Recent glacier variations in Mongolia

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I Introduction

Glaciers grow and shrink in response to changing climate. Glaciers, therefore, are a potential indicator of changing climate, especially in high and remote mountain regions where no permanent climate station exists. The critical link between glaciers and climate is the glacier mass balance. Glacier mass balance, and especially its seasonal components, can be considered as the critical tool for the monitoring of climate from glaciological data. Such glaciological data, however, have been mostly from Europe and North America, but few from Northern Eurasia where prominent climatic change could occur due to global warming. Glacier monitoring enables us to detect influences of global warming in high mountain region.

As an initiation for establishing glacier-monitoring network in Northern Eurasia, we studied recent variations of glaciers in Mongolia using presently available materials.

II Study area

Glaciers in Mongolia exist in Altai Mountains which stretch for approximately 1,400 km within Russia, China and Mongolia (Fig. 1). Four regions are selected as study area, which are shown in Fig. 1. Glaciers in Khuiten region are characterized by valley-type, in Turgen and Kharkhiraa massif by mixed with two types (valley-type and flat-top-type) whereas in Tsambagarav massif flat-top-type glaciers are dominant. Glaciers in Turgen massif retreated 200-500 m between 1948 and 1991 (Lehmkuhl, 1998).

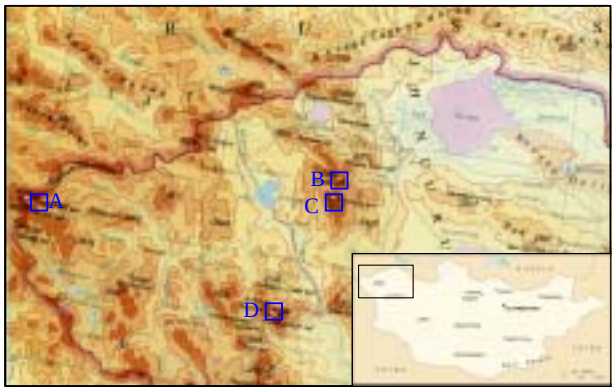

Fig. 1 Study areas in the Altai Mts. in Mongolia. A: Khuiten region, B: Turgen massif, C: Kharkhiraa massif, D: Tsambagarav massif

III Data

1) Topographical maps (scale 1:100,000) published in 1970 and 1971
   Khuiten region: M45-104
   Turgen massif: M46-75, M46-87 and M46-88
   Kharkhiraa massif: M46-87
   Tsambagarav massif: M46-110, M46-122
   Note: These maps are based on air photographs taken in 1940s by Russia.
2) LANDSAT7 ETM+ band 8 Path-row-year/month/day
   Khuiten region: 143-26-2000/8/06
   Turgen/Kharkhiraa massifs: 142-25-2000/9/10
   Tsambagarav massif: 142-26-2000/9/10
3) CORONA photos (black and white positives)
   Khuiten region: 1962/06/22
   Tsambagarav massif: 1963/8/26, 1968/8/11
4) Aerial photographs (scale 1:43,000 to 1:45,000)
   Khuiten region: 1988/9/4, 1988/9/7
   Turgen massif: 1988/7/21
   Kharkhiraa massif: 1988/7/2
   Tsambagarav massif: 1987/7/20, 1987/9/19

IV Method

1. Step 1

1) Geometrical rectification of the LANDSAT images with the maps
2) Comparison between the maps and the LANDSAT images

The images were geometrically rectified using about 20 points identified in the corresponding maps, evenly distributed around the massif. Then areas of glaciers in the images were measured and compared with those in the maps. Fig. 2 shows an overlay view of the image of Kharkhiraa massif as an example.

2. Step 2

1) Comparison between LANDSAT images and CO-RONA photos
2) Comparison between LANDSAT images and aerial photos
3) Comparison between CORONA photos and aerial photos

These procedures were visually carried out, because we could not rectify aerial photos and CORONA photos with the maps and/or LANDSAT images. Figs. 3 to 5 show examples of pairs for comparison.

V Results

The obtained changes in area through the Step 1 are

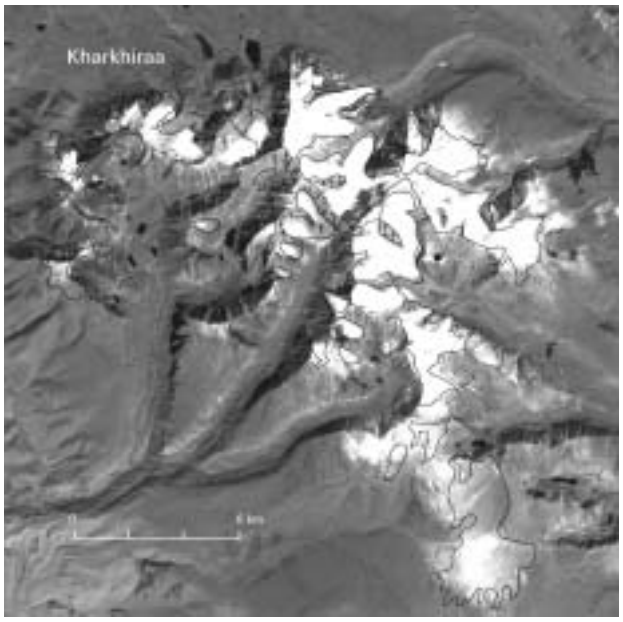

Fig. 2 An overlay view of the image of Kharkhiraa massif. The solid lines denote glacier area drawn in the topographical map. The image is LANDSAT7 ETM+ Band8, path-row 142-25, taken on 10 September 2000.
The southernmost glacier area described in the map, pointed by an arrow, was neglected in this study due to doubtful identification.

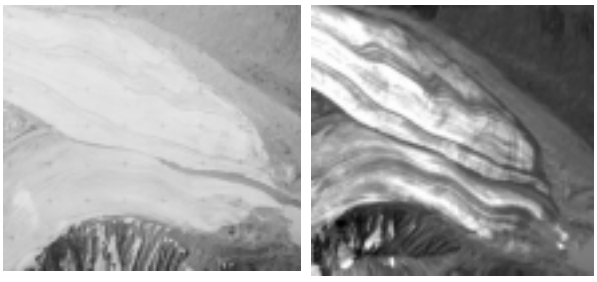

Fig. 3 The tongue of Potanin Glacier in 1988 (left) and in 2000 (right). There are no obvious change in its shape or position.

compiled in Table 1. Glaciers in the studied area reduced their area about 10% to 30% during the period from 1940s to 2000.

As shown in Figs. 3 to 5, the glaciers in Khuiten, Kharkhiraa and Turgen regions were almost stationary since 1987/1988. This means that retreat of the glaciers, which are obtained in the Step 1, occurred between 1940s and 1987/1988 although details are unknown. Glaciers in Tsambagarav massif showed no remarkable changes in area since 1963. The glaciers lost their area shown in Table 1 between 1940s and 1963.

VI Discussion

Within the four regions, Tsambagarav region shows the largest loss of glacier area. As described in the previous section, flat-top-type glaciers are dominant in Tsambagarav region. Flat-top-type glaciers are more

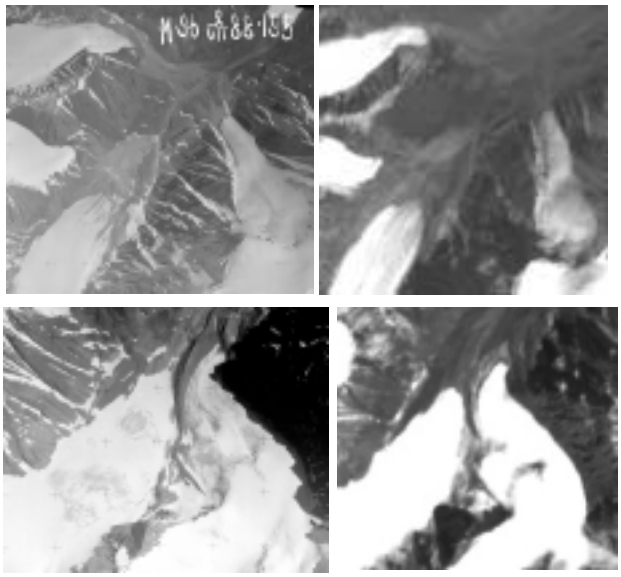

Fig. 4 Tongues of glaciers in Turgen (above) and Kharkhiraa (below) massifs in 1988 (left) and in 2000 (right). No obvious change is identified between the two years'.

sensitive to ELA (Equilibrium Line Altitude) change than valley-type glaciers. This is because even small shift of ELA affects their large area of flat-top-type glaciers. This implies that climatic warming, especially in summer, caused this shrinkage of glaciers.

Climatologically derived data shows that over the last 60 years the average annual air temperature in whole Mongolia has increased by about 1.56 °C (Dagvadorj, 1994, 1999). This increase arose from mostly increase of winter temperature (+3.6 °C) and spring/fall (+1.5 °C). Summer temperature decreased by 0.3 °C, although data of the nearby meteorological stations show no clear tendency. Shrinkage of glaciers between 1940s and 2000 suggests climatic warming occurred in the glacierized regions in Mongolia. However over the last decade, at least, Mongolian glaciers showed no remarkable change. Sofiyskiy Glacier, located in Russian Altai Mountains, has retreated steadily since the beginning of 20th century. Average retreat rates are 18.3 ma^{-1}, 17.3 ma^{-1} and 8.6 ma^{-1} during the periods of 1898-2000, 1939-1963 and 1963-2000 respectively (after Pattyn and others, 2003).

Table 1 Changes of glacier areas in four regions derived by comparing the maps with the satellite images. Note that some glacier area was neglected from the map of Kharkhiraa massif (see Fig. 2).

Region	Area as of 1970/71 map Km^2	Area lost by 2000 km^2 (%)
Khuiten	88.88	9.11(10.2)
Turgen	43.02	8.28 (19.3)
Kharkhiraa	50.13	14.05 (28.0)
Tsambagarav	105.09	30.29 (28.8)

Behavior of Mongolian glaciers seems different from many other glaciers which have been experiencing steady shrinkage.

VII Concluding remarks

Glacier variations detected in this study are limited to their shapes or area. Study on mass balance is required to link between glaciers and climate.

In order to initiate glacier mass balance measurement, we set 9 stakes (3 stakes per line × 3 lines) on the tongue of Potanin Glacier (located in Khuiten region), the largest glacier in Mongolia, in September 2003 and in 2004 added 3 stakes. We resurveyed the stakes in June and September 2004. Then we obtained annual balance at the points and surface flow velocities. The results will be reported elsewhere. We also made reconnaissance to Turgen massif for future research.

As for glacier variations in Mongolia, compilation of glacier inventory is desired, using reliable materials, especially large scale topographical maps, which is to be basic information for development of climate-glacier study.

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