Computations of melting under moraine as a part of regional modelling of glacier runoff

VLADIMIR KONOVALOV

Central Asian Hydrometeorological Research Institute, 72 K. Makhsumov Str., Tashkent 700052, Uzbekistan

e-mail: fyyf98@silk.org

Abstract This paper considers: (a) measurements on melting under moraine cover on glaciers of central Asia, the Caucasus and the Altai; (b) a mathematical model of the influence of moraine cover on glacier melting; (c) regional formulae to compute melting under moraine; (d) determination of the mean moraine depth $h_C(Z_E)$ at the glacier terminus and modelling of the spatial distribution of $\bar{h}_C$ within the ablation area of a glacier.

INTRODUCTION

The moraine cover on glaciers within the Pamir-Alai river basins varies between 2% and 26% according to current estimations and totals 676.4 km^2. The author has developed a regional model of glacier runoff that incorporates the method of computation of total ice melting $M(h_C)$ under a moraine cover of depth h_C. The formula used in a regional model for calculation of the total volume of glacier melt $v_M(t)$ at time t is:

$$v_M(t) = M_C(\tilde{z}_{im}, t)S_{im} + M(\tilde{z}_i, t)S_i + M(\tilde{z}_f, t)S_f + M(\tilde{z}_{ws}, t)S_{ws} + M(\tilde{z}_{ss}, t)S_{ss} \quad (1)$$

where $M_C = M$ f(h_C) is the intensity of icemelt under the moraine cover; M is the intensity of bare ice melting; f(h_C) is the function of change in ice melt under moraine cover h_C; $\tilde{z}$ is mean weighted altitude for area S of a particular glacier surface. Subscripts used in (1) are:

im is ice under moraine,
i is bare ice,
f is old firn,
ws is winter snow,
ss is summer snow.

To obtain the total melt volume V_M and icemelt runoff W_{gl} it is necessary to compute and summarize the proper components of (1):

$$V_M = \sum_{t_1=D_{SC}}^{t_2=D_{EC}} v_M(t)$$

$$W_{gl} = \sum_{t_3=D_{SI}}^{t_4=D_{EI}} M_C(\tilde{z}_{im}, t)S_{im} + M(\tilde{z}_i, t)S_i + M(\tilde{z}_f, t)S_f$$

where D_{SC} and D_{EC} are dates of the beginning and the end of the calculation period, which include melting of all types of glacier surface; D_{SI} and D_{EI} are dates of the beginning and the end of the icemelt period. Equation (1) is the regional model REGMOD of glacier mass balance and runoff formation in high mountain areas of central Asia, which has been elaborated in Konovalov (1985; 1997a,b).

The following methods and information are necessary to calculate the volume of icemelt under moraine using equation (1):

(a) Data on the area of solid moraine cover S_{im}.

(b) Modelling and computation of the interannual variability of $S_{im}(t)$ related to the movement of the seasonal snow line $Z_{SSL}(t)$ on glaciers at the condition:

$$Z_E < Z_{SSL}(t) < Z_{UML}$$

(c) Regional or local functions $f(h_C) = M(h_C)/M$ of icemelt change dependent upon depth h_C of solid moraine cover.

(d) Data on the spatial distribution of the mean moraine depth $\overline{h}_C$ for the debris-covered glacier area S_{im} or part of this area $S_{im}(t)$, located between altitudes Z_E and $Z_{SSL}(t)$, where Z_E is the altitude of the glacier terminus and Z_{UML} is the highest altitude of solid moraine distribution.

The mean moraine depth $\overline{h}_C$ at $Z_{SSL}(t)$ Z_{UML} may be defined as:

$$\overline{h}_C = \frac{1}{\Delta Z_C} \int_{Z_E}^{Z_{UML}} h_C(z)\,\mathrm{d}z \tag{2}$$

where $\Delta Z_C = Z_{UML} - Z_E$. But when $Z_E < Z_{SSL}(t) < Z_{UML}$:

$$\overline{h}_C(t) = \frac{1}{\Delta Z_C(t)} \int_{Z_E}^{Z_{SSL}(t)} h_C(z)\,\mathrm{d}z \tag{3}$$

where $\Delta Z_C(t) = Z_{SSL}(t) - Z_E$.

The generalized values of S_{im} and Z_E used in the REGMOD model could be obtained from Glacier Inventory data. The interannual variability $S_{im}(t)$ when $Z_E < Z_{SSL}(t) < Z_{UML}$ is expressed by:

$$S_{im}(t) = \int_{Z_E}^{Z_{SSL}(t)} s(z)\,\mathrm{d}z$$

where $s(z)$ is the distribution of the glacier area as a function of altitude. The method of estimating $Z_{SSL}(t)$ is described by Konovalov (1985, 1997a,b) and $s(z)$ by Schetinnikov (1997). All regionally available experimental measurements of ice melt under moraine are analysed further as the empirical basis to model $f(h_C)$, $h_C(Z_E)$ and $h_C(z)$ in REGMOD. Here $h_C(Z_E)$ is the mean moraine depth at the altitude of the glacier terminus.

REGIONAL MEASUREMENTS OF MELTING UNDER MORAINE COVER

At present field measurements of ice melting under moraine are made on at least 15 central Asian glaciers. Similar data are available for the glaciers of the Caucasus and Altai. Averaged data of measurements in the form of relative melting values $M(h_C)/M$

Table 1 Relative intensity of ice melt under moraine cover (f(h_C) in %). Names of glaciers and references are given in Konovalov (1985).

h_C (cm)	0	0.2	0.5	0.8	1.0	2.0	5.0	10	20	30	50	100	150	200	250	300
f(h_C)	100	106	110	105	102	86	60	43	26	17	12	8	5	3	1	1

are used to plot $M(h_C)/M$ = f(h_C) which shows that this function has its maximum value at $h_C > 0$ and two characteristic points where f(h_C) = 1. One of these points represents the relative intensity of ice melt without moraine. The existence of the other is explained by total absorption inside layer h_C of the additional heat obtained due to the albedo difference between ice and moraine. The generalized numerical values f(h_C) for different moraine depths are presented in Table 1 and Fig. 1.

The temporal variability of f(h_C) in the central Asia region has been estimated by combining all available measurements M and $M(h_C)$ on glaciers at different depths of

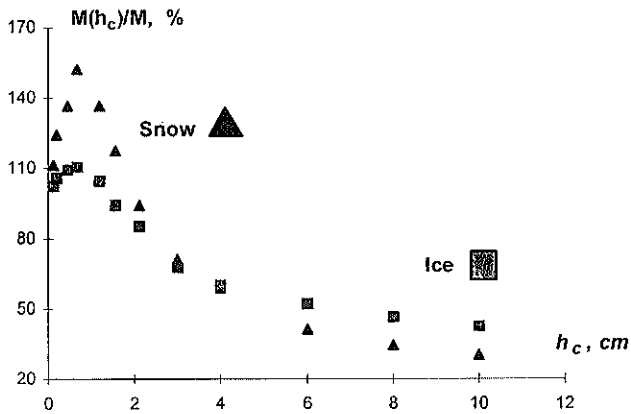

Fig. 1 Empirical curves of the melting intensity under different depths of moraine. From data of Konovalov (1985), Schetinnikov (1997), Kamalov (1974), Fujii (1977).

Table 2 Values of f(h_C) in central Asia (as % of the melting of bare ice). The names of more then 15 central Asian glaciers and sources of data used in this table are given in Konovalov (1985).

Months	Ten days	Depth of the moraine cover (cm): 5	10	20	30	50
July	I	69	41	26	16	
	II	66	38	23	16	
	III	72	49	34	16	15
Mean for month		70	44	29	16	
August	I	64	50	33	18	11
	II	72	67	36	28	
	III	67	48	37	21	15
Mean for month		67	53	35	22	16
September	I	67	38	37	13	
	II	43	30	21	10	
	III	41	22	8	4	
Mean for month		52	28	22	8	
Mean for July–September		68	49	34	22	16

moraine cover. These data averaged for some values of h_C are presented in Table 2. The list of glaciers used in both tables and the sources of the data are given by Konovalov (1985).

The results given in Table 2 are for altitudes 3000–3400 m a.s.l. To determine the generalized values f(h_C) for the period July–September some additional data are taken into account which are not used to compute monthly values of f(h_C). The temporal variability of f(h_C) for certain h_C values in the Table 2 can be explained partly by the absence of quantitative characteristics of bare surfaces of the glacier. However the main reasons for changes of f(h_C) have not yet been properly studied. Therefore, one of the main objectives of this paper is to evaluate the variability of f(h_C) as a function of spatial and temporal coordinates.

MODEL OF MORAINE INFLUENCE ON THE MELTING PROCESS

For the purposes of the computation of melting under moraine with thickness h_C, it is useful to obtain the analytical form of f(h_C,) which when $h_C = 0$ gives the ice melt value for a bare ice surface. We may use a common approach to solve this problem by considering the daily fluxes of heat onto bare ice (P_i), moraine surface $P_C(0)$, and to the moraine–ice interface $P(h_C)$ at $h_C > 0$.

Let us assume that the process of heat assimilation in the layer h_C could be described by a simple differential equation:

$$\frac{\mathrm{d}P_C}{\mathrm{d}h_C} = -\beta P_C \tag{4}$$

After integrating (4) we obtain:

$$P(h_C) = P_C(0)\exp(-\beta h_C) \tag{5}$$

and, after dividing both parts of (5) by $P_C(0)$ and taking only the first two terms of decomposition exp($-\beta h_C$) to the power series,

$$\frac{P(h_C)}{P_C(0)} \approx \frac{1}{1+\beta h_C} \tag{6}$$

where β is the coefficient of heat absorption.

As can be seen, formula (5) and its approximate version (6) characterize the exponential extinction of heat flux at the moraine–ice boundary at $h_C > 0$ related to $P_C(0)$, the heat flux to the moraine surface. The relation between heat fluxes P_i and $P_C(0)$ can be written as $P_C(0) = P_i + \Delta P$, where ΔP is stipulated by increasing absorbed solar radiation due to differences in the albedo. After that the approximate formula (6) will be as follows:

$$\frac{P(h_C)}{P_i} = \frac{1+\dfrac{\Delta P}{P_i}}{1+\beta h_C} \tag{7}$$

A similar formula was obtained earlier by Khodakov (1972), but it doesn't meet with the experimental data at $h_C = 0$, since it gives $M(h_C) > M$. Equation (7) must be transformed in order to satisfy the conditions given earlier. It is obvious that fulfilling these conditions, i.e. $f(h_C) = 1$ at $h_C = 0$ and $f(h_C) = \max$ at $h_C > 0$ is possible if the argument of (7) is presented as $\xi = (h_C - h_0)^2$, where h_0 is a parameter having the dimension of length. Changing h_C by means of a power expression is necessary to preserve the positive sign of the product in the denominator of (7) at $h_C < h_0$. Thus instead of (7) it is suggested that:

$$\frac{P(h_C)}{P_i} = \frac{1 + \dfrac{\Delta P}{P_i}}{1 + \beta_1 (h_C - h_0)^2} \tag{8}$$

Then, using the condition $f(h_C) = 1$ at $h_C = 0$, we may define:

$$h_0 = \sqrt{\frac{\Delta P}{\beta_1 P_i}} \tag{9}$$

It follows from (9) that the parameter h_0 provides adjustment of $P_C(0)$ to P_i. The analysis of heat fluxes inside a moraine cover based on the multi-phase and multi-component theory is performed by Denisov (1980). Finally he obtained $f(h_C)$, which agrees well with known experimental data. However Denisov's solution could not be used for regional calculations since it includes many specific physical parameters (moraine density, wind velocity, air temperature and vapour pressure above and inside the moraine, etc).

METHOD TO COMPUTE MELT UNDER MORAINE

Analysis of $f(h_C)$ in the form of (8) shows that this function has maximum at $h_C = h_0$ and two characteristic points where $f(h_C) = 1$ at $h_C = 0$ and $h_C = 2h_0$. Therefore formula (8) satisfies all conditions for the correct computation of ice melt under moraine if values of melting, $M(h_C)$ and M, are used instead of heat fluxes $P(h_C)$ and P_i, i.e.

$$\frac{M(h_C)}{M} = \frac{1 + \dfrac{\Delta P}{c_* M}}{1 + \beta_1 (h_C - h_0)^2} \tag{10}$$

where c_* is the specific heat of phase transition.

For an approximate evaluation of $\Delta P / c_* M$ we suggest that $\Delta P = \Delta B_S$, where $\Delta B_S = B_{SM} - B_{SI}$ is the difference between values of absorbed solar radiation at the ice surface and moraine surface. The difference ΔB_S may be presented as $\Delta B_S = Q_o(1 - A_{SM}) - Q_o(1 - A_{SI}) = Q_o(A_{SI} - A_{SM})$ where Q_o is the global radiation; A_{SM} the albedo of the moraine; and A_{SI} the albedo of ice. Thus we may write $Q_o(A_{SI} - A_{SM}) = B_{SM} - B_{SI}$ and after simple transformation of this expression:

$$\frac{B_{SM}}{B_{SI}} = 1 + \frac{Q_o(A_{SI} - A_{SM})}{Q_o(1 - A_{SI})} = \frac{1 - A_{SM}}{1 - A_{SI}} \tag{11}$$

or:

$$B_{SM} = B_{SI} \frac{(1 - A_{SM})}{(1 - A_{SI})} \tag{12}$$

The nondimensional expression (12) presenting the coefficient of magnification of absorbed solar radiation was introduced first by the author (Konovalov, 1967) when considering the effect of artificial impact on glacier melting. Therefore, for ΔB_S we may write:

$$\Delta B_S = B_{SI}\left(\frac{1 - A_{SM}}{1 - A_{SI}} - 1\right) = B_{SI}\left(\frac{A_{SI} - A_{SM}}{1 - A_{SI}}\right) \tag{13}$$

and, after substitution into (10), we get:

$$\frac{M(h_C)}{M} = \frac{1 + \frac{B_{SI}}{c_* M}\left(\frac{A_{SI} - A_{SM}}{1 - A_{SI}}\right)}{1 + \beta_1 (h_C - h_0)^2} \tag{14}$$

Equation (14) represents the general form of $f(h_C)$ where the right-hand components should be defined as regional or local functions of spatial coordinates and time. It is obvious that the relation $\phi = B_{SI}/c_* M$ characterizes the influence of absorbed solar energy on ice melt. An analysis of the spatial variability of ϕ reveals that in the central Asia region it may be defined adequately as a linear function of elevation Z (in km), i.e. $\phi(Z) = a_0 + b_0 Z$. Both parameters of $\phi(Z)$ have temporal variability, which is determined empirically as follows:

$$a_0(t) = 87.67 - 0.525 * t + 0.000\,841 * t^2$$

$$b_0(t) = 0.179 * t - 0.000\,28 * t^2 - 29.99$$

where t is the number of the day in the hydrological year, i.e. October–September period. The next equation to compute the mean monthly albedo of slightly dusted ice A_{SId} is obtained by data from long-term measurements on central Asia glaciers:

$$A_{SId}(T) = 0.0068 * T^2 - 0.1086 * T + 0.72$$

where T is the number of the month during the May–October period. The correlation coefficient of this empirical formula is 0.931. The albedo of the moraine is defined by field estimations as: $A_{SM} = 0.12 \approx$ constant. Ultimately we have equation (15) describing the influence of moraine cover on ice melt during May–October:

$$\mathrm{f}(h_C)_{Id} = \frac{1 + (a_0(t) + b_0(t) * Z) * [(A_{SId}(T) - 0.12)/(1 - A_{SId}(T))]}{1 + \beta_1 (h_C - h_0)^2} \tag{15}$$

Similar formulae may be obtained for clean ice, firn and snow. The components of (15) β_1 and h_0 are considered so far as permanent parameters.

Adopting permanent averaged values of albedos and ϕ we may write equation (14) as follows:

$$\frac{M(h_C)}{M} = \frac{K_C}{1 + \beta_1 (h_C - h_0)^2} \tag{16}$$

where from our research (Konovalov, 1969, 1972, 1985) K_C = 1.34 at $\overline{\phi}$ = 0.80, $\bar{A}_{SM}$ = 0.12, and $\bar{A}_{SI}$ = 0.38 for clean ice. Values for β_1 and h_0 may be obtained by combining experimental measurements of $M(h_C)$ and M, with equation (9).

The common approach states that melting under moraine can be computed regardless of the type of glacier surface. This means that the value of K_C in formula (16) depends upon the albedo of any natural surface A_S whether it is ice, firn or snow. The relationship K_C = f(A_S) attains a general form if $B_S/c_*M = 0.80 \approx$ constant, A_{SM} = 0.12, and if we use the averaged values of albedo for the different types of glacier surface. Those revealed by the author earlier (Konovalov, 1969, 1972) are as follows: clear ice (A_S = 0.38), old snow/firn (A_S = 0.47), wet snow/clear firn (A_S = 0.58), clear dry snow (A_S = 0.76). Having used the least squares fit for K_C = f(A_S) we finally obtain the universal formula:

$$M(h_C) = M\frac{0.97 + 0.0145A_S^{2.18}}{1+\beta_1(h_C - h_0)^2} \tag{17}$$

for computation of the melting under moraine dependent on its depth h_C and intensity of melting M on the bare glacier surface (ice, firn, snow). The coefficients in (17) are considered as constants which in some cases may be accepted as a satisfactory approximation.

Several values of A_S listed above may be used to represent graphically the function (16). The set of these curves is characterized by the location of maximum $M(h_C)$ and speed of the function changes in its vicinity. The analysis of this graph is useful since it explains first the variability of dots on the empirical dependencies f(h_C) and secondly it facilitates selecting an optimal option of glacier dusting in the numerical modelling of artificially modifying glacier melt.

An example of the function f(h_C) is shown on Fig. 1 which presents empirical curves of the relative melting intensity under moraine on the surface of ice and snow. Data published by Kamalov (1974, Schetinnikov (1997), and Fujii (1977) have been used to prepare this graph. These curves make it easy to determine the value h_0, which equals certain h_C where each of the functions f(h_C) are at their maximum and to find the coefficient β_1 in (17). Then $\beta_1 = (K_C - 1)/h_0^2$ if $h_C = 2h_0$, and f(h_C) = 1. For example, β_1 = 6.0 cm^{-2}, when $\bar{A}_S$ for snow is 76%, and β_1 = 0.58 cm^{-2} when $\bar{A}_S$ for ice is 30%.

MODEL FOR MORAINE DISTRIBUTION ON GLACIER SURFACE

In order to estimate the form of function $h_C(z)$ we use the equation of moraine mass changing along the length of a glacier suggested by Glazyrin (1969):

$$\frac{\mathrm{d}m}{\mathrm{d}z} = -\frac{\Phi_m B(z)}{v_{GL}\sin\lambda} \tag{18}$$

where $B(z)$ is the balance of accumulation and ablation of ice, Φ_m is the coefficient characterizing the long-term input of moraine material from outside; v_{GL} and λ are respectively the glacier velocity and slope at altitude Z. Adopting certain averaged values of B, v_{GL} and λ for altitudes $\Delta Z_C = Z_{UML} - Z_E$ we may write:

$$\frac{\Phi_m \overline{B}}{\overline{v_{GL} \sin \lambda}} = \chi_C = \text{constant} \tag{19}$$

Integrating by z the simplified version of (18), i.e. $dm/dz = -\chi_C$ we get the expression $m(z) = m(z_0) - \chi_C(z - z_1)$ where $z_1 = Z_E$, and $z \in \Delta Z_C$. Using the obvious condition $m(z) = 0$ at $z = Z_{UML}$ we have:

$$\chi_C = \frac{m(Z_E)}{Z_{UML} - Z_E} \tag{20}$$

Here Z_E is the elevation of the glacier terminus; Z_{UML} is the elevation of upper solid moraine limit. Using the expression for χ_C we obtain:

$$m(z) = m(Z_E) - \frac{m(Z_E)}{Z_{UML} - Z_E}(z - Z_E) = m(Z_E)\frac{Z_{UML} - z}{Z_{UML} - Z_E} \tag{21}$$

After dividing both parts of equation (21) by the moraine density we get a mean depth of moraine distribution along the glacier surface:

$$h_C(z) = h_C(Z_E)\frac{Z_{UML} - z}{Z_{UML} - Z_E} \tag{22}$$

It is necessary to have data on $h_C(Z_E)$ in order to compute $h_C(z)$ by formula (22). The suggested solution of this task is based on the empirical dependence $h_C(Z_E) = f(\Omega)$, where $\Omega = S_m/S_{ab}$ is the ratio between areas of solid moraine S_m and ablation S_{ab} of a glacier. The form of dependence $h_C(Z_E) = f(\Omega)$ is shown in Fig. 2 based on the author's data and other measured data (Konovalov, 1985). This dependence is approximated by:

$$h_C(Z_E) = 88 * \Omega \text{ cm} \tag{23}$$

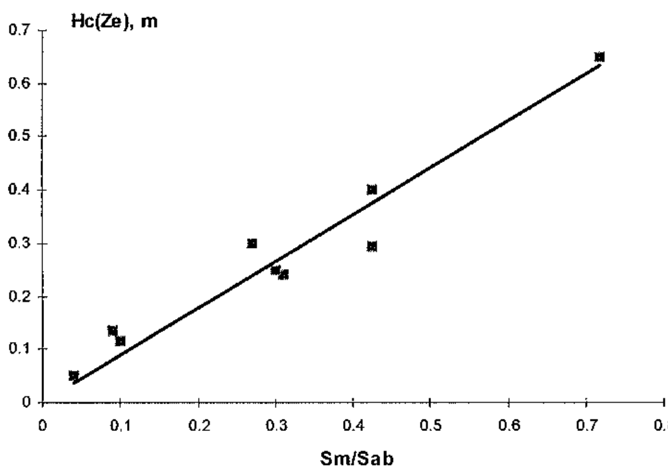

Fig. 2 Dependence of the moraine mean depth at the glacier terminus on the relative area of solid moraine. The glaciers presented on the graph are located in the following regions: Caucasus (the Shkheldy and Amanauz glaciers), Pamir (the Medvezhii, Fedchenko and Bivachnii glaciers), Tien Shan (the Pakhtakor, Ayutor-2, Karabatkak and Inylchek glaciers).

The coefficient of correlation of (23) is 0.97. After $h_C(Z_E)$ is determined it is not difficult to compute the average thickness of moraine $\bar{h}_C(\Delta z)$ in the altitude interval $\Delta z = z - Z_E$ at $Z_{UML} \geq z \geq Z_E$ by the formula:

$$\begin{aligned} \bar{h}_C(\Delta z) &= 0.5 * h_C(Z_E) * [1 + (Z_{UML} - z)/(Z_{UML} - Z_E)] \\ &= 44 * \Omega * [1 + (Z_{UML} - z)/(Z_{UML} - Z_E)] \quad \text{cm} \end{aligned} \tag{24}$$

CONCLUSION

The most significant outcome of this research is as follows:

- The results of regional field experimental measurements of ice melt under moraine cover are collected and analysed.
- A simple and physically substantiated model of the influence of moraine cover on glacier melting is elaborated. This model is based on the empirical function f(h_C) for the melting intensity under a moraine cover.
- A general analytical expression is obtained for f(h_C). The recommended working formulae for f(h_C) may be used in the regional model of glacier runoff both with permanent and distributed parameters.
- The function of mean moraine thickness distribution is obtained for the debris-covered area of ablation on a glacier. This is necessary to calculate the total volume of ice ablation under moraine cover, which represents an essential part of the area of a glacier.

Acknowledgement This research is performed within the framework of the scientific project "Glaciers of central Asia and their relation to the global hydrological cycle", kindly supported by NATO CL Grant ENVIR 974676.

REFERENCES

Denisov, Yu. M. (1980). Metod rascheta vliyania morennyh otlozhenii na tayanie lednikov (Method to compute the influence of moraine on glacier melting). *Trydy SANII* **71**(152), 67–80.

Fujii, Y. (1977) Field experiment on glacier ablation under a layer of debris cover. *J. Japan. Soc. Snow Ice (Seppyo)* **39**, 20–21.

Glazyrin, G. E. (1969) Ablatsionnie moreny kak istochnik informatsii o protsessah, proishodyaschih v verhov'yah lednikov (Ablation moraine as the source of information about the processes in a glacier head). *Meteorologiya i Gidrologiya* no. 2, 71–77.

Kamalov, B. A. (1974) Sovremennoe oledenenie i stok lednikov v basseine Syr-Daryi (State of contemporary glaciers and their runoff in the Syrdarya River basin). *Trudi SARNIGMI* **12**(93).

Konovalov, V. G. (1967) Izmenenie teplovogo balansa ablatsii i svoistv deyatelnoi poverhnosti snega i l'da pod deistviem iskusstvennogo zachernenia (Changing the ablation heat balance and features of the snow and ice surface after artificial dusting). *Trudi SANIGMI* **30**(45), 51–57.

Khodakov, V. G. (1972) Raschet ablatsii l'da pod sloem moreny (Calculation of ice ablation under a moraine layer). *MGI* (Data of Glaciological Studies), no. 20, 105–107.

Konovalov V. G. (1969) Problemi klassifikatsii i prostranstvennaya izmenchivost albedo odnorodnoi poverhnosti lednikov v period ablatsii. *Trudi SANIGMI* **44**(59), 102–107.

Konovalov, V. G. (1972) O srednih znacheniah albedo lednikov v period ablatsii (On the mean values of glacier albedo during of the ablation period). *Trudi SARNIGMI* **65**(80), 111–122.

Konovalov, V. G. (1985) *Tayanie i Stok s Lednikov v Basseinah rek Srednei Azii* (Melting and glacier runoff within central Asia river basins). Gidrometeoizdat, Leningrad.

Konovalov, V. G. (1997a) The hydrological regime of Pamir-Altai Glaciers. ICSI (IAHS), UNESCO Symp. on Glacier Mass Balance (Innsbruck, Austria, September 1994). *Z. Gletscherk. Glazialgeol.* **33**(2), 125–131.

Konovalov, V. G. (1997b) Regional model of runoff for high mountain basins: main components and results of realization in the Pamirs and Hindukush river basins. *Data of Glaciological Studies* no. 81, 21–29. Moscow.

Konovalov, V. G. (1997c) Snow line and formation of glacier-derived runoff in glacial basins. In: *34 Selected Papers on Soviet Glaciology, 1940s–1980s* (compiled and ed. by V. M. Kotlyakov), 402–410. Moscow.

Schetinnikov, A. S. (1997) *Morfologia Oledenenia Rechnih Basseinov Pamiro-Alaya po Sostoyaniu na 1980 god. Spravochnik* (Morphology of glaciers in 1980 within the Pamir-Altai river basins. Reference book). Izd-vo SANIGMI, Tashkent.