Bulletin of Glacier Research 15 (1997) *53–58*

Basic studies for assessing the impacts of the global warming on the Himalayan cryosphere, 1994–1996

Masayoshi NAKAWO[1], Koji FUJITA[1], Yutaka AGETA[1], Kiran SHANKAR[2], Adarsha P. POKHREL[2] and YAO Tandong[3]

1 Institute for Hydrospheric-Atmospheric Sciences, Nagoya University, Nagoya 464-01 Japan

2 Department of Hydrology and Meteorology, Ministry of Science and Technology, Kathmandu, Nepal

3 Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, Lanzhou, China

(Received March 26, 1997 ; Revised manuscript received April 11, 1997)

Abstract

A three-year project has been carried out to obtain basic knowledge for assessing the impact of the recent global warming on the Himalayas, of which many glaciers and permafrost are considered very vulnerable to the warming. The field study was made both in the Nepal Himalayas and the Tibetan Plateau from 1994 to 1996 under a collaboration between Japanese, Nepalese and Chinese scientists. It was found that many glaciers in the area were shrinking. Detailed process of individual glacier was also studied, in particular on debris covered glaciers for which the melting process has been poorly understood so far. Many of wood and snow/ice samples have been collected for reconstructing the recent climate change over the area.

1. Introduction

The Himalayan cryosphere constructed with glaciers and permafrost is very important in water circulation in the area. In Nepal, for example, most of the rivers are nourished by glaciers in the Himalayas in particular during the dry season when the water demand is intense. The cryosphere, however, is very vulnerable to the rise in air temperature, and the recent global warming could affect significantly the present runoff regime. It is important, therefore, to examine the recent changes of glaciers, meteorological and hydrological elements concerned, and to understand variety of processes among them.

A three-year project was elected and the field investigations conducted in Nepal Himalayas and in Tanggula Mountains, central Tibet, from 1994 to 1996. The field activity included the detection of the recent change of glaciers (glacier monitoring), continuous data collection of meteorological elements at two stations (one in Nepal and one in Tibet), wood and snow/ice sampling for reconstructing past climate in the mountains, and glaciological, hydrological and meteorological process studies for assessing and predicting the impact of the past and/or further change in climate on the cryosphere. The present report describes briefly the field investigations and introduces some of the results so far obtained.

2. Observations

The investigations were carried out in Tanggula Mountains and Xixiabangma area in Tibet as shown in Fig. 1, where TG and XB indicate the two sites respectively. In Nepal, five sites were selected for the studies : Khumbu(KB), Shorong(SH), Rolwaling(RW), Langtang(LT) and Hidden Valley(HV). Their locations are shown in Fig. 2, where Xixiabangma in Tibet is also marked.

The time sequence of the field observations for the three years are shown in Fig. 3. Horizontal bars indicate the rough time periods during which the abbreviated study sites as shown above were visited. AWS in the figure indicates the visits to an automatic weather station installed at Syamboche, southern margin of the Khumbu area. Another weather sta-

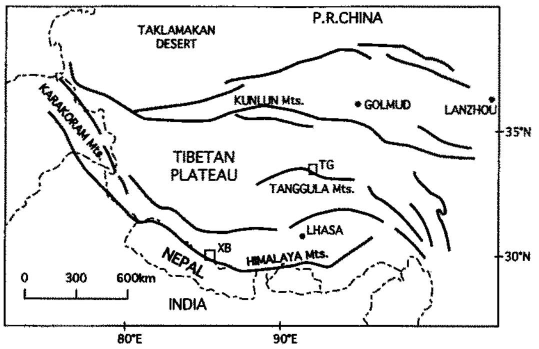

Fig. 1 Study area. TG : Tanggula Mountains ; XB : Xixabangma.

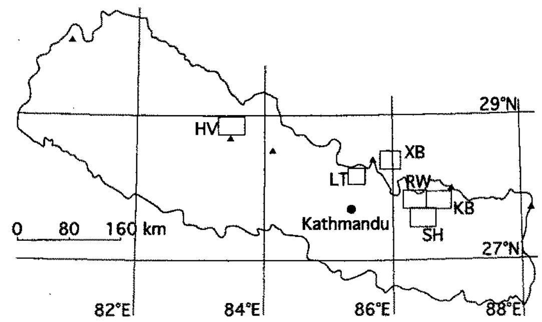

Fig. 2 Study sites in Nepal. HV : Hidden Valley ; LT : Langtang ; RW : Rolwaling ; SH : Shorong ; KB : Khumbu ; XB : Xixabangma.

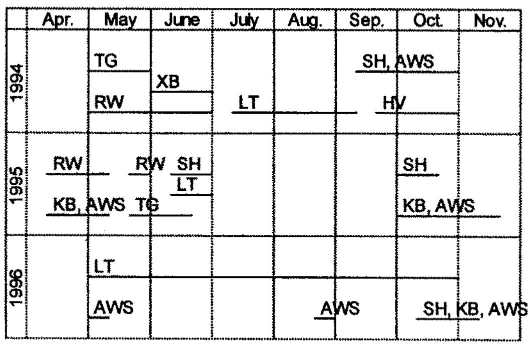

Fig. 3 Time series of field investigations. AW S: Automatic Weather Station at Syamboche. Abbreviations for the study sites are given in Figs. 1 and 2.

tion was installed and maintained in Tanggula mountains, but the visits to the station, in Fig. 3, are included in the activities in Tanggula(TG). Participants for each field sites in particular periods are listed in Table 1, in which people for only logistic support are excluded. The investigations at Rolwaling were made with a collaboration with Water and Energy Commission Secretariat (WECS), His Majesty's Government of Nepal, and a couple of researchers were with us, but their names are not listed either.

3. Glacier fluctuations

The mass balance and the size of glaciers have been measured, since 1973, in the Himalayas. Glacier AX010 in Shorong, is one of the well studied glaciers among those in the Himalayas (*e.g.* Ageta and Higuchi, 1984 ; Ageta and Kadota, 1992 ; Kadota and Ageta, 1992). The glacier was selected for further monitoring. The Rikha Samba Glacier in Hidden Valley and the Gyajo Glacier in Khumbu were also selected to be monitored, since the glaciers were surveyed at least once and the mass balance data were also obtained (Tanaka, 1972 ; Fushimi, 1978 ; Fujii *et al.*, 1976 ; Nakawo *et al.*, 1976), although they were not as in detail as for Glacier AX010. The Yala Glacier in Langtang was also decided to be monitored, which has been surveyed intermittently since 1981(Yokoyama, 1984). In Tibet, the mass balance study was started in 1989 and in 1991 at the Xiao Dongkemadi Glacier in Tanggula (Seko *et al.*, 1994 ; Pu and Yao, 1994 ; Fujita *et al.*, 1996) and Kangwure Glacier in Xixiabangma (Liu *et al.*, 1996) respectively, and the study has been continued in this project.

In those studies of mass balance, all the glaciers were found to have decreased significantly in their total mass. The decreasing rate was very high in compared with glaciers in the other part of the world. Additionally, in Glacier AX010, the flow speed was found to have decreased lately, which could be correlated with the decrease in mass balance. The detailed results will be published elsewhere.

The above six glaciers selected for monitoring are roughly debris free at their surfaces and relatively small in size. In Nepal Himalayas, however, large glaciers are mostly covered with thick debris at the surfaces in the ablation area. It was expected that the debris covered glaciers would respond to the climate change in a different way from the small glaciers. Additional two glaciers (Khumbu Glacier in

Table 1. The list of participants in the field observations.

	Research site	Months	Members
1994	Tanggula	5	Fujita[1], Gao[2], Hou[2], Kang[2], Ma[2], Nakawo[1] Pu[2], Sun[2], Xiao[2], Yabuki[1], Zhang[2]
	Rolwaling	5-6	Kayastha[3], Sakai[4], Takeuchi[5], Yamada[4], (WECS)
	Xixabanama	6	Fujita[1], Liu[2], Pu[2], Sun[2], Yabuki[1], Yao[2], Zhang[2]
	Langtang	7-9	Fujita[1], Kayastha[3], Takeuchi[5], Seko[1], Yoshimura[5]
	Shorong	9-10	Kakastha[3], Kubota[6], Suzuki[7], Ueno[8]
	AWS	10	Kayastha[3], Kubota[6], Suzuki[7], Ueno[8]
	Hidden Valley	10	Fujii[9], Fujita[1], Paudyal[3]
1995	Rolwaling	4-5	Fujita[1], Kadota[1]
	Khumbu	4-5	Aoki (Te)[10], Aryal[3], Seko[1], Yoshimura[5]
	AWS	5	Aoki (Te)[10] Aryal[13], Iida[11], Seko[1], Yoshimura[5]
	Tanggula	5-6	Leng[2], Pu[2], Seko[1], Wang[2], Yoshimura[5], Zhang[2]
	Rolwaling	5	Chikita[12], Sakai[1], (WECS)
	Langtang	6	Kojima[7], Kubota[6], Naito[1], Nakawo[1], Rana[1]
	Shorong	6	Fujita[1], Kadota[1], Yadav[3]
	Shorong	10	Fujita[1], Kayastha[3], Sakai[1], Takeuchi[5], Yamaguchi[4]
	AWS	10	Seko[1], Yabuki[1]
	Khumbu	10-11	Aoki (Ta)[13], Aryal[3], Fujita[1], Fushimi[14], Iwata[15], Kadota[1], Kayastha[3], Kohshima[5], Sakai[1], Seko[1], Takeuchi[5], Yabuki[1], Yamaguchi[4]
1996	Langtang	5-10	Adhikary[1], Aoki (Ta)[13], Aoki (Te)[10], Asahi[15], Batt[1], Chettri[3], Fujita[1], Kayastha[3], Kubota[6], Masuzawa[1], Mishra[3], Nakawo[1], Ooishi[6], Rana[1], Sakai[1], Shakya[3], Sweda[16], Takeuchi[5]
	AWS	5	Ueno[14], Fujinami[8], Kayastha[3]
	AWS	8	Kayastha[3], Pokharel[3]
	Shorong	10	Ageta[1], Kadota[1], Kayastha[3]
	Khumbu	11	Kadota[1]
	AWS	11	Kadota[1]

Affiliations : 1. Institute for Hydrospheric-Atmospheric Sciences, Nagoya University. 2. Lanzhou Institute of Glaciology and Geocryology. 3. Department of Hydrology and Meteorology. 4. Institute of Low Temperature Science, Hokkaido University. 5. Tokyo Institute of Technology. 6. Tokyo University of Agriculture and Technology. 7. Iwate University. 8. Tsukuba University. 9. National Institute of Polar Research. 10. Meteorological Research Institute. 11.Toyama Prefectural Government. 12. Faculty of Science, Hokkaido University. 13. The University of Tokyo. 14. The University of Shiga Prefecture. 15. Tokyo Metropolitan University. 16. School of Agriculture, Nagoya University.

Khumbu and Lirung Glacier in Langtang) with supra-glacial debris were selected, therefore, to be examined in the recent change in their total mass since they were surveyed in 1978 and 1987 respectively (Iwata *et al.*, 1980 ; Yamada *et al.*, 1992). Detailed mapping of the glaciers disclosed the significant decrease of their mass (thinning) after the previous survey.

The response of glaciers to the climate change can also be detected by observing the change in terminus position of glaciers, although the dynamics of individual glacier has to be taken into account for the quantitative assessment. Since the terminus position is a rather easy measure of estimating glacier mass, data have been piled up at least in the areas chosen for the present project (*e.g.* Fushimi and Ohata, 1980 ; Yamada *et al.*, 1992). The terminus position was measured in Khumbu, Hidden Valley, Shorong and Langtang, and examined with published maps in Hongu region near Khumbu during the present three-year project. It was found that the termini have basically retreated and no glacier appeared to have advanced.

In addition to the glacier change, the change of permafrost was also studied by detecting its lower limit in Hidden Valley and Khumbu, since it was observed in 1970s (Fujii and Higuchi, 1976).

4. Automatic weather stations (AWS)

In the mountainous area in the central part of Asia, there are few meteorological stations. In this project, therefore, we made an effort to establishand maintain two automatic meteorological stations in the study area. One station was established at Syamboche, Khumbu, Nepal in 1994. The measured components at the station are listed in Tables 2, and they have been measured every 30 minutes. Another was prepared at Tanggula Mountains, China, where similar observation had been carried out already (Ohata *et al.*, 1994). The previous station was modified, renewed and re-arranged in 1994 and maintained afterwards. The basic elements were the same as the previous observation. Table 3 shows the observed elements at the Tanggula station, where the data have been collected every 1 hour. The both stations have worked satisfactorily (Ueno *et al.*, 1996), and we plan to continue the observation further beyond 1997.

5. Sampling of wood and snow/ice

To examine the response of glaciers to the climate change, it is essential to know the recent regional climate change over the area. In the mountains, however, as mentioned in the previous section, instrumental record of the climate is rather poor. In the present study, therefore, we planned to reconstruct the recent climate change with proxy data through dendro-chronological analysis and ice core analysis. A total of 188 increment cores of tree-ring representing 94 individual trees were sampled from 4 study sites in Langtang Valley, Nepal, and a snow/ice core of 23 m in length at the accumulation area of Rikha Samba

Table 2. Syamboche Automatic Weather Station

Channel	Element	Sensors	Catalogue accuracy	Manufacturer
2	Wind speed	3-cup anemometer	2%	Aanderaa Co. (2740)
4	Wind direction	Potentiometer type	5°	same (3150)
5	Relative humidity	Hygrophiber	3%	same (2820)
6	Downward shortwave radiation	Temperature difference type (0.3-2.5μm)	2mW/cm^2	same (2770)
7	Pressure	Silicon chip	0.2hpa	same (2810)
8	Soil temperature (15cm)	Platinum resistor		
9	Air temperature	Platinum resister	0.1°C	same (2775)
10	Downward all wave radiation	Temperture difference type (0.3-60μm)	3%	same (2811)
11	Upward shortwave radiation	Temperature difference type	2mW/cm^2	same (2770)
12	Soil temperature (0.5cm)	Platinum resister		
*	Rain gauge	Tipping bucket type	0.5mm	
*	Net radiation	Temperature difference (0.25-60μm)		REBS (Q*7)
*	Snow depth	Supersonic	1mm	Keyence C0. (UD-320)

Table 3. Tanggula Automatic Weather Station

Channel	Element	Sensor	Catalogue accuracy	Manufacturer
1	Ground Temperature (0cm)	Platinum resister	0.1°C	Aanderaa Co. (2812)
2	Wind speed	3-cup anemometer	2%	Aanderaa Co. (2740)
3	Wind Direction	Potentiometer	5°	Aanderaa Co. (3150)
4	Global Radiation	Temperature difference type (0.3-2.5μm)	20W/m^2	Aanderaa Co. (2770)
5	Atmospheric Radiation	Temperature difference type (0.3-60μm)	40W/m^2	Aanderaa Co. (2811)
6	Ground Temperature (5cm)	Platinum resister	0.1°C	Aanderaa Co. (2812)
7	Relative Humidity	Hygroscopic hair	3%	Aanderaa Co. (2820)
8	Air Temperature	Platinum resister	0.1°C	Aanderaa Co. (2740)
9	Ground Temperature (20cm)	Platinum resister	0.1°C	Aanderaa Co. (2812)
10	Global Radiation	Temperature difference type (0.25-60μm)	20W/m^2	Aanderaa Co. (2770)
11	Atmospheric Radiation	Temperature difference type (0.3-60μm)	40W/m^2	Aanderaa Co. (2811)

Glacier, Hidden Valley, Nepal (Fujii *et al.*, 1996). The snow/ice core is considered to cover the last 90 years, based on a preliminary analysis of Tritium content. The samples are under examination and the results will be reported elsewhere.

6. Debris-covered glaciers

Most of large glaciers in Nepal Himalayas are covered with debris at their ablation area. The melting process of this type of glaciers had not been well studied except a few works (*e.g.* Inoue and Yoshida, 1980), and even the rate of melting at the glacier surface was rather difficult to estimate because of the presence of debris. The process has been intensively examined within the present project.

The ablation rate was estimated, for Lirung Glacier in Langtang, with an energy model for debris cover (Nakawo and Takahashi, 1982), and the estimate was combined with a hydrological model (Fukushima, 1988) to calculate the discharge from the glacier. The estimation was compatible with the discharge observation, indicating that the developed method can be used for deriving the ablation rate at debris-covered glaciers and runoff from those glaciers (Rana *et al.*, 1997). The method could be further used to predict the ablation/discharge for different climatic conditions such as with doubling CO_2 (Rana, 1997). It was found also that the shrinkage of the debris-covered glacier contributed significantly to the river flow and the annual amount of discharge was much larger than the annual precipitation.

Many supraglacial lakes have been found over the debris-covered area of many large glaciers. The presence of the lakes could play an important role in the melting or the deterioration process of the glaciers. Tsho Rolpa Lake near the terminus of Trambau Glacier seemed to be a kind of final stage of the supraglacial lakes, and the heat budget observations were made at the lake. The lake was considered to be one of the most dangerous glacier lakes which could cause Glacier Lake Outburst Flood (Yamada, 1993). Water and Energy Commission Secretariat (WECS) was also interested in the lake from the view point of disaster prevention, and the field investigations were carried out jointly with members from WECS. The supraglacial lakes were studied not only at Trambau Glacier but also at Khumbu Glacier and Lirung Glacier. It was found, by examining the three glaciers, that there can be two types of lakes, of which one type seemed to have linked with the englacial hydrological system, and the other type being independent individually without any water channel connected with the other lakes nor streams. The difference could lead to different effect or contribution to the melting process for debris-covered glaciers.

Chemical balance for Lirung Glacier was also examined taking into account the chemical constituents in precipitation, englacial and supraglacial streams, lakes, glacier ice , and runoff water.

7. Heat budget observations

To relate the glacier change with the climate, the heat budget study is of great importance. During the present project, heat exchange between the atmosphere, glacier surfaces and soil surfaces was also investigated. Solar radiation is the principal heat source for glacier ablation in the Himalayas. Detailed observations were hence made on how the radiation is absorbed in snow/ice with respect to variety of snow/ice types such as particle size, dust content and so on for respective wave lengths. Significant contribution of long wave radiation from the steep valley wall (including the reflection) was identified. Also, the characteristics of wind and moisture movement (including evaporation) were investigated in Langtang Valley for assessing the water circulation, and accordingly the heat budget in the basin scale.

Acknowledgments

We would like to express our sincere gratitude to Ministry of Water Resources and National Council for Science and Technology, His Majesty's Government of Nepal, and Chinese Academy of Sciences for the special consideration to this project with the permission for the research. Water and Energy Commission Secretariat, MWR, HMG of Nepal, in particular, has supported us in the field investigations in Rolwaling. Mr. Om Bajracharya and the other many staffs of Department of Hydrology and Meteorology have supported us during the preparation stage as well as in the field work in Nepal. Also, we have received a number of hearty support from many staffs from Lanzhou Institute of Glaciology and Geocryology, Embassy of Japan in Kathmandu, Kathmandu Club House, Guide for All Seasons Co. Ltd. Their kind helps to our project are greatly appreciated. Our thanks are due to friendly cooperation of many local people in the field, without which our work would not have been possible.

The expense of this project was supported by a Grant-in-Aid for International Scientific Research Program (Project No. 06041051) from the Ministry of Education, Science, Sports and Culture, Japanese Government.

References

1. Ageta, Y. and K. Higuchi (1984) : Estimation of mass balance components of a summer-accumulation type glacier in the Nepal Himalaya. Geografiska Annaler, **66A**, 249−255.
2. Ageta, Y. and T. Kadota (1992) : Predictions of changes of glacier mass balance in the Nepal Himalaya and Tibetan Plateau : a case study of air temperature increase for three glaciers. Annals of Glaciology, **16**, 89−94.
3. Fujii, Y. and K. Higuchi (1976) : Ground temperature and its relation to permafrost occurrences in the Khumbu region and Hidden Valley. Seppyo, **38**, Special Issue, 125−128.
4. Fujii, Y., M. Nakawo and M. L. Shrestha (1976) : Mass balance studies of the glaciers in Hidden Valley, Mukut Himal. Seppyo, **38**, Special Issue, 17−21.
5. Fujii, Y., K. Fujita and P. Paudyal (1996) : Glaciological research in Hidden Valley, Mukut Himal in 1994. Bulletin of Glacier Research, **14**, 7−11.
6. Fujita, K., K. Seko, Y. Ageta, J. Pu and T. Yao (1996) : Superimposed ice in glacier mass balance on the Tibetan Plateau. Journal of Glaciology, **42**, 454−460.
7. Fukushima, Y. (1988) : A model of river flow forecasting for a small forested mountain catchment. Hydrological Processes, **2**, 167−185.
8. Fushimi, H. (1978) : Stratigraphic studies of the Gyajo Glacier, Khumbu Himal. Seppyo, **40**, Special Issue, 17−20.
9. Fushimi, H. and T. Ohata (1980) : Fluctuations of glaciers from 1970 to 1978 in the Khumbu Himal, East Nepal. Seppyo, **41**, Special Issue, 71−81.
10. Inoue, J. and M. Yoshida (1980) : Ablation and heat exchange over the Khumbu Glacier. Seppyo, **41**, Special Issue, 26−33.
11. Iwata, S., O. Watanabe and H. Fushimi (1980) : Surface morphology in the ablation area of the Khumbu Glacier. Seppyo, **41**, Special Issue, 9−17.
12. Kadota, T. and Y. Ageta (1992) : On the relation between climate and retreat of Glacier AX010 in the Nepal Himalaya from 1978 to 1989. Bulletin of Glacier Research, **10**, 1−10.
13. Liu, S., Z. Xie, G. Song, L., Ma and Y. Ageta (1996) : Mass balance of Kangwure (flat top) Glacier on the north side of Mt. Xixiabangma, China. Bulletin of Glacier Research, **14**, 37−43.
14. Nakawo M., Y. Fujii and M. L. Shrestha (1976) : Flow of glaciers in Hidden Valley, Mukut Himal. Seppyo, **38**, Special Issue, 39−43.
15. Nakawo, M. and S. Takahashi (1982) : A simplified model for estimating glacier ablation under a debris layer. IAHS Publication No. **138**, 137−145.
16. Ohata T., K. Ueno, N. Endoh and Y. Zhang (1994) : Meteorological observations in the Tanggula Mountains, Qingzang(Tibet) Plateau from 1989 to 1993. Bulletin of Glacier Research, **12**, 77−86.
17. Pu, J. and T. Yao (1994) : Mass balance of glaciers in the East Kunlun and Tanggula Mountains, Tibetan Plateau. Bulletin of Glacier Research, **12**, 105−107.
18. Rana, B. (1997) : Study on glacier ablation under debris-cover for runoff modeling of a river basin in Langtang Valley, Nepal Himalaya. PhD thesis, Nagoya University.
19. Rana, B., M. Nakawo, Y. Fukushima and Y. Ageta (1997) : Application of a conceptual precipitation-runoff model (HYCYMODEL) in the debris-covered glacierized basin of Langtang Valley, Nepal Himalaya. Annals of Glaciology, **25**, in press.
20. Seko, K., J. Pu, K. Fujita., Y. Ageta, T. Ohata and T. Yao (1994) : Glaciological observations in the Tanggula Mts., Tibetan Plateau. Bulletin of Glacier Research, **12**, 57−67.
21. Tanaka H. (1972) : On preferred orientation of glacier and experimentally deformed ice. Journal of the Geological Society of Japan, **78**, 659−675.
22. Ueno, K., H. Iida, H. Yabuki, K. Seko, A. Sakai, G. S. Lhakupa, R. B. Kayastha, A. P. pokhrel, M. L. Shrestha, T. Yasunari and M. Nakawo (1996) : Establishment of the GEN automatic weather station (AWS) in Khumbu region, Nepal Himalayas. Bulletin of Glacier Research, **14**, 13−22.
23. Yamada T., T. Shiraiwa, H. Iida, T. Kadota, T. Watanabe, B. Rana, Y. Ageta and H. Fushimi (1992) : Fluctuations of the glaciers from the 1970s to 1989 in the Khumbu, Shorong and Langtang regions, Nepal Himalayas. Bulletin of Glacier Research, **10**, 11−19.
24. Yamada, T. (1993) : Glacier lakes and their outburst floods in the Nepal Himalaya. Published by Water and Energy Commission Secretariat, pp.37.
25. Yokoyama, K. (1984) : Ground photogrammetry of Yala Glacier, Langtang Himal, Nepal Himalaya. Glacial Studies in Langtang Valley, Report of the Glacier Boring Project 1981−82 in the Nepal Himalaya, published by the Data Center for Glacier Research, Japanese Society of Snow and Ice, 99−105.