Paired Perspectives on Global Change

Christine Laluet

The biological pump refers to a suite of biologically mediated processes that transport carbon from the ocean’s surface layer to its interior. Its efficiency depends on the balance between the rates of carbon photo-assimilation, export and mineralization. Our knowledge of the biological pump relies on the mechanistic understanding of factors controlling phytoplankton distributions and marine food webs, and the associated biochemical cycles. To assess the extent to which the strength and efficiency of this pump will change in the future, we need to know how these factors—light, nutrients and temperature—will change in a warmer ocean. Models coupling an ecosystem module to a global circulation model provide important tools for understanding the dynamics of the carbon pump and its response to warming. But as pointed out by Sarmento et al. (2004), existing tools are still not mature enough to allow this.

The last decade has seen increasing awareness of the relationship between key phytoplankton groups and their pivotal role for climate regulation: the biological oceanic carbon pump (e.g. Boyd et al. 2010). Until recently, the picture was of a simple subdivision between efficient carbon export via a diatom-coppepod-fish linear subdivision between efficient carbon export and nutrient retention by coccolithophores, with uncertain consequences for the efficiency of the biological pump. On the whole, the smallest phytoplankton seem to have a competitive advantage in a warmer ocean. In contrast, diatoms are at an advantage in surface waters with transient nutrient pulses. In particular, they will benefit in coastal regions from stronger wind-driven upwelling events that are expected from increased storm and frequency resulting from climate warming. Improving the evaluation of changes to the biological carbon pump via ocean models is currently hampered by several uncertainties on mechanisms controlling phytoplankton dominance and food-web structures. Also, many global circulation models remain coarse in resolution and don’t serve high frequency model outputs. In the Baltic Sea, the complexity in biology needs to be matched with an appropriate dynamic model. As indicated by the recent work of Cai et al. (2011), the increased nutrient load into the Baltic Sea (from 0.6 mg N L⁻¹ in 1970’s to 5.4 mg N L⁻¹ in 2000’s) will change the biological processes in the Baltic Sea. Changes in the productivity of the phytoplankton community will be reflected in the size structure of the zooplankton community.

The potential large ocean deoxygenation due to the increased temperature and stratification projected for a warmer ocean (Keeling et al. 2010) will have direct consequences for marine birds, but only an indirect effect on ocean productivity and nutrient and carbon cycling. An expansion of suboxic/anoxic conditions would increase the release of phosphate and iron from sediments while some active nitrogen would be eliminated by denitrification or anaerobic ammonia oxidation. The subsequent shift in the ocean nitrate-to-phosphate balance will affect the composition and productivity of marine organisms, notably diazotrophic cyanobacteria, with uncertain consequences for the efficiency of the biological pump. The potentially large ocean deoxygenation due to the increased temperature and stratification projected for a warmer ocean (Keeling et al. 2010) will have direct consequences for marine birds, but only an indirect effect on ocean productivity and nutrient and carbon cycling. An expansion of suboxic/anoxic conditions would increase the release of phosphate and iron from sediments while some active nitrogen would be eliminated by denitrification or anaerobic ammonia oxidation. The subsequent shift in the ocean nitrate-to-phosphate balance will affect the composition and productivity of marine organisms, notably diazotrophic cyanobacteria, with uncertain consequences for the efficiency of the biological pump.

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Figure 1: Summer conditions in the upper water layers of the North Atlantic (Cooltemperate region). The lower panel shows the climatological temperature and salinity fields for the region. The upper part shows the time series of phytoplankton biomass during the same period. Figure modified from Lin et al., 2003.

Changes in oceanic carbon storage have been hypothesized to be the cause of the ~100 ppm variations in atmospheric CO2 between glacial and interglacial periods (Raymo et al. 2000). If the ocean stores more carbon in colder than in warmer climates this implies that a positive feedback exists: as climate warms, the ocean releases carbon, which increases atmospheric CO2, and amplifies the original warming. However, presently we don’t know how much ocean carbon stores may change in the past and why.

Carbon isotope data from Last Glacial Maximum (LGM, 19-22 ka) sediments indicate that more carbon was stored in the deepest ocean layers, particularly in the Atlantic (Fig. 1). δ13C is fractionated during carbon uptake by phytoplankton, which favors the light isotope 13C. Its distribution in the deep ocean is therefore determined to a large degree by the efficiency of the biological pump, carbon uptake rates of carbon photo-assimilation, export and mineralization. Our knowledge of light, nutrients and temperature – the factors controlling the biological carbon pump – is still not mature enough to allow this. During deep ocean warming events that are expected from increased storm and frequency resulting from climate warming, improving the evaluation of changes to the biological carbon pump via ocean models is currently hampered by several uncertainties on mechanisms controlling phytoplankton dominance and food-web structures. Also, many global circulation models remain coarse in resolution and don’t serve high frequency model outputs. In the Baltic Sea, the complexity in biology needs to be matched with an appropriate dynamic model. As indicated by the recent work of Cai et al. (2011), the increased nutrient load into the Baltic Sea (from 0.6 mg N L⁻¹ in 1970’s to 5.4 mg N L⁻¹ in 2000’s) will change the biological processes in the Baltic Sea. Changes in the productivity of the phytoplankton community will be reflected in the size structure of the zooplankton community.

The efficiency of plankton to use nitrate and phosphate may have been enhanced by more iron input to the surface ocean by dust deposition (Brovkin et al., 2007, estimate 37 ppm). A giant dust plume from Patagonia may partly explain lower 13C in Southern Atlantic bottom waters but the increase in aeolian iron input may have been counteracted by a decrease in sedimentary sources due to lower sea level (Moore and Braucher 2008). It is also possible that the biologically active nitrogen inventory of the glacial ocean was overall larger than today because denitrification was lower due to higher dissolved oxygen concentrations in the colder glacial ocean and reduced continental shelf area due to the sea level drop. However, these processes have not been quantified yet with a realistic 3-dimensional model.

Some or all of the processes that control changes in the glacial-interglacial ocean carbon storage may also be important for our warming planet. Decreased CO2 solubility in a warming ocean will certainly occur. However, how important some of the other processes will be in the future is more uncertain. Better understanding of how and why ocean carbon storage varied in the past and in the future may now be possible due to coordinated international modeling projects and efforts to synthesize and increase the spatial coverage of paleodatume.

Selected references


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Marine nutrient cycling - How will the ocean's capacity of biological carbon pumping change?

Andreas Schmittner

College of Oceanic and Atmospheric Sciences, Oregon State University, USA; aschmitt@coas.oregonstate.edu

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