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Abnormal Precipitation Before the Landslide in Akhaldaba (A Suburb of Tbilisi, Georgia) on June 13, 2015 According to Radar Measurements

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ABSTRACT

Results of the analysis of radar measurements of precipitation intensity (P) preceding the landslide in the vicinity of Akhaldaba (a suburb of Tbilisi, Georgia) on June 13, 2015 from 21.00 to 23.97 h are presented. In particular, the following results are obtained. Time-series of precipitation intensity under zone with the maximum radar reflectivity of the cloud has the form of a fifth power of polynomial. Time series of areas of precipitation of different intensity under the cloud were obtained and their statistical characteristics were studied. Dependence of the average intensity of precipitation under the cloud on the effective radius from the zone with the maximum radar reflectivity is obtained.
Statistical characteristics of precipitation intensity over the center of the landslide top is presented. Sum of precipitation under zone with the maximum radar reflectivity of the cloud and over the center of the landslide top on 13 June 2015 from 21.00 to 23.97 h and before landslide from 21.00 to 22.45 h is assessed.

Key words: *atmospheric precipitation, radar observations, landslides.*

Introduction

Almost all types of natural disasters are observed in Georgia (earthquakes, floods, hurricanes, thunderstorms, hail, droughts, landslides, mudflows, avalanches, tornadoes, forest fires, etc.), often causing heavy economic damage and human casualties [1-18]. The last such example is the landslide-mudflow process that occurred on August 3, 2023 in the Oni municipality of Racha-Lechkhumi and Kvemo Svaneti region of Georgia, which led to a many-meter filling of the central part of the Shovi resort with mudflows and more than thirty human victims [https://civil .ge/archives/554327]. The last case, in terms of the scale of human losses, exceeded the consequences of the flood in Tbilisi on June 13-14, 2015, when 20 people were confirmed dead [14,15; https://en.wikipedia.org/wiki/2015_Tbilisi_flood].

At the same time, many of these processes are associated with climate change in Georgia [10, 18-22], which affects regime of temperature, atmospheric precipitation, melting glaciers and other parameters that provoke an increase in the number of natural disasters (droughts, floods, landslides, mudflows, forest fires, etc.).

As regards the study of landslide-mudflow processes, the activation of which is often associated with the regime of atmospheric precipitation of various time scales (from minutes to several years) [23], we have created and are improving a modern database of these processes [12, 13], as well as precipitation based on ground, satellite and radar observations [14,15,24-28].

Using this database, in recent years, we have studied the relationship of landslides and mudflows with atmospheric precipitation of various time scales (from hours to climatic scales) and territories (landslide site, regions of Georgia, the territory of Georgia [14,15,29-34].

In particular, in the works [14,15] data on the radar characteristics of a rain cloud that caused a landslide in Akhaldaba and a catastrophic flood in Tbilisi on June 13-14, 2015 are presented. The temporal variability of the maximum radar reflectivity of the cloud, precipitation intensity, etc. was studied. It is noteworthy that the cloud did not move much and was over the zone where the landslide descended for more than 5 hours. The consequences of this landslide are well known - the closure of the Vere River, the accumulation of water, the breaking of an artificial dam and the catastrophic flood in Tbilisi.

This work is a continuation of previous studies [14,15]. The results of a more detailed analysis of the temporal variability of precipitation over the landslide zone in Akhaldaba on June 13, 2015 are presented below.

Study Area, Materials and Methods

Study Area – landslide zone in Akhaldaba (a suburb of Tbilisi, Georgia, Fig. 1).

Fig.1. Landslide in Akhaldaba on June 13, 2015 [https://reliefweb.int/map/georgia/landslide-affected-areas-west-tbilisi-georgia-16-jul-2015].

Fig.1 illustrates satellite-detected areas of landslide damage in Akhaldaba. Following flash floods in the region on 14 June 2014, a landslide on the Vere River near the village of Akhaldaba damaged several road sections in the area. Using a satellite image acquired 24 June 2015 by the GeoEye-1 satellite, UNOSAT delineated the primary landslide areas stretching southeast of the Vere River, between Akhaldaba and Tskneti. The area directly affected by the landslide measures about 537065 square meters, while 1110 meters of roadway were buried or damaged by the landslide.

Coordinates of the center of the landslide top: 41.68 N°, 44.68 E°,1289 m a.s.l. [14].

Precipitation intensity was measured using meteorological radar "METEOR 735 CDP 10 - Doppler Weather Radar". Radar is established in the village Chotori of the Signagi municipality of Kakheti region of Georgia [35,36]. In this work radar product MPPI (dBz) is used [37-39]. Example of this radar product on Fig. 2 is presented. Time designation (Fig. 2), for example, t = 14 hour 33 min – 14:33 h. In Fig. 3-5 minutes are given in fractions of an hour, for example, t = 21 hour 55 min – 21.92 h, etc. The data of the Georgian Environment Agency on atmospheric precipitation were also used in the work.

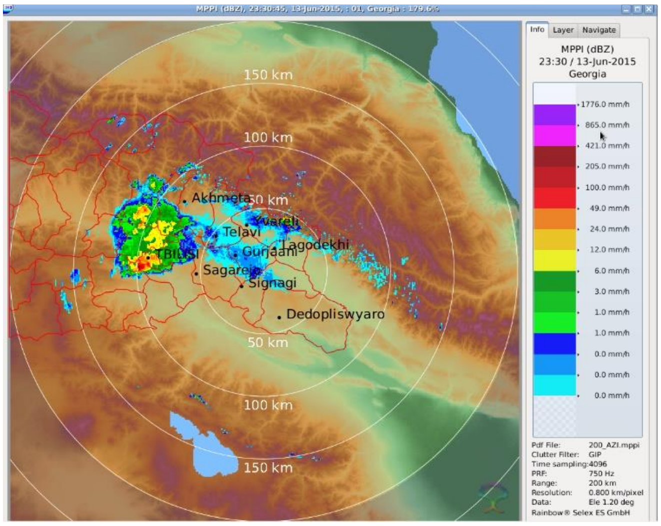


Fig. 2. Example of radar data of the precipitation intensity in Tbilisi on 13 June 2015 in 23:30 h.

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods [20].

The following designations will be used below: Max - maximal values; Min – minimal values; Range – Max-Min; St Dev - standard deviation; St Err - standard error; C_v – coefficient of variation = 100·St Dev/Mean, %; R^2 - coefficient of determination; R - coefficient of linear correlation; K_{DW} - Durbin-Watson statistic; P - precipitation intensity, mm/h; P_s – sum of precipitation, mm; P_a - average intensity of precipitation under the cloud, mm/h; S - areas of precipitation of different intensity, km² - S(P≥3 mm/h) … S(P≥100 mm/h); r - the effective radius from the zone with the maximum radar reflectivity to average intensity of precipitation under different cloud zones, km.

Results and Discussions

Results in Table 1-5 and Fig. 3-7 are presented.

In Fig. 3 real and calculated time-series of precipitation intensity P under zone with the maximum radar reflectivity of the cloud on 13 June 2015 from 21.00 to 23.97 h are presented. Statistical characteristics of the time-series of P and the values of the coefficients of the corresponding regression equation in Table 1 are presented. As follows from Fig. 3 and Table 1 the average value of P for the entire observation period was 134.7 mm/h, the range of variability was 23.5÷371.4 mm/h. The time series of P values is satisfactorily described by a fifth power polynomial (corresponding values of the parameters R^2 and K_{DW}).

In Fig. 4 time-series of areas of precipitation of different intensity S under the cloud from 21.00 to 23.97 h are presented. Corresponding statistical characteristics of S values in Table 2 are presented.

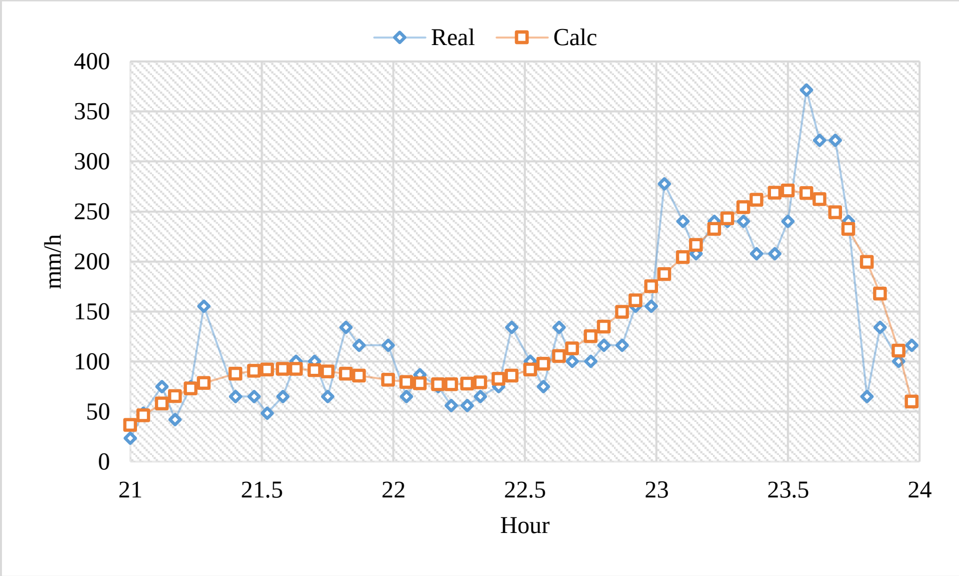


Fig.3. Time-series of precipitation intensity under zone with the maximum radar reflectivity of the cloud on 13 June 2015 from 21.00 to 23.97 h.

Table 1. Statistical characteristics of the precipitation intensity of cloud in the region of Akhaldaba on 13 June 2015 with 21.00 to 23.97 h. under the zone with the maximum radar reflectivity (mm/h).

Max	Min	Average	St Dev	R^2	K_{DW}
371.4	23.5	134.7	83.4	0.76	1.46
$P = a{\cdot}t^5+b{\cdot}\ t^4+c{\cdot}\ t^3+d{\cdot}\ t^2+e{\cdot}t+f$					
a	b	c	d	e	f
-31.243	3420.807	-149678	3271531	-3.6E+07	1.56E+08

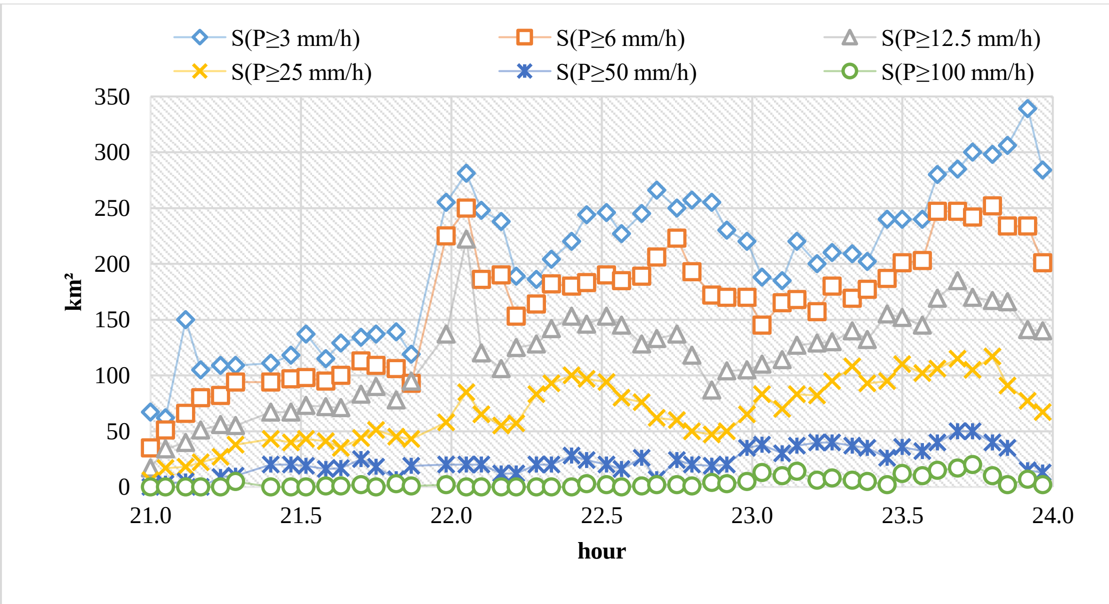


Fig.4. Time-series of areas of precipitation of different intensity under the cloud from 21.00 to 23.97 h.

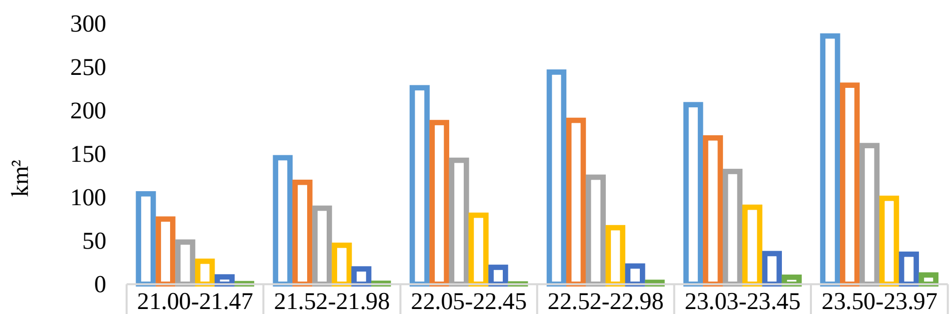
As follows from Fig. 4 and Table 2 average values of S change from 3.9 km² (P≥100 mm/h) to 204.6 km² (P≥3 mm/h). The range of variability – from 0 (P≥100 mm/h) to 339 km² (P≥3 mm/h).

Coefficient of linear correlation between S values change from 0.42 (pair S(P≥3 mm/h)÷ S(P≥100 mm/h), low correlation) to 0.96 (pair S(P≥3 mm/h)÷ S(P≥6 mm/h), very high correlation).

Table 2. Statistical characteristics of areas of precipitation of different intensity under the cloud from 21.00 to 23.97 h (km²).

Variable	S(P≥3 mm/h)	S(P≥6 mm/h)	S(P≥12.5 mm/h)	S(P≥25 mm/h)	S(P≥50 mm/h)	S(P≥100 mm/h)
Max	339	252	222	117	50	20
Min	62	35	17	6	0	0
Range	277	217	205	111	50	20
Average	204.6	162.7	116.2	67.8	22.9	3.9
St Dev	67.8	56.9	42.6	28.7	12.3	5.1
Cv,%	33.1	35.0	36.7	42.3	53.6	130.1
St Err	9.68	8.13	6.09	4.10	1.75	0.73
Correlation Matrix						
S(P≥3 mm/h)	1	0.96	0.86	0.73	0.52	0.42
S(P≥6 mm/h)	0.96	1	0.93	0.81	0.60	0.47
S(P≥12.5 mm/h)	0.86	0.93	1	0.89	0.65	0.43
S(P≥25 mm/h)	0.73	0.81	0.89	1	0.80	0.60
S(P≥50 mm/h)	0.52	0.60	0.65	0.80	1	0.77
S(P≥100 mm/h)	0.42	0.47	0.43	0.60	0.77	1

The minimum value of R between adjacent values of S is 0.77 (pair S(P≥50 mm/h) - S(P≥100 mm/h), high correlation)



	21.00-21.47	21.52-21.98	22.05-22.45	22.52-22.98	23.03-23.45	23.50-23.97
S(P≥3 mm/h)	104	146	226	244	207	286
S(P≥6 mm/h)	75	117	186	189	169	229
S(P≥12.5 mm/h)	48	87	143	123	130	159
S(P≥25 mm/h)	26	45	79	65	89	99
S(P≥50 mm/h)	8	18	20	21	35	35
S(P≥100 mm/h)	0.6	1.3	0.4	2.2	8.0	10.6

Hour

Fig.5. Areas of precipitation of different intensity under the cloud at different time intervals.

In Fig. 5 areas of precipitation of different intensity under the cloud at different time intervals are presented. For example, this area in time interval 21.00-21.47 h change from 0.6 km² (P≥100 mm/h) to 104 km² (P≥3 mm/h). In time interval 23.50-23.97 h value of S change from 10.6 km² (P≥100 mm/h) to 286 km² (P≥3 mm/h). About half an hour before the landslide (22.05-22.45 h) value of S change from 0.4 km² (P≥100 mm/h) to 226 km² (P≥3 mm/h).

In Fig. 6 graph of dependence of the average intensity of precipitation under different cloud zones (with P≥3 mm/h … P≥100 mm/h) on the effective radius from the zone with the maximum radar reflectivity (r).

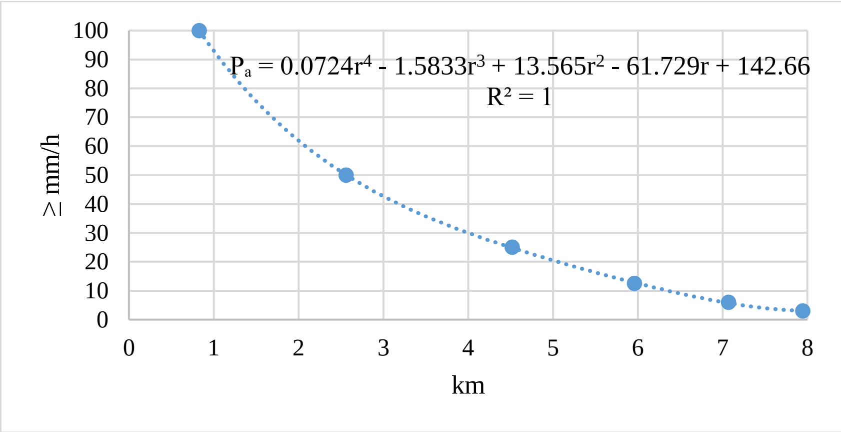


Fig.6. Dependence of the average intensity of precipitation under different cloud zones (P_a) on the effective radius from the zone with the maximum radar reflectivity (r).

This dependence has the form of a fourth power polynomial (Fig. 6). This regularity was used to estimate the intensity of precipitation over the center of the landslide top (Table 3).

Table 3. Statistical characteristics of precipitation intensity over the center of the landslide top on June 13, 2015 from 21.00 to 23.97 (≥mm/h)

Max	Min	Average	St Dev
65.1	1.0	43.6	28.8

As follows from Table 3 average value of precipitation intensity over the center of the landslide top on June 13, 2015 from 21.00 to 23.97 was ≥43.6 mm/h, min - ≥1.0 mm/h and max - ≥65.1 mm/h.

Sum of precipitation (P_s) under zone with the maximum radar reflectivity of the cloud and over the center of the landslide top on 13 June 2015 from 21.00 to 23.97 h and before landslide from 21.00 to 22.45 h are also evaluated (Table 4).

Table 4. Sum of precipitation under zone with the maximum radar reflectivity of the cloud and over the center of the landslide top on 13 June 2015 from 21.00 to 23.97 h and before landslide from 21.00 to 22.45 h.

Location	Time	Sum of precipitation, mm
Under zone with the maximum radar reflectivity of the cloud	21-23.97	402
	21-22.45	120
Center of the landslide top	21-23.97	≥134
	21-22.55	≥53

As follows from this Table P_s value under zone with the maximum radar reflectivity of the cloud was 402 mm in 21-23.97 h and 120 mm in 21-22.45 h (before landslide). P_s value over center of the landslide top was ≥134 mm in 21-23.97 h and ≥53 mm in 21-22.45 h (before landslide).

For comparison in the Table 5 data of the mean accumulated sum of precipitation in Tbilisi in days with landslides and 3, 5, 7, 10, 20 and 30 days before landslides' onset and on 15.05-13.06.2015, and in Fig. 7 daily sum of precipitation in Tbilisi from 1901 to 2020 are presented.

Table 5. Data of the mean accumulated sum of precipitation in Tbilisi in days with landslides and 3, 5, 7, 10, 20 and 30 days before landslides' onset [34] and on 15.05-13.06.2015, (mm).

Days	1 day	3 days	5 days	7 days	10 days	20 days	30 days
Average for 21 landslide	14.5	21.2	27.4	37.0	40.5	62.5	74.8
15.05-13.06.2015	49.3	49.3	51.0	51.7	58.9	143.8	146.6

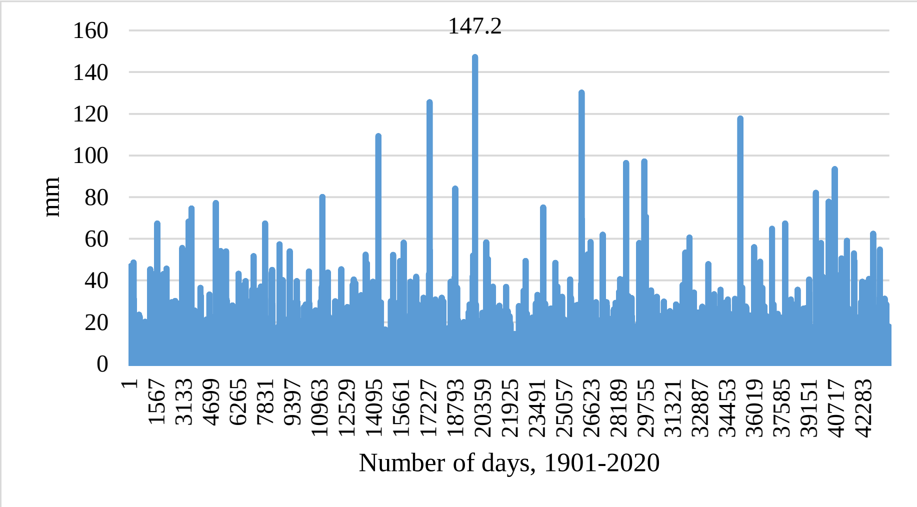


Fig.7. Daily sum of precipitation in Tbilisi from 1901 to 2020 (max sum of precipitation = 147.2 mm on August 16, 1955)

Over a 120-year period max sum of daily precipitation was 147.2 mm and on August 16, 1955 was observed. Note that the sum of precipitation under zone with the maximum radar reflectivity of the cloud in 21-23.97 h (Table 4) 2.73 times higher than max daily P_s value in Tbilisi in 1901-2020 (Fig. 7) and 2.74 times higher than 30 days sum of precipitation before landslide on 15.05-13.06.2015 (Table 5).

Value of P_s over the center of the landslide top before landslide activation (≥53 mm) at least 3.66 times higher landslide daily thresholds level for Tbilisi (14.5 mm, Table 5).

It should be noted that at the meteorological station in Tbilisi, a daily amount of precipitation equal to 49.3 mm was recorded, which is also higher landslide daily thresholds level for Tbilisi.

Thus, all conditions were created for the activation of the landslide process, followed by a catastrophic flood in Tbilisi.

Conclusion

As this study showed, radar measurements of precipitation intensity can be an effective tool for monitoring and short-term forecasting of the activation of landslide processes. This is especially true for locations where ground-based precipitation measurements are not available. In the future, we plan to deepen research in this direction.

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ანომალური ნალექი 2015 წლის 13 ივნისს ახალდაბაში (თბილისის შემოგარენი, საქართველო) მეწყერამდე რადარის გაზომვების მიხედვით

ა. ამირანაშვილი, თ. ჭელიძე, დ. სვანაძე, თ. წამალაშვილი, გ. თვაური

რეზიუმე

წარმოდგენილია 2015 წლის 13 ივნისს 21:00-დან 23:97 საათამდე ახალდაბის რაიონში (თბილისის გარეუბანში) მეწყერის წინ ნალექის ინტენსივობის (P) რადარული გაზომვების ანალიზის შედეგები. კერძოდ, მიღებულია შემდეგი შედეგები. ღრუბლის მაქსიმალური რადარის არეკვლის ზონაში ნალექების ინტენსივობის დროის სერიას აქვს მეხუთე ხარისხის პოლინომის ფორმა. მიღებულ იქნა ღრუბლის ქვეშ სხვადასხვა ინტენსივობის ნალექის არეების დროის სერია და შესწავლილი იქნა მათი სტატისტიკური მახასიათებლები. მიღებულია ღრუბლის ქვეშ ნალექების საშუალო ინტენსივობის დამოკიდებულება მაქსიმალური რადიოამრეკვლადობის ზონის ეფექტურ რადიუსზე.
მოცემულია ნალექის ინტენსივობის სტატისტიკური მახასიათებლები მეწყრული მწვერვალის ცენტრში. შეფასებულია ნალექების რაოდენობა ღრუბლის რადარის მაქსიმალური არეკვლის ზონაში და მეწყრის მწვერვალის ცენტრის ზემოთ 2015 წლის 13 ივნისს 21:00 საათიდან 23:97 საათამდე და მეწყერამდე 21:00 საათიდან 22:45 საათამდე.

საკვანძო სიტყვები: ატმოსფერული ნალექები, რადიოლოკაციური დაკვირვებები, მეწყერები.

Аномальные осадки перед оползнем в Ахалдаба (пригород Тбилиси, Грузия) 13 июня 2015 г. по данным радиолокационных измерений

А.Г. Амиранашвили, Т.Л. Челидзе, Д.Т. Сванадзе,
Т.Н. Цамалашвили, Г.А. Тваури

Резюме

Представлены результаты анализа радиолокационных измерений интенсивности осадков (P), предшествующих оползню в районе Ахалдаба (пригород Тбилиси, Грузия) 13 июня 2015 г. с 21.00 до 23.97 ч. В частности, получены следующие результаты. Временной ряд интенсивности осадков в зоне максимальной радиолокационной отражаемости облака имеет вид полинома пятой степени. Были получены временные ряды областей выпадения осадков разной интенсивности под облаком и изучены их статистические характеристики. Получена зависимость средней интенсивности осадков под облаком от эффективного радиуса от зоны с максимальной радиоотражательной способностью.

Приведены статистические характеристики интенсивности осадков над центром вершины оползня. Оценивается сумма осадков под зоной максимальной радиолокационной отражаемости облака и над центром вершины оползня 13 июня 2015 г. с 21.00 до 23.97 ч. и перед оползнем с 21.00 до 22.45 ч.

Ключевые слова: атмосферные осадки, радиолокационные наблюдения, оползни.