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THE REACTION OF THE ENVIRONMENT TO CLIMATE CHANGE IN NORTHERN LATITUDES (ON THE EXAMPLE OF THE TAIGA ZONE OF THE KHANTY-MANSIYSK AUTONOMOUS OKRUG-YUGRA)

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The article presents some results of research on the impact of modern climate change on the environment in the taiga zone of the Khanty-Mansiysk Autonomous Okrug-Yugra. Long-term indicators of the average annual air temperature and the duration of the occurrence of stable snow cover are given according to the data of some weather stations in the region. The reaction of the natural environment is determined based on the analysis of technological processes in the conditions of climate change in the studied territory. Observed dangerous hydrometeorological phenomena on the territory of KHMAO-Yugra are presented.

Keywords: climate change, phenology, taiga zone, Northern regions, dangerous hydrometeorological phenomena.

INTRODUCTION

According to the results of monitoring the state of the surface atmosphere, in recent years there has been a continuing trend towards warming in various regions of the globe and, especially, in high latitudes. During 1936-2018, there was a statistically significant (at a 5% significance level) positive linear trend in the average annual temperature for the latitudinal zones of 60-70 and 70-85° C, and in general for the Northern polar region [Doklad ob osobennostyakh klimata na territorii Rossiyskoy Federatsi, 2018].

Climate change and its impact on the functioning of landscapes, phenological processes and the structure of seasonal rhythms, as well as on the economic activity of the population, are now clearly manifested in the Northern regions, including the territory of the West Siberian plain, which is reflected in the works of a number of scientists [Gashev S.N. 2012; Bakhmutov V.A. at al., 2011,; Evseeva N.S., Filandysheva L.B., 2016; Evseeva N.S. at al., 2015; Zemtsov V.A., Filandysheva L.B., 2012; Kuznetsova V.P., 2016l; Okisheva L.N., 2010; Okisheva L.N., 1984; Okisheva L.N., Filandysheva L.B., 2015; Filandysheva L.B., Okisheva L.N., 2002; Shiryaev A.G., 2009].

Scientists' research confirm that in the territory of Western Siberia, warming causes a reaction of the environment and can lead to a shift in the boundaries of natural zones, so it is necessary to review the conditions for the functioning of geosystems of various natural zones and provinces and clarify their boundaries. For example, the southern border of the Northern taiga should be drawn North in the West and East, compared to the proposed schemes of natural zoning; the Northern border of the Northern taiga in the East can also be drawn slightly North (above Igarka); the southern border of the tundra is North of the Tazovsky (usually South); the southern border of the Arctic tundra is much further South in the West (via Marre-Sale, not via Tambey) [Okisheva L.N., Filandysheva L.B., 2015].

In the Urals, there are recorded facts of northward displacement of the range boundaries of many species of fungi (Clavaria incarnata Weinm., Clavariadelphus truncatus (Quél.) Donk, Polyporus alveolaris (DC.) Bondartsev & Singer, Polyporus rhizophilus (Pat.) Sacc., Sarcodontia crocea (Schwein.) Kotl. and others), previously found exclusively in broad-leaved and mixed forests, in the steppes of the Ural-Siberian region, and now it is common in the forests of the South of the Sverdlovsk and Tyumen regions [Shiryaev A.G., 2009]. In addition, scientists associate the advance of the Northern border of the forest along the Yamal and the increase in the upper border of the forest in the mountains of the Circumpolar and Polar Urals with global warming. Climate changes explain the appearance of one of the endangered species of fungi (Clavulina amethystina (Bull.) Donk) in the middle taiga forests of the Sverdlovsk region and the Western part of the Khanty-Mansiysk Autonomous Okrug-Yugra [Shiryaev A.G., 2009].

The average growth rate of the average annual air temperature on the territory of Russia for 1976-2018 was 0,47°C /10 years [6], which leads to intensive melting of permafrost and is of great importance for the nature of the Northern regions [Evseeva N.S. at al., 2015]. During the period of systematic observations (since about the mid-1990s), monitoring sites have shown an increase in the average depth of seasonal thawing of permafrost by 1-2 cm in Western Siberia. This is significantly influenced by annual variability in air temperature and precipitation [Vtoroy otsenochnyy doklad Rosgidrometa ob izmeneniyakh klimata i ikh posledstviyakh na territorii Rossiyskoy Federatsii, 2014]. Scientists associate the increase in the average long-term air temperature caused by global climate warming with changes in the areas of thermokarst lakes in the cryolithozone in the permafrost zones of Western Siberia, which requires the development of methodological issues for identifying lake-thermokarst landscapes [Bryksina N.A. at al., 2009, Bryksina N.A at al., 2012, Polishchuk Yu.M., Bogdanov A.N., 2015].

Modern climate change is accompanied by an increase in the growth of dangerous hydrometeorological phenomena, including floods, strong winds, heavy rains, hail, droughts, which cause serious damage to the economy and the life of the population, which is also observed in the territory of the Khanty-Mansiysk Autonomous Okrug-Yugra [Doklad ob osobennostyakh klimata na territorii Rossiyskoy Federatsi, 2018]. The issue of climate change and its impact on the nature of natural processes, which result in an increase in the number of dangerous hydrometeorological phenomena, is very relevant. In this regard, it is important to study adverse and dangerous hydrometeorological phenomena that pose a threat to the environment, economy, life and health of the population, which can lead to environmental and economic damage.

Khanty-Mansiysk Autonomous Okrug-Ugra refers to territories with uncomfortable and extreme living conditions, with a moderate, severe continental climate and is equated to the regions of the Far North. The climate is characterized by a variety and rapid change of weather in all seasons, especially during the transition from autumn to winter and from spring to summer. Daily and seasonal fluctuations in air temperature, long and cold winters, and short cold summers also characterize the climate of the territory [Zuevskii V.P., 2000].

When studying climate change, it is becoming increasingly important to study phenological phenomena that reflect the seasonal rhythm of nature. The purpose of this work is to study the reaction of the natural environment to modern climate change using the analysis of phenological phenomena, as well as the analysis of dangerous hydrometeorological phenomena on the territory of KHMAO-Yugra.

OBJECTS AND METHODS OF RESEARCH

To identify the reaction of the natural environment to climate change in the taiga zone of the Khanty-Mansiysk Autonomous Okrug-Yugra, we have collected, processed and combined analysis of long-term series of climate and phenological information on the studied territory. The analysis of long-term series of meteorological parameters was carried out based on data for individual months of specialized arrays for climate research of the All-Russian research Institute of hydrometeorological information (ARRIHMI-WDC).

According to the data of the aviation meteorological station of Nizhnevartovsk, the author calculated the values of individual monthly and average annual climate indicators. The sources of phenological information are the nature chronicles of specially protected natural territories, data from the phenological archive of the Russian geographical society, as well as our own observations, based on which we have compiled the nature calendar of the city of Nizhnevartovsk and its vicinities for 2007-2019.

The main methods used in the study were historical, cartographic, mathematical, statistical, information analysis and synthesis, and phenological monitoring. The analysis of the timing of the onset of phenological phenomena allowed us to draw conclusions about the time limits and trends in the timing of the phenological seasons onset at some points in the taiga zone of the KHMAO-Yugra.

To date based on the results of our observations; we have accumulated information about the timing of the phenological phenomena onset in the city of Nizhnevartovsk for the period 2007-2019 and analyzed the meteorological series for the corresponding years (table 1).

To determine the spatial and temporal variability of climate conditions in the region, we analyzed long-term average annual air temperature, precipitation and snow depth at the weather stations Berezovo, Oktyabrskoe, Khanty-Mansiysk, Ugut, and Nizhnevartovsk (table 1).

Table 1. Analyzed data of weather stations and points of phenological observations on the territory of KHMAO-Yugra

Weather station, coordinates	Monitoring period			Phenological observation points	Monitoring period
	Air temperature	Amount of precipitation	Snow depth		
Berezovo 63°93' N. L. 65°05' E. L.	32 (1988-2019)	31 (1983-2013)	29 (1983-2012)	«Berezovsky» Habitat Management Area	17 (1997-2013)
				«Vogulka» Habitat Management Area	16 (1997-2012)
Oktyabrskoe 62°45' N.L. 66°05' E.L .	32 (1988-2019)	31 (1983-2013)	29 (1983-2012)	«Untorsky» Habitat Management Area	12 (2002-2013)
Khanty-Mansiysk 61°02' N.L. 69°03' E.L.	32 (1988-2019)	31 (1983-2013)	no data		
Ugut 60°50' N.L. 74°02' E.L.	29 (1988-1995; 1997; 1999-2018)	29 (1983-1995;1997; 1999-2013)	30 (1983-2013)	«Yugansky» Nature reserve	26 (1988-2013)
Nizhnevartovsk 60°57' N.L. 76°32' E.L.	32 (1988-2019)	32 (1988-2019)	31 (1988-2019)	Nizhnevartovsk and its vicinities	13 (2007-2019)

RESULTS

Natural phenomena that occur periodically after a certain period can reflect the impact of climate change on the natural environment, since they are complex indicators of local physical and geographical conditions. In this regard, information about phenological processes allows us to determine the characteristics of the reaction of the natural environment to observed climate changes in a particular region. Previous studies [Kuznetsova V.P., 2016] have been supplemented with new analytical data, which allows us to identify the features of the influence of the main meteorological factors on the dynamics of phenological processes in the conditions of climate change in the taiga zone of the Khanty-Mansiysk Autonomous Okrug-Yugra.

Analysis of the long-term course of the main meteorological indicators – air temperature, precipitation and snow depth at the weather stations Berezovo, Oktyabrskoe, Khanty-Mansiysk, Ugut, Nizhnevartovsk, allows us to draw certain conclusions about the climate and weather conditions of the taiga zone of the district. It is necessary to study the phenological reaction to climate conditions. These meteorological observation points are located in various natural and climatic conditions that determine the features and differences of meteorological conditions at the local level within the Khanty-Mansiysk Autonomous Okrug-Yugra (table 2).

The study found that common features characterize these points in the long-term variability of air temperature. Thus, at the latitudes of the weather stations Berezovo, Oktyabrskoe, Khanty-Mansiysk, Ugut, Nizhnevartovsk, during the studied time frame, periods of warming followed by cooling are clearly distinguished. The corresponding time frames in all the designated points cooling cycles with the lowest average annual air temperatures were in 1992, 1998, 2006, 2009, 2010, 2014 and 2018. According to the weather stations' data, the years with the highest average air temperature for the warming periods characteristic of each observation point are identified: 1991, 1995, 2005, 2007, 2008, 2011 and 2016. Especially expressed is the increase in the average annual air temperature over a long period on the territory of KHMAO-Yugra in 1995 and 2005. The average frequency of air temperature fluctuations is 5 years (Fig. 1).

Graphical analysis of long-term air temperature series based on data from weather stations shows a trend in increase the average annual air temperature in the taiga zone of the Khanty-Mansiysk Autonomous Okrug-Yugra over the past 32 years (Fig. 1).

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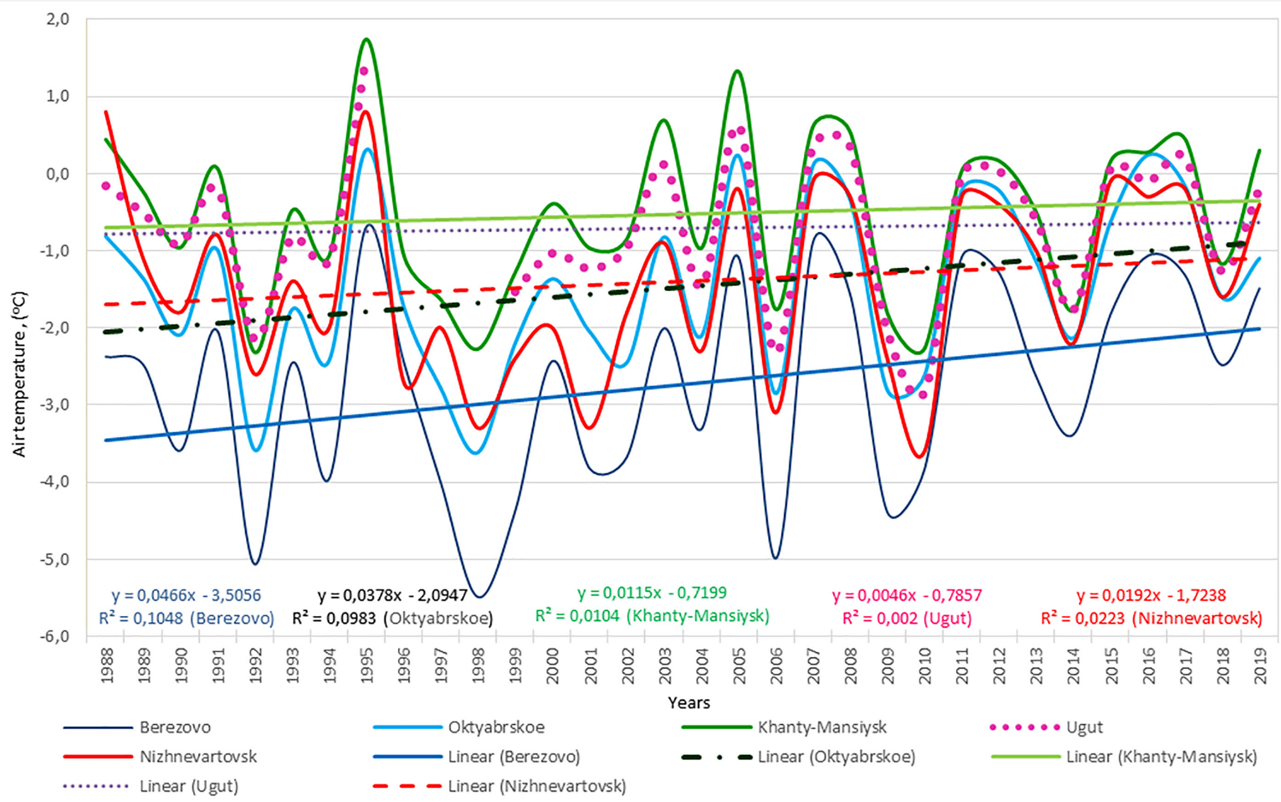


Analysis of the accuracy of determining values of the trend equation parameters

Weather station	Statistical significance (at a significance level of 0,05)	
	coefficient a	coefficient b
Berezovo	Is not confirmed	confirmed
Oktyabrskoe	Is not confirmed	confirmed
Khanty-Mansiysk	Is not confirmed	not confirmed
Ugut	Is not confirmed	not confirmed
Nizhnevartovsk	Is not confirmed	confirmed

Fig. 1 Graph of the long-term course of the average annual air temperature (°C) according to the weather stations Berezovo, Oktyabrskoe, Khanty-Mansiysk, Ugut, Nizhnevartovsk for the period 1988-2019.
Air temperature (°C) Berezovo, Oktyabrskoe, Khanty-Mansiysk, Ugut, Nizhnevartovsk years
Linear trend (Khanty-Mansiysk) Linear trend (Berezovo) Linear trend (Ugut) Linear trend (Nizhnevartovsk) Linear trend (Oktyabrskoe)

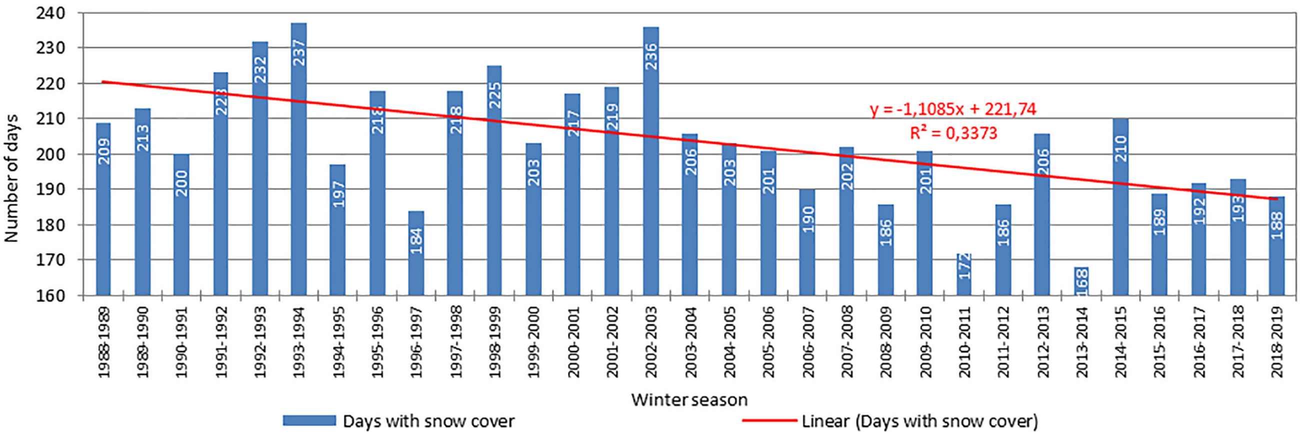
The average annual air temperature in Nizhnevartovsk for the last 10 years (period 2010-2019) is-1 oC. For the period 1988-2019, 2010 is characterized by the lowest air temperature (-3,6 oC), which is 0,3 oC lower than the values in 1998 and 2001. When analyzing the dynamics of the average annual air temperature in Nizhnevartovsk over the past three decades, it was found that the last decade was the warmest. The highest growth rates of average annual air temperature were found for the periods 1990-1999 and 2000-2009 (table 3).

Table 3. Characteristics of the dynamics of the average annual air temperature in the city of Nizhnevartovsk for 10-year periods from 1990 to 2019

Period	Average annual temperature, °C	Minimum for the period, °C	Maximum for the period, °C	Average air temperature growth rate for the specified period, %	Average change in air temperature over the specified period, °C	b trend coefficient
10 years (2010-2019)	-1,0	-3,6	-0,1	0,78	+0,36	0,15 (statistically is not significant)
10 years (2000-2009)	-1,6	-3,3	-0,1	1,02	-0,04	0,13 (statistically is not significant)
10 years (1990-1999)	-1,8	-3,3	+0,8	1,03	-0,06	-0,12 (statisticallyis not significant)
30 years (1990-2019)	**-1,5**	**-3,6**	**+0,8**	**0,94**	**+0,04**	**0,04 (statistically is not significant)**

The average long-term amount of precipitation for these years in the observation points (table 2) is 558,6 mm. In the paper [Kuznetsova V.P., 2016], periods of increasing precipitation were identified: 1985-1986, 1990-1991, 1994-1995, 1998-2003, 2006-2008, 2011-2013. The most expressed intervals with a low annual precipitation amount were observed in 1987-1989, 1992-1993, 1996-1997, 2004-2005 and 2009-2010 [Kuznetsova V.P., 2016]. During the study period, in the observation points of Nizhnevartovsk, Ugut, and Berezovo, a steady growth trend in the average snow depth was observed [Kuznetsova V.P., 2016].

One of the important indicators of the reaction of the natural environment to changes in the climatic conditions of the territories of Northern latitudes is the timing of the formation and loss of snow cover, which characterizes the duration of the frost period. The territory of the taiga zone in the East of the Khanty-Mansiysk Autonomous Okrug-Yugra (Nizhnevartovsk) is characterized by a noticeable decrease in the duration of the period with a stable snow cover, which determines the phenological boundaries of the winter season. As a result of the analysis of the duration of snow cover on the territory of the city of Nizhnevartovsk, the trend of reducing the period with stable snow cover for the period 1988-2019 was determined (Fig. 2).



Analysis of the accuracy of determining values of the trend equation parameters

Nizhnevartovsk	Statistical significance (at a significance level of 0,05)	
	coefficient a	coefficient b
Winter season	confirmed	confirmed

Fig. 2 Graph of the number of days with snow cover in the city of Nizhnevartovsk for 1988-2019

Abnormally warm weather for November with a maximum air temperature of +4,6°C in 2008, +5,1°C in 2010, and +2,8°C in 2013 led to a late formation of snow cover – i.e. at the beginning and in the second decade of the month, resulting in a violation of the biorhythms of fauna representatives. In Nizhnevartovsk, loss of snow cover occurs mainly in the first decade of May, sometimes in April. Adverse weather conditions in the spring of 2013, characterized by sharp changes in air temperature, close to normal, but relatively low average air temperature in May (+3,8°C) contributed to a relatively late loss of snow cover – in mid-May (table 4). For the period 1988-2019 for the territory of the city of Nizhnevartovsk, the average duration of the period with a stable snow cover is 204 days.

Thus, meteorological conditions affect the dynamics of processes and the winter season. For example, in January 2011, at the earliest time during the study period, against the background of an increase in the duration of sunshine and an increase in air temperature, in the vicinity of Nizhnevartovsk, snow degradation processes were observed as well as signs characteristic of the early stage of the spring phenological season were shown. In the abnormally warm 2012 year, in Nizhnevartovsk there was an early loss of snow cover. In addition, the meteorological situation contributed to the early loss of snow cover (in April) in 2016 and 2017. (table 4).

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Table 4. Characteristics of the duration of snow cover in the vicinity of Nizhnevartovsk for 2007-2019

Winter season	Date of formation of a stable snow cover	Date of loss of snow cover	Duration of the frost period (days)
2018-2019	30 October	06 May	188
2017-2018	28 October	09 May	193
2016-2017	19 October	29 April	192
2015-2016	20 October	26 April	189
2014-2015	07 October	05 May	210
2013-2014	17 November	04 May	168
2012-2013	21 October	15 May	206
2011-2012	30 October	03 May	186
2010-2011	16 November	07 May	172
2009-2010	20 October	09 May	201
2008-2009	02 November	07 May	186
2007-2008	21 October	10 May	202

The reaction of the natural environment to climate change is accompanied by the occurrence of dangerous hydrometeorological phenomena in the Northern region. On the territory of the Khanty-Mansiysk Autonomous Okrug-Yugra, adverse and dangerous hydrometeorological phenomena are observed, those caused by modern climate change, including spring and summer flooding, which leads to flooding of low-lying areas. For example, the last of the large-scale floods in the region was also affected by a large stock of snow in the winter of 2014-2015, as well as intense rainfall in the summer of 2015 [Kuznetsova V.P., 2016]. High water levels cause serious damage to the environment, residential areas, transport and engineering infrastructure, as a result of which the established boundaries of flood zones and flooding of settlements are being revised [Kuznetsova V.P. at al., 2018]. Features of meteorological conditions determine the functioning of natural complexes and economic activities of the population. The temperature regime, precipitation distribution, timing of formation and loss of snow cover, water levels in rivers and reservoirs have a significant impact on the development of the fire season, as happened, for example, in 2012 on the territory of the region [Kuznetsova V.P., 2016].

Common occurrence within the district (okrug Yugra) – very strong wind (wind speed 25 m/s and more are noted all year-round), severe snowstorm (reduced visibility less than 500 m at a wind speed of 15 m/s, lasting more than 12 hours, observed during the entire cold period of the year and spring, until early June), bitter cold (in the period from mid-December to mid-February for 3 nights or more maintained minimum air temperatures below -45°C) [Kuznetsova V.P., 2016; Doklady ob ekologicheskoy situatsii v Khanty-Mansiyskom avtonomnom okruge – Yugre za 2014-2018 [Electronic resource]]. In addition, climate change is accompanied by dangerous hydrometeorological phenomena that are not typical for the physical and geographical conditions of the territory of the Khanty-Mansiysk Autonomous Okrug-Yugra. For example, in recent years, tornadoes have been observed in the vicinity of the cities of Nefteyugansk (summer 2010), Khanty-Mansiysk (June 2012) and Surgut (July 2016). In the city of Nizhnevartovsk, on February 28, 2017, a snowstorm was observed – a rare natural phenomenon that has never been previously recorded in Yugra.

As a result of the observed climate changes, there is an increase in the frequency of extreme and catastrophic natural phenomena in 2007-2019 on the territory of the KHMAO-Yugra. Many of the most important characteristics of the climate such as frost-free period, the timing of snow cover formation, the occurrence of first and last frost and rainfall patterns become more variable and change the local climate is most severe in the transitional seasons – spring and fall. In vulnerable Northern regions, it is necessary to continue research on adverse and dangerous hydrometeorological phenomena that pose a threat to the natural environment, economy, life and health of the population and lead to environmental as well as economic damage.

For these points of phenological observations (table 1), the timing of the occurrence of phenomena taken as the beginning of the spring, summer, autumn and winter phenological seasons, as well as their duration (according to T. N. Butorina, 1974) on the territory of Western Siberia were analyzed (table 5) [Kuznetsova V.P., 2016].

Table 5. Phenological periodization of the taiga zone of Western Siberia

Seasons	Sub-seasons	Stages	Phenological limits	Thermal limits
Spring	Pre-vegetation	Primary	From the beginning to the complete loss of the snow cover.	The transition of daytime temperatures from 0°C to + 5°C (which corresponds to average daily temperatures from -5°C to 0°C).
		Basic	From the loss of snow cover to the beginning of active vegetation (the beginning of sap ascent in the birch trees).	From the transition of maximum daytime temperatures through +5°C in the upward direction, to the transition of night, minimum through 0°C in the upward direction (which corresponds to the average daily temperatures of 0°C and +3°C)
	Spring vegetation	Primary	From the onset of vegetation to the onset of the phytomass production by trees and shrubs.	From the transition of minimum temperatures through 0°C in the upward direction to their transition through +5°C (daily values, respectively, are above +3°C and +8°C).
		Main («green spring»)	From the beginning of budding leaves on birch trees to the blossom of bird cherry trees.	From the transition of minimum temperatures through +5°C to the upward direction to their transition through +10°C (respectively is above +8°C and +12°C).
		Final («Pre-summer»)	From the onset of bird cherry tree blossom and full deployment of aspen foliage to the blossom of rosehips and raspberries	From the first transition of minimum temperatures through +10oC in the upward direction to their steady transition through the same temperature limit
Summer	Summer vegetation	Is not divided	From the blossom of local species of rosehip to the start of birch leaves yellowing	A period with stable minimum temperatures through +10°C in the upward direction (respectively, the average daily temperature is above 15°C at the beginning and below 15°C at the end of the summer season).
Autumn	Autumn vegetation	Primary (pre-autumn)	The appearance of the first spots of autumn colour in the birch trees.	From the transition of minimum air temperatures through +10°C to the downward direction (respectively, the transition of average daily temperatures below +15°C).
		Main (Golden autumn)	Mass yellowing of leaves on birch trees.	From the transition of minimum temperatures through +5°C to the downward direction (respectively below +8°C average daily temperatures).
	Post vegetation	Main («late autumn»)	From the complete yellowing leaves of the birch trees to the end of its leaf fall and temporary snow cover.	From the transition of minimum air temperatures through +5°C to the downward direction and to their transition below 0°C (respectively, the average daily temperatures below +8°C at the beginning and below +2°C at the end of the period).
		Final («pre-winter»)	From the end of leaf fall to the formation of snow cover for winter.	From the transition through 0°C in the direction of lowering the minimum temperatures to their transition below this limit of maximum temperatures (respectively, the average daily temperatures - from +2°C to-5°C).
Winter	Early winter Late winter Pre-spring	Is not divided	From the formation of a stable snow cover to the beginning of its loss – the beginning of snowmelt and the appearance of the first thawing.	From the transition of the maximum air temperatures through 0°C in the downward direction at the beginning to their transition through 0°C in the upward direction at the end of the season (respectively, the average daily temperatures below -5°C).

For phenological observations points, average dates and trends of changes in the timing of the start of phenological seasons determined by the meteorological conditions of the area were identified (table 6).

On the territory of the city of Nizhnevartovsk, located in the East of the KHMAO – Yugra, the course of phenological processes differs significantly from other studied territories of the district. Here, urban environment conditions have a certain influence on phenological phenomena. In the spring season, the timing of occurrence of phenomena in Nizhnevartovsk significantly outstrips the development of phenological processes in other studied areas (the appearance of thawing, loss of snow cover). During the transition from spring to summer, the difference in the average time of occurrence of phenological phenomena decreases, and the development of most autumn and winter events in the vicinity of Nizhnevartovsk occurs later (table 6).

Table 6. Average long-term periods of occurrence of phenomena in the taiga zone of the KHMAO - Yugra

Phenological indicators	Average dates of occurrence of a phenological phenomenon				
	Berezovsky habitat management area (1997-2013)	«Vogulka» habitat management area (1997-2012)	«Untorsky» habitat management area (2002-2013)	Yugansky nature reserve (1988-2013)	Nizhnevartovsk (2007-2019)
The geographical coordinates of the observation points	64° 10' N.L. 65° 38' E.L.	63° 52' N.L. 64° 15' E.L.	62 36' N.L. 65 5' E.L..	59°39' N.L. 74°37' E.L.	60°57' N.L. 76°32' E.L.
The appearance of thawing on the southern slopes	18.04	18.04	16.04	14.03	29.02
Loss of snow cover in the dark coniferous forest	20.05	19.05	15.05	07.05	06.05
The onset of sap ascent of the birch trees	11.05	08.05	20.04	20.04	02.05
Full unfolding of leaves at the birch trees	30.05	27.05	20.05	14.05	01.06
Full bird cherry trees blossom	11.06	08.06	04.06	29.05	06.06
The onset of raspberry blossom	22.06	20.06	17.06	18.06	16.06
Rosehip blossom	20.06	22.06	18.06	16.06	18.06
Appearance of yellow strands on birch trees	07.08	08.08	20.08	13.08	22.08
Complete yellowing leaves of birch trees	24.08	23.08	12.09	09.09	23.09
Complete exposure of birch trees	24.09	23.09	03.10	18.10	08.10
The first snow flies through the air	30.09	30.09	28.09	30.09	26.09
The formation of constant snow cover	21.10	21.10	23.10	25.10	26.10

Results of the analysis of a number of long-term phenological data, it is established that in the spring season there is a trend of earlier start of phenological events on the territories of the habitat management areas Berezovsky, «Vogulka» and the city of Nizhnevartovsk,. The summer season is characterized by a trend of early start over the analyzed period of time on the territory of the habitat management areas Berezovsky, «Vogulka», Yugansky nature reserve and the city of Nizhnevartovsk. It is clearly expressed in certain years, cooling in the spring and summer periods and warming in the autumn and winter seasons in the territory of the city of Nizhnevartovsk affected the phenological processes (table 7).

There is a trend for the first signs of spring to appear earlier on the territory of the city of Nizhnevartovsk. The end of the pre-vegetation sub-season, determined by the loss of snow cover, for 2007-2019 in the vicinity of Nizhnevartovsk, tends to occur at a somewhat early date. Many of the observed phenological phenomena show a distinct reaction (early start) to the warming of the spring periods in 2009, 2011, 2012 and 2017. After overcoming the primary phenological stages, there is a return of cold weather and weather conditions deterioration. For example, in the city of Nizhnevartovsk the full unfolding of leaves on birch trees, the full blossom of bird cherry trees in some years is observed relatively late in 2010, 2014.

The timing of the autumn phenological season dominance in the taiga zone of the KHMAO-Yugra is diverse in a long-term record. Depending on meteorological conditions and the nature of changing weather types, autumn on the territory of KHMAO - Yugra may start relatively sooner or end later. In 2010, when there was a cold snap, there was an unfavorable weather situation throughout the district, which led to the early onset of signs of the autumn season. In some years, the duration of autumn is reduced due to the early establishment of permanent snow cover-a phenological indicator of the beginning of winter. During the study period in the taiga zone of the Khanty-Mansiysk Autonomous Okrug - Ugra, the most clearly observed shift in the timing of the onset of phenological phenomena in the autumn period in the direction of delay.

During the studied long-term period, the establishment of permanent snow cover in some years in Nizhnevartovsk occurred much later than the average long-term period – at the beginning and in the second half of November (2008, 2010 and 2013) [Kuznetsova V.P., 2016]. The observed warming processes in the autumn and winter seasons are also manifested in the delay in the formation of ice on rivers and lakes, the occurrence of thaws, precipitation in the form of rain in winter. Long-term periods of snow cover formation on the territory of the Berezovsky habitat management area, the «Vogulka» habitat management area and the Untorsky habitat management area are characterized by a positive trend (table 7).

Table 7. Identified features of the taiga zone phenological processes

Season	**Phenological indicators**	**Trends in the timing of phenological seasons**				
		Berezovsky habitat management area (1997-2013)	**«Vogulka» habitat management area (1997-2012)**	**Untorsky habitat management area (2002-2013)**	**Yugansky nature reserve (1988-2013)**	**Nizhnevartovsk (2007-2019)**
SPRING	The appearance of thawing on the southern slopes	early onset	early onset	no definite trend	late onset	early onset
	Loss of snow cover in the dark coniferous forest	no definite trend	no definite trend	early onset	late onset	early onset
	The onset of sap ascent of the birch trees	late onset	late onset	early onset	early onset	no definite trend
	Full unfolding of leaves at the birch trees	late onset	early onset	early onset	late onset	no definite trend
	Full bird cherry trees blossom	early onset	late onset	early onset	no definite trend	early onset
SUMMER	The onset of raspberry blossom	early onset	early onset	no definite trend	early onset	early onset
	Rosehip blossom	early onset	early onset	no definite trend	early onset	early onset
AUTUMN	Appearance of yellow strands on birch trees	early onset	early onset	late onset	late onset	late onset
	Complete yellowing leaves of birch trees	late onset	late onset	late onset	late onset	late onset
	Complete exposure of birch trees	late onset	late onset	late onset	late onset	no definite trend
	The first snow flies through the air	late onset	late onset	early onset	early onset	late onset
WINTER	The The formation of constant snow cover	late onset	late onset	late onset	no definite trend	no definite trend

early onset — no definite trend (smooth running) — late onset

We have established differences in the duration of the seasons between explored points, which can be explained by the physical and geographical features of a particular area in the taiga zone. In particular, for the city of Nizhnevartovsk and its vicinities located in the Eastern part of the district, the spring season is characterized by the longest duration, compared to other studied areas. In the vicinity of Nizhnevartovsk, the longest spring season (139 days) was observed in 2011, and the shortest (86 days) – in 2007. Thus, the average duration of spring in the East of the district is 107 days. As in the entire region, the summer period is the shortest and, in the vicinity of Nizhnevartovsk, lasts on average 66 days. The average duration of phenological autumn is about 65 days. In 2014, the short phenological autumn season was only 38 days (Fig. 3).

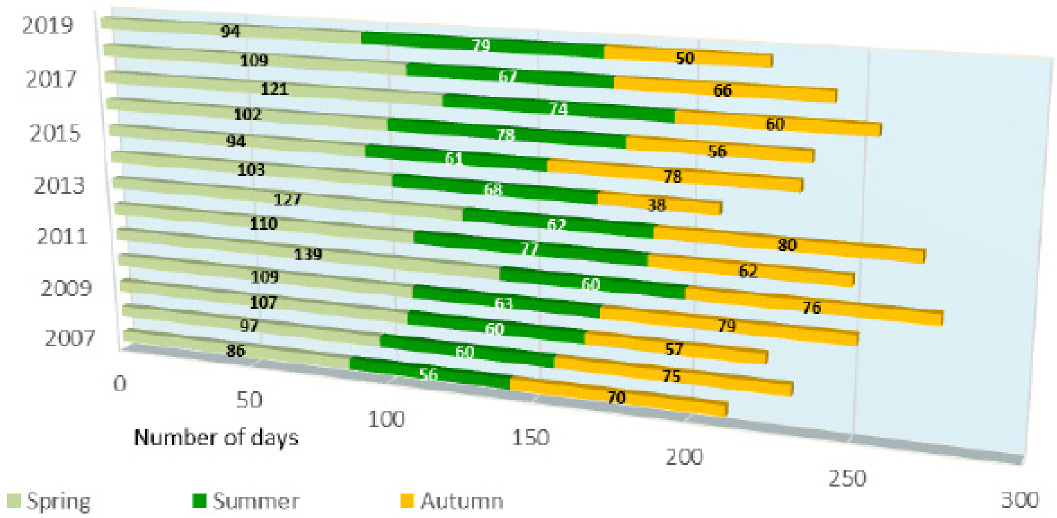

Fig. 3 Duration (in days) of the spring, summer and autumn phenological seasons in the city of Nizhnevartovsk and its vicinity for the period 2007-2019.

The average duration of the winter phenological season for 2007-2019, in the vicinity of Nizhnevartovsk is only 123 days, including the very first signs of loss of snow cover (for example, in January 2011 and in February 2012, 2013). Since in an urbanized environment, phenological phenomena of the initial stage of the spring season are observed earlier in some years (table 8).

Table 8. Characteristics of the average long-term duration of phenological seasons for certain periods of observations on the territory of the taiga zone of the KHMAO - Yugra

Location	Average long-term number of days of phenological seasons				Observation period
	Spring	Summer	Autumn	Winter	
Berezovsky habitat management area	63	48	75	179	17 years (1997-2013)
«Vogulka» habitat management area	63	49	75	180	16 years (1997-2012)
Untorsky habitat management area	63	63	65	176	12 years (2002-2013)
Yugansky nature reserve	93	57	74	140	26 years (1988-2013)
Nizhnevartovsk	107	66	65	123	13 years (2007-2019)

For the period from 2007 to 2019, the territory of the city of Nizhnevartovsk and its vicinity is characterized by an increase in the duration of the spring period, compared to the average long-term value: in 2010 (+ 2 days), in 2011 (+ 32 days), 2012 (+ 3 days), 2013 (+ 20 days), in 2017 (+ 14 days) and in 2018 (+2 days). There is also a steady trend of increasing the period of the summer season, exceeding the long-term average, especially in 2012 (+11 days), 2016 (+12 days), 2017. (+ 8 days) and in 2019 (+ 13 days). The autumn season has a tendency to decrease in duration, as evidenced by a negative linear trend (Fig. 4).

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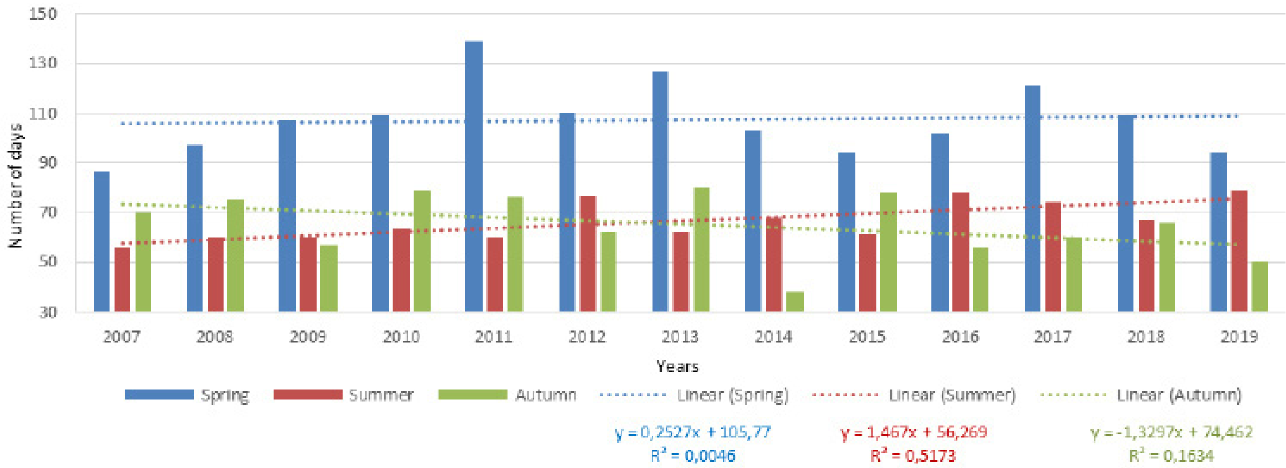


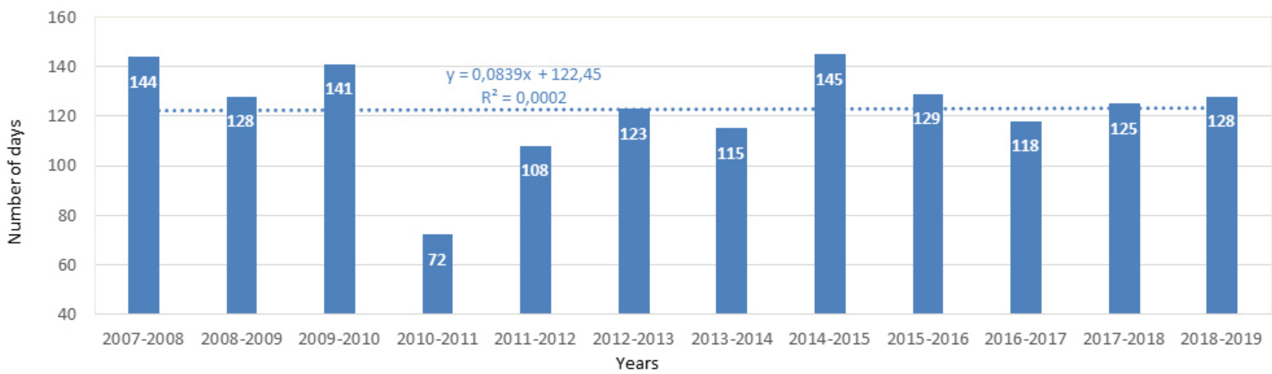
Number of days Spring Summer Autumn Linear trend (Spring) Linear trend (Summer) Linear trend (Autumn)

Analysis of the accuracy of determining values of the trend equation parameters

Nizhnevartovsk	Statistical significance (at a significance level of 0,05)	
	coefficient a	coefficient b
Spring	is not confirmed	confirmed
Summer	confirmed	confirmed
Autumn	s not confirmed	confirmed

Fig. 4 Duration (in days) of spring, summer and autumn phenological seasons in the city of Nizhnevartovsk and its vicinity for 2007-2019.

The timing of the start of phenological events, there is a decrease in the duration of winter on the territory of Berezovsky habitat management area (trend is not statistically significant), «Vogulka» habitat management area (trend is not statistically significant) and Untorsky habitat management area (trend is statistically significant). The territory of the Yugansky reserve is characterized by an increase in the winter period for 1988-2013 (the trend is statistically significant). For the city of Nizhnevartovsk and its vicinities, the average long-term duration of phenological winter days is characterized by the absence of a distinct reduction or increase. For 2007-2019 on the territory of Nizhnevartovsk and its vicinities revealed a smooth course of the duration of the winter period. The winter seasons of 2007-2008, 2009-2010, and especially 2014-2015 were the longest (Fig. 5).



Analysis of the accuracy of determining values of the trend equation parameters

Nizhnevartovsk	Statistical significance (at a significance level of 0,05)	
	coefficient a	coefficient b
Winter	not confirmed	confirmed

Fig. 5 Duration (days) of the winter phenological season in the city of Nizhnevartovsk and its vicinities for 2007-2019.

CONCLUSIONS

A distinct reaction of the natural environment to modern climate processes is evident in the Northern regions, which include the territory of the Khanty-Mansiysk Autonomous Okrug-Yugra, located in the taiga zone of the Central part of the West Siberian plain.

The conducted research allowed us to formulate some conclusions:

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