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ASSESSMENT OF THE RELIABILITY OF A STATISTICAL MODEL FOR DEVELOPING A SCENARIO OF POSSIBLE AIR TEMPERATURE CHANGES IN THE WINTER SEASON OVER THE TERRITORY OF AZERBAIJAN

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Abstract: The article presents the results of assessing the reliability of a statistical model for developing a scenario of possible changes in the average winter air temperature over the territory of Azerbaijan. The model is based on the assumption of homogeneous soil cover in the horizontal direction, which allows the soil to be considered as a non-stationary one-dimensional system with a vertical spatial coordinate and time. The statistical model used is grounded in the assumptions that the temporal structure of winter temperature consists of periodic and non-periodic changes over various time intervals, and the existence of a trend in the long-term dynamics of air temperature is a widely recognized and reliably established fact. Here, the random components of the time series are calculated using Schuster's method and multiple cyclicities, and spectral analysis is conducted to identify short- and long-period fluctuations in these series. Furthermore, the expected values of air temperature residuals are computed. After this, the overall trend of the expected air temperature values was calculated as the sum of the values obtained from the linear trend and the computed residuals of air temperature. Given that the behavior of the climate system exhibits patterns of both short-period and long-period cyclicities, and their alternation within a certain time interval persists, we conducted numerical experiments based on the spectral analysis of time series of winter air temperature residuals. The calculations showed that the optimal approach is the use of a combination of cycles of 6, 9-10, and 14-15 years. Only in the Nakhchivan Autonomous Republic was a combination of 6 and 9-10 year cycles used. To assess the quality of the proposed model, the correlation coefficient between the actual and calculated values of winter air temperature was utilized. To verify the reliability of the obtained research results using independent data (from 1998 to 2022), we compared the estimates of both current climatic changes and their expected magnitudes. The model was tested using both five-year averaged temperature changes and annual temperature changes, analyzed through graphical representations. It was found that across all physical-geographical zones and climatic periods, in 44 cases (73 %), the absolute calculation errors were $\Delta T \leq 1.00C$, and in 58 cases (97 %), $\Delta T \leq 2.00C$. These results, along with other data and the model's reliability measure, demonstrate that the proposed model adequately describes changes in winter temperature and can be used to develop a scenario for changes in average winter air temperature over the next 20-25 years.

Keywords: Statistical model, climate change scenario, winter temperature, physical-geographical zones of Azerbaijan, model adequacy

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INTRODUCTION

Recently, increased attention has been paid to the natural, social, and economic consequences of global and regional climatic changes (Schumacher & Strob, 2011). As a result of these factors, the damage inflicted on the global economy by natural disasters associated with hazardous weather events has reached a record level of 90 billion US dollars, nearly exceeding the 1996 record by 50 % (Neumayer & Barthel, 2011).

As noted in source (Loginov, 2008), based on data from a number of historical and scientific sources, the 20th century was the warmest century of the last millennium. Research by NOAA indicates that since 1990, the Earth's average temperature has increased significantly (https://www.noaa.gov/news/2024-was-worlds-warmest-year-on-record?utm_source). Specifically, the last decade has been recorded as the warmest decade since the beginning of hydrometeorological measurements. The global temperature in 2024 was 1.29^0C higher than the 20th-century average, in 2023 it was 1.17^0C higher, in 2016 it was 1.0^0C higher, in 2020 it was 0.98^0C higher, in 2019 it was 0.95^0C higher, in 2015 it was 0.93^0C higher, in 2017 it was 0.91^0C higher, in 2022 it was 0.86^0C higher, in 2021 it was 0.84^0C higher, and in 2018 it was 0.82^0C higher. This trend highlights the persistent impact of climate change and demonstrates its effect on the annual rise in global temperature.

The data emphasize the urgency of implementing significant strategies to address greenhouse gas emissions and reduce further warming (https://www.noaa.gov/news/2024-was-worlds-warmest-year-on-record?utm_source). The last eight years have been the warmest on record globally. For example, the average global temperature in 2022 was approximately 1.15^0C

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above pre-industrial levels (1850-1900). The year 2022 marked the eighth consecutive year in which the annual global temperature exceeded pre-industrial levels by at least 1^0C (https://news.un.org/ru/story/2023/01/1436587).

June 2024 became the hottest month on record globally and the 13th consecutive month to set a monthly temperature record. This is evidenced by new data published by the European Union's Copernicus Climate Change Service. For 12 consecutive months, the global average temperature has been 1.5^0C higher than in the pre-industrial era (https://news.un.org/ru/story/2024/07/1454031). August 2024 and 2023 were the hottest globally, with an average temperature of 16.82^0C. July 2024 was slightly cooler than July 2023, but since June 2024 was significantly hotter than June 2023, this summer as a whole became the hottest on record (https://ru.euronews.com/green/2024/09/06/summer-2024-is-the-hottest-on-record-making-it-likely-this-will-be-the-hottest-year-ever).

Climate change is also being observed in Azerbaijan. This is because the zone of influence of global climate change is continuously expanding, and the South Caucasus region, including Azerbaijan, falls within this zone. Supporting evidence can be found in the results of various research studies conducted in this direction (Perevedentsev et al., 2011; Suleymanov, et al., 2016; Huseynov et al., 2024; Safarov &Mahmudov, 2011). The next important issue is the possibility of predicting the behavior of various elements of the climate system in the future. This requires detailed scenarios of global and regional features of climatic changes. It is worth noting that climate change scenarios are not intended to forecast future climatic conditions. They can be used to provide a schematic picture of probable future climatic conditions and should serve as a basis for assessing their impact on various sectors of the economy (Gordon & Scott, 2018).

Currently, various approaches are being proposed, and corresponding methods are being developed to address these tasks. These methods include general atmospheric circulation models (Angela et al., 2013; Satoh, 2013; Smith & Bustamante, 2018; Zhao & Zeng, 2014), paleoclimatic analogs of the future based on past climate changes, and empirical-statistical methods based on the processing of measured values of meteorological elements over the last 50-100 years (Droesch, 2018; Perevedentsev et al., 2018), which have been successfully applied over the past 25-35 years. For example, some methods for developing scenarios using instrumental observation data are presented in the research of M.I. Budyko (Budyko et al., 2013) and others. Their essence lies in studying the linear relationship between regional seasonal variables and a series of data on the temperature of the surface air layer in the Northern Hemisphere (Zumwald et al., 2020).

In addition to these approaches, other methods for assessing global climate changes have also been developed.

The estimates of climate changes obtained through the aforementioned methods are referred to as scenarios in scientific literature. It is important to note that methods for constructing regional climate change scenarios using instrumental observations are based on relatively small temperature changes compared to those expected in the future. Therefore, as a first approximation, these scenarios can only be used as analogs of climatic conditions during the initial phase of warming, which can be expected in the first decades of the 21st century (Budyko et al., 1993; Reichmuth et al., 2025; Saadene & Salhi, 2025).

The brief analytical review above of works on climate changes and methods for their study once again highlights the complex nature and multifaceted direction of research into modern trends in the climate system. The main conclusion is that the fact of changes in both global and regional climates is confirmed. The methods used to develop scenarios of future climatic conditions have different physical and mathematical foundations, which complicates the process of obtaining accurate results. All of this demonstrates that, due to the insufficient understanding of regional climate changes and the inclusion of new data in the series of used elements, the problem under consideration remains relevant both from a practical and a scientific-methodological perspective. Therefore, any research on modern climatic changes will remain relevant for a long time and can contribute scientifically and practically to addressing this issue.

MATERIALS AND METHODS

The methodology used is based on a series of methods (Isaev & Sherstyukov, 1996; Basso & Liu, 2019; Yakushev et al., 2020), and their detailed description is provided in (Safarov, 2000). Here, it is important to note only the following assumptions when using the statistical method:

1) The indicators of the temporal structure of winter air temperature can be divided into two groups. The first group includes characteristics of periodic changes, while the second group encompasses non-periodic changes over various time intervals.

2) The existence of a trend in the long-term dynamics of air temperature is a widely recognized and reliably established fact, and the identification of this trend can be achieved using various methods (Hennemuth, 2013; Wilks, 2011; Yakushev et al., 2020). A necessary condition is the assessment of the correctness of trend identification, and deviations from the moving trend should represent a stationary random process.

3) The success of linear extrapolation will depend both on the measure of change in the calculation period and on the period over which the linear extrapolation is obtained, as the connection between the past and the future gradually weakens over time due to the inclusion of new factors or changes in their nature (Huseynov & Tagiyev, 2024).

The random components of the time series were calculated using Schuster's method and multiple cyclicities, and spectral analysis was conducted to identify short- and long-period fluctuations in these series. Subsequently, the expected values of air temperature residuals were computed. Following this, the overall trend of the expected air temperature values was calculated as the sum of the values obtained from the linear trend and the computed residuals of air temperature. A brief description of the statistical method we used is provided below.

The time series $Y(t)$ is represented as the sum of deterministic ($Y_1(t)$), correlated random ($Y_2(t)$), and uncorrelated random ($Y_3(t)$) components. Given that averaging uncorrelated random variables $Y_3(t)$ over a sufficiently long series yields a value close to zero (Droesch, 2018), the expression can be written as: $Y(t)=Y_1(t)+ Y_2(t)$

To account for earlier observational data, which carry some information about the process, and to assign greater weights to more recent observations compared to earlier data, the method of harmonic weights proposed by Helwig was used.

In this method, the average increment is calculated using the formula:

$$\overline{W} = \sum_{r=1}^{n=1} C_{r+1}^{n} * W_{r+1}$$

$W_{t+1} = Y_1(t+1) - Y_1(t)$

$C_{t+1}^{n} > 0$ *(t=1, 2, ...n-1) and* $\sum_{t=1}^{n-1} C_{t+1}^{n} = 1$

where, W_t+1 - increments of the function Y_1(t); C_{t+1}^{n}>0- harmonic coefficients.

The predicted value of the time series for air temperature, i.e., the extrapolation of the trend for the nearest years under the initial condition Y_t=Y_n, can be determined using the expression (Safarov & Mahmudov, 2011):

$$Y_{t+1} = Y_t + \overline{W} \quad (5)$$

Next, by removing the deterministic component $Y_1(t)$ from the time series *Y*(*t*), a quasi-stationary data series can be obtained, to which methods of multiple cyclicities and Schuster's method can be applied.

Further, considering the regularity of cyclicity in long-term air temperature series and the preservation of their alternation over a certain time interval *t*, the series *X* is divided into *n* segments of length *t*. This procedure should begin from the end of the series. Then, using the method of variance analysis, the contribution of inter-level variance (*St*) to the total variance can be estimated (Sherstyukov, 2008):

$$S_t = \frac{D_1}{D_0} \quad (6)$$

where, D_1 - inter-level variance; D_0 - total variance. To select and evaluate *t*, the following procedure must be carried out.

By varying the value of *t* from 3 to *N*/2 and calculating S_t, we can search for the two largest values of S_t corresponding to t_1 and t_2. The following conditions must be met: t_1 and t_2 should not be multiples of each other, and they should not be adjacent, describing the same cycle (Sherstyukov & Isaev, 1999). After identifying t_1 and t_2, the time series of residuals can be represented as the following harmonic function [45]:

$$\mathrm{Y_2(t) = A_0 + A_1 \cdot \sin\left(\frac{2\pi}{t_1} + \phi_1\right) + A_2 \cdot \sin\left(\frac{2\pi}{t_2} + \phi_2\right)} \quad (7)$$

where, $\mathrm{A_0} = \frac{1}{\mathrm{N}}\sum_{\mathrm{k=1}}^{\mathrm{N}} \mathrm{X_k} = \mathrm{X_{cp}}$, $\mathrm{A_m} = \sqrt{\mathrm{a_m^2 + b_m^2}}$ (8)

$$\mathbf{a_m = \frac{2}{t_m} X_{cp} \cos\frac{2\pi}{t_m}\tau,\ b_m = \frac{2}{t_m} X_{cp} \sin\frac{2\pi}{t_m}\tau,\ \phi_m = arctg\frac{a_m}{b_m}},\ \mathrm{\phi_m = arctg\frac{a_m}{b_m}},\ \mathrm{m=1,\ 2} \quad (9)$$

It should be noted that representing the residuals of the time series as two components is aimed at accounting for both short-period and long-period oscillatory processes. As a result, to develop scenarios for air temperature changes, the extrapolated values obtained using the linear trend and the extrapolated values of the time series residuals are summed. In this case, equation (2) can be written in the following form:

$$T_c = B_T \cdot t + A_T + Y_2(t) \quad (10)$$

Where, B_t and A_t are the coefficients of the linear trend; t is the ordinal number of the year from the beginning of the count (in our case, the beginning of the count is the year 1968, and t=1).

RESULTS AND DISCUSSION

In the scientific literature, it is noted that identifying current trends in climate change and developing future climate change scenarios involve not only general atmospheric circulation models and paleoclimatic analogs but also empirical-statistical methods and instrumental observation data (Droesch, 2018; Ghazi & Jeihouni, 2022; Hansen & Stone, 2016; Magnan, 2021; Lee et al., 2021). In (Perevedentsev et al., 2011; Kreienkamp et al., 2019), the advantages and disadvantages of both physical-mathematical and statistical models of climate change are discussed.

Physical-mathematical models use discretized differential equations with corresponding boundary and initial conditions, which have a physical basis. Statistical models, on the other hand, are not based on physical mechanisms; they are typically developed through the analysis of past meteorological conditions. In (Kreienkamp et al., 2019), it is also noted that harmonic analysis is used to model the dynamics of time series of meteorological elements. It is shown that a general methodology has been developed for the stochastic modeling of meteorological processes, which includes identifying intra-annual and interannual variability of the elements under consideration.

The authors highlight that a set of effective statistical methods has been developed, including methods for separating intra-annual variability into climatic and synoptic components, methods for clipping and smoothing cycle amplitudes to extract different time scales from long-term observational series of climatic characteristics, and methods for classification and constructing spatial linear models. For example, it is demonstrated that manifestations of climate change in long-term time series can take the form of monotonic changes (trends) and harmonic changes, which characterize transitions from one stationary state to another. The most common method for representing cyclic fluctuations is harmonic analysis (Smith & Bustamante, 2018). The guide for using climate scenarios developed based on statistical methods is presented in (Wilby et al., 2004; Zumwald et al., 2020). In (Aurelien et al., 2017), a new statistical approach to detecting and explaining climate changes is discussed, based on additive decomposition and simple hypothesis testing, where procedures for estimation and testing are introduced using maximum likelihood. This approach was applied to the linear trend of global average temperature over the period 1951-2010.

It was substantiated that a significant portion of the observed warming during this period (+0.65 K) was due to anthropogenic influences, with a very limited contribution from natural factors. In (Aurelien, 2018), the question is raised: Can statistical methods predict future climate? Here, statistical models and methods used in climatology to assess the sensitivity of Earth's climate to greenhouse gases based on observations are briefly presented. To this end, the context of climatology is first described, explaining how statistics can interact with the use of climate models. This is followed by a description of the main models used, which are original variants of error-in-variables models.

In (Sherstyukov, 2008), a statistical model of climate change based on rhythms is presented. Here, an analysis of existing atmospheric rhythms over the last 50-70 years was conducted, revealing the presence of rhythms of approximately 6, 8, 12, 16, 17-18, and 35-37 years. Based on numerical experiments, it was established that rhythms shorter than 6 years do not remain unchanged for 20 years, so only long-term rhythms (6 years or more) were used for the stated task.

A detailed analysis of statistical methods for analyzing modeled and observed climate data, applied in projects and institutions dealing with climate change impacts and adaptation, is provided in (Budyko, 1987; Aurelien et al., 2017). An example of statistical modeling related to the consequences of climate change can be found in (Brohan et al., 2006; Mukherjee et al., 2018; Srinivas et al., 2005), where changes in the average monthly sea level at coastal tidal stations along the Indian subcontinent are examined using statistical modeling methods.

In our presented work, the results of testing a statistical method for obtaining some generalized predictive estimates of the average winter air temperature on an annual basis up to 2022 are reviewed and analyzed. As noted in (Sherstyukov, 2008; Chilingar et al., 2009), a full-fledged forecast with such lead time is not possible, but generalized estimates of upcoming climate change trends can be obtained based on statistical methods of analyzing accumulated data. It should be noted that in our earlier studies, the results of a developed scenario for changes in seasonal air temperatures over the territory of Azerbaijan for the coming decades were presented using statistical methods and actual meteorological data for the period 1968-1997, and regional features of expected air temperature values up to 2030 were assessed (Safarov, 2000).

In this article, checking the adequacy of the model refers to the justification of ultra-long-term forecasts of seasonal air temperatures with lead times ranging from 1 year to 33 years. This involves assessing the degree of correspondence between the predicted winter air temperatures and the actually observed temperatures. Naturally, this correspondence decreases as the lead time of the forecast increases (Huseynov et al., 2024).

In (Lapina & Morozova, 2016; Markku, 2016), the issues of the reliability of long-term forecasts for precipitation periods are discussed, and it is demonstrated how criteria and approaches used for evaluating short-term forecasts can be applied to assess the reliability of long-term forecasts. As noted in (Alimpieva & Morozova, 2020), the challenges of long-term and ultra-long-term forecasts for various meteorological elements represent quite complex scientific tasks. It is also highlighted that the reliability of such forecasts remains relatively low, and synoptic and physical-statistical methods are increasingly being used for these tasks. According to the World Meteorological Organization, short-term weather forecasts are considered successful with a reliability of 85-90%, while long-term forecasts are deemed reliable at 60-65% (http://vcgms.ru/eshhe-raz-o-prognozah-pogody-i-ih-opravdy-vaemosti/) [54]. In this study, the following statistical criteria are used to check the adequacy of the model:

1. The correlation coefficient between calculated and actual values;
2. The mean error (ME).

$$ME = \frac{1}{N} \cdot \left(T_{fi} - T_{ci}\right) \quad (11)$$

3. The mean absolute error (MAE);
4. The root mean square error (RMSE).

5. $$RMSE = \sqrt{\frac{1}{N} \cdot \left(\sum_{i=1}^{N} \left(T_{fi} - T_{ci}\right)^2\right)} \quad (12)$$

Where, T_{fi} – actual value of winter temperature; T_{ci} – actual value of winter temperature; N – sample size.

It can be noted that the value of the root mean square error (RMSE) is always somewhat larger than the mean absolute error (MAE), but both characterize the average deviation of the calculated values obtained from the model compared to the actual data. We have also, based on data on the success of the model forecast of average daily air temperature (Steppeler et al., 2003), assessed the reliability of the forecast for given values of absolute error ($\Delta T \leq 1.0^0C$; $\Delta T \leq 2.0^0C$; $\Delta T \leq 3.0^0C$; $\Delta T \leq 4.0^0C$). The calculations used data from the vast majority of meteorological stations located on the territory of Azerbaijan for the period 1968–2022. These data were taken from the meteorological data bank (Safarov, 2002).The winter air temperature data for the period 1968-1997 were used to develop a scenario of expected winter temperatures, while the data for the period 1998-2022 were used to verify the reliability of the obtained scenario values of the considered indicator. In developing the scenario for changes in winter air temperature, preference was given to data averaged over specific physical-geographical zones, as this increases the accuracy of the calculations. Taking this into account, we used data from the following physical-geographical zones of Azerbaijan, based on synoptic-climatic zoning: 1)The Absheron Peninsula and the adjacent marine area; 2)The Lankaran-Astara zone; 3) The Kura-Araz lowland; 4)The Ganja-Gazakh zone; 5)The northeastern slope of the Lesser Caucasus; 6) The southern slope of the Greater Caucasus; 7)The Gobustan zone; 8) The northeastern slope of the Greater Caucasus; 9)The plain part of the Nakhchivan Autonomous Republic; 10)The foothill region of the Nakhchivan Autonomous Republic (Figure 1).

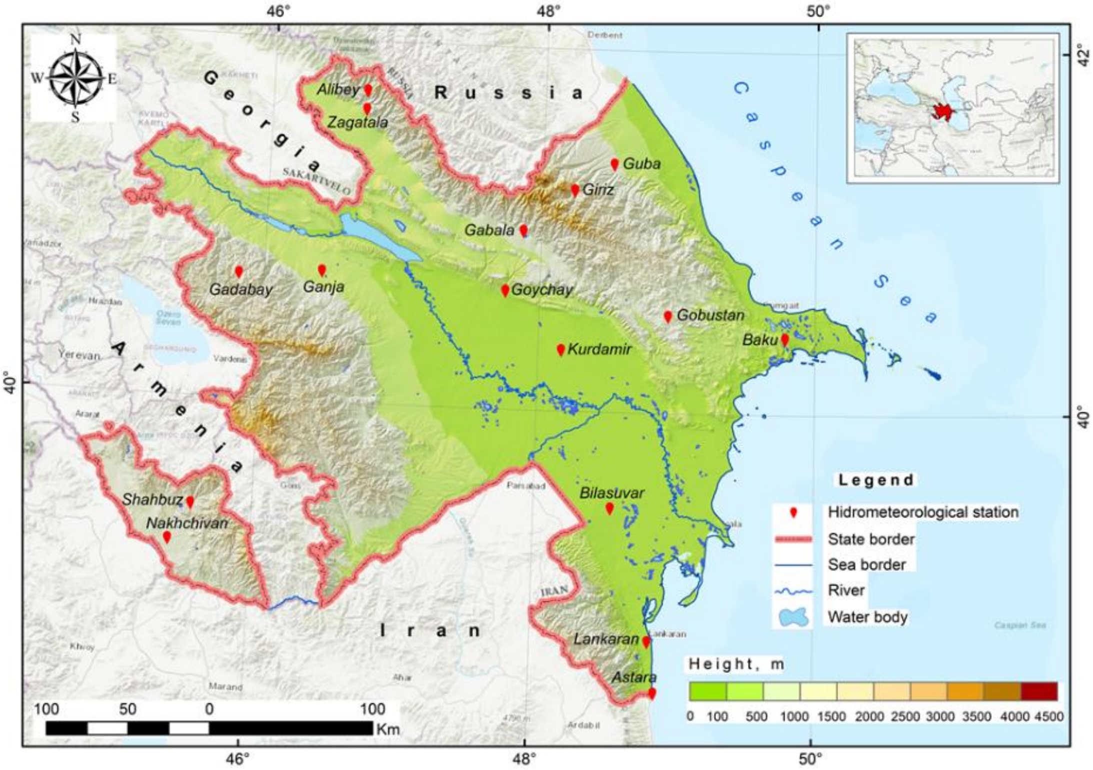

Figure 1. Map of Azerbaijan with the location of the analyzed zones

The comparison results are presented in tabular and graphical form. It is known that the behavior of the climate system exhibits patterns of both short-period and long-period cyclicities, and their alternation within a certain time interval persists. The numerical experiments we conducted, based on spectral analysis of time series of winter air temperature residuals, showed that the optimal approach is the use of a combination of cycles of 6, 9-10, and 14-15 years. Only in the Nakhchivan Autonomous Republic was a combination of 6 and 9-10 year cycles used [9].

To assess the quality of the proposed model, the correlation coefficient between the actual and calculated values of winter air temperature was used (https://studfile.net/preview/2829143). Table 1 presents some statistical characteristics of the linear trend when comparing actual and calculated air temperature values. The following notations are used: r (T_f, T_{1c}): the correlation coefficient between actual and calculated air temperature values based on the linear trend; r (T_f, T_{2c}): the correlation coefficient between actual and calculated air temperature series, obtained as the sum of values derived from the linear trend with weighting coefficients (formula 5) and the approximation of air temperature residuals over the period 1968-1997. The data in Table 1 show that in this season, the values of the linear trend coefficient (B_T) are positive, indicating a trend of increasing air temperature, which varied over a wide range.

The relatively highest values were obtained from observational data in the Ganja-Gazakh zone and the Kura-Araz lowland (B_T=0.05), while the lowest values were observed in the Gobustan zone (B_T=0.01).

Table 1. Statistical characteristics of the linear trend and comparison of actual and calculated values of winter air temperature

Physical-geographical zones	$r(T_f, T_{1c})$	$r(T_f, T_{2c})$	B_T	A_T
Absheron	0.20	0.47	0.02	4.8
Lankaran	0.26	0.45	0.04	4.0
Kura-Araz lowland	0.32	0.36	0.05	3.0
Ganja-Gazakh	0.34	0.54	0.05	1.7
The north-eastern slope of the Lesser Caucasus	0.11	0.57	0.02	-2.3
Southern slope of the Greater Caucasus	0.26	0.52	0.04	-0.1
Gobustans	0.05	0.45	0.01	-0.3
North-eastern slope of the Greater Caucasus	0.22	0.49	0.03	-1.1
Plain part of Nakhchivan AR	0.22	0.61	0.06	-0.2
The foothill part of the Nakhchivan AR	0.16	0.61	0.04	-2.1

Incorporating the dynamics of air temperature residuals into the study of their interannual variability significantly improved the statistical relationship between the calculated and actual series of this element. As seen in Table 1, with the exception of the Kura-Araz lowland (r (T_f, T_{2p}) =0.36), relatively high correlation coefficients were obtained for all zones, ranging from 0.45 to 0.61. The results obtained in (Safarov, 2000) allowed us to use two approaches for assessing possible changes in air temperature up to 2030: 1) Temperature changes averaged over five-year periods, presented in tabular form; 2) Annual temperature change values using graphs, which show the actual long-term dynamics of air temperature for the period 1968-1997, the dynamics of expected values of this element up to 2030, and the linear trend for the period 1968-1997 with its extrapolation up to 2030. In doing so, the assumption was made that extrapolating the anthropogenic trend of air temperature change, associated solely with a uniform increase in CO_2, is considered feasible (Budyko, 1989; Smith & Bustamante, 2018). To verify the reliability of the obtained research results using independent data (from 1998 to 2022), we examined the possibilities of comparing the obtained estimates of both current climatic changes and their expected magnitudes. To test the model using five-year averaged temperature changes, the expected air temperature values were compared with actual data. Averaging was performed for the following climatic periods: 1998-1999; 2001-2005; 2006-2010; 2011-2015; 2016-2020; and 2021-2022.

The correlation coefficient (r) and the absolute error (S_a,^{0}C) of the calculations of expected winter air temperature values were calculated for the zones of the republic. The obtained results are presented in Table 2. As can be seen from Table 2, in the winter season of 1998–2000, the calculated and actual air temperatures are generally close, with absolute errors not exceeding 0.8^{0}C (except for the northeastern slope of the Lesser Caucasus). The model's reliability (R^2) is very high, at 0.965. In the period 2001-2005, the absolute errors of the model are generally close, ranging from 0.3 to 1.8^{0}C (except for the data from the northeastern slope of the Lesser Caucasus), and the model's reliability (R^2) is 0.831. In the period 2006-2010, the absolute errors of the model are also generally close, ranging from 0.1 to 1.5^{0}C (except for the data from the plain part of the Nakhchivan Autonomous Republic), and the model's reliability (R^2) is 0.850.

Table 2. Averaged calculated (T_c) and actual (T_f) values of winter air temperature for different climatic periods across the zones of the republic

Zone	Years											
	1998-2000		2001-2005		2006-2010		2011-2015		2016-2020		2021-2022	
	T_c	T_f	T_c	T_f	T_c	T_f	T_c	T_f	T_c	T_f	T_c	T_f
Absheron	6.4	6.3	5.1	6.2	6.6	5.5	5.5	6.0	6.0	6.7	6.0	7.0
Lankaran	6.4	6.4	4.7	6.5	6.4	5.8	5.6	6.3	6.3	6.8	6.7	7.1
Kura-Araz lowland	5.6	5.1	4.5	4.8	4.4	4.3	5.4	4.7	5.6	5.4	5.0	5.6
Ganja-Gazakh	4.2	4.1	3.1	4.1	4.1	3.3	4.1	3.8	4.4	4.5	4.6	4.8
The north-eastern slope of the Lesser Caucasus	1.9	1.6	0.7	1.3	1.3	1.0	2.0	1.7	1.2	2.1	2.0	3.8
Southern slope of the Greater Caucasus	1.0	1.2	-0.9	0.9	0.4	0.7	0.0	0.9	0.3	1.7	-1.0	2.4
Gobustan	1.0	0.5	-0.9	-0.2	1.2	-0.3	0.0	0.1	0.9	0.7	0.1	2.0
North-eastern slope of the Greater Caucasus	-0.9	0.3	-2.2	0.3	-1.8	-0.4	-0.6	0.1	-1.9	0.2	-2.0	0.5
Plain part of Nakhchivan AR	1.9	2.7	1.5	0.3	2.3	-0.3	1.7	1.6	2.8	2.0	2.8	2.0
The foothill part of the Nakhchivan AR	-0.3	0.0	-0.7	-1.8	-0.1	-1.4	-0.7	0.4	0.4	-0.4	0.3	0.7
R^2 - model confidence value	0.965		0.831		0.850		0.951		0.891		0.847	

In the period 2011-2015, the absolute errors of the model are also generally close, ranging from 0.1 to 1.1^{0}C, and the model's reliability (R^2) is 0.951. In the period 2016-2020, the absolute errors of the model are generally close, ranging from 0.1 to 1.4^{0}C (except for the data from the northeastern slope of the Lesser Caucasus), and the model's reliability (R^2) is 0.891. In the period 2021-2022, the absolute errors of the model are generally close, ranging from 0.2 to 1.8^{0}C (except for the data from the Gobustan zone and the northeastern slope of the Lesser Caucasus), and the model's reliability (R^2) is 0.847. Across all zones and climatic periods (10 zones × 6 climatic periods = 60 cases), in 44 cases (73 %), the absolute calculation errors were $\Delta T \leq 1.0^0C$, and in 58 cases (97 %), $\Delta T \leq 2.0^0C$. These data and the model's reliability indicate that the proposed model adequately describes changes in winter temperature, averaged over two-, three-, and five-year periods, and can be used to develop a scenario for changes in average winter air temperature over the next 20-25 years.

Verification of the model's reliability based on annual temperature change values using graphs. These graphs (Figures 2-11) present the actual long-term dynamics of air temperature for the period 1968-2022, the dynamics of expected values of this element up to 2030, and the linear trend for the period 1968-1997 along with its extrapolation up to 2030.

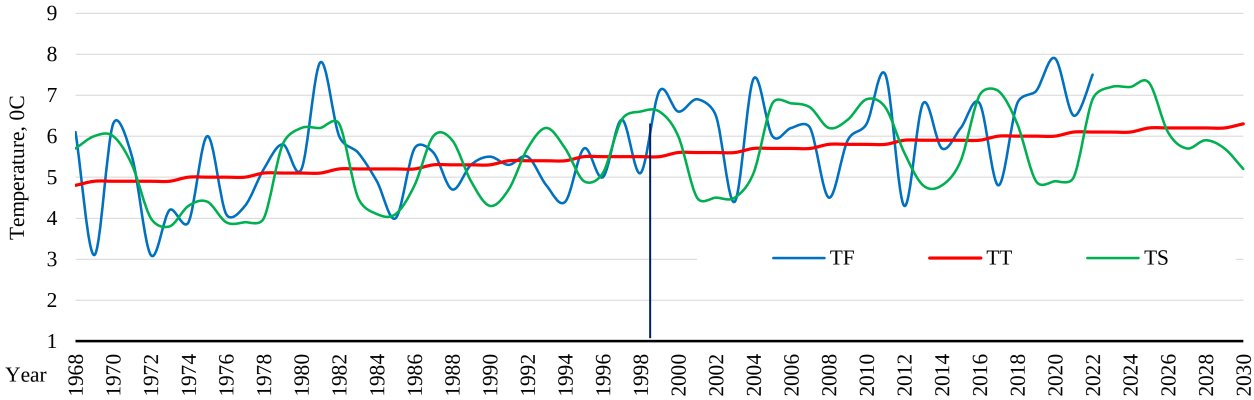

Figure 2. Actual (TF), expected (TS) values, and linear trend (TT) of winter air temperature on the Absheron Peninsula (Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

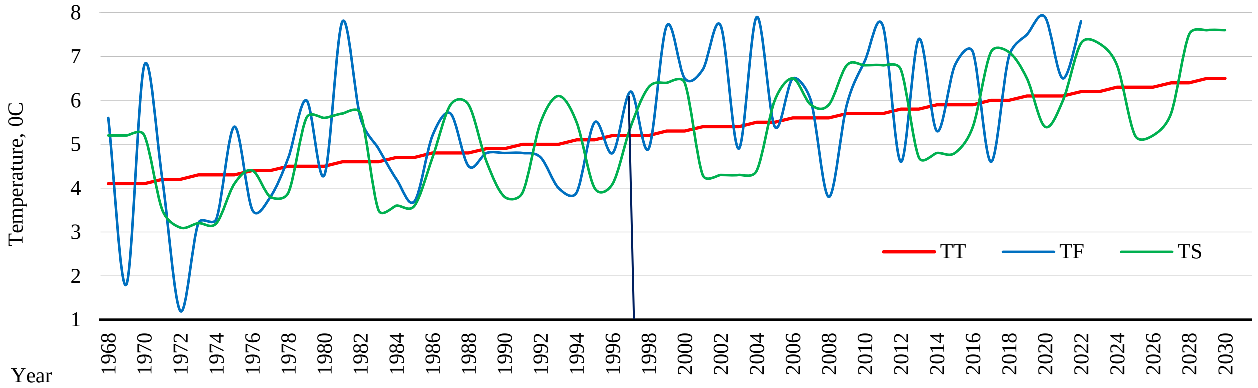

Figure 3. Actual (TF), expected (TS) values, and linear trend (TT) of winter air temperature in the Lankaran-Astara zone (Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

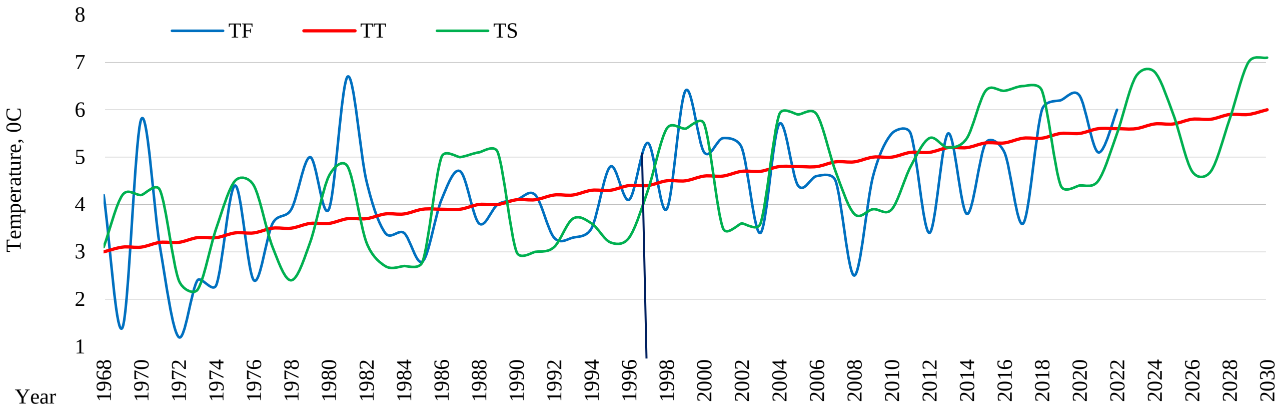

Figure 4. Actual (TF), expected (TS) values, and linear trend (TT) of winter air temperature in the Kura-Araz lowland (Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

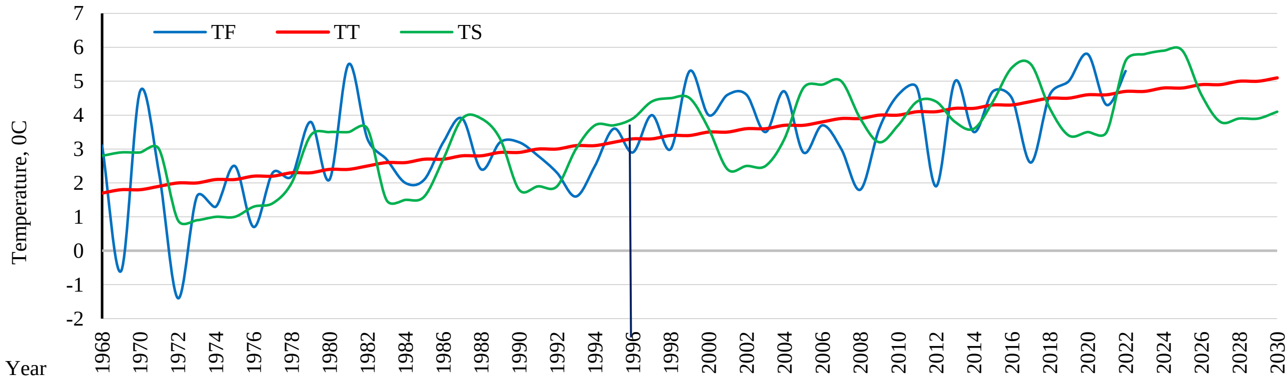

Figure 5. Actual (TF), expected (TS) values, and linear trend (TT) of winter air temperature in the Ganja-Gazakh zone (Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

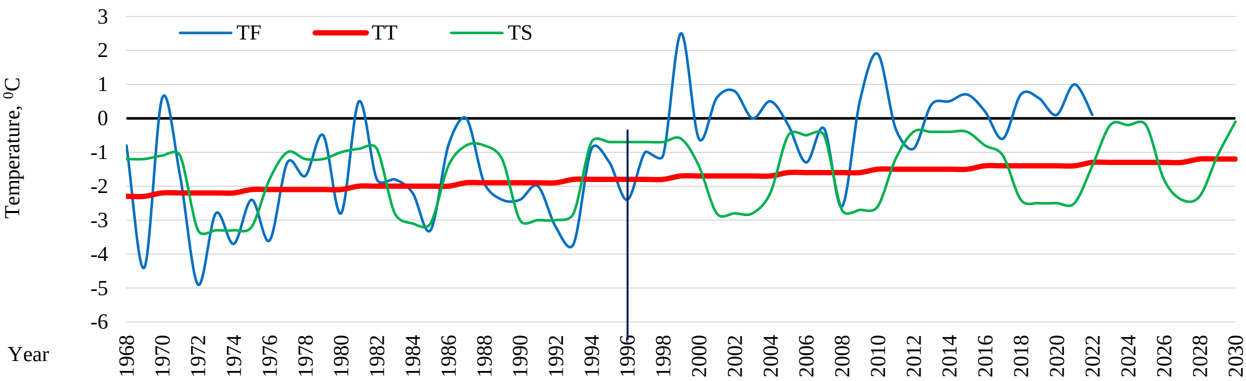

Figure 6. Actual (TF), expected (TS) values, and linear trend (TT) of winter air temperature on the northeastern slope of the Lesser Caucasus (Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

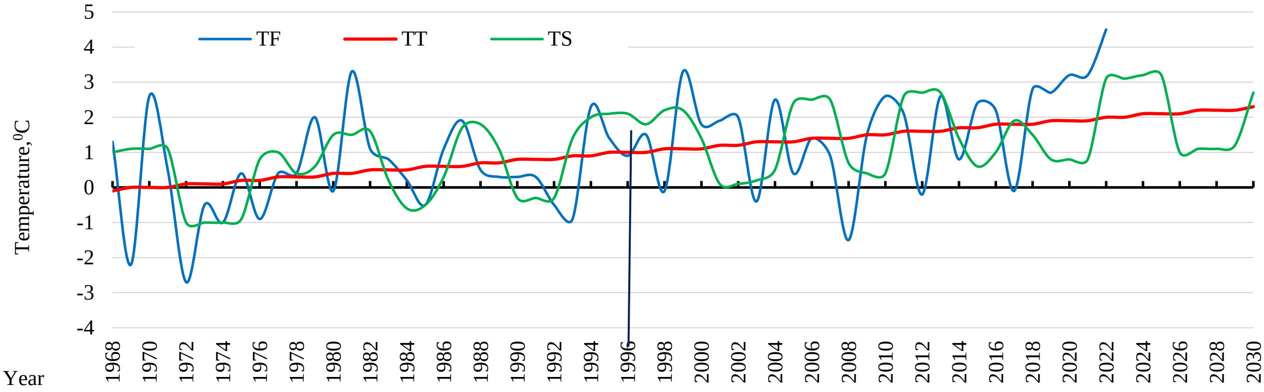

Figure 7. Actual (TF), expected (T) values, and linear trend (TT) of winter air temperature on the southern slope of the Greater Caucasus (Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

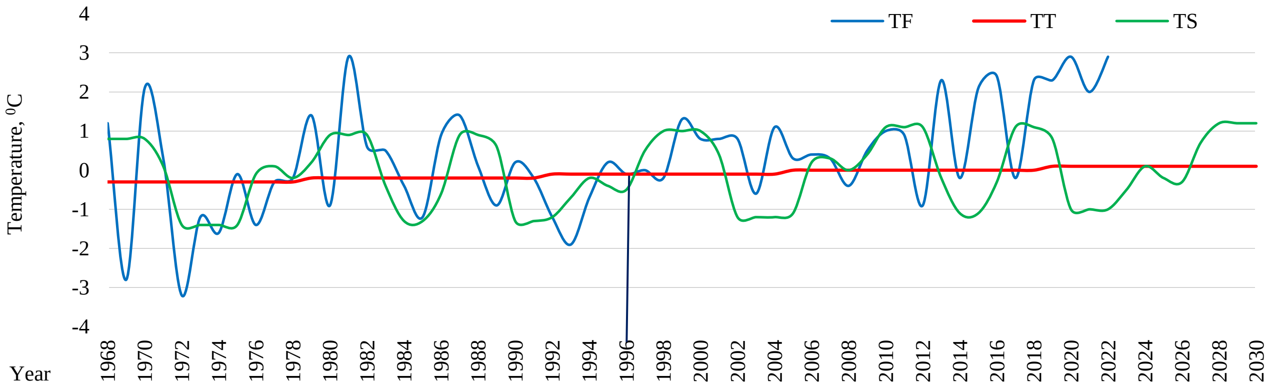

Figure 8. Actual (TF), expected (TS) values, and linear trend (TT) of winter air temperature in the Shamakhi-Gobustan zone (Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

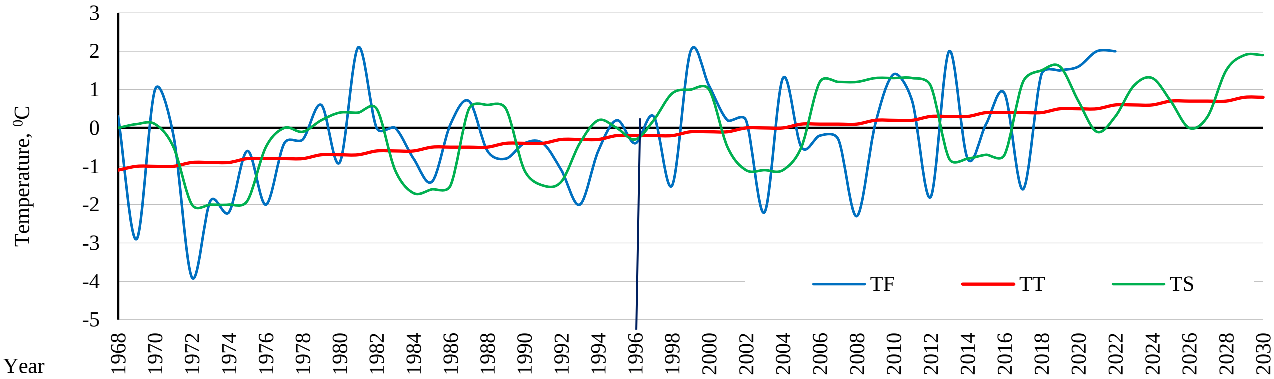

Figure 9. Actual (TF), expected (TS) values, and linear trend (TT) of winter air temperature on the northeastern slope of the Greater Caucasus (Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

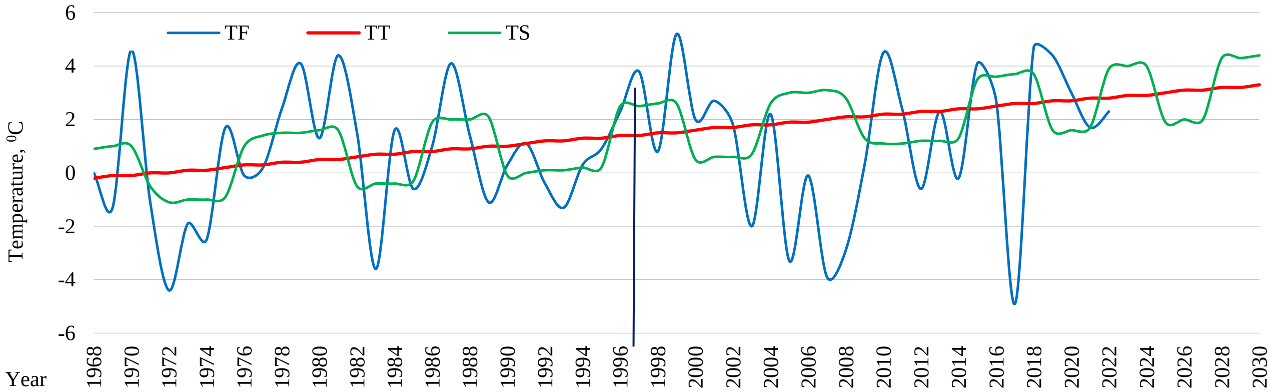

Figure 10. Actual (TF), expected (TS) values, and linear trend (TT) of winter air temperature in the plain part of the Nakhchivan AR (Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

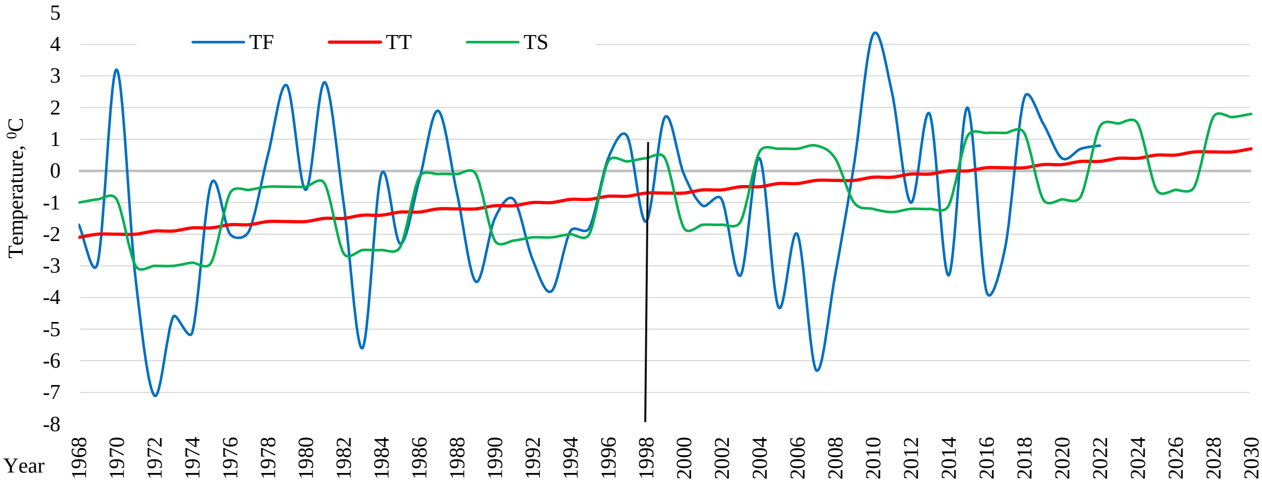

Figure 11. Actual (TF), expected (TS) values, and linear trend (TT) of winter air temperature in the foothill part of the Nakhchivan Autonomous Republic (Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

The graphical representation of the comparison between actual (*TF*) and calculated (*TS*) values of winter air temperature also confirms the adequacy of the statistical model we used. Table 3 presents the success indicators of the model scenario for average winter air temperature in various physical-geographical zones of Azerbaijan.

Table 3. Indicators of the success of the model scenario for average winter air temperature, ^{0}C
(Source: Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, Hydrometeorological station data)

Physical-geographical zones	MSE	MAE	RMSE	Scenario reliability at a given absolute error value, %			
				ΔT≤1.0	ΔT≤2.0	ΔT≤3.0	ΔT≤4.0
Absheron	0.5	1.2	1.4	56	80	100	100
Lankaran	0.6	1.3	1.7	52	68	92	100
Kura-Araz lowland	-0.2	1.1	1.3	44	96	100	100
Ganja-Gazakh	0.0	1.3	1.5	48	76	100	100
The north-eastern slope of the Lesser Caucasus	1.7	1.7	2.2	52	60	68	96
Southern slope of the Greater Caucasus	0.3	2.0	2.3	32	48	72	100
Gobustan	1.0	1.4	1.9	44	72	88	100
North-eastern slope of the Greater Caucasus	-0.1	1.3	1.7	44	72	96	100
Plain part of Nakhchivan AR	-1.0	2.5	3.3	24	60	76	84
The foothill part of the Nakhchivan AR	-0.3	2.4	2.9	24	60	68	84

From Table 3, it can be seen that for an absolute error of $\Delta T \leq 1.0^0C$, the reliability of the winter air temperature change scenario ranges from 24 % to 56 %. For $\Delta T \leq 2.0^0C$, it ranges from 60 % to 96 % (except for data from the southern slope of the Greater Caucasus). For $\Delta T \leq 3.0^0C$, it ranges from 68 % to 100 %, and for $\Delta T \leq 4.0^0C$, it ranges from 84 % to 100 %. As mentioned earlier, according to the World Meteorological Organization, long-term forecasts with a reliability of 60-65 % are considered successful (http://vcgms.ru/eshhe-raz-o-prognozah-pogody-i-ih-opravdy-vaemosti/). Based on this, it can be concluded that the scenario of winter air temperature changes developed using the proposed model is adequate, as even for $\Delta T \leq 2.0^0C$, the reliability of the scenario or conditional forecast ranges from 60 % to 96 %.

From Table 3, it can be seen that for an absolute error of $\Delta T \leq 1.0^0C$, the reliability of the winter air temperature change scenario ranges from 24 % to 56 %. For $\Delta T \leq 2.0 \circ C$, it ranges from 60% to 96 % (except for data from the southern slope of the Greater Caucasus). For $\Delta T \leq 3.0^0C$, it ranges from 68 % to 100 %, and for $\Delta T \leq 4.0^0C$, it ranges from 84 % to 100%. As mentioned earlier, according to the World Meteorological Organization, long-term forecasts with a reliability of 60-65% are considered successful [54, 55]. Based on this, it can be concluded that the scenario of winter air temperature changes developed using the proposed model is adequate, as even for $\Delta T \leq 2.0^0C$, the reliability of the scenario or conditional forecast ranges from 60 % to 96 %.

CONCLUSION

The obtained results generally indicate that the proposed methodology for developing a scenario of future winter air temperature changes is sufficiently adequate and can be used as one of the options for solving various climatic tasks. It can also be said that for the regional assessment of possible air temperature changes, an approach based on the methods of least squares, harmonic weights, Schuster's method, and multiple cyclicities was applied. The methodology used, compared to the linear trend, can more accurately describe the main patterns of temporal changes in air temperature and, thus, their expected future values. This is because the linear trend only describes possible trends in changes of this element and largely characterizes a qualitative picture. The use of periodic patterns in air temperature time series, along with the application of the linear trend, more satisfactorily describes both the trend of changes and their assessment.

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