Role of glacier runoff in the Heihe Basin

Akiko SAKAI[1], Koji FUJITA[1], Masayoshi NAKAWO[2], Tandong YAO[3]

1 Nagoya University, Japan
2 Research Institute for Humanity and Nature, Japan
3 Institute of Tibet Plateau Research, Chinese Academy of Sciences, China

Abstract

We estimated the fluctuation of precipitation and air temperature from Dunde ice core data since 1606 comparing to meteorological data taken near the July 1st glacier since 1930s. Then, we calculated the discharges from glaciers and glacier-free area.

Furthermore, we analyzed the sensitivity of those discharges to meteorological factor. The result revealed that calculated discharge from glacier-free area increased with precipitation. Meanwhile, calculated discharge from glaciers decreased with precipitation. Since little precipitation cause expose the glacier ice surface, which can absorb almost solar radiation, then glacier melt accelerated. Then, relatively large discharge from glacier can be provided when the discharge from glacier-free area is less. Therefore, discharge from glacier make up for the shortage of discharge from glacier-free area due to less precipitation. Then, water supply for living people in the oasis and desert would have been maintained from ancient days.

Introduction

There are several vast arid region in the north west of China. There is relatively high precipitation (more than 300 mm yr^{-1}) at high elevations in mountain areas. On the other hand, there is little precipitation (less than 50 mm yr^{-1}) downstream along the river. From olden days, melt water of glaciers and snow on those mountains have provided

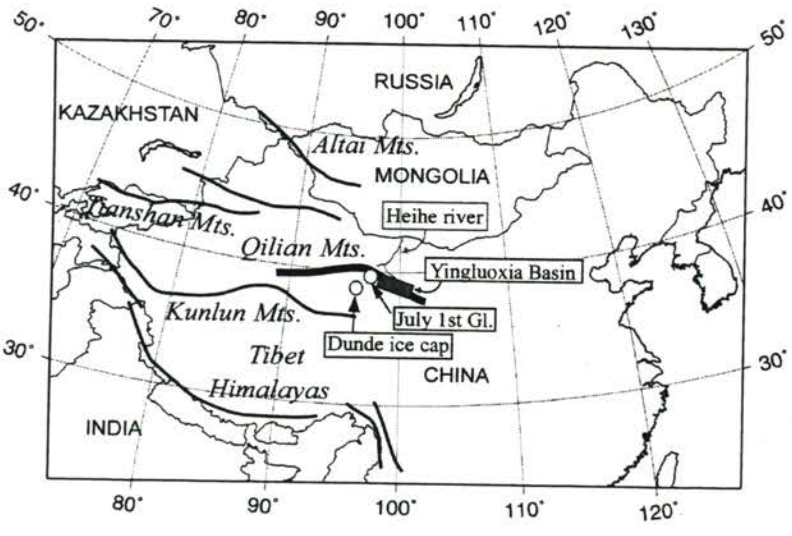

Figure 1. Location map of Heihe River and Yingluoxia Basin.

drinking water and water for irrigation to the people living in those oasis cities. Purpose of this study, therefore, is to estimate the discharge from glaciers using the ice core data and elucidate the characteristic of the discharge.

Location

Heihe river basin comprises Qilian mountains in the southern part, oasis cities in the middle part and vast Gobi Desert in the northern part. Qilian mountains locates on the northern fringe of the Tibetan plateau, Northwest China (Fig. 1), and there are relatively a lot of precipitation. There have been a lot of irrigated area in the Oasis cities, and nomad people have been living in the desert area from ancient days. Yingluoxia basin locates at the mountain portion of the Heihe river basin (Fig. 1), and we can assume that the discharge from this basin has not been influenced by human activity. Yingluoxia basin was 10009 km^2 in area and there area 73 km^2 of glacier area in this basin (Gao and Yang, 1985). Glacier area, therefore, attain 0.7 % of the whole Yingluoxia basin.

Data set for calculation

Reconstruction of historical air temperature

Air temperature and precipitation was estimated from ice core taken at Dunde ice cap (Thompson *et al.*, 1998). Dunde ice cap locates at 100 km south-west from July 1st Glacier in Qilian mountains (38°06'N, 96°24'E). In this region, stable isotope of precipitation is high when air temperature is high, and variation of stable isotope of precipitation reflect variation of air temperature (Tian et al., 2003; Araguas-Araguas *et al.*, 1998; Johnson and Ingram, 2004), and there are relatively large precipitation during summer season (from June to August) (Ding and Kang, 1985). We, therefore, compared the summer (JJA) temperature and isotope of ice core data. Figure 2 shows the 12 years running mean of variation of stable

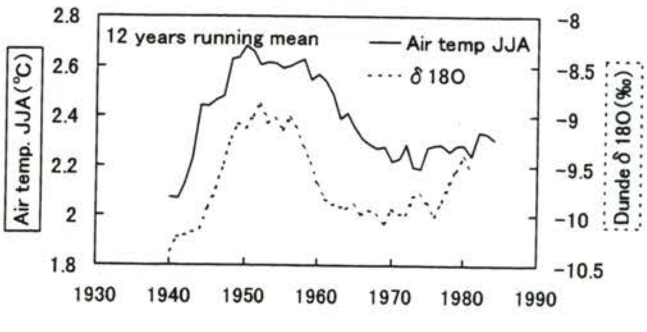

Figure 2. 12 years running mean of summer (JJA) air temperature and isotope of Dunde ice core.

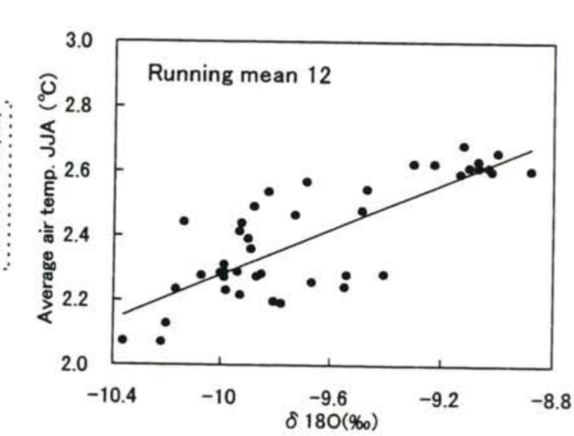

Figure 3. Relation between 12 years running means of JJA temperature at Jiuquan and stable isotope in the Dunde ice core.

isotope fluctuation in the Dunde ice core and temperature at Jiuquan 90 km north east from July 1st Glacier. And we can estimate JJA air temperature from the relation in Fig. 3. Then, annual air temperature was estimated from JJA air temperature since mean difference between annual air temperature and air temperature averaged during summer (JJA) was 9.3 °C since 1935.

Reconstruction of historical precipitation

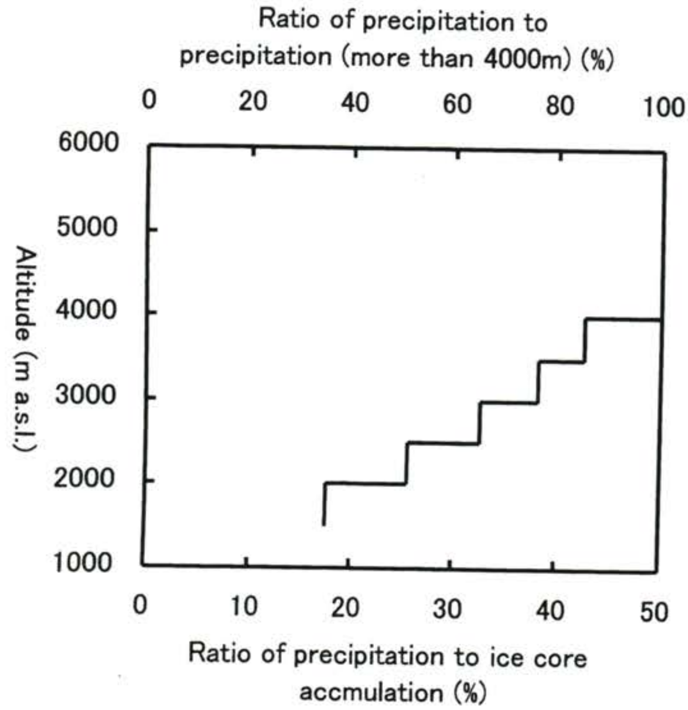

Figure 4. Altitudinal distribution of precipitation in the Heihe Basin.

Observed precipitation at several altitude in Heihe river basin were summarized by Ding and Kang (1985). Figure 4 shows the altitudinal distribution of precipitation ratio assuming precipitation at more than 4000m altitude was 100 %.

Precipitation in the Yingluoxia basin was assumed to be equal fluctuation with Dunde ice core.

Precipitation using calculation for discharge was adjusted so as to the fluctuation of ice thickness would have peaks, in other words, not to simple increase or decrease since terminus of the glaciers in Qilian mountains has repeated to advance and retreat since 1600s (王, 1991).

Figure 5 shows annual air temperature and precipitation data since 1606 reconstructed from ice core data.

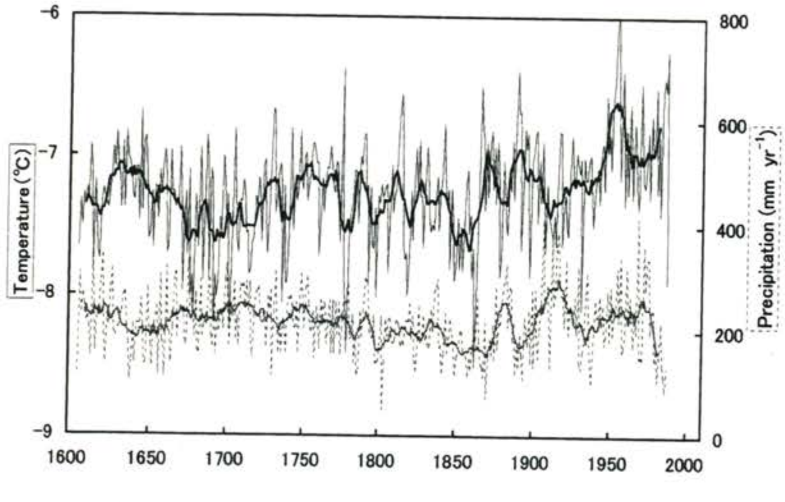

Figure 5. Reconstructed air temperature at 4300 m and precipitation at more than 4000 m altitude from the ice core.

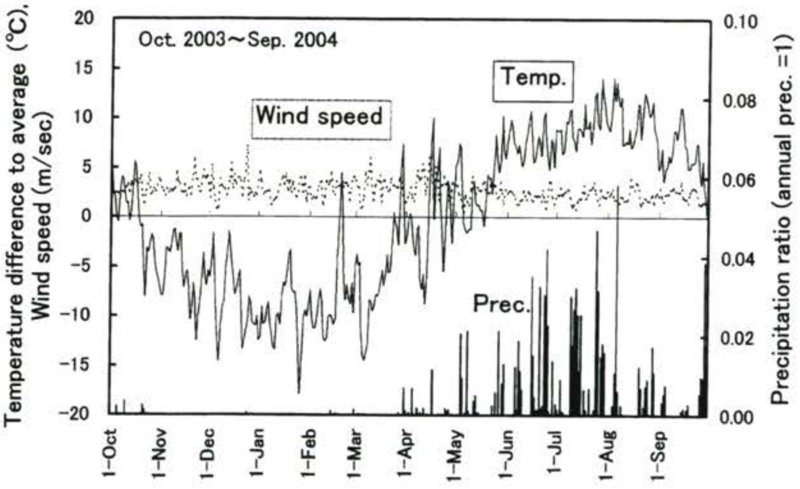

Figure 6
Fluctuation of daily air temperature assuming that the annual air temperature was zero. Precipitation ratio shows the ratio of the daily precipitation to annual precipitation (=1). Wind speed

Daily precipitation and temperature have estimated from annual data estimated from ice core. There was a observed temperature and precipitation data set at the July 1st glacier at the altitude of 4295 m a.s.l. from October, 2003 to September, 2004. We calculated the daily temperature difference from annual average of temperature, and daily precipitation ratio to annual precipitation as shown in the Fig. 6. Then daily temperature and precipitation were calculated by assuming that the daily variation of the temperature and precipitation (as shown in the Fig. 5) were unchanged.

Calculation

Discharge calculation at glacier area

Discharge from glacier area can be calculated as follows,

$$Q_g = P_r + M - R$$

where, Q_g = discharge from glacier area

P_r = liquid precipitation (rain),
M = glacier melt
R = Refreezing of rain or meltwater.

Precipitation can be divided depending on the air temperature. Here, 100 %, 0 % of provability of solid precipitation (snow) occurrences were 0 C° and 6 C°, respectively.

Degree-day factor has been put into common use to estimate melt rate of glaciers in the world (Braithwate, 1995; Johannesson et al., 1995; Hock, 2003; Singh et al., 2000 and so on) But, the method was assumed that the ice or snow melt rate is proportional to only air temperature. Although, the actual melt rate of glaciers depend on not only air temperature, but also solar radiation, albedo, wind speed, humidity and so on. Degree-day factor, therefore, have wide-ranging value depending on the ratio of heat balance elements to total incoming heat as shown in the previous studies (Braithwate, 1995; Johannesson et al., 1995; Hock, 2003; Singh et al., 2000; Kayastha, 2003). Then, it would vary with climate change during past few thousands or hundreds of years, and estimating melt rate with constant degree-day factor would us lead to misunderstand the essence of past environment of glaciers.

But, heat balance methods requires many kinds of meteorological elements, which we can not get from proxy data, such as ice core data, tree-ring data and lake sediment core. There are only air temperature and precipitation, which we can get from those proxy data. Then, we estimated solar radiation and humidity, which was difficult to estimate from proxy records, from precipitation or air temperature, which can be relatively easy to get.

Downward shortwave radiation (:SR_d) can be defined by transmissivity (: τ) and shortwave radiation at the top of the atmosphere (:SR_{top}) ,

$$SR_d = \tau\, SR_{top}$$

We found the following relation between monthly downward shortwave radiation and monthly precipitation observed at July 1st Glacier at the altitude of 4295 m a.s.l.(Fig. 7). Since precipitation generally increases with cloud amount, which cover over the sun and reduces the ratio of the downward shortwave radiation to shortwave radiation at the top of the atmosphere, in other words, transmissivity.

Figure 8 shows the relation between precipitation and relative humidity. The relation indicates that the precipitation increase with relative humidity.

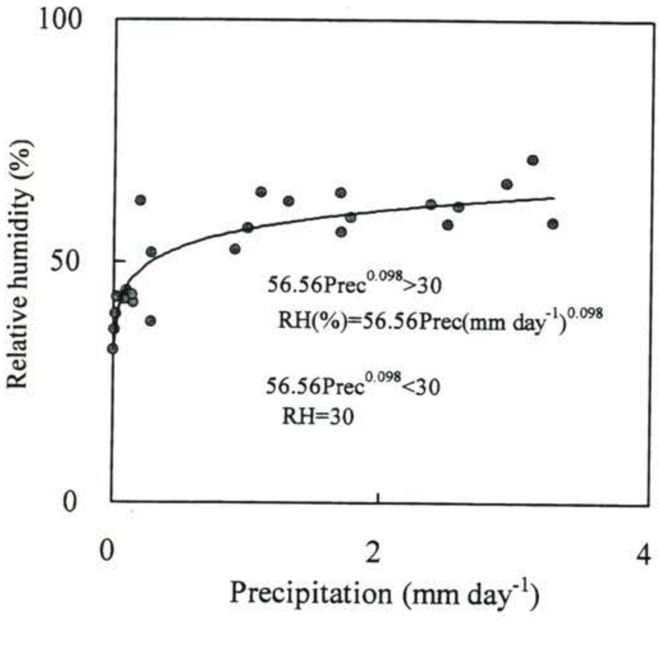

Figure 8.
Relation between monthly average transmissivity (Downward solar radiation/solar radiation at the top of the atmosphere) and daily precipitation in monthly average.

Then, we can estimate relative humidity and downward shortwave radiation from precipitation. Calculation of surface heat balance of glaciers was referred from Fujita and Ageta (2000), which takes into account the ice temperature change and refreezing ice.

Discharge calculation at Glacier-free area

It was assumed that there was no change of annual ground water. Therefore, we can calculated the annual discharge from the glacier free-area as follows,

$$Q_f = P - E_f$$

Evaporation at glacier-free area can be calculated from Kang *et al.*(1999) which equation was applied to calculate the evaporation at Urumqi River basin.

For further study, we will estimate evaporation from heat balance method as using in the glacier melt calculation.

Result

Figure 9 shows the fluctuation of cumulative mass balance in other words, ice thickness averaged in whole glacier area at July 1st Glacier. Those are calculated from air temperature and precipitation data from the Dunde ice core and NCDC data at Jiuquan. Precipitation was adjusted so as to the fluctuation of ice thickness would have peaks, in other words, not to simple increase or decrease since terminus of the glaciers in Qilian mountains has repeated to advance and retreat since 1600s (王, 1991).

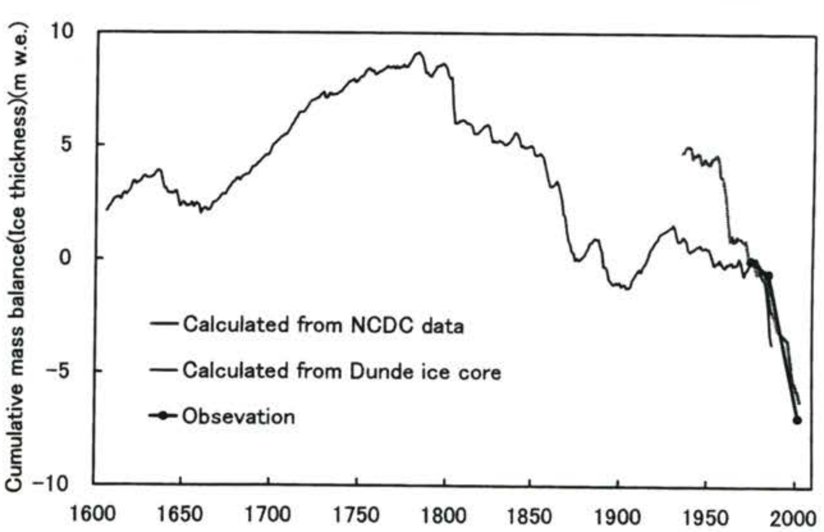

Figure 9. Fluctuation of cumulative mass balance in other words, ice thickness averaged in whole glacier area at the July 1st Glacier.

Figure 10 shows calculated annual discharge and evaporation at the glacier-free area in Yingluoxia Basin since 1606. The total value of the annual runoff and evaporation of each year represents the annual precipitation at the glacier-free area. This figure indicates that the magnitude of fluctuation in precipitation was relatively larger than that of evaporation, and annual discharge depends on mainly precipitation.

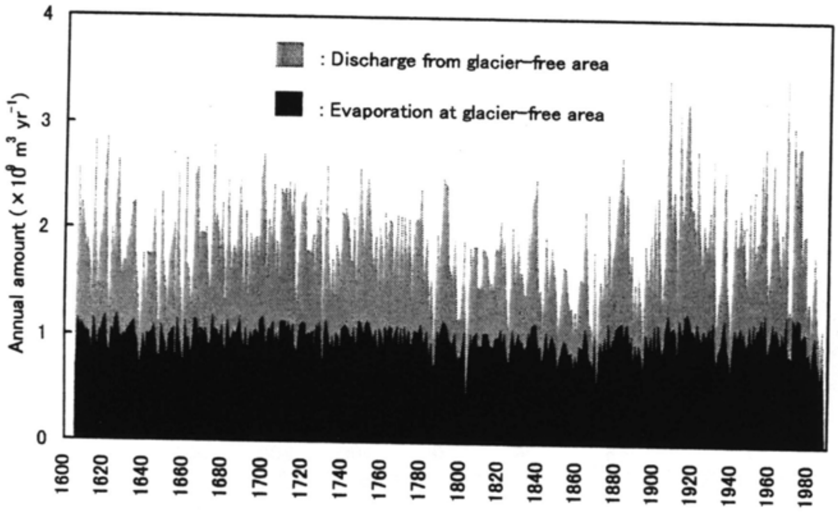

Figure 10.
Calculated discharge and evaporation at the glacier-free area.

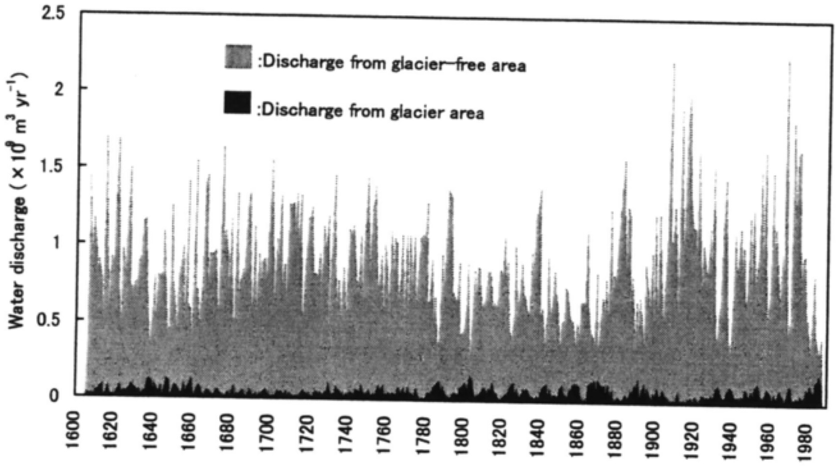

Figure 11.
Calculated discharge from glacier and glacier-free area.

Figure 11 shows the variation of annual water discharge from glacier and glacier-free area since 1606. Average discharge from glacier attain about 10 % of total discharge from this basin since 1606. Observed discharge at Yingluoxia basin was $1.3 - 2.1\times10^9$ m^3 yr^{-1} from 1993 to 1999. Calculated discharge was relatively small. Because the precipitation was adjusted to that in the west side of the basin, where precipitation was rather small than the east side.

Discussion

Sensitivity of the discharge from glacier and glacier-free area to meteorological condition has analyzed to elucidate the characteristic of discharge in mountain area.

Figure 12 shows the relation between discharge from glacier-free area and air temperature and precipitation. It is very clear that the discharge from glacier-free area depend on precipitation.

Figure 13 shows the relation between discharge from glacier area and air temperature and precipitation. Discharge from glacier increase with air temperature, and decrease with precipitation. Little precipitation cause expose the glacier ice surface, which can absorb almost solar radiation, then glacier melt accelerated. Meanwhile, snow tends to cover the glacier surface when there is much precipitation, and snow, which has high albedo, reflect almost solar radiation and glacier was prevented to melt.

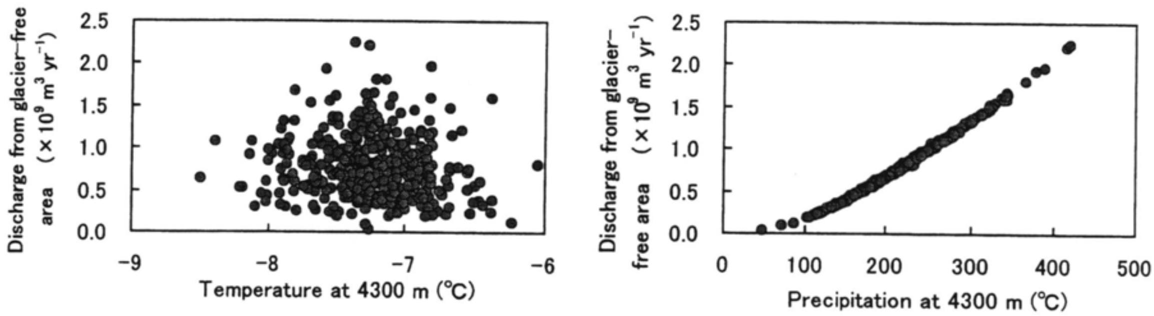

Figure 12. Relation between discharge from glacier-free area and air temperature (left) and precipitation (right).

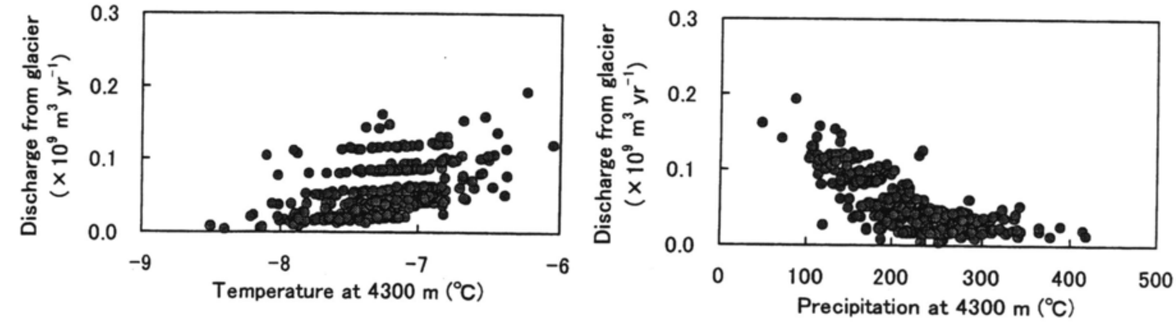

Figure 13. Relation between discharge from glacier area and air temperature (left) and precipitation (right).

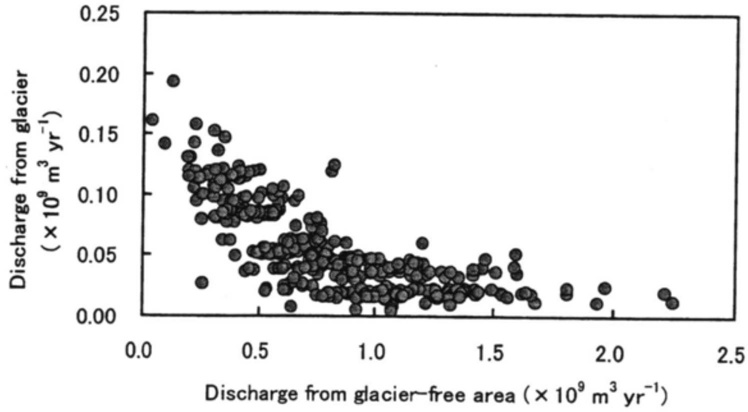

Figure 14.
Relation between discharge from glacier-free area and from glacier area.

Figure 14 shows the relation between discharge from glacier and glacier-free area. The relation can obtained since each sensitivity of discharges to precipitation has in opposite sense. Discharge from glaciers compensate the shortage of discharge from glacier-free area, and play a role of water discharge regulator for stable runoff.

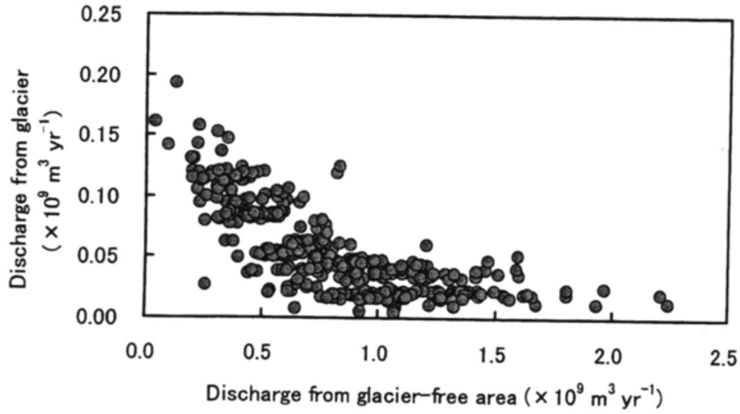

Figure 14.
Relation between discharge from glacier-free area and from glacier area.

Conclusion

Discharges from glacier and glacier-free area has calculated using air temperature and precipitation estimated from ice core data from 1606 to 1987. Sensitivity of calculated discharge from glacier and glacier-free area has revealed that the discharge from glacier area increase when the discharge from glacier-free area decrease.

We can conclude that the discharge from glacier area has been made up for the shortage of discharge from glacier-free area and has supplied stable waters for drinking and irrigation to the people living in the oasis cities and desert area from ancient days.

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