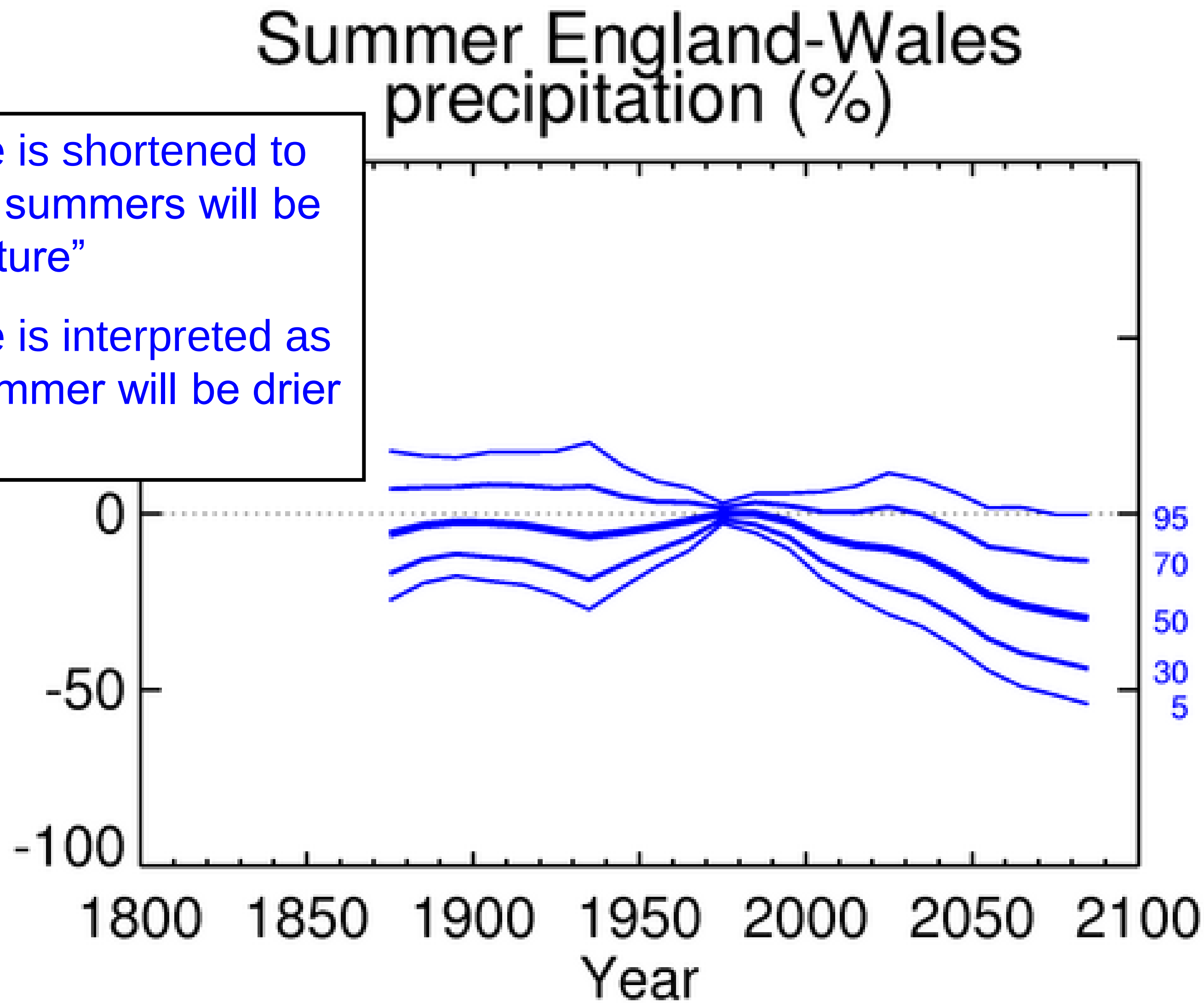
Year-to-year summertime change



Unperturbed model
16 x perturbed models

Met Office
Hadley Centre

Using 1-year averages for UKCP09



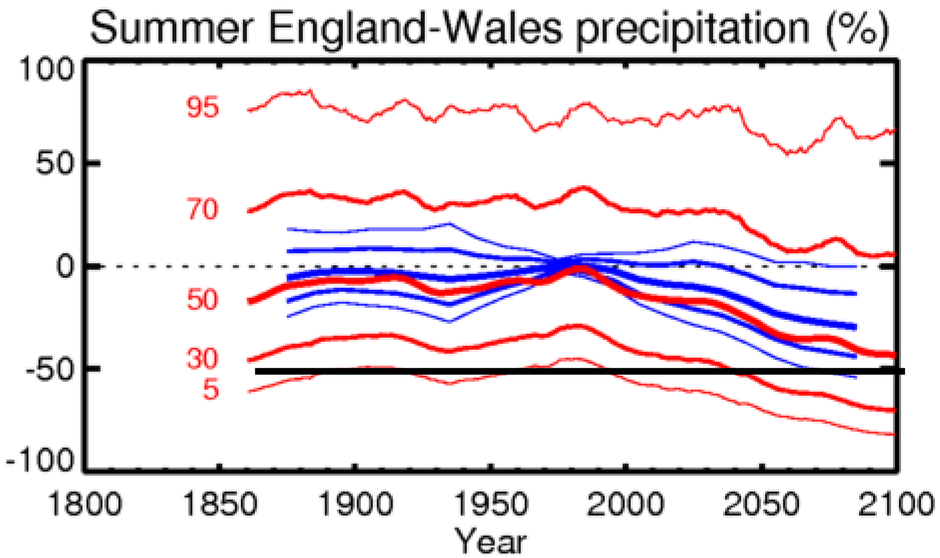
- Message is shortened to "(Typical) summers will be drier in future"
- Message is interpreted as "every summer will be drier in future"

Met Office
Hadley Centre

UKCP09: 1-year averages v 30-year averages

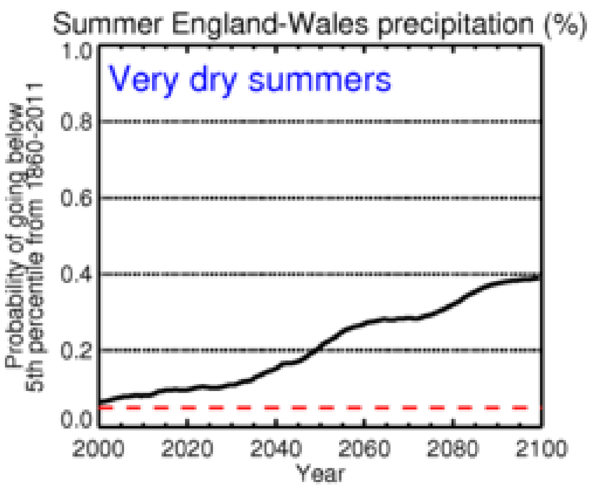
Blue lines are original UKCP09 30-year averages

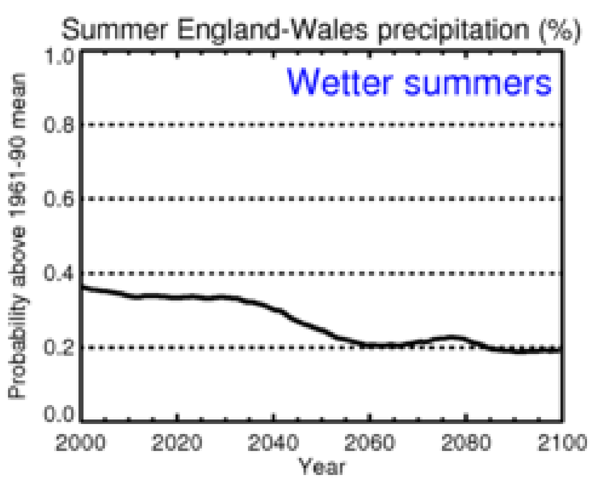
Red lines are UKCP09 using 1-year averages



30-year means and 1-year means both show the importance of climate change in the 21st century (compare 50th percentiles).

More informative…



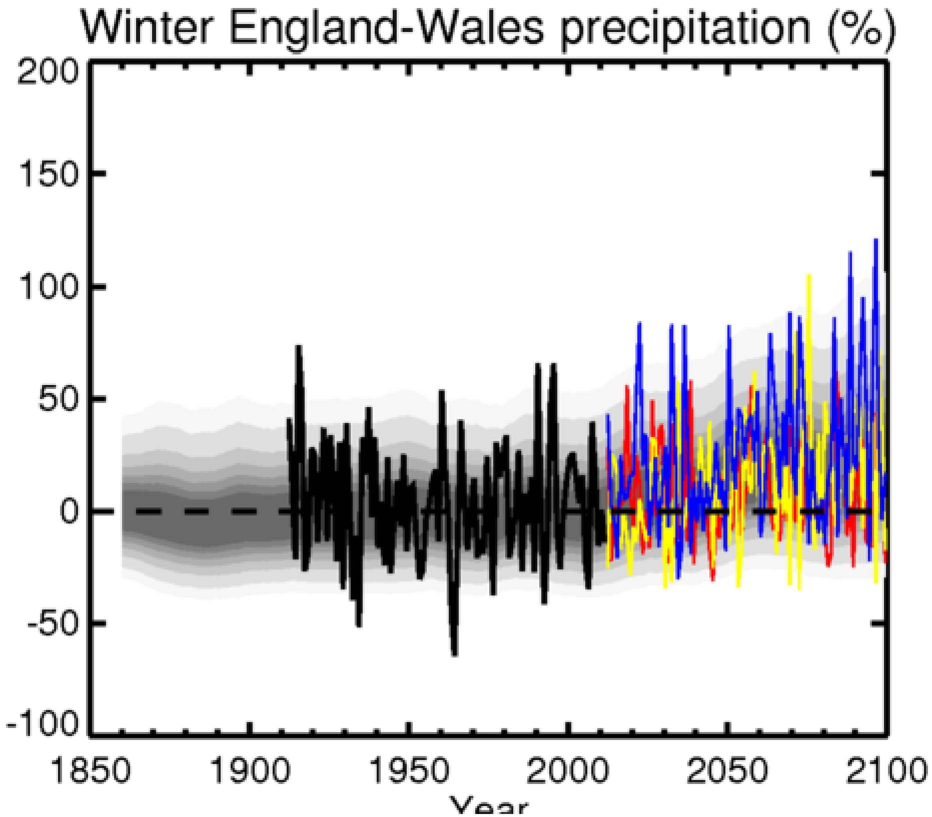


People will be able to relate such extreme seasons to their experience and understand the impact.

There will be a substantial increase in the probability of seasons that were considered extreme in the historical period. Happens when climate variability reinforces climate change signal.

Met Office
Hadley Centre

Simple verification



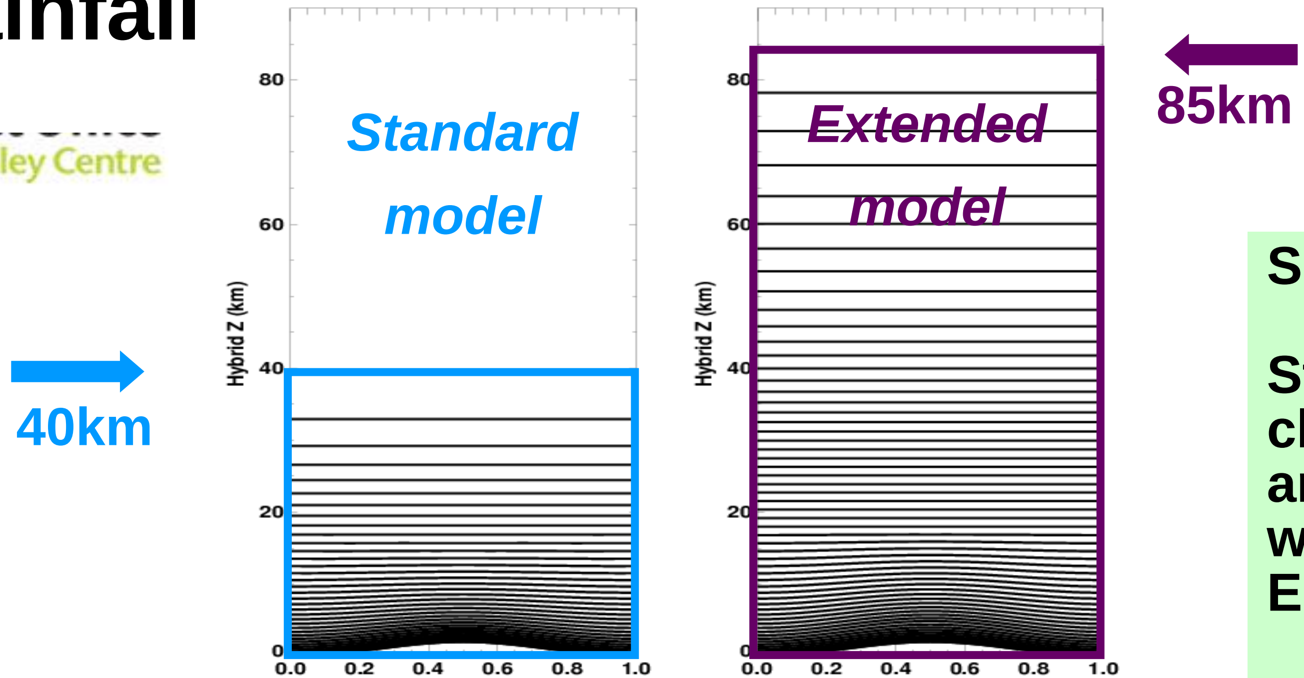
Aim is to give users an idea of when climate projections are suffering from systematic errors common to all climate models used as evidence here

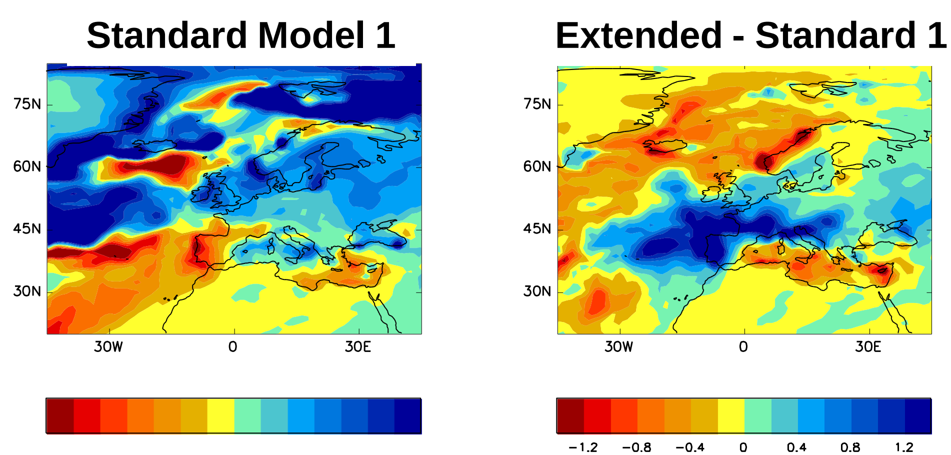
Met Office
Hadley Centre

Does UKCP09 need updating yet?

Effect of increased vertical resolution on rainfall

Hadley Centre





Scaife et al 2012

Standard climate models are wetter in winter in N Europe

Extended models make a *robust* difference that is some regions e.g. Spain offsets the response in the standard model

Consequence of new model results

- On one hand, yes, newer models that include different physics can produce apparently different answers to UKCP09
- But remember UKCIP02, which is based on the standard variant of our UKCP09 model, was extreme compared to UKCP09 for change in summer rainfall
- We need to take a balanced view
- We need to wait to see the results of **several** models with the new physics
- We need to better understand the main drivers behind the range of climate change over the UK e.g. circulation patterns over Atlantic and Europe, Atlantic temperatures, soil moisture. Can then put UKCP09 and new model results in this context (Pidgeon and Baruch Fischhoff 2011)

Met Office
Hadley Centre

Summary

- Need to include multiple lines of evidence. UKCP09 is a robust assessment of several lines of evidence.
- Caveat is that there are systematic errors common to all climate models used here and they are not accounted for. Need to give users some idea of where this occurs.
- If someone asks for one number they can use in their decision making, it can only be the risk of realising some vulnerability threshold in the impact in question
- UKCP09 is still the latest climate projection product. We are working towards an incremental update (1-year PDFs) and will soon start to assess which parts of UKCP09 are out-of-date relative to new results from forthcoming 5th IPCC assessment.

Met Office
Hadley Centre

Any questions?

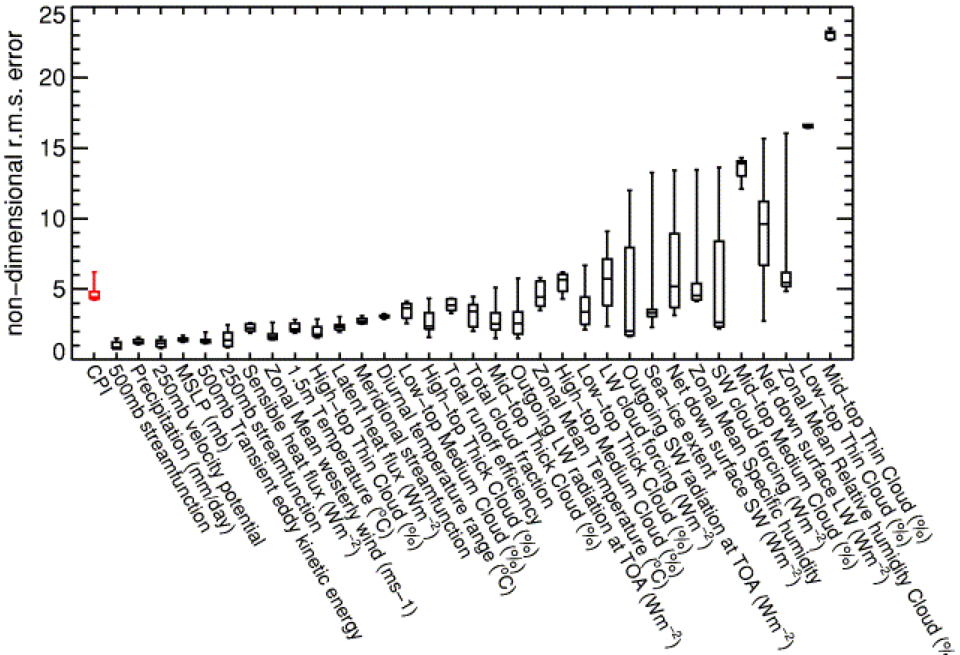
Back-up slides

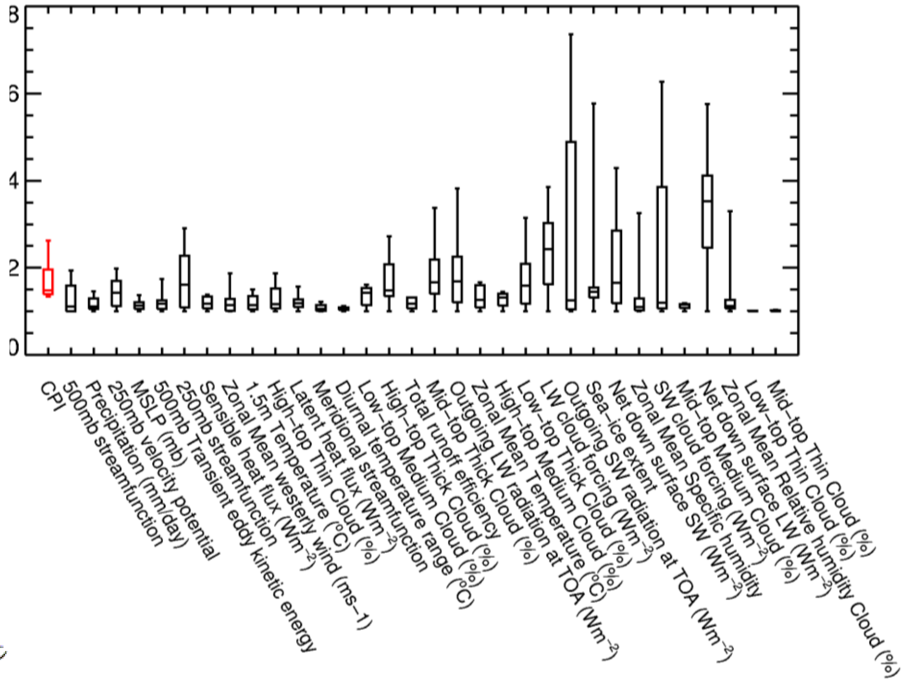
Advantages of this Bayesian framework

- Makes predictions for many variables at once
- Can use lots of observations to constrain the prediction
- Allows for model imperfections
- Rigorous synthesis of the evidence
- Can test sensitivity to expert choices
- Lends itself to providing something for risk-based decision making
- Provides us with a language and some rigour with which to discuss the problem

Met Office
Hadley Centre

Discrepancy – a schematic of what it does

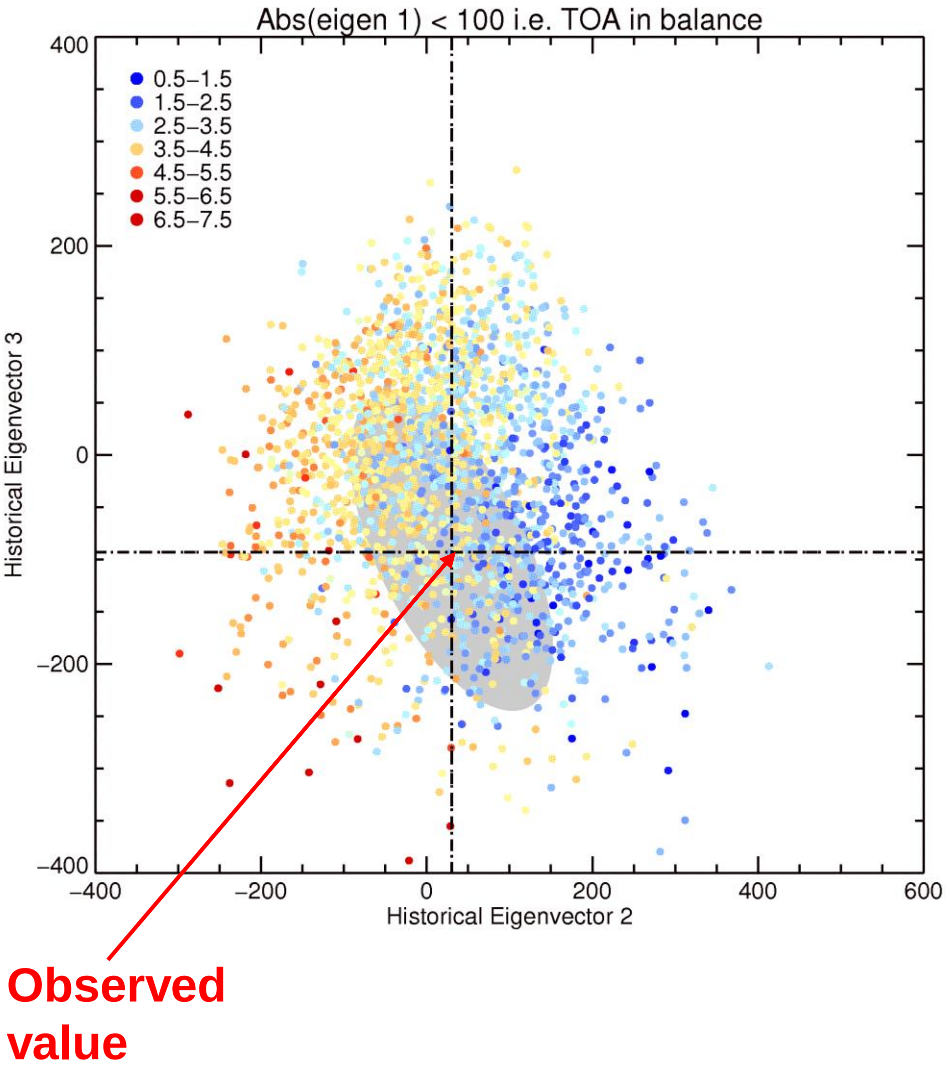




- Avoids contradictions from subsequent analyses when some observations have been allowed to constrain the problem too strongly.

Met Office
Hadley Centre

Constraining predictions



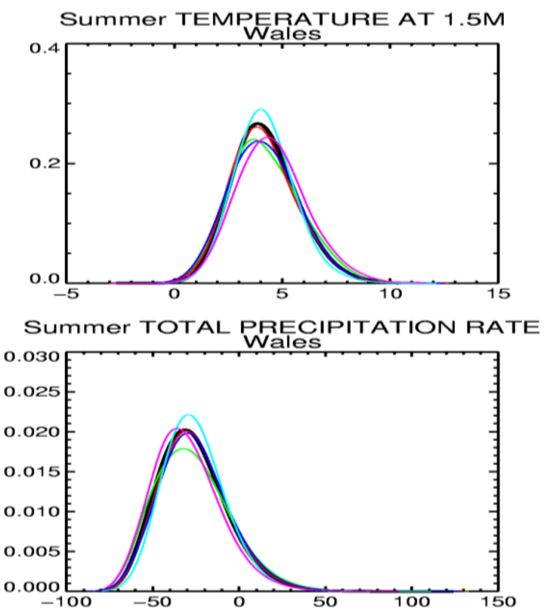
- Weighting particularly effective if there exists a strong relationship between a historical climate variable and a parameter AND that parameter and a future climate variable. So weighting can still have a different effect on different prediction variables.

Met Office
Hadley Centre

Improving evidence

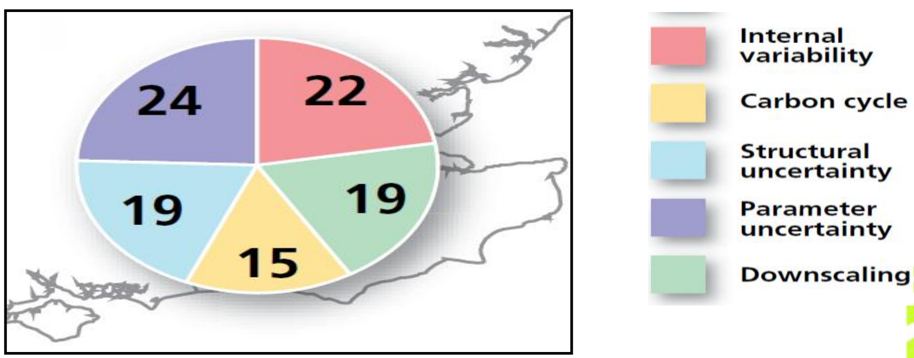
•UKCP09 assessment of current evidence so subject to errors common to all current models. Evidence will change in future due to improvements in methods, observations, climate models, and initialisation with observations.

•But sensitivity tests and inclusion of major sources of spread in climate projections demonstrate a robustness of this assessment of current evidence.



Sensitivity studies

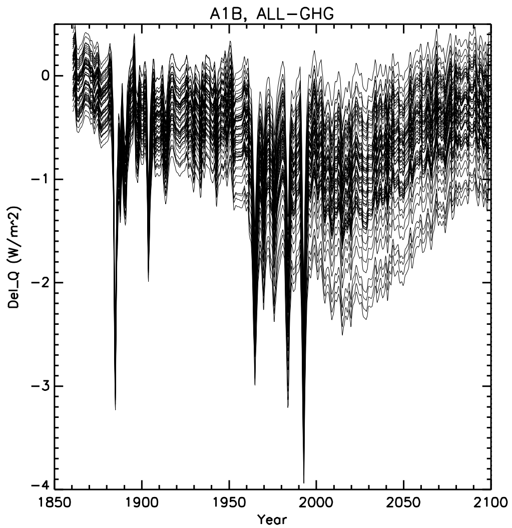
Relative contributions to range of climate response

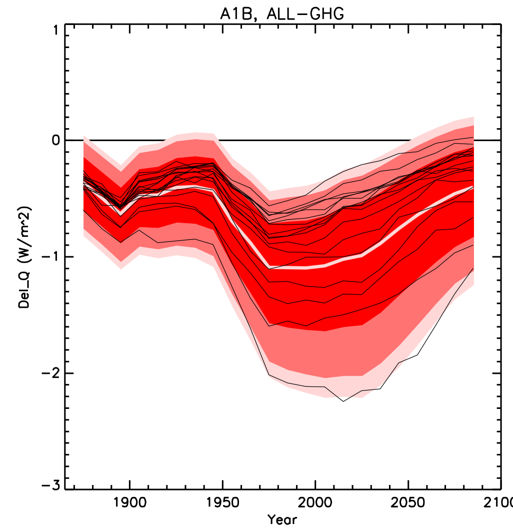


Met Office Hadley Centre

UKCP09 aerosol forcing uncertainty

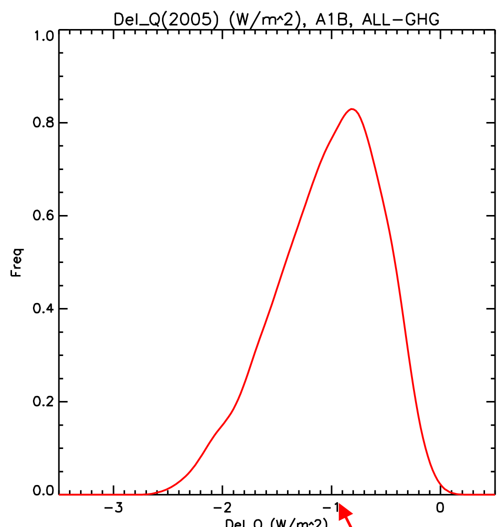
17 runs with all forcings except greenhouse gases

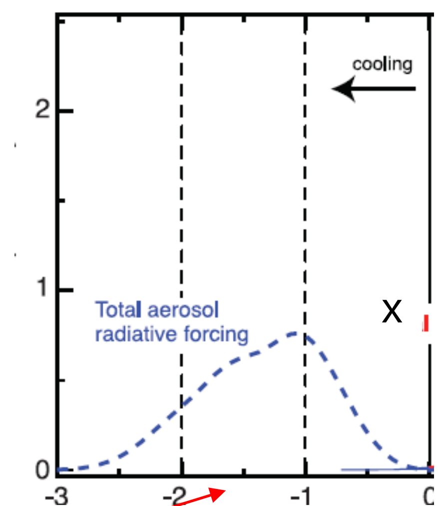




Red: 2.5, 5, 16.7, 83.3, 95, 97.5% percentiles.

Aerosol forcing is found to be inversely proportional to climate sensitivity and this implies a distribution of aerosol forcing uncertainty in UKCP09



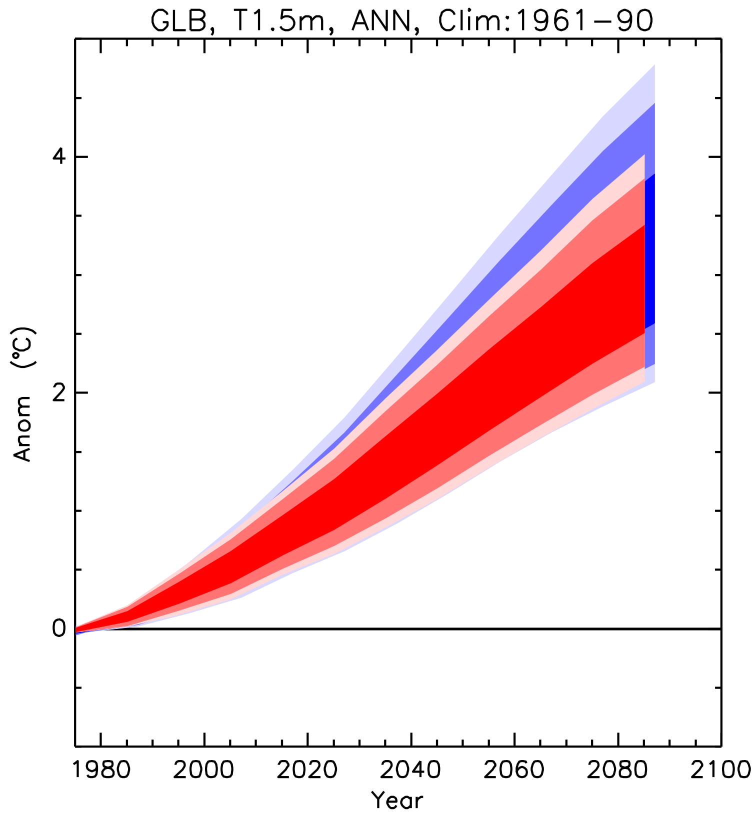


From IPCC Fourth assessment report

Different scales

Met Office
Hadley Centre

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).

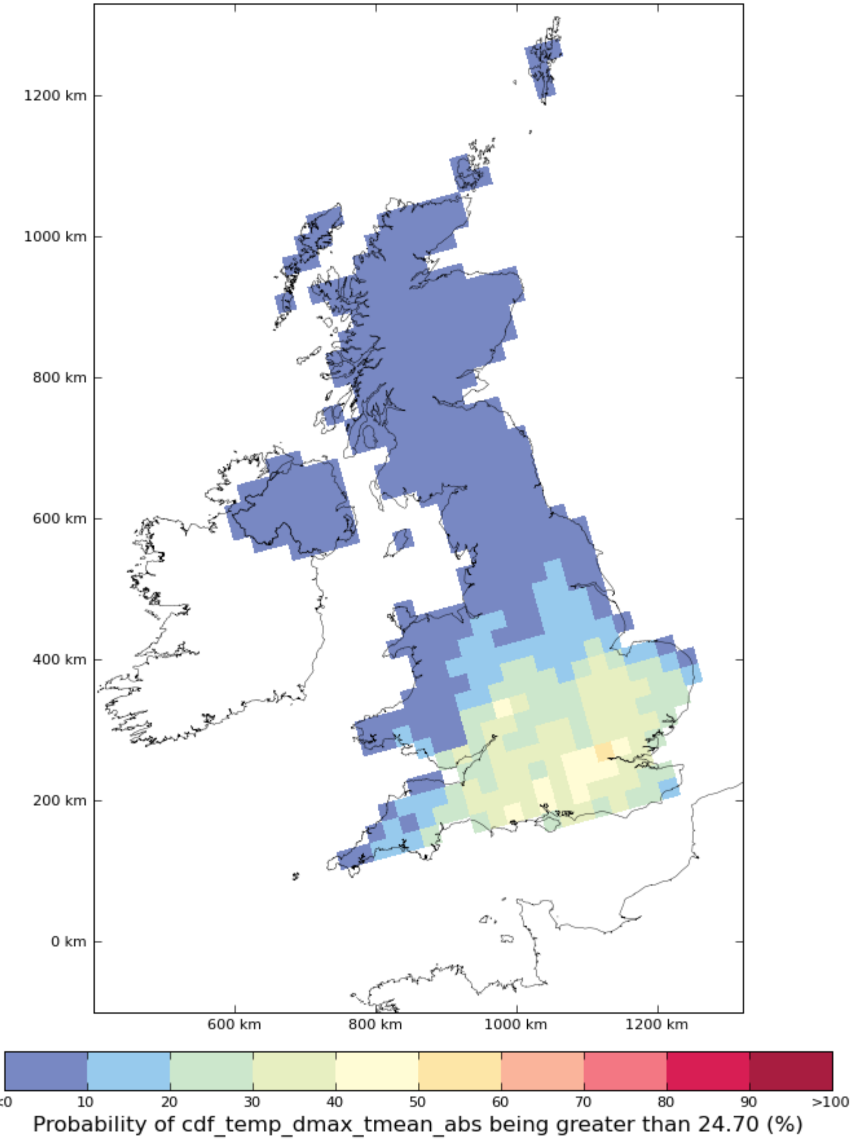
Met Office
Hadley Centre

Probability of exceeding a threshold…

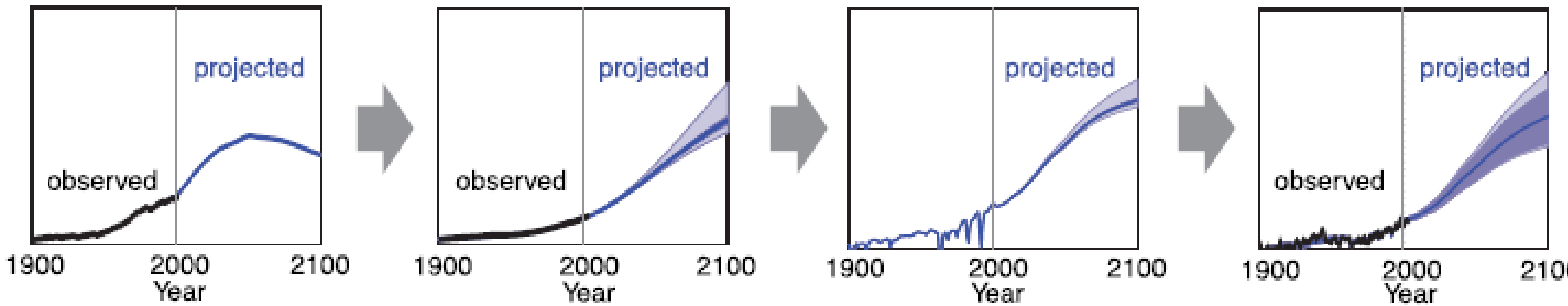
- First need assessment of vulnerability
- Here, use 2003 summer average of daily maximum temperatures

Plot Details:

Time Period: 2040-2069	Data Source: Probabilistic Land
Emissions Scenario: Medium	Location: -10.00, 48.00, 4.00, 61.00
Spatial Average: Grid Box 25Km	Temporal Average: JJA
Variables: temp_dmax_tmean_abs	Future Absolute Climate: True
Probability Data Type: cdf	Condition: greater than 24.700



A range of climate response…



Man-made greenhouse gas emissions

Greenhouse gas concentrations

Change in energy balance in the atmosphere

Climate response

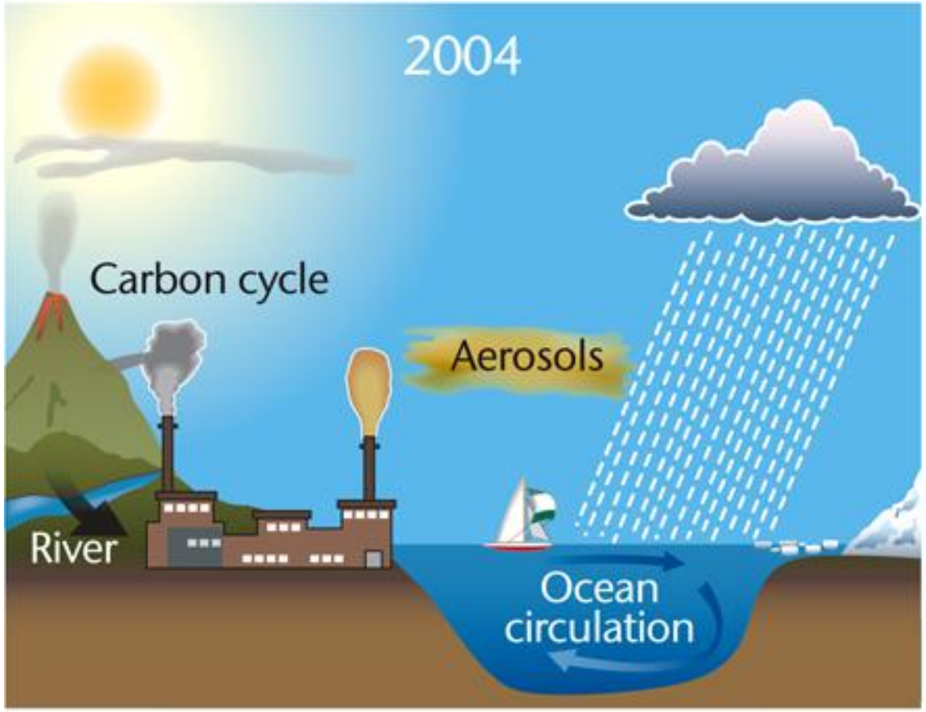
Earth System/climate models

• Computer code that represents the key laws of physics, chemistry, and biology.

•The computer code is called a climate model (or Earth System model).

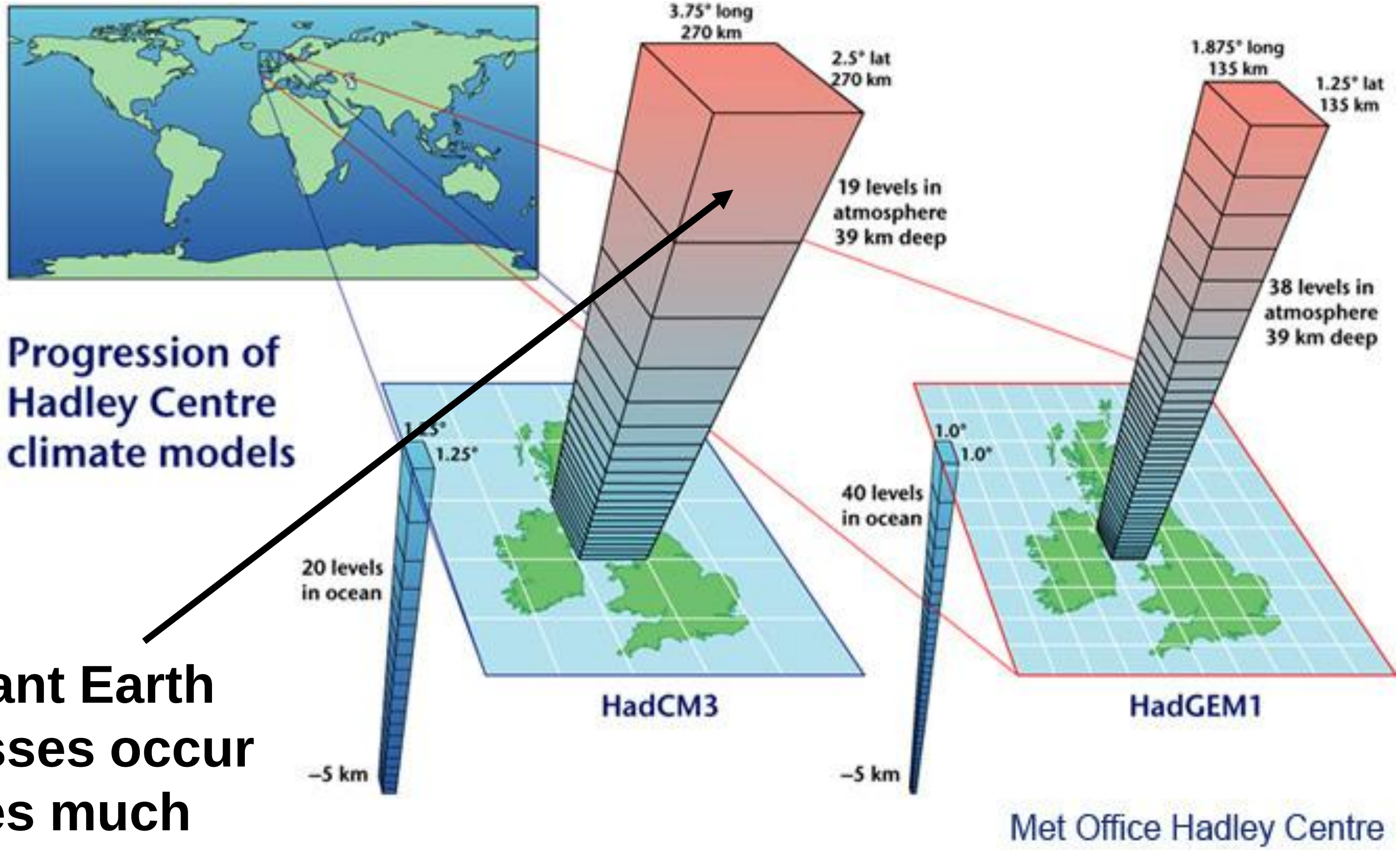
•Climate models take inputs e.g. man-made greenhouse gas emissions.

•The solution, which is the simulated response of the climate system to the inputs, “emerges”.



Met Office
Hadley Centre

Model resolution



Lots of important Earth System processes occur at spatial scales much smaller than size of this box (e.g. turbulence, water droplets in clouds, leaves, particulate matter etc)

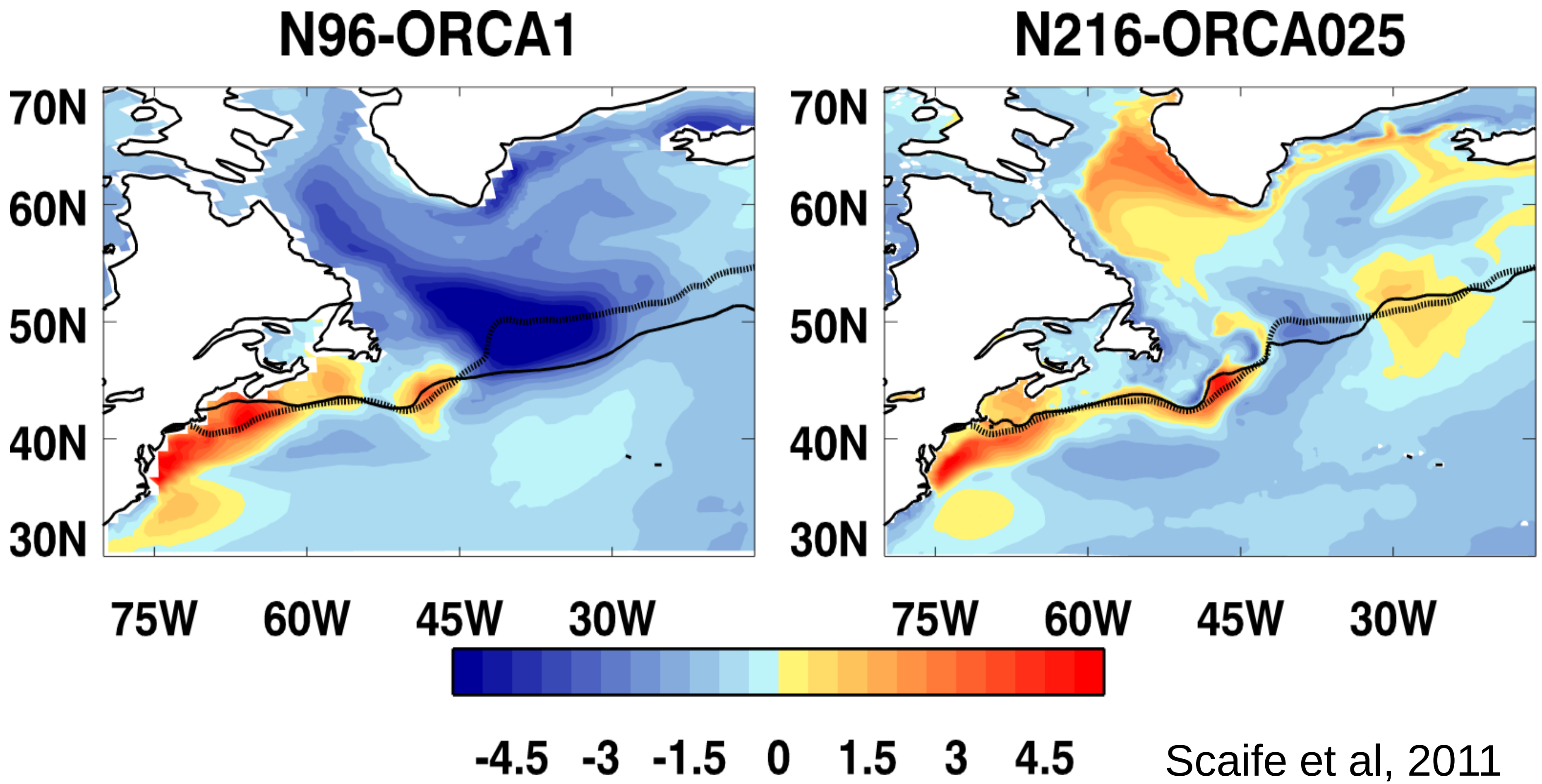
Met Office
Hadley Centre

2. Increasing resolution

- Users impacted by weather systems yet climate models offer robust climate signals on longer time scales
- Yet are the climate change signals correct if the variability is not simulated adequately.
- So are we getting the variability right?
- Model variability often improved by increasing resolution and cannot be solved by changing values of model parameters. For example…

Met Office
Hadley Centre

North Atlantic SST bias in coupled models



Scaife et al, 2011