Ocean Model Uncertainty

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Outline

- Sources of uncertainty in climate forecasts and how they are treated.
- Parameter perturbations
- Experimental Set-up
- Global mean effects on transient climate change
- Regional climate change
- Effects on the thermohaline circulation.

Uncertainties in Projections

- Each projection has 3 forms of uncertainty:
  - Initial Condition uncertainty (sampled in ensemble weather prediction)
  - Scenario uncertainty (how much GHG will be emitted, when will volcanoes go off, etc.)
  - Model uncertainty (from errors in the model)

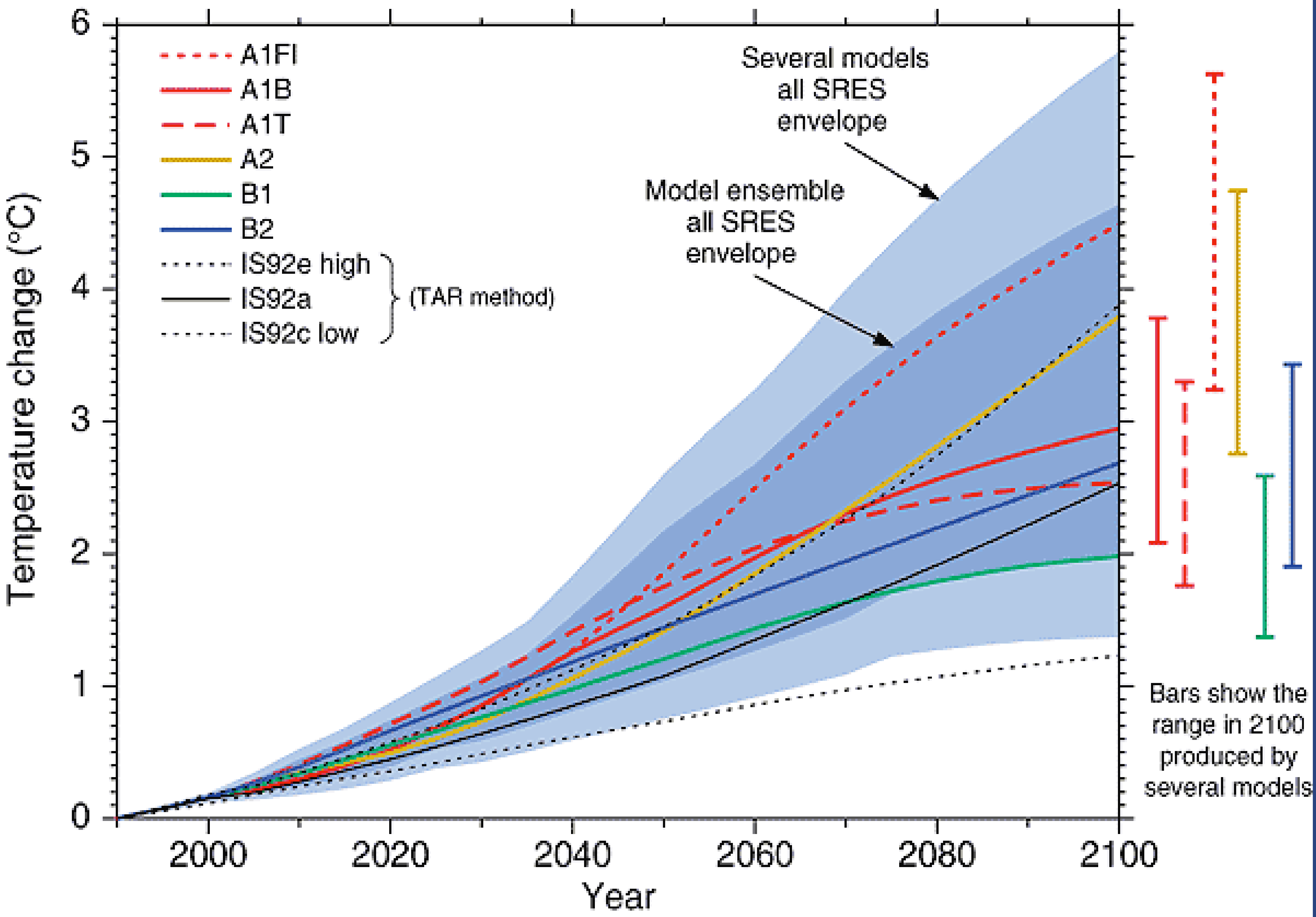
Imperfect Models

- Numerical Models have a finite grid spacing - can’t resolve everything.
- Need to parameterise sub-grid scale processes.
- The values of parameters in these schemes are not well known.
- However hard we try, there will always be approximations, and therefore errors (although they can be reduced).
- Useful to know how big the errors are.

Multi-Model Ensembles

- TAR uses multi-model ensemble to estimate initial condition and model uncertainty combined.
  - Models not chosen to sample phase evenly.
  - Can’t provide error estimates for a single model run, only considered as a whole.
- More rigourous approach needed to provide probability climate forecasts

IPCC Models



Only an envelope is shown, not relative probabilities.

Source, Climate Change – The Scientific Basis, IPCC, fig 9.14

Types of Model Uncertainty

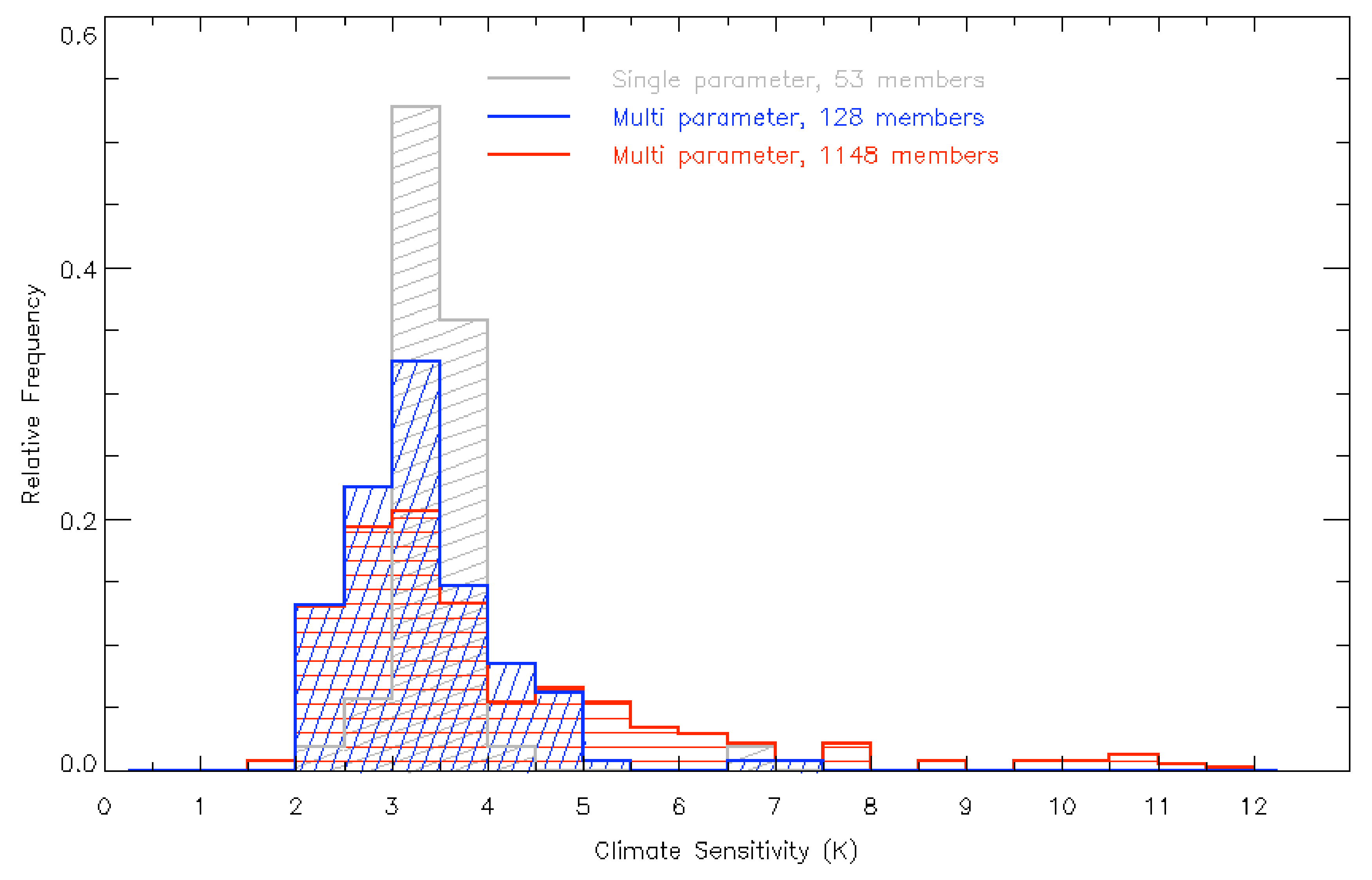
- Model uncertainty can be sub-divided into manageable chunks:
  - Uncertainty in parameterisations of the physics in the Atmosphere model.
  - Uncertainty in parameterisations of the physics in the ocean model
  - Structural uncertainty from the way the model is built and coupled.

QUMP and climateprediction.net

- Both perturb parameters with a range constrained by observations
- Both started off using a slab model, so only considered parameters in the atmosphere.
- Looked at uncertainty in equilibrium global mean temperature response to a doubling of CO2 (climate sensitivity).

More Slab-Model Ensemble Simulations

- 128 HadSM3 (atmosphere-slab ocean model) ensemble with parameters perturbed simultaneously
- Additional simulations underway to explore more of parameter space



Murphy et al., 2004
Webb et al., 2006
Stainforth et al., 2005

Transient Projections

- The atmosphere equilibibriates quickly compared to the ocean, because of its smaller heat capacity.
- So need an ocean model for a transient projection.
- The ocean model will have its own parameterisations, and therefore uncertainties.
- I’ve set out to investigate the ocean model uncertainty.

Questions

1. Can we detect the effects of ocean model uncertainty in a climate change experiment?

Method I

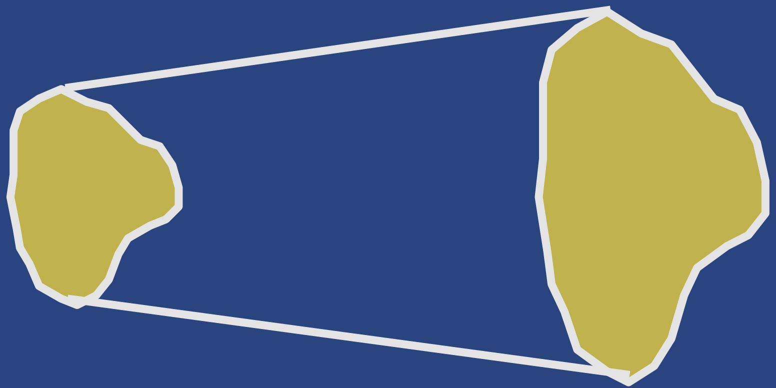
- Create a perturbed ocean physics ensemble, to sample the ocean model uncertainty.
- Perform a transient climate change experiment
- Compare the spread in the ensemble to the spread expected from internal (natural) variability.
- If the ensemble spread is larger, ocean model uncertainty has detectable effects.

Problems

- Many parameters, each with many values, that can be combined in many ways.
- But limited computer resources.

Method II

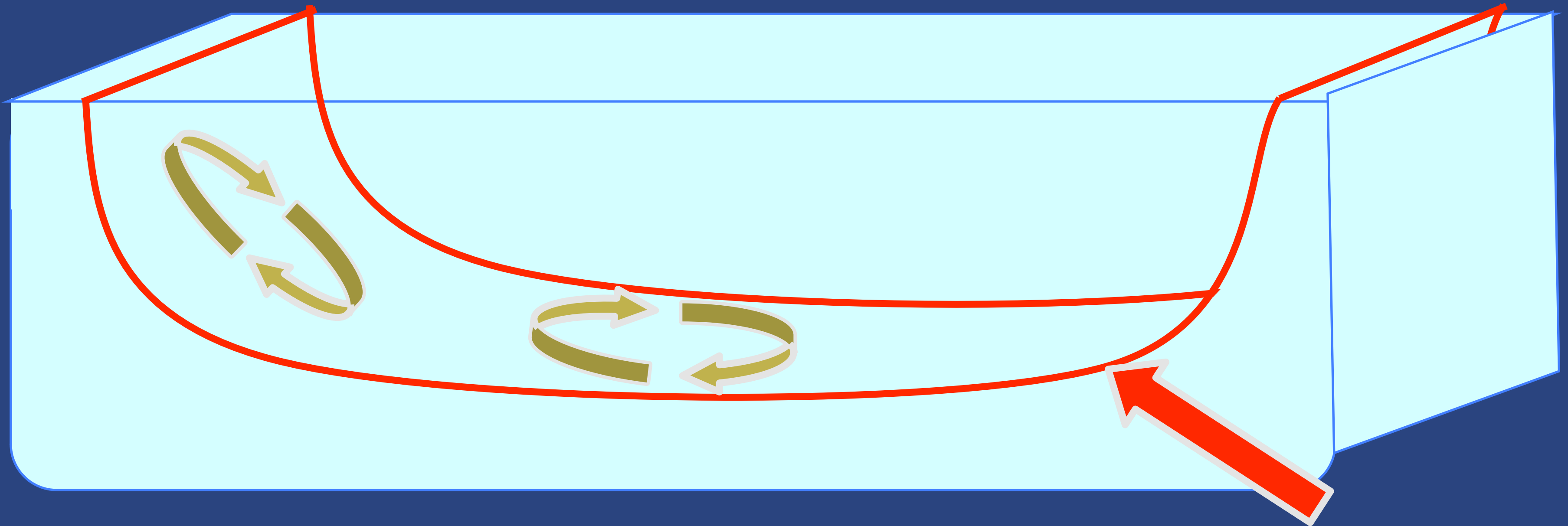
- Try to sample the largest extent
- So perturb most important parameters to their maximum and minimum.
- Can't get probability from answers, only an idea of envelope caused.



Expert Elicitation

- 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.

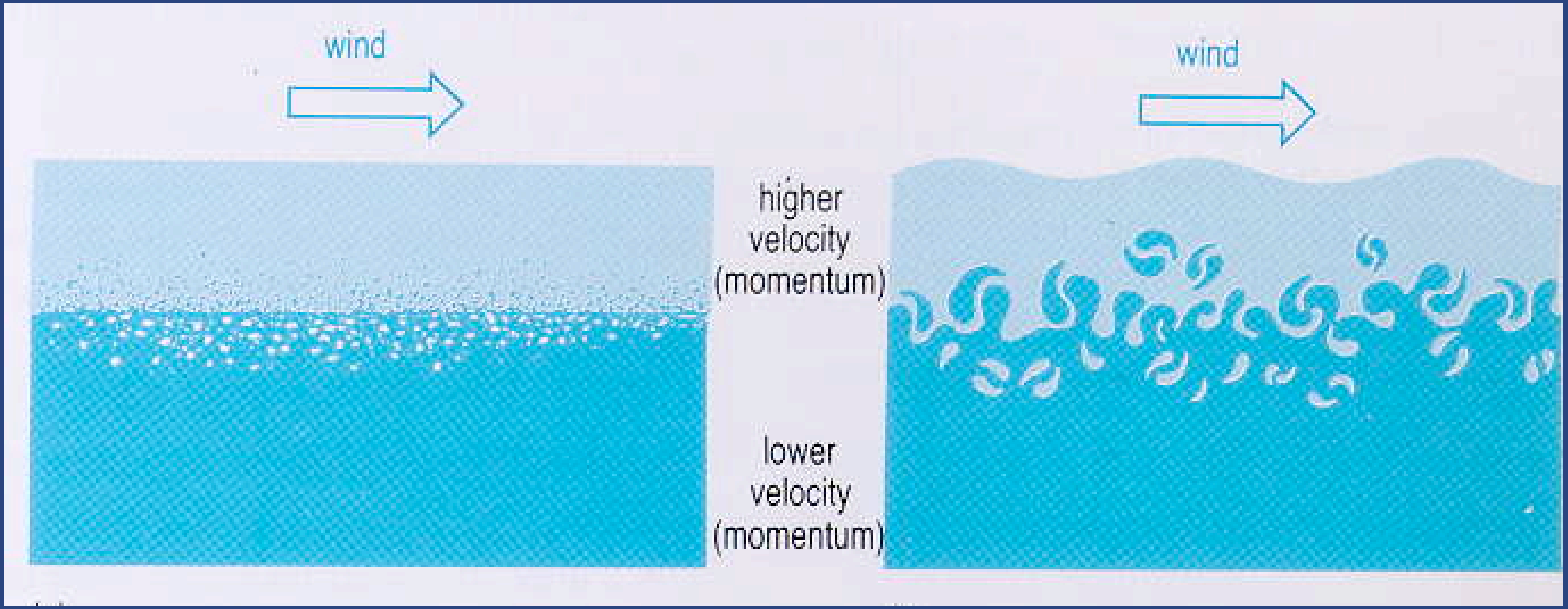
Isopycnal diffusion



line of constant density

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

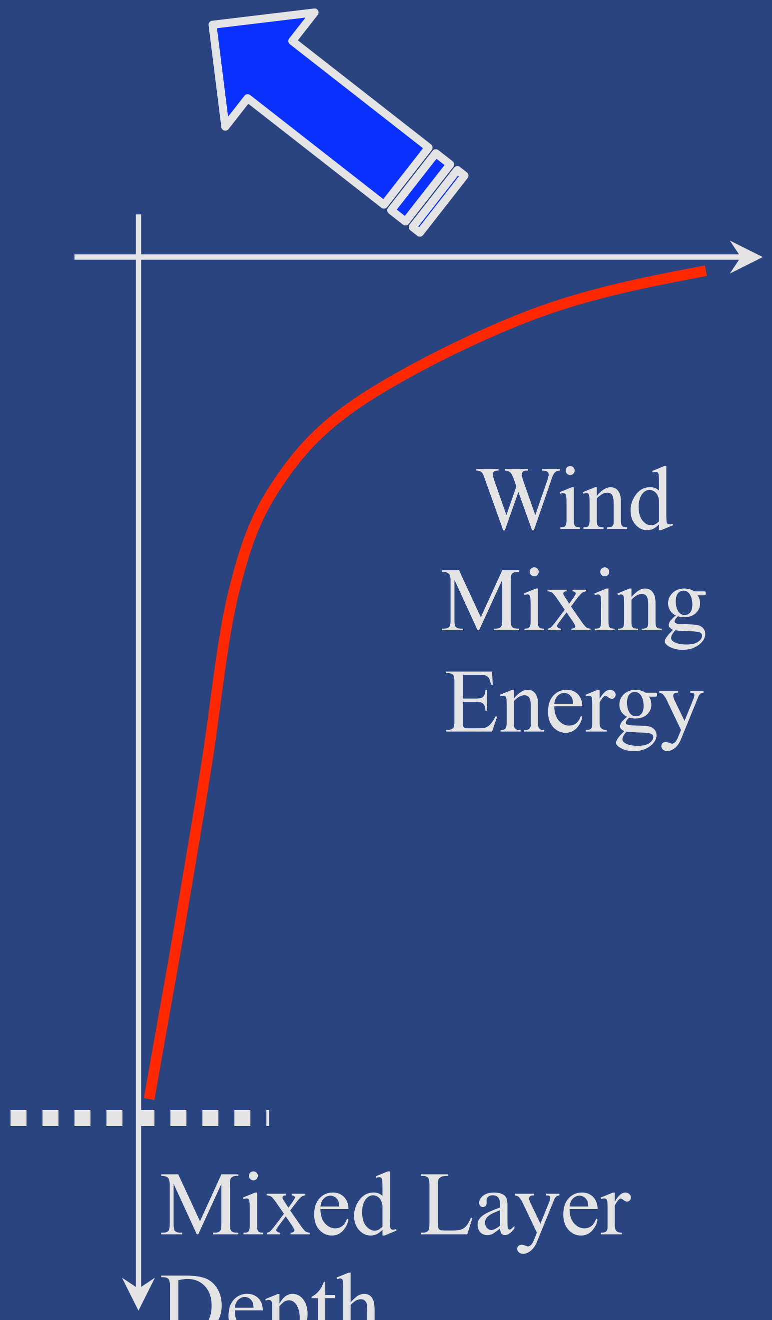
Vertical Diffusion



Molecular Diffusion Eddy Diffusion

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

Mixed Layer



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

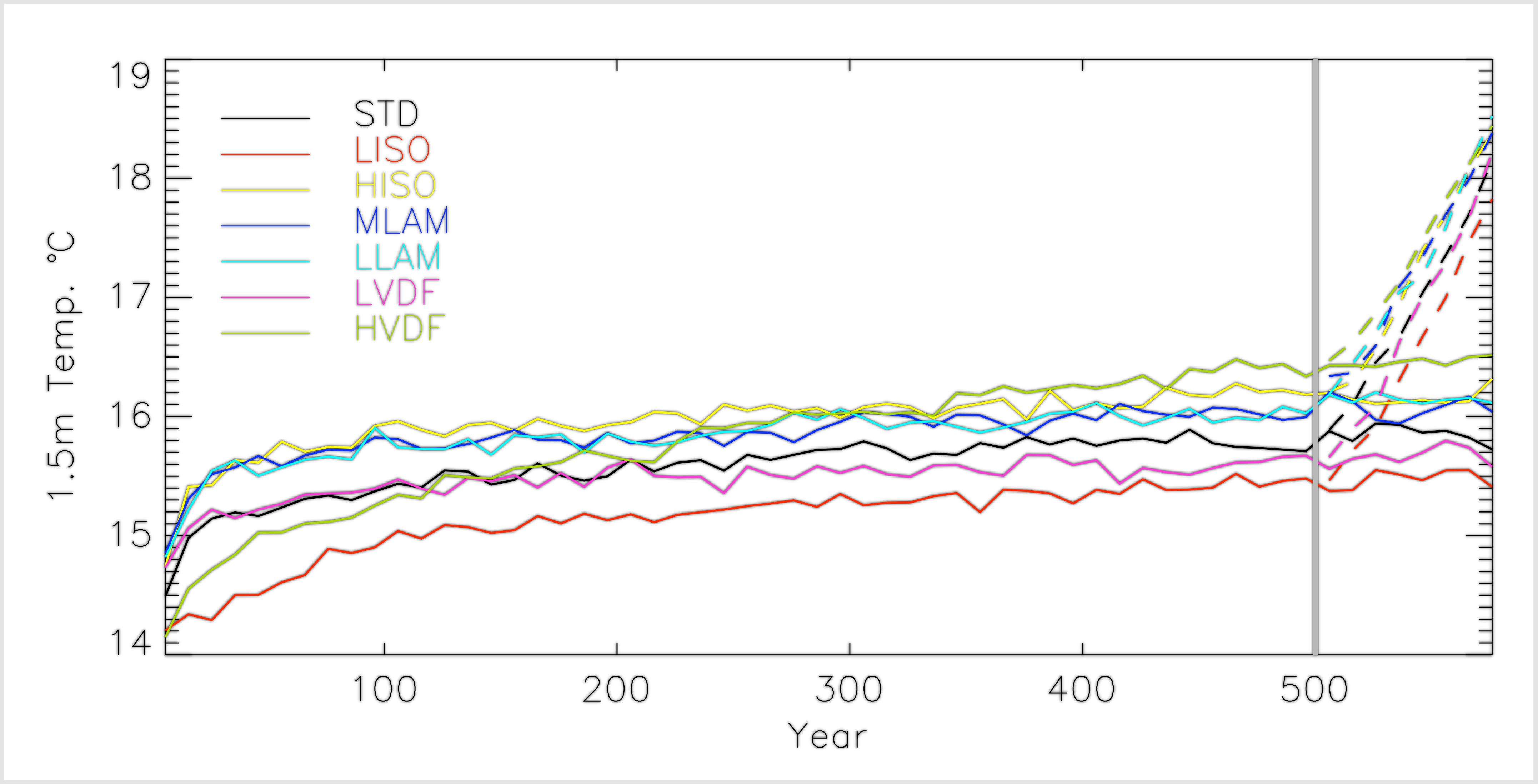
7 Ensemble Members

	Isopycnal Diffusivity (m^2s^{-1})	Background Vertical Diffusivity profile ($\times 10^{-5}$ 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

Experimental Setup

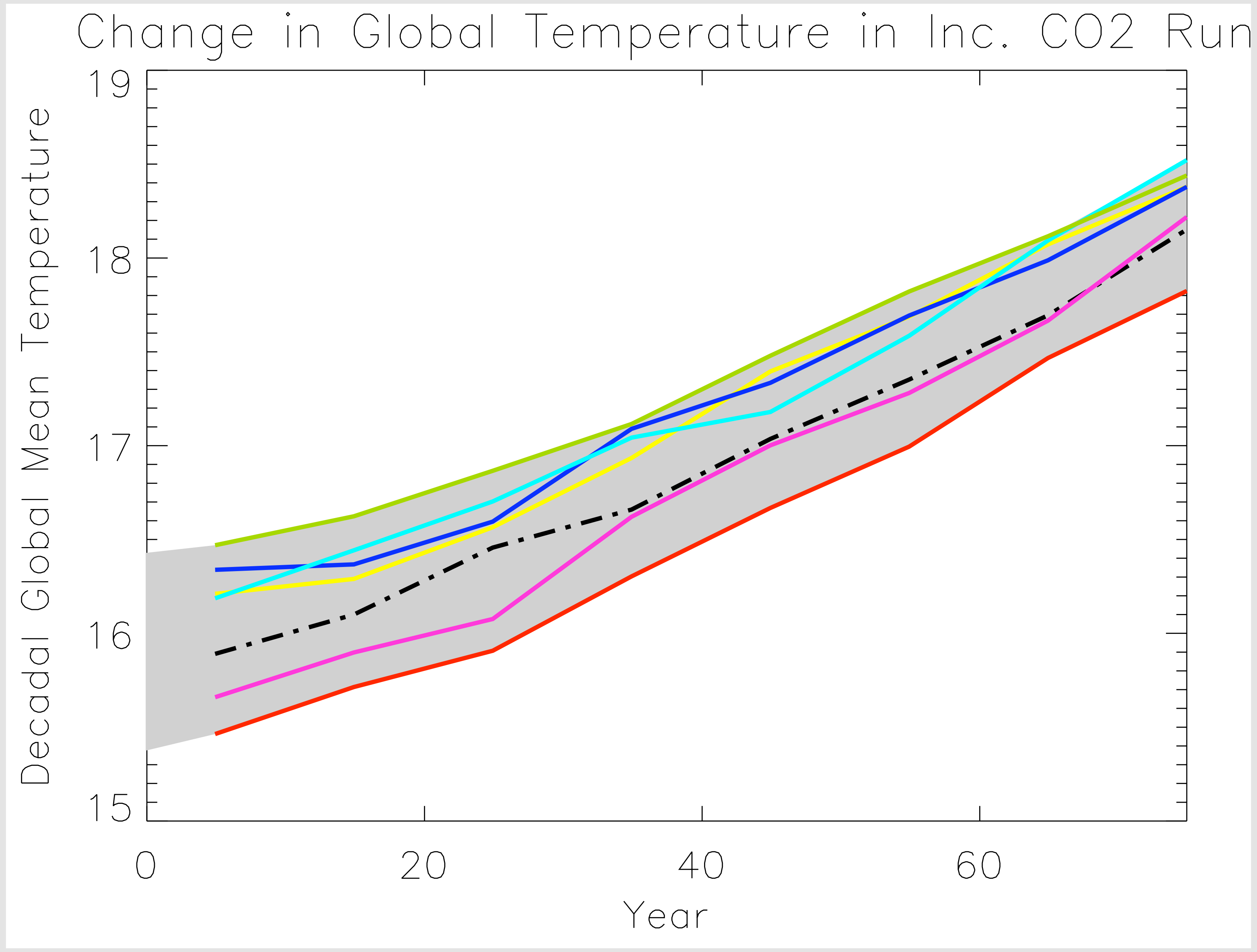
- 500 year spin-up to let the perturbations take effect.
- 80 year control run.
- 80 year run with CO_2 increasing by 1% per year
  - CMIP idealised scenario
  - Equivalent to a linear increase in radiative forcing
  - CO_2 levels are doubled in year 70.

Global Mean Temperature in Spin Up



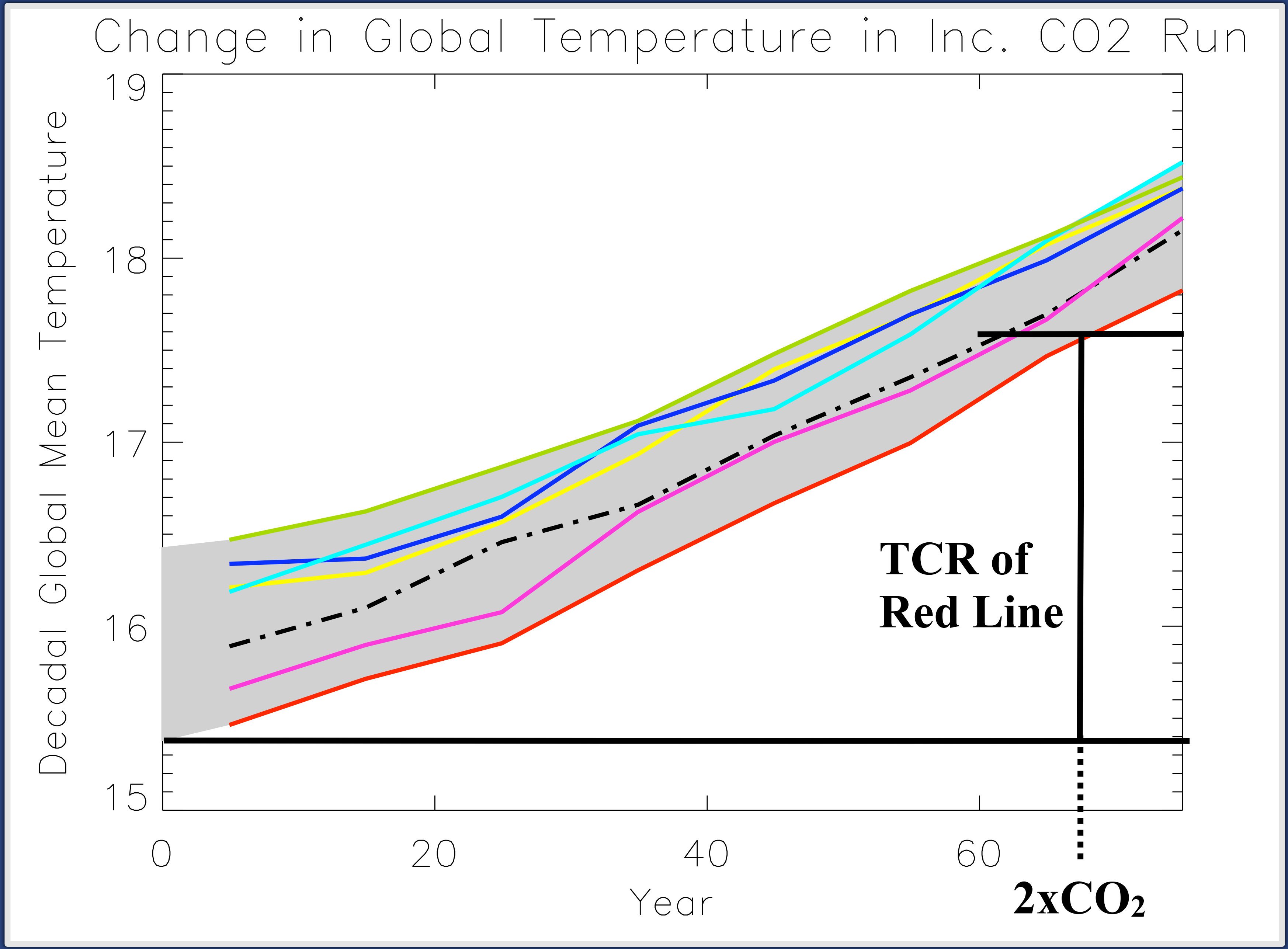
- The grey bar marks the beginning of the experiment, and dotted lines are the increasing CO_2 runs

Temperature in Increasing CO_2 Run



Not all temperature responses are the same

Transient Climate Response



Difference between 20 year average centred on time of 2xCO$_2$ in 1% and the control state (IPCC, 2001)

Detection

- Variations in Transient Climate Response in ensemble.
  - Ensemble mean of 2.10K
  - Range of 0.48K
  - Standard deviation of 0.14K
- Standard deviation of modeled internal variations in 20 yr average global mean temp. is 0.05K.
- Ensemble variations are larger than those expected from natural variability at 5% confidence.
- Ocean model uncertainty has a detectable effect on climate projections.

Questions

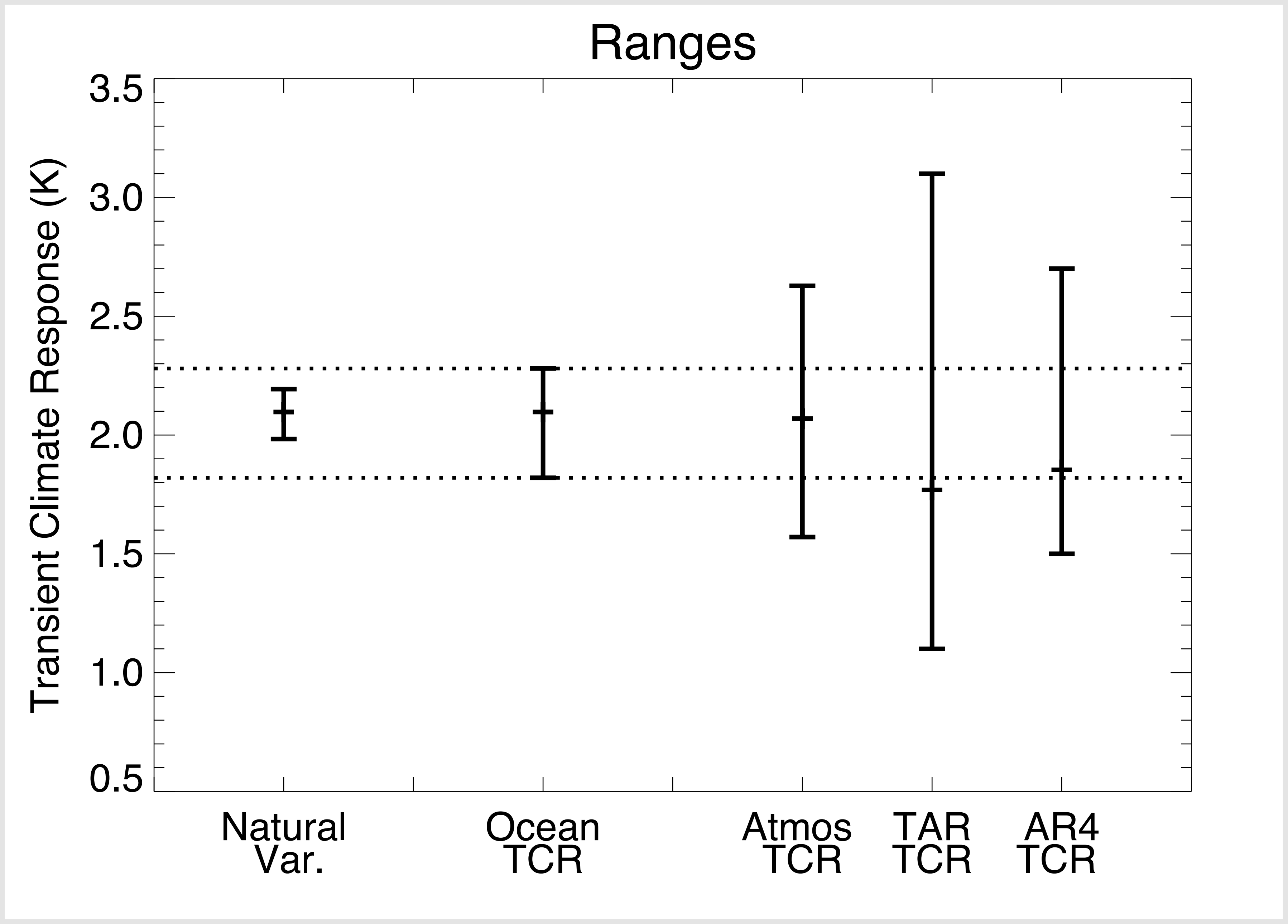
1. Can we detect the effects of ocean model uncertainty in a climate change experiment?
    - ➡ Yes

- Which leads us to ask some further questions about the ocean model uncertainty.....

Questions II

2. How important is this uncertainty?
3. What are the mechanisms by which the ocean model uncertainty causes uncertainty in the transient response?
4. Is it spatially uniform? If not what shape does it take?

Comparison of TCR Ranges



Using standard deviation instead of range gives a substantively similar plot

Relative Size

- TCR Range of 1.8-2.3K from Ensemble
- 25% of ensemble mean signal.
- Smaller than range from atmosphere model uncertainties (Collins et al., 2006).
- Smaller than multi-model range.
- Smaller than scenario uncertainty.
  - Range after 80yrs of 1.9K in HadCM3 for SRES scenarios (Johns et al., 2003)

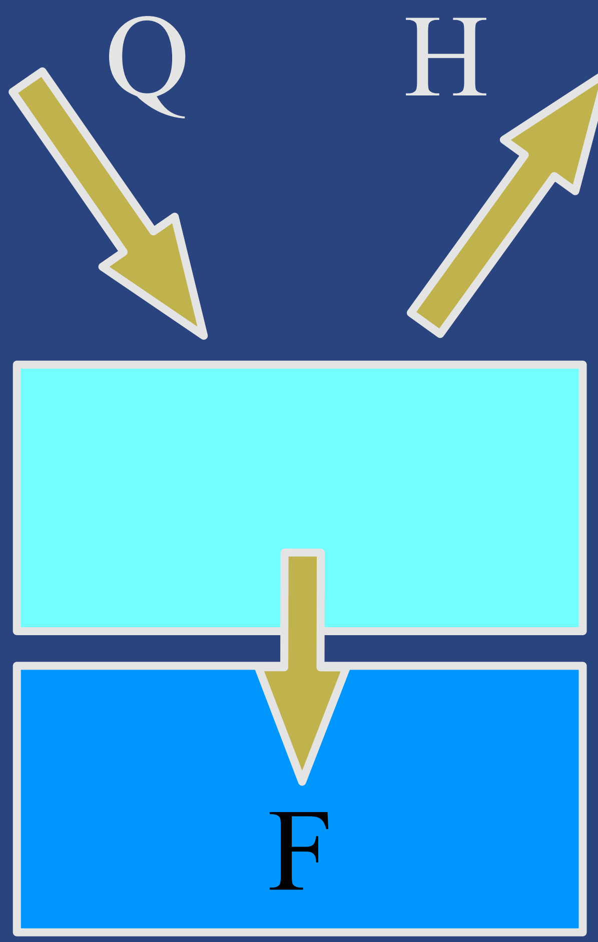
Relative Size II

- Ocean ensemble is created with maximum and minimum perturbations only.
- Larger ensembles are more likely to find outliers.
- However ensemble is only 7 members.
- Comparison of variances with f-tests confirms results at 5% level.
- Ocean Model Uncertainty is relatively small

Questions II

2. How important is this uncertainty?
    - Small in global mean.
3. What are the mechanisms by which the ocean model uncertainty causes uncertainty in the transient response?
4. Is it spatially uniform? If not what shape does it take?

Global Energy Balance



- Increase in CO_2 causes an increase in the net flux entering the earth system
- The properties of the earth respond to restore the system to balance
- Imbalance = Forcing - Response
- F = Q - H

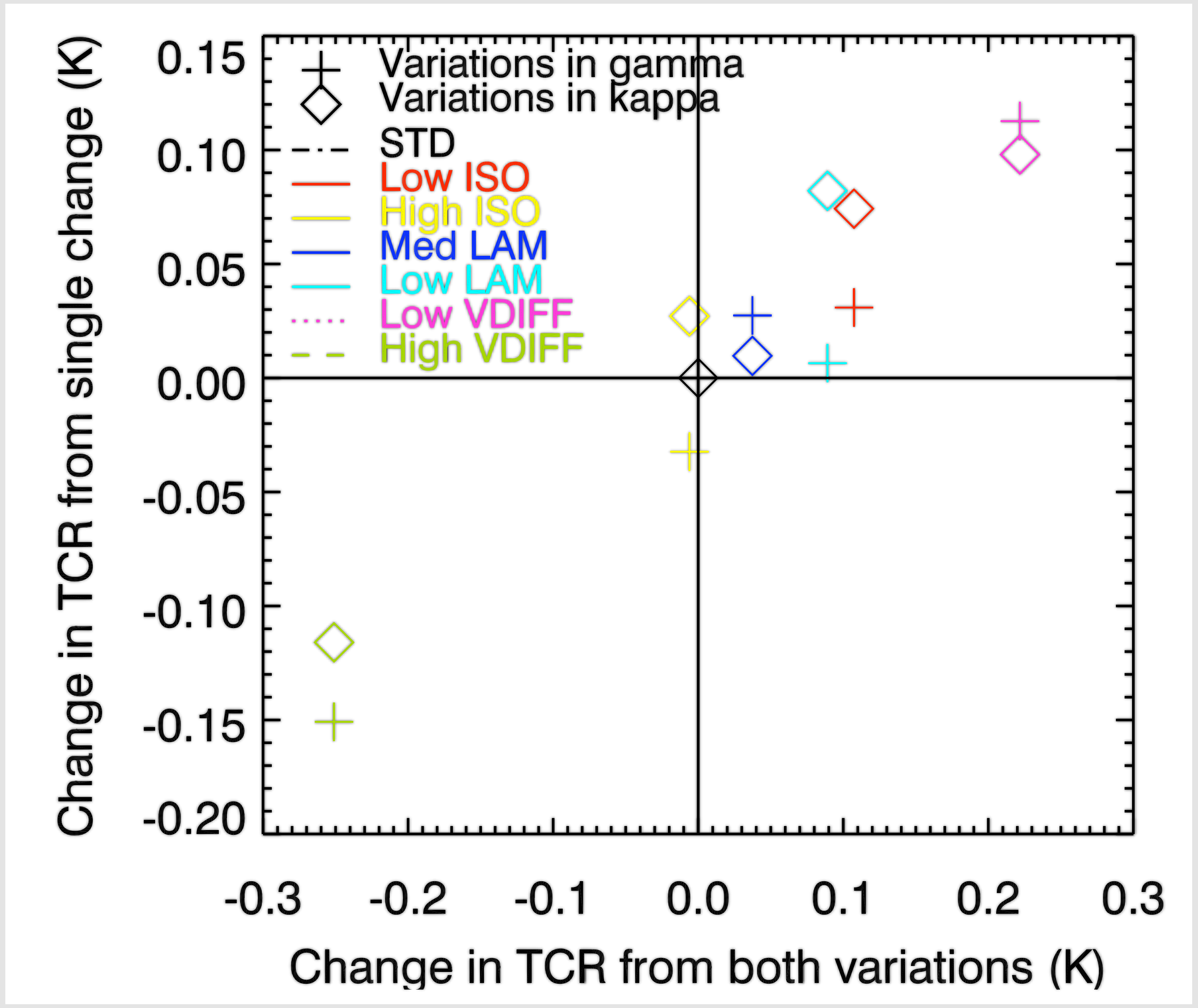
2 Climate Diagnostics

- Primarily response of earth system is a change in the global mean temperature, ΔT.
- Observed that both imbalance and response are linearly proportional to ΔT (Gregory and Mitchell, 1997)
- $\kappa \Delta T \quad = \quad Q \quad - \quad \gamma \Delta T$
- γ is the climate feedback parameter (3.75/climate sensitivity)
- κ is the ocean heat uptake efficiency

Diagnosing these parameters

- Take 20 year averages and remove control mean (like the TCR).
- ΔT = TCR, $Q = 3.75\ \mathrm{Wm^{-2}}$ and F is a model diagnostic.
- $\mathrm{TCR}_i = Q/(\kappa_i + \gamma_i)$
- $\mathrm{TCR}_{\mathrm{STD}} + \delta\mathrm{TCR} = Q/(\kappa_{\mathrm{STD}} + \delta\kappa + \gamma_{\mathrm{STD}} + \delta\gamma)$

Relative Effects



- No Compensation occurring.

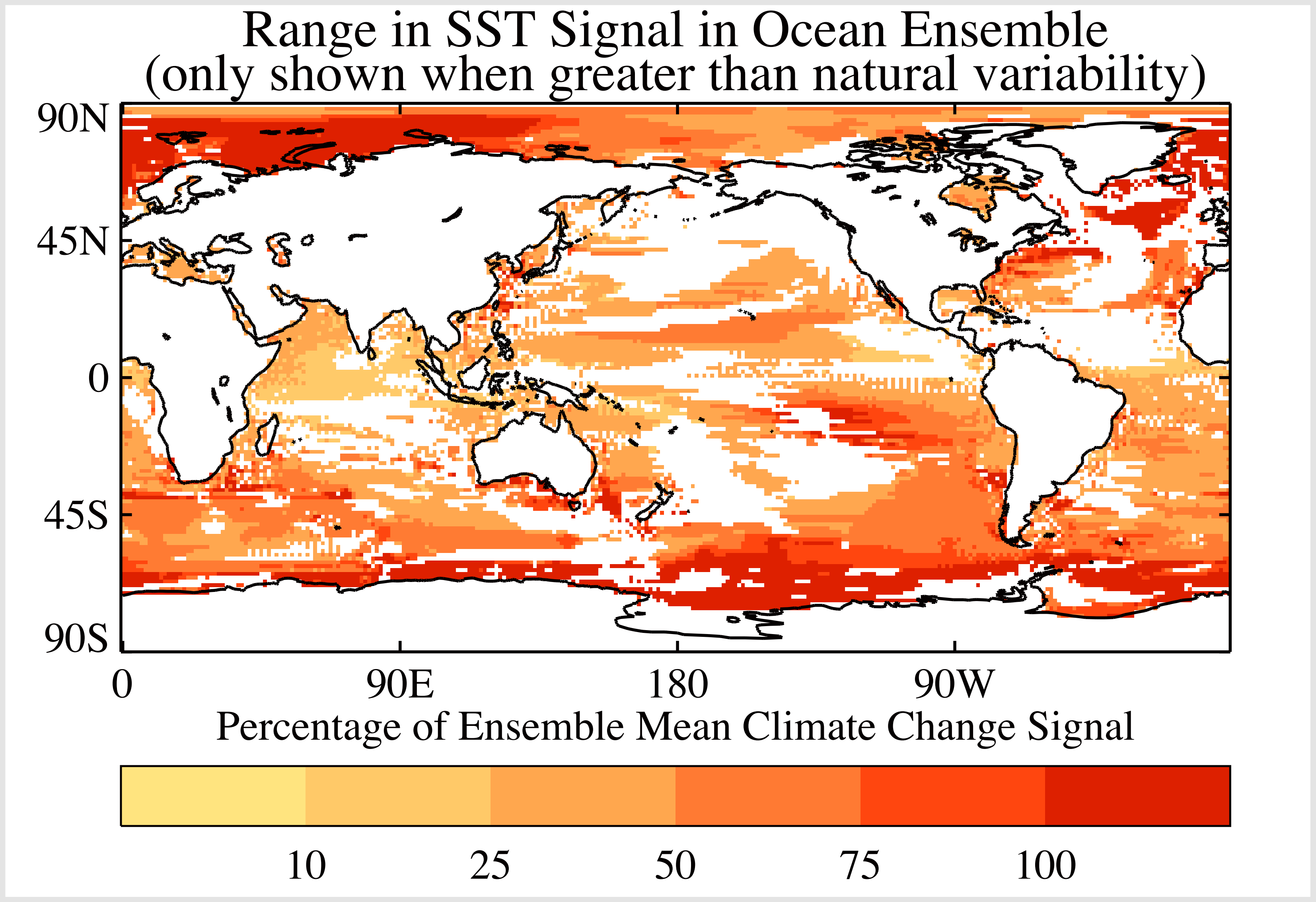
Feedbacks or Ocean rates?

- Changes in γ are most important ($\approx$ equilibrium feedback strengths).
- Changes in κ (strength of ocean heat uptake) are less important in determining the transient temperature response.
- Largest effect of ocean model uncertainty is through feedback strengths (parameterised in the atmosphere model) rather than the ocean physics.
- Compensation between the two diagnostics is not the reason for the small effect of ocean model uncertainty.

Questions II

2. How important is this uncertainty?
   - Small in global mean.
3. What are the mechanisms by which the ocean model uncertainty causes uncertainty in the transient response?
   - Primarily changes in climate sensitivity, but also changes in ocean heat uptake efficiency. Compensation does not explain its small magnitude.
4. Is it spatially uniform? If not what shape does it take?

Uniform Spatial Pattern?

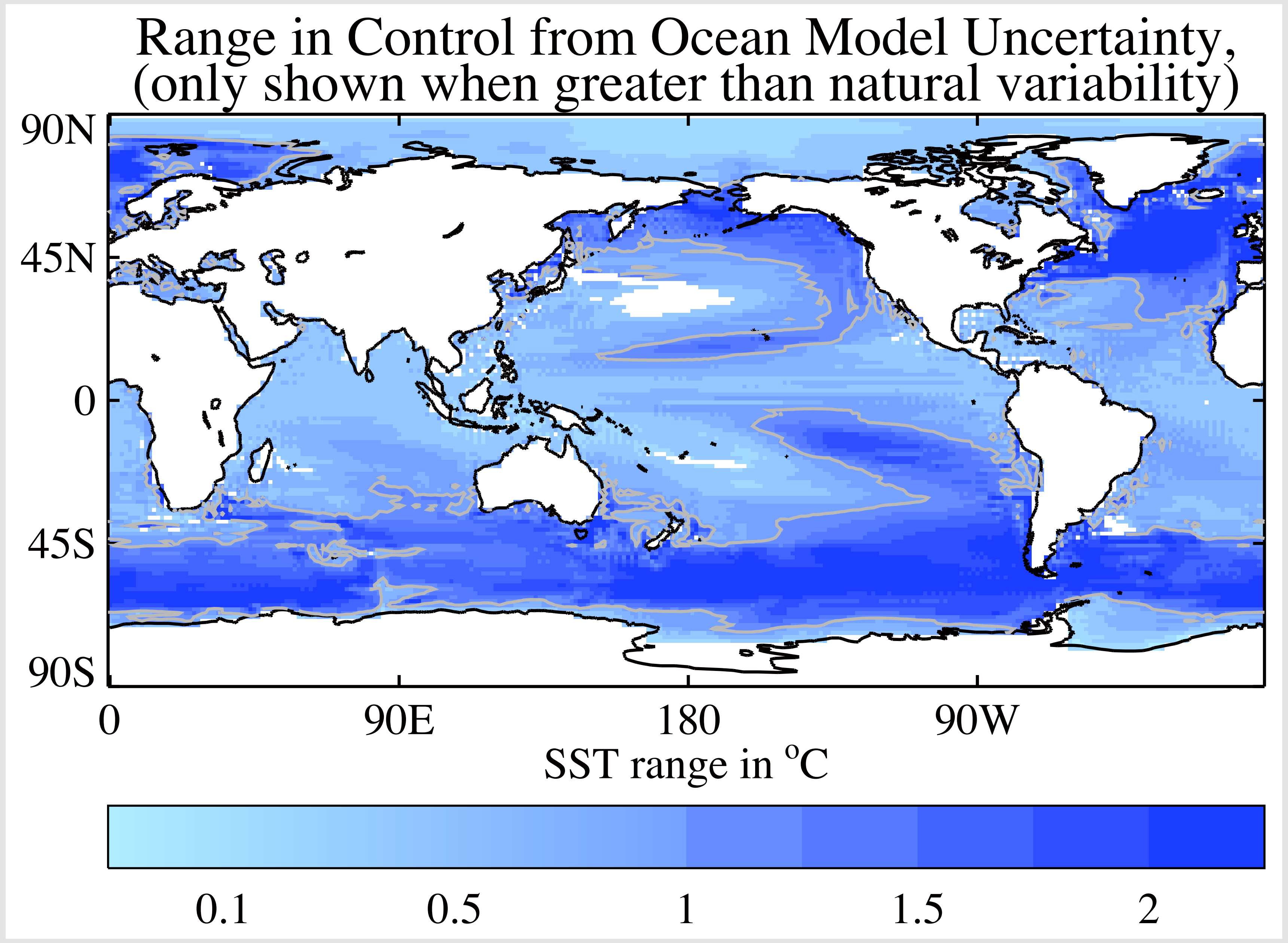


- Ensemble spread in SST signal, as a percentage of the ensemble mean signal.

Questions II

3. What are the mechanisms by which the ocean model uncertainty causes uncertainty in the transient response?
    - Primarily changes in climate sensitivity, but also changes in ocean heat uptake efficiency. Compensation does not explain its small magnitude.
4. Is it spatially uniform? If not what shape does it take?
    - No.

What Shape?



- Ensemble spread in SST in the control simulation

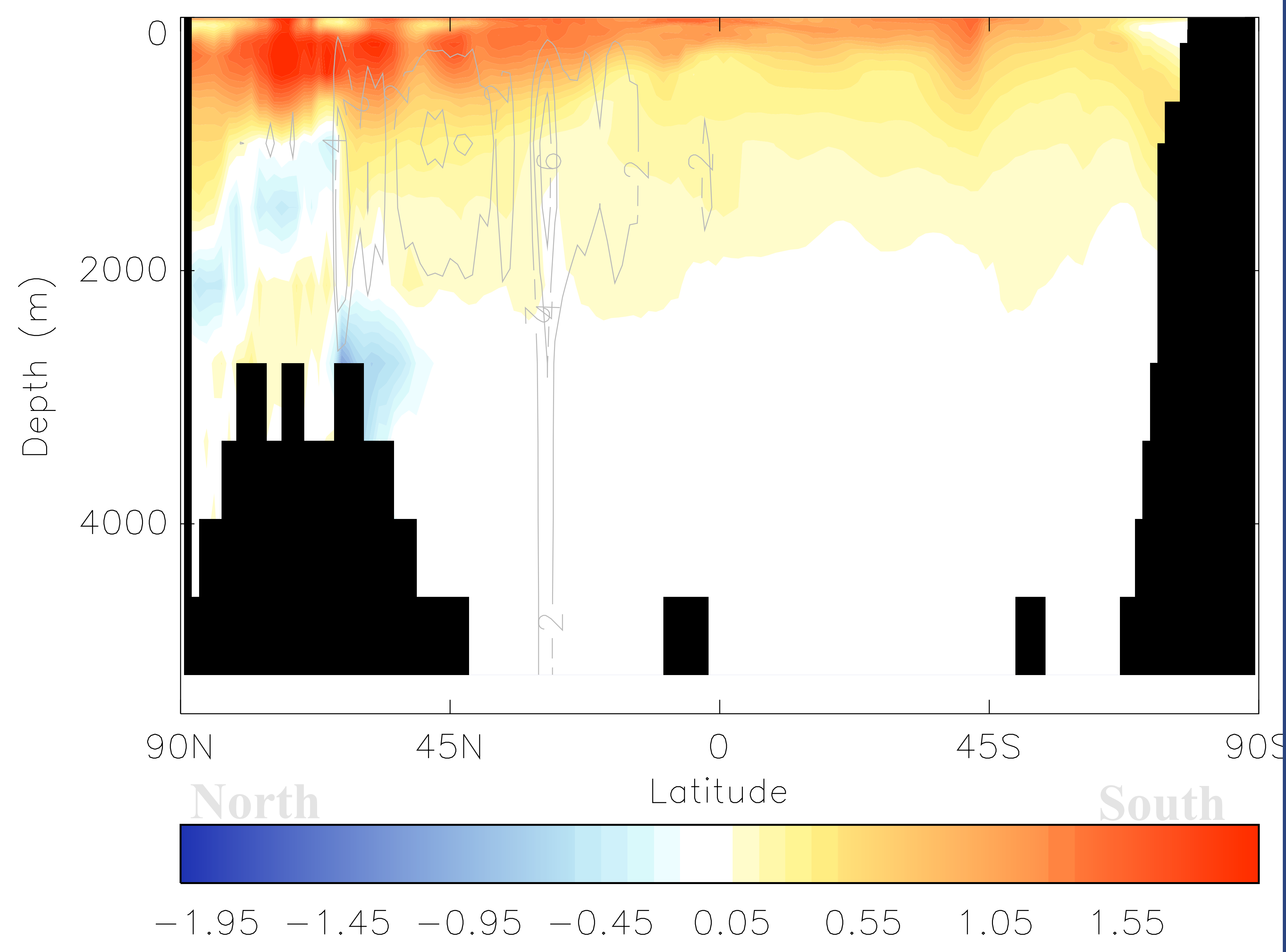
Questions II

3. What are the mechanisms by which the ocean model uncertainty causes uncertainty in the transient response?
    - Primarily changes in climate sensitivity, but also changes in ocean heat uptake efficiency. Compensation does not explain its small magnitude.
4. Is it spatially uniform? If not what shape does it take?
    - No. The same pattern as the uncertainty in the control climate.

Questions III

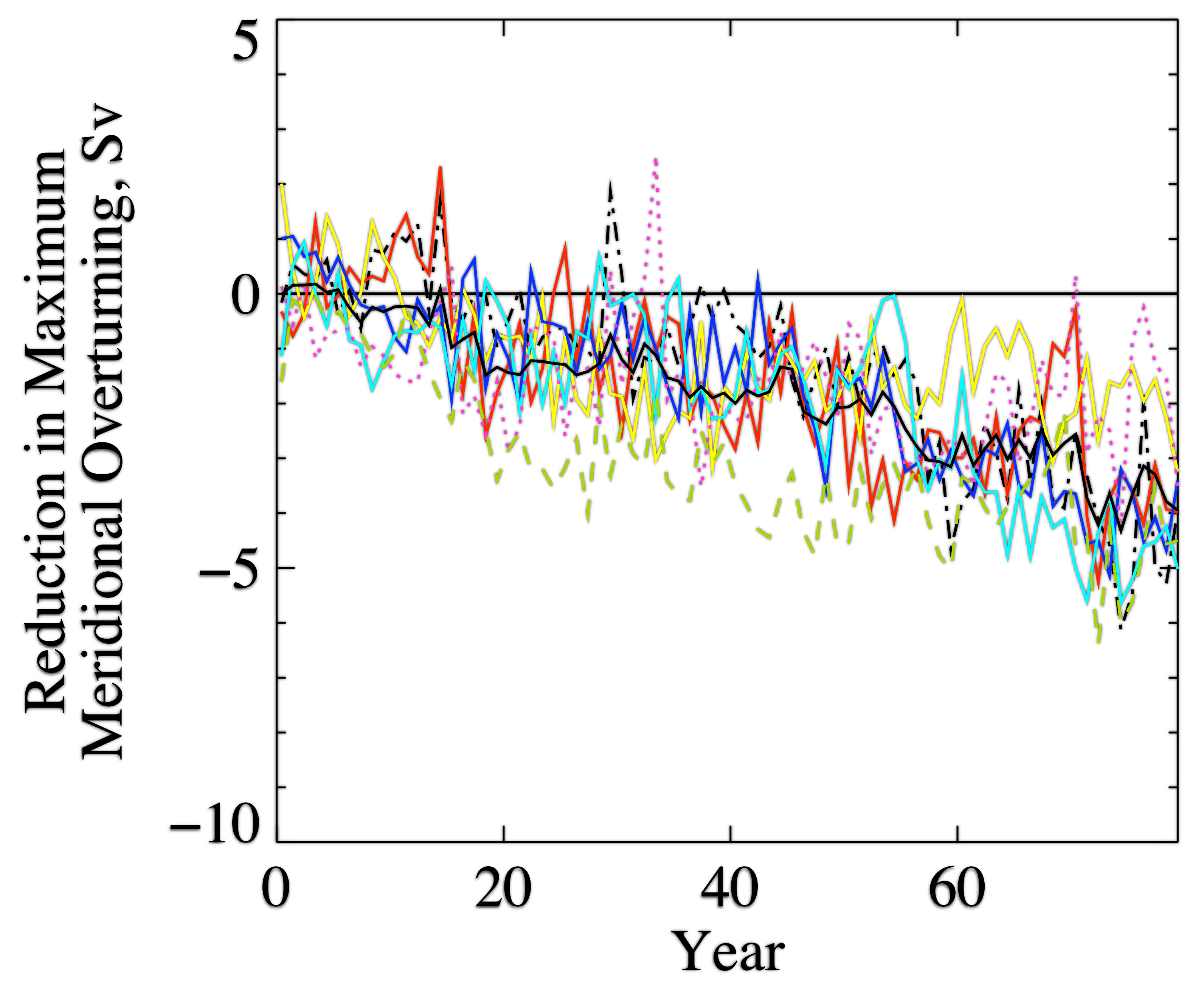
5. Are there changes in the Thermohaline Circulation?
6. Is the small global mean temperature spread due to regional compensation?
7. Climate sensitivity and ocean heat uptake efficiency are global mean diagnostics - what physical processes are behind the spread in them?

Ensemble Mean Atlantic Changes



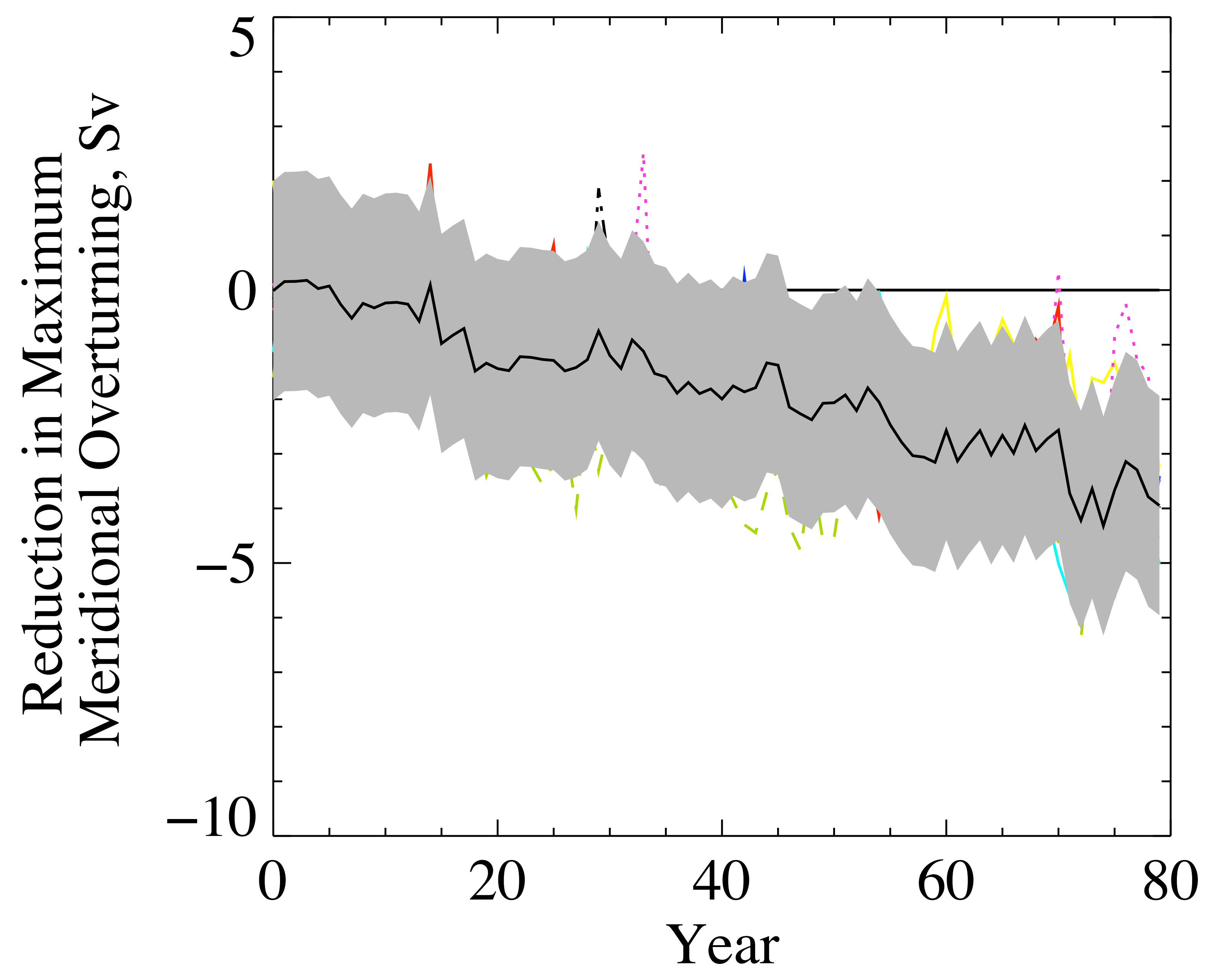
Colours = Temp change (K), white is “no change”,
Contours = circulation change in Sv

Thermohaline Circ.



- Timeseries of the reduction for each ensemble member

Thermohaline Circ.



- The same figure with the ensemble mean ± 2 standard deviations of natural variability overplotted.

THC Spread

- There is ensemble spread in the magnitude reduction in the thermohaline circulation due to an increase in CO2.
- The spread is hard to differentiate from natural variability.

Conclusions

- Ocean model uncertainty has a detectable effect on the transient climate response.
- This effect is small compared to other uncertainties.
- Changes to climate sensitivity are more important in determining these effects than changes to the vertical heat transfers in the ocean itself.

Conclusions II

- The spatial patterns of climate change are not identical throughout the ensemble (unlike with forcing uncertainty).
- Significant differences in the response where there are differences in the control climate.
- Thermohaline signals hard to detect, but all reductions seem similar.

Future Work

- Two unanswered questions:
  - Is the small global mean response due to spatial compensation?
  - What are the physical process behind changes in climate sensitivity and ocean heat uptake efficiency