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Response of the benthic methane cycle to climate variability: insights from reaction–transport simulations

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Methanogenesis by microorganisms within anoxic sediments is a very slow process of CH4 production. Yet, over thousands or millions of years methanogenesis has resulted in vast CH4 accumulation, either dissolved in the interstitial water, in the form of gas bubbles, or condensed as gas hydrates (Buffett and Archer, 2004). On a global scale, sediments are thus the largest methane reservoir on Earth (Buffett and Archer, 2004), and they may exert a significant influence on the carbon cycle and Earth climate. For instance, CH4 release due to destabilization of gas hydrates has resulted in significant increases in atmospheric CH4 concentration during Earth's history (e.g. Dickens, 2003). Geochemical and microbiological evidence, together with mass balance calculations, nonetheless suggest that currently, up to 90% of the methane produced globally in marine sediments is consumed in situ before reaching the seafloor by the biogeochemical process of anaerobic oxidation of methane (AOM). Yet, the extent to which the efficiency of this methane sink could be affected by climate change remains essentially unknown.

This contribution reviews how recent model developments, including improved representations of the physical, chemical and biological components of the benthic system, have led to novel insights into the transient response of the benthic methane cycle at the centennial timescale. Reactive-transport model simulations combined with high resolution data are used to quantify present-day rates of methanogenesis and methanotrophy in shelf sediments where free methane gas is widespread. Results reveal that in passive sediments AOM is currently a very efficient subsurface barrier against both the aqueous and gaseous methane flux migrating towards the seafloor. Numerical experiments are then carried out to forecast the evolution of the methane cycle over the next century, triggered by changes in climate. Simulations predict that the gaseous methane inventory will increase, but the extent to which this will conduct to an enhanced flux to the atmosphere remains uncertain. Finally, we investigate the response of the AOM subsurface barrier to changes in upward methane flux induced by, e.g., climate-induced destabilization of gas-hydrates. Here, we show that the kinetic response of the microbial ecosystem is most likely too slow to cope with the sudden methane substrate supply and could lead to a significant transient efflux of methane from the sediment to the ocean-atmosphere system.

References:

Buffett, B., Archer, D. (2004). Global inventory of methane clathrate: sensitivity to changes in the deep ocean. Earth and Planetary Science Letters 227:185–199.

Dickens, G.R. (2003). Rethinking the global carbon cycle with a large, dynamic and microbially mediated gas hydrate capacitor. Earth and Planetary Science Letters 213:169–183.