VARIABILITY IN THE NUMBER OF DAYS WITH HAIL IN THE WARM HALF OF THE YEAR ON THE TERRITORY OF GEORGIA IN 1941-2021

Mikheil Pipia[1,2], Avtandil Amiranashvili[1], Elizbar Elizbarashvili[2],
Otar Varazanashvili[1], Nazibrola Beglarashvili[2,3], Nino Jamrishvili[1]

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[1]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, GEORGIA
[2]Institute of Hydrometeorology of Technical University, GEORGIA
[3]Samtskhe-Javakheti State University, Akhaltsikhe, GEORGIA
mikheil.pipia@tsu.ge
avtandilamiranashvili@gmail.com
otarivar@yahoo.com
n.jamrishvili76@gmail.com
eelizbar@hotmail.com
beglarashvilinani@yahoo.com

Abstract

Some results of a study of the variability of the number of days with hail in the warm half of the year (April-October) for 22 weather stations in Georgia from 1941 to 2021, on average for five climatic zones, which includes four climatic groups according to the Köppen classification, are presented. Zones I and III – warm oceanic climate/humid subtropical climate (Cfa): Zone I – Kutaisi, Mta-Sabueti, Senaki, Shovi, Zugdidi; Zone III – Kvareli, Lagodekhi, Telavi. Zone II – warm continental climate/humid continental climate (Dfa): Bolnisi, Gori, Khashuri, Marneuli, Pasanauri, Stepantsminda, Tbilisi, Tianeti. Zone IV – temperate oceanic climate (Cfb): Bakhmaro, Chakvi, Khulo. Zone V - temperate continental climate/ humid continental climate (Dfa): Bakuriani, Borjomi, Tsalka. The statistical characteristics of the following parameters were studied. H(I)…H(V) - average number of days with hail per meteorological station in the warm half of the year for climatic zones I...V, respectively. H(I-V) - average number of days with hail per meteorological station for all climatic zones. H(I)'…H(I-V)' - mean per decade rate of change of the H(I)…H(I-V) in 1941-1950 … 2011-2021. In particular, the following results were obtained. The smallest range of changes in H values is observed in the first climatic zone (0÷1.8), the largest - in the fifth (0÷8.3). The linear correlation between the studied parameters between individual zones vary from 0.27 (pair H(I) - H(IV), negligible correlation) to 0.55 (pairs H(II) - H(III) and H(II) - H(V), moderate correlation). The variability of the average ten-decade number of days with hail per weather station change from 0 (Zone IV, 2011-2021) to 5.9 (Zone V, 1941-1950). Trend of the mean number of days with hail per meteorological station year for all climatic zones in Georgia in 1941-2021 is quite satisfactorily described by a fourth power polynomial. The variability of H(I)'…H(I-V)' change from -1.48 in 1941-1950 to 2.09 in 2011-2021 (Zone V).

Keywords: natural disaster, hail, Köppen climate classification, statistical analysis

I. Introduction

Georgia is one of the most hail-prone countries in the world. Therefore, in this country, many works are devoted to the problem of hail damage, the basis of which is hail climatology. The study of the number of days with hail, both in general in Georgia and in its individual regions, has been carried out for many decades [1-11]. In particular, the features of the distribution of the number of days with hail in the warm half of the year for 15 climatic zones of Georgia in the period 1941-1990 were studied [3,11], data on damage from hail storms are provided [5,6,8,11], the variability of the number of days with hail and the connection of this variability with aerosol pollution of the atmosphere have been studied [11], etc.

In 2022-2023, work was carried out to prepare [12,13] and create [14] a systematized catalog for five types of natural disasters in Georgia (landslides, mudflows, hurricane winds, floods and hail).

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 [15], analysis of damage from hail to agricultural crops in Kvemo Kartli (Georgia) [16], studying of long-term variability in the number of days with hail in Tbilisi (1891-2021) [17] and forecasting this variability until 2085 [18].

Our last paper [19] 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. In particular, the following results were obtained: data on the average and maximum values of the number of days with hail in 1941-2021, 1941-1980 are provided (first time period) and 1981-2021 (second time period); correlations between the studied parameters for the specified time periods were studied; it was found that in the second period of time, compared to the first, at 21 stations there is a decrease in the average number of days with hail, at 8 stations this number does not change, and only at one station there is an increase in the average number of days with hail; the dependence of the average and maximum number of days with hail on the terrain height was studied for 24 meteorological stations located at a level of less than 1500 m for the specified time periods; it was found that in the second period of time, compared to the first, the tightness of the correlation between the number of days with hail and the altitude of the area weakens.

This study is a continuation of work [19]. Some results of a study of the variability of the number of days with hail in the warm half of the year (April-October) for 22 weather stations in Georgia from 1941 to 2021, on average for five climatic zones, which includes four climatic groups according to the Köppen classification, are presented below.

II. Study area, material and methods

Study area is Georgia and their five climatic zones, including four climatic groups according to the Köppen classification (Fig. 1, Table 1).

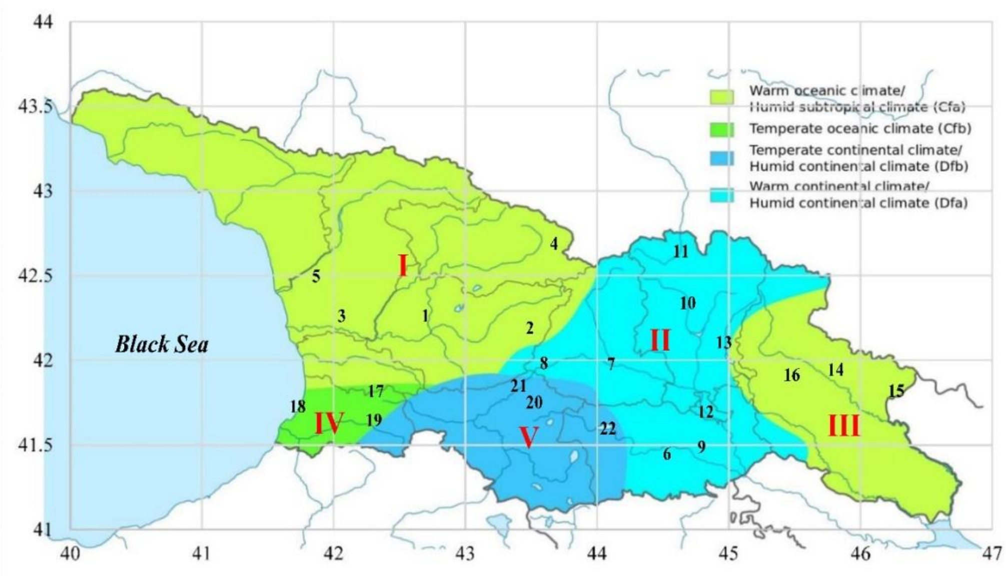


Figure 1: *Köppen climate classification map of Georgia.*
https://commons.wikimedia.org/wiki/File:Köppen_climate_classification_map_of_Georgia.svg

Table 1: *The number of meteorological stations, their coordinates, altitudes and the number of zones of their location (Fig. 1).*

N	Zone	Location	Lat, °N	Lon, °E	H,m	N	Zone	Location	Lat, °N	Lon, °E	H,m
1	I	Kutaisi	42.27	42.70	120	12	II	Tbilisi	41.70	44.83	437
2	I	Mta-Sabueti	42.20	43.50	2470	13	II	Tianeti	42.11	44.97	1100
3	I	Senaki	42.27	42.07	28	14	III	Kvareli	41.95	45.82	450
4	I	Shovi	42.70	43.68	1520	15	III	Lagodekhi	41.82	46.28	450
5	I	Zugdidi	42.51	41.87	100	16	III	Telavi	41.92	45.48	490
6	II	Bolnisi	41.45	44.54	550	17	IV	Bakhmaro	41.85	42.33	1950
7	II	Gori	41.98	44.11	588	18	IV	Chakvi	41.73	41.73	30
8	II	Khashuri	41.99	43.60	680	19	IV	Khulo	41.65	42.31	1044
9	II	Marneuli	41.49	44.80	420	20	V	Bakuriani	41.75	43.53	1700
10	II	Pasanauri	42.35	44.69	1050	21	V	Borjomi	41.85	43.41	850
11	II	Stepantsminda	42.65	44.64	1750	22	V	Tsalka	41.60	44.09	1450

As follows from Fig. 1 and Table 1, the distribution of meteorological stations by climatic zones is as follows. Zones I and III – warm oceanic climate/humid subtropical climate (Cfa): Zone I – Kutaisi (1), Mta-Sabueti (2), Senaki (3), Shovi (4), Zugdidi (5); Zone III – Kvareli (14), Lagodekhi (15), Telavi (16). Zone II – warm continental climate/humid continental climate (Dfa): Bolnisi (6), Gori (7), Khashuri (8), Marneuli (9), Pasanauri (10), Stepantsminda (11), Tbilisi (12), Tianeti (13). Zone IV – temperate oceanic climate (Cfb): Bakhmaro (17), Chakvi (18), Khulo (19). Zone V - temperate continental climate/ humid continental climate (Dfa): Bakuriani (20), Borjomi (21), Tsalka (22).

The work used catalog data [14] on the number of days of hail in warm period of year (April-October) for the above indicated meteorological stations in 1941-2021.

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 [20-22].

The following designations will be used below: Mean – average values; Max - maximal values; Min – minimal values; St Dev - standard deviation; R^2 – coefficient of determination; R – coefficient of linear correlation; α - level of significance; the difference between two average values was determined using the Student's criterion with $\alpha \leq 0.05$; K_{DW} – Durbin-Watson statistic. The curve of trend is equation of the regression of the connection of the investigated parameter with the time at the significant value of the determination coefficient and such values of K_{DW}, where the residual values are accidental. If the residual values are not accidental the connection of the investigated parameter with the time we will consider as simply regression.

The degree of correlation was determined in accordance with [20]: very high correlation ($0.9 \leq R \leq 1.0$); high correlation ($0.7 \leq R < 0.9$); moderate correlation ($0.5 \leq R < 0.7$); low correlation ($0.3 \leq R < 0.5$); negligible correlation ($0 \leq R < 0.3$).

H(I)…H(V) - average number of days with hail per meteorological station in the warm half of the year for climatic zones I...V, respectively. H(I-V) - average number of days with hail per meteorological station for all climatic zones. H(I)'…H(I-V)' - mean per decade rate of change of the H(I)…H(I-V) in 1941-1950 … 2011-2021.

III. Results

The results in Fig. 2-5 and Table 2,3 are represented.

In Fig. 2 time-series of the mean number of days with hail per meteorological station in the warm half of the year for climatic zones in Georgia in 1941-2021 are presented. In Table 2 statistical characteristics of Fig. 1 data is represented.

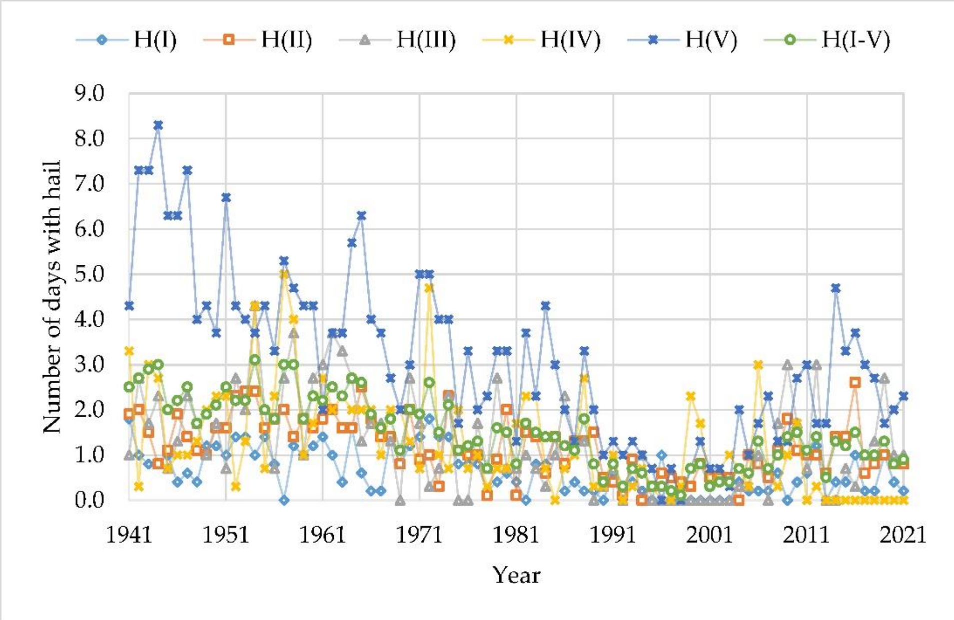


Figure 2: *Variability of the mean number of days with hail per meteorological station in the warm half of the year for climatic zones in Georgia in 1941-2021.*

Table 2. *Statistical characteristics of the mean number of days with hail per meteorological station in the warm half of the year for climatic zones in Georgia in 1941-2021. R_{min} = 0.22, α = 0.05*

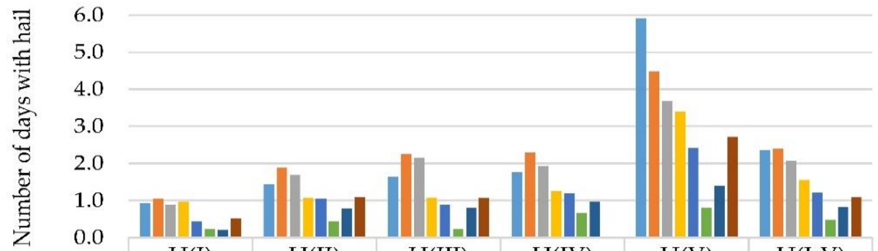
Variable	H(I)	H(II)	H(III)	H(IV)	H(V)	H(I-V)
Max	1.8	2.6	4.3	5.0	8.3	3.1
Min	0	0	0	0	0	0.1
Mean	0.6	1.2	1.3	1.2	3.1	1.5
St Dev	0.51	0.64	1.09	1.17	1.88	0.79
	Correlation Matrix					
H(I)	1	0.46	0.38	0.27	0.47	0.61
H(II)	0.46	1	0.55	0.33	0.55	0.73
H(III)	0.38	0.55	1	0.36	0.41	0.71
H(IV)	0.27	0.33	0.36	1	0.37	0.66
H(V)	0.47	0.55	0.41	0.37	1	0.85
H(I-V)	0.61	0.73	0.71	0.66	0.85	1

As follows from Fig. 1 and Table. 2, the distribution of the mean number of days with hail per weather station on the territory of Georgia is quite uneven. In particular, the smallest range of changes in H values is observed in the first climatic zone (0÷1.8), the largest - in the fifth (0÷8.3). In general, in Georgia the H values vary from 0.1 to 3.1. Average values of H changes from 0.6 (first zone) to 3.1 (fifth zone). Mean value of H(I-V) is 1.5.

In general, the linear correlation between the studied parameters is significant. At the same time, between individual zones the R values vary from 0.27 (pair H(I) - H(IV), negligible correlation) to 0.55 (pairs H(II) - H(III) and H(II) - H(V), moderate correlation).

From Fig. 2 it follows that in general the number of days with hail in Georgia for averaging intervals of 20-30 years tends to decrease. So, in 2001-2021 compared to 1941-1960 the average number of days with hail per meteorological station decreased as follows: H(I) from 1.0 to 0.4, H(II) from 1.7 to 0.9, H(III) from 1.9 to 0.9, H(IV) from 2.0 to 0.5, H(V) from 5.2 to 2.1, H(I-V) from 2.4 to 1.0. In 1991-2021 compared to 1941-1970 the average number of days with hail per meteorological station decreased as follows: H(I) from 0.9 to 0.3, H(II) from 1.7 to 0.8, H(III) from

2.0 to 0.7, H(IV) from 2.0 to 0.5, H(V) from 4.7 to 1.7, H(I-V) from 2.3 to 0.8.



	H(I)	H(II)	H(III)	H(IV)	H(V)	H(I-V)
1941-1950	0.9	1.4	1.6	1.8	5.9	2.4
1951-1960	1.0	1.9	2.3	2.3	4.5	2.4
1961-1970	0.9	1.7	2.1	1.9	3.7	2.1
1971-1980	1.0	1.1	1.1	1.3	3.4	1.6
1981-1990	0.4	1.0	0.9	1.2	2.4	1.2
1991-2000	0.2	0.4	0.2	0.7	0.8	0.5
2001-2010	0.2	0.8	0.8	1.0	1.4	0.8
2011-2021	0.5	1.1	1.1	0.0	2.7	1.1

Figure 3: *Variability of the mean decade number of days with hail per meteorological station in the warm half of the year for climatic zones in Georgia in 1941-2021.*

The variability of the average ten-decade number of days with hail per weather station is as follows (Fig. 3): H(I) - weak variability from 0.9 to 1.0 in 1941-1980, a sharp decrease from 0.4 to 0.2 in 1981-2010, an increase to 0.5 in 2011-2021 ; H(II) - increase from 1.4 to 1.9 in 1941-1960, constant decrease from 1.7 to 0.4 in 1961-2000, increase from 0.8 to 1.1 in 2001-2021; H(III) - dynamics similar to the previous zone, growth from 1.6 to 2.3 in 1941-1960, constant decrease from 2.1 to 0.2 in 1961-2000, growth from 0.8 to 1.1 in 2001-2021; H(IV) - increase from 1.8 to 2.3 in 1941-1960, decrease from 1.9 to 0.7 in 1991-2000, increase to 1.0 in 2001-2010, decrease to 0 in 2011-2021; H(V) - continuous decrease from 5.9 to 0.8 in 1941-2000, increase from 1.4 to 2.7 in 2001-2021; H(I-V) - unchanged in 1941-1960 (according to 2.4), constant decrease from 2.1 to 0.5 in 1961-2000, increase from 0.8 to 1.1 in 2001-2021.

Trend of the mean number of days with hail per meteorological station in the warm half of the year for all climatic zones in Georgia in 1941-2021 is quite satisfactorily described by a fourth order polynomial (Table 3, Fig. 4).

Table 3. *Coefficients of the regression equation for the trend of the mean number of days with hail per meteorological station in the warm half of the year for climatic zones in Georgia in 1941-2021.*

$\alpha(R^2) < 0.005;\ 0.01 < \alpha(K_{DW}) < 0.05$

$H = a \cdot X^4 + b \cdot X^3 + c \cdot X^2 + d \cdot X + e$, *X – number of years, 1-1941….81-2021*

Variable	a	b	c	d	e	R^2	K_{DW}
H(I)	1.67E-07	-1.33E-05	-0.00021	0.01231	0.924484	0.371	1.64
H(II)	-3.85E-07	8.40E-05	-0.00566	0.112247	1.148299	0.400	1.88
H(III)	-6.48E-07	0.000144	-0.00992	0.207335	0.959126	0.346	1.84
H(IV)	-8.21E-07	0.000145	-0.0086	0.162483	1.274063	0.329	1.99
H(V)	8.53E-07	-0.00011	0.005349	-0.19542	6.788456	0.659	1.55
H(I-V)	-1.41E-07	4.52E-05	-0.00353	0.053348	2.265498	0.719	1.56

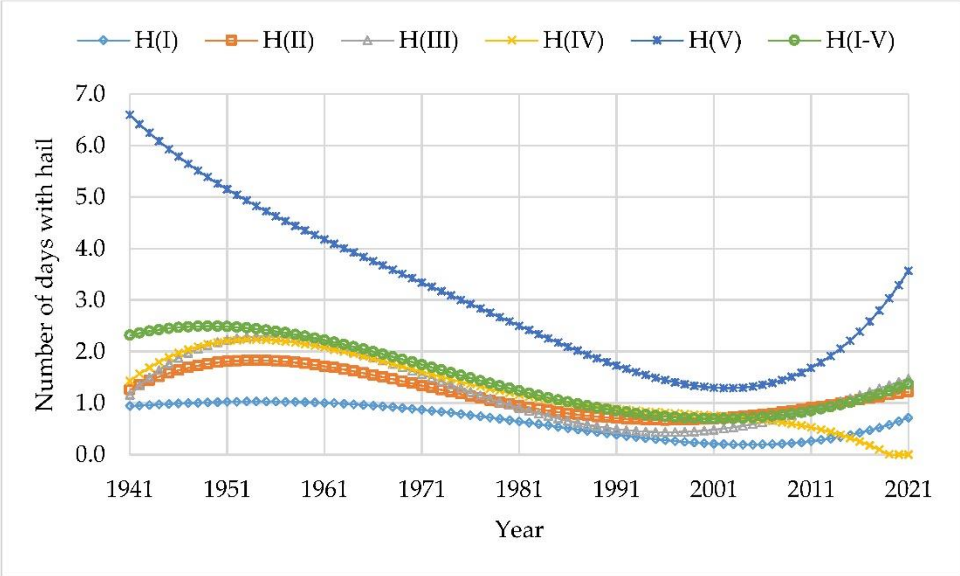
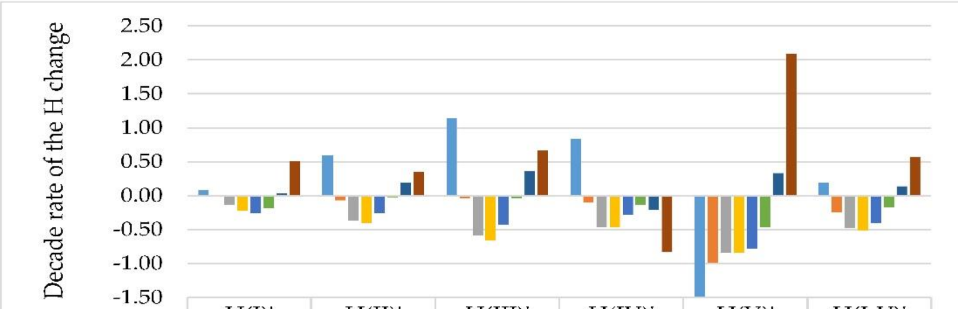


Figure 4: *Trend of the mean number of days with hail per meteorological station in the warm half of the year for climatic zones in Georgia in 1941-2021.*

Using the data from Fig. 4 mean per decade rate of change of the mean number of days with hail per meteorological station in the warm half of the year for climatic zones in Georgia in 1941-2021 are calculated (Fig. 5). H(I)'… H(I-V)' = 10·mean dH/dX, for X from 1 to 70 and = 11·mean dH/dX, for X from 71 to 81 (Table 3).



	H(I)'	H(II)'	H(III)'	H(IV)'	H(V)'	H(I-V)'
1941-1950	0.09	0.59	1.14	0.84	-1.48	0.20
1951-1960	-0.01	-0.07	-0.03	-0.10	-0.99	-0.25
1961-1970	-0.13	-0.37	-0.58	-0.46	-0.84	-0.47
1971-1980	-0.22	-0.40	-0.66	-0.46	-0.84	-0.51
1981-1990	-0.25	-0.25	-0.43	-0.28	-0.78	-0.40
1991-2000	-0.18	-0.02	-0.03	-0.14	-0.46	-0.17
2001-2010	0.03	0.20	0.36	-0.21	0.33	0.14
2011-2021	0.50	0.35	0.67	-0.82	2.09	0.57

Figure 5: *Mean per decade rate of change of the mean number of days with hail per meteorological station in the warm half of the year for climatic zones in Georgia in 1941-2021.*

The variability of average per decade rate of change of the mean number of days with hail per meteorological station is as follows (Fig. 5): H(I)' - from -0.25 in 1981-1990 to 0.50 in 2011-2021; H(II)' - from -0.40 in 1971-1980 to 0.59 in 1941-1950; H(III)' – from -0.66 in 1971-1980 to 1.14 in 1941-1950; H(IV)' – from -0.46 in 1961-1970 and 1971-1980 to 0.84 in 1941-1950; H(V)' - from -1.48 in 1941-1950 to 2.09 in 2011-2021; H(I-V)' – from -0.51 in 1971-1980 to 0.57 in 2011-2021.

IV. Discussion

In Georgia, as one of the most hail-prone countries in the world, many studies have been devoted to the study of hail processes, the basis of which is hail climatology. In 2023, a systematic catalog of five types of natural disasters in Georgia was created (landslides, mudflows, hurricane winds, floods and hail) [14]. From this catalog, data on the number of days with hail in the warm half of the year (April-October) was selected for 22 weather stations in Georgia from 1941 to 2021.

Our early studies used long-term continuous data (1941-1990) on number of hail days at 123 weather stations [3]. Accordingly, statistical characteristics were studied in detail, including the variability in the number of days with hail for 15 climatic zones of Georgia over the specified 50-year period of time. After 1990, the number of weather stations decreased significantly, and we proposed a different approach to studying long-term variations in the number of days with hail. Namely, an analysis of the variability of the number of days with hail averaged per meteorological station for five climatic zones, which includes four climatic groups according to the Köppen classification. In our opinion, this approach is promising and will be developed by us in the future.

V. Conclusion

In the future, it is planned to study in more detail time series of number of days with hail averaged per one meteorological station for indicated above 5 climatic zones (autocorrelation analysis, periodicity, etc.), as well as to conduct an interval forecast of the number of days with hail, taking into account periodicity, etc.

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