Temperature Monitoring of Marsh Landscapes and Development of Exogenous Processes in the West Siberian Plain (Russia)

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Abstract

The research touches upon marsh landscapes in the context of temperature monitoring and in connection with exogenous processes during engineering intervention. The monitoring of temperature regimes was conducted in the mid-taiga subzone of marsh landscapes for revealing the dynamics of exogenous processes. The authors used the method of recording systems for the field measurement of the temperature of the peat and underlying soils. The measurements were conducted on a territory that belongs to the middle taiga landscapes of Western Siberia. The authors of the research analyze the data obtained from thermowells 5, 5a and 6. During the observation period of 2015-2016, the average annual temperature was 8.3 ºC for thermowell 5a (technogenic area), which is 3.8 ºC and 4.2 ºC higher than the average annual values of thermowell 5 and thermowell 6 respectively. The latter belongs to natural marsh landscapes. Observations conducted in 2016-2017 confirmed this fact with a difference of 4.8 ºC and 3.7 ºC for thermowells 5 and 6 respectively. As compared to natural marsh landscapes not affected by man-made impact, a higher temperature was observed on soils, which affects the manifestation of exogenous processes.

Key words: temperature monitoring; marsh landscapes; exogenous processes; technogenic impact; engineering impact

Introduction

Marsh landscapes occupy a fairly large part (more than 35%) of the territory of the taiga zone of Western Siberia. The marshland of individual landscape provinces is more than 70%. Marshes support the stability of the habitat and the growth of plants and animals, thus ensuring the preservation of their gene pool. The geomorphological functions of marshes are manifested in the processes of equalizing the primary forms of the relief, which is a favourable anti-erosion factor. Marshes participate in the formation of the thermal and water balance of vast territories, which has a significant impact on the climate (Lopatina, 2012). This territory is subject to intensive engineering development, which leads to the violation of natural conditions. Since marsh landscapes are very susceptible to anthropogenic load, this can lead to adverse consequences for humans. Engineering development results in a change in surface conditions, in a succession change and, as a rule, in changes in soil temperatures and properties, which, in turn, can lead to a complex of exogenous processes.

Melnikov et al. (2016) note the dependence of soil temperatures on landscapes. In their studies, a number of scientists, in particular, Pavlov (2008), Vasiliev et al. (2016), and Orekhov (2008) indicate that the response of the upper horizons of the lithosphere to modern climate changes strongly depends on the landscape-geological conditions. In addition, they point to the existence of a certain correspondence between the parameters of frozen rocks and the hierarchical level of landscapes. This leads to a holistic understanding of the responsiveness and interaction between the atmosphere of the ocean and the land in the Northern Eurasian region (Lappalainen et al., 2016). Like any dynamic geosystem, the marsh landscape has its own cycles, stages of development and the limit of stability. For marsh landscapes, temperature parameters of soils have the greatest influence on the manifestation of exogenous processes in the context of exogenous relief formation. Soil temperature is a key factor that controls many biotic and antibiotic processes occurring in soils, in particular, vegetation growth and productivity, decomposition and mineralization of soil organic matter, emission of greenhouse gases (Prokushkin and Guggenberger, 2007), and separation of dissolved organic carbon (Dyukarev, 2017). The mid-taiga subzone of Western Siberia is located within the island distribution of permafrost. An important indicator obtained is related to the dynamics of soil temperature at key sites (Korkin et al., 2015). It is necessary to pay attention to the self-healing processes of the Middle Ob River disturbed by technogenesis (Korkina, 2015). The natural landscapes of the Middle Ob Region (Korkin et al., 2016; 2017) and the Siberian Reefs (Sheinkman et al., 2016) are comprehensivelyexamined, and especially the conditions of modern temperature monitoring are touched upon. The aim of the research is to monitor the temperature patterns for marsh landscapes in the middle taigs subzone of the West Siberian Plain in order to identify the dynamics of exogenous processes during the engineering development of this territory and the analysis of the impact of climatic parameters on global changes.

Research area

The research was carried out in the Sredneobsky Lowland, which occupies the eastern part of the West Siberian Plain, within the latitudinal course of the Ob River (Fig.1) between 60 and 64° N and between 72 and 78° E. The terrain of this territory is flat-leveled with prevailing heights from 40 to 80 m and from 100 to 120 m above the Baltic Sea level on watersheds. The main stream flow of the research territory is the Middle Ob River, from the mouth of the Svetlaya waterway to the Lokosovskaya waterway. In the Nizhnevartovsk Region, the Middle Ob has a length of 134 km and the width of the bottomland varies from 18 to 20 km. Climate plays a leading role in the development of exogenous processes of relief-formation. The most important meteorological factors for the research area include the variation of air temperature, the amount and annual distribution of precipitation, as well as wind patterns. The major relief-forming processes are manifested in warm weather under conditions of positive values of air and soil temperatures, as well as liquid precipitation. The warm period starts when average monthly temperatures exceed 0 °C, which mainly takes place in early May. Cold and snowy weather starts when average daily temperatures drop below 0 °C at the end of September to the middle of October. According to long-term data, a high average monthly temperature – up to +26.7 ºC – is recorded in June. The average annual temperature of air in the Ob River is -2.3 ºC. The annual precipitation for the Ob Valley varies from 225 to 722 mm. In the research area, winds of western and south-western direction prevail, and the frequency of these rhumbs is about 17% per year. For the taiga forests of the middle taiga, the zonal types include spruce and cedar trees, which were replaced (by felling and logging) by secondary forests with dark coniferous, pine, and small-leaved trees. In the vegetation cover of the oligotrophic marshes of the research area sphagnum pine and shrub complexes with small lakes and sphanum mosses prevail and involve Ledum-cassandra-sphagnum groups with pines, as well as cedars on the ridge of forests.

Fig.1. Area for Marsh Landscape Research (the Black Square Denotes the Actual Research Location).

Materials and Methods

The goal of the research is to monitor the temperature patterns for marsh landscapes under conditions of exogenous relief-formation. The key area presented in this article is equipped with thermowell 5 (natural control area with observation periods of 2015-2016 and 2016-2017), 5a (technogenic area with observation periods of 2015-2016 and 2016-2017) and thermowell 6 (natural control area with observation periods of 2013-2014, 2014-2015, 2015-2016, and 2016-2017). Due to the high intensity of the technogenic impact associated with oil production, thermowells were laid on marsh landscapes in natural conditions and on marsh landscapes in conditions susceptible to technogenic impact (in the collector corridor of pipelines). The natural marsh landscape of this key area corresponds to temperature well (thermowell) 6 with depths of 20, 40, 60 cm, 1, 2, and 3 m activated on 15.11.2010, temperature well 5 with depths of 20, 40, and 60 cm, and temperature well 5a with a technogenic effect and analogous depths.

Thermowell 5 was first launched in 2010. After eliminating technical problems, an updated launch was made in the fall of 2015. The air temperature for this key area was obtained using a recorder installed in the vicinity of thermowell 6. The authors of this research used methods of recording systems for the actual measurement of soil temperature. This method is described in detail by Popov et al. (2017), Kazantsev (2017), Konstantinov et al. (2011). Investigations dealing with the features of the temperature regime of the peat deposit of the oligotrophic marsh in the southern taiga of Western Siberia are presented in the works of E.A. Dyukarev (2017). The results of the measurements of air and soil temperatures on the monitoring network during the implementation of the German-Russian project "Kulunda" cause a great scientific interest as research methods (Belyaev et al., 2017).

The international experience of studying the temperature regime of soils is of great importance for setting up monitoring (Zang et al., 2005; Wisser et al., 2011; Sheng et al., 2004). A temperature recorder of type DS1921G-F5 with a temperature range from -40 ºC to +85 ºC and a sensitivity of 0.5 ºC was used to measure soil temperature at depths of 20, 40, 60 cm and 1 m. For depths of more than 1 m, DS1921Z-F5 with recorded temperatures ranging from -5 ºC to +26 ºC and a sensitivity of 0.125 ºC was used. A thermocouple of type DS1921G-F5 was used to fix the air temperature. The frequency of registration of all used loggers is 4 hours. 5-6 measurements were carried out to analyze the diurnal course. Mean daily and monthly values of soil and air temperatures were calculated based on the observation data. The recorders had protective capsules that excluded any violation of sensitivity with immersion in the wells equipped with a casing polyethylene pipe (50 mm in diameter) with thermal insulation in the wellhead. The data was obtained by reading the recorded information in the fall of the year. The full-scale data on the temperature regime of peat soils and air presented below is analyzed using the Microsoft Office Excel 2007 software product. As a result of the operation of this equipment, the following technical problems were identified: a) for soils in the region of study, the sufficient recorded temperatures range from -5 ºC to +26 ºC with a sensitivity of 0.125 ºC, which allows more accurate calculation of the mean values per day, month, season and year, b) it is necessary to use thermo-cosmetics with an output channel for communication media.

Results

The presented article analyzes the data of four observation seasons: a) 2013-2014; b) 2014-2015, and c) 2016-2017 for thermowell 6 (natural control area) and includes an analysis of air temperature. For technical reasons, the data related to thermowells 5 and 5a was obtained during two observation seasons: a) 2015-2016 and b) 2016-2017. This work does not provide a detailed analysis of the obtained parameters of soil and air temperatures for the period of 2010-2013 since the latter was previously published (Liss et al., 2001). The authors of the research choose this series of observations to identify the natural trend of changes in the temperatures of air and peat soils as one of the main factors of exogenous relief formation and engineering impact. For the study period (2013-2016), the air temperature in January had the following values: -22.3 ºC (2013-2014), -19.2 ºC (2014-2015), -21.9 ºC (2015-2016), and -21.3 ºC (2016-2017), which corresponds to the average long-term data of -22.5 ºC. In the cold snowy period of 2013-2014, February – but not January – was the coldest month with a temperature of -24.6 ºC. In 2014-2015, the warmest month was June with a mean monthly temperature of 19.2 ºC, while July was 2.3 ºC colder (Tab.1). The mean annual temperature was -0.6 ºC (2013-2014), 0.2 ºC (2014-2015), and 1.3 ºC (2015-2016). According to the meteorological station of the city of Nizhnevartovsk, the mean annual air temperature was -2.3 ºC from 1998 to 2004. Analyzing the results demonstrated in Table 1, the authors came to the conclusion that the mean annual temperature obtained positive values during the observation periods of 2014-2015 and 2015-2016. In 2016-2017, there was a decrease in the mean annual temperature, which was due to the cold winter, when the minimum temperature values reached -21.7 ºC in December.

The data in Table 1 evidences the transition to the positive values of the mean annual temperature during the observation periods of 2014-2015 and 2015-2016. The period of 2016-2017 saw the return to the negative values.

Temperature is a key factor in exogenous relief formation, which affects the growth, productivity and decomposition of vegetation. The authors analyzed the mean annual and monthly temperatures recorded in the key area of the middle taiga subzone in Western Siberia. The results of monitoring the temperatures of the soils on the marsh reflect the general patterns of the arrival and consumption of solar radiation.

The mean annual temperature for thermowell 6 (Tab.2) has a positive indicator for the observation period considered in this study. The highest mean annual temperature, 4.8 ºC, was registered in 2015-2016, while the lowest indicator, 3.7 °C, was observed in 2013-2014, which generally correlates with the mean annual air temperature (Tab.1). These indicators depend on the mean annual temperature.

A temperature transition through 0 ºC was observed at a depth of 20 cm during the observation periods of 2015-2016 and 2016-2017, as well as at a depth of 60 cm and 1 m during the observation period of 2016-2017.

Figures 2 and 3 reflect the singularities of temperature variation at different depths. During the observation period of 2015-2016, high temperatures were recorded in July. In the middle taiga subzone of Western Siberia, the average temperature for the 4 periods was 4.4 ° C in thermowell 6.

To study the impact of engineering development of marsh landscapes, thermowell 5 was updated at the technogenic facility 5a (the area of the Samotlor-Nizhnevartovk oil pipeline) in 2015. The temperature of the transported oil is 17 ° C through a pipe with a diameter of 1220 mm laid at a depth of 1 m from the surface of the upper ridge-moss marsh. The well is located in the immediate vicinity of the pipeline, and thermowell 5 is drilled in 20 meters. In thermowell 5, the mean annual temperature had a positive value of 4.2 ° C for the period of 2015-2016 and - 4.3 ºC for the period of 2016-2017, which is 3.8 ºC and 4.0 ºC lower in thermowell 5a for the periods of 2015-2016 and 2016-2017 respectively (Tab.3).

Comparing the data obtained from the two wells, several differences are observed. At a depth of 20 cm, the mean annual temperature is 2.3 °C warmer in thermowell 5a. After considering all the depths, it is possible to state that the recorded tendency is maintained with the following values: 40 cm - 3.9 °C, 60 cm - 4.1 °C, 1 m – 5.1 ºC, and 2 m – 3.8 ºC. At a depth of 20 cm, the mean annual temperature was 2.3 ºC warmer in thermowell 5a for the observation period of 2016-2017. The recorded tendency is maintained with the following values: 40 cm - 4.7 °C, 60 cm - 5.0 °C, 1 m - 4.8 °C, and 2 m – 4.2 ºC.

For more clarity, Figures 4 and 5 demonstrate a summary graph of the mean temperatures for the depths of thermowells 5 (natural landscape) and 5a (technogenic landscape), and Figures 5 and 6 show a summary graph of the mean monthly temperatures for depths from 0.2 m to 2 m during the observation period of 2016-2017.

Tab.1. Data of the Basic Air Temperature Parameters

month / time period	2013-2014	2014-2015	2015-2016	2016-2017
December	-10.9	-12.8	-14.5	-21.7
January	-22.3	-19.2	-21.9	-21.3
February	-24.6	-10.9	-8.6	-15.7
June	14.9	19.2	19.2	18.9
July	16.4	16.9	20.0	17.4
August	14.5	12.9	17.4	15.6
mean annual	-0.6	0.3	1.3	-1.0
sum of positive temperatures	1907.6	2176.5	2541.2	2096.6
sum of negative temperatures	2041.4	2081.6	2064.3	2424.4

Tab.2. Mean Annual Soil Temperature Parameters for Thermowell 6 (Natural Area)

depth / time period	2013-2014			2014-2015			2015-2016			2016-2017		
m	avg.	max	min	avg.	max	min	avg.	max	min	avg.	max	min
0.2	3.5	12.7	0.0	-	-	-	5.7	18.2	-0.2	5.0	18.5	-1.0
0.4	4.0	11.1	0.4	5.2	13.7	0.1	5.6	15.2	0.4	5.1	15.5	0.0
0.6	3.5	9.2	0.2	4.5	11.6	0.0	4.7	12.4	0.0	4.3	12.4	-0.5
1	3.8	9.2	0.5	4.7	11.1	0.5	4.9	11.7	0.6	4.6	11.5	-0.1
2	3.7	5.5	2.3	3.9	6.1	2.3	4.1	6.1	2.5	4.1	6.4	1.9
3	3.7	4.4	3.0	3.8	4.6	3.0	4.0	4.8	3.3	4.2	5.0	3.4
mean annual	3.7			4.4			4.8			4.6		

Tab.3. Soil Temperatures for Thermowells 5 and 5a for 2015-2016 and 2016-2017

measurement depth, m	t°C			
	thermowell 5		thermowell 5a	
	2015-2016	2016-2017	2015-2016	2016-2017
0.2	4.6	4.2	6.9	5.7
0.4	3.6	3.7	7.5	8.4
0.6	4.2	4.3	8.3	9.3
1	4.2	4.6	9.3	9.4
2	4.5	4.6	8.3	8.8
mean annual temperature	4.2	4.3	8.0	8.3

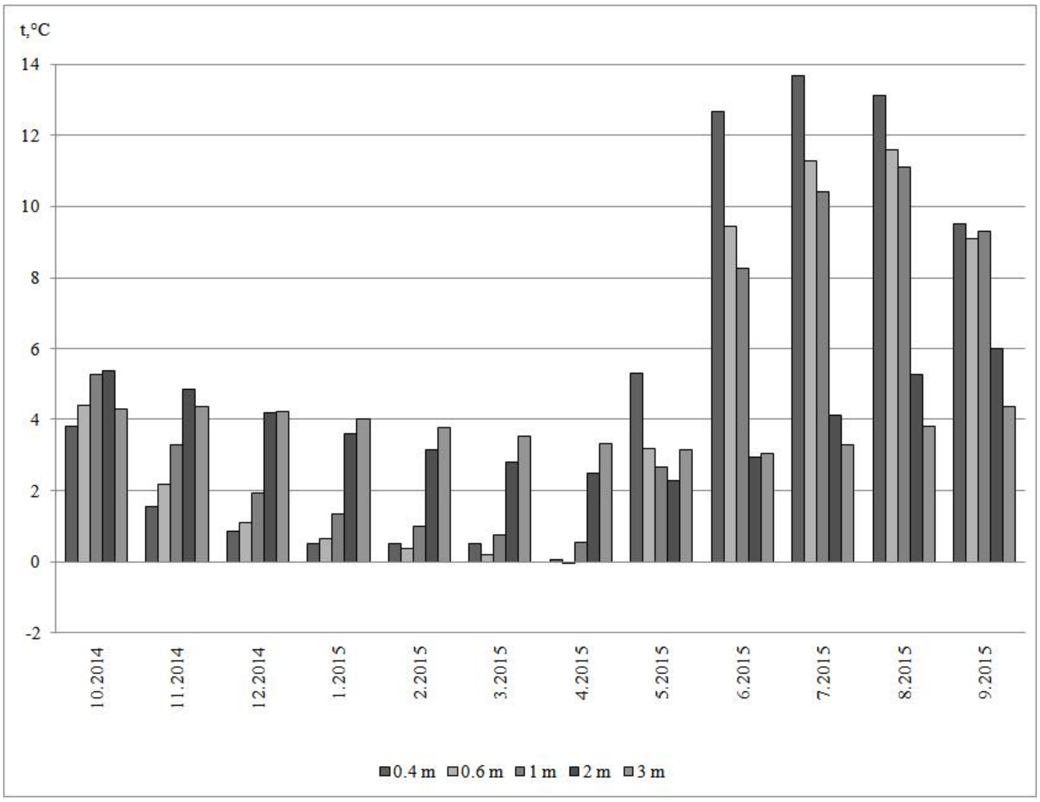

Fig.2. Soil Temperature for Thermowell 6 (Natural Area) for 2014-2015

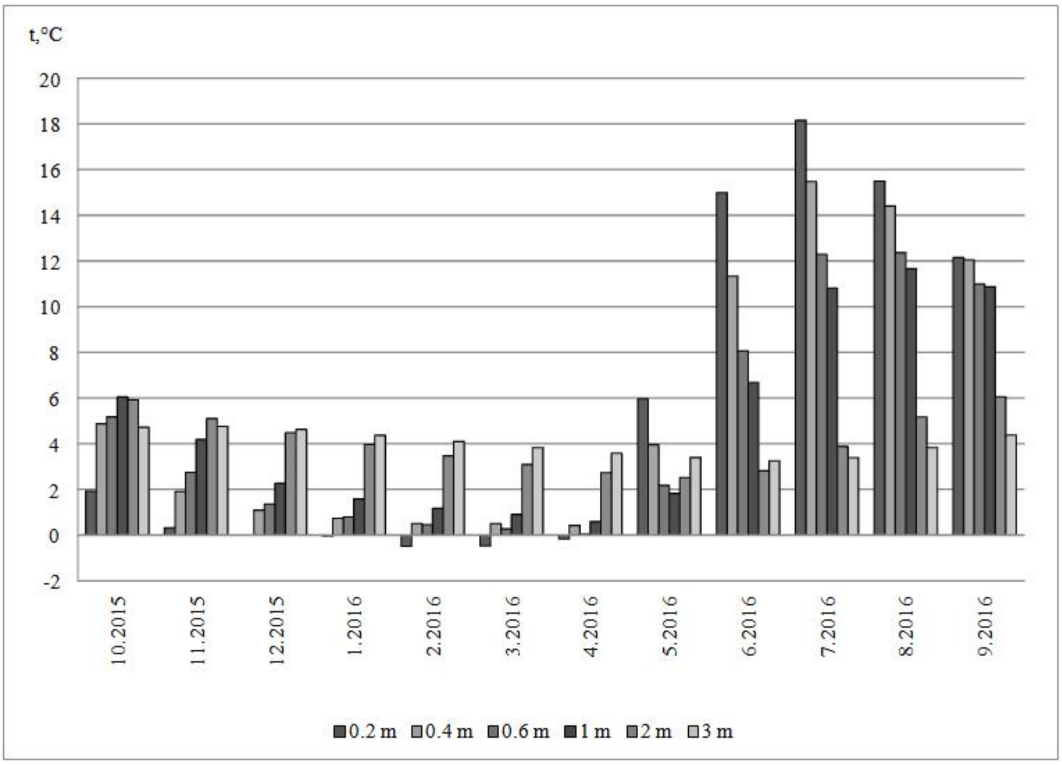

Fig.3. Soil Temperature for Thermowell 6 (Natural Area) for 2015-2016

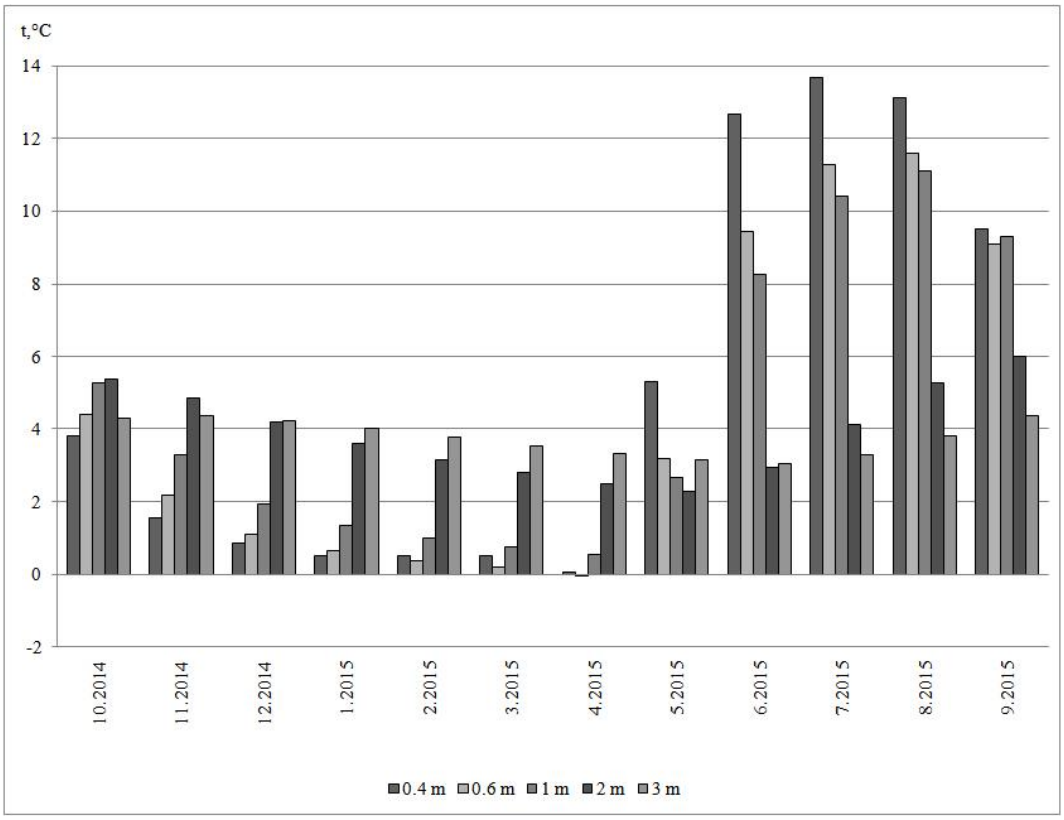

Fig.4. Mean Temperatures for Thermowells 5 (Natural Area) for 2015-2016

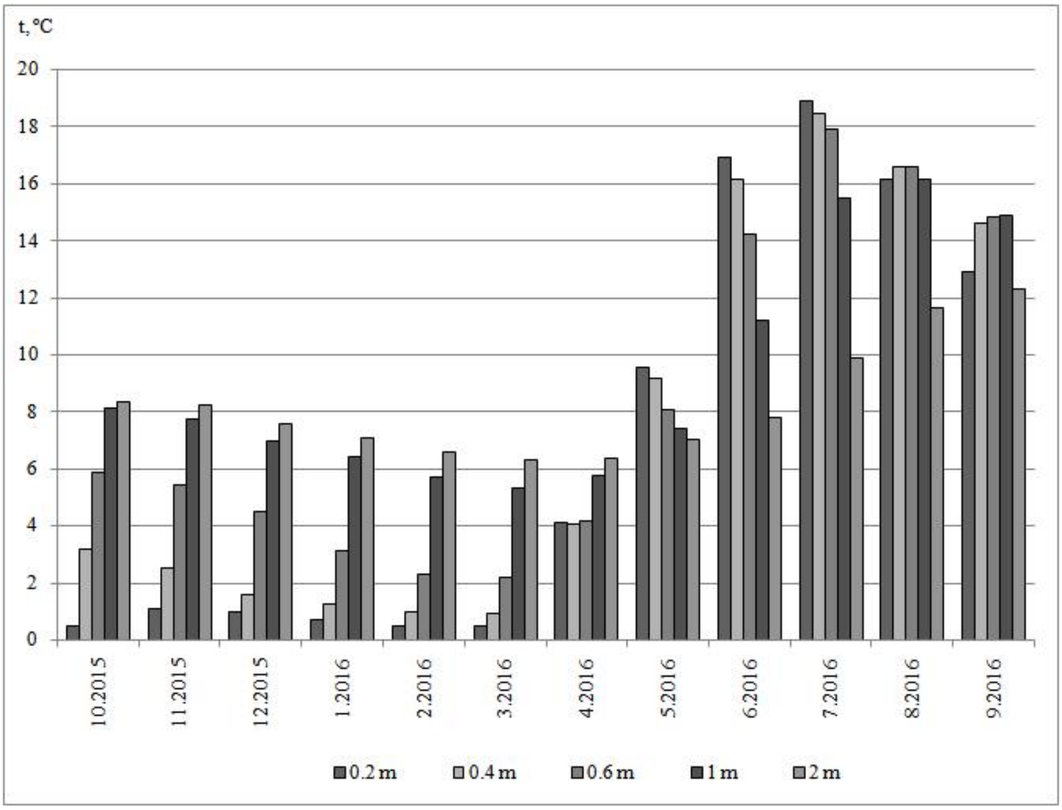

Fig.5. Mean Temperatures for Thermowells 5a (Natural Area) for 2015-2016

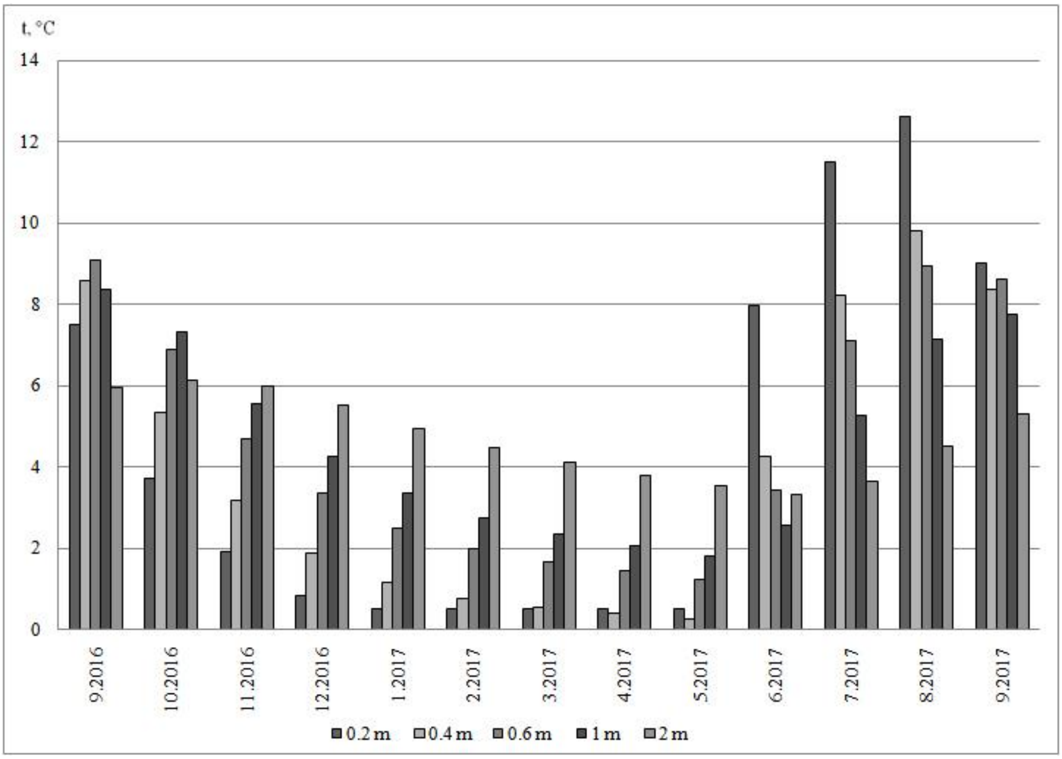

Fig.6. Mean Temperatures for Thermowells 5 (Natural Area) for 2016-2017

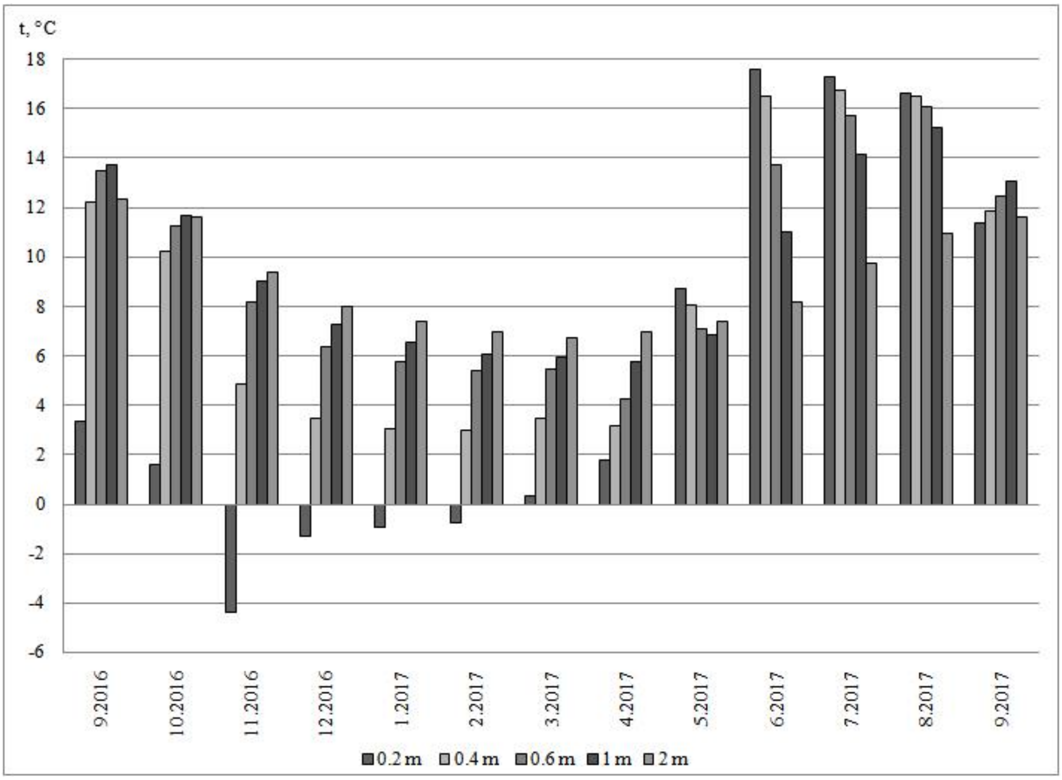

Fig.7. Summary Graph of Mean Temperatures for Thermowell 5a (Technogenic Area) for 2016-2017

Discussions

Like any dynamic geosystem, the marsh landscape has its own cycles, stages of development and the limit of stability. For marsh landscapes, temperature parameters of soils have the greatest influence on the manifestation of exogenous processes in the context of biogenic relief formation. For the observation period of 2015-2016, the mean annual temperature had a value of 8.3 ºC at all depths for thermowell 5a (technogenic area), which is 3.8 ºC above the mean annual values of thermowell 5 and 4.2 ºC above the mean annual values of thermowell 6, which belong to natural marsh landscapes. Observations conducted in 2016-2017 confirmed this fact with a difference of 4.8 ºC and 3.7 ºC for thermowells 5 and 6 respectively. Well 6 is located 10 km to the south-west of well 5 and corresponds to the natural area for a long period of observation. In thermowell 5, the mean annual temperature is 0.6 °C and 0.3 °C lower than in thermowell 6 for the periods of 2015-2016 and 2016-2017 respectively.

The collective monograph of O. L. Liss, L. I. Abramova and N. A. Avetova discloses the unified concept of the marsh formation process and presents the average rates of vertical peat accumulation: 0.37 mm / year for the northern taiga and 0.57 mm / year for the middle taiga. The data concerning the marshland surrounding Lake Samotlor is - 0.32 mm / year, the age of peak thickness being 7700 ± 60 years and the average thickness being 2.5 m (Liss et al., 2001). The presented reduced rate of peat accumulation cannot be the same for the entire marshland due to the differences observed in the hollows, ridges and lakes. This rate is a general quantitative indicator. Currently, bogging occurs due to the growth of existing marsh systems in the vastness, and the emergence of new bogging foci in natural conditions is quite rare. New bogging foci arise as a consequence of man-made impact, in particular, the absence of spillway structures in the places of roads, oil and gas pipelines, as well as stagnation of small rivers and streams.

Conclusions

Based on the results of the research, it is possible to conclude that the heating capacity of engineering facilities for pipeline transport is limited by protection in a zone of 25 m from the line of the pipe. This fact suggests that the recorded increased temperature in the immediate vicinity of the pipeline contributes to the restoration of the marsh landscape disturbed by the engineering impact. However, the change in climatic parameters is affected by the warming up of the surface layers of the atmosphere. Increasing temperature leads to the acceleration of the process of biogenic relief formation. With the participation of marsh vegetation on the technogenic area, the peat accumulation process is restored. The above-presented results for points 6 (for four observation periods), 5 and 5a (for two observation periods) are included in the database of the background temperature indices of the upper part of the annual heat-exchange in the middle taiga subzone of the West Siberian Plain. As a result of the temperature monitoring of marsh landscapes, the main regularities of soil temperature changes were identified on natural marsh landscapes, which depends on the influence of the modern climate. As compared to natural marsh landscapes that are not disturbed by technogenic influence, a higher temperature was observed on soils that are under technogenic objects, which is a factor of the development of heating effects during the engineering development of the territory. Considering the fairly large length of pipeline facilities within the taiga zone of Western Siberia and the results of this research, it is possible to speak of the underestimated contribution of these engineering objects to changes in climatic indices.

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