https://doi.org/10.48047/AFJBS.6.14.2024.6132-6139

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

Modeling the Distribution of Mean Max Hail Damage to Vineyards on the Territory of Kakheti (Georgia) using Data of the Freezing Level in the Atmosphere and Radar Measurements

[1] Mikheil G. Pipia, [2]Avtandil G. Amiranashvili, [3]Elizbar Sh. Elizbarashvili, [4]Otar Sh. Varazanashvili, [5] Nazibrola G. Beglarashvili, [6] Nino K. Jamrishvili

[1]M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University, 1. M. Aleksidze str., Tbilisi 0160, Georgia; Institute of Hydrometeorology of Georgian Technical University, 150c David Agmashenebeli Ave., Tbilisi 0112, Georgia

[2]M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University, 1. M. Aleksidze str., Tbilisi 0160, Georgia

[3]Institute of Hydrometeorology of Georgian Technical University, 150C David Agmashenebeli Ave., Tbilisi 0112, Georgia

[4]M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University, 1. M. Aleksidze str., Tbilisi 0160, Georgia

[5] Institute of Hydrometeorology of Georgian Technical University, 150C David Agmashenebeli Ave., Tbilisi 0112, Georgia

[6] M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University, 1. M. Aleksidze str., Tbilisi 0160, Georgia,

[1]mikheil.pipia@tsu.ge, [2] avtandilamiranashvili@gmail.com, [3] eelizbar@hotmail.com, [4] otarivar@yahoo.com, [5] beglarashvilinani@yahoo.com, [6] n.jamrishvili76@gmail.com

Volume 6, Issue 14, Aug 2024
Received: 15 June 2024
Accepted: 25 July 2024
Published: 15 Aug 2024
doi: 10.48047/AFJBS.6.14.2024.6132-6139

Abstract— Results of modeling of the distribution of monthly mean max hail damage to vineyards (HDV) and their 99% values of the lower and upper levels (HDV_Low, HDV_Upp) on the territory of Kakheti (Georgia) are presented. Calculations have been carried out using data of the freezing level in the atmosphere and radar measurements of hail max sizes in clouds, also known information about degree of damage to vineyards, depending on the size of the fallen hail. The agricultural area of Kakheti (7050 km²) was divided into 290 squares, the range of heights - 0.21 ÷ 1.19 km. Period of investigation - from April to September. As example map of the distribution of HDV on the territory of Kakheti for May have been built. Data on statistical characteristics on HDV, HDV_Low and HDV_Upp from April to September are presented. The vertical distribution of HDV and HDV_Upp on the indicated territory was studied. It is shown that the calculated values of HDV are in satisfactory agreement with their actual values obtained during the inspection of hail-damaged areas by special commissions.

Index Terms— *Dangerous meteorological processes, empirical modeling, hail damage assessment, radar monitoring.*

I. INTRODUCTION

Hail processes are observed in many regions of the world [1-3], including Georgia [4-7]. Annual global losses of agricultural products from hail damage range from 4 to 18% of the crop, and in monetary terms exceed 11 billion US dollars [https://www.meteorf.ru/activity/activ/antigrad/obs-info /]. At the same time, in terms of damage from hail, Georgia is one of the most hail-prone countries in the world. Therefore, numerous works are devoted to the problem of hail in this country, covering a wide range of studies, such as hail climatology [4-9], radar observations of hail processes [10-12], theoretical and experimental studies of hail, mechanisms of hail formation [13-14], methods of influencing hail processes [3,11], analysis of impact results [15], etc.

To solve various problems of scientific or applied importance (the impact of climate change on hail processes, comparison of experimental data on hail processes with theoretical models of hail processes, assessment of expected damage from hail processes, planning work on active influence on hail processes, etc.), it is necessary detailed information on the spatiotemporal characteristics of hail distribution and its size in different locations. Corresponding ground-based network studies (number of days with hail per year, determination of hail size, its structure, kinetic energy, etc.) have been and are being widely carried out both in different countries of the world [2,3,16] and in Georgia [1,4-8,17].

To construct spatiotemporal maps of the distribution of hail processes, data from radar observations of convective clouds are also used [3,12,14]. In particular, work [12] presents the results of a statistical analysis of such parameters of hail processes for individual municipalities of Kakheti in the period from 2016 to 2019, such as: maximum height of hail clouds, maximum diameter of hail clouds, number of hail clouds of various categories, frequency of hail clouds different categories, the average relative hail hazard coefficient is G. It was found that during the study period the greatest hail hazard was observed in the Gurjaani municipality (G = 1.74) and the smallest in the municipality of Dedoplistskaro (G = 0.39).

The next stage in the study of the spatial distribution of hail damage was modeling of the distribution of hailstones by mean max diameter (D) on the territory of Kakheti (Georgia) using data of the freezing level in the atmosphere and radar measurements of hail max sizes in clouds. The expected diameter of hailstones falling out to the earth's surface according to the Zimenkov-Ivanov model of hail melting in the atmosphere [1,17] by taking into account the radar data about their max diameter in the clouds and freezing level in atmosphere was calculated [18-22].

In [23] to calculate the mean max diameter of hailstones (D) on the surface of the earth, the territory of Kakheti was divided into 465 squares, the range of heights was 0.11 ÷ 3.84 km. The monthly average values of the max sizes of hailstones and their 99% values of the lower and upper levels of the average were calculated. Maps of the distribution of hail by the average maximum diameter in the territory of Kakheti for individual months, from April to September, have been built. The vertical distribution of D on the indicated territory in the range of heights from 0.11 to 3.84 km was studied [23]. In the next work [24] data about D on the territories of 8 municipalities of the Kakheti region for individual months, from April to September, are presented. The vertical distribution of D on the indicated territories was studied.

The results of assessing the size of hailstones that fell on the earth's surface, according to radar measurements of their sizes in the clouds, made it possible to assess the expected damage from hailstorms of various agricultural crops. In our latest work [25] 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.

The presented work is a continuation of previous studies [23-25]. Results of modeling of the distribution of monthly mean max hail damage to vineyards and their 99% values of the lower and upper levels on the agricultural area of Kakheti (Georgia) from April to September are presented below.

STUDY AREA, MATERIAL AND METHODS

Study area – Kakheti region of Georgia. Kakheti is an eastern border region of Georgia bounded by the Russian Federation to the north and Azerbaijan to the south. The total area of the region is 11 309.5 km^2. The region has 9 cities and 276 villages, and the administrative center is Telavi (41.75˚ Northern Latitude, 45.72˚ East Longitude). Kakheti has a total of 8 administrative entities. The region has an agriculture-dominated mono-profile economy with a low level of urbanization. Kakheti is the nation's foremost wine region, it produces nearly three-quarters of the country's wine grapes, which are grown on land that has been dedicated to viticulture for thousands of years. Therefore, problems related to hail processes are very relevant for this region, including the development of active and passive methods of protection against hail and assessment of possible damage from them.

Data of meteorological radar "METEOR 735 CDP 10 - Doppler Weather Radar" of Anti-hail service of Georgia about the max diameter of hailstones in the clouds (cm) are used. The radar is installed in the village Chotori (1090 m height from sea level) of the Signagi municipality of the Kakheti region. The products of radar are sufficiently varied [10]. For the anti-hail works the optimal radius of action of radar is 100-120 km, (distance, which practically covers the territory of Kakheti). In this work radar product HAILSZ (Size) is used [26]. The expected diameter of hailstones falling out to the earth's surface according to the Zimenkov-Ivanov model of hail melting in the atmosphere [1,18,21,22] by taking into account the radar data about their max diameter in the clouds and freezing level in atmosphere was calculated [19, 20]. Period of observation: April-September, 2016-2019.

To calculate the mean max diameter of hailstones (D) on the surface of the earth, the territory of Kakheti was divided into 465 squares, the range of heights was 0.11 ÷ 3.84 km. The monthly average values of the max sizes of hailstones and their 99% values of the lower and upper levels of the average were calculated. In Fig. 1 example of distribution of hailstones by mean max diameter on the territory of Kakheti in May is presented [23].

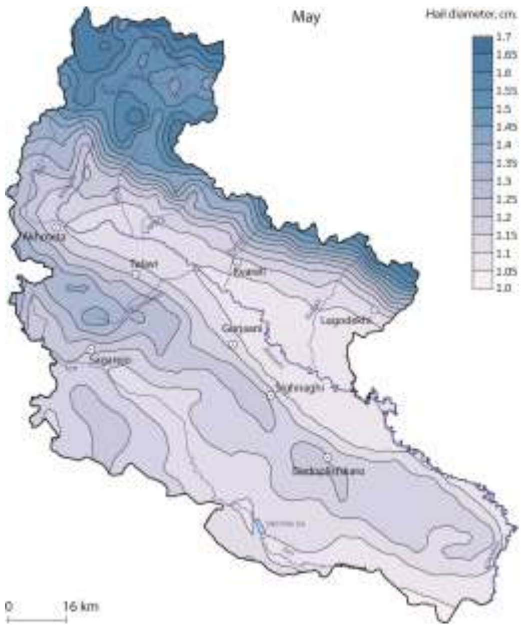

Fig. 1. Distribution of hailstones by mean max diameter on the territory of Kakheti in May [23].

The degree of damage to vineyards, depending on the size of the fallen hail, was determined by compiling data on damage to these crops at different hail kinetic energy [3] and data on the average kinetic energy of hail of various sizes according to TORRO Hail Scale [https://www.torro.org.uk/research/hail/hscale].

Based on this compilation, regression equations were obtained for the relationship between the degree of damage to this crop (HDV) and the size of hailstones (D), which has the form of the sixth power of polynomial [25]:

$$HDV = a \cdot D^6 + b \cdot D^5 + c \cdot D^4 + d \cdot D^3 + e \cdot D^2 + f \cdot D + g$$

Table 1. Coefficients of the regression equation between the hail diameter (D) and the degree of damage to vineyards (HDV).

Coefficient	a	b	c	d	e	f	g	Range of D, cm

HDV, %	-90.668476	730.212998	-2417.48576	4233.39018	-4188.7252	2315.21576	-525.51178	0.57÷1.94

Table 2. Modified TORRO Hail Scale: The Intensity (H) of Hail and Possible Damage (https://www.torro.org.uk/research/hail/hscale and [25])

H	Intensity Category	Typical Hail Diameter (cm)	Typical Damage Impacts
H0	Hard Hail	0.5	No damage.
H1	Potentially Damaging	0.5-1.5	Slight general damage to plants, crops. Damage to vineyards up to 84%
H2	Significant	1.0-2.0	Significant damage to fruit, crops, vegetation. Damage to vineyards (56-100)%

Calculations were carried out for the agricultural territory of Kakheti (7050 km^2), divided into 290 squares. Altitude range - 0.21 ÷ 1.19 km.

For the data analysis the standard statistical methods are used. The following designations of statistical information are used below: Mean – average values; Min – minimal values; Max - maximal values; Range - Max – Min; St Dev - standard deviation; R^2 - coefficient of determination; 99% _Low and 99%_Upp – 99% of lower and upper levels of the mean accordingly (below - Low and Upp).

RESULTS

Results in Fig. 2-5 and Table 3-6 are presented.

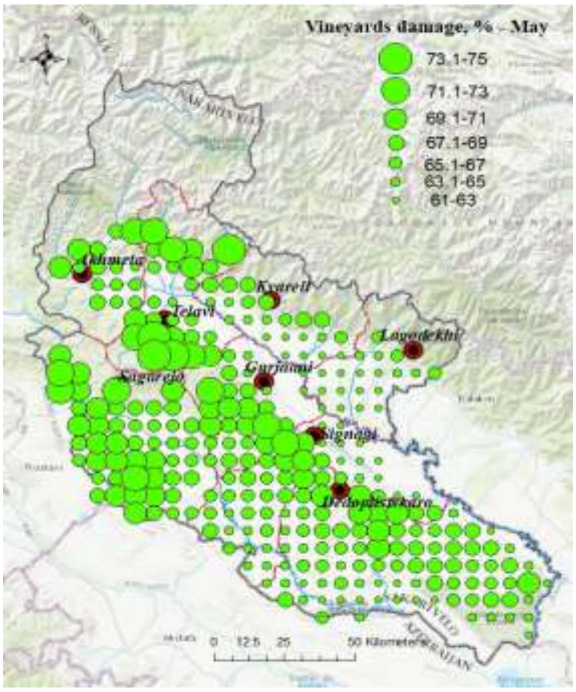

Fig. 2. Distribution of mean max hail damage to vineyards on the agricultural area of Kakheti in May.

In Fig. 2 example of distribution of mean max hail damage to vineyards on the agricultural area of Kakheti in May is presented. In particular, as follows from this figure, the mean max of HDV in the study area is quite heterogeneous and varies from 61.5% to 74.6%. Similar pictures also for other months are observed.

In Table 2,3 the statistical characteristics of hailstones by mean max diameter on the earth surface and mean max damage from them to vineyards on the agricultural area of Kakheti from April to September are presented.

Table 3. The statistical characteristics of hailstones by mean max diameter on the earth surface and mean max damage from them to vineyards on the agricultural area of Kakheti from April to June.

Month	April			May			June		
Parameter	Low	Mean	Upp	Low	Mean	Upp	Low	Mean	Upp
	Hailstones by mean max diameter on the earth surface (cm)								
Mean	0.14	0.67	1.02	0.94	1.15	1.35	1.08	1.34	1.58
Min	0.00	0.56	0.94	0.85	1.07	1.28	0.99	1.26	1.51
Max	0.49	0.85	1.16	1.10	1.29	1.47	1.24	1.48	1.70

Range	0.49	0.29	0.21	0.25	0.22	0.20	0.25	0.22	0.19
St Dev	0.13	0.06	0.05	0.05	0.05	0.04	0.05	0.05	0.04
Parameter	Mean max hail damage to vineyards (%)								
Mean	0	20.1	57.9	51.5	66.6	77.3	62.0	76.9	87.2
Min	0	0.0	52.0	43.4	61.5	73.9	55.5	73.0	84.5
Max	0	43.3	67.1	63.4	74.6	83.0	71.9	83.1	92.0
Range	0	43.3	15.1	20.0	13.1	9.1	16.4	10.2	7.5
St Dev	0	10.3	3.3	4.5	2.9	2.0	3.6	2.2	1.6

Table 4. The statistical characteristics of hailstones by mean max diameter on the earth surface and mean max damage from them to vineyards on the agricultural area of Kakheti from July to September.

Month	July			August		September		
Parameter	Low	Mean	Upp	Mean	Upp	Low	Mean	Upp
	Hailstones by mean max diameter on the earth surface (cm)							
Mean	0.77	1.16	1.50	0	0.96	0.71	1.16	1.54
Min	0.64	1.07	1.43	0	0.86	0.58	1.07	1.48
Max	0.98	1.33	1.64	0	1.15	0.91	1.31	1.67
Range	0.35	0.26	0.21	0	0.96	0.33	0.23	0.19
St Dev	0.08	0.06	0.05	0	0.86	0.71	1.16	1.54
Parameter	Mean max hail damage to vineyards (%)							
Mean	34.3	67.3	84.2	0	53.4	26.3	67.1	85.9
Min	16.4	61.4	81.0	0	44.3	5.5	61.7	83.1
Max	55.1	76.4	89.6	0	66.6	49.5	75.4	90.6
Range	38.7	15.0	8.6	0	22.4	43.9	13.7	7.5
St Dev	9.0	3.4	1.9	0	5.0	10.3	3.0	1.6

In particular, Table 2, 3 shows, that the variability of the mean max of D and HDV on the territory of Kakheti in the range of heights from 0.21 to 1.19 km is as follows:

- **D_Low.** April: 0÷0.49 cm; May: 0.85÷1.10 cm; June: 0.99÷1.24 cm; July: 0.64÷0.98 cm; August: 0÷0 cm; September: 0.58÷0.91 cm.
- **HDV_Low.** April: 0÷0 %; May: 43.4÷63.4%; June: 55.5÷71.9 %; July: 16.4÷55.1%; August: 0÷0 %; September: 5.5÷49.5 %.
- **D_Mean.** April: 0.56÷0.85 cm; May: 1.07÷1.29 cm; June: 1.26÷1.48 cm; July: 1.07÷1.33 cm; August: 0÷0 cm; September: 1.07÷1.31 cm.
- **HDV_Mean.** April: 0÷43.3 %; May: 61.5÷ 74.6%; June: 73.0÷83.1 %; July: 61.4÷76.4 %; August: 0÷0 %; September: 61.7÷75.4 %.
- **D_Upp.** April: 0.94÷1.16 cm; May: 1.28÷1.47 cm; June: 1.51÷1.70 cm; July: 1.43÷1.64 cm; August: 0.86÷1.15 cm; September: 1.48÷1.67 cm.
- **HDV_Upp.** April: 43.4÷63.4 %; May: 73.9÷83.0 %; June: 84.5÷92.0 %; July: 81.0÷89.6 %; August: 44.3÷66.6 %; September: 83.1÷90.6 %.

In Fig. 3-5 vertical distribution of mean max HDV and their 99% upper levels in Kakheti from April to September are presented.

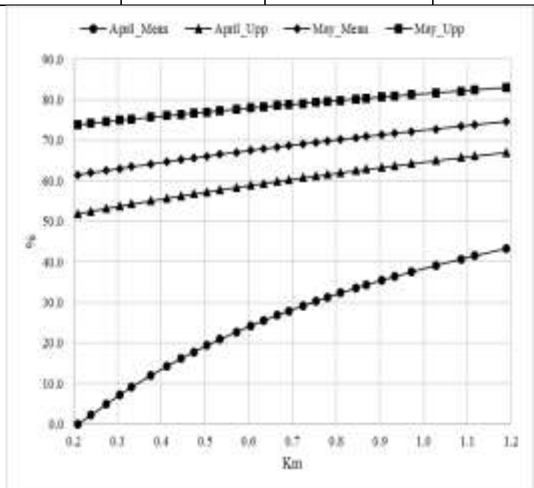

Fig. 3. Vertical distribution of mean max hail damage to vineyards and their 99% upper levels on the agricultural area of Kakheti in April and May.

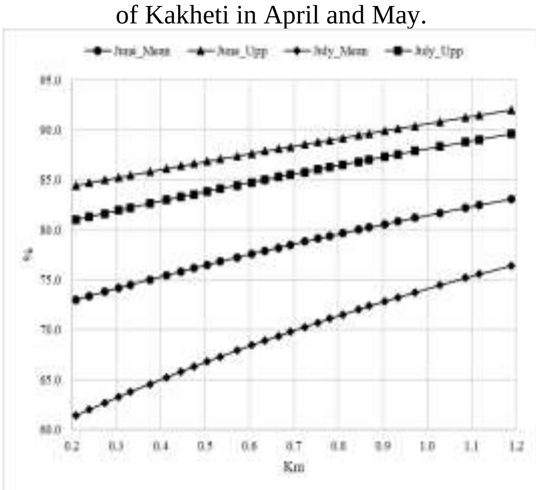

Fig. 4. Vertical distribution of mean max hail damage to vineyards and their 99% upper levels on the agricultural area of Kakheti in June and July.

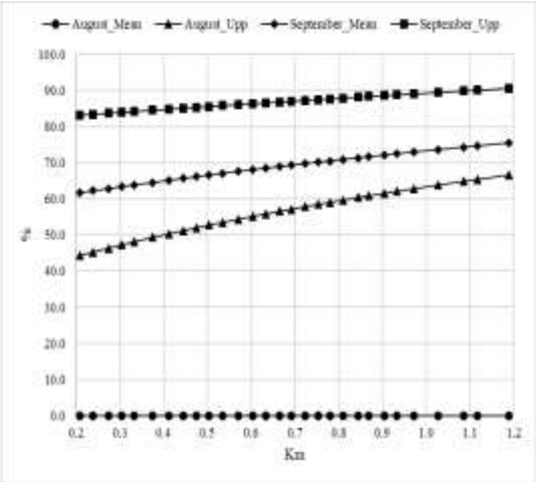

Fig. 5. Vertical distribution of mean max hail damage to vineyards and their 99% upper levels on the agricultural area of Kakheti in August and September.

All these distributions have the form of a second power polynomial. The regression equation coefficients for these dependencies are presented in Table 5.

Table 5. Coefficients of the regression equation for the dependence of mean max hail damage to vineyards on terrain height H on the agricultural area of Kakheti from April to September ($HDV = a \cdot H^2 + b \cdot H + c$, $R^2 \approx 1$)

Month	April		May		June		July		August	September	
Coeff.	Mean	Upp	Mean	Upp	Mean	Upp	Mean	Upp	Upp	Mean	Upp
a	-28.54	-3.85	-3.25	-2.06	-2.33	-0.80	-4.34	-1.34	-8.19	-3.90	-0.96
b	82.31	20.63	17.75	12.10	13.47	8.71	21.22	10.60	33.85	19.34	8.93
c	-15.15	47.91	57.98	71.45	70.32	82.70	57.23	78.84	37.74	57.84	81.32

Using the data of Table 5, the average rate of increase in HDV values in the above altitude range can be determined.

- **HDV_Mean.** April: 42.4 %/km; May: 13.2 %/km; June: 10.2 %/km; July: 15.2 %/km; August: 0 %/km; September: 13.9 %/km.
- **HDV_Upp.** April: 15.3 %/km; May: 9.2 %/km; June: 7.6 %/km; July: 8.7 % /km; August: 22.4 %/km; September: 7.6 %/km.

For comparison with model calculations (Table 3,4), in Table 6 and 7 the statistical characteristics of hail damage to vineyards and mean max HDV on the agricultural area of Kakheti in 2016-2019 are presented. Data on HDV were obtained during the inspection of hail-damaged areas by special commissions of Kakheti municipalities. Note that Table 7 does not contain data on mean max HDV values for April and August, since hail damage was only observed for one year in these months (2019 and 2018, respectively).

Table 6. The statistical characteristics of hail damage to vineyards on the agricultural area of Kakheti in 2016-2019 (%).

Month	April	May	June	July	August	September
Mean	38.3	39.9	37.6	32.8	47.9	32.1
Min	25.0	0	5.5	0	20.0	6.5
Max	55.0	90.0	95.0	70.0	95.0	95.0
Range	30.0	90.0	89.5	70.0	75.0	88.5
StDev	13.7	22.5	21.4	18.8	28.0	23.4
HDV_Low	22.6	33.5	29.4	22.5	18.4	20.7
HDV_Upp	54.1	46.4	45.7	43.2	77.3	43.5
Period of observation	2019	2016-2019	2016-2019	2016,2017,2019	2018	2016-2019

As follows from Table 6 mean values of HDV change from 32.1% (September) to 47.9% (August). Max values of HDV in June and August and September were observed (95%). HDV_Low change from 18.4% (August) to 33.5% (May). HDV_Upp change from 43.2% (July) to 77.3% (August).

Table 7. The statistical characteristics of mean max hail damage to vineyards on the agricultural area of Kakheti in 2016-2019 (%).

Month	May	June	July	September
Mean	73.8	67.5	60.0	62.5

StDev	13.8	31.0	13.2	25.0
HDV_Low	53.3	21.5	35.9	25.3
HDV_Upp	94.2	100.0	84.1	99.7

As follows from Table 7 mean max values of HDV change from 60.0 % (July) to 73.8 % (May). HDV_Low change from 21.5 % (June) to 53.3 % (May). HDV_Upp change from 84.1 % (July) to 100.0 % (June). HDV_Low change from 21.5% (June) to 53.3% (May). HDV_Upp change from 84.1% (July) to 100.0% (June).

Comparison of the data given in tables 3,4 and 6,7 shows that, in general, the calculated HDV values are in satisfactory agreement with their real values.

So, for example, with the exception of June, there is satisfactory agreement between calculated and real data on the following statistical parameters mean max HDV and HDV (Tables 3 and 6).

April: 54.1% (Upp Real) ≈ 52.0 % (Mean Min Calc)**;**

May: 39.9% (Upp Real) ≈ 43.4% (Min Low Calc)**;**

June: 46.4% (Upp Real) < 55.5% (Mean Low Calc) - unsatisfactory compliance**;**

July: 34.3% (Mean Low Calc) < 45.7% (Upp Real) < 61.4% (Mean Min Calc)**;**

August: 47.9% (Mean Real) ≈ 53.4 % (Mean Upp Calc)**;**

September: 26.3 % (Mean Low Calc) < 43.5% (Upp Real) < 61.7 % (Mean Min Calc)**.**

The calculated and real data on mean max HDV agree even better (Tables 3 and 7).

May: 51.5% (Mean Low Calc) < 73.8% (Mean Real) < 77.3% (Mean Upp Calc)**;**

June: 62.0% (Mean Low Calc) < 67.5% (Mean Real) < 87.2% (Mean Upp Calc)**;**

July: 34.3% (Mean Low Calc) < 60.0% (Mean Real) < 84.2% (Mean Upp Calc)**;**

September: 26.3 % (Mean Low Calc) < 62.5% (Mean Real) < 85.9% (Mean Upp Calc)**.**

DISCUSSION

Radar studies of hail clouds are an important tool for assessing the maximum extent of hail damage to crops and other vegetation using various models, one of which is proposed in this work. Comparison of calculated data on the degree of damage to vineyards from hail with their actual values generally showed their satisfactory agreement. The results of the work, in addition to scientific interest, may also have practical significance (planning the expansion of agricultural land; optimization of the location of missile points for impact on hail clouds; selecting areas for protection from hail using nets, etc.).

CONCLUSION

In the near future, we plan to model the degree of hail damage to vineyards for the municipalities of Kakheti.

In the future, we intend to conduct modeling and construct maps of the degree of hail damage to wheat and corn in Kakheti and its municipalities in different months of the year. It is also planned to conduct model assessments of damage from hail and other crops.

As new experimental data are obtained in the future, it is planned to refine the results obtained.

ACKNOWLEDGMENTS

This work was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG), Grant number - FR-22-2882.

REFERENCES

[1] G.K. Sulakvelidze, "Livnevyye osadki i grad," L., Gidrometeoizdat, 412 s., 1967, (in Russian).

[2] J. Dessens, and R. Frale, “Haistone Size Distributions in Southwestern France,” Atmospheric Research, vol. 33, pp. 57-73, 1994.

[3] A.M. Abshaev, M.T. Abshaev, M.V. Barekova, and A.M. Malkarova, “Rukovodstvo po organizacii i provedeniu protivogradovih rabot,” Pechatni dvor, Nalchik, 500 p., 2014, (in Russian).

[4] O. Varazanashvili, N. Tsereteli, A. Amiranashvili, E. Tsereteli, E. Elizbarashvili, J. Dolidze, L. Qaldani, M. Saluqvadze, Sh. Adamia, N. Arevadze, and A. Gventcadze, “Vulnerability, Hazards and Multiple Risk Assessment for Georgia,” Natural Hazards, vol. 64, pp. 2021-2056, December 2012.

[5] E. Elizbarashvili, A. Amiranashvili, O. Varazanashvili , N. Tsereteli, M. Elizbarashvili, Sh. Elizbarashvili, and M. Pipia, “Hailstorms in the Territory of Georgia,” European Geographical Studies, vol. 2, No 2, pp. 55-69, 2014, (in Russian).

[6] L. Kartvelishvili, M. Tatishvili, A. Amiranashvili, L. Megrelidze, and Kutaladze N., “Weather, Climate and their Change Regularities for the Conditions of Georgia,” Publishing House “UNIVERSAL”, Tbilisi, 406 p., 2023.

[7] N. Beglarashvili, I. Janelidze I., M. Pipia, N. Varamashvili, “Hail Storms in Kakheti (Georgia) in 2014-2018,” Int. Sc. Conf. „Modern Problems of Ecology“, proc. vol. 7. Tbilisi-Telavi, Georgia, pp. 176-179, 26-28 September, 2020.

[8] A. Amiranashvili, Ts. Basilashvili, E. Elizbarashvili, G. Gaprindashvili and O. Varazanashvili, “Statistical Analysis of the Number of Days with Hail in Georgia According to Meteorological Stations Data in 2006-2021,” Int. Conf. of Young Scientists “Modern Problems of Earth Sciences”, proc., Tbilisi, pp. 164-168, November 21-22, 2022.

[9] A. Amiranashvili, E. Elizbarashvili, O. Varazanashvili, and M. Pipia, “Statistical Analysis of the Number of Days with Hail During the Warm Season in Tbilisi in 1891-2021,” Trans. IHM, GTU, vol. 133, pp. 74-77, 2023, (in Georgian).

[10] O. Abaiadze, Kh. Avlokhashvili, A. Amiranashvili, U. Dzodzuashvili, J. Kiria, J. Lomtadze, A. Osepashvili, I. Sauri, Sh. Telia, A. Khetashvili, G. Tskhvediashvili, and V. Chikhladze, “Radar Providing of Anti-Hail Service in Kakheti, “ Trans. of Mikheil Nodia Institute of Geophysics, vol. 66, pp. 28-38, 2016, (in Russian).

[11] A. Amiranashvili, V. Chikhladze, U. Dzodzuashvili, N. Ghlonti, I. Sauri, Sh. Telia, and T. Tsintsadze, “Weather Modification in Georgia: Past, Present, Prospects for Development,” Int. Sc. Conf. „Natural Disasters in Georgia: Monitoring, Prevention, Mitigation“, proc., Tbilisi, Georgia, pp. 213-219, December 12-14, 2019.

[12] A. Amiranashvili, V. Chikhladze, N. Kveselava, N. Kvilitaia, I. Sauri, and Sh. Shavlakadze, “Some Characteristics of Hail Processes in Kakheti (Georgia) According to Radar

Observations into 2016-2019," Journal of the Georgian Geophysical Society, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, vol. 23(2), pp. 50 – 56, 2020.

[13] I.T. Bartishvili, G.A. Nadibaidze, N.A. Begalishvili, and Sh.L. Gudushauri, "K fizicheskim osnovam metoda ZakNIGMI, " Tr. ZakNIGMI, vip. 67(73), s. 73-82, 1978, (in Russian).

[14] A. Amiranashvili, T. Bliadze, N. Jamrishvili, E. Kekenadze, Kh. Tavidashvili, and M. Mitin, "Some Characteristics of Hail Process in Georgia and Azerbaijan on May 28, 2019," Journal of the Georgian Geophysical Society, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, vol. 22(2), pp. 40–54, 2019.

[15] A. Amiranashvili, N. Kveselava, N. Kvilitaia, I. Sauri, Sh. Shavlakadze, and V. Chikhladze,"Some Results of Anti-Hail Works in Kakheti into 2016-2020," Trans. of M. Nodia Institute of Geophisics, vol. LXXII, Tbilisi, pp. 123-128, 2020, (in Georgian).

[16] K. Tsitouridis, "The Greek Hailpad Network 2008 to 2019: Analysis of the Hailpad Data - The Equivalent Hail Diameter," International Journal of Engineering Science Invention (IJESI), vol. 10, iss. 9, series II, pp. 18-32, 2021.

[17] O. Varazanashvili, G. Gaprindashvili, E. Elizbarashvili, Ts. Basilashvili, A. Amiranashvili, and S. Fuchs, "The First Natural Hazard Event Database for the Republic of Georgia (GeNHs)," Catalog, 270 p., 2023, DOI: 10.13140/RG.2.2.12474.57286

[18] V.A. Zimenkov, and V.V. Ivanov, "Raschet tayaniya gradin v estestvennykh protsessakh," Tr. VGI. vyp. 3(5), 1966, (in Russian).

[19] A.G. Amiranashvili, N.T. Berianidze, N.K. Jamrishvili, and Kh.Z. Tavidashvili, "Statistical Characteristics of the Monthly Average Values of the Air Temperature in the Layer of Atmosphere 0.54-27 km above the Kakheti Territory (Georgia) in 2012-2016," Journal of the Georgian Geophysical Society, Issue B. Physics of Atmosphere, Ocean and Space Plasma, vol. 20B, pp.24 –42, 2017.

[20] N. Jamrishvili, "Monthly and Ten-Day Average Values of Freezing Level in the Atmosphere Above Kakheti Territory (Georgia) from April to October," Journal of the Georgian Geophysical Society, iss. A, Physics of Solid Earth, vol. 20A, pp. 57-64, 2017.

[21] N. K. Jamrishvili, and Kh. Z. Tavidashvili, "Estimation of the Diameter of Fallen to the Earth's Surface Hail Stones Taking Into Account Their Size in the Cloud and the Heights of Zero Isotherm Under the Conditions of Kakheti Region of Georgia," Int. Sc. Conf. „Modern Problems of Ecology", proc., vol. 6, Kutaisi, Georgia, pp. 130-133, 21-22 September, 2018.

[22] N. Jamrishvili, and Kh. Tavidashvili, "Estimation of the Critical Size of Hailstones in Clouds non Prejudiced to Agriculture in Kakheti," Int. Sc. Conf. „Natural Disasters in Georgia: Monitoring, Prevention, Mitigation", proc., Tbilisi, Georgia, pp. 126-129, December 12-14, 2019.

[23] A.G. Amiranashvili, N.R. Bolashvili, Z.M. Gulashvili, N.K. Jamrishvili, N.E. Suknidze, and Kh.Z. Tavidashvili, "Modeling the Distribution of Hailstones by Mean Max Sizes on the Territory of Kakheti (Georgia) using Data of the Freezing Level in the Atmosphere and Radar Measurements," Journal of the Georgian Geophysical Society, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, vol. 24(1), pp. 25-36, 2021.

[24] A. Amiranashvili, N. Bolashvili, Z. Gulashvili, N. Jamrishvili, N. Suknidze, and Kh. Tavidashvili, "Distribution of Hail by Mean Max Size on the Territories of Municipalities of the Kakheti Region of Georgia," Int. Sc. Conf. „Natural Disasters in the 21st Century: Monitoring, Prevention, Mitigation", proc., Tbilisi, Georgia, pp. 84-87, December 20-22, 2021.

[25] M. Pipia, A. Amiranashvili, N. Beglarashvili, E. Elizbarashvili, and O. Varazanashvili, "Analysis and Damage Assessment of Hail Processes in Georgia and Azerbaijan Using Radar Data (On the Example of May 28 and July 13, 2019)," Reliability: Theory & Applications, vol. 18, iss. SI 5 (75), pp. 267-274, 2023.

[26] Selex ES GmbH · Gematronik Weather Radar Systems. Rainbow®5 User Guide, 464 p., 2015, www. gematronik.com