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A novel 1D thermo-hydro-biogeochemical hydrate model to assess the full benthic environmental impact of methane gas hydrate dissociation

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Large quantities of methane (CH_4) are stored in gas hydrates at shallow depths within marine sediments. These reservoirs are highly sensitive to ocean warming and if destabilized could lead to significant CH_4 release and global environmental impacts. However, the existence of such a positive feedback loop has recently been questioned as efficient CH_4 sinks within the sediment-ocean continuum likely mitigate the impact of gas hydrate-derived CH_4 emissions on global climate. In particular, benthic anaerobic oxidation of methane (AOM) represents an important CH_4 sink capable of completely consuming CH_4 fluxes before they reach the seafloor. However, the efficiency of this benthic biofilter is controlled by a complex interplay of multiphase methane transport and microbial oxidation processes and is thus highly variable (0-100%). In addition, AOM potentially enhances benthic alkalinity fluxes with important, yet largely overlooked implications for ocean pH, saturation state and CO_2 emissions. As a consequence, the full environmental impact of hydrate-derived CH_4 release to the ocean-atmosphere system and its feedbacks on global biogeochemical cycles and climate still remain poorly quantified. To the best our knowledge, currently available modelling tools to assess the benthic CH_4 sink and its environmental impact during hydrate dissociation do not account for the full complexity of the problem. Available codes generally do not explicitly resolve the dynamics of the microbial community and thus fail to represent transient changes in AOM biofilter efficiency and windows of opportunity for CH_4 escape. They also highly simplify the representation of multiphase CH_4 transport processes and gas hydrate dynamics and rarely assess the influence of hydrate-derived CH_4 fluxes on benthic-pelagic alkalinity and dissolved inorganic carbon fluxes. To overcome these limitations, we have developed a novel 1D thermo-hydro-biogeochemical hydrate model that improve the quantitative understanding of the benthic CH_4 sink and benthic carbon cycle-climate feedbacks in response to methane hydrate dissociation caused by temperature and sea-level perturbations. Our mathematical model builds on previous thermo-hydraulic hydrate simulators, expanding them to include the dominant microbial processes affecting CH_4 fluxes in a consistent and coupled mathematical formulation. The micro-biogeochemical reaction network accounts for the main redox reactions (i.e., aerobic degradation, organoclastic sulphate reduction

(OSR), methanogenesis and aerobic-anaerobic oxidation of methane (AeOM-AOM)), carbonate dissolution/precipitation and equilibrium reactions that drive biogeochemical dynamics in marine hydrate-bearing sediments . In particular, the AOM rate is expressed as a bioenergetic rate law that explicitly accounts for biomass dynamics. Finally, the model allows tracking the carbon isotope signatures of all dissolved and solid carbon species. In this talk we will present the model structure for the multiphase-multicomponent hydrate system, describe the specific constitutive and reaction equations used in the formulation, discuss the numerical strategy implemented and illustrate the potential capabilities of the model.