Comparing the CHIME coupled model with HadCM3

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Rapid Climate Change

Overview

- Introduction
  - The CHIME model
  - What do we expect?

- Results
  - Meridional overturning
  - Heat budget and transports
  - Surface errors
  - Horizontal circulation
  - Thermocline evolution
  - Deep water preservation
  - Summary

- 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.

Set up under a NERC COAPEC funded project, and now continued under the NERC Oceans 2025 programme and the RAPID THCMIP modelling project.

The ocean model

- HYCOM v2.1.34 with KPP mixing.

- Uses 2000 dbar reference pressure for potential density (σ_2), and applies a 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)

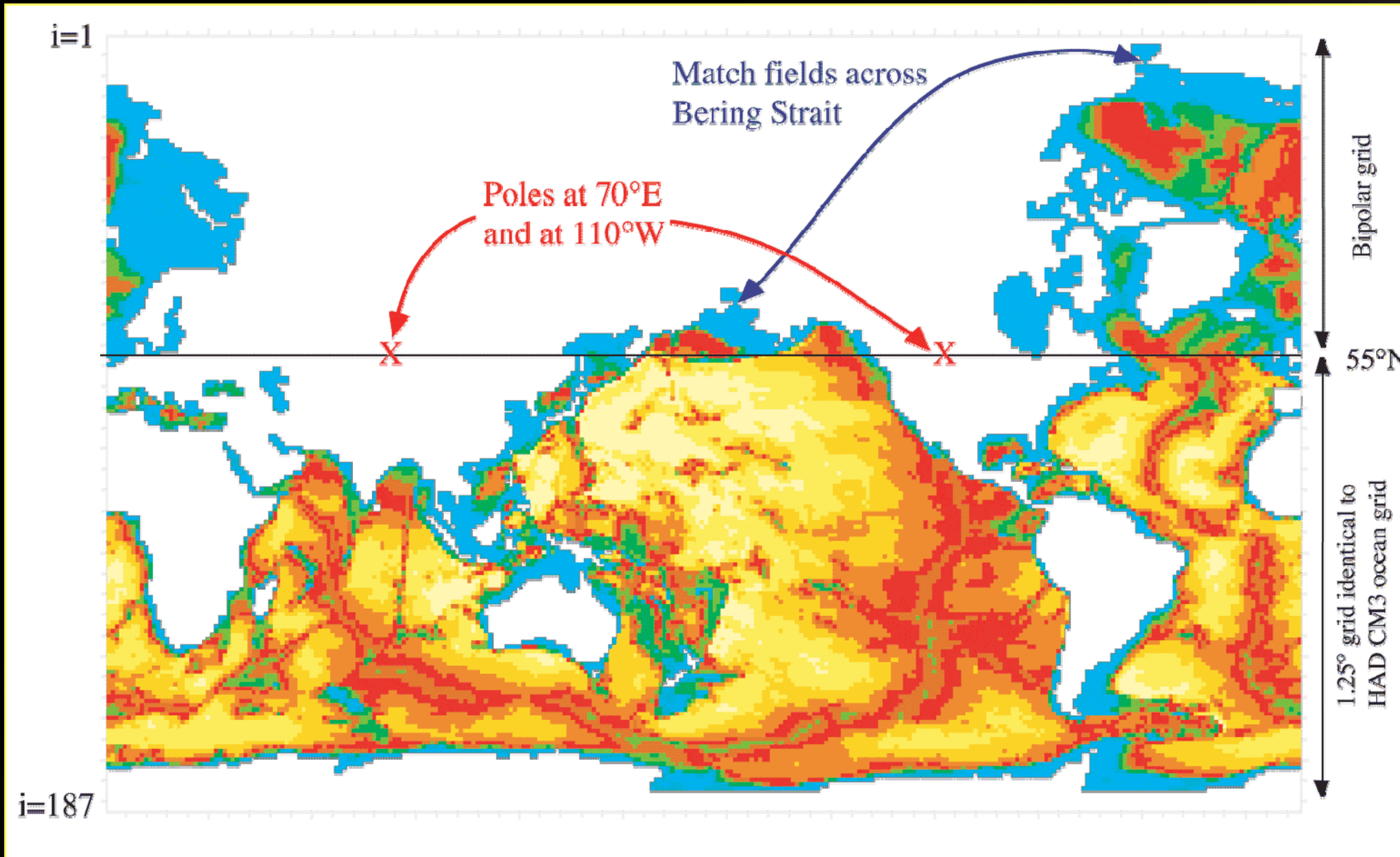
- Bering and Gibraltar Straits open.

Ice

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

Atmosphere

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



Chime ocean grid and bathymetry

What would we expect?

- Less diffusion in ocean interior (but not clear whether this holds in transition region between isopycnic and constant-depth regimes)

- Differences in penetration of heat from the surface to the ocean interior

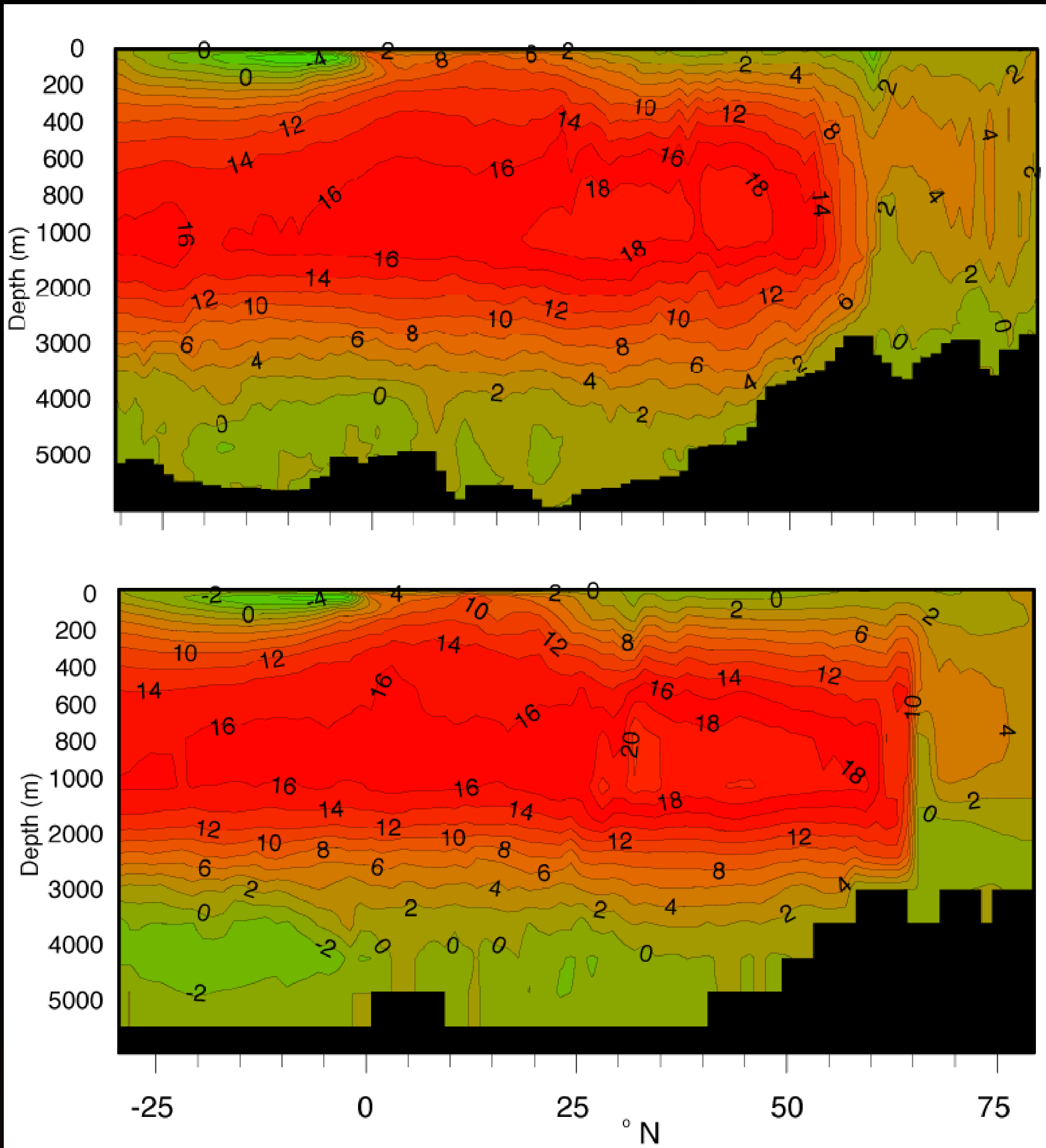
- Better representation and preservation of water masses

- Differences in gyre circulation (already seen in ocean-only comparisons)

But...

- HadCM3 is well tuned, particularly for realistic surface temperature (in present-day climate at least). Substituting a different ocean may give unexpected results – and may not necessarily be better.

- HadCM3 and CHIME use different mixing schemes, so cannot separate unambiguously the effects of vertical coordinates.



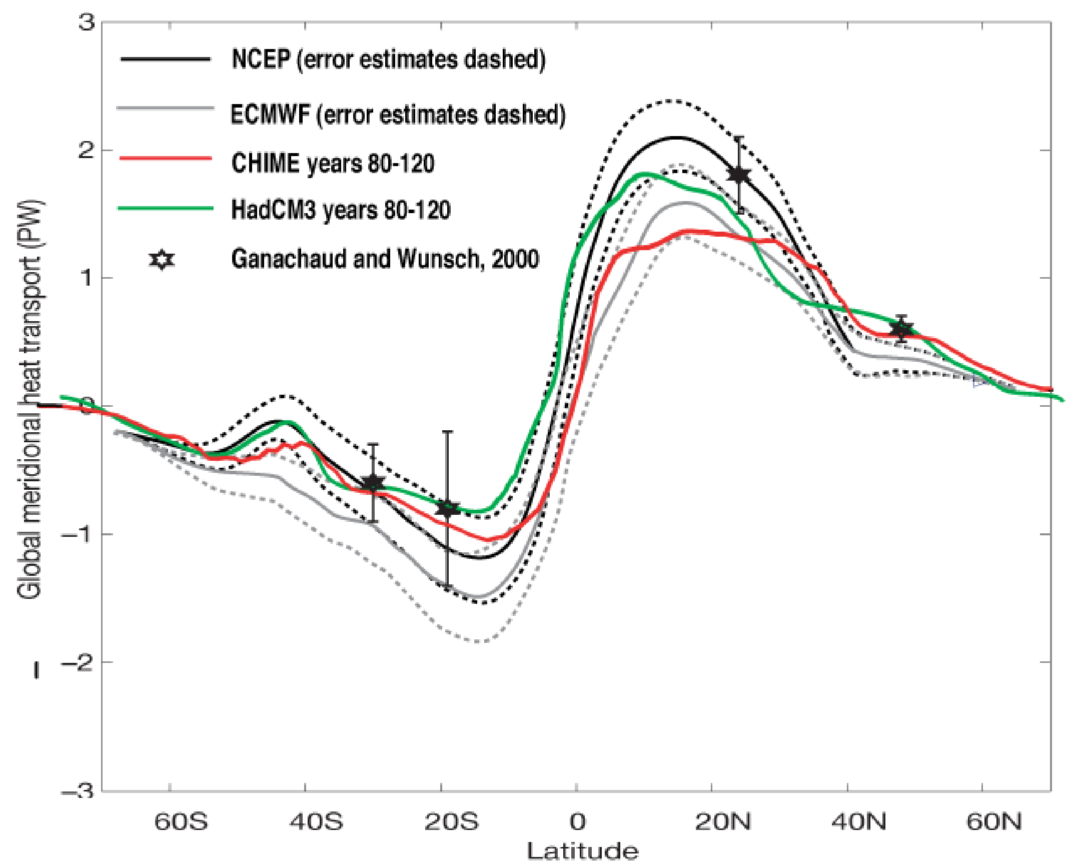
CHIME

Atlantic overturning circulation

HadCM3

Heat transport

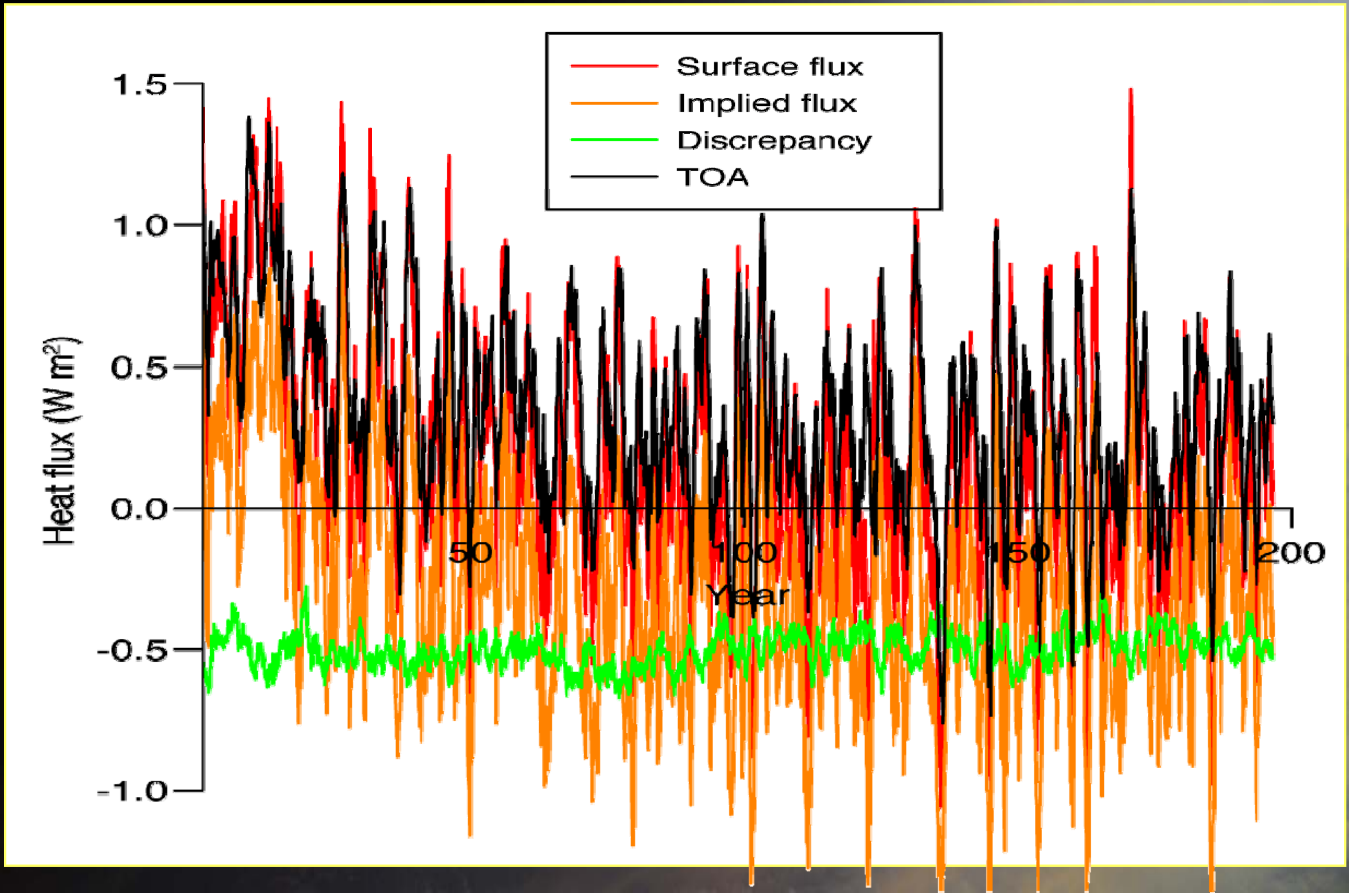
Meridional heat transports are within bounds of estimates of Trenberth & Caron (2001), although transport in NH subtropics is lower in CHIME.



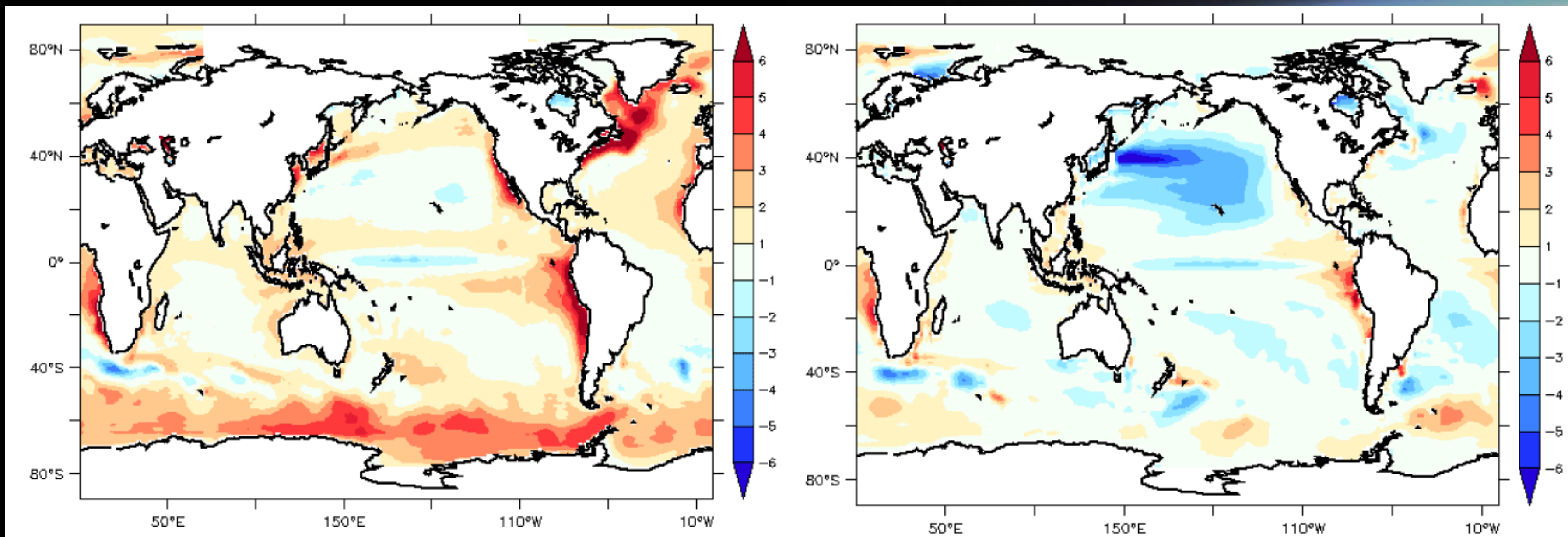
Global mean ocean heat transport in HadCM3 (green curve) and CHIME (red curve). The black and grey lines are from the reanalyis of Trenberth and Caron (2001), and the stars show the estimates of Ganachaud and Wunsch (2000).

Overall model heat budget

HYCOM loses internally about 0.5 Wm^{-2} (due to non-adiabatic layer thickness smoothing).



Surface temperature errors

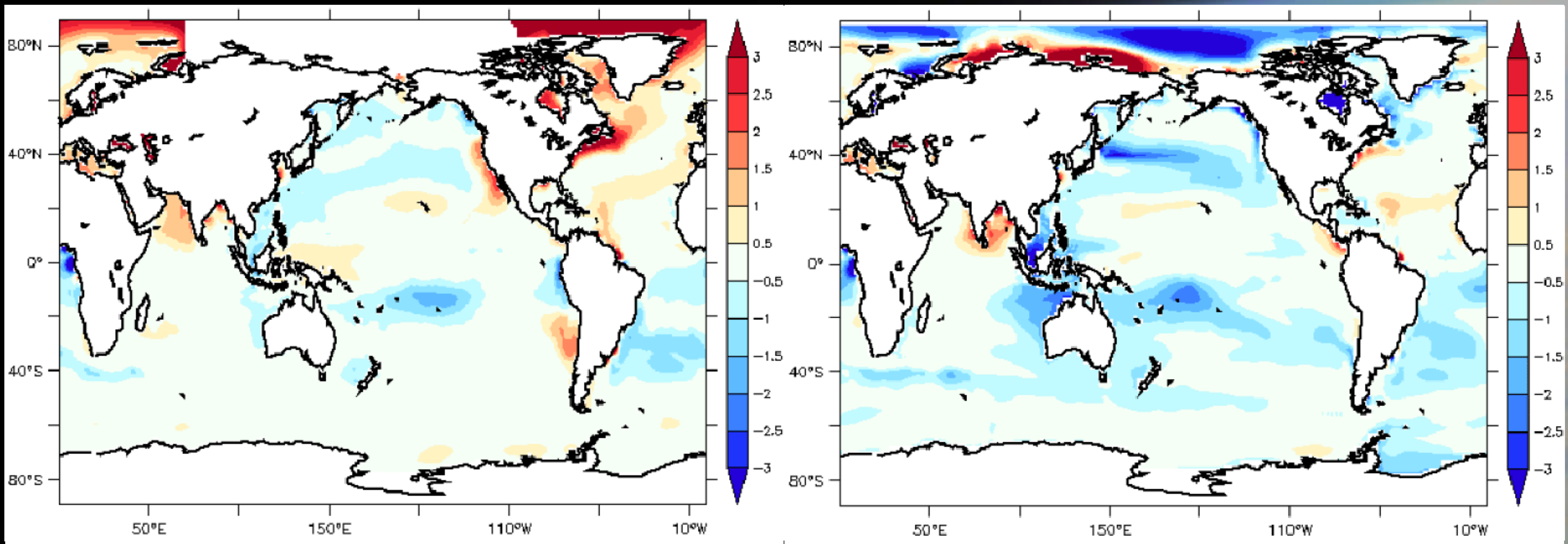


CHIME Year 80 to year 119 mean surface temperature minus NOCS climatology

HC Year 80 to year 119 mean surface temperature minus NOCS climatology

- CHIME is generally warmer at the surface than climatology, while global mean SST error in HadCM3 is small.
- HadCM3's North Pacific cold error is absent in CHIME.
- CHIME has warm error in Southern Ocean, due to shallow summer mixed layers in KPP mixing scheme.
- CHIME is also too warm in North Atlantic subpolar gyre.

Surface salinity errors



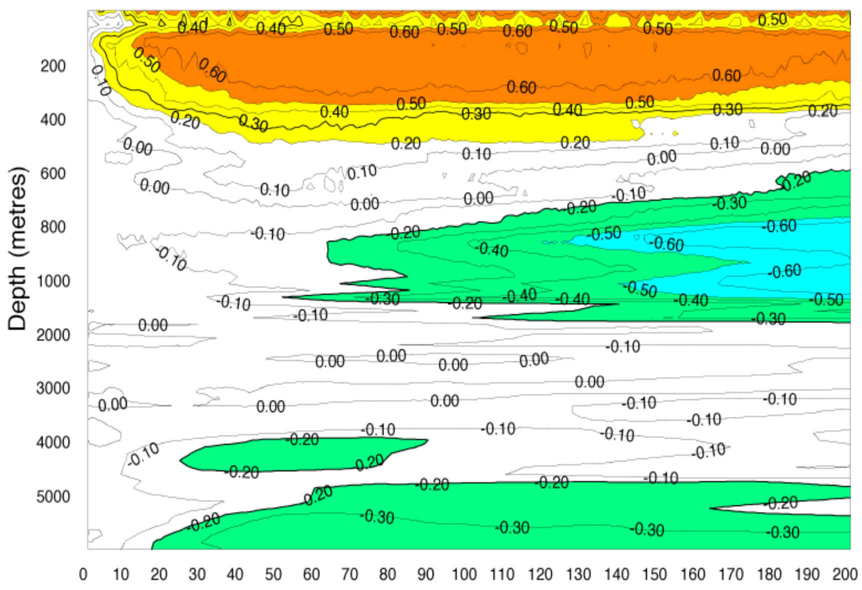
CHIME year 80 to year 119 mean surface salinity minus Levitus (1998) climatology

HC Year 80 to year 119 mean surface salinity minus Levitus (1998) climatology

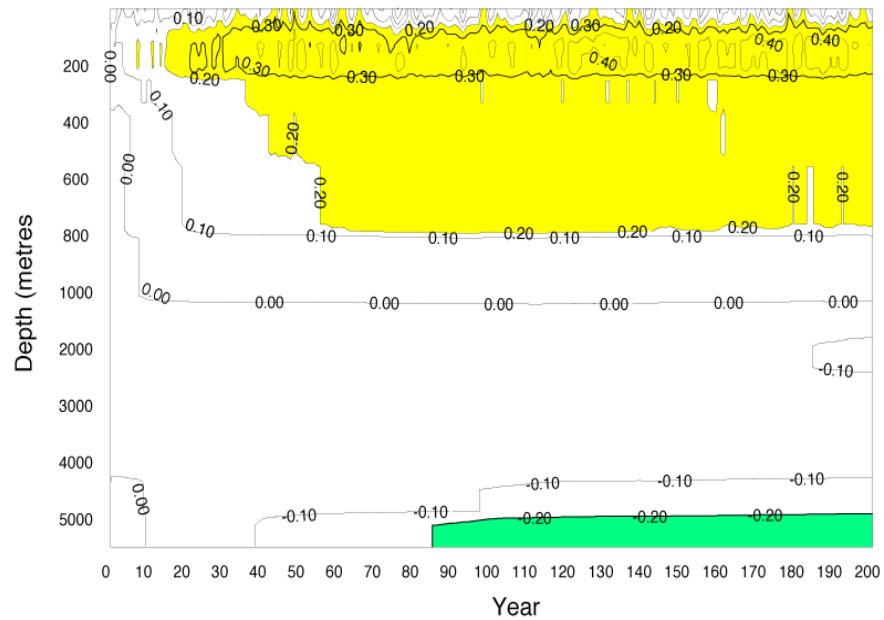
- HadCM3 is generally too fresh at the surface, and continues to freshen.
- CHIME error is lower overall.
- Arctic surface waters are too salty in CHIME, due to mixing with Atlantic water inflow (possible bug in ice model implementation).

Temperature drift by depth

- CHIME warms at the surface and between 100 and 400 metres, and cools below 600 metres.
- HadCM3 surface drift is much lower, but warming extends to below 800 metres depth: consistent with increased diffusion below base of subtropical thermocline.



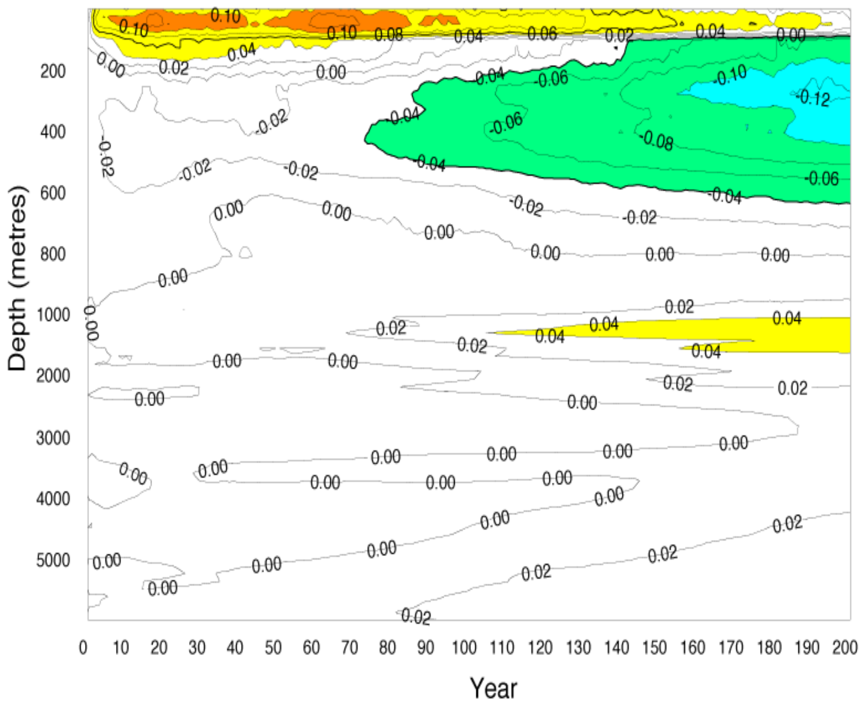
Global temperature drift in CHIME as a function of depth



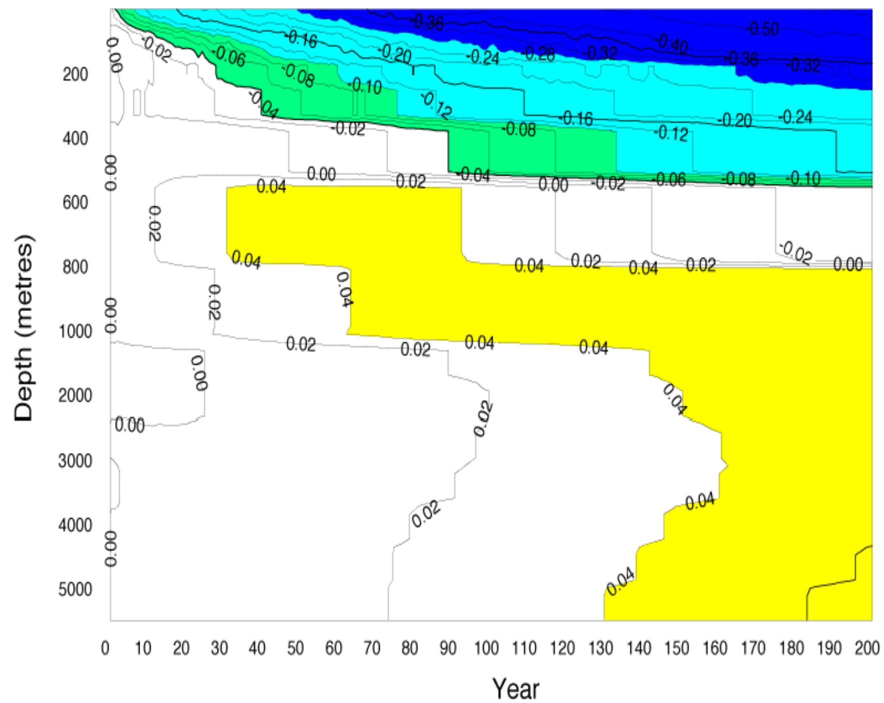
Global temperature drift in HadCM3 as a function of depth

Salinity drift by depth

- In upper 100m salinity rises in CHIME, but freshens at 500 metres.
- In HadCM3 strong freshening in upper 600 metres, but below 1000m salinity continues to increase at 0.03 PSU/century. Increasing salinity at depth is also consistent with downward diffusion of thermocline water.

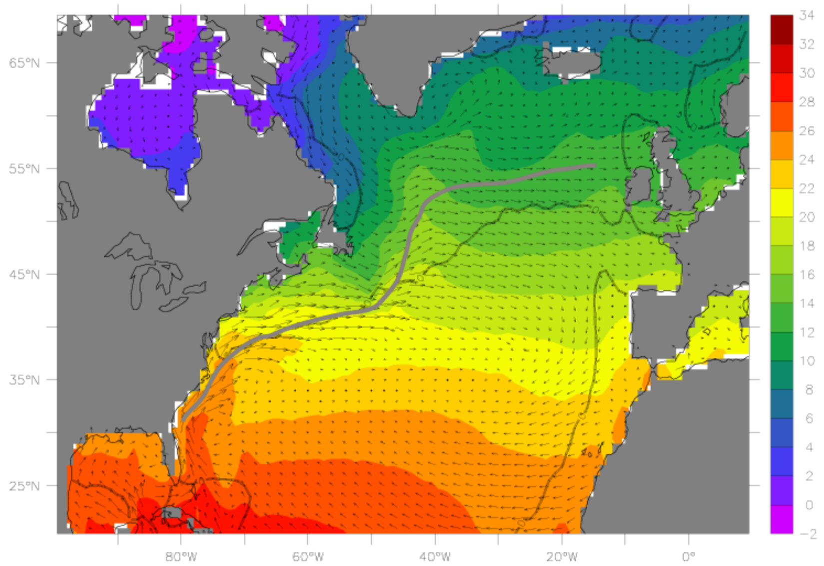


Global salinity drift in CHIME as a function of depth

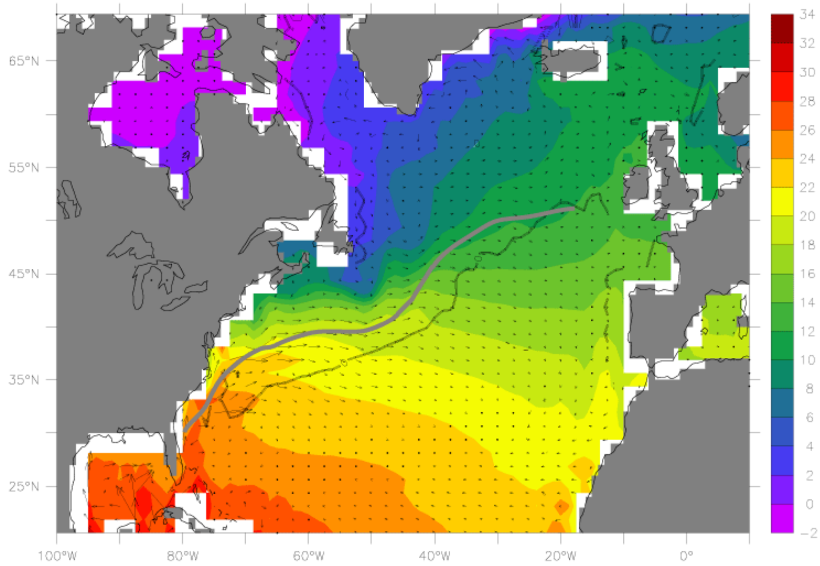


Global salinity drift in HadCM3 as a function of depth

North Atlantic circulation



Surface temperature and velocity in the North Atlantic in CHIME; solid lines show position of the zero wind stress curl



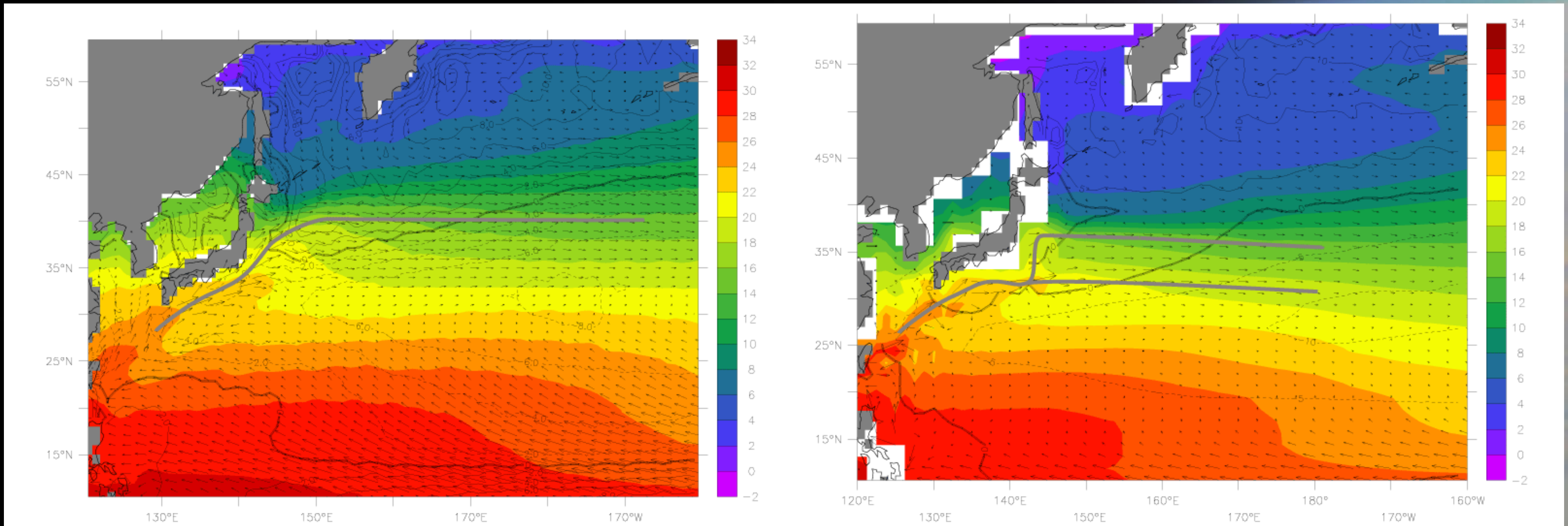
Surface temperature and velocity in the North Atlantic in HadCM3; solid lines show position of the zero wind stress curl

CHIME HadCM3

North Atlantic surface circulation: colours are SST; black lines show zero wind stress curl; vectors show the surface velocity, and grey lines show the approximate path of the NAC.

- Wind stress is too weak in both models: approx. 60% of climatology
- NAC in CHIME is too far north: possible link with warm SST

North Pacific circulation



Surface temperature and velocity in the North Pacific in CHIME; solid lines show position of the zero wind stress curl

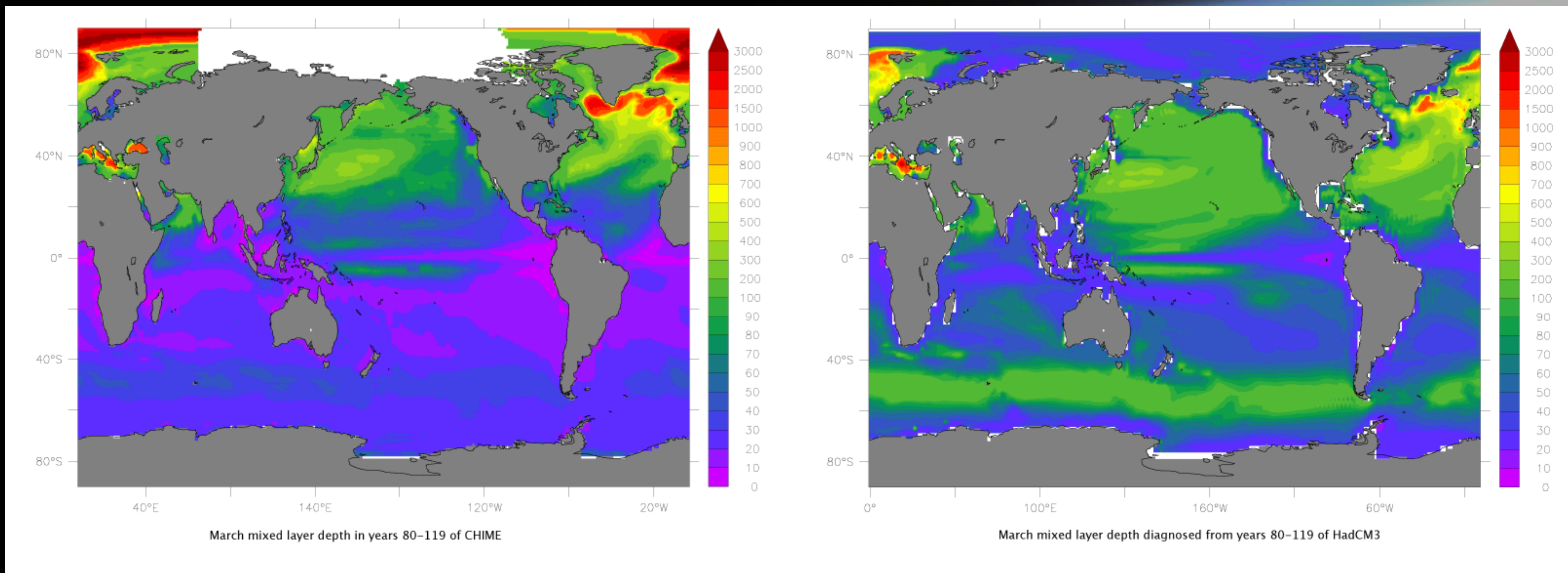
Surface temperature and velocity in the North Pacific in HadCM3; solid lines show position of the zero wind stress curl

CHIME HadCM3

North Pacific surface circulation: colours are SST; black lines are zero wind stress curl; vectors show the surface velocity, and grey lines show the approximate path(s) of the current.

• Zero stress curl lines, and Kuroshio separation positions, are too far north in CHIME, and too far south in HadCM3

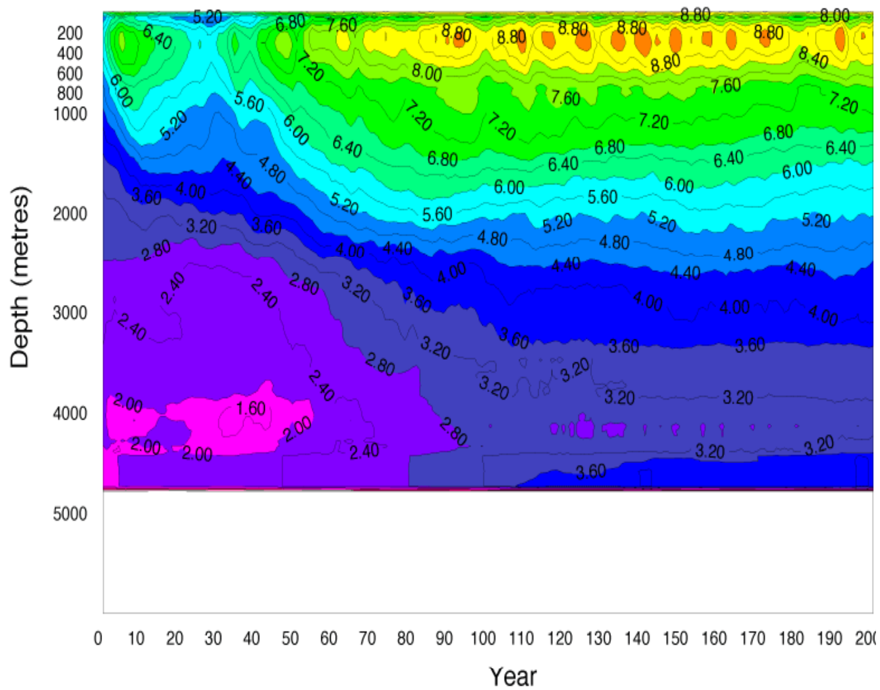
Mixed layer depth



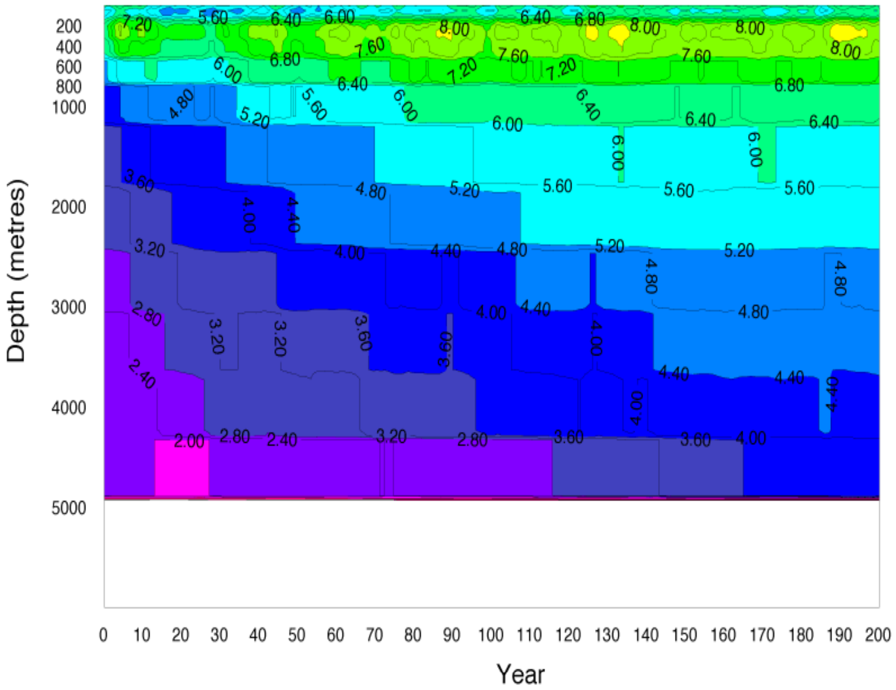
- Wintertime deep mixing in North Atlantic and Nordic Seas is much deeper in CHIME (2,000 metres) than in HadCM3 (mostly less than 500 metres). Climatology lies intermediate between models.
- Summertime mixing in Southern Hemisphere (particularly in Southern Ocean) is much too shallow in CHIME: prime suspect is KPP mixing scheme.
- Link with warm SSTs in CHIME in Southern Ocean.

Atlantic subpolar gyre temperature changes

- The subpolar gyre warms in both models: more so in CHIME.
- In CHIME the warming is mainly localised at 200-300 metres, but in HadCM3 heat is steadily mixed down into the abyss.



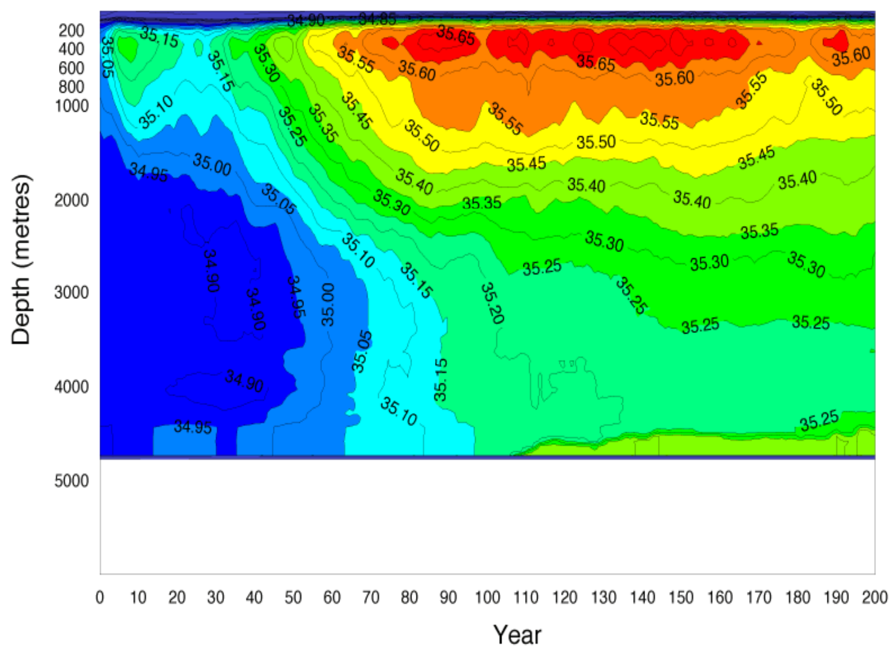
N. Atlantic subpolar gyre mean temperature in CHIME as a function of depth



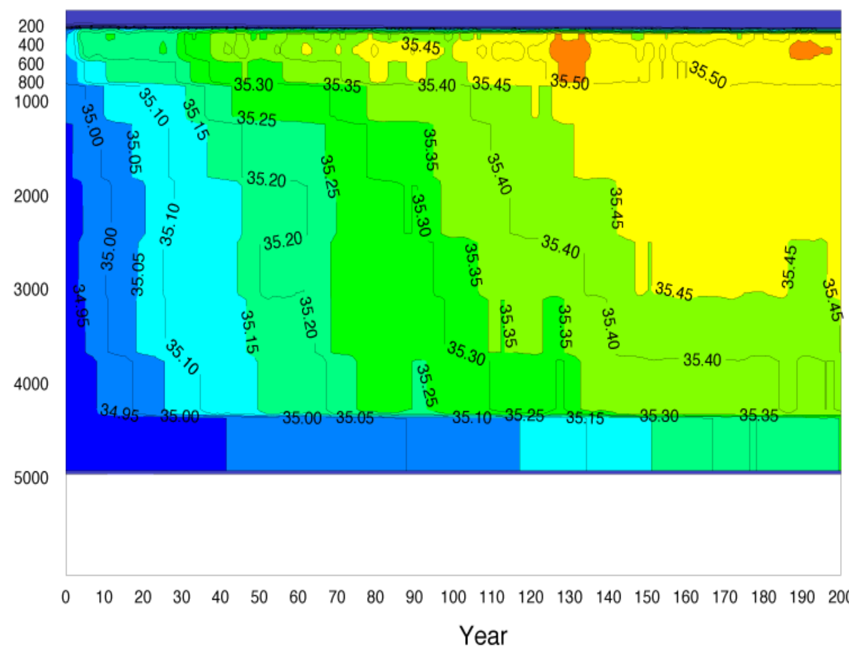
N. Atlantic subpolar gyre mean temperature in HadCM3 as a function of depth

Atlantic subpolar gyre salinity changes

• The subpolar gyre becomes saltier in both models: again, more so in CHIME.
• In CHIME the increase is again more localised at 200-300 metres.
• In HadCM3 a very fresh surface layer persists down to 200 metres, which inhibits winter mixing and conceals deeper changes in SST plots.



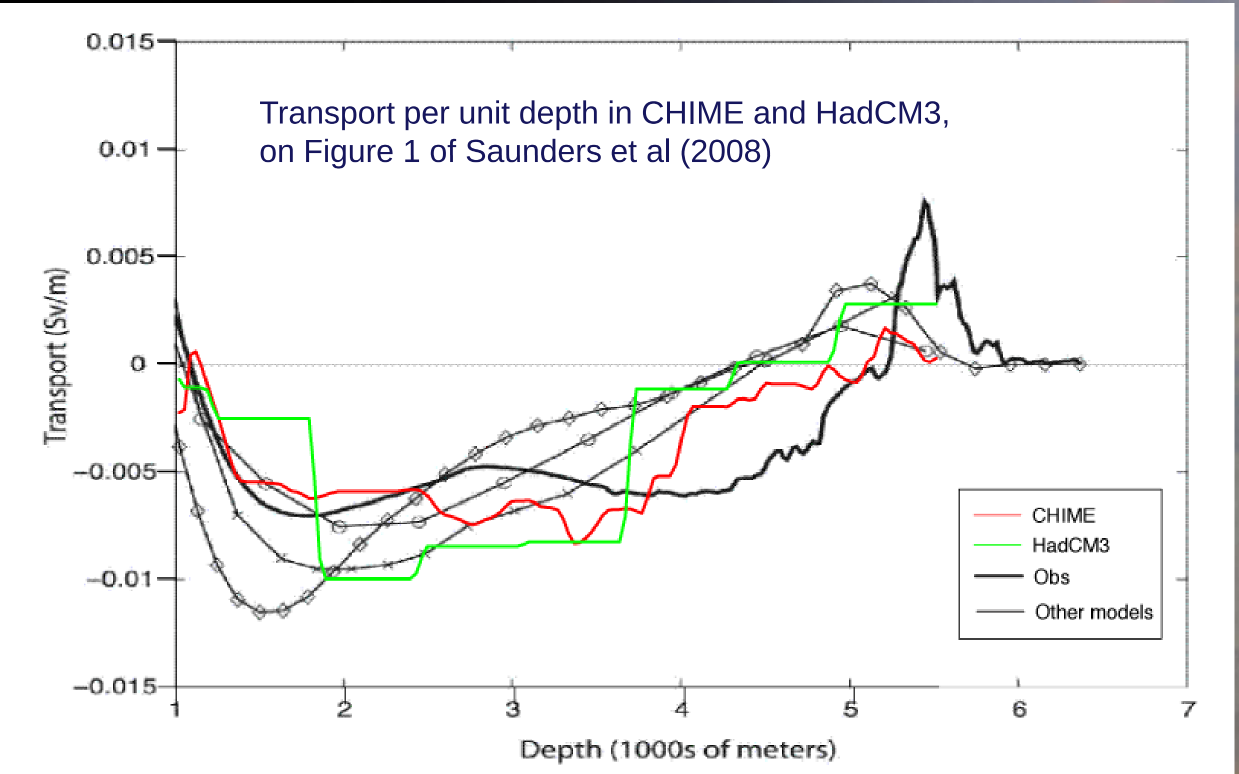
N. Atlantic subpolar gyre mean salinity in CHIME as a function of depth



N. Atlantic subpolar gyre mean salinity in HadCM3 as a function of depth

North Atlantic Deep Water

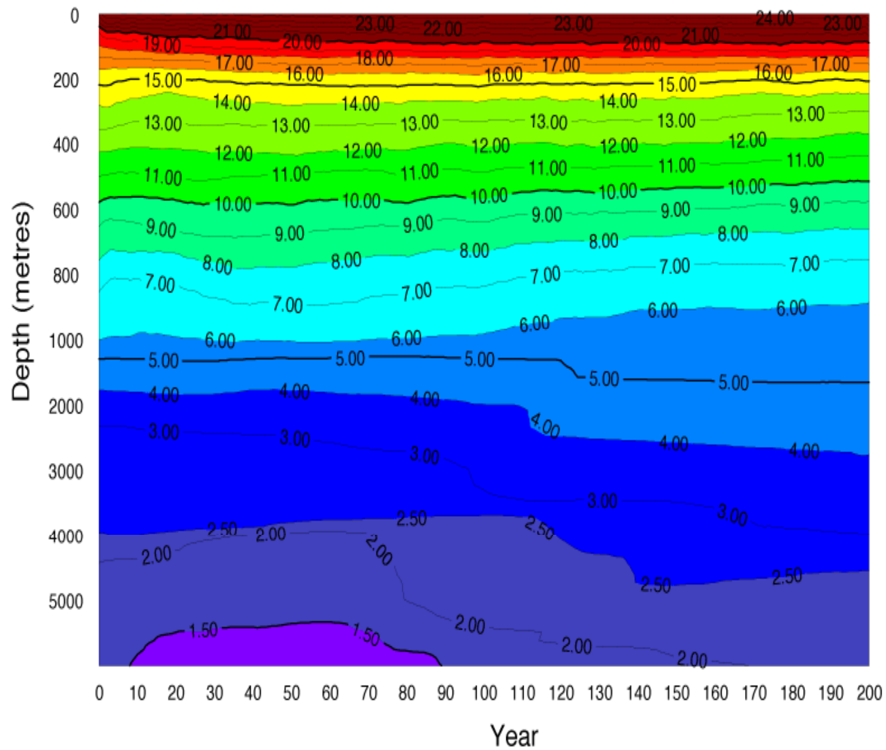
• In HadCM3 southward path of NADW is too shallow (as seen in MOC plot).
• CHIME reproduces vertical shear in the NADW more realistically .



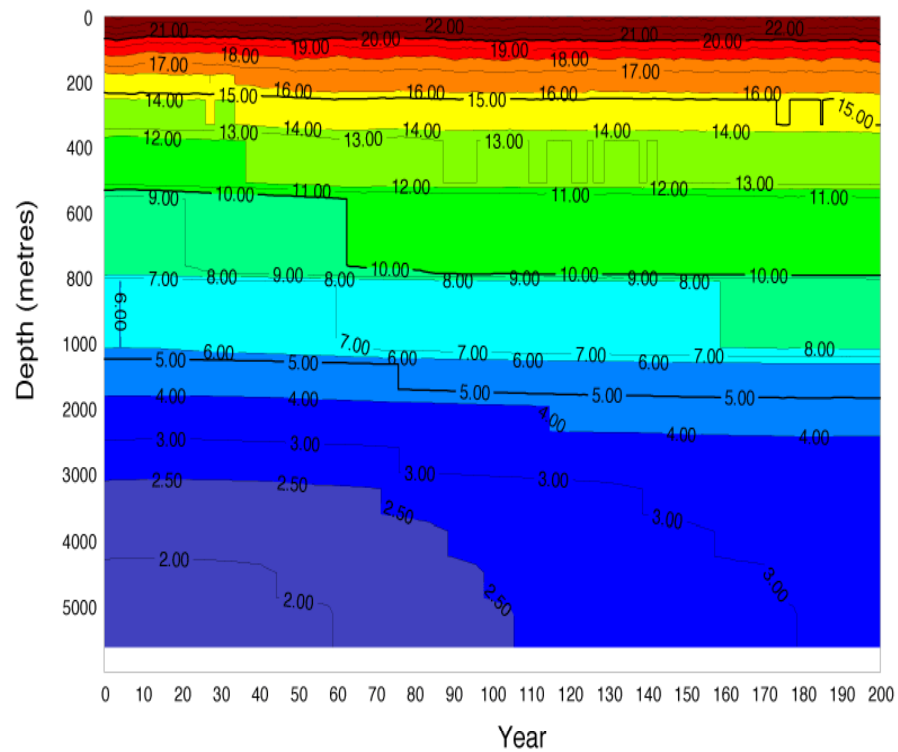
Transport per unit depth in the Atlantic at 25°N in years 80-119 of HadCM3 (green) and CHIME (red). Also shown are the data from Figure 1 of Saunders et al. (2008): three high-resolution ocean-only models (diamonds, circles and crosses), and the bold black line shows estimation from observations.

Subtropical thermocline evolution

• CHIME preserves sharpness of N. Atlantic subtropical thermocline, where in HadCM3 thermocline becomes progressively more diffuse.



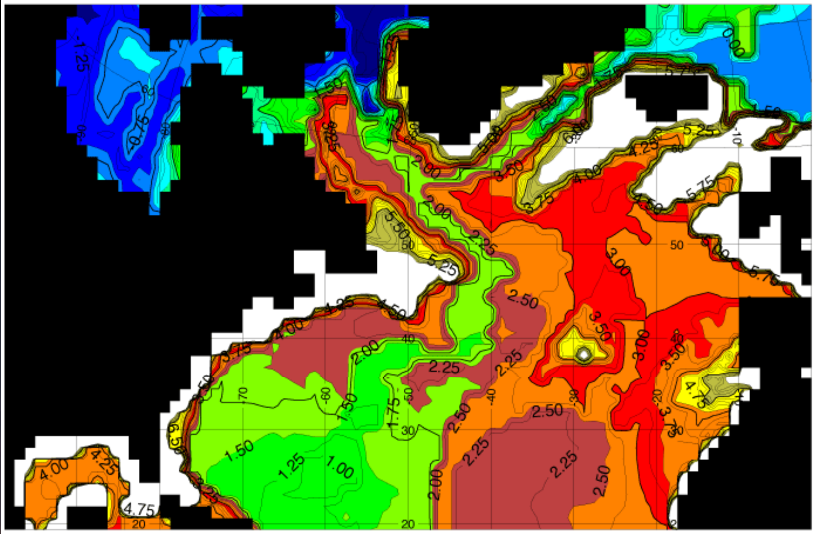
N. Atlantic subtropical gyre mean temperature in CHIME as a function of depth

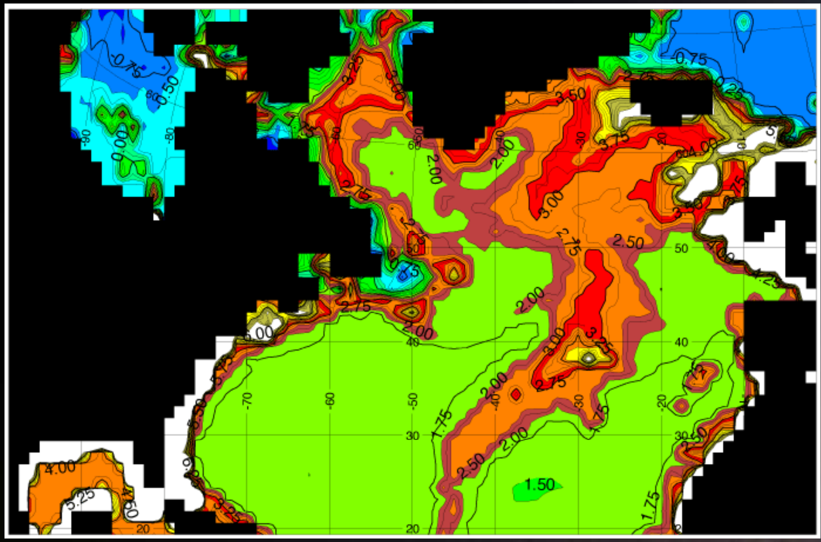


N. Atlantic subtropical gyre mean temperature in HadCM3 as a function of depth

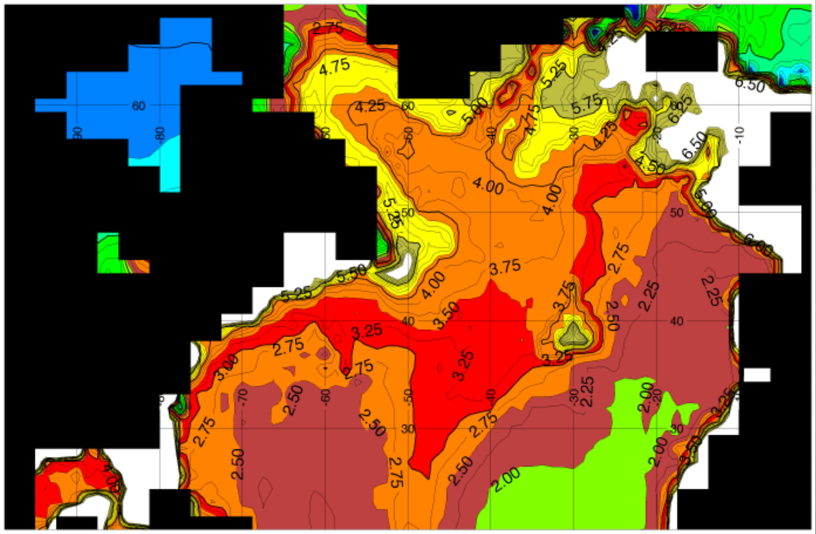
North Atlantic bottom water

- CHIME represents dense plume of overflow water in N. Atlantic, which is mixed (and not well resolved anyway) in HadCM3.



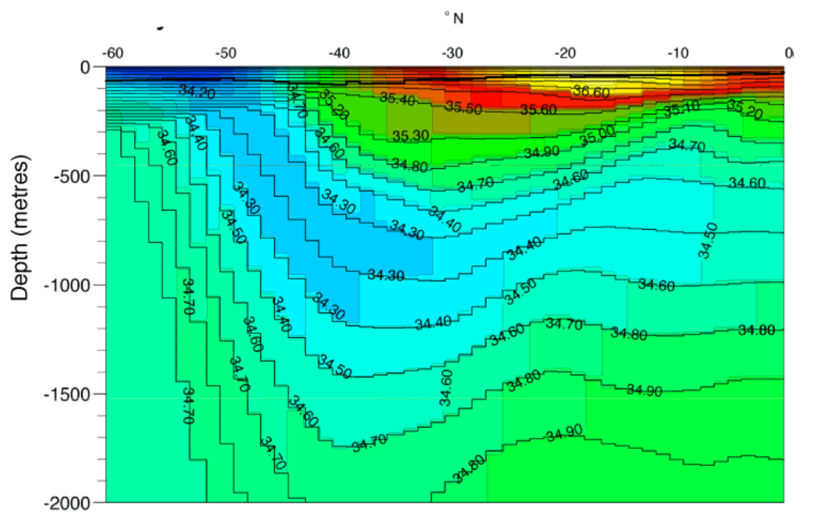


Temperature in bottom 50 metres at initialisation and at 80 years of CHIME (top) and HadCM3 (bottom)

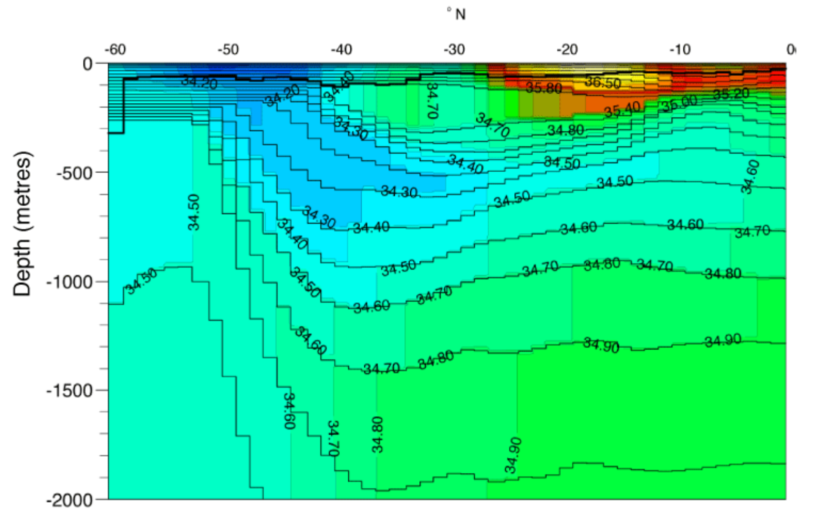


Representation of Antarctic Intermediate Water

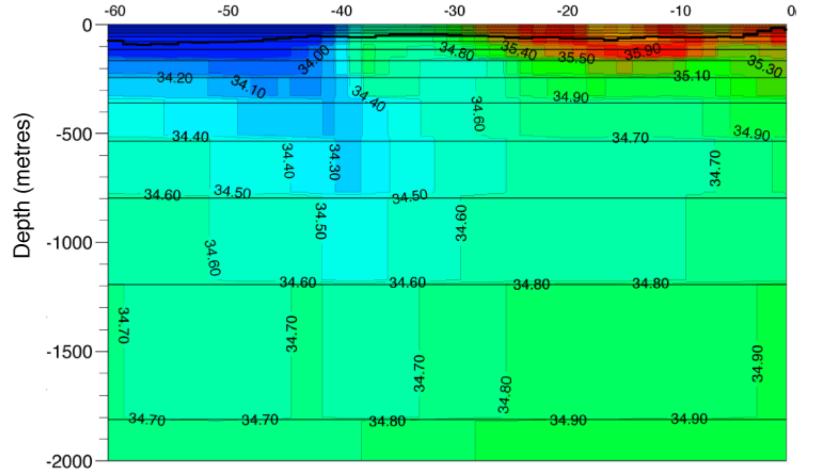
- The fresh tongue of AAIW is well represented in CHIME, but is rapidly diffused away in HadCM3.



Mean salinity in year 0 of CHIME at 30°W



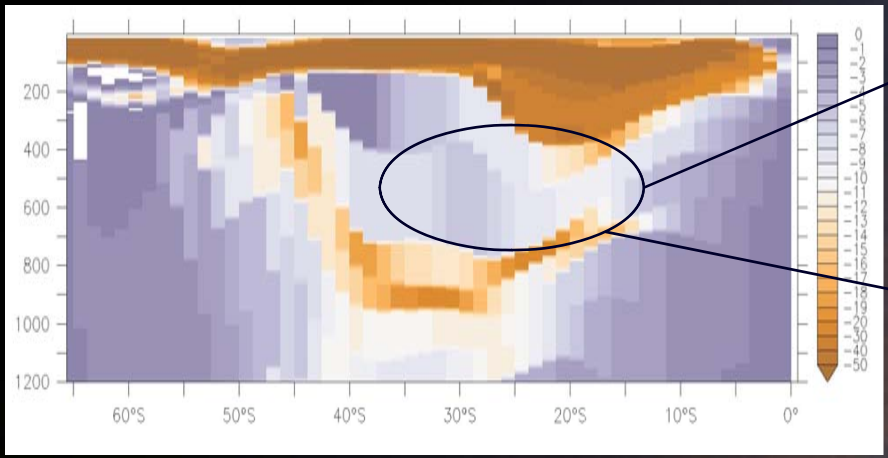
Mean salinity in year 80 of CHIME at 30°W

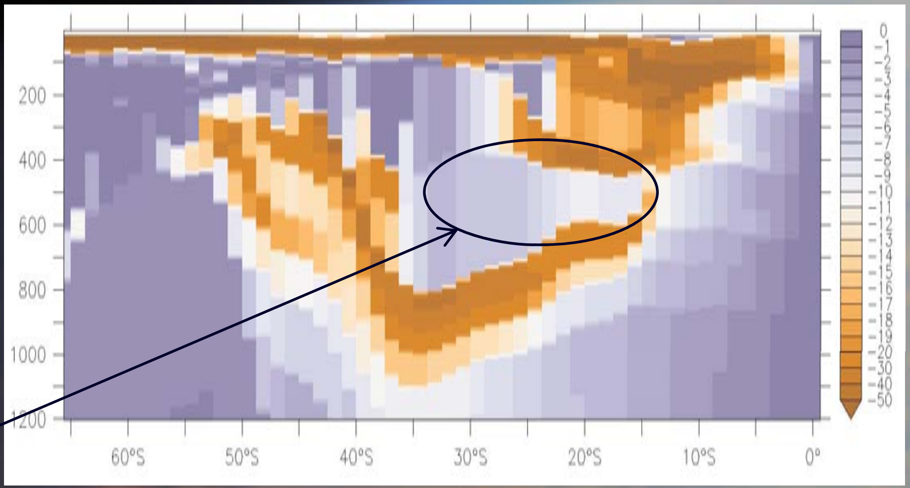


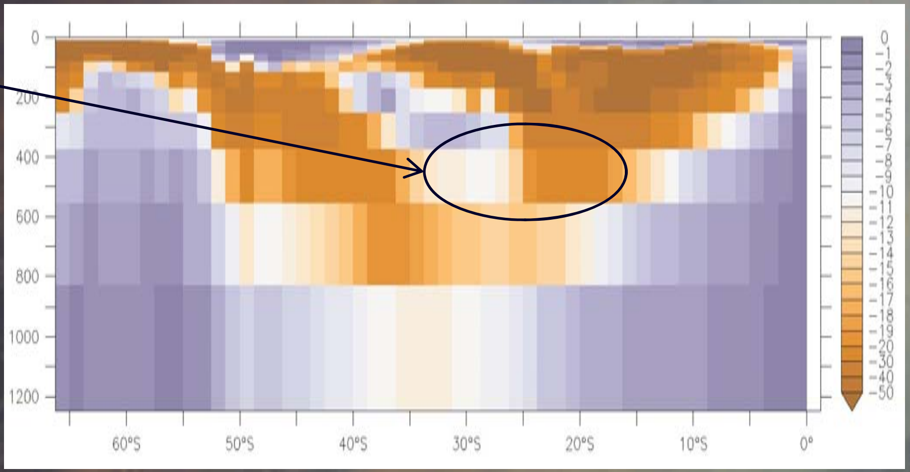
Mean salinity in year 80 of HadCM3 at 30°W

Preservation of Subantarctic Mode Water

This climatically important water mass is identified by a PV minimum, which is maintained after 80 years in CHIME, but diffused away in HadCM3. Shown here at 80ºE.







Summary

• We have successfully coupled the HYCOM ocean model to the Hadley Centre's HadAM3 atmosphere. Completed over 200 years.

• CHIME has meridional heat transports similar to those in HadCM3, and well within bounds of Trenberth et al. estimates.

• Mean MOC is 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:

- Lower penetration of heat and salt into interior;
- Better preservation of subtropical thermocline;
- Better representation of NADW;
- More realistic representation of SAMW.

• …but CHIME not unequivocally superior (N. Atlantic, S. Ocean…)

Next steps

- Port CHIME to new hardware at NOCS
- Carry out runs with different mixing schemes
- Compare with GOLD ocean?
- Run with more realistic forcing scenario
- Install new version of Unified Model (v6.6) – potential for more realistic N. Atlantic winds.

- We also have funding (NERC RAPIT project) to set up CHIME within *climateprediction.net,* and run large ensembles.