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Thaw pond dynamics and carbon emissions in a Siberian lowland tundra landscape

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Arctic climate change induces drastic changes in permafrost surface wetness. As a result of thawing ground ice bodies, ice wedge troughs and thaw ponds are formed. Alternatively, ongoing thaw may enhance drainage as a result of increased interconnectedness of thawing ice wedge troughs, as inferred from a model study (Liljedahl et al., 2016, Nature Geoscience, DOI: 10.1038/NGEO$_2$674). However, a recent review highlighted the limited predictability of consequences of thawing permafrost on hydrology (Walvoord and Kurylyk, 2016, Vadose Zone J., DOI:10.2136/vzj2016.01.0010). Overall, these changes in tundra wetness modify carbon cycling in the Arctic and in particular the emissions of CO_2 and CH_4 to the atmosphere, providing a possibly positive feedback on climate change.

Here we present the results of a combined remote sensing, geomorphological, vegetation and biogechemical study of thaw ponds in Arctic Siberian tundra, at Kytalyk research station near Chokurdakh, Indigirka lowlands. The station is located in an area dominated by Pleistocene ice-rich 'yedoma' sediments and drained thaw lake bottoms of Holocene age. The development of three types of ponds in the Kytalyk area (polygon centre ponds, ice wedge troughs and thaw ponds) has been traced with high resolution satellite and aerial imagery.

The remote sensing data show net areal expansion of all types of ponds. Next to formation of new ponds, local vegetation change from dry vegetation types to wet, sedge-dominated vegetation is common. Thawing ice wedges and thaw ponds show an increase in area and number at most studied locations. In particular the area of polygon centre ponds increased strongly between 2010 and 2015, but this is highly sensitive to antecedent precipitation conditions. Despite a nearly 60% increase of the area of thawing ice wedge troughs, there is no evidence of decreasing water surfaces by increasing drainage through connected ice wedge troughs.

The number of thaw ponds shows an equilibrium between newly formed and disappearing ponds, although their net area increased by 16%. The disappearing of ponds was mostly the result of vegetation succession, rather than drainage. This vegetation succession results from an invasion by sedges, followed by establishment of Sphagnum and seedlings of dwarf shrubs.

The formation of thaw ponds and troughs resulting from small-scale permafrost collapse results in a drastic change of CH_4 and CO_2 emissions, from near-zero emission or uptake to high emission. New water surfaces with drowned dry tundra vegetation show the highest emission. However, rapid vegetation succession may mitigate these emissions over time, in particular in the relatively shallow thaw ponds. In contrast, the polygon centre ponds with a stable, oligotrophic vegetation show modest and constant CH_4 emission and CO_2 uptake.