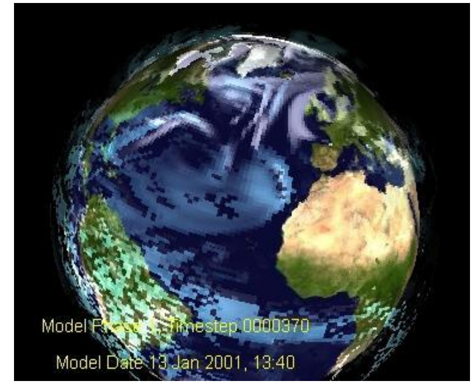
Ensembles and Uncertainty II

Dave Stainforth

Acknowledgements to: Lenny Smith, Falk Niehörster & Joe Daron

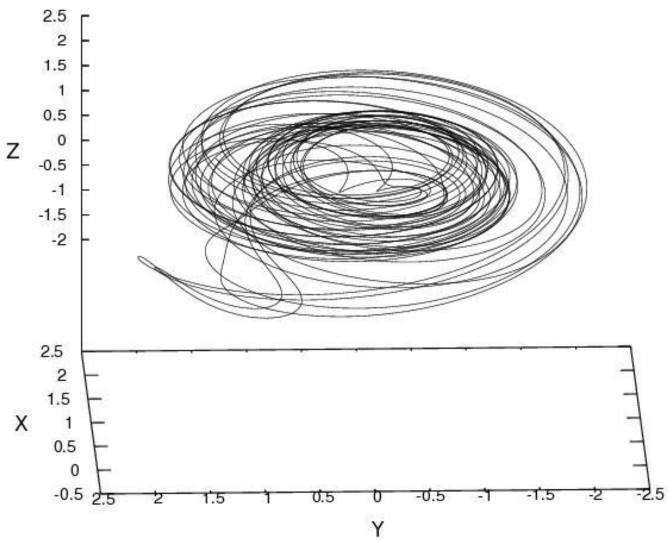
Centre for the Analysis of Timeseries and Grantham Research Institute on Climate Change and the Environment, **London School of Economics**.



DCMIP Summer School

Boulder

31st July 2012



"Research is the act of going up alleys to see if they are blind."
Plutarch(?), 46-120AD.

THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

Layout – Today II

- Uncertainty in climate predictions and their relationship to types of ensembles
- Reality .vs. models
- The Galton board –
- NAG board
- Climateprediction.net design
- Interpretational philosophies

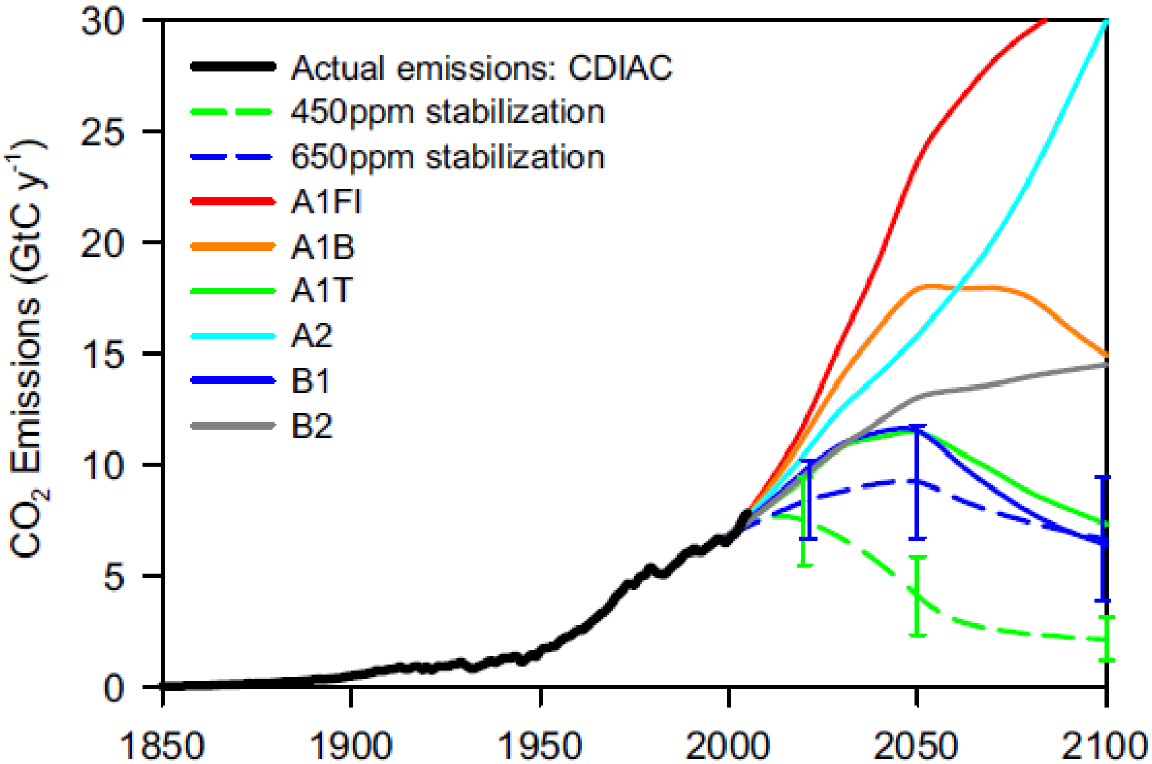
Sources of Uncertainty In Climate Forecasts

- External Influence Uncertainty.
- Initial Condition Uncertainty
  - Microscopic Initial Condition Uncertainty.
  - Macroscopic Initial Condition Uncertainty.
- Model imperfections
  - Model Inadequacy.
  - Model Uncertainty.

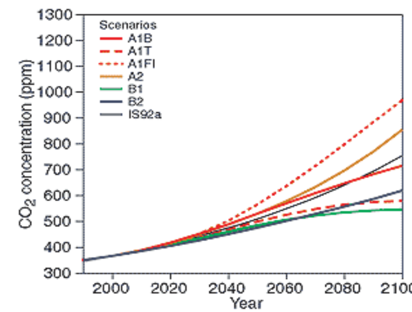
Sources of Uncertainty

- 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.

Emissions



Concentrations:



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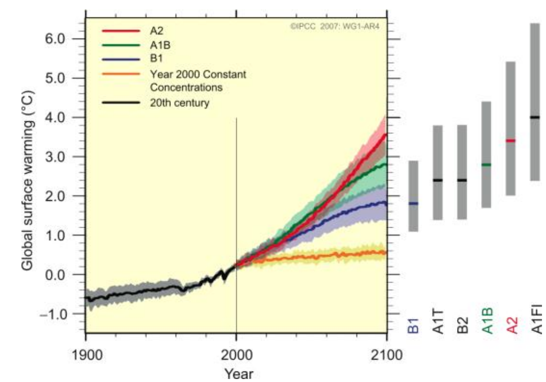

Source: Raupach et al. 2007, PNAS;

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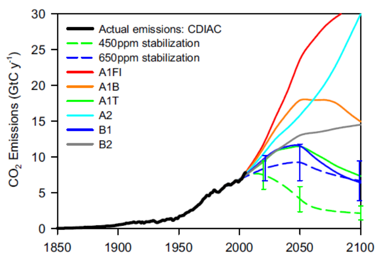

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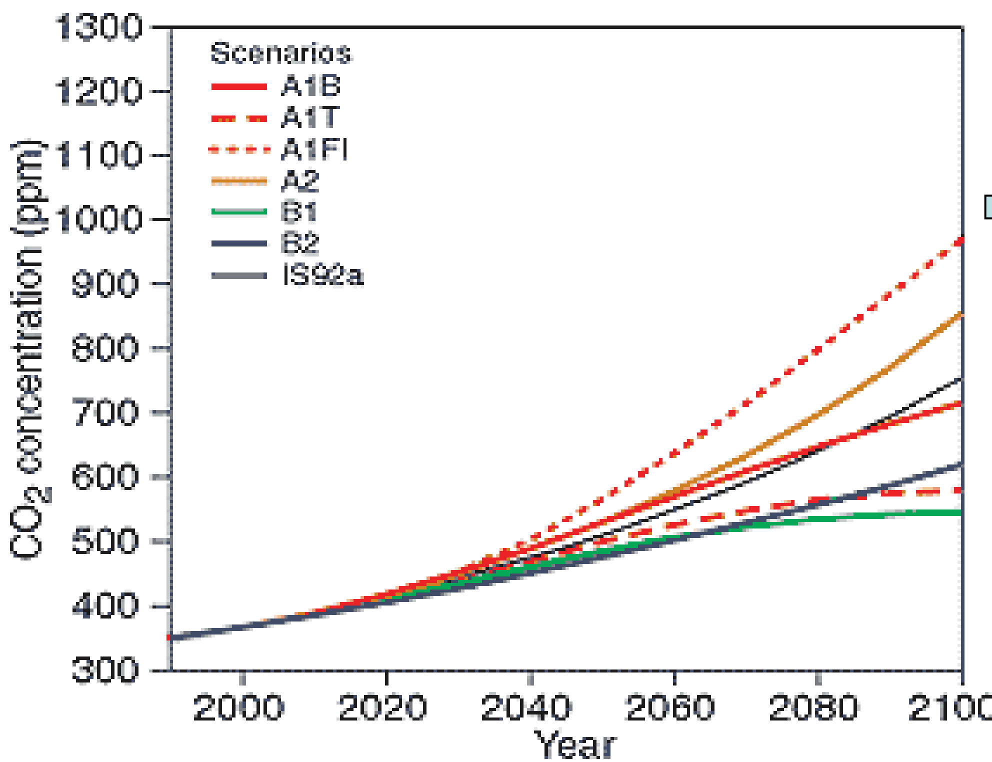

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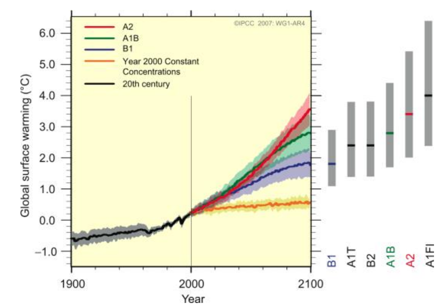

Source: IPCC TAR, 2001

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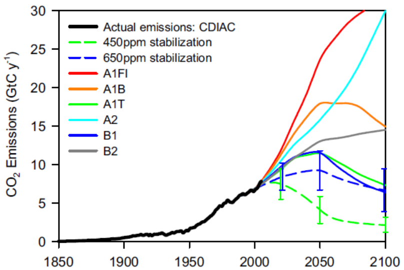

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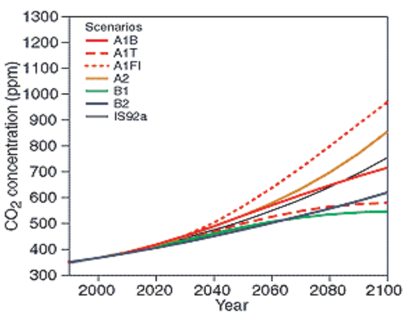

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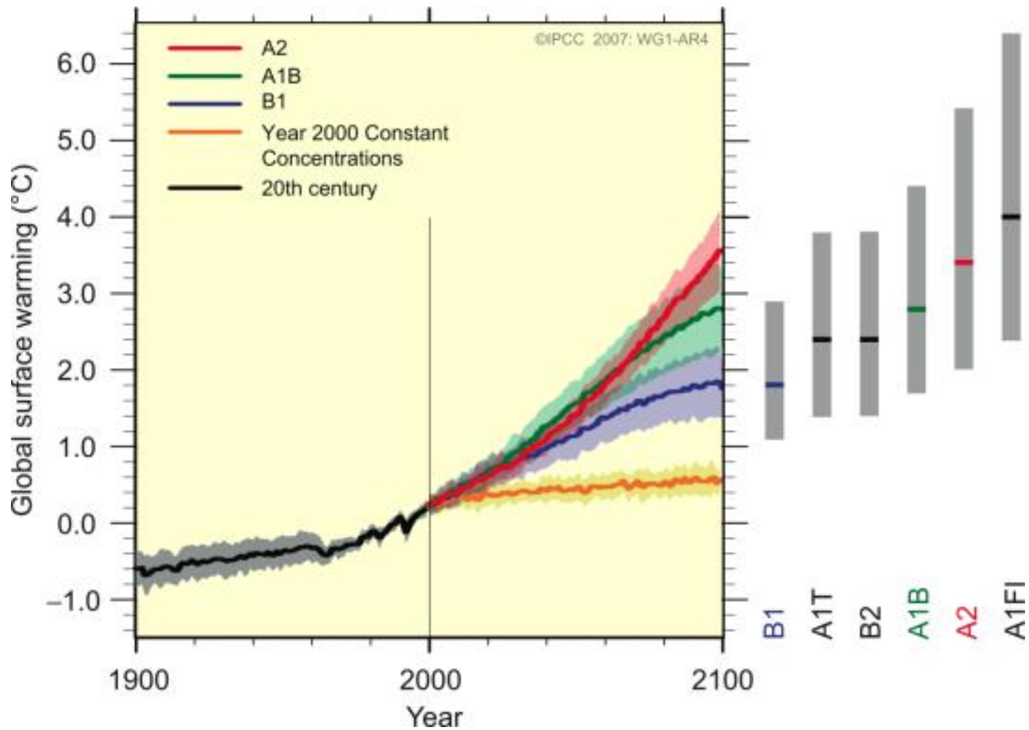
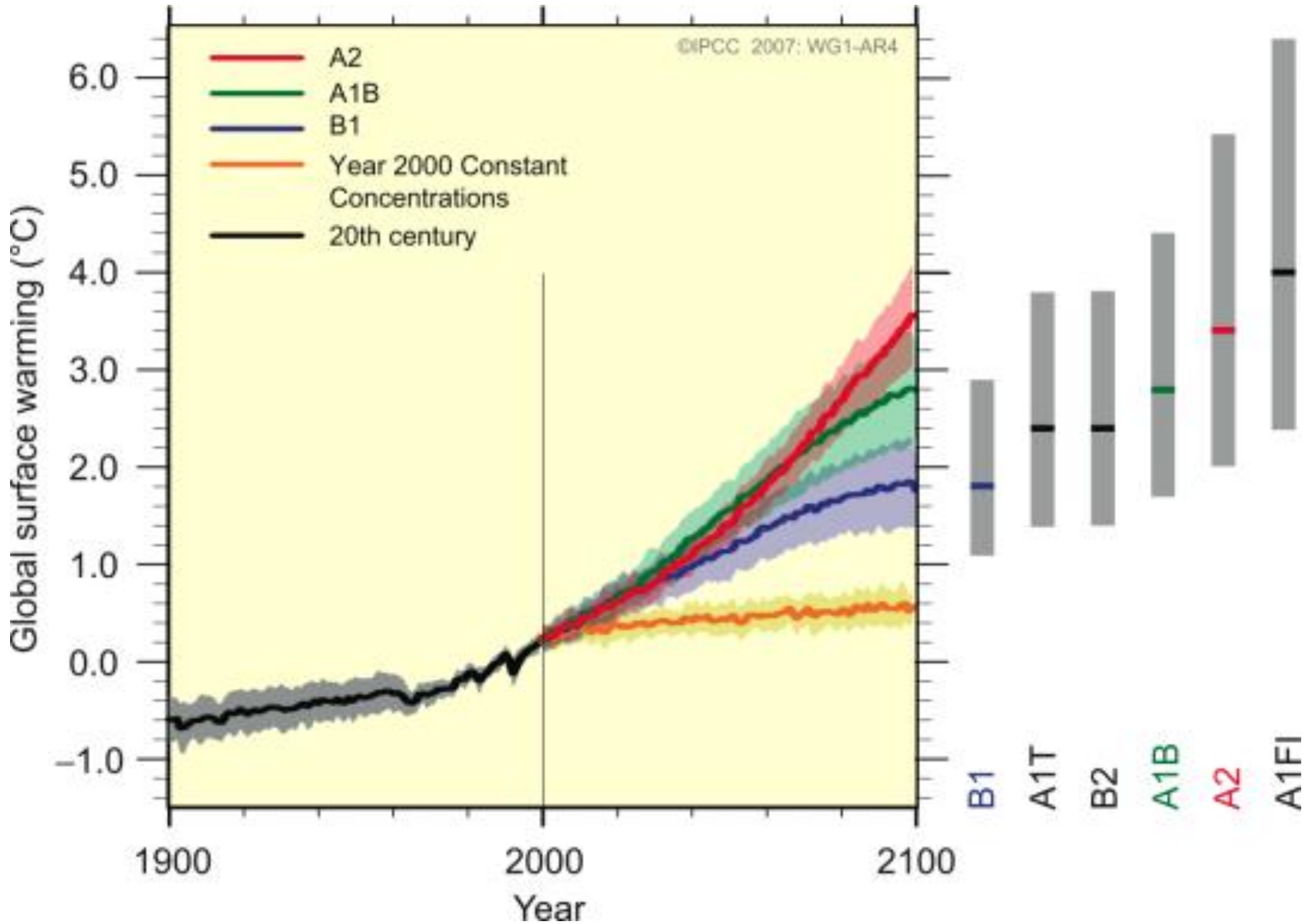


Source: IPCC AR4 SPM

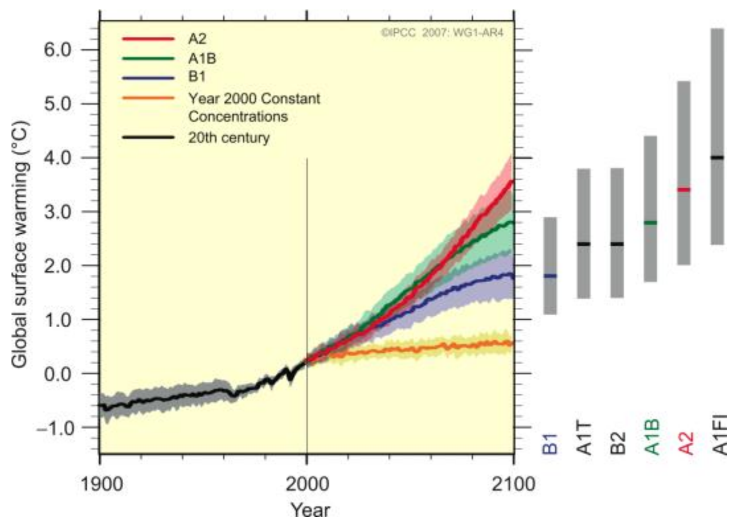
Predictions .vs. Projections



External Influence Uncertainty and Ensembles

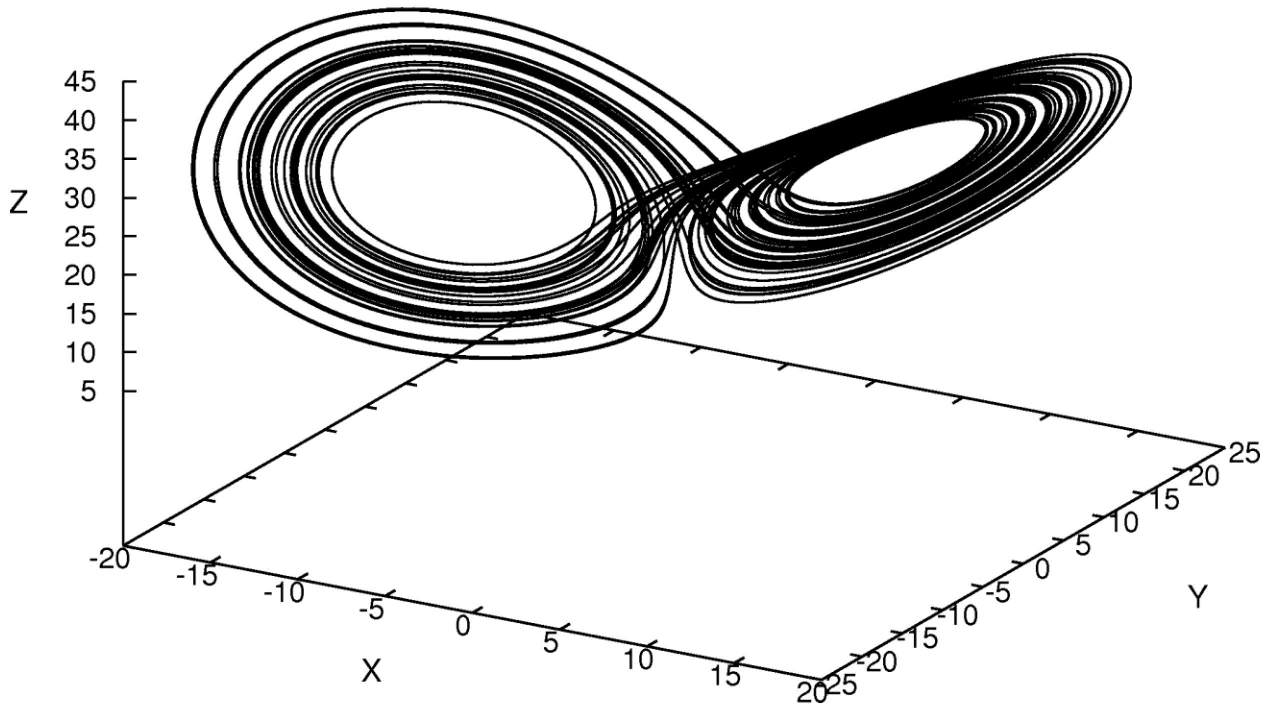
- “Ensembles” exploring the model consequences of emission or concentration scenarios

- CMIP5: Move to Representative Concentration Pathways (RCPs) This helps avoid ensembles/simulations exploring very similar concentration pathways which might result from quite different socio-economic scenarios,.



Sources of Uncertainty

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



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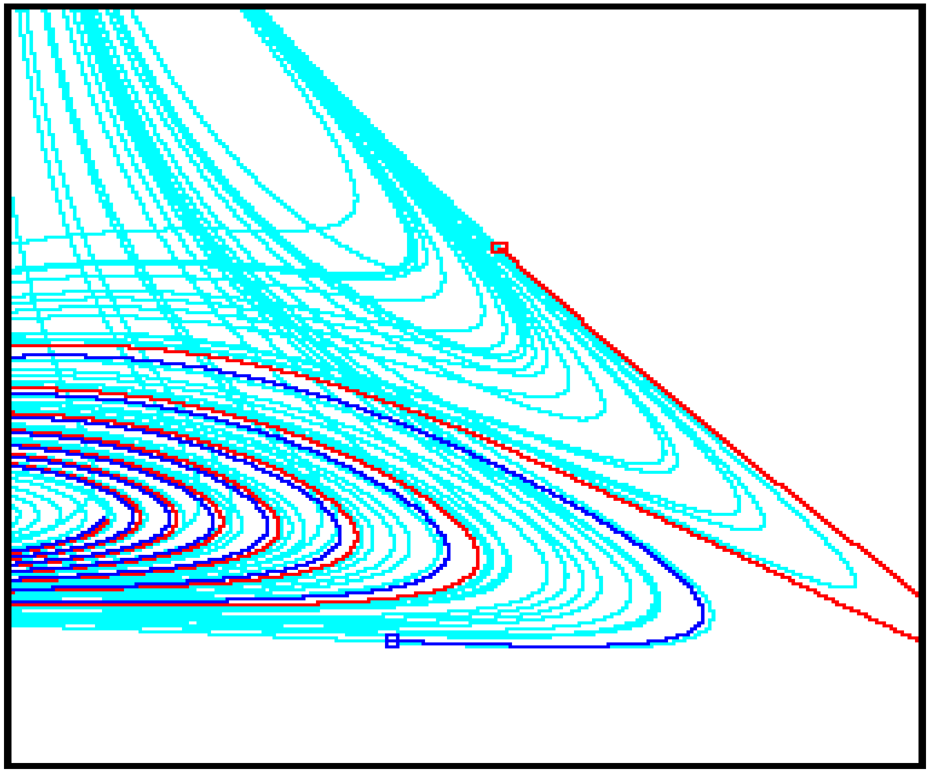

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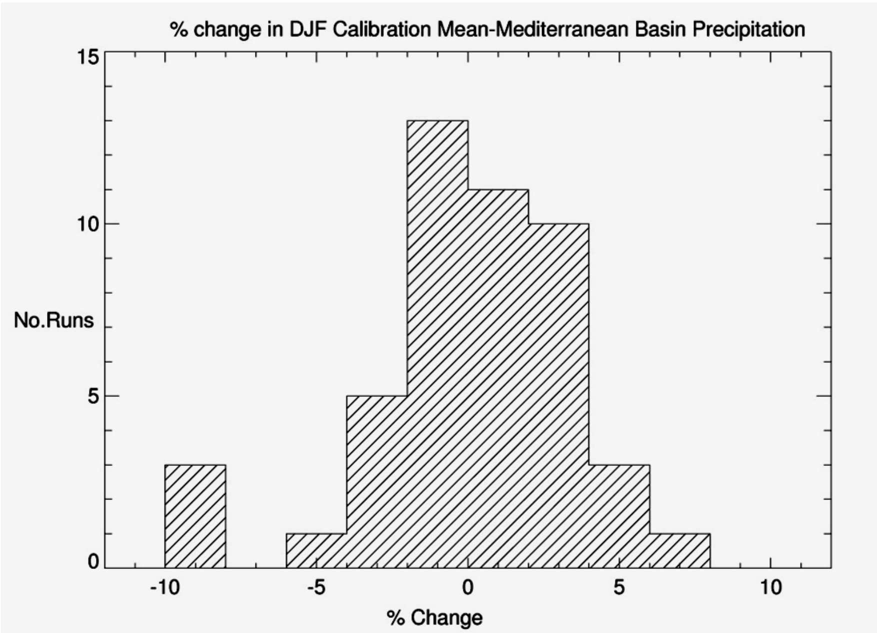
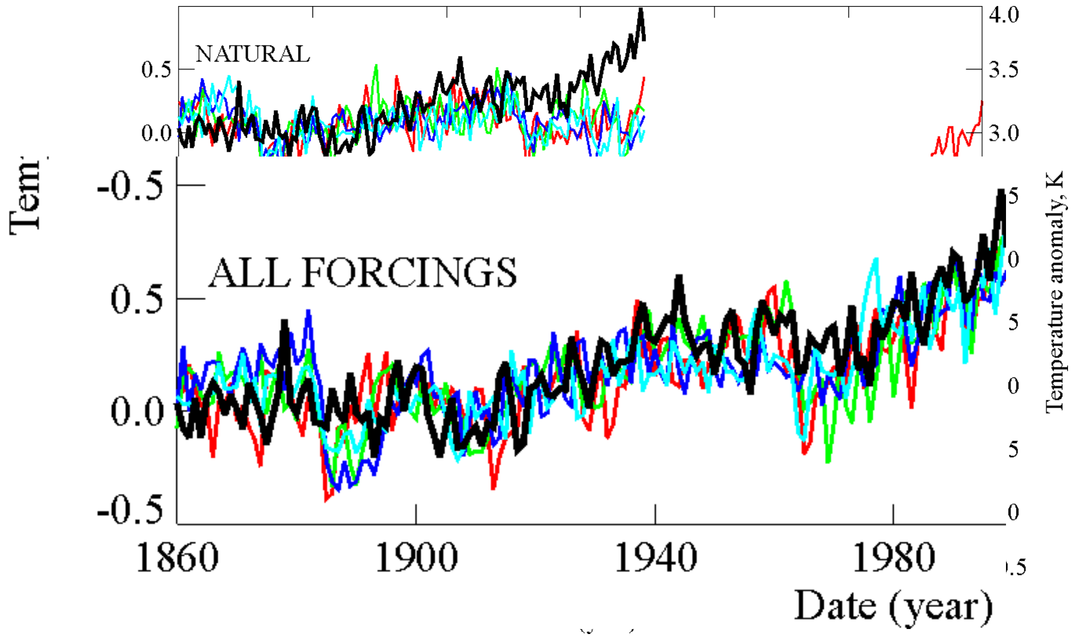


Source: Large (50 member) IC ensemble from climateprediction.net.

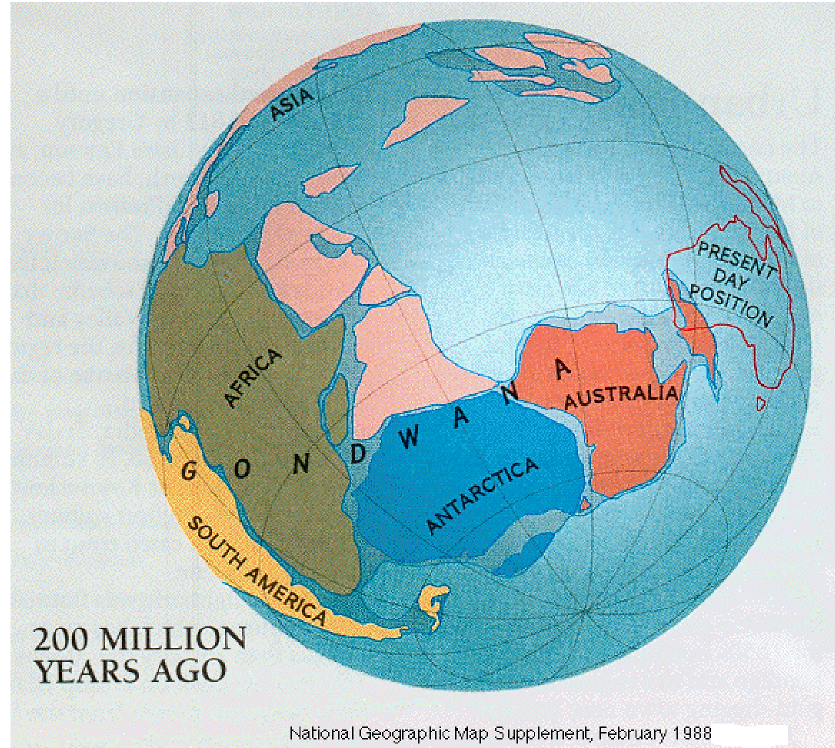


Source: IPCC, TAR

Sources of Uncertainty

and How to Include Them In a Climate Forecast

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



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

Sources of Uncertainty

and How to Include Them In a Climate Forecast

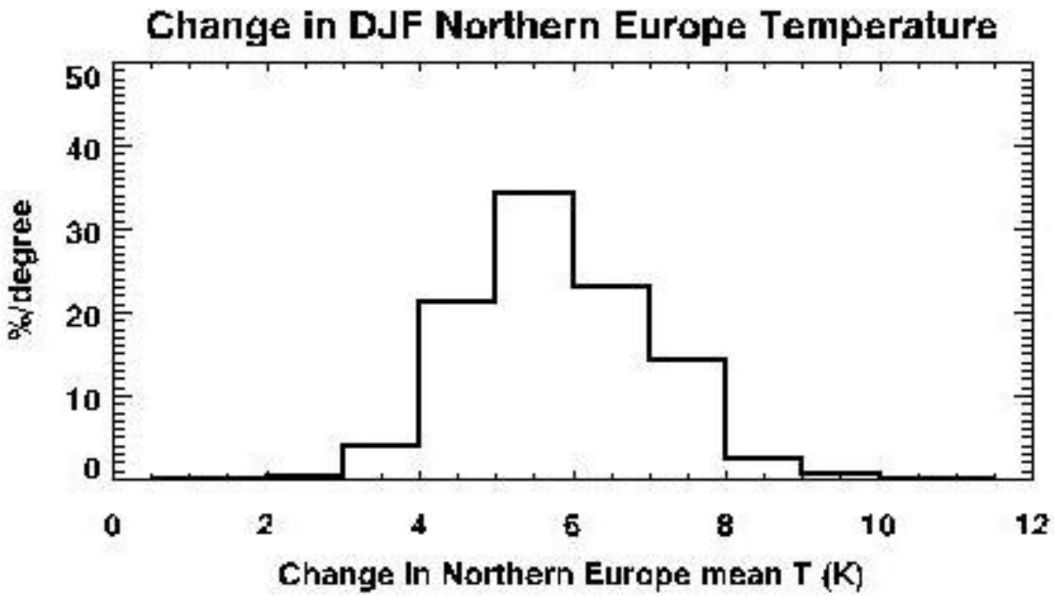
- Model Inadequacy
  All models are unrealistic representations of many relevant aspects of the real world system.
- Response: A context for all climate forecasts.

  - *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

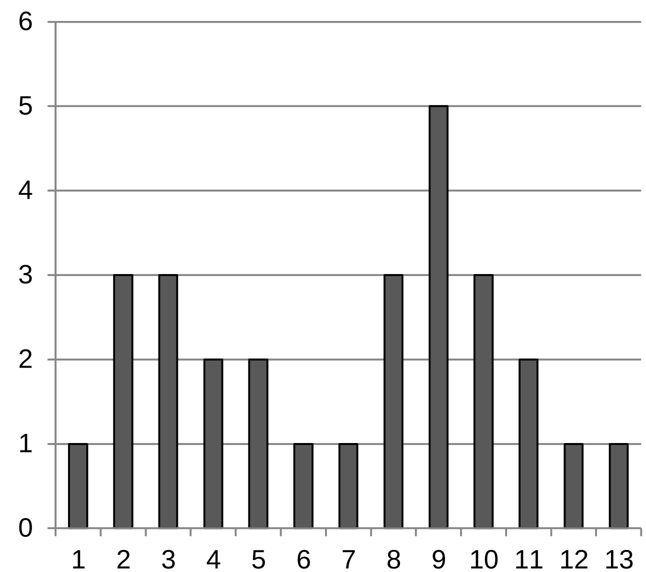
Relating Models and Reality

- The Galton board, quincunx, bean machine
- Developed by Sir Francis Galton to demonstrate the central limit theorem.

The Computer Model

- www.confidenceinclimate.net/games/galton.html

Does our model match reality?



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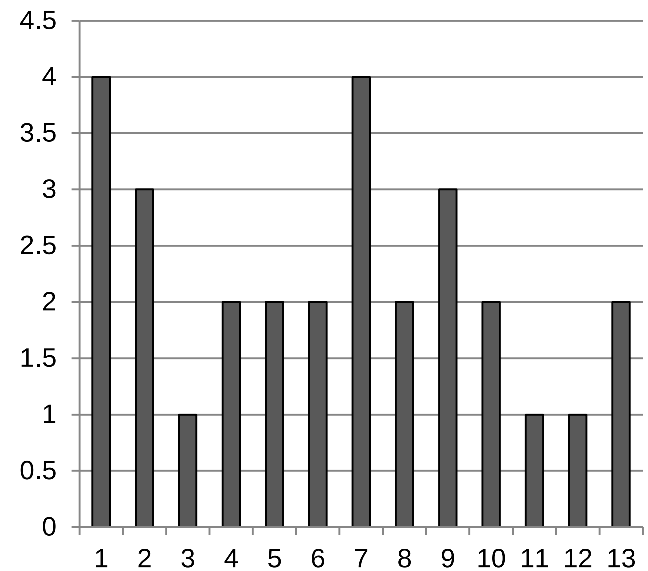

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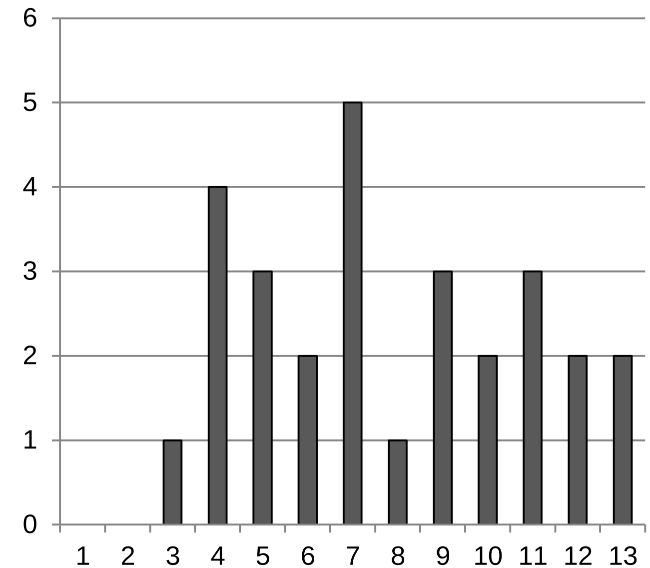
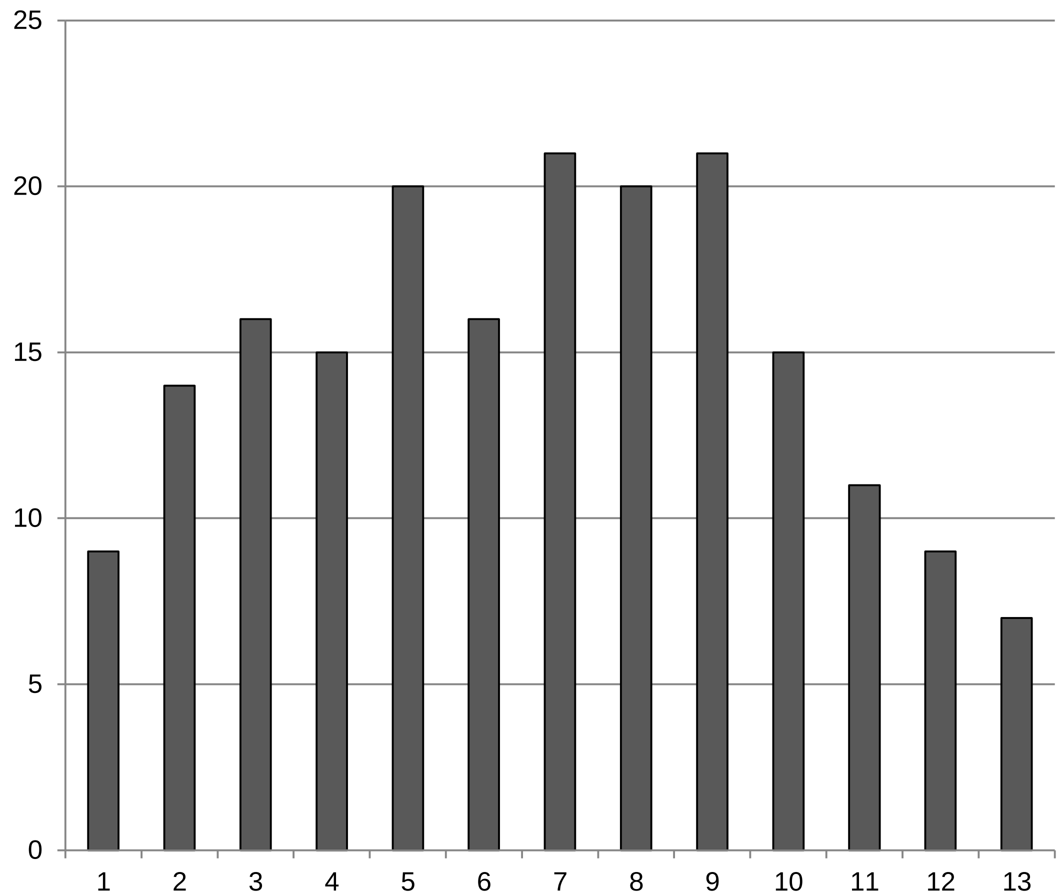




N=194

Enough of analogies – how should we do it in climate models?

Multi-Model Ensembles

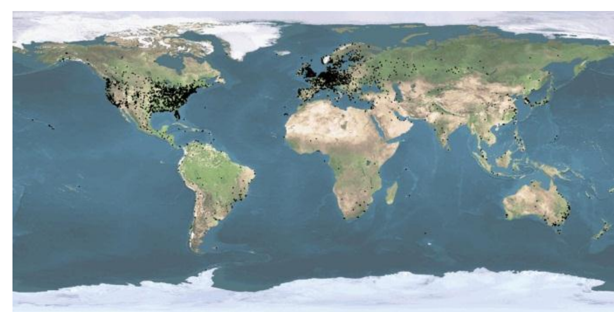
- Model Intercomparison Projects
- Coupled Model Intercomparison Project (CMIP5, CMIP3 …)
- Atmospheric Model Intercomparison Project (AMIP)
- Cloud Feedback Model Intercomparison Project (CFMIP)
- Dynamical Core Model Intercomparison Project (DCMIP)
- Paleoclimate Model Intercomparison Project (PMIPs)

Perturbed-Physics Ensembles (PPEs)

- Create many models by changing the value of uncertain “physical” parameters within the models

Perturbed Physics Experiments

• Climate*prediction*.net	100,000s
• QUMP (Quantifying Uncertainty in Model Predictions) UK Hadley Centre; underpinning work for UK Climate Projections 2009.	A few hundred
• NCAR (National Centre for Atmospheric Research – Colorado)	10s to 100s
• German ensemble	10s
• Japanese ensemble	

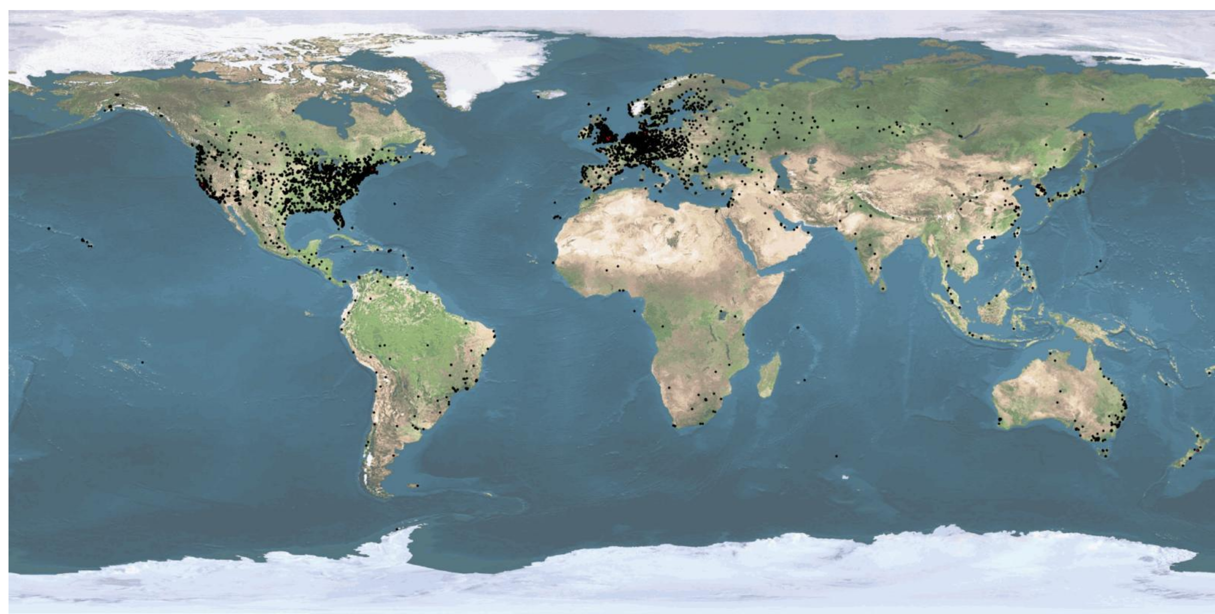


Public Resource Distributed Computing Projects (PRDC – aka Volunteer Computing) Climate*prediction*.net

GIMPS	SETI@home	Folding@home
LHC@home	Einstein@home	Lifemapper
Find-a-drug	FightAIDS@home	Evolution@home
Eon	Compute Against Cancer	Drug Design Online
Muon1	Seventeen of Bust	

Climate*prediction*.net Statistics

- \> 300,000 participants over last 10 years
- \> 130M years simulated.
- \>> 600,000 completed simulations. (Each 45 years of model time or more)
- \>30000 active hosts



climate*prediction*.net

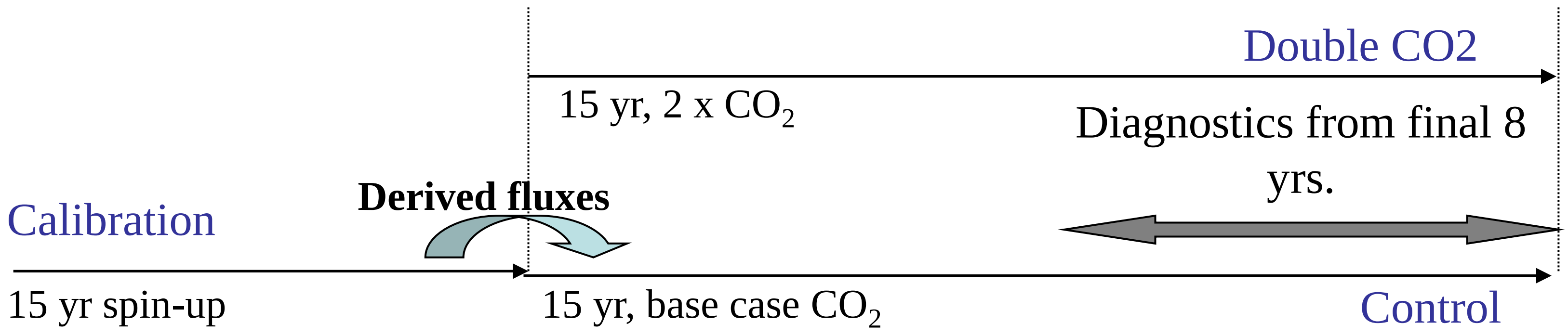
Climateprediction.net History

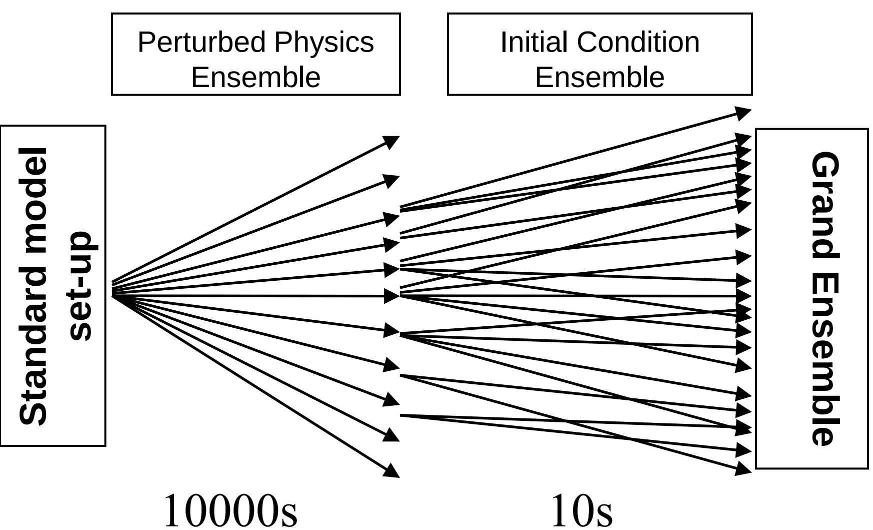
- Conceived in 1998 by Myles Allen
- Development began in earnest in 2000 when I joined Myles to make it happen.
- Launched in 2003
- First results published in 2005.
- Includes a wide variety of experiments.
  I’m using results from the first experiment which has by far the largest exploration of parameter uncertainty of any climateprediction.net or other ensemble.

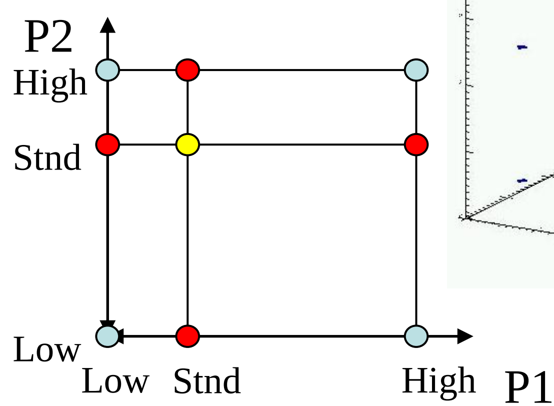
- Early funding saw it only as a communication exercise!

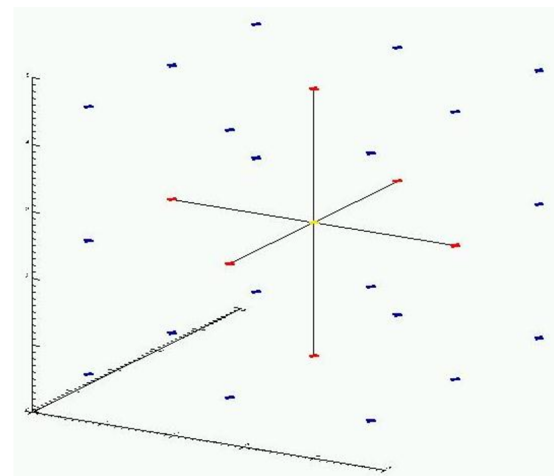
Climate*prediction*.net: The Slab Model Experiment

- Unified Model with thermodynamic ocean. (HadSM3)



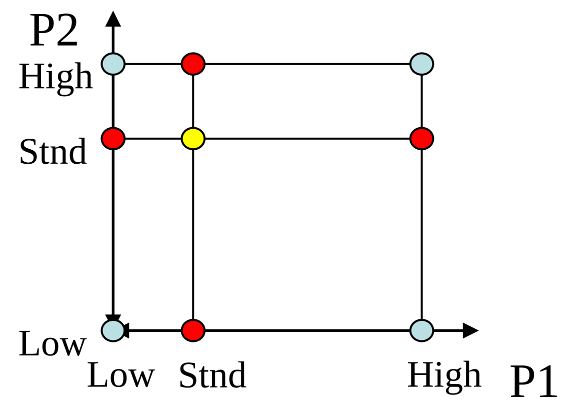






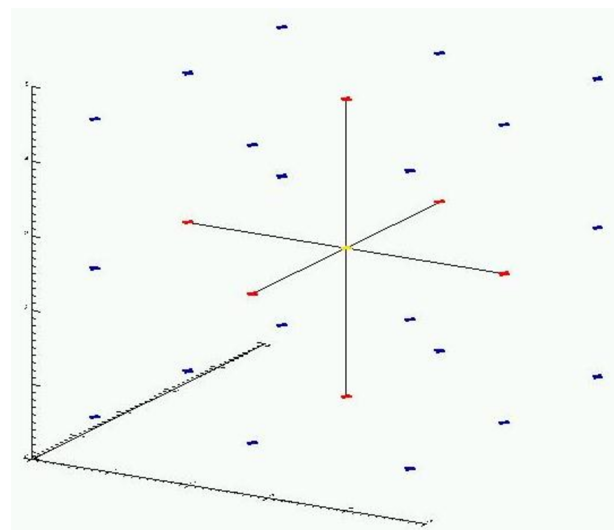
The need for large ensembles

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



Required number of simulations:

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}

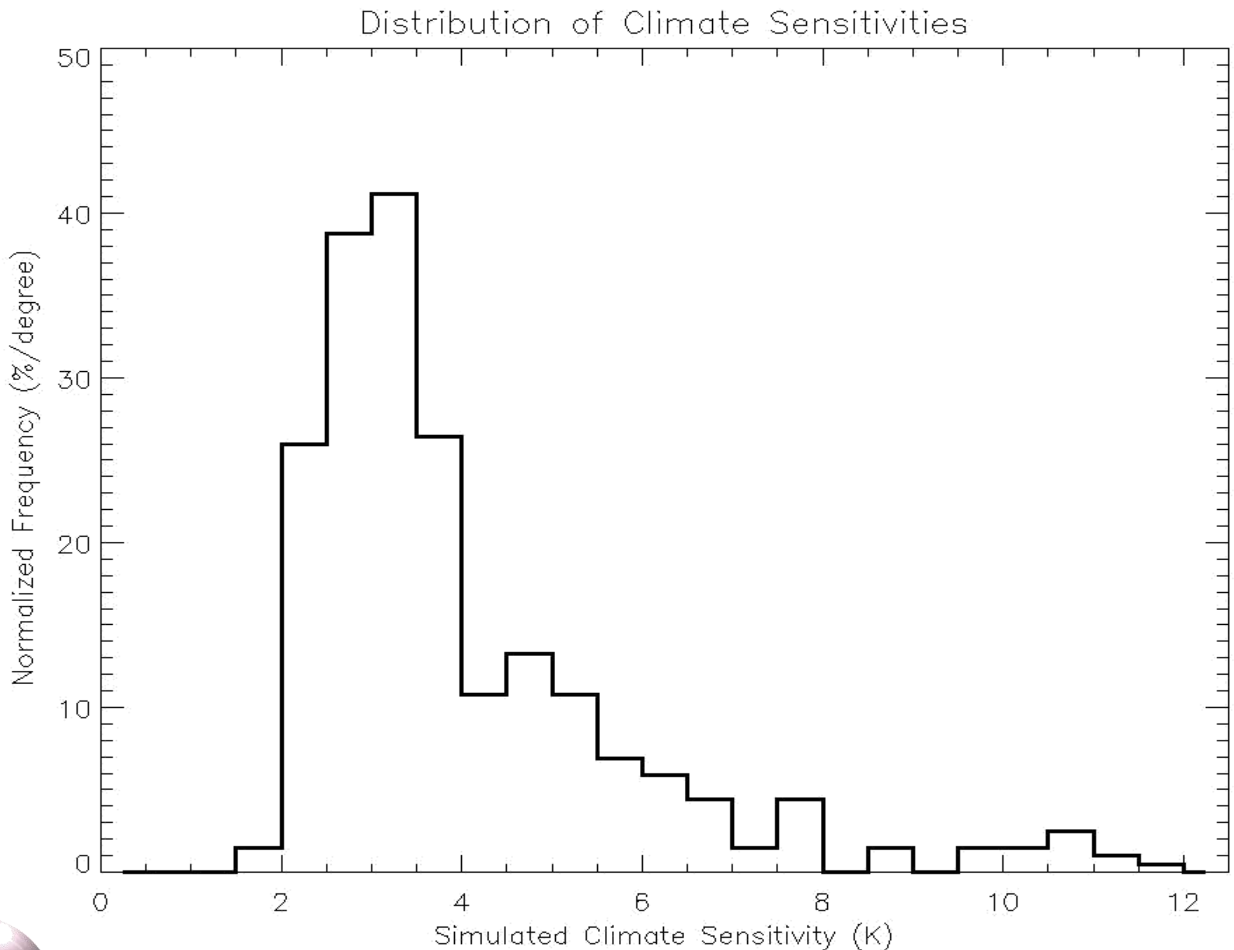


Perturbed Physics Ensembles

- How should we design them?
- How should we interpret them?

First Results: *Grand Ensemble Frequency Distribution of Climate Sensitivity*

Climate sensitivity is defined as the equilibrium global mean surface temperature change for a doubling of CO_2 levels.



climateprediction.net

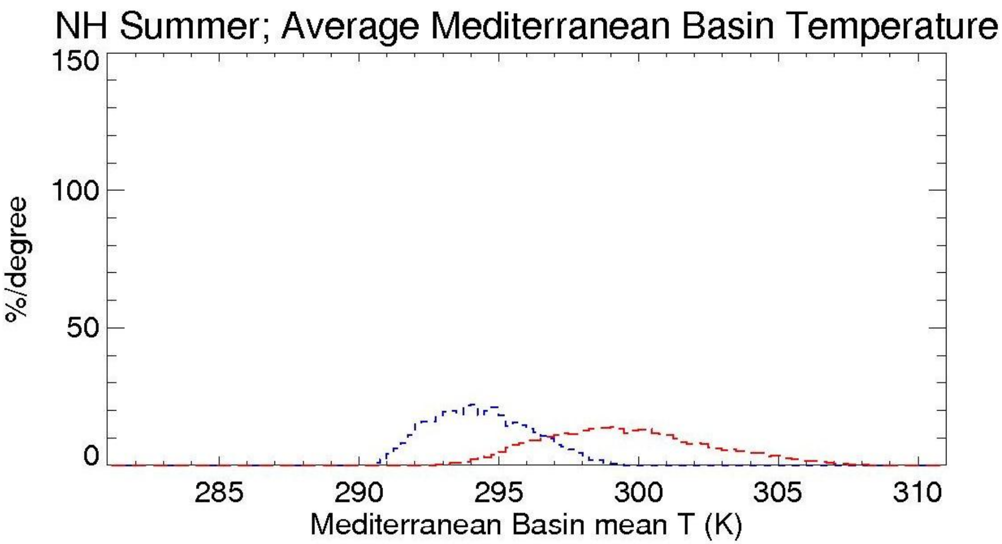
From Stainforth et al. 2005

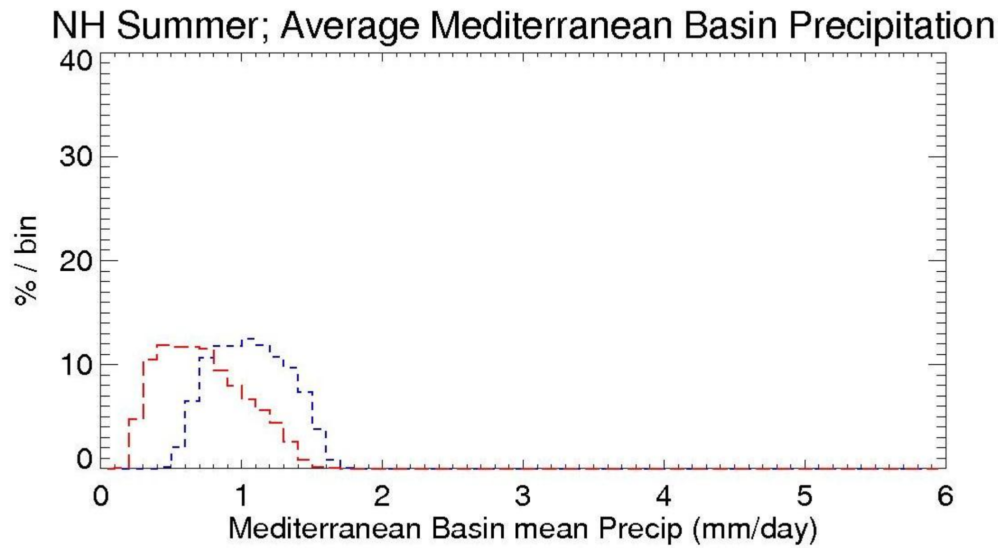
What do we take from this?

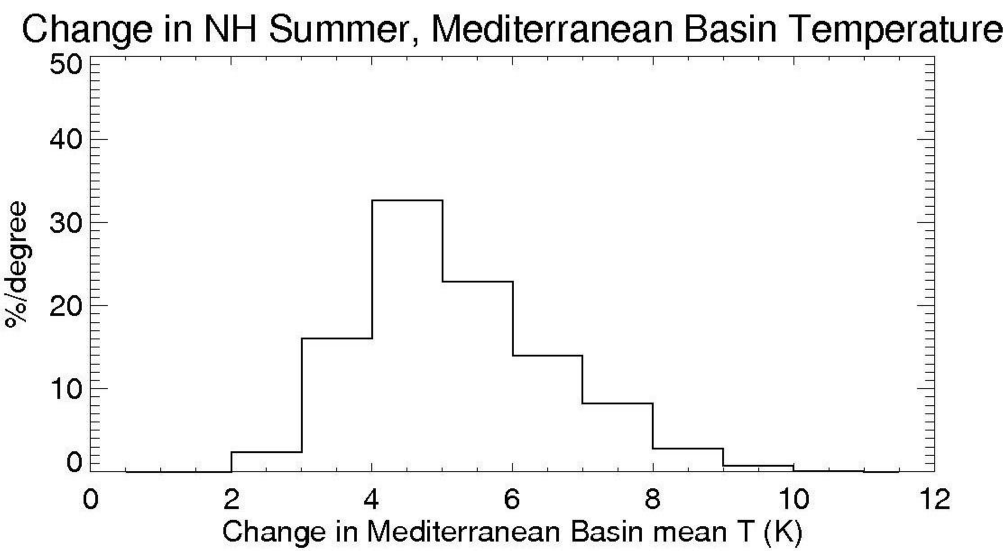
- Nothing to do with probabilities of real world behaviour
- Perhaps:
  - A non-discountable envelope
  - A domain of possibility
  - A lower pound on the maximum range of uncertainty.

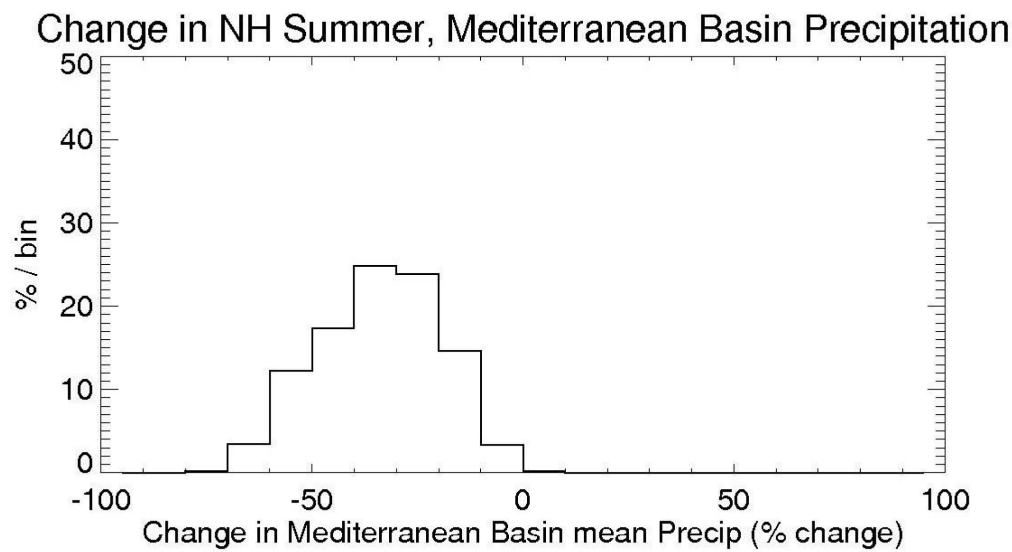
- The first big problem: Independence
  - These model versions are not independent samples of possible model versions.
  - Neither are multi-model ensembles. **Why?**
  - Weighting can't remove this problem.

Many Models Many Possibilities

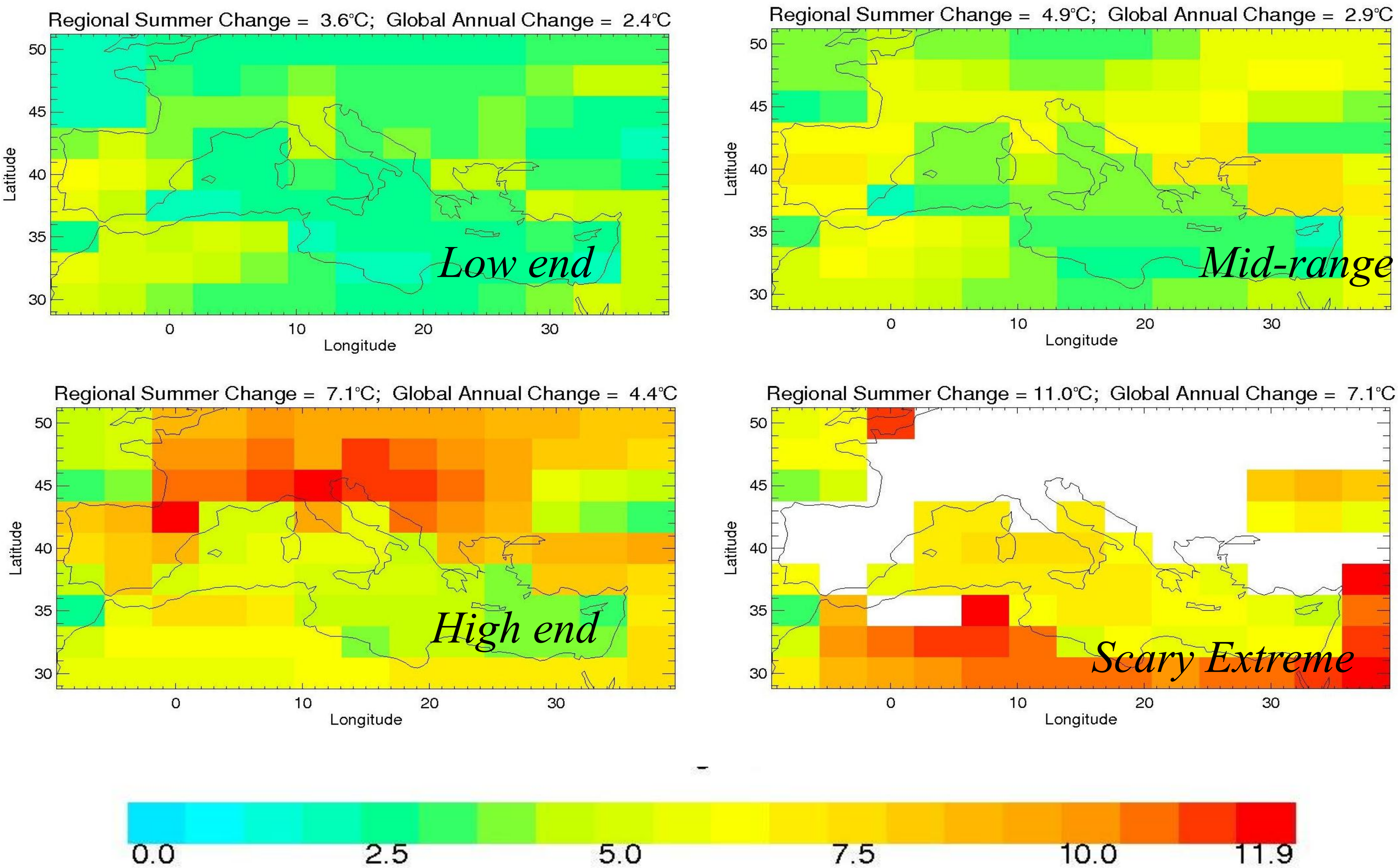








Many Models, Many Possibilities



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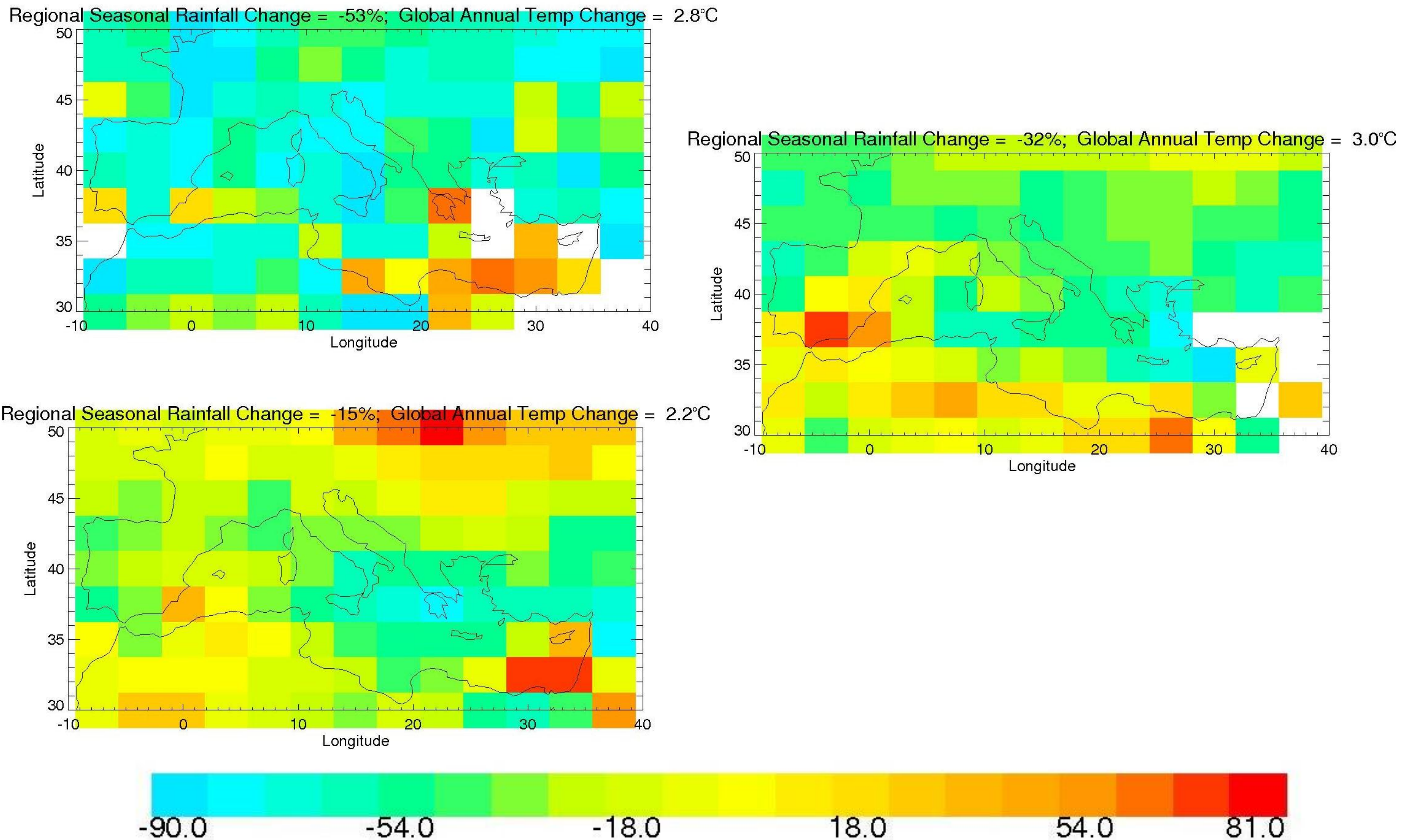
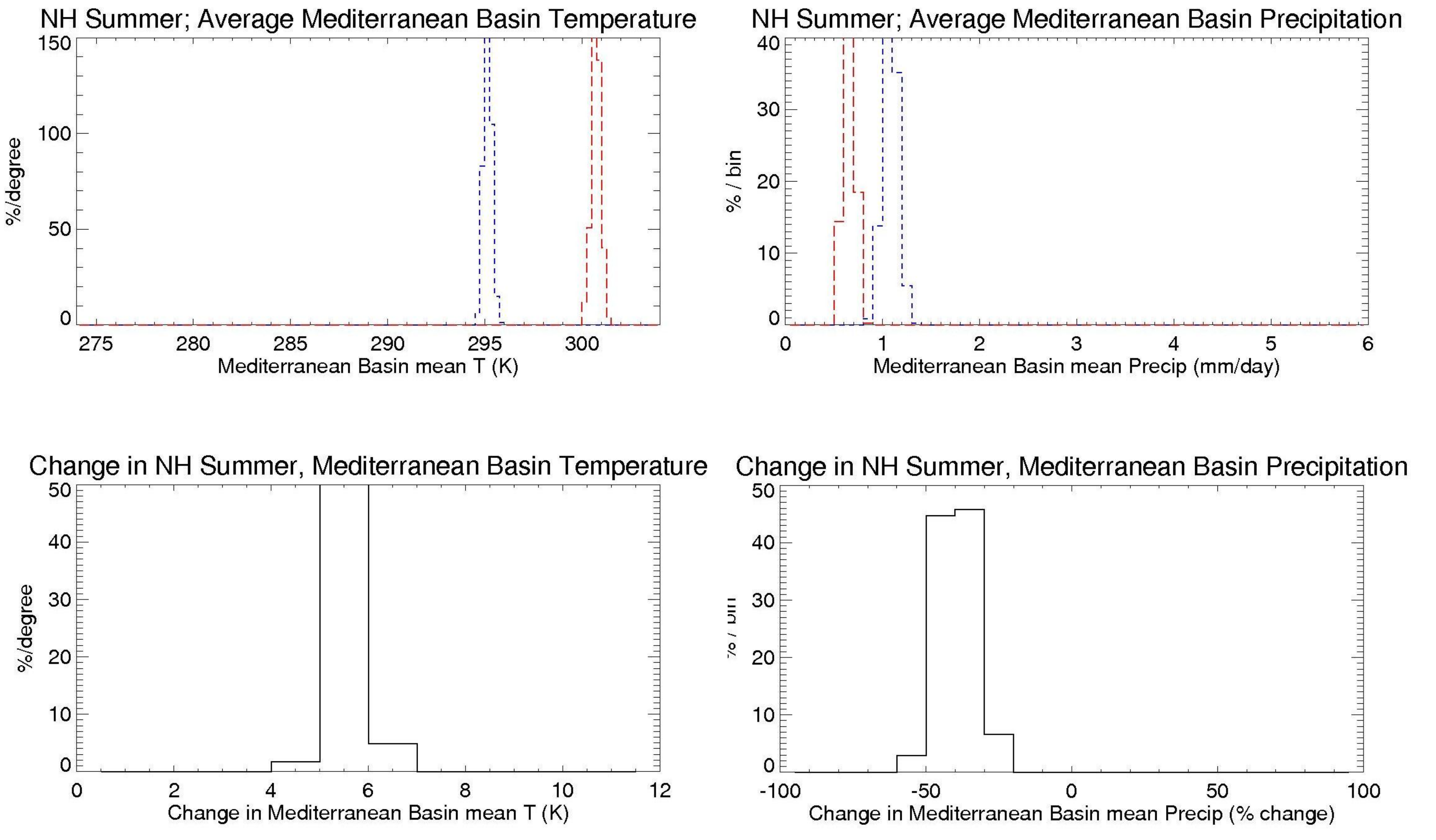


One Model Many Possibilities



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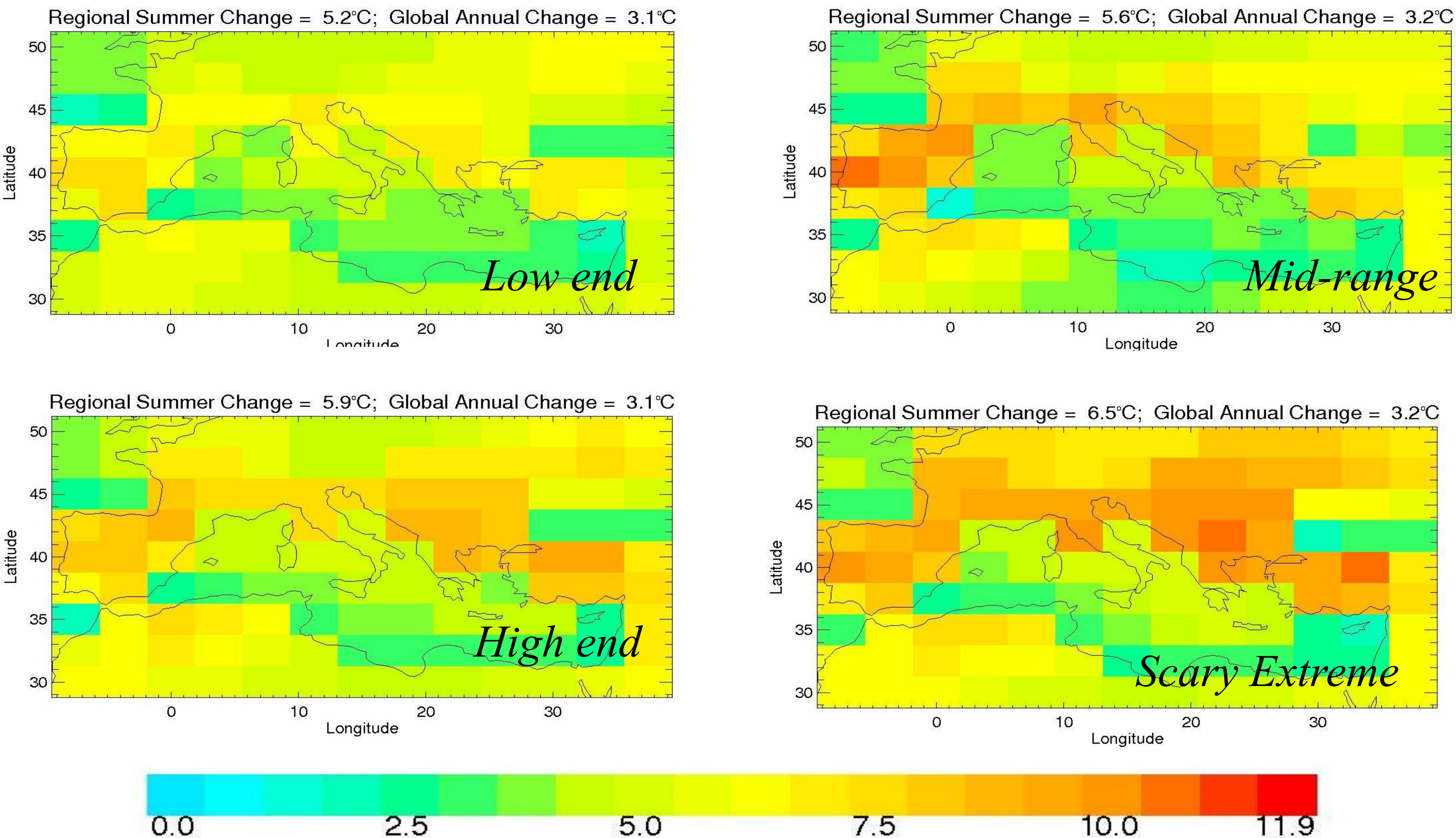

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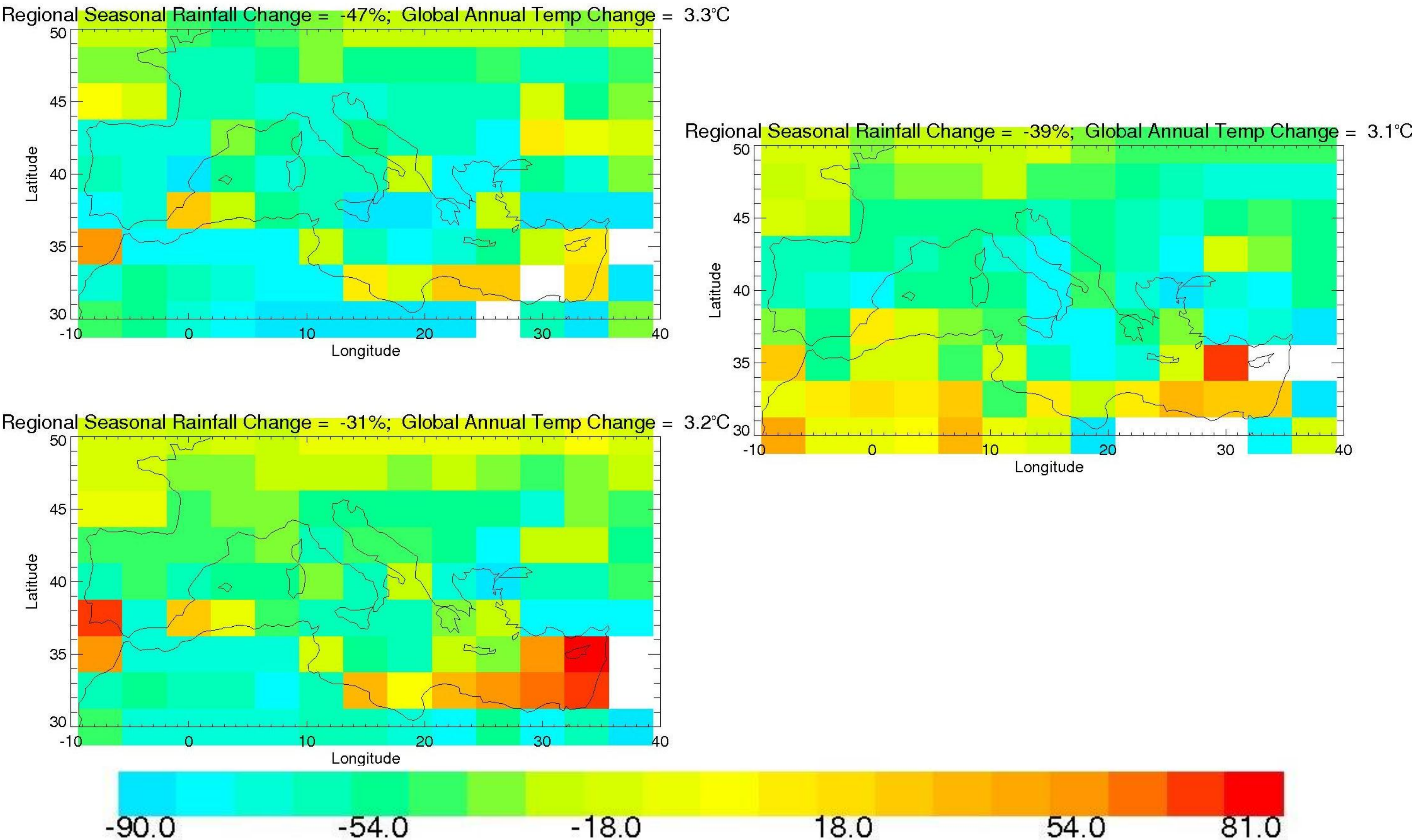


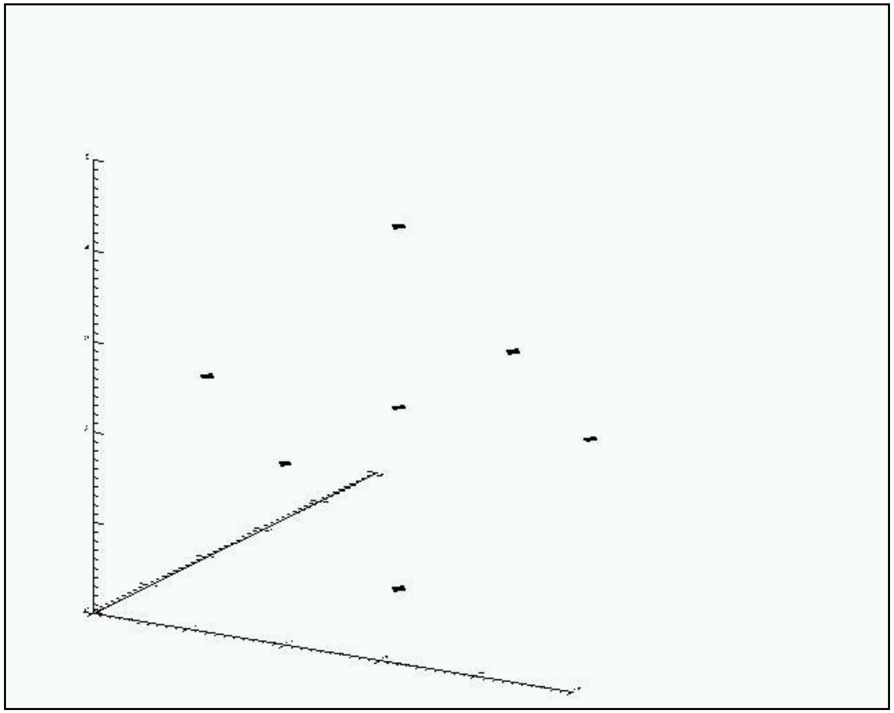
Alternative Approaches to Model Interpretation

Assume diversity of behaviour across parameter space relates to probabilities of the real world response

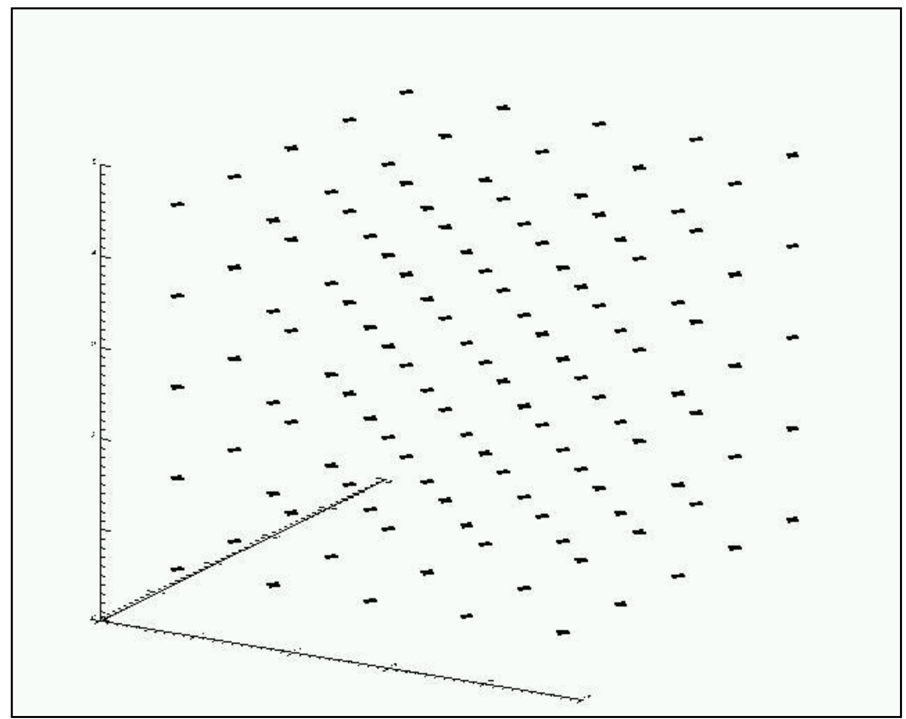
UK Climate Projections 2009 (UKCP09)

A Very Basic Summary of my understanding of the UKCP09 Process

- sample parameters,
- run ensemble,
- “emulate” to span parameter space
- weight by fit to observations

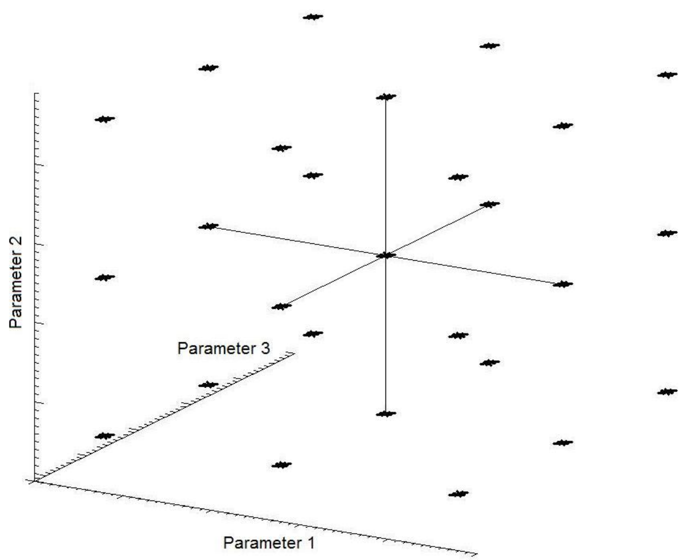


Emulate

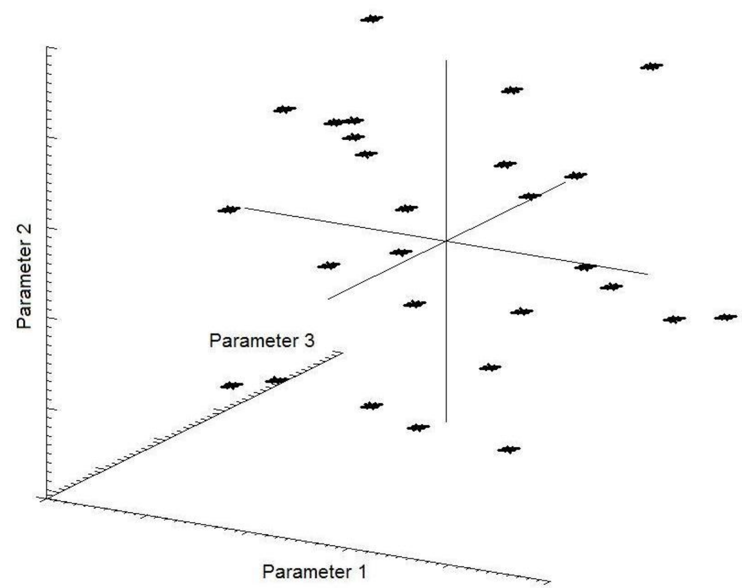


Choices in exploring parameter space

Factorial Sampling



Latin Hypercube Sampling



Extreme response sampling?; Emulator guided sampling?

- If you want to build an emulator you want an “efficient” sampling of the parameter space.
- If you want to generate a diversity of response you want something different.
- If you want to be able to separate the influence of individual parameters, you want a factorial sampling strategy.

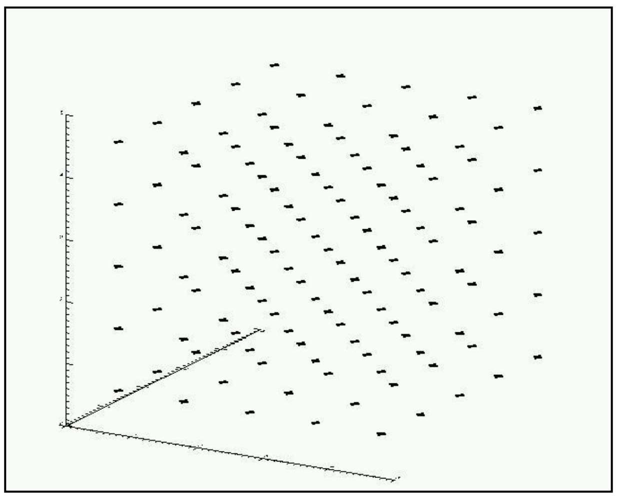
What's the meaning of a distribution in parameter space?

How do you relate a model parameter and reality?

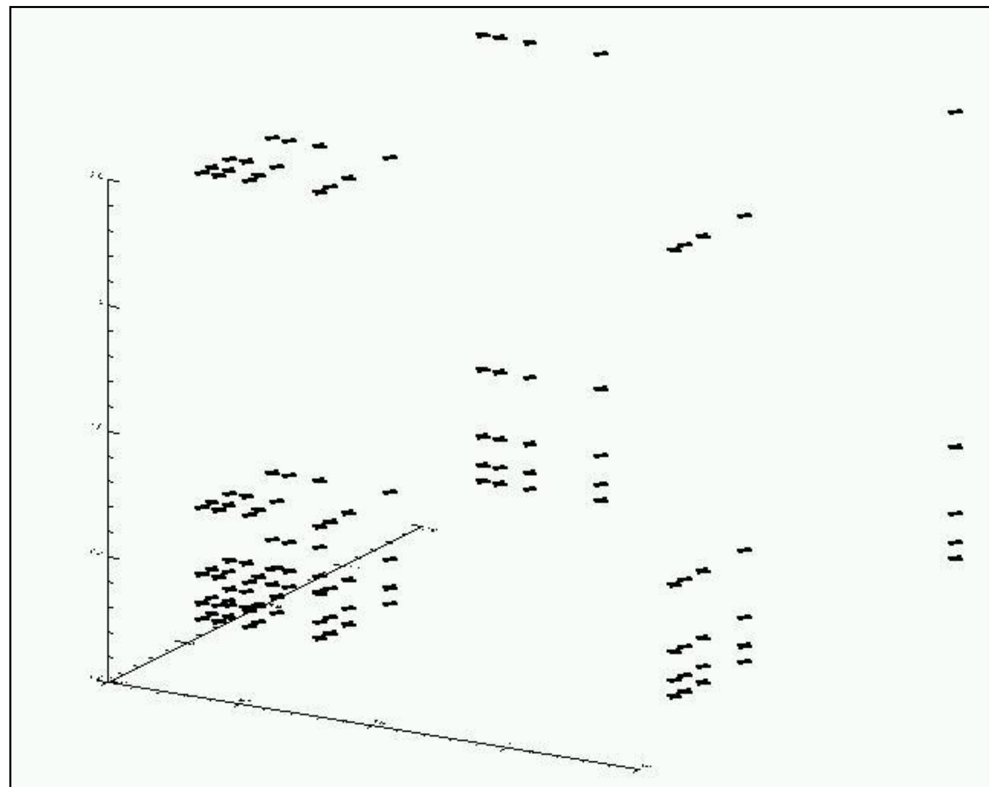
- The ice fall rate in a cloud parameterisation.
- Entrainment coefficient in the convection scheme.

Issues with an emulator/parameter space approach

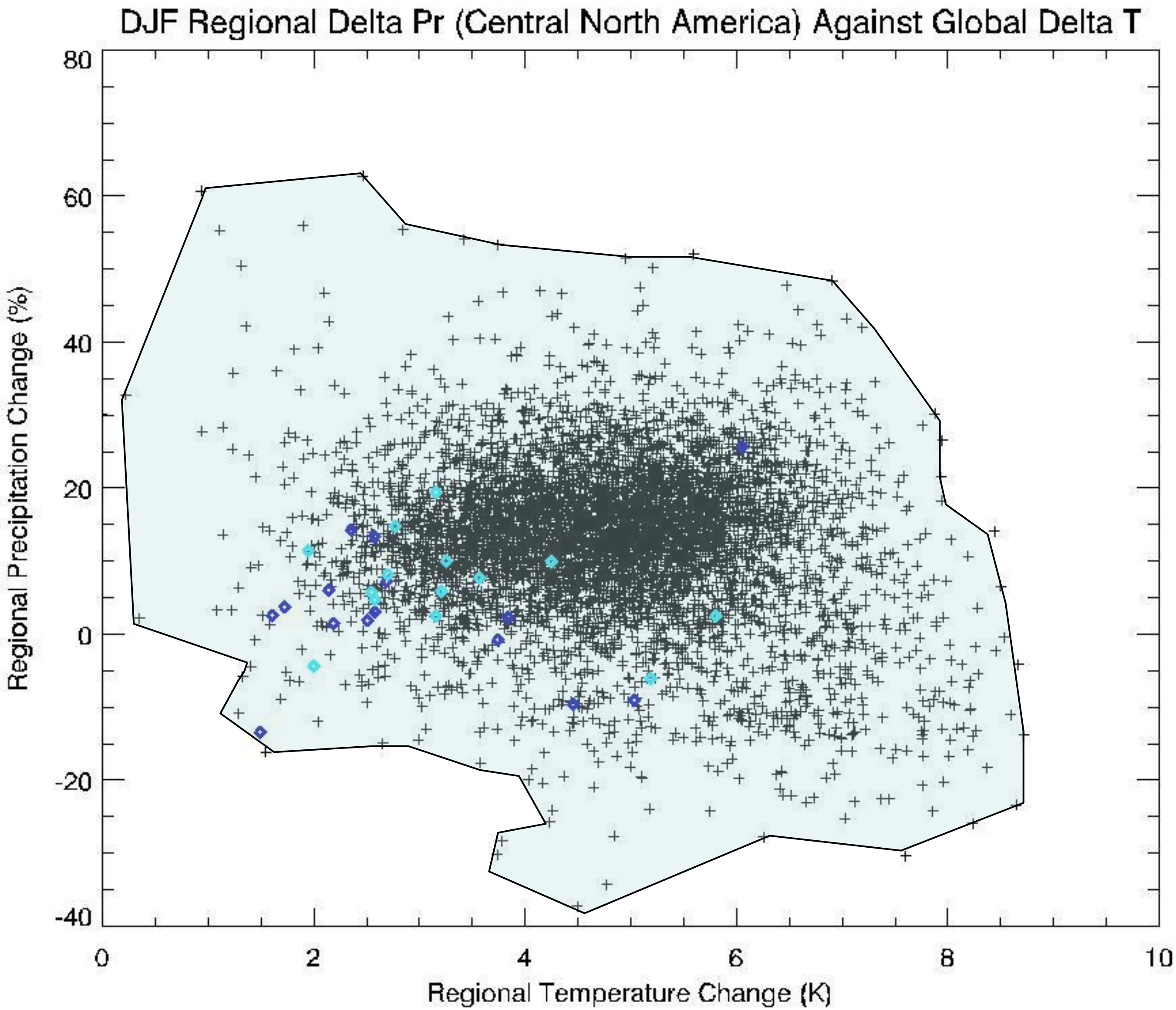
- Size of ensemble given size of parameter space.
- The ability of the emulator to capture non-linear effects.
- The justification for weighting models.
- On what scales do we believe the models have information?
- **The choice of prior i.e. how to sample parameter space**.



Choice of parameter definition

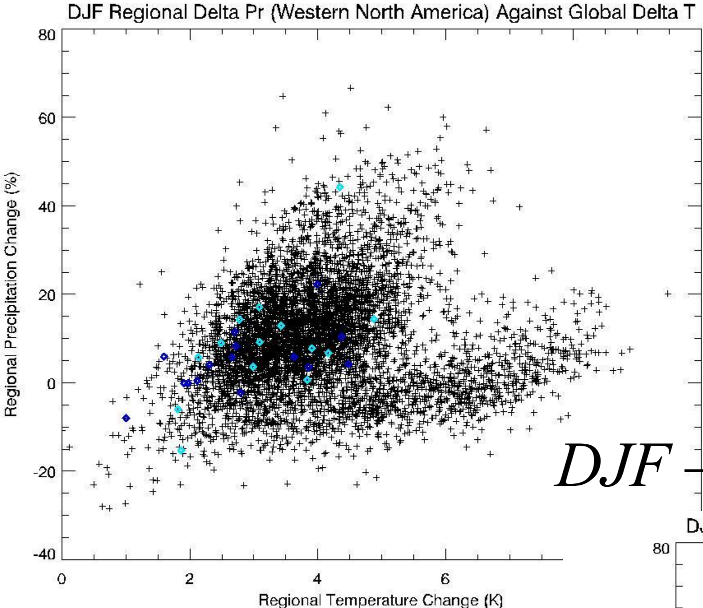


Non-discountable Envelopes

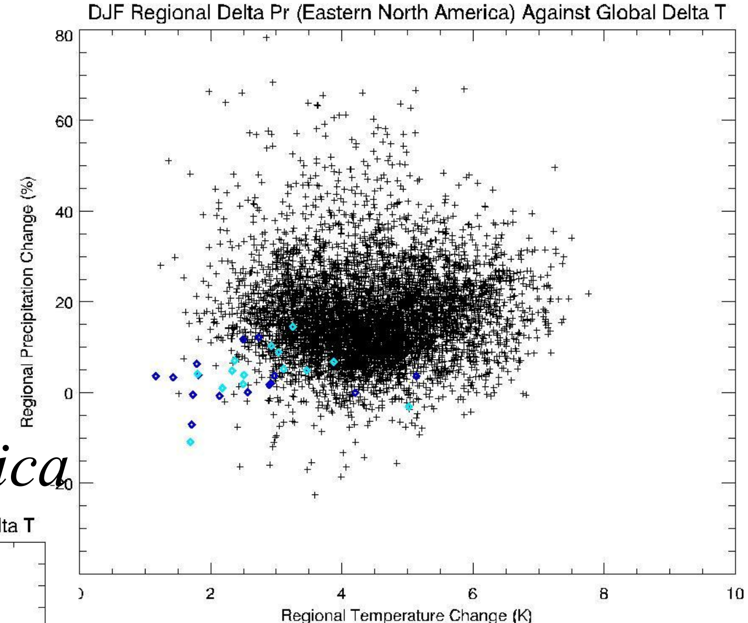


Non-discountable Envelopes

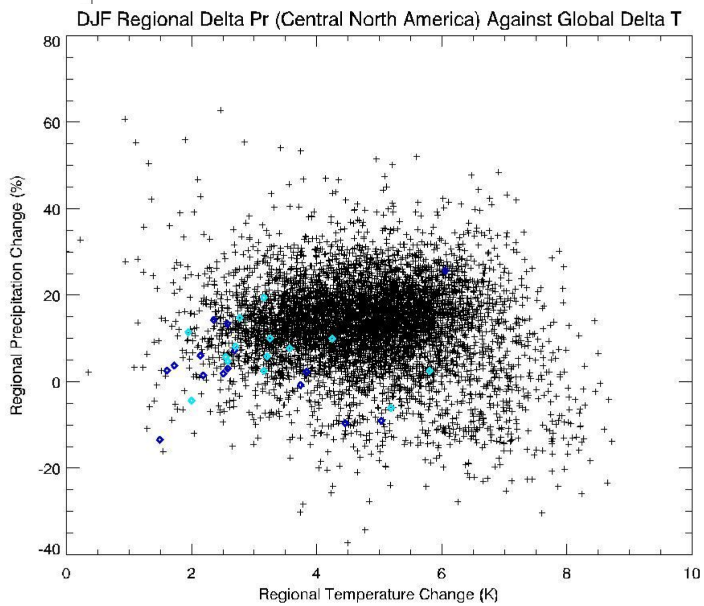
DJF – Western North America



DJF – Eastern North America



DJF – Central North America



So what should be our aim in the design of perturbed physics ensemble?

Questions?

(and answers?)

- *Stainforth DA, Allen MR, Tredger ER, Smith LA.* ***Confidence, uncertainty and decision-support relevance in climate predictions.*** *Philos Trans R Soc A-Math Phys Eng Sci. 2007 Aug;365(1857):2145-61.*
- *Stainforth DA, Downing TE, Washington R, Lopez A, New M.* ***Issues in the interpretation of climate model ensembles to inform decisions.*** *Philos Trans R Soc A-Math Phys Eng Sci. 2007 Aug;365(1857):2163-77.*
- *Stainforth DA, Aina T, Christensen C, Collins M, Faull N, Frame DJ, et al.* ***Uncertainty in predictions of the climate response to rising levels of greenhouse gases****. Nature. 2005 Jan;433(7024):403-6.*
- *Frame DJ, Booth BBB, Kettleborough JA, Stainforth DA, Gregory JM, Collins M, et al.* ***Constraining climate forecasts: The role of prior assumptions****. Geophysical Research Letters. 2005;32(9).*