Abstract

The marine carbon cycle is of importance to sequester carbon dioxide from the atmosphere into the ocean. A substantial oceanic carbon reservoir is that of dissolved organic carbon (DOC), which exists in the forms of labile (DOCl), semilabile (DOCsl), and refractory DOC (DOCr). This paper investigates the critical role of microbial activity on the refractory DOC in the Community Earth System Model (CESM) to enhance predictions of carbon sequestration, particularly in the bathypelagic zone. The microbial loop, dependent on temperature, bacterial biomass, mortality rates, and metabolic activity, is integrated as part of this study into CESM2.1.5, that has the updated the Marine Biogeochemistry Library (MARBL). Preliminary results reveal an improved prediction simulating deep ocean carbon, but model-data biases remains linked to both limitations of predicting the microbial loop as well uncertainties in the observations. Discrepancies exist primarily in the deep ocean below 1,000m, and discrepancies of 2-4uM exist in all oceans. The study aims to improve predictions of DOC abundance, with implications for understanding ocean stratification, changes in oceanic particle fluxes. Ongoing and future experiments will explore the microbial loop's influence on DOC's residence time in the ocean, parameterization of bacteria's temperature sensitivity, and the microbial loop's responses to climate-induced changes.

Microbial Loop's influence on the carbon cycle in the deep ocean

Wilson, K. L.[1], Winguth, A. M. E.[1]

(1) Department of Earth and Environmental Sciences, University of Texas Arlington, Arlington, Texas, United States

Discover 2024

Introduction

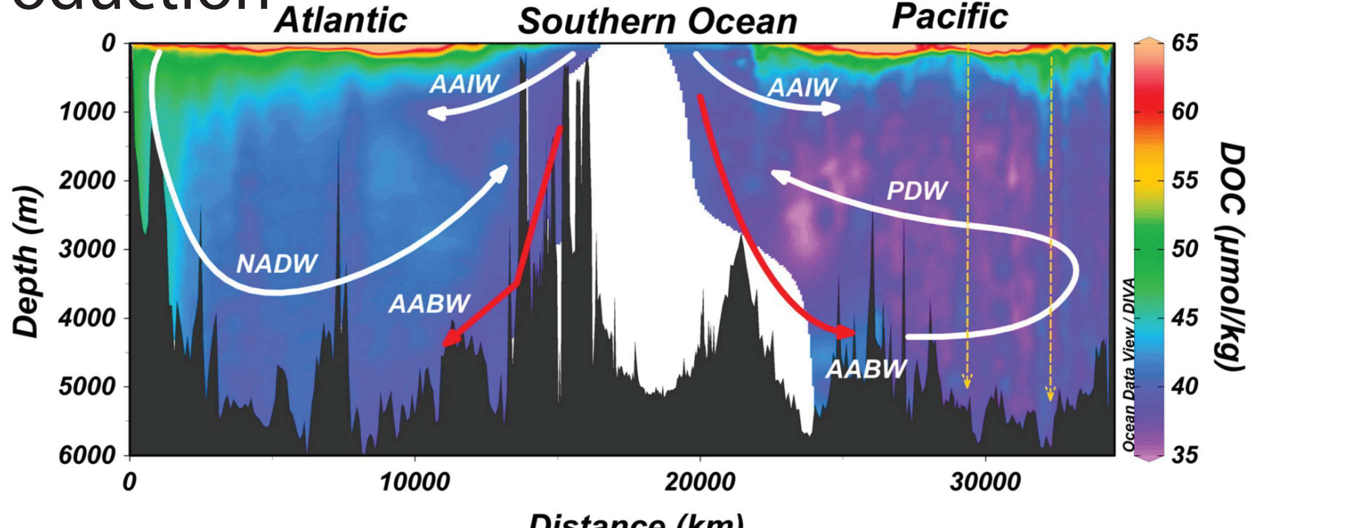

Figure 1. Vertical Distributions of DOC along A16 and P16. Solid arrows show density driven overturning patterns (NADW, AABW, AAIW, and PDW), and dashed arrows represent the apparent sinking of exported particles from the surface ocean to the deep, which serve as substrate for bacteria in the deep ocean (Hansell & Orellana, 2021)

Dissolved Organic Carbon in the Ocean:

- DOC concentrations are high at the surface in areas of primary productivity that is mixed down through the water column (Sarmiento & Gruber, 2006) and low in areas of strong upwelling (Hansell, 2001), which controls the vertical gradient seen in the ocean (Figure 1)
- DOCr has a lifetime of multiple millennia, and DOCsl has a lifetime of a few months to decades
- DOCr is difficult to simulate due to its long lifetime
- Biodegradable DOC (DOCb) makes up 2-15% of the total DOC in the ocean

Importance of Carbon:

- Carbon is an important substrate for biological activity and is necessary for life
- The ocean is one of the largest reservoirs of anthropogenic carbon, so having a thorough understanding of how carbon is stored and moved through the various reservoirs is important for understanding how changes in climate forcings will change the ocean's storage of carbon

Objectives:

1) Incorporate the Microbial Loop into the Community Earth System Model version 2 (CESM2)

2) Determine whether adding a bacterial component to CESM2 will imporve the resolution of carbon storage in the deep ocean by adding an important part of the Carbon Cycle to the model

CESM2 Model Description

The Community Earth System Model version 2 (CESM2) is a comprehensive climate model in which several components (POP2, CAM6, CICE5, CLM5, & MOSART) interact with a central coupler (CIME5) to simulate various components of the global ecosystem and exchange information (Danabasoglu, 2020).

Model Resolution:

- POP2, representing the ocean, has 60 vertical layers with a higher resolution in the top 160m of the ocean and a courser resolution in the deep and has the North Pole displaced over Greenland. POP2 and CICE5 share a horizontal resolution is 1º and 1.25º in the zonal direction
- The atmosphere component is represented by CAM6, which has 32 vertical layers with a 1º resolution, and for these experiments, a moderate 1ºx1º horizontal resolution

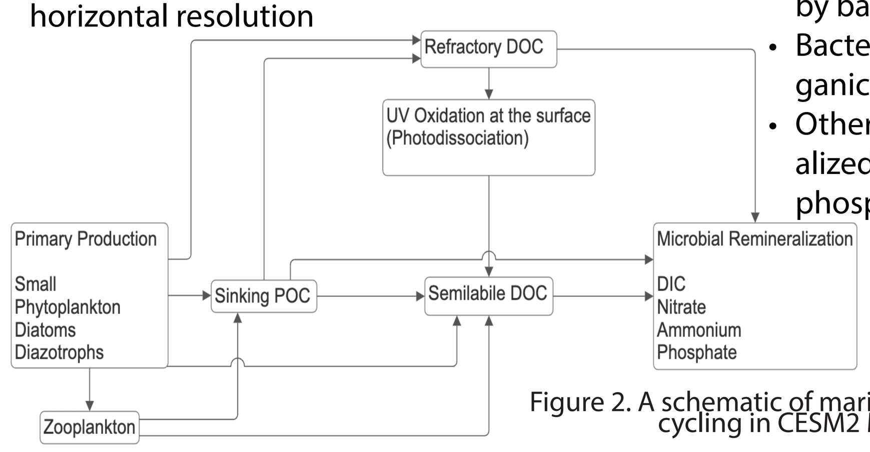

Figure 2. A schematic of marine organic matter cycling in CESM2 MARBL.

DOC Cycling in MARBL:

- DOC and POC are created in the surface ocean by primary production and zooplankton
- DOCr is converted to DOCsl by UV radiation in the surface
- A portion of DOCsl production is converted to DOCr
- POC sinks to depths where it becomes substrate for benthic bacterial metabolism
- DOC is advected with the currents and shredded by bacteria to form DOCsl
- Bacteria remineralize DOCsl into dissolved inorganic carbon (DIC)
- Other productions of phytoplankton are remineralized in the deep to ammonium, nitrate, and phosphate

DOC Observations vs. CESM Simulations

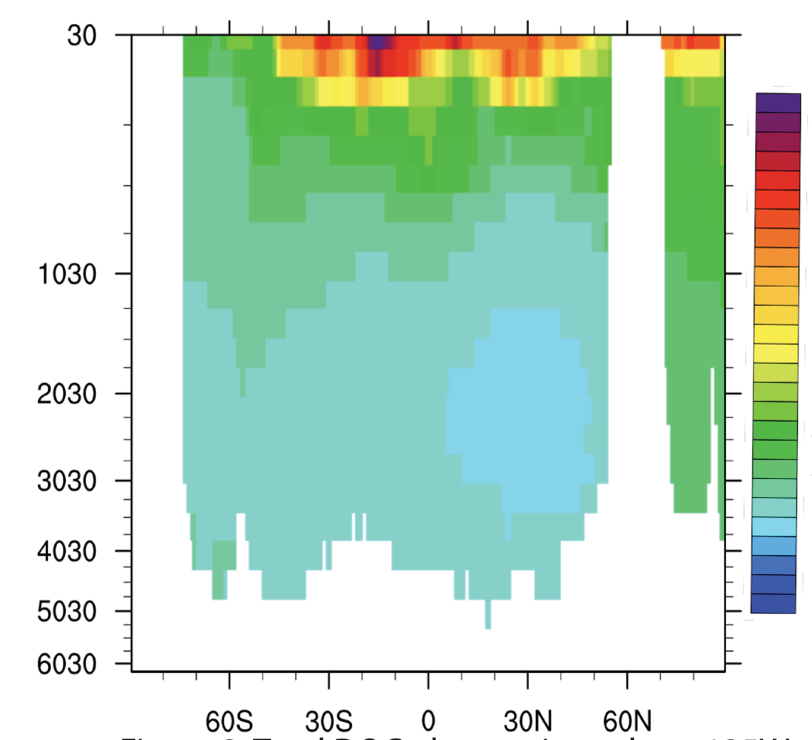

Figure 3. Total DOC observations along 135W.

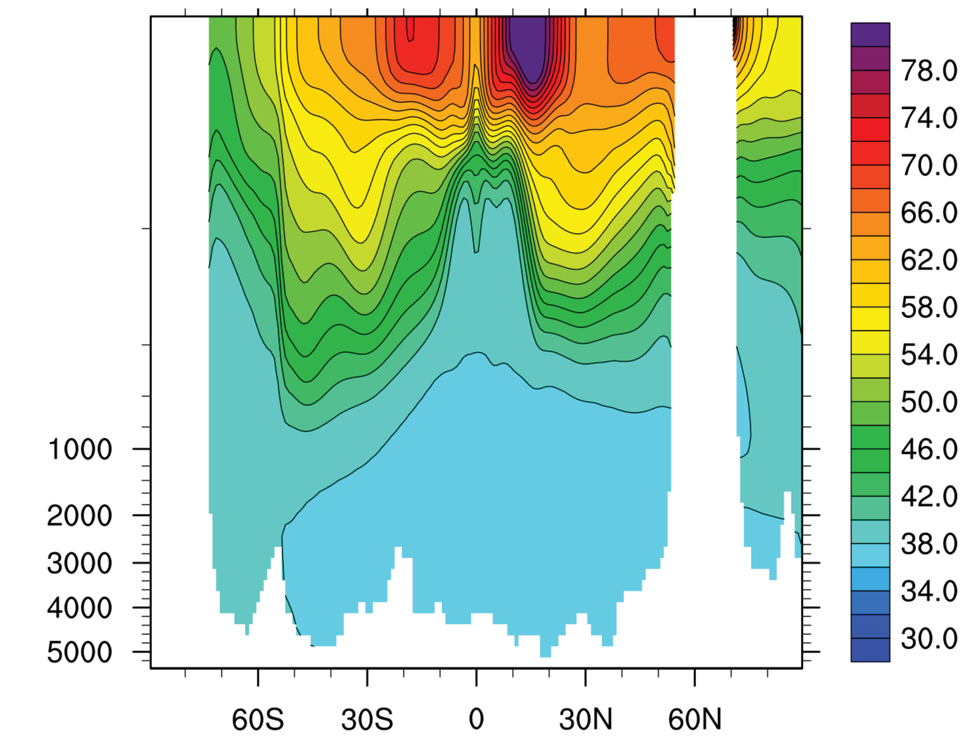

Figure 4. Simulated total DOC concentrations from a pre-industrial CESM1.2 case along 135W.

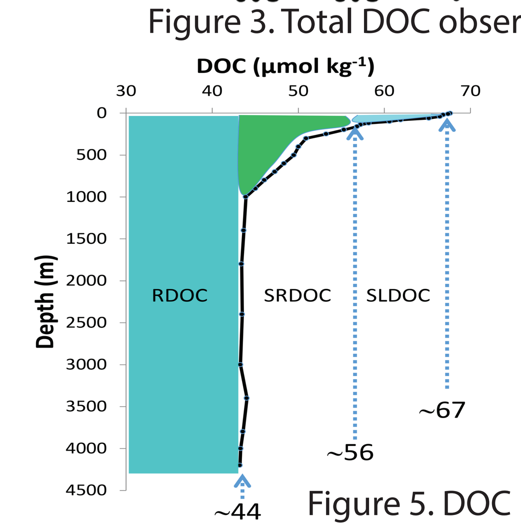

Figure 5. DOC profile with fractions of DOCr, DOCsl (Hansell & Carleson, 2015)

- Sampled DOC includes DOCsl and DOCr
- Modeled DOC includes on DOCsl
- Averaged value of DOCr in the Pacific Ocean is 38µM and in the Atlantic Ocean is 44µM
- Average disparity of 3-4µM

Simulated Biodegradable DOC in the Deep Ocean

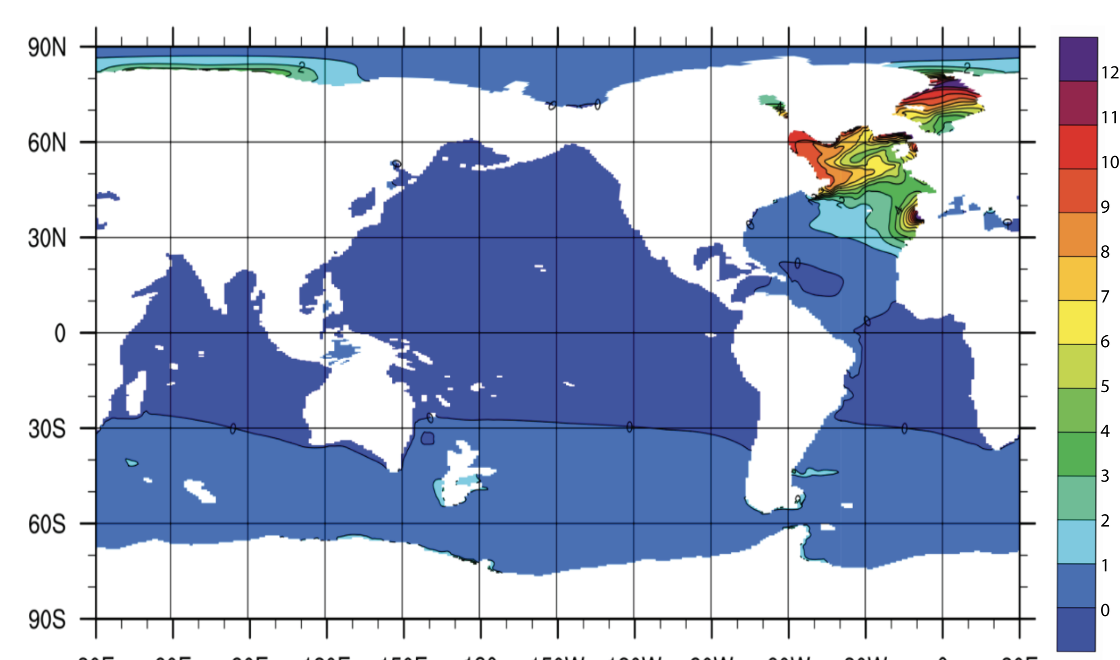

Figure 6. DOCb concentration in uM at 1041m depth (Level 40) from a pre-industrial CESM case.

- Biodegradable DOC (DOCb) is the fraction of DOC that is readily available for biologial processes
- DOCsl concentrations at 1000m are high in areas of hicher productivity and higher microbial activity
- General DOCb conventrations are low in the deep ocean
- CESM modeled values are higher than theHAMOCC2 bacterial case by 4-5µM

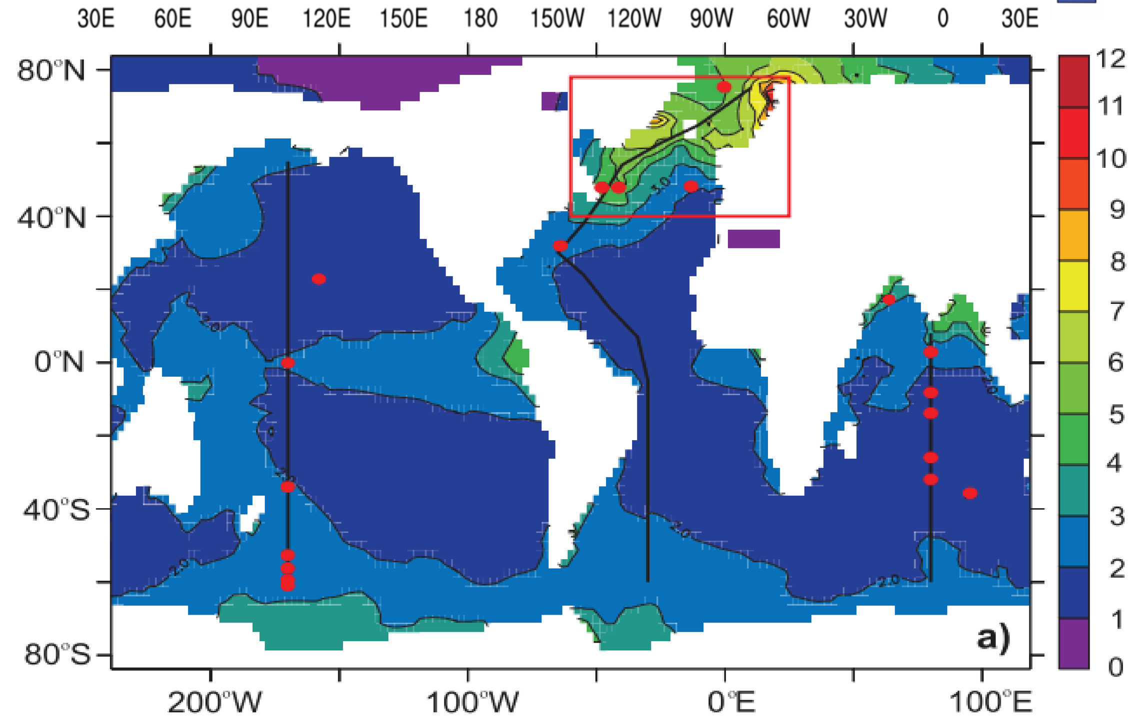

Figure 7. HAMOCC2 Model solution for vertical mean DOCb concentration (uM) below 1000m (Bendtsen et al., 2002).

Methods

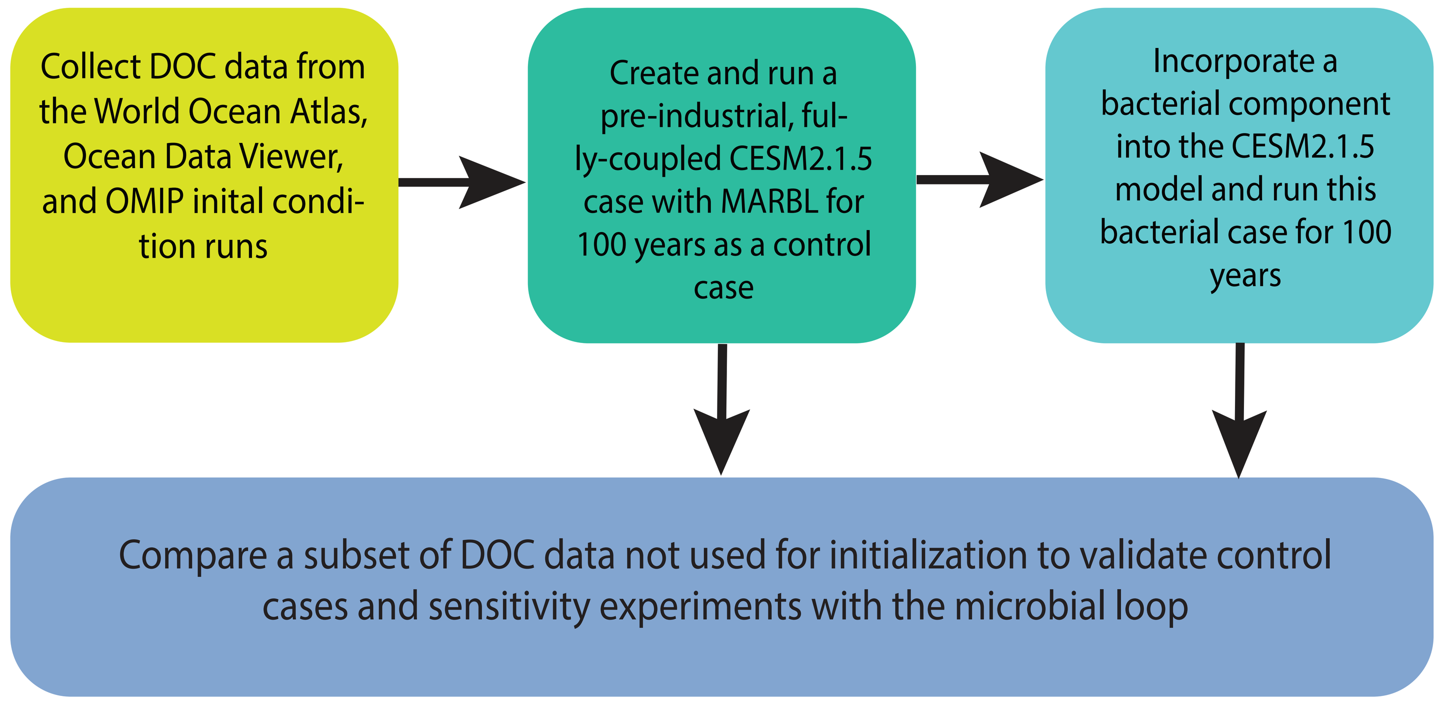

Figure 8. Methodology to inforporate a bacterial component to CESM2.1.5 and metrics for assessing model improvements.

Conclusions

- Disparities between model output and observations could be from a lack of knowledge of the role bacteria plays in the marine carbon pump, to the models not including components that parameterize biological activity in the deep oceans, or to a lack of parameterization of DOCr
- Determining the temperature dependence of the bacterial biomass is important for determining how the microbial loop will react to future changes in climate and forcings

Future Work

- How sensitive is the DOCr pool to changes in the deep sea circulation and CO_2 release to the atmosphere under a changing climate?
- Can the parameterizations of bacteria in the microbial loop be better constrained?
- How does the microbial loop change the residence time of DOCr in the deep sea?
- How might the microbial loop respond to changes with future warming scenarios?

References

- Bendtsen, J., C. Lundsgaard, M. Middelboe, and D. Archer (2002), Influence of bacterial uptake on deep--ocean dissolved Organic Carbon, Global Biogeochemical Cycles, 16(4), doi:10.1029/2002gb001947.
- Danabasoglu, G. et al. (2020), The Community Earth System Model Version 2 (CESM2), Journal of Advances in Modeling Earth Systems, 12(2), doi:10.1029/2019ms001916.
- Hansell, D. (2001), Marine dissolved organic matter and the carbon cycle, Oceanography, 14(4), 41–49, doi:10.5670/oceanog.2001.05.
- Hansell, D. A., and M. V. Orellana (2021), Dissolved organic matter in the Global Ocean: A Primer, Gels, 7(3), 128, doi:10.3390/gels7030128.
- Sarmiento, J. L., and N. Gruber (2006), Ocean Biogeochemical Dynamics, Princeton University Press, Princeton.
- Long, M. C., J. K. Moore, K. Lindsay, M. Levy, S. C. Doney, J. Y. Luo, K. M. Krumhardt, R. T. Letscher, M. Grover, and Z. T. Sylvester (2021), Simulations with the Marine Biogeochemistry Library (MARBL), Journal of Advances in Modeling Earth Systems, 13(12), doi:10.1029/2021ms002647.
- Hansell, D., and C. Carlson (2015), Dissolved organic matter in the ocean carbon cycle, Eos, 96, doi:10.1029/2015eo033011.

Acknowledgements

We'd like to acknowlege the National Center for Atmospheric Research their technical support with developing and cultivating these model simulations.
Additionally, we would like to thank the University Corporation for Atmospheric Research for granting the Univeristy Exploratory Allottment for Derecho, without which this project would not be possible.

All model simulations presented here were carried out on NCAR Cheyenne Super Computer, and future simulations will be carried out on NCAR Derecho Super Computer funded by the NSF.