INTERRELATION BETWEEN GLACIER SUMMER MASS BALANCE AND RUNOFF IN MOUNTAIN RIVER BASINS

ABSTRACT. Measurements of summer mass balance $B_s$, made over the period 1946-2016, on 56 continental glaciers, located in the basins of mountain rivers in 14 countries, were analysed for the purpose of resolving several tasks: (a) constructing physically based interrelations between river flow $W_{bas}$ and $B_s$; (b) estimating the representativeness of local measurement of $B_s$ for enhancement of hydrological computations and for control of modelled values $W_{bas}$; and (c) use of time series of $B_s$ for the evaluation of norms and extrema of $W_{bas}$. Results of the study of the outlined problem serve as the basis for making the transition of local glaciological characteristics to the basin-wide level by using the relationship between runoff and summer balance of glaciers. It includes also analysis and conclusions on the spatial and temporal homogeneity of averaging glaciological mass balance data by the sampling method.

KEY WORDS: summer mass balance, glacier runoff, glaciers representativeness, extremes and norm, multi-year series, statistical averaging

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INTRODUCTION AND OBJECTIVE OF THE STUDY

According to the definitions in Kotlyakov (1984), Kotlyakov and Smolyarova (1990), and Cogley et al. (2011), the summer balance $B_s$ is equal to the change in the glacier’s mass starting from the time of maximum of snow accumulation to the end of the ablation period. During this interval of time, it is possible to determine the integral value of $B_s$ as a whole for the season, or for the specific ten days/months inside the year. As a result of applying the best methods and techniques of measurements, the obtained volume of $B_s$ characterizes output of melt water from the area of a glacier, which is necessary to calculate and forecast the river’s runoff formed by the melting snow and ice.

At present, the continuous measurements $B_s$ with the minimal number $N_{min} \geq 10$ of yearly data during 1946-2016 are available (Dyurgerov and Meier 2005; Fluctuations of Glaciers Database 2017) on a 56 continental glaciers, which distributed extremely unevenly on the Earth, see Fig. 1. Similar spatio-temporal distributions of annual mass balance $B_s$ for 144 glaciers illustrates Fig. 3a-b, prepared by data from (Mernild et al.
For this figure, we used decadal averages of $B_s$ during 1971-2008.

The list of 56 glaciers selected for $B_s$ analysis is given in the Table A1. In this set of data, the adopted value of $N_{\text{min}}$ satisfies more or less to statistical requirements for correct averaging. Principally, such empirical sample have to be equal to not less than 15 years. However, following known rules of statistic leads to diminishing the size of glacier sample. In particular, at $N_{\text{min}} \geq 15$ it will consist 45 instead of 56 glaciers with long-term asynchronous data of $B_s$. Zemp et al. (2015) concluded, that for climate change assessments with >30 observation years, the glaciological dataset currently contains 37 reference glaciers.

There are exist opinion (Dyurgerov and Meier 2005; Zemp et al. 2009; Fluctuations of Glaciers Database 2017, and many others), that glaciers, included in WGMS mass balance network are considered a priori as reference or representative for regional/global monitoring of changes in the annual mass balance $B$, and its components (winter $B_w$ and summer $B_s$ balances) in glacier populations. Analysis (Kotlyakov et al. 1997; Braithwaite 2009; Fountain 2009; Konovalov 2015; Zemp et al. 2009) based on the 60-years information on $B_w$, $B_s$, and $B$, at such reference glaciers has revealed the following properties of the WGMS network for measurements the glacier mass balance. 1) Selection of the so-called “representative/benchmark” glaciers is often basing on the principle of lowest cost for fieldwork instead of previous analyzing the spatial distribution of area, altitude-morphological and other characteristics of glaciers in the corresponding population. 2) Predomiance of European data leads to distortion of global average values of annual and summer mass balances of glaciers. The amount of distortion is unknown because averaging measurements on “reference” glaciers ignores regional accumulation and ablation patterns. 3) Completeness of the series and the timing of observations is very low, due to many omissions.

The other problem of using initial data on $B_s$ (Dyurgerov and Meier 2005; Fluctuations of Glaciers Database 2017) for regional/global averaging is their significant asynchrony. Table 1 illustrates the asynchrony of $B_s$ yearly data in ten-year periods during 1946-2015.

Currently, the vast majority of glaciological publications contain climatic, physical and dynamic characteristics on the regime of individual glaciers having local spatial and temporal distribution. The peculiarity of calculations and forecasts of runoff at the scale of mountain watersheds is the necessity of estimating the annual/seasonal volume of melt water $W_{bas} = W_{snow} + W_{gl}$ formed on the total area of $F_{bas}$ river basin, above the outlet hydrologic station. Here $W_{snow}$ is the volume of snowmelt and $W_{gl}$ – is glacier runoff. In models (e.g. Borovikova et al. 1972; Rets et al. 2011, 2017,2018; WaSiM Model 2015) for rivers of snow-glacial type, the catchment area presented as a set of elementary sites having known plane and altitude coordinates, parameters of exposure and slope of the surface. The total volume of water formed at all elementary sites is using to transform it into a flow hydrograph. In order to assess the quality of modeled $W_{bas}$ we may use the initial measurements of ablation/summer mass balance. Similar assessment the modeled values of $W_{bas}$ can be performed by comparing the measured runoff and calculated one on

| Index | Ten-year time intervals |
|-------|------------------------|
|       | 1946-55 | 1956-65 | 1966-75 | 1976-85 | 1986-95 | 1996-2005 | 2006-2015 |
| M     | 20      | 109     | 293     | 337     | 381     | 304      | 219       |
| $M_{\%}$ | 3.4  | 18.5    | 49.7    | 57.1    | 64.6    | 51.5     | 37.1      |

$M$ – is actual number of measurements $B_s$ for ten-years, $M_{\%}$ – is percentage of $M$ from possible maximum $M_0 = N_{gl} * 10$, where $N_{gl}$ is total number of selected glaciers in the each decade, i.e. 56 in our case.
Fig. 1. Number of years with B₃ data on glaciers in different states within 1946-2016. Reference on source of information see in the text.

Fig. 2. Monthly runoff of Vernagtferner River in May-October. Reference on data source see in the text.

Fig. 3. Temporal distribution of B₃ data (a), and spatial distribution of averaged B₃ data (b). Reference on source of information for figures a-b see in the text.
the basis of application the equation of the annual water balance (Konovalov 2014; Konovalov 2015; Konovalov and Pimankina 2016).

The objectives of our research are the following. a) To understand how suitable current $B_s$ data in (Dyurgerov and Meier 2005; Fluctuations of Glaciers Database 2017) for statistically substantiated spatial and temporal averaging. It means that our assessment concerns only existence or absence of data and not of their quality. The last one characteristic needs rigorous analysis for each case, but not fulfilled yet, and one may discover not compatible data of $B_s$ for the same glacier in different sources. (b) To study physically based relationships between $W_{bas}$ and $B_s$ for simplified verification of modelled values of $W_{bas}$. c) To use time series $B_s$ to characterize the norms and extremes of $W_{bas}$. d) To verify the possibility of spatial extrapolation of $B_s$ data, obtained on glaciers, which have been considered as representative/reference in the WGMS network.

**STUDY REGION, OBJECTS AND METHODS**

The regions of and subjects for the present study are continental glaciers of the Earth, contained in the system of WGMS - World Glaciers Monitoring Service (Dyurgerov and Meier 2005; Fluctuations of Glaciers Database 2017). Several glaciers suitable for our analysis are in the Table 2. Their number is mainly limited of extremely rare or inaccessi- ble hydrological information at runoff measurement stations, have located near the glaciers with $B_s$, $B_w$, and $B_d$ data. Information on the runoff for the rivers of snow-glacial type are taken from the special glaciologi- cal editions and hydrological reference books such as the following: Glacier Aktru 1987; Bodo 2000; Dahlke et al. 2012; Glacier Djankuat 1978; Escher-Vetter and Reinwarth 1994; Kamnyanskiy 2001; Krimmel 2000; USGS Alaska Water Science Center; Vilesov and Uvarov 2001. At selecting the time interval for averaging the runoff and $B_s$ data, took into account the interannual distribution of runoff at the hydrological stations near the glaciers. A typical example of such distribution presented in Fig. 2. Source of data is Escher-Vetter and Reinwarth (1994).

High level correlation dependences $Q=f(B_s)$, presented in the Table 2, serve as a basis for obtaining empirical functions of distribution for $Q$ and $B_s$, building links between statistical probability (Prob) of flow and summer mass balance, and ultimately assessing the probability of extreme flow values.

**Table 2. Studied glaciers and correlation between runoff $Q$ and summer mass balance $B_s$**

| State       | Glacier name | $F_{bas}$ | $F_{gl1}$ | $F_{gl2}$ | $N$ | $R^2$ | $Q_1$ | $Q_2$ | $Q_3$ | $Q_4$ |
|-------------|--------------|-----------|-----------|-----------|-----|-------|-------|-------|-------|-------|
| Kyrgyzstan  | Abramova     | 55.5      | 26.1      | 47.0      | 21  | 0.80  | 0.84  | 0.84  | 0.89  |
| Austria     | Vernagtferner| 11.4      | 9.3       | 81.6      | 31  | 0.82  | 0.91  | 0.92  | 0.91  |
| Russia      | Djankuat     | 8.0       | 3.1       | 38.8      | 6   | 0.80  | 0.87  | 0.95  |
| Russia      | Maly Aktru   | 36.0      | 2.5       | 6.9       | 7   | 0.56  | 0.85  | 0.85  |
| Kazakhstan  | Centralny Tyuksu | 21.0    | 2.9       | 13.7      | 22  | 0.36  | 0.22  | 0.31  | 0.22  |
| USA         | Wolverine    | 31.3      | 18.0      | 57.5      | 37  | 0.22  | 0.25  | 0.26  | 0.27  |
| Sweden      | Stor         | 19.6      | 3.1       | 15.9      | 16  | 0.15  | 0.15  | 0.15  | 0.12  |

Definition of symbols: $R^2$ is coefficient of determination; $F_{bas}$ is area of basin above site of runoff measurement, km$^2$; $F_{gl1}$ is area of reference glacier, km$^2$; $F_{gl2}=F_{gl1}/F_{bas}$ in %. Hence, value $F_{gl2}$ reflects significance of reference glacier in a area of basin; $N$ is number of measurement years; $Q_s$ is average of $Q$(VI-VIII) as $f(B_s)$; $Q_1$ is average of $Q$(VI-IX) as $f(B_s)$, $Q_2$ is average of $Q$(VI-X) as $f(B_s)$, $Q_3$ is average of $Q$(V-X) as $f(B_s)$, $V$-$X$ are the months May through October.
Calculations of probabilities $Q$ and $B_s$ (empirical non-exceedance $X>x$) were done by the method from (Alexeev 1971):

$$p_i(x_i) = \frac{m(x_i) - 0.25}{N_i} + 0.5 \times 100$$  \hspace{1cm} (1)

where $m(x_i) = 1, 2, ..., N_i$ - the sequence numbers of the values $x_i$ after their arrangement in descending order.

Besides the determining empirical functions of distribution $Q$ and $B_s$, there included selection of the most appropriate type of standard function of probability distribution (see parameter $Freq B_s$ in the Table 3). The computer program in (Oosterbaan 1994) used for that purpose.

RESULTS AND DISCUSSION

In principle, the process of runoff formation from the glacier area and from the not glaciated surface measured on a point, located near the terminus of the glacier, includes such closely related characteristics as the intensity of melting, air temperature, solar radiation, clouds, and water vapor pressure in the air. This fact serves as a justification for the search for correlation $Q=f(B_s)$, which turned out to be quite successful on the example of four glaciers from seven in the Table 2. Variation in the coefficient $R^2$ for $Q = f(B_s)$ in the other three cases need further study, and they may be due to inaccuracies in determining the flow and/or summer balance $B_s$ of glaciers, which was corrected (e.g. Dyurgerov and Meier 2005; Fluctuations of Glaciers Database 2017) and turned out to be not compatible in different sources of data.

Examples of subsequent use of dependencies $Q = f(B_s)$ on the Vernagtferner and Abramova glaciers, used to obtain equations $Prob=f(B_s)$, $Freq B_s=f(B_s)$, $Prob Y_i÷Y_4=f(Prob B_s)$, are presented in the table 3. Here Prob is statistical probability, and $Freq B_s$ is the equation of the chosen standard function of probability distribution.

Forcing the line of dependences $Prob Y_i ÷ Y_4 = f(Prob B_s)$ through the origin of the coordinate axes in order to estimate the influence of the runoff from the non-glacial part of the basin leads to a slight decrease in the determination coefficient $R^2$. In this case, the values of $R^2$ for the glaciers Abramova and Hintereisferner in the order $Y_1÷Y_4$, as

| Table 3. Formulas for calculating the distribution functions of the mass balance $B_s$ |
|-------------------------------|-------------------------------|-----------------|
| Abramova Glacier | Vernagtferner Glacier |
| Prob $B_s$ / $Freq B_s$ | Prob $B_s$ / $Freq B_s$ | $R^2$ | Prob $B_s$ / $Freq B_s$ | Prob $B_s$ / $Freq B_s$ | $R^2$ |
| $Prob B_s = -0.05B_s + 137.1$ | $Prob B_s = -0.05B_s + 137.1$ | 0.79 | $Prob B_s = 0.92B_s + 3.9$ | $Prob B_s = 0.92B_s + 3.9$ | 0.85 |
| $Freq B_s = 1/(1+exp(A B_s + B))$ | $Freq B_s = 1/(1+exp(A B_s + B))$ | 0.74 | $Freq B_s = 0.95B_s + 2.5$ | $Freq B_s = 0.95B_s + 2.5$ | 0.90 |
| $A = -0.00246$ | $A = -2.29E-002$ | $B = 4.6$ | $B = 5.13$ | $B = 3.9$ | $A = 11.2$ | $A = 10.6$ |

| $Prob Y_i = 0.89Prob B_s + 5.5; \Delta=13.1$ | $Prob Y_i = 0.89Prob B_s + 5.5; \Delta=13.1$ | 0.72 | $Prob Y_i = 0.93B_s + 3.5$ | $Prob Y_i = 0.93B_s + 3.5$ | 0.86 |
| $Y_2 = 0.85Prob B_s + 7.6; \Delta=15.3$ | $Y_2 = 0.85Prob B_s + 7.6; \Delta=15.3$ | 0.72 | $Prob Y_i = 0.92B_s + 3.9; \Delta=11.2$ | $Prob Y_i = 0.92B_s + 3.9; \Delta=11.2$ | 0.85 |
| $Y_3 = 0.86Prob B_s + 6.9; \Delta=14.6$ | $Y_3 = 0.86Prob B_s + 6.9; \Delta=14.6$ | 0.74 | $Prob Y_i = 0.95B_s + 2.5; \Delta=9.0$ | $Prob Y_i = 0.95B_s + 2.5; \Delta=9.0$ | 0.90 |
| $Y_4 = 0.85Prob B_s + 7.5; \Delta=15.2$ | $Y_4 = 0.85Prob B_s + 7.5; \Delta=15.2$ | 0.72 | $Prob Y_i = 0.94B_s + 2.9; \Delta=9.6$ | $Prob Y_i = 0.94B_s + 2.9; \Delta=9.6$ | 0.89 |

Definition of symbols: $B_s$ is summer mass balance, mm; $Prob B_s$ is $B_s$ statistical probability by formula (1), in %; $Freq B_s$ is integral function of distribution, %; $R^2$ is coefficient of determination; $Y_i$ is equation to calculate $Prob Q(Jun-Aug)$ as function of $Prob B_s$; $Y_i$ is equation to calculate $Prob Q(Jun-Sep)$ as function of $Prob B_s$; $Y_i$ is equation to calculate $Prob Q(Jun-Oct)$ as function of $Prob B_s$; $Y_i$ is equation to calculate $Prob Q(May-Oct)$ as function of $Prob B_s$; $\Delta$ is RMS error of calculating $Prob Y_i÷Y_4$ in %.
in Table 3, are as follows: 0.78 (13.4), 0.70 (15.8), 0.73 (14.7), 0.70 (15.7) and 0.85 (11.3), 0.86 (10.8), 0.90 (9.1), 0.89 (9.7); the number in parentheses are the rms error of calculation Prob Y1÷Y4, in%.

As an analogue of the glacial flow \( W_{gl} \) it is also possible to use other known characteristics: data on the annual mass balance \( B_a \), AAR, relationships between areas of accumulation and the entire glacier, and ELA, altitudinal boundary of equality between accumulation and ablation at the end of the ablation period. Annual information on the listed variables (except ELA) for 1971-2008 is contained in the work of Mernild et al. (2013). For glaciers in Table 3 it was not found to be useful to replace \( W_{gl} \) with \( B_a \).

Spatial and temporal homogeneity of averaging mass balance data by sampling method

It is known, that the modern network of measurements of glacier mass balance components (\( B_a, B_s, B_w \)) includes several hundred objects (Dyurgerov and Meier 2005; Mernild et al. 2013; Zemp et al. 2015). Along with the diverse using of local time series on individual glaciers, the averaging of \( B_a \) and \( B_s \) is widely used on regional and global scales. For example, at averaging \( B_s \) over 10, 15, or 30 years during 1940-2016, in the sample remains unsynchronized spatial data only on consequently 56, 45, and 37 glaciers out of the total number of those in the WGMS network. Table 1 and Tables A1-2 present data density for decadal averaging of \( B_s \) for 56 glaciers and composition of the used sample. In addition to these, Tables 4-5 characterize the number of RGI 6 regions, where data of \( B_s \) are available for spatio-temporal averaging. After processing such information, Zemp et al. (2015) have determined decade-average \( B_s \) values for 19 regions of RGI 6 (RGI Consortium 2017).

As can be seen, the completeness and synchronicity of the time series \( B_a \) and \( B_s \) presented in Fig. 1, 3, Tables 1, 4-5 and Tables A1-2, raise great doubts about the statistical validity of regional and global averages of \( B_a \) and \( B_s \). Accordingly, this is reflected in the findings on the impact of these characteristics on the associated other natural processes, for example, relation to the climate change, changing the level of the ocean, etc.

Hydrological justification of the representativeness \( Q_f \) \( B_s \)

Given the way in which was formed an empirical sample of 56 glaciers (see paragraph Introduction and Objectives of the

Table 4. Density of RGI 6 regions for spatial averaging of total data on \( B_s \)

| Index | 1941–50 | 1951–60 | 1961–70 | 1971–80 | 1981–90 | 1991–2000 | 2001–10 |
|-------|---------|---------|---------|---------|---------|-----------|---------|
| \( M \) | 3       | 7       | 10      | 15      | 17      | 16        | 16      |
| \( M_1 \ % \) | 15.8    | 36.8    | 52.6    | 78.9    | 89.5    | 84.2      | 84.2    |

\( M \) – is actual number of RGI 6 regions, \( M_1 \ % \) – is percentage of \( M \) from possible maximum of RGI 6 regions, i.e. 19 in our case.

Table 5. Density of decades for temporal averaging of \( B_s \) at 19 regions of RGI 6

| Index | Numbers of RGI 6 regions |
|-------|--------------------------|
| 1     | 2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17 18 19 |
| \( M \) | 6  2  7  2  6  2  5  3  5  7  4  3  4  2  4  7  5  4  6 |
| \( M_1 \ % \) | 86  29  100  29  86  29  71  43  71  100  57  43  57  29  57  100  71  57  86 |

\( M \) – is actual number of decades in RGI 6 regions, \( M_1 \ % \) – is percentage of \( M \) from possible maximum of decades with \( B_s \) data in RGI 6 regions, i.e. 7 in our case.
research), it is evident that such a scanty sample cannot be representative regarding population of 215,547 (RGI Consortium 2017) continental glaciers on Earth. However, an estimate of the spatial representativeness of the summer mass balance measured on individual glaciers is of interest for the rationalization of methods for calculating and forecasting the flow of rivers fed by snow and ice melt.

The solution of this problem, obtained with the example of river basins in the Pamir-Alai and Central Caucasus (see Table 6), is based on an assessment of the effect of using local measurements of $B_s$ as one of the main or additional arguments in the equations of multiple linear regression for calculation of the runoff for June-September and June-August. In this case we adopted model of river runoff $W_{bas}$ as a regression function of precipitation $P$ and air temperature $T$, i.e. $W_{bas}=f(P, T)$, where both arguments cover the certain characteristic intervals of time. In this combination of independent variables the seasonal air temperature is considered as the index of the thawed component of the river flow. The regression analysis also includes calculating, by means of Alekseev’s method (1971), the relative contributions $\delta$ of independent variables $T$, $P$, and $B_s$ for describing $W_{bas}$ variance for VI-VIII, VI-IX, and IV-IX (June-August, June-September, and April-September) seasons. The expression in order to estimate $\delta$ for the independent variable no 1 has the general form:

$$\delta_1 = \frac{r_{01}^2}{(r_{01}^2 + r_{02}^2 + r_{03}^2)}$$

where $r_{01}^2$ – is the square of paired correlation between the given function, labelled as 0, and independent variable no 1. And so on for the next variable in the numerator of (2) and the rest of the parameters $\delta$.

Multi-year mass balance measurements, available on the Abramova and Dzhankuat reference glaciers (Dyurgerov and Meier 2005; Fluctuations of Glaciers Database 2017; Kamnyanskiy 2001), were used for modeling seasonal runoff $W_{bas}$ in river basins of the Pamir-Alai and Central Caucasus, respectively. Local measurements of $B_s$ on these glaciers might be considered representative at the basin scale, if it is true that $B_s$ as an additional independent variable provides an increase in the coefficient of multiple linear correlation for equation $W_{bas}=f(P, T)$. And also, if $B_s$ can be used instead of $T$ in the equation $W_{bas}=f(P, T)$ for a certain basin.

After performing numerical experiments it is found out, that only in one catchment (the Akbura River) of six in the Pamir-Alai, the empirical equations $W_{bas}=f(P, T)$ for calculating the river runoff for IV-IX, VI-IX and

| River basin     | Outlet point | $F_{bas}$ km$^2$ | $\delta F_{gl}=F_{gl}/F_{bas}$ % | R1/R2 |
|-----------------|--------------|------------------|----------------------------------|-------|
| Isfara (P-A)    | Tashkurgan   | 1560             | 8.3                              | 0.78/0.73 |
| Sokh (P-A)      | Sarykanda    | 2480             | 10.2                             | 0.91/0.79 |
| Shahimardan (P-A)| Djidalik     | 1180             | 4.0                              | 0.70/0.69 |
| Isfayram-1 (P-A)| Uchkorgon    | 2200             | 4.6                              | 0.72/0.56 |
| Isfayram-2 (P-A)| Lyangar      | 697              | 14.6                             | 0.76/0.60 |
| Akbura (P-A)    | Papan        | 2200             | 5.0                              | 0.82/0.83 |
| Baksan-1 (CC)   | Zayukovo     | 2100             | 6.7                              | 0.61/0.39 |
| Baksan-2 (CC)   | Tegenekly    | 210              | 27.1                             | 0.58/0.73 |

$R1$ – coefficient of correlation for equation $W_{bas}=f(P, T)$, $R2$ – the same parameter after using $B_s$ instead of $T$ in equation for $W_{bas}$.
VI-VIII included data of the summer mass balance $B_s$ on the Abramova glacier, located outside the Akbura basin. Here we used the next time averaging for the independent variables $P$, $T$, measured at meteorological stations: $P(X-IV)$, $T(VI-VIII)$.

As it seen from the Table 7, measurements of $B_s$ on the Abramova glacier we may consider as basin-wide representative for calculating of seasonal runoff in the neighboring Akbura watershed by equation $W_{bas}=f(P, T, B_s)$.

For estimating basin-wide applicability of the $B_s$ frequency distributions obtained on the Abramova reference glacier (see Table 3), we used again $W_{bas}$ data for the six Pamir-Alay river basins. After correlation analysis as of all basins, the highest $R^2$ coefficient between frequencies of $W_{bas}$ and $B_s$ for VI-IX and VI-VIII was in the Sokh river basin. There, the empirical equation for computing cumulative frequency distribution of $W_{bas}(VI-VIII)$ by the corresponding of $B_s$ data at the Abramova Glacier has coefficient of correlation, equal to 0.66. After that, for transition from the obtained frequency distribution value to the runoff data we should use equation $W_{bas}(VI-VIII) = f(\text{Freq } W_{bas}(VI-VIII))$, obtained earlier for the Sokh river basin. Consequently, this analysis also confirms limited basin-wide applicability of the $B_s$ frequency distributions obtained on the Abramova reference glacier.

CONCLUSION

1. Research of the outlined problem, illustrated by the Tables 1-7 and Appendix A, (available at https://ges.rgo.ru) serves as the basis for the practically important transition from the local to the regional level of glaciological assessments by means of using the relationship between runoff and summer balance of glaciers. In this case, as repeatedly shown, the contribution of $B_s$ in the formation of the river flow and, accordingly, the correlation $Q=f(B_s)$ becomes weaker as the relative area of the glaciation decreases above the site of runoff measurement. However, it is still possible to use parameters (mean, extremums, coefficient of variation, etc.) of empirical functions of spatial and temporal distributions of $B_s$ and $\text{Prob } B_s$, regardless of flow data and data from the World Glaciers Monitoring Service. The possible source of getting wide spread information about $B_s$ is its determination (Davaze et al. 2018) as a function of the surface albedo of a glacier, measured by remote sensing at the end of ablation season.

2. The investigation has shown that the correlation coefficient between the total summer mass balance, characterizing the glacier’s water output, and the river runoff $W_{bas}$ at the hydrological outlet site for the time intervals: June-August, June-September, June-October, and May-October varies in a wide range: from 0.97 to 0.39 (Table 1). Study and understanding of this is insufficient.

3. The hydrological representativeness of a glacier is a new characteristic, of practical importance for basin-wide tasks of hydrology and glaciology. For its evaluation, we propose to replace the seasonal air temperature with the summer mass balance of glaciers $B_s$ or to include $B_s$ in the multi-

| Months  | Mean $W_{bas}$, m$^3$/s | Equation for calculating $W_{bas}$ | $R^2$ | rmse  | $\delta P$ | $\delta T$ | $\delta B_s$ |
|---------|-------------------------|-----------------------------------|------|-------|-----------|-----------|------------|
| IV-IX   | 32.4                    | $18.1-0.012B_s+5.77T+0.035P$     | 0.70 | 3.0   | 0.41      | 0.21      | 0.38       |
| VI-IX   | 38.7                    | $23.8-0.016B_s+7.30T+0.038P$     | 0.67 | 3.9   | 0.35      | 0.17      | 0.48       |
| VI-VIII | 44.3                    | $27.2-0.012B_s+8.95T+0.044P$     | 0.67 | 4.8   | 0.33      | 0.16      | 0.51       |

**Table 7. Parameters of equations for calculating seasonal runoff $W_{bas}$ in the Akbura river basin**

**Definition of symbols:** $R^2$ – coefficient of determination; rmse – root mean square error of calculated $W_{bas}$ in m$^3$/s; $\delta P$, $\delta T$, $\delta B_s$ – are consequently relative contributions of precipitation $P$, air temperature $T$, and $B_s$ for describing $W_{bas}$ variance.
multiple regression equations for calculating the runoff of rivers fed by melting of snow and ice. This method can be recommended for at least of some glaciers in the existing network of the WGMS (World Glacier Monitoring Service).

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