IOP Conference Series: Earth and Environmental Science

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To cite this article: M V Kiselev *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **138** 012006

Features of seasonal temperature variations in peat soils of oligotrophic bogs in south taiga of Western Siberia

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Abstract. The work presents 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. The soil temperature regime was studied using the atmospheric-soil measuring complex at different depths from surface down to 240 cm. All sites were divided into two groups according to the bog water level: flooded sites (hollow and open fen) and drained sites (ridge, tall and low ryam). The 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 in July. The minimum temperature on the surface is 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 in February and 1.1 °C/cm in October. The peak of formation of the seasonally frozen layer occurs at the end of autumn or in the beginning of winter. The degradation of the seasonally frozen layer was observed both from top and bottom, but the degradation rate from the top is faster.

1. Introduction

The mires are unique natural landscapes involved in the regulation of the gaseous composition of the atmosphere, the water balance of the biosphere, biological diversity of the Earth [1, 2]. The soil temperature affects the growth of ground vegetation (mosses, sedges, shrubs, etc.). The soil microclimate is a key factor controlling many biotic and abiotic processes in the peat soils: decomposition and mineralization of soil organic matter [3], emissions of greenhouse gases (CO_2, CH_4, N_2O) [4], excretion of dissolved organic carbon [2].

The thermal regimes of peat and mineral soils are significantly different. Peat deposit is a complex organic system, which has specific properties: high water content and porosity composed of a large number of weakly decomposed organic matter [12]. The main storages of peat are located in Western Siberia. The 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.

The investigation of thermal regime of peat soils in the background of the global warming observed throughout the entire territory of Russia [9] is a vital scientific task. The purpose of this study is the analysis of soil temperature regime of typical bog ecosystems in the South Taiga of Western Siberia based on results of long-term monitoring.

2. Methods

The research of the temperature regime of soils was carried out in the geophysical scientific field station "Vasyuganje" at the Bakcharskoe bog (area of about 1400 km^2) [6, 10], located in the interfluves of the rivers Iksa and Bakchar in Bakcharsky district of Tomsk region, Russia [7]. Four typical bog ecosystems were chosen for soil temperature monitoring: pine-shrub-sphagnum ecosystem with trees height about 18 m (tall ryam), ryam with oppressed tree stand 2-3 m (low ryam), open sedge-sphagnum fen and ridge-hollow complex (RHC). The observation sites at RHC were organized both at oligotrophic ridge and sheizeria-sphagnum hollow [2].

The measurements of soil temperature were performed at several depths from surface to 240 cm (0, 2, 5, 10, 15, 20, 30, 40, 60, 80, 120, 160, 240 cm), and the air temperature was measured at a height of 2 m using the atmospheric-soil measuring complex [8]. The measurements were carried out from 1 April 2011 till 30 April 2016 (during 1858 days) with a time step of 15 minutes. The data on snow depth and air temperature from the nearest weather station "Bakchar" were derived from the archive (http://www.meteo.ru/).

The depth of peat freezeing was determined by the penetration depth of 0 °C temperature into the ground [5]. The depth of freezing was calculated by linear interpolation of the soil temperatures between two adjacent layers, providing that the temperature in one of the layers was negative.

3. Results and discussions

The 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 located in the 300-1000 m from each other, and that the density and moisture content of the peat at the sites varies little, all sites may be divided in two groups. The sites of the first group warmed up better during the warm period than the 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). The water level at sites from the second group (tall and low ryam, ridge at RHC) decreases to 20-30 cm in the end of summer. While the maximum annual surface temperature in July on 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 level, but also with the characteristics of the vegetation cover [6]. 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.

In winter, the ridge at RHC is the coolest site, because the thickness of the snow cover is less than at ryams, where shrubs and trees linger the snow. A hollow at RHC and an open fen in winter even with small snow depth is warmer than a ridge at RHC, as high level of bog water prevents the rapid cooling of the peat deposit. These features affect the time of occurrence of minimum temperatures. In most areas the minimum temperatures on the surface are observed in February (-0.8, -1.7, -2.4 and -2.5 °C for a hollow at RHC, an open fen, low and tall ryam, respectively), and on ridge at RHC the minimum temperature (-5.2 °C) is observed in January (figure 1).

During the study period, the maximum average daily temperature was noted in the top 20 cm layer in 2012 due to the anomaly hot 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 the depth of 20 cm. Deeper than 30 cm the maximum temperature of the peat deposits ranged between 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) strongly influenced the air temperature and the features of the peat deposits (peat density, water content, vegetation cover, etc.).

The minimum average daily temperature was noted in the upper 20 layer and it raised from -9.5 to 2.3 °C from the surface to 20 cm, respectively. This distribution was observed due to several factors: formation of a stable snow cover, snow depth and bog water level. For example, in 2015, due to severe frosts in early November, the temperature in the layer 0-20 cm at tall ryam was lower by 3 °C than in the same period in 2012. The greatest frost penetration was observed at tall ryam in 2012, when the soil temperature at 60 cm depth was -0.2 °C as the height of the snow during the winter varied from 0.9 cm in October 2012 to 23.5 cm in March 2013. The snow depth in 2015 varied from 2.8 cm in October 2015 to 96.2 cm in March 2016 and even when strong frosts in December 2015 did not allow to freeze peat deposit for more than 30 cm depth.

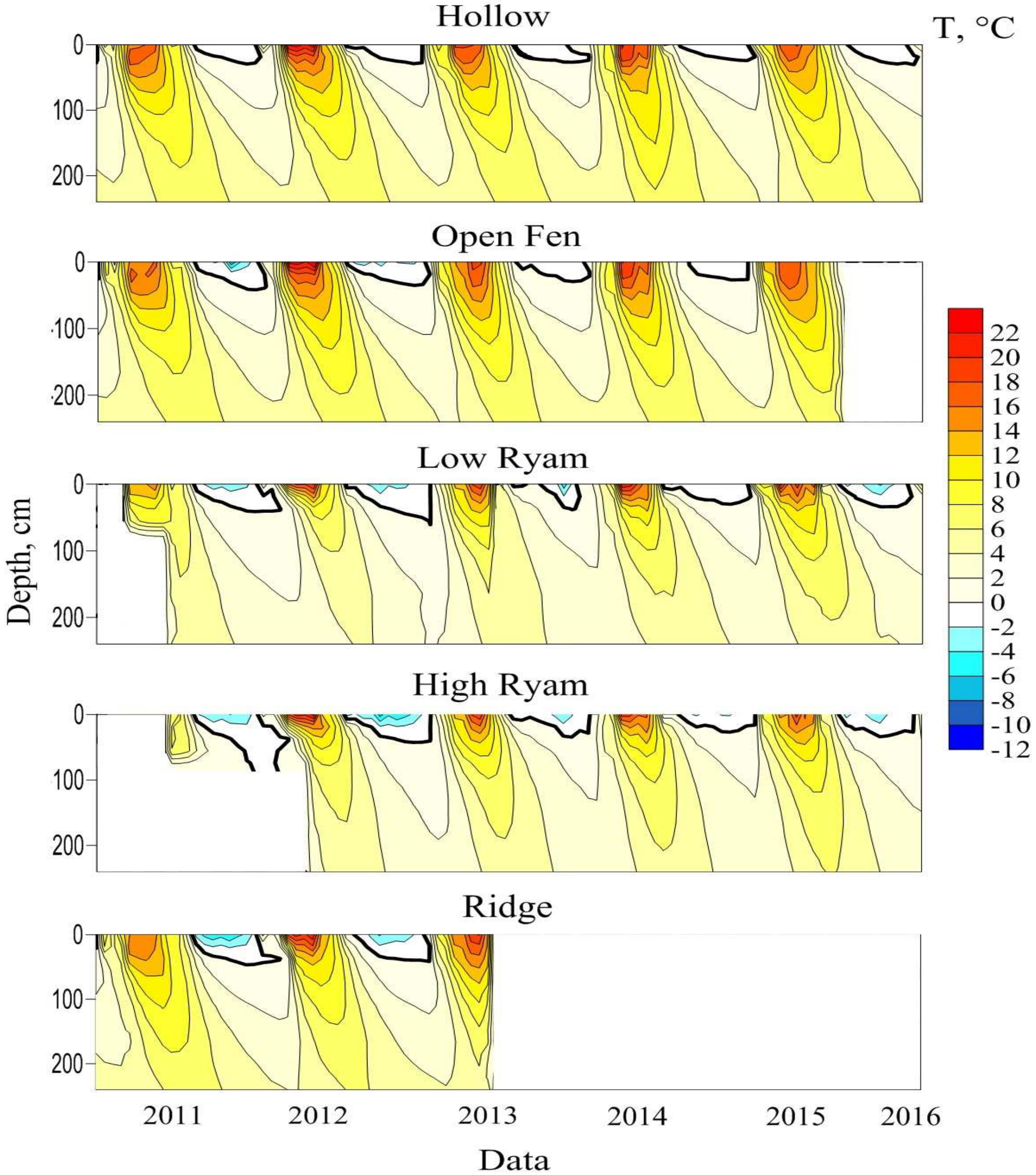

Figure 1. Distribution of daily average soil temperature in the studied peat deposits.

The temperature gradient in the soil has the highest variations in the layer 0-2 cm. Its value changes from -2.0 °C/cm in February 2012 to 1.1 °C/cm in October 2014 at the open fen, and from -1.1 °C/cm in October 2012 to 0.8 °C/cm in July 2012 at tall ryam. In the warm period the greatest fluctuations in the soil temperature gradient was observed in the layer 2-60 cm. In July they varied in the range from 0.05 °C/cm in open areas (open fen, hollow at RHC) to 0.33-0.36 °C/cm in the forested bogs (tall and low ryam). The value of the gradient is decreasing with depth increase. At 240 cm depth the value of gradient at all sites over the entire observation period does not exceed 0.1 °C/cm. In the cold period, the greatest fluctuations of temperature gradients in the soil were observed in the layer 2-40 cm. In February, they varied from -0.01 °C/cm in open areas (open fen, hollow at RHC) to 0.15-0.21 °C/cm 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. figure 2 shows the lag time of occurrence of maximum daily average temperature at different depths for 2011, 2013 and 2015. Timing of the maximum temperature depends not only on the type of site (open, forested), but also on weather conditions of a particular year. The lag of the daily averaged 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 the depth increase there is a slowdown in the propagation of a thermal wave and at the depth of 240 cm the maximum is reached on average after 100 days. On the surface, the average is 24-27 °C and it is 5-8 °C at the depth of 240 cm depending on site.

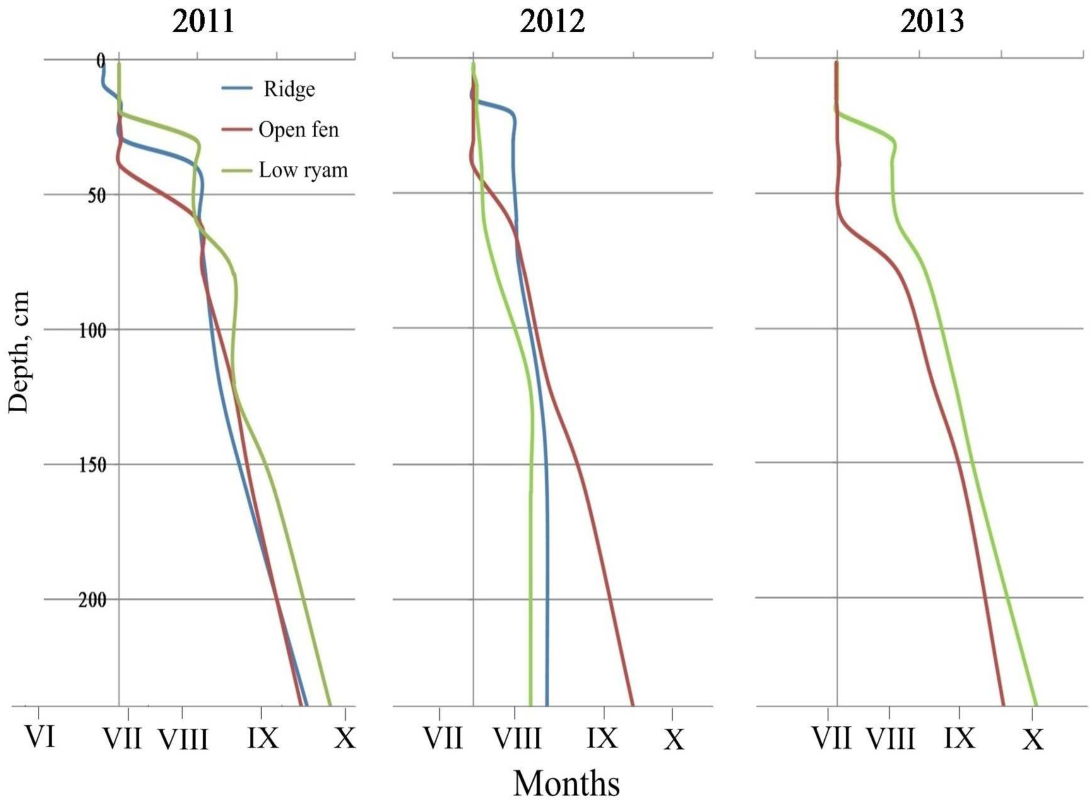

Figure 2. Time of occurrence of maximum daily average soil temperature at different depths for ridge at RHC, open fen and low ryam.

In the cold period, the particular importance in the penetration of the temperature wave and the delay of occurrence of minima with depth will play year-round warm lower part of the peat deposit. The layer below 60 cm act as a "battery" of heat, which slows down the process when the soil is freezing. The snow cover reduces the amplitude of temperature fluctuations on the surface and influences the maximum depth of penetration of negative temperatures into the peat deposit [5].

The minimum temperature in the layer 0-30 cm is observed at the beginning of the cold period when the snow cover is minimal or absent. Therefore, in this layer the lag of the temperature wave is not large and ranges from several days to weeks. Increasing the height of snow cover leads to a slowing of thermal wave and a significant increase in the delay of the minima at depths below 60 cm.

The formation of a seasonally frozen layer starts in October-November at all sites. In these months in the South Taiga zone of Western Siberia there is a decrease in the air temperature and precipitation

IOP Conf. Series: Earth and Environmental Science **138** (2018) 012006 doi:10.1088/1755-1315/138/1/012006

in the form of snow, which in the subsequent period, forms a steady snow cover [5]. A further lowering of air temperature leads to the formation of the seasonally frozen layer at the depths of 40-60 cm in February-March. In the same period, the maximum freezing depth of peat deposits is reached (table 1).

Table 1. Maximum depth of freezing of the peat deposit (cm) and their dates.

Sites	Data				
	2012	2013	2014	2015	2016
Hollow RHC	16 March	14 April	3 April	16 April	9 April
	33.1	39.1	28.4	27.1	33.1
Open fen	18 April	21 April	4 April	15 April	–
	44.1	36.1	33.9	32.4	–
Low ryam	18 March	15 April	25 February	10 March	10 March
	40.2	51.8	38.6	31.4	36.2
Tall ryam	12 April	28 March	3 March	19 April	2 February
	61.4	42.5	35.0	32.6	35.1
Ridge RHC	13 March	9 April	–	–	–
	48.7	41.8	–	–	–

The maximum duration of the existence of seasonally frozen layer was observed in the layer of 0-15 cm and the average is 140-160 days, the lowest duration was at the depths below 40 cm and the lowest average was of 80 days. Peat soil freezing proceeds with a rate of 0.2-0.3 cm/day on average from the surface up to the maximum depth. The maximum recorded rate of freezing of 0.51 cm/day was observed in 2012 at tall ryam.

Thus if we split the rate of freezing into two parts, freezing is more intense in the layer 0-20 cm than in the layer from 20 cm to the maximum depth of frost penetration. The rate of freezing from the surface to 20 cm is 0.6-0.7 cm/day on average. But the maximum freezing rate may vary considerably, for example, in 2011 it reached 1.43 cm/day on the ridge, and in 2015 it was 1.67 cm/day in tall ryam. The freezing rate is higher in forested bogs than in open areas. The average freezing rate is 0.21 cm/day in the layer below 20 cm. The maximum rate (0.81 cm/day) was observed in 2014.

The degradation of the seasonally frozen layer starts both from the top and from the bottom. This contributes to a relatively warm ice-free peat deposit, which is below the seasonally frozen layer. Since mid-to late winter the snow depth is significant, the effect of the negative temperatures of the air for maintaining low temperatures of the seasonally frozen layer is weakened and the process of thawing peat thickness starts from bottom. However, the rate of thawing of seasonally frozen layer is very slow from the bottom at the initial stage and its destruction proceeds faster from the top. Thus, the most significant degradation of the seasonally frozen layer occurs from the top. To estimate the rate of thawing, we use the period of thawing start, which coincides with the stable transition of soil temperature above 0 °C. The rate of peat thawing from the top varies from 1 to 5 cm/day to 30-35 cm/day. In addition to the thawing rate increase from the top, the thawing rate from the bottom also slightly increases and varies from 0.3 to 0.5 cm/day.

4. Conclusions

The sites with high water level (hollow at RHC, open fen) warm up better in the summer period and have a higher temperature on the surface in comparison with forested bog sites with lowered water level (ridge at RHC, high and tall ryam). In the cold period, open bogs remain warmer than the forested sites. Warming of the peat deposits at depths of 2 m stops in October due to large lag in the

IOP Conf. Series: Earth and Environmental Science **138** (2018) 012006 doi:10.1088/1755-1315/138/1/012006

heat wave propagation. The maximum depth of freezing was observed in the tall ryam (61.4 cm) in January 2012, and the greatest duration of existence of the seasonally frozen layer was 195 days.

The rate of soil freezing from the surface to the maximum depth of freezing varies from 0.2 to 0.3 cm/day on average. The degradation of the seasonally frozen layer proceeds simultaneously both from the top and from the bottom. The rate of degradation of the seasonally frozen layer on top exceeds significantly the rate of freezing, and it ranges from 1 to 5 cm/day to the complete disappearance of the frozen layer. The rate of degradation of the bottom is smaller and it varies from 0.3 to 0.5 cm/day.

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