Ensembles, Uncertainty and Climate Projections

Chris Brierley
(Room 117)

Definitions

- **Ensemble:** group of model simulations
- **Uncertainty:** doubt and ambiguity about future conditions
- **Climate Projection:** modeled climate state under a specified scenario

Uncertainty

- We do not know **exactly** what will happen in the future.
- We do have rough idea of the chance of an event happening.
- Formalize that rough idea (quantifying the uncertainty) to produce a probability

Adaptation and Mitigation

- Two responses to climate change require different knowledge of the future.
  - Mitigation (prevention) needs an “if … then… will happen”
  - Adaptation (coping with) needs a more definite “… will happen”
- Only the first kind of forecast is routinely performed for long-time scale climate change

Adaptation: Example

- **Suppose we want to build coastal defenses for New Haven to last 100 years.**
- What information would you want?
    - What is the sea-level rise going to be at New Haven in 2100?

Coastal Defenses II

- Cost of build up to a certain height
- Possible losses if you don’t build up to a certain height
- Other solutions and their cost/loss => Risk Analysis
- What information is provided by climate scientists to help us with our decision?
- Let’s look in the IPCC’s most recent report….

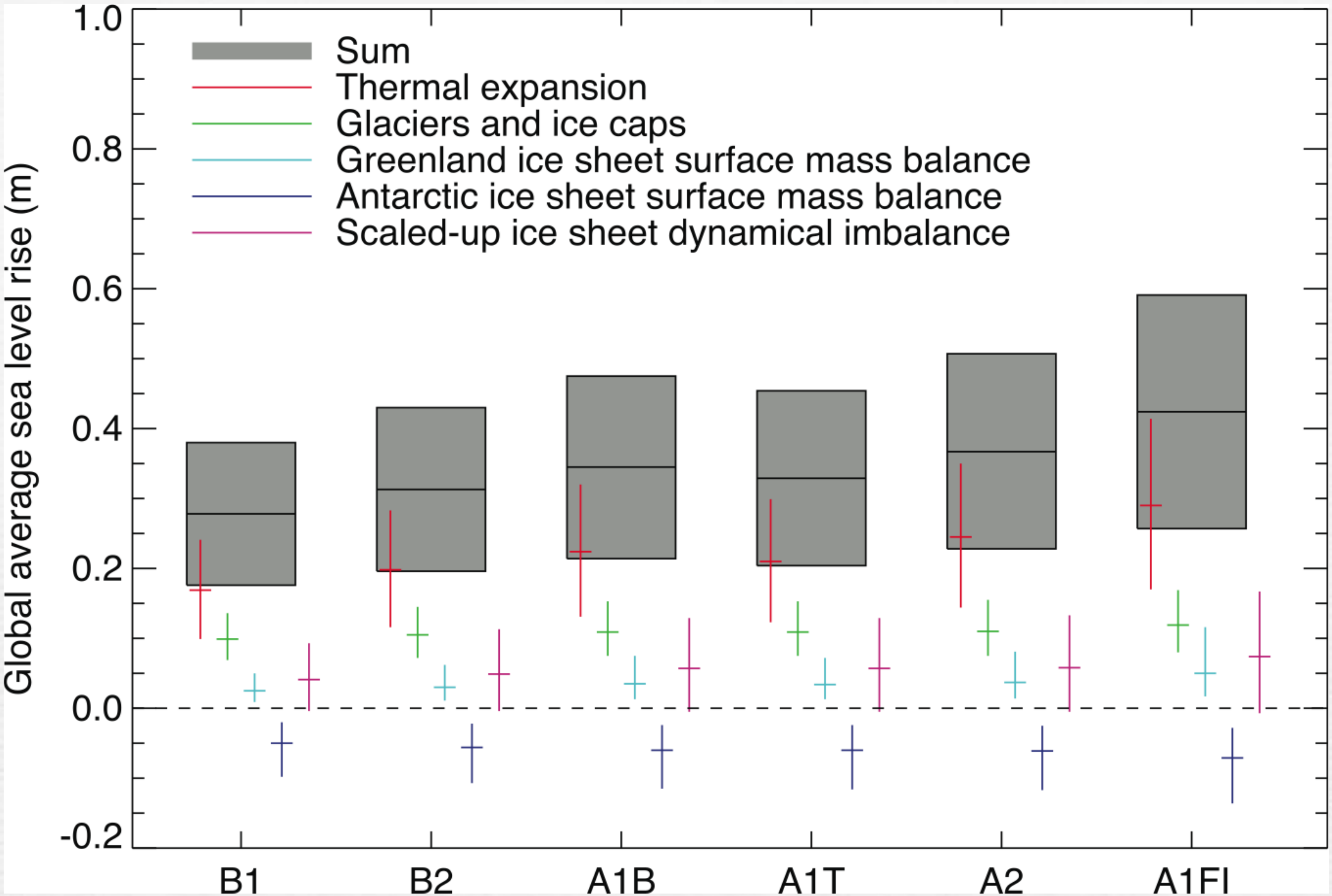
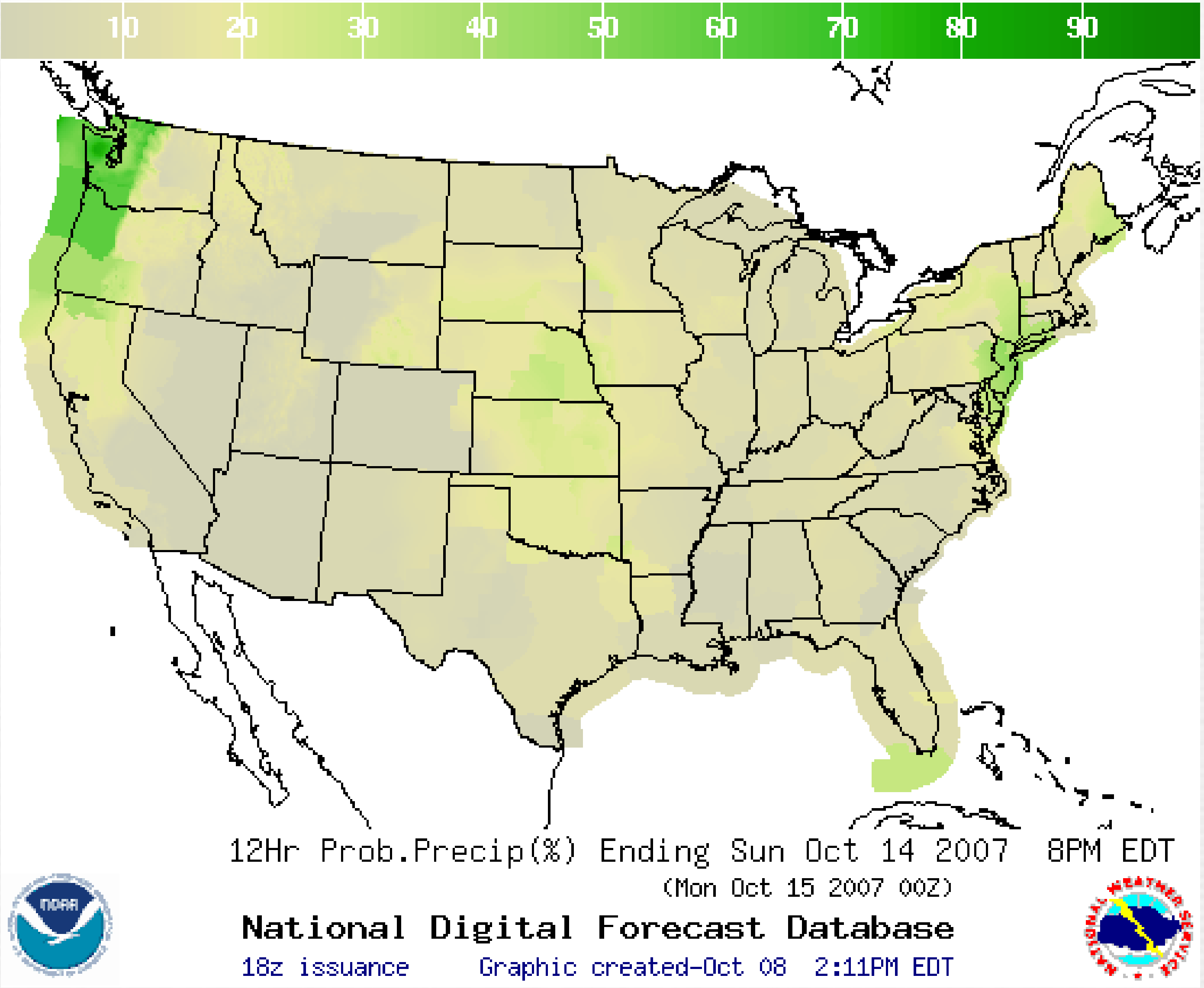


Figure 10.33. Projections and uncertainties (5 to 95% ranges) of global average sea level rise and its components in 2090 to 2099 (relative to 1980 to 1999) for the six SRES marker scenarios. The projected sea level rise assumes that the part of the present-day ice sheet mass imbalance that is due to recent ice flow acceleration will persist unchanged. It does not include the contribution shown from scaled-up ice sheet discharge, which is an alternative possibility. It is also possible that the present imbalance might be transient, in which case the projected sea level rise is reduced by 0.02 m. **It must be emphasized that we cannot assess the likelihood** of any of these three alternatives, which are presented as illustrative**. The state of**

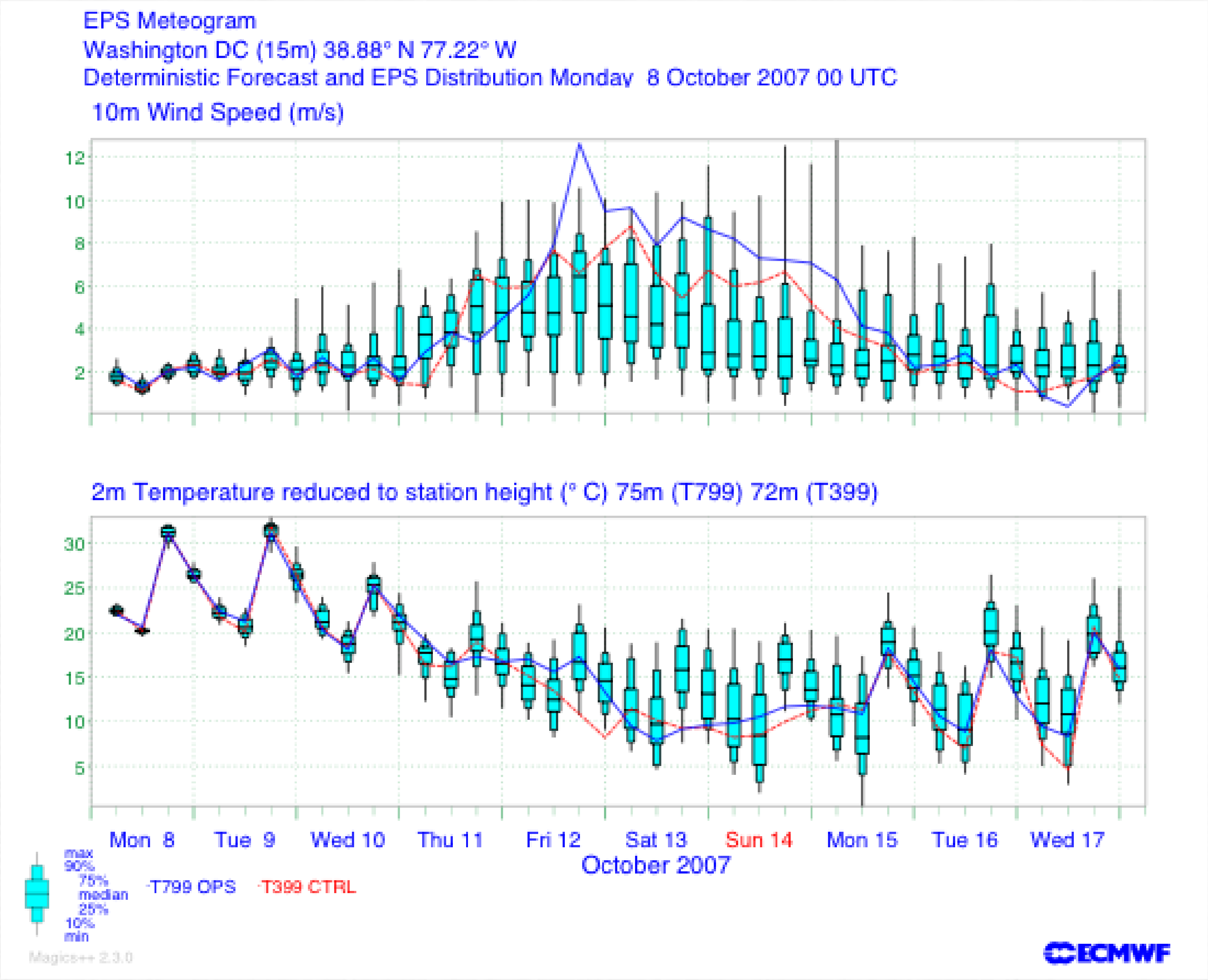
Probability

- Obviously, this information is not the most useful.
- Probabilities are essential for risk-analysis
- Probabilities are provided for weather forecasts

NOAA Probability Forecast



ECMWF Meteogram



Ensemble Weather Prediction

- Many different simulations of the same model with slightly different initial conditions
- Samples “Natural Variability”
- Can we use the same methodology to provide probability for climate predictions?

Natural Variability- The Butterfly Effect

- There is a limit to the predictability of a chaotic system.
- Arises from **uncertainty in the initial conditions** of the atmosphere.
- Other aspect of the climate system can also have uncertain initial conditions.
  - Upper ocean on seasonal timescales
  - Cryosphere (ice) and deep ocean on longer timescales

Scenarios

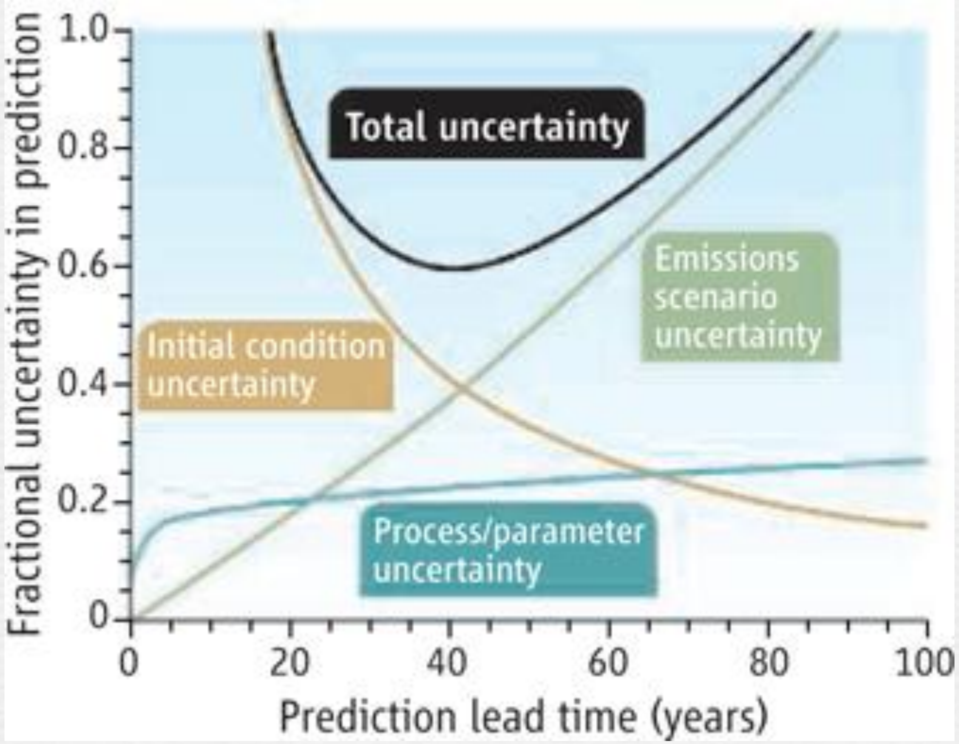
- What, if anything, will we do reduce CO_2 emissions in the future?
- Will a series of big volcanoes go off?
- Will effect the climate system, but are external to it.
- Requires expertise of vast amount of fields

Model Uncertainty

- How can we model the whole climate?
- We have to make choices:
  - What to exclude?
  - What scale do we need?
  - How do we include important things that happen below that scale?

3 Uncertainties = 1 Big Problem

- What is relative importance of these factors?
- No-one really knows, but all agree scenario uncertainty dominates at about 50 years



Cox and Stephenson (2007)

How do we cope with this?

- Two approaches:
    - Reduce the uncertainties to make more accurate
    - Accept the uncertainty and produce probabilistic forecast
- We need to do both, but the latter has been mainly ignored.

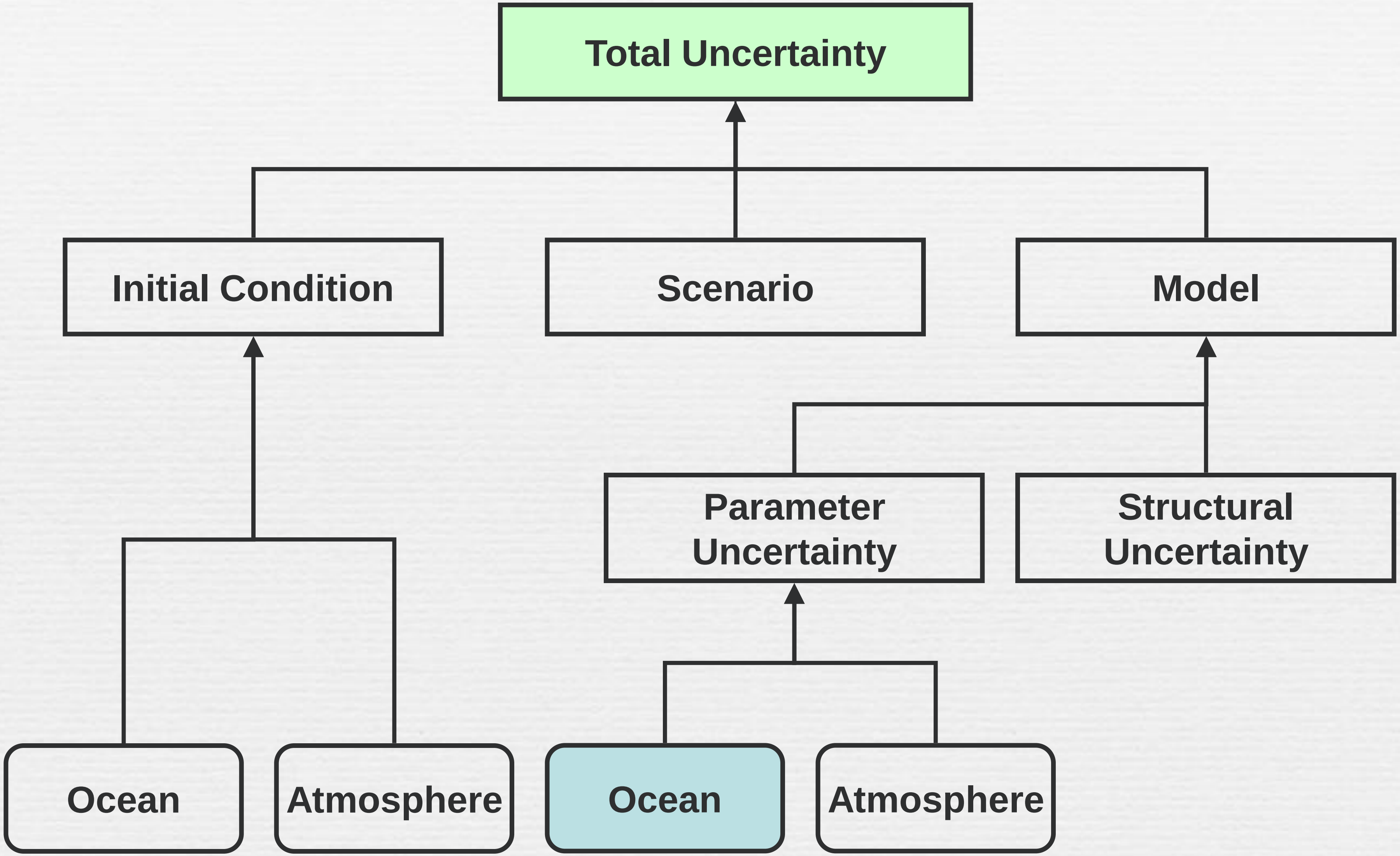
Doing a probabilistic climate forecast

- Need to sample all 3 uncertainties in a systematic manner
- Probability In -> Probability Out
    - Compare initial conditions to observations
    - Question politicians and economist for scenario probabilities
    - How do we even sample model uncertainty?

Model Uncertainty II

- **Structural -** Resolution, Numerical choices, Dynamic vegetation, Interactive sulfur cycle?
- **Parameter -** Values of constants in parameterization not well constrained by observations

The Uncertaintree



My Work

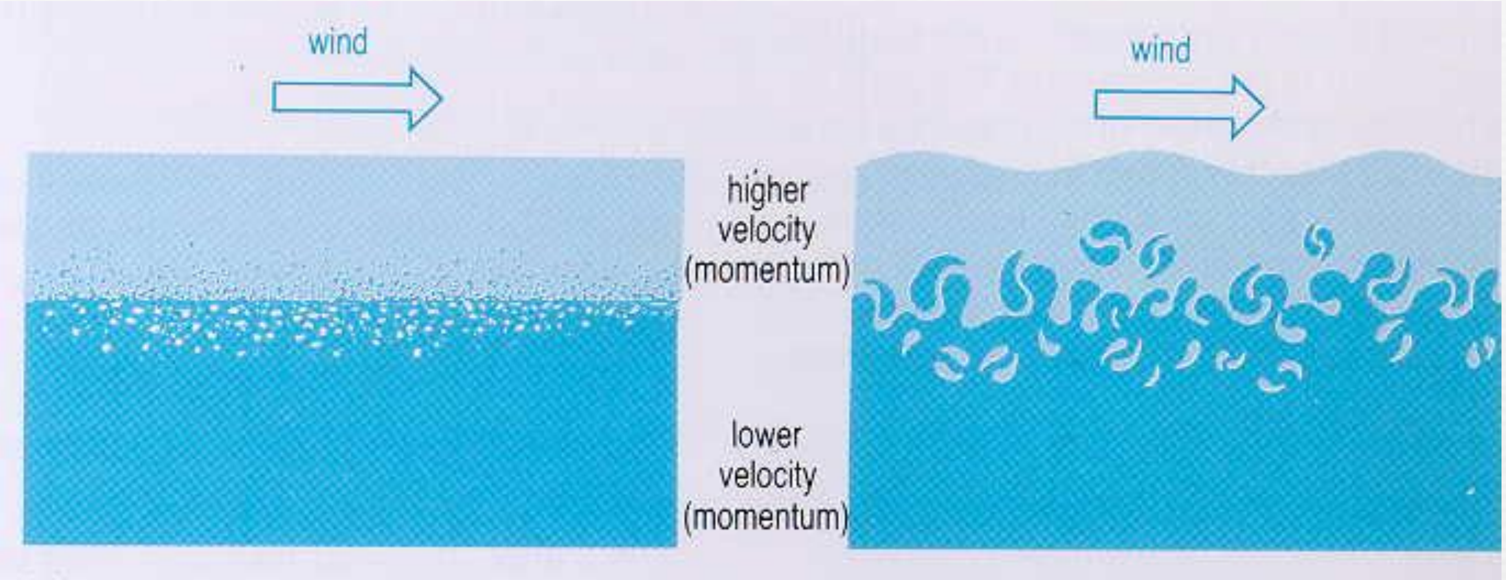
- Set out to make an initial investigation into ocean parameter uncertainty

1. What parameters are uncertain and by how much?
2. How big/important is it?
3. Do we need to include in future predictions?

Expert Consultation

- Ask lots of experts in ocean modelling, what the most important parameters are.
- Find a range for those parameters (either from the observational studies or asking experts).
- Prioritise the parameters by their expected effect on transient climate change.

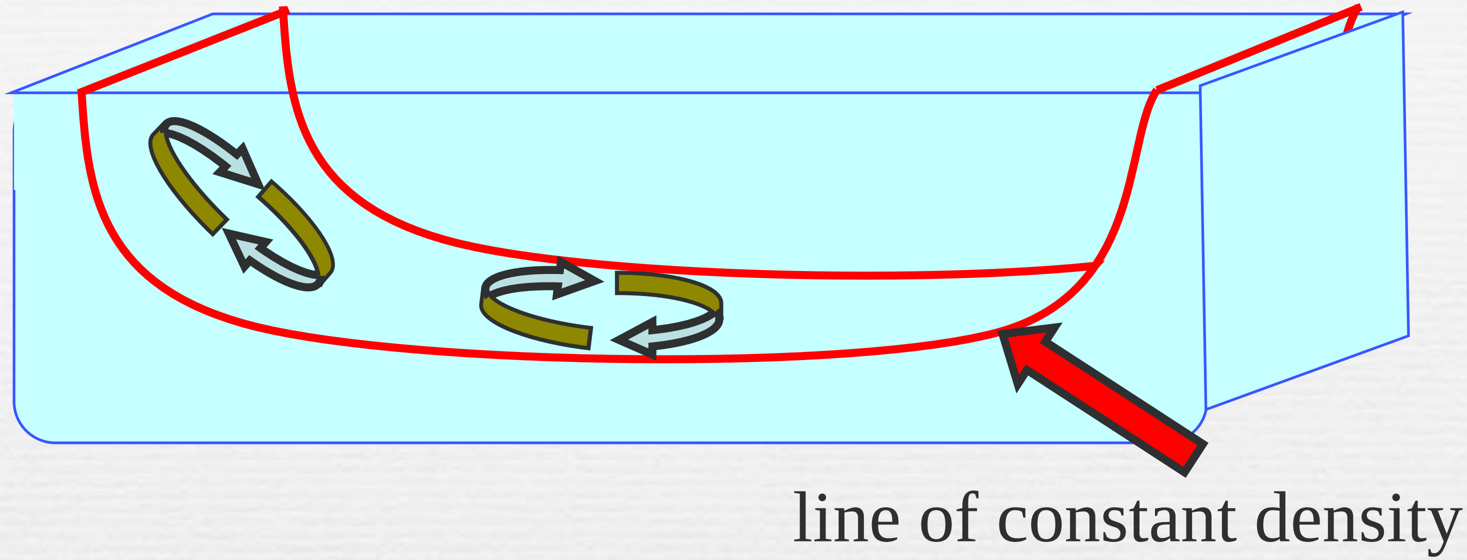
Vertical Diffusion



Molecular Diffusion Eddy Diffusion

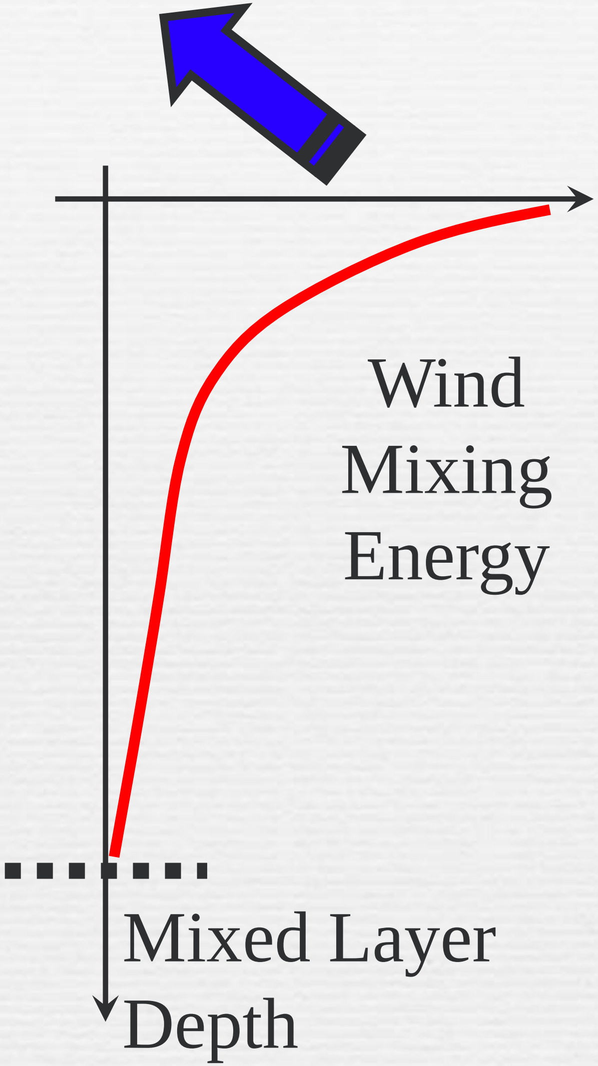
- Small compared to horizontal mixing.
- However all mixing is small vertically, due to stratification.
- Diffusivity varies with depth.

Isopycnal diffusion



- Parameterises effects of Mesoscale Eddies
- Mainly horizontal
- Vertical transfers possible at high latitudes
- Largest in Southern Ocean

Mixed Layer

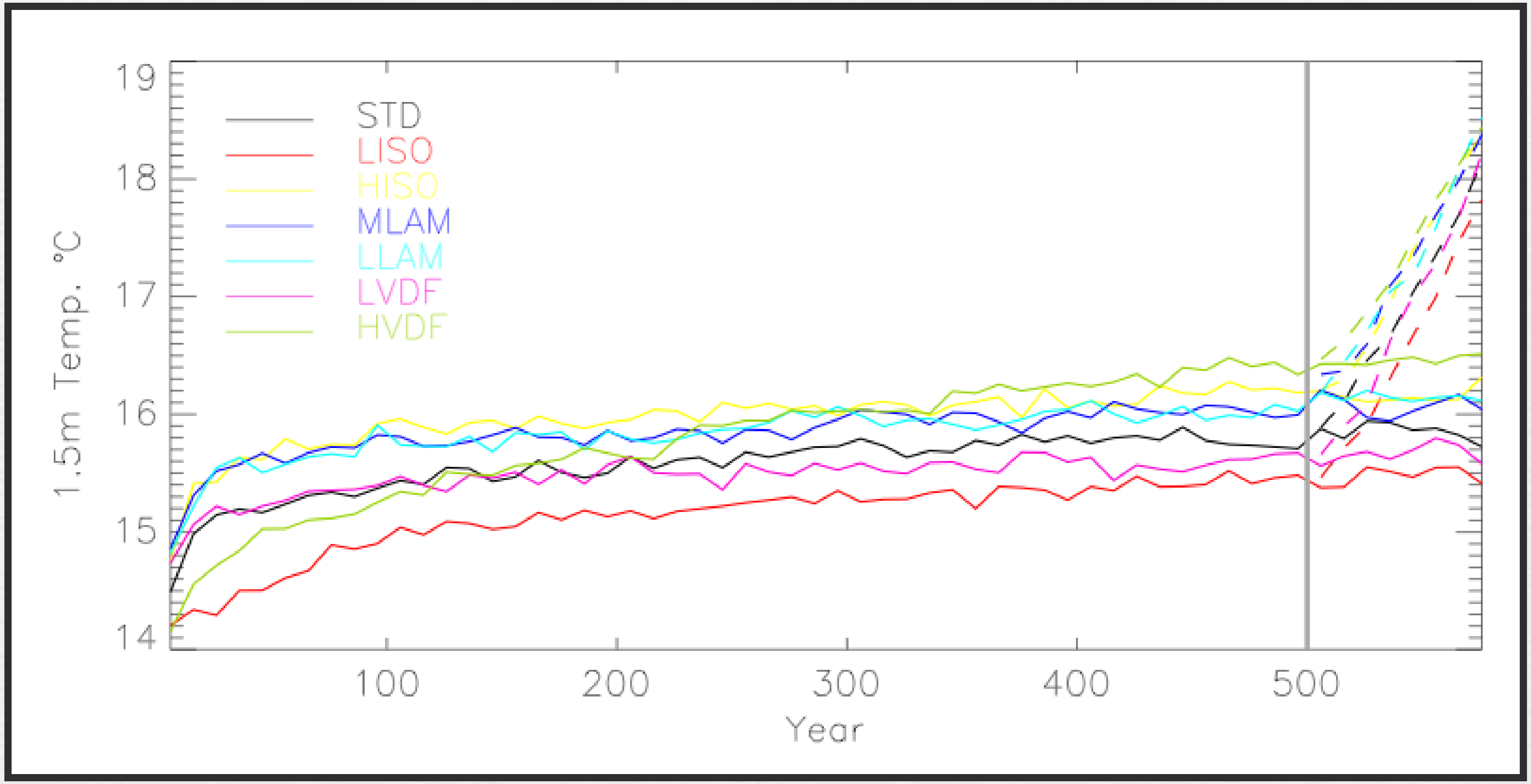


- Parameterise the mixed layer by working out the mixed layer depth and then mixing above (Kraus-Turner).
- Mixed Layer Depth is when turbulent energy runs out.
- Scheme has 2 parameters - fraction and a decay length

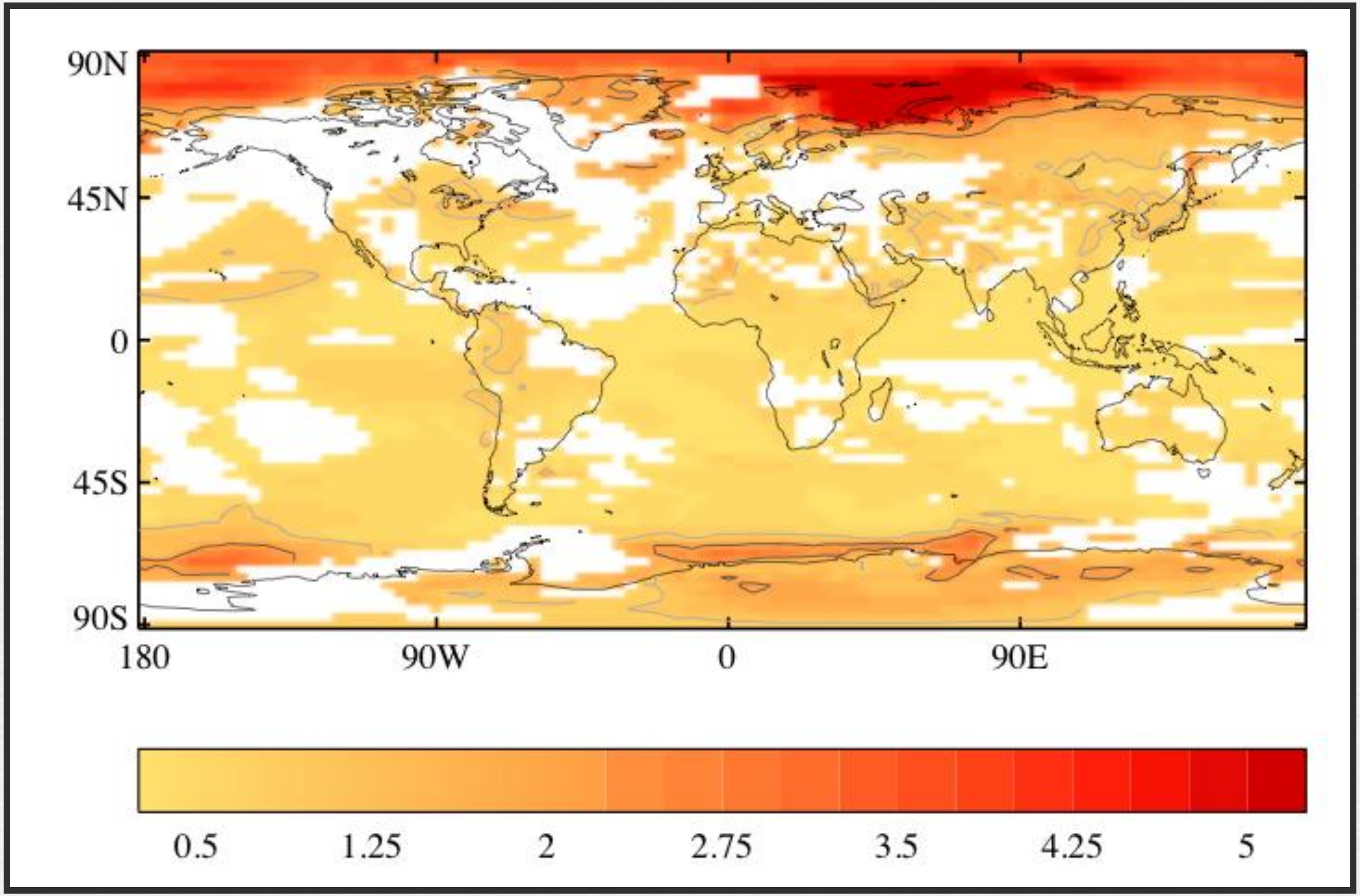
7 Ensemble Members

	Isopycnal Diffusivity (m^2s^{-1})	Background Vertical Diffusivity profile ($x10^{-5}$ m^2s^{-1})	Mixed Layer Parameters, fraction, depth (m)	
Standard	1000	1-15	0.7	100
Low ISO	200	1-15	0.7	100
High ISO	2000	1-15	0.7	100
Low VDiff	1000	0.5-4	0.7	100
High VDiff	1000	2-50	0.7	100
Low LAM	1000	1-15	0.3	100
Med LAM	1000	1-15	0.5	50

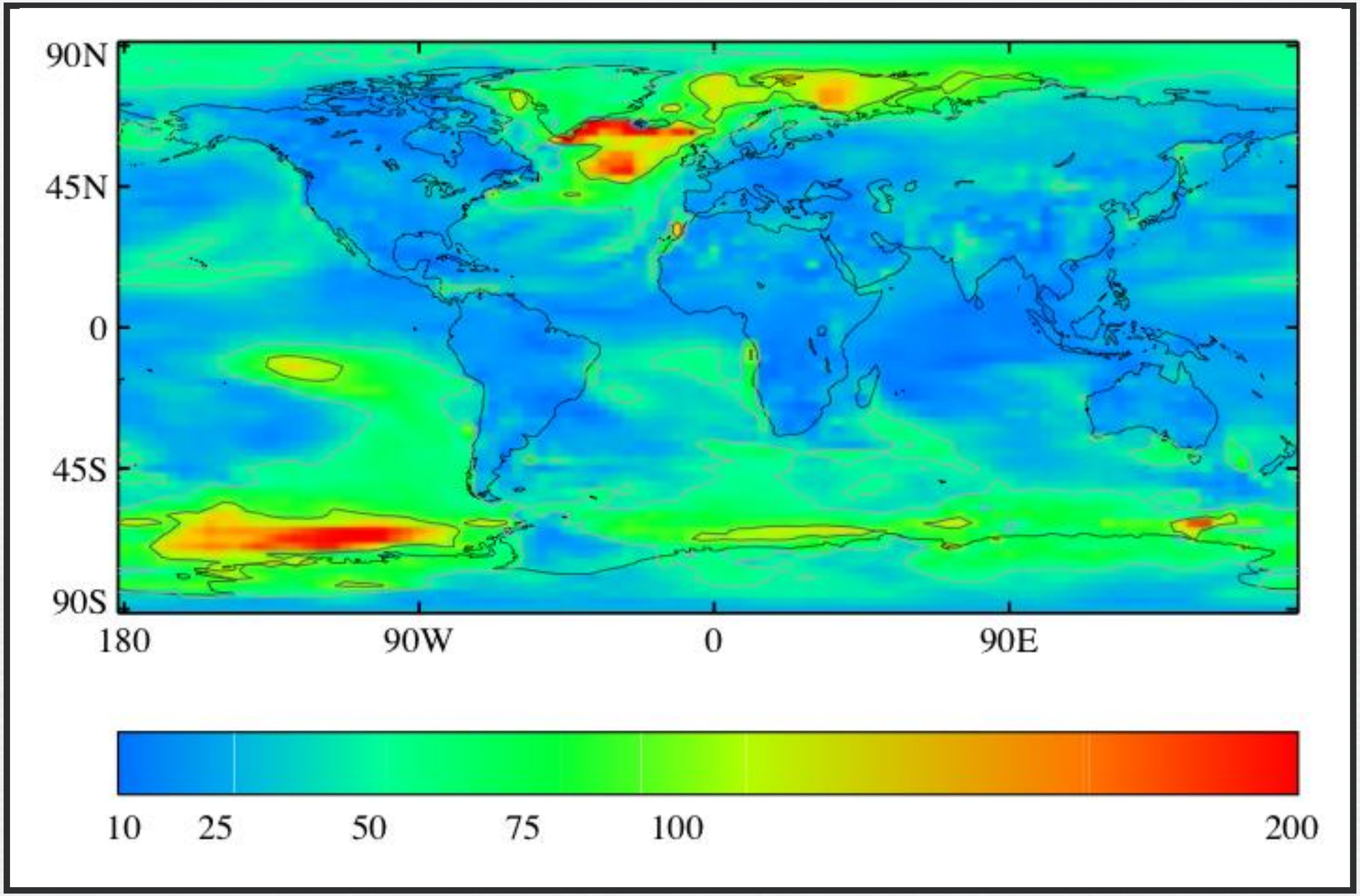
Global Mean Temperature



- The grey bar marks the beginning of the experiment, and dotted lines are the increasing CO_2 runs



- Ensemble spread (range) in surface temperature climate change signal.



- Ensemble spread (range) in surface temperature climate change signal, **as a percentage of the ensemble mean signal**.

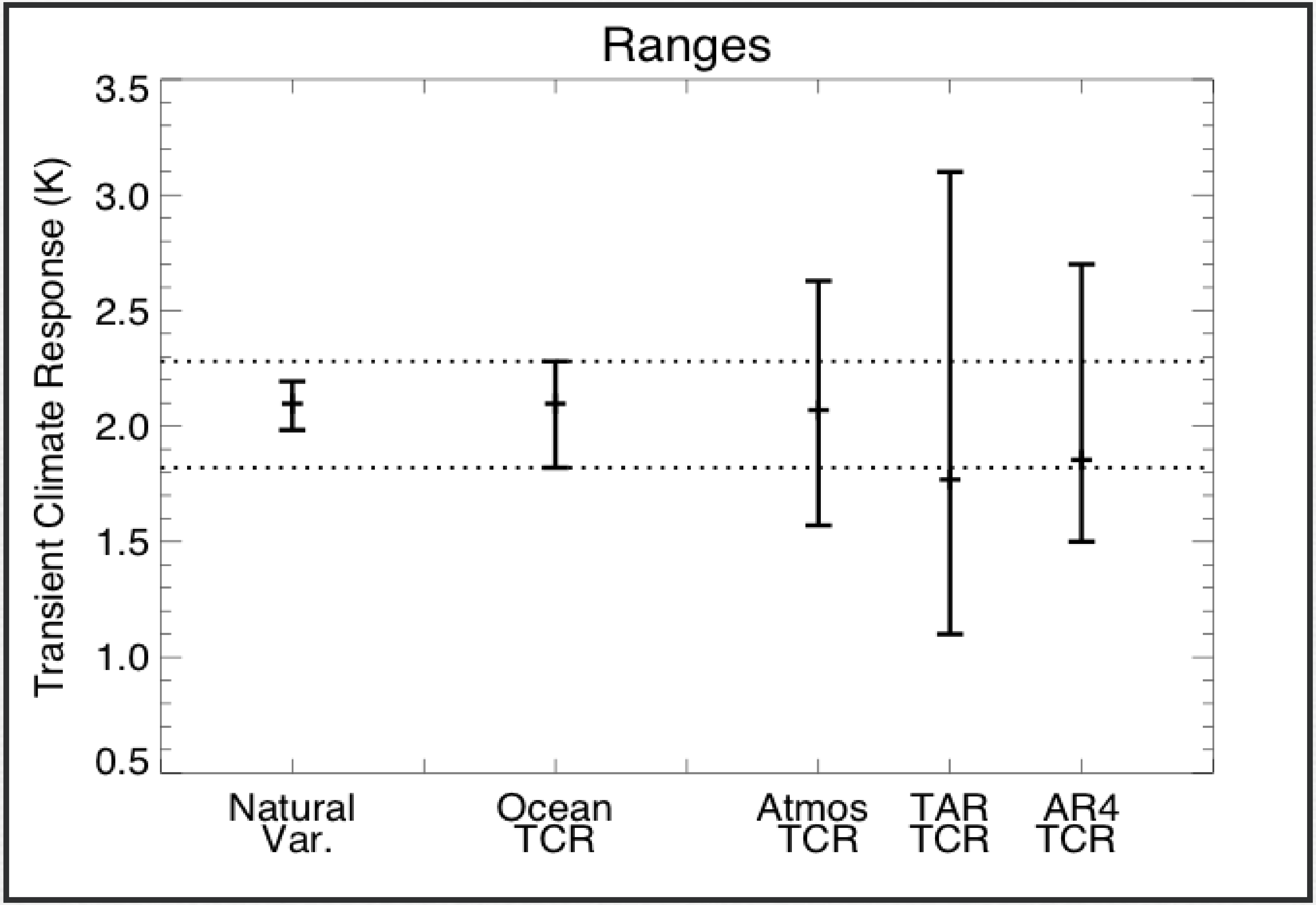
Aside: Other Results

- Can’t detect changes in thermohaline circulation behavior from ocean model uncertainty in these runs
- Atmospheric differences dominate ocean heat uptake differences
- Climate sensitivity may be sensitive to current climate

The Bigger Context

- So I’ve shown that ocean parameter uncertainty can have detectable results that are important in some localities, but so what?
- How does it compare to other sources of uncertainty?

Comparison of TCR Ranges



Note: Using standard deviation instead of range gives a substantively similar plot

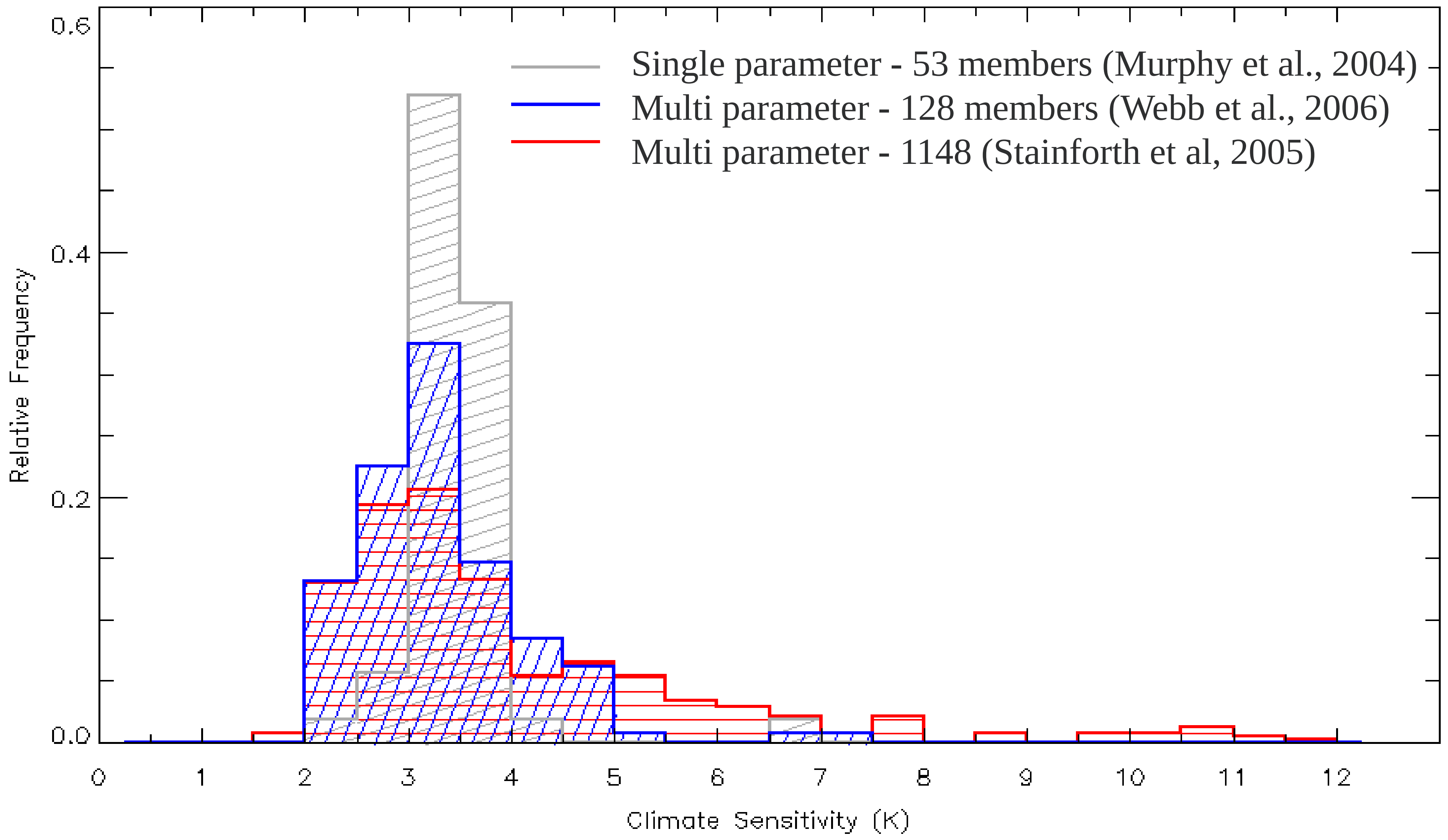
Importance

- So uncertainty related to the ocean parameters exists.
- Less important on the global scale than other modeling uncertainties.
- It *is* important locally though, so should be included in probabilistic climate prediction.

Other ingredients

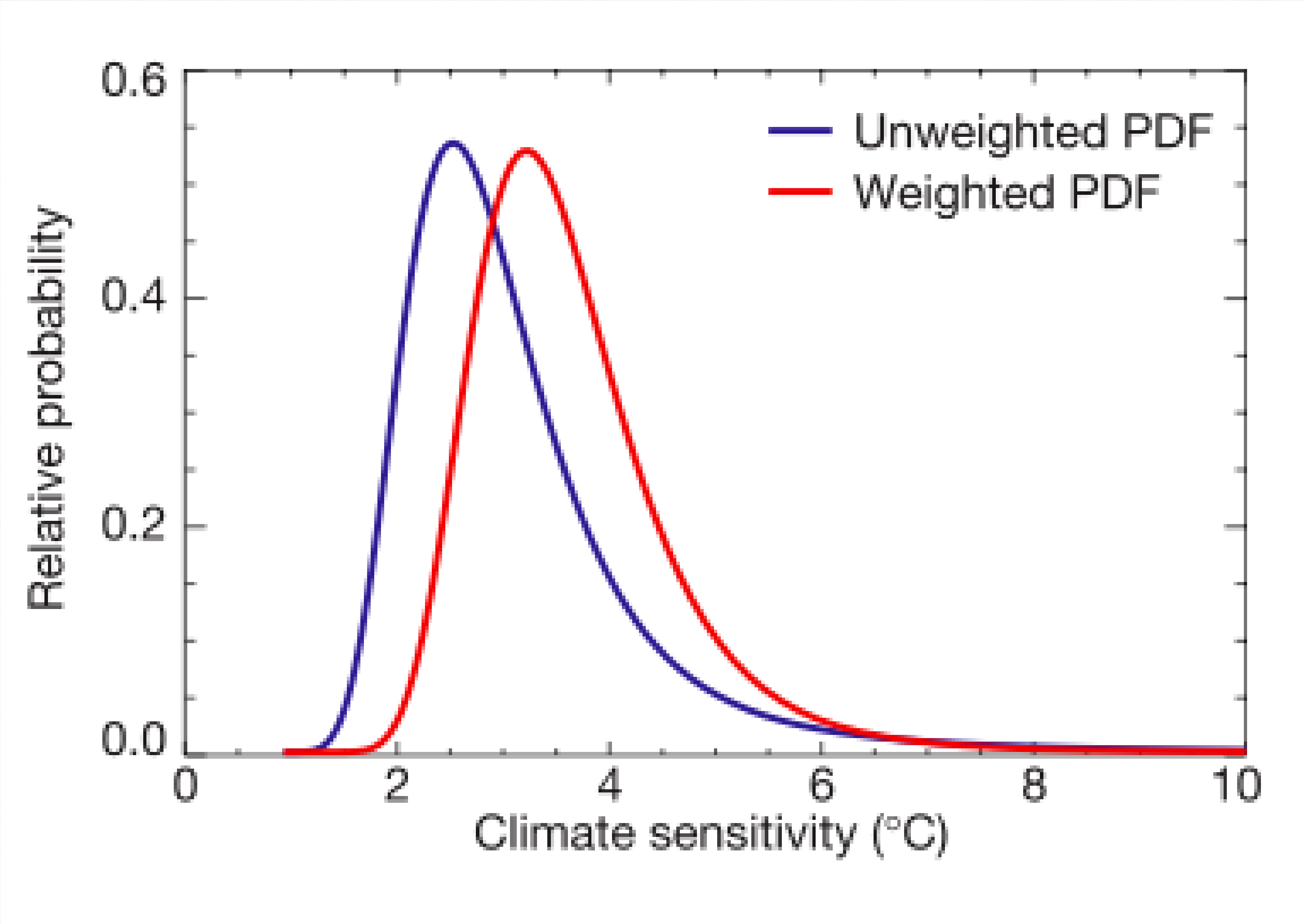
- Systematic sampling - multiple perturbations
- Assigning probabilities
- Getting enough computer power to run it.

Multiple Perturbations



Mat Collins

Weighting for Simulation Quality



Distributed Computing

- Climate*Prediction*.net is a version of the UK Met Office's climate model
- Downloadable as a screensaver
- BBC experiment

Take Home Messages

I. Climate prediction contains much uncertainty

II. Some of it comes from the models themselves

III. Probabilistic forecasts provide more information than a single prediction

IV. Probabilistic forecasts need “grand” ensembles

V. We are moving towards creating these ensembles

Climate Sensitivity