Ekaterina Rets[1], Julia Chizhova[2], Nadine Budantseva[3], Natalia Frolova[3], Maria Kireeva[3], Nadezda Loshakova[3], Igor Tokarev[4], Yurij Vasil'chuk[3]
[1]Water Problems Institute, Russian Academy of Sciences, 119333, Russian Federation, Moscow, ul. Gubkina 3
[2]IGEM RAS, 1190176 Russian Federation, Moscow, Staromonetniy per., 35
[3]Lomonosov Moscow State University, Moscow, Russia. 119991, Russian Federation, Moscow, GSP-1, Leninskie Gory, Faculty of Geography
[4]Center for Geo-Environmental Research and Modeling (GEOMODEL) at St. Petersburg University. 198504, Russian Federation, St. Petersburg, Ulianovskaya st., 1.
*** Corresponding author:** Ju. Chizhova (eacentr@yandex.ru)

EVALUATION OF GLACIER MELT CONTRIBUTION TO RUNOFF IN THE NORTH CAUCASUS ALPINE CATCHMENTS USING ISOTOPIC METHODS AND ENERGY BALANCE MODELING

ABSTRACT. Frequency and intensity of river floods rise observed in the North Caucasus during last decades is considered to be driven by recent climate change. In order to predict possible future trends in extreme hydrological events in the context of climate change, it is essential to estimate the contribution of different feed sources in complicated flow-forming processes in the alpine part of the North Caucasus. A study was carried out for the Djankuat River basin, the representative for the North Caucasus system. Simultaneous measurements of electrical conductivity, isotopic and ion balance equations, and energy balance modeling of ice and snow melt were used to evaluate the contribution of different sources and processes in the Djankuat River runoff regime formation. A forecast of possible future changes in the Djankuat glacier melting regime according to the predicted climate changes was done.

KEY WORDS: stable isotope, electrical conductivity, Caucasus, alpine river, hydrograph separation

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INTRODUCTION

There is an urgent need for improving our understanding of the controls on water sources and flow paths in high mountainous systems. Floods are observed in the North Caucasus during the spring-summer period and are usually caused by superimposition of heavy rainfall on intensive melting wave. The same factors bring about other various hazardous natural processes in this region, such as debris flows, avalanches, and glacier lakes outburst floods. In the beginning of the XXI century, frequency and intensity of dangerous hydrological processes in the North Caucasus was much higher then during the previous years, which is usually associated with recent climate change (Rets and Kireeva 2010; Semenov and Korshunov 2008; Seynova 2008).

The main tendencies in recent climate change in the North Caucasus include an increase in mean annual air temperature due to both summer and winter period and decrease in the number of days with negative air temperature in the plain territory. A gradual rise in mean annual air temperature has been registered during the entire observational period (since the 1930s); however, the intensity of this process has increased dramatically since 1986. The linear trend of the mean annual temperature increase for the period from 1986 till now varies from 0.5–0.7ºC in ten years in the north-east of the plain territory to 0.7–0.8ºC in the south-east of the plain territory.

In central and eastern mountainous part of the North Caucasus, a decrease in mean annual temperature was registered from the beginning of the observational period (1940s–1960s) to the early 1990s. The mean annual temperature value fluctuations have become stable since the end of the 1980s–the beginning of the 1990s; for some meteorological stations, the upward tendency was manifested.

A substantial spatial heterogeneity of long-term fluctuations of the precipitation characteristics was observed, especially in plain territories during summer. Consequently, long-term fluctuations of the annual precipitation sum show multidirectional tendencies. A statistically significant rise in the annual precipitation sum was observed during the entire observation period at most of the sites located in the western part of the study area. In the central and southern parts, the statistically insignificant increase was quite common. Cyclical fluctuations of the annual precipitation sum are characteristic of the driest eastern part of the North Caucasus.

An important indicator of climate change within the study area is a long-term regime of glaciers in the North Caucasus. Degradation of glaciers indicates a trend of climate warming since the end of the XIX century.

General glacier retreat in the North Caucasus started in the late 1840s, with four to five minor readvances in the 1860s-1880s and three readvances or steady states in the XX century (1910s, 1920s, and 1970s-1980s). Since the last Little Ice Age maximum in the middle of the XIX century, most glaciers have decreased in length by more than 1000 m, and the rise in the elevation of the glacier fronts has exceeded 200 m (Solomina et al. 2016). At present glaciation is in a regressive phase, and the overall reduction is about 20% of the area of the 1970s (Seynova 2008). The observed tendencies of climate change and deglaciation clearly explain the ongoing increase of extremeness of hydrological regime in the North Caucasus. On the one hand, a rise in mean annual temperature provokes an increase in the glaciers melt rate and, hence, a drawdown in long-term ice reserve and rise in the overall water flow in the region. On the other hand, an increase in precipitation sum contributes to the process through more frequent rain flooding.

Modeling of extreme hydrological events and prediction of possible future trends in the North Caucasus are difficult due to complicacy of flow-forming processes. An extremely complicated structure of river flow feed is characteristic of high-altitude territories that play a definitive role in the formation of hydrological regime in the North Caucasus. The following components can be distinguished: (a) ice and firn melting in accumulation and ablation zones of glaciers; (b) seasonal snow melting on glacier covered and non-glacier area of watersheds; (c) liquid precipitation; and (d) underground waters. In addition, each of these components can run off the watershed surface in different ways.

According to this, estimation of the contribution of different feed sources to flow forming processes is essential to understanding the mechanism of flow formation and the genesis of the extreme hydrological events in the North Caucasus. One of the advanced approaches to study the hydrological cycle and the response of glaciers to climate change is the stable isotopes method (Vasil'chuk et al. 2013).

Consequently, oxygen isotopes can be applied to determine the timing and origin of changes in water sources and flow paths, because different water sources often have isotopically different compositions due to their exposure to different isotopic fractionation processes (Yde et al. 2016).

Since the 1970s, this technique has been widely used for hydrograph separation (Dinçer et al. 1970) and then a series of papers was published, describing runoff hydrograph separation by nourishment sources with the use of 18O (Fritz et al. 1976; Hermann et al. 1978; Herrmann and Stichler 1980; Martinec et al. 1974; Meiman et al. 1973; Mook et al. 1974; Sklash and Farvolden 1979).

Most often a conceptual two-component mixing model is applied, where an old-water component (e.g., groundwater) is mixed with a new-water component (e.g., snowmelt), assuming that both components have spatial and temporal homogeneous compositions. The general mixing model is given by the equation

$$QC=Q_1C_1+Q_2C_{2+}\ldots Q_nC_n$$

where the discharge Q and the isotopic value C are equal to the sum of their components. The water isotope mixing models can provide valuable information on spatial differences in hydrological processes on diurnal to annual timescales (Ohlanders et al. 2013; Kendall et al. 2014; Wang et al. 2015).

In glacier-fed river systems, the principal water sources to bulk run-off are associated with ice melt, snowmelt, rainfall, and groundwater components. Depending on the objectives of the study and on the environmental setting, hydrograph separation of glacial rivers has been based on assumed endmember isotope mixing between two or three prevailing components. In detailed studies it may even be necessary to divide a main component, such as ice melt, into several ice facies sub-components (Yde and Knudsen 2004, Yde et al. 2016).

STUDY AREA AND PREVIOUS RESEARCH

The study was carried out in the Djankuat River basin, chosen as representative for the North Caucasus, in course of the International Hydrological Decade (IHD, 1964-1974).

Djankuat glacier (43.2°N, 42.75°E) is located on the northern slope of the Main Caucasian Ridge in the Elbrus area (Fig. 1); it is a small (9.09 km2) high-altitude river basin with mean elevation of 3285 m and glaciation ratio of about 0.5. The glacier system of the Djankuat River basin is represented by 4 glaciers: a typical valley glacier Djankuat and 3 small glaciers (Visyachiy, Viatau, Kojavgan) (Fig. 1). The lower limit of glaciation is at 3230 m. Complex observations in the Djankuat River basin started in 1965 under the IHD and have been carried out without interruptions until now (Lednik Dzhankuat 1978). Recently, the observations are carried on by the Glaciological and Hydrological departments of Lomonosov Moscow State University (MSU).

A tendency of the glacier's passage from a quasi-stationary state to degradation up to the end of the XX century identified based on direct measurements and data on changes in the hypsometry of Djankuat glacier (Aleinikov 2001; Popovnin and Petrakov 2005). The overall retreat of the glacier tongue from 1968 to 2000 was 105 m, the process, in general, being extremely uneven.

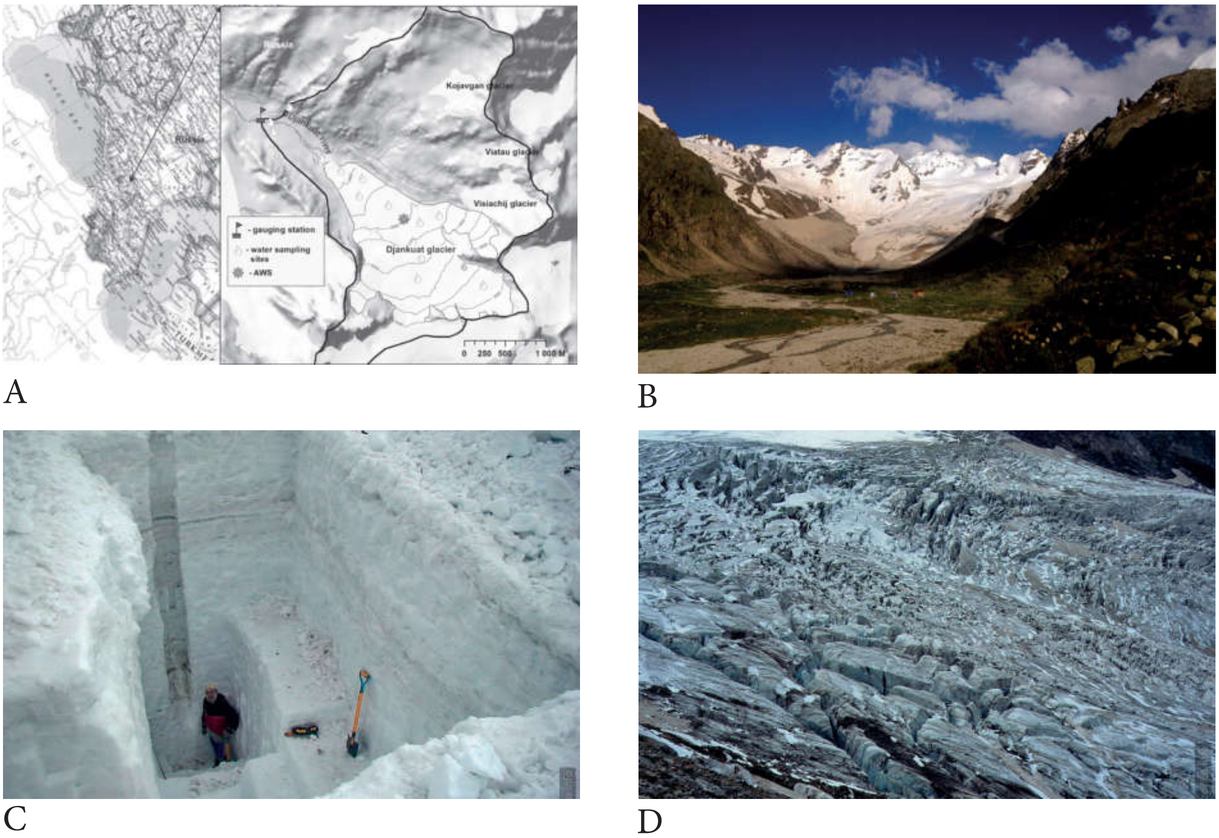

Fig. 1. The Djankuat river basin (a), view of the valley, photo by N. Loschakova (b), snow pit in the middle of the Djankuat glacier, photo by E. Nosenko (c), cracking zone in the middle of the Djankuat glacier, photo by E. Nosenko (d).

For the Djankuat basin a distributed model of snow and ice melting in high altitude zones has been applied for the ablation season of 2008 (Rets et al. 2014). The model is based on the up-to-date measurements and is focused on hydrological processes modeling in relatively small high-altitude catchments.

Ice/snow melting calculation is based on the surface heat balance equation. The input data are represented by the results of complex meteorological observations, including global short-wave radiation, incoming long-wave radiation, wind speed, air temperature vs altitude profile, dates of snowfall, DEM, and cartographic information about snow line dynamic and debris cover. The components of heat balance are distributed over the regular net with the assigned resolution.

Comparison of the calculated and measured melting depth and the ablation stakes net showed that the developed model gives correct results for all parts of the glacier. No systematic deviation is observed, even in condition of inaccurate location of the stakes. The correlation coefficient is 0.96.

The simulation results were compared to the Djankuat River discharge measurements at the gauging station (Fig. 1). The Djankuat River hydrograph during ablation in 2008 had a typical for glacial rivers saw-tooth shape with pronounced daily maximum and minimum (Fig. 2 a). In (Golubev 1976) was proposed a term "rapid runoff" to determine the component of glacial rivers flow, forming a range of diurnal fluctuations in water level. The river flow component with a much longer lag-time was called "underlying flow." Comparison of the daily volume of runoff with the total melting in the Djankuat basin allows, first of all, drawing a conclusion that not all melt water is discharged from the catchment area of the river during the ablation season (Fig. 2 b). This is mostly due to congelation processes and melt water storage in natural regulating reservoirs on the watershed that feed the Djankuat River flow during winter period (Golubev 1976). In general, diurnal snowmelt waves in areas of the watershed with a significant snow

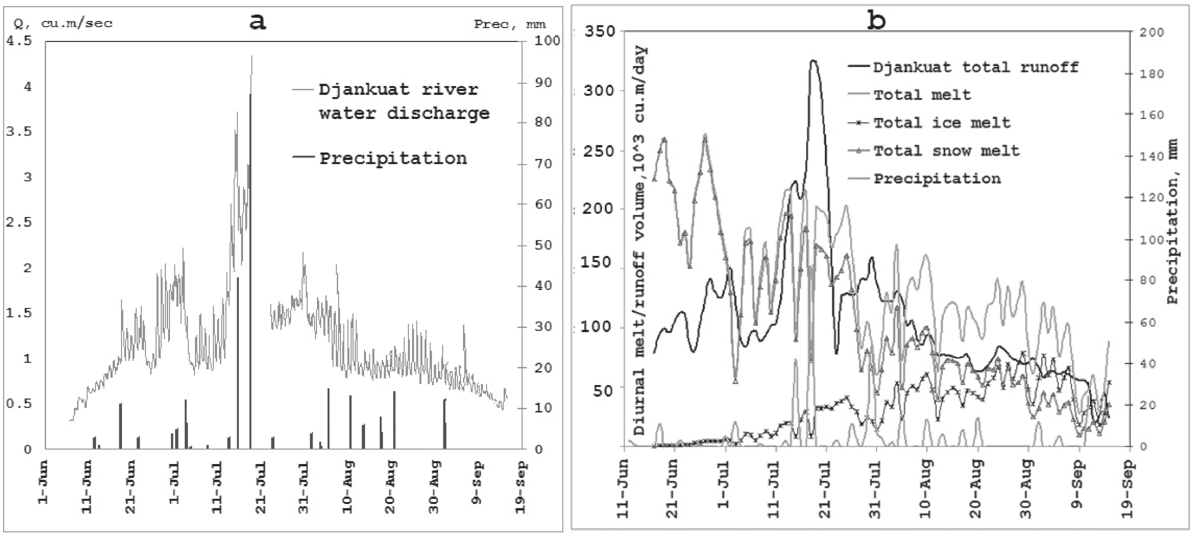

Fig. 2. The Djankuat river hydrograph in the ablation period of 2008 with one-hour step (a) and one-day step (b) in comparison with the precipitation regime and melting rate (b)

cover depth are strongly flattened in the course of lag. Time required for percolation through a 4–6 meters of snow cover can be, depending on the physical properties and characteristics of the process of melting, from 5–7 to 15–18 days (Rets et al. 2014). Further time lag of meltwater from the firn zone of Djankuat glacier to the gauging station in late July – early August, according to the estimates of (Golubev 1976), is about 5 days. As a result, against a background of general synchrony of the total daily melting and runoff there is a significant scatter of the points on the corresponding empirical dependence (Fig. 3 a). At the beginning of the ablation period, when snow cover depth is maximum, the total melting in the watershed is much larger than the total runoff (Fig. 2 a, b), and the dependence of the daily volume of runoff on the total melting is not even expressed (June points in Fig. 3 a).

Thus, runoff fluctuations show a delay and relatively higher smoothness compared to the dynamics of melting. A considerable degree of inertia in runoff processes from the basin is reflected by high values of the autocorrelation coefficient. In-row coherence can be traced up to 1 week. The autocorrelation coefficient of daily volumes of runoff with 1 day shift is 0.95, with 2 day shift – 0.87, 5 days – 0.64. The maximum release of water accumulated by the glacier is reached in mid-July, which causes an overall increase in the Djankuat River flow in this month and an excess of the runoff volume over the melting volume (Fig. 2 a,b).

A diurnal fluctuation range of runoff, the so-called "rapid runoff," is formed by meltwater part with the basin lag time of about 3–4 hours in June and July and 2–3 hours in August and September (Golubev 1976; Lednik Dzhankuat 1978). According to studies (Golubev 1976; Rets et al. 2014), this component most likely corresponds to melting on the Djankuat glacier tongue. The second component involved in the formation of a day-to-day variation in glacial river runoff is snow melt on the non-glacierized part of the watershed. An average slope time lag of meltwater runoff through the surface sediments mass to the channel network in the Djankuat River basin is from 15–16 to 25–35 hours (Rets et al. 2014). Thus, an overlay of diurnal waves of meltwater with relatively rapid lag is occurring in the Djankuat River basin. This process is reflected in the fact that the dependence of daily "rapid runoff" volume on daily volumes of melting on the Djankuat glacier tongue has a character of a family of curves (Fig. 3 b). The points fall on the upper curve in the periods of a respectively intensive melting, and on the lower one after periods of cold weather.

The distributed model of snow and ice melting permits also simulation of changes in the glacier-derived liquid runoff responding to the anticipated climate change and progressive deglaciation. If the counter-radiation of the atmosphere increases by 1.5 W/m2 (which corresponds to the changes that have occurred over the last 100 years), the mean air temperature will increase by 4°C (according to the forecast of IPCC – Intergovernmental Panel on Climate Change), the debris cover will increase will by 180% (equal to the changes, occurred from 1968 to 1999), the atmosphere transparency index will decrease by 5%, and the Djankuat glacier melting rate will increase by 12–40%, depending on an elevation-slope zone of the glacier. Thus, as area of the glacier is expected to diminish, an increase in the glacier melting volume will not be dramatic. If the area decreases by 30%, which corresponds to the changes that occurred from 1910 to 1999, a decrease in the volume of Djankuat glacier melting will be 8%.

MATERIALS AND METHODS

The observation program in the Djankuat River basin includes: 1) measurements of meteorological parameters by means of AWS Campbell Scientific CR-1000 (Fig. 1); 2) air temperature measurements in several elevation points by 3 TinyTag temperature loggers with 1-hour time step; 3) complex glaciological observations: snow course surveys at the maximum snow storage period, comprised of 250 evenly distributed measurement points, observation on the ablation stakes net (50–55 stakes throughout the Djankuat glacier area); snow density measurements, carried out in 3 representative pits every 15–20 days; and 4) the Djankuat River runoff and conductivity measurements on the gauging station (see Fig. 1). Water level was recorded with hourly motion by an automated level recorder ADU-02 and Solinst. A rating curve was electrical conductivity and was measured by a field conductometer Econics-Expert 5 times daily.

In 2013 and 2014, the program also included daily collection of water samples for natural stable isotopes analysis at the Djankuat River gauging station (90 samples in 2013, 242 water samples in 2014) (Fig. 1). The $\delta^{18}O$ values of river water at the end of the 2013 ablation period, when the glacier melting was completely finished, are taken as isotope composition of the ground water component. Liquid precipitation was sampled at every event in 2014 (31 samples) and once in 2013. Ice, firn, and snow sampling sites were evenly distributed over the river basin (overall, 9 samples were taken in 2013 and 58 samples, in 2014). The samples from the corresponding sites were taken several times during the ablation season. A vertical structure of isotopic composition of snowpack was studied in 3 representative snow pits on the Djankuat glacier in June, July, and August 2014.

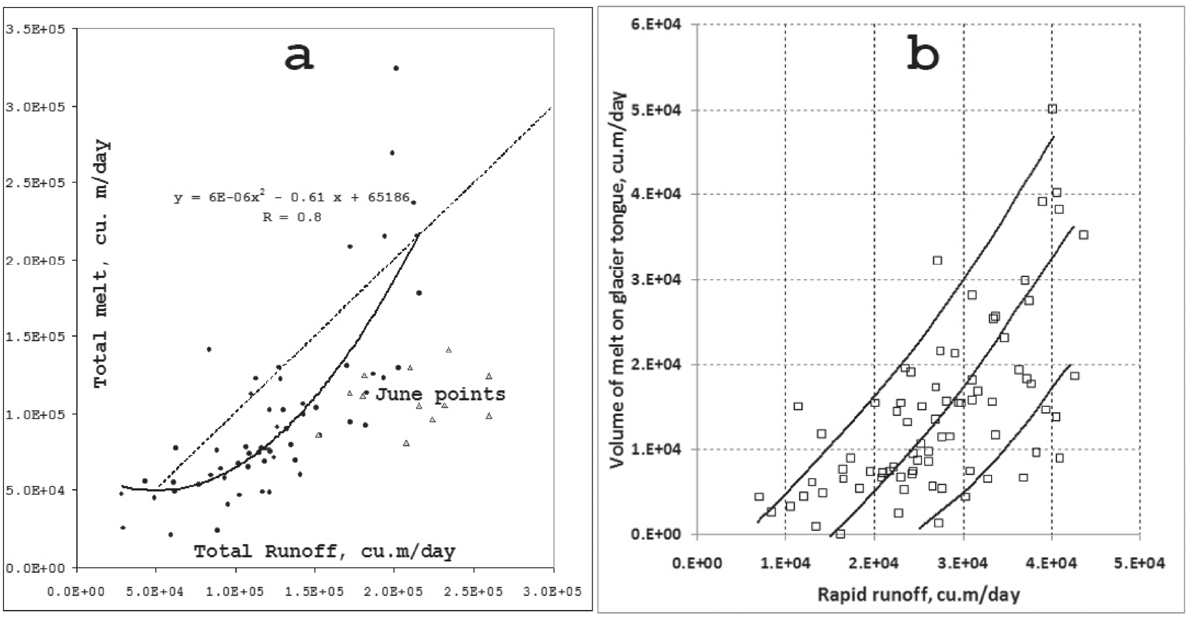

Fig. 3. Dependence of the total Djankuat river runoff on the total melt in the watershed (a); dependence of rapid runoff on melting on Djankuat glacier's tongue (b)

All samples collected in the curse of the study were measured by a Finnigan Delta-V isotope ratio mass spectrometer in the Stable Isotope Laboratory, the Department of Geography, MSU.

The isotope composition data were expressed conventionally as δ-notion (‰), representing deviation in parts per thousand, relating to the isotopic composition of V-SMOW (Vienna Standard Mean Ocean Water). International standards V-SMOW2, GISP, SLAP2, and a proprietary MSU laboratory standard (snow glacier Garabashi: $\delta^{18}O$ = –15.60‰) were used daily for the calibration measurement. The measurement precision for $\delta^{18}O$ was ±0.1‰. Measurements were made in He continues flow regime; time of equilibration sample with CO_2 was 24 hours by 24 °C. Concurrently, isotopic determinations were made in the Saint Petersburg State University Resource Center for Geo-Environmental Research and Modeling (GEOMODEL) by Picarro L-2120i. The analytical results that have been obtained independently by the two laboratories are similar; the mean difference in the definition for the same sample does not exceed 0.2‰. For final modeling the mean values (rounded to the whole number, without decimals) were taken.

SEPARATION OF THE ALPINE RIVER HYDROGRAPH USING STABLE ISOTOPES AND CONDUCTIVITY

The seasonal dynamics of water isotope composition of the Djankuat River and its runoff components show appreciable variations. The values of water $\delta^{18}O$ in 2013 varied from –11.27 to –15.04‰. The value of $\delta^{18}O$ in the Djankuat water in 2014 varied from –9.1 to –13.3‰ (Fig. 4).

In the ablation period of 2013, $\delta^{18}O$ values of the Djankuat river water show a general monotonic increase from –14.75 to –14.85‰ in early June, to –11.8 to –12.8‰ in late September. This regularity is typical of glacier rivers and originates from the considerable contribution of melting of isotopically light winter snow in the first half of the ablation season. The isotopic composition of glacier runoff within a day in June 2013 varies insignificantly: the values of $\delta^{18}O$ changed by less than 1‰ from –15 to –14‰.

In 2014, heavy spring snowfalls resulted in the formation of a thick layer (~1–1.5 m) of isotopically heavy snow, overlying winter snow. Because of this, the isotopic composition of the snowmelt runoff in 2014 is appreciably heavier and the seasonal variations are not typical: the minimums of $\delta^{18}O$ values, determined by the melting of winter, isotopically "cold" snow, can be seen only after the predominantly melting of spring snow deposits, i.e., from the second half of June to late July. The further regular shift of the isotope composition of the Djankuat River water toward heavier isotopes is due to the increasing share of ice and firn melting and liquid precipitation in the structure of glacier nourishment. Thus, the mean value of $\delta^{18}O$ was –12.06 in June 2014, –12.44 in July, –11.50 in August, and –11.7‰ in September. Thus, in 2014, the oxygen isotope composition of melt flow shows nearly no seasonal melting regularity because of the specific weather conditions in 2014, i.e., abundant spring snowfalls.

The method of isotopic markers coupled with hydrochemistry method allows solving various problems in study of mechanisms of runoff formation in mountainous river basins. Simultaneous solution of isotopes, ion, and water balance equations allows estimating seasonal dynamics of various genetic components of river flow (Williams et al. 2009).

Alpine rivers in the North Caucasus are characterized by a multicomponent feed structure and complexity of flow-forming processes. That causes rather complex regularities of isotope and ionic composition (electrical conductivity) formation.

The most positive isotope values are typical of liquid summer precipitation. The mean ™18O value in collected samples of rain water was –4.7‰ (Table 1). Winter snow had the most negative isotope values (from –19.0 to –12.3‰ for $\delta^{18}O$).

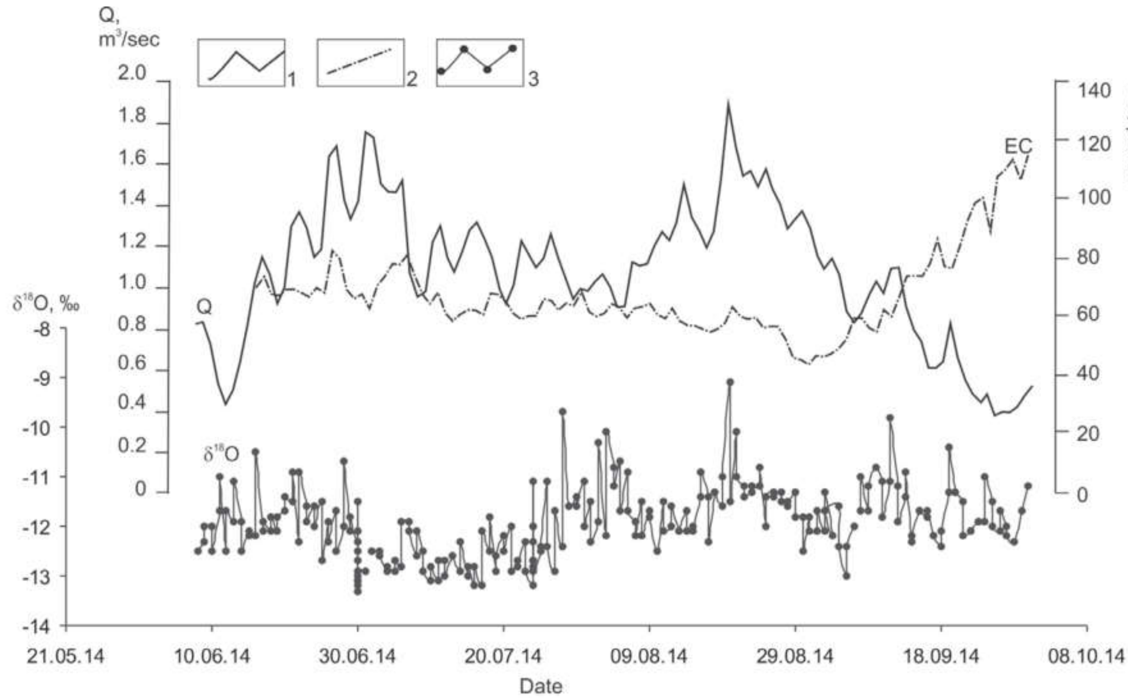

Fig. 4. Variations of the total discharge Q (1), electrical conductivity EC (2), and $\delta^{18}O$ values (3) in the Djankuat river water during the ablation period 2014

Temporal fluctuation of combination of these components in river flow forms river water isotope composition regime. Rather dry winter and anomalously high spring snowfalls observed in the study area in 2014 influenced greatly isotope composition regime of the Djankuat River during ablation period 2014. Hence, it was rather heavy compared to the previous year's samples, especially in June 2013 (Chizhova et al. 2014).

Unlike oxygen isotope, ion composition is a nonconservative characteristic; it can show how the water ran down the watershed. The part of water that ran down over a glacier surface and then through stream channels doesn't get enriched with dissolved salts and has a relatively low mineralization, not substantially different from the original values (Table 1). Ground water and water that ran down over a non-glacier surface, filtrating through comminuted surficial deposits, is significantly greater enriched with dissolved salts, which is expressed in the value of electrical conductivity. Estimated conductivity of this component reaches 105 µS/cm (Table 1).

Due to complexity of water flow feed structure in alpine conditions, an electrical

Table 1. The $\delta^{18}O$ values and conductivity in components of river runoff in 2014

	Winter Snow	Spring Snow	Firn	Ice	Rain	Ground-water
Average $\delta^{18}O$, ‰	-14.6	–7.3	–7.3	–12.8	–4.7	–11.5
Range of variation $\delta^{18}O$, ‰	–12.32… –19.0	–6.76 … –7.68	–7.64… –13.75	–9.65 … –14.36	–1.2… –11.7	–11.13 … –11.89
Average Conductivity, µS/cm	11.6	8.67	13.3	15.1	12.3	96.7
Range of variation	6.4…33.5	7.36…9.71	6.14…22.5	9.8…39.6	-	83.2…105

conductivity and $\delta^{18}O$ balance equation was derived for seasons, when it is possible to neglect some of the components in order to obtain a needed number of variables (Vasil'chuk et al. 2016, Chizhova et al. 2016). In the end of the ablation season (Mid-August – September), it is possible to neglect the seasonal snow component, as it is generally almost completely melted away by this time. Thus, the following system can be drawn:

$$\begin{cases} \delta^{18}O = (q_i + q_f)\delta^{18}O_{if} + q_{gr}\delta^{18}O_{gr} + q_p\delta^{18}O_p \\ q_i + q_f + q_{gr} + q_p = 1 \\ M = (q_i + q_f)M_{if} + (q_{gr} + q_p)M_{gr} \end{cases} \quad (1)$$

where indexes i, f, gr, and p denote ice, firn melt, ground water, and liquid precipitation; parameters without indexes refer to the Djankuat River water, q is a share of each component in total runoff, and M is conductivity.

Solution of linked (b) and (c) equations in system (1) provided opportunity to estimate the base flow share in the Djankuat River runoff for days without significant precipitation. In September 2014, it varied from 30% to almost 100%. Calculated ground water discharge for this period was practically constant (0.45, on average, from 0.36 to 0.64 m^3/sec, Fig. 5). Value of ground water discharge for the days with significant precipitation is interpolated, which is admissible due to high level of persistence of this component of river flow. Further, the co-solution of (a) and (b) equations with the known value of groundwater allows separating the melt and precipitation components in the total Djankuat River runoff (see Fig. 5). Runoff

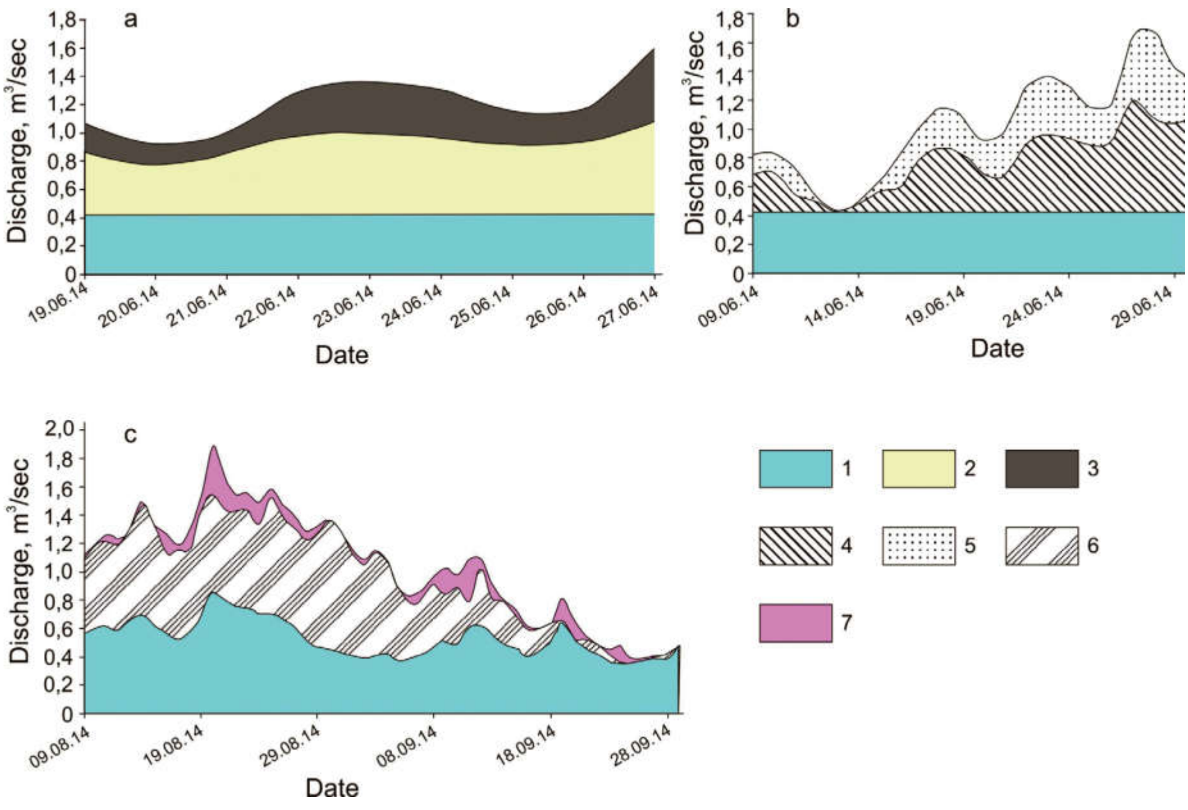

Fig. 5. The Djankuat River hydrograph separation: a – for June 2014 using ionic balance equation (2), b – for June 2014 using isotope balance equation (3), c – for September 2014 using system of equations isotope, ion and water balance (1) from (Vasil'chuk et al. 2016): 1 – base flow, 2 – snow melt on non-glacier territory 3 – snow melt on glacier, 4 – winter snow melt, 5 – spring snow and precipitation, 6 – ice and firn melt, 7 – precipitation.

formed due to ice and firn melting gradually decreases to the end of the ablation period and runs dry in late September. That illustrates process of seasonal melt water resources drainage from the Djankuat River basin at the end of the ablation season.

An unessential difference in isotope composition of firn and ice in terms of ™^{18}O does not make an attempt to separate this components by solving the system (1) credible.

spring snow had a substantial share in the Djankuat River runoff in June 2014 (15–20%). That makes it possible to conclude that under the condition of dry winter 2014, if not for heavy spring snowfalls, river runoff in the region in 2014 would be lower than the long-term average.

For the middle phase of ablation period (July), such a system of balance equations cannot be solved due to the insufficient number of equations allowing to eliminate one or the other variable.

$$\begin{cases} M = q_{sn}^{GI} M_{sn} + (q_{sn}^{NGI} + q_{sr}) M_{gr} \\ q_{sn}^{GI} + q_{snc}^{NGI} + q_{gr} = 1 \end{cases} \quad (2)$$

$$\begin{cases} \delta^{18}O = q_{snw}\delta^{18}O_{snw} + q_{snc}\delta^{18}O_{snc} + q_{gr}\delta^{18}O_{gr} \\ q_{snw} + q_{snc} + q_{gr} = 1 \end{cases} \quad (3)$$

The corresponding system of balance equations for the beginning of ablation period (June) is more complex. Two different systems should be drawn in the context of ionic balance and isotope balance:
where qsnGI and qsnNGI are shares of snow melt in the glacierized and non-glacierized parts of the watershed and qsnw, qsnc are shares of warm and cold snow melt, correspondingly.

Here we assume, firstly, that ice melt is insignificant for the beginning of ablation period and can be neglected, secondly, that the snow melt water, running down over a non-glacierized surface, filtrating through comminuted surficial deposits is enriched with salts to the rate of ground water, on average.

The system (2) can be solved if we exclude one variable; for example, we can accept the ground water discharge to be similar to the ground water discharge in August. Then, a section of the Djankuat River hydrograph in June 2014 can be divided in base flow (25–40% during the concerned period), snow melt on the glacierized part of the watershed (40–45%) and snow melt on the non-glacierized part of the watershed (15–30%) (Fig. 5).

The same assumption allows solving the system (3). According to the results (Fig. 5),

CONCLUSIONS

New results on alpine rivers water regime formation were obtained, which is extremely important in the context of increase in extremeness of the hydrological regime in the North Caucasus. The study was carried out for the Djankuat River basin which was chosen as representative of the North Caucasus during the International Hydrological Decade.

For two seasons (2013 and 2014), the isotopic characteristics of the Djankuat snowmelt runoff have been identified. Superposition of lag waves of different components of river flow results in a complex shape of the alpine river hydrograph. Application of the energy balance model of snow and ice melt with distributed parameters allowed identifying the Djankuat River runoff response to glaciers melt regime and seasonal redistribution of melt water. The diurnal amplitude of oscillation of the Djankuat River runoff in the days without precipitation is formed by melting at almost snow-free areas of the Djankuat glacier tongue. Snowmelt water from the non-glacierized part contributes to the formation of the next-day runoff. A wave of snow and firn melt in upper zones of the glacier flattens considerably during filtration through snow and run-off over the surface and in the body of the glacier. This determines a general significant inertia of the Djankuat River runoff, reflected in high rates of autocorrelation and a considerable scatter of the points on the curve of dependence of daily runoff on the total daily melting. Not all meltwater reaches the gauging station during the ablation season. Some part of melt water is stored in natural regulating reservoirs of the watershed that supply the Djankuat River flow during winter.

Simulation of changes in the glacier-derived liquid runoff responding to anticipated climate change and progressive deglaciation has shown that if the counter-radiation of the atmosphere increases by 1.5 W/m^2, the mean air temperature will increase by 4°C, the debris cover will increase by 180%, the atmosphere transparency index will decrease by 5%, and Djankuat glacier's melting rate will increase by 12–40%, depending on an elevation-slope zone of the glacier. Intensification of glacier melting can dramatically affect the occurrence of dangerous hydrological phenomena in the North Caucasus. With the decrease in area of glaciers in the Djankuat River basin after the increase in melt water recourses at some certain level a decrease will start. If Djankuat glacier shrinks by 30%, which corresponds to the changes that occurred from 1910 to 1999, a decrease in the volume of Djankuat glacier melting will be 8%.

Due to complexity of water flow feed structure in alpine conditions a solution of the ionic and δ18O balance equation was carried out for the seasons, when it is possible to neglect some of the components in order to reach a needed number of variables. A substantial excess of ™^{18}O content in spring snow over winter snow allowed distinguishing this component in the Djankuat River runoff in June. It was rather significant in ablation period of 2014 due to anomalously high spring snowfall that year. Unlike $\delta^{18}O$, mineralization is a non-conservative characteristic; it can show how the water ran down the watershed: over the glacier surface and then through stream channels or over a non-glacierized surface, filtrating through comminuted surficial deposits. Solution of the conductivity balance equation allows identifying the base flow component in the Djankuat River runoff in August and separating the glacierized snow melt component from snow melt on the non-glacierized part of the watershed.

In general, the isotopic hydrograph separation showed that in June 2014, melting spring snow contributed about 15–20% to the Djankuat River runoff; on some days, the input of this component reached 36%. The contribution of winter snow melting ranged from 20% in the beginning of the month to 50% at the end of June 2014.

For August-September 2014, the contribution of groundwater ranged from 30% to almost 100%, the contribution of rainfall ranged from 0 to 30% (an average of 6% for the period), and the part of melt water from the firn and ice was between 0–70% (average 38.6%).

In further study we plan to use other natural markers, such as hydrogen isotope composition and macrocomponents of hydrochemical composition in order to meet the needed number of balance equations in a system to perform a full hydrograph separation.

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Rets Ekaterina, PhD in geography, Research Associate, Water Problems Institute. Her main scientific interests are mountain hydrology, modeling of hydrological processes, and programming. Ekaterina Rets is highly involved in several project on representative alpine river basins in the North Caucasus and Central Asia, field work in alpine areas, and teaching a course in mountain hydrology. Her goal is to investigate poorly understood mechanisms of flow formation and origin of dangerous hydrological processes in mountainous areas.

Chizhova Julia, PhD in geography, Senior Researcher of the Laboratory of Isotope Geochemistry and Geochronology, IGEM RAS. In 2007 she began her employment in the mass-spectrometry laboratory. Her research interests are associated with the use of stable isotopes in permafrost, meromictic lakes, glacier ice, snow, and glaciers research, and isotope study of origin of hydrological processes in mountainous areas. She is a co-author author of research monograph and text book "Stable isotope geochemistry of atmosphere and hydrosphere" published in 2013 in the series "Isotope Ratios in the Environment".

Budantseva Nadine, PhD in geography, Senior Research Scientists of the Department of Landscape Geochemistry and Soil Geography of the Lomonosov Moscow State University. In 2007 she began her employment in the mass-spectrometry laboratory. Her research interests are associated with the use of stable isotopes in ice wedge, pingo, lithalsa, massive ice, meromictic lakes, and glaciers research, and isotope study of the origin of hydrological processes in mountainous areas. She is a co-author of research monograph and text book "Stable isotope geochemistry of atmosphere and hydrosphere" published in 2013 in the series "Isotope Ratios in the Environment".

Frolova Natalia, DSc in Geography, Professor of the Department of Hydrology of the Lomonosov Moscow State University. Member of the IAHS, a Member of the Hydrological Commission of the International Geographical Union. Scientific interests: estimates and forecast of river flow, dangerous hydrological processes, and mountain hydrology.

Kireeva Maria, PhD in geography, Senior Researcher of the Department of Hydrology of the Lomonosov Moscow State University. Her main scientific interests are mountain hydrology, modeling of hydrological processes, and programming.

Loshakova Nadezhda, a first year Master program student of the Lomonosov Moscow State University, Department of Hydrology. Her main scientific interests are mountain hydrology and glaciology; she conducted filed research in the Caucasus (Djankuat glacier), the Eastern Sayan Mountains, and the Scandinavian Alps (Tarfala Valley ,Sweden).

Tokarev Igor, PhD. in geology, Senior Researcher of Resource Center "Geomodel", Research Park of Saint-Petersburg State University (Saint-Petersburg, Russian Federation). Specialist in the isotope hydrology and hydrogeology, using δ2H, δ18O, 3H, δ13C, and δ15N environmental tracers, and 3H/3He, U/4He, and 14C groundwater dating. His main scientific interests are associated with climate variations and anthropogenic impact on groundwater and aquatic system. He has practical experience in water management and groundwater flow and mass-transport investigation. He studied water balance and water quality formation, e.g., estimation of the potable groundwater resource in province Almeria (Spain), the Naryn river balance in Kyrgyzstan (Central Asia), and in several regions of Russia. He also studied the clay formations for the underground radioactive wastes repository construction.

Vasil'chuk Yurij, DSc in Geology and Mineralogy, Professor of the Department of Landscape Geochemistry and Soil Geography of the Lomonosov Moscow State University. He has held professor positions at the Cryolithology and Glaciology Department of the Moscow State University in 1996, and was appointed to the positions of Full Professor at the Department of Landscape Geochemistry and Soil Geography in 2009 and Head of the mass-spectrometry laboratory. His research interests are associated with the use of stable and radioactive isotopes in ice wedge, massive ice, palsa, lithalsa, pingo, glaciers, and meromictic lakes research, as well as in isotope studies of soils and landscapes and the origin of hydrological processes in mountainous areas. He was elected to the Russian Academy of Natural Sciences in 2004. He is the author of three university-level textbooks and 15 monographs.