New insights into carbon export and storage by the biological pump

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The biological pump transfers carbon from surface to deep ocean waters, thereby regulating the atmosphere-ocean partition of CO_2 and global climate. Two factors determine the magnitude of carbon storage by this pump: (i) the rate of particulate organic matter export from the surface layer, and (ii) the timescale of carbon sequestration in the ocean interior, which is governed by the depth of particle remineralization to CO_2. In this talk, I review recent insights that expand and revise our understanding of both carbon export and remineralization mechanisms.

Traditionally, the particulate carbon export flux is largely attributed to gravitational settling, yet observed settling rates are insufficient to balance mesopelagic carbon budgets or meet the energetic demands of the subsurface biota. Recently, a number of alternative export pathways have been identified that inject particles to depth, mediated either physically (e.g. by subduction and seasonal mixed layers) or biologically (e.g. by migrating zooplankton). Here I review the mechanisms that drive these "particle injection pumps" (PIPs), and quantify their contribution to deep ocean carbon storage by synthesizing numerous previous observations with new model calculations. I show that together the PIPs may sequester as much carbon as gravitational settling, due to their substantial export rates and their ability to inject particles to greater depth before remineralization begins.

Advances have also been made in our understanding of carbon remineralization depth and sequestration time, as the traditional statistical view of particle flux attenuation (i.e. the "Martin Curve") has been replaced by a new mechanistic view. Important mechanistic insights have been derived from remineralization tracers (e.g. nutrients and oxygen utilization), which offer wider spatial coverage than direct flux measurements, and integrate across temporal variations. These tracers reveal systematic variations in particle flux attunation, which is slowest in polar oceans and fastest in the oligotrophic subtropics. Here, I use particle models to elucidate the contribution of temperature, particle size, ballast, and oxygen to this pattern. Additionally, I use idealized model experiments to hypothesize changes in ocean carbon storage that might be expected in a warming and deoxygenating ocean.

I close this talk by identifying critical gaps in our understanding of carbon export and remineralization, and highlight the most promising approaches to resolve them.