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REGIONAL SHORT–TERM FORECAST OF DEBRIS FLOW INITIATION FOR GLACIATED HIGH MOUNTAIN ZONE OF THE CAUCASUS

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ABSTRACT

We present a methodology for generalised regional-scale forecast of debris flow activity for territories with uniform conditions of debris flows formation. In the high mountain region of the Central Caucasus the trend of activation of debris flows processes is connected with the degradation of glaciers. For the development of debris flows forecast combined physical–statistical models based on long-term observation series are shown to be optimal. The authors develop an original and simple method of debris flows forecast for high mountains region with glaciation. The method is based on predictors readily available in practice, namely daily temperatures and precipitation. The method of compilation of a short- term debris flows forecast for high mountain zone of the Central Caucasus is proposed and recommendations for its practical usage are presented.

Key words: *forecast, debris flows, physical-statistical modelling, Central Caucasus*

INTRODUCTION

The high mountainous zone of the Caucasus Mountains is well developed (Fig. 1) and is characterised by the presence of abundant infrastructure (towns, resorts and communication routes). Significant part of this infrastructure is subjected to risks, typical of mountains regions. Among them debris flows cause appreciable damage not only in the zone of their formation, but also far from it. Through the channels of the big rivers disastrous torrents can reach foothill plains with the developed agriculture and urbanization. The local experience of constructing debris flow protection structures does not provide for sufficient safety of the population;

Fig. 1 - Map of debris flow channels for study area. Legend: 1 – river channels with traces of debris flows, 2 – rivers with no evidence of debris flows, 3 – boundary of Main Caucasus Range (and state boundary), 4 – towns and settlements, 5 - glaciers, 6 – mountain summits, 7 – areas of temporary stay for large numbers of people (ski resorts, mountaineering camps etc), 8 - area, shown on the figure 2 (see below) (Compiled by Kapitanov A.N., Chernomorets S.S. and Tutubalina O.V. on the base of Landsat ETM+ satellite imagery of 2000-2001, aerial imagery of 2004, topographic maps at scales of 1:25000 to 1:200000 (various years), as well as field data of Seinova IB., Dokukin M.D. and Chernomorets S.S.)

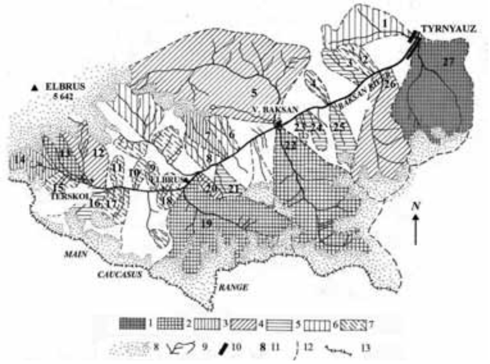


Fig. 2 - The map of debris flow basins for the Baksan River tributaries. Legend: 1-7 –maximum volume of debris flow deposits for one event (1000m³): 1. > 5000, 2. 5000 - 1000, 3. 1000 - 500, 4. 500 – 200, 5. 200 – 100, 6. 100 – 50, 7. 50 – 10; 8 – glaciers, 9 – rivers, 10 –settlements, 11 – catalogue numbers of debris flow basins, 12 –boundaries of debris flow basins, 13 – boundary of the Main Caucasus Range

therefore the problem of the forecast of debris flow situations is always important.

The forecast method, developed by the authors, is based on the 6-day cumulative sums of daily temperatures and precipitation and on forecasted values of air temperature and precipitation for the next day. The method has been successfully applied in Hydrometeorological Center of the Republic of Kabardino-Balkaria (Russian Federation).

THE FORECASTING METHODOLOGY

When complex glacial and rainfall-induced debris flows are formed it is necessary to consider the simultaneous influence of temperature and precipitation (Seinova & Zolotarev, 2001). The temperature regulates the processes of ice and a frozen-ground thawing, thus reducing internal cohesion and static friction in glacial moraine deposits, where the debris flows originate. Precipitation increases the weight of moraine masses. It also reduces cohesive forces in moraine due to washout of a material. Thus, the meteorological conditions define the state of debris flow material and the time of debris flow initiation.

But the forecast success rate of our method, based only on the critical values of meteorological parameters for debris flow triggering, was 53% (Andreev & Seinova, 1984). Such low forecast accuracy testifies only to the presence of unstable potential debris flow material on a slope. To improve forecasting results we had to develop a more detailed physical-statistical method.

The technique of forecasting uses information about physico-geographical, geological, hydro-meteorological conditions of debris flows formation with the purpose to find out the set of factors, both necessary and sufficient for debris flows initiation.

The process of development of such techniques consists of three stages: 1 - retrospection, 2 - diagnosis and 3 - prospection (Talanov, 2007).

At the stage of retrospection the collection and analysis of data about past debris flows are carried out to reveal regional and local conditions of their formation and to estimate their parameters quantitatively. As a result, catalogues, maps and databases of debris flow basins are made and spatial-temporal analysis of debris flow hazard for the area is carried out (Fig. 2). At the stage of diagnosis deterministic analysis of observation data is carried out. The first step of diagnosis is determining the range of the values of meteorological parameters, which are necessary and sufficient for initiation and development of debris flow processes. The choice of the algorithm for modelling depends on the forecast time interval chosen (long-term and short-term) and research area. The deterministic methods are used for local areas from a specific debris flow initiation zone to a river basin. For large regions, including several river basins with homogeneous conditions of debris flow formation, physical-statistical methods are more applicable. The final step at the stage of diagnosis is the drawing up of recommendations, containing algorithms and technology of forecast issues.

The stage of prospection includes experimental forecasts and evaluation of the forecast success rate by comparison of modeling results with data on actual debris flows.

In this work we adopt a physical-statistical approach for the short-term regional forecast, in which the development of mathematical algorithms is preceded by the analysis of the physical nature of debris flows.

RETROSPECTIVE REVIEW OF CONDITIONS AND FACTORS FOR DEBRIS FLOWS FORMATION

The development and validation of a short-term regional debris flows forecast was based on a 58 year - long observation series (1951–2009) in the high moun-

Fig 3 - Debris flow initiation zone at the marginal moraine of Kyaarty glacier, 2000 (helicopter photo by Valeriy Perekrest)

tain region of the Central Caucasus. Available data were collected and systematized by authors (Seinova & Tatyan, 1977; Andreev & Seinova, 1984; Seinova & Zolotarev, 2001). Our observations were carried out in the upper stream of the Baksan River basin and in its major tributaries Chegem and Cherek, with a total area of 2100 km^2, including 112 debris flow basins. The tributaries of the main river collect their waters on the north slope of the Main Caucasus Range with maximum elevations over 5000 m. The glaciers cover an area of 550 km^2. The 75 tributaries with the highest debris flow hazard originate from glaciers. The Baksan River originates from glaciers of the highest mountain of Caucasus, the Elbrus volcano (5,642 m) and flows into the Terek River, which runs into the Caspian Sea.

At the first stage of the debris flows forecast the assessment of deposits, available for entrainment in debris flows is carried out.

GEOLOGICAL AND GLACIAL PRECONDITIONS OF POTENTIAL DEBRIS FLOW MASSES FORMATION IN THE DEBRIS FLOWS ORIGINATON SITES

In the conditions of glacier degradation the marginal moraine complexes of retreating glaciers are sources of material for potential debris flows. The debris flow source area is a morphological formation with sufficient slope, capable to concentrate runoff and containing unconsolidated rock material (Figure 3). Tectonically active high-mountainous relief with glaciation creates favorable preconditions for debris flow origination with a high energy potential. The long-term geological factors define the development of the abrupt bare slopes and of unconsolidated rock material. The contribution of glacial-nival factor leads to formation of a contrast relief of the alpine type with the sharp peaks carlings and grandiose walls. The intensive weathering of rocks of high durability, such as granites, grandiorites, gneisses and crystalline slates, is highly developed. This process is considerably accelerated at the heights of 3100-3200 m above sea level, along the so-called “weariness line” of the rocks, caused by seasonal thawing and freezing of snow-ice cover (Gorshkov, 1982). These areas are characterised by constant rockfalls and transport of denudated material to the bottoms of glacial cirques. At the elevations from 2500 m (the regional level of valley glacier terminuses) up to 3500 m (the regional border of cirque glaciers) the potential debris flows source area represents an interconnected system of moraine, fluvioglacial and gravitational deposits, consolidated by permafrost, with layers and lenses of buried stagnant ice, with marginal and thermokarst lakes and rock glaciers. Here the potential debris flows source areas are constantly replenished by solid, liquid and ice materials. Thermo-erosive processes of destruction of friable unconsolidated rocks of the periglacial zone under the influence of hydrothermal factors are the principal cause of the formation of catastrophic debris flows in the high mountains of the Central Caucasus.

THE CHARACTERISTICS OF THE DEBRIS FLOW FOR THE PERIOD OF OBSERVATIONS

At the boundary of glaciosphere, where debris flows originate, the nature system is unstable. In such conditions insignificant deviations from stable trend of weather and mass balance of glaciers could lead to significant debris flow activity.

We have analysed the heterogeneity of debris flow events in the time and space, the differences in their scale and in the triggering meteorological conditions during the period of observations. For the period from 1951 to 2009 there were 38 situations of high debris flow activity in the Baksan River basin, during which 414 debris flow events occurred. The distribution of their quantity from year to year was unstable - from single cases to mass events on numerous tributaries of different hydrological orders. Mass occurrences of debris flow events, from 30 to 100 of simultaneous debris flow events, took place in 1953, 1966, 1967, 1975, 1977, 1983, 1996, 1999 and 2002.

The release of millions of cubic meters of mud and debris material from the tributaries in the main channels formed powerful debris flows, which reached the foothills of Caucasus mountains. The trigger of debris flows in all known cases were extreme rains with quantity of precipitation from 23 to 86 mm. The values of precipitation were recorded in the zone of formation of catastrophic debris flows in 1953, 1967, 1975, 1977, 1983 and 1996 and also by data of the representative Terskol meteorological station.

The most catastrophic debris flows in high mountain zone of the Central Caucasus as a whole were caused by an extreme rain of 1% probability. A 85.7 mm rain occurred on 5-6 August 1967. The maximum intensity was 4 mm/min (data from Terskol meteorological station). The average day air temperature at the height 2100 m on this day was 9°C, the level of the 0°C isotherm was 3500 m above sea level. It provided liquid precipitation at heights 3000-3200 m, in periglacial zone of debris flow origination. Catastrophic debris flow passed along the channel of the Terek River, the main river of the Central Caucasus. In its valley the highway Vladikavkaz–Tbilisi, a gas pipeline and other communications were washed off. In the valley of the Baksan River debris flow descended on settlements. In the valley of the Baksan River debris flow descended on the Verkhnii Baksan settlement, destroyed the Tyrnyauz – Terskol highway and other communications. The phenomenon of mass occurence of numerous debris flows of a various order in the Terek River basin due to extreme rain is indicative. The meteorological parameters of the debris flow situation of 1967 year was taken as the reference point between debris flow-inducing and non-inducing rainfall, according to the height level of 0°C isotherm position.

In the Baksan River basin the events of 19 July 1983 were the most significant by number of simultaneously forming debris flows. Debris flows formed in 83 basins of high mountains tributaries of the Baksan River. The catastrophic debris flow on the Chegem River totally washed off the main road connecting the foothills to the high mountains settlements. In the Adyr-Su valley extreme debris flow destroyed an alpine hotel (ZAPOROZHCHENKO, 1985). After 6 day of hot weather, when the level of snow line was above 4000 m, at 4 am on 19 July a rainfall of 33.7 mm occurred and led to mass debris flow releases.

The local debris flow releases (in 10-20 basins simultaneously) were observed more frequently and occurred after showers with amount from 20 to 52 mm. Such situations were observed in 1970, 1972, 1979, 1980, 1984, 1985, 1986, 1994, 1995, 2001, 2003 and 2005.

For the 400 cases of precipitation from 20 mm (annually repeated) to 86 mm (1% probability) only 38 debris flow events were registered, so their probability is less than 10%. The observation data do not show a clear dependence between the magnitude of debris flow events and quantity of precipitation. Part of the reason is in different phase states of precipitation (liquid, solid). In high mountains precipitation is accompanied by sharp decrease of air temperature. As a result of summer snowfall the glaciers are covered by snow and thaw runoff decreases. The role of rainfall is 14% from the runoff of glacial-nival zone of the Caucasus (WATER RESOURCES, 1973). The possibility of debris flow initiation during rainfall also depends on air temperature. There is not enough time for thawing of frozen masses in a cold summer season and after extremely cold winters, as a result debris flows processes do not developed. Such situation was observed at the Baksan River basin in 1985-1995. During this decade in high mountains debris flows were not observed, while at lower heights in 1986–1987 catastrophic debris flows did occur.

In all observed situations with various combinations of water –temperature regime, the genesis of debris flows formation was complex (glacial and rainfall-induced), where the rainfall had the triggering role.

During periods of extremely high temperatures one of the catastrophic mechanisms of debris flows formation is the lake outburst. Such debris flows are glacial-induced and take place usually without rainfall triggering. In the Baksan River basin debris flows of glacial genesis had especially individual character unlike mass events of debris flows of glacial - rainfall genesis. In 1958-1959 year the outburst of Lake Bashkara in the upper reach of the Adyl-Su River occurred twice. In 1968, 1975 and 1983 the outbursts of the lake Izmyaltsi at the Cherek River basin occurred. Debris flow due to lake outburst also took place in 1978 and 1979 in the upper sources of the Azay and Adyr-Su valleys respectively. The debris flow that descended on national resort Dzhily-Su in 2006 and Bulungu settlement in 2007 were catastrophic. The trigger in these cases was accumulation of big amount of thawed glacial waters during periods of extremely hot weather. Cumulative air temperatures for the 6 days before debris flow reached the maximum values 90-105°C (data from Terskol meteorological station).

During the period of observation there were 17 events of hot weather with the sum of average daily temperatures for the 6 days more than 90°C. 13 of these cases were of glacial and glacial-shower genesis. Among them, the 19 July 1983 event was the most catastrophic by quantity of debris flows in one day and those of 19-24 July 2000 at Gerkhozhan-Su River (Seinova *et alii*, 2003) were the maximum by volume with 3.2 million m3 of sediment released. The probability of debris flows at the maximum values of meteorological predictors (daily cumulative temperatures for 6 days from 90 to 105°C and precipitation from 50 to 86 mm) was 80%, sufficient to use for a forecast. But they constitute only 33% (13 from 38) cases of debris flow releases for the last 58 years. Often glacial and rainfall-induced debris flows take place at minimum values of meteorological predictors, as a result we have some uncertainty. To improve the forecast, a statistical forecast function based on the long period of observations data has been constructed.

DEVELOPING OF THE FORECAST FORMULA

We use the long-term observations of debris flows initiation conditions, which were carried out using a unified method (Rukovodstvo, 1976). For interpretation of meteorological factors, data from Terskol meteorological station, representative for our territory, have been used. It was established that to obtain optimum meteorological parameters describing conditions for debris flow occurrence, a 60 years period of observations is necessary. The authors have 58-year data series, so it is practically enough for the formula construction.

ESTIMATION OF OPTIMUM VALUES OF METEOPREDICTORS

The first task during construction of the forecast formula was the determination of the range of optimum values of meteorological predictors of situations of debris flows hazard and determination of their importance in complex process of debris flow initiation. The 38 basic cases of debris flow formation were used, from the earliest (5 July) to the latest (4 September) seasonal date of debris flow events.

These debris flows occurred at following values of the air temperature and precipitation (the critical values of meteorological parameters are designated by an index "cr" and mean boundary conditions between situations of debris flow hazard and no hazard):

1. Sum of the daily air temperatures from the date of steady transition above 0 °C to the date of debris flow (Q): $1450 \geq Q \geq Q_{cr}$ (Q_{cr}=670°C);
2. Sum of the precipitation for the same period (W): $540 \geq W \geq W_{cr}$ (W_{cr}=180 mm);
3. Sum of the daily air temperatures for 6 days before debris flow $(\sum_{1}^{6} T)$: $105 \geq \sum_{1}^{6} T \geq \sum_{1}^{6} T_{cr}$ ($\sum_{1}^{6} T_{cr}$ =72°C);
4. Daily sum of precipitation (X): $70 \geq X \geq X_{cr}$ (X_{cr}=20 mm);
5. Daily air temperature in the day with precipitation (T): $14 \geq T \geq T_{cr}$ (Tcr=9.0 °C).

The values of meteorological predictors vary considerably, but they have a certain optimum range. From data between 1951 and 2005 years, 400 cases with extreme rains have been determined. The debris flows of glacial–rainfall genesis were formed only if extreme rains with critical parameters coincided in time with periods of optimum values of other meteorological predictors. Such overlap occurred in 38 from 400 cases.

Obviously, this forecast method, which is based on an expert analysis of critical values of meteorological parameters, has some uncertainty. Construction of a function with use of statistical algorithms was carried out for increasing the efficiency of the forecast of debris flows of complex genesis.

METHODOLOGY OF DEVELOPING THE FORECAST FORMULA

It is possible to present the generalized description of physical process of debris flow formation as a formula depending on considered parameters, valid in the chosen critical range of meteorological predictors.

We used several combinations of meteorological parameters in developing the forecast formula:

1. Results of multiplying of meteorological parameters. Product of air temperature and quantity of precipitation is one of versions of the hydrothermal factor,

which is widely used in climatology.

2. Sum of daily values of meteorological parameters for a certain time period - for the description of preparation of potential debris flow materials in this period.

The formula is as follows:

$$F=AXT+BQW+C\sum_{1}^{6}T\,, \tag{1}$$

where *A, B, C* – specific coefficients (as described below); *X* - daily sum of precipitation; *T* – projected daily air temperature in the day with triggering precipitation; Q – cumulative air temperatures from date of steady transition above 0 °C to the date of debris flow; *W* – cumulative precipitation for the same period, $\sum T$ - cumulative sum of air temperatures for 6 days before the debris flow.

For calculation of coefficients A, B, C the following data are used:

1. the mean (optimal) values of meteorological parameters X_{opt}, T_{opt}, $\sum_{1}^{6}T_{opt}$, Q_{opt}, W_{opt}, which have been determined from observation data as average values of meteorological parameters *X*, T, $\sum_{1}^{6}T$, Q, W.
2. the values of weighting coefficient for each meteorological factor P_X, P_T, P_Q, P_W, $P\sum_{1}^{6}T$

or for their joint influence on debris flow initiation P_{XT}, P_{QW}, P_{XTQW}.

The weight of factors (P_i) was defined as a relative frequency of of debris flow cases to the total number of days with meteorological parameters above critical values.

$$P_i=N_r/N_i, \tag{2}$$

where N_r - quantity of daily observations with debris flow events occurring at achievement or in excess of critical values on each of meteorological predictors, N_i – total number of days with meteorological parameters above critical values.

The following values of weighting coefficient have been received from data of observations from 1951 to 2005: $P_X=0.11$; $P_T=0.05$; $P_Q=0,14$; $PW=0.06$; $P_{XT}=0,27$, $P_{QW}=0.07$,

$$P\sum_{1}^{6}T=0.76;\ P_{XTQW}=0,53.$$

The coefficients A, B, C have been defined as normalized weights of meteorological factors and their combinations:

$$A=\frac{P_{XT}}{X_{opt}T_{opt}}\,,\ B=\frac{P_{QW}}{Q_{opt}W_{opt}}\,,\qquad C=\frac{P\sum_{1}^{6}T}{\sum_{1}^{6}T_{opt}} \tag{3}$$

Authors received the first version of the forecast formula from observation data for 1953-1983 years (Andreev & Seinova, 1985).

$$F=7{,}15\ 10^{-3}XT+2{,}4\cdot10^{-6}QW \tag{4}$$

The weights of meteorological factors defining values of coefficients *A, B, C* possess wide confidence intervals. These intervals show that our estimations differ by 1.5 - 2 times from statistical sample, which can be received from the full set of tests. Using formulas for calculation of errors (Korn & Korn, 1968), we defined that the relative error due to uncertainty of coefficients *A, B, C* reaches 16%, while an internal integrity error due to errors in definition of values of parameters is only 2%. Thus, the efficiency of the forecast formula is defined basically by reliability of the coefficients estimation.

Later the formula has been transformed on the basis of a 44-year series of observations (1951–1995). It is established that values of critical parameters, received for a longer series of data, have not changed and correspond to the 95% confidence interval, except for the temperature factor for which the confidence probability increases to 99%. It means that the factor of cumulative air temperatures for 6 days is the most informative factor. Its forecast success rate reaches 80% while for the rainfall factor it is 20% only, but the latter is important for debris flows of polygenic glacial-rainfall genesis.

Taking into account the new information, the final version of the formula, has been accepted:

$$F=8\cdot10^{-4}XT+10^{-2}\sum_{1}^{6}T \tag{5}$$

where *X* – forecasted amount of precipitation, mm, *T* - forecasted air temperature in the day with precipitation, °C,

$\sum_{1}^{6}T$ – cumulative air temperatures for 6 days, including the day of weather forecast release, °C

The forecast for debris flows is given in the case when F exceeds 1:

$$F \geq Fcr\ (Fcr=1) \tag{6}$$

ASSESSMENTS OF FORECAST FORMULA EFFICIENCY AND RECOMMENDATIONS FOR REAL-TIME FORECAST

Efficiency of the formula was checked by authors on dependent (1951-1995) and independent (1995-2005, Tab. 1) observation data and also through its practical use in Hydrometeorological Center of the Republic Kabardino-Balkaria in 1995-1996 and 2000-2009. To estimate forecast success rate FSR (the relation of correctly predicted cases of debris flow to the total number of forecasts) statistical processing of the calculated values forecast function from 1953 for 2005 was carried out.

The following values have been received for all periods of observations:

FSR = 79% for 1953–1983 – a so-called theoretical estimation.

There are 23 coincidences from 29 cases predicted under the formula.

FSR = 77% for 1984–1995 – the first period of validation.

There are 17 coincidences from 22 cases predicted under the formula.

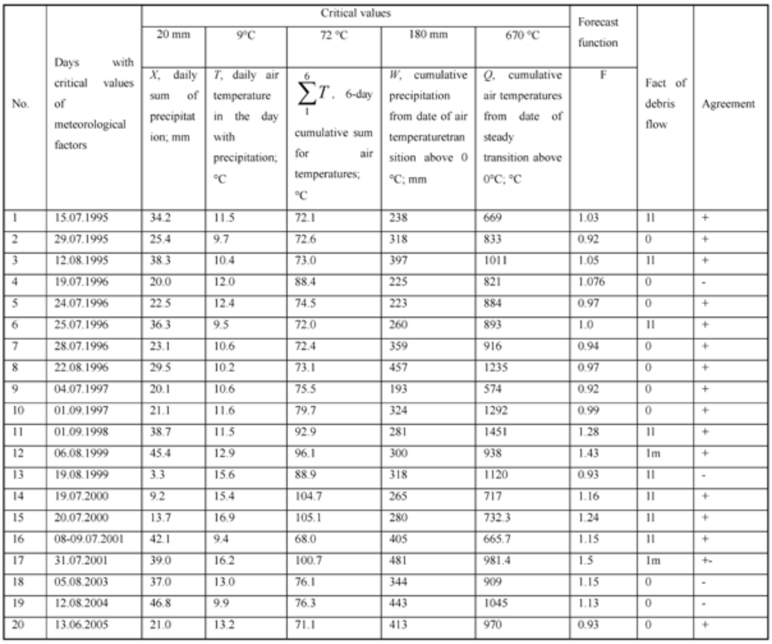
FSR = 80% for 1995–2005 –the second period of validation.

There are 16 coincidences from 19 cases predicted under the formula.

Average forecast success rate of the formula during 1953–2005 is 78%. Practical verification of the forecast function has shown satisfactory results. Debris flow events on 15 and 25 July 1996 and on 12 August 1996, catastrophic debris flows of glacial genesis on 19 July 2000 and 7 August 2006 were all predicted

THE ANALYSIS OF A LONG-TERM SERIES OF FORECAST FUNCTION VALUES

Analyzing structure of the formula it is possible to present forecast function F as the hydrothermal indicator, whose fluctuations reflect fluctuations of the climate, virtually included in it. It has changed within last 58 years in the range from 1 to 1.3 for local debris



No.	Days with critical values of meteorological factors	Critical values					Forecast function	Fact of debris flow	Agreement
		20 mm	9°C	72 °C	180 mm	670 °C			
		X, daily sum of precipitation; mm	*T*, daily air temperature in the day with precipitation; °C	$\sum_{1}^{6} T$, 6-day cumulative sum for air temperatures; °C	*W*, cumulative precipitation from date of air temperaturetransition above 0 °C; mm	*Q*, cumulative air temperatures from date of steady transition above 0°C; °C	F		
1	15.07.1995	34.2	11.5	72.1	238	669	1.03	1l	+
2	29.07.1995	25.4	9.7	72.6	318	833	0.92	0	+
3	12.08.1995	38.3	10.4	73.0	397	1011	1.05	1l	+
4	19.07.1996	20.0	12.0	88.4	225	821	1.076	0	-
5	24.07.1996	22.5	12.4	74.5	223	884	0.97	0	+
6	25.07.1996	36.3	9.5	72.0	260	893	1.0	1l	+
7	28.07.1996	23.1	10.6	72.4	359	916	0.94	0	+
8	22.08.1996	29.5	10.2	73.1	457	1235	0.97	0	+
9	04.07.1997	20.1	10.6	75.5	193	574	0.92	0	+
10	01.09.1997	21.1	11.6	79.7	324	1292	0.99	0	+
11	01.09.1998	38.7	11.5	92.9	281	1451	1.28	1l	+
12	06.08.1999	45.4	12.9	96.1	300	938	1.43	1m	+
13	19.08.1999	3.3	15.6	88.9	318	1120	0.93	1l	-
14	19.07.2000	9.2	15.4	104.7	265	717	1.16	1l	+
15	20.07.2000	13.7	16.9	105.1	280	732.3	1.24	1l	+
16	08-09.07.2001	42.1	9.4	68.0	405	665.7	1.15	1l	+
17	31.07.2001	39.0	16.2	100.7	481	981.4	1.5	1m	+-
18	05.08.2003	37.0	13.0	76.1	344	909	1.15	0	-
19	12.08.2004	46.8	9.9	76.3	443	1045	1.13	0	-
20	13.06.2005	21.0	13.2	71.1	413	970	0.93	0	+

Tab. 1 - Data for verification of the forecast formula
Symbols of the table: 0 – debris flow absence, 1 – debris flow event (1l- local, 10- 20 cases; 1m – mass occurrence, more than 20 cases)

flows and from 1.3 to 1.5 for catastrophic events. Obviously, the maximum and minimum testify the intensification and decreasing of the debris flow activity. On the basis of a 5-year moving average, it has been established that the obtained values fluctuate on a sinusoid with the period about 16-17 years. Real cycles of change of regime of debris flow activity depend on long-term fluctuations of climate and have periods from 18 (1967-1984) to 23 years (1985-2007) (Seinova *et alii*, 2007). As a result of the further statistical processing it is received that the obtained forecast function values are quasinormally distributed around the average value of 1.16 with deviation in ±0.17. So there was no significant trend of debris flow activity during period of observations. Thus it was established that meteorological predictors of debris flows have a natural cycles of about 16-17 years. Therefore the developed technique of the forecast formula construction can be applied for shorter series of observations. Observations data during one cycle of meteorological parameters change (16-17 years in our case) can be enough for the forecast formula construction.

RECOMMENDATIONS FOR REAL-TIME FORECAST OF DEBRIS FLOWS

The following recommendations have been developed for the central Caucasus.

The forecast of time of the debris flow release is carried out stage-by-stage on the basis of the representative meteorological station Terskol data and weather forecast.

1. The forecast of the beginning of debris flow hazard period consists in the summation of current daily average air temperatures from date of steady transition above 0°C and the precipitation for the same period. On reaching the critical values $Q \geq 670°C$ and $W \geq 180mm$ the debris flow hazard period is declared
2. The second step is the forecast of debris flow hazard situation. The real-time observation by temperature regime of weather and summation of air temperatures for 6 day before the forecast day is carried out. If the critical sum

$$\sum T$$

is above 70°C, the high probability of debris flow releases is possible in the following conditions:

–in the cases of extremely hot weather (the sum of temperatures reaches 100-105°C at the height of 2000 m, corresponding to height of 0°C isotherm during many days above 4000 m) the outbursts of glacial lakes and debris flows of glacial genesis are possible. In the case of invasion of moisture-laden air when the level of 0°C temperature line is above 3500 m, the local or mass occurrence (depending on quantity of precipitation) of debris flows of glacial –rainfall genesis is possible.

3. The final forecast of the time of the debris flow event is given by the formula on the basis of meteorological forecast of values of air temperature and precipitation. In the case of $F \geq 1$ the short-term regional forecast of debris flow release is given.

CONCLUSION

The basis of the proposed method of the regional debris flow forecast of glacial-rainfall genesis is the long-term series of observations of debris flows and meteorological predictors. The verification of the forecast formula efficiency has shown forecast success rate from 70 to 80%. This result has been reached by using the complex systemic approach to the solution of the forecast problem. The physical - statistical modelling which considered multifactor processes of debris flows formation, has allowed to simplify the methodology considerably and to raise the forecast success rate by 30%.

It has been established, that for this method it is sufficient to use observation data for one relatively short natural cycle of meteorological parameters. It is important for regions, where long series of observations of debris flow activity are not available.

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