The Interpretation and Design of Ensembles of Complex Models for Climate Change Decision Making

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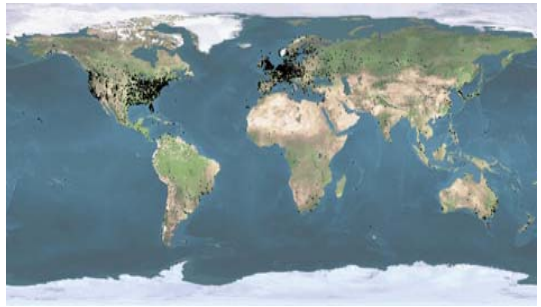

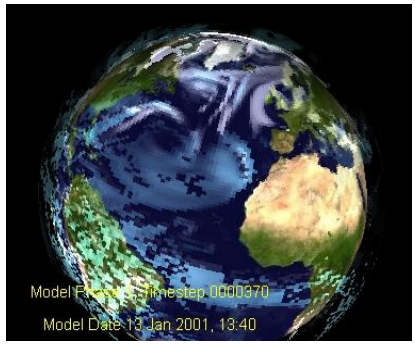

MPI PKS Workshop

30th July 2009

1. Sources of Uncertainty
2. Approaches to Ensemble Interpretation
3. Influence on Ensemble Design
4. Weighting and Excluding
5. Communication

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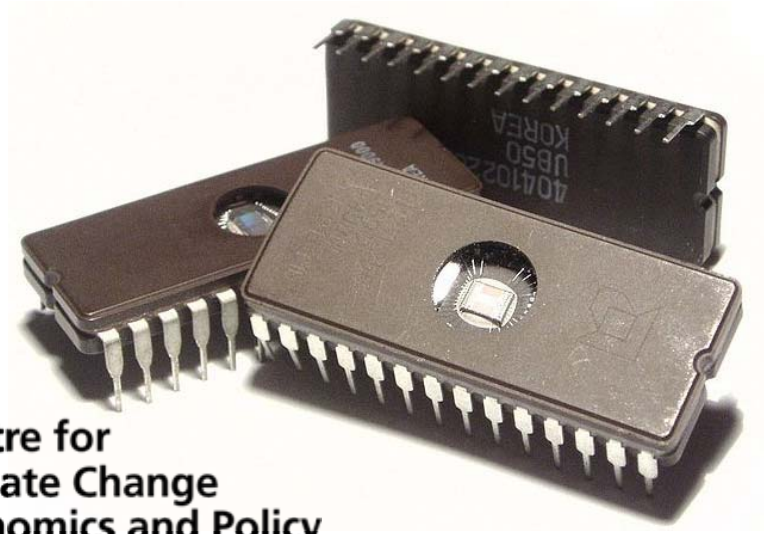
A Comment on Computing

- Opportunities for massive increase in computing power for modelling. But what for:
  - Increased resolution → 1km globally?
  - Increased complexity (earth system models).
  - Increased ensemble size
- What is sufficient for any specific purpose?
  - Academic understanding.
  - Informing decision makers.



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Sources of Uncertainty

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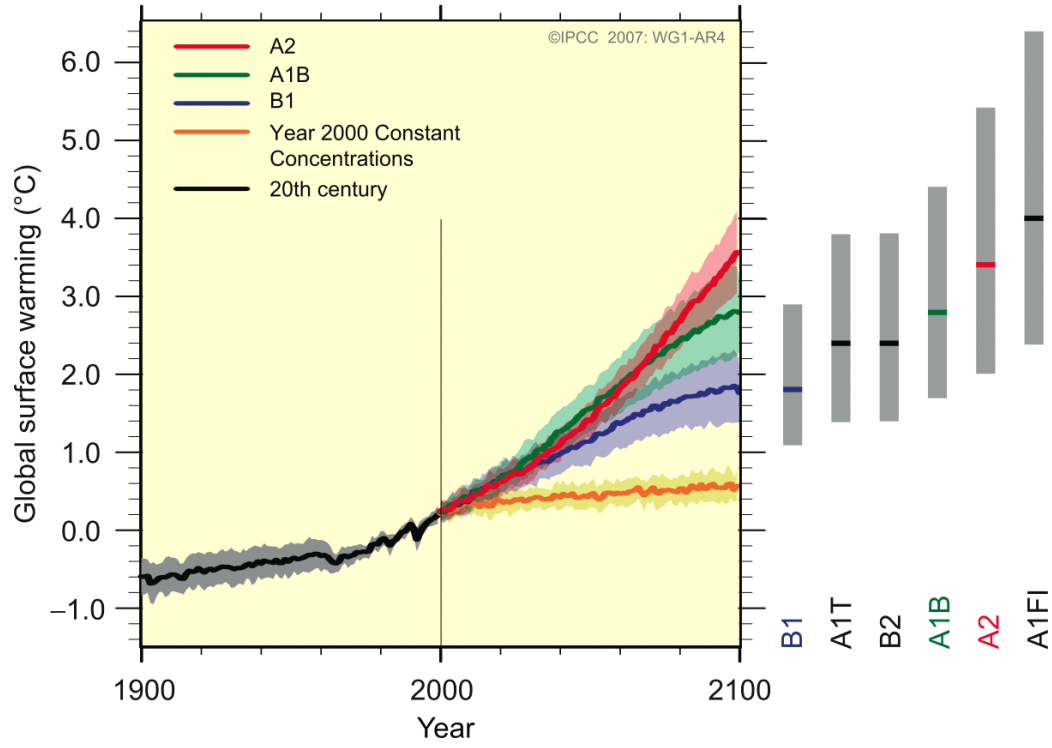
Sources of Uncertainty In Climate Forecasts

- External Influence Uncertainty.
- Initial Condition Uncertainty
  - Microscopic Initial Condition Uncertainty. (Aleatory)
  - Macroscopic Initial Condition Uncertainty. (Epistemic)
- Model imperfections (Epistemic)
  - Model Inadequacy.
  - Model Uncertainty.

Sources of Uncertainty

- External influences uncertainty:
  Changes due to factors external to the climate system e.g. greenhouse gas emissions (natural and anthropogenic), solar radiation, volcanic emissions etc.
  Response: Scenarios for possible futures.



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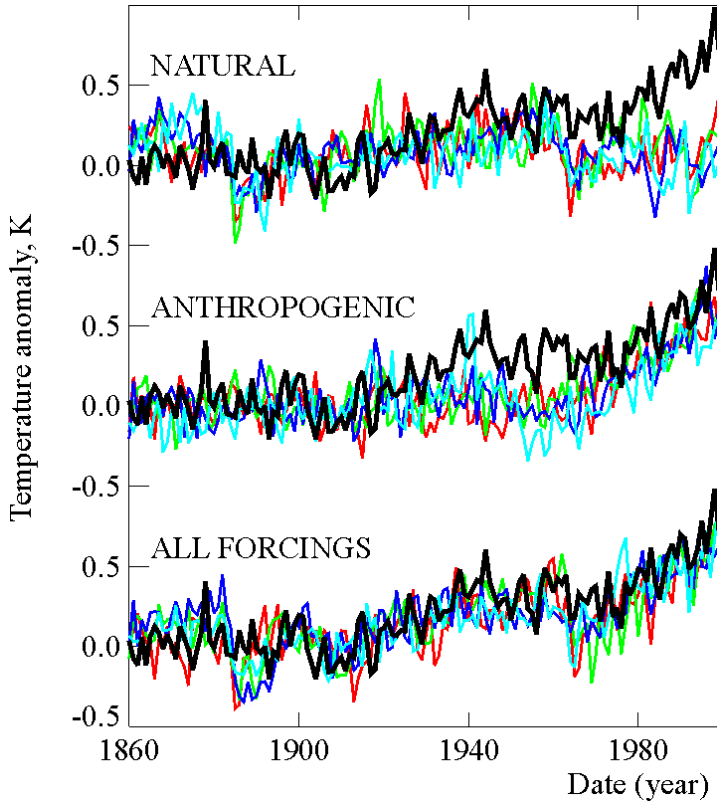
Source: IPCC, Fourth Assessment Report, Summary for Policy Makers

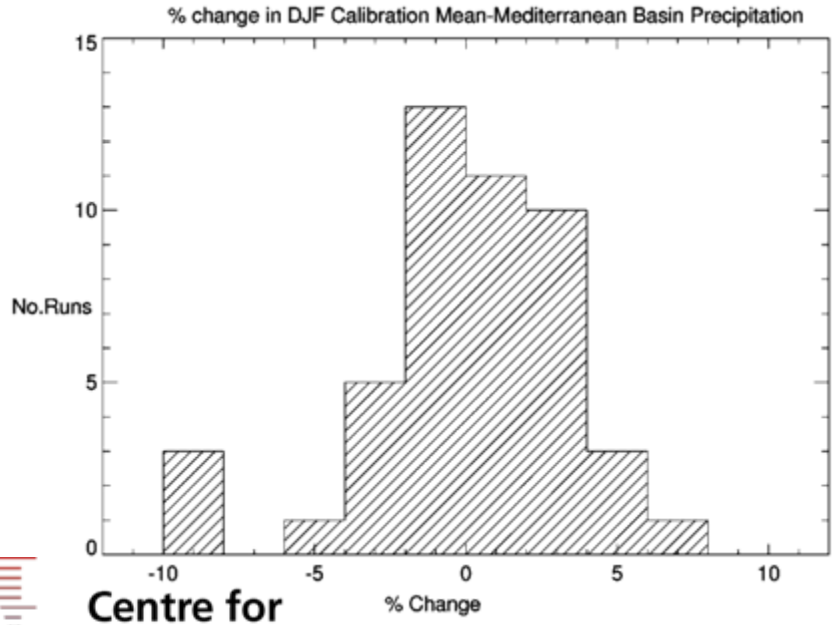
Sources of Uncertainty

and How to Include Them In a Climate Forecast

- Microscopic Initial Condition Uncertainty
  How is the prediction is affected by our imprecise knowledge of the current state of the system at small, rapidly mixing, scales?
  Response: Initial Condition Ensembles



Source: IPCC, Third Assessment



Source: 50 member IC ensemble from climateprediction.net.

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Sources of Uncertainty

and How to Include Them In a Climate Forecast

- Macroscopic Initial Condition Uncertainty
  How is the prediction is affected by our imprecise knowledge of the current state of the system on relatively large, slowly mixing, scales?
- Response: Better Observations / Directed Observations (informed by model ensembles?)

  - Ocean temperature and salinity structure.
    Sutton and Hodson, Science, 2005
  - State of the quasi-biennial oscillation.

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Sources of Uncertainty

and How to Include Them In a Climate Forecast

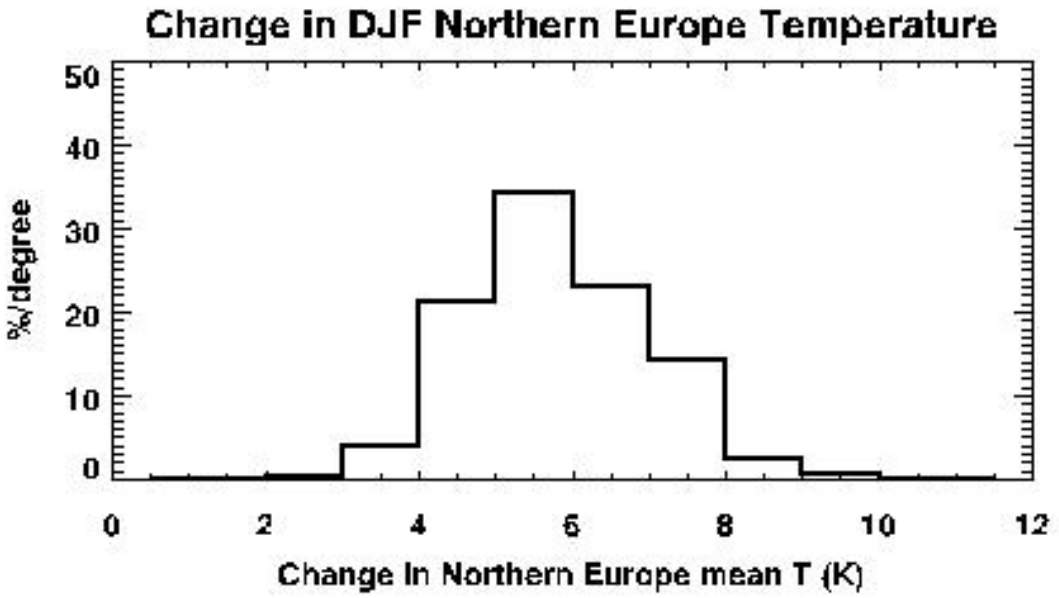
- Model Inadequacy
  All models are unrealistic representations of many relevant aspects of the real world system.
- Response: A context for all climate forecasts.

  - Processes known to be important are absent.
    e.g. ice sheet dynamics, atmospheric and oceanic chemistry, stratosphere circulation.
  - Parameterized processes are unlikely to capture small scale feedbacks.
  - Inadequate simulation of some processes which should result from the fundamental processes included.
    e.g. hurricanes, diurnal cycle of tropical precipitation.

Sources of Uncertainty

and How to Include Them In a Climate Forecast

- Model uncertainty:
  Climatic processes can be represented in models in different ways e.g. different parameter values, different parameterization schemes, different resolutions. What are the most useful parameter values and model versions to study within the available model class? What is the range of possibilities?
  Response: Perturbed-Physics Ensembles



Stainforth et al.2006

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Approaches to Model Interpretation

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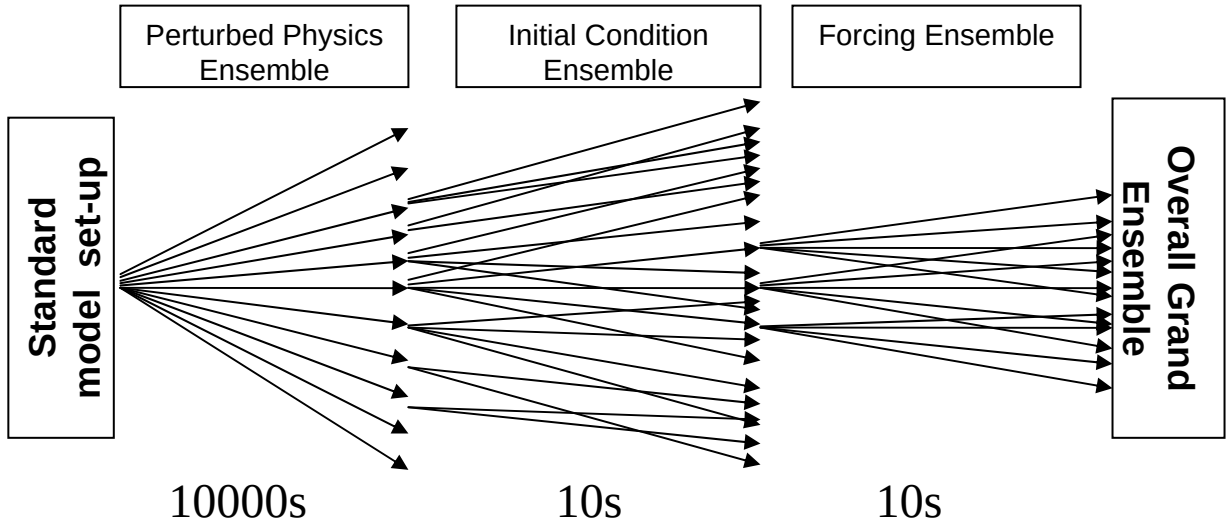
Available Simulations Which Explore Model Uncertainty

- Climate*prediction*.net – perturbed physics ensemble
- QUMP – perturbed physics ensemble
- Multi-model ensembles: CMIP IV / IPCC.

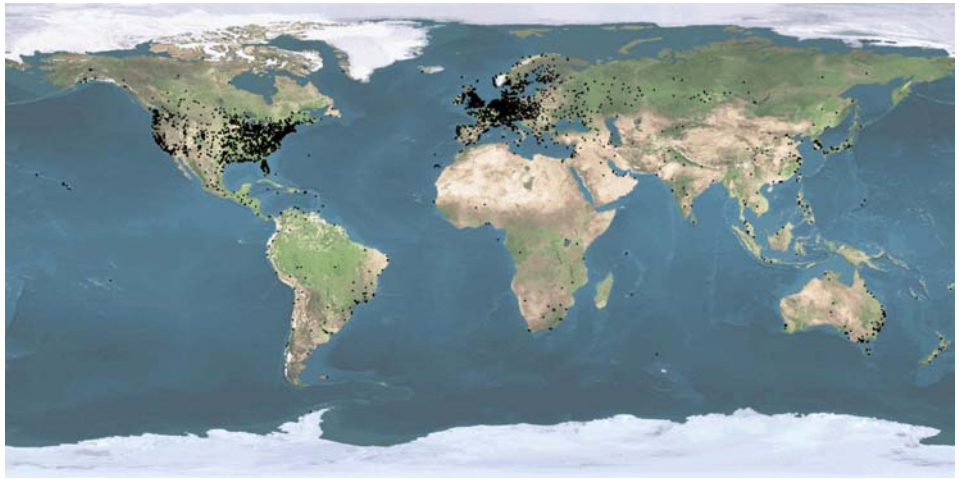
- Differences:
  - Numbers of simulations.
  - Interpretational approach.

The Climate*prediction*.net Experiment



Statistics

- > 300,000 participants.
- > 24M years simulated.
- > 150,000 completed simulations. (Each 45years of model time)
- 10000 years of computing time.



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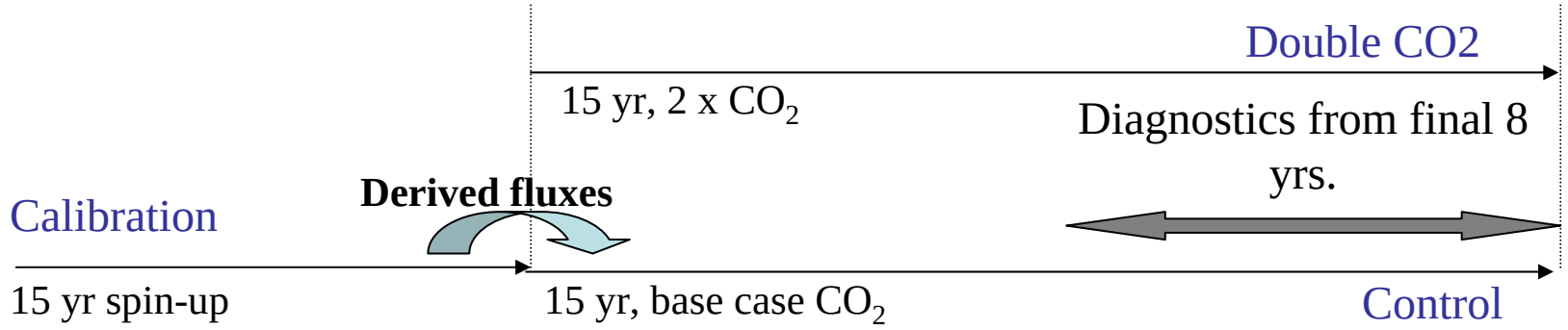
Climate*prediction*.net 1st Experimental Design

- First Experiment: Unified Model with thermodynamic ocean. (HadSM3)
  [Full climate resolution atmosphere: HadAM3; 3.75º x 2.5º]
  - Aim: To identify parameter combinations which have little effect on the mean climate but a large effect on climate sensitivity.
  - Evaluate perturbations to atmosphere/ocean fluxes.



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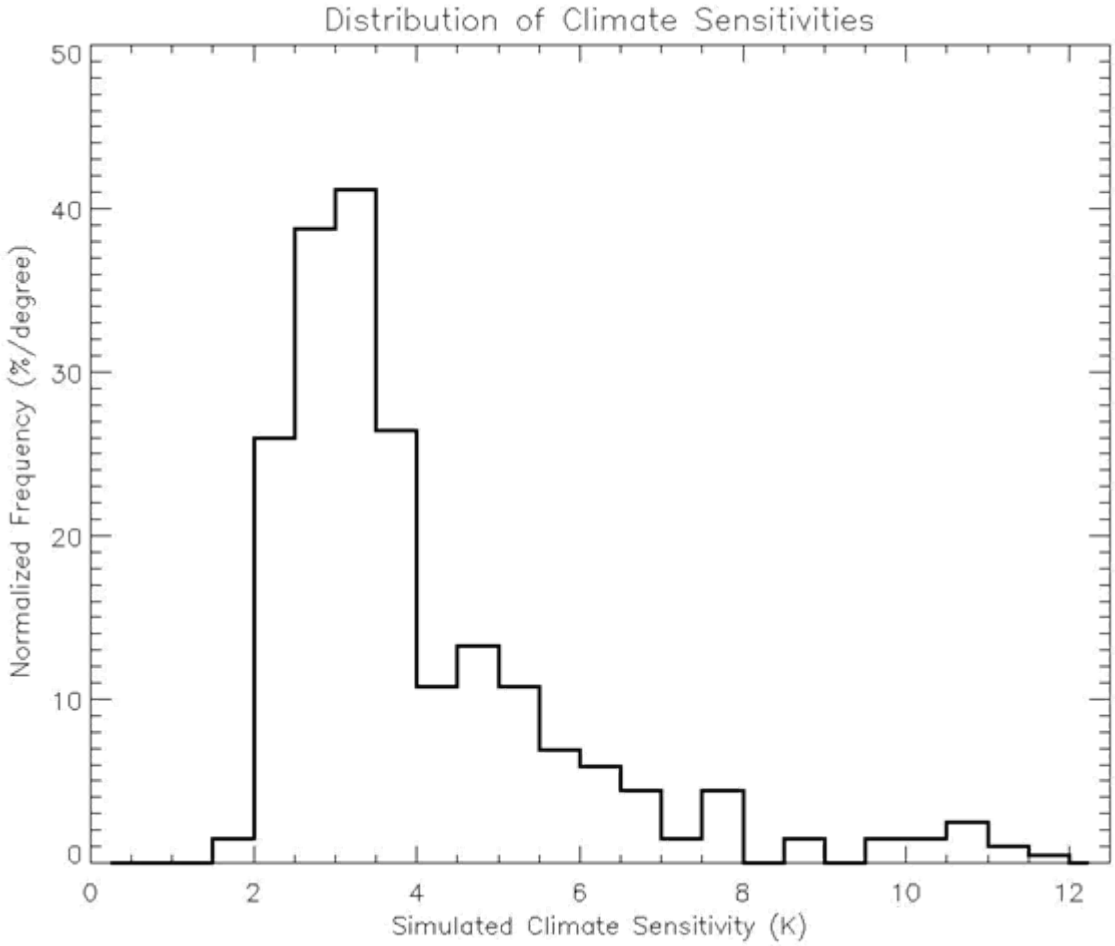
Interpretational Approaches 1: A range of plausible possibilities

Grand Ensemble Frequency Distribution of Climate Sensitivity



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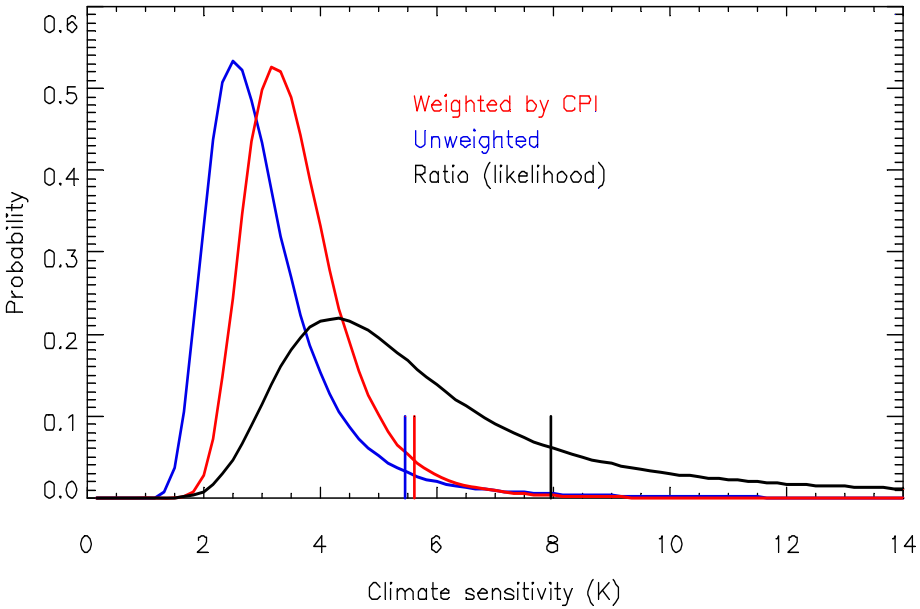
From Stainforth et al. 2005

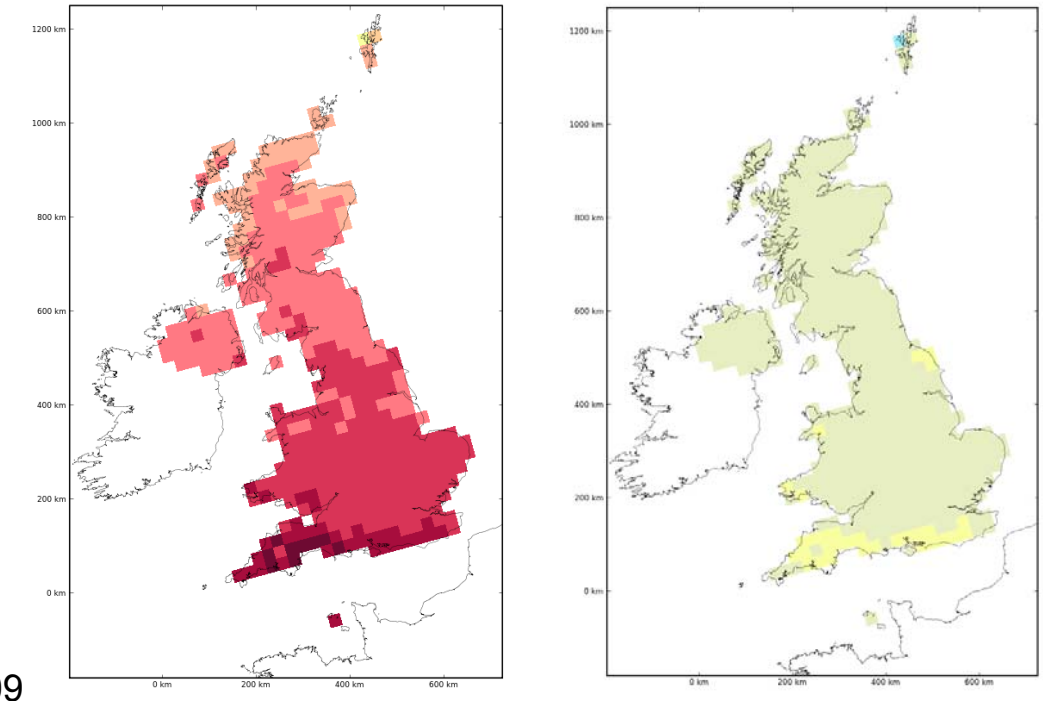
Interpretational Approaches 2: Deduce (subjective) Probabilities



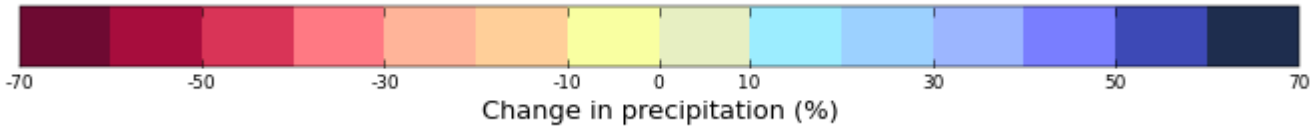
Murphy et al, 2004

Change in mean summer precip:

10% **90%**



UKCIP, 2009



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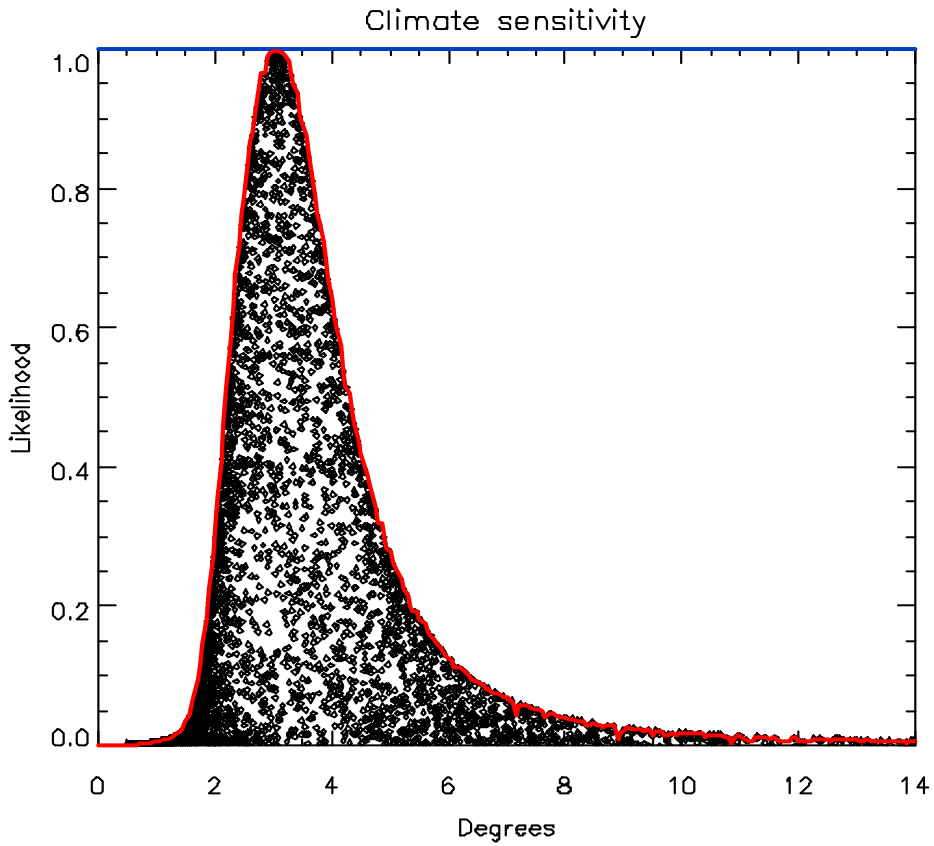
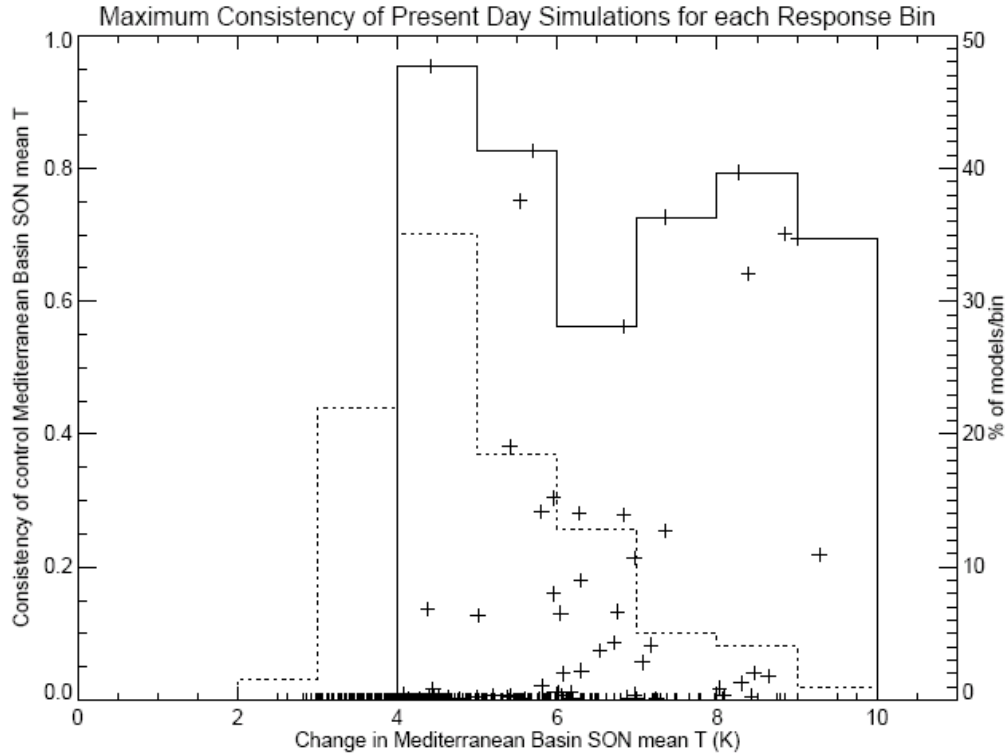
Interpretational Approaches 3: Maximum Consistency / Likelihood



Allen et al. 2008, not yet published.



Stainforth et al. 2007

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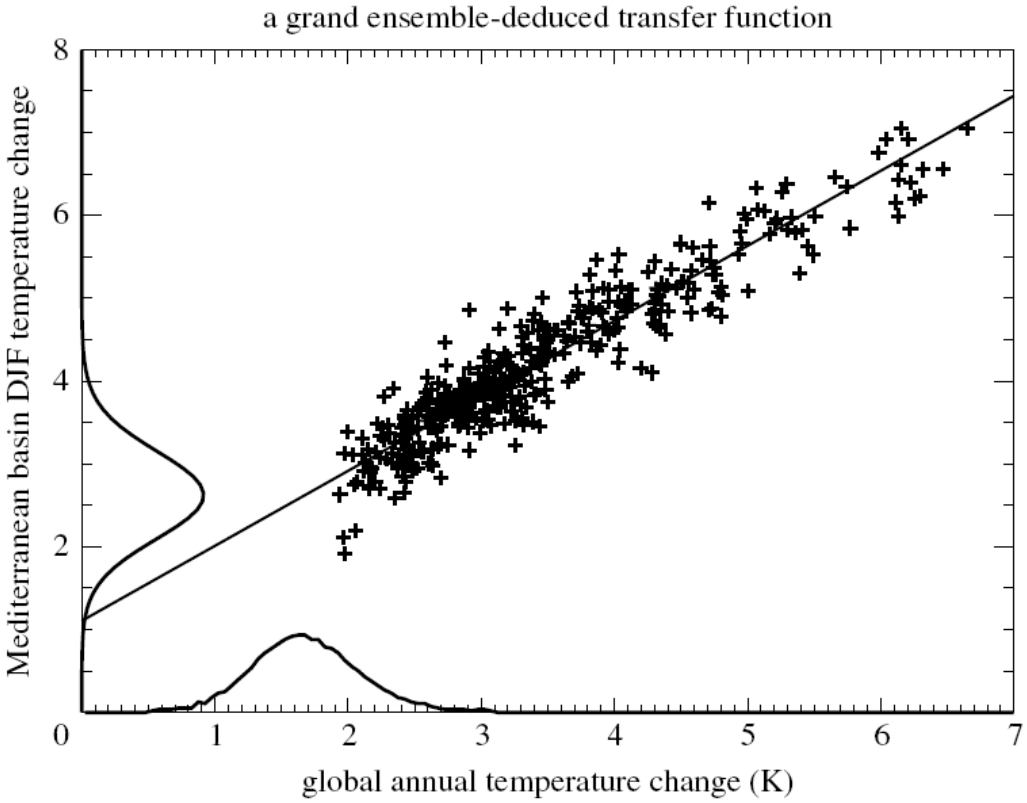
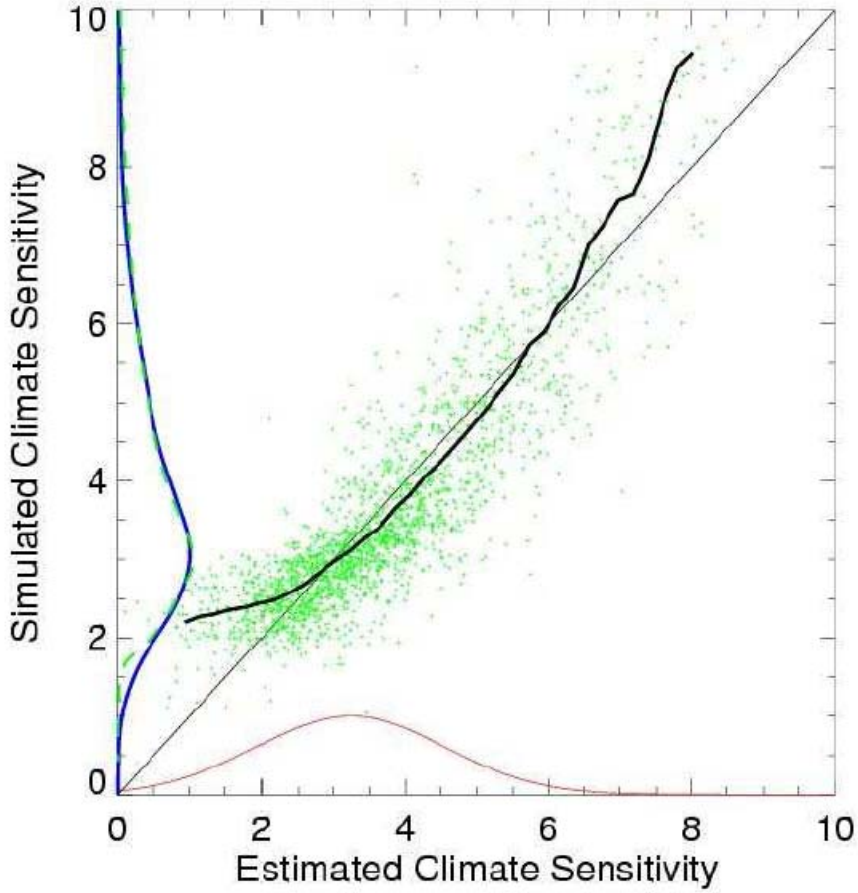
Interpretational Approaches 4: Transfer Functions



Stainforth et al. 2007



Piani et al. 2005

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Approaches to Model Interpretation
Issues and Concerns

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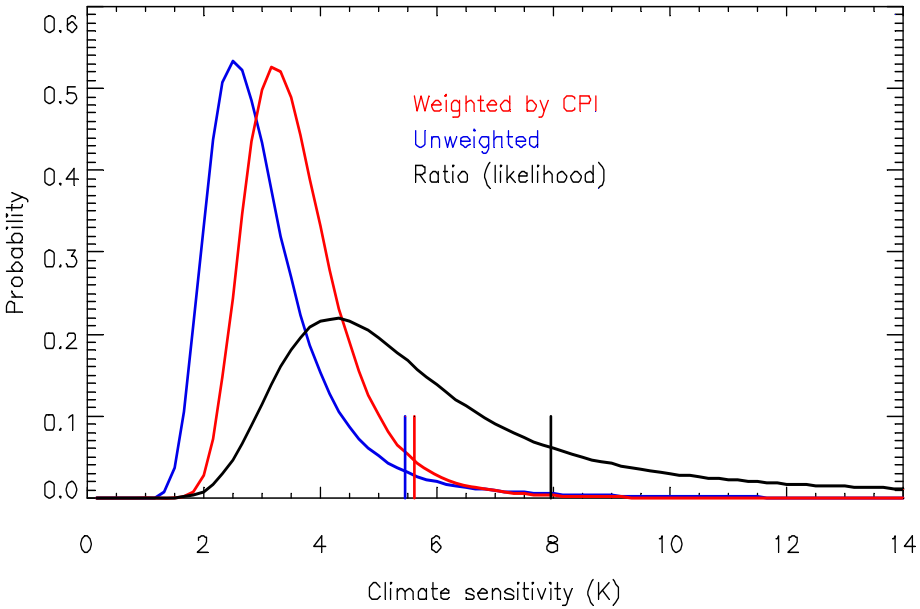
Interpretational Approaches 2: Deduce (subjective) Probabilities



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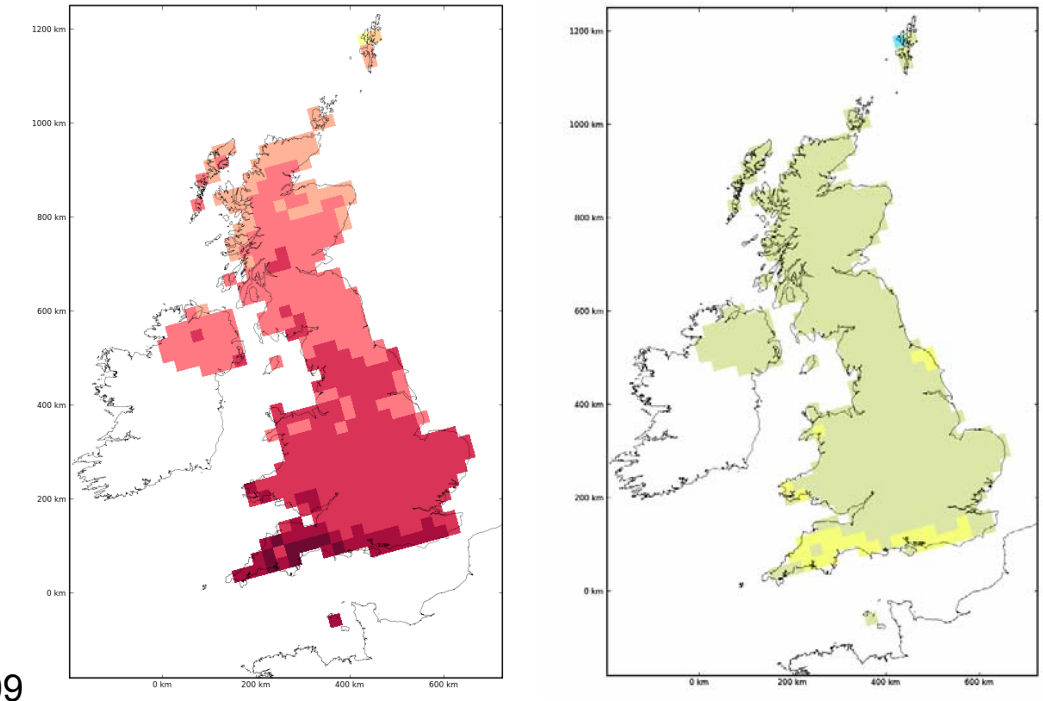
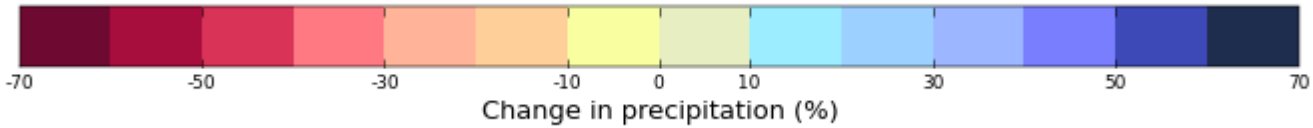


UKCIP, 2009



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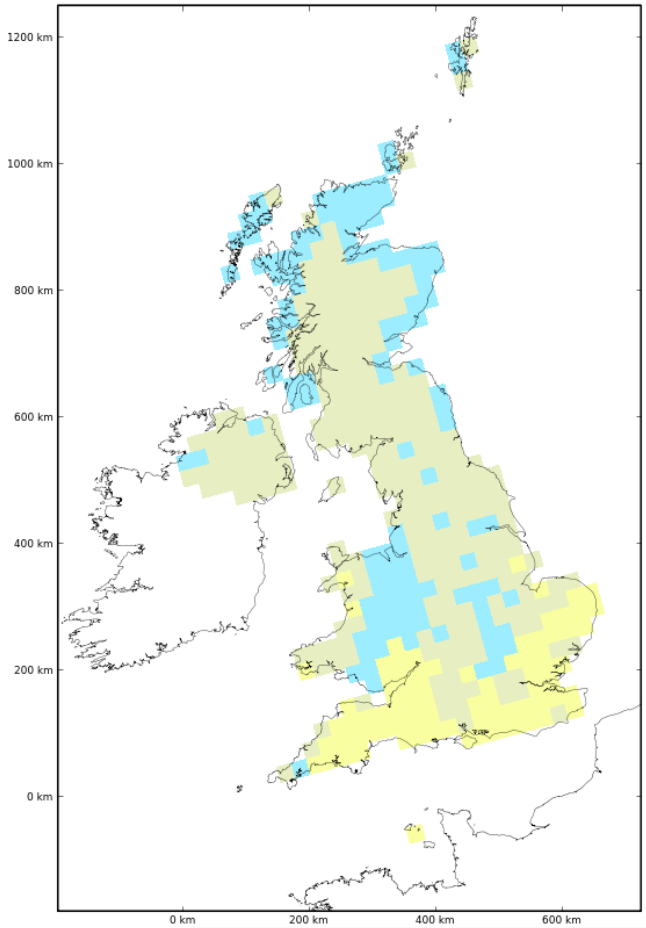
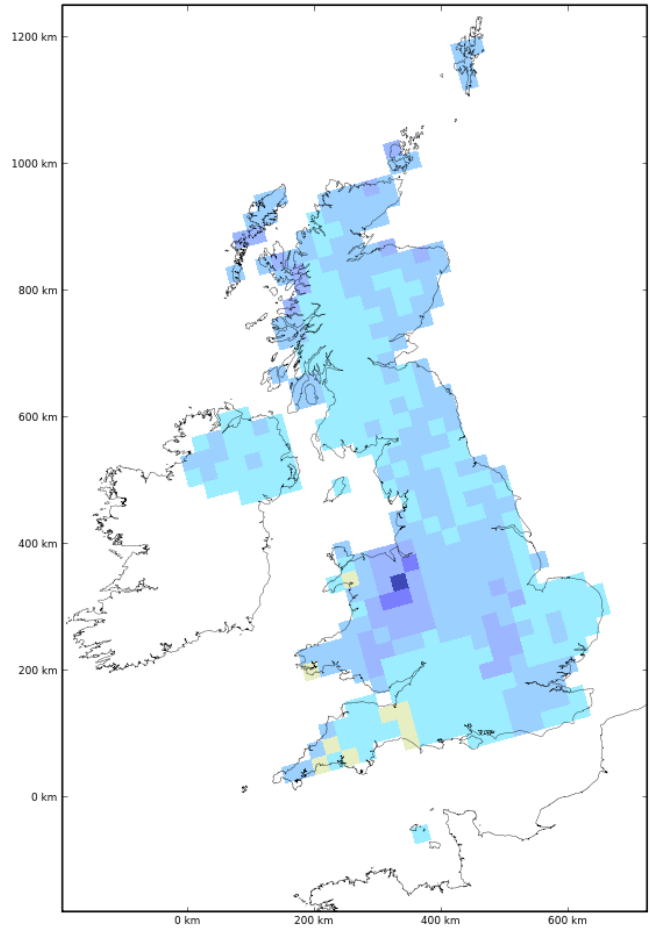
UK Climate Projections 2009:
Change in Wettest Day in Summer Medium (A1B) scenario

2080s : 67% probability level: unlikely to be greater than



2080s: 90% probability level: very unlikely to be greater than



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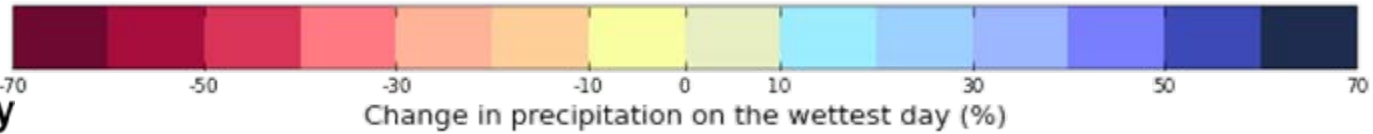
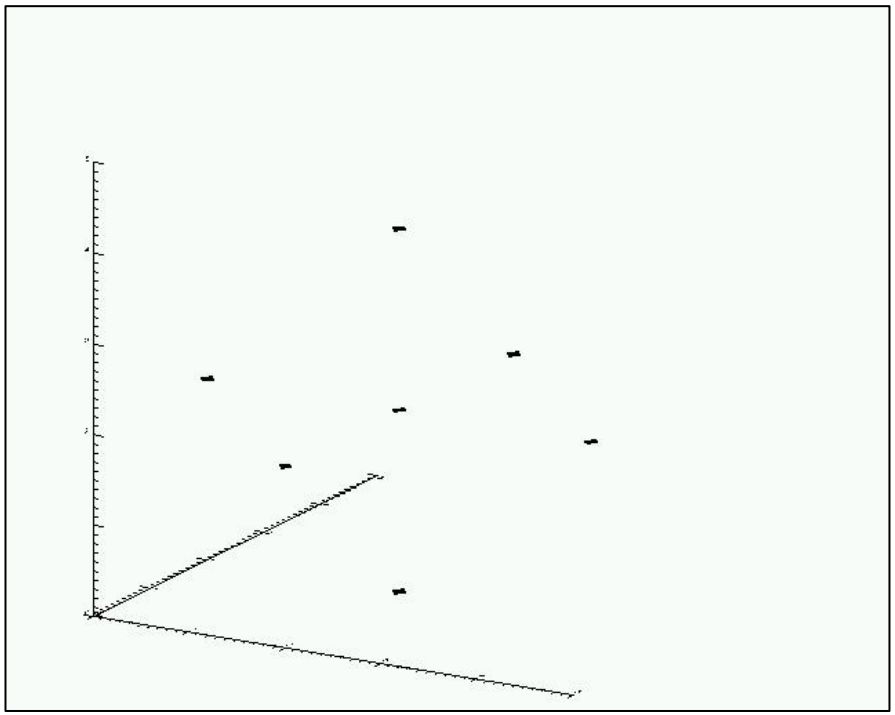
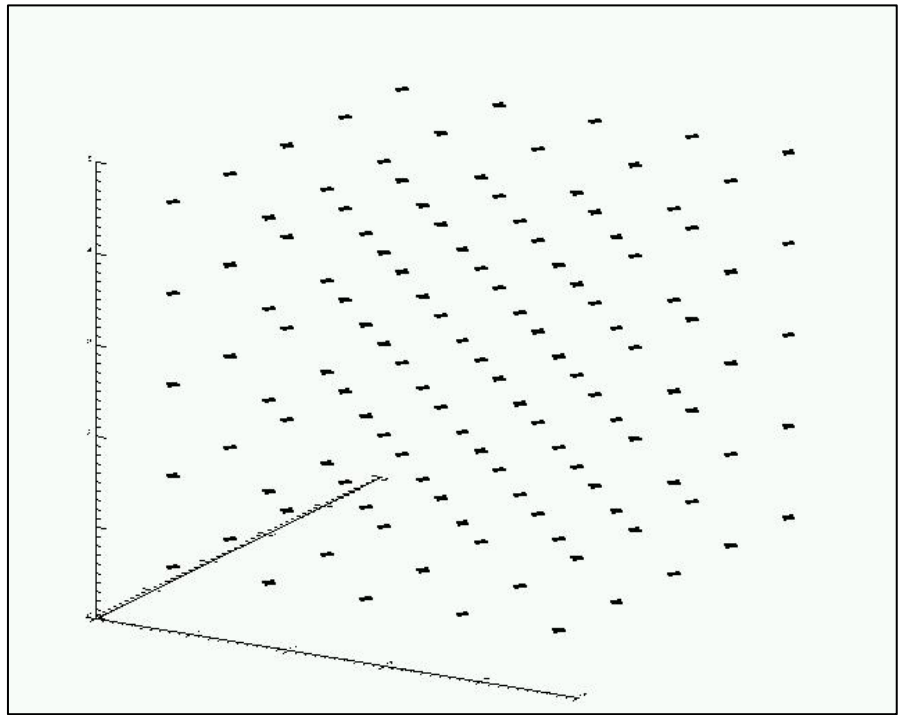


A (Very) Basic Summary of My Understanding of the Process



- sample parameters,
- run ensemble,
- "emulate",
- weight by fit to observations

Emulate



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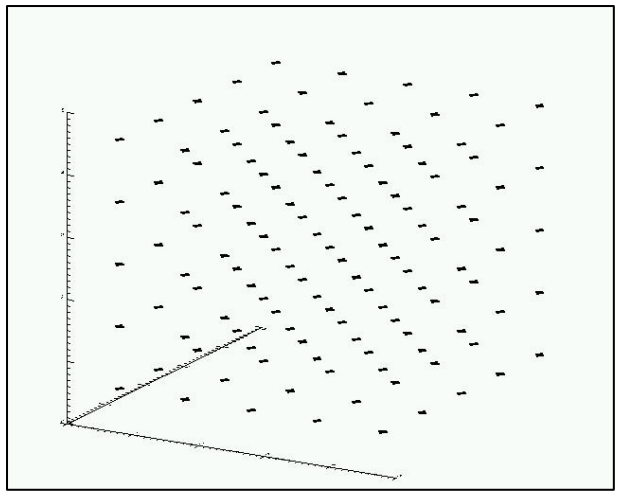
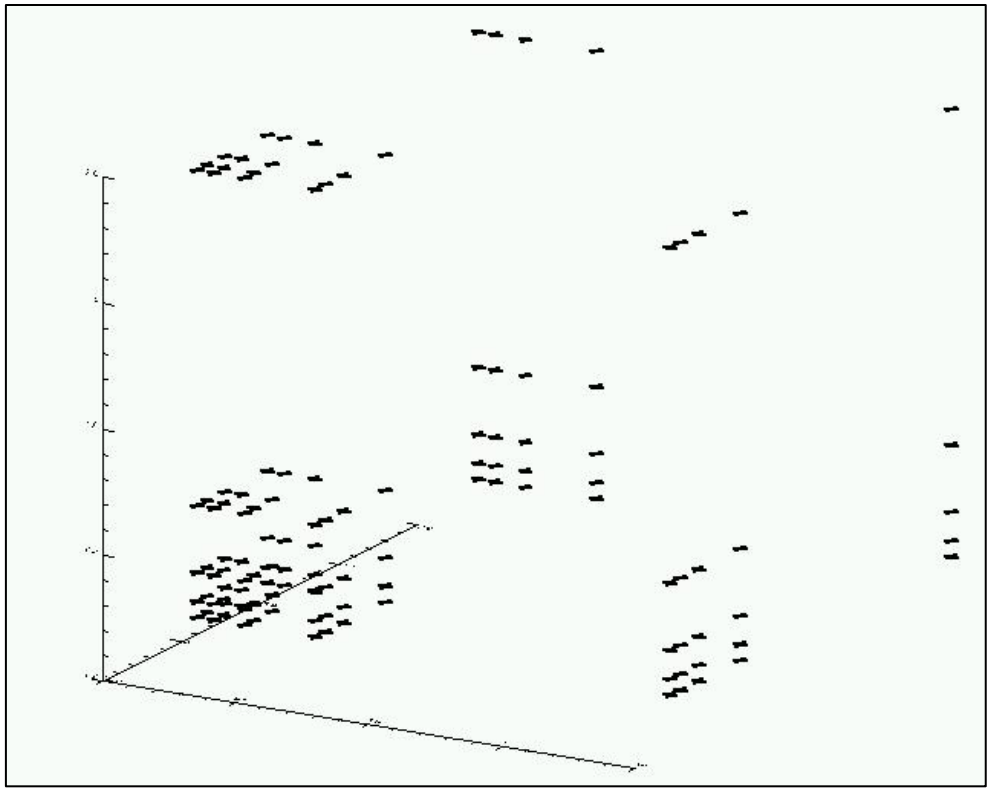
Issues

- Size of ensemble given size of parameter space.
- The ability of the emulator to capture non-linear effects.
- **The choice of prior i.e. how to sample parameter space.**
- The justification for weighting models.
- On what scales do we believe the models have information?



Choice of parameter definition



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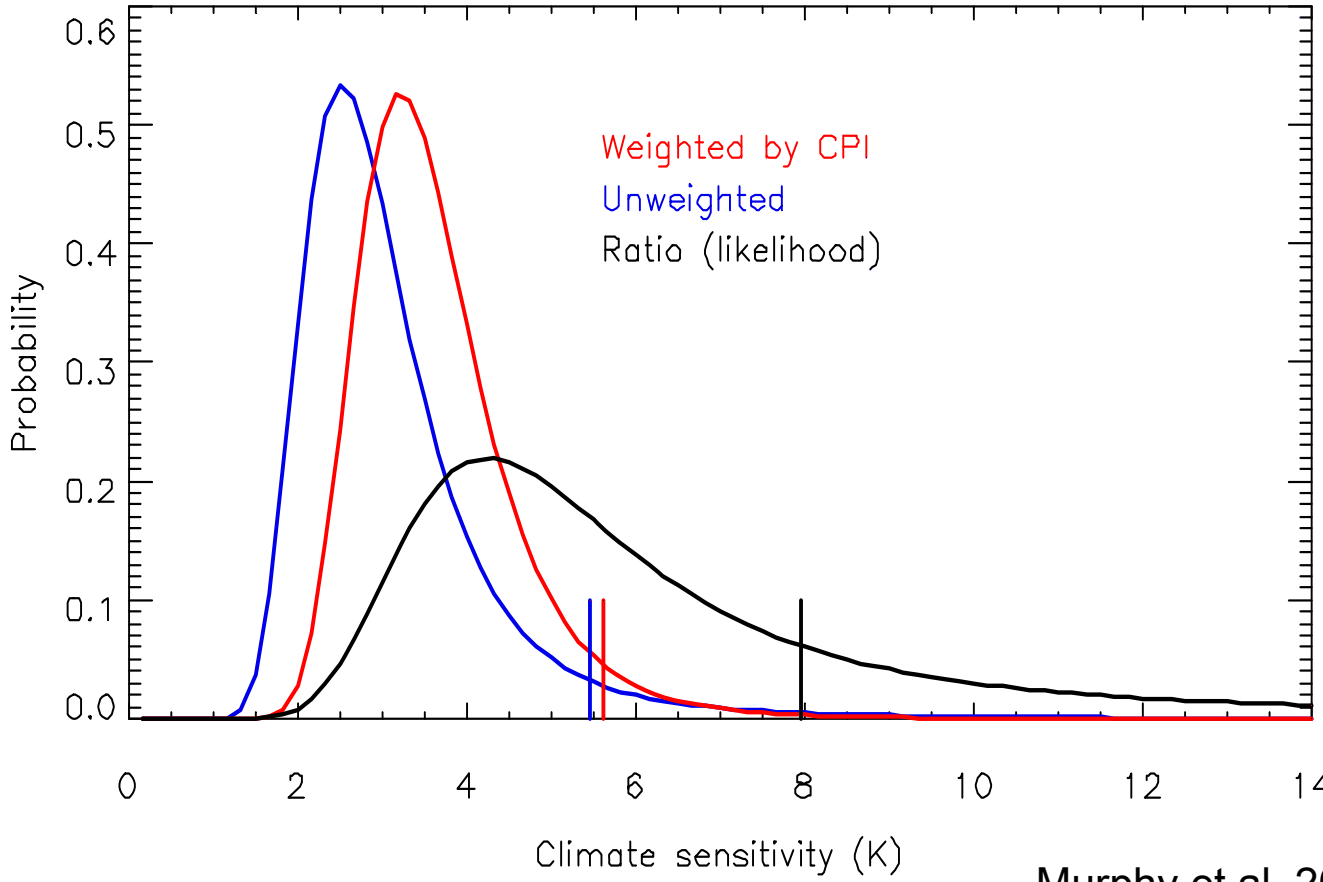
A Bayesian Method. But is it Subjective



Murphy et al, 2004
Ratio added by Myles Allen

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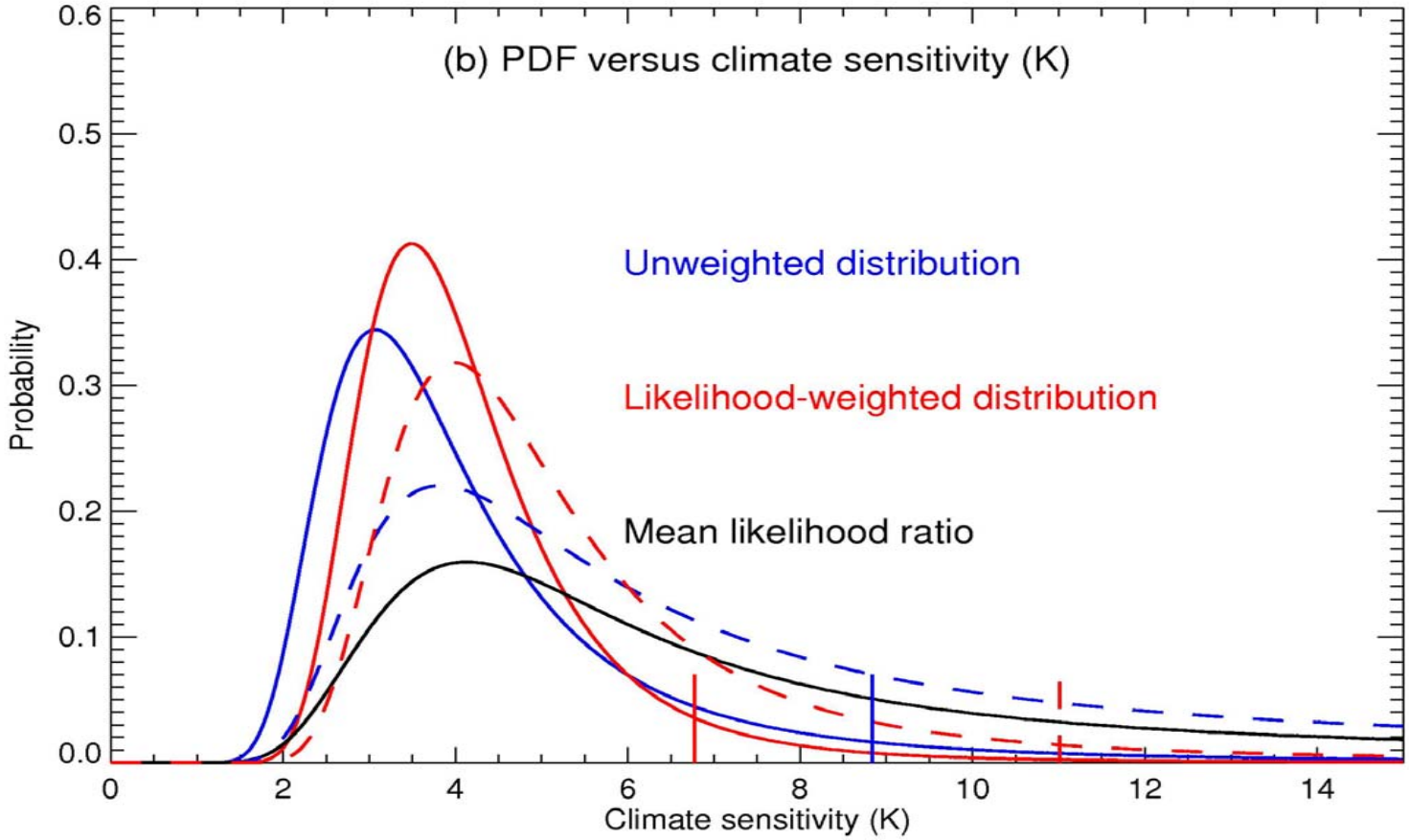
Adopting alternative plausible parameter sampling designs has a big impact on results



Plot: Myles Allen
Refs: Frame et al., 2005, Allen et al., 2005

Who has a prior "belief" that cloud parameterisations can have a parameter for ice fall rate but not for ice residence time?

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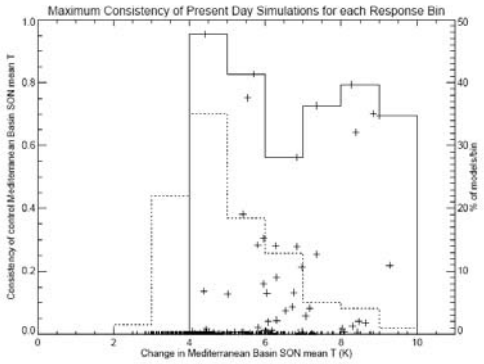
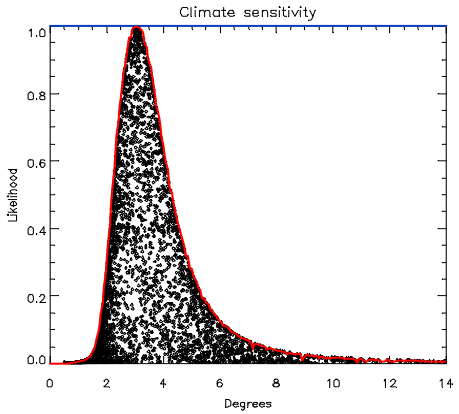
Interpretational Approaches 3: Maximum Consistency / Likelihood



Stainforth et al. 2007



Allen et al. 2008, not yet published.

- Informative for global scale variables.
- For regional variables – how do we interpret models which are consistent for some variables in some regions but not for others?

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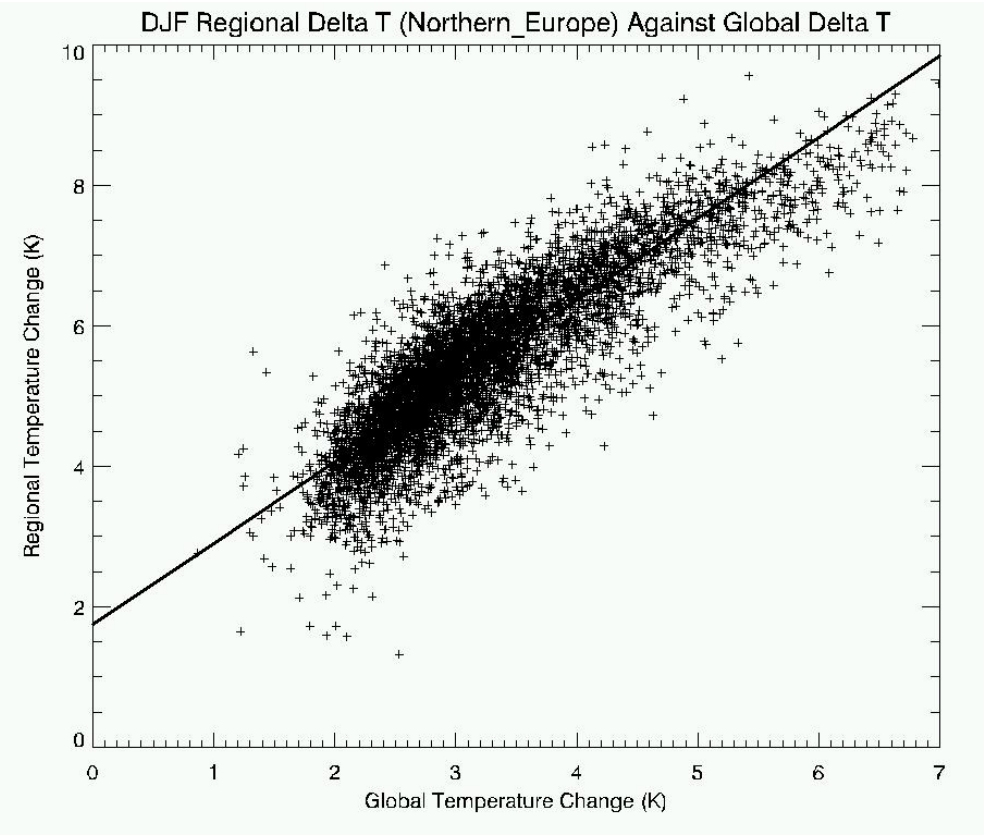
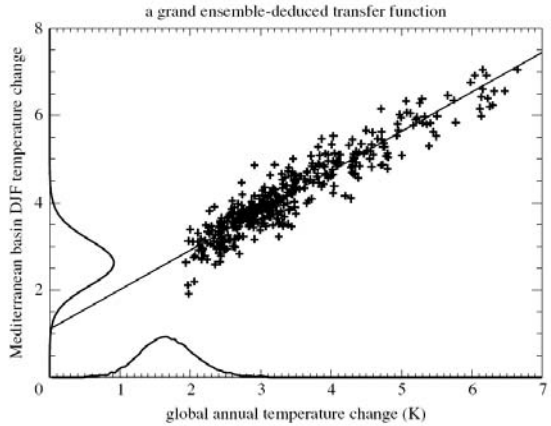
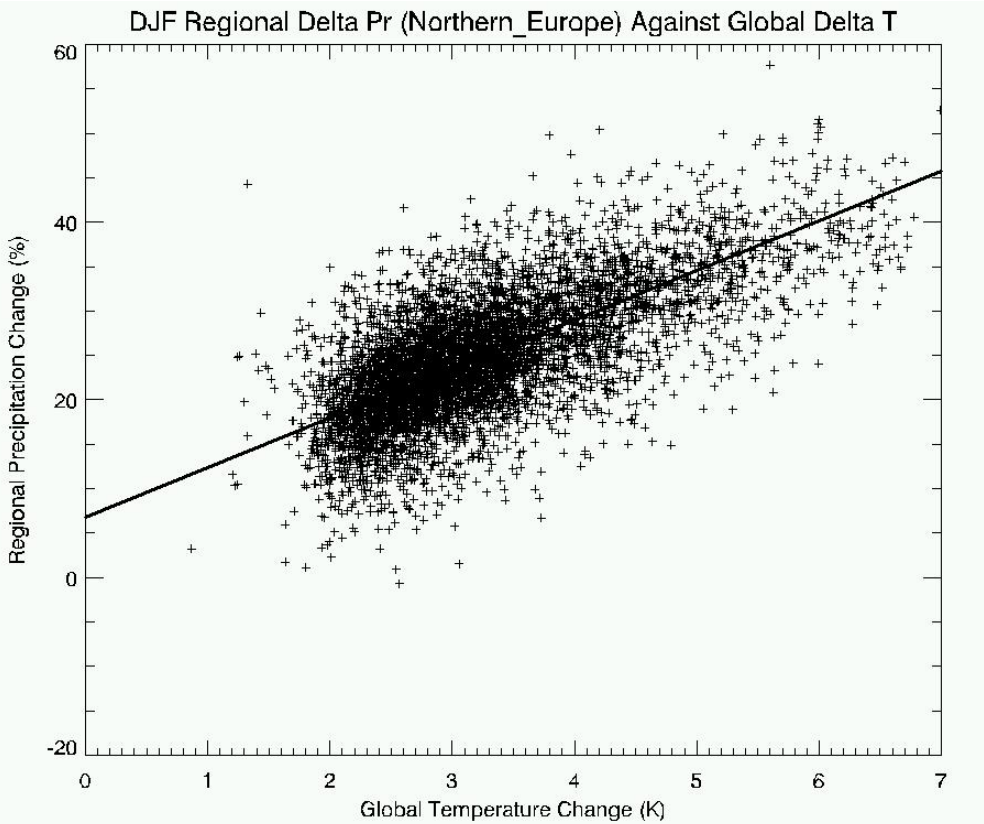
Interpretational Approaches 4: Transfer Functions







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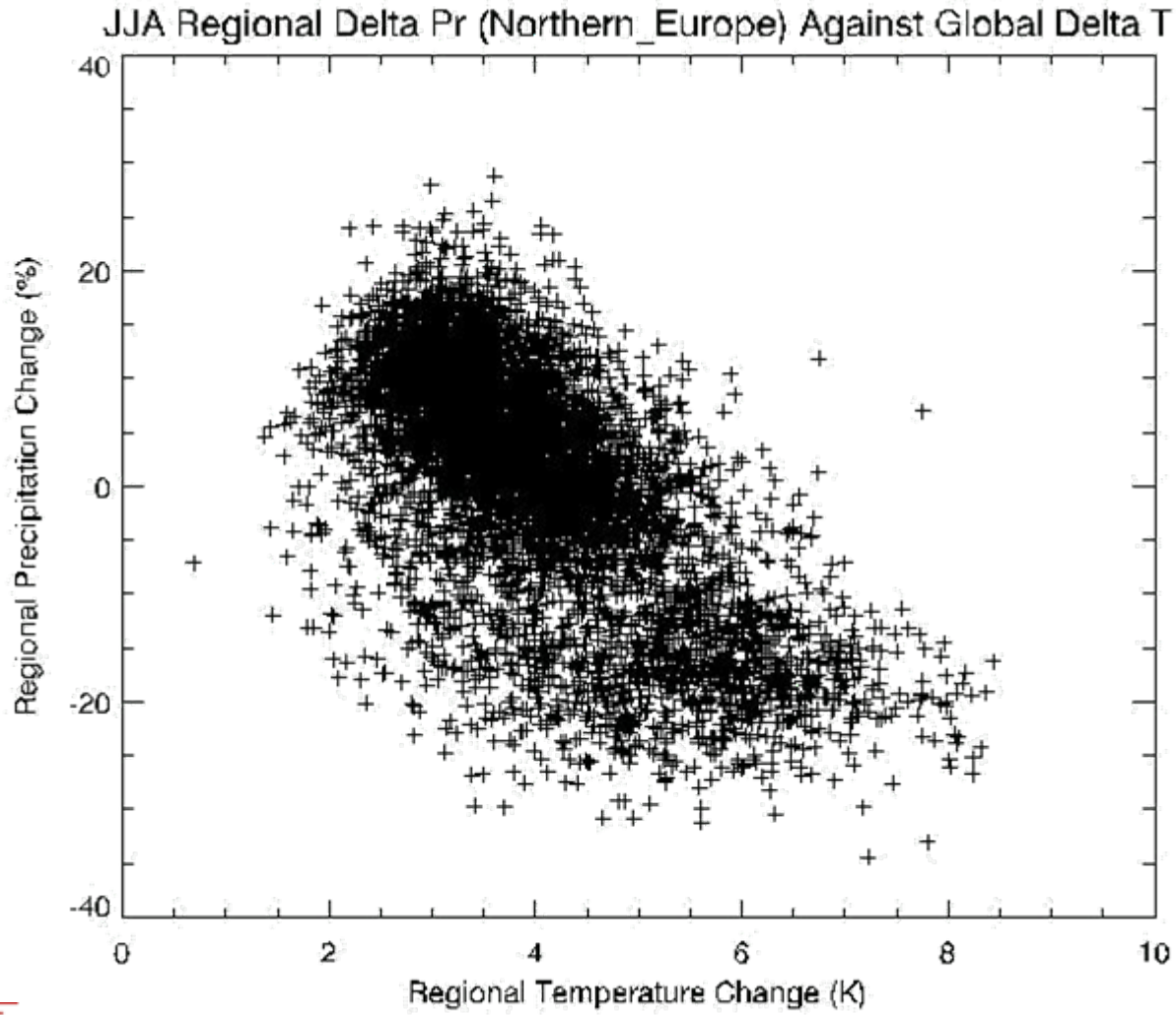
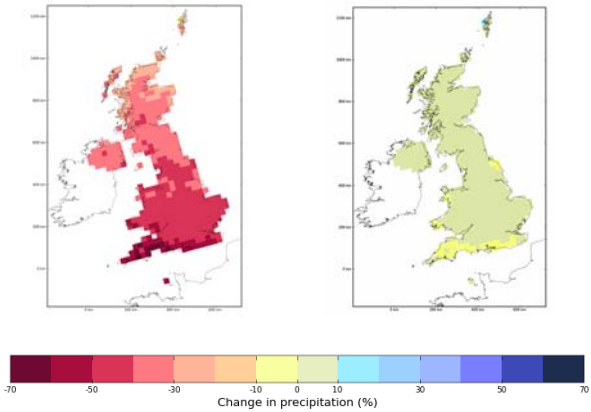
Okay as far as they go





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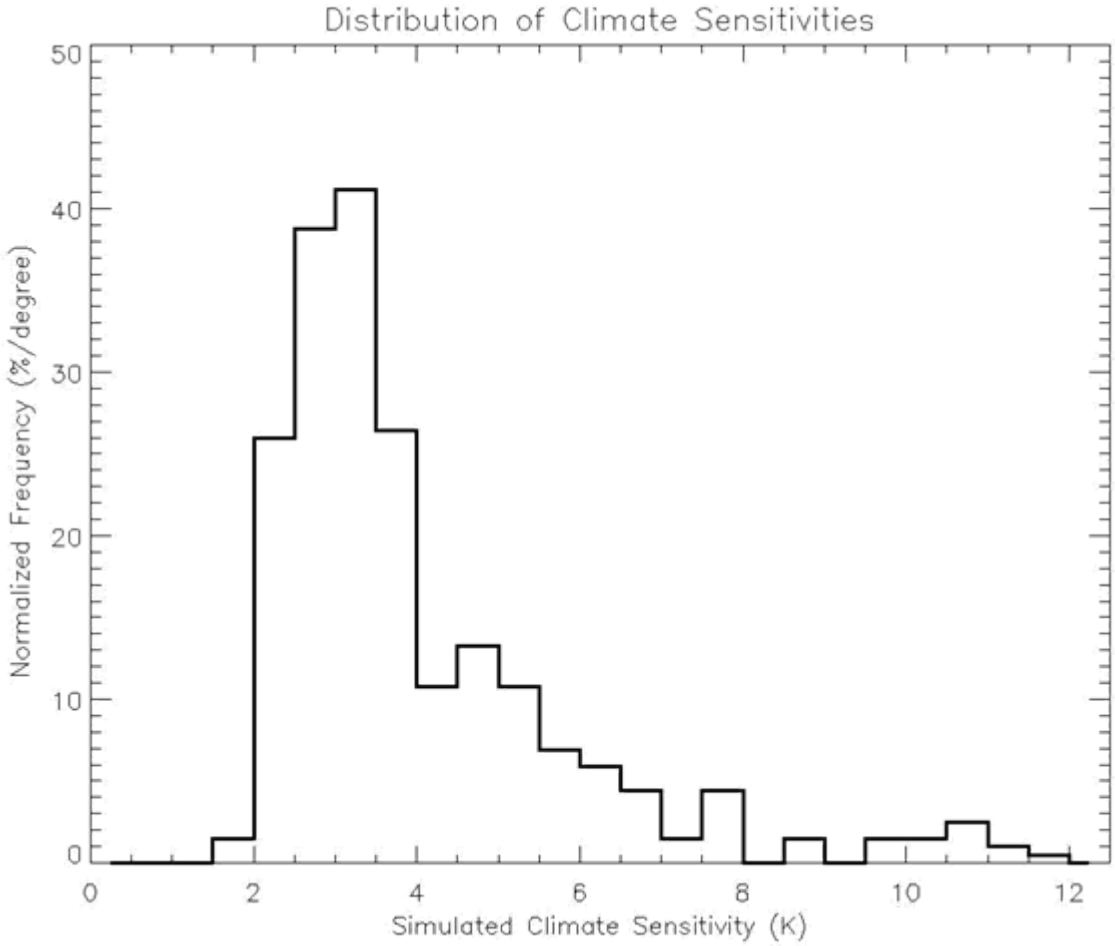
Interpretational Approaches 1: A range of plausible possibilities

Grand Ensemble Frequency Distribution of Climate Sensitivity



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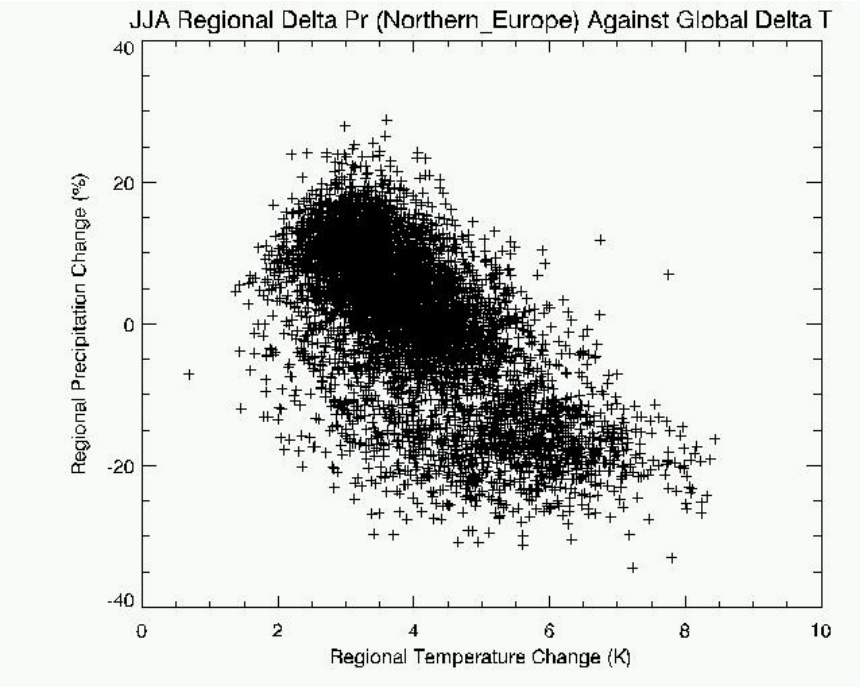
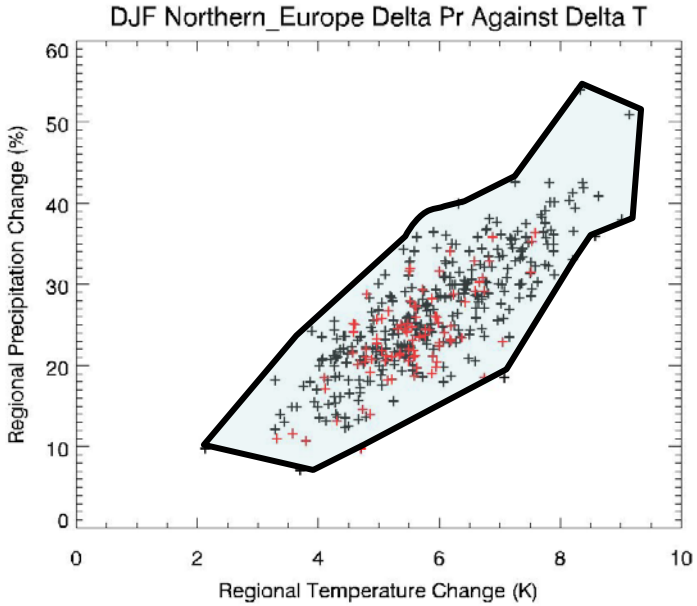
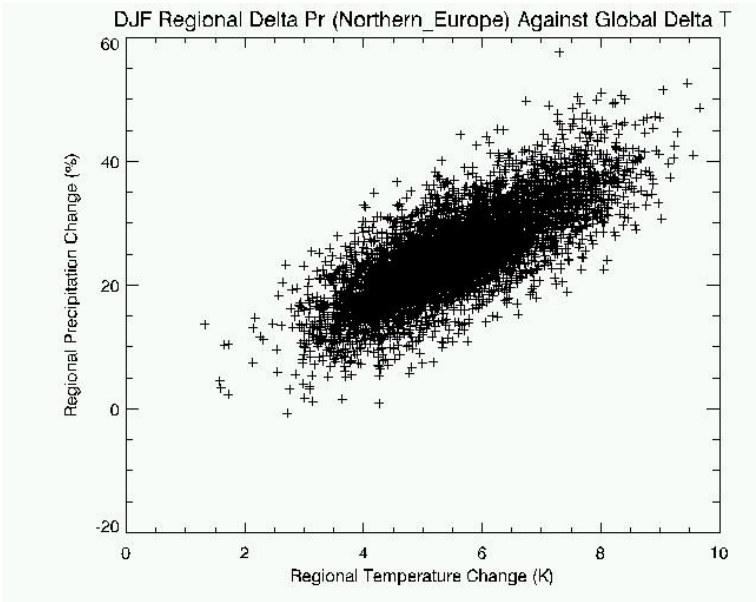
From Stainforth et al. 2005

Non-discountable Envelopes of Possibilities? Useful?

Combined Distributions of Regional, Seasonal Temperature and Precipitation:







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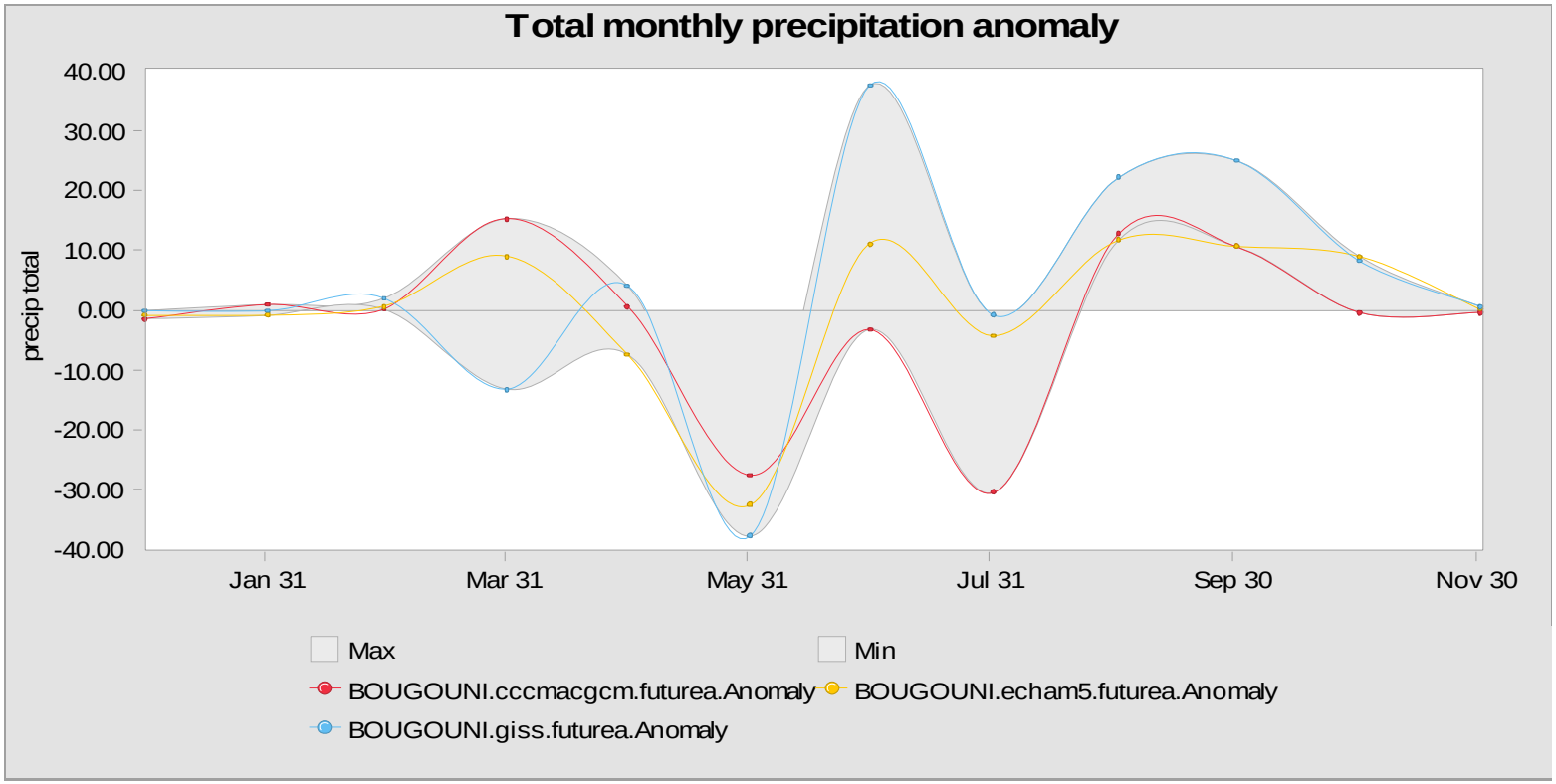
weADAPT.org: Climate Change Explorer: Future rainfall - Mali



Implications for Model Design

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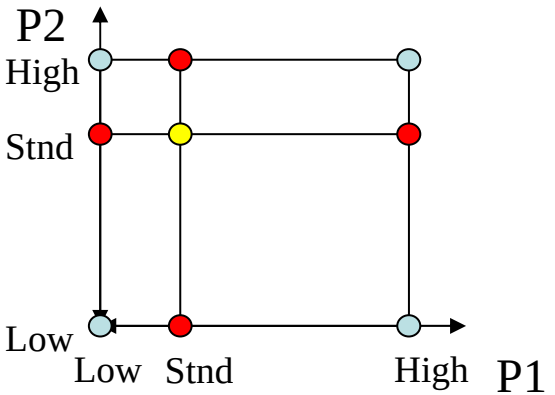
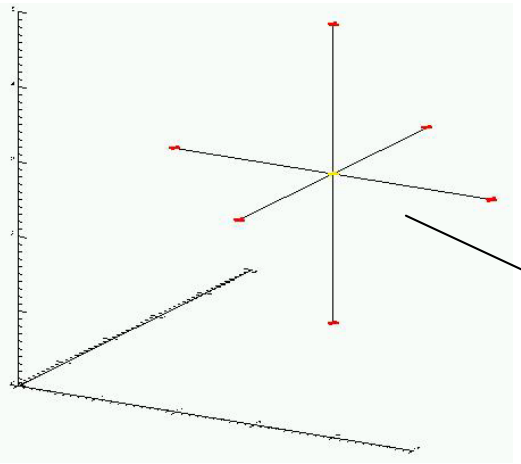
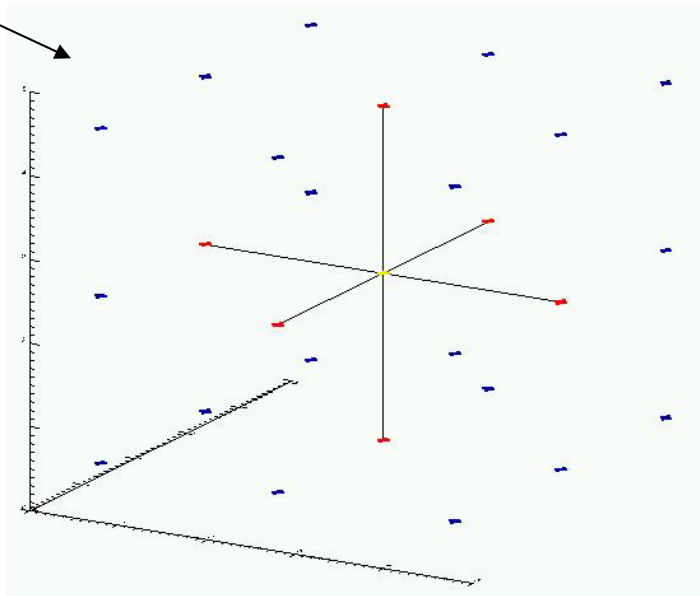
Exploration of Parameter Space

- There are hundreds of uncertain parameters in a GCM.
- To study them one at a time is relatively easy.
- But they interact non-linearly so we need to explore multiple perturbations simultaneously.



No. of parameters	One at a time	All combinations
1	3	3
2	5	9
3	7	27
6	13	729
21	42	10^{10}





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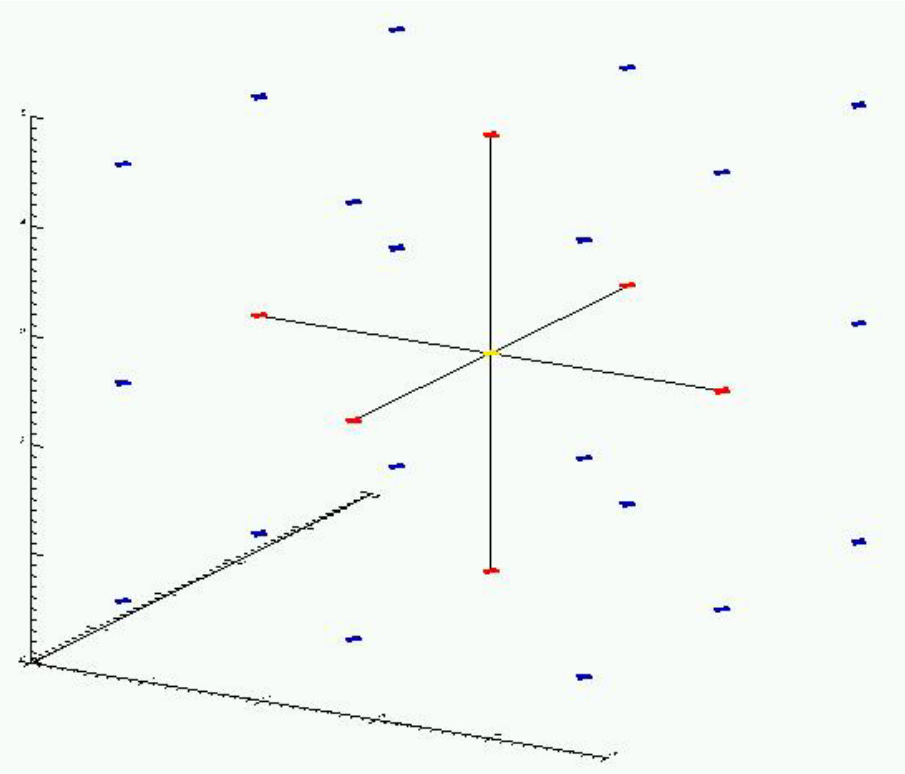
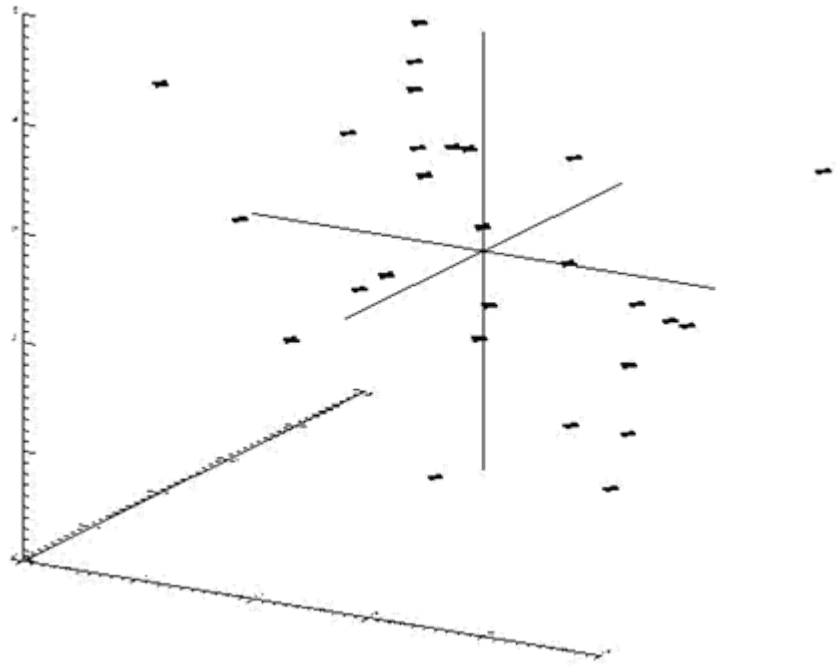
Exploration of Parameter Space (2)





Is a latin hypercube design of value?

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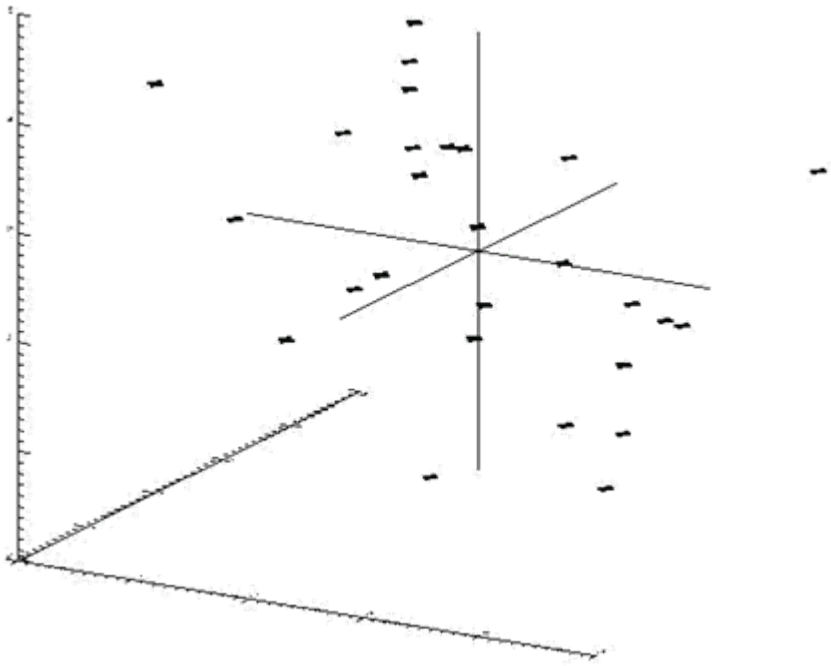
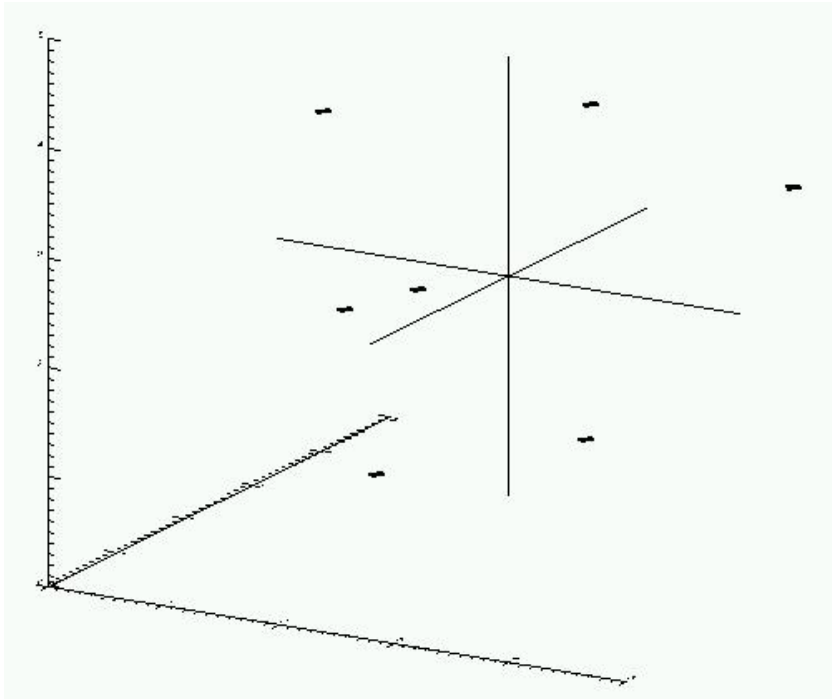
Remember the size of parameter space





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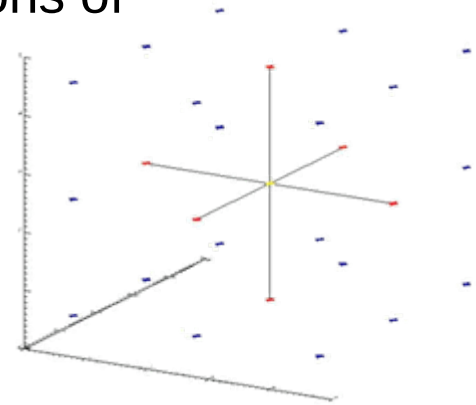
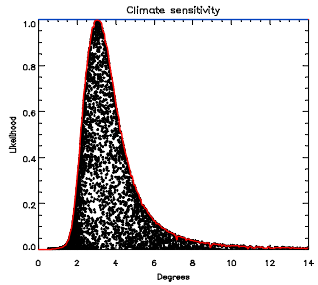
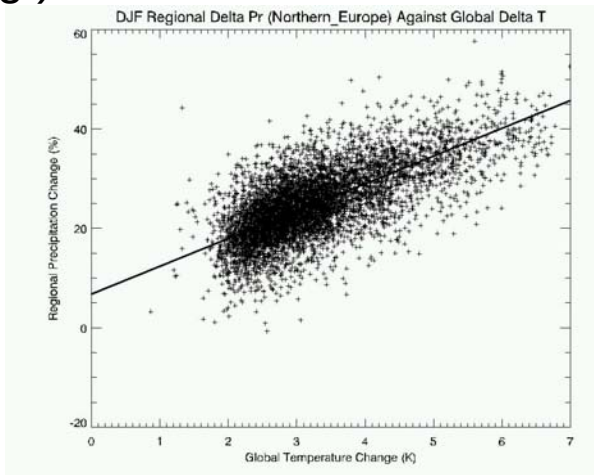
Options for the aims of Parameter Space Exploration

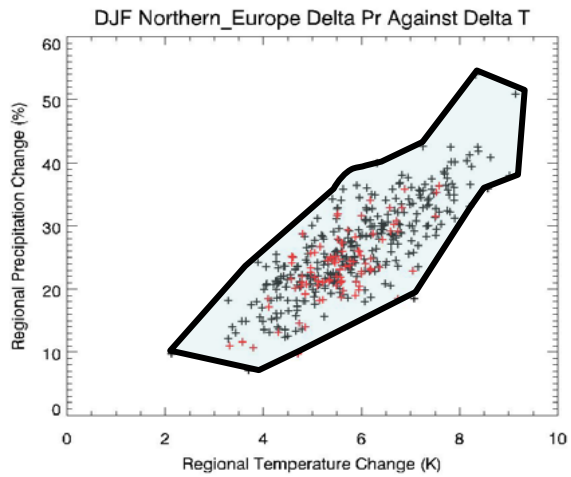
- Understanding the influence, implications and interactions of parameters.



- Push out the bounds of:
  - Likelihood / consistency distributions.
  - Increase the bounds of plausible envelopes.
  - Find examples which contradict previously deduced transfer functions.
  - (Preferably do this in terms of variables relevant to decisions or specific questions of understanding.)







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Weighting and Excluding

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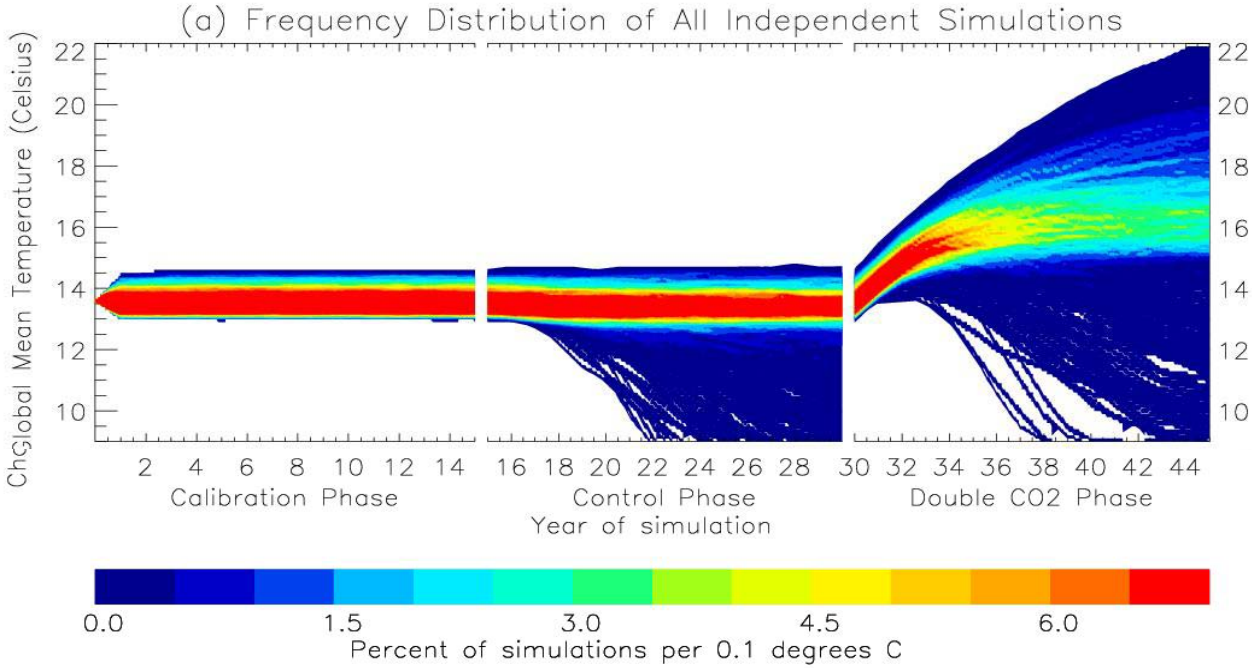
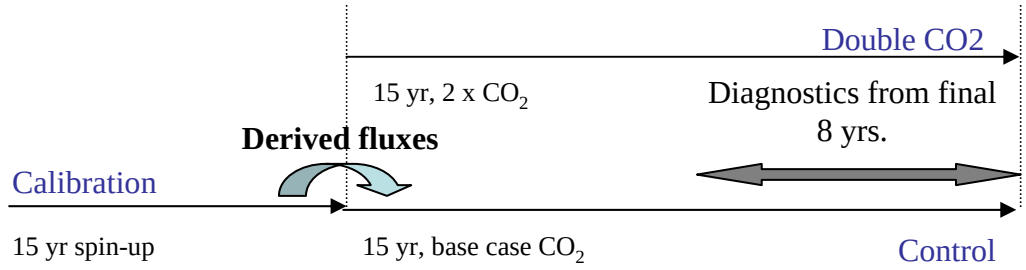
Weighting and Excluding

- How do we judge these large ensembles?
- What is sufficiently unphysical, unreasonable, implausible?
- Given that all models are wrong, are inconsistent with reality, what's the basis for giving them relative weights
- Or for excluding models entirely?

Frequency Distribution of Simulations





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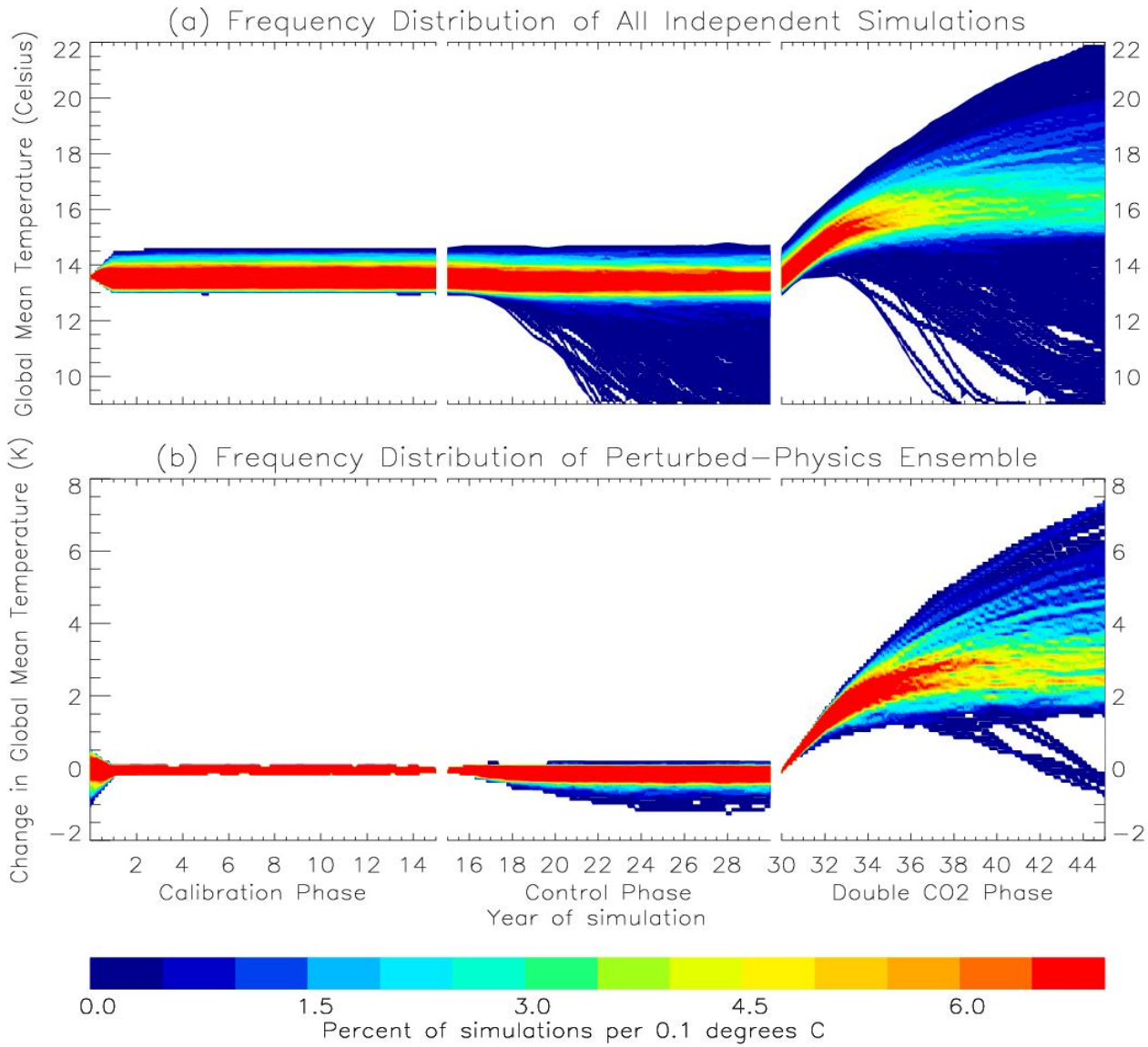
From Stainforth et al. 2005

Frequency Distribution of Simulations and Model Versions

To find potentially realistic model versions we remove those which are unstable in the control.

The remaining negatively drifting 2xCO_2 model versions are an unrealistic consequence of using a slab ocean.



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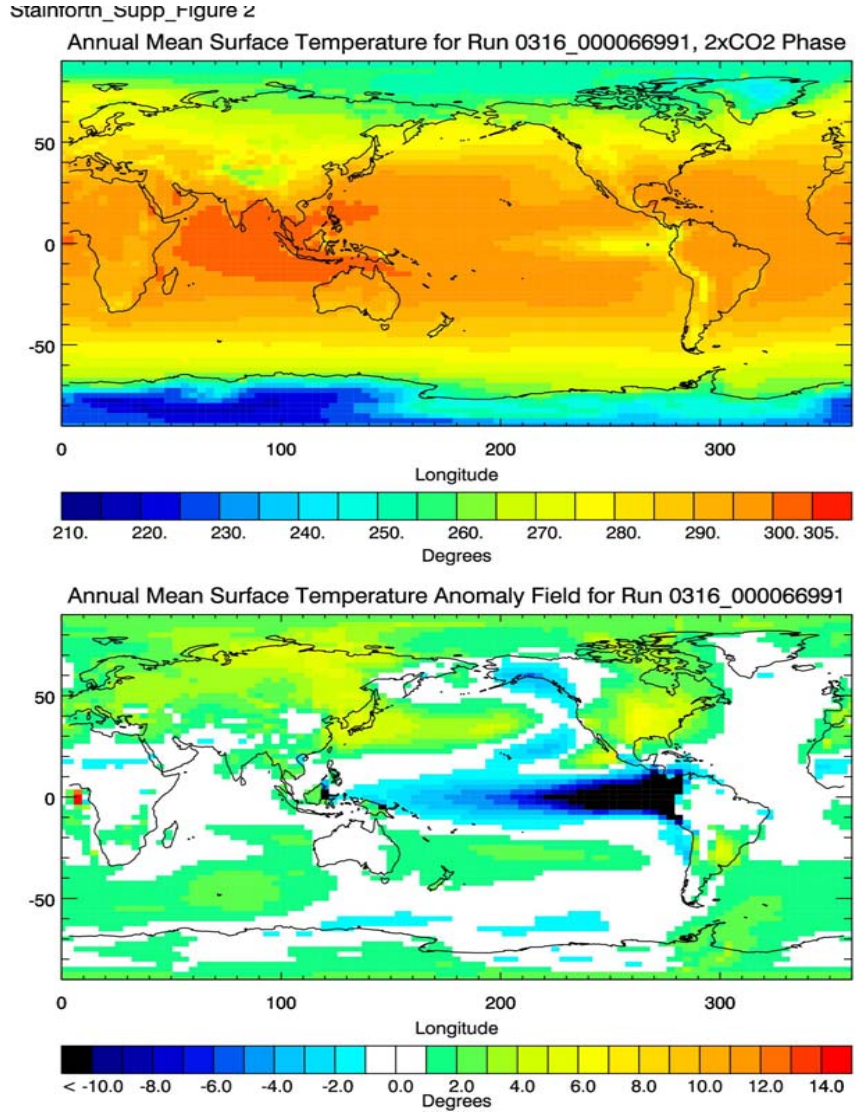
From Stainforth et al. 2005

Rejection of Negative Sensitivities



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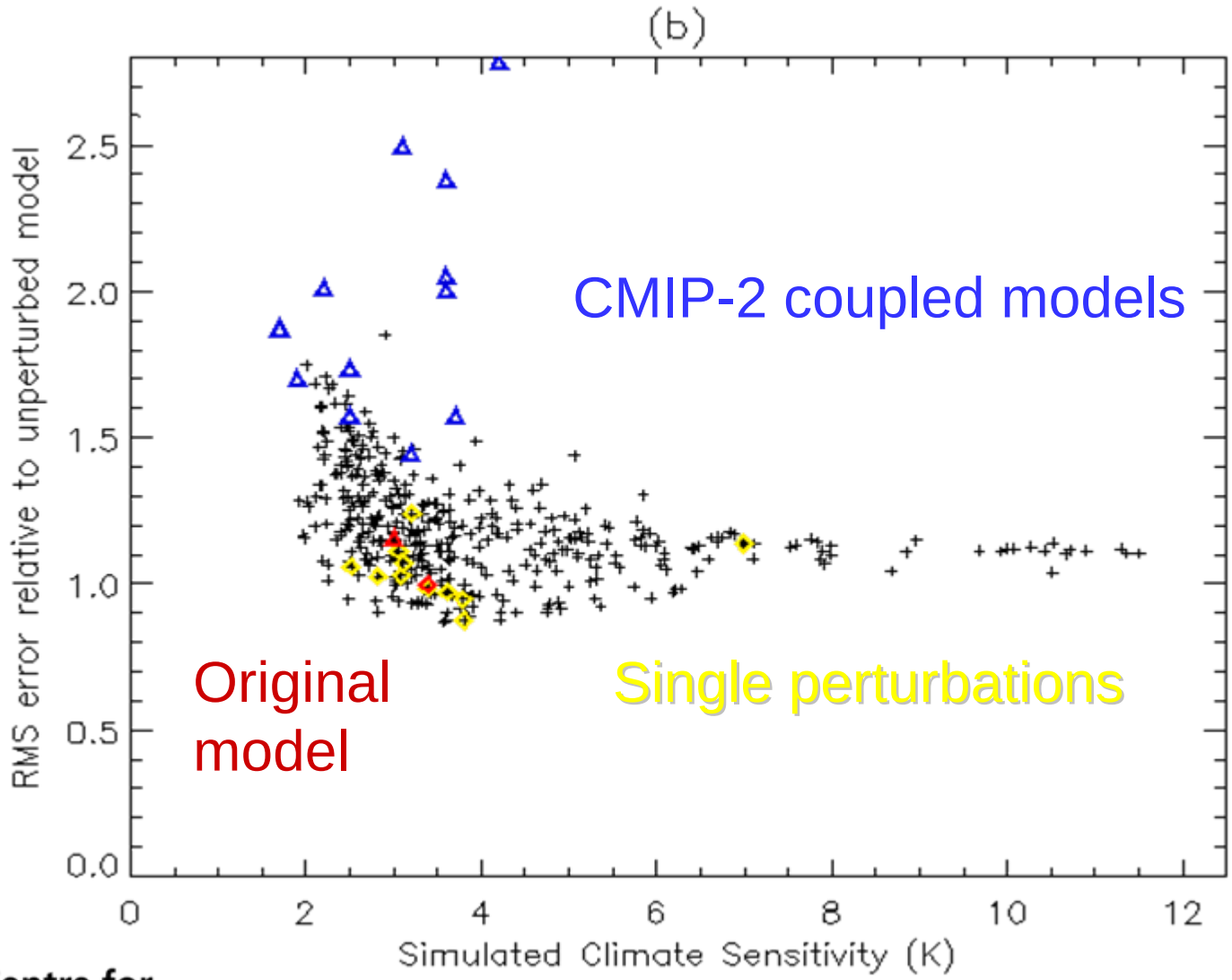
From Stainforth et al. 2005

Can observations constrain the distribution?



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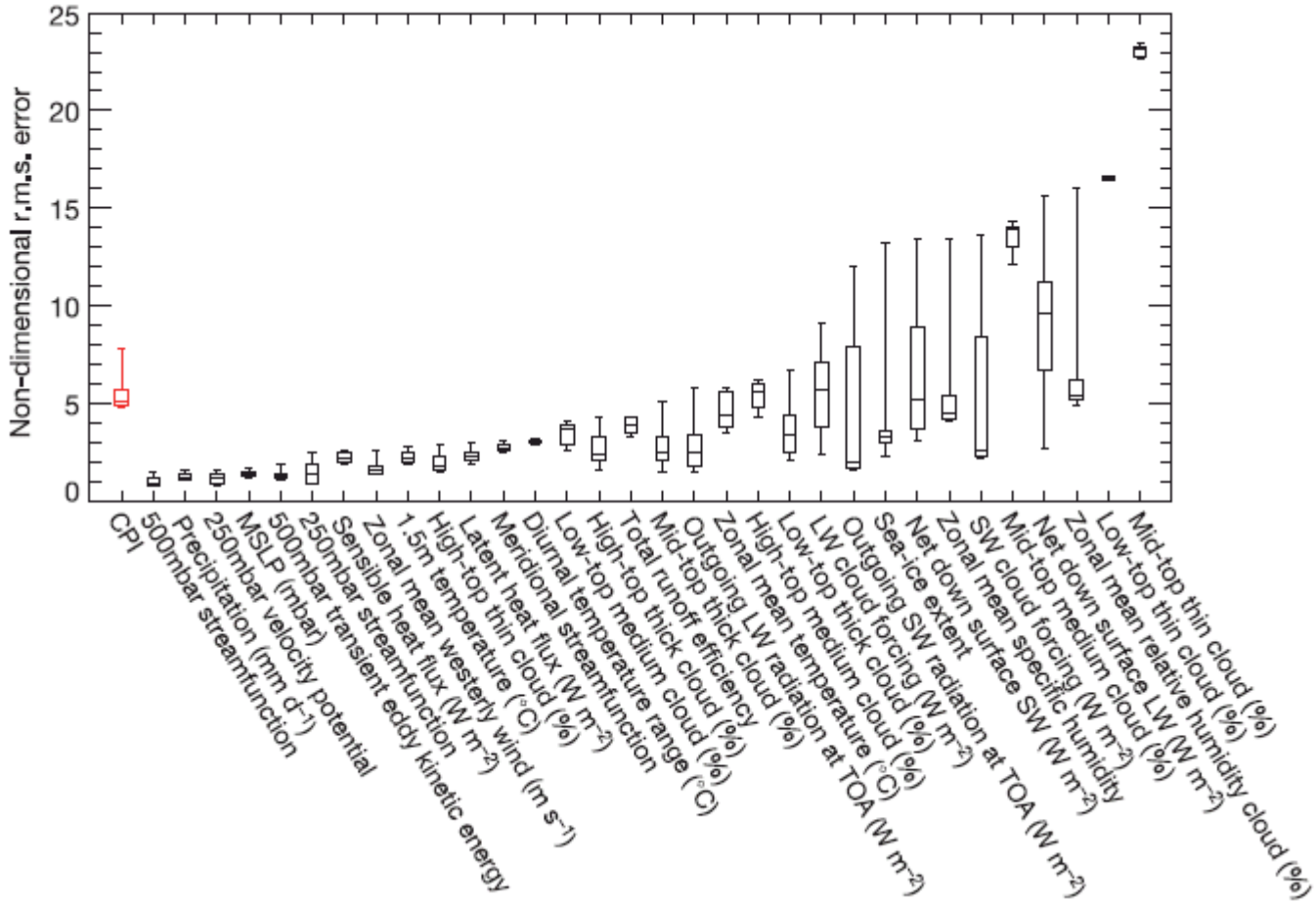
From Stainforth et al. 2005

The Climate Prediction Index



Murphy et al, 2004

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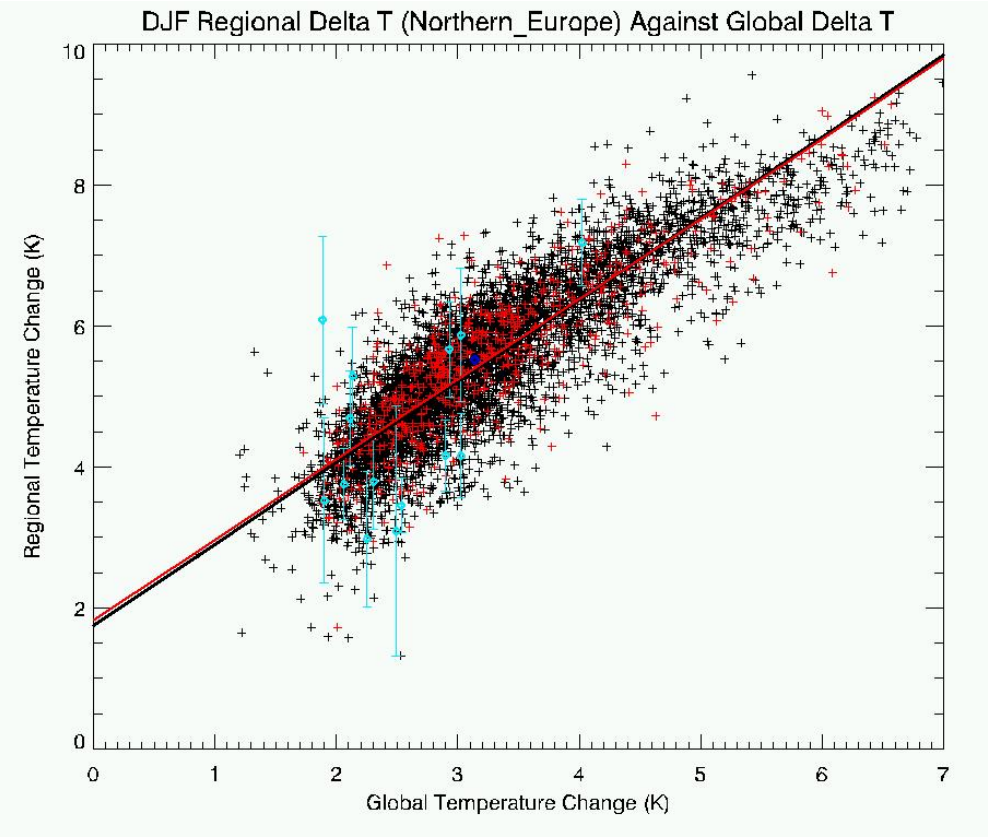
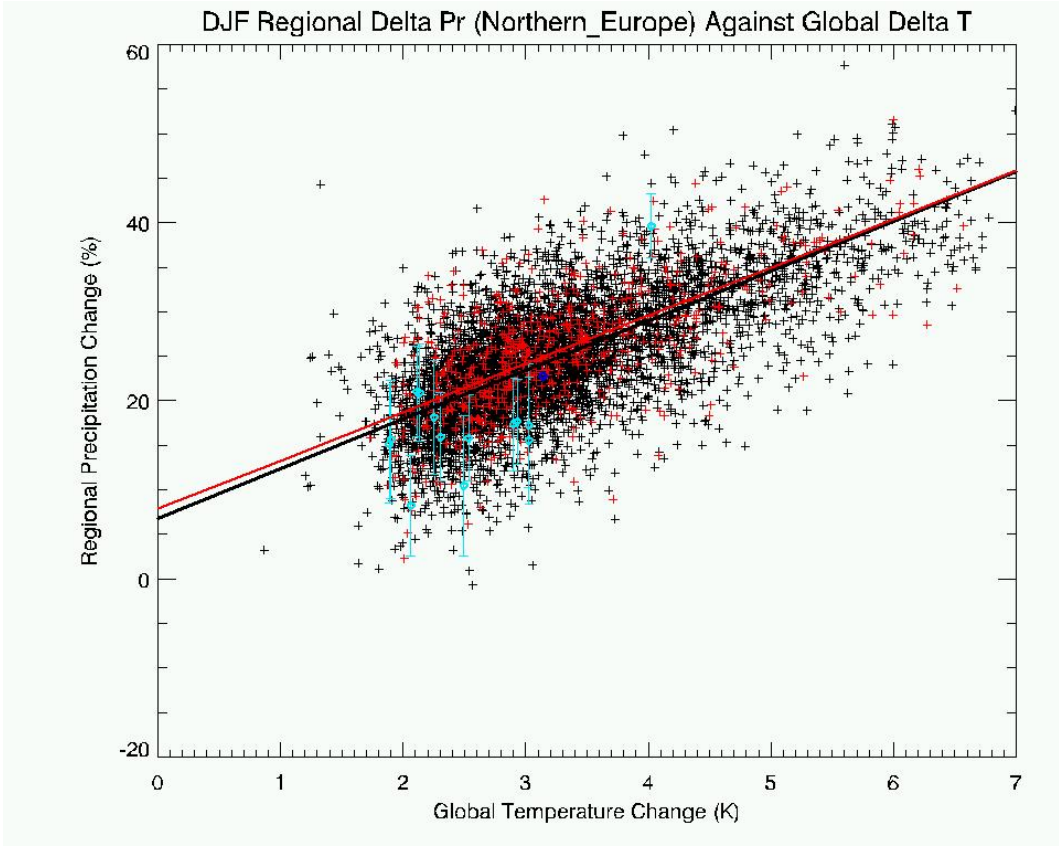
Sensitivity Analysis – Does a constraint change the result?
Global Mean Heat Flux





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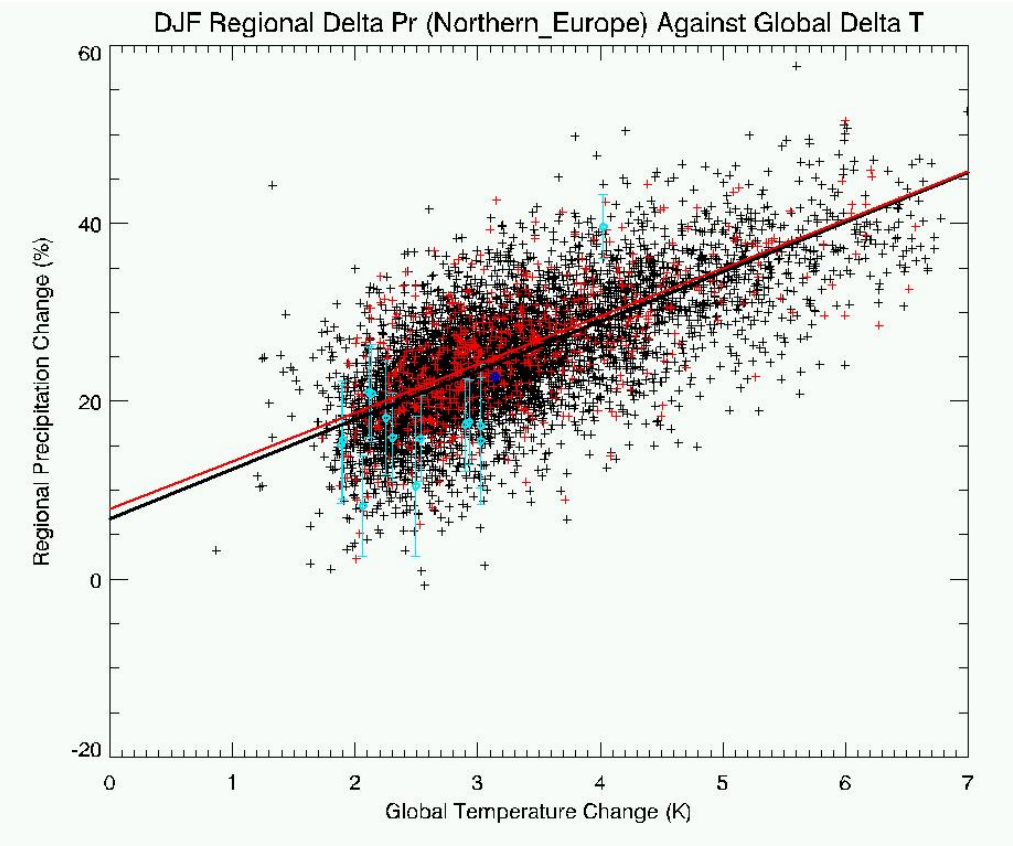
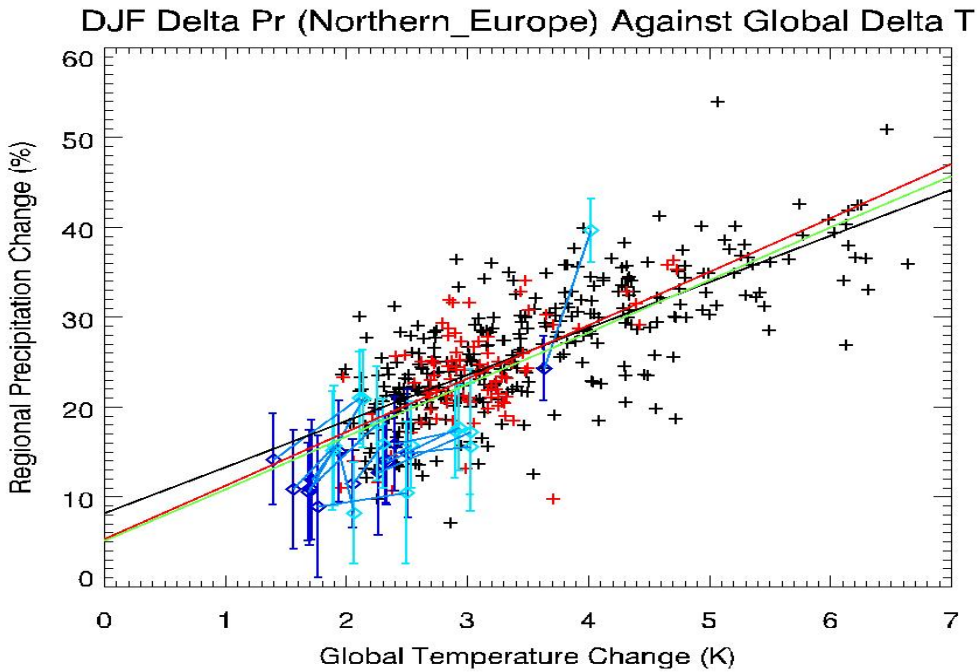
- Yet models and model versions are not independent.

In-Sample .vs. Out of Sample Analysis





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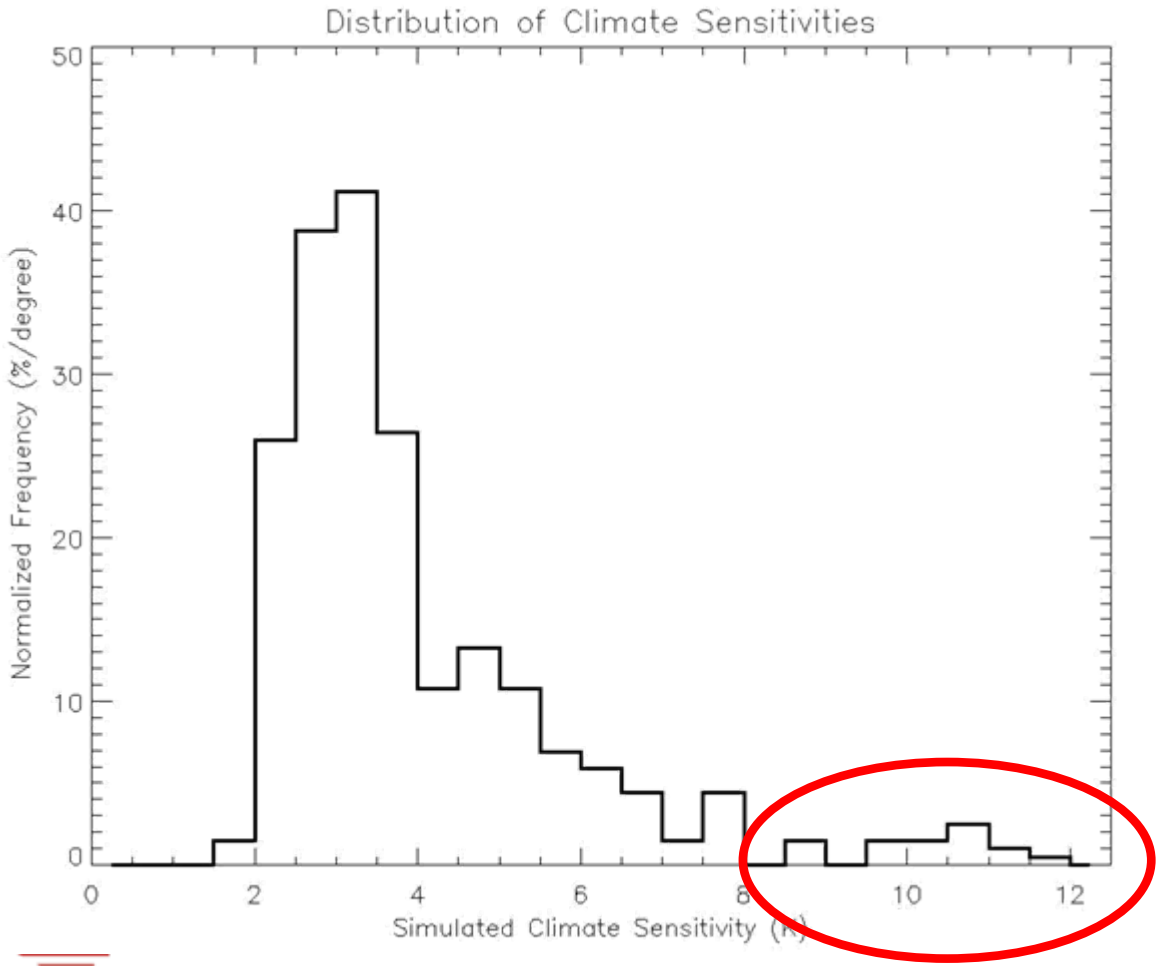
In-Sample .vs. Out-of-Sample Analysis

Grand Ensemble Frequency Distribution of Climate Sensitivity



- Not only do we not have the possibility to verify a climate forecast for the real world
- we also run risks relating to conclusions about particular models due to:
  - difficulties in running old model versions,
  - difficulties repeating large ensembles.

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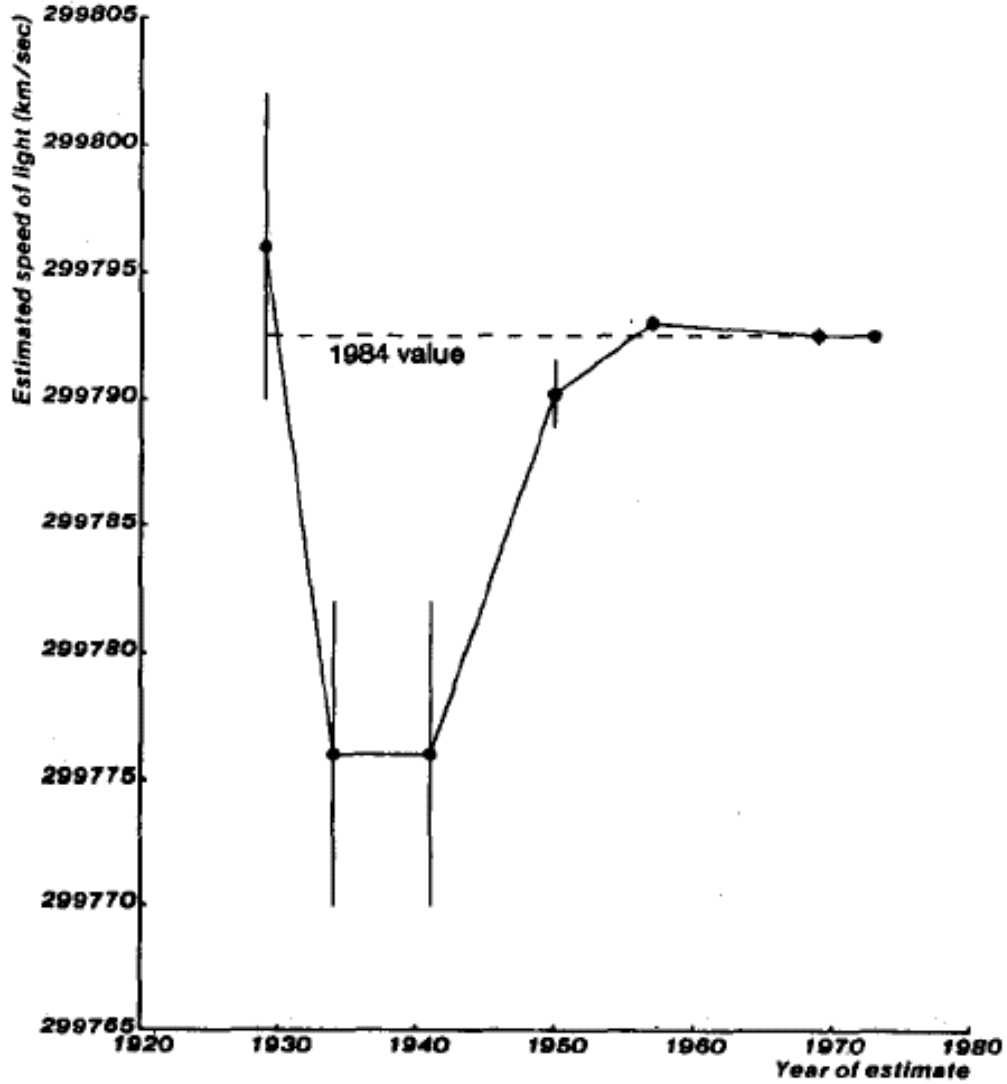
From Stainforth et al. 2005

Communicating / Informing

- Communicating what we understand
- Researching what is relevant to society.
- Developing models and understanding what will be valuable in 10 years time.
  (Focus on developing a more useful model rather than a better model.)

The Speed of Light

Recommended values of the speed of light: 1929-1983
From Henrion and Fischhoff, 1985.



"Thus, after a long and, at times, hectic history, the value for c has at last settled down into a fairly satisfactory steady state''

R.T. Birge, 1942

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Let’s Be Careful Out There

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