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Intra-seasonal variation of surface air temperature in Nepal Himalayas

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सार - इस शोध पत्र में नेपाल हिमालय के कुम्भू क्षेत्र में स्यांगपो स्थित स्वचालित मौसम केन्द्र द्वारा प्राप्त किए गए धरातल वायुतापमान में पाए गए अंतः मौसम परिवर्तनों का विश्लेषण किया गया है। मानसूनी मेघों के कारण सूर्य के ताप में काफी कमी आने के परिणामस्वरूप मानसून ऋतु में तापमान लगभग स्थिर रहता है। दूसरी ओर, अस्थायी सिनॉप्टिक स्केल उच्च दाब के कारण तापमान में हुई बढ़ोतरी से शीत ऋतु के दौरान बड़े पैमाने पर अंतः मौसमी परिवर्तन होते हैं; जो हिमाच्छादित परिस्थितियों में रात्रि के समय की तीव्र विकिरणित शीतलन के फलस्वरूप तापमान में कमी आने के साथ-साथ स्थानीय परिसंचरण पैर्टनों को अव्यवस्थित करते हैं। मानसूनी मेघों और गहन घाटी तंत्र के परिणामस्वरूप धरातलीय तापमान में उल्लेखनीय परिवर्तन होता है।

ABSTRACT. Intra-seasonal variation of surface air temperature observed by the automatic weather station at Syangpoche in Khumbu region, Nepal Himalayas, is analyzed. In the monsoon season, temperature was nearly constant with large decrease in insolation due to monsoon clouds. On the other hand, large intra-seasonal variation existed in the winter with increase in temperature associated with passing synoptic scale high-pressure system which disturb local circulation pattern as well as decrease in temperature due to the nighttime strong radiative cooling under the condition of snow covers. Monsoon clouds and deep valley system caused unique surface temperature variation.

Key words – Nepal Himalayas, Temperature, Intra-seasonal variation, Mountain weather.

1. Introduction

Water resources in Nepal Himalayas are strongly dependent on the meltwater from the glacier supplied through out the year. In the past several ten years, it is reported that many glaciers are in the retreating tendency (Fujita *et al*., 1997, Kadota *et al*., 1997). Growth of the glacial lake and its outburst flood are one of the most serious problems for the natural disaster prevention in the Nepal (Yamada and Sharma, 1992). Scientists, who conclude the shrinkage of glaciers by the global warming, are not few. Recently, Shrestha *et al*.(1999) analyzed the decadal scale change of daily maximum temperature which has comparatively small effects of the urbanization, and showed remarkable increase in temperature after 1975 in the Himalayas. For example, in the winter of Trans-Himalaya, remarkable large increase ratio of +0.12 degree/year was reported. Besides, according to the hemispheric scale distribution of recent temperature trend summarized by the IPCC (Parker *et al*., 1995; Jones, 1994), tendency of the temperature trends intermingles by the season and increase of temperature is not obvious in the Nepal region. Fig. 1 shows a time sequence of 500 hPa monthly mean temperature for 1958-1998 over the Nepal by NCEP re-analysis data (Kalnay *et al*., 1996). If linear regression is applied for the winter data after 1970's, there appears a positive trend. But the trend is not statistically significant. There might be two causes for this contradiction of trend between the results of field observation, such as by the Shrestha *et al*. (1999), and global analytical data, such as by the NCEP data. First possibility is due to insufficient field-oriented historical data at high altitudes. In the Himalayas, especially over 3000m above sea level (a.s.l.), there are very few observatories continued since 1960's. In the analysis of Shrestha *et al*.(1999), only two stations were categorized in the Trans-Himalaya to conclude such large increase rate and only three stations data above 2500m a.s.l. were used for the analysis. May the temperature rising in the Himalayas be generalized from such little samples? The

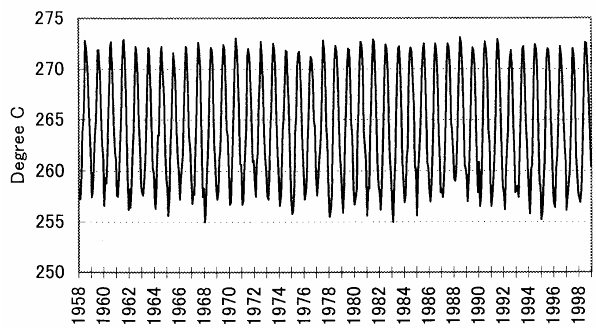
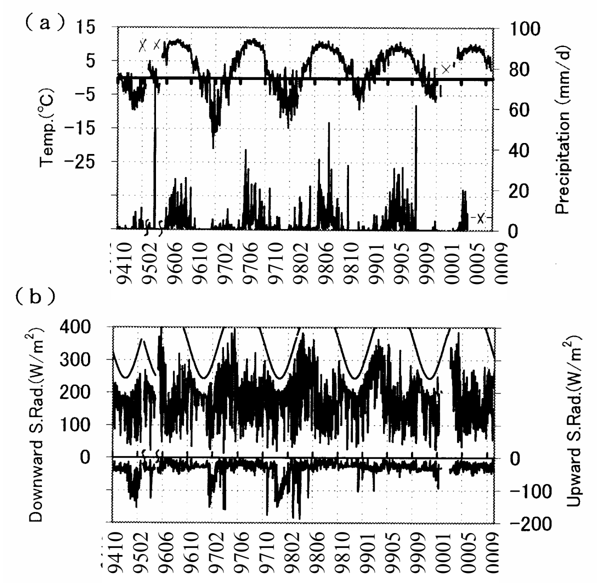


Fig. 1. Monthly temperature variation at 500 hPa in NCEP re-analysis data for 1958-1989. In the 2.5 degree interval data, three grids over the Nepal Himalayas are averaged to produce a monthly data



Figs. 2(a&b). Daily temperature and precipitation change at SY from October 1994 to November 2000. Data are missing from March to September 1995, December 1995 to May 1996 and February to April 2000, as marked by × and (b) The same as (a), but for downward short-wave radiation (above 0 using left side axis) with theoretical insolation at the top of the atmosphere shown as smooth solid curves and upward shortwave radiation (below 0 using right side axis)

second possibility is a problem for global scale data analysis itself to represent surface temperature. Generally, such grid data are constructed based on global circulation model with envelope topography assimilated with surface observation data, and hence, each grid cannot describe local weather accurately, especially in the Himalayas that is having very complex topography. Then, it is very important to observe the behavior of local temperature and investigate the mechanisms to link the global climate variability. To reveal the true tendency and cause of the temperature variations in the Himalayas and utilize for the local hydrological processes and water resource studies, characteristics of the variability of mountain weather should be understood at first based on the continuous and precise observation activities, at least for 10 years. Then, the observed variation should be compared and analyzed with global scale data sets to clarify the impact of hemispheric climate variability.

As a part of Cryosphere Research Expedition in the Himalayas (CREH, Nakawo *et al.*, 1997) and Asian AWS Network of GEWEX Asian Monsoon Experiment (GAME-AAN, GAME International Science Panel, 1998), automated weather station (AWS) was established in the Khumbu Himalayas in 1994 and keep running successfully. This study focuses on characteristics of intra-seasonal variation of surface air temperature observed by the AWS for past 5 years and mechanisms of the intra-seasonal time scale variation are examined in relation to the modification of local mountain weather and topography.

2. Observation

An AWS was established in October 1994 in Syangboche Village (SY), Solukhumbu district, at 3833m a.s.l. as part of CREH project. Location of the observatory was designated as, (*i*) data usage for glaciorology in Khumbu districts, (*ii*) easy access from Katmandu for maintenance, (*iii*) holding comparatively flat area to evaluate surface energy flux. AWS maintenance was taken over to GAME/AAN project after 1998 and about 5 years data were successfully accumulated. Instruments are installed in the center in the flat land (Yak's farming land), exposed to the middle of deep valley (Imja Drangka) running north to south direction. Bottom of the valley is about 3000m a.s.l. and ridges reaches 5000-6000m a.s.l. Along the cross section of the valley, about 2000m difference of vertical distance exists within about 6km horizontal distance that characterize quite deep valley forming the Himalayas. Meteorological elements, such as temperature, humidity, wind, up and downward short wave radiation and atmospheric pressure at 3.2m above the ground and 0.5cm and 15cm soil temperature are observed by using AWS manufactured by AANDERAA Co. Rainfall is also observed by using tipping-bucket type gauge. Snow fall amount is also measured by counting melting water in the container by strong insolation, but those data are recorded with certain time lag and seriously under estimated due to

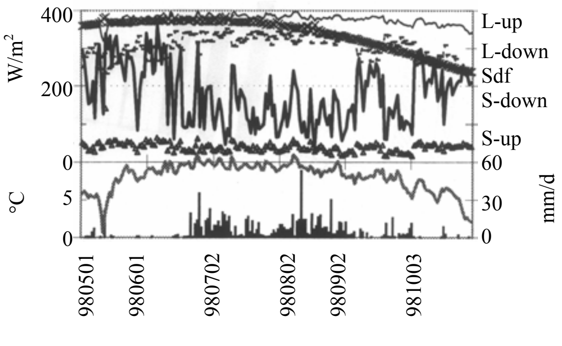


Fig. 3. Daily radiation balance from May to October in 1998. S-down and S-up are observed values, L-up, L-down and sdf are estimated by using methods of Kondo (1994). Daily temperature (gray line) and precipitation (solid bar) are shown together in the lower portion

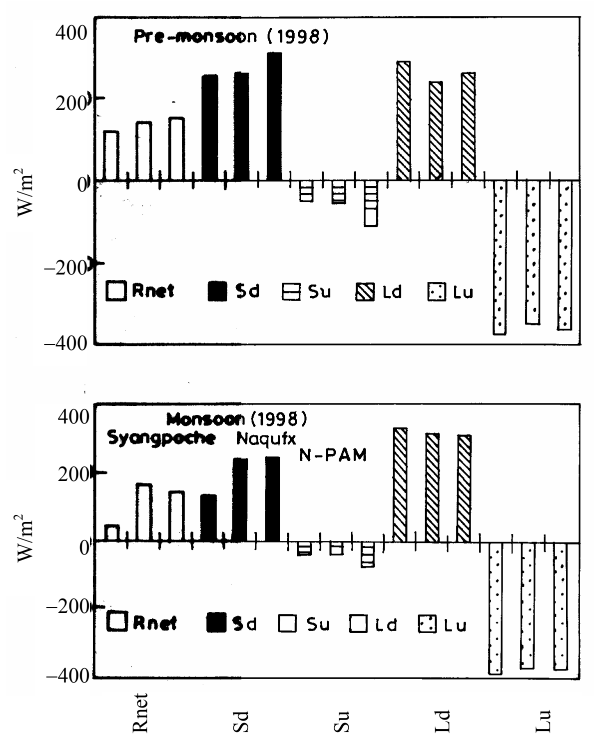


Fig. 4. Radiation balance averaged for pre-monsoon (May 5 to June 14) and monsoon (June 15 to September 3) in 1998. Rnet: net radiation, Sd: downward short-wave radiation, Su: upward short-wave radiation, Ld: downward long-wave radiation, Lu: upward long-wave radiation. Naqufx (N 31:28.7′, E 92:3.0′) and N-PAM (N 31:55.6′, E 91:43.0′) are the stations in the Tibetan Plateau at 4500m a.s.l.

the wind induced and mechanical errors. Instantaneous value in the 30-minute interval is accumulated in a data storage unit and retrieved for once in 1-2 year. Details of the maintenance history and climatology at SY are reported by Ueno *et al.* (1996 and 2001).

3. Results

3.1. *Climate variability in past 5 years*

Fig. 2 shows the variations of daily temperature, precipitation and short wave radiation for past 5 years. The daily mean temperature at SY ranged from -15° C to 10° C and annual precipitation reached 900-1000mm, where large underestimate of the winter precipitation is included. Rainy period (monsoon season) at SY appears from the middle of June to the end of September, when average amount of precipitation for past 5 years was 746mm (Ueno *et al*., 2001). Day average downward and upward short wave radiation (S-down and S-up) was 188 W/m^2 and 32 W/m^2 respectively and average albedo became 0.17. By comparing the daily S-down estimated at the top of atmosphere and that measured in the days by the AWS, atmospheric conductivity (β dust) was estimated as 0.02 - 0.03 which proved that the atmosphere in the Nepal Himalaya is quite clean.

As for the variability of each element, following three characteristics are found, (*i*) In the monsoon season, intra-seasonal and year-to-year variation of the temperature is small. Abrupt decrease of the downward short wave radiation (insolation) occurs, reaching the winter season's level. Maximum insolation arises in June, just before the monsoon onset. (*ii*) In the winter season, large intra-seasonal temperature variation exists with the amplitude of more than 10° C and some days showed the average temperature above 0° C. Year-to-year change of the winter average temperature is also large, but we can not conclude the increase trend of winter temperature because of too short observation period and missing data (as marked × in the Fig. 2). Increase of negative S-up value indicates that number of the days with snow cover drastically changes by the years. (*iii*) Sporadic heavy precipitation, such as more than 40mm per day, are found in the non-monsoon season. Accordingly, year-to-year variation of precipitation in non-monsoon season is larger than that of the monsoon season. To examine the characteristics of (*i*) and (*ii*), following sections focused especially on the mechanisms of intra-seasonal variation of the surface air temperature in monsoon and winter season, respectively.

3.2. *Stable temperature and radiation balance in the monsoon season*

To examine the temperature variation during the monsoon season, the year 1998 was chosen when an

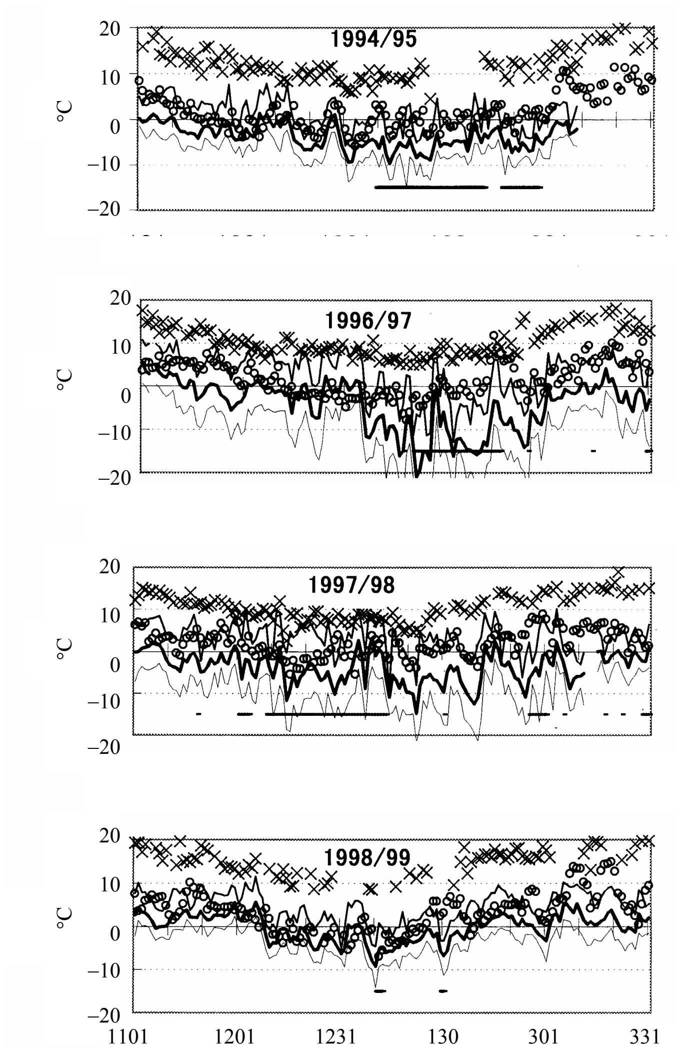
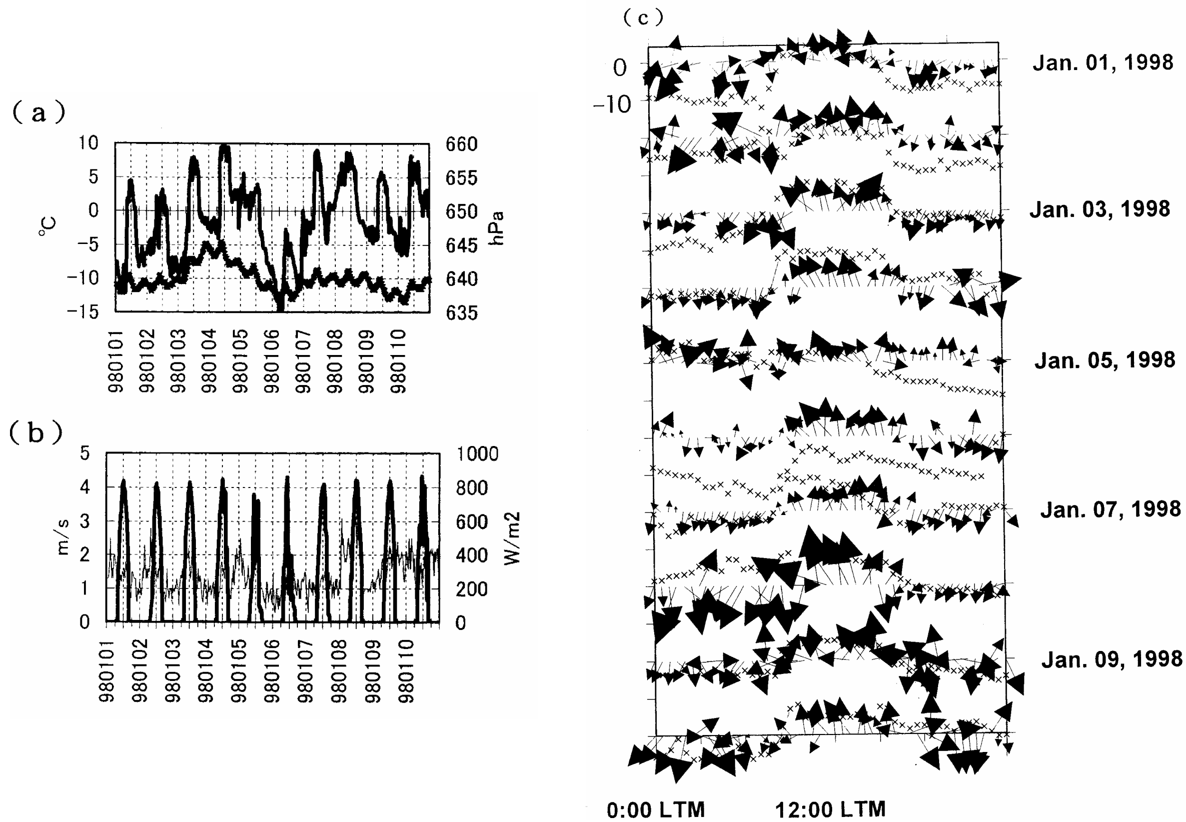


Fig. 5. Daily temperature variations in four winters, from November 1 to March 31. Thick line and accompanied thin and middle lines are daily average, minimum and maximum temperature at SY. Circle and cross marks corresponds to the daily temperature at Kathmandu and Lhasa respectively

intensive meteorological observation was conducted by the GAME/Tibet project (Koike *et al*., 1999) in the Tibetan plateau. Fig. 3 shows time sequences of daily temperature, precipitation and radiation balance from May to September in 1998. Short wave components (S-down and S-up) in the radiation balance were observed values. Upward long-wave radiation (L-up) was estimated by using 0.5cm soil temperature. Downward long-wave radiation (L-down) and daily short-wave radiation in the fair weather condition (Sdf) were estimated using the experimental functions given by Kondo (1994), where the L-down in the fair days was calculated by temperature and humidity data at first, then it was modified to that in the cloudy days as a function of cloud amount determined by the S-down data. The S-down in the fair weather days corresponded well with Sdf. Temperature reached its maximum just before the start of rainy season and it follows almost constant afterwards till the end of August. S-down reached its maximum 380 W/m^2 in the beginning of June when the Sdf is still not reached the maximum, and it abruptly decreased to the level less than 100 W/m^2 after the rainy season started, end of June, due to the cloud development. Estimated L-down and L-up are both dependent on the temperature condition near the surface and showed almost parallel variation. Albedo did not change greatly and the upward short wave radiation was



Figs. 6(a-c). (a) Temperature (solid line) and pressure change (thick line) from January 1 to 10 in 1998, (b) the same for S-down (solid line) and wind speed (thin line) and (c) diurnal change of temperature (cross) and wind vectors

30 W/m^2 or less. As a result, net radiation remarkably decreased after the monsoon onset due to the lowering of S-down. Radiation components before and after the monsoon onset are compared with observation data in the Tibetan plateau (Fig. 4), where the data for the plateau are observed by Tsukamoto *et al.* (1999) at N-PAM and Naqufx located at 4500m a.s.l. In the pre-monsoon season, each component was nearly the same between the data of Himalayas and Tibet. Slight decrease of S-down and increase of L-down, such as at SY and Naqufx, may be caused by the increase of cloud amount in the south. In the monsoon season, long-wave components were not different among three points indicating that estimated values of long-wave radiation at SY are reasonable. Only the S-down at SY was extremely low causing decrease of Rnet.

To summarize the features, extreme small net radiation due to the deficiency of S-down by the orographic cloud development and latent heat flux under the condition of frequent monsoon precipitation are the important factors to produce unique stable daily to day temperature variation at SY during the monsoon season. In other words, heat balance under the Himalayan orographic clouds primarily controls surface temperature during the monsoon.

3.3. *Large temperature variation and local weather in the winter season*

Daily maximum, minimum, and average temperature change at SY for the past four winter seasons are shown in the Fig. 5. Days with snow cover, determined by the condition of daily mean albedo as more than 0.5 and almost no variation of 0.5cm soil temperature at around 0° C continued more than half days, are also marked. Daily temperature at Kathmandu in Nepal and Lhasa in the Tibetan plateau (NCDC/CBS, 1999) are shown together. Large intra-seasonal temperature variation is prevailed at SY especially for 1996-97 winter. Day-to-day difference sometimes exceeded more than 10° C, and days with temperature lower than –10° C and more than 0°C appeared together in the same winter. At Kathmandu, such large variation was not evident. The variation at Lhasa is more similar to SY although the amplitude is rather small. Thus, such large intra-seasonal

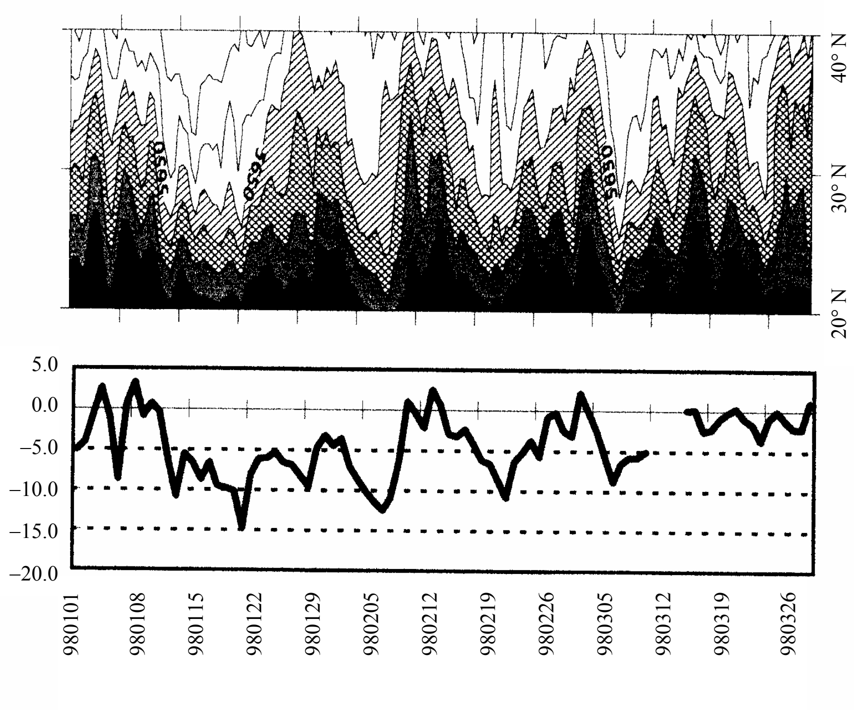
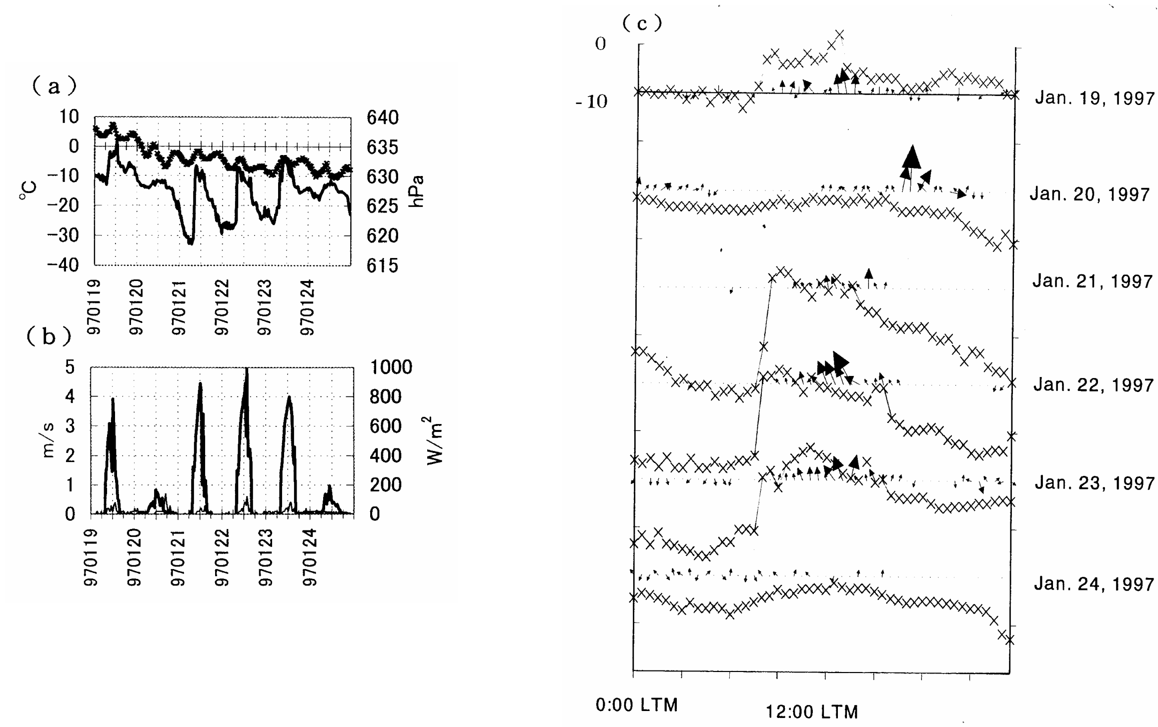


Fig. 7. Latitude-time cross section of 500 hPa pressure height (up) and daily temperature variation at SY (low), from January to March 1998. Dark colors correspond to the increase of height. NCEP re-analysis data are used for the cross section

variation of the temperature is the unique characteristics in the mountains with high elevations, such as at SY.

To examine the local weather for the case with abrupt temperature increase, variations of meteorological elements through January 1-10 in 1998 are shown in Fig. 6. Increase of temperature occurred from 4-5 and 7-8 [Fig.6(a)], which is not in a single day or hourly time scale. During these warm periods, both daytime (maximum) and nighttime (minimum) temperature increased associated with increase in pressure. S-down data showed decrease after the daily temperature peaks on 6 and 10 [Fig. 6(b)], indicating the development of clouds. Diurnal change of the wind vector is shown with temperature change in Fig. 6(c). From the afternoon on 2 to evening on 4, and from the morning on 7 to morning of 9, the typical valley and mountain wind system was clearly observed, such as sudden increase of temperature accompanied with southerly strong wind in the daytime and relatively low temperature with weak northerly wind in the night. Besides, when the warm period started on 4, mountain wind in the night is not clear and turbulent wind was observed such as on 6, 9 and 10. Daily temperature change at SY from January to March in 1998 is compared with synoptic scale pressure fields as shown by time-latitude cross section of NCEP 500 hPa geopotential height in Fig. 7. Increase of pressure (ridge at 500 hPa) corresponded well with increase of surface temperature, which agrees with the behavior of observed surface pressure as shown in Fig. 6(a). The high-pressure at 500 hPa appeared in the whole regions between 20°-40° N. Accordingly, warm temperatures events are accompanied with disappear of local circulation and successive disturbance with cloudy weather due to the passing of synoptic scale high-pressure system around the Tibetan plateau.

Next, to examine the case of abrupt temperature decrease, daily changes of meteorological elements from January 19-24 in 1997 are shown in Fig.8. Marked decrease in temperature occurred during nighttime from 21 to 23 [Fig. 8(a)]. On 20, daily insolation became quite low and next-day albedo suddenly increased Fig. 8(b), and the tipping bucket gauge recorded precipitation. Insolation increased for 21-23. These features obviously indicate that there were snowfall events on 20 and snow cover existed in the following days with fair weather. During this cold period, night temperature fell below



Figs. 8(a-c). Same as Fig.6, but for the period from January 19 to 24 in 1997

–20° C, but increased sharply (above 0° C) in the morning due to insolation. However, the wind speed was almost below 1m/s and mountain-valley wind system was not obvious Fig. 8(c). Major cold temperature periods also tend to appear with snow cover days as shown in Fig.5. Probably, radiative cooling associated with snow cover under weak wind condition in the night caused such extreme low temperature periods. Generally, mountain weather is characterized with strong wind condition. But in the Nepal Himalayas, extreme elevated ridges prevent general wind flow and provide calm condition within the valley. Especially at SY, the deep valley runs north to south direction which is perpendicular to westerlies and this effect is expected to be enhanced.

4. Summary

By using the meteorological data which has been observed by the automatic weather station at Syangpoche in the Nepal Himalayas since 1994, intra-seasonal variation of the surface temperature and mechanisms of variation were examined. Followings are the important findings.

(*i*) During the monsoon season, daily surface temperature change is nearly flat and year-to-year variation is also small. This may be caused by the small net-radiation balance with small insolation and large latent heat flux due to prevailing of orographic monsoon clouds and precipitation.

(*ii*) During the winter season, large intra-seasonal temperature variation exists, which affects the seasonal mean temperature value. This large variations are associated with warm temperature period, caused by passing synoptic scale high pressure system followed with a disturbance, and cold temperature period, produced by radiation cooling with snow-cover and weak wind condition.

This study pointed out the important functions of monsoon clouds and modification of winter local circulation to determine the surface air temperature variability in the deep valley. Most of the observatories in the Himalayas are located in such deep valley and the variability is quite dependent on the local topography. Since 1990, Italian research group also started meteorological observation in Khumbu valley, and comparison studies have started to reveal local weather characteristics (Bollasina *et al.*, 2002). To understand the impact of large-scale climate change to local weather condition and to assess the year-to-year variation in Nepal, we need to continue the monitoring observations for atleast ten years to increase sample years under the international co-operation framework, and also the meso-scale modelling studies are expected in the future.

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