White Sea catchment area: changes in soil temperature

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Abstract. In the situation of climate warming, no less important than changes in air temperature are estimates of changes in soil temperature both on the surface and at different depths. The article examines the current state and changes in the thermal regime of soils in the White Sea catchment area based on long-term data from weather stations located in the study area. Changes in mean annual and monthly soil temperatures were estimated for the new reference period 1991-2020. The analysis shows that the temperatures on the soil surface and at depths have increased since the beginning of the 21st century throughout the White Sea catchment area.

1 Introduction

The White Sea catchment takes more than 10% of the Russian Arctic Zone, occupying some 720 000 km^2, and includes significant parts of the Murmansk, Arkhangelsk, Vologda Regions, the Republic of Karelia and the Komi Republic, as well as a small part of the Kirov Region and the Nenets Autonomous Okrug. The region in question features a variety of physiographical and climatic characteristics. The climate of the study area can be described as subarctic, with a transition in northernmost parts to arctic climate in the Nenets District, subarctic maritime with some continentality in the Murmansk Region and northwestern Arkhangelsk Region, transitional from maritime to continental in Karelia, and temperate-continental in the Vologda Region and Komi Republic. The climatic conditions are shaped by Arctic and Antarctic air mass transfers. Frequent shifts of air masses cause constant weather variations.

Changes in the air temperature regime in the White Sea catchment area in the late 20th - early 21st centuries have been studied quite thoroughly [1-8]. The comparison of the climate normals of mean annual air temperature at different weather stations (WSs) in the White Sea catchment area between two standard climatological periods 1961-1990 and 1991-2020 indicates that the 30-year mean annual air temperatures at the end of the 20th – beginning of the 21st centuries exceed the climate normals of the previous period by 0.8-1.2°C throughout the area. Air temperature changes go along with alteration of the temperature regime of the soil. However, changes in soil temperature have been studied much less than changes in air temperature. Meanwhile, it is the soil temperature that

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determines the functioning of terrestrial biogeocoenoses, providing insights into the sensitivity of landscapes to human impact, changes in the natural environment and climatic fluctuations.

2 Material and methods

The putative changes in the soil temperature regime of the White Sea catchment area were assessed using data from long-term observations at weather stations of the Russian Federal Service for Hydrometeorology and Meteorology (Roshydromet). Data from 7 WS in Karelia, 5 WS in the Murmansk Region, 7 WS in the Arkhangelsk Region, 4 WS in the Vologda Region, 2 WS in the Nenets Autonomous District, and 2 WS in the Komi Republic were used. The general description of the soil surface temperature regime for the White Sea catchment area was compiled using data from the Applied-scientific Electronic Reference Book "Climate of Russia" prepared at the Climatology Unit of the All-Russian Research Institute of Hydrometeorological Information - World Data Center. Mean annual and mean monthly values, as well as the results of daily observations were used in the study. The climate normals were computed as the means over the standard reference periods established by the World Meteorological Organization – 1961-1990 and 1991-2020. The climate series were processed by statistical data processing methods.

3 Results

Soil surface temperature is measured by thermometers deployed on the surface cleared of vegetation in the warm period of the year and on snow surface in winter. Mean annual soil surface temperature varies across the White Sea catchment area from -0.9..-1.0 ˚C in Cape Kanin Nos area, 0.0-0.5 oC in the Murmansk Region, 1.5-2.5 ˚C in Karelia and the Arkhangelsk Region, and the highest values of mean annual soil temperature, up to 3.7 ˚C, are found in the Vologda Region. In the annual cycle of soil surface temperatures, the minimum is in January-February and the maximum is in July. Mean multidecadal January temperatures in the study area range from -10.0 to -17.0 ˚C. The absolute minimum at a majority of the stations was recorded in December 1978, ranging from -47.0 ˚C in the Mezen' area to -54.0 ˚C at the Sura WS. Mean multidecadal soil surface temperatures in the warmest month (July) vary from 10.6 ˚C as recorded at Kanin Nos WS to 21.2-21.5 ˚C in the Vologda Region. The all-time maximum temperatures were recorded in different years depending on the station, being 35.0-55.5 ˚C in different parts of the catchment area.

The analysis of ground-air temperature data from long-term instrumental observations at the weather stations situated in the White Sea catchment area revealed the common traits and trends of the mean annual temperature in the study area during the 20th – early 21st centuries. The temperature rise from the beginning of the century towards the mid-1950s was succeeded by a cooling, but starting from 1989-1990 mean annual air temperatures in the White Sea catchment have positively deviated from the climate normal in almost all years [9, 10]. Studies of among-year variations in mean annual soil surface temperature prove the same trends apply to this climatological parameter as well (Fig. 1).

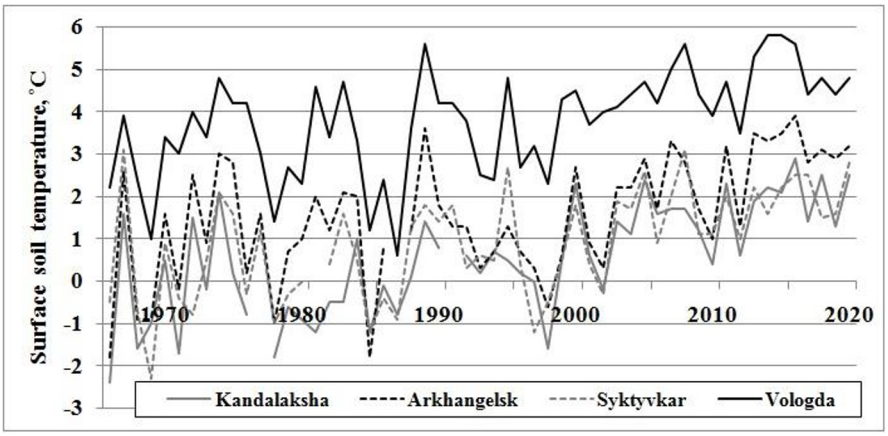

Fig. 1. Mean annual soil surface temperatures, 1966-2020.

Soil temperatures at different depths fluctuate much less among years than the temperature of the soil surface and the adjoining air. Still, a significant temperature rise since the beginning of the 21st century has taken place even at depths down to 160 cm. This can be illustrated by data on the long-term variation of mean annual soil temperatures at 20, 80, and 160 cm depths from the Kalevala WS (Fig. 2).

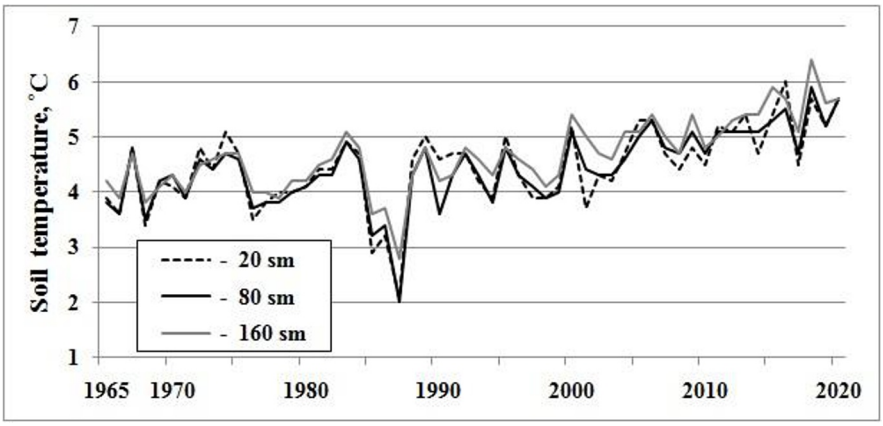

Fig. 2. Mean annual soil temperatures at different depths, Kalevala WS, 1965-2020.

As detected previously, the air temperature rise has been the most pronounced in the winter months, especially in January (the values averaged over 1991-2020 are 1.7– 2.5 ˚C above the climate normals). That is why we were the most interested in the variations of soil temperatures specifically in the winter period.

Similarly to the air temperatures, changes in the soil surface temperatures were the greatest in the winter period of the year, especially in January, when the 1991-2020 averages were 2.4-3.2 ˚C higher than the previous period's averages (Fig. 3). The deviations for December and February were 1.3-2.4 ˚C. This is explained by the frequent thaws occurring during the passage of cyclones formed over the Atlantic. A trend for a reduction in the number of thaw-free days has been observed since the early 2000s. A thaw-free day is a day with maximum daily air temperatures not rising above 0˚C. The number of thaw-free days has decreased by 6-12 days over the winter season throughout the White Sea catchment area.

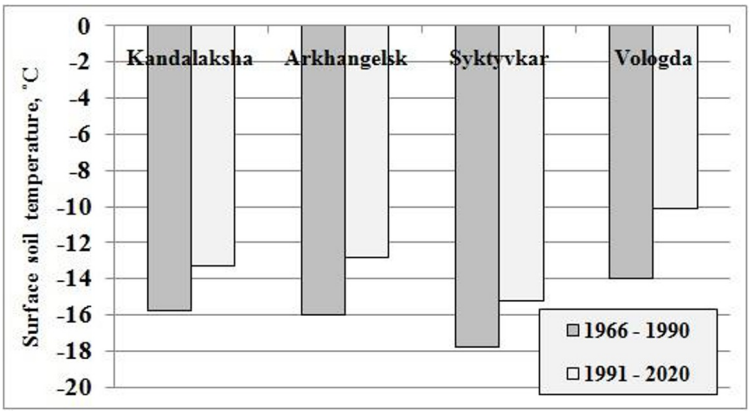

Fig. 3. Mean January soil surface temperatures, ˚C.

In March, April, and November, mean soil surface temperatures mostly remained within the climate normal range. In the summer period and early fall, the soil got 0.5-1.7 ˚C warmer each month on average than in the 1966-1990 period.

Temperatures down the soil profile are measured by mercury-in-glass thermometers. The observations are carried out throughout the year at depths of 20 to 320 cm under the natural land cover using soil thermometers. The measurements are taken once a day. In our study, we used daily data collected at weather stations in the period from 1960-67 through 2020 at 20 cm depth. The findings from this analysis are the following.

During the cold time of the year (XI-IV), decade-averaged soil temperatures at 20 cm depth over the 1991-2020 period differed significantly from the corresponding values for the 1960-67 – 1990 period. In modern times, soil freezing at 20 cm depth (soil temperature going below 0oC) occurs 10-15 days later than it did in the previous period. The soil freezing depth depends on many factors: air temperature, snow and plant cover, soil type and texture, soil wetness, topographic characteristics, land use. Peat soils freeze down less than loamy soils, and loamy soils less than sandy soils. Mean decadal soil temperatures in January-March, and in northern regions also in December, were 1.0-1.5 ˚C higher than the 1960-67 – 1990 averages. Soil thawing at 20 cm depth in spring roughly coincides with the climatological reference timing.

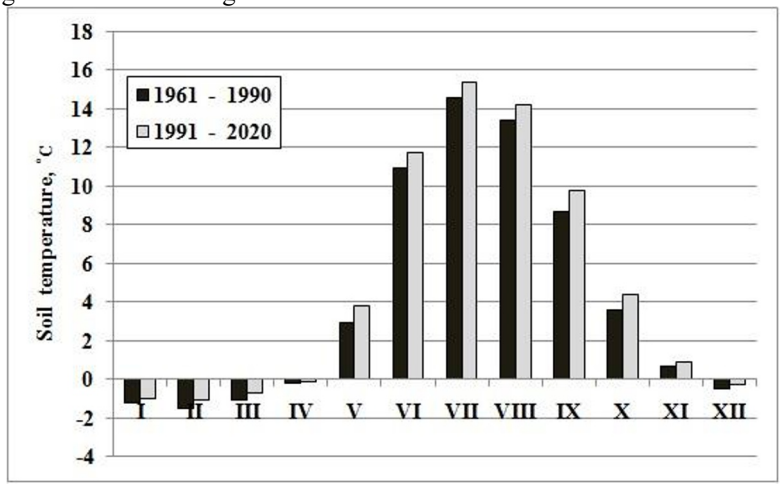

Fig. 4. Mean monthly soil temperatures, ˚C, at 20 cm depth, Kalevala WS.

Figure 4 provides data on mean monthly soil temperatures at 20 cm depth observed at the Kalevala weather station. Analysis of the information shows that in all months of the year the current climate normals (1991-2020) exceed the previous (1961-1990) period's normals. Speaking of the air, its mean monthly temperatures in the White Sea catchment area over the past 30 years were higher than the climate normal in all months except November. For November, some weather stations (Kargopol, Kotlas, Sura, Shenkursk) did not record any significant temperature deviations.

In-depth soil temperature change was greater in southern parts of the White Sea catchment area. Thus, according to the Vologda WS data, soil temperature at 20 cm depth in December-January in the late 20th century was 0.4…-3.7 ˚C. Starting from the winter season 2002-2003, daily soil temperatures in these months did not go below zero except for the winter 2009-2010. In some years (2004, 2008, 2009), soil at this depth did not get frozen in any of the winter months.

During the warm time of the year, soil temperatures at 20 cm depth steadily exceeded the multiannual means by 1-2 ˚C in all months.

4 Conclusions

Soil temperature is a crucial factor in the life of plants and soil microorganisms, having a significant impact on the physical, chemical and biological processes in soil. Insufficient or excessive thermal in the soil adversely affects the germination of plant seeds. Additionally, soil temperature affects the availability of nutrients to plants, as well as the activity of beneficial microorganisms in the soil [11-13] Soil temperature alters the rate of organic matter decomposition and mineralization of different organic materials. It also affects soil water content, its conductivity and availability to plants [14]. That is why in the situation of climate warming it is essential to study changes not only in air and water temperatures but also in the temperature regime of soils. Our analysis of data from long-term observations of soil temperatures in the White Sea catchment area gives rise to the following conclusions. Starting from the late 20th century, mean annual soil surface temperatures have been rising throughout the study area. Current climate normals for this parameter are 1.2-1.4 ˚C higher than the normals for the previous reference period. The rise in soil surface temperatures is the most pronounced in winter months, especially January (multiannual means increased by 2.4-3.2 ˚C). Normal mean annual temperatures down the soil profile have also grown by 0.6-0.8 ˚C. Soil temperatures at 20 cm depth exceed the previous climate normals by 0.2-1.2 ˚C in all months of the year.

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References

1. IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). IPCC, Geneva, Switzerland. 151 p. (2014)
2. N.N. Filatov, D.V. Pozdnyakov, O.M. Johannessen et al. White Sea. Its marine environment and dynamics influenced by global change. Chichester: Springer – Praxis Publ. 472 p. (2005)
3. V.A. Semenov, Izvestiya, Atmospheric and Oceanic Physics. 57, **1**, 18-28. (2021)
4. G. Alekseev, A. Urazgildeeva, S. Kuzmina, L. Bobylev, N. Gnatiuk, Int. J. of Clim., **39, 8**, P. 3582-3592. (2019)

5. N. Filatov, V. Baklagin, T. Efremova, L. Nazarova, N. Palshin, Inland Waters, **9**, P. 130–141. (2019)
6. A.N. Petrov, S. Burn Silver, F.S Chapin, G. Fondahl, J.K. Graybill, K. Keil, A.E. Nilsson, R. Riedlsperger, *Arctic sustainability research: Past, present and future.* Routledge. 110 p. (2017)
7. V.I. Byshev, V.G. Neiman, Yu.A. Romanov, I.V. Serykh. Dok. Earth Sc. **438, 2**. P. 887–892. (2011)
8. V. Ivanov, V. Alexeev, N.V. Koldunov, I. Repina, A.B. Sandø, L.H. Smedsrud, A. Smirnov. J. of Phys. Ocean. **46 (5)**. P. 1437–1456. (2016)
9. L. Nazarova, *Climate dynamics of the White Sea catchment area.* Vide. Tehnologija. Resursi – Environment, Technology, Resources. Proceedings of the 10th Intern. Sc. and Pract. Conf. P. 232-234. (2015)
10. I.V. Serykh, A.V. Tolstikov, *On the climatic changes of the surface air temperature in the White Sea region.* IOP Conference Series: Earth and Environmental Science. 606 p. (2020)
11. M. Sanaullah, A. Chabbi, C. Girardin, C. Rumpel, J.-L. Durand, M. Poirier, Plant and soil. **374, 1-2**. P.767-778. (2014)
12. O. Sultashova, Ya. Khudaybergenov, M. Oteuliev, M. Reimov, Int. J. of Psych. Rehabilitation, **24**, **04**, 2020 ISSN: 1475-7192. 6057-6068 p. (2020)
13. L.M. Babenko, K.O. Pomanenko, I.V. Kosakivska, M.G. Kholodn, The Ukr. Bioch. J. **93**, **6**. P.130-138. (2021)
14. R. Geiger, R.N. Aron, P. Todhunter, The climate near the ground. Lanham, USA: Rownaan and little field publishers, p. 42–50. (2003)