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Physical and biogeochemical controls on dissolved oxygen in coastal upwelling systems: insights from a low complexity coupled model

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The global oceanic oxygen content decline, especially marked in coastal and shelf regions, has been attributed to intricate biological and physical factors. Eastern-boundary upwelling systems are particularly vulnerable to deoxygenation due to the highly productive upper ocean ecosystem and to physical transport bringing low oxygen levels from subsurface open ocean waters. Despite commonalities, the oxygenation states of upwelling systems worldwide are not comparable but the reasons behind these discrepancies remain puzzling. Here we develop a low complexity biogeochemical model simulating Oxygen-Phytoplankton-Zooplankton (OPZ) to better understand the causes of these different responses at short time-scales. After studying the stability and sensitivity of the OPZ model in 0-dimension, we extended the model formulation to the water column by including additional processes such as air-sea exchange and light dependency. By comparing two 1-dimensional configurations mimicking an oxygenated and a non-oxygenated upwelling systems, we gain insights into the processes controlling the vertical distribution of oxygen. The OPZ model was then coupled with the ROMS hydrodynamical model to build a 3-dimensional configuration of an idealized coastal upwelling system forced by upwelling-favorable wind stress. It forces the surfacing of cold, nutrient-rich waters promoting phytoplankton growth and oxygen production by photosynthesis nearshore. The unstable front generates a field of mesoscale and submesoscale turbulence that controls the stirring of dissolved oxygen which is redistributed across the shelf. While the upwelling circulation results in oxygenated waters inshore and depleted waters offshore the front, small-scale turbulence tends to homogenize this gradient by transporting oxygen-rich submesoscale filaments. Oxygen dynamics in coastal upwelling is sensitive to wind regime and phytoplankton growth rate. Our coupled model results suggest that sustained upwelling lowers the enrichment rate due to continuous low oxygen injection from below; conversely, a wind relaxation period following an upwelling event increases the enrichment rate due to the cessation of low oxygen input, allowing photosynthesis to replenish the oxygen levels. Changes in the phytoplankton growth rate substantially reduce the rates of oxygen enrichment due to strong non-linear interactions between biological and physical factors. On-going work aims at further disentangling those complex processes to better understand how they control dissolved oxygen variability.