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Five decades of changes in the glaciers on the Friendship Peak in the Altai Mountains, China: Changes in area and ice surface elevation

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ABSTRACT

Mountain glaciers are indicators of climate change and of current water resources. They are important ecological systems and can be used to support sustainable development of industry and agriculture. However, due to climate warming, most glaciers are in a state of rapid retreat. Using topographic maps in 1959, ASTER remote sensing data in 2008 and ASTER digital elevation models (DEMs), area, ice surface elevation, and volume changes of glaciers on the Friendship Peak in the Chinese Altai Mountains were analyzed. Results showed that the collective area of all 201 glaciers investigated was reduced by 30.4% from 1959 to 2008. Fifty-five glaciers disappeared entirely. The average rates of reduction in area of glaciers with sizes <0.5, 0.5–1, 1–4, 4–10, and >10 km^2 were 25.9%, 30.8%, 30.9%, 35.9%, and 27.4%, respectively. From 1959 to 2008, the elevation of the glacier surface decreased by 20 m at an average rate of 0.4 m a^{-1}. For the Kanas Glacier, the changes in ice surface elevation ranged from −101 to +38 m. Results showed that glaciers at lower altitudes and smaller sizes experienced more extensive changes in elevation. The intensive glacier ablation over the Friendship Peak in the Altai Mountains was found to be caused by increases in the regional temperature, which occurred at an average rate of 0.52 °C per decade.

1. Introduction

The Altai Mountains, located on the border of China, Russia, and Mongolia, are the highest latitude glaciated region in China, and they provide important water resources for local residents and economic development. The region is affected by the westerlies and there is plentiful ice and snow during the winter. Glaciers and snow melt are the main sources of the Irtysh River (Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, 1982; Shi, 2008). This area is the only representative of the Siberian taiga ecosystem in China. At present, the government of the Xinjiang Uygur Autonomous Region has paid significant attention to forestry, wildlife protection, and development of tourism resources in the area. However, work related to glacier and snow monitoring and local hydrometeorology is still limited. Research into changes in the glaciers is urgently needed because the glaciers in the Chinese Altai Mountains are extremely sensitive to climate change due to their relatively small individual area (average of approximately 0.82 km^2; Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, 1982). Conducting glacier change research in the Altai Mountains has considerable practical significance given the predicted effects of global climate change.

Research into changes in glaciers in China has mainly focused on the Tianshan Mountains, Kunlun Mountains, Qilian Mountains, and Hengduan Mountains. However, glacier research in the Chinese Altai Mountains has been sparse. The glacier inventory in the Altai Mountains was completed from 1978 to 1980 using aerial photographs and topographic maps (Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, 1982). In 1980, a field survey was conducted for the Kanas Glacier, the largest valley glacier in the Altai Mountains, which included glacier ablation, temperature, and glacier velocity. Results indicated that the maximum terminus retreat reached 424 m at an annual rate of 20 m a^{-1} from 1959 to 1980 (Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, 1982). Wang et al. (2011a) found that glaciers in the Altai Mountains were in a state of retreat from 1959 to 2000 based on topographic maps and Landsat ETM images. During this period, the glacier shrinkage in the Chinese Altai Mountains was more severe than that in the Russian

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part of the mountain range. In the Burjin River Basin, 100 glaciers disappeared entirely. The annual shrinkage rate was 29.94% by area, and the total area of the Kanas Glacier decreased by 4.21% with an annual rate of 0.0011 $km^2\ a^{-1}$. In order to study changes in the glaciers in the Chinese Altai Mountains in greater depth, an expedition was jointly organized by the Tianshan Glaciological Station, the Chinese Academy of Sciences, and the government of Xinjiang Uygur Autonomous Region. The survey quantified glaciological, ecological, and hydrological conditions on Friendship Peak of the Altai Mountains during August 2009. In 2011, Kanas Station (Altai Mountains) was established to monitor the glaciers, snow, and ecology of this region.

The elevation of the glacier surface was determined through repeated measurement by global positioning system (GPS) surveys (e.g. Jezek, 2012; Nuimura et al., 2012; Rivera et al., 2005; Wang et al., 2012, 2014). However, this method can be costly and labor intensive. Several studies have utilized satellite images and DEMs for calculation of changes in glacier area, elevation, and volume by comparison to earlier topographic maps and aerial photographs (e.g. Aizen et al., 2006; Herzfeld and Wallin, 2014; Larsen et al., 2007; Rignot et al., 2003; Sauber et al., 2005; Schiefer et al., 2007; Surazakov and Aizen, 2006; Vanlooy and Forster, 2011). Herein, multi-temporal remote-sensing images and digital elevation models were used to calculate glacier area, surface elevation, and spatial variability of a sample of 201 glaciers on the Friendship Peak of Altai Mountains. The interactions between climate change and glacier variation are discussed.

2. Study area

The Altai Mountains are a mountain range in East-Central Asia on the borders of Russia, China, Mongolia, and Kazakhstan. These mountains contain the headwaters from the Irtysh River and the Ob River. Friendship Peak (4374 m a.s.l.) is the highest peak in the Chinese Altai Mountains and the Friendship Peak Region (48.67°–49.17° N, 87°–88° E) is the highest latitude glaciated region in China. The Burqin River is a branch of the Irtysh River that is supplied by glaciers in the region. Glacier meltwater does not account for a large amount of river runoff; however, seasonal snowmelt accounts for 45–50% and is the main source of the rivers in this region (Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, 1982). The river runoff in the Altai Mountains is $12.611 \times 10^9\ m^3$ and accounts for 16% of the total river runoff in Xinjiang Uygur Autonomous Region. This is the second highest level in China after Yili Prefecture. The local climate is controlled by westerlies and polar air masses. In the Altai Mountains, the annual mean temperature is below 4.7 °C and the annual temperature range is relatively large. The annual precipitation is usually above 150 mm, which is more plentiful than the nearby Junggar Basin and precipitation is relatively evenly distributed across the year. Both the temperature and precipitation decrease gradually from west to east along the mountains (Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, 1982).

According to the Glacier Inventory of China, there are 416 glaciers in the Altai Mountains, with a collective area of 293.20 km^2 and an average individual area of 0.70 km^2 (Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, 1982). Glaciers on the Friendship Peak account for 72.6%, 84.4%, and 89.7% of the number, area, and total volume, respectively, of all the glaciers in the Altai Mountains. The average area of glaciers on this peak is 0.82 km^2 and the average glacier terminus is approximately 2600 m (Wang et al., 1983). The largest glacier in this area is the Kanas Glacier, which had an area of 30.13 km^2 and length of 10.8 km in 1959. It is a compound valley glacier with a northwest aspect. It is the glacier with the lowest terminus elevation in China, approximately 2416 m a.s.l. (Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, 1982). Kanas glacier tongue terminates on a very low altitude of around 2400 m a.s.l. in comparison with the other glacier terminus. It is even surrounded with a rich plant cover depending on certain environmental factors such as the availability of soil moisture, air temperature and light which are indicating a moderate summer climate (Fig. 1).

3. Data and methods

3.1. Data and processing

Topographic maps, satellite images, and digital elevation models (DEMs) from different periods were used to assess changes in the glaciers on the Friendship Peak in the Altai Mountains. The Glacier Inventory of China for the Altai Mountains was also included to investigate the glacier distribution (Lanzhou Institute of Glaciology and

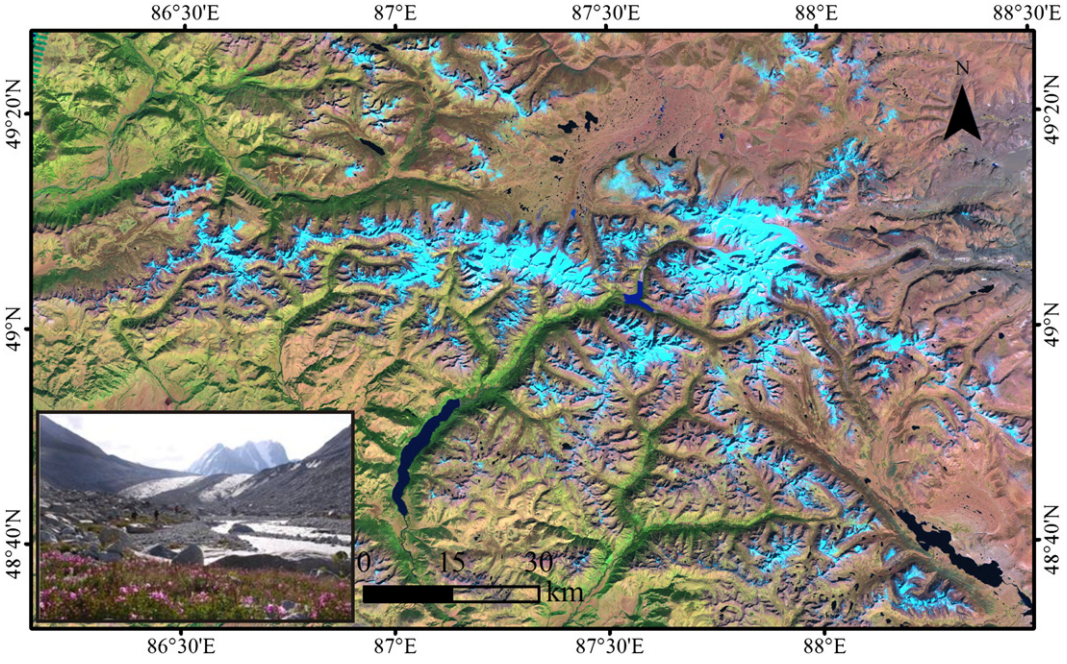

Fig. 1. Locations of glaciers on the Friendship Peak in the Altai Mountains. The photo in the lower-left corner was taken in 2009 by Zhongqin Li.