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

> Taka Ito Georgia Tech

Ocean Carbon Hotspot Workshop, 2017

Biological pump & Vertical gradient of nutrient



Zonal mean PO₄ (Pacific)



Figure 1

Particle aggregation processes and how they affect particles in the marine environment. Biological aggregation (e.g., fecal pellet production) and physical aggregation by (a) shear and (b) differential sedimentation form large, heterogeneous, rapidly settling particles in the surface waters. In deeper waters, fragmentation and repackaging of this material by zooplankton are the dominant processes that affect aggregate sizes and properties. Microbes decompose material throughout the water column.

Burd and Jackson (2009)

World Ocean Atlas 2009

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Zonal mean PO₄ (Atlantic)



World Ocean Atlas 2009

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?

(MOC) x (Zonal mean Δ P) (southward P flux)

=



Ocean transport and P budget

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Net transport ~ 0



Nutrient stream

1.5

0.5

60

40

50



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

Nutrient stream



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).

- → Nutrient stream sustains biological productivity in the downstream (Williams et al., 2006)
- → What happens to the nutrient & biogeochemical cycling under global warming?

Trends in CMIP5 projection (rcp8.5)

• Upper ocean temperature: 0-700m

-2

• 21st century change: (2070-2100) – (1970-2000)



0

+2

+4

Ocean Warming

- 21st century change: (2070-2100) (1970-2000)
- Contrasting the two basins; upper ocean (0-700m) volumeweighted averages (10°N – 50°N)
- Atlantic warming > Pacific warming



Ocean Deoxygenation

- Ocean Warming ightarrow Solubility Loss
- Increasing Stratification ightarrow Weakened Ventilation



Ocean Deoxygenation

- Ocean Warming \rightarrow Solubility Loss
- Increasing Stratification ightarrow Weakened Ventilation
- Even though Atlantic is warming faster, deoxygenation is stronger in the Pacific



Observed 60-year O₂ trend

Linear trend of O_2 from 1958 to 2015 at 400m based on World Ocean Database 2013v2 (Ito et al., 2017, GRL)



$$\Delta O_2 = \Delta O_{2sat} - \Delta AOU$$

• Solubility decreases in all basins; more strongly in the North Atlantic



$$\Delta O_2 = \Delta O_{2sat} - \Delta AOU$$

• AOU decreases in the subtropical N. Atlantic (Tagklis et al., 2017) but increases in the N. Pacific (Long et al., 2016)



 $\Delta O_2 = \Delta O_{2sat} - \Delta AOU$

- Solubility decreases in both basins (more in Atlantic)
- AOU increases in the Pacific (stronger O₂ decline)
 - Weakened mode water ventilation (e.g. Xu and Xie, 2013).
- AOU decreases in the Atlantic (weaker O₂ decline); Why?



Upper ocean PO₄

- PO₄ decreases in the North Atlantic
- Patterns do not agree in the N Pacific



Upper ocean PO₄

- PO₄ 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 \rightarrow nutrient stream



Upper Ocean Current Speed

• Gulf Stream (GS) slows down \rightarrow nutrient stream



Export production (epc100)

 Biologial production weakens globally (e.g. Bopp et al., 2014; Doney et al., 2014); cannot explain the reduced PO₄ pool



Mechanisms



North Pacific: mode water ventilation



North Atlantic: Nutrient stream



Summary and questions

- In global warming simulations, thermocline ventilation weakens, leading to large-scale O₂ loss
- However, in the N Atlantic, weakened nutrient stream leads to a reduction in 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?