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Meteorological conditions of the West Kunlun Mountains in the summer of 1987

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Abstract

The surface and upper-air meteorological data were obtained at the southern side (35°N, 80°E) of West Kunlun Mountains, China in June-August of 1987. One station was set near the top of the Chongce Ice Cap (6327 m a.s.l.) and four stations were distributed at lower altitudes, including one near Gozha Co (lake) (5,125 m a.s.l.). Quite high precipitation was measured at these stations in comparison with the precipitation at permanent weather stations in the surrounding valley and low land. Effects of the ice cap on the surface air temperature, wind and global solar radiation were discussed in relation with the heat and mass balance of the glacier area. The occurrence of precipitation in this region corresponds to easterly wind in the lower layers (up to 1000 - 2000 m above the ground). A foehn-like phenomenon was observed during the observation period.

1. Introduction

Meteorological observations in the West Kunlun Mountains, Western China have been made only by some mountaineering expeditions and preliminary scientific surveys (Watanabe and Zheng, 1987), and there have been no systematic observations longer than a month. During glaciological studies in the West Kunlun Mountains in the summer of 1987 (Zheng *et al.*, 1988), meteorological observations were also made simultaneously in the glacier region and on low-altitude barren slopes north of Gozha Co (lake). The results of surface meteorological observations and aerological observations will be presented, together with some discussions.

2. Observation stations and meteorological elements

Six main stations of surface meteorological observation are shown in Fig. 1, and few temporary stations were occupied the slope and glaciers. The measured elements and elevations of the six stations are shown in Table 1. The periods of meteorological observation varied for stations and meteorlogical elements. The longest observation was made at BC (35°09'N, 81°03'E) from June 23 to August 31, 1987. The meteorological instruments used for observations are listed in Table 2. Digital data loggers with sampling intervals of 10 to 20 minutes were used at BC, ABC, No. 1 and No. 12. Data at LS and No. 4 were recorded on paper charts. The time used in the present report is the Beijing Standard Time (GMT + 8 hours). Local time of the observation area is approximately 2.5 hours behind the Beijing Standard Time.

Radiosonde and pibal observations were made at BC to measure the wind, air temperature, humidity and height of a certain pressure level, and used intsruments are shown in Table 3. No automatic tracking system of rawinsonde was available, so wind speed and wind direction were measured with a theodolite, in the same way as the pibal observation. Rawinsondes were launched every day at 20:00 (12 GMT) from July 23 to August 22. From August 6 to 10, additional observations were made at 08:00 (00 GMT).

Pibal observations were made more frequently at

Table 1. List of meteorological sations, its altitude, surface condition, measured elements and observation period. The observation period varies in elements, but the longest period is shown. Abbreviations for elements are: T air temperature; H humidity; WS wind speed; WD wind direction; P precipitation; GR global solar radiation; GT ground temperature; CA cloud amount and type; E evaporation; AP air pressure.

Station	Alititude	Surface condition	Elements	Period
LS	5125 m	sparse grass	AT,H,WS,P	July 12–Aug. 21
BC	5260	sparse grass	AT,H,WS,WD,P,GR,GT,CA,E,AP	June 23–Aug. 31
ABC	5805	bare ground	AT,H,WS,P,GT	July 20–Aug. 25
No. 1	5850	snow/ice	AT,H,WS	July 20–Aug. 18
No. 4	5974	snow	AT,H	July 18–Aug. 27
No.12	6327	snow	AT,H,WD,P,GR	July 22–Aug. 25

Table 2. List of surface meteorogical instruments.

Elements	Sensor	Accuracy	Manufacturer	Station
Air temperature	Platinum resistor (naturally ventilated shelter)	±0.1°C	Aanderra Co.	BC, No. 12
	Platinum resistor (naturally ventilated shelter)	±0.1°C	Nakaasa Co.	ABC, No. 1
	Bimetal	±0.5°C	China	LS, No. 4
Wind speed	3-cup anemometer	±0.2% or ±20cm/s whichever greater	Aanderra Co.	BC, No. 12
	3-cup anemometer	±0.1m/s	Makino Co.	LS, ABC, No. 1
Wind direction	Potentiometer type	5°	Aanderra Co.	BC, No. 12
	Potentiometer type	3°	Makino Co.	ABC, No. 1
Humidity	Hygroscopic hair	±3%	Aanderra Co.	BC, No. 12
	Hydroscopic hair	———	China	LS, No. 4
	Hydroscopic macromolecular material	±1%	Nakaasa Co.	ABC, No. 1
Global solar radiation	Temperature difference type (wavelength 0.3–2.5m)	±2mW/cm^2	Aanderra Co.	BC, No. 12
	Silicon photodiode (wavelength 0.43–1.06m)	±5mW/cm^2	Hamamatu Photonics	ABC, No. 1
Air Pressure	Silicon chip	±0.8mb	Aanderra Co.	BC
Ground temperature	Platinum resistor	±0.1°C	Aanderra Co.	BC
	Platinum resistor	±0.1°C	China Co., Ltd.	ABC, No. 1
Evaporation	Evaporimeter (20cm)	———	———	BC
Precipitation	Reserving rain gauge (20cm)	———	———	BC, ABC, LS, No. 12

BC on 08:00 (00 GMT) and 14:00 (06 GMT). When the radiosonde was not launched at 20:00, pibal observation was made instead. On some occasions, observations were also made at 11:00 (03 GMT) and 17:00 (09 GMT); on August 10, pibal observations were made every 1.5 hours from morning till night.

In addition to the present observations, surface meteorological data taken at permanent weather stations at Kangxiwar (3,986 m a.s.l., 240km WNW of BC), Yecheng (1,200 m a.s.l., 450km NW of BC) and Hotan (1,375 m a.s.l., 230 km NW of BC) are used in this report.

3. Wind speed

The daily mean wind speed at five stations are shown in Fig. 2, exibiting wind speed increase with altitude. The wind speed at BC was about 3 m/s; the average wind speed ratio of No. 12 to BC was 1.45, 1.35 for No. 1, 1.30 for ABC, and 0.71 for LS. Wind speed fluctuation at BC was small, but it was amplified at higher stations, especially at No. 12.

Wind speed showed a typical diurnal variation. On the Chongce Ice Cap, wind speed usually had a daily maximum near the sunset at about 20:00, as seen from the example at No. 1 (Fig. 3). The diurnal varia-

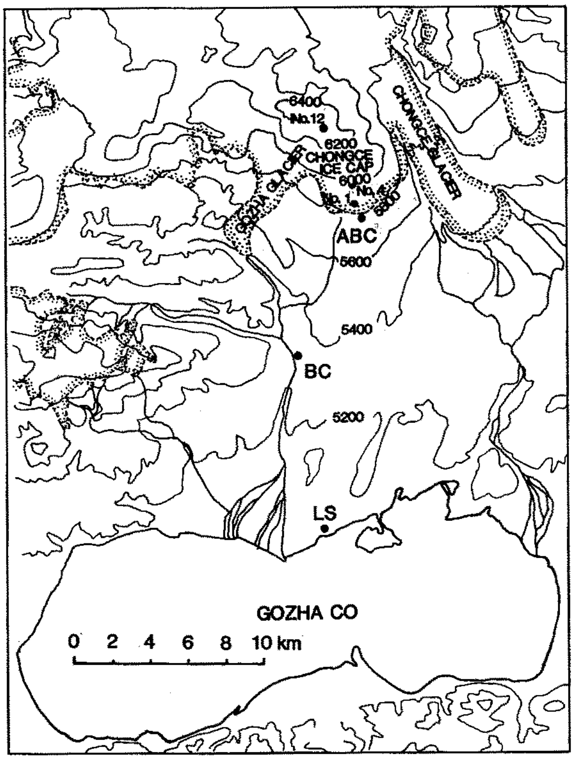

Fig. 1. Map of the observation area on the southern slope of the West Kunlun Mountains. Main observation stations are shown by dark circle with station names. Margins of the glaciated area are dotted.

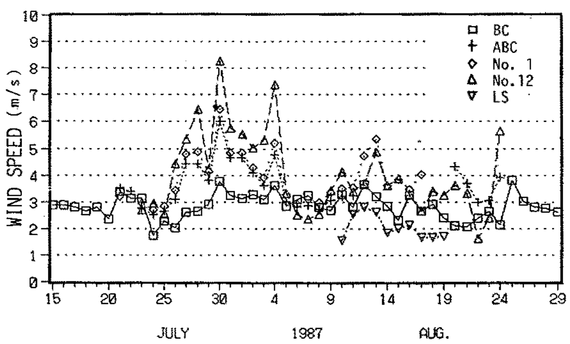

Fig. 2. Daily mean wind speed at five stations for July 15 – August 29, 1987.

tion was more pronounced at LS and the maxima appeared at late hours around the midnight (Fig. 4). This diurnal variation of wind speed and the late occurrence of wind maxima at LS should be related to the local atmospheric circulation in this region.

At the margin of the Chongce Ice Cap, such as at No. 1 and ABC, nocturnal katabatic wind was oc-

Table 3. List of instruments used fof radiosonde and pibal observations.

Radiosonde observation

Type of receiver	Recovery receiver (No. 32649) (Meisei Electric Co., Ltd.)
Type of sonde	RS2-80 type rawinsonde (Meisei Electric Co., Ltd.)
Wave length	1680 MHz
Weight of balloon	600g
Total number of observations	35 times
Frequency	1 – 2 times a day

Pibal observation

Type of theodolite	JMA-58 (Tamaya Co.)
Weight of balloon	20, 30g
Total number of observations	140 times
Frequency	1 – 8 times a day

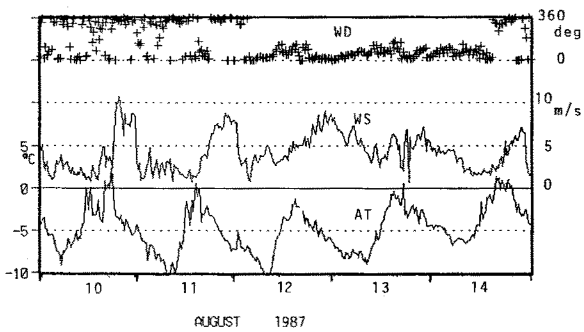

Fig. 3. Wind direction (WD), wind speed (WS) and air temperature (AT) at No. 1 for August 10–14, 1987.

casionally observed. At No. 1, when the air temperature decreased to near the minimum value before dawn on a clear day, the wind direction changed from W (the prevailing wind direction) to NE, and the wind speed slightly increased (Fig. 5). Since the slope direction was SW, this increase of wind speed should be due to the nocturnal katabatic wind. As the topography around No. 1 and ABC was convex, the effect of nocturnal katabatic wind was small. On a concave topography, as in the valley on the south side of the Chongce Ice Cap, the katabatic wind should be stronger.

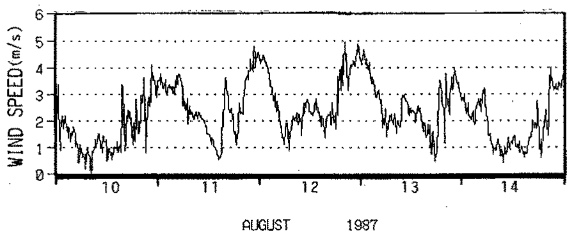

Fig. 4. Wind speed at LS for August 10 – 14, 1987.

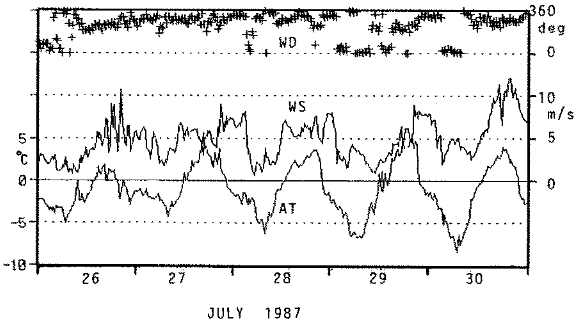

Fig. 5. Wind direction (WD), wind speed (WS) and air temperature (AT) at No. 1 for July 26 – August 5, 1987.

4. Air temperature

Figure 6 shows daily mean air temperature of about 4°C at BC, and sub–zero temperatures on the Chongce Ice Cap (No. 1 and No. 12). Diurnal range on the Chongce Ice Cap was larger than that on the bare ground (ABC).

The maximum temperature at No. 1 usually occurred at about 16:00 (Fig. 3), approximately 2 hours after local noon. The diurnal range was large, about 15°C on a clear day, which was due to the strong nocturnal cooling under thin atmosphere at such high altitude.

Values of temperature lapse rate were calculated from temperature difference between BC and other stations (Fig. 7). The average lapse rate (°C/100m) was 0.99 between BC and ABC, 1.16 between BC and No. 1, and 0.80 between BC and No. 12. The free atmosphere lapse rate from aerological data at 20:00 for the same observation period was approximately 0.65°C/100m, which was smaller than the surface lapse rate. This can be explained by the cooling effect of the Chongce Ice Cap. The free atmosphere lapse rate was similar to that of the ICAO standard atmosphere 0.65°C/100m.

5. Humidity

Figure 8 shows similar changes of daily mean relative humidity at four stations; it was high during July 23 – 26 and August 5 – 10, low during July 27 – 31, and very low on August 17.

Though the relative humidity was slightly high at high altitudes, the daily mean vapor pressure was low at high altitudes because of low air temperature. The vapor pressure at No. 12 was usually 1.5 mb lower than that at BC.

6. Precipitation

Figure 9 shows the daily precipitation at BC and two permanent meteorological stations, Kanxiwar and Yecheng. Kangxiwar is located on a large valley floor, and Yecheng at the periphery of the Taklimakan Desert. There is no meteorological station in the east of the survey area. The precipitation was high in July

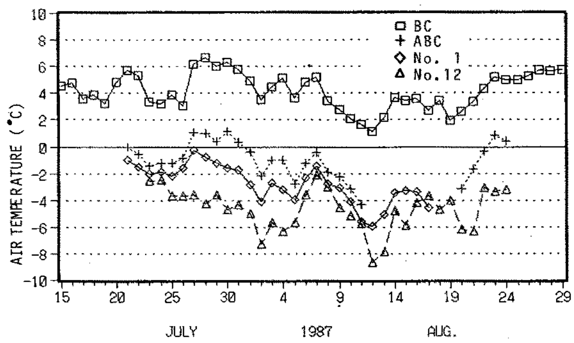

Fig. 6. Daily mean air temperature at BC, ABC, No. 1 and No. 12 for July 15 – August 29, 1987.

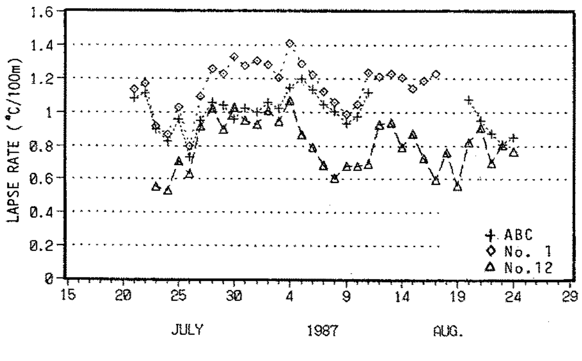

Fig. 7. Daily mean lapse rate between BC and three other stations (ABC, No. 1 and No. 12).

and low in August at these stations, but there is almost no correlation in daily precipitation. For example, when high precipitation was observed at Kangxiwar on July 17 and August 4, there was no precipitation at Yecheng and only a little precipitation at BC. This is the same for peak values observed at Yecheng and BC. In Fig. 10, the variation of 5–day total precipitation is shown for three stations. This also shows very weak correlation. These facts suggest that the precipitation in this region occurs quite randomly for a short time scale.

The total amount of precipitation for July–August for BC, Kangxiwar and Yecheng were 91.8, 18.9 and 13.9 mm respectively (Table 4). The ratio is 1:0.21:0.15. High precipitation, more than 4.8 times that at Kangxiwar, occurred at BC. As Kangxiwar is closer to BC than Yecheng, it will be assumed that this ratio holds at two stations throughout the year. Then, the annual precipitation can be calculated for BC from annual data at Kangxiwar, and the result is shown in Table 4. The estimated annual precipitation at BC is 183 mm.

The altitudinal difference in precipitation in the observation area will be investigated on the basis of data at BC and ABC. Precipitation was measured every 12 hours at BC and ABC simultaneously for certain days from the end of July to the middle of August. In Fig. 11, frequencies of daytime (08:00–20:00) and nighttime (20:00–08:00) precipitation at BC and ABC are compared. In the daytime, the precipita-

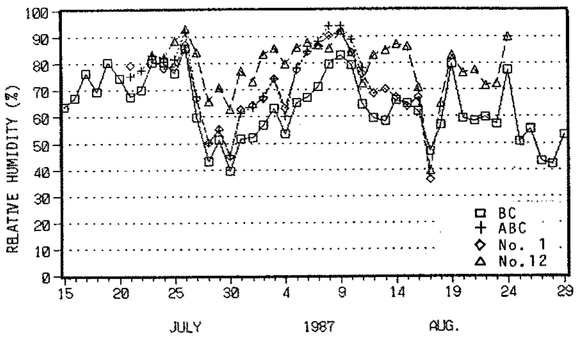

Fig. 8. Daily mean relative humidity at BC, ABC, No. 1 and No. 12 for July 15 – August 29, 1987.

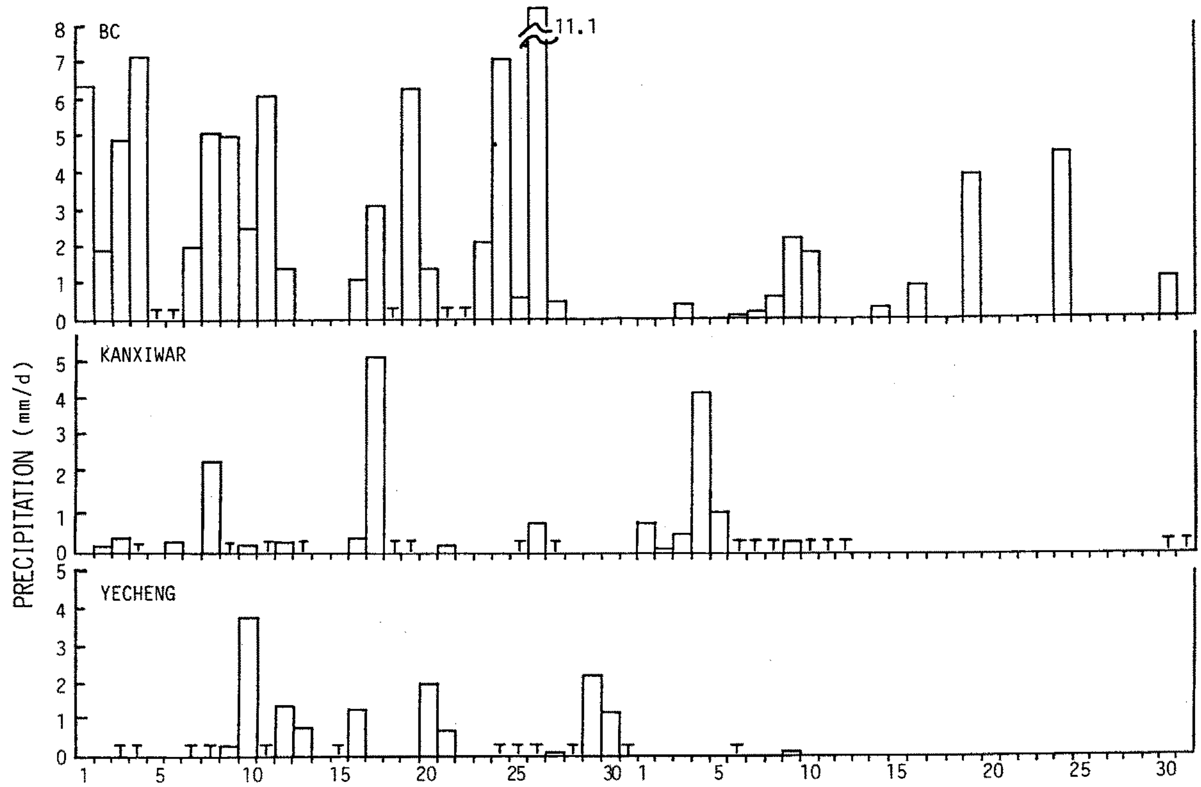

Fig. 9. Daily precipitation (20:00–20:00) at BC, Yecheng and Kangxiwar for July–August 1987. T: Trace.

Table 4. Precipitation at BC, ABC and No. 12 in the observation area, and Kangxiwar and Yecheng in surrounding regions. Figures in parentheses are estimated values.

Station	July-August 1987 (mm)	July-August 1987 (mm)	Mean Annual (mm)
Kangxiwar	18.9		37.7
Yecheng	13.9		35
BC	91.8	24.3	(183)
ABC		34.4	(260)
No. 12			(330)

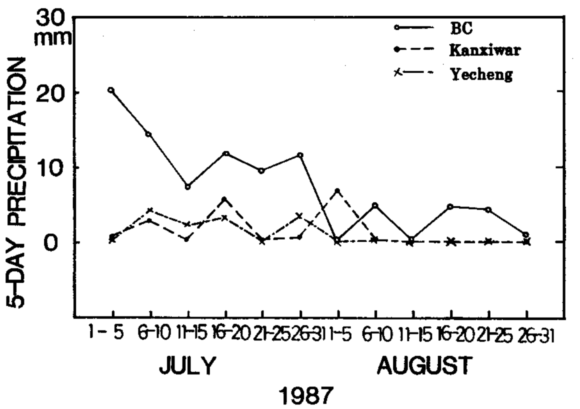

Fig. 10. Five-day total precipitation at BC, Yecheng and Kangxiwar for July – August 1987.

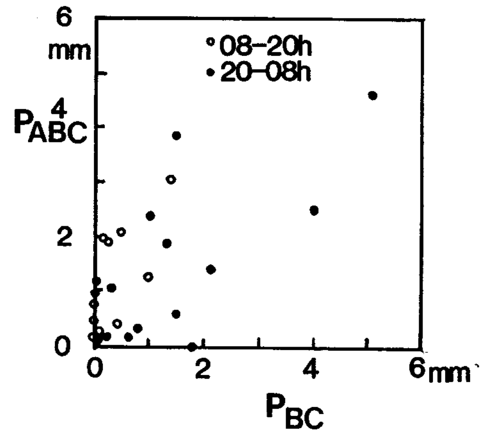

Fig. 11. Relation between half-day precipitation at ABC and BC.

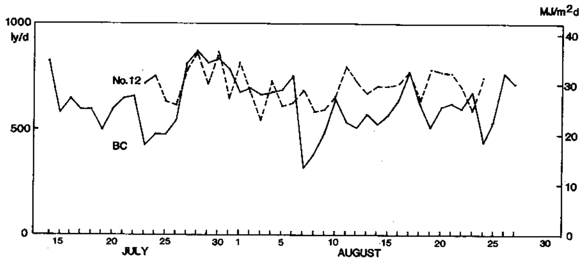

Fig. 12. Variation of daily global solar radiation at BC and No. 12. The observation period at BC was July 14 – August 27, and at No. 12, July 23 – August 24.

tion at ABC was more than that at BC, but in the nighttime, no marked difference is seen. The daytime and nighttime total amount for BC were 4.0 and 20.3 mm respectively, and 12.5 and 21.9 mm respectively for ABC. This might mean that different precipitation processes occur in the daytime and nighttime. The total precipitation based on the 12-hourly observation at BC and ABC amounts to be 24.3 and 34.4 mm respectively (Table 4), which ratio is 1:1.42. In this table, the mean annual precipitation at ABC was calculated, multiplying 1.42 by the value of 183 mm at BC. In calculating the precipitation at No. 12, the altitude-precipitation relation between BC and ABC was extrapolated to the altitude of No. 12, which gave 330 mm at No. 12. The result shows that the estimated annual precipitation on the ice cap area (5,800-6,400 m a.s.l.) is 260-330 mm.

The precipitation near the Gozha Co seems to be less than at BC, because the total precipitation measured at LS for about one week was 30-40% of the amount at BC. However, the value at LS seems to include much error which was due to evaporation, and nothing definite can be said at present.

7. Global solar radiation

Global solar radiation was observed at 4 sites (BC, ABC, No. 1, No. 12) using two types of sensors (Table 2). In the present report, the result at BC and No. 12 will be presented and discussed.

Figure 12 shows the day-to-day variations of global solar radiation at BC (I_{BC}) and No. 12 (I_{12}). For the same observation period from July 23 to August 24, I_{BC} was 23.1MJ/m^2 d (551 ly/d) and I_{12} was 29.1MJ/m^2 d (694 ly/d). I_{12} was 26% larger than I_{BC}. The following ratios between measured radiation (I_{12} and I_{BC}) and global solar radiation at the top of the atmosphere (I_0) will be calculated.

$$R_{12}=I_{12}/I_0 \ ; \ R_{BC}=I_{BC}/I_0$$

For this period, mean values of R_{12} and R_{BC} were 74%

and 64% respectively. These values, especially R_{12}, are very high compared with the values at other mountain regions. This is probably due mainly to the high altitude and relatively thin clouds in this dry climate region. Day–to–day variation is relatively small at No. 12 and large at BC. Comparing I_{12} and I_{BC}, there are periods when these two values are nearly the same, such as the period from the end of July to the beginning of August when the weather was fine. The difference at two sites arises on cloudy days.

In order to investigate the difference in radiative regime at the two sites, R_{12} and R_{BC} are taken in relation to mean cloud amount (N) at 11:00, 14:00 and 17:00 at BC (Fig. 13). No cloud observation was made at No. 12 which was an automatic unmanned station. However, the distance between two stations is less than 12 km on the same gentle (approximately 4°) slope, so cloud amount at BC was assumed to be the same at No. 12. Figure 13 shows that the two stations have different R–N relations, giving different slopes of regression lines. Such a relation has been found in other radiation studies on snow covered and glaciated areas. For example, different R–N relation was reported in accumulation area and ablation area of Greenland (Ambach, 1973). The conceivable reason for the difference in the slope of regression lines of R_{12} and R_{BC} may be due to the difference in the actual cloud amount or other factors related to cloud conditions, or the multiple reflection of radiation between a high–albedo snow surface and the cloud at No. 12. The last situation seems to be the most plausible reason, because BC is located on the grass ground.

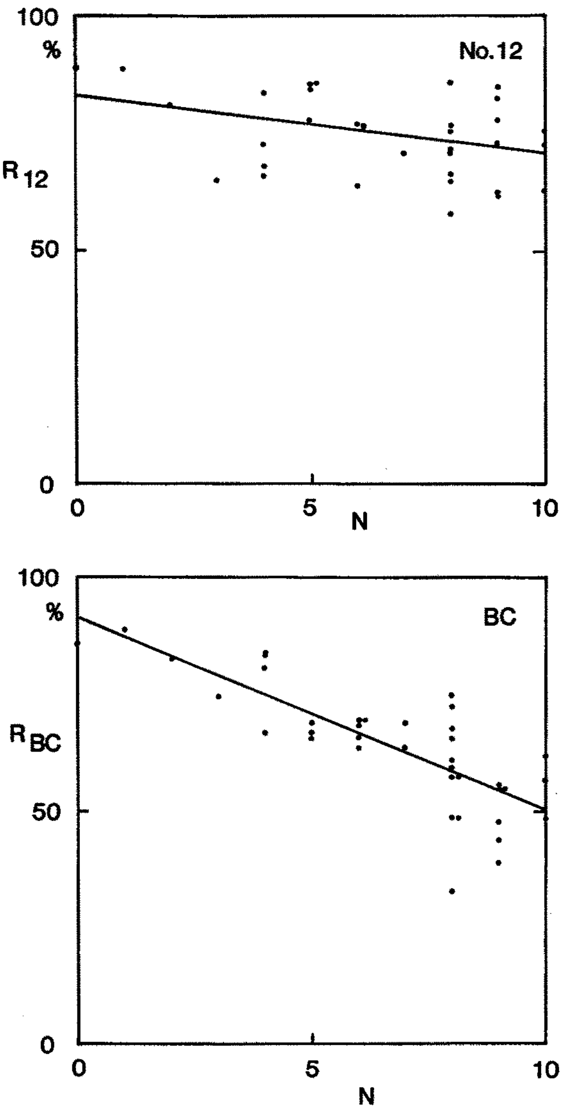

Fig. 13. The relation between R_{12} and R_{BC} and cloud amount (N) at BC.

8. Aerological observations

Figure 14 shows time–height cross section of wind profile at 14:00. Wind data are only available to approximately 3000m above the ground, depending on the weather. Upper wind was mainly from W to SW, and it was strong from late July to the beginning of August, when the weather was good. Especially, from July 27 to August 1, the daily mean cloud amount was lower than 5. When the weather was cloudy or rainy (for example, July 22–23 and August 11–13), the lowest 1000 or 2000m air layer showed easterly wind. This occurs only when the upper wind is weak. Such easterly wind is said to occur at the northern periphery of Tibetan Plateau when the heating on the plateau was intensified (Synthetical Expedition Groups of Qinghai–Xizang Plateau, Academia Sinica, China, 1984). The easterly wind blew during bad weather in this region.

Figure 15 shows the air temperature up to 10,000 gpm, which does not indicate large variation. During the good weather period (July 27–August 2), the lower air layer was relatively warm probably because of strong heating at the ground surface. On August 7, when the weather started to deteriorate, highest air temperatures were recorded at most of the air layers. The lapse rate of the lowest 2000 m layer (5,500 to 7, 500 m a.s.l.) was 0.65°C/100m.

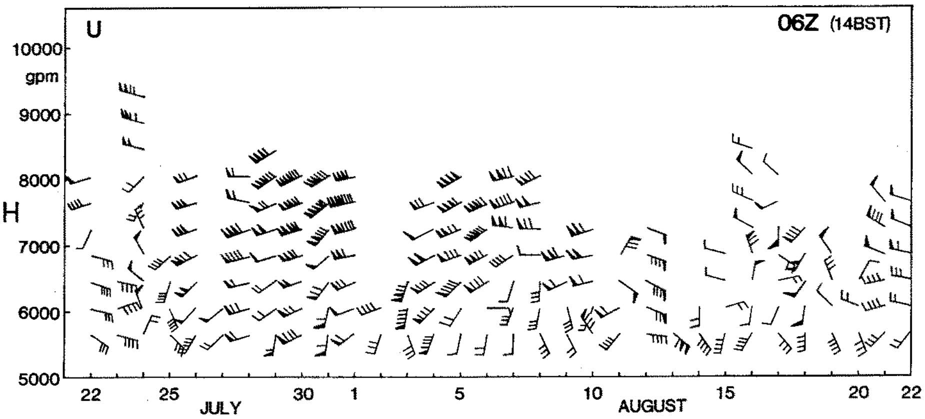

Fig. 14. Vertical profile of wind at BC from July 22 to August 22. Observations were made at 14:00 (06 GMT) with few days exception at 11:00 and 17:00. Thin line of wind scale stands for 1m/s, and thick line for 5 m/s.

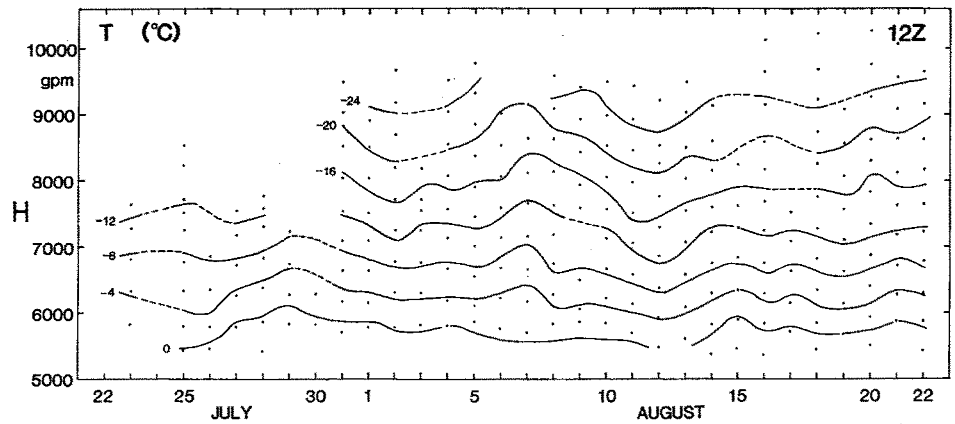

Fig. 15. Time—height cross section of air temperature (T) at BC for July 22 – August 22, 1987 based on radiosonde observations at 20:00 (12 GMT). Observed points are marked with dots.

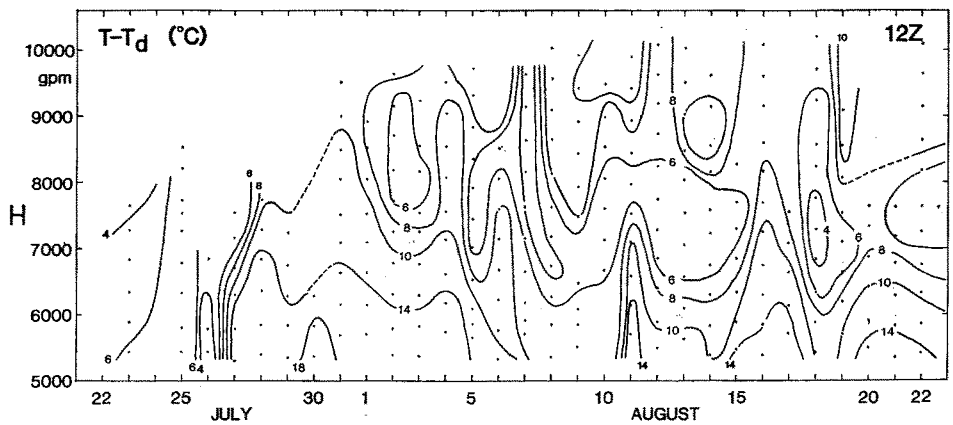

Fig. 16. Dew point depression ($T-T_d$) at BC; same period as Fig. 15.

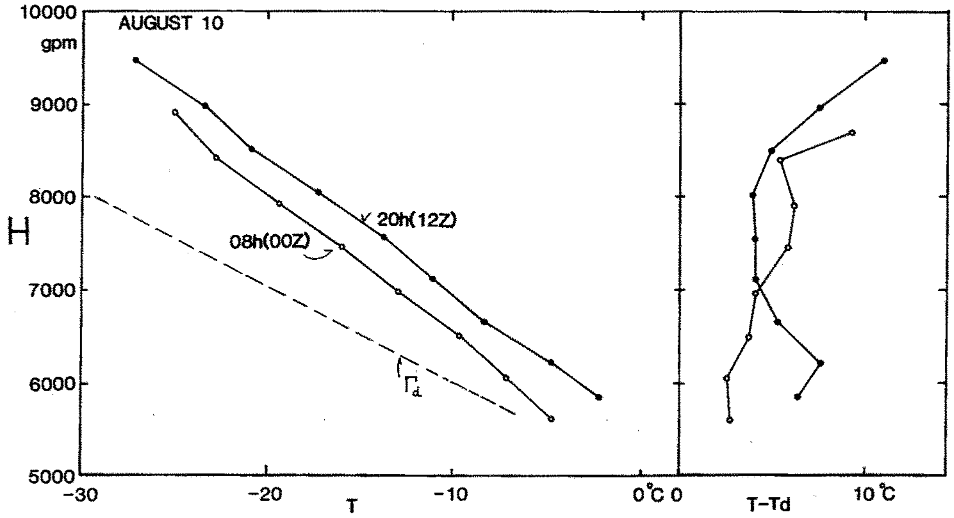

Fig.17. Vertical profiles of air temperature (T) and dew-point depression ($T - T_d$) at 08:00 (00 GMT) and 20:00 (12 GMT) of August 10, 1987. Γ_d means a line for dry adiabatic lapse rate.

Figure 16 shows dew-point depression ($T-T_d$), showing much more variation than the air temperature. During the good weather period, the lowest 2,000-3,000m layer was quite dry. In August humid air layer (less than 6°C in dew-point depression) appeared at various height. From August 1 to 4 humid layer existed at 2,500-4,000 m above the ground, but after August 8 it descended to 1,500-3,000 m. These heights can be considered as the level of cloud formation. Actually in the former period, there was high level cloud, but only little precipitation occurred as shown in Fig. 9. In the latter period, precipitation occurred on several days. Apparently the precipitation occurs when the moist layer is at 1,500-3,000 m above the ground.

Figure 17 shows profiles of air temperature and dew-point depression on the morning (08:00) and evening (20:00) of August 10. The air temperature was higher in the evening at all levels up to 10,000 m. This implies that the height of the boundary layer may extend to the tropopause.

There are few aerological stations on or near the Tibetan Plateau. Including the data at Hotan about 230 km NW of BC, Fig. 18 shows wind vector, geopotential height (H), air temperature (T), dew-point depression ($T-T_d$) at 500mb level (approximately 6,000 m) at BC and Hotan for the period of July 20 to August 22. The 500mb level is within the boundary layer at BC (5,260 m a.s.l.). The geopotential height (H) changed similarly at two stations, a little higher at Hotan. Air temperatures (T) at BC were generally higher than Hotan. Dew point depression ($T-T_d$) showed similar values at two stations except for the period from the end of July to August 5, during which period BC was extremely dry. This period also corresponds to large difference in T, but the large difference in $T-T_d$ cannot be explained only by the difference in T. Strong upper winds were observed during this period (Fig. 14). At the same period, a traverse party in the northern side of the West Kunlun Mountains observed high cloudiness there, whereas low cloud amount was observed at BC which is located in the southern side. From these facts, it seems that some foehn-like phenomeno occurred from the end of July to around August 5, exibiting the northern side moist and relatively cool and the southern side dry and relatively warm. Precipitation data at Kangxiwar, 240km WNW of BC, during the period of August 1-5 showed the highest in any 5-day period in July and August, but at BC it was nearly zero (Fig. 10). This fact supports the possibility of the occurrence of foehn noted above. However, the upper wind at Hotan does not necessarily show a northerly wind component which is needed for the occurrence of continuous foehn throughout this period. Most of the facts support the occurrence of foehn, but there is still some doubts.

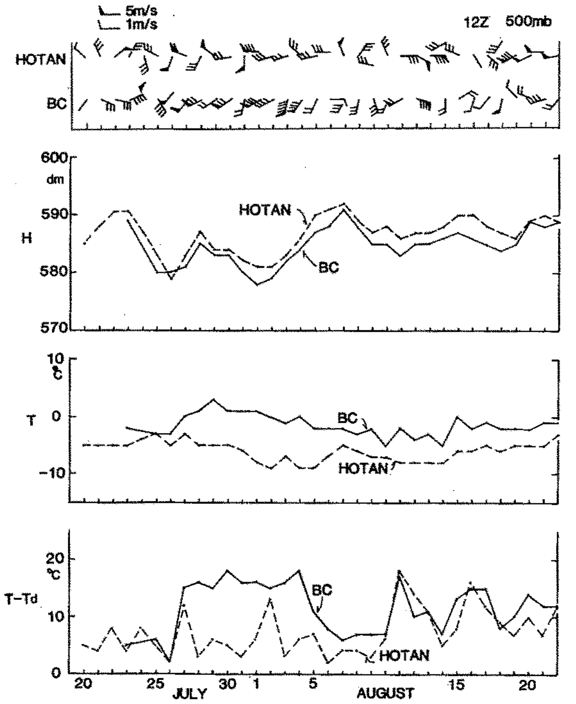

Fig. 18. Wind vector, geopotential height (H), air temperature (T) and dew−point depression ($T-T_d$) at 500mb level at Hotan and BC observed on 20:00 (12 GMT) for the period of July 20−August 22, 1987.

9. Concluding remarks

The meteorological conditions in the West Kunlun Mountains in the summer of 1987 were presented. Main characteristics are summarized as follows:

(1) The precipitation in the West Kunlun Mountains is estimated to be about 5 times larger than the value at Kangxiwar, a low altitude valley station. Precipitation at West Kunlun showed weak correlation in daily and 5−day total precipitation with Kangxibar and Yecheng.

(2) The annual precipitation in the Chongce Ice Cap (5,800−6,400 m a.s.l.) was estimated in a range of 260 to 330 mm.

(3) Marked effects of the ice cap on the air temperature, wind and global solar radiation were observed. These will affect on the heat and mass balance of the glacier area.

(4) Rainy weather in this mountain area corresponds to the easterly wind in the lowest layers (1,000 − 2,000 m above the ground) of the troposphere.

(5) Foehn−like phenomenon was observed in this mountain.

It is to be added that the automatic meteorological station at BC recorded one−year data till August 14, 1988. This is probably the first full−year meteorological data taken at such a high altitude. The data will be used to investigate the annual course of meteorological condition in this area.

Acknowledgment

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References

Ambach, von W. (1973): Zum Strahlungshaushalt des grönländischen Inlandeises: vergleichende Studie im Akkumulations− und Ablationsgebiet. Polarforschung, **43**, 10−22.

Synthetical Expedition Groups of Qinghai−Xizang Plateau, Academia Sinica, China (1984): The Climate of Xizang, Beijing, Science Press, 300p (in Chinese).

Watanabe, O. and Zheng, B. (1987): First glaciological expedition to West Kunlun Mountains 1985, Bulletin of Glacier Research, **5**, 77−84.

Zheng, B., Chen, J. and Ageta, Y. (1988): The preliminary report of Sino−Japanese Joint Glaciological Expedition in West Kunlun Mountains 1987. Bulletin of Glacier Research, **6**, 75−80.