Influence of Land Slumping From Permafrost Thaw on Methane Ebullition in Lakes within the Yukon-Kuskokwim Delta

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Background and Motivation

Motivation

The world is experiencing dynamic warming due to anthropogenic climate change. The Arctic is warming at a much faster rate than most of the planet. Permafrost is thawing and the resulting destabilization from warming and increased fire frequency is leading to significant ground slumping. Deposition of this Pleistocene-aged organic matter into anoxic lake sediments has the potential to significantly shift biogeochemical cycling of methane in these ecosystems. Specifically, this erosion may fuel methane release in the form of ebullition (bubbling) from sediments. Ebullition is very spatially and temporally variable and has therefore been difficult to quantify or include in climate models. The majority of methane emissions from sub-arctic, thermokarst lakes, however, may come from ebullition. By studying ebullition in conjunction with slumping, we will improve our understanding of the factors influencing this large source of CH_4 emissions.

Hypothesis

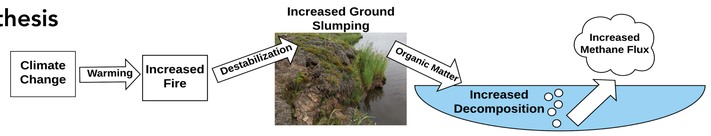

Figure 1. Conceptual model of hypothesized forcing between climate change, fire, ground slumping, and ebullition

Study Site

- The primary lake in this study was Landing Lake (unofficial name) in the Yukon Kuskokwim (YK) Delta.

Figure 2. (Left) Map of Alaska highlighting the YK Delta. (Right) Map of Landing Lake with blue markers illustrating locations of bubble trap sites. Areas in red display burned region in 2015 fire.

Methods

Ebullition Flux

- We used bubble traps placed above the sediment in order to capture and monitor ebullition rates over a two week period in July 2019 (Figure 3).
- Ebullition rates in areas with ground slumping were compared to areas of similar slope without ground slumping.
- Bubble rate was measured and gas bubbles were collected for analysis of CO_2 and CH_4 in a gas chromatograph.
- Diffusive CH_4 flux was measured in the field using a Los Gatos Greenhouse Gas Analyzer (LGR) and a floating chamber.

Figure 3. Image of deployed bubble trap

Incubation

- Sediment cores were taken from each bubble trap site, sealed, and transported frozen within the core tube.
- Sediments were incubated at 4˚C in the dark and CH_4 and CO_2 production were measured using an LGR.
- To ensure anoxic conditions, cores were flushed with N_2 for 5 minutes before and after flux measurements (Figure 4).

Figure 4. Image of sediment incubations being flushed with N_2

Figures

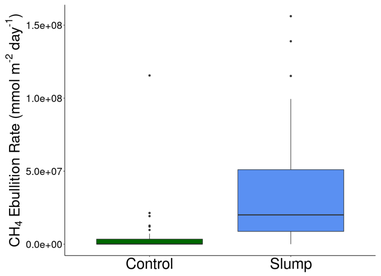

Figure 5. CH_4 ebullition rate comparing control and slumped sites

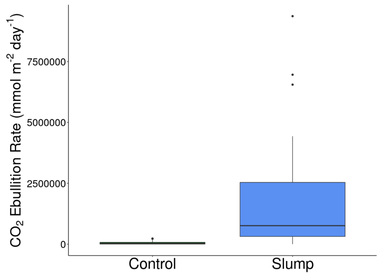

Figure 6. CO_2 ebullition rate comparing control and slumped sites

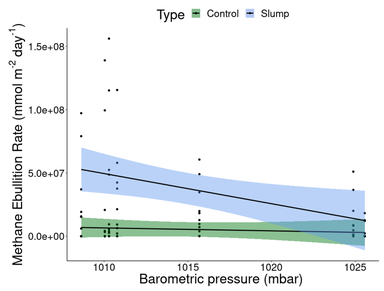

Figure 7. CH_4 ebullition compared to barometric pressure for control and slump sites

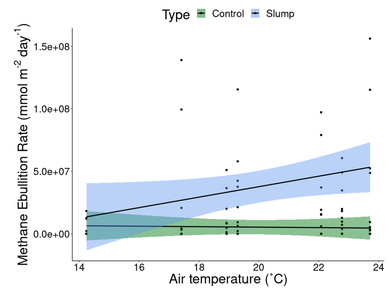

Figure 8. CH_4 ebullition compared to air temperature for control and slump sites

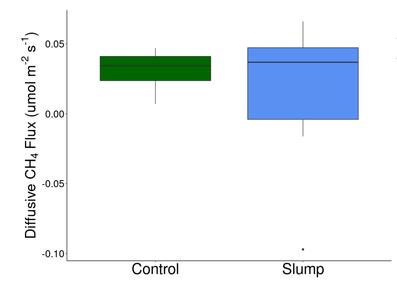

Figure 9. Diffusive CH_4 flux comparing control and slumped sites

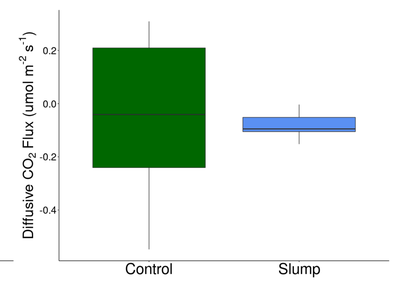

Figure 10. Diffusive CO_2 flux comparing control and slumped sites

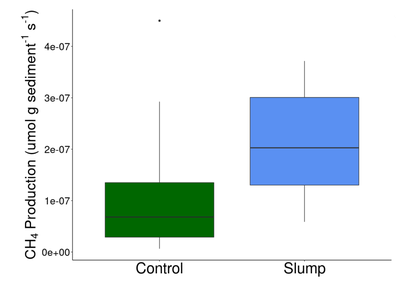

Figure 11. Incubated CH_4 production comparing control and slumped sediment cores

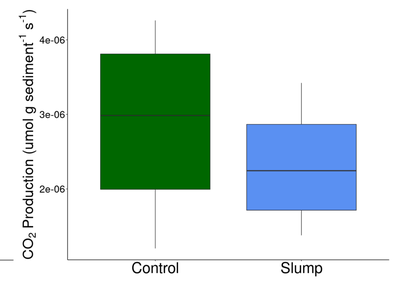

Figure 12. Incubated CO_2 production comparing control and slumped sediment cores

Results

- CH_4 and CO_2 ebullition rates were significantly higher in regions of ground slumping (Fig. 5 and 6).
- CH_4 ebullition rates were greater at low pressure and high air temperature, yet only within slumped sites (Fig. 7 and 8).
- Diffusive CH_4 and CO_2 were not significantly different between the two types of sites (Fig. 9 and 10).
- Incubated sediments from slumped sites had higher CH_4 production than the control but statistically equivalent CO_2 (Figures 11 and 12).

Conclusions and Future Work

Conclusions

Fire and warming conditions are leading to increased permafrost degradation and ground slumping. Our results suggest that slumping increases ebullitive methane flux rates from thermokarst lakes. This variation in ebullition of methane is likely driven by the change in sediment composition as a result of ground slumping. As frequency and severity of Arctic fires increase, we expect more slumping to occur. In addition, as the climate warms, elevated fire frequency, increased slumping, and the increased methane emissions that result may induce a positive feedback loop, worsening climate change and increasing the vulnerability of Arctic tundra ecosystems.

Future Work

- More work is needed to understand the carbon composition of sediment organic matter.
- Investigating microbial DNA from sediments will allow us to learn about variation in methanogenic communities.
- Future sediment incubations could shed light on the possible shift in the methane production pathway.
- Isotopic analysis of CH_4 from ebullition would clarify the age and potential sources of this organic material.

Acknowledgments

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