Bulletin of Glaciological Research 21 (2004) *17－22*

Meteorological characteristics in upstream regions of the Qira River, Kunlun Mountains, China

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(Received August 20, 2003; Revised manuscript received November 11, 2003)

Abstract

The meteorological characteristics at Kartash were investigated using surface data obtained in situ during a 6-year period from September 1991 to August 1997. Kartash is located in the upstream regions of the Qira River, Kunlun Mountains, and its elevation is about 2800 m a.s.l. Local circulation occurs constantly in this area, and wind direction switches frequently throughout the year: northeasterly during the day, to southwesterly at night, along a streamline of the slope. In the monsoon season from May to August, the heaviest rainfall occurs between 1700-2300 (Beijing time) when upstream wind blows as a result of the local circulation. A comparison of monthly air temperatures between Kartash and Qira reveals that the local circulation in summer contains dry air over the desert, and a cold air mass is formed at the foot of the mountains during the winter months.

1. Introduction

Meteorological characteristics in high mountainous areas are important for estimating the amount of water flow in rivers, especially in desert areas. It has been reported that some glaciers are retreating due to global warming in Central Asia (Ageta, 1995; Aizen *et al.*, 1997; Wang *et al.*, 2001). In addition, climatic information has been obtained from ice core samples from the Kunlun Mountains by Nakawo *et al.* (1990). However, to date, long-term direct meteorological observations have not been carried out in the Kunlun Mountains. In 1991, a data collection platform was installed at the upstream regions of the Qira River, Kunlun Mountains, and a complete data set covering 6 years was stored. In this paper, meteorological characteristics at the observation site are reported using the data set.

2. Observations

2.1. *Observation site*

The observation site is located in a valley in the upstream regions of the Qira River. The geometric position is latitude 36°16′ N and longitude 80°25′ E, and the site is approximately 2800 m above sea level (symbol A in Fig. 1). The valley faces 55° from north to east, and its mean inclination is approximately 1/20. The observation site is named 'Kartash' after the small nearby village. The meteorological data observed at Kartash is compared with that at Qira, which

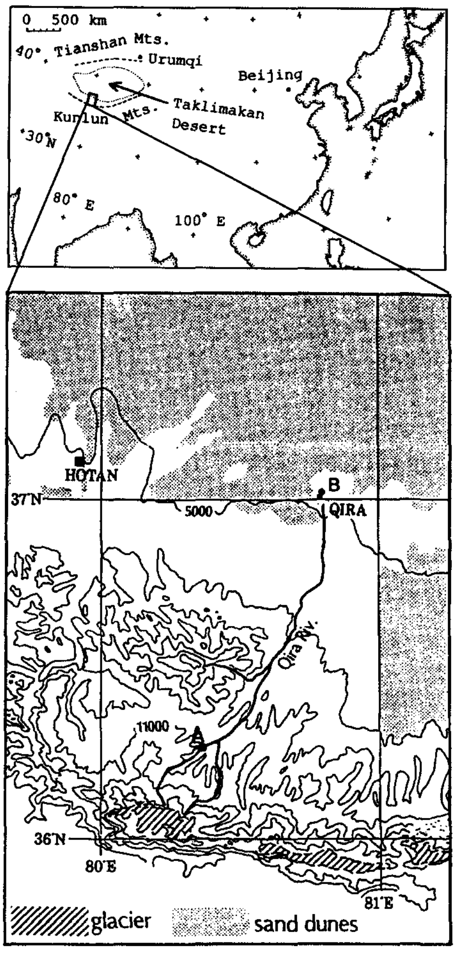

Fig. 1. Topography around the meteorological observation sites. Elevation is expressed in feet. A: Kartash (2800 m a.s.l.), B: Qira (1400 m a.s.l.).

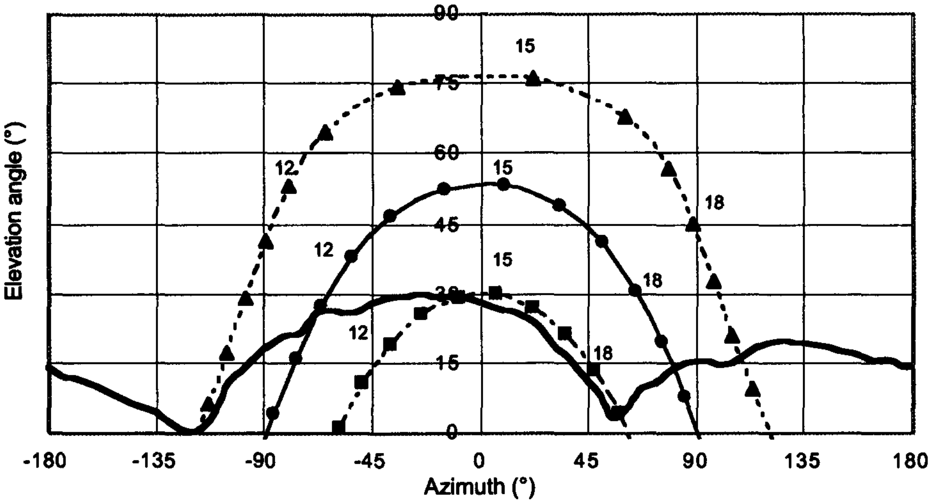

Fig. 2. The mountain ridge and sun path diagrams for each season. ▲: summer solstice, ●: spring and autumn equinoxes, ■: winter solstice. 0° of azimuth means to the south. Time is Beijing time.

is located at the foot (37°01′ N, 80°48′ E, 1400 m a.s.l.) of the Kunlun Mountains (symbol B in Fig. 1). The ridge of the mountain obstructs part of the sky around the site of Kartash. Figure 2 shows the mountain ridge at Kartash and the tracks of the sun during the spring and autumn equinoxes, the summer and winter solstices. In this paper, only Chinese Standard Time (Beijing time), which is 8 hours earlier than Coordinated Universal Time (UTC), is used. Noon at Kartash appears about 2 hours 40 minutes later than Beijing time. The maximum elevation angle of the surrounding hills is 30° in the southern direction, so the sun is mostly hidden by the mountains in winter.

2.2. Observation method

A Data Collection Platform (DCP) was developed by T. Kimura (Abe *et al.*, 1995) and installed in September 1991 (Fig. 3). The DCP was used to obtain data on the following meteorological items: air temperature, soil temperature, wind speed, wind direction, solar radiation, albedo, precipitation and snow weight. Table 1 shows the height, unit, instrument and recording method for each measurement item. The air temperature was measured using a platinum resistance thermometer with a naturally aspirated radiation shield. A snow-weight meter was used to observe snow accumulation instead of a rain gauge in winter, because the rain gauge was not available at temperatures below 0 °C unless a snow-melting heater was additionally equipped. The power source for all instruments was supplied by lithium batteries. Albedo is calculated from upward solar radiation divided by downward solar radiation. All data was stored into a data logger on an hourly basis and downloaded to a computer once a year in autumn.

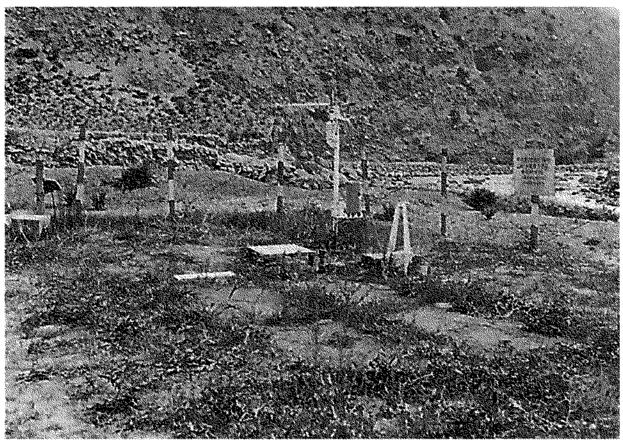

Fig. 3. Data Collection Platform installed at Kartash.

Table 1. Height, unit, instrument and recording type for each measurement item.

Item	Height (m)	Unit	Instrument	Record Type
Air Temperature	1.5	°C	Pt. Resistance	Instance
Soil Temperature*	−0.1	°C	Pt. Resistance	Instance
Wind Direction	1.5	°	Potentio Meter	Instance
Wind Speed	1.5	ms^{-1}	Coreless Generator	Instance
Solar Radiation	1.5	MJm^{-2}	Thermopile	Summation
Albedo	1.5	-	Thermopile	Average
Precipitation	0.5	mm	Rain Gauge	Summation
Snow Weight	0.0	kgm^{-2}	Snow Weight Meter	Instance

*: Under metal wafer of the snow weight meter

3. Results and discussion

3.1. *Daily variations*

A complete set of meteorological data was collected at Kartash during the 6-year period from September 1991 to August 1997. Regarding the meteorological conditions at Kartash, Fig. 4 shows daily variations in air temperature, soil temperature, wind speed, wind direction, precipitation and solar radiation in the middle of specific months in 1992; namely, the 15th of January, April, July and October, respectively. The time in the figure is expressed in Beijing time (BT). Maximum air temperatures appear at 1700 BT for all seasons, and maximum soil temperatures appear 1 hour later than the maximum air temperatures. Wind direction switches frequently, northeasterly during 1200–2300 BT, to southwesterly 2300–1100 BT throughout the year, because the slope faces the northeast. Weak winds were observed to appear twice a day around 1100 and 2300 BT when the wind direction changed. Excluding those periods, wind speeds stayed at levels between 1-4 ms^{-1}. As mentioned before, the sun passes the meridian at around 1440 BT; consequently, the largest solar radiation appears at 1500 BT. There was no rainfall in any of the days.

3.2. *Long-term variations*

The meteorological data in Kartash for the 5-year period from 1992 to 1996, which is complete throughout each year, is shown in Table 2 (Abe *et al.*, 2000). Mean air temperature and precipitation during the same period at Qira are also shown in this table. Qira is located at the foot (1400 m a.s.l.) of the Kunlun Mountains as shown in Fig. 1. The annual mean air temperature in Kartash decreased gradually from 2.6 °C for 1992 to −2.1 °C for 1996. However, mean air temperature at the foot of the mountain (Qira) was observed to remain at virtually constant levels of 11.7 to 12.7 °C. The same trend of temperature decrease observed in Kartash was found in the monthly air temperature for January at Daxiguo (3539 m a.s.l.) in the Tianshan Mountains (Han *et al.*, 2002) and the annual air temperature in the Qilian Mountains (Wang *et al.*, 2001). Shi (2003) reported that the air temperature during the 1990s in the middle and western regions of northwest China is the warmest period recorded in the past 1000 years. However, from $\delta^{18}O$ analysis of the ice core obtained in the central Qinghai-Tibetan Plateau, it was found that the temperature decrease was temporary in the 1990s, perhaps caused by the strength of the summer monsoon (Wang *et al.*, 2003). From the above results, in the period from 1992 to 1996, the air temperature shows a temporary decrease in the high mountainous areas of the west China. The annual mean wind speeds at Kartash were within an almost constant range of 2.2 to 2.4 ms^{-1}. The amount of annual solar radiation decreased gradually with annual air temperatures between 1992 and 1996, except in 1993 when data revealed an increase in temperatures. The amount of

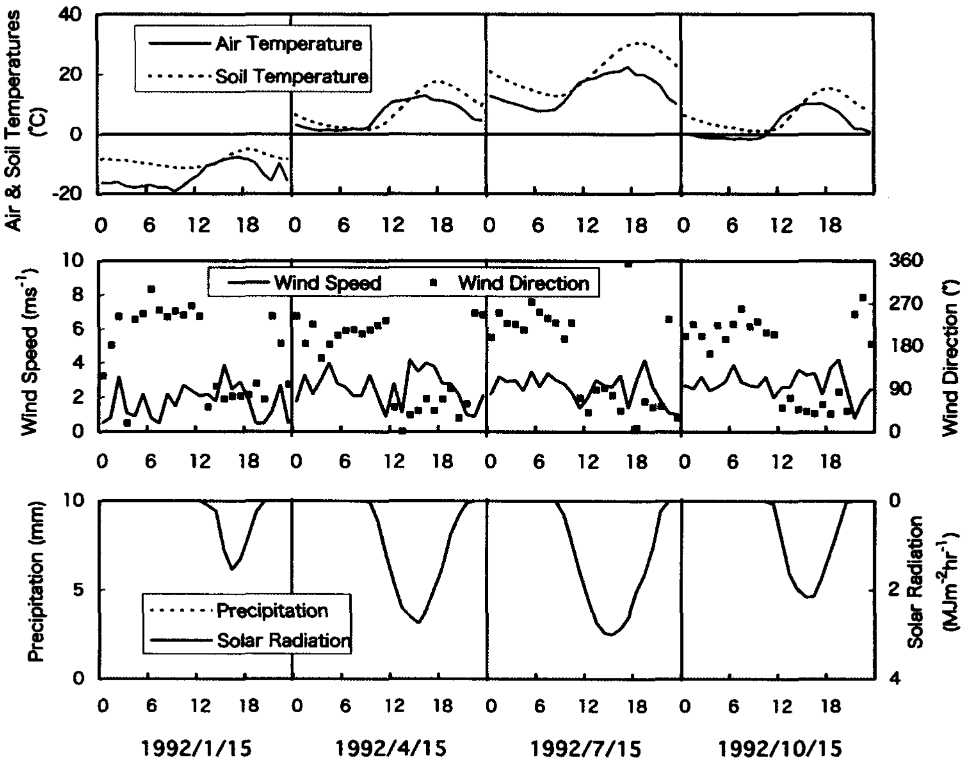

Fig. 4. Daily variations in the meteorological elements in the middle of the four seasons in 1992 at Kartash. Time is Beijing time.

Table 2. Monthly and annual values of meteorological data at Kartash and Qira in 1992-1996. Shaded cell indicates precipitation measured by snow weight meter instead of rain gauge.

	1992		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total	Mean
Kartash	Air temperature (°C)	Mean	-9.3	-8.0	-3.9	6.7	8.1	11.0	13.6	12.9	7.9	0.9	-3.2	-5.9	–	2.6
		Max.	7.8	13.4	11.9	19.3	19.6	23.3	23.9	23.4	18.2	12.3	9.9	6.7	–	15.8
		Min.	-20.7	-17.1	-12.2	-3.2	-2.7	2.6	4.3	3.9	1.0	-7.6	-15.1	-17.3	–	-7.0
	Wind speed (ms^{-1})	Mean	2.2	2.6	2.2	2.7	2.6	2.5	2.2	2.1	2.3	2.6	2.6	2.6	–	2.4
		Max.	5.6	5.8	6.8	7.5	6.8	6.4	6.4	5.3	6.2	5.6	5.4	5.2	–	6.1
	Solar radiation ($MJm^{-2}day^{-1}$)	Mean	4.15	9.40	8.05	13.84	16.02	17.24	17.41	14.83	12.49	10.38	6.33	2.11	132.25	–
	Precipitation (mm)	Total	2	5	18.5	1.0	26.5	71.5	17.5	12.0	1.5	5.5	0.0	0.0	161	–
Qira	Air tempreature (°C)	Mean	-4.8	1.1	7.7	18.6	19.7	23.3	25.0	23.1	19.1	10.3	3.1	-1.6	–	12.1
	Precipitation (mm)	Total	4.2	0.3	0.0	0.0	6.5	13.7	4.4	0.2	0.0	0.0	0.0	0.0	29.3	–

	1993		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total	Mean
Kartash	Air temperature (°C)	Mean	-13.4	-6.4	-3.6	5.2	6.5	9.7	10.9	9.3	8.9	0.4	-4.0	-10.3	–	1.1
		Max.	2.2	12.0	13.5	21.1	20.4	22.1	23.8	19.8	19.9	16.1	14.2	8.5	–	16.1
		Min.	-26.7	-17.2	-16.0	-9.0	-6.1	1.6	3.4	0.4	1.3	-12.4	-19.4	-23.7	–	-10.3
	Wind speed (ms^{-1})	Mean	2.3	2.5	2.4	2.6	2.4	2.4	2.1	2.0	2.4	2.5	2.5	2.3	–	2.4
		Max.	6.4	5.4	6.4	7.4	6.6	7.7	6.6	5.3	8.2	5.7	5.4	6.0	–	6.4
	Solar radiation ($MJm^{-2}day^{-1}$)	Mean	5.14	8.56	12.39	17.19	15.25	17.55	13.90	13.83	14.97	11.50	6.58	1.62	138.48	–
	Precipitation (mm)	Total	13	12	28	0.0	24.0	48.5	31.0	48.0	0.0	0.0	0.5	0.0	205	–
Qira	Air tempreature (°C)	Mean	-5.5	3	8.7	18.0	19.9	23.8	24.6	22.0	20.3	10.5	3.6	-3.5	–	12.1
	Precipitation (mm)	Total	2	1.1	15	0.0	11.0	4.4	3.3	9.8	0.0	0.0	0.2	0.0	46.8	–

	1994		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total	Mean
Kartash	Air temperature (°C)	Mean	-12.9	-10.7	-4.0	0.2	6.5	9.1	13.0	11.7	6.1	0.5	-1.6	-10.1	–	0.7
		Max.	2.8	0.7	8.4	18.2	18.1	20.3	22.8	22.6	18.2	12.7	13.2	11.1	–	14.1
		Min.	-25.4	-19.3	-14.7	-10.4	-6.2	1.3	2.7	1.7	-2.6	-9.8	-12.0	-21.5	–	-9.7
	Wind speed (ms^{-1})	Mean	2.2	2.3	2.6	2.5	2.6	2.4	2.2	2.2	2.2	2.6	2.6	2.2	–	2.4
		Max.	5.8	6.2	6.7	6.8	7.3	8.1	7.7	6.2	6.1	6.3	6.4	6.6	–	6.7
	Solar radiation ($MJm^{-2}day^{-1}$)	Mean	3.99	7.00	11.77	11.30	16.09	17.37	18.61	16.88	11.76	10.82	7.06	1.91	134.56	–
	Precipitation (mm)	Total	9	0	0	1.5	10.0	41.5	7.0	4.0	0.0	0.0	0.0	5.0	78	–
Qira	Air tempreature (°C)	Mean	-4.4	1.5	9.1	15.4	21.5	25.0	27.5	25.1	18.3	11.0	6.3	-3.7	–	12.7
	Precipitation (mm)	Total	0.0	0.1	0.0	0.0	0.1	23.1	0.4	6.3	0.0	0.0	0.0	4.4	34.4	–

	1995		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total	Mean
Kartash	Air temperature (°C)	Mean	-13.0	-10.6	-5.2	0.2	8.0	10.5	12.0	12.6	5.8	-0.6	-8.3	-14.7	–	-0.3
		Max.	1.3	7.5	12.1	16.0	23.3	20.1	24.8	22.9	16.2	12.2	3.3	-5.2	–	12.9
		Min.	-23.7	-21.6	-16.6	-10.9	-2.9	2.9	3.3	2.5	0.1	-10.6	-20.0	-24.7	–	-10.2
	Wind speed (ms^{-1})	Mean	2.3	2.3	2.5	2.3	2.4	2.4	2.1	2.2	2.0	2.3	2.4	2.2	–	2.3
		Max.	4.9	5.4	7.3	6.5	6.3	6.4	7.0	6.4	5.7	6.2	5.3	5.5	–	6.1
	Solar radiation ($MJm^{-2}day^{-1}$)	Mean	4.55	7.87	10.02	10.25	15.27	15.32	16.15	16.24	11.44	9.65	6.78	1.88	125.42	–
	Precipitation (mm)	Total	4	5	0	7.5	25.0	31.0	32.5	0.5	39.5	1.0	0.0	1.0	147	–
Qira	Air tempreature (°C)	Mean	-8.5	0.2	7.9	14.4	22.0	25.2	25.5	25.1	17.9	12.1	3.4	-4.0	–	11.8
	Precipitation (mm)	Total	0.7	1.0	0.0	0.0	0.0	0.0	0.0	0.1	45.9	4.8	0.0	0.0	52.5	–

	1996		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total	Mean
Kartash	Air temperature (°C)	Mean	-15.1	-13.0	-6.2	-0.1	2.5	6.9	7.7	8.7	5.7	-1.6	-9.5	-11.1	–	-2.1
		Max.	-1.3	9.3	11.4	16.3	14.2	21.3	19.2	20.3	17.5	11.7	5.8	5.6	–	12.6
		Min.	-25.1	-24.8	-16.3	-13.5	-5.9	-2.6	-0.4	0.0	-1.8	-10.2	-20.9	-25.7	–	-12.3
	Wind speed (ms^{-1})	Mean	2.3	2.1	2.2	2.4	2.2	2.1	1.9	1.8	2.3	2.4	2.3	2.6	–	2.2
		Max.	5.5	5.7	6.2	6.8	7.4	6.8	5.9	5.6	5.3	5.9	5.1	6.2	–	6.0
	Solar radiation ($MJm^{-2}day^{-1}$)	Mean	4.07	8.01	9.46	12.01	13.18	13.94	14.72	13.62	12.83	10.78	6.11	1.37	120.10	–
	Precipitation (mm)	Total	8	0	10	3.5	17.0	42.5	44.5	25.0	1.0	17.5	0.0	0.0	169	–
Qira	Air tempreature (°C)	Mean	-5.0	-0.2	8.2	15.2	19.3	23.4	23.4	24.0	19.9	11.8	4.4	-3.8	–	11.7
	Precipitation (mm)	Total	0.3	0.0	14.1	1.8	1.1	1.4	20.4	0.6	0.0	0.3	0.0	0.0	40.0	–

precipitation at Kartash varied widely from 78 to 205 mm with an average of 152 mm, and was 2-6 times that in Qira for each year measured. Precipitation at Kartash during each winter (from November to the following April) was estimated from the results of snow weight measurements. Ratios of precipitation during the winter to annual precipitation for each year were 13 to 26%.

3.3. *Diurnal variation of rainfall*

Kartash is located under a jet stream from west to east. The monsoon season descends suddenly on Kartash at the beginning of May each year. Throughout East Asia the majority of precipitation is accounted for by the rainfall in the monsoon season (Zhang and Lin, 1992; Ding, 1994). Precipitation at Kartash in the monsoon was also dominant, and the total precipitation from May to August was 74% of the annual

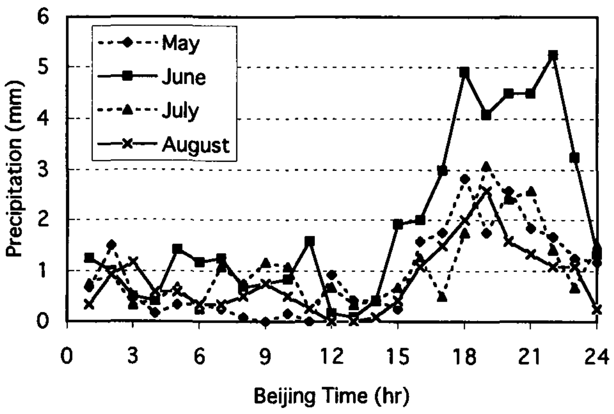

Fig. 5. Diurnal variation of average rainfall for each month.

precipitation during 1992-1996. Figure 5 shows average diurnal variation of rainfall for each month in summer at Kartash. In this period the heaviest rainfall appears between 1700-2300 BT. It is considered that most of this evening rainfall is carried by clouds formed by northwesterly anabatic wind, and similar phenomena have been observed in the Himalayas (Ageta, 1976; Yasunari and Inoue, 1978).

3.4. Correlation of monthly precipitations between Kartash and Qira

Precipitation in high mountainous areas is usually greater than that in the foot areas. Figure 6 shows the relationship of monthly precipitations between Kartash and Qira. The monthly precipitation at Kartash has a strong correlation with that at Qira. The total precipitation at Kartash is approximately 3.7 times that at Qira, as shown by the solid line in Fig. 6. Frequency in percent of 4 cases of monthly precipitation pattern at Kartash and Qira is shown in Table 3; Case (a): precipitation occurs at both Kartash and Qira, Case (b): precipitation does not occur at both Kartash and Qira, Cases (c) and (d): precipitation occurs at either Kartash or Qira. Cases (a) and (b), in which similar precipitation patterns appeared at both the high elevation area and its foot, covers 71% of total cases. Case (a) mostly appeared in the monsoon season.

Table 3. Frequency (in %) of monthly precipitation patterns in Kartashi and Qira.

		Qira	
	Precipitation	Occur	Not occur
Kartash	Occur	a: 34	c; 9
	Not occur	d: 20	b: 37

3.5. Correlation of monthly mean air temperatures between Kartash and Qira

In order to estimate air temperatures in high mountainous areas it is necessary to take measurements of air temperature at the foot of the mountains. Generally, the air temperature is used to estimate the amount of melt water from glaciers, because of the lack of data available for high mountainous areas. Figure 7 shows the relationship between monthly mean air temperatures in Kartash and Qira. These monthly means can be divided into two parts: April-September and October-March. The correlations among the various temperatures are expressed by the following equations:

$$y = 0.92x - 12.2, \text{ April-September} \quad (1)$$

$$y = 0.69x - 9.0, \text{ October-March} \quad (2)$$

where x is air temperature in Qira, and y is air temperature in Kartash. As seen from Fig. 7, Eqs. (1) and (2) can also be separated by the air temperature of approximately 0 °C at Kartash. The differences in the air temperatures at Qira and Kartash are 12.2 °C for

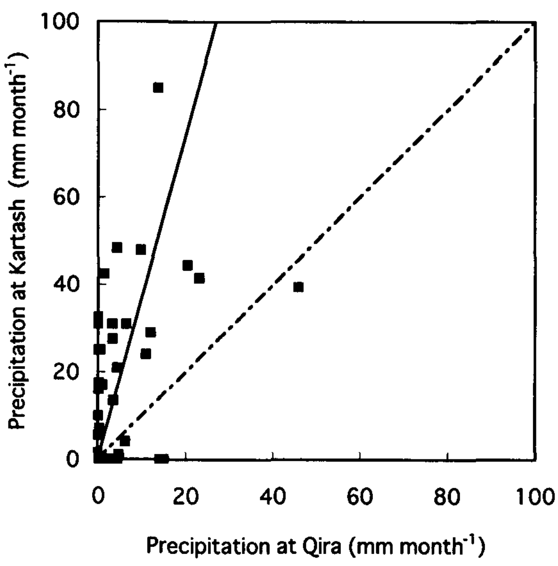

Fig. 6. Correlation of monthly precipitations between Kartash and Qira.

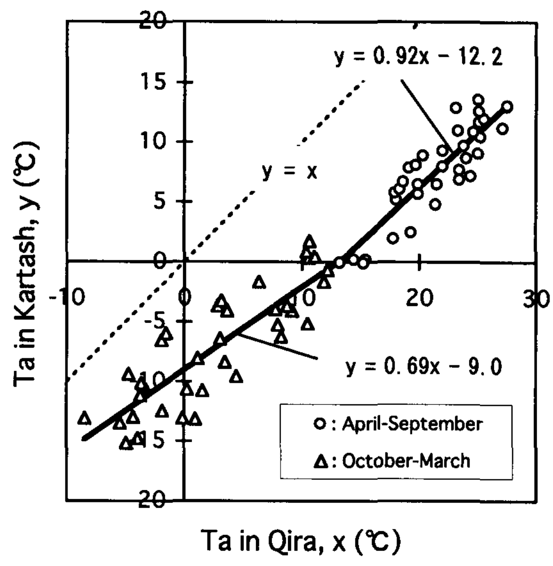

Fig. 7. Correlation of monthly mean air temperatures between Kartash and Qira.

Eq. (1) in summer and 9.0 °C for Eq. (2) in winter. The rates of temperature change of summer and winter, which can be calculated from the temperature differences and the elevation difference between Kartash and Qira, are 8.7 $°Ckm^{-1}$ (12.2 °C/1.4 km) and 6.4 $°Ckm^{-1}$ (9.0 °C/1.4 km). The rate of temperature change for summer is close to the dry adiabatic lapse rate. Mikami *et al.* (1995) reported basic characteristics of meteorological elements in Qira, and that relative humidity in summer is less than that in winter. The rate of temperature change for winter is close to that for the standard atmosphere; however it is reported that the specific humidity at Qira is small in winter (Mikami *et al.*, 1995). As shown in Eq. (2) the difference between the air temperatures in Qira and Kartash is not consistent with the air temperature at Qira in winter. It is considered that a cold air mass is formed at the foot of the mountains in winter, so that the difference in air temperature between Qira and Kartash in low-temperature seasons (*i.e.* winter) is less than that in high-temperature seasons (*i.e.* summer). In Japan, differences in air temperature at the summit and the foot of mountainous areas are almost constant regardless of the air temperature from October to the following June (Shimizu and Abe, 2001).

4. Concluding remarks

Meteorological characteristics at Kartash obtained during a 6-year observation period are as follows:

1) Wind direction switches frequently, from northeasterly during daytime, to southwesterly at night throughout the year.
2) The annual mean air temperature decreased gradually from 2.6 °C in 1992, to −2.1 °C in 1996. However, mean air temperature at the foot (Qira) was almost constant, ranging from 11.7 to 12.7 °C.
3) Amounts of precipitation varied widely from 78 to 205 mm annually. Ratios of winter precipitation to annual precipitation for each year were 13 to 26%.
4) During the monsoon season, the heaviest rainfall appeared between 1700 to 2300 BT. It is considered that most of this evening rainfall is carried by clouds formed by northeasterly anabatic wind.
5) Local circulation in summer contains dry air over the desert; however, a cold air mass is formed at the foot of the mountain in winter months.

Acknowledgments

The authors wish to thank Mr. X. Tang, Lanzhou Institute of Glaciology and Geocryology for his support. Meteorological data for Qira was obtained in the Qira Desert Observatory, Xinjiang Institute of Ecology and Geography, CAS. This study was partly supported through Special Coordination Funds for Promoting Science and Technology of MEXT, the Japanese Government. The authors would like to thank Dr. Y. Kodama, Hokkaido University and one anonymous reviewer for their valuable comments.

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