Variations of oxygen and age along Line W

Jordan Thomas, Anand Gnanadesikan, Darryn Waugh

Department of Earth and Planetary Sciences, Johns Hopkins University

1. Introduction

Because dissolved oxygen is high when waters are in contact with the atmosphere but declines as waters in the ocean interior experience respiration from rotting organic material, we expect that as the age of water increases, the oxygen concentration should decrease and oxygen utilization should increase.

If this relationship is constant with time, oxygen could serve to estimate age, and thus rate of ventilation into the past.

There are very few sections where the relationship between age and oxygen can be tested.

This work uses models and observations to evaluate how age and oxygen might co-vary in the ocean.

2. Setup

Observations: Line W section between Woods Hole and Bermuda (below at left)

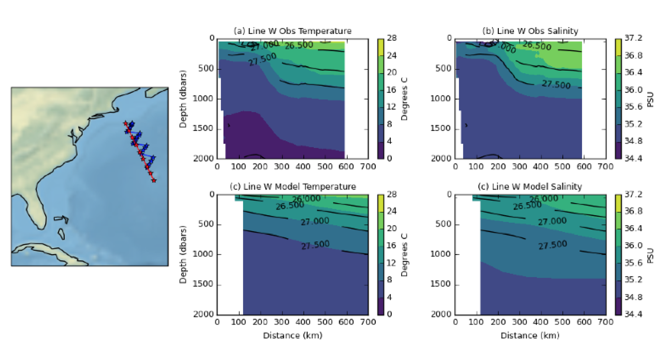


Figure 1: Observational Line W and model interpolation. (a) and (b) climatologies of observational temperature and salinity. (c) and (d) Line W interpolated model temperature and salinity.

Model: Coarse-resolution ESM2Mc model run at JHU (3x2 degree ocean, 3.875x3 degree atmosphere, Galbraith et al., 2011 for further details) with simplified ocean biogeochemistry module (Biology, Light, Iron, Nutrients and Gasses, Galbraith et al., 2010) and ideal age tracer.

Observed age is estimated using CFCs along Line W. Atmospheric partial pressures shown below

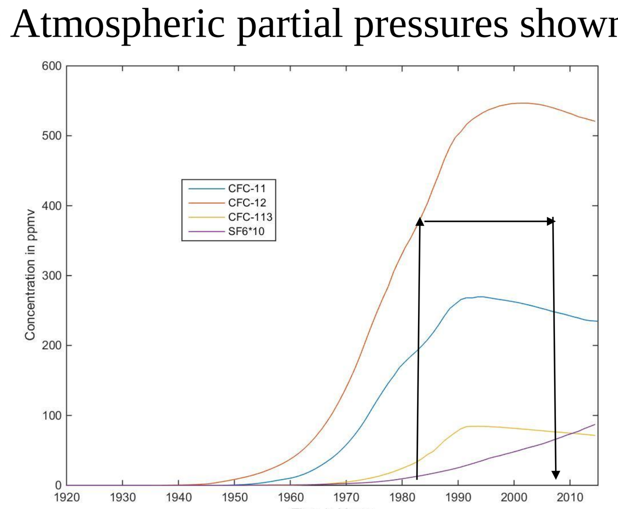


Figure 2: Historical partial pressure for multiple gasses. Arrows illustrate the simplest way of estimating age.

Arrows in Fig. 2 illustrate the simplest way of estimating age- matching observed pCFC to a particular date, then taking the difference between the observation and the date. Such a method, however is not robust in the presence of mixing.

In our study, observed age is estimated by assuming that CFC concentration represents the convolution of the atmospheric concentration with a transit-time distribution. Typical TTDs are shown below for different values of mixing, which produce different widths of the resulting inverse Gaussian.

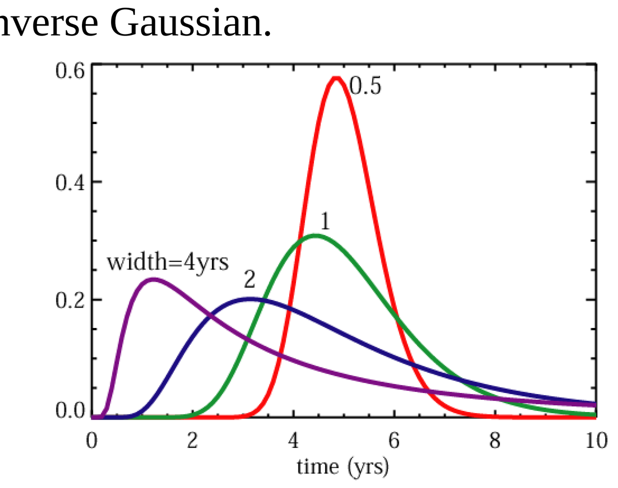


Figure 3: Transit time distributions with same advection, different mixing.

In this work, we assume that the ratio of the width Δ to the advection time Γ is 1 (resulting distribution is closer to the purple curve above.

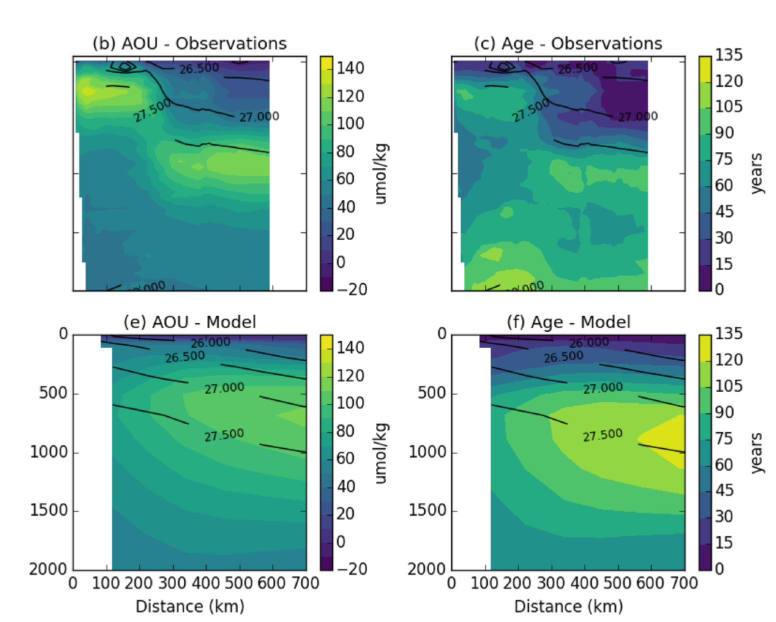


Figure 4: Depth-distance offshore plots of the climatology of (a) AOU and (b) age from observations along Line W, and (c) AOU and (d) age from the model simulation. Contour lines show the average neutral density.

Comparison with model (Fig. 4, above) shows good qualitative agreement between mean observed age, oxygen utilization along line W, although strong front in the middle of Gulf Stream isn't seen in the coarse model.

Note that using TTD-based ages allows us to produce relatively high ages in intermediate waters that agree well with model ages.

3. Variability

Both age and oxygen show variability along Line W in the observations (Figure. 5).

Clear signals include

1. Shift of center of Gulf Stream
2. Changes in deep oxygen in core of NADW
3. Offshore changes in both age and oxygen in deep waters.

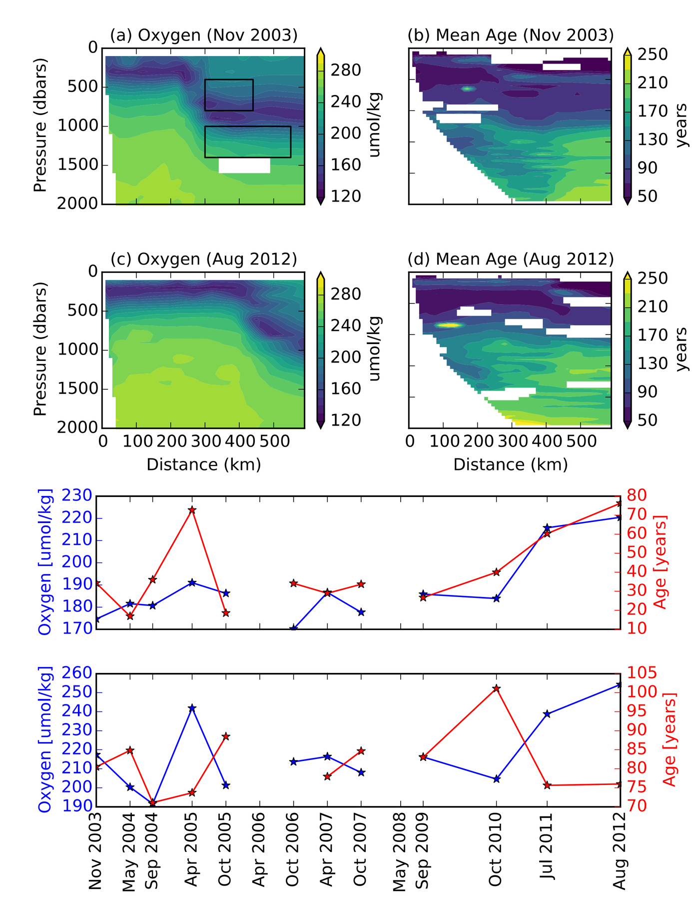


Figure 5: Variation of age and oxygen along Line W in observations. a) Oxygen in Nov. 2003. b) Age in Nov. 2003. c) Age in Aug. 2012. (d) Oxygen in August 2012. e) Time series of oxygen (blue) and age (red) in top box in panel a. f.) Time series of oxygen and age in bottom box in panel a

However, focusing on individual regions (lower panels of Fig. 5), we see changes are not always coherent. This is even clearer when looking at maps of correlation (below, Fig. 6).

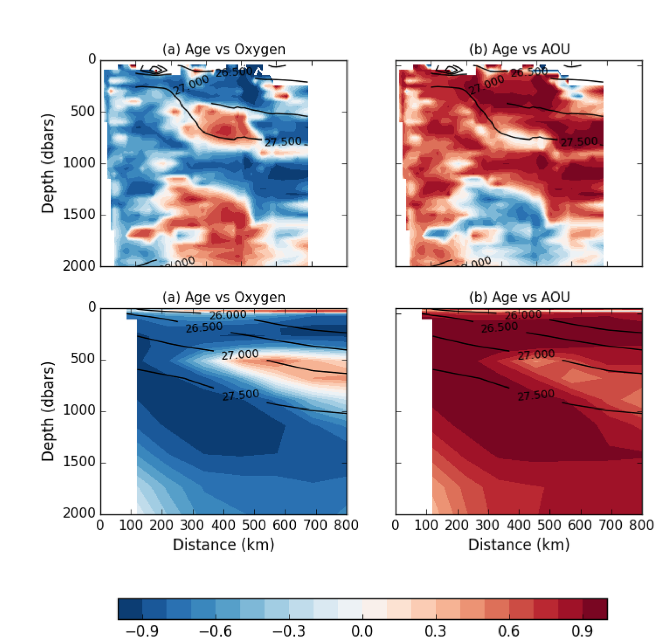


Fig. 6: Correlation between age and oxygen (left), and AOU (right). Top row shows observations along Line W, bottom row model output from ESM2Mc.

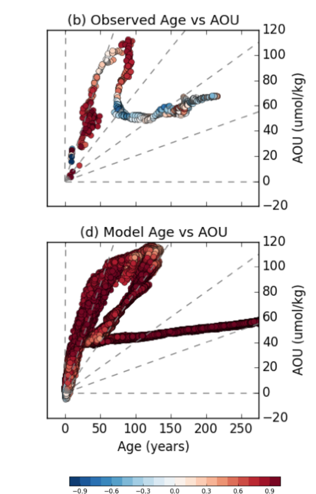
Oxygen shows positive correlations (opposite of what would be expected) in both observations and model.

4. Age-AOU decoupling

When AOU is used, negative correlations largely , but do not entirely vanish.

Still regons of very low correlation with AOU. What's going on?

Figure 7: Scatterplot of age vs. AOU, dashed lines show constant relationships Colors show magnitude of correlation.



Model qualitatively reproduces shape of point cloud, but correlations are quite different.

Lower correlation is model found in regions where the maxima in age and AOU are offset.

Unclear at present whether observations are showing changes in respiration rate or changes in mixing. If mixing, then the mixing changes are not simply shifting watermasses along the mixing line.

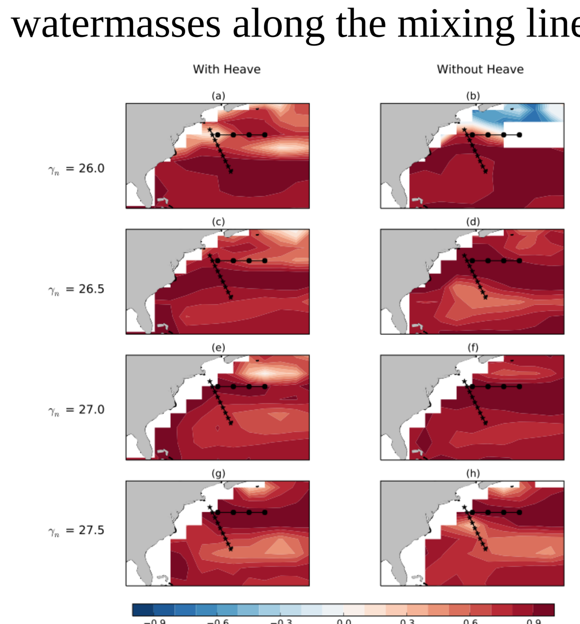


Figure 8: Correlation between age and AOU on various isopycnal surfaces. Left column indicate correlation calculated on average depth of the isopycnal surface, and therefore including contributions from isopycnal heave. Right column shows correlation calculated on the isopycnal surface and does not include contributions from heave.

Above, we consider two possible sections, Line W and a second, zonal. We consider correlations along a fixed depth of an isopycnal surface (which will see changes due to heave) and changes on the time-varying isopycnal surface. Both show low correlation in the gyre interior.

5. Understanding decorrelation in the gyre interior

The fundamental reasons for the decoupling can be understood by looking at the structure of age and oxygen along an isopycnal

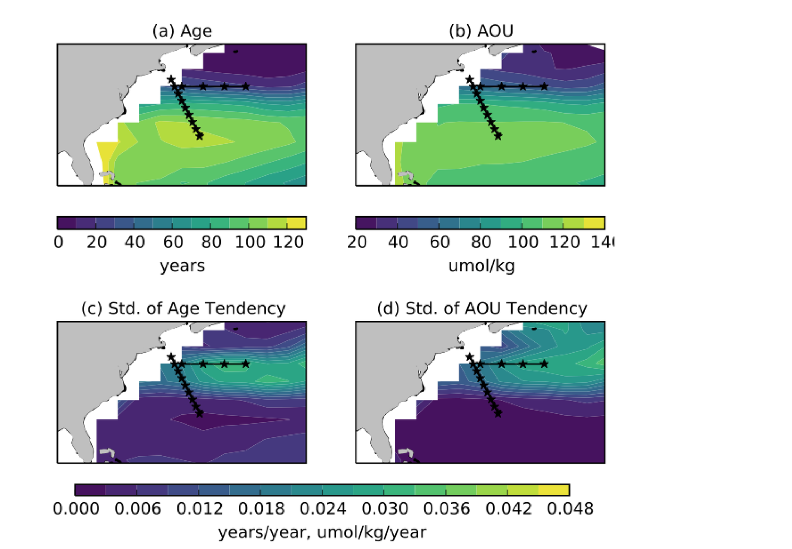


Figure 9: Climatologies of (a) age and (b) AOU interpolated on neutral density surface 27.0. Bottom: Standard deviation of (c) age tendency and (d) AOU tendency interpolated on neutral density surface 27.0. Bottom plots are the standard deviation of the tendency on a fixed neutral density surface.

In the region where the two fields decouple, we see maxima in age and AOU that are slightly offset from each other. The result is to produce the effect below, where a shift in transport produces a change in one field but not the other.

Lower panels on Fig. 9 show that the changes in these low-gradient regions are small. In the regions where correlations are high, changes in in both age and AOU are large.

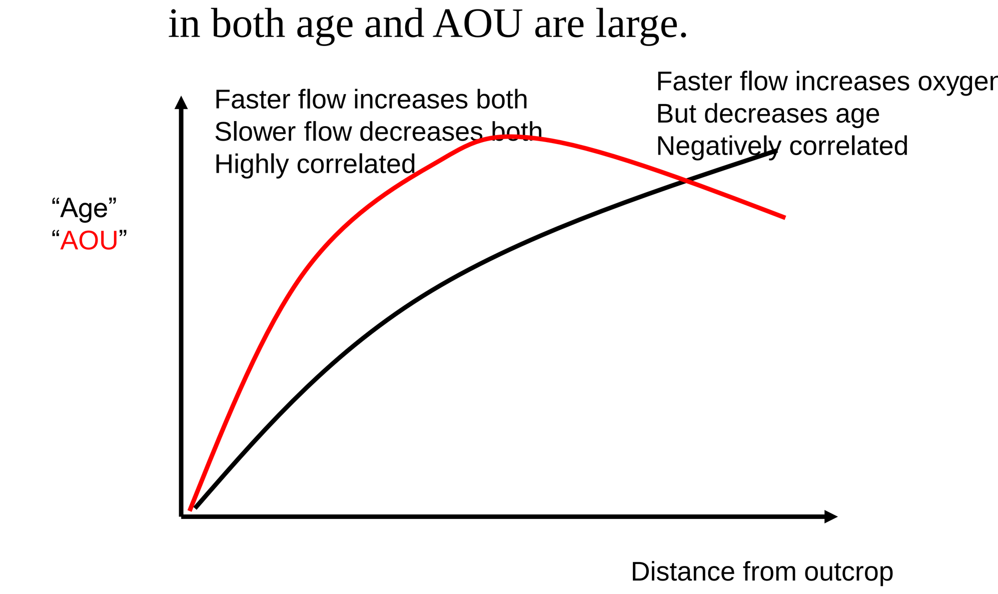


Figure 10: Illustration of how different spatial structure of AOU and age fields can lead to decoupling of the two.

Results similar to previous work in Pacific by Shao et al.(2016).

References

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