EURASIAN JOURNAL OF MATHEMATICAL AND COMPUTER APPLICATIONS
ISSN 2306–6172
Volume 5, Issue 4 (2017) 14 – 26

MID-LATE HOLOCENE MEAN TEMPERATURE FLUCTUATIONS OF A WARM PERIOD IN HIGH MOUNTAINS OF THE CENTRAL RUSSIAN ALTAI

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Abstract The aim of the study is to estimate the amplitudes of mean temperature fluctuations in the central Russian Altai during the warm period in the late Holocene. The simulation model for glaciers budget developed by Galakhov was applied to paleogeographic reconstructions. The model is based on the data obtained experimentally from two glacier catchments in the central Russian Altai, i.e. the Aktru River basin (the North-Chuisky ridge) in 1977-1986, and the Multa River basin (the Katunsky ridge) in 1969-1973. The simulation model was tested in the Multa River basin. The model for the Multa basin was used to evaluate changes in mean temperature of the warm period for the Aktru cooling that occurred 750-150 years ago (-0.2°C) and the Akkem one 4900-4200 years ago (-0.9°C). The results suggest a good correlation with paleoclimatic reconstructions of the Aktru River basin.

Key words: Altai Mountains, glacier, Holocene, simulation, temperature, moraine

AMS Mathematics Subject Classification: 92F99.

1 Introduction

Recent research made in the Russian Altai has produced a series of radiocarbon dates from glacial and related sediments as well as dendrochronological and lichenmetric data. The obtained results allow to present the changes to natural conditions occurred in this mountainous country during the second half of the Holocene. The period following the Holocene Climate Optimum saw several cold spells associated with glaciers advance in the Russian Altai. L.N. Ivanovsky [1] and other researchers identify three stages of glacier advance: Akkem, Historical and Aktru [2]. The latter two are divided into phases.

The data was collected for several mountain-glacial basins of the central Russian Altai. For instance, for the Aktru basin (the North-Chuisky ridge) we report 26 radiocarbon dates for the well-defined moraine complexes of the Akkem (4900-4200 years ago) and the Aktru (750-150 years ago) stages. In sites with poorly expressed terminal moraines the glacier tongues position and the period of their existence during various phases of the Historical stage (3100-1600 years ago) were defined using lichenometry.

In the Khaidun River basin (the Kholzun ridge) with well defined terminal moraines of the Historical stage are, 20 radiocarbon dates were obtained directly from the glacial and related lacustrine sediments and 2 for the moraine of the Akkem stage in the Multa basin.

The results of radiocarbon dating presented in [1], [3–5] support the fact that warming and cooling periods in the central Russian Altai have been reliably identified. Using the results mainly on the Khaidun basin, a comparison of the periods of glaciers advance in the Altai and in the Alps was undertaken [5]. The duration and scale of warm periods were defined as a difference between the current and the ancient forest boundaries [6]. As for the amplitude of cooling, this issue is still open for discussion.

2 Material and methods

The scale of cold spells during the glaciers advance and the formation of moraine complexes can be evaluated using the Hoefer method or the simulation technique based on simplified calculation of the ice balance parameters [7–11] .

The aim of the study is to estimate the amplitudes of mean temperature fluctuations in the central Russian Altai during the warm period of the late Holocene using the simulation technique. Galakhov developed the simulation model based on the ice balance equation [12]. The complete ice balance equation for any glacier is as follows [13]:

$$X_s \pm D \pm E \pm U - A_{i+s} \pm F_{i+f} = \Delta I \tag{1}$$

where X_s - the solid precipitation , D - the balance of drifting snow, E - the evaporation / condensation difference, U -the balance of avalanche snow, A_{i+s} - the ablation of snow and ice on the glacier, F_{i+f} - the mass of refrozen water in the firn thickness, ΔI - the change in ice mass.

Mass balance models investigate the change in mass of a glacier including its temporal and spatial distribution [14]. Changing of climate conditions in the mass balance model can be used to study the properties of palaeoglaciers. At terminal moraines formation the glaciers were stationary, i.e. ice balance was close to zero [1].

To derive a zero balance for the reconstructed glacier, we define the paleoglacier's surface by the position of terminal and lateral moraines with further determination of meteocharacteristics required for simulation. It is common knowledge that not a precipitation but the temperature of the warm period has the major effect on the ice balance of inland glaciers. Because of that, we calculated zero balance for the reconstructed glacier by reducing the modern temperature of the warm period. The temperature data are obtained due to present-day instrumental observations at a weather station that should be at a 10-15 km distance or closer from the modern glacier tongues.

Thus, the temperature difference characterizing a zero balance of modern and paleoglaciers will give a value of cooling for the appropriate period. The developed simulation model for calculation of ice balance parameters [12] requires a large body of source information. The researcher should have the data on the basin topography, daily temperature and precipitation for the balance year (from 01.08 of the previous up to 30.09 of the calculated year) from the reference weather station, the snow reserve gradients in the basin as well as the coefficients of melting snow and ice, the data on temperature rise at the transition from the ice to the off-glacial surface including the data on precipitation gradients and the coefficients of melting fresh snow (for summer).

The data for the model were obtained in the Aktru River basin (the North-Chuisky ridge) in 1977-1986 and the Multa River basin (the Katunsky ridge) in 1969-1973 [15]. The study area is a part of the so-called Central Altai, the highest in the Russian Altai. It is formed by two mountain ridges of 4,000 m asl (the North-Chuisky and

Katunsky ridges) and some lower ridges of 2000-3000 m asl. Mt. Belukha (4506 m asl), the highest peak of the Russian Altai, is situated within the Katunsky ridge. The hydrological regime of both rivers is strongly influenced by glacier melt and snowmelt with maximum monthly discharge in summer (June-August) and minimum monthly discharge in February and March.

Background snow reserves were measured in the graded sites not exposed to the snow cover transformation. Altitudinal gradients of snow reserves are calculated based on the measurements in the mountain-glacial basin with regard to the data from the reference weather station. The uniform increase in snow reserves with altitude is characteristic of the central Russian Altai. Observational data show the snowy winter dependence of snow reserves in different altitude zones (the ratio of a current to an average year over the observation period).

According to the observations [15], fresh snow is not retained on slopes with a gradient exceeding 50°. At a gradient of 25-50°, resh snow is retained forming the seasonal snow thickness. In winter or when early snowmelt period starts, this seasonal snow moves down as avalanches. Avalanche-induced snow transport does not occur if the background snow reserve is less than 250 mm. When avalanching, the snow is partially retained (about 150-250 mm in the water layer) in avalanche channels. The process of snow transport by avalanching continues until the gradient of the slope site becomes less than 25°.

Numerous land-based surveys of glaciers are indicative of wind-induced transport of snow from the graded surface (at a slope gradient up to 10°) to the steeper slopes or the rugged terrain. Snow transport is carried out by drifting snow from flat sites both of glaciers and watersheds with an air run at least 0.5 km down along the glacier [13]. A wind run is observed not only over the glaciers but also over the flat parts of the Earth surface adjacent to the glaciers. Seasonal snow cover begins to form by falling to the melted ("warm") surface. Not long after it partially freezes up to the surface that makes its transport by drift impossible (at 300-400 mm in water layer).

Thus, for calculation of a snowdrift transport the following conditions were assumed

- if a water reserve in a snow cover is less than 400 mm, snowdrift transport does not occur;
- if graded sites exceed 250 m in length, water reserve is greater than 400 mm and slope steepness is less than 10°, then snow transport moves along the glacier until the slope steepness reaches more than 10°.

Because of strict localization of avalanche and snow drifting processes on modern glaciers, the relative change in snow reserves varies insignificantly with years. The same was reported for glacier Grisgletcher in the Alps [16].

Observations of the condensation/evaporation difference demonstrate 40 mm evaporation of seasonal snow for the ablation period [15]. When simulating, we did not consider evaporation from the melting surface of the Altai glaciers for the ablation period. Actually, evaporation was insignificant, much less than errors at direct measurements of accumulation and ablation.

Melting of snow and ice on the glaciers is largely dependent on the influx of solar radiation. The thermal balance observations indicate that solar radiation varies within 80

- 40% depending on the surface albedo [15]. However, the calculation of melting based on heat balance parameters is very complicated, often it increases a number of calculation errors. This is particularly evident when melting is calculated for the ablation period, not for short-time intervals. For calculations, we used the accepted coefficients of melting determined by positive accumulated temperature. When calculating, we made slope exposure corrections. On the southern slopes, the rate of melting was assumed half higher than that for the flat sites and the northern slopes. The melting coefficients were found experimentally, separately for snow and ice in different altitude zones (for the northern slopes). The melted layer is calculated for the entire ablation period. According to the results of field experiments [17], the measurement errors of melted snow and ice do not exceed 7-10% .

To assess the processes of ice formation in the snow-firn thickness, we studied the change in density of seasonal snow and firn before and after ablation. Experimental observations in deep pits of glacier Tomich are evident of complete soaking of snow and firn thickness due to melt water and liquid precipitation during the ablation period. The realization of store of cold in full by an active layer occurs [15]).

The difference between the accumulated and the melted snow is calculated using the observational data [17]

$$F_{i+f} = 0.54bnf \tag{2}$$

where bnf is the value of the firn residue.

The model was tested through the comparison of the data on experimental observations and the numerical experiments for the years 1981-1986. The data for this period were not used for the algorithm development. The maximum error under ablation or accumulation determination for any year of the mentioned period made up 20-25%, while the absolute error for the glacier budget varied from 0 to 20 g/cm^2 [12].

The model is implemented in Fortran-77.

3 Results and discussion

The obtained factual and literature data on the central Russian Altai, namely the Aktru, Multa and Khaidun basins suggest specify major events of the Holocene second half (Table 1).

As Table 1 suggests, cooling offers the largest problem. By simulation, we tried to fill up the gaps associated with cold spells occurred in the best provided for the data Aktru basin. The simulation results of the basin made it possible to assess the scale of some cold periods represented by the moraine complexes well-defined in the relief of the Aktru basin [12].

We established the relationship between the amplitudes and the duration of warm and cold periods (Table 2, Figure 1). It was made to evaluate the undefinable (by glacial deposits and the upper edge of the forest in the Aktru basin) amplitudes of "problem" warming and cooling occurred 4500-1700 years ago. This dependence was used for filling up a warming-cooling "gap" (4500-1700 years ago) on the curve of the average annual temperature variation in the second half of the Holocene (Figure 2).

It should be noted that since the moraine complexes and the forest boundary used for determination of thermal changes form for hundreds of years, the obtained thermal

Table 1: Fluctuation of mean summer air temperature in the central part of the Russian Altai in the late Holocene (by glacial deposits and the position of the ancient boundary of the forest)

Years ago, event	Deviation of average summer temperature from the modern one	Object and method of determination	Source of information
150-500, the Aktru stage	-0.2	moraines, C14, dendrochronology	[22–24]
500-600, the Aktru stage	+0.4	forest boundary, dendrochronology	[23], [25]
700-800, the Aktru stage	?	moraines, C14	[1], [22], [26]
1200-1300, Medieval Climate Optimum	+0.7	forest boundary, C14	[4]
1600-1700, final phase of the Historical stage	?	moraines, C14, lichenometry	[4], [22]
2500, second phase of the Historical stage	?	moraines, C14	[22]
2600-2700	? (warming)	numerous archaeological burials, C14	[27]
3100, first phase of the Historical stage	?	C14	[22]
3200-3400	+0.9	forest boundary, C14	[6], [28]
about 4500, the Akkem stage	?	moraines, C14	[22]
6000, Holocene Climate Optimum	+1.5 - +1.8	forest boundary, C14	[6], [24]

Table 2: Determination of amplitude and duration of warm and cold periods by glacial deposits and the upper edge of the forest

Change in mean temperature, °C			**Time of a period (years ago) and its duration (years)**		
maximum	minimum	amplitude	beginning	end	duration
+1.8	-0.9	2.7	6000	4500	1500
-0.3	+0.7	1.0	1700	1200	500
+0.7	-0.0	0.7	1200	800	400
+0.4	+0.0	0.4	800	600	200
+0.4	-0.2	0.6	600	250	350

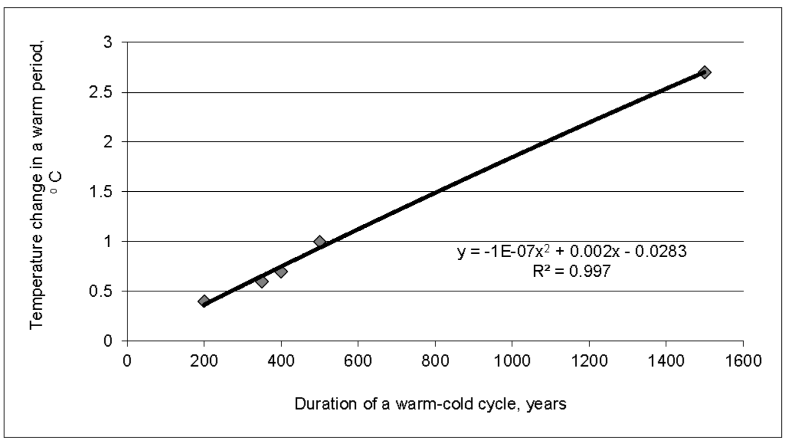

Figure 1: Duration dependence of warming-cooling amplitudes

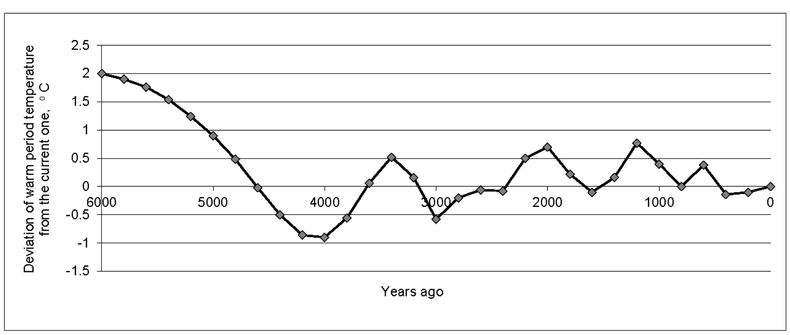

Figure 2: Mean summer temperature in the alpine zone of the Altai in the second half of the Holocene

variations are valid at an averaging period of hundreds of years. When considering shorter period fluctuations (e.g. by spore and pollen spectra or dendrochronology), maximum deviation for warming and cooling is more significant. For instance, the instrumental observations at the Barnaul weather station conducted from the year 1838 call for increasing the amplitude of short-period fluctuations by 1.0-1.5°C.

To compare our results with those in the wider body of literature, we studied the data for the last two thousand years in more detail. The data on thermal changes in the Northern Hemisphere were taken from [18]. Two constructed curves demonstrate considerable synchronism that supports validity of our findings.

The calculation results of ice balance in the Multa River basin for the balance year 1972-1973 We tested the developed simulation model for calculation of glacier budget parameters and the established cold periods during the Akkem and Aktru stages in the Multa basin. To estimate the glacier budget parameters, the territory covered by glacier Tomich in the Multa basin was divided in grid of squares with a side of 250 m (Figure 3; 4a). The calculation of solid precipitation for the non-glacial points

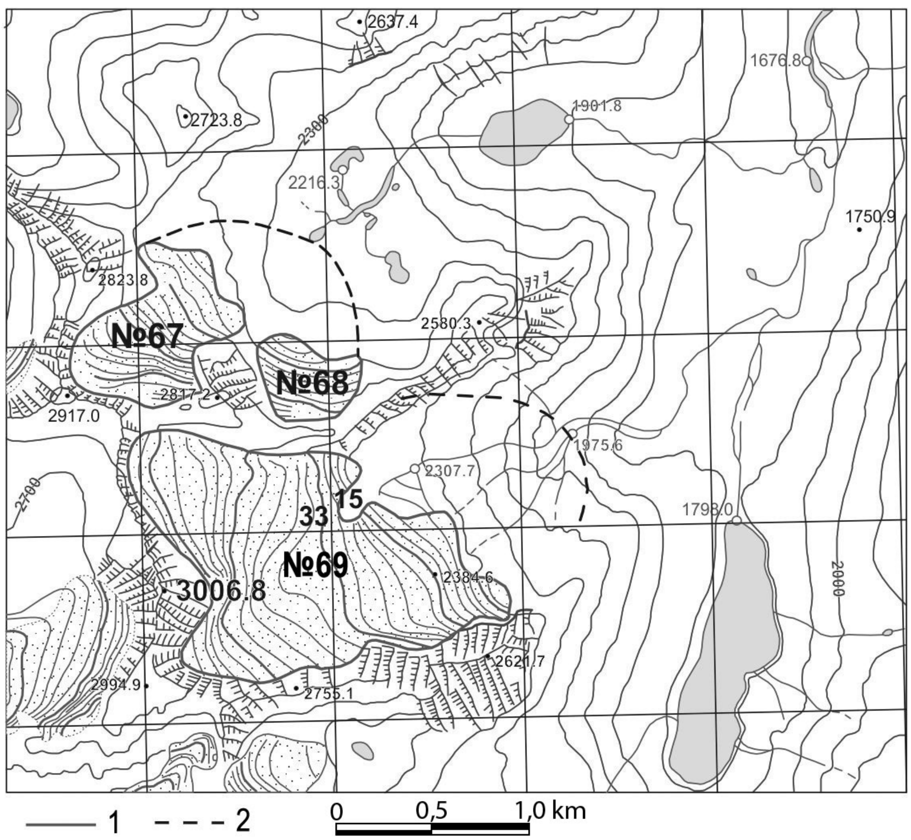

Figure 3: The position of glacier Tomich (№ 69 [21]) and glaciers № 67-68 at present and in the Aktru stage. Grid of 1 km was used for a topographic map, grid for points of simulation made up 250 m. 1 – modern position of glaciers; 2 – glaciers position in the Aktru stage

was made as its total for the winter period based on the data from the reference weather station and with regard to altitudinal gradients. Similarly, we calculated the solid precipitation total for ice points but reducing air temperature by the value of temperature rise depending on the glacier area.

$$\Delta t = 0.4 + 0.5S^{0.5} \tag{3}$$

With absolute elevation, the uniform increase in the background snow reserves is greatly transformed by snow redistribution in the basin (Figure 4b). Note that viewing of points of probable snow redistribution by avalanche is feasible for the whole matrix area.

The melted snow calculated as the sum of positive temperatures multiplied by the coefficient of melting snow and ice [17] see in Figure 4c. We allowed for the exposition of a calculation point and the effect of summer snowfalls. Evaporation rate was taken as constant and equal to 40 mm. The simulated budget of glaciers is given in Figure 4d.

a

.	2	2	.	.	.	.	.	.	.	.	.
2	2	2	.	.	.	.	.	.	.	.	.
.	3	.	.	2	.	.	.	.	.	.	.
.	.	.	.	1	.	.	.	.	.	.	.
.	2	3	3	3	3	.	.	.	.	.	.
.	.	4	4	4	4	4	2	.	.	.	.
.	.	4	4	3	4	5	3	.	.	.	.
.	.	1	4	4	4	5	5	2	.	.	.
.	.	2	4	2	1	.	.	.	.	.	.

b

5	5	5	7	4	4	4	1	1	1	1	.
5	5	5	1	6	4	4	4	1	1	1	.
5	7	5	1	1	5	5	4	1	1	3	.
.	1	5	5	5	5	4	4	4	3	2	.
.	5	5	5	5	5	4	4	4	3	3	.
.	1	5	5	4	5	4	4	4	4	3	.
.	1	1	5	5	1	5	4	4	4	1	.
.	1	7	5	1	6	1	1	1	1	.	.
.	5	5	5	5	5	5	6	6	.	.	.

c

.	4	6	.	.	.	.	.	.	.	.	.
3	4	4	.	.	.	.	.	.	.	.	.
.	2	.	.	5	.	.	.	.	.	.	.
.	.	.	.	4	.	.	.	.	.	.	.
.	1	2	4	4	5	.	.	.	.	.	.
.	.	4	4	6	4	6	6	.	.	.	.
.	.	3	3	4	5	6	6	.	.	.	.
.	.	2	4	5	4	5	5	5	.	.	.
.	.	2	2	3	1	.	.	.	.	.	.

d

.	6	1	.	.	.	.	.	.	.	.	.
8	7	4	.	.	.	.	.	.	.	.	.
.	a	.	.	1	.	.	.	.	.	.	.
.	.	.	.	5	.	.	.	.	.	.	.
.	9	8	7	4	4	.	.	.	.	.	.
.	.	6	4	1	5	1	1	.	.	.	.
.	.	2	7	4	1	4	1	.	.	.	.
.	.	a	6	1	8	1	1	1	.	.	.
.	.	8	8	7	9	.	.	.	.	.	.

Figure 4: a)A matrix of position and thickness of glacier Tomich (№ 69) and two neighboring glaciers (№ 67-68) in 1970. Glacier thickness: 1 - 10-20 m, 2 - 20-30 m, 3 - 30-40 m, 4 - 40-50 m, 5 - 50-60 m. Note: The thickness of glacier Tomich for the year 2000 was defined by radar measurements [20] . Decrease in the glacier surface area in 1970-2000 was specified by means of topographic surveys [29] . Thickness of glaciers № 67-68 was determined based on their area [20] . b)Distribution of the simulated solid precipitation totals (g/cm^2) in the winter of 1972-1973: 1 - 0-50, 2 - 50-75 3 - 75-100, 4 - 100-150, 5-150-250, 6 - 250-350, 7 - more than 350. c)Distribution of the simulated melted layer of snow and ice (g/cm^2) in the summer of 1973: 1 - 0-50 2 - 50-75 3 - 75-100, 4 - 100-150 5 - 150-250 6 - 250 -350. d)The simulated glaciers budget of the basin for 1972-1973 (g/cm^2): 1 - 250 - 100 2 - 100 - 50, 3 - 50-0, 4 - 0-50, 5 - 50-75, 6 - 75-100, 7 - 100-150 8 - 150-250 9 - 250-350, a - more than 350

Validity and Verification of the model using modern data

Numerical experiments made by the example of the balance year 1972-1973 report the simulated budget of glacier Tomich as 45 g/cm^2, and the actually measured one - 41 g/cm^2 [15]. If values of ablation and accumulation make up 220 and 210 g/cm^2, respectively, the error calculation is quite satisfactory. Unfortunately, the data on thermal regime and precipitation in the Multa basin are available solely for the 1972-1973 balance year. The observations of the glacier Tomich budget were conducted in 1969-1973. This period is characterized by a positive ice balance. In the similar Aktru basin, the budget of glacier M.Aktru for the 1961-1962 and 1988-1989 balance years [19] made up -4 g/cm^2. In order the glacier Tomich budget could achieve -6 g/cm^2 at average amount of annual precipitation, it is necessary to increase the warm period temperature by 0.1°C for the 1972-1973 balance year. Let us take this value as the reference for further reconstructions.

The first check of the model can be performed based on the observations of glacier Tomich retreat started in 1969-1973 and continued up to 2010 when re-survey of the glacier was made. The increase in average summer temperature for this observation period at weather station Karatyurek (2600 m asl) is estimated as 0.1°C.

Simulation of change in the glacier budget and its further probable retreat for the given period is shown in Figure 5a. The simulated retreat of the glacier front made up approximately 200 m that agrees well with instrumental observations.

The second step of the model checking was carried out for the Aktru stage. The terminal moraines of this stage are quite clearly seen in satellite images. To do numerical simulation, we need to know as the planned position of glaciers as the change in glacier thickness. Using the data on radar imagery of glaciers [20], the area dependence of the average ice thickness was calculated. The Tomich glacier area in 1970 [21] made up 1.6 km^2 at average glacier thickness of 60 m that was proved by the survey data [20]. At the glacier area of 2.5 km^2 in the Aktru stage, the average thickness of the glacier should reach 80 m. The dependence obtained experimentally suggests the Tomich glacier thickness be 90 m. According to our research made in the Aktru basin [22] and using modern precipitation amount, the temperature change in the warm period equals -0.2°C.

When simulating the glacier balance for the set area and temperature, we derive the balance resultant that is close to zero (Figure 5b): for glacier Tomich it is 1.9 g/cm^2, for a single glacier formed by small glaciers № 67-68 +1.6 g/cm^2.

Interestingly, the numerical simulation of glaciers in the Multa River basin provides the support for a cooling value of – 0.2°C during the Aktru stage previously received for the Aktru river basin [3].

The final validation of the model included a simulation of the Akkem cold episode. Its age was defined of 4300-4500 thousand years ago by dating the lacustrine sediments from the moraine dammed lake. This cold period is fairly well expressed in the relief of the Multa River valley. The area of glacier Tomich, that time consisting of glaciers № 66, 67, 68 reached 4.5 km^2. According to the studies of the Aktru River basin, the cooling made up 0.9°C. Using the data on modern precipitation amounts, we calculated the glacier budget for this stage that was close to zero, i.e. -1.3 g/cm^2 (Figure 5c). As is obvious from the foregoing, the numerical simulation has confirmed the value of cooling in the Akkem stage obtained for the Aktru River basin.

a

.	1	1	.	.	.	.	.	.	.	.	.
.	4	1	.	.	.	.	.	.	.	.	.
7	5	1	.	.	.	.	.	.	.	.	.
.	a	.	.	X	.	.	.	.	.	.	.
.	.	.	.	4	.	.	.	.	.	.	.
.	8	8	4	1	1	.	.	.	.	.	.
.	.	1	1	1	4	1	X	.	.	.	.
.	.	2	5	1	1	1	X	.	.	.	.
.	.	a	4	1	8	1	1	X	.	.	.
.	.	8	7	6	8	.	.	.	.	.	.

b

.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	1	1	.	.	.	.	.	.	.
.	.	1	1	1	1	.	.	.	.	.	.
.	7	4	a	1	1	.	.	.	.	.	.
8	7	6	.	4	1	.	.	.	.	.	.
.	a	8	.	1	4	.	.	.	.	.	.
.	.	.	.	.	.	1	1	1	1	.	.
.	9	8	7	6	4	1	1	1	1	.	.
.	.	7	4	4	5	1	1	1	1	.	.
.	.	2	7	7	2	4	1	1	1	.	.
.	.	a	7	2	8	1	1	2	.	.	.
.	.	8	8	8	9	.	.	.	.	.	.

c

.	.	.	.	.	.	1	1	1	.	.	.
.	.	.	.	.	.	.	1	1	.	.	.
.	.	.	.	.	.	1	1	.	.	.	.
9	a	8	2	2	1	1	1	.	.	.	.
9	5	8	3	2	1	2	2	.	.	.	.
9	9	8	6	2	.	1	1	2	3	5	9
.	.	8	7	2	2	2	2	2	5	8	8
.	.	9	6	3	2	2	2	6	8	a	.
.	6	9	9	9	6	3	8	9	9	7	.
.	.	.	9	9	7	8	9	9	7	a	.
.	.	.	.	8	8	9	9	5	.	.	.
.	.	.	.	.	.	.	9	.	.	.	.

Figure 5: a)The simulated budget of glaciers in the Tomichka basin g/cm^2 and their retreat in 1969-2010 on conditions that it is an average balance year. 1 - 250 - 100, 2 - 100 - 50, 3 - 50-0 , 4 - 0-50 , 5 - 50-75 , 6 - 75-100 , 7 - 100-150, 8 - 150-250, 9 - 250-350, and - more than 350. X - the points in which the glacier thawed up to its bed (compared to 1970) . ΔL = 250 m. b)Budget of glaciers Tomich (№ 69) and № 67-68 (g/cm^2) in the Aktru stage: 1 - 450 - 100, 2 - 100 - 50, 3 - 50-0, 4 - 0-50, 5 - 50-75, 6 - 75-100, 7 - 100-150, 8 - 150-250, 9 - 250-350, a - more than 350 g/cm^2. ΔL = 250 m. c)Budget of glacier Tomich (g/cm^2) in the Akkem stage: 1 - 500 - 250, 2 - 250 - 100, 3 - 100 - 50, 4 - 50-0, 5 - 0-50, 6 - 50-75, 7 - 75-100, 8 - 100-150, 9 - 150-250, a - more than 250 g/cm^2. ΔL = 0.5 km

Conclusions

The original simulation model previously developed for glaciers budget was applied to paleogeographic reconstructions in the Russian Altai. First, the model was tested in the Aktru basin for which a long-standing series of data on the glaciers budget are available. The moraine complexes of late Holocene cooling in the Aktru stage (Fernau) are well-preserved. The simulation results for the Aktru basin show that the mean temperature of the warm period during the Aktru stage was 0.2°C lower than that at present.

The simulation model for the calculation of glacier budget components was tested on glacier Tomich in the Multa River basin. The simulated ice balance of glacier Tomich for 1972-1973 makes up 45 g/cm^2 , whereas the really measured one - 41 g/cm^2. We simulated the glacier budget in the Multa River basin for the Aktru cooling stage (Fernau). The glacier position was well defined by its terminal moraines and space images. The simulation data point to the fact that the mean temperature of the warm period during the Aktru stage in the Multa and Aktru basins was lower by 0.2°C. The final stage of the model validation involved the simulation of the Akkem cooling which age (4900-4200 years ago) was defined from dating the lacustrine sediments formed behind the moraine after the glacier retreat. The simulation results show that during the Akkem cooling the mean temperature of the warm period in the Multa basin was 0.2°C lower than that nowadays. Testing the model based on the modern data shows good conformity of numerical calculations and actual measurements results. The obtained outcomes do not contradict previously made paleoclimatic reconstructions.

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Received 19.09.2017, Accepted 22.09.2017