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Hydrological characteristics of Soler Glacier drainage, Patagonia.

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Abstract

Hydrological observations were carried out in the Soler Glacier drainage, eastern side of the Northern Patagonia Icefield. The discharge amount, water temperature, electrical conductivity and concentrations of dissolved substances were measured in the runoff river (the Cacho River) from Soler Glacier, from October 20 to December 8, 1985. The results showed that the Cacho River discharge was greatly affected by the ice ablation on Soler Glacier. The concentrations of dissolved substances in proglacial water systems were measured in Soler Glacier drainage. These chemical analyses suggested that the subglacial system was important for recognizing the composition ratio of dissolved substances in the Cacho River.

1. Introduction

Soler Glacier is an outlet valley glacier, on the eastern side of the Northern Patagonia Icefield. The total area of Soler Glacier is about 50.9 km^2 ; the areas of the accumulation and ablation zones are about 36.4 km^2 and 14.5 km^2 respectively (Aniya and Naruse, 1987). About 50% of the surface in the ablation zone was covered by debris. The Cacho River runs out from the glacier terminus, collecting not only the glacier water but also water from the ice free area.

Preliminary hydrological observations were made in the Cacho River from the middle of December 1983 to early January 1984 (Saito and Kobayashi, 1985). Hydrological information in mid-summer was collected. Longer-term hydrological observations were carried out in the Cacho River from October 20 to December 8, 1985, including chemical analyses of the proglacial waters around Soler Glacier.

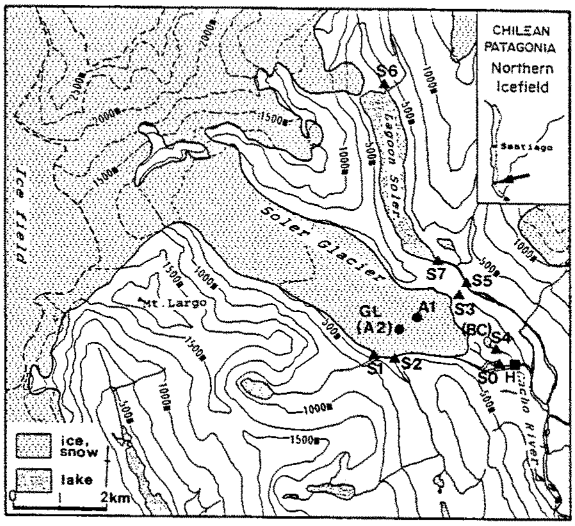

Fig. 1. Location of observation site.
H : discharge measurement site. S0 : water temperature and electrical conductivity measurement site. S0–S7 : water sampling site. A1 : ablation measurement site in debris-covered zone. GL(A2) : ablation measurement site in bare ice zone. BC : precipitation measurement site.

2. Observation sites and method

Figure 1 is a map of Soler Glacier and its surroundings. Granitic rock constitutes the major rock type around Soler Glacier. The mountains on the eastern side of Lagoon Soler consist mainly of schistic rock (Naruse and Endo, 1967). Moraine deposits exist in front of the terminus of Soler Glacier. The flat area where the Cacho River flows is the outwash plane (Aniya, 1985).

Observation sites are also indicated in Fig. 1. The Cacho River discharge was measured at site H, about 1.3 km downstream from the glacier terminus. The catchment area of the Cacho River at H is about 81.0 km^2, about 64% of which is ice-covered area. A float-type water gauge was set up at H for continuous measurement of river water level. The river cross section and vertical mean flow velocity were measured by current-meter at intervals of 1 m, when we could cross the river. When the water was high, the surface flow velocity was measured by float at intervals of 1 m across the river. The surface velocity was corrected to the depth-mean flow velocity by using the results of current-meter measurements. The obtained discharge, Q, was related to the river water level, h, as shown in Fig. 2.

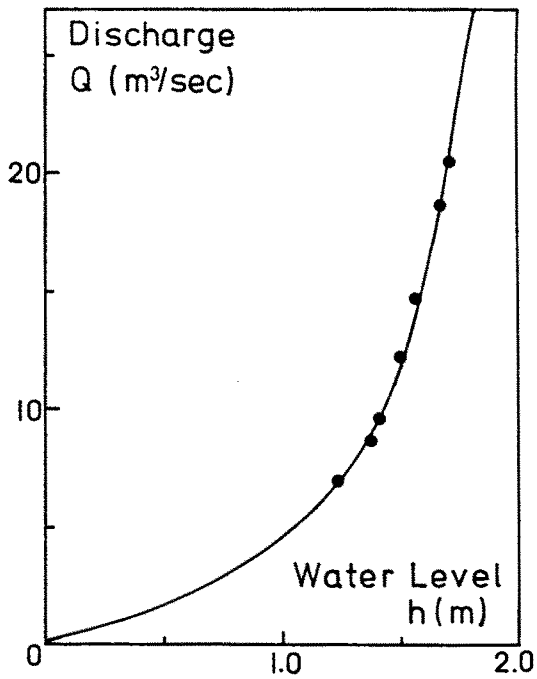

Fig. 2. Relation of discharge to river water level (stage-discharge curve)

Measurements of water temperature and electrical conductivity of the Cacho River were made at S0 site, about 1.0 km downstream from the glacier terminus. Water temperature was measured continuously by a thermistor thermometer. Water sampling for the Cacho River was done at S0.

To recognize the hydrological characteristics of the Soler Glacier drainage, waters were sampled at sites from S1 to S7 (see Fig. 1). Both S1 and S2 are sites of inlet rivers to Soler Glacier; S3 and S4, the upstream and downstream parts of the small stream in the terminal moraine, respectively; S5, the main branch of the Cacho River which runs from Lagoon Soler and the schistic rock area; and S6 and S7, the inlet and outlet of Lagoon Soler, respectively. Water temperature and electrical conductivity were also measured at the time of sampling. The pH and HCO_3^- concentration were measured *in situ*. The water samples were kept in pre-cleaned air-tight polyethylene bottles, and sent to Japan. The remaining analyses (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} and SiO_2) were conducted in the labolatory. The analysis method for each dissolved substance was listed in Table 1.

Table 1. Dissolved substance and method of analvsis

Substance	Method
Na^+, K^+	Flame spectrophotometry
Ca^{2+}, Mg^{2+}	Atomic absorption method
Cl^-, SO_4^{2-}	Ion chromatography method
HCO_3^-	Bromocresol purple alkality
Soulble SiO_2	Colorimetric analysis by molybdenum yellow

The meteorological observations and the ablation measurements on Soler Glacier were made in the same period. The detailed results are presented by Fukami *et al.* (1987), and Fukami and Naruse (1987).

3. Results

3. 1. *Variation of discharge in the Cacho River*

Figure 3 shows the variation of daily mean discharge in the Cacho River from October 20 to December 7, 1985, together with the daily ice ablation on the glacier and precipitation. Figure 4 shows 3-hourly variations of the discharge, water temperature and electrical conductivity in the river.

As noted in Figs. 3 and 4, the discharge variation can be largely divided into two periods. The first half period was characterized by small discharge amount and small diurnal variation, and the second half period by large discharge amount and large diurnal variation. The ablation amount also became large in the second half (see Fig. 3).

The influence of precipitation on the discharge is not clear in Fig. 3. Our observations were made from late spring to early summer. Air temperature was relatively low, so that precipitation at high altitude became snow. On the other hand, Saito and Kobayashi (1985) showed that the discharge amount was greatly

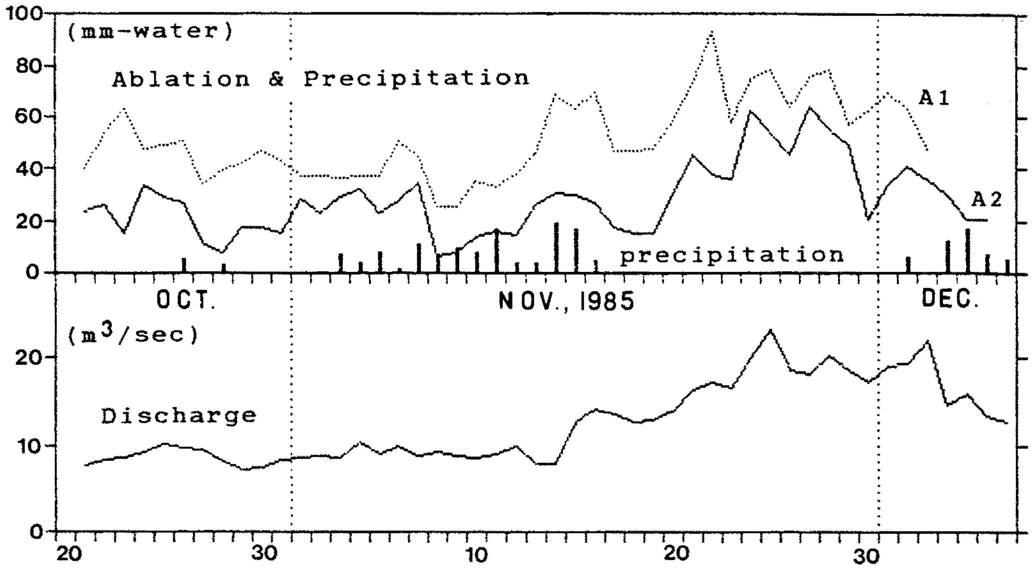

Fig. 3. Variation of daily mean discharge in the Cacho River, daily total ablation on Soler Glacier and daily total precipitation at BC.

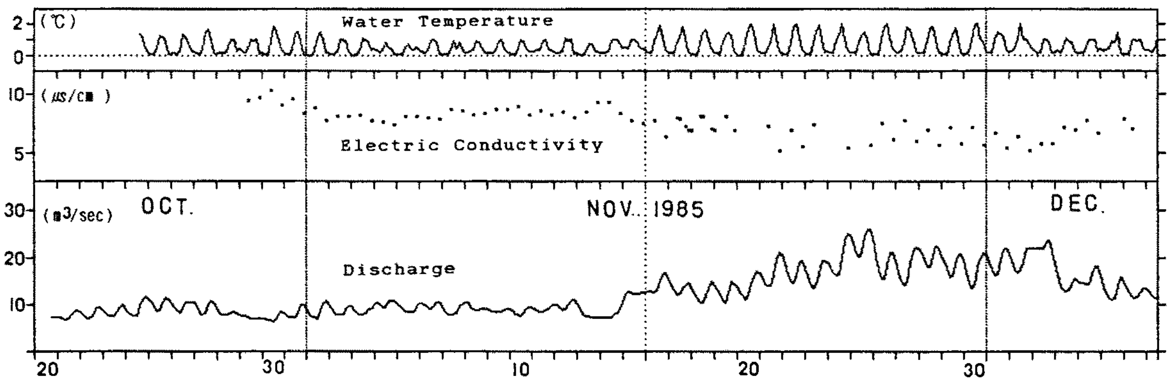

Fig. 4. 3-hourly variation of discharge, water temperature and electrical conductivity in the Cacho River.

affected by precipitation. This may be due to the higher air temperature in mid-summer, and the precipitation might be supplied by rain even at higher altitude.

The electrical conductivity should be affected by the discharge variation (Fig. 4). Then, the relation of the discharge amount to the electrical conductivity was examined, as shown in Fig. 5. The electrical conductivity is almost inversely propotional to the discharge. Since the electrical conductivity of the supraglacial water was 0.00 μS/cm, this inverse relation could be caused by an increase of supraglacial melt water in the discharge. Diurnal variation of the discharge in the Cacho River could be caused by ice ablation on Soler Glacier. The electrical conductivity became small in the second half of the observation period. It suggests that the rate of the supraglacial melt water to the Cacho River discharge increased in the second half.

There was a time lag between ice ablation on the glacier and the river discharge. Measurements on a supraglacial stream were made near GL(A2) in Fig. 1, to examine the time lag in the discharge. Figure 6 shows the hourly variations of water levels in two bore holes measured from the ice surface, and the discharge in the supraglacial stream, together with the discharge in the Cacho River. The catchment area of the supraglacial stream is about 4000 m^2. The weather was fine for the whole observation period, and the daily maximum values of global radiation were observed at about 14:00 L.S.T.

The water levels in bore holes and the discharge in the supraglacial stream started increasing at 7:00–8:00 L.S.T., immediately the global radiation insolated on the ice surface. The maximum discharge amounts in the supraglacial stream was seen at 12:00–15:00 L.S.T.; after that the discharge amount decreased rapidly with time. The ice body kept the higher water level in the afternoon. The variations of the supraglacial stream discharge and the water level almost followed the variation of ice ablation without time lag. On the other hand, the Cacho River discharge started increasing at about 12:00 L.S.T., and its maximum was seen at 18:00–22:00 L.S.T. The time lag of the maximum between ice ablation and the Cacho River discharge at H was estimated to be about 6 hours on fine days.

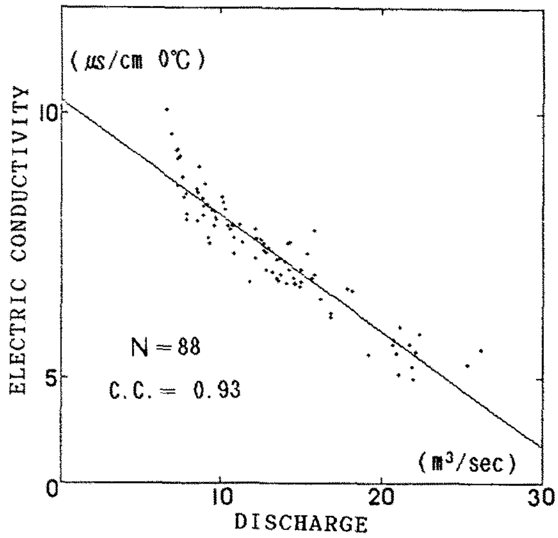

Fig. 5. Relation of discharge to electrical conductivity in the Cacho River.

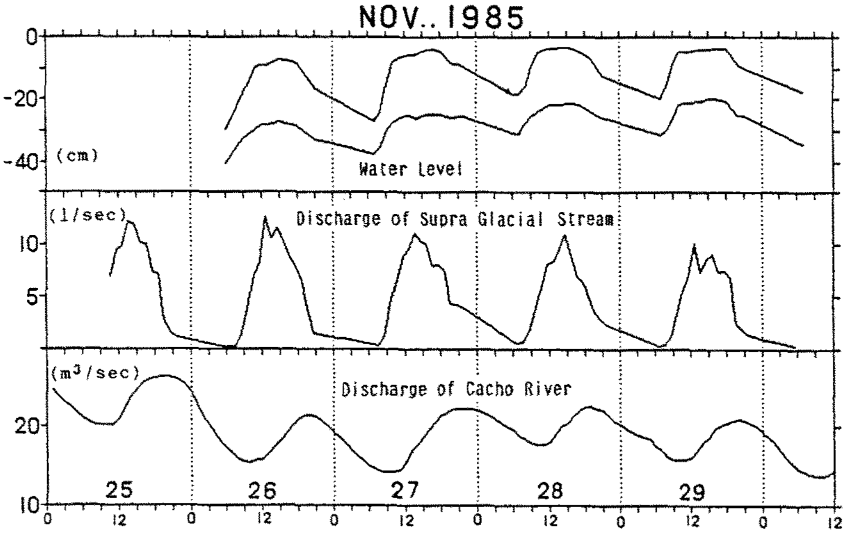

Fig. 6. Hourly variation of water level in surface ice body, discharge in supraglacial stream on Soler Glacier and discharge in the Cacho River, November 25–30, 1985.

3. 2. Dissolved substances in water

The results of chemical analyses are summarized in Table 2. The concentrations of dissolved substances were higher in the stream in the terminal moraine (S3 and S4), and lower in the Cacho River (S0) and the inlet river to Soler Glacier (S1 and S2). The composition ratios of the dissolved substances were different from site to site, as shown in Fig. 7. From the key diagram of Fig. 7, it was found that all of the waters in the Soler Glacier drainage could be classified into carbonate hardness types. The component ratio of dissolved substances in the main branch of the Cacho River (S5) was found to be different from those in other water systems by the key diagram. This can be ascribed to the different rock type in the mountains on the east side of Lagoon Soler.

The component ratio of dissolved substances in the Cacho River (S0) also differed from those in the surrounding watersheds. Since the supraglacial river

Table 2. Mean value of dissolved substance at each site.
Value in ( ) indicates standard deviation.

Site	Number	pH	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	HCO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	SiO_2 (mg/l)	EC-25°C (μs/cm)	Σ+ (epm)
S 0	41	6.5-6.8	0.38 (.077)	0.77 (.123)	1.59 (.287)	0.19 (.030)	7.51 (1.27)	0.26 (.054)	0.71 (.137)	2.51 (.365)	17.40	.151
S 1	4	6.6-6.7	0.40	0.24	1.63	0.11	7.93	0.44	0.30	2.21	15.46	.114
S 2	2	6.7-6.8	0.46	0.24	2.51	0.15	9.46	0.39	0.24	2.22	19.70	.163
S 3	5	6.7-6.8	0.84	1.78	6.85	0.49	21.7	0.50	3.31	8.21	46.08	.464
S 4	5	7.4-7.6	2.20	2.56	11.36	1.92	45.0	0.52	6.22	7.42	83.55	.886
S 5	5	7.0-7.1	0.53	1.04	6.20	0.81	18.7	0.31	3.89	2.20	44.62	.425
S 6	1	7.1	0.49	1.38	5.18	0.53	17.1	0.33	1.17	2.04	40.38	.358
S 7	2	7.0-7.1	0.44	1.10	4.31	0.58	15.9	0.41	1.29	2.23	34.82	.310

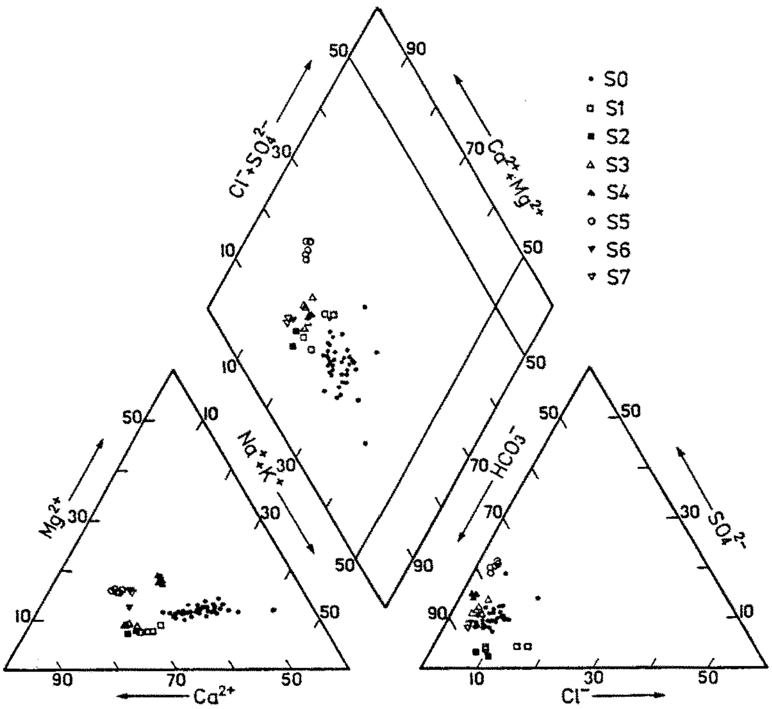

Fig. 7. Piper's diagram of Soler Glacier drainage.

had practically no dissolved substances, the water in the Cacho River could not be composed of only proglacial and supraglacial water systems. The composition ratio of dissolved substances in the Cacho River was characterized by rich K^+, compared with those in other water systems (see Table 2 and the triliner diagram of cations in Fig. 7). It is inferred that the subglacial system caused this by affecting the composition ratio of dissolved substances in the Cacho River.

4. Concluding Remarks

Hydrological observations were carried out from October 20 to December 8, 1985, in the Soler Glacier drainage. The discharge amount, water temperature, electrical conductivity and concentrations of dissolved substances were measured in the Cacho River, which runs out from Soler Glacier. The concentrations of dissolved substances in the proglacial water systems were also measured in the Soler Glacier drainage.

The discharge amount and diurnal variation became large in the second half of the observation period, owing to the large ice ablation on the glacier. The discharge variation in the Cacho River could be caused by ice ablation on Soler Glacier. The electrical conductivity variation of the Cacho River supported this, because the electrical conductivity was almost inversely propotional to the discharge. The time lag of the maximum between ice ablation and the Cacho River discharge was estimated to be about 6 hours on fine day.

The results of chemical analyses of waters indicated that the waters in the Soler Glacier drainage could be classified into carbonate hardness types. It was inffered that the composition ratio of dissolved substances in the Cacho River was affected by the subglacial systems.

In this paper, we did not discuss about the water balance of the drainage and the separation of glacier water from the Cacho River discharge. These will be presented in another paper. Some hydrological characteristics of the Soler Glacier drainage were revealed by two studies. Annual hydrological measurements will give us more useful information.

Acknowledgments

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Resumen

Características hidrológicas del escurrimiento del Glaciar Soler, Patagonia

Desde el 20 de Octubre al 8 de Diciembre de 1985 se llevó a cabo observaciones hidrológicas en la zona de desagüe del Glaciar Soler, margen oriental del Hielo Patagónico Norte. Los lugares de observación se muestran en la Fig. 1. En la estación H se midió el gasto del Río Cacho. En S0 se midió la temperatura del agua y conductividad eléctrica del río. Para individualizar las sustancias que se encuentras disueltas en agua en la zona, se recolectó muestras de agua en las estaciones S0 a S7.

La Figura 3 muestra la variación del caudal medio diario en el Río Cacho, junto con la ablación diaria de hielo sobre el glaciar y la precipitación. La Figura 4 muestra los valores cada tres horas del gasto, temperatura del agua y conductividad eléctrica del río. La relación entre el gasto y la conductividad eléctrica se examina en la Fig. 5. Al observar estas figuras se sugiere que la variación del gasto del Río Cacho depende en gran medida de la ablación de hielo del Glaciar Soler. El tiempo de desfase entre máximos de ablación de hielo y gasto del río se estimó en unas 6 horas (Fig. 6).

En la Tabla 2 se presenta un resumen de los resultados de los análisis químicos. La razón de composición de sustancias disueltas fue diferente en cada estación, tal como se muestra en la Fig. 7. Esta razón también difirió entre el Río Cacho y el sistema hídrico circundante, estimándose que el efecto del sistema subglacial sería importante al respecto.