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Article

Assessment of glacier shrinkage from the maximum in the Little Ice Age in the Suntar-Khayata Range, North-East Siberia

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Abstract

This paper presents new estimates and a preliminary analysis of some key glaciers' shrinkage in the Northern and Southern massifs of the Suntar-Khayata Range, North-East Siberia, on the basis of expedition data, archived air-photo images of the 1940-s and 1970-s, and evidence of glacial changes in the Chersky Range from literary sources (Koreisha, 1991, Sheiknman, 1987). For Glaciers 29-31, located within the Northern Massif, values of linear regression for the following time slices: 1957-1970-2001 were defined. These values for, in particular, Glacier 31 were compared with mass losses in the same periods: the ratio was quite stable (equals 1.1/10 years). This argues for rather high inertia of Suntar-Khayata glaciers. Glaciers 29-31 of the same massif shrank from the Little Ice Age (LIA) until 1973 as much as 50-150 m; those in the Southern Massif (No. 141-154) showed bigger shrinkage - 100-200 m. The reason lies in difference of climatic conditions, which influenced these glacier groups. The latter are partly under Pacific cyclonic activity: winter temperatures are much higher, and precipitation is heavier, making the Southern Massif glaciers warmer (and easier to shrink) than those of the Northern Massif.

The shrinkage of glaciers in the Cherskiy Range from the LIA until 1972 reached 300 m for the Obruchev Glacier (one of the biggest within the range) and 250 m for the Sumgin Glacier, which are comparable with the shrinkage of the Suntar-Khayata Northern Massif glaciers.

1. Introduction

One of the objectives of the large international program "Global Land Ice Measurement from Space (GLIMS)", of which Russian regional center is the Institute of Geography RAS, is a comparison of digital data about glacier extent obtained from space images with data on glacial extent in the past. It aims at the assessment of spatial glacier change during the period since modern instruments have become available for glacier measurement. This has special importance for Northern Eurasia glacier change due to observed climate warming.

As an intermediate stage of evaluation of glacier change in North-East Siberia, expedition observations, archived air-photo images of the 1940-s and 1970-s, and space images have been analyzed for evidence of glacial shrinkage for the Northern and Southern massifs of the Suntar-Khayata Range. Koreisha (1991) and Sheiknman (1987) also gave evidence of glacial change in the Chersky Range (Fig. 1).

2. Glacier shrinkage in the Suntar-Khayata Range

Study of climate and glaciers in this region was started during the IGY (International Geophysical Year: 1957/58). Field work was conducted on glaciers in the Central Massif in 1957-1959 (Fig. 2). The Central Massif is close to the Northern Massif in distance and in climate, and sometimes classified as part of the Northern Massif. The most extensive observations were performed on Glacier 31, considered as representative of the region (Fig. 3). Later, in 1970, within the project "Compilation of the Catalogue of the USSR glaciers", an expedition of the Institute of Geography,

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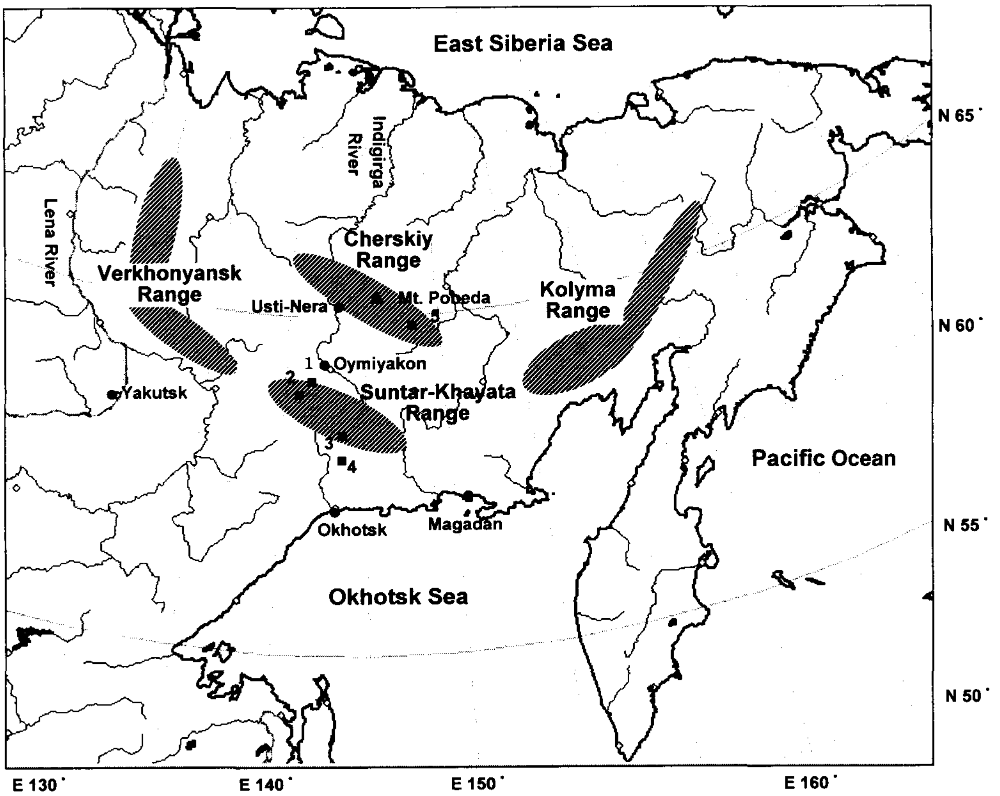

Fig. 1. Location of the Suntar-Khayata Range. 1-4 are meteorological stations ; 1 : Agayakan (777 m a.s.l.), 2 : Nizhnya Basa (1350 m), 3 : Vherkhne-Okhotskaya (1280 m), 4 : Uega (400 m), 5 : Darpir (840 m).

RAS (in 1970 – the USSR Academy of Sciences), was sent to the region. As a result, new data about Glacier 31's accumulation and ablation in 1970 as well as during 1960–1969 were published (Vinogradov *et al.*, 1972). In this paper shrinkage and changes in morphology of Glaciers 31, 29 and 32 were determined, and other glaciers of various morphological types were evaluated. In 2001, observations on Glacier 31 were made by a group of Russian (Institute of Geography, RAS) and Japanese scientists (Hokkaido University and Kitami Institute of Technology) to determine the position, mass balance and meteorological parameters of Glacier 31 (Yamada *et al.*, 2002).

Table 1 presents shrinkage values for glaciers 29, 32 and 31. For glaciers 29 and 32, the shrinkage was determined by visual assessment with taking into account the terminal moraine length (the distance between the glacier forefront and modern terminal moraine). The contemporary position of Glacier 31 was determined by topographic survey performed in summer 2001. In the paper (Yamada *et al.*, 2002) one can see a map of the Glacier 31 terminus in 2001 superimposed on that of the 1957 survey spatial pattern.

The glacier shrank as little as 15 m in 1957–1970 along the central axis and as 120 m in 1957–2001. The extent of moraine deposits in 2001 was 350 m in length. Assuming that the terminal moraine position shows the maximum glacier extent in the Little Ice Age (LIA), Glacier 31 shrank as much as 200 m from the LIA to 1947 from historical air-photo images (the aerial survey of 1947). Consequently, the shrinkage during 1947–57 was 30 m (350 m-200m-120 m). The time-sequence of this shrinkage is shown in Fig. 4. According to the view that the LIA in this area lasted about 300 years having a peak development around 1800 (Grove, 1988), considering that the maximum of glacier advance was estimated to be in the mid 19th century (Koreisha, 1963), the glacier shrinkage in the past 50 years was more rapid than that from the LIA to the 1950's.

The Glacier 31 mass balance *Bn* calculation (Ananicheva *et al.*, 2003a) makes it possible to compare its shrinkage with mass losses in different time periods (Table 2). To evaluate mass balance the authors used the relationship between ablation and *Bn* for the warming period, which started in this region in 1958 (Ananicheva *et al.*, 2003b) based upon direct measurements of *Bn* during the IGY. The ablation was reconstructed by its relationship to summer air temperature (the empirical equation of this relationship is given in section 5) on the glacier ELA, defined by Suntar-Khayata weather station records located near the glacier (2068 m a.s.l.) and Agayakan weather station (777 m) located in the Glacier 31 valley in the foothills. A detailed description of the *Bn* reconstruction method is given in (Ananicheva and Koreisha, 2004) together with validation of the estimates by

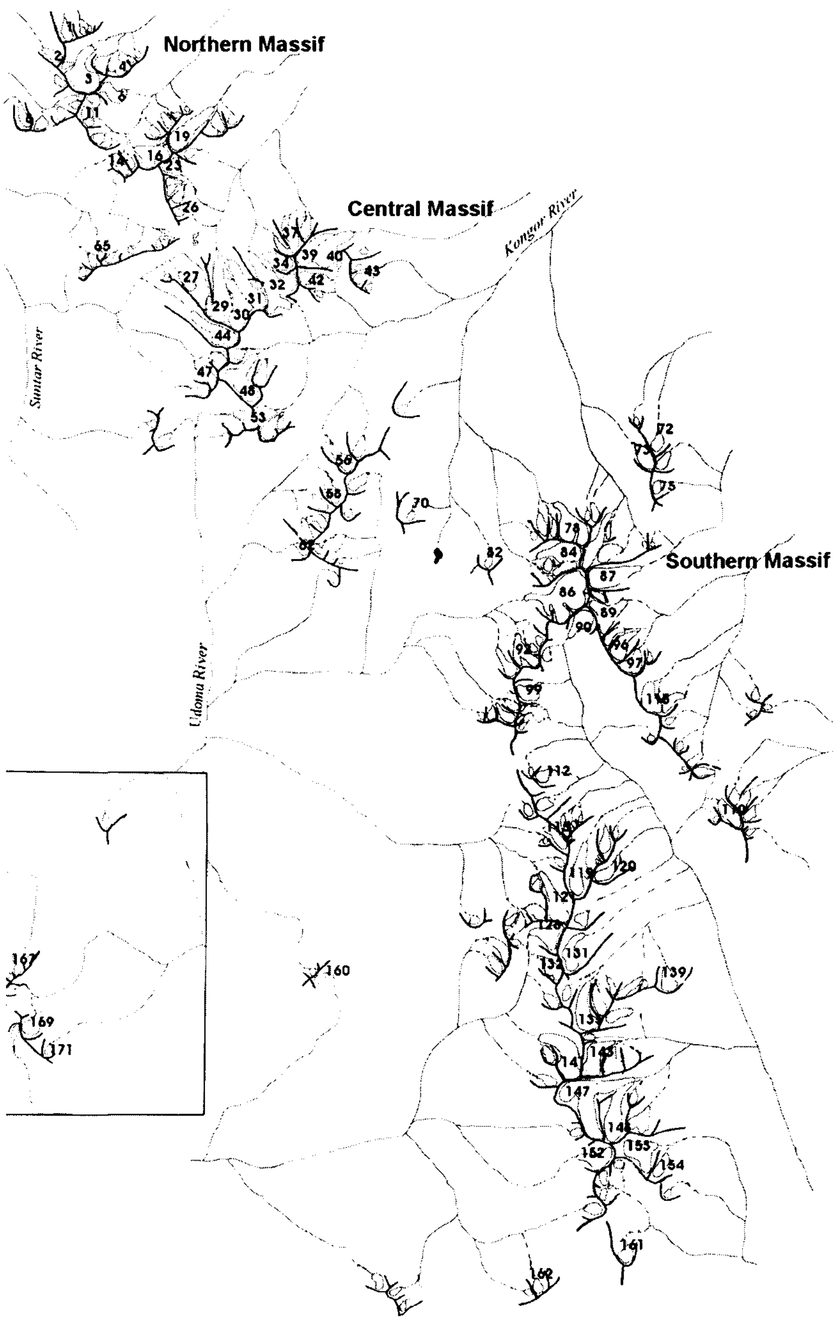

Fig. 2. Glacier locations in the Suntar-Khayata Range.

comparison with different data.

The ratio Bn/L was rather stable, 0.12–0.14, in 1947–1969. This means that proportionality of the mass-loss process and glacier shrinkage has been preserved for the former twenty years, and confirms the mass balance calculation in Vinogradov *et al.* (1972). In the last 30 years (1970–2001), the mass balance was largely negative compared with the previous 20 years, but glacier shrinkage did not change so much, which resulted in a large ratio of Bn/L. This means that the rather sharp warming results in large negative mass balance on glaciers in the Suntar-Khayata Range (Ananicheva *et al.*, 2003b) but the shrinkage of a glacier in the glacier terminus cannot respond so rapidly by the delay of glacier dynamics change. The ratio Bn/L remained equal to around 0.1 on average for each 10 years within this period, which is evidence of the significant inertia of these glaciers. This is mainly due to the Suntar-Khayata glaciers being of the cold type: the glacier temperature at the depth of 10 m remains minus 9.8℃ throughout the year; the bottom temperature is estimated as about minus 4℃ (Koreisha, 1991).

The shrinkage of other glaciers in the Northern Massif has been roughly evaluated by comparison of their positions in 1944 and 1947 (air-photo surveys), and in 1973 (Russian satellite space images). The results are given in Table 3. In the Table Moraine length means the distance between the glacier terminus and

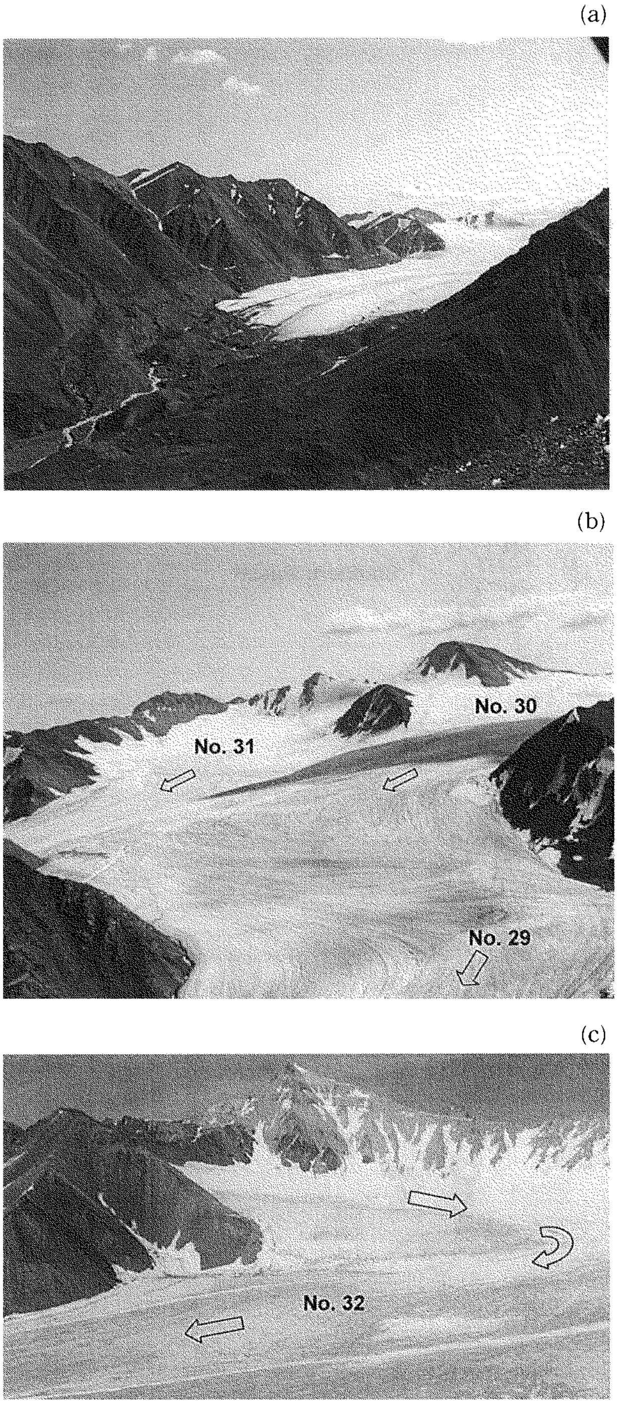

Fig. 3. Glacier 29, 30, 31, 32 in the Suntar-Khayata Range.
(a) Terminus of Glacier 31.
(b) Glacier 29, 30, 31.
(c) Glacier 32. Central peak is Mus-Khaya : thehighest Mountain in the Suntar-Khayata Range.

the end of terminal moraine at LIA.

Table 4 presents estimates of the scope of glacier shrinkage in the Southern Massif (Suntar-Khayata Range) in the period of approximately 30 years before 1973, obtained in the same way. From these data of glacier length and moraine length, the glacier length in the 1970's, the shrinkage in the 1940's-1970's and in the shrinkage in the LIA-1940's are shown in Fig. 5,

Table 1. Shrinkage of some Central Massif glaciers of Suntar-Khayata : 1957-1970-2001.

Glacier name		Shrinkage in 1957-1970 (m)	Shrinkage in 1957-2001 (m)
No. 31 :	along the central axis	15 m	
	at the left side	5	>120 m
	at right side	25	
No. 29		34.5	>100
No. 32		28.5	>100

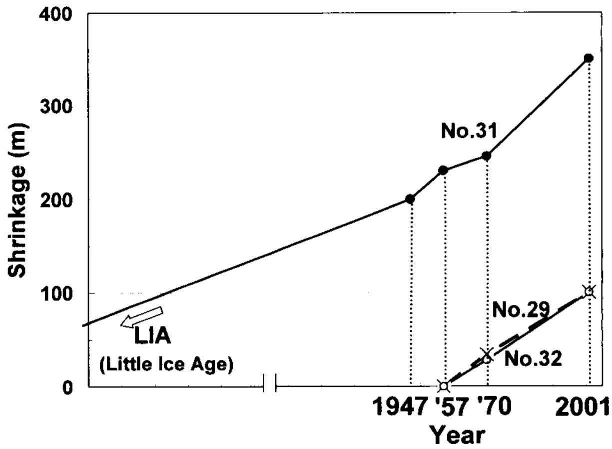

Fig. 4. Shrinkage of Glaciers 29, 31, 32.

Table 2. Mass balance and shrinkage of Glacier 31.

Years	Mean mass balance [Bn] (million ton year^{-1}) [mm w.e. year^{-1}]	Mean shrinkage [L] (m year^{-1})	| Bn/L |
1947-57	−0.28 [88]	2.0	0.14
1958-69	−0.14 [44]	1.2	0.12
1970-2001	−1.1 [343]	3.4	0.32

where Glacier 31 in the Central Massif is classified as part of the Northern Massif. In Fig. 5, larger glaciers are more in the Southern Massif and the ratios of shrinkage to glacier length are rather more in the Southern Massif than the Northern in Fig. 6.

3. Climate difference in the Suntar-Khayata Range

The difference in climatic conditions between north and south of the Suntar-Khayata Range can be illustrated by mean multi-annual characteristics of weather stations, located on the Northern and Southern macro-slopes of the Range respectively. The climate data presented are averaged over 1940-1993 (Table 5). The southern region is comparatively warmer and has more precipitation.

Comparing data of Tables 3 and 4, glacier shrinkage was significantly larger in the Southern Massif than in the Northern Massif (on average 100-150 m

Table 3. Shrinkage of glaciers in the Northern Massif of the Suntar–Khayata Range in 1944/47-1973.

Glacier	Years	Moraine length (m) 1944/47	Moraine length (m) 1973	Shrinkage (m)	Glacier length (km)
No. 1	1944-1973			insignificant	1.8
No. 2	1944-1973	450	500	50	2.2
No. 6	1944-1973	240	390	150	2.8
No. 14	1944-1973			insignificant	1.8
No. 19	1944-1973	250	300	100	4.4
No. 20	1944-1973	135	185	50	1.5
No. 8	1947-1973	20	70	50	2.2
No. 9	1947-1973	155	205	50	1.3
No. 39*, 40*	1947-1973			insignificant	3.6-3.4

* *-flowing together.*

Table 4. Shrinkage of glaciers in the Southern Massif of the Suntar-Khayata Range in 1945-1973.

Glacier	1945 Glacier length (m)	1945 Moraine length (m)	1973 Moraine length (m)	1973 Moraine length (m)	Glacier shrinkage (m)
No. 147	7000	865	6800	1065	200
No. 148	4400	600	4200	800	200
No. 143	2800	420	2850	470	50
No. 144	2000	700	1900	800	100
No. 141	4300	180	4200	280	100
No. 153	1950	550	1850	650	100
No. 154	1700	185	1650	235	50

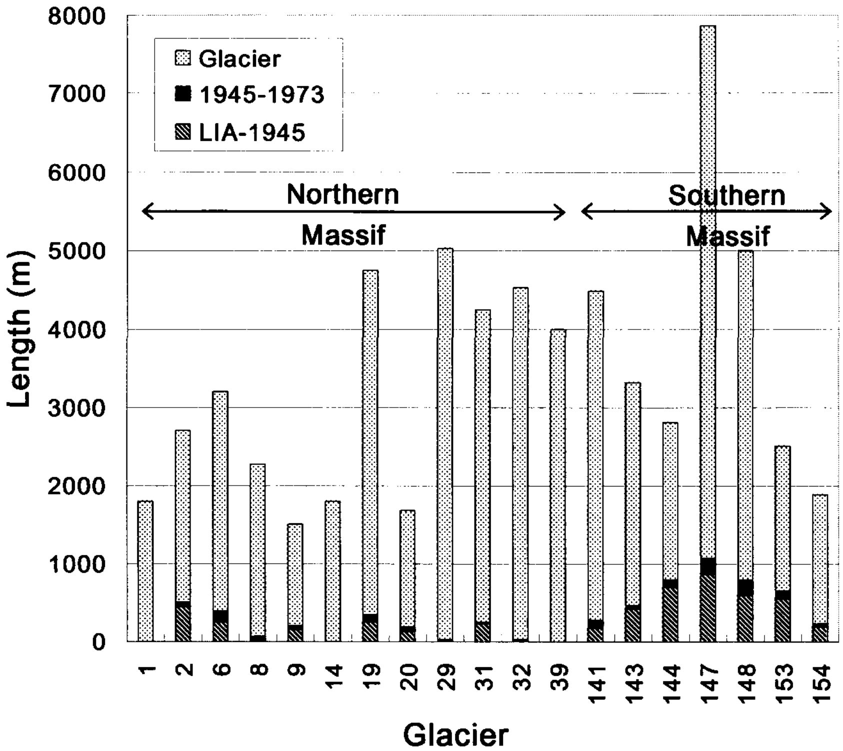

Fig. 5. Glacier shrinkage in the Northern and Southern Massifs in the Suntar-Khayata Range. The upper part of a bar is glacier length around 1973, the middle part is glacier shrinkage from 1945-1973 and the lower is shrinkage from Little Ice Age to 1973 estimated by moraine.

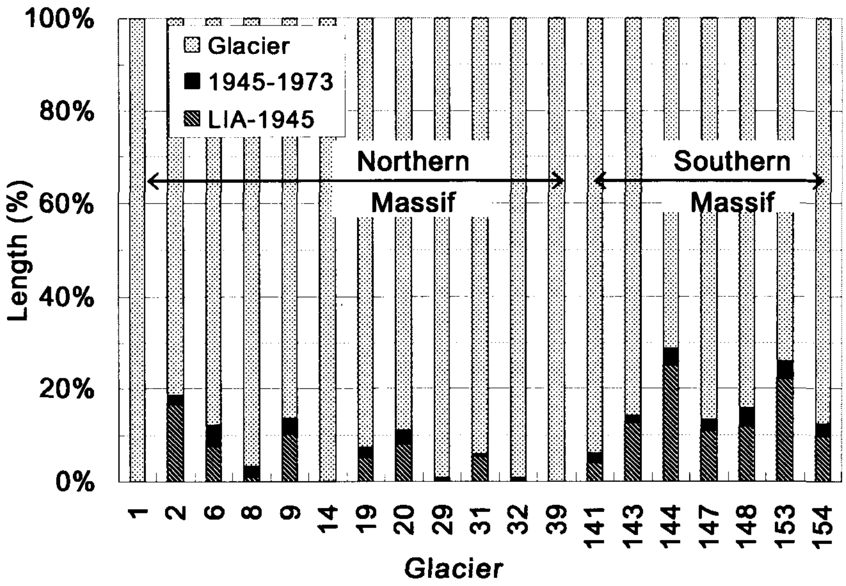

Fig. 6. Ratio of glacier shrinkage to a total of glacier and moraine lengths in the Suntar-Khayata Range. The basis data are the same as that in Fig. 5.

Table 5. Main climatic parameters in the Northern and the Southern Massifs of the Suntar-Khayata Range.

Northern macro-slope

Weather station	Altitude (m)	Air temperature January (℃)	July (℃)	Annual mean (℃)	Annual precipitation (mm)
Agayakan	770	−49.0	14.0	−15.9	227
Nizhnya Baza	1350	−34.4	11.3	−13.8	no data
Southern macro-slope					
Uega	400	−29.2	14.1	− 7.2	450
Verkhne-Okhotskaya	1280	−29	13.4	− 9.4	no data

greater) mainly due to different climatic conditions. From Table 5, summer temperatures on the macro-slopes are close to each other (the difference is only 2-3℃) and the mean annual temperature difference is 5-8 ℃, whereas winter temperatures vary greatly - as much as 5-20℃ (stations at lower altitudes reflect the regional characteristics of temperature inversions).

Annual precipitation on the Southern macro-slope is double that on the Northern due to the moderate-monsoon climate influence of the Pacific (Okhotsk Sea). So, despite the small difference in summer temperatures, glacier shrinkage in the Southern Massif is bigger than in the Northern because of significant radiation melting and lesser "reserves of cold" in glaciers (higher winter temperatures and greater snow cover, which has a warming effect on the glacier surface). The latter factor encourages more intensive melting under otherwise equal conditions (such as temperature in the ablation period).

Ananicheva *et al.* (2003b) presents temperature and precipitation trends in North-East Siberia and their spatial distribution. The Suntar-Khayata region appears to be at an intersection of regions of opposite "directions" of warming growth based on winter and summer trends (winter warming is enhanced from Central Asia toward the NE, summer warming is enhanced from the Okhotsk Sea toward the NW). Both high summer temperatures and very high winter temperature trends are characteristic of the Suntar-Khayata Range. This tendency is more pronounced in the Southern Massif, therefore it is possible to expect more intensive melting and shrinkage of glaciers here (than in the Northern Massif) over the last several decades.

We failed to estimate the shrinkage rate of glaciers of the Central Massif by air-photo images because of cloud cover over this area; however, it would be intermediate between those of the Southern and Northern massifs.

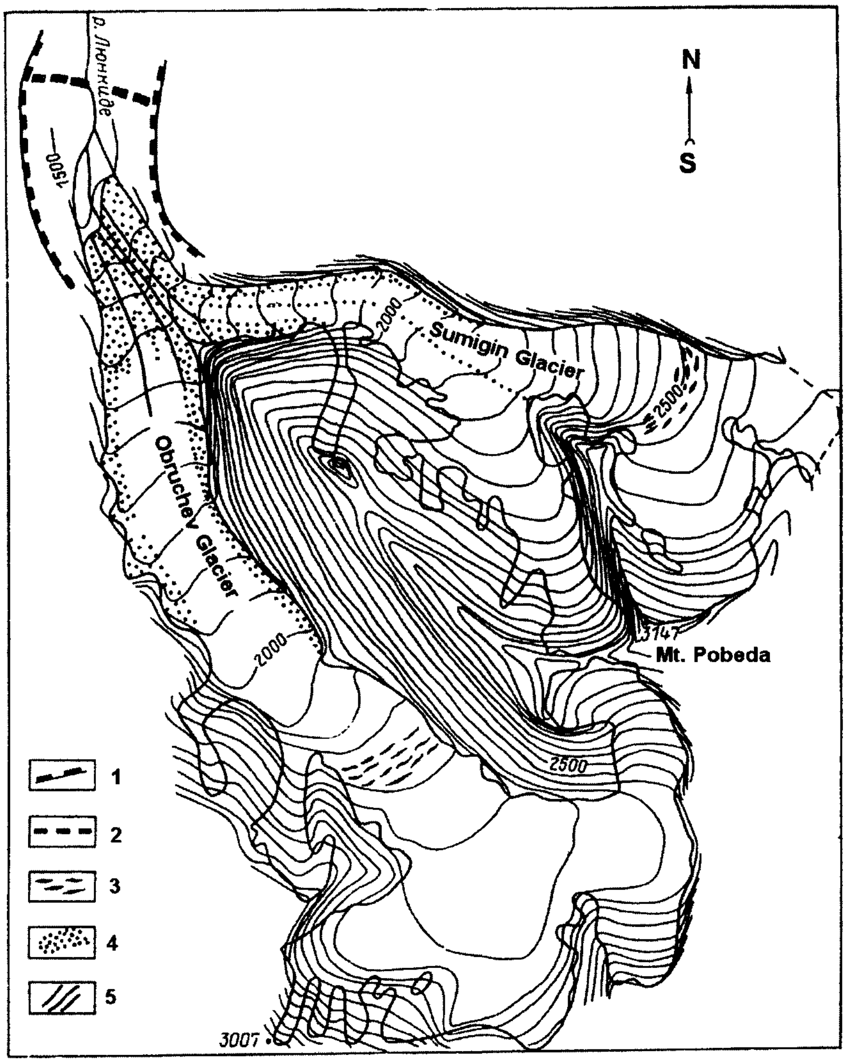

Fig. 7. The Obruchev and Sumgin glaciers (Chersky Range). 1- border of the trough, related to Upper Weichsel (Upper Wisconsin) time, 2- terminal moraine of the LIA, 3- crevasses on ice falls, 4- compact moraine cover, 5- longitudinal crevasses (scours).

Table 6. Main climatic parameters of the Cherskiy Range.

Weather station	Altitude (m)	Air temperature			Annual precipitation (mm)
		January (℃)	July (℃)	Annual mean (℃)	
Ust'-Nera	521	−48.9	15.3	−15.6	224
Darpir	840	−38.4	12.6	−13.5	264

4. Evidence of glacier change in the Cherskiy Range

The mountain system of Cherskiy consists of many ridges and massifs situated along the Indigirka River banks. The elevation of the ridges reaches 2500–3000 m. Mt. Pobeda (3147 m a.s.l.) is the highest peak of the Verkhoyansk-Kolyma Region (Koreisha, 1991). The Cherskiy Range hosts more than 300 glaciers, which cover 152 km^2, and 70 permanent snow patches 3 km^2 in total area.

According to Koreisha (1991), the moraine lengths from the LIA of Obruchev Glacier (65,17° N, 145,85° E, one of the largest of the Range) and Sumgin Glacier (65,18° N, 145,98° E, next to Obruchev Glacier), were 1.3 km and 0.75 km respectively (Fig. 7, modified from Sheiknman (1987). In 1972 these terminal moraines were 1000 m and 500 m in length, *i.e.* the shrinkage for this period was 300 m for Obruchev Glacier and 250 m for Sumgin glacier. This is comparable with the shrinkage of glaciers of the Suntar-Khayata Northern Massif; however, the latter have shrunk notably less. The

Table 7. Estimated ablation rate at equilibrium line and glacier tongue.

Glacier region	H_{ELA} (m)	A on H_{ELA} (g cm^{-2})	H_{gt} (m)	A on H_{gt} (g cm^{-2})	Gradient A (mm m^{-1})
Suntar-Khayata	2360	63	2000	145	2.3
Cherskiy	2180	61	1850	143	2.2

reason is partly the greater size of these glaciers as compared with those of the Northern Massif of Suntar-Khayata, and partly the intensive moraine cover abundant on the glacier surface. Climatic parameters from weather stations in areas adjacent to Suntar-Khayata and Cherskiy (compare data from Tables 5 and 6, taking into account the difference in the stations' altitudes) point to a more severe temperature regime in the Northern Massif than in Cherskiy. The Southern Massif is characterized by higher winter and annual mean temperatures than the Northern Massif and Cherskiy. The latter receives less precipitation than Suntar-Khayata. The difference in climate parameters is consistent with the different shrinkage rate of these glaciers.

5. Discussion

What has happened to glaciers in the Suntar-Khayata and Cherskiy ranges in the last 3 decades? Some observations of the Northern Massif are described above. In Koreisha (1991) the total ablation at the averaged altitudes of the equilibrium line (H_{ELA}) and glacier tongues (H_{gt}) for the Suntar-Khayata and Cherskiy ranges as a whole were calculated by the regional formula, obtained with the help of an empirical relationship between ablation rate (A) and mean summer temperature (T_{sum}) at the ELA (equilibrium line altitude):

$$A = 0.1(T_{sum} + 7.0)^3. \qquad (1)$$

The results of the calculation, referred to the early 1990-s, are presented in Table 7. Though the H_{ELA} and H_{gt} of the Suntar-Khayata glaciers is higher than those of the Chersky glaciers, the ablation rate at these altitudes is greater than on the Cherskiy Range to the north. From this difference one can suppose that recent glacier melting (and shrinkage) of Suntar-Khayata should be more intense than that in the Cherskiy Range, whereas the estimated values in Table 7 are averaged values for glacier systems of both ranges using all of data available up to that time and the empirical equation Eq. (1). Despite the fact that both Cherskiy system and Suntar-Khayata Mountains belong to the Pacific-influence province (Krenke and Chernova, 1980) and glaciers are fed from moisture from the East, the thermal regime seems to be a major factor in glacier variation in the 20th century decline. Therefore it is important to take into account the difference in scale of current climate warming, which is bigger in the Suntar-Khayata region than in Cherskiy (Ananicheva *et al.*, 2003b). All this requires confirmation by recent data on the glacier dynamics of those regions, which, the authors hope, will become easier to access as the GLIMS program develops.

6. Concluding remarks

Glacial shrinkage in the Northern and Southern massifs of the Suntar-Khayata Range, North-East Siberia, on the basis of expedition data and archived air-photo images of the 1940-s and 1970-s has been investigated. For Glaciers 29–31 in the Northern Massif, the shrinkage was almost linear shrinkage in 1957–1970–2001; this shrinkage rate was larger than that from the Little Ice Age maximum advance to the 1950's.

From analysis of data on glacier length and terminal moraine extent in the Northern and Southern massifs of the Suntar-Khayata Mountains we conclude that glaciers shrank more in the Southern Massif due to the difference in climatic conditions. As the Southern Massif is under Pacific cyclonic activity, winter temperatures are much higher and precipitation is heavier, which makes the Southern Massif glaciers warmer (and easier to shrink) than in the Northern Massif.

The shrinkage of glaciers in the Cherskiy Range from the LIA until 1972 reached 300 m for the Obruchev Glacier (one of the biggest within the range) and 250 m for the Sumgin Glacier, comparable with the shrinkage of the Suntar-Khayata Northern Massif glaciers.

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References

Ananicheva, M. D, Davidovich, N. V., Kononov, Y. M. and Koreisha, M. M. (2003a): Glaciers of Northern Massif of Suntar-Khayata mountains: change since the IGY. Data of Glaciological Studies[1], **95**, 77–86.

Ananicheva, M. D., Davidovich,,N. V. and Mercier, J. L. (2003 b): Climate change in North-East of Siberia in the last hundred years and recession of Suntar-Khayata glaciers. Data of Glaciological Studies[1], **94**, 2003b, 216–225.

Ananicheva, M. D. and Koreisha, M. M. (2004): Retreat of Northern and Southern Massif of Suntar-Khayata and Chersky ranges under climate warming. Data of Glaciological Studies[1], **98** (in press)

Grove, J. M. (1988): The Little Ice Age. Routledge, London and New York, 498 pp.

Koreisha, M. M. (1963): Present glaciers of the Suntar-Khayta Range. The results of the IGY studies. Glaciologia, No. 11. Moscow, 98 pp. (in Russian)

Koreisha, M. M. (1991): Glaciation of Verkhoyansk-Kolima Region.—Moscow, 143 pp.

Krenke, A. N. and Chernova, L. P. (1980): Glacier systems of the USSR North-East.—Izvestiya RAN, geogr. series., Moscow, N1., 17–33. (in Russian)

Sheiknman, V. S. (1987): Glaciology and paleoglaciology of Cherskiy mountain system and adjacent region of the USSR North-East. Moscow, 153 pp. (in Russian)

Vinogradov, O. N., Golodkovskaya, N. A., Koreisha, M. M. and Serebryaniy, L. R. (1972): New data about modern and former glaciation of Suntar-Khayata.. Data of Glaciological Studies[1], **19**, 80–91.

Yamada, T., Takahashi, S., Shiraiwa, T., Fujii, Y., Kononov, Y. M., Ananicheva, M. D., Koreisha, M. M., Muraviev, Y. D and Samborsky, T. V. (2002): Reconnaissance of the 31 Glacier in the Suntar-Khayata Range, Sakha Republic, Russian Federation. Bulletin of Glaciological Research. **19**, 101–106.