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.

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

1. Take pCFC in water
2. Find year corresponding to that level in atmosphere
3. Compute age as difference

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

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

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.

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

Figure 5: Schematic illustrating how mixing can bias pCFC age
Distributions show same mean age with different widths... mixing biases peak low.

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

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

Oxygen – age relationship (Figure 9) is quite constant for ages > ~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 alternative ways for inverting for age- allowing for multiple watermasses.
Examine changes in biogeochemical cycling vs. watermass mixing.

References:

Supported under Grant NA16OAR4310174.