OB44D-0992

Ocean Biogeochemical Fingerprints of Fast-Sinking Tunicate and Fish Detritus

Jessica Y. Luo[1]*, Charles A. Stock[1], John P. Dunne[1], Grace K. Saba[2], Lauren Cook[2]

[1] Geophysical Fluid Dynamics Laboratory, NOAA Ocean and Atmospheric Research, Princeton, NJ, USA
[2] Department of Marine and Coastal Sciences, Rutgers University, New Brunswick, NJ

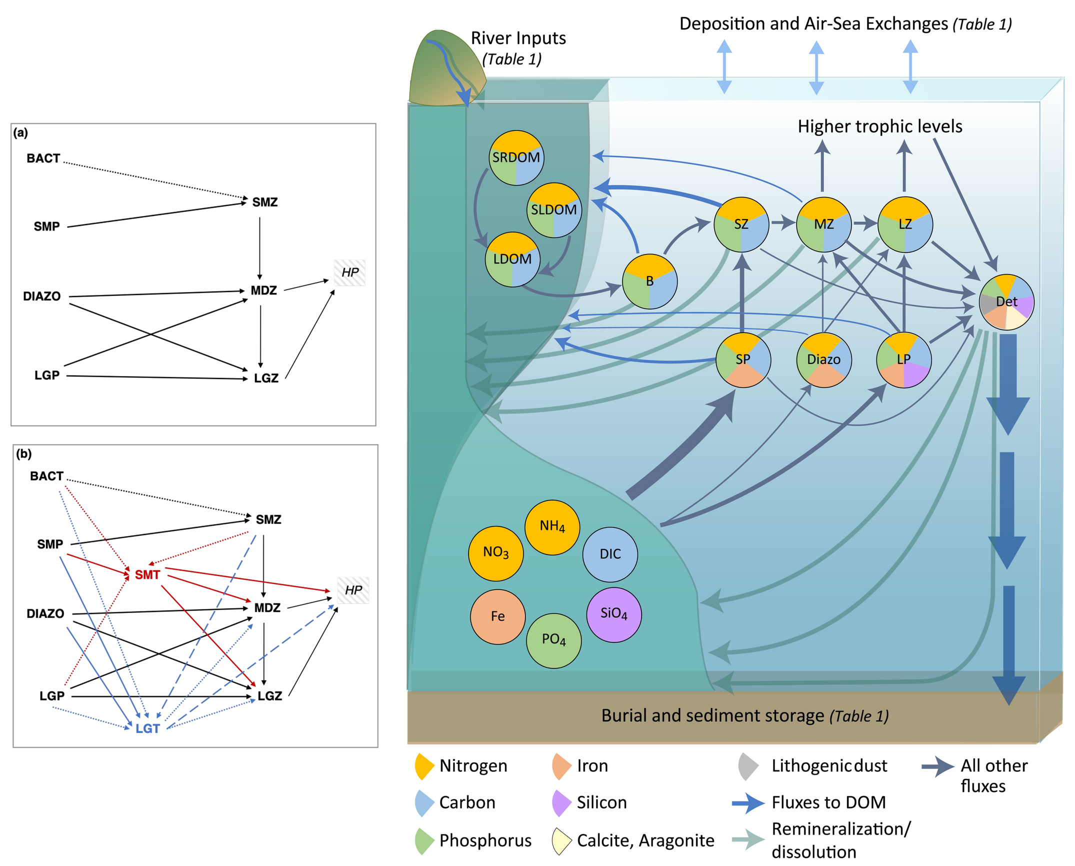
*email: Jessica.Luo@noaa.gov

Introduction

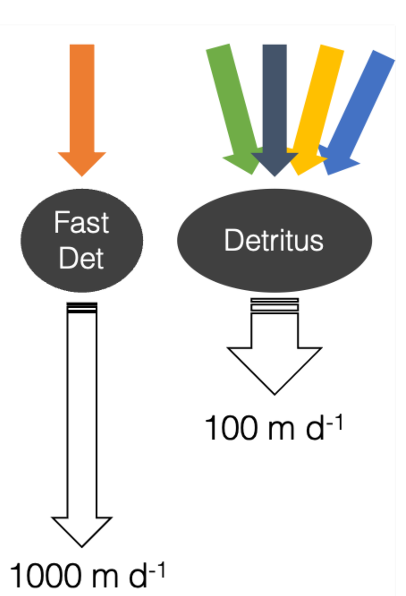
- Gelatinous zooplankton (GZ) and fishes have fast-sinking detritus (700-1500+ m/d), which is ~10x faster than bulk oceanic detritus.
- Studies show that fast-sinking GZ detritus increases the transfer efficiency of the biological pump, but their broader impact on ocean biogeochemical cycles in the deep-sea is unknown.
- Especially unknown are the impacts of fast-sinking detritus on ocean oxygen, both in the oxygen minimum zones (OMZs) and at the seafloor.
- We use a coupled physical-biogeochemical model with explicit GZ (specifically, pelagic tunicates) and implicit fish to investigate the model sensitivity to fast-sinking detritus from GZ, fish, and both.

Methods

Fig. 1. GFDL COBALT ocean biogeochemical model. (a) original food web, (b) modified GZ-COBALT food web with two size classes of pelagic tunicates (small tunicate, and large tunicate; fig. from Luo et al. 2022), and (c) full model schematic (fig. from Stock et al. 2020).



- We used a modified version of the GFDL COBALT model with two explicit size classes of pelagic tunicates (GZ-COBALT; Luo et al. 2022) and implicit higher trophic level predators (fish) (Fig. 1).
- Fast-sinking detritus were separated from bulk detritus, and sank at 1000 m d^{-1} compared to the bulk rate (100 m d^{-1}).
- Fast-sinking detritus included:
  Fish: all detritus (represents fecal pellets only)
  GZ: all detritus from jelly-falls, and 75% of the fecal pellets.
- 4 experiments were run with
  1) no fast-sinking detritus (Control)
  2) fast-sinking GZ detritus only,
  3) fast-sinking fish detritus only,
  4) fast-sinking fish and GZ detritus combined.



- Simulations were run with MOM6, SIS2, and GZ-COBALT at 0.5 degree horizontal resolution for 300 years with 5 60-year repeating COREII-IAF cycles, representing 1948-2008. The last 20 years of the 5th cycle was averaged for analysis.

Results

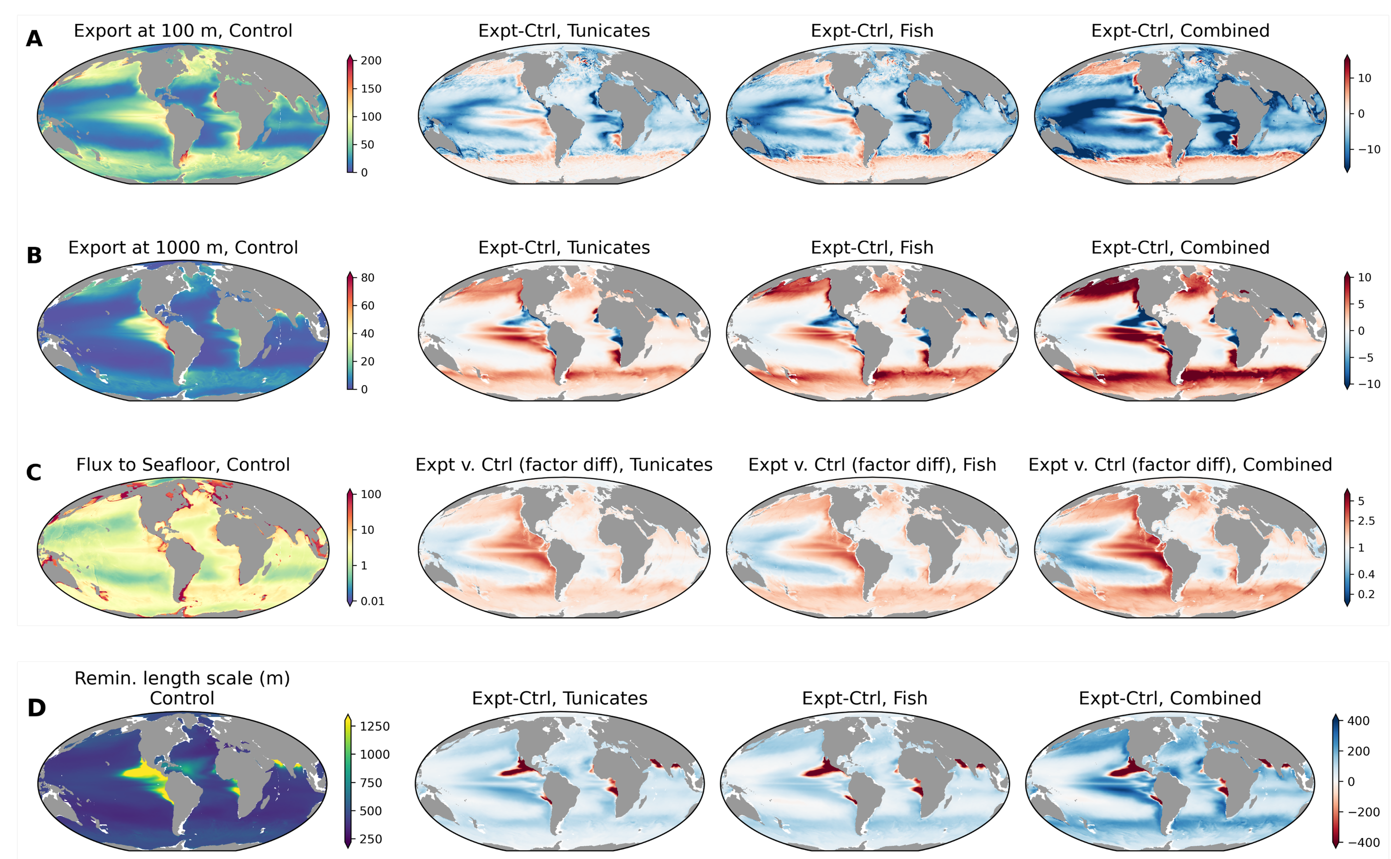


Fig. 2. Detrital carbon fluxes and remineralization. Particulate organic carbon (POC) export (mg C m^{-2} d^{-1}) at different depths, showing (left) raw values from the GZ-COBALT control (center to right) the differences between the control and experiments.
(a) 100 m;
(b) 1000 m;
(c) seafloor.
(d) Average remineralization length scale between 100 and 1000 m.

- Incorporating fast-sinking detritus resulted in a **global decrease** in NPP and surface export flux. This effect was strongest in the subtropical gyres, where nutrients were already limiting (Fig. 2).
- POC flux at 1000 m and to the seafloor increased, particularly at upwelling zones and high latitudes. In the combined fish + GZ case, POC flux at 1000 m increased 37%, and flux to the seafloor increased 11%.
- Remineralization length scales increased globally, **except near OMZs,** where fast-sinking detritus reduced remineralization overall, leading to less oxygen loss and less anaerobic remineralization.
- **This leads to smaller OMZs with fast-sinking detritus**, and associated improvements in simulated nitrate and N* at the mid-depths (Fig 5).
- Comparisons to observations (Dinauer et al. 2022; Fig 3), the simulations with fast-sinking detritus improved the model-data fit at sites near the OMZs. The fit at other sites were degraded — but this is consistent with modifying a component of a tuned model (Laufkotter et al. 2017).

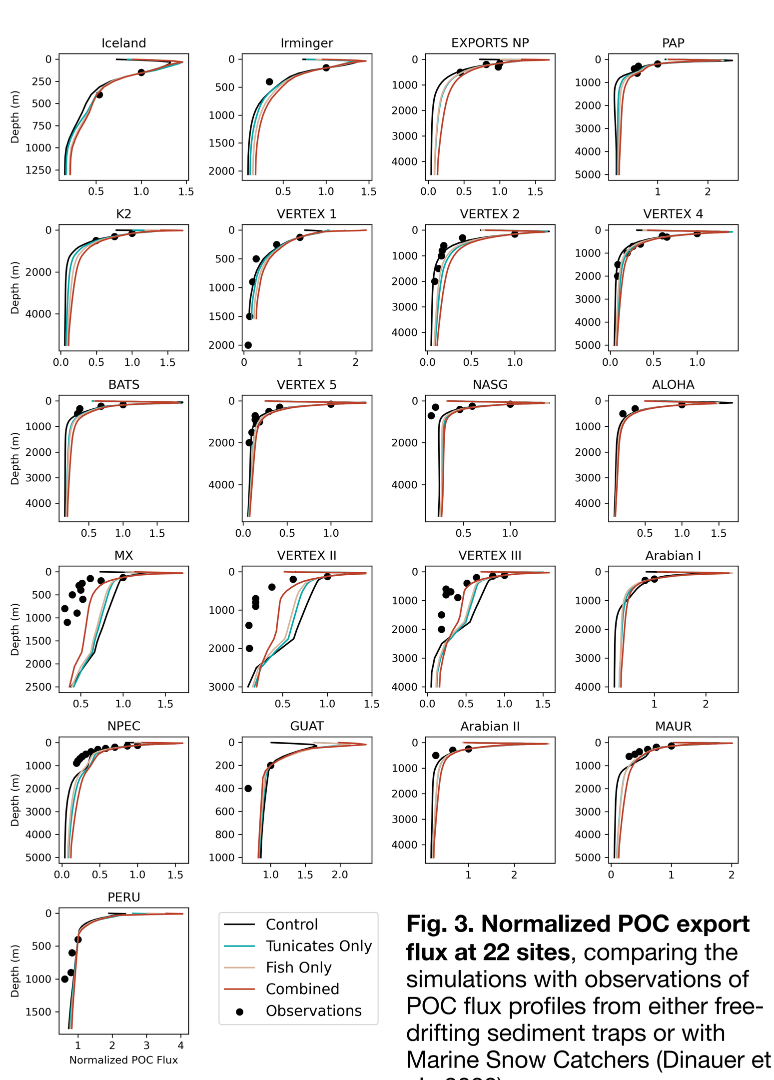


Fig. 3. Normalized POC export flux at 22 sites, comparing the simulations with observations of POC flux profiles from either free-drifting sediment traps or with Marine Snow Catchers (Dinauer et al., 2022).

- Increased supply of POC to seafloor increased benthic oxygen utilization rates (OUR) (Fig. 4).
- But, compared to the Jørgensen et al. (2022) data product, **simulated OUR even with fast-sinking detritus is significantly lower.**

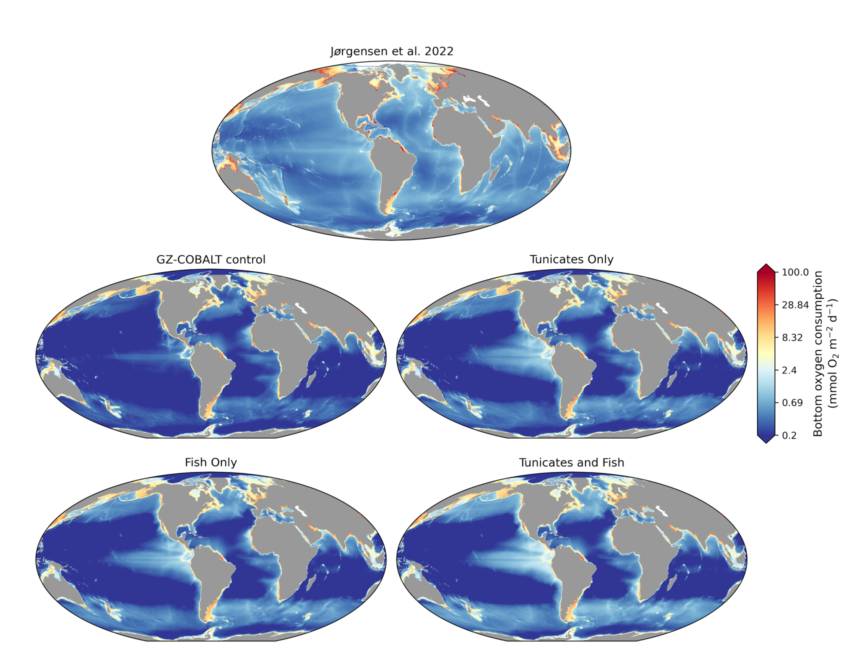


Fig. 4. Benthic oxygen utilization. Comparisons between the Jørgensen et al. (2022) observational product (top) and simulated oxygen consumption at the ocean bottom in the GZ-COBALT control and three experimental cases (tunicate-only, fish only, and tunicates and fish combined).

Results, con't

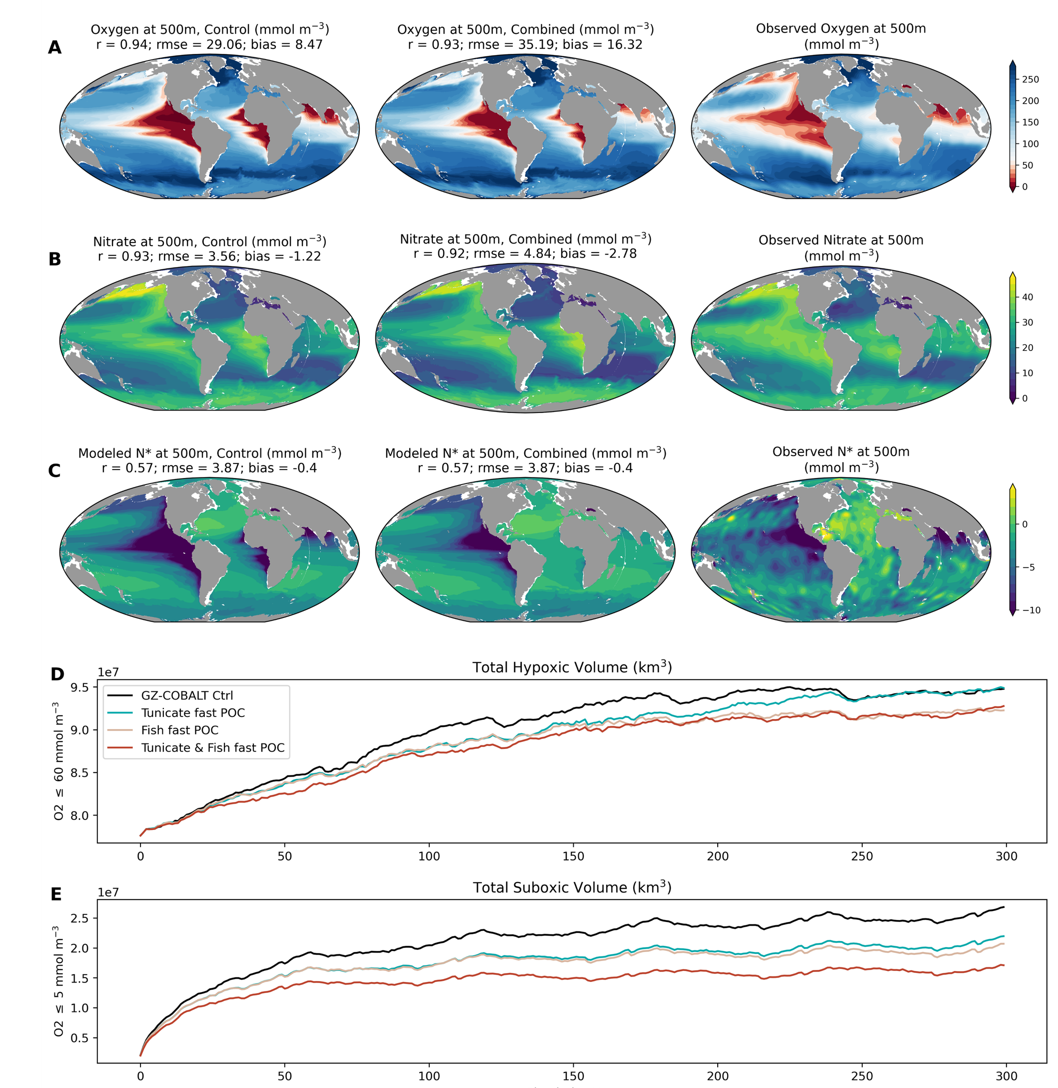


Fig. 5. Ocean biogeochemical impacts of fast-sinking detritus. Comparisons of (a) oxygen concentrations (mmol O_2 m^{-3}), (b) nitrate concentrations (mmol NO_3 m^{-3}), and (c) N* ($NO_3 - 16^* PO_4$; mmol m^{-3}) at 500 m depth between the GZ-COBALT control, the tunicates and fish combined case, and observations from World Ocean Atlas (WOA) observations. Total (d) hypoxic (O2 <= 60 mmol m^{-3}) and (e) suboxic (O2 <= 5 mmol m^{-3}) ocean volume (in km^3) by simulation year, shown for the GZ-COBALT control and all three fast-sinking detritus cases. Note that simulations were initialized from WOA, so the size of the departure from the initial condition in panels (d) and (e) is proportional to the model bias.

Discussion

- Fast-sinking detritus cases with fish- and GZ- only had similar global values. The fish-only case was higher at the coasts and in high-productivity areas, consistent with the broad contrast between fish and GZ.
- NPP and export flux decreased globally due to the stripping of nutrients from the surface oceans, and persisted for at least 300 years.
- Modeled OMZs expanded slower with fast-sinking detritus. OMZs did shift deeper, but the total hypoxic and suboxic volume were still lower than the Control. This is due to the interactive effect of fast-sinking detritus on oxygen and remineralization rates.
- This implies at a biological mechanism for improving models' representation of OMZ size and change with climate change — a key model bias.
- Sedimentary oxygen utilization may be an independent constraint on fast POC fluxes. Recent seafloor OUR observations (Fig. 4) suggest at significantly more benthic oxygen consumption than our model suggests.
- This is a puzzling discrepancy — possibly due to biases in both observations and coastal productivity in models — but nonetheless suggests that the observations are able to accommodate increased bottom fluxes from fast-sinking detritus.

References

- Dinauer, A., Laufkötter, C., Doney, S. C., & Joos, F. (2022). What controls the large-scale efficiency of carbon transfer through the ocean's mesopelagic zone? Insights from a new, mechanistic model (MSPACMAM). Global Biogeochemical Cycles, 36(10). https://doi.org/10.1029/ 2021GB007131
- Jørgensen, B. B., Wenzhöfer, F., Egger, M., & Glud, R. N. (2022). Sediment oxygen consumption: Role in the global marine carbon cycle. Earth- Science Reviews, 228, 103987. https://doi.org/10.1016/j.earscirev.2022.103987
- Laufkötter, C., John, J. G., Stock, C. A., & Dunne, J. P. (2017). Temperature and oxygen dependence of the remineralization of organic matter. Global Biogeochemical Cycles, 31(7), 1038–1050. https://doi.org/10.1002/2017GB005643
- Luo, J. Y., Stock, C. A., Henschke, N., Dunne, J. P., & O'Brien, T. D. (2022). Global ecological and biogeochemical impacts of pelagic tunicates. Progress in Oceanography, 205, 102822. https://doi.org/10.1016/j.pocean.2022.102822
- Stock, C. A., Dunne, J. P., Fan, S., Ginoux, P., John, J., Krasting, J. P., et al. (2020). Ocean biogeochemistry in GFDL's Earth system model 4.1 and its response to increasing atmospheric CO2. Journal of Advances in Modeling Earth Systems, 12(10). https://doi.org/10.1029/2019MS002043

Published manuscript