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Investigating Spatial Controls on Ocean Oxygenation Dynamics

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Marine habitability for aerobic life requires the supply of dissolved oxygen and nutrients. However, the transition to an oxygenated atmosphere and ocean on Earth was a long-term, spatially uneven process affected by physiography and both local- and global-scale changes. Ocean O_2 dynamics include local O_2 production and consumption as well as the global-scale circulation of dissolved O_2 to the ocean interior. Oxygen production by photosynthesis on local scales depends on nutrients and can be limited by the presence of alternative electron donors—namely ferrous iron and sulfide—the distributions of which could impact globally integrated O_2 production and net accumulation under an anoxic atmosphere. Simultaneously, continental configuration is a first-order control on planetary ocean circulation and hence nutrient transport and ocean redox. Thus, circulation patterns defined by landmasses can directly shape patterns of primary productivity and the oxygenation state of ocean basins, impacting global O_2 production and habitats for aerobic life.

We use an atmospheric GCM (ExoPlaSim) and a 3D Earth system model (cGEnIE) to simulate a large ensemble of randomized continental configurations, and explore the impact of changing continental distribution on ocean oxygenation state. We find that continents drastically change the spatial patterns of upwelling and deep-water formation, which respectively control surface primary productivity and dissolved O_2 in the deep ocean. Importantly, varying continental distribution alone is capable of generating widespread ocean anoxia, and poorly oxygenated ocean states are possible even under modern levels of atmospheric O_2. We also suggest that spatial heterogeneity in marine redox impacts net surface O_2 production and may control the likelihood of an oxygenation event. Finally, we discuss the range of planetary landscapes most favorable to surface oxygenation.