

Field study of the Pole Markova glacier system, Kronotsky peninsula, Kamchatka, Russia in 2000

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Abstract

In the summer season of 2000, ice flow velocity, ablation rates and change of the surface level since 1960 were measured at the Pole Markova glaciers (Kamchatka, Russia) for the first time. Average ice flow velocity reached about $14\text{--}17\text{ m a}^{-1}$ during the period from August 19 to September 9, being faster for the steeper stream. Daily ablation rates changed from 31 to 63 mm w.e. on average demonstrating some patchy impact on ice flow velocities along the established profiles. Surface has been depressed since 1960 by 20–30 m in the tongue part and just for 0–5 m in the accumulation area. Some degradation of total area of the glacier and retreat of its termini are also noticed. Mean specific annual mass balance of the Right Pole Markova glacier in 1999/2000 was estimated as $-0.37\text{ m w.e. a}^{-1}$ that is rather close to $-0.56\text{ m w.e. a}^{-1}$ for the neighboring Koryto glacier. There is some evidence that these glaciers have similar regime of external mass exchange.

1. Introduction

Kronotsky peninsula is the outspread eastern area of Kamchatka, one of the easternmost parts of Russia. Mountain glaciers here can be characterized with high level of sensitivity to environmental variations due to the most intensive mass exchange processes among all glaciated regions of Eurasia and even of the whole northern hemisphere (Vinogradov and Khodakov, 1973; Dyurgerov and Meier, 1999). That is why the study of glaciation systems of Kamchatka and particularly of the Kronotsky peninsula is one of the effective ways to trace climatic changes in this region and in the global scale.

In the central mountainous part of this peninsula, the Kronotsky ice knot is situated (Fig. 1). It consists of more than 30 glaciers with a total area of 90 km^2 approximately (Vinogradov, 1968). Most of them are not studied at all. In the previous years more or less complete investigations were produced only at the large valley glacier Koryto having area of 7.87 km^2 (revised after Muravyev *et al.*, 1999).

In August and September 2000 for the first time a number of studies were produced at the neighboring Pole Markova glacier system (Fig. 2, Table 1), which had been a joint complex up to the middle of 20th century (Preobrazhensky and Model, 1965) but since that time has degraded into three substantive glaciers: 1) Right Pole Markova (hereinafter RPM); 2) Left Pole Markova (hereinafter LPM), – these two still have junction in their upper parts, with common ice-

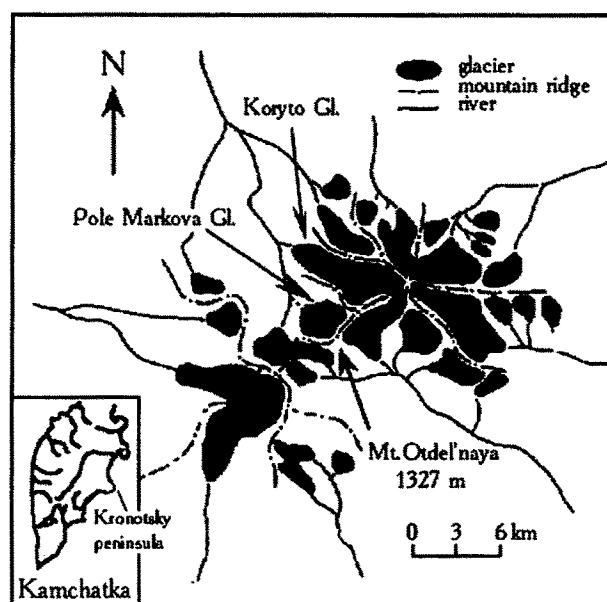


Fig. 1. Study area (after Vinogradov, 1968; with edition of the authors of the present report).

shed; and 3) small previously nameless one, hereinafter Khodakov Glacier, as it was proposed for commemorating the name of the Russian glaciologist V. G. Khodakov (Ya. D. Muravyev, personal communication). On the two of them (LPM and RPM), ablation and ice flow velocity on the surface were measured in the middle of ablation season; moreover, change of the surface level since 1960 was obtained along their flowlines. In the present report, results of this field study are summarized.

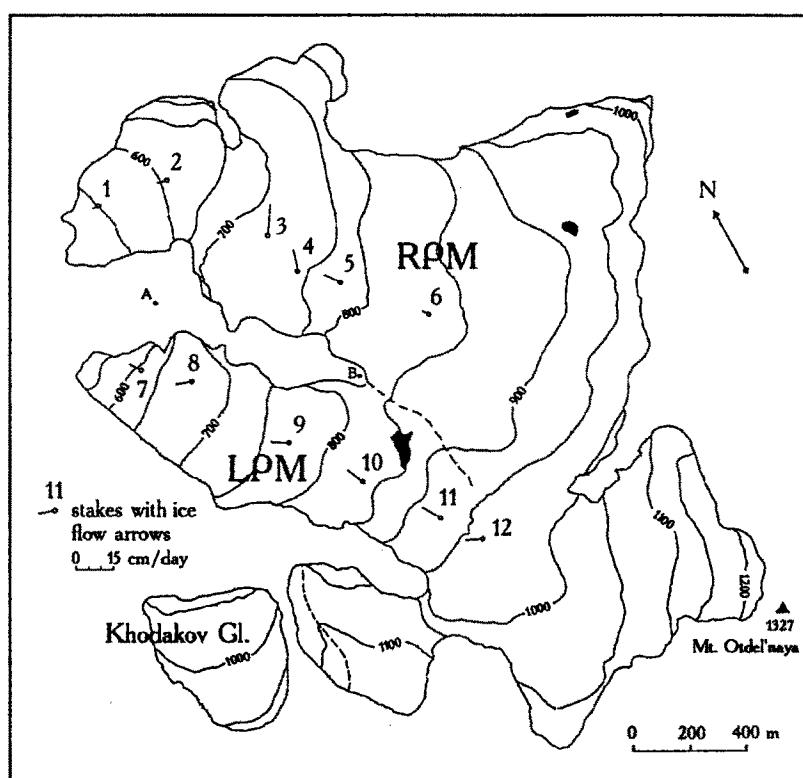


Fig. 2. Map of the Pole Markova glaciers. Dashed lines show remarkable icesheds. Contours and surface topography of the glaciers are taken from the map of D. G. Tsvetkov, 1960, and corrected in accordance with our field observations in 2000 (see explanations in the paragraph 3.3).

Table 1. Some important parameters of the Pole Markova glaciers according to the field observations in 2000.

Parameter	Right Pole Markova	Left Pole Markova	Small Pole Markova (Khodakov)	In total
Length, km	2.73	2.78	0.54	—
Area, km ²	2.16	1.70	0.22	4.08
Exposition	NW	NNW	N	NW
Max elevation, m	1060	1220	1060	1220
Min elevation, m	≈510	≈530	≈940	≈510
Mean slope	11.4	14.0	12.5	—
ELA in 2000, m	800–850	950–1000	≈1000	—
Estimated mass balance, m w.e.	−0.37	(negative ?)	(negative ?)	—
Mass balance gradient, mm m ^{−1}	14.7	(14.7 ?)	no data	(14.7 ?)
AAR, %	55	45	<10	48
Average ice flow velocity, m a ^{−1}	14	17	no data	≈15

2. Previous observations

First investigations at the Pole Markova glaciers were carried out in 1960 by the expedition of the Institute of Geography, Academy of Sciences of the Soviet Union (Russian Academy of Sciences, at present). From September 14 up to October 23 several glaciers of the Kronotsky peninsula were surveyed, namely Koryto, Bunin, Brovko, Pole Markova and others (Preobrazhensky and Model, 1965). As for the Pole Markova glacier system, following data was reported: in 1960 it had been a complex valley glacier having length of 2.8 km and area of 8.5 km²; the firm line altitude was reported as 750 m a.s.l. on September

20. As there is no zone of superimposed ice at the Pole Markova glaciers and observations were done in the end of ablation season, this level can be considered as the equilibrium line altitude (ELA) of the Pole Markova glaciers in 1959/60 balance year. Some information about surface topography and geometry of the glacier system was also given in the paper. Among other important features, connection with accumulation areas of the neighboring glaciers Koryto, Shirokiy and Brovko was observed.

On the base of the photo-theodolite survey, 1960, D. G. Tsvetkov had produced a topographical map of the glaciers Koryto and Pole Markova, 1:10 000 (the full map is still unpublished; its autographic original is

stored in the Institute of Volcanology, Russian Academy of Sciences; a partial, small and rough copy was published in Macheret *et al.*, 2001; outlines of the Koryto glacier derived from the Tsvetkov's map were published in some other papers; outlines of the Pole Markova glaciers at Fig. 2 are based on this map but with corrections made after our field observations in 2000, see paragraph 3.3 of this paper).

According to the Tsvetkov's map of 1960 and to the report of Preobrazhensky and Model (1965), in 1960 two flows of ice, LPM and RPM, had been already separated, but the distance between their tongues was much less than that in the recent time. The hanging Khodakov glacier was also separated from the LPM ice stream just with small rocky riegel, still feeding LPM with water and ice.

Next glaciological expedition worked in the Kronotsky ice knot in 1971 (Vinogradov and Khodakov, 1973; 1976) but they had not studied Pole Markova at all and concentrated their efforts at the Koryto glacier. The same was in 1981/82 during joint glaciological expedition of the Institute of Geography and the Institute of Volcanology. Even if some observations of the Pole Markova system took place at that time (and according Ya. D. Muravyev's personal communication, they did), results are still unknown.

In 1984, Ya. D. Muravyev took several air photographs of the Kronotsky ice knot (Muravyev *et al.*, 1999). The Pole Markova glaciers were represented there too (Fig. 3).



Fig. 3. Left and Right Pole Markova glaciers in September 1984 seen from northwest (photo by Ya. D. Muravyev).

In 1996, field study of Kronotsky peninsula glaciers and environments was started again by Russo-Japanese Joint Glaciological Expedition (Kobayashi *et al.*, 1997; Kodama *et al.*, 1996; 1997; etc.), continued then in 1997 (Muravyev *et al.*, 1999; Nishimura *et al.*, 1999; Solomina *et al.*, 1999; etc.), in 1999 and in 2000 (Muravyev *et al.*, 2001; Matsumoto *et al.*, 2001; Tchoumitchev and Yamaguchi, 2001; etc.). Within these studies, some visual observations of the Pole Markova glaciers were made by Ya. D. Muravyev and A. A. Ovsyannikov (personal communications), but

not reported.

On September 12, 1997, O.N. Solomina and S. A. Tchoumitchev have examined lateral and terminal moraines of the Pole Markova glaciers (results are published in Solomina *et al.*, 1999; Solomina, 1999) and then climbed up RPM to the pass between Pole Markova and Koryto valleys. During this excursion, it was noticed that RPM and LPM were almost completely covered with snow and firn of 1996/97. In turn, as the end of ablation season of that year came just several days after the excursion, in the middle of September 1997 according to Muravyev *et al.* (1999), ELA in 1996/97 balance year must be estimated thus very close to the altitude of termini, or as about 550–600 m a.s.l.

The most recent investigation of Pole Markova was produced in 2000 (this study); also, T. Aoki and S. Tchoumitchev have studied its moraine complexes in 2000 more detailed than it had been done in 1997, but results are still unpublished.

3. Field measurements in 2000: results and discussion

In the middle of August 2000, six stakes were established at the surface of each glacier (LPG and RPG) along their flowlines (Fig. 2), with 150–450 m distance between neighboring stakes. For measurement of ice flow velocity we conducted a theodolite/EDM survey of stakes positions from two solid basepoints, A and B, on August 19 and 25, and September 1 and 9. Coordinates and absolute altitudes of the basepoints were obtained by GPS survey. As there were no snowfalls during the period of our field works on the glacier, we could measure ablation rates. It was done directly for each stake by tracing the change of height between the top of the stake and glacier surface for 2–3 days intervals, with the use of metal tape. Data obtained for elevation of stakes, ablation rates and ice flow velocity is given in Table 2.

Table 2. Ablation and horizontal ice flow velocities at the Pole Markova glaciers, averaged for 21-days period (19.08 – 09.09.2000), and lowering of the glacier surface since 1960.

	Stakes	Elevation m a.s.l.	Lowering since 1960, m	Ablation rate, mm, w.e day ⁻¹	Ice flow, cm day ⁻¹
RPM glacier	1	551	29	57.0	2.5
	2	607	33	54.4	3.9
	3	720	10	55.2	11.2
	4	742	18	62.6	8.0
	5	782	10	41.5	6.6
	6	835	5	36.7	2.7
LPM glacier	7	607	23	46.4	4.5
	8	677	15	48.0	5.8
	9	770	10	50.6	5.9
	10	843	17	51.7	6.9
	11	923	0	48.8	7.1
	12	967	3	31.9	5.9

3.1. Ablation rates

Average ablation rate from August 19 to September 9 reached its maximum of $62.6 \text{ mm w.e. day}^{-1}$ at the stake #4 having altitude close to the normal year ELA of the RPM glacier detected with the classical method of Hess as 750–800 m a.s.l. All-in-all, as it is shown in Fig. 4a, on the RPM tongue it was 10–15 mm w.e. day^{-1} greater than on the tongue of LPM (at the same altitudes) because the last one occurs in the shadow of its left steep bank for the longer part of day. In the upper section of the LPM glacier it was 15–20 mm w.e. day^{-1} greater than in the upper section of RPM, possibly due to special features of air circulation: the LPM exposition coincides with the main direction of the valley of the river Bolshaya Chazhma, so LPM is open to the warm air masses from the lower parts of the valley. On the contrary, RPM is situated in a niche aside from the main axis of the valley, and occupies a wide circus where one could suggest stagnation of cold air.

3.2. Ice flow velocities

Altitudinal distributions of average ice flow speeds from August 19 to September 9 are shown in Fig. 4b. On August 19–25, in the middle of ablation season, ice flow velocity reached 14.5 cm day^{-1} near the level of normal year ELA of the RPM glacier (stake #3). The minimal values for RPM were observed on September 1–9, they were 1.6 cm day^{-1} in the accumulation area (stake #6) and 0.3 cm day^{-1} at the terminus (stake #1).

Ice flow velocities did not differ in significant scale from one glacier to another, though the maximum velocity of the RPM glacier was 1.5 times faster than that of the LPM glacier. In turn, the minimum velocity of the LPM glacier was higher than the minimum velocity of RPM (1.5 cm day^{-1} at the stake #9 on August 25 – September 1). These differences could be explained with features of topography and

morphometry of each stream.

As a first approximation, we can estimate area-weighted average ice flow velocities to be about 14 m a^{-1} for the RPM glacier and about 17 m a^{-1} for the LPM glacier. For obtaining these values we have roughly assumed that for the whole glacier average ice flow velocity should be nearly constant within a year, and that in those parts of the glaciers where surface speed had not been measured directly, ice flow velocity could be extrapolated. The result is a little higher on LPM, but it is not so unexpected, because the surface slope of the LPM glacier (14°) is steeper than that of RPM (11.4°). Of course, values of ice flow speed averaged with such a method are provisional because we do not know the inter-annual variation of velocities and their exact distribution within the glaciers. However, they could serve as indices of englacial mass exchange intensity when comparing glaciers to each other.

Obviously, any local differences in distribution of ice flow velocity between two glaciers, LPM and RPM, correspond to local features of bed relief. Also we can assume them to be connected with distribution of melting rates by dint of basal sliding. It can be seen from Fig. 4 that there was some connection between maximum values of ice flow velocities, and of ablation rates. Moreover, having considered differences in ice flow for the three periods of measurements (August 19 – 25, August 25 – September 1, September 1 – 9) it is possible to conclude that there was strong variability of the flow velocity near normal year ELA of each glacier, connected with changes in melting rate. Really, the stake #3, for example (Fig. 5), had shifted with a speed of 14.5 cm day^{-1} during the first and the third periods of those mentioned above and just with 4.9 cm day^{-1} during the second one that was characterized also with decrease of air temperature (K. Konya, personal communication) and of melting rate (from 60.0 down to $35.0 \text{ mm w.e. day}^{-1}$ for the

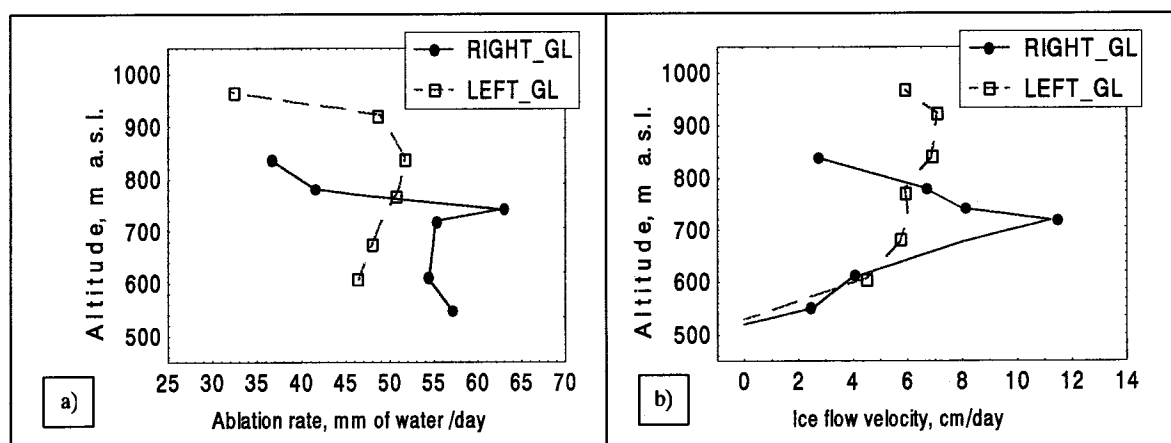


Fig. 4. Altitudinal distributions of a) ablation rates; b) ice flow velocities at the Pole Markova glaciers, both averaged for the period from August 19 – September 9, 2000. At the termini ice flow velocities equal zero.

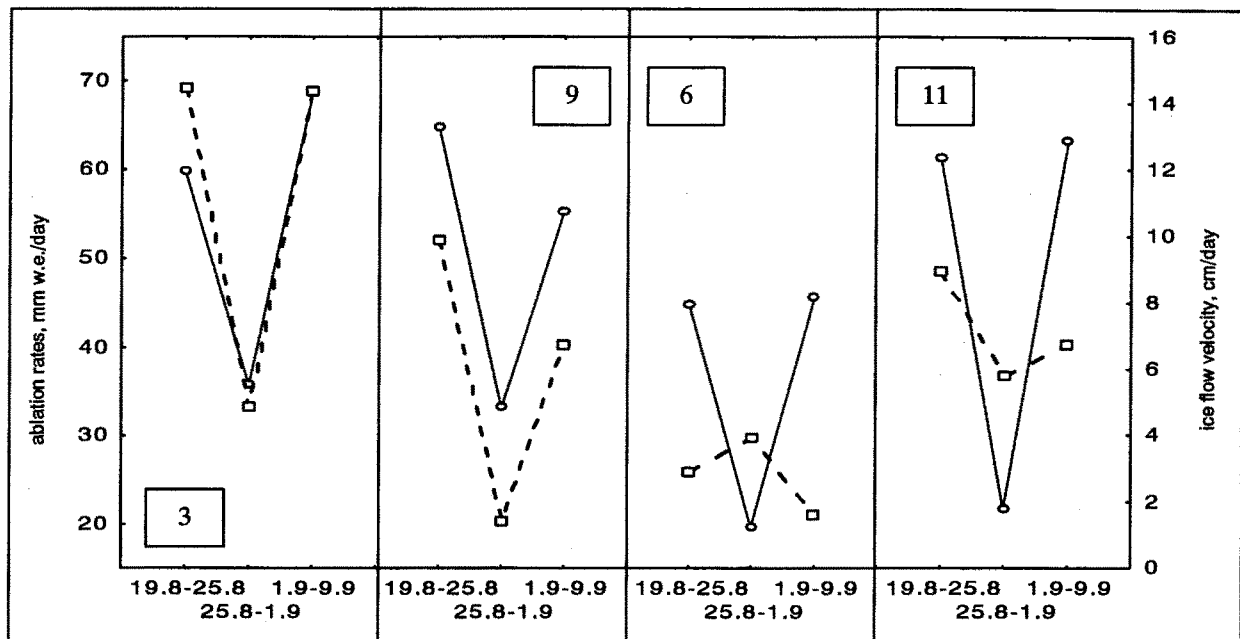


Fig. 5. Examples of changes of ice flow velocity and ablation rates for the three periods of measurements. Ablation rates (left scale) are shown with solid lines. Ice flow (right scale) is shown with broken lines. Numbers of the stakes are given in the rectangles. The stakes #3 and 9 demonstrate significant change of ice flow velocity in connection with the change of melting rate, and the stakes #6 and 11 do not.

stake #3). Such significant difference between ice flow velocities of these periods was also observed at the stake #4 of RPM (a lapse from 10.6 to 5.6 cm day^{-1}) and at the stake #9 of LPM (9.9 cm day^{-1} and 1.5 cm day^{-1} , respectively). As for the other stakes, their ice flow variability was not so large though the changes of melting rates were of the same scale as for the stake #3 (Fig. 5). However, absolute values of ablation were less in the latter case. Out of this, we can conclude that in those areas of the observed glaciers where ablation was greater, basal sliding had to be more significant for the process of ice flow than in other parts.

3.3. Surface lowering and revision of the map

To estimate surface lowering since 1960 we have compared altitudes, calculated from our theodolite survey with those from the Tsvetkov's map, 1960. Then, presentation of surface topography was corrected and new isohypses answering the present state of the glacier system were pictured at the map by shifting 1960's isohypses so that their position could satisfy altitudes of the stakes in 2000 (see Fig. 2). Terminal positions in 2000 were detected by GPS survey, and pictured too.

Unfortunately, it was difficult to identify positions of termini at the map of Tsvetkov, because drawings for this part are uncertain. That is why we have pictured only 2000's termini known from direct field observations.

As shown in Fig. 6, surface lowering of the RPM

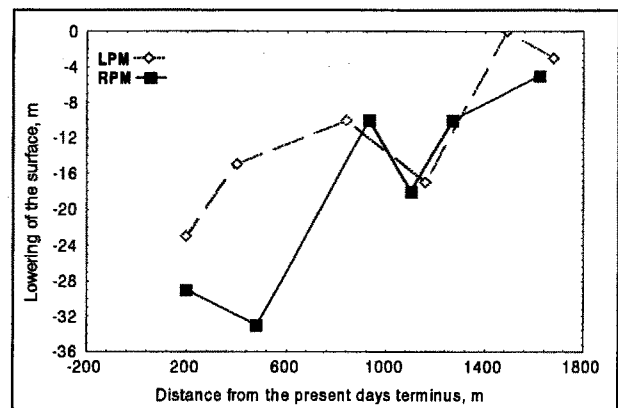


Fig. 6. Changes in the surface elevation of the Left and Right Pole Markova glaciers since 1960.

glacier since 1960 was 5–30 m (minimal lowering among observed was in the accumulation area, at the stake #6; maximal one was on the tongue), and surface lowering of the LPM glacier within the same time interval was 3–20 m respectively.

3.4. Mass balance

Finally, annual mass balance of the RPM glacier was approximated. At first, from the neighboring Koryto glacier we have extrapolated the reconstructed specific winter mass balance. For that reconstruction we used data about the thickness of 1999/2000 firn layer in the borehole on 840 m a.s.l. on August 4, and degree-day factor of ablation at the same place, measured also in August and having value of 4.74 mm

w.e. $^{\circ}\text{C}^{-1} \text{ d}^{-1}$ (K. Konya, personal communication). To get the temperatures of the earlier summer months when there were not direct measurements at the Koryto glacier (June and July) we took data from the Automatic Weather Station (AWS) "Ridge" at 1160 m a.s.l. in the uppermost part of the Koryto valley (Matsumoto *et al.*, 1999; 2001), and arranged temperature to the surface of the Koryto glacier through the lapse rate of $0.0035 \text{ }^{\circ}\text{C m}^{-1}$ and $1 \text{ }^{\circ}\text{C}$ amendment for the glacier cooling effect (Vinogradov and Khodakov, 1976). Then, we could find the sum of ablation of the earlier summer months using degree-day factor, and thus, it was possible to obtain winter balance by adding the thickness of the melted layer to that observed in the borehole. Altitudinal distribution of specific annual accumulation at Koryto was assumed similar to that of 1996/97 (Muravyev *et al.*, 1999), but the curve of distribution was shifted to fit the reconstructed value.

As the areas of the Koryto and Pole Markova glaciers are of the same order of several square kilometers, and they are situated very close to each other and have similar exposition, in general we could assume them having similar features of snow accumulation. That is why we have tried to extrapolate specific winter balance of Koryto altitudinal belts to the corresponding altitudinal belts of RPM. Distribution of the RPM area with height was derived from the map presented at Fig. 2, so we could approximate RPM mean specific winter balance of 1999/2000, and it was $4.95 \text{ m w.e. a}^{-1}$.

Next, summer balance of RPM was calculated on the base of the measured ablation rates (Table 2) with use of degree-day factor for each stake. We could obtain the latter as a quotient of dividing the melted layer thickness measured for a certain period, by the sum of mean daily air temperatures within the same time interval. Temperatures for RPM were derived with the same scheme as it was described above for Koryto. For those altitudinal belts of the glacier where observations of ablation were not carried out, we have extrapolated or interpolated the data according to the observed gradients of ablation. At the end, mean specific value of summer mass balance was calculated.

As such estimation was enough rough, we have checked the result with a different method, previously used for the reconstruction of mean specific summer mass balance on the Koryto glacier in Vinogradov and Khodakov (1976). There, a simple model was applied for obtaining that value:

$$b_s = 10 (t + 1.3 B_{sh}^{0.5} + 4)^3, \quad (1)$$

where, b_s is mean specific summer balance, m w.e. a^{-1} , t is average summer temperature for the whole glacier, $^{\circ}\text{C}$, and B_{sh} is short-wave radiation balance,

kcal cm^{-2} . In the model, it is taken that B_{sh} is constant from year to year and for the glacier surface in the region of study takes value of $21.8 \text{ kcal cm}^{-2}$ (Vinogradov and Khodakov, 1976). Average summer temperature was taken from the AWS "Ridge" (Matsumoto *et al.*, 1999; 2001) and arranged to the surface of RPM through the lapse rate of $0.0035 \text{ }^{\circ}\text{C m}^{-1}$ and $1 \text{ }^{\circ}\text{C}$ amendment for the glacier cooling effect (Vinogradov and Khodakov, 1976).

Values of mean specific summer mass balance on the RPM glacier, obtained with these two methods, appeared to be very close to each other: $-5.32 \text{ m w.e. a}^{-1}$ for our first estimation and $-5.5 \text{ m w.e. a}^{-1}$ for the estimation by the above-described model of Vinogradov and Khodakov. One of the most strong evidence for the reconstruction adequacy was the fact that, according to our calculation, specific winter mass balance had equalled specific summer mass balance at 800–850 m a.s.l., and at the end of ablation season (middle of September) equilibrium line was detected in field at the same altitude (Table 1).

Mean specific annual mass balance of the RPM glacier in 1999/2000 has been estimated then as $-0.37 \text{ m w.e. a}^{-1}$ without amendment for ablation decrement (i.e. internal accumulation) and for income of matter through the duct from the accumulation area of the LPM glacier (see Fig. 2). Almost the same was the value of mean specific annual mass balance of this year at the Koryto glacier: $-0.56 \text{ m w.e. a}^{-1}$ according to Muravyev *et al.* (2001).

3.5. Final remarks

Table 1 shows some important parameters of the Pole Markova glaciers obtained during this field season and following processing of data. It is interesting to compare them with those reported by Preobrazhensky and Model (1965). So, in 1960, the total area of the glacier system was 8.5 km^2 and its length reached 2.8 km. Now, the total area of the Pole Markova glaciers is only 4.08 km^2 that means disappearance of more than a half of the glacier for the last 40 years. This seems untrue because glacier length has not changed significantly (see Table 1); the only remarkable loss of area we observed was due to some retreat of the RPM terminus and disappearance of several small parts of the glacier in the accumulation area. But, anyway, they could not explain such dramatic changes, so we would rather suppose that 1960's area value had been overestimated. As it was mentioned before, drawings for the terminal part are uncertain at the map of Tsvetkov, so we still do not know the real area of the glacier in 1960. This data will be available after interpretation of moraine study conducted in 2000. However, even on the base of preliminary conclusions on that study it is possible to declare that glacier area in 1960 could not be larger than 5.0 km^2 .

ELA in 2000 was 50–250 m higher than that in

1960 (800–850 m a.s.l. for RPM and 950–1000 m a.s.l. for LPM in 2000 versus 750 m a.s.l. for both two glaciers in 1960), and lower it seemed to be in 1997 (around 550–600 m a.s.l.). These variations correspond those of the Koryto glacier (Muravyev *et al.*, 2001). Moreover, in 1959/60 mean specific annual mass balance of Koryto was around zero (-0.09 m w.e. a^{-1}) according to Vinogradov and Khodakov (1976), and at the same time, for the neighboring Pole Markova glacier system, equilibrium line detected in field fitted the level of normal year ELA (750–800 m a.s.l.). Basing on all these facts, one can suppose significant correlation of Koryto and Pole Markova mass balances. Herewith, ELA of the Pole Markova glacier system was always observed around 50–100 m higher than ELA of Koryto.

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References

- Dyrgerov, M. B. and Meier, M. F. (1999): Analysis of winter and summer glacier mass balances. *Geografiska Annaler, Special Iss.*, **81A**, 4, 541–554.
- Kobayashi, D., Muravyev, Ya. D., Kodama, Y. and Shiraiwa, T. (1997): An outline of Russo–Japanese joint glacier research in Kamchatka, 1996. *Bulletin of Glacier Research*, **15**, 19–26.
- Kodama, Y., Shiraiwa, T., Kobayashi, D., Matsumoto, T., Yamaguchi, S., Muravyev, Ya. D. and Glazirin, G. E. (1996): Hydrometeorological and glaciological observations in the Koryto and Ushkovsky glaciers, Kamchatka, 1996. *Low Temperature Science, Ser.A.*, **55**, Data Report, 120–149.
- Kodama, Y., Matsumoto, T., Glazirin, G. E., Muravyev, Ya. D., Shiraiwa, T. and Yamaguchi, S. (1997): Hydrometeorological features of Koryto glacier in the Kronotsky peninsula, Russia. *Bulletin of Glacier Research*, **15**, 37–45.
- Macheret, Y., Vasilenko, E., Glazovsky, A., Moshina, O., Miroshnichenko, D. and Shiraiwa, T. (2001): Radio-echo sounding of Koryto glacier (Kamchatka, Russia) in 2000. *Proceedings of the International Symposium on Atmosphere–Ocean–Cryosphere Interaction in the Sea of Okhotsk and the Surrounding Environment* (held at Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan on December 12–15, 2000), eds. M. Wakatsuchi and T. Hara, 160–161.
- Matsumoto, T., Kodama, Y., Shiraiwa, T., Yamaguchi, S., Sone, T., Nishimura, K., Muravyev, Y. D., Khomentovsky, P. A. and Yamagata, K. (1999): Meteorological observations by Automatic Weather Stations (AWS) in alpine regions of Kamchatka, Russia, 1996–1997. *Cryospheric Studies in Kamchatka II*, 155–170.
- Matsumoto, T., Konya, K., Muravyev, Ya. D., Shiraiwa, T., Kodama, Y., Nishimura, K., Yamada, T., Glazirin, G. E., Yamaguchi, S., Aoki, T. and Naruse, R. (2001): Climatic features of Koryto glacier, Kamchatka peninsula, Russia. *Proceedings of the International Symposium on Atmosphere–Ocean–Cryosphere Interaction in the Sea of Okhotsk and the Surrounding Environment* (held at Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan on December 12–15, 2000), eds. M. Wakatsuchi and T. Hara, 156–157.
- Muravyev, Ya. D., Shiraiwa, T., Yamaguchi, S., Matsumoto, T., Nishimura, K., Kohshima, S. and Ovsyannikov, A. A. (1999): Mass balance of glacier in condition of maritime climate (Koryto Glacier in Kamchatka, Russia. *Cryospheric Studies in Kamchatka II*, 51–61.
- Muravyev, Ya. D., Shiraiwa, T., Matsumoto, T., Yamaguchi, S. and Keiko, K. (2001): Mass balances of Koryto glacier 1996–2000: Response of a maritime glacier to changing climate in Kamchatka. *Proceedings of the International Symposium on Atmosphere–Ocean–Cryosphere Interaction in the Sea of Okhotsk and the Surrounding Environment* (held at Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan on December 12–15, 2000), eds. M. Wakatsuchi and T. Hara, 158–159.
- Nishimura, K., Shiraiwa, T., Matsumoto, T. and Muravyev, Ya. D. (1999): Meteorological observations in the Koryto glacier, Kamchatka, 1997. *Cryospheric Studies in Kamchatka II*, 62–69.
- Preobrazhensky, V. S. and Model, Y. M. (1965): *Kronotsky lednikovyi uzel (Kronotsky ice knot). Thermal and Water Regime of Snow and Glacier Deposits*. Moscow, Nauka, 5–30 (in Russian).
- Solomina, O. N. (1999): Mountain glaciation of Northern Eurasia in the Holocene. Moscow, Scientific World, 272 p. (in Russian, with English abstract).
- Solomina, O. N., Muravyev, Ya. D., Shiraiwa, T., Yamagata, K. and Sawaguchi, S. (1999): Lichenometric studies of moraines in Kronotsky peninsula, Kamchatka, Russia. *Cryospheric Studies in Kamchatka II*, 76–78.
- Tchoumitchev, S. and Yamaguchi, S. (2001): Some preliminary results of the study of mass exchange processes of the Kronotsky peninsula glaciers (Kamchatka) in 2000. *Proceedings of the International Symposium on Atmosphere–Ocean–Cryosphere Interaction in the Sea of Okhotsk and the Surrounding Environment* (held at Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan on December 12–15, 2000), eds. M. Wakatsuchi and T. Hara, 148–149.
- Vinogradov, V. N. (1968): *Catalogue of USSR Glaciers*, vol. **20**, Kamchatka, Pt.2–4, Leningrad, Gidrometeoizdat, 67 p. (in Russian).
- Vinogradov, V. N. and Khodakov, V. G. (1973): Snezhnyi pokrov Kronotskogo Massiva i balans l'da lednika Koryto (Snow cover of the Kronotsky Massif and the ice budget of the Koryto glacier). *Data of Glaciological Studies* **22**, 143–152 (in Russian).
- Vinogradov, V. N. and Khodakov, V. G. (1976): Balance of ice of Koryto Glacier, Kronotsky Mts. Results of Researches on the International Geophysical Projects. *Glaciological Research* **25**, Moscow, Nauka, 18–26 (in Russian).