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Impact of Current Climate Change on Frost Characteristic Parameters in Western Georgia using 2007-2022 Year Meteorological Data

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ABSTRACT

According to the weather stations 2007-2022 data in Western Georgia, the distribution of the intensity of frosts of different intensity has been studied. The early, average and late dates of the last spring and the first autumn frost in the research period have been determined. In 2007-2022 period in comparison with the 1951-1965 one, a shift in the average values of freezing has been revealed for the last spring frosts for about 1-14 days earlier, and for the first autumn frosts 7-10 days later, which increased the duration of frost-free periods and, accordingly, the duration of the vegetation period by 11- 21 days, which corresponds to 10-17%. An exception is Akhaltsikhe, where the reduction of frost-free periods by 15 (9%) days has been detected against the background of climate change. The dependence of frost-free periods on the Arctic Oscillation has been found.

Key words: *freezing, frost-free period, freezing intensity, arctic oscillation.*

Introduction

The modern world is facing many challenges. Among them, the most important and large-scale climate change poses a great threat to the country's sustainable development. The consequences of climate change are already visible, which is evidenced by the increase in temperature, change in precipitation regime, limitation of water availability, rise in the level of the Black Sea, increase in the frequency and intensity of floods, landslides and mudslides.

Almost half of the population of our country is involved in the agricultural sector, which makes the country highly sensitive to changes in weather and climatic conditions. The negative impact of climate change on agriculture is reflected in the direct connection with the increase in the level of poverty and socio-economic development, which implies an increase in the income of the population to the level that should actually ensure the population's access to sufficient, safe and quality food. Freezing is one of the problems of getting abundant and quality food from unfavorable hydro-meteorological events.

It is true that, considering the types of threats, the conditions of occurrence, the type of events and the main consequences, such a dangerous event as frost for agriculture was not included in the international classified standard list of dangers, but considering the damage caused by it to Georgia and other countries of the world, it is worth thinking about its negative consequences and taking certain actions [1,2].

In Georgia, the researches about glaciations have a long history and have been studied in great detail by our great scientists: T. Davitaia, Sh. Tsertsvadze, M. Zakashvili, E. Elizbarashvili, J. Vachnadze, R. Samukashvili, G. Meladze, M. Meladze and others. However, in the results of the research based on the materials of the 70s of the last century, the influence of the current climate change on the characteristic parameters of freezing was clearly not reflected. Therefore, we considered it appropriate, similar to the studies conducted for the territory of Eastern Georgia [3], to find out whether the characteristic parameters of freezing have changed in the territory of Western Georgia and, if so, what are the quantitative indicators of this change.

The North Atlantic Oscillation (NAO)

The North Atlantic Oscillation (NAO) is a prominent “seesaw” of atmospheric surface pressure fluctuation between the Azores and Iceland that has been meteorologically well defined since at least the late 19th century (e.g., Hurrell, Kushnir, Ottersen, & Visbeck, 2003). It is defined using the NAO index, which is typically a normalized mean sea-level pressure (SLP) index between a southern station located in the Azores or continental Iberia and a northern station in western Iceland (Cropper, Hanna, Valente & Jónsson, 2015; Hurrell, 1995; Jones, Jónsson, & Wheeler, 1997; van Loon & Rogers, 1978). The NAO has historically been recognized since at least the time of the Vikings; pioneering work based on early instrumental meteorological records was undertaken by Hildebrandsson (1897), who using surface air pressure data discovered the inverse relation between Iceland and Azores pressure, and by Sir Gilbert Walker who in works published in 1924 and 1932 (the latter with Bliss) undertook correlation analysis and constructed a robust multivariate NAO index based on surface air pressure and surface air temperature data from several European stations (Stephenson, Wanner, Brönnimann, & Luterbacher, 2003) [4].

The strength of the pressure difference between the high- and low-SLP centers of action exerts a strong control over the strength and direction of the mid-latitude westerly storm tracks. As such, the NAO has been linked to a variety of climatological, biological, hydrological, and ecological variables across several locations (Ottersen et al., 2001; Westgarth-Smith, Roy, Scholze, Tucker, & Sumpter, 2012) but is most frequently recognized as directly affecting the west of Europe (from Iberia to Scandinavia) and North America. A greater than normal pressure difference between the Azores and Iceland is a positive NAO, and a weaker than normal pressure difference is a negative NAO. During the winter months, a positive NAO is associated with warmer and wetter conditions across northwest Europe and cooler and drier conditions across southern Europe as the stronger pressure gradient between the Azores and Iceland drives the storm tracks poleward (Fig. 1). The opposite is generally true for negative NAO conditions as the weaker pressure gradient generally results in southward-shifted storm tracks, and a SLP reversal will typically result in more easterly conditions. As such, the NAO index is strongly related to favored positions of the North Atlantic atmospheric polar jet stream (Hall, Erdélyi, Hanna, Jones & Scaife, 2015; Overland et al., 2015; Woollings et al., 2015) [4].

The NAO and AO are preferred modes of variability of atmospheric circulation in the Northern Hemisphere. The alternative designation Northern Annular Mode (NAM, which is the same as the AO) is not as widely used as its southern counterpart the Southern Annular Mode (Abram et al., 2014). The NAO can be regarded as an Atlantic sector regional expression of the hemisphere-wide AO (or NAM). The NAO reflects changes in the position and strength of the North Atlantic polar front jet stream and has associated effects on the weather and climate of mid-to-high latitudes within and around the Atlantic (Fig. 1). A more positive (negative) NAO/AO index represents stronger (weaker) airflow around the Northern Hemisphere and a jet stream that is shifted further north (south) over the North Atlantic.

The NAO/NAM pattern is a result of the eddy-driven extratropical atmospheric circulation: specifically, the transport of heat and momentum by stationary eddies (longwaves or planetary waves in the northern polar jet stream) and transient eddies (cyclones and anticyclones forming within or along the jet stream) (e.g., Kaspi & Schneider, 2013). The polar jet stream is directly related to NAO changes and has a mean latitude somewhere between 50°N and 60°N over the eastern North Atlantic. The strongest westerly winds (of up to about 200 km/hr in the core of the jet near the tropopause) are typically experienced at these latitudes, and there is a clear clustering of extratropical storm tracks along the polar jet stream. The prevailing direction is westerly due to the Coriolis Effect of earth’s rotation, which deflects air masses to the right of their direction of motion in the Northern Hemisphere. Longwaves develop in the jet stream because of orographic obstacles (e.g., the Rocky Mountains over North America) or east–west heating contrasts between land and sea, or variations in latent heating due to condensation and rainfall. Low- and high-pressure systems form due to strong horizontal contrasts in temperature, typically where cold polar air meets relatively warm tropical air masses. These transient eddies are very important in providing energy for maintaining the polar jet stream flow and mid-latitude westerlies, otherwise friction with the surface would slow and eventually halt the winds. However, a significant contribution to maintaining the westerlies—greater than in the Southern Hemisphere—comes from the stationary eddies: this is due to the much stronger land–ocean contrast effects in northern mid-latitudes [4].

Being linked with the jet stream, there is a deep and pronounced vertical structure to the AO and NAO, which extends up into the stratosphere; this is most notable for the AO, which lies further north and is more directly linked with the polar vortex. What happens in the stratosphere in polar winter can also have a big bearing on conditions in the troposphere: for example, stratospheric sudden warmings are associated with a weakening and sometimes reversal of the polar vortex and development of negative NAO/ AO that sometimes occurs in mid- to late winter (e.g., Cohen et al., 2014; Marshall & Scaife, 2010). Stratosphere–troposphere interaction and coupling is not very well understood, yet is important for NAO dynamics (Kidston et al., 2015). It appears from theory and observations that planetary-scale Rossby waves can propagate upwards from the troposphere into the stratosphere under conditions of moderate westerly flow during boreal winter; the stratosphere is effectively decoupled from the troposphere in other seasons. If the wintertime polar vortex is weak (strong), the upward-propagating waves can (cannot readily) interact with and slow the upper-level westerly flow. There is also a kind of reverse effect where airflow anomalies in the stratosphere can propagate down to affect the near-surface circulation (Baldwin & Dunkerton, 2001). The time of operation of these changes is typically 2–3 weeks, although dynamical couplings range over timescales from daily to multidecadal (Kidston et al., 2015) [4].

The NAO/AO exist in atmosphere-only computer models of the global climate system, so the NAO does not depend on the ocean for its existence. However, it is thought that low-frequency variations of oceanic circulation in the Atlantic—which comprise the Atlantic Multidecadal Oscillation (AMO)—are driven at least partly by the NAO (Clement et al., 2015). The AMO may in turn drive the NAO in a distinctly seasonal response, with a warm AMO phase promoting a negative NAO in winter (Gastineau & Frankignoul, 2015) [4].

The AO and NAO tend to be strongest in winter because this is when one of the key factors driving the jet stream—the equator-pole temperature gradient—is greatest, due to less seasonal cooling in the tropics than the polar regions. The jet stream and NAO correspondingly tend to weaken in summer. The summertime NAO is shifted northwards, having its southern node over northwest Europe and a smaller accompanying pressure pattern. A detailed discussion of NAO patterns and changes during this season is provided by Folland et al. (2009), who develop a summer NAO index that they compare with changes in European summertime climate. These authors also note a small but significant link of interannual variation in SNAO with La Niña sea-surface temperatures in the eastern tropical Pacific, as well as a persistent link with the AMO.

Due to the seasonal migration of the jet stream, which generally lies further south (north) in winter (summer), the association between NAO and, for example, British weather conditions varies markedly depending on the season. Thus, in winter, a positive (negative) NAO is generally associated with mild, wet (cold, dry) weather over the United Kingdom but a positive (negative) NAO in summer is often linked with dry and sunny (wet and cool) conditions. Key examples are the exceptionally cold 2009/2010 U.K. winter, with a record low (Hurrell PC) NAO value of -2.93 and the exceptionally wet 2007 and 2012 U.K. summers with low NAO values of -1.15 and -1.59. However, the NAO-U.K. weather relation in summer is less clear than in winter: for example, summer 2015 had a similarly low NAO value of -1.61 but had only slightly above average rainfall, e.g., 113% of the 1981–2010 summer average for U.K. precipitation (http://www.metoffice.gov.uk/climate/ uk/summaries/2015/summer). While the NAO is the single most important factor determining changes in weather and climate over the North Atlantic region, it does not explain everything, and most notably the East Atlantic and Scandinavian atmospheric circulation patterns—with respective main centers to the west of Ireland and around Bergen, Norway—also need to be considered (Moore, Renfrew, & Pickart, 2013) [4].

The North Atlantic Oscillation is usually described as a movement of atmospheric mass between the Arctic and the subtropical Atlantic (Wanner et al. 2001). There is no unique way to define the NAO. However, there are two pressure areas often used when describing the phenomenon, the Icelandic low- and the Azores high-pressure systems. The variations in sea level pressure between these two areas generate a pressure gradient. Because of this pressure gradient, westerly winds over the North Atlantic are generated (Wanner et al. 2001). The westerly winds, also known as “jets”, reach their maximum speed of 40 m/s at about 12 km up in the troposphere (Hurrell et al. 2003). When measuring the NAO different statistical methods can be used, either station-based or pattern based (Wanner et al. 2001). A station-based index is measured as the normalized sea level pressure differences between two monitoring stations in the vicinity of the Icelandic low and Azores high. Alternatively, a spatial-based index, or a principal component-based index, can be calculated from performing principle component analysis on the mean sea level pressure anomalies over the North Atlantic sector (usually beween 20-80ºN and 90ºW-40ºE) (Wanner et al. 2001) The NAO is described as being in an either positive or negative phase (see Figure 1). These phases are describing the strength of the circulation pattern. In a positive (NAO+) state the Icelandic low and the Azores high are well developed, resulting in a greater pressure gradient between these two areas. A greater pressure gradient causes stronger and more northern westerly winds. In a negative (NAO-) phase the pressure anomalies at the nodes of the NAO are less developed than normal and as a result the westerly winds get weaker and are positioned further south.

However, it is important to point out, is that there is not only a confined positive and negative phase of the NAO, but also everything in between (Wanner 2001). The NAO affects the climate mainly during wintertime when the NAO accounts for more than one-third of the total sea level pressure variance over the North Atlantic Ocean (Hurrell et al. 2003). During summertime the spatial extent of the NAO and the sea level pressure variance are smaller than during winter. Atmospheric variations are lager during wintertime which makes the effect of the NAO on surface climate bigger than during summertime. Because of this, most research on the NAO is restricted to wintertime, however the NAO is still noticeable all year around (Hurrell et al. 2003). There have been periods when the NAO persisted in an either positive or negative phase. During the beginning of the last century until approximately 1930 the NAO winters were characterized by a positive phase. During the 1960s the NAO winters instead showed persistent negative NAO anomalies (Hurrell et al. 2003). Although decadal NAO trends is shown, it is observed that variations in the NAO can occur on very different timescales, making it hard to assess any preferred timescale of the NAO variability.

The different wind patterns as a result of the various phases of the NAO are accompanied by different patterns of temperature and precipitation over the North Atlantic area. It has been shown that there are statistically significant correlations between sea level pressure anomalies and air temperature anomalies over a wide region in the northern hemisphere (Van Loon & Rogers 1978). Normally during strong positive NAO phases, warm maritime air is moved over the North Atlantic Ocean because of the enhanced westerly winds (Hurrell et al. 2003). This makes winter temperatures higher than normal in eastern United States and over northern Europe. Simultaneously in Greenland and the Mediterranean area temperatures are normally below average. During strong negative NAO phases the temperature pattern is opposite (Wanner et al. 2001). This reversing temperature pattern is often referred to as the Greenland seesaw (Van Loon & Rogers 1978). The positive and negative NAO phases are also connected to different patterns of precipitation as a result of variations in the strength and paths of storms generated over the Atlantic. During a positive NAO the North Atlantic storm track is usually directed more north-eastward over northern Europe than during negative NAO winters (Hurrell et al. 2003). This makes positive NAO phases associated to precipitation anomalies above normal in northern Europe and Scandinavia, while the precipitation levels over southern and central Europe are below average. The opposite precipitation pattern is notable during negative NAO phases (Wanner et al. 2001). It is seen that the ocean and the atmosphere interact, which makes variations in the ocean affect the NAO (Visbeck et al. 2013). The NAO is also known to force responses in different layers of the ocean (Visbeck et al. 2013). It is shown that NAO variations cause responses in the ocean on multiple time scales. Fluctuations in the NAO seems to be synchronized with interdecadal changes in convection triggering the renewal of intermediate and deep water in the Labrador Sea. On a decadal time, scale this has been shown to affect the thermohaline circulation and thereby also of sea surface temperatures.

The NAO has been linked with a variety of meteorological and non-meteorological effects across a wide spatial and multiple temporal scales, and only a selection of these impacts can be mentioned here. For example, Nesje, Lie, and Dahl (2000) showed a strong relationship between the mass balance of Scandinavian glaciers and the NAO due to the controlling influence of the storm tracks by the NAO, which influenced precipitation amounts, and glacier mass balance as a result. Coincidentally, the NAO has been shown to explain a large amount of the variance in Norwegian streamflow (55%) and hydropower output (30%), influencing electricity consumption and prices (Cherry et al., 2005). Baltic sea-ice extent is also strongly related to NAO changes (Karpechko, Peterson, Scaife, Vainiko, & Gregow, 2015). Cropper, Hanna, and Bigg (2014) found an influence of the NAO as far south as 20°N in coastal upwelling-inducing winds along the northwest African coastline. The great-circle distance between northwest Africa and Scandinavia is ~5,700 km, indicating the great spatial extent of the NAO influence. Recent NAO–climate linkages literature includes a strong signal of the (non-summer) NAO on precipitation in Iraq (Khidher & Pilesjö, 2015), an influence on sea-ice breakup date in south-central Ontario (Fu & Yao, 2015) and even a Southern Hemisphere influence, via a decadal-scale mechanism, on subtropical eastern Australian rainfall.

The NAO has also been shown to directly influence energy-generating capabilities. Colantuono, Wang, Hanna, and Erdélyi (2014) identify a negative relationship between the NAO and solar radiation availability across the United Kingdom, also showing a clear and intriguing zonal contrast between west and east regions, which they attribute to a topographic rain-shadow effect (more clouds and rain in the west of the United Kingdom under a positive NAO can sometimes be linked with cloud breakup and clear, sunnier weather in eastern England). Jerez et al. (2013) identify that for southern Europe, negative NAO conditions enhance hydropower resources and wind power by up to 30% while diminishing solar potential by 10–20% (the contrasting influence on solar availability in these studies is a function of the spatial locations analyzed, e.g., Fig. 1 shows they are regions which correlate differently with the NAO). Curtis, Lynch, and Zubiate (2016) show that the NAO-induced variability in the Irish electrical grid could cause detectable signals in the total carbon dioxide emissions from the system. Ely, Brayshaw, Methven, Cox, and Pearce (2013) call for improved understanding of the potential effects of the NAO on European power generation, as they surmise that under negative NAO conditions, lower temperatures, and less wind power generation across the United Kingdom/Scandinavia lead to an increased demand and lowered supply. On this note, while negative NAO conditions may be less favorable for the U.K.-Scandinavian renewable energy system, for regions like Iberia, the European Alps, or the Middle East, negative NAO conditions may be more favorable (Beniston, 2012; Sowers, Vengosh, & Weinthal, 2011; Trigo et al., 2004). The energy industry is already very weather-dependent due not only to demand fluctuations with temperature and hence the NAO but also because Germany and other countries rely so heavily on wind power. Therefore, NAO predictability will be an even more valuable asset in the medium- to long-term future, when renewable energy sources are expected to contribute much more significantly toward total power generation.

It is still unclear what will happen to the NAO with ongoing anthropogenic climate change, even discounting other external forcing factors and natural (internal) variability. The tropopause is highest at the equator (about 15 km above the surface) and slopes down toward the poles (about 10 km altitude). With increasing greenhouse gas levels, temperatures warm at the surface and in the lower troposphere while the stratosphere cools. This effect has been well observed in recent decades and is due to a denser blanket of greenhouse gases trapping infrared radiation in the lower atmosphere. At the same time, the surface has been warming most rapidly at high latitudes: called polar (or here Arctic) amplification of global warming (Overland et al., 2014). This latter change has the effect of reducing the meridional (north–south) temperature gradient, which might be expected to reduce the amount of energy available for driving the polar jet stream, all other factors being equal (Francis & Vavrus 2015; Overland et al., 2015). But this is just a (near-)surface expression of global warming. Meanwhile, in the upper troposphere at low latitudes, there is a higher specific humidity under global warming, and this raises the tropopause and increases upper troposphere temperatures near the equator (about 15 km up) while the same altitude near the poles (i.e., well within the stratosphere at these high latitudes) significantly cools with global warming. Therefore, there is a significantly enhanced meridional temperature gradient at this higher altitude just at the same time that the north–south temperature gradient reduces near the surface (Harvey, Shaffrey, & Woollings, 2015) [4]. Thus, there are two competing influences that can result in changes in mid-latitude (i.e., polar) jet-stream dynamics under conditions of global warming. One recent model-based study (Harvey et al., 2015) suggests that the near-surface meridional temperature gradient change is most important for determining changes in the wintertime North Atlantic storm track, but overall this is far from certain and more work is undoubtedly needed.

Data and method

In order to solve the task, we obtained data from the National Environment Agency for meteorological stations in Western Georgia (Mta- Sabueti, Sachkhere, Zestafoni, Kutaisi, Zugdidi, Poti, Kobuleti, Khulo, Keda, Ambrolauri, Shovi) for 2007-2022. Based on the data, we studied the intensity of late spring and early autumn frosts, estimated the impact of climate change on the dates of the last spring and first autumn frosts and the average, minimum and maximum values of frost-free periods as a temperature characteristic of climate change in 2007-2022. and 1951-1965 By comparing the corresponding data of the periods [3,5,6]. We also wanted to assess the extent to which the global climate determines the climate of our study region, using the so-called Arctic Oscillation (AO) index graph. Comparison of the positive and negative deviations of the template [5] with the course of the graph depicting the frost-free periods of Western Georgia.

Discussion

The Table 1 shows the change in frost intensity of the meteorological stations in the territory of Western Georgia in 2007-2022. According to the data. As can be seen from the table, 345 frosty days were recorded during the study period, of which 59% (205 days) were frosts of weak intensity, 36% (125 days) were moderate. Frosts of moderate and severe intensity will be observed only in 3% (10 days) and 1% (4 days) cases respectively.

Table 1. Distribution of the intensity of the first autumn frosts and the last spring frosts in Western Georgia in the period 2007-2022.

Station	Intensity							
	Weak 0.1-(-1.0)		Moderate -1.1-(-3.0) °C		Average -3.1- (-4.0) °C		Strong -4.1- (-8.0) °C	
	I frost Day %	Last frost day	I frost Day %	Last frost day	I frost Day %	Last frost day	I frost Day %	Last frost day
Mta-Sabueti	9	6	5	9			1 (33)	1
Sachkhere	9	9	7	6		1		
Zestaphoni	9	13	5	3	2			
Kutaisi	13	11	1	3				
Zugdidi	7	9	9	6		1		
Poti	11	12	5	3				
Qobuleti	6	9	9	5		1		
Khulo	9	14	4	11	1	1	1	
Qeda	7	6	5	7	1			
Ambrolauri	10	8	5	7		1	1	
Shovi	11	8	5	5		1		
Total	101 (29)	105 (30)	60 (17)	65(19)	4 (1)	6 (2)	3 (1)	1(0)

Table 1 shows that at the meteorological stations of Western Georgia, as well as at most stations of Eastern Georgia, the majority of freezing days - 206 days - are of weak intensity, of which 101 cases belong to the first frosts of autumn, and 105 to the last frosts of spring. The first autumn and last spring frosts of moderate intensity vary almost equally according to the meteorological stations and amount to 60 (17%) and 65 (19%) days, respectively. The number of frosts of medium intensity is relatively small and is equal to 4 (1%) days for the first frosts of autumn, and 6 (2%) days for the last frosts of spring. As for frosts of strong intensity, only 4 cases were noted during the observation period at the research meteorological stations of the entire Western Georgia. One case of severe frost was recorded in autumn and spring in Mta-Sabueti, Khulo and Ambrolauri. Very strong frosts (<-8°C) did not occur at all at the meteorological station in Western Georgia during the period 2007-2022.

Table 2 shows the early, average and late values of the dates of the last spring and the first autumn frosts in the territory of Western Georgia.

Table 2. Dates of the last spring and first autumn frosts in the territory of Western Georgia in the period 2007-2022.

Station	H elevation, m	Dates of the last spring frosts					Dates of the first autumn frosts				
		Early	Year	Ave.	Late	Year	Early	Year	Ave.	Late	Year
Mta-Sabueti	1242	6/X	2013	2/XI	24/XI	2012	3/IV	2012	21/IV	11/V	2021
Sachkhere	415	22/X	2014	16/XI	21/XII	2010	19/II	2009	29/III	26/IV	2017
Zestaphoni	160	15/XI	2011	21/XII	26/I	2009	29/I	2016	10/III	17/IV	2007
Kutaisi	114	26/XI	2016	8/I	26/I	2022	11/I	2015	25/II	28/III	2012
Zugdidi	117	15/XI	2011	14/XII	21/I	2020	1/II	2017	9/III	13/IV	2009
Poti	3	26/XI	2016	1/I	26/I	2022	10/I	2015	19/II	18/III	2022
Qobuleti	7	15/XI	2011	16/XII	22/I	2020	19/II	2020	14/III	28/III	2012
Khulo	92	I/IX	2020	5/XI	11/XII	2008	18/III	2008	17/IV	11/V	2021
Qeda	256	20/X	2011	1/XII	1/I	2022	4/XII	2013	5/III	23/IV	2019
Ambrolauri	544	20/X	2014	13/XI	22/XII	2022	11/III	2015	31/III	26/IV	2017
Shovi	1507	26/IX	2016	21/X	17/XI	2012	1/IV	2013	25/IV	15/V	2021

The comparison of the average values of frosts with the corresponding values of multi-year data (1891-1960) showed us that in the period 2007-2022, similar to the studies conducted in East Georgia [6], the average frosts of spring moved earlier, and the average of the last autumn frosts - later (nine 3). This shift for spring frosts was particularly high for Kutaisi, Kobuleti and Keda (16-16 days), Zestafoni (25 days) is distinguished by the maximum shift for the last autumn freezes, followed by Poti (17 days), Shovi (16 days), Sachkhere and Zugdidi (15 -15 days) etc. Khulo is the only station where, compared to previous years, the onset of frost was 3 days later in spring, and it stopped 1 day earlier in autumn.

Table 3. Comparison results of the average dates of frost occurrence for the periods 1891-1960 (I) and 2007-2022 (II).

Station	Period					
	I	II	II-I	I	II	II-I
Mta-Sabueti	25/IV	21/IV	-4	25/X	2/XI	8
Sachkhere	8/IV	29/III	-10	I/XI	16/XI	15
Zestaphoni	20/III	10/III	-10	26/XI	21/XII	25
Kutaisi	12/III	25/II	-16	26/XII	8/I	13
Zugdidi	23/III	9/III	-14	29/XI	14/XII	15
Poti	3/III	19/II	-12	14/XII	1/I	17
Qobuleti	30/III	14/III	-16	2/XII	16/XII	14
Khulo	14/IV	17/IV	3	6/XI	5/XI	-1
Qeda	21/III	5/III	-16	4/XII	1/XII	-3
Ambrolauri	7/IV	31/III	-6	12/XI	13/XI	1
Shovi	6/V	25/IV	-10	5/X	21/X	16

The shift of the average values of freezing increased the duration of frost-free periods at all weather stations of Western Georgia, exception is Khulo, where the reduction of the frost-free period by 3 days was noted (Table 4).

Table 4. Comparison of average, minimum and maximum values of frost-free periods between the first (1951-1965) and second (2007-2022) periods.

Station	Duration of frost-free days by periods (%)			Least values of frost-free periods %			Highest values of frost-free periods %		
	I	II	II-I	I	II	II-I	I	II	II-I
Mta-Sabueti	182	195	13	149	163	14	152	234	82
Sachkhere	206	232	26	187	190	3	233	282	49
Zestaphoni	250	286	36	192	221	29	322	342	20
Kutaisi	268	317	49	222	271	49	330	343	13
Zugdidi	250	277	27	196	223	27	317	337	20
Poti	280	317	37	224	272	48	347	370	23
Qobuleti	246	275	29	202	244	42	290	337	47
Khulo	205	202	-3	160	131	-29	238	267	29
Qeda	257	268	11	167	179	12	322	364	42
Ambrolauri	218	226	8	180	190	10	247	267	20
Shovi	151	177	26	112	137	25	180	224	44

A comparison of the average, minimum and maximum values of the frost-free periods of 1951-1965 and 2007-2022 showed us that in the last period, compared to the previous one, the average duration of the frost-free period increased by 49 days in Kutaisi, by 37 days in Poti, and by 36 days in Zestafon. A significant increase was also noted in Zugdidi (27 days), Shov and Sachkhere (26-26 days). A similar result was observed for extreme values of the duration of the frost-free period. The minimum values of frost-free periods range from 3-49 days, and the maximum values - from 13 to 82 days. An exception is Khulo, where there is a decrease in the average and minimum values of frost-free periods, and an increase in the maximum value.

The change of the average values of frost-free periods for visibility between the mentioned periods of time is presented in Figure 1, from which it is clear that in the second period, compared to the previous one, the duration of the frost-free periods has significantly increased.

It is known from the literature that frost occurs mainly in cloudless calm weather and is especially noticeable during the invasion of arctic air masses from dry latitudes [8]. Along with this, the Arctic Oscillation (AO) is an important indicator of the Arctic climate, which with its positive and negative phases determines the state of the atmospheric circulation in the Arctic. In order to determine the influence of AO on the climate of Georgia, we compared the graph showing the frost-free periods calculated for the meteorological stations of Western Georgia with the graph of the arctic oscillation indices as a template (Fig. 1 and Fig. 2).

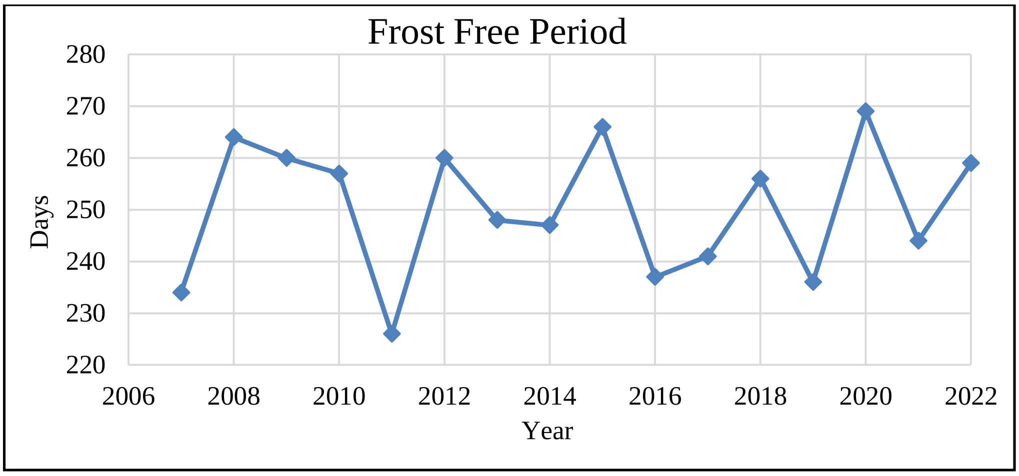

Fig. 1. Change of the average values of durations of frost-free periods in the territory of Western Georgia (2007-2022).

Comparison of Fig. 1 and 2 shows that the duration of frost-free periods in Western Georgia follows the positive and negative phases of the Arctic Oscillation almost proportionally. In particular, a relatively long frost-free period corresponds to each positive phase of the AO indices, and when moving to a negative phase, a decrease in the frost-free period is also recorded in the second diagram. If there was a small shift of positive and negative phases in eastern Georgia until 2012, the exception is 2010 in Samtskhe-Javakheti, where in the case of a negative phase of the AO, a relatively long frost-free period was observed in Samtskhe-Javakheti [8], in western Georgia there are arctic oscillations and frost-free periods. representing the harmonious flow of graphs. After all that, we can confirm that the global climate really determines the climate of Georgia.

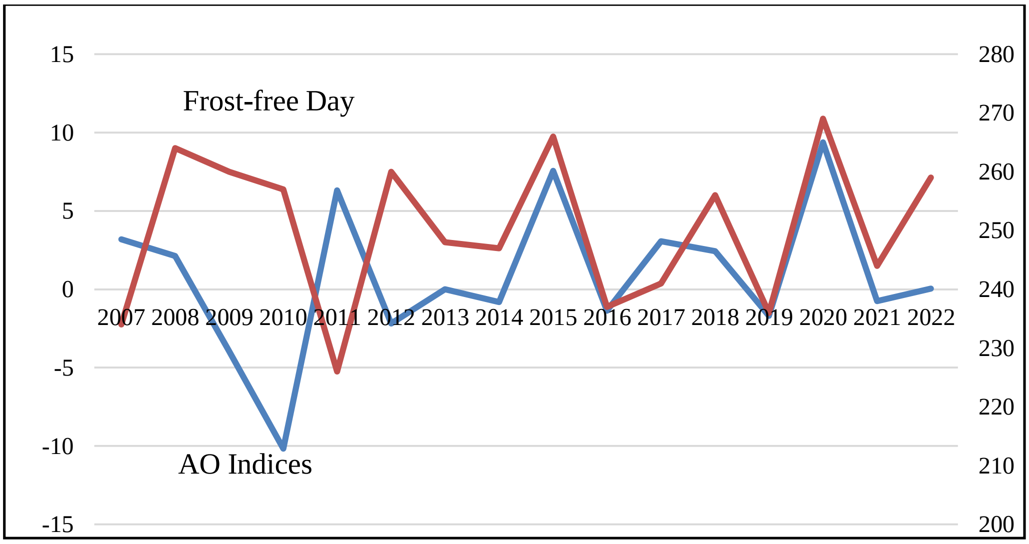

Fig. 2. Distribution of average values of arctic oscillation indices and durations of frost-free periods in the territory of Western Georgia in the period 2007-2022.

Conclusion

The NAO is the primary variation in barometric pressure variation over the North Atlantic that affects the weather and climate of much of Europe. It is subject to internal variability or chaos in the climate system but is also influenced by slowly varying climatic forcing factors including anthropogenic greenhouse warming and solar and volcanic variability, which makes the NAO inherently predictable—at least in part—on a timescale of up to at least several months. Between the 1960s and 1990s the NAO was becoming more positive, but since then this trend has tended to reverse. Recently updated observational records and reanalyses show increasing variability of winter NAO and AO, which is a feature not just of the 2000s and early 2010s but has been ongoing during the 20th century. We have also noted during the last 20–30 years a statistically significant decline in the NAO in summer—and to a lesser extent winter (with a recent record negative December value, although the winter negative trend appears strongest during the period 1989–2011 but has returned to more positive/neutral values in the last 5–6 years)— whereas no significant change has occurred in spring and autumn. This asymmetric seasonal response of the NAO, and its increased winter variability, was not foreseen in previous general circulation climate model predictions analyzed here but may have resulted from several climatic forcing factors and feedbacks conspiring together: these include enhanced blocking arising from cryosphere–atmosphere couplings, solar variability, and/or changes in North Atlantic sea temperatures. The increasingly more variable winter NAO that we have detected based on the last century or so of observations appears to be a seasonally uneven change and does not show up as a forced response—i.e., responding to an external climatic driving factor—in state-of-the-art (CMIP5) climate models. Although the winter increase in NAO variance was sustained over the 20th century and there may be errors in climate models, we still cannot discount the possibility that this feature is due to internal variability (random noise and chaos generation in the climate system), particularly as there was no prior reason to expect this change to occur in winter as opposed to some other season. It is currently uncertain how the NAO will change during the rest of the current century, as both the climate models and our understanding of the physical processes causing NAO variations need to be improved. Whatever the reason(s) behind the observed seasonal NAO changes, there are also clearly important consequences for the heavily populated circum–North Atlantic land masses if these changes continue.

Based on the analysis of the results of our research, it can be concluded that the current climate change has a certain influence on the characteristic parameters of freezing. This influence is manifested by the shift of the average values of the dates of occurrence of frosts and the increase of frost-free periods, or what is the same, the length of the vegetation period by 8-49 days, which is based on the high and quality harvest of agricultural crops in the subtropical zone of Western Georgia, the success of agriculture and socio-economic conditions. It guarantees development

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კლიმატის მიმდინარე ცვლილების გავლენა წაყინვის მახასიათებელ პარამეტრებზე დასავლეთ საქართველოში მეტეოროლოგიური სადგურების მიხედვით

ნ. კაპანაძე, მ. ტატიშვილი, ი. მკურნალიძე, ა. ფალავანდიშვილი

რეზიუმე

დასავლეთ საქართველოში არსებული მეტეოსადგურების 2007-2022 წწ. მონაცემების მიხედვით შესწავლილია სხვავასხვა სიმძლავრის წაყინვების ინტენსივობის განაწილება. დადგენილია საკვლევ პერიოდში გაზაფხულის ბოლო და შემოდგომის პირველი წაყინვის დადგომის თარიღების ნაადრევი, საშუალო და ნაგვიანები მნიშვნელობები. გამოვლენილია 2007-2022 წწ პერიოდში 1951-1965 წწ პერიოდთან შედარებით წაყინვის საშუალო მნიშვნელობების წანაცვლება გაზაფხულის ბოლო წაყინვებისთვის 1-14 დღით უფრო წინ, ხოლო შემოდგომის პირველი წაყინვებისთვის 7-10 დღით უფრო გვიან, რამაც გაზარდა უყინვო პერიოდებისა და, შესაბამისად, სავეგეტაციო პერიოდის ხანგრძლივობები 11-21 დღით, რაც 10-17 %-ს შეესაბამება. გამონაკლისს წარმოადგენს ახალციხე, სადაც გამოვლენილია კლიმატის ცვლილების ფონზე უყინვო პერიოდების შემცირება 15 (9%) დღით. აღმოჩენილია უყინვო პერიოდების არქტიკულ ოსცილაციაზე დამოკიდებულება.

საკვანძო სიტყვები: წაყინვა, უყინვო პერიოდი, წაყინვის ინტენსივობა, არქტიკული ოსცილაცია.

Влияние современных изменений климата на характеристики заморозков в Западной Грузии по метеорологическим данным за 2007-2022 гг.

Н. Капанадзе, М. Татишвили, И. Мкурналидзе, А. Палавандишвили

Резюме

По данным метеостанций 2007-2022 гг. в Западной Грузии изучено распределение интенсивности заморозков разной интенсивности. Определены ранние, средние и поздние сроки последних весенних и первых осенних заморозков за период исследований. В период 2007-2022 гг. по сравнению с 1951-1965 гг. выявлено смещение средних значений замерзания последних весенних заморозков примерно на 1-14 дней раньше, а первых осенних заморозков на 7-10 дней позже, что увеличило продолжительность безморозного периода и, соответственно, продолжительность вегетационного периода на 11-21 день, что соответствует 10-17%. Исключением является Ахалцихе, где на фоне изменения климата зафиксировано сокращение безморозных периодов на 15 (9%) дней. Обнаружена зависимость безморозных периодов от арктического колебания.

Ключевые слова: заморозки, безморозный период, интенсивность замерзания, арктическое колебание.