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Landscape analysis of changes in the number of thermokarst lakes in west-siberian permafrost based on satellite images

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Changes in the number of thermokarst lakes were investigated using multi-temporal satellite images. On the territory of West-Siberian permafrost, 33 test sites located in different landscape zones was selected. 134 cloudless multi-temporal images Landsat, obtained during the warmer months in the period 1973-2013 yrs, were used for remote research. Processing and interpretation of satellite images were performed using software tools of modern geographic information systems ENVI 4.7 and ArcGIS 9.3. Total number of thermokarst lakes in 33 test areas of Western Siberia was more than 50,000. It is shown that the number of disappeared lakes during the period of research in average decreases with increasing geographical latitude, and the number of appeared lakes in average significantly increases with increasing latitude. A comparison of the number of disappeared and formed lakes showed that the tendency to form new lakes dominated in tundra, and a tendency to reduce the number of lakes revealed in forest-tundra and the northern and middle taiga. Number of the newly appeared thermokarst lakes are significantly larger than number of disappeared lakes. So we can assume that the increase in methane emissions to the atmosphere with an increasing number of small thermokarst lakes in Western Siberia will contribute to the greenhouse effect.

Keywords: Thermokarst lakes, space images, permafrost, landscape analysis, Western Siberia

Introduction

It is common knowledge that the increase in mean annual temperature of the earth surface observed for the last 3-4 decades results in degradation of permafrost landscapes in Northern Eurasia. It is thermokarst lake landscapes that turn out to be extremely sensitive to temperature changes in the permafrost territory. In connection with permafrost thawing thermokarst lakes emerge and develop in rather a short period of time – several decades, and they may disappear very quickly turning to khasyreys (ditches of drained lakes). However, a life period of some of these lakes can be as long as hundreds or even thousands of years [1].

There were periods when thermokarst lakes appeared en masse and everywhere. Thus, during a starting period of climate optimum of Holocene in the north of western Siberia mass and progressive formation of embryonic lakes was stated [2,3]. Nowadays formation of thermokarst water bodies and depressions in connection with permafrost degradation for the last 50 years is observed in Alaska, Canada, and Europe [3-5]. Our researches [6,7] also have shown that permafrost thawing under the conditions of global warming results in speeding-up thermokarst processes and changes in lakes' areas in the permafrost zone in Western Siberia. However, none of the papers cited above as well as other published papers considers the issues of changes in the quantity of thermokarst lakes in the permafrost zone.

In accordance with the aim of the given paper distance studying the quantity of thermokarst lakes depending on landscape peculiarities of the territory under study based on the analysis of the data on changes in the number of extinct and emerged lakes in the permafrost zone of western Siberia during the period of research (1973 - 2013) was conducted.

Data and object of research

Research into changes in the quantity of thermokarst lakes was done using satellite images Landsat made at different times. 33 test sites in western Siberia were chosen for the research. Test sites (TS) were selected in the light of specific features of landscape and zone differentiation of the area [8]. In each landscape zone (subzone) several TS were selected, which made it possible to study the dynamics of the quantity of thermokarst lakes depending on the landscape zone of the area. Fig. 1 shows the scheme map of landscape zones in western Siberia; one can see that test sites are evenly distributed all around the area under study. Distribution of test sites around landscape zones and subzones is given in Table 1, which shows that there are 15 sites in taiga zone and 13 in tundra zone.

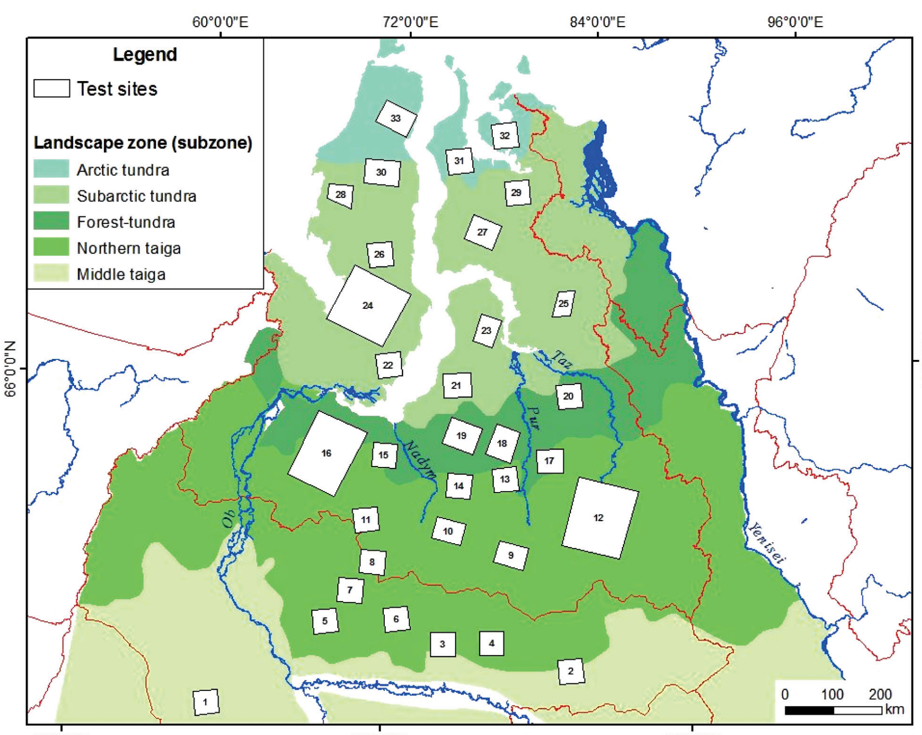

Fig. 1. Scheme-map of landscape zones location in Western Siberia with plotted boundaries of test sites

Table 1. Distribution of test sites in various landscape zones

Landscape zones (subzones)	Quantity of test sites (TS)	TS numbers
Arctic tundra	3	TS-31 – TS-33
Subarctic tundra	10	TS-21 – TS-30
Forest-tundra	4	TS-17 – TS-20
Northern taiga	12	TS-4 – TS-16
Middle taiga	3	TS-1 – TS-3

For distance research 134 cloudless Landsat images of the territory under study were selected made at different times during warm months in 1973-2013 yrs. Images from Landsat collection have geographical reference to transferred projection UTM (WGS-84). Table 2 contains the data about the used satellite images taken within the research period in 1973-2013 yrs.

The satellite images were processed and decoded with the help of modern geo information systems (GIS) ENVI 4.7 and ArcGIS 9.3. On each test site from several hundred to several thousands of thermokarst lakes were detected by means of GIS. The total amount of explored lakes on 33 TS in Western Siberia exceeded 50 thousand. Decoding satellite images made at different times enabled us to form digital maps depicting lakes' location on each TS for the year of survey.

Table 2. List of used satellite images

TS number	Starting year of the research	Final year of the research
TS-1	Landsat-4; 19.07.1988	Landsat-8; 30.06.2013
TS-2	Landsat-1; 27.06.1973	Landsat-8; 22.06.2013
TS-3	Landsat-1; 24.08.1973	Landsat-8; 11.06.2013
TS-4	Landsat-1; 12.06.1973	Landsat-8; 22.07.2013
TS-5	Landsat-1; 16.06.1973	Landsat-8; 18.07.2013
TS-6	Landsat-1; 24.08.1973	Landsat-8; 20.07.2013
TS-7	Landsat-1; 16.06.1973	Landsat-8; 18.07.2013
TS-8	Landsat-5; 21.08.1987	Landsat-8; 27.07.2013
TS-9	Landsat-1; 23.08.1973	Landsat-8; 08.09.2013
TS-10	Landsat-1; 24.08.1973	Landsat-8; 18.06.2013
TS-11	Landsat-1; 08.10.1973	Landsat-8; 09.07.2013
TS-12	Landsat-1; 27.06.1973	Landsat-8; 24.07.2013
TS-13	Landsat-1; 23.08.1973	Landsat-8; 20.07.2013
TS-14	Landsat-5; 27.07.1984	Landsat-8; 27.07.2013
TS-15	Landsat-1; 17.06.1973	Landsat-8; 25.07.2013
TS-16	Landsat-5; 23.06.1987	Landsat-8; 08.08.2013
TS-17	Landsat-1; 23.08.1973	Landsat-8; 17.09.2013
TS-18	Landsat-1; 23.08.1973	Landsat-8; 20.07.2013
TS-19	Landsat-5; 27.07.1984	Landsat-8; 20.07.2013
TS-20	Landsat-1; 22.08.1973	Landsat-8; 22.07.2013
TS-21	Landsat-5; 13.09.1987	Landsat-8; 27.07.2013
TS-22	Landsat-1; 10.08.1973	Landsat-8; 30.06.2013
TS-23	Landsat-4; 26.07.1983	Landsat-8; 18.07.2013

TS-24	Landsat-5; 07.07.1987	Landsat-8; 23.07.2013
TS-25	Landsat-4; 15.07.1988	Landsat-8; 22.07.2013
TS-26	Landsat-4; 10.07.1988	Landsat-8; 21.07.2013
TS-27	Landsat-4; 04.08.1988	Landsat-8; 18.07.2013
TS-28	Landsat-4; 07.08.1988	Landsat-8; 19.07.2013
TS-29	Landsat-4; 12.07.1988	Landsat-8; 18.07.2013
TS-30	Landsat-5; 28.07.1984	Landsat-8; 21.07.2013
TS-31	Landsat-2; 28.07.1981	Landsat-8; 01.08.2013
TS-32	Landsat-2; 28.07.1981	Landsat-8; 18.07.2013
TS-33	Landsat-5; 28.07.1984	Landsat-8; 21.07.2013

The thermokarst lak5es that disappeared and then formed again within the period of study were detected by means of comparison between an initial and final map of lakes' location on each TS. As Table 2 shows to make initial maps the images Landsat-1 (1973), Landsat-2 (1981), Landsat-4 (1983 and 1988), Landsat-5 (1984 and 1987) were used, and final maps were made with the help of images Landsat-8, made in 2013. Images Landsat-1 (1973) were used to make similar initial maps on 16 test sites, for the rest of test sites the images Landsat made in 1981 – 1988 were used. Consequently, using images from spacecraft Landsat-8 brought into service in May 2013 makes it possible to assess changes (decrease or increase) in the quantity of thermokarst lakes on different TS within periods of time from 25 to 40 years.

As it follows from the foregoing comparison between an initial and final map of lakes location on each TS reveals both the thermokarst lakes that disappeared and the ones that formed during the study period. Further centers of disappeared and newly formed lakes were detected with ArcGIS 9.3, which are convenient for mapping these lakes.

Research results and analysis

The map of extinct lakes location in western Siberia is shown in Fig. 2, from which one can see that the number of disappeared lakes during the study period differs in various landscape zones. Black triangles in Fig. 2 mark the centers of disappeared lakes. The largest density of lakes is characteristic for subarctic tundra, forest-tundra and the northern taiga.

The whole number of disappeared lakes on 33 test sites representing permafrost zone in Western Siberia was 390 for the study period. The total area of shrunk water surface due to extinction of lakes on the territory under study was 14826 ha for this period. It is interesting to consider changes in the number of disappeared lakes depending on the latitude of their location and a landscape zone.

In Fig. 3 there is a graph of changes in the number of disappeared lakes depending on the latitude of their location and a landscape zone. A separate point on the graph plotted in the form of triangles, squares or diamonds in accordance with the landscape zone shows the number of disappeared lakes on each TS. As the graph shows (Fig. 3) the number of disappeared lakes in arctic tundra is noticeably smaller than in landscape subzones located southward. It is of interest to analyze changes of mean values of the number of disappeared lakes calculated for different landscape zones and subzones given in Table 3.

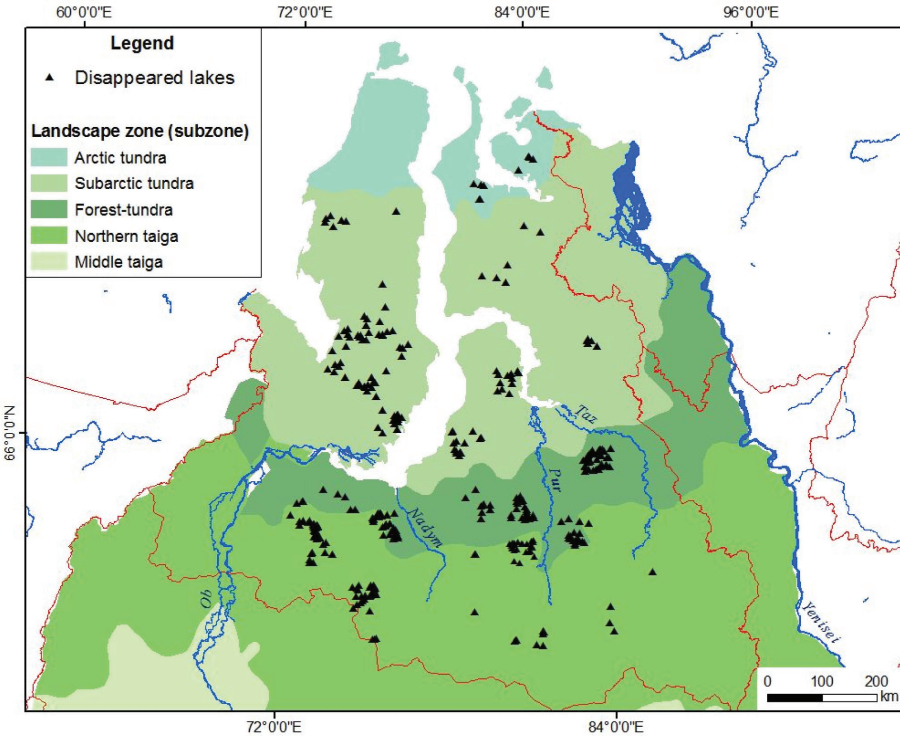

Fig. 2. Map of location of disappeared lakes' centers in various landscape zones (subzones) in Western Siberia

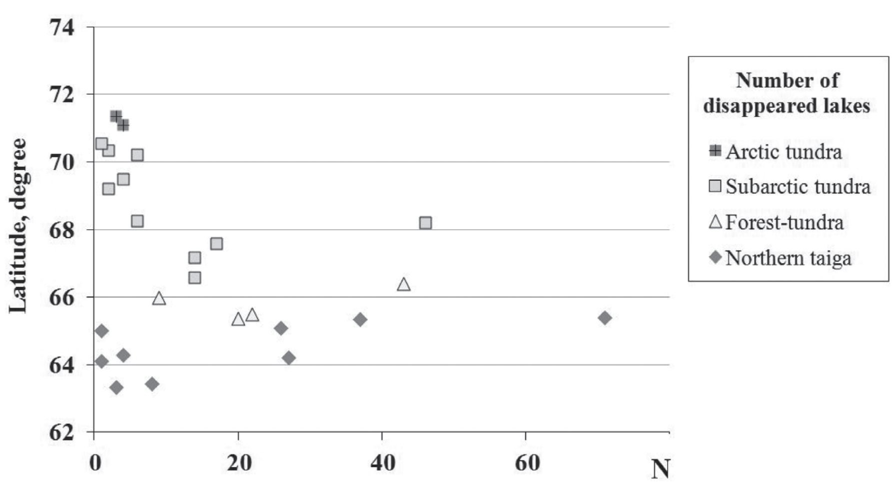

Fig. 3. Dependence of the number of disappeared lakes on the latitude

Table 3. The average number of disappeared and appeared lakes lakes over landscape zones (subzones)

Landscape zones (subzones)	Average number of disappeared lakes	Average number of formed lakes
Arctic tundra	3,5	369
Subarctic tundra	11,2	372
Forest-tundra	23,5	188
North taiga	19,8	156,2
Middle taiga		47

The analysis of Table 3 shows that in the subzone of arctic tundra on average the number of disappeared lakes is several times smaller than in other landscape subzones. In subarctic tundra the number of disappeared lakes is noticeably smaller as compared to forest-tundra and north taiga located southward. Consequently, on the territory under study in the permafrost of Western Siberia the number of disappeared lakes decreases on average with increasing latitude during the period under study.

A similar analysis was done on the data concerning changes in the number of newly appeared lakes. It was stated that the number of appeared lakes for the period under study in West-Siberian permafrost exceeded 7000 with total water surface area 13649 ha. Comparison of the data on the total number of disappeared and appeared lakes and their total areas shows that in spite of practically similar total areas the number of appeared lakes exceeds the number of disappeared lakes considerably (almost 18-fold). Consequently, newly appeared thermokarst lakes are much larger than disappeared lakes. So we can assume that the observed speed-up of thermokarst processes in the result of global warming will be accompanied by increase in a number of small thermokarst lakes in West Siberian permafrost landscapes.

In Fig. 4 there is a graph of dependence of the number of appeared lakes for the period under study on the latitude of TS location. In the same way as in Fig. 3, each point in the graph depicts a number of appeared lakes on a separate TS. As it can be seen from the graph the number of appeared lakes on average rises together with increase in latitude. Mean values of the number of appeared lakes in each landscape zone (subzone) are given in Table 3.

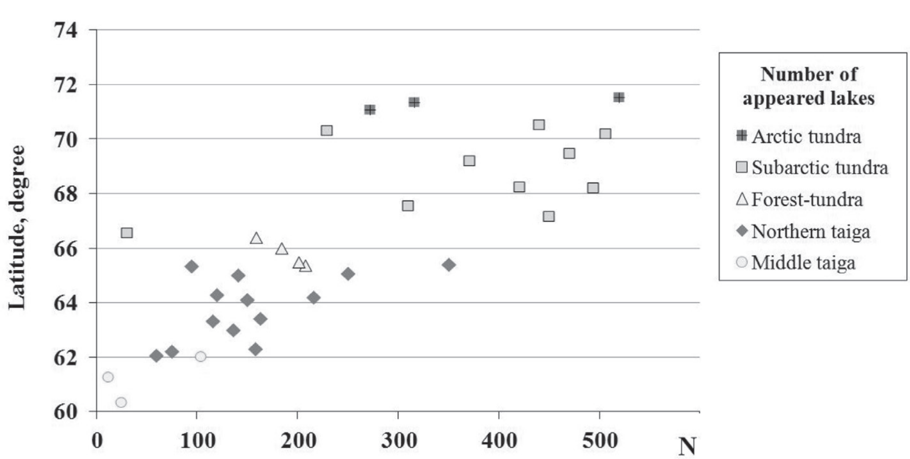

Fig. 4. Dependence of the number of appeared lakes on the latitude

The analysis of the data from Table 3 shows that mean number of appeared lakes in tundra subzones exceeds by several times a number of appeared lakes in landscape zones (subzones) located to the south. Consequently, thermokarst processes in arctic and subarctic tundra cause more intensive forming new lakes than it happens in forest-tundra and taiga zone in Western Siberia.

Comparing the data in Table 3 on the number of disappeared and appeared lakes makes it possible to conclude that in the north of Western Siberia in the tundra zone the trend of forming new lakes prevails while the number of lakes in forest-tundra and northern and middle taiga tends to decrease.

Conclusion

The results of investigation show that in West-Siberian permafrost zone due to thermokarst spurt under the influence of global warming two contrasting processes are taking place: thermokarst lakes' disappearing because of drainage and forming new thermokarst lakes, the latter process prevailing and accompanied by relative increase in small lakes. As experiments in Western Siberia have shown [9-11], little thermokarst lakes can be viewed as natural sources of greenhouse gases, methane in particular. Therefore, it is possible to assume that rising emission of methane into the atmosphere caused by increase in number of small thermokarst lakes in Western Siberia will promote growth of greenhouse effect.

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