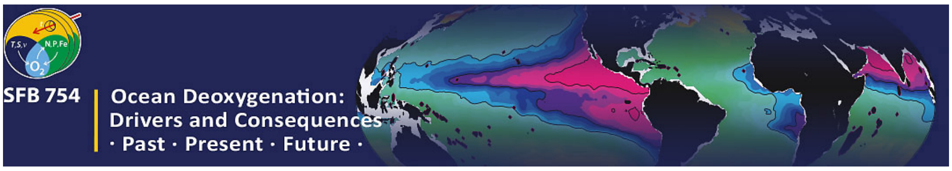

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Ocean deoxygenation and N2O emissions projected in multi-millennial global warming simulations

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We investigate century and multi-millennial scale changes in marine oxygen (O2), marine emissions of nitrous oxide (N2O), warming, and compound hazard in terms of metabolic conditions for a range of temperature targets, including those mentioned in the Paris Agreement. Scenarios, where radiative forcing is stabilized by 2300, are used in ensemble simulations with the Bern3D Earth System Model of Intermediate Complexity. We attribute the contributions of O2 changes from changes in solubility, and the interplay of ocean biology and ventilation by carrying four explicit O2 tracers and an ideal age tracer. Transiently, the global mean ocean oxygen concentration decreases by a few percent under low and by 40% under high forcing. Deoxygenation peaks about thousand years after stabilization of radiative forcing and new steady state conditions establish after AD 8000 in our model. Hypoxic waters expand over the next millennium and recovery is slow and remains incomplete under high forcing. The equilibration timescale of oceanic oxygen is therefore longer than the thermal equilibration timescale of both the atmosphere (~1000 years) and the ocean (~4000 years). The changes in O2 strongly correlate with water mass age, linked to changes in Indo-Pacific and Atlantic overturning, and are also impacted by gradual oxygen loss due to warming. Distinct and close to linear relationships between the equilibrium temperature response and marine O2 loss emerge. For example in the upper ocean, the decline of a metabolic index, quantified by the ratio of O2 supply to an organism's O2 demand, is reduced by 6.2% per degree of avoided equilibrium warming. Measures of peak hypoxia exhibit a strong sensitivity to additional warming. Volumes of water with less than 50 microM O2, for instance, increase between 36% to 76% per degree warming. Turning to N2O, surface and deep ocean N2O observations constrain N2O production from nitrification and denitrification to 4.5 (3 – 6.1) TgN per year in our model. The modelled changes in physical transport, oxygen concentrations and organic matter remineralization affect N2O production, consumption and emissions. Under high forcing, N2O production decreases by about 8% over this century due to decreasing organic matter export and remineralization. Thereafter, production increases slowly by about 20% due to widespread deoxygenation and high remineralization, and enhanced emission lead to a small positive N2O-climate feedback. Our simulations reveal a tight coupling between marine physical changes, the carbon cycle, O2, N2O and climate change and long time scales of key ocean processes.

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