The rates of thermocirque development and driving factors of their activation on Central Yamal, Russia

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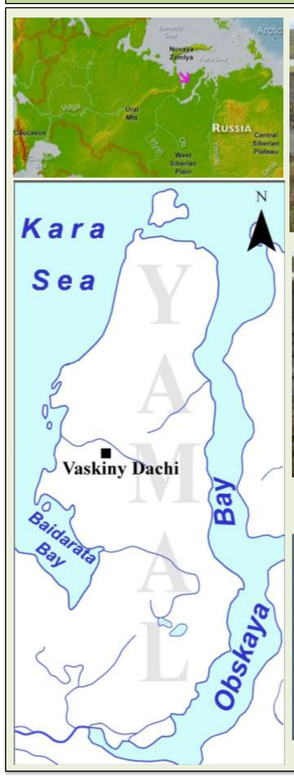
Climatic fluctuations over the past few years significantly affected the increase of cryogenic processes activity in the tundra zone of the Yamal Peninsula. On Central Yamal a large-scale cryogenic landsliding was observed in 1989, while cryogenic earth flows were actively developing since 2012 through tabular ground ice thawing. As a result, thermocirques form on lakeshores.

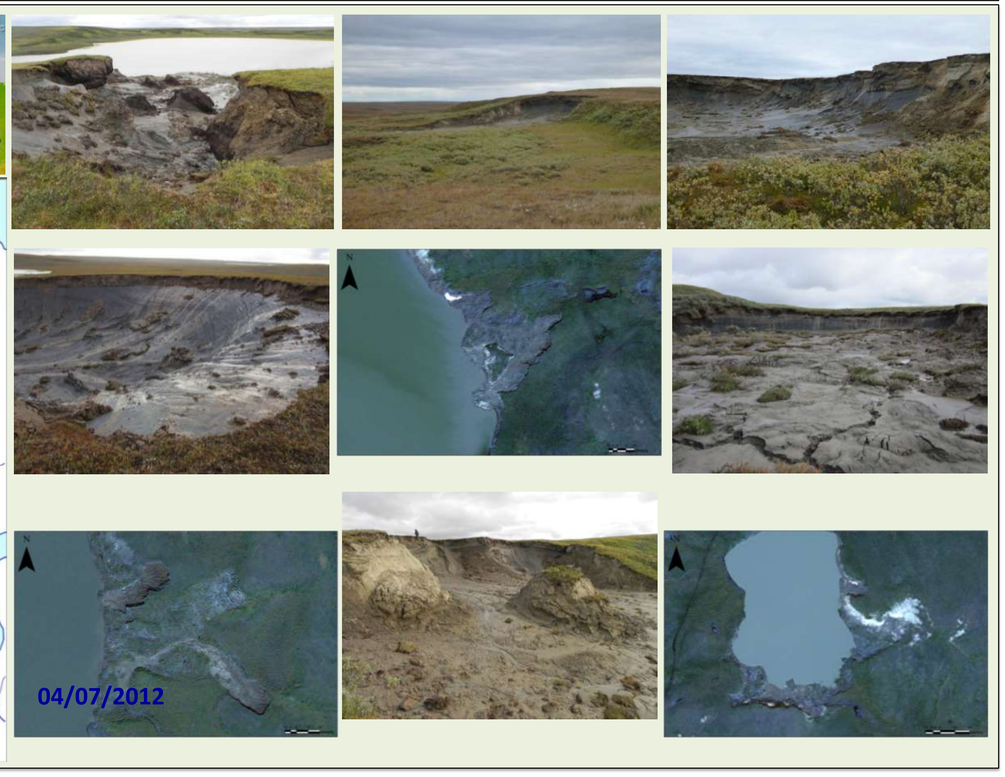
Key area (research station "Vaskiny Dachi" on the Se-Yakha and the Mordy-Yakha interfluve) during the period from 1989 to 2012 was characterized by a local occurrence of thermal denudation. By 2010, remote sensing data showed that this process in the study area was usually inactive and thermocirques looked stabilized, overgrown by vegetation.

Extremely warm summer of 2012 resulted in formation of new thermal denudation features, such as cryogenic translational landslides (active-layer detachments), cryogenic earth flows and furthermore, thermocirques, complex landforms resulting from ice wedges and tabular ground ice thaw. The 2012 warm season was characterized by a deeper active layer: at the end of the warm period deeper by 15% than the average for the 1993-2011. Observed were indications of a high pore pressure in the active layer: effuse of liquefied clay in the tension cracks* on many slopes.

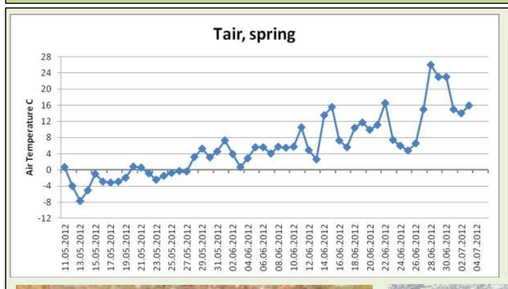
Under such extreme deepening of active layer, a number of new landslides appeared, only very few being translational landslides (active-layer detachments). Most landslides were earth and mud flows. While translational landslide events are separated by decades of centuries and form landslide cirques, earth/mud flows form thermocirques which once being triggered, develop until either ice exhausted, or insulated by landslide bodies from further thaw.

Study area & examples of thermocirques (after 2012)

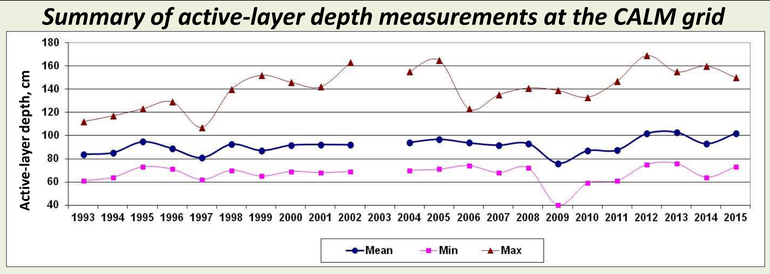




Activation of slope processes in 2012



Summary of active-layer depth measurements at the CALM grid



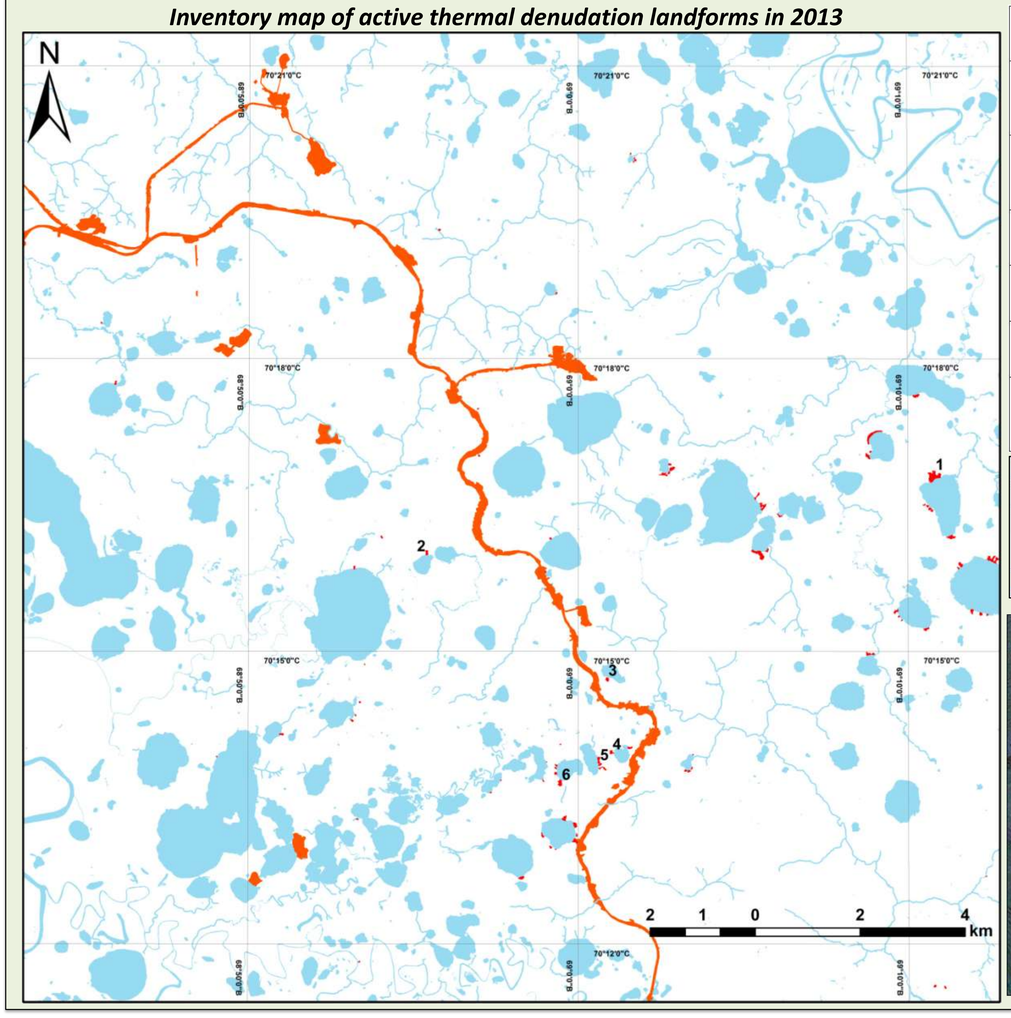
By 2013, according to the field and remote sensing data, there were more than 90 active thermal denudation landforms from 66 to 25000 m² in size on the territory of 345 km².

Comparison of satellite images of 2010 and 2013 for the same area of 315 sq.km showed that the number of active thermal denudation forms in technogenically undisturbed environments has increased from 11 to 65. In 2010 there was only non-significant activity in the upper part of overgrowing thermocirques and thermoterraces, while in 2013 there were mostly new and re-activated thermocirques with considerable backwall retreat.

Six thermocirques originating from the thaw of tabular ground ice or both tabular and ice-wedge ice, having high retreat rates, are annually monitored since 2012-2013. Monitoring shows that at an initial stage of activation the rate of retreat is the highest. During the first year of activation thermocirque area increase twofold from initial size for the new ones, and increase by 50% of their initial area for re-activated thermocirques and thermocirques with ice wedges on top. Maximum annual retreat can reach up to 25-30 m/year, with average values of 15 m/year.

Thermal denudation landforms location and monitoring

Inventory map of active thermal denudation landforms in 2013



Thermocirque ID	Ground ice	Date of retreat measurement	Area of thermocirque, th.sq.m (area increase, %)
1	Tabular ice	05.07.2013 26.08.2013 27.08.2014 26.08.2015	25,7 30,8 (19,8) 35,9 (16,5) 40,8 (13,6)
2	Tabular ice and ice wedges	05.09.2012 05.07.2013 27.08.2013 30.08.2015	2,3 2,9 (26,9) 4,2 (45,9) 6,4 (50,2)
3	Tabular ice	05.07.2013 31.08.2014 25.08.2015	3,3 5,0 (51,5) 5,7 (14,0)
4	Tabular ice and ice wedges	05.07.2013 27.08.2013 26.08.2015	2,6 4,1 (57,7) 4,7 (14,6)
5	Tabular ice	05.07.2013 27.08.2013 26.08.2015	1,3 2,9 (123,1) 5,1 (75,9)
6	Tabular ice	05.07.2013 27.08.2013 27.08.2014 26.08.2015	5,8 7,6 (31,0) 8,5 (11,8) 10,2 (20,0)

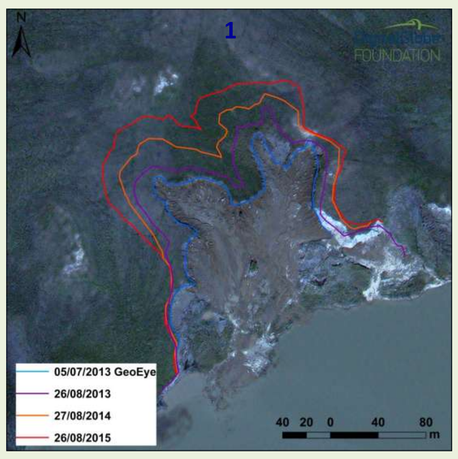
a. Large rivers and streams; b. Lakes, ponds

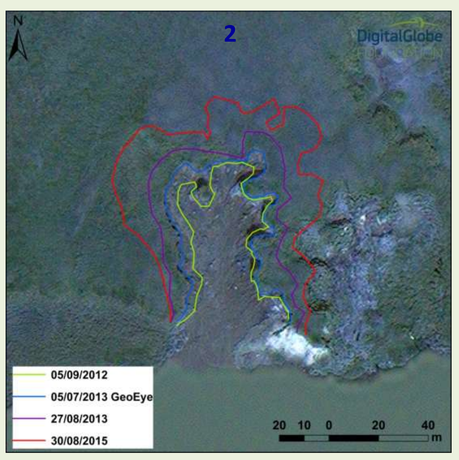
Small rivers and streams

Active thermal denudation landforms

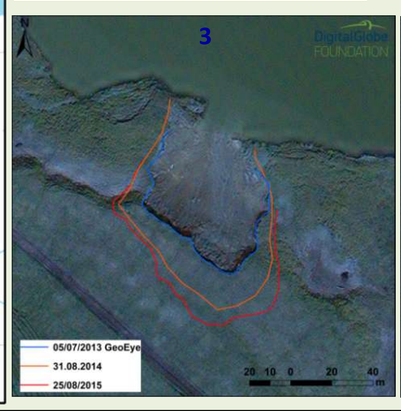
1 - 6 Thermal denudation landforms under monitoring since 2012-2013

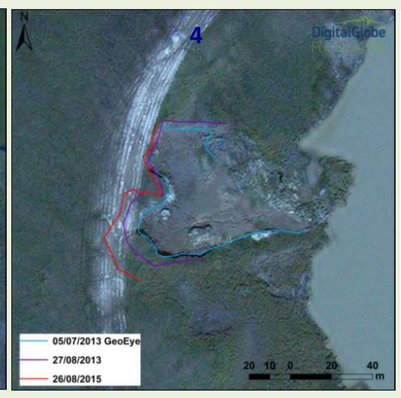
Technogenic objects

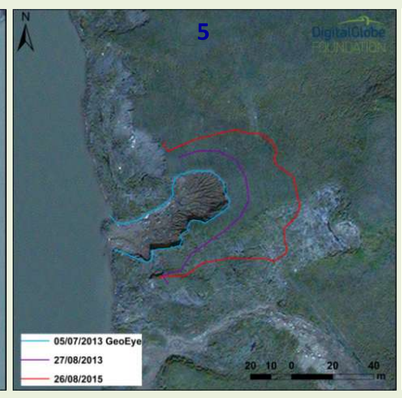


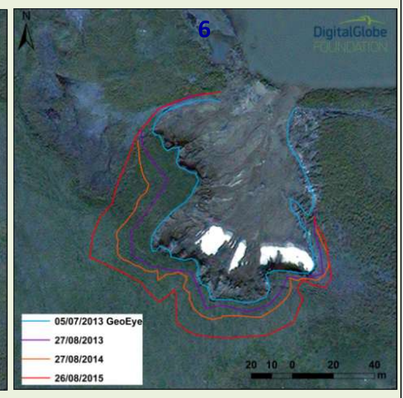


The thermocirque backwall position on satellite image in the first half of the warm period of 2013 and the field data at the end of summer of 2012-2015 are compared. Comparison shows that rate of the thermocirque area increase slows down following gradual increase of their total area. However, field measurements of 2015 shows that backwall retreat rate is still high.









Thus, at present in the Yamal Peninsula tundra predominance of processes associated with tabular ground ice thawing (cryogenic earth flows) over the processes associated with the ice formation at the bottom of the active layer (cryogenic translational landslides) is observed. It is caused by both a periodic deepening of the active layer, and consecutive increase of ground temperature.

Activation of thermal denudation observed on the Yamal Peninsula last years is associated with extremely warm spring and summer of 2012. By the end of the warm season thawing of the top of icy permafrost and tabular ground ice on some slopes resulted in cryogenic landsliding and further thermocirques development.

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