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

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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):

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

\[
\begin{align*}
\text{AOU} & = \text{oxy}_{\text{sat}} - \text{oxy}_{\text{meas}} \\
\text{OUR} & = \frac{\text{AOU}}{\text{pCFC-12 age}}
\end{align*}
\]

- 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)

Advection-diffusion model:
- Model domain from late winter outcrop to 10°N
- Isopycnals: $\sigma_0 = 23.0-26.6$ 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
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

without adjustments

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 $\sigma_\theta = 26.6$ 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 24°N 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