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Variability in the Number of Days with Hail in the Warm Half of the Year in Bolnisi and Tsalka in 1941-2021 and their Expected Change until 2045

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ABSTRACT

The paper presents the results of a study of the features of variations in the number of days with hail in the warm half of the year (HD) in Bolnisi and Tsalka in 1941-2021 and their expected change until 2045. The stability of time series of the number of days with hail at the indicated points was studied by determining the HD correlations with time (linear correlation, Kendall's and Spearmen's rank correlation). The level of autocorrelation in HD time series in Bolnisi and Tsalka was determined. The periodicity of these time series has been studied. Interval forecasting of the number of days with hail in Bolnisi and Tsalka until 2045 was carried out, taking into account the periodicity in the HD time series.

Key words: *Natural disasters, number of days with hail, statistical analysis, long-term interval forecast.*

Introduction

Almost all types of geophysical disasters occur in Georgia, including hydrometeorological ones [1-4]. Regarding hail processes, Georgia is one of the hail-prone regions of the world [1-3]. As in other countries, in Georgia hail regularly causes serious material damage to agriculture, buildings, structures, infrastructure, transport, etc. Therefore, given the importance of the problem, special attention has always been paid to the study of hail processes here, especially taking into account climate change [5-7].

Most studies of hail processes are usually associated with the analysis of weather station data on the number of days with hail, as well as assessment of damage from hail in various regions of Georgia [8-18], and especially in Kakheti, the main wine-growing region of Georgia [8,15,16,18] .

However, in recent years, it has become possible, based on radar data [19,20], to study various characteristics of hail processes in Eastern Georgia and its neighboring countries (Azerbaijan, Armenia), including determining the maximum size of hail in the clouds and simulating the size of fallen hail [21-26].

For example, works [21,22] present the results of modeling the distribution of hailstones by average maximum diameter (D) on the territory of Kakheti (Georgia) using data on the freezing level in the atmosphere and radar measurements of the maximum size of hail in the clouds. Maps of hail distribution according to the average maximum diameter on the territory of Kakheti for individual months were constructed - from April to September. The vertical distribution of D in the specified territory was studied in the altitude range from 0.11 to 3.84 km, etc.

The works [23-25] present a preliminary analysis of data from radar studies of hail processes in Georgia, Armenia and Azerbaijan. In [26] the results of the analysis of radar studies of hail processes over the territories of Georgia and Azerbaijan on May 28 and July 13, 2019 are presented. Based on the values of the maximum size of hailstones in clouds, using the Zimenkov-Ivanov model, the expected sizes of hailstones falling on the earth's surface are calculated. The degree of damage to vineyards, wheat and corn, depending on the size of the hail, was determined by summarizing the known data on damage to these crops at different kinetic energy of hail and data on the average kinetic energy of hail of different magnitudes. Based on this compilation, regression equations were obtained for the relationship between the degree of damage to these crops and the size of hailstones, which have the form of a sixth degree of a polynomial.

According to this equation, calculations were made of the degree of maximum damage to vineyards, wheat and corn along the trajectories of hail clouds over the territories of Georgia and Azerbaijan.

In 2022-2023, work was carried out to prepare [27,28] and create [29] a systematized catalog for five types of natural disasters in Georgia (landslides, mudflows, hurricane winds, floods and hail), as well as ways to interpret the data from this catalog [30 ,31].

In particular, using the data from this catalog, work was carried out on a statistical analysis of the number of days with hail in Georgia in 2006-2021 [32], as well as an analysis of damage from hail to agricultural crops in Kvemo Kartli (Georgia) [33]. The work [34] studied the long-term variability of the number of days with hail in Tbilisi (1891-2021).

In continuation of work [34] in [35] predictive estimates of the number of hail days (HD) and their moving averages (for 3, 5, 7, 9 and 11 years – HD_3…HD_11) per warm period of year to 2050 and 2085 an example of Tbilisi was performed. Forecasting was carried out using the AAA version of the exponential smoothing (ETS) algorithm taking into account the periodicity in the pre-forecast time series. In particular, the following results were obtained.

For the time series of the measured number of days with hail and HD_11 years, no pronounced peak in periodicity is observed. For time series HD_3, the periodicity is 14 years, HD_5 – 32 years, HD_7 and HD_9 – 31 years.

In the period from 2022 to 2050, the range of variability of the average values of the central points of the forecast for the number of days with hail and the values of their 95% upper level is as follows: HD - from 0.9 to 3.8, HD_3 - from 1.0 to 3.0, HD_11 – from 1.0 to 1.6. In the period from 2022 to 2085, the range of variability of the average values of the central points of the forecast for the number of days with hail and the values of their 95% upper level is as follows: HD_5 - from 0.4 to 3.0, HD_7 - from 0.7 to 1.8, HD_9 - from 0.5 to 3.

Our last paper [36] presents some results of a statistical analysis of data from 30 meteorological stations of Georgia on the number of days with hail in the warm half of the year in 1941-2021.

This work is a continuation of previous studies [32-36]. Results of a study of the features of variations in the number of days with hail in the warm half of the year in Bolnisi and Tsalka in 1941-2021 and their expected change until 2045 are presented below.

Study area, material and methods

Study area – Bolnisi (41.45° N, 44.54° E, 550 m a.s.l.) and Tsalka (41.60° N, 44.09° E, 1450 m a.s.l.) – Kvemo Kartli region of Georgia.

The work used catalog data on the number of days with hail in the warm season of the year (April-October) in Bolnisi and Tsalka from 1941 to 2021 [29].

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods of random events and methods of mathematical statistics for the non-accidental time-series of observations [37-40].

Forecasting the number of hail days was performed using the AAA version of the exponential smoothing (ETS) algorithm taking into account the periodicity in the pre-forecast time series [40].

The following designations will be used below: Mean – average values; Min – minimal values; Max - maximal values; St Dev - standard deviation; R – coefficient of linear correlation; R_k - Kendall's rank correlation coefficient; R_s - Spearmen's rank correlation coefficient; R_a – autocorrelation coefficient; Lag = 1, 2…27 years; HD - the number of days with hail in the warm season; Forecast - forecast center point; 67%_Upp...99.99%_Upp - 67%...99.99% upper forecast level of HD; Lower forecast level of HD is 0.

The degree of correlation was determined in accordance with [37]: very high correlation ($0.9 \le R \le 1.0$); high correlation ($0.7 \le R < 0.9$); moderate correlation ($0.5 \le R < 0.7$); low correlation ($0.3 \le R < 0.5$); negligible correlation ($0 \le R < 0.3$).

The statistical programs Mesosaur and Excel 19 were used for calculations.

Results

Results in Table 1,2 and Fig. 1-8 are presented.

In Table 1 data about correlation level of the number of days with hail in the warm season in Bolnisi and Tsalka in 1941-2021 with years are presented.

Table 1. Correlation of the number of days with hail in the warm season in Bolnisi and Tsalka in 1941-2021 with years.

Location	Bolnisi					
Parameter	R	α (R)	R_k	α(R_k)	R_s	α(R_s)
Value	-0.16	0.2	-0.14	0.074	-0.13	0.233
Location	Tsalka					
Parameter	R	α (R)	R_k	α(R_k)	R_s	α(R_s)
Value	-0.62	<0.005	-0.44	<0.005	-0.59	<0.005

As follows from Table 1, in general, the correlation of HD with years in both Bolnisi and Tsalka is negative. However, the level of all types of HD correlations with the years in Bolnisi is lower than in Tsalka ("Negligible correlation" for Bolnisi, and "Low correlation" and "Moderate correlation" for Tsalka).

That is, the dependence HD on time in Bolnisi is lower than in Tsalka. The data in Table 1 confirms the results of work [36], which in particular shows that in 1981-2021 compared to 1941-1980 the average number of days with hail in Bolnisi decreased by 0.6 (43% of the average number of days with hail in 1941-2021), while in Tsalka by 2.5 (81% of the average number of days for the entire observation period).

The level of autocorrelation in the HD time series in Bolnisi is also lower than in Tsalka (Fig. 1,2).

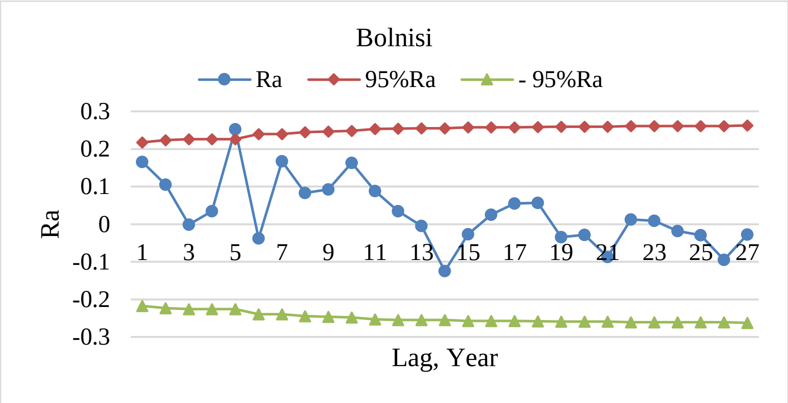

Fig. 1. Autocorrelation in time-series of observations on the number of days with hail in the warm season in Bolnisi from 1941 to 2021.

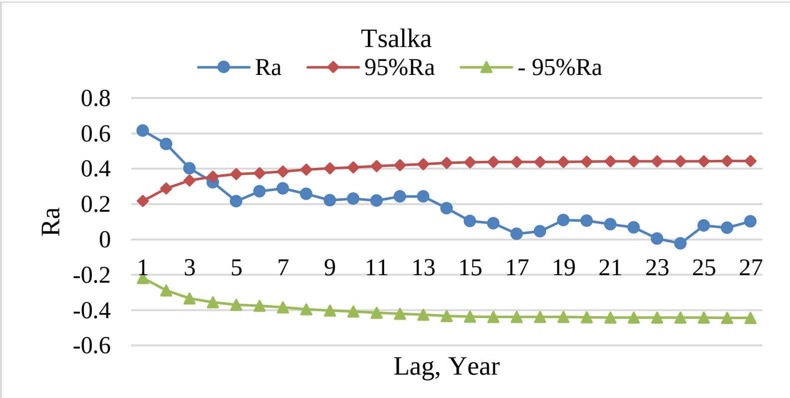

Fig. 2. Autocorrelation in time-series of observations on the number of days with hail in the warm season in Tsalka from 1941 to 2021.

Thus, in Bolnisi, autocorrelation appears only in the fifth lag (R_a = 0.26), while in Tsalka in the first three lags (R_a = 0.62, 0.54 and 0.40, respectively).

In Bolnisi, the HD time series shows two periodicity peaks – the main one ≈ 6 years and the auxiliary one ≈ 10 years (Fig. 3).

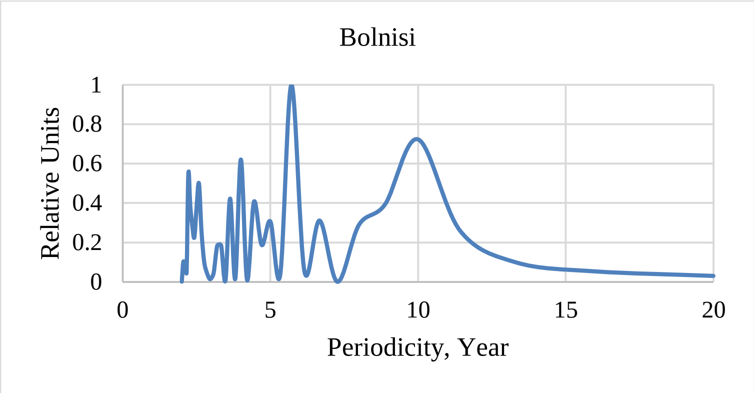

Fig. 3. Periodicity of the number of days with hail in the warm season in Bolnisi from 1941 to 2021.

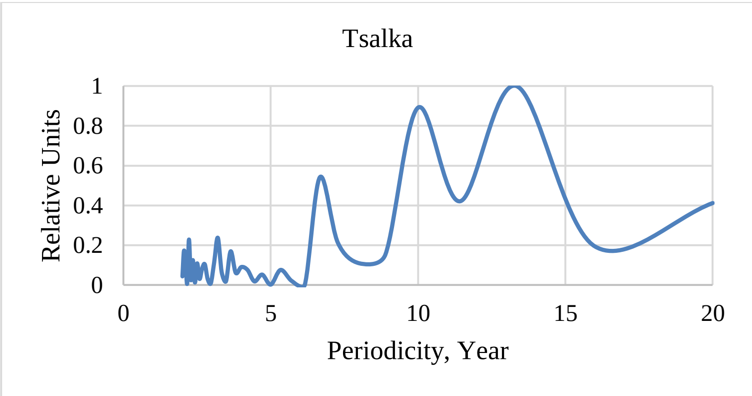

Fig. 4. Periodicity of the number of days with hail in the warm season in Tsalka from 1941 to 2021.

In Tsalka, the HD time series shows three periodicity peaks – the main one ≈ 13 years and two auxiliary ones ≈ 10 years and ≈ 7 years (Fig. 4).

Data on the main peak periodicity values in the HD time series are taken into account when conducting interval forecasting of the number of days with hail in Bolnisi and Tsalka until 2045 (Fig. 5-8).

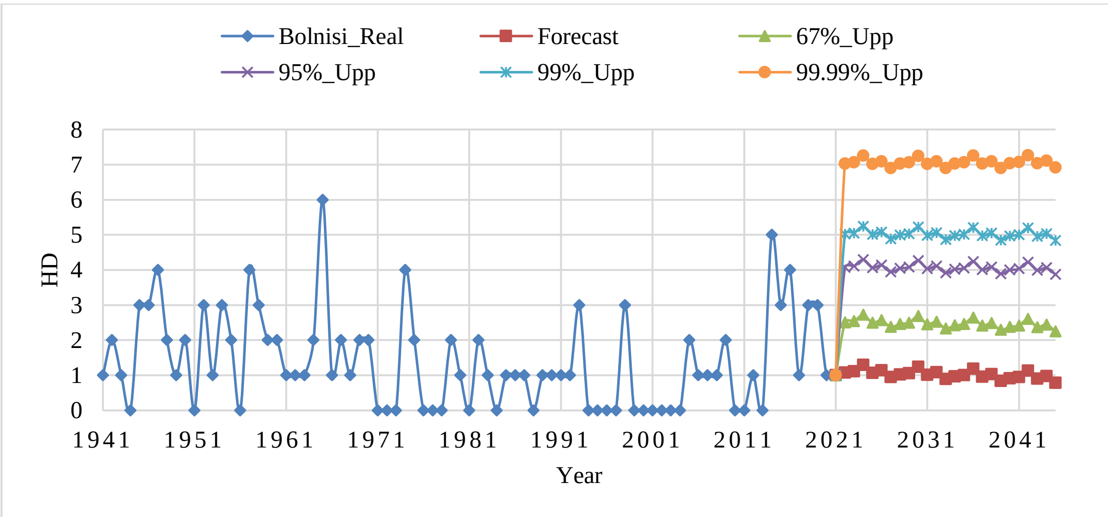

Fig. 5. Time-series of real (1941-2021) and forecasting (2022-2045) values of the number of days with hail in the warm season in Bolnisi.

In particular, the five-year average values of the central points of the HD forecast in 2026-2045 in Bolnisi they vary from 0.9 to 1.1 (Fig. 6), and in Tsalka – from 0.5 to 1.1 (Fig. 8).

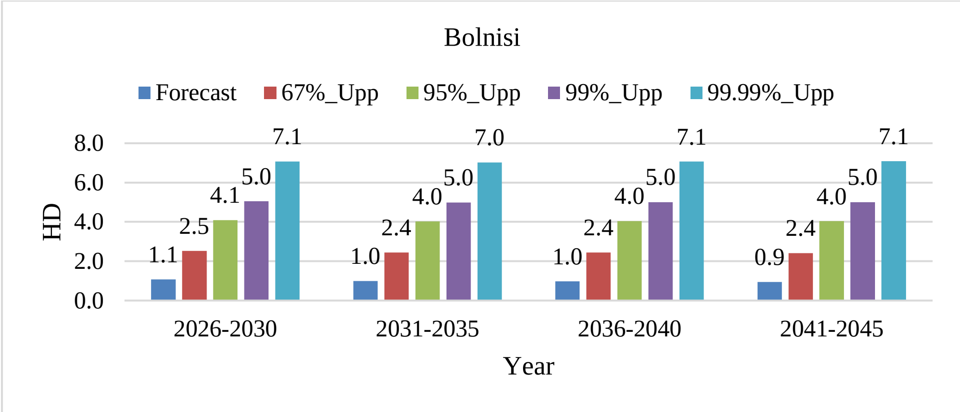

Fig. 6. Five-year averages forecasting values of the number of days with hail in the warm season in Bolnisi from 2026 to 2045.

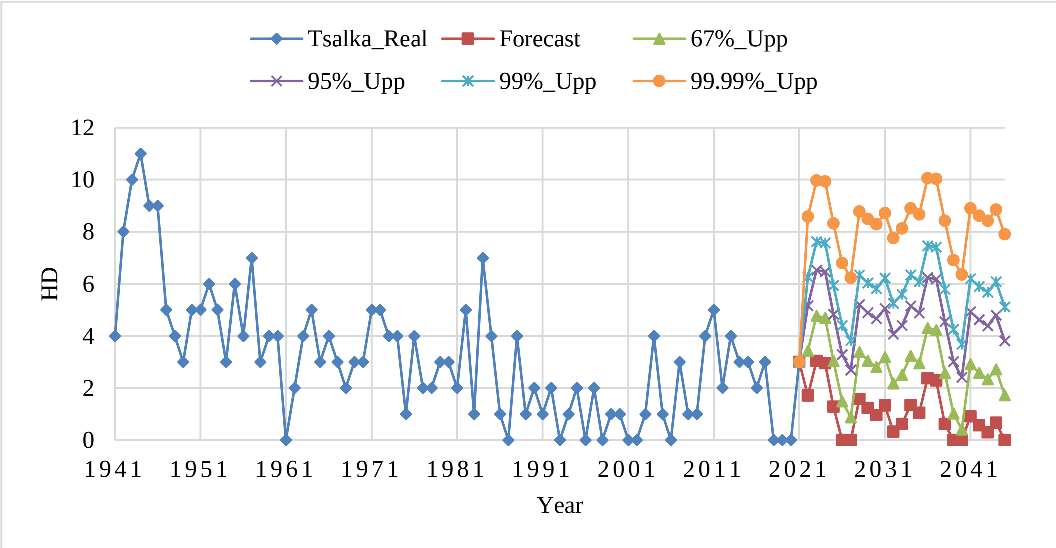

Fig. 7. Time-series of real (1941-2021) and forecasting (2022-2045) values of the number of days with hail in the warm season in Tsalka.

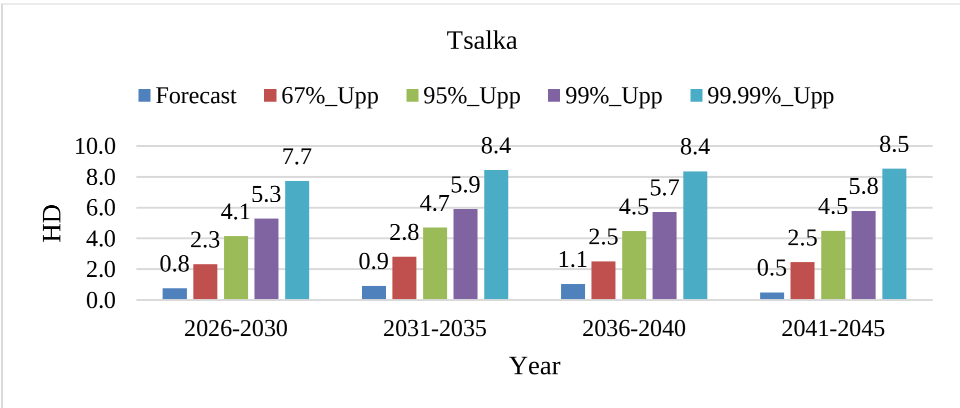

Fig. 8. Five-year averages forecasting values of the number of days with hail in the warm season in Tsalka from 2026 to 2045.

The five-year average values of the 99.99% upper level of HD forecast points in Bolnisi vary from 7.0 to 7.1 (Fig. 6), and in Tsalka – from 7.7 to 8.5 (Fig. 8).

Table 2 compares the actual average HD values in Bolnisi and Tsalka in 1941-2021 and 2002-2021 with their prognostic values in 2026-2045.

Table 2. Statistical characteristics of real (1941-2021, 2002-2021) and forecasting (2026-2045) values of the number of days with hail in the warm season in Bolnisi and Tsalka.

Years	1941-2021	2002-2021	2026-2045				
Variable	Real	Real	Forecast	67%_Upp	95%_Upp	99%_Upp	99.99%_Upp
Location	Bolnisi						
Max	6.0	5.0	1.2	2.7	4.3	5.2	7.3
Min	0.0	0.0	0.8	2.3	3.9	4.8	6.9
Mean	1.4	1.5	1.0	2.5	4.1	5.0	7.1
StDev	1.3	1.5	0.1	0.1	0.1	0.1	0.1
Location	Tsalka						
Max	11	5.0	2.4	4.3	6.2	7.5	10.1
Min	0	0.0	0.0	0.4	2.4	3.7	6.2
Mean	3.1	2.0	0.8	2.5	4.5	5.7	8.3
StDev	2.4	1.6	0.7	1.0	1.0	1.0	1.0

In particular, as follows from Table 2, in Bolnisi the average real HD values during the indicated time periods fall into their forecast range “Forecast - 67%_Upp”, and in Tsalka – into the range “Forecast - 95%_Upp”.

Conclusion

In the future, similar forecast estimates of the number of days with hail (HD) will be carried out for other individual settlements in Georgia, both for annual data and moving averages of these data.

It is also planned to study of the variability of the number of days with hail in the warm half of the year (April-October) for 22 weather stations of Georgia from 1941 to 2021, on average for five climatic zones, which includes four climatic groups according to the Köppen classification, and conducting HD interval forecasting for indicated climate zones.

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სეტყვათა დღეთა რაოდენობის ცვალებადობა ბოლნისსა და წალკაში წლის თბილ ნახევარში 1941-2021 წლებში და მოსალოდნელი ცვლილება 2045 წლამდე

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რეზიუმე

ნაშრომში წარმოდგენილია ბოლნისსა და წალკაში სეტყვათა დღეთა რაოდენობის წლის თბილ ნახევარში (HD) 1941-2021 წლებში ცვალებადობის მახასიათებლების შესწავლის შედეგები და მათი მოსალოდნელი ცვლილება 2045 წლამდე. აღნიშნულ პუნქტებში შესწავლილი იქნა სეტყვათა დღეთა რაოდენობის დროის სერიების სტაბილურობა HD-ს დროთან კორელაციების განსაზღვრით (წრფივი კორელაცია, კენდალის და სპირმანის რანგის კორელაცია). განისაზღვრა ავტოკორელაციის დონე HD-ს დროის რიგებში ბოლნისსა და წალკაში. შესწავლილია ამ დროის რიგების პერიოდულობა. განხორციელდა ბოლნისსა და წალკაში სეტყვათა დღეთა რაოდენობის ინტერვალური პროგნოზირება 2045 წლამდე HD-ს დროის რიგებში პერიოდულობის გათვალისწინებით.
საკვანძო სიტყვები: სტიქიური მოვლენები, სეტყვათა დღეთა რაოდენობა, სტატისტიკური ანალიზი, მრავალწლიანი ინტერვალური პროგნოზი.

Вариации числа дней с градом в теплое полугодие в Болниси и Цалке в 1941-2021 гг. и их ожидаемое изменение до 2045 г.

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Резюме

В работе представлены результаты исследования особенностей вариаций числа дней с градом в теплое полугодие (HD) в Болниси и Цалке в 1941-2021 гг. и их ожидаемое изменение до 2045 г. Изучена устойчивость временных рядов числа дней с градом числа в указанных пунктах путем определения корреляционных связей HD со временем (линейная корреляция, ранговая корреляция Кендалла и Спирмена). Определен уровень автокорреляции во временных рядах HD в Болниси и Цалке. Изучена периодичность указанных временных рядов. Проведено интервальное прогнозирование числа дней с градом в Болниси и Цалке до 2045 г. с учетом периодичности во временных рядах HD.
Ключевые слова: Стихийные бедствия, количество дней с градом, статистический анализ, многолетний интервальный прогноз.