ASSESSMENT OF THE LONG-TERM RISK OF DANGEROUS HURRICANES ON THE TERRITORY OF GEORGIA USING DATA FROM 1961 TO 2022

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Abstract

Based on the data from the catalog we compiled about natural disasters in Georgia, the frequency and probability of max hurricane magnitude in various zones of Georgia for the period 1961-2022 was studied. On the nature of the distribution of wind speed, frequency, intensity and magnitude of hurricanes, 3 zones are distinguished on the territory of Georgia. Zone 1 covers the Main Caucasus Range, the Likhi Range, as well as a small area of the interior of the Colchis Lowland and a small area of the flat part of Kvemo Kartli. Zone 2 covers the intermountain depression of Georgia - the Black Sea coast, the Colchis lowland, the Imereti Upland, the plains and foothills of eastern Georgia, with the exception of a small territory of the interior of the Colchis lowland and a small territory of the flat part of Kvemo Kartli, which are included in zone 1. Zone 3 covers the western part of Meskheti ridge, a significant part of the Trialeti ridge and the Akhalkalaki plateau. In particular, the following results were obtained. The most active hurricane zone is zone 1 (the frequency of hurricanes is 15 per year and the repeatability period is 0.09 years, ≈ 1 month). The least active hurricane zone is zone 3 (1-2 hurricanes occur per year, repeatability period is 0.9 years, ≈ 10-11 months). The highest frequency of hurricane magnitudes by zone is as follows: zone 1 - 3.6÷4.0 (87%), zone 2 - 3.1÷3.5 (44%), zone 3 - 3.6÷4.0 (more than 60%). In the first two zones, as magnitudes increase, their frequency decreases significantly. The probability curves for the max magnitude of hurricanes are well approximated by polynomials of the 5th degree. The expected hurricane magnitudes in these zones are: in zone 1 - 5.8, in zone 2 - 5.5 and in zone 3 - 4.5 with a probability of 0.2%, 0.5% and 1%. The repeatability periods of such magnitudes are 500 years, 200 years and 100 years, respectively. Thus, in the coming decades, it is most likely that the magnitude of hurricanes in zone 3 will increase to 4.5; some increase in the magnitude of hurricanes to 5.5 in the long term is possible in zone 2, and in zone 1, hurricanes will intensify to magnitude 6 is unlikely. A map of zoning the territory of Georgia according to the max possible hurricane magnitudes has been developed. There are two areas with the highest max magnitude, reaching 6 (the Southern part of the Likhi Range in Western Georgia and a small area of the flat part of Kvemo Kartli in Eastern Georgia). Hurricanes with magnitudes 5 and 5.5 are possible in some areas. In a significant part of Georgia, the max hurricane magnitude can reach 4.5.

Keywords: hurricane, provision, frequency, period, magnitude

I. Introduction

The strongest gusts of wind recorded on Earth are associated with tornadoes and reach speeds of up to 500 km/h. If a tornado of such force passes through a populated area, there will be practically nothing left of it [https://www.meteovesti.ru/news/63388088280-kakovo-maksimalnoe-znachenie-skorosti-vetra-zafiksirovannoe-na-zemle]. An automatic weather station on the Australian island of Barrow during Cyclone Olivia on April 10, 1996 recorded a gust speed of 113 m/s (408 km/h) [https://en.wikipedia.org/wiki/Cyclone_Olivia], and on April 12, 1934 at the Mount Washington Observatory in New Hampshire the speed the wind gust was 103 m/s (371 km/h) [1]. Winds of 333 km/h (about 87 m/s) were recorded at the US air force base in Greenland and Adélie Land in Antarctica (https://ru.wikipedia.org/wiki/%D0%92%D0%B5%D1%82%D0%B5%D1%) [80].

Along the entire Gulf Coast, wind speed reaches 157 knots (more than 80 m/s), (1 knot = 0.514 m/s). The highest wind speeds are along the Gulf Coast from Texas to Alabama. Using the Bayesian approach, the maximum possible coastal wind speed here can be 208 knots (more than 106 m/s) [2].

A study of high winds in Florida found that the city of Miami can expect hurricane-force winds of 50 m/s (45.5–54.5 m/s - 90% confidence interval) or stronger to occur on average once every 12 years, and in the city of Pensacola hurricane winds of 50 m/s (46.9–53.1 m/s, 90%) or stronger can be expected to occur every 24 years [3].

The Monte Carlo simulation method was used to estimate hurricane wind speeds along the Persian Gulf and the east coast of the United States. Estimated calculations of hurricane wind speeds were made at a height of 10 m above the ground in open areas near the coastline and at a distance of 200 km inland. Estimated hurricane wind speeds were found to best fit Weibull distributions [4].

Maximum hurricane wind speeds in China show a decreasing trend over large areas. Only in the southeast of the Tibetan Plateau does the wind speed not significantly decrease, but, on the contrary, even increase [5,6].

A weakening of hurricane winds was also noted in North America [7,8], regions of Europe [9,10], Australia [11], etc. Tendencies of increasing strong and stormy winds over the world's oceans were noted [12]. According to passive microwave satellite data [13], wind speed in the tropics for the period 1987–2006 increased on average by 0.6% per decade, while for all oceans the average trend was 1.0% per decade.

Hurricanes pose a danger to Georgia. Research on hurricane winds in Georgia has a long history, although the most relevant work has been carried out in recent years. In the article [14] 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 areas were studied. The monograph [15] examined the geography, structure, areas and dynamics of hurricane winds, and in article [16] the spatial distribution of hurricane winds was assessed, the maximum economic losses were calculated, and a map of expected risks was constructed. The paper [17] presents preliminary studies of hurricanes winds in Georgia in the period 1961-2022. 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.

This article is a logical continuation of these studies [14-17]. It uses observational materials for the period 1961-2022 to assess the long-term risk of dangerous hurricanes in Georgia [18].

II. Methods

The article uses materials from the catalog about natural disasters in Georgia [18]. These data comply with World Meteorological Organization standards. All measurements of wind speed were carried out at a height of 10 m above the ground surface. In the catalog, the strength of a hurricane is expressed through magnitude (M), which was defined as a value proportional to wind speed, the proportionality coefficient is conventionally taken to be 0.1 s/m.

Statistical methods for processing climatological data were used. The assessment of the long-term risk of dangerous hurricanes is carried out on the basis of an empirical probability curve showing the probability or probability of exceeding a given value among the totality of the series. The coordinates of the supply curve were calculated directly from the values of the initial series of observations; for each member of the series, the empirical supply was determined using the Gauss formula:

$$P = m/n \cdot 100\%$$

where m is the number of hurricane events of a given magnitude, n is the total number of hurricane events.

III. Results

Based on the nature of the distribution of wind speed, frequency, intensity and magnitude of hurricanes on the territory of Georgia, 3 zones have been identified [19].

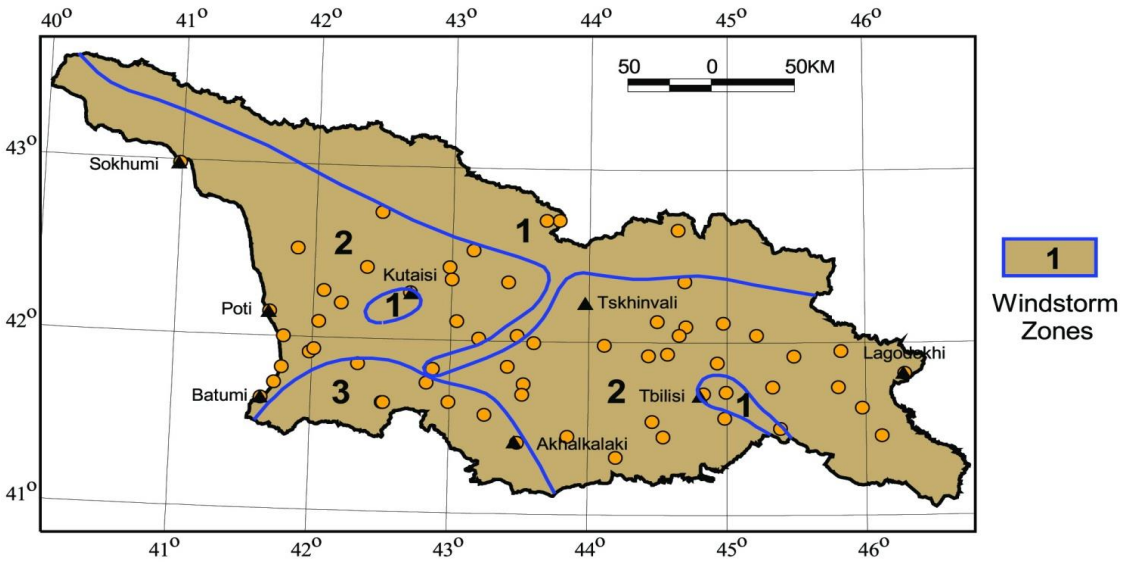

Figure 1: *Zoning of the territory of Georgia according to the nature of the distribution of wind speed, frequency, intensity and magnitude of hurricanes, and the distribution of observation points whose data were used [19].*

Zone 1 covers the Main Caucasus Range, the Likhi Range, as well as a small area of the interior of the Colchis Lowland and a small area of the flat part of Kvemo Kartli. Zone 2 covers the intermountain depression of Georgia - the Black Sea coast, the Colchis lowland, the Imereti Upland, the plains and foothills of Eastern Georgia, with the exception of a small territory of the interior of the Colchis lowland and a small territory of the flat part of Kvemo Kartli, which are included in zone 1. Zone 3 covers the western part of Meskheti ridge, a significant part of the Trialeti ridge and the Akhalkalaki plateau.

From Fig. 1 it follows that the selected zones are not uniformly illuminated by meteorological observations. The densest observation network is in zone 2, which occupies mainly the flat part of the territory of Georgia. In zone 3, on the Main Caucasus Ridge, there is a very sparse observation network.

Table 1 presents information about the meteorological coverage of these zones and the main statistical characteristics of hurricanes in zones of Georgia that differ in the nature of hurricanes. It follows from the table that the most active hurricane zone is zone 1, where the frequency of hurricanes is 15 per year and the repeatability period is 0.09 years (about 1 month). The frequency of hurricanes in zone 2 is 7, and their repeatability period is reduced to 0.14 years (2-3 months). The least active hurricane zone is zone 3, where only 1-2 hurricanes occur per year, and their repeatability period is 0.9 years, i.e. 10-11 months. When converted to one point, the frequency of hurricanes by zones are: 1.7; 0.15 and 0.2; the repeatability period - 0.6, 7 and 5 years, respectively.

Table 1: *Density of the meteorological network and average statistical characteristics of hurricanes in different zones.*

Zone	Number of points (m)	Frequency of hurricanes per year (N)	Repeatability period, T(N) years	Hurricane frequency per 1 point (n= N/ m)	Repeatability period for 1 point on average, T(n) years
1	9	15	0.09	1.7	0.6
2	45	7	0.14	0.15	7
3	6	1.2	0.9	0.2	5

Figure 2 shows histograms of the frequency of occurrence of various hurricane magnitudes. As it follows from this Figure the nature of the distribution of magnitude frequency in different zones is significantly different. In zone 1, in most cases (87%), the smallest magnitudes of 3.6-4.0 characteristic of the zone prevail, and with increasing magnitudes their frequency also decreases. In zone 2, the highest frequency of occurrence of 44% corresponds to gradation 3.1-3.5, and with increasing magnitudes their frequency of occurrence decreases significantly. In zone 3, the predominant frequency of gradation with the highest magnitude values is 3.6-4.0, which exceeds 60%.

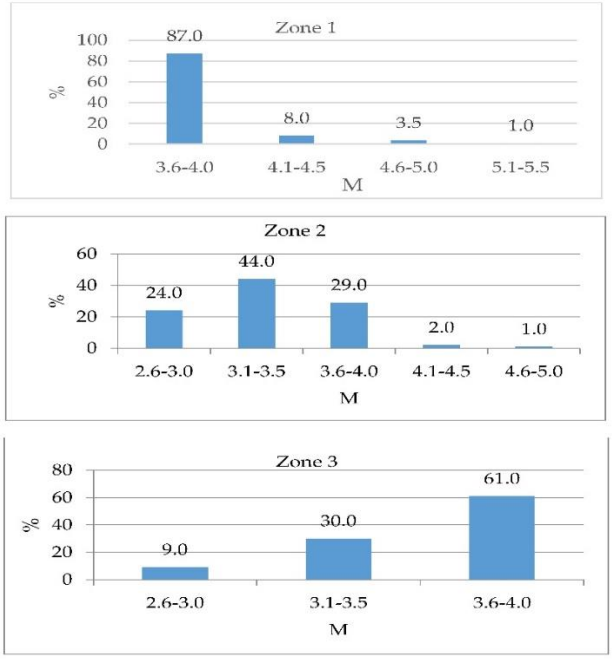

Figure 2: *Repeatability of different gradations of hurricane magnitudes in different zones.*

Figure 3 shows the probability curves for the maximum magnitude of hurricanes in different zones of Georgia, characterized by different wind speed regimes, and with different values of

frequency, intensity and magnitude of hurricanes, as well as their approximation by a 5th degree polynomial.

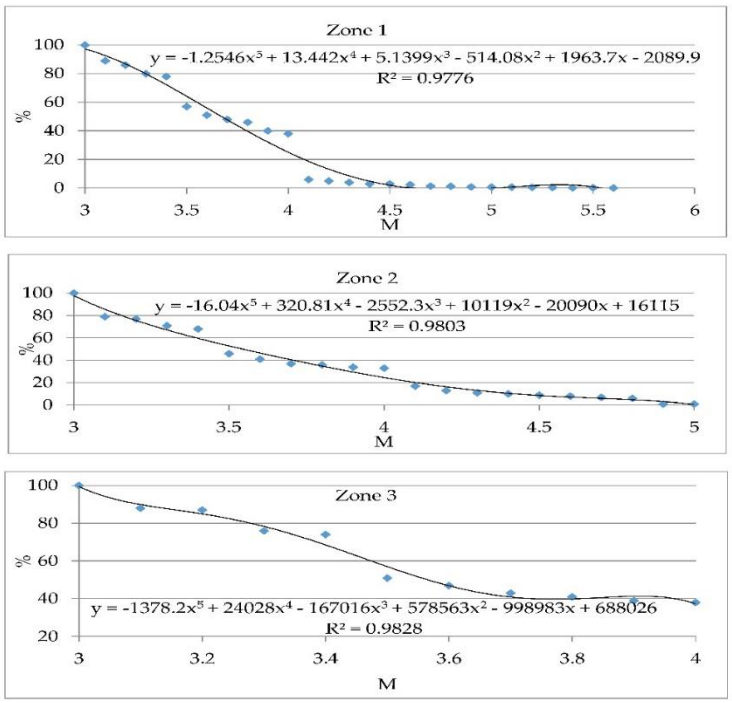

Figure 3: *Curves of provision for the maximum magnitude of hurricanes and their approximation by a 5th degree polynomial for various zones (R^2 - coefficient of determination).*

From Figure 3 it follows that the coordinates of points calculated directly from the values of the initial series of observations are well approximated by polynomials of the 5th degree. The coefficient of determination is significant and exceeds 0.97. Thus, the resulting equations can be used to calculate the magnitude of hurricanes of any provision.

Table 2 presents the observed and expected hurricane magnitudes, according to our expert estimates, and the corresponding probabilities for various zones of Georgia.

Table 2: *Values of observed and expected hurricane magnitudes (M_{max}) and corresponding provision (P%) and repeatability periods.*

Zone	Observed M_{max}	Provision, P%	Repeatability period, years	Possible M_{max}	Provision, P%	Repeatability period, years
1	5.6	0.4	250	5.8	0.2	500
2	5.0	1	100	5.5	0.5	200
3	4.0	38	2.6	4.5	1	100

From Table 2 it follows that in the most hurricane-active zone 1, the magnitude reaches 5.6 with a provision of 0.4%, i.e. the repeatability period is about 250 years. In zone 2, the highest magnitude reached 5.0, the provision of which is only 1%, and the repeatability period is 100 years. The highest hurricane magnitude in zone 3 was recorded as 4.0 with a provision of about 40%. Therefore, the repeatability period for this magnitude is about 2.6 years. According to expert estimates, the expected hurricane magnitudes in these zones are 5.8, 5.5 and 4.5, respectively, with provision of 0.2%, 0.5% and 1%. The repeatability periods of such magnitudes are 500 years, 200 years and 100 years, respectively.

Thus, in the coming decades, it is most likely that the magnitude of hurricanes in zone 3 will increase to 4.5; a slight increase in the magnitude of hurricanes to 5.5 in the long term is possible in

zone 2, and in zone 1, an increase in hurricane magnitude to 6 is unlikely.

IV. Discussion

1. Based on the nature of the distribution of wind speed, frequency, intensity and magnitude of hurricanes, 3 zones are distinguished on the territory of Georgia. The most active hurricane zone is zone 1, where the frequency of hurricanes is 15 per year and the return period is 0.09 years (about 1 month). The frequency of hurricanes in zone 2 is 7, and their repeatability period is reduced to 0.14 years (2-3 months). The least active hurricane zone is zone 3, where only 1-2 hurricanes occur per year, and their repeatability period is 0.9 years, i.e. 10-11 months. When converted to one point, the frequency of hurricanes by zone is 1.7; 0.15 and 0.2, and the repeatability period is 0.6, respectively; 7 and 5 years old.

2. The nature of the distribution of magnitude frequency in different zones is significantly different. In zone 1, in most cases (87%), the smallest magnitudes of 3.6-4.0 characteristic of the zone prevail, and with increasing magnitudes their frequency also decreases. In zone 2, the highest frequency of occurrence of 44% corresponds to gradation 3.1-3.5, and with increasing magnitudes their frequency of occurrence decreases significantly. In zone 3, the predominant frequency of gradation with the highest magnitude values is 3.6-4.0, which exceeds 60%.

3. The probability curves for the maximum magnitude of hurricanes are well approximated by polynomials of the 5th degree. The coefficient of determination is significant and exceeds 0.97.

4. In the most hurricane-active zone 1, the magnitude reaches 5.6 with a probability of 0.4%, i.e. The r repeatability period is about 250 years. In zone 2, the highest magnitude reached 5.0, the probability of which is only 1%, and the repeatability period is 100 years. The highest hurricane magnitude in zone 3 was recorded as 4.0 with a probability of about 40%. Therefore, the repeatability period for this magnitude is about 2.6 years.

5. The expected magnitudes of hurricanes in these zones are in zone 1 -5.8, in zone 2 - 5.5 and in zone 3 - 4.5 with a probability of 0.2%, 0.5% and 1%. The repeatability periods of such magnitudes are 500 years, 200 years and 100 years, respectively. Thus, in the coming decades, it is most likely that the magnitude of hurricanes in zone 3 will increase to 4.5; some increase in the magnitude of hurricanes to 5.5 in the long term is possible in zone 2, and in zone 1, hurricanes will intensify to magnitude 6.

V. Conclusion

In the future, an even more detailed study of hurricane winds in Georgia is planned, including studies of tornadoes that have appeared in recent years in the continental part of the country.

Acknowledgments

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