ANALYSIS AND DAMAGE ASSESSMENT OF HAIL PROCESSES IN GEORGIA AND AZERBAIJAN USING RADAR DATA (ON THE EXAMPLE OF MAY 28 AND JULY 13, 2019)

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Abstract

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.

Keywords: Radar monitoring, dangerous meteorological processes, hail, damage assessment

I. Introduction

Almost all types of natural disasters, including hail processes, are observed in the territories of Georgia and Azerbaijan. 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 in Georgia and Azerbaijan [1-4]. Given the significant economic damage caused by hail, in both countries at the end of the last century, work was carried out to combat this dangerous weather phenomenon [1,5]. In Georgia, these works continued until 1989 and were resumed using the latest technologies in Kakheti in 2015 [5]. The anti-hail service of Georgia is equipped with a modern meteorological radar "METEOR 735 CDP 10 - Doppler Weather Radar" [6], which in the future, in addition to anti-hail measures, is planned to be used for operational monitoring of various dangerous hydrometeorological processes in eastern Georgia and adjacent territories [7].

Most studies of hail processes are usually associated with the analysis of data from meteorological stations on the number of days with hail [4, 8–10], the results of which are used to compile catalogs of natural disasters [11, 12]. However, in recent years, it has become possible, based on radar data, to study various characteristics of hail processes in Eastern Georgia and its neighboring countries (Azerbaijan, Armenia), including determining the maximum size of hail in clouds and modeling the size of the fallen hail [13-16].

For example, in work [16] results of 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 are presented. 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.

The works [13-15] provide a preliminary analysis of data from radar studies of hail processes in Georgia and Azerbaijan on May 28 and July 13, 2019. This work is a continuation of these studies. Below are the results of estimates of the maximum damage to crops such as vineyards, wheat and corn located in these areas in places with the maximum size of fallen hail.

II. Material and methods, study regions

The Anti-hail service is equipped with contemporary C-band, dual polarized Doppler meteorological radar "METEOR 735 CDP 10 – Doppler Weather Radar", which is installed in the village Chotori (1090 m height from sea level) of the Signagi municipality of the Kakheti region of Georgia. The products of radar are sufficiently varied. For the anti-hail works the optimal radius of action of radar is 100-120 km, (distance, which practically covers the territory of Kakheti and some parts of the territories of Azerbaijan. In this work radar product HAILSZ (Size) is used [17]. The expected size of hailstones falling out to the earth's surface was calculated according to the Zimenkov-Ivanov model of hail melting in the atmosphere by taking into account the radar data about their diameter in the clouds [18]. As noted above, this study used data from works [13-15] with some clarifications.

The degree of damage to vineyards, wheat and corn, depending on the size of the fallen hail, was determined by compiling data on damage to these crops at different hail kinetic energy [1] 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 these crops (E) and the size of hailstones (D), which have the form of the sixth power of polynomial:

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

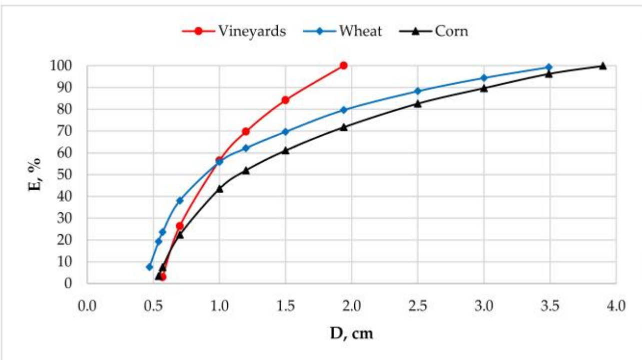

Fig. 1: *Estimated values of the degree of damage to vineyards, wheat and corn, depending on the hail diameter*

The graph of the dependence of E on D and the corresponding values of the coefficients of the regression equations in fig. 1 and table 1 are presented.

Table 1: *Coefficients of the regression equation between the hail diameter(D) and the degree of damage to vineyards, wheat and corn (E).*

Coefficient	Vineyards, E(V), %	Wheat, E(W), %	Corn, E(C), %
a	-90.668476	-3.172890	-1.055694
b	730.212998	41.423518	15.570944
c	-2417.485762	-217.770722	-93.078903
d	4233.390175	589.590662	289.192073
e	-4188.725197	-872.075534	-498.263105
f	2315.215755	696.428514	479.987909
g	-525.511778	-178.662752	-148.866255
Range of D, cm	0.57÷1.94	0.47÷3.49	0.54÷3.90

Taking into account the above calculations, we have proposed a modified TORRO scale, which also takes into account the degree of damage to vineyards, wheat and corn at different hail sizes (H0-H5 scale range, Table 2).

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

H	Intensity Category	Typical Hail Diameter (cm)	Typical Damage Impacts
H0	Hard Hail	0.5	No damage. Wheat damage up to 13%
H1	Potentially Damaging	0.5-1.5	Slight general damage to plants, crops. Damage to vineyards up to 84%, wheat - (13-70)%, corn - up to 61%
H2	Significant	1.0-2.0	Significant damage to fruit, crops, vegetation. Damage to vineyards (56-100)%, wheat - (56-81)%, corn - (44-73)%
H3	Severe	2.0-3.0	Severe damage to fruit and crops, damage to glass and plastic structures, paint and wood scored. Damage to vineyards -100%, wheat - (81-94)%, corn - (73-90)%.
H4	Severe	2.5-4.0	Severe damage to fruit and crops. Widespread glass damage, vehicle bodywork damage. Damage to vineyards -100%, wheat - (88-100)%, corn - (83-100)%.
H5	Destructive	3.0-5.0	Wholesale destruction of glass, damage to tiled roofs, significant risk of injuries. Damage to vineyards -100%, wheat - (94-100)%, corn - (90-100)%.
H6	Destructive	4.0-6.0	Bodywork of grounded aircraft dented, brick walls pitted
H7	Destructive	5.0-7.5	Severe roof damage, risk of serious injuries
H8	Destructive	6.0-9.0	(Severest recorded in the British Isles) Severe damage to aircraft bodywork
H9	Super Hailstorms	7.5-10.0	Extensive structural damage. Risk of severe or even fatal injuries to persons caught in the open
H10	Super Hailstorms	>10.0	Extensive structural damage. Risk of severe or even fatal injuries to persons caught in the open

The following designations will be used below. Study Regions. Georgia: GEO-1 (Sagarejo municipality), GEO-2 (Signagi municipality). Azerbaijan: AZE-1 (Aghstafa and Tovuz districts),

AZE-2 (Balakan district), AZE-3 (Zagatala district).
D – maximum hail diameter at the ground level, cm; time designation, for example, 14 hours 33 min – 14.55 h (hour and minutes in fractions of an hour). In Figures 2 and 4 time is represented as hour and minutes in fractions of an hour and a serial number. Hours and time number for each study region are presented in the Table 3.

III. Results

The results in Fig. 2-7 and Table 3 are clearly represented.

In Fig. 2 hail size changeability in at the ground level in Georgia and Azerbaijan on May 28 and July 13, 2019 in five researched locations are presented.

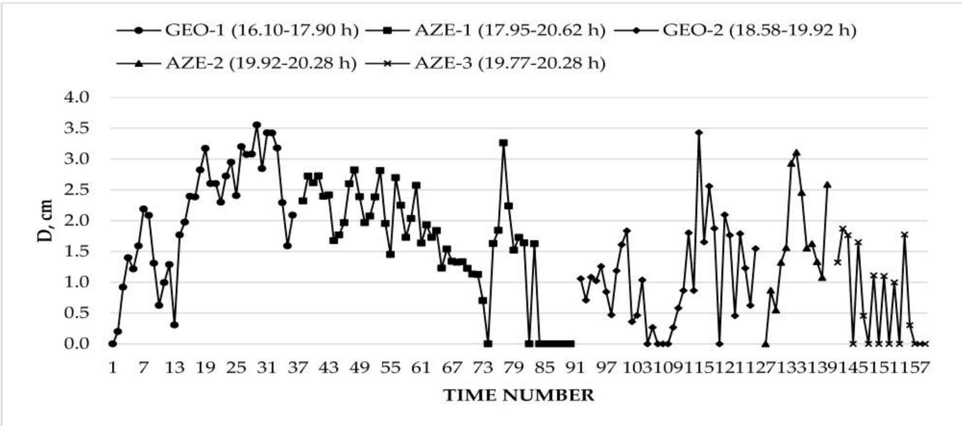

Fig. 2: *Hail size changeability in at the ground level in Georgia and Azerbaijan on May 28, 2019 (GEO-1, AZE-1) and July 13, 2019 (GEO-2, AZE-2, AZE-3)*

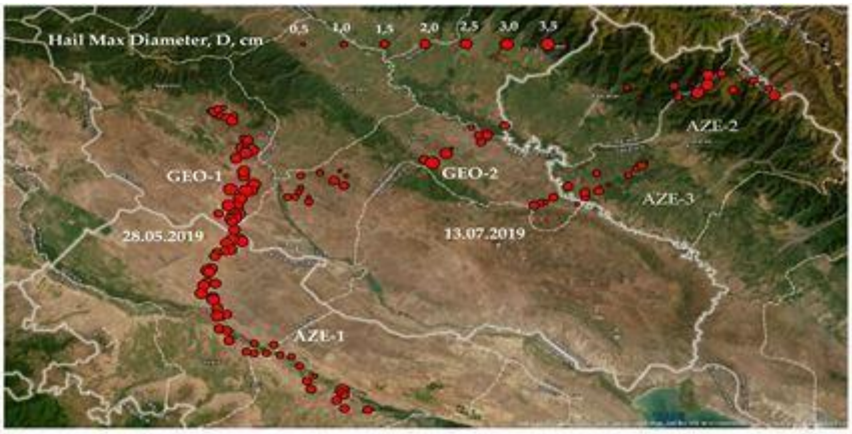

Fig. 3: *Trajectory of hailstones with maximum diameter at the ground level in Georgia and Azerbaijan during the study period*

In Fig. 3 trajectory of hailstones with maximum diameter at the ground level in Georgia and Azerbaijan during the study period are presented. In Table 3 statistical characteristics of the maximum hail diameter at the ground level and the degree of damage to vineyards, wheat and corn in the study regions are presented.

As follows from Fig. 2,3 and Table 3, the maximum D value varied from 1.9 cm (AZE-3) to 3.6 cm (GEO-1). Mean D values varied from 0.7 cm (AZE-3) to 2.1 cm (GEO-1). On the territory of Azerbaijan, the maximum D value was 3.3 cm (AZE-1), the maximum average hail diameter - 1.6

cm (AZE-1 and AZE-2).

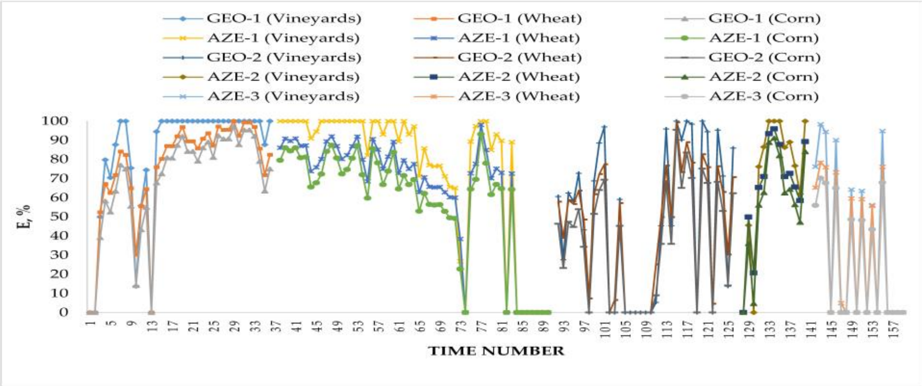

Fig. 4: *Changeability of vineyards, wheat and corn damage in Georgia and Azerbaijan on May 28, 2019 (GEO-1, AZE-1) and July 13, 2019 (GEO-2, AZE-2, AZE-23)*

In Fig. 4 data about changeability of vineyards, wheat and corn damage in Georgia and Azerbaijan in all researched locations are presented.

In Fig. 5-7 maps of maximum damage of vineyards, wheat and corn locations in Georgia and Azerbaijan during the study period are presented.

Fig. 5: *Maximum vineyards damage locations in Georgia and Azerbaijan during the study period*

Fig. 6: *Maximum wheat damage locations in Georgia and Azerbaijan during the study period*

Fig. 7: *Maximum corn damage locations in Georgia and Azerbaijan during the study period*

As follows from Fig. 4-7 and Table 3, the maximum values of E(V) varied from 98% (AZE-3) to 100% (all other locations). Mean E(V) values varied from 35% (AZE-3) to 83% (GEO-1). On the territory of Azerbaijan, the maximum value of E(V) was 100% (AZE-1 and AZE-2), the maximum average value - 75% (AZE-1).

The range of variability of the maximum values of E(W) is from 78% (AZE-3) to 100% (GEO-1). The range of variability of the average values of E(W) is from 30% (AZE-3) to 75% (GEO-1). The maximum value of E(W) on the territory of Azerbaijan was 98% (AZE-1), the maximum average value - 65% (AZE-1 and AZE-2).

Table 3: *Statistical characteristics of the maximum hail diameter at the ground level and the degree of damage to vineyards, wheat and corn in Georgia and Azerbaijan on May 28 and July 13, 2019 (minimum hail diameter = 0 cm)*

Date	Hour (Time number)	Count	Variable	D, cm	Vineyards, E(V),%	Wheat, E(W),%	Corn, E(C),%	Location
28.05	16.10-17.90 (1-36)	36	Max	3.6	100	100	97	GEO-1
			Average	2.1	83	75	69	
			St Dev	1.0	31	28	28	
	17.95-20.62 (37-89)	53	Max	3.3	100	98	93	AZE-1
			Average	1.6	75	65	58	
			St Dev	0.9	37	31	29	
13.07	18.58-19.92 (90-124)	35	Max	3.4	100	99	95	GEO-2
			Average	1.0	48	44	37	
			St Dev	0.8	40	33	31	
	19.92-20.58 (125-137)	13	Max	3.1	100	96	91	AZE-2
			Average	1.6	71	65	57	
			St Dev	0.9	35	28	29	
	19.77-20.28 (138-155)	18	Max	1.9	98	78	70	AZE-3
			Average	0.7	35	30	26	
			St Dev	0.7	42	35	31	

The maximum values of E(C) varied from 70% (AZE-3) to 97% (GEO-1). Mean E(C) values varied from 26% (AZE-3) to 69% (GEO-1). On the territory of Azerbaijan, the maximum value of E(C) was 93%, the maximum average value - 58% (AZE-1).

IV. Discussion

Radar studies of hail clouds are an important tool for assessing the maximum degree of hail damage to crops and other vegetation using various models, one of which is proposed in this paper. Comparison of calculated data with real ones showed the following.

According to the anti-hail service of Georgia, on May 28, 2019, 120 hectares of vineyards were damaged on the territory of the Sagarejo municipality (GEO-1) with an average degree of damage of 45%, (calculated average values of E(V) in places with hail fall with the largest size = 83%) and also 808 ha of wheat with a damage rate of 66.5% (calculated values of E(W) = 75%). On July 13, 2019 in Signagi municipality (GEO-1) hail damaged 700 ha of vineyards with an average damage rate of 28.3% (calculated values of E(V) = 48%).

V. Conclusion

Given that the calculated values of the degree of damage to agricultural crops were carried out for places with the largest hail fall, these data exceed the real ones (for vineyards by 1.84 times and 1.7 times, and for wheat by 1.13). Considering the above, we can conclude that the calculated values of E are generally in good agreement with their real values.

In the future, we intend to continue these studies using more extensive experimental material. In particular, it is planned to build maps of the degree of damage from hail of vineyards, wheat and corn on the territory of Kakheti in different months of the year. It is also planned to carry out model assessments of damage from hail and other agricultural crops.

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