Small scale oxygen heterogeneity enhances nitrogen cycling and nitrous oxide production in oxygen minimum zones

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Oxygen variability in the suboxic range shapes the cycles of nitrogen and other elements in the ocean's oxygen minimum zones (OMZs). This variability stems from the turbulent nature of the oceanic circulation, which includes mesoscale eddies, jets, and submesoscale currents. Here, we use a suite of numerical models to investigate the effects of small-scale oxygen heterogeneity on the pathways and magnitude of nitrogen transformation in OMZs, including denitrification, anammox and nitrous oxide production. We build a mechanistic model that represents known nitrogen transformations and their sensitivity to oxygen and other substrates, using environmental dependencies that reflect known microbial processes. We optimize the model in a one-dimensional framework, by using a combination of tracer concentration and rate measurements. We incorporate the optimized solution into a suite of increasingly higher resolution numerical simulations of the Pacific Ocean, which resolve the variability and chemical heterogeneity of OMZs driven by eddies and fine scale circulation. We show that interaction of aerobic and anaerobic processes at the OMZ boundaries enhances the rates of anammox, nitrite re-oxidation, and nitrous oxide production. We further show that denitrification is a major source of nitrous oxide production, both in the ocean interior and near coastal upwelling systems, where a direct conduit for atmospheric outgassing exists. Finally, we speculate on the role of a different source of chemical heterogeneity on the nitrogen cycle, namely, micro-scale redox gradients within organic aggregates sinking through low oxygen waters.