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Diatoms in a future ocean: stirring it up

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A recent review by Falkowski and Oliver[1] argues that coccolithoforid algae and possibly cyanobacteria and other pico and nanoplankton should dominate the upper mixed layer of the open ocean in the future. A scenario with increased ocean temperature would result in larger water column stability and reduced turbulent mixing that consequently would reduce the input of inorganic nutrients from the deep ocean. This situation favours the growth of small plankton with high surface to volume ratios over larger organisms such as diatoms. I contend here that there are enough other factors to consider that renders the prediction of a generalised pico and nanoplankton ocean uncertain.

Let me first consider the assumption that a future upper open ocean will become more stabilised. Air temperature is increasing to an even larger extent than ocean water temperature[2]. Consequently, larger water vapour in the atmosphere more likely than not increases storm frequency and intensity. Wind and storm events that temporarily increase turbulence in the upper mixed layer, pulsing nutrients into the euphotic zone, are the ideal growth conditions for diatoms. But changes in predominance of one type of life form *sensu* Margalef[3] over an annual cycle are hard to predict. It boils down to a trade off between an overall water column stabilisation and an increase in destabilisation events. The uncertainty is large. Regionally, the global warming trend is melting large areas of the Arctic, greatly reducing the summer ice-covered area. Just in summer 2007, the Arctic ice-free area was over 10^6 km^2 larger than the previous record of 2005[4]. This exposes large areas of the ocean to high wind energy inputs that should favour organisms such as diatoms. In addition, the differential warming between the poles and the equator seems to intensify the westerlies[5], entraining further mechanical energy into the upper ocean. It is clear that when not only the water warming trends are considered, future oceanic conditions do not seem unfavourable for diatoms.

Let me now assume that the increase in upper ocean temperature would indeed result in a stronger thermal stratification and an average higher stability of the water column. The average nutrient availability from deep waters is reduced. Our current tropical oceans are templates of this situation with development of deep chlorophyll maxima (DCM) where enough nutrients meet sufficient radiation energy. Modelling shows that the reduced vertical diffusivity in the water column results in a more fluctuating nutrient field near the DCM and an increase in the diversity of organisms[6]. This is because of mismatches between vertical settling rates of particulate organic matter and upward flow velocities. It also explains the increase in diatom diversity with increasing temperature observed in the

geological record shown by Falkowski and Oliver[1], and contradicts the conclusion that diatoms are "losers" in such a situation.

In ocean areas of high nutrient-low chlorophyll (HNLC), the export production after the pulsed addition of iron, which could represent an aeolian micronutrient input, is inversely related to the depth of the wind-mixed layer[7]. Diatoms take advantage of such pulsed conditions and are also primarily responsible for export because of their heavy silicate frustules. A shoaling of the mixed layer in the vast HNLC areas, punctuated by micronutrient pulses, should then increase the export of organic matter to the deep ocean. This would reduce the excess atmospheric CO_2, resulting in a negative feedback that would alleviate further temperature rises. Whether pulsing events or background stability would dominate the budget at annual scales, and consequently the relative importance of diatoms, is again uncertain.

Thus, fluctuations or pulses caused by meteorological fronts, storms or aeolian inputs, expected to increase in a global warming scenario, have to be considered as drivers in the open ocean. Diversity should increase if such fluctuations can be considered as system disturbances of the right frequency[8,9]. Overall, future open ocean scenarios do not point towards a decrease in the predominance of diatoms.

References

[1]Falkowski, P.J., Oliver M.J. 2007. Mix and match: how climate selects phytoplankton. *Nat Rev Microbiol*. **5**: 813-819.

[2]Solomon, S. *et al.* (eds.). 2007. IPCC, 2007: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, N.Y., USA, 996 pp.

[3]Margalef, R. 1978. Life forms of phytoplankton as survival alternatives in an unstable environment. *Oceanologica Acta*. **1**: 493-509.

[4]Cressey, D. 2007. Arctic melts opens Northwest passage. *Nature*. **449**: 267-267.

[5]Toggweiler, J.R., Russell, J. 2008. Ocean circulation in a warming climate. *Nature*. **451**: 286-288.

[6]Huisman, J.,Pham Thi, N.N., Karl, D.M., Sommeijer, B. 2006. Reduced mixing generates oscillations and chaos in the oceanic deep chlorophyll maximum. *Nature*. **439**: 322-325.

[7]Boyd, P.W. *et al.* 2007. Mesoscale Iron Enrichment Experiments 1993–2005: Synthesis and Future Directions. *Science*. **315**: 612-617.

[8]Sommer, U. 1995. An experimental test of the intermediate disturbance hypothesis using cultures of marine phytoplankton. *Limnol Oceanogr*. **40**: 1271-1277.

[9]Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. *Science*. **129**: 1302-1310.

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