FLUCTUATIONS OF CAUCASIAN GLACIERS IN 20TH CENTURY

Irina Bushueva

Institute of Geography Russian Academy of Sciences

ABSTRACT

We present detailed reconstructions of variations of seven mountain glaciers situated in the Northern Caucasus: Alibek, Bezengi, Mizhirgi, Kashkatash, Terskol, Ullukam, Tsey. Created using remote sensing data, maps, old photographs and historical descriptions, these highly precise reconstructions cover the period from the end of 19th to the beginning of 20th centuries. For each glacier we identified 5 to 14 front positions and configurations and assessed the change of glacier length and area. Over the period from late 19th to early 21th century the glaciers have been retreating with minor readvances or still stands in 1910s, 1920s and 1960s-1980s. The variations of Caucasus glaciers are similar to those of the European Alps.

Mountain glaciers, remote sensing, maps, reconstructions

1. INTRODUCTION

During the last decades mountain glaciers are generally retreating all over the world. This corresponds with meteorological observations, showing the global increase of annual temperature by 0.89 ºC over the period from 1901 to 2012 [6]. Mountain glaciers are sensitive indicators of climate changes and their fluctuations are important sources of paleoclimatic information. This information allows to consider the modern climate changes in a broader context [10].

The size of glaciers in the recent past can be obtained from historical descriptions, old maps, photographs, pictures and by dating of moraines, e.g. using the tree-ring approach.

The study of Caucasian mountain glaciers begun about 150 years ago [1]. Although some important information is collected by now, the comparison with other mountains of the world (the Alps, the Rocky Mountains, mountains of Scandinavia etc.) shows that the Caucasian reconstructions are less detailed and many conclusions are being made on shaky basis. Many episodes of glaciers' history are still based on the analogues with Alpine history. The serious problem is lack of spatial reference of glaciers' tongues' positions and moraines over time. Until now only very rough schemes of variations of glaciers' positions over 19-20th centuries exist for majority of Caucasian glaciers, while

Figure 1. Study area

modern techniques in cartography and remote sensing can provide much better resolution of these reconstructions in space and time. Also, with these precise methods we can process numerous field observations made by several generations of researchers [4, 8, 12, 13, 16] for reconstructions and modeling.

In this work we provide information on the fluctuations of seven glaciers of the Northern Caucasus: Alibek, Bezengi, Mizhirgi, Kashkatash, Terskol, Ullukam, Tsey based on space images, maps and historical information from 19th to 20th century. The glaciers are situated in the region between Teberda river basin in the West and Tseydon river basin in the East. The distance from the most eastern region to the most western is about 200 km. All glaciers are situated on the northern macroslope of the Caucasus, but they differ from each other by local conditions: orography, orientation, climate, morphology etc.

2. DATA AND METHODS

In this paper we used aerial and satellite images taken between 1940 and 2000. Those images were created in visible (panchromatic and multispectral) and near infrared channels with spatial resolution from 0.5 to 15 m. Due to high mountain relief all remote sensing data had to be orthorectified, which was conducted in two steps. For each glacier the modern orthocorrected satellite image was taken as a reference. Firstly, we collected about 25 reference points equally distributed over the image with slight concentration near glacier forefield. Then using polynomial

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transformation of second order we corrected those images. At the second step we additionally collected 15-25 reference points in the area of interest and using rubber sheeting transformation completed the image correction. This processing gives a good co-registration of images. More details on this method can be found in [3].

Recently a lot of attempts were made to create an automatic method of glacier's delineation. Paul et al. [11] analyzed the advantages and disadvantages of visual and automatic methods and preferred the last one. Unfortunately the automatic method has some limitations: the images must be of a good quality. In our case many images cannot be used for automatic delineation, because of debris-covered tongues of glaciers, snow cover and shadows. Therefore all glaciers were digitized manually.

The length of glaciers were determined according to GLIMS recommendations (www.glims.com). The maximum glacier's length equals the length of the longest glacier's flow. This flow was determined manually as perpendicular to the isohypes.

Old maps and and schemes were reprojected when it was possible or georectified by reference points. We used repeated photographs to identify the location of glacier tongues in 19th- early 20th centuries.

3. RESULTS

3.1. Kashkatash Glacier

Kashkatash glacier (43.2N, 42.68E) is situated in the Adilsu valley to the east of Elbrus volcano. For the Kashkatash glacier we reconstructed 14 positions from the end of 19th century to 2008. Over this period the glacier front has retreated by 690 m, its area decreased by 0.25 km^2 (6.6%) and the elevation of the tongue raised by 225 m. The retreat was interrupted several times. Last advance of Kashkatash glacier occurred in 1970s - 1980s, also on its forefields we identified 2 moraines of the 20th century. One dates back to the 1920s based on the photograph of V.Ya. Altberg [2]. Another one, according to the photograph of G. Burmeister [5], was deposited in the beginning of 1910s.

3.2. Ullukam Glacier

Ullukam glacier (43.32N, 42.39E) is situated on the west slope of Elbrus volcano. We reconstructed 9 positions of this glacier from 1884 to 2009 and found out that the retreat over this period was 730 m. Although, from the beginning of 1970s till the end of 1980s the glacier advanced by 36 m, and the half of this advance occurred from 1983 to 1986. We also assume that the Ullukam glacier slightly advanced in 1930s.

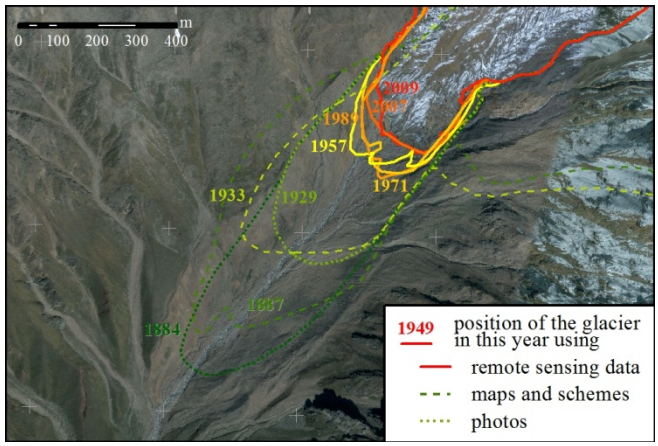

Figure 2. Changes of Ullukam glacier

3.3. Terskol Glacier

Terskol glacier (43.30N, 42.50E) is situated at the southeast slope of Elbrus volcano. Its tongue lies on the high rock bar. This glacier is frequently visited by tourists therefore there are a lot of photos of its front with the earliest dating back to 1884 [7]. Using these materials we were able to reconstruct 14 positions of glacier tongue. Since 1880s the glacier has retreated by 900 m in plane with its tongue raised by 400 m. Based on remote sensing data, Terskol glacier advanced in 1970s-1980s, and this data corresponds with instrumental observations. With the help of the old photographs and historical descriptions we also dated the moraines of 1910s and 1920s and identified their precise coordinates.

3.4. Alibek Glacier

Alibek glacier (43.28N, 41.53E) is the most western glacier in this analysis. We have identified the position of this glacier for 1895, 1904, 1957, 1987, 2007 and 2012. Over this period the estimated linear retreat of this glacier is 340 m. The glacier area decreased by 0.35 km^2 (6%) and the front position raised by 105 m. Basing on remote sensing data, we identified a small advance in 1970s.

3.5. Bezengi Glacier

Bezengi glacier (43.08N, 43.10E) more than 15 km long is the largest glacier on the Northern Caucasus. We have 5 remote sensing images for this glacier from 1946 to 2011. Over this period Bezengi glacier retreated by 870 m and decreased by 0.58 km^2 (1.6%). An advance was observed in 1946-1949. We georeferenced the old scheme of glacier fluctuations [9], analyzed the numerous historical descriptions and identified the location of glacier front during the two advances in the end of 1930s and 1910s.

3.6. Mizhirgi Glacier

In 19th century Mizhirgi glacier (43.07N, 43.16E) was the tributary of Bezengi glacier. There is a suggestion that this glacier is of surge type. From 1946 to 2011 the area of the glacier decreased by 0.24 km^2 (2.3%) and the length diminished by 560 m, while its tongue raised by 120 m. Unlike other Caucasian glaciers that were retreating in the beginning of 21th century, Mizhirgi glacier was in a steady state in the beginning of 2000s and deposited a stadial moraine at that time. Comparing the space images we found out that this glacier was smaller in 1980s in comparison to 2011, which is also unusual for Caucasian glaciers. In the beginning of 1950s the Mizhirgi glacier also advanced and formed a moraine.

3.7. Tsey Glacier

Tsey glacier (42.76N, 43.85E) located in the northern Osetia is the most eastern glacier in our dataset. In addition to four remote sensing images we have an old map (1880s) for this glacier, but based on proxy data and historical descriptions we identified that the glacier's tongue is shown incorrectly on this map. The retreat of Tsey glacier from 1946 to 2007 is 615 m and the area reduction is 0.48 km^2 (3.6%). On the Tsey forefields we dated moraines of 1950s and 1960s-1970s basing on remote sensing data. Also we identified the positions of moraines formed in 1910s and 1920s, which were dated on the basis of historical data [9,13].

4. DISCUSSION

4.1. Accuracy of identification of glacier parameters

Remote sensing data and maps used in this study have different spatial resolution (from 0.5 m to 15 m) therefore the accuracy of information obtained from them is also different. For the CORONA data the accuracy of georeferencing is less than 15 m, for aerial images - 5-10 m, for high resolution satellite images - 1-5 m.

4.2. Comparison with other reconstructions of glacier fluctuations using remote sensing data for the Caucasus

There are several reconstructions of Caucasian glaciers' fluctuations using the remote sensing data [14, 15, 17]. The two last reconstructions are based on the middle resolution images (Landsat and ASTER), therefore they have lower accuracy. The approach of Zolotarev et al. [17] who used old maps and aerial images is similar to our technique but these studies were focused on the glaciers on the Elbrus volcano. All these reconstructions are in good correspondence with results, but we used the wider spectrum of data and focused on individual glaciers which allowed somewhat better resolution and accuracy.

4.3. Comparison with the glaciers in the European Alps

Caucasian glaciers are frequently compared with those from the European Alps. It is reasonable because the two regions are similar in many ways (of equal geological age, young alpine relief, similar maritime climate, mean elevation, influence of NAO etc.) The comparison of fluctuations of seven Caucasian glaciers reported here with those of Lower Grindelwald and Mer de Glace [18] in the Alps shows that in 20th century they were almost identical. In both regions the general trend of retreat was interrupted by glacier advances in 1910s, 1920s and 1970-1980s. Cumulative curves of the length changes of Lower Grindelwald glacier and Tsey glaciers are even equal in magnitude.

5. CONCLUSION

We presented here new detailed reconstructions of fluctuations of seven glaciers Kashkatash, Ullukam, Terskol, Alibek, Bezengi, Mizhirgi and Tsey from the Northern marcoslope of the Great Caucasus. We have identified from 5 to 14 positions of glaciers' tongues from the late 19th to the early 21th century basing on remote sensing data, maps, photographs and historical descriptions. We assessed the changes of their length, area and height of tongues.

Although the glaciers are quite different in many aspects and are spread out from the western to central Caucasus their behavior is quite similar: in the last century the glaciers are retreating although the retreat was interrupted by readvances or still stands in 1910s, 1920s and 1960s-1980s.

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