Changes in the Ventilation of the Southern Oceans

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CLIVAR/OCB Workshop, December 2014

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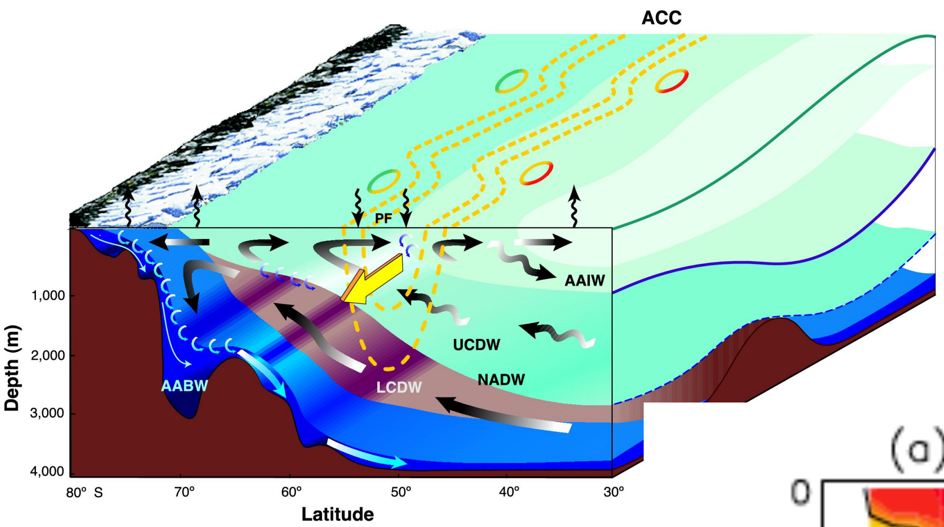
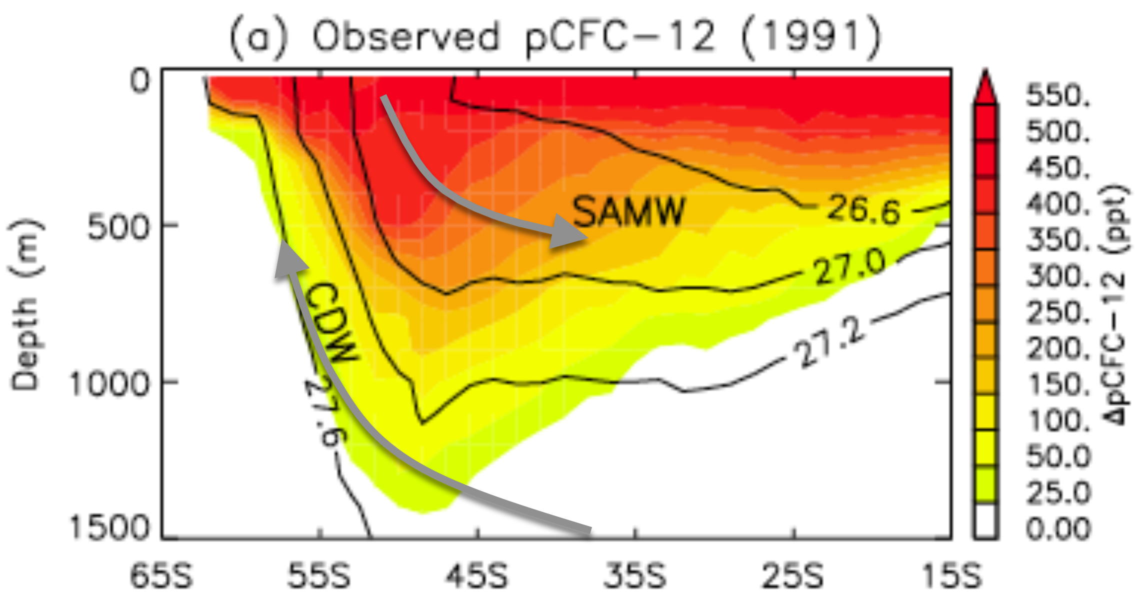
Winds and Southern Ocean Circulation

The meridional circulation and transport of tracers in the southern oceans are coupled to overlying westerly winds.





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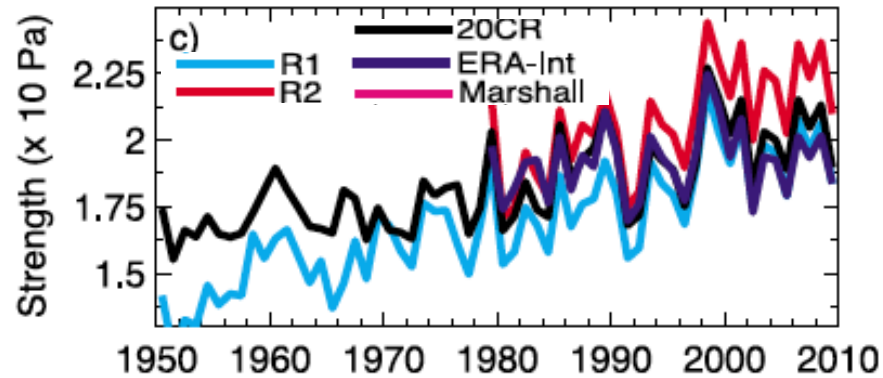
Changes in Wind Stress

Observations show an increase in SH wind stress in recent decades (due mainly to ozone depletion).



[Swart & Fyfe, GRL, 2012]

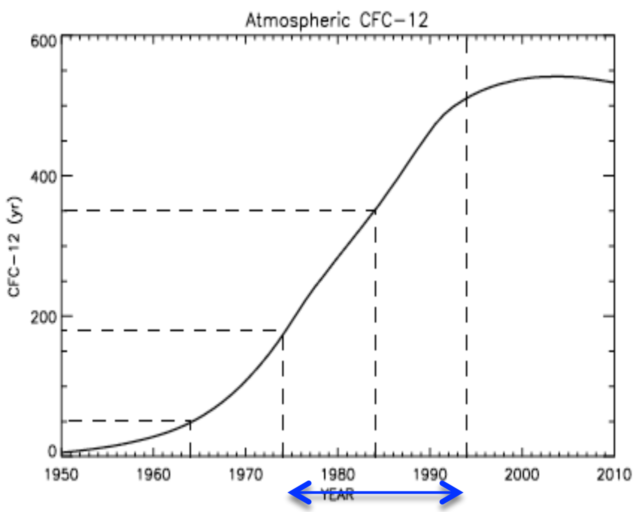
Theoretical and modeling studies indicate that this will lead to *changes in ocean circulation and ventilation*. But some debate …

=> Examine ocean measurements of chlorofluorocarbons (CFCs)

CFCs as ocean tracers

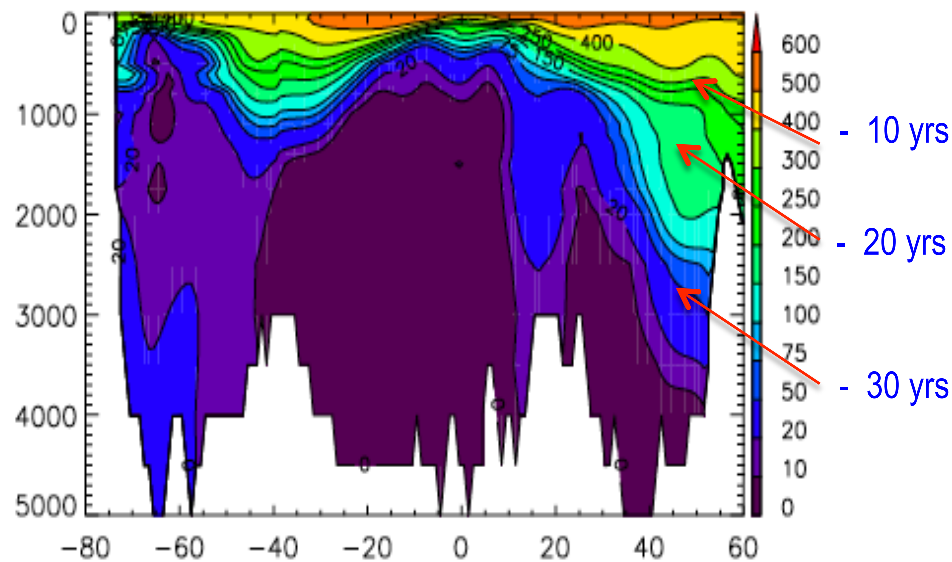
CFCs provide an indicator of surface-interior transport (ventilation) times in the ocean, because

- they are conserved in oceans, and
- their atmospheric concentrations increased from 1950 to 2000.

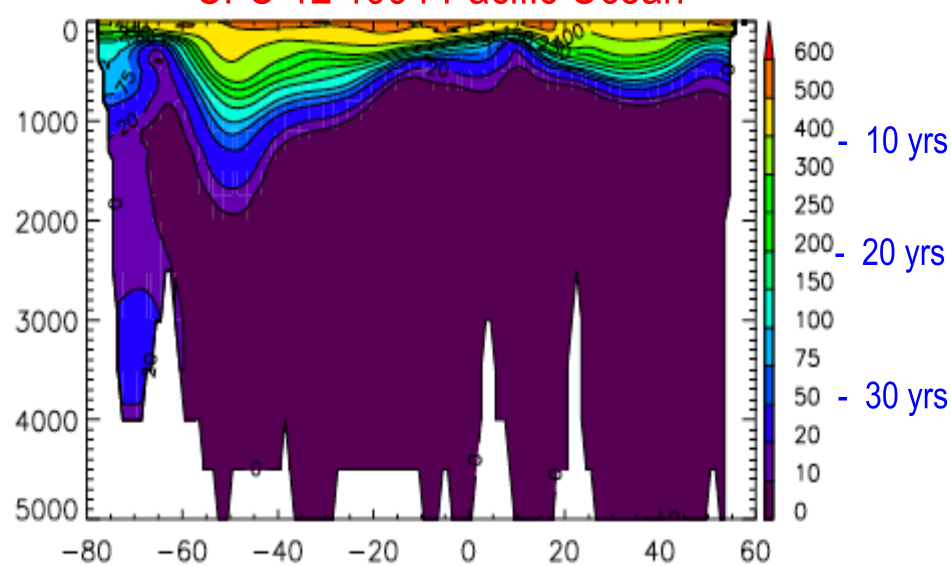


CFC age ~ 20 yrs

CFC-12 1994 Atlantic Ocean



CFC-12 1994 Pacific Ocean



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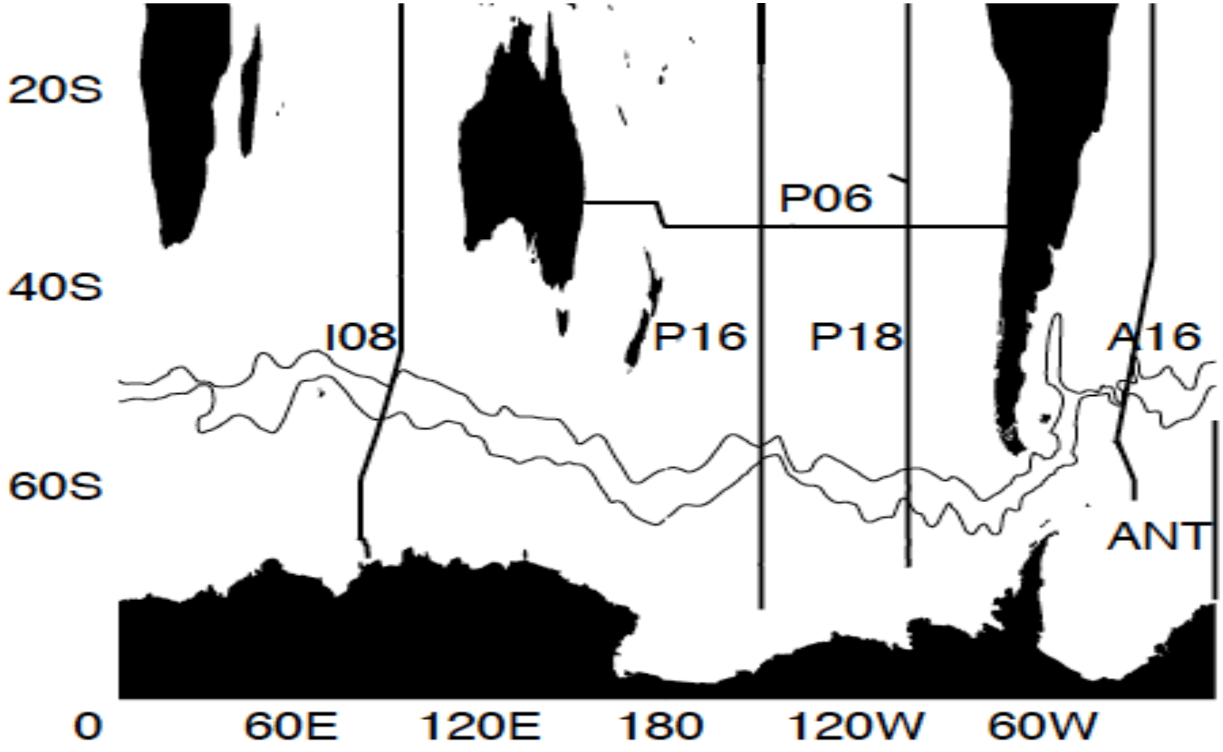
*** CFC-age is not a transport time; CFC-age < Mean age ***

Ocean CFC Measurements

Measurements of CFC-12 were made along sections in Southern Oceans during early 1990s (WOCE) and mid to late 2000s (CLIVAR Repeat Hydrography).



Focus on sections P16 (1991,2005), P18 (1994,2008), P06 (1992,2003,2009), A16 (1989,2005) and I08 (1994,2008)

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Approach

Null Hypothesis: Increases in CFC-12 can be explained by steady transport.

Assume steady transport, make predictions of CFC-12 for repeat cruise based on data from original cruise, and compare with observed CFC-12 increases. If significant differences then suggests a change in ventilation.

Use two different models that **include mixing** and are **constrained to match 1990s CFCs**:

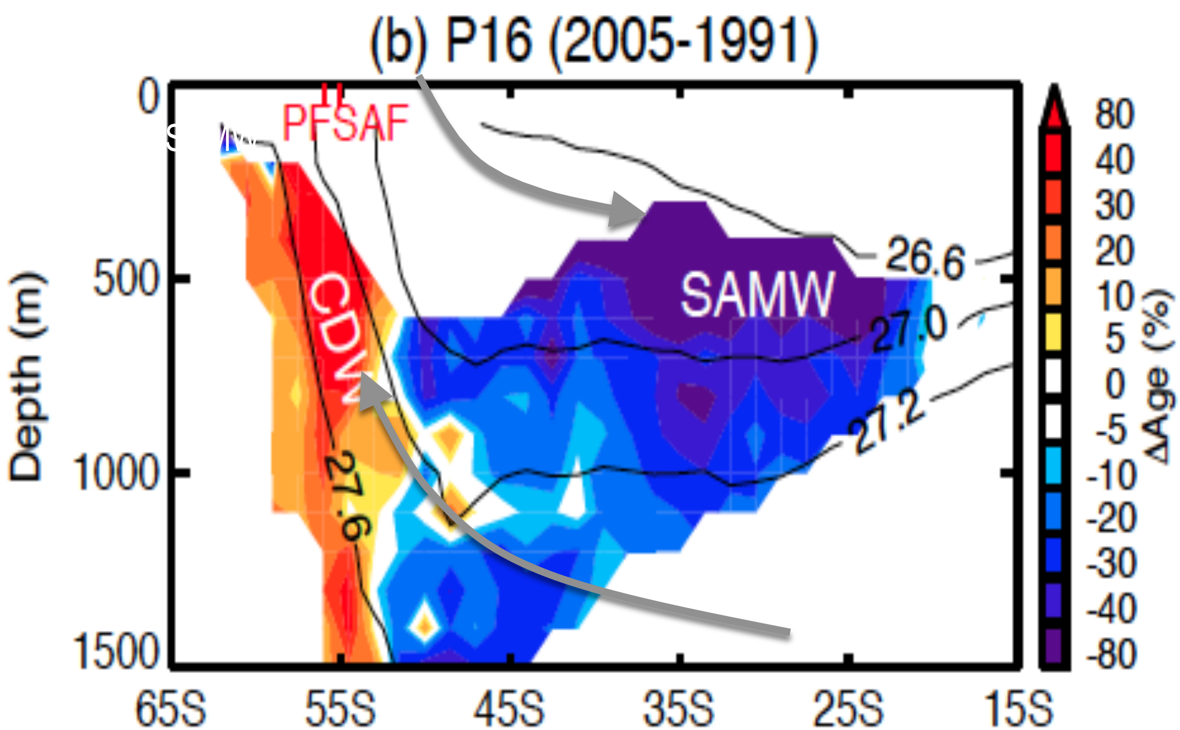
1. Transit Time Distribution (TTD) model.
2. Data Assimilation model [DeVries and Primeau 2011] .

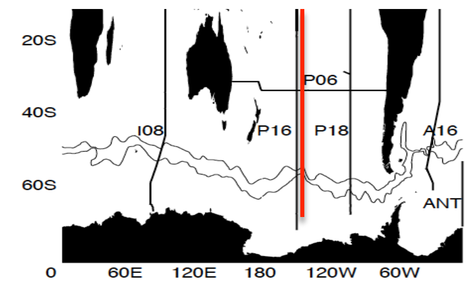
Change in Mean Water-Mass Age

Observed increases in CFC-12 within subtropical” waters smaller than expected for steady transport, and larger than expected within polar waters:

=> **Decrease of “age” within SAMW and increase within CDW.**

% difference in mean age between occupation.





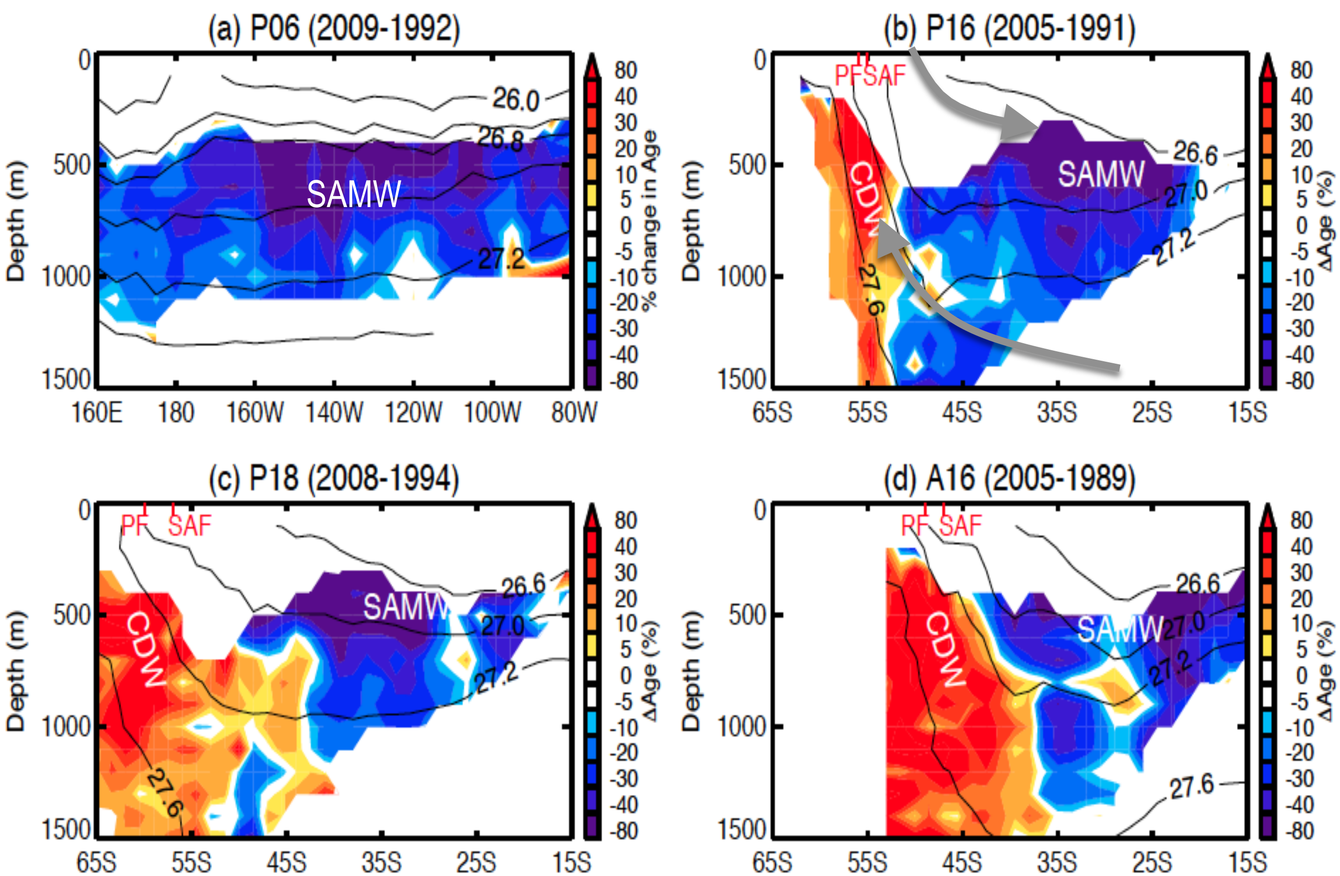
Waugh et al. (Science, 2013).

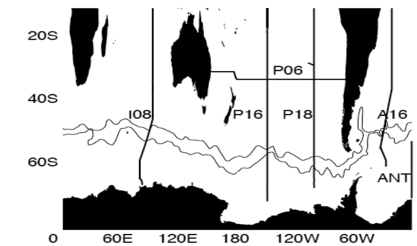
Change in Mean Water-Mass Age

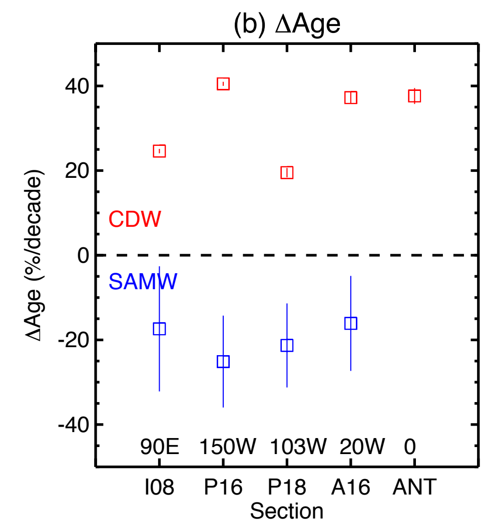
Consistent picture for all sections:

Decrease of "age" within SAMW and increase within CDW.

% difference in mean age between occupation.







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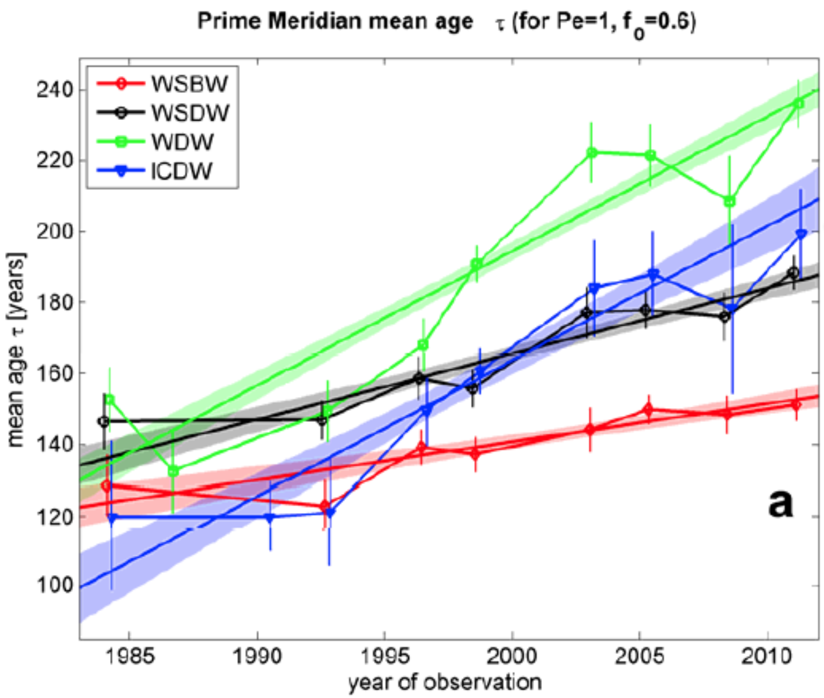
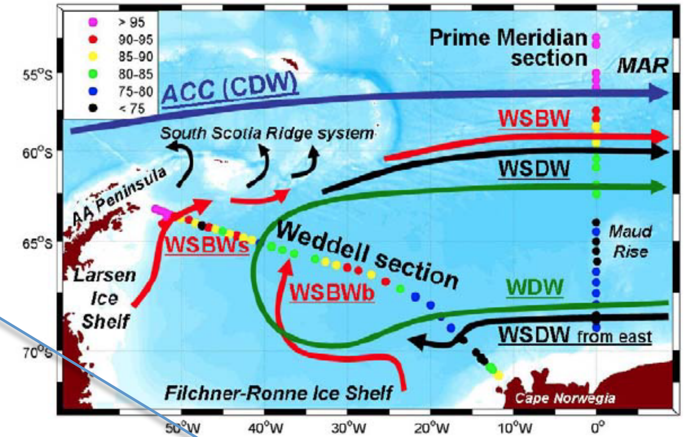
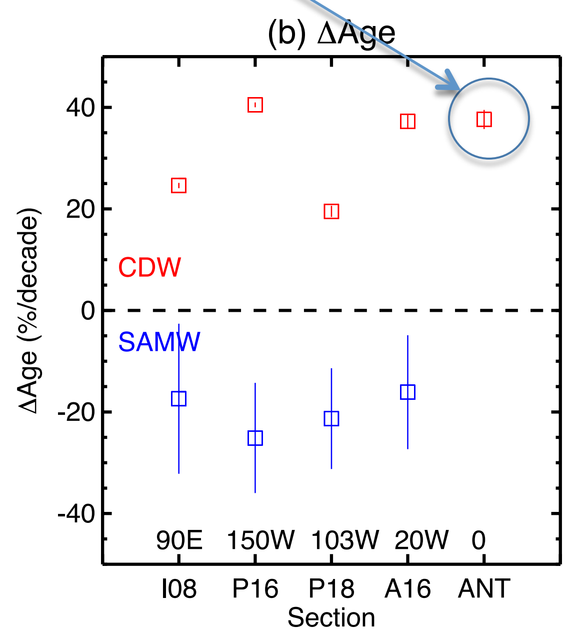
Waugh et al. (Science, 2013).

Age Changes in Weddell Sea

[Huhn et al., DSR, 2013]







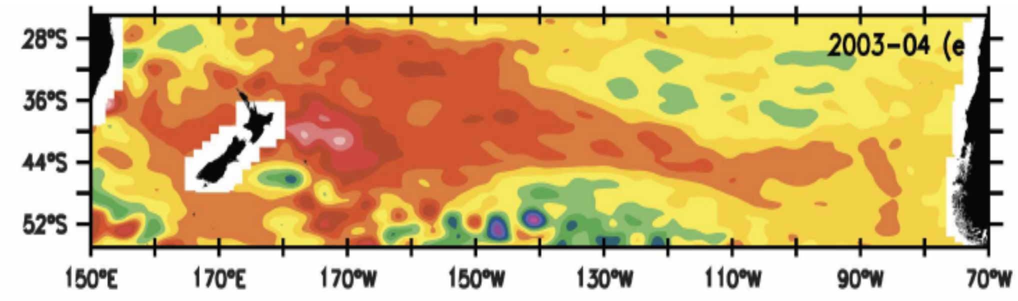
Increase in age of deep water also inferred from CFC observations in the Weddell Sea.

Increase in CDW same as for A16 section.

Consistency with other Studies

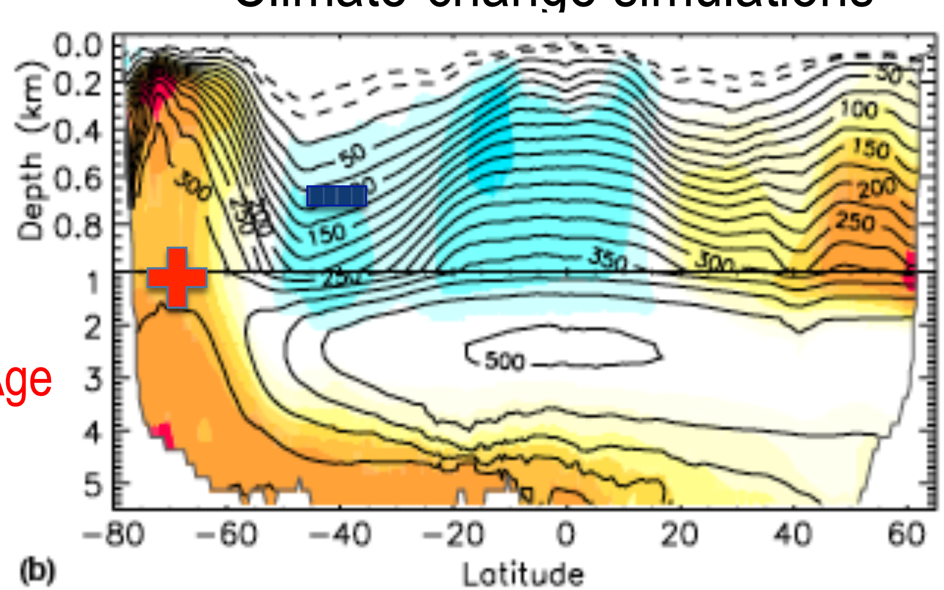
Spin-up of southern subtropical gyres
[e.g., Roemmich et al. 2006].

ΔSSH 2003/04 – 1993/94



Climate-change simulations

ΔAge



[CCSM; Bryan et al. 2006; GFDL; Gnanadesikan et al. 2007]

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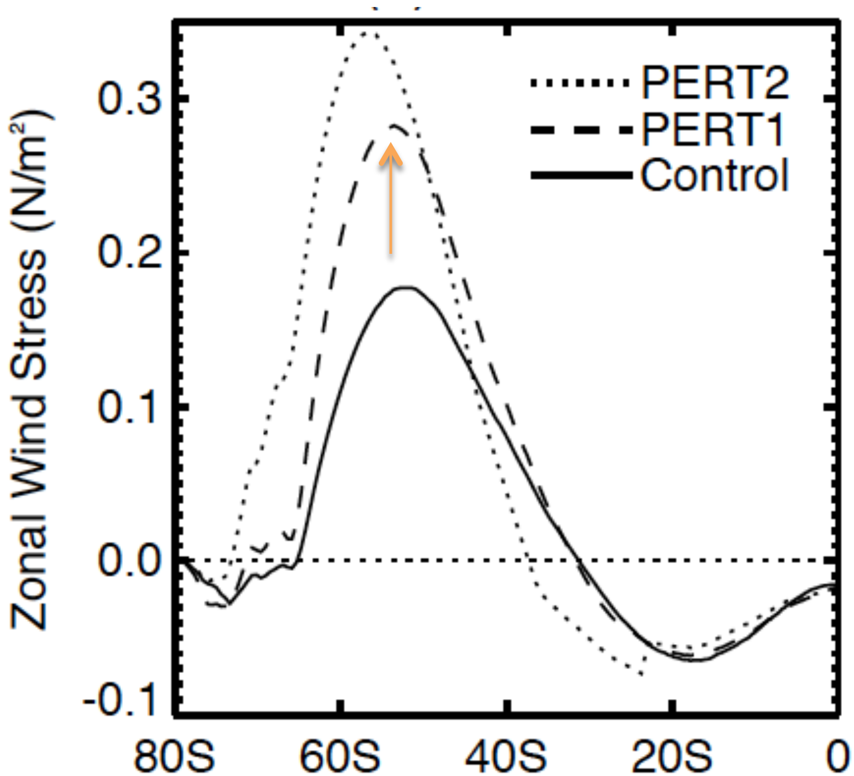
Climate Model Perturbation Experiments

Examine changes in the **ideal age** in the perturbation experiments of CCSM4 where the wind stress is instantaneously increased [Gent & Danabasoglu, 2011].



PERT1: 50% increase in wind stress.

PERT2: 75% increase, plus 3° poleward movement of maximum.

[Note: Change in wind stress in model is much larger than observed increase over last 30 years.]

In steady state, the ideal age = mean water-mass age

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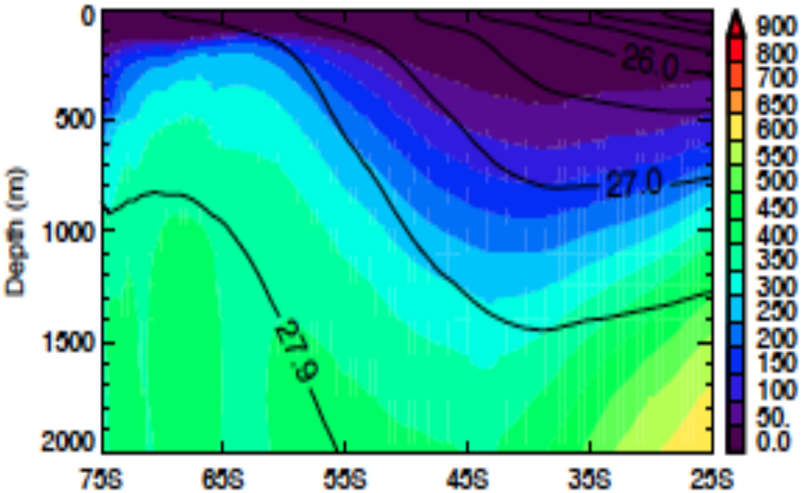
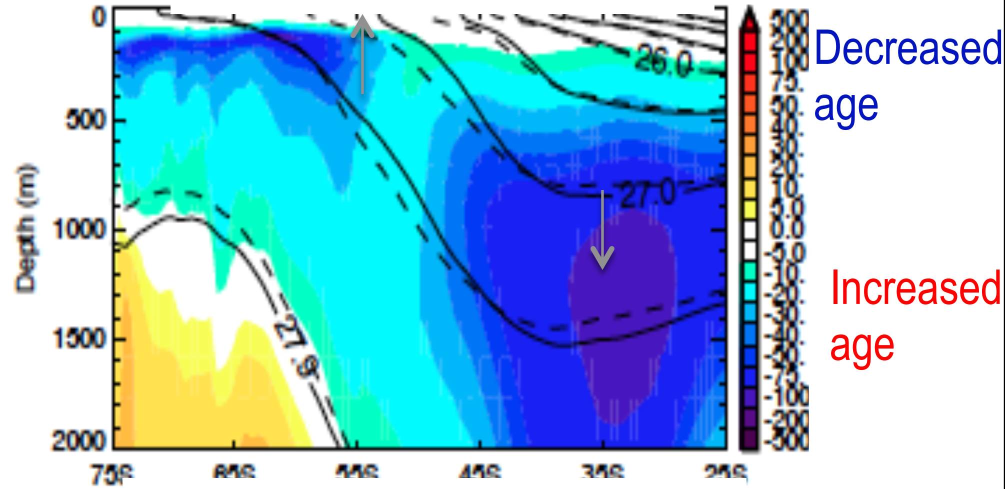
Zonal-mean Ideal Age

Increased wind stress leads to younger ages in subtropical thermocline and (slightly) older ages in circumpolar deep water.

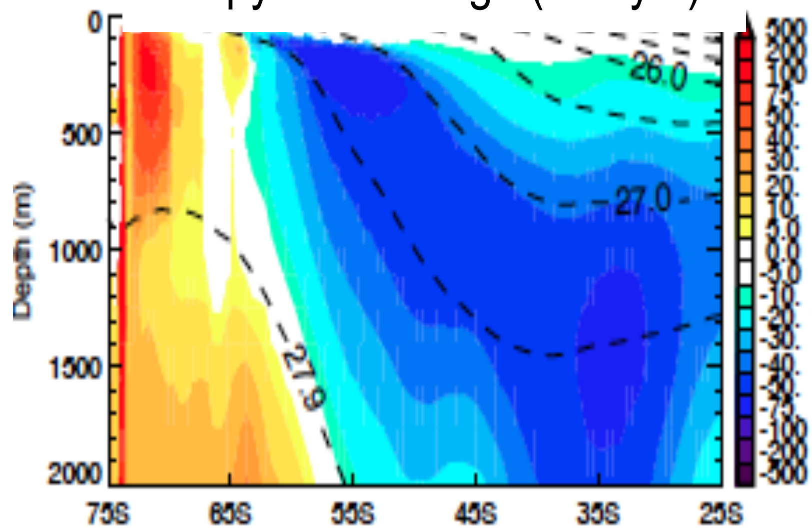
Control



PERT1-Control (100 yrs)



Isopycnal Change (100 yrs)



Decrease in ages is due to combination of *movement of isopycnals* and *along-isopycnal transport.*

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Evolution of ideal age

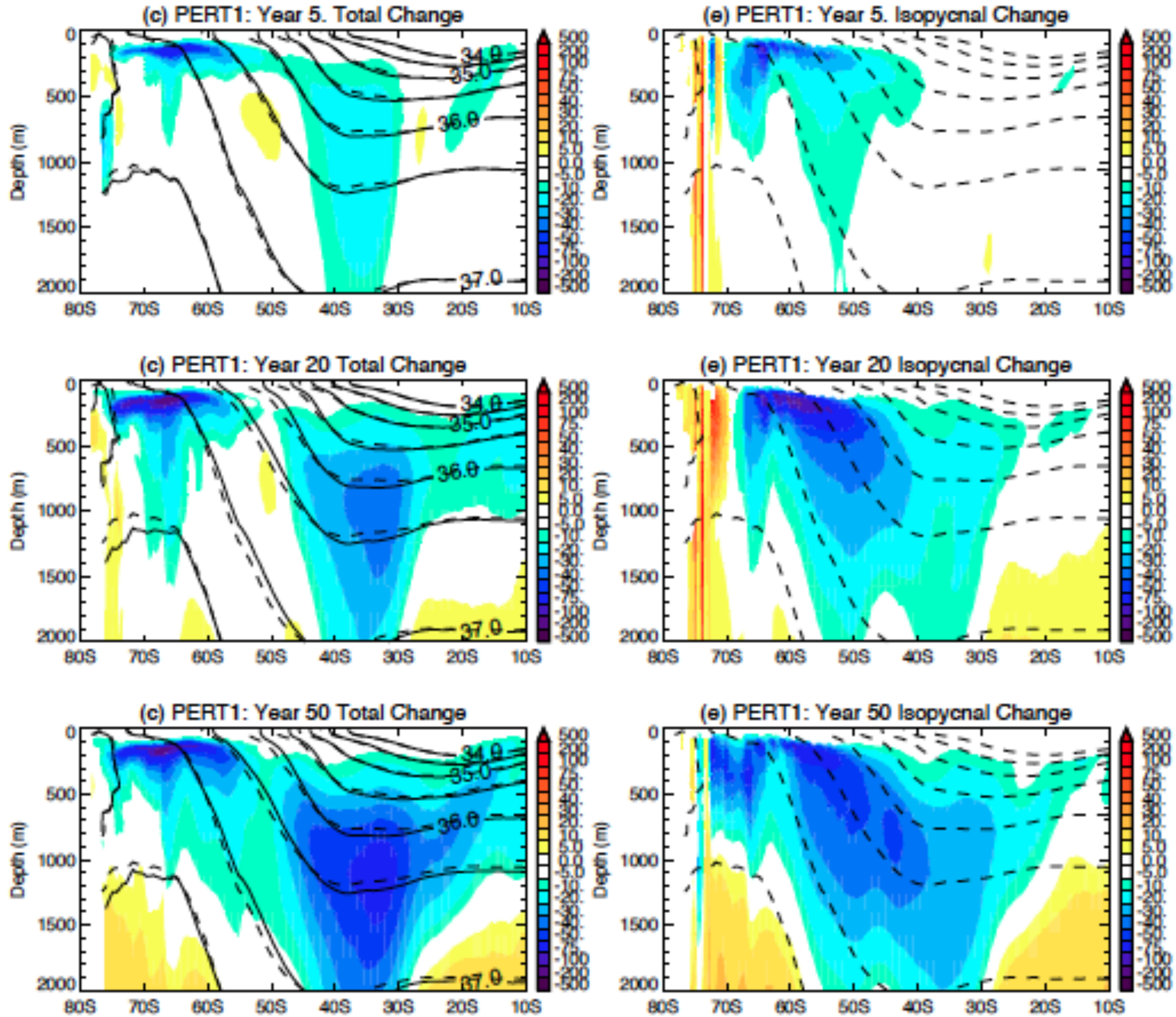
PERT1 – Control
after

Total change | Isopycnal change

5 years

20 years

50 years



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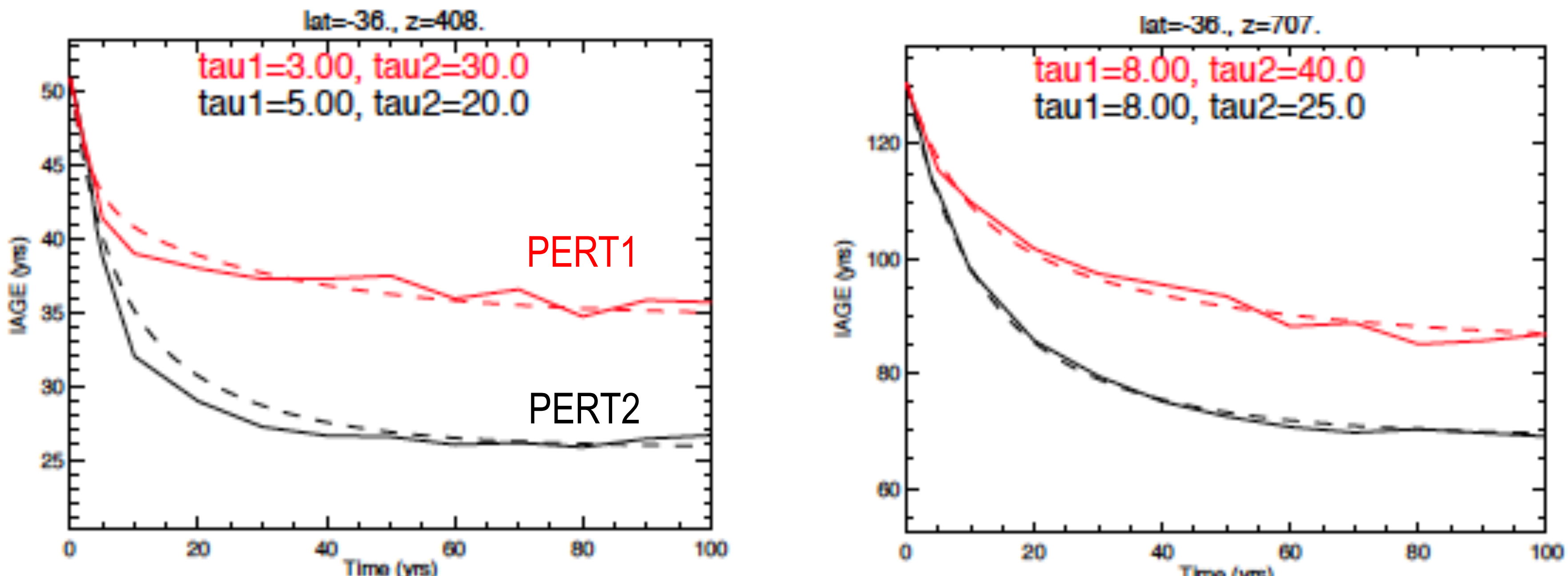
Response Time Scales

Two time-scale response:

(i) Rapid change (primarily) due to movement of isopycnals

(ii) Slower response due (primarily) to isopycnal transport.

Age(t) @ 36S, 400 & 700m



$$R(t) = \alpha_1 \left(\exp\left(-\frac{t}{\tau_1}\right) - 1\right) + \alpha_2 \left(\exp\left(-\frac{t}{\tau_2}\right) - 1\right)$$

τ_1 ~ 3-8 yr,
τ_2 ~ 20-40 yr

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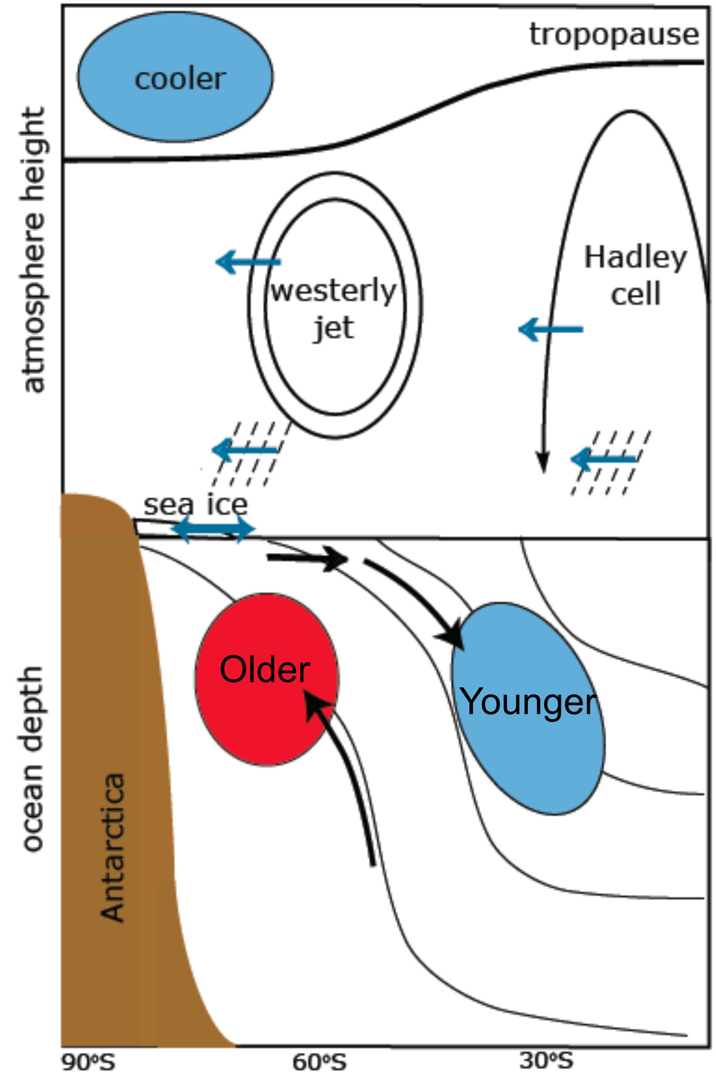
Conclusions

CFC observations indicate a decrease in age of subtropical mode waters and an increase in the age of upwelling circumpolar deep waters, over last few decades.

Consistent with expected/modeled response to an intensification of surface westerlies.

Response time to wind stress is several decades.



Open Questions

- Role of ocean eddies
- Future changes in ventilation (as Ozone recovers, GHGs continue to increase).
- Impact on uptake of heat, freshwater, carbon, and nutrients.
- What doe the 2014-2016 data show?

THE END