Ebullition of CO_2 and CH_4 from an upland stream network in Northeastern Siberia

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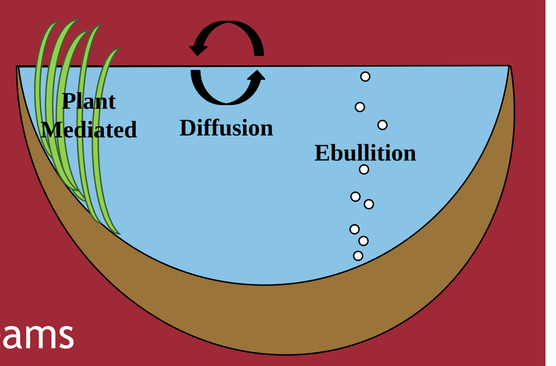
Carbon Emissions From Arctic Streams

- Arctic ecosystems contain nearly 50% of all soil carbon (C) *(Tarnocai et al. 2009, Hugelius et al. 2014)*
- Warming in the arctic has made this C vulnerable to mineralization *(Schuur et al. 2008)*
- Aquatic ecosystems are sites of C mineralization and emissions *(Cole et al. 2007)*
- CH_4 may be a considerable proportion of this gaseous C-flux *(Bastviken et al. 2011)*
- Field based approaches may grossly over-estimate CH_4 source fluxes *(Kirsche et al. 2013)*
  - Perhaps due to geospatial and examined flux pathway biases
- CH_4 follows three source flux pathways



- Ebullition is routinely overlooked
  - Exhibits extreme spacio-temporal variability
  - Can represent up to 60% of a stream's CH_4 flux
  - 5 studies to date have quantified ebullition in rivers and streams
  - ***Ebullition from streams/rivers has not been quantified north of 49˚N***

Accurate and geographically diverse estimates of individual source flux pathways help constrain source estimates and facilitate more accurate predictions of future fluxes in a changing environment

Objectives

- Quantify CO_2 and CH_4 ebullition from Arctic streams
- Identify potential controls on ebullition from these systems

Methods

Flux Estimate

- 24 funnel-type bubble traps distributed randomly in accessible reaches
- Gas volumes sampled every 2 – 4 days from early July to mid August
- Gas collected twice to determine the mole fractions of CO_2 and CH_4

Upscaling

- Stream area from GIS derived stream lengths and a survey of measured stream widths taken throughout the watershed (n = 96)

- Landscape estimates calculated using Monte Carlo simulations (n = 10,000) that draw from distributions of measured fluxes and stream area (as in Crawford et al. 2014)
- CH_4 estimates from lakes taken from Walter et al. 2006

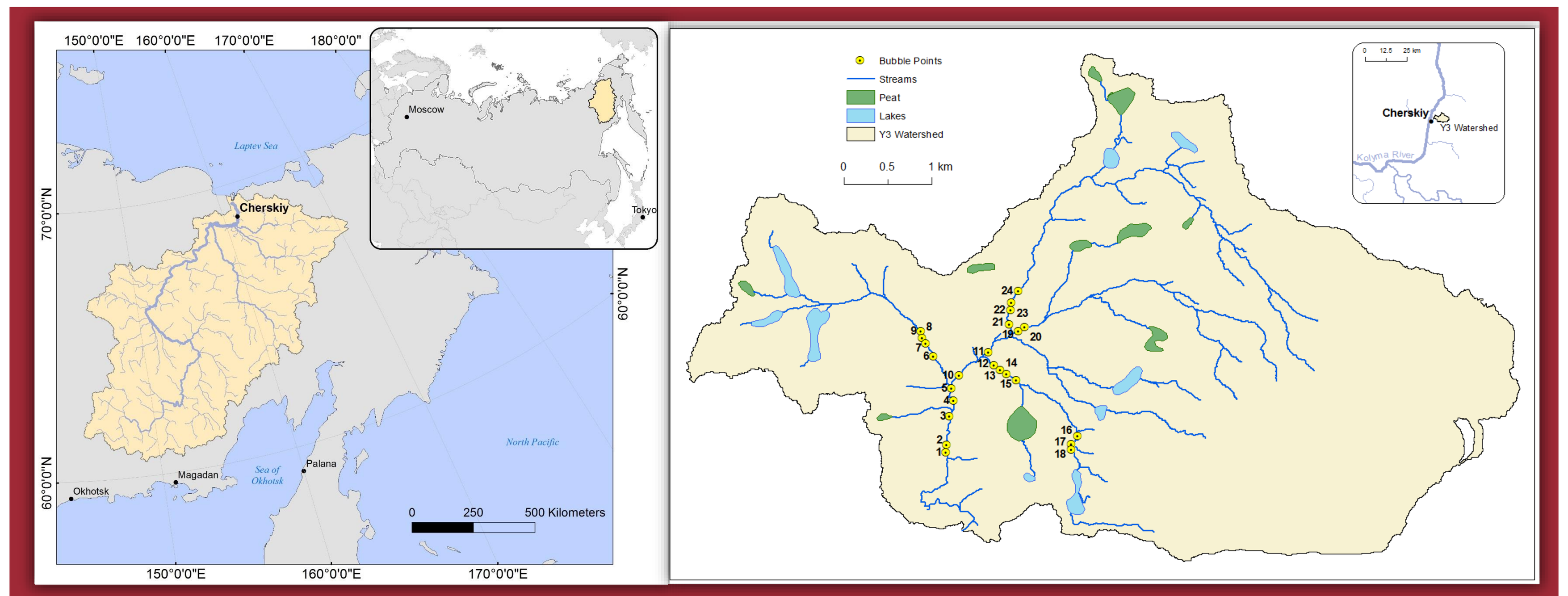
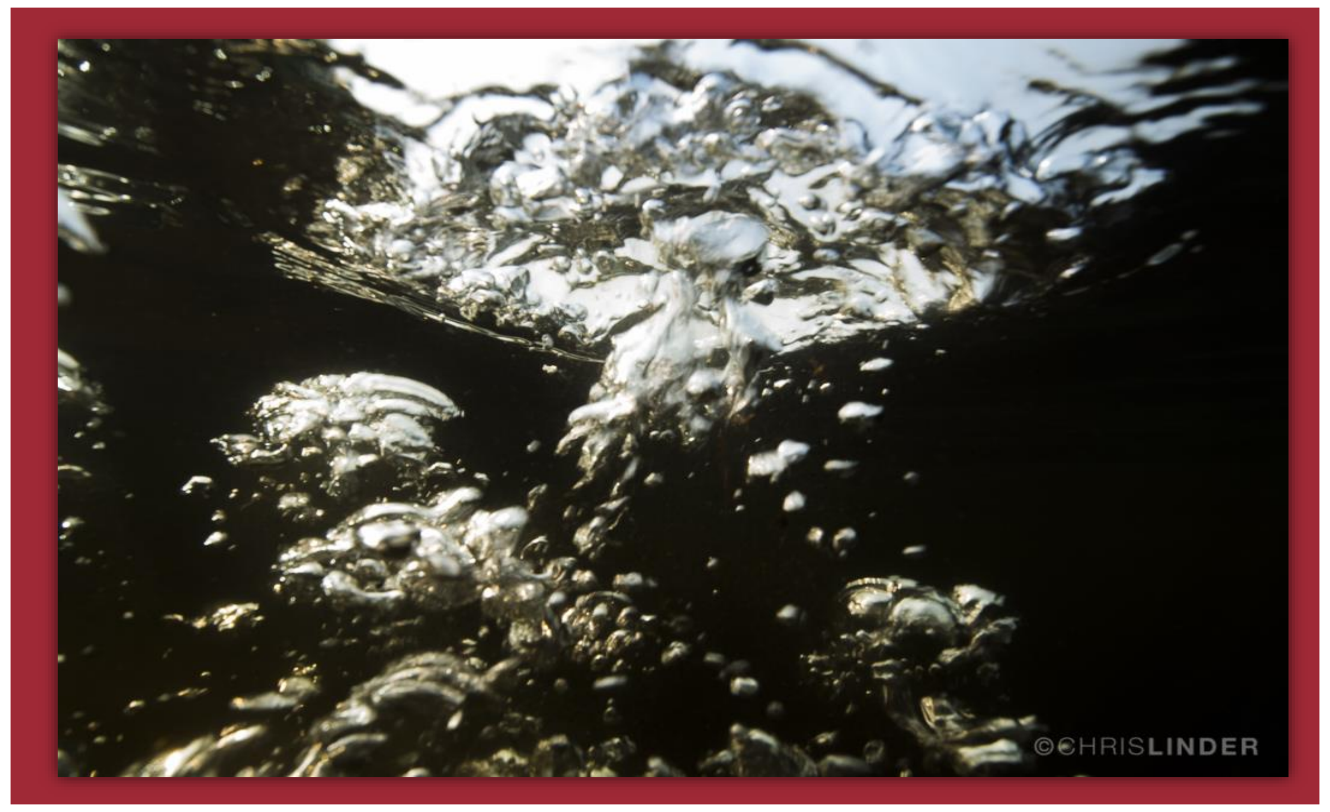


Figure 1. The greater Kolyma river watershed (left) and our study catchment, "Y3" (right). The Y3 watershed is 16.84 km². Lakes account for 2.3% of that area and streams represent 0.8% of that area. The watershed is underlain by C and ice-rich permafrost known locally as "yedoma".



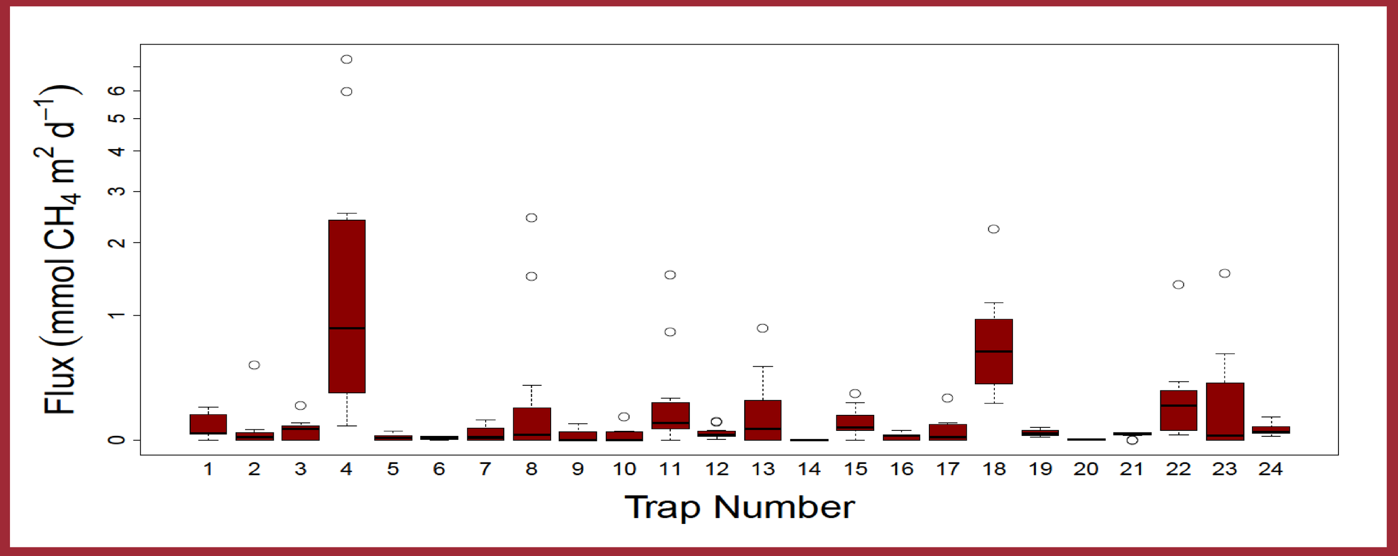


Figure 2. Ebullitive CH_4 flux by site.

- Mole fraction CH_4: 6.9% (Range: 0.5 – 29%)
- Mean CH_4 flux: **0.21 mmol m^{-2} d^{-1}** (95% CI: 0 – 1.56 mmol m^{-2} d^{-1})
- Open water CH_4 flux (120 days) : **59.8 kg CH_4-C yr^{-1}**

- Mole fraction CO_2: 1.2% (Range: 0.2 – 3.4%)
- Mean CO_2 flux: **0.04 mmol m^{-2} d^{-1}** (95% CI: 0 – 0.34 mmol m^{-2} d^{-1})
- Open water CO_2 flux (120 days): **10.6 kg CO_2-C yr^{-1}**

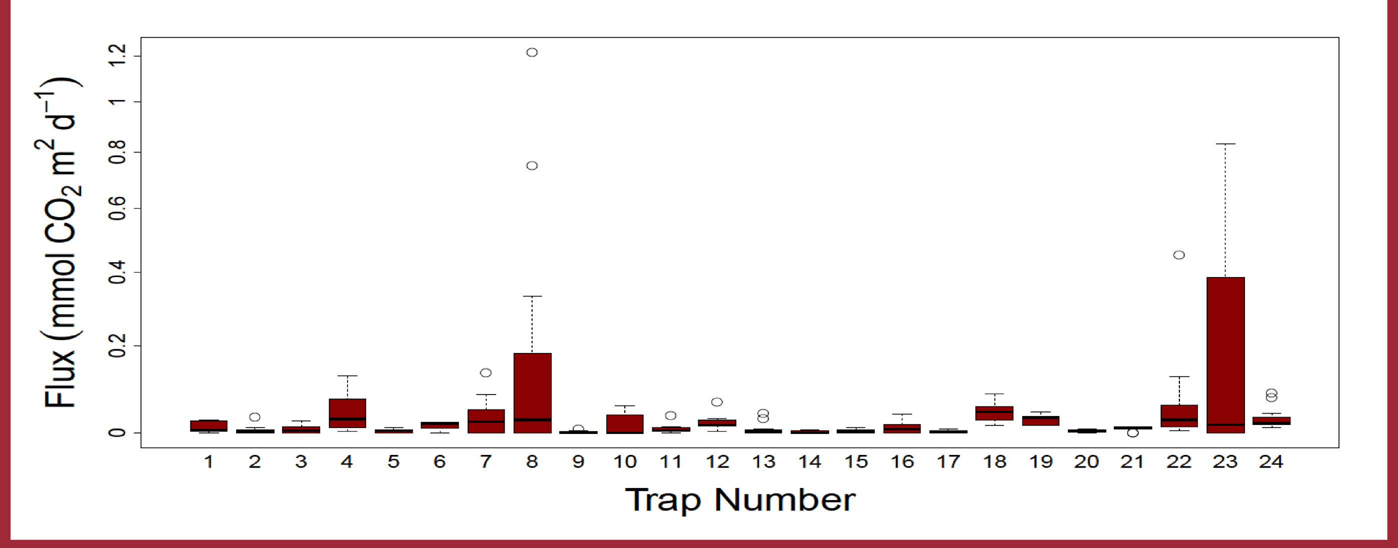


Figure 3. Ebullitive CO_2 flux by site.

Implications

Local Contributions

- Y3 lakes are significant CH_4 sources *(Zimov et al. 1997, Walter et al. 2006)*
  - 95% of lake CH_4 emissions via ebullition during the open water season
- Streams represent 6% of landscape CH_4 ebullition
- Stream contributions may increase with bubble CH_4 enrichment due to the removal of present metabolic constraints

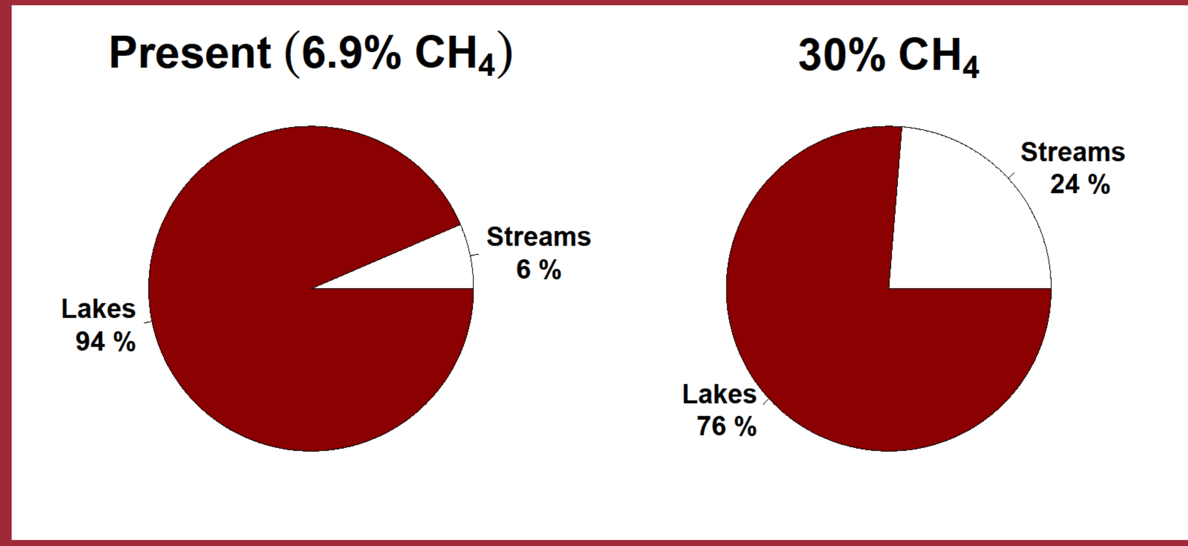


Figure 4. Relative contributions of lakes and streams to the open water ebullitive CH_4 flux under present conditions and if the composition of bubbles were to increase to 30% CH_4.

Global Comparisons

Table 1. Comparison of all published riverine CH_4 ebullition estimates from around the globe.

Region	Study	Latitude	Mean Volume	Mean Mole Fraction	CO_2:CH_4 Range	Mean Flux (mmol CH_4 m^{-2} d^{-1})
Russian Arctic	This Study	69 ˚N	86 mL	6.9 %	0.52	0.21
North Temperate Germany	Maeck et al. 2013	49 ˚N				0.02
North Temperate USA	Crawford et al. 2014	46 ˚N	123	22 %	0.08	1.25
Temperate Canada	Baulch et al. 2011	44 ˚N	104	26 %	0.01 – 0.07 *	1.41
Amazon River and Tributaries	Sawakuchi et al. 2014	2 ˚S				0.6
Agricultural Streams New Zealand	Wilcock & Sorrell, 2008	32 ˚S		41 %	0.03 – 0.3 *	1.68

* Range calculated as the minimum and maximum ratios from the minimum and maximum CO_2 and CH_4 mole fractions reported.

- Low CH_4 fluxes compared to other regions of the globe
- Low fluxes result from bubbles with low quantities of CH_4
- High CO_2:CH_4 suggests that alternative electron acceptors or CH_4 oxidation may inhibit CH_4 production in this region
- If redox environments change, fluxes may increase significantly