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Thermokarst lake drainage in the continuous permafrost zone of NW Alaska and climate feedbacks

Guido Grosse (1), Katey Walter Anthony (1), Benjamin Jones (1), Lawrence Plug (2), and Vladimir Romanovsky (1)

(1) University of Alaska, Fairbanks, USA (ggrosse@gi.alaska.edu), (2) University of Dalhousie, Halifax, Canada

Thermokarst lakes (TKL) are considered an important source of atmospheric CH4 in past, current and future budgets. Previous research reports the loss of TKL in discontinuous permafrost due to drainage, and an increase in TKL in continuous permafrost due to thermokarst. Contrary to this current hypothesis, we observe a massive loss of TKL in ice-rich continuous permafrost in a 12,200 km2 study region on the Seward Peninsula (Alaska) using long-term remote sensing data. Of the 1443 TKL >5 ha in 1950, 118 (8.2%) drained completely (-100% in area) and 523 (36.3%) largely or considerably (-99% to -10%) by 2008. Lake area of 8611 ha was lost over the 58 year period within these two classes, equaling 22% of the total TKL area (39,156 ha) in 1950. Though most TKL continuously expanded at rates of up to 1.5 m/yr, the growth did not offset the area loss from drainage. 273 TKL (18.9%) show area increase (>+10%), while 529 TKL (36.7%) remained relatively stable (-10% to +10%). TKL formation is extremely rare in the study area and only detectable with high-resolution imagery. Our TKL drainage rates are an order of magnitude higher than any previously reported for continuous permafrost zones. Field data, remote sensing, and numerical modeling show that growth of TKL in ice-rich permafrost of the study region is likely limited by relief gradients, increasingly causing rapid drainage. Frequency and magnitude of drainage events depend on current TKL areal coverage, and on number and gradient of potential drainage pathways. In regions less deeply incised by basins and channels, possibly including parts of the Siberian Yedoma, we assume TKL drainage area to be delayed. Erosion of ice wedge polygonal networks and gully formation are central mechanisms for TKL drainage in ice-rich continuous permafrost, highlighting the potential impact of continued surface permafrost degradation on drainage rates. The refreezing of drained TKL basins in continuous permafrost results in formation of new permafrost. Long-term flux measurements imply that replacement of CH4- and CO2-emitting TKL with carbon-sequestering frozen peatlands during post-drainage succession results in a net reduction of greenhouse gas emissions. Remote sensing data also indicates increases in land surface reflectance properties after TKL drainage, namely land surface albedo, skin temperature, and vegetation indices. The normalized difference vegetation index in a freshly drained basin increased from near 0 to 0.8 within 3 years after lake drainage, caused mainly by re-vegetation of nutrient-rich lake sediments with highly productive grasses. This 'greening' effect peaks after several years as vegetation transitions to typical sedge-moss tundra. Changes in carbon budgets and surface reflectance properties are sustained for several decades to millennia until new TKL form in the basin. Our results indicate that surface permafrost degradation probably will increase TKL drainage in some ice-rich continuous permafrost areas, producing complex non-linear environmental feedbacks with the Arctic land surface and climate, and representing a potentially negative climate feedback.