# Multi-century climate integrations at NOC

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# Multi-century climate integrations at NOC

- Background
- Model configuration
- Issues with development
- How we saved ENSO
- Some results
- Climate change experiments
- Can we say anything about HYCOM v2.1.34 vs. 2.2.18?
- Concluding remarks

# Background

- CHIME has been developed at NOCS over the last ten years or so.
- Identical to the UK Met Office's HadCM3, except that z-coordinate ocean is replaced by HYCOM
- Original version run for 200 years with pre-industrial forcing
- Two additional climate sensitivity experiments: with $CO_2$ increasing at 1% per year; and with 0.1 Sv of freshwater hosing in the North Atlantic

**Publications**

- Comparison of control integrations: Megann et al., J. Clim (2010)
- Rapid variability of AMOC in obs and models: Balan Sarojini et al. (2011)
- Decadal variability of AMOC in CHIME: Persechino et al., (2012)
- Propagation of N. Atlantic salinity anomalies Megann et al. (2013, in revision)

# New model configuration

**Ocean grid:** 1.25° x 1.25° spherical grid, with bipolar patch in Arctic north of 55°N; 25 layers.

**Atmosphere grid:** 3.75° E-W, 2.5° N-S, 19 levels.

Old version used mixture of parallelisation methods: new hardware platform required new parallel communications structure

HYCOM v2.2.18 already has MPI coupling hooks for CCSM3, so these were used

| | Old CHIME | New CHIME |
|---|---|---|
| **Ocean version:** | HYCOM v2.1.34 | HYCOM v2.2.18 |
| **Coupler:** | OASIS v2.4 | OASIS v3.0 |
| **Parallel comms:** | Ocean: OpenMP<br>Atmos: PVM<br>Coupler: MPI | Ocean: MPI2<br>Atmos: MPI2<br>Coupler: MPI2 |

# Issues in development

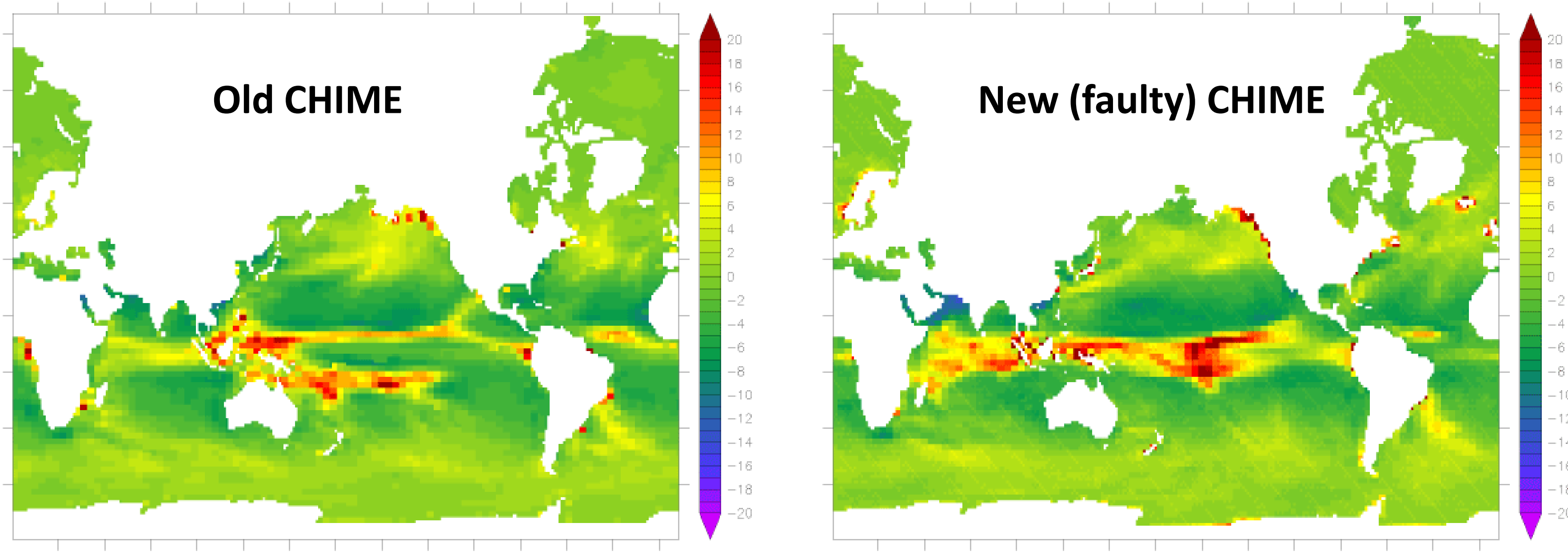
- MPI communications took several months to debug and get running correctly

- Discovered several (mostly minor) errors in old (published) CHIME model:
  - Land snow thickness reset to zero at each daily coupling
  - Instantaneous, rather than daily mean, ocean fields passed to atmos
  - Error (small) in surface fluxes (visible as persistent diagonal features in time averaged fields)
  - Error in ice advection code
  - Error in Bering Strait exchange

- Development of new model set back for many months with mysterious tendency for ENSO to drift into permanent El Nino state after a decade or so (even though rest of global domain looked very similar to old model).

# What went wrong with the tropical Pacific?

- The normal "double ITCZ" precipitation pattern coalesced into a single maximum close to the Equator.
- This decreased surface salinity and hence density on the Equator to the point where the eastern upwelling was suppressed
- A permanent El Nino state ensued.



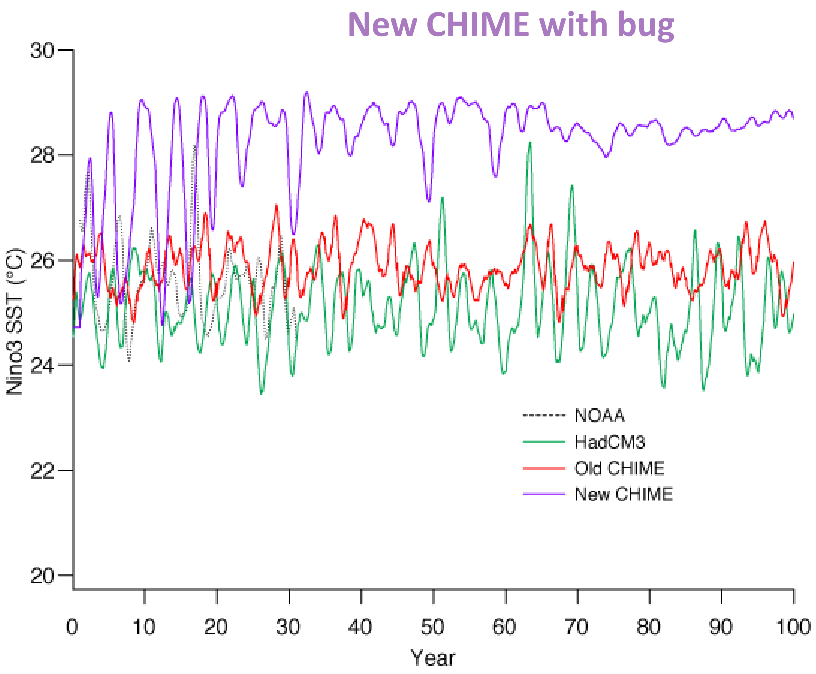

**Surface freshwater flux, years 10-19**

# Why did ENSO collapse?

Comparison of monthly mean freshwater fluxes between dumps from the atmosphere model, and fields passed to the ocean, revealed that the coupling fluxes were about 2% smaller than those calculated by the atmosphere.

An error in the OASIS *namcouple* file caused the atmosphere to export fluxes 30 minutes (1 atmos timestep) early: scaling fluxes by a factor of 48/47 fixed the error!

Equatorial region must be ***very*** sensitive to surface fluxes (though whether primarily to freshwater or heat fluxes is not yet known)




**Annual mean Nino3 SST**

# Why is this interesting?

We are hugely relieved to have found the bug, but…

Wara et al. (2005) and others speculate that in the warm climate of the Pliocene era (2.5-3.5 Myr BP) a permanent El Nino state existed (although this is disputed: e.g. Watanabe et al., 2011).

It would be interesting to more closely investigate the strong sensitivity to surface fluxes seen in this model and compare it with other models (e.g. HadCM3).

The error seen in CHIME is conceptually similar to a freshwater “hosing”, as routinely carried out in the N. Atlantic (though it must actually result from a fundamentally coupled process).

# Current CHIME status

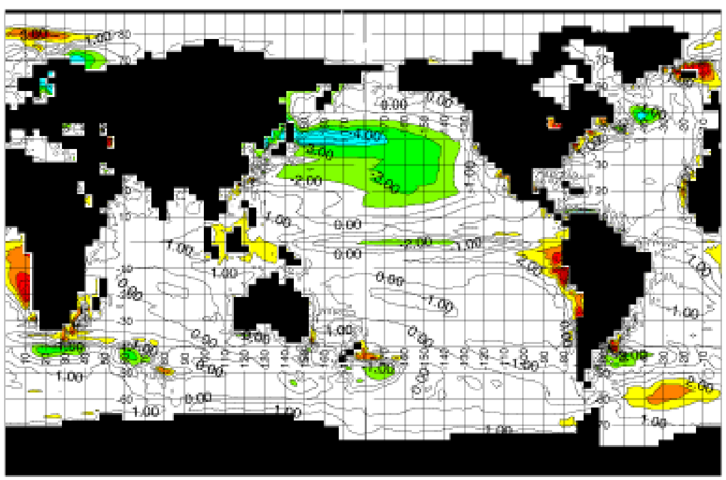
- A new control integration of the model is currently running, and has now reached 900 years.

- Two experiments with 0.1 Sv of freshwater applied to N. Atlantic between 50° and 70°N for 100 years, followed by 100 years recovery: one starting from year 100 of the control and the other from year 200.

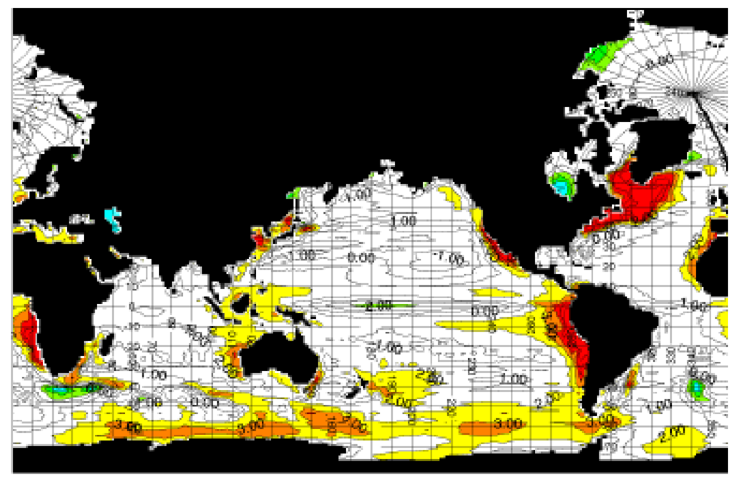
- One experiment with $CO_2$ increasing at 1% per year from year 100 of the control.

# Global surface temperature errors

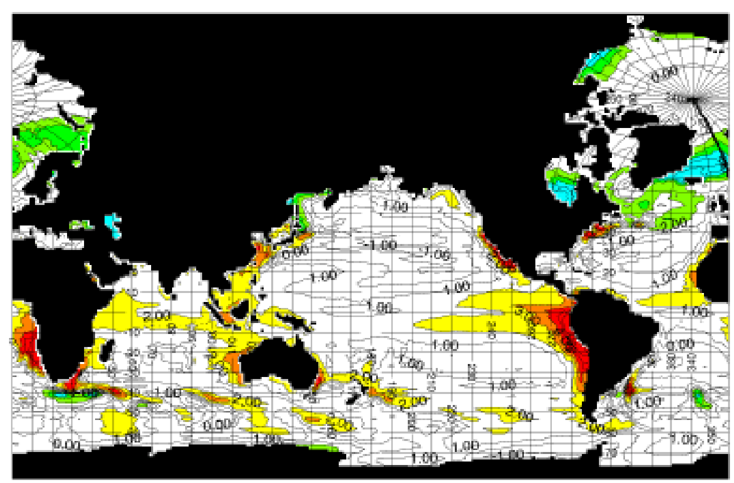
- SST bias overall similar in both versions of CHIME – generally warm
- Southern Ocean bias reduced
- NW Atlantic cooler than in old model.



**HadCM3**



**Old CHIME**

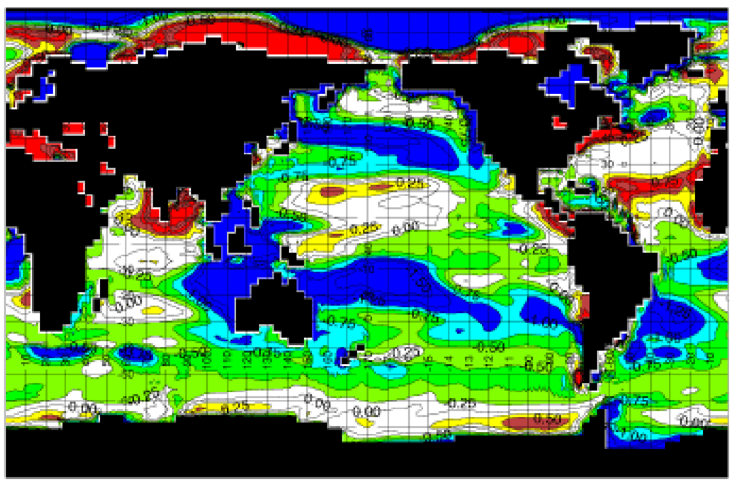


**New CHIME**

**Global SST errors with respect to NOCS climatology in years 100-199**

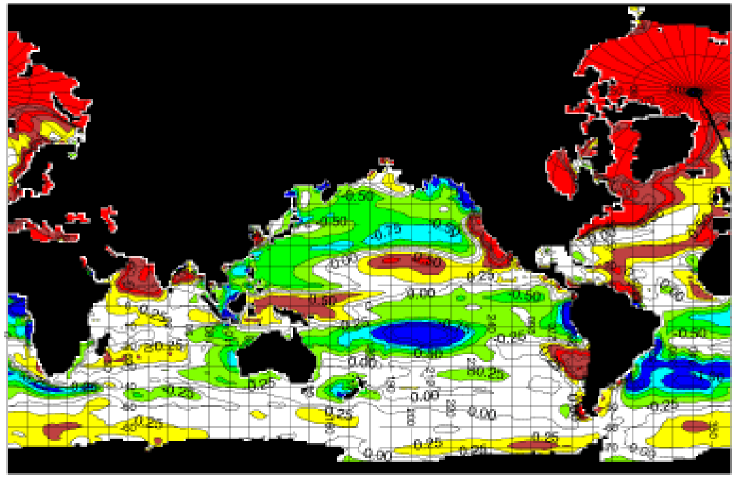
# Global surface salinity errors

- There are regional differences between old and new models
- NW Atlantic is fresher in new CHIME.

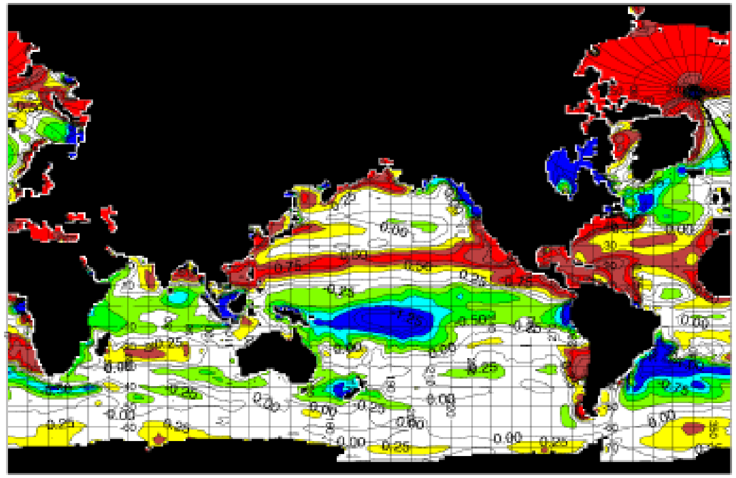


**HadCM3**

**Global SSS errors with respect to NOCS climatology in years 100-199**



**Old CHIME**

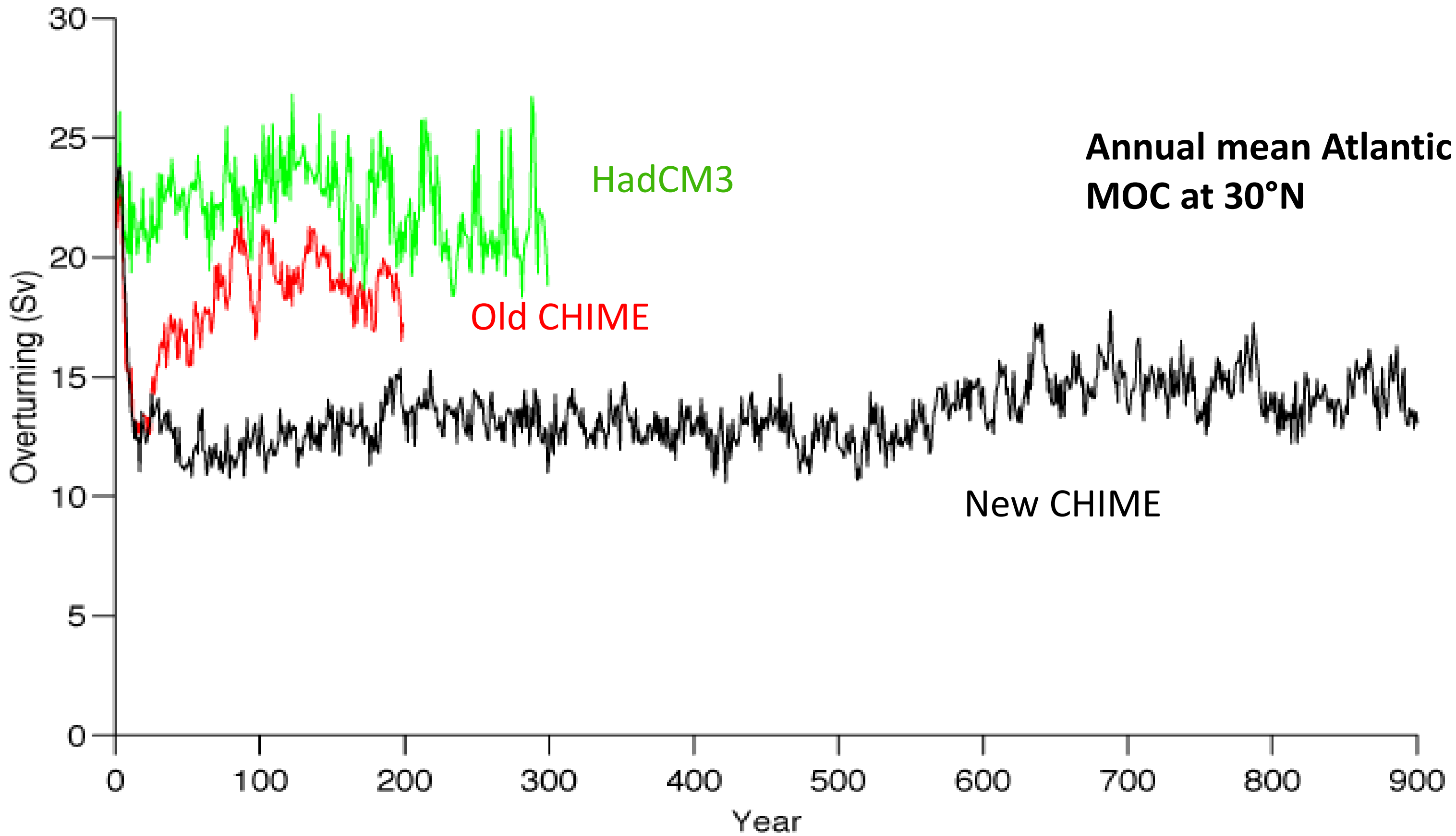


**New CHIME**

# Atlantic MOC strength

AMOC in new CHIME is weak compared with that in the older model, HadCM3 and observations, but shows vigorous variability over a range of time scales.

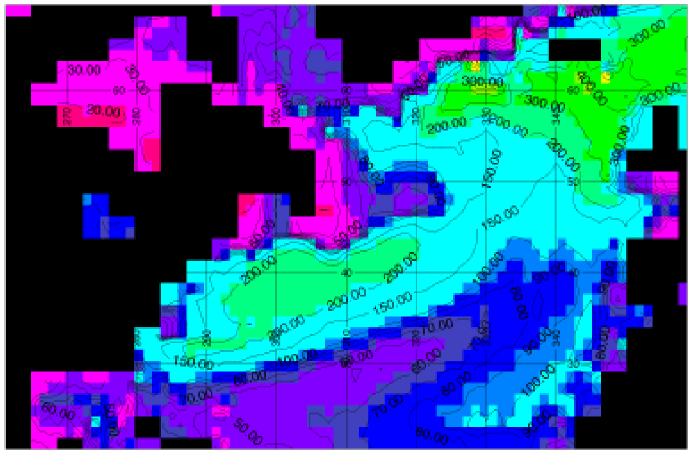
There is a "step function" increase in AMOC by 15-20% at around year 600.



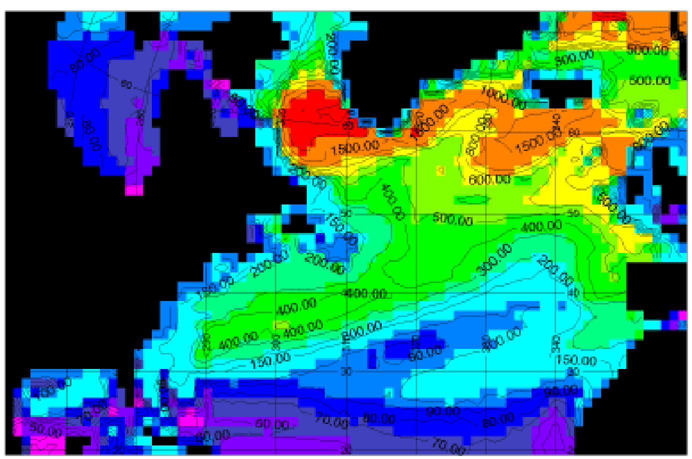
# North Atlantic winter mixing

**March mixed layer depth in years 100-200**

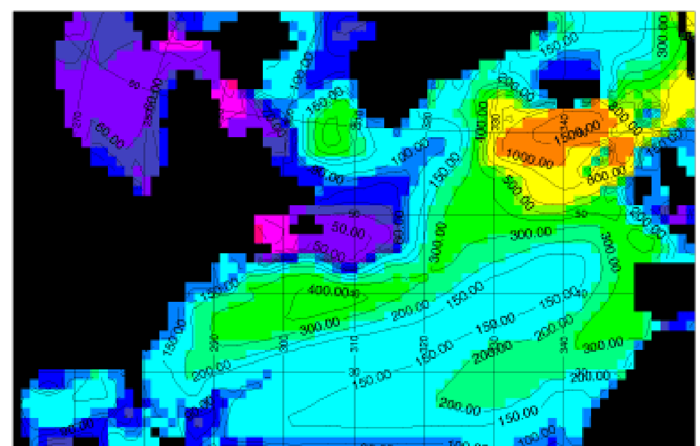
- Mixing in Labrador Sea is shallower in new CHIME than in old CHIME, and is closer in this respect to HadCM3.
- Consistent with fresh bias in new CHIME
- … and also with lower AMOC



**HadCM3**

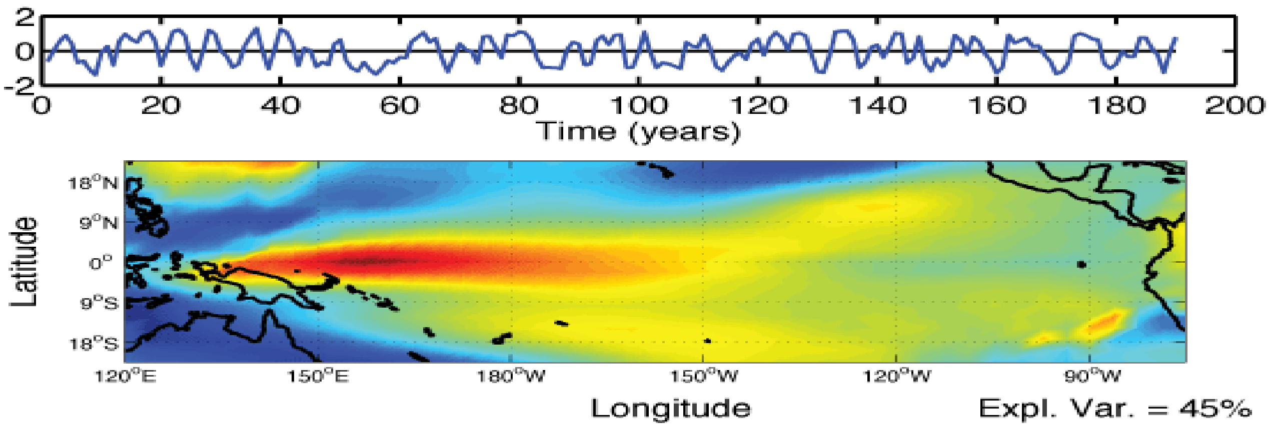


**Old CHIME**

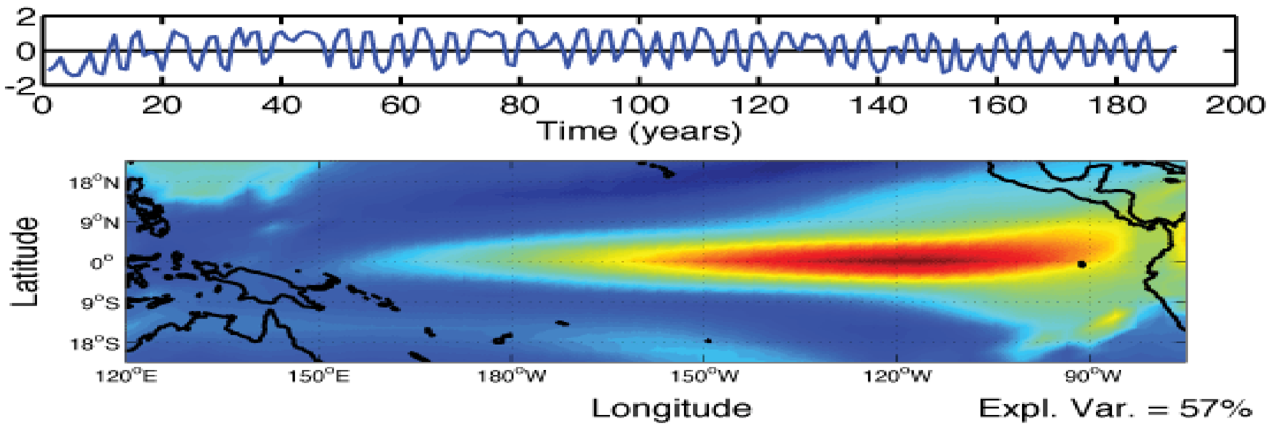


**New CHIME**

# ENSO variability




**Old CHIME SST EOF1**

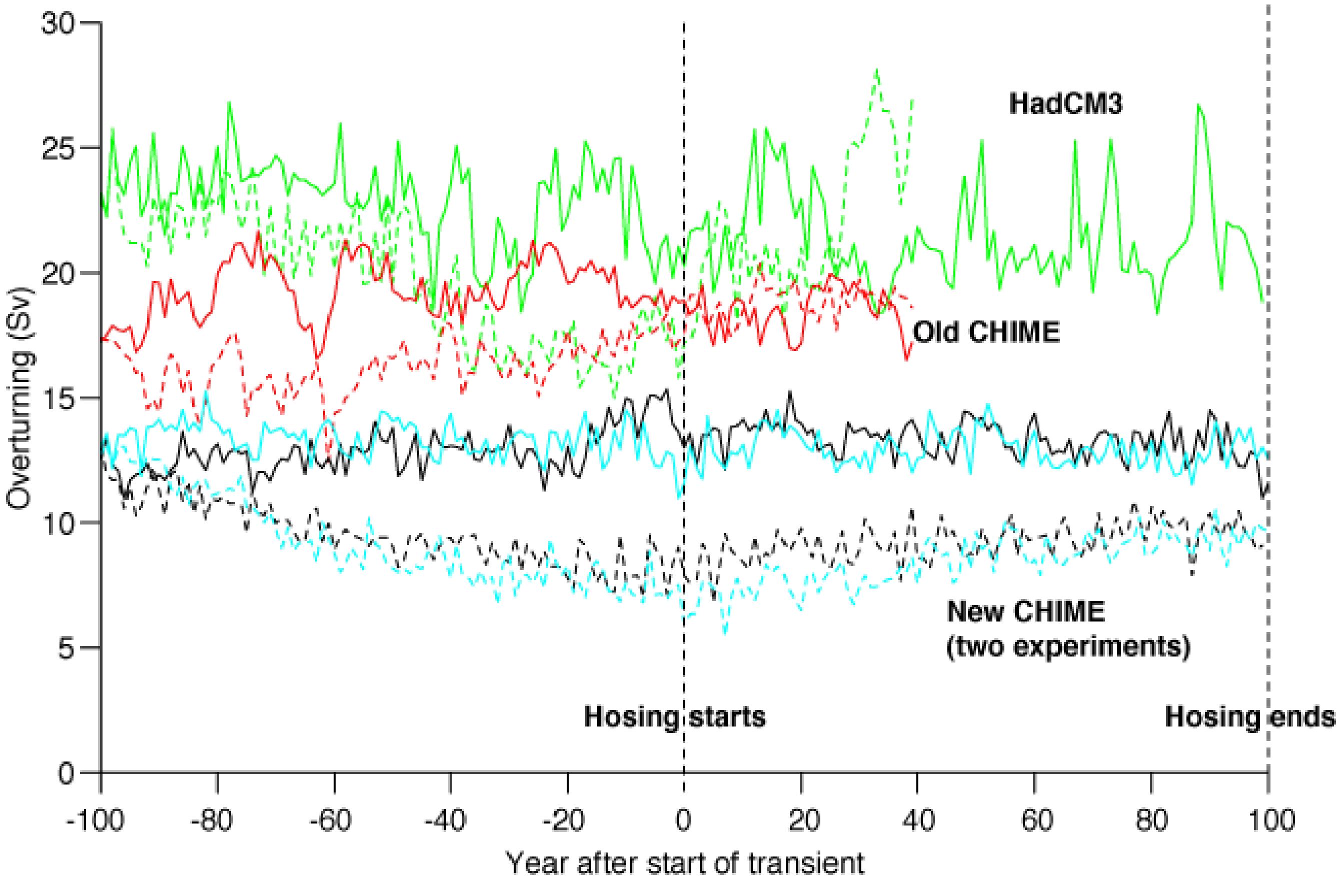



**New CHIME SST EOF1**

- New model has a vigorous ENSO with a more realistic centre of action further east
- Variability is more regular (possibly too much so) than in old model

# Freshwater hosing experiments

New model appears to have different response to hosing from both HadCM3 and original CHIME. Possibly related to different surface biases in NW Atlantic.




**HadCM3**: AMOC reduces by ~5 Sv during hosing then overshoots

**Old CHIME**: AMOC quickly reduces by ~5 Sv then recovers spontaneously before hosing is removed

**New CHIME**: AMOC steadily reduces by ~5 Sv during hosing then recovers slowly

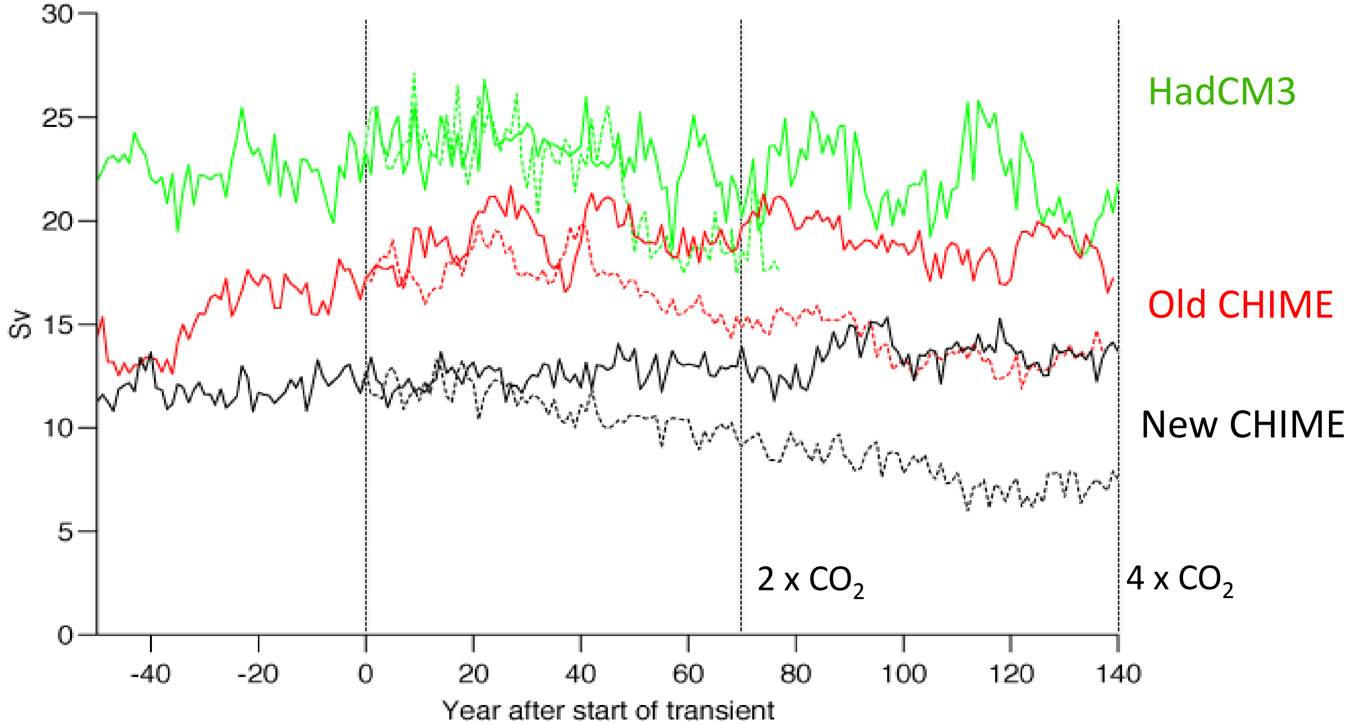
# Experiment with increasing $CO_2$

An experiment was run with $CO_2$ increasing at 1% per year from year 100 of the control.

**AMOC at 30°N**

Solid line: control

Dashed line: 1% $CO_2$




- All three models respond similarly to increasing $CO_2$, with ~5 Sv reduction in AMOC by doubling $CO_2$ (70 years).
- Looking at regional changes and differences in oceanic heat uptake.

# Can we say anything about HYCOM v2.2.18?

We have changed ocean component of CHIME from HYCOM v2.1 to v2.2, so some differences in the coupled model may be due primarily to this

… though we have at the same time removed some bugs in the old coupled model (and likely introduced one or two new ones!) so this may not be the only reason for observed differences.

We can make a couple of meaningful comparisons, however:

# Ocean heat and salt conservation

HYCOM is notorious in some quarters for its non-conservation of ocean tracers: this is blamed on: (i) smoothing of tracer fields at two time levels; and (ii) inconsistencies in surface height between barotropic and baroclinic fields.

This is (allegedly) not an issue in z-coordinate models, nor is it in GOLD, which uses a single time level and appropriate numerics in time stepping (Hallberg and Adcroft, 2009). Some lengths have been taken in HYCOM 2.2.18 to improve this.

**Global heat imbalance in CHIME runs:**

HYCOM v2.1: -0.50 $Wm^{-2}$ HYCOM v2.2: +0.21 $W\ m^{-2}$

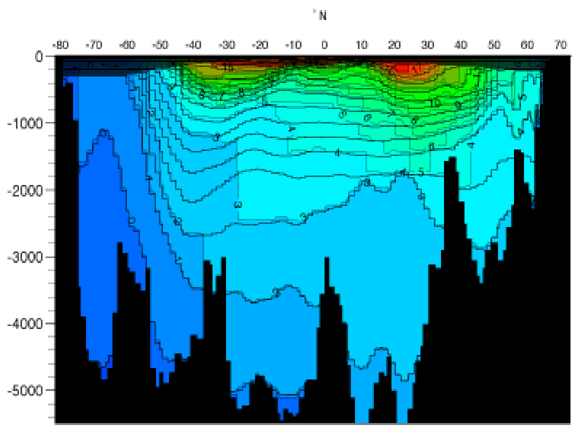
The temperature non-conservation is reduced, but is still significant!

**Salinity conserved within much closer limits**

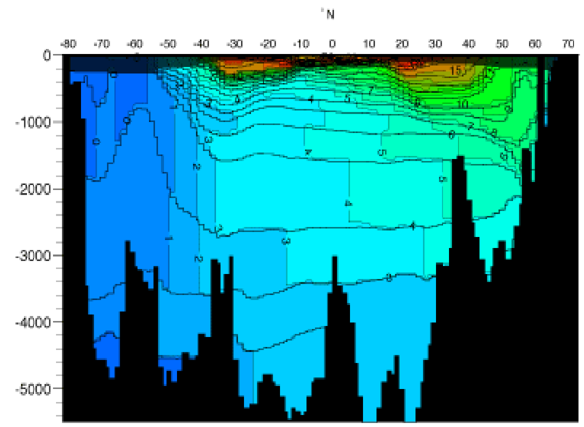
**- much better than in v2.1 version**

# Ocean watermass preservation: temperature

The new CHIME uses "WENO-like" vertical regridding, which should be less diffusive than the piecewise linear scheme used in the old version.



Initial state

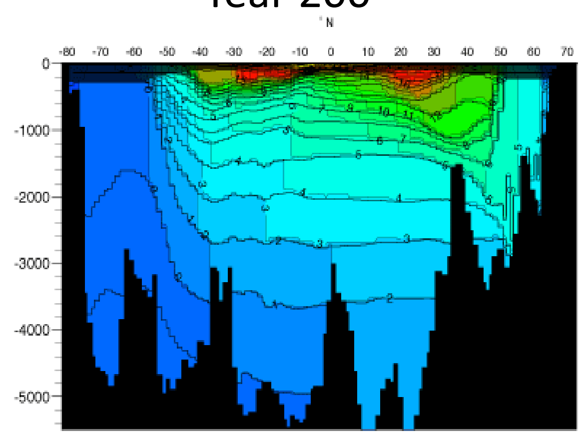


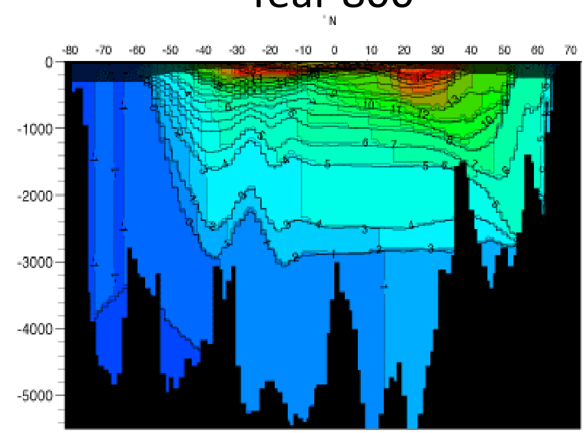
Year 200

**Temperature sections at 30°W in old (top) and new (bottom) CHIME integrations**

New model shows buildup of very cold AABW which starts to fill abyss.

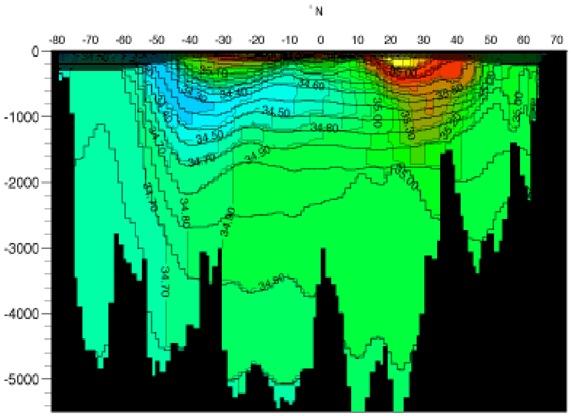
- Consistent with κ too small



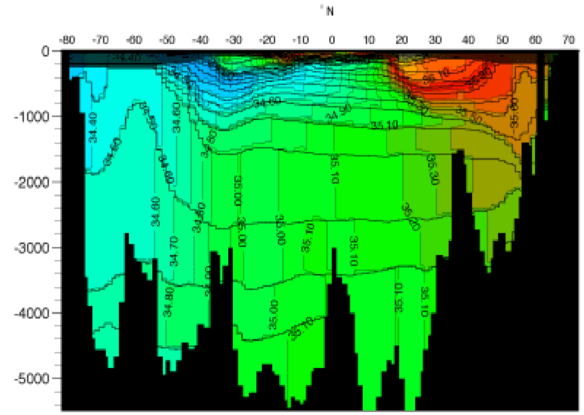


Year 800

# Ocean watermass preservation: salinity



Initial state

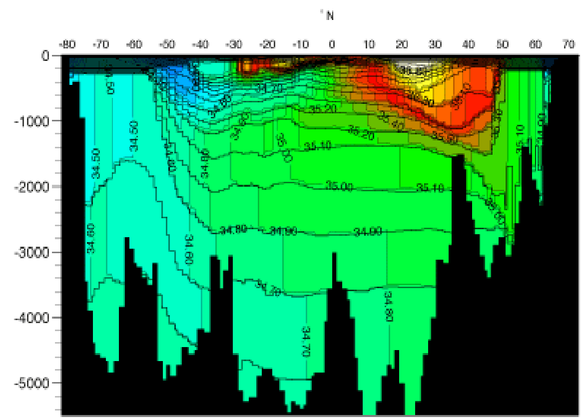


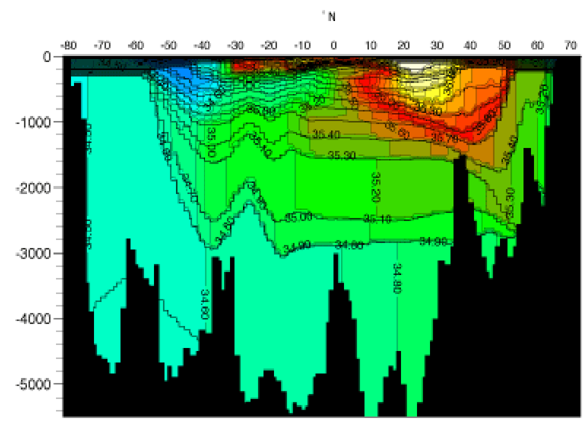
Year 200

**Salinity sections at 30°W in old (top) and new (bottom) CHIME integrations**

Year 800

New model also shows buildup of very fresh AABW.





# Concluding remarks

A new control integration of the CHIME coupled model has now reached 900 years.

Have also completed two 0.1 Sv freshwater hosing experiments starting from years 100 and 200 of the control, and a 1%/year $CO_2$ run up to 4 x $CO_2$.

The new model is intriguingly different from the original CHIME run, though certainly no less acceptable in its realism.

- Surface errors are stable and acceptably low
- Warm salty bias in NW Atlantic seen in old CHIME not present in new model.
- ENSO is strong and perhaps too regular.
- AMOC starts a little weak (13 Sv at 30°N), but increases later in the run. Variability seen at time scales from interannual to multidecadal.
- Deep drift consistent with low numerical diffusion in HYCOM v2.2.

# What's next for CHIME?

- CHIME has been deprioritised by NERC/NOC in favour of a NEMO monoculture.

- No more model development of CHIME.

- Current control experiment will be run to 1,000 years: will carry out preliminary analysis of AMOC variability along lines of UK RAPID-RAPIT programme.
- Will make output available to research students.

- Planning new funding proposal for December 2013 on mechanisms and efficiencies of ocean heat uptake under warming scenarios. This may well include CHIME, and will relate to other coupled models with a layered ocean.