The role of WBCs in Biogeochemical Cycling and its Centennial Trends under Global Warming

Taka Ito
Georgia Tech

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Biological pump & Vertical gradient of nutrient

Burd and Jackson (2009)

World Ocean Atlas 2009
Biological pump & Vertical gradient of nutrient

Ocean transport and P budget

- Subtropical and deep overturning circulation exports nutrient southward
- Nutrient mass balance requires vanishing nutrient flux when vertically integrated.
- What processes supply nutrient to the North Atlantic?

\[(\text{MOC}) \times (\text{Zonal mean } \Delta P) = (\text{southward P flux})\]
Ocean transport and P budget

- Subtropical and deep overturning circulation exports nutrient southward

- Nutrient mass balance requires vanishing nutrient flux when vertically integrated.

- What processes supply nutrient to the North Atlantic?
Nutrient stream

MITgcm-ECCO hindcast (Ito et al., 2016)

“Nutrient stream”
(Williams, Roussenov & Follows, 2006, GBC)
WBCs are the conduits of the poleward nutrient flux.
Elevated nutrient levels in the WBCs

The origin of this nutrient is in the tropics (Palter and Lozier, 2008).

\[ \rightarrow \text{Nutrient stream sustains biological productivity in the downstream} \]

(Williams et al., 2006)

\[ \rightarrow \text{What happens to the nutrient & biogeochemical cycling under global warming?} \]
Trends in CMIP5 projection (rcp8.5)

- Upper ocean temperature: 0-700m

Centennial T change, °C
Ocean Warming

• Contrasting the two basins; upper ocean (0-700m) volume-weighted averages (10°N – 50°N)
• Atlantic warming > Pacific warming
Ocean Deoxygenation

- Ocean Warming $\rightarrow$ Solubility Loss
- Increasing Stratification $\rightarrow$ Weakened Ventilation

Centennial $O_2$ change, $\mu$M
Ocean Deoxygenation

- Ocean Warming $\rightarrow$ Solubility Loss
- Increasing Stratification $\rightarrow$ Weakened Ventilation
- Even though Atlantic is warming faster, deoxygenation is stronger in the Pacific
Observed 60-year $O_2$ trend

Linear trend of $O_2$ from 1958 to 2015 at 400m based on World Ocean Database 2013v2 (Ito et al., 2017, GRL)
\[ \Delta \text{O}_2 = \Delta \text{O}_{2\text{sat}} - \Delta \text{AOU} \]

- Solubility decreases in all basins; more strongly in the North Atlantic
\[ \Delta O_2 = \Delta O_{2\text{sat}} - \Delta \text{AOU} \]

- AOU decreases in the subtropical N. Atlantic (Tagkis et al., 2017) but increases in the N. Pacific (Long et al., 2016)
\[ \Delta O_2 = \Delta O_{2\text{sat}} - \Delta \text{AOU} \]

- Solubility decreases in both basins (more in Atlantic)
- AOU increases in the Pacific (stronger O_2 decline)
  - Weakened mode water ventilation (e.g. Xu and Xie, 2013).
- AOU decreases in the Atlantic (weaker O_2 decline); Why?
Upper ocean PO$_4$

- PO$_4$ decreases in the North Atlantic
- Patterns do not agree in the N Pacific
Upper ocean PO$_4$

- PO$_4$ decreases in the North Atlantic, much more strongly relative to the North Pacific. Potential mechanisms?
  - Weakened physical supply?
  - Stronger biological consumption?
Upper Ocean Current Speed

- Gulf Stream (GS) slows down → nutrient stream
Upper Ocean Current Speed

- Gulf Stream (GS) slows down → nutrient stream
Export production (epc100)

- Biological production weakens globally (e.g. Bopp et al., 2014; Doney et al., 2014); cannot explain the reduced PO$_4$ pool.

Centennial change in EPC100, molC/m$^2$/day
Mechanisms

- Nutrient Stream
- Heat loss
- CO₂, O₂ uptake
- SST + O₂
- Ventilation
- Cold & O₂-rich
- MLD
North Pacific: mode water ventilation

- Heat loss
- CO₂, O₂ uptake

- Nutrient Stream
- Weakened Ventilation
- MLD shoaling
- Weakened subduction of O₂
North Atlantic: Nutrient stream
Summary and questions

• In global warming simulations, thermocline ventilation weakens, leading to large-scale \( \text{O}_2 \) loss

• However, in the N Atlantic, weakened nutrient stream leads to a reduction in \( \text{PO}_4 \) and AOU, partially compensating the solubility loss

• …but are the models capturing critical mechanisms?

• How can we improve process representations in the models?

• What type of model experiments will illuminate our interpretation of observation?