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Dynamics of oxygen-deficient zones and the marine nitrogen cycle during the warm Miocene

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Modern oceans host extensive oxygen-deficient zones (ODZs, dissolved $[O_2] < 5$ μmol kg^{-1}) in the Pacific, where water-column denitrification is intense, but virtually none in the Atlantic. Although global warming is generally expected to reduce global mean ocean $[O_2]$ and expand ODZs, observations from the warm Miocene instead suggest a contraction of Pacific ODZs and weaker water-column denitrification. The mechanisms underlying these Miocene changes remain unclear. Here we use two independent Earth system models to diagnose ODZ and nitrogen-cycle dynamics under Miocene boundary conditions. Both models simulate an initial decrease in global mean $[O_2]$, followed by a net increase in $[O_2]$ over multi-millennial timescales. Regionally, the Pacific ODZ contracts while the Atlantic ODZ expands, likely driven by paleogeographic changes associated with opening of the Central American Seaway that altered ocean circulation and nutrient pathways. In contrast, changes in atmospheric CO_2 exert a comparatively minor influence on ODZ changes.