PAST AND PROSPECTIVE CHANGE IN STATE OF CENTRAL ASIAN GLACIERS

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Abstract. The paper presents estimations long term change of glaciers area and regime of their runoff in the Aral Sea Basin. This new information is based on materials of glaciers inventorying, data of remote sensing from satellites and modeling hydrological regime of glacier aggregations. Detailed results considered below include the following: (a) Quality and homogeneity of regionally generalized glaciological data; (b) Long term change of glaciers area in the Central Asia watersheds during 1961-2020; (c) Methods on calculating past and projected glaciers area; (d) Modeling and computation glaciers runoff; e) Spatial and temporal variability glaciers total melting and runoff.

Introduction

Comprehensive analysis and forecast long term regime of glaciation at the scale of large river basins or mountain areas is one of the most important and urgent problem of the up-to-date glaciology. Geometrical parameters of glaciers and their snow and ice melted output at the scale of large river basins are the most informative and widely used in theoretical and applied research. In comparison with historical ranges of routine hydrological and meteorological observations, the quality and quantity of similar glaciological information is far behind. Very limited number (one-four) of regional temporal cuts available for description of glaciers state is obviously not enough for valuable and statistically substantiated research of relationship between fluctuations of climate and characteristics of glaciers regime. Particularly, author's attempt to find published information on the size of Asia continental glaciation has resulted to the following. By data in (Dolgushin, 2000) and (Dyurgerov, 2002) its area was estimated correspondingly as 119730 km^2 and 120680 km^2, but latest Ohmura's (2007) value was 185204 km^2 by 1989 year. Large discrepancy between different sources exists also for glaciers area in separate states in the Asia continent. For example, according to Ohmura (2007) the number of glaciers in China is 46377 and their area 56481 km2, but on the Website of Chinese Glaciers Inventory (http://wdcdgg.westgis.ac.cn/DATABASE/Glacier/Glacier.asp) the same parameters were given at first as 51250 and 69069 km^2 but later as 46394 and 60027 km^2. At that, data on individual objects in the China Inventory of Glaciers related to the very broad temporal range: from 1928 till 1986 year. By data of Joe and Sandeep, (2005) total values of glaciers number and area in Nepal and Bhutan equal to 3577 and 6640.6 km^2 but following to Ohmura (2007) the same parameters are 226 and 7500 km^2. In the several published materials (Joe and Sandeep, 2005; Mool et al, 2003; Ohmura, 2007; and others) user come across with significant discrepancy in data on glaciers area for India and Pakistan. List of the same examples and disadvantages of current regional information on state and fluctuation glaciers area could be easily continued.

Long term variability of annual, seasonal and monthly values of glaciers runoff is the subject of great applied interest. Runoff from the glaciers area in a large river basin presents integral result of ablation process for hundreds and thousands individual glaciers. Regional solution to the problem of modeling and computation long term variability of glaciers runoff, taking into account peculiarities of its formation, was suggested in (Konovalov, 1979, 1985, 1993, 2000, 2006). The last version of author's model envisages calculating influence of glaciers fluctuation on their runoff. Rather good quality of computed values is confirmed (Konovalov, 2007) by means of determination all components of water balance. Below are described results, obtained by author, on the regional estimating key characteristics of glaciers state – their area and spatial-temporal variability statistical parameters of ranges of glaciers runoff within the Central Asia river basins.

Fluctuation glaciers area

Total glaciers area in a river basin is important but not single parameter of their regime. Large scientific and applied importance has also: water resources of glaciers or their volume, annual mass balance, glaciers runoff, glacier's coefficient and other altitudinal and area characteristics both separate glaciers and their groups and aggregations. Aggregation or glaciers integrity consists of discrete objects whose characteristics listed above and others are changing in space and time. Comparative analysis to the spatial and temporal variability of glaciers area and runoff have to be based on using data for total population of separate glaciers or their representative sample.

Homogeneity of initial data

It is necessary to use both unified method identification of glaciers boundary and the same statistical ensemble of objects and topography background in order to get pure estimation glaciers area change in different temporal cuts. Initial data used for monitoring glaciers state as a rule are not fitted to this condition. For example, boundaries morphological parts of glacier in the USSR Glaciers Inventory were determined by recognition on air-photo images in 1:24000 scale but at repeatedly inventorying (Schetinnikov, 1997) of the same objects were used data of space-photo survey in 1:200000 scale having lower resolution. Therefore reliability bounding of glaciers was less in the second case. Monitoring of glaciers state in upstream of the Amudarya river basin was continued (Konovalov&Desinov, 2007) by means of images obtained in 2000-2002 from satellites LANDAST 7 (scanner ETM+) and TERRA (scanner ASTER). Spatial resolution of those images varies from 15 till 30 m. Thus, only due to inhomogeneity of initial data there is arise not controlled error in the estimations glaciers area change. Particularly, usage different materials and methods for determination change of area of bare ice for 1955-1990 on glaciers within Northern slope of Zailiskiy Alatau gave scattering of final results from 27.6% till 32.0% (Severskiy&Tokmagambetov, 2005). Noticeable differences between field and remote sensing determinations the length of Austrian glaciers are reported in (Hall et al, 2003). In this case were used images from satellite IKONOS that have spatial resolution four meters.

Reliability glaciers bounding on any kind of their images essentially depends from a regime of summer snowfalls. Summer snow masks glacier boundary caused by annual or long term mass balance and makes doubtful comparison glaciers area determined in dry in wet ablation seasons. This problem could not be fixed because of coincidence between dates of snowfalls in certain region and its sounding from satellites has random character. Brief analysis on quality and homogeneity data on change of glaciers size shows that regional estimations on temporal fluctuations of glaciers area objectively include unavoidable and qualitatively indefinite errors. In one's turn inaccuracy in determination glaciers area influence on the quality estimation of water resources, mass balance and volume of glaciers runoff. These errors could be diminished by enlarging size of statistical samples of glaciers.

Glaciers area in the Aral Sea Basin

Area of glaciers has changed essentially in this region during the last centenary. Certain information on past and future state of glaciers is presented in the Table 1. It was obtained after compiling glaciers morphometry data (Ivan'kov, 1970; USSR Glaciers Inventory, 1971-1978; Schetinnikov, 1997), processing remote sensing images from satellite LANDAST 7 and TERRA, and by applying calculation methods (Agaltseva, Konovalov, 2005; Konovalov, Williams, 2005; Konovalov and Desinov, 2007).

Table 1 Long term change of glaciers area in the Central Asia watersheds

Basin/Region	Fgl km^2					dFgl km^2	dFgl %
	1961	1980	1991	2000	2020	1961-2000	1961-2000
Western Tienshan	171	147	133	120	107*	-51	-29.8
Matcha river	506	438	398	358	318*	-148	-29.3
Syrdarya (1)	548	450	408	367	326*	-181	-33.0
Syrdarya (2)	304	205	164	147	130*	-157	-51.6
Vakhsh river	**3779**	**3538**	**3413**	**3243**	**3073***	**-536**	**-14.2**
Panj Right Tributaries	**3548**	**2905**	**2780**	**2389**	**1998***	**-1159**	**-32.7**
Panj Left Tributaries	**4270**	**3956**	**3799**	**3642**	**3484***	**-629**	**-14.7**
Panj river at all	**7818**	**6861**	**6579**	**6031**	**5482***	**-1787**	**-22.9**
Amudarya upstream	**11597**	**10399**	**9992**	**9273**	**8555***	**-2324**	**-20.0**
All basins	13126	11638	11095	10265	9435*	-2860	-21.8

Note: Syrdarya (1) – left tributaries from Aksu mouth and below, Syrdarya (2) – left tributaries between Karadarya and Aksu mouths, * – glaciers area at the mean rate of summer air temperature equaled 0.007 ^{o}C/year for 2001-2020.

Rather significant shrinkage glaciers area in the Aral Sea Basin during 1961-2000 years corresponds well with estimations of glaciers fluctuations in the other mountain regions. Namely:

- As reported in Vilesov and Uvarov (2001) area and volume of glaciers during of 1955-1990 in Zailiiskiy Range (Kazakhstan) diminished on 29.2% and 32.3% correspondingly;
- By data Tao Che et al (2003) total area of glaciers in the Pumku river basin (Tibet, China) was equaled to 1556 km^2 in 1987 but in 2001 it become less on 14.5%;
- Batirov and Yakovlev (2004) determined that glaciers area in three river basins (Sokh, Shahimardan, Isfara) of Gissaro-Alai Range become less during 1957-2001 on 69 km2 or 16.6%;
- According to Kuzmichenok (2006) total glaciers area in Kyrgyzstan over 1950-1960 estimated as 8100 km^2, then over 1977-1980 it diminished till 7400 km^2 and by 2000 glaciers area again reduced till 6500 km^2. Thus, shrinkage of area during of 40 years equaled to 19.8 %;
- The paper of Stokes et al (2006) presents information on changes in the terminus position of 113 selected glaciers in the Caucasus region between 1985 and 2000. The vast majority (~94%) of the glaciers have retreated since 1985, with a mean retreat distance of 121m (8.1ma^{-1}).
- By using digitized glacier outlines inferred from the 1973 inventory and Landsat Thematic Mapper (TM) satellite data from 1985 to 1999, it was revealed in Paul et al (2004) that area reduction of all Alpine glaciers for the period 1985 to 1999 equaled to 22.0%.
- Repeatedly inventorying Austrian glaciers revealed that their area diminished on 17.1% during 1969-1998 (http://meteo9.uibk.ac.at/IceClim/inventory.html).
- Shrinkage of glaciers area ΔF_{GL} in the Northern Tien-Shan for 1955-1999. By Bolch (2006)

Characteristics	River Basins					
	Malaja-Almatinka	Bolshya-Almatinka	Levyj-Talgar	Turgen	Chon-Aksu	Chon-Kemin
ΔF_{GL} km²	-3,4	-8,7	-24,3	-13,0	-24,0	-6,3
ΔF_{GL} %	-37,6	-34,5	-33,6	-36,5	-38,2	-16,4

Scientific background which was used to get data in the Table 1 consists of several independent components.

1. Adjusting glaciers area values to the certain unified temporal cut. It was done by simple linear interpolation or extrapolation when we had at least two estimations of area.
2. Determination glaciers area F outside of known empirical temporal range. Firstly it could be done by extrapolation linear trend and secondly by means of equations:

$$F_{t+1} = F_t + \frac{dF}{dt}\Delta T \qquad (1)$$

and $$\frac{dF}{dt} = f(I_{Ac}, I_{Ab}) \qquad (2)$$

or $$\frac{dF}{dt} = f(\bar{T}_S) \qquad (3)$$

where $\Delta T = T_{i+1} - T_i$ is time interval, I_{Ac} and I_{Ab} are indexes of yearly accumulation and ablation. Instead of I_{Ac} was used sum of precipitation for characteristic season and instead of I_{Ab} - mean summer air temperature $\bar{T}_S$. More detail information on getting and using equations (1-3) is contented in Konovalov and Williams (2005) and Agaltseva, Konovalov (2005).

3. Recognition and digitizing glacier contours on remote sensing images and processing sets of such contours by means of known GIS software, e.g. MapWindow, IDRISI and others in order to calculate glacier areas.

Since method 2 plays significant role for estimation future glaciers area, Table 2 presents some independent data on results of quality control for this method.

Table 2. Comparisons glaciers area determined by different methods

Basin/Region	Determinations F_{gl} in km^2		ΔF, %
	$F_{gl} = f(\overline{T}_S)$	Other estimations F_{gl} and their sources	
Oigaing river (part) - TienShan	39.6	38.8 (Batirov, Yakovlev, 2003) ▲ 43.7 (Glazyrin, Schetinnikov; 2001a)	2.0 -10.4
Pskem and Chatkal rivers - TienShan	119.9	107.8 (Glazyrin, Schetinnikov; 2001a)	10.1
Gissaro-Alai mountain region	1503.7	1579.0 (Glazyrin,Schetinnikov; 2001b)	-5.0
Pumku river (Tibet, China)	1356.5	1330.0 (Tao Che et al.,2003) ▲	2.0
Obihingou river - Pamir	575.9	608.5 (author) ▲	-5.7
Kyzylsu West river - Pamir	397.3	449.7 (author) ▲	-13.2
Yazgulem river - Pamir	214.6	200.3 (author) ▲	6.7
Vanch river - Pamir	238.2	255.1 (author) ▲	-7.1

Notes: 1. $F_{gl} = f(\overline{T}_S)$ – results obtained according to the method in Agaltseva, Konovalov (2005), 2. symbol ▲ means, that glaciers area is determined by processing remote sensing images obtained from LANDSAT 7 and TERRA satellites. 3. ΔF is relative difference between the considered estimations.

As one may see the relative difference between glacier areas determined from remote sensing images and computed by dependence $F_{gl} = f(\overline{T}_S)$ varies from 2% till 13% that confirms reliability of the suggested method.

Completeness of data

It is known that perennial snow fields are component in the system of natural ice on the Earth. They are wide spread and occupy significant area in the large centers of contemporary glaciation like basin of Fedchenko Glacier, upstream of rivers Obihingou, Sauksai, Vanch, Yazgulem, Inylchek and others that located in Pamir and Tien-Shan. These perennial snow fields frequently but not obligatory adjoin to the accumulation area of glaciers (see fig. 1) and play essential role in forming local climate and mass balance of glacierized basins. Good example on studying perennial snow fields contented in (Kulkarni, et al 1999). However identification, inventorying and analysis regime of perennial snow fields is continued to be problem for future regional researches.

Modeling and computation glaciers runoff

The main sources of the river runoff formation within Aral Sea Basin are melting of seasonal snow and long-term storage of ice and firn, which are preserving in the numerous Pamir and Tien-Shan glaciers.

Regional determination of glaciers regime are necessary for analysis of their evolution at different scales, in the researches of water resources variability under climate fluctuation, for solving the problems of water consumption and forecasts of runoff. The specific character of the examined problem is that the data on the regime of water balance elements in the glacial areas can be obtained only by calculations. And it makes a high demand to the substantiation of description of runoff formation process in glacial areas. This process has a number of essential peculiarities in comparison with the areas of basin located beyond the glaciers. All these features were taken into account during developing the physic-and statistical regional model REGMOD of total ice and snowmelt process in glacial areas (Konovalov; 1979, 1985, 2006). A set of PC programs and informational base were elaborated for computation long-term series of glaciers hydrological regime by means of REGMOD model. The formula used in the REGMOD for calculation total volume of glaciers melting v_m in the moment t, has the form:

$$v_m(t) = M_c(\tilde{z}_{im}, t)S_{im} + M(\tilde{z}_i, t)S_i + M(\tilde{z}_f, t)S_f + M(\tilde{z}_{ws}, t)S_{ws} + M(\tilde{z}_{ss}, t)S_{ss} \quad (4)$$

Here $M_c = M \cdot f(h_c)$ is the intensity of ice melt under the solid moraine cover (*im*), *i* is the bare ice, *f* is the old firn, *ws* is the winter snow, *ss* is the summer snow, $f(h_c)$ is the function of extinction of ice melting under the moraine cover of the thickness h_c, $\tilde{z}$ - is mean weighted altitude for the S area of certain type of glacier's surface. To obtain data for the total melt volumes V_M and the ice-melt runoff W_{gl} it is necessary to summarize the appropriated components:

$$V_M = \sum_{d_{bp}}^{d_{ep}} v_m(t) \tag{5}$$

$$W_{gl} = \sum_{d_{bi}}^{d_{ei}} v_{im}(t) + v_i(t) + v_f(t) \tag{6}$$

where d_{bp} and d_{ep}- are dates of the beginning and the end of the calculation period, d_{bi} and d_{ei} - are dates of the beginning and the end of ice-melt period. Computations of V_M and W_{gl} by REGMOD model include certain methods described total melting and runoff process of glaciers. These methods are the following:

(a) Statistical model (Konovalov, 1979, 1985) of glaciers aggregation presents quantitative form of regionalization of the following morphometry parameters related for quasi-homogeneous groups of glaciers within a river basin: areas of glaciers and solid moraine; distribution of area along altitude; altitudinal values of glacier beginning, end, firn boundary, upper limit of solid moraine cover; mean values of slope and azimuth of glacier surface. By means of computation parameters of the typical object or "average glacier", the method of regionalization provides obtaining data on intra annual and long term regime of total melting volumes that related to the whole aggregation of glaciers within the considered river basin. Advantage of the regionalization method is also an opportunity to compute characteristics of glaciers regime depended from the relationship between accumulation and ablation areas. It is process of glaciers runoff, for example.

(b) Local and regional formulae of melting intensity of snow, bare ice and ice under moraine cover which were derived for the majority of Central Asian glacial areas. General form of those formulae is $M=M(B_k,T)$, where B_k is absorbed solar radiation, T is air temperature. For calculation of ice melting intensity under the moraine cover were derived (Konovalov, 1985, 2000): universal function of extinction of ice and snow melt intensity depending on moraine thickness; function of moraine thickness distribution on the glaciers surface; equation for calculation mean thickness of moraine at the termini of glaciers.

(c) Method calculation data of the beginning and end of ice melt period and glaciers runoff formation based on separate modeling of seasonal snow line movement Z_{ssl} inside of glaciers area and outside of glacierized basins.

(d) Model of snow line movement $Z_{ssl}(t)$ on glaciers surface during ablation period.

(e) A new method was elaborated and used for computing precipitation, air temperature and humidity at the arbitrary point of glaciers area (Konovalov, 1993, 2006). It based on spatial extrapolation of initial climate data measured at some basic meteorological station by means of local dependences precipitation, air temperature and humidity from altitude and geographical coordinates. The proposed method has the following advantages: (i) possibility to extrapolate precipitation and air temperature data measured at several basic meteorological stations over the mountainous territory of Central Asia in the ranges 35-45^{o}N and 67-81^{o}E ; (ii) increasing the quality of extrapolation after averaging results computed from several basic meteorological stations; (iii) estimation intra-annual course of precipitation or air temperature in high-mountain basins, where meteorological stations are absent or their number is not sufficient.

(f) The method of albedo A_k computation. It includes: (i) mean values of A_k for main types of glacier surface (Konovalov,1985); (ii) conclusion on stability or small changing of A_k during of 20-30 days interval for the homogeneous surface of glacier; (iii) experimental function which describe $A_k(t)$ variability over a glacier termini depending on the ratio between the areas of solid moraine and bare ice.

Application of the described model for the river Pyandge, Vakhsh, Syrdarya, Sarydzhas and other basins within Pamir-Alay and Tien-Shan glacier areas showed (Konovalov, 1985, 2006) good correspondence between the computed parameters of glaciers hydrological regime and similar estimations of other authors or field measurements of glaciers mass balance characteristics.

Spatial and temporal variability glaciers total melting and runoff

Combined analysis long-term variability of the Amudarya, Syrdarya and other rivers flow components during of May-October showed that relative contributions of glacial runoff and total melting increase in low flow years and decrease in high flow ones. This peculiarity of glacial runoff is highly important for water supply of agriculture and hydropower in the Central Asian states because it provides natural regulation of intra-seasonal distribution of runoff. Table 3 presents extended new data on the role of glaciers total melting in the runoff of several main rivers of Central Asia.

Table 3 Contribution of glaciers total melting into river runoff during 1961-1990 for different seasons

River – gorging site	Fbas	Fgl	V_m/Wb for (IV-IX), %			statistics		V_m/Wb for (I-XII), %			statistics	
	km^2		**min**	**mean**	**max**	Cv	Cs/Cv	**min**	**mean**	**max**	Cv	Cs/Cv
Zeravshan-Dupuli	10200	530	**15.0**	**28.5**	**43.5**	0.24	0.36	**13.0**	**24.4**	**37.5**	0.24	0.53
Naryn-Naryn	10500	954	**9.0**	**26.2**	**54.1**	0.43	1.37	**7.3**	**19.8**	**46.7**	0.47	1.82
Vakhsh-Komsomolabad	29500	3413	**9.7**	**23.6**	**38.6**	0.31	0.98	**8.7**	**20.9**	**35.6**	0.31	0.90
Panj-Nizhniy Panj	158412	6579	**13.4**	**34.6**	**56.8**	0.30	-1.12	**10.1**	**26.2**	**44.2**	0.31	-0.74
Amudarya-upstream*	187912	9992	**13.3**	**30.4**	**50.0**	0.29	-0.32	**10.2**	**23.4**	**39.6**	0.30	0.01

Notes: Fbas – area of basin above gorging site, Fgl – area of glaciers by 1991, determined by V.G. Konovalov, except of Naryn basin where data of USSR Glaciers Inventory (~1960 year) were used, V_m/W_b – relative contribution of total melting within glaciers area into the river runoff for the proper time interval, IV-IX – is April-September, I-XII – is January-December, Cv – is coefficient variation, Cs – coefficient of skewness, ***** - means area above confluence Vakhsh and Panj rivers.

Statistical analysis of the computed long-term series of monthly and seasonal volumes of total melting, snow and glacier's runoff of the Vakhsh and Panj river basins and their meteorological factors showed the following:

- intra-seasonal distribution of monthly volumes of glaciers runoff in the average and low water years provides rather stable water consumption in the Amudarya river basin;
- spatial variability of glaciers runoff in low water years is more significant within Pamirs river basins then in high water ones;
- air temperature averaged for June-September is representative index for estimation water input from glacierized areas of the Pamirs.

Stabilization role of glaciers runoff in the Amudarya river basin becomes less effective due to shrinkage glaciers area on 831.8 km^2 or 13% during of 1981-2000. Analysis of climate characteristics should be done for understanding noticeable differences between extreme and average values of glaciers runoff and it has practical interest for river runoff forecasting and improvement projects of utilization water resources. Long term ranges (1935-1994) measured volumes of monthly runoff $\boldsymbol{W_b}$ for Vakhsh and Panj rivers in May-October and computed volumes of glaciers melting $\boldsymbol{V_m}$ during the same time were used for solving the outlined problem. Total number of glaciers within Vakhsh and Panj river basins were divided on 127 their groups for calculations melted output from ice and snow. This output consists of volumes $\boldsymbol{W_{gl}}$ (melted firn, open ice, ice under moraine) and $\boldsymbol{W_{sn}}$ – melted winter and summer snow. Spatial and temporal variability of $\boldsymbol{V_m}$ and $\boldsymbol{W_{gl}}$ within Vakhsh and Panj river basins was studied in average and extreme years on statistical probability $\boldsymbol{P(V_m)}$. Years when $7\% \geq P(V_m) \geq 93\%$ were related to extreme and when $45\% \leq P(V_m) \leq 55\%$ were considered as average. Statistical probabilities of precipitation and mean air temperature measured on high mountain meteostations were calculated for the years chosen by above method. Analysis revealed that intra-seasonal distribution of total melting, snow and ice feeding from glacier areas and relationship between these volumes are definitely connected with type of year on water yield (see fig. 3). Specifically, glaciers feeding for Vakhsh and Pyandzh rivers in maximal and average years concentrated in July-August when winter-spring accumulation of snow have exhausted outside of glaciers area. Statistical probabilities of seasonal air temperature in average and extreme years entirely correspond to its role as index for ablation and runoff formation. Also, low water vegetation season is consequence of cool summer and vice versa. The described relation was used in order to characterize influence of climate change on water resources of glaciers.

Conclusions.

1. Regional identification and inventorying perennial snow fields is necessary for comprehensive estimation, analysis of changes and forecasting water resources in glacial areas.

2. At the first time long term variability of glaciers area during 1961-2000 was estimated at several temporal cuts. These data should be considered as rather reliable because percentage of results based on using large scale maps, air-photo survey, and remote sensing images for monitoring glaciers change is equaled by years: 1961 – 100%, 1980 – 66%, 2000 – 74%. The other determinations of glaciers area in the Table 1 were performed by author. Quality control of the used method showed rather good results.

3. Data on glaciers shrinkage presented in the Table 1 coordinate well with other known similar information in mountain regions of Asia and Europe.

4. Extreme and average contributions of total melting volumes in glaciers area to the annual and seasonal runoff in the Aral Sea Basin stress vital role of glaciers water resources there.

5. Projected values of glaciers area by 2020 were obtained by linear extrapolation of dF/dt during 1991-2000 and they turned out larger in comparison with the same one but after using trend equation for the whole 1961-2000 period. It means that dF/dt should be described as function of time for rather long period.

6. Statistical distribution of total melting values is essentially asymmetrical and differs from binomial curve at $C_S=2C_V$.

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Fig. 1 Location perennial snow fields in the Pamir river basins outside of glacier contours marked by black solid lines.

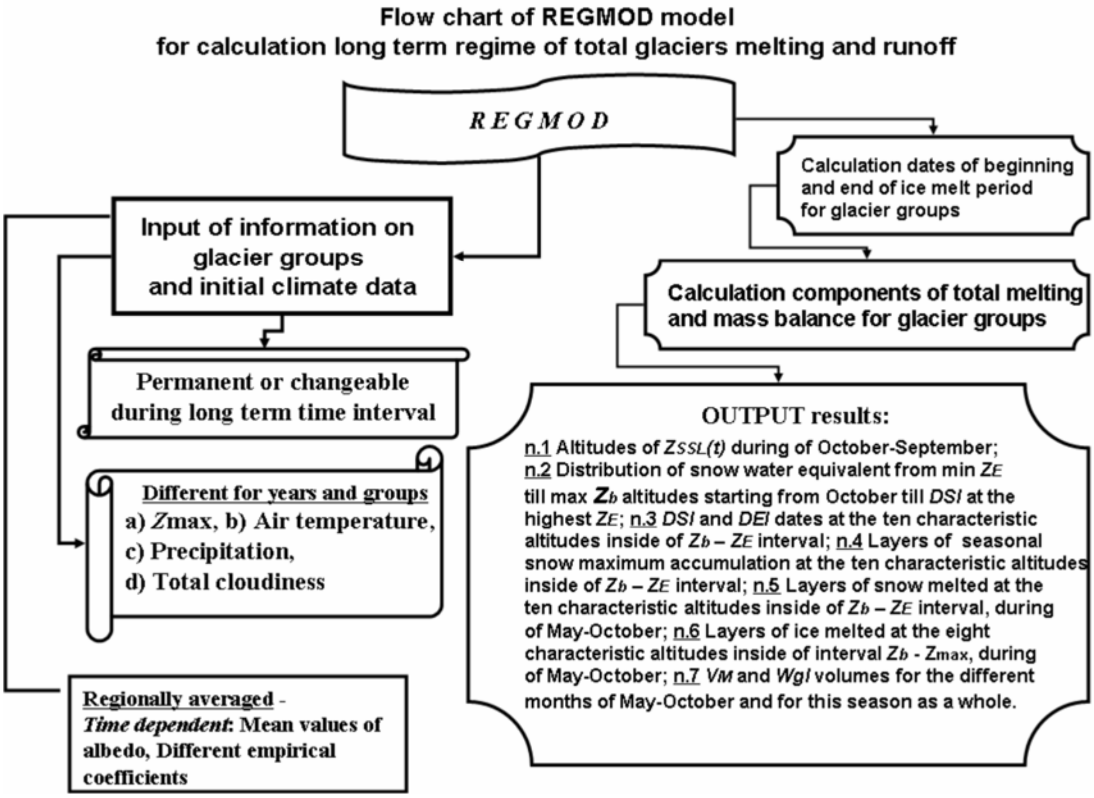

Fig. 2 Flow-chart of the REGMOD model. Zmax – is maximum altitude of snow line during ablation season, *Zssl(t)* – is seasonal snow line altitude on glacier surface at the moment *t*, Ze and Zb – are consequently altitudes of the glacier's end and beginning, *DSI* and *DEI* are consequently dates of start and end of icemelt season.

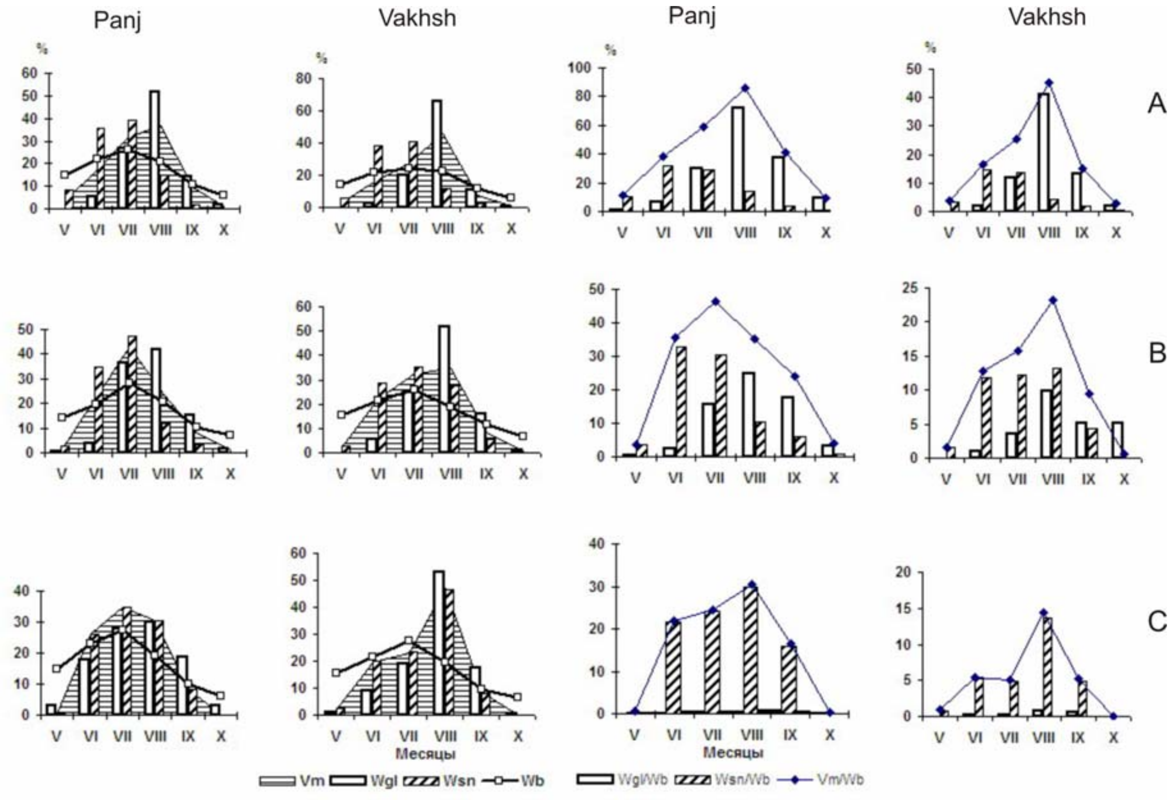

Fig. 3 Intra-seasonal distribution of runoff and components of total melting of glaciers in the years with different water yield in the Panj and Vakhsh River Basins. **Wb** is total river runoff, **Vm** is total melting, **Wsn** – is snowmelt runoff from a glacierized area, **Wgl** is runoff produced from melting of ice and old firn. Left pair of graphs presents percentage of **Vm**, **Wsn**, **Wgl**, and **Wb** to their sums for May-October season. Right pair of graphs presents percentage of **Wgl**, **Wsn**, and **Vm** to the total river runoff for May-October. Graphs on line "A" are related to high flow years; "B" – for average flow years, "C" - for low flow years.