Rapid thaw pond formation in Northeast Siberia transfers permafrost carbon to the atmosphere.

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The formation of small ponds by shallow thawing of ice-rich permafrost may represent an immediate reaction of permafrost soils to climate change, contrasting with thaw lakes which take a longer development and may be inherited from the past. We studied thaw ponds in arctic tundra on ice-rich continuous permafrost in the Indigirka lowlands of Northeast Siberia, an area that has experienced modest warming. Dominating landforms are thaw lakes, drained lake basins, thaw lakes and remnants of Pleistocene ice complex deposits ('yedoma'). With increasing age, the drained lake basin soils accumulate more ice in ice wedges and mineral palsas.

Thaw ponds in the area result from melting of ice wedges (ice wedge ponds, IWP) or from degradation of mineral palsas (palsa thaw ponds, PP). The PP’s have a diameter of a few meters, a depth up to 0.5 m and may be intermittently dry. The IWP’s are deeper, and have an elongate ditch-like shape. IWP and PP can be discriminated from ice wedge polygon centre ponds (PCP) which show a regular polygonal pattern and do not show die-back of dry tundra vegetation by paludification as in IWP and PP. PP’s show more rapid vegetation succession than the IP’s, leading to the (partial) recovery of vegetation. Most of the PP’s appear to have formed spontaneously. However, pond formation was also induced by accidental or experimental disturbance of the tundra vegetation cover. Comparison of a Keyhole image from 1977 with a Geo-eye image from 2010 shows that the number of PP’s increased significantly. This indicates a 2.9 ± 0.9 times increase in the number of ponds in 33 years.

The ponds are significant sources of CH$_4$ and CO$_2$, derived from decomposition of dead vegetation and soil organic matter. Averaged CO$_2$ fluxes measured with static chambers amount for PP’s $+106±29$ mg CO$_2$ m$^{-2}$ hr$^{-1}$, for PCP ponds $-77±30$ mg CO$_2$ m$^{-2}$ hr$^{-1}$, for dry palsa surface with Betula nana $-180±22$ mg CO$_2$ m$^{-2}$ hr$^{-1}$. When PP’s revegetate, a sedge vegetation develops, with an uptake flux of $-224±42$ mg CO$_2$ m$^{-2}$ hr$^{-1}$. CH$_4$ fluxes for the same areas are $3.60±1.2$ mg CH$_4$ m$^{-2}$ hr$^{-1}$ (PP), $3.69±0.56$ mg CH$_4$ m$^{-2}$ hr$^{-1}$ (PCP), $-0.38±0.15$ mg CH$_4$ m$^{-2}$ hr$^{-1}$ (dry palsa), $3.97±0.25$ mg CH$_4$ m$^{-2}$ hr$^{-1}$ (revegetated pond). IWP’s show the highest CH$_4$ fluxes, $4.42±3.60$ mg CH$_4$ m$^{-2}$ hr$^{-1}$; CO$_2$ fluxes not measured. The thaw ponds therefore transfer areas of dry tundra vegetation with CO$_2$ and CH$_4$ uptake to areas of strong emission of both greenhouse gases. Upon revegetation, high CH$_4$ emissions remain but this is balanced by strong CO$_2$ uptake. The speed of the revegetation process is under study, likely in the order of several years to decades.

By contrast to ponds, thaw lakes in the same area show minor expansion. Our data suggest that a drastic increase in the number of small thaw ponds, rather than thaw lake expansion, represents a fast response of ice-rich permafrost soils to climate change and may contribute significantly to the increase of greenhouse gas emissions and carbon from permafrost soils. Moreover, the creation of similar ponds by anthropogenic vegetation disturbance suggests that increase of human activity in permafrost areas aggravates greenhouse gas emissions from permafrost soils.