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)

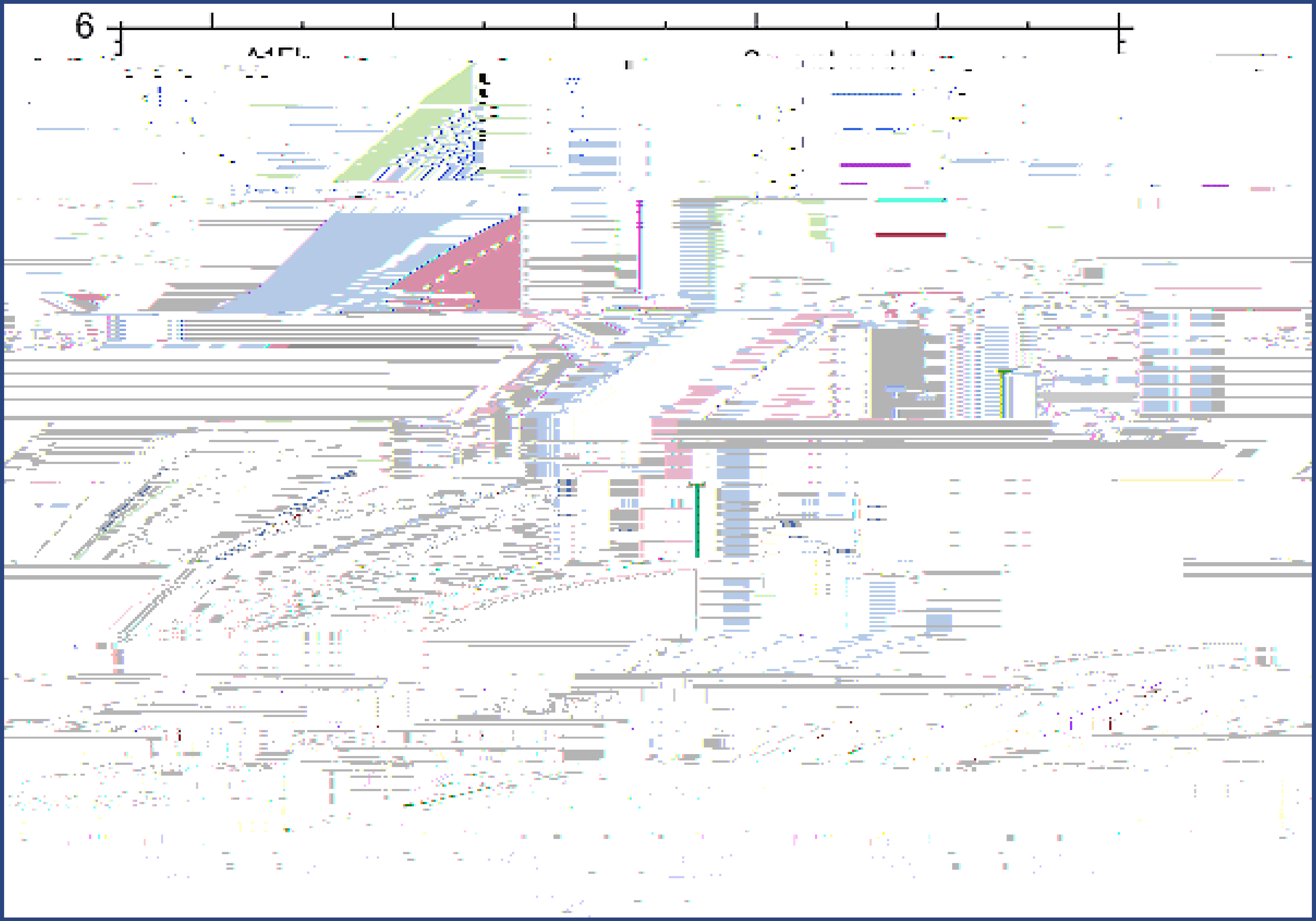
Imperfect Models

- 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



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).

Questions

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

Method I

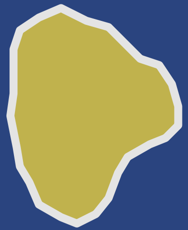
- Create a perturbed ocean physics ensemble, to sample the ocean model uncertainty.
- Perform a transient climate change experiment
- Compare the spread in the ensemble to the spread expected from internal (natural) variability.
- If the ensemble spread is larger

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

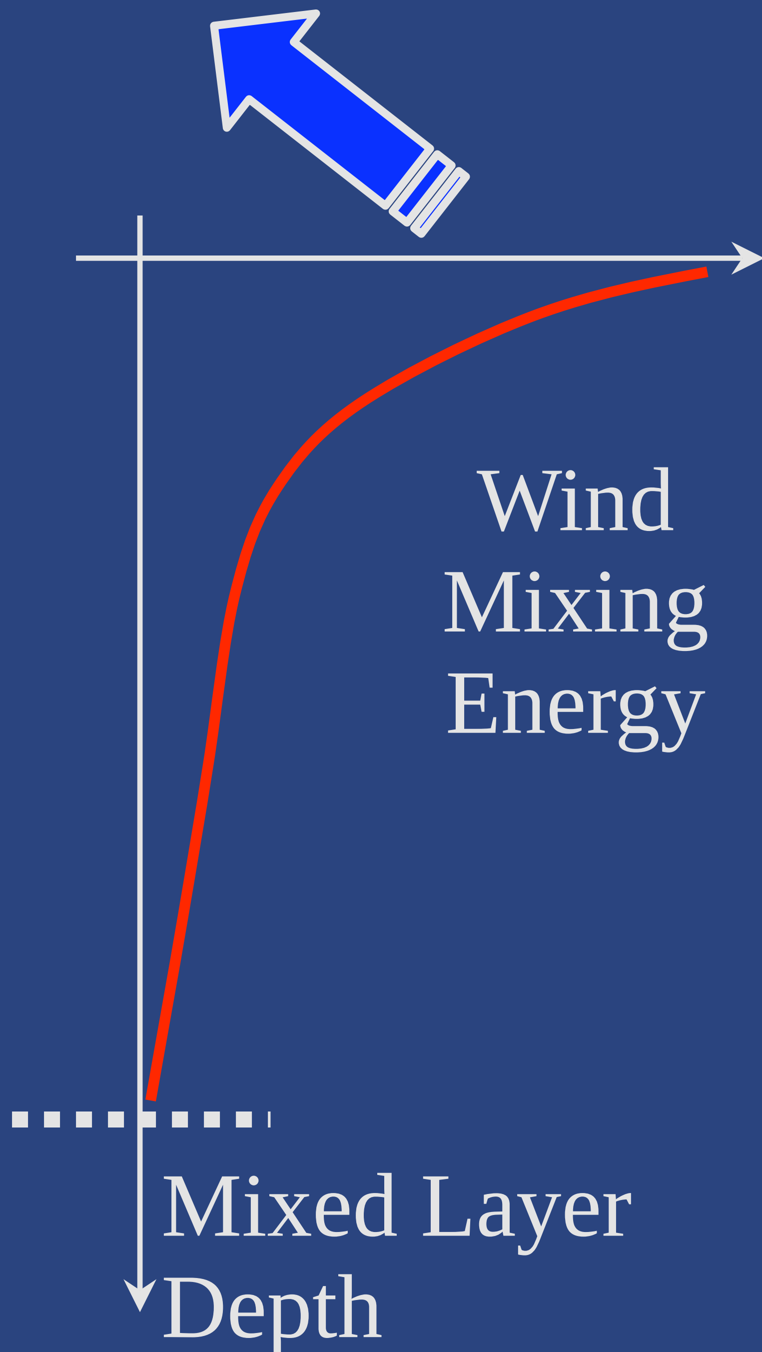
- Ask lots of experts in ocean modelling, what the most important parameters are.
- Find a range for those parameters (either from the

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

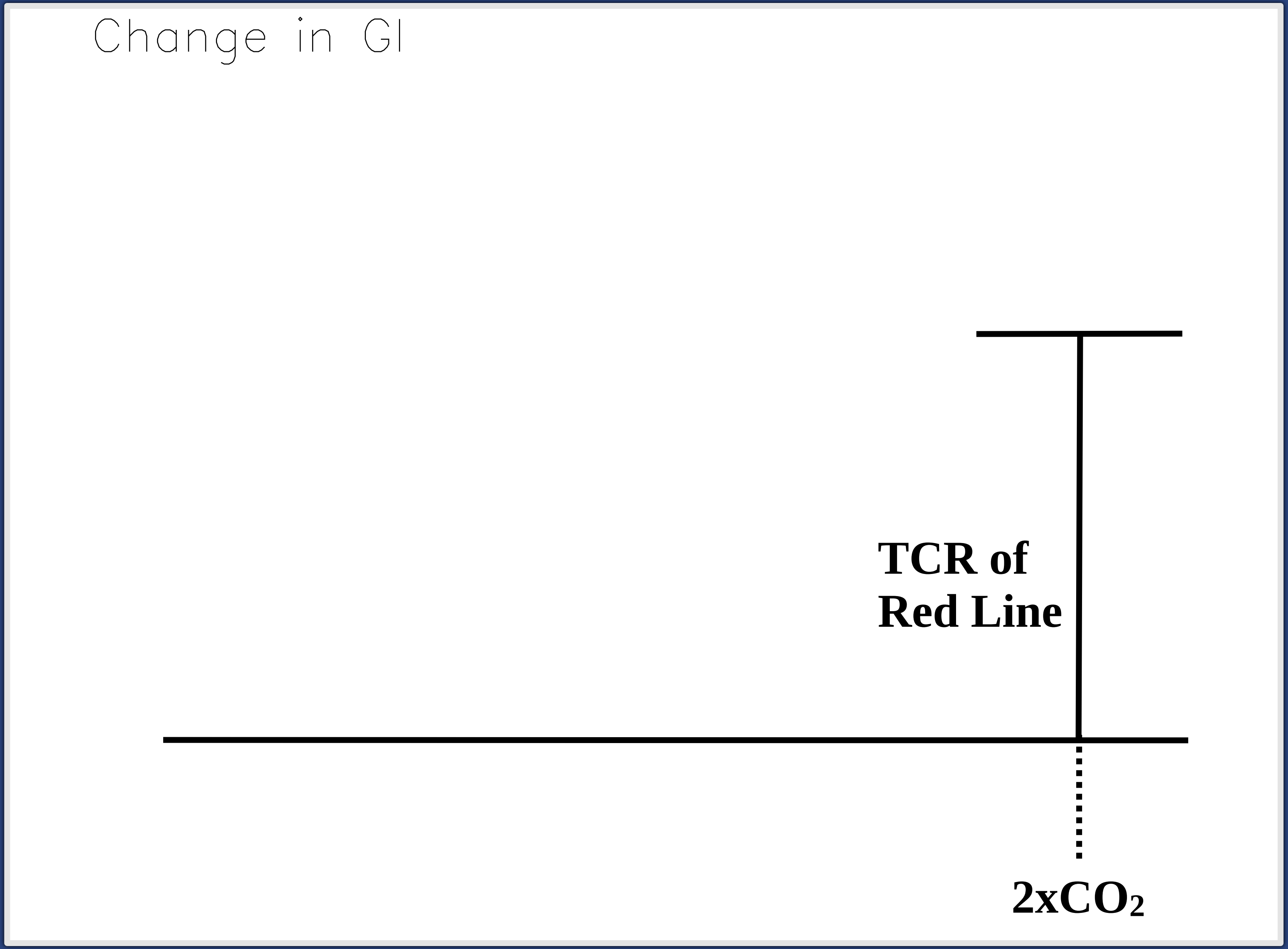
7 Ensemble Members

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.

Temperature in Increasing CO_2 Run

Transient Climate Response



Difference between 20 year average centred on time of $2xCO_2$ in 1% and the control state (IPCC, 2001)

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

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)

- Ocean ensemble is created with maximum and minimum perturbations only.
- Larger ensembles are more likely to find outliers.
- However ensemble is only 7 members.
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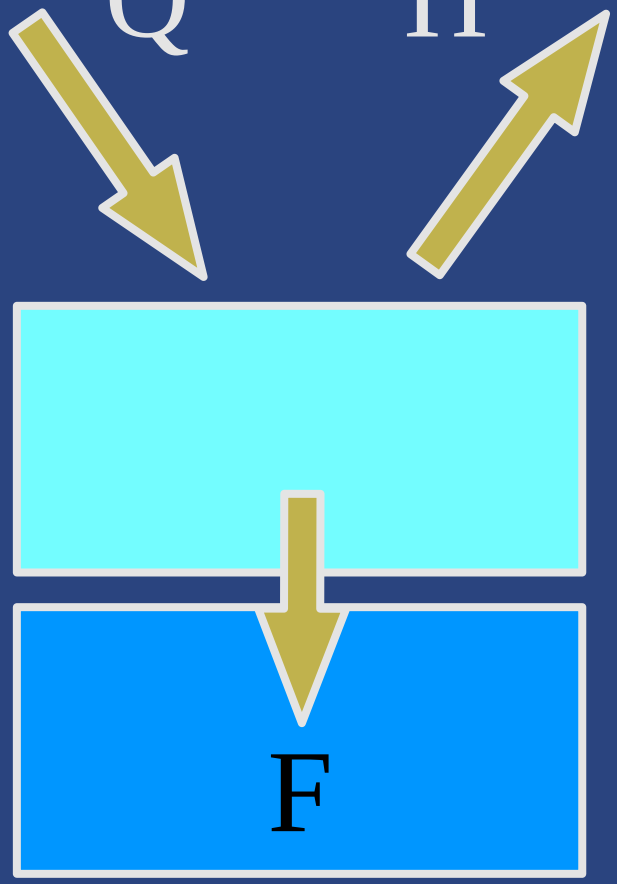
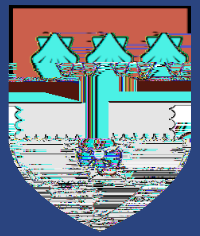
Global Energy Balance



- 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

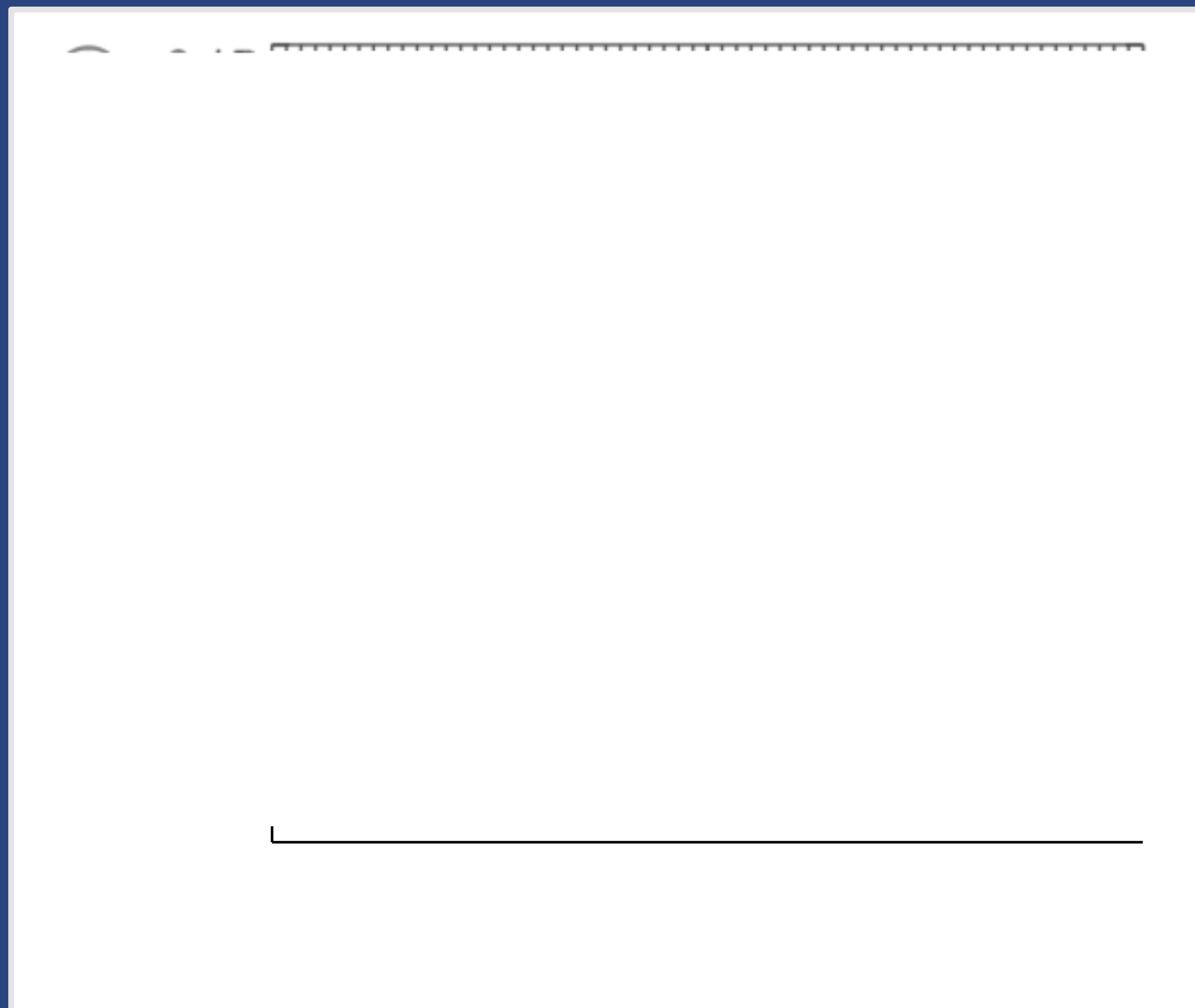
- Imbalance = Forcing - Response
- F = Q - H



Diagnosing these parameters

- Take 20 year averages and remove control mean (like the TCR).
- ! T = TCR, Q = 3.75 Wm^{-2} and F is a model diagnostic.
- TCR$_i$ = Q/("$_i$ + #$_i$)
- TCR$_{STD}$ + $TCR = Q/("$_{STD}$ + $" + #$_{STD}$ + $#)

Relative Effects



- No Compensation occurring.

- Changes in # are most important (% equilibrium feedback strengths).
- Changes in " (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

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?

What Shape?

- Ensemble spread in SST in the control simulation

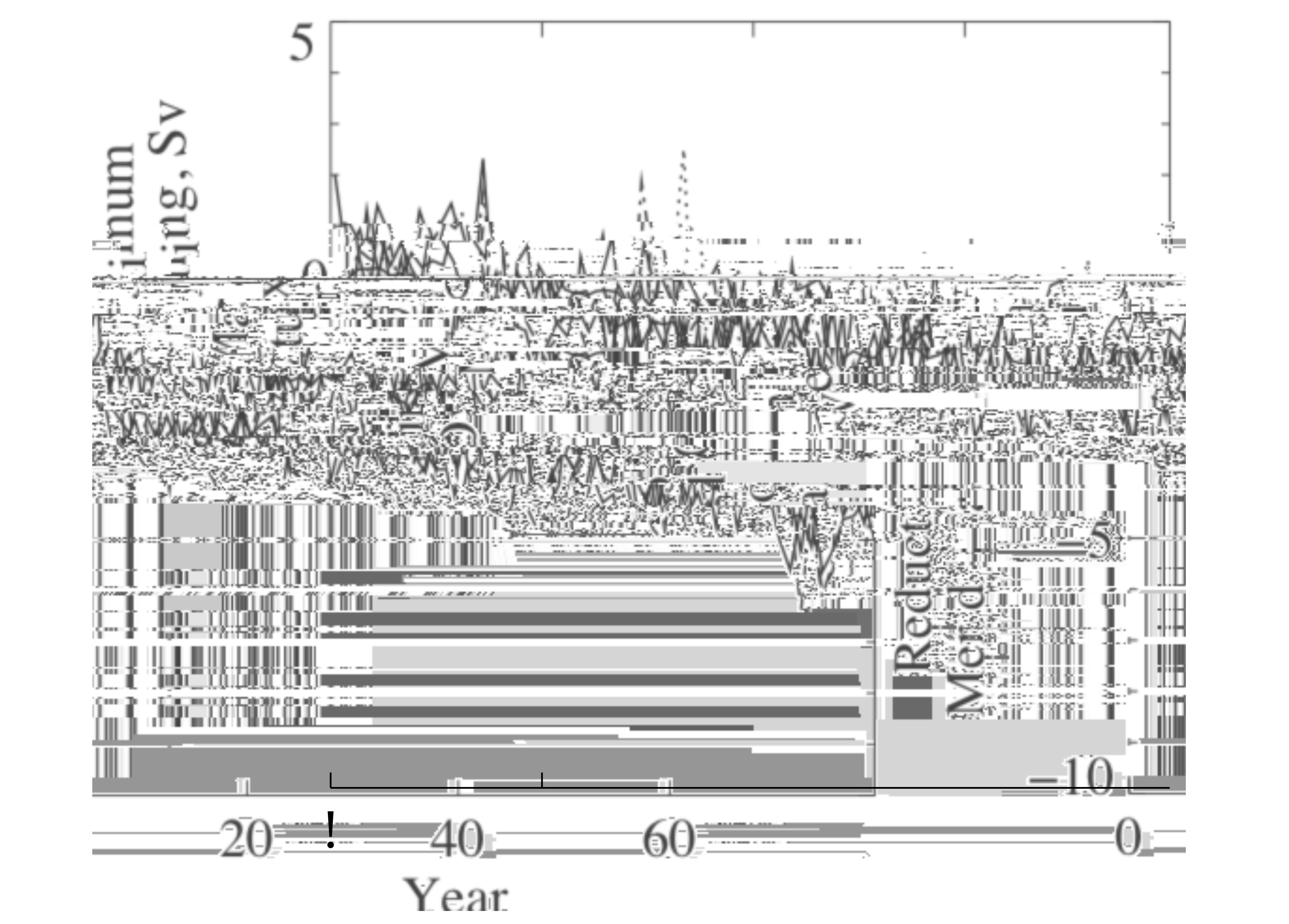
Questions II

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?

Thermohaline Circ.



- Timeseries of the reduction for each ensemble member

Thermohaline Circ.

THC Spread

- There is ensemble spread in the magnitude reduction in the thermohaline circulation due to an increase in CO_2.
- 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.

Future