Influence of vegetation cover on the temperature dynamics of sandy soil

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Abstract. To study the temperature regime of soils, an autonomous atmospheric-soil temperature complex is used. The complex is installed at three sites with sandy soil and various kinds of vegetation cover: burnt areas, pine forest, and open sand. Observations are made from October 13, 2011 to August 16, 2019 in a soil profile from the surface to the 320 cm depth. An analysis of the temperature regime of sandy soil reveals main similarities and differences between the three sites with different types of vegetation cover. In summer, the sites with pine forest and burnt areas of pine forest warm up less intensively than the site with open sand. Due to the greater openness, this site is the warmest during the warm period. In winter, pine forest, due to its high vegetation, is a barrier to wind, reducing snow blowing, and prevents the radiation cooling of the surface. To a slightly lesser extent, these functions are performed by loose vegetation in the burnt areas. The influence of vegetation under different weather conditions (clear sky/overcast) is considered. Cloud cover, as well as vegetation, helps to reduce the variability of soil temperature. The results of the study show that after forest fire restoration of vegetation cover naturally contributes to the partial restoration of the soil temperature regime.

1. Introduction

Soil temperature is of primary importance for many applied and fundamental tasks related to assessing the response of the earth’s surface to climate change. Soil temperature is the most important characteristic of climatic, soil-forming, permafrost, and engineering-geological conditions. It determines the functioning of terrestrial ecosystems, allowing us to reveal the sensitivity of landscapes to anthropogenic impact, changes in the natural environment, and climate fluctuations. Particular interest is dictated by the growing attention of the scientific community to the problem of global warming [1].

The soil temperature regime is a change in the soil temperature at the soil profile depth at different times. There is a daily and annual course of soil temperature. Each type of soil has its own characteristic of temperature variations at different depths [2].

The thermal regime of soils depends on atmospheric climatic characteristics, terrain features, vegetation and snow cover, thermal properties of the soil, as well as human activity. It is mainly caused by the radiation balance, which depends on the ratio of solar radiation energy absorbed by the
soil and thermal radiation.Logging, fires, and plowing have a significant impact on the thermal and physical state of the soil.

The main source of heat entering the soil is the radiant energy of the Sun, which is absorbed by the surface layer. This heat is transferred to the underlying layers, and is also used to heat the air and evaporate water.

The soil layer in which there are daily and annual temperature fluctuations depending on the influx of solar radiation is called the active layer.

Daily and annual fluctuations in the temperature of the soil surface due to heat transfer are transmitted to its deeper layers. The propagation of temperature fluctuations deep into the soil (with a homogeneous soil composition) occurs in accordance with the following Fourier laws [3]:

- The period of fluctuations with depth does not change, i.e., both on the soil surface and at all depths, the interval between two consecutive minima and maxima of temperature is 24 hours per day, and 12 months per year.
- If the depth increases in an arithmetic progression, the amplitude decreases exponentially, i.e. the amplitude decreases rapidly as the depth increases.
- The soil layer where the temperature does not change during the day is called the daily temperature layer. In the mid-latitudes, this layer starts from a depth of 70-100 cm. The layer of constant annual temperature in the middle latitudes lies deeper than 15-20 m.
- Maximum and minimum temperatures at depths occur later than at the soil surface. This delay is directly proportional to the depth. Daily maximums and minimums are late for every 10-cm depth on average for 2.5-3.5 hours, and the annual depth for each meter is delayed by 20-30 days.

According to Fourier's theoretical calculations, the depth to which the annual change in soil temperature manifests itself should be approximately 19 times greater than the depth of daily fluctuations. In fact, there are significant deviations from the theoretical calculations, and in many cases the depth of penetration of annual fluctuations is greater than the calculated one. This is due to differences in soil moisture by depth and time, changes in soil thermal conductivity with depth, and the presence of vegetation/snow cover on top of the soil.

### 2. Objects, data and methods

To assess the influence of vegetation on the dynamics of temperature of sandy soil, we used hourly data on the soil temperature at standard depths [4] from the surface to a depth of 320 cm for three sites with sandy soil and various vegetation cover: burnt areas (A26), pine forest (A27), and open sand (A35). The full characteristics of all three sites are presented in Table 1.

To measure the soil temperature, an autonomous atmospheric-soil temperature complex, abbreviated as ASMC, was used. In the basic configuration, the ASMC (Figure 1) allows continuous long-term automatic measurements of the main meteorological parameters of the atmosphere and soil from a depth of 3.2 m to a height of 10 m [5]. Correctness of the study of the soil temperature regime by using the ASMC is shown in [6].

Observations of the temperature of sandy soils were carried out on the basis of the Tunkinskaya depression by the V. B. Sochava Institute of Geography SB RAS with an interval of 1 hour in the period from October 13, 2011 to August 16, 2019. The location of the studied territory within the south-western part of the Baikal rift zone in the South Siberian physical and geographical region imposed a number of peculiar features on the natural conditions of this region. The description of the natural conditions concerns mainly the Tunkinskaya and adjacent depressions, with primary attention given to the area of the Tunkinskaya depression and its northern mountain frame as the main object of research. The Tunkinskie Goltcy range and the system of depressions of the same name stretch for 175 km in the latitudinal direction. The ridge is a mountain structure with a sharply dissected Alpine relief [7].

A significant elevation and complexity of the Eastern Sayan orography determines the climate of this territory. A peculiarity of the climate is that the territory is located in Central Asia and the
atmospheric circulation is characterized by the fact that almost no Atlantic or Pacific air masses come here. The source of their replenishment is mainly the Arctic air masses, which are transformed over the continent into moderate ones. However, the main forms of general atmospheric circulation in mountainous terrain differ significantly from each other in the mode of meteorological elements [8].

| Site ID, start of observations, depth, m | Coordinates Height, m a.s.l. | Landscape | Vegetation community |
|----------------------------------------|------------------------------|-----------|----------------------|
| A 26 Oct 2011 3.2                     | 51°44.427′/102°19.644′       | Bottoms of the depressions (on outwash and lacustrine sands) with an undergrowth of Daurian rhododendron | burned out cowberry pine forest |
| A 27 Oct 2011 3.2                     | 51°46.122′/102°19.100′       | Lowlands with undergrowth of Daurian rhododendron | pine forest with undergrowth of Daurian rhododendron, lingonberry |
| A 35 Aug 2012 3.2                     | 51°45.310′/102°26.971′       | Depression bottom | Sand dunes, vegetation is not formed |

The climate of the region is sharply continental, characterized by large daily and annual temperature amplitudes and a small amount of annual precipitation. In winter, the Siberian High dominates here. In summer, there are cyclones with cloudy rainy weather. The average January temperature is from -22...-24°C in the lowest places of the basin to -19...-21 °C in the mountains. The average July temperature is from +17°C in the basin to +11...+14°C in the mountains. The absolute minimum is to -50°C, and the maximum one +34°C. The average long-term annual precipitation in the basin is 300...350 mm, in the mountains 500...600 mm, and on the slopes of the Hamar-Daban Ridge up to 1000 mm. The radiation balance of the highlands, according to the Il’chir weather station, is about 1337 MJ/m², its minimum value is in January and the maximum in July. The prevailing winds are from the west and east directions in accordance with the stretch of the Irkut River and the basin itself from west to east [9].

During observations of the ASMC at different times, mainly in spring, there were failures that led to omissions in the data. Short gaps (no more than a week) were replaced with restored data [10]. To compare the sites, we selected 4 time periods with synchronous observations in which there are no long data gaps:

1) 15.10.11-25.10.12 (only for two sites: burned (A26) and forest (A27))
2) 14.08.13–21.09.14
3) 18.06.16–7.08.17
4) 22.07.18–14.07.19
3. Results and discussion

In this work, priority was given to calculating the average, maximum, and minimum monthly temperatures at different depths. According to the obtained data, the area with open sand (A35) has the largest amplitude of fluctuations in the average monthly temperature of the soil surface. This area is the coldest in winter (-15°C) and the warmest in summer (+24.1°C). With depth, the annual amplitude decreases, but also remains maximum compared to the other sites. The site with pine forest (A27) has the most smoothed annual course of the soil temperature. The monthly average surface temperatures vary from +18.3°C (July) to -12.1°C (January).

Vegetation in the burned site (A26), although insignificant, also helps to reduce the variability of the soil temperature, but to a lesser extent than the forest. For example, the values in January 2017 at this site ranged from -13°C at a depth of 5 cm to +1.7°C at a depth of 320 cm, the temperature range in the soil profile is 14.7°C; in the site with pine forest from -10.8°C to +1.2°C, respectively; the range is 12°C.

Site A27 is under the least influence of solar radiation, which contributes to the minimum warming of the soil (Figure 2), which is confirmed by the profile of the average monthly soil temperature in the 0-320 cm layer in summer, in the warmest month (August 2017). When comparing the sites in the winter season, this site turned out to be warmer than the other two, due to the fact that the crowns prevent the radiation cooling of the surface.

The maximum temperature of the soil in the site with open sand is more variable than the maximum temperature of the soil under a developed vegetation cover.

Minimum temperatures (of the surface) on the burned and pine forest sites are observed in January (-15.7°C and -14.0°C), and on open sand in November (-18.6°C). The differences are due to the fact that the vegetation cover has low thermal conductivity; therefore, this leads to a decrease in the heat loss by the soil. Analysis of the minimum values of the soil temperatures showed that in the site with forest in winter the soil cooling is less throughout the thickness. In the sites with open sand and burning, the minimum temperature values on the soil surface are negative in the period from September to May, and in the site with pine forest, from October to April.

The difference between the temperature regimes of soil with different vegetation cover on cloudy and clear days was considered. According to the Federal Hydrometeorological Center data [11] for the Tunka weather station, periods with clear and cloudy days were selected for the period from 01.01.2016 to 31.12.2017.

Figure 3 shows that between February 8 and 9, 2017 there was clear weather with 0 grade of cloudiness. When comparing the sites, the following has been revealed: on the soil surface in all sites there is a pronounced daily course of the soil temperature with one minimum and one maximum, at a
depth of 20 cm the fluctuations fade. On cloudy days with a cloud cover of 10 points (December 18 - 20, 2016), the fluctuations can be traced to a level of 30 cm, and at a depth of 40 cm they are absent.

**Figure 2.** Profile of monthly soil temperature in the 0-320 cm layer in January and August 2017.

**Figure 3.** Diurnal variation of soil temperature depending on cloudiness in winter.
In the summer period from 20 to 22 June 2017 (cloudless), the most significant fluctuations in the daily course of the soil surface temperature can be traced in the site with open sand (A35) and burning (A26). Warming of the soil under the pine forest is slow. From a depth of 40 cm or more, there are no fluctuations in all three sites. On cloudy days from August 10 to August 11, 2016, the soil temperature values measured in the site with pine forest have a more smoothed daily course. Fluctuations at all three sites can be traced to a depth of 20 cm (Figure 4).

The differences in the soil temperature between the sites on clear and cloudy days are greater in summer, because the snow cover does not prevent the soil from warming up and cooling. The analysis also leads to the conclusion that the amplitude of the daily course of the soil surface temperature decreases in the presence of clouds, the maximum and minimum are less pronounced and shift to another time. Thus, in winter in sites A26 and A27 the maximum temperature on a clear day is observed 2 hours later than on a cloudy day, and in site A35, 4 hours later. The minimum is 2 hours later in all sites. In summer, when the cloud cover is 10 points, the daily maximum and minimum temperatures occurred earlier than in cloudless weather, at 1h in all three sites.
During forest fires, the vegetation cover is destroyed and the properties of the underlying surface change; this leads to an increase in insolation and a decrease in the reflectivity of the surface, which changes the temperature regime of the soil. The territory where site A26 is located was occupied for a long time by a pine forest (vegetation cover: cranberry pine). In 2011, a forest fire occurred in this area, after which this type of cover was destroyed. When comparing the average monthly and extreme values of the soil temperature at site A26 (burnt areas) with the other sites, A27 (pine forest) and A35 (open sand), it is possible to identify changes in the temperature regime that occurred during the restoration of the vegetation cover at this site over 10 years (long-term course). After the fire, the burnt area had values of the soil temperature similar to the area with open sand (Figure 5). If the vegetation cover increases, the difference in the soil temperature values between these sites should increase, which we observe.

Figures 5. Difference in soil temperatures at different depths between sites A35 (open sand) and A26 (burnt) (February).

If we compare the burnt and pine forests sites, then when restoring the vegetation cover their difference should decrease over the years or be absent altogether. At the beginning of the study period, the differences were maximal. In 2018, the differences tend to decrease to zero. It is possible to trace a tendency to decrease the difference in the soil temperature values at all depths between the two sites. It can be concluded that the gradual renewal of vegetation cover on the soil surface over 10 years on the site with burning contributes to the restoration of the soil temperature regime.

4. Conclusions
Thus, the analysis of the temperature regime of sandy soil revealed main similarities and differences between the three sites with different types of vegetation cover. Vegetation cover has a significant impact on the temperature regime of soils. Its influence is clearly visible in the warm and cold periods. With high and dense vegetation in summer, the influence of solar radiation and, therefore, the heat input to the soil surface, is minimal. The sites with pine forest and burning in the pine forest area were warmed up less intensively than the site with open sand. Due to the greater openness, this site is the warmest during the warm period. In winter, the open area is exposed to more freezing. Any vegetation cover prevents rapid cooling of the soil surface and reduces temperature fluctuations. The soil surface is warmer in winter, when there is a snow cover. Based on the analysis, pine forest, due to its high vegetation, is a barrier to wind, reducing snow blowing and preventing radiation cooling of the surface. To a slightly lesser extent, these functions are performed by vegetation on burning pine forest.

Cloud cover, as well as abundant vegetation, helps to reduce the variability of soil temperature, since it prevents daytime warming and nighttime cooling, as a result of which the daily course of soil
temperature values becomes more smooth.

It is known that during forest fires vegetation cover is destroyed and the properties of the underlying surface change; this leads to an increase in the insolation and a decrease in the reflectivity of the surface, as a result of which the temperature regime of the soil changes. The results of the study have shown that the restoration of vegetation cover naturally contributes to the partial restoration of the soil temperature regime.

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