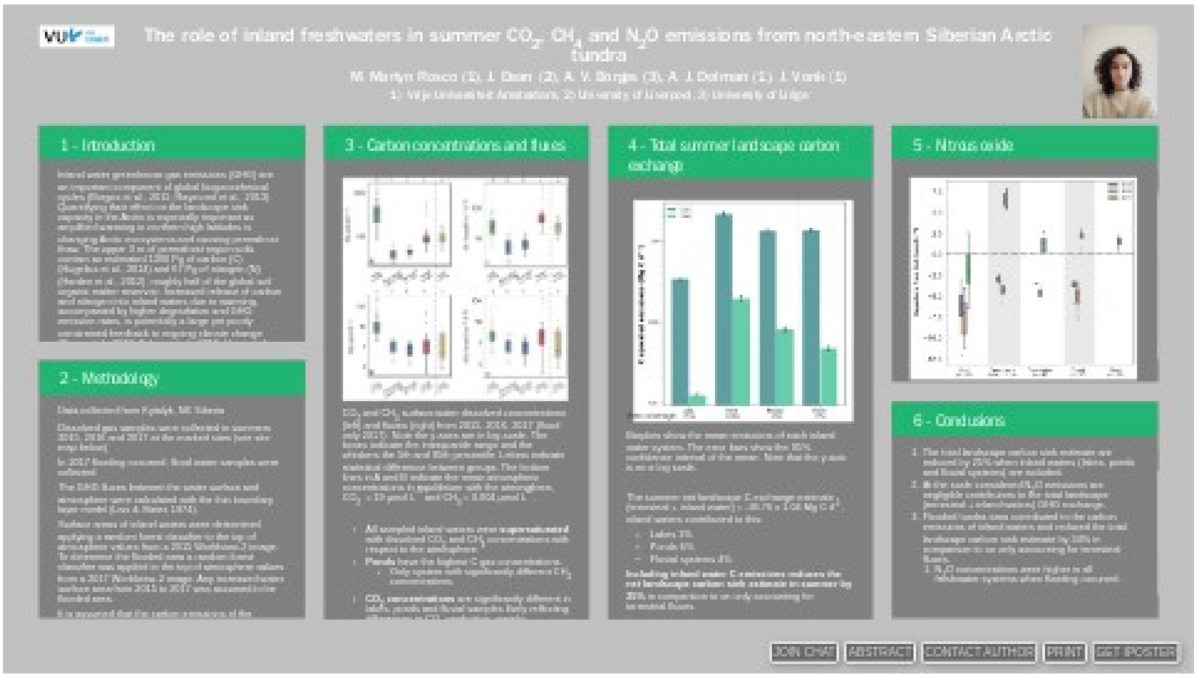
The role of inland freshwaters in summer CO_2, CH_4 and N_2O emissions from north-eastern Siberian Arctic tundra



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PRESENTED AT:

1 - INTRODUCTION

Inland water greenhouse gas emissions (GHG) are an important component of global biogeocehmical cycles (Borges et al., 2015; Raymond et al., 2013). Quantifying their effect on the landscape sink capacity in the Arctic is especially important as amplified warming in northern high latitudes is changing Arctic ecosystems and causing permafrost thaw. The upper 3 m of permafrost region soils contain an estimated 1300 Pg of carbon (C) (Hugelius et al., 2014) and 67 Pg of nitrogen (N) (Harden et al., 2012), roughly half of the global soil organic matter reservoir. Increased release of carbon and nitrogen into inland waters due to warming, accompanied by higher degradation and GHG emission rates, is potentially a large yet poorly constrained feedback to ongoing climate change (Dean et al., 2018; Schuur et al., 2015; Voigt et al., 2017). Inland water bodies tend to lie on a sub-pixel scale of the satellite images, which usually have a resolution of 250 m to 1 km, that are used to derive parameters for regional and global climate and ecosystem models. This could be introducing bias into derived parameters; determining the quantitative contribution of inland water emissions on the landscape carbon source or sink at a smaller scale will provide insight into their significance.

Research questions

1. How are total landscape carbon emission estimates of a bounded area (17.81 km^2, see figure in methods) affected by the inclusion of inland water emissions?
2. How important are N_2O emissions to the atmosphere relative to CO_2 and C_H4 in a range of Siberian Arctic freshwaters?
3. How does flooding affect the total landscape terrestrial carbon and N_2O emissions in summer?

2 - METHODOLOGY

Data collected from Kytalyk, NE Siberia

Dissolved gas samples were collected in summers 2015, 2016 and 2017 at the marked sites (see site map below)

In 2017 flooding occurred, flood water samples were collected

The GHG fluxes between the water surface and atmosphere were calculated with the thin boundary layer model (Liss & Slater, 1974).

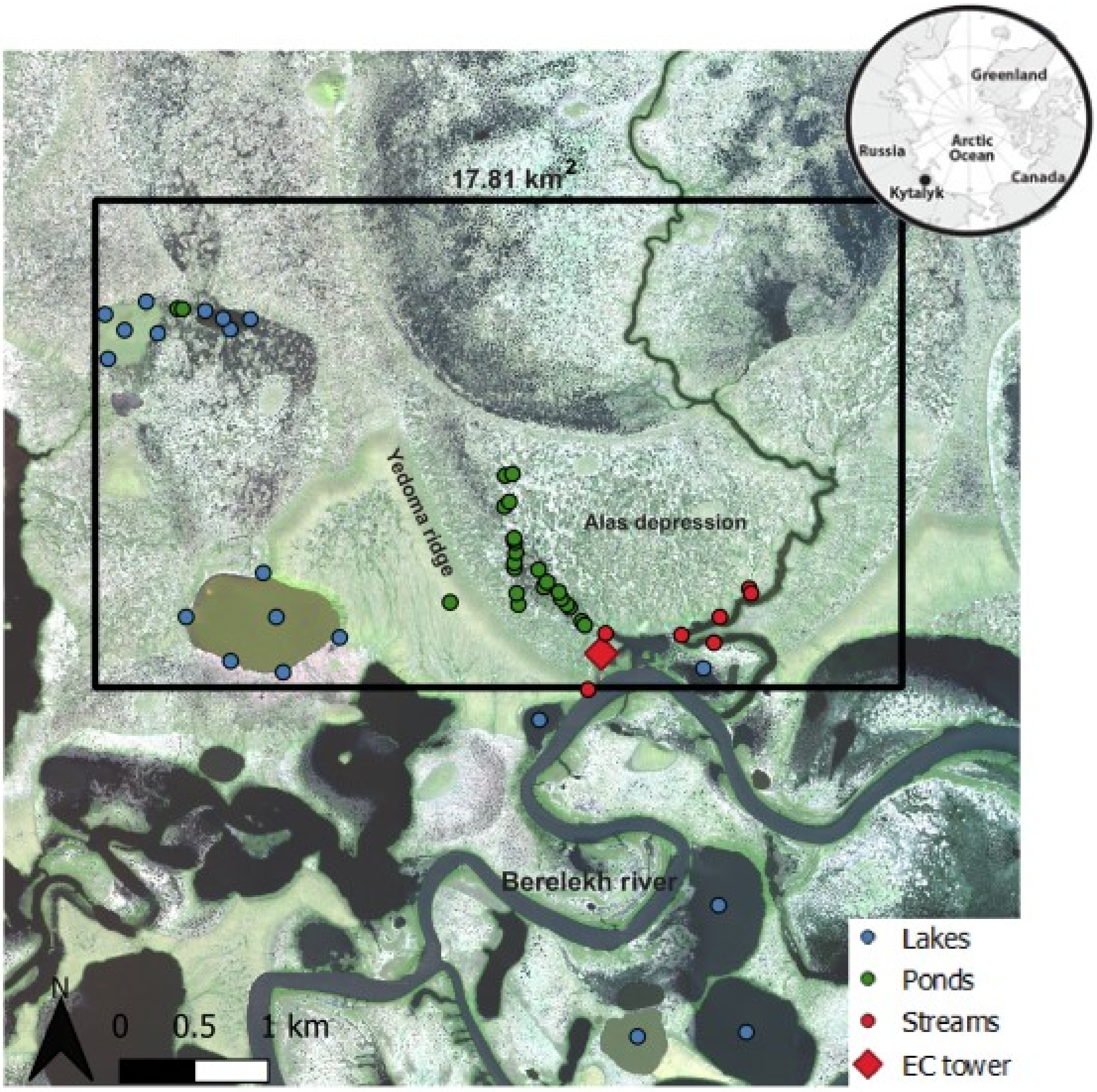
Surface areas of inland waters were determined applying a random forest classifier to the top of atmosphere values from a 2015 Worldview-2 image. To determine the flooded area a random forest classifier was applied to the top of atmosphere values from a 2017 Worldview-2 image. Any increased water surface area from 2015 to 2017 was assumed to be flooded area.

It is assumed that the carbon emissions of the bounded study area are a linear combination of CO_2 and CH_4 fluxes from lakes, ponds, fluvial systems and tundra (and flood water in 2017). To estimate the carbon flux exchange of the study area with the atmosphere a Monte Carlo uncertainty analysis was used. The uncertainties of gas concentrations, the gas transfer velocity and the surface area distribution were incorporated by randomly selecting values from a normal distribution of mean and standard deviation for 1,000 iterations.

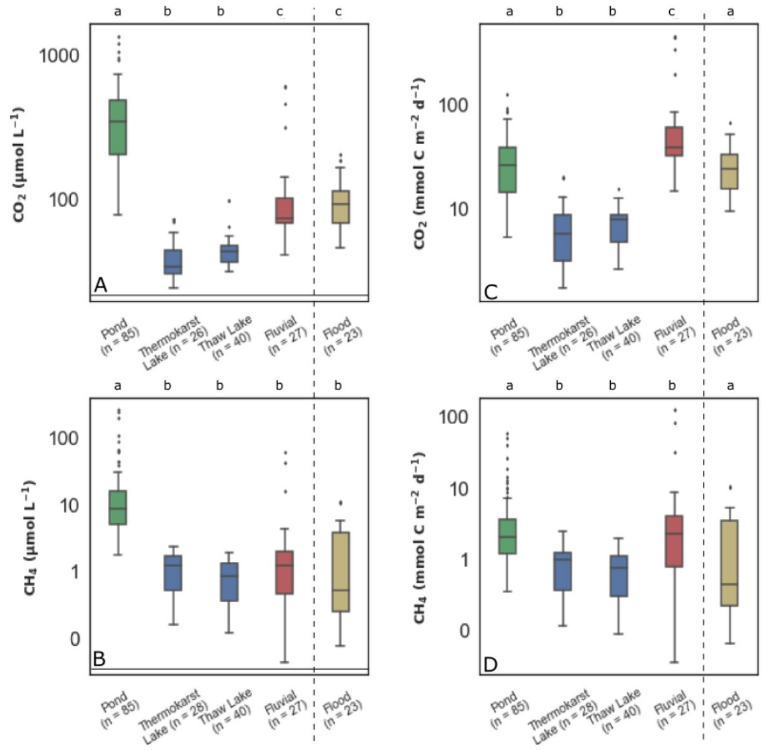
Mean eddy covariance tower measurements from summer 2015 (July-Aug) were used as tundra fluxes due to limited availability (Dean et al., 2020):

CO_2: -2784 ± 349 mg C m^{-2} d^{-1}

CH_4: 42 ± 5 mg C m^{-2} d^{-1}



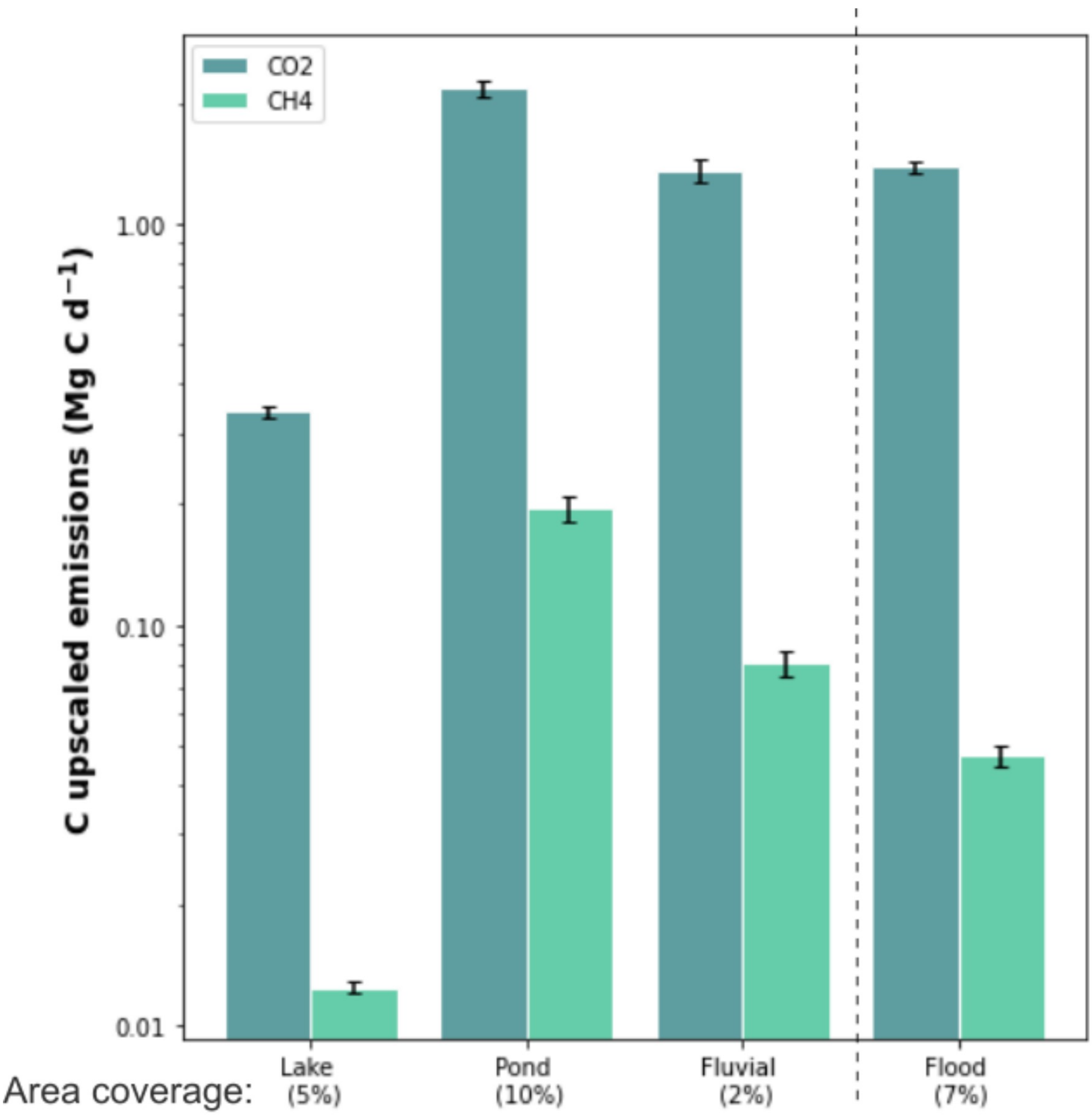
3 - CARBON CONCENTRATIONS AND FLUXES



CO_2 and CH_4 surface water dissolved concentrations (left) and fluxes (right) from 2015, 2016, 2017 (flood only 2017). Note the y-axes are in log-scale. The boxes indicate the interquartile range and the whiskers the 5th and 95th percentile. Letters indicate statistical difference between groups. The bottom lines in A and B indicate the mean atmospheric concentrations in equilibrium with the atmosphere, CO_2 = 19 µmol L^{-1} and CH_4 = 0.004 µmol L^{-1}.

- All sampled inland waters were **supersaturated** with dissolved CO_2 and CH_4 concentrations with respect to the atmosphere.
- **Ponds** have the highest C gas concentrations.
  - Only system with significantly different CH_4 concentrations.
- **CO_2 concentrations** are significantly different in lakes, ponds and fluvial samples likely reflecting differences in CO_2 production, mainly:
  - Respiration in lake sediments and water column.
  - External input to streams from large catchment area.
  - High localized input to ponds due to high perimeter to volume ratio.
- **Fluvial systems** have the highest flux rates due to a high gas exchange velocity ($k = 2.59 \pm 0.16$ m d^{-1}, mean ± std). Whereas:
  - Lake $k = 1.20 \pm 0.32$ m d^{-1}
  - Pond $k = 0.30 \pm 0.03$ m d^{-1}
  - Flood $k = 1.15 \pm 0.13$ m d^{-1}

4 - TOTAL SUMMER LANDSCAPE CARBON EXCHANGE



Barplots show the mean emissions of each inland water system. The error bars show the 95% confidence interval of the mean. Note that the y-axis is on a log scale.

The summer net landscape C exchange estimate (terrestrial + inland water) = -36.76 ± 1.04 Mg C d^{-1}, inland waters contributed to this:

- Lakes 1%
- Ponds 6%
- Fluvial systems 4%

Including inland water C emissions reduces the net landscape carbon sink estimate in summer by 25% in comparison to on only accounting for terrestrial fluxes.

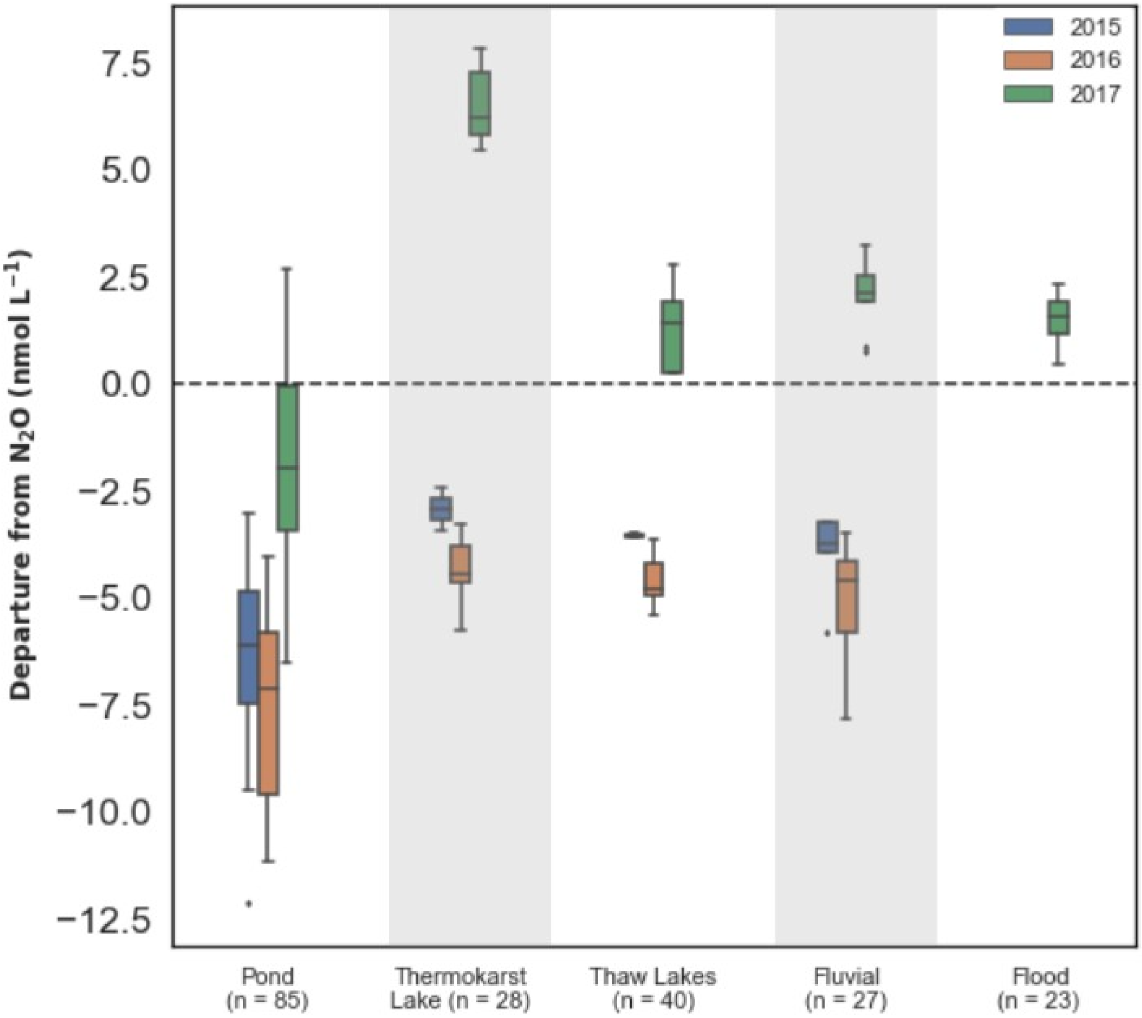
The summer 2017 net landscape C exchange estimate (terrestrial + inland water) = -32.18 ± 1.09 Mg C d^{-1}, inland waters contributed to this:

- Flood water contributed 5%

Adding an estimated 7% of flooded area, that previously was tundra, to the inland waters reduces the net landscape C

exchange estimate in summer by 34%, in comparison to on only accounting for terrestrial fluxes.

5 - NITROUS OXIDE



Departure from N_2O gas saturation per year and inland water system. Departure from saturation is the difference between the surface water concentration and the concentration in equilibrium with the atmosphere. Positive values indicate flux to the atmosphere, negative values indicate flux to the surface water.

Lake, pond and fluvial systems vary between **weak N_2O sources and sinks**.

Concentrations in 2017 when flooding occurred are higher in all inland waters.

- A predicted increase in snow water equivalent and decrease in snow cover duration could increase the magnitude and/or duration of flood events in Siberia in the future (Callaghan et al., 2011). Thus, studies monitoring N_2O concentrations and fluxes, and investigating the source and drivers of these in the Arctic are warranted.

CH_4 and N_2O fluxes were converted to CO_2-equivalent using sustained global warming and cooling potentials (Neubauer & Megonigal, 2015) to be able to determine the total inland waters GHG exchange with the atmosphere. **N_2O contributed less than 0.1% to the total GHG emissions of the inland waters** (0.002% in 2015 and 0.003% in 2017) . Thus, at the considered scale N_2O fluxes are negligible in the Arctic Siberian tundra.

6 - CONCLUSIONS

1. The total landscape carbon sink estimate are reduced by 25% when inland waters (lakes, ponds and flvuial systems) are included.
2. At the scale considered N_2O emissions are negligible contributors to the total landscape (terrestrial + inland waters) GHG exchange.
3. Flooded tundra area contributed to the carbon emissions of inland waters and reduced the total landscape carbon sink estimate by 34% in comparison to on only accounting for terrestrial fluxes.
    1. N_2O concentrations were higher in all freshwater systems when flooding occurred.

Takeaway:

- Carbon emissions from inland waters, especially with small surface areas (ponds and streams), need to be integrated into terrestrial carbon balances in the Siberian Arctic tundra.
- Flooding of Arctic lowlands requires more systematic process investigation to determine controls on greenhouse gases.

ABSTRACT

Inland waters are an ubiquitous feature of Arctic landscapes, with carbon (C) and nutrient cycles that are closely coupled to terrestrial processes. They act as important conduits of terrestrial matter by not only transporting but also actively storing and processing it, subsequently emitting greenhouse gases (GHG) of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) to the atmosphere. Amplified climate warming at northern high-latitudes is changing contemporary carbon and nitrogen cycles and driving permafrost thawing which has the potential to mobilise organic matter from vast stocks stored in Arctic tundra permafrost soils. Released carbon and nitrogen becomes available to degradation producing GHGs which inland waters emit to the atmosphere, thus forming a positive feedback to climate change.

GHG emissions from tundra ecosystems vary regionally with local environmental and climate factors. Dissolved GHG concentrations in collected samples from the Indigirka watershed were measured and fluxes computed during three growing seasons (2015, 2016, 2017) to provide insight into the role of each type of aquatic system in this region. Fluvial CO_2 and CH_4 fluxes (85.7 ± 29.7 mmol C m^{-2} d^{-1}, 10.6 ± 27.3 mmol C m^{-2} d^{-1}, respectively mean ± STD) were the highest, followed by pond fluxes (30.0 ± 21.0 mmol C m^{-2} d^{-1}, 4.9 ± 9.4 mmol C m^{-2} d^{-1}) and finally fluxes from lake sites (8.6 ± 7.6 mmol C m^{-2} d^{-1}, 0.84 ± 0.57 mmol C m^{-2} d^{-1}).

The aim of this study was to quantify the effect of inland water emissions on the landscape C exchange. This was done by using remote sensing information to upscale emissions and integrate them into the terrestrial C exchange of the study area. As N_2O has a large warming potential and received scant attention in the Arctic biome so far its contribution to terrestrial aquatic fluxes was also assessed. The effect of an extensive flooding event in 2017 on the landscape GHG exchange was also evaluated since increased flooding occurrence is what climate change might hold for this region. Greater insight into these aspects will increase understanding of GHG dynamics among inland waters in the north-eastern Siberian Arctic tundra lowlands which is essential for forecasting, climate-impact-assessment and to better constrain the feedback to climate warming.