Acta geographica Slovenica, 53-2, 2013, 257–293

THE TRIGLAV GLACIER BETWEEN THE YEARS 1999 AND 2012

TRIGLAVSKI LEDENIK MED LETOMA 1999 IN 2012

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MILAN OROŽEN ADAMIČ

Georadar measurements of the Triglav glacier in the year 1999.
Georadarske meritve Triglavskega ledenika leta 1999.

The Triglav Glacier between the years 1999 and 2012

DOI: 10.3986/AGS53202
UDK: 911.2:551.324(234.323.6)
528.4:551.324(234.323.6)
COBISS: 1.02

ABSTRACT: The Triglav glacier is situated in the Julian Alps in the northwest of Slovenia. Presented are the results of investigations and measurements of the Triglav glacier done between the years 1999 and 2012. During this period its depth was measured by means of georadar for the first time. Its area was measured on a yearly basis by means of various land surveying methods. The dynamics of the glacier shrinkage is explained by using the weather data of each respective year. Due to the glacier's concave form, accumulated winter snow did not melt until the late summer in the past few years, particularly in the central and lower sections of the glacier. If such weather conditions continue, and the amount of winter precipitation further increases, the remainder of the Triglav glacier, though small in size, will continue to exist for a few years.

KEY WORDS: Triglav glacier, glacier measurements, climate change, Julian Alps, Slovenia

The article was submitted for publication on May 30, 2013.

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1 Introduction

The Triglav glacier is situated in the Julian Alps in the northwest of Slovenia, more precisely on the north-eastern slope of the highest mountain in the state, Mt. Triglav. The Anton Melik Geographical Institute of the Scientific Research Centre at the Slovenian Academy of Sciences and Arts has regularly performed measurements since 1946. The results of the measurements have been published approximately in ten-year intervals (Meze 1955; Šifrer 1963; 1987; Šifrer and Košir 1976; Gabrovec 1998). The current paper presents the results of research performed from 1999 through 2012. The size of the glacier, measured in 1946, was 14.4 hectares (Meze 1955), and by the year 2012 the glacier had shrunk to a half of a hectare. It no longer has all the characteristics of a glacier, since it shows no crevasses, for example. These used to occur until the end of the 1980s (Šifrer 1987) and can be seen on old photos. Because the glacier is trapped in the concave part of the slope, the fluctuation of ice is detected no more. It can be designated as a »very small glacier« (Kuhn 1995), or, following the terminology of the *World Glacier Monitoring Service*, a »*glacieret*« (Fluctuations … 2012). Due to its small size, the Triglav glacier is highly sensitive to climatic changes and hence a good indicator of them. The direct vicinity of the meteorological station on Mt. Kredarica makes possible an analysis of the dependency of the glacier's fluctuation on weather changes (Gams 1994; Nadbath 1999; Gabrovec 2002b; Gabrovec and Zakšek 2007; Gabrovec 2008; Gabrovec et al. 2009; Erhartič and Polajnar Horvat 2010; Pavšek 2010). The Triglav glacier lies in the extreme south-east part of the Alps. As regards its location and size, it is not comparable to the large Alpine glaciers, while reasonable is a comparison with very small glaciers in the neighbouring Austria (Kuhn 1995; Kaufmann and Ladstädter 2008; Triglav Čekada et al. 2012), Italy (where regular measurements of the Kanin glacier are performed in the west part of the Julian Alps; Tintor 1993; Forte, Pipan and Colucci 2012), and Germany (Hagg et al. 2012). In Slovenia, apart from the Triglav glacier, the glacier of Ledenik pod Skuto (The Glacier below Mt. Skuta) is regularly observed too (Pavšek 2004; 2007, Pavšek and Trobec 2010).

Outside the Alps, glaciers with similar properties as those of the Triglav glacier occur individually in south-east Europe; they are remnants of the onetime extensive Holocene glaciation, e.g. Debeli Namet in the Durmitor mountain range, Montenegro (Hughes 2007; 2008; Djurović 2009; 2012), the glacier in the Prokletije mountain range, Albania (Milivojević et al. 2007), or two glaciers in the Pirin Mountains, Bulgaria (Gachev et al. 2009; Grunewald and Scheithauer 2010). These glaciers are similar in size (a few hectares, or less than a hectare), they lack glacier tongue, while their width often exceeds their length (Djurović 2012). Typical of the glaciers in the above-mentioned mountain ranges are their rather low altitude and their location on north-facing slopes. Supposedly, carbonate bedrock has also been supportive to the conservation of these glaciers. On light-coloured limestone and marble, albedo is higher; besides, due to the karst surface, the glacier water drains underground, and pools which could retain warmth do not occur in the glacial cirques (Grunewald and Scheithauer 2010). Observations of the glaciers in south-east Europe in the past decade show that in individual years they changed similarly to the Triglav glacier (Hughes 2008; 2010; Djurović 2009; 2012).

The paper briefly resumes the results of glacier measurements done before 1999. Next comes a description of weather conditions and changes in the glacier's size by individual glacier years. In the course of the years discussed, we introduced several new methods of measuring (Verbič and Gabrovec 2002; Gabrovec 2002a; Triglav Čekada and Gabrovec 2008; Triglav Čekada 2012) which are also presented within the descriptions of individual years. Besides regular annual measurements performed at the end of melting seasons, the Triglav glacier has also been photographed monthly since 1975, from two fixed positions on Mt. Kredarica; the photographs have been taken with the panoramic *Horizont* camera (Triglav, Kosmatin Fras and Gvozdanovič 2000). The camera was calibrated on the testing field of the Vienna University of Technology in 1999. The selected photographs, showing the glacier at the end of the melting season, were treated with the method of interactive orientation of two-dimensional image by means of a detailed three-dimensional (3-D) elevation model. The applied digital elevation model (DEM) with a grid of 2-by-2-metre cells was made by means of photogrammetric measurements conducted in 2005. It was used for capturing the 3D boundary of the glacier which is a enabled the calculation of the area and the volume of the glacier (Triglav Čekada, Štrumbelj and Jakovac 2007; Triglav Čekada et al. 2011; Triglav Čekada and Gabrovec 2013).

2 Fluctuation of the Triglav glacier between the years 1946 and 1998

Typical of the first decade after the Second World War was more intensive shrinking of the glacier. The glacier mainly kept thinning intensely during the first years, while in the last years of this decade its horizontal recession also occurred in the lower section. Thus, the tongue of the glacier receded during this period by 23.5 metres under Mt. Glava, and east of this point, at one of the measuring points, as much as by nearly 50 metres. Exceptions were only the years 1948 and 1951, when the glacier slightly increased (Meze 1955). Intense shrinking of the glacier continued all until the end of the 1950s; during this period the glacier further retreated by 28 metres (Šifrer 1963). However, the year 1960 was an important turning point in the glacier's development. Typical of the 1960s was the above-average depth of snow cover, and snow remained on the glacier the major part of the melting period in late spring and summer. Though, the shrinking of the glacier continued, but it slowed down significantly. Thus, in the initial 14 years of observation, the glacier annually shrank by three metres on the average, but in the following 14 years –between 1960 and 1973– only by 0.8 meters on the average. The recession mostly occurred in the years 1964 and 1967, when the snow of the preceding winters completely melted (Šifrer and Košir 1976). In the second half of the 1970s, the retreat of the glacier further slowed down or almost completely stopped. In these years the lower section of the glacier was mainly covered with snow at the end of melting seasons, and only a smaller central section of the glacier was bare. In this period, the average depth of snow cover at the end of the accumulation period in April amounted to over 4.5 metres, while in the period from 1955 through 1962, the average was 3 metres only (Šifrer 1987). The turning point occurred in 1982. The investigations of that time revealed intense shrinking and ablation of the glacier caused by the extremely warm summer. The size of the glacier was then the smallest in the entire period of regular measurements, i.e. from the year 1946 onwards. In the succeeding years, the shrinking of the glacier was even more intense. At the east end of the glacier a broad bedrock exposure occurred in 1986, which separated the glacier's tongue from its central section. Typical of the following years was also intense thinning of the glacier, particularly in its upper section. The glacier annually thinned by 1 to 2 metres. Due to the intensive thinning, the extent of outcropping rocks which had been revealed from under the ice in the previous years increased so much that the glacier disintegrated into several parts (Gabrovec 1996). The turning point in the glacier's disintegration was the year 1990, when its north-east lower section completely separated from it, while its west lower section was linked to the central section of the glacier with a 30-cm-wide stripe of ice only. Due to the above-average deep snow cover in the late spring of 1991 (in mid-June, there was still 570 cm of snow at the snow stake located at the glacier's lower section), the retreat of the glacier temporarily stopped. In the years 1992 and 1993, the glacier thinned again, each time by 2 metres, outcropping rocks in the middle of the glacier and in between its individual sections kept becoming ever larger. In 1990, the lower section of the glacier was separated from the central section by a 3-metre bedrock exposure, while in 1993 the bedrock partition between them was already a few tens of metres wide. Furthermore, the lower section was to a large extent covered with rubble. The original measuring points at the lower edge of the glacier became completely useless. In 1995, when the glacier was measured for the first time with a theodolite since the year 1952, its area amounted to 3 hectares. In the following three years the shrinking of the glacier continued. From half a metre to one metre of ice melted annually, which resulted in the horizontal retreat of two to four metres at the lower edge of the glacier (Gabrovec 1998; 2002b; 2003; 2008; Gabrovec and Peršolja 2004).

3 Annual reports

3.1 The 1998–1999 glacier year

In 1998, the melting season ended already on 28 August, when 10 cm of snow fell. Due to cold weather the snow did not melt, and on 12 September, 35 cm of snow fell again. The snow cover reached its greatest depth in the second half of April; on 20 April, the average depth of snow at snow stakes installed at the lower edge of the glacier amounted to 425 cm. By this day, 1605 mm of precipitation fell, the sum of daily new snow amounts was 920 cm (Figure 5). In the first half of March and in April, two large slab avalanches were triggered from below the ridge between Mt. Mali Triglav and Mt. Veliki Triglav. On 18 May, 260 cm

Figure 1: The Triglav glacier on 14 September 1999.

of snow on the average were measured. In the second half of May and at the beginning of June the snow quickly melted, so that on 10 June 135 cm of snow were measured, which is below the average for this time of a year. Ice was revealed from under the snow on 17 July (Gartner 1998–2006). The melting season of the glacier lasted 80 days, during which the average daily air temperature was + 6.0 °C, and the sun shone 339.5 hours (Gartner 1998–2006; Agencija … 2013). We conducted our regular annual researches of the glacier between 13 and 15 September. In 1999, we employed photogrammetric measurements of the Triglav glacier for the first time. For this task, we associated with the Institute of Geodesy and Photogrammetry of the University of Ljubljana (the present Geodetic Institute of Slovenia) and the DFG Consulting Company. For the needs of the photogrammetric measurement we marked control points in the area around the glacier (circles of 0.8 m in diameter) with perishable violet paint. The control points, the boundary of the glacier and three profiles on it were still measured by means of the classical land surveying method with theodolite. Photographs of the glacier were taken from a helicopter of the Slovenian Army as well as from the ground with a classical medium-format metric camera *Rolleiflex* 6006 (Triglav and Gabrovec 2008; Kosmatin Fras et al. 1999). In comparison with the surveying measurements of 1995, the glacier reduced to a third of its previous area, i.e. from 3 ha to 1.1 ha (the first published information on the glacier's area in that year stated 1.375 ha (Peršolja 2000), but this number presents the actual area of the inclined surface and not its projection on a horizontal surface). The glacier retreated most intensely in the north-west lower section. Already in the photo published in 1997 (Gabrovec 1998, 99) it is possible to see the outcropping rocks which actually cut away its west lower section; due to the thin layer of ice, the glacier retreated most intensely at this point again in 1999.

In that year, we established the depth of ice for the first time by means of georadar measurements (Introductory figure). The measurements were done by D. Najdovski in cooperation with T. Verbič. Along two profiles we obtained the data on the relief under the glacier. The greatest depth of ice along these two profiles was between 7 and 8 metres (Peršolja 2000).

3.2 The 1999–2000 glacier year

In 1999, the ablation season ended at the beginning of October, when 15 cm of snow fell. The snow cover reached the highest level on 31 March, when the average depth on snow stakes below the glacier was 3 metres.

Figure 2: The Triglav glacier on 12 September 2000.

Measured in the accumulation season on Mt. Kredarica were 814.9 mm of precipitation, and 601 cm were new snow (Figure 6). Ice was exposed on the central steep part of the glacier around 5 July. Until the beginning of the new accumulation season 94 days elapsed, during which the sun shone 534.4 hours, the average air temperature was + 5.5 °C (Gartner 1998–2006; Agencija … 2013). In 2000, we repeated georadar measurements, and the depth of ice was successfully measured along 12 profiles. We performed the measurements in cooperation with T. Verbič on 4 and 5 July. The profiles were scanned by 500 MHz antenna. During the scanning the glacier was still covered with up to 3-metre deep snow. It was deeper in the lower part and on both lateral sides of the glacier, while in the central section the depth of snow cover did not exceed one metre. Clearly visible on the radar-graphs is the boundary between ice and bedrock and likewise is the boundary between snow and ice. The greatest measured depth of ice amounted to 9.5 metres. Locations of geo-radar profiles were also geodetically measured during the scanning. We measured the beginning and the end of each profile, and intermediate points at every five to ten metres. Altogether 195 points were measured along the 12 profiles. On the basis of these data the volume of the glacier was assessed at 35,000 m^3 (Verbič and Gabrovec 2002). From the photogrammetric measurements in the following years and the calculated reduced depth of ice we judge that the volume assessed at that time was underestimated. At the end of the melting season the area of the glacier was similar to that of the previous year, i.e. about 1 hectare. The glacier had mainly thinned, and, resultantly, its upper edge was slightly lower, which can be discerned when the photos are analysed in detail.

3.3 The 2000–2001 glacier year

The accumulation season started in the first days of October. When the weather changed on 30 September, it first rained and later began to snow, so by 10 October, 70 cm of snow had fallen. In March, large slab avalanches were triggered in the entire area of the glacier. The deepest snow was on the lower rim section of the glacier on 22 April; the measured depths at snow stakes were 690, 740 and 730 cm (Gartner 1998–2006). The officially measured depth of snow on that day (700 cm) was the greatest measured depth of snow since the beginning of measurements on Mt. Kredarica in 1954 (Vrhovec and Velkavrh 2001). It should be noted that, due to the changed method and location of measuring the depth of snow cover on Mt. Kredarica, the measurements obtained between 1978 and 2010 are not directly comparable to older measurements (Dolinar et al. 2010) and later ones (after 2010). The stated depth exceeds by 3 metres all April values of the preceding 15 years. The record value occurred due to: intensive snowfall in November and December, abundant snow in March and additional snowfall and low air temperatures in April (Vrhovec and Velkavrh 2001). Figure 3 shows snow conditions on the glacier in May. From the beginning of the accu-


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Figure 3: The Triglav glacier on 10 May 2001.


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Figure 4: The Triglav glacier on 18 October 2001.

mulation season until 22 April, 2160.9 mm of precipitation fell on Mt. Kredarica, or 1597 cm of new snow (Figure 6; Agencija … 2013). At the beginning of June, there was about 500 cm of snow there, at the beginning of July still 330 cm on the average, and 90 cm at the beginning of August. The glacier and its surroundings were covered with snow until the end of the melting season, and new snow fell already at the beginning of September (Gartner 1998–2006). On 16 and 17 October 2001, we stabilized nine fixed ground control points for the aerial-photogrammetric measurement of the glacier. The control points were screwed down into the bedrock and protected with a nut. On the screw of the original control point a 0.5 m long pole with a round pink 0.6 m diameter signal was screwed down. It was for the first time that we measured the points with the global navigation satellite system (GNSS). We took the aerial photographs of the glacier from a helicopter, and with the same medium-format metric camera as in the year 1999 (Elaborat … 2001; Triglav Čekada and Gabrovec 2008). Unfortunately, the glacier was covered with snow this year, so we could not calculate the area and volume of the glacier on the basis of photogrammetric measurements.

3.4 The 2001–2002 glacier year

In spite of the warm and sunny weather in October 2001, when photogrammetric measurements were made, the snow did not melt, neither the September snow nor the snow of the previous winter, so that the accumulation season had actually begun at the beginning of September. In April it snowed several times while the south wind was blowing and bringing the Sahara sand. At this time, a large avalanche was triggered in the central part of the glacier and only stopped on its level part below Mt. Glava. At the end of April the snow stakes read only about 220 cm of snow on the average. Measured by that time on Mt. Kredarica had been 917.5 mm of precipitation, or 604 cm of new snow (Figure 6; Agencija … 2013). On the upper part of the glacier, snow of the previous winter was revealed on 11 June, in mid-June snow at the snow stakes melted (Gartner 1998–2006). Regular observation of the glacier on 14 and 15 September 2002 was combined with the excursion of the Ljubljana Geographical Society (Gabrovec 2003). On the larger part of the glacier snow of the preceding winter melted, in its lower part the glacier remained covered with the firn of the previous winter. The glacier's area therefore remained the same as in the year 1999, a minor retreat occurred only at the upper rim. A part of the glacier was snowless only for four days, when the average air temperature was + 5.3 °C, and the sun shone 13.2 hours (Agencija … 2013).

3.5 The 2002–2003 glacier year

The accumulation season began on 22 September, when 65 cm of snow fell. The maximum depth of snow in the accumulation season was in the first half of April, when the average snow depth at snow stakes read 360 cm. By then, 995.6 mm of precipitation, or 628 cm of snow, had fallen (Figure 12). At the end of May, there was still about 2 metres of snow at the snow stakes, and it melted in the warm and rainy June. The ice showed on 4 July and was uncovered for 93 days. The average air temperature was + 7.2 °C, the sun shone 626.3 hours (Gartner 1998–2006; Agencija … 2013). Field work on the glacier took place from 25 through 27 August 2003. Aerial imaging of the glacier was done again from a helicopter, with the *Rolleiflex* 6006 metric camera. We additionally fixed six new control points for aerial photography. By means of the classical theodolite method we measured the control points for photogrammetric measurement and the polygon points of the year 1999, in order to establish relation with the past measurements, and certain measurement points which had been used in the previous years for manual measurement of the glacier's retreat (Elaborat … 2003; Triglav Čekada and Gabrovec 2008). The measured area of the glacier was 0.7 ha, which was the smallest measured value by that time. After the measurements had been made, the melting season continued all until the end of September, so the glacier's area was eventually even smaller. The

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Figure 5: The Triglav glacier on 19 September 2002.

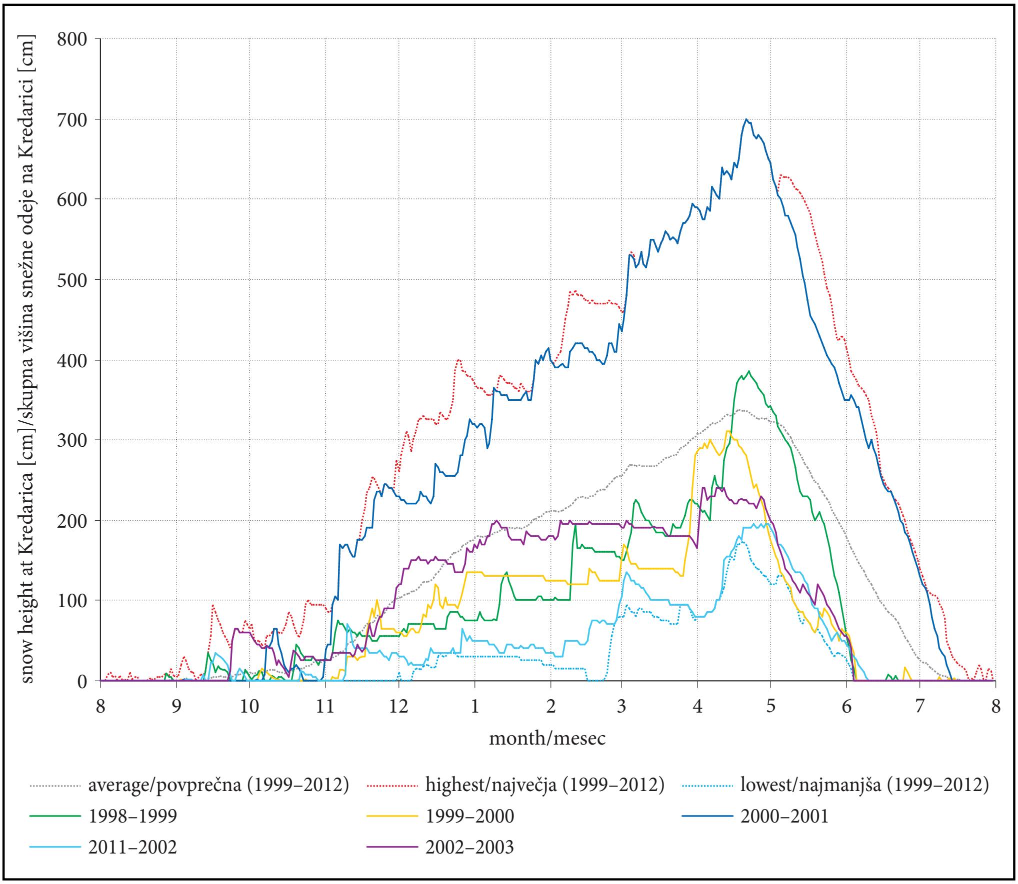

Figure 6: Total depth of snow at Mt. Kredarica in the glacier years 1998–1999, 1999–2000, 2000–2001 and 2001–2002 (Agencija … 2013).

Figure 7: The Triglav glacier on 3rd October 2003.

glacier had thinned by 1 to 2 metres since the year 1999. The rims of the glacier were covered with rubble (Peršolja 2003). The result of ice thinning was an approximate ten-metre retreat of the glacier both on its upper and its lower edges, while the lateral edges were approximately on the same positions. After the year 2003 the shrinking of the glacier slowed down and the glacier remained under the snow cover of previous winters until the end of the melting season in most of the years. The retreat of the glacier was thus limited to its upper edge.

3.6 The 2003–2004 glacier year

In September 2003, a few centimetres of snow fell repeatedly but it did not last. The accumulation season began at the beginning of October, when 25 cm of snow fell. At the end of October, large slab avalanches were triggered from the ridge between Mt. Mali Triglav and Mt. Triglav, and they stopped on the more gently sloping part of the glacier. The snow cover reached the greatest depth on 10 May, when it measured about four metres and a half; by this day, 1086 mm of precipitation had fallen, and 1090 cm were new snow (Figure 12). At the beginning of June, there was still about 4 metres of snow at snow stakes, and more than 2 metres still at the beginning of July. While snow in the surroundings of the glacier melted, it remained on the glacier throughout the melting season (Gartner 1998–2006; Agencija … 2013). Since the glacier was covered with snow, it would not have been reasonable to carry out field measurements, therefore they were not made this year.

3.7 The 2004–2005 glacier year

In mid-September the weather became rainy and at the end of the month it began to snow. The new snow covered that of the previous year and would not melt. At the end of March the amount of snow was below the average, about a meter and a half only. More abundant snowfall occurred in April, so that at the end of this month the snow stakes read 2.5 metres of snow on the average. Altogether, 1042.3 mm of precipitation fell, and 732 cm were snow (Figure 12). By mid-July the snow of the previous winter had melted, while the firn of the previous winter still lay on the glacier. On 18 August, ice was revealed in the upper part of the glacier. Before the new accumulation season began, 31 days had passed, during which the average air temperature was + 5.9 °C, and the sun shone 145.3 hours (Gartner 1998–2006; Agencija … 2013). In order to relate the more recent and earlier measurements we measured a broader area of the glacier, between the edge of Mt. Triglav's north face and the top of Mt. Triglav. Assisted by the employees of the

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Figure 8: The Triglav glacier on 13 September 2004.

Figure 9: The Triglav glacier on 16 September 2005.

Geodetic Institute of Slovenia, we carried out classical aerial photographing of the glacier in colour technique in the morning of 25 August 2005. We made use of the photogrammetric large-format *Leica* RC 30 camera. A day before the aerial photographing, we had conducted in the broader area of the Triglavski podi the classical measurement with theodolite and the GNSS measurements of the control points. We stabilized some of the new control points with the screw and marked them with crosses coloured with perishable pink paint. The snow on the glacier and its surroundings had not yet melted by the time of aerial photographing, therefore the area of the glacier measured by means of the photogrammetric method appears larger than the area measured in 2003 (Triglav Čekada and Gabrovec 2008; Gabrovec et al. 2009). The measured area was 1.2 ha, while the intersection with the smallest extent of the glacier in 2003 shows the area of 0.7 ha. The enlarged area was the result of the 2004 snowfall, yet it should be stressed that the glacier thinned in the upper part (Gabrovec 2006). During August measurements, geomorphological survey was also conducted of Mt. Triglav and its surroundings; it was continued also in mid-September (14 and 15 September) of the same year. In the previous decades, the area was investigated mainly from the aspect of glacier phenomena and less from the aspect of landforms (Hrvatin, Komac and Zorn 2005). Prior to this survey, a similar one was made by M. Šifrer (1963).

3.8 The 2005–2006 glacier year

The accumulation season began on 17 September, when 35 cm of snow fell (Gartner 1998–2006). This winter was snowy above the average (the highest total depth of snow cover on Mt. Kredarica was 495 cm, by that time 1215 mm of precipitation had fallen, or max. 1170 cm of snow (Figure 12; Agencija … 2013). However, ablation in the melting season was likewise above the average, especially in July. As to the average monthly air temperature, this month was the second warmest month on Mt. Kredarica after the year 1955. We visited the glacier on 4 and 5 September 2006. About three quarters of its area were covered with the snow of the previous winter, and on one quarter of its area older layers of firn were revealed. No geodetic measurements were performed in 2006, but we measured the distances with a manual laser distance meter and assessed the area of the glacier on this basis. The measured area of the glacier (1 ha) shrank in comparison with the previous year, but it was still larger than that in the year 2003, when the smallest area was measured. Ice thinning also continued. The central part of the glacier is completely concave and the former deep marginal crevasses at the edges no longer exist. According to the assessments of the researchers, the depth of the glacier nowhere exceeded five metres (Gabrovec et al. 2009). After the measurements had been performed, the melting of snow on the glacier continued. At the end of September, ice was revealed on almost a half of the glacier's surface. After the extremely warm autumn, the new accu-

Figure 10: The Triglav glacier on 30 September 2006.

mulation season only began on 19 November 2006 (the average autumn air temperature on Mt. Kredarica was as high as + 3.1 °C, or 2.9 °C above the long-term average; Cegnar 2006, 36). The glacier was at least partly revealed for 62 days, the average air temperature at that time was + 2.3 °C, the sun shone 300.5 hours (Agencija … 2013).

3.9 The 2006–2007 glacier year

After the glacier year 2006–2007 no further meteorological reports are available, such as were written between the years 1998 and 2006 along with regular imaging of the Triglav glacier (Gartner 1998–2006) and were partly based on subjective observations of the author. Therefore, stated for the last five years that are discussed in the paper are only the official weather data from the Kredarica meteorological station (Agencija … 2013) which, however, are not the most representative as regards the depth of snow on the glacier. The 2006–2007

Figure 11: The Triglav glacier on 24 August 2007.

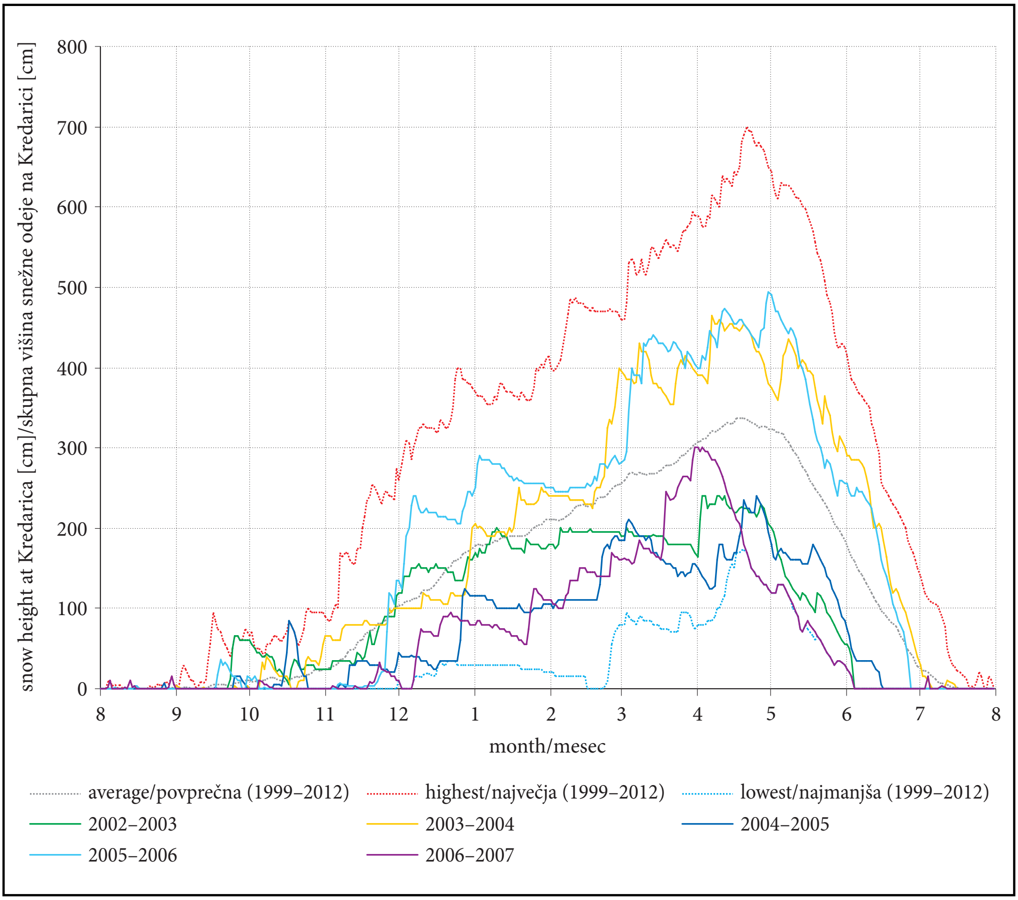

Figure 12: Total depth of snow cover on Mt. Kredarica in the glacier years 2002–2003, 2003–2004, 2004–2005, 2005–2006 in 2006–2007 (Agencija … 2013).

accumulation season began on 19 November 2006, the greatest total depth of snow cover (3 m) was registered on 1 April 2007; by that time, 514.9 mm of total precipitation, or 606 cm of snow, had fallen (Figure 12). The period when the glacier was at least partly revealed lasted 57 days. During this time, the average air temperature was + 2.3 °C, the sun shone 200.5 hours (Table 2; Agencija … 2013). Before we started the measurements of 13 and 14 September 2007, some snow had fallen which prevented a detailed determination of the glacier's edge on the basis of photographs. We decided to determine the edge of the glacier and measure it on the spot by means of the classical measurements with theodolite, and to make use of the photogrammetric measurements only as a help in the measuring of details. For the purpose of terrestrial photogrammetric imaging we set up temporary control points which were stuck into the glacier; we also measured them with the theodolite technique. The imaging was done with the metric camera *Rolleiflex* 6006. The points along the boundary of the glacier were measured every 5 metres, and measurements were also made along several profiles in the centre of the glacier. Within the discussed period, the glacier was exposed already for the third time (after 1999 and 2003) and snow remained only along the lower edge of the west part. Ice showed from under the snow around 1 August 2007. The measured area amounted to 0.6 ha. Comparison of the glacier's extent with that of the year 2003 showed that, due to the snow cover on the glacier, we measured a larger area at the lower edge than the actual area of ice was. Intersection of the measured areas in 2003 and 2007 shows that the actual area of ice was only 0.5 ha.

3.10 The 2007–2008 glacier year

The accumulation season of the glacier year 2007–2008 began on 27 September 2007, and the greatest total depth of snow cover was registered on 22 April 2008, which was 435 cm; by that time 998 cm of snow had fallen in total. In the entire glacier year, 867 mm of precipitation fell, or 1121 cm of snow (Figure 19). The period of uncovered glacier lasted 47 days. During this time, the average air temperature was + 3.3 °C, the sun shone 217.2 hours (Agencija … 2013).

We visited the Triglav glacier on 27 and 28 August 2008. During the measurements it was mainly covered with old snow, therefore the edge of the glacier was determined at field measurements. Since the combination of theodolite and terrestrial photogrammetric measurements of the past year had proved to be rather simple and efficient, we performed the same kind of measurements this year. The terrestrial photogrammetric measurement was done with the same metric camera, and the temporary control points on the glacier were used as described for the measurements of the year 2006. The measured area was 1.1 ha.

3.11 The 2008–2009 glacier year

The accumulation season of the glacier year 2008–2009 began on 3 October 2008, and the greatest total depth of snow cover was registered on 31 March 2009, which was 560 cm; by that time 1091 cm of snow had fallen in total. In the entire glacier year, 1026 mm of precipitation fell, or 1332 cm of snow (Figure 19). In this glacier year, the snow of the previous winter did not melt on the glacier (Table 2; Agencija … 2013). We assume that this layer of snow, or later firn, remained on the glacier all until 2012.

We visited the glacier on 22 and 23 August 2009. Once again, we performed the combination of theodolite and terrestrial photogrammetric measurements, as described for the measurements of the year 2006. During the measuring, the glacier was completely covered with snow of the previous winter, therefore the boundary of the glacier was determined on the spot, having been measured by means of the classical method with theodolite. The measured area was 2.9 ha.

3.12 The 2009–2010 glacier year

The accumulation season of the glacier year 2009–2010 began on 10 October 2009, and the greatest total depth of snow cover was registered on 19 April 2010, which was 450 cm; by that time 985 cm of snow had


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Figure 13: The Triglav glacier on 17 September 2008.

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Figure 14: The Triglav glacier on 13 September 2009.

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Figure 15: The Triglav glacier on 13 September 2010.

fallen in total. In the entire glacier year, 876 mm of precipitation fell, or 1157 cm of snow (Figure 19). In this glacier year, the snow of the 2009/2010 winter did not melt on the glacier (Table 2; Agencija … 2013) and it lay at least until the end of the 2011 melting season.

We visited the glacier on 14 and 15 September 2010. Once again, we performed the combination of theodolite and terrestrial photogrammetric measurements, as described for the measurements of the year 2006. The boundary of the glacier, and the (control) points on it were mainly measured with theodolite, and its area was smaller than that of the previous year, but it still measured 2.5 ha.

3.13 The 2010–2011 glacier year

The accumulation season of the 2010–2011 glacier year began on 17 October 2010. The greatest total depth of snow cover was registered as early as 25 December 2010, and was 400 cm, while the secondary maxi-

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Figure 16: The Triglav glacier on 13 September 2011.

mum was registered on 18 March 2011, with 395 cm of snow (Figure 19). By that time, 755.9 mm of precipitation had fallen, or 921 cm of snow. In the entire glacier year, 1126 cm of snow fell in total. In this glacier year, too, the glacier remained covered with snow, though the snow of the previous winter and part of the older firn melted completely (Table 2; Agencija … 2013).

We visited the Triglav glacier on 13 and 14 September 2011 and performed again the combination of theodolite and terrestrial photogrammetric measurements of the glacier's boundary and control points. We used the metric camera *Rolleiflex* 6006 again and also tested a non-professional metric *Nikon* D300 camera with calibrated 50 mm objective. The measured area was similar to that of the previous year: we measured 2.4 ha.

3.14 The 2011–2012 glacier year

The accumulation period of the 2011–2012 glacier year began on 20 October 2011. The greatest total depth of snow cover was registered on 25 April 2011 and was 240 cm. By that time, 683 cm of snow had fallen in total. In the entire glacier year, 641.9 mm of precipitation fell in total, and 788 cm was snow (Figure 19) (Table 2; Agencija … 2013). By the time of September observations, the snow of the previous winter on the glacier had already melted, though the ice was not visible due to a layer of firn of the past winters – supposedly of the 2008/2009 winter. By October, firn had melted practically on the entire glacier except for its north (lower) part, where some older firn remained on it.

In 2012, the Triglav glacier was investigated within the 'Natural disasters without borders' (NH-WF; Internet 1) Slovenian–Austrian international project: we twice performed aerial laser scanning (LIDAR) and aerial imaging of the glacier. The first scanning was done on 18 May 2012, when the glacier and its entire surroundings were covered with snow, and the second was done at the end of the melting season, on 18 September 2012. Unfortunately, a few days before the second laser scanning snowfall began. The laser scanning was performed from a helicopter by means of the Riegl LM5600 laser system. The average density of laser points in both cases was 8 pts/m^2. For the second scanning we installed on the glacier rectangular control points of durable paper, in the size of 1 m by 0.6 m, to control laser points rebounding from the wet snow. On the basis of the two measurements we determined the prevailing depth of snow cover in May 2012 as being from 1 m to 4 m (Triglav Čekada et al. 2013). During our visit to the glacier on 17 and 18 September 2012 we took photographs of it from different stands with the non-professional metric camera Nikon D300 with 20 mm objective. We also performed control measurements of the glacier's boundary by means of the GNSS method, using a gadget GPS Trimble Geoexplorer XT, which allows measurements with the accuracy of 0.5 m. Since the edge of the glacier at our September measurements was

Figure 17: The Triglav glacier on 11 September 2012.

covered with newly fallen snow, on 11 October 2012 we repeated the GNSS-measurements with the R8 gadget, which allows much greater accuracy of measurements (below 0.1 m). Since the measurements on the upper edge of the glacier failed, we determined this edge on the basis of photographs. While we were performing our measurements, we also noticed marginal crevasses, deeper than 2 metres.

The area measured was smaller than that in the year 2007, and was 0.5 ha. The actual area of ice was smaller than it had been in the years 2003 and 2007, because if compared to these two years the glacier retreated at its upper edge, while its lower edge was still covered with the firn of previous winters. The intersection of the three areas shows that there was only 0.4 ha of ice in 2012. The shrinking of the glacier in the discussed period is shown in Figure 18.

Table 1: Basic data on the measurements of the Triglav glacier between 1999 and 2012

Run. no.	Year	Date of measurement	Measured area (in ha)	Intersection* (in ha)
1	1999	13–15 Sept.	1.1	1.1
2	2000	4–5 July	–	–
3	2001	16–17 Oct.	–	–
4	2002	14–15 Sept.	–	–
5	2003	25–27 Aug.	0.7	0.7
6	2004	–	–	
7	2005	24–25 Aug.	1.2	0.7
8	2006	4–5 Sept.	1.0	–
9	2007	13–14 Sept.	0.6	0.5
10	2008	27–28 Aug.	1.1	–
11	2009	22–23 Sept.	2.9	–
12	2010	14–15 Sept.	2.5	–
13	2011	13–14 Sept.	2.4	–
14	2012	17–18 Sept and 11 Oct.	0.5	0.4

*This value represents probable ice area which was derived as an intersection of the measured area of the respective year and the areas in the past years.

Figure 18: The changing extent of the Triglav glacier between 1999 and 2012. ➤

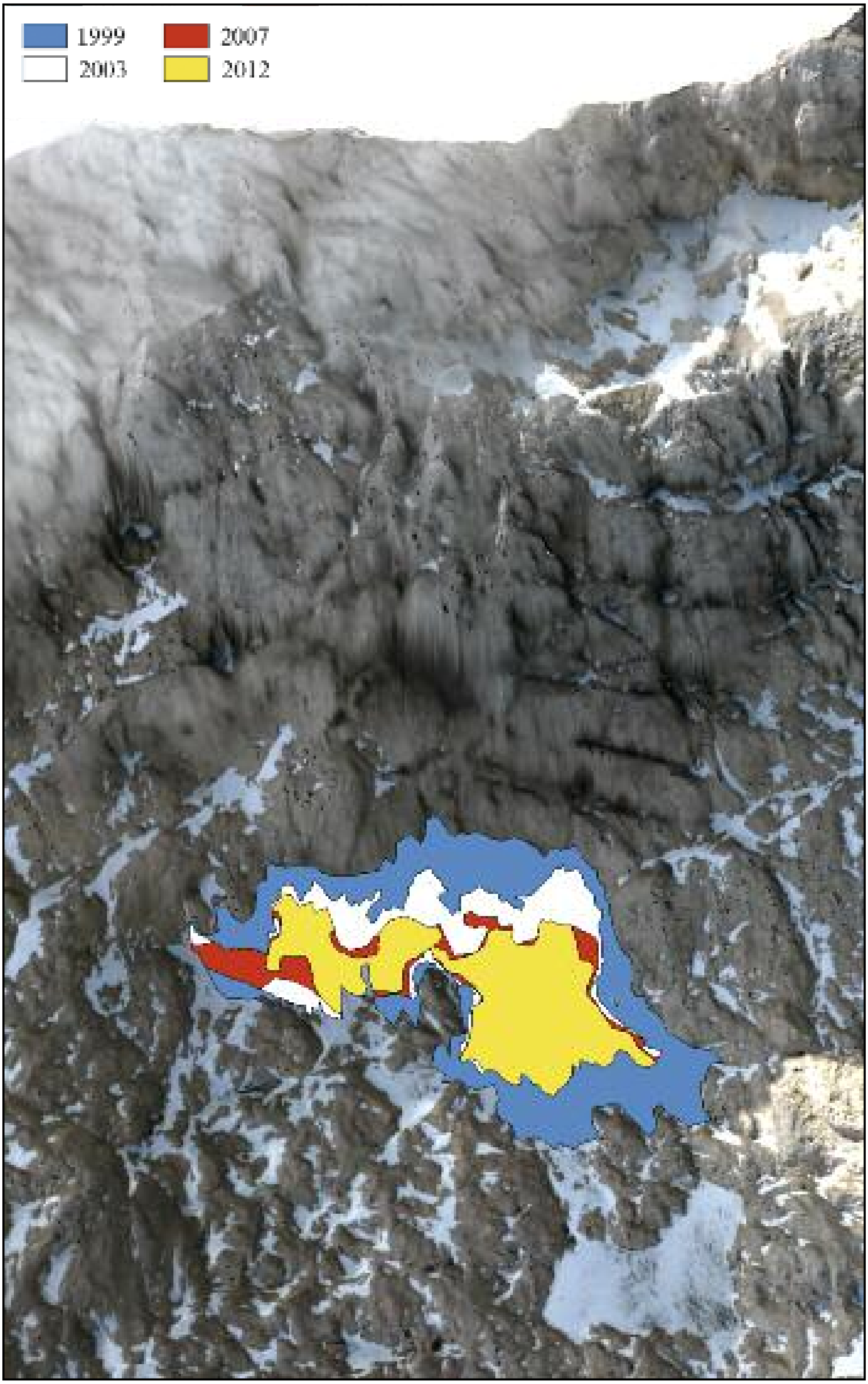
1999
2007
2003
2012

Table 2: Basic data on the accumulation and ablation seasons of the Triglav glacier collected at the meteorological station on Mt. Kredarica, by individual glacier years (Agencija … 2013).

	1999–2000	2000–2001	2001–2002	2002–2003	2003–2004	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012
Beginning of accumulation season	5 Oct.	7 Oct.	5 Sept.	23 Sept.	5 Oct.	17 Sept.	18 Sept.	19 Nov.	27. Sept.	3. Oct.	11. Oct.	17. Oct.	20. Oct.
Date of the greatest total depth of snow cover	13 Apr.	22 Apr.	25 Apr.	4 Apr.	7 Apr.	26 Apr.	1 May	1 Apr.	22. Apr.	31. Mar.	19. Apr.	25. Dec. (18. 3.)	25. Apr.
The greatest total depth of snow cover	310 cm	700 cm	195 cm	240 cm	465 cm	240 cm	495 cm	300 cm	435 cm	560 cm	450 cm	400 cm (395 cm)	240 cm
Sum of 24-hour depths of fresh snow from the beginning of accumulation season until the day of the greatest total depth of snow cover	665 cm	1602 cm	604 cm	628 cm	906 cm	732 cm	1170 cm	606 cm	998 cm	1091 cm	985 cm	921 cm	683 cm
Sum of 24-hour depths of fresh snow in the entire glacier year	787 cm	1657 cm	650 cm	759 cm	1225 cm	806 cm	1310 cm	724 cm	1121 cm	1332 cm	1157 cm	1126 cm	788 cm
Date when ice on the glacier was revealed for the first time	5 July	Snow did not melt	19 Sept.	4 July	Snow did not melt	18 Aug.	18 Sept. (*)	1 Aug. (*)	17. Aug.	Snow did not melt	Snow did not melt	Snow did not melt	Snow did not melt
Number of days of exposed ice	94 days	/	4 days	93 days	/	31 days	62 days (*)	57 days (*)	47 days	/	/	/	/
Average temperature during ice exposure	+5.5 °C		+5.3 °C	+7.2 °C		+5.9 °C	+2.3 °C	+4.7 °C	+3.3 °C				
Duration of insolation during ice exposure	534.4 hours		13.2 hours	636.4 hours		145.3 hours	300.5 hours	308.3 hours	217.2 hours				

*assessment

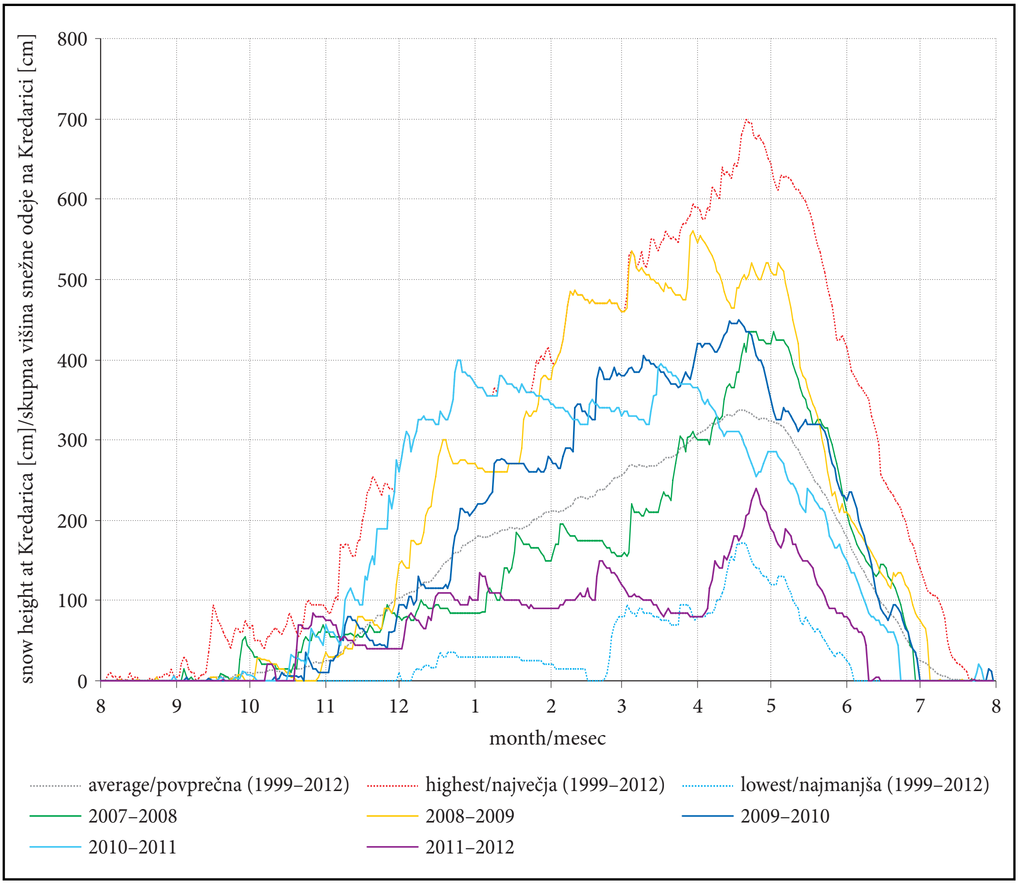

Figure 19: Total depth of snow cover on Mt. Kredarica in the glacier years 2007–2008, 2008–2009, 2009–2010, 2010–2011 and 2011–2012 (Agencija … 2013).

4 Conclusion

The paper presents the results of studies of the Triglav glacier carried out between 1999 and 2012. The stated period differs from the previous research decades, both by the research methods employed and by the glacier's shrinking dynamics. During the initial 50 years of measurements, the glacier was measured geodetically by means of theodolite only twice (in 1952 and 1995), while the rest of the measurements were done with a tape meter to measure the distance between the edge of the glacier and the measurement points (Meze 1955; Šifrer 1963; 1987; Šifrer and Košir 1976; Gabrovec 1998). Since 1999 we have regularly performed photogrammetric measurements of the glacier, which render possible exact calculations of changes in the glacier's area and volume by individual years (Gabrovec 2002a; Triglav Čekada and Gabrovec 2008). In addition, we also performed georadar measurements in 1999 and 2000. The depth of ice was measured along 12 vertical profiles. On the basis of these data we assessed the volume of the glacier (Verbič and Gabrovec 2002). While for the last decade of the 20th century we reported that the glacier »… *has not only retreated but literally disintegrated* …« (Gabrovec 1998, 110), in the first decade of the 21st century we can observe its stagnation. In 1999 the glacier shrank from its 2.5 ha to 1.1 ha. The next major recession of the glacier was registered after the above-average hot summer of 2003; the measured area was 0.7 ha. In most of the following years, the snow on the glacier had not melted by the beginning of the next accumulation season, or ice was exposed from under the snow in August only (See Table 2). After the year 2003, the glacier has never been completely exposed. Table 1 shows the results of measurements by individual years. When the glacier was entirely or partly covered with firn and/or snow, the measurements did not show the actual area of the ice. Therefore, in the last column we added extra data on the actual size of the ice, which represents the intersection of the measured area in the respective year and the areas of the glacier in the past years. Most of the ice melted at the upper edge of the glacier. Due to the firn cover of previous winters, the area of the glacier still measured 0.5 ha in that year. The events of the recent years thus cast doubt on the anticipated imminent disappearance of the Triglav glacier. The climate changes are also manifested by the increased precipitation in wintertime (Cegnar 2012). On the Triglav glacier this precipitation occurs as snow. Due to the concave form of the glacier's surface, snow remains on it late into summer, and since the year 2007, the ice of the lower part of the glacier has not been revealed even at the end of the melting season but has remained covered with the firn and snow of previous winters. Should such weather conditions continue and the amount of winter precipitation further increase, the remainder of the Triglav glacier will, though very small in size, continue to exist for a longer time than we forecasted years ago (Gabrovec 2002b).

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Triglavski ledenik med letoma 1999 in 2012

DOI: 10.3986/AGS53202
UDK: 911.2:551.324(234.323.6)
528.4:551.324(234.323.6)
COBISS: 1.02

IZVLEČEK: Triglavski ledenik leži v Julijskih Alpah na severozahodu Slovenije. Prikazani so rezultati raziskovanj in meritev Triglavskega ledenika med letoma 1999 in 2012. V tem obdobju smo njegovo debelino prvič izmerili z georadarjem. Njegovo vsakoletno površino smo računali s pomočjo različnih geodetskih metod, ki so natančno navedene. Dinamiko krčenja ledenika po letih smo utemeljili z vsakokratnimi vremenskimi razmerami. Zaradi konkavne oblike ledenika se je sneg v zadnjih letih posebno na srednjem in spodnjem delu ledenika obdržal do poznega poletja. Če se bodo takšne vremenske razmere nadaljevale in se bo količina zimskih padavin še povečevala, se bo ostanek Triglavskega ledenika, sicer v zelo majhnem obsegu, ohranil še nekaj let.

KLJUČNE BESEDE: Triglavski ledenik, merjenje ledenika, podnebne spremembe, Julijske Alpe, Slovenija

Uredništvo je prejelo prispevek 30. maja 2013.

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Vsebina

1 Uvod

Triglavski ledenik leži v Julijskih Alpah na severozahodu Slovenije, natančneje na severovzhodnem pobočju najvišjega vrha v državi, Triglava. Geografski inštitut Antona Melika Znanstvenoraziskovalnega centra Slovenske akademije znanosti in umetnosti redno letno meri ledenik že od leta 1946. Rezultati meritev so objavljeni približno po desetletnih razdobjih (Meze 1955; Šifrer 1963; 1987; Šifrer in Košir 1976; Gabrovec 1998). V tem članku poročamo o rezultatih raziskovanj od leta 1999 do leta 2012. Leta 1946 je bila izmerjena površina ledenika 14,4 ha (Meze 1955), do leta 2012 se je ledenik skrčil na polovico hektarja. Nima več vseh značilnosti ledenika, saj na njem, na primer, ni ledeniških razpok. Te so se pojavljale do konca 80. let 20. stoletja (Šifrer 1987) in so opazne na fotografijah. Zaradi ujetosti ledenika v konkavni del pobočja tudi ne zaznavamo več premikanja ledu. Označimo ga lahko kot »zelo majhen ledenik« (Kuhn 1995) oziroma po terminologiji *World Glacier Monitoring Service* (Služba za opazovanje ledenikov po svetu) za *»glacieret« (*Fluctuations … 2012). Zaradi svoje majhnosti je Triglavski ledenik zelo občutljiv na podnebne spremembe in je njihov dober pokazatelj. Neposredna bližina meteorološke postaje na Kredarici omogoča kakovostno analizo odvisnosti kolebanja ledenika od vremenskih razmer (Gams 1994; Nadbath 1999; Gabrovec 2002b; Gabrovec in Zakšek 2007; Gabrovec 2008; Gabrovec in ostali 2009; Erhartič in Polajnar Horvat 2010, Pavšek 2010). Triglavski ledenik leži na skrajnem jugovzhodu Alp. Glede na svojo lego in velikost ni primerljiv z velikimi alpskimi ledeniki, smiselne pa so primerjave z zelo majhnimi ledeniki v sosednji Avstriji (Kuhn 1995; Kaufmann in Ladstädter 2008; Triglav Čekada in ostali 2012) in Italiji, kjer v zahodnem delu Julijskih Alp potekajo tudi redne meritve Kaninskega ledenika (Tintor 1993; Forte, Pipan in Colucci 2012), ter Nemčiji (Hagg in ostali 2012). V Sloveniji poleg Triglavskega ledenika opazujemo še Ledenik pod Skuto (Pavšek 2004; 2007, Pavšek in Trobec 2010).

Zunaj Alp imajo podobne lastnosti kot Triglavski ledenik posamezni ledeniki v jugovzhodni Evropi, ki so ostanek nekdaj obsežnejše holocenske poledenitve, na primer Debeli Namet na Durmitorju v Črni Gori (Hughes 2007; 2008; Djurović 2009; 2012), ledenik na Prokletijah v Albaniji (Milivojević in ostali 2007) ali ledenika na Pirinu v Bolgariji (Gachev in ostali 2009; Grunewald in Scheithauer 2010). Ti ledeniki so si podobni po velikosti (nekaj hektarjev ali manj kot hektar), nimajo ledeniškega jezika, širina ledenika pa pogosto presega njegovo dolžino (Djurović 2012). Za ledenike v omenjenih gorovjih je značilna razmeroma nizka nadmorska višina in lega na severnih pobočjih. K ohranitvi ledenikov naj bi prispevala tudi karbonatna kamninska podlaga. Na svetlih apnencih in marmorjih je višji albedo, poleg tega zaradi zakraselega površja ledeniška voda odteče v podzemlje, v ledeniških krnicah pa ni jezer, ki bi zadrževala toploto (Grunewald in Scheithauer 2010). Opazovanja ledenikov v jugovzhodni Evropi v zadnjem desetletju so pokazala, da se v posameznih letih spreminjajo podobno kot Triglavski ledenik (Hughes 2008; 2010; Djurović 2009; 2012).

V članku na kratko povzemamo rezultate ledeniških meritev pred letom 1999. Sledijo opisi vremenskih razmer in spreminjanja obsega ledenika po posameznih ledeniških letih. V obravnavanih letih smo uvedli več novih merilnih metod (Verbič in Gabrovec 2002; Gabrovec 2002a; Triglav Čekada in Gabrovec 2008; Triglav Čekada 2012), ki jih prav tako predstavljamo v okviru opisov posameznih let. Poleg rednih letnih meritev ob koncu talilne dobe Triglavski ledenik od leta 1975 tudi mesečno fotografiramo z dveh stalnih točk na Kredarici, in sicer s panoramskim fotoaparatom Horizont (Triglav, Kosmatin Fras in Gvozdanovič 2000). Fotoaparat so leta 1999 kalibrirali na testnem polju Tehniške univerze na Dunaju. Izbrane posnetke, ki kažejo ledenik ob koncu talilne dobe, smo obdelali s pomočjo interaktivne metode orientacije dvorazsežne podobe s pomočjo trorazsežnega detajlnega modela višin. Uporabljeni digitalni model reliefa z velikostjo celice 2 m × 2 m so izdelali s pomočjo fotogrametričnega zajema na podlagi posebnega fotogrametričnega snemanja ledenika leta 2005. Rezultat zajema so 3D obodi ledenika, ki so namenjeni izračunu površine in prostornine ledenika (Triglav Čekada, Štrumbelj in Jakovac 2007; Triglav Čekada in ostali 2011; Triglav Čekada in Gabrovec 2013).

2 Kolebanje Triglavskega ledenika med letoma 1946 in 1998

Za prvo desetletje po drugi svetovni vojni je bilo značilno močno krčenje ledenika. Potem, ko se je ledenik v prvih letih predvsem močno tanjšal, je prišlo v zadnjih letih tega desetletja na spodnjem delu tudi do močnega vodoravnega umika. Tako se je ledeniški jezik pod Glavo v tem razdobju umaknil za 23,5 m, na eni izmed merilnih točk vzhodno od tod pa celo za slabih 50 m. Izjemo sta predstavljali le leti 1948 in 1951, ko se je ledenik nekoliko povečal (Meze 1955). Močno krčenje ledenika se je nadaljevalo vse do konca petdesetih let; v tem času se je ledenik umaknil še za nadaljnjih 28 m (Šifrer 1963). Leto 1960 pomeni v razvoju ledenika pomembno prelomnico. Za šestdeseta leta 20. stoletja je bila značilna nadpovprečna debelina snežne odeje in sneg se je na ledeniku zadrževal še večji del talilne dobe v pozni pomladi in poleti. Krčenje ledenika se je sicer nadaljevalo, vendar je bilo bistveno počasnejše. Tako se je ledenik v prvih 14 letih opazovanja letno v povprečju skrčil za tri metre, v naslednjih 14 letih – med 1960 in 1973 – pa v povprečju le za 0,8 m. Do umika je prišlo v glavnem le v letih 1964 in 1967, ko je sneg iz preteklih zim povsem skopnel (Šifrer in Košir 1976). V drugi polovici sedemdesetih let se je umikanje ledenika še bolj upočasnilo oziroma skoraj povsem ustavilo. V teh letih je bil spodnji del ledenika ob koncu talilne dobe večinoma pokrit s snegom, razkrit pa je bil le manjši osrednji del ledenika. V tem času je povprečna debelina snežne odeje ob koncu redilne dobe ledenika v mesecu aprilu znašala prek 4,5 m, medtem ko je bilo v razdobju od leta 1955 do 1962 to povprečje le 3 m (Šifrer 1987). Do preobrata je prišlo leta 1982. Takratne raziskave so pokazale močno krčenje in tanjšanje ledenika, ki ju je povzročilo izjemno toplo poletje. Ledenikov obseg je bil tedaj najmanjši v obdobju rednih meritev, to je od leta 1946. V naslednjih letih je bilo krčenje ledenika še močnejše. Leta 1986 je izpod ledenika na spodnjem vzhodnem koncu pogledal širok živoskalni prag, ki je ločil spodnji jezik ledenika od njegovega osrednjega dela. Za naslednja leta je bilo značilno tudi močno tanjšanje ledenika, predvsem v njegovem zgornjem delu. Ledenik se je letno stanjšal za 1 do 2 metra. Zaradi intenzivnega tanjšanja se je obseg skalnih grbin, ki so pogledale izpod ledu v prejšnjih letih, tako povečal, da je ledenik razpadel na več delov (Gabrovec 1996). Pri razpadanju ledenika je bilo prelomno leto 1990, ko se je od ledenika povsem ločil njegov spodnji, severovzhodni del, ves spodnji zahodni del pa je z osrednjim delom ledenika povezoval le 30 cm širok pas ledu. V letu 1991 se je zaradi nadpovprečno visoke snežne odeje v pozni pomladi (sredi junija je bilo ob snegomeru pod ledenikom še vedno 570 cm snega) umikanje ledenika prehodno ustavilo. V letih 1992 in 1993 se je ledenik spet stanjšal, vsakokrat za 2 metra, skalne grbine sredi ledenika in med njegovimi posameznimi deli pa so postajale vse obsežnejše. Spodnji del ledenika je od osrednjega dela v letu 1990 ločil le trimetrski skalni skok, v letu 1993 pa je bila med njima že nekaj deset metrov široka skalna pregrada. Poleg tega je spodnji del v veliki meri prekril grušč. Prvotne merilne točke na spodnjem robu ledenika so postale povsem neuporabne. V letu 1995, ko smo ledenik prvič po letu 1952 izmerili s teodolitom, je bila njegova površina 3 ha. V naslednjih treh letih se je krčenje nadaljevalo. Letno se je stalilo od pol metra do enega metra ledu, posledica tega pa je bil tudi dvo- do štirimetrski vodoravni umik na spodnjem robu (Gabrovec 1998; 2002b; 2003; 2008; Gabrovec in Peršolja 2004).

3 Letna poročila

3.1 Ledeniško leto 1998–1999

Leta 1998 se je talilna doba končala že 28. avgusta, ko je zapadlo 10 cm snega. Ta sneg zaradi hladnega vremena ni skopnel, 12. septembra pa je zapadlo 35 cm snega. Snežna odeja je dosegla največjo debelino v drugi polovici aprila; 20. aprila je bila povprečna višina snega na snegomerih pod ledenikom 425 cm. Do tega dne je padlo 1605,4 mm padavin, snega pa 920 cm (slika 6). V prvi polovici marca in v aprilu sta se izpod grebena med Malim in Velikim Triglavom sprožila velika kložasta plazova. 18. maja je bilo izmerjeno v povprečju 260 cm snega. V drugi polovici maja in v začetku junija se je sneg hitro talil, tako da je bilo 10. junija izmerjeno za ta čas podpovprečnih 135 cm. Led se je pojavil izpod snega 17. julija (Gartner 1998–2006). Talilna doba ledenika je trajala 80 dni, v katerih je bila povprečna dnevna temperatura zraka + 6,0 °C, sončnih ur pa je bilo 339,5 (Gartner 1998–2006; Agencija … 2013). Redne letne raziskave ledenika smo izvedli med 13. in 15. septembrom. Leta 1999 smo se prvič lotili fotogrametričnih meritev Triglavskega ledenika. Pri tem delu smo sodelovali z Inštitutom za geodezijo in fotogrametrijo Univerze v Ljubljani (sedanjim Geodetskim inštitutom Slovenije) in podjetjem DFG Consulting. Za namene fotogrametrične obdelave smo na območju okoli ledenika označili oslonilne točke (krogi premera 0,8 m) z neobstojno vijoličasto barvo. Oslonilne točke, obod ledenika in tri prereze na njem smo izmerili še s klasično tahimetrično metodo. Ledenik smo iz helikopterja Slovenske vojske in tudi s tal posneli s klasičnim srednjeformatnim merskim fotoaparatom Rolleiflex 6006 (Triglav in Gabrovec 2008; Kosmatin Fras in ostali 1999). Glede na predhodne geodetske meritve leta 1995 se je ledenik skrčil na dobro tretjino takratne površine, to je s 3 ha na 1,1 ha (prva objavljena površina ledenika tega leta je bila 1,375 ha (Peršolja 2000), a vrednost pomeni dejansko površino poševne ploskve, ne pa njene projekcije na vodoravno površino). Najbolj se je ledenik umaknil na severozahodnem spodnjem delu. Že na objavljeni sliki iz leta 1997 (Gabrovec 1998, 99) so vidne grbine, ki so praktično odrezale njegov spodnji zahodni del; na tem mestu se je ledenik v letu 1999 zaradi tanke plasti ledu ponovno najbolj umaknil.

V tem letu smo prvič ugotovili debelino ledu z georadarskimi meritvami (uvodna slika). Meritve je opravil D. Najdovski s sodelovanjem T. Verbiča. Na dveh prerezih smo dobili podatke o izoblikovanosti reliefa pod ledenikom. Največja debelina ledu v teh dveh prerezih je bila med 7 in 8 m (Peršolja 2000).

Slika 1: Triglavski ledenik 14. 9. 1999.
Glej angleški del prispevka.

3.2 Ledeniško leto 1999–2000

Talilna doba se je leta 1999 končala v začetku oktobra, ko je zapadlo do 15 cm snega. Snežna odeja je dosegla najvišjo višino 31. marca, ko je bila povprečna višina na snegomerih pod ledenikom 3 m. V redilni dobi je bilo na Kredarici izmerjeno 814,9 mm padavin, novega snega pa 601 cm (slika 6). Led se je pojavil na osrednjem strmem delu ledenika okoli 5. julija. Do začetka nove redilne dobe je minilo 94 dni, v katerih je sonce sijalo 534,4 ure, povprečna temperatura zraka pa je bila + 5,5 °C (Gartner 1998–2006; Agencija … 2013). Leta 2000 smo ponovili georadarske meritve in debelino ledu uspešno izmerili na 12 prerezih. Meritve smo v sodelovanju s T. Verbičem opravili 4. in 5. julija. Prereze smo snemali s 500 MHz anteno. V času snemanja je bil ledenik še prekrit z do 3 m debelo snežno odejo. Ta je bila večja na spodnjem delu in na obeh bokih ledenika, medtem ko v osrednjem delu ni presegala enega metra. Na radargramih je jasno vidna meja med ledom in skalno podlago, prav tako meja med snegom in ledom. Največja izmerjena debelina ledu je bila 9,5 m. Lego georadarskih prerezov smo med snemanjem tudi geodetsko izmerili. Izmerili smo začetek in konec vsakega prereza, vmesne točke pa na vsakih pet do deset metrov. Skupaj je bilo tako na 12 prerezih izmerjenih 195 točk. Na podlagi teh podatkov smo ocenili prostornino ledenika na 35.000 m^3 (Verbič in Gabrovec 2002). Na podlagi fotogrametričnih meritev v naslednjih letih in izračunane zmanjšane debeline ledu ocenjujemo, da je bila takrat ocenjena prostornina podcenjena. Ob koncu talilne dobe je bila površina ledenika podobna kot prejšnje leto, torej približno 1 ha. Ledenik se je predvsem stanjšal, posledično je zgornji rob nekoliko nižji, kar je razvidno iz podrobne analize fotografij.

Slika 2: Triglavski ledenik 12. 9. 2000.
Glej angleški del prispevka.

3.3 Ledeniško leto 2000–2001

Redilna doba se je začela v prvih dneh oktobra. Ob poslabšanju vremena 30. septembra je najprej deževalo, potem pa je dež prešel v sneg in do 10. oktobra je zapadlo 70 cm snega. V marcu so se na celotnem območju ledenika sprožili veliki kložasti plazovi. Največ snega je bilo na spodnjem robnem delu ledenika 22. aprila; izmerjena višina na snegomerih je bila 690, 740 in 730 cm (Gartner 1998–2006). Uradno izmerjena višina snega tega dne (700 cm) je bila najvišja izmerjena višina snega od začetka meritev na Kredarici leta 1954 (Vrhovec in Velkavrh 2001). Pri tem »rekordu« je treba pripomniti, da zaradi spremembe metode in lokacije merjenja višine snežne odeje na Kredarici meritve med letoma 1978 in 2010 niso neposredno primerljive s starejšimi (Dolinar in ostali 2010) in kasnejšimi meritvami (po letu 2010). Navedena debelina za 3 m presega vse aprilske vrednosti v predhodnih 15 letih. K rekordni vrednosti so pripomogli: intenzivno sneženje novembra in decembra, obilica snega v marcu ter dodatno sneženje in nizke temperature aprila (Vrhovec in Velkavrh 2001). Slika 4 prikazuje majske snežne razmere na ledeniku. Od začetka redilne dobe do 22. aprila je na Kredarici padlo 2160,9 mm padavin oziroma 1597 cm novega snega pa (slika 6; Agencija … 2013). V začetku junija je bilo tam okoli 500 cm snega, v začetku julija še vedno povprečno 330 cm, v začetku avgusta pa 90 cm. Ledenik z okolico je do konca talilne dobe prekrival sneg, v začetku septembra pa je že zapadel nov sneg (Gartner 1998–2006). Za aerofotogrametrično izmero ledenika smo med 16. in 17. oktobrom 2001 devet stalnih oslonilnih točk stabilizirali z vijakom, privitim v skalo in zaščitenim z matico. Na vijak smo privili 0,5 m dolg drog, nanj pa okrogel signal roza barve premera 0,6 m. Prvič smo točke izmerili z globalnim navigacijskim satelitskim sistemom (GNSS). Aerofotografiranje ledenika smo izvedli s pomočjo helikopterja in z istim srednjeformatnim merskim fotoaparatom kot v letu 1999 (Elaborat … 2001; Triglav Čekada in Gabrovec 2008). Žal je v tem letu ledenik prekrival sneg, tako da na podlagi fotogrametričnih meritev ne moremo izračunati površine in prostornine ledenika.

Slika 3: Triglavski ledenik 10. 5. 2001.
Glej angleški del prispevka.

Slika 4: Triglavski ledenik 18. 10. 2001.
Glej angleški del prispevka.

3.4 Ledeniško leto 2001–2002

Kljub toplemu in sončnemu vremenu v oktobru leta 2001, v katerem je bilo opravljeno tudi fotogrametrično snemanje, se v tem času ni stalil niti septembrski sneg niti sneg prejšnje zime, zato se je redilna doba dejansko začela že v začetku septembra. Aprila je večkrat snežilo ob južnem vetru, ki je prinesel saharski pesek. V tem času se je sprožil večji plaz na osrednjem delu ledenika in se ustavil šele na ravnem delu pod Glavo. Ob koncu aprila je bilo na snegomerih v povprečju le 220 cm snega. Do takrat so na Kredarici izmerili 917,5 mm padavin oz. 604 cm novega snega (slika 6; Agencija … 2013). Na zgornjem delu ledenika se je 11. junija razkril sneg prejšnje zime, sredi junija je skopnel sneg ob snegomerih (Gartner 1998–2006). Redno opazovanje ledenika 14. in 15. septembra 2002 je bilo povezano z ekskurzijo Ljubljanskega geografskega društva (Gabrovec 2003). Na večjem delu ledenika se je sneg zadnje zime stalil, v spodnjem delu pa je ostal prekrit s firnom prejšnje zime. Površina ledenika je zato ostala enaka kot v letu 1999, do manjšega umika je prišlo le na zgornjem robu. Del ledenika je bil brez snega le 4 dni, v katerih je bila povprečna temperatura zraka + 5,3 °C, sonce pa je sijalo 13,2 uri (Agencija … 2013).

Slika 5: Triglavski ledenik 19. 9. 2002.
Glej angleški del prispevka.

Slika 6: Skupna višina snežne odeje na Kredarici v ledeniških letih 1998–1999, 1999–2000, 2000–2001 in 2001–2002 (Agencija … 2013).
Glej angleški del prispevka.

3.5 Ledeniško leto 2002–2003

Redilna doba se je začela 22. septembra, ko je zapadlo 65 cm novega snega. Maksimalna višina snega v redilni dobi je bila v prvi polovici aprila, ko je bila ob snegomerih povprečna višina snega 360 cm. Do takrat je padlo 995,6 mm padavin, novega snega pa 628 cm (slika 12). Ob koncu maja je bilo ob snegomerih še okoli 2 m snega in ta je skopnel v toplem in deževnem juniju. Led se je pojavil 4. julija, odkrit je bil 93 dni. Povprečna temperatura je bila + 7,2 °C, sonce pa je sijalo 626,3 ure (Gartner 1998–2006; Agencija … 2013). Terensko delo na ledeniku je potekalo od 25. do 27. avgusta 2003. Ponovno aerofotografiranje ledenika smo izvedli s pomočjo helikopterja z merskim fotoaparatom *Rolleiflex* 6006. Dodatno smo stabilizirali šest novih oslonilnih točk za aerofotografiranje. S klasično tahimetrično metodo smo izmerili oslonilne točke za fotogrametrično izmero ter poligonske točke iz leta 1999 za navezavo na pretekle meritve in nekatere merilne točke, ki smo jih v preteklih letih uporabljali za ročno izmero odmika ledenika (Elaborat … 2003; Triglav Čekada in Gabrovec 2008). Izmerjena površina ledenika je bila 0,7 ha, kar je najmanjša izmerjena vrednost dotlej. Talilna doba je po meritvah trajala še do konca septembra, površina ledenika je bila zato takrat še manjša od izmerjene. Ledenik se je od leta 1999 stanjšal za 1 do 2 m. Robni deli ledenika so bili prekriti z gruščem (Peršolja 2003). Posledica tanjšanja debeline ledu je bil približno desetmetrski umik ledenika tako na zgornjem kot na spodnjem robu, medtem ko sta bila oba stranska robova približno na istem mestu. Po letu 2003 je bilo krčenje ledenika počasnejše, v večini let je ledenik do konca talilne dobe ostal prekrit s snegom preteklih zim. Umik ledenika je bil tako omejen na njegov zgornji rob.

Slika 7: Triglavski ledenik 3. 10. 2003.
Glej angleški del prispevka.

3.6 Ledeniško leto 2003–2004

Septembra 2003 je večkrat zapadlo po nekaj centimetrov snega, ki pa se ni obdržal. Redilna doba se je začela v začetku oktobra, ko je zapadlo 25 cm snega. Konec oktobra so se izpod grebena med Malim Triglavom in Triglavom prožili veliki kložasti plazovi, ki so se ustavili na položnejšem delu ledenika. Snežna odeja je dosegla največjo debelino 10. maja, ko je merila približno štiri metre in pol; do tega dne je padlo 1086 mm padavin oz. 1090 cm novega snega (slika 12). Na začetku junija je bilo na snegomerih še vedno okoli 4 m snega, na začetku julija pa še vedno več kot 2 metra. Medtem ko se je v avgustu sneg v okolici ledenika stalil, pa se je na ledeniku obdržal do konca talilne dobe (Gartner 1998–2006; Agencija … 2013). Ker je bil ledenik prekrit s snegom, terenske meritve ne bi bile smiselne in zato tega leta niso bile opravljene.

Slika 8: Triglavski ledenik 13. 9. 2004.
Glej angleški del prispevka.

3.7 Ledeniško leto 2004–2005

Sredi septembra je nastopilo poslabšanje vremena z dežjem, ki je ob koncu prešel v sneg. Nov sneg je prekril lanskega in ni več skopnel. Konec marca je bila za ta čas količina snega podpovprečna, le okoli poldrugi meter. Obilnejše sneženje je bilo aprila, tako je bilo ob koncu meseca na snegomerih v povprečju 2,5 m snega. Padlo je 1042,3 mm padavin, snega pa 732 cm (slika 12). Do sredine julija je skopnel sneg zadnje zime, na ledeniku pa je še ležal firn prejšnje zime. 18. avgusta se je odkril led na zgornjem delu ledenika. Do začetka nove redilne sezone je minilo 31 dni, v katerih je bila povprečna temperatura zraka + 5,9 °C, sonce pa je sijalo 145,3 ure (Gartner 1998–2006; Agencija … 2013). Da bi lahko povezali novejše in starejše meritve, smo izmerili širše območje ledenika med robom Triglavske severne stene in vrhom Triglava. 25. avgusta 2005 zjutraj smo s pomočjo sodelavcev Geodetskega zavoda Slovenije izvedli klasično letalsko fotografiranje ledenika v barvni tehniki. Uporabili smo fotogrametrično kamero velikega formata *Leica* RC 30. Dan pred aerosnemanjem smo na širšem območju Triglavskih podov izvedli tahimetrično in GNSS-izmero oslonilnih točk za fotogrametrično obdelavo. Nekatere nove oslonilne točke smo stabilizirali z vijakom in označili s pobarvanimi kraki križa neobstojne roza barve. V času snemanja se sneg na ledeniku in v njegovi okolici še ni stalil, zato fotogrametrično izmerjena površina ledenika pokriva večje območje kot leta 2003 (Triglav Čekada in Gabrovec 2008; Gabrovec in ostali 2009). Izmerjena površina je bila 1,2 ha, presek z najmanjšim obsegom ledenika leta 2003 pa ima površino 0,7 ha. Povečan obseg je posledica snega iz leta 2004, poudariti pa je treba, da se je ledenik v zgornjem delu stanjšal (Gabrovec 2006). V času avgustovskih meritev je bil izveden tudi geomorfološki pregled Triglava in okolice; nadaljevali smo ga tudi sredi septembra (14.–15. 9.) istega leta. Območje je bilo namreč v preteklih desetletjih preučevano predvsem z vidika ledeniških pojavov, manj pa z vidika reliefa (Hrvatin, Komac in Zorn 2005). Pred nami je naredil soroden pregled Šifrer (1963).

Slika 9: Triglavski ledenik 16. 9. 2005.
Glej angleški del prispevka.

3.8 Ledeniško leto 2005–2006

Redilna doba se je začela 17. septembra, ko je zapadlo 35 cm snega (Gartner 1998–2006). Zima je bila nadpovprečno snežna (največja skupna višina snežne odeje na Kredarici je bila 495 cm, do takrat je padlo 1215 mm padavin oz. 1170 cm snega (slika 12) Agencija … 2013). Vendar je bila prav tako nadpovprečna ablacija v talilni dobi, predvsem v mesecu juliju. Ta je bil na Kredarici po povprečni mesečni temperaturi zraka drugi najtoplejši po letu 1955. Triglavski ledenik smo obiskali 4. in 5. septembra 2006. Ledenik je bil približno na treh četrtinah površine pokrit s snegom zadnje zime, na četrtini pa so bile razkrite starejše plasti firna. V letu 2006 geodetskih meritev nismo opravili, pač pa smo dolžine na ledeniku izmerili z ročnim laserskim razdaljemerom in na tej podlagi ocenili ledeniško površino. Izmerjena površina ledenika (1 ha) se je glede na predhodno leto skrčila, še vedno pa je bila večja kot v letu 2003, ko je bila izmerjena najmanjša površina. Nadaljevalo se je tudi tanjšanje ledenika. Osrednji del ledenika je povsem konkaven, na robovih tudi ni več nekdaj globokih krajnih zevi. Po ocenah opazovalcev debelina ledenika nikjer več ni presegala petih metrov (Gabrovec in ostali 2009). Po meritvah se je taljenje snega na ledeniku nadaljevalo. Konec septembra je bil led razkrit že skoraj na polovici površine ledenika. Nova redilna doba se je po rekordno topli jeseni začela šele 19. novembra 2006 (povprečna jesenska temperatura na Kredarici je bila kar + 3,1 °C oziroma 2,9° nad dolgoletnim povprečjem; Cegnar 2006, 36). Ledenik je bil vsaj deloma razgaljen 62 dni, povprečna temperatura zraka je bila takrat + 2,3 °C, sonce je sijalo 300,5 ur (Agencija … 2013).

Slika 10: Triglavski ledenik 30. 9. 2006.
Glej angleški del prispevka.

3.9 Ledeniško leto 2006–2007

Od ledeniškega leta 2006–2007 naprej nimamo na voljo meteoroloških poročil, kakršna so bila med letoma 1998 in 2006 pisana ob rednih fotografiranjih Triglavskega ledenika (Gartner 1998–2006) in so deloma temeljila na subjektivnem opažanju avtorja. Zaradi tega za zadnjih pet ledeniških let, ki jih obravnavamo v nadaljevanju, navajamo le uradne vremenske podatke meteorološke postaje na Kredarici (Agencija … 2013), ki pa za višino snega na ledeniku niso najbolj reprezentativne. Redilna doba ledeniškega leta 2006–2007 se je začela 19. novembra 2006, najvišja skupna višina snežne odeje je bila zabeležena 1. aprila 2007 in sicer tri metre, do takrat je skupaj padlo 514,9 mm padavin oz. 606 cm snega (slika 12). Obdobje, ko je bil ledenik vsaj deloma razgaljen, je trajalo 57 dni. V tem obdobju je bila povprečna temperatura zraka + 2,3 °C, sonce pa je sijalo 300,5 ur (preglednica 1; Agencija … 2013). Pred meritvami 13. in 14. septembra 2007 nas je prehitel novozapadli sneg, ki je preprečil natančnejšo določitev roba ledenika na podlagi fotografij. Odločili smo se, da rob ledenika določimo in izmerimo na terenu s pomočjo tahimetričnih meritev, fotogrametrične meritve pa uporabimo le kot pomoč pri izmeri detajlov. Za terestrično fotogrametrično snemanje smo postavili začasne oslonilne točke, ki smo jih zapičili v ledenik; izmerili smo jih tudi tahimetrično. Za snemanje smo uporabili merski fotoaparat *Rolleiflex* 6006. Točke oboda ledenika smo merili na vsakih 5 m, meritve pa smo na več prerezih opravili tudi po sredi ledenika. Ledenik je bil v obravnavanem obdobju (po letih 1999 in 2003) še tretjič razkrit, sneg se je obdržal le na spodnjem robu na zahodnem delu. Led se je izpod snega pojavil okrog 1. avgusta 2007. Izmerjena površina je znašala 0,6 ha. Primerjava obsega ledenika z letom 2003 je pokazala, da smo na spodnjem robu zaradi pokritosti ledenika s snegom izmerili večjo površino od dejanske površine ledu. Presek izmerjenih površin leta 2003 in 2007 kaže, da je bila dejanska površina ledu le še 0,5 ha.

Slika 11: Triglavski ledenik 24. 8. 2007.
Glej angleški del prispevka.

Slika 12: Skupna višina snežne odeje na Kredarici v ledeniških letih 2002–2003, 2003–2004, 2004–2005, 2005–2006 in 2006–2007 (Agencija … 2013).
Glej angleški del prispevka.

3.10 Ledeniško leto 2007–2008

Redilna doba ledeniškega leta 2007–2008 se je pričela 27. septembra 2007, najvišja skupna višina snežne odeje pa je bila zabeležena 22. aprila 2008 in sicer 435 cm, do takrat je skupaj padlo 998 cm snega; v celotnem ledeniškem letu je padlo 867 mm padavin oziroma 1121 cm snega (slika 19). Obdobje, ko je bil ledenik razgaljen, je trajalo 47 dni. V tem obdobju je bila povprečna temperatura zraka + 3,3 °C, sonce pa je sijalo 217,2 ur (Agencija … 2013). Triglavski ledenik smo obiskali 27. in 28. avgusta 2008. Ob meritvah je bil večinoma prekrit s starim snegom, zato smo rob ledenika določili ob terenskih meritvah. Ker se je kombinacija tahimetrične in terestrične fotogrametrične izmere v preteklem letu izkazala za relativno enostavno in učinkovito, smo izvedli enake meritve. Terestrično fotogrametrično izmero smo izvedli z istim merskim fotoaparatom in z uporabo začasnih oslonilnih točk na ledeniku, kot je opisano pri meritvah iz leta 2006. Izmerjena površina je bila 1,1 ha.

Slika 13: Triglavski ledenik 17. 9. 2008.
Glej angleški del prispevka.

3.11 Ledeniško leto 2008–2009

Redilna doba ledeniškega leta 2008–2009 se je pričela 3. oktobra 2008, najvišja skupna višina snežne odeje pa je bila zabeležena 31. marca 2009 in sicer 560 cm, do takrat je skupaj padlo 1091 cm snega; v celotnem ledeniškem letu je padlo 1026 mm padavin oz. 1332 cm snega (slika 19). V tem ledeniškem letu sneg pretekle zime na ledeniku ni skopnel (preglednica 1; Agencija … 2013). Domnevamo, da se je ta plast snega oziroma pozneje firna na ledeniku ohranila vse do leta 2012.

Triglavski ledenik smo obiskali 22. in 23. avgusta 2009. Ponovno smo izvedli kombinacijo tahimetrične in terestrične fotogrametrične izmere kot je opisano pri meritvah iz leta 2006. Ledenik je bil v času meritev popolnoma zakrit s snegom iz pretekle zime, zato smo obod ledenika določili na terenu ter ga izmerili tahimetrično. Izmerjena površina je bila 2,9 ha.

Slika 14: Triglavski ledenik 13. 9. 2009.
Glej angleški del prispevka.

3.12 Ledeniško leto 2009–2010

Redilna doba ledeniškega leta 2009–2010 se je začela 10. oktobra 2009, najvišja skupna višina snežne odeje pa je bila zabeležena 19. aprila 2010 in sicer 450 cm; do takrat je skupaj padlo 985 cm snega. v celem ledeniškem letu je padlo 876 mm padavin oz. 1157 cm snega (slika 19). V tem ledeniškem letu sneg zime 2009–2010 na ledeniku ni skopnel (preglednica 1; Agencija … 2013), ohranil pa se je vsaj do konca talilne sezone leta 2011.

Triglavski ledenik smo obiskali 14. in 15. septembra 2010. Ponovno smo izvedli kombinacijo tahimetrične in terestrične fotogrametrične izmere kot je opisano pri meritvah iz leta 2006. Obod ledenika in točke na njem smo večinoma izmerili tahimetrično, površina je bila manjša kot v preteklem letu, a še vedno 2,5 ha.

Slika 15: Triglavski ledenik 13. 9. 2010.
Glej angleški del prispevka.

3.13 Ledeniško leto 2010–2011

Redilna doba ledeniškega leta 2010–2011 se je pričela 17. oktobra 2010. Najvišja skupna višina snežne odeje je bila zabeležena že 25. decembra 2010 in sicer 400 cm, sekundarni višek pa je bil 18. marca 2011 s 395 cm snega (slika 20). Do takrat je skupaj padlo 755,9 mm padavin oz. 921 cm snega. V celotem ledeniškem letu je padlo skupaj 1126 cm snega. Tudi v tem ledeniškem letu je ledenik ostal prekrit s snegom; v celoti je sicer skopnel sneg pretekle zime ter del starejšega firna (preglednica 1; Agencija … 2013).

Triglavski ledenik smo obiskali 13. in 14. septembra 2011 ter tudi tokrat izvedli kombinacijo tahimetrične in terestrične fotogrametrične izmere oboda ledenika ter oslonilnih točk. Zopet smo uporabili merski fotoaparat Rolleiflex 6006, preizkusili pa smo tudi neprofesionalni merski fotoaparat Nikon D300 s kalibriranim 50 mm objektivom. Izmerjena površina je bila podobna tisti iz preteklega leta, izmerili smo namreč 2,4 ha.

Slika 16: Triglavski ledenik 13. 9. 2011.
Glej angleški del prispevka.

3.14 Ledeniško leto 2011–2012

Redilna doba ledeniškega leta 2011–2012 se je začela 20. oktobra 2011. Najvišja skupna višina snežne odeje je bila zabeležena 25. aprila 2011 in sicer 240 cm. Do takrat je skupaj padlo 683 cm snega. V celotnem ledeniškem letu je skupaj padlo 641,9 mm padavin oz. 788 cm snega (slika 19) (preglednica 1; Agencija … 2013). Do septembrskih opazovanj je sneg pretekle zime na ledeniku sicer skopnel, a led ni bil viden zaradi plasti firna preteklih zim – domnevno iz zime 2008–2009. Do oktobra je firn skopnel praktično na celotnem ledeniku razen na severnem (spodnjem) delu, kjer je ostalo še nekaj starejšega firna.

Preglednica 1: Temeljni podatki o redilni in talilni dobi Triglavskega ledenika z meteorološke postaje na Kredarici za posamezna ledeniška leta (Agencija … 2013, Gartner 1998–2006).

	1999–2000	2000–2001	2001–2002	2002–2003	2003–2004	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012
začetek redilne dobe	5. 10.	7. 10.	5. 9.	23. 9.	5. 10.	17. 9.	18. 9.	19. 11.	27. 9.	3. 10.	11. 10.	17. 10.	20. 10.
datum najvišje skupne višine snežne odeje	13. 4.	22. 4.	25. 4.	4. 4.	7. 4.	26. 4.	1. 5.	1. 4.	22. 4.	31. 3.	19. 4.	25. 12. (18. 3.)	25. 4.
najvišja skupna višina snežne odeje	310 cm	700 cm	195 cm	240 cm	465 cm	240 cm	495 cm	300 cm	435 cm	560 cm	450 cm	400 cm (395 cm)	240 cm
vsota 24-urnih višin novozapadlega snega od začetka redilne dobe do dne z najvišjo skupno višino snežne odeje	665 cm	1602 cm	604 cm	628 cm	906 cm	732 cm	1170 cm	606 cm	998 cm	1091 cm	985 cm	921 cm	683 cm
vsota 24-urnih višin novozapadlega snega v celotnem ledeniškem letu	787 cm	1657 cm	650 cm	759 cm	1225 cm	806 cm	1310 cm	724 cm	1121 cm	1332 cm	1157 cm	1126 cm	788 cm
datum, ko je bil na ledeniku prvič razkrit led	5. 7.	sneg ni skopnel	19. 9.	4. 7.	sneg ni skopnel	18. 8.	18. 9.(*)	1. 8.(*)	17. 8.	sneg ni skopnel	sneg ni skopnel	sneg ni skopnel	sneg ni skopnel
število dni z razgaljenim ledom	94 dni	/	4 dnevi	93 dni	/	31 dni	62 dni (*)	57 dni (*)	47 dni	/	/	/	/
povprečna temperatura v času, ko je bil led razgaljen	+5,5 °C		+5,3 °C	+7,2 °C		+5,9 °C	+2,3 °C	+4,7 °C	+3,3 °C				
trajanje sončevega obsevanja, ko je bil led razgaljen	534,4 ur		13,2 ur	636,4 ur		145,3 ur	300,5 ur	308,3 ur	217,2 ur				

* ocena

Preglednica 2: Temeljni podatki o meritvah na Triglavskem ledeniku med letoma 1999 in 2012.

Zap. št.	Leto	Datum meritve	Izmerjena površina (v ha)	Presek* (v ha)
1	1999	13.–15. 9.	1,1	1,1
2	2000	4.–5. 7.	–	–
3	2001	16.–17. 10.	–	–
4	2002	14.–15. 9.	–	–
5	2003	25.–27. 8.	0,7	0,7
6	2004	–	–	
7	2005	24.–25. 8.	1,2	0,7
8	2006	4.–5. 9.	1,0	–
9	2007	13.–14. 9.	0,6	0,5
10	2008	27.–28. 8.	1,1	–
11	2009	22.–23. 9.	2,9	–
12	2010	14.–15. 9.	2,5	–
13	2011	13.–14. 9.	2,4	–
14	2012	17.–18. 9. in 11. 10.	0,5	0,4

*Navedena vrednost predstavlja verjetno površino ledu, ki predstavlja presek med izmerjeno površino tega leta in površinami preteklih let.

Leta 2012 je bil Triglavski ledenik deležen raziskav v okviru meddržavnega projekta Slovenija–Avstrija 'Naravne nesreče brez meja' (NH-WF; Internet 1): dvakrat smo izvedli aerolasersko (lidarsko) snemanje in aerofotografiranje ledenika. Prvo snemanje je bilo izvedeno 18. maja 2012, ko je bil ledenik s celotno okolico pokrit s snegom, drugo snemanje pa ob koncu talilne sezone 18. septembra 2012. Žal nas je nekaj dni pred drugim snemanjem prehitel sneg. Snemanje je bilo izvedeno iz helikopterja z laserskim sistemom Riegl LM5600. Povprečna gostota laserskih točk je bila v obeh primerih 8 točk/m^2. V času drugega snemanja smo namestili na ledeniku kontrolne točke v obliki pravokotnikov iz trpežnega papirja dimenzij 1 m × 0,6 m za kontrolo odboja laserskih točk od mokrega snega. Na podlagi obeh meritev smo določili prevladujočo višino snežne odeje v maju 2012 od 1 do 4 m (Triglav Čekada in ostali 2013). Ob obisku ledenika 17. in 18. septembra 2012 smo ledenik fotografirali z različnih stojišč z neprofesionalnim merskim fotoaparatom Nikon D300 z 20 mm objektivom. Izvedli smo še kontrolne meritve oboda ledenika z GNSS-metodo z napravo GPS Trimble Geoexplorer XT, ki omogoča izmero z natančnostjo 0,5 m.

Ker je bil rob ledenika ob septembrskih meritvah prekrit z novozapadlim snegom, smo 11. oktobra 2012 ponovili GNSS-meritve z napravo R8, ki ima mnogo večjo natančnost izmere (pod 0,1 m). Ker na zgornjem robu ledenika meritve niso bile uspešne, smo na tem delu rob ledenika določili na podlagi fotografij. V času meritev smo opazili tudi krajne zevi, globlje od 2 m.

Izmerjena površina je bila manjša kot v letu 2007, to je 0,5 ha. Dejanska površina ledu je manjša kot v letih 2003 in 2007, saj se je ledenik glede na omenjeni leti umaknil na zgornjem robu, na spodnjem robu pa je še bil prekrit s firnom preteklih zim. Presek vseh treh obsegov nam kaže, da je bilo leta 2012 ledu le še 0,4 ha. Krčenje ledenika v obravnavanem obdobju prikazuje slika 18.

Slika 17: Triglavski ledenik 11. 9. 2012.
Glej angleški del prispevka.

Slika 18: Spreminjanje obsega Triglavskega ledenika med leti 1999 in 2012.
Glej angleški del prispevka.

Slika 19: Skupna višina snežne odeje na Kredarici v ledeniških letih 2007–2008, 2008–2009, 2009–2010, 2010–2011 in 2011–2012 (Agencija … 2013).
Glej angleški del prispevka.

4 Sklep

V razpravi so opisani rezultati raziskovanj Triglavskega ledenika med letoma 1999 in 2012. Navedeno obdobje se od predhodnih desetletij razlikuje tako po metodah raziskovanj kot tudi po dinamiki krčenja ledenika.

V prvih 50 letih meritev je bil ledenik le dvakrat geodetsko izmerjen s teodolitom (leta 1952 in 1995), sicer pa so bile meritve opravljene le z merilnim trakom; z njim so raziskovalci merili razdaljo med robom ledenika in merilnimi točkami (Meze 1955; Šifrer 1963; 1987; Šifrer in Košir 1976; Gabrovec 1998). Od leta 1999 redno opravljamo fotogrametrične meritve ledenika, ki omogočajo natančen izračun sprememb površine in prostornine med posameznimi leti (Gabrovec 2002a; Triglav Čekada in Gabrovec 2008). Poleg tega smo v letih 1999 in 2000 izvedli georadarske meritve. Debelino ledu smo izmerili na 12 vertikalnih prerezih. Na podlagi teh podatkov smo ocenili prostornino ledenika (Verbič in Gabrovec 2002). Medtem ko smo za zadnje desetletje 20. stoletja poročali, da se ledenik »… *ni samo umikal, ampak je dobesedno razpadal* …« (Gabrovec 1998, 110), pa v prvem desetletju 21. stoletja opazujemo njegovo stagnacijo. Leta 1999 se je ledenik skrčil z 2,5 ha na 1,1 ha. Naslednji večji umik ledenika smo po nadpovprečno vročem poletju izmerili leta 2003; izmerjena površina je bila 0,7 ha. V večini naslednjih let sneg na ledeniku do začetka naslednje redilne dobe ni skopnel ali pa se je led pokazal izpod snega šele v avgustu (glej preglednico 1). Po letu 2003 ledenik nikoli ni bil v celoti razgaljen. V preglednici 2 so prikazani rezultati meritev po posameznih letih. Kadar je bil ledenik v celoti ali deloma prekrit s firnom in/ali snegom, meritve ne kažejo dejanske površine ledu. Zato smo v zadnjem stolpcu dodali podatek o dejanski površini ledu, ki predstavlja presek izmerjene površine v tistem letu s površinami ledenika prejšnjih let. Največ ledu je skopnelo na zgornjem robu ledenika. Izmerjena površina ledenika je bila tega leta zaradi prekritosti s firnom preteklih zim še vedno 0,5 ha. Dogajanje zadnjih let torej postavlja pod vprašaj napovedi o skorajšnjem izginotju Triglavskega ledenika. Podnebne spremembe naj bi se kazale tudi v povečanju padavin v zimskem času (Cegnar 2012). Na Triglavskem ledeniku so te padavine v obliki snega. Zaradi konkavne oblike površja ledenika se sneg obdrži na ledeniku še pozno poleti, po letu 2007 pa led na spodnjem delu ledenika tudi ob koncu talilne dobe nikoli ni bil razkrit, ampak je bil prekrit s firnom in snegom preteklih zim. Če se bodo takšne vremenske razmere nadaljevale in se bo količina zimskih padavin še povečevala, se bo ostanek Triglavskega ledenika, v sicer zelo majhnem obsegu, ohranil dalj časa, kot smo napovedovali pred leti (Gabrovec 2002b).

5 Literatura

Glej angleški del prispevka.