Glacier changes in the Tabyn-Bogda Ola mountain massif from 1994 to 2015

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Abstract. In 2015, according to the Landsat and ASTER satellite imagery decoding, the contemporary glaciation of the Tavan Bogd (Tabyn-Bogda Ola) mountain massif range is represented by 82 glaciers, with a total area of 167.19 km². For the period from 1994 to 2015, the area of glaciation decreased by 3.61 km². The greatest changes occurred on glaciers of a complex-valley type with an area of more than 3 km².

1. Introduction
Modern climate change is a determining factor in the development of highland areas. Along with the arctic, high-mountain geosystems are the most vulnerable structural components of the geographic shell. The most significant consequence of contemporary climate change in the Altai is a steady trend of decreasing glaciation. The result is a reduction in water resources and, in the long term, aridization of the territory. In the continental regions of Central Asia, glacier melting is most acute, since glaciers are the main sources of river feeding and regulators of the hydrological regime of rivers in this region.

The Tavan Bogd (Tabyn-Bogda-Ola) mountain massif is the second highest after the Belukha mountain massif in the Altai-Sayan mountainous country. Within this mountainous country are the largest in area Potanin glacier. The Tavan Bogd (Tabyn-Bogd-Ola) is located on the territory of three states, such as Russia, China and Mongolia, at the junction of the Southern Altai, Sailyugem and Mongolian Altai ranges.

The study of the territory of the mountain massif is limited to the passes of Betsu-Kanas (in the west), Tsast-Daba (in the east), Postigyn-Daba (in the south). The glaciers located in the Russian part belong to the Ak-Alakha river basin, other glaciers located in the Mongolian part feed the Tsagan-Sala-Gol and Postigin-Gol rivers. Those glaciers that are located on the territory of China belong to the Sangadyr and Poshkyr river basins.

Over the years, the research of glaciation in this area was carried out by V. V. Sapozhnikov [7], brothers B. V. Tronov, and M. V. Tronov [9], V. S. Revyakin [6], V. P. Galakhov and A. G. Redkin [1], N. N. Mikhailov, O. V. Ostanin [4], D. A. Ganyushkin [3], T. Kadota and G. Davaa [10], U. Kamp and C. Pan [11] C. Liu, G. You and J. Pu [12], and others.

2. Materials and Methods
The study of changes in the glaciation of the Tavan Bogd (Tabyn-Bogd-Ola) mountain massif was carried out by visual interpretation of Landsat and ASTER “Terra” satellite images and data from the Bing maps internet map service, providing space images with a spatial resolution of 1.5 m in a pixel.
over a given area. Data processing and calculation of the glaciers area was carried out in the software ArcGIS 10.3.1 and ENVI 5.0.

When distinguishing the boundaries of glaciers, there was both an objective and a subjective error. The first can be attributed to the spatial resolution of the images themselves, which is due to the technical characteristics of the imaging equipment and image processing technology. The resolution of Landsat-7 and Landsat-8 images is 14.25 meters per pixel, in the panchromatic channel; 28.5 meters per pixel, in the multispectral channel, and for ASTER images the resolution is from 15 meters per pixel (depending on the channel). The second group includes discrepancies resulting from the ambiguous interpretation of the position of frozen glacier tongues and the glacier boundaries in the places where snowfields adjoin them.

The main criterion for choosing space images is the condition for confidently interpreting the boundaries of glaciers, taking into account their light and shade conditions, the lack of cloudiness, and the presence or absence of seasonal snow on the surface of the glacier. The shooting date was chosen in such a way that it fell at the time of maximum glacial ablation for the region (July-August). Panchromatic and spectrozonal data were combined into one color snapshot.

In ArcGIS, all selected glaciers were assigned attribute information, including a serial number, a type, an exposure, a length, a square, a river basin.

3. Results and Discussion

The contours of 82 contemporary glaciers with an area of 167.19 km² (as of 2015) were identified in the territory of the Tavan Bogd (Tabyn-Bogdo-Ola) mountain massif. According to the results of the interpretation of satellite images, it was found that from 1994 to 2015, the glaciation of the Tavan Bogd (Tabyn-Bodo-Ola) massif changed only slightly. Changes in square glaciers range from 0.01 km² to 0.47 km². The largest change is observed in large glaciers: their square has decreased by 0.1 km² and more.

![Figure 1. The positions of the glaciers of the Tavan Bogd (Tabyn-Bogdo-Ola) mountain massif for 2015](image)

On the territory of Russia was allocated 14 glaciers. Numbering the glaciers of the Russian part of the Tavan Bogd (Tabyn-Bogdo-Ola) mountain massif was carried out in accordance with the Catalog of the USSR glaciers [3].

In 2015, the total square glaciation of the Russian part of the massif was 21.01 km². The largest glaciers No. 253 are a series of glacier flows merging with each other, covering dome-shaped peaks. The largest of them are glaciers No. 253 and No. 253. In 2015, their square was 4.64 km² and 3.15 km², respectively.
On the territory of Mongolia, 25 glaciers were allocated. Seventeen of them belong to the Tsagan-Sala-Gol river basin, and nine to the Postiyn-Gol river basin. The glaciers’ numbering is given according to V. P. Galakhov [1]. Interpretation of satellite images showed that the large glaciers were divided into several streams and / or parts; therefore, the glacier numbers in brackets indicate the numbers of glacier streams and / or its parts into which the glacier was divided. Among the glaciers of the Tsagan-Sala-Gol river basin, crust and complex valley glaciers prevail. This basin includes the four largest glaciers, such as the Potanin Glacier No. 32(1), Alexandra Glacier No. 32(2), Granet Glacier No. 30, and Krylov Glacier No. 29(1). These glaciers in the upper reaches are closed with each other, constituting an almost continuous ice shell along the main watershed. The biggest change occurred in the area of the glacier Potanin. The area was decreased by 0.47 km² (1994-2015). The square was decreased by 0.47 km² (1994-2015).

The most elevated section with peaks exceeding 4000 m above sea level is stretched along the feeding zone of the Potanin and Alexandra glaciers. Further, the watershed turns to the east, and the height of the peaks decreases to 3,600-3,700 meters above sea level. With a decrease in the height of the mountains, the square of glaciers decreases by approximately 5 times.

Among the glaciers of the Postiyn-Gol river basin, the valley-type glaciers prevail. The largest glaciers of the basin are No. 49 and No. 50. Their square is 4.23 km² and 6.53 km², respectively. These are the eastern glacier valley exposure. During the study period the glacier No. 50(2) changed most significantly. Its square has decreased by 0.1 km². The remaining glaciers of the basin have changed slightly.

The boundaries of 42 glaciers belonging to the basins of the Sangadyr and Poshtyk rivers were identified in China. Glacier numbers were assigned in accordance with the Glacier Catalog of China [12]. The icing is most developed along the centerline of the Mongolian Altai ridge. Among the glaciers of the Sangadyr river basin, small crusty glaciers with an area of up to 1 km² prevail. The largest glacier of the basin No. E21(1), has an square of 25.29 km² (2015). From 1994 to 2006 there were no changes in the square of the glacier, and from 2006 to 2015. the square of the glacier decreased by 0.16 km². Among the large glaciers of the basin, one should also mention the glaciers No. E18 (contemporary square 9.88 km²), No. E24 (8.51 km²)6 and No. E16(3) (2.72 km²). During the study period, each of them decreased by less than 1 km².

The glaciers of the Poshtyk River Basin remained almost unchanged during the study. The largest glacier of the territory is glacier No. F2(2). This is a valley glacier southern exposure. Its square for 2015 was 6.07 km². Since 1994, it has changed to 0.28 km². The remaining glaciers of the basin, by their morphological type, are crust and do not exceed 2 km² in square.

Not all glaciers have shortened lengths; but the immutability of their area does not indicate a stable state. It is possible that in the period from 1994 to 2015, there were changes in the volume, which cannot be established as a result of the interpretation of satellite images.

The glaciation of the Tavan Bogd (Tabyn-Bodo-Ola) mountain massif is mainly concentrated on the slopes of the Mongolian Altai Range from China (45.5% of the total glaciation of the massif) and Mongolia (41.9%). In Russia, the process of glaciation is 12.6%. Despite the fact that the territory of China has the most glaciers, retreats are observed more on the glaciers of Mongolia (1.89 km²), where the largest glaciers of the massif are located. The areas of glaciers in the mountain range in China decreased by 1.32 km², the glaciers of the Russian part decreased by 0.4 km².

4. Conclusion
From 1994 to 2015, based on the interpretation of satellite images and images, a decrease in the glaciation area of the Tavan Bogd (Tabyn-Bogd-Ola) massif by 3.61 km² was revealed, with half of the glaciers of the massif (40 of 82) remaining unchanged.

The materials of this work can be used to monitor changes in the area of glaciers in the region. In the future, this will provide an opportunity to obtain homogeneous data for a comparative analysis of the reaction of glaciers of various morphological types, sizes and exposures to current climate change.
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