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Methane release from the East-Siberian Arctic Shelf and its connection with permafrost and hydrate destabilization: First results and potential future developments

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The East Siberian Arctic Shelf (ESAS) is home to the world's largest hydrocarbon stocks, which consist of natural gas, coal bed methane (CH4), and shallow Arctic hydrates. Until recently, the ESAS was not considered a CH4 source due to the supposed impermeability of sub-sea permafrost, which was thought to completely isolate the CH4 beneath from modern biogeochemical cycles. However, the ESAS represents an enormous potential CH4 source that could be responsive to ongoing global warming. Such response could occur in substantially shorter time than that of terrestrial Arctic ecosystems, because sub-sea permafrost has experienced long-lasting destabilization initiated by its inundation during the Holocene ocean transgression. ESAS permafrost stability and integrity is key to whether sequestered ancient carbon escapes as the potent greenhouse gas CH4. Recent data suggest the sub-sea permafrost is currently experiencing significant changes in its thermal regime. For example, our recent data obtained in the ESAS during the drilling expedition of 2011 showed no frozen sediments at all within the 53 m long drilling core at water temperatures varying from -0.6°C to -1.3°C.

Unfrozen sediments provide multiple potential CH4 migration pathways. We suggest that open taliks have formed beneath the areas underlain or influenced by the nearby occurrence of fault zones, under paleo-valleys, and beneath thaw lakes submerged several thousand years ago during the ocean transgression. Temporary gas migration pathways might occur subsequent to seismic and tectonic activity in an area, due to sediment settlement and subsidence; hydrates could destabilize due to development of thermokarst-related features or ice-scouring. Recently obtained geophysical data identified numerous gas seeps, mostly above prominent reflectors, and the ubiquitous occurrence of shallow gas-charged sediments containing numerous gas chimneys, underscoring the likelihood that the ability of sub-sea permafrost to capture CH4 released from the seabed is failing.

Available data suggest the ESAS sub-sea permafrost is currently leaking a substantial amount of CH4. We propose that a few different types of CH4 exist, and are becoming involved in the modern carbon cycle due to permafrost destabilization in the ESAS: modern biogenic CH4 produced from ancient substrate, relatively old biogenic CH4 mobilized from hydrate deposits, and old thermogenic CH4 accumulated within seabed deposits. Isotopic data obtained by sampling CH4 in the water column and atmospheric CH4 in close proximity to the sea surface confirm the contribution from different sources, and demonstrate that the isotopic signature of CH4 from the ESAS can be used to create an interpretive plot for defining hydrates. CH4 fluxes could occur as numerous weak seeps, as large areas of strong bubble plumes, or as sites where CH4 releases are flare- or torch-like and the emissions are non-gradual. Due to the shallow and oligotrophic nature of the ESAS, the majority of aqueous CH4 may avoid biological oxidation in the water column and escape to the atmosphere. Further investigations should be focused on quantifying the total CH4 pool of the ESAS, improving our understanding of the mechanisms responsible for sub-sea permafrost destabilization and gas migration pathways formation, and decreasing uncertainties regarding the current CH4 emission mode and its future alteration by progressing permafrost degradation.