How choice of depth horizon influences estimated spatial patterns and global magnitude of ocean carbon export flux

Hilary I. Palevsky[1] and Scott Doney[1,2]

[1]Department of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution, Woods Hole, MA

[2]Department of Environmental Sciences, University of Virginia, Charlottesville, VA

Introduction

- Different observational, remote sensing, and modeling approaches have led to widely varying estimates of the global magnitude and spatial patterns of biological carbon export from the surface ocean.
- Modeling studies have generally chosen a single constant global depth horizon for analysis, despite acknowledging sensitivity to the choice of depth horizon [e.g. 1-3].
- Observational estimates have demonstrated the importance of using the maximum annual mixed layer depth horizon for areas that experience deep winter mixing [4-6], but the importance of the choice of depth horizon has not been evaluated on a global scale.

Approach

- We evaluate sinking particulate organic carbon (POC) flux rates and efficiency (e-ratio: net primary production (NPP)/POC flux) in a single global earth system model using a range of depth horizons commonly used to define export.
- We demonstrate that estimates of the rate and efficiency of export are sensitive to differences in the depth horizons used to define export, which often vary across methodological approaches.

Model output for analysis

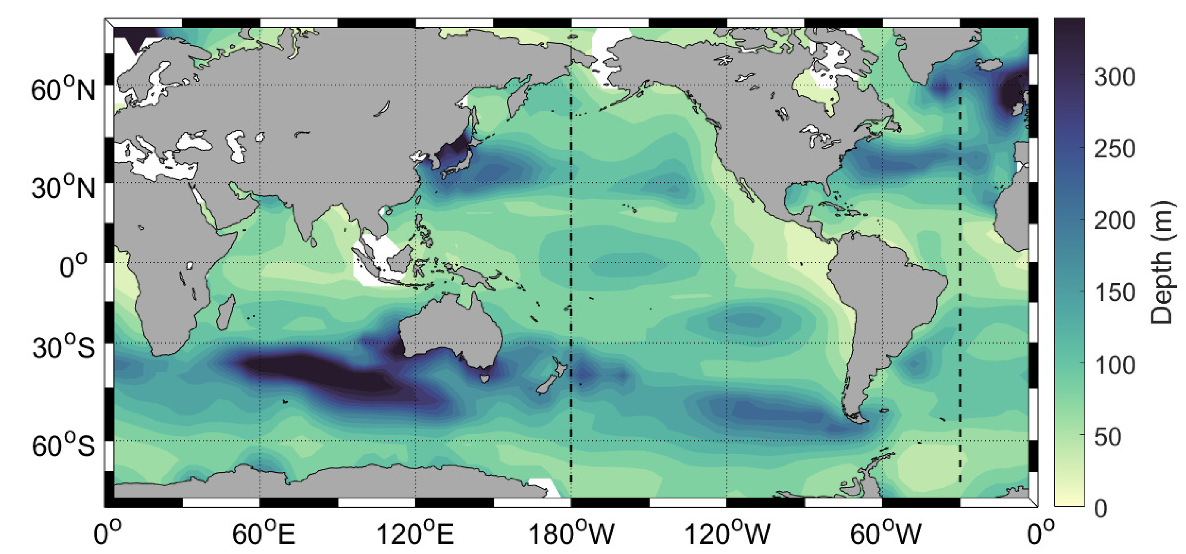
- CCSM-BEC: 3.6º longitude x 0.8-1.8º latitude, 25 vertical levels, repeated normal year forcing with pre-industrial CO_2. See [7] for details.
- Caveat: Output does not include DOC flux or vertical zooplankton migration, so we focus solely on export by POC flux.
- Caveat: Model POC dynamics are simplistic as compared with the real world, but enable us to analyze the importance of the choice of depth horizon.

Depth horizons to define export

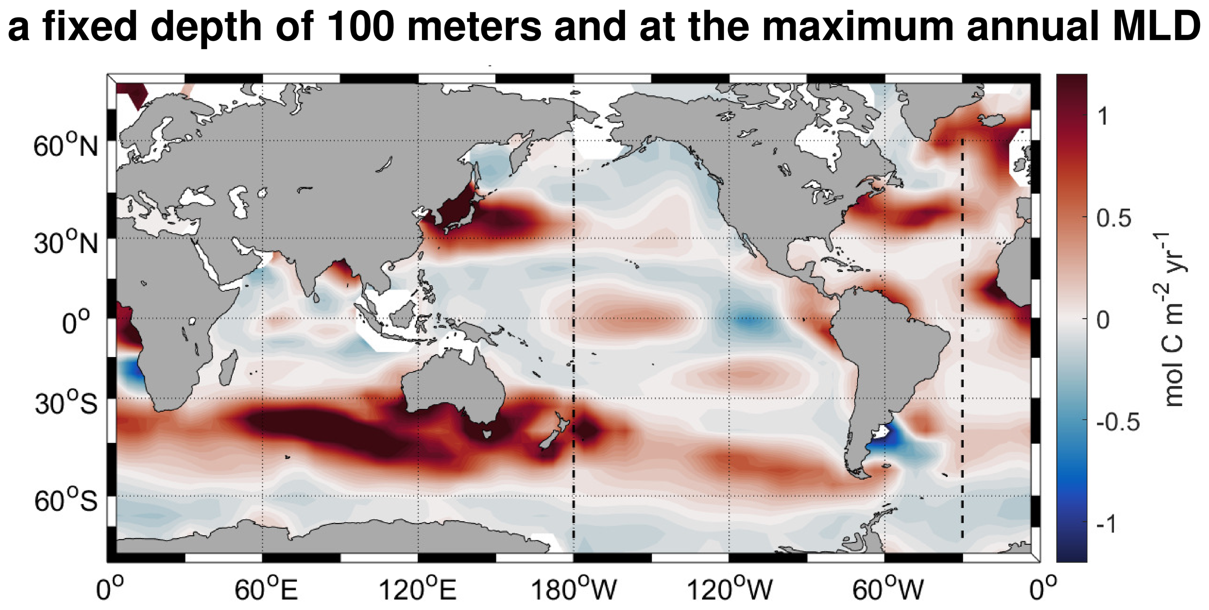
	Depth horizon definition for this analysis	Methods commonly using this depth horizon
Seasonally-varying mixed layer depth	From model physics, determined for each grid point in each month	Biogeochemical mass balance (e.g. O_2/Ar), especially over short time scales
Particle compensation depth	Depth with maximum POC flux rate, determined for each grid point in each month	Difficult to measure in practice
Euphotic depth	Depth where POC production =1% of max, determined for each grid point in each month	Sediment trap and ^{234}Th observational studies; Satellite e-ratio algorithms
100 meters	Constant for all grid points and months	Earth system models; Sediment trap and ^{234}Th observational studies
Maximum annual mixed layer depth	From model physics, determined for each grid point and constant throughout year	Biogeochemical mass balance, especially with deep winter mixing

Results: Depth horizon choice influences spatial patterns of export

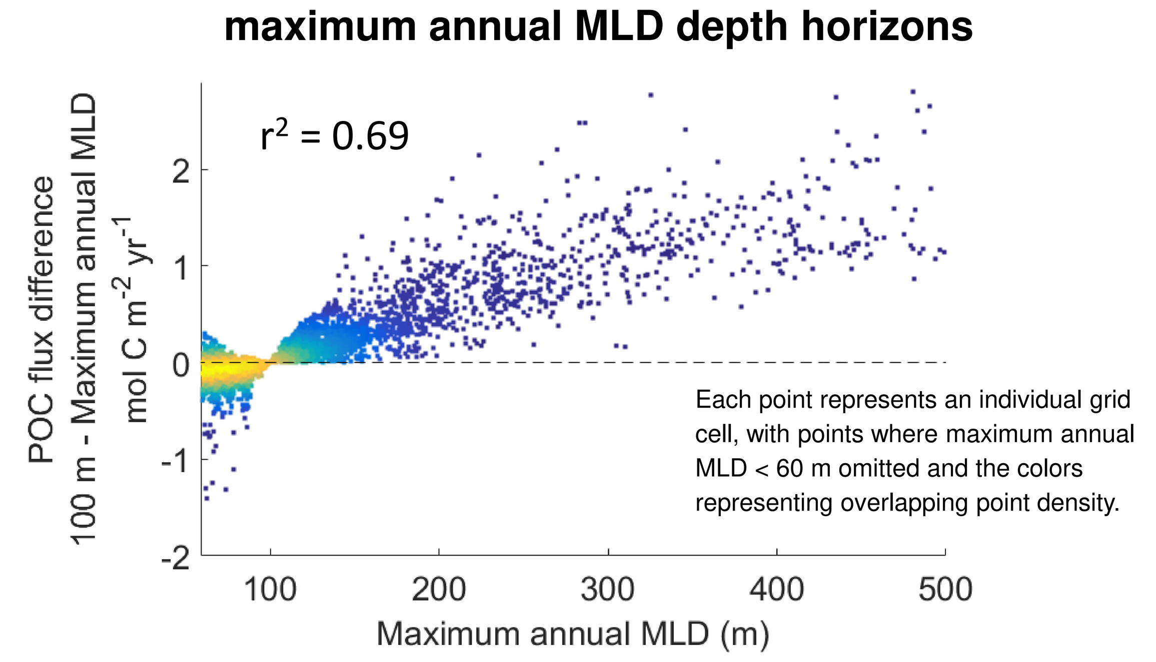
Maximum annual (winter) mixed layer depth (MLD)



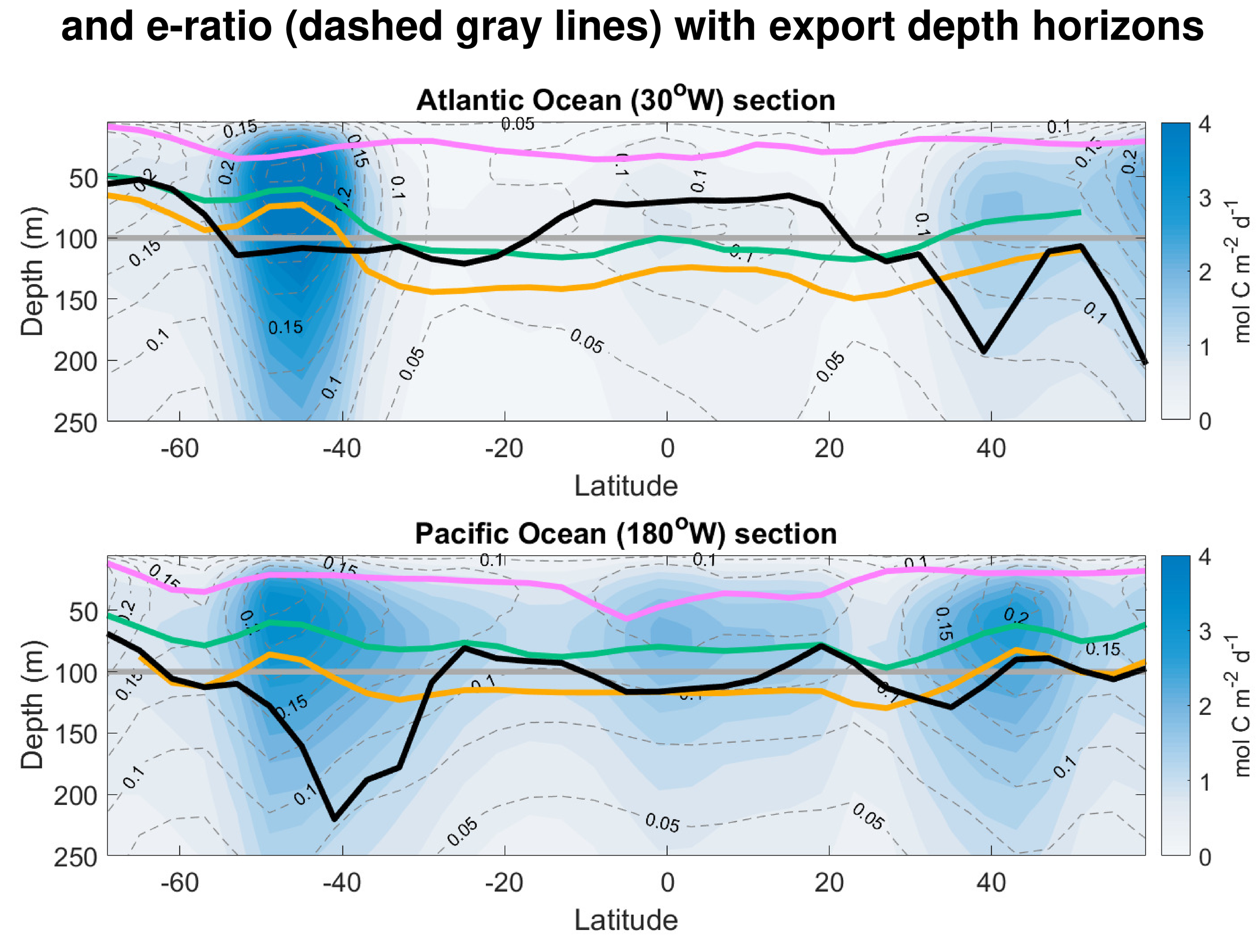
Difference between POC flux determined at a fixed depth of 100 meters and at the maximum annual MLD



Correlation between the maximum annual MLD and the POC flux difference between the fixed 100 meter and maximum annual MLD depth horizons



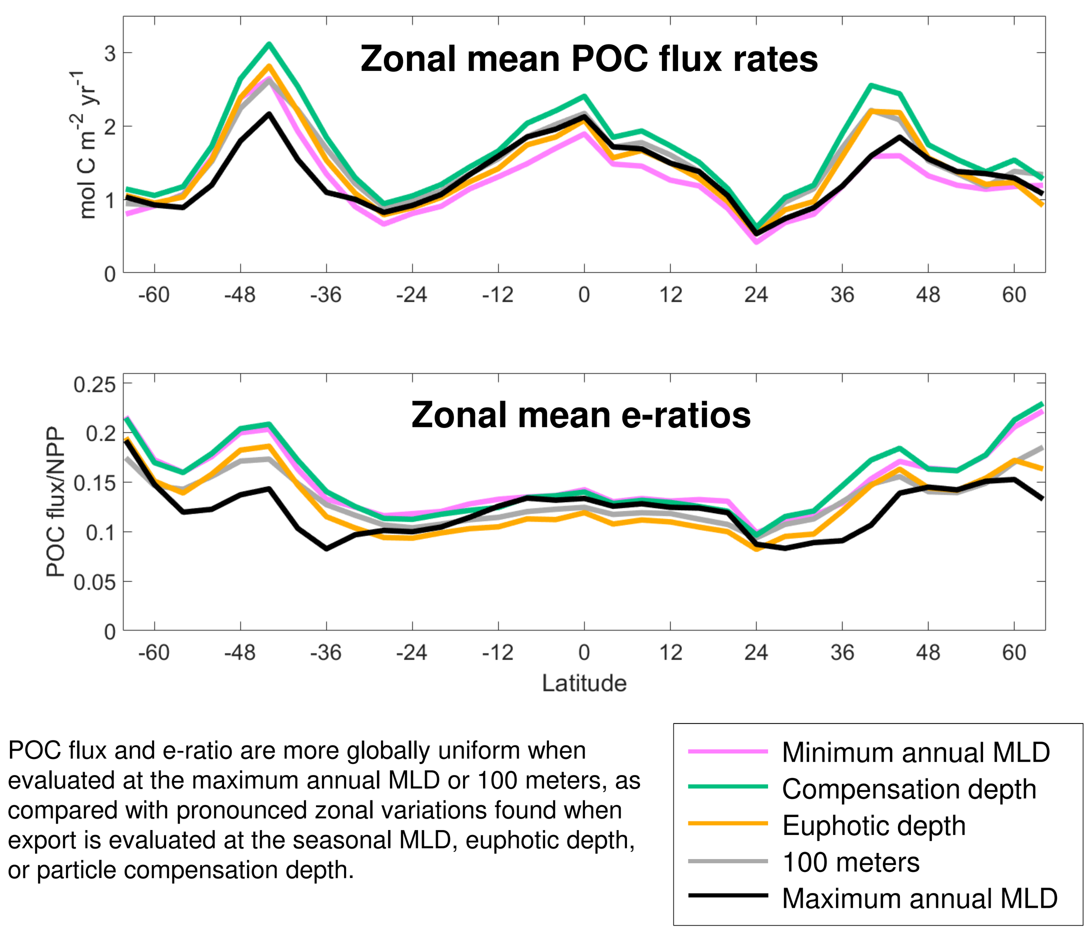
Meridional sections of mean annual POC flux (colorscale) and e-ratio (dashed gray lines) with export depth horizons



For the particle compensation depth and euphotic depths, which vary seasonally, the depth shown is the annual mean weighted by monthly POC flux rates. The seasonal MLD export horizon varies between the annual minimum (pink) and maximum (black).

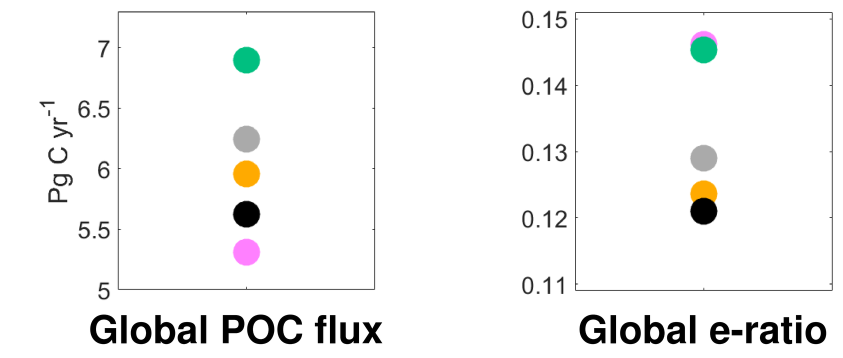
Results: Zonal variability and global magnitude of export

Zonal variability in POC flux and e-ratio depends on the choice of export depth horizon



POC flux and e-ratio are more globally uniform when evaluated at the maximum annual MLD or 100 meters, as compared with pronounced zonal variations found when export is evaluated at the seasonal MLD, euphotic depth, or particle compensation depth.

Overall global POC flux and e-ratio vary with different export depth horizon choices



Conclusions

- Global POC flux rates vary by 30% and global e-ratios by 21% across different depth horizon choices within this single dynamically consistent model framework.
- Zonal variability in POC flux and e-ratio also depends on the depth horizon, particularly due to the pronounced influence of deep winter mixing in subpolar regions.
- Efforts to reconcile conflicting estimates of export from multiple approaches need to account for these systematic discrepancies created by differing depth horizon choices.

Literature Cited

1. Doney, S.C., K. Lindsay, J.K. Moore (2003), Global ocean carbon cycle modeling, in Ocean Biogeochemistry, ed. M. Fasham, Springer, 217-238.
2. Najjar, R. G. et al. (2007), Impact of circulation on export production, dissolved organic matter, and dissolved oxygen in the ocean: Results from Phase II of the Ocean Carbon-cycle Model Intercomparison Project (OCMIP-2), *Global Biogeochem. Cycles*, *21*(3), doi:10.1029/2006GB002857.
3. Laufkötter, C. et al. (2016), Projected decreases in future marine export production: The role of the carbon flux through the upper ocean ecosystem, *Biogeosciences*, *13*(13), 4023–4047, doi:10.5194/bg-13-4023-2016.
4. Körtzinger, A., U. Send, R. S. Lampitt, S. Hartman, D. W. R. Wallace, J. Karstensen, M. G. Villagarcia, O. Llinás, and M. D. DeGrandpre (2008), The seasonal pCO_2 cycle at 49° N/16.5° W in the northeastern Atlantic Ocean and what it tells us about biological productivity, *J. Geophys. Res.*, *113*, C04020, doi:10.1029/2007JC004347.
5. Bushinsky, S. M., and S. Emerson (2015), Marine biological production from in situ oxygen measurements on a profiling float in the subarctic Pacific Ocean, *Glob. Biogeochem. Cycles*, *29*, doi:10.1002/2015GB005251.
6. Palevsky, H. I., P. D. Quay, D. E. Lockwood, and D. P. Nicholson (2016), The annual cycle of gross primary production, net community production, and export efficiency across the North Pacific Ocean, *Glob. Biogeochem. Cycles*, *30*, doi:10.1002/2015GB005318.
7. Lima, I. D., P. J. Lam, and S. C. Doney (2014), Dynamics of particulate organic carbon flux in a global ocean model, *Biogeosciences*, *11*, 1177–1198, doi:10.5194/bg-11-1177-2014.

Acknowledgments

Thanks to Ivan Lima, who generously provided the model output used in this analysis, and to the Postdoctoral Scholar Program at the Woods Hole Oceanographic Institution, with funding provided by the Weston Howland Jr. Postdoctoral Scholarship.