Long-Term Measurements of Methane Ebullition From Thaw Ponds

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Introduction

- Arctic regions are warming much more rapidly than other parts of the globe[1 - 2] (Fig 1)
- Warming of this magnitude in this region is of concern due to the vast OC stores in permafrost[3 - 4] (frozen ground)
- Thaw ponds are the result of thawing permafrost peatlands and have been shown to emit CH_4 (Fig 2) yet there are few long-term studies of these water bodies[5]
- CH_4 from peatlands is emitted to the atmosphere via three pathways: (1) plant mediated transport, (2) hydrodynamic flux, and **ebullition (bubbling)**[6 – 8]
- Ebullition is often the dominant pathway but is also the least understood[6 – 8]

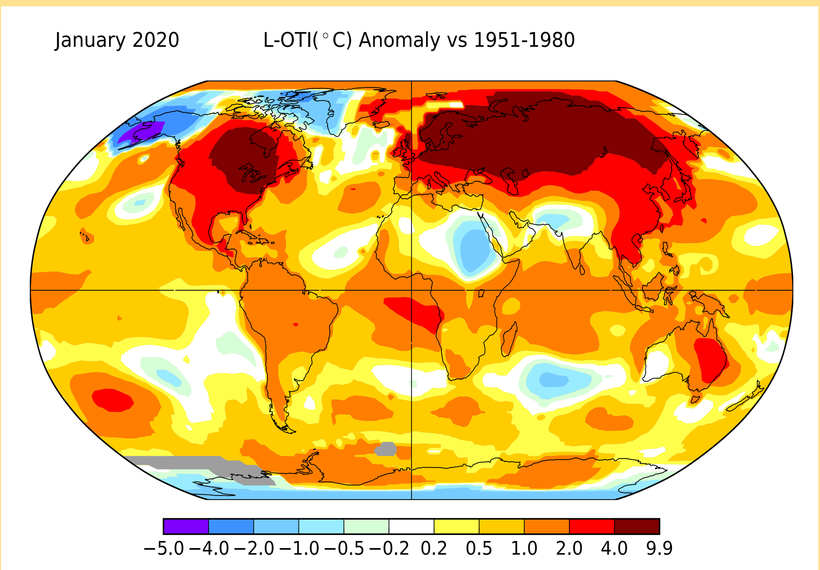


Figure 1 Temperature in January 2020 compared to the mean January temperature during 1951 – 1980[1 - 2].

Objective: Investigating the seasonal and interannual controls of ebullitive flux from a subarctic thaw pond system

Figure 2A-C *Development of Pond E through time. Photo 2A and 2B Credit: Patrick Crill.*

Methods

- Eight ponds studied within Stordalen Mire, northern Sweden (68°21'N, 19°02'E) (Fig 3)
- Ponds sampled for bubbles during the growing season (June - September, every 1 – 3 days) in 2012 to 2015 with pond temperature measured continuously in all ponds since July 2013 (Fig 4)
- Samples analyzed on a Gas Chromatograph for CH_4 concentration (Fig 5)
- Drone imagery over Stordalen Mire from 2016 used to estimate pond size[9]
- Used non-parametric statistical tests to investigate drivers of ebullitive flux

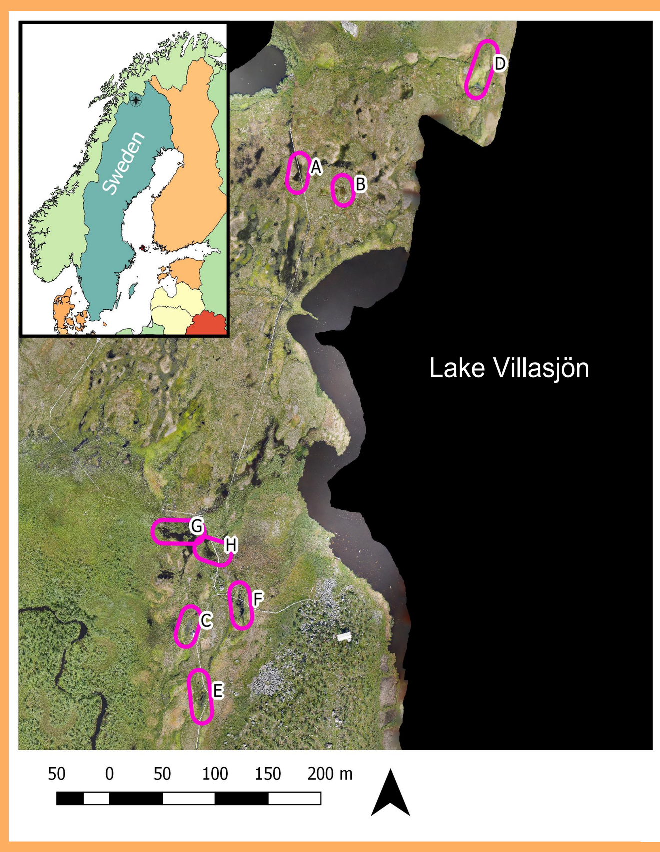


Figure 3 *Pond sampling locations. Image Credit: Michael Palace, Jessica DelGreco, Christina Herrick.*

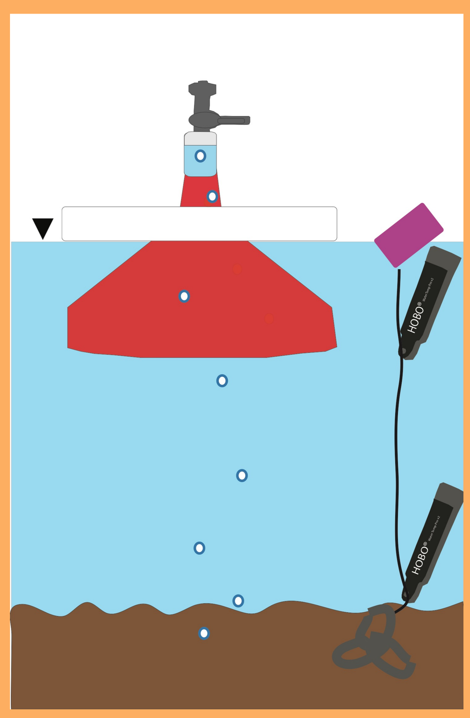


Figure 4 *Schematic of funnel system and temperature loggers.*

Figure 5 *Gas samples run on a Gas Chromatograph within 24 hours of collection. Photo credit: Clarice Perryman.*

Results

- Over the four-sampling season study, our eight ponds emitted on average **20 mg CH_4 m^{-2} d^{-1}**
- Episodic events (peaks in ebullitive flux) occurred in all ponds, sometimes associated with drops in atmospheric pressure but not always (Fig 6)
- Meteorological variables considered important to ebullition[10 - 12] correlated significantly with flux but did not explain much variability in flux
- Ebullitive flux varied significantly by pond, with the eight ponds appearing to fall into four distinct groups (Fig 7; Table 1)

Table 1 *Physical characteristics of the ponds broken down by type*

	Type 1	Type 2	Type 3	Type 4
Depth (cm)	18 - 22	35 - 41	43 - 85	41 - 47
Sphagnum spp. present?	✓	✓	✓	✕
Sedges present?	*Eriophorum spp.*	↑ from Type 1	*Eriophorum spp.* & *Carex spp.* ↑ from Type 2	*Eriophorum spp.* & *Carex spp.* ↑ from Type 2
Hydrologic Connectivity[13]	Isolated	Transitioning	Isolated	Open Water; Connected to adjacent Fen

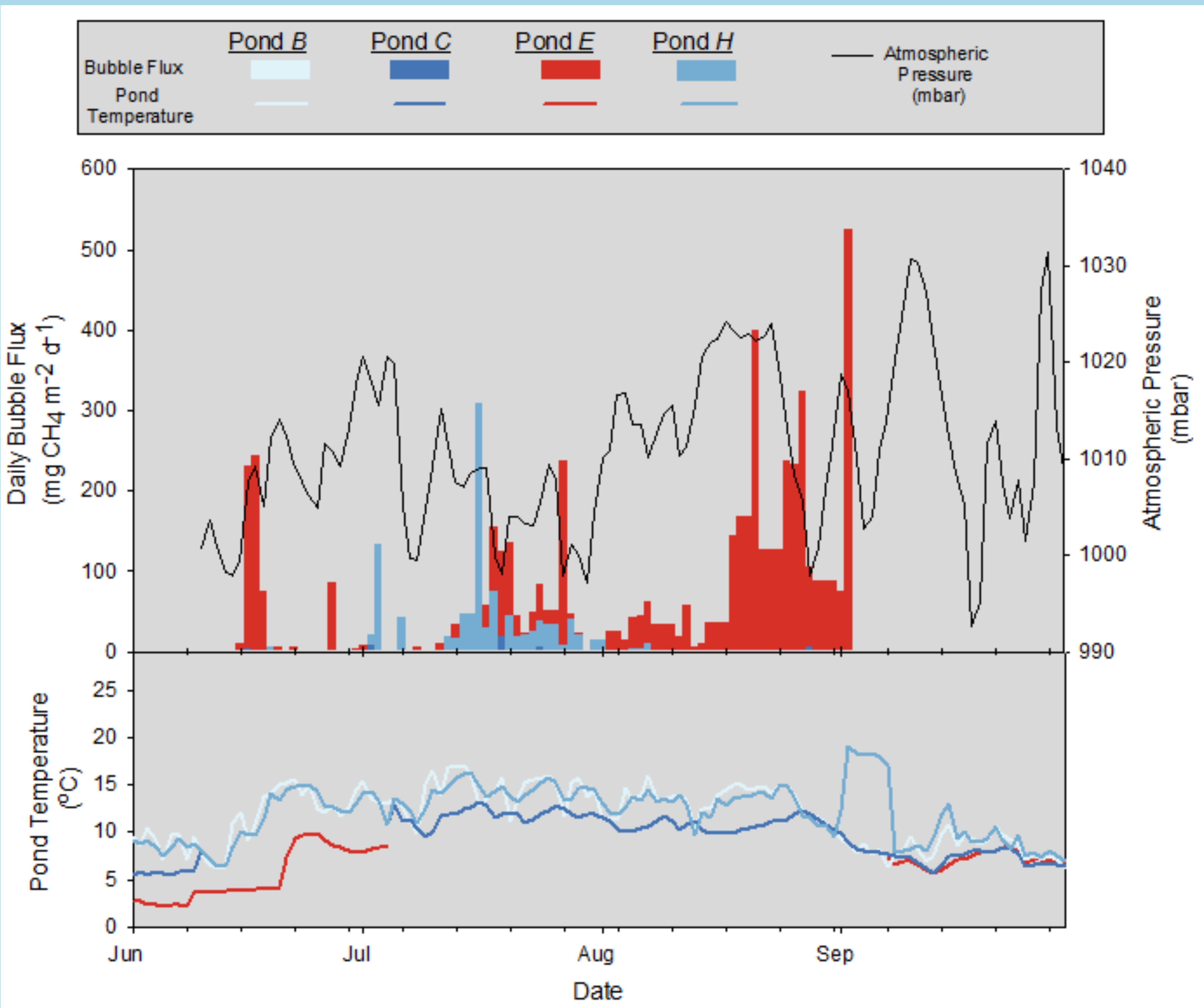


Figure 6 *Daily bubble flux (mg CH_4 m^{-2} d^{-1}) and pond temperature (°C) from selected ponds in 2015. Daily average atmospheric pressure (mbar) for each sampling season is displayed as a black line[14].*

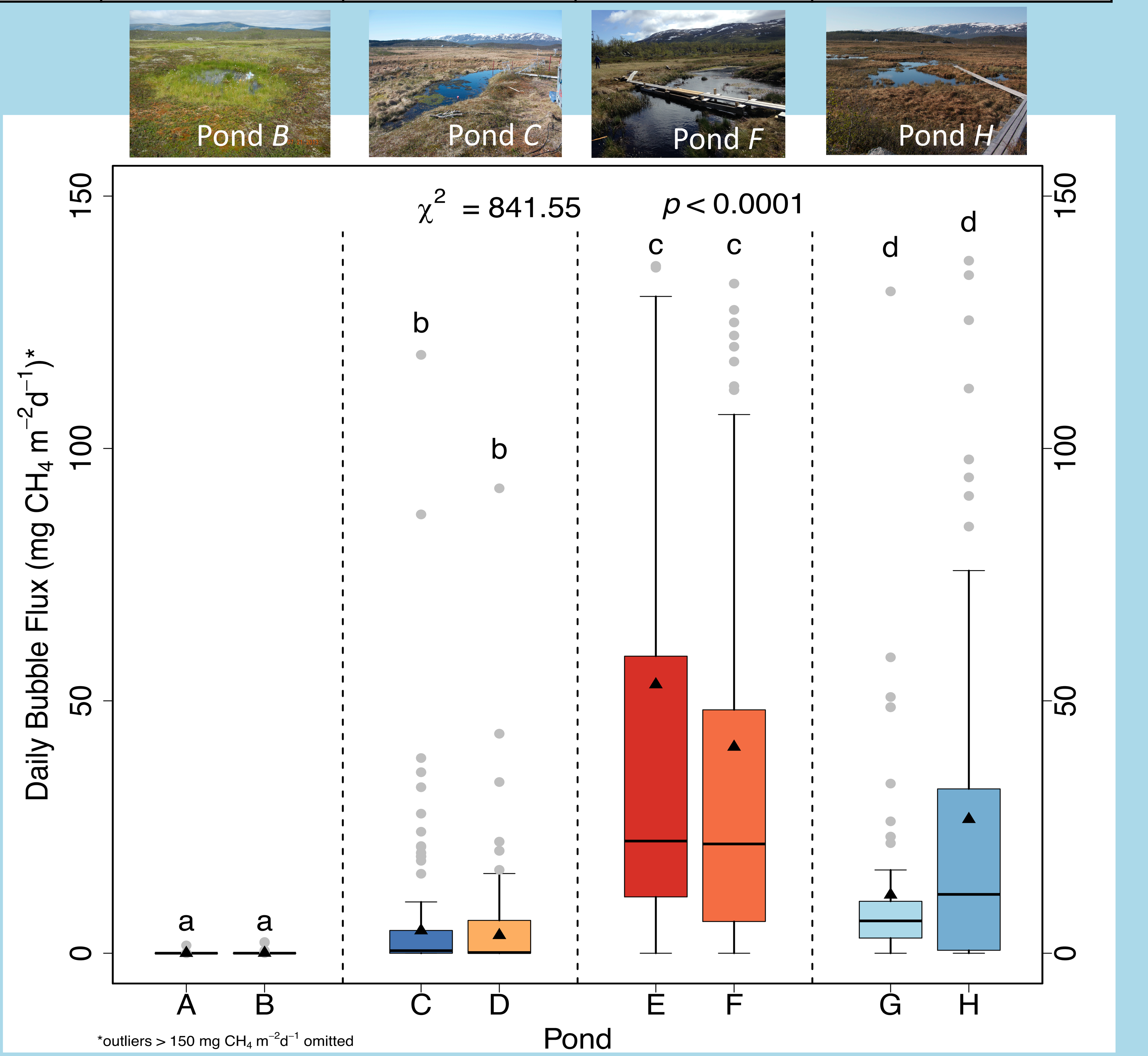
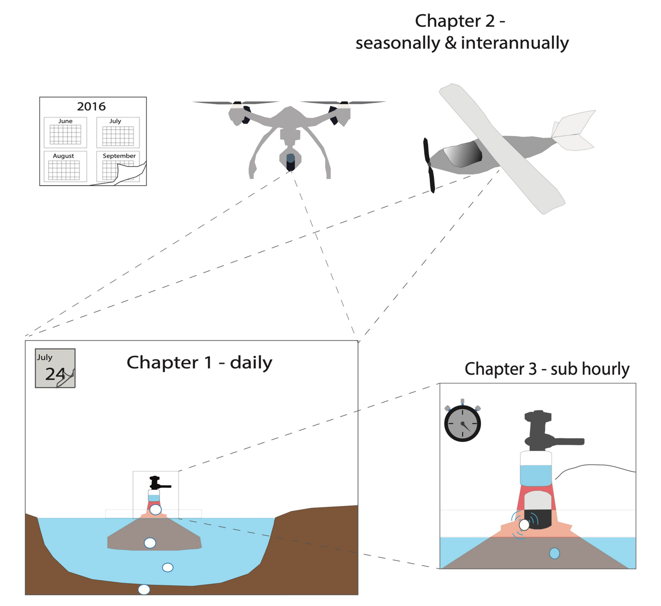


Figure 7 *Daily bubble flux 2012 – 2015 for each pond with mean daily bubble flux as ▲. Letters represent significant differences. χ^2 and p are from the Kruskal-Wallis rank sum test.*

Conclusions

- Meteorological variables were very weakly correlated with thaw pond ebullition potential
- Using our average ebullitive flux, the estimated extent of small ponds above 50°N[15-16], and an estimated 149 days ice-free season[5], we estimate thaw ponds of < 0.001 km^2 to emit between 0.2 and 1.0 Tg CH_4
- High frequency ebullition measurements over multiple seasons are important in constraining the CH_4 from small thaw ponds

Figure 8 *Schematic showing the various spatial and temporal scales of my PhD.*



Future Work

Further examine ebullition from these ponds in both high *temporal* and *spatial* resolution using acoustic sensors and repeat drone fly overs (Fig 8).

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[1] GISTEMP Team, 2020: *GISS Surface Temperature Analysis (GISTEMP)*. NASA Goddard Institute for Space Studies. Dataset accessed 2020-03-30 at https://data.giss.nasa.gov/gistemp/. [2] Hansen et al. (2010), *Rev. Geophys.* [3] Loisel et al. (2014). *The Holocene*. [4] Yu et al. (2010). *Geophy. Res. Lett*. [5] Wik et al. (2016). *Nat. Geosci*. [6] Bastviken et al. (2011). *Science*. [7] Coulthard et al. (2009). In *Carbon Cycling in Northern Peatlands* (pp. 173–186). [8] Fechner-Levy & Hemond (1996), *Limnol. Oceanogr.* [9] Palace et al. (2018). *Remote Sens.* [10] Goodrich et al. (2011). *Geophys. Res. Lett.* [11] Weyhenmeyer (1999). *Global Biogeochem. Cycles*. [12] Wik et al. (2014). *Geophys. Res. Lett.* [13] Olefeldt & Roulet (2012). J. Geophys. Res. [14] ANS. (2017). Abisko Weather Station Data. (A. S. R. Station, Ed.). Abisko Scientific Research Station. Retrieved from http://polar.se/abisko. [15] Holgerson & Raymond (2016), *Nat. Geosci.* [16] Verpoorter et al. (2014). *Geophys. Res. Lett*. [17] Burke, S. A., Wik, M., Lang, A., Contosta, A. R., Palace, M., Crill, P. M., & Varner, R. K. (2019). Long-Term Measurements of Methane Ebullition From Thaw Ponds. *Journal of Geophysical Research: Biogeosciences*, 2018JG004786. https://doi.org/10.1029/2018JG004786