The temperature characteristics of biological active period of the peat soils of Bakchar swamp

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Abstract. The results of the study of the peculiarities of the temperature regime in the five basic ecosystems of oligotrophic bogs in the south taiga zone of Western Siberia in 2011-2016 are presented. The soil temperature regime was studied using the atmospheric-soil measuring complex at different depths from surface to 240 cm. All sites were divided into two groups according the bog water level: flooded sites (hollow and open fen) and drained sites (ridge, tall and low ryam). Waterlogged sites are better warmed in the summer period, and slowly freeze in the winter period. The analysis of the annual cycle of temperature showed that the maximum surface temperature is observed in July. The minimum temperature on the surface observed in February or January. The greatest temperature gradient was recorded in the upper 2 cm layer. The gradient at the open fen was -2 °C·cm⁻¹ in February and 1.1 °C·cm⁻¹ in October. The peak of formation of the seasonally frozen layer occurs at the end of autumn, beginning of winter. The degradation of the seasonally frozen layer was observed both from top and bottom, but degradation from the top is faster.

1. Introduction

Bog complexes occupy a small area of 3-5% of the land surface, but play a significant role in regulating the gaseous composition of the atmosphere, the water balance of the biosphere, biological diversity on Earth [1, 2].

Thermal and water regimes of peat and mineral soils were significantly different. Peat accumulation is a complex organic system, which has specific properties: high water content and porosity, content of a large number of little decomposed organic matter [3, 4].

The temperature of peat soils affects the growth of ground vegetation (mosses, shrubs, etc.), the formation of climate of the territory is a key factor in controlling many biotic and abiotic processes that occur in soils: decomposition and mineralization of soil organic matter, emissions of greenhouse gases (CO₂, CH₄, N₂O), excretion of dissolved organic carbon [5-10].

In Western Siberia are located the main storages of peat. Peatland ecosystems of West Siberia contain up to 70 billion tons of carbon [11]. Such a large reservoir potentially may go into the atmosphere as CO₂ or CH₄ as the result of climate change or anthropogenic impacts and make a significant contribution to the carbon balance of the atmosphere.
2. Methods
Studies of the temperature regime of soils was carried out in the geophysical field station "the Vasyuganje" Institute of monitoring of climatic and ecological systems SB RAS, at the Bakhcharskoe bog (area of about 1400 km²), located in the interfluves of the rivers Iksa and Bakchar in Bakchasky district of Tomsk region [12].

For the study we used 5 sites with different levels of bog waters (LBW), which were divided into two groups. Flooded areas – hollow on the ridge-hollow complex (RHC), Osaka-sphagnum bog (mean level of bog water 5 cm). Low-water sites – pine-dwarf shrub sphagnum phytocenosis with a normal forest is 18 m (high ryam) and oppressed the stand is 2-3 m (low ryam), the range on the MMC (mean level of bog water 25 cm) [13].

In the study sites for studying temperature regime was measured the soil temperature at 14 depths from the surface peat soil up to 320 cm and air temperature at a height of 2 m, using atmospheric and soil measuring complex [14]. The measurements were carried out in the period 1 April 2011 to 30 April 2016 (1858 days) with a time step of 15 minutes.

3. Results and discussions
Analysis of annual temperature of peat soil in the profile 0-240 cm can identify a number of differences between the observation sites. Despite the fact that the sites are located in the 300-1000 m from each other, density and moisture content of the peat at the sites varies little, all sites can be divided into two groups. Sites of the first group during the warm period are warmed up better than sites of the second group. The first group includes sites with water level located at 3-7 cm from the surface (hollow at RHC and open fen). Water level at the sites from the second group (tall and low ryam, ridge at RHC) decreases to 20-30 cm in the end of summer. While maximum annual surface temperature in July at hollow and open fen was 18.1 and 17.4 °C, respectively; for low ryam, tall ryam and ridge of RHC it was 17.3, 14.1 and 17.7 °C, respectively.

The soil temperature in the warm period is associated not only with the bog water table level, but also with the characteristics of the vegetation cover [7]. Low and tall ryams in the upper 60 cm layer have a lower temperature than the ridge at RHC, where the wood layer is very tenuous. Ryams due to the dense vegetation cover receive less solar radiation, and in conjunction with a low level of bog waters become colder than ridge at RHC.

During the study period, maximum average daily temperature was noted in the top 20 cm layer in 2012 due to the anomaly hot weather in June. The soil temperature ranged from 23.5 (ridge at RHC) to 24.9 °C (low ryam) on the surface and from 16.2 (tall ryam) to 19.5 °C (open fen) at a depth of 20 cm. Deeper than 30 cm the maximum temperature of the peat deposits ranged from 12.6 (low ryam) to 16.9 °C (open fen) at 40 cm and 5.5 (low ryam) to 7.9 °C (open fen) at 240 cm, respectively. The maximum temperature of the upper layers (0-60 cm) is strongly influenced by the air temperature and the features of the peat deposits (peat density, water content, vegetation cover, etc.).

The temperature gradient in the soil has the highest variations in layer 0-2 cm. Its value changes from -2.0 °C·cm⁻¹ in February 2012 to 1.1 °C·cm⁻¹ in October 2014 at the open fen, and from -1.1°C·cm⁻¹ in October 2012 to 0.8 °C·cm⁻¹ in July 2012 at tall ryam. In the warm period the greatest fluctuations in soil temperature gradient was observed in the layer 2-60 cm. In July they vary in the range from 0.05 °C·cm⁻¹ in open areas (open fen, hollow at RHC) to 0.33-0.36 °C·cm⁻¹ in the forested bogs (tall and low ryam). The value of the gradient decreases with increasing depth. At 240 cm depth the value of gradient at all sites over the entire observation period does not exceed 0.1 °C·cm⁻¹. In the cold period, the greatest fluctuations of temperature gradients in the soil are observed in the layer 2-40 cm. In February, they vary from -0.01 °C·cm⁻¹ in open areas (open fen, hollow at RHC) to 0.15-0.21 °C·cm⁻¹ for forested bogs (ridge at RHC, tall and low ryams).

During the propagation of thermal wave from the surface into the soil there is a lag of this wave. The timing of the maximum temperature depends not only on the type of site (open, forested), but also on weather conditions of a particular year [1]. The lag of the daily average temperature wave in the layer 0-15 cm is almost absent. In some cases, the maximum temperature in the layer of 0-5 cm can be
recorded later than in the underlying layer. The greatest variation in the lag of the temperature wave is observed at depths of 20-80 cm and varies from 0 to 50 days. With increasing depth there is slowing of the propagation of a thermal wave and at a depth of 240 cm the maximum is reached on average in 100 days. With increasing depth in addition to the lag in occurrence of maxima decreases the maximum temperature itself. On the surface it is an average of 24-27 °C and at a depth of 240 cm – 5-8 °C, depending on the site.

To estimate biologically active period for the flora and fauna of a peat deposit was identified periods with temperatures above 10 °C. The biologically active period was defined as a time when the peat provides a maximum activity of bacteria, growth of vegetation (mosses, sedges, shrubs) [15]. The activity of the bacteria increases the rate of decomposition of organic materials within the peat, which leads to some increase in the formation of carbon dioxide and methane in peat deposits and higher emissions.

| Hollow | T, °C |
|--------|-------|
| 0      | 0     |
| 100    | 100   |
| 200    | 200   |

| Open Fen |
|----------|
| Depth, cm |
| 0        |
| 100      |
| 200      |

| Low Ryam |
|----------|
| Depth, cm |
| 0        |
| 100      |
| 200      |

| High Ryam |
|-----------|
| Depth, cm |
| 0        |
| 100      |
| 200      |

| Ridge |
|-------|
| Depth, cm |
| 0        |
| 100      |
| 200      |

**Figure 1.** Distribution of daily average soil temperature in the studied peat deposits.

The duration of the frost-free period (temperature above 0 °C) at the studied sites varies at depths ranging from surface to 60-80 cm (figure 1). The temperature of the deeper peat layers is always positive. The average duration of the frost-free period for all sites is 180-230 days throughout the whole peat column. The transition of soil temperature above 0 °C in the direction to positive temperatures occurs in April – May on the surface and with increasing depth shifts towards the summer months. At 40-80 cm the transition to the frost-free period occurs in June – July. Transition into the negative temperature occurs in October-November on the surface and with depth shifted to December-January.
The depth where the biological active period was observed varies from 60 cm at forested sites (high and low ryam, ridge at RHC) up to 120 cm at open areas (hollow at RHC and open fen). The duration of the biological active period is less than frost-free period by 2-3 times. On open sites at surface and depth up to 60 cm the duration is 110-120 days, deeper (to 120 cm) – 85-95 days. At the same time in 2014 at the open fen and in 2013 at hollow the duration of the biologically active period in the top 120 cm layer was about the same – an average of 90 days, the reason for that was the slow warming of peat deposits at the beginning of the warm period.

At low-water sites at depths from 15 cm the average length of biologically active period was 85-90 days, at 20-60 cm depth – 70-75 days. It should be noted that in some years the duration of this period at depths of 40-60 cm can be reduced to 40-50 days.

On flooded sites, the transition temperature of the peat deposit from +10 °C to higher temperatures is observed mainly in May and June at depths from the surface to 80 cm, deeper than 80 cm - in July. The end of biologically active period at these sites is mainly observed in September and early October at depths and deeper than 80 cm in October. On low-water sites the biologically active period is shorter and occurs from June to September at depths of 0-40 cm and deeper than 40 cm from July to end of August – beginning of September.

The sum of active temperatures (above 10 °C) on low-water sites changes from 2000 to 1500 °C in the layer 0-20 cm, and then it decreases with depth up to 800 °C for 60 cm. Flooded sites are warmed up better and the sum of active temperatures on them varies from 2500 to 1900 °C in the layer of 0-20 cm, then it decreases to 1000-500 °C at a depth of 80-120 cm, respectively.

4. Conclusions
The sites with high water level (hollow at RHC, open fen) are warm up better in the summer period and have a higher temperature on the surface than at forested bog sites with lowered water level (ridge at RHC, high and tall ryam). While maximum annual surface temperature in July on hollow and open fen it is 18.1 and 17.4 °C, respectively; for low ryam, tall ryam and ridge of RHC it was 17.3, 14.1 and 17.7 °C, respectively. The full heating of the peat deposits at depths of 2 m is ending in October due to large lag in the heat wave propagation.

The start of warm period is a march on surface and August-September on 60 cm warm period for all sites is 180-230 days throughout the peat column. The biological active period have maximum depth 120 cm for flooded sites and 80 cm for low-water sites with different duration. Duration on that period more on flooded sites – average 110-120 days from 0 to 60 cm and about 90 deeper. The sum of active temperature more too on flooded sites and ii more about 500-300 °C.

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