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Meteorological observations during 1994-2000 at the Automatic Weather Station (GEN-AWS) in Khumbu region, Nepal Himalayas

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Abstract

Meteorological observations and characteristics of annual and daily meteorological variables measured by the GEN-AWS in the Nepal Himalayas from October 1994 to October 2000 are presented in this report. The history of maintenance of the observation system from May 1996 to October 2000 is also summarized. The observations show unique seasonal changes in the mountain weather in the Khumbu Himalayas with large year-to-year changes in winter air temperature and snow cover conditions, and heavy precipitation events, even though data have been accumulated for about 5 years.

1. Introduction

Automatic Weather Station (AWS) conducted as a part of Glaciological Expedition in Nepal (GEN) was established at Syangboche Village, Solukhumbu district, in October 1994, in order to observe quantitatively the peculiar local weather and monitor the climate variability in the Nepal Himalayas (Ueno *et al.*, 1996). Since that time, AWS has been running smoothly with the help of many researchers, technicians and local inhabitants. In this report, the characteristics of annual and daily variation of the data for almost 5 years (from October 1994 to October 2000) are presented together with maintenance activities since 1996.

2. Data collection and maintenance

GEN-AWS is located at 86° 43′ E, 27° 49′ N, and altitude 3833 m a.s.l. The observation field is located almost in the center of the Livestock Development Farm (LDF) in Solukhumbu, on the flat and hilly pasture land for yak between Syangboche and Khumjung Village, where grass about 10 cm high has grown sparsely in the bare field. As of October 2000, GEN-AWS was operated automatically by AANDERAA 2740 AWS system with 12 channels at 30 minute time intervals. Measured variables of each channel are shown in Table 1. Data are stored in the Data Storage Unit (DSU), and are retrieved once per a year. The staff of LDF notes the data number displayed on the DSU once per a week. Engineers of the Department of Hydrology and Meteorology (DHM) in Kathmandu mainly carry out data retrieval and maintenance of the system. Once every two years, Japanese researchers carry out sensor exchange and maintenance of the whole system. In the following, the maintenance activities after 1996 are summarized.

a) 1996 May (K. Ueno, R. B. Kayastha, H. Fujinami)
To prevent abnormally low levels of lithium battery power, which cause a serious deletion of data, a solar cell

Table 1. List of components of observation in GEN-AWS in 2000. System and sensors were manufactured by the AANDERAA instruments, Norway.

Channel	Element	Abbreviation	Sensors type
1	Reference channel		
2	Wind speed	WS	3-cup anemometer
3	Max. wind speed	WSmax	
4	Wind direction	WD	Potentiometer
5	Relative humidity	RH	Hygrophiber
6	Downward shortwave radiation	Sd	Temperature difference
7	Pressure	PRESS	Silicon chip
8	Soil temperature at 15 cm	Ts15	Platinum resistor
9	Air temperature	AT	Platinum resistor
10	Precipitation	PRECIP	Tipping bucket
11	Upward shortwave radiation	Su	Temperature difference
12	Soil temperature at 0.5 cm	Ts05	Platinum resistor

power module was introduced. Due to the difficulty of maintaining adequate power supply, the snow depth sensor was removed. Calibration procedures for the temperature, humidity, insolation, and soil temperature sensors were carried out. Training in the data-retrieval operations was performed.

b) 1996 August (A. P. Pokhrel, R. B. Kayastha)
Data were retrieved from the DSU, and maintenance work was performed only by Nepalese for the first time. The humidity and atmospheric pressure sensors were exchanged. Since then, the data number displayed on DSU has been noted by staffs of the LDF once per a week. They are instructed to report to DHM in case of an abnormality, such as no change in the data number from the previous value. This task assures earlier detection and recovery of the AWS system.

c) 1996 November (T. Kadota)
Data were retrieved and maintenance works were carried out. There was a problem in the rain data retrieval from a data memory unit manufactured by the Kadec Co. The necessity of combining two data units into one in the future was examined.

d) 1997 April (O. R. Bajracharya, R. B. Kayastha)
The wind velocity sensor was replaced with a new one. All radiation sensors were detached, and the rain gauge pulse input, which used the KADEC memory, was shifted in AANDERAA DSU. The operation of the KADEC unit was abolished. Afterward, all elements were recorded simultaneously in one DSU. Also, the data retrieved and maintenance of the system were shifted to once a year.

e) 1998 March (K. Ueno, M. R. Chitrakar, D. P. Manandhar, M. Hattori)
Wind speed data were missing since 7 December 1997. The wind speed, upward shortwave radiation, and temperature sensor were replaced. Installation depths of the soil temperature sensor were checked at 0.5 cm and 15 cm. The dome of the net radiation sensor was broken by a bird, and the sensor was removed. System and sensor maintenance training were carried out.

f) 1999 May (R. B. Kayastha)
Data were retrieved and maintenance works were conducted. It was reported that a yak broken through the fence of the observatory on 26 November 1998 and overturned the AWS. The wind speed and direction sensors were broken. The wind speed sensor was manually recovered, but the wind direction sensor was removed. A facsimile machine was introduced into the office of the LDF.

g) 2000 October (K.Ueno, M.R. Chitrakar, H. Iida)
Data were retrieved and maintenance works were conducted. Air temperature, relative humidity, wind speed and direction, upward and downward radiation and pressure sensors were replaced. Due to the battery consumption, some of the nighttime data in the winter 1999 were lost. The replacement of the solar pole is expected in the next field visit.

3. Data processing

Data in DSU are ASCII type and recorded everyday with a time stamp and continuous values of 12 channels with a 30-minute interval (called N value). The previous DSU is replaced with a new one for data acquisition. The N values are retrieved into a portable personal computer through the DSU reader, and are converted into physical quantity (meteorological values) with calibration coefficients for every sensor. The coefficients are determined in Japan before sensors are installed. The calibration coefficients for each observation period are the most important information to determine the accuracy of recorded values. The data are retrieved at the station, then in Kathmandu, and finally in Japan. Retrieval of data, especially at the station, is important to find out the fault signal of the sensor for the maintenance work. Since the data retrieval process takes several hours, power conditions sometimes do not allow the retrieval of data at the station.

Data were recorded almost continuously, except for wind speed data after June 1996. Data correction for wind direction and precipitation is not carried out, even though inaccurate values due to freezing or under-catch of snowfall may be recorded with several hours delay. Unusual wind speed data were sometimes recorded, and these were treated as missing data. According to the data of strong insolation with continuous wind speed data, it was considered that the wind sensor did not freeze for more than several days. Since observation of the radiation is conducted in non-ventilation conditions, dew condensation may exist especially in the morning, but data correction has not been performed. The insertion of missing data and value checks are carried out in Japan, and corrected data are returned to DHM.

4. Climatological aspect of data

Daily mean values are calculated from the meteorological parameters observed at 30-minute intervals, and the time series are shown in Figs. 1-4. Monthly mean values are calculated for the months in which there were no more than 10 days of missing data, and they are presented with the annual mean values in Table 2. Maximum and minimum temperatures in the table correspond to the monthly averages of daily maximum and minimum temperatures, respectively. The precipitation is shown as an integrated value. For 3 years, from June 1996 to May 1999, when data were acquired for the entire season, the seasonal average for each 30-minute interval was calculated and shown as diurnal variations in Fig. 5. Characteristics of each meteorological variable are summarized in the following section by using these figures and tables. The spring, summer, autumn and winter seasons correspond to the months of March-May, June-August, September-November, and December-February, respectively. Here, the year of the winter is defined in which January and February exist.

4.1. Air and soil temperature

Maxima of both air and soil temperatures appear in June, just before the onset of the monsoon. During the monsoon season, almost flat or declining tendencies of these variables are observed due to the cloud development with precipitation (Figs. 1 and 2). Year-to-year variation of the monthly averaged temperature during the monsoon is very small, almost within 1 degree. In winter, the daily minimum temperature reached around -10 ℃, but there were several days with a daily average temperature higher than 0 ℃. The winter averaged temperature fluctuates greatly due to the existence on these warm days or periods. Frequent occurrences of such warm-period may lead to a reduction of the heat storage in winter, and possibly cause the retreating of low altitude glaciers. Average winter temperature is warmest in 1999, which causes the annual mean temperature to increase by more than 1 ℃ over that of other years (Table 2).

Soil temperature at 0.5 cm and upward shortwave radia-

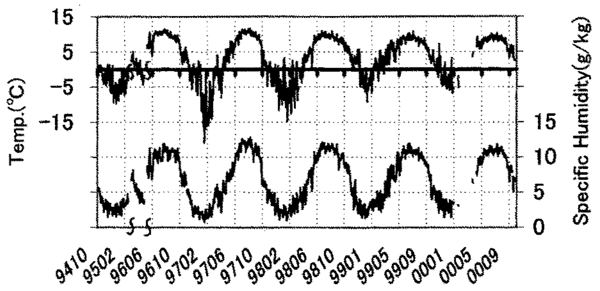

Fig. 1. Daily average air temperature (upper) and specific humidity (lower) from October 1994 to October 2000. Data from March to September 1995, from December 1995 to May 1996, and from February to April 2000 are missing.

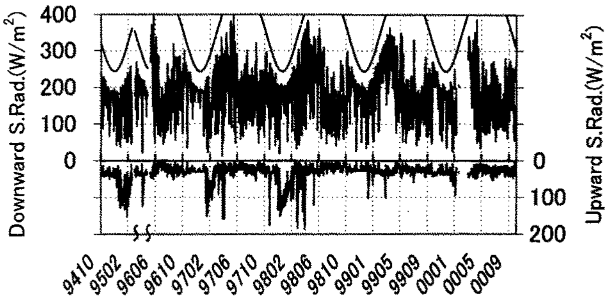

Fig. 3. Same as Fig. 1, except for downward (upper) and upward (lower) short-wave radiation. Solar radiation estimated at the top of atmosphere is shown by smooth curves (upper).

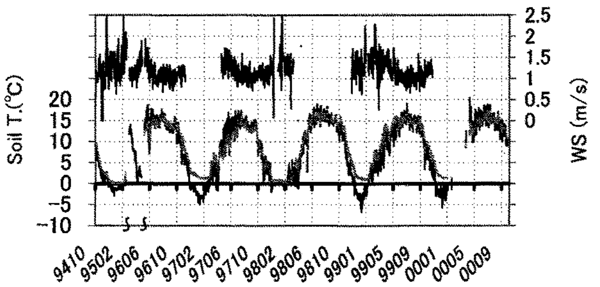

Fig. 2. Same as Fig. 1, except for wind speed (upper), soil temperature at 0.5 cm (lower black line), and soil temperature at 15 cm (lower gray line).

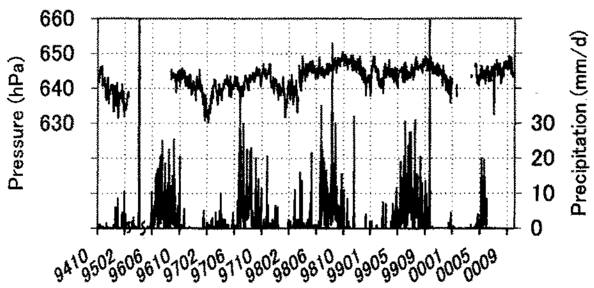

Fig. 4. Same as Fig. 1, except for surface pressure (upper) and daily precipitation (lower). Precipitation data from July to October 2000 are missing.

Table 2. Monthly average of meteorological elements.
Blanks are for missing data.
(AT: air temperature, ST: soil temperature, RH: relative humidity, WS: wind speed, PRES: pressure, Sd: downward short-wave radiation, Su: upward short-wave radiation, PR: precipitation, and q: specific humidity)

AT(℃)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1994											-1.6	-2.9	
1995	-6.4	-4.6								2.4	-0.7		
1996						8.8	10.5	10.1	8.9	4.8	0.0	-1.4	
1997	-9.3	-10.7	-1.4	0.3	5.4	8.8	10.6	10.4	8.8	1.4	-1.3	-4.9	1.5
1998	-5.5	-5.2	-2.2	3.2	6.6	9.5	9.6	9.3	8.0	5.5	2.3	-1.4	3.3
1999	-3.7	0.3	1.6	5.2	5.9	8.0	8.9	8.6	7.6	3.9	1.1	-2.7	3.7
2000	-3.8				7.0	8.3	9.0	8.8	6.9	4.7			
ATmax(℃)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1994											3.5	1.8	
1995	-1.4	-0.7								14.8	9.8		
1996						11.4	12.1	12.6	11.7	9.5	6.5	5.9	
1997	-0.9	-2.9	5.4	6.3	10.2	11.8	13.1	13.0	11.4	7.1	5.1	4.0	7.0
1998	2.8	2.2	2.8	8.5	11.1	12.9	11.8	11.4	10.9	9.0	7.1	3.1	7.8
1999	1.1	5.0	7.0	11.2	9.9	11.1	11.4	11.2	10.6	7.6	6.0	1.7	7.8
2000	0.7			9.4	10.5	11.0	11.8	11.3	10.0	8.5			
ATmin(℃)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1994											-4.8	-6.3	
1995	-10.1	-8.0								-1.9	-5.2		
1996						6.7	9.4	8.2	6.8	0.9	-5.3	-7.9	
1997	-16.7	-17.4	-7.1	-4.7	1.4	6.6	8.7	8.4	6.7	-2.9	-6.5	-11.6	-2.9
1998	-12.4	-11.6	-6.7	-0.6	3.4	7.2	8.1	7.9	6.0	2.6	-0.8	-4.6	-0.1
1999	-7.2	-3.0	-2.5	0.6	3.1	5.9	7.2	6.9	5.3	1.2	-2.5	-6.0	0.8
2000	-7.0				4.7	6.5	7.3	7.3	4.8	2.3			

ST05(℃)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul	Aug.	Sep.	Oct	Nov.	Dec.	Average
1994											3.0	0.7	
1995	-1.3	-0.4								10.7	3.3		
1996						14.0	15.3	14.6	13.4	11.0	5.0	-1.0	
1997	-3.1	-1.5	3.5	5.8	12.0	14.2	15.1	13.9	13.5	7.0	3.5	-0.4	7.0
1998	-0.3	1.0	2.1	7.0	12.2	15.8	16.1	15.8	14.3	11.7	3.7	-1.5	8.2
1999	-2.9	1.1	4.9	9.8	10.8	13.1	15.2	15.1	14.5	9.6	4.3	-1.3	7.8
2000	-2.5				14.1	15.4	16.2	15.3	14.1	12.1			

ST15(℃)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1994											4.4	1.6	
1995	0.2	0.2											
1996						13.5	14.9	14.7	13.8	12.2	7.3	2.6	
1997	1.5	1.3	4.8	5.7	9.3	11.9	14.1	13.3	12.9	7.6	3.9	0.8	7.3
1998	0.6	0.9	3.3	7.6	12.7	16.0	16.0	15.7	14.8	13.6	7.3	2.5	9.2
1999	1.1	2.5	6.4	10.6	12.4	14.6	15.1	15.1	14.6	11.0	7.0	2.8	9.4
2000	1.4				12.8	14.6	15.8	15.4	14.6	12.4			

RH(%)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1994											70.8	59.9	
1995	70.6	81.3								90.7	77.8		
1996						85.7	84.4	87.9	94.2	88.4	74.2	44.3	
1997	66.7	84.9	81.2	84.9	86.5	93.8	94.1	92.9	95.8	87.2	77.2	60.2	83.8
1998	57.0	74.2	81.0	76.4	87.6	93.6	96.7	98.4	94.4	92.4	62.5	57.1	80.9
1999	62.0	60.5	59.2	76.3	90.4	94.8	97.7	97.3	95.7	84.3	66.9	67.7	79.4
2000	67.0				90.4	96.7	97.2	98.5	96.5	88.7			

WS(m/s)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1994											1.0	1.3	
1995	1.3	1.3								1.1	1.2		
1996						1.2	1.0	1.1	1.0	1.1	1.2		
1997				1.3	1.4	1.2	1.1	1.1	1.0	1.1	1.2	1.2	
1998	1.5	1.2									1.3	1.2	
1999	1.2	1.4	1.4	1.4	1.3	1.1	1.0	1.0	1.0	1.1	1.2		
2000													

PRES(hPa)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1994											642.3	639.3	
1995	637.0	636.3											
1996									642.9	643.5	641.4	640.9	
1997	637.2	634.7	639.6	640.3	640.8	640.7	641.0	642.6	643.9	644.4	642.6	640.2	640.7
1998	638.0	639.2	640.7	645.3	645.7	645.1	644.9	646.5	648.3	647.8	647.0	645.2	644.5
1999	642.1	646.2	642.3	645.1	643.9	644.5	644.1	645.7	646.8	647.0	645.6	643.9	644.8
2000	640.6				643.8	644.1	644.4	644.9	645.6	646.5			

Sd(W/m²)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1994											176.1	161.0	
1995	144.9	147.3								198.7	185.5		
1996						162.9	133.4	176.5	167.6	203.4	192.5	189.4	
1997	155.2	150.6	199.2	212.4	243.9	177.8	184.2	181.5	153.3	186.7	184.7	166.8	183.0
1998	186.8	193.4	218.3	272.7	242.7	203.0	130.9	123.4	159.3	206.3	180.2	174.2	190.9
1999	177.2	196.9	272.4	288.3	201.5	180.4	142.4	135.5	167.8	178.5	203.5	148.3	191.1
2000	152.7			260.5	172.6	161.3	156.4	134.7	163.7	198.0			

Su(W/m²)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1994											33.8	34.6	
1995	76.4	79.3								31.2	48.3		
1996						16.6	16.8	26.5	21.5	26.4	26.1	29.2	
1997	54.0	58.3	30.4	37.4	24.6	17.5	23.3	26.4	17.4	38.0	26.6	97.5	37.6
1998	83.1	46.9	56.6	36.7	27.6	22.0	14.9	15.2	16.8	23.8	22.0	22.4	32.3
1999	36.4	24.9	37.0	32.4	19.1	19.3	24.5	24.4	27.3	26.7	33.3	26.6	27.7
2000	34.0			34.9	23.6	24.2	28.9	25.8	27.3	30.1			

PR(mm/m)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1994											3.0	2.5	
1995	22.0	26.0	25.5	20.0	37.0	99.0	240.0	256.0	144.0	8.5	122.5	9.0	1009.5
1996	6.5	39.5	30.5	19.0		139.5	235.5	216.0	136.5	58.0	0.5	0.0	
1997	9.5	15.0	15.5	29.0	18.5	144.5	225.5	212.5	91.5	52.5	9.0	16.0	839.0
1998	3.5	24.0	55.0	10.0	39.0	144.5	215.5	342.5	83.0	36.0	41.5	0.0	994.5
1999	6.5	3.5	13.5	7.0	70.5	94.0	316.0	203.0	115.5	131.0	0.5	0.0	961.0
2000	7.0				18.5	173.5							

q(g/kg)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1994											3.7	2.7	
1995	2.4	3.3								6.5	4.3		
1996						9.6	10.5	10.6	10.5	7.5	4.4	2.2	
1997	1.7	2.1	4.3	5.2	7.6	10.5	11.9	11.5	10.7	5.8	4.1	2.4	6.5
1998	2.1	2.8	4.0	5.7	8.4	10.9	11.3	11.3	9.9	8.2	4.3	2.9	6.8
1999	2.6	3.6	3.9	6.7	8.3	10.0	11.0	10.7	9.8	6.7	4.2	3.2	6.7
2000	2.9				8.9	10.4	11.0	11.0	9.4	7.4			

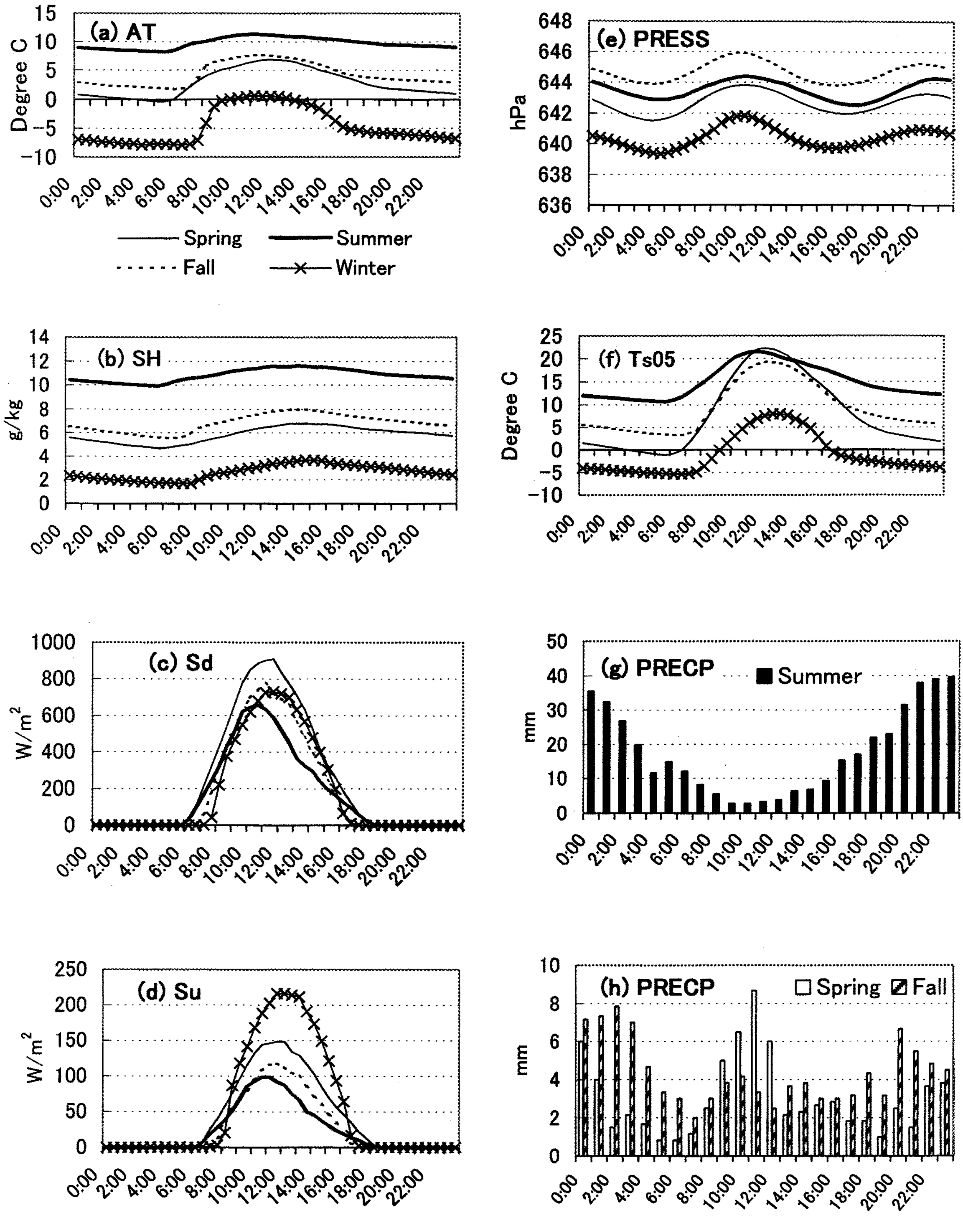

Fig. 5. Diurnal variation in the air temperature (a), specific humidity (b), downward shortwave radiation (c), upward shortwave radiation (d), pressure (e), soil temperature at 0.5 cm (f), and hourly precipitation in summer (g) and spring/fall (h). Thick, thin, dashed and crossed lines correspond to spring, summer, fall and winter season, respectively.

tion data are very useful to detect the existence of snow cover. Snow covered days are defined as when the 0.5 cm soil temperature is at a constant value below 0 ℃ and when daytime albedo is over 50%. The number of snow covered days was 36 days in 1996/97, 73 days in 1997/98-68, and 5 days in 1998/99 during winter, which shows large year-to-year fluctuations. At the station, ground does not freeze, because the 15 cm soil temperature is above 0 ℃ throughout the year. Day-to-day variations of soil temperature become large from December to February, because the diurnal variation of solar radiation flux results in freezing and thawing in the ground. The amplitude of the daily variation of air temperature and soil temperature is the smallest in summer and largest in winter (Fig. 5a,f). This is due to the effects of cloudiness, which prevents surface heating in the daytime and radiative cooling in the nighttime. Besides, soil temperature at 0.5 cm becomes nearly the same at around noon troughout spring to fall.

4.2. *Humidity and precipitation*

To indicate an absolute amount of moisture, the specific humidity is calculated using relative humidity, temperature, and pressure data. Daily averaged specific humidity is almost above 10 g/kg (maximum at around 13 hPa as vapor pressure) during the monsoon season, but it lowers rapidly less than 5 g/kg during the post monsoon and winter season (Fig. 1). Diurnal range of the specific humidity is small in compare with that of the seasonal range (Fig. 5b). Monsoon onset and offset at Syangboche are defined according to the succession of precipitation days, such as three continuous days of non-precipitation before or after the abrupt increase of the amount as onset and offset, respectively. The monsoon periods are defined as 6/3-10/1 (total amount of 740.0 mm) for 1995, 6/16-10/5 (752.5 mm) for 1996, 6/19-10/2 (682.0 mm) for 1997, 6/13-9/14 (744.5 mm) for 1998, and 6/3-10/6 (812.5mm), for 1999 respectively. During 1995 to 1999, 79 % of the annual precipitation occurred during the monsoon season, and daily average precipitation during the monsoon season was 6.7 mm/d. Year-to-year change in the total monsoon precipitation amount was less than 70 mm. Continuous heavy precipitation tends to prevail in the first half of the monsoon period in any years. Heavy precipitation events are not limited to the monsoon periods, as it occurs in the non-monsoon period. For instance, abnormally heavy precipitation in November 9 to 11 in 1995 (122.5 mm) caused a serious avalanche disaster upstream of the Solukhumbu region. It is noteworthy that such a non-monsoon disturbance caused a grater year-to-year change in the annual precipitation amount than that by monsoon precipitation.

The winter precipitation amount in Table 2 could be under-estimated due to under-catch for the gauge or delay of data recording due to the freezing of the tipping bucket. The diurnal change in precipitation amount except in winter is shown in Fig. 5h. In summer, there is a remarkable increase in precipitation from sunset to midnight, with a peak around 21:00-23:00PM. Total precipitation from 16:00PM to 6:00AM corresponds to 88% of the daily total amount. In spring, a peak appears around noon in diurnal variation, although the absolute amount is small. Diurnal variation of the precipitation frequency (not shown) shows similar variations, except that the daytime peak is not evident in spring, and the frequency increases early at night in fall. The seasonal difference in the diurnal precipitation change may be closely related to the melting of snow over a gauge or change of local circulation system associated with seasonal progress of the monsoon system, and future studies are expected.

4.3. *Pressure and wind*

Atmospheric pressure shows seasonal variations within 630-650 hPa at 3833 m a.s.l., with a tendency to high pressure in summer and low pressure in winter (Fig. 4). Westerlies cause weekly fluctuations in the non-monsoon season, but the fluctuation diminishes in the monsoon season. In every season, pressure oscillations prevail twice per a day due to the atmospheric tide (Fig. 5e). Wind speed is comparatively small even at the high elevations. This is because the station is located in a deep valley running in the south-north direction, where mountains shade the upper zonal winds. In addition, the station is located several hundreds meters higher above the valley floor, and the location prevents detection of the shallow wind system along the bottom of the valley. Though the annual variation of wind speed is not accurately observed due to the much missing data, at least the tendency to increasing wind speed in the pre-monsoon season is shown in Fig. 2 and Table 2. Figure 6 shows the seasonally averaged diurnal variation in the wind vector. The valley wind from the south prevails in the daytime from spring throughout the fall, and continues until midnight during the summer. From winter to spring, it tends to blow from the southwest, affected by the general wind above the valley. Mountain breeze continues only in winter at night, and especially in the early morning around 5:00-7:00 from the northwest to north.

4.4. *Radiation*

Daily averaged insolation (downward shortwave radiation) peaks just before the monsoon onset, and is abruptly depressed after the monsoon onset to the same or lower level in the winter season due to the cloud cover (Fig. 3). In Fig. 3,

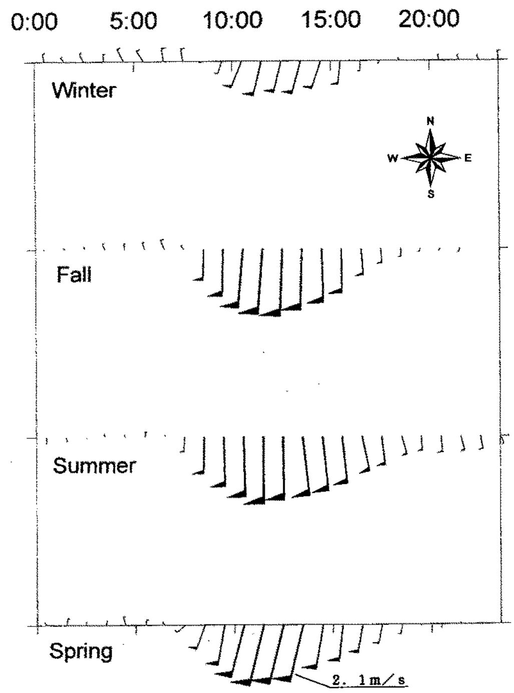

Fig. 6. Diurnal variation of wind vector in each season.

seasonal changes in daily solar radiation calculated at the top of the atmosphere are also shown by the solid curves. Atmospheric conductivity (β-dust) for fair weather days equals around 0.015–0.02, which shows the very clear atmosphere in the Himalayas. Snow cover directly affects the variation in upward short wave radiation. In winter, the tendency of abrupt increases with gradual decreases in upward radiation, which is apparent in winter 1997 and 1998, reflects the change of snow cover areas not only in the observatory but also at the mountain slopes surrounding the observatory. Less upward radiation in winter 1999 indicates less snow cover, which corresponds to the warm winter indicated by the temperature data. Another seasonal change in the upward radiation in the non-winter seasons may be due to the effect of grass. Daily mean albedoes calculated during the snow covered and non-snow covered period are 0.56 and 0.14, respectively. The larger albedo value of the snow covered period (0.56) is the result of the reflection from the surrounding mountain slopes, and it may be one of the characteristics of strong upward radiation in the deep valley with snow cover. The amplitude of the daily variation in insolation is the largest in spring. In summer, insolation peaks at around 11:00, then rapidly lowers due to the cloud development (Fig. 5c). In the meantime, the largest diurnal variation of upward radiation exists in winter because of no cloud condition with snow cover (Fig. 5d).

4.5 Comparison with earlier observations and future plan

Meteorological observation in all seasons at the Khumbu Himalaya was initiated by the GEN science group in 1970 with manual instruments. Seasonal changes of the meteorological elements were successfully observed at Lhajung station, 4420 m a.s.l. in 1973–74 (Inoue, 1976; Yasunari, 1976). According to the differences in observation methods and decades, it is difficult to compare directly the data between Lhajung and Syangpoche. But, qualitative comparison revealed a drier climate at Lhajung; the precipitation amount, for example, is two thirds of that at Shangpoche, with a water vapor pressure less than 10 hPa even in the monsoon season. The temperature at Lhajung is about 2-degrees lower and more frequent snowfall is expected than in the Syangpoche. Mountain-valley wind prevails at both stations, but rather strong wind speed are reported at Lhajung, which may be due to the exposed topography. In 1985-86, the GEN-LP (GEN Langtang project) group conducted meteorological observations at Kyangchen (3920 m a.s.l.) in the bottom of the Langtang Valley, located 120 km west of the Khumbu Valley (60 km north from Kathmandu) with manual and self-recording instruments (Takahashi *et al.*, 1987). More monsoon precipitation than at Syangpoche and heavy non-monsoonal snowfall exceeding 60 cm in depth were reported. The langtang Valley runs in the west-east direction, which caused more influence of westerlies in non-monsoon season and provided larger wind speed than that at Syangpoche. In 1996, Fujita *et al.* (1997) also conducted continuous meteorological observations by automated instruments around a debris-covered glacier in 1996. The automated observation could provide more precise variations, and the results were compared with those in 1980. In this year, heavy precipitation was also recorded in October 1996, which emphasezed sporadic heavy precipitation event in the non-monsoon season as a common important aspect in the Himalayas. Intra-seasonal variation of daily mean short wave radiation reported by Fujita *et al.* (1997) is also found at Syangpoche with around 11 and 20 days frequency analyzed by Fourier series expansion. Automated intensive meteorological observations in the Tibetan plateau were also conducted in the Tanggula mountains since 1989 (Ohata *et al.*, 1994).

The above-mentioned meteorological observations were conducted in connection with glaciological and hydrological research projects, and they were not always aimed at long-term monitoring of weather or climate change at a fixed station. Besides, DHM has established mountain hydro-climatological stations in the Himalayan mountains since 1987 as a part of its Snow and Glacier Hydrology Project (Grabs and Pokhrel, 1993). The observations include water level measurement, and data have been accumulated for the analysis of water resources and climate variability. In the river head of the Khumbu region, an Italian Pyramid Meteorological Group started automated meteorological observations at the foot of Mt. Everest, 5050 m a.s.l., since 1994 (Bertolani *et al.*, 2000). Bertolani and Bollasina (2000) found remarkable year to year changes in the winter meteorological data at the Pyramid station, and relations to a biennial oscillation was discussed. Bollasina *et al.* (2000) reported a different pattern in the diurnal change of precipitation associated with different local and plateau-scale atmospheric circulation. These evidences may be closely related to the results shown in Section 4.1 and 4.2. Comparison of simultaneous data observed at different altitudes in the same basin is very important to confirm the characteristics of such remote mountain weather and also to validate the impact of climate change. Future co-operation between the Pyramid and GEN-AWS meteorological groups is eagerly anticipated.

5. Concluding remarks

Meteorological observations in the Nepal Himalayas from October 1994 to October 2000 are reported. Major characteristics are summarized as follows.

1) In the monsoon season, cloud development with precipitation abruptly reduces the insolation and radiative cooling, which induces lower daily temperatures with small diurnal variation.
2) Wind speed is comparatively weak even at the altitude of 3833 m a.s.l., and the wind system prevails along the major valley running south to north. Valley wind continues from the daytime to midnight in summer, while mountain wind prevails from the mid-night to early morning in winter.
3) Warm periods with daily mean temperature surpassing 0 ℃ frequently occur in the winter season. Frequency and duration of the warm period and snow cover days change from year to year.
4) The precipitation amount is about 700 mm during the monsoon season. Heavy precipitation of more than 30 mm per day is recorded in the non-monsoon period. The diurnal variation in precipitation is maximum during the night in the monsoon period, and a small daytime peak appears during the pre-monsoon period.

Automated meteorological observation by the GEN-AWS has shown large year-to-year changes in the temperature and snow cover conditions, including extremely heavy precipitation events, even though data have been accumulated for only 4 years. To monitor the weather of the Himalayas in relation to the climate variation on a global scale, GEN-AWS must continue to provide even more continuous and qualitative data. Establishment of real time data transmission to the DHM at Kathmandu is one of the urgent tasks to utilize the data not only for system maintenance but also for a possible use in regional weather forecasting or disaster prevention. Further continuous support for GEN-AWS is expected.

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