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Exploring the Marine Methane Paradox in a Data-assimilation Model

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Methane is a potent greenhouse gas that has been accumulating rapidly in the atmosphere due to anthropogenic emissions. At the same time, a wide range of natural methane sources are susceptible to perturbation driven by on-going environmental changes. The global ocean is one such source, accounting for up to 10% of all natural methane emissions. While marine emissions largely occur in coastal regions where sediment-sourced methane reaches the surface, open ocean surface waters are also ubiquitously supersaturated with methane driving a diffusive flux to the atmosphere. This implies that widespread methane production occurs in-situ within oxygenated surface waters, which is referred to as the marine methane paradox because aerobic methanogenesis pathways remain poorly understood. We developed a global model of the marine methane cycle that includes the major sources and sinks of CH_4 in the open ocean: equilibration with the changing atmospheric concentration, microbial oxidation, benthic sources, and biological production in surface waters. The production term was parameterized to test a range of hypothesized methanogenesis pathways, including egestion from zooplankton digestive tracts, bacterial degradation of methylphosphonate (MPn), leakage from organic aggregates, and production during phytoplankton growth. Transect data from the MEMENTO archive were then assimilated to constrain parameters and determine the methane production pattern that is most consistent with observations. Our model demonstrates that with no in-situ methane production, surface methane concentrations are underestimated, especially throughout the low-latitude ocean. To best reproduce the observations, our model links production rates to phosphate scarcity and dissolved organic carbon accumulation, supporting the MPn hypothesis and concentrating methanogenesis between 0-500m depth in the subtropics. Our results suggest that biological methane production in open ocean surface waters and marine methane emissions to the atmosphere may increase over the next century as nutrient limitation intensifies in response to ocean stratification.