SPATIAL-TEMPORAL DYNAMICS OF MORPHOMETRIC PARAMETERS OF LAKES ON THE YAMAL PENINSULA AND THE LENA RIVER DELTA AREA

Master Thesis

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by

Alina Karpova

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Supervisors:

Dr. Irina V. Fedorova

Hydrology Department, Institute of Earth Science, Saint Petersburg State University, 10-ya lin. V.O. 33-35, 199178, Sankt-Peterburg, Russia

Dr. Guido Grosse

Helmholtz Centre for Polar and Marine Research, The Alfred Wegener Institute, Telegrafenberg A43-121, 14473 Potsdam, Germany

Abstract

Last years between scientists become popular a theory about rising of surface temperature in permafrost regions. The possibility of temperature rising has a big influence on thermokarst degradation. The thawing of permafrost that can generate dramatic changes in ecosystems and in infrastructure performance.

Since the beginning of the 21st century, scientists have carried out numerous studies of the dynamics of thermokarst lakes, based on the analysis of different time periods images. Some of them point to a direct relationship between changes in lake area and climate warming, others do not.

Researching on thermokarst degradation helping scientist to make a prediction about possible subsequent thawing of permafrost in world and particular in Siberia region. In future it can make changes in ecosystems. In work exactly thermokarst lakes and dynamic of its degradation is an object of research.

Revealing changes in the area of lakes is the main stage in researching of thermokarst lakes dynamic. It includes: processing of the results of thermokarst lakes remote sensing (vectorization, remote sensing; combination of lakes consisting of several vector objects).

For researching was chose two study areas in Northern Eurasia region: Lena Delta area from East Siberia and Yamal peninsula from West Siberia.

Keywords: thermokarst lakes, permafrost, remote sensing, satellite images, GIS, climate change, the Lena River Delta, Yamal Peninsula, Siberia, Arctic

Аннотация

В последние годы между учеными становится популярной теория о повышении температуры в районах многолетней мерзлоты. Возможность дальнейшего повышения температуры может оказать большое влияние на динамику изменений термокарстовых озер. Оттаивание многолетней мерзлоты может привести к резким изменениям в экосистемах и производительности инфраструктуры.

С начала XXI века ученые провели многочисленные исследования динамики изменений термокарстовых озер, основанные на анализе изображений за разные периоды времени. Некоторые из них указывают на прямую связь между изменениями площади озёр и потеплением климата, другие - нет. Исследование изменения термокарстовых озер помогает ученым предсказать возможное последующее оттаивание многолетней мерзлоты в мире и особенно в Сибири. В будущем этот процесс может вносить изменения в экосистемы.

В данной работе предметом исследования являются именно термокарстовые озера и динамика их изменений.

Выявление изменений динамики озер является основным этапом в исследовании термокарстовых процессов. Этот этап включает в себя обработку результатов дистанционного зондирования термокарстовых озер.

Для нашего исследования мы выбрали две области исследований в регионе Северной Евразии: район дельты Лены в Восточной Сибири и район на полуострове Ямал в Западной Сибири.

Chapter 1. Introduction

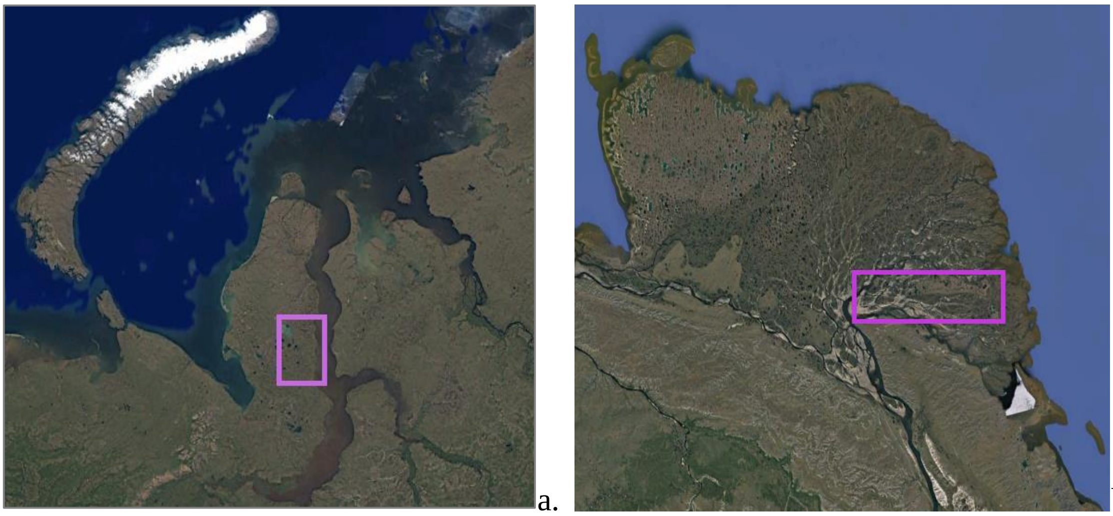
The aim of the work are:

-to analyze the dynamics of thermokarst lakes within the Area of study in the eastern-central sector of the Yamal Peninsula, and on the Sobo-Sise Island, in the eastern part of the Lena River Delta;

- to identificate of factors affecting the expected change in the number and square of thermokarst lakes;

- to determinate of the links between the dynamics of thermokarst lakes, and changes in meteorological parameters, such as air temperature and precipitation at the nearest meteorological stations.

- to compare thermokarst lakes dynamics of two areas of interest in accordance to their geographic location and changing of climatic parameters.



a. b.

Fig. 1.a) Yamal Peninsula AOI; b) The Lena River Delta AOI.(in the purple rectangle) Image Landsat, Google Earth

The Areas of study (AOI) were chosen for territories located in zone of continuous permafrost. Both sites have direct access to the seas of Arctic Ocean and extend in subarctic climatic zone with typical arctic tundra landscapes. Either Area of interest range in a plain with low elevation and lacustrine-marine plains and terraces. In climatic terms, it is more northern in the Lena River Delta than on Yamal Peninsula, which is due to its geographical location. In addition, the choice of the Yamal area is determined by the possibility to analyze the areas that have not been studied enough, which will make the research relevant.

Thermokarst process is the most noticeable type of surface dissection, which forms the relief outwardly. Thermokarst lakes, their shape, size, dynamics of their shorelines can indicate current exogenous processes and the processes occurring in the upper part of permafrost formation.

For studying the thermokarst lakes dynamics used a method of diverse analyzing the temporal materials of remote sensing. This study is aimed to search relationship between thermokarst relief and the dynamics of climate change.

Main characteristic of hydrological conditions are high waterlogging of the territory. The distribution of temperatures depends on landscape conditions.

To achieve the main goal, indispensably implement following objects:

-According to meteorological parameters (air temperature and precipitation), to determine the trend parameters and the possibility educe a tendency in temperature and precipitation time series. Nearby weather stations to our Areas are Novyi Port on Yamal Peninsula and Tiksi in the Lena River.

-One of the importance goal is to identify the main features and factors that determine thermokarst lakes dynamics within the Area of interest; To count the number of thermokarst lakes and lakes square for each area and for different seasons of years;

- To appreciate the impact of meteorological parameters changes on the dynamics of thermokarst lakes and between the date of satellite images.

The first period is an interval between satellite images: from first to second date of satellite image; the second period from second to third satellite image. In accordance to meteorological data was calculated air temperature and precipitations parameters precedent all satellite images. So there are three periods of meteorological data preceding each of three satellite image.

To sum up the key points, the work mostly directed analyze three periods over air temperature and precipitation time series and comparing with analyzing of the number of lakes and square.

The choice of two sites was not accidental. It was important to find satellite images of high quality without greater barriers for the concrete areas for three years. The images of Yamal Peninsula have a smaller time interval between the first and second picture. Therefore, it is important to note, that in the given work the aim is not compare territory between each other, only to collate two periods between pictures in relation to an increase of number and square of lakes on the basis of three chosen Areas in each Area of Interest (the Yamal Peninsula AOI and the Lena River Delta AOI). Owning to long-term data of air temperature and precipitations it is possible to investigate a one more period, what finally could interpret the processes before the first date of satellite image.

Six satellite images, for the period of years 1973 – 2016was found for this research. In work following methods have been used: remote sensing, cartographic, geoinformation and statistical methods. As the main materials for studying the dynamics of thermokarst lakes were used Landsat satellite images of different resolution. All work with satellite images performed in ArcGIS 10.2 Software, statistics calculations counted in Microsoft Excel 2016 Software.

1.1.Permafrost and climate change

Research of processes related to climate change is one of the most advanced tasks. Up to date, most scientists have proved that climate change effects on natural environment. Recent climate conditions characterized by more inclement climatic and cryogenic conditions than in climatic optimums when temperature was warmer than today. The amount of ice in the vulnerable Arctic was significantly less than today. Such processes significantly influenced on «development» of permafrost distribution.

The observed climate changes will lead to an increase in the frequency of extreme events, an increase in the intensity of precipitations, sudden changes in air temperature, an increase in the amount of precipitation (Watson, 2007). Calculations show that a significant increase in winter precipitation expected, and a change in the amount of summer precipitation will be less pronounced and in the high latitudes, it may go downward (Mokhov, et al, 2002). Territorial differences will depend first of all on the physical-geographical features of the region. Lowlands for example always guess complicated interrelation with hydrological regime and together it could produce such as thermokarst for example.

According to the International Permafrost Association (IPA) Permafrost is defined as ground (soil or rock and included ice or organic material) that remains at or below 0°C for at least two consecutive years. Lowland permafrost regions are traditionally divided into several zones based on estimated geographic continuity in the landscape. Temperatures in the permafrost have risen by up to 2 °C over the past two to three decades, particularly in colder sites (typical permafrost temperatures range from -16 °C to just below 0 °C, depending on the location. (AMAP report, 2011). The formation of frozen strata began in the far north-east of Eurasia in the range of 2.5-1.5 million years ago and is still being formed (Yershov, 1998).

Recent conditions of climate change have a significant impact on the permafrost zone. So it is important to devote high attention to the thermokarst processes study, especially in tundra of subarctic and arctic climatic zones, because thermokarst lakes could be perceived as an indicator of permafrost landscapes conditions in global attitude.

The Eurasia covered of two big plain territories – West Siberian Plain and North Siberian Lowland. Abundant wetting for lowland areas prepare a favorable place for further evolvement of thermokarst lakes. Such places as Yamal peninsula and the Lena river Delta area.

Holocene epoch, which continues to this day, is characterized by more severe climatic and geocryological conditions than in climatic optimum. At the beginning of this Holocene period, aggradation of permafrost occurs and take place the southward extension (Romanovsky, 1993). The previous author also confirmed that the process of cryogenic cracking and growth of repeatedly-wedge ice was activated. The drainage of thermokarst lakes, formation of *alas* and *hasyrey*, accompanied by the freezing of the sub-surface *taliks* and during this stage occurred periodic changes in natural conditions, that led to the attenuation of the thermokarst process (Romanovsky, 1993).

According the information from summary book by Arctic Monitoring and Assessment Program (AMAP, 2011) the Arctic is warming, surface air temperatures in the Arctic since 2005 have been higher than for any five-year period since measurements began around 1880. Evidence from lake sediments, tree rings and ice cores indicates that Arctic summer temperatures have been higher in the past few decades than at any time in the past 2000 years. Permafrost cover most part of the Arctic region. This fact shows us how is it important look on permafrost phenomena with a big attention (AMAP, 2011). Permafrost considered to be a sensitive indicator of climate change and monitoring of frozen ground in Alaska and northwest Siberia has shown that the substrates in both regions have been warming in recent years (Pavlov 1994) in conjunction with climate patterns in the northern hemisphere.

The layer above permafrost that regularly freezes and thaws called active layer has become progressively thicker over the last 20 years in Scandinavia and Arctic Russia. It is now up to 20 cm thicker in some places. Underlying about 24 % of the land surface of the Northern Hemisphere (Zhang et al. 1999), permafrost is an ideal indicator of environmental changes, as its stability depends on a set of environmental and climatic factors.

To Sum up, safely to say that research in the field of thermokarst lakes dynamics has a very important value in relation to climate change study. Despite the fact that thermokarst lakes have been studied for decades, there are ambiguous results indicated these studies are still only at intermediate stage and it is still difficult to talk about the reliability of certain estimations. But nevertheless it is important to take into account the main facts, which are backed by actual data.

1.2. The Area of study

The Yamal Peninsula AOI

The Yamal Peninsula (Figure 1, Figure 2) locate in the North of the Tyumen Oblast, and lies entirely within the low Arctic tundra and continuous permafrost zones (Bliss & Matveyeva, 1992). Ice-rich permafrost is common and the landscapes range from moderately to highly unstable (Vilchek & Bykova 1992; Nelson & Anisimov 1993). In terms of the surface area covered, roads and off-road vehicle traffic are two of the most extensive anthropogenic disturbance types in boreal and Arctic regions, with numerous direct and cumulative impacts (Forbes, 1999, Walker 1997). Rapid and relatively cryptic but significant effects include changes in hydrology, eventually wetlands drained, or commonly waterlogging. (Martens et al. 1996).

The Yamal Peninsula is located in the North of the West Siberian Plain. This determines smooth forms of relief. Terraced type of relief is the main feature for Yamal Peninsula. It was formed during the intermittent lowering of the Arctic basin level.

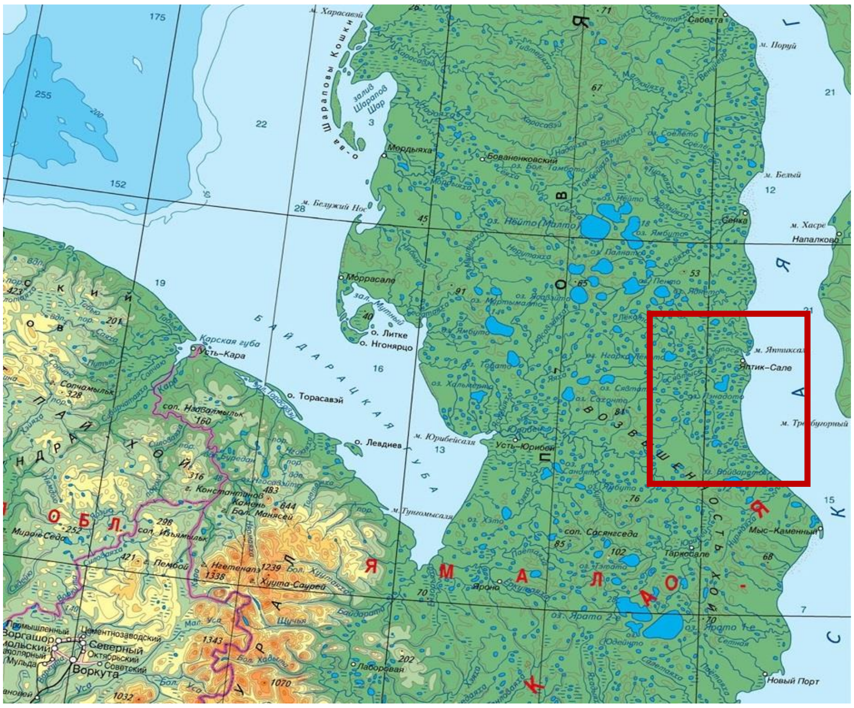


Fig.2. Topographic map of the study area (in the red rectangle)Yamal Peninsula

Even without industrial disturbance, a slight change of the climate, with warmer spring and summer temperatures and additional precipitation, is expected to result in massive thermokarst erosion throughout the entire West Siberian Basin (Nelson & Anisimov 1993; Anisimov & Nelson 1997).

More than 90% of rivers in Yamal tundra are less than 10 km long. From total square of 60 000 lakes, 90% of total are small, which have square less than 1sq. km (Romanenko ,1999). Lakes compose the main characteristic of relief. In tundra most part of small rivers originates from lakes, therefore, it plays a prominent role in relief plain changing. In addition, it is a factor of river discharge forming (Romanenko, 1999). Such small rivers comprise over 80% of the total length of all rivers. The same scale of cryogenic and hydrologic processes for just small catchments is the main reason for relation and interaction of hydrologic and cryogenic processes (Leibman, 2015). Permafrost thickness reaches up to 500 m and more on the marine and coastal-marine plains and reduces to 100–150 m at the younger river terraces (Yershov, 1998).

The Lena River Delta

The Lena River Delta (Figure 1, Figure 3) located in the Northern Siberia. It flows into the Laptev Sea in the Arctic Ocean. Lena Delta is the largest Arctic delta and biggest river in Russia.

The Lena River divided into several areas differing in the gradient of water, surface elevation, fluvial forms, hydraulics, and transporting capacity. As it passes through its estuarine area, the main Lena flow is divided into numerous arms and transverse branches, creating the largest delta in the Russian Arctic (Fedorova et.al., 2015). The Lena Delta is a unique Arctic delta landscape formed on the border of land and sea, in the conditions of permafrost and severe northern climate.

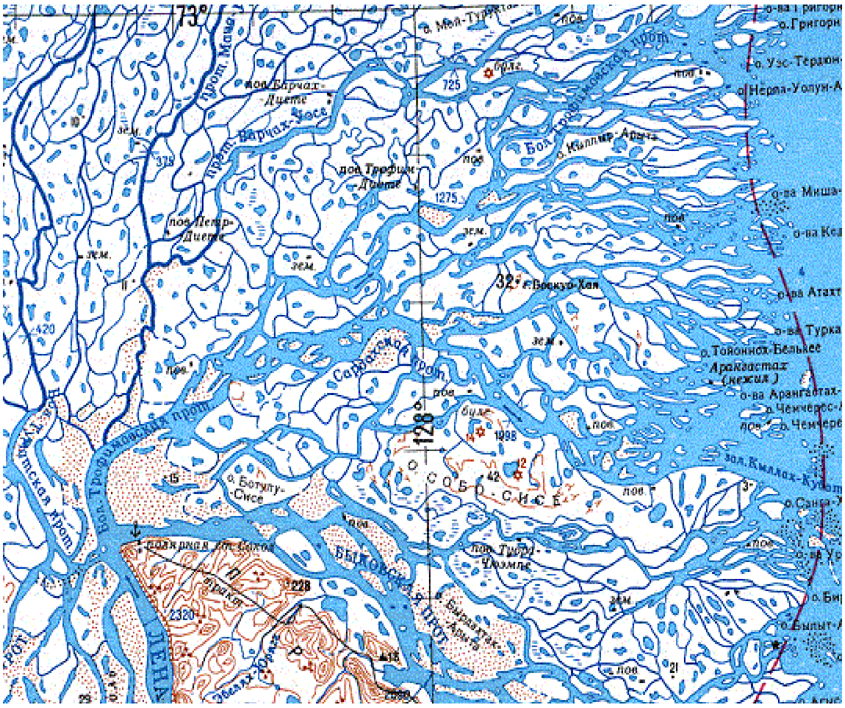


Fig 3. Topographic map of the study area on Sobo-Sise Island (in the red rectangle) Lena Delta

The Lena River Delta is located in zone of continuous permafrost with permafrost depths of 500 – 600m (Grigoriev et al., 1996), and it dominated by fluvial-deltaic and periglacial processes. It features Ice Complex deposits on insular remnants of a Late Pleistocene accumulation plain in the foreland of the Chekanovsky and Kharaulakh ridges, which now form the third Lena Delta terrace (Grigoriev, 1993).

Three main terraces can distinguish by their geomorphology (Are & Reimnitz 2000, Schwamborn et al. 2002). The first main terrace, which represents the modern active delta, is comprised of the lower and upper floodplains and the first terrace above the floodplain and the modern outlines and surface patterns of the third terrace are the result of 12,000 years of permafrost degradation and of deltaic processes that have been ongoing since the mid Holocene (Schwamborn et al., 2002). Thermokarst processes have greatly influenced the landscapes in this region and during the early Holocene (Kaplina and Lozhkin, 1979; Romanovskii et al., 2000; Kaplina, 2009). Pingos have formed in some of the basins, with heights up to 30 m above the basin surface and diameters of up to 150 m (Grigoriev, 1993). The Lena Delta area also comprises two large regions of late Pleistocene accumulation plains that are mostly untouched by modern active deltaic processes (Schwamborn et al., 2002). The total area of the Lena River delta is over 25000 km2 and includes more than 1500 islands, about 60000 lakes, and many branches of the Lena River (Antonov, 1967). If the delta's upstream limit is defined as including the Bulkurskaya Lena River branch to Tit-Ary Island, the delta area exceeds 32000km2 (Walker, 1983). The Lena River delta is a complex of more than 800 branches with a total length of 6500km (Fedorova et.al., 2015).

The highest part of the Sobo-Sise Island composed of ice-complex rocks. To this ancient body are leant younger formations composed mostly from sand layer (Bolshyanov ,2013)

In 1939-1940 years, Moscow Aerogeodesy Organization (now GUGK) was performed aerial photography throughout the delta and a map scale of 1: 100,000, published in 1940-1944. As a result of this survey it was made possible to create the first geomorphological map of the delta on a scale of 1: 300,000 (Gusev, 1953).

1.3. Historical background of thermokarst study

The term thermokarst first used by (Ermolaev, 1932) to describe irregular, hummocky terrain due to the melt and thermal abrasion of “ice-complex” sediments exposed along the coastal lowlands of the Laptev Sea, northern Siberia. Subsequently, the term applied to the processes associated with the thaw of permafrost that lead to local or widespread collapse, subsidence, erosion, and instability of the ground surface. In fact, the term thermokarst now encompasses the whole range of geomorphic effects resulting from subsurface water on landforms in permafrost regions (French, 2007).

Thermokarst is one of the most obvious forms of permafrost degradation in arctic landscapes. Thermokarst defined as the process by which characteristic landforms result from the thawing of ice-rich permafrost or the melting of massive ice (van Everdingen, 2005) (see Figure 3). During a phase of global warming about ten to twelve thousand years ago, thermokarst affected large areas in arctic lowlands with ice rich permafrost (Romanovsky et al., 2000; Walter et al., 2007).

In the Late Pleistocene, such ice-rich deposits of the Yedoma site deposited in northern Siberia (Schur et al., 1987; Schirrmeister et al., 2011). Today, thermokarst lakes and basins alternate with ice-rich Yedoma uplands in this region. Thermokarst has important effects on the ecology, geomorphology, hydrology, and local climate of affected landscapes (Osterkamp et al., 2000; Grosse et al., 2011).

Thermokarst processes on the territory of Russian was studied in detail in the middle of last century (Kachurin, 1961; Suhodrovsky, 1979). Thermokarst lake is well shown on aerial photographs and satellite images. It possible to see the appearance or disappearance of thermokarst lakes, increasing or decreasing in size. Main focus for satellite image observing in relate to thermokarst study is identification a changes which happened and could be notice. With the study of several areas of Alaska was found strong reduction of the areas of thermokarst lakes from 1950 and 2001 (Fitzgerald, Riordan, 2003). Similar Research carried out for the Over Western Siberia for the period 1973-2005 years, showed a reduction of thermokarst lakes in discontinuous and increasing their space in continuous permafrost zone (Bryksina et al., 2006; Dneprovskaya, Polishchuk, 2008; Kirpotin et al., 2008; Kravtsova, Bustrova, 2009; Bolshiyanov, 2011).

Researching of cryolitozone in Yakutya are coming from the end of 19th from first Cossacks explorers. In 1891-1982 appeared an interesting information about ground ice, thermokarst relief and *boolgoonnyakhs*. However, the term Thermokarst came only in 1932 year by Ermolaev. After what the main meaning of the term had been changing. As might be expected, many of the earliest observations made by the European explorers. For example, in Russian Alaska, members of the Otto von Kotzebue expedition observed the peculiarities of frozen ground in 1816 as they traveled through the Bering Strait region. The presence of massive bodies of ground ice subsequently become a major component of periglacial study in the latter part of the 20th century.

Elsewhere in Russia, Karl Ernst von Baer, an Estonian-German naturalist who had traveled to Novaya-Zemlya and Lapland in 1837, was the first to report (Baer, 1838) upon the excavation of a well in perennially frozen ground at Yakutsk, central Siberia. Subsequently.The temperatures that was measured (Middendorf, 1862) are the earliest published information on the thermal regime of what is now termed permafrost. Middendorf correctly interpreted the ground temperature variations with depth and recognized what now referred to as the depth of zero-annual amplitude (French, 2007).

There is an opinion that first talks about permafrost comes from 17 centuries. There were only some notes from *yakut* governors of a province who were exploring unknown lands (Sumgin, 1937, Chwezov, 1955). Before 1840 years there were a few scientific notes concerning Yakutia. First detailed knowledge about cryozone which was obtained after drilling in a yakutian mine by Schergin and also after Middendorf researches of geothermal regime in Yakutsk and Amga settlements, which took place in 1844. Another interesting observation about buried ice and thermokarst relief and boolgoonnyakhs reported by Zubrilov in 1891 and 1892.

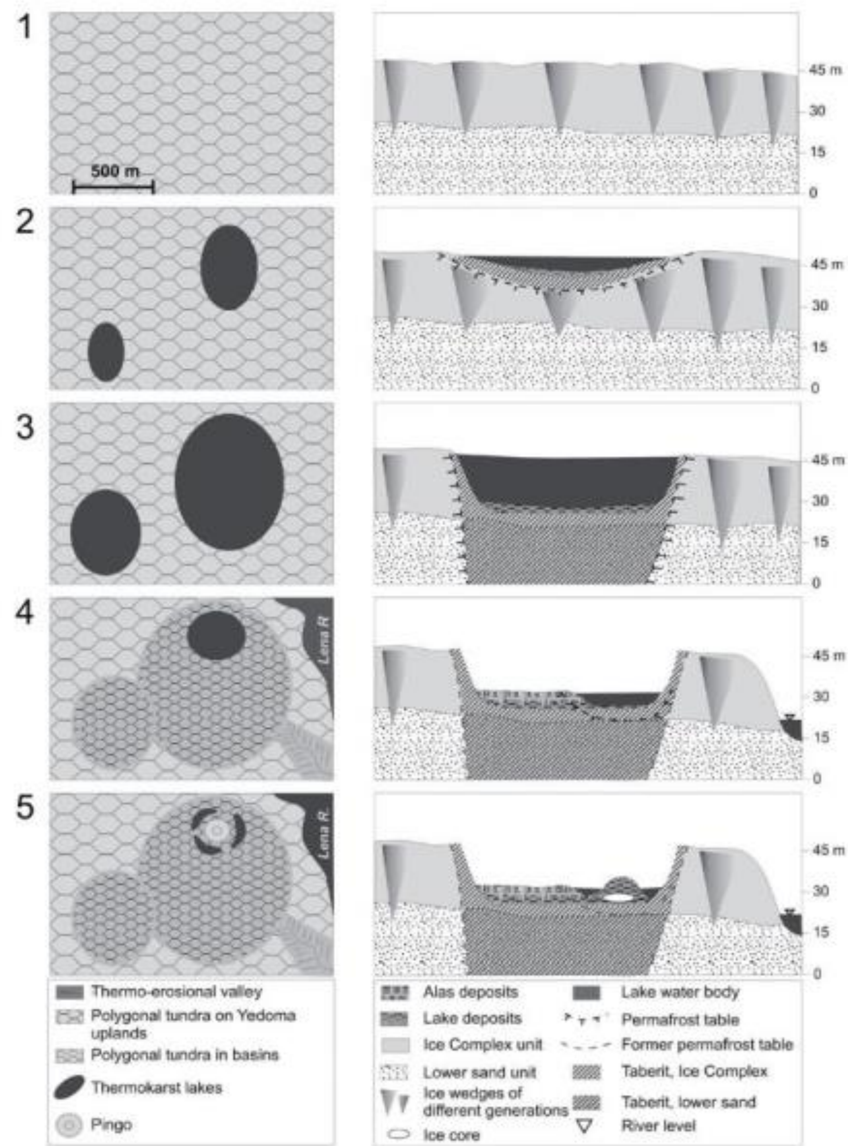


Fig. 3**.** Scheme of thermokarst development in Yedoma landscapes of the Lena River Delta in plain view (left) and cross section (right). 1: Flat, undisturbed Yedoma uplands with polygonal tundra. 2: Thermokarst lakes on yedoma uplands-initial stage with lateral and vertical thermokarst development, lake sedimentation, talik in non-steady state. 3: Thermokarst lakes on yedoma uplands- mature stage with lateral expansion only, lake sedimentation, talik fully developed. 4: Partially drained, coalesced thermokarst basin with remaining or secondgeneration thermokarst lake – partial refreezing of former talik, taberites, and lake sediments with ice aggradation and peat accumulation. 5: Partially drained coalesced thermokarst basin with pingo. (Morgenstern, Grosse, Günther, Fedorova, Schirrmeister, 2011)

Subsea permafrost is a permafrost beneath the Arctic Ocean. It mostly occurs where land inundated by ocean at the end of the last ice age, 10 000 years ago. Its thawing could lead to large releases of methane to the atmosphere (Grosse et.al, 2006).

Lake drainage is rather important process in thermokarst development (see Figure 4) processes. Lake drainage events caused by coastal erosion, by expanding alases, drainage development within alases and along valleys. Lakes and water are not decreased and over 40 years there are no lake forming. According to this knowledge build a theory about the dynamic of thermokarst lakes degradation in Siberia and another northern territory (see Figure 4) (Grosse et.al., 2006).

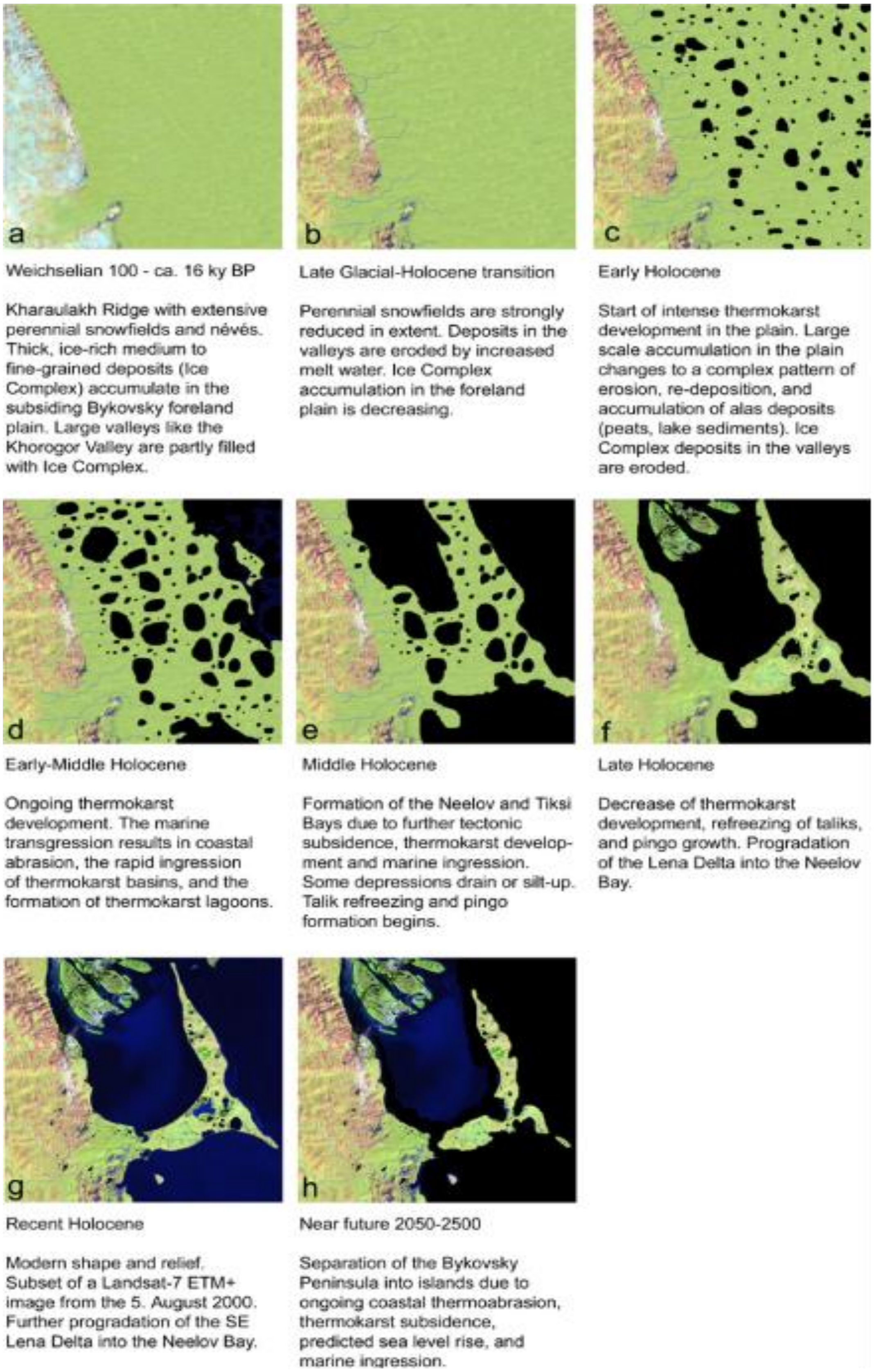


Fig.4. Schematic view of major phases of Late Quaternary landscape evolution southeast of the Lena Delta, based on a Landsat-7 ETM+image and its manipulation. (Geological and geomorphological evolution of a sedimentary periglacial landscape in Northeast Siberia during the Late Quaternary. Guido Grosse , Lutz Schirrmeister , Christine Siegert , Viktor V. Kunitsky ,E.A. Slagoda c, A. A. Andreev a, A. Y. Dereviagyn)

Chapter 2. Materials and Methods

2.1. Meteorological data

In climate change study superventions, commonly used two meteorological parameters: air temperature and precipitations. To identify the climatic fluctuations were using a set of meteorological data of air temperature and precipitation for different periods of years.

The largest amount of data on various meteorological parameters of urgent, daily and monthly permits is available on the website of Research Institute of Hydrometeorological Information - World Data Centre (RIHMI-WDC) in electronic archive. There is a data for 600 Russian weather stations.

From this electronic archive ware taken a mean monthly data for Novyi Port on Yamal Peninsula and Tiksi weather stations on the Lena River Delta. (Bulygina O., Razuvaev V., Trofimenko L., Shvets N) («Description of the mass mean monthly air temperature data at Russian weather stations» and «Description of the mass mean monthly precipitations data at Russian stations».

The meteorological data represented as monthly data of air temperature and amount of precipitations over the time periods: from 1961 to 2016 (Novyi Port) and from 1933 to 2016 (Tiksi) and monthly data of precipitation over time periods: from 1966 to 2016 (Novyi Port) and from 1966 to 2016 (Tiksi). The reason why there is a different time interval is that there was available data only for this years. Tiksi weather station has the longest range of meteorological elements for the Lena Delta region.

Time periods of meteorological data on weather stations

Temperature Data		Precipitation Data	
Tiksi	1933-2016 years	Tiksi	1966-2016 years
Novyi Port	1961-2016 years	Novyi Port	1966-2016 years

Table 1.

2.2. Statistical methods

An important point in meteorological parameters analysis to identify presence or absence the trend component in the time series. The main stages of any climate analysis are: formation of climatological data series; obtaining general climate information and assessing its accuracy; obtaining information for the climate forecast; development of climatic indicators for applied purposes and their calculation; spatial generalization of climate information. The method of time series analysis - one of the probabilistic-statistical apparatus methods, which is applicable for forecasting changes in climatic parameters, as air temperature and precipitations. Identifying the structure of the series and using this knowledge will help to predict its future behavior.

All data (see Table 1.) comparable and presented in the same units (centigrade; millimeters) obtained by averaging the mean monthly air temperatures at the Tiksi weather station (the Lena River Delta) and New Port weather station (Yamal Peninsula) from the electronic archive of World Data Centre (WDC).

All time series with mean annual air temperatures and precipitation are sufficient to identify climatic conditions and phenomena and account for more than 50 values in a row. In the appearance of the augmented series distinguish areas of the direction of movement-trends. The presence of trend implies the dependence of neighboring values (Climatology, 1989).

Trend – is a value that allows to determine the main trend of the time series, stationarity or non-stationary processes occurring in it (Climatology, 1989). Trend is identified by the methods of multidimensional regression. The identification of the main trend of development is called the alignment of the time series, and methods for identifying the main trend - methods of fitting. Important point of the analysis is the identification of trend component in time series of the presence or absence (Mathematic methods in geography, 1999).

To construct a diagram of air temperature and precipitation change, used the climatic indices obtained as a result of mathematical processing of meteorological time series. All climatic indicators were computed by averaging the monthly air temperatures for each year, as a result, got the arithmetic mean - average annual temperature. The arithmetic mean is an estimate of the parameters of many theoretical distributions and is convenient for various mathematical calculations.

The estimation of modern climate dynamics is carried out with the help of coefficients of linear trends of changes in mean annual air temperature and precipitation values if it necessary. For precipitations was taken an annual sum of allowed entries

To determine the reliability of the difference in the mean for two samples used Student's criteria, and in order to judge the differences between three or more samples, - Fisher's criteria.

To assess the statistical significance of the regression and correlation coefficients, the Student's t-test and the confidence were calculated intervals of each indicator. The H0 hypothesis is advanced on the random nature of indicators. One of the simplest methods of detecting the general trend of phenomenon development is enlargement of series interval dynamic. The meaning of this technique is that the original series of dynamics transformed and replaced by another, the levels of which are related to longer periods of time.

The main trend can also be identified by the moving average method. Enlarged intervals consisting of the same number of levels are formed to determine the moving average. Each subsequent interval is obtained, gradually moving from the initial level of the dynamic series to one value.

Based on the aggregated data generated, was calculate the moving averages, which refer to the middle of the enlarged interval. The study of the main trend extension by the moving average method is an empirical method of preliminary analysis.

The identification of main trends called time series alignment and methods for studying the main trends - processes alignment.

To find the equation parameters used least squares method, the way of counting time from the conditional beginning.

The system of Ordinary Least Squares (OLS) equations for a linear trend has the form (Mathematical methods in geography, 1999):

$$a_0 n + a_1 \sum t = \sum y$$

$$a_0 \sum t + a_1 \sum t^2 = \sum y \cdot t$$

The system of equations OLS:

$$a0n + a1\sum t + a2\sum t2 = \sum y$$

$$a0\sum t + a1\sum t2 + a2\sum t3 = \sum yt$$

$$a0\sum t2 + a1\sum t3 + a2\sum t4 = \sum yt2$$

-Significance level

The significance level, also denoted as alpha or α, is the probability of rejecting the null hypothesis when it is true. For example, a significance level of 0.05 indicates a 5% risk of concluding that a difference exists when there is no actual difference (Climatology, 1989).

The significance level determines how far out from the null hypothesis value we'll draw that line on the graph. To graph a significance level of 0.05, we need to shade the 5% of the distribution that is furthest away from the null hypothesis (Mathematical methods in geography, 1999).

-Student's test criterion

Student's test, t-statistics is designed to determine the statistical significance of each coefficient of the equation. To establish the similarity or difference in arithmetic mean values in two samples, use this t-test (Mathematical methods in geography, 1999).

- F Fisher criterion

Defined by the ratio of the between-class scatter to the within-class scatter. By maximizing this criterion, one can obtain an optimal discriminant projection axis. After the sample being projected on to this projection axis, the within-class scatter is minimized and the between-class scatter is maximized (Mathematical methods in geography, 1999).

2.3. Satellite images

A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. ArcGIS - one of many multifunctional geographic information systems.

GIS applications include cartographic data, photographic data, digital data, or data in spreadsheets. Photographic interpretation is a major part of GIS. Photo interpretation involves analyzing aerial photographs and assessing the features that appear. GIS help to understand spatial patterns and relationships better. Digital data can be entered into GIS. An example of this kind of information is computer data collected by satellites that show land use-the location of farms, towns, and forests. A lot of theoretical and practical information for work taken from the ESRI Tutorials where given the definitions and explanations for all types of work in ArcGIS.

There are several satellite systems, such as LANDSAT, WorldView, GeoEye, Pleiades, QuickBird, KOMPSAT, IKONOS, SPOT and others. Providing remote sensing data to end users. Landsat satellite images used for work, as the most accessible, multispectral data. The Landsat series ensure the longest time recording of multispectral data of moderate resolution on the Earth surface. All datasets were found in digital format on Earth Explorer, USGS Global Visualization Viewer (GloVis) and LandsatLook Viewer.

In this work used ESRI ArcGIS 10.2 software. All processes were performed in the Universal Transverse Mercator (UTM) projection Zone 52◦N for Yamal peninsula and Lena Delta and study areas, with the geodetic datum WGS 1984. It is the original projection for Landsat Mosaic.

In tables (Table 2; Table 3) there is a list of available high resolution satellite data for study territories. Unfortunately, the selection contains no data for same month in different years because they could be no suitable and have disturbances as clouds or bad quality of image.

According to US Geological Survey (USGS), the Landsat Multispectral Scanner (MSS) sensor was onboard Landsat 1- 5 and acquired images of the Earth nearly continuously from July 1972 to October 1992. For both researching sites on Yamal Peninsula and Lena Delta were found quite good satellite images. Unfortunately, there are a difference between them, 1973 for Lena Delta and 1988 for Yamal peninsula, but this images were the best for concrete researching territory, all another available data had disturbances in terms of clouds or image noise. Continuing to describe available satellite date of USGS next is the Landsat Enhanced Thematic Mapper Plus (ETM+) sensor onboard the Landsat

7 satellite, which has acquired images of the Earth nearly continuously since July 1999, with a 16-day repeat cycle. Landsat 7 images are referenced to the Worldwide Reference System-2. For research was found two good satellite images for both sits in the nearest years- 2000 and 2001. The next and most modern is Landsat Operational Land Imager (OLI) with Thermal Infrared Sensor (TIRS) which was launched in February 2013. The satellite collects images of the Earth with a 16-day repeat cycle, referenced to the Worldwide Reference System-2. For research was search fresh satellite images with combined data (both OLI and TIRS data) over 2016 year. Next, with the help of Esri Handbook will try to review next steps in work.

Firstly was find a general area of intersections between three satellite images for different years. After data classified was used one of many standard classification methods provided in ArcGIS, or can manually define own custom class ranges.

If to define own classes, manually add class breaks and set class ranges that are appropriate for the data. Or to start with one of the standard classifications and make adjustments. In researching work was used three methods of Remote Sensing manipulations. There are manual and automated methods and also Index MNDWI.

Manual method used while was making a digitizing of polygons. Automated feature extraction from satellite images data has such tools as: Interactive Supervised Classification and Cluster Analysis. The Interactive Supervised Classification tool accelerates the maximum likelihood classification process. All the bands from the selected image layer are used by this tool in the classification. The classified image is added to ArcMap as a raster layer. Here was concreating on area of interests (AOI). For each AOI was appropriate the value of class. After generating of classes typesetting was actuate the classification process.

The image Analyst uses an autonomous method of multi-zonal classification. All that is required of it is to specify the number of classes to divide the image into. Image Analyst implements the ISODATA method, which uses the specified number of iterations and the convergence threshold for data classification. The classification procedure recognizes similar pixels by their values in the spectral channels. Then the pixels are assigned the class numbers, and the classes - symbols and labels. Next step will be using water indice - The Modified Normalized Difference Water Index (MNDWI). Image indices calculated from multiband images. The images detach a specific occurrence that is present, while attenuate other factors that degrade the effects in the image. It using for comparison of the same object across multiple images over time. MNDWI use green and SWIR bands for the enhancement of open water features. It also diminishes built-up area features that are often correlated with open water in other indices. (Xu, H., 2006)

MNDWI = (Green - SWIR) / (Green + SWIR)

Green = pixel values from the green band,

SWIR = pixel values from the short-wave infrared band.

Available satellite data for Yamal peninsula AOI

Date of image	**System**	**Spatial Resolution**	**Path/Row**	**Image ID**
10 jul 1988	Landsat 1-5 MSS	79-meter	163/011	LM41630111988192AAA03
6 aug 2001	Landsat 7ETM+ C1 Level-1	30-meter	164/011	LE71640112001218SGS00
15 jul 2016	L8 OLITIRS C1 Level-1	30-meter	163/011	LC81630112016197LGN01

Table 2.

Available satellite data for the Lena River Delta AOI

Date of image	**System**	**Spatial Resolution**	**Path/Row**	**Image ID**
26 jul 1973	Landsat 1 MSS	79-meter	141/009	LM11410091973207AAA05
27 jul 2000	Landsat 7 ETM+C1 Level-1	30-meter	131/009	LE71310092000209SG01
3 sep 2016	Landsat 8 OLI/TIRS C1 Level-1	30-meter (Pnhr-15;Trl-100)	129/009	LC81290092016247LGN01

Table 3.

It is important to recall that in this paper compare pictures of different spatial resolution: images obtained by the Landsat TM / ETM + surveying system with a resolution of 30 m, as well as images obtained by the Landsat MSS survey system with a spatial resolution of 80 m.

Chapter 3. Results

3.1. Analysis of air temperature and precipitations

This chapter devote to mathematical aspects of time series analysis from air temperature and precipitation data. The complex statistical structure of time series is one of the reasons for the ambiguous conclusions about the nature of changes in climate system. Interpretation of such changes usually made on the basis of time series analysis statistical characteristics, analysis findings by averaging.

To characterize climatic changes in the work given time series of air temperature, and precipitation sum for a sufficiently long period of time, different for each parameter, but ending in 2016. Trends in the extreme daily precipitation indices also showed seasonal variability.

Air temperature

Novyi Port weather station

For Novyi Port weather station used an available data of mean annual temperature for 56 years, from 1961-2016 (see Diagram 1). During the observation period the absolute minimum of annual air temperature in Novyi Port was in 1966 reached -10,6 degrees below zero. The maximum of annual temperature was in 2011, when temperature reach -4,8 degree below zero.

Having located the observed values from the years 1966-2016 in chronological order, obtained time series of 56 variables. The probability of significance for all series is greater than the critical value $\alpha = 0.05$. This mean that at the 5% level of significance, the hypothesis significance.

Evaluation of the trend

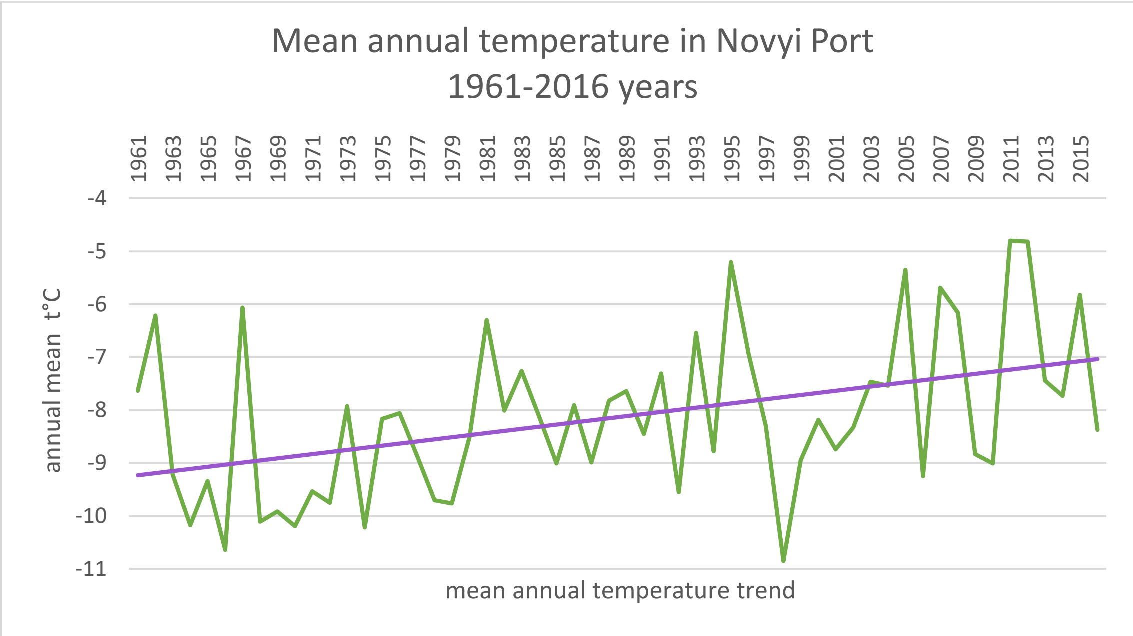


Diagram 1. Mean annual temperature with trend. Novyi Port weather station, Yamal Peninsula

Apparently, there is an increasing trend, then smoothed out the moving average series with period t = 3.

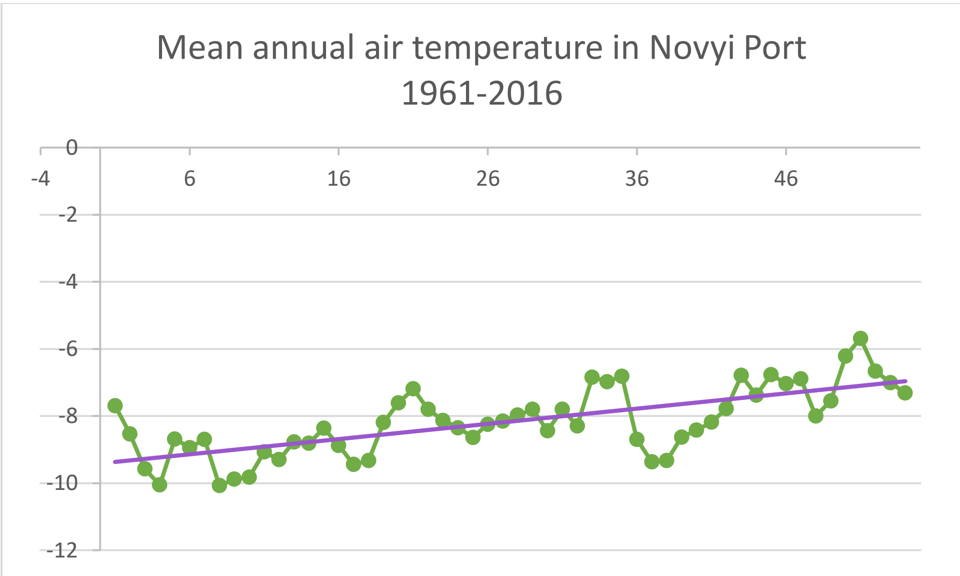
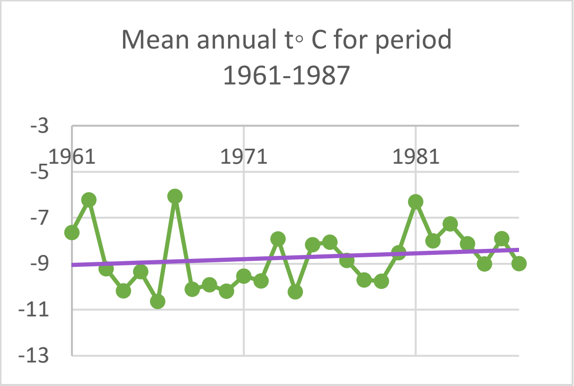
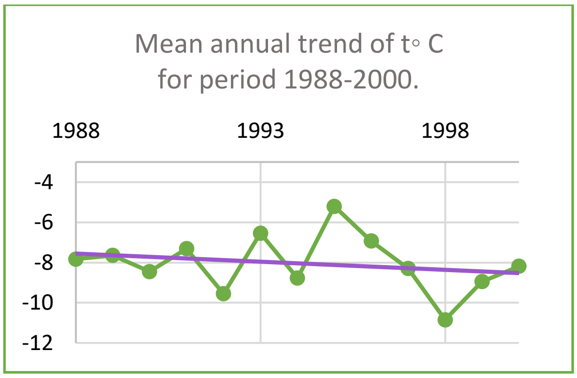


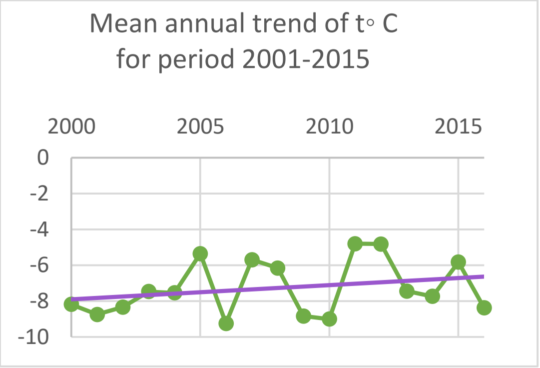
Diagram 2. Mean annual temperature with moving average. Novyi Port weather station, Yamal Peninsula

The rising trend is more obvious. This means that the temperature increase. More detailed trend of periods shows that in the period from 1988-2000 was a small tendency to decrease. At the same time was a little increase of lakes number in Area 1 and Area 2.



a





b c

Diagram 3. a, b, c. Mean annual air temperature trend for three periods of time. Novyi Port. Yamal Peninsula AOI

The linear equation of the trend has the form $y = a1t + a0$

Findings of equation parameters by the method of least squares.

The system of equations for OLS (Ordinary Least Squares):

$$a_0 n + a_1 \sum t = \sum y$$

$$a_0 \sum t + a_1 \sum t^2 = \sum y \cdot t$$

For data, the system of equations has the form:

$$56a_0 + 1596a_1 = -455.48$$

$$1596a_0 + 60116a_1 = -12396.67$$

From the first equation express a0 and substitute in the second equation

obtain $a_0 = -9.272$, $a_1 = 0.0399$

The trend equation: $y = 0.0399\ t - 9.272$

Coefficient of determination: $R^2 = 0{,}1843$

The nonlinear trend equation has the form $y = a_2 t^2 + a_1 t + a_0$

The system of equations for OLS:

$$a_0 n + a_1\sum t + a_2\sum t^2 = \sum y$$

$$a_0\sum t + a_1\sum t^2 + a_2\sum t^3 = \sum yt$$

$$a_0\sum t^2 + a_1\sum t^3 + a_2\sum t^4 = \sum yt^2$$

For data, the system of equations has the form

$$56a_0 + 1596a_1 + 60116a_2 = -455.48$$

$$1596a_0 + 60116a_1 + 2547216a_2 = -12396.67$$

$$60116a_0 + 2547216a_1 + 115122140a_2 = -453685.64$$

obtain $a_2 = 0.000641$, $a_1 = 0.00344$, $a_0 = -8.919$

The equation of the trend: $y = 0.000641t^2+0.00344t-8.919$

Coefficient of determination: $R^2 = 0,1943$

Since the coefficient of determination is larger for a nonlinear trend approximated by a parabola, then for the analysis choose this equation.

Student's criterion, Fisher's criterion

Dispersion of the error of the equation.

$$S_y^2 = \frac{\sum(y_i - y_t)^2}{n-m-1}$$

Where m = 2 is the number of influencing factors in the trend model.

$$S_y^2 = \frac{102.037}{53} = 1.925$$

The standard error of the equation.

$$S_y = \sqrt{S_y^2} = \sqrt{1.925} = 1.39$$

$$S^2_{a0} = \left(\frac{1}{56} + \frac{28.5^2 903350.25\cdot 56 + 1073.5^2 261.25\cdot 56 - 2\cdot 28.5\cdot 1073.5\cdot 833910}{261.25\cdot 903350.25\cdot 56^2 - 833910^2}\right)1.925 = 0.33$$

$$S^2_{a1} = \frac{903350.25\cdot 56}{261.25\cdot 903350.25\cdot 56^2 - 833910^2}1.925 = 0.00218$$

$$S^2_{a2} = \frac{261.25\cdot 56}{261.25\cdot 903350.25\cdot 56^2 - 833910^2}1.925 = 1.0E-6$$

Where $\sum(x_i-x_{icp})(x_i^2-x_{icp}^2) = 833910$ (Column N of the sheet "Temperature 1 (Y) - Parabola")

Standard error coefficient:

$$S_{a0} = \sqrt{0.33} = 0.5767$$

$$S_{a1} = \sqrt{0.00218} = 0.04668$$

$$S_{a2} = \sqrt{1.0E-6} = 0.000794$$

t-statistics. Student's test.

According to the Student's table, find the Table

$$T_{табл}\ (n\text{-}m\text{-}1;\alpha/2) = (53;0.025) = 2$$

$$t_{aj} = \frac{a_j}{S_{aj}}$$

$$t_{a0} = \frac{|-8.92|}{0.58} = 15.47$$

Since 15.47> 2, the statistical significance of the regression coefficient a0 is confirmed (reject the hypothesis that this coefficient is zero).

$$t_{a1} = \frac{0.00344}{0.0467} = 0.0737$$

Since 0.0737 <2, the statistical significance of the regression coefficient a1 is not confirmed (accept the hypothesis that this coefficient is zero).

$$t_{a2} = \frac{0.000641}{0.000794} = 0.8068$$

Since 0.81 <2, the statistical significance of the regression coefficient a2 is not confirmed (accept the hypothesis that this coefficient is zero).

2) F-statistics. Fisher's criterion.

$$F = \frac{R^2}{1 - R^2}\frac{(n - m - 1)}{m} = \frac{0.1943}{1 - 0.1943}\frac{(56\text{-}2\text{-}1)}{2} = 6.39$$

find from the table Fkp (2; 53; 0.05) = 3.17

Where m is the number of factors in the trend equation (m = 2).

Since F> Fkp, the determination coefficient is statistically significant.

Determination the significance of the series

Since F> Fkp, the trend equation as a whole is statistically significant.

Creation a Forecast

Point forecast, $t = 57: y(2017) = 0.000641*57^2 + 0.00344*57 -8.919 = -6.64$

Point forecast, $t = 58: y(2018) = 0.000641*58^2 + 0.00344*58 -8.919 = -6.57$

Point forecast, $t = 59: y(2019) = 0.000641*59^2 + 0.00344*59 -8.919 = -6.49$

It should be noted that the obtained trend equation is not desirable to be used for the forecast, since the significance of the coefficients a_1, a_2 is not confirmed.

Tiksi weather station

From the Lena River delta AOI elected Tiksi weather station, which is a nearest with long-term meteorological data. The data include mean annual temperature for 84 years, from years 1933-2016 (see Diagram 4). During the observation period the absolute minimum of annual air temperature on Tiksi was in 1979 and reach -16, 6 degrees below zero. The maximum of annual temperature was in 2011, when temperature reach -10,09 degree centigrade below zero.

According to the Diagram (see Diagram 4) of Tiksi weather station from 1933-2016 marked trend increasing, in connection with this it probable melting of permafrost which increases the possibility of drainage

The Diagram shows first decreasing then increasing, temperature values (see Diagram 4).

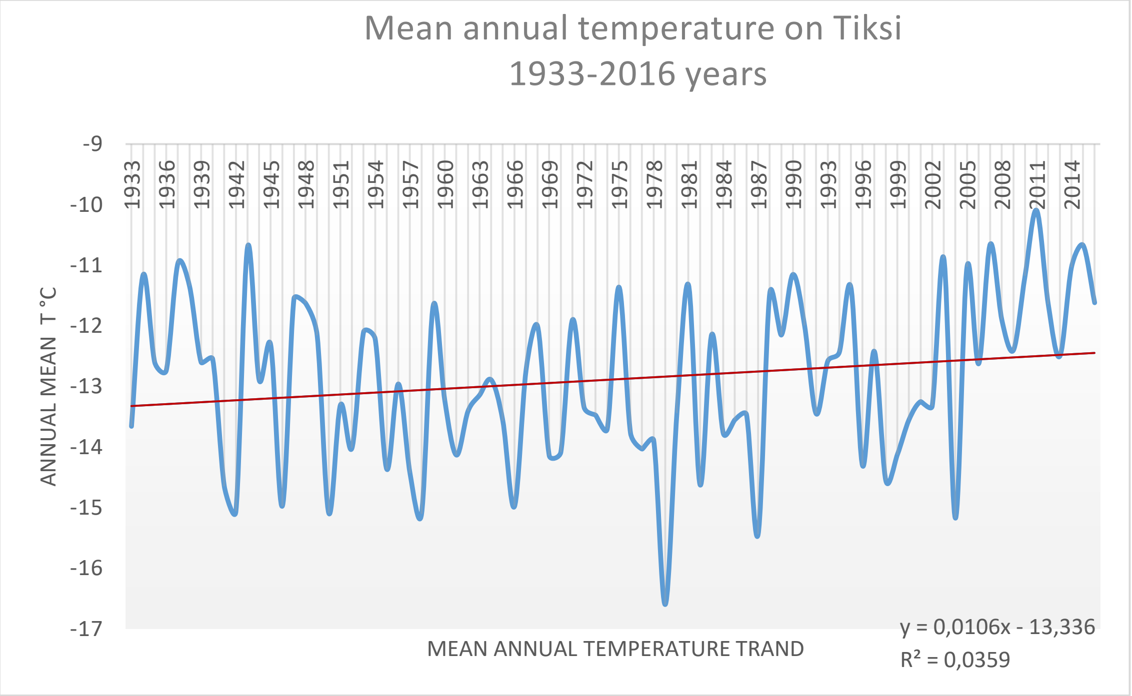
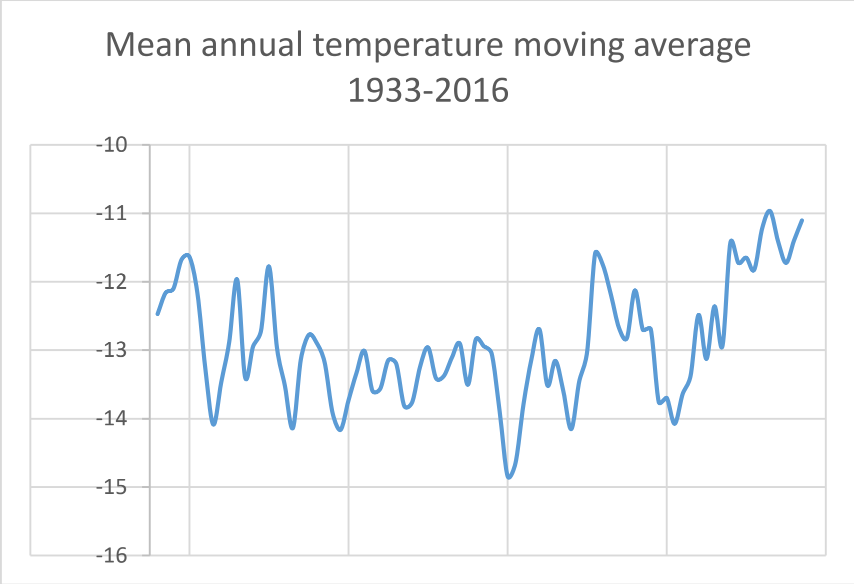


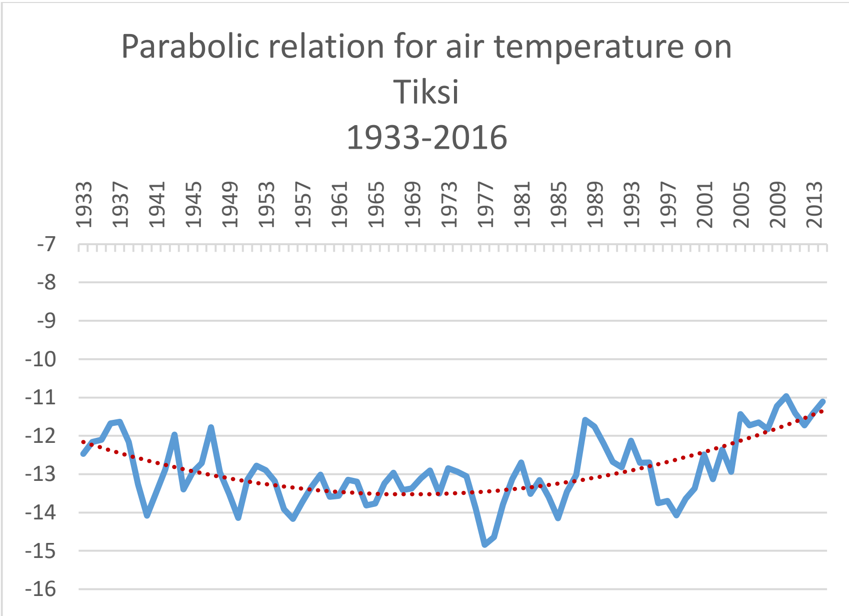
Diagram 4. Mean annual air temperature in Tiksi weather station, the Lena River Delta

Presented Diagram immediately talked about the non-linearity of the trend. For a more visual representation, smoothed out the moving average series (Diagram 5a).

Since the temperature values first decrease, then increase, assume the parabolic dependence. (Diagram 5b)



a)



b)

Diagram 5. a) Mean annual air temperature moving average in Tiksi weather station, the Lena River Delta b) Parabolic dependence for mean annual temperature on Tiksi, The Lena River

The parabola trend equation has the form $y = a_2t^2 + a_1t + a_0$

$$84a_0 + 3570a_1 + 201110a_2 = -1082.45$$
$$3570a_0 + 201110a_1 + 12744900a_2 = -45481.7$$
$$201110a_0 + 12744900a_1 + 861515018a_2 = -2523306.15$$

Was obtain $a_2 = 0.00103$, $a_1 = -0.0767$, $a_0 = -12.084$

The equation of the trend: $y = 0.00103t^2 - 0.0767t - 12.084$

Student's criterion, Fisher's criterion

Dispersion of the error of the equation.

$$S_y^2 = \frac{\sum(y_i - y_t)^2}{n-m-1}$$

Where m = 2 is the number of influencing factors in the trend model.

$$S_y^2 = \frac{124.009}{81} = 1.531$$

The standard error of the equation.

$$S_y = \sqrt{S_y^2} = \sqrt{1.531} = 1.24$$

$$S^2_{a0} = \left(\frac{1}{84} + \frac{42.5^2 4524097.139\cdot 84 + 2394.167^2 587.92\cdot 84 - 2\cdot 42.5\cdot 2394.167\cdot 4197725}{587.92\cdot 4524097.139\cdot 84^2 - 4197725^2}\right)1.531 = 0.17$$

$$S^2_{a1} = \frac{4524097.139\cdot 84}{587.92\cdot 4524097.139\cdot 84^2 - 4197725^2}1.531 = 0.000507$$

$$S^2_{a2} = \frac{587.92\cdot 84}{587.92\cdot 4524097.139\cdot 84^2 - 4197725^2}1.531 = 0.000001$$

$$where \sum(x_i-x_{icp})(x_i^2-x_{icp}^2) = 4197725$$

Standard error coefficient:

$$S_{a0} = \sqrt{0.17} = 0.415$$

$$S_{a1} = \sqrt{0.000507} = 0.0225$$

$$S_{a2} = \sqrt{0.0000001} = 0.000245$$

Student's test. t-statistics.

According to the Student's table, find the Table

$$T_{табл}\ (n-m-1;\alpha/2) = (81;0.025) = 1.989$$

$$t_{aj} = \frac{a_j}{S_{aj}}$$

$$t_{a0} = \frac{|-12.08|}{0.41} = 29.13$$

Since 29.13> 1.989, the statistical significance of the regression coefficient a0 is confirmed (reject the hypothesis that this coefficient is zero).

$$t_{a1} = \frac{|-0.0767|}{0.0225} = 3.41$$

Since 3.41> 1.989, the statistical significance of the regression coefficient a1 is confirmed (reject the hypothesis that this coefficient is zero).

$$t_{a2} = \frac{0.00103}{0.000245} = 4.0$$

Since 4.0> 1.989, the statistical significance of the regression coefficient a2 is confirmed (reject the hypothesis that this coefficient is zero).

F-statistics. Fisher's criterion.

Coefficient of determination.

$$R^2 = 1 - \frac{\sum(y_i - y_t)^2}{\sum(y_i - \overline{y})^2} = 1 - \frac{124.01}{154.04} = 0.195$$

$$F = \frac{R^2}{1 - R^2}\frac{(n - m - 1)}{m} = \frac{0.195}{1 - 0.195}\frac{(84-2-1)}{2} = 9.81$$

Find from the table $Fkp(2;81;0.05) = 3.109$

Determination the significance of time series

Since F> Fkp, the coefficient of determination (and, in general, the trend equation) is statistically significant

Creation a forecast

Point forecast, t = 85: y(2017) = $0.00103*85^2 - 0.0767*85 - 12.084 = -11.19$

Point forecast, t = 86: y(2018) = $0.00103*86^2 - 0.0767*86 - 12.084 = -11.09$

Point forecast, t = 87: y(2019) = $0.00103*87^2 - 0.0767*87 - 12.084 = -10.99$

This trend equation can be used for the forecast, since all the coefficients are statistically significant, and in general the equation is statistically reliable.

Now known that data from Tiksi weather station appropriate for further forecast.

Mean annual temperature trend for three periods of time according to gaps between satellite images.

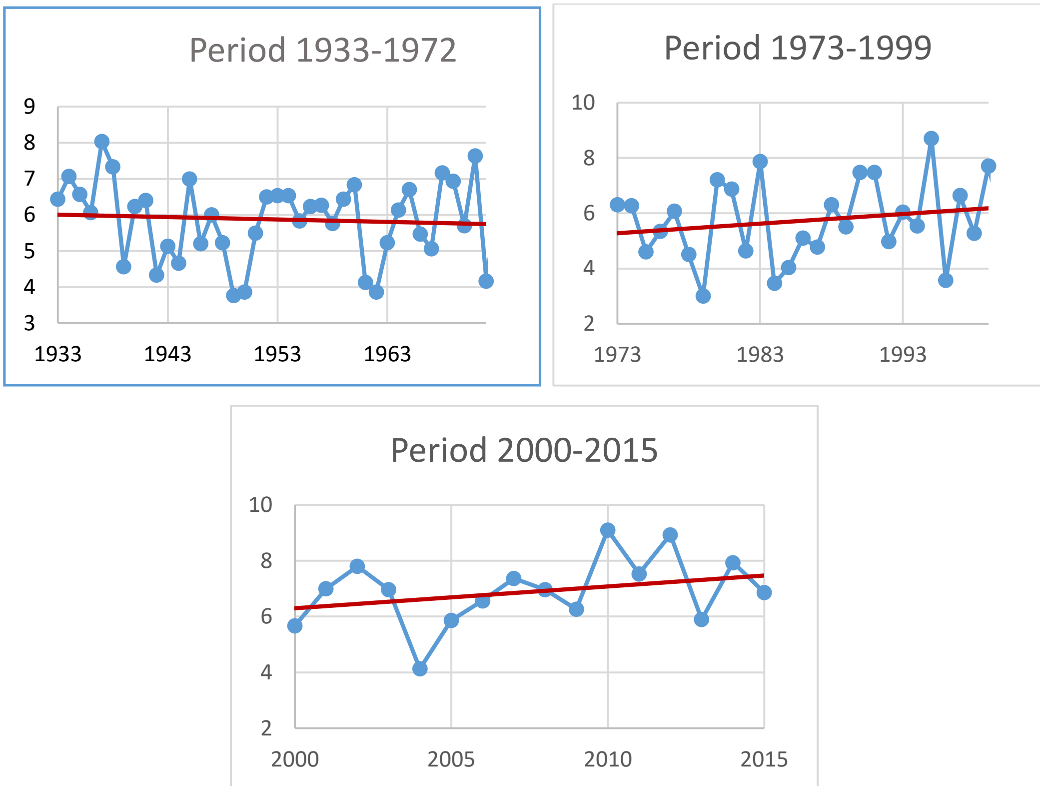


Diagram 6. a, b, c. Mean annual temperature trend for different time periods. Tiksi weather station, The Lena River Delta AOI

Precipitations

Novyi Port weather station

Represented analysis of dataset for Novyi Port weather station in time period for years 1966-2016. Constructed a diagram (see Diagram 7) with linear trend, which shows mean annual precipitation in Novyi Port weather station. The data were counted from all months by sum of mean annual precipitations in millimeters (mm). As seen on Diagram, the less value was in 2013 with the annual sum of 142,6 mm and the biggest value in 1968 with the value of 595,8 mm.

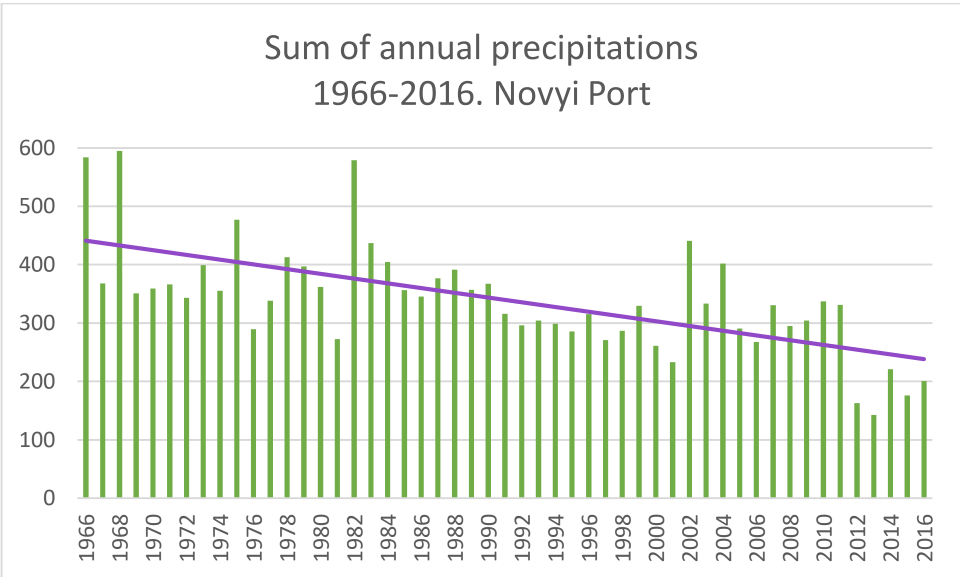
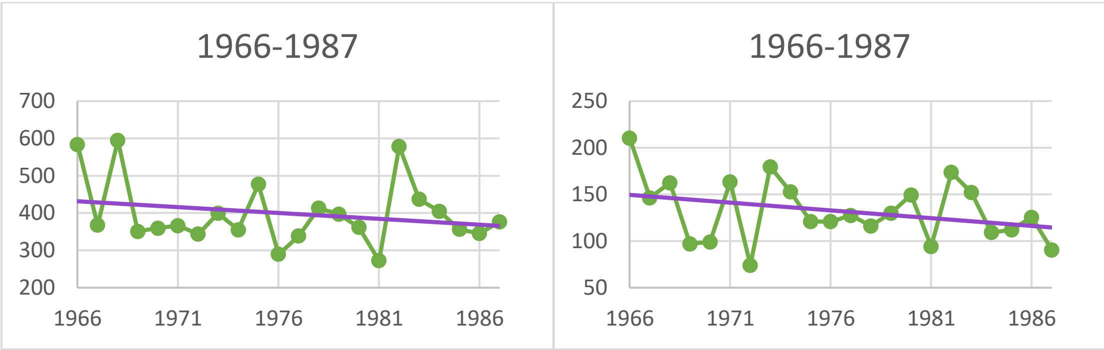


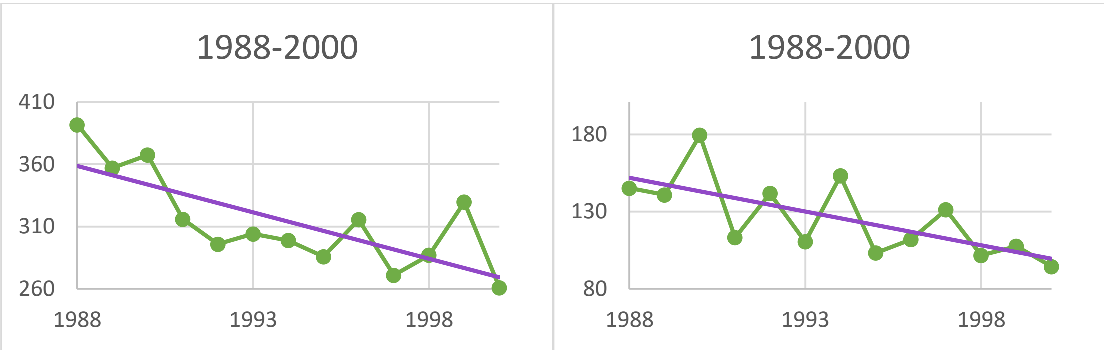
Diagram 7. Mean annual amount of precipitations trend on Novyi Port weather station, Yamal Peninsula

On Diagram (see Diagram 7) presented the linear trend of atmospheric precipitations in general for sum of annual precipitations per year. Estimates are obtained from the time series of sum from annual and seasonal precipitation data for 1966-2016. On the total Russia territory trend of annual precipitations has a tendency to growth. Known, that precipitations amount is grows from South to North. But on Novyi Port weather station showed an opposite tendency. Sum of annual precipitations decreasing.

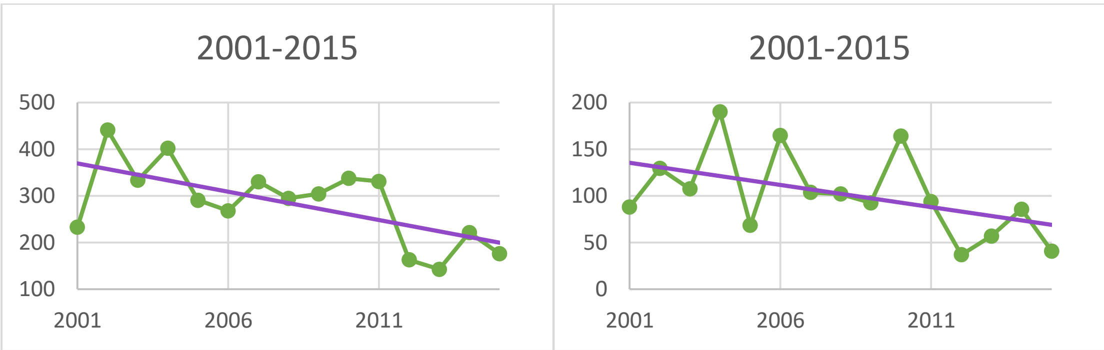
Comparing between sum of annual precipitations per year for season September-December.



a.1; b.1



a.2; b.2



a.3; b.3

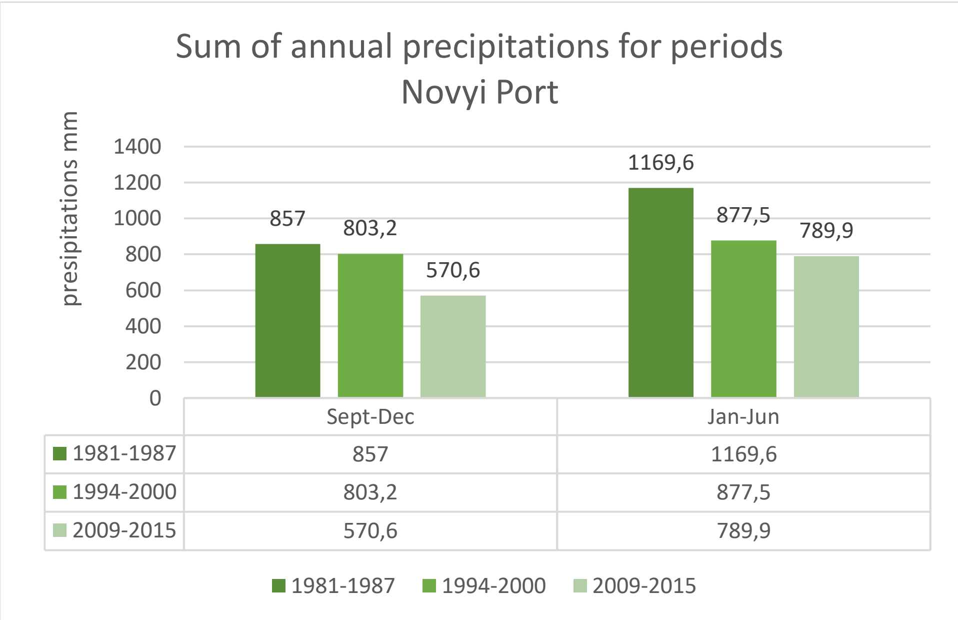
Diagram 8. Sum of annual and seasonal precipitation trends for three periods of time.
Novyi Port weather station, Yamal Peninsula. (a.1;a.2;a.3 – mean annual precipitation trend; b.1;b.2;b.3 – mean seasonal precipitation trends for September-December period)

The diagram (see Diagram 8) show a trends of sum of annual precipitations from different periods. This comparing explained us that precipitations have the same tendency as for hole period then for season September-December (see Table 4). Seasonal component very important for, because precipitations in different seasons have various consequences. Autumn and early winter sum of precipitations could say more than annual.

Amount of precipitations for periods on Novyi Port weather station							
September-December				January-June			Total
Period of 7 years		Previous 1 year		Period of 7 years	Year of satellite image		
1981-1987	857	1987	90,5	1169,6	1988	144,1	2026,6
1994-2000	803,2	2000	94,4	877,5	2001	116,1	1680,7
2009-2015	570,6	2015	40,6	789,9	2016	80,8	1360,5

Table.4. Seasonal dynamic of precipitations sum for different years and periods. Novyi Port, Yamal Peninsula

According to the calculations, given in the table on the basis of sum annual precipitations data, seen a clear tendency to decreasing of seasonal precipitation sum in all periods preceding the year of satellite images. The sum of precipitations affects on the square of lakes. In table counted precipitation summation of season from September to December for the previous 6 years, including one year before the satellite image and a year of image. Sum of season January-June shows the same tendency of precipitations decrease, particularly in the last period of time between satellite images. This conclusion may indicate that a decrease in the area of lakes is clearly associated with a decrease in the sum of precipitations (see Diagram 9).



	Sept-Dec	Jan-Jun
1981-1987	857	1169,6
1994-2000	803,2	877,5
2009-2015	570,6	789,9

Diagram 9. Seasonal distribution of sum precipitations for periods of time before the date of satellite image

Tiksi weather station

The precipitation data high importance for observation of hydrological regime. Precipitation data collected in order to provide optimal climatic predictions. In work analyzed precipitations dataset for Tiksi weather station in period for years 1966-2016.

During the observation period, the annual precipitation data has maximum of precipitations in 2003, with value 41,06 mm. and minimum was in 2001 with value 17,67 mm.

The data were counted from all months by summing annual precipitations in millimeters per year.

As could be seen on diagram, the trend is not significant visually, but it is slowly rising. The annual dynamics of precipitations has a direct effect on the amount of water, therefore it could be relative to the square of lakes (see Diagram 10).

The data on the Tiksi weather station were used for the work. In order to take into account, the precipitation that fell in the years antecedent to the date of the satellite image and remained in a solid state, precipitation was summed up for the periods September-November and January-July 1966-1972, 1973-1999, 2000-2016

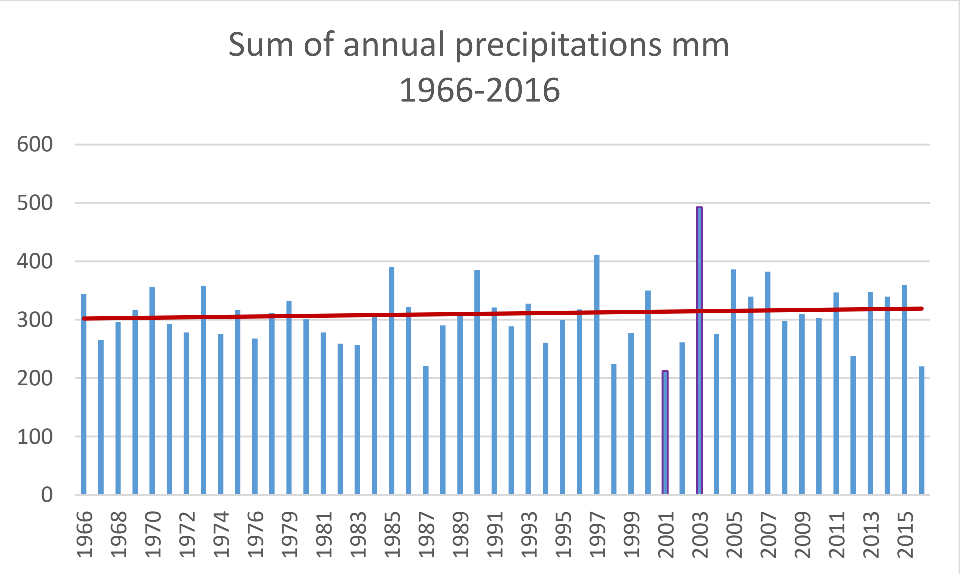
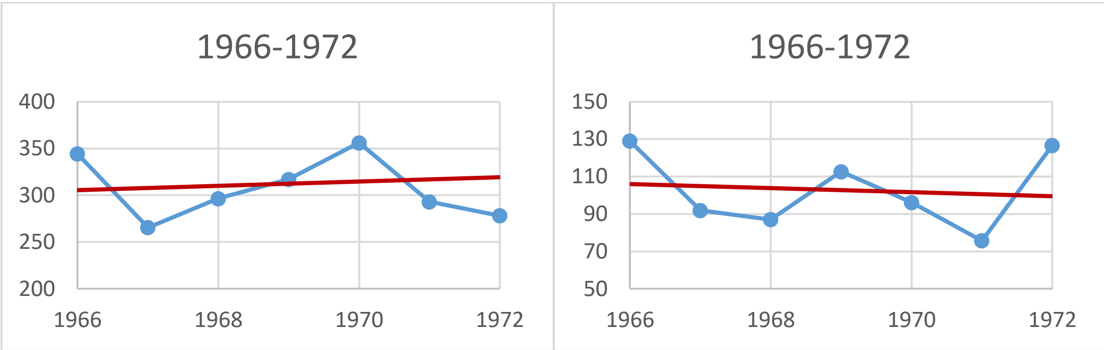
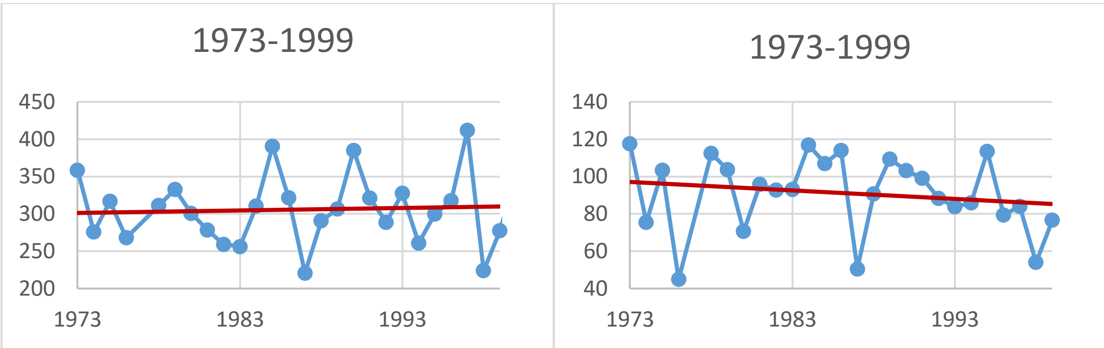


Diagram 10. Sum of annual precipitations in Tiksi, the Lena River Delta AOI

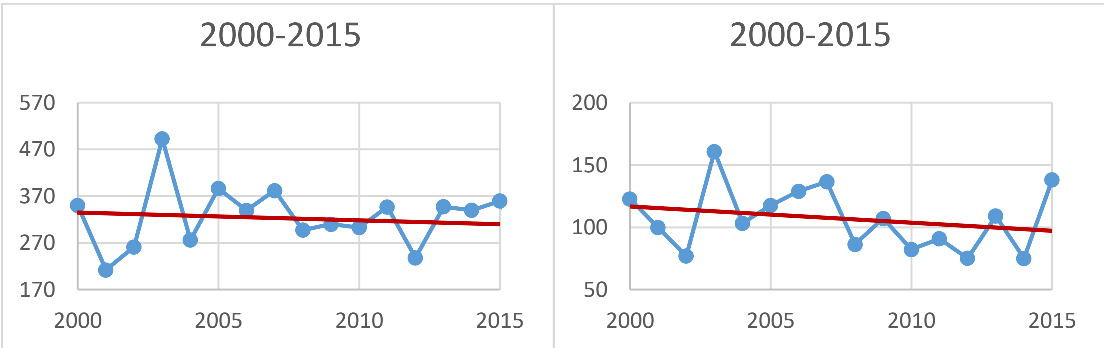
Mean annual and mean seasonal precipitation trends for three periods of time.



a.1 ; b.1



a.2 ; b.2



a.3; b.3

Diagram 11. Mean annual and mean annual seasonal precipitation trends for three periods of time. Tiksi weather station, The Lena River Delta

a.1;a.2;a.3 – mean annual precipitation trend; b.1;b.2;b.3 – mean seasonal precipitation trends for September-December period

Elevations of the whole trend possibly does not show any perspectives for making a forecast. Therefor would be more rational attend to seasonal aspects.

The table (see Table 5) shows a summation of precipitation in the period from September to December for the previous 7 years, including one year before the satellite image date.

Amount of precipitations for different periods on Tiksi weather station							
September-December				January-June			Total
Period of 7 years		Previous 1 year		Period of 7 years	Year of satellite image		
1966-1972	719,1	1972	126,7	831,1	1973	138	1550,2
1993-1999	577	1999	83,8	747,1	2000	107	1324,1
2009-2015	677,8	2015	138,1	772,5	2016	75,6	1450,3

Table 5. Seasonal dynamic of precipitations sum for different years and periods. Tiksi, The Lena River Delta

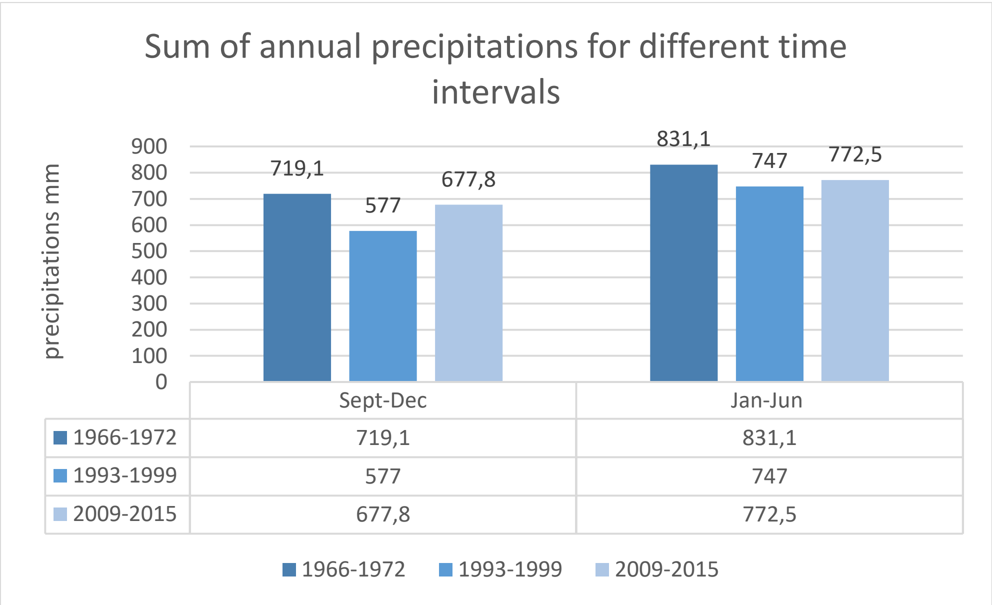


Diagram 12. Seasonal dynamic of precipitations sum for different years and periods. Tiksi, The Lena River Delta AOI

On Diagram (see Diagram 12) of seasonal precipitations for Tiksi represented columns with September-December sum of precipitations, which shows a decreasing in the period of years from 1993-1999 and the same tendency for January-June season but with less gaps between sum of precipitations.

3.3. Satellite image processing and analysis

Within the Area of Interest on Yamal Peninsula situated in the eastern part of central Yamal, and the Lena River Delta AOI on Sobo-Sise Island. For both areas were analyzed long-term changes in the area of lakes for a pair of different satellite images from the Landsat satellite images. On each AOI were chosen for three areas, hereafter: Area 1, Area 2, Area 3.

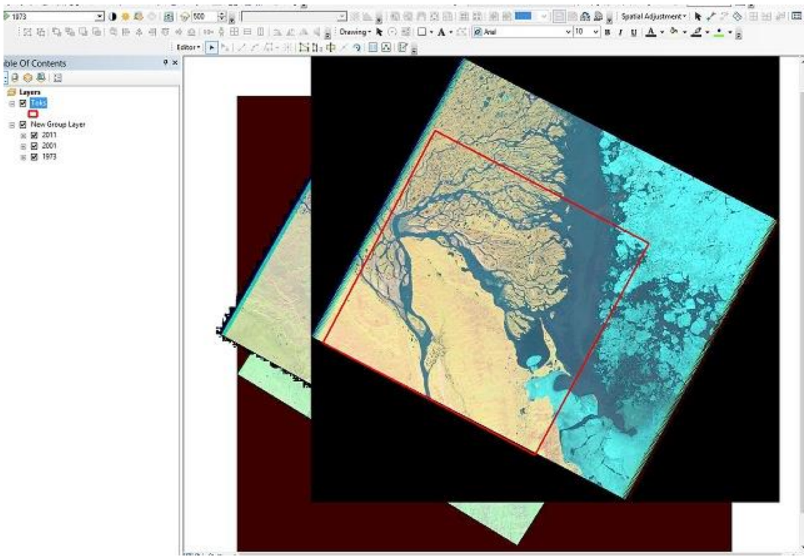


Figure 5. ArcMap Desktop. ArcGIS software

For analyzing of remote sensing images, was taken images from July, August and September months. Because there is predominantly no ice in lakes and less clouds, which could create disturbance for work with images. The analyzing of thermokarst lakes changing require to work in big scales, from 1:200 000 and more. For both study regions were used different satellite images from The U.S. Geological Survey web page (USGS).

As the main materials for the first and second satellite images, were used the images obtained by the MSS system for first year, ETM for second year and OLI for third year. which allowed to analyze changes in the lakes from two periods:

-First period 1988-2000;

- Second period 2000-2016 for Yamal Peninsula AOI and 1973-2001;2001-2016 for the Lena River Delta AOI. Despite the longer considered time interval between first period, was a comparison of different space images of different satellite systems. Working with images from different years allows as to observe the change in the number of lakes in different years and different resolution.

In this work were analyzed three images for the warm period: 1988, 2001 and 2016 years for Yamal Peninsula AOI and three for 1973, 2000, 2016 years for the Lena River Delta AOI. In this work focus was to count the quantity of lakes and lakes surface. It is important to see the possible dynamic of morphometric parameters on the images from different periods. In the software ArcMap 10.2. were raised the contours of lakes. After that, countours were automatically counted.

Yamal Peninsula AOI

As a result, for Yamal Peninsula AOI was determined:

- The number of lakes decreased in area, the number of lakes, the area of which increased;
- The square of lakes in AOI and for each area;
- Calculated indicators brought under the table (see Table 6) and shown in the diagram (Diagram) also deducted the delta (Δ) between two following values.

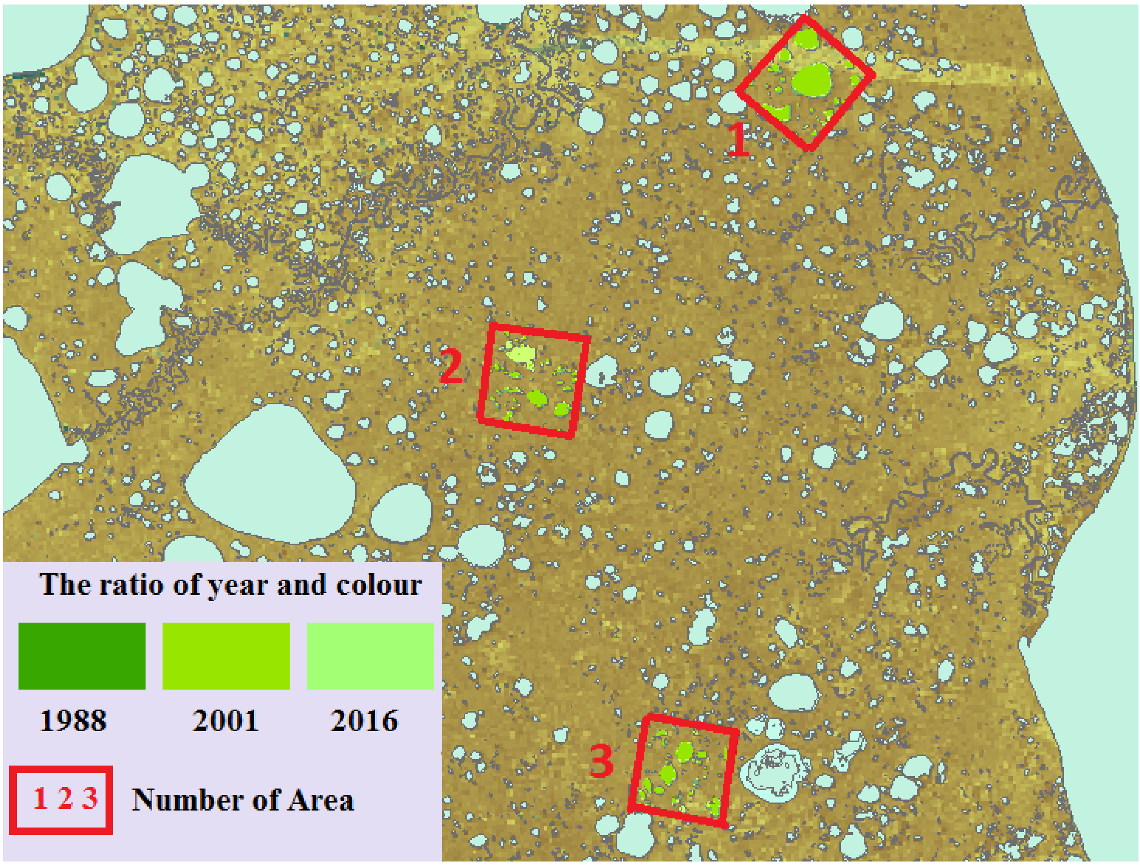


Figure 6. Yamal Peninsula AOI. Satellite image in ArcGIS

Lakes dynamics on the Yamal peninsula AOI											
Year	Number of lakes			S of lakes						S of lakes on three Areas	
	area 1	area 2	area 3	area 1	Δ	area 2	Δ	area 3	Δ		Δ
1988	36	55	59	8,45		4,35		4,32		17,13	
	Δ20	Δ7	Δ42		0,67		0,04		0,2		0,92
2000	56	63	101	7,78		4,31		4,12		16,22	
	Δ13	Δ0	Δ24		0,61		1,51		0,41		2,53
2016	49	63	77	7,17		2,79		3,71		13,69	

Table 6. Δ- lettered delta. Square in sq.km

According to the obtained data of area1, area 2, area 3 on Yamal Peninsula AOI, observed processes such as increasing the number of lakes, as well as the unchanged process like in area 3 (see Table 6). Regarding the change in the Square of lakes in three areas, there is a visible tendency to reduce the square of lakes, but not significant. What about area 2, one of the lake withering, but it is not the one reason why the square decreased. As seen in (see Diagram 13, Diagram 14) the number of lakes in Area 2 become less, and there is the main tendency of lakes dynamic in this area.

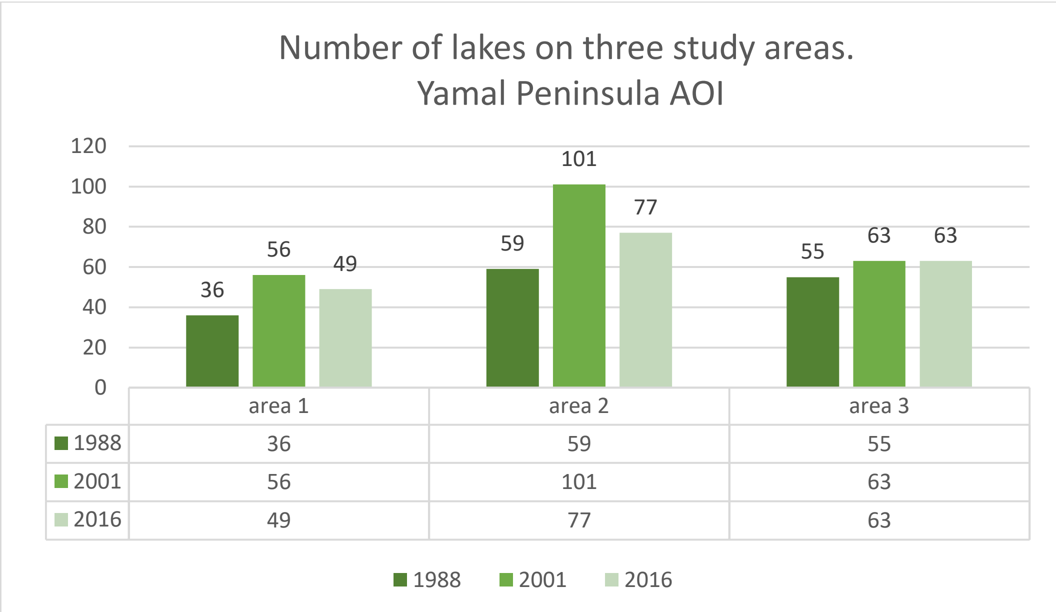


Diagram 13. Number of lakes in study Area 1, Area 2, Area 3 on Yamal Peninsula AOI.

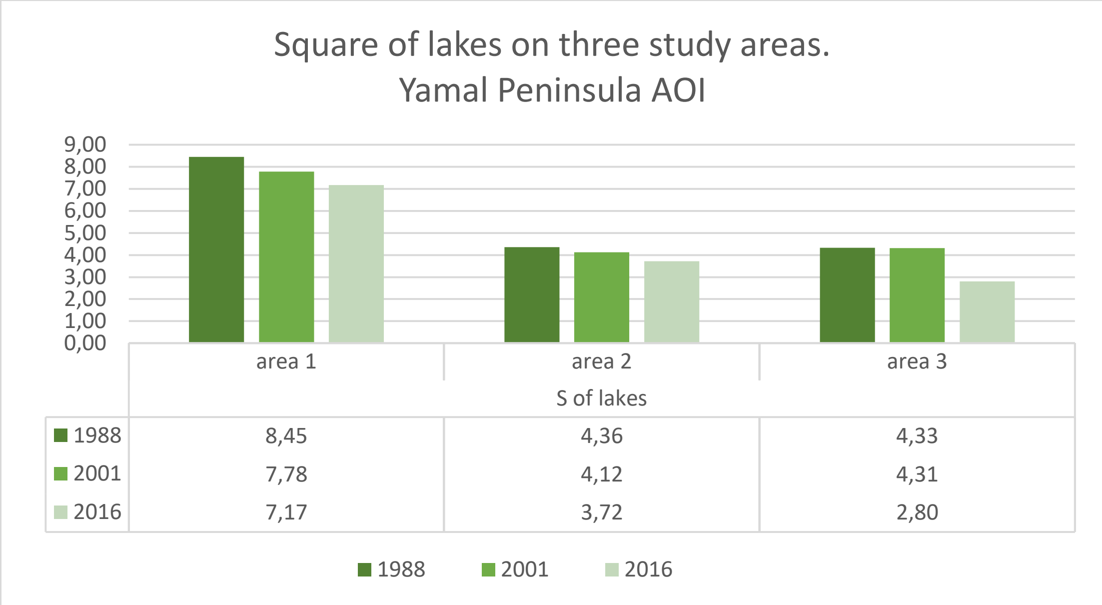


Diagram 14. Square of lakes in study Area 1, Area 2, Area 3 on Yamal Peninsula AOI. Square in sq.km

On the Yamal Peninsula AOI was detected lakes with square more than 100 ha (1 sq.km), less than 100 ha (1sq.km) and less than 0,2 ha (0,002sq.km). During whole period from 1988-2016, the overall square of lakes changed from 17.1 sq.km to 13,6 sq.km. From the first interval 1988-2001 the square of lakes decreased from 17,1 to 16,2(0,92). In second period from 16,2-13,6 (2,53) sq.km.(see Table) That's mean that in the last period of years showed decreasing of lakes square and decreasing of lakes number. In the opposite side (see Diagram 13) first period from 1988-2001 characterized by increasing of lakes number with slow decreasing of lakes square. Predominated increase of lakes number less than 0,2 ha (0,002 sq.km) from 1988 on Area 1, decrease on Area 2 and slow decrease in Area 3, where doesn't noticed big dynamic of lakes number in the years from 1988-2016, only decreasing of lakes square.

Three Areas on Yamal Peninsula AOI arrangementы on three different terraces:
Area 1 located on coastal marine terrace 2 on pediment plain. Area 2 extension is on plane terrace 3 with polygonal grounds predomination on pediment plain. This lays lay in interfluve therefore it could provide rather deep depressions. Typically, lakes on terrace 3 have more lakes with thermokarst origin. Thermodenudation process affects on it mostly, and lakes does't profound deeper. The biggest lake on this Area drained possibly along of channel and watercourses (see Figure) Landslide ablation also could be a reason of the drain. Area 3 laying on river floodplain laida with accumulative genesis. Floodplain lakes typically deep, sometimes could be deeper then lakes on terrace 3. Hasyrei basins typically located on floodplains in interfluves.

Because of the proximity to the river, some of lakes drains faster because of the channel system, subsequently such channels have erosion forms. In Spring time lakes in interfluves rarely change their outlines as they have a smaller drainage area refills with thawed water. Therefore, it is important to consider the role of snow evaporation, temperature and precipitation.

According to the calculated data, the total decrease in the area occupied by lakes in the period 2001-2016 is traced. The decrease can be attributed to the change in the areas of large and medium-sized lakes, floodplains and vozorazdelah. The reason for this can be the change in precipitation, as well as the descent of lakes through waterways as in Area 2. the total area of lakes depends on the annual amount of precipitation.

Reductions of lakes square in continuous permafrost distribution zone could considered as degradation of permafrost under the influence of climate warming and dripping of water from lakes into thawed ground. Dynamic of lake basins suffers from the water level. Precipitations and seasonal changes in snowmelting have a great impact on it. On satellite images of Yamal Peninsula AOI determined changes in the square of lakes. Increasing in first period and decreasing in second between dates of satellite images. Sum of precipitation in season January-June shows the same tendency of precipitations decrease, particularly in the last period of time between satellite images 2001-2016. This conclusion may indicate that decrease in lakes square and total number of lakes is clearly associated with a decrease in the sum of precipitations.

Changing of lakes numbers concerning the lakes square.

Changing the square of lakes number in the Area 1 (Yamal Peninsula)				
ha.	>100ha	100-1 ha	1 ha<	
Sq km	>1sq.km	1-0,01sq.km	0,01sq,km<	Total
Year				
1988	3	25	8	36
2001	3	31	24	56
2016	2	23	24	49

Changing the square of lakes number in the Area 2 (Yamal Peninsula)				
ha.	>100ha	100-1 ha	1 ha<	
Sq km	>1sq.km	1-0,01sq.km	0,01sq.km<	Total
Year				
1988	0	30	28	59
2001	0	28	73	101
2016	0	23	50	77

Changing the square of lakes number in the Area 3 (Yamal Peninsula)				
ha.	>100ha	100-1 ha	1 ha<	
Sq km	>1sq.km	1-0,01sq.km	0,01sq.km<	Total
Year				
1988	1	30	24	55
2001	1	37	25	63
2016	0	37	26	63

Table 7. Changing the square of lakes number on three Areas (Yamal Peninsula)

Lakes square change on the Yamal Peninsula AOI Areas

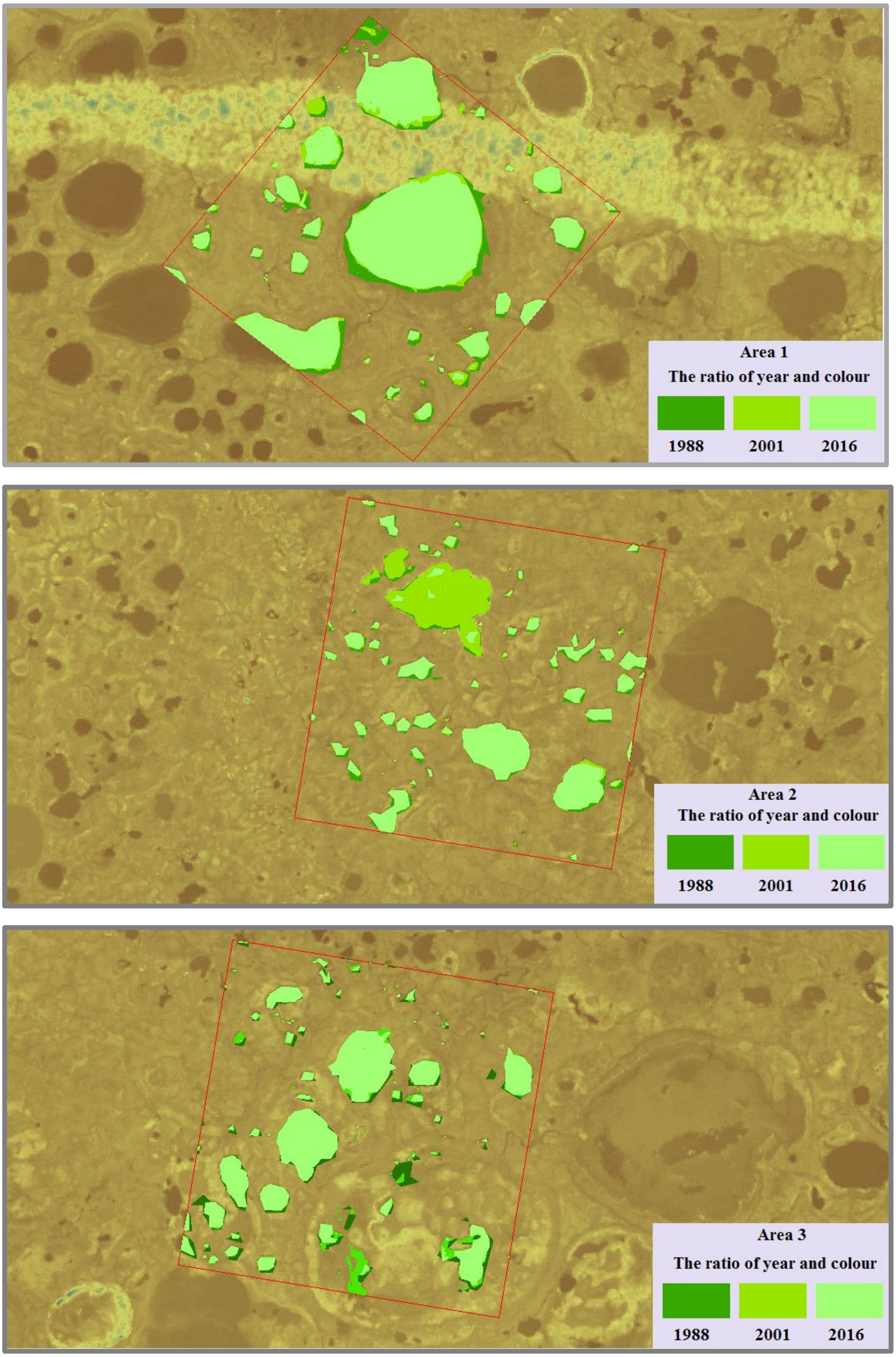


Figure 7. Yamal Peninsula AOI Areas: Area 1, Area 2, Area 3. Satellite images overlapping for different years. ArcMAP 10.2 Software

The Lena River Delta AOI

Was obtained data for Area1, Area 2, Area 3 on the Lena River Delta AOI, which observed processes of lakes increasing on first period and decreasing in srcond(see Table 5). On the diagrams (Diagram 15, Diagram 16) trace a tendency. This process for lakes numbers from all Areas is synchronous to lakes square also for three Areas.

Lakes square change on the Lena River Delta AOI Areas

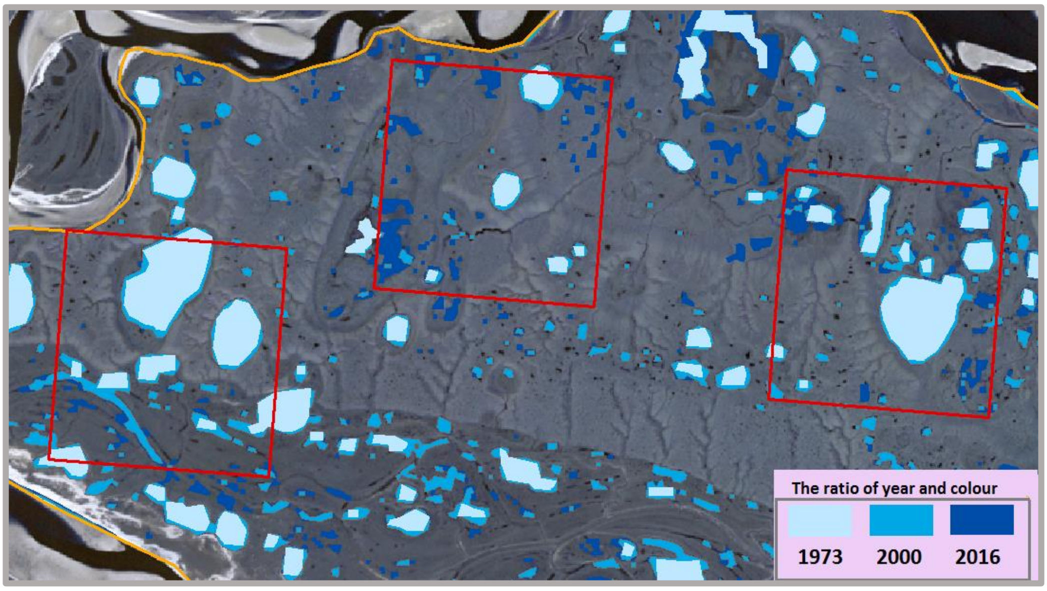


Fig.8 The Dynamic of thermokarst lakes changes on the map on the satellite image base map. The Lena River Delta AOI

.

This conclusion may indicate that according to the calculations given, apparently the greatest humidification is characteristic for the period preceding 1973 and 2016, what determine an abundant humidification in the period up to 2000 year. The amount of precipitation possibly has no effect on the area of lakes.

The results on diagram of lakes square dynamic (see Diagram 16) illustrate following tendency. There is an increasing between first and second satellite images up to 2000 year and decreasing in second period up to 2016 year. That result designate disconnections of lakes dynamic with the sum of precipitations decreasing. But there are two ways of looking at this. Decrease in precipitations amount could cause the increase in square of lakes and their number or precipitations have no big influence on lakes dynamic and another factor could be more appropriate. All things consider time series of air temperature has a parabolic relation, the conclusion to be drawn is that tracing a tendency between increasing lakes number and square in the period of 1973-2000. Exactly this year are in the bottom of parabolic process (Diagram 2.b) It only remains to say that low air temperature decreasing have influence

Small changes in the Lena River delta, can associated with the draining of isolated thermokarst lakes on the terraces of the high floodplain.

Lakes dynamics on the Lena River Delta AOI											
Year	Number of lakes			Square of lakes						Square of lakes on three Areas	
	area 1	area 2	area 3	area 1	Δ delta	area 2	Δ delta	area 3	Δ delta		Δ
1973	8	6	10	4,78		1,02		3,88		9,70	
	Δ25	Δ29	Δ28		2,74		2,74		3,17		8,67
2000	33	35	38	7,53		3,77		7,06		18,37	
	Δ6	Δ16	Δ7		0,55		2,08		1,56		4,20
2016	27	19	31	6,98		1,68		5,500		14,17	

Table 8. Δ- lettered delta. Square in sq.km

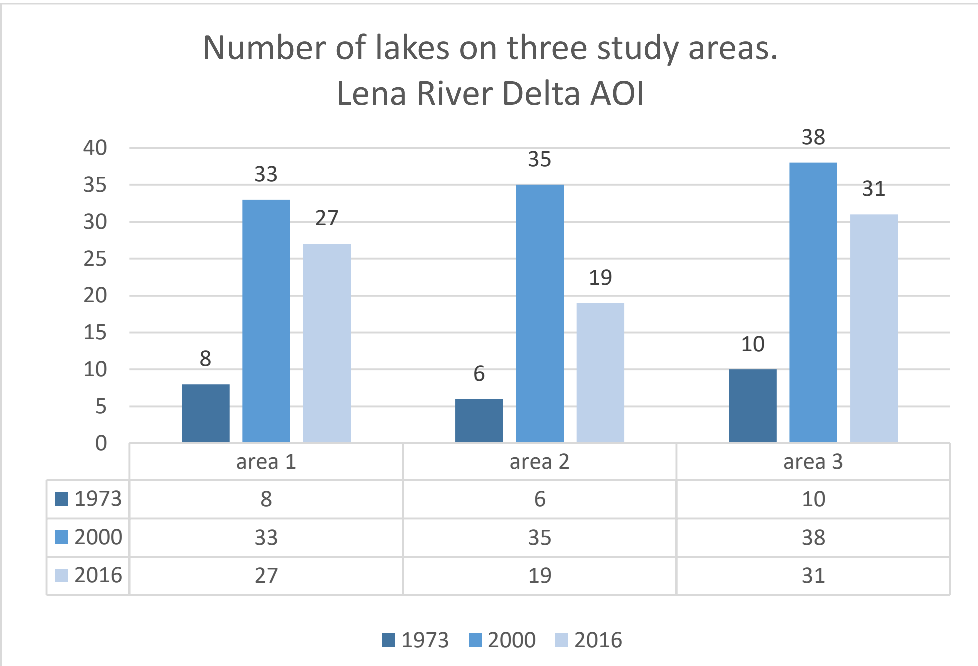


Diagram 15. Number of lakes on study Area 1, Area 2, Area 3 on the Lena River Delta AOI.

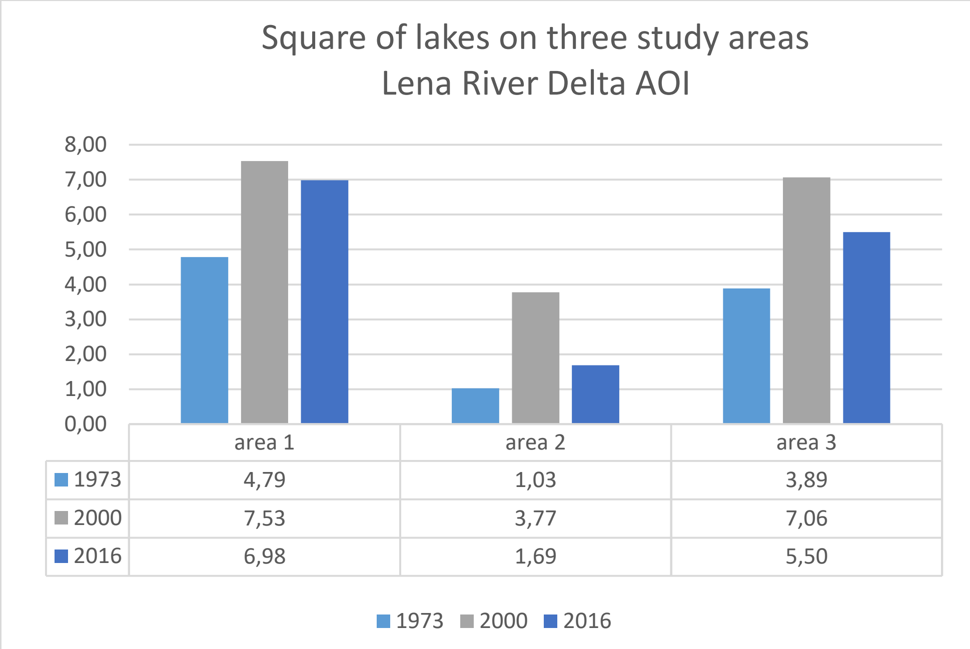


Diagram 16. Square of lakes on study Area 1, Area 2, Area 3 on the Lena River AOI. Square in sq.km

On the Lena River Delta AOI was detected lakes with square more than 100 ha (1 sq.km), less than 100 ha(1sq.km). During whole observation period from 1973-2016, the overall square of lakes changed from 9,69 sq.km to 14,15 in compare with total AOI the lakes square changed from 36,37 to 69,9 sq.km with the increase in 1973-2000 on 44,76 sq.km and decrease on 16,22 sq., km. in 2000-2016. The same picture in Square of three Areas where first increase was on 8,66 sq.km. and decrease in second period was on 4,2 sq.km. On all Areas on The Lena River Delta deduced the same tendency: lake square and number increase in first period 1973-2000 and decrease in 2000-2016.

Area 1 and Area 3 spreading between geomorphological terraces 1 and 3 on flat polygonal and alluvial plains, Area 2 on plain terrace 3, slightly sloping Yeadoma plains.

Changes in lakes decrease can be associated with drain of single thermokarst lakes on terraces from high floodplains. Insignificant number of changed lakes in period 1973-2000 can be connected with a bigger time interval between satellite images, practically at all, the decrease in lakes square and lakes number after 2000 year is noticeable. And good example is Area 2, laying on terrace 3. The differences between date of images is significantly bigger than in Area 1 and Area 3 (see Table 9).

Changing of lakes numbers concerning the lakes square.

Changing the square of lakes number in the Area 1 The Lena River Delta AOI				
ha.	>100ha	100-1 ha	1 ha<	
Sq km	>1km	1-0,01km	0,01<	Total
Year				
1973	2	6	0	8
2000	3	26	4	33
2016	2	20	5	27

Changing the square of lakes number in the Area 2 The Lena River Delta AOI				
ha.	>100ha	100-1 ha	1 ha<	
Sq km	>1km	1-0,01km	0,01<	Total
Year				
1973	0	6	0	6
2000	0	28	7	35
2016	0	14	5	19

Changing the square of lakes number in the Area 3 The Lena River Delta AOI				
ha.	>100ha	100-1 ha	1 ha<	
Sq km	>1km	1-0,01km	0,01<	Total
Year				
1973	1	9	0	10
2000	1	30	6	37
2016	1	20	10	31

Table 9. Changing the square of lakes number on three Areas (The Lena River Delta)

Chapter 4. Discussion

Thermokarst lakes are very good object for researching from the view of remote sensing study. One of the methods, which allow us to study thermokarst conditions and dynamic, is the analyzing of remote satellite images. In this work were used a Landsat images data on thermokarst lakes in study areas of West and East Siberia. All Areas of Interest located in continuous permafrost (see Figure 9). Consolidate (Romanovsky, 2010) that thawing of permafrost that is already occurring at the southern limits of the permafrost zone can generate dramatic changes in ecosystems and in infrastructure performance.

Depend on the map of potential activation of permafrost processes (see Figure 10) under the influence of modern climatic changes a northern part of Western Siberia in a zone of continuous permafrost gets to the area of the strong and very strong activation of permafrost processes. More less there are sites with medium risk. Yamal Peninsula AOI has a strong potential activation of permafrost, while the Lena River Delta AOI has a very strong potential activation.

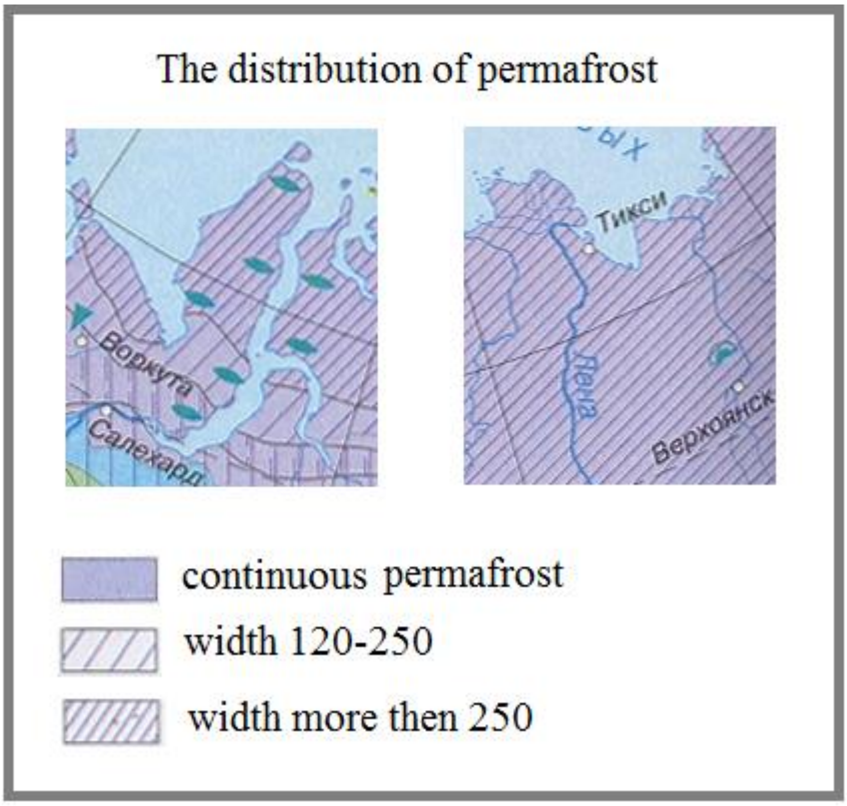


Fig.9 The distribution of permafrost on the Yamal Peninsula AOI(left) and The Lena River Delta AOI(right). Compiled on the basis of map from Ecological Atlas of Russia. Scale 1:30 000 000. (Blue ellipse on Yamal Peninsula mean bedded ice).

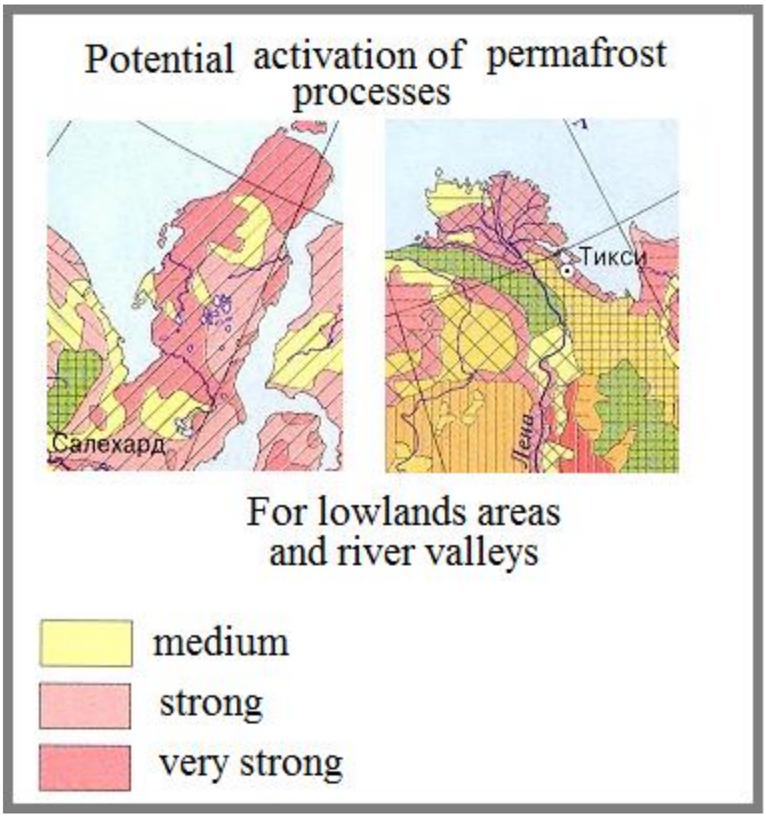


Fig.11 Potential activation of permafrost processes. Compiled on the basis of map from Ecological Atlas of Russia. Scale 1:30 000 000

Choosing an images for analyzing of thermokarst lakes the season played big role. More expediency to use images from the end of summer season because the ice cover on lakes could be keeping. For Analyzing of remote sensing images, was taken images from July, August and September months. Because there is predominantly no ice in lakes and less clouds, which could create disturbance for work with images. The analyzing of thermokarst lakes changing require to work in big scales, from 1:200 000 and more. For both study regions were used different satellite images from The U.S. Geological Survey web page (USGS).

Lake basins are negative forms. The basin morphology depends mainly on the origin and specificity of geological and geomorphological processes in the region. The relief formation and geological structure plays a big role in changing the lake areas, formation of thermokarst on floodplains.

Working with images from different years allows to observe the change of lakes number in different years and different Landsat's spatial resolution (30 meters and 80 meters). Were analyzed three images for the warm period: 1988, 2001 and 2016 years for the Yamal Peninsula AOI and three for 1973, 2000, 2016 years for the Lena River Delta AOI.

Main focus of this work was to count the quantity of lakes and lakes surface. It is important to see the possible dynamic of morphometric parameters on the images from different periods of time. In the software ArcMap 10.2. were raised the contours of lakes. After that contours were automatically counted. At the present time, it is impossible to study the materials of satellite images without the use of GIS technologies and data processing software for Remote Sensing.

Analysis of changes in water mirrors of thermokarst lakes with the help of satellite images can establish the evolution of the dynamics of changes in recent decades. Lakes proximity to neighboring alasses, thermoerosion ravines and channels less likely the further development of thermokarst. Accordingly, to this criteria Areas were chosen.

According to calculated data, noticeable total decrease in the Areas on the Yamal Peninsula occupied by lakes in the period 2001-2016 and on the Lena River Delta from 2000-2016. These changes may indicate a change in the balance of precipitation, as well as the weediness of large lakes, or indicates drain of lakes as a result of erosion. Different amounts of precipitation certainly lead to a change in areas.

The decrease possibly attributed to the change in the areas of large and medium-size lakes, on floodplains and watershed. The reason for can be sum of annual precipitations change as well as the drain of lakes through waterways as in Area 2 on the Yamal Peninsula AOI. All in all, it is evident that lakes square reductions in continuous permafrost distribution could considered as degradation of permafrost under the influence of climate warming and dripping water from lakes into thawed ground somewhere more and somewhere less.

An important role plays geomorphological factor – position on terraces. Areas in the Lena Delta lays on Yedoma complex. Complex on Yedoma uplands has a high ground ice content; therefore, it is very sensitive to potential thermokarst development in a warming climate (Morgenstern et al, 2011). A prime example of lakes drainage located on the island of Sobo-Sise in the eastern Lena Delta, where a mid-sized thermokarst lake (ca. 1 km^2) completely drained during the observation period (Nitze, Grosse, 2016). In this research also reported that several examples of rapidly changing thermokarst lakes were found in the study area, predominantly on the third terrace and partial or complete drainage was noticed during the observation period. This period was from 1999-2014. Most lake drainage events occurred in the active parts of the Lena Delta, predominantly in the vicinity of river channels, which tap and drain lakes by lateral erosion (Nitze, Grosse, 2016).

Because the proximity to river, some of lakes drains faster because of the channel system and subsequently such channels have erosion forms. In Spring time interfluves lakes in rarely change their outlines as they have a smaller drainage area refills with thawed water. Therefore, it is important to consider the role of snow evaporation, temperature and precipitation. Newly formed lakes possibly formed due to thawing of ice and as a result of primary puddles deepening. It possibly can start formation of thermokarst lakes.

Among the thermokarst evolution controls, the precipitation - evaporation ratio represents more critical than warming air temperature (Konichshev, 2011). For example, in Central Yakutia, the formation of new and expansion of existing lakes in alases therefore occurs only in years with high annual precipitation, which enhances both moistening and thickening of the active layer (Bosikov, 2007; Iijima et al., 2012). In climate change research mostly important two meteorological parameters of air temperature and atmospheric precipitation. That’s why for analyzing was taken these two parameters. The largest amount of data on various meteorological parameters of urgent, daily and monthly permits for 600 Russian weather stations is available on the website of All-Russian Research Institute of Hydrometeorological Information - World Data Centre (WDC). This data is used in present research.

Addressing the report of data of WDC (The Arctic. XXI Century, 2015), the most intensive warming of air is observed during the transitional seasons (spring and fall), the field of its distribution covers a cryolithozone. Intensive warming of air in the spring in total with moderate increase air temperatures create prerequisites for increase in depth of seasonal thawing in summer period. Climate change tendencies usually estimate the size of the average annual linear trend and mean seasonal meteorological values mainly of air temperature and quantity of atmospheric precipitation. According to reports from this issue of trends analysis of monthly maximal temperatures on all territory of Siberia (The Arctic. XXI Century, 2015), the most intensive warming of air is observed during the transitional seasons (Spring and Fall), the field of its distribution covers cryolithozone. Intensive warming of air temperature in total with moderate air temperature increase in the spring are prerequisites for increase in depth seasonal in the summer thawing.

Observed climatic warming has resulted in a permafrost temperature increase of 0.5-2◦C over the last three decades in the Russian Arctic (Romanovsky et al, 2010). Concerning an amount of precipitation, in general in the territory of Russia prevails increase of annual sums of precipitations. Commonly for Siberia the annual amount of precipitation decreases from the South to the North from 400 up to 300 m less. In areas of perennially frozen ground distribution precipitation increase happened mainly during a summer season and decrease in middle latitudes of Siberia in winter time, but not too much. Decreasing of winter precipitations promotes weakening of a heat insulating snow cover layer and to strengthening of communication between changes of air temperature in cold period and temperature of perennially frozen ground.

A strong relationship between thawing and active layer thickness has been demonstrated by several studies showing that warm summers on average produce a deeper active layer and cold summers produce shallow depths of thaw (Romanovsky, 2010).

Arctic warming has accelerated since the 1980s, driving an array of complex physical and ecological changes in the region. Particularly puzzling has been evidence for perturbations to the terrestrial water cycle, which plays an integral role in nearly every aspect of the Arctic system (Sheng et. al, 2005). The magnitude of changes in precipitation and air temperature is large enough to alter the hydrological regime of the Lena River (Yang et al., 2002). Precipitation variability is a primary factor controlling the change in river discharge in northern regions.

Study of permafrost playing an important role in researching of climate change. In last century satellite images became a leading tool in permafrost study. The value of remote sensing in permafrost research has already been demonstrated (Pollard & French 1980; Ermolin et al., 2002), but only a few approaches discuss permafrost degradation and related landscapes (Sellmann 1975; Grosse et al. 2005).

The results on lakes researching showed that for 13 years between 1952-1965 years size of most part researched lakes have a quite change because of some process developments like: drying thermokarst process and overgrowing (Are, 1969). Wide famous modern thermokarst processes which influence on increasing lakes in size, which have drainage. Most lakes without runoff drying have an overgrowing process. Because of simultaneously thermokarst development and overgrowing, some of lakes moving across bottom of alas basin (Are, 1969).

According to report (Ulrich et al., 2009) important environmental parameters in Arctic periglacial landscapes (i.e. permafrost temperature, active-layer depth, soil moisture, precipitation, vegetation cover) will very likely change in a warming climate. According to (Schur, 1973) the main causes of thermokarst appearance are climatic. But according to (Tomirdiaro., 1975) it is debatable reason. Vegetation changing lead to micro relief changing and surface irrigation. Exactly this is a cause of thermokarst appearance. (Grigoriev, 1993) think that exactly wind erosion of vegetation cover one of the causes thermokarst appearance.

Addressing to the popular paper (Smith et al, 2005) where the authors considered changes mainly large Siberian lakes with an area of more than 40 hectares. As a result, increase in the area of lakes in continuous permafrost by 12% and lakes decrease in the zone of discontinuous permafrost up to 9%. And disappearing of 125 lakes (see Figure 12). According to this report, the increase in the area of lakes in continuous permafrost extension is associated with the melting of permafrost, which in the first stages cause an increase in the volume of water, which can subsequently lead to the disappearance of the lake. The presence of disappearing lakes in the permafrost in particular due to the heterogeneity of the power of permafrost. As a result of another study (Polychuk et.al. 2006) was found that in continuous permafrost was thermokarst lakes increase from 7 to 12%. But in another study (Bryksina, et al, 2009; Dneprovskaya, et al, 2009) saying that with the increase in geographical latitude, there is a transition from a shrinking area to an increase, (as a border of N-70) and also that in continuous permafrost only in half of territories have an increase of lakes surface. There are also contradictory claims concerning lakes decrease in continuous permafrost on the territory of Western Siberia (Kravcova, Bystrova , 2009).

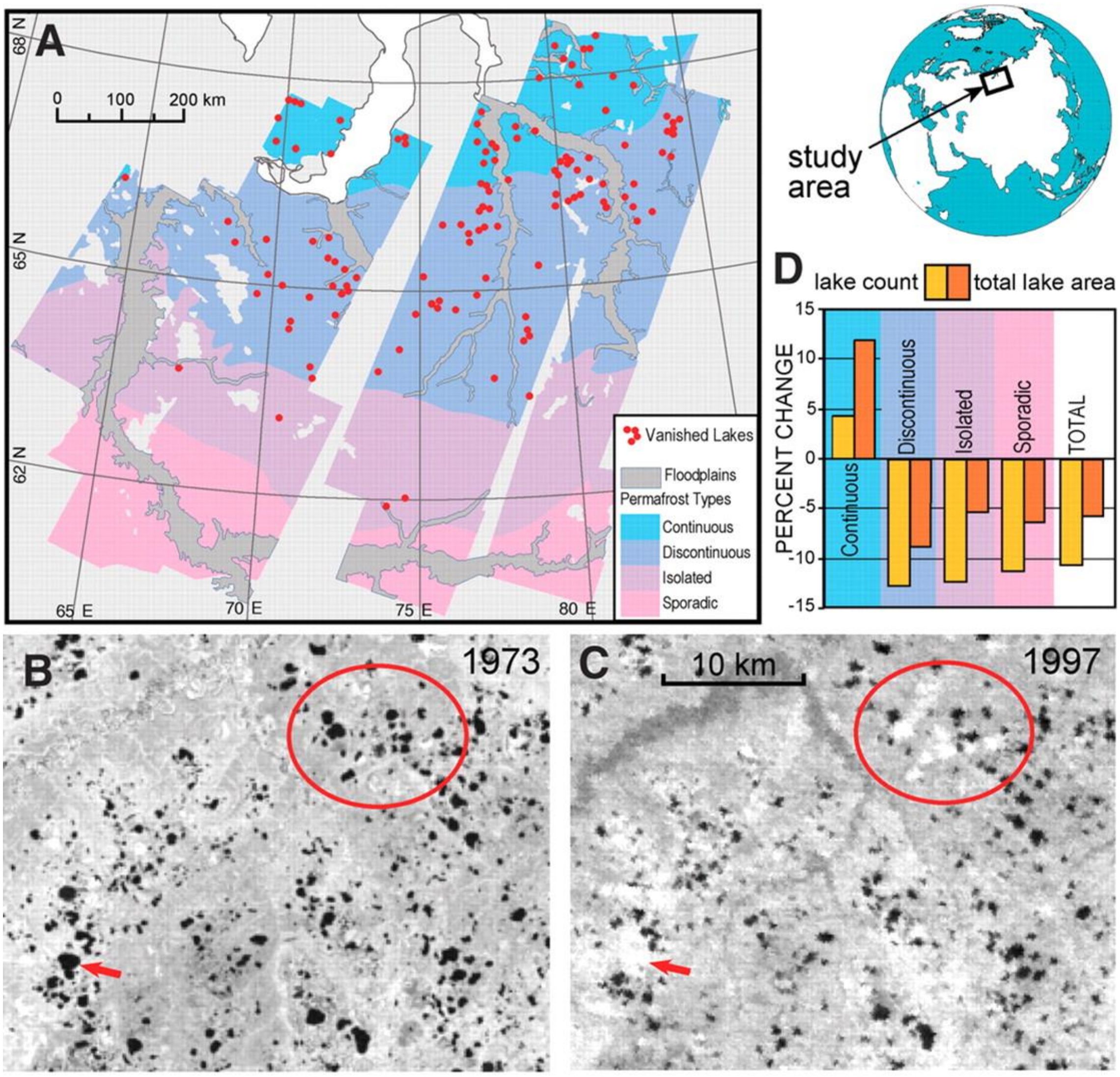


Fig.12 (a) locations of Siberian lake inventories, permafrost distribution, and vanished lakes. Total lake abundance and inundation area have declined since 1973 (b), including permanent drainage and revegetation of former lakebeds (c). Interestingly, net increases in lake abundance and area have occurred in continuous permafrost (d), suggesting an initial but transitory increase in surface ponding. (L.C. Smith et al.,2005)

Today know that in natural condition thermokarst could appeared because an icy concentration in ground ice rather high. Next reason is a seasonal thawing depth. When this seasonal depth became exceed, ground ice bedding depth and in this case thermokarst appears. The geomorphological factor is a presence of plain character of the territory, which hamper surface water flow (Romanovsky, 1993). Favorable character of drainage could be form thermoerosion, alases valleys or drainage system from thermokarst basins. Exceed of wetting also lead to thermokarst processes.

Spatial data gaps in researching on thermokarst lakes is actual topic. In large regions, like Siberia there are no lake bathymetry data for lakes at all. Therefor lake bathymetry data and thermokarst lake study cannot be realized in most areas. In this case researching thermokarst lakes with satellite images best way to understand the dynamic of thermokarst lakes degradation and construct further theories based on comparison retrospective images like Declassified Satellite Imagenary-1 (1960-1972) with modern images like Landsat 8 OLI, which today are the longest running enterprise for acquisition of satellite imagery of Earth. Declassified satellite images also provide an important worldwide record of land-surface change for scientists. First release of classified satellite photography was in 1995. Landsat images primary purpose is to provide scientists with data to assess the earth's vegetation, crop and mineral rescues. However, Landsat bands 3,2,1 are close to the red green and blue wavelength that the human eye is sensitive too. These bands can be inserted into a RGB color model and will produce image that are very satisfactory for visualization. Scientists often combine other Landsat bands 4,3,2 which are commonly used a highlight vegetation (Landsat and Spot Pan Sharpening, 2010).

This study (Morgenstern et.al, 2008) was aimed to create a lake dataset of the Lena Delta including morphometric and spatial characteristics using remote sensing and GIS techniques to analyze the dataset regarding a morphometric lake classification, and to investigate possible hypotheses of the morphogenesis of the lakes in this periglacial delta environment. Thermokarst lakes are the brightest morphological and hydrological occurrence of thermokarst. Geocryologists give more attention on permafrost thawing under lakes, reforming of lakes coastal zone, thermo influencing of lakes on permafrost ground around it, forming of underground water regime under talik zone effect, formations of new permafrost material under the drying and overgrowing, which attended by heaving, frost cracking with formation of repeated wedge ice (Schur, 1977).

Conclusions

According to the results obtained in diagrams of lakes dynamic, in compare with temperature, annual and seasonal sum of precipitations data and trends, the lakes common in the territory of the permafrost zone of Russia, within two Areas of interest on Yamal Peninsula and the Lena River Delta are characterized by small variability, and multidirectional dynamics both in the direction of diminishing and increasing their area and quantity.

Thawing of permafrost, especially, might cause massive landscape changes due to thermokarst and an enhanced release of greenhouse gasses from the large amounts of carbon stored in frozen deposits, resulting in positive climate-warming feedback. For the identification, mapping, and quantification of such changes on various scales up to the entire circum the Arctic, remote sensing and spatial data analysis are essential tools.

According to approaches, must make a practical review on the topic of satellite images in researching of thermokarst lakes. For work was chosen areas (AOI) in West and East Siberia. The Yamal peninsula and the Lena River Delta are much claimed study areas in permafrost researching.

On the Yamal Peninsula AOI Areas detected an increasing of lakes number from 1988-2001 and decreasing in 2001-2016 with slow decreasing of Lakes square in all period from 1988-2016. On the Lena River Delta AOI detected increasing of lakes number and square in 1973-2000 and its decreasing from 2000-2016.

Thermokarst associated with the conditions of heat exchange of permafrost and with the atmosphere affecting on thawing. It turns out that the total area of lakes significantly controlled by the amount of precipitations. Important to consider the role of snow evaporation, temperature and precipitation. The sum of seasonal precipitation for 7 years before the images showed decreasing tendency on the Yamal Peninsula. On the Lena River Delta another picture, increasing before 1973 and 2016 years and decreasing before 2000. Therefore, it possible to conclude that with the fall of precipitations, the square and lakes number rising up. On the Yamal Peninsula decreasing in sum of precipitations in compare with lakes dynamic could be connected with decreasing of lakes square in whole period from 1988-2016. That's proved the theory of precipitations influence on lakes square dynamic. That's mean that precipitations, which affected on snow accumulations was not accumulated more than in previous years therefor lakes square could be mostly decreased because of this process.

As a result of the study, were obtained the following main conclusions:

Revealed that the diagrams of annual seasonal sum precipitations indicated the presence of pronounced fluctuations.

To assure in the role of atmospheric precipitation, influenced on the dynamics on of lakes, additionally considered different time intervals before the date of satellite images.

Besides reducing of amount precipitation the increase in evaporation affected increasing of air temperature could reduce the area of lakes. This is more typical, for Yamal Peninsula, the trend is more indicative temperature increase and precipitation decrease along with total decreasing of lakes square in whole period 1988-2016 which also can be connected with lakes drain into the nearest channels or another large lake. Appearance of new lakes could be connected with the reaction on slow rising temperature with decreasing precipitations. Analysis of annual changes in lakes on the territory of the Yamal Peninsula AOI showed that atmospheric precipitation is superimposed a significant imprint on changes in the area of thermokarst lakes. Analysis showed that the main reasons of lakes square decreasing are lakes overgrowing and rivers erosion, especially when the lakes are located in close proximity to rivers and small watercourses. These facts are confirmed by compiled diagrams of lakes dynamics and diagrams of air temperature and precipitations.

On the Lena River Delta AOI Areas another processes have influence. Presented annual sum of precipitations have an increasing trend, while fluctuations in the amount of precipitation, have an ambiguous effect and have contrary increases and decreases in precipitation amounts in previous years of seasonal amounts from September to December and from January-June of the current year of satellite image. In this case, the precipitation less likely to have an effect on lakes dynamic on these areas. Increase in air temperature could cause thawing of frozen rocks and activation of the thermokarst process. In despite of this, air temperature increasing trend have no big influence on lakes square and number, therefore this meteorological factors are not the singular. The massive reduction of lakes square observed in the territory of the permafrost zone in last period 2000-2016 is mainly due to hydrological factors and overgrowing of water bodies. Hydrological factors cause both a decrease and an increase in the lakes square. In result is cyclical changes from year to year. In case of hydrological activities of the watercourses connecting the lake occurs the descent of lakes or the filling of lake basins.

In a complex set of factors affecting the change in the size of lakes impossible to apparent the impact of current climate warming. Thermokarst lakes dynamics cannot be considered only from the point of view of the influence of one climate warming, it is necessary to take into account a number of the factors

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Statement on the thesis originality

Herewith I, Karpova Alina, declare that I wrote the thesis independently and did not use any other resces than those named in the bibliography, and, in particular, did not use any internet resces except for those named in the bibliography.

The master thesis has not been used previously as part of an examination. The master thesis has not been previously published.