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 CH4 emissions.

Hypothesis

Increased Ground Slumping

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.

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 CO2 and CH4 in a gas chromatograph.
- Diffusive CH4 flux was measured in the field using a Los Gatos Greenhouse Gas Analyzer (LGR) and a floating chamber.

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 CH4 and CO2 production were measured using an LGR.
- To ensure anoxic conditions, cores were flushed with N2 for 5 minutes before and after flux measurements (Figure 4).

Results

- CH4 and CO2 ebullition rates were significantly higher in regions of ground slumping (Fig. 5 and 6).
- CH4 ebullition rates were greater at low pressure and high air temperature, yet only within slumped sites (Fig. 7 and 8).
- Diffusive CH4 and CO2 were not significantly different between the two types of sites (Fig. 9 and 10).
- Incubated sediments from slumped sites had higher CH4 production than the control but statistically equivalent CO2 (Figures 11 and 12).

Figure 5. CH4 ebullition rate comparing control and slumped sites

Figure 6. CO2 ebullition rate comparing control and slumped sites

Figure 7. CH4 ebullition compared to barometric pressure for control and slump sites

Future Work
- 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.

Figure 8. CH4 ebullition compared to air temperature for control and slump sites

Figure 9. Diffusive CH4 flux comparing control and slumped sites

Figure 10. Diffusive CO2 flux comparing control and slumped sites

Figure 11. Incubated CH4 production comparing control and slumped sediment cores

Figure 12. Incubated CO2 production comparing control and slumped sediment cores

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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.