Slow particle remineralization, rather than suppressed disaggregation, drives efficient flux transfer in the Eastern Tropical North Pacific Oxygen Deficient Zone

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Key Points:

- The upper mesopelagic of the oligotrophic Eastern Tropical North Pacific Oxygen Deficient Zone (ODZ) has low flux attenuation
- Comparison of these observations to models suggests that the breakdown of particles of all sizes is slow throughout the ODZ.
- Zooplankton appear to transport organic matter into, and disaggregate particles within, the ODZ above 500m.

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Abstract

Models and observations suggest that particle flux attenuation is lower across the mesopelagic zone of anoxic environments compared to oxic ones. Flux attenuation is controlled by microbial metabolism and aggregation and disaggregation by zooplankton, which also shape the relative abundance of different sized particles. Observing and modeling particle spectra can provide information about the contributions of these processes. We measured particle size spectrum profiles at one station in the oligotrophic Eastern Tropical North Pacific Oxygen Deficient Zone (ETNP ODZ) using an underwater vision profiler (UVP), a high resolution camera that counts and sizes particles. Measurements were taken at different times of day, over the course of a week. Comparing these data to particle flux measurements from sediment traps collected over the same time period allowed us to constrain the particle size to flux relationship, and to generate highly resolved depth and time estimates of particle flux rates. We found that particle flux attenuated very little throughout the anoxic water column, and at some time-points appeared to increase. Comparing our observations to model predictions suggested that particles of all sizes remineralize more slowly in the ODZ than in oxic waters, and that large particles disaggregate into smaller particles, primarily between the base of the photic zone and 500 m. Acoustic measurements of multiple size classes of organisms suggested that many organisms migrated, during the day, to the region with high particle disaggregation. Our data suggest that diel-migrating organisms both actively transport biomass and disaggregate particles in the ODZ core.

Plain Language Summary

Marine snow are microscopic particles that form in the surface of the ocean and sink into the deep ocean. Most of these particles are the remains of dead algae and faeces of tiny animals (zooplankton). The deeper the particles sink into the ocean before microbes or animals eat them, the longer it takes before the carbon in those particles can return to the atmosphere. In parts of the ocean where there is very little oxygen more particles sink to greater depths for reasons that are not well-understood. We used an underwater camera to observe marine snow particles in a part of the ocean (just west of Mexico) where there is very limited oxygen at depth. We compared the observations to predictions from different computer simulations to see which simulations were most accurate. Our measurements suggest that one reason that particles sink to deeper depths here is because microbes consume the particles slowly when there is no oxygen. Meanwhile, tiny animals break large particles into smaller ones and produce fecal pellets in these low oxygen waters.

1 Introduction

The biological pump, in which sinking particles transport carbon from the surface into the deep ocean, is a key part of the global carbon cycle (Neuer et al., n.d.). Things

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(Ahmed et al., n.d.)

(Agogu, Brink, et al., n.d.; Agogu, Lamy, et al., n.d.; Agrawal et al., n.d.)

[@neuerOceanBiologicalCarbon2014; @turnerZooplanktonFecalPellets2015] (Neuer, Iversen, and Fischer 2014; Turner 2015). Organic matter flux into the deep ocean is a function both of export from the photic zone into the mesopelagic (export flux), and the fraction of that flux that crosses through the mesopelagic (transfer efficiency) (Passow and Carlson 2012; Siegel et al. 2016; Francois et al. 2002). The transfer efficiency of the biological pump may affect global atmospheric carbon levels (Kwon, Primeau, and Sarmiento 2009). Thus, understanding the processes that shape organic matter degradation in the mesopelagic is critical. (Ackermann, n.d.; Albert & Barabsi, n.d.; Bashir et al., n.d.)(Ackermann, n.d.; Albert & Barabsi, n.d.; Barker et al., n.d.; Bashir et al., n.d.)

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(Baird et al., n.d.; Bakewell & Lumley, n.d.; Bakken & Olsen, n.d.; Balch et al., n.d.)

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Enter acknowledgments, including your data availability statement, here.

References

Ackermann, H.-W. (n.d.). 5500 Phages examined in the electron microscope. , *152*(2), 227–243. Retrieved 2014-09-11, from `http://link.springer.com/10.1007/s00705-006-0849-1` doi: 10.1007/s00705-006-0849-1

Agogu, H., Brink, M., Dinasquet, J., & Herndl, G. J. (n.d.). Major gradients in putatively nitrifying and non-nitrifying Archaea in the deep North Atlantic. , *456*(7223), 788–791. Retrieved 2010-03-21, from `http://apps.isiknowledge.com.libproxy.usc.edu/full_record.do?product=UA&search_mode=Refine&qid=80&SID=4ED6koDdkMAinJBPDA8&page=1&doc=2&colname=WOS&cacheurlFromRightClick=no` doi: 10.1038/nature07535

Agogu, H., Lamy, D., Neal, P. R., Sogin, M. L., & Herndl, G. J. (n.d.). Water mass-specificity of bacterial communities in the North Atlantic revealed by massively parallel sequencing. , *20*(2), 258–274. Retrieved 2014-04-30, from `http://onlinelibrary.wiley.com/doi/10.1111/j.1365-294X.2010.04932.x/abstract` doi: 10.1111/j.1365-294X.2010.04932.x

Agrawal, R., Imieliski, T., & Swami, A. (n.d.). Mining association rules between sets of items in large databases. In *ACM SIGMOD Record* (Vol. 22, pp. 207–216). Retrieved 2013-02-01, from `http://dl.acm.org/citation.cfm?id=170072`

Ahmed, W., Angel, N., Edson, J., Bibby, K., Bivins, A., O'Brien, J. W., ... Mueller, J. F. (n.d.). First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: A proof of concept for the wastewater surveillance of COVID-19 in the community. , 138764. Retrieved 2020-04-23, from `http://www.sciencedirect.com/science/article/pii/S0048969720322816` doi: 10.1016/j.scitotenv.2020.138764

Albert, R., & Barabsi, A.-L. (n.d.). Statistical mechanics of complex networks. , *74*(1), 47–97. Retrieved 2013-02-08, from `http://link.aps.org/doi/10.1103/RevModPhys.74.47` doi: 10.1103/RevModPhys.74.47

Baird, D., Christian, R. R., Peterson, C. H., & Johnson, G. A. (n.d.). Consequences of Hypoxia on Estuarine Ecosystem Function: Energy Diversion from Consumers to Microbes. , *14*(3), 805–822.

Bakewell, H. P., & Lumley, J. L. (n.d.). Viscous Sublayer and Adjacent Wall Region in Turbulent Pipe Flow. , *10*(9), 1880–1889. Retrieved 2019-02-11, from `https://aip.scitation.org/doi/10.1063/1.1762382` doi: 10.1063/1.1762382

Bakken, L. R., & Olsen, R. A. (n.d.). Buoyant Densities and Dry-Matter Contents of

Microorganisms: Conversion of a Measured Biovolume into Biomass. , *45*(4), 1188–1195. Retrieved 2016-08-05, from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC242437/

Balch, W. M., Bowler, B. C., Drapeau, D. T., Poulton, A. J., & Holligan, P. M. (n.d.). Biominerals and the vertical flux of particulate organic carbon from the surface ocean. , *37*(22), L22605. Retrieved 2015-06-24, from http://onlinelibrary.wiley.com/doi/10.1029/2010GL044640/abstract doi: 10.1029/2010GL044640

Barker, S., Slingsby, D., & Tilling, S. (n.d.). Teaching biology outside the classroom. , 14–19.

Bashir, M., Ahmed, M., Weinmaier, T., Ciobanu, D., Ivanova, N., Pieber, T. R., & Vaishampayan, P. A. (n.d.). Functional Metagenomics of Spacecraft Assembly Cleanrooms: Presence of Virulence Factors Associated with Human Pathogens. , 1321. Retrieved 2016-10-06, from http://journal.frontiersin.org/article/10.3389/fmicb.2016.01321/full doi: 10.3389/fmicb.2016.01321

Neuer, S., Iversen, M., & Fischer, G. (n.d.). The Ocean's Biological Carbon pump as part of the global Carbon Cycle. , *4*(4), 1–51. Retrieved 2020-03-20, from https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.4319/lol.2014.sneuer.miversen.gfischer.9 doi: 10.4319/lol.2014.sneuer.miversen.gfischer.9