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The conundrum of marine oxygen: why is the future ocean loosing oxygen despite declining export production?

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The current generation of climate models leaves us with a conundrum. On the one hand, the models project a decline of the export of organic matter from the surface ocean and a decline in biological oxygen consumption in the ocean interior, which should be consistent with an increase of the ocean's oxygen content. On the other hand, they project an increase in apparent oxygen utilization (AOU), an explanation of a large share of the overall loss of marine oxygen in the same models. A decrease of the export of organic matter and an increase of its degradation product (the oxygen debt, i.e. AOU) appears contradictory.

Using a global ocean biogeochemical model we quantify how aerobic respiration (oxygen utilization per time) is translated into its respective storage product (AOU) and find large regional variations and different depth dependencies of the respective storage-to-respiration ratio. We designed idealised model tracers accumulating AOU from the degradation of organic matter stemming from predefined ocean regions. By combining a large number of regional/depth specific AOU tracers, we can resolve the regional and depth specific variations of the storage-to-respiration ratio.

Dividing the ocean into 20 latitudinal zones, we find that the storage-to-export ratio in the Southern Ocean is 10 times larger than in the subtropics. Using one AOU tracer per 2.8x2.8 degree area (the horizontal resolution of our model) increases the spread of regional storage-to-export ratio again by a factor of 10. We finally quantify how oxygen consumption in different depth layers contributes to global AOU. 90% of the integrated respiration takes place in the upper 1000m, but only 37% of global AOU originates from there. About 44% of the global AOU is associated with about 4% of global respiration, which takes place in the deep ocean below 2000m. The horizontally averaged storage-to-respiration ratio increases with depth; it is 16 times larger in the deepest model layers than the global mean.

The observed regional decoupling between the driving force of the biological carbon pump (export) and its imprint (storage of degradation products) is key to understand why future ocean projections often find an increase in global AOU (ocean deoxygenation) with a concomitant decrease in export production.

Position

Senior Scientist

Affiliation

GEOMAR, Biogeochemical Modelling

Email Address

Düsternbrooker Weg 20, 24105 Kiel

Are you a SFB 754 / Future Ocean member?

Yes

Primary author(s) : KOEVE, Wolfgang (GEOMAR, Biogeochemical Modelling); KÄHLER, Paul (GEOMAR, Scientist); Dr LANDOLFI, Angela (GEOMAR, Biogeochemical Modelling); Prof. OSCHLIES, Andreas (Helmholtz-Zentrum für Ozeanforschung Kiel (GEOMAR))

Presenter(s) : KOEVE, Wolfgang (GEOMAR, Biogeochemical Modelling)

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