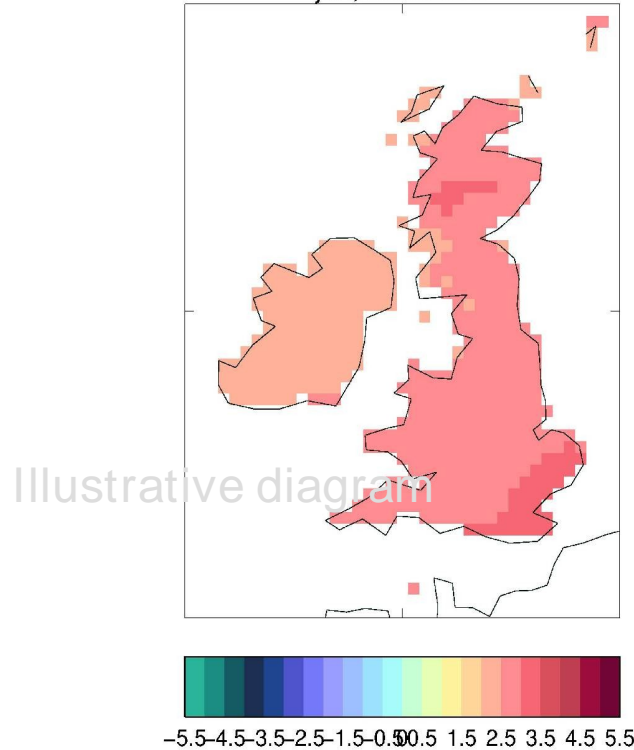


Prediction of climate change using perturbed physics and multi-model ensembles

Ben Booth, B. Bhaskaran, Penny Boorman, Kate Brown, Robin Clark, Mat Collins, Glen Harris, Hugo Lambert, James Murphy, Jonty Rougier*, David Sexton, Mark Webb, ...

Climate change impacts and adaptation: Dangerous rates of change, Exeter 22-24th September.

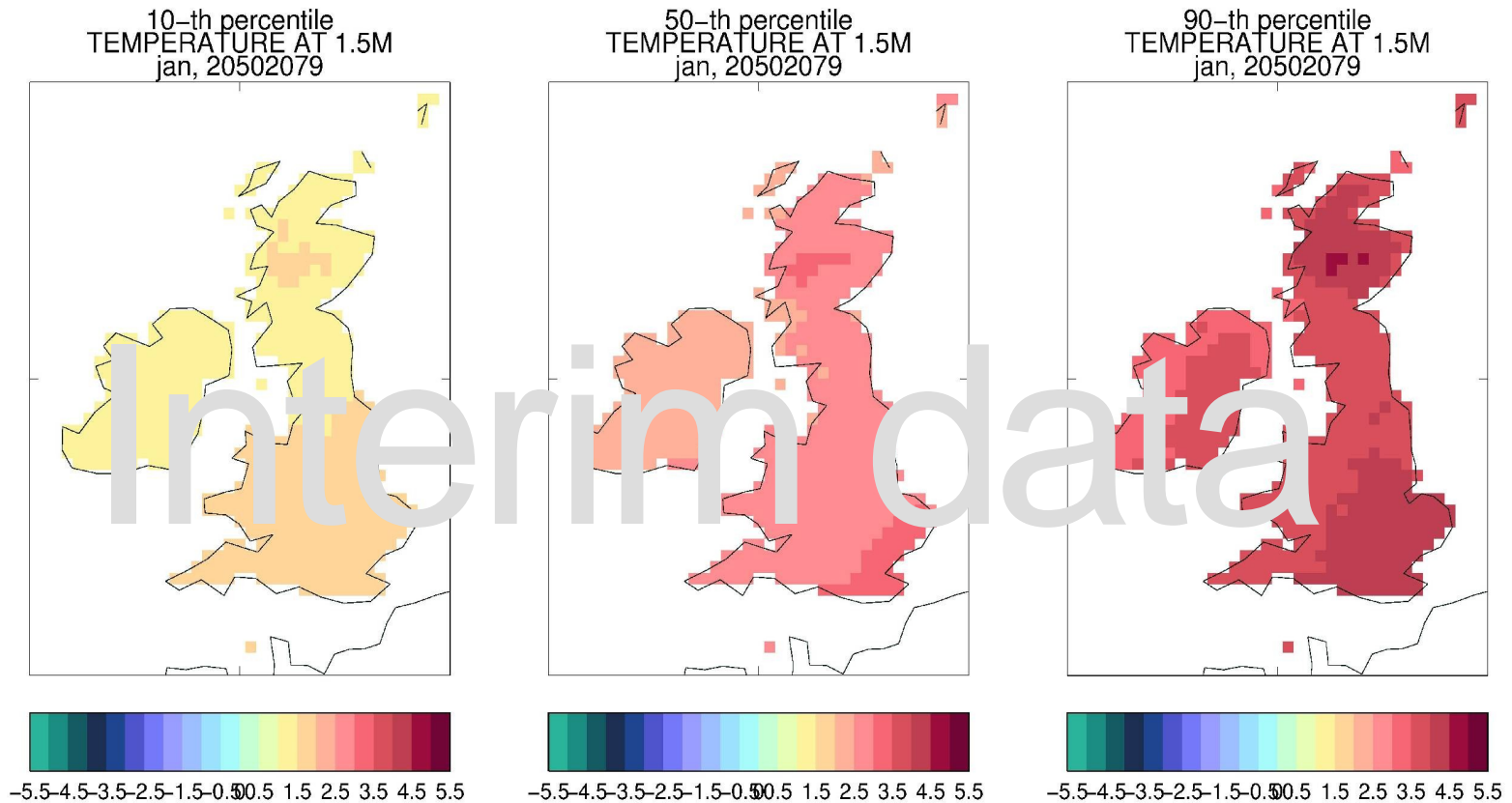
UK Climate Impacts Program



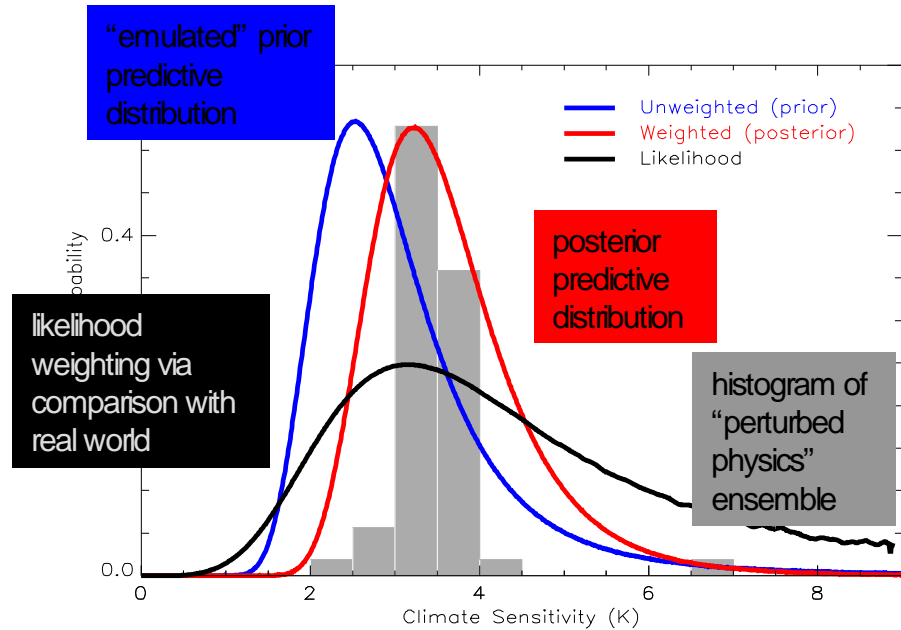
UKCIP 02 presented maps of change based on projections from a single model

UK Climate Impacts Program 2008

We aim to provide PDFs, joint PDFs, CDFs, maps of percentiles



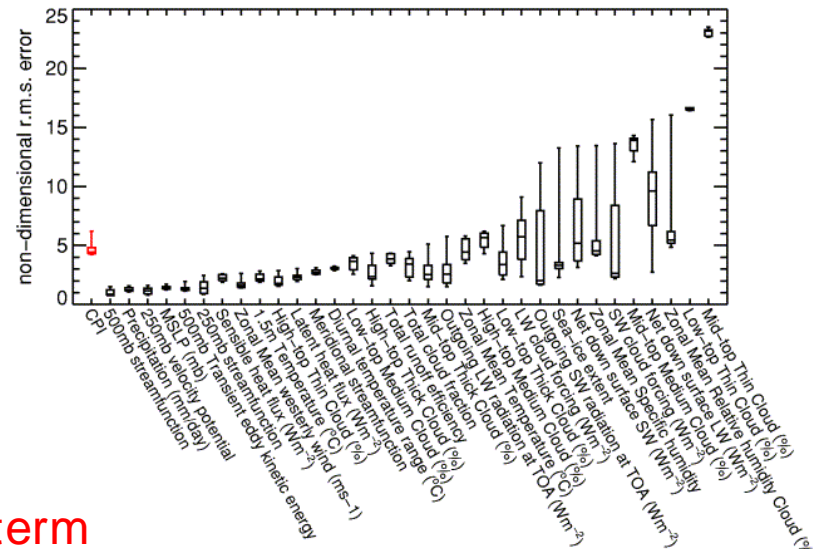
Applying Bayes – Murphy et al. 2004



- Likelihood, L_0 , of each model based on comparison with observations

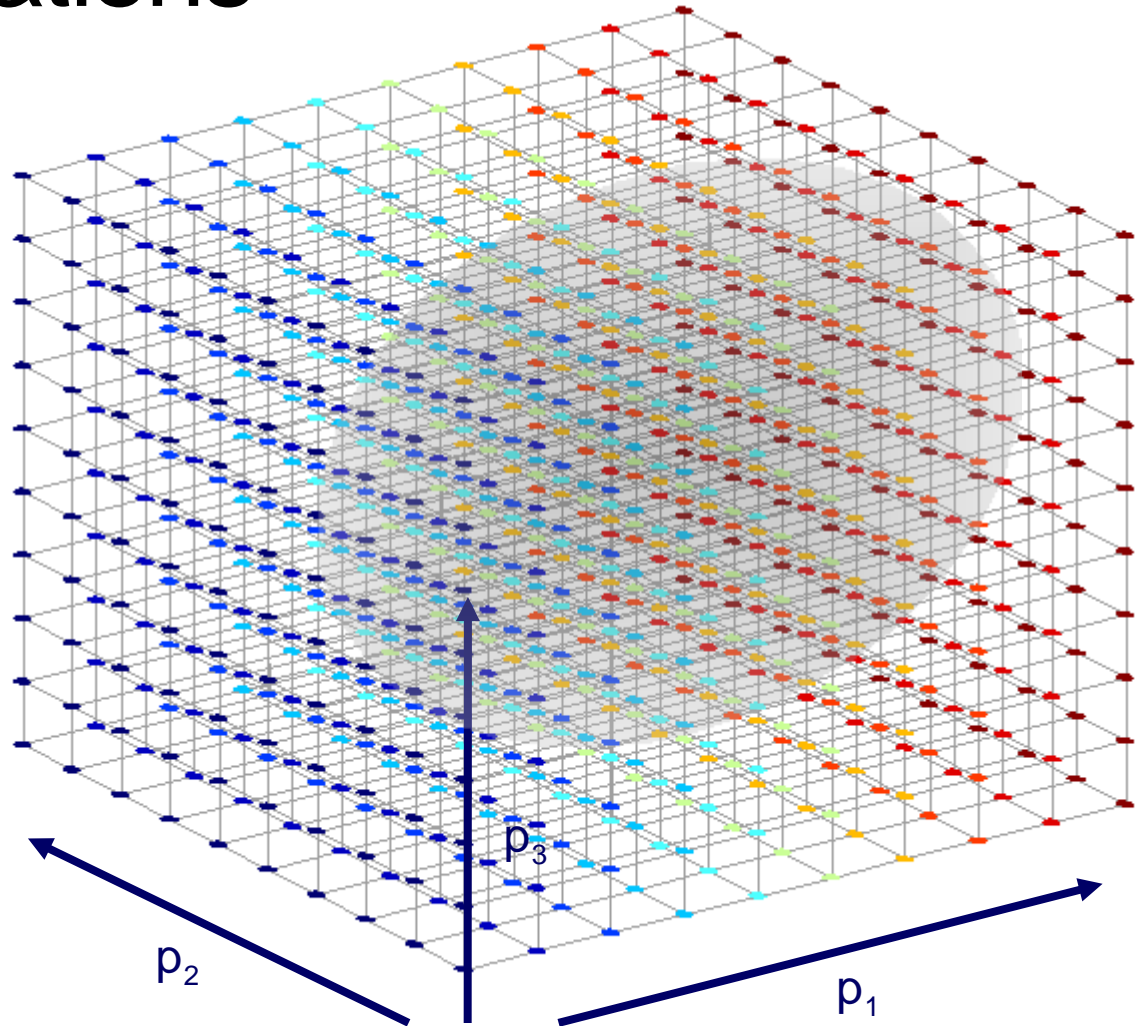
- CPI: $\log L_0 - \frac{(m_i - o_i)^2}{\sigma_i^2}$ Model "error" term

- Histogram based on 53-members each with a perturbation to one parameter
- Emulated prior distribution based on uniform parameter distributions and linear modelling (accounting for some non-linearity)

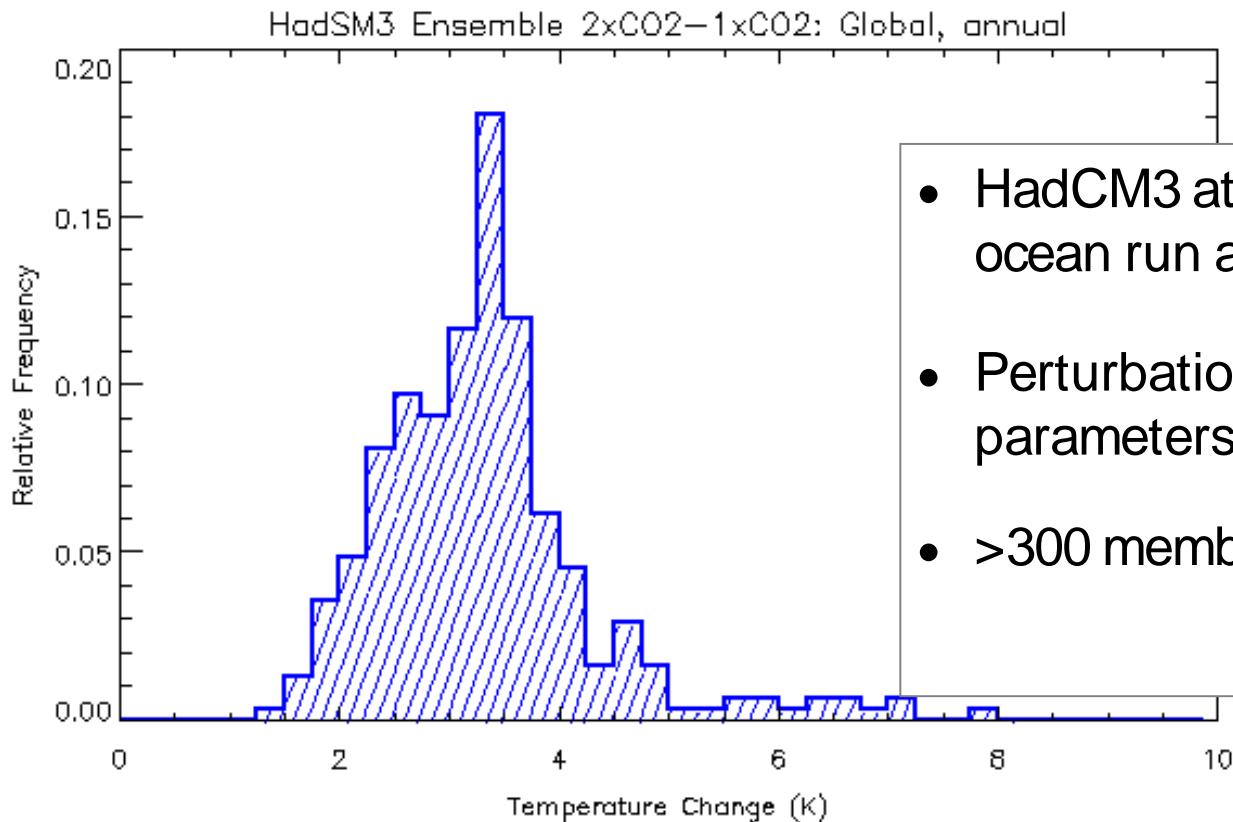


Constraining Models with Observations

- Draw a large sample from the space of all possible versions of one model – HadCM3
- Compare each model with observations (calculate model error term)
- Give less weight to regions of parameter space which look less like the real world
- Adding more and more variables can result in greater or lesser constraint



Perturbed Physics Equilibrium Simulations

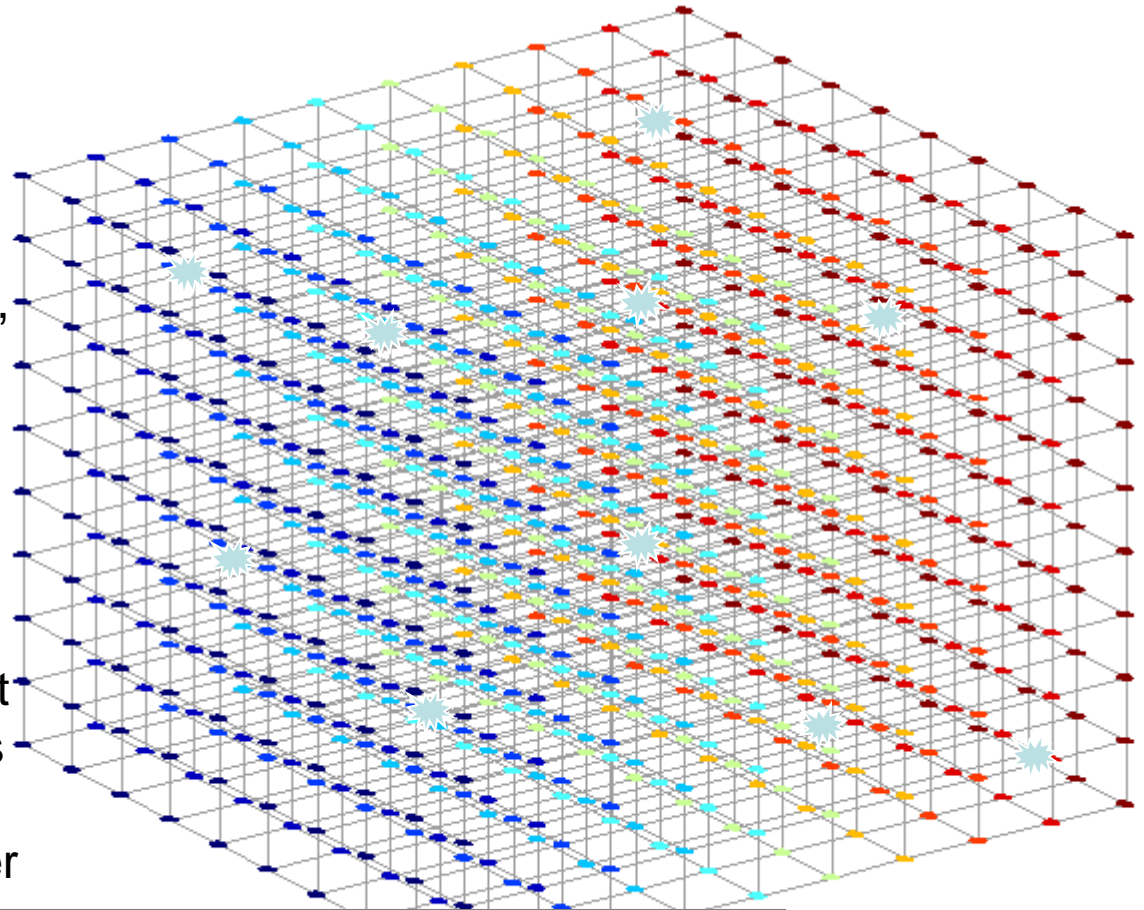


- HadCM3 atmosphere-slab ocean run at 1x and 2xCO₂
- Perturbations to (up to) 29 parameters
- >300 members

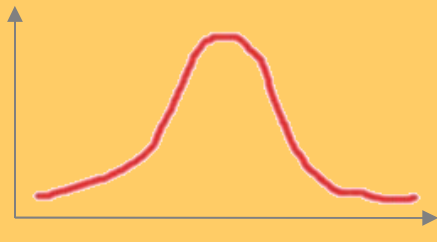
Murphy et al., 2004
Webb et al., 2006
+ extras

Emulator Schematic

- Use regression trained on ensemble runs to estimate past and future variables, \mathbf{m} , at any point of parameter space, \mathbf{x} , (use transformed variables and take into account some non-linearities)
- Note – need to run models at some quite “remote” regions of parameter space and where response in parameter space is not smooth.



Account for the errors in emulation for the final pdfs

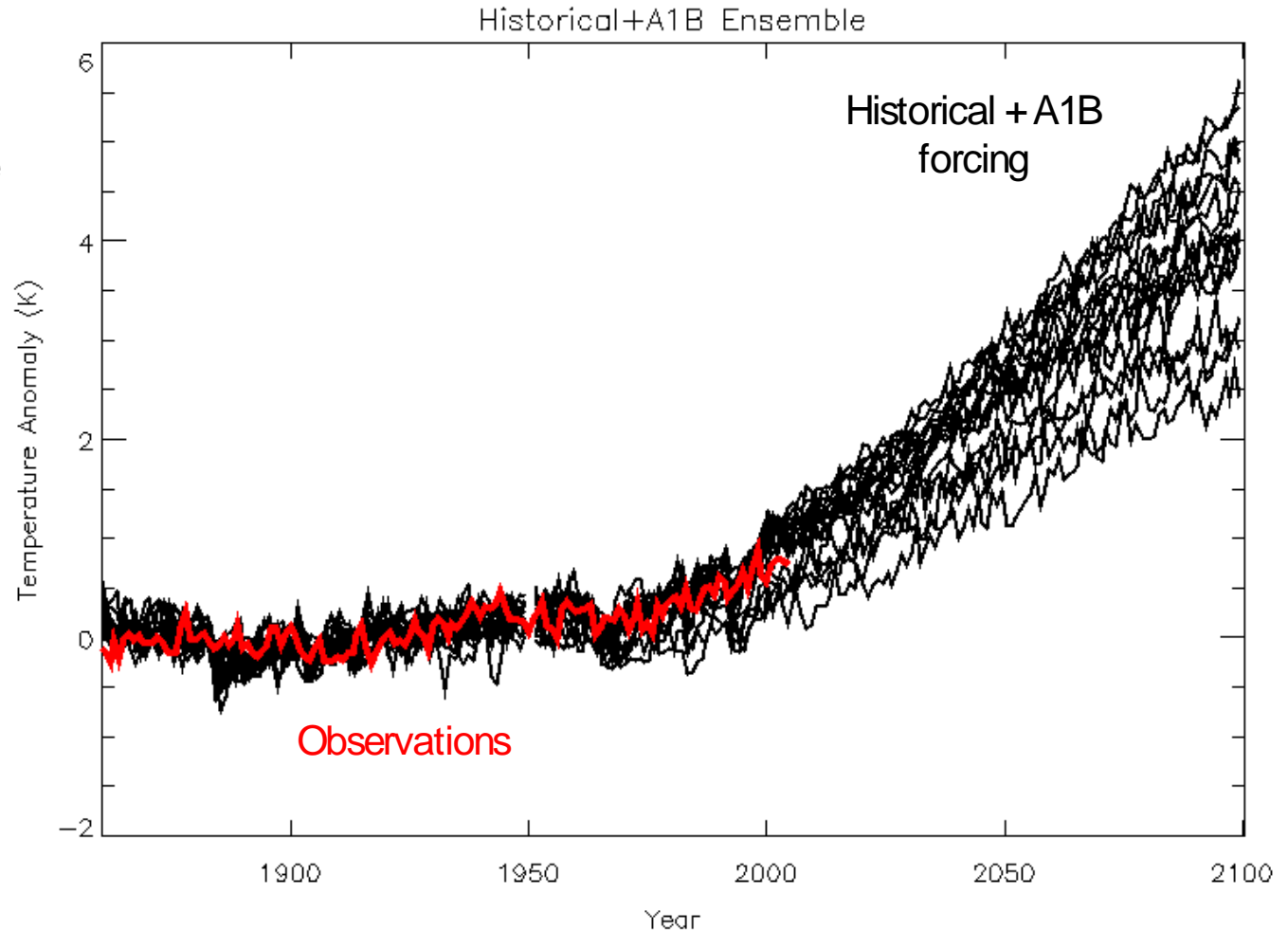




Met Office
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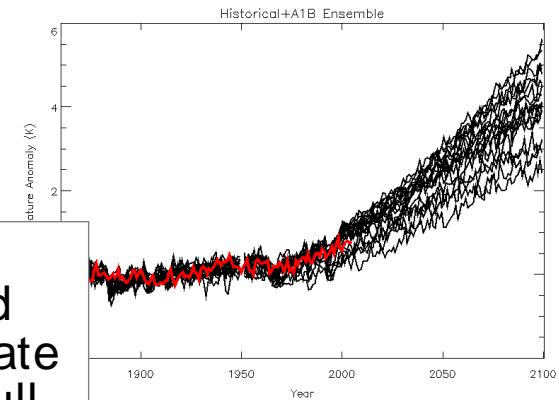
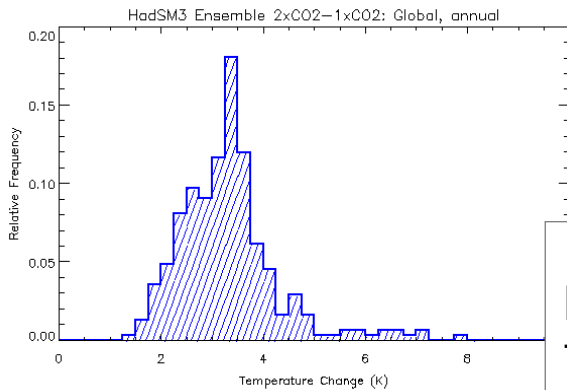
Transient Climate Change

- Smaller ensembles of HadCM3 because of spin-up issues
- Perturbations to atmosphere-model parameters with equivalent HadSM3 versions
- Flux adjustments used to keep models stable and reduce SST biases



Collins et al. 2006

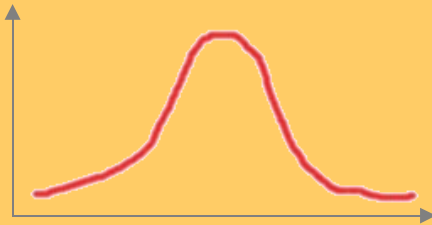
Using relationships between Slab and Transient ensembles



Using relationships between pairs of slab and transient models to emulate transient responses for full range of slab models

- Distributions based on scaling the equilibrium pattern of climate change from equilibrium experiments
- Uses an EBM
- Relationships trained using 17 coupled model experiments with same parameter perturbations

Uncertainties in this emulation can be quantified

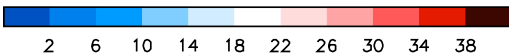
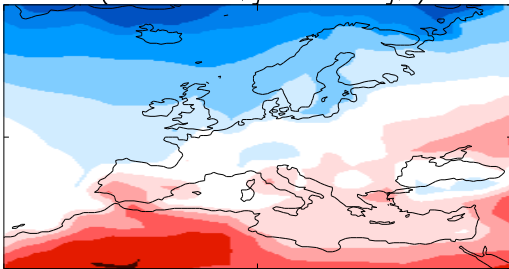


Based on Harris, et al., 2006, Clim Dyn

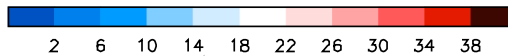
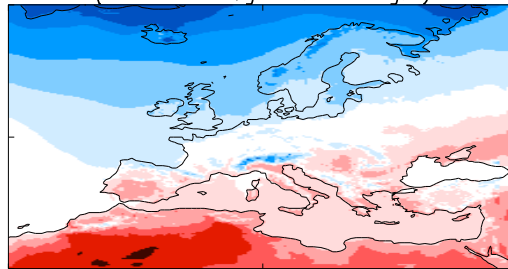
Regional Model PPE

- 17-member 25km European regional model ensemble driven by boundary conditions from the perturbed atmosphere-parameter ensemble
- Transient pdfs will be down scaled using simple linear relationship derived by regression between global model grid-box values and regional model grid box values

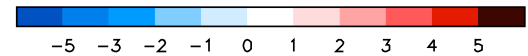
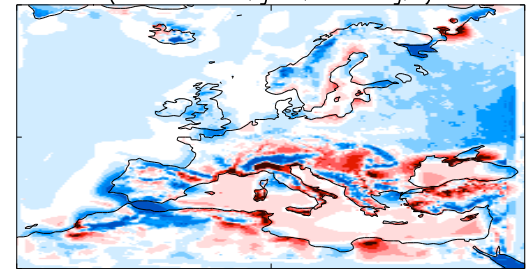
July tmean_1_5m GCM (aenwh)
(clim area avg=18.556deg.C)



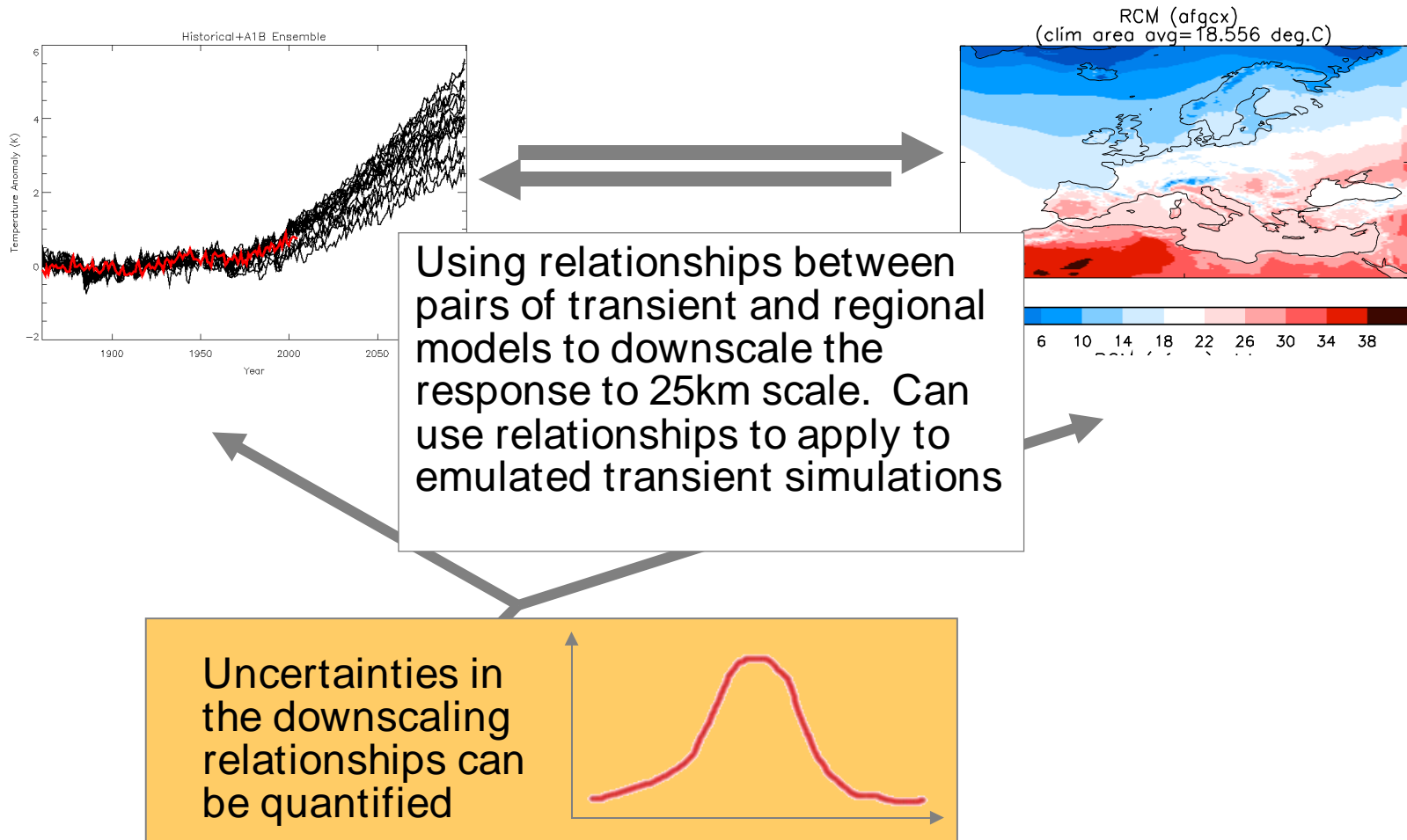
RCM (afgcx)
(clim area avg=18.556 deg.C)



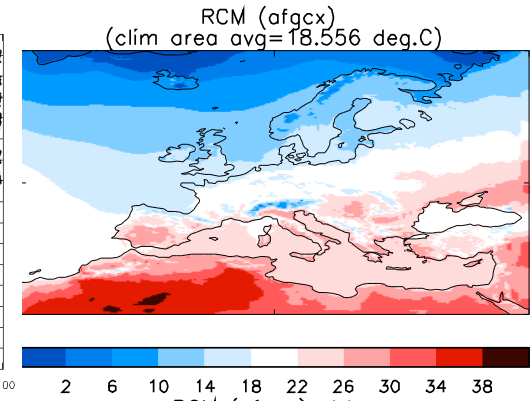
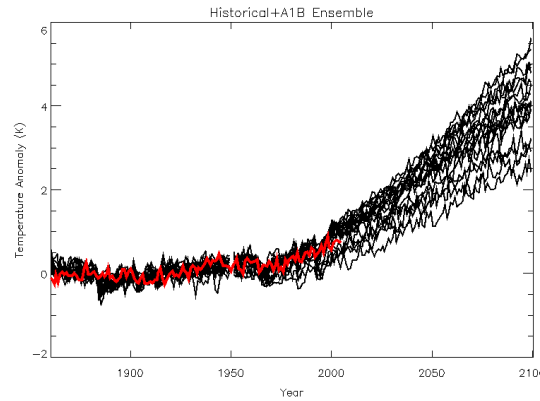
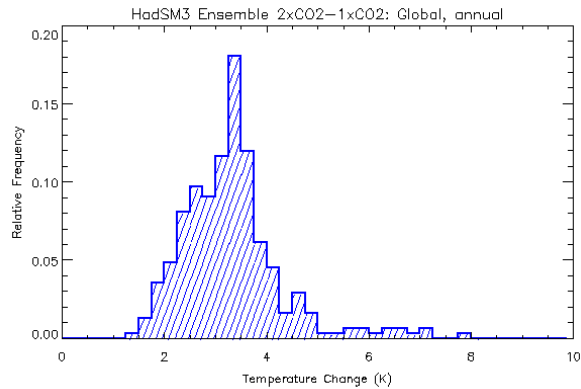
RCM (afgcx) - GCM (aenwh)
(clim area avg=0.0007deg.C)



Using relationships between Transient and Regional ensembles



Modelling framework

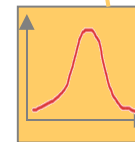
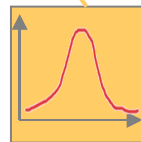
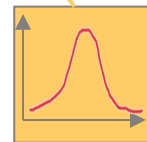
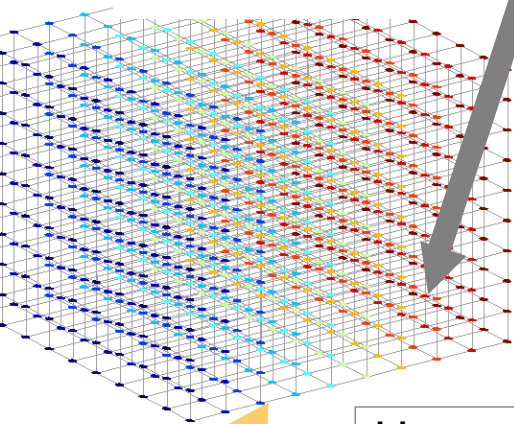
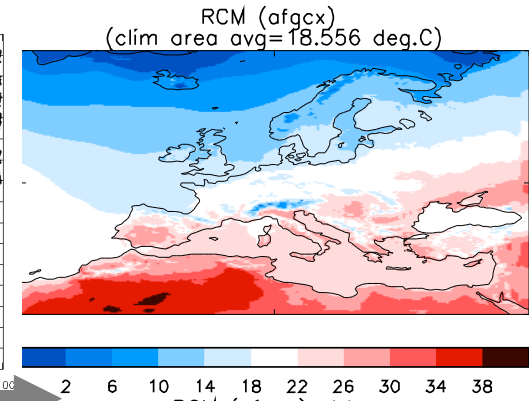
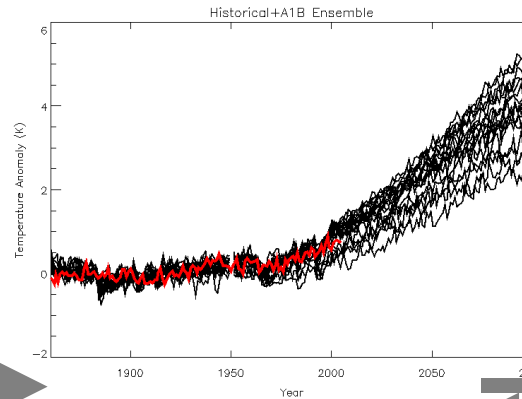
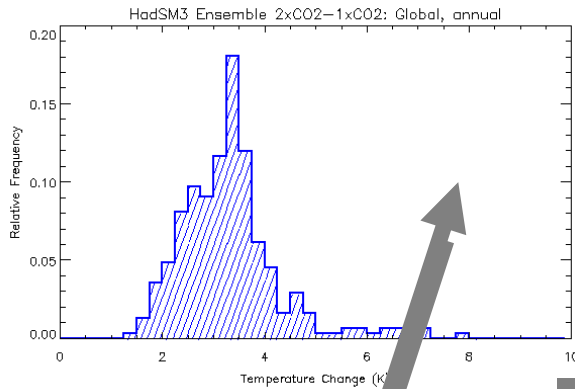


Equilibrium climate change

Transient climate change

Regional climate change

Statistical framework

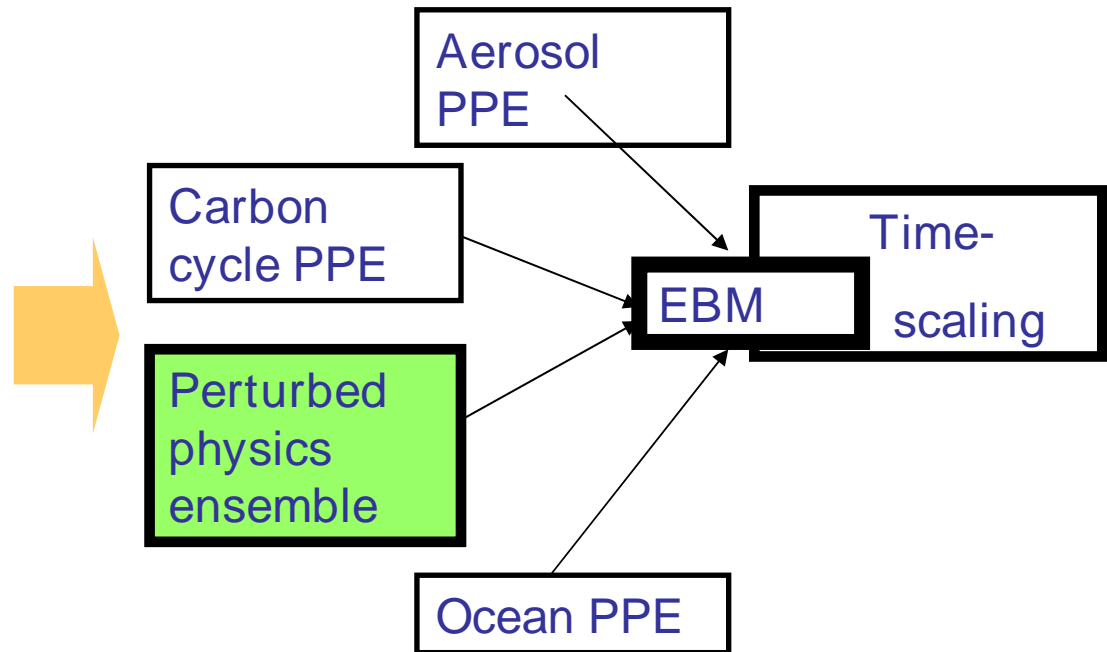
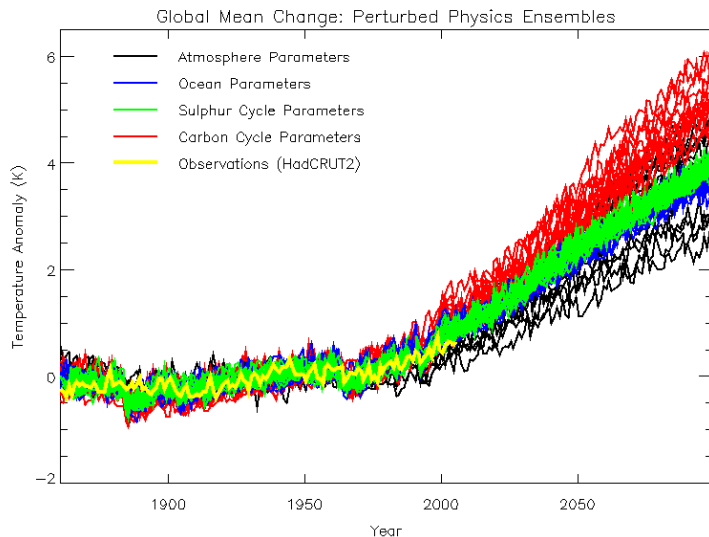


Use very large number of emulations which sample parameter space (and uncertainties in the emulation process).

We can use the statistical emulation and the relationships between the three stages of modeling to emulate regional climate responses consistent with a wide range of physics uncertainty in HadCM3

Incorporating ensemble results into transient pdfs

- Ocean, sulphur and carbon-cycle ensemble results will be incorporated via their influence on global mean temperature in the EBM component of the time scaling (relationship between equilibrium and transient)
- Use the ensemble results to fit relevant parameters in the EBM and then sample those parameters

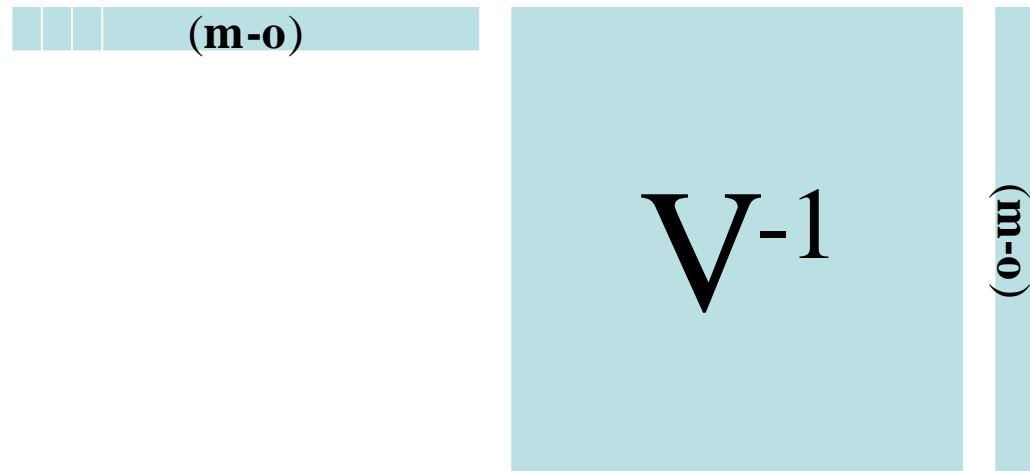


Estimating Likelihood

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

\mathbf{V} = obs uncertainty + emulator error + discrepancy

$$\log L_o(\mathbf{m}) \sim$$



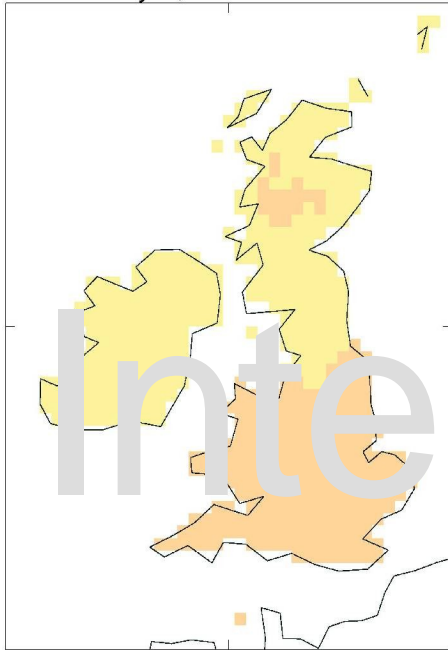
\mathbf{V} is calculated from the perturbed physics and multi-model runs

Estimating discrepancy

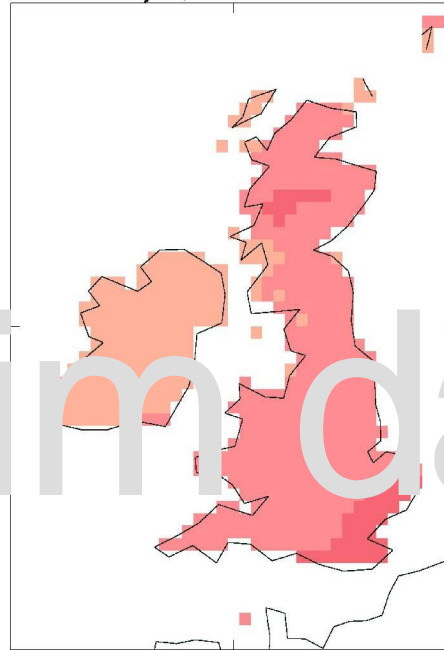
- Use multimodel ensemble from IPCC AR4 and CFMIP
- For each multimodel ensemble member, find point in HadCM3 parameter space that is closest to that member
- There is a distance between climates of this multimodel ensemble member and this point in parameter space i.e. effect of processes not explored by perturbed physics ensemble
- Pool these distances over all multimodel ensemble members
- Uses model data from the past and the future

Interim data: UK Climate Impacts Program

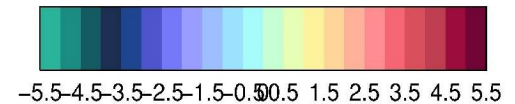
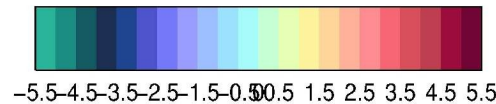
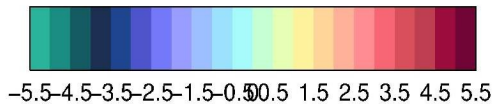
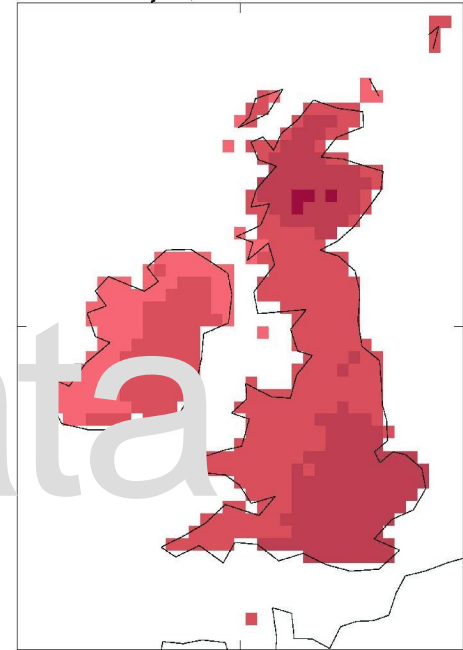
10-th percentile
TEMPERATURE AT 1.5M
jan, 20502079



50-th percentile
TEMPERATURE AT 1.5M
jan, 20502079



90-th percentile
TEMPERATURE AT 1.5M
jan, 20502079



Issues

- Dependence on prior – deal with by assessing sensitivity to prior assumptions (e.g. parameter distributions). Also, “likelihood profiling” could be easily implemented using the methodology we have
- Are models/PDFs informative about the real world?
- Will models be significantly better in a few years time?
- Working with users to make sure they use the pdfs sensibly

Probabilistic framework

Hopefully this gives you an overview of the probabilistic approach that we are taking.

The probabilistic framework should enable us to:

- Explore **impact of assumptions**
- Provide insight to what are the **dominant uncertainties** on different spatial and temporal scales
- We now have a **baseline** to measure future improvements and advances.



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Questions & Answers