Chinese Science Bulletin

Quick ice mass loss and abrupt retreat of the maritime glaciers in the Kangri Karpo Mountains, southeast Tibetan Plateau

YANG Wei[1,3], YAO TanDong[1,2†], XU BaiQing[1], WU GuangJian[1], MA LingLong[1,3] & XIN XiaoDong[1,3]

[1] Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100085, China;
[2] National Key Laboratory of Cryospheric Science, Chinese Academy of Sciences, Lanzhou 730000, China;
[3] Graduate University of the Chinese Academy of Sciences, Beijing 100049, China

The maritime glaciers are sensitive to climate change because of high annual precipitation and high air temperature in the region. A combined comprehensive study was carried out based on glacier mass balance observation, GPS-based glacier terminus position survey, glacier Ground Penetrating Radar, topography maps and RS satellite images in the Kangri Karpo Mountains, Southeast Tibet. The study revealed a strong ice mass loss and quick glacier retreat since the 1970s. Ata Glacier, one glacier from the south slope of the Kangri Karpo Mountains, has formed a 6-km-long terminal moraine zone at the end of the glacier since the 1970s, and the accelerating retreat is largely due to the strong glacier surface melting. Mass balance study on the other four glaciers on the northern side of the Kangri Karpo Mountains shows that they are in large negative mass balance and the glaciers had retreated 15—19 m from May 2006 to May 2007. The *in-situ* glacier observation also shows that the glacier retreat is more obvious in small glaciers. The enhanced ice mass deficit caused by climate warming and the ongoing extinction of many small glaciers in this region could seriously affect the water resources, environments, local climate and regional sustainable development in the near future.

glacier shrinkage, mass balance, climate change, Kangri Karpo Mountains

1 Intruduction

Maritime glaciers, accounting for 18.6% of the total glacial number and 22.2% of the total glaciated area in China, are mainly located in the southeast Tibetan Plateau[1]. In response to global warming, glaciers on the Tibetan Plateau showed a dramatic retreating trend[2−8]. These maritime glaciers are sensitive to climate change[9,10] and capture the warm and humid moisture while the southwest monsoon penetrates into the Tibetan Plateau. Thus, it helps to improve the understanding of the relationship between glaciers and southwest monsoon by studying the variation of maritime glaciers in this region. In addition, the glacier variation is also related to the changing water resources and water-related disasters which will impact the local sustainable development. Such disasters include glacial-lake outburst floods, glacial debris-flow hazards, which have become more serious since the 1980s. The glaciers in the southwest Tibetan Plateau were investigated in the 1970s by groups organized by the Chinese Academy Sciences (CAS). Afterward, this kind of investigation was stopped. Starting in May 2006, a glaciological and meteorological investigation was carried out in the Kangri Karpo Mountains by Institute of Tibetan Plateau Research, CAS. This paper will give the new progresses of the glacier variation in this region and discuss how the climate change impacts the glacier variation.

Received October 30, 2007; accepted May 26, 2008
doi: 10.1007/s11434-008-0288-3
†Corresponding author (email: tdyao@itpcas.ac.cn)
Supported by the National Basic Research Program of China (Grant No. 2005CB422004), and the National Natural Science Foundation of China (Grant Nos. 40571039 and 40121101)

2 Results

The Kangri Karpo Mountains are located at the east end of the Nyainqêntanglha Range. Large numbers of glaciers developed around the mountains. According to the Chinese Glacier Inventory (CGI)[11], there are about 1320 glaciers with a total area of 2655.2 km^2 in this region. Lhagu Glacier is the largest one among these glaciers, while the Ata Glacier is the glacier with the lowest glacier tongue position (Figure 1). Ata Glacier (CGI code: 5O291B0181, 16.7 km in length and 13.75 km^2 in area)[11], lies on the south slope of the Kangri Karpo Mountains. This glacier was surveyed by Ward in 1933[12]. In 1973, this glacier was investigated in the CAS 1973 Expedition, focused mainly on the meteorology and glacier variation[13]. In 1980, Zhang[13] worked on this glacier again. According to Li[13], there was only 2-km-long moraine zone at the end of the glacier and all the other parts were debris-free ice, suggesting an active glacier movement condition[13]. However, both glacier terminus and surface have changed dramatically when we observed in 2007, characterized with a 6-km-long moraine at the end of the glacier. The glacier terminus was divided into several segments and formed several large subglacial melt water channels, from which melt water rushed rapidly. Moreover, small moraine lakes also formed in front of the glacier terminus. According to descriptions of the inhabitants who helped the expedition of CAS in the 1970s and the local hunters who often pass through this glacier, both the terminus and glacier surface of Ata Glacier have apparently changed recently. The recession was dramatic and has shown an accelerating trend in the past years. Furthermore, comparison of photographs taken in the 1930s, 1970s, 1980s and 2007 found that both ice volume and glacial surface conditions have changed greatly in the past decades (Figure 2). These changes are in agreement with other studies which indicated significant ice loss and accelerating retreats in the Himalayas and Tibetan Plateau, especially since the end of 1980s[2−8,14].

A monitoring program has been carried out since May 2006 on four glaciers (named Parlang No.4, No.10, No.12 and No.94, respectively) at the headwaters of the Parlang Zangbo River, on the northern slope of the Kangri Karpo Mountains (Figure 1 and Table 1), aiming for quantifying recent glacier mass loss. The field work includes mass balance observation and glacier terminal position measurements. This study found a large ice deficit of the monitored glaciers during the observation period.

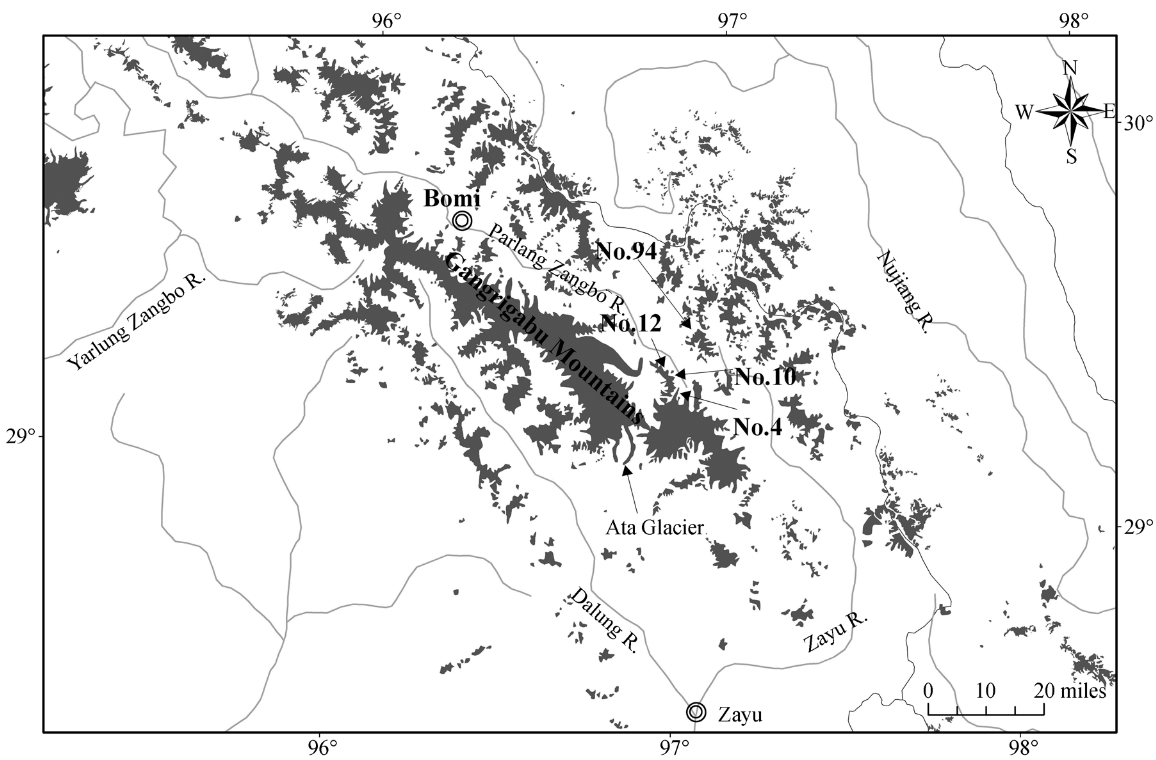

Figure 1 Glacier distribution and location of five monitored glaciers in Kangri Karpo Mountains, southeast Tibetan Plateau.

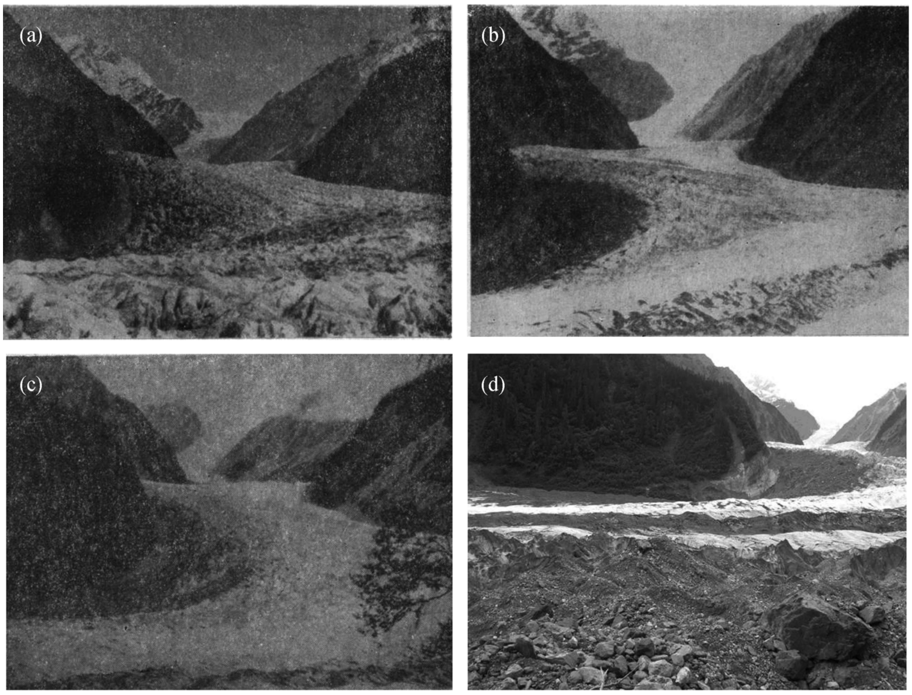

Figure 2 Variation of Ata Glacier surface in different years. (a) Taken by Ward in 1933[12]; (b) by Zhang Xiangsong in 1973[13]; (c) by Zhang Wenjing in 1980[13]; (d) this study in 2007.

Table 1 Measured glacier mass balance and retreat of the four glaciers on the northern slope of Kangri Karpo Mountains, southeast Tibetan Plateau monitored from May 2006 to May 2007

Glacier	Lat (N)	Lon (E)	Area (km^2)	Length (km)	Terminus altitude (m a.s.l.)	Terminus retreat (m)	Terminus ice wastage (m)	Summer mass balance (m w.e.)	Winter mass balance (m w.e.)
No.4	29°13′	96°55′	12.75	8	4650	15	5.2	−1.44	+0.73
No.10	29°17′	96°54′	5.1	3.5	4900	14.6	4.15	−1.46	+0.63
No.12	29°18′	96°54′	0.95	1.8	5100	–	2.9	−2.13	+0.55
No.94	29°23′	96°58′	3.08	2.9	5000	19	3.75	−1.34	+0.58

The four glacier terminals thinned 5.2 m, 4.15 m, 2.9 m and 3.75 m, respectively and retreated 15—19 m from May 2006 to May 2007 (Table 1). This measured glacier retreat ratio is higher than the retreat rate from other glacier regions reported in recent years[6,7]. The observation showed that the mean daily melting rate at the terminus of Glacier No.4 can be as high as 47 mm/d in July, while it is about 45 mm/d at the altitude of 4600 m from July to August at Baishui Glacier No.1 in the Yulong Mountains in Yunnan Province observed by Su[15], and 26 mm/d to 39.6 mm/d at 4460—4600 m a.s.l. from July to August for the Yangbark Glacier in the Muztag Ata Mountains observed by Pu et al.[16]. Compared with continental glaciers (such as Meikuang Glacier and Small Dongkemadi Glacier), the melt rate of the maritime glaciers in the southeast Tibetan Plateau is obviously higher[17,18].

A comparison of the 1:50000 topographic maps compiled by aerial photographs in 1980 and one China-Brazil Earth Resources Satellite image with a resolution of 19 m taken on September 8, 2005, can show how large the shrinkage of Glacier No.12 was in the past two decades (Figure 3). The glacier in 1980 formed into two separate glaciers in 2005. Two glacial-melting water lakes formed near their terminus, with an area of about 0.21 km^2 and 0.14 km^2, respectively. The glacier terminus has receded about 700 m and the surface area reduced by 55.3% since 1980. In 2007, the depth of the right branch of the glacier was measured using 100 MHz ground-penetrating radar (GPR). The glacier depth section shows that the glacier ice is composed of two parts (Figure 4). The lower part outside the glacial cirque is the buried dead ice. The upper part remains inside the cirque and the maximum depth is approximately 40 m. We estimate using the glacier thickness measured in 2007 and mass loss rate sine 2006 that this glacier could disappear entirely in the next few decades if the present

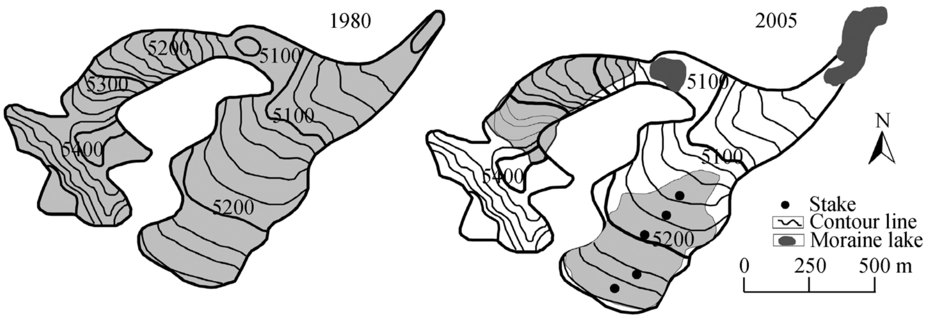

Figure 3 Sketch maps showing area change of Glacier No.12 between 1980 and 2005.

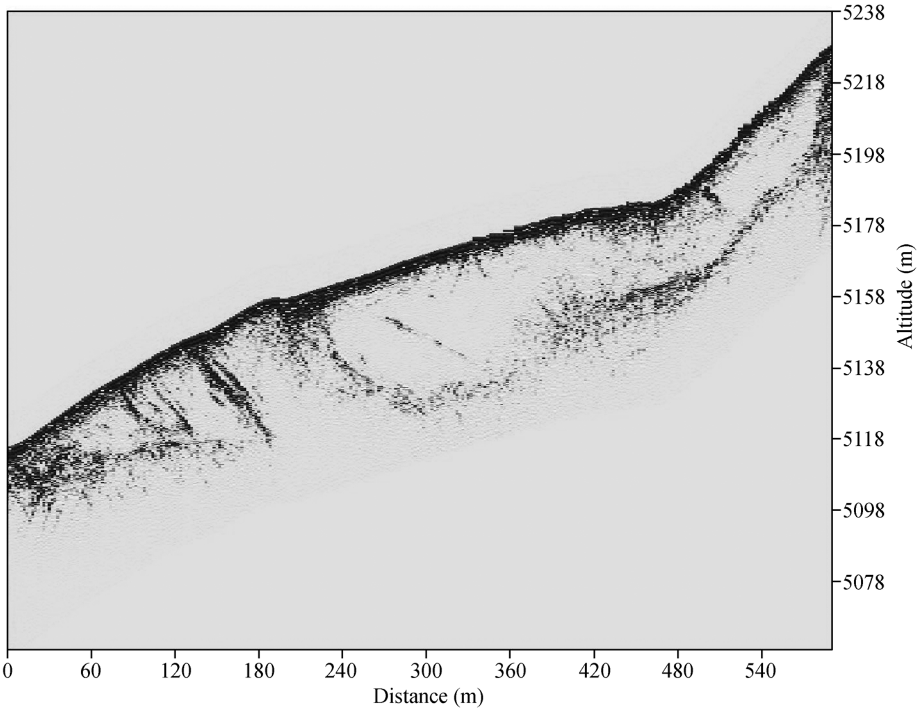

Figure 4 The longitudinal profile of Glacier No.12 measured by 100 MHz GPR.

climate conditions continue. However, the larger glaciers in the region will still survive in the consistent climate warming. Although the comparison of the satellite image, topography maps and field measurements shows that the large glaciers also shrink dramatically, the percentage of glacier area retreat is relatively small. For example, Glacier No.4 has retreated about 390 m with width shrinkage since 1980. However, the glacier area loss is only about 11%. Taking account of the variations in glacier area, mass balance and terminus retreat as we got from this study, there will be faster ice loss in the smaller valley glaciers with the climate warming. Chinese Glacier Inventory shows that 66% of the glaciers in this region range from 0.01 to 1 km^2 in area. The mean altitude of 73% of these small glaciers is lower than 5200 m a.s.l. and similar to the altitude of Glacier No.12. If such a large number of small glaciers disappear in the coming few decades, it will significantly impact the local climate and water resource at high elevation.

3 Discussions

Since the automatic weather stations had been set up for only one year, it is impossible to analyze the climate trend in this region. However, the data in 1969—2005 from the meteorological stations of Bomi (28°43′N, 99°17′E; 2423 m a.s.l.) and Zayu (29°52′N, 95°46′E; 2736 m a.s.l.) can be used here to discuss how the climate change impacts local glacier variation. The meteorological data show that the annual temperature significantly increased near the Kangri Karpo Mountains. The increase rate is 0.20℃/10a for Bomi and 0.11℃/10a for Zayu, respectively. As for the rainfall trend, although there were two increasing phases at the end of the 1980s and 1990s, statistically significant trends are not evident in annual precipitation at both stations. Moreover, many studies have confirmed that the amplitude of climate warming ratio increases with elevation[19−21]. Consequently, glacier shrinkage and large ice mass deficits in the Kangri Karpo Mountains could mainly be attributed to the rapid air temperature rising.

Although not all the glaciers were monitored in this region, this study on the five glaciers gives us a scenario on how the glacier will change with the climate warming in the region and how it will impact the glacier melting related water problems. While the large glaciers have larger accumulation areas at the higher altitude, the small glaciers with low altitude (e.g., Glacier No.12) are suffering enhanced summer ablation and receive less snow accumulation in the winter. This will favor the intensive melting and more glacial retreat of the small glaciers. Other factors favoring this trend include: the decreasing of snow/rainfall ratio with the climate warming, the decrease in the glacier surface albedo and thereby more intensive solar radiation after the melting of surface snow. The prospective impact on glacier melted water resource is probably the increasing of the river runoff in this region. In the coming decades, intensive glacial mass loss would cause the increase of river discharge and glacier-melting disasters. It is worth while keeping an open eye on these maritime glaciers in the Kangri Karpo Mountains, because of their first disappearance in the coming decades with the climate warming and their intensive impact on water resources.

The authors thank the anonymous reviewers for their suggestions and comments on improving this paper.

1 Su Z, Shi Y F. Response of monsoonal temperate glaciers to global warming since the Little Ice Age. Quat Int, 2002, 97-98: 123−131[DOI]
2 Braithwaite R J, Zhang Y. Sensitivity of mass balance of five Swiss glaciers to temperature changes assessed by tuning a degree-day model. J Glaciol, 2000, 46(152): 7−14[DOI]
3 Zhang Y S, Fujita K, Ageta Y, et al. The response of glacier ELA to climate fluctuations in High Asian. Bull Glacier Res, 1998, 16: 1−11
4 Yao T D, Wang Y Q, Liu S Y, et al. Recent glacial retreat in High Asia in China and its impact on water resource in Northwest China. Sci China Ser D-Earth Sci, 2004, 47(12): 1065−1075
5 Fujita K, Takeuchi N, Seko K. Glaciological observations of Yala Glacier in Langtang Valley, Nepal Himalayas, 1994 and 1996. Bull Glacier Res, 1998, 16: 75−81
6 Fujita K, Nakawo M, Fujii Y, et al. Change in glaciers in Hidden Valley, Mukut Himal, Nepal Himalayas, from 1974 to 1994. J Glaciol, 1997, 43(145): 583−588
7 Shi Y F. Estimation on the response of glaciers in China to the global warming in the 21st century. Chin Sci Bull, 2000, 45(7): 668−672
8 Ren J W, Qin D H, Kang S C, et al. Glacier variations and climate warming and drying in the central Himalayas. Chin Sci Bull, 2004, 49(1): 65−69
9 Pu J C, Yao T D, Wang N L, et al. Fluctuations of the glaciers on the Qinghai-Tibetan Plateau during the Past Century. J Glaciol Geocryol (in Chinese), 2004, 26(5): 517−522
10 Liu S Y, Ding Y J, Li J, et al. Glaciers in response to recent climate warming in western China. Quat Sci (in Chinese), 2006, 26(5): 762−771
11 Mi D S, Xie Z C, Feng Q H, et al. Glacier Inventory of China, XI, the Ganga Drainage Basin (in Chinese). Xi′an: Xi′an Cartographic Press, 2002. 9−437
12 Ward F. The Himalaya east of the Tsangpo. Geor Jour, 1934, 84(5): 369−397
13 Li J J, Zheng B X, Yang X J, et al. Glaciers in Tibet (in Chinese). Beijing: Science Press, 1986. 140−148
14 Dyurgerov M, Meier M. Twentieth century climate change: Evidence from small glaciers. PNAS, 2000, 97(4): 1406−1411[DOI]
15 Su Z, Wang L L. Characteristics of ablation, hydrology and hydrogeochemistry of glaciers in the Henduan Mountains region. In: Li J J, Su Z, eds. Glaciers in the Henduan Mountains (in Chinese). Beijing: Science Press, 1995. 70−78
16 Pu J C, Yao T D, Duan K Q. An observation on surface ablation on the Yangbark Glacier in the Muztag Ata, China. J Glaciol Geocryol (in Chinese), 2003, 25(6): 680−684
17 Pu J C, Yao T D. Study on Mass Balance of Small Dongkemadi Glacier. In: Yao T D, Ageta Y, et al. eds. Glaciological Climate and Environment on Qing-Zang Plateau (in Chinese). Beijing: Science Press, 1993. 60−67
18 Pu J C, Yao T D. Study of Mass Balance on Meikuang Glacier. In: Yao T D, Ageta Y, et al. eds. Glaciological Climate and Environment on Qing-Zang Plateau (in Chinese). Beijing: Science Press, 1993. 69−73
19 Aizen V B, Aizen E M, Melack J M, et al. Climatic and hydrological change in the Tien Shan, central Asian. J Clim, 1997, 10(6): 1393−1404[DOI]
20 Liu X, Chen B. Climatic warming in the Tibetan Plateau during recent decades. Int J Climatol 2000, 20(14): 1729−1742[DOI]
21 Kang S C, Zhang Y J, Qin D H, et al. Recent temperature increase recorded in an ice core in the source region of Yangtze River. Chin Sci Bull, 2007, 52(6): 825−831