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Intensification and deepening of the Arabian Sea Oxygen Minimum Zone in response to increase in Indian monsoon wind intensity

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The decline in oxygen supply to the ocean associated with global warming of sea-surface temperatures is expected to expand the oxygen minimum zones (OMZs). This global trend can be attenuated or amplified by regional processes. In the Arabian Sea, the World's thickest OMZ is highly vulnerable to changes in the Indian monsoon wind. Evidence from paleo records and future climate projections indicate strong variations of the Indian monsoon wind intensity over climatic timescales. Yet, the response of the OMZ to these wind changes remains poorly understood and its amplitude and timescale unexplored. Here, we investigate the impacts of perturbations in Indian monsoon wind intensity (from -50% to +50%) on the size and intensity of the Arabian Sea OMZ, and examine the biogeochemical and ecological implications of these changes. To this end, we conducted a series of eddy-resolving simulations of the Arabian Sea using the Regional Oceanic Modeling System (ROMS) coupled to a nitrogen based Nutrient-Phytoplankton-Zooplankton-Detritus (NPZD) ecosystem model that includes a representation of the O_2 cycle. We show that the Arabian Sea productivity increases and its OMZ expands and deepens in response to monsoon wind intensification. These responses are dominated by the perturbation of the summer monsoon wind, whereas the changes in the winter monsoon wind play a secondary role. While the productivity responds quickly and nearly linearly to wind increase (i.e., on a timescale of years), the OMZ response is much slower (i.e., a timescale of decades). Our analysis reveals that the OMZ expansion at depth is driven by increased oxygen biological consumption, whereas its surface weakening is induced by increased lateral ventilation. The enhanced lateral ventilation favors episodic intrusions of oxic waters in the lower epipelagic zone (100-200m) of the western and central Arabian Sea, leading to intermittent expansions of habitats and a more frequent alternation of hypoxic and oxic conditions there. The increased productivity and deepening of the OMZ also lead to a strong intensification of denitrification at depth, resulting in a substantial amplification of fixed nitrogen depletion in the Arabian Sea. We conclude that changes in the Indian monsoon can affect, on longer timescales, the large-scale biogeochemical cycles of nitrogen and carbon, with a positive feedback on climate change in the case of stronger winds.