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Hydrological observations in the Tanggula Mountains, the Tibetan Plateau —— discharge, soil moisture and ground temperature ——

Takeshi OHTA[1], Hironori YABUKI[2], Tosio KOIKE[3], Tetsuo OHATA[2], Masako KOIKE[3] and ZHANG Yinsheng[4]

1 Faculty of Agriculture, Iwate University, Morioka 020 Japan

2 Institute of Hydrospheric-Atmospheric Sciences, Nagoya University, Nagoya 464–01 Japan

3 Department of Civil Engineering, Nagaoka University of Technology, Nagaoka 940–21 Japan

4 Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Science, Lanzhou, China

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Abstract

Hydrological observations were carried out in the Tanggula Mountains on the Qingzang Plateau as a part of the CREQ (Cryosphere Research on Qingzang Plateau) project. The main hydrological items observed in CREQ were discharge, soil moisture contents and ground temperature. All items were measured from October 1992 to September 1993 with some of these items being measured from October 1991. Almost all of the annual discharge occurred during the summer season, from June to September, regardless of the watershed size and ratios of glacier areas in the watersheds. The percentages of the summer discharge were more than 85 % of the annual discharge. A glacial run-off formed a seasonal variation of discharge, and inter-diurnal variations of run-off were caused by discharge of precipitation through soil layers. Depths of active layers in dry fields were deeper than that in the Wetland. The annual range of ground temperature was smaller in the Wetland than in the dry fields. Heat conductivity of the soil layer which was an index of soil moisture contents changed largely in the surface soil layer above 20 cm depth in the dry fields. On the other hand in the Wetland, the heat conductivity was constant, due to little variation of the soil moisture content.

1. Introduction

The cryosphere in the Qingzang Plateau consists of seasonal snow covers, glaciers and permafrost which control the hydrological cycle in this region. An understanding of cryospheric effects on run-off characteristics, soil moisture movements, melting layers in permafrost and other hydrological processes is indispensable for analyzing the water cycle system in the Qingzang Plateau. However, hydrological observations in this area have been scarce owing to severe climate and geographical conditions.

Ohata *et al.* (1991) carried out meteorological and hydrological observations in the Tanggula Mountains in May and June 1989. It was reported that a permafrost table functioned as an impermeable layer, and that the saturated soil layer was formed on the table. Hydrological analyses for a full water year could not be done in these investigations, and the discharge data was not obtained. Yang and Woo (1988) analyzed the stream flow characteristics from monthly discharge data in the Northern Qingzang Plateau and reported that run-off characteristics were different between continuous and discontinuous permafrost areas. However, relations between hydrological characteristics, for instance, water budget or run-off characteristics, and cryospheric variations were not clear, and water budgets at several basin scales were not obtained.

The hydrological observations in CREQ (Ageta *et al.*, 1994) aimed to gather continuous and high quality data through one or several water years. Main pur poses of the hydrological observations are as follows :

1) To analyze water budgets and cryospheric

effects at several basin scales in the Qingzang Plateau.

2) To analyze relations between run-off characteristics and cryospheric variations.

3) To analyze interactions between hydrological processes, especially evapotranspiration and run-off, and atmospheric conditions.

This paper is a preliminary report on the hydrological observations in CREQ. The outlines of the hydrological observations are shown in this report, and the water budget in this area is preliminarily investigated by a basin water balance method. Detailed results about the soil moisture contents and the ground temperature are reported by Yabuki *et al.* (1994).

2. Watersheds and methods of observation

2.1. Outline of watersheds

Hydrological observations were mainly carried out in three watersheds of which the smaller one is the head water of the larger one. These watersheds were called the Small Watershed, the Middle Watershed and the Large Watershed. The watersheds were selected to analyze effects of glaciers and permafrost on hydrological processes in different watershed scales. The observations were carried out from October 1992 to September 1993. Hydrological items were also observed at the terminus of Dongkemadi Glacier, which was located at the head of the Small Watershed, during the 1993 summer season only, from July 1st to September 16th. The location and the topographical feature of the watersheds are shown in Fig. 1, and the outline of the watersheds are presented in Table 1. Fig. 2 shows percentages of each area in every 200 m interval of altitudes for the three main watersheds.

2.2. Methods of observation

Hydrological items observed in this project are summarized in Table 2.

Items observed at the outlets of these watersheds were water level, water temperature and electric

Table 1. Outline of the watersheds.

Watershed Name	Altitude of the outlet (m)	Watershed area (km^2)	Percentage of glacial area (%)	Observing period
Large Watershed	4700	4538.0	4.5	1992/10 -
Middle Watershed	5030	563.63	7.9	1992/10 -
Small Watershed	5060	50.50	32.9	1992/10 -
Terminus of Glacier	5300	21.49	74.0	1993/7- 9

Table 2. List of the hydrological measurements.

Observation site	Altitude	Obs. items	Interval	Obs. Period	Remarks
Large	4700	W	1 hr.	1992/10 -	
		E, Tw	1 hr.	1993/6 -	Summer season only
Middle	5030	W	1 hr.	1992/10 -	
		E, Tw	1 hr.	1993/5 -	Summer season only
Small	5060	W	1 hr.	1992/10 -	
		E, Tw	1 hr.	1993/5 -	Summer season only
Terminus	5300	W	1 hr.	1993/7 - 9	
		E, Tw	1 hr.	1993/7 - 9	
D100	4800	K, Ts	12 hrs.	1992/10 - 1993/9	4 depths
		P	10 min.	1993/5 - 8	
D105	5040	K, Ts	12 hrs.	1991/9 - 1993/9	7 depths
		P	10 min.	1993/5 - 9	
Wetland (WL)	5140	K, Ts	12 hrs.	1992/10 - 1993/9	4 depths
Tanggula Pass (SH)	5206	P	10 min.	1993/5 - 9	

W : Water level
E : Electric conductivity of stream water
Tw: Temperature of stream water
K : Heat conductivity of soil layers
Ts : Temperature of soil layers
P : Precipitation

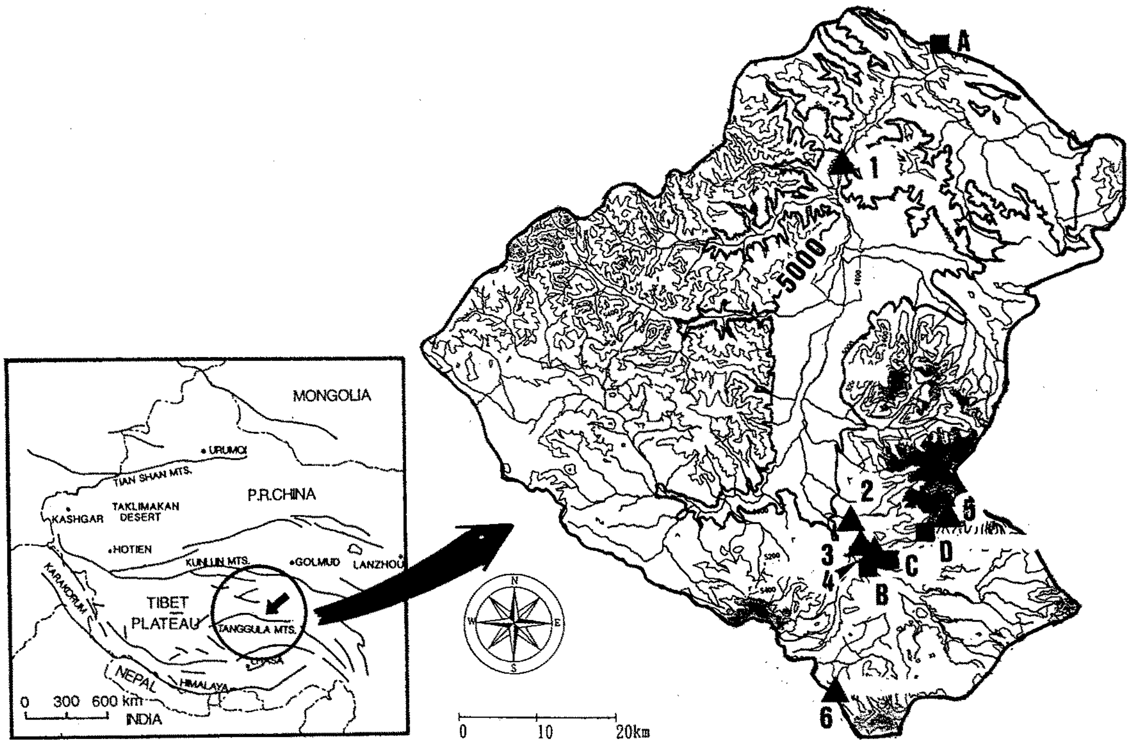

Fig. 1. Location and topographical features of the watersheds.
note A : The Large Watershed (Yangshiping, 4700 m a.s.l.)
B : The Middle Watershed (5030 m a.s.l.)
C : The Small Watershed (5060 m a.s.l)
D : The terminus of Dongkemadi Glacier (5300 m.a.s.l.)
1 : D100 (4800 m a.s.l.) 2 : D105 (5040 m a.s.l.)
3 : Wetland (5140 m a.s.l.) 4 : Base Camp (5060 m a.s.l.)
5 : Glacier Camp (5500 m a.s.l.) 6 : Tanggula pass (5206 m a.s.l.)
Contour line are drawn at 200 m interval.
Dot places are glaciers.

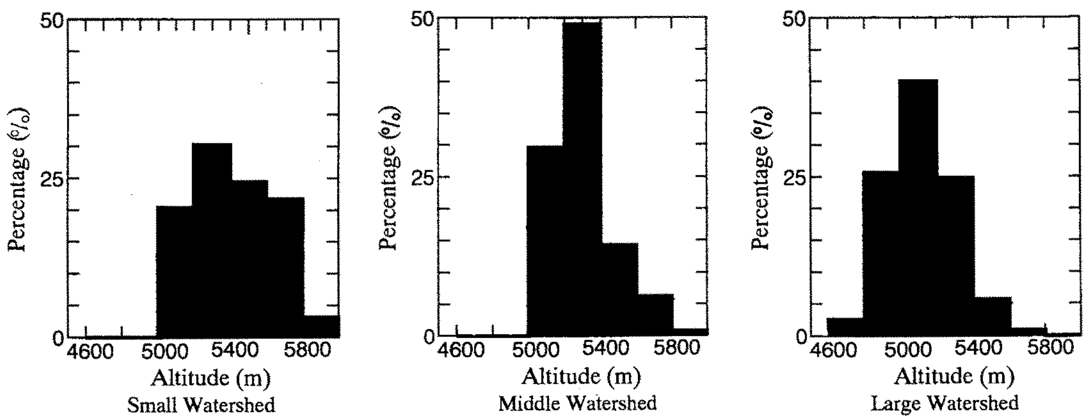

Fig. 2. Distributions of altitudes at 200 m intervals in the watersheds.

conductivity, and they were observed once every hour. Discharge was calculated by relations between water level and the amount of discharge. These relations were obtained by cross section surveys of channels and mean flow speed measurements at the 60 % water depth. Water level was measured by pressure sensors and the minimum resolution of the pressure sensor for a summer season, May-September, was 1 cm, for a winter season, October-April, it was 10 cm. Water temperature and electric conductivity were used to separate run-off from glaciers and soil layers. Water temperature was also used to obtain values of electric conductivities at a water temperature of 25 °C.

As the soil moisture content increases so do the values of heat conductivity of soil layers, and soil moisture contents can be estimated from the relations between them. So, heat conductivities and ground temperature were measured at three sites, D100 (4800 m a.s.l.), D105 (5020 m a.s.l.) and the Wetland (5100 m a.s.l.). Ground surfaces at D100 and D105 were sparsely covered with grass, and the surface condition was flat. On the other hand, dense grass covered the ground surface at the Wetland, and formed earth hummock in which the surface was very rugged. Locations of the study sites are also indicated in Fig. 1. Heat conductivities were observed by heat probe sensors, and ground temperature was measured by thermistor sensors, every 12 hours, 6 : 00 and 18 : 00 B. S.T. for a year. These items were observed at four depths at the site D100, at four depths at the Wetland and at seven depths at the site D105. The observations were carried out from October 1991 to September 1993, at D105 and from October 1992 to September 1993 at D100 and the Wetland.

3. Results and Discussions

3.1. Seasonal variations in daily discharge rates

Figure 3 shows daily discharge from the three main watersheds for the observed year. Discharge increased late in June irrespective of watershed scales and ratios of glaciers. Almost all of the annual discharge occurred from the end of June to September, and the percentages of discharge for the summer season, from June to September, to the annual discharge at the Small, the Middle and the Large Watershed were 87.0 % (320 mm), 92.1 % (329 mm) and 94.6 % (135 mm), respectively.

It can be seen in Fig. 3 that the discharge fluctuated widely during the summer season at the three watersheds. Discharge at Langtang Khola, of which the basin size is similar to the Middle Watershed and the glacial percentage to the Small Watershed, Nepal Himalaya from 1985 to 1986 varied smoothly (Fuku-

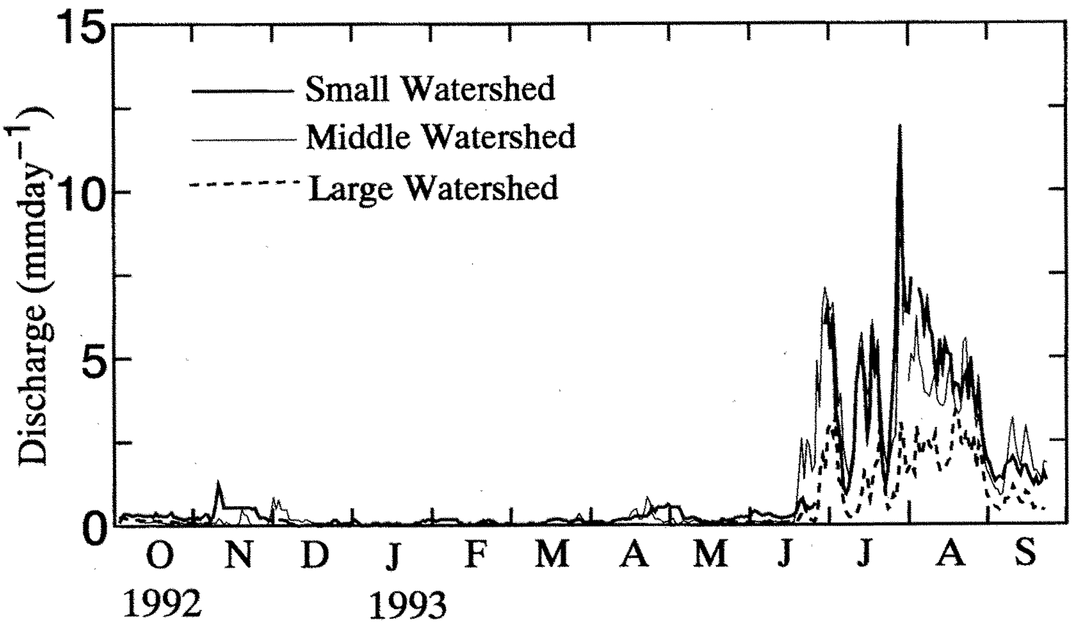

Fig. 3. Annual variation of discharge from the three main watersheds.

shima *et al.*, 1987). The wide fluctuation of discharge during the summer season is one of run-off characteristics in this area.

3.2. Relations between meteorological elements and daily discharge in a summer season

Figure 4 shows the daily discharge at the four hydrological stations. The daily mean temperature and precipitation rates every half day were also shown in this figure. Temperature and precipitation were measured at the Base Camp, 5060 m a.s.l., and more details are reported by Ueno *et al.* (1994).

Seasonal variations of discharge from the all watersheds were similar during the 1993 summer season. The abrupt decrease of discharge, at the beginning and around 20th of July and at the beginning of September, occurred when daily mean temperature also dropped. Precipitation rates were also low when the temperature dropped. Glacial discharge decreases with the drop in the temperature, and discharge from soil layers diminishes with the decrease of precipitation. Since decreases in the temperature and the precipitation occurred at the same time, the totalized discharge from glaciers and soil layers decreased abruptly.

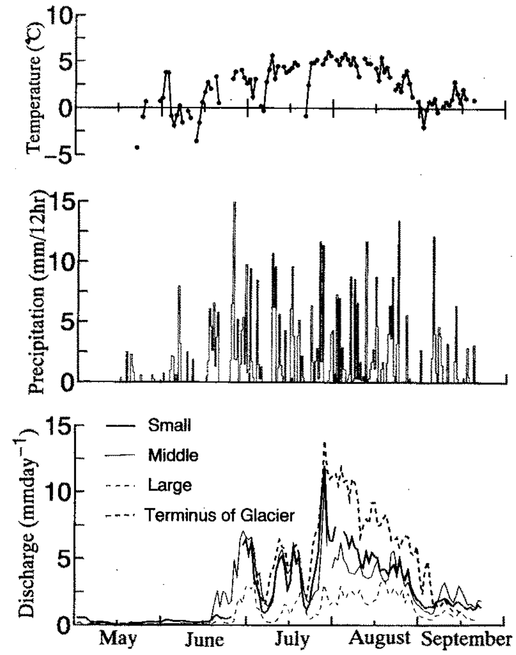

Fig. 4. Seasonal variations of the discharge, the amount of precipitation and the daily mean temperature during the 1993 summer season. The amount of precipitation and the daily mean temperature were reported by Ueno *et al.* (1994).

3.3. Run-off from a glacier and a soil layer in the Small Watershed

Figure 5 shows the daily discharge at the terminus of Dongkemadi Glacier, at the Small Watershed and the difference between them. The unit of daily discharge in this figure is m^3day^{-1}, since it is aimed in this section to obtain the total quantity of the discharge from a glacier and a soil layer in the Small Watershed. Discharge at the terminus of the glacier was considered not to be formed by only glacier melt water, because the glacial percentage was not 100 %, as shown in Table 1, and values of the electric conductivity at the hydrological station were higher than those of water flow on the glacier surface. But the major part of the discharge can be regarded as the run-off from the glacier, because the glacial percentage was high in the catchment.

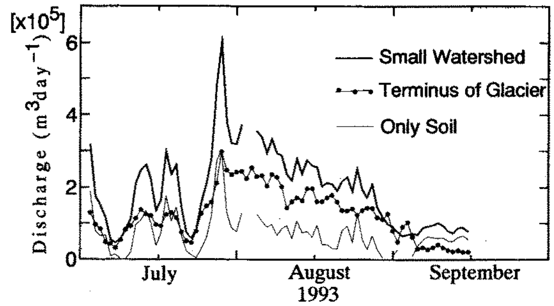

Fig. 5. Hydrographs of the small watershed, glacier runoff and soil layer runoff in the summer, 1993.

The variation of the glacial run-off was smoother than that of the discharge from the soil layer. The glacial run-off affected the seasonal discharge variation strongly in the Small Watershed. On the other hand, discharge from the soil layer was widely varied, and it is considered that this component formed the inter-diurnal variation. The variation of discharge at Langtang Khola was smoother than those in Tanggula Mountains, as mentioned in Section 3.1. These results appear to suggest that discharge from soil layers contributes more strongly to the total discharge in the Small Watershed than at Langtang Khola, Nepal.

Peak discharge rates from the soil layers were not related to the precipitation rates shown in Fig. 4. Discharge from the soil does not necessarily increase with increasing precipitation if the most precipitation is in the form of snowfall. Precipitation form, rainfall or snowfall, changes with the temperature. Then the areal percentage in which the precipitation type is rainfall in watersheds is variable according to the temperature. This is probably due to the effect of temperature through precipitation form.

3.4. Preliminary estimation of water budget in the Small and the Middle Watersheds

In a glaciated watershed, the water balance can be written as ;

$$P=Q+E+dS+dG \quad (1)$$

where P is precipitation (mm) ; Q is discharge (mm) ; E is evapotranspiration (mm) ; dS is the change of water storage in soil layers at the beginning and the end of a water budget period (mm) and dG is a water equivalent of a mass balance of a glacier during a water budget period (mm). The value of dS, in general, is regarded as 0 for one water year.

The annual discharge in the Small and the Middle Watersheds which were head waters of the Large Watershed were 367 mm and 357 mm, respectively. The number of days observed at the watersheds are around 350, so these are not values for a full water year. Percentages of the amount of precipitation for the summer seasons only at D100, 4800 m a.s.l., and Tanggula Pass, 5206 m a.s.l., to that at the Base Camp, 5060 m a.s.l., were 97 % and 91 %, respectively, and the percentage at the Glacier Camp, 5500 m a.s.l., was 135 % (Ueno *et al.*, 1994). The amount of precipitation did not vary much with the location along the main river in the Large Watershed. On the other hand, the amount of precipitation increased with the altitudes in tributaries. So, relations between the amount of precipitation and altitudes in the head water of Tanggula Mountains were roughly assumed as ;

$$P(h)=P_{BC} \quad ; h<5200 \quad (2)$$
$$P(h)=(1+0.00117(h-5200))\ P_{BC} \ ; h\geq 5200$$

where $P(h)$ is the amount of precipitation (mm) at h m a.s.l. and P_{BC} is the amount of precipitation (mm) at the Base Camp. The amount of precipitation in the Small and the Middle Watersheds from 23rd May to 20th September 1993 were estimated to be 561 mm and 507 mm, respectively. The annual precipitations at these watersheds were calculated 679 mm and 614 mm, respectively, on the basis of the monthly percentages to the annual precipitation at Yangshiping which was the hydrological station of the Large Watershed (Yang and Woo, 1988). Then the annual evapotranspiration in the Small and the Middle Watershed can be estimated to be 312 mm and 257 mm, respectively, from the difference between the annual precipitation and discharge on an assumption of the equilibrium annual balance of glaciers. In this case, the annual evapotranspiration in the Small Watershed is equal to 45.9 % of the annual precipitation, and 41.8 % in the Middle Watershed.

These values of evapotranspiration may be overestimated, because a glacier's mass balance is considered to be positive for this water year (Seko *et al.*, 1994) and the amount of discharge used for these calculations are not for a full year. Effects of a glacier mass balance on the water budget is considered to be relatively larger at the Small Watershed than at the other watersheds, since the percentage of the glacial area is large, as shown in Table 1. The water budget presented in this section is consequently preliminary values, and it is hereafter needed to estimate effects of glaciers on the water budget at the several basin scales.

3.5. Soil moisture content and ground temperature

Only a brief description of the soil moisture and the ground temperature variation during the study period is given in this section. The detailed results are presented by Yabuki *et al.* (1994).

Figure 6 shows annual variations in the ground temperature at the three sites from October 1992 to September 1993. Active layer depths at D100 and D105 where soil moisture conditions were comparatively dry were more than 80 cm depth, and that at the Wetland where a ground water table was usually near a soil surface was about 80 cm depth. The permafrost melted earlier at D100 than at D105. This is probably because the air temperature higher at the former site than at the D105. D105 was located about 200 m above D100.

Figure 7 shows the seasonal variations of the heat conductivity at D100, D105 and the Wetland from October 1992 to September 1993. Soil water was frozen during the winter season. The heat conductivity of ice at the temperature near 0 °C (2.2 $Wm^{-1}K^{-1}$) is about four times that of water at the temperature of 0 °C (0.566 $Wm^{-1}K^{-1}$), and the conductivity of a frozen soil layer is consequently larger than that of a melted layer under the same moisture condition. The rela-

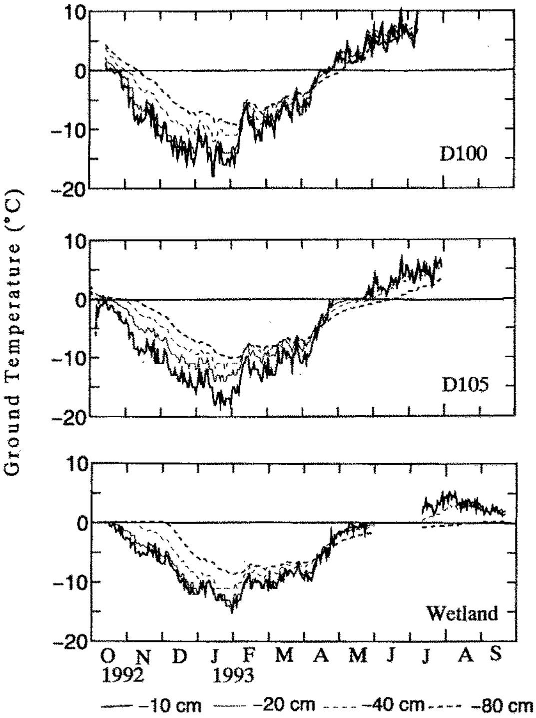

Fig. 6. Annual variations of the ground temperature at D100, D105 and Wetland.

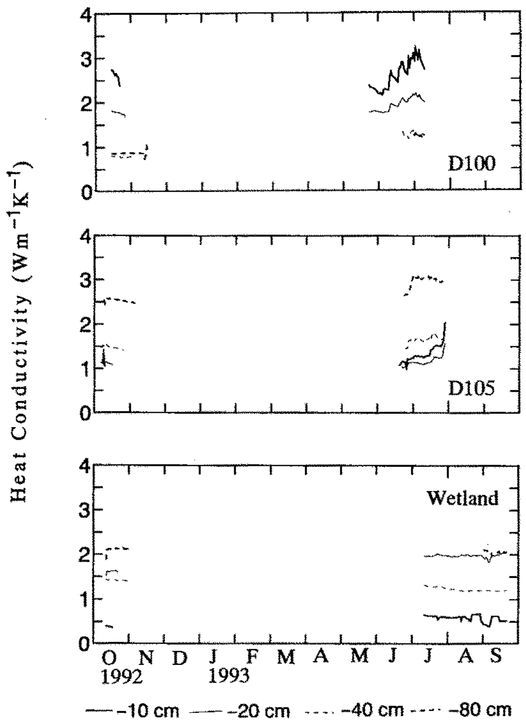

Fig. 7. Seasonal variations of the heat conductivity at D100, D105 and Wetland.

tion between the heat conductivity and the moisture content in the melted layer is considered to be different from that in the frozen one. The apparent heat conductivity of soil, besides, is fluctuated widely in a day by the effect of latent heat at the soil temperature near 0 °C. Thus, the variations of the heat conductivity for the summer season only are shown in Fig. 7.

As the soil moisture content increases, in general, so does the heat conductivity, but exact relations between the heat conductivity and the soil moisture content have not yet been obtained for the study sites. Seasonal variations of the soil moisture contents were therefore inferred from the heat conductivity measurements. Heat conductivities at D100 and D105 varied rapidly above 20 cm depth, and the soil moisture content increases towards midsummer. On the other hand, the soil moisture contents were kept at high through the summer season at the Wetland site, since variations of heat conductivities were very small.

4. Concluding remarks

Preliminary results obtained by the hydrological observations are as follows ;

1) Most of the run-off occurred from June to September, and percentages to the annual discharge were more than 85 % in all the watersheds.

2) Discharge decreased abruptly at the three watershed as the drop of air temperature and the decrease of precipitation occurred.

3) The glacial run-off affected the seasonal variation of the totalized discharge at the Small Watershed, and the inter-diurnal variation was controlled by the discharge from the soil layer.

4) Annual evapotranspiration was estimated to be about 45 % of the annual precipitation. This is only a crude estimate that is to be improved by considering the glacier mass balance effect.

5) Depths of active layers at dry fields and a wet field were more than 80 cm and about 80 cm, respectively.

6) Through the summer season, soil moisture content was low and varied quickly in the dry fields, whereas it was high and nearly constant values in the wet field through the summer season.

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