Report 7

Heat balance on Soler Glacier

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Abstract. In the summer of 1983, a short term heat balance was studied on Soler Glacier, the Patagonia Northern Icefield. To calculate the terms of the heat balance equation, various meteorological measurements were done on the glacier. Downward short-wave radiation and the albedo of the glacier were measured independently by use of two pyranometers. The albedos of bare ice and moraine-covered ice were 31% and 9.8%, respectively. The global radiation changed between 5.8 MJ/m^{2}d (138 ly/d) and 33.3 MJ/m^{2}d (794 ly/d), and the daily mean value was 22.6 MJ/m^{2}d (539 ly/d). The ablation was measured by the stake method and its values in the lower part of the glacier were between 14 and 6 cm/day, and a mean value was 13.1 cm/day in ice thickness.

Among the energy required to give the observed melting of the ice, the net radiation over all wavelengths contributed 27%, the latent heat 27%, and the sensible heat a large 46%. When Föhn phenomenon occurred above Soler Glacier, the sensible heat flux remarkably increased. The high turbulent term (sum of sensible and latent heat) at Soler Glacier is probably due to the occurrence of Föhn which is accompanied with strong wind and high temperature.

1. Introduction

Heat balance studies on glacier surfaces are very important in understanding climates and local climatic differences. No systematic study of the glacial heat balance in the Patagonia Northern Icefield has ever been carried out. Therefore, in summer 1983 a short-term heat balance investigation was carried out on Soler Glacier in that region.

The instrumentation used in this investigation is described in Report 5.

2. Heat fluxes at glacier surface

The heat fluxes at the glacier surface were calculated hourly and summed for half-day periods (9–20 and 20–9 hr). As the glacier is a "temperate glacier", there is no heat flux into or out of the glacier ice. Therefore the heat balance equation at the glacier surface can be written as follows:

$$N_S+N_L+S+L+V+M=0 \qquad (1)$$

where N_S is shortwave radiation balance, N_L long wave radiation balance, S sensible heat flux, L latent hear flux, V heat transport by precipitation, and M heat used in melting ice. All fluxes towards the surface were considered to be positive, while those away from the surface were considered to be negative.

2.1. Shortwave radiation balance

Downward shortwave radiation ($SW\downarrow$) and albedo were measured independently. Reflected shortwave radiation ($SW\uparrow$) was calculated using spot measurements of albedo (a) as $SW\uparrow = aSW\downarrow$. Then, the shortwave balance $N_S = (1-a)\,SW\downarrow$ was calculated.

The mean value of albedo was 31 % on bare ice and 9.8 % on debris-covered ice surfaces. The global radiation changed between 5.8 MJ/m²d (138 ly/d) and 33.3 MJ/m²d (794 ly/d); the daily mean value was 22.6 MJ/m²d (539ly/d).

2.2. Longwave radiation balance

To measure the radiation balance over all wavelengths a net radiometer (EKO CN-11) was initially placed on the glacier; however, it was relocated to the base camp located in the old end moraine area because it was difficult to keep the instrument horizontal. Therefore, the sum of the longwave balance was obtained as the remainder of the heat balance equation.

As data of net raditation above the glacier were obtained by a net radiometer on December 19, 1983 (Fig. 1), we can compare with the value of remainder of the heat balance equation. Figure 1 shows the hourly variation of net radiation (NR), shortwave balance (N_S) and longwave balance (N_L). The longwave balance was −9.6 MJ/m²d (229 ly/d) while the value of longwave balance as the remainder of the heat balance equation was −8.1MJ/m²d (193 ly/d) in a half day. As shown in Figure 1 the observed longwave balance in night time was taken to be zero, therefore, both agreed with each other.

2.3. Sensible heat flux

The flux was calculated using the following equation:

$$S = \rho C_p k U_* \frac{T_2 - T_0}{\ln(Z_2/Z_0)} \tag{2}$$

where ρ is the density of air, C_p the specific heat of air under constant pressure, k von Karman constant equal to 0.4, U_* the friction velocity, T_2 and T_0 are air temperatures at height Z_2 (= 1.5 m) and Z_0 the roughness length. The values of Z_0 and U_* could be determined from

$$\overline{U}_z = \frac{U_*}{k} \ln\frac{Z}{Z_0} \tag{3}$$

where $\overline{U}_z$ is the mean wind speed at a height Z. Therefore, vertical profiles of wind speed

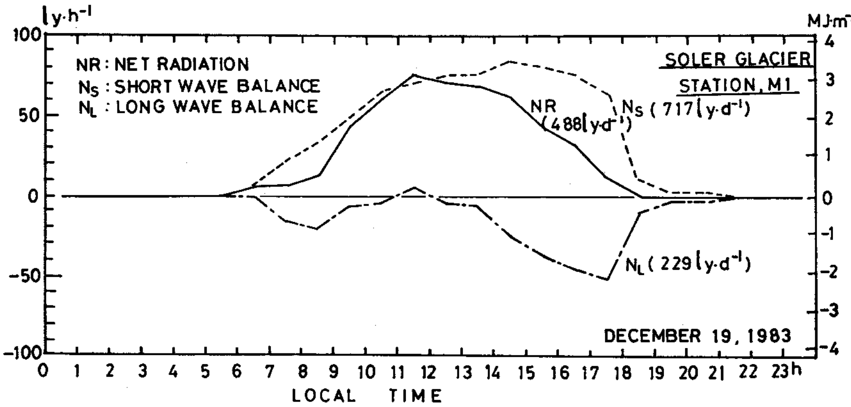

Fig. 1. Hourly variation of radiative balances, December 19, 1983.

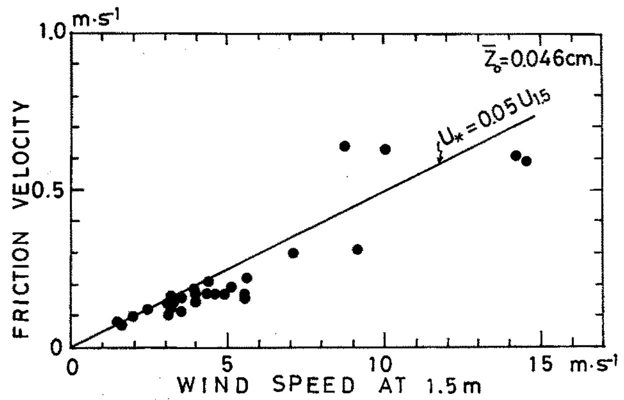

Fig. 2. Friction velocity as function of wind speed at 1.5 m height.

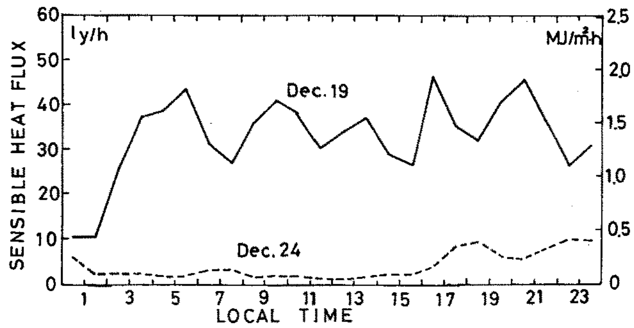

Fig. 3. Comparison of the sensible heat flux between Föhn (December 19) and non-Föhn (December 24) conditions.

above the ice surface were measured at three heights, 25, 50 and 150 cm. Most of the wind profiles were logarithmic. From these data of wind speed profile, the relation between the friction velocity and the wind speed at 1.5 m was obtained as shown in Figure 2; i.e. $U_* = 0.05U_{1.5}$. Also the mean value of Z_0 was 0.046 cm for melting conditions. On the other hand, the air temperature at Z_0 was assumed to be 0°C, i.e. the surface temperature for melting ice.

Sometimes the Föhn occurred on the glacier in which the wind speed and the air temperature increased, so that the sensible heat flux remarkably increased. For example, Figure 3 shows the variations of hourly heat flux in Föhn and non-Föhn conditions.

2.4. Latent heat flux

Latent heat flux was calculated in the same manner as for sensible heat flux. The equation is given by

$$L = \rho l k U_* \frac{e_2 - e_0}{\ln(Z_2/Z_0)} \cdot \frac{0.622}{p} \qquad (4)$$

were l is latent heat of condensation or evaporation equal to 250 J/g (597 cal/g), e_2 and e_0 are water vapor pressures at Z_2 and at the ice surface respectively. Thus, using the values of temperature and relative humidity measured at known heights above the surface the latent heat flux can be calculated.

Figure 4 shows the variation in the mean daily values of water vapor pressure. As the sur-

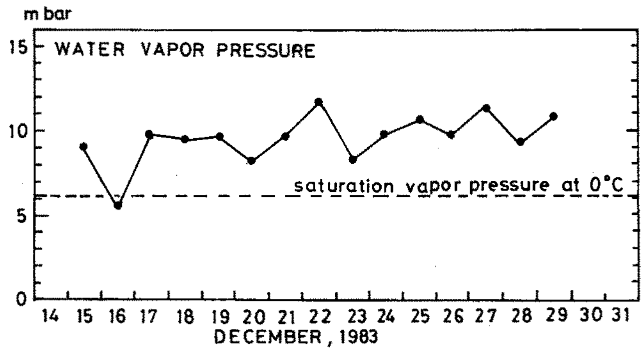

Fig. 4. Daily variation of water vapor pressure.

face was always melting the temperature was always 0°C. Positive latent heat transport (condensation) was predominant through the observational period; the only period of evaporation occurred on December 16.

2.5. Melting of ice

Ablation was measured by the stake method. The daily amounts of ablation in the lower part of the glacier were changed from 14 to 6 cm of ice, and a mean value was 13.1 cm of ice. The average over the whole glacier was 9.8 cm of ice. As the ice density is 900 kg/m^3, the energy required for melting the amount of 9.8 cm of ice is 706 cal/cm^{2}day.

2.6. Heat transport by precipitation

Heat transport due to precipitation is small. The total precipitation in the form of rain was 131.2 mm for the 22-day period. The average air temperature for that period was around 7.5°C, so the heat transport to the glacier surface due to rainfall can be considered to be 4.2 cal/cm^{2}day. So this term was also neglected.

3. Heat balance at glacier surface

The heat balance on a daily day-time basis and the mean percentage components are shown diagrammatically in Figure 5. In Table 1, the components of the balance are also shown as mean daytime, mean nighttime, and daily values; the percentage components of both sources and sinks are also given. The percentage components of the heat balance shown in Table 1 are different values from those on San Rafael Glacier (see Report 6), where the radiative component was 50 %, the sensible 36 %, and the latent 16 %. Therefore, on the eastern glacier of the icefield the sensible heat is a more important factor to ablation compared with the western glacier of the icefield.

Table 1. Components of the heat balance, Soler Glacier, December 15–29, 1983.

	Average daytime (09–20 h)			Average nighttime (20–09 h)			Average daily		
Components	ly	MJm^{-2}	%	ly	MJm^{-2}	%	ly	MJm^{-2}	%
Radiation balance	193	8.0	43	−25	−1.0	−13	168	7.0	27
Sensible heat flux	172	7.1	38	114	4.7	58	286	11.9	46
Latent heat flux	87	3.6	19	84	3.5	42	171	7.1	27
Ablation (stakes)	−452	−18.8	−100	−173	−7.2	−87	−625	−25.9	−100

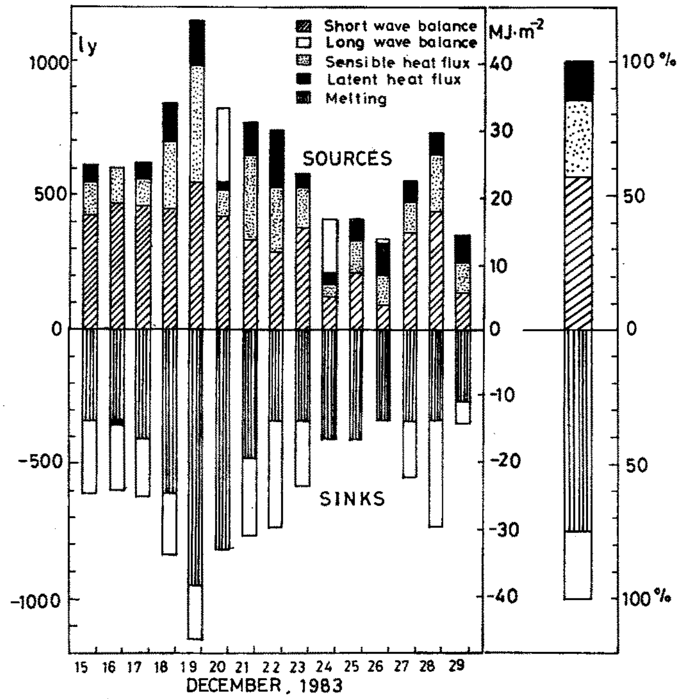

Fig. 5. Components of daytime (09–20 h) heat balance over ice surface, December 15–29, 1983.

Also the component percentage values may be compared with those found from observations by Wendler and Ishikawa (1973) for 11 days on McCall Glacier in Alaska, U.S.A. (lat. 69°18'N, long. 143°48'W), who found the radiative component to be 68.9%, sensible 30.3% and latent 0.8%.

4. Concluding remark

The results of the heat balance and the ablation will be compared with the discharge of Cacho River (see Report 9). The contrast in the meteorological conditions in the western (San Rafael Glacier) and eastern side (Soler Glacier) was discussed (Report 8). In this report the amount of ice melt obtained by stake measurements on the glacier was only compared with heat balance calculations.

Occasionally the Föhn occurred on the glacier in which the wind speed and air temperature increased, causing the considerable increase of the sensible heat flux.

About 50% of the surface area of Soler Glacier is covered by debris, with the remainder consisting of bare ice surface. In the present analysis, the differences in ablation and albedo at two surfaces were not discussed. Therefore, further study has to be continued to determine the differences in the meteorological elements at the debris-covered and bare ice surfaces.

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Reference

WENDLER, G. and ISHIKAWA, N. (1973): Experimental study of the amount of ice melt using three different methods: a contribution to the international hydrological decade. J. Glaciology, **12**, 399–410.

Resumen. Balance energético en el Glaciar Soler

Se efectuó un estudio del balance energético en el Glaciar Soler durante el período del 12 de Diciembre de 1983 al 2 de Enero de 1984. Para calcular los términos de la ecuación del balance energético, se efectuaron diversas mediciones meteorológicas en la lengua de hielo a la cota de 400 m. Radiación incidente de onda corta y albedo del glaciar se midieron independientemente utilizando dos prianómetros. Los albedos del hielo puro y del hielo cubierto por morrenas fueron 31 % y 9,8 %, respectivamente. La radiación global varió entre 138 y 794 ly/día, y el valor diario medio fue 539 ly/día.

También la ablación fue medida con el método de estacas. La ablación en el frente del glaciar fue entre 14 y 6 cm/día en hielo, con un valor medio de 13,1 cm/día.

Ocasionalmente ocurrió el fenómeno de "Föhn" sobre el glaciar. En este caso se incrementó la velocidad del viento y la temperatura del aire, de manera que el flujo de calor sensible aumentó considerablemente. Aún más, el flujo de calor latente siempre contribuyó a la condensación a través de todo el período de observación, vale decir, acelerando la fusión del hielo.

Por ejemplo, en el caso de ocurrencia de "Föhn", los porcentajes de fuentes de calor, como calor sensible, radiación neta y calor latente fueron 53, 32 y 15 %, respectivamente. Por otra parte, en días nublados (sin "Föhn"), ellos fueron 38, 39 y 23 % respectivamente.

Como pérdida de calor, la cantidad promedio de ablación de las dieciséis estacas fue de 8,1 cm de hielo durante el día, 1,7 cm de hielo durante la noche y 9,8 cm de hielo para el día y la noche.