Bulletin of Glacier Research 8 (1990) *87–91*

© Data Center for Glacier Research, Japanese Society of Snow and Ice

Preliminary studies on the temperature in the surface layer of Guozha Glacier and Chongce Ice Cap in the West Kunlun Mountains, China.

SHAO Wenzhang and LIU Zongxiang
Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, Lanzhou, 730000, China

(Received December 12,1988; Revised manuscript received March 22, 1989)

Abstract

During July and August 1987, the Sino-Japanese Joint Expedition to the West Kunlun Mountains systematically investigated the Guozha Glacier and Chongce Ice Cap. Four boreholes were drilled at various elevations to measure temperature in the surface layers of both glaciers. Observation showed that the lowest temperature of −16.4°C occured at 8-10 m deep in a borehole at 6327 m a.s.l., which is also the lowest record on glaciers to date in China.

The variations in temperature with depth and elevation are analyzed in the present paper. Temperature decreases to a depth and then increases. It is apparent that temperature drops as elevation increases. The heat transfer equation was applied to calculate the equilibrium temperature, $T_0(y)$, and the amplitude, $T_s \exp[-y(w/2k)^{1/2}]$, at various depths. The lowest $T_0(y)$ is calculated at 12-13 m deep in the borehole at 5974 m a.s.l., while the lowest temperature −13.5°C was observed at 14-15 m. Above the depth of 4 m, heat is tranferred by multiple processes, but below it, conduction prevails.

1. Temperature measurements

For convenience in comparison, four boreholes for temperature measurement were sited as follows : one at 5700 m a.s.l. in the ablation area of Guozha glacier ajoining the accumulation area of Chongce ice cap; the others at 5805 m, 5974 m (near the equilibrium line) and 6327 m (near the summit) a.s.l. respectively on the ice cap (see Fig. 1 and Table 1). The borehole at 6327 m a.s.l. was drilled by ice-core auger, the others with a steam drill. No sooner had the drilling been finished than temperature sensors with an accuracy of 0.1°C were buried into the holes at intervals of 2 m downward from 1 m depth. After 6-10 days the first temperature measurement was made. The observation results are given in Table 2.

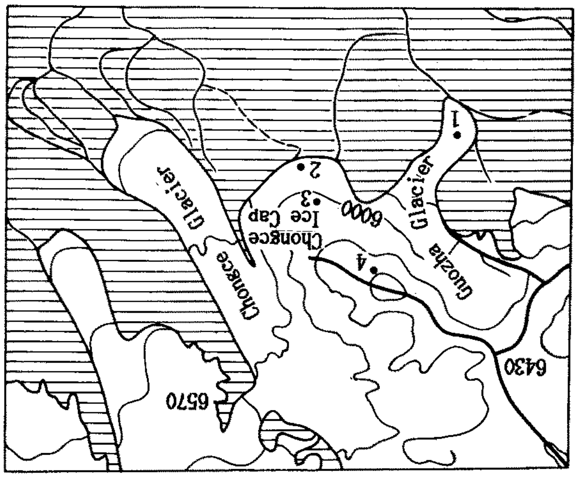

Fig. 1. Location map of boreholes.

2. Analysis of measured temperature

2.1. Temperature variation with depth

The temperature observed in each borehole at the latest date (Aug. 26) are shown in Fig. 2. Temperature decreases to a certain depth, then increases. The depth at which the minimum temperature occurs increased from 8 m to 10 m with elevation.

Table 1. Locations of Bore Holes for Temperature measurement.

Bore holes No.	Altitude (m)	Depth of bore hole (m)	Date of drilling	Observation period	Drilled by
1	5700	12	8.8	8.14−8.26 2	steam drill
2	5805	14	7.17	7.22−8.26 4	steam drill
3	5974	13	7.16	7.22−8.26 4	steam drill
4	6327	25	8.16	8.16−8.26 1	ice core auger

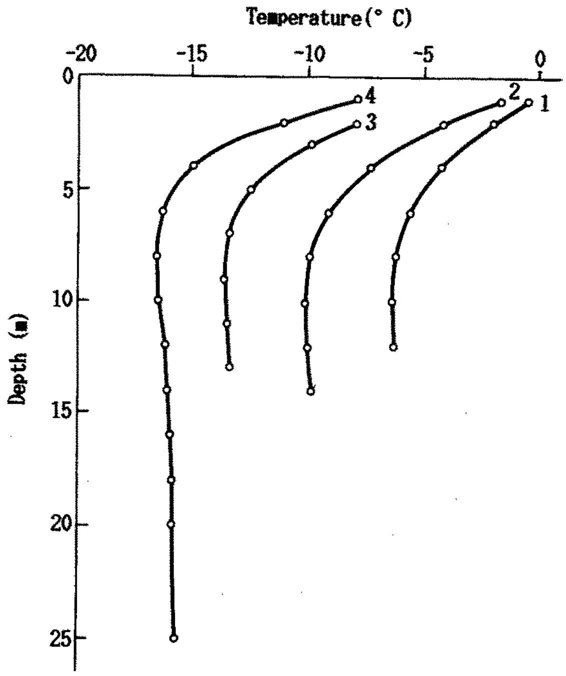

Fig. 2. Measured temperature profiles in boreholes on Chongce Ice Cap and Guozha Glacier on Aug. 26, 1987.

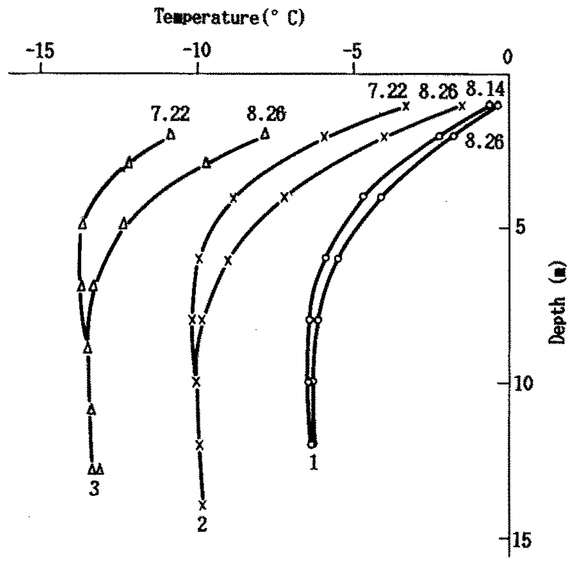

Fig. 3. Temperature variations with time.

2.2. Variations of temperature with elevation

Temperatures at a depth of 12-15 m were −6.2°C, −9.8°C, −13.3°C and −16.0°C in the four boreholes, appearing to decrease with elevation (Fig. 2). A temperature of −16.4°C was observed in Borehole No. 4, which is the minimum among measured temperatures to date on glaciers in China (Table 3).

2.3. Temperature variations with time

As shown in Fig. 3, temperature above a depth of about 9 m changes with time, especially near the surface; in borehole No. 4 measurement was made only once. Moreover, the change seemed to be larger at higher elevations.

2.4. Calculations of temperature in the active layer

In general the depth of 15 m can be regarded as the lower bound of the active layer, below which temperature varies little all year (within 0.1-0.2°C). Our observation lasted about a month, so the measured temperature almost does not change below 10 m.

Paterson (1981) thought that the temperature in the active layer was mainly controlled by seasonal change of surface temperature, and so can be describ-

Table 2. Records of Ice Temperature Observed on Chongce Ice Cap.

Bore Hole: No. 1

Date \ Depth (m)	1	2	4	6	8	10	12
August 14	-0.6	-2.2	-4.7	-5.9	-6.4	-6.4	-6.3
August 26	-0.4	-1.8	-4.1	-5.5	-6.1	-6.3	-6.2

Bore Hole: No. 2

Date \ Depth (m)	1	2	4	6	8	10	12	14
July 22	-3.2	-5.9	-8.8	-9.9	-10.1	-10.0	-9.9	-9.8
July 29	-2.7	-5.5	-8.5	-9.8	-10.1	-10.1	-9.9	-9.8
August 15	-2.3	-4.3	-7.7	-9.3	-10.0	-10.0	-9.9	-9.8
August 26	-1.5	-4.0	-7.2	-9.0	- 9.8	-10.0	-9.9	-9.8

Bore Hole: No. 3

Date \ Depth (m)	2	3	5	7	9	11	13
July 22	-10.9	-12.4	-13.7	-13.7	-13.5	-13.3	-13.1
July 29	-10.2	-12.1	-13.4	-13.8	-13.6	-13.4	-13.2
August15	- 8.5	-10.6	-12.9	-13.6	-13.7	-13.4	-13.4
August26	- 7.8	- 9.8	-12.4	-13.3	-13.5	-13.4	-13.3

Bore Hole: No. 4

Date \ Depth (m)	1	2	4	6	8	10	12	14	16	18	20	25
August 24	- 7.7	-10.5	-14.9	-16.2	-16.4	-16.4	-16.1	-16.0	-15.9	-15.8	-15.8	-15.6

Table 3. Records of Ice Temperature Observed on Some Glaciers in China.

Mountain ranges	Name of glacier	Altitude of equilibrium line (m)	Altitude of observation point (m)	Lowest temperature observed and depth [°C(m)]	Reference
Tian	Xiqiongtailan	4500	4050	− 3.9 (6)	Wang Lilun 1978.6.30
	URumqi River No. 1	4075	3825	− 6.5 (3.2)	Xie Zichu 1962.6-9
Mts.	Bogda Heigou No. 8	4100	4000	− 6.0 (7.7−9.7)	Shao Wenzhang 1986.8.26
	Shuiguan River No. 4	4450	4520	− 3.9 (4)	Wu Guanghe 1976.7.30
Qilian	Yanglong River No. 5	4600	4648	−10.7 (4.8)	Huang Maohuan 1977.6-8
Mts.	Qiyi Glacier	4550	4737	− 7.4 (6)	Wang Lilun 1975.7-8
	Laohugou No. 12	4700	4650	−12.8 (7)	Wang Lilun 1976.6-8
Himalaya	Yebokangjial	6000	5650	− 5.1 (6)	Huang Maohuan 1964.4.20
Mts.	Rongbu	5800	5400	− 3.9 (3)	Xie Zichu 1966.5.29
West Kunlun Mts.	Chongce Ice Cap	5974	6327	−16.4 (8−10)	Shao Wenzhang 1987.8.26

ed by the heat transfer equation for a semi-infinite medium:

$$k(\partial^2T/\partial y^2)=\partial T/\partial t \qquad (1)$$

with the boundary condition:

$$T(0,t)=T_s\times \sin(wt) \qquad (2)$$

where T is the temperature at time t and depth y, k thermal diffusivity, T_s the amplitude at the surface, and w the frequency of temperature change.

The solution, when the transient term is neglected, is:

$$T(y,t)=T_s\times \exp[-y(w/2k)^{1/2}] \times \sin[wt-y(w/2k)^{1/2}] \qquad (3)$$

The amplitude of temperature fluctuation at y, the term $T_s\times \exp[-y(w/2k)^{1/2}]$ in Equation (3), attenuates exponentally with increase of y; the higher the frequency, the more rapid the attenuation. That the initial phase, y(w/2k), is a linear function of y means that the time lapse between temperature fluc-

Tablee 4. Equilibrium Temperature To(y) and Temperature Variation Amplitude at Depth y in Bore Hole No. 1

Y (m)	1	2	4	6	8	10	12
$T_o(y)$ (°C)	−1.2	−2.6	−4.7	−5.4	−5.9	−5.6	−6.5
$T_S \times \exp(-Y \times (w/(2 \times k))^{\frac{1}{2}})$	25.21	18.76	10.39	5.76	3.19	1.77	0.98

Table 5. Equilibrium Temperature To(y) and Temperature Variation Amplitude at Depth y in Bore Hole No. 2.

Y (m)	1	2	4	6	8	10	12	14
$T_o(y)$ (°C)	−1.2	−3.6	−2.6	−10.2	−10.1	−10.0	−9.9	−9.8
$T_S \times \exp(-Y \times (w/(2 \times k))^{\frac{1}{2}})$	2.75	2.05	1.14	0.63	0.35	0.20	0.11	0.06

Table 6. Equilibrium Temperature To(y) and Temperature Variation Amplitude at Depth y in Bore Hole No. 3

Y (m)	2	3	5	7	9	11	13
$T_o(y)$ (°C)	−9.3	−10.9	−12.7	−13.2	−13.1	−13.4	−13.5
$T_S \times \exp(-Y \times (w/(2 \times k))^{\frac{1}{2}})$	3.49	2.60	1.45	0.80	0.45	0.25	0.14

tuation waves at a certain depth and the surface is proportional to depth. When we assume that the major cycle of temperature variation at the surface is caused by the seasonal changes of air temperature, $w/2\pi = 1/\text{yr}$. A modified form of Equation (3) proposed by Ren and Huang (1981) based on the characteristics of temperature variations in continental glaciers in China is as follows :

$$T(y,t) = T_s \times \exp[-y(w/2k)^{1/2}] \times \sin[wt - y(w/2k)^{1/2}] + T_o(y) \quad (4)$$

where $T_0(y)$ is the equilibrium temperature at y, which is a function of y. Substituting the measured temperatures in boreholes at 5700 m, 5805 m and 5974 m a.s.l. into Equation (4), the values of $T_0(y)$ and $T_s \times \exp[-y(w/2k)^{1/2}]$ at various depths were obtained and listed in Tables 4, 5 and 6.

Here K was assumed to be 1.0×10^{-2} cm²/s according to Hobbs (1974), who proposed a range of 0.843 to 1.247×10^{-2} cm²/s for 0-40°C. We can see from Table 5,4-6 that the minimum $T_0(y)$ of −13.5°C occurs at the depth of 12-13 m, 2 m deeper than that of the minimum temperature, and that $T_0(y)$ varies considerably with y for $y < 4$m, implying that heat is not transferred only by conduction.

The following analyses were based on the calculated values of annual equilibrium temperature and the amplitude of temperature variation:

A. Amplitudes of temperature variations in different boreholes :

Tables 4, 5 and 6 show that the amplitude of temperature vairations at the same depth is generally larger in the borehole at 5700 m a.s.l. than those in boreholes at 5805 m and 5974 m a.s.l., especially for $y < 4$ m with a maximum of 25.3°C. This shows different influences of the environment on different glacier zones.

The amplitude of temperature variation decreases with depth at rates of 0.79, 0.07 and 0.16°C/m in boreholes at 5700 m, 5805 m and 5974 m a.s.l. respectively for $y > 4$ m. It is estimated by using these rates that the amplitude would almost be zero at the depth of 15 m on Chongce Ice Cap.

B. Temperature variations in different boreholes :

(1) The borehole at 5700 m a.s.l. is situated in the ablation area of Guozha Glacier, where temperature is higher than at the same depth in other boreholes ; the minimum is −6.5°C. It is inferred from the fact that a measured temperature in the summer is −0.4°C at 1 m depth that there is a certain thickness of 0°C isothermal layer at the surface.

(2) Although the borehole at 5805 m a.s.l. is in the ablation area of Chongce Ice Cap, the temperature in it is much lower than that in the borehole at 5700 m a.s.l. on Guozha Glacier, with a minimum value of −10°C. Such difference is not only due to the influence of

elevation, but also due to glacial type. The ice cap, for example, is quite different from Guozha glacier in movement, ablation amount and cold reserves.

(3) In the borehole at 5974 m a.s.l. near the equilibrium line, temperature is lower than those in both boreholes mentioned above, with a minimum of −13.5°C, whereas it is still lower in the borehole at 6327 m a.s.l. with a minimum of −16.4°C, which reflects very small ablation in the upper reaches of the glacier.

References

Hobbs, P. V. (1974) : Ice Physics. Clarendon Press, Oxford.

Paterson, W. S. B. (1981) : The Physics of Glaciers. Chap. 10, Distribution of Temperature in Glaciers and Ice Sheets. Pergamon Press.

Ren, Jiawen and Huang, Maohuan (1981) : Analysis of Heat Conduction in the Active Layer of Glaciers. Journal of Glaciology and Geocryology, Vol. 3, No. **3**, 23−28.