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CURRENT STATE OF THE HYDROMETEOROLOGICAL REGIMEN OF THE ARCTIC ZONE OF RUSSIA

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Abstract

Based on data from 176 weather stations located in the Arctic, an assessment of changes in the amount of precipitation, surface air temperature, atmospheric pressure, duration of sunshine, relative air humidity, water vapor pressure, soil temperature at depths was made the past decades. The assessment was carried out by statistical methods. It was found that such characteristics as the duration of sunshine, precipitation, air temperature and soil temperature at 5 and 10 cm depths are the most sensitive to climate changes and human-induced impact. The relative air humidity and water vapor pressure on the territory of the Russian Arctic changed little over the entire period under study, and the revealed few significant trends depend on the local features of the areas. The revealed significant trends with different signs depend on the local features of the areas. Water vapor pressure turned out to be more sensitive to external impacts. The most sensitive to climate change hydrometeorological characteristics in the Arctic zone of the Russian Federation can be taken into account when obtaining hydrological forecast models.

Keywords: Arctic, air humidity, climate changes, human-induced impact, surface air temperature, water vapor pressure

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1. Introduction

The ongoing climatic changes are reflected in meteorological and hydrological indicators (. Moreover, climatic changes can occur under the influence of both natural factors and human-induced impact (Dokuchayeva et al., 2024; Tang & Yang, 2024). Assessment of this impact is a priority task of the present time, since it allows assessing the current situation, and taking into account the existing changes in prospective studies. This assessment is most relevant for strategically important economic regions, including the Arctic zone of the Russian Federation (Bedritsky et al., 2017; Kovalenko et al., 2008).

2. Problem Statement

In the course of the study, an assessment of the current state of the hydrometeorological regimen of the Russian Arctic with identification of changes that occurred under the influence of climate, long-term characteristics and their intra-annual distribution was obtained, and hydrometeorological characteristics in the Arctic zone of the Russian Federation most sensitive to climate changes, that can be taken into account when obtaining hydrological forecast models were determined (Kovalenko & Gaidukova, 2015).

3. Research Questions

According to data from 176 weather stations located in the Arctic (from the source meteo.ru (Sikan, 2007) weather stations located above 60°N were selected – Figure 01), an assessment was made of the characteristics like: – amount of precipitation, – surface air temperature, – atmospheric pressure at sea level, – duration of the sunshine, – relative humidity, – water vapor pressure, – soil temperature at depths of up to 20 cm according to Savinov’s elbowed thermometers (Lipich & Balahura, 2024; Regnerová et al., 2024; Shumilina & Antsiferova, 2024).

4. Purpose of the Study

The purpose of the article is to assess the hydrometeorological regimen of the Arctic zone of the Russian Federation under possible climate changes and human-induced impact on river catchments.

5. Research Methods

According to the listed characteristics, databases are formed in a form convenient for processing.

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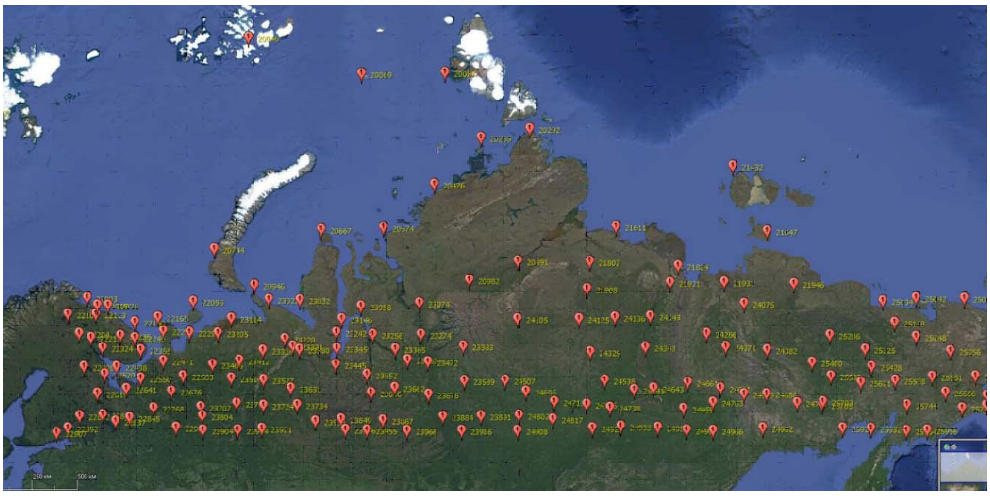

Figure 1. Location of weather stations located above 60°N (Sikan, 2007)

Statistical processing of the observation series was carried out (Bulygina et al., 2015): – chronological charts for monthly and average annual values have been built and analyzed; – the series was checked with regard to homogeneity according to Fisher's and Student's criteria; – statistical characteristics (average long-term value, coefficients of variation and skewness) were calculated and their errors were determined (Ahmad et al., 2024; Singh et al., 2024; Waite, 2024).

The long-term average values and values of coefficients of variation were calculated with the increasing duration of the series with a step of one year, starting from the first 30 years of observation.

Series with gaps for more than one month were not considered (Chernykh & Aldukhov, 2020).

6. Findings

Estimated sunshine duration

The duration of sunshine is quoted in hours and is the total amount of time when the sun is above the horizon in a particular area and is not covered with clouds, fog, haze, etc., that is, when the sun beams leave a trace on the sunshine card.

90 weather stations were processed in total. Series with gaps for more than one month were not considered in the study.

Analysis of the chronological charts of the sunshine duration by months showed that, in general, the greatest duration of sunshine was from May to July.

In the course of testing for homogeneity of 90 series of sunshine duration, 47 series were revealed that were heterogeneous according to Fisher's criterion and 37 – according to Student's criterion.

In the course of study of the significance of the trend based on long-term data, 34 series were identified, the trend thereof is significant at significance level of 5 % (see, for example, Figure 02). This suggests that the series are not stationary, that is, there is a change in the average annual values over time. Of the 34 rows, 11 have a downward trend in the sunshine duration, and 23 – have an increase trend. Moreover, downward trends are observed mainly in the Far East.

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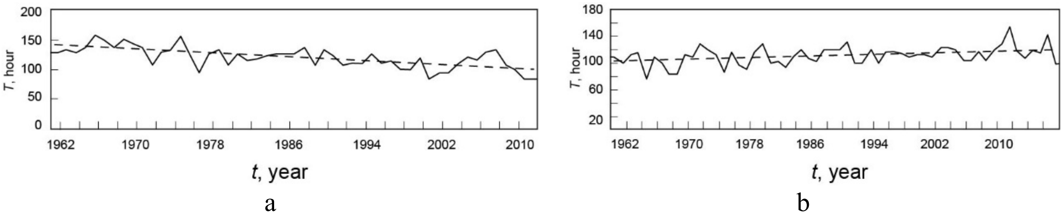

Figure 2. Chronological graph of average annual sunshine duration according to the data of Saskylakh (index 21802) (a) and Murmansk weather stations (index 22113) (b)

In the course of the analysis of the long-term average values and coefficients of variation for the increasing series duration, it was revealed that the overwhelming part of the sunshine duration series can be attributed to the series with a non-stationary regimen, i.e., stabilization of the long-term average values and coefficients of variation does not occur with an increase in the series (see, for example, Figure 03). This fact can be interpreted as a manifestation of the sensitivity of such an indicator as the sunshine duration to climate change in the Arctic.

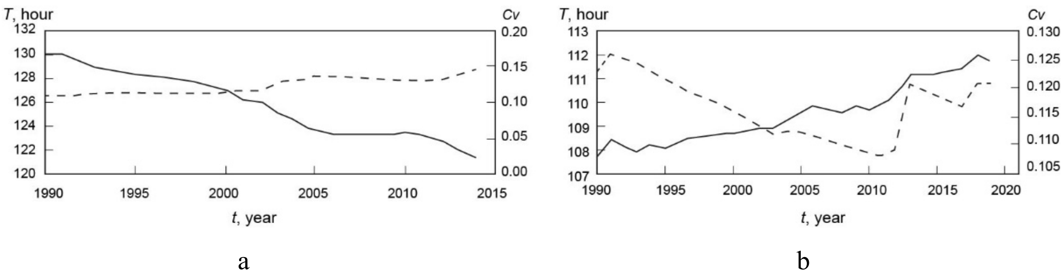

Figure 3. Graph of long-term average values (solid line) of sunshine duration and coefficients of variation (dashed line) using rolling average method based on the data of Saskylakh (a) and Murmansk weather stations (b)

Assessment of the relative humidity of the air and pressure of water vapor

The analyzed meteorological values (relative air humidity and water vapor pressure) are related to each other and directly depend on the air temperature; therefore, they can be considered as indirect indicators of climate warming or cooling.

According to the website meteo.ru, 176 weather stations were found, of which we selected those that have series with maximum duration of observations (at least 50 years) and without temporary gaps, as well as those located in areas with different physical, geographical and climatic conditions. 14 representative weather stations were selected.

Figure 04 shows, for example, chronological graphs of the average annual values of the relative air humidity and water vapor pressure for the Anadyr and Murmansk weather stations. The graphs, respectively a, b, c, d, show that: a – average annual values of relative air humidity vary from 73 to 86.5%, the highest average value was in 2009; b – average annual values of water vapor pressure vary from 3.7 to 5.3 hPa, maximum values were observed in 2007 and 2014, the minimum value – in 1981; c – average annual values of relative humidity vary from 74.5 to 82.4%, the maximum value was observed in 1980; d – the average annual values of water vapor pressure vary from 4.5 to 6.45 hPa, the maximum values were observed in 1974 and 2000, and the minimum – in 1988.

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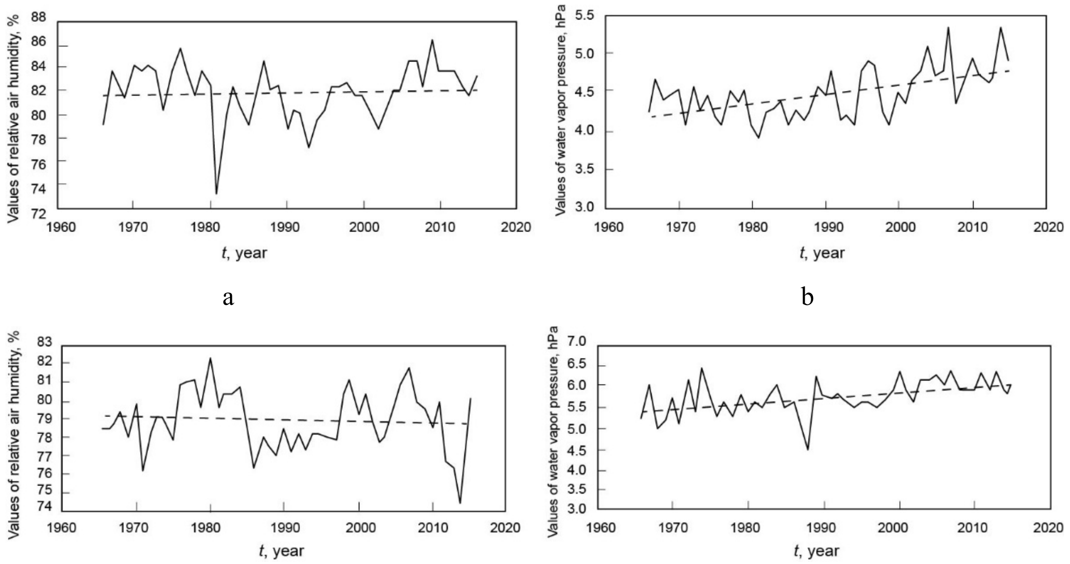
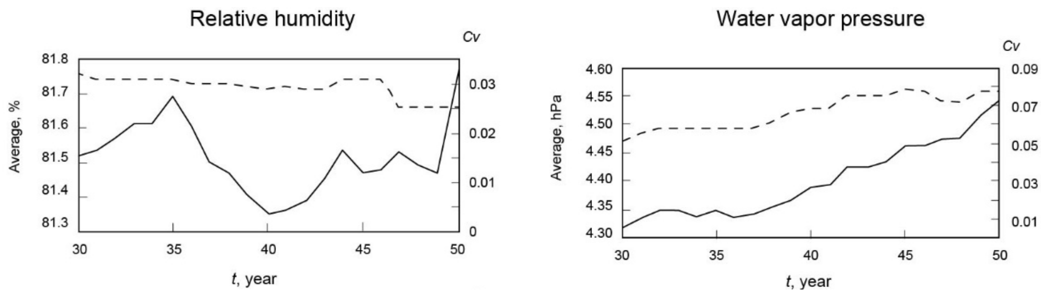


Figure 4. Chronological graphs of relative humidity and water vapor pressure for the Anadyr (a, b) and Murmansk (c, d) weather stations

Assessment of trends for relative humidity for all stations under study showed that 10 stations (Anadyr, Velikiy Ustyug, Koinas, Oymyakon, Sortavala, Srednekolymsk, Sura, Tiksi, Ust-Chakra, and Khatanga) have an increase trend, 4 stations (Arkhangelsk, Vyborg, Murmansk, Naryan-Mar) – a downward one. And for water vapor pressure, a trend towards an increase in average annual values was established at all 14 stations.

The homogeneity of the series was checked according to Fisher's and Student's criteria at 5% significance level. Most of the series of water vapor pressure are heterogeneous in their average value – 12 out of 14. The heterogeneity of the series can be associated with extreme values in the chronological course of the quantities under study.

Starting with a series duration of 30 years, average annual values and coefficients of variation were calculated with an increase in the calculation period by 1 year. Figure 5 shows, for example, such graphs for the Anadyr and Murmansk weather stations. It can be seen that the average value of the water vapor pressure tends to increase, whereas average values for humidity become relatively unchanged with an increase in the duration of the series (a similar situation for the values of the coefficient of variation). A similar conclusion can be made for most of the other stations under study.



a b

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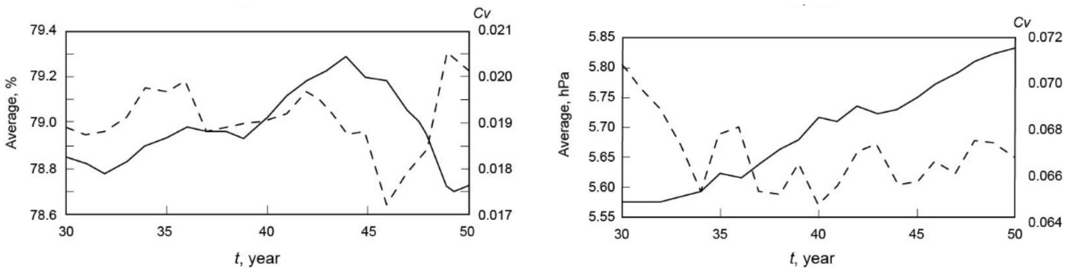

c d

Figure 5. Change in average values (solid line) and values of variation coefficients (dashed line) with an increase in the duration of the series of relative humidity and water vapor pressure for the Anadyr (a, b) and Murmansk (c, d) weather stations

Assessment of atmospheric pressure

Atmospheric pressure is the force exerting pressure on the earth's surface and on all objects on it.

From 176 weather stations we excluded the weather stations with a short series of observations or with numerous time gaps were eliminated. 50 weather stations were selected for the study.

In the course of statistical processing of the series of average annual values of atmospheric pressure, we revealed the following.

a) Average values range from 934 to 1011 hPa. The highest average value is observed at Sortavala station (index 22802), Vyborg (index 22892), and the lowest – at Susuman station (index 22790). The calculated relative error for the average value turned out to be low – from 0.01 to 0.11%.

b) The coefficient of variation changes insignificantly, from 0.0009 to 0.0022, with an average value of 0.0015 for all the selected weather stations. It should be noted that there is very slight variation in the coefficient of variation from station to station.

c) A significant trend was revealed at 2 weather stations out of 50 at a significance level of 5%. Such weather stations refer to Kalevala (index 22408) and Mirny (index 24726). The insignificance of the trend indicates that the atmospheric pressure is not affected by climate change and human-induced impact. Figure 06 shows an example of trend estimation. Chronological graphs are presented for two weather stations located in different parts of the territory under consideration: the Kalevala weather station is located on the territory of the Republic of Karelia (index 22408), Seimchan weather station – in the Magadan region (index 25703).

Among the considered weather stations, only the Kalevala weather station has a significant trend line, which may indicate a decrease in the average annual values of atmospheric pressure over time on the territory of the Republic of Karelia; we could not establish the reason for such a change at this stage of the study.

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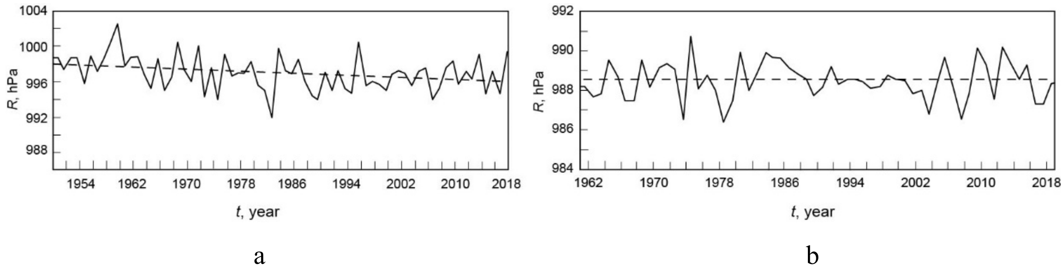

Figure 6. Chronological graphs of the average annual values of atmospheric pressure at the Kalevala (a), and Seimchan weather stations (b)

d) Checking the homogeneity of the atmospheric pressure series showed the following results: 6 series are heterogeneous in terms of average value, 13 series in terms of variance, heterogeneity in terms of dispersion and in terms of average is observed in 2 series for the Kalevala (index 22408), which had a significant downward trend earlier, and Baykit weather stations (index 23891).

e) In the course of the analysis of long-term average values and coefficients of variation with an increase in the calculation period with a step of 1 year, we revealed that, first: the dependence of the value of the coefficient of variation on the average value is not traced, i.e., with an increase in the average value, the coefficient of variation can be also increased, second: there is no stabilization of values due to relatively short series and a small change from year to year in the characteristic itself – atmospheric pressure.

An example of graphs is shown in Figure 07. It can be seen that for the Kalevala weather station the maximum average values and coefficient of variation approximately coincide in time, and since 1985, both characteristics decrease with time. The remaining two stations have both a period of decrease and increase in the values of characteristics, starting approximately from 2005.

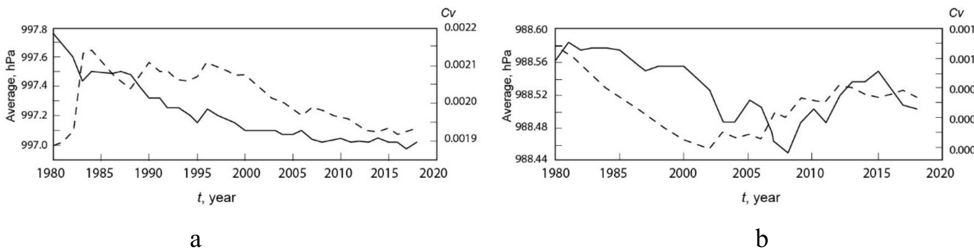

Figure 7. Values of average annual values (solid line) of atmospheric pressure and coefficient of variation (dashed line) for the Kalevala (a), and Seimchan weather stations (b)

Assessment of the amount of precipitation and surface air temperature

Representative stations were selected that characterize the meteorological conditions of different physical-geographical and climatic regions. The selected stations have long observation series without gaps in monthly data. 25 stations were processed. The minimum series duration is 52 years (Gogland weather station), the maximum – 84 years (Zyryanka, Aleksandrovskoe, Ust-Usa, Kotelny, and Suntar weather stations), on average, the duration of the precipitation and air temperature observation series was 76 years for most weather stations until 2019.

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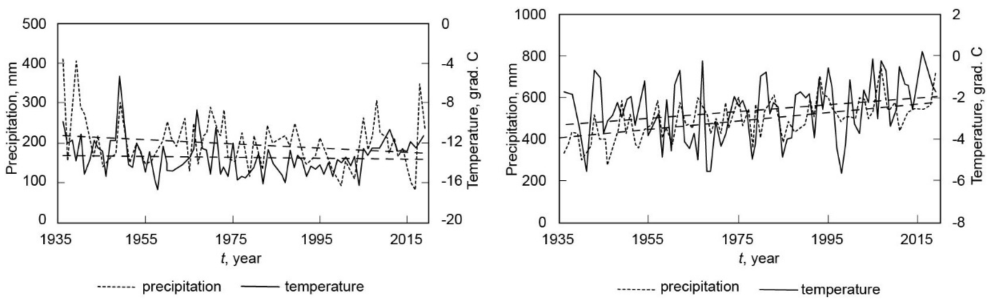
Analysis of chronological graphs (for example, Figure 08) made it possible to identify significant trends, at 5 % level, in changes in the characteristics under study. According to the series of precipitation, 21 increase trends were revealed, 12 of them turned out to be significant and, accordingly, 4 downward trends, one significant – the Saskylakh weather station. As for air temperature series: 3 decrease trends (no significant ones) and 22 increase trends, of which 18 are significant.

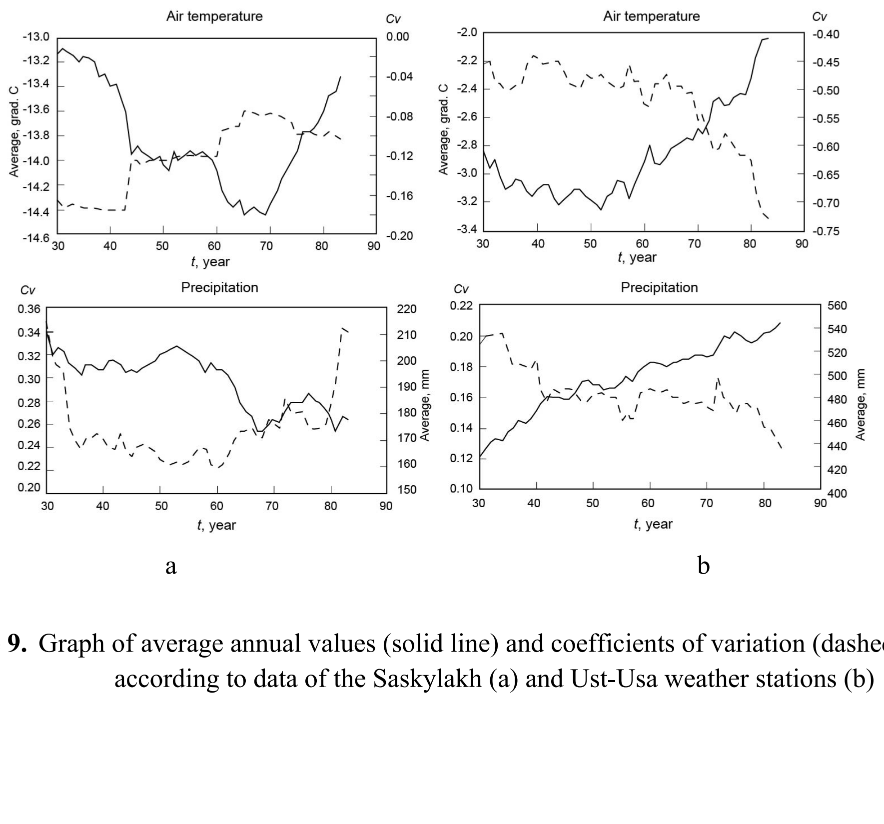


a b

Figure 8. Chronological graphs of precipitation and air temperature of the Saskylakh (a) and Ust-Usa weather stations (b)

The construction of difference-integral curves was an attempt to estimate cold and warm periods from air temperature series and estimate periods more and less than the average annual precipitation. It was revealed that the majority of weather stations are characterized by a period of increased precipitation and low air temperatures relative to the long-term average values of these characteristics.

In the course of study of homogeneity of 25 series of precipitation, 16 series were revealed that were heterogeneous according to Fisher's criterion and 7 – according to Student's criterion. Among the air temperature series, 15 non-uniform series were identified according to Fisher's criterion and 7 – according to Student's criterion.



a b

Figure 9. Graph of average annual values (solid line) and coefficients of variation (dashed line) according to data of the Saskylakh (a) and Ust-Usa weather stations (b)

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In the course of the analysis of the calculated long-term average values and coefficients of variation with increasing duration, it was revealed that the overwhelming part of the series of precipitation and air temperature can be attributed to the series with a non-stationary regimen, i.e., when one year is added, the average values and variation coefficients change, there is no stabilization of the values (see, for example, Figure 9). This fact can be interpreted as sensitivity of precipitation and air temperature for the selected weather stations to climate change in the Arctic.

Assessment of soil temperature using Savinov's elbowed thermometers

Soil temperature is the most important characteristic of climatic, soil-forming, permafrost and engineering-geological conditions. It determines functioning of terrestrial biogeocenoses, making it possible to establish the sensitivity of landscapes to human-induced impact and changes in the natural environment.

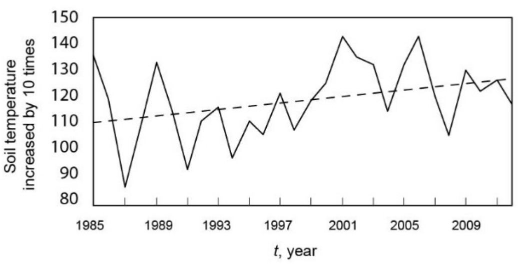
The soil temperature is monitored at 112 weather stations. Those weather stations were investigated at which there was a long series of observations without gaps. For the series of soil temperature according to Savinov's elbowed thermometers, there are 15 such stations, which are located mainly in the European part of the Arctic.

The data set contains daily values of soil temperature at depths at depths of 5, 10, 15, 20 cm under areas free from vegetation over the last three decades from 1984 to 2012. For the convenience of calculations by the site meteo.ru temperature data is provided, increased by 10 times.

In the course of statistical processing of the series of average annual temperatures soil according to Savinov's crank thermometers, the following was established.

a) The hypothesis about the homogeneity of the series according to Fisher's criterion is not disputed for all stations, except for the Kalevala station. The hypothesis about the homogeneity of the series according to the Student's criterion is not disputed for most stations, with the exception of Kandalaksha, Mezen, Sortavala stations, and a number of temperatures at a depth of 20 cm at the Kalevala station.

b) When assessing the trend, it was concluded that its significance at 5 % level at depths of 5 and 10 cm at 7 out of 15 stations, at depths of 15 and 20 cm, the number of significant trends is reduced to 6. The maximum trend is observed at the Mezen weather station (for an example, see Figures 10 and 11).



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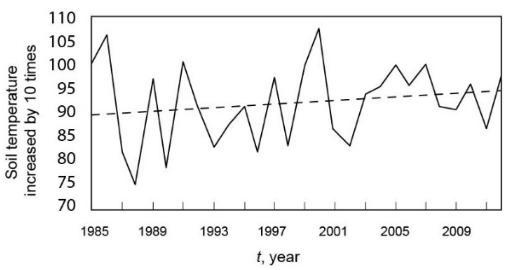

b

Figure 10. Chronological graphs with trend lines for a number of soil temperatures at depth of 10 cm, increased 10 times, for the Kandalaksha (index 22217) (a) and Krasnoshchelye weather stations (index 22235) (b)

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c) According to the graphs of long-term average values and coefficients of variation, calculated with an increase in the duration of the series, starting from 10 years and with a step of 1 year, we can conclude on non-stationarity of the process (see, for example, Figure 11).

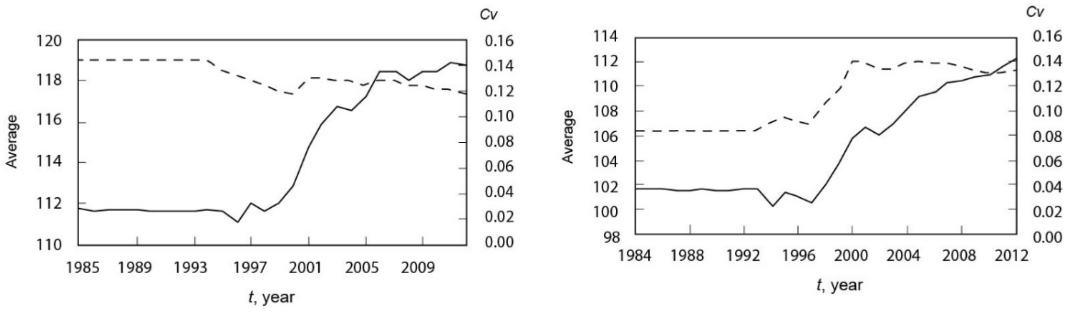

Figure 11. Average values (solid line) and coefficient of variation (dashed line) of soil temperature at depth of 10 cm, increased by 10 times, for the Kandalaksha (index 22217) (a) and Mezen weather stations (index 22471) (b)

7. Conclusion

During the assessment of changes in meteorological parameters over the past decades, we concluded that the following characteristics are sensitive to climate change and human-induced impact: sunshine duration, precipitation, air temperature and soil temperature at depth of 5 and 10 cm.

Relative air humidity and water vapor pressure in the territory of the Russian Arctic changed little over the entire observation period. The revealed significant trends with different signs depend on the local features of the areas. Water vapor pressure turned out to be more sensitive to external impacts.

In the course of assessment of changes in atmospheric pressure over the past several decades, the sensitivity of this characteristic to climate change in the Arctic was not revealed. The Kalevala weather station was the only one that showed possible sensitivity to climate change or huma-induced factors.

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