Activation of cryogenic processes in Central Yamal as a result of climate change and thermal state of permafrost

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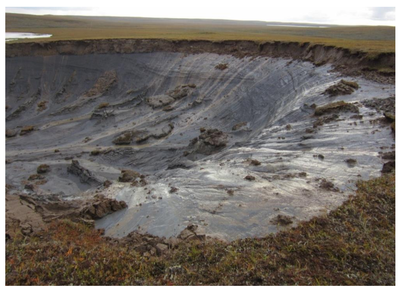
The central part of the Yamal Peninsula is known for wide distribution of tabular ground ice.

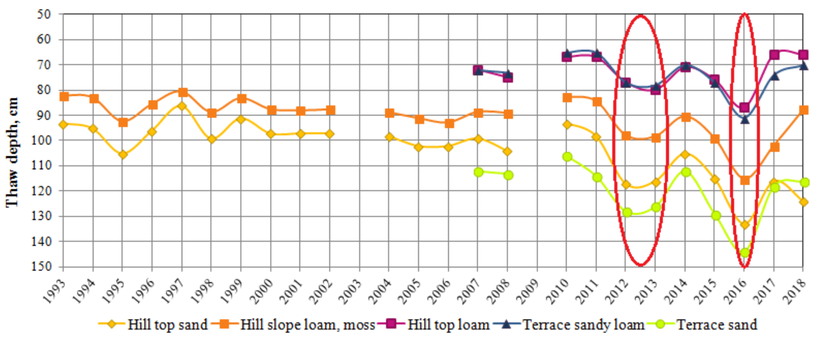
Abnormal weather conditions over the past few years significantly affected increase of activity of cryogenic processes associated with ground ice thawing in Central Yamal. Air temperature rise resulted in increased warm season thawing reaching the top of ground ice. Thus thermodenudation started and caused formation of thermocirques.

Thermocirques in Central Yamal



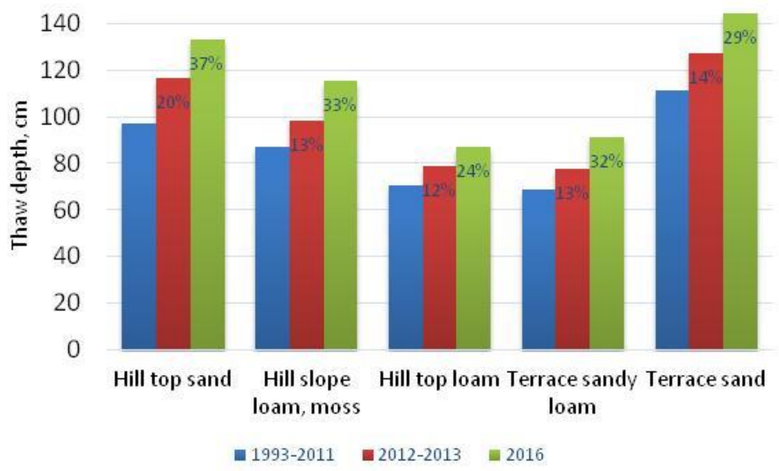
The warm season thawing dynamics was studied along four grids with various surface features in the research station "Vaskiny Dachi" in Central Yamal within the framework of CALM program.

Perennial dynamics of the thaw depth for various surfaces



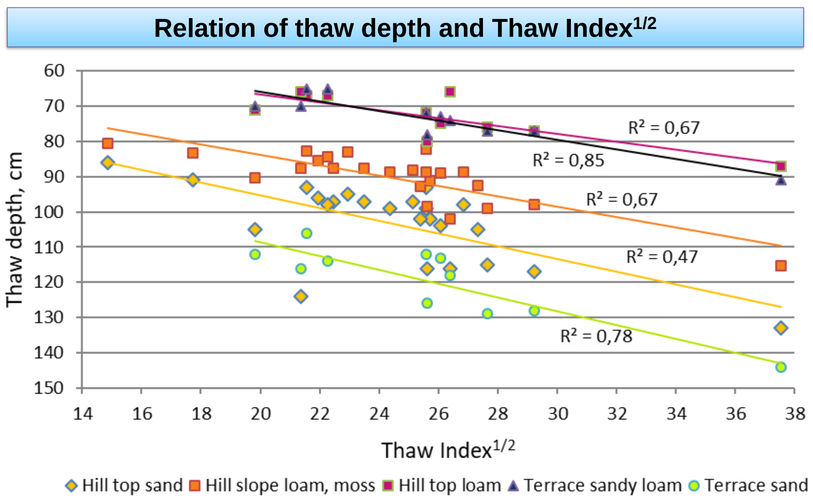
All types of surface are characterized by a significant deepening of active layer in 2012-2013 and 2016 compared to the previous period 1993-2011.

Thaw depth increase



Years of 2012 and 2016 are characterized by the highest thaw index and the largest sum of summer precipitation.

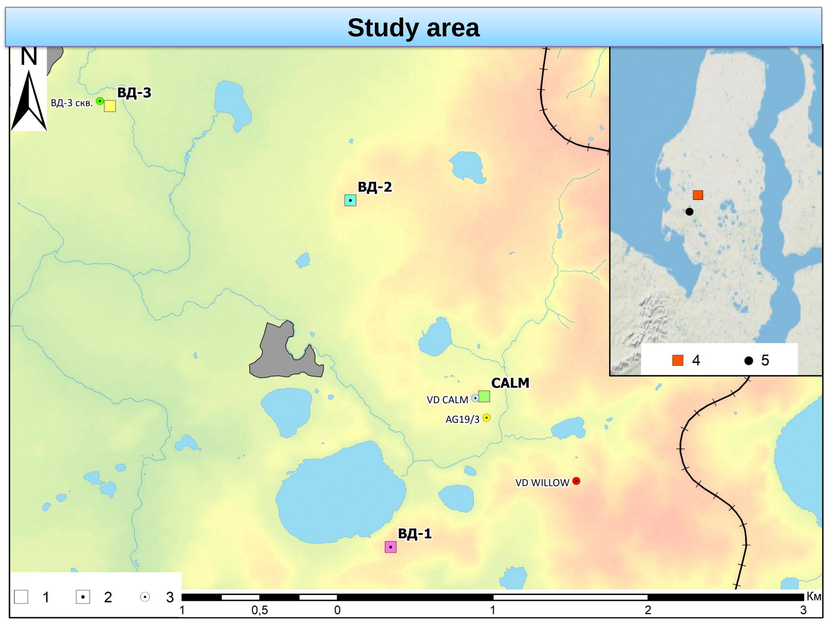
Relation of thaw depth and Thaw Index$^{1/2}$



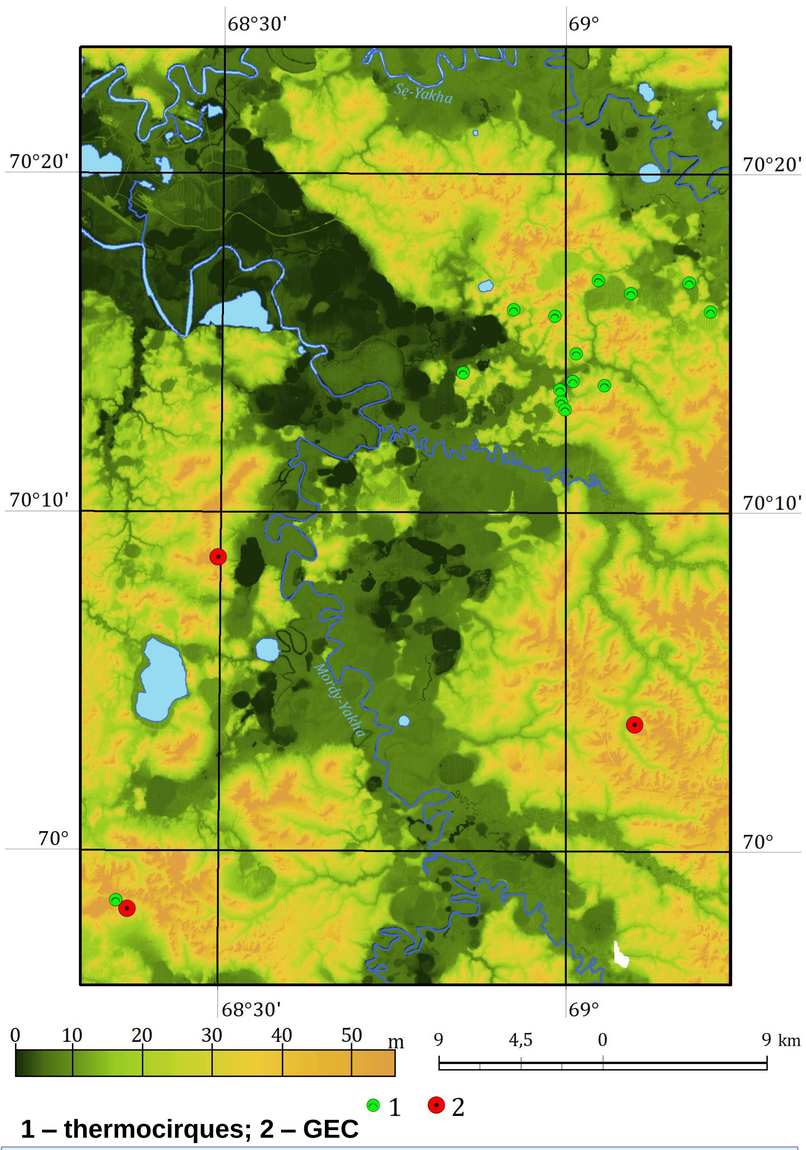
The thaw depth at all grids of this site correlates well with Thaw Index$^{1/2}$ from the Marrre-Sale weather station records

Thus, an increase of summer air temperature and amount of summer precipitation influenced the formation of thermocirques through warm season thawing increase.

Study area

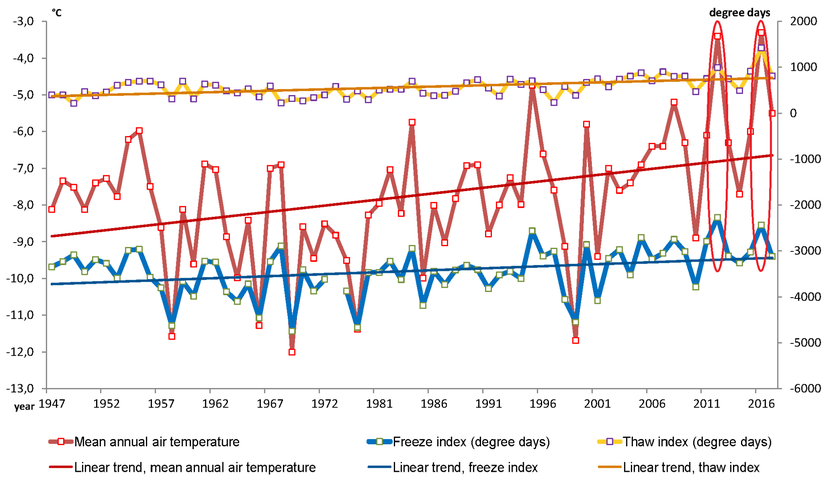


1 – thaw depth monitoring grids; 2 – thaw depth monitoring grids with a borehole; 3 – standing separately boreholes; 4 – Research station «Vaskiny Dachi»; 5 – GEC-1



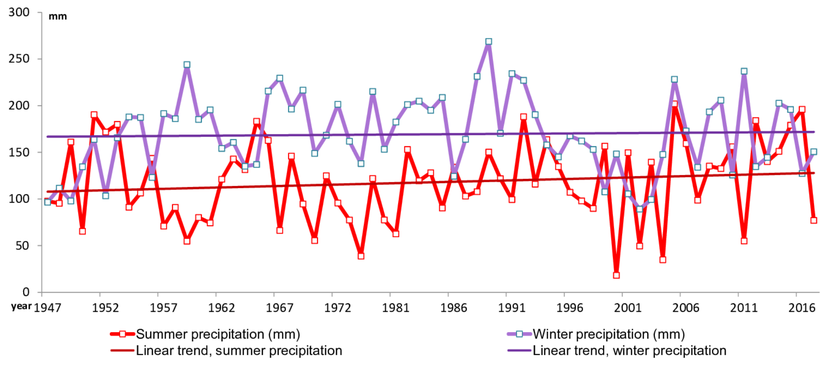
1 – thermocirques; 2 – GEC

Interannual fluctuations of air temperature



We use the records of the weather station Marre-Sale closest to the key area.

Interannual fluctuations of air temperature



Analysis of climatic parameters showed that there is a warming trend over the period from 1947, the expected year of the beginning of gas release within permafrost and the growth of the mound.

From 1947 there is increasing trend of the winter air temperature till 2013 with the highest value in 2012. Trend of the sum of winter precipitation was not observed.

Acknowledgments

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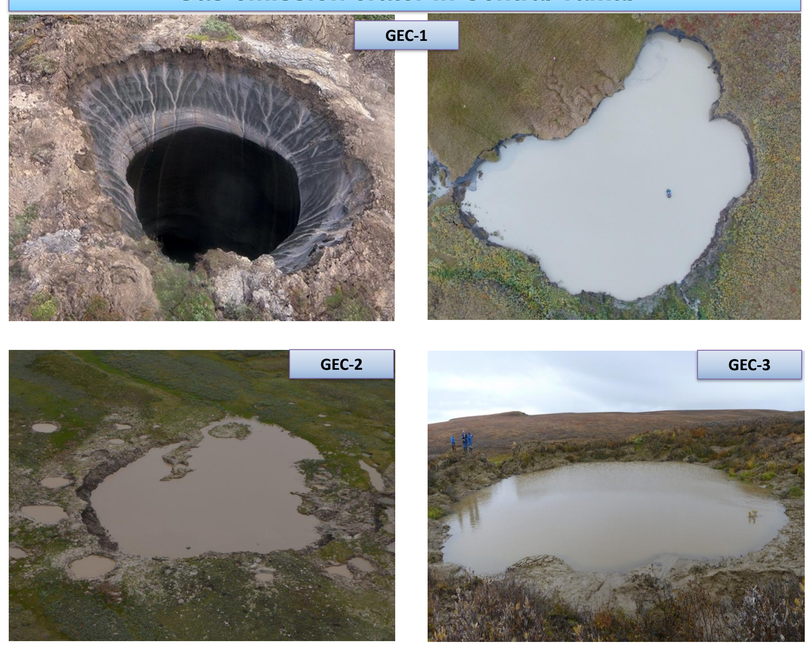
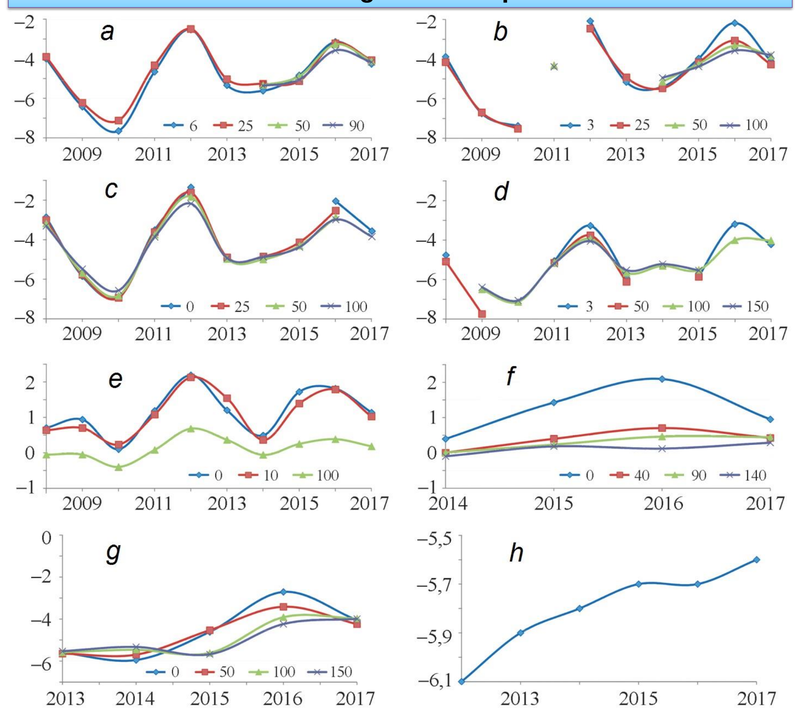
Climate fluctuations also lead to increase of ground temperature, which triggers gas-emission crater (GEC) formation through decomposition of methane clathrates up to formation of high pressure under the tabular ground ice layer until it breaks.

Gas-emission crater in Central Yamal



To explain the reasons for the GEC formation, ground temperature data obtained within the framework of TSP program were analyzed. Dynamics of the measured temperature at different depths in thermometric boreholes located in different landscape and geological conditions (from sparsely vegetated sands to shrubby clay) were considered.

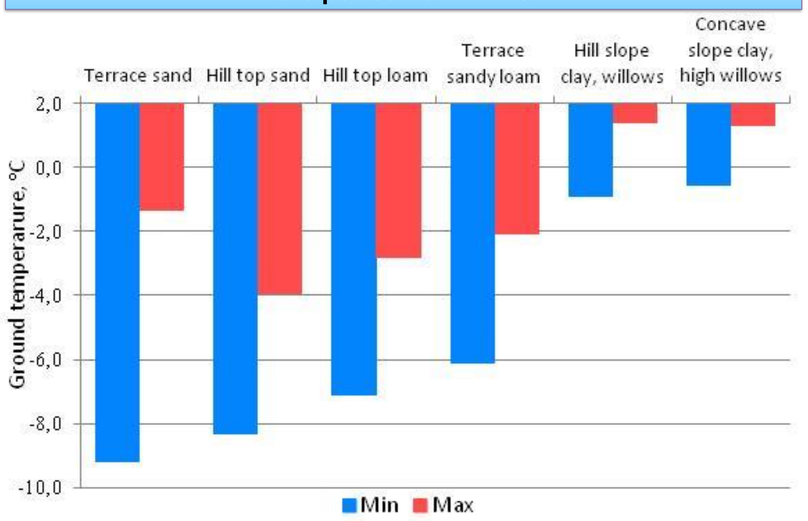
Mean annual ground temperature



a-hill top loam; b-terrace sandy loam; c-terrace sand; d-hill top sand; e-hill slope clay willows; f-concave slope clay, willows; g, h-hill top sand

The mean annual active layer temperature tends to substantial increase in 2012 and 2016. Also, there is a significant increase of the ground temperature at 10 m depth, starting from the moment the borehole was established (the growth over 5 years is 0.5°C).

Min and max ground temperature at the active-layer base for the period 1947-2013



T_g, °C (2015 r.)									
						GEC-1			
Hill slope clay, willows	Concave slope clay, high willows	Hill top sand	Hill top loam	Terrace sandy loam	Terrace sand	Shrubby upper part of slope	Nearest vicinity of GEC-1 edge	Thermokarst lake coast	Khasyrey
0,2	0,2	-5,5	-5,1	-4,4	-4,4	-4,3	-1,2	-1,6	-2,7

A regression analysis was carried out to reconstruct the ground temperature in earlier periods of time in the years preceding the appearance of GEC. It was found that the mean annual ground temperature increased by approximately 0.4°C at the shrubby landscape most similar to that around GEC. It follows then that in 1947 ground temperature at a depth of 70 m was -1°C, which corresponds to our observations of the temperature at which ice lenses exist in saline clay.

Most likely, ground temperature increase in the clay from -1 to -0.5°C provoked increase of unfrozen water content, provided permeability of clayey deposits to migration of gas and its accumulation under tabular ground ice.