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Climatology and Historical Trends in Tropical Nights over the Georgian Territory

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Abstract: Based on the materials of observation of 50 meteorological stations of Georgia for the period between 1936-2013, research has been made of geography, structure, intensity, duration and dynamics of tropical nights on the Georgian territory. Nights are considered tropical if minimum air temperature is above 20°C (TR20). Tropical nights are most widespread in the intermountain trough – Kolkheti lowland, the plains of Central and Lower Kartli, Alazani valley, where the average number of tropical nights during one year reaches 35. With the growth of altitude, the number of tropical nights naturally decreases, and on the height of 1000m there are no tropical nights detected. As a result of global warming the increase in the number of tropical nights has been most notable on the Black Sea coast and in the region of the nearby Kolkheti lowland (4-6 days per decade). In the internal regions of the lowland and in the Eastern Georgia the rate of change decreases. On the Black Sea coast tropical nights start in April and last until October. They are most intense in July and August, exceeding 27°C. On the Kolkheti Lowland tropical nights start in March and last until November. Here they are more intense (27-30°C, June-July). In the Eastern Georgia the duration of tropical nights decreases. In Kartli they last from May until September, whereas in Kakheti they last from June until September. Maximum intensity of tropical is nights peaks in July or August, when it comprises 24-26.5°C. The intensity of tropical nights has increased by 0.1-0.3°C per decade.

Keywords: Tropical Night, Recurrence, Decadal Trend Rate, Coefficient of Determination, Intensity

1. Introduction

Tropical nights are one of the basic climate change indices, the study of which has been proposed by World Meteorological Organization (WMO) and the Expert Team on Climate Change Detection and Indices (ETCCDI). The aim is to reveal extreme deviations in climatic phenomena in conditions of global warming and generalization of the data for major regions and the entire globe, as well as implementation of a corresponding comparative analysis [16]

According to the ETCCDI, nights are considered tropical if minimum air temperature is above 20°C (TR20). Such nights are generally characteristic of low latitudes. In middle and high latitudes tropical nights are rare and occur mostly in the beginning of summer. In such conditions the water in natural reservoirs becomes warm at night.

In the subtropical regions of Georgia tropical nights are frequent. They are conditioned by the advection of warm and

dry air masses from the South, Asia Minor, or advection of warm and humid air masses from the Atlantic and the Mediterranean, occurring during the intensification of Azorean anticyclone over South Caucasus. The recurrence of these processes is 25%. High air temperatures and humidity, characteristic of Western Georgia, is damaging to human health, and impacts workplace performance and productivity. As a result, tropical nights are unbearable. On hot days (when daily maximum temperature exceeds 25°C), on the plains of Georgia the temperature often exceeds 40°C, and during the tropical nights it exceeds 30^{O}C. Such conditions have a negative impact on the human body and may lead to stress thermal load, which cannot be relieved even by means of complete hygienic and town-planning measures.

In general, Georgia is sensitive to the global warming [1, 3]. As a result of change in the temperature and precipitation regime related to the global warming there are notable tendencies of transformation of certain ecosystems – desertification of steppe landscapes, mountain glacial retreat, humidification or aridity of certain landscapes, eustasy and increase of stormy currents in the Black Sea and other changes [2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. Further intensification of the global warming may significantly change the climate of Georgia.

The given article is a logical continuation of the above-mentioned research. It provides results of research regarding the geography, structure, intensity, duration and dynamics of the number of tropical nights on the territory of Georgia. This enhances our knowledge of the response of the regional climate to global warming.

2. Research Object

Georgia is located in the South-Western part of the Caucasus, on the border of the Mediterranean, arid Aral-Caspian cavity and the plateau of Asia Minor. Its area embraces 69.7 thousand km^2. It occupies the utmost Northern part of the subtropical climatic zone. All types of climate characteristic of this zone are found in Georgia: from the nival zone and glaciers to continental steppe climate of the Eastern Georgia and humid subtropical climate of the Black Sea coast (fig. 1).

The Georgian territory is a sharply cross-country locality, embracing high mountains, medium height mountains, hills, lowlands, uplands and plateaus. Some lowlands are on the sea level, whereas some mountains peaks reach the height of 5000 m above sea level (fig. 2).

In the Northern part of the territory, from the North-West to the South-East stretches the Great Caucasus Range. In the Southern part of Georgia, the Lesser Caucasus runs parallel to the Great Caucasus Range. Between the Great Caucasus and the South-Georgian Plateau there is a tectonic depression, represented by lowlands, river valleys, plains and plateaus.

The Great Caucasus and Lesser Caucasus ranges are connected by the Likhi Range, which is the watershed, dividing the basins of the Black and the Caspian Seas. Georgia's climatic peculiarities are largely conditioned by the Caucasus mountain range, to the north and the Black Sea to the west.

Figure 1. *Location of Georgia.*

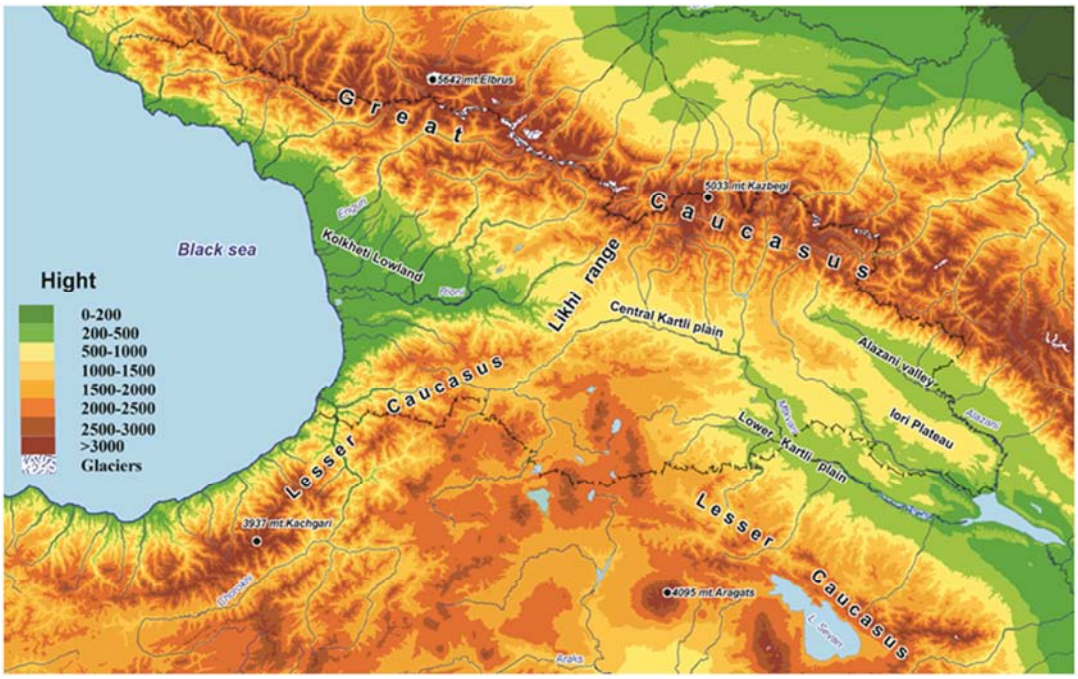

Figure 2. *The Relief of Georgia.*

In addition, the country is divided by the Likhi Range into two different climatic zones: Western, with humid subtropical climate, and the Eastern, with mild dry continental climate.

3. Research Materials and Methods

The research is based on the materials of observation of 50 meteorological stations in Georgia for the period of 1936-2013. Nights are considered tropical if the minimum air temperature exceeds 20°C (TR20). In order to fill certain gaps in the data, the following procedure was applied: correlation matrixes were compiled for every station, and, based on statistical analysis, envisaging physical-geographical conditions of the location, groups of highly correlate stations were identified, the coefficients of correlation of which for the index under analysis were significant on the level of 95% and more. Furthermore, inside each group the gaps were identified using the method of correlating differences. The intensity of tropical nights is revealed in the maximum of daily minimum temperatures (TNx °C). The higher the index, the more intense are the tropical nights.

4. Discussion of Results

4.1. Geographical Laws of Distribution of the Number of Tropical Nights and Their Relation to Hot Days

Tropical nights are most frequent on the Black Sea Coast and intermountain trough - Kolkheti Lowland, Central and Lower Kartli plains, Alazani valley, Iori Plateau, where the average number of tropical nights during the year comprises 35. Here the absolute maximum temperature exceeds 40-41°C, whereas the number of hot days with maximum temperature exceeding 25°C (SU25) is above 100. In certain cases, during the tropical nights, the minimum temperature exceeds 25°C. In the internal regions of Kolkheti Lowland, the number of tropical nights with the temperature exceeding 25°C reaches 3 during the year. With the increase in altitude, the number of tropical nights decreases, and on the altitude of about 1000 meters, tropical nights reduce to zero (fig. 3).

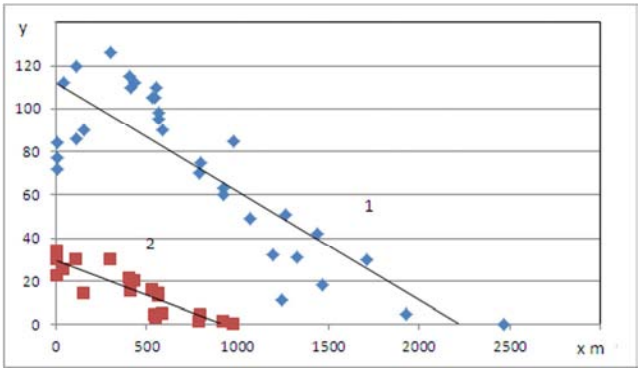

Figure 3. *Change according to the altitude (x) of the number of hot days (1) and tropical nights (2), corresponding equations of regression (y=-0.05x+111.9; y=-0.032x+29.36) and coefficients of determination (R^2=0.71; 0.79).*

According to figure 3, we can also conclude that, with the altitude of the location, tropical nights change parallel to the number of hot days. The difference between them on the sea level comprises about 80 days, decreasing in the mountains to 60. The coefficients of determination in both cases are quite high, comprising 0.71 for hot days and 0.79 for tropical nights. This proves that the contribution of the factor of altitude in the change of these indices comprises 71% and 79% respectively. Based on the equations of regression, the

vertical gradient of the number of tropical nights comprises over 3 days per 100m, whereas the vertical gradient of the number of hot days comprises 5 days per 100 m.

The interdependence between the change in the number of tropical nights and the number of hot days on the entire Georgian territory is not strong, the spots are scattered, and the coefficient of linear correlation between them is less than 0.4. However, in separate geographical regions there is a close linear connection between the number of hot days and the number of tropical nights. The interdependence can be described as follows:

$$N(RT20) = KN(SU25) + b, \quad (1)$$

where N(SU25) is the number of hot days, N(RT20) is the number of tropical nights, K and b – are statistical parameters, K is the coefficient of regression, b is a free member of the equation.

Table 1 gives the meanings of statistical parameters and the coefficients of correlation and the number of observed stations according to regions.

Table 1. *Statistical parameters for equation (1) and coefficients of correlation (R).*

Region	Parameter			
	K	b	R	Number of stations
Eastern Georgia	0.394	-27.67	0.79	15
Kolkheti Lowland	0.625	-45	0.88	4
Mountains of Western Georgia	0.041	-0.95	0.91	6

According to Table 1, the coefficient of correlation between the number of tropical nights and the number of hot days is significantly higher in the Western Georgia. This means that in Western Georgia tropical nights frequently occur in conditions of hot days. In the Eastern Georgia, due to the aridity of climate, the daily amplitudes of temperature increase. Therefore, on hot days the minimum temperature is often below 20°C, as a result of which, the nights are not tropical.

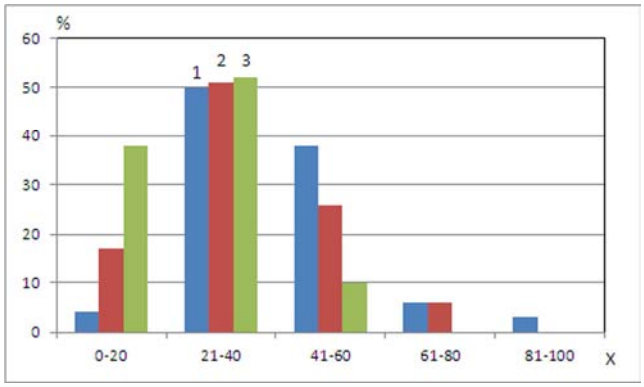

Figure 4. *Recurrences of different gradations of the number of tropical nights per year (x): 1-Batumi, 2-Kutaisi, 3-Tbilisi.*

Based on equation (1) and statistical parameters, it can be concluded that in the Eastern Georgia and on Kolkheti Lowland tropical nights occur in the regions where the number of hot days exceeds 70-72, whereas in the mountains of Western Georgia tropical nights occur in places where the number of hot days reaches 20-23. There is no such regularity in case of the Black Sea coast, where the number of hot days fluctuates between 75-90, and the number of tropical nights fluctuates between 14-35.

Figure 4 represents recurrences of different gradations of the number of tropical nights in various physical-geographical conditions of Georgia: Batumi, located on the Black Sea Coast, Kutaisi – located on Kolkheti Lowland, and Tbilisi – located in Eastern Georgia, for the period between the years 1936-2013.

Based on Figure 4, we can conclude that, despite physical-geographical conditions, there is highest likelihood of 21-40 occurrences of tropical nights per year, the recurrence of which comprises 50-52%. Besides, low gradations of the number of tropical nights are evident in Tbilisi (0-20 and 21-40 days), which is located in the arid zone. Hence, they are rare in Batumi, which is characterized by humid subtropical climate. With the increase in the gradation of the number of tropical nights (41-60 days), the situation is opposite: there are corresponding recurrences in the humid subtropical zone (Batumi, Kutaisi). Tropical nights with the gradation of 80 days and more are entirely absent in Tbilisi.

4.2. Interannual Change in the Number of Tropical Nights

Figure 5 represents interannual number of tropical nights in Batumi, Kutaisi and Tbilisi for the period of 1936-2013.

Based on Figure 5, it can be concluded that in the period between 1936 and 2013 the number of tropical nights in the above-mentioned places fluctuated significantly, yet, increased on a regular basis. Based on the equations of regression, the trend rate of increase in the number of tropical nights was 2 days in Batumi, 2.3 – in Kutaisi, and 1.3 in Tbilisi per decade.

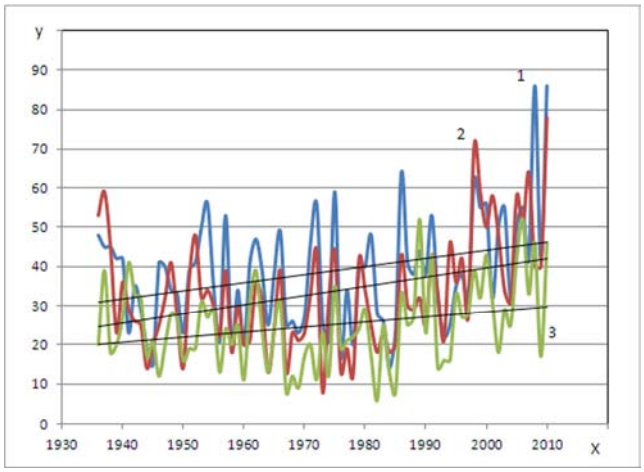

Figure 5. *Interannual change in the number of tropical nights (y): 1-Batumi, 2-Kutaisi, 3-Tbilisi, corresponding equations of regression (y=0.206x-369.4; y=0.234x-429.7; y=0.131x-0.234.7) and coefficients of determination (R^2=0.095; 0.124; 0.073).*

The trend rate of increase in the number of tropical nights is higher in the period of global warming (1991-2013). This

can be proved by Table 2, which represents decadal trend rate of change in the number of tropical nights, corresponding coefficients of determination and their statistical values for the period of intense global warming in various physical-geographical conditions of Georgia.

Table 2. *Decadal trend rate of change in the number of tropical nights (k), corresponding coefficients of determination (R^2) and their statistical values (p) for the period of intense global warming (1991-2013).*

Region	Location	Altitude m	K days per decade	R^2	p
Black Sea Coast	Poti	5	5.8	0.42	< 0.01
	Batumi	10	4.7	0.24	0.02
	Kobuleti	7	4.9	0.35	0
Kolkheti Lowland	Senaki	40	4.6	0.21	< 0.01
	Kutaisi	114	2.7	0.15	< 0.01
Eastern Georgia (Kartli)	Tbilisi	403	1.4	0.25	< 0.01
	Gardabani	300	2.3	0.11	0.02
	Bolnisi	534	1.2	0.16	< 0.01
Eastern Georgia (Kakheti)	Telavi	568	2.2	0.13	0.01
	Akhmeta	574	3.3	0.18	0.01
	Dedoplistskaro	800	1.5	0.19	< 0.01

According to Table 2, the trend rate of increase in the number of tropical nights on the Georgian territory in highest on the Black Sea Coast. In its central region (Poti) the decadal trend rate reaches 6 days per decade, whereas in the Southern regions of the Black Sea coast, in Achara (Batumi, Kobuleti) it comprises 5 days per decade. Based on the data of the coefficient of determination, the contribution of the global component in the total change of the number of tropical nights is quite significant, comprising 42% in Poti and 24-35% in Achara.

In the regions of Kolkheti Lowland, close to the coast, the decadal trend rate of the increase in the number of tropical nights is analogous to the trend rate of the change in the number of tropical nights in Achara (in Senaki, 4.6 days per decade). In the internal regions of the Lowland it decreases to a certain extent (in Kutaisi, 2.7 days per decade).

The trend rate of change in the number of tropical nights is less in the Eastern, continental part of Georgia. On the plains of Central and Lower Kartli (Tbilisi, Gardabani, Bolnisi) it comprises 1.2-2.3 days per decade, and the contribution of the global factor is 25%. On the Alazani Valley the decadal trend rate of change in the number of tropical nights increases to a certain extent (Akhmeta, 3.3), whereas in the low mountain zone of the Caucasus it decreases (Dedoplistskaro, 1.5). The contribution of the global factor in these changes is only 13-19%.

According to the data of Table 2, all the above-mentioned changes are statistically significant on a high level of significance.

4.3. Statistical Structure of Tropical Nights for Different Average Periods

Table 3. compares average annual and extreme values of the number of tropical nights for different average periods in Batumi, Kutaisi and Tbilisi.

Table 3. *Average and extreme annual values of the number of tropical nights for different average periods.*

Location	Characteristic	Periods			
		1900-1935	1936-1960	1961-1990	1991-2013
Batumi	Average	-	35	35	47
	Maximum	-	56	54	86
	Minimum	-	15	14	22
Kutaisi	Average	-	31	30	41
	Maximum	-	59	44	78
	Minimum	-	14	8	21
Tbilisi	Average	17	21	23	27
	Maximum	32	41	52	52
	Minimum	5	11	6	14

Table 3. illustrates that during the period of intense global warming (1991-2013) in all places, both the average number and extreme values of tropical nights increased significantly in comparison with the previous periods. For example, in Batumi during the period of intense global warming the average number of tropical nights was 47, whereas during the previous years it did not exceed 35. In Kutaisi the average number of tropical nights reached 41; in Tbilisi-27, surpassing the corresponding figures for previous periods. The extreme values of the number of tropical nights increased as well. All these changes are statistically significant.

These differences in average and extreme values for different periods are caused by changes in the statistical structure of the number of tropical nights, which, in all likelihood, is influenced by the global warming. The above mentioned is confirmed by the example of proportion of frequency of different gradations of tropical nights in Tbilisi for 4 periods represented in Figure 6: 1900-1935-Hydrometeorological Service of Georgia was set up; 1935-1960 years relevant to the conditions of less intense warming, 1961-1990 years, the baseline period recommended by the World Meteorological Organization and the 1991-2013

years- the period of most intense global warming.

Figure 6. shows that during the first period (1900-1935) the occurrence of 1-20 tropical nights was prevalent (80%), while the incidence of 21-40 tropical nights was comparatively rare (20%). During the second period the recurrence of the above mentioned gradation made up 40% and there were cases of more than 40 tropical nights per year.

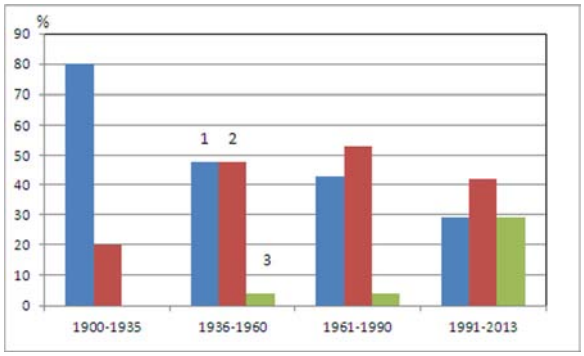

Figure 6. *Frequency of different gradations of the number of tropical nights in Tbilisi for different periods Gradations: 1) 1-20 days; 2) 21-40 days; 3) 41-60 days.*

During the baseline period WMO the highest frequency (53%) corresponded to 21-40 tropical nights, and the occurrence of 1-20 tropical nights constituted 43%.

Over the period of the intense global warming (1991-2013), the frequency of occurrence of tropical nights in the range of 41-60 increased substantially up to 29% and maximum frequency amounted to 42% relevant to gradation of 21-40 nights. Overall, the frequency of tropical nights with gradation less than 20 days decreased proportionately, whereas there was an increase in the frequency of gradation of 41-60 days.

4.4. Period of Onset and Intensity of Tropical Nights

Table 4. gives the data on the periods of onset and intensity of tropical nights. The intensity of tropical nights is defined by the maximum of daily minimum temperature. (TN x °C), the higher this rate, the more intense is the occurrence of tropical nights. Table 4. indicates that the period of occurrence, as well as the intensity of tropical nights, depends on physical and geographical conditions of the area.

Table 4. *Period of onset and intensity of tropical nights (°C).*

Region	Location	Altitude	Period, months								
			Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov
Black Sea Coast	Poti	5	-	20.6	23.6	24.0	27.6	27.2	24.5	21.5	-
	Batumi	10	-	-	21.0	24.3	26.8	26.4	25.7	20.4	-
	Kobuleti	7	-	20.1	20.3	24.5	26.4	26.4	24.0	21.2	-
Kolkheti Lowland	Senaki	40	-	22.0	25.0	27.4	24.0	27.0	26.0	21.6	20.6
	Kutaisi	114	21.0	22.6	28.0	30.2	30.2	29.4	29.1	25.6	20.2
East Georgia (Kartli)	Tbilisi	403	-	-	20.1	24.0	25.5	26.0	23.1	-	-
	Gardabani	300	-	-	22.8	24.1	26.4	25.9	24.1	-	-
	Bolnisi	534	-	-	21.0	23.2	25.3	25.9	24.0	-	-
East Georgia (Kakheti)	Telavi	568	-	-	-	22.3	25.1	26.1	23.4	-	-
	Akhmeta	574	-	-	-	23.3	24.8	24.1	21.4	-	-
	Dedoplistskaro	800	-	-	-	23.2	24.0	24.0	21.9	-	-

Thus, on the Black Sea Coast the occurrence of tropical nights starts from April and lasts until October. The intensity of tropical nights reaches its maximum in July and August, with the temperature a bit higher than 27°C. On Kolkheti Lowland tropical nights occur from March to November. Here, the tropical nights are more intense and their maximum reaches 27-30°C (June-July). Due to humidity, characteristic for tropical nights, a person experiences a sense of stuffiness that has negative impact on health, work and rest, and, therefore, makes tropical nights unbearable.

In Eastern Georgia, in a continental climate, the length of tropical nights decreases; in Kartli tropical nights occur from May to September (Tbilisi, Gardabani, Bolnisi); in Kakheti, due to increasing aridity, tropical nights are shorter and they occur from June to September (Telavi, Akhmeta, Dedoplistskaro).

Table 5. *Decadal trend rate of change in the intensity of tropical nights (k), corresponding determination coefficients (R^2), and their statistical significance (p) for the period of 1991-2013.*

Location	Altitude, M	K °C per decade	R^2	p
Batumi	10	0.14	0.31	0.01
Kutaisi	114	0.33	0.15	0.01
Tbilisi	403	0.13	0.16	0

The maximum intensity of tropical nights appears in July or August, reaching 24-26.5°C. Having been formed at low humidity, tropical nights in Eastern Georgia are sultrier.

Table 5. represents the decadal trend rate of change in the intensity of tropical nights, corresponding determination coefficients, and their statistical significance over the period of 1991-2013.

It is obvious from Table 5. that in the event of global warming, changes in the intensity of tropical nights are statistically significant in a variety of physical and geographical conditions in Georgia at a high level of statistical significance. The speed of increase in the intensity

of tropical nights constitutes 0.1-0.30, and it is greater for a decade. According to the data on determination coefficient, the proportion of global factor to the change in the intensity of tropical nights fluctuates in the range of 15-30%.

5. Conclusions

1. Tropical nights are most common for the Black Sea Coast and intermountain trough of Georgia-Kolkheti Lowland, Central and Lower Kartli plains, Alazani valley, Iori Plateau, where the average number of tropical nights during the year accounts for 35. With the increase of the altitude of a place, the number of tropical nights decreases appropriately and they do not occur at the height of 1000 m.
2. In the event of global warming, the number of tropical nights grows. The trend rate of the increase in the number of tropical nights is highest on the Black Sea Coast and in the regions of Kolkheti Lowland situated nearby the coast (4-6 days per a decade), the proportion of the global component of the total variability of tropical nights makes up (24-42%). In the inner regions of the lowland the decadal trend rate of the change is slightly lower (2-3 days), while in eastern continental parts of Georgia it constitutes 1-3 days, with the proportion of the global factor of 13-15%.
3. During the period of global warming (1991-2013гг), in all places both the average number and extreme values of tropical nights increased substantially compared to previous years. The changes of this kind are caused by the changes in the statistical structure of the number of tropical nights - the frequency of tropical nights with the gradation up to 20 days decreased appropriately throughout the time, while the frequency with gradation of 41-60 days increased, which, in all likelihood, is influenced by global warming.
4. On the Black Sea Coast, the occurrence of tropical nights starts in April and lasts until October. The intensity of tropical nights reaches its maximum in July and August, more than 27 ^{O}C. On Kolkheti Lowland tropical nights occur from March to November. Here the tropical nights are more intense and their maximum reaches 27-30 ^{O}C (June-July). In Eastern Georgia, in a continental climate, the length of the tropical nights decreases; in Kartli they appear from May to September, whereas in Kakheti, due to increasing aridity, this period is shorter, lasting from June to September. The maximum intensity of tropical nights appears in July or August, reaching 24-26.50.
5. In the event of global warming, changes in the intensity of tropical nights are statistically significant at a high level of statistical significance. The trend rate of the increase in the intensity of tropical nights constitutes 0.1-0.30. The proportion of the global factor of the change in the intensity of tropical nights fluctuates in the range of 15-30%.

The conducted research expands our understanding of the climate change in Georgia due to the global warming. The recent findings that describe the changes in the tropical nights under severe physical and geographical conditions, allows policy makers to take timely measures to minimize unfavorable consequences of climatic change. Actually, it does not eliminate the problem of climate change in Georgia, and many issues still remain unresolved. For further research of the problem, it is reasonable to develop it in the direction of detailed study of spatial and temporal patterns of other climatic indices, their frequency, intensity and cycle, based on morphometric factors and circulation patterns of the atmosphere.

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