Climate sensitivity of coupled models with differing ocean components

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Overview

- Introduction
  - The CHIME model
  - Summary of results from the control experiment
- Transient experiments
  - 1% CO_2
  - 0.1 Sv hosing
- Global and regional change in the 1% CO_2 experiment
- Why do CHIME and HadCM3 respond differently to hosing?
- Further plans

The CHIME Project

The Coupled Hadley-Isopycnic Model Experiment (CHIME) is a new coupled climate model, which

- Uses same atmosphere and ice models as in the Hadley Centre's HadCM3 coupled model

- Ocean model has same horizontal resolution as in HadCM3, but uses HYCOM (Hybrid Coordinate Ocean Model) instead of HadCM3's constant-depth coordinate model. Allows detailed examination of the influence of the vertical coordinate of the ocean component in a coupled system.

- Funded under the NERC Oceans 2025 programme and the NERC RAPID THCMIP project.

The ocean model

- HYCOM v2.1.34 with KPP mixing.

- Uses 2,000 dbar reference pressure for potential density (σ_2), and applies Sun et al. (1999) correction for thermobaricity.

- Spherical 1.25° x 1.25° grid south of 55°N, with bipolar grid covering Arctic (poles at 110°W and 70°E); 25 layers.

- Bering and Gibraltar Straits open.

Ice

- Semtner thermodynamics, plus drift with ocean surface current (same as in HadCM3).

Atmosphere

- 3.75° x 2.5° x 19 levels, hybrid coordinates.

The CHIME control experiment

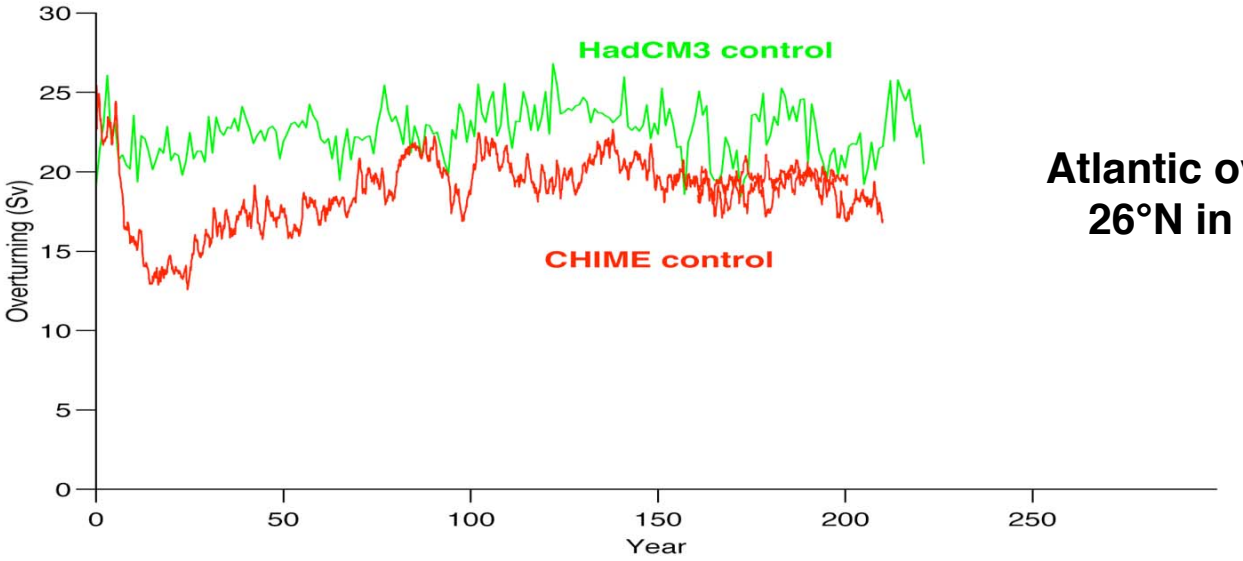
CHIME has been run for 200 years with pre-industrial CO_2 levels. Comparison with a control experiment of HadCM3 reveals that:

- Meridional heat transports similar in models and well within bounds of observational estimates.
- Mean AMOC similar in spatial structure and amplitude to that of HadCM3.
- CHIME does not show HadCM3's North Pacific cold anomaly.
- Evidence that CHIME has less numerical diapycnal mixing than HadCM3:
  - Less penetration of heat and salt into interior;
  - Better preservation of subtropical thermocline;
  - Better representation and preservation of NADW and SAMW

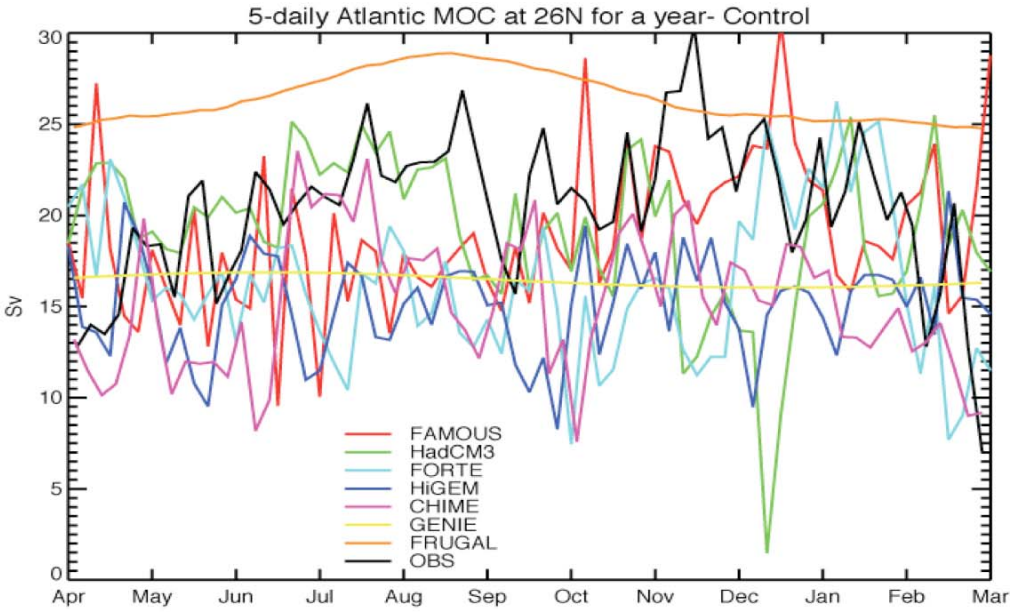
…but CHIME not unequivocally superior:

- too warm and salty in N. Atlantic (advection? Weak winds?)
- surface too warm in Southern Ocean (KPP ML bias)
- ACC spindown (remedied by WENO and reducing ice cover)

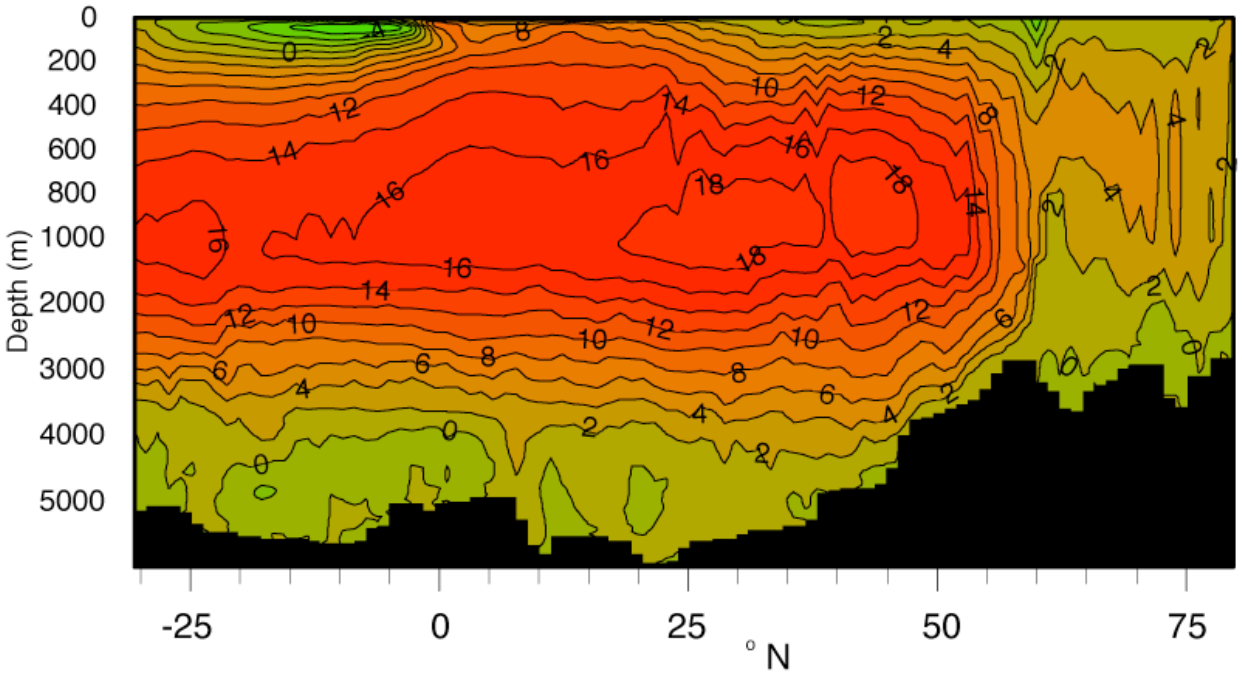
Atlantic MOC in CHIME and HadCM3 control runs



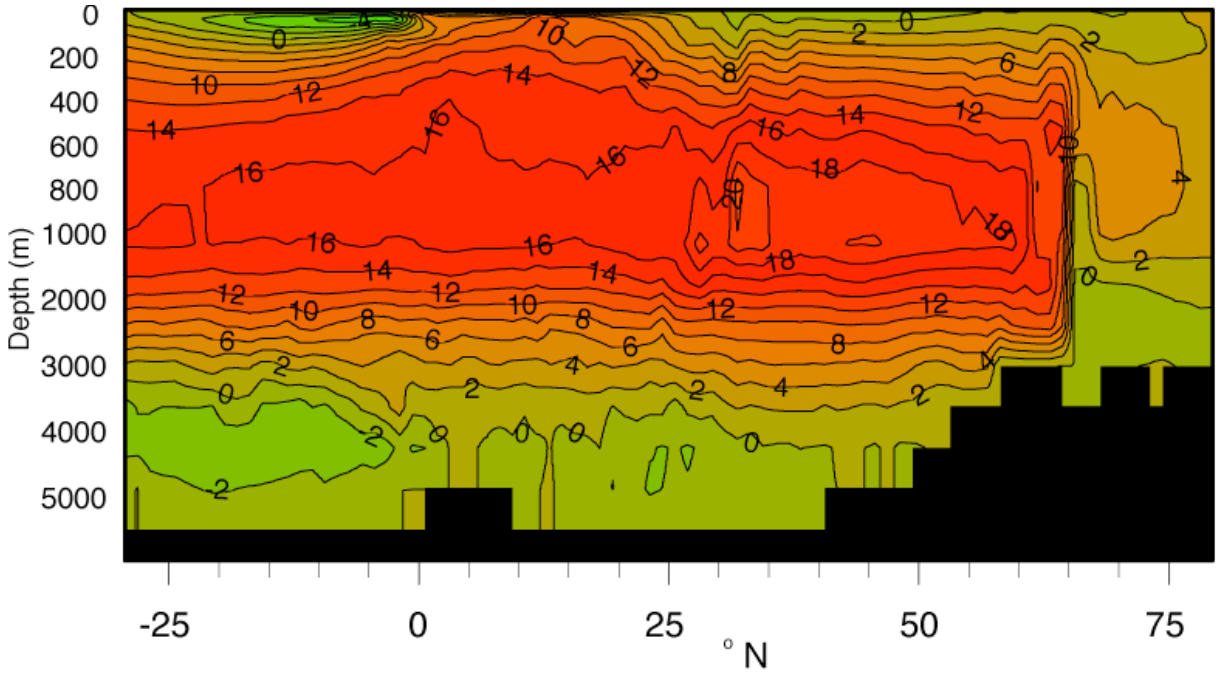
Atlantic overturning strength at 26°N in HadCM3 and CHIME



Annual cycle of AMOC at 26°N in RAPID THCMIP model ensemble (from Sarojini et al., 2011)



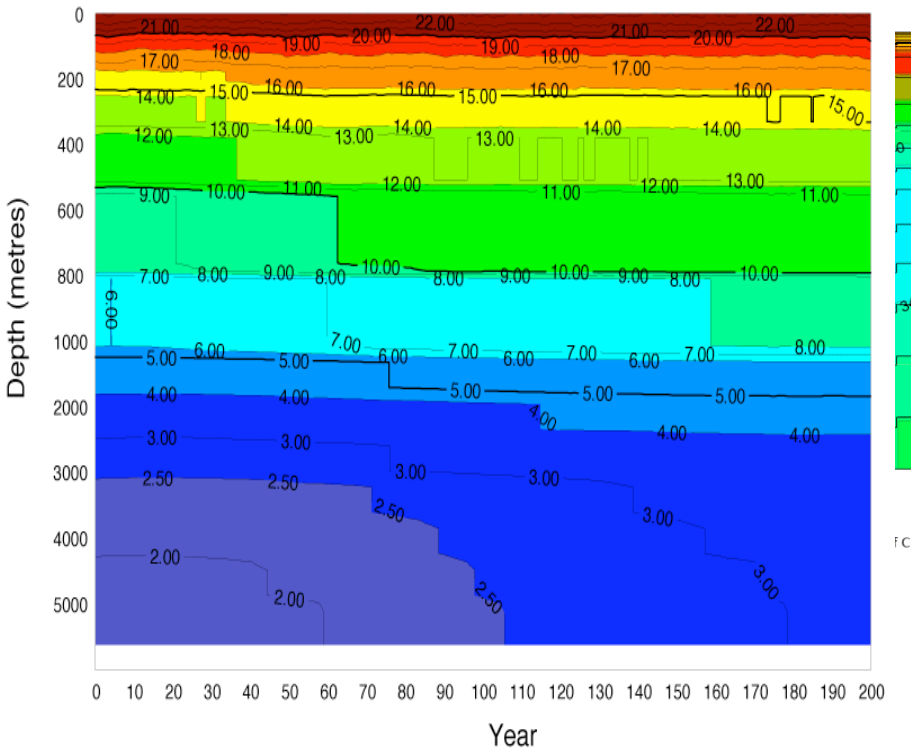
CHIME



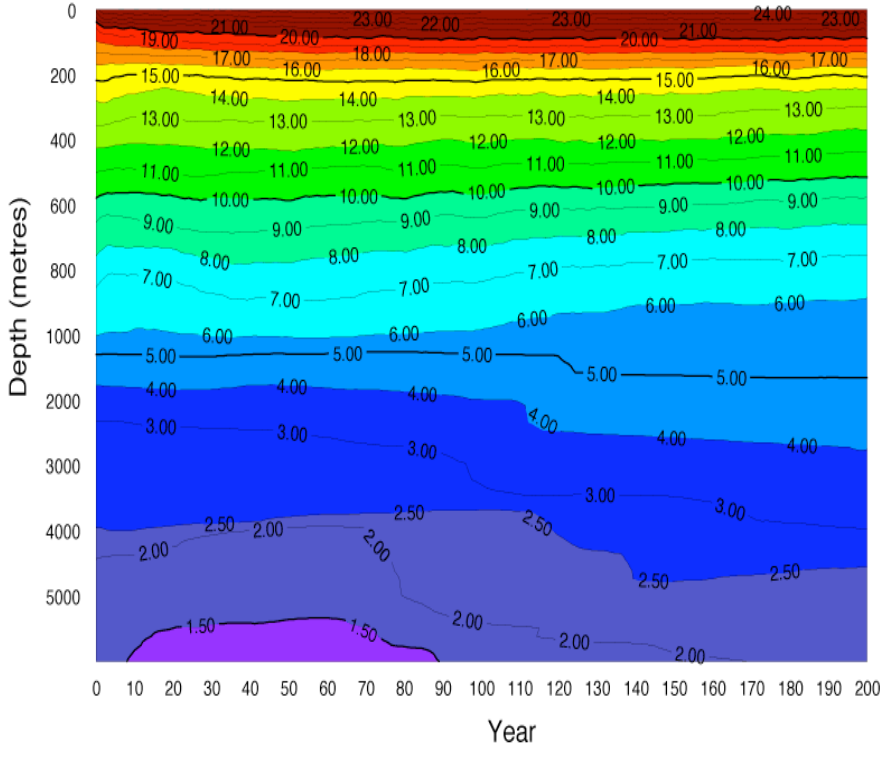
Atlantic overturning circulation

HadCM3

North Atlantic subtropical thermocline evolution



HadCM3

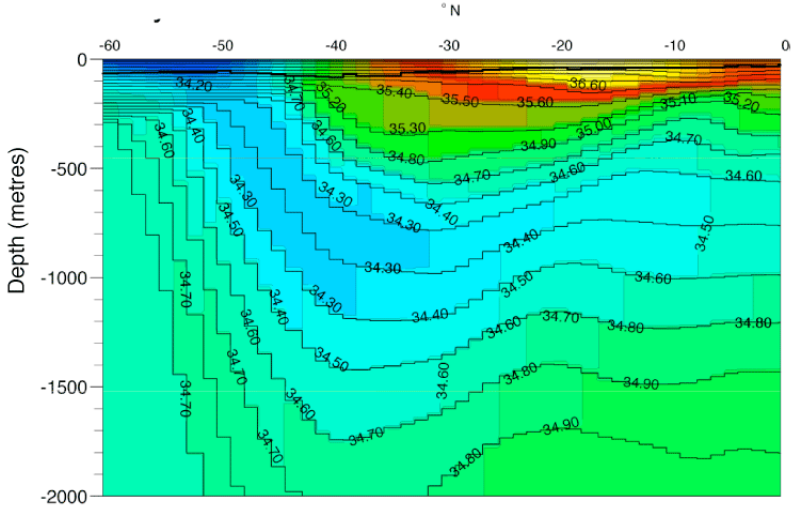


CHIME

- Thermocline becomes more diffuse in HadCM3, but sharper in CHIME (similar effect in Pacific but less pronounced).

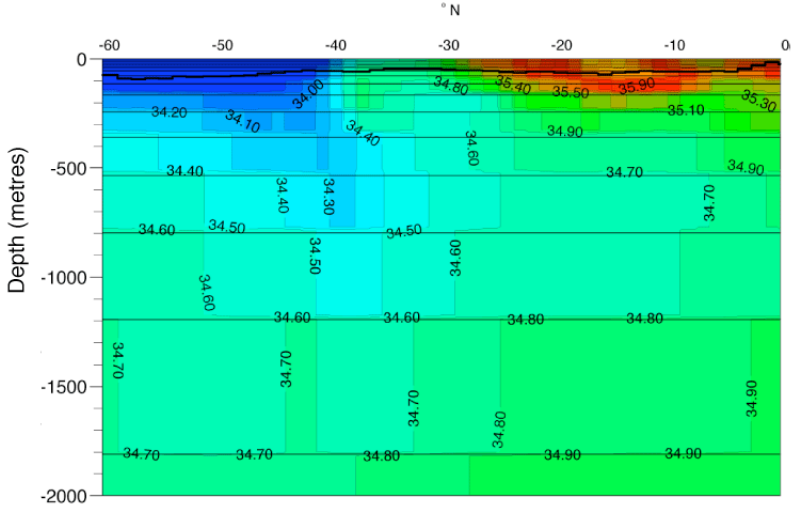
… so HYCOM may be under-diffusive…

Water Mass Preservation – Antarctic Intermediate Water

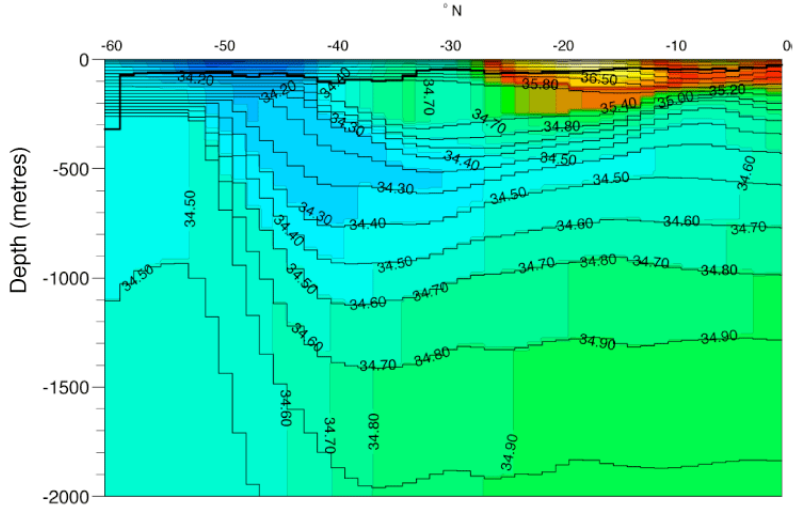


Salinity Sections at 30° W

Observations
(CHIME initial state)



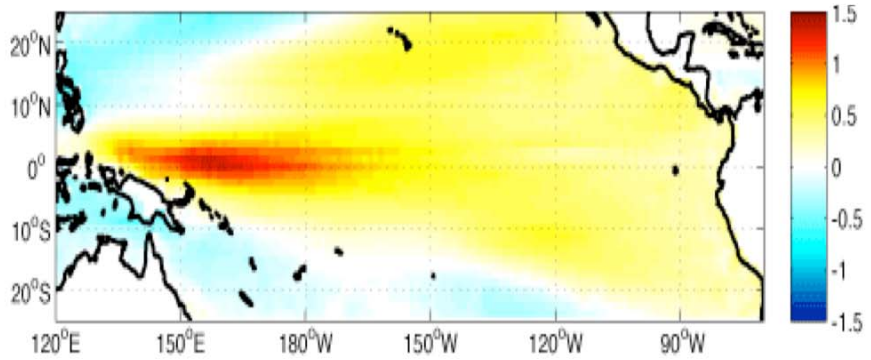
HadCM3, year 80



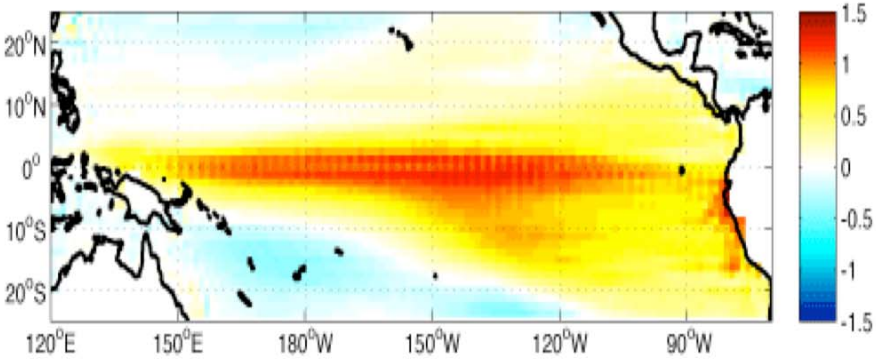
CHIME, year 80

ENSO signatures (surface)

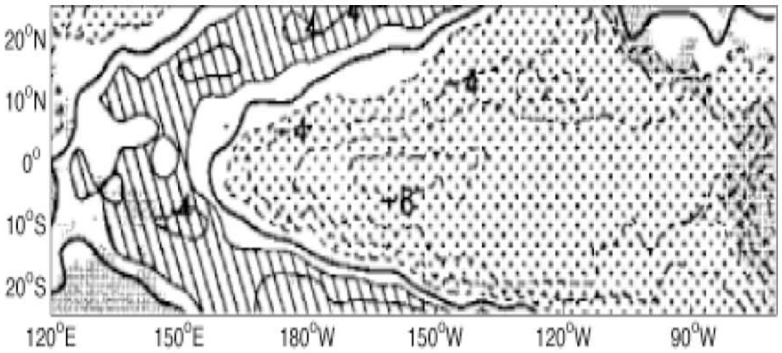
SST differences between ENSO plus and minus phases



CHIME



HadCM3

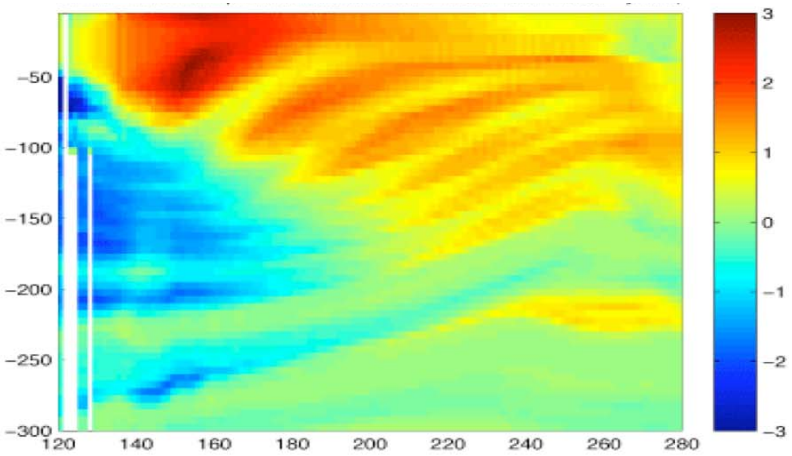


Correlation coefficient between SST anomalies and Southern Oscillation Index (Trenberth and Caron, 2000)

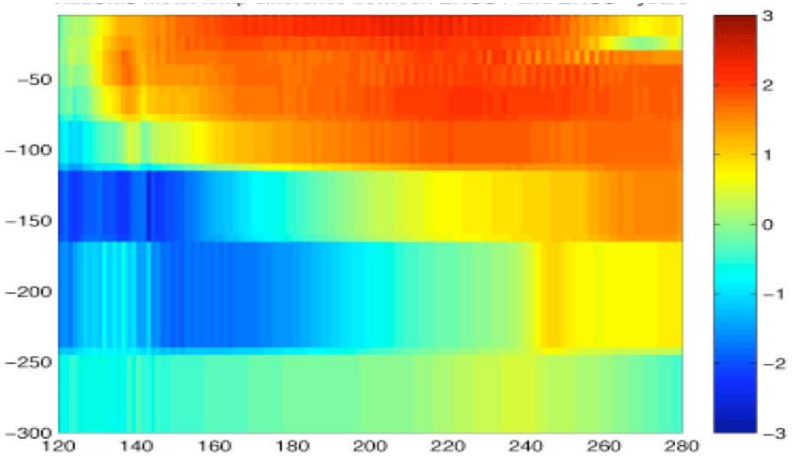
In both models the projection of the Southern Oscillation onto SST has a signature which is too zonally extended, and in CHIME the centre of action is too far west.

ENSO signatures (subsurface)

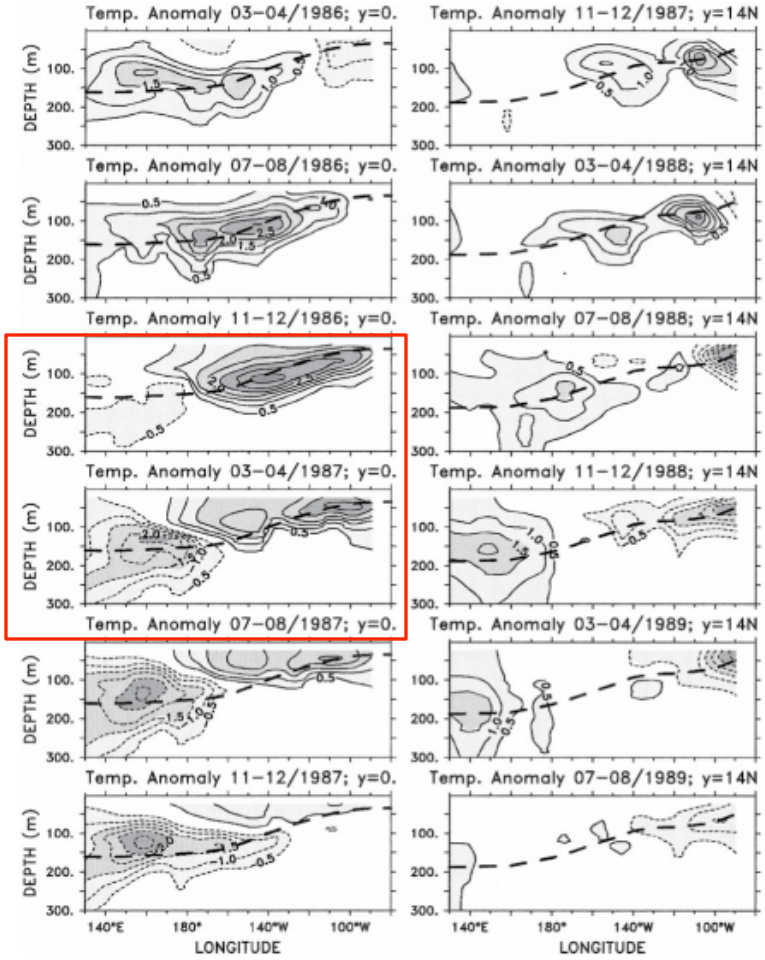
Temperature differences between ENSO plus and minus phases on section at 0°N



CHIME



HadCM3



Temperature anomalies from 1986-88 ENSO (Durand & Delcroix, 2000)

Sensitivity to climate change

Question: how sensitive is the climate change response of a model to the choice of vertical coordinate system of its ocean component?

SST is different in the two models (both globally and regionally), so we would expect differences.

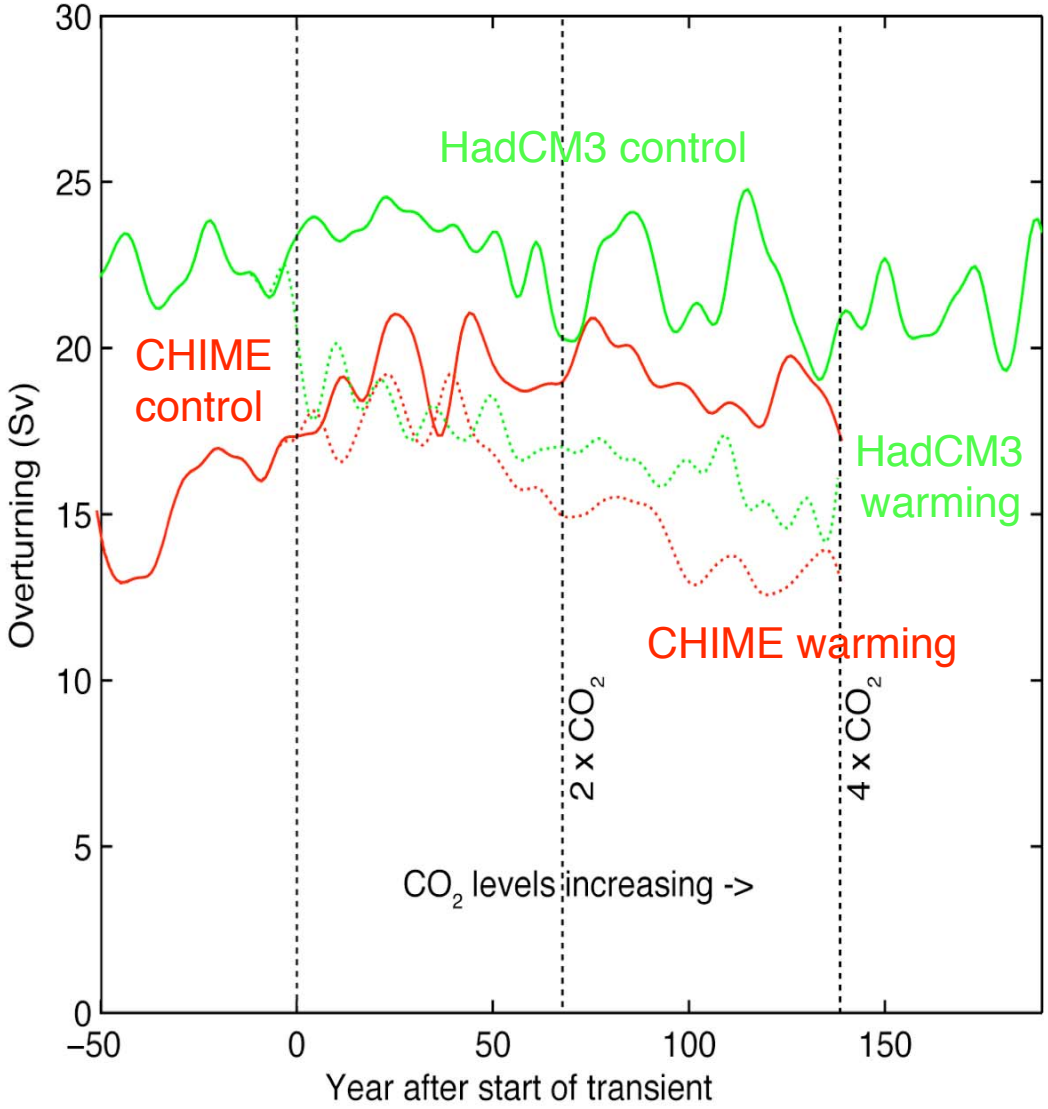
We address this issue by carrying out standard CMIP sensitivity experiments with CHIME and HadCM3.

Extra runs started from year 60 of the CHIME control run:

- Increase atmospheric CO_2 level by 1% per year
  (higher than the rate of increase in the real world, but establishes the sensitivity to GHG increases)

- Hosing experiment:
  Add freshwater to the surface of the North Atlantic between 50°N and 70°N at a rate of 100,000 m^3/s (0.1 Sv).

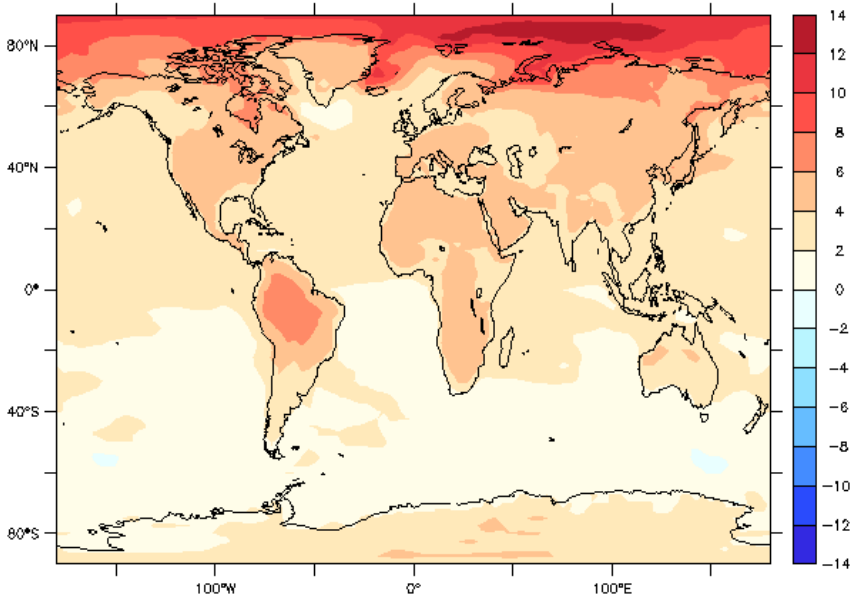
Effect of global warming on North Atlantic overturning



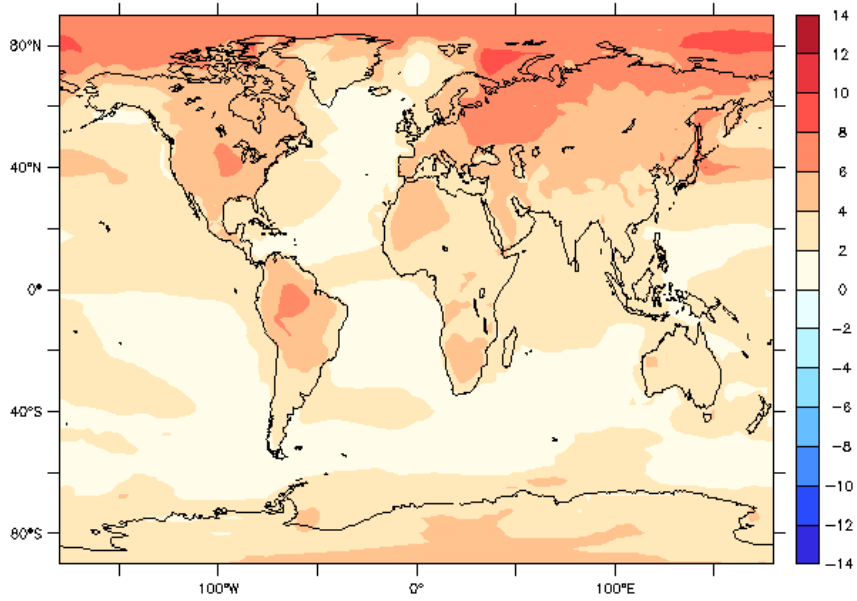
North Atlantic overturning in HadCM3 and CHIME 1% CO_2 runs

Similar reduction in overturning circulation in both models by about 5 Sv (20%).

Air temperature changes in warming experiments



CHIME



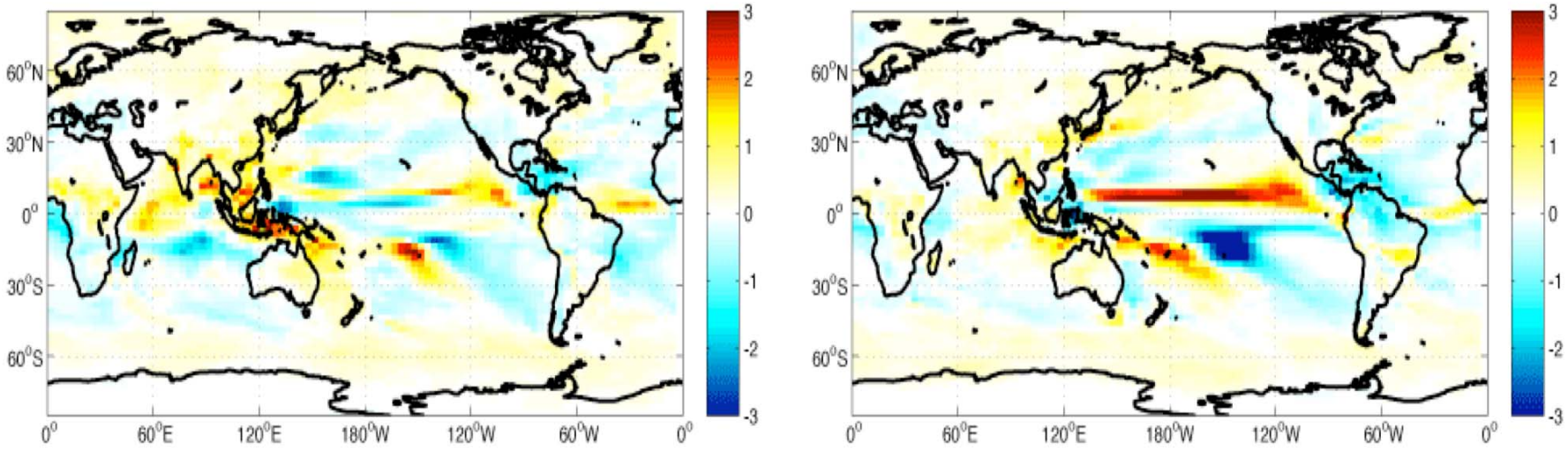
HadCM3

Global Surface Air Temperature anomalies (CO_2 minus control) at doubled CO_2

- Both models show the Arctic as the region of most rapid warming,
- … but much more warming there in CHIME than in HadCM3

  - so Arctic is the most uncertain region for predictions

Large-scale precipitation changes under increasing CO_2



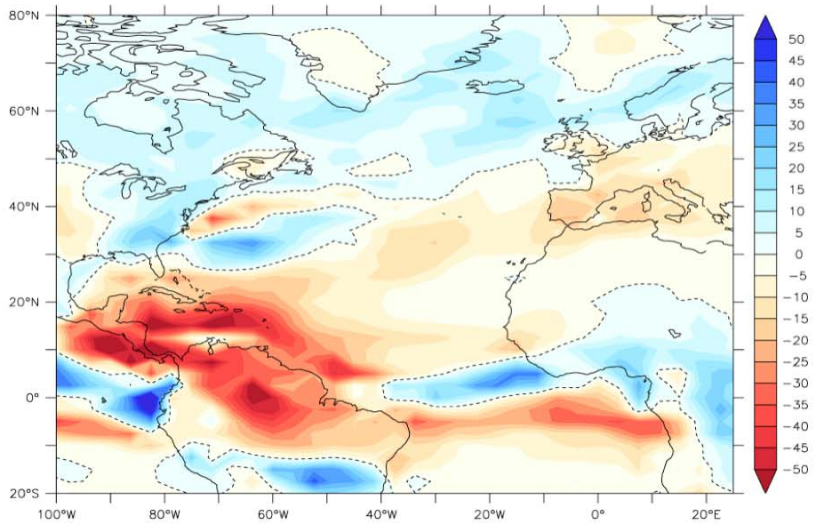
CHIME **HadCM3**

Global rainfall anomalies (CO_2 minus control) at doubled CO_2

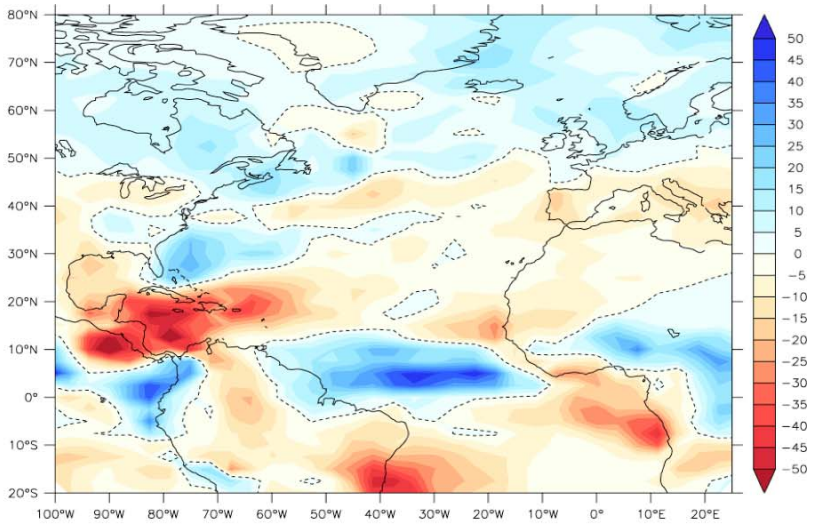
- Similar overall patterns
- … but regional changes are different – especially in Pacific

Changes in North Atlantic rainfall under increasing CO_2

CHIME



HadCM3

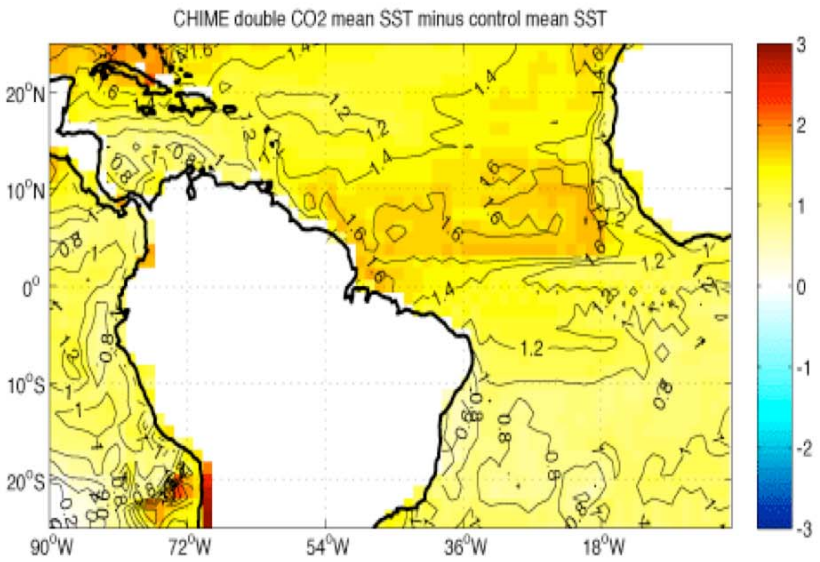


Precipitation change on doubling CO_2

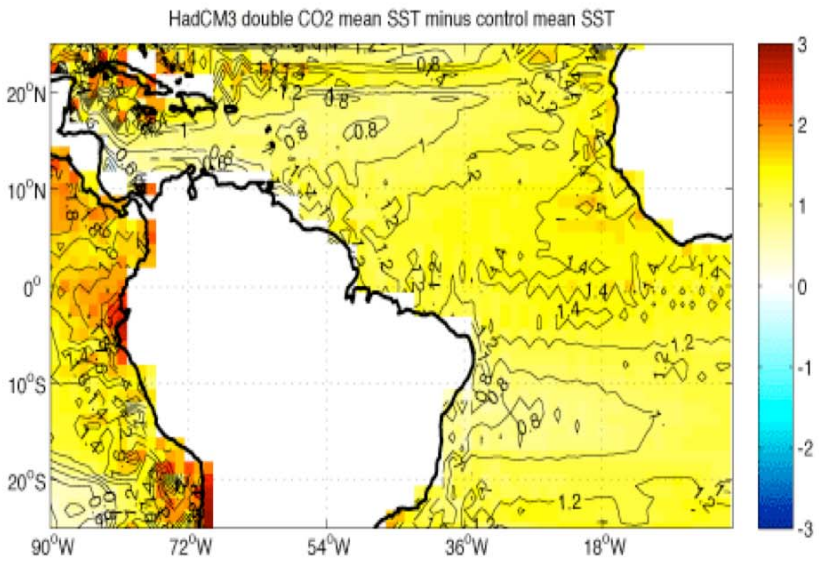
- "Amazon dieback" reported in HadCM3 (Cox et al., 2004) is not seen in CHIME.

Tropical Atlantic SST under increasing CO_2

CHIME



HadCM3

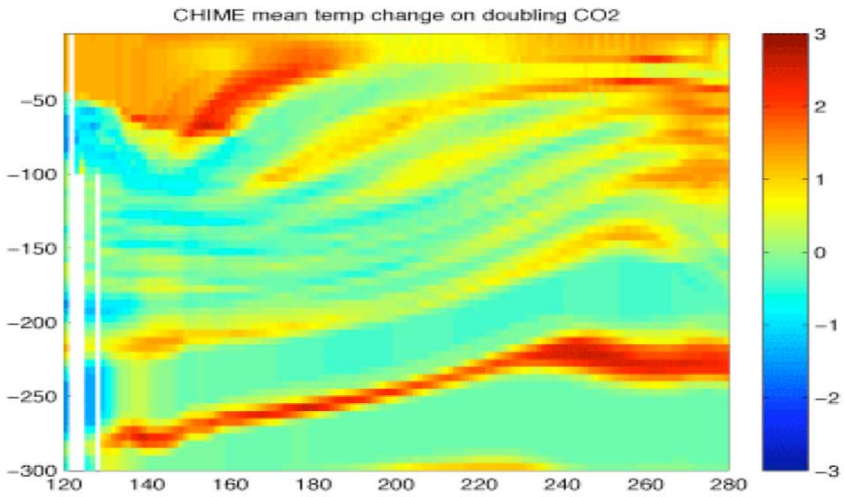


SST change on doubling CO_2

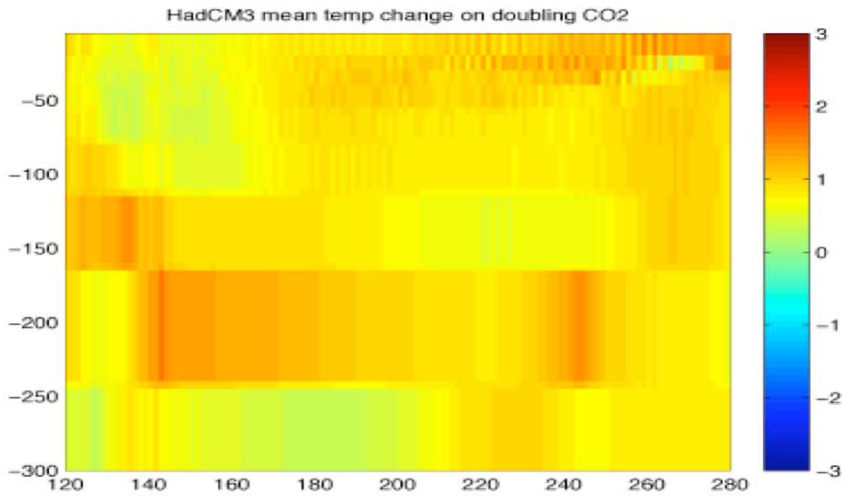
- Enhanced warming north of Equator in CHIME: 1.7°C vs. 1.3°C in HadCM3
- SST gradient across Equator increases and ITCZ intensifies.

Penetration of heat in equatorial Pacific in warming experiment

CHIME



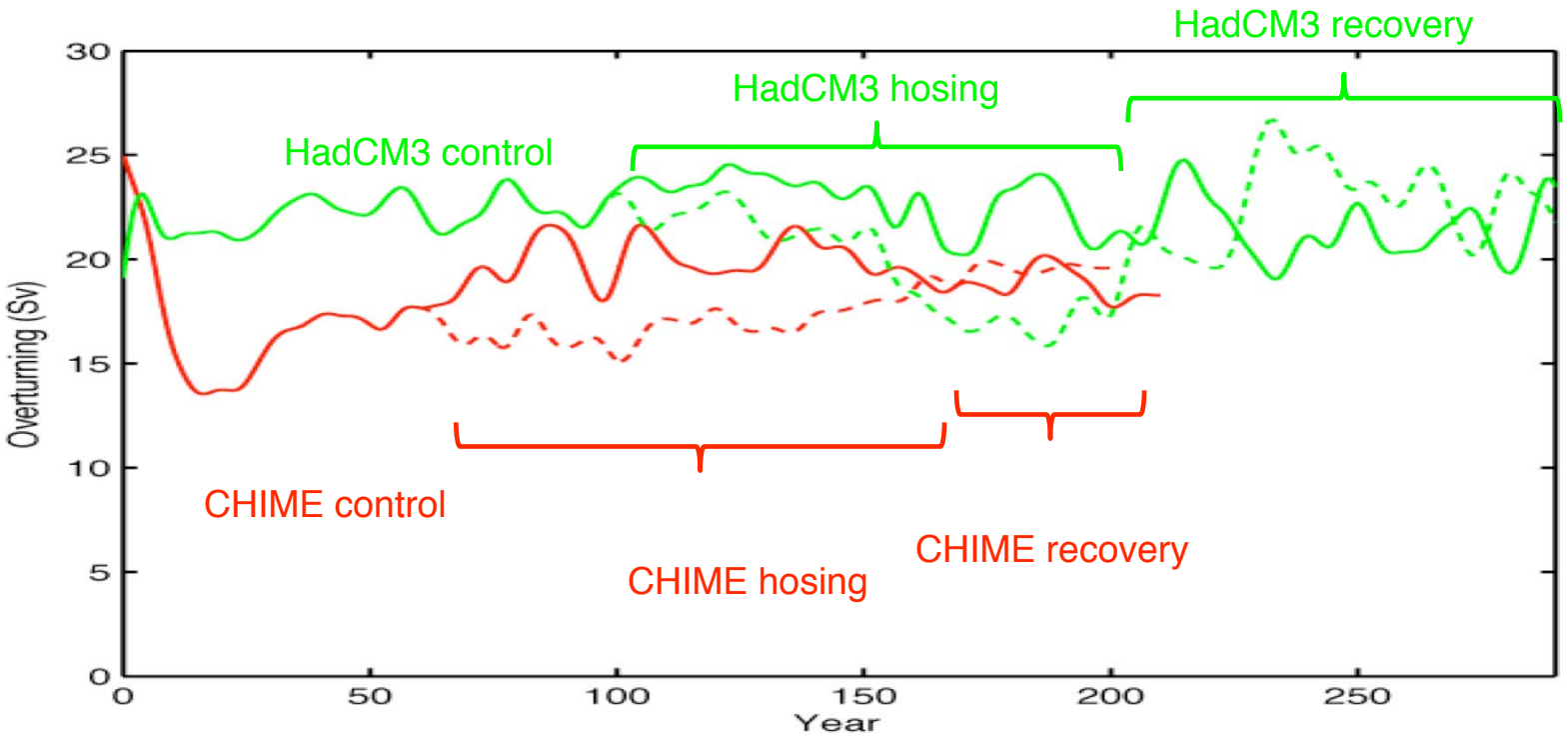
HadCM3



Temperature change on equatorial Pacific section at doubled CO_2

- Although thermocline signatures of ENSO cycle in control experiments are similar in two models, heat is transferred downwards very differently!
- Below thermocline, changes in CHIME appear to be adiabatic (heaving of isopycnals), but strongly diabatic in HadCM3.
- … more analysis on global scale needed.

AMOC changes in hosing experiments



Response to 0.1 Sv of freshwater hosing is different in two models:

- In HadCM3 MOC reduces steadily, then rebounds after hosing is removed;
- In CHIME reduction is ~ 5 Sv after 40 years, and the model recovers by itself before hosing is removed.

Why does CHIME respond differently to freshwater hosing?

Overturning in CHIME appears to be less sensitive to hosing than that in HadCM3.

Several possible reasons:

- CHIME is intrinsically more stable than HadCM3 because of its coordinate system (c.f. ECHAM4/OPYC model in IPCC AR3; Sun & Bleck, 2001);

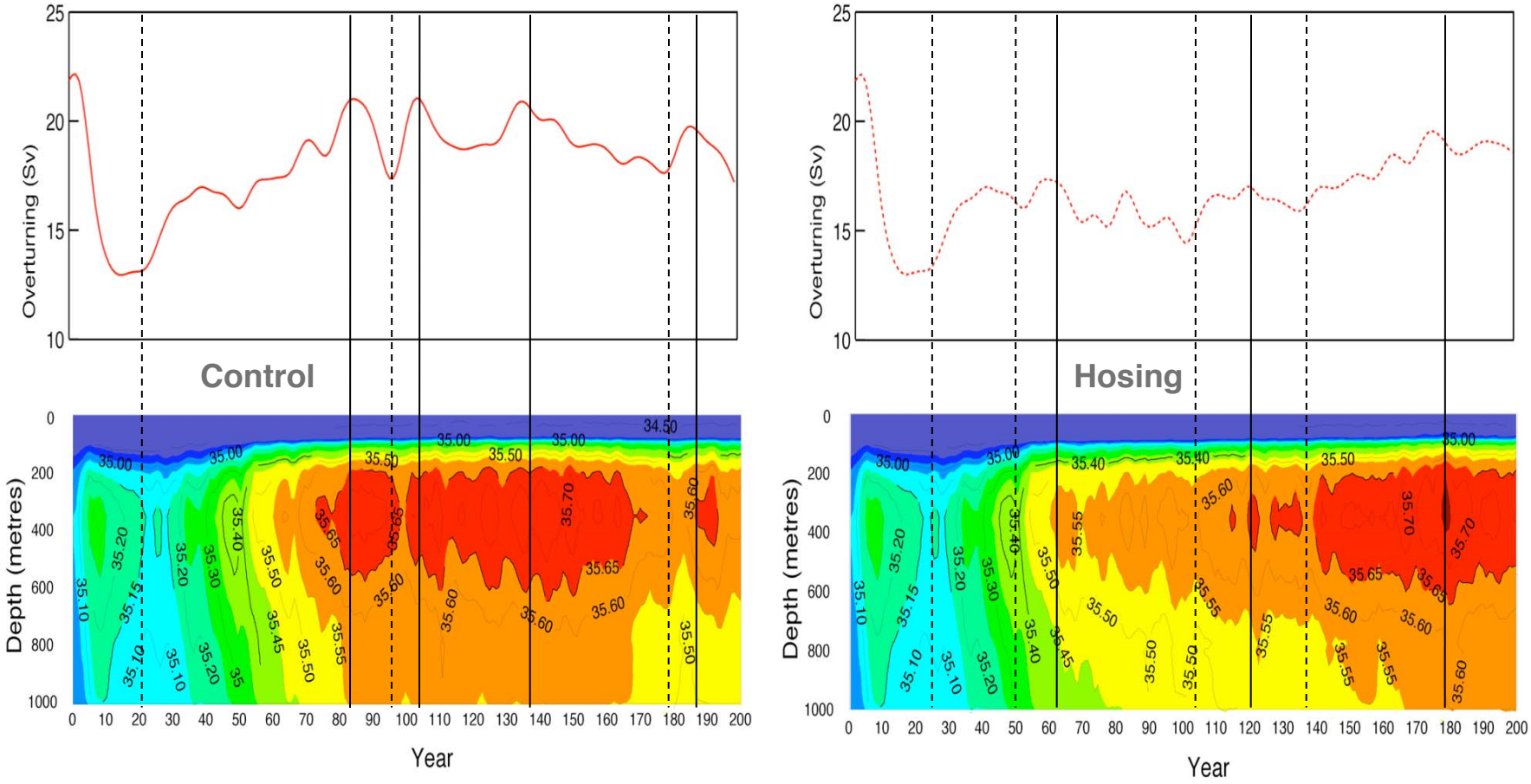
- or CHIME is intrinsically more stable than HadCM3 because of the salty error in the subpolar North Atlantic;

- or the CHIME ocean has a more efficient adjustment system e.g. isopycnal propagation of salinity anomalies, or convective mixing.

AMOC and North Atlantic salinity

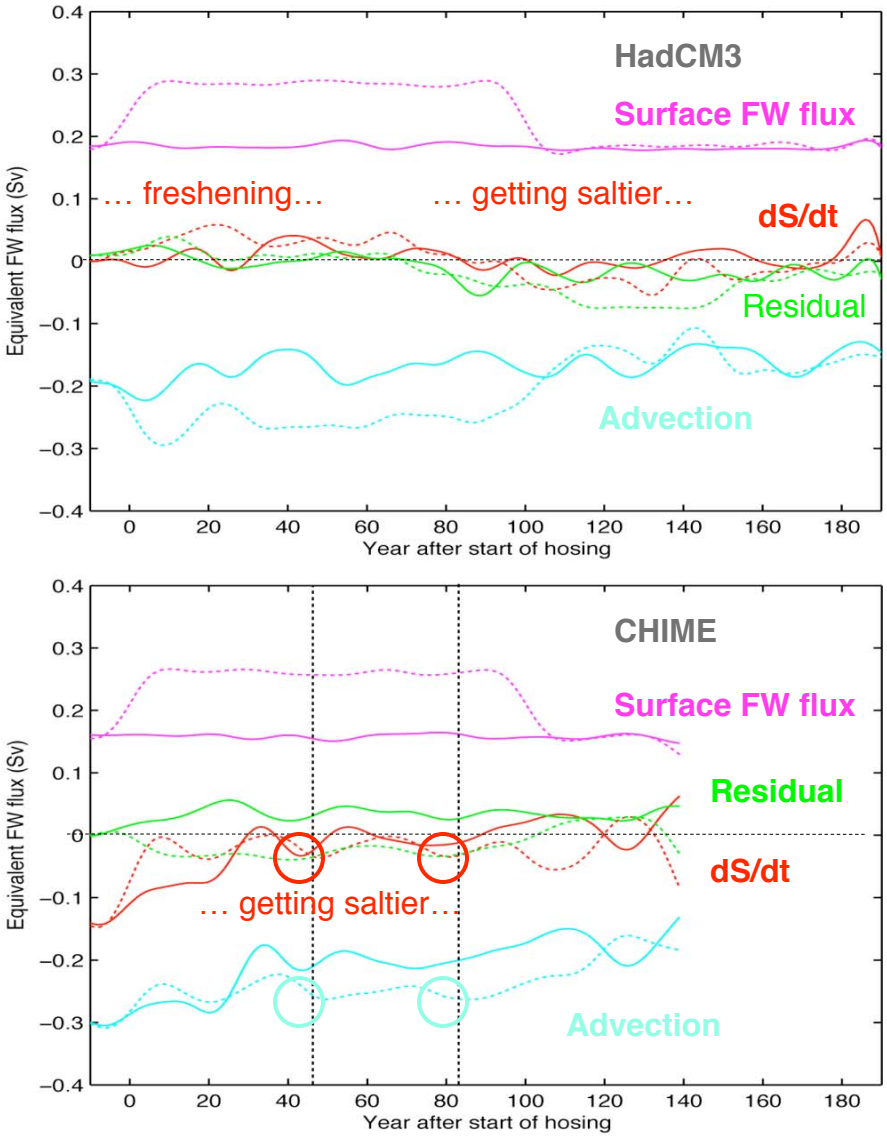
- Clear connection in CHIME (as in HadCM3) between overturning and upper ocean salinity north of 50°N

MOC at 30°N



Mean salinity 50°-70°N in CHIME

Subpolar freshwater balance



Freshwater budgets in N .Atlantic, 50°N - 70°N (hosing runs dashed)

- Natural variability of surface fluxes is relatively small.

- In both models, salt advection increases to (almost) balance extra freshwater input from hosing.

- Decadal variability in salt content dominated by changes in advection: two increases in CHIME hosing run correspond to increasing salinity in subpolar region.

- CHIME is less spun-up than HadCM3, as control run is still getting saltier at start of transient.

Summary

• Have compared two coupled models with same atmosphere and ice models, but one (HadCM3) has z-coordinate ocean and the other (CHIME) has HYCOM.

• CHIME is “as good as” HadCM3 in most respects, but shows evidence of reduced spurious numerical mixing in the ocean (Megann et al., J. Climate 2010).

• Response of both models to increasing CO_2 is similar, but significant differences include:

- patterns of rainfall change (especially Pacific and Amazon)
- more warming in Arctic in CHIME
- different heat transfer from surface to interior

• CHIME appears more stable to freshwater hosing in the North Atlantic than HadCM3 – possibly different dispersal mechanism for freshwater?

Next steps

• Ongoing analysis of AMOC variability (Persechino et al.)

• Analysis of heat penetration in 1% CO_2 experiments

• Have recently ported CHIME to new hardware at NOCS. Have just started long (multi-century) control integration to look at

- decadal MOC variability
- ENSO

• Carry out experiments with different mixing schemes and parameter choices (e.g. make CHIME ocean more diffusive)

• Run with more realistic forcing scenario

• We also have funding under NERC RAPIT project to set up CHIME within *climateprediction.net,* and run large ensembles (Adam's talk!).