



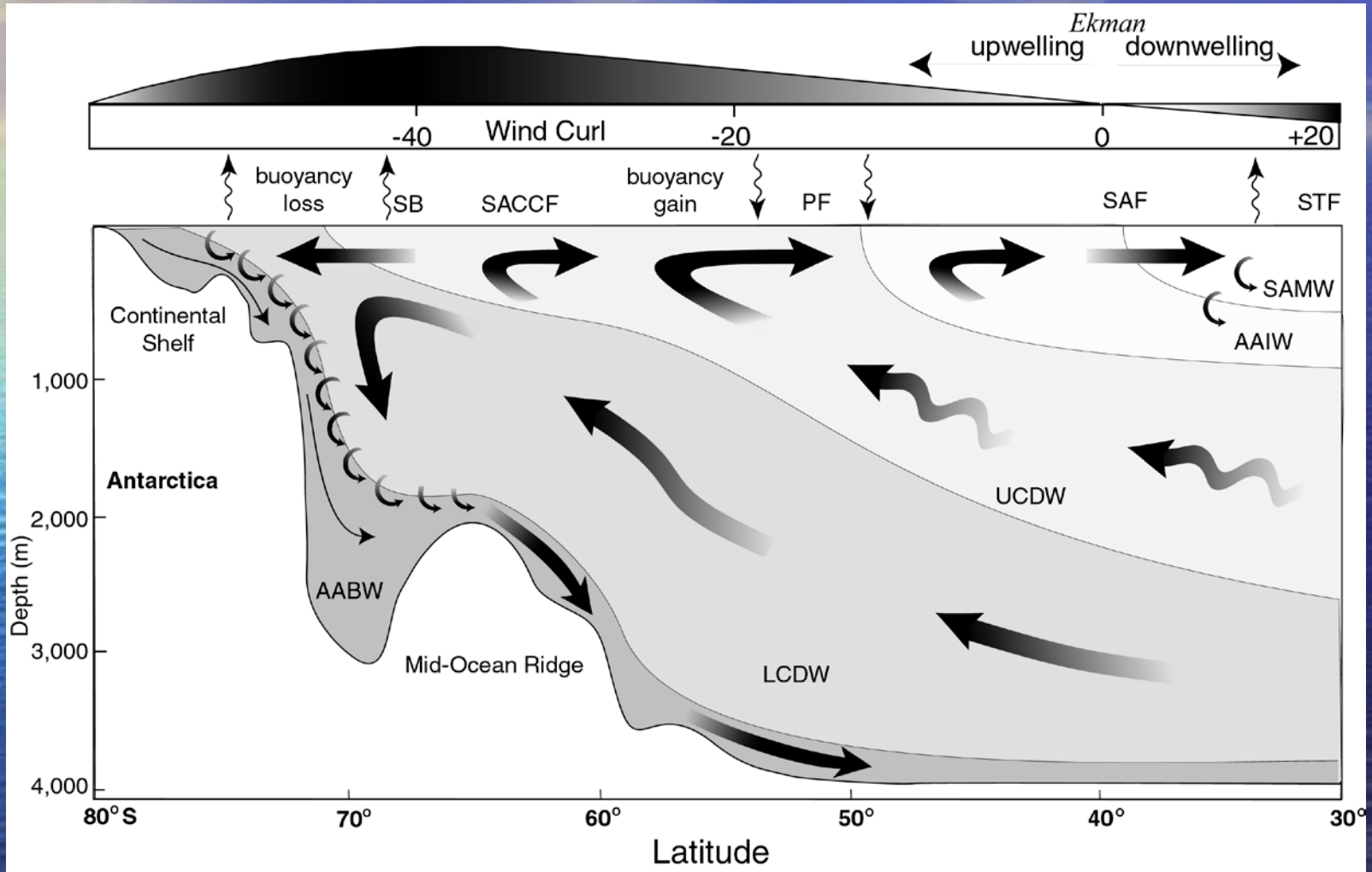
Tracer uptake in the Southern Ocean

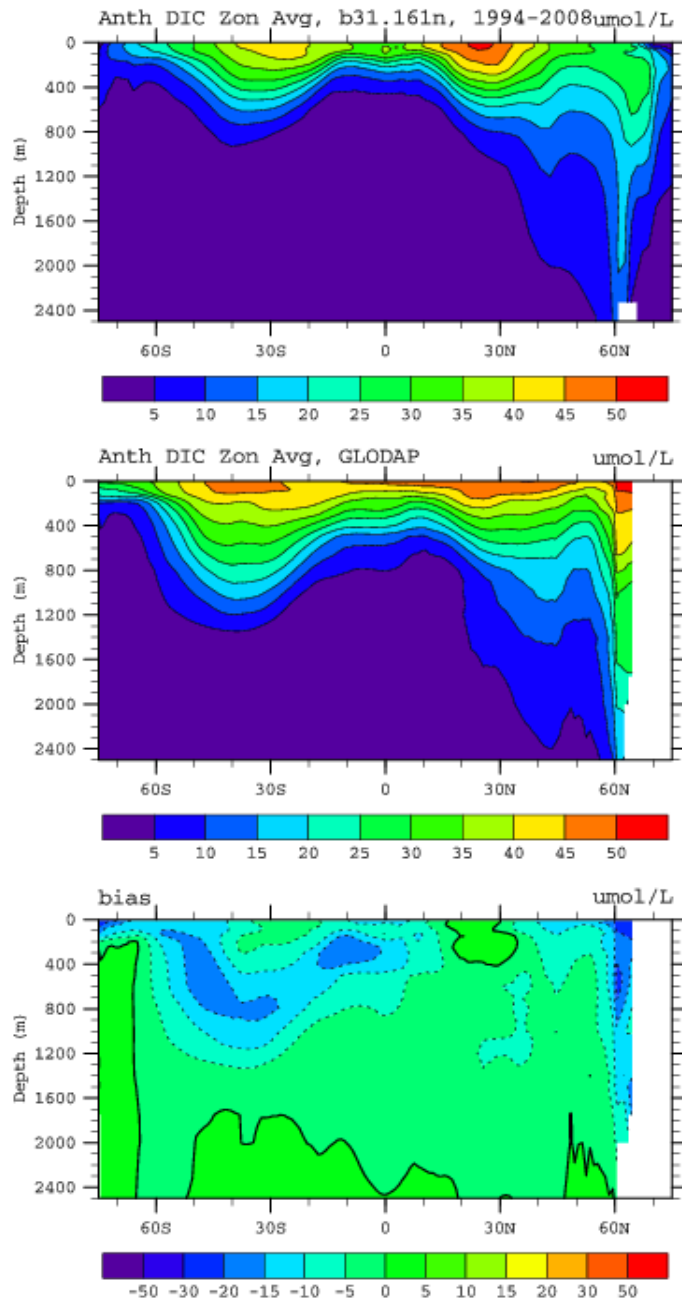
Synte Peacock

Markus Jochum

Gokhan Danabasoglu

Major water masses in the Southern Ocean

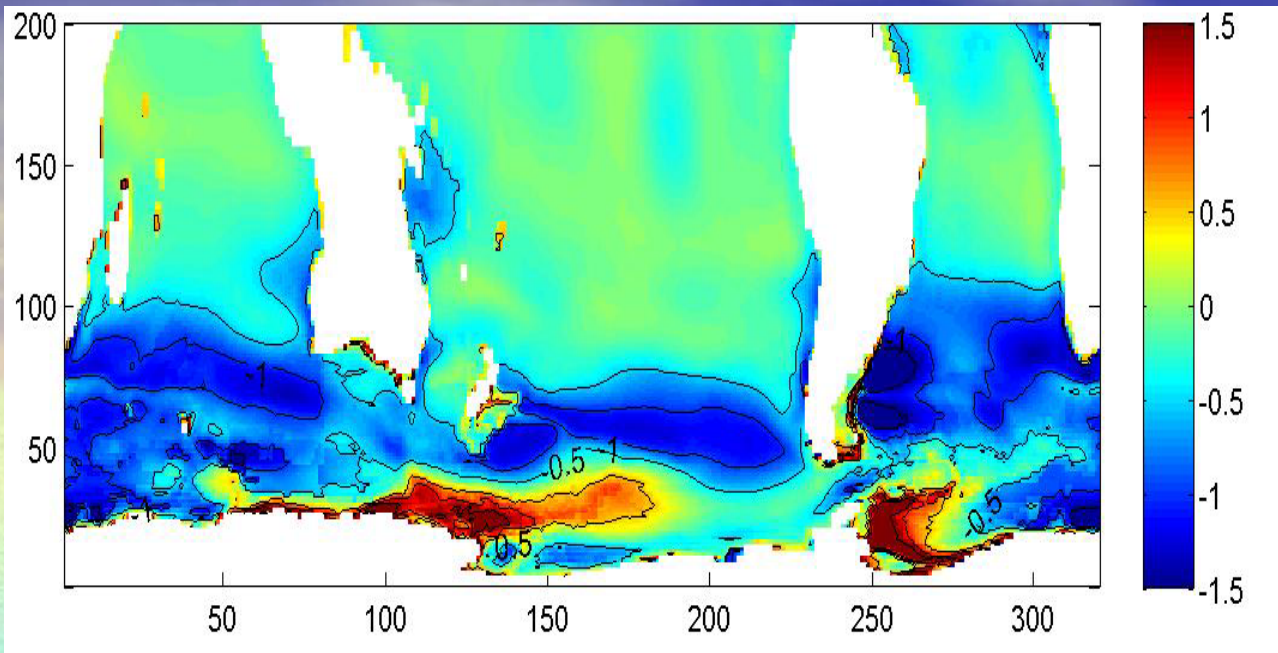




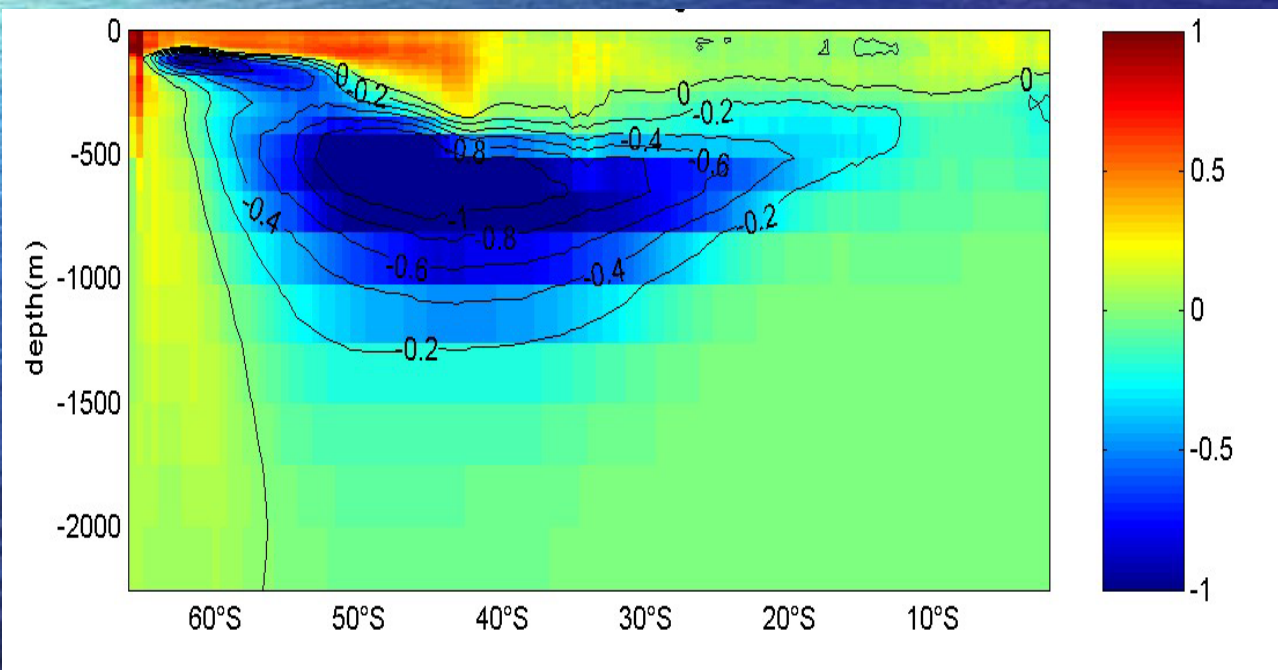
It is very difficult to get SAMW/AAIW tracer uptake right in CCSM models.

For example, the simulated anthropogenic CO_2 inventory (in the CCSM3.1 fully coupled carbon simulation) for the WOCE period is 42% lower than observed estimates, (which are assigned a 16% uncertainty).

There is also a corresponding negative CFC deficit in SAMW/AAIW, which tends to be worse in the ocean-only simulations than in the coupled runs (due to large positive biases in the Southern Ocean winds in the coupled simulations)

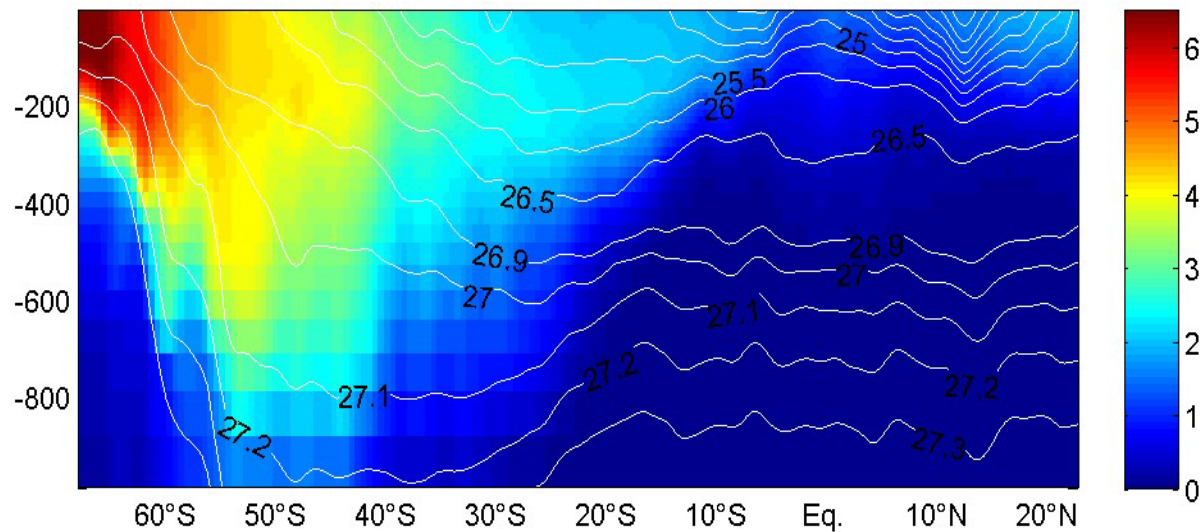


CFC11 column inventory in
CCSM3.0 ocean only
normal-year forced run:
model minus observations

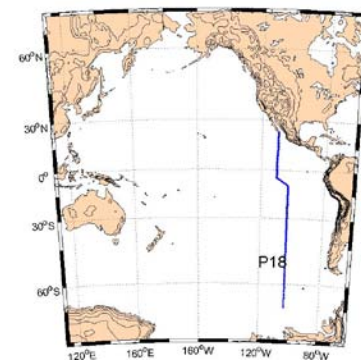
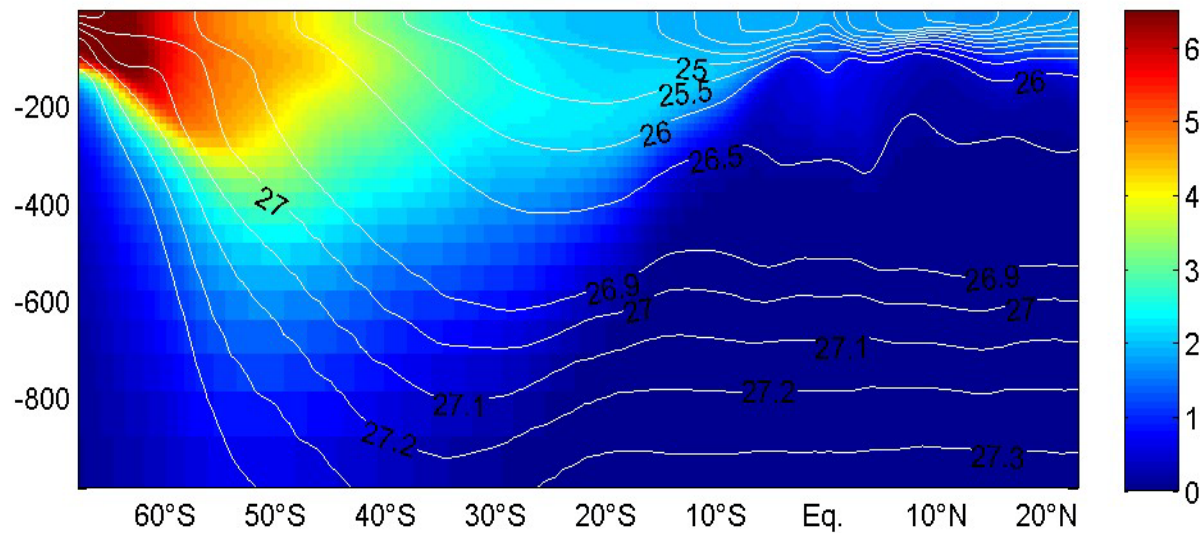


Zonally averaged CFC11:
model minus observations

P18 CFC11 OBS FEB 1994



CCSM4.0 CONTROL CFC 1994



Why do we care about Southern Ocean intermediate-depth water-masses?

- The Southern Ocean is responsible for about 60% of the global oceanic anthropogenic CO₂ uptake.
- Most of this CO₂ is found in the thermocline (SAMW/AAIW)
- The ability of the ocean to take up CO₂ is controlled by oceanic ventilation, which determines how rapidly ocean surface properties are transported to the interior, and how deep the main thermocline is.
- There has recently been vigorous debate about the future role of the Southern Ocean in uptake of anthropogenic CO₂. The question of whether these waters are saturated, and uptake has been declining in recent decades, is directly related to uncertainties of how the ventilation of SAMW and AAIW change under global warming (*LeQuere et al 2007; Zickfeld et al, 2008; Matear and Lenton 2008; Boning et al 2008*)
- In the next IPCC runs, it would be desirable to have realistic anthropogenic CO₂ uptake in present-day runs in order to have faith in future predictions.

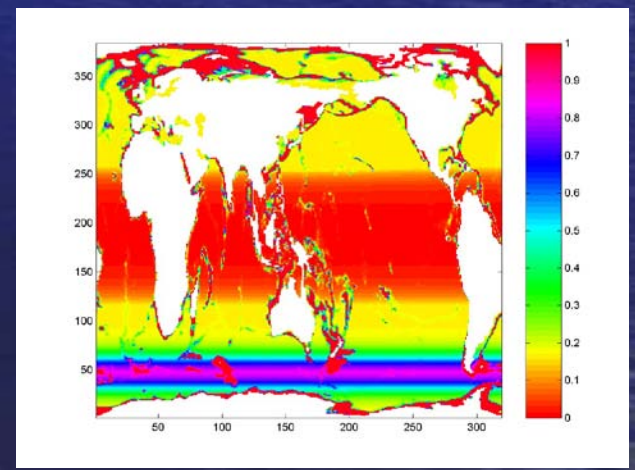
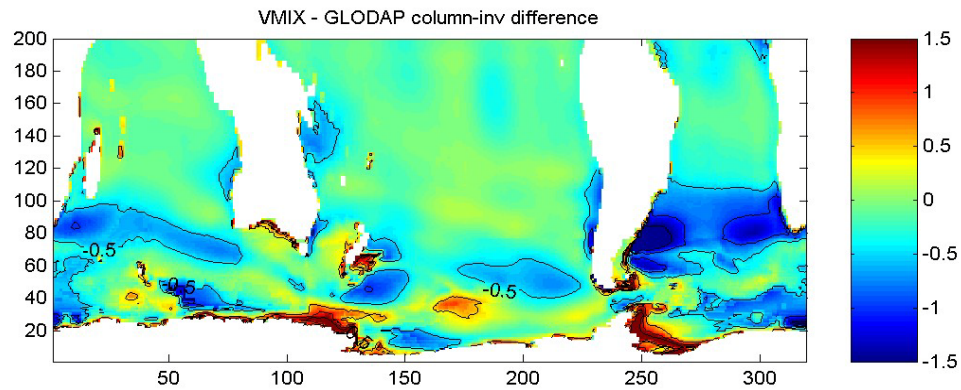
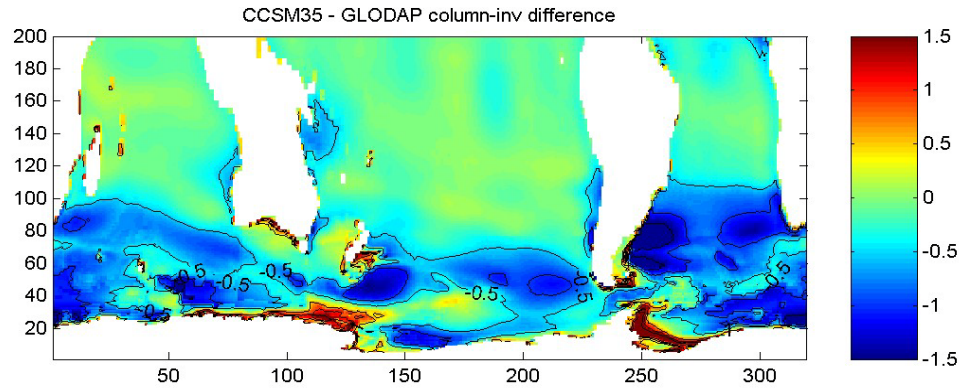
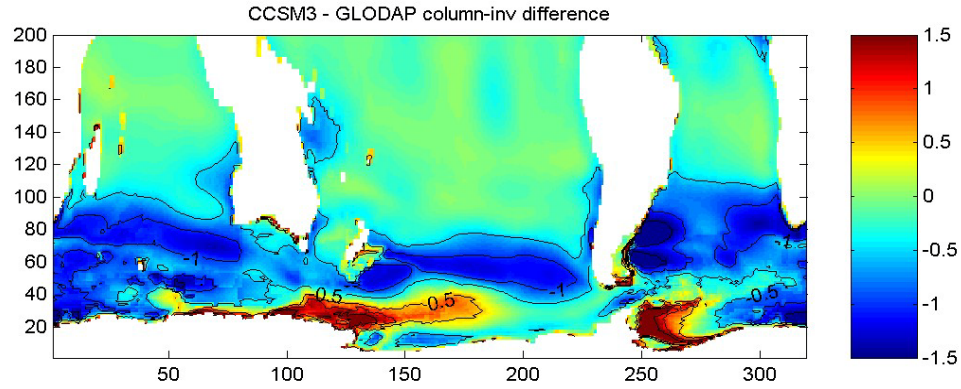
Why is there not enough tracer uptake in the CCSM Southern Ocean water-masses?

Possibilities:

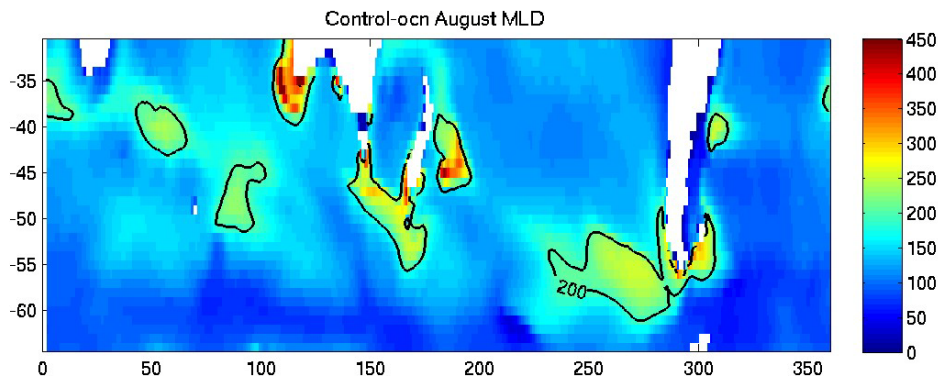
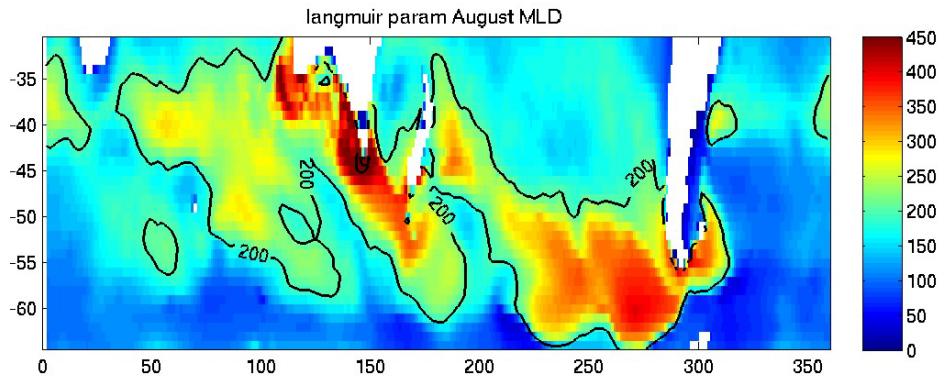
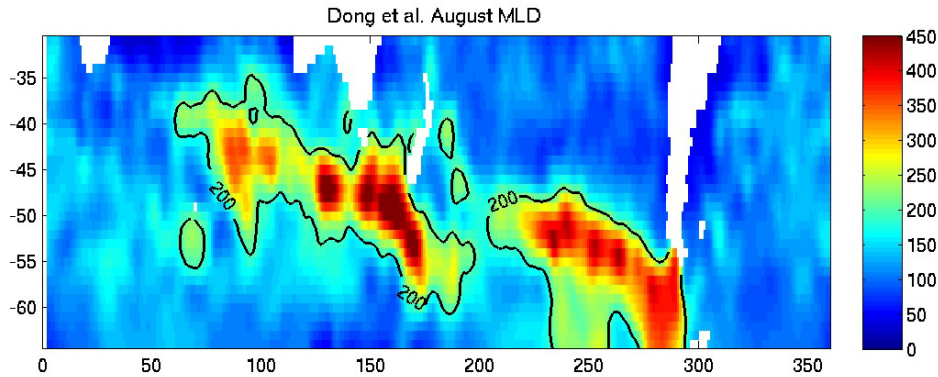
- Circulation bias? Advection? Mixing?
- Temperature (solubility) bias? Surface density bias?
- Bias in Mixed Layer Depth?

Is model tracer uptake highly sensitive to any of the above?

Sensitivity of CFC uptake to Vertical Mixing (in KPP)



Sensitivity of CFC uptake to changes in winter-time Mixed Layer Depth (Langmuir parameterization; Fox-Kemper)

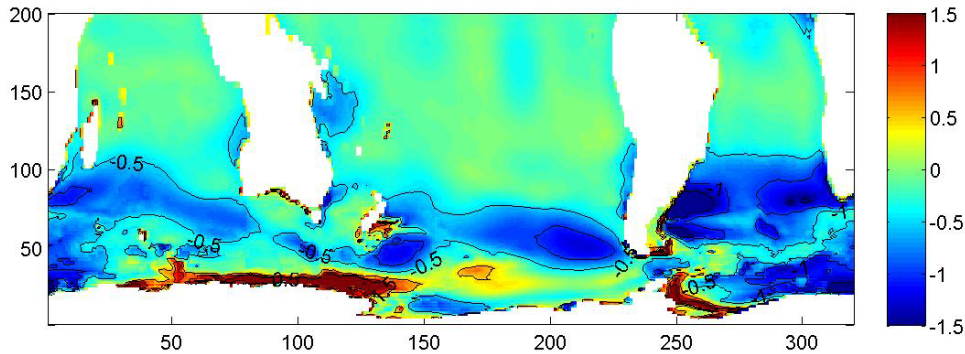


Langmuir parameterization:

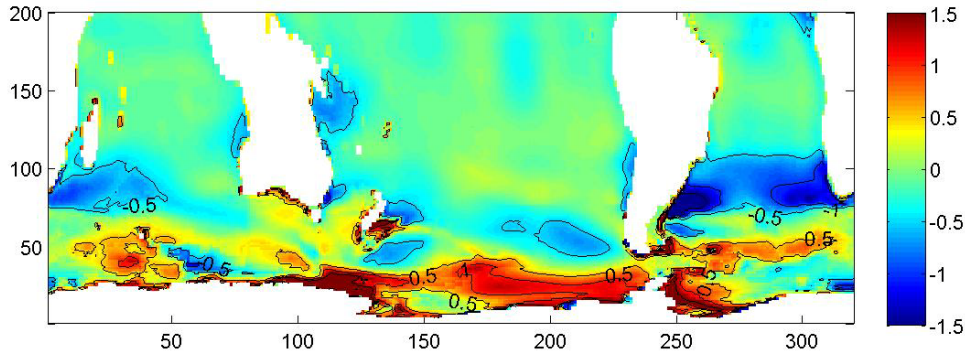
CFC bias reduced when
winter-time MLD deepens;

Solution fairly sensitive to
details of parameterization.

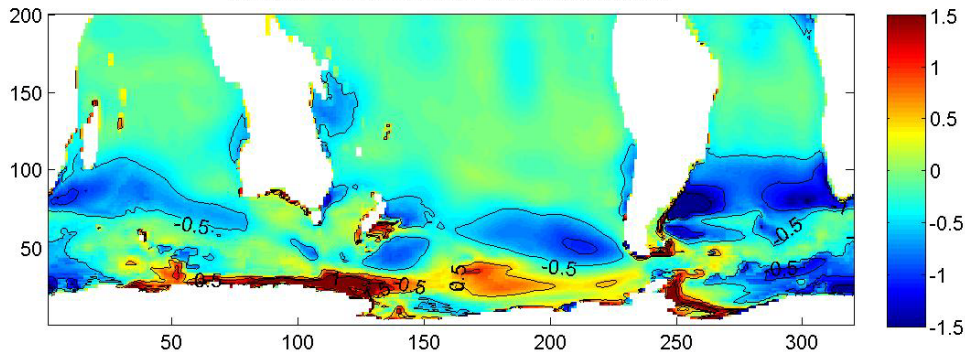
CONTROL - GLODAP column-inv difference



LANGMUIR.001 - GLODAP column-inv difference

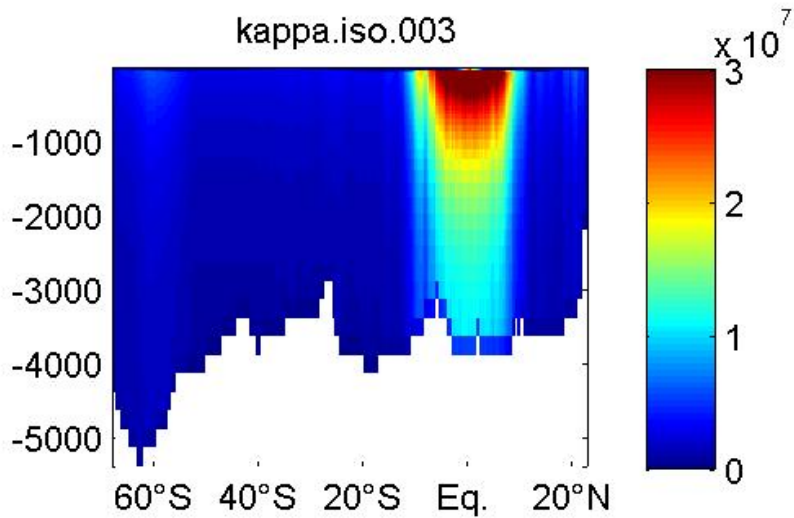


LANGMUIR.006 - GLODAP column-inv difference

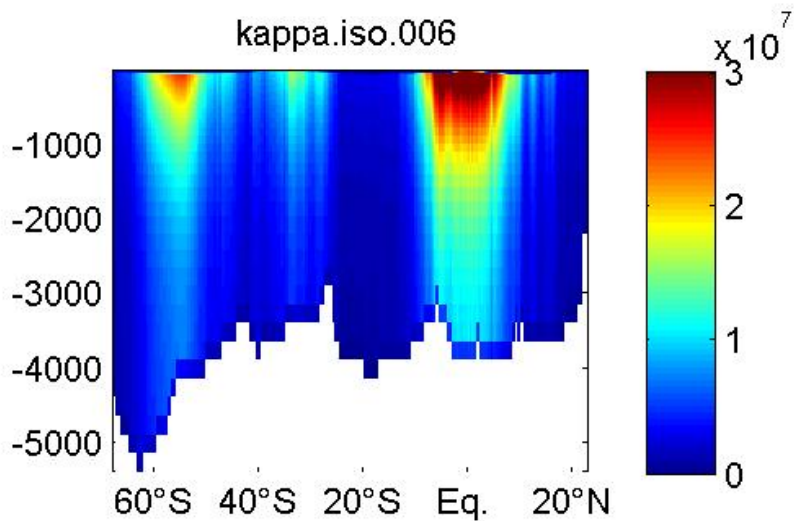


Isopycnal Mixing I

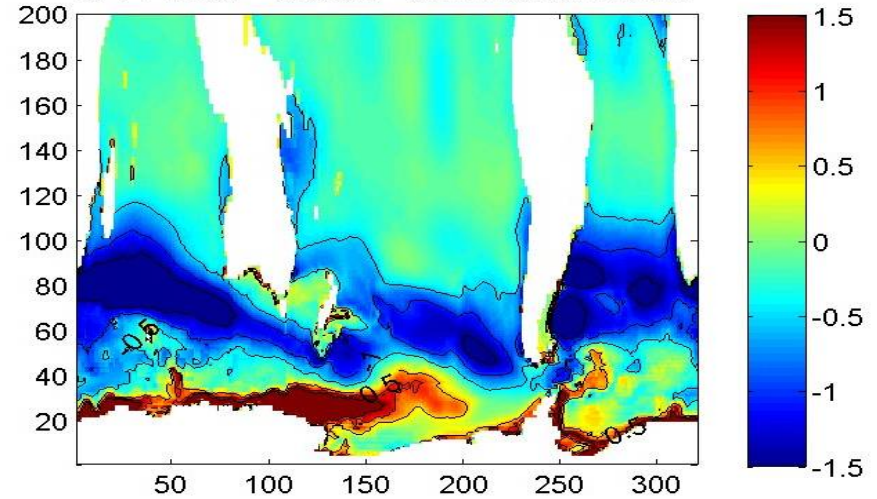
kappa.iso.003



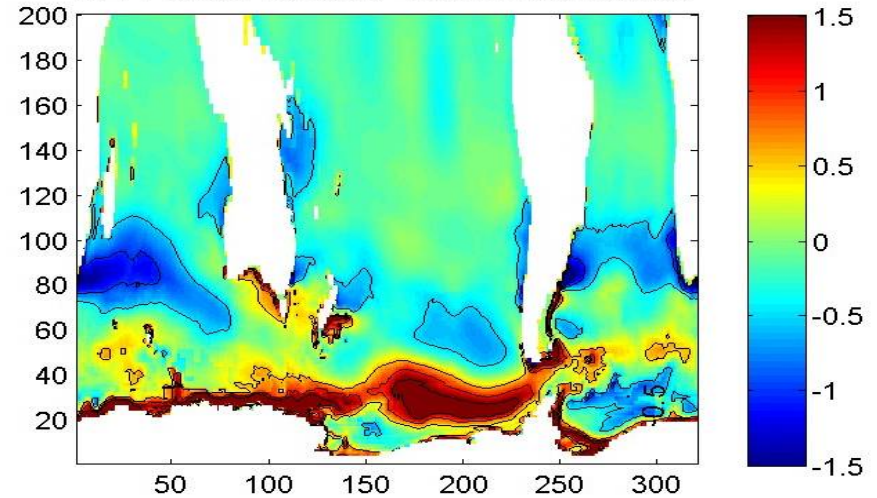
kappa.iso.006



KAPPA.003 - GLODAP column-inv difference



KAPPA.006 - GLODAP column-inv difference

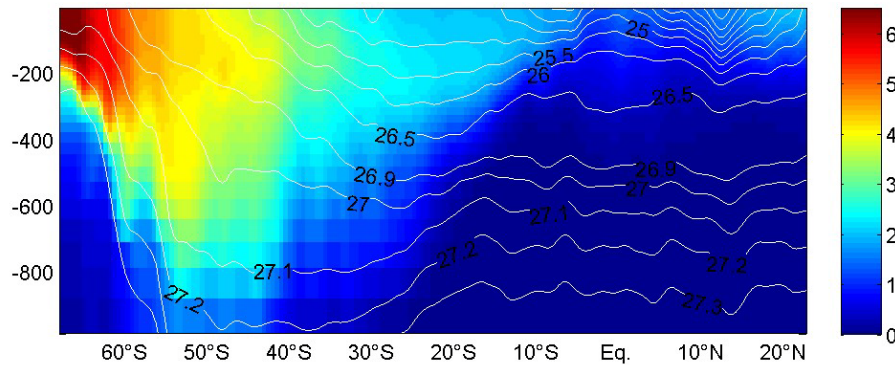


Isopycnal Mixing II

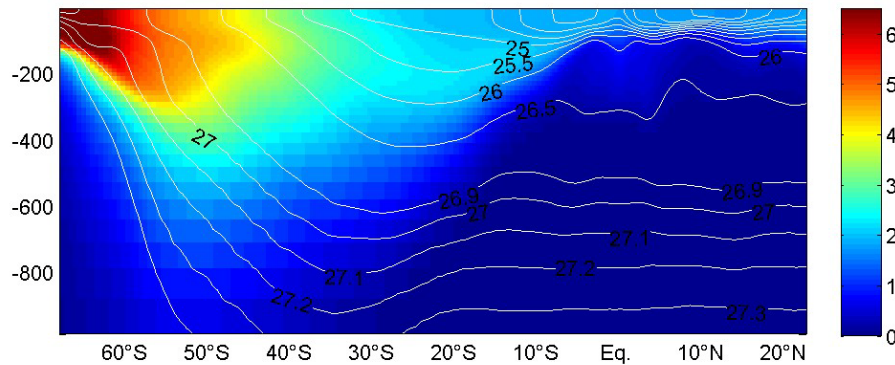
Recently there has been an effort towards implementing the Eden-Greatbatch scheme (EKE-based scheme for computing kappa in GM; Jochum, Danabasoglu)

However, there is a trade-off between CFC uptake in the Southern Ocean and ACC strength/heat transport. Also an issue in the Arctic. Needs further work.

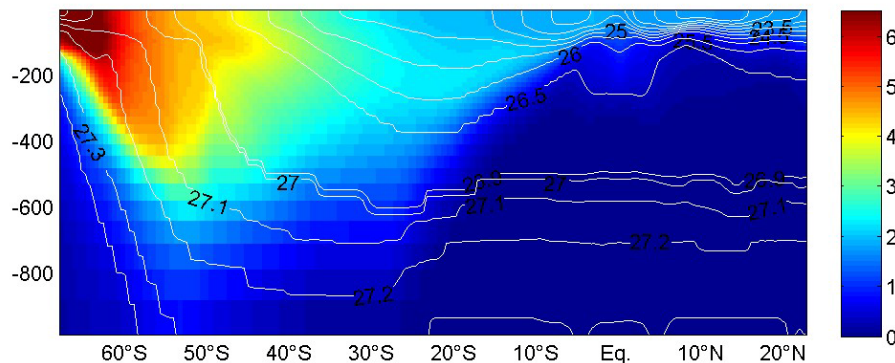
P18 CFC11 OBS FEB 1994



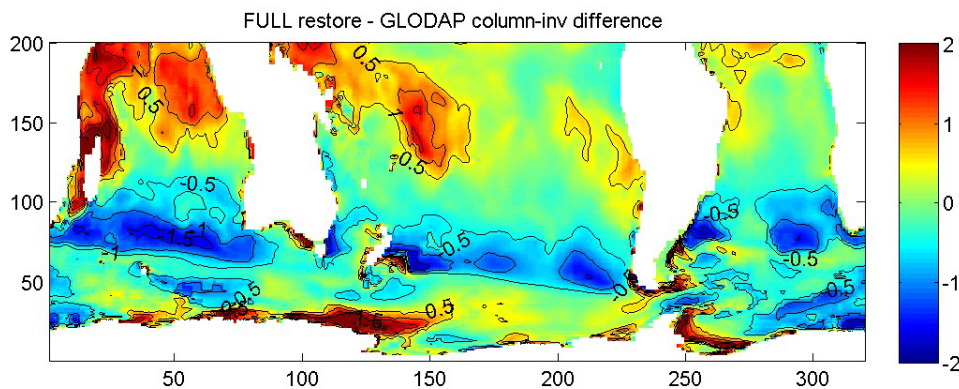
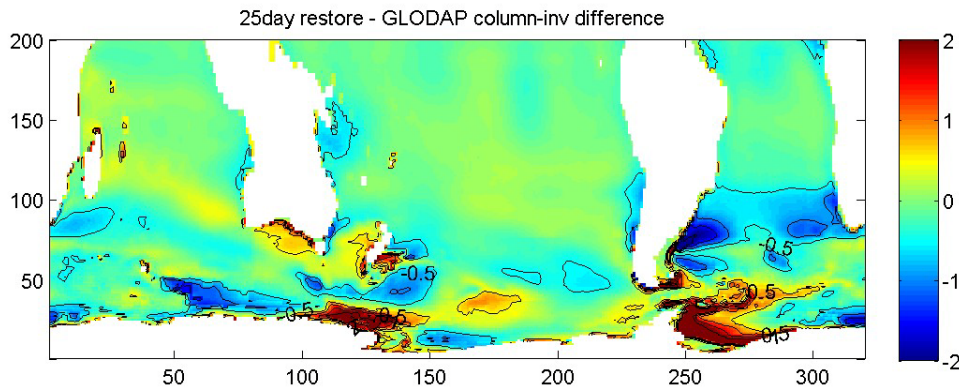
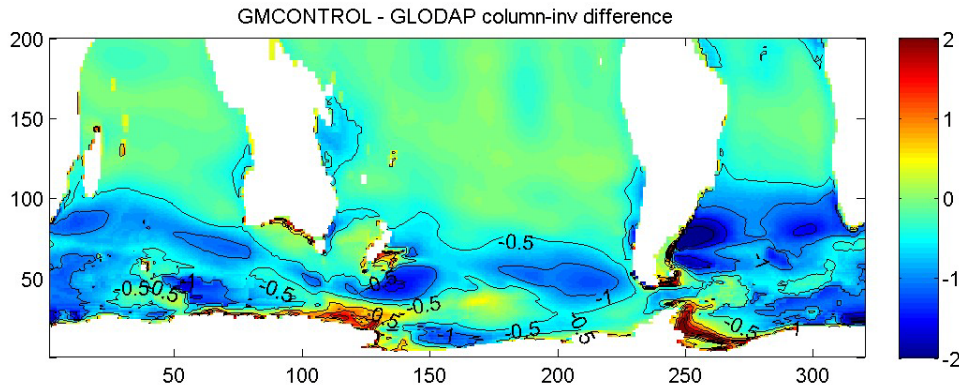
CCSM4.0 CONTROL CFC 1994



CCSM4.0 GMEFINAL3 CFC 1994



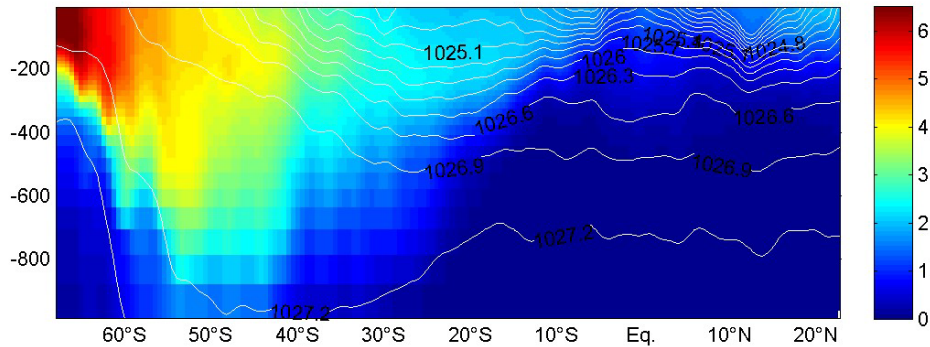
T-S Restoring Experiments



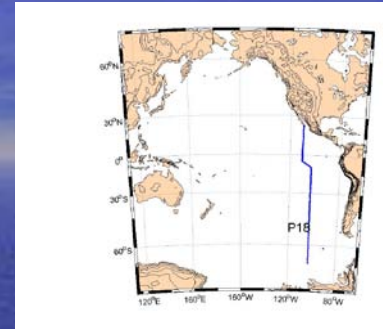
Strong surface restoring of T/S produces a CFC distribution in good agreement with observations, but degrades T and S in the interior.

Full depth restoring of T/S produces a good agreement of T/S with observations (by definition) but a very poor CFC distribution

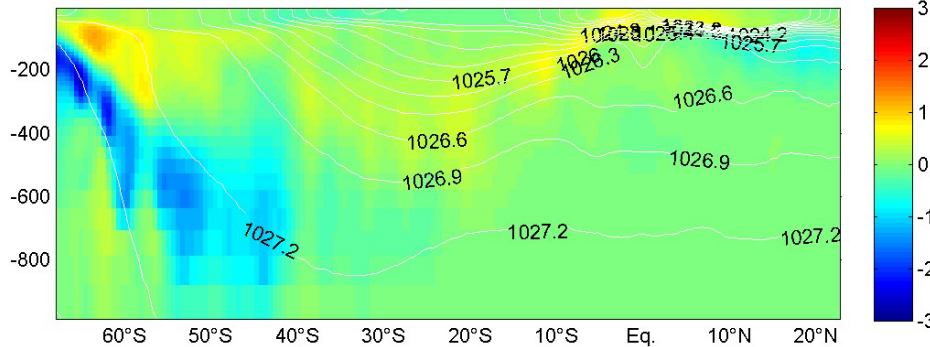
WOCE P18 CFC11



Observed CFC11 along WOCE P18 section

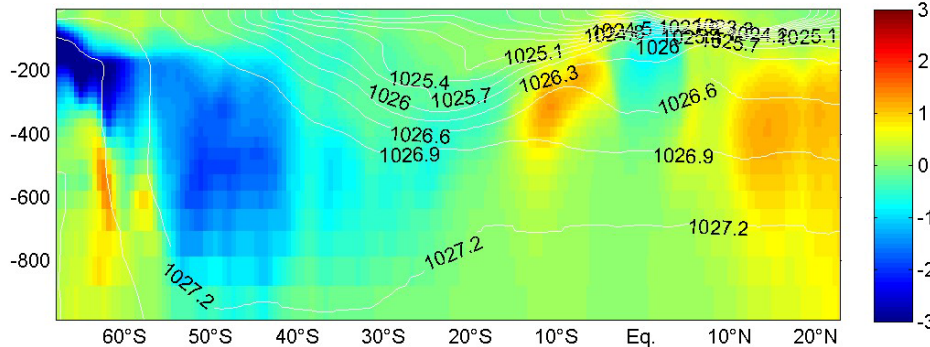


x1 25day TSrestore CFC11 MINUS WOCE along P18



Strong surface T/S restoring:
Model CFC minus observations
along P18 section

x1 fulldepth TSrestore CFC11 MINUS WOCE along P18



Full depth T/S restoring:
Model CFC minus observations
along P18 section

Is there a sensitivity of Southern Ocean tracer uptake to:

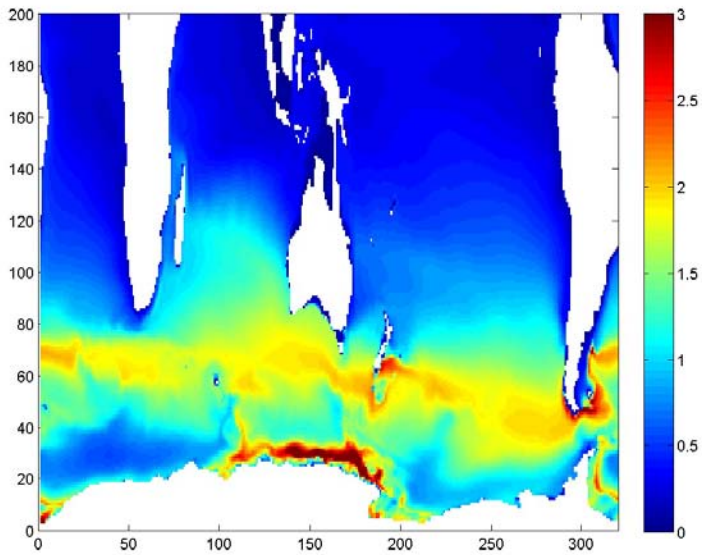
- Circulation? [Advection? Mixing?] 

- Solubility? 

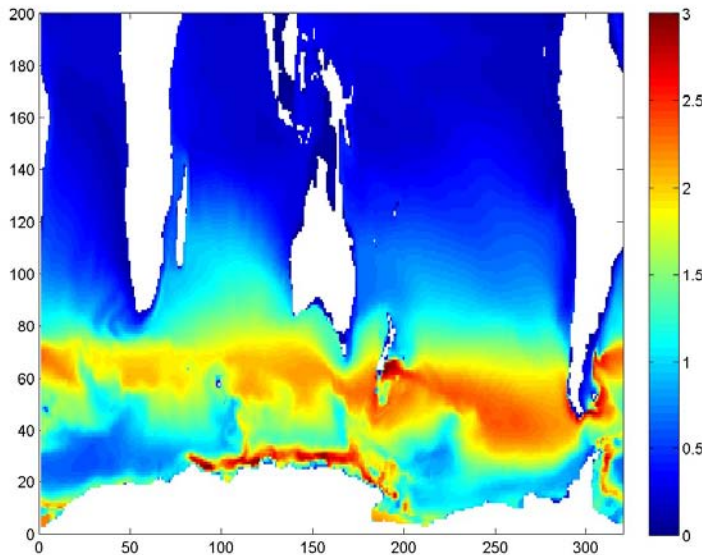
- Mixed Layer Depth? 

Changes in isopycnal mixing, vertical mixing, etc in isolation all have a strong impact on the negative tracer bias in SAMW/AAIW, but none completely eliminate the bias in CFC, T and S. It seems likely that there are short-comings in many of the model parameterizations, and that fixing the bias in Southern Ocean tracer uptake is not as straight-forward as one might hope...

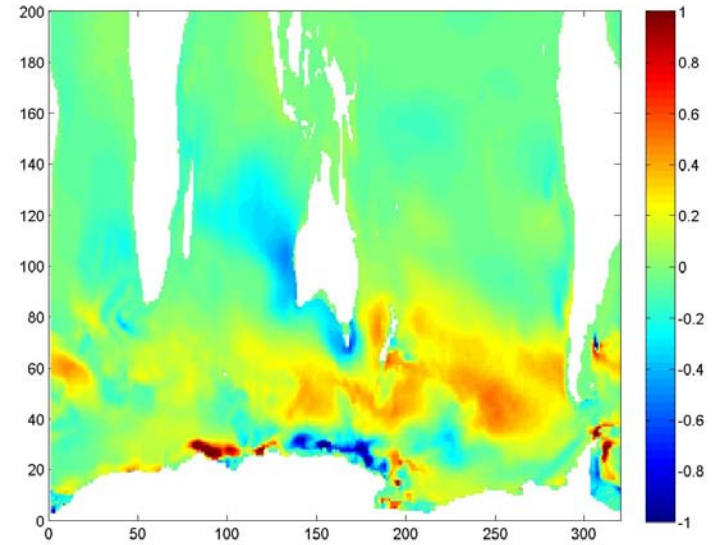
1985 CFC column inventory



Ocean only CCSM4.0



Coupled CCSM4.0



Difference: Coupled minus ocean only