Estimating overturning changes from tracers in the North Atlantic

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Introduction:

Ventilation age or ideal age (Thiele and Sarmiento, JGR, 1990) is defined as in models by being set to zero in the surface layer and increasing at 1 yr/yr in the interior.

As shown at right, this age increases from the North Atlantic to the North Pacific.

Under global warming, previous work, shown at right (Gnanadesikan et al., , 2007) shows that age would be expected to decrease in the deep ocean under global warming, consistent with lower rates of ventilation.

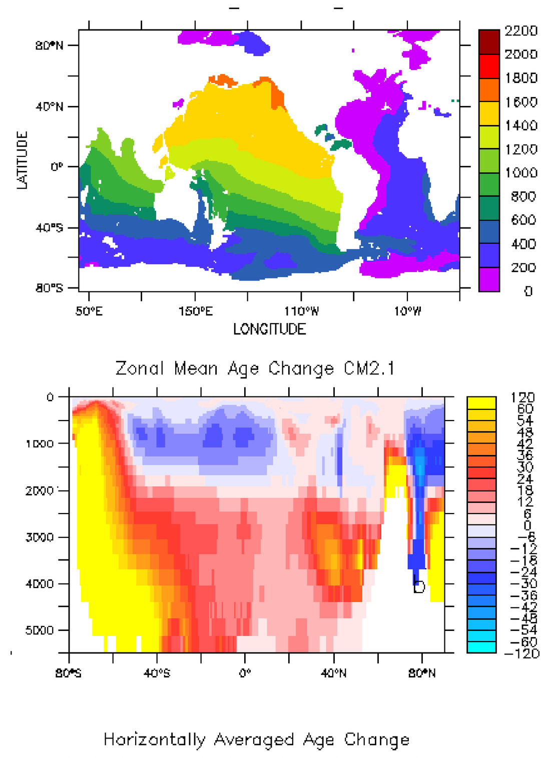

Figure 1: Top ideal age from CM2.1 model. Bottom: Age change under global warming

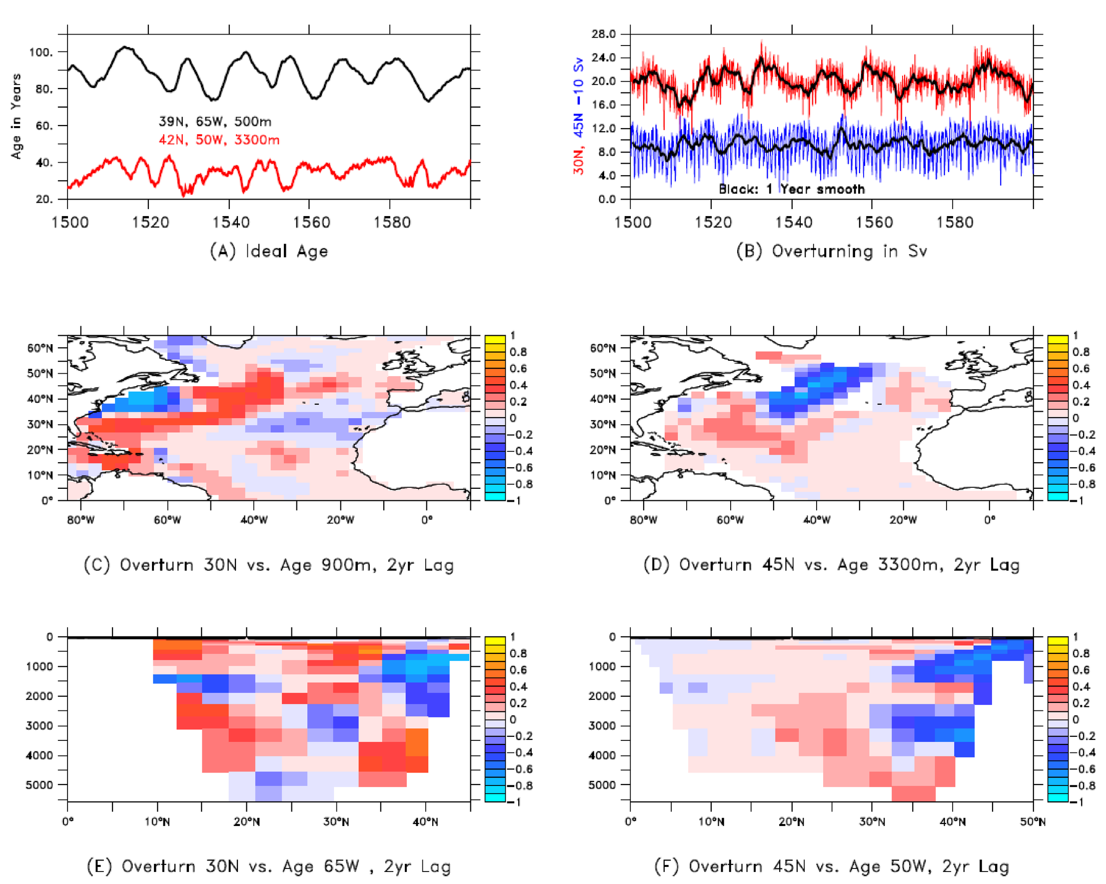

Figure 2: Age and overturning variation in GFDL CM2Mc model. (A) Ideal age at two points. (B) Overturning at 45N (red) and 30N (blue). Black lines show annual smooth. (C) Correlation between 30n overturn and age at 900m. (D) Correlation between 45N overturning and age at 2000m.(E) Correlation between 30N

In CM2Mc model…

Monthly age at single points (Fig. 2a) can be better related to annual-mean overturning than the monthly mean overturning.

Correlations have strong spatial structure.

Deep waters get younger as overturning increases.

Intermediate waters can get either older or younger.

Can we find ways to estimate age from observations?

Methods 1:pCFC age

Method used along Line W in a number of papers- pCFC age

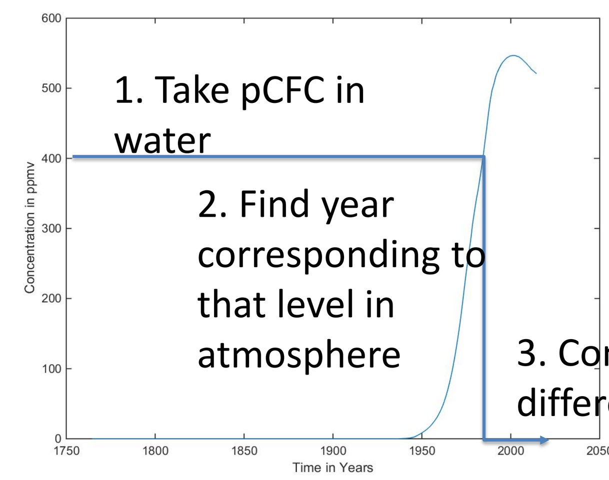

Figure 3: Schematic illustrating computation of CFC age

Large number of CFC measurements taken along Line W between Woods Hole and Bermuda by Smethie and collaborators (thank you!). Two sample sections for years separated by about a decade shown below

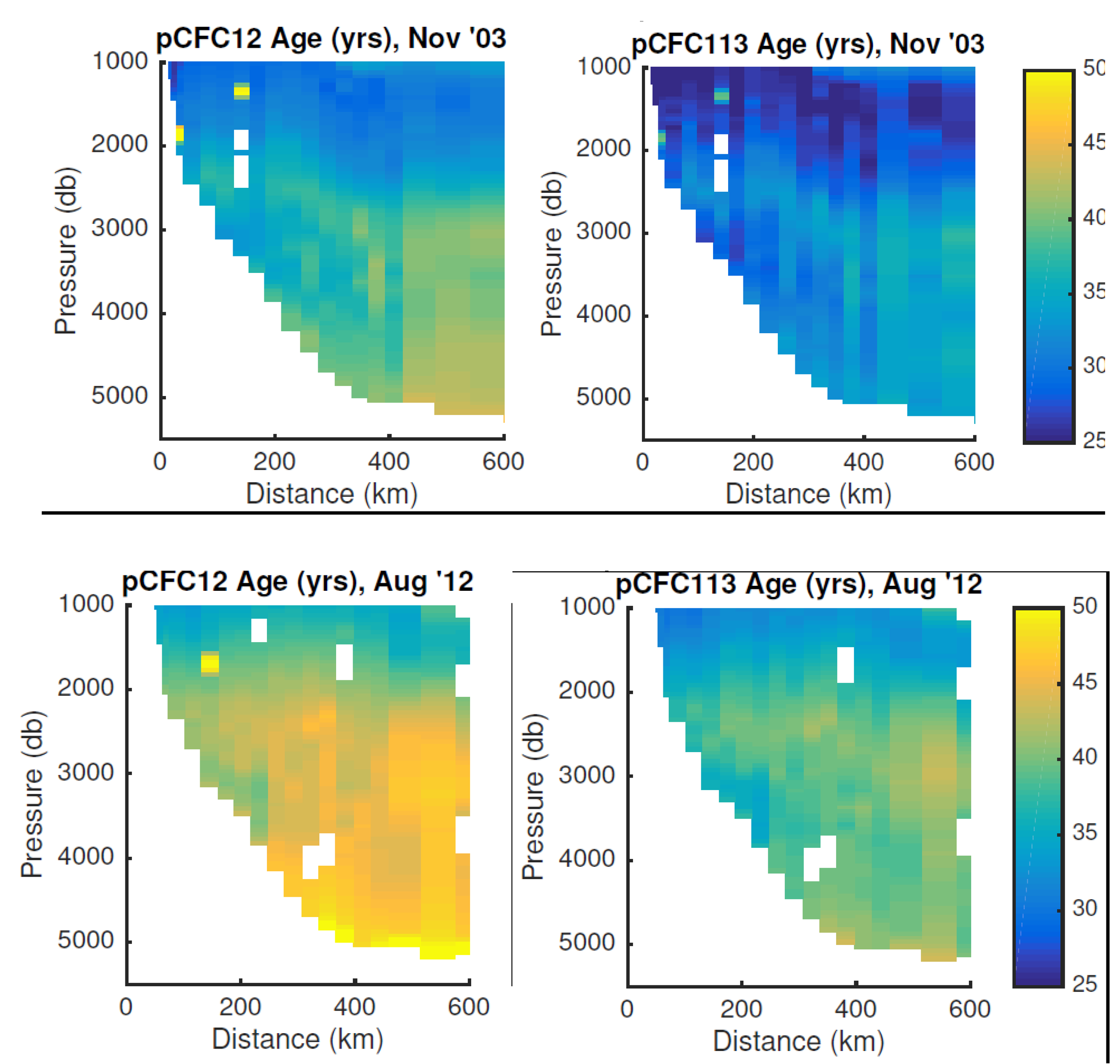

Figure 4: pCFC-12 age in years (left) and pCFC113 age in years (right) for Line W sections in 2002 (top) and 2012 (bottom).

In all four plots in Figure 4, age generally increases as we go deeper but the Deep Western Boundary Current shows up as low(er) age core along slope, but…

.. different ages for different tracers.

Increase in age of about 10-15 years in interior- comparable to time between sections.

Is this a sign of a slowing overturning?

Methods 2: TTD age

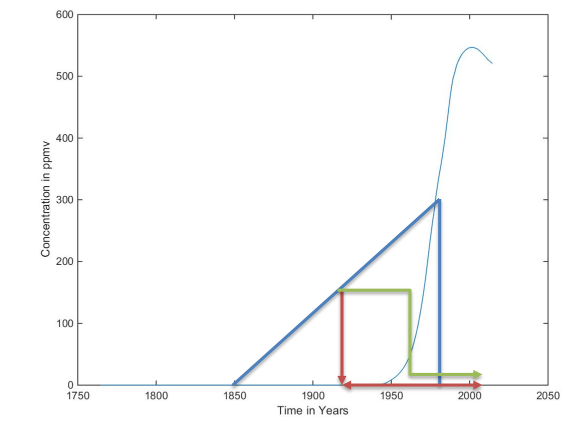

Figure 5: Schematic illustrating how mixing can bias pCFC age

50% Mixing with preindustrial water results in true age (estimation process shown by red arrows) being greatly underestimated (green arrows)

Resulting bias changes with time.

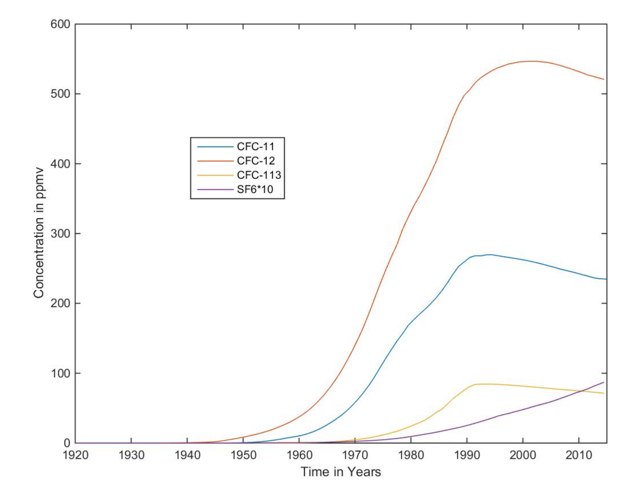

Figure 6: Historical partial pressure for multiple gasses.

Distributions show same mean age with different widths… mixing biases peak low.

Solution: Use multiple tracers (CFCs shown in Fig. 6) to estimate parameters associated with an inverse Gaussian transit time distribution (Fig. 7).

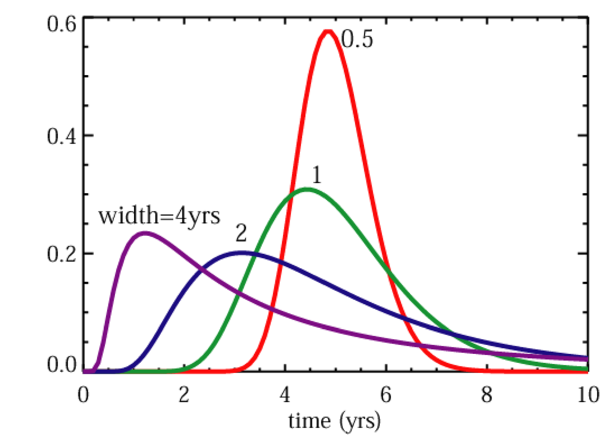

Figure 7: Transit time distributions with same advection, different mixing.

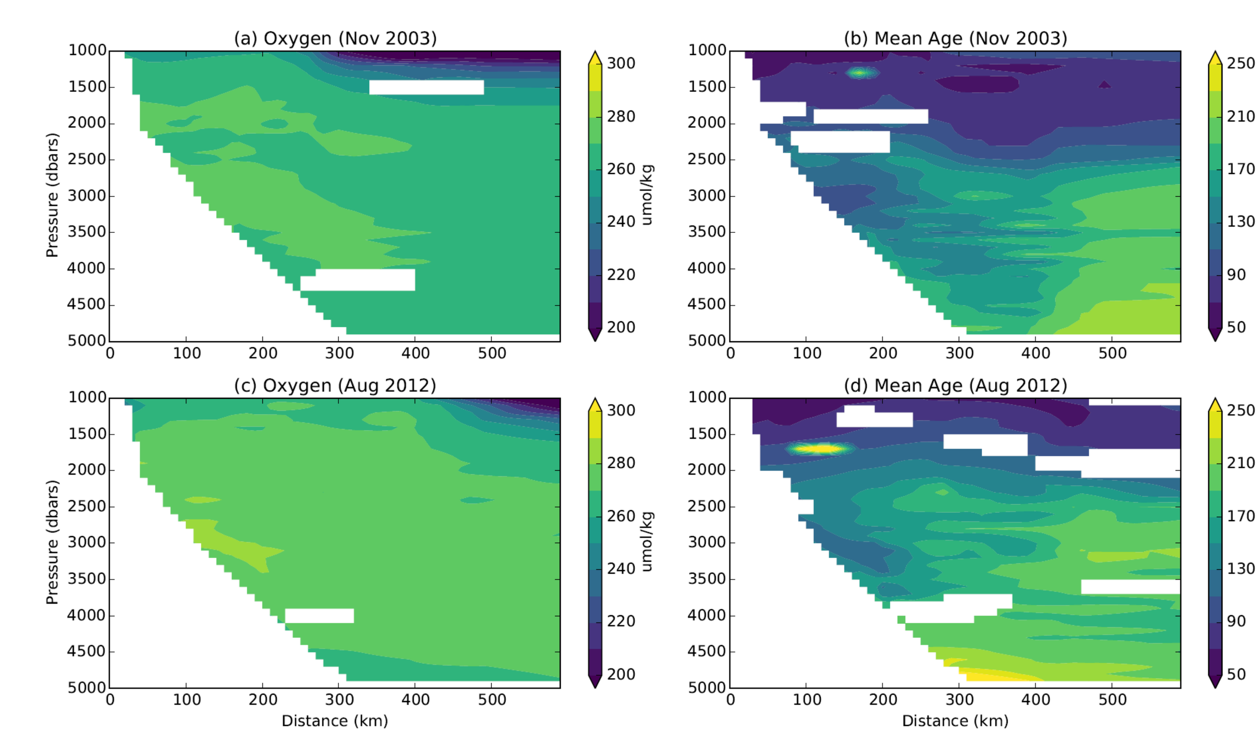

Figure 8: Oxygen in µM (left) and TTD-based age (right) for Line W sections in 2002 (top) and 2012 (bottom).

TTD age and oxygen (Figure 8) show

Clear correspondence in some structures along slope.
- 2 separate cores in 2003
- High-oxygen, low age tongue at ~2500-3000m in 2012

Provides independent confirmation that we can distinguish different water masses with an "age-like" tracer.

No large-scale increase in age in ocean interior away from current.

Increase in age at the very bottom of the section.

But increase in oxygen in center of section as well….

Oxygen and age:

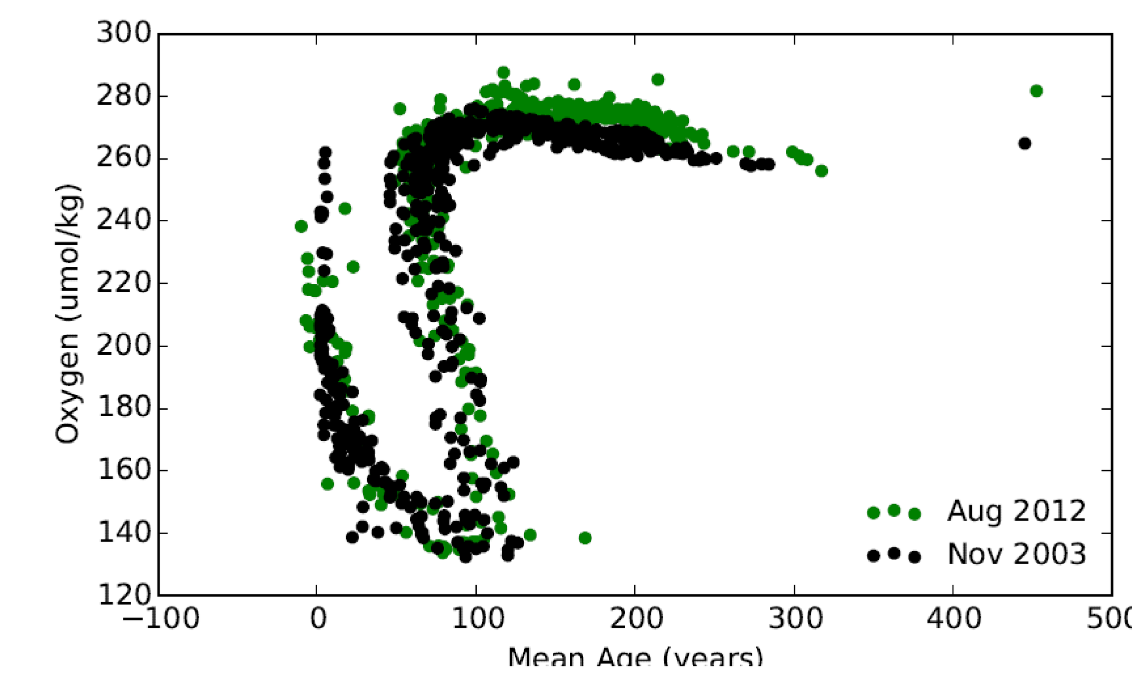

Figure 9: TTD age in years vs. oxygen in µM for sections in Figure 8.

Oxygen –age relationship (Figure 9) is quite constant for ages than ~150 years- suggests that remineralization rates are relatively constant

Oxygen-age relationship appears to change for older waters- is this circulation or remineralization?

Conclusions:

Tracer ages offer promising insights into changes in ventilation…

But only if care is taken to deal with the impacts of mixing (as is done in this and other recent work).

Oxygen may also be useful (much better historical coverage), *if* the oxygen-age relationship remains constant…

But it is not clear that this is true in all regions.

Future work: Create series of maps, examine EOFs of patterns on shelf.

Examine alternate ways for inverting for age- allowing for multiple watermasses.

Examine changes in biogeochemical cycling vs. watermass mixing.

References:

Gnanadesikan, A., J. Russell and F. Zeng, How does ocean ventilation change under global warming? *Ocean Science*,3, 43-53, 2007

Waugh, D., T. Hall and T.W.N. Haine, Relationship between tracer ages, *J. Geophys. Res. - Oceans*, 108 (5), 10.1029/2002JC001325, 2003.

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