High variability in GHG emissions from Arctic ponds, explained by erosional activity and pond morphology

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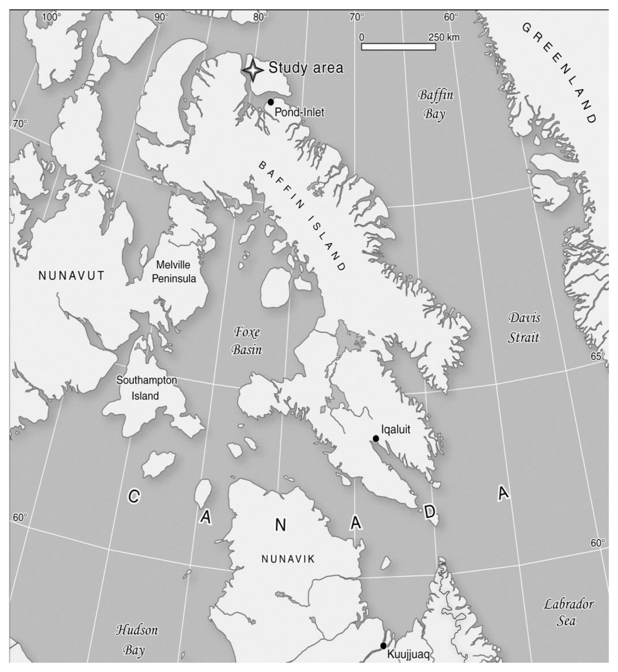
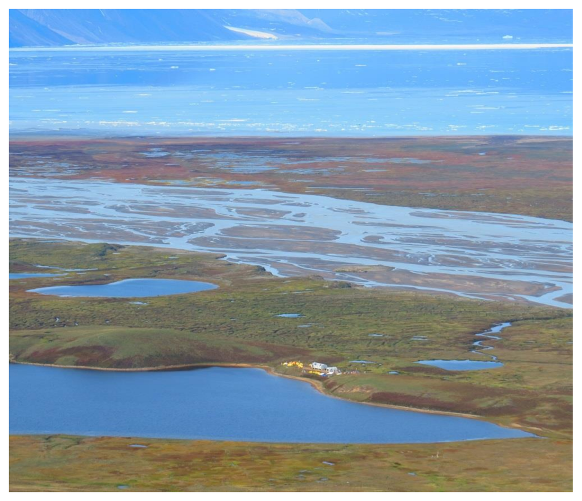
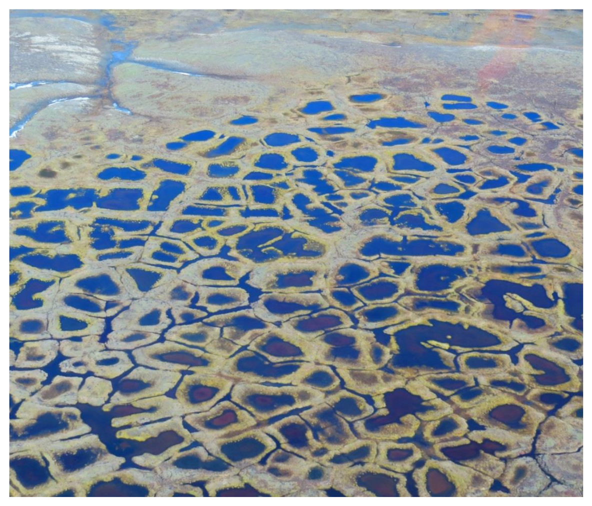
Rationale

With ongoing climate change, longer summer and increased annual precipitations are expected over Arctic regions[1]. These conditions are favourable for intensive and extensive permafrost thaw, mobilising organic matter and intensifying its transfer to aquatic ecosystems, with the potential to act as a positive feedback to climate warming[2]. These systems are abundant over Arctic lowlands and are hot-spots of microbial activity. The micro-topography of Arctic polygonal landscapes produces ponds with different morphology and intensity of shore erosion. My PhD project aims to relate these characteristics to present and future GHG emissions from such systems.





Study site with glaciofluvial outwash, ice-wedge polygon terrace, and lakes



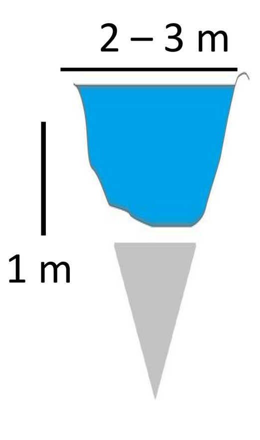
Abundant tundra ponds on the ice-wedge polygon terrace

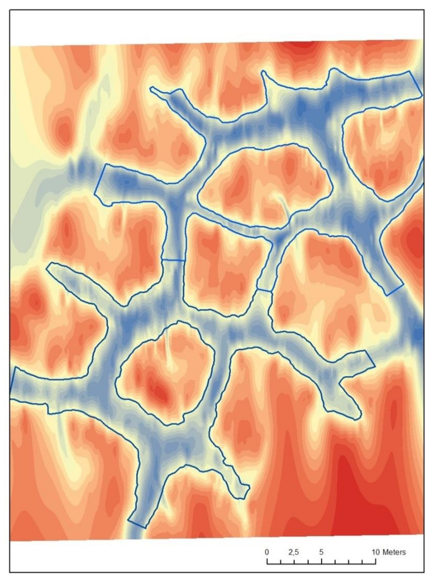
Study site

- Bylot Island CEN station (73°09'N, 79°59'W), Sirmilik National Park, Nunavut, CANADA
- Valley covered by organic-rich (15-45%) Holocene deposits comprised of peat and aeolian silt, region of deep continuous cold permafrost
- Dense ice-wedge network and snowmelt water shape the landscape, composed of dry tundra patches and shallow aquatic ecosystems (~6% of the valley bottom)
- Water bodies deeper than ~2 m present taliks, while shallower ponds freeze to bottom for approximately ¾ of the year

Pond types

A,B,C - stratified ice-wedge trough ponds





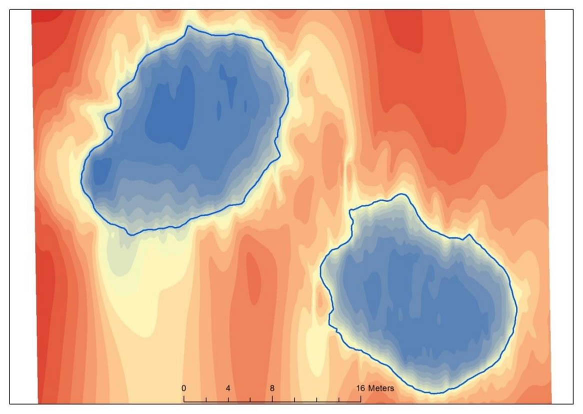
A – actively eroding shores

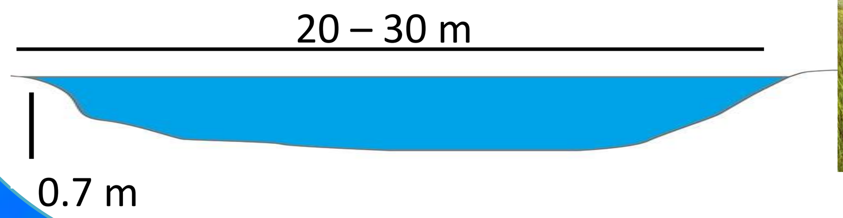
B – partially stabilised shores

C – stable shores

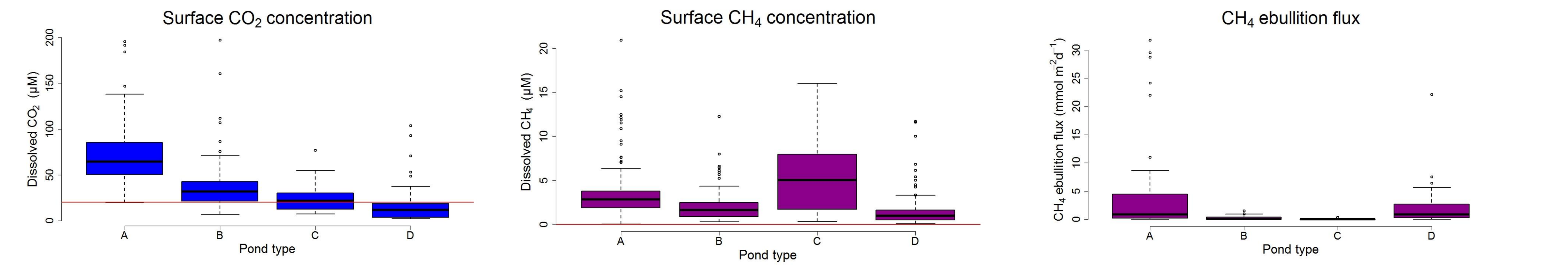
D – fully mixed ponds

D – fully mixed ponds (including polygonal and coalesced ponds)



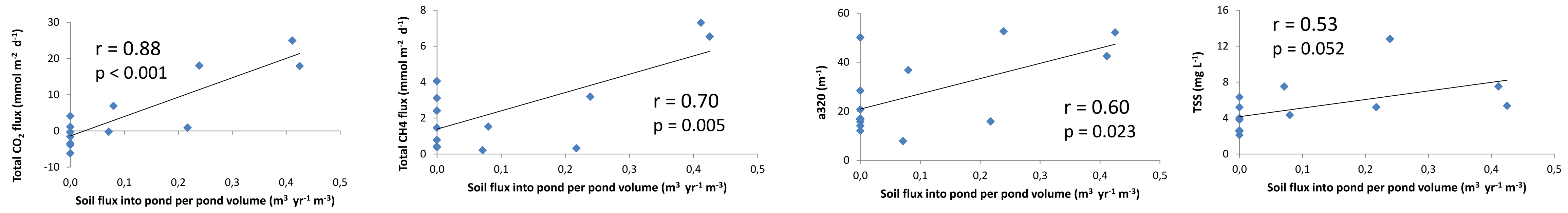


Surface dissolved GHG concentrations and CH_4 ebullition flux for the 4 pond types



- On average, both well-mixed ponds (group D) and stratified ponds with stable shores (group C) remain understaturated with CO_2 (i.e., close to or below the red line, indicating the equilibrium with the atmosphere), while groups A and B show high levels of CO_2 supersaturation, and thus represent a carbon source to the atmosphere.
- All studied ponds are sources of CH_4 to the atmosphere (all supersaturated; by up to 11 times), while those with higher level of erosion (group A) tend to emit more through ebullition. Ebullition flux is also high for fully-mixed ponds (group D), possibly linked to the high primary production of these ponds that fuels methanogenesis.

Do erosion indices correlate with GHG emissions and limnological properties?



- Using high precision GNSS mapping and ArcMap, erosion indices were calculated for 14 ponds to quantify the soil-water contact level.
- GHG fluxes correlate well with the soil flux per year normalized to the pond volume. The a320 absorption coefficient (amount of CDOM) and total suspended solids (TSS) also correlate with this erosion index, illustrating the flux of colored DOM and sestonic particles caused by erosion.
- GHG and limnological properties also correlate (R = 0.70, 0.55, 0.40, and 0.45, respectively) with the proportion of exposed shore (not vegetated and prone to erosion and direct leaching).
- DOC concentration shows low correlation with GHG and erosion indices, while the chromophoric fraction of DOM (e.g., SUVA and absorption coefficient) correlates well with GHG emissions, and thus could be used as a proxy.

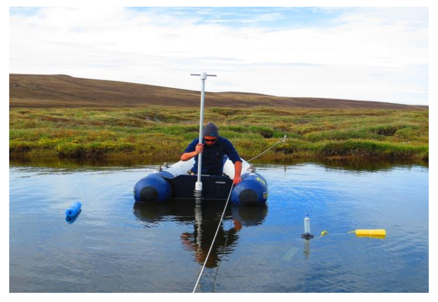
What else is done in this PhD project?

- High precision mapping of pond bathymetry and shore erosion.
- Water sampling for concentrations of C, P, N and other elements.
- Dissolved oxygen and temperature profiles.
- Incubation experiments of the different pools of organic matter found at this study site, to assess the lability of permafrost peat, active layer peat and pond/lake sediments, where DOM properties, respiration rates (oxygen loss and DIC production), and bacterial production are followed over 30 days.

Permafrost coring

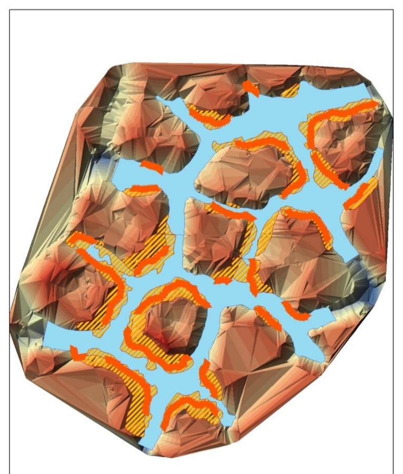
GNSS mapping

Bubble traps for ebullition flux



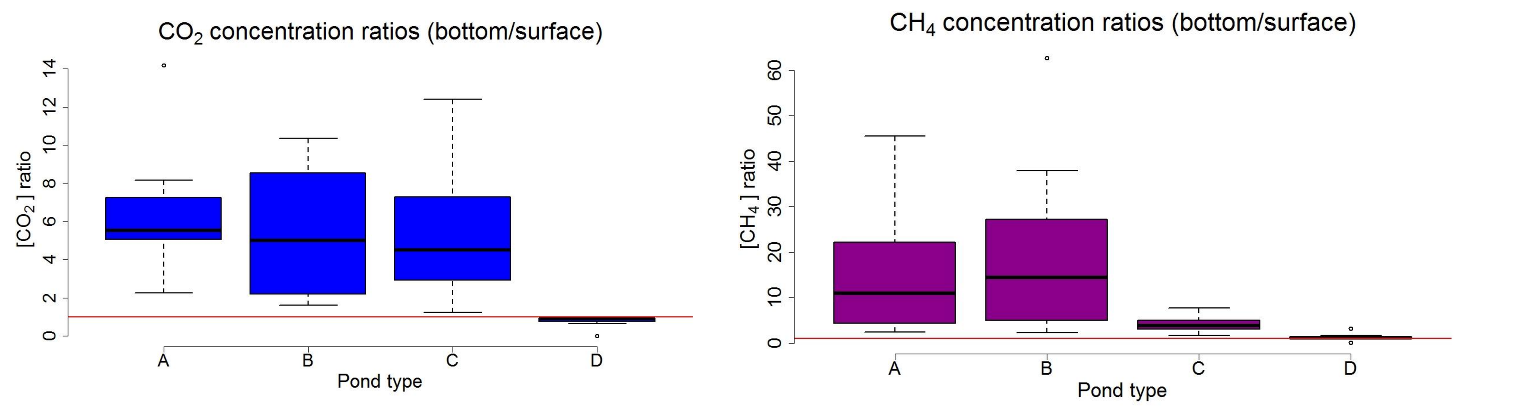
Pond sediment coring

Water sampling and diffusive flux measurements



Mapping erosional activity

Effect of thermal stratification on GHG storage



Ponds that are stratified and receive inputs of eroded terrestrial (allochthonous) matter (groups A & B) tend to accumulate more CH_4 and CO_2 during the thaw season. Stratification allows the accumulation of dissolved gases in bottom waters that rarely mix with the surface, while the higher influx of terrestrial matter (associated to the hypoxia/anoxia generated) induce intensive methanogenesis, despite of low sediment temperature of trough ponds, in close contact to ice wedges.

Take home message:

1. Ice-wedge trough ponds with actively eroding shorelines are the largest sources of GHG in tundra landscapes
2. Stratification is an important feature to take into account when sampling GHG for flux estimation, even for shallow ponds of only a few m^2

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References:
1 IPCC 2017
2 Schuur et al. 2015, Nature

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