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Determining Parameters of Tbilisi's Winter Regime under Conditions of Climate Change and the Accuracy of their Determination

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Abstract

This study examines the winter temperature regime of Tbilisi, Georgia, over the period 1881–2018 using four analytical approaches: difference, linear, cyclic, and non-linear approximations. Nine temperature-related parameters were analysed, their probability density distributions were calculated, and the performance of each method was evaluated. The results indicate a gradual warming trend in average frosty-day temperatures and cumulative frost-related indices, accompanied by a decrease in the number of frosty days. Absolute minimum temperatures increased by approximately 0.5 °C over an 87-year period. The study demonstrates the usefulness of applying multiple approximation methods for assessing regional climate trends, particularly in areas with limited data coverage.

Keywords: Global climate, frosty days, winter regime

Introduction

Accurate assessment of winter temperature regimes at the regional scale is of particular importance under conditions of ongoing climate change, as winter temperatures strongly influence energy demand, ecosystem stability, hydrological processes, and the frequency of hazardous meteorological events. In mountainous and basin-shaped regions such as Tbilisi, winter thermal conditions are especially sensitive to both long-term climatic trends and local factors, including relief, atmospheric circulation patterns, and temperature inversions. Consequently, reliable identification of changes in winter temperature characteristics is essential for understanding regional manifestations of climate change and for supporting evidence-based adaptation strategies.

Recent advances in climate research increasingly emphasise the need to move beyond single-parameter analyses and to evaluate multiple temperature indicators simultaneously. Studies focusing on winter regimes often highlight not only mean temperature changes but also variations in extreme indices, such as the frequency of frosty days, absolute minimum temperatures, and cumulative frost intensity. These parameters are particularly informative in assessing shifts in climatic thresholds that affect infrastructure resilience, agriculture, and public health. However, the accuracy of their determination depends strongly on the analytical methods applied, especially when working with long-term observational series characterised by temporal inhomogeneities and data gaps.

Within the state of the art, a growing body of literature demonstrates that different approximation techniques may yield substantially different estimates of regional climate trends. Linear approaches remain widely used due to their simplicity and interpretability, yet they may fail to capture non-stationary or cyclic behaviour inherent in climate systems. Cyclic approximations attempt to account for periodic variability associated with solar activity, while non-linear methods allow for more complex temporal dynamics but introduce additional uncertainty related to model selection and parameterisation. The comparative evaluation of these methods has therefore become an important research direction in regional climatology.

In this context, the assessment of winter temperature parameters in Tbilisi provides an opportunity to examine not only the magnitude and direction of climatic changes but also the reliability of different methodological approaches used to quantify them. By analysing multiple temperature-related parameters and evaluating their probability distributions, it becomes possible to characterise the internal structure of the winter temperature regime and to assess the stability or transformation of its dominant modes. Such an approach contributes to the broader scientific effort to improve the robustness of regional climate assessments under conditions of limited observational coverage and complex local influences.

Determining the modern change of the Earth's global climate is still possible only theoretically, namely by building of energy-balance model. The main reason for this is the long-term (several decades) empirical data of the main air parameters, which can be used to determine the stability or change of the Earth's global climate are known only for less than one-tenth of the Earth's surface. If we take into account that the temperature change according to the regions is remarkably uneven (in some places there even cooling has taken place), it is clear that under such conditions the temperature of one tenth of the Earth cannot characterize the global change of the air.

As for the possibility of building energy-balance model of the Earth (together with the atmosphere), the fact that the energy system of the Earth placed in a vacuum is formed only at the expense of solar radial energy and climate parameters are mainly determined by this energy. Thus, the energy-balance model determines the Earth's energy potential, that is the ratio of received and released energies, which forms the global atmosphere. The energy potential, in addition to the intensity of the solar radiation energy, depends on the gaseous composition of the atmosphere and the ability of the subsurface to absorb the radiation energy. In a stable equilibrium of energy potential, the global atmosphere is unchanged. Under conditions of unstable equilibrium, the global climate experiences cooling or warming.

Determining regional climate changes in the same way as global weather is impossible. Because it is not the isolated system and neighbouring regions influence it. Determining their influence is difficult task. Regional climate can only be determined empirically. At present, the empirical data of ground surface temperature for a long time period in particular several decades, is used. As far as is known, the determination of regional climate changes is produced in four different ways:

1. Long (several decades) empirical data divided into three periods with the average temperature difference of the third and first periods (the so-called "difference" method);
2. Linear approximation based on the determination of the dynamic norm (Tavartkiladze 2010);
3. Cyclic approximation, where the periodic variation of solar radiation energy is taken into account.
4. With non-linear approximation, when the temperature change over time is modelled by a high-order polynomial.

In order to assess the change or stability of the regional, terrestrial temperature field, we take nine parameters characteristic of the temperature field (see below), determine their probability densities (thus uniquely characterizing their mode structure) and determine the accuracy of their calculation using the four mentioned methods.

Methods and Materials

The winter season (December–February) was selected because the effects of weather changes in Georgia are more pronounced during the winter than during the year, and it has a frosty period, which can be characterized by extreme deviations and better characterizes the weather changes than the average annual temperature.

Empirical data of Tbilisi winter temperatures for 1881–2018 were analyzed. Critical analysis of daily data and filling of randomly missed observations was carried out by the method of decomposition of the random function into natural-orthogonal coefficients (Obukhov 1960, Tavartkiladze et al. 2011, Tavartkiladze 2012, Tavartkiladze, et al. 2019, Tavartkiladze, et al. 2020, Bolashvili et al. 2024, Tavartkiladze, Bolashvili 2022, Tavartkiladze et al. 2023). To determine that every parameter of the air changes even slightly, an autocorrelation matrix of the parameters was built. Probability densities of each parameter were also calculated (Fig. 1).

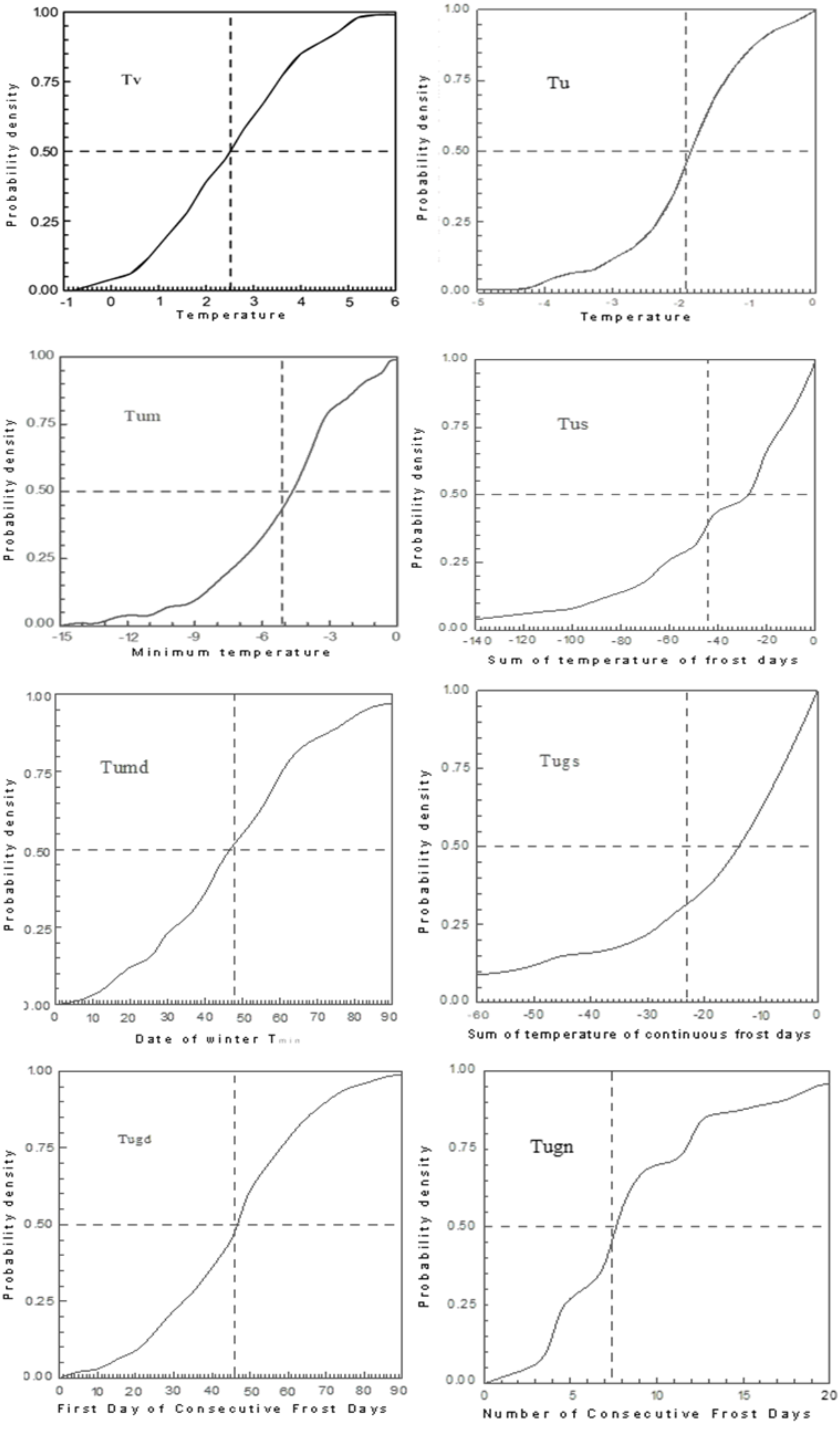


Figure 1. Probability densities of parameters characteristic of the regime structure of Tbilisi winter season

The change of parameters was determined using four methods: 1. Difference method, 2. Linear approximation, 3. Cyclic approximation and 4. Non-linear approximation.

The parameters analysed are:

1. Day-night average temperature (Tv °C)

2. The average temperature of frosty days and nights (Tu °C)
3. Number of frosty days and nights (Tun days)
4. Sum of temperatures of frosty days and nights (Tus °C)
5. Minimum temperature of frosty days (Tum °C)
6. The maximum number of frozen days (Tugn days)
7. The sum of the temperatures of consecutive frosty days (Tugs °C)
8. Date of occurrence of minimum temperature from frosty days (Tumd number, month)
9. The date of the first day of consecutive frosty days (Tugd number, month)

The accuracy of each method was evaluated by comparing the mean squared deviations relative to the arithmetic mean of each parameter over the entire period. Absolute minimum temperatures were determined using the least squares parabola method (Mazmishvili 1968) to reduce random errors.

Results

The autocorrelation matrix (Tab. 1) indicates that each parameter provides small but different information. The calculated probability density of each parameter characterizes the expected range and likelihood of values (Fig. 1). For example, the average temperature of the Tbilisi winter season during 1881–2018 covers the range from -1°C to +5°C.

Table 1. Autocorrelation matrix of winter season parameters (Tbilisi, 1881–2018)

	Tv	Tu	Tun	Tus	Tum	Tugn	Tugs	Tumd	Tugd
Tv	1	0.72	-0.91	0.83	0.77	-0.72	0.68	-0.13	0.05
Tu		1	-0.72	0.87	0.91	-0.73	0.82	0.05	-0.09
Tun			1	-0.89	-0.76	0.82	-0.72	0.05	-0.09
Tus				1	0.84	-0.85	0.90	-0.01	0.16
Tum					1	-0.68	0.77	-0.05	0.09
Tugn						1	-0.89	-0.01	-0.18
Tugs							1	0.02	0.19
Tumd								1	0.54
Tugd									1

The average temperature of frosty days, the sum of temperatures of frosty days, minimum temperatures, and total freezing-day temperatures gradually increased. The number of frosty days and the maximum number of frosty days decreased. Dates of minimum temperature and the first day of consecutive frosty days remained unchanged (Fig. 2).

The reduction of standard errors relative to the arithmetic mean is shown in Tab.2. Difference and linear approximations improve accuracy by 4–7% for most parameters. Cyclic and non-linear approximations further improve results for cumulative and extreme measures. Frost-date parameters remain largely stable.

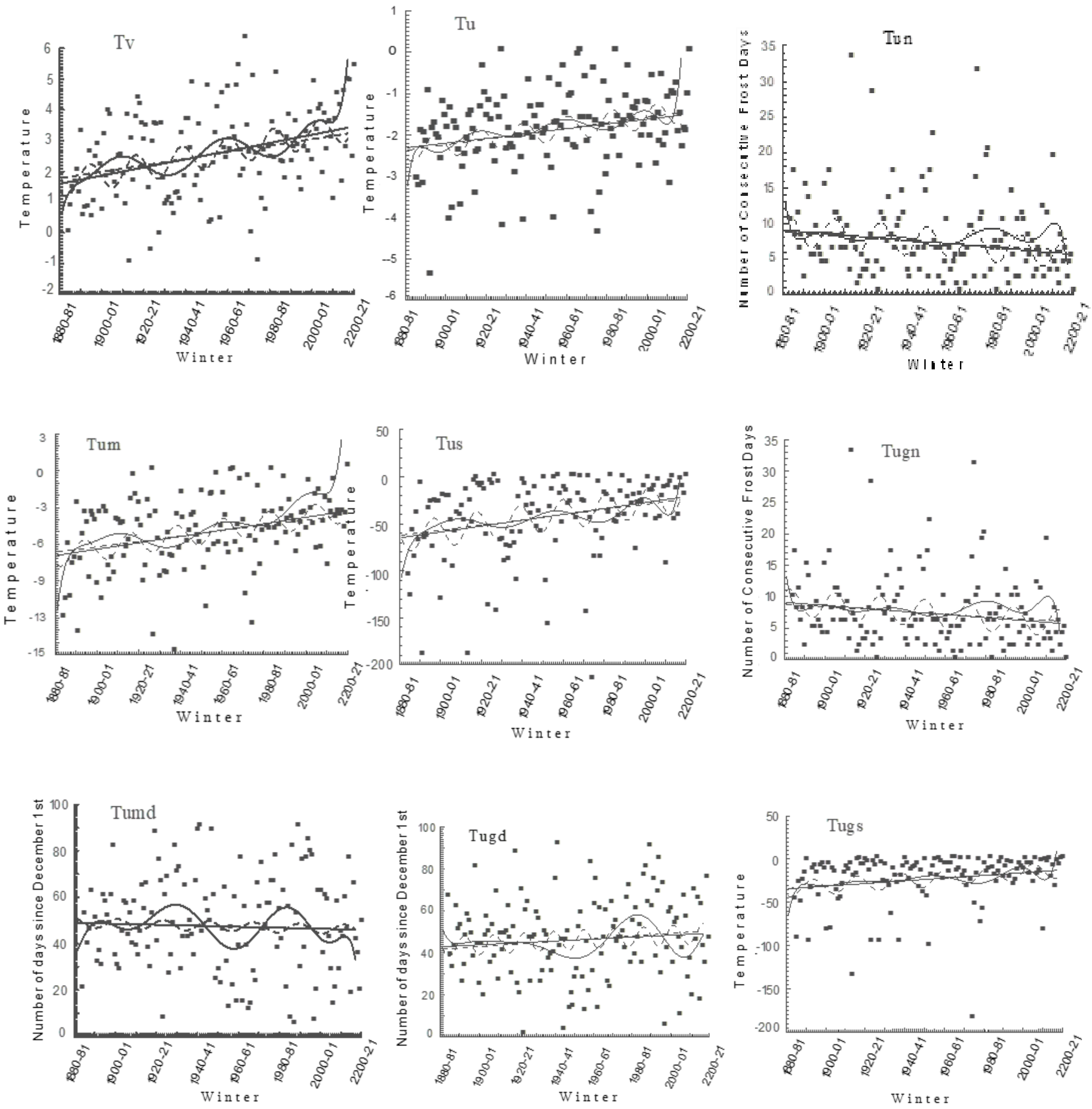
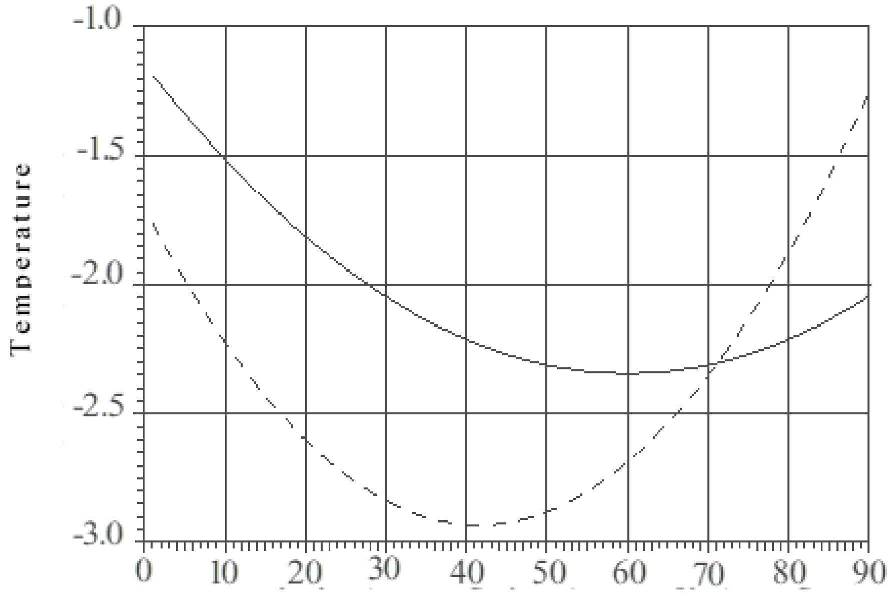


Figure 2. Changes in the characteristic parameters of the winter season of Tbilisi during the global warming period, with linear approximation (straight line), cyclical approximation (dashed curve) and non-linear approximation (continuous curve)

Table 2. Reduction of standard errors (%) compared with arithmetic mean

Winter season determining parameter	Reducing of standard error in % compared with static norm error			
	Difference	Linear approximation	Linear cyclic approximation	Nonlinear approximation
Tv	6.69	6.96	9.82	9.82
Tu	3.82	3.89	6.41	5.86
Tun	4.09	4.39	8.35	7.56
Tus	4.48	4.42	8.31	6.54
Tum	6.07	6.22	9.10	4.73
Tugn	1.34	1.40	3.97	0.27
Tugs	3.31	3.31	4.95	4.28
Tumd	0.09	0.09	0.40	3.99
Tugd	0.41	0.46	1.93	4.42

The absolute minimum temperature increased from -2.90°C in 1904 to -2.40°C in 1991, a rise of 0.50°C over 87 years (Fig. 4).



Number of Days After December 1
Figure 4. Probability density distribution of absolutely minimum temperature of the winter season size and occurrence date in Tbilisi¸ 1945-46 (dashed curve) and 1946-47 2017-18 (continuous curve) by years.

Conclusion

The defining parameters of the winter regime show that during the period of global warming, the average temperature of frosty days, the sum of temperatures of frosty days, the minimum temperature of frosty days, and the total number of freezing-day temperatures gradually increased, as expected. The number of frosty days and the maximum number of frosty days decreased. The dates of minimum temperature and first frost days do not change.

The results obtained by the difference and linear approximation are almost identical, about 4–7 percent, correcting the results obtained with Tv, Tu, Tun, Tus, and Tum. Only, the results obtained by difference are slightly less accurate than the results obtained by linear approximation. The parameters determining the interpolated frost days approach the true distribution with less precision (about 1–4%). The dates of minimum temperature remain stable.

The analysis of absolute minimum temperatures shows a modest increase of 0.50°C over 87 years, reflecting a reduction in extreme cold events. Probability density and autocorrelation analyses demonstrate that even small differences in parameters provide useful information about the winter temperature regime. Overall, the combination of multiple approximation methods provides a reliable assessment of regional climate change in Tbilisi.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

K.T. took the lead in writing the manuscript. N.B. was responsible for editing the manuscript. N.S. took responsibility for data visualization, including the preparation and drawing of all graphs and figures. All authors provided critical feedback and contributed to the research design, analysis, and final preparation of the manuscript.

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