Using perturbed parameter ensembles to quantify uncertainty in model predictions (QUMP)

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IMAGe TOY Integrated Uncertainty Workshop

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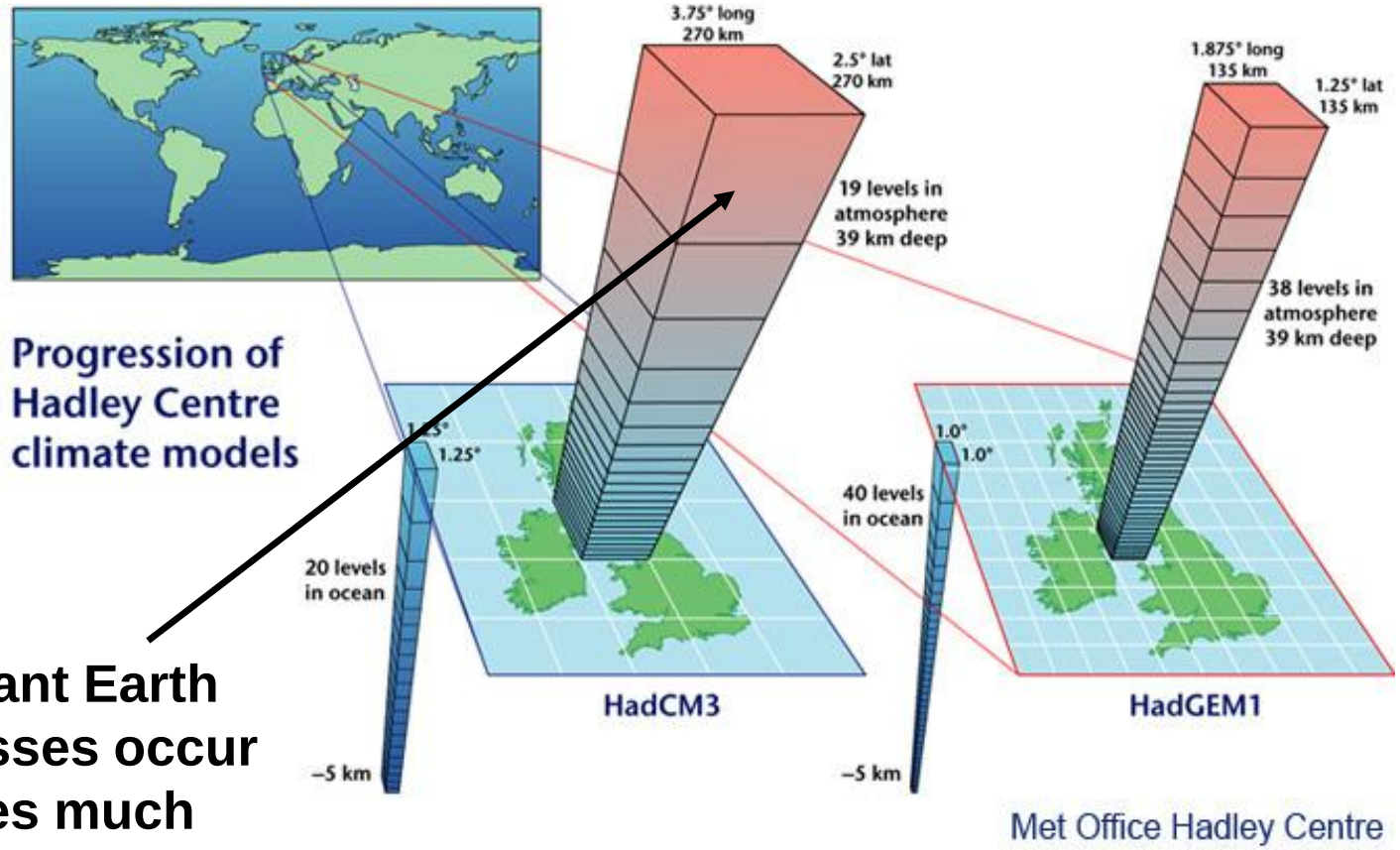
Contents

- What is a perturbed parameter ensemble (PPE) and how do you make one
- Different types of PPEs
- Ways to use PPEs

What is a perturbed parameter ensemble (PPE) and how do you make one

Members of a perturbed parameter ensemble differ in the values of their input parameters

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)

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Recipe for making a PPE

- Decide what you want to investigate?
- Pick baseline model
- Design suitable experiment

- Ask experts about which parameters to perturb and their plausible ranges
- Sample parameter space and repeat experiment for each model variant

Quantifying Uncertainty in Model Projections (QUMP)

•Investigate climate feedbacks to doubling CO2

•HadCM3

•Difference between slab model HadSM3 with 1x and 2xCO2 forcing

•31 parameters

•280 ensemble members

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Atmosphere Parameters (HadCM3 QUMP experiments)

Large Scale Cloud

Ice fall speed

Critical relative humidity for formation

Cloud droplet to rain: conversion rate and threshold

Cloud fraction calculation

Convection

Entrainment rate

Intensity of mass flux

Shape of cloud (anvils) (*)

Cloud water seen by radiation (*)

Radiation

Ice particle size/shape

Cloud overlap assumptions

Water vapour continuum absorption (*)

Boundary layer

Turbulent mixing coefficients: stability-dependence, neutral mixing length

Roughness length over sea: Charnock constant, free convective value

Dynamics

Diffusion: order and e-folding time

Gravity wave drag: surface and trapped lee wave constants

Gravity wave drag start level

Land surface processes

Root depths

Forest roughness lengths

Surface-canopy coupling

CO2 dependence of stomatal conductance (*)

Sea ice

Albedo dependence on temperature

Ocean-ice heat transfer

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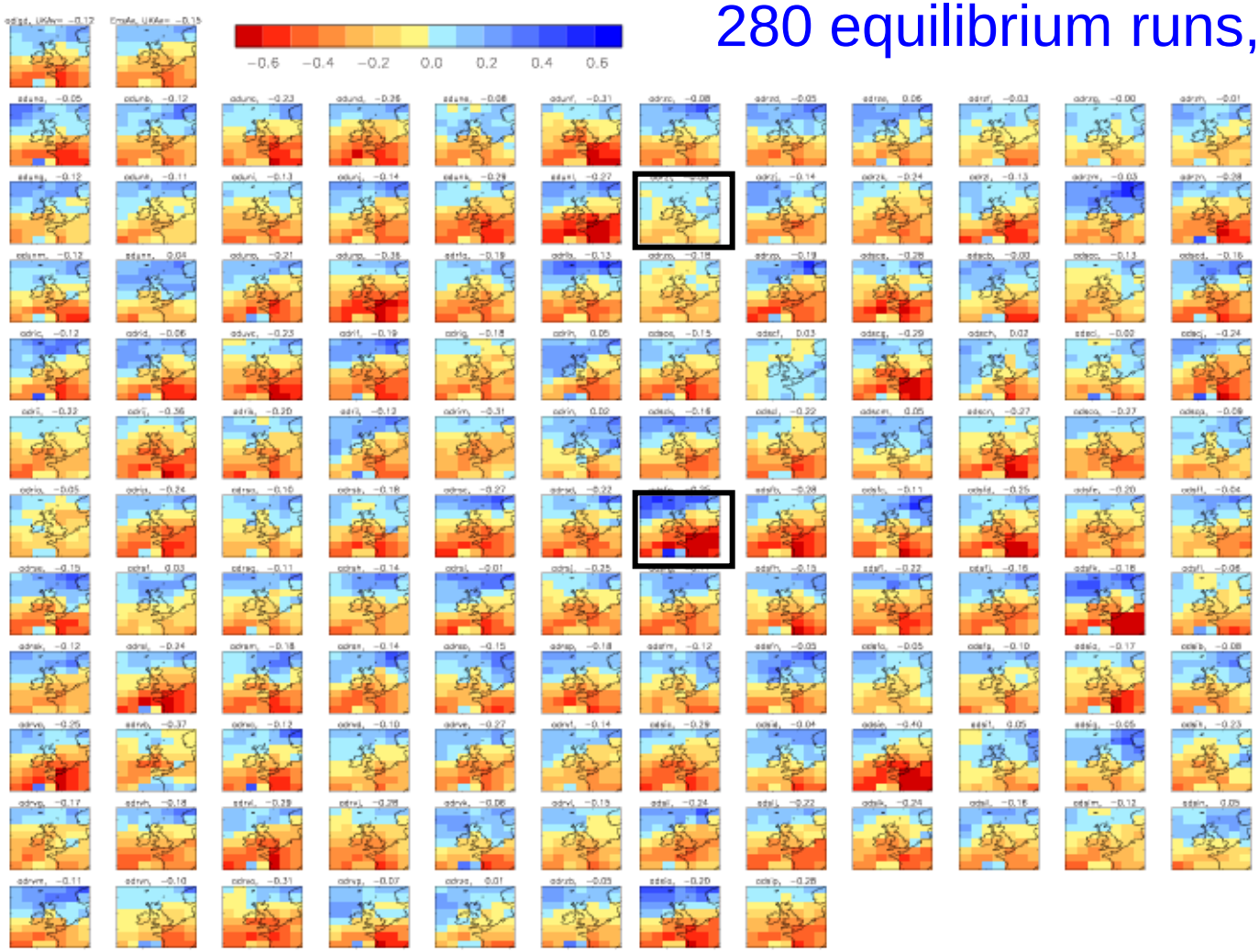
UKCP09 underpinned by perturbed parameter ensemble



280 equilibrium runs, 31 parameters

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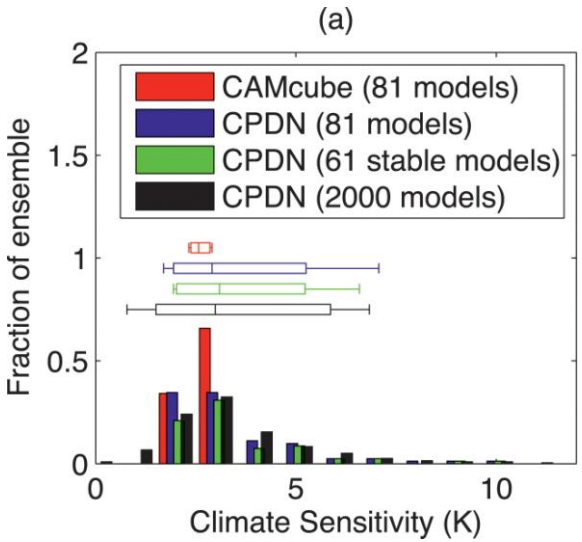
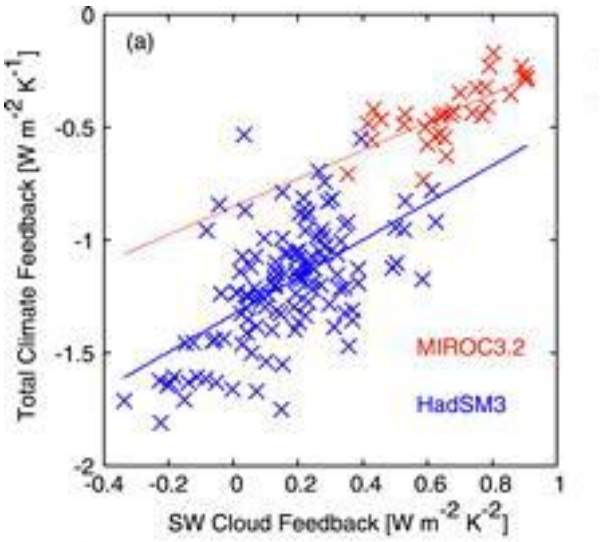
Effectiveness in sampling feedbacks



Climateprediction.net HadCM3 PPEs cf CAMcube PPE (Sanderson, 2010)



MIROC PPE cf HadCM3 PPE (Yokohata et al., 2010)

Some climate models seem to have large parametric uncertainty, some do not

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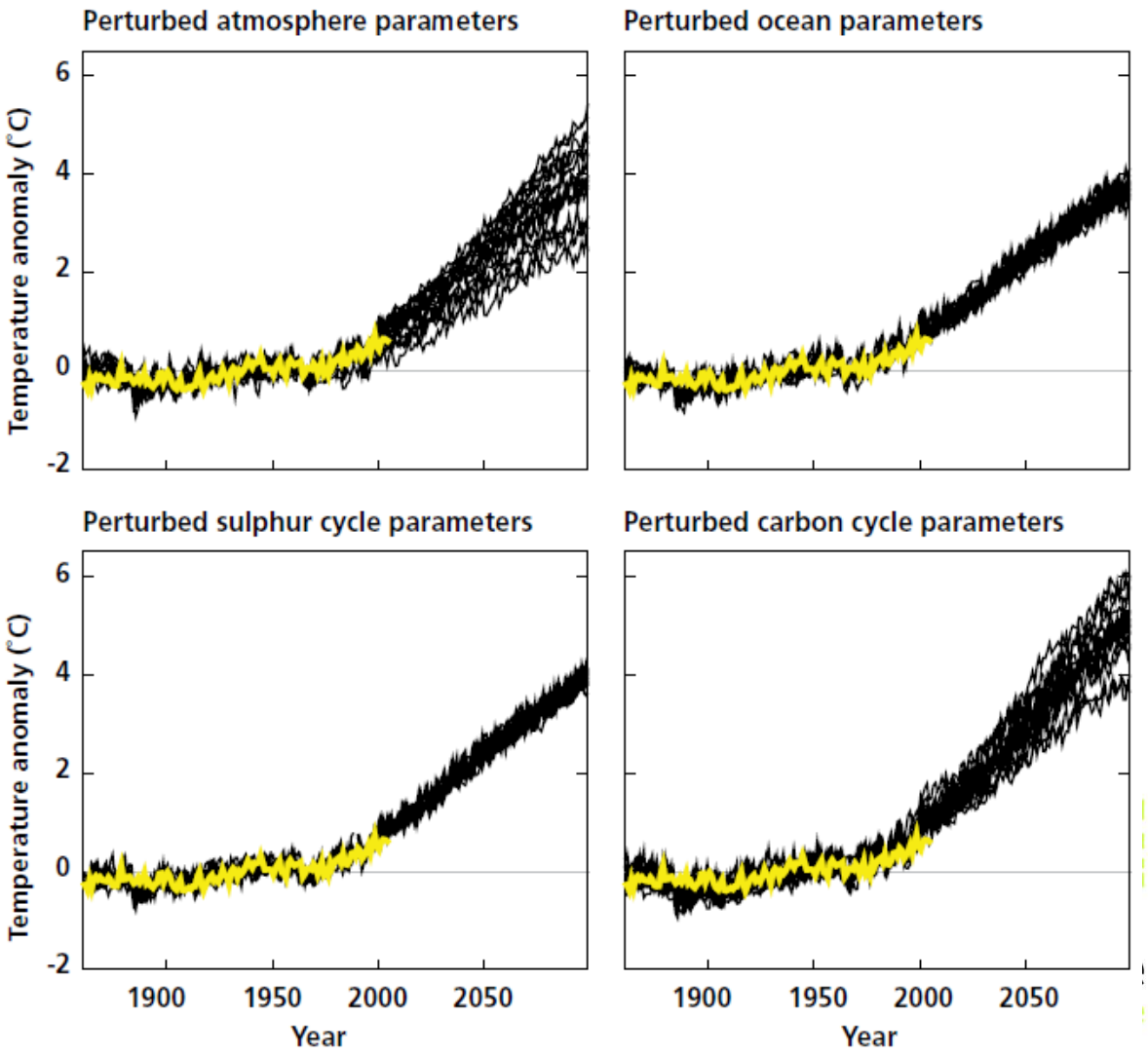
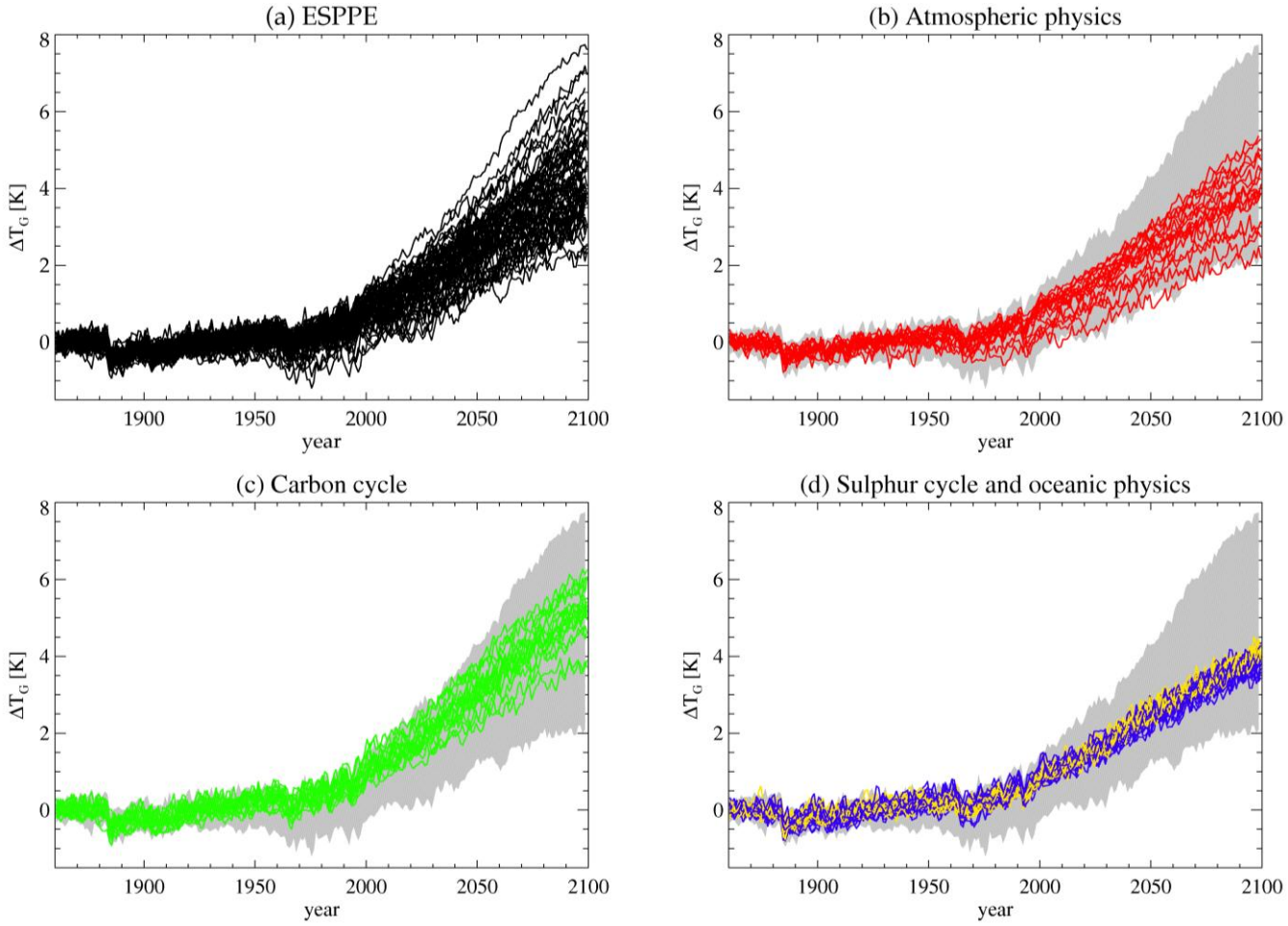
Different types of perturbed parameter ensembles

4 Perturbed physics ensembles



New 57 member Earth System Ensemble (how uncertainty in different Earth System components interact)



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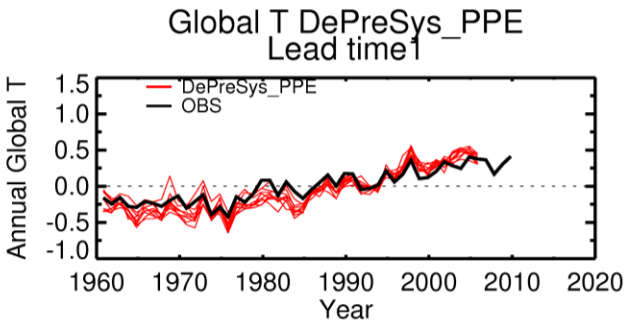
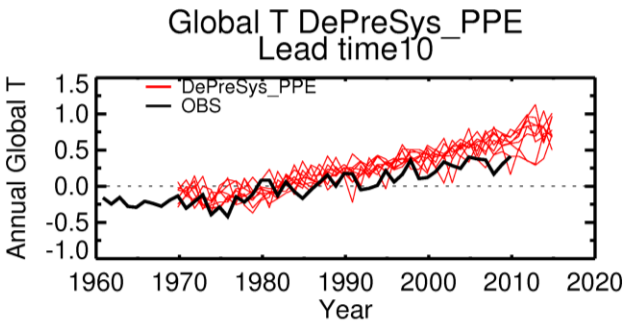
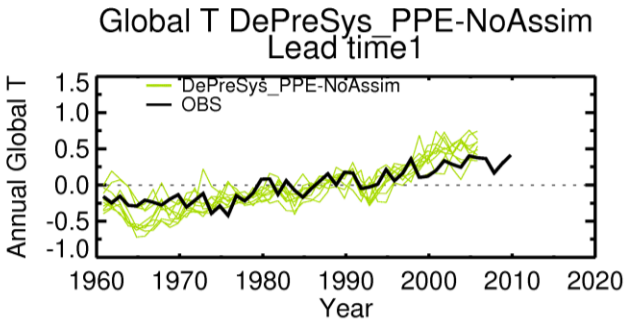
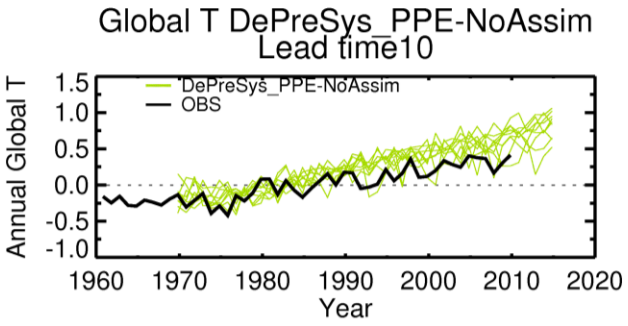
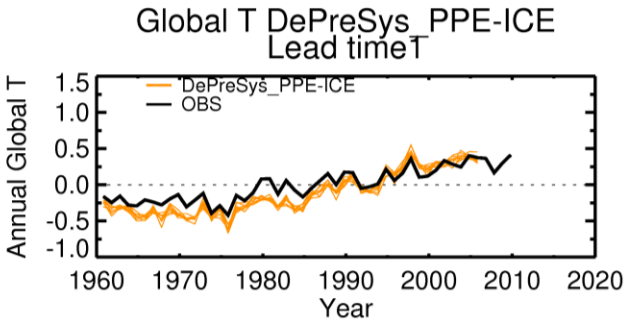
Importance of sampling modelling uncertainty in decadal projections

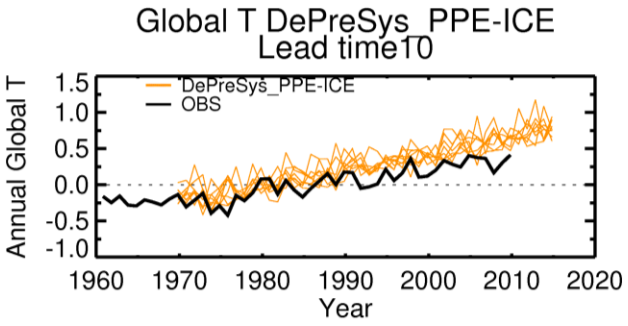












Thanks to Doug Smith,

Leon Hermanson,

Malcolm McVean,

Glen Harris

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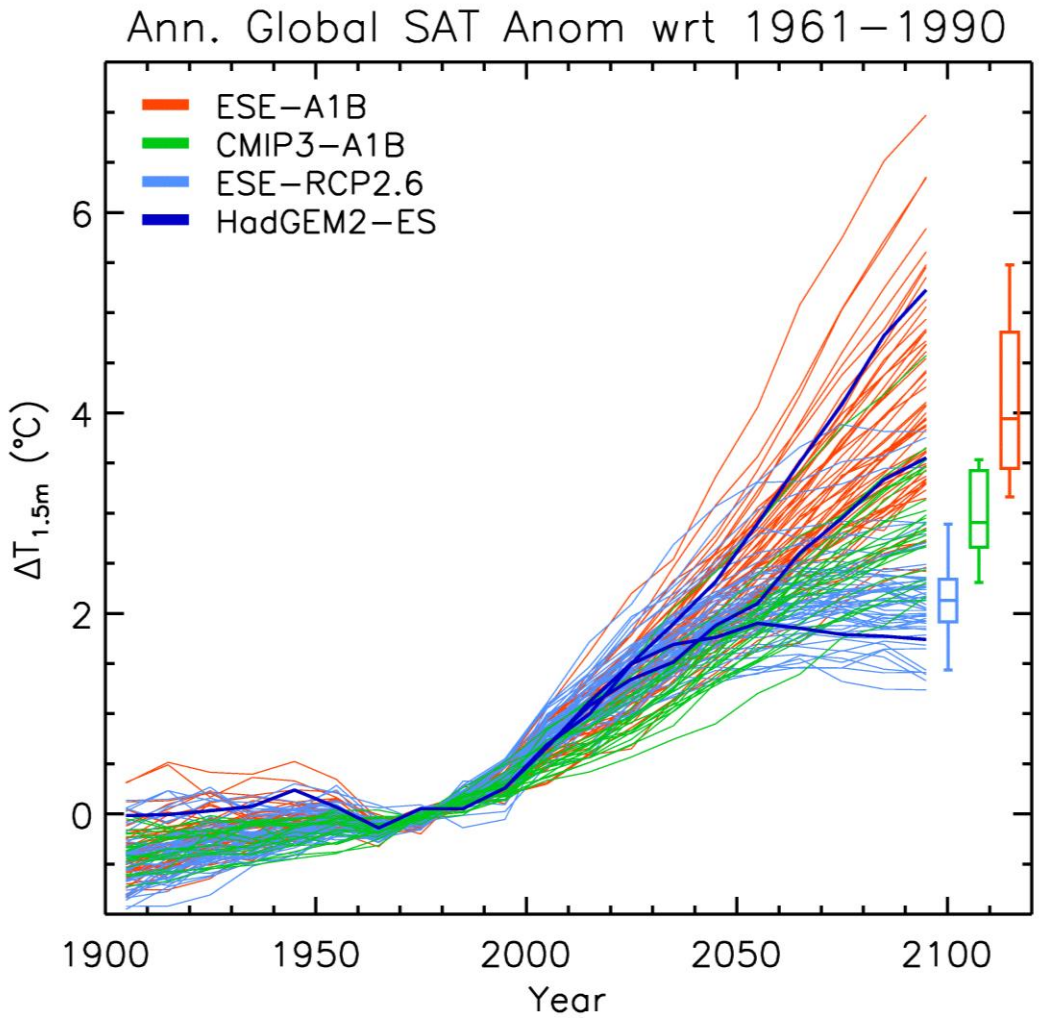
Spread can depend on emission scenarios



Warmer responses expected due to carbon cycle feedbacks, but are the ESE values what we would expect ?

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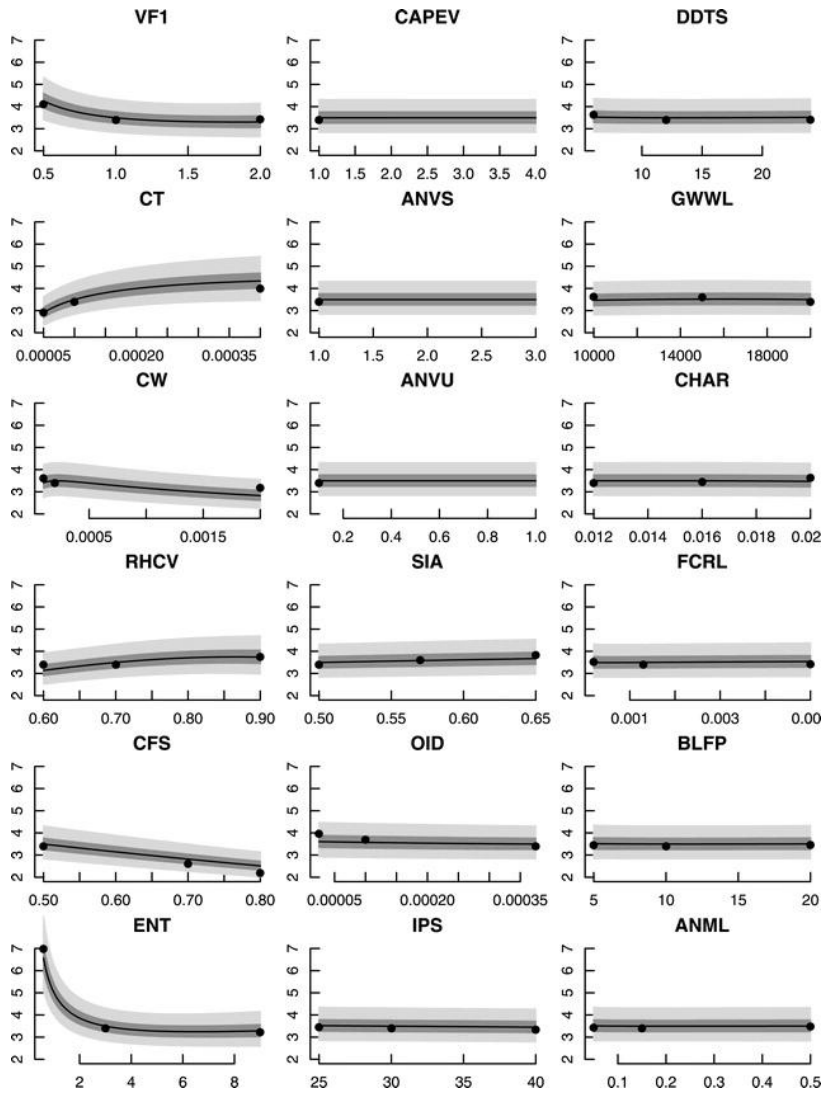
Different ways to use PPEs

- **Sensitivity studies**
- **Emergent behaviour**
  - **Understand how uncertainties interact**
  - **Understand key processes and effect of biases**
- **Using PPEs to underpin projections**

Sensitivity studies - sampling parameters in a controlled way



Global climate sensitivity (Rougier et al., 2009)

From QUMP and cpdn ensembles of HadSM3

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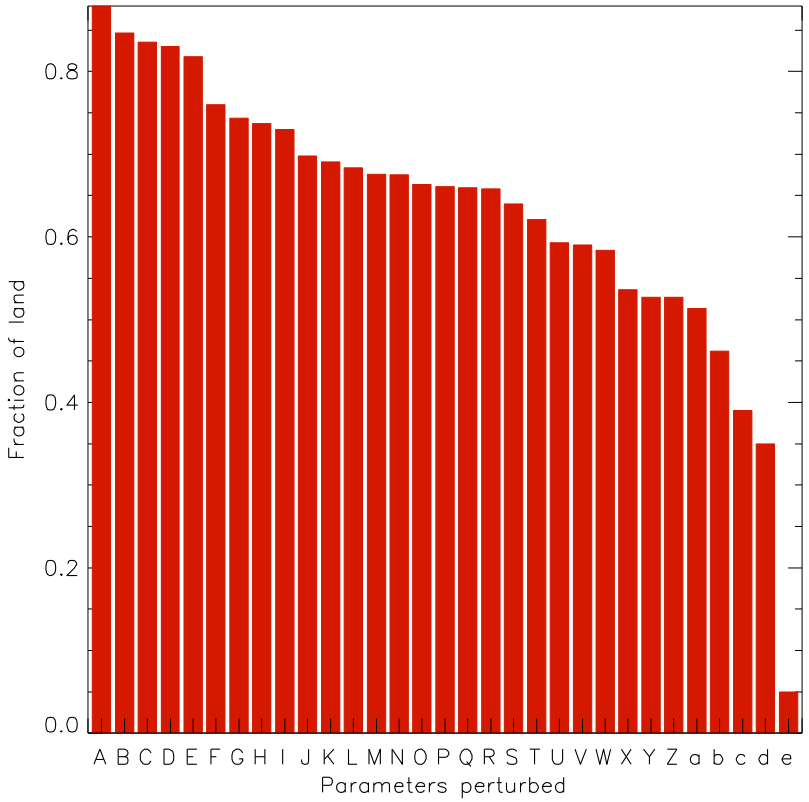
Perturb parameters to explore a wide range of processes

- Our aim is for an ensemble prediction system that can provide worldwide information at the regional level for a wide variety of climate variables. Therefore we need to perturb parameters that affect a comprehensive range of process uncertainties in major parts of the model dynamics, physics, and biogeochemistry.
- For example, we do not wish to restrict our focus to a subset of parameters that might affect global mean climate sensitivity e.g. Clark et al (2009) looked at heatwaves



A: Forest roughness
B: Stomatal conductance switch
C: Boundary layer cloud fraction at saturation
D: Vegetation root depth
E: Sea ice albedo temperature dependence
F: Cloud droplet to rain conversion rate
G: Lowest model level with gravity wave drag
H: Ocean ice diffusion
I: Radius of cloud ice spheres
J: Roughness length over sea
K: Shape of convective cloud
L: Boundary layer flux profile
M: Cloud droplet to rain conversion threshold
N: Ice fall speed
O: Surface gravity lee wave parameters
P: Interactive sulphur cycle calculations
Q: Non−spherical ice particle inclusion
R: Intensity of convective mass flux
S: Convective roughness length over sea
T: Sea ice albedo at 0deg.C
U: Entrainment coefficient
V: Fraction of convective cloud where up−draughts can occur
W: Asymptotic neutral mixing lengths
X: Flow dependent cloud formation critical relative humidity
Y: Vertical gradient of cloud water
Z: Relative humidity threshold for cloud formation
a: Vegatation canopy inclusion
b: Diffusion coefficients
c: Order of dynamic diffusion
d: Shortwave water vapour continuum absorption
e: Internal variability

Top 5 parameters for climate sensitivity

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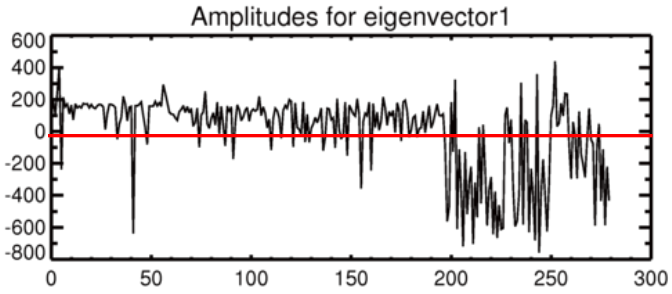
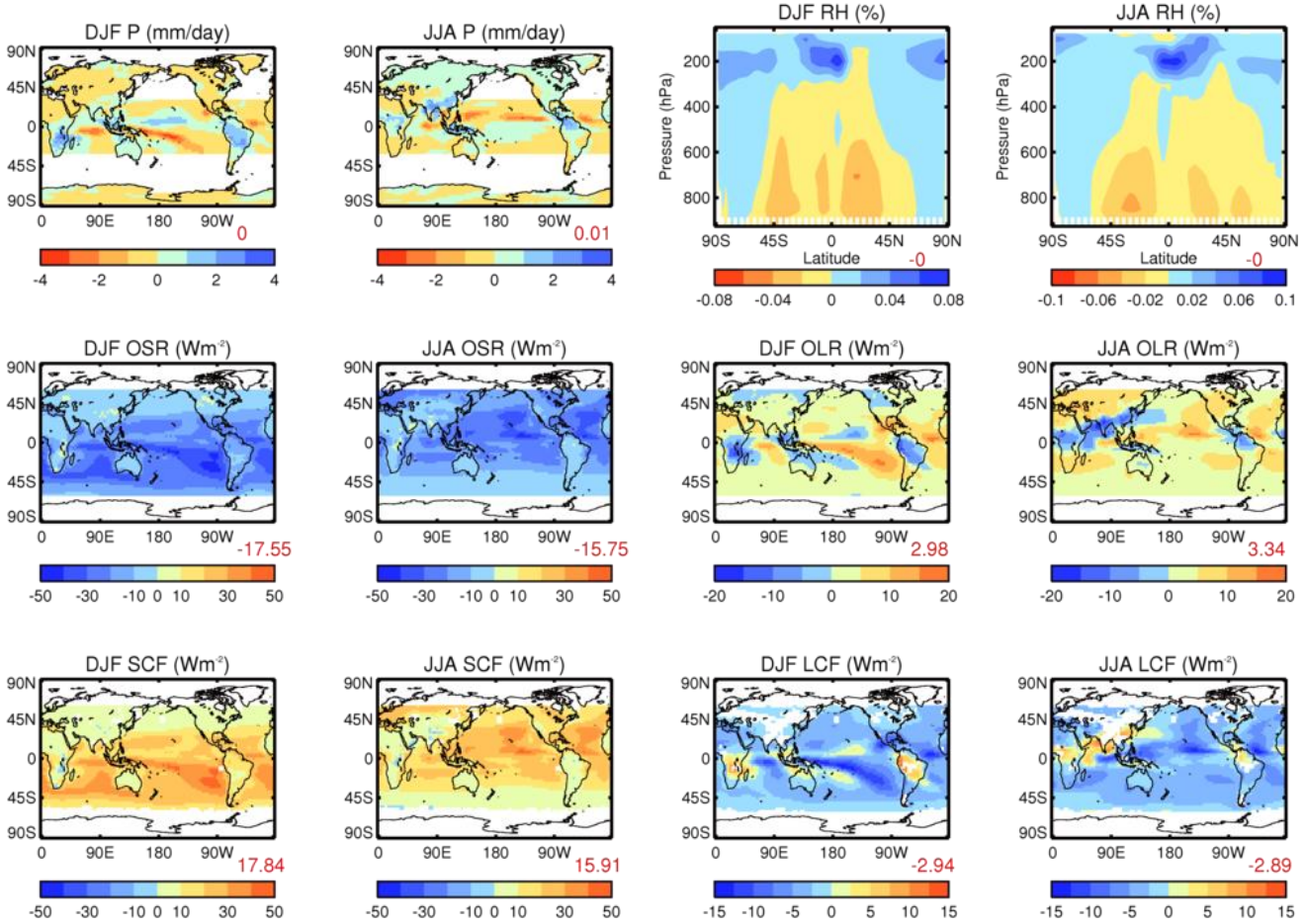
Emergent behaviour - Leading variations of control climate across slab PPE





First of six metrics used in Sexton et al (2012) and UKCP09

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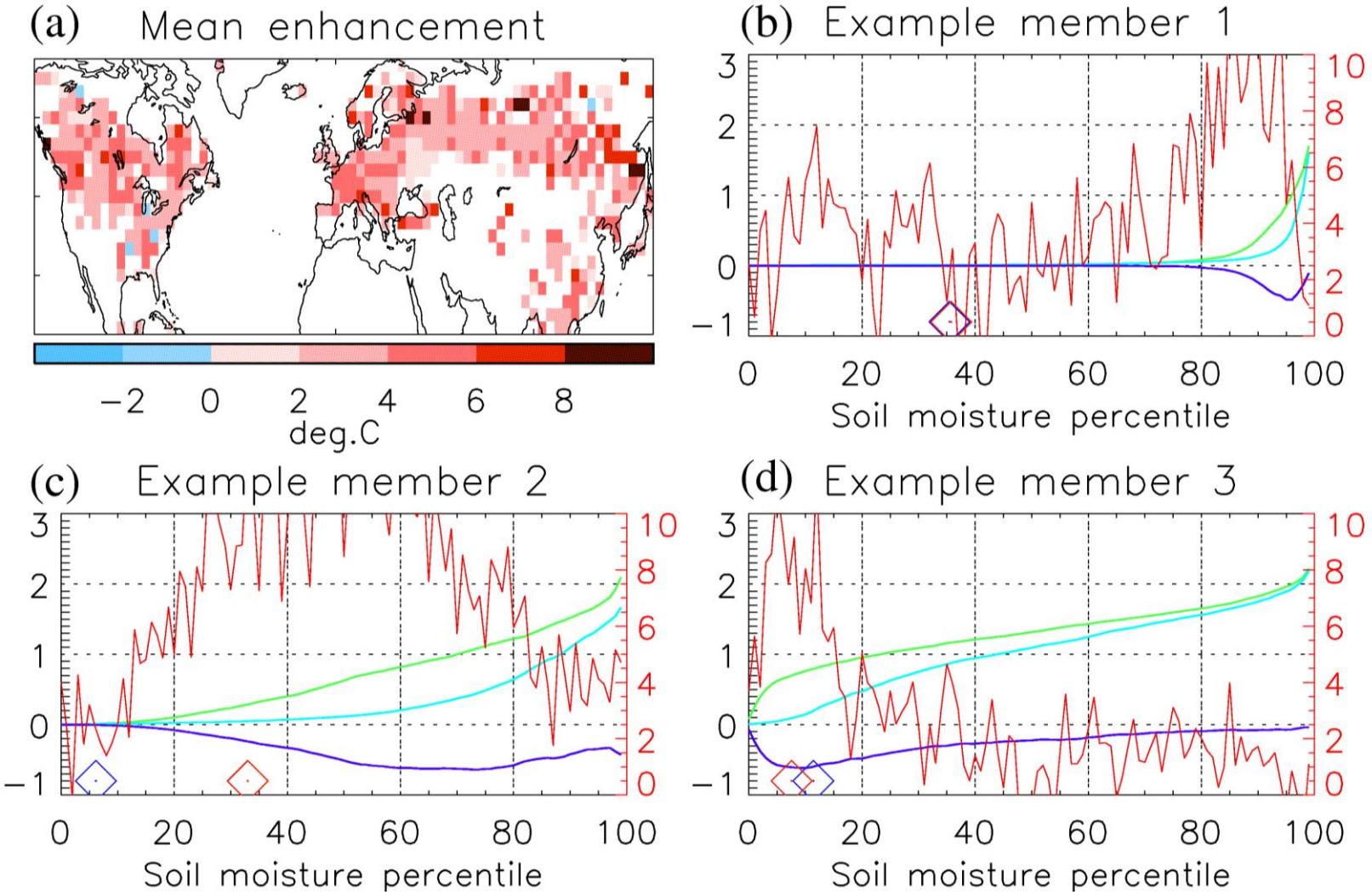
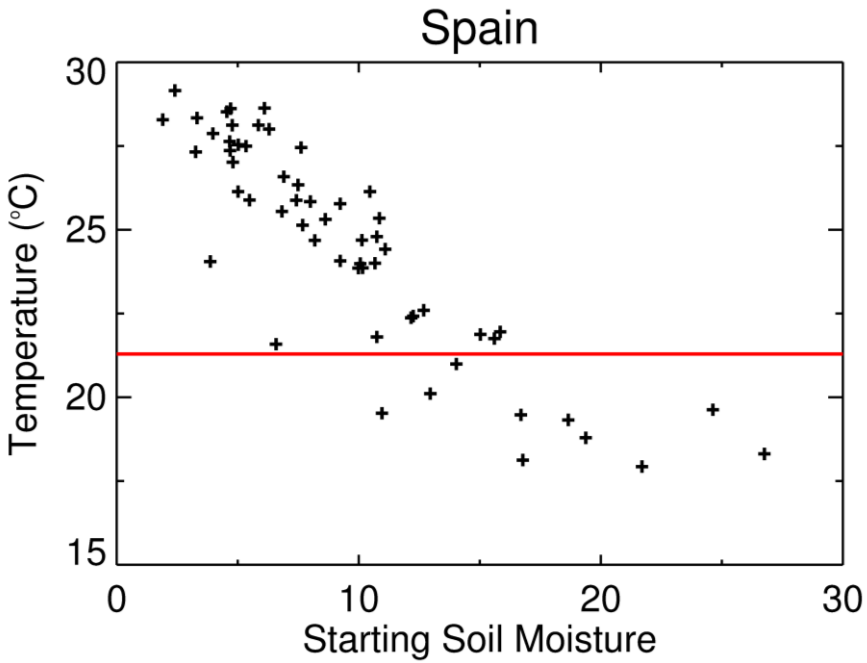
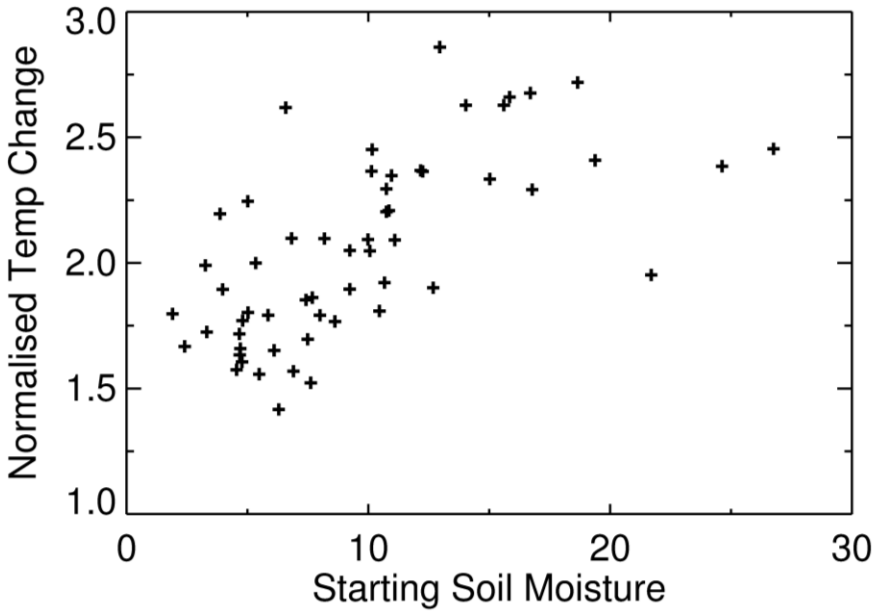
Understanding key processes e.g. effect of soil moisture biases on response in extreme temperatures (Clark et al GRL 2010)



Understanding regional responses, and links to historical simulation errors





In southern Europe, ESE members with large warm biases in historical summer temperatures tend to possess less soil moisture, and simulate SMALLER levels of future regional warming, per degree of global warming. More work needed to understand- e.g. could we rule out or downweight some ensemble members ?

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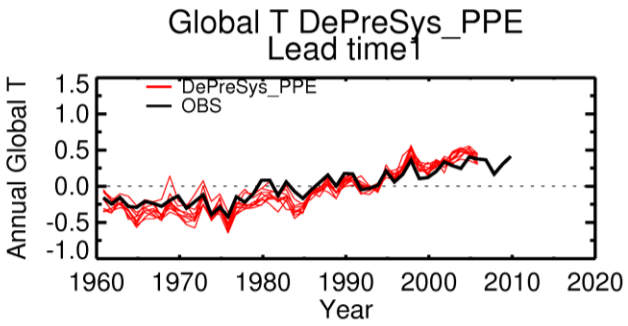
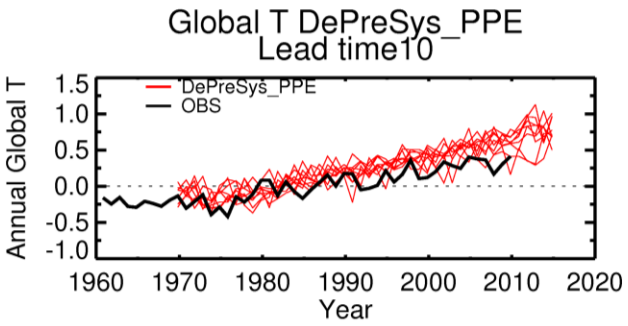
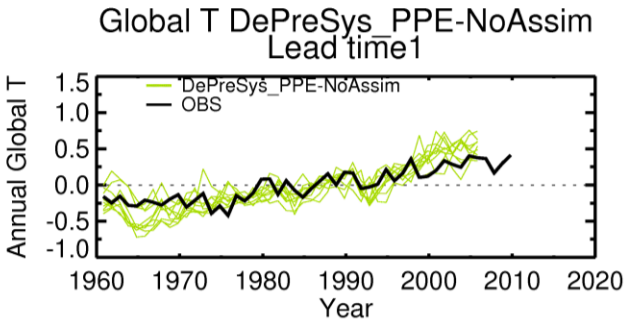
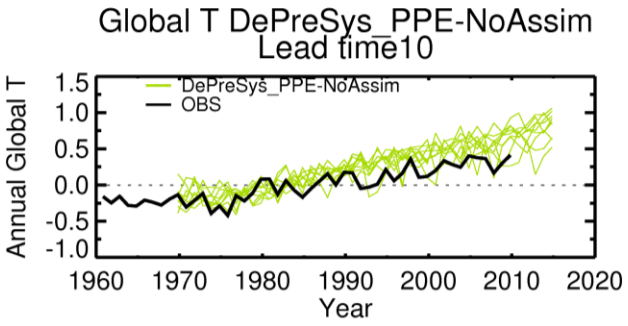
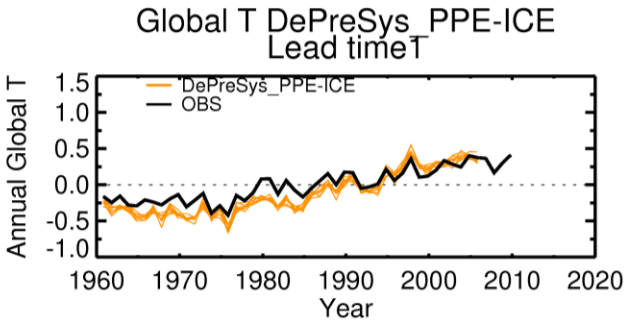
Understanding which uncertainties to worry about

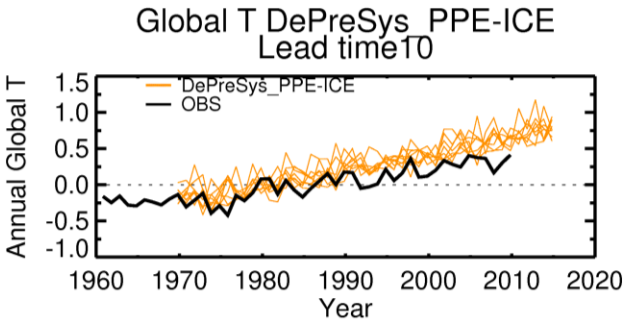












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Using perturbed parameter ensemble for climate projections

- 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
- So need to use observations to find these regions of plausible model variants

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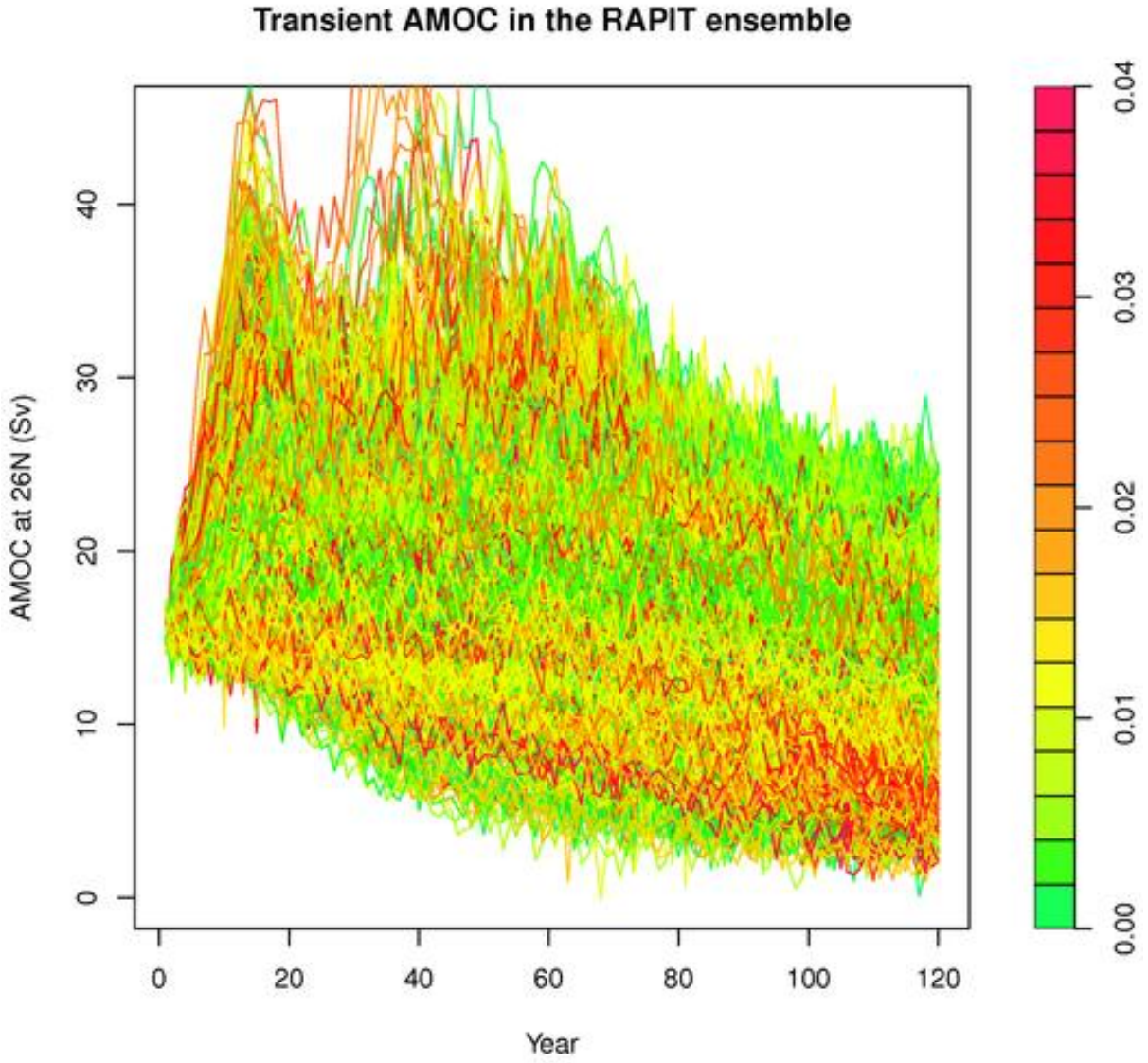
RAPIT – transient AMOC under CO2 ramp down



NERC RAPIT project

CPDN, Durham University, NOC, Met Office

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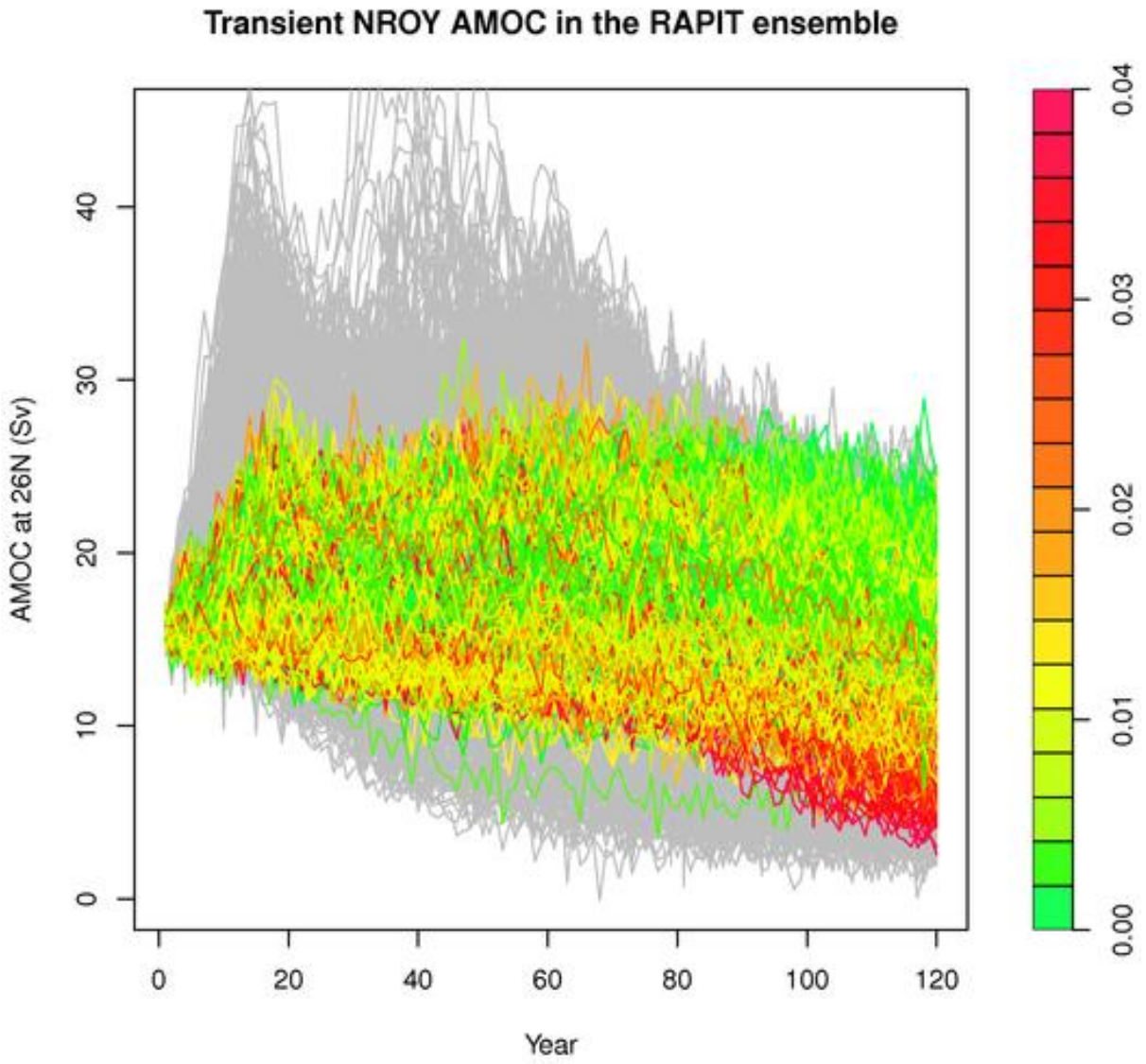
RAPIT – transient AMOC under CO2 ramp down



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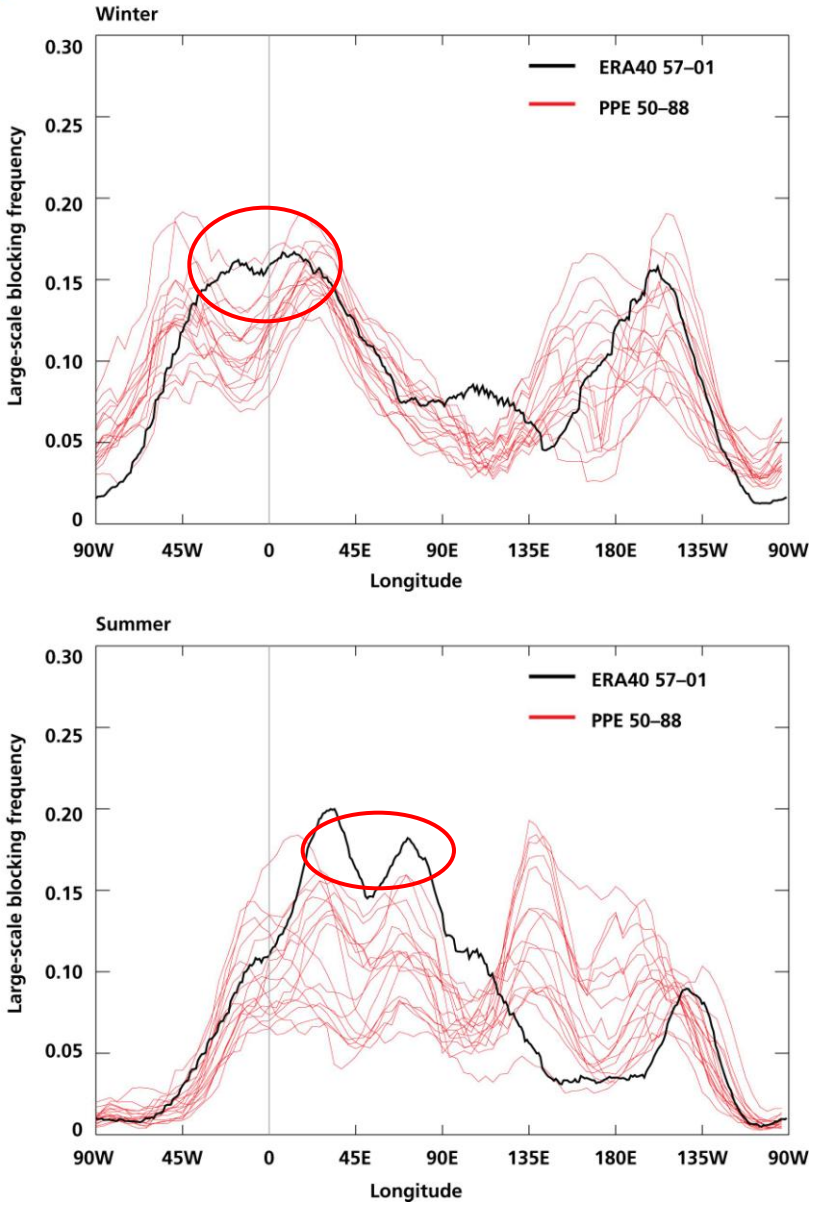
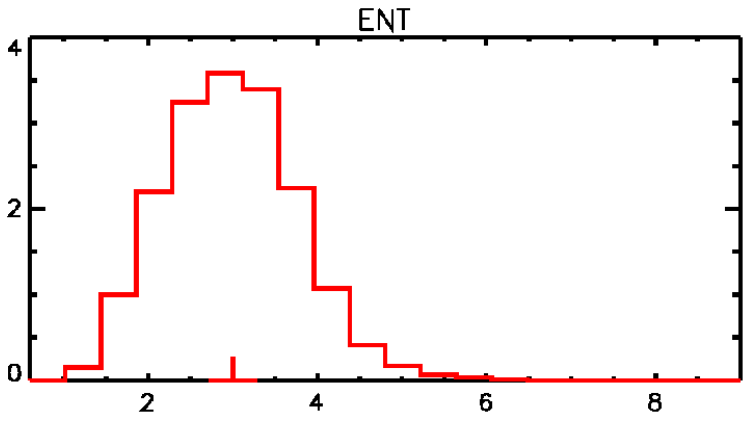
Importance of spanning the observations

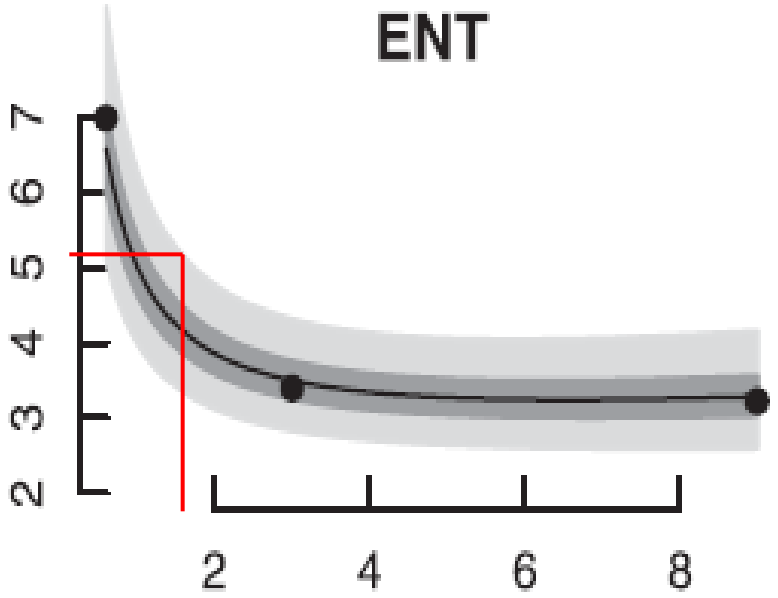


- Blocking frequency for 17 QUMP transient coupled-ocean atmosphere models as a function of longitude
- Winter blocking frequency over UK is underestimated by 16 out of 17 ensemble members
- Summer blocking frequency over much of Europe is considerably underestimated by all 17 QUMP transient runs

…and their effect on constraining climate response



Sexton et al (2012)



Rougier et al (2008)

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Summary

- Members of a perturbed parameter ensemble differ in the values of their input parameters
- They can be used to explore parametric modelling uncertainty across a variety of experiments
- They can be used:
  - In sensitivity studies
  - To investigate emergent behaviour
    - Understand how uncertainties interact
    - Understand key processes and effect of biases
  - To underpin projections

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Any questions?

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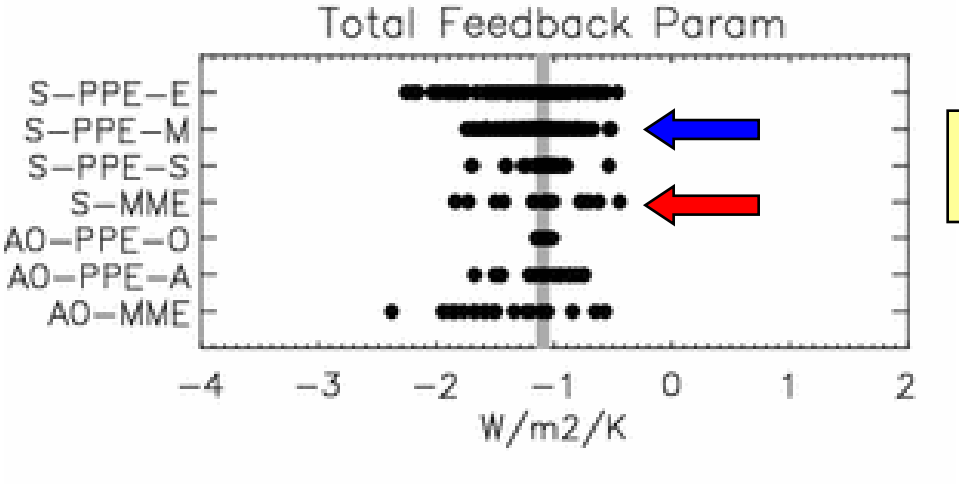
Effectiveness in sampling feedbacks

- PPEs sample a spread of global climate feedbacks, in some cases comparable to CMIP3
- Multimodel ensembles have advantage that they sample structural uncertainties but they do not sample in a controlled way
- Both ensembles obviously do not sample systematic errors common to all state of the art models



Different Met Office HadCM3 PPEs cf CMIP3 multi-model ensembles (Collins et al., 2010)

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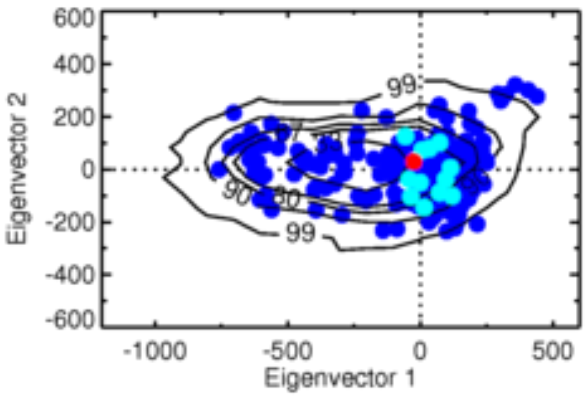
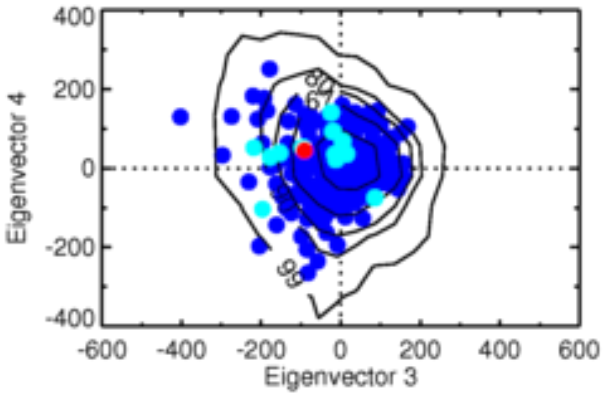
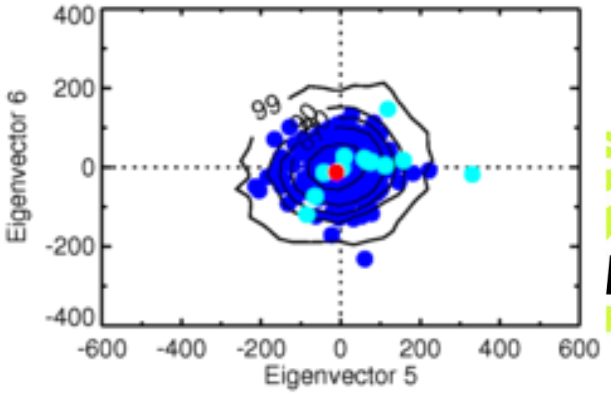
Importance of spanning the observations

- These are six metrics used to constrain probabilistic projections in UKCP09. They are six leading eigenvectors of a climate state vector
- **Dark blue dots** are 280 QUMP members
- **Black lines** are joint probability density of emulated points
- Light blue dots are multimodel ensemble members
- Red dot is observed value







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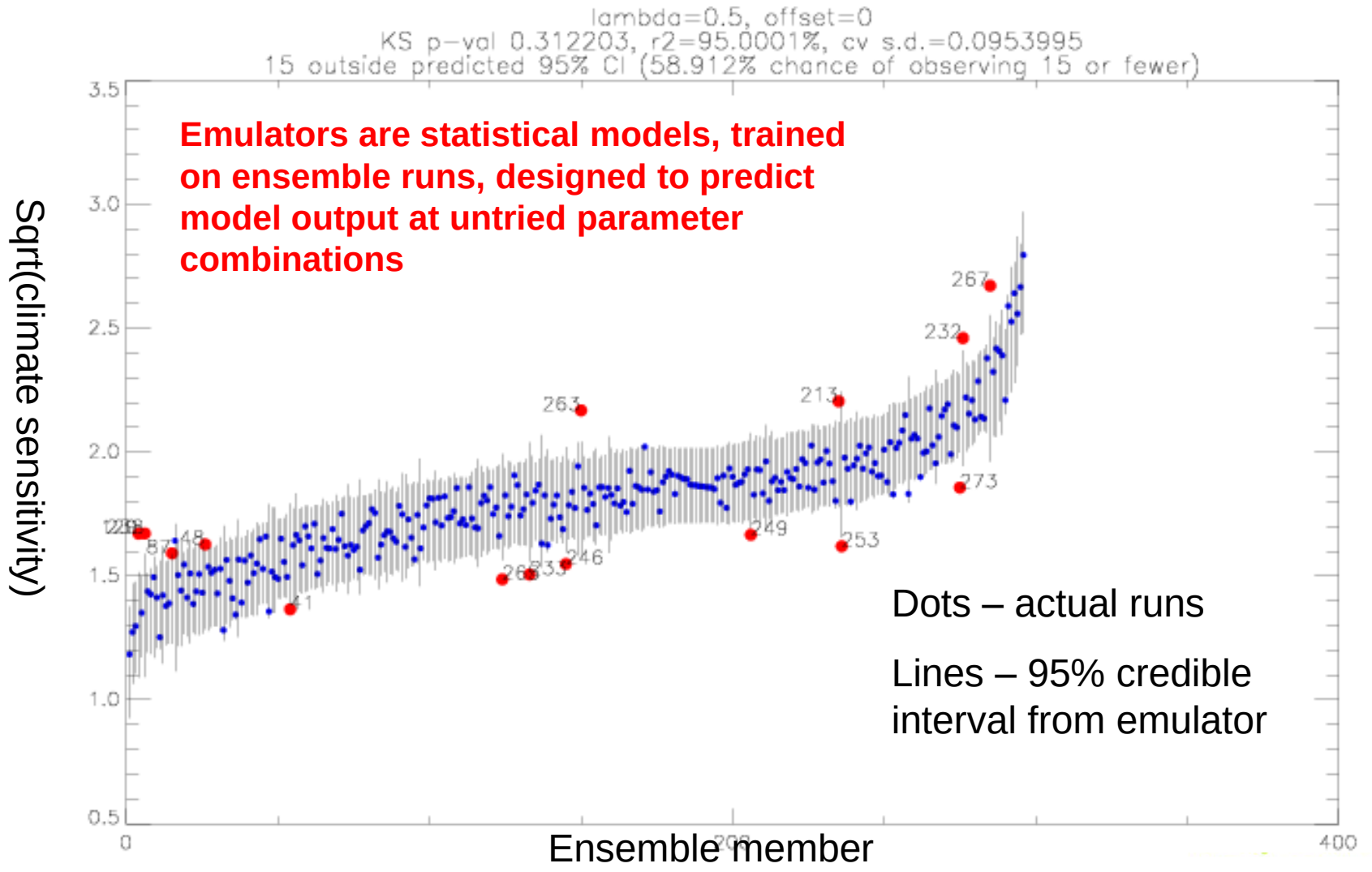
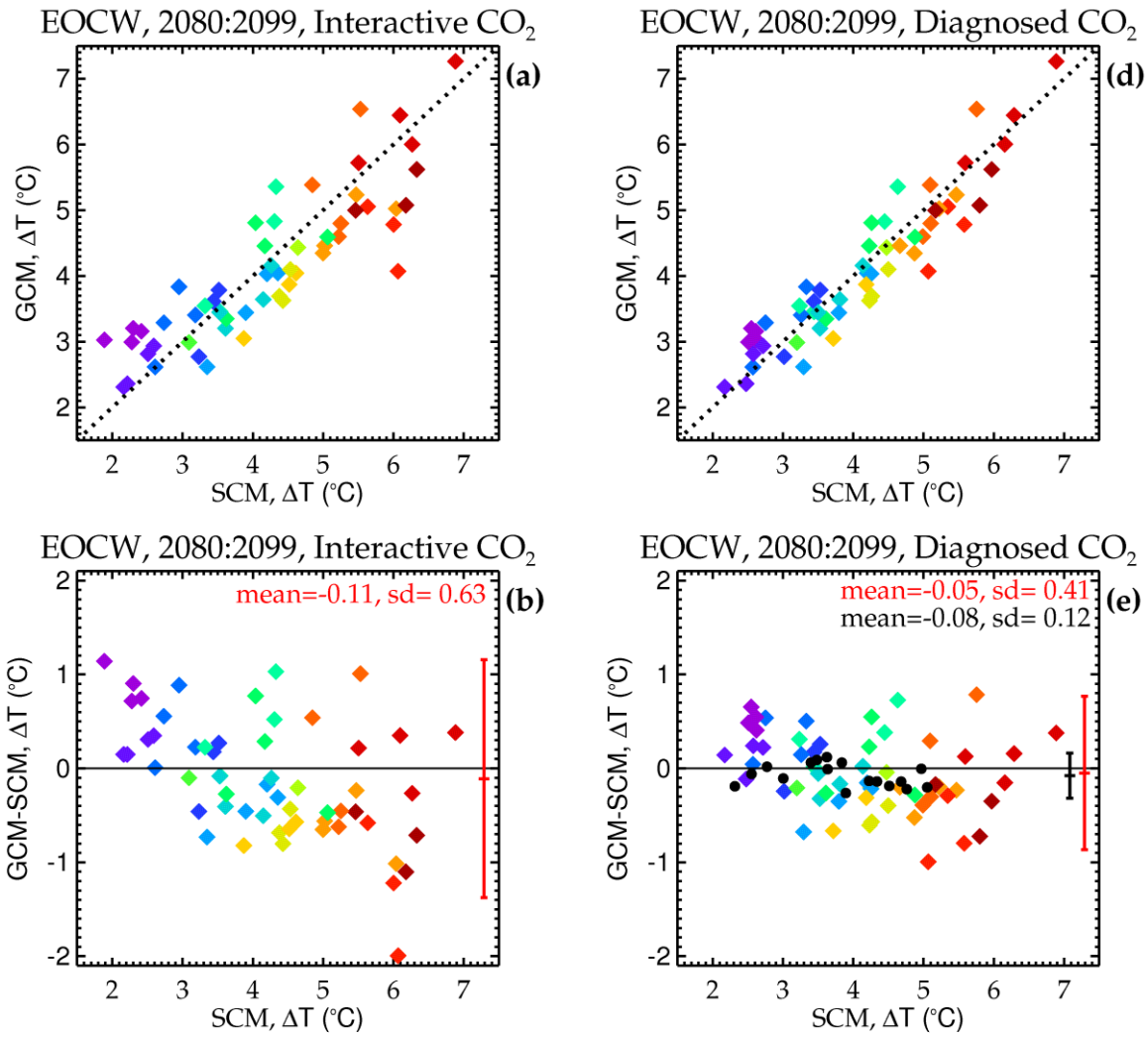
Emulators e.g. climate sensitivity



Testing how uncertainties interact



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