Annals of Glaciology 16 1992

Progress and prospect for research on mountain glaciers in China

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ABSTRACT. In the past decade the interest of many scientists worldwide has been attracted to the central Asian area of China. A number of gaps in scientific knowledge have been closed, and many significant discoveries have been made.

The most important achievement is the ice-core research by the Sino-American Joint Expedition to the Dunde Ice Cap, Qilian mountains, that established a record of ten thousand years of climatic and environmental change. In addition, in cooperation with scientists from Japan, Switzerland and the Soviet Union, studies have been carried out focusing on glacier mass balance, heat balance, the mechanism and formation of glacial runoff, and high mountain climates. This work has been done in the Tien Shan, west Kunlun, Tanggula, Nyaingentanglha and Gongga mountains.

In addition, through joint efforts of scientists from China, Nepal and Canada, important advances have also been made in studies of glacier lake outburst floods and debris flows in the Karakoram and the Himalayas, and in mountainous areas in southeastern Tibet.

The glaciers in central Asia will continue to be an important research area for glaciologists from all over the world in the coming decade.

INTRODUCTION

The mountainous region of Chinese central Asia is the largest glacierized area in the world outside the south and north polar regions. Owing to its high altitude, large area, middle-to-low latitude and intimate connection to human economic activities, this region occupies a special position in international scientific projects concerning both global change and the mitigation of natural calamities.

Systematic glaciological studies in this region were initiated in 1958 when a special institution, the present Lanzhou Institute of Glaciology and Geocryology of the Chinese Academy of Sciences, was established. Initially, the glaciers were taken as a water resource for arid regions. Therefore research was limited to mountain ranges adjacent to irrigated farmlands, such as the Qilian and Tien Shan mountains. Since the 1960s, expeditions have been extended to the Himalayas (Chinese Academy of Sciences, 1975). From these it was found that most of the glaciers in China possess features that distinguish them from glaciers in other mid-latitude regions, such as low accumulation rate, low ablation rate, low ice temperature, and low velocity. The prevalent concept of a temperate glacier did not fit these glaciers. Consequently, the concept of continental glaciers with special types of ice formation was proposed for glaciers in this region (Shi and Xie, 1964). In 1975, Chinese glaciologists carried out a large expedition to the Batura Glacier in the Karakoram in Pakistan. Additional glaciological expeditions were carried out on the southern Tibetan Plateau (Li and others, 1986). Throughout the 1970s and during the 1980s, great progress was made in glaciological research in China, both in extent and intensity. The following is a brief review of these latter studies.

PROGRESS IN GLACIOLOGICAL RESEARCH IN CHINA

1. Mass-balance studies

Owing to the strong influence of the monsoon, the principal periods of accumulation and ablation overlap completely in most of this region. Thus the mass exchange processes of glaciers are different from those of glaciers nourished principally in the winter period (Fig. 1). Traditional research methods used in other parts of the world do not work well in this region. Thus, new concepts, new observational methods and new calculation procedures for such summer-nourished glaciers were suggested (Xie, 1980). Similar results were also obtained in studies on the south slope of the Himalayas by Ageta and Higuchi (1984) and a new concept of altitudinal structure of mass balance was proposed by Durgerov (1991).

2. Physical characteristics of glaciers

Boreholes to bedrock provide opportunities for study of ice temperature distribution in continental glaciers.

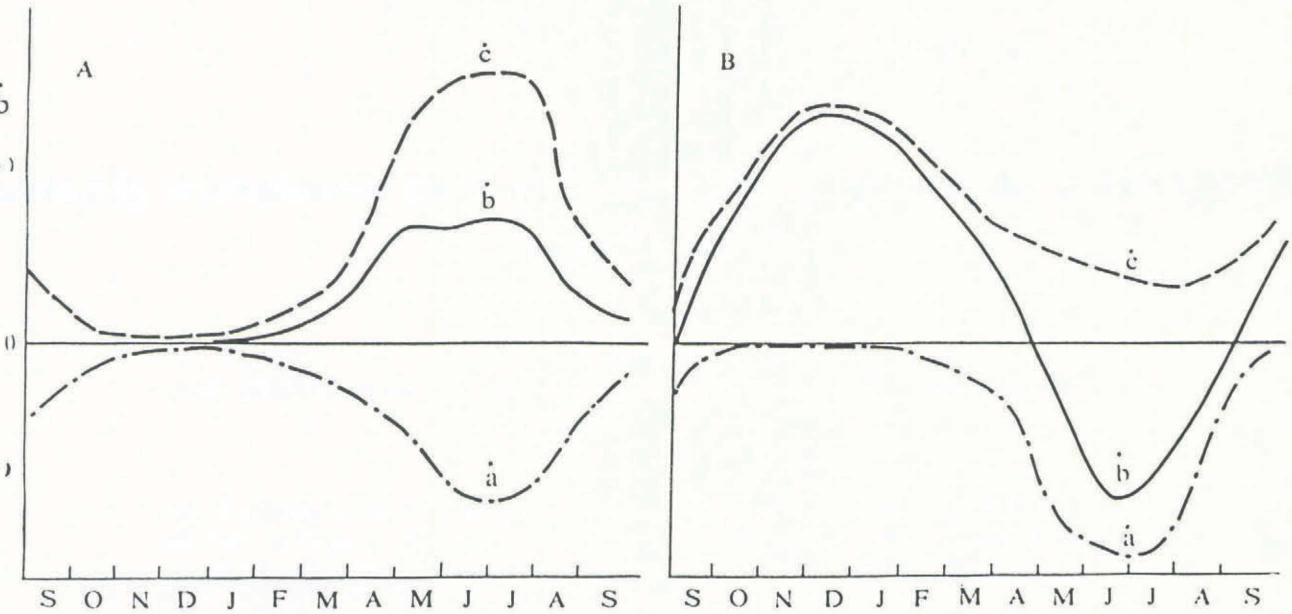

Fig. 1. Illustration of variation of accumulation (c), ablation (a) and net balance (b) for glaciers of the summer-accumulation type (A) and the winter-accumulation type (B) in the accumulation area.

Observations on Glacier No. 1 in the headwaters of the Ürümqi River, Tien Shan mountains, show that as a result of the influence of infiltration, the minimum ice temperature is not near the equilibrium line, but rather in the upper part of the ablation zone (Cai and others, 1988). At the bottom (138 m) of the Dunde Ice Cap in the Qilian mountains, the ice temperature is –4.7°C, which is lower than expected (Wang, 1990).

Observations in an artificial ice tunnel at the bottom of Glacier No. 1 show that a signficiant part of the glacier flow occurs through deformation in a debris-laden ice layer at the bottom. This may be the principal mode of movement of some cold glaciers (Echelmeyer and Wang, 1987). Further study shows that there are shear planes in this debris-laden ice layer.

4. Ice cores

Between 1984 and 1987, the Chinese-American expeditions to Dunde Ice Cap were carried out. Three boreholes were drilled to bedrock and nearly continuous core was obtained. The oldest ice dates back to the last glaciation. Microparticles are plentiful. $\delta^{18}O$ ratios and concentrations of NO_3^-, SO_4^{2-} and Cl^- are very low. The climatic optimum of the Holocene occurred before 6000–8000 a BP. The past 60 years has been the warmest period in the Holocene (Thompson and others, 1989). The core also contains a detailed record of two warm periods and two cold periods during the Little Ice Age (Fig. 2) (Yao and others, 1991).

4. Glacier lake outburst floods

Between 1985 and 1987, glaciologists from Lanzhou Institute of Glaciology and Geocryology and hydrologists from Xingjiang Uygur Autonomous Region carried out a systematic investigation in the headwaters of the Yarkant River, aimed at obtaining a better understanding of mechanisms of glacier lake outbursts and at predicting the occurrence of such floods. It was found that a lake there was formed by an advance of two 20 km long glaciers which dammed the valley. An outburst resulted from the rapid enlargement of subglacial channels when the lake level became sufficiently high. There was no

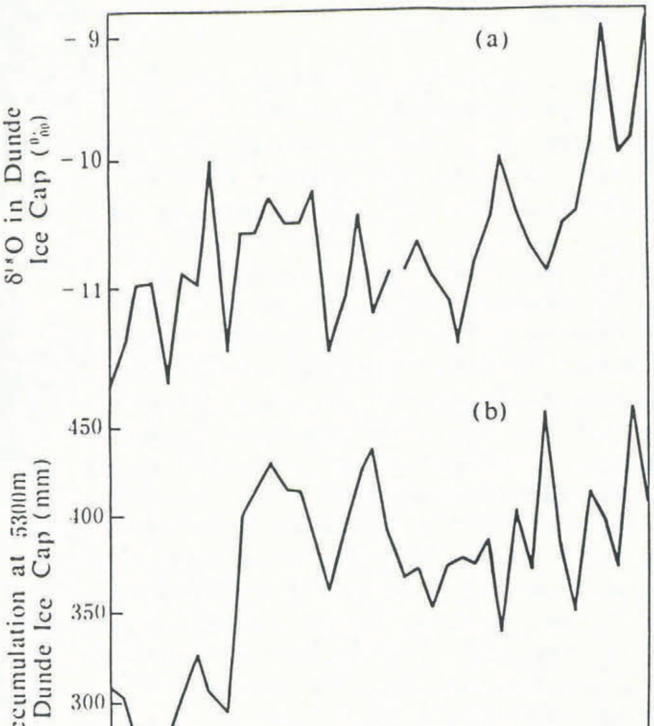

Fig. 2. Temperature ($\delta^{18}O$) and precipitation (glacial accumulation) fluctuations recorded in the Dunde ice core (reproduced from Yao and others, 1991).

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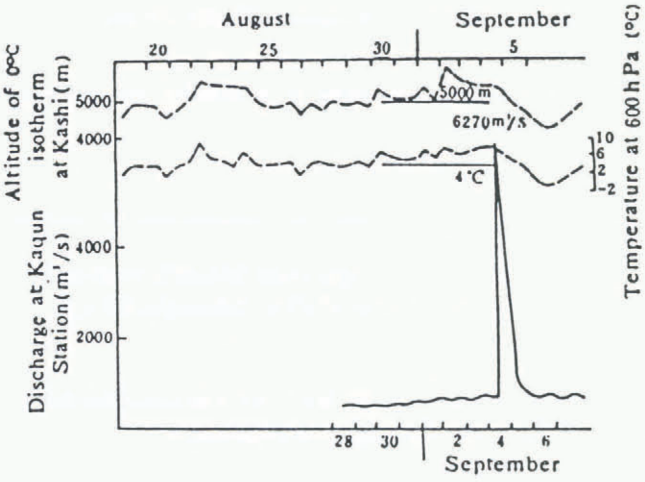

Fig. 3. Hydrograph of the 1961 glacial flood of the Yarkant River (reproduced from Feng and Liu, 1990).

direct correlation with air temperature (Fig. 3) (Feng and Liu, 1990).

In 1987, scientists from China, Canada, and Nepal investigated dangerous moraine-dammed lakes on the north flank of the Himalayas. An inventory of glacier lakes was completed (Liu and Sharma, 1988).

In 1990, Chinese scientists made an expedition to southeastern Tibet and found that outburst floods there may be caused by surging of glaciers (personal communication from Zhang Wenjing).

5. Glaciers as water resources

During the past decade, the following developments in research on glaciers as water resources have occurred:

a. Glacier inventory

80% of the glacier inventory in China has been finished. The inventory of glaciers in the Himalayas and southeastern Tibet is delayed due to the wide distribution and high altitude of glaciers there, and the consequent arduous field conditions and lack of aerial photographs. It is estimated that the total area of glaciers in China is about 58 000 km^2.

b. Hydrometeorological studies

Hydrometeorological studies have been carried out mainly in the Ürümqi River basin. One of the most prominent investigations involved cooperation between Chinese and Swiss scientists between 1985 and 1987. Heat balances on glaciers and precipitation in high mountainous areas were observed and analyzed. Additional results were obtained during a joint Chinese-Japanese expedition to the Kunlun mountains (Higuchi and Xie, 1989).

c. Forecasting runoff from snow cover by remote sensing

During the past several years, Lanzhou Institute of Glaciology and Geocryology had been endeavouring to monitor and forecast snowmelt runoff in the headwaters of the Yellow River, using NOAA images. Results of forecasts have been used to adjust reservoir capacity at large hydroelectric stations in the upper reaches of the Yellow River (Zeng, 1990; Feng and others, 1990).

CHARACTERISTICS OF GLACIOLOGICAL RESEARCH IN CHINA

The following three changes characterize the development of glaciological research in China during the past decade.

1. The research area has expanded rapidly to all parts of the region in a short time. In addition, the number of research topics has increased greatly and new research techniques have been applied.
2. Traditional research that viewed glaciers as a water resource gave way gradually to studies emphasizing variations of glaciers and their relationship to climatic and environmental change. In addition, measures for mitigation of snow–ice hazards were sought, and geographical studies on glacier surfaces were supplanted by glaciodynamical and other studies on the frontiers of science.
3. The most notable aspect of glaciological research in China is its internationalization. China's "open door" policy provided a chance for scientists abroad to share in studies of the largest glacier–permafrost zone in the middle and low latitudes. During the past ten years, extensive international scientific cooperation has developed among scientists from China, Japan, the USA, the

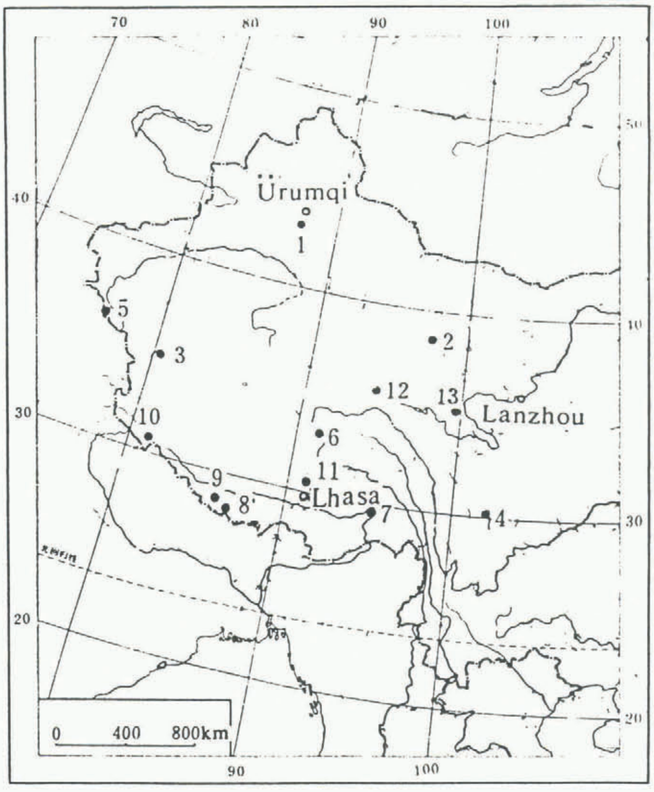

Fig. 4. Map of places where international glaciological studies have been carried out in China since 1981. Numbers refer to projects listed in Table 1.

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Table 1. The regions or glaciers, collaborating countries, and main topics of joint studies in China in the past ten years

No. (see Fig. 4)	*Region or glacier*	*Collaborating countries*	*Year*	*Subjects*
1	Glaciological Station, Tien Shan	Japan, USA, Switzerland, USSR Germany, Finland	1981 to present	Hydrometeorology, mass balance, physics of glaciers, ice-core studies, palaeoglaciology
2	Dunde Ice Cap, Qilian mountains	Germany, USA	1981 1984–87	Palaeoglaciology, ice cores, glaciometeorology, physics of glaciers, mass balance
3	Chongce Ice Cap and Guliya Ice Cap, west Kunlun mountains	Japan USA	1987, 1991 1990, 1991	Ice cores, hydrometeorology, hydrology, mass balance, palaeoglaciology, physics of glaciers
4	Hailuogou Glacier, Gongga mountains	USSR	1990	Mass balance, hydrometeorology, structure of glaciers, ice-core studies, palaeoglaciology
5	K2, Karakoram	Germany	1986	Palaeoglaciology, hydrometeorology, glaciology, glacier lake outburst floods
6	Tanggula mountains	Japan, Germany, USA	1989–91 1989 1990	Mass balance, hydrometeorology, ice-core studies, palaeoglaciology
7	Nanjagbarwa, Himalayas	Germany	1989	Palaeoglaciology, glacier lake outburst floods, meteorology
8	Qomolangma, Himalayas	Germany, Canada, Nepal	1984 1987	Palaeoglaciology, meteorology, glacier lake outburst floods
9	Xixiabangma, Himalayas	Germany USSR, USA	1984 1991	Palaeoglaciology, mass balance, meteorology, ice cores, physics of glaciers
10	Namulaly, Himalayas	Japan	1985	Palaeoglaciology, meteorology
11	Nyainqêntangla Range	Japan Germany	1989	Hydrometeorology, mass balance, palaeoglaciology
12	Eastern Kunlun mountains	Japan	1989	Mass balance, meteorology, palaeoglaciology
13	A'nyêmaqên mountains	Germany	1981	Palaeoglaciology, glaciology

Soviet Union, Switzerland, Germany and so forth, and much progress has been made as a result. Table 1 lists collaborative research in China in the past decade, and Figure 4 shows the locations of these studies.

FUTURE PROSPECTS

The above studies will continue along the following lines.
1. Along with development of international projects on global change, ice-core research will intensify. Ice cores drilled from high plateaux of Asia will be of significant scientific value for their unique characteristics, which include low accumulation rate, low ice temperature and low strain rate.
2. With the commencement of the International Glacier Year in 1992, a number of synchronous monitoring projects will be carried out on glaciers in central Asia. Studies of glaciers as indicators of climate variation will become more significant.

3. In conjunction with the commencement of the International Decade of Natural Disaster Reduction, local governments will focus more attention on forecasting and mitigating snow and ice disasters. This offers opportunities for intensive research on such disasters. The Himalayas and southeastern Tibet will become a focal point for such research.

4. As a result of the increase in atmopsheric CO_2 and the consequent global warming, central Asia will become warmer and more arid (Shi and Ren, 1990). In this region, variations of glaciers, which serve as valuable water resources, will attract more attention. Therefore, forecasting glacier variations and modelling of climate-glacier runoff will be further encouraged.

5. As a result of relaxation of international tensions, as well as the economical and political reforms appearing in many countries, glaciological research in central Asia will become more active and promising in the coming decade.

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