Simulated 21st century's increase in oceanic suboxia by CO_2-enhanced biotic carbon export

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At depths between several tens and hundreds of meters, large parts of the tropical oceans are poorly supplied with dissolved oxygen, and are therefore hostile to most marine life. Using a global biogeochemical model, we found that emission-stimulated increases in the carbon content of marine organic matter might lead to a further depletion of oxygen in tropical oceans.

Scientific Highlights

The primary impacts of anthropogenic CO_2 emissions on marine biogeochemical cycles predicted so far include ocean acidification, global-warming induced shifts in biogeographical provinces, and a possible negative feedback on atmospheric CO_2 levels by CO_2-fertilized biological production. In a modelling study we reported a new potentially significant impact on the oxygen minimum zones of the tropical oceans. Using a model of global climate, ocean circulation and biogeochemical cycling, mesocosm-derived experimental findings of a pCO_2-sensitive increase in biotic carbon-to-nitrogen (C:N) drawdown were extrapolated to the global ocean. For a simulation run from the onset of the industrial revolution until A.D. 2100 under a "business-as-usual" scenario for anthropogenic CO_2 emissions, the model predicts a negative feedback on atmospheric CO_2 levels, which amounts to 34GtC by the end of this century. While this represents only a relatively small alteration of the anthropogenic perturbation of the carbon cycle to be expected, the model results reveal a dramatic 50% increase in the suboxic water volume by the end of this century in response to the respiration of excess organic carbon formed at higher CO_2 levels. This represents a significant expansion of the marine "dead zones" with severe implications not only for all higher life forms, but also for oxygen-sensitive nutrient recycling and hence for oceanic nutrient inventories.

A special feature of today's marine oxygen distribution is the presence of extended oxygen minimum zones in the tropical oceans, with suboxic conditions at relatively shallow depths from several tens to hundreds of meters (Figure 1). Besides providing a hostile environment for almost all marine life, these regions are of particular biogeochemical relevance because they allow for anaerobic conversion of fixed nitrogen, a major nutrient essential for biological production, into gaseous N_2 not accessible to most organisms. Sediment records provide evidence that the regional patterns of this oxygen-sensitive nutrient loss have varied on millennial and longer time scales in the past, in concert with changes in the extent of the suboxic ocean areas. Such changes can be driven by variations in biotically controlled local remineralization and associated oxygen

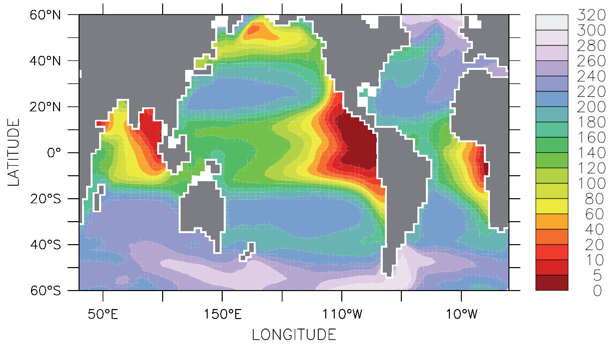

Figure 1: Dissolved oxygen at 300m depth as simulated by the model for year 2100. Units are µmol/kg.

consumption, or by changes in the physical oxygen supply via circulation and temperature-dependent oxygen solubility.

Using a coupled carbon-climate model, the new study suggests that circulation changes expected under a business-as-usual CO_2 emission scenario have relatively little impact on the extent of the oxygen minimum zones. Although warming and reduced ventilation of deep waters lead to a reduction of the overall oceanic oxygen content by about 5% by the end of the 21st century, the volume of the oxygen minimum zones changes relatively little unless possible changes in the marine biology are taken into account. The new study focuses on changes in the ratio of carbon-to-nitrogen drawdown by marine algal blooms, which was observed in recent mesocosm experiments run under different atmospheric CO_2 levels (Riebesell et al., 2007). Based on these experimental

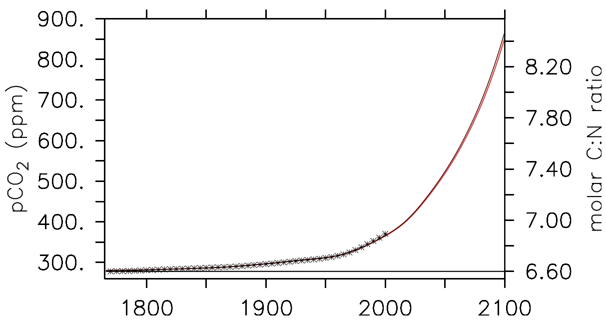

Figure 2: Simulated (lines) and observed (crosses) annual mean atmospheric pCO_2 (left axis). The red curve is for the model with molar C:N varying as a function of pCO_2 according to the right axis. The thin black line just above the red line is pCO_2 simulated by the control run with constant molar C:N=6.6.

results, we assumed that the C:N ratio of organic matter exported from the surface ocean is proportional to the atmospheric CO_2 concentrations simulated by the coupled carbon-climate model (Figure 2).

The inclusion of pCO_2-sensitive C:N ratios has only limited impact on simulated atmospheric CO_2 levels. The enhanced biological carbon drawdown and export lowers atmospheric pCO_2 predicted for the year 2100 by merely 15µatm from 866µatm in the constant C:N run to 851µatm in the pCO_2-sensitive C:N run (Figure 2). This corresponds to an additional oceanic uptake of 34GtC by the year 2100 and thus represents a negative feedback in the anthropogenically perturbed climate system. While this is significant with respect to CO_2 natural changes, including glacial-interglacial swings, the magnitude of this feedback effect is small in terms of the ongoing anthropogenic perturbation, and the difference in atmospheric CO_2 between the two model runs is barely visible in Figure 2.

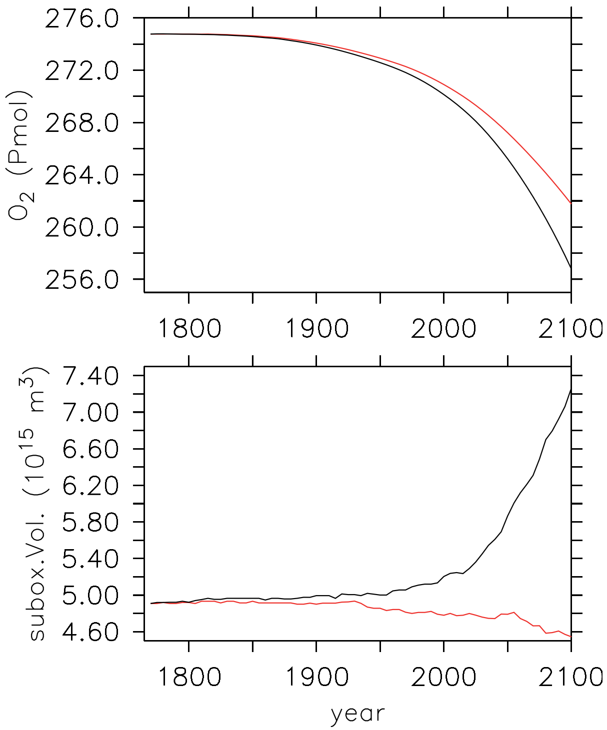

Figure 3: Simulated marine oxygen inventory (top) and suboxic volume (bottom) as a function of time. Black curves are for the model run with constant C:N ratios, red curves for the new run with pCO_2-sensitive C:N ratios.

In contrast to the relatively small impact on atmospheric CO_2, the inclusion of pCO_2-sensitive C:N ratios turns out to generate more dramatic changes in the oxygenation state of the tropical thermocline. Here, our model switches from a net oxygen gain under constant Redfield stoichiometry to a net oxygen loss by the end of this century when C:N ratios increase with pCO_2. Overall, the volume of suboxic waters increases by about 50% until A.D. 2100 in the model run with pCO_2-sensitive stoichiometry (Figure 3). Our model results suggest that relatively small changes in the C:N ratio of organic matter can have profound impacts on the extent of the ecologically and biogeochemically relevant oxygen minimum zones on surprisingly short time scales of decades to centuries. Because of the immediate response of oxygen-sensitive losses of fixed nitrogen, the view of a homeostatic nitrogen cycle may not be anymore appropriate as we move from predominantly astronomical to anthropogenic climate forcing in the 21st century.

References:

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