Slowdown of the nutrient stream mediates the deoxygenation of the North Atlantic

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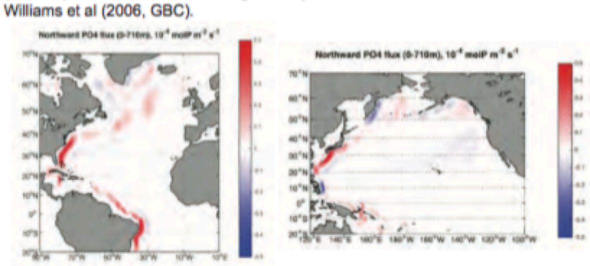
Objectives

The objective of this paper is (1) to examine the centennial-scale changes of ocean biogeochemistry in the North Atlantic using a subset of CMIP5 models, and (2) analyze and interpret the model output in the context of the AMOC slowdown. In particualr, we aim to quantify the contribution of the AMOC's nutrient streams in the centennial-scale deoxygenation of the North Atlantic.

Nutrient Streams

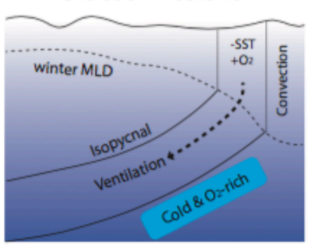
Western boundary currents are the main transport pathway of high-nutrient tropical waters to the mid and high latitudes. The diagrams below show the simulated climatological, northward transport of phosphate integrated over the upper ocean (0-710m). These features are figuratively termed as the **"nutrient streams"** by Williams et al (2006, GBC).



Ocean Deoxygenation

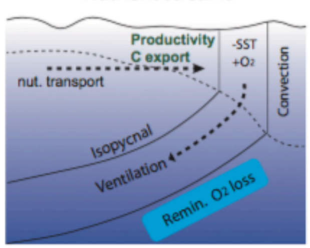
- Under warming climate, dissolved oxygen is expected to decline due to warming-induced decrease of solubility and due to weakened ocean ventilation.
- Can slowdown of AMOC accelerate the ocean deoxygenation through the reduction in ocean ventilation?
- What are the impacts of weakened nutrient streams on the oxygen trend?

Ventilation mechanism



AMOC supplies oxygen to the interior oceans by physically trasporting O_2-rich surface waters to depths. Slowdown of AMOC will weaken this supply.

Nutrient streams



Nutrient streams supply nutrients to the mid and high latitude oceans, and the resultant carbon export consumes oxygen in the sub-surface waters. Slowdown of AMOC will weaken this O_2 sink (i.e. O_2 may increase).

Acknowledgement

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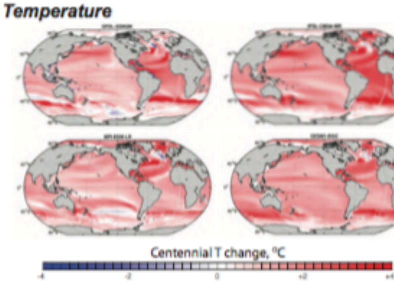
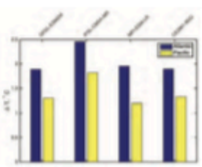
Centennial trends in CMIP5

- Upper ocean trends (0-700m) from 1985 (1970-2000 ave) to 2085 (2070 to 2100 ave).
- Contrasting the two northern basins, the Atlantic warms faster than the Pacific.

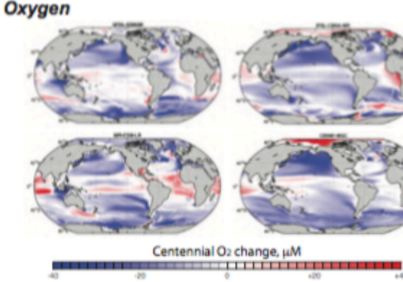
Temperature

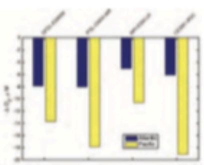




Temperature change averaged between 10°N and 50°N for respective basins and for the upper 700m.

Oxygen

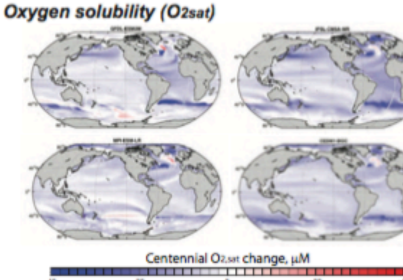


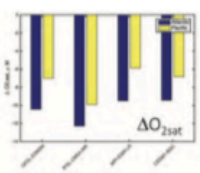


Even though the Atlantic warms up more than the Pacific, oxygen decline is relatively moderate in the Atlantic relative to the Pacific.

What causes this difference?

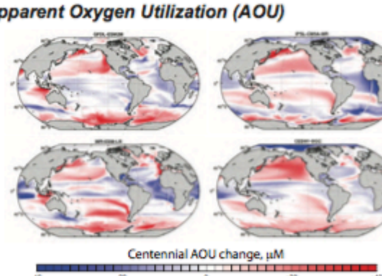
Oxygen solubility (O_{2sat})

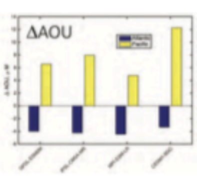




Oxygen solubility is inverely proportional to temperature. Thus, solubility decline is more pronounced in the Atlantic and cannot explain the relatively moderate O_2 decline of the Atlantic.

Apparent Oxygen Utilization (AOU)





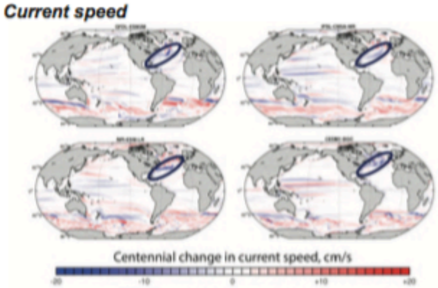
$O_2 = O_{2sat} - AOU$. Thus the decline of AOU causes O_2 to increase in the Atlantic basin. The different response of AOU explains the inter-basin difference.

Why is AOU decreasing in the sub-tropical Atlantic basin?

What drives the AOU change?

- Weakened ventilation can increase AOU by shifting the balance between physical supply and biological O_2 consumption. As water spends longer time in the interior ocean, it accumulates the effect of respiration leading to a decline of O_2. This occurs in the North Pacific and subpolar North Atlantic.
- Slowdown of AMOC reduces the nutrient supply to the North Atlantic, weakening the biological carbon export and remineralization, leaving behind higher O_2 levels in the interior ocean.

Current speed

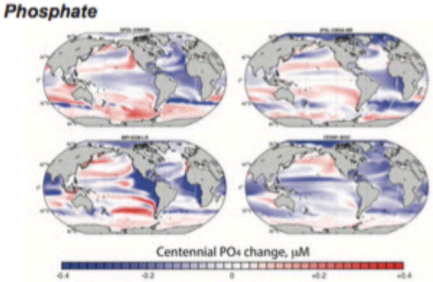


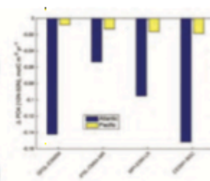
In all four ESMs we examined, the current speed decreases in the Gulf Stream and its extension. Weakened deep water formation in the North Atlantic is expected to incraese AOU there.

However, the weakened "nutrient stream" may limit the biological productivity, thus carbon export and remineralization in the interior ocean. This will cause an increase in AOU.

Below we examine the nutrient (phosphorus) content and the biological C export in both baisns.

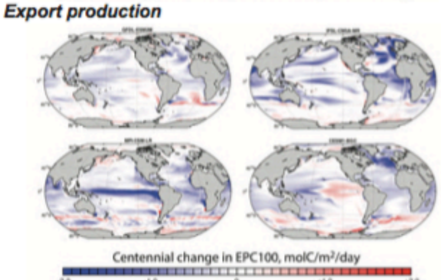
Phosphate





All models predicted significant decline of phosphate inventory in the North Atlantic. This reflects the weakened supply by the slowdown of nutrient stream.

Export production



Export production decrases globally, but the magnitue of the decline is particularly strong in the North Atlantic. Again, this is consistent with the decline in the nutrient supply to the North Atlantic.

The fact that AOU increases in the North Pacific despite weakened C export suggests that the deoxygenation is driven by the weakened ventilation there.

In contrast, nutrient inventory, C export and AOU together decreases in the North Atlantic. This change must be driven by the weakened biological activity in the Atlantic basin.

Conclusion

- Warming and incrased stratificaiton will decrease O_2 in the interior ocean. Weakened nutrient stream of the North Atlantic resists this deoxygenation by diminishing the nutrient supply and biological productivity, reducing the biological O_2 consumption. The AMOC slowdown explains the difference between the Atlantic and Pacific basins in terms of the centennial trends in nutrients and oxygen.

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