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Geography and Dynamics of Some Temperature Indices for Assessing the Climate Change in Georgia

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Abstract—Using observational data from 50 meteorological stations in Georgia for 1936–2011, some temperature indices were studied for assessing the climate change: extreme values of temperature, the number of frosty, cold, and hot days and tropical nights as well as indices based on distribution percentiles. Geoinformation maps of the spatial structure are plotted and the dynamics of these indices for the period of global warming is studied. Determined are the mean values of indices for different averaging periods. The obtained results can be used for generalizing corresponding indices for the Caucasian region, the Black Sea basin, or Western Asia.

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INTRODUCTION

According to the data of numerous researches [1, 2, 6, 9, 10, 12], the frequency of many extreme weather and climatic phenomena increases under conditions of the global warming intensification. This can result in serious consequences for economy, agriculture, and even national security as well as for the human health. Therefore, the study and analysis of extreme climatic phenomena is of great importance.

In view of this, the WMO and Intergovernmental Panel on Climate Change (IPCC) of the United Nations worked out 27 major indices characterizing extreme climatic events and recommended some countries to investigate these indices in order to generalize them and use for assessing the climate change in large regions or in the globe as a whole [11, 13]. These indices include climatic extremes, the number of cold, frosty, and hot days and tropical nights as well as indices based on the percentiles of the distribution of the number of rainy and arid periods, etc.

Georgia is a mountainous country with complex physiographic and landscape-climate conditions [3]. Long-term variations of average annual, seasonal, and monthly values of air temperature and amount of precipitation were commonly used for describing the spatial pattern of the climate change on the territory of Georgia [5, 6]. The present paper is the continuation of the papers dealing with the problem of the climate change in Georgia [5–7]. It presents the results of studying the geography and dynamics of major temperature indices proposed by IPCC.

Observational data from 50 meteorological stations of Georgia for 1936–2011 were used for the present research. The specific character of the computation of temperature indices ruled out the possibility of using the methods for recovering missing data. Therefore, the computation of temperature indices for every month was carried out if the data were absent for not more than 3 days; for every year if the data were absent for not more than 36 days. To compute indices based on distribution percentiles, the use of more than 70% of the data was considered a compulsory condition. In all other cases, the computation of indices was interrupted automatically.

To recover some missing data in the series of temperature values, the following procedure was used. Taking account of data on temperature for all stations, correlation matrices were made. As a result of their statistical analysis and taking account of physiographic conditions of the station location, the groups were formed of high-correlated stations between which the coefficients of correlation for a certain index were significant at the level of 95% and more. After that, missing data within each group were determined by the method of corresponding differences. The method of differences was chosen due to the specific character of the parameter under study (temperature) for which difference in the data of two or several stations located in similar physiographic conditions varies insignificantly from year to year.

SPATIAL STRUCTURE OF TEMPERATURE INDICES

The days when the maximum value of air temperature is negative, are considered frosty (IDO), and the days when the minimum value of air temperature is negative, cold (FDO). The latters include the days with frosts in transition seasons. As the number of cold days increases, the night-time temperature has a trend towards decrease and, on the contrary, temperature at night rises as the number of cold days decreases. The days when the maximum air temperature exceeded 25 C, are considered hot (SU25). This index is one of the indicators of warming. Increase in the number of hot days is associated with increase in accumulated active temperature that influences positively the growth and development of the majority of crops. In transition seasons, increase in the number of hot days indicates increase in the duration of vegetation period (the change in the date of the beginning or end of the vegetation period). This is quite urgent for planning and carrying out the selection of crops with the vegetation period corresponding to new climatic conditions in the best way.

Besides, the authors considered maximum (Txx) and minimum (Tnn) values of temperature in 24 hours, the duration of the vegetation period when accumulated active temperatures exceed 5 C (GSL), and the number of tropical nights when the minimum value of temperature exceeds 20 C (TR20). To estimate the number of extremely warm days in winter and extremely cold days in summer, the minimum number of the absolute maxima of temperature Txn and the maximum number of its absolute minima TNx were determined.

The following indices based on temperature distribution percentiles were considered: Tx90p, the number of days when the maximum air temperature exceeds the threshold value (90% percentile of the temperature maximum), and Tn10p, the number of days when the minimum air temperature is below the threshold value (10% percentile of the temperature minimum).

The number of frosty, cold, and hot days and tropical nights as well as the duration of vegetation period were computed using the data obtained for the year. The rest of the indices characterizing diurnal extremes including temperature percentiles were obtained from the data for the month; in particular, the maximum values of temperature in the warmest months (July–August) and the minimum ones in the coldest months (December–January) were taken into account.

In case of extremely low temperatures on frosty days, there is a risk of frostbite for people outdoors, the system of building upkeep is disturbed, and conditions for machinery operation become more complicated. Due to extremely high values of temperature during long hot periods, the human's organism is affected by stress heat loads, and such periods are usually accompanied by precipitation absence and drought risk.

In Fig. 1, the geoinformation maps are presented of the distribution of two indices (the number of cold and hot days) for 1961–1990, the period recommended by the WMO as the basic one.

It is clear that the minimum number of cold days (<10) on the territory of Georgia was registered on the Adzharian coast of the Black Sea where the absolute minimum of temperature was not below –6…–8 C. In the rest part of the territory of the Georgian Black Sea coast and on the Colchis Lowland, the number of cold days increases to 30 and the absolute minimum of temperature reaches –10…–12 C. In the flat part of eastern Georgia, the number of cold days increases to 50–100, on the South Georgian Plateau, to 200, and in the central part of the Greater Caucasus, 300. In these areas, the absolute minimum of temperature is –16…–26 C and –32…–36 C, respectively.

The distribution of the number of hot (when the maximum air temperature is above 25 C) and frosty days is opposite. The maximum number of such days (more than 140) is registered in the south of Georgia in the area of Lower Kartli. The number of hot days is more than 100 in the Alazan Valley and in the central part of the Colchis Lowland where the absolute maximum of temperature exceeds 40–41 C, it is less than

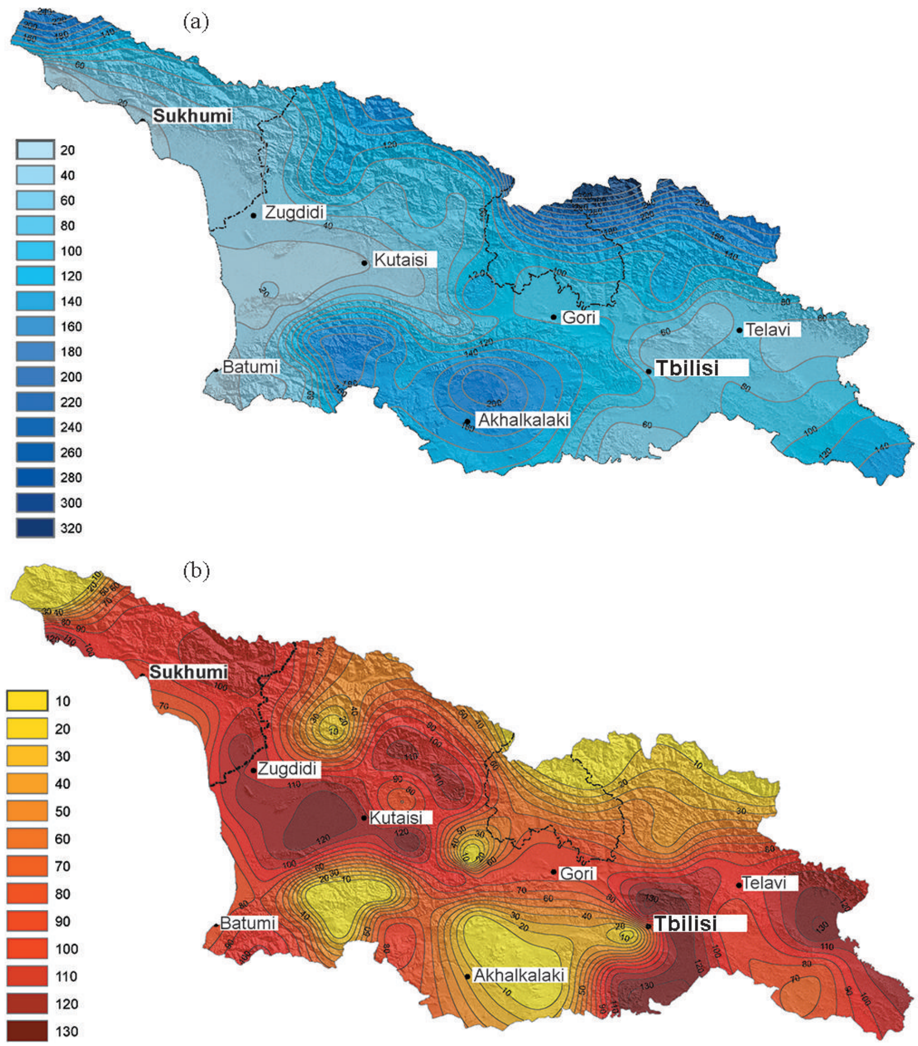

Fig. 1. Geoinformation maps of distribution of the number of (a) cold and (b) hot days per year in 1960–1990. The figures presented by the authors also include the territories of Abkhazia and southern Osetia (editorial note).

100 on the Black Sea coast, 0–50 on the South Georgian Plateau, and 0–30 in the central part of the Greater Caucasus, where the absolute maximum of temperature drops below 20 C.

In the Colchis Lowland and in the flat part of eastern Georgia, the number of hot days is larger than the number of cold days; the opposite picture is observed in Pasanauri, on the southern slope of the Greater Caucasus at the height of about 1100 m above the sea level. The equality in the number of cold and hot days is possible in low-mountain areas at the height of about 700–800 m above the sea level.

The nature of the spatial distribution of other indices can be judged by the data of Table 1. According to them, frosty days are absent on the Black Sea coast and Colchis Lowland, their number reaches 7 in the flat areas of eastern Georgia, increases to 60 on the South Georgian Plateau, is about 20 in the lower part of the Greater Caucasus, and increases to 200 in its upper zone.

The duration of the vegetation period exceeds 350 days on the Georgian Black Sea coast and Colchis Lowland, slightly decreases in eastern Georgia, and is about 200–220 days on the South Georgian Plateau and in the lower part of the Greater Caucasus; such period is absent in the upper zone of the Greater Caucasus. Tropical nights are also absent in the area of the Greater Caucasus and on the South Georgian Plateau. Their number is from 10 to 23 per year in eastern Georgia and exceeds 30 on the Black Sea coast and Colchis Lowland.

It also follows from the data of Table 1 that the index of percentiles of temperature maxima and minima, i.e., the number of days with the temperature exceeding over respective thresholds varied within

Table 1. Mean values of some climatic indices (day) for 1961–1990 in different physiographic regions of Georgia

Region	Station	Height, m above the sea level	Index				
			IDO	GSL	TR20	Tx90p	Tn10p
Black Sea coast and Colchis Lowland	Batumi	2	0	355	32	3.7	3.0
	Poti	3	0	352	32	3.3	2.7
	Kutaisi	114	0	350	30	3.3	3.0
Eastern Georgia	Tbilisi	403	4	300	23	3.6	3.0
	Telavi	568	7	295	13	3.6	3.3
South Georgian Plateau	Akhalkalaki	1717	57	200	0	3.6	3.0
	Abastumani	1265	28	220	0	3.3	3.0
Greater Caucasus	Kazbegi (high-mountain)	3653	210	0	0	3.0	2.7
	Pasanauri	1070	21	220	0	3.6	3.0

2.7–3.7 days and the indices of 90% percentiles of maximum values of temperature slightly prevail. Considerable differences in the spatial distribution of percentile indices have not been registered.

LONG-TERM TRENDS OF TEMPERATURE INDICES

Table 2 presents the values of the rate of change in some temperature indices as well as the respective determination coefficients which enable judging about the contribution of the trend to their total variability; the table also presents statistical significance for meteorological stations characterizing different physiographic areas of Georgia: the Black Sea coast (Poti), the Colchis Lowland (Kutaisi), the flat part of eastern Georgia (Tbilisi), and the mountain areas of the Caucasus (Pasanauri). As follows from the data of Table 2, the rate of change in temperature indices during the global warming period is affected considerably by physiographic conditions of the location of stations. Besides, different temperature indices respond to the global warming in different ways. Extreme values of temperature, especially the absolute maximum, are less sensitive to the warming process. The rate of change in extreme values of temperature is insignificant and does not exceed 0.5 C/10 years. These changes are statistically insignificant; the exception is the absolute minima of temperature in Tbilisi and Kutaisi for which changes are statistically significant at the level of 95% and more; the contribution of the trend to the increase in the absolute minima of temperature in Tbilisi reaches 20%. Some changes were registered in the dynamics of the maxima of minimum values of temperature TNx; the increase in this index is statistically significant. The change in the minima of maximum values of temperature Txn is less significant.

The number of cold and hot days and the number of tropical nights are the most dependent on the global warming. The number of cold days under conditions of the global warming decreased everywhere. The rate of decrease in the number of days per 10 years is about one day in the significant part of Georgia; it increases to 2–3 days on the plains of eastern Georgia. The contribution of the trend to the total change in the number of cold days is 12–33%. Decrease in the number of cold days affects decrease in the number of days with frosts in transition seasons that is a positive factor for the agricultural regions of Georgia. Such investigation of reasons for frosts on the territory of Georgia was presented in our paper [4] and in the monograph [8]. Under conditions of the global warming, the number of hot days increased considerably on the Black Sea coast as well as in eastern Georgia and in the lower and upper areas of the Greater Caucasus. The variations of these indices are statistically significant on the Black Sea coast and in the low-mountain zone of Georgia. The contribution of the global process to the increase in the number of hot days on the Georgian Black Sea coast makes up more than 40%; in low-mountain areas, in spite of high statistical significance, only 7% of interannual variations of the number of hot days can be explained by the global warming processes.

The number of tropical nights turned out to be the most sensitive to the global warming. Their number per 10 years increased by six on the Black Sea coast, by three on the Colchis Lowland, and by two on the plains of eastern Georgia. These changes are statistically significant. Judging by the values of determination coefficients, the contribution of the trend to the total variability of the number of tropical nights is significant, exceeds 40% on the Black Sea coast, and varies within 15–25% in the rest of the flat areas of Georgia.

Table 2. Rate of change in temperature indices per 10 years (*K*), respective determination coefficients (R^2), and statistical significance (*p*) under different physiographic conditions

Index, unit	Poti (3)			Kutaisi (114)			Tbilisi (404)			Pasanauri (1070)		
	K	R^2	p	K	R^2	p	K	R^2	p	K	R^2	p
Txx, C	0.37	0.06	0.08	0.03	0.02	0.21	0.02	0.03	0.17	0.18	0.05	0.07
TNn, C	0.36	0.07	0.06	0.32	0.07	0.03	0.41	0.20	0.00	0.20	0.03	0.17
Txn, C	0.12	1.01	0.48	0.15	0.30	0.15	0.16	0.05	0.02	0.18	0.11	0.06
TNx, C	0.26	0.17	0.00	0.18	0.03	0.14	0.13	0.16	0.00	0.38	0.03	0.00
IDO, day	0.00	–	–	0.00	–	–	–0.27	0.03	0.05	–1.00	0.04	0.09
FDO, day	–1.33	0.12	0.05	–1.00	0.25	0.07	–2.56	0.33	0.00	–1.05	0.23	0.18
SU25, day	2.41	0.34	0.00	0.10	0.05	0.90	2.31	0.28	0.34	1.73	0.07	0.03
Tx90p, day	0.40	0.08	0.00	–0.03	0.03	0.60	0.03	0.03	0.51	0.30	0.15	0.04
Tn10p, day	–0.06	0.15	0.00	–0.20	0.12	0.00	–0.30	0.41	0.00	–0.05	0.02	0.30
GSL, day	0.36	0.02	0.90	–1.00	0.02	0.22	3.12	0.13	0.00	1.13	0.10	0.28
TR20, day	5.70	0.42	0.00	2.66	0.15	0.00	2.40	0.25	0.00	0.00	–	–

Note: The height in meters above the sea level is given in brack.

Table 3. Mean values of temperature indices for different averaging periods

Station	Period, years	Index				
		FDO	SU25	TR20	Tx90p	Tn10p
		day				
Poti	1936–1960	**18**	**85**	**28**	**3.6**	**3.0**
	1961–1990	**14**	**88**	**32**	**3.3**	**2.7**
	1991–2011	**11**	**105**	**43**	**4.5**	**2.1**
Kutaisi	1936–1960	17	125	**30**	3.3	**3.6**
	1961–1990	16	122	**30**	3.3	**3.0**
	1991–2011	15	125	**40**	3.6	**2.1**
Tbilisi	1936–1960	**62**	118	**20**	3.6	**3.6**
	1961–1990	**63**	116	**23**	3.6	**3.0**
	1991–2011	**52**	120	**26**	3.9	**2.0**
Pasanauri	1936–1960	**140**	**52**	0	**3.0**	3.0
	1961–1990	**130**	**48**	0	**3.3**	3.3
	1991–2011	**128**	**65**	0	**3.9**	2.7

Note: Statistically significant differences are bolded.

The duration of the vegetation period is sensitive to the global warming on the plains and in the piedmont and low-mountain regions of eastern Georgia. For example, according to the data of Table 2, the rate of increase in the vegetation period duration per 10 years exceeds three days on the plains in eastern Georgia and is one day at the boundary between the low- and high-mountain zones although the variations of vegetation period duration is statistically significant for Tbilisi only.

The certain decrease in the number of frosty days under conditions of global warming at the statistical significance of 90% and more was registered in the mountain areas of Georgia and amounts to one day/10 years on average; however, the contribution of the global process to the change in the number of frosty days is very small and makes up 4% only.

Unlike extreme values of temperature, the change in temperature percentile indices is more considerable. Their variations are statistically significant in the most part of Georgia. Increase in the index of 90% percentiles on the Black Sea coast exceeds two days/10 years. The index of 10% percentiles of temperature minima decreases with the rate of about 1 day/10 years. The indices of percentiles of seasonal values of temperature vary in a similar way. Regardless of the season, the percentiles of maximum values of tempera-

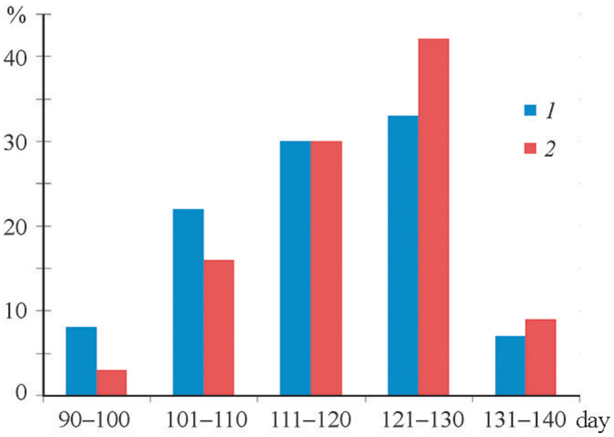

Fig. 2. Frequency of the number of hot days in Tbilisi (*1*) in 1936–1975 and (*2*) during the period of intensive global warming 1976–2010.

ture have a trend towards increase and the percentiles of minimum values of temperature, a trend towards decrease. The considerable increase in the number of hot days and tropical nights obviously can be explained just by increase in the maxima percentiles and by decrease in temperature minima percentiles.

TEMPERATURE INDICES FOR DIFFERENT AVERAGING PERIODS

In Table 3, the mean values are compared of some temperature indices being the most sensitive to the global warming for different averaging periods for four meteorological stations characterizing different physiographic conditions. The data are compared for the period till 1960, for 1961–1990 (the basic period recommended by the WMO), and for the period after 1990.

As follows from Table 3, statistically significant differences between the mean values of temperature indices for different averaging periods are registered on the Georgian Black Sea coast for all presented indices. For example, the number of cold days for 1991–2011 decreased as compared with 1936–1960 by seven. The number of hot days for the same period increased by 20 and the number of tropical nights, by 15. As compared with the basic period of 1961–1990, these changes amounted to 3, 17, and 11 days, respectively. The number of cold days in Tbilisi decreased by 10 and the number of tropical nights increased by six in Pasanauri and on the southern slope of the Greater Caucasus as compared with the period before 1960. The number of frosty days decreased from 140 (1936–1960) to 128 (1990–2011), i.e., by 12 days; in 1990–2011 the number of hot days increased by 17 as compared with 1960–1990. All these differences are significant at the level of not less than 95%. It also follows from the data of Table 3 that the variations of indices of percentiles of extreme values of temperature in Poti, the minimum values of temperature in Tbilisi and Kutaisi, and the maximum values of temperature in Pasanauri are statistically significant.

Such differences in the mean values of indices for different averaging periods are caused by the change in their statistical structure. In particular, as for the number of hot days during the period of intensive global warming (1976–2011) as compared with the period before 1975, the frequency of their small values decreased and the frequency of large values increased. This is corroborated by the data in Fig. 2 that presents the histogram for the number of hot days for the periods before and after 1975 for Tbilisi, when the rate of change in the number of hot days after 1975 increased only by two days per 10 years. It is clear from Fig. 2 that in Tbilisi during the period of intensive global warming the frequency of hot days in the range of 121–130 increased considerably as compared with the period before 1975 (from 33 to 42%). The frequency of hot days in the range of 131–140 also increased there.

CONCLUSIONS

According to the data obtained as a result of the present research, the catalog was formed of some temperature indices: temperature extremes, the number of frosty, cold, and hot days, the number of tropical nights, and indices based on distribution percentiles for 1936–2011. Geoinformation maps of the spatial structure of temperature indices were plotted and their trends for the global warming period were estimated.

It was revealed that different temperature indices indicate the global warming in different ways: temperature extremes are less sensitive to it and the number of cold and hot days is more sensitive. Under conditions of the global warming, the number of cold days decreases everywhere; the number of hot days increases considerably on the Black Sea coast, in eastern Georgia, and in the piedmont and low-mountain areas of the Greater Caucasus.

The number of tropical nights is the most sensitive to the global warming. The rate of increase in their number is six, three, and two nights per 10 years on the Georgian Black Sea coast, Colchis Lowland, and plains in eastern Georgia. The variations of indices of percentiles of temperature extremes are statistically significant in the most part of Georgia. Increase in the index of 90% percentiles on the Black Sea coast exceeds two days/10 years. The index of 10% percentiles of temperature minima decreases with the rate of about one day/10 years.

The obtained results can be used for generalizing the values of respective indices for the Caucasian region, Black Sea basin, or Western Asia [11, 13].

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