1 Chapter 3 Plan:

1. What is the relationship between age and oxygen in GFDL ESM2Mc?
    (a) What is the spatial variability of this relationship?
    (b) What does this relationship say about the underlying mechanisms changing oxygen concentration?
2. How have Southern Ocean ventilation rates have changed over the last three decades using ship-based repeat hydrography measurements of CFC-11 and CFC-12 (following method used in Waugh et al., 2013).
3. What is the impact of changing circulation on oxygen?

2 Motivation

- Recent data assimilating ocean circulation model study suggest strength of upper-ocean overturning circulation has strengthened in the last decade (2000–2009) resulting in an increase of the upper ocean carbon sink [1].
- This is a direct reversal in the trend documented by observations and modeling studies in the previous decade (1990–1999) [2, 3, 6].
- Unclear whether these decadal trends are a result of changing anthropogenic forcing, or decadal variability in ocean circulation.
- Also observed decrease in oxygen concentration in the Southern Ocean over the period 1960–2009 is consistent with a previous study citing an observed decline of deep water formation of Antarctic water masses [4] and may also represent changes in the wind-driven ventilation [5].

3 Model Analysis:

What is the relationship between age and oxygen in GFDL ESM2Mc?

- What is the spatial variability of this relationship?
- What does this relationship say about the underlying mechanisms changing oxygen concentration?

To Do List:

1. Plot correlation and regression coefficients between age and oxygen for each depth level in ocean.
2. Define and calculate AOU and OUR.
3. Plot zonal averaged age, oxygen, and AOU for each ocean basin (Atlantic, Pacific, Indian)

4. Plot correlation between age and oxygen for lat vs depth for each ocean basin.

Ventilation, overturning and consumption. Current understanding of oceans attributes deep-ocean oxygen loss to four processes:

1. A reduction of ventilation in deep convective regions which provides less ventilated waters in high latitudes and a reduction of mixed layer subduction in mid and high latitudes. The timescales of these changes are long (50-100 years) because of the time it takes for oxygen-reduced waters to advect through the global basins before affecting older waters.

2. A slowdown of the meridional overturning circulation which would reduce the amount of oxygenated waters that are mixed with older waters and thus increase the age of deep waters in general.

3. An increase in biological activity in the upper ocean. This would increase remineralization and thus oxygen consumption at depth.

4. Natural multi-decadal variability that is not accurately captured by the sparse data available.

TTD Analysis to Constrain Estimates of Age.

Why use transit time distributions?

- Tracer ages from different tracers yield different times. It is not clear what aspects of the transport are measured by different tracers.

- Can use a *distribution of transit times* to compare the timescales derived from different tracers.

- It is the distribution, rather than the particular tracers age, that is a fundamental descriptor of the flow.

- Each tracer, because of its different boundary condition or decay rate, weights the features of the distribution differently.

Oxygen Distribution in the Oceans

Separation of Preformed and Remineralized Components:

To study the impact of aerobic remineralization on the ocean interior distribution of oxygen we can estimate the remineralized component i.e. the change in O_2 since the water parcel was last in contact with the atmosphere:

$$\Delta[O_2]_{remin} = [O_2]_{observed} + [O_2]_{preformed}$$

For oxygen, the surface ocean is generally close to saturation (the gas exchange of oxygen is more rapid than the residence time at the surface). Therefore we can generally assume that the $[O_2]_{preformed} = [O_2]_{saturation}$. Since the saturation can be computed from the potential temperature and salinity, we can thus estimate the remineralized component of oxygen, for which the term *Apparent Oxygen Utilization* is commonly used:

$$AOU = [O_2]_{sat} - [O_2]$$

where $AOU = -\Delta[O_2]_{remin}$. The assumption that the preformed oxygen concentration is equal to the oxygen saturation is not always valid. In particulat, the low latitude

References

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