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Flow of Koryto Glacier in the Kronotsky Peninsula, Kamchatka, Russia

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Abstract

Ice flow velocities were measured at the Koryto Glacier in the Kronotsky Peninsula, eastern Kamchatka, in July 1996. Velocities on the center line were obtained as 0.23 m d^{-1} near the glacier terminus, and 0.17 m d^{-1} at the usual equilibrium line altitude (ELA : about 800 m a.s.l.). Velocity at the usual ELA has decreased by an amount of about 30 m a^{-1} since the 1960's. Hourly variations in velocity measured at the terminal part of the glacier showed that the fastest velocity appeared in the afternoon and the lowest appeared in the early mooning, which was considered to be due to basal sliding fluctuations.

1. Introduction

In Kamchatka, there are numerous glaciers that are the nearest ones to Japan. It is very interesting to study Kamchatkan glaciers from points of view how perennial snow patches change into glaciers and what differences exist between the perennial snow patches and the glaciers. In addition to this, a comparison of climate conditions between Japan and Kamchatka has been considered to be essential for further understanding of nature of perennial snow patches in Japan (Higuchi *et al.*, 1979). It had been difficult, however, due to political problems, to survey glaciers in Kamchatka before 1991 when Kamchatka was opened for foreigners.

A joint Russo-Japanese glaciological research on Kamchatka glaciers started in 1996 (Kobayashi *et al.*, 1997). In this report, a preliminary result on flow of the Koryto Glacier in the Kronotsky Peninsula, eastern Kamchatka, is presented.

2. Regional settings

The Kronotsky Peninsula is located at the eastern coast of Kamchatka as a prominent massif intruding into the Pacific Ocean. According to the report of Vinogradov (1968), there are 32 glaciers in this region. They lie at the lowest altitude in Kamchatka, some of which flowing down to an the altitude of 250 m.

The Koryto Glacier is the third largest glacier in this region, which has an area of 8.9 km^2 and extends from 1200 m to 250 m a.s.l. toward northwest exposure (Vinogradov, 1968). The glacier surface has no debris and lacks any icefalls or intensive crevasses (Fig. 1). The equilibrium line altitude (ELA) was reported to be 780 m in the balance year of 1981/82 (IAHS(ICSI)-UNEP-UNESCO, 1988).

In the 1960's, flow velocities of the Koryto Glacier were surveyed by Russian scientists, and an annual mean velocity of 90 m a^{-1} was obtained near the ELA (Muravyev, person. commu.).

3. Methods of measurements

3.1. Transverse survey

Transverse surveys of flow velocity at the Koryto Glacier were carried out between July 11 and 17, 1996. Two lines of snow stakes, the upper and the lower lines, were established on the glacier (Fig. 1). The snow stakes were made of 2 m-long metallic pipes.

The upper line was composed of eleven snow stakes and established along a contour line of about 800 m. The specific net balance and ELA in 1981/82 was −284 mm and 780 m (IAHS(ICSI)-UNEP-UNESCO, 1988), therefore, the upper line is considered to be located near the ELA in the normal years. The lower line was composed of thirteen snow stakes and the altitude was about 560 m which was estimated to be the ELA in the balance year 1995/96 (Shiraiwa *et al.*, 1997). Horizontal and vertical angles, and distance to the individual stake were measured from control points (upper line : A, lower line : B) on the left bank of the glacier by an electric distance meter (Topcon EDM-theodolite Guppy GTS-2R : the minimum angle and distance readings : 10 seconds and 1 mm). In the distance survey, a mirror was attached to each stake. Error of survey became larger with distance between the control point and the snow stake. The largest error in distance was 0.06 m for the case of U1 which is about 1400 m from the control point A.

3.2. Surveys in the terminal area

Ice-flow measurements were carried out with short intervals at two points α and β near the glacier terminus (Fig. 1). ; each was made by a survey stake with a reflection mirror. A control point C was established on a bedrock bump approximately 300 m down from the glacier terminus, and the direction from α and β to C was considered to coincide with the ice-flow direction. Distance between the control point and α (or β) was measured every three hours by using the electric distance meter (Topcon EDM) between 8 : 00 on July 18 and 8 : 00 on July 19, 1996. In order to get more detail change in flow velocities, surveys were also made at every hour between 8 : 00 and 15 : 00 on July 19. During the survey period, the theodolite was fixed on the control point and the leaning of survey stakes was checked before every measurements. An error of distance survey, which was caused by the leaning of stake (2∼ 3 mm) and by the atmospheric condition (1∼2 mm), was estimated to be less than ±5 mm.

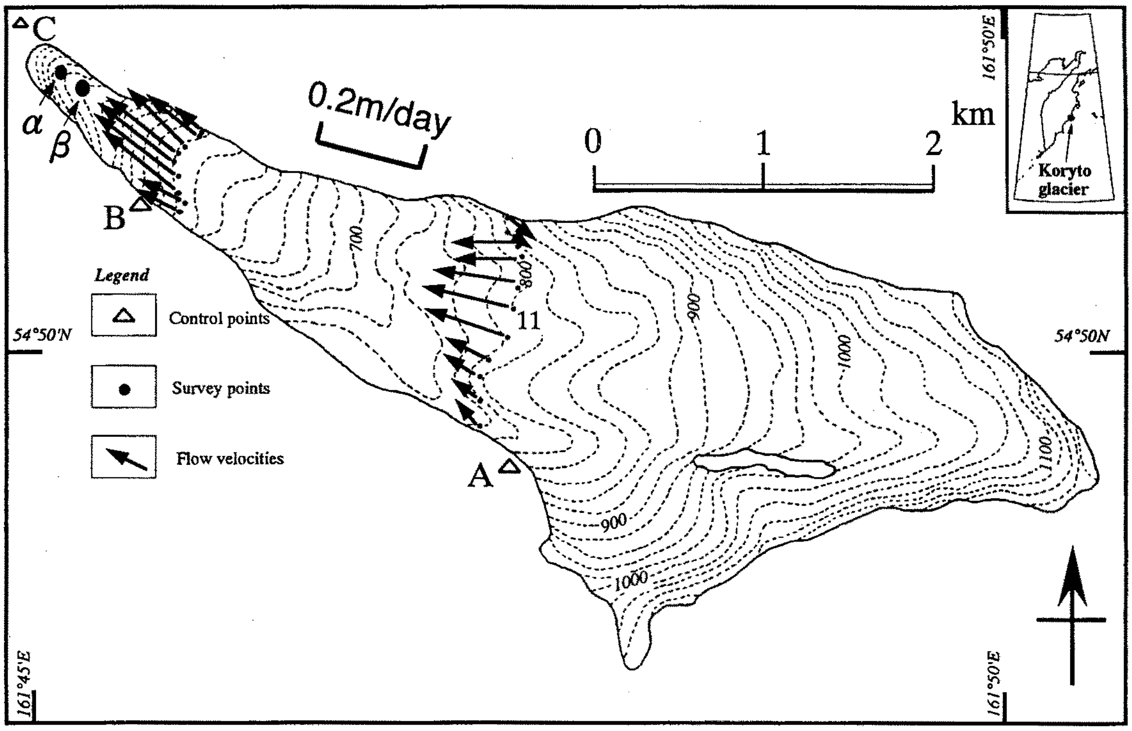

Fig. 1. Counter map of the Koryto Glacier and holizontal vectors of surface velocities at two tranverse lines. Locations of control points and survey points are plotted by symbols.

4. Results and discussions

4.1. Distribution of flow velocities

Horizontal and vertical components of flow velocities obtained along the two transverse lines are compiled in Table 1. Fig. 2 and 3 show distributions of horizontal vectors of surface flow at the two lines, together with the surface profiles of the lines. The velocities are shown as daily mean values during the survey period, and each surface profile is shown as a relative height to the control point A or B.

The maximum horizontal velocity in the upper line was found near the center of the glacier (U5) and it was 0.17 m d^{-1} (Table 1; Fig . 2). In Fig. 2, directions of velocity at two points in the right side are different from those at the other points. The reason is that the two points were set on a debris cone of avalanches from the right side cliff of the glacier, and the direction of the surface slope of the debris was much different from that of the glacier surface.

Table 1. Result of transverse surveys
Vertical velocities + : emergence velocity
− : submergence velocity

Upper line

Stake number	Horizontal velocity (m day^{-1})	Vertical velocity (m day^{-1})
U1 (right)	0.04	0.04
U2	0.03	-0.04
U3	0.10	-0.01
U4	0.10	0.03
U5	0.17	-0.07
S11	0.16	-0.01
U6	0.15	0.02
U7	0.09	-0.01
U8	0.09	-0.01
U9	0.05	-0.02
U10 (left)	0.04	-0.01

Lower line

Stake number	Horizontal velocity (m day^{-1})	Vertical velocity (m day^{-1})
L1 (right)	0.00	0.01
L2	0.04	-0.02
L3	0.08	-0.01
L4	0.19	-0.01
L5	0.21	-0.02
L6	0.22	-0.02
L7	0.22	-0.01
L8	0.23	-0.01
L9	0.22	-0.01
L10	0.20	0.00
L11	0.16	0.03
L12	0.15	0.00
L13 (left)	0.01	-0.02

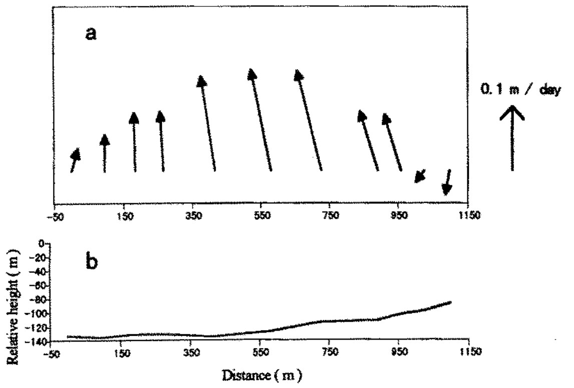

Fig. 2. Distribution of horizontal flow velocities (a) and the surface profile in the upper line (b), which shown by the relative height to the control point A

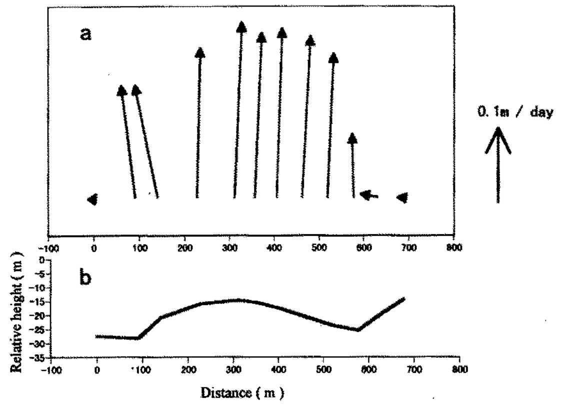

Fig. 3. Distribution of horizontal flow velocities (a) and the surface profile in the lower line (b), which is shown by the relative height to the control point B

Submergence velocity was dominant in the upper line and the maximum was -0.07 m d^{-1} (Table 1). In the lower line, large horizontal velocities from 0.20 m d^{-1} to 0.23 m d^{-1} were obtained near the center of glacier (L5-L10) (Table 1 ; Fig. 3). These values were larger than the maximum value in the upper line. Slight submergence velocity was also found in the lower line (Table 1).

In the 1960's, flow velocities of the Koryto Glacier were measured by Russian scientists (Muravyev, person. commu.). In that report, the maximum flow velocity near the usual ELA was 90 m a^{-1}. The observation in 1996 covers only one week and surface velocity of a glacier shows seasonal changes in general. We tried to estimate a maximum possible annual velocity using the center-line value of 0.17 m d^{-1}

measured in this year, and obtained a result of about 60 m a^{-1}. The comparison of this value with that in the 1960's indicates that annual flow velocity has probably decreased by an amount of about 30 m a^{-1} during this period. According to IAHS(ICSI)-UNEP-UNESCO (1988), the terminus of the Koryto Glacier retreated 80m between 1971 and 1982. If this terminus recession may have been caused by a thinning of ice, it can be possible to consider that the decrease in flow velocities was also caused by the shrinkage of the glacier.

4.2. Short-term variations in ice-flow

Fluctuations in flow velocity obtained at the points α and β from July 18 to 19 are shown in Fig. 4, together with air temperature at the ablation area (545 m a.s.l.) and discharge of a stream from the glacier terminus (Kodama *et al.*, 1996). The flow velocity was larger in the afternoon and smaller in the early morning as clearly seen at the point β. This trend is the same as that observed at Moreno Glacier, Patagonia (Naruse *et al.*, 1995). However, at the point α, such trend was not seen on July 18, although the flow velocity became larger in the afternoon on July 19. The maximum velocity was about two times larger than the minimum for the case of β. This hourly variation in velocity is much larger than the survey error mentioned before. In general, surface flow of a glacier is a sum of plastic internal deformation of ice and basal sliding. It is difficult to consider that the plastic deformation rate change within this short time. This short term variation in flow velocity is, therefore, regarded as the influence of basal sliding variation. Assuming that there was no basal sliding when velocity was minimum, the rate of basal sliding was estimated as about 50 % of total flow at the surface, by dividing ($V_{max}-V_{min}$) by V_{max}, where V_{max} and V_{min} denote the maximum and the minimum velocities. This rate is the same order as those of temperate glaciers reported elsewhere (Kamb, 1964).

It is often pointed out that the basal sliding is closely connected with water discharge from glacier (*e.g.* Naruse *et al.*, 1992). In this observation, however, a relation between variations in flow velocity and discharge from the glacier terminus was not found (Fig.4). The reason is not clear at present, but the observation period may be too short for this kind of work.

5. Concluding remarks

Flow velocities at the Koryto Glacier in the Kronotsky Peninsula, Kamchatka, were measured from July 8 to 20, 1996. Transverse surveys showed that the fastest velocities were 0.23 m d^{-1} at the lower line (560 m a.s.l) and 0.17 m d^{-1} at the upper line (800 m a.s.l., at the usual ELA). The annual velocity in the upper line may have decreased by an amount of about 30 m a^{-1} since the 1960's.

Short interval measurement of ice-flow at the terminal area suggested that the Koryto Glacier could be sliding at the base, and the rate of basal sliding could be estimated as about 50 %. The flow velocities became the highest in the afternoon and the smallest in the early mooning. We could not find any clear relation between the variations in flow velocity and the water discharge from the glacier.

In order to make clear the dynamical characteristics of the Kortyo Glacier and glaciological boundaries between snow patches and glaciers, more precise surveys on the distribution of ice-flow and short-term fluctuations in flow velocities are planned to be carried out at this glacier in the summer of 1997.

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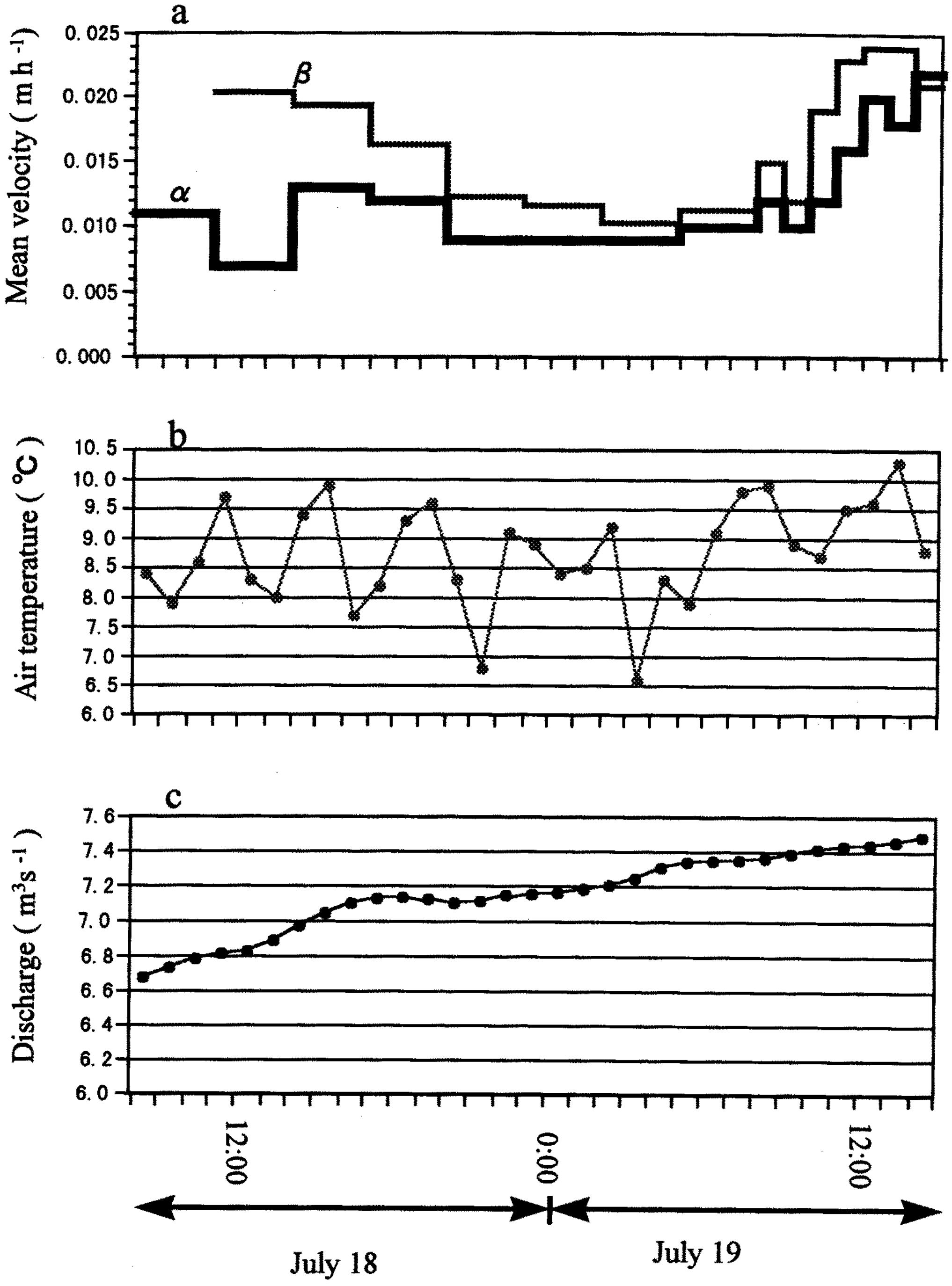

Fig. 4. Variation in flow velocity (3 hours average between 8 : 00 on July 18 and 8 : 00 on July 19, 1 hour average between 8 : 00 and 15 : 00 on July 19) obtained at points α and β (a), and air temperature (1 hour average) in the ablation area (545 m a.s.l.) (b) and dischage of dischage of stream (1 hour average) from the glacier terminus (c).

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