SHORT COMMUNICATIONS

THE USE OF AUTOMATIC WEATHER STATIONS TO MEASURE THE SOIL TEMPERATURE IN THE MORDOVIA STATE NATURE RESERVE (RUSSIA) IN 2016

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The article presents the soil temperature data obtained using two automatic weather stations located in the Mordovia State Nature Reserve (Russia). Measurements were carried out at the soil surface and at depths of 20 cm, 40 cm and 60 cm. The meteorological stations are located 15 km apart, in general, in similar landscapes. This caused similar results of meteorological measurements. Differences in the average of the daily temperature at corresponding depths are less than 2°C. The average annual temperature differs less than 0.5°C, i.e. within a sensor's error. The annual temperature trend is typical for Central Russia. And it is characterised by well warming in summer and stagnation in winter. The diurnal amplitudes are small. This can be explained by the location of both weather stations under the forest canopy and a well-developed ground vegetation cover.

Key words: annual temperature trend, automatic weather station, daily temperature trend, soil temperature

Introduction

Environment monitoring is an important task in the studies of natural complexes in Protected Areas. Since 1938, a departmental meteorological station has operated in the Mordovia State Nature Reserve. Measurements were carried out according to the typical methodic adopted for most meteorological stations of the USSR Hydrometeorological Service (Gafferberg, 1960). The results of the measurements were included in the annual Chronicles of Nature. This work was discontinued in 1980s. Since this time, data of the nearest weather station (Temnikov City) have been used. This weather station operates till date using old equipment. Temnikov's meteorological station is located 10 km away from the border of the Mordovia Reserve and, therefore, it has significantly different local natural conditions. In particular, it is located at the open area on the hill near the River Moksha floodplain. It should also be noted that the vast majority of meteorological stations in the Republic of Mordovia are located in non-forested sites, as a rule, in populated areas. In late 2014, two automatic weather stations «Weather Envoy Vantage Pro2» were installed in the Mordovia State Nature Reserve for monitoring purposes. In addition to measuring of air conditions (temperature, humidity, atmospheric pressure, precipitation, etc.), these weather stations measure the temperature and humidity of soil. Their characteristic difference from the Roshydromet stations is that they are located directly within the forest massif with an undamaged vegetation cover, but not at specially equipped sites. These landscapes are most common in the Mordovia Reserve as well as in the Republic of Mordovia. These are especially commonly distributed in the adjacent Nizhny Novgorod region, Vladimir region and Ryazan region. Hence, the obtained data can serve as «control» in investigations of weather conditions outside our study area for these landscapes, and also exploited agricultural lands.

Measurements of soil temperatures in Russia have a long history and an important scientific-applied value in the planning of economic activities, primarily for agriculture needs. In the Republic of Mordovia, the meteorological data have been obtained only from Roshydromet weather stations. In the neighbouring regions, more particular scientific issues are also considered. Among them are the dynamics of arable land temperature (Arkhangelskaya et al., 2008; Arkhangelskaya, 2012) and differences in soil temperature under different plant communities (Demakov & Isaev, 2013). There are many sources in literature devoted to the influence of the vegetation on the soil temperature (Bityukov, 2012; Demakov & Isaev, 2013; Kiselev et al., 2016). In the last decade automatic sensors have been actively used to measure the soil temperature (Pavlikova & Gaspar, 2012; Bolotov, 2014; Kiselev et al., 2016; Shtabrovskaya & Zenkova, 2017).

In 2016, for the first time, a continuous series of soil temperature data was obtained for different depths at both meteorological stations in the Mordovia State Nature Reserve (in 2015 there were «omissions» in data due to technical reasons). It can serve as a starting point for further research. In addition, this study was aimed to identify possible differences in western and central parts of the Mordovia State Nature Reserve, due to differences in their initial natural conditions.

Material and Methods

The Mordovia State Nature Reserve is located at the southern border of the zone of mixed and broad-leaved forests, in the centre of the Russian Plain in the north-east of the Oka-Don Lowland. The landscape of this area has been formed during the Holocene as a result of the melting of the glacier and the activity of surface waters. The water-glacial plain (northeastern part) and the ancient alluvial terraces of the River Moksha occupy approximately equal areas. Small sites refer to the modern area of the River Moksha floodplain and valleys of small rivers. The relief is flat, and it has a general slope from the north-east to the south-west. Erosion dissection is very weak. The main rivers are Moksha and its tributaries: the River Satis, River Pushta, River Vorsklay, River Chernaya, and the River Shavets (Gafferberg, 1960). The soils are predominantly sod-podzolic (Remezov, 1960). Pine (*Pinus sylvestris* L.) forests prevail in the vegetation cover. The following communities are less presented: birch (*Betula pendula* Roth) forests, aspen (*Populus tremula* L.) forests, linden (*Tilia cordata* Mill.) forests, and fir (*Picea abies* (L.) H. Karst.) forests and bogs (Kuznetsov, 1960).

Meteorological station 1 (54.741710° N, 43.171019° E, 109 m a.s.l.) was installed in forest compartment 424 in the western part of the Mordovia State Nature Reserve, north of the Inorsky cordon (Fig. 1). The relief surface is flat. The general exposition of the mesolandscape is southwestern (the terraces of the River Moksha, complicated by the activity of the River Pushta). The meteorological station is located on a small forest glade. The surrounding plant community is a lichen pine forest. Two *Sphagnum* bogs are in the immediate vicinity on the north and west sides. The soils are sod-podzolic (Remezov, 1960). According to the landscape structure (Grishutkin, 2014), this meteorological station is located in a moderately-moistened natural landmark on ancient alluvial deposits of terraces underlain by terrigenous Middle Jurassic sediments with sod-podzolic soils under mixed forests.

Meteorological station 2 (54.769590° N, 43.404228° E, 165 m a.s.l.) is located in forest compartment 396 in the centre of the Mordovia State Nature Reserve, north of the Pavlovsky cordon (Fig. 1). The relief surface is flat. The general exposition of the mesolandscape is southern. The meteorological station is in the sparsed old-aged pine-cowberry forest with a well-developed moss cover. The soils are sod-podzolic (Remezov, 1960). According to the landscape structure (Grishutkin, 2014), this meteorological station is located in a weakly-moistened natural landmark on ancient alluvial deposits of terraces underlain by terrigenous Middle Jurassic sediments with sod-podzolic and podzolic soils under coniferous forests. The distance between both meteorological stations is 15 km.

The weather stations were installed, first of all, to cover the area of the Mordovia Reserve to capture possible climatic differences along a longitude. Also, meteorological station 1 is located near the River Moksha floodplain (2 km) and in the immediate vicinity of the River Pushta valley (0.3 km). Meteorological station 2 is considerably less affected by the influence of riverine landscapes, because the River Moksha floodplain is located 8 km away, and the nearest (small) watercourse is at a distance of approximately 1 km. The installation of one more meteorological station has been planned at the eastern boundary of the Mordovia Reserve (180 m a.s.l., eastern slope exposition, 20 km from the Moksha river floodplain), but this has not been implemented yet. Of course, the differences cannot be large in such a relatively small area (almost 40 km between extreme eastern and western points). But these can reflect the mesoclimate properties.

Sensors for measuring soil temperature were installed at the meteorological stations in the following order: 1 – at the soil surface, 2 – at a depth of 20 cm, 3 – at a depth of 40 cm, 4 – at a depth of 60 cm. This scheme, in a whole, corresponds with the traditional methodic to study the soil temperature regime (Popovich, 1987). Data were recorded every hour. The sensors' resolution is 0.1°C, the sensor’s error is 0.5°C. The vegetation cover was hardly or not damaged during the installation of the sensors, i.e. the measurement conditions are maximally close to natural ones.

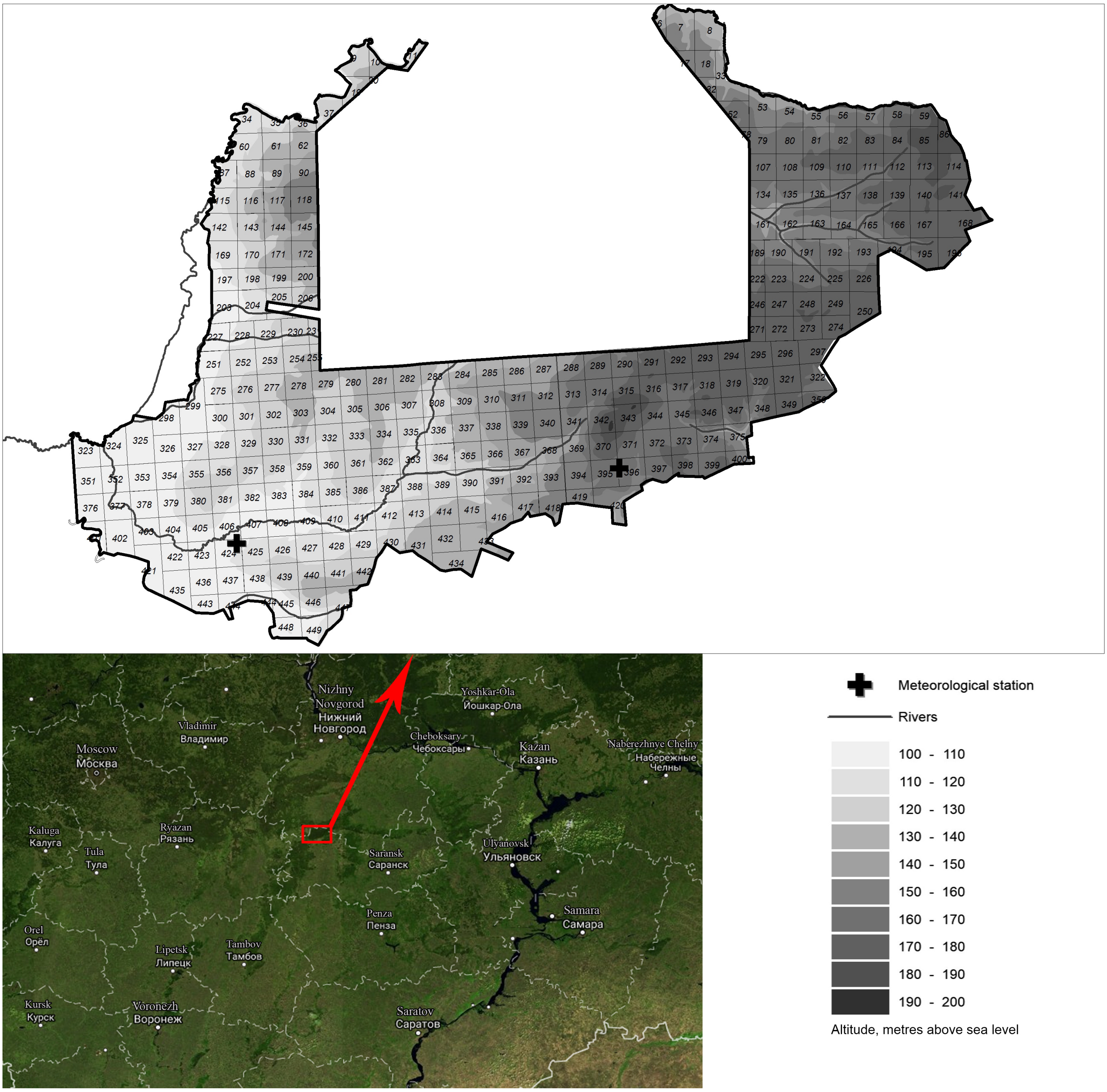

Fig. 1. The map with locations of weather stations.

Results and Discussion

The values of air temperature at both meteorological stations were highly similar. Some differences were observed under weather changes, or under local weather phenomena (for example, showers). However, these differences tended to be smoothed out in the average daily values. The strongest differences were manifested during the winter frosts. As a rule, the air temperature in forest compartment 424 was a few (1–3) degrees lower than in forest compartment 396. The minimum values were recorded on 25 January 2016 when the temperature was -28.1°C at meteorological station 1, while the minimal values at meteorological station 2 were 2.1°C higher. In March, the average daily air temperature in forest compartment 424 was slightly higher than in forest compartment 396. And this situation persisted until November 2016. The maximal temperature values were recorded in August. These amounted to 32.9°C at meteorological station 1 and 0.5°C lower at meteorological station 2. In general, the air temperature at both sites differed weakly. The differences in the average daily temperature rarely exceeded 1°C, and usually these fluctuated within 0.5–1.0°C. The amplitude of air temperatures (both daily and annual values) is slightly higher in forest compartment 424. The same differences are also typical for soil temperature.

As a result of soil temperature measurements, very similar data were obtained at both weather stations (Fig. 2). The difference in primary data (obtained hourly) was rarely more than 1°C at all depths. The greatest differences were typical for data obtained at the soil surface in the warm season. The difference was less noticeable with the increase of depth. At a depth of 60 cm, the winter data were coincided completely during a significant time period (from mid-January till mid-April). A sharp increase in soil temperature began simultaneously with the loss of the snow cover which indicates their relationship. In 2016 it was observed on 10–11 April.

The curve of the annual soil temperature along the soil profile is shown in Fig. 3 for meteorological station 1. The curve of meteorological station 2 is very similar. It can be seen, that until mid-April, the deeper layers retained a constant temperature which was somewhat higher than at the soil surface. The top soil layer got weakly frozen. The temperature was not below 0°C already at the depth of 20 cm in forest compartment 396, while during three days of strong frosts in January in forest compartment 424 the temperature was -0.6°C at the same depth. The minimum temperature values were observed in January. On 5 January 2016, the average daily minimum temperature was recorded at both meteorological stations. The temperature at the soil surface was -1.7°C at meteorological station 1, while -2.2°C at meteorological station 2. The temperature values became slightly higher with the increase of depth of snow cover, and then these passed through 0°C. The soil began to warm up quickly after the melting of snow. So, on 11 April, the temperature at the soil surface had increased by 5 degrees. At that time there was a high daily amplitude of temperature values due to morning frosts. The temperature gradually increased until late June. Then the growth of the average daily temperature has slowed down. In forest compartment 424, the average daily maximum (21.5°C) was registered on 17 July 2016, while the maximum temperature value (24.4°C) was registered on the same day and on the day before. In forest compartment 396, the maximal daily average temperature was 20.0°C, while the maximum temperature value was 21.1°C. In late August, a sharp decrease of soil temperature had begun. It continued until late October, when the rates of temperature decrease had dropped significantly. In November, there were frosts at the soil surface, even before the snow cover had been established. As a result, the soil temperature can have negative values under such conditions. So, on 24 November 2016, the temperature at the soil surface had decreased to -1.7°C in forest compartment 424, while on 19 November 2016 its value was -0.6°C in forest compartment 396.

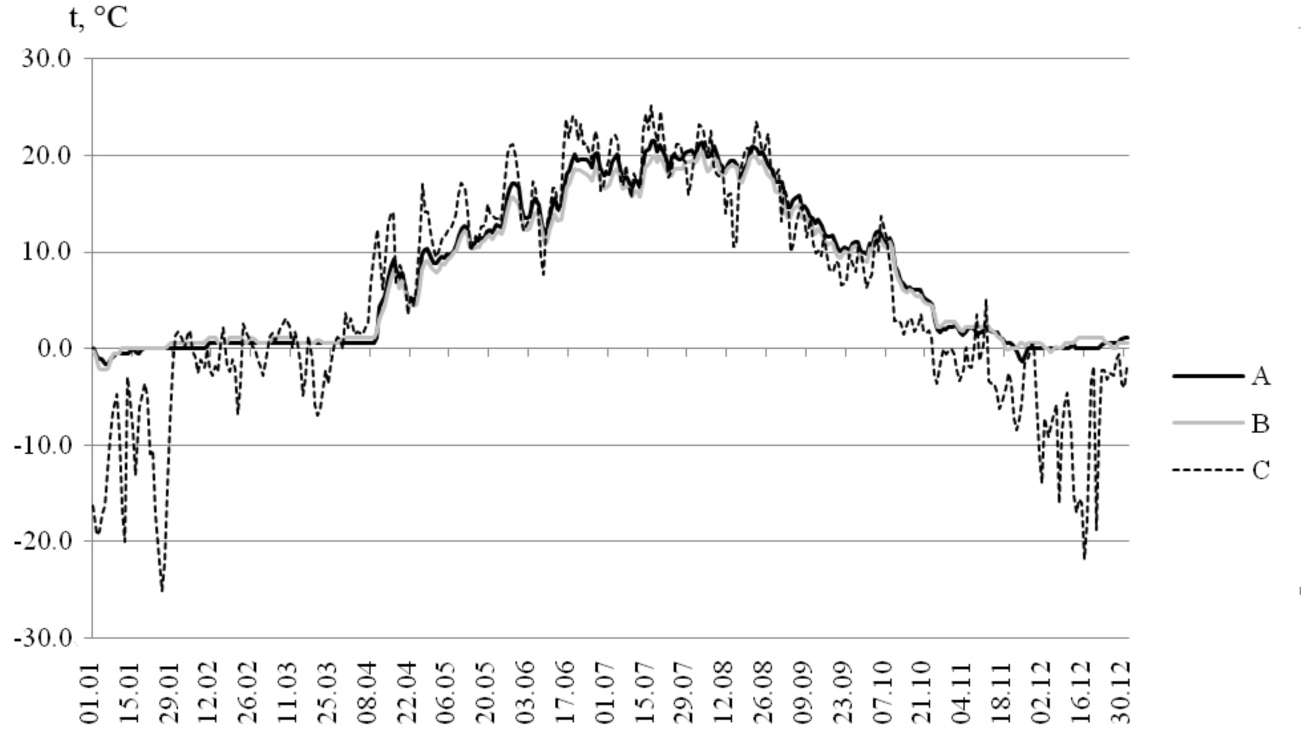

Fig. 2. Average daily temperature at the soil surface and air temperature (°C): A – soil temperature at the meteorological station in forest compartment 424; B – soil temperature at the meteorological station in forest compartment 396; C – air temperature in forest compartment 424.

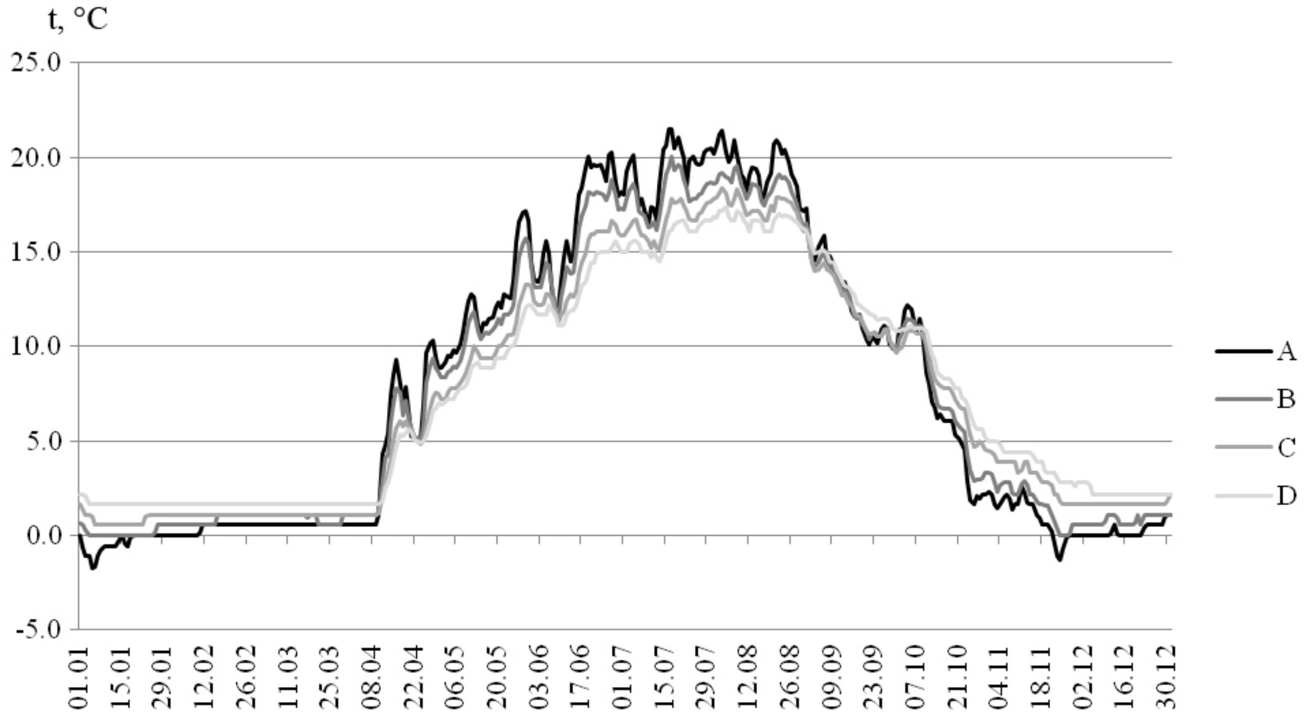

Fig. 3. Average daily temperature along the soil profile at the meteorological station in forest compartment 424: A – temperature at the soil surface; B – temperature at depth of 20 cm; C – temperature at depth of 40 cm; D – temperature at depth of 60 cm.

The amplitude of the temperature values was low both during the year and during the day. It is especially noticeable in comparison with the open areas without a herb cover (Nebolsin, 1925; Hanks & Ashcroft, 1980; Arkhangelskaya, 2012). But in general it is typical for similar natural conditions (Dimo, 1972). Apparently, small amplitudes of temperature values were due to the fact that both study sites were completely under the forest canopy, or most of their area was shaded. At both locations, the soil is covered by a well-developed cover of shrubs, herbs and mosses. This greatly limits the heating and cooling of the soil. At both meteorological stations the highest daily amplitudes of temperature at the soil surface were recorded in spring (up to 6 °C) and summer (up to 4°C). At the same time, during the daily cycle the soil was evenly heated up to the depth of 40 cm and it well correlated with the air temperature, while at the depth of 60 cm the soil temperature had practically not changed during the day, and its amplitude did not exceed 1°C. In forest compartment 424, the annual amplitude of temperature at the soil surface was 26.1 °C, and 16.1°C at the depth of 60 cm, while in forest compartment 396 the annual amplitude of temperature at the soil surface was 24.9°C, while 16.7°C at the depth of 60 cm.

In Fig. 4 is shown the difference in the average daily temperatures at the soil surface in both meteorological stations during the whole year. The difference above 0°C shows an exceeding of values at the meteorological station in forest compartment 424. The difference below 0°C shows an exceeding of values at the meteorological station in forest compartment 396. The greatest differences were registered for the soil surface and the depth of 20 cm. However, even this (maximal) difference in values did not exceed 2°C. The temperature values were more different during summer and in early winter. Almost throughout the whole year, the difference of soil temperatures was insignificant at depths of 40 and 60 cm. And it has passed the mark of 0.5°C only in autumn and early winter.

The average monthly values of temperature are shown in Table. Similarly to figures, here the difference in soil temperature between the meteorological stations is well traced, especially in summer. So, in July the average monthly values of temperature at the soil surface in the meteorological station located in forest compartment 424 were more than 1°C higher than in the other weather station. However, the differences in the average annual temperature along the soil profile did not exceed 0.5°C, while there was no difference at all at the depth of 60 cm.

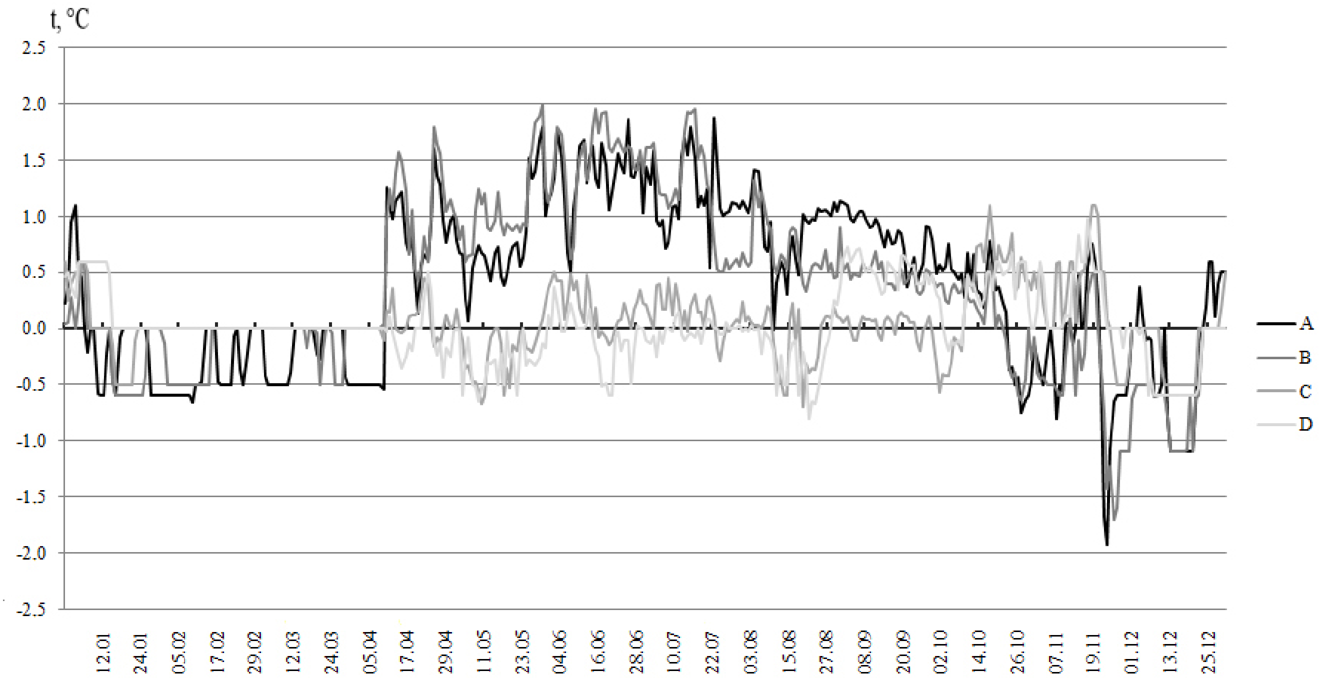

Fig. 4. Differences between values of soil temperature in two meteorological stations. Above 0°C is exceeding of values at the meteorological station in forest compartment 424, below 0°C is exceeding of values at the meteorological station in forest compartment 396. A – temperature at the soil surface; B – temperature at depth of 20 cm; C – temperature at depth of 40 cm; D – temperature at depth of 60 cm.

Table. Average values of monthly soil temperature (°C)

Months	Forest compartment 424, depth, cm				Forest compartment 396, depth, cm				Air temperature (forest compartment 424)
	0	20	40	60	0	20	40	60	
January	-0.4	0.1	0.8	1.7	-0.3	0.3	0.8	1.5	-11.1
February	0.4	0.8	1.1	1.7	0.8	1.1	1.1	1.7	-0.9
March	0.6	1,0	1.1	1.7	0.8	1.0	1.1	1.7	-0.6
April	5.1	4.7	3.9	3.8	4.6	4,0	3.9	3.9	7.9
May	12.2	11.3	9.8	9.1	11.5	10.2	10.0	9.4	14.2
June	16.7	15.6	14.0	13.1	15.3	14.1	13.8	13.2	17.7
July	19.3	18.1	16.7	15.8	18.2	16.9	16.5	15.8	19.9
August	19.4	18.3	17.4	16.7	18.5	17.7	17.5	16.9	18.9
September	12.5	12.4	12.2	13.0	11.6	11.9	12.2	12.5	10.4
October	6.7	7.2	7.9	8.5	6.5	7.1	7.6	8.3	3.7
November	0.9	1.7	3.0	3.8	1.2	2.2	2.7	3.6	-2.9
December	0.3	0.8	1.7	2.3	0.6	1.4	1.9	2.6	-8.2
Average annual temperature	7.8	7.7	7.5	7.6	7.4	7.3	7.4	7.6	5.8

Conclusions

Thus, the obtained data allow us to conclude a high similarity of the temperature regime of soils at the two sites, due to the relatively small distance between the two meteorological stations and only a slightly different exposition of mesolandscapes. The average monthly values exceeded 0.5°C (sensor's error) only in summer. The meteorological station in forest compartment 424 is characterised by a somewhat higher correlation of soil and air temperatures. It can be explained both by landscape features and local conditions of the site. So, in summer a slightly different exposition (southwestern vs. southern) of a slope can influence that, while in winter it can be influenced by the proximity to river valleys. Among local conditions, a sparser vegetation cover, including both the forest stands and shrub and herb-moss layers can be the reason for a higher correlation of soil and air temperatures mentioned above. The annual temperature trend is typical for these latitudes and prevailing landscapes. It is characterised by stable temperature values in winter which is associated with the establishment of a permanent thick snow cover. Also, relatively good warmth in summer and considerable daily temperature fluctuations at the upper soil layer are typical for this annual temperature trend.

The measurements taken are the first of such work for the Mordovia State Nature Reserve. In future, it is necessary to compare obtained data with ones of other weather stations in the Republic of Mordovia and neighbouring regions, as well as with newly obtained meteorological data in the Mordovia State Nature Reserve. Such data can serve as a supplement to the measurements of the Roshydromet meteorological stations. These can be also helpful in determining the differences in local natural conditions, and the vegetation effect on soil temperature.

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ИССЛЕДОВАНИЕ ТЕМПЕРАТУРЫ ПОЧВЫ В МОРДОВСКОМ ЗАПОВЕДНИКЕ (РОССИЯ) В 2016 Г. С ПОМОЩЬЮ АВТОМАТИЧЕСКИХ МЕТЕОСТАНЦИЙ

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В статье приведены данные температуры почвы, полученные с помощью двух автоматических метеостанций, расположенных на территории Мордовского заповедника (Россия). Измерения проведены на поверхности почвы и глубинах 20 см, 40 см, 60 см. Метеостанции расположены в 15 км друг от друга, но занимают в целом похожие ландшафты. Это обуславливает и схожие результаты измерений метеостанций. Различия средних суточных значений по соответствующим глубинам не превышают 2°C, средние годовые значения отличаются менее, чем на 0.5°C, т.е. в пределах погрешности датчиков. Годовой ход температур является типичным для средней полосы России и характеризуется хорошим прогреванием в летний период и стагнацией в зимний. Суточные амплитуды невелики, что объясняется нахождением метеостанций под пологом леса и хорошо развитым напочвенным растительным покровом.

Ключевые слова: автоматическая метеостанция, годовой ход температуры, суточный ход температуры, температура почвы