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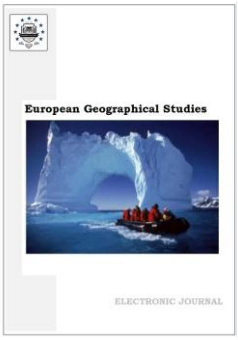

Statistical Characteristics of Hurricane Winds over Georgia for the Period 1961–2022

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Abstract

A catalog of hurricanes over the territory of Georgia for the period 1961–2022 has been compiled, containing the period of onset, geographical coordinates of the epicenter, speed, magnitude, intensity, area of distribution, material damage, human casualties. Over the entire study period, about 1600 cases of hurricane winds were recorded. During the year, hurricanes occur on average 20 times, with the highest number of cases recorded in 2002 – 81. The average speed of hurricane winds in general for Georgia is 36 m/s, the highest speed reached 56 m/s. The average hurricane area is about 1200 sq. km, and the maximum hurricane area exceeds 10000 sq. km. There is no clear relationship between the hurricane area and the corresponding material damage, which can most likely be explained by the heterogeneity of the level of urbanization of comparable areas that experience varying degrees of damage. The long-term changes in hurricane activity reveal a cyclical nature, which can be explained by the peculiarities of atmospheric circulation. In general, over the entire period there has been a tendency for hurricane activity to weaken.

Keywords: hurricane, speed, intensity, magnitude, frequency.

1. Introduction

Hurricanes are deadly and serious events, making it important to understand their regional characteristics and assess the long-term risk they pose to society. In connection with this study, a large literature is devoted to these phenomena, which examines various problems of climatology, research and forecasting of hurricane winds in various parts of the Globe. In particular, hurricane wind speeds are assessed for the Southeastern United States region, including South Carolina, North Carolina and eastern Virginia (Lee, Rosovsky, 2007), the risk of dealing with high and hurricane winds in Florida cities (Malmstadt et al., 2010), analyzed changes in the average and maximum wind speed, the number of days with strong winds over China (Jiang et al., 2010), examined the features of the conditions of squalls and tornadoes observed in the European part of Russia (Chernokulsky et al., 2022), analyzed long-term fluctuations in wind speed in Czech Republic (Brazdil et al., 2009), climatology and wind speed trends in Australia were studied (McVicar et al., 2008), hurricane wind speeds along the Persian Gulf and the east coast of the USA

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were simulated using Monte Carlo method (Xu et al 1980; Batts Martin et al., 1980), solved hurricane equations of motion for use in high-speed simulations (Vickery et al., 2000), and reviewed climatological models of extreme hurricane winds for the entire US coastline, as well as the Gulf, Florida, and East Coasts (Jagger, Elsner, 2006), a forecast of hurricane winds of extratropical cyclones in Russia was carried out (Alekseeva, 2017), using all hurricanes of 2003 and 2004 in the Atlantic and Gulf of Mexico, a hurricane wind forecast model was developed (Xie et al., 2006), etc. Hurricane winds cause significant damage to the economy and population of Georgia: they damage communication and power lines, disrupt transport, cause disturbances in the sea and reservoirs, dust storms, snow transport, avalanches, soil erosion and other adverse phenomena, and sometimes cause loss of life . On the territory of Georgia, hurricane winds are mainly in the western or eastern direction. The first of them occur when a cyclone of Mediterranean origin or a deep trough of low pressure associated with Atlantic cyclones passes over Transcaucasia. At the same time, the pressure gradient is directed from west to east, which causes an increase in western and northwestern winds. Eastern winds are observed when a high pressure area is established over the central and eastern regions of Transcaucasia, and a cyclone spreads to the Black Sea from the west. In this case, the pressure gradient is directed from east to west, and eastern winds, which are most developed in Western Georgia, intensify (Elizbarashvili, Elizbarashvili. 2012). Research on strong, including hurricane, winds in the territory of Georgia also has a long history, although the most relevant work has been carried out in recent years. In the article (Elizbarashvili et al., 2013) for the period 1961-2008, the statistical structure of hurricane winds was studied, the number of days and duration of hurricane winds were determined, the empirical functions of their distribution and the size of their habitats were studied, and the geography, the structure, areas and dynamics of natural meteorological phenomena, including hurricane winds, and in the article (Varazanashvili et al., 2012) the spatial distribution of hurricane winds was assessed, the maximum economic losses were calculated, and a map of expected risks was constructed. This article, which was financially supported by the Shota Rustaveli National Science Foundation (grant No. FR-21-1808, 2022–2024), is a logical continuation of these studies. It presents the results of a study of the statistical characteristics of hurricane winds over Georgia for the period 1961–2022.

2. Materials and methods

The research methodology included: 1. Compilation of a catalog of hurricane winds for the period 1961–2022; 2. Study of the spatial and temporal characteristics of hurricane winds. In preparing the catalog, all available information was used (observation materials from the National Environmental Agency of Georgia for the period 1961–2022, personal archives, literary records and manuscripts, printed and electronic media and other materials). These data comply with World Meteorological Organization standards. All measurements were carried out at a height of 10 m above the ground surface. Regular meteorological observations in Georgia began in 1844. By the beginning of the 20th century, about 30 weather stations were operating, and in the 40s their number reached about 160. By the beginning of the 90s, observations were carried out at more than 120 meteorological stations, and by the end of the 90s, due to the collapse of the USSR, the number weather stations decreased to 50. In 2005–2010, about 20 weather stations operated in Georgia, and currently their number is less than 50 (Elizbarashvili et al., 2013a).

The principles of compiling catalogs of hazardous natural phenomena, including hurricane winds, and the classification of magnitudes are discussed in detail in our previous article (Varazanashvili et al., 2022).

The preparation of materials for the catalog was carried out in several stages: at the first stage, factual data was collected and systematized, then primary data processing was carried out, calculation of various hurricane parameters and compilation of a chronological basis in which all the prepared data, as well as the results of their primary analysis, were entered in strict order. processing. In total, observational materials from 50 weather stations were used for the period 1961-2022. As a result, a catalog of hurricanes was compiled containing such indicators of the phenomenon as the period of occurrence (year, month, day), geographical coordinates of the epicenter (latitude, longitude), speed (Vm/s), magnitude (M), intensity (I) and area hurricane spread (Sq.km), material damage (Q US dollars X1000), human casualties (Varazanashvili et al. 2023).

The magnitude of a hurricane was determined as a value proportional to wind speed, the proportionality coefficient was conventionally taken as 0.1. Magnitude expresses the strength of a hurricane. The intensity of the hurricane was determined according to the scale we developed earlier (Varazanashvili et al., 2012) (Table 1).

Table 1. Hurricane intensity scale (Varazanashvili et al., 2012)

Intensity balls	wind speed m/s	Effect	Economic losses in US dollars per unit area (km²)
1	30–34	Weak	100
2	35–40	Average	101–1000
3	40–45	Strong	1 001–5 000
4	>45	Very strong	>5000

From Table 1 it can be seen that, depending on the wind speed, there are 4 types of hurricane wind intensities: weak, medium, strong and very strong. Hurricane activity was assessed by its frequency (N) over a certain period of time (number of cases).

Such catalogues-databases were compiled by different authors, for example in (Lee, Rosowsky, 2007). For the southeastern United States, a database has been compiled that includes time index (year), duration of strong winds and peak surface wind speeds (both gusty and sustained), etc.

The study of the temporal and spatial patterns of the characteristics of hurricane winds implied the determination of the frequency and range of hurricanes, and the identification of patterns of their spatio-temporal distribution.

Long-term changes in the frequency and magnitude of hurricane winds were assessed using the moving average method. This made it possible to smooth out short-term fluctuations and highlight the main trends in their change (Bulashev, 2003). The moving average is numerically equal to the arithmetic mean of the values of the original function over a specified period. The resulting moving average value in climatology is referred to as the middle of the selected interval.

3. Discussion

In accordance with the developed catalog, about 1,600 cases of hurricane winds were recorded in Guzia. Thus, during the year, hurricanes occur on average 20 times; their largest number of cases was recorded in 2002 – 81. The most probable (46 %) are up to 20 cases of hurricanes per year, gradations of 21-40 and 41-60 cases correspond to a frequency of 26 and 23 %, and gradations of 61-80 and more than 80 are observed in 3 and 2 % of cases, respectively (Figure 1).

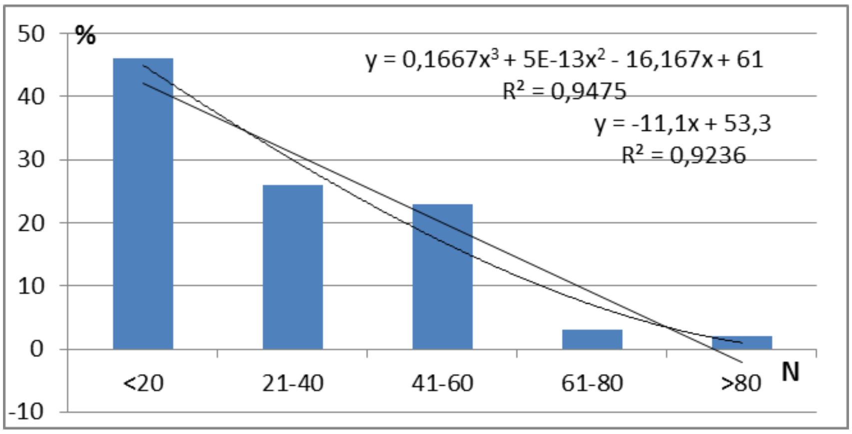


Fig. 1. Repeatability of the number of cases of hurricane winds on the territory of Georgia per year and its approximation by a 3rd degree polynomial and linear function (R2 – determination coefficient)

From Figure 1 it follows that the coefficient of determination in both cases is very high (>0.9), however, the empirical distribution of the number of hurricane winds is better approximated by a third-degree polynomial than by a linear function. In the first case, the coefficient of determination is 0.94, and in the second case it is 0.92.

Table 2 provides information on the most catastrophic hurricanes. As follows from the table, the capital of Georgia is one of the most hurricane-prone cities. For example, in 2005–2006 alone, 4 hurricanes with wind speeds of more than 50 m/s were recorded in Tbilisi.

Table 2. Most intense hurricanes

Speed, m/s	Epicenter	Year	Month	Date	Square distribution sq.km
56	Zekari, Udabno	1981	2	3	9000
55	Tbilisi	2005	4	20	1200
53	Tbilisi	2006	3	10	1400
52	Tbilisi	2006	9	16	1200
51	Tbilisi	2005	3	4	1200

The average speed of hurricane winds in general for Georgia is 36 m/s, the highest speed is 56 m/s, the average hurricane intensity is 1.57, and the maximum intensity is 4 points. The average hurricane area is about 1200 sq. km, and the maximum hurricane area exceeds 10000 sq. km. In general, hurricanes with intensity 1 and 2 points predominate in the territory of Georgia, the frequency of each of them is 48 %. These are hurricanes of weak and medium intensity with a speed of 40 m/s or less. Their total repeatability is 96 %. The remaining 4 % of hurricane cases are hurricanes of strong (40-45 m/s) and very strong (more than 45 m/s) intensity, accounting for 3 and 1 %, respectively (Figure 2).

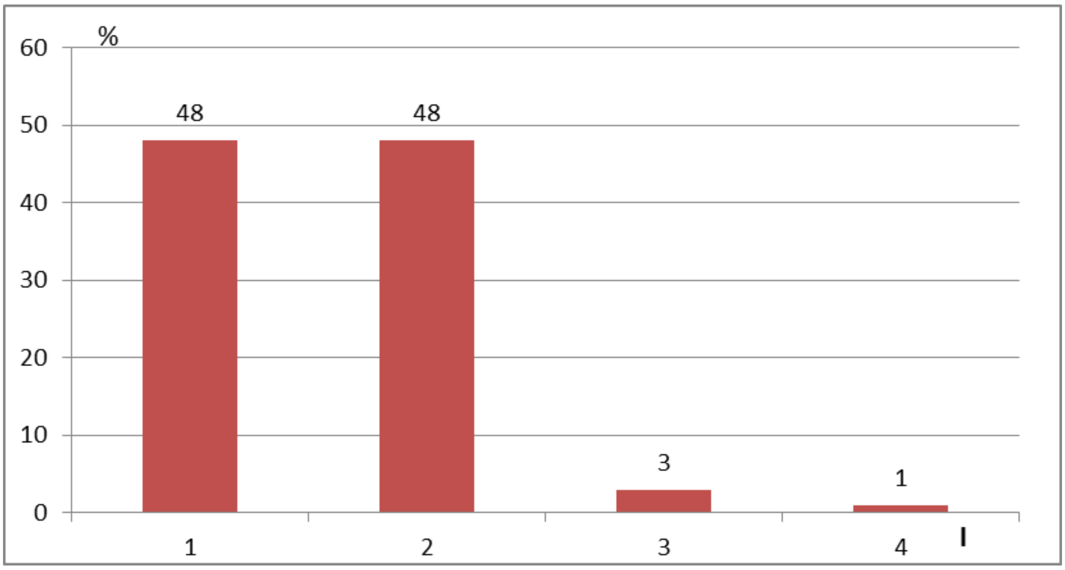


Fig. 2. Frequency of hurricane winds of varying intensity

The hurricane area varies widely (Figure 3). The average area of distribution of a hurricane of low intensity (point 1) is more than 1,500 sq. km, although the range of fluctuations is significant (100-10000 km). The area of distribution of a hurricane with average intensity (2 points) is on average about 2400 sq. km., with a similar amplitude of fluctuations. The average area of a hurricane with strong intensity (3 points) is more than 1000 sq. km (varies between 400-6000 sq. km), and the average area of a hurricane with very strong intensity (4 points) is about 1600 sq. km. (400-9000 sq.km.).

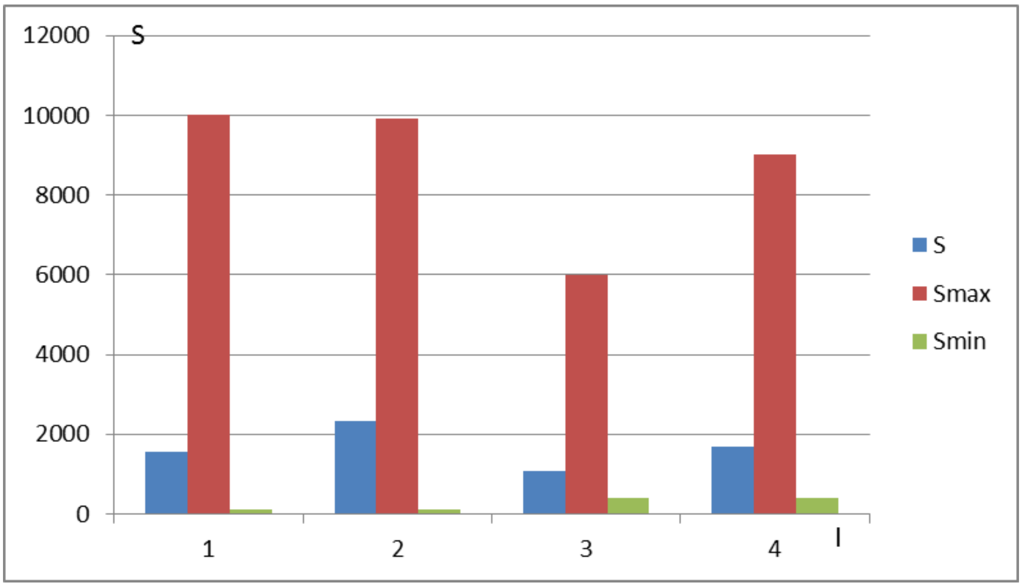


Fig. 3. Hurricane area of varying intensity (sq. km); S-average; Smax-largest; Smin-smallest

Figure 4 shows an empirical histogram of the frequency of occurrence of hurricane winds of varying intensity. From Fig. It follows that hurricane-force winds can cover an area of several thousand square kilometers, but hurricanes are most likely to occur with an area of less than 2000 square kilometers. Frequency of habitats with an area of less than 1000 square kilometers, depending on their intensity, ranges from 42-49 %, and the frequency of habitats with an area of 1000-2000 sq. km ranges from 27-44 %. The frequency of occurrence of areas of other gradations is significantly less.

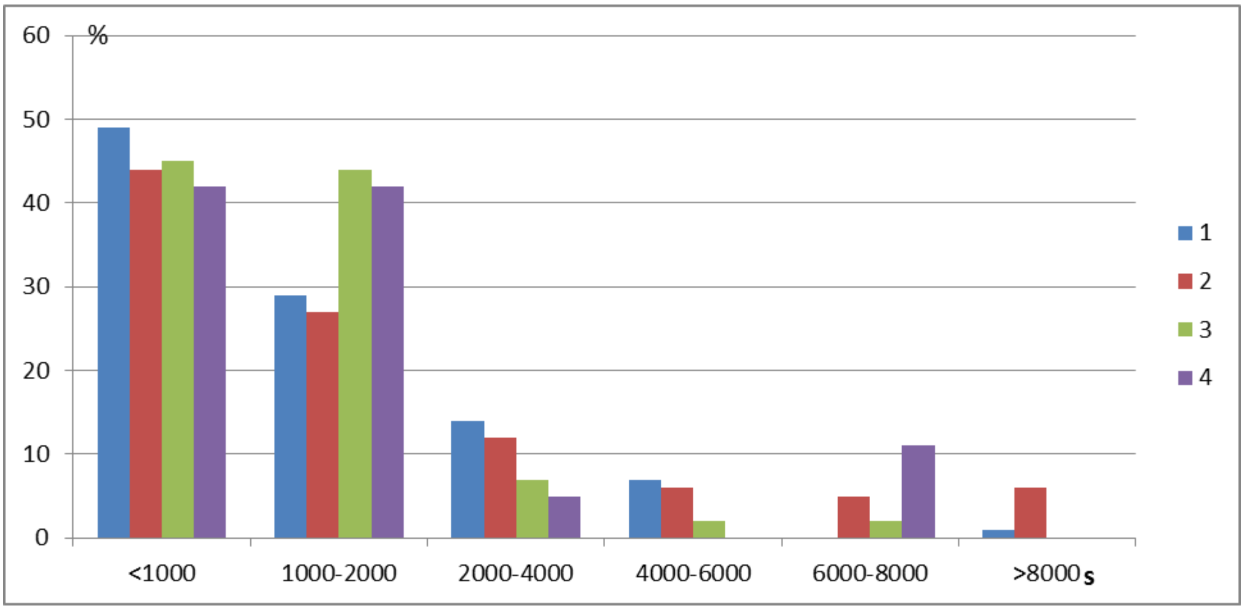


Fig. 4. Histogram of the frequency of occurrence of hurricane winds of varying intensity: I = 1; I = 2;I = 3;I = 4.

In addition, from Figure 4 it follows that on an area of less than 1000 sq. km are dominated by hurricanes of low intensity (about 50 %), with wind speeds of less than 34 m/s. On an area of 1000-2000 sq. km, hurricanes of strong and very strong intensity most often spread, the frequency of each of them is more than 40 %. The speed of such hurricanes exceeds 40 m/s. On a large area, more than 6000 sq. km, hurricanes of very strong and medium intensity are predominant.

In general, the frequency of occurrence of hurricanes of varying intensity naturally decreases with increasing area of the area, with the exception of hurricanes of very strong intensity, the frequency of which over large areas (6-8 thousand sq. km.) slightly increases. According to our estimates, hurricanes spreading over an area of 8-10 thousand square meters. km or more can cause material damage up to 10 million US dollars.

At the same time, there is no clear relationship between the hurricane area and the corresponding material damage, which can most likely be explained by the heterogeneity of the level of urbanization of comparable areas that experience damage of varying degrees (Figure 5).

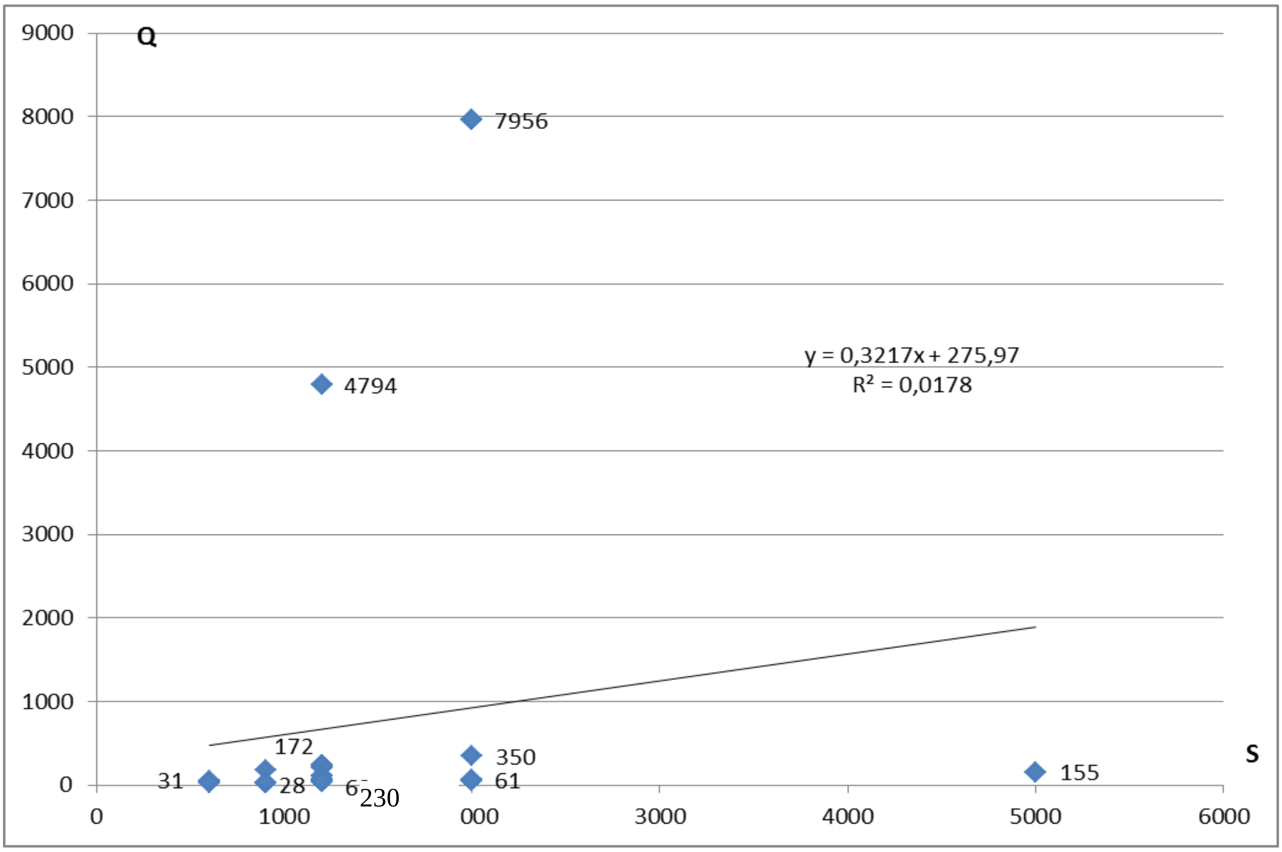


Fig. 5. The relationship between the area of hurricane spread (S sq. km) and the corresponding material damage (Q thousand dollars), and its approximation by a linear function (R^2 – coefficient of determination) for the period 1995–2002

The relationship presented in Figure 5 is very weak R^2 = 0.017, this means that the material damage caused by a hurricane is only 1-2 % due to differences in the hurricane's areas of action, and 98-99 % is due to the influence of other factors. The first factor among these factors is the level of urbanization.

The geographic distribution of the characteristics of hurricane winds is complex and depends not only on general physical and geographical conditions, but also to a large extent on local conditions (Table 3).

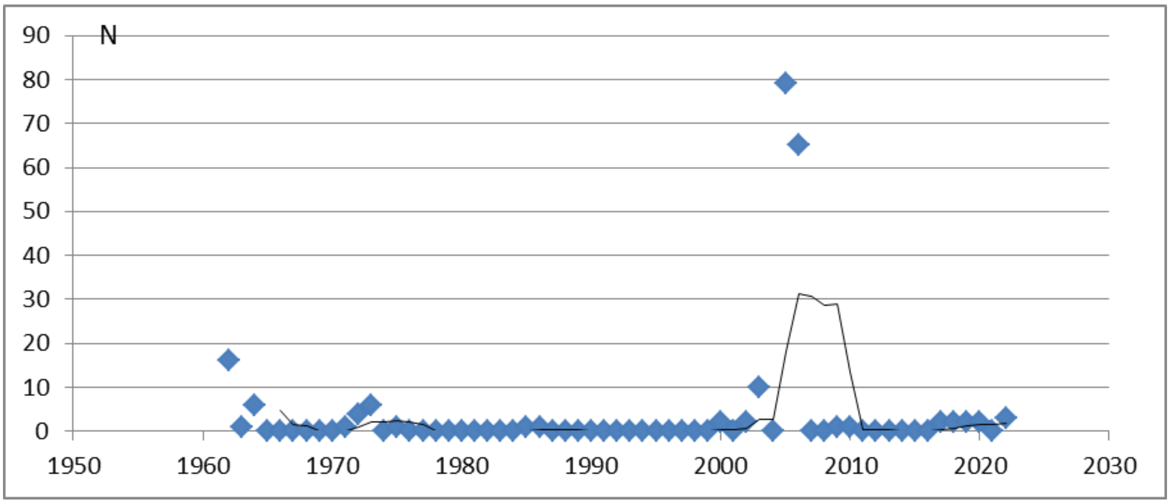
In Table 3, N is the average frequency of hurricanes per year (number of events), Nmax is the highest frequency of hurricanes per year (number of events), Mmax is the highest magnitude, a dash in the table means that this value was observed several times. . From Table 3 it follows that the highest frequency of hurricane winds is typical for the Kvemo Kartli region (Udabno, Tbilisi), where it amounts to 4.4 and 3.7 cases on average per year, respectively. In the Colchis Lowland, the frequency of hurricane winds is somewhat less (Kutaisi, Senaki, 2.5-1.8 cases). The frequency of hurricane winds is significantly lower in the South Georgian Plateau, where it does not reach 1 case on average per year. Large frequency values are typical for the passes (Mamisonsky, Goderdzsky, Zekarsky, 1.4-2.5 cases). The highest magnitudes of hurricane magnitudes are also characteristic of

Kvemo Kartli, the Colchis lowland and mountain pass areas (on average 1-2 points or more), and the lowest magnitudes are characteristic of the South Georgian Highlands (less than 1).

Table 3. Some characteristics of hurricane winds in various physical and geographical conditions

Region	Paragraph	N	Nmax	Year	Mmax	Year
Black Sea coast and Colchis Lowland	Kutaisi Senaki Batumi	2,5 1,8 0,2	14 9 2	1977 1993 1976	4,6 4,5 4	1970 1993 -
Kvemo Kartli	Udabno Tbilisi Bolnisi	4,4 3,7 0,1	34 79 2	1990 2005 2013	4,1 5,5 3,5	1973 200 5 2013
South Georgian Highlands	Akhaltsikhe Akhalkalaki Paravani	0,08 0,06 0,13	4 1 3	1972 - 1977	4 4 3,4	1972 1972 -
Passes	Mamisoni Goderdzi Zekari	2,4 1,4 1,5	17 8 9	1973 1961 1990	4,3 4 4,1	1969 - 1973

In Figures 6 and 7 presents the long-term course of changes in the frequency and maximum magnitude of hurricanes for 3 weather stations characterized by high hurricane danger, covering various physical-geographical and climatic conditions: Tbilisi-plain part of Eastern Georgia (404 m above sea level), Kutaisi-Colchis lowland (114m above sea level) .a.s.l.), Mta Sabueti-Likhsky ridge (1242m a.s.l.).



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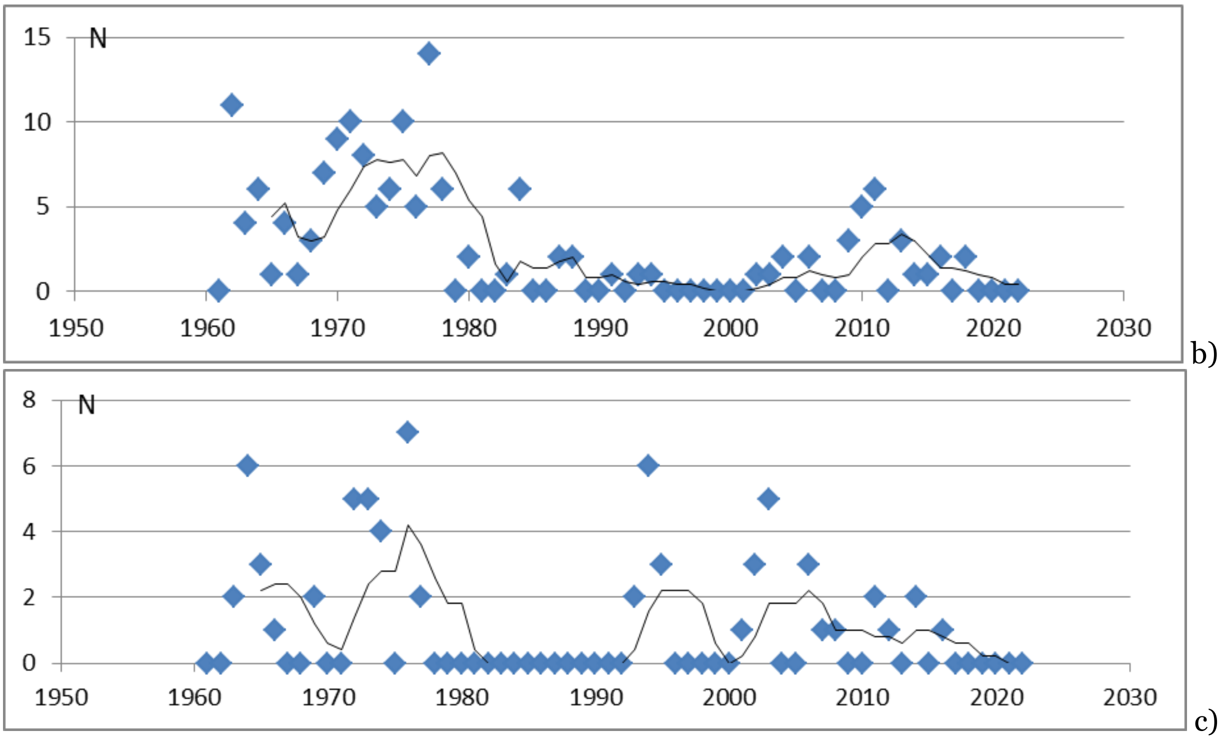
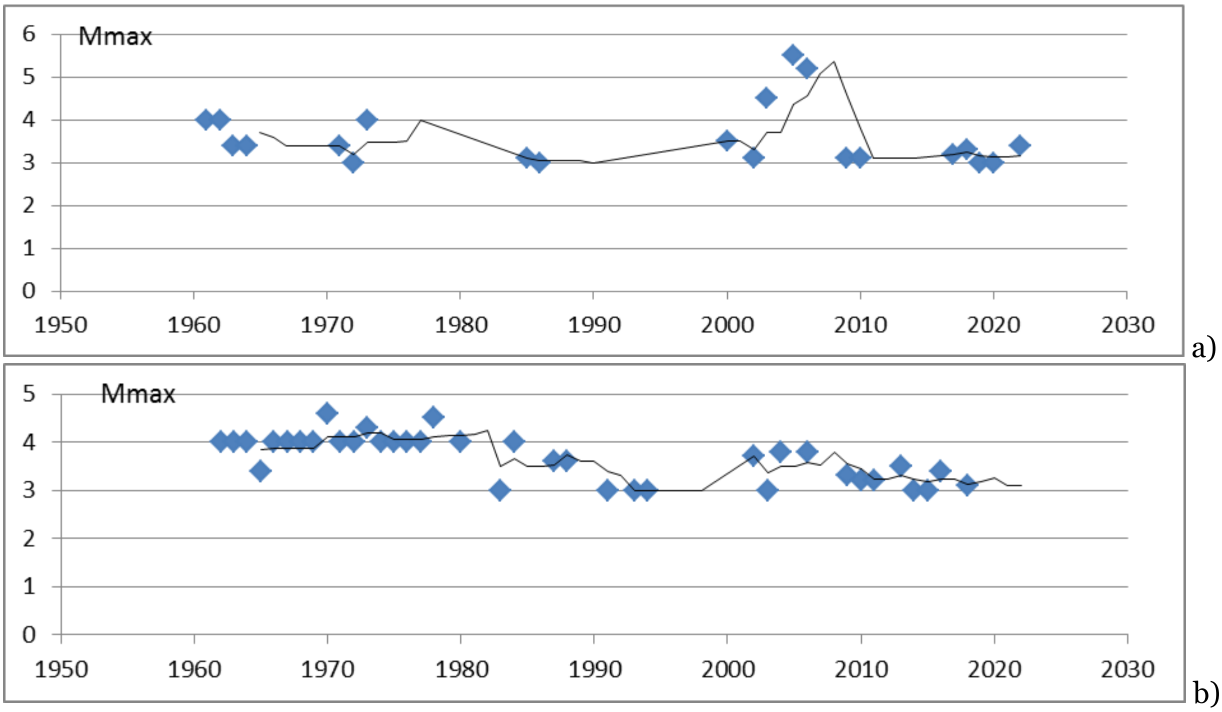
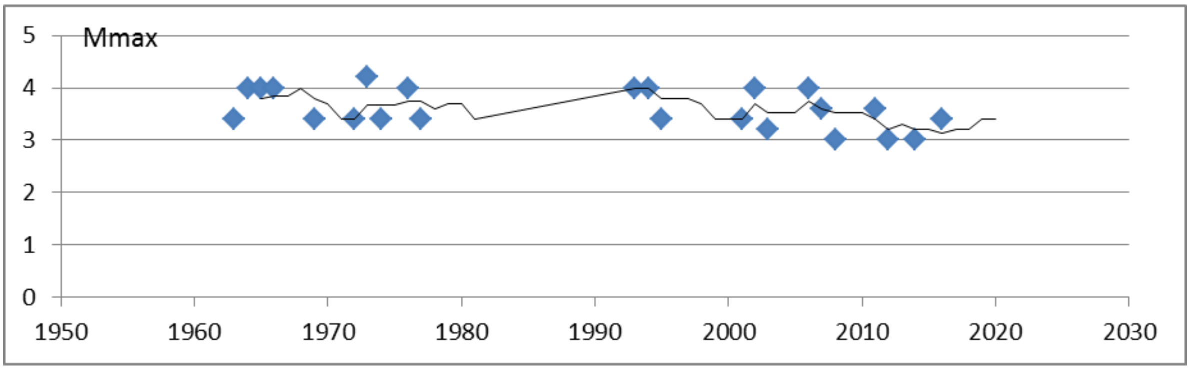


Fig. 6. Long-term changes in frequency (N) of hurricanes: annual data and 5-year moving averages: a) Tbilisi; b) Kutaisi; c) Mta Sabueti





c)

Fig. 7. Long-term changes in maximum magnitude (Mmax) of hurricanes: annual data and 5-year moving averages: a)- Tbilisi; b)- Kutaisi; c)- Mta Sabueti

From Figures 6 and 7 it follows that the annual data on the frequency and maximum magnitude of hurricanes are widely scattered, while moving averages, which are obtained by smoothing short-term fluctuations, make it possible to identify the main trends in their changes. According to Fig. 6, changes in hurricane activity reveal a cyclical nature. The first maximum in the long-term course of hurricanes was observed in the 60s of the last century, the second in 1970–1975, the third in 2000–2010. In Mta-Sabueti, the maximum is also detected at the end of the 90s. The same maximums generally correspond to the maximum magnitudes of hurricanes. In particular, in Tbilisi, the largest number of hurricane cases was noted for the period 2000–2010, the highest magnitude of 5.6 corresponds to the same period. During the same cycle in Kutaisi and Mga Sabueti, the frequency of hurricanes is 5-6 cases per year, and the highest magnitude reaches 4 points. In Kutaisi and Mga Sabueti, the main maximum in the frequency and magnitude of hurricanes is observed in 1970–1975 and amounts to up to 14 cases in Kutaisi, with a maximum magnitude of 4.6, and in Mta Sabueti 6-7 cases per year, with a magnitude of 4.2 points. The cyclical nature of changes in hurricane activity can be explained by the peculiarities of atmospheric circulation. The decrease in the activity of hurricane winds after the 60s may be caused by the weakening of the zonal and strengthening of the meridional circulation of the atmosphere, and the increased activity of hurricanes in the 70s and 90s may be caused by the increased activity of the eastern form of atmospheric circulation in those years. The increase in the frequency of hurricanes in 2000-2010 may be caused by the intensification of the western form of atmospheric circulation (Long-term changes..., 2001).

In general, over the entire period there is a certain tendency for hurricane activity to weaken, which cannot be said for the maximum magnitude. In addition, the long-term course of hurricane activity in the considered locations has an individual character, which is formed by local physical-geographical and climatic features.

4. Conclusion

1. A catalog of hurricanes has been compiled, containing the period of occurrence (year, month, date), geographical coordinates of the epicenter (latitude, longitude), speed (Vm/s), magnitude (M), intensity (I), area of distribution (S sq. km) , property damage (Q US dollars X1000), loss of life.

2. During the period 1961-2022, about 1,600 cases of hurricane winds were recorded. During the year, hurricanes occur on average 20 times, with the highest number of cases recorded in 2002 – 81. The most probable (46 %) are up to 20 cases of hurricanes per year, gradations of 21-40 and 41-60 cases correspond to a frequency of 26 and 23 %, and gradations of 61-80 and more than 80 are observed in 3 and 2 % of cases, respectively

3. The average speed of hurricane winds in general for Georgia is 36 m/s, the highest speed reached 56 m/s, the average hurricane intensity is 1.57, and the maximum intensity is -4 points. The average hurricane area is about 1200 sq. km, and the maximum hurricane area exceeds 10000 sq. km.

4. In general, hurricanes with intensity 1 and 2 points predominate in the territory of Georgia, the frequency of each of them is 48 %. These are hurricanes of weak and medium intensity

with a speed of 40 m/s or less. Their total repeatability is 96 %. The remaining 4 % of hurricane cases are hurricanes of strong (40-45 m/s) and very strong (more than 45 m/s) intensity, accounting for 3 and 1 %, respectively.

5. Hurricane-force winds can cover an area of several thousand square kilometers, but hurricanes are most likely to occur within an area of less than 2000 square kilometers. Frequency of habitats with an area of less than 1000 square meters. km, depending on their intensity, ranges from 42-49 %, and the frequency of habitats with an area of 1000-2000 sq. km ranges from 27-44 %. The frequency of occurrence of areas of other gradations is significantly less.

6. There is no clear relationship between the area of hurricane spread and the corresponding material damage, which in all likelihood can be explained by the heterogeneity of the level of urbanization of comparable areas that experience damage of varying degrees.

7. The long-term changes in hurricane activity reveal a cyclical nature, which can be explained by the peculiarities of atmospheric circulation. The first maximum during hurricanes was observed in the 60s of the last century, the second in 1970–1975, although weakly expressed in Tbilisi, the third in 2000–2010. In Mta-Sabueti, the maximum is also detected at the end of the 90s. The same maximums correspond to the maximum magnitudes of hurricanes.

8. Over the entire period, there is a certain tendency for hurricane activity to weaken, which cannot be said for the maximum magnitude. In addition, the long-term course of hurricane activity in the considered locations has an individual character, which is formed by local physical-geographical and climatic features.

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