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Meteorological observations in the Tanggula Mountains, Qingzang (Tibet) Plateau from 1989 to 1993

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Abstract

This report summarizes meteorological observations made in the Tanggula Mountain Region in the central part of Qingzang (Tibet) Plateau under the CREQ (Cryosphere Research on Qingzang Plateau) Project from 1989 to 1993. The observation sites, observed items and other information are given and several data for the research year (October 1992 to September 1993) and IOP (Intensive Observation Period : May to September 1993) are shown.

1. Introduction

The main study topic of the CREQ (Cryosphere Research on Qingzang Plateau) Project (Ageta *et al.*, 1994) is to investigate the characteristics of the water cycle on Tibet Plateau (Qingzang Plateau in Chinese). Special attention is given to the role of snow and ice in this cycle as it is under a cold environment. The atmospheric processes such as precipitation for the water input to the land surface, and radiational heating of the land surface which determines the surface water/heat balance, plays an important role in the water cycle. However, there are only a limited number of permanent meteorological stations of the Chinese Meteorological Administration in this area, and measured elements are too few to obtain such information. These stations are generally located at altitude lower than the average altitude of the Plateau which is 4500 m. Results obtained from measurements made only at such stations will not be representative for the Plateau.

The annual climate in this region is characterized by a dry cold winter and wet warm summer due to the monsoon circulation, although the daily mean air temperature does not exceed 10 °C. Snowfall is frequently observed in summer, and strong insolation is present even in winter because of the low latitude.

Important topics related to meteorological and ground surface conditions which need to be solved are the following.

(1) The intensity of the precipitation in these mountain regions compared with other lower altitude parts of the Plateau.

(2) Annual cycle and interannual variability of surface heat/water fluxes, especially evaporation at the surface in relation to ground texture, snow cover which is quite frequent and permafrost conditions.

(3) Characteristics of the atmospheric boundary layer on the Plateau.

(4) Characteristics of the precipitation system in this region.

(5) Memory of the atmospheric conditions which are stored in the ground layers.

(6) Intensity of the areal evaporation and precipitation recycling in this region.

In order to investigate these topics, the following observations of meteorological elements and related land surface conditions were made in the Tanggula Mountains.

(1) Long term variation of surface meteorological conditions including radiation terms.

(2) Summer meteorological conditions in various parts of the study drainage area.

(3) Areal distribution of precipitation.

(4) Aerological observations.
(5) Intensive measurement of surface sensible heat fluxes.
(6) Precipitation sampling for obtaining information for a wide area water cycle study.

The present report will focus on the description of the study area, observed items and sites during the study period 1989−93, and general characteristics of the meteorlogical elements, mainly during the year October 1992 to September 1993, including the Intensive Observation Period (IOP ; May to September 1993).

2. Sites and measured elements

A map of the largest drainage area where the present study was made is shown in Fig. 1. This is located in the central part of Qingzang Plateau along the Qingzang Highway. The altitude of this area lies between 4800 and 6600 m a.s.l. Positions of sites where meteorological observations were made are shown in Fig. 1. Most of the measurement sites were situated in the south-central part of the drainage area. The names of the sites such as D105 were taken from the station numbers of the road maintainance facilities (Doufang in Chinese) which are situated along the highway.

Table 1 lists the sites, altitudes, surface conditions, observed and measured elements, and their periods and measurement intervals. Site GT2 for ground temperature measurements was situated on a hilltop between WL and BC. Sites, elements and long-term monitoring of meteorological elements since 1989 are shown in Table 2.

Basic meteorological measurements including visual observations were made at BC during the IOP. Meteorological stations to obtain surface fluxes and areal distribution of meteorological elements were set up at five sites (D100, D105, WL, TS and GL) using an Aanderaa Automatic Meteorological System. The measurement height was 2 m for all cases and the measured values were 10 min. average before the hour for wind speed, and instantaneous values on the hour for the other elements. Measurements of ground temperature with other systems were similar. An additional system was set up at BC during the IOP ; it was also used for heat flux measurements. These systems were distributed to cover the whole drainage area from north to south, and from lower to higher glaciated area.

The vegetation in this region was rather scarce with only grasses, shorter than a few cm. The surface was classified into four types : Dense grass, sparse grass, bare ground, and snow/ice. Dense grass surface was defined to have a *LAI* (Leaf area index) of more than 2 m^2m^{-2} ; generally, earth hummocks, a type of periglacial land form, developed on these surfaces. The predominant type of vegetation was *Robresia humilis Serg (from Cyperacese)* at WL and BC which showed similar surface conditions, with earth hummocks, and *Leontopodium nanum (Hook. f. et Thomas) Hand.-Mazz (from Asteraceae)* at D105.

Detailed measurements of heat fluxes were made by the gradient method and eddy correlation method (using a sonic anemothermometer) at WL, D105 and GL on selected days. Precipitation measurements were made at 8 sites, differing in the instruments used and measurement intervals ; details are given by Ueno *et al.* (1994). Aerological observations of upper wind, air temperature and humidity were made at BC, and are reported in detail by Endo *et al.* (1994). Instrumentation and results of the temperature and ground moisture conditions are described by Ohta *et al.* (1994) and Yabuki *et al.* (1994).

3. Annual variation of meteorological elements in 1992−93

The daily mean values of meteorological elements for nearly one year from October 1992 to September 1993 at 5000 m level are shown in Fig. 2. The data shown are from the WL (5100 m a.s.l.) and/or D105 (5020 m a.s.l.) (WL ; Wind speed (*WS*), Air temperature (*AT*), Relative humidity (*RH*), Global solar radiation (*GSR*) : D105 ; Air pressure (*AP*)). When data are not available at WL, the data at D105 were used.

Air pressure (*AP*) fell from October to mid-winter, and increased from around April, until it became constant in summer. The annual range of *AP* is less than 18 hPa. There was an intense decrease of AP to less than 540 hPa from March 18 to 20.

The daily mean air temperature (*AT*) became lower than 0 °C in the middle of October. The lowest was −24.1 °C on January 14. The lowest *AT* was −31.1 °C on the morning of January 15. During the winter, there were six continuous days in February (7th to 12th) when *AT* was higher than −10 °C. The daily maximum *AT* of these days exceeded 0 °C with strong south to west winds. After exceeding 0 °C at

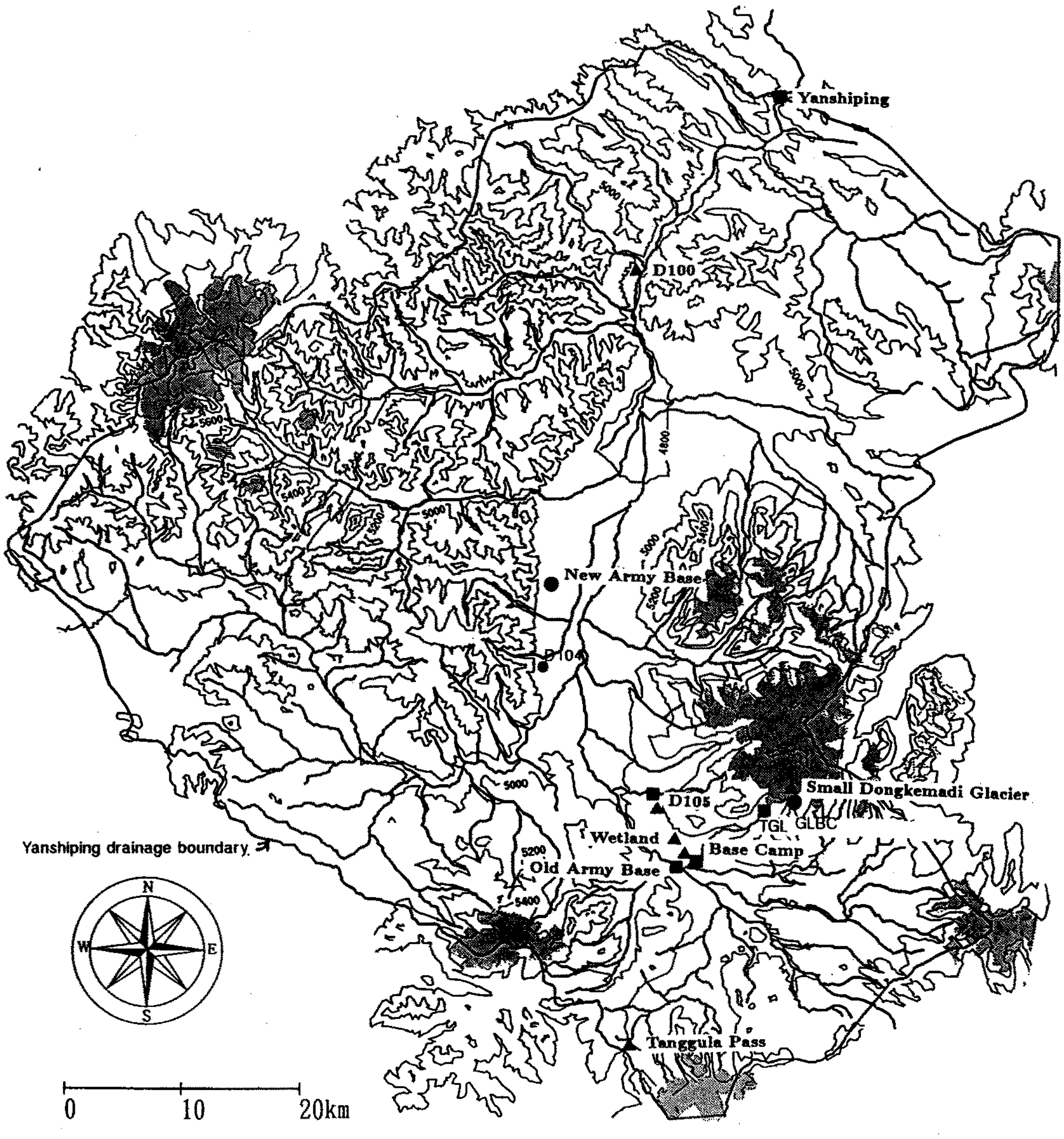

Fig. 1. Positions of sites of the meteorological observations.

Table 1. List of meteorological and land surface measurements during the IOP period.
( ) : Elements, in case of ground temperature and ground heat flux, depth.
[ ] : Type of Instrument
<-, -> : Started before IOP, continued after IOP.

Site	Altitude (m)	Surface condition	Observation items	Measurement interval or frequency	Period
D100	4800	SG	Surface meteorological elements [AND] (WS, WD, AT, RH, GSR, RSR, TRD, GST)	10min	<-May 20 - Sep. 15->
			Precipitation [TTRG]	10min	May 20 - Aug. 17
			Ground temperature (5, 10, 20, 40, 80cm)	1h	<-May 20 - Sep. 16
			Ground heat flux (2.5, 20, 80cm)	1h	<-May 20 - Sep. 16
Tanggula Army Base	4850	SG	Precipitation [CRG]	several days	May 22 - Aug. 14
D105	5020	SG	Surface meteorological elements [AND] (WS, WD, AT, RH, GSR, RSR, TRD, TRU, AP, GST)	10min	<-May 20 - Sep. 15->
			Precipitation [TTRG]	10min	May 20 - Sep. 20
			Surface heat/water flux (AT, RH, WS profile ; [SAT])	1h	Several days during IOP
			Grass density	three times during IOP	
			Ground temperature (0, 5, 10, 20, 40, 80cm)	1h	<-May 20 - Sep. 22
			Ground heat flux (2.5, 20, 80cm)	1h	<-May 20 - Sep. 22
Wetland (WL)	5100	DS	Surface meteorological elements [AND] (WS, WD, AT, RH, GSR, RSR, TRD, TRU,)	10min	<-May 20 - Sep. 15->
			Surface heat/water flux (AT, RH, WS profile ; [SAT])	1h	Several days during IOP
			Precipitation [TTRG]	10min	May 18 - Sep. 20
			Grass density		
			Ground temperature (0, 5, 10, 20, 40, 80cm)	1h	<-May 20 - Jun. 16
			Ground heat flux (2.5, 20, 80cm)	1h	<-May 20 - Jun. 16
Base camp (BC)	5070	DG	Surface heat/water flux (WA, AT, RH profile ; NR, GST ; GT profile, GHF)	30min	May 21 - Sep. 21
			Cloud (amount, type)	every 3 hours	May 18 - Sep. 20
			Aerological Obs. (WS, WD, AT, RH, GPH)	1 to 8 times/day	May 18 - Aug. 7
			Precipitation [CRG, TTRG, TRG]	10min 12h	May 18 - Sep. 21
			Precipitation sampling	2times/day	May 19 - Aug. 8
			Ground temperature (0, 5, 10, 20, 40, 80cm)	1h	Jun. 29 - Sep. 22
GT2	5120	SG	Ground temperature (0, 5, 10, 20, 40, 80cm)	1h	Jun. 29 - Sep. 22
Tanggula Pass (TS)	5206	SG	Surface meteorological elements [AND] (WS, WD, AT, RH, GSR, RSR, TRD, GST)	10min	<-May 20 - Sep. 12
			Precipitation [TTRG]	10min	May 22 - Sep. 12
			Ground temperature (0, 5, 10, 20, 40cm)	1h	<-May 22 - Sep. 12
TGL	≈5250	BG	Precipitation [CRG]	several days	
GL	5600	SI	Surface meteorological elements [AND] (WS, WD, AT, RH, GSR, RSR, TRD, TRU)	10min	<-May 20 - Sep. 15->
Glacier Base camp (GLBC)	5400	BG	Precipitation [CRG, TTRG]	2 times/day	May 24 - Sep. 18

Notation of meteorological elements
- WS : Wind speed
- WD : Wind direction
- AT : Air temperature
- RH : Relative humidity
- GSR : Global solar radiation
- RSR : Reflected solar radiation
- TRD : Total radiation downward
- TRU : Total radiation upward
- AP : Air pressure
- GPH : Geopotential height
- GT : Ground temperature
- GST : Ground surface temperature
- NR : Net radiation
- GHF : Ground heat flux

Notation of instruments
- CRG : Chinese type rain gauge
- TTRG : Tipping type rain gauge
- TRG : Trechakov rain gauge
- SAT : Sonic anemothermometer
- AND : Aanderaa met. system

Notation of surface conditions
- SG : Sparse grass
- DG : Dense grass
- BG : Bare ground
- SI : Snow/ice

Table 2. List of long-term meteorological observations at Tanggula Mountains from 1989 to 1993.
o : Manned observations
------ : Period of automatic met. obs.
〉 : Continued

Site/Year [Altitude]	1989	1990	1991	1992	1993
	1. . . . .7.	1. . . . .7.	1. . . . .7.	1. . . . .7.	1. . . . .7. . . . .
	oo o	o o	o o	o o	ooooo IOP
D105 [5020]	------------------------ WS, WD, AT, RH, AP, GSR, RSR GST, GT20 (from 90/Apr. GT10, GT35)		------------------------------------〉 WS, WD, AT, RH, AP, GSR, RSR TRD, TRU, GST, GT20 GT(5, 10, 20, 40, 80)		
D104 [4880]			--------- WS, WD, AT, RH, AP, GSR, RSR TRD, TRU GST, GT (10, 20, 35)		
Xiao Dongkemadi Glacier (GL) [5600]			------------------------------------〉 WS, WD, AT, GSR, RSR, TRD, TRU		
Tanggula Pass (TS) [5206]				-------------------- WS, WD, AT, RH, GSR, RSR, GST, TRD GT (5, 10, 20, 40)	
Wetland (WL) [5100]				------------------〉 WS, WD, AT, RH, GSR, RSR, GST, TRD, TRU GT (5, 10, 20, 40, 80)	
D100 [4800]				------------------〉 WS, WD, AT, RH, GSR, RSR, GST, TRD, TRU GT (5, 10, 20, 40, 80)	
D66 [4700]		-------------- WS, WD, AT, RH, GST, GSR, RSR, TRD, TRU			

[NOTATIONS]

WS :	Wind speed
WD :	Wind direction
AT :	Air temperature
RH :	Relative humidity
GSR :	Global solar radiation
RSR :	Reflected solar radiation
TRD :	Total radiation downward
TRU :	Total radiation downward
AP :	Air pressure
GST :	Ground surface temperature
GT :	Ground temperature
GTxx, GT(xx) :	Ground temperature xx cm below surface

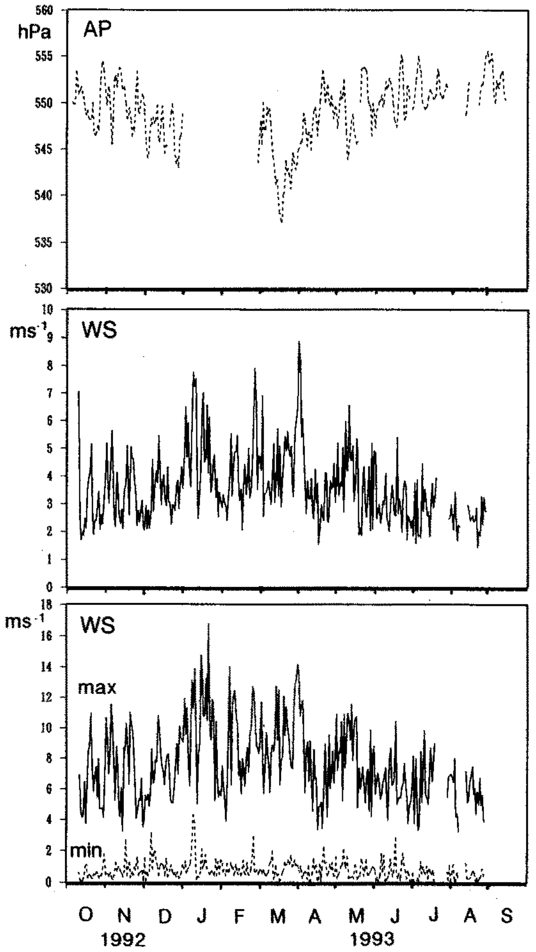

Fig. 2a. Meteorological elements (Air pressure, wind speed) from October 1992 to September 1993 at WL (or D105) which are located 5 km apart with altitude difference of only 80 m.

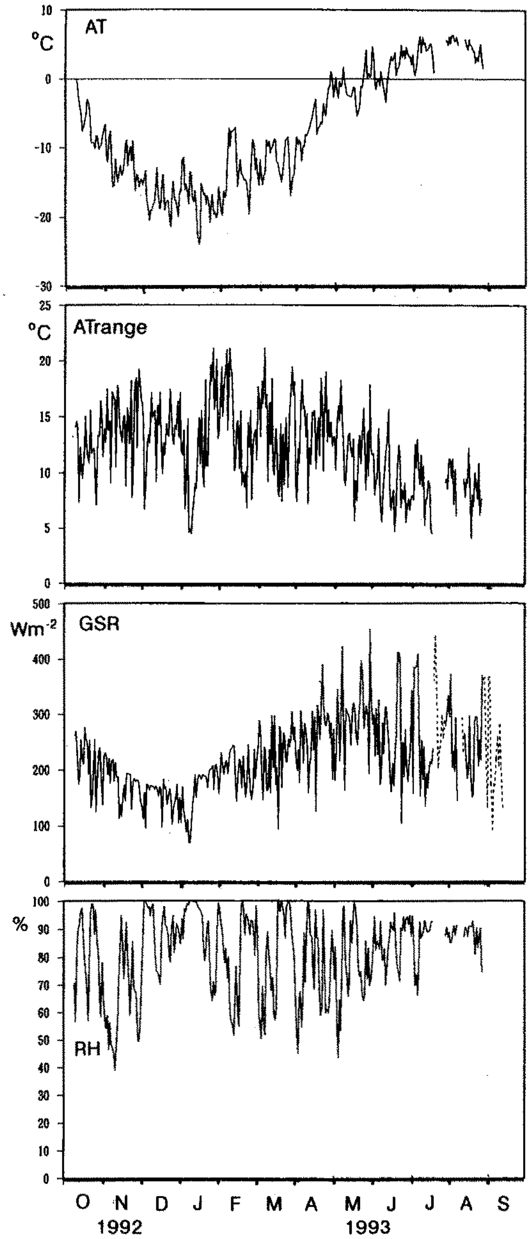

Fig. 2b. Same as Fig. 2a, but for air temperature, daily range of air temperature, relative humidity and global solar radiation.

the end of April, the highest AT, 6 to 7 °C, was observed from the beginning of July to beginning of August. The daily range of AT shown in Fig. 2b indicates that the daily range is rather large, nearly 20 °C, at its maximum in winter and 15 °C in seasonal mean. In summer, the mean daily range decreases to slightly less than 10 °C. In comparison with the annual range of AT, which is 20 to 25 °C, the daily range is quite large. One of the reasons for the large daily range of AT may be the strong insolation and low density of air due to the high altitude. Due to such conditions, there are days in mid-winter when daily maximum air temperature becomes higher than 0 °C, and days in mid-summer when daily minimum air temperature drops below 0 °C.

Wind speed (*WS*) shows stronger wind in winter, and lower in summer. The highest daily *WS* was 8.9 m s^{-1} on April 4, and the lowest was 1.4 m s^{-1} on August 22. The *WS* measured at 2 m level was quite large throughout the year probably due to the high altitude. Daily maximum and minimum *WS* shown in Fig. 2a shows that the annual trend of *WS* follows the maximum. The daily minimum was rather strong in winter, but decreased to nearly zero in summer.

Relative humidity (*RH*) shows strong variation in winter with high and low values, but in summer it is rather constant. Continuous high value days seen in winter corresponded to snow covered days, which probably maintained inversion conditions during most of the day. It must be noted that, these *RH* data have errors of about 10 % in operational procedure (manufacturer value : 5 %) due to changes in sensor sensitivity.

GSR shows a typical annual cycle with lower transmissivity in summer. The lowest value was 69 W m^{-2} on January 7 and 8 ; the highest value was 454 W m^{-2} on May 31. The highest monthly mean value occurred in May, before the monsoon season.

The annual mean values of meteorological elements at 5100 m level (Basically taking WL data, and suppplemented by D105 data) for 1992−1993 were −6. 3 °C for AT, and 3.4 m s^{-1} for *WS*. *AP* was 549.0 hPa at D105.

4. Meteorological conditions during IOP

Figure 3 shows the daily mean/total values of seven meteorological elements (wind speed (*WS*), air temperature (AT), air pressure (*AP*), relative humidity (*RH*), global solar radiation (*GSR*), total cloud cover (*CC*), and precipitation (*P*)). *WS*, AT, *RH* and *GSR* were basically taken at the WL site ; in case data are not available (July 21 to 28, Aug. 29 to Sep. 13) the data at D105 are shown. *CC* was observed at BC, and additional precipitation sampling was done to obtain the $\delta^{18}O$ value of precipitation at BC. Five-day running mean values are shown for *WS*, *AP*, *RH*, *GSR* and *CC*. Daily maximum and minimum are shown for AT. The numerical values for each five-day period are listed in Table 3. *P* is obtained as the total value from 08 : 00 to 08 : 00 the next day ; *CC* is the mean value of five three-hourly observations from 08 : 00 to 20 : 00; $\delta^{18}O$ is the value of precipitation sample taken at 08 : 00 and 20 : 00. Other elements are the mean values of the period from 00 : 00 to 00 : 00 the next day.

AP varies in a quite small range of less than 10hPa, but shows periodic variations.

In summer, the daily minimum AT was near 0 °C or frequently became sub-zero, while the maximum became as high as 15 °C. This means that ground surface will freeze in the nighttime even in summer. There were several days in mid-summer when the daily air temperature was below 0 °C.

Daily mean *WS* seldom became less than 2 m s^{-1}, due to strong wind in the daytime.

Precipitation occured quite frequently ; the strongest was 21.5 mm d^{-1} on June 25. The highest daily precipitation in 1989 (Ohata *et al.*, 1991) was also approximately 25mm d^{-1}. These values seem to be the maximum values of daily precipitation as the cloud system cannot become so thick due to the thin atmosphere. Cloud amount shows an inverse relation with air pressure : high pressure corresponds to low cloud amount. The mean cloud amount for July ~August was 6.9, slightly lower than the climatological mean 7.5 at Nachu (150 km south) for the same period.

The $\delta^{18}O$ value of precipitation showed strong variation during the summer. This is important for determining characteristics of the water cycle, as changes in the stable isotopes of transported water vapors to this area are mainly determined through evaporation from land surfaces and condensation processes during cloud and precipitation formation. The lowest value was −26.3 ‰ on July 27, and the highest value was 2.3 ‰ on July 5. A $\delta^{18}O$ value higher than SMOW indicates that some special water cycle process was occurring during these period. The 5-day mean values of this (Table 3) which were

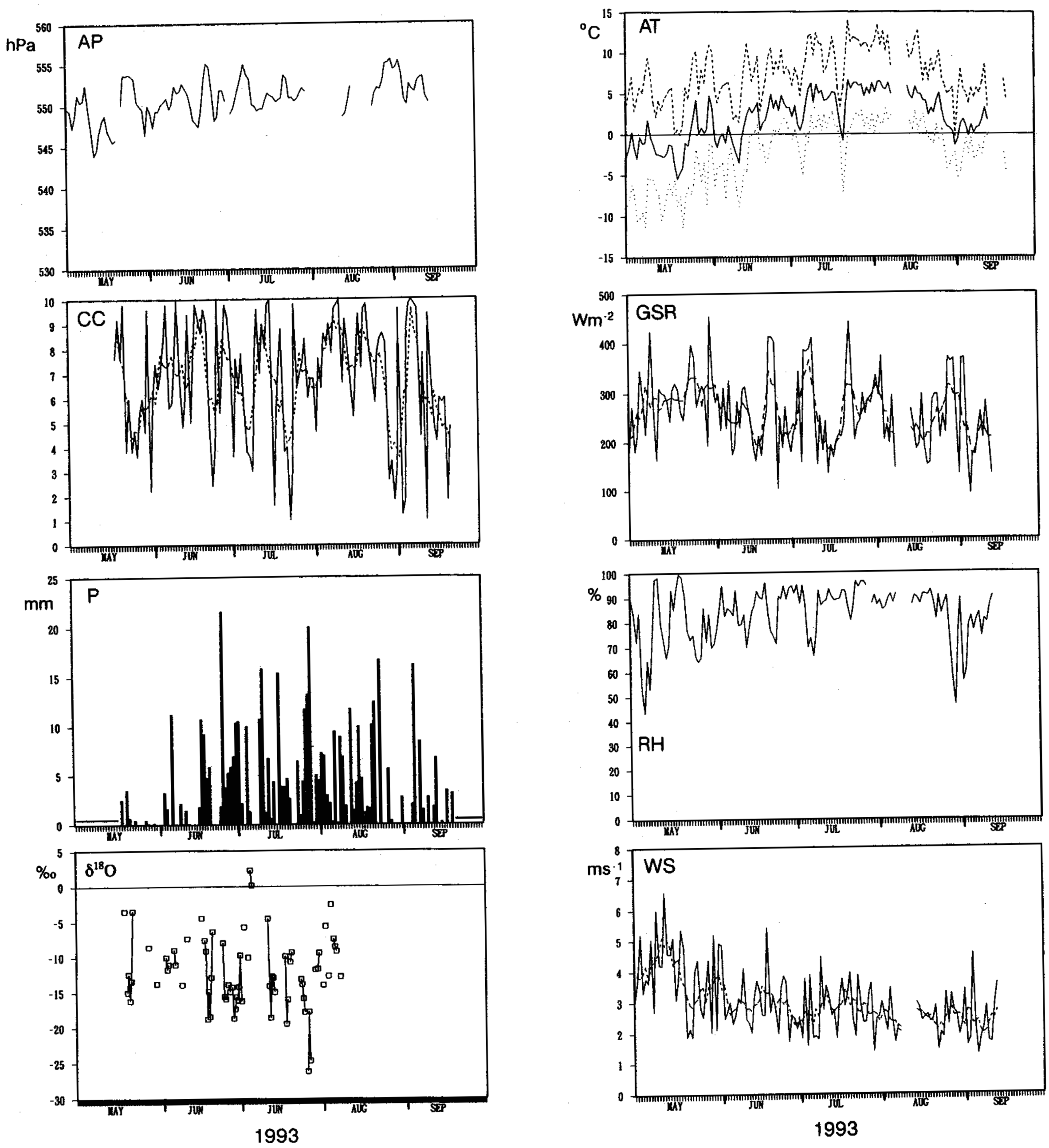

Fig. 3. Variations of seven meteorological elements and $\delta^{18}O$ values taken at 5000 m level site (WL, D105, BC) from May 1 to September 30. Five-day running means of *WS*, *GSR* and *CC* are also shown due to their large fluctuation.

Table 3. Five-day mean or total values of meteorological elements shown in Fig. 3.

Site		WL				D105	BC		
Element		AT °C	WS m/s	RH %	GSR W/m^2	AP hPa	P mm	CC 10.0	σ^{18}O ‰
MAY	1	-1.7	3.8	76	239	549.2			
	2	-0.2	4.3	67	299	549.9			
	3	-2.3	5	77	272	546.3			
	4	-2.8	3.7	94	288	546.1	5.9	8.1	
	5	-2.2	3	76	326	552.9	1.1	5.6	-12.4
	6	1.4	3.5	74	305	549.9	0.6	5.2	
JUNE	1	1.1	3.6	82	289	549.0	4.8	7.0	-11.8
	2	-0.3	3	85	240	550.6	13.3	7.7	-11.3
	3	-0.7	2.7	79	273	551.8	1.4	6.4	
	4	2.7	3.3	91	193	548.5	32.2	9.0	-13.4
	5	2.9	3	79	318	552.5	23.4	6.0	-15.6
	6	3.7	2.5	92	219	550.6	31.9	7.9	-16.7
JULY	1	2.1	2.7	91	268	551.0	23.8	6.2	-13.1
	2	4.1	2.5	76	318	552.3	26.5	5.5	
	3	4.9	2.7	90	201	550.0	12.8	8.8	-14.6
	4	3.7	3.4	91	206	550.7	30.2	5.4	-15.4
	5	*4.3	*2.7	*88	*314	551.2	11.6	4.8	
	6	*5.4	*2.9	*94	*282	551.7	54.4	7.1	-15.0
AUG.	1	6.0	2.7	87	288		19.6	7.1	-10.8
	2	(5.5)	(2.0)	(90)	(212)		27.2	9.2	-11.0
	3					550.0	27.2	7.1	
	4	4.8	2.4	90	204		19.2	8.7	
	5	3.2	2.3	87	247		29.1	7.4	
	6	*1.9	(*2.7)	*71	*314	554.1	8.6	4.9	
SEP.	1	*0.4	*2.7	*73	*227	552.8	18.2	6.2	
	2	*0.5	*2.0	*79	*206	552.4	12.6	8.3	
	3	(*2.2)	(*2.7)	(*85)	(*207)	551.5	8.6	5.2	
	4						6.5	4.9	
	5								
	6								

*: Data of D105
( ) : Lacks a few data

obtained as the arithmetic means of data when the half day precipitation exceeded 2 mm, show lower values in case of strong precipitation. The δD value of BC precipitation, and precipitation samples at other sites will be analyzed soon to investigate the processes related to these variations. It can be seen from Fig. 3 that there is a negative correlation tendency between *P* and also *AP*, and the δ^{18}O value.

5. Areal variation of meteorlogical elements

Five meteorological observation sites (D100, D105, WL, TS and GL) were set in the drainage area from October, 1992. *AT*, *WS* and *GSR* were compared for the summer period.

Daily mean *AT* shows parallel variation between sites. The lapse rate of *AT* was taken for all periods within the IOP when the data were available for D100 and other sites. The values were 6.4 °C km^{-1} and 6.5 °C km^{-1} between GL and D100, and TS and D100 respectively, where an altitude span of more than 400 m could be taken. This lapse rate took larger values in winter.

WS data show that the strongest *WS* occurs at TS, stronger than on the glacier at GL where the altitude is higher. The reason for this seems to be the topographical effect of TS, a saddle point where wind was intensified (refer Fig. 1). The other three sites (WL, D105, D100) located near the bottom of the wide valley show weaker *WS* than these two sites.

GSR shows a similar trend with cyclic variation at five sites, which is probably strongly related to cloud amount (Fig. 3) in this region. *GSR* was highest on GL generally, but there were periods, such as middle of August, when GL showed lowest value. The range of difference of solar radiation between sites were smaller than 20 Wm^{-2}, but there were periods when the range was larger than 100 Wm^{-2}, for example in the middle of August.

WS and *GSR* varied much within this small drainage area of 4,538 km^2.

6. Other measurements and concluding remarks

Intensive automatic observations in 1992–93 and IOP in 1993 were the main part of the Glaciological/Meteorological/Hydrological research work done since 1989 in this region. The results obtained on meteorological elements will be used to obtain the components of the water cycle in this area. During the IOP, precipitation samples were collected at seven sites along the Qingzang Highway, other than BC (sec. 4) for stable isotope analysis. These will be analyzed to obtain information on the water circulation and the problem of precipitation recycling in these regions cited in Sec. 1.

Details of the study and observations and obtained results will be published in other reports in this volume and separately in other journals. The result of long-term monitoring of meteorological elements will be also published as IHAS Reports from the Institute for Hydrospheric-Atmospheric Sciences, Nagoya University.

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