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Geophysics

Georgian Large Glaciers Retreat Due to the Impact of Modern Climate Change

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(Presented by Academy Member Tamaz Chelidze)

High-resolution satellite remote sensing (SRS) is used to study large glaciers with necessary accuracy and detail. For effective studies of large glaciers, data obtained from Landsat satellites (resolution 15-30 m) for the period up to 2015 and recent data from 2020 – of the SPOT satellite (resolution 1-1.5 m) and several satellite data archives are used. Quantitative characteristics of large glacier retreats are determined to study the negative impact of climate change on glaciers in detail. Data quality control/quality assessment (QA/QC) is carried out to ensure reliable outputs, using ground-based observations (GBO) data sets. Glacier retreat regression equations are utilised to determine the likely dates of large glaciers' full melting and the total melting of glacial basins under the worst scenario of current climate change. *© 2024 Bull. Georg. Natl. Acad. Sci.*

glacial basins, large glaciers, degradation dynamics, climate change, satellite remote sensing

Observations of Georgian glaciers began in the second half of the 19th century. At the beginning of the 20th century, based on large-scale military topographic maps, all the glaciers of the Caucasus were listed and a corresponding catalogue was compiled. Important works were carried out by researchers of various institutions (National Meteorological and Hydrological Service (NMHS) of Georgia, Transcaucasian Institute of Hydrometeorology (Tbilisi), Institute of Geography of the Georgian Academy of Sciences) [1,2]. The observations on glaciers were mainly carried out by GBO. The results of century-long research on the glaciers of Georgia have been summarised and cited in various editions of the detailed catalogue of glaciers of the former Soviet Union (from now on the catalogue) [3]. Due to the importance of this catalogue, its main results are included in the World Glacier Register in digital form www.wgms.ch [4].

In the last century, approaching the glaciers and moving over them was not always possible. This makes it difficult and even impossible to obtain the necessary spatial resolution data based on GBO in needed scales. It should be noted that GBO studies are associated with large sums of financing. At the same time, only a few glacial basins can be covered annually by the results of field observations. Thus, it is not surprising that remote sensing of glaciers was used, which considerably reduced the risks associated with GBO surveys.

Nowadays, artificial high-resolution Earth satellites are used for research on the Earth's surface. High-resolution SRS is widely used to produce high temporal and spatial resolution observations of glaciers. SRS materials (directly SRS data, Internet portals and various databases) make it possible to receive and process information for the glacial basins of Georgia annually with high reliability [5].

Methodology

Large glaciers (area > 2 km^2) are observed in 4 glacial River basins: Kodori, Enguri, and Rioni in the western and Tergi in the eastern Georgia.

The method for measuring termini retreat rates for large glaciers uses different Landsat remote sensing data. It utilizes high-resolution SRS images, particularly Landsat data, 15 m resolution satellite data from the National Aeronautics and Space Administration (NASA) and data from the project Global Land Ice Measurements from Space (GLIMS). These bases were created using the data of the ASTER sensor of the TERRA satellite, the spatial resolution of which is 15 m. The ASTER sensor together with multispectral satellite data gives the possibility to generate a 30 m resolution ASTER DEM [6]. The Azerbaijan spot satellite (resolution 1-1.5 m) data for 2020 are also used and included for the analysis of the large glacier retreat. Satellite data are processed with the help of softwares: Google Earth (0.5-0.8 m), SAGA-GIS [7], STEP-ESA [8] etc. Google Earth provides high-resolution satellite images that allow the creation of glacier contours with high precision but the use of this data is not always available.

One of the most visible effects of ongoing climate change on glacier degradation is the retreat of large glaciers. The approximately 60-year difference in time between SRS data and catalogue data creates conditions for estimating the retreat dynamic of large glaciers, which is effective for studying the impact of current climate change on glaciers.

The dynamics of the retreat of large glaciers for about 60 years have been studied separately in western and eastern Georgia, taking into account the significant difference in climate between these regions. The climate of western Georgia is maritime-humid and that of the eastern part of the country is continental. To facilitate the problem solution, in the research, the glaciers are chosen, whose termini are free from debris. Technological and methodological research proved that the study of the dynamics of glacier degradation based on innovative high-resolution SRS be effective since the best practices [9, 10] were used in conjunction with the methods developed by the authors [11,12].

Discussion

To study the retreat of large glaciers, it is crucial to accurately determine the location of the end of the glacier tongue, since the characteristics (in particular, the length of the glacier and the minimum height) are determined from this point.

The use of expert knowledge is essential, when the glacier tongue is covered by moraines and/or debris. Accurate determination of the location of the tip of the glacier tongue is vital for the study of the retreat dynamics of large glaciers. Such glaciers, whose tip of the tongue is formed, is outlined and is not covered by either broken material or cloud, have been selected for the study.

To carry out the QA/QC procedures, additionally, the comparison of the data of the SRS with the data of GBO, in particular with the GBO data of the NMHS of Georgia is used. Based on SRS-processed data, the location of glaciers in different years is shown with different colour contours. The length of retreat of the glaciers is calculated using a broken white line crossing the contours.

The basins of Bzibi, Kelasuri and Kodori rivers are located in the Republic of Abkhazia. Of these three basins, only the Kodori basin has large glaciers. These are Marukhi, Sofruju, South Ptishi and Sakeni, although none of them was acceptable for our purposes, i.e. to determine the features and trend of the retreat of the glacier. Of the glaciers of Abkhazia, only No. 125, the Chepara glacier, is valid. Fig. 1 shows a schematic picture of the retreat of the Chepara glacier according to the data of SRS.

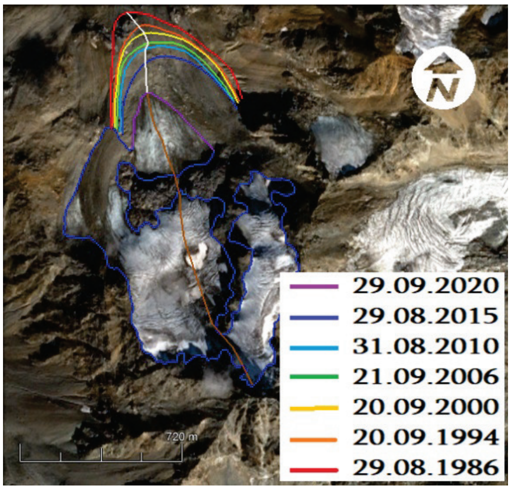

Fig. 1. Schematic image of the retreating Chepara Glacier, shown against the backdrop of a September 29, 2020, image from the SPOT 6 satellite.

From the locations of the end of the Chepara glacier tongue, the retreat distances can be determined and the corresponding graph and trend constructed with the data of SRS (Fig. 2 a). The initial condition corresponds to 1986. To detail the characterization of the impact of the current climate change on the Chepara glacier, the graphs (Fig. 2 b) are constructed, where the observational period is divided into two sub-periods: 1986-2010 and 2010-2020.

The analysis shows the retreat in the second sub-period is significantly greater than the retreat in the first sub-period, that is, the retreat of the glacier is non-linear.

The calculations showed that the non-linear retreat of the Chepara glacier is with high accuracy described by the second-order parabola curve (Fig. 3).

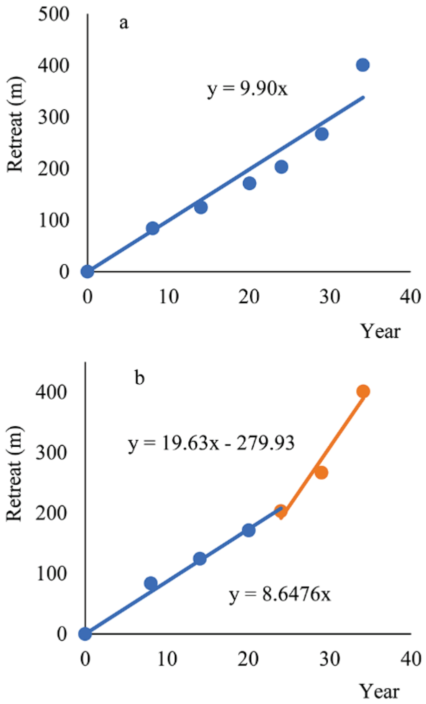

Fig. 2. The graph and trend of Chepara glacier retreat: a – for the full period of observation, b – for two sub-periods of observation.

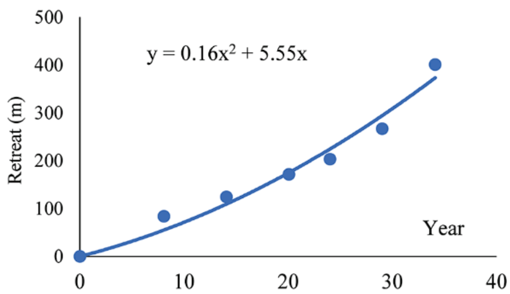

Fig. 3. Glacier Chepara's retreat schedule.

The equation describing Glacier Chepara's retreat is:

$$y = 0.16x^2 + 5.55x, \quad (1)$$

where x and y denote correspondingly time and the retreat.

Similarly, let's consider the degradation of large glaciers of other glacial basins of Georgia.

From the large glaciers of the Enguri River basin, firstly let's consider the **North Liadeshti glacier** using satellite images. A comparison of the obtained contours from SRS with the data from the catalogue shows that the area is equal to 3.4km^2

which means that the data from the catalogue is wrong. Correction with a topographic map determined that the glacier area was 4.3 km^2 by GBO. A detailed analysis of the retreat of the Liadeshti glacier showed us that the retreat of the glacier is described by a parabola curve:

$$y = 0.13x^2 + 7.15x - 12.03. \quad (2)$$

Glaciers Qvishi and Adishi are the next large glaciers in the Enguri glacial basin, from West to East, which have been studied. The issues of their retreat are discussed in detail in the IV Initial National Communication [11]. It should be noted that we added the recent data for 2020, however, this did not change the nature of the retreat of the glaciers. Their retreat (correspondingly Glaciers Qvishi and Adishi) are described by parabola curves:

$$y = 0.51x^2 + 3.28x, \quad (3)$$

$$y = 0.2439x^2 + 8.4474x. \quad (4)$$

Fig. 4 shows the contours of the **Shkhara Glaciers'** based on the satellite images and the corresponding contours of the glacier by GBO data. For the comparison, the SRS was searched for the closest by date to the existing glacier retreat GBO data (Fig. 4). The retreat of the Shkhara glacier, as well as the retreat of other large glaciers of Georgia, is described with high accuracy by a parabola curve. Also, with great accuracy, the graph of the retreat of the glacier built according to the GBO used for the quality assessment and control of the results, is described with a parabola curve. Figure 5 shows that GBO and SRS data are in good agreement with each other. It means that the Shkhara glacier retreat equation is right with high confidence and all QA/QC procedures used to prove the confidence of Shkhara glacier retreat are well established. Glacier Shkhara retreat is described by equations (5) and (6) correspondingly based on SRS and GBO data:

$$y = 0.19x^2 + 4.04x - 5.43, \quad (5)$$

$$y = 0.13x^2 + 5.41x - 0.30. \quad (6)$$

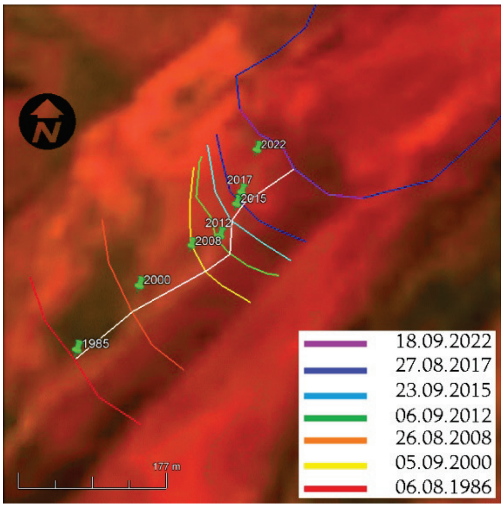

Fig. 4. Schematic image of Shkhara glacier retreat against the backdrop of the September 18, 2022, Landsat 9 OLI TIRS sensor image. Green pins show the data determined by the GBO.

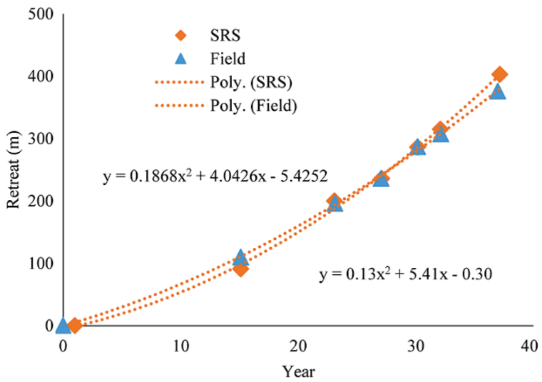

Fig. 5. Graphs of Shkhara glacier retreat based on GBO and SRS data.

Kirtisho glacier (R. Rioni basin) area is 4.6 km^2 according to the catalogue and correspondingly – 4.0 km^2 according to SRS.

The calculations show that the non-linear retreat of the Kirtisho glacier is described with high accuracy by a second-order parabola curve:

$$y = 0.48x^2 - 4.22x + 11.11. \quad (7)$$

Boko glacier (R. Rioni basin) area is 4.6 km^2 according to the catalogue and correspondingly – 3.7 km^2 according to SRS.

The calculations show that the non-linear retreat of the Kirtisho glacier is described with high accuracy by the parabola curve:

$$y = 0.24x^2 + 8.45x. \quad (8)$$

Glacier Gergeti is the large glacier of the r. Tergi glacial basin (East Georgia). As a result of specifying the contours, the shape of the contour of the Gergeti glacier has changed significantly. According to the satellite image of September 1, 2010, in the contours preserved in the GLIMS database, most of the glacier plateau belonged to the Gergeti Glacier. Using the Digital Elevation Model (DEM), the watershed was specified as a result of the use of the height isolines – hypsometric curves marked with a 30 m grid. This caused a correction of the picture.

The calculations show that the non-linear retreat of the Gergeti glacier is described by the parabola curve:

$$y = 0.19x^2 + 12.8x. \qquad (9)$$

Calculations show that the analytical equation for the retreat of the **East Suatisi Glacier** (r. Tergi glacial basin, East Georgia) is:

$$y = 0.09x^2 + 15.36x - 9.62. \qquad (10)$$

It is important to study not only the current state of glaciers but also to determine the approximate dates of their complete melting during their degradation. It is solved in the conditions that climate change will continue as it has been. This scenario, in climatology, as in other activities, is called Business as Usual (BaU).

To determine the likely dates of the complete melting of large glaciers, let's use the analytical form of their retreat. Let's consider, for example, the melting of the North Liadeshti glacier. The equation of the retreat of North Liadeshti glacier retreat is described by (eq. 2). To determine the date of complete melting, the retreat length y_1 (for the total time of observation) is calculated and the distance y_2, which remains for the complete melting of the glacier according to the last data of the glacier retreat dynamics, is added to it. The North Liadeshti glacier length is 4,273 m according to the 2022. From 1986 to 2022, the glacier was shortened by 392 m. The sum of these two numbers should be equal to the glacial Liadeshti ordinate in the Liadeshti regression equation (eq. 2) and solving the equation gives approximately 163 years. If we add this amount to the initial moment (1986), we get that the glacier North Liadeshti's likely date of complete melting will be 2149.

Likely dates of the complete melting of other large glaciers are calculated similarly. The results, likely dates for the melting of the glaciers, are as follows: 1. Chepara Glacier – 2077; 2. North Liadeshti Glacier – 2149; 3. Qvishi Glacier – 2095; 4. Adishi Glacier – 2031; 5. Kirtisho Glacier – 2087; 6. Boko Glacier – 2087; 7. East Suatisi Glacier – 2087; 8. Gergeti Glacier – 2147.

Let us use the likely dates of the complete melting of large glaciers defined above and perform a small analysis to determine the likely dates of the complete melting of each considered glacial basin. As a result, we get: 1. The approximate date of complete melting for the Abkhazia glacial basin is 2077; 2 for the r. Enguri glacial basin, this date is 2149; 3 for the r. Rioni glacial basin, this date is 2161; and 4. For the glacial basin of Eastern Georgia, this date is 2153.

Conclusion

High-resolution SRS is used to quantitatively study the dynamics of the degradation of the Georgian glacial basins, carry out detailed research on the large glacier changes, determine the nature of their retreat and define the approximate dates of the complete melting of the large glacial basins. It is worth noting that: i. The melting of glaciers has a non-linear character; ii. Glacier retreat patterns are determined with a high degree of confidence, and all quality assurance/quality control procedures used to confirm the reliability of glacier retreats are well established; iii. Degradation of glaciers is much faster in eastern Georgia than in its western part, which is due to the big difference in climate between these parts.

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გეოფიზიკა

საქართველოს დიდი მყინვარების უკან დახევა თანამედროვე კლიმატის ცვლილების გამო

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მაღალი გარჩევადობის თანამგზავრული დისტანციური ზონდირება (SRS) გამოიყენება მყინვარების შესასწავლად საჭირო სიზუსტით და დეტალებით. დიდი მყინვარების ეფექტური კვლევებისთვის გამოყენებულია Landsat-ის თანამგზავრებიდან (გარჩევადობა 15-30 მ) მიღებული მონაცემები 2015 წლამდე პერიოდისთვის და 2020 წლის უახლესი მონაცემები – SPOT თანამგზავრის (გარჩევადობა 1-1,5 მ) და რამდენიმე თანამგზავრულ მონაცემთა არქივი. კლიმატის ცვლილების უარყოფითი ზემოქმედების დეტალურად შესასწავლად განისაზღვრა დიდი მყინვარების უკან დახევის რაოდენობრივი მახასიათებლები. მონაცემთა ხარისხის კონტროლი/ხარისხის შეფასება (QA/QC) ხორციელდება საიმედო შედეგების უზრუნველსაყოფად, მიწისზედა დაკვირვებების მონაცემთა ნაკრების გამოყენებით. მყინვარების უკან დახევის რეგრესიის განტოლებები გამოიყენება დიდი მყინვარების სრული დნობის სავარაუდო თარიღების დასადგენად და მყინვარული აუზების მთლიანი დნობის კლიმატის ამჟამინდელი ცვლილების ყველაზე უარესი სცენარის მიხედვით.

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