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Soil temperature of peatland landscapes as a factor in the development of exogenous processes of biogenic relief formation in engineering development of territory

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Abstract. In the presented work we consider mire landscapes in the context of temperature monitoring. The mire landscapes in engineering development of the territory are very sensitive to anthropogenic impact that leads to a change in surface conditions, changes in natural succession and, as a rule, to changes in soil temperature and properties, which in turn may develop a complex of hostile geodynamic processes. For this study we used recording systems for field measurement of peat and subsoil temperatures. The measurements were made in two key areas: the territory of the north-taiga landscapes of Western Siberia (the Siberian Ridges), and the territory of the middle-taiga landscapes of Western Siberia (the Ob middle-river lowland). The paper analyses the data obtained from five observation sites (3, 5, 5a, 6 and 8) referred to hydromorphic landscapes. For the territory of the Siberian Ridges the 5-year average soil temperature was 3ºC. For the Ob middle-river lowland the 6-year average soil temperature was 4.2°C. The annual soil temperature in the period 2015-2016 for Site 5a (man-disturbed area) was 8.3ºC at all depths, which is 3.8ºC higher than in a natural bog (Site 5 was a control area).

1. Introduction

The peatland landscapes occupy a fairly large part (more than 35%) of the territory in the middle taiga zone of Western Siberia; the wetland cover of an individual landscape province reaches 70%. Mires support the stability of the environment and they contribute to the thermal and water balance formation [2]. The study area is subjected to intense engineering development, in connection with which the natural conditions are disturbed. Since mire landscapes are very susceptible to anthropogenic load, this may lead to adverse consequences for humans. The engineering development leads to a change in surface conditions, to a change in natural succession and, as a rule, to a change in the temperatures and properties of the soil, which in turn may develop a complex of geodynamic processes. The team of authors in monograph of 2010 "Cryogenic Geosystems" noted the dependence of grounds temperatures on landscapes and vegetation characteristics [10]. A number of scientists [1, 11, 12, 14] in their studies indicate that the response of the upper horizons of the lithosphere to modern climate changes strongly depends on the landscape-geological conditions. They also note the existence of a certain correspondence between the parameters of frozen rocks and the hierarchical level of landscapes [7]. The mire landscape as any dynamic geosystem has its own cycles, stages of development and limit of stability. The temperature indexes of grounds have the greatest influence on the manifestations of exogenous processes for bog landscapes within the framework of biogenic morphogenesis. The soil temperature is a key factor controlling many biotic and abiotic processes occurring in the soils: growth and productivity of vegetation, decomposition and mineralization of soil organic matter, emission of greenhouse gases [22, 23, 24], the release of dissolved organic carbon [25]. The north and middle taiga zones of Western Siberia are located within sporadic permafrost. A very important indicator, that we have obtained, is the dynamic component of soil temperature within the southern permafrost zone for the key sites [8].

2. Object and methods

The aim of the study is to monitor the temperature regimes of the north and middle taiga subzones of bog landscapes to reveal the dynamics of biogenic relief formation in the process of engineering development of the territory.

The measurements were made in two key areas: the territory relating to the north-taiga landscapes of Western Siberia (the Siberian Ridges – observation Sites 3 and 8), and the territory relating to the middle-taiga landscapes of Western Siberia (the Ob middle-river lowland – Sites 5, 5a and 6).

The purpose of the research is to determine the temperature regime of the bog landscapes of the West Siberian Plain, which are under conditions of biogenic relief formation. The first key area is located in the subzone of the northern taiga and is under conditions of rare sporadic frozen grounds at different natural conditions. This characteristic allows us to obtain net data indicators for undisturbed landscapes in the conditions of the northern taiga. The choice of locations for arranging temperature observation sites was based on a number of different criteria: position in the relief, lithological composition, microclimate conditions and surface moistening, composition of soil and vegetation cover. The mire landscapes within this key area were presented by Sites 3 and 8. The third observation site started to operate on 22.07.2010. Site 3 is located in the high hummock-ridge bog at Meggen-Neg-Kui [3]. Site 8 started to operate on 12.08.2011. It is located 1.2 km to the north-west from the meteorological station at the permafrost peat on the hummock-ridge bog. The peat core examined at the hummock-ridge bog is of 2 m thickness. The morphometric parameters of the low ridge were the following: height is 70 cm, width is 4 m, length is 10 m. Poor decomposition of thawed peat was observed from the surface down to 50 cm depth. The thickness of the permafrost peat is 20 cm starting from 50 cm deep down to 70 cm deep from the surface of the low ridge.

The second key area was arranged in the subzone of the middle taiga located on the right bank of the Ob middle-river lowland. In connection with the increased man's activity associated with the oil production industry, the observation sites were established in bog landscapes. Site 6 (with temperature sensors located at depths 20, 40, 60, 100, 200 and 300 cm started to operate on 15.11.2010) is situated in natural conditions, Site 5a (depths 20, 40, 60, 100, and 200 cm) and Site 5 (control point) are in the collector corridor of pipelines. The observations at Site 5 were started in 2010, but no data were received. They were restarted in 2015 after coping with technical problems. The air temperature for the second key area was obtained by means of a temperature registering sensor installed at Site 6.

In this paper we used the methods of recording systems designed for in-situ measurement of the soil temperature. The method is described in details in [3, 4, 13]. The researches for the temperature regime features in the peat deposits of oligotrophic bog in the southern taiga of the Western Siberia are presented in the works [16, 17, 18]. A great scientific interest has been drawn to the results of temperature measurements of the air and soil made by the monitoring network deployed during the implementation of the German-Russian project "Kulunda" [15]. The international experience in studying the soil temperature regimes is important for monitoring development [19, 20, 21]. A temperature recorder DS1921G-F5 (Dallas Semiconductors, USA) with a temperature range from -40 °C to + 85 °C with the sensitivity of 0.5 °C was used for measuring the soil temperatures at the depths of 20, 40, 60, and 100 cm. For the depths from 1 m and deeper we used a temperature recorder DS1921Z-F5 with a temperature range from -5 °C to + 26 °C and with a sensitivity of 0.125 °C. To monitor the air temperature we used a temperature recorder DS1921G-F5. The periodicity of temperature recording was 4 hours for all loggers used for that. The analysis of the diurnal course was carried out based on 5-6 measurements. The daily mean and then monthly mean values for the soil temperature were calculated based on the observation results. The temperature recorders had protective capsules excluding the interference with the temperature sensitivity by submerging them in the wells equipped with a D50 mm case polyethylene pipe with a thermal insulation at the wellhead. The data were collected once a year in autumn. The obtained full-scale data on the temperature regime of the peat soils were processed using the Microsoft Office Excel 2007 software.

The presented material analyzes the data for three seasons of observations: a. 2013-2014; b. 2014-2015; c. 2015-2016. We haven't given the detailed analysis of the obtained values for soil and air temperatures from 2010 to 2013 in this work since it is already published [5, 6]. For the average annual temperatures to compare in the period from 2010 to 2013 see table 3 and table 4.

3. Results

The lowest air temperature was registered in January -26.3 °C (2014), -22.9 °C (2015), -25.7 °C (2016) at the first key site within the studied period (2013-2016). It corresponds to the average long-term value of -23.7 °C [26]. In winter 2013-2014 the coldest month was February with a temperature of -26.9 ºC and not January as it used to be for the study area. The high positive monthly average temperature was obtained for July +17.2 ºC [26]. The summer 2015 was characterized by the warmest month of June with an average monthly temperature of 17.4 ºC, and July was colder by 1.4 ºC (see table 1). In July 2016 the average monthly temperature was at 3.6 °C higher than the long-term average. For the first key area the average annual air temperature was -3.3 °C (2014), -2.8 °C (2015) and -1.3 °C (2016).

Table 1. Comparative data on the basic air temperature characteristics for sites of the first key area in three observation seasons.

Month	2013-2014	2014-2015	2015-2016
December	-13.8	-14.1	-16.2
January	-26.3	-22.9	-25.7
February	-26.9	-15.5	-12.1
June	12.9	17.4	19.8
July	16.5	16.0	20.8
August	12.0	11.8	15.5
Annual average t ºC	-3.3	-2.8	-1.3
Total of plus t ºC	1540.8	1706.2	2131.9
Total of minus t ºC	2713.9	2744.7	2594.0

For the second key area within the study period (2013-2016), the air temperature in January was: -22.3 °C (2014), -19.2 °C (2015), -21.9 °C (2016), which corresponds to the average long-term data of -22.5 °C [27]. In the cold season 2013-2014, February was the coldest month with a temperature of -24.6 ºC. But the average monthly temperature was warmer by 4.1 ºC in January and by 2.4 ºC in February in the second key area. June 2015 was the warmest month, same as for the first key area, with an average monthly temperature of 19.2 ºC, and July was by 2.3 ºC colder (see table 2). The average annual air temperature was -0.6 °C (2014), 0.2 °C (2015), 1.3 °C (2016) for the second key area. The long-term annual air temperature was -2.3 °C averaged from 1998 to 2004 according to the meteorological station Nizhnevartovsk [27]. Analyzing the results obtained in table 1 and in table 2, we come to a conclusion that the average annual temperature has increased for the observation period studied in the work.

The temperature is a key factor in biogenic relief formation. It affects the growth and productivity of vegetation and its decomposition. The analysis stated below applies to the average and average monthly temperatures obtained at the key sites. The results of soil temperature monitoring in the bog show general patterns of the solar radiation supply and consumption.

The minimum temperature was -0.5 ºC (27.01.2014) at 20 cm depth on Site 3, and 0º C in the period from 10.12.2014 to 16.05.2015. The maximum temperature was 15.5 ºC (08.07.2014) and 16.9 °C (04.08.2015). The average annual temperature varied from 3.3 ºC in 2014 to 4.6 ºC in 2015.

Table 2. Comparative data of the main air temperature parameters for the second key section.

Month	2013-2014	2014-2015	2015-2016
December	-10.9	-12.8	-14.5
January	-22.3	-19.2	-21.9
February	-24.6	-10.9	-8.6
June	14.9	19.2	19.2
July	16.4	16.9	20.0
August	14.5	12.9	17.4
Annual average t ºC	-0.6	0.3	1.3
Total of plus t ºC	1907.6	2176.5	2541.2
Total of minus t ºC	2041.4	2081.6	2064.3

The minimum soil temperatures in the annual cycle depends on the temperature of the underlying surface, the transitions during water freezing in the peat, the thickness of the snow cover and the amount of heat accumulated by the peat deposit within the warm period [18]. In the period 2014-2015 zero temperature was registered on November 24, 2014 at 20 cm depth on Site 8 and the transition through 0 °C was continued from November 27, 2014 to April 7, 2015. The positive temperature values were observed from May 24, 2015. The average annual temperature was 2.9 °C. The minimum temperature was -5.5 ºC (24-25.01.2015), the maximum temperature was 16.5 ºC (04.08.2015).

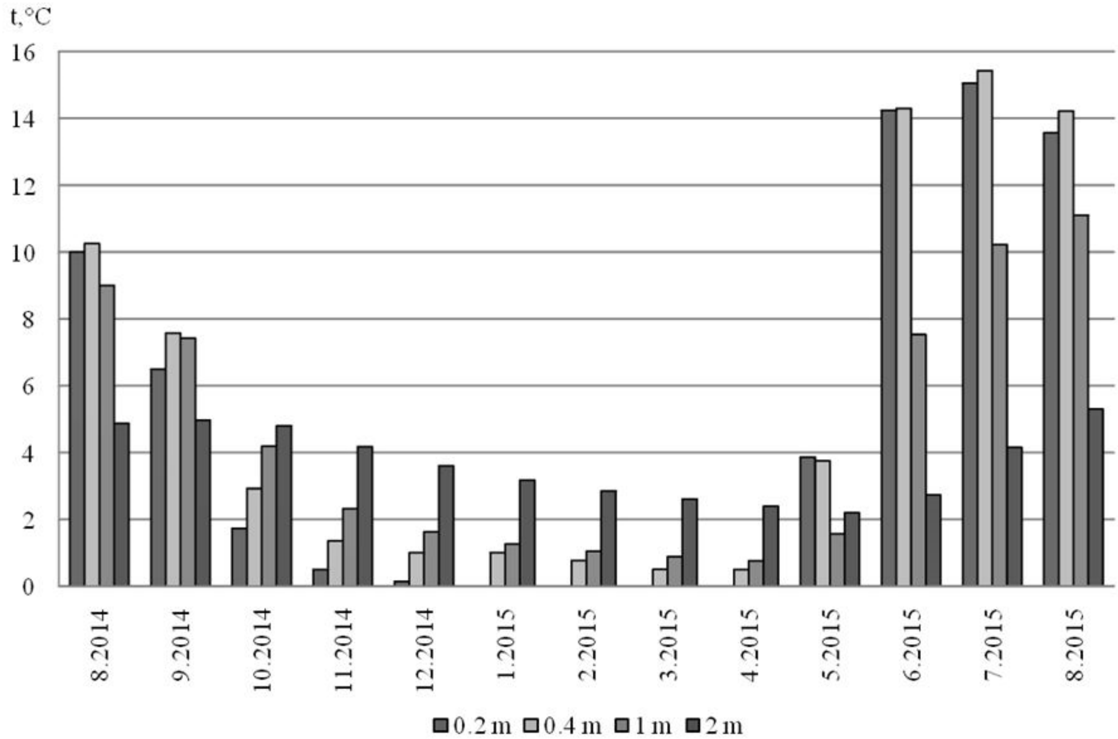

Figure 1. Summary graph of the monthly soil temperature at Site 3.

The difference between the soil temperature values obtained at Site 3 and Site 8 in 2015 is due to the landscape factor, since Site 3 is located in a wet hollow and Site 8 is on a ridge. In the period 2015-2016 the zero temperature was observed on November 16, 2015 and the transitions through 0°C were registered from November 20, 2015 to April 1, 2016. The positive temperature values at this depth were observed from June 7, 2016. The average annual temperature was 3.14 ºC. The minimum value was 2 ºC (26.01-02.02., 05-10.03.2016), the maximum value was 17.5 ºC (09.07-10.07.2016). Comparing the totals of positive temperatures we come to a conclusion that the total of negative temperatures has decreased. The total of positive temperatures was 1218.7 ºC in 2015 and 1202.4 ºC in 2016 and the totals of negative temperatures was 195.0 ºC in 2015 and 131.2 ºC in 2016.

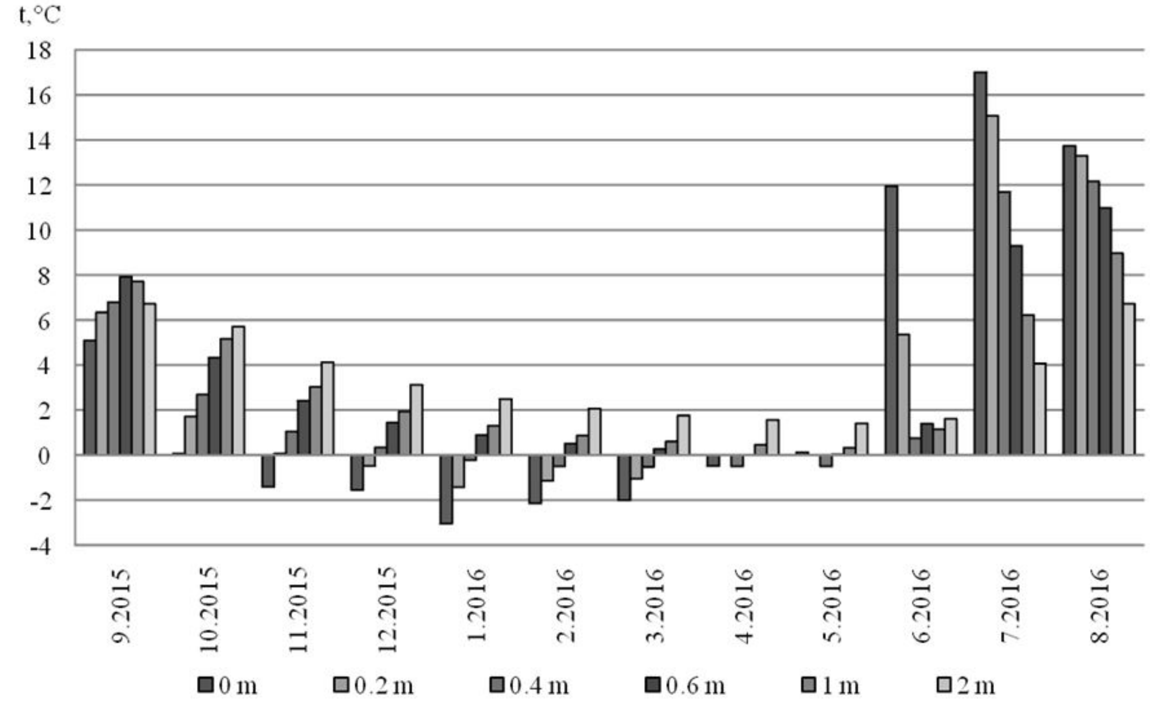

Figure 2. Summary graph of monthly soil temperature at Site 8.

The penetration depth of 0 ºC temperature into the soil is an important characteristic of the thermal regime in a cold period, which determines the depth of the layer with negative temperatures [18]. In the period 2013-2014 the zero temperature was registered on November 14, 2013 for the depths of 40 and 60 cm at Site 8, and the transition through 0 °C was being registered starting from December 7, 2013 to June 20, 2014. The positive values were noted starting from June 23, 2014. The average annual temperature was 1.2 ºC. The minimum value was -1.5 °C (15-28.02.2014), the maximum was 10 °C (August 25, 2014). The total of positive temperatures was 509.7 ºC, the total of negative temperatures was -125.1 ºC. In the period 2014-2015 the zero temperature was registered on November 30, 2014, and the transition through 0°C was registered in the period from December 25, 2014 to May 26, 2015. The positive values were observed starting from May 30, 2015. The average annual temperature was 2.7 °C. The minimum value was -5.5 ºC (24-25.01.2015), the maximum value was 16.5 ºC (04.08.2015). The total of positive temperatures was 1044.3 ºC, the total of negative temperatures was -99.6 ºC. In the period 2015-2016 the zero temperature was registered in December 22, 2015, and the transitions through 0 ºC were recorded from January 17, 2016 to June 13, 2016. The positive values started in June 19, 2016. The average annual temperature was 2.8 ºC. The minimum value was -1 ºC (07-09.03.2016) and the maximum value was 14.5 ºC (07.08.2016). The total of positive temperatures was 1001.6 ºC, the total of negative temperatures was -74.4 ºC. In 2013-2014 the average annual temperature was 1.47 °C at the depth of 60 cm and the total of positive temperatures was 525.9 ºC. In 2014-2015 it was 2.98 °C. The minimum value was 0 °C in the period from January 28 to June 30, 2014, the maximum value was 7°C (August 25, 2014). From 05.09.2014 to 04.03.2015, the temperature lowered to 0 ºC. The zero temperature lasted until May 25, 2015. After that the temperature raised to positive values and maintained at this point until August 14, 2015. In the period from 01.08 to 14.08.2015 the peak temperature was 11.5 ºC. The sum of positive temperatures was 1062.52 ºC. In the period 2015-2016 the zero temperature was established from March 21 to May 28, 2016. The average annual temperature was 3.3 ºC. The sum of positive temperatures was 1099.7 °C.

In 2013-2014 the average annual temperature for Site 3 was 3.5 ºC, in 2014-2015 it was 4.4 ºC. At Site 8 the average annual temperature was 1.4 ºC in 2013-2014, it was 2.8 ºC in 2014-2015 and it was 3.2 ºC in 2015-2016. The calculations were made using the average annual temperatures according to the depth values given in table 3.

Table 3. Annual average soil temperature at Site 3 and Site 8 of the first key area for the period from 2010 to 2016.

Observation site	Depth, *m*	Period						
		2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	Average for 2010-2016
3	0.2	3.9	4.5	3.4	3.3	4.6	-	4.0
	0.4	3.6	4.2	3.9	3.8	5.3	-	4.2
	0.6	3.6	4.2	3.2	-	4.3	-	3.8
	1.0	3.1	3.7	3.6	3.3	4.2	-	3.6
	2.0	-	-	3.6	-	3.6	-	3.6
8	0.2	-	2.5	1.8	-	2.9	3.1	2.6
	0.4	-	1.1	1.5	1.2	2.6	2.8	1.8
	0.6	-	0.7	1.4	1.5	3.0	3.3	1.9
	1.0	-	1.1	-	1.6	2.9	3.1	2.2
	2.0	-	-	-	-	-	3.4	3.4

Note: “-“ – no date.

No transitions through 0º C were registered at the depth of 1 m. In 2013-2014 the average annual temperature was 3.3 ºC at 1 m depth and it was 4.2 ºC in 2014-2015. For 2013-2014 the minimum value was 0.5 ºC (08.04.2014) and the maximum value was 9.62 ºC (08.08.2014). From 01.09.2014 to 16.05.2015 the temperature was 0.63 ºC, then from 17.05 to 08.08.2015 the temperature started to rise up to 11.5 ºC. In the period from 08.08 to 11.08.2015 the temperature remained at the value of 11.5 ºC, after which it started to decline slowly (stick-slip nature of the peak of positive temperature). The maximum value of soil temperature variation was in the period from 08.08 to 11.08.2015 (11.5 ºC). The minimum value of temperature variation was 0.6 ºC in the period from 08.05 to 16.05.2015. From 01.09.2014 to 28.05.2015 the temperature slowly decreased at the 2 m depth, then from 29.05 to 29.08.2015 the temperature started to rise up to 5.8 ºC. The maximum value of the temperature was 5.8 ºC in the period from 28.08 to 29.08.2015. The minimum value of the annual temperature variation was 2.13 ºC in the interval from 19.05 to 28.05.2015. The average annual temperature was 3.4 ºC. In 2013-2014 the average annual temperature was 1.6 ºC at the 1 m depth with the total of positive temperatures of 586.3 ºC, and it was 2.9 °C in 2014-2015. The minimum value was 0 ºC (15.05.-11.06.2014) and the maximum value was 5.5º C (30.08.-02.09.2014). During the period 2014-2015 the average annual temperature was 2.9 ºC. The minimum value was 0.3 ºC (28.04-24.05.2015), the maximum value was 9.1 ºC (12-23.08.2015). The total of positive temperatures was 1015.37 ºC. In the period 2015-2016 the average annual temperature was 3.1 ºC. The minimum value was 0.3 ºC (11-25.05.2016) and the maximum value was 9.3 ºC (19.08.-01.09.2016). The total of the positive temperatures was 1047.3 ºC.

In the period 2015-2016 the average annual temperature was 3.4 °C at the 2 m depth. The minimum value was 1.3 ºC from 11 to 25 May 2016 and the maximum value was 9.3 ºC from August 19 to September 1, 2016. The total of the positive temperatures was 1047.3 ºC.

For the territory of the first key area in the northern taiga landscapes of Western Siberia, the average temperature for 5 years at the two sites was 3.0 ºC, which is 1 ºC above the isoline temperature at this latitude given in the paper [28].

The annual average soil temperature at Site 6 had positive values in the observation period (table 4). The highest temperature was 4.8 ºC for 2015-2016 and the lowest one was 3.7 ºC for 2013-2014. The temperature maintained positive at all depths, without dropping below 0 °C (table 4).

Table 4. Annual average soil temperature for Site 6 at the second key area from 2013 to 2016.

Depth, *m*	2013-2014			2014-2015			2015-2016		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
0.2	3.5	12.7	0.0	-	-	-	5.7	18.2	-0.2
0.4	4.0	11.1	0.4	5.2	13.7	0.1	5.6	15.5	0.4
0.6	3.5	9.2	0.2	4.5	11.6	0.0	4.7	12.4	0.0
1.0	3.8	9.2	0.5	4.7	11.1	0.5	4.9	11.7	0.6
2.0	3.7	5.5	2.3	3.9	6.1	2.3	4.1	6.1	2.5
3.0	3.7	4.4	3.0	3.8	4.6	3.0	4.0	4.8	3.3
Annual average	3.7	8.7	1.1	4.4	9.4	1.2	4.8	11.5	1.1

Note: “-“ – no date.

The highest annual average temperatures for all depths of measurements was recorded in the period from 2015 to 2016. The lowest value of average annual temperatures for all depths of measurements was registered in the period from 2013 to 2014. The maximum difference between the values was 2.1 °C at the 20 cm depth. The minimal difference was 0.3 °C at the 2 meters depth. The soil temperature variations are shown in figures 3, 4.

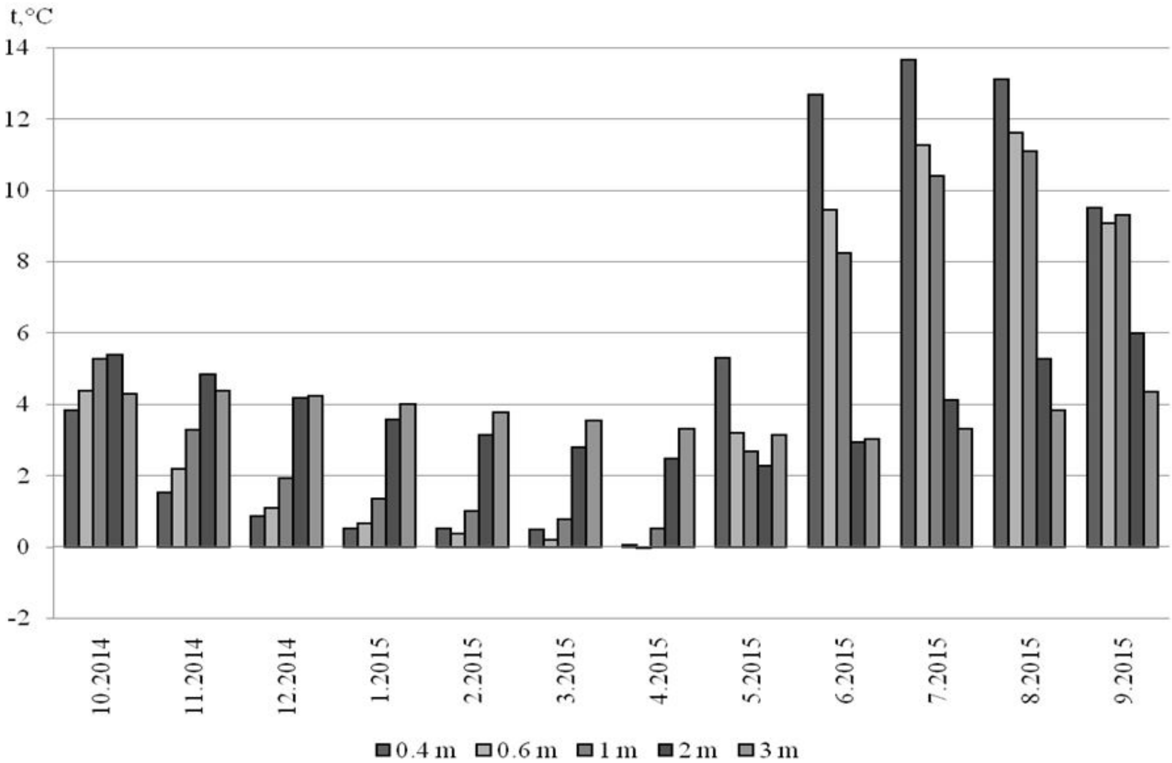

Figure 3. Summary graph of the soil temperature at Site 6 for 2014-2015.

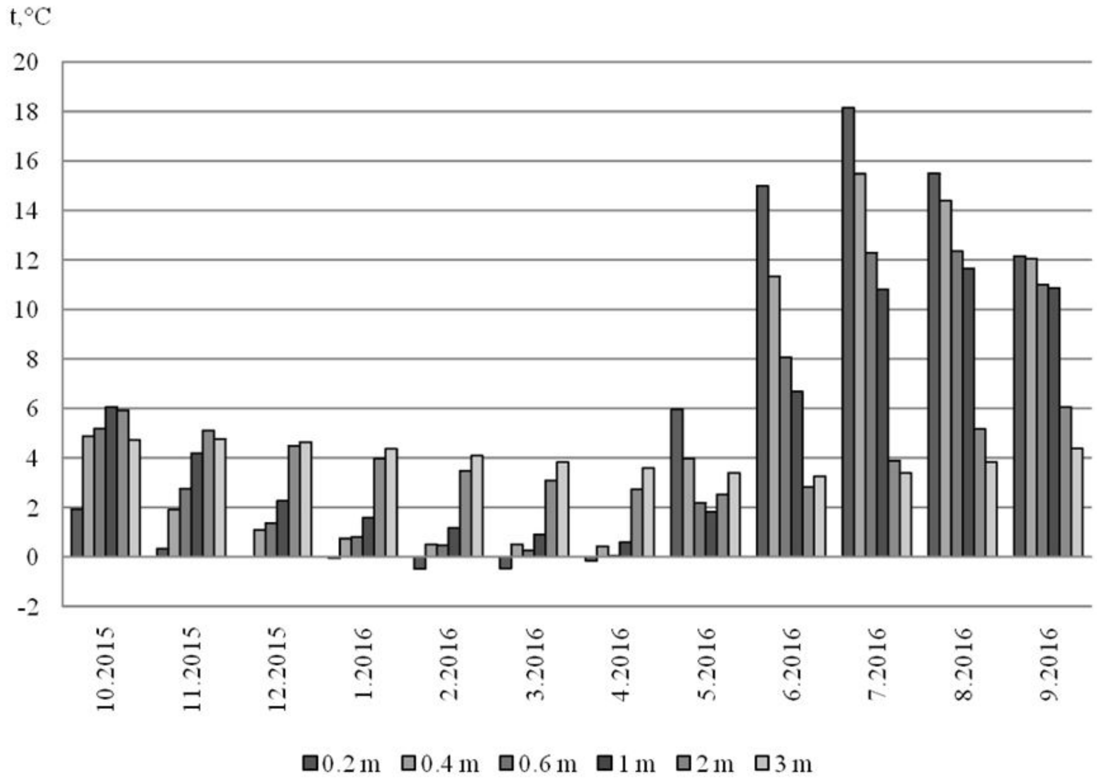

Figure 4. Summary plot of the soil temperature at Site 6 for 2015-2016.

The temperature transition through 0 ºC was observed on 22.10.12 at the 20 cm depth; it was at the 40 cm depth on 21.01.13 and it was at the 60 cm depth on 01.01.2013. No deeper transition through 0º C was registered. The transition through 0 ºC was as well in 2015-2016 at the 20 cm depth on 20.01.16 and no temperature transition was detected below. For the latitude of the Ob river valley the average temperature was 4.2 °C at Site 6 in the period of 6 years.

To study the impact of the pipeline transport on the bog landscapes in 2015, Site 5 was updated and a new site 5a was set up at the man-disturbed area (section of pipeline Samotlor-Nizhnevartovk). The temperature of the oil transported through the pipeline with a diameter of 1220 mm is 17°C. The pipe is laid at the 1 m depth from the surface of the upper hummock-ridge bog. Site 5a is located within the immediate vicinity of the pipeline and Site 5 is located in 20 m from the pipeline. For the period 2015-2016 the annual average temperature at Site 5 was positive with the value of 4.2°C and it is 3.8°C lower than the temperature at Site 5a (table 5).

4. Discussions

The bog landscape as a dynamic geosystem has its own cycles and stages of development, as well as a limit of stability. The greatest influence on the manifestations of exogenous processes for bog landscapes is exerted by the soil temperature within the framework of biogenic morphogenesis. For the territory of the first key area, the average temperature was 3 ºC at the two sites for the 5 year period. For the Ob middle-river lowland, the average temperature was 4.2 °C at Site 6 for the 6 year period. For the period 2015-2016 the average annual temperature was 8.3 ºC at Site 5a (man-disturbed area) at all depths and this value is 3.8 ºC higher than in the natural bog (Site 5 – control section). Site 6 is located at the distance of 10 km to the south-west from Site 5. The average annual temperature at Site 5 was less by 0.8 °C than at Site 6. At the 20 cm depth the difference was up to 1.1 ºC, at the 40 cm depth it was 2 ºC, at the 60 cm depth it was 0.5 ºC, at the 1 m depth it was 0.7 ºC and at the 2 m it was 0.4 ºC.

5. Conclusions

It can be concluded that the heating capacity of engineering facilities for pipeline transport is limited within the 25 m protection zone from the pipe line. This fact suggests that the observed higher temperature in the immediate vicinity of the pipeline contributes to the process of restoring the disturbed terrain. The process of biogenic morphogenesis accelerates under temperature increase, and in our case, the peat accumulation process is occurring under restauration of the bog vegetation. In the collective monograph [29], which discloses a single concept of the bog formation process, the average rates of vertical peat accumulation for the northern taiga are 0.37 mm/year and for the middle taiga they are 0.57 mm/year. For a bog massif framing The Lake Samotlor (the second key area) the peat growth rate is 0.32 mm/year, with the peat deposit age of 7700 ± 60 years and the average thickness of 2.5 m [30]. The appearing rate of peat accumulation can't be considered as the same for the whole bog massif, since differences will be observed within the hollows, low ridges and lakes. This rate is a common quantitative indicator. At present, bogging occurs at the expense of the growth of the existing bog systems in broadwise and the emergence of new hearths of bogging in natural conditions occurs rarely. New hearths of bogging arise as a consequence of the man-made activity effect under lack of spillway structures in the places of roads, oil and gas pipelines, impoundment of small rivers and streams. As a result of temperature monitoring of bog landscapes, it is possible to identify the patterns of soil temperature change in natural bog landscapes to a greater extent depending on the influence of meteorological characteristics. For soils under man-disturbed facilities a higher temperature is observed in comparison with the natural bog landscapes, which is a factor of development of heating effects in the process of engineering development of the territory. These results are presented in the database of net soil temperature data of the upper part of the annual heat cycle layer, on the basis of which it is possible to build change forecasts and use data in project-supporting works.

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