Report 8

The east-west contrast in meteorological conditions and its effect on glacier ablation

TETSUO OHATA
Water Research Institute, Nagoya University, Nagoya, 464 Japan
SHUN'ICHI KOBAYASHI
Institute of Low Temperature Science, Hokkaido University, Sapporo, 060 Japan
HIROYUKI ENOMOTO
Graduate School of Environmental Sciences, Tsukuba University, Ibaraki, 305 Japan
HIROSHI KONDO, TAKASHI SAITO and CHOTARO NAKAJIMA
Disaster Prevention Research Institute, Kyoto University, Uji, 611 Japan

Abstract. Glaciers are large on the western side and small on the eastern side of the Patagonia Northern Icefield. This is due to differences in topographical and meteorological conditions. The contrast in the meteorological conditions in the western (San Rafael Glacier) and eastern side (Soler Glacier) is due to three main factors. One is the difference in cloud distribution and related meteorological elements due to the orographic effect of the mountains on the westerly circulation. Second is the existence of an almost permanent glacier wind. Last is the occurrence of strong wind considered to be Föhn in the eastern side. The amount of surface melting (ablation) was greater by 50% in the ablation area of Soler Glacier. As for the heat source for the melting of ice the net radiation is an important factor on both sides, but the difference in the heat supplied to the glacier surface on the western and eastern side depends on the turbulent terms (sensible heat and latent heat) not on the radiation terms. The large turbulent terms on the Soler Glacier are probably due to the occurrence of Föhn winds.

1. Introduction

The climate of Patagonia Icefield is characterized by the strong influence of mountain ranges running north-south against the Southern hemisphere westerlies. As a result, differential distribution of cloud cover and related meteorological elements occur within and around the icefield. These climatological conditions have great influence on the condition of the icefield and the distribution of the glaciers.

In an inventory of this Northern Icefield (VALDIVIA. 1979), it is written that there are 244 glaciers, and 1195 sq. km are covered with ice and snow. In this inventory, nothing is reported on the distribution of the equilibrium line or transient snow line. From the present observations in December 1983, transient snow lines approximately were 1000 m on San Rafael Glacier and 1500 m on Soler Glacier. The snow lines were 500 m lower on the west side. The lengths of glaciers are generally longer on the west side (e.g., San Rafael Glacier, San Quintin Glacier) and shorter on the east side (e.g. Soler Glacier, Neff Glacier). Among the factors determining the difference in length of the glacier, landform is one important factor. In the Northern Icefield, a large accumulation basin faces westward, so large glaciers can be formed on the west side. Second is the climatological factors which will also have an influence. However these two factors cannot be easily separated. The difference in the climatological conditions is a result of the landform in this region. On the other hand the landform may be the result of the long term (millions of years or longer) differential development of glaciers due primary to climatological characteristics. These two factors are interrelated to each other in the long-time scale, but in the short-time scale, landform can be considered to be a fixed factor.

In this paper, the east-west contrast in the meteorological conditions which occurred mainly due to the topographical conditions, will be shown, and its effect on the ice melting in the ablation area of the glaciers will be discussed.

2. Characteristics of weather on the icefield

Weather conditions related to the mass balance of the glaciers are characterized by three main phenomena.

The passing of the trough centered around 50 to 60° S latitude and development of the mid-latitude high pressure system have the main influence in the variation of the weather here (Report 3). The influence of these can be seen clearly in the distribution of clouds and rainfall and other related meteorological elements.

The second interesting phenomenona is the glacier wind (Report 4) which is localized in the atmospheric boundary layer above the glacier. This has no effect on the larger scale atmospheric condition, but its effect on heat transport to the glacier surface is considered important. The frequency of the glacier wind on San Rafael Glacier is high (Report 4) and probably also on Soler Glacier. The main reason for the existence of this localized wind is the high ambient air temperature.

The third phenomenon is a strong wind at the east side of the icefield on Soler Glacier (Report 5). These winds were not observed on San Rafael Glacier, and it is thought to be a Föhn phenomenon. The local occurrence of this type of wind affects the surface air temperature, humidity and wind speed conditions.

3. Comparison of meteorological elements

Meteorological elements at observation sites MS and UC1-3 (Map 2, see front page) on San Rafael Glacier and M1 and BC near the terminus of Soler Glacier (Report 5) was compared (Table 1). These two sites at Soler were close to each other and will be denoted as SL

Table 1. Comparison of meteorological elements at three sites in the Northern Icefield, MS and UC1-3 at San Rafael Glacier and SL in Soler Glacier.

Meteorological elements	Site			
	San Rafael		Soler	
	MS	UC	SL	Period
Cloud amount	8.6	8.6	5.3	Dec. 12–28
Precipitation amount	192.5 mm	242.0	131.2	Dec. 12–28
Global radiation	108–685 ly/d		138–794	Dec. 12–Jan. 1
mean	327		539	
Air temperature	6.1–17.5°C		3.5–17.1	Dec. 12–Jan. 1
mean	10.9		8.6	
Wind speed	2.3 m/s		3.1	Dec. 13–Jan. 1
Relative humidity	67%		56	Dec. 16–Jan. 1 (16 days)

together. The periods which were taken for the statistics vary little among the elements. The amounts of cloud cover are 8.6, 8.6 and 5.4. The cause of these differences is given in Report 3. Precipitation amount showed a maximum at UC. The ratios at the three sites were 1:1.3:0.7; little rain on the eastern side. Much rain in the west is the result of the above mentioned cloud distribution which is primarily due to the orographic effect. The range of global radiation showed similar values at MS (San Rafael) and SL (Soler). However, the mean values were 13.7 MJ/m²d (327 ly/d) and 22.6 MJ/m²d (539 ly/d) respectively, meaning that at MS it is 60% of that at SL. The extreme low and high values occurred on days of low cloud distribution on both side of the icefield (type 1 in Report 3) and high cloud distribution on both side of the Icefield (type 3) respectively. Due to high frequency of the intermediate type 2, the mean values differed greatly. Comparing sites MS and SL, slightly higher air temperature, lower wind speed and higher relative humidity were observed at MS. High wind speed at SL is due to the occurrence of a strong wind which is thought to be a Föhn.

4. Heat balance on the glacier surface

The differences in meteorological conditions strongly influence differential development of glaciers through both accumulation and ablation. As the present observations were made in the ablation area in the ablation season, the effect of meteorological conditions on ice melting will be discussed. These effects can be evaluated through the heat balance on the glacier surface. The heat balance study at both glaciers is reported in Reports 6 and 7. The observation period differed at these two sites, December 29 to January 1 on San Rafael Glacier and December 15 to 29 on Soler Glacier. The observation period on Soler was long enough to show nearly the mean condition in December. Average values of wind speed, air temperature, relative humidity, solar radiation and cloud amount during the four days of observations on San Rafael were 3.0 m/s, 9.9°C, 14.1 MJ/m²d (337 ly/d), 66% and 9.5 respectively. Comparing these values with averages for the latter half of December (Table 1), wind speed was higher, air temperature lower and global radiation, relative humidity and cloud amount were approximately the same. No large difference was seen between these four days and the mean values.

Heat balance components were derived differently on San Rafael and Soler in Reports 6 and 7. Each component was derived independently on San Rafael, but on Soler, net longwave radiation was derived as residue. The San Rafael data were recalculated in the same manner as for Soler, and the result at both sites in daytime (09–20 h) when ablation is pre-

Table 2. Comparison of heat balance components in the ablation areas of San Rafael and Soler Glacier. The values shown are mean daytime (09–20 h) values in MJ/m² and in ly (in parentheses). The percentages of components in the heat source are also shown.

	San Rafael		Soler	
Components	MJ/m² (ly)	%	MJ/m² (ly)	%
Net shortwave radiation (a)	9.5 (226)		14.4 (344)	
Net longwave radiation (b)	−1.9 (−46)		−6.3 (−151)	
Net radiation (a)+(b)	7.5 (180)	58	8.1 (193)	43
Sensible heat flux (c)	3.9 (93)	30	7.2 (172)	38
Latent heat flux (d)	1.5 (37)	12	3.6 (87)	19
Heat for melting of ice	−13.0 (−310)		−19.9 (−452)	
Net turbulent flux (c)+(d)	5.4 (130)		10.8 (254)	
Albedo of surface	0.26		0.30	

dominant is shown in Table 2. The heat flux fowards the surface is taken as positive. As the surface albedos on San Rafael and Soler had nearly the same value, 0.26 and 0.30 respectively, the difference can be neglected. The net shortwave radiations were 9.5 and 14.4 MJ/m^2 (226 and 344 ly) showing a higher value on Soler. Net longwave radiation was -1.9 and -6.3 MJ/m^2 (-46 and -151 ly) respectively, resulting in similar values of 7.5 and 8.1 MJ/m^2 (180 and 193 ly) for the net radiation on San Rafael and Soler. This means that although the cloud amount is less at Soler, increase in net shortwave radiation is compensated for by decrease in incoming longwave radiation. Outgoing longwave radiation should remain the same due to constant surface temperature. The turbulent terms, that is the sum of sensible and latent heat flux, were 5.4 and 10.8 MJ/m^2 (130 and 259 ly) on San Rafael and Soler, or twice as large on Soler. This is probably due to the fact that the turbulent term is proportionate to the square of wind speed, which was stronger at Soler due to the Föhn winds. The relative role of the heat sources shows a different tendency than we expected. The relative role of net radiation is larger on San Rafael where it is cloudy. The higher melting rate (approximately 1.5 times more) on Soler is produced by the high turbulent terms, not the radiation terms.

5. Concluding remarks

The difference in meteorological conditions and heat sources for ice melting on the western and eastern side of the icefield have been clarified. The difference in ice melting seems to be due to strong winds considered to be Föhn winds. These winds increase the turbulent heat transport to the glacier surface. These strong winds are the result of the air flow above mountain ridges 2000–3000 m a.s.l. running north-south. The easterly local glacier wind component on San Rafael may oppose the large scale westerly wind and maintain rather constant small turbulent heat transfer to the surface. Soler probably has such a glacier wind system, but it is often destroyed by the strong Föhn winds, increasing heat transport to the surface. This glacier wind has strong influence on ablation but it is not connected to the difference in the ablation rate at both glaciers. In the present analysis, ablation was not discussed as a mean value over the ablation area but only at certain sites with similar value of albedo. Further analysis must be done if the present conclusion is to be extended to the whole ablation area.

As for the results from the present observations, the contrast in cloud distribution on the eastern and western sides has no significant effect on ice melting at the glacier surface. The main cause is the wind system. However, the areal difference in cloud distribution and related meteorological elements certainly affect the accumulation part of the glacier mass balance. These will be discussed in another paper.

Resumen. El contraste este-oeste en las condiciones meteorológicas y su efecto en la ablación de los glaciares

Los glaciares son extensos al lado oeste y pequeños al lado este de la banquisa norte de la Patagonia. Esto se debe a las diferencias en las condiciones topográficas y meteorológicas. El contraste de condiciones meteorológicas entre los lados oeste (Glaciar San Rafael) y este (Glaciar Soler) se debe a tres factores principales. Uno es la diferencia en la distribución de

nubes y los elementos meteorológicos relacionados debido al efecto orográfico de las montañas de la circulación oeste. El segundo factor es la existencia casi permanente de viento en los glaciares. El último factor es la ocurrencia de vientos Föhn en el lado este. La superficie derritiéndose (ablación) fue mayor en un 50% en el área de ablación del lado del Glaciar Soler. En lo que respecta a la fuente de calor para derretir el hielo, la radiación neta es un factor importante en ambos lados, pero la diferencia en el calor suministrado a la superficie del glaciar en los lados este y oeste depende de las condiciones de turbulencia (calor sensible y calor latente), no de las condiciones de radiación. Las grandes condiciones de turbulencia en el Glaciar Soler se deben probablemente a la ocurrencia de los vientos Föhn.