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AN EXPERIMENTAL STUDY OF CLIMATE AND ABLATION AT THE EQUILIBRIUM LINE OF DONGKEMADI GLACIER, TANGGULA MOUNTAINS, QINGHAI-XIZANG PLATEAU

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With 8 figures

ABSTRACT

Climatic features at the equilibrium line altitude on Dongkemadi Glacier in the Tanggula Mountains, Qinghai-Xizang Plateau, were analyzed from automatic observations including snow depth data at an altitude of 5600 m a.s.l., from May 1992 to April 1993. The energy budget was calculated, and its relationship to the measured mass balance is discussed.

KLIMA UND ABLATION AN DER GLEICHGEWICHTSLINIE DES DONGKEMADIGLETSCHERS IM TANGGULAGEBIRGE

ZUSAMMENFASSUNG

Am Dongkemadigletscher (Tanggulagebirge, Qinghai-Xizang-Plateau) wurden von Mai 1992 bis April 1993 automatische Klimabeobachtungen durchgeführt. Die Höhe von 5600 m wurde durch Massenbilanzmessungen als Höhe der Gleichgewichtslinie ermittelt. Die Energiebilanz wurde berechnet und ihre Beziehung zur Massenbilanz diskutiert.

INTRODUCTION

Dongkemadi Glacier is located in the middle of the Tanggula Mountains in the central region of the Qinghai-Xizang Plateau (33°02 N, 90°02 E, see fig. 1) and is the headwater of Dongkemadi River. It is a valley glacier with an area of 16.4 km^2; its maximum length is 5.3 km; the mean equilibrium line altitude is at 5600 m a.s.l.

The automatic meteorological and energy budget observations were carried out on the glacier surface close to the equilibrium line altitude. From May 1992 to April 1993 the following data were recorded at hourly intervals: air temperature; wind speed and wind direction; radiation; surface temperature and snow depth.

From these data the climatic features, and the heat exchange were analyzed and the mass balance at the equilibrium line altitude was estimated.

THE CLIMATIC FEATURES AT THE EQUILIBRIUM LINE ALTITUDE

The seasonal course of monthly mean air temperature, vapour pressure and wind speed at the equilibrium line altitude on the surface of Dongkemadi Glacier from May 1992 to April 1993 is shown in fig. 2. The annual mean air temperature is –9.8 °C and the annual air

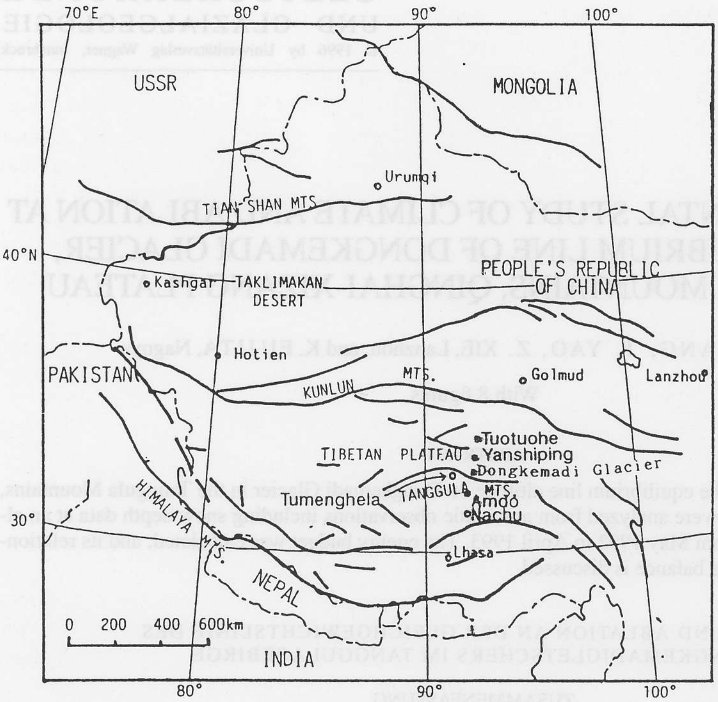

Fig. 1: Location of study area

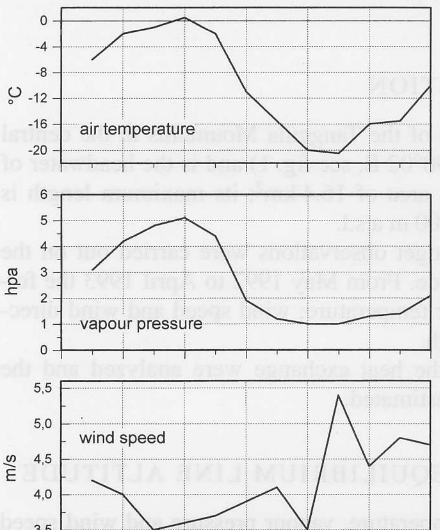

Fig. 2: The seasonal variation of air temperature, vapour pressure and wind speed on the glacier at equilibrium line altitude

temperature range is 20.9 °C; the absolute maximum of air temperature is 3.5 °C and the absolute minimum is –26.3 °C; the warmest month is August with temperatures slightly higher than 0 °C; there are only 21 days with mean temperatures above 0 °C, the annual accumulated positive temperature sum is 44.3 °C, so there is little melting at our observation point.

The seasonal variation of monthly mean vapour pressure is quite similar to that of temperature, the maximum monthly mean vapour pressure is 5.4 hPa in August; the annual mean is 2.6 hPa; the difference of vapour pressure between daytime and nighttime in different seasons is shown in Table 1.

Table 1: The changes of vapour pressure between daytime and nighttime at the equilibrium line altitude of Dongkemadi Glacier

	Vapour pressure (hPa)			
	mean daily range	mean daytime value	mean nighttime value	mean difference
January	0.4	1.0	0.8	0.2
April	0.7	2.0	1.6	0.4
July	1.5	4.9	4.3	0.6
October	1.1	4.2	3.8	0.4

The maximum monthly mean wind speed occurred in winter (January), but the wind was much weaker during the glacier melting period. Average curves of daily course of wind speed for different seasons are shown in fig. 3, with sharp changes in winter (January) and gentle changes in summer. Stronger winds were observed in the early and late evening hours in all seasons.

From the analysis of wind direction and the local topography of the glacier it is obvious that the mountain valley wind is the main circulation system above the glacier. Seasonal variation of valley and mountain wind frequencies are shown in fig. 4 together with the seasonal wind speed variations. The valley breeze is stronger and more frequent from January to February; valley breeze and mountain breeze are similar in May and June; the mountain breeze is stronger and more frequent in October and November.

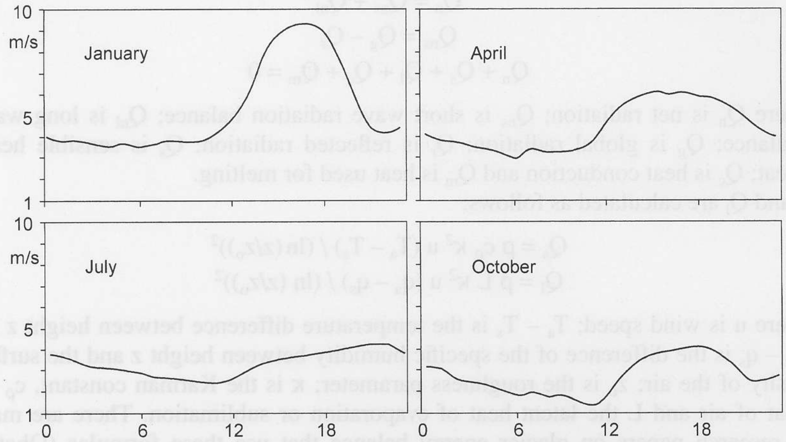

Fig. 3: Mean daily wind speed variation for January, April and October

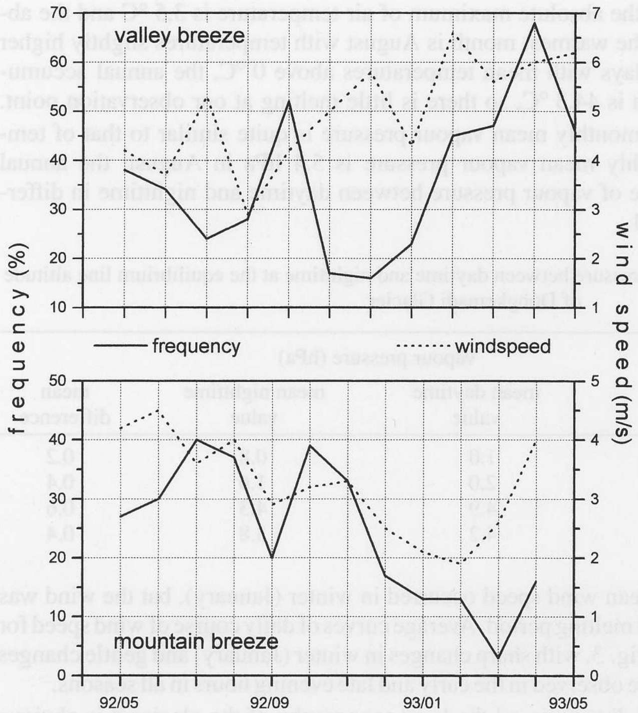

Fig. 4: The distribution of valley breeze and mountain breeze

ENERGY BALANCE AT THE EQUILIBRIUM LINE ALTITUDE

For every glacier surface, the energy balance can be described by the following formulas:

$$Q_n = Q_{ns} + Q_{nl} \tag{1}$$

$$Q_{ns} = Q_g - Q_r \tag{2}$$

$$Q_n + Q_s + Q_l + Q_c + Q_m = 0 \tag{3}$$

Where Q_n is net radiation; Q_{ns} is short wave radiation balance; Q_{nl} is long wave radiation balance; Q_g is global radiation; Q_r is reflected radiation; Q_s is sensible heat; Q_l is latent heat; Q_c is heat conduction and Q_m is heat used for melting.

Q_s and Q_l are calculated as follows:

$$Q_s = \rho\, c_\rho\, \kappa^2\, u\, (T_a - T_s) / (\ln(z/z_o))^2 \tag{4}$$

$$Q_l = \rho\, L\, \kappa^2\, u\, (q_a - q_s) / (\ln(z/z_o))^2 \tag{5}$$

Where u is wind speed; $T_a - T_s$ is the temperature difference between height z and surface; $q_a - q_s$ is the difference of the specific humidity between height z and the surface; ρ is the density of the air; z_o is the roughness parameter; κ is the Karman constant, c_ρ the specific heat of air and L the latent heat of evaporation or sublimation. There are many successful research papers on glacier energy balance that use these formulas (Ohata et al., 1989; Braithwaite, 1981; Kuhn, 1979; Wendler et al., 1974, among others).

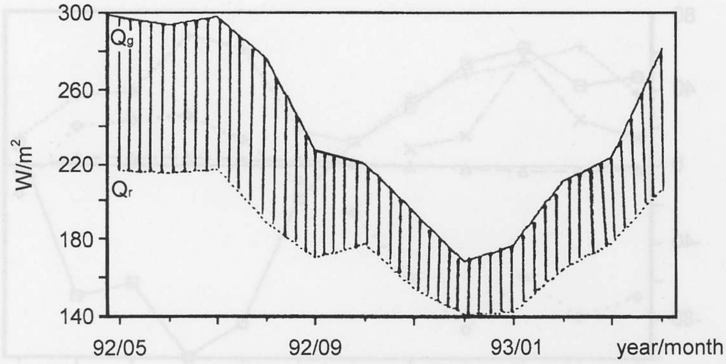

Fig. 5: The variation of global rad. and reflective rad. on the glacier at equilibrium line altitude (the area of shadow is amount of rad. absorbed)

Both the seasonal variation of global radiation and the reflected radiation are shown in fig. 5 (the shaded area is the amount of absorbed radiation). The global radiation has an obvious seasonal variation; reflected radiation does not vary synchronously with global radiation because of surface albedo changes. The total annual global radiation at the equilibrium line altitude was calculated as 7440 MJ/m^2; the annual mean albedo is 0.75.

Short wave balance and long wave balance are shown in fig. 6. It can be seen that the glacier surface at the equilibrium line altitude gains energy from radiation from April to October and loses energy during the remainder of the year. The incoming radiation was calculated as 434 MJ/m^2 and the outgoing as 618 MJ/m^2, the annual net radiation is 184 MJ/m^2.

All terms of the energy balance are shown in fig. 7. The sensible heat is positive for all seasons but it has maxima in summer and winter; the latent heat has the opposite sign of the net radiation most of the time, i. e. maximum evaporation occurs at the time of maximum energy gain from radiation; heat is available for melting only from May to September; heat conduction is small throughout the year.

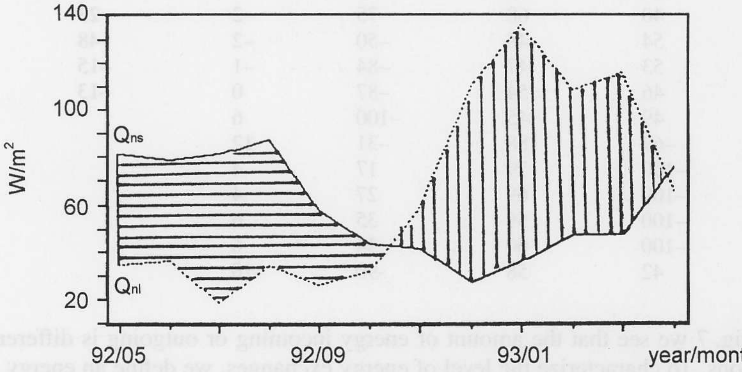

Fig. 6: The variation of short wave radiation budget and long wave radiation budget on the glacier at equilibrium line altitude.

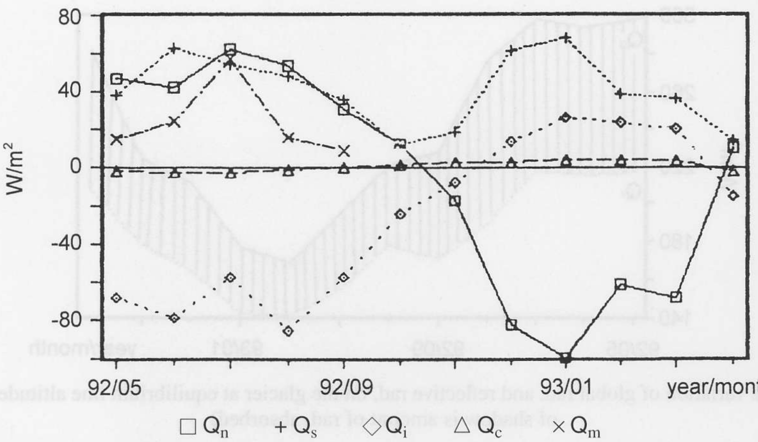

Fig. 7: The variation of all energy balance components at equilibrium line altitude. In this diagram Q_m has positive values.

All the terms in the energy exchange system on the glacier are related to each other. Table 2 lists the monthly mean percentages of the individual energy exchange terms. Both the net radiation and latent heat change their sign seasonally. Sensible heat is positive for all season, it is the main heat source; heat conduction is too faible to play any role in the system.

Table 2: Energy budget terms on the glacier surface at the equilibrium line altitude May 1991–April 1993 and the energy exchange coefficient (C_e). Q_b is the sum of positive terms on the left hand side of equ. (3); Q_g is global radiation. Positive values mean energy income and negative values mean energy loss.

year/month	relative contribution to the energy budget %					C_e
	Q_n	Q_s	Q_l	Q_c	Q_m	(Q_b/Q_g)
92/5	55	45	–80	–2	–18	0.28
92/6	40	60	–75	–2	–23	0.38
92/7	54	46	–50	–2	–48	0.39
92/8	53	47	–84	–1	–15	0.37
92/9	46	54	–87	0	–13	0.29
92/10	49	45	–100	6		0.12
92/11	–69	88	–31	12		0.13
92/12	–100	79	17	4		0.60
93/1	–100	69	27	4		0.70
93/2	–100	59	35	6		0.35
93/3	–100	60	34	6		0.35
93/4	42	58	-90	–10		0.07

From fig. 7 we see that the amount of energy incoming or outgoing is different for different seasons. To characterize the level of energy exchanges, we define an energy exchange coefficient C_e:

$$C_e = Q_b / Q_g \tag{6}$$

Where Q_b is the sum of positive terms on the left hand side of equ. (3); Q_g is global radiation; the monthly mean C_e is also shown in Tab. 2; it is larger in summer and winter than during the other seasons.

ABLATION ESTIMATES AND DISCUSSION

For every point of the glacier surface, the specific mass balance b is:

$$b = a + c \tag{7}$$

Where a is the specific ablation; c is the specific accumulation.
The condition at the equilibrium line is:

$$b = 0 \quad \text{or} \quad a = -c \tag{8}$$

Based on the calculated values of the energy balance and on formula 8, the individual terms and their contribution to the mass balance are shown in fig. 8a. The evaporation on the glacier surface at equilibrium line altitude plays an important role in the glacier mass balance, especially during weak melting and non melting periods. The annual evaporation is estimated to contribute 28 % to the annual ablation. Annual snow melting occurs from May to September and makes up 72 % of total ablation. The accumulation of the glacier is mainly precipitation, condensation occurs from November to March, but makes up only 6 % of the accumulation. Thus, surface evaporation and surface condensation can not be ignored in the calculation of the annual balance at equilibrium line altitude. For glaciers in higher regions evaporation and condensation become even more important for the mass balance.

The mass balance was also estimated from data of the snow depth on the glacier surface at equilibrium line altitude, its seasonal variation is shown in fig. 8b. The density used for the calculation was estimated from the surface albedo. This approach is based on the result from research work in the Tien Shan area, China (Bai et al., 1989). We are aware that there are some errors in estimating density due to the neglected influence of drift snow, but the

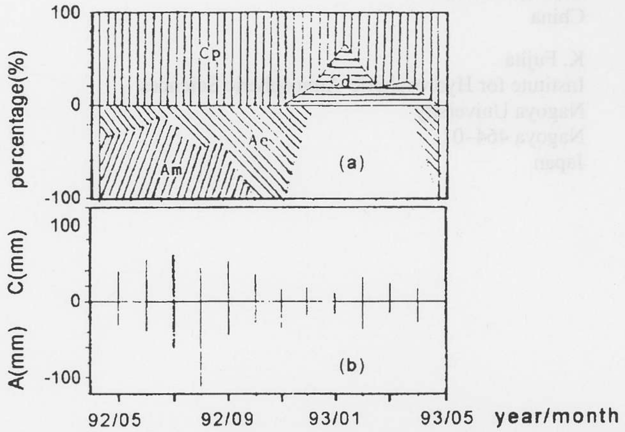

Fig. 8: Sketch of the combination of mass balance (a) and its value estimated from snow depth (b) on the glacier at equilibrium line altitude. Am: ablation by melting, Ae: by evaporation, Cp: precipitation, Cd: accumulation by drift

annual course of ablation and of accumulation appear reasonable in fig. 8. The main ablation processes and the main accumulation processes are coinciding in time. The amount of the annual ablation at equilibrium line altitude was estimated as 480 mm and the accumulation as 510 mm.

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