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Gene-based modeling of methane oxidation in coastal sediments: constraints on the efficiency of the microbial methane filter

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Microbial-mediated methane (CH_4) oxidation strongly regulates the release of CH_4 from aquatic systems to the atmosphere. Coastal sediments are typically characterized by high rates of CH_4 production but generally release little CH_4 because of efficient sedimentary CH_4 oxidation. This CH_4 oxidation is predominantly coupled to oxygen and sulfate reduction. The quantitative role of other electron acceptors, such as iron and manganese oxides, is largely unknown.

Here, we present a reactive transport model (RTM) for sediment CH_4 dynamics that includes geochemical and microbial dynamics to assess the microbial constraints on the efficiency of sedimentary CH_4 oxidation under transient scenarios. We applied this RTM to a data set for a brackish coastal site with oxic bottom waters and sediment that is rich in CH_4 and metal oxides. With the RTM we show that upto 10% of the CH_4 produced in the sediment is oxidized by metal oxides while the remainder is removed through oxidation with oxygen and sulfate. We also show that in-situ cell specific rates and doubling times for CH_4-oxidizing micro-organisms ultimately determine the efficiency of the microbial CH_4 filter. In the model, the slow growth rate of anaerobic CH_4 oxidizing microbes limits the ability of the microbial CH_4 filter to quickly adjust to transient changes at the sediment-water interface, thereby leading to periodic benthic release of CH_4. A sensitivity analysis shows that the capacity of sediments to oxidize CH_4 deteriorates upon environmental perturbations such as deoxygenation and eutrophication. As a consequence, oxidation of CH_4 in the water column will become increasingly important for the mitigation of CH_4 release from aquatic systems to the atmosphere in the future.