Influence of anthropogenic activities on the temperature regime of soils of the South-Western Baikal region

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Abstract. Soil temperature is a key factor controlling many biotic and abiotic processes in soils. Monitoring of the soil temperature in the different habitats is an urgent task, as a rare meteorological network does not allow to assess in detail the hydrothermal regime of different territories. The territory of the study is the Tunka intermountain basin – the area of discontinuous distribution of permafrost. The atmospheric-soil measuring complex was used to investigate the hydrothermal regime of soils. Observations were carried out in automatic mode with a step of 1 hour from 2011 to 2018 year in the soil profiles from the surface to 10 m depth. The studied areas at different times undergo various anthropogenic impacts. It leads to changes in the vegetation cover, morphology structure and granulometric composition of the soils, its temperature and moisture conditions. Thus, the soils at anthropogenically disturbed sites are better warmed up and cools down faster than on undisturbed areas. The depth of the isotherm of +10°C on average is more than 50 cm deep on anthropogenically disturbed areas and the greatest negative temperatures are observed here. The depth of freezing and the magnitude of negative temperatures are directly related to the level of mire waters in the peaty soils. If the water level of the mire increases, as a result of human intervention, the depth of thawing decreased by 20 cm and the winter peat deposit became warmer.

1. Introduction

The climate of the soil is commonly understood as a long-term regime of temperature, humidity and air content of the soil, which has a cyclic course (daily, annual, century) and depends on natural and anthropogenic factors. Temperature is a key factor controlling many biotic and abiotic processes occurring in soils [1]. The environmental conditions for the formation of soil climate include: atmospheric climate, altitude, topography and exposure of slopes, geological structure, vegetation and snow cover, groundwater level, proximity (neighborhood) of rivers and water reservoirs, etc. Anthropogenic factors are the destruction of forests, plowing, construction of irrigation or drainage systems, laying of roads, pipelines and other infrastructure, etc. [2, 3].

In recent decades one of the most important scientific issues is the global warming [4-6], which leads to a change in the temperature regime of soils and the degradation of permafrost thickness [7], the change of plant associations, and, as a consequence, a change in landscape appearance as a whole. In this regard, assessing the response of soils to climate change is an important task [8, 9].
2. Objects, data and methods

2.1. Study area
The study of soil temperature regimes in conditionally undisturbed and anthropogenically transformed landscapes was carried out on the territory of the Tunka depression (South-Western Baikal Region). It is part of the system of intermountain depressions of the Eastern Sayan mountains and is a Cenozoic dry depression. Length of the depression is about 65 km, width – 25 km. The boundaries of the basin were drawn along a steepness of 10 degrees [10]. The absolute height of the surrounding mountains – 2000-3200 m, the interval of absolute heights of the bottom – 700 – 900 m. In the north part, the Tunkinskoe Goltsy ridge drops steeply down to the depression. From the south, the basin is limited by the massive plateau-like Khamar-Daban ridge. The accumulative part of the Tunka depression is composed by Cenozoic sedimentary complex, characterized by a variety of lithological composition, sharp facies variability and diversity of deposit genetic types [11, 12].

The main drainage river of Tunka depression is Irkut. The considerable area of the central part of the basin occupied by Koimorskie and Engarginski lake-marsh areas.

The climate of the study area is sharply continental, characterized by large amplitudes of seasonal and daily air temperature and the predominance of summer precipitation in warm but short summer and cold dry winter. The radiation balance, according to long-term data of the nearest actinometric station Ilchir is about 1340 MJ/m² [13].

The average annual air temperature according to the weather station Arshan is -1.4°C, the average monthly January temperature is -19.9°C, July +16°C. At the same time, the minimum temperatures in January fall to -42°C, the maximum in July rise to +36°C. According to long-term observations, the temperature at the station Arshan is 3-6°C higher than in the central part of the depression, in winter and 2-4°C lower in the summer months [14-16].

The annual precipitation in Tunkinskoe Goltsy ridge is minimal throughout the Eastern and Central Sayan and amounts to 350-400 mm in the depressions, in the mountains – 500-600 mm, on the slopes of Khamar-Daban ridge – up to 1000 mm. The bulk of precipitation falls in the summer during three summer months (VI-VIII) and account for up to 72%.

2.2. Sites characteristics
The study area is characterized by heterogeneity of climatic, geological, geomorphological and phytocenotic conditions, which is the cause of a wide variety of landscapes and soils. Favorable conditions for human habitation and farming determined the long history of the development of this territory, which became the reason for a significant anthropogenic transformation of its modern landscapes. The main causes of anthropogenic changes of landscapes on the territory of the Tunka depression are forest fires, deforestation and further plowing, as well as the transformation of peat soils as result of the drainage melioration in the 60-ies of the XX century with the aim of creating productive hayfields.

Based on the foregoing, in order to assess the impact of these changes on the annual dynamics of temperature, the regime of freezing and thawing of soils in the central part of the depression, three pairs of sites were laid (table 1). Each of them has a control area with undisturbed (or restored to natural) soil and vegetation cover, as well as a site in which soils and vegetation have undergone significant transformations (fire, disboscation and plowing, drainage).

The first pair of sites (table 1) is the sandy massif Badar, composed by ancient lake-alluvial deposits. This massif rises 150 m above the swampy bottom of the depression. The surface has affected by aeolian activity and there are many ridges and hollows of blowing. The control site (A27) is dedicated to the cowberry pine forest on Arenosols Protic. To study the impact of forest fires on soil temperature, the second site (A26) was placed 3 km south. In 2011 the forest was burned out and the trunks were subsequently removed with using special equipment.

The second pair of sites (table 1) placed on the sand outliers of ancient river terraces within the zone of the latest tectonic lowering. An increased level of groundwater and the presence of
discontinuous permafrost create favorable conditions for the formation of Cryosols Gleyic under spruce forests. In these conditions, the control site A38 is located. As an anthropogenic disturbed site we chose a twenty-year fallow land under community of couch-grass (A37). According to the topographic maps at the beginning of the XX century this area was occupied by pine-spruce and spruce forests, which were cut down in the 50s years, and soils were plowed. Currently, the soils are represented by Anthrosols with oxidized-gley horizon.

Table 1. Characteristics of the experimental sites.

| Site Pair | Site Number | The coefficient of disturbance of landscapes | Plant community | Soils          |
|-----------|-------------|----------------------------------------------|-----------------|----------------|
| I         | A27         | <0.3                                         | Cowberry pine forest | Arenosols Protic |
| I         | A26         | >0.5                                         | Burned-out cowberry pine forest | Arenosols Protic |
| II        | A38         | <0.3                                         | Spruce forest    | Cryosols Gleyic |
| III       | A37         | >0.5                                         | Wheat grass creeping, fallow land | Anthrosols    |
| III       | A34         | >0.3                                         | Barley-sedge peaty meadow | Histosols Sapric |
| III       | A36         | <0.5                                         | Mesotrophic sedge swamp | Histosols Sapric |

The third pair of sites (table 1) located within the swampy area of the depression. Control site (A34) located on Histosols Sapric soil under barley-sedge peaty meadow. On the second site (A36) the soil is represented the same type under the mesotrophic sedge swamp. At a distance of 50 m from the site there is arable land, on which drainage reclamation was carried out. This caused an increase in the water content of the investigated area.

2.3. Materials and methods
The measurements were performed in the period 2012-2018 with atmospheric and soil measurement system (ASMS) [17]. Soil temperature sensors devices are located on the soil surface and depths: 2, 5, 10, 15, 20, 30, 40, 50, 60, 80, 120, 160, 240, 320 cm. Temperature measurement error is ±0.1 ºC. The frequency of measurements is 1 hour.

Correlation coefficients between the depth-soil thermometers used at meteorological stations of Federal Service for Hydrometeorology and Environmental Monitoring and ASMS have high values at all depths for each month (from 90% and higher). The greatest deviations in soil temperature from ASMS observed at a depth of 20 cm (higher by 1.8-2.0°C) in the cold season. Differences in soil temperature values decrease with the transition from the cold period to the warm one. In summer at a depth of 20 cm they are minimal and average 0.5-0.8°C. With increasing depth, there is a decrease in deviations between the ASMS and the exhaust depth-soil thermometers. So at a depth of 160 cm, the soil temperature in the ASMS is more by 1.0-1.5°C in spring and summer and less by 0.1-0.3°C in autumn and winter [17].

Physical and chemical properties of soils and underlying deposits were studied by generally accepted in soil science methods [18, 19].

Processing of experimental data was carried out using the ASMS program and Microsoft Excel. The Surfer and Grapher programs were used to graphical representation of data.

The degree of landscape disturbance was assessed according to the classification proposed by A V Silaev [20]. The coefficient of anthropogenic disturbance varies from 0 to 1. The value 0 equate to absolutely unaffected by anthropogenic impact geosystems. And 1 corresponds to the maximum anthropogenic transformation (villages, roads, careers).

3. Results and discussion
The analysis of the obtained data on the I and II pairs of sites shows the degree of influence of vegetation cover on the temperature regime.
Physical and chemical characteristics of soils and underlying deposits on the A27 and A26 sites (I pair) are similar. Granulometric composition represented by cohesive sands, interspersed to a depth of 3.5 m with loose sands. Humus horizons are underdeveloped and contain a significant amount of coarse organic matter. The inclusion of charcoal along with low thickness of forest litter (up to 3 cm) indicate the frequency of recurrent fires occurring here. On the area subjected to forest fire with the complete destruction of tree and shrub vegetation (A26) thickness of litter does not exceed 1.5 cm. Destruction of the vegetation cover at the site has led to the fact that during the warm period, the soil began to warm up stronger. The maximum depth of the isotherm of +10°C on site A26 is about 170 cm while in the control site A27 under a pine forest, the maximum depth of the isotherm of +10°C in the warm period is about 95 cm.

The reduction of forest cover also causes to an increase in the depth of freezing. At the same time on the site uncovered of vegetation, there are lower negative temperatures in the 20-30 cm surface layer, compared with the control. Therefore, on the site A26 (without forest) the depth of the -2°C isotherm in the winter of 2011/12 was about 230 cm, with a minimum surface temperature of -20.0°C. At the depth of 30 cm, it was -17.4 and at the 240 cm, it was -1.7°C. While on the site A27 (pine cranberry forest) the depth of the -2°C isotherm in the winter of 2011/12 was about 195 cm, the minimum temperature of the soil on the surface amounted to -21.4°C. At the depth of 30 cm, it was -16.1 and at the 240 cm, it was -0.8°C.

On the example of the second pair of sites (A38 and A37), we estimate the change in the temperature regime of soils, due to the destruction of vegetation and the transformation of the upper part of the soil profile as a result of plowing. For its reason, at the site A37 there was the destruction of humus-coarse humus horizon and mixing of its substance with the underlying sandy horizon, resulting in a homogeneous arable horizon of sandy granulometric composition. The filler cryogenic wedges, leaving the humus-coarse humus horizon to its cultivation presents a light loam. The same composition has a coarse humus horizon of undisturbed soil on the site A38 and cryogenic wedges coming out of it. Below the humus horizons at both sites overlie layers of the ancient fluviolacustrine sandy sediments. Under the spruce forest (A38) they have a relatively less uniform distribution of fractions of granulometric composition along the profile: from the surface to 130 cm the proportion of coarse sand (fraction size 0.5-1.0 mm) is from 10 to 35%, with a maximum (30-35%) in the layer of 50-110 cm. The underlying stack of deposits is represented mainly by medium sand (fraction size 0.25-0.5 mm). On ledge (A37), the content of the coarse sand fraction varies from 8-10 to 20% throughout the profile. At the same time, the main share also falls on the average sand. Thus, the ledges has a more uniform distribution of fractions of the particle size distribution on the profile. Due to this, the heating of the soil thickness under other identical conditions can occur more evenly and to a greater depth, which during the anthropogenic use of the site led to the degradation of permafrost and lowering its upper boundary. In favor of this is also evidenced by the difference in the color of the glued soil-forming rocks. On ledge (site A37), soil-forming rocks differ mainly in ochre shades of gley, which is the basis for its assignment to the oxidized gley and indicates drier modern conditions at this site, compared with natural soil (site A38).

At site A37, deforestation and plowing caused an increase in the depth of soil thawing. Here the zero isotherm during the warm period falls much deeper 320 cm and in the layer 240-320 cm soil warms up to 2.5°C. However, during the cold period, the minimum soil temperature at the surface is -11.3°C, at the depth of 320 cm is -1.2°C. On the control site A38 in this same period, the minimum soil temperature at the surface -4.1°C, at the depth of 320 cm -0.1°C. The maximum depth of the isotherm of +10°C at the site A37 is observed at a depth of 100 cm. At the same time on the control site A38 under the spruce forest, the maximum depth of the isotherm of +10°C is about 20 cm, and deeper than 130 cm fixed permafrost.

Plowing led to a change in the power of the humus horizon, the content and quality of organic matter. Therefore, the power of arable horizon on the A37 is 25-30 cm, while the power of the humus-coarse humus horizon of the natural soil on the A38 – 15-20 cm. The content of organic matter ranges from 15 to 25%, in the arable horizon it is only 2.5%.
The third pair of sites (A34 and A36) is also located in the zone of distribution of discontinuous permafrost. The capacity of peat thickness at the control site A34 is 130 cm. Below it’s layer lies gel horizon of the sandy loam granulometric composition. The hydrological regime at this site depends on the water level in the lake, placed on 60 m to the North-West of it.

At the site A36 depth of the peat horizon exceeds 45 cm, to be replaced with depth by glevum horizon fixed-sandy composition. As mentioned above, on this site occurred anthropogenic change in hydrological regime due to ploughing nearby land and the establishment of the separation channel to the North of the site A36. Due to this, the bog water level is constantly within the peat horizon, which affects the temperature regime of the soil. Because the melting depth is 70-80 cm, which is slightly less than at the control site A34 where it is 80-90 cm. Heating pad A34 is faster and in greater depth. So on the surface at the site A34 soil temperature passes through +0 on average a week earlier than the A36, and at the depth of 80 cm transition occurs on average 10-12 days earlier. Such differences are formed due to the better thermal conductivity of the dry peat horizon (A34) compared to the water-saturated horizon (A36). However, the main differences in these areas occur in the winter. So at the site of the A36 on the surface, the minimum soil temperature is -6.2°C and at a depth of 60 cm a -0.7°C. Then, at the A34 minimum soil temperature at the surface -12.6°C and at a depth of 60 cm -3.7°C. This is a consequence of the smaller thermal diffusivity of water-saturated peat compared to dry. Thus, the change in the hydrological regime leads to significant differences in winter temperatures, which are higher in the secondary wetlands, as well as in the depth of thawing, which differs less significantly.

Therefore, agrogenic use led to changes in chemical (partial mineralization of organic matter, depletion of organic matter and nitrogen) and physical (granulometric composition, density) properties of the humus horizon of the soil, which caused changes in such characteristics as thermal conductivity and moisture capacity.

4. Conclusion

The main factors of the formation of the soil climate on the presented sites are the same: atmospheric climate, landform, underlying permafrost, altitude, vegetation cover and its varieties. The above-mentioned factors alone make a relatively small contribution to changes in the temperature regime, but with the combined effects of all factors, these changes are significant. First of all, this is reflected in the depth of penetration of daily and seasonal fluctuations and, as a consequence, the rate of warming/freezing of the soil. However, against the background of complex effects can be identified the most important factor in the warm period, which affects the temperature regime. This is a decrease or increase in the amount of incoming and outgoing solar radiation due to the effect of thermal insulation of the soil by vegetation cover. Our data show that the heat transfers between the soil and the atmosphere will primarily be affected by forest type and tree density. Denser forest, such as spruce, prevents soil heating more. Also in the spruce forest will be observed thicker litter, the thickness of which is an average of 5 cm and is some insulating layer. A similar effect can be achieved by thick tall grass.

Thus, in the warm period, vegetation has a great influence on the absorption of part of the incoming short-wave solar radiation and delays part of the reflected short-wave and long-wave outgoing radiation. This leads to a strong thermal insulation effect and contributes to less warming of the soil, and in some cases the preservation of permafrost soil thickness. At the same time, the difference in the speed and magnitude of heating varies significantly for open areas and areas with low rare forest. Therefore, any restoration work aimed at increasing the number of trees in the disturbed area can play an important role in maintaining the temperature regime of soils in the territory.

In the cold period, the influence of vegetation is not so obvious. As well as an important role in the formation of the temperature regime playing such factors like a soil moisture, time and speed of formation of a stable snow cover, granulometric composition of the soil.
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