Age and AOU increases at the North Pacific subtropical-subpolar gyre boundary

PICES 13th Annual Meeting, Honolulu, HI

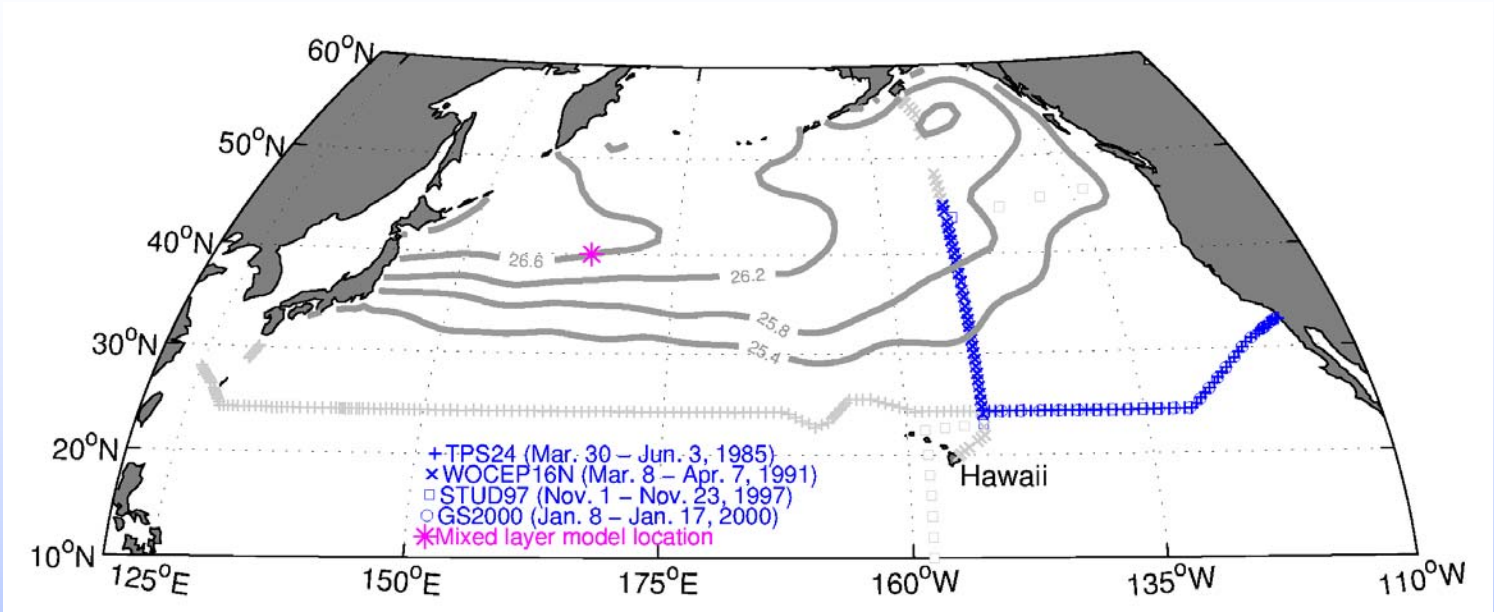
Sabine Mecking
Woods Hole Oceanographic Institution, Woods Hole, MA
E-mail: smecking@whoi.edu

Collaborators:

Mark J. Warner
University of Washington, Seattle, WA

John L. Bullister
Pacific Marine Environmental Laboratory/NOAA, Seattle, WA

manuscript under review (*Deep-Sea Research)*



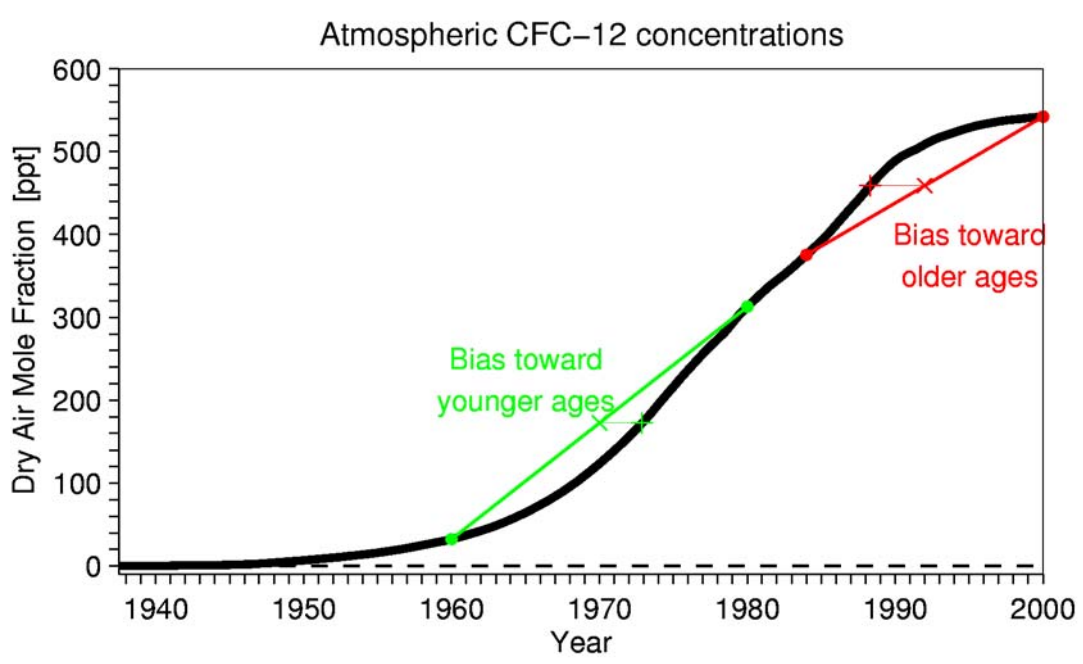
- CFC-12 and oxygen data from two UW student cruises in the eastern North Pacific Pacific along 152ºW and 24ºN (repeating portions of WOCEP16N and TPS24):

$pCFC\text{-}12 = CFC\text{-}12_{meas}/(f_{sat} \times F_{sol}) \rightarrow$ pCFC-12 age

$AOU = oxy_{sat} - oxy_{meas}$

$OUR = AOU/pCFC\text{-}12$ age

- consider effects of pCFC-12 age mixing biases (advection-diffusion model) and of possible outcrop undersaturations (simple mixed layer model)



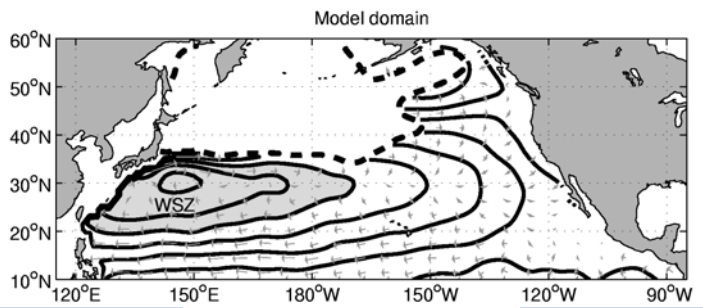
Curvature of atmospheric source function causes mixing biases:

First toward younger pCFC-12 ages and recently toward older pCFC-12 ages.

→ pCFC-12 ages are getting older with time independently of ocean circulation

Results from advection-diffusion model of North Pacific thermocline

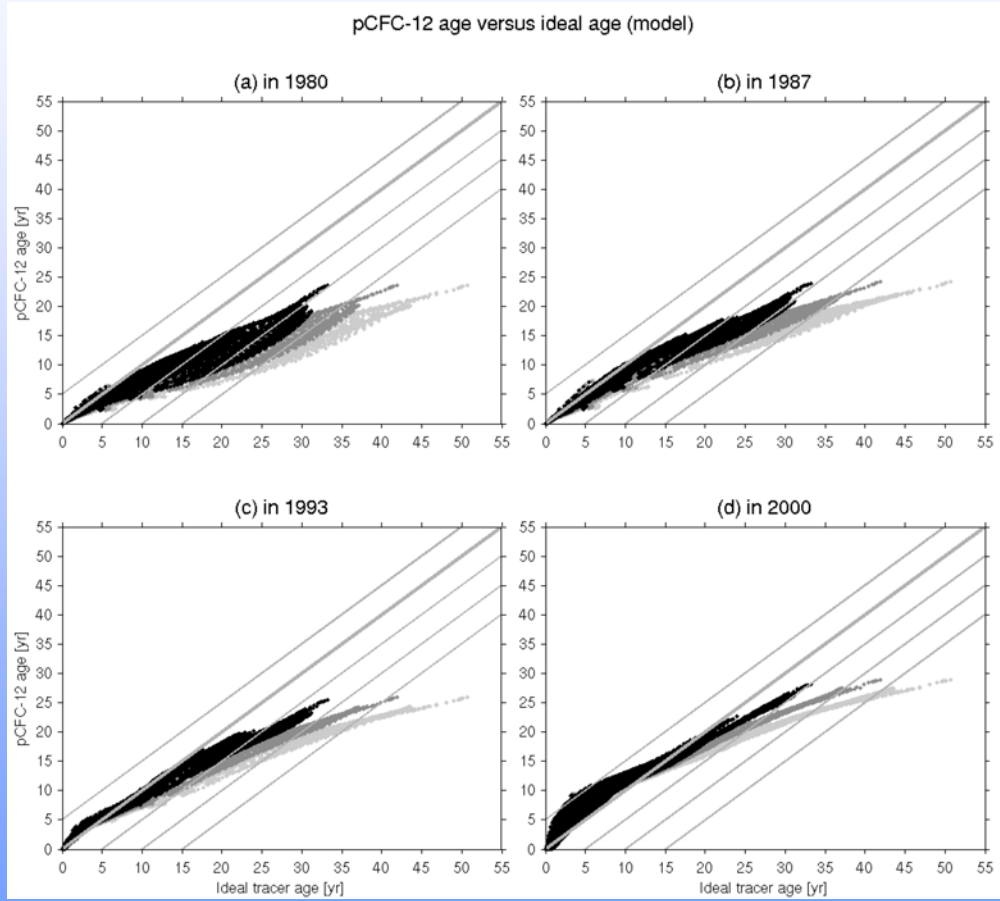
(Mecking et al., JGR, 2004)



Example: σ_θ = 26.0 kg m^{-3}

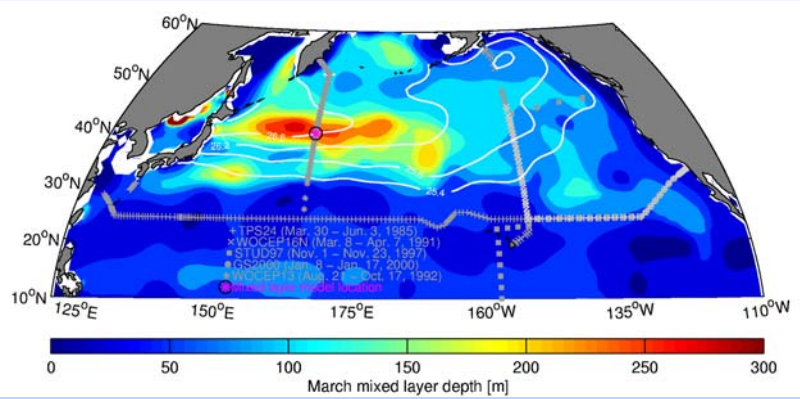
Advection-diffusion model:

- Model domain from late winter outcrop to 10°N
- Isopycnals: σ_θ = 23.0-26.6 kg m^{-3} (in 0.2 increments)
- Advection fields based on Levitus 1994 climatology
- Isopycnal diffusion by tuning to WOCE data: 2000 m^{2}s^{-1} (5000 m^{2}s^{-1} in Kuroshio Extension region)
- Model parameters: CFCs and ideal age tracer



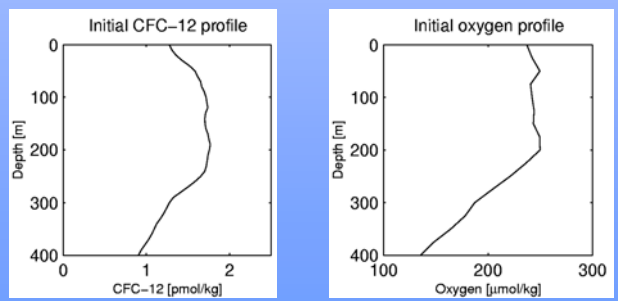
→ use pCFC-12 age to ideal age relationship from model to correct observed pCFC-12 ages for mixing biases

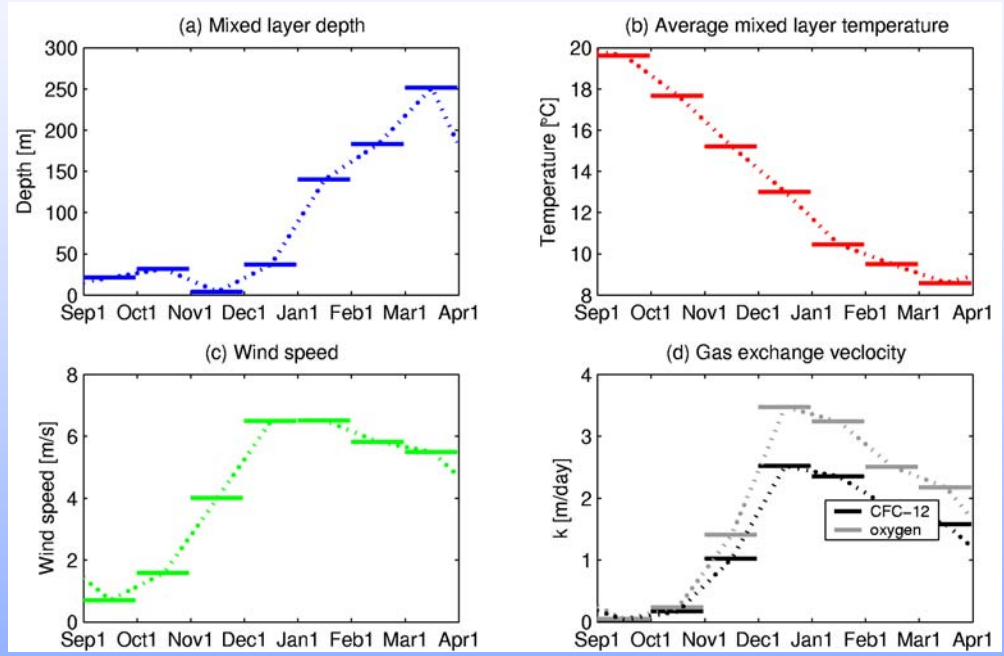
Model of mixed layer gas equilibration



Model location: 165˚E, 40˚N

Initial CFC-12 and oxygen profiles from WOCEP13 (Sept. 2003)

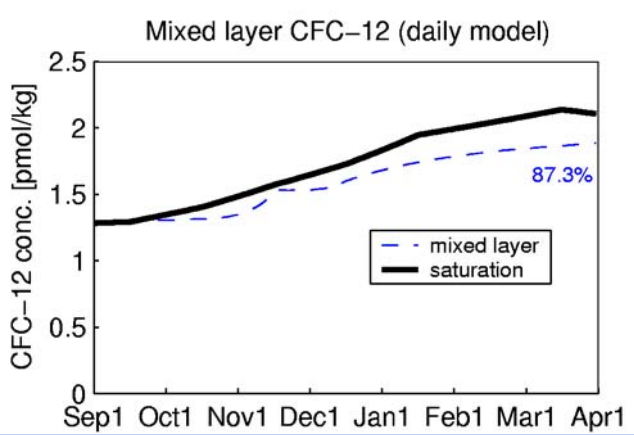


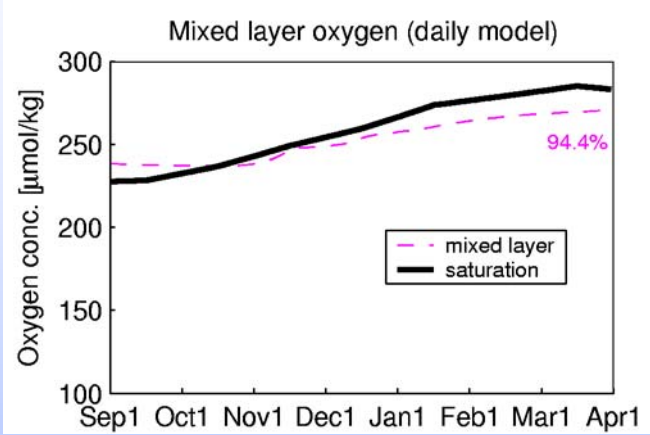


Evolution of model parameters from Sept. to end of March (based on Levitus 1994 climatology and NCEP winds)

→ CFC-12 and oxygen saturations at end of March

Resulting CFC-12 and oxygen concentrations (extreme values)



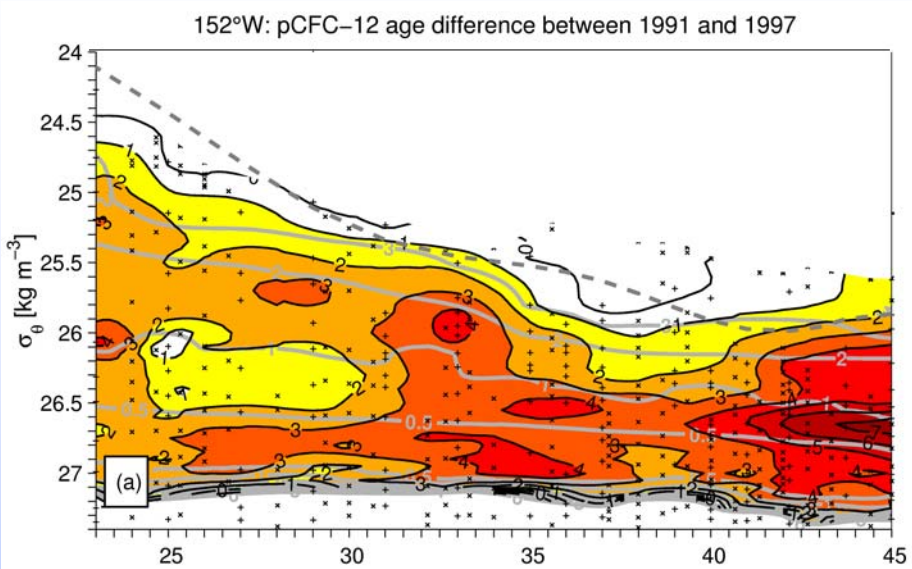


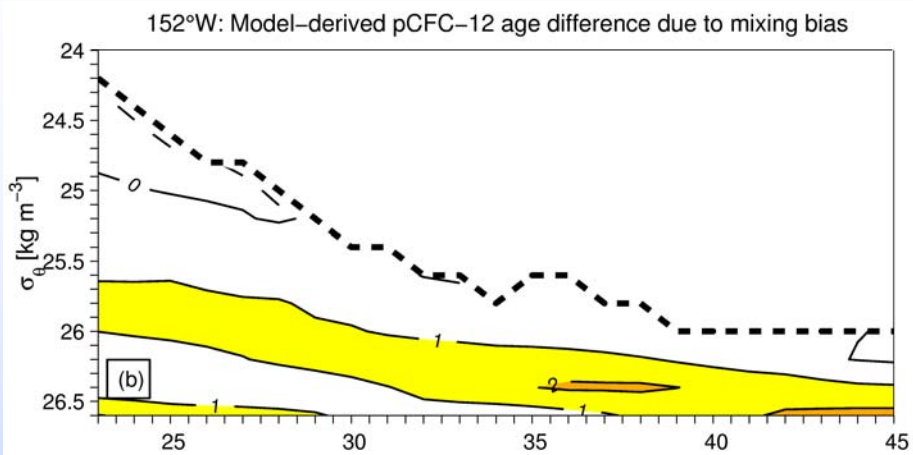
Maximal CFC-12 undersaturation: 10-15%

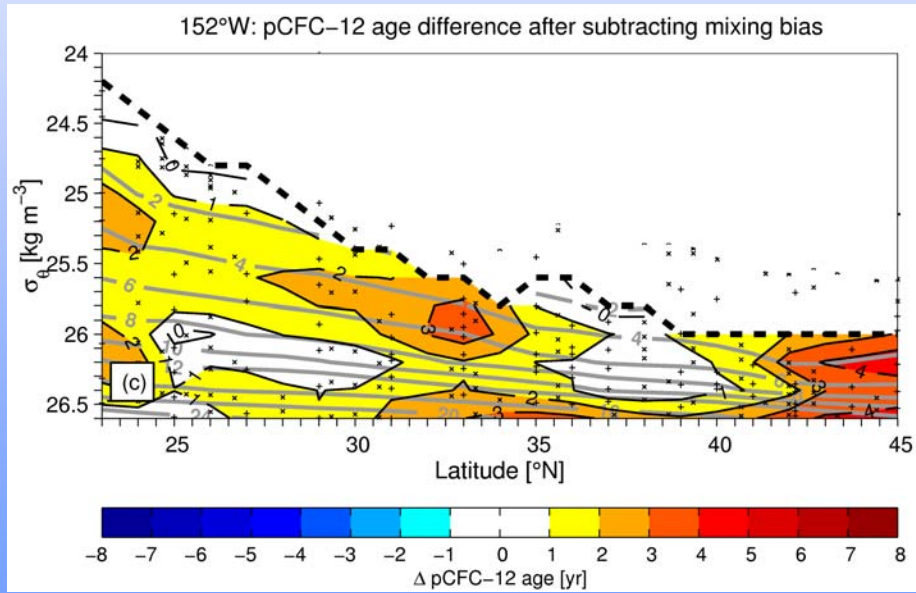
Maximal oxygen undersaturation: ~5%

→ oxygen less undersaturated than CFC-12

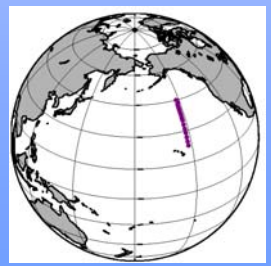
→ test age and OUR differences between cruises for possible undersaturations



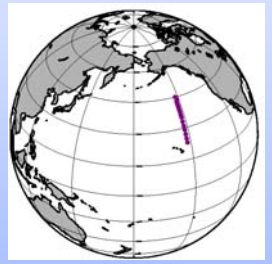


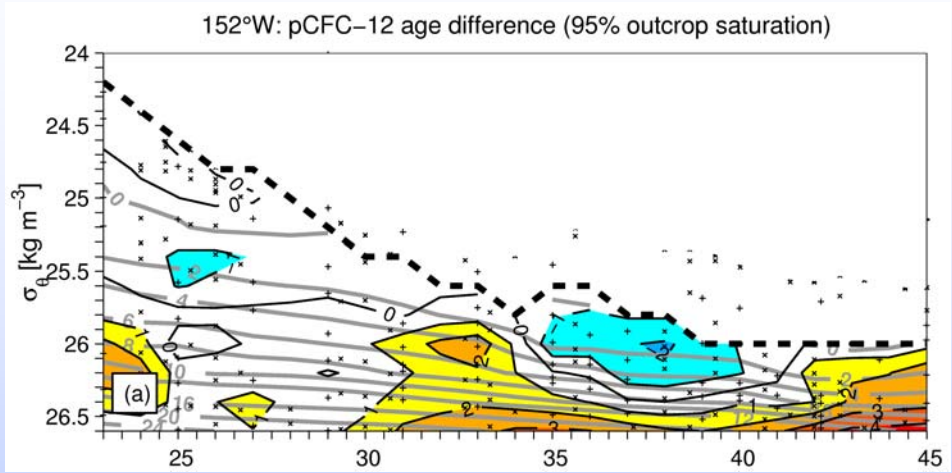


pCFC-12 age differences
along 152˚W (1997-1991)

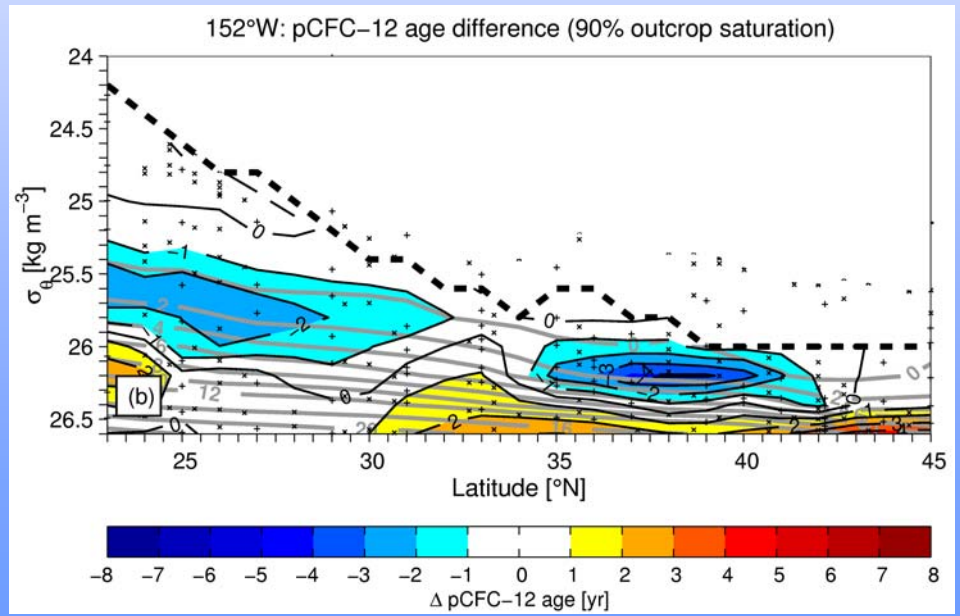


pCFC-12 age differences along 152˚W assuming undersaturation at the outcrops

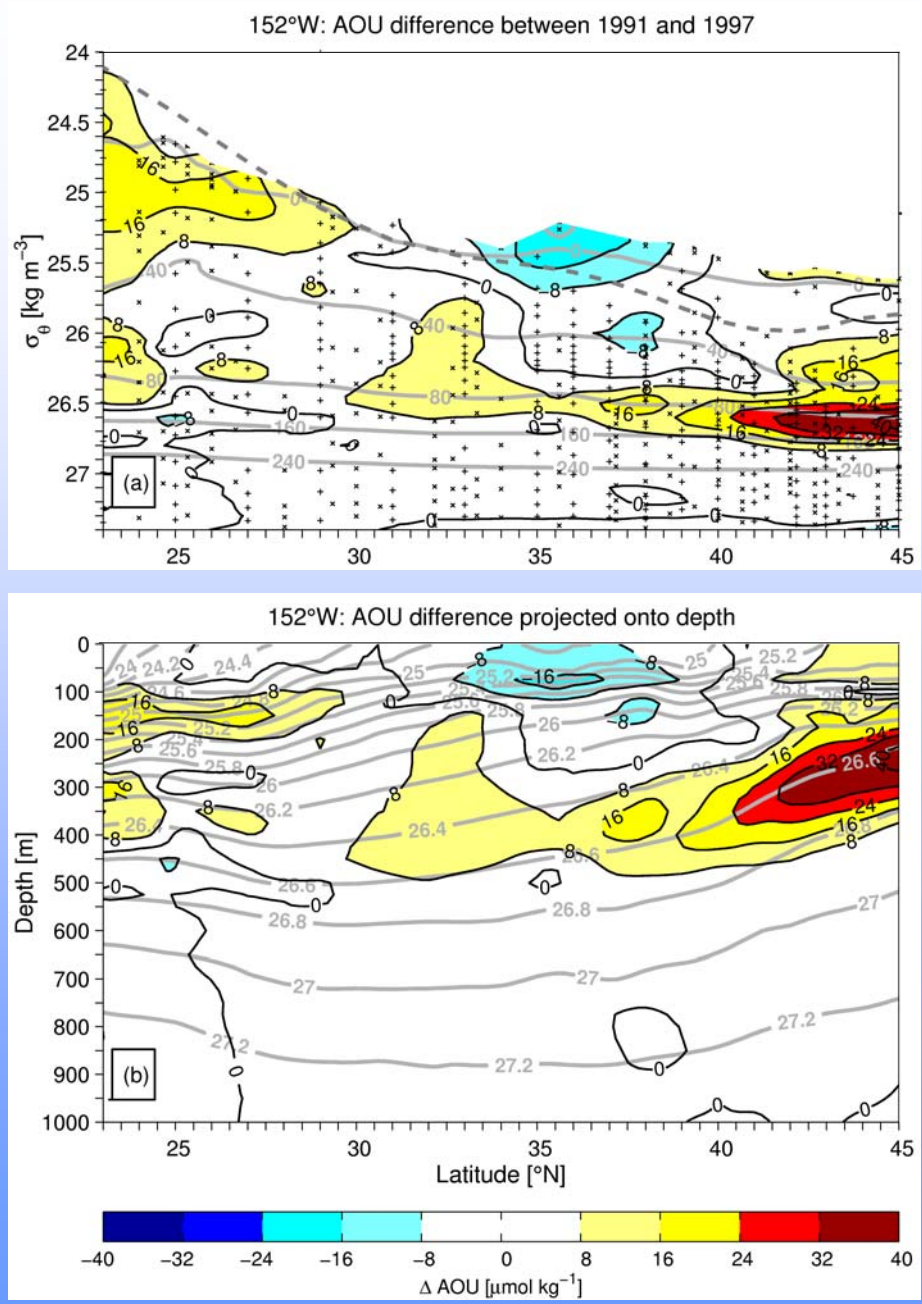




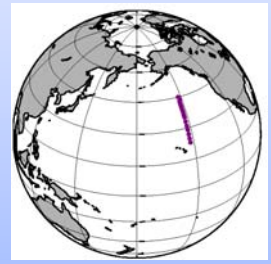
5% undersaturation



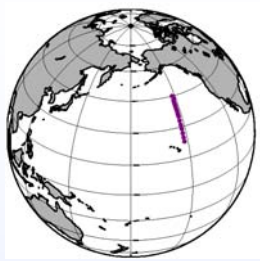
10% undersaturation

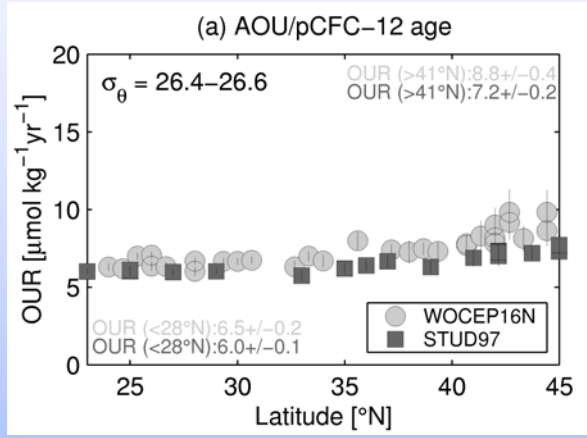


AOU differences along 152°W

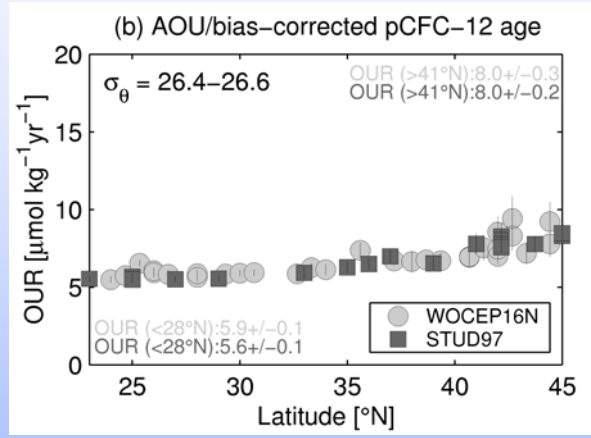


OURs along 152°W

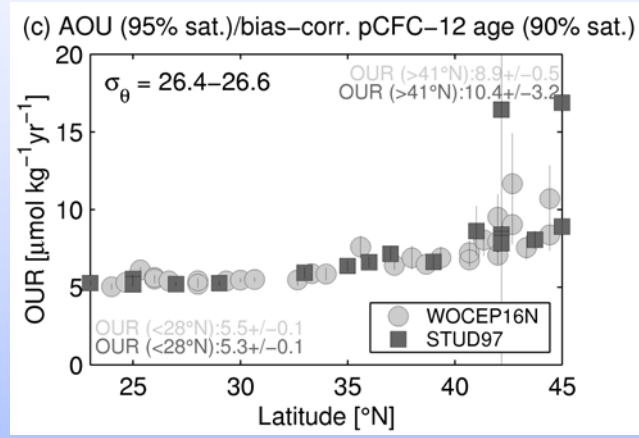




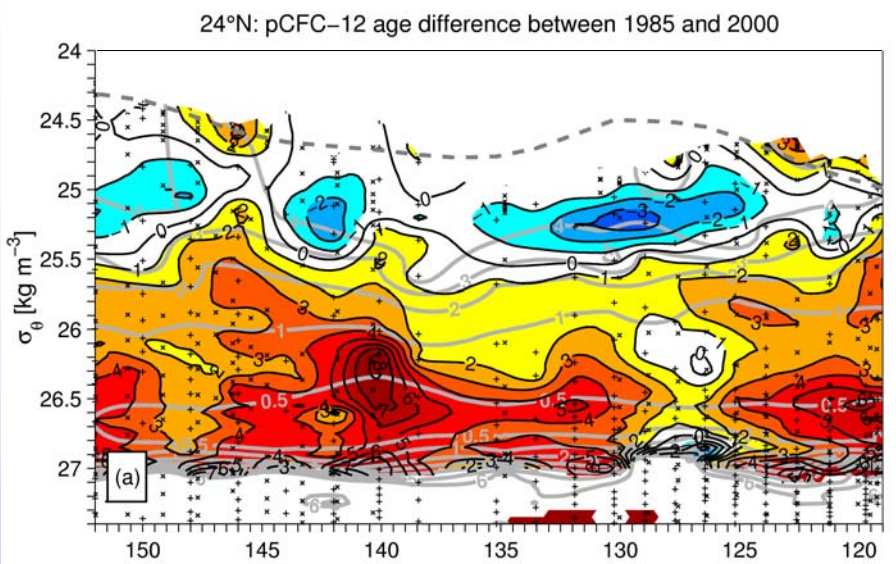
without adjustments

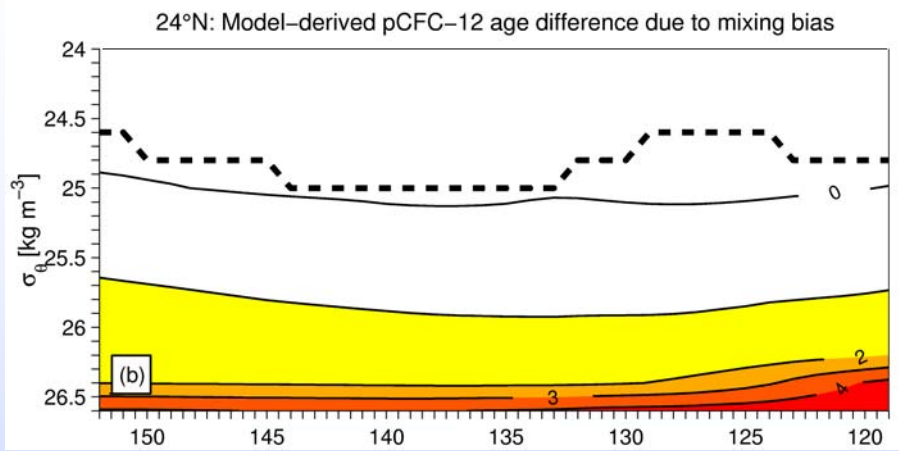


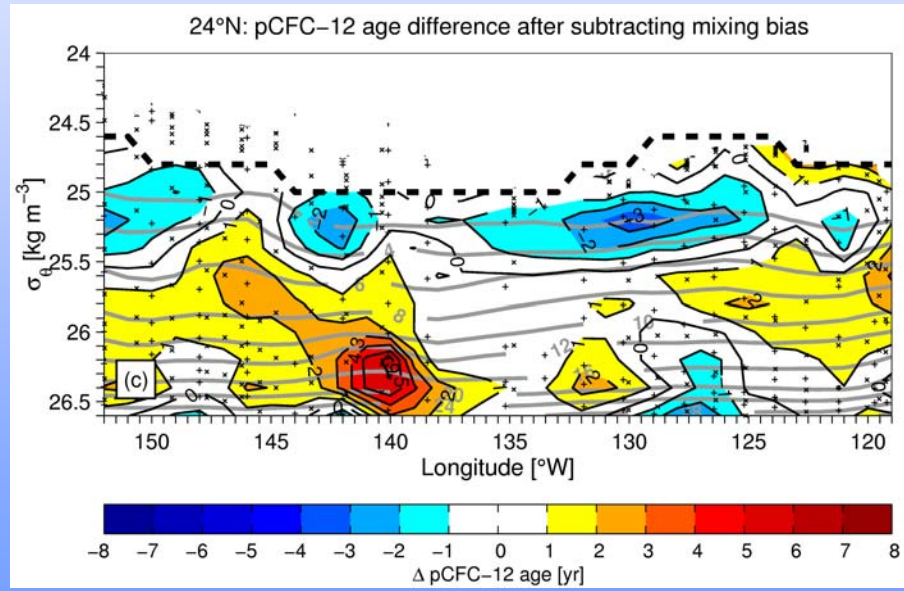
after subtracting pCFC-12 age mixing biases



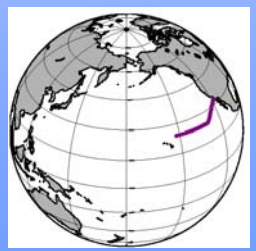
also assuming CFC-12 and oxygen undersaturations



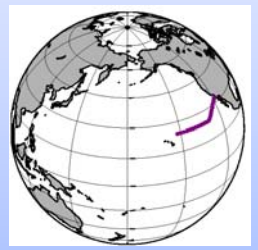


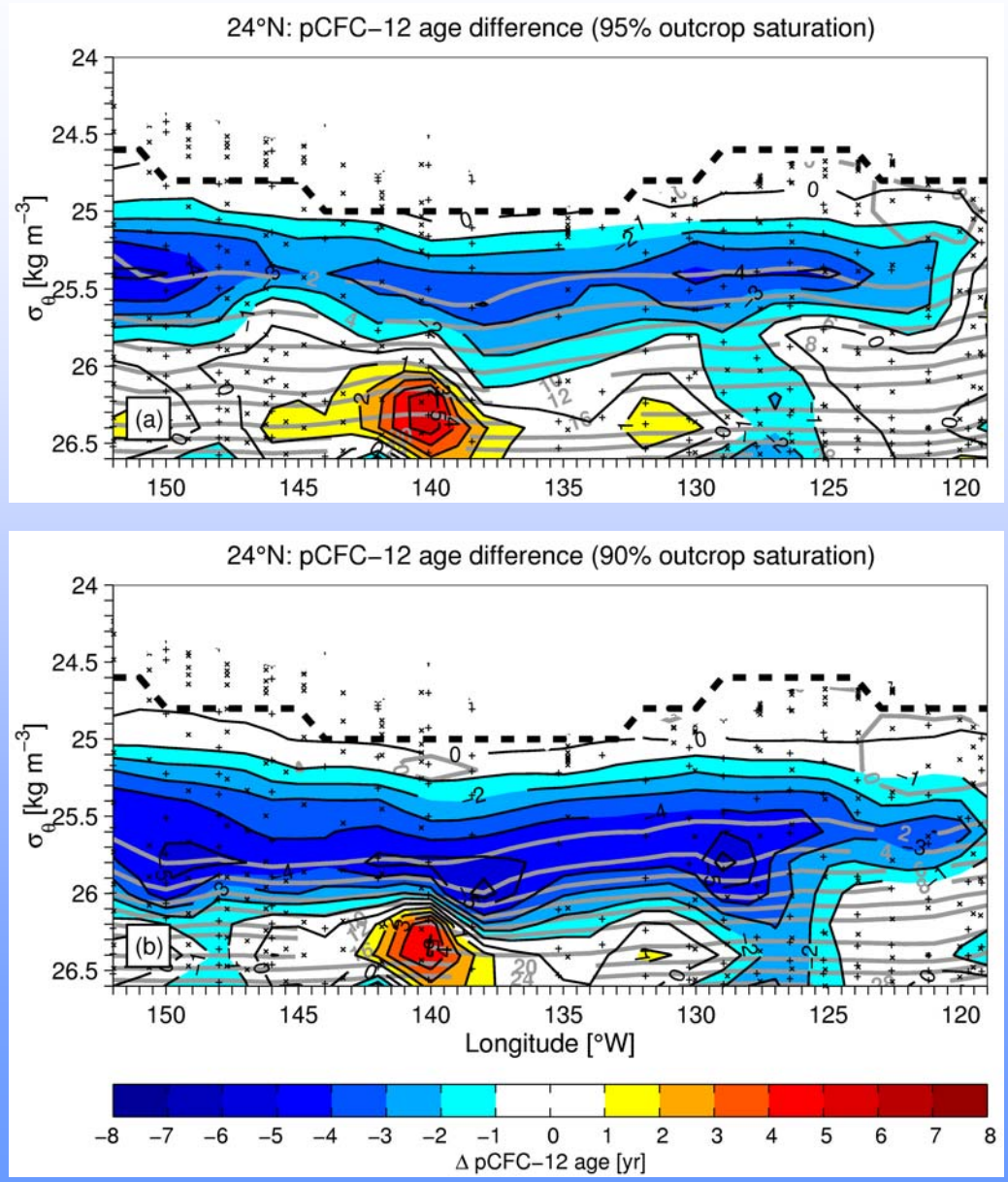


pCFC-12 age differences along 24˚N (2000-1985)



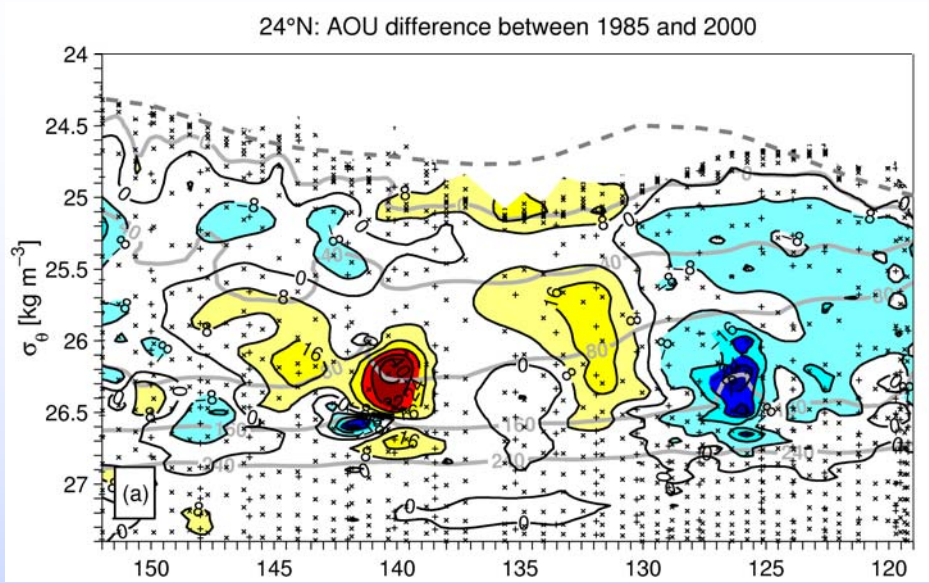
pCFC-12 age differences along 24˚N assuming undersaturation at the outcrops

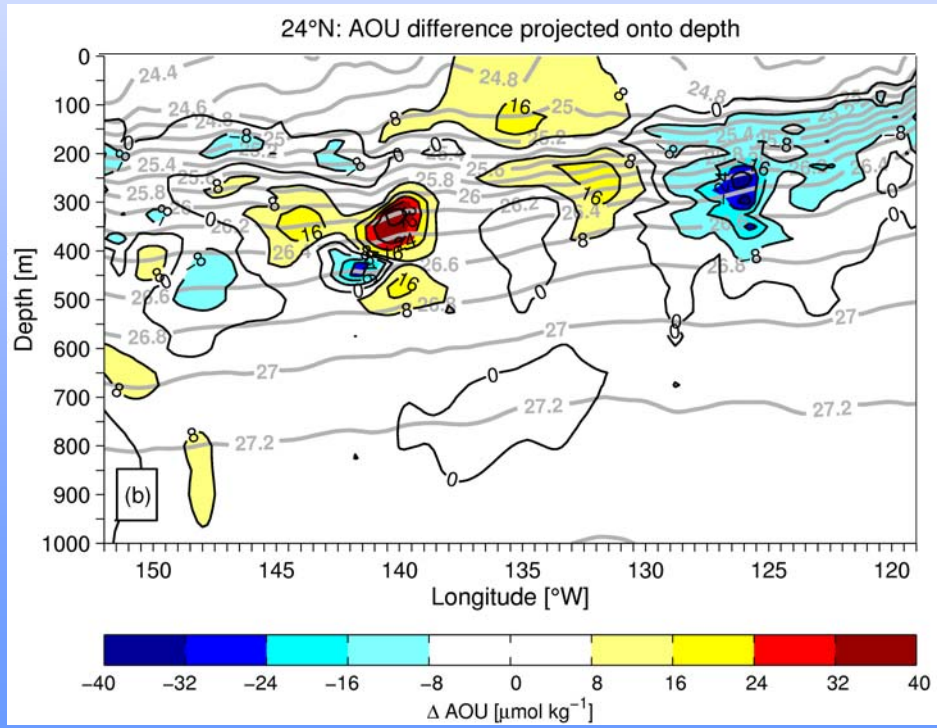




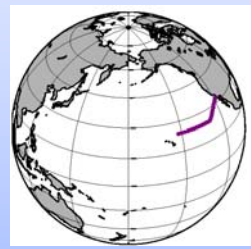
5% undersaturation

10% undersaturation

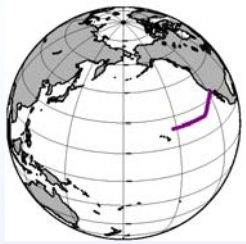


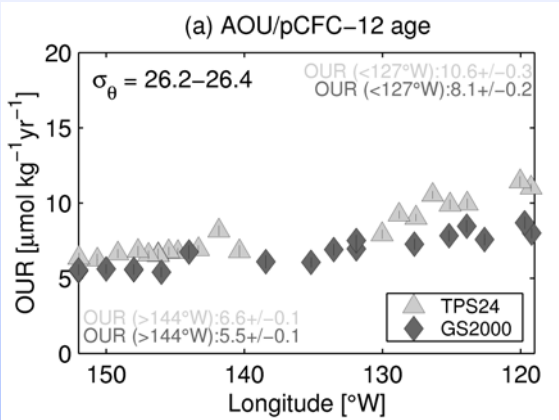


AOU differences along 24°N



OURs along 24°N





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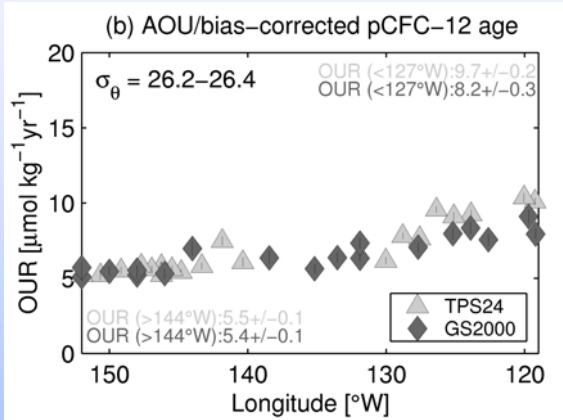
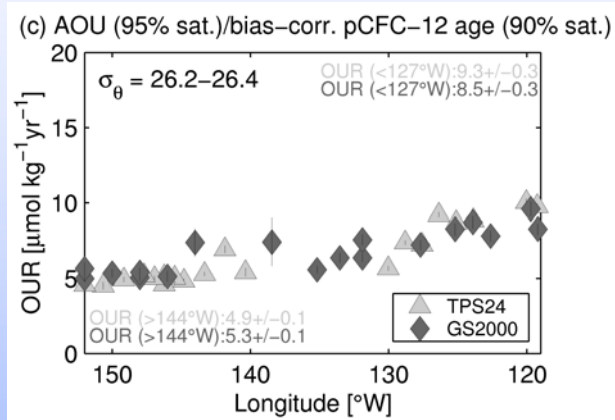


after subtracting pCFC-12 age mixing biases



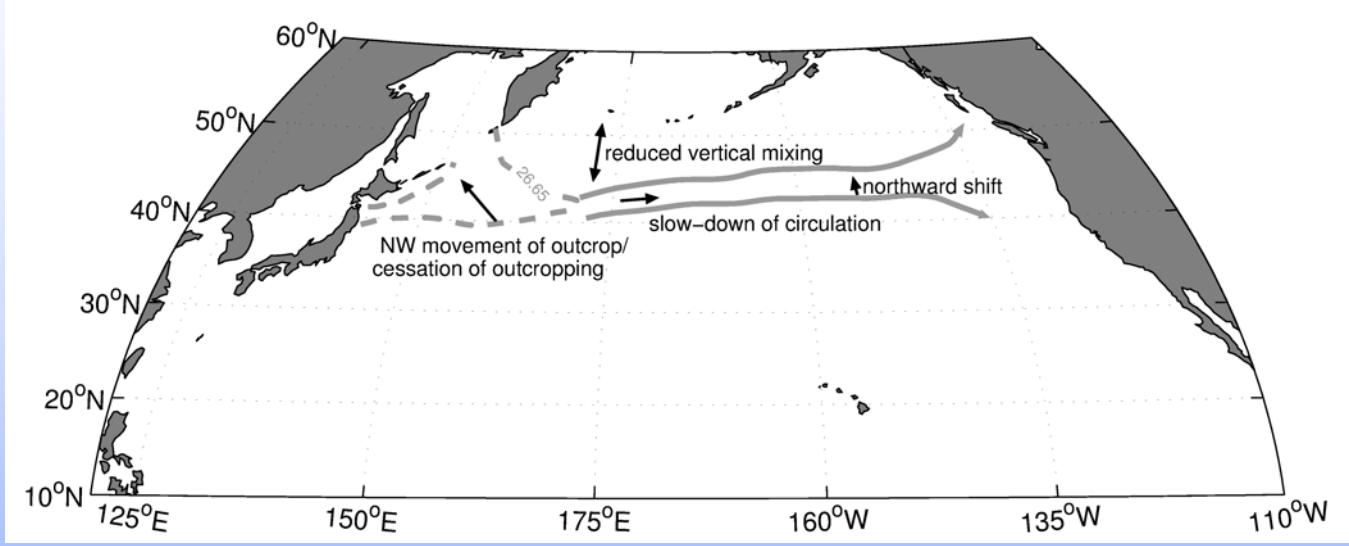
also assuming CFC-12 and oxygen undersaturations

Conclusions

- For pCFC-12 age and OUR comparisons along repeat sections (including future CLIVAR repeat hydrography), it is important to consider mixing biases in the ages and possible CFC-12 and oxygen undersaturations at the isopycnal outcrops.

- pCFC-12 age increases from 1991 to 1997 that are centered around σ_θ = 26.6 kg m^{-3} at the subtropical-subpolar gyre boundary at 152˚W are robust and consistent with previous studies (Watanabe et al., 2001, Ono et al., 2001, Emerson et al., 2004) indicating changes in physical processes (ventilation, circulation, vertical mixing, gyre shift).

- pCFC-12 age changes from 1985 to 2000 at 24ºN are mostly insignificant. OURs (and associated export production) in the subpolar waters off the coast of California may have decreased by a small amount.



Mechanisms for reducing ventilation ages at subtropical-subpolar gyre boundary