Impetuous CO_2 release from eroding permafrost coasts

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Abstract

The warming of the Earth results in extensive permafrost thaw in the Northern Hemisphere. With thaw, large amounts of organic carbon are mobilized, some of which is converted and released into the atmosphere as greenhouse gases. This in turn, facilitates a positive permafrost carbon feedback and thus further warming. Permafrost thaw and subsequent greenhouse gas release is presumed to be caused primarily by the vertical deepening of the active layer. Yet, abrupt thaw and erosion processes are neglected in carbon budgets and models. Here we show that thaw-induced lateral erosion of permafrost coasts is a major source of greenhouse gases. In addition, this greenhouse gas release is an order of magnitude relevant for the Arctic carbon cycle. With accelerating erosion rates, longer open water seasons, and warming air temperatures, this lateral flux and subsequent greenhouse gas release will increase and potentially contribute to the Earth's warming.

Keywords: Arctic Ocean, Canadian Arctic, Coastal erosion, Lateral fluxes, Biogeochemical cycling, Greenhouse gases

Introduction

Climate warming causes extensive thaw of permafrost in the Northern Hemisphere with far-reaching implications for nature and human society (Schuur *et al.*, 2015). The northern permafrost region stores vast amounts of organic carbon (~1307 Gt; Hugelius *et al.*, 2014). With permafrost thaw, large portions of this freeze-locked organic carbon pool are converted into greenhouse gases, resulting in a positive permafrost carbon feedback and thus further climate warming (Schädel *et al.*, 2014). This process is included in models as a gradual deepening of the active layer. Yet, the erosion of Arctic coasts and thermokarst processes result in rapid mobilization of deep permafrost organic carbon but are not included in the models (Schuur *et al.*, 2015). Most of the erosion-derived organic carbon is assumed to be directly buried in nearshore sediments or transported offshore, excluding turnover into greenhouse gases in the coastal zone (e.g., Vonk & Gustafsson, 2013). We hypothesize that permafrost organic carbon is subject to extensive mineralization upon erosion in nearshore waters, which result in the production of greenhouse gases in quantities significant to the Arctic carbon budget and the Earth's climate.

Methods

We mimicked the coastal erosion process in an incubation experiment by mixing permafrost with seawater under aerobic conditions for a single Arctic open-water season (~4 months) and different temperature scenarios (4°C and 16°C). Permafrost and seawater samples were taken at a continuous permafrost site - *Qikiqtaruk* – Herschel Island (Yukon Coast, western Canadian Arctic) and the adjacent coastal waters of the Beaufort Sea. Permafrost and seawater samples were kept frozen until start of the incubation experiment in the lab to avoid microbial turnover prior to incubation. Greenhouse gases (carbon dioxide and methane) were quantified systematically at certain time intervals using gas chromatography. Total and dissolved organic carbon, organic carbon/nitrogen-ratios and δ^{13}C-organic carbon isotope signatures were quantified prior (T = 0) and after (T = 1) the experiment and resulting differences (Δ T = 0 : T = 1) used to detect degradation processes.

Results

Our results show that large amounts of carbon dioxide are rapidly produced within nearshore waters along eroding permafrost coast. The amounts produced within the coastal zone are comparable to carbon dioxide emissions detected from permafrost thaw on land (e.g., Knoblauch *et al.*, 2013). We found that at ambient Arctic summer temperatures (4°C scenario) the production of carbon dioxide from permafrost is almost as efficient as production without seawater added. With higher temperatures (16°C scenario) carbon dioxide production further increases by up to 115%.

Discussion

The rapid production of carbon dioxide in coastal waters is most likely caused by the turnover of the fast and labile permafrost carbon pool (Schädel *et al.*, 2014). Although organic carbon/nitrogen-ratios decrease and $\delta^{13}C$-organic carbon isotope concentrations increase only slightly, TOC and DOC contents decrease substantially in almost all incubation setups; both indicating overall degradation of organic carbon (e.g., Strauss *et al.*, 2015) and subsequent turnover into carbon dioxide (e.g., Elberling *et al.*, 2013). A simple upscaling approach based on the latest numbers on circum-Arctic sediment fluxes (up to 14 Tg yr^{-1}; Wegner *et al.*, 2015), reveals that the carbon dioxide release from nearshore zones could be significant to the Arctic carbon budget and permafrost carbon feedback loops. With expected acceleration of erosion, higher air and seawater temperatures, and longer open waters seasons (Barnhart *et al.*, 2014 and references therein), we expect a substantial increase of carbon dioxide emissions from nearshore waters along eroding permafrost coasts.

Conclusion

We conclude that lateral erosion in general and the erosion of permafrost coasts and subsequent carbon dioxide emission from nearshore waters in particular are neglected sources of greenhouse gases into the atmosphere. These emissions are important within the Arctic carbon cycle and potentially contribute to the Earth's warming.

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