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Assessment of trends of air temperature based on 140-year observations of V.A. Mikhelson Meteorological Observatory

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ABSTRACT

The article deals with the test of the main hypothesis about regional climate warming based on the analysis of unique continuous long-term observations of air temperature in 1879-2018 at V.A. Mikhelson meteorological observatory. The authors present annual and seasonal trends of air temperature for 140 years, which indicate its increase practically during the entire observation period. All considered statistical series can be characterized by the normal distribution of random variables. The cyclical nature of changes in air temperature for all series relative to their long-term average values and a period of a clear significant increase in temperature, which falls on the last three decades of both annual values and seasonal time intervals, have been revealed. Statistical criteria determined a clearly heterogeneous pattern of this period in relation to both the previous observation years and the entire 140-year period; in particular, its average air temperature is quite higher, which proves the warming of the region's climate over the past decades. It has been noted that the degree of air temperature rise in winter is higher than in summer. Positive changes in the elements of the heat balance, both during the growing season and throughout the year, in particular, the improvement of the conditions for overwintering agricultural crops, predetermines the need for research in the possible expansion of their varieties for cultivation in the Moscow region. Based on a comprehensive analysis and logical conclusions, we made a hypothesis about the influence of intensive development of heated buildings around the meteorological station on the air temperature rise in the last half century; however, it is impossible to measure such an influence today, as well as the influence of global warming due to other factors.

Keywords: Climate change, Air temperature, Trends, Statistical characteristics, Homogeneity criteria.
Article type: Research Article.

INTRODUCTION

The problem of climate warming and its characteristics, in particular, an increase in the surface air temperature, has been constantly discussed since the end of the last century (Belolubtsev 2010; Alekseev *et al.* 2014). Heat waves are expected to become more intense than now (Belolubtsev 2010; Dmowska 2011). Testing the hypothesis about climate warming for a specific region requires to use long-term air temperature data of the standard meteorological station and fairly objective statistical criteria. the considered case is an urban region, with the territory of Russian State Agrarian University, Moscow Timiryazev Agricultural Academy, and the immediately adjacent areas. The territory of the academy locates V.A. Mikhelson meteorological observatory, which has been continuously monitoring air temperature according to unified methods and in the same place since 1879 (Gruza & Rankova 2012). Only a few meteorological stations in Europe and the world, including A.I. Voeikov Main

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Geophysical Observatory in St. Petersburg started observations a little earlier, which, however, were interrupted during the Second World War. This fact, therefore, makes unique a series of observations of V.A. Mikhelson Observatory; the data provide fairly objective estimates of changes in temperature characteristics, which are primarily important for ensuring the safety of life of the population, for meteorological forecasts, as well as for assessing the growth and development of crops (Hatfield *et al.* 2011; Asadifard *et al.* 2018; Masoudi *et al.* 2019; History of VA Mikhelson Meteorogical Observatory 2021; Attafi *et al.* 2021). The objective was to test the main hypothesis of a long-term increase in temperature characteristics in the considered Moscow region and to assess their trends over 140 years of continuous monitoring. For this purpose, the following tasks were solved: determination of traditional linear trends of air temperature based on long-term series of observation; highlighting of the characteristic periods of trends of air temperature changes relative to the long-term average; evaluation of the homogeneity of a series of observations of air temperatures by statistical criteria. The assessment of changes in air temperature included the average annual air temperature and air temperature for the warm and cold periods of the year.

RESULTS AND DISCUSSION

The presented hypothesis was tested according to the data of a series of observations of V.A. Mikhelson meteorological observatory, Russian State Agrarian University, Moscow Timiryazev Agricultural Academy. A 140-year long-term series of observations of verified air temperature values from 1879 to 2018 was used. The average daily values have served as the basis for the following statistical series: average annual air temperatures, average air temperatures for the growing season (May - September) and from September to April. The period from May to September inclusive can be considered the growing season for most crops in the region. Accordingly, the observation data were grouped into three statistical series: average annual air temperatures and average air temperatures for the considered periods. Fig. 1 shows their chronological charts, which clearly show positive linear trends.

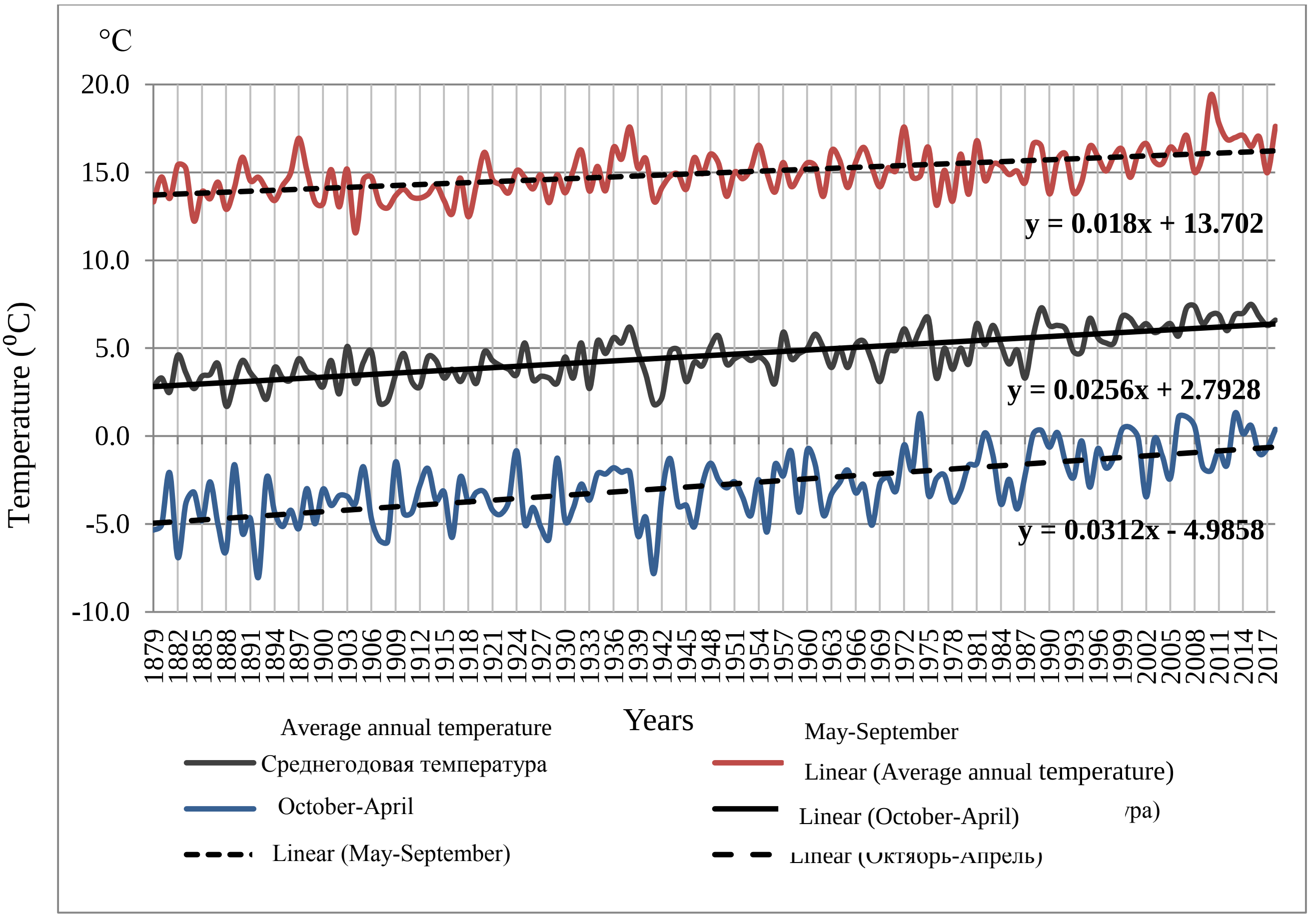

Fig. 1. Chronological graphs of the long-term air temperature changes by annual and seasonal values.

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To identify the most different periods of changes in temperature characteristics relative to their mean long-term value, a difference integral temperature curve was used, with the ordinates (R_i) calculated by the formula:

$$R_i = \sum_i (K - 1), \quad \textbf{(1)}$$

where: i is the number of the year in chronological order (I = 1 ÷ n), K_i is the modular coefficient of the annual temperature;
Ki = Ti/T_{av}, where T_{av} is the average long-term air temperature relative to annual values and, accordingly, relative to the considered seasonal values. Fig. 2 shows the integral curves of annual and seasonal air temperatures from May to September and from October to April.

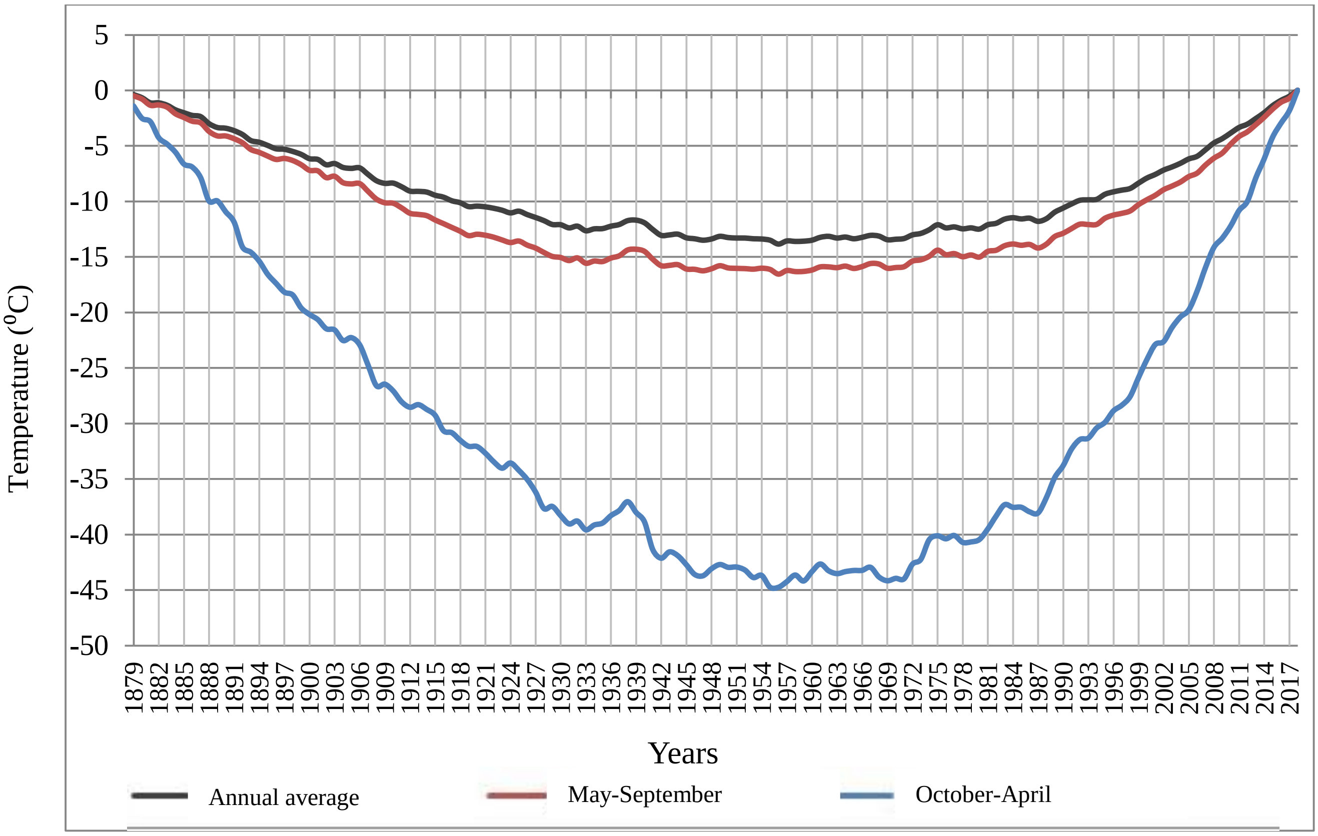

Fig. 2. Difference integral curves of average annual air temperatures and average temperatures for the growing season.

The curves actually reflect the accumulating differences between the current temperatures for the considered period and their long-term average (for modular coefficients: average – K = 1). If the first derivative of the curve function is negative (the curve decreases) in the considered period at positive temperatures, then during this period the temperature was below the long-term average; thus, we can assert that the period was cold, and otherwise, when the curve rises upwards, it is warm. Fig. 2 shows that after 1987 there were basically always only “warm” years and “warm seasons”, and practically the entire period from 1988 to 2018 was warm. Therefore, to assess the homogeneity of each (annual and seasonal) series of observations of air temperature using the traditional Student’s t-test and Fishers f-test (Knowles *et al.* 2006; Hatfield & Prueger 2015), the entire series (series 1) was preliminarily divided into the following periods: 1879-1987 years (series 2) and 1988-2018 (series 3).
Previously, for all analyzed series, using the traditional method of moments, the main statistical parameters were calculated: mean value, dispersion (D) and standard deviation (σ), coefficient of variation (C_v). Table 1 presents their numerical results. It should be specially noted that the full series of 140 years, due to its exceptional duration, allows estimating the method of moments and the coefficient of asymmetry. Its numerical values were obtained by the formula (Knowles *et al.* 2006; Hatfield & Prueger 2015):

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$$Cs = \frac{[n * \sum_{i=1}^{n}(K_i - 1)^3]}{(n-1)*(n-2)*Cv^3}, \qquad (2)$$

where: K_i and n are the same designations as in formula 1, and C_v is the well-known coefficient of variation (mean-to-standard deviation ratio). The asymmetry coefficient for the series of annual temperature and seasonal series turned out to be relatively insignificant (Knowles *et al.* 2006; Hatfield & Prueger 2015):
Cs = 0.05/0.2. This confirmed the a priori accepted hypothesis that temperature data can be characterized by the normal law of distribution of random variables, and, accordingly, it is quite appropriate to characterize the degree of homogeneity of statistical series by Fisher's f- and Student's t-tests.

Table 1. Statistical characteristics of the observation series.

Year of observation	mean	D	σ	C_v
Series 1, years	4.6	1.9	1.38	0.30
Series 2, years	4.1	1.2	1.1	0.27
Series 3, years	6.3	0.51	0.71	0.11
Series 1, summer	15.0	1.65	1.29	0.09
Series 2, summer	14.6	1.25	1.12	0.08
Series 3, summer	16.1	1.36	1.17	0.1
Series 1, winter	- 2.8	3.7	1.93	0.69
Series 2, winter	- 3.45	2.7	1.6	0.5
Series 3, winter	- 0.6	1.51	1.23	1.9

Fisher's f-test was determined by the ratio:

$$F = \frac{D}{D^*} \qquad (3)$$

where: D is the dispersion of the series with the largest numerical value; D* is the dispersion of the series with the smallest numerical value. To assess the homogeneity of the series, the degrees of freedom of the considered statistical series were preliminarily determined: $\upsilon_1 = n_1 — 1$ и $\upsilon_2 = n_2 — 1$. The obtained F was compared with the admissible tabular F* relative to the degrees of freedom (Knowles *et al.* 2006) with the traditionally accepted characteristic of the level of significance α = 0.05. To assess the significance of the difference in the average air temperature, we used the statistics of the Student's t-test calculated by the formula:

$$t = \frac{\overline{T_1} - \overline{T_2}}{\sqrt{n_1\sigma_1^2 + n_2\sigma_2^2}} * \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}, \qquad (4)$$

where: $\overline{T_1}$ and $\overline{T_2}$ are the average values according to observational data for n_1 and n_2 years, respectively; while σ_1 and σ_2 are the standard deviations of the values of the compared series. The distribution of statistics t depends on the number of degrees of freedom, in this case $\gamma = n_1 + n_2 - 2$. The critical value t_α with the same characteristic of the significance level α = 0.05 was compared with the admissible values according to the Students t-test distribution table (Knowles *et al.* 2006) – t_α, which further served as the basis for a decision regarding the homogeneity of the series. Table 2 presents the resulting values of the homogeneity criteria for the observation series relative to the significance level α = 0.05 together with the critical tabular values.

Table 2. Homogeneity criteria for the observation series.

Compared series	F	F*	1	t*	Homogeneity
Series 1 and 3 (years)	3.74	1.68	10.3	1.98	Non-homogeneous by F and t
Series 2 and 3 (years)	2.37	1.7	6.62	1.98	Non-homogeneous by F and t
Series 1 and 3 (summer)	1.21	1.68	4.2	1.98	Non-homogeneous by t
Series 2 and 3 (summer)	1.09	1.7	6.45	1.98	Non-homogeneous by t
Series 1 and 3 (summer)	2.45	1.68	6.0	1.98	Non-homogeneous by F and t
Series 2 and 3 (winter)	1.79	1.7	8.26	1.98	Non-homogeneous by F and t

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The last column of Table 2 shows that the considered hypothesis cannot be rejected only by F-test regarding the summer (growing) seasons. In general, based on the results of Table 2, we can unambiguously conclude that the hypothesis of the homogeneity of the considered cannot be supported both with respect to the annual and seasonal air temperatures. This result allows us to conclude about a significant increase in air temperature in the region over the past three decades. Climate warming is primarily due to an increase in the winter temperature, which is evident from the results of both the present study and earlier reports (Meehl *et al.* 2007; Porter *et al.* 2014). Given that numerous studies carried out all over the world and theoretical conclusions of applied mathematical statistics and probability theory (Sikan 2007; WMO 2017) state 30-year observation series to be sufficient for the necessary agrometeorological and construction design calculations, a series of observations for the last 30-40 years is more objective for real results regarding air temperature, while the previous years of observations, obviously, will underestimate the calculated standard values.

CONCLUSION

Our research demonstrates that the differential integral curve can serve as a fairly objective tool for identifying periods with a significant difference in the surface air temperature. Almost all indicators and criteria of temperature change used in the presented study prove real climate warming in the Petrovsko-Razumovskoye area. This process has been most significant during the last 30 years. A noticeable increase in air temperature during the growing season and an improvement in the overwintering conditions for agricultural crops predetermine the need for further research in the possible expansion of their varieties for cultivation in the Moscow region. The continuing development of the area with heated buildings has significant influence on the increase in winter air temperatures. This process had been especially intensive in the last half century. However, today it is impossible to measure the influence of this process.

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