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Comparison of Satellite Remote Sensing and Field Ground Observation Data for the Large Glaciers Retreat Study in Georgia

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ABSTRACT

The results of the comparison of satellite remote sensing (SRS) data and ground-based observation (GBO) information on the large glaciers (Adishi, Shkhara and Gergeti) of Georgia are presented. From each satellite image, the location of the tip of the glacier's tongue was determined, a chronological order of the data was made, and the average rate of glacier retreat was calculated. Using SRS, the dynamics of the retreat of glaciers are studied based on the determination of individual places of movement of the tip of the glacier tongue. The dynamics of some large glaciers retreat based on the GBO data of the National Hydrometeorological Service (NEA) of Georgia is presented and is additionally used for quality assessment and quality control (QA/QC) of the results. The analyses show that based on SRS and GBO data the retreats of studied glaciers are nonlinear and by high confidence can be presented by a parabola curve. The comparison of SRS and GBO data shows that they are in good agreement with each other.

Keywords: *Georgian glaciers, satellite remote sensing, ground-based observations, climate change.*

Introduction

Over the last decades, global warming has led to a widespread shrinking of the cryosphere, with mass loss from ice sheets and glaciers (*very high confidence*) [1]. Projected physical changes include global glacier mass loss expected to continue in the near future (2031–2050) due to rising surface air temperatures (high confidence), with imminent consequences for river flows and local hazards (*high confidence*) [1].

To study the impact of climate change on glaciers, along with the SRS data the GBO data is needed. This is preconditioned by the fact that using high-resolution SRS allows the simultaneous study of the state of large glaciers with the required resolution and accuracy, under conditions of limited material resources and time [2,3]. The GBO data is needed for the QA/QC of the results.

Used satellite data that is available through Earth Resources Observation Systems (EROS). This archive, which is under the jurisdiction of the US Department of the Interior, preserves data obtained by Landsat satellites, as well as satellite images at the disposal of NASA. For the QA/QC of the results, complex use of historical glacier catalogue data, existing field material and expert knowledge is necessary.

Materials and methods

The impact of ongoing climate change on glacier degradation is one of the most visible when studying the retreat of large glaciers (area > 2 km^2). A methodology has been developed to study the dynamics of retreat of large glaciers.

Weather conditions have a significant impact on the use of SRS, in particular, in case of cloudiness, it is impossible to use satellite images. When observing glaciers, this limitation is added to the state of the surface of the glacier itself. The surface of the glacier should be as free as possible from snow cover, in particular, SRS should be carried out from the end of the ablation until the first snowfall. In the Earth, this period depends on the location of the glacier, altitude, climate and weather conditions. Under the conditions of the modern climate, this time interval for Georgia covers the period from the end of June to the beginning of October.

The contouring of glaciers is carried out by manual digitization, during which expert knowledge is taken into account. ASTER DEM digital terrain model and topographic maps of the USSR (1:50,000) of the 60s of the last century were used to identify the studied glaciers and specify their contours.

When studying the dynamics of the retreat of large glaciers, it is especially important to accurately determine the location of the end of the glacier tongue. The use of expert knowledge is essential when the glacier tongue is covered by moraines and/or debris.

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. The methodology for determining the dynamics and rate of retreat at the end of the glacier tongue for large glaciers is presented in [4, 5].

Results

Only nine large glaciers were selected from the large glaciers of Georgia, the condition of which was satisfactory for our purposes. Of these nine glaciers, only three glaciers could be compared with NEAs' GBO data. These glaciers are Adishi and Shkhara belonging to the R. Enguri glacia basin and Gerget glacier of the R. Tergi glacial basin.

For example, let's consider in detail the dynamics of the change in the location of the end of the tongue of the Adishi glacier based on the determination of individual places of the movement of the tip of the tongue. According to each satellite image, let's make a chronological order of the data and calculate the average speed of glacier retreat. For the QA/QC of the obtained results, NEAs' data is used.

Fig. 1 shows a schematic image of the retreat of the Adishi Glacier on the background of the August 25, 2022, Landsat 8 OLI TIRS satellite image, where the green pins show the results obtained by GBO data. In different years, the location of the glacier is shown with a different coloured outline. The length of glacier retreat can be calculated through the white dashed line crossing the contours. From September 13, 1977 to August 25, 2022, this figure was approximately 601 m.

Table 1 below summarizes the features of the Adishi Glacier retreat. The satellite image from 1977 is considered the starting point. 23 different satellite data files taken between 1977 and 2022 from satellite data are selected to study the retreat of the Adishi Glacier. To avoid overloading the image in Figure 1, only 8 contours of the location of the tip of the glacier tongue are plotted in different years. Table 1 summarizes the individual characteristics of these satellite data.

Tables 1 and 2 show the coordinates and retreat distances of the end of the Adishi glacier tongue according to satellite data (period 1977 and 2020) and correspondingly GBO data covering the period of 1985-2022.

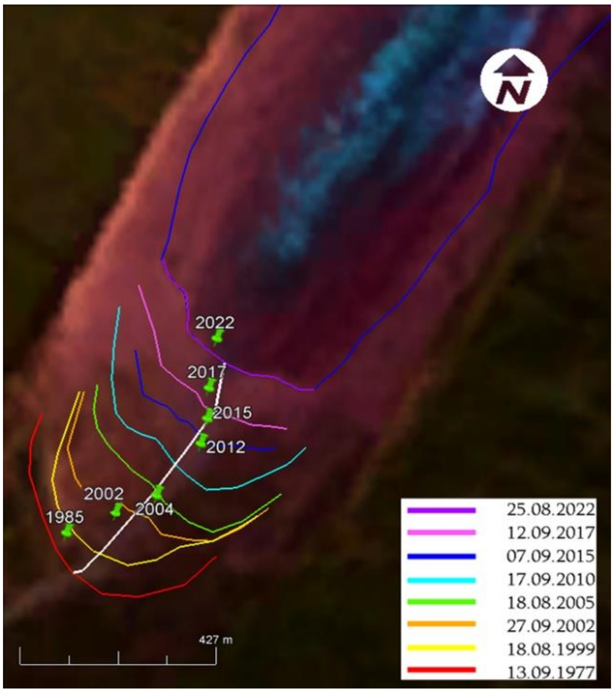


Fig. 1. Schematic picture of the retreat of the Adishi Glacier (r. Enguri Basin).

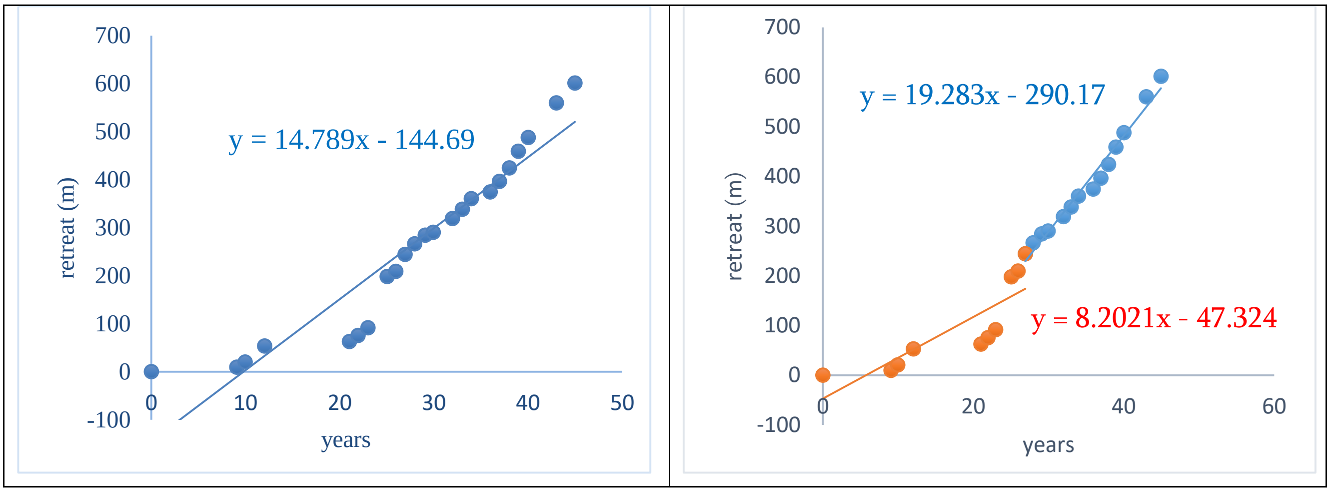
Table 1. According to SRS data, the location of the end of the Adishi glacier tongue and retreat distances.

№	Satellite Type	Date	Coordinates (Grad.)		Retreat (m)
			Latitude	Longitude	
1	Landsat 2 MSS	13.09.1977	42.989233°	42.984633°	0
2	Landsat 5 TM	09.10.1986	42.989254°	42.984746°	9.39
3	Landsat 5 TM	01.09.1987	42.989281°	42.984876°	20.2
4	Landsat 4 TM	23.09.1989	42.989486°	42.985144°	53
5	Landsat 5 TM	15.09.1998	42.989552°	42.985231°	62.3
6	Landsat 7 ETM+	18.08.1999	42.989630°	42.985334°	75.1
7	Landsat 7 ETM+	05.09.2000	42.990473°	42.986319°	91.2
8	Landsat 7 ETM+	27.09.2002	42.989572°	42.985452°	198
9	Landsat 5 TM	28.08.2003	42.990546°	42.986400°	209
10	Landsat 7 ETM+	08.15.2004	42.990784°	42.986682°	244
11	Landsat 7 ETM+	18.08.2005	42.990946°	42.986846°	266
12	Landsat 7 ETM+	08.10.2006	42.991070°	42.986972°	284
13	Landsat 5 TM	16.08.2007	42.991120°	42.987025°	290
14	Landsat 7 ETM+	29.08.2009	42.991328°	42.987225°	319
15	Landsat 7 ETM+	17.09.2010	42.991471°	42.987368°	338
16	Landsat 5 TM	27.08.2011	42.991630°	42.987524°	360
17	Landsat 8 OLI TIRS	23.08.2013	42.991732°	42.987623°	374
18	Landsat 8 OLI TIRS	26.08.2014	42.991891°	42.987775°	396
19	Landsat 8 OLI TIRS	07.09.2015	42.992109°	42.987981°	424
20	Landsat 8 OLI TIRS	24.08.2016	42.992361°	42.988220°	459
21	Landsat 8 OLI TIRS	12.09.2017	42.992570°	42.988423°	488
22	Landsat 8 OLI TIRS	11.09.2020	42.993209°	42.988620°	560
23	Landsat 8 OLI TIRS	25.08.2022	42.993568°	42.988683°	601

Table 2. Location of the end of Adishi glacier tongue and retreat distances according to GBO data.

№	Date	Coordinates (Grad.)		Retreat (m)
		Latitude	Longitude	
1	15.09.1985	42.989886	42.984383	0
2	20.08.2002	42.990296	42.985645	116
3	15.08.2004	42.990659	42.986799	220
4	10.08.2012	42.991733	42.987981	371
5	19.09.2015	42.992250	42.988157	432
6	05.07.2017	42.992881	42.988198	501
7	10.07.2022	42.993902	42.988410	614

Fig. 2.a presents the graph of the change in the location of the Adishi glacier tongue and the corresponding trend, constructed using SRS data. The initial condition corresponds to 1977. To detail the characterisation of the impact of the current climate change on the Adishi glacier, the graphs (Fig. 2. b) are constructed, where the observational period is divided into two sub-periods: 1977-1998 and 1999-2020.



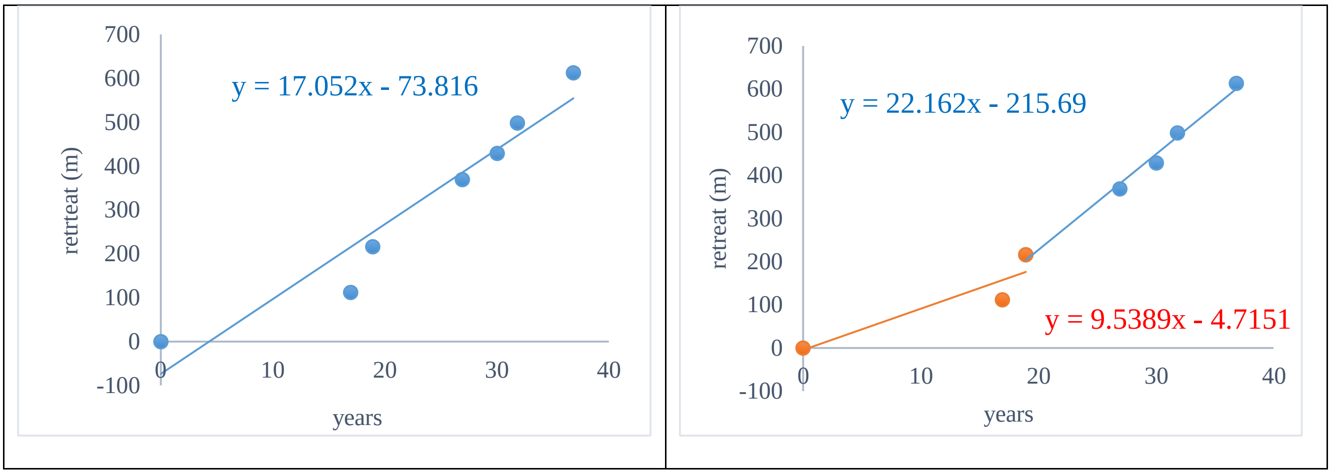
a b

Fig. 2. The dynamics of the retreat of the Adishi glacier according to SRS: a - for the full period of observation, b - for two sub-periods of observation.

The same actions for the GBA data give a graph of the retreat of the Adishi glacier (Fig. 3 a). The initial state corresponds to 1985. For more information, the observation period is divided into two sub-periods: 1985-2004 and 2004-2022. The corresponding graphs are given in Fig. 3 b.

The analysis shows that the rate of retreat of Addishi glacier according to SRS and GBO data are: during the whole period was about 14.8 and correspondingly 17.0 m/year. In the first subperiod, the velocity is approximately 8.2 and 9.5 m/year and in the second subperiod - about 19.3 and 22.2 m/year respectively. Both the SRS and GBO data show that the retreat in the second subperiod is significantly greater than the retreat in the first subperiod, that is, the retreat of the glacier is non-linear.

The analysis shows that the difference between SRS and GBO data for the entire period is about 2.9 m/year, while the difference for the first period is about 1.3 m/year and about 2.9 m/year for the second period. This difference is due to the differences between the periods of satellite and ground observations, as well as the differences in reference measurements.



a b

Fig. 3. The dynamics of the retreat of the Adisho glacier according to GBO: a - for the full period of observation, b - for two sub-periods of observation.

These data confirm that the rapid degradation of the Adishi glacier is caused by modern climate change. On the other hand, glacier retreat data is an effective indicator of current climate change and its acceleration in time. The non-linear retreat of the Adishi glacier by SRS and GBO, as well as the retreat of other large glaciers of Georgia discussed by us [6-8] is described with high accuracy by a parabola curve.

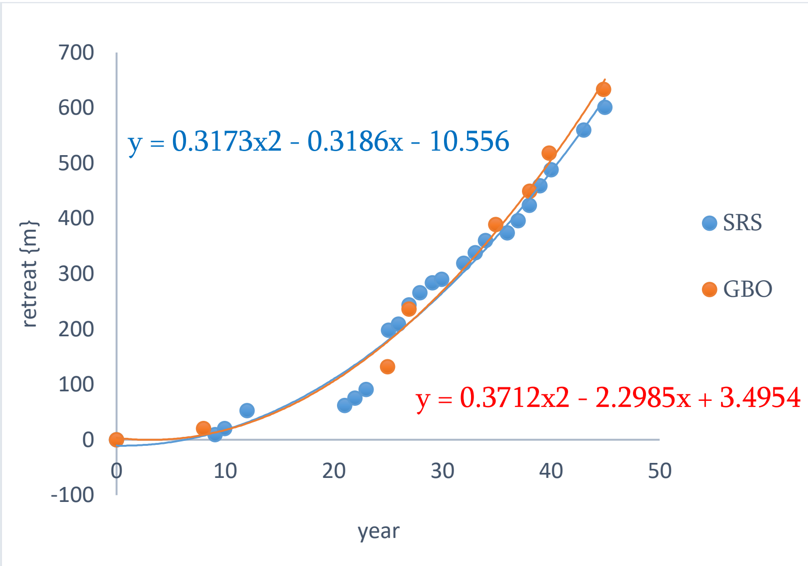


Fig. 4. Retreat graphs of Adishi Glacier based on SRS and GBO data

A comparison of the graphs in Fig. 4 shows that the graphs created based on SRS and GBO data are in satisfactory agreement with each other.

Fig. 5 shows a schematic image of the retreat of the Shkhara Glacier on the background of the September August 25, 2022, Landsat 8 OLI TIRS satellite image, where the green pins show the results obtained by the GBO data. In different years, the location of the glacier is shown with a different coloured outline. The same activities that were carried out for the Adishi glacier give for Shkhara glacier retreat the same picture i.e. the glacier retreat is nonlinear, it is well described by the parabola curve both for the SRS and GBO. A comparison of the graphs in Fig. 5 shows that the SRS and GBO graphs are in satisfactory agreement with each other.

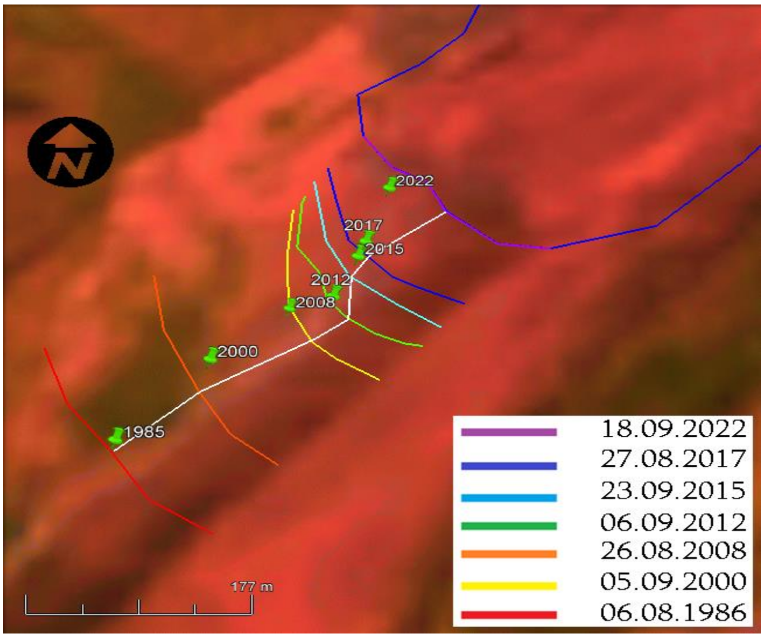


Fig. 5. Schematic image of Shkhara glacier retreat on the background of the September 18, 2022, Landsat 9 OLI TIRS sensor image. The green pins show the results obtained based on GBO data.

The retreat of the Shkhara glacier is discussed analogously as it was done for the Adishi glacier. It is received that 1. the retreat is non-linear, and 2. the retreat of the Shkhara glacier is described with high accuracy by a parabola curve (Fig. 6) based on SRS and SBO data. A comparison of the SRS and GBO graphs in Figure 6 shows that they are in good agreement with each other.

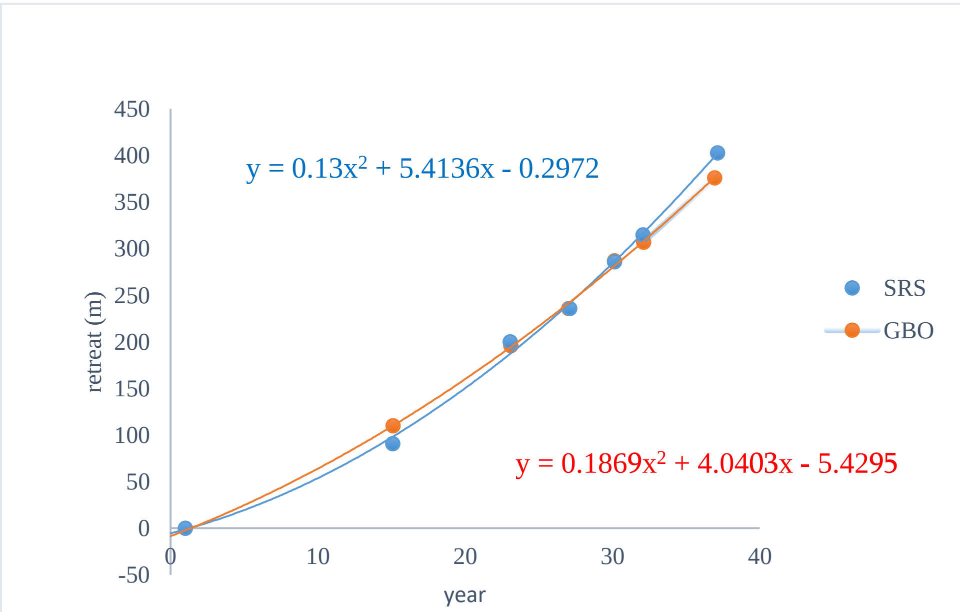


Fig. 6. Retreat graphs of Shkhara glacier based on SRS and GBO data

Among the large glaciers of Eastern Georgia, only the end of the Gergeti glacier is not covered with debris, which allows the use of multispectral sensors. To study the physical picture of the Gergeti Glacier retreat, Landsat satellite sensor data is used.

To study the retreat of the Gergeti glacier, 12 different satellite data files from 1977-2022 are selected. According to each satellite image, the location of the tip of the Gergeti glacier tongue was determined, and the data were chronologically ordered (Fig. 7).

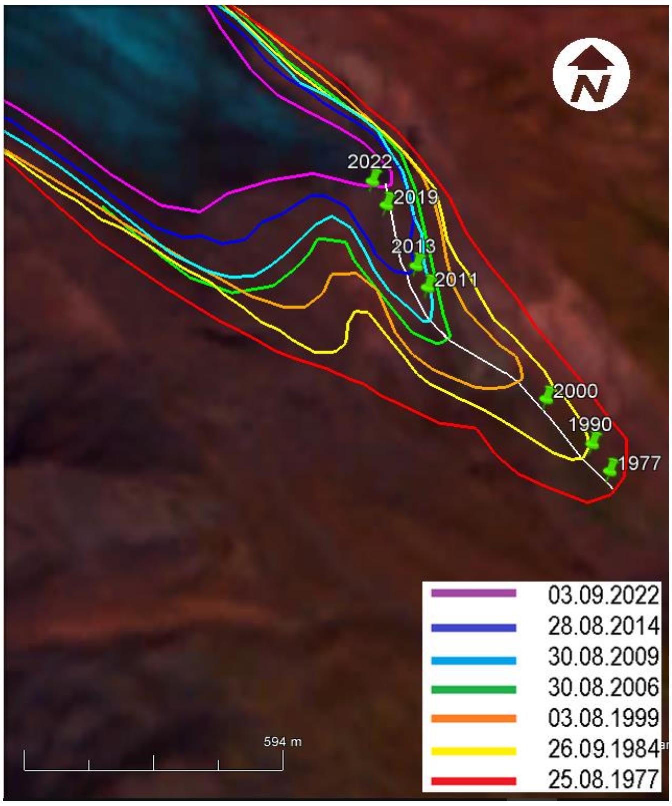


Fig. 7. Schematic image of Gergeti glacier retreat on the background of the September 3, 2022, Landsat 8 OLI TIRS sensor image. The green pins show the GBO data.

The steps to reveal the retreat dependence on time of the Gergeti glacier are the same steps that were carried out for the Adishi glacier. The same results are received i.e. the retreat of the Gergeti glacier is non-linear and is described with high accuracy by parabola curves correspondingly for SRS and GBO data (Fig. 8). A comparison of the SRS and GBO graphs in Figure 8 shows that they are in good agreement with each other.

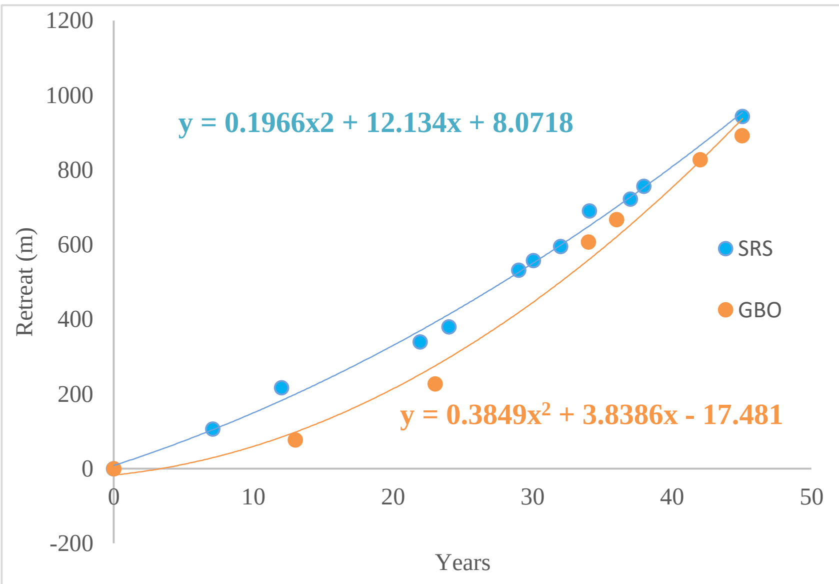


Fig. 8. Retreat graphs of Gergeti glacier based on SRS and GBO data.

Conclusion

Large glacier degradation under modern climate change poses a significant threat to the country's sustainable development and the study of their retreat is considered one of the priority activities. To obtain a scientifically based answer regarding the large glaciers' degradation issues, taking into account the impact of current climate change, it is necessary to use SRS and GBO data. If we analyse the graphs of SRS and GBO data for all three glaciers, it is evident that glacier retreat is nonlinear both for SRS and GBO data and is described with high confidence by parabola curves. A comparison of the SRS and GBO graphs shows that they are in good agreement with each other. The detail considering the corresponding graphs shows that the differences in the SRS and GBO data at the beginning of the graphs are bigger than in recent years. This is explained by the fact that earlier field ground observations were carried out using the geodetic planning method, and since 2004 - using a special field Global Positioning System (GPS), which also uses satellite information and has high accuracy. A comparison of SRS and GBO graphs that define good agreement with each other confirms the relevance of using GBO data for quality assessment and quality control (OA/OC) of SRS data.

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საქართველოს დიდი მყინვარების უკანდახევის კვლევისთვის თანამგზავრული დისტანციური ზონდირების და საველე მიწისპირა დაკვირვების მონაცემების შედარება

გ. კორძახია, ლ. შენგელია, გ. თვაური, მ. ძაძამია, გ. გულიაშვილი, ს. ბერიძე

რეზიუმე

წარმოდგენილია საქართველოს დიდ მყინვარებზე (ადიში, შხარა გერგეთი) თანამგზავრული დისტანციური დაკვირვების და საველე მიწისპირა დაკვირვების მონაცემების შედარების შედეგები. თითოეული თანამგზავრული სურათის მიხედვით დადგინდა მყინვარის ენის ბოლოს მდებარეობა, შედგა მონაცემთა ქრონოლოგიური რიგი და გამოთვლილ იქნა მყინვარის უკანდახევის საშუალო სიჩქარე. თდზ-ის გამოყენებით შესწავლილია მყინვარების უკანდახევის დინამიკა მყინვარის ენის წვერის მოძრაობის ცალკეული ადგილების განსაზღვრის საფუძველზე. შედეგების ხარისხის შეფასებისა და კონტროლისათვის გამოყენებულია გარემოს ეროვნული სააგენტოს საველე დაკვირვებების მიწისპირა მონაცემები. დადგინდა, რომ შესწავლილი მყინვარების უკანდახევა არაწრფივი ხასიათისაა და მაღალი სიზუსტით აღიწერება პარაბოლის მრუდით. ასევე დიდი სიზუსტით პარაბოლის მრუდით აღიწერება შედეგების ხარისხის შეფასებისა და კონტროლისათვის გამოყენებული საველე ექსპედიციის მონაცემების მიხედვით აგებული მყინვარების უკანდახევის გრაფიკი. თანამგზავრული დისტანციური დაკვირვების და საველე მიწისპირა დაკვირვების მონაცემების შედარება გვიჩვენებს, რომ შესწავლილი მყინვარების თდზ-ისა და საველე დაკვირვებების მიწისპირა მონაცემები ერთმანეთთან კარგ თანხვედრაშია.

საკვანძო სიტყვები: საქართველოს მყინვარები, სატელიტური დისტანციური ზონდირება, მიწისზედა დაკვირვებები, კლიმატის ცვლილება.

Сравнение данных спутникового дистанционного зондирования и полевых наземных наблюдений для исследования отступления Больших ледников Грузии

Г. Кордзахия, Л. Шенгелия, Г. Тваури, М. Дзадзамиа,
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Резюме

Представлены результаты сравнения данных спутникового дистанционного зондирования (СДН) с данными полевых наземных наблюдений за большими ледниками Грузии (Адиши, Шхара Гергети). По каждому спутниковому снимку определялось положение вершины языка ледника, приводилась хронологическая упорядоченность данных и рассчитывалась средняя скорость отступания ледника. С помощью СДН изучается динамика отступания ледников на основе определения местонахождения кончика языка ледника при движении. Для оценки и контроля качества результатов используются наземные данные полевых наблюдений Национального агентства по охране окружающей среды. Установлено, что отступление изученных ледников носит нелинейный характер и с высокой точностью описывается параболической кривой. Также график отступления ледников, построенный по данным полевой экспедиции, используемый для оценки качества и контроля результатов, с большой точностью описывается кривой параболы. Сравнение данных спутниковых дистанционных наблюдений и данных полевых наземных наблюдений показывает, что СДН изученных ледников и наземные данные полевых наблюдений хорошо согласуются друг с другом.

Ключевые слова: Ледники Грузии, спутниковое дистанционное зондирование, наземные наблюдения, изменение климата.