Geocryological conditions triggering thermokarst processes in Central Yakutia

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HYDROGRAPH MODEL

Relevance

Climate change

multidirectional dynamic of thermokarst lakes in different regions of Russia

Thermokarst lakes

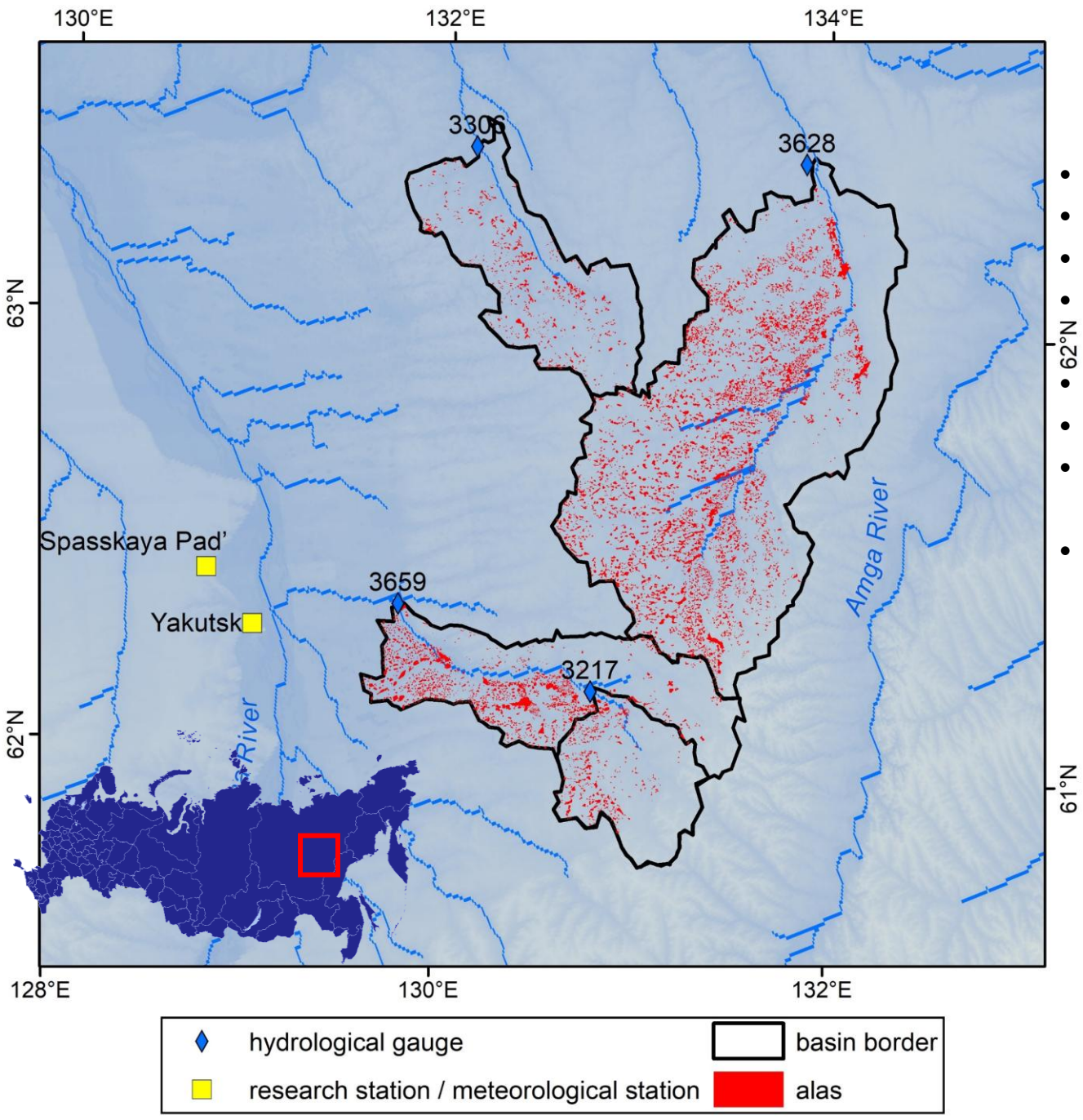
the most common lakes in Central Yakutia

80 %

of the total number of lakes in Yakutia

to investigate the conditions that lead to the nonlinear dynamics thermokarst lakes development in Central Yakutia, based on the analysis of remote sensing data and detailed observations of the state of active layer of soil.

Study area



- The South-Eastern part of the Central Yakutia.
- Average absolute height of 250 m.
- The climate is sharply continental.
- Air temperature is -8.8 ºC (Yakutsk weather station, 1966-2018).
- Annual precipitation is 237 mm (75-85 % falls in the summer).
- Continuous permafrost zone.
- Grassy-lingonberry larch on permafrost-taiga field and podzol soils.
- The most mature thermokarst forms, **the alases**, are covered with meadow-steppe vegetation with saline soils.

Index	River basin	Basin area, km²	Alas area, km²/%	Lake area, 09.06.2019, km² / %	Number of images	Min lake area, km² /year	Max lake area, km² /year
3217	**Suola River– Buteidah**	1270	81.7/6.4	17.85/1.41	58	**8.89 /2003**	**19.4 / 2018**
3306	**Tanda River - Baria**	2000	97.9/4.9	27.67/1.38	11	**23.4 / 2001**	**29.4 / 2018**
3628	**Taatta River – Uolba**	8290	776/9.4	213.28/2.57	7	**118 / 2001**	**225 / 2018**
3659	**Suola River– Bedeme**	3380	326/9.7	66.05/1.95	27	**34.0 / 2004**	**70.8 / 2008**

Method

Remote sensing data

54 images from Landsat satellites (TM, ETM+, OLI sensors).
Period from 2000 to 2019.
Summer season (from June to September).
Large lakes (more than 1 ha).

The method steps:

1) conversion of brightness values in spectral channels from the initial values to reflectivity and atmospheric correction using the DOS method, using the Qgis semi-automated image classifier (SCP) module;
2) selection of water surface by the threshold value of the normalized difference water index NDWI (the threshold is set to 0.3);
3) conversion to a vector data format, calculation of areas, removal of objects with an area of less than 1 ha.

Land-based observations

Observations at the Spasskaya Pad' research station Characteristics of active layer and snow cover with the dynamics of the thermokarst lakes:

1) daily observations of soil moisture at depths of 0.1, 0.2, 0.4, 0.6, 0.8 m (1998-2010).
2) daily observations of soil temperature to a depth of 1.2 m (1998-2010).
3) soil moisture (up to 1.5 m) and soil temperature (up to 3.2 m), which were collected 1-2 times a month for the period 1998-2018 (data provided by A. N. Fedorov, Melnikov Permafrost Institute).
4) The data on snow cover and soil temperature at a depth of 1.6 m at Yakutsk weather station.

The sites representing for larch forest and typical landscape conditions of the Central Yakutia.

Result. Dynamic of thermokarst lakes

The area of thermokarst lakes increased twice within three of the four study basins in 2000-2019.

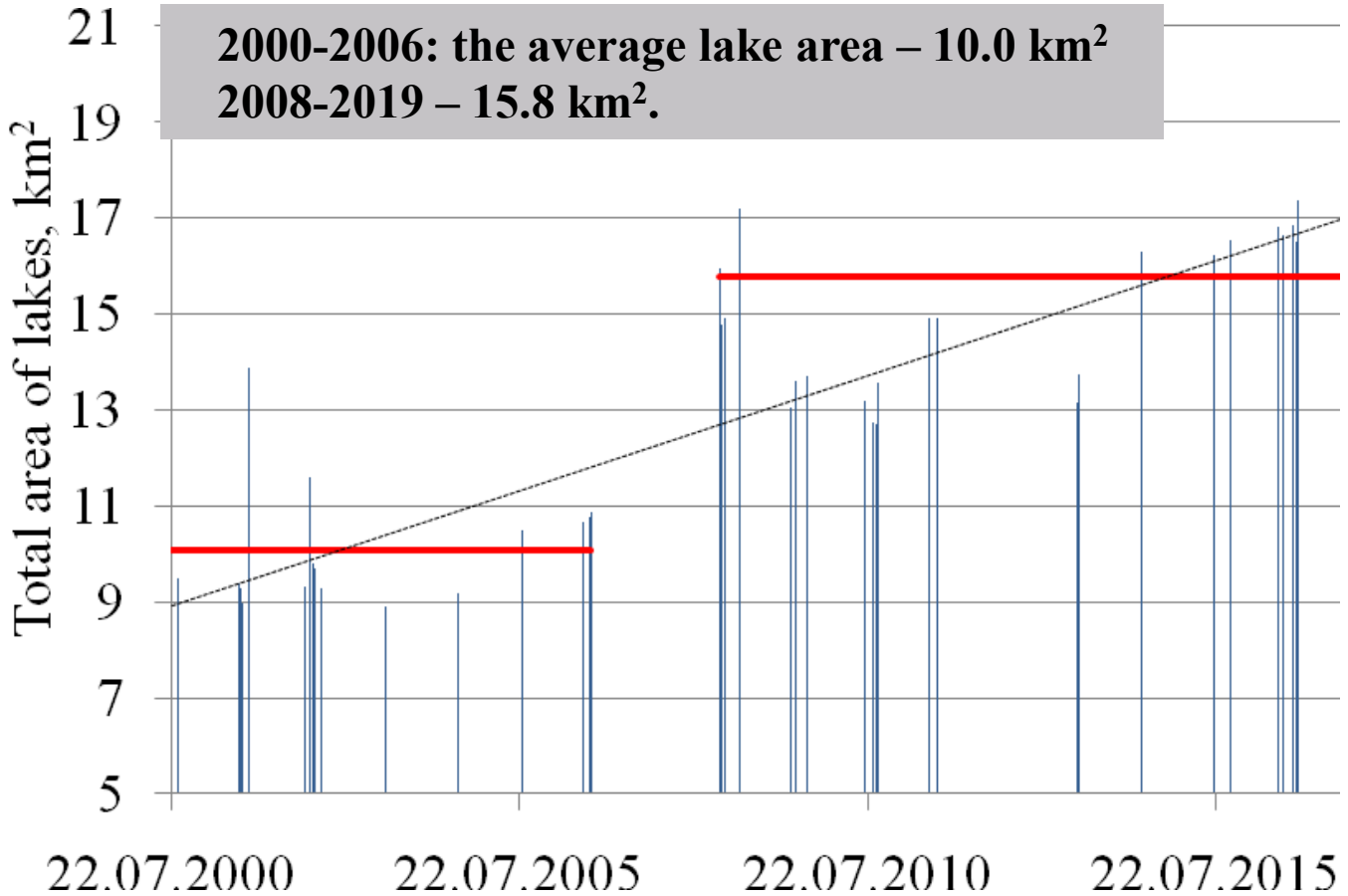
Maximum development of lake is found in 2007, 2008 and 2018,
minimum – for the period 2001-2004.

The changes of area occur abruptly despite the presence of a general increasing linear trend.

Thus, in 2007-2008, there was a sharp increase of the lakes area, which has determined its dynamics in subsequent years.

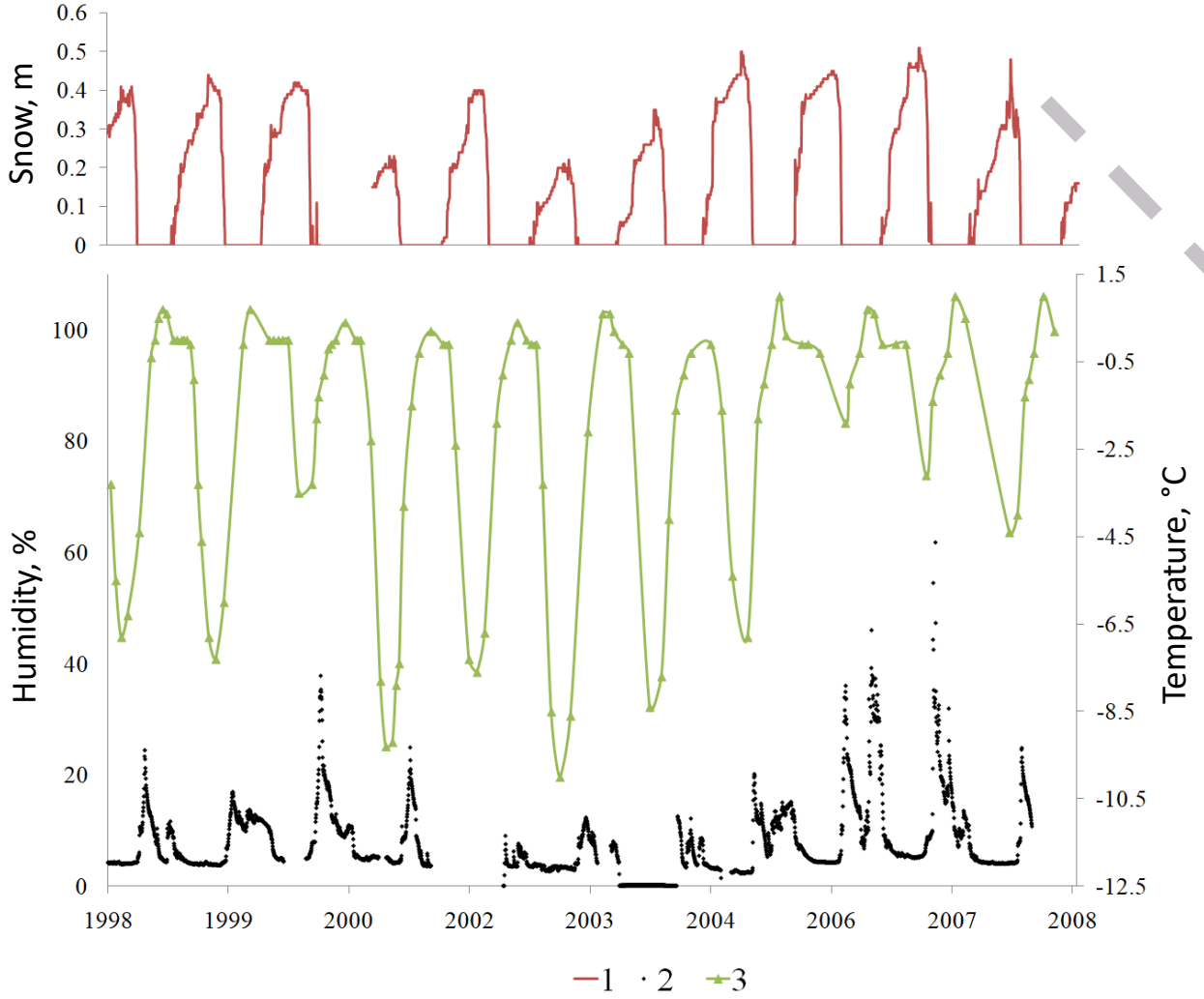
Dynamic of thermokarst lakes area in **the Suola River basin – Buteidah** for the period 2000 – 2019. This basin is characterised by the **largest number of available satellite images** without clouds (without 2007 and 2012).

2000-2006: the average lake area – 10.0 km²
2008-2019 – 15.8 km².



Result

1-snow cover thickness (Yakutsk station), m;
2-humidity of the top layer of soil 10 cm thick,%;
3-soil temperature at a depth of 1.2 m, ° C (2.3 – according to the Spasskaya Pad station).



Precipitation

A sharp increase in the area of lakes in 2007-2008 was preceded by a period (2005-2008) with abnormally snowy winters:

during this period total annual precipitation **was above normal by 20-43 %** (the average value of SWE was 59 mm, 1966-2018). In 2005-2007 it amounted to 88, 86 and 78 mm exceeding the norm by 50, 46 and 32 %.

Mean annual precipitation was 303 mm for the period 2005-2008 (with a norm of 237 mm).

There is no direct functional relationship between the area of thermokarst lakes and the amount of solid, liquid or total sums of precipitation.

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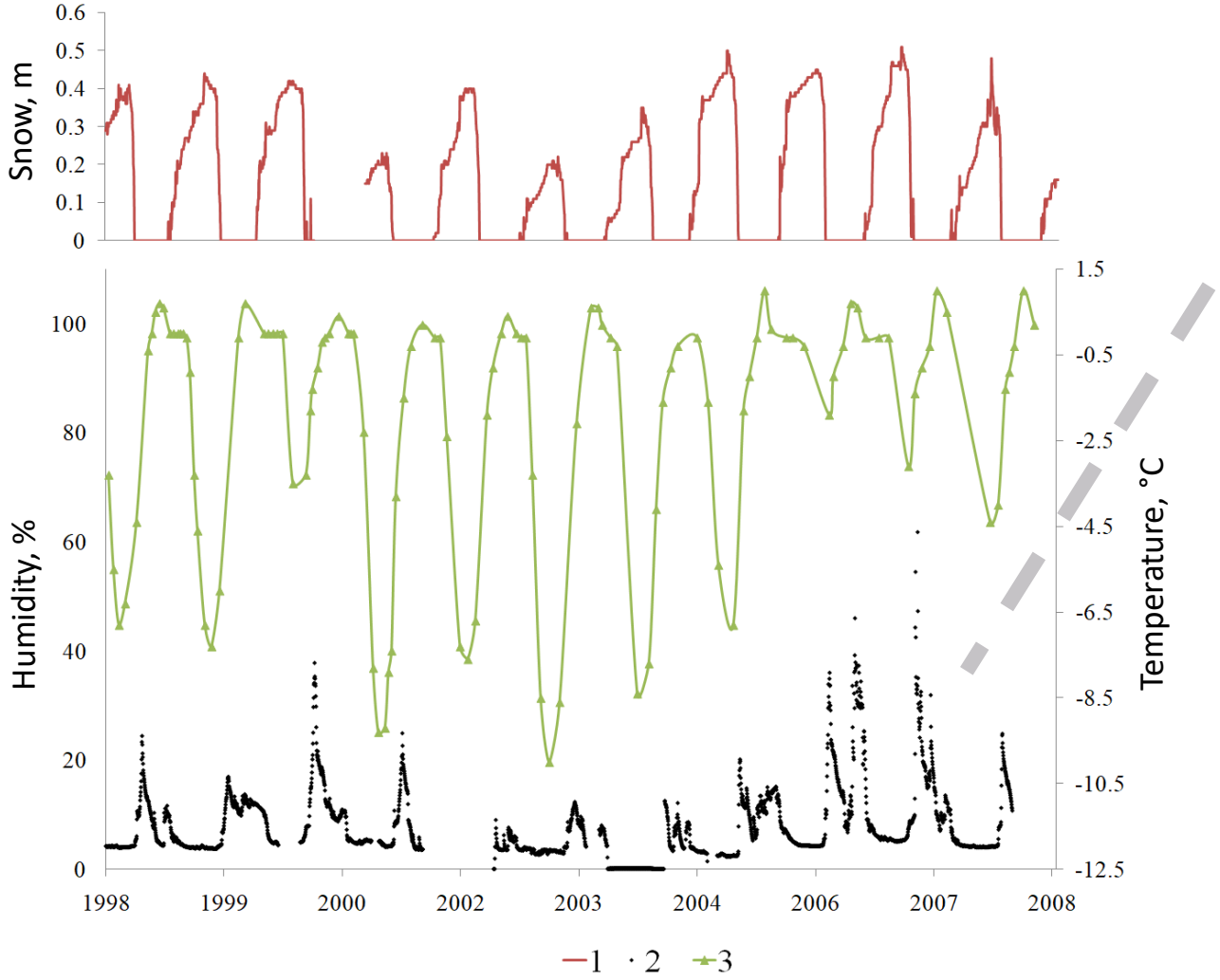

Soil moisture content

Abnormally high snow water equivalent and significant rains in previous autumn have led to continuous period of high soil moisture content.

The average moisture content of the upper 80-centimeter layer of soil during the warm period (May – September) was 24 % of the dry weight in 2006, compared to 11% in 2003.

The humidity of the upper 10-cm layer amounted to 50 % and 80-cm layer to 46 % on the 1st of October 2006 (before soil freezing), so the soil was in a state of complete saturation at the beginning of snowmelt in 2007.

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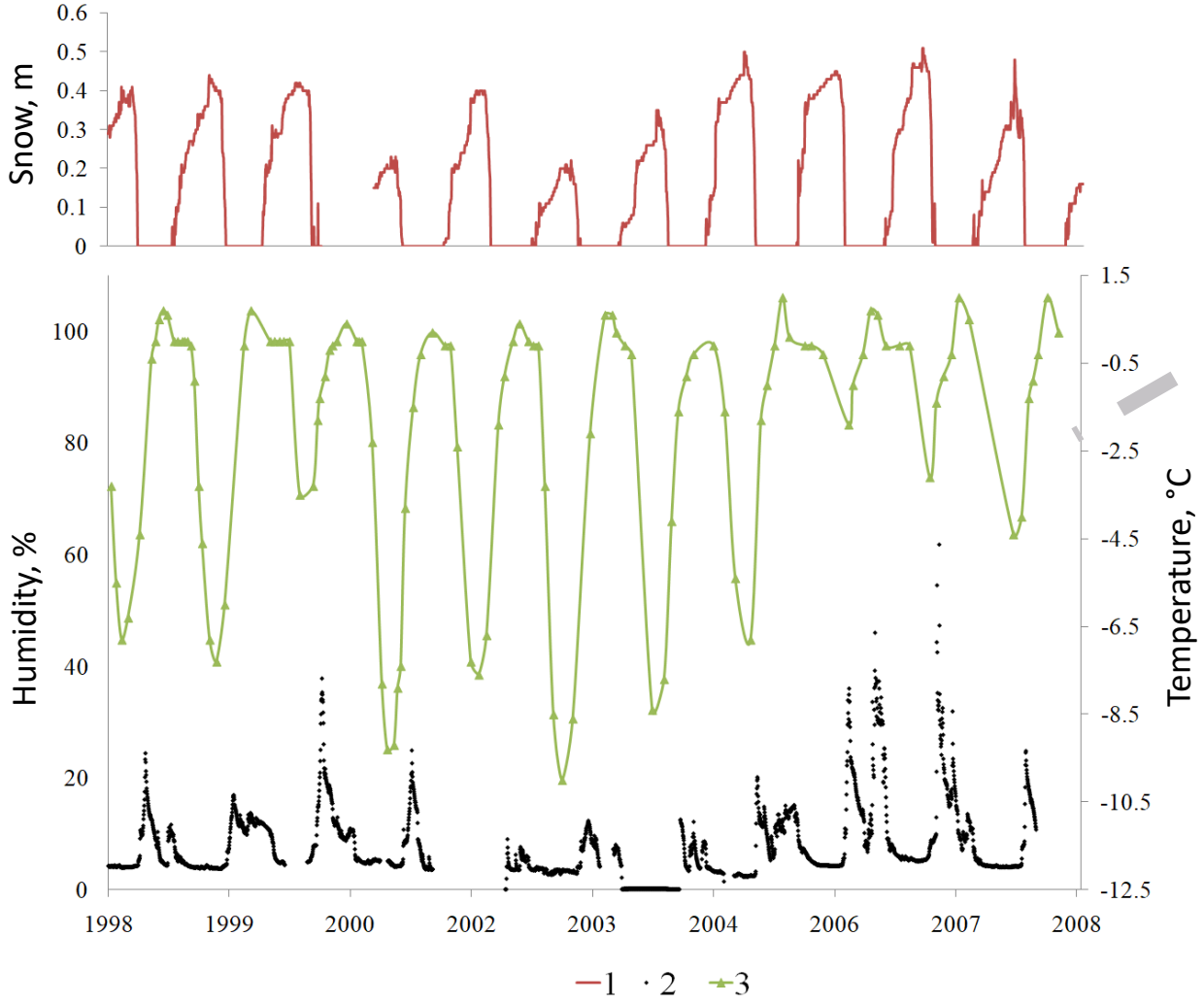


Soil temperature

The thermal regime of soils changed as a result of the combined action of two interrelated factors:
1) significant soil moisture,
2) abnormally high snow equivalent.

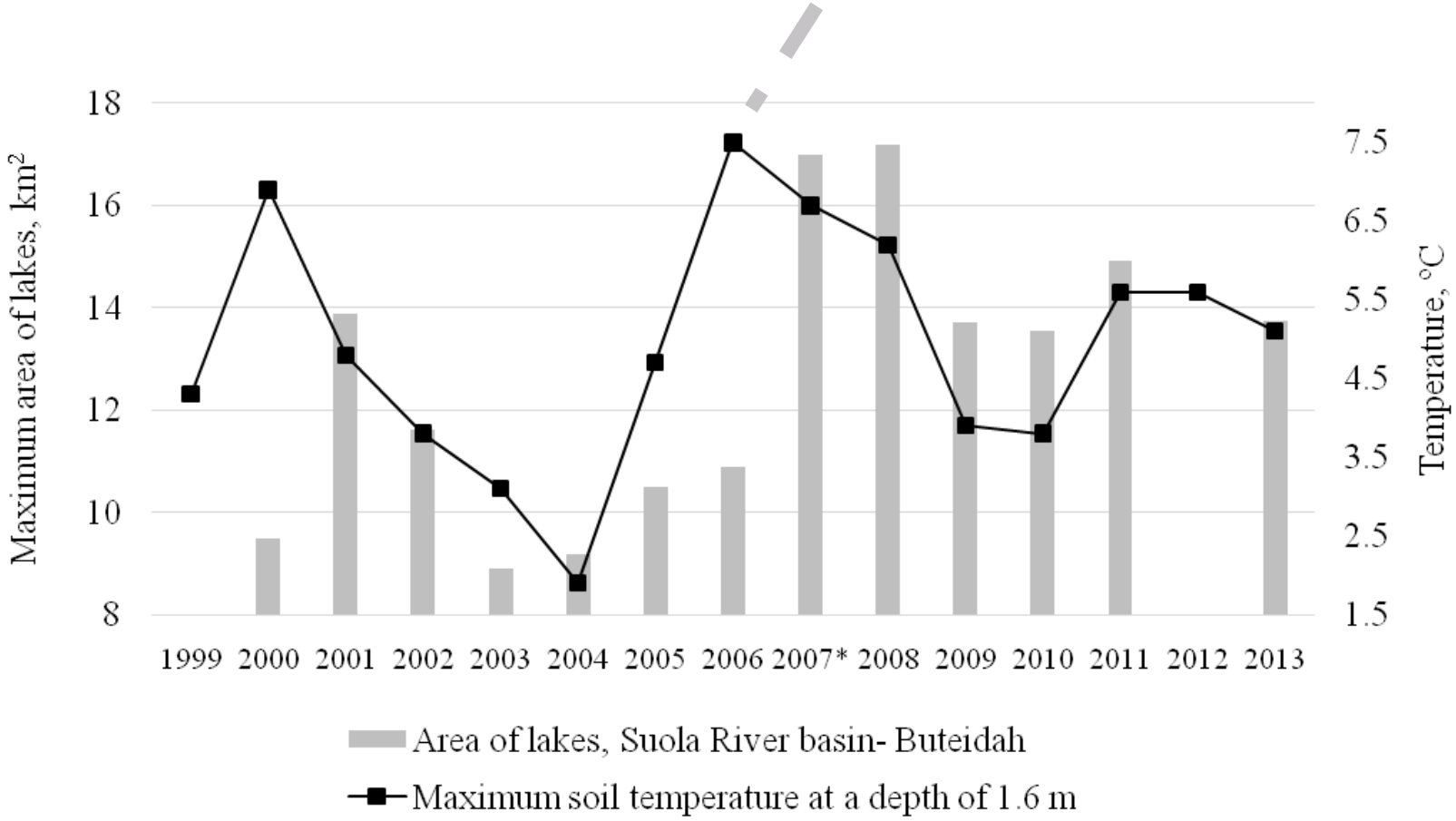
It was prevented soil freezing and resulted in sharp increase of soil temperature.

Minimum and maximum temperature at 1.2 m depth was -10.4 ° C and 0.0 ° C in 2004, and -3.1 ° C and +2.2 ° C in 2007 at Spasskaya Pad' station. The maximum thaw depth varied from 1.37 to 1.57 m before 2004, and it was 1.67 m in 2007.

Result

The maximum area of thermokarst lakes and the maximum soil temperature at a depth of 1.6 m at the Yakutsk station
*** provided that the area of lakes in 2007 is not lower than the value of 2008.**

The increase in soil temperature from 1.9 to 7.5 ° C in 2004-2006 is followed by a sharp increase of lakes area from 8.9 to 17.2 km^2 in 2007-2008.



A sharp increase of maximum soil temperature from 4.3 to 6.9 ° C in 2000 is accompanied by increase of the lakes area from 9.5 to 13.9 km^2.

The direction of changes in the lakes area repeats the trends of soil temperature with a delay of 1-2 year.

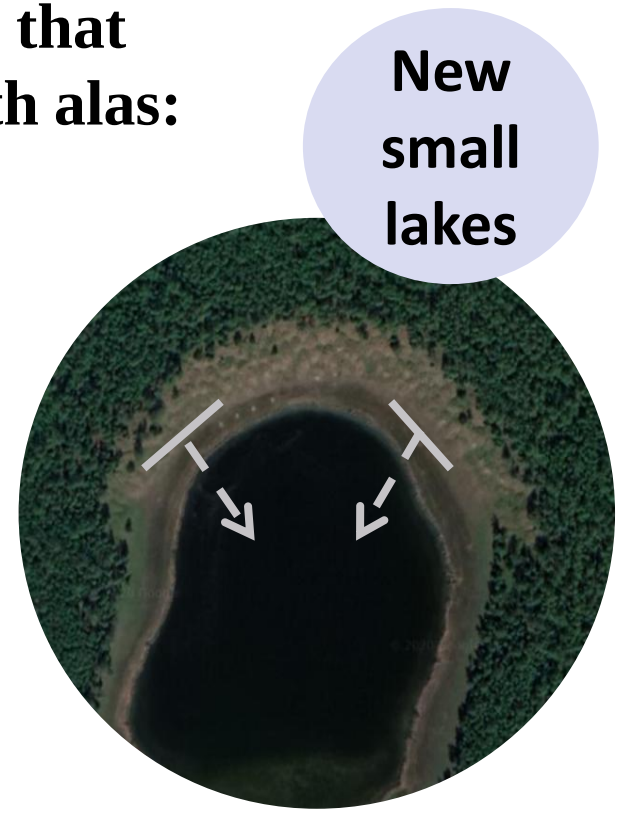
Intensification of thermokarst processes

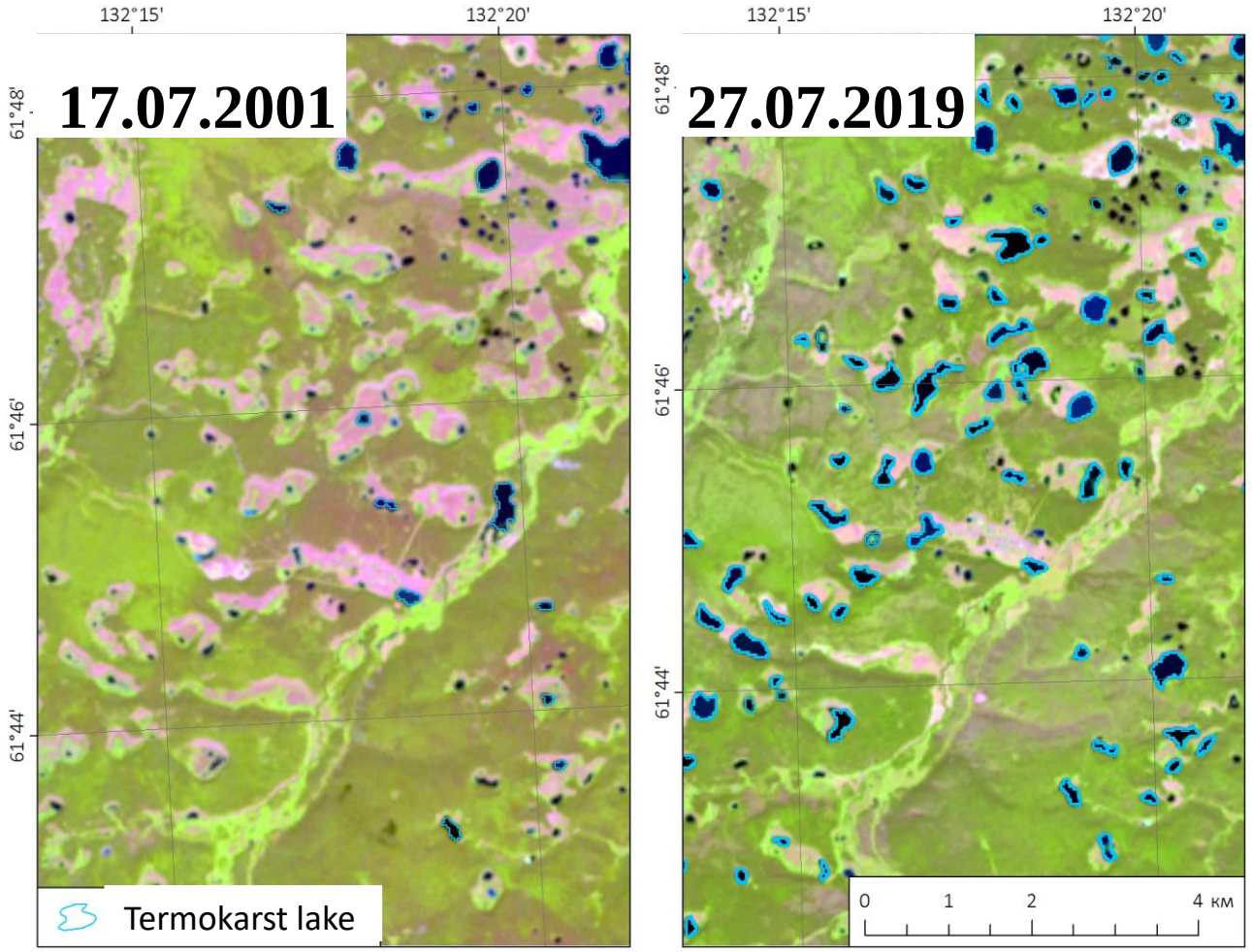
One of the possible mechanisms for increasing the area of thermokarst lakes may be **thaw slumping**, which indicate the activation of thermokarst processes.

The area of lakes that do not intersect with alas:

The Suola river basin
2001: 1.1 km^2
2019: 2.2 km^2

The Tanda River basin
2001: 4.6 km^2
2019: 6.4 km^2





Results

1. The lake area **increased** twice over the 20 years in the basins of the Suola and Taatta Rivers and by 25% in the Tanda River basin.
2. It was found that the increase in the lake area occurs **abruptly**, determining the dynamics of the lakes development in the subsequent period, despite the presence of a general linear trend.
3. The relationship between the changes in the state of the upper layer of permafrost and a sharp increase of thermokarst lake area was revealed. The main factor that leads to a change of the stable state of thermokarst forms are short-term (1-3 years) periods of **abnormal temperature increase of the top ground layer**. Such periods may be caused by a rare combination of hydrometeorological conditions. The three-year period of 2005-2007 was characterized by abnormally **high values of snow water equivalent** and total annual precipitation. Increased soil moisture and the warming effect of snow cover led to the **decrease of soil freezing intensity** and increase of the ground top layer temperature.
4. The combination of these factors triggered the **activation of thermokarst processes**, which led to a sharp increase of the thermokarst lakes area in 2007-2008, in average more than 1.5 times.

Thank you for your attention!

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