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Assessment of the reliability of a statistical model for developing a scenario of possible air temperature changes in the spring season over the territory of Azerbaijan

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ABSTRACT

Problem Statement. This study validates statistical estimates of Azerbaijan's mean spring temperatures up to 2022. Although precise long-term forecasts remain difficult, analysis of meteorological data from 1968–2022 demonstrates that statistical methods effectively capture regional spring temperature trends and provide a reliable basis for future climate research and scenario development.

Purpose. The study aims to develop a statistical spectral model that reliably identifies climate-induced changes in meteorological elements, particularly air temperature. The model employs optimized analytical methods whose adequacy is verified through comparisons of observed and calculated temperature series using smoothing techniques, Schuster tests, and correlation analyses. Establishing this model and its optimal application enhances the development of regional climate models and scenarios, improving the reliability of projected climatic trends.

Methods. The methodology is based on analyzing long-term air temperature series, classified into periodic and non-periodic variability indicators, the latter being useful for studying future temperature changes. Given the non-stationary nature of meteorological variables, trends in long-term series are treated as reliable, but series must first be transformed into stationary sequences for analysis using statistical techniques. Extrapolating observed trends beyond a few years is physically unreliable due to natural variability; thus, only anthropogenic trends linked to CO_2 increases are suitable for climate scenario development. Additionally, the length of meteorological records is critical, as classical climatology assumes stationarity and estimation accuracy improves with longer observational series.

Results. Spectral analysis revealed dominant 3-, 5-, and 7–9-year temperature cycles across most of Azerbaijan, while Nakhchivan exhibited only 3- and 9-year cycles. The model showed strong agreement between observed and simulated spring temperatures, with R^2 values of 0.906 (1998–2000), 0.953 (2001–2005), and 0.933 (2006–2010). Error assessment showed that 36–56% of cases had $\Delta T \leq 1$°C, 76–88% had $\Delta T \leq 2$°C, and nearly all cases had $\Delta T \leq 3$–4°C. For $\Delta T \leq 2$°C, the forecast accuracy reached 76–94%, confirming the reliability of the proposed spring temperature scenario.

Conclusions. Using a statistical spectral model, a new scenario of spring temperature change for Azerbaijan was developed. Projections recalculated from linear trend equations for 1968–2010 demonstrate higher accuracy compared with earlier approaches, and the post-2023 estimates can be treated as updated climate scenarios, improving the reliability of future assessments. A five-year (2026–2030) averaged spring temperature map for the country's physiographic zones was also compiled. Overall, the model offers a robust and scientifically grounded basis for future spring temperature projections and broader climate-related analyses.

Keywords*: Statistical model, climate change, climate scenario, spring air temperature, periodicity, physiographic zones, model adequacy.*

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Introduction. Current evidence confirms that anthropogenic influence is driving a global-scale warming process in the Earth's atmosphere [4]. This warming is expected to intensify significantly in the coming decades [11]. The facts of modern climate change have been established through analysis of meteorological observation data from the past 165 years (since 1860) using various methods [3, 8].

Research on contemporary global warming reveals that the dynamics of average annual temperatures in the Northern Hemisphere correlate with fluctuations in atmospheric transparency, as well as changes in carbon dioxide and other greenhouse gas concentrations [1; 19]. Consequently, 20th-century climate changes were largely determined by the increasing rate of greenhouse gases, a trend likely to persist in the future [9, 13].

These findings have compelled scientists, business leaders, and policymakers worldwide to recognize climate as a critical natural resource. The uneven distribution of this resource among nations has already led to significant socio-economic and political consequences, as reflected in the demands of international organizations like the UNFCCC (COP) [22, 24].

The resolution of climate change-induced challenges remains a focal point of intensive research within global political, scientific, and economic spheres [17]. Within the framework of international cooperation on climate change adaptation and mitigation measures, the Republic of Azerbaijan signed the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and ratified it in 1995. Over the past 25-30 years, intensive research has been conducted in Azerbaijan on various aspects of regional climate change [24].

In this regard, one of the most critical directions in contemporary climate change research involves determining its projected or potential future values. The foundation of such forecasting lies in general atmospheric circulation models, paleoclimate analog methods based on historical climate variations, and statistical prediction methods. The first two approaches successfully employ statistical techniques grounded in instrumental observational data. The evaluation of anticipated future climate changes through these methodologies is formally recognized in scientific literature under the term "climate scenarios" [18].

Some sources note that climate scenarios are not intended for predicting future climate. Therefore, climate scenarios can primarily provide a schematic representation of possible future climatic conditions. They may also serve as a fundamental basis for assessing the impact of potential climate changes on economic sectors [17].

However, it should be noted that most climate change scenarios have been developed for the entire planet or the Northern Hemisphere. Consequently, the most realistic methods for constructing climate change scenarios must undergo refinement and detailing when applied to specific regions and localities.

The statistical spectral models employed in this research are not based on physical mechanisms but are typically developed through analysis of historical meteorological conditions. Furthermore, harmonic analysis is utilized here to model the dynamics of meteorological element time series. A general methodology has been developed for stochastic modeling of meteorological processes, which includes determining the interannual and intra-annual variability of the elements under consideration. The manifestation of climate change in long-term time series may take the form of monotonic variations (trends, etc.) or harmonic oscillations characterizing transitions between stationary states. Harmonic analysis represents the most widely used method for detecting periodic fluctuations [6, 14].

The guidelines for using climate scenarios developed through statistical methods are provided in reference document [21]. Study [2] presents a new statistical approach for detecting and explaining climate change based on additive decomposition and simple hypothesis testing, utilizing maximum likelihood estimation, evaluation and testing procedures. This approach was applied to the linear trend of global mean temperature during 1951-2010, where the observed warming (+0.65 K) is claimed to be primarily associated with anthropogenic influences.

The calculations utilized data from the absolute majority of meteorological stations located in Azerbaijan's territory for the period 1968-2022. These data were obtained from the meteorological database [8, 20]. The mean seasonal air temperature data for 1968-1997 were used to develop the projected spring temperature scenario, while the 1998-2022 data were employed to verify the reliability of the obtained scenario values for the considered parameter.

When developing the spring temperature scenario, preference was given to averaged data across all physiographic zones of the country [12], as this method increases calculation accuracy. In this context, the following physiographic zones of the republic were selected considering synoptic and climatic regionalization: 1. Absheron zone; 2. Lankaran-Astara zone; 3. Kura-Araz lowland; 4. Ganja-Gazakh zone; 5. Northeastern slope of Lesser Caucasus; 6. Southern slope of Greater Caucasus; 7. Shamakhi-Gobustan zone; 8. Northeastern slope of Greater Caucasus; 9. Plain part of Nakhchivan AR; 10. Foothill part of Nakhchivan AR.

Analysis of recent research. The article verifies results obtained through statistical methods to derive some generalized prognostic estimates of multiannual mean spring temperatures for the period up to 2022. It is not possible to produce reliable forecasts for such an extended lead time period. However, through statistical analysis of accumulated data, it is possible to obtain generalized assessments of future climate change trends.

In our previous studies, using statistical methods based on observational data covering the period 1968-1997, we developed scenarios of air temperature variations for different periods (seasonal, annual) in the territory of Azerbaijan for the coming decades. Additionally, we assessed the regional characteristics of projected air temperature indicators up to 2030 [19].

Highlighting previously unsolved parts. In previous studies conducted in the territory of the Republic of Azerbaijan, climate change has been investigated through the dynamics of time series of local climatic elements and their fluctuation characteristics [15]. Such research has examined formation features of atmospheric precipitation across different time periods, regional variations, and spatiotemporal changes. Recent studies have focused more prominently on comparative analyses with various climatic norms [22].

While these investigations have identified impacts of climate change, the expected variations in specific regions remain undetermined to date. Although international climate models provide scenarios based on certain characteristics of time series, they have largely overlooked local climatic features and physiographic conditions. Consequently, this study employs a statistical spectral model to comprehensively analyze spring temperature variations.

The foundation of the research methodology consists of a series of methods comprehensively explained in the text with reference [16, 21].

However, since the climate system's transformation process is non-stationary, there exists uncertainty regarding how long the meteorological time series should be. Therefore, the accuracy of linear extrapolation depends heavily both on the length of the calculation period and on the duration of the linear extrapolation extension. This is because the relationship between past and future weakens over time. This weakening is linked to either the introduction of new factors into the research or changes in the nature of their influence.

Based on this methodology, the determination of the linear trend equation-that is, the selection of the deterministic component and the estimation of its parameters-was implemented using the least squares method. The extrapolation of the linear trend was used to calculate projected annual temperature values ($T_1(t)$) for future periods.

To compute the stochastic component of the temperature series, spectral analysis was employed to identify the periodicities of short- and long-phase fluctuations within the series. The influence of the calculation period length on these computations was accounted for using the harmonic weighting method.

Then, the values calculated by the trend equation were subtracted from the general series to obtain the temperature residuals. Subsequently, using Schuster and periodicity methods, the projected temperature values ($T_2(\mathbf{t})$) were computed. It should be noted that the temperature series may also contain an uncorrelated random component ($T_3(t)$). Following these procedures, the overall trend of projected air temperature values was calculated as the sum of these temperatures:

$$T(t) = T_1(t) + T_2(t) + T_3(t). \quad (1)$$

Let us examine the components of equation (1). First, we note that averaging uncorrelated random variables $Y_3(t)$ over a sufficiently long series yields values approaching zero [21]. The equation represents the linear trend of the multiannual temperature series.

$$Y_1(t) = A_T \cdot t + B_T. \quad (2)$$

The temperature residual values calculated by equation (3):

$$Y_2(t) = A_0 + A_1 \cdot sin\left(\frac{2\pi}{t_1} + \phi_1\right) + A_2 \cdot sin\left(\frac{2\pi}{t_2} + \phi_2\right) + A_3 \cdot sin\left(\frac{2\pi}{t_3} + \phi_3\right), \quad (3)$$

where,

$$A_0 = \frac{1}{N}\sum_{k=1}^{N} T_k = \overline{T}, A_m = \sqrt{a_m^2 + b_m^2}, \ \ m = 1,2,3. \quad (4)$$

$$a_m = \frac{2}{t_m} \cdot \overline{T} \cdot cos\frac{2\pi}{t_m}\tau, b_m = \frac{2}{t_m} \cdot \overline{T} \cdot sin\frac{2\pi}{t_m}\tau, \phi_m = arctg\frac{a_m}{b_m}, \ \ m = 1,2,3. \quad (5)$$

where, $\boldsymbol{\tau}$ - serial number of years; $\bar{\boldsymbol{T}}$ - mean multiannual temperature; t_1, t_2, t_3- represent values of short-, medium-, and long-phase fluctuations in the temperature residual series, respectively.

Let us note that presenting the temperature residual series as the sum of three components is related to accounting for short, medium, and long-phase fluctuations. In this case, t_1, t_2, and t_3 must not be divisible by each other and should not be in adjacent positions describing the same cycle. Fulfilling these specified conditions is crucial. The calculation procedure for them is provided in [19].

Consequently, to develop and prepare the air temperature variation scenario, the values obtained through the linear trend are summed with the extrapolated values of the multiannual series residuals.

$$T_c = A_T \cdot \tau + B_T + T_2(t). \quad (6)$$

The computational experiments conducted based on spectral analysis of time series of mean spring temperature residuals have demonstrated that the optimal approach involves utilizing a combination of 3, 5, and 7-9 year cycles. However, in the Nakhchivan, only a combination of 3 and 9-year cycles was employed [20].

To evaluate the quality of the proposed model, the correlation coefficient between actual and calculated values of mean spring temperatures was computed [25]. Table 1 presents some statistical characteristics of the linear trend:

$r(T_f,T_{1h})$ - correlation coefficient between actual air temperature (T_f) and temperature calculated based on linear trend (T_{1h});

$r(T_f,T_{1h})$ - correlation coefficient between the actual air temperature (T_f) and the temperature represented as the sum of the linear trend and multiannual series harmonic residuals $r(T_f,T_{2h})$;

A_T and B_T - coefficients of equation (6) for the 1968-1997 time interval.

Table 1 shows that the values of r (T_f,T_{1h}) indicate a long-term negative trend in spring temperature series during 1968-1997 across all zones except Ganja-Gazakh and Lankaran-Astara. Generally, the rate of temperature change is low, as confirmed by the small values of the linear trend and coefficient A_T.

The application of equation (6) for estimations significantly improved the statistical relationship between calculated and actual series of this element, meaning the calculated values better approximate the observed values. The correlation coefficients r (T_f, T_{2h}) range between 0.39-0.64. These results are further corroborated by the graphical data pre-

Table 1

Statistical characteristics of linear trends for spring temperature series

Physiographic Zones	$r(T_f,T_{1h})$	$r(T_f, T_{2h})$	A_T	B_T
Absheron	-0.18	0.45	-0.02	11.7
Lankaran-Astara	0.01	0.44	-0.00	12.5
Kura-Araz lowland	-0.03	0.44	0.00	13.6
Ganja-Gazakh	0.06	0.44	0.01	12.1
Northeastern slope of Lesser Caucasus	-0.07	0.42	-0.01	5.8
Southern slope of Greater Caucasus	-0.06	0.44	-0.01	-0.01
Shamakhi-Gobustan	-0.22	0.50	-0.03	-0.03
Northeastern slope of Greater Caucasus	-0.11	0.44	-0.01	-0.01
Plain part of Nakhchivan	-0.16	0.51	-0.02	-0.02
Foothill part of Nakhchivan	-0.29	0.64	-0.04	-0.04

sented in Figures 1 (a, b, c, d, e, f, g, h, s, t).

The graphs in the figures display the projected annual values of mean spring temperature, while Table 2 provides the five-year averaged projected values. These data indicate relatively minor temperature variations from one five-year period to another.

Verification of model adequacy. Verification of model adequacy involves validating the long-term seasonal air temperature scenario over periods ranging from 1 to 33 years, specifically examining the degree of agreement between predicted spring temperatures and actual observed values. Naturally, as the forecast period lengthens, this agreement diminishes [26]. The problems of multiannual and long-term forecasting of various meteorological elements represent sufficiently complex scientific tasks. It is also indicated here that the accuracy of such forecasts still remains at a relatively low level. In addressing these issues, synoptic and physical-statistical methods are being increasingly utilized.

According to the World Meteorological Organization, short-term weather forecasts with 85-90% accuracy and long-term forecasts with 60-65% accuracy are considered successful [18]. In this study, the following statistical criteria were used to verify the model's adequacy:

1. The correlation coefficient between calculated and actual air temperature values;
2. Mean Absolute Error (MAE):

$$MAE = \frac{1}{N} \cdot (T_{fi} - T_{hi})$$

3. Root Mean Square Error (RMSE):

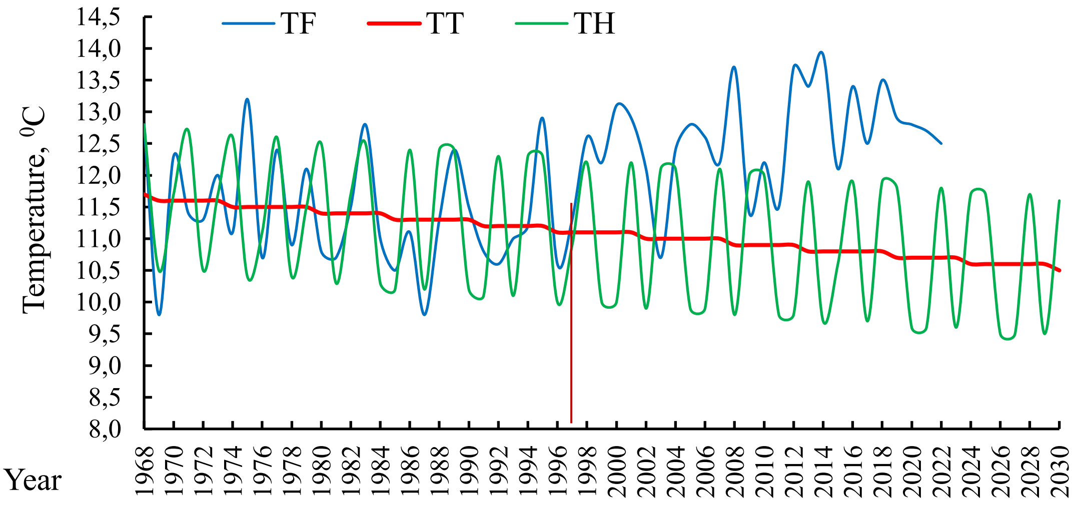
$$RMSE = \sqrt{\frac{1}{N} \cdot \left(\sum_{i=1}^{N} (T_{fi} - T_{hi})^2\right)}$$

Here, T_{fi} - actual value of spring temperature by year; T_{hi} - calculated value of spring temperature by year; N - represents the length of the calculation period.

The study also utilized specified absolute error criteria (ΔT≤1.0°C; ΔT≤2.0°C; ΔT≤3.0°C; ΔT≤4.0°C) for validating the model forecast of mean daily air temperature [14] to assess the reliability of the developed scenario (long-term forecast).

The above results employed two scenario variants to assess potential temperature changes in the summer season up to 2030:

1. Temperature variations averaged over five-year periods, presented in tabular form;
2. Projected annual dynamics of this element's values through 2030. In this case, the analysis incorporated the hypothesis that extrapolation



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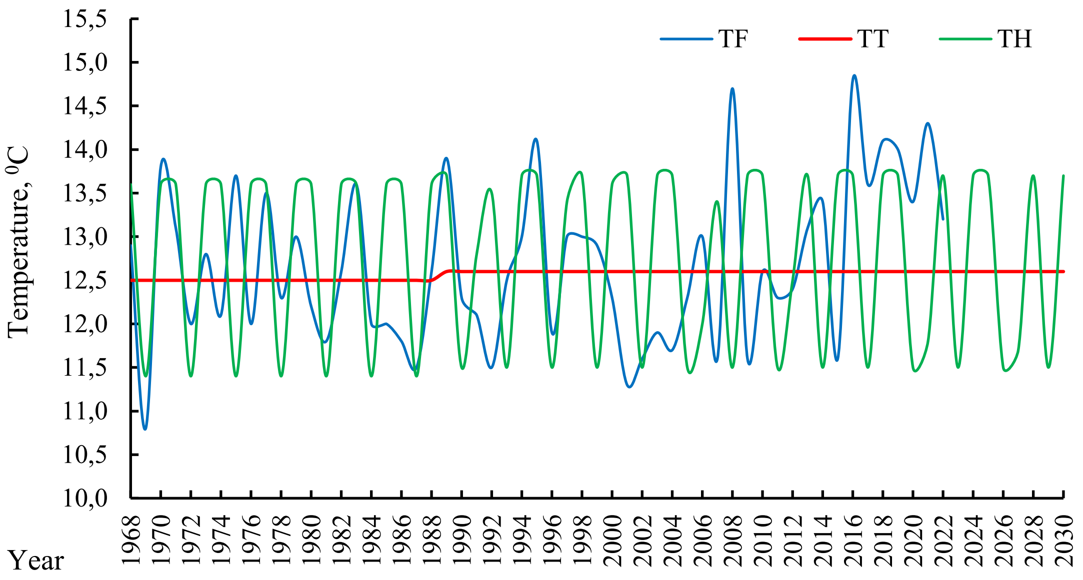
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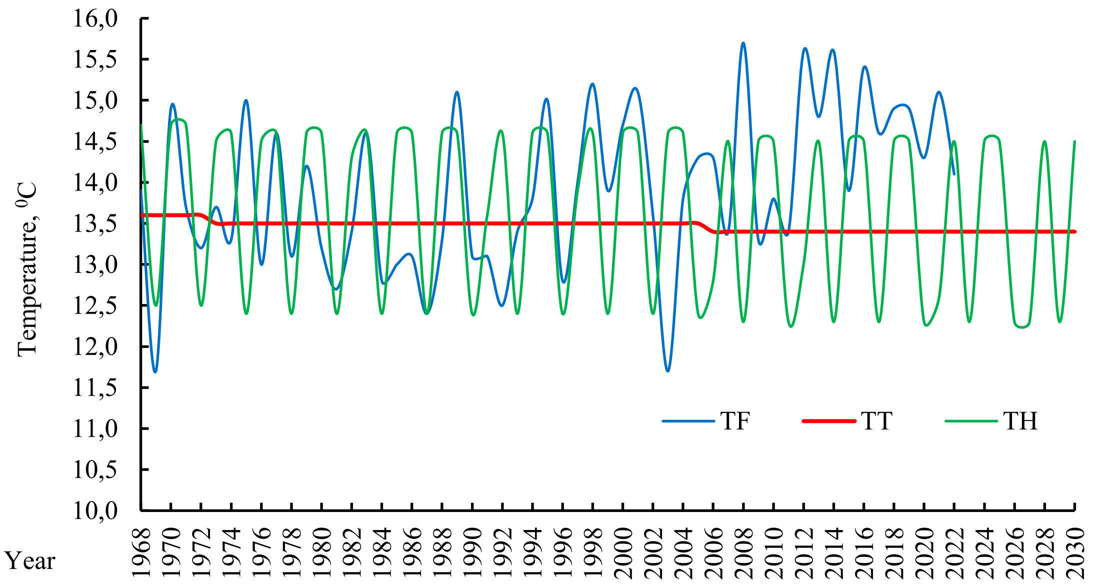
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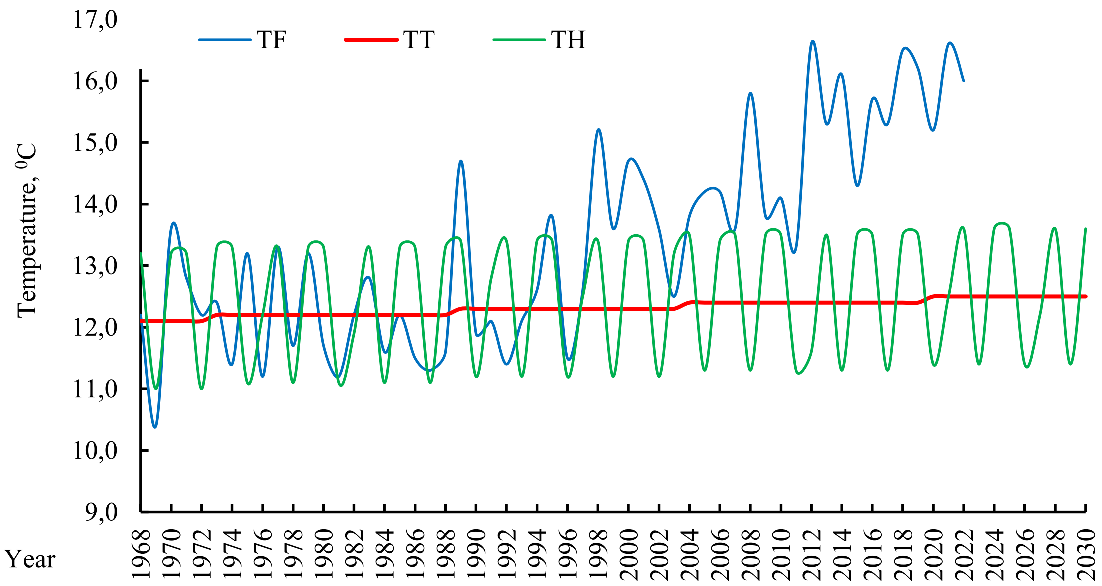
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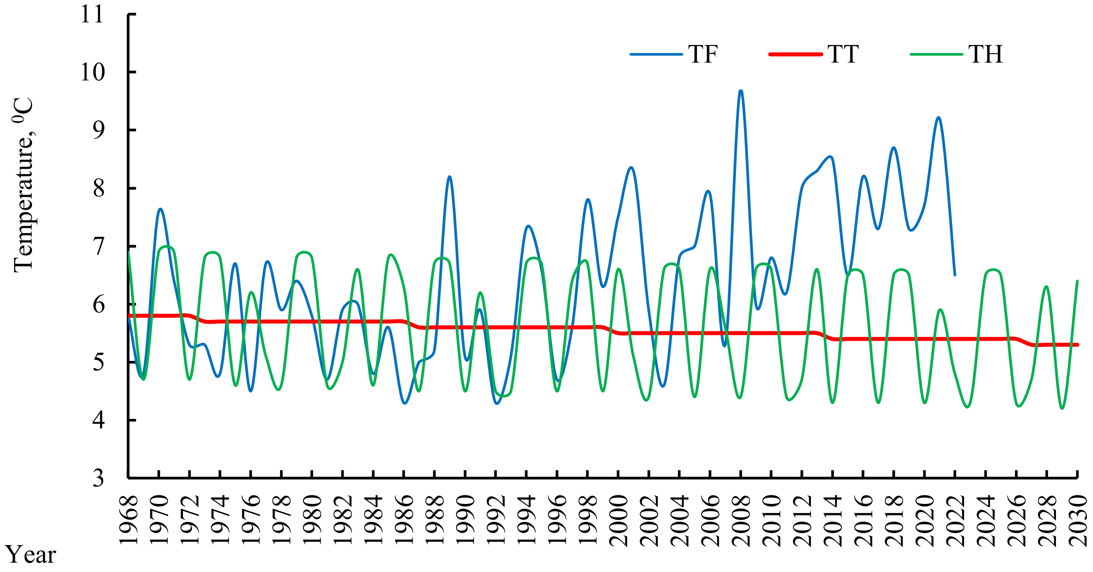
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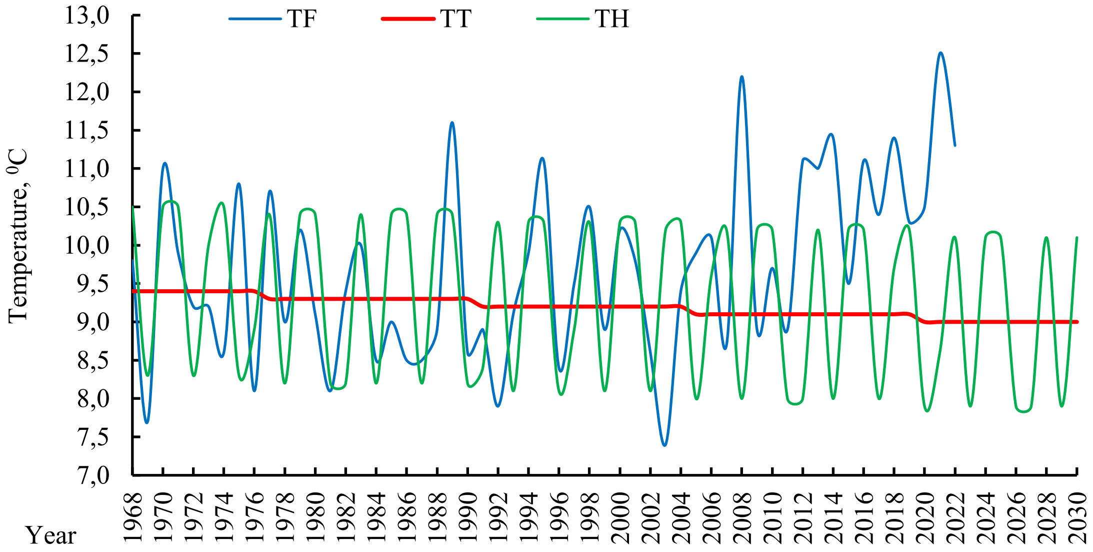
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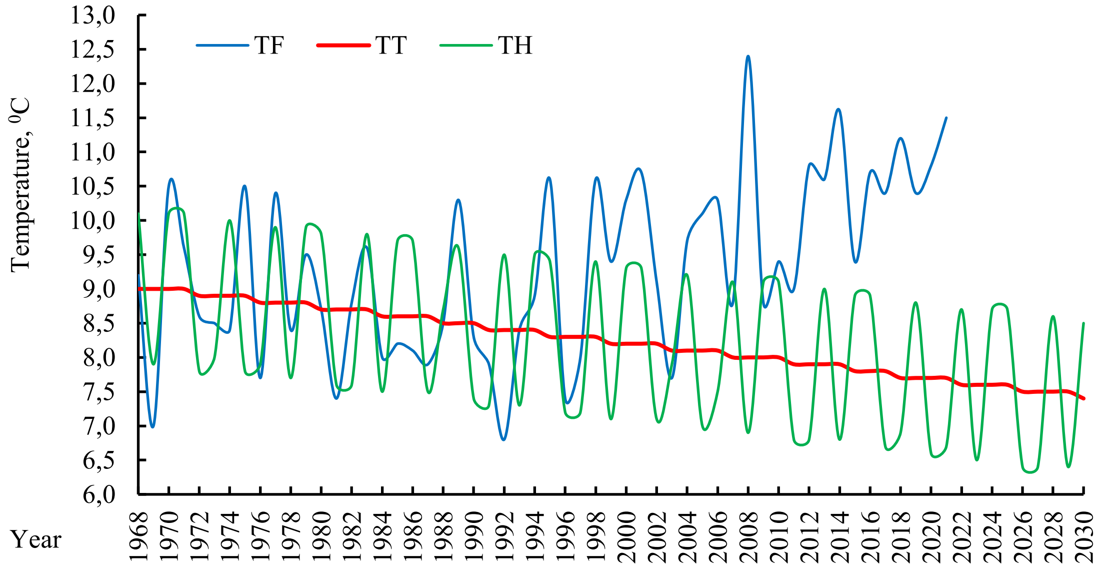
f)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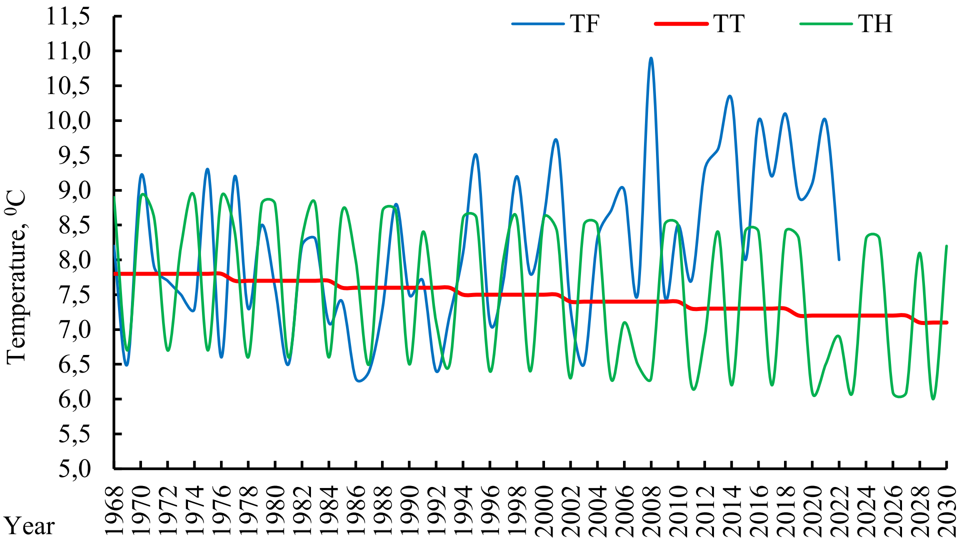
Year

g)



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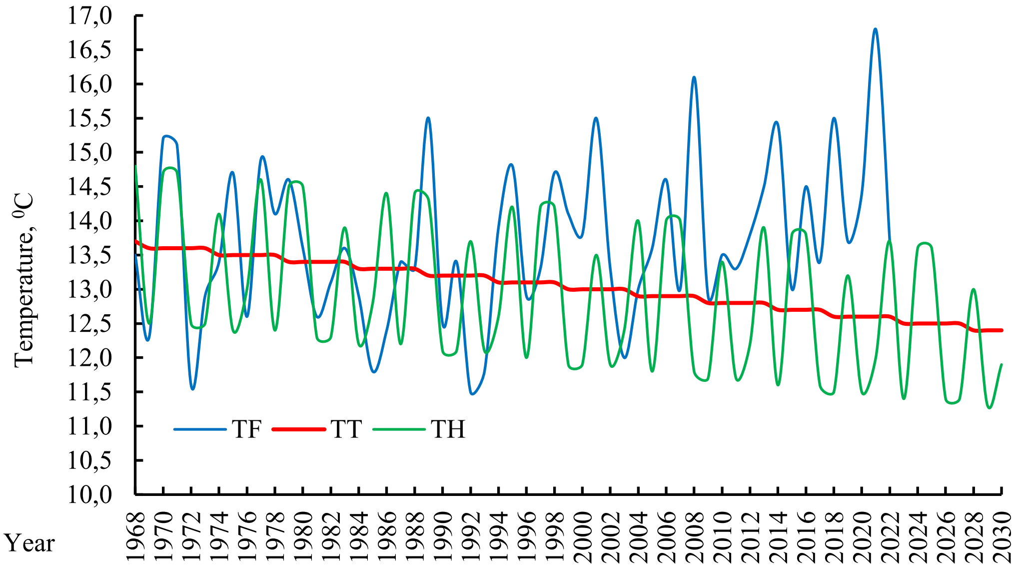
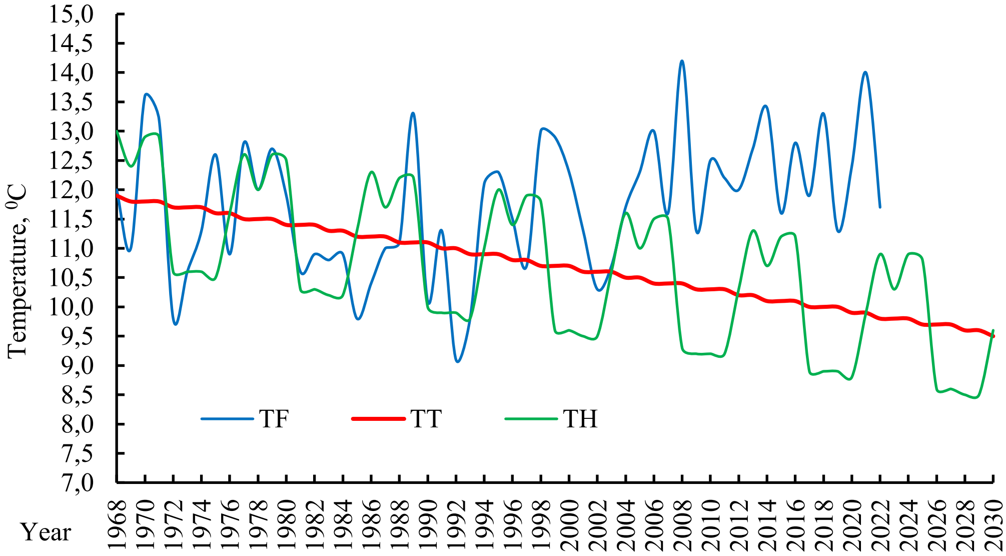


s)



t)

Fig. 1. Multiannual dynamics of actual (TF), calculated (TH) and linear trend (TT) values of spring air temperature for Absheron (a), Lankaran-Astara (b), Kura-Araz lowland (c), Ganja-Gazakh (d), northeastern slope of Lesser Caucasus (e), southern slope of Greater Caucasus (f), Shamakhi-Gobustan (g), northeastern slope of Greater Caucasus (h), plain area of Nakhchivan (s) and foothill area of Nakhchivan (t) (1968-1997)

Table 2

Scenario of projected mean spring temperature values in Azerbaijan for 2001-2030

Physiographic Zones	Five-year periods					
	2001-2005	2006-2010	2011-2015	2016-2020	2021-2025	2026-2030
Absheron	11.2	11.2	10.4	11.0	10.9	10.4
Lankaran-Astara	12.8	12.9	12.6	12.8	12.9	12.4
Kura-Araz lowland	13.7	13.7	13.3	13.6	13.7	13.2
Ganja-Gazakh	12.5	13.0	12.2	12.6	12.9	12.4
Northeastern slope of Lesser Caucasus	5.4	6.0	5.3	5.6	5.6	5.2
Southern slope of Greater Caucasus	9.4	9.6	8.9	9.2	9.4	8.8
Shamakhi-Gobustan	8.1	8.3	7.7	7.6	7.9	7.3
Northeastern slope of Greater Caucasus	7.6	7.4	7.2	7.5	7.2	6.9
Plain part of Nakhchivan	12.7	13.0	12.6	12.3	12.9	11.8
Foothill part of Nakhchivan	10.4	10.1	10.5	9.3	10.6	8.8

of the anthropogenic trend in air temperature changes -linked to the proportional annual increase of CO_2 - can be considered feasible [5; 23; 27].

The materials not included in the model's implementation (1998-2022) were used to verify the reliability of the research results. By utilizing five-year averaged temperature variations, the projected temperature values were compared with their actual values to test the model. The averaging was performed for the following climatic periods: 1998-2000; 2001-2005; 2006-2010; 2011-2015; 2016-2020; 2021-2022. The obtained results are presented in Table 3 and Figures 1 ((a, b, c, d, e, f, g, h, s, t).

Table 3

Averaged values of calculated (T_h) and observed (T_f) indicators of mean spring temperature across various physiographic zones by climatic periods

Physiographic Zones	1998-2000		2001-2005		2006-2010		2011-2015		2016-2020		2021-2022	
	T_h	T_f	T_h	T_f	T_h	T_f	T_h	T_f	T_h	T_f	T_h	T_f
Absheron	10.7	12.6	11.2	12.2	11.2	12.4	10.4	12.9	11.0	13.0	10.7	12.6
Lankaran-Astara	12.9	12.7	12.8	12.8	12.9	12.9	12.6	12.6	12.8	12.8	12.8	13.7
Kura-Araz lowland	13.9	14.6	13.7	13.7	13.7	14.1	13.3	14.6	13.6	14.8	13.6	14.6
Ganja-Gazakh	12.7	14.5	12.5	13.7	13.0	14.3	12.2	15.1	12.6	15.8	13.0	16.3
Northeastern slope of Lesser Caucasus	5.9	7.2	5.4	6.5	6.0	7.1	5.3	7.5	5.6	7.8	5.4	7.8
Southern slope of Greater Caucasus	9.6	9.9	9.4	9.0	9.6	9.9	8.9	10.4	9.2	10.7	9.4	11.9
Shamakhi-Gobustan	8.6	10.1	8.1	9.4	8.3	9.9	7.7	10.3	7.6	10.7	7.7	10.7
Northeastern slope of Greater Caucasus	7.9	8.5	7.6	8.1	7.4	8.8	7.2	9.0	7.5	9.5	6.7	9.0
Plain part of Nakhchivan	12.7	14.2	12.7	13.5	13.0	14.0	12.6	14.0	12.3	14.3	12.9	15.2
Foothill part of Nakhchivan	10.3	12.7	10.4	11.3	10.1	12.5	10.5	12.4	9.3	12.3	10.4	12.8
R^2	0.906		0.953		0.933		0.906		0.870		0.932	

The evaluation results revealed significant agreement between calculated and actual spring temperature values, particularly during the 1998-2010 period. As shown in Table 3, the model's reliability metric (R^2) for the climatic periods of 1998-2000, 2001-2005, and 2006-2010 was 0.906, 0.953, and 0.933, respectively. In the subsequent two periods, these values decreased, while showing a relative increase for the 2021-2022 timeframe. For temperature calculations, the model employed linear trend equations derived from the 1968-2010 period.

During the 1998-2000 period, the difference between actual and calculated spring temperature values was positive across all physiographic zones except Lankaran-Astara, ranging between 0.3-2.4°C. During the 2001-2005 period, the difference between actual and calculated spring temperature values remained positive across all physiographic zones except the southern slope of Greater Caucasus [7], stabilizing within a range of 0.0-1.2°C.

During the 2006-2010 period the difference between actual and calculated spring temperature values was positive ranging between 0.0-2.4°C across physiographic zones these differences fluctuated within intervals of 0.0-2.9°C during 2011-2015 0.0-3.2°C during 2016-2020 and 0.9-3.3°C during 2021-2022 the mean absolute errors (MAE) of calculations were around 1.5-2.2°C while root mean square errors (RMSE) ranged between 1.6-2.7°C.

Partially observable from Table 4 across all zones and climatic periods the average calculations show 7-13 cases (28-52 % of total cases) with absolute errors ΔT≤ 1.0°C 12-19 cases (48-76 %) ΔT≤ 2.0°C 17-24 cases (68-96 %) ΔT≤ 3.0°C and 20-25 cases (80-100 %) ΔT≤ 4.0°C. As with others the model utilized linear trend equations derived from the 1968-1997 period for temperature calculations.

The analysis reveals that beginning approximately in 2011, the discrepancy between observed and modeled spring temperature values started increasing significantly compared to previous periods. This shift primarily resulted from a transition to a pronounced warming trend in spring temperatures commencing around 2011, as clearly evidenced by the data presented in Figures 1 (a, b, c, d, e, f, g, h, s, t). The graphical representations demonstrate marked upward deviations in actual temperature dynamics during this period. Consequently, while the model outputs demonstrate higher reliability for the 1998-2010 timeframe, these findings necessitate methodological refinements for subsequent periods to enhance predictive accuracy.

Table 4

Performance indicators of the model scenario for mean spring temperature (^{0}C)

Physiographic Zones	MAE	RMSE	Guarantee level of scenario at specified absolute error values, %			
			ΔT≤ 1.0	ΔT≤ 2.0	ΔT≤ 3.0	ΔT≤ 4.0
Absheron	1.9	2.2	28	56	76	96
Lankaran-Astara	1.4	1.6	40	76	96	100
Kura-Araz lowland	1.4	1.7	44	76	92	100
Ganja-Gazakh	2.2	2.7	32	48	76	84
Northeastern slope of Lesser Caucasus	1.9	2.3	28	64	72	88
Southern slope of Greater Caucasus	1.5	1.9	52	72	84	96
Shamakhi-Gobustan	2.2	2.7	28	56	68	80
Northeastern slope of Greater Caucasus	1.7	2.0	36	72	88	92
Plain part of Nakhchivan	1.7	2.1	44	76	84	92
Foothill part of Nakhchivan	2.1	2.5	24	52	76	88

For refining the scenario projections of spring temperatures across Azerbaijan's diverse natural-climatic zones, the 1968-2010 period was examined as the observational baseline, with corresponding recalculations performed to redefine the linear trend equations.

As evident from Table 1, the multiannual spring temperature series during 1968-1997 exhibited a decreasing trend in most physiographic zones except Lankaran-Astara and Ganja-Gazakh. This declining tendency is identified through negative correlation coefficients of the linear trend equations.

Analysis of the multiannual spring temperature series for 1968-2010 reveals a persistent positive trend. This warming pattern is evidenced by positive correlation coefficients of the linear trends, with temperature increases across most physiographic zones demonstrating statistical significance [7, 10].

The correlation coefficients of the linear trend were -0.51 for Absheron zone, -0.26 for Lankaran-Astara zone, -0.42 for Kura-Araz lowland, -0.78 for Ganja-Gazakh zone, -0.56 for northeastern slope of Lesser Caucasus, -0.41 for southern slope of Greater Caucasus, 0.50 for Shamakhi-Gobustan zone, 0.46 for northeastern slope of Greater Caucasus, -0.26 for plain part of Nakhchivan AR and -0.30 for foothill part of Nakhchivan AR.

The averaged values of calculated (T_h) and observed (T_f) mean spring temperature indicators across various physiographic zones of the republic for different climatic periods are presented in Table 5. The model temperatures were calculated using linear trend equations derived from the 1968-2010 period [8, 25].

During the 1998-2000 period the difference between actual and calculated spring temperature values was positive ranging between 0.0-1.5°C across physiographic zones For subsequent periods these differences fluctuated within -0.7 to +0.2°C during 2001-2005, -0.2 to +1.0°C during 2006-2010, 0.2-1.1°C during 2011-2015, 0.2-1.9°C during 2016-2020 and 0.2-1.1°C during 2021-2022.

Table 5

Averaged values of calculated (T_h) and observed (T_f) indicators of mean spring temperature across physiographic zones by climatic periods

Physiographic Zones	1998-2000		2001-2005		2006-2010		2011-2015		2016-2020		2021-2022	
	T_h	T_f	T_h	T_f	T_h	T_f	T_h	T_f	T_h	T_f	T_h	T_f
Absheron	11.5	12.6	12.2	12.2	12.3	12.4	11.8	12.9	12.6	13.0	12.4	12.6
Lankaran-Astara	12.8	12.7	12.6	12.8	12.7	12.9	12.4	12.6	12.6	12.8	12.5	13.7
Kura-Araz lowland	14.2	14.6	14.1	13.7	14.2	14.1	13.9	14.6	14.3	14.8	14.3	14.6
Ganja-Gazakh	13.7	14.5	13.8	13.7	14.5	14.3	14.0	15.1	14.7	15.8	15.3	16.3
Northeastern slope of Lesser Caucasus	6.7	7.2	6.4	6.5	7.2	7.1	6.7	7.5	7.3	7.8	7.1	7.8
Southern slope of Greater Caucasus	9.9	9.9	9.7	9.0	10.0	9.9	9.4	10.4	9.7	10.7	10.0	11.9
Shamakhi-Gobustan	9.6	10.1	9.3	9.4	9.8	9.9	9.4	10.3	9.6	10.7	9.9	10.7
Northeastern slope of Greater Caucasus	8.5	8.5	8.3	8.1	8.3	8.8	8.3	9.0	8.7	9.5	8.0	9.0
Plain part of Nakhchivan	13.1	14.2	13.3	13.5	13.7	14.0	13.5	14.0	13.3	14.3	13.9	15.2
Foothill part of Nakhchivan	11.2	12.7	11.6	11.3	11.5	12.5	12.1	12.4	11.2	12.3	12.4	12.8
R^2	0.960		0.987		0.979		0.985		0.982		0.964	

Table 5 shows that during the 1998-2000, 2001-2005 and 2006-2010 climatic periods the model's reliability metric (R^2) was 0.960, 0.987 and 0.979 respectively In the subsequent three periods these values remained very high at 0.985, 0.982 and 0.964 respectively. The mean absolute errors (MAE) of calculations ranged between 1.2-1.4°C while root mean square errors (RMSE) were within 1.5-1.7°C.

A comparative analysis of these indicators with corresponding values in Table 4 demonstrates that when using linear trend equations derived from the 1968-2010 period for temperature calculations, both the mean absolute error and root mean square error were significantly reduced. This confirms the necessity for progressive refinement of prognostic values over time.

Table 6 shows that partially across all zones and climatic periods on average 9-14 cases (36-56% of total cases) had absolute calculation errors $\Delta T \leq 10°C$, 19-22 cases (76-88%) $\Delta T \leq 20°C$, 22-25 cases (88-100%) $\Delta T \leq 30°C$, and 24-25 cases (96-100%) $\Delta T \leq 40°C$. Here the model utilized linear trend equations derived from the 1968-2010 period for temperature calculations.

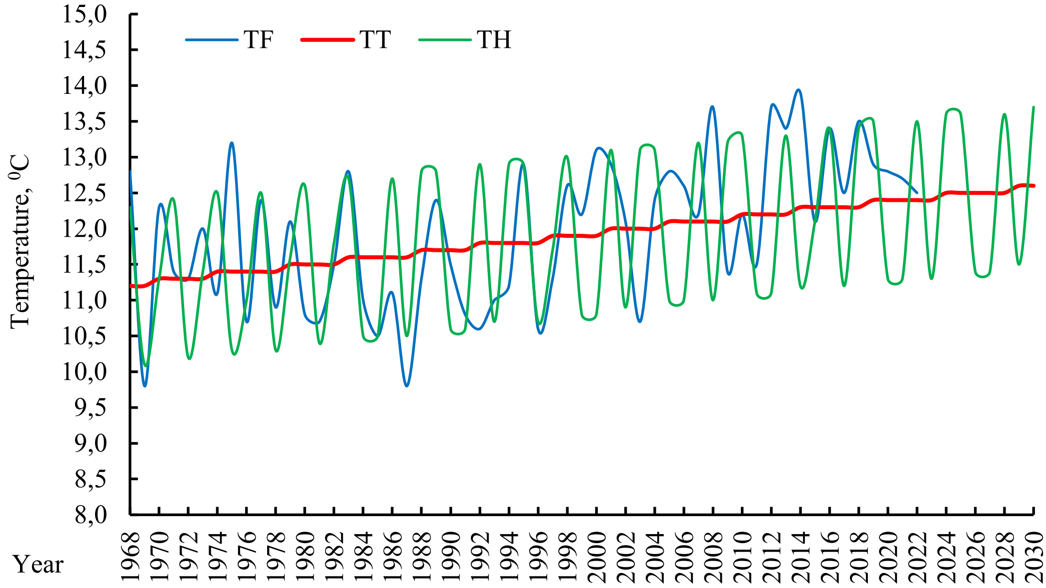
Table 6

Performance indicators of the model scenario for mean spring temperature

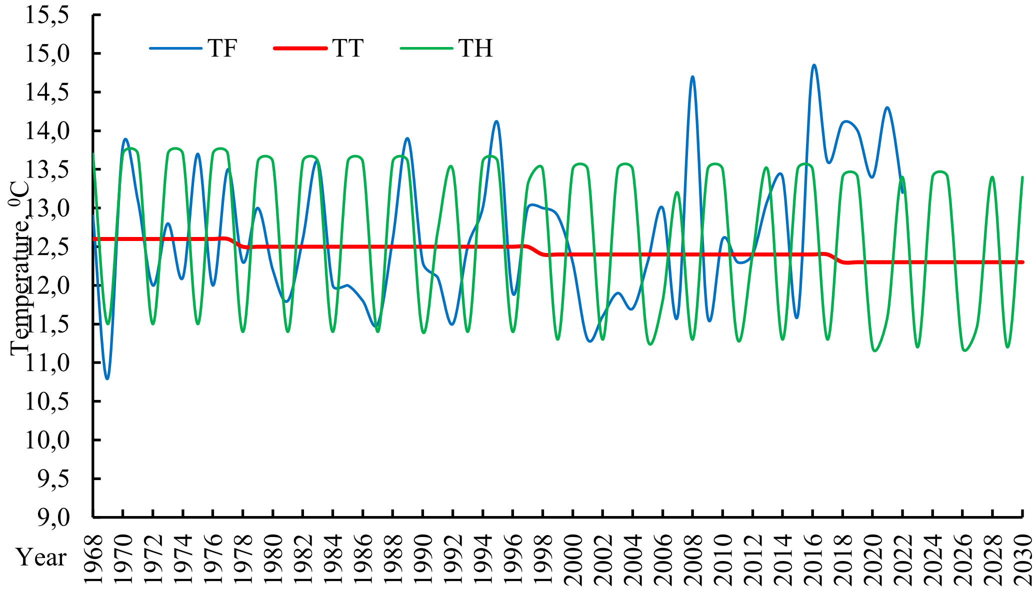
Physiographic Zones	MAE	RMSE	Guarantee level of scenario at specified absolute error values, %			
			$\Delta T \leq 1.0$	$\Delta T \leq 2.0$	$\Delta T \leq 3.0$	$\Delta T \leq 4.0$
Absheron	1.2	1.5	44	80	100	100
Lankaran-Astara	1.4	1.6	40	76	96	100
Kura-Araz lowland	1.2	1.5	36	88	96	100
Ganja-Gazakh	1.2	1.5	48	88	96	100
Northeastern slope of Lesser Caucasus	1.3	1.6	48	84	96	96
Southern slope of Greater Caucasus	1.3	1.7	48	80	88	100
Shamakhi-Gobustan	1.4	1.7	40	76	92	100
Northeastern slope of Greater Caucasus	1.2	1.5	56	84	96	100
Plain part of Nakhchivan	1.3	1.7	52	84	92	100
Foothill part of Nakhchivan	1.2	1.5	40	84	96	100

As previously noted, according to the WMO, long-term forecasts with 60-65% accuracy are considered successful [22; 28]. Based on this, it can be stated that the spring temperature variation scenario developed using the proposed model is adequate, as its accuracy already ranges between 76-94% for $\Delta T \leq 2.0°C$.

The recalculated projections of future spring temperature values are presented in Figure 2. The model utilized linear trend equations derived from


TF
TT
TH
Temperature, 0C
Year

a)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Temperature, 0C
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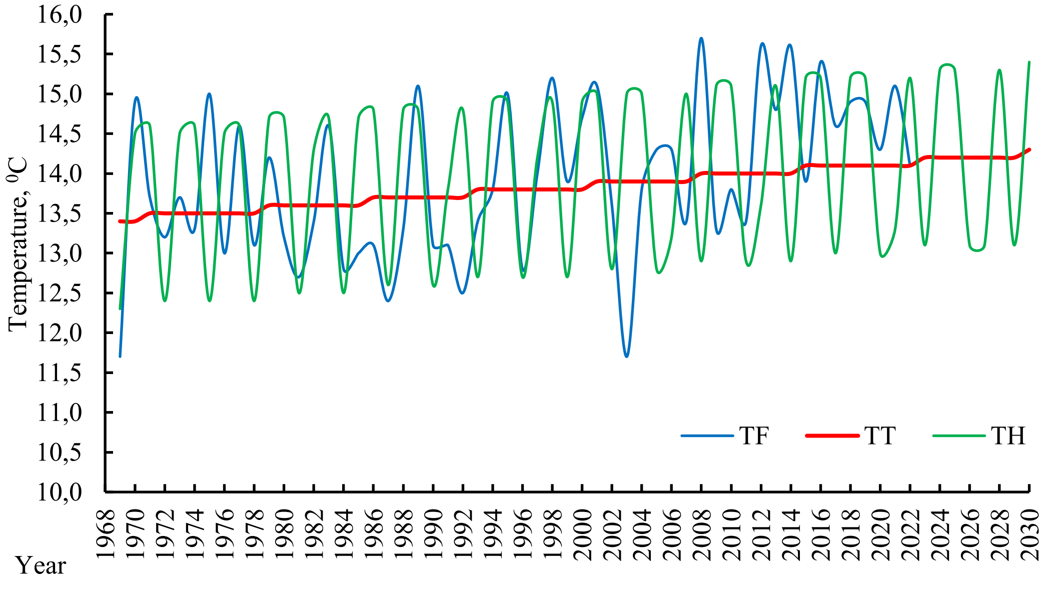
b)


TF
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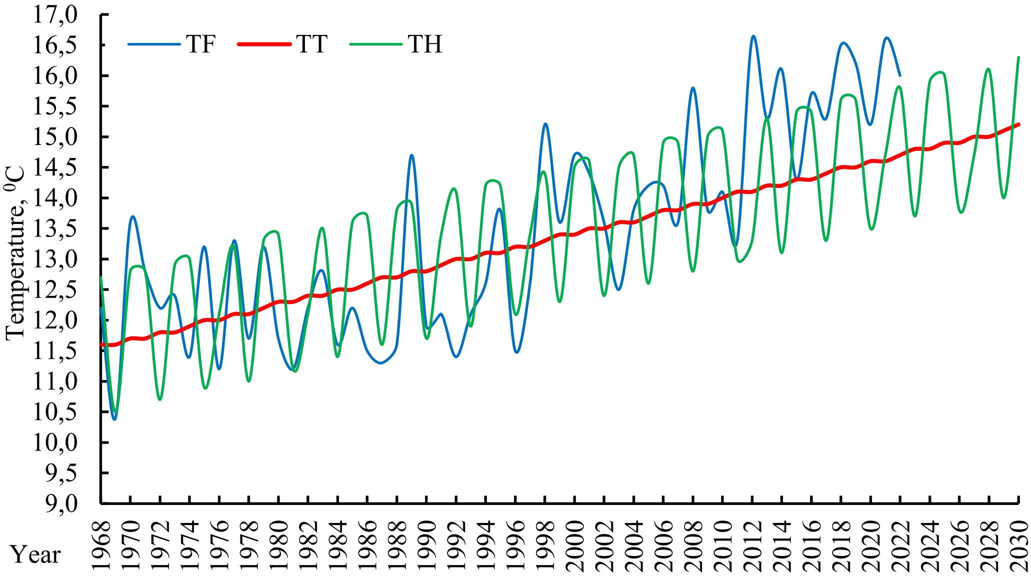
TH
Temperature, 0C
Year

c)



TF
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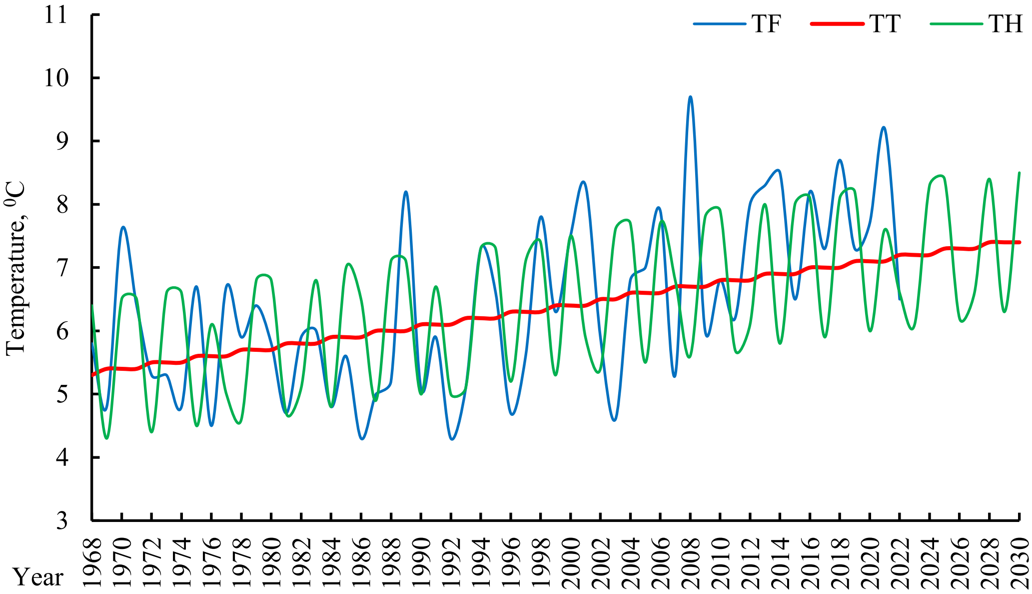
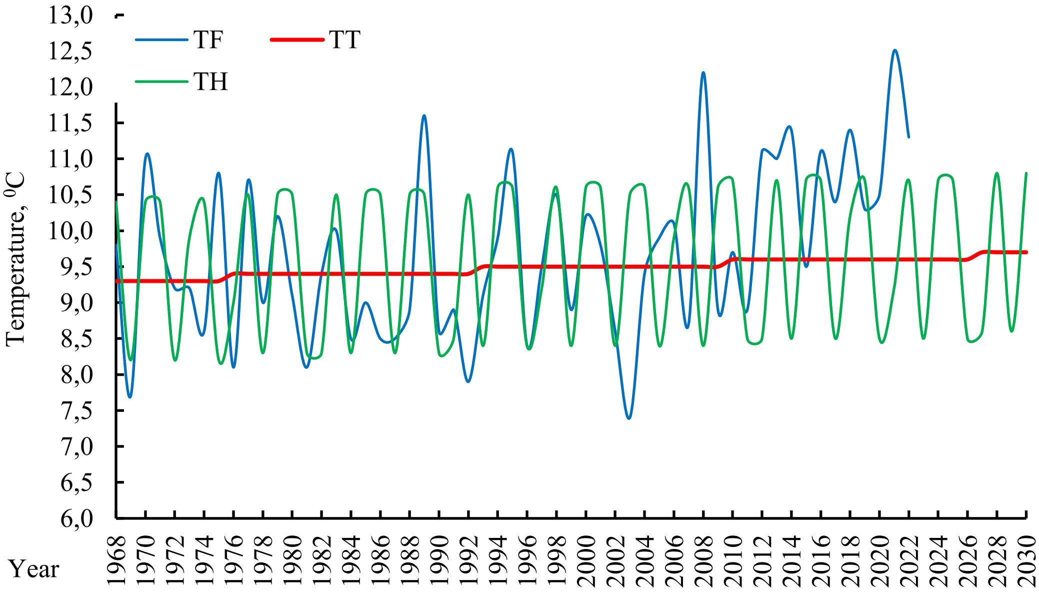
TH
Temperature, ⁰C
Year

d)



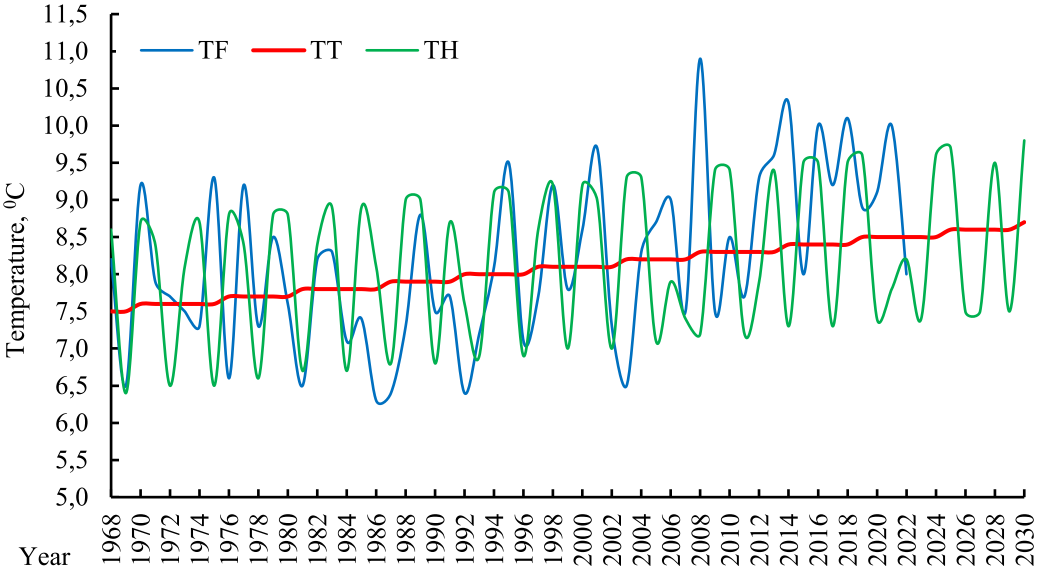
TF
TT
TH
Temperature, ⁰C
Year

e)

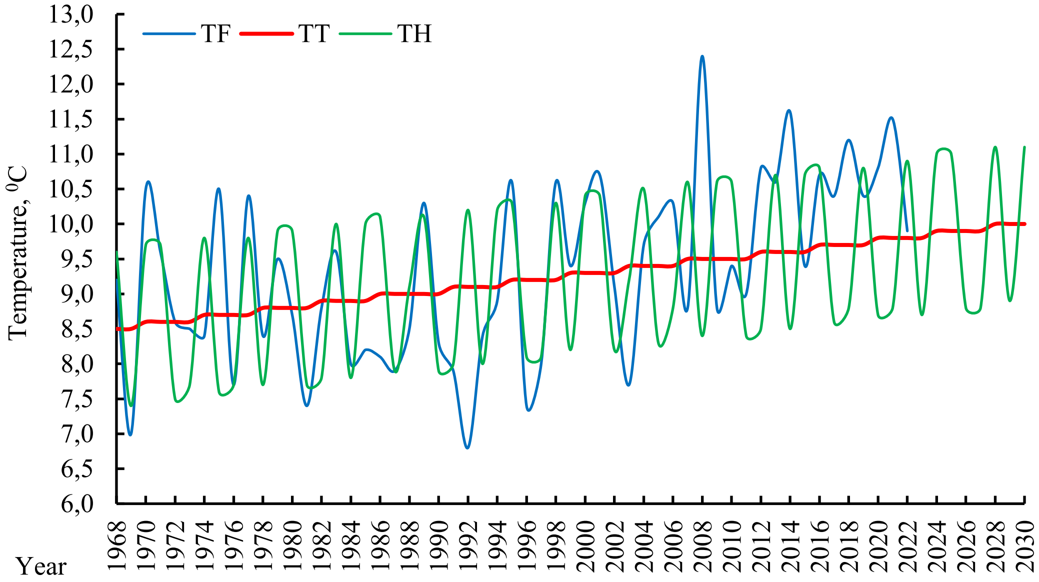


TF
TT
TH
Temperature, ⁰C
Year

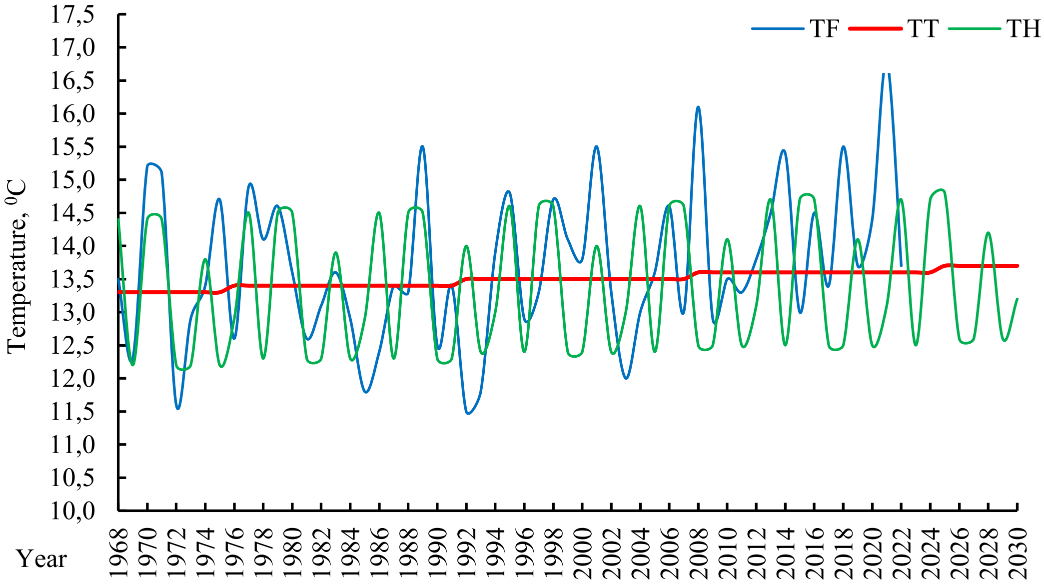
f)


TF
TT
TH
Temperature, ^{0}C
Year

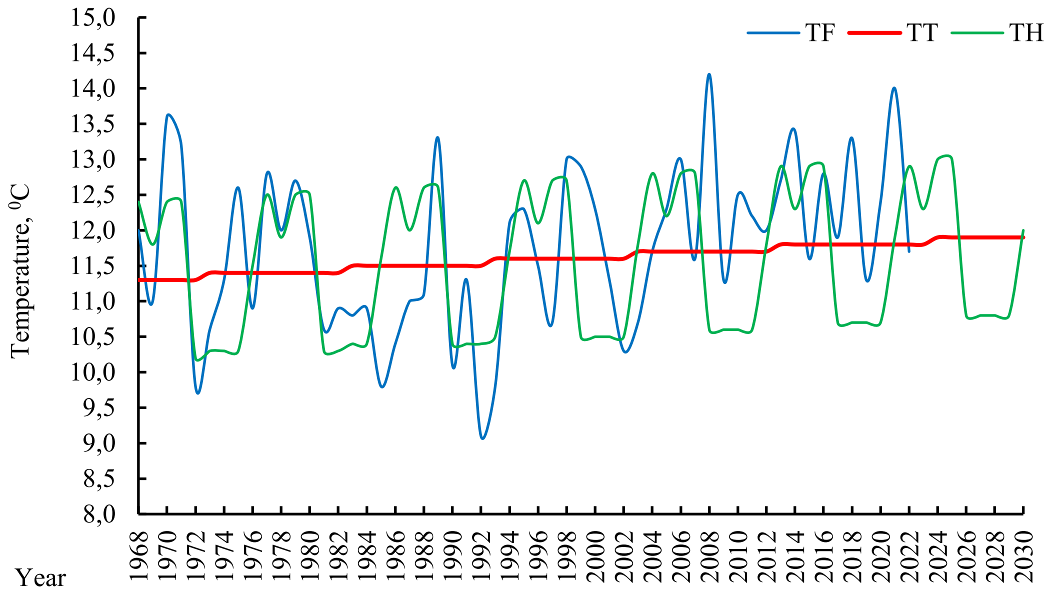
g)


TF
TT
TH
Temperature, ^{0}C
Year

h)


TF
TT
TH
Temperature, ^{0}C
Year

i)



j)

Fig. 2. Multiannual dynamics of actual (TF), calculated (TH) and linear trend (TT) values of spring air temperature for Absheron (a), Lankaran-Astara (b), Kura-Araz lowland (c), Ganja-Gazakh (d), northeastern slope of Lesser Caucasus (e), southern slope of Greater Caucasus (f), Shamakhi-Gobustan (g), northeastern slope of Greater Caucasus (h), plain area of Nakhchivan (s) and foothill area of Nakhchivan (t) (1968-2010)

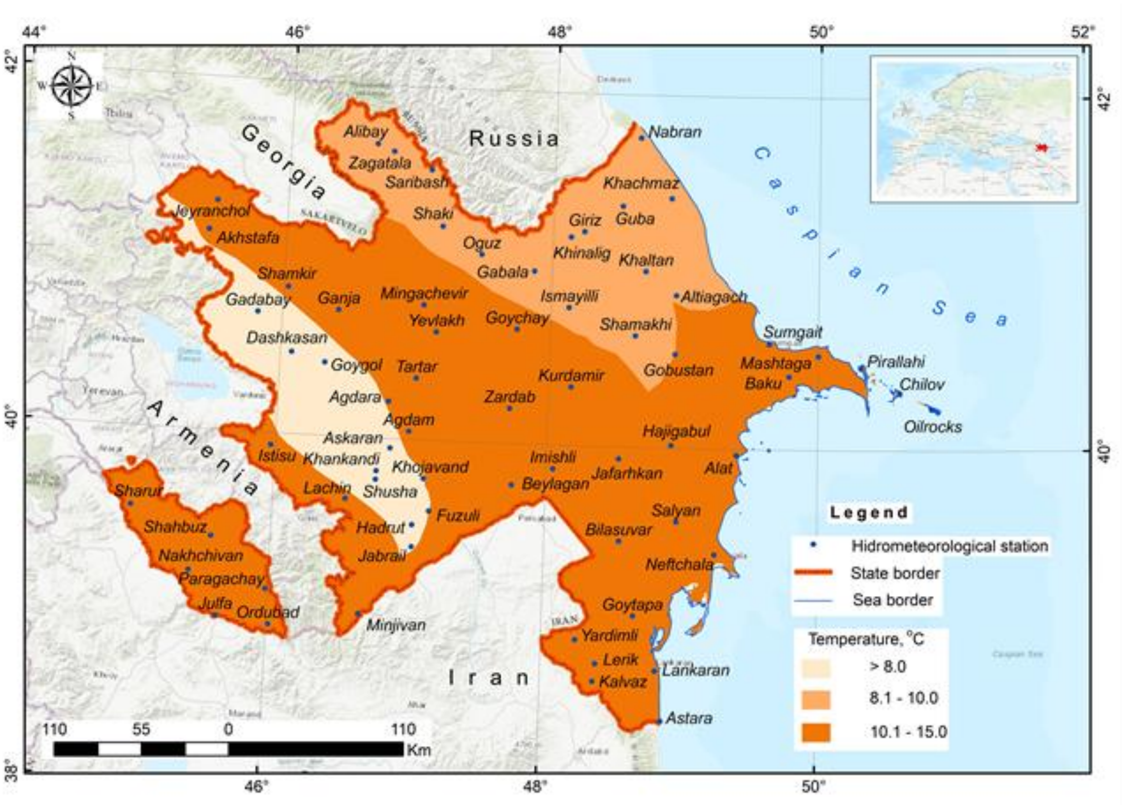


Fig. 3. Spatial distribution map of five-year averaged spring temperature prognostic/scenario values across physiographic zones (2026-2030)

the 1968-2010 period for temperature calculations.

A comparative analysis with corresponding graphs in Figure 2 demonstrates significant refinements in the annual projections of mean spring temperature. For post-2023 values in Figure 2, it is more appropriate to consider the calculated values as new scenarios.

Alongside the data presented in these graphs, Figure 3 provides a spatial distribution map of five-year averaged (2026-2030) prognostic/scenario spring temperature values across Azerbaijan's physiographic zones.

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Оцінка надійності статистичної моделі для розробки сценарію можливих змін температури повітря у весняний сезон над територією Азербайджану

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Це дослідження перевіряє статистичні оцінки середніх весняних температур в Азербайджані до 2022 року. Хоча точні довгострокові прогнози залишаються складними, аналіз метеорологічних даних за 1968–2022 роки демонструє, що статистичні методи ефективно фіксують регіональні тенденції весняної температури та забезпечують надійну основу для майбутніх кліматичних досліджень та розробки сценаріїв. Метою дослідження є розробка статистичної спектральної моделі, яка надійно ідентифікує кліматично-індуковані зміни метеорологічних елементів, зокрема температури повітря. Модель використовує оптимізовані аналітичні методи, адекватність яких перевіряється шляхом порівняння спостережуваних та розрахованих температурних рядів з використанням методів згладжування, тестів Шустера та кореляційного аналізу. Створення цієї моделі та її оптимальне застосування сприяє розвитку регіональних кліматичних моделей та сценаріїв, підвищуючи надійність прогнозованих кліматичних тенденцій. Методологія базується на аналізі довгострокових рядів температури повітря, класифікованих на періодичні та неперіодичні показники мінливості, останні корисні для вивчення майбутніх змін температури. Враховуючи нестаціонарний характер метеорологічних змінних, тенденції в довгострокових рядах розглядаються як надійні, але ряди спочатку необхідно перетворити на стаціонарні послідовності для аналізу за допомогою статистичних методів. Екстраполяція спостережуваних тенденцій на період понад кілька років є фізично ненадійною через природну мінливість; таким чином, лише антропогенні тенденції, пов'язані зі збільшенням CO_2, підходять для розробки кліматичних сценаріїв. Крім того, тривалість метеорологічних записів є критично важливою, оскільки класична кліматологія припускає стаціонарність, а точність оцінки покращується з довшими серіями спостережень. За допомогою статистичної спектральної моделі було розроблено новий сценарій зміни весняної температури для Азербайджану. Прогнози, перераховані з лінійних рівнянь тренду для 1968–2010 років, демонструють вищу точність порівняно з попередніми підходами, а оцінки після 2023 року можна розглядати як оновлені кліматичні сценарії, що підвищує надійність майбутніх оцінок. Також було складено п'ятирічну (2026–2030 роки) карту усереднених весняних температур для фізико-географічних зон країни. Загалом, модель пропонує надійну та науково обгрунтовану основу для майбутніх прогнозів весняної температури та ширших аналізів, пов'язаних з кліматом.

Ключові слова: *Статистична модель, зміна клімату, кліматичний сценарій, весняна температура повітря, періодичність, фізико-географічні зони, адекватність моделі.*

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