Glaciers in arid regions

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Abstract

Glaciers in mountains play an important role as water resources in an arid area. Observations for glacier mass balance process were hence carried out at the July 1st glaciers in Qilian Mountains in northern Tibetan Plateau for estimating fluctuations of discharge from glaciers. The heat balance calculation indicated that strong solar radiation contributes to melt the glacier ice with low surface albedo, caused by the abundance of the black organism 'Cryoconite' living on the glacier surface. Observational results indicated that roughly half of the water, percolated into the surface layer such as meltwater and rain was refrozen in the glacier. The refreezing process has to be taken into account in estimating the discharge from the glacier. These characteristics, which affect the mass balance of the glacier have to be elucidated in order to estimate the fluctuation in the discharge from glaciers in accordance with the climate change.

1. Introduction

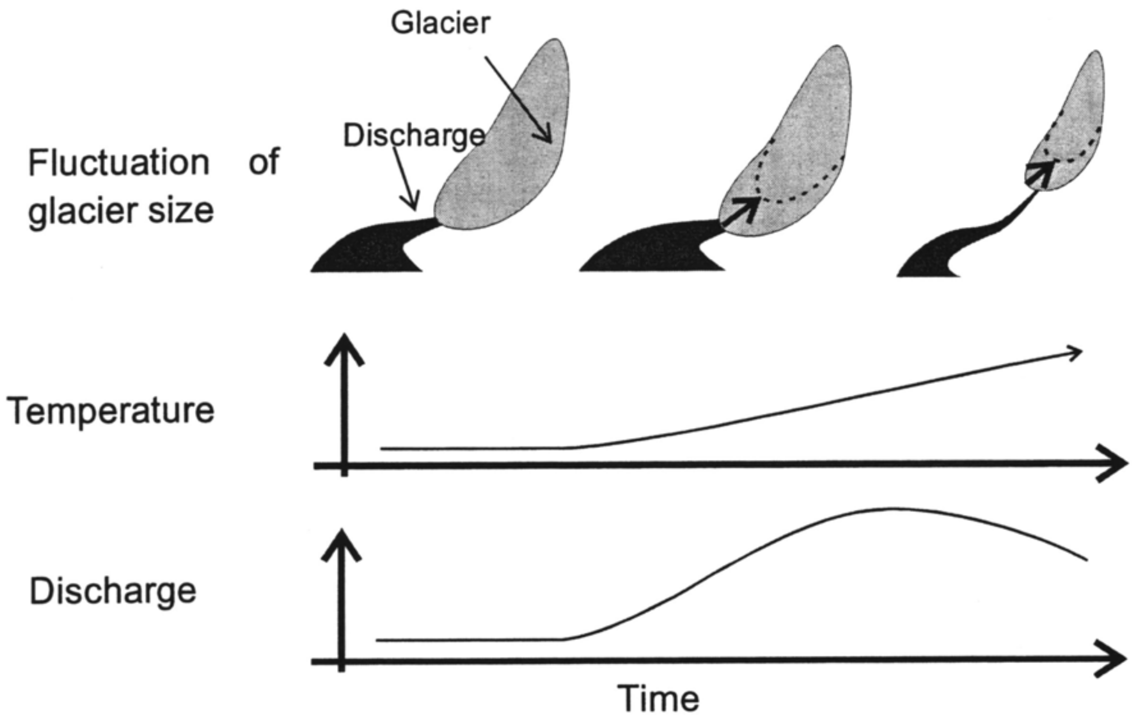


Figure 1 Schematic figure of glacier size variation (upper figure) and fluctuation of discharge from a glacier (lowest figure) during air temperature increasing (middle figure), when the precipitation is assumed to be constant.

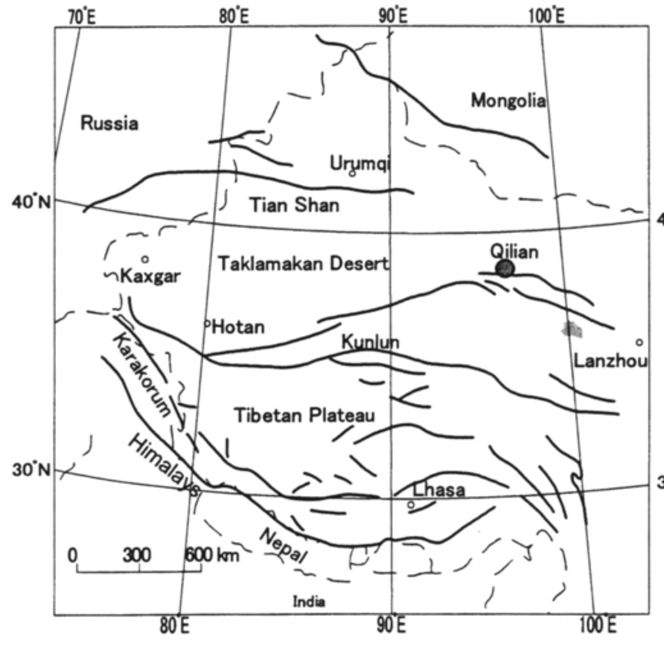
It has been pointed out that the contribution of discharge from glaciers into river water is significant in the Central Eurasian arid region (Ujihashi et al., 1998).

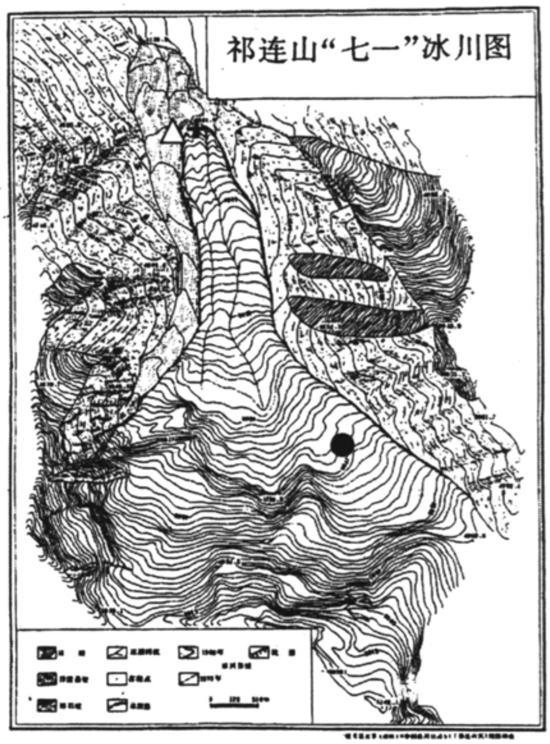
Recent a few tens of years, glaciers in the middle latitude area have been retreating (Haeberli et al, 2001). Glaciers in Qilian Mountains, northern Tibetan Plateau, west China are also retreating year by year (謝 他, 1984).

Figure 1 shows schematically a fluctuation of discharge from a glacier when air temperature changes assuming a constant precipitation. Air temperature is assumed constant in the beginning, and the glacier size does not change in the equilibrium condition. At that time, the discharge from the glacier is equal to the amount of precipitation. As air temperature increases, the glacier would shrink, leading to a greater discharge. If the air temperature continues to rise, glaciers shrink further, and the ablation area would also shrink. Thus, the shrinkage rate of the glacier volume gradually decreases and then, discharge from the glacier also decreases slightly as shown in Fig. 1. As a result, there would be a peak of discharge from glaciers in the process of the glacier shrinkage. One must take into account the glacier size fluctuation to estimate the discharge from a glacier.

The fluctuation of discharge from a glacier shown in the Fig.1 can be estimated by elucidating the mass balance process of a glacier.

2. Observations





(After 「中国冰川概論」)

Figure 2 Location map of Qilian Mountains in high Asia (left side) and topographical map of July 1st glacier (right side). Mark ●, △ and ＋indicate the location of stake 8-2, discharge measurement point and meteorological station, respectively.

Observations were carried out at July 1st (Qiyi) glacier (Fig. 2) (altitude 4295-5088 m a.s.l.) at Qilian Mountains (location 39°15'N, 97°45'E: Fig. 2; left side) during the melting season (from early June to early September) in 2002.

Figure 3 shows a photograph of the July 1st glacier taken from the terminal moraine. Discharge from the glacier, meteorological data and glacier mass balance data were obtained.

Figure 3 July 1st glacier seen from the terminal moraine. (June, 2002)

3. Heat balance on glacier surface

Four heat fluxes are to be taken into account to estimate the heat balance at the glacier surface: net shortwave radiation, which is subtracted reflected shortwave radiation from the glacier surface from downward solar radiation; net longwave radiation, which is subtracted longwave radiation from the ground from longwave radiation from the air and clouds, sensible heat from air, and latent heat with evaporation: (water vapor). Here, all fluxes are positive if directed towards the glacier surface. If the total incoming heat flux at the glacier surface is positive and temperature of the glacier ice is zero degree, melting would occur at the glacier surface.

Heat balance on the glacier surface was calculated to assess which elements affect on the melt amount during the melting season from June to September in 2002. Surface temperature was assumed to be 0 °C. The results are shown in Fig. 4. The largest heat element was net shortwave radiation.

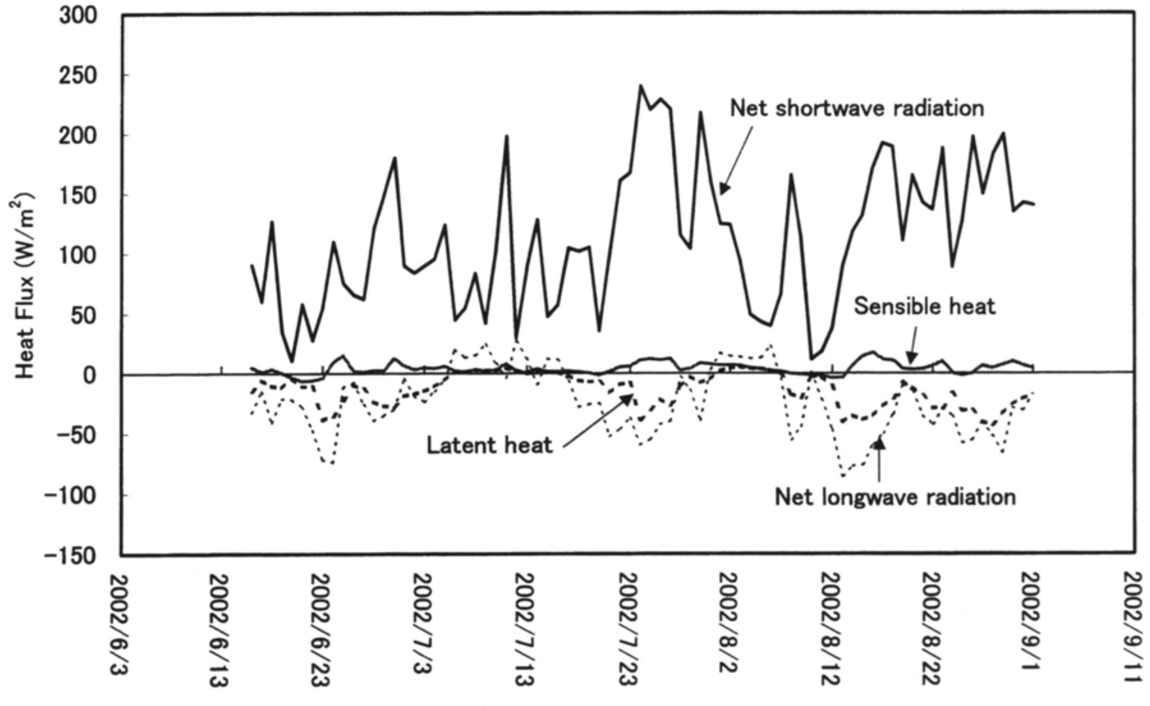
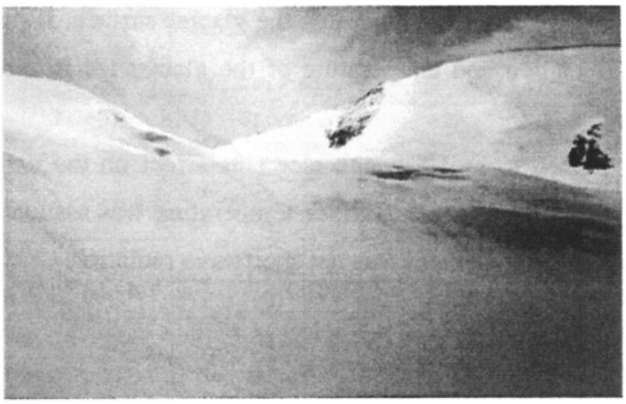


Figure 4 Heat elements for ice melt from June to September.

Downward solar radiation reflects on the glacier surface depending on the surface albedo. The albedo is related with the color of a glacier surface. With a white surface, the albedo is high and solar radiation would be mostly reflected. A black surface (i.e., low albedo), on the other hand, could absorb most of incoming solar radiation. Thus, a large amount of ice can melt with a black surface.

Figure 5 shows photographs of the glacier surface at July 1st glacier on June and September 2002. The surface was covered with snow in June became black in September.

June 2002



September 2002

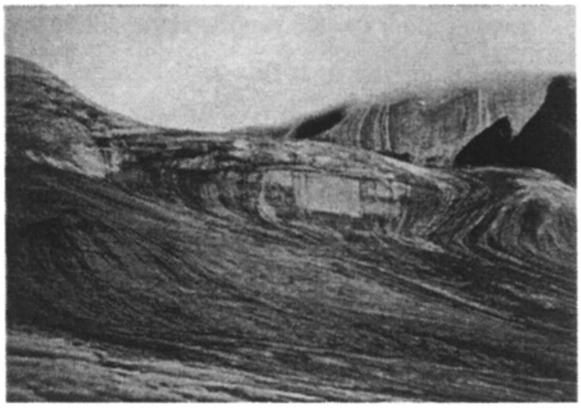


Figure 5 Photographs of glacier surface in June and September, 2002.

The surface blackness was caused by a living organism, called 'Cryoconite'. Solar radiation, meltwater and nutrients are necessary to grow the Cryoconite to form this black surface (Takeuchi *et al*, 2000; Kohshima, 1989). If the relation between Cryoconite growth rate (Albedo change) and meteorological data (solar radiation and air temperature and others) is clarified quantitatively, it will be possible to estimate the albedo fluctuation from meteorological data.

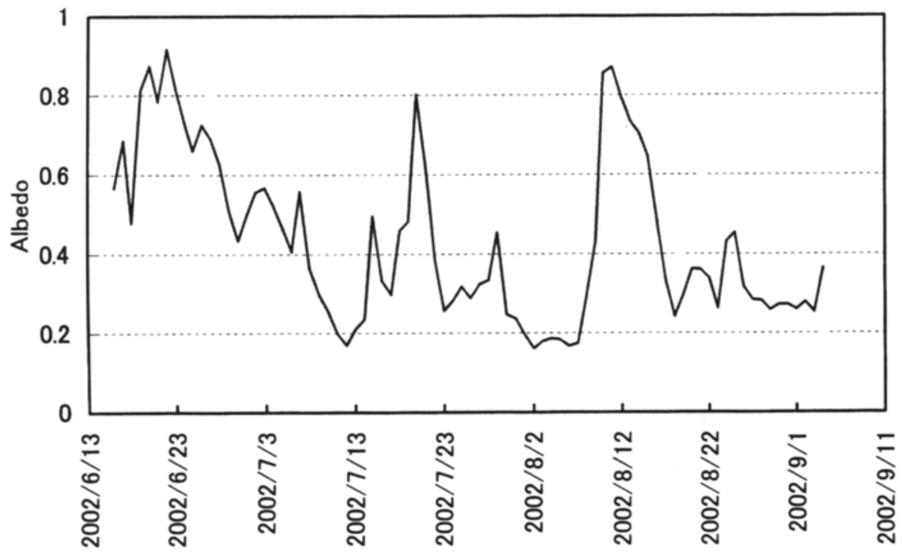


Figure 6 Fluctuation of glacier surface albedo from June to September 2002 at stake 8-2 in the middle of July 1st glacier. The location of stake 8-2 is shown in Fig. 1.

Figure 6 shows the albedo fluctuation at stake 8-2 in July 1st glacier. Albedo became low with the increase in blackness of the glacier surface. At the beginning of June, the surface was white, and gradually became black as shown in Fig. 6. Observed albedo at July 1st glacier was sometimes lower than the clean ice albedo, which ranged from 0.3 to 0.5 (Peterson, 1994). Therefore, the melt amount at July 1st glacier would be larger than those on the other clean type glaciers.

Figure 7 shows a cross section of snow layers at the accumulation area (upper part of the equilibrium line) of the glacier. Usually, the black layer forms once or twice in a year. At the ablation area (lower part of the equilibrium line), the surface snow will melt away to expose the lower dirty layer of the surface, and those dirty layers would be combined into one. Then, the surface black would become thick, causing an increase in absorbed solar radiation at the glacier surface of the ablation area.

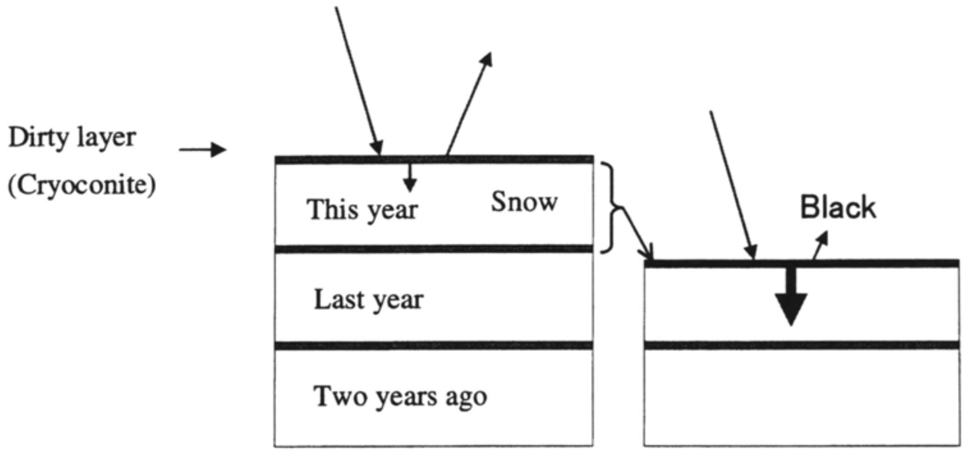


Figure 7 Cross section of snow layer at the surface portion of the glacier.

Those albedo variation processes have to be clarified to estimate the melt amount of the glacier.

4. Refrozen amount

Distribution of meltwater and precipitation on the glacier surface is illustrated in Fig. 8. Precipitation would be rain or snow, depending on the air temperature. After snow deposits on the surface of the glacier, a part of snow is missed by evaporation, and some part of snow will melt in accordance with the surface heat balance. Meltwater and rain will partly refreeze in the snow layer, when the snow temperature is below zero. Other portion of the water, which does not refreeze, would flow out from the glacier. If there is no snow layer on the glacier ice and ice is exposed at the glacier surface, there would be no refrozen since the water would wash out in a flash (Fujita et al., 1996).

Glaciers are polar type glacier in the Qilian mountains (中国冰川概論, 1988). The glacier ice temperature at more than 10 meters depth is relatively low even during the summer season, since the air temperature reaches approximately 20 or 30 degrees below zero, and winter coldness is stored in glacier ice during the winter season. Therefore, melt water would refreeze in the snow layer during the summer. (Fujita et al., 1996)

The refrozen amount for the whole glacier was estimated from residual value between rain and melt water at the whole glacier area and discharge from Fig. 8. Precipitation was separated into rain and snow by air temperature. The air temperature of 50 % probability of occurrences of rain and snow was assumed to be 3°C based on few observations. Melt amount was calculated from meteorological and albedo data. Wind velocity and downward longwave radiation were assumed to be uniform at all glacier area. Air temperature at each elevation was calculated using the temperature lapse rate 0.6°C/100 m. The fluctuation of albedo at stake 8-2, which is located at the middle of the glacier (the location was shown in Fig. 1), was applied to the whole area of the glacier. Surface temperature of the ice was assumed to be 0°C. Melt rate and the amount of rain was calculated and at each altitude the interval of 100 m, using daily data. Then, the refrozen amount was estimated from rain, meltwater and observed discharge amount during the observation period from 11th June to 4th September in 2002.

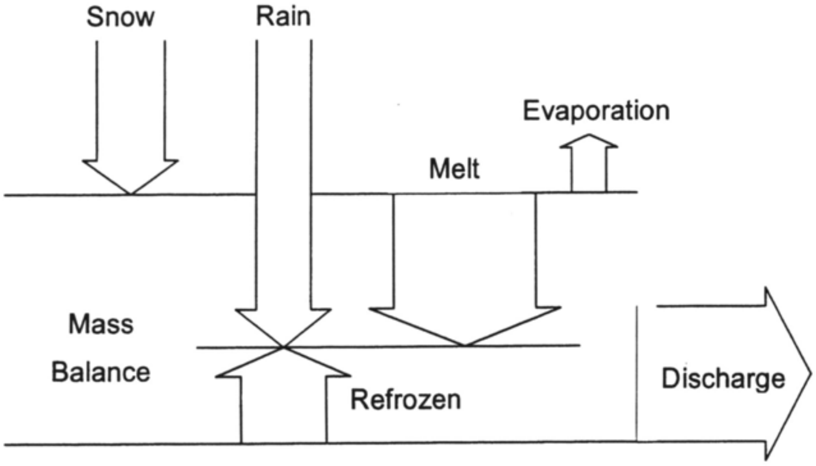


Figure 8 Schematic representation of destination of meltwater, snow and rain at glacier surface (modified Fujita (2000)).

The result of the calculation shows that the refrozen amount was accounted for nearly half of the total amount of surface melt water and rain water. If the refrozen amount was not taken into account, the discharge amount would be overestimated by nearly two-fold.

Large value for the ratio of refrozen water was observed in Tibetan Plateau (Fujita et al., 2003), caused by a very cold ice temperature. The temperature is a function not only of the summer air temperature, which contributes the melt amount, but also the temperature during the winter season. Recently, winter temperatures are reported become higher, particularly in the northern hemisphere (IPCC, 2001). It is necessary to evaluate the reduction of refrozen amount with the increasing winter temperature.

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