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Study project on the recent rapid shrinkage of summer-accumulation type glaciers in the Himalayas, 1997-1999

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Abstract

A three-year glaciological project was carried out in Nepal and Bhutan Himalayas to verify progressing glacier variations under the global climate change, to study on the variation mechanism and to predict the future variation, in succession to the studies from 1994 to 1996. Recent rapid shrinkage of glaciers and its acceleration tendency were verified. Such tendency was found in large debris-covered glaciers as well as small debris-free glaciers. Expansion of glacier lakes in recent decades in the Bhutan Himalayas was also observed as a result of glacier retreat. Related meteorological data at high altitudes and proxy data from snow/ice and tree-rings to reconstruct climate change were collected for further analyses. A simulation model for the glacier variation has been developed.

1. Introduction

Rapid shrinkage of the summer-accumulation type glaciers has been observed in the Himalayas during recent decades (e.g. Yamada *et al.*, 1992; Kadota *et al.*, 1997; Fujita *et al.*, 1997) and such trend seems to be accelerating now under the global warming. Glaciers are very vulnerable to the increase in air temperature, specially for the summer-accumulation type glaciers due to the strong negative effect on glacier mass balance, since proportion of snow is decreased by the temperature rise during summer monsoon season and accumulation decreases; surface albedo is decreased by the snowfall decrease and ablation increases (e.g. Ageta and Higuchi, 1984; Ageta and Kadota, 1992; Fujita and Ageta, 2000). The glacier shrinkage could affect significantly water resources, geo-hazards, landscapes and the global sea-level change.

Based on the above background, the present study project aimed to verify the present situation, to study on the variation mechanism and to predict the future variation of the Himalayan glaciers by developing the simulation model. The three-year research project was carried out in the Nepal Himalayas during the period from 1997 to 1999 in succession to the studies from 1994 to 1996 (Nakawo *et al.*, 1997) as the joint research of Glaciological Expedition in Nepal (GEN since 1970s) between Japan and Nepal (Department of Hydrology and Meteorology, Ministry of Science and Technology). In the Bhutan Himalayas, the field observations were carried out in 1998 and 1999 as the newly established joint research between Japan and Bhutan (Geological Survey of Bhutan, Ministry of Trade and Industry). The present report describes briefly the outline and preliminary results of the field research.

2. Observations in Nepal

2.1. Outline

The field research in Nepal during the period from 1997 to 1999 included the detection of the recent change of glaciers and glacier lakes, continuous data collection of meteorological elements, snow/ice and tree-ring coring for reconstruction of past climates, and glaciological process studies for prediction of the future glacier variation. The observations were carried out in four areas in Nepal as shown in Fig. 1. The time sequence of the field observations in Nepal is indicated in Fig. 2, in which horizontal bars indicate the observation periods in the abbreviated areas. The researchers participated in each field site are listed in Table 1.

For the previous project from 1994 to 1996, Nakawo *et al.* (1997) reviewed on the items of glacier fluctuations, automatic weather stations, sampling of wood and snow/ice, debris-covered glaciers and heat budget observations. Besides during the previous and present projects, a glacier inventory for east Nepal was compiled on the basis of new

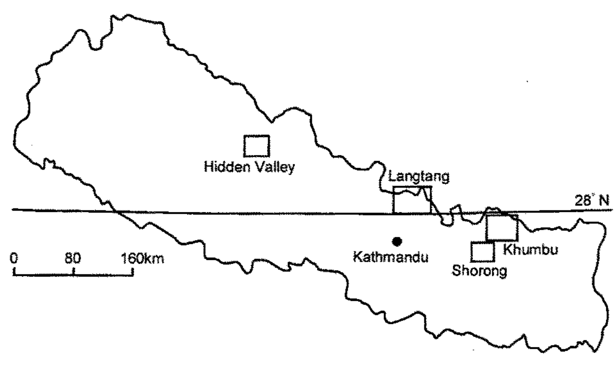

Fig. 1. Observation sites in Nepal (1997-1999).

Table 1. List of researchers participated in field observations in Nepal (1997-1999).

	Research site	Month	Members
1997	AWS	4	Bajracharya[1], Kayastha[1]
	Khumbu	7	Chikita[2], Hasegawa[2], Yamada[3]
	Shorong	10-11	Fujita[4], Naito[4], Nakazawa[4], Rana[1]
1998	AWS	3	Chitrakar[1], Hattori[5], Manandhar[1], Ueno[5]
	Hidden Valley	9-10	Azuma[6], Fujita[4], Kobayashi[7], Nakawo[4], Nakazawa[4], Rana[1], N. Takeuchi[8]
	Shorong	10	Fujita[4], Nakazawa[4]
1999	Langtang	4-5	Conway[9], Gades[9], Kadota, Naito[4], Nereson[9]
	Khumbu & AWS	5-6	Conway[9], Gades[9], Kadota, Kayastha[4], Naito[4], Nereson[9], Y. Takeuchi[10]
	Hidden Valley	9-10	Fujita[4], Nakazawa[4]
	Shorong	10-11	Fujita[4], Kobayashi[7]

AWS: Automatic Weather Station at Syamboche
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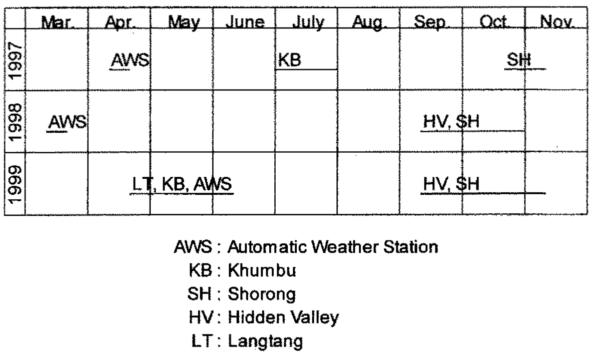

Fig. 2. Periods of field observations in Nepal (1997-1999).

topographical maps (1:50,000 by Survey Department, Nepal from aerial photographs in 1992 cooperated with Finland), and each glacier extent was compared with maps in 1950s. This inventory will be published near future by Asahi *et al.* (in preparation). In this chapter, observations of the present project are described on the corresponding items as follows.

2.2. Glacier variations

Stake measurements on mass balance and surveys on volume changes, terminus positions and flow velocities of debris-free glaciers were carried out on Glacier AX010 in Shorong Himal every autumn and on Rikha Samba Glacier in Hidden Valley, the north slope of Mt. Dhaulagiri in the last two autumns during the present three-year project (Figs. 1 and 2). Observations on variations of debris-covered glaciers are described later.

Glacier AX010 was observed in 1978, 1979, 1989, 1991 and every year since 1995. In averaged annual rates from 1978 to 1996 and from 1996 to 1999, area-averaged mass balances were -70 cm/a and -74 cm/a; terminus retreats were 3.9 m/a and 30.0 m/a; area decreases were 0.005 km^2/a and 0.02 km^2/a, respectively (Fujita *et al.*, 2001a; Kadota *et al.*, 1997) for the glacier length 1.7 km and its area 0.57 km^2 in 1978. The annual balances for 1996/97 and 1997/98 were negative for the whole glacier area, namely no accumulation area during these two measurement years (Fujita *et al.*, 2001a).

Averaged annual terminus retreats of Rikha Samba Glacier were obtained including the previous data in 1974 and 1994 (Fujita *et al.*, 1997); those were 10 m/a from 1974 to 1994 and 16.9 m/a from 1994 to 1999 (Fujita *et al.*, 2001b) for the glacier length about 6.3 km in 1974. The above results from two glaciers in east and west Nepal show the acceleration of glacier shrinkage in the recent years.

In combination with the above observations, automatic meteorological data were collected on Glacier AX010 (air temperature at 5247 m a.s.l. from Nov. 1997 to Oct. 1999) and Rikha Samba Glacier (air temperature, solar radiation, wind speed and precipitation at 5267m from Oct. 1998 to Sep. 1999).

2.3. Automatic Weather Station

An automatic weather station was installed in 1994 at Syamboche (3833 m a.s.l.), southern margin of the Khumbu Himal (Ueno *et al.*, 1996). The maintenance and the data collection at the weather station have been carried out every year (AWS in Fig. 2) with a collaboration with GAME (GEWEX in Asian Monsoon Experiment) project, and continuous data during the period were obtained successfully (Ueno *et al.*, 2001).

2.4. Sampling of snow/ice and wood cores

Hand-coring was carried out at an altitude of 5884 m in the accumulation area of Rikha Samba Glacier in 1998, and snow/ice samples in 15 m depth were collected to recover climatic change in recent 30 years, approximately. The frozen samples were transported to Japan without melting; physical (stratigraphy, air bubble, grain size), chemical (including amino acids), micro-biological and pollen analyses have been made including study on origin and transformation process of dusts.

Tree-ring core samples for dendro-chronological analysis were collected at the southern foot of Mt. Dhaulagiri (south of Hidden Valley), 1998 and in Shorong region, 1999. The samples are under examination to recover air temperature and precipitation for several hundreds years.

2.5. Debris-covered glaciers

Surveys on glacier variations and ice thickness measurements were carried out on Khumbu Glacier in Khumbu Himal and Lirung Glacier in Langtang Himal in the pre-monsoon season, 1999 (Figs. 1 and 2). In comparison with the previous surveys on Khumbu Glacier in 1978 and 1995 (Kadota *et al.*, 2000), the averaged annual rate of surface lowering in the upper ablation area was about 2 m/a from 1995 to 1999, roughly two times of that for the former 17 years; the averaged annual flow speed in the same area was 18 m/a, roughly half of the former (Kadota *et al.*, in preparation). The surface lowering in the ablation area of Lirung Glacier was in a range of 1-1.5 m/a in averaged annual rates from the previous survey in 1996 (Naito *et al.*, in preparation). These results show accelerating shrinkage of debris-covered glaciers as well as debris-free glaciers in the recent years.

Ice thickness was measured jointly with members from Geophysics Program, University of Washington by the use of a portable radio echo-sounding system developed by them. Successful measurements were made up to 450 m thick on Khumbu Glacier and 160 m thick on Lirung Glacier through thick supraglacial debris (Gades *et al.*, 2000). These results provide valuable data for modeling of glacier response to climatic change. For example, Naito *et al.* (2000) developed a new model for coupled mass-balance and flow of a debris-covered glacier to account for the effects of supraglacial debris on glacier evolution in addition to their model for debris-free glaciers (Naito *et al.*, 2001).

Ablation and heat balance measurements were carried out at debris-covered and debris-free sites in the ablation area of Khumbu Glacier together with meteorological observations during the end of May, 1999; insulating effect of debris to ablation was studied and major role of net radiation in ablation controlled by albedo and debris was revealed (Takeuchi *et al.*, 2000; Takeuchi *et al.*, 2001; Kayastha *et al.*, 2000).

In recent decades, proglacial lakes of debris-covered glaciers in the Nepal Himalayas have been expanding and danger of glacier lake outburst floods (GLOF) is increasing (Yamada, 1998). At one of such large lakes, Imja Lake of Imja Glacier in Khumbu, physical conditions, water budget and heat budget were observed in July 1997 and mechanism of the lake expansion was analyzed with these data (Chikita *et al.*, 2000).

3. Observations in Bhutan

3.1. Outline

The monsoon precipitation in Bhutan in eastern Himalayas is much higher than that in Nepal and western Himalayas. Therefore, decrease of glacier mass balance and associated glacier retreat with similar summer warming is likely to be more pronounced in Bhutan. However, no study has been published on glacier variations in Bhutan after exploratory works in the 1960s by Gansser (1970). Since the rapid change of glaciers impacts geo-hazards such as GLOF, combined monitoring of the variations of glacier lakes and the surrounding glaciers is needed for assessment of future risk potential.

Joint research with Geological Survey of Bhutan was initiated in 1998 for the study on the variations of glacier lakes and surrounding glaciers. Field research was executed in northern and northwestern parts of Bhutan in September and October 1998 and in the same season 1999. On the basis of this research and other available information, inventories for 30 glacier lakes and risk assessments of the glacier lake outburst flood were made. The related observations were also carried out on glacial geomorphology and climates. The research route in 1998 and the inventoried 30 lakes with code numbers are shown in Fig. 3. Research members in 1998 and 1999 are listed in Table 2.

The field research aimed to obtain a broad view of conditions in a large area where ground observations have been scarce. Brief results of the GLOF assessment are published elsewhere (Ageta *et al.*, 2000); preliminary results on recent variations of glaciers and glacier lakes and related weather data collection are introduced in the followings.

3.2. Variations of glaciers and glacier lakes

On the basis of the field observations, historical variations of glacier lakes and glacier termini were examined comparing photographs, satellite images and maps in different years (Ageta *et al.*, 2000). In the northern region of Bhutan, supraglacial ponds on some debris-covered glaciers in the 1950s have subsequently grown into moraine-dammed lakes. Also, major proglacial lakes have expanded substantially as a result of retreat of glacier termini in a range of 30-35 m/a in average for 1980s-1990s with some larger rates due to irregular calving of glacier tongues.

Debris-free glaciers which have no proglacial lakes have been also retreating in comparison with photos in 1984. The one-year shrinkage of Jichu Dramo Glacier (length about 2.5 km; mark A along the eastern route in Fig. 3) between 1998 and 1999 was surveyed. Surface lowering of the lowest glacier area and the terminus retreat along the long fringe was measured. Another small glacier (mark B in Fig. 3), north of Jichu Dramo Glacier was mapped in 1999 for the future resurvey.

3.3. Automatic weather data

Automatic instruments for air temperature and precipitation were set at three sites in the eastern headwaters area of Pho Chu (river) in 1998. One was Thanza village (4160 m

Table 2. List of researchers participated in field observations in Bhutan (1998-1999).

	Research site	Month	Members
1998	northwest-north Bhutan	9-10	Ageta[1], Iwata[2], Karma[3], Naito[1], Narama[2], Sakai[1]
1999	north Bhutan	9-10	Naito[1], Nishikawa[4]

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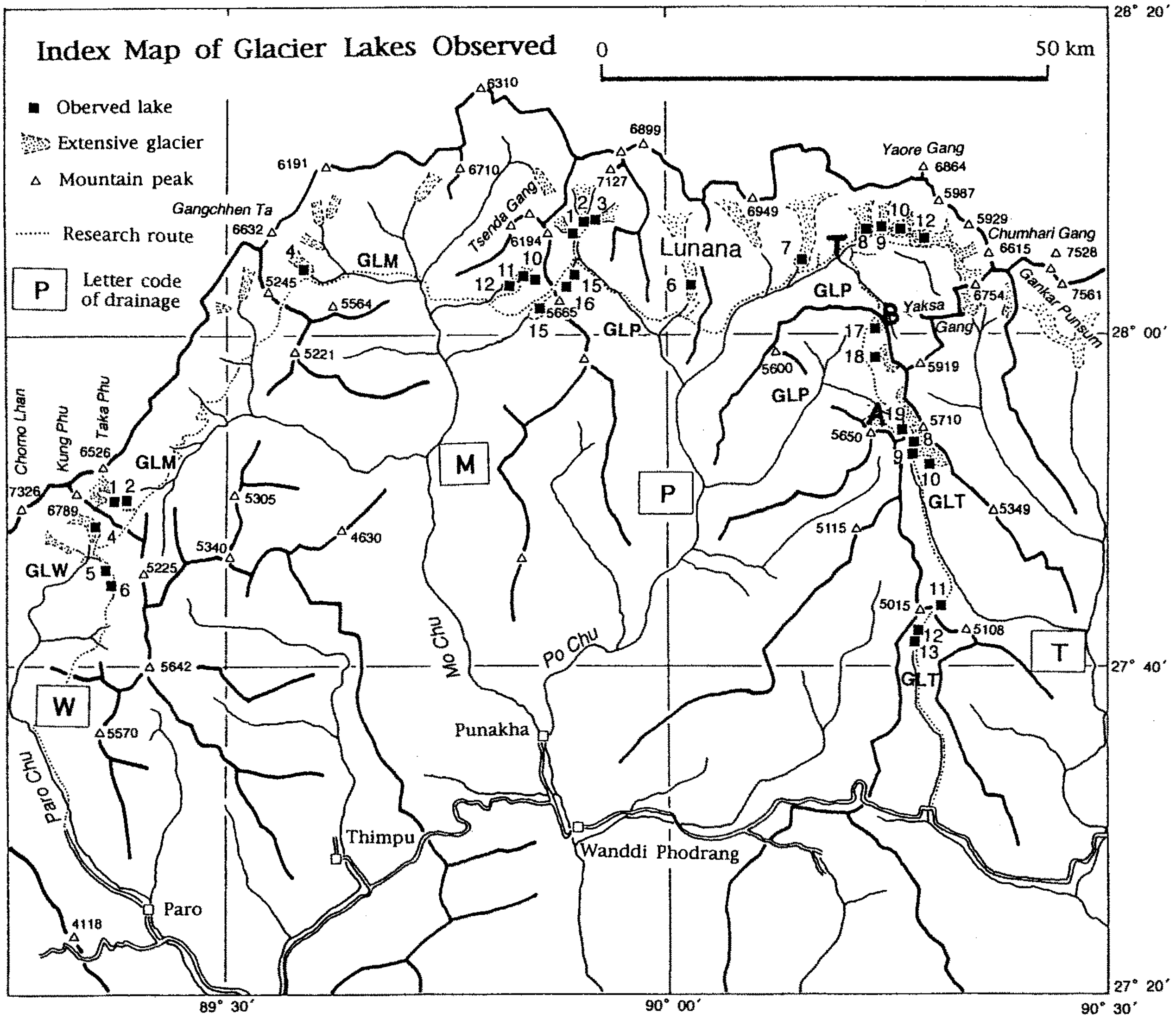

Fig. 3. Index map of glacier lakes in north and northwest Bhutan and a research route in 1998 (Ageta et al., 2000). Code numbers of glacier lakes are based on Geological Survey of Bhutan (1999).

a.s.l.; mark T in Fig. 3) in Lunana which appears to be the most vulnerable area for GLOF; the others were at altitudes of 5115 m and 5245 m beside Jichu Dramo Glacier. One-year data were collected in 1999.

4. Concluding remarks

Recent rapid shrinkage of glaciers and its acceleration tendency were verified in Nepal and Bhutan Himalayas from the observational results during the present project. Such tendency could be seen in large debris-covered glaciers as well as small debris-free glaciers, though response time scales and sensitivity to the climate change are quite different between them. Further monitoring and prediction on variations of both types' glaciers and glacier lakes are very important to understand the future change of the local water resources & geo-hazards and the global sea-level under the progressing climate change. In addition, comparative studies on glacier variations under different magnitude of Asian monsoon effect over the great Himalayan Range and surrounding high mountainous areas are required, since the vulnerable summer-accumulation type glaciers controlled by the monsoon are widely distributed with various characteristics in Asia.

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