Georgian Geographical Journal

Assessment of the Climate Change Impact on the Characteristic Parameters of Freezing in Georgia by Regions

Georgian Geographical Journal, 2025, 5(2) 12-16

DOI:
https://journals.4science.ge/index.php/GGJ

Naili Kapanadze[1,*], Marika Tatishvili[1,2*], Irine Mkurnalidze[1], Ana Palavandishvili[1,2]

[1] Weather Forecast and Disaster Modeling Department of Institute of Hydrometeorology of Georgian Technical University, Tbilisi, Georgia
[2] TSU, Vakhushti Bagrationi Institute of Geography, Tbilisi, Georgia
* Corresponding author: m.tatishvili@gtu.ge

Citation: Kapanadze, N.; Tatishvili, M.; Mkurnalidze, I.; Palavandishvili, M. Assessment of the Climate Change Impact on the Characteristic Parameters of Freezing in Georgia by Regions. *Georgian Geographical Journal* 2025, 5(2), 12-16. https://doi.org/10.52340/ggj.2025.05.02.02

Abstract

The change tendency in the duration of the frost-free period in the territory of Georgia is analysed by comparing the last 16 years of data (2007-2022) with the similar one of the previous periods (1951-1965). The early, average and late values of the last spring and first autumn frost dates in the study regions were evaluated. It was revealed that in the period 2007-2022 compared to 1951-1965, the average values of frosts shifted earlier for the last spring frost and later for the first autumn frost, which led to frost-free periods increasing and, accordingly, the length of the vegetation period. The map depicting the duration of increased frost-free periods is presented, the trend of increasing frost-free periods under climate change is revealed, and the dependence of these periods on the North Atlantic Oscillation is also fixed.

Keywords: Spring and autumn freezing, frost-free period, growth trend, North Atlantic Oscillation

Introduction

Agriculture is widely recognized as one of the most vulnerable sectors to climate change across the globe. Variations in temperature and precipitation regimes, evapotranspiration rates, and soil moisture—along with the increasing frequency of extreme weather events such as droughts, floods, and heavy rainfall—lead to soil degradation, erosion, and nutrient depletion. These processes reduce agricultural productivity and negatively impact both the quantity and quality of food production.

In Georgia, complex topography, diverse meteorological conditions, and significant anthropogenic pressures create particularly favourable conditions for the occurrence of various natural hazards. Recent decades have seen a marked increase in the frequency of such events, driven by deviations from long-term climatic norms in precipitation, air temperature, humidity, and other meteorological parameters. These deviations amplify the occurrence of catastrophic processes within the broader context of global climate change.

Among the hydrometeorological hazards affecting Georgian agriculture, frost represents one of the most significant threats. Notably, frost—despite its substantial impacts—has not been included in the internationally standardized classification of hazards established by the United Nations in the 2015 Sendai Framework for Disaster Risk Reduction (Sendai Framework 2015–2030) (NDRR / ISC Sendai Hazard Definition and Classification Review, Technical Report, 2019; Kapanadze et al., 2023). Nonetheless, frost continues to inflict considerable damage on agricultural systems in Georgia, as well as in many other countries worldwide (Mkurnalidze et al., 2023).

Given this context, there is growing scientific interest in assessing the impacts of contemporary climate change on frost characteristics across different regions of Georgia. Such assessments require the analysis of observational data from individual meteorological stations, which are located within diverse climatic zones and may therefore exhibit variations in frost dynamics under changing climatic conditions (Kapanadze et al., 2023; Kapanadze et al., 2024).

Accordingly, the central objective of this study is to quantify changes in the frost-free period—a key temperature-based indicator of climate change—and to determine the average timing of the last spring frost and the first autumn frost across different regions of Georgia. This regional approach will allow for a more nuanced understanding of how frost regimes are shifting in response to ongoing climatic transformations.

Methods and Materials

To address the research objectives, data from 26 meteorological stations of the ground observation network operated by the National Environmental Agency of Georgia were utilized, covering the period 2007–2022. Based on these observational records, the frost-free periods and the dates marking the onset and cessation of freezing were calculated for each region. To assess the influence of climate change, these calculated values were compared with corresponding long-term averages derived from historical climate records (Handbook on the Climate of the USSR, 1967; Handbook on the Climate of the USSR, 1971).

Given that frosts are most pronounced under clear, calm conditions during the incursion of Arctic air masses from dry latitudes, it is important to consider broader climatic drivers. One such driver is the Arctic Oscillation (AO), a key indicator of Arctic climate variability that governs the state of atmospheric circulation in the high latitudes. The AO index, available from the Climate Prediction Center (CPC, 2025) was therefore incorporated into this analysis to explore potential links between global climate variability and regional frost dynamics in Georgia.

The Arctic Oscillation refers to an atmospheric circulation pattern over the mid-to-high latitudes of the Northern Hemisphere, whose most notable manifestation is the latitudinal shift of the mid-latitude jet stream. The AO strongly influences weather and climate patterns in North America, Europe, and Asia, particularly during winter.

During the AO's positive phase, surface air pressure is lower than average over the Arctic and higher than average over the northern Pacific and Atlantic Oceans. This configuration shifts the jet stream farther north, redirecting storm tracks and generally reducing the occurrence of cold air outbreaks in the mid-latitudes of North America, Europe, Siberia, and East Asia. Conversely, in the AO's negative phase, surface air pressure is higher than average over the Arctic and lower than average over the northern Pacific and Atlantic Oceans. This causes the jet stream to shift toward lower latitudes, facilitating the penetration of frigid polar air into the mid-latitudes and increasing the likelihood of severe frost events. For example, higher frequencies of coastal storms, such as Nor'easters in New England, have been linked to the AO's negative phase.

The AO index quantifies these dynamics by measuring surface atmospheric pressure anomalies at 1000 hPa across latitudes 20° N to 90° N. These anomalies are projected onto the AO loading pattern, defined as the first empirical orthogonal function (EOF) of monthly mean 1000 hPa geopotential height. The resulting time series is normalized by the monthly standard deviation of the index. Variations in the AO index thus directly reflect the degree of Arctic air penetration into middle latitudes, with a positive AO index corresponding to stronger zonal winds that confine cold Arctic air to the polar region, and a negative AO index corresponding to weaker zonal winds and greater incursions of polar air into temperate regions.

By comparing the AO index with frost-free period data from Georgia's regions, this study aims to elucidate potential connections between large-scale atmospheric circulation patterns and local frost dynamics under contemporary climate change.

Results

In spring, advection of warm air masses from the southwest frequently occurs, often persisting for extended periods. This process triggers the premature termination of plant dormancy and initiates the onset of vegetation. However, during this transitional period, Arctic and Siberian anticyclones frequently invade the entire territory of Georgia from the northwest almost simultaneously. Such incursions result in sudden cooling and intense frosts, significantly increasing the risk of damage to thermophilic crops.

The timing of plant vegetation onset and frost impacts on newly formed organs varies from year to year. Identifying these critical timings is essential, as they provide valuable information for predicting the likely dates of frost onset and cessation. This knowledge is crucial for farmers and agricultural practitioners to develop targeted strategies to prevent or mitigate frost-related damage.

Table 1 presents the average dates marking the beginning and end of frost-free periods for two study intervals (1951–1965 and 2007–2022) across various regions of Georgia. The data reveal notable spatial and temporal variations. In Samegrelo, the frost-free period begins earliest (March 13 and March 1 for periods I and II, respectively) and ends latest (December 7 and December 23). This region is followed by Shida Kartli, where the average frost-free period spans from March 28 to November 21 in the first period and from March 16 to November 25 in the second period. Imereti and Adjara-Guria follow with slightly shorter frost-free durations.

Table 1. Average dates of the beginning and end of frost-free periods

Region	1951-1965	2007-2022
Shida Kakheti	28 III - 21 XI	16 III - 25 XI
Gare Kakheti	7 IV - 9 XI	27 III - 25 XI
Shida Kartli	7 IV - 4 XI	4 IV - 8 XI
Kvemo Kartli	17 IV - 27 X	16 IV - 30 X
Mtskheta-Mtianeti	18 IV - 20 X	18 IV - 27 X
Samtskhe-Javakheti	9 V - 7X	5 V - 12 X
Imereti	1 IV - 20 XI	22 III - 5 II
Samegrelo	13 III - 7 XII	1 III - 23 II
Adjara-Guria	1 IV - 24 XI	26 III - 29 XI
Racha	21 IV – 24 X	13 IV - 2 XI

Conversely, the latest onset of frost-free conditions occurs in Samtskhe-Javakheti, where average dates for the beginning of frost-free periods are in the first decade of May (May 9 and May 5 for periods I and II, respectively). The frost-free period in this region ends by October 7 and October 12, yielding the shortest vegetation period of approximately 150–159 days. Such variations in frost-free periods across regions underscore the influence of local climatic conditions on agricultural cycles and highlight the importance of region-specific frost prediction for sustainable crop management.

Overall, in the period 2007–2022, these shifts in frost timing have resulted in a notable increase in the duration of frost-free periods across most regions (Fig. 1). This pattern provides empirical evidence of

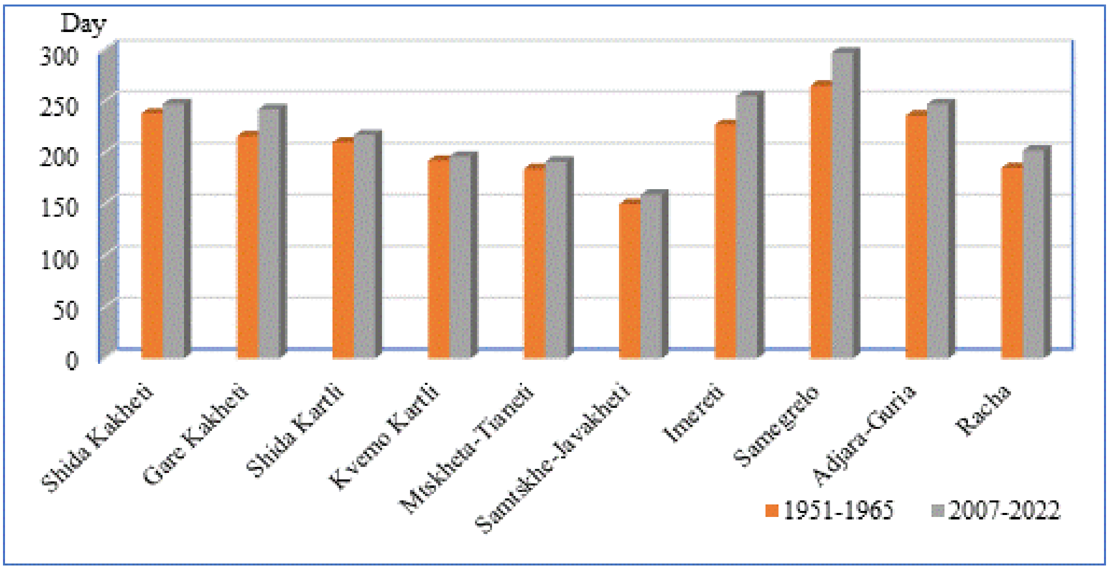

Figure 1. Change of frost-free periods according to regions 1951-1965 and between 2007-2022

the influence of contemporary climate change on key frost-related climatic parameters.

It should also be noted that during the second study period (2007–2022), compared to the earlier period (1951–1965), the average dates of spring frosts tend to occur earlier, while autumn frosts occur later. This shift contributes to a general lengthening of the frost-free period. However, this trend is not uniform across all regions, as some local meteorological data reveal deviations. Specifically, at the Tsalka station in Kvemo Kartli and the Gori station in Shida Kartli, the second period records later average dates of spring frosts and earlier dates of autumn frosts compared to the earlier period.Fig. 2 shows the distribution of arctic oscillation indices and the duration of frost-free periods averaged by region as a temperature characteristic of climate change in the territory of Georgia in the 2007-2022 period.

Discussions

As illustrated in the figures, a pattern similar to that observed in graphs of frost-free period duration at individual stations (Kapanadze et al., 2023; Kapanadze et al., 2024; Kapanadze, Tatishvili et al., 2024) is evident across the regions. Specifically, a minor phase shift is observed until approximately 2013, after which each positive phase of the Arctic Oscillation (AO) corresponds to a relatively extended frost-free period (Fig. 2). This consistent relationship suggests that the climate of Georgia is, to a notable extent, influenced by global climate variability.

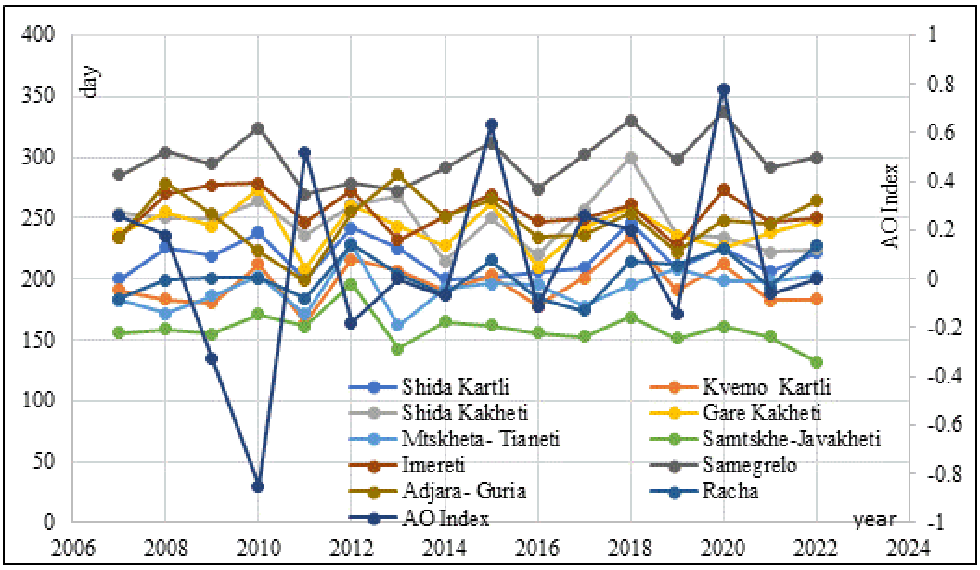

Figure 2. Distribution of the durations of frost-free periods averaged according to regions and Arctic Oscillation Indices in the territory of Georgia in the 2007-2022 period

Conclusion

Based on the analysis of our results, it can be concluded that contemporary climate change exerts a discernible influence on the key parameters of freezing. This influence is manifested in shifts in the average dates of frost occurrence and an extension of frost-free periods, which correspond to an overall lengthening of the vegetation period. However, changes in the length of the growing season may have both positive and negative implications for crop productivity.

An extended growing season can alter the functioning and structure of regional ecosystems, potentially changing the distribution of animal species, facilitating the spread of invasive plants or weeds, and increasing irrigation demands. Conversely, a longer warm period may offer agricultural benefits, enabling farmers to obtain multiple and more diverse harvests from the same plots. This could enhance the productivity and stability of agriculture, supporting higher and more reliable yields of crops in specific regions. These contrasting effects highlight the importance of region-specific strategies for adapting agricultural practices to evolving climatic conditions.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

N. K. and M. T. conceived of the presented idea. I. M., A. P. performed the analytic calculations. N. K. and M. T. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

ORCID iD

Naili Kapanadze http://orchid/0000-0001-7790-8867
Marika Tatishvili https://orcid.org/0000-0003-3327-2208
Ana Palavandishvili http://orchid.org/0000-0002-7254-685X
Irine Mkurnalidze http://orchid/0009-0005-5071-4225

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