RECENZIRANI ČLANKI | PEER-REVIEWED ARTICLES

POVRŠINA KANINSKIH IN TRIGLAVSKEGA LEDENIKA OD LETA 1893, DOLOČENA NA PODLAGI ARHIVSKIH POSNETKOV TER AEROLASERSKIH PODATKOV

CHANGES IN THE AREA OF THE CANIN (ITALY) AND TRIGLAV GLACIERS (SLOVENIA) SINCE 1893 BASED ON ARCHIVE IMAGES AND AERIAL LASER SCANNING

Mihaela Triglav Čekada, Matija Zorn, Renato R. Colucci

UDK: 528.715:551.324(497.4)
Klasifikacija prispevka po COBISS.SI: 1.01
Prispelo: 21.7.2013
Sprejeto: 29.1.2014

DOI: 10.15292/geodetski-vestnik.2014.02.274-313
SCIENTIFIC ARTICLE
Received: 21.7.2013
Accepted: 29.1.2014

SI | EN

IZVLEČEK

V članku primerjamo tri zelo majhne ledenike v Julijskih Alpah: Vzhodni in Zahodni Kaninski ledenik v Italiji ter Triglavski ledenik v Sloveniji. Na kratko je predstavljena zgodovina meritev z merskim trakom in geodetskih meritev na Kaninskih ledenikih, večji del članka pa je posvečen obdelavi arhivskih posnetkov na podlagi interaktivne orientacije z aerolaserskimi digitalnimi modeli reliefa. Obdelanih je bilo sedem arhivskih nemerskih posnetkov Kaninskih ledenikov med letom 1893 in 70. leti 20. stoletja ter dva aeroposnetka cikličnega aerofotografiranja Slovenije iz let 2000 in 2011. Uporabili smo tudi načrt Kaninskih ledenikov iz leta 1908. Za primerjavo smo preučili pet arhivskih nemerskih posnetkov Triglavskega ledenika med letoma 1897 in 1962. Opisane so težave, ki se pojavljajo pri tej metodi obdelave posnetkov (deli ledenikov so zakriti s skalami ali grebeni pred njimi, deli so v senci), in mogoče metodološke rešitve. Poudarjena je uporabnost arhivskih posnetkov za dolgoletna spremljanja ledenikov in pomen starejše gorniške literature, ki je bogat vir tovrstnih posnetkov.

ABSTRACT

Three very small Alpine glaciers in the Julian Alps are presented: the Eastern and the Western Canin glaciers in Italy and the Triglav glacier in Slovenia. The history of measurements using a measuring tape and via geodetic means on Canin glaciers is presented in brief; the majority of the paper deals with the acquisition of glacier boundaries from archive non-metrical images. The acquisition is based on interactive orientation method (mono-plotting) using lidar DTM. Seven archive non-metrical images of Mount Canin from 1893 to the mid-1970s and two aero-photogrametric images from periodic aerial photogrammetric surveys of Slovenia from 2000 and 2011 were used to determine the glaciers' areas. In addition, a map of Canin glaciers from 1908 was geo-referenced. Five archive non-metrical images of Triglav glacier from 1897 to 1962 were used to determine the glacier area. Problems with obstructed areas are presented, and possible solutions are also given for deriving areas behind the obstructions. The usefulness of archival imagery for long-time monitoring of glaciers is presented, and the importance of old mountaineering publications as a source of such images is emphasized.

KLJUČNE BESEDE

mali alpski ledeniki, geodetska izmera, fotogrametrična izmera, aerolasersko skeniranje, Kaninski ledeniki, Triglavski ledenik, Italija, Slovenija

KEY WORDS

small Alpine glaciers, geodetic measurements, photogrammetric measurements, lidar, Canin glaciers, Triglav glacier, Italy, Slovenia

1 INTRODUCTION

Very small Alpine glaciers represent important natural heritage. In addition, they are also important for studying climate change (e.g., Nadbath, 1999; Pavšek, 2007; Erhartič and Polajnar Horvat, 2010). Methods for monitoring their changes developed from the first measurements carried out using a tape measure to the latest performed by geodetic and geophysics methods (Triglav Čekada et al., 2012). In the last few decades, different remote sensing methods like photogrammetric and satellite images and laser scanning have been also used for these purposes (Gabrovec et al., 2013).

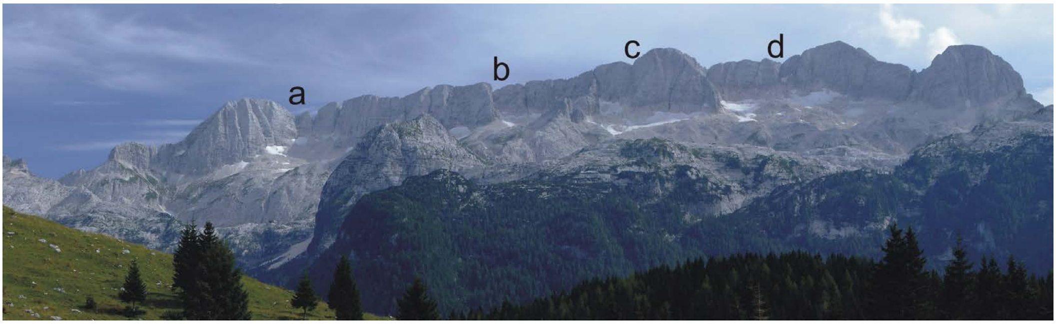


Figure 1: a) Prestreljenik glacier, b) Ursic glacier, c) Eastern Canin glacier, and d) Western Canin glacier on 29 August 2011 (photo: Renato R. Colucci).

This paper focuses on processing archive images of glaciers for studying their evolution in time. The oldest available images from the end of the nineteenth century show three glaciers in the Julian Alps: the Triglav glacier and the two Canin glaciers, known as the Eastern Canin glacier and the Western Canin glacier. Besides these also Ursic glacier and Prestreljenik glacier are accounted under the name Canin glaciers (Figure 1). Three of them (Western Canin, Eastern Canin and Ursic) were jointed into a single glacier during the Little Ice Age (LIA). In the mid-1980s there were a total of eight very small glaciers in the Julian Alps (Serandrei Barbero, 2001): in addition to the four Canin glaciers and the Triglav glacier, there were also three small glaciers in the sector of Mount Montasio known as Eastern, Western and Minor Montasio glaciers. For translation of these names in different languages see Table 1. Among these, only the Eastern and the Western Canin glaciers and the Western Montasio glacier can still be classified as very small glaciers (or glacierets) in the Western Julian Alps today, whereas the others can be described only as occasional snowfields (Serandrei Barbero et al., 1989; Serandrei Barbero, 2001).

The glacier remnants between Mount Canin and Mount Prestreljenik were showing the typical flow characteristics of true glaciers in the past. Still in 1976, some likely transverse crevasses were visible on the Prestreljenik glacier as shown in Figure 2, where a part of the aerial image, produced in the scope of the special aerial photogrammetric measurements of Slovenia in that year, is presented (the national border is just 100 m away). Because this glacier has always been smaller than the two glaciers below Mount Canin, it can be concluded that its two larger neighbors were also moving at that time.

In this paper the term glacier is used for snow-covered current or former glacier areas that can be interpreted from images. First, the past measurements of the Canin glaciers will be presented in detail, similarly to the Triglav glacier measurements already presented by Triglav Čekada et al. (2012). This will be followed by processing amateur archive images of the Canin and Triglav glaciers, and finally the comparison of the results will be given.

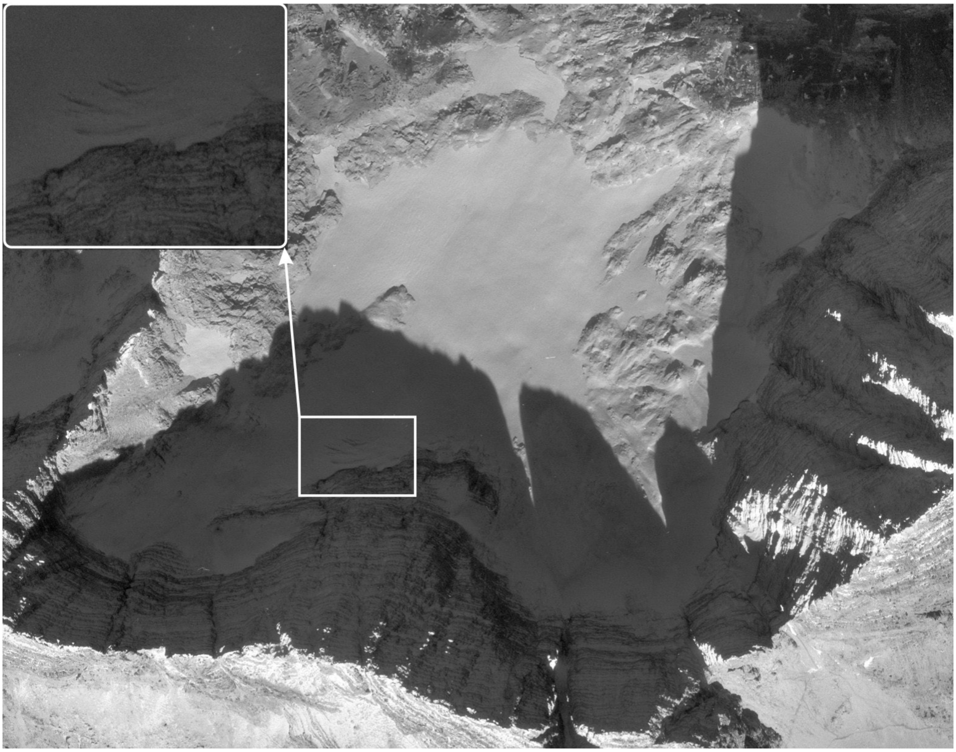


Figure 2: Transverse crevasses on the Prestreljenik glacier, 20 September 1976 (source: aerial photogrammetric images of the Slovenian Surveying and Mapping Authority).

2 GLACIERS IN THE JULIAN ALPS

The glaciers in the Italian part of the Julian Alps represent only a small part of the glaciers in Italy. The last aerial photogrammetric inventory of the Italian glaciers was made in 1988 and 1989 presenting 787 glaciers larger than 5 ha. They covered more than 474 km^2, which accounts for approximately 20% of all glaciers in the Alps. The members of the Italian Glaciology Committee (Ital. *Comitato Glaciologico Italiano*) regularly monitor approximately 150 glaciers in terms of their glacier terminus retreat from ground control points. In addition, they also perform snow/firn/ice density measurements in dedicated snow pits on some of the largest glaciers, in order to determine their mass balance (Serandrei Barbero et al., 1999; Baroni, 2012). Table 1 compares the area of glaciers in the Julian Alps and their mean elevation in 1985. For a comparison also the Skuta glacier (Pavšek, 2007), a similar glacier in the Kamnik-Savinja Alps (Slovenia), is reported. The table shows that the Canin glaciers have the largest area among the glaciers in the Julian Alps and that they lie approximately 200 m lower than the Triglav glacier. This is probably connected to local climate factors. Even though the distance between mountain peaks of Triglav and Canin is only approximately 30 km, the precipitation in the southern and western parts of the Julian Alps, and especially in the Canin area, is greater than in the central part of the mountain range where Mount Triglav is located, due to the influence of the Mediterranean Sea and windward orientation (Kunaver, 1998).

In terms of their size and elevation, the Montasio glaciers are comparable to the Skuta glacier. Measurements of the glacier terminus retreat from the control points, using a tape measure on the Canin and Montasio glaciers, have been carried out regularly since the 1920s. The Canin glaciers have been observed for the longest time. The first mentioning of measurements on the Western Canin glacier date back to 1880, and those on the Eastern Canin glacier date back to 1896; measurements on the Ursic glacier were first documented in 1901 (Serandrei Barbero et al., 1989).

Table 1: The area and the mean elevation of glaciers in 1985. The data for the Italian glaciers are taken from Serandrei Barbero et al. (1989), the area of the Triglav glacier was determined from archival images taken with a Horizont camera (Triglav Čekada & Gabrovec, 2013), and the area of the Skuta glacier was measured with a tape measure in 1989 (Triglav Čekada et al., 2012).

Glacier (English name used in this paper)	Country	Glacier (Italian name)	Glacier (Slovenian name)	Area (ha)	Mean elevation (m)
Minor Montasio glacier	Italy	Ghiacciaio Minore di Montasio	Mali Montažev ledenik	1	1,850
Eastern Montasio glacier	Italy	Ghiacciaio orientale di Montasio	Vzhodni Montažev ledenik	7	1,920
Western Montasio glacier	Italy	Ghiacciaio occidentale di Montasio	Zahodni Montažev ledenik	8	1,940
Prestreljenik glacier	Italy	Ghiacciaio del Prestreljenik	Prestreljeniški ledenik,	3	2,200
Ursic glacier	Italy	Ghiacciaio dell'Ursic	Vršiški ledenik	9	2,240
Eastern Canin glacier	Italy	Ghiacciaio orientale del Canin	Vzhodni Kaninski ledenik,	15	2,220
Western Canin glacier	Italy	Ghiacciaio occidentale del Canin	Zahodni Kaninski ledenik,	27	2,250
Triglav glacier	Slovenia	Ghiacciaio del Tricorno	Triglavski ledenik	10	2,480
Skuta glacier	Slovenia	-	Ledenik pod Skuto	1	2,070

The Canin glaciers can be found in older Slovenian geographic literature because they are located near the Slovenian-Italian border. Melik (1954, 304) wrote: *"…but it is precisely here that three glaciers have developed on the slopes, similar to the Triglav glacier, on the north side along the main ridge between Mount Canin and Mount Prestreljenik. … The true Canin glacier is composed of two parts that are not well connected; at 30 ha the Western Canin glacier is the largest of the three, whereas the area of the Eastern Canin glacier is 13 ha. The third glacier lies on the north side of Mount Ursic and a rocky ridge separates it from the other two; at 8 ha it is the smallest among them."* Here Melik (1954) cites Italian works from the 1920s; for example Desio (1927). Interestingly, the areas of the glaciers are not significantly larger than those mentioned by Serandrei Barbero et al. (1989) for year 1985 (Table 1).

In Austrian literature, the Canin, Montasio, and Triglav glaciers are discussed by Tintor (1993). With regard to the size of the Canin glaciers in 1908, he cites Marinelli (1909), who reports that the area of the Western Canin glacier was 30 ha and the Eastern Canin glacier 13 ha. Additionally Tintor (1993) determined the area in 1950 based on Italian topographic maps (*Carta d'Italia* 1:25,000): 21.2 ha for the Western Canin glacier and 10.6 ha for the Eastern Canin glacier. With regard to the areas in the early 1960s, he cites Messerli (1967, 178), according to whom the area of the Western Canin glacier decreased to 9 ha and the area of the Eastern Canin glacier was 9.5 ha.

The Canin glacier is also mentioned in older editions of the journal *Planinski vestnik* (Slovenian Mountaineering Journal); a 1954 issue mentions its crevasses (Prešern, 1954, 243), and an issue published a year later mentions it as "wide" (Lipovšek, 1955, 102). Julius Kugy (1968, 176) should be especially mentioned among writers of the mountaineering literature. He visited the glacier in 1895 and wrote that Mount Canin "*is the only mountain in the Julian Alps that one climbs by crossing a real glacier.*" In 1902 he also visited the Western Montasio glacier and described this as "*a steep glacial triangle* [it is still shaped this way today]..." that has "*a series of features typical of a small glacier and often, especially in the summer, I saw it in such a condition that I thought to myself: 'This could be the third glacier in the Julian Alps if it had better conditions for development'* " (Kugy, 1968, 200–201).

3 MEASUREMENTS OF THE CANIN GLACIERS

The first measurements of the Western Canin glacier date back to 1880; they were carried out by Giacomo Savorgnan di Brazzà with the assistance of the local guide Antonio Siega. The measurements were performed only occasionally and not every year. The first series of annual measurements of the Eastern and the Western Canin glaciers, which highlighted glacier terminus retreats from the control points using a tape measure, were performed from 1893 to 1909 by Giovanni and Olinto Marinelli (Marinelli, 1909; Serandrei Barbero, 2001). Geographer Olinto Marinelli performed a terrestrial photogrammetric measurement of the Eastern and Western Canin glaciers and the Ursic glacier as early as 1908 in order to determine the elevation of the snow line and to assess the thickness and age of the glaciers. Marinelli performed the terrestrial photogrammetric measurement using the Finsterwalder phototheodolite (Marinelli, 1909), which employed 12 cm × 16 cm glass plates. This instrument was a predecessor of the more widely used TAF (Ger. *Terrestrische Ausrüstung Finsterwalder*), a light terrestrial photo-theodolite that was produced approximately a decade later by the Carl Zeiss Jena (Germany). It was used for studying various glaciers and for high-mountain cartography performed by the Cartographic sections of mountaineering societies (Brunner & Welsch, 2002; Kaufmann, 2012). Marinelli used photogrammetric measurements of September 1908 for mapping the glacier at a scale of 1:25,000 (Figure 5). Interestingly, Marinelli wondered as early as 1909 whether the glaciers would soon completely disappear because his measurements, spanning fifteen years, showed a rapid glacier retreat (Marinelli, 1909).

In 1910 and 1911, Giovanni Battista De Gàsperi conducted measurements on the Ursic glacier in order to determine the speed of its retreat. He placed some control points in the form of signals (measurement points) on the glacier's surface. Unfortunately, De Gàsperi fell in the First World War, and by the time the annual measurements on the Canin glaciers resumed (in 1920), his measurement points had already disappeared (Serandrei Barbero, 2001).

In 1920, annual measurements of the Canin glaciers retreat by using a tape measure resumed, and have been performed fairly uninterruptedly ever since. Today's measurements take place under the supervision of the Italian Glaciology Committee. Ardito Desio, who measured the glaciers after the First World War, is said to have found several measurement points from the first measurement series, which he used to stabilize the new control points. During the Second World War, the measurements were partly halted; however some observations made by Bruno Martinis are available for this period (Serandrei Barbero, 2001). Following 1920, longer periods of manual measurements on the Canin glaciers were performed by Ardito Desio, Arrigo Giovanni Tonini, Egidio Feruglio, and Manfredi Mazzocca until the Second World War, and afterwards by Dino Di Colbertaldo, Giancarlo Di Colbertaldo, Rossana Serandrei Barbero, Alberto Beinat, G. C. Rossi, Carlo Pohar, and Claudio Pohar.

Thus, since 1920, the retreat of the Canin glaciers has been regularly monitored based on the glacier terminus retreat from fixed control points. The same nine control points on the Western Canin glacier, and the same seven on the Eastern Canin glacier have been always used (Serandrei Barbero et al., 1989). These measurements are used to monitor the retreat of the Canin glaciers and to study the influence of different climate parameters on it. Serandrei Barbero et al. (1989) determined a two-year glacier response time to changes in climate factors between 1921 and 1989. They highlighted the fact that the most important parameter affecting the retreat of Canin glaciers is the change in summer temperature and in part also the maximum depth of the snow cover in winter. The maximum depth of the snow cover in June is also a very important parameter for the retreat of the Triglav glacier between 1976 and 2011 (Triglav Čekada and Gabrovec, 2013).

In the past few years, more detailed geodetic and geophysical measurements have been performed on the Canin glaciers in order to study their mass balance and their thickness as part of the projects "Cryosphere of Friuli Venezia Giulia" (Ital. *Progetto criosfera FVG*), MONICA (MONitoring of Ice within Caves) and Climaparks, which are being carried out by the Department of Mathematics and Geosciences of the University of Trieste, the Department of Earth System Science and Environmental Technologies (ISMAR-CNR Trieste), the Department of Theoretical and Applied Science of Insubria University and the Regional Julian Prealps Nature Park (Ital. *Parco Naturale Regionale delle Prealpi Giulie*). Selected findings of these projects are presented in Colucci et al. (2011; 2012) and Forte et al. (2012; 2013).

The first aerial laser scanning of the Canin glaciers was performed as part of the regional laser scanning of Friuli Venezia Giulia, which was performed between 2006 and 2009. The first detailed aerial laser measurements (using laser scanning and aerial photography simultaneously) intended for studying the Eastern Canin glacier and the Western Canin glacier were performed on 29 September 2011. The latter, used in this work, has been commissioned by the Friuli Venezia Giulia Meteorological Association (Ital. *Unione Meteorologica del Friuli Venezia Giulia*). The scanning was performed with a density of 4 points/m^2 and a 1,047 nm wavelength laser scanner. Based on this, a 1 m × 1 m grid digital terrain model (DTM) was produced, which was also used in this study.

On 4 October 2011, only a few days after the aerial laser scanning, the first ground penetrating radar (GPR) measurements of ice and snow thickness were conducted on the Eastern Canin glacier, using a 250 MHz shielded antenna (Forte et al., 2012). In June 2012, the same GPR measurements were also performed on the east side of the Western Canin glacier. In addition, reference points were determined through global navigation satellite system (GNSS) measurements for the purposes of GPR measurements positioning. However, due to the difficulty of performing GNSS measurements under the steep north walls of Mount Canin and Mount Ursic (the measurements are not sufficiently accurate due to the poor visibility of satellites), the GPR measurements were spatially positioned using a traditional tachymetric survey based on the GNSS reference points. GPR measurements and aerial laser scanning measurements were used to determine, among others, thickness and the glacier's volume. Dedicated snow pits were used to determine the average density of the glacial body, a basic information for a correct mass balance computation (Forte et al., 2013).

4 PROCESSING ARCHIVAL DATA

4.1 Interactive orientation method

The boundaries of the Canin and the Triglav glaciers were measured from the archival images by applying the method of DTM-based absolute orientation of images. This is a monoplotting method that makes it possible to obtain 3D-data from a single image. It is based on seeking the best-fitting projection of DTM points onto the image, in which the parameters of the external image orientation (three coordinates of the camera's projection center, three rotation angles, and the scale of the projected model) are determined through a visual search for the best fit. This method is interactive and requires that the operator knows the details on the image very well in order to derive best fit of the image to the DTM projection. In analyzing archival images of glaciers, it is assumed that the surface below the glacier did not significantly change between the time when the image was taken and the time when the basic data were measured for producing the DTM. Therefore, a past boundary of the glacier can be displayed on the current DTM (Triglav Čekada et al., 2011). This makes it possible to determine the glaciers size even from old images. This assumption has also been confirmed for the Canin and Triglav glaciers because no major geomorphic changes (e.g., rockfalls) have been recorded in the close surroundings of these glaciers in the past 120 years, and minor movements can be overlooked.

The interactive orientation procedure is also based on the assumption that the image is in the central projection and that all of the errors (especially any distortions) have been removed. Unfortunately, if very old images are used (older than 100 years), no information on the distortion is available. Old images of glaciers have another weakness: they show areas with no manmade elements in the landscape (roads and paths) that could be used to estimate the distortion of the image.

To avoid old image problems we tried to obtain the best fit between the image and the DTM projection (Figure 3a) based on the known approximate location of the camera (accurate on approximately 500 m). In the majority of cases this was not sufficient, especially in studying the details on the edges of the images, where the greatest errors are generally expected, and so we also took into account corrections due to radial distortion in DTM projection onto the image (Figure 3b). The central projection equations with added corrections due to radial distortion were used for the projection. The radial distortion parameters were interactively changed. Thus the distortion corrections were not used for prior resampling of images into a central projection without distortions, as was done in the case of the panoramic Horizont images used in analyzing the Triglav glacier (Triglav Čekada and Gabrovec, 2013). The accuracy of the method itself is described in detail in Triglav Čekada et al. (2011).

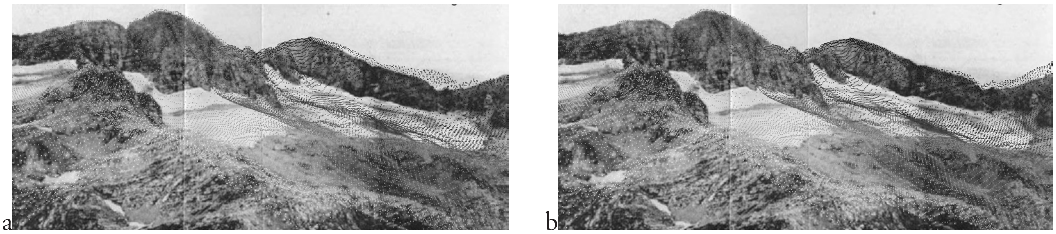


Figure 3: Results of the interactive orientation of the Canin glacier on the right side of an 1893 photo (photo: Arturo Ferrucci (Marinelli, 1910)). DTM projection is shaded from white to black according to the distance from the camera location. DTM projection: a) with radial distortion b) with radial distortion removed.

4.2 Aerial laser scanning data on the Mount Canin and the Mount Triglav

The success of the interactive orientation method depends strongly on the resolution of the DTM used. A 1 m × 1 m grid DTM based on aerial laser scanning data was used to analyze all three glaciers. The aerial laser scanning data on the Canin Massif show only the area of the Eastern Canin glacier and the Western Canin glacier and are provided in the Italian Gauss–Boaga coordinate system; the scanning was performed at the end of the 2011 melting season. The previous winters had abundant snow, thus from these data the real extent of glacier ice is not assessable.

The aerial lasers scanning data of the Mount Triglav are provided in the Slovenian Gauss–Krüger coordinate system (D48). Aerial laser scanning was performed on 18 September 2012 with a 1,550 nm wavelength. The average density of laser points was 8 points/m². The scanning took place at the end of the melt season, after a previous winter without abundant snow cover. Just a few days before the scanning the first autumn snow fell, hiding the real extent of the glacier at the end of melting season.

5 RESULTS

The main motivation for comparing the Canin and Triglav glaciers was provided by two photos (Figure 4) published in the Slovenian edition of Kugy's 1968 book *Iz življenja gornika* (Ger. original *Aus dem Leben eines Bergsteigers*). Unfortunately, the photos do not indicate neither the year nor season in which they were taken. Figure 4a shows both Canin glaciers connected together, with the Western Canin glacier and its snowfields covering 31.2 ha and the Eastern glacier covering 11.5 ha. Figure 4b shows Triglav glacier covering 23 ha and the snowfield below the summit of Mount Triglav having 2.3 ha.

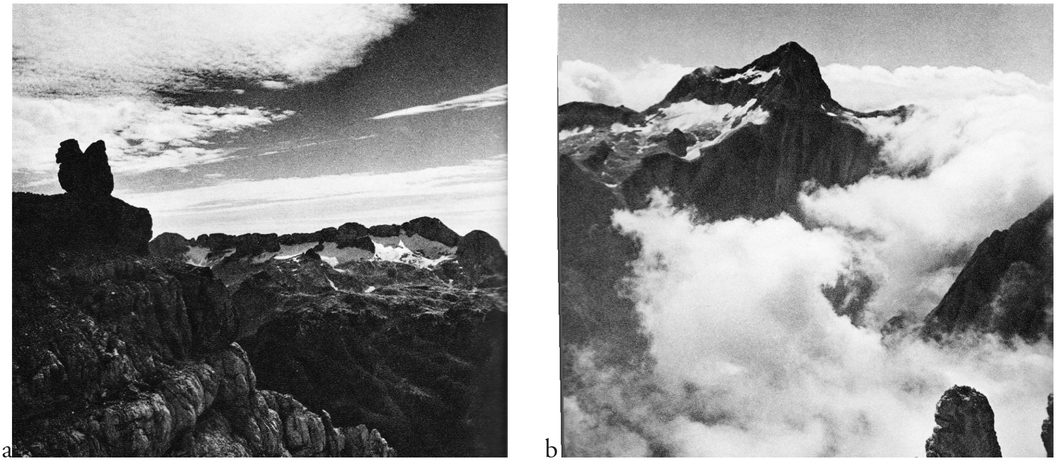


Figure 4: Photos from the Kugy (1968): a) the Canin glaciers (photo: L. Dolhar) and b) Triglav glacier (photo: J. Čop).

5.1 The Canin glaciers after 1893

As already mentioned above, we georeferenced the photogrammetric map of the Canin glaciers produced by Marinelli in 1908 (Figure 5). The break lines between the ridges are clearly visible on the map, which makes it possible to position the map in the area using shaded aerial laser scanning DTM. We only had to change the map scale so that it fits perfectly with the DTM in the Gauss-Boaga coordinate system. We used the map as a reference for completing the details that were not visible on the archival photos. After georeferencing, we again measured the areas of the Eastern and the Western Canin glaciers from the 1908 map (Table 2), which matched the areas defined by Marinelli (1909): 30 ha for the West Canin glacier and 13 ha for the Eastern Canin glacier.

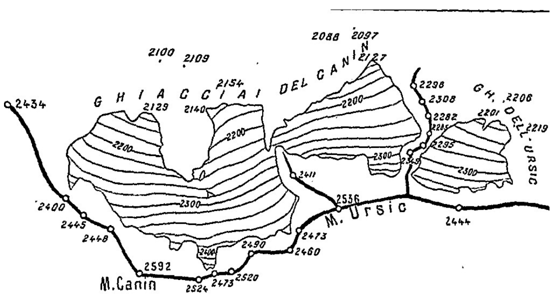


Figure 5: Marinelli's 1908 map of the Canin glaciers produced using terrestrial photogrammetric measurements (Marinelli, 1909).

One of the oldest photos of the Canin glaciers (Figure 6 below) was taken by Arturo Ferrucci on 30 July 1893 from the top of Mount Bila Pec (Slo. *Bela Peč*). The photo also shows the Ursic glacier (left), but because it is not covered by the used 2011 DTM we could not determine its size. The Canin glaciers were again photographed on 8 September 2011 from the top of Mount Bila Pec, almost from the same location, which makes it possible to directly compare the photos (Figure 6 below). All three of the glaciers became significantly smaller and thinner over 118 years. For example, in 1893 the upper boundary of Eastern Canin glacier was 35 to 58 m higher up along the steep slope of Mount Ursic (Slo. *Srednji Vršič*) than in 2011. The glacier's former upper boundary (trim line), which marks the thicker glacial body of the LIA, is clearly visible in Figure 6 below as a change in color of the rock (rocks are darker above the former trim line).

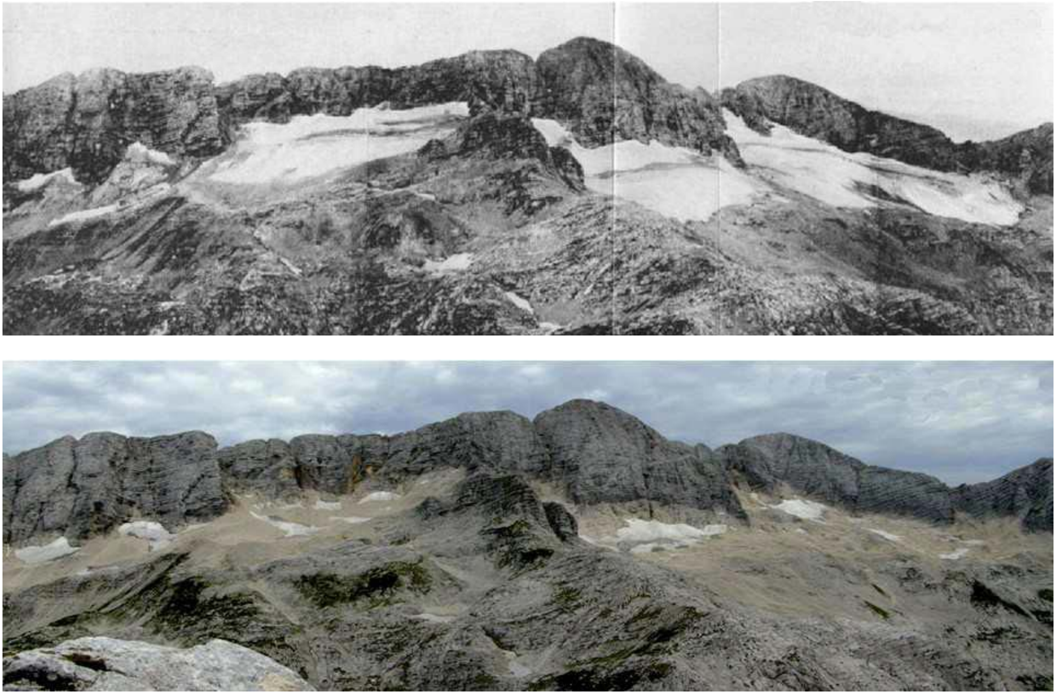


Figure 6: Ursic glacier (left) and Eastern and Western Canin glaciers (right) on 30 July 1893 (above; photo: Arturo Ferrucci (Marinelli, 1910)) and 8 September 2011 (below; photo: Renato R. Colucci).

We also took radial distortion into account in the interactive orientation of both photos (Figure 3). This has the greatest effect on the western part of the Western Canin glacier because, if the distortion is not taken into account in the 1893 photo, the size of this part is 2 ha smaller. Another problem with determining the total size of the glacier between 1893 and 2011 is that the majority of the Western Canin glacier and the eastern part of the Eastern Canin glacier are hidden behind the ridge of Mount Ursic. The overall size of Western Canin glacier in 1893 can be determined by assuming that the glacier's upper boundary was approximately at the same elevation, or that the difference in elevation of the glacier's upper boundary between 1893 and 1908 remained approximately the same along its entire upper boundary. In 1893, the upper boundary was at least 20 m higher than in 1908, as indicated on Marinelli's map (Figure 7). In this case it is reasonable to approximate the section of the glaciers that is not visible on the 1893 photo, with the boundary measured in 1908. Thus, we obtain the most probable glacier area of 1893 (Table 2). Without this assumption, the area of the Western Canin glacier would be 4.5 ha smaller, and that one of the Eastern Canin glacier would be 6.5 ha smaller.

Figure 7 can be used to directly compare the areas in 1893 and 2011. On 8 September 2011, only separate patches remained from the Western Canin glacier. Unfortunately the photo (Figure 6 below) does not show the largest, eastern part of the Western Canin glacier. The glacial remnants that are visible cover a total area of 1.3 ha. The easternmost part of the Eastern Canin glacier is also hidden, and so Figure 6 below also makes it impossible to see and measure the entire glacier; the visible area of ice covers 1.2 ha (Table 2).

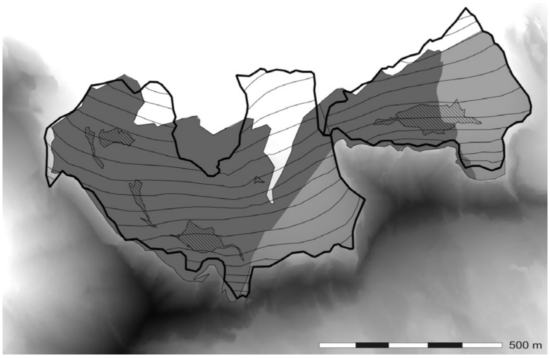


Figure 7: The Canin glaciers in 1893 and 1908, presented on a shaded relief map from 2011. The dark gray surface represents the glacier area determined directly from the 1893 photo, and the light gray area represents the increased area according to the assumptions described in the text. The thick black line marks the glacier's boundary, and the thinner black lines represent the contour lines at 20-meter intervals from Marinelli's 1908 map (Figure 5). The hatched area represents the glaciers remnants measured from the 2011 photo in Figure 6 below.

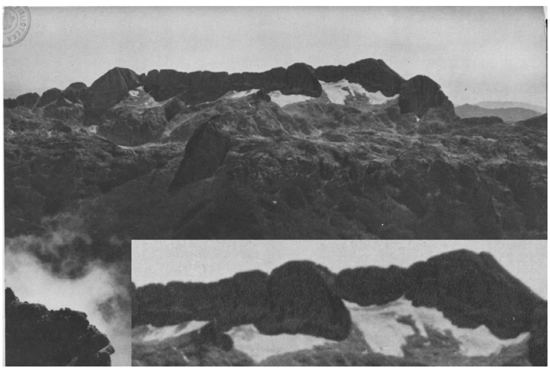


Figure 8: Prestreljenik glacier (left), Ursic glacier, and Eastern and Western Canin glaciers before 1934 (photo: Wilhelm Dronowicz (Kugy, 1934)).

The 1934 Kugy's book *Die Julischen Alpen im Bilde* features a photo of the Canin glaciers (Figure 8) as well as a photo of the Triglav glacier (Figure 15b). Based on Kugy's descriptions, it is possible to estimate how old the photos are. The two photos were most likely taken at the end of the 1920s or beginning of the 1930s. Kugy's photo (Figure 8) of the Canin glaciers was taken approximately from the direction of Mount Montasio, like the photo in Figure 4a. Fortunately, the Canin glaciers are not located on the edge of the photo and so we did not have problems with radial distortion. Due to the shadows that the summits cast on the glaciers, it was fairly difficult to determine the glaciers' upper boundary. We first measured the sun-exposed parts of the glaciers and then used the slight changes in the gray color to determine the glaciers' upper boundary. Based on the differences in the gray, we could identify, at least to a certain extent, two upper boundaries: the actual upper boundary and the former one, which is clearly visible in Figure 6 below. The difference can easily be identified on the Ursic glacier in the lower corner of the enlarged photo in Figure 8. In parts where we were able to determine the upper glacier boundary to a satisfactory degree of accuracy, the upper boundary matches the upper boundary of 1908 (Figure 9). Therefore, when taking the entire length of the glacier boundary of Figure 8 into account, we assumed that the upper boundary matches the one of 1908. The area of the sun-exposed part of the Eastern Canin glacier is 8.4 ha, and the one of the Western Canin glacier is 18.3 ha. When the shaded part of the glacier is added, the area of the Eastern Canin glacier increases by 1.7 ha and the one of Western Canin glacier by 4.1 ha. As in the 1893 photo (Figure 6 above), parts of both glaciers on Figure 8 are hidden behind the slopes of Mount Ursic. Based on the above assumption, that the upper boundary matches the one from 1908, we approximated the parts of the glaciers not visible in the photo (Figure 8). In this way we obtained the final areas presented in Table 2. It is clearly evident that the important shrinking phase occurred after 1908, which is already indicated by their lower boundary on Figure 9. The lower boundary have a similar shape as in 1908, but its horizontal retreat is equal to about 20 to 40 m.

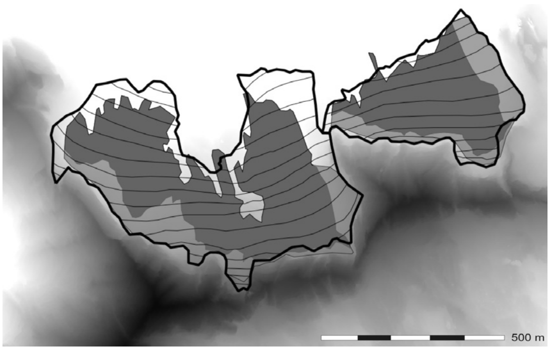


Figure 9: The Canin glaciers before 1934 and in 1908, presented on a shaded relief map from 2011. The dark gray surface represents the sun-exposed area of the glaciers determined directly from the 1934 photo, and the light gray area represents the increased area according to the assumptions described in the text. The bold black line marks the glacier's boundary, and the thinner black lines represent the contour lines from Marinelli's 1908 map.

The interactive orientation of Di Colbertaldo's photo of the Western Canin glacier from 1957 (Figure 10; Di Colbertaldo, 1959) was quite challenging. The photo shows a very small section of the north face of Mount Canin, where only a few relief forms (rifts and various discontinuities in the rock) can be used for accurate photo orientation. The photo was taken in front of the Western Canin glacier. The final result of the interactive orientation relies on the presentation of six rifts on Mount Canin face and the overall appearance of the relief in the front of the photo (Figure 10). After a relatively good fit was achieved, we also made some radial distortion corrections to better match the DTM with the photo. Due to poor orientation, the two boundaries from 1957 and 1970 of the major part of the Western Canin glacier (Figure 11) were moved in an east-west direction by 20 to 40 m. Unfortunately, Figure 10 does not show all of the Western Canin glacier, its easternmost and lower parts are missing. When extracting its area, we had to take into account two colors of snow: white snow covers the exposed glacier and darker snow, which is clearly visible in the front of the photo, is snow/firn from the previous winters. The darker snow from the previous winters also connects two white patches labeled 4 in Figure 10. Because the year 1957 is approximately midway between 1908 and 2011, for which the most reliable data on the overall glacier sizes are available, we were unable to enlarge the glacier through approximation. Figure 11 shows a total of 7.6 ha, and the larger remaining part of the Western Canin glacier labeled 1 in Figure 10 covers 5 ha (Table 2). The part labeled 2 in Figure 10 covers 1.4 ha, and the other numbered parts cover approximately 0.5 ha. Parts 2 and 3 are partly hidden behind the relief and so they had to be larger in reality. Hence, Di Colbertaldo's photo shows the minimum size of the glacier during the 1950s. This also agrees with Messerli's report (1967) that at the beginning of the 1960s the Eastern and the Western Canin glaciers covered approximately 9.0 ha each.

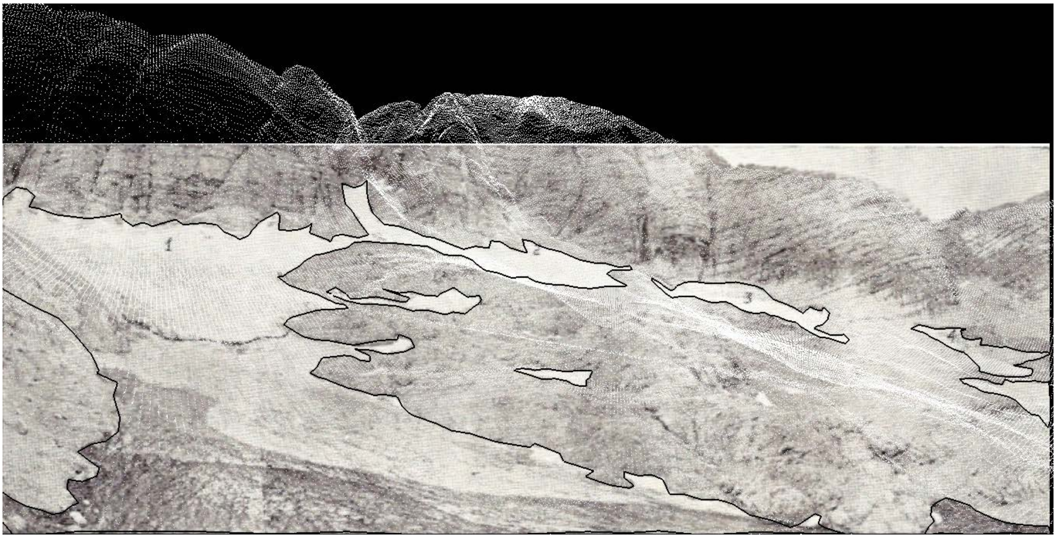


Figure 10: Canin glaciers on 10 September 1957: DTM backprojection and the determined snow edges marked with a black line (photo: Dino Di Colbertaldo (Di Colbertaldo, 1959, 324)).

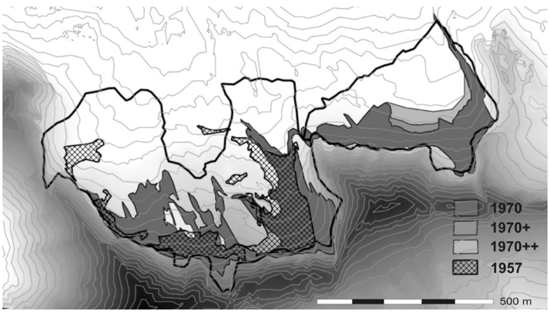


Figure 11: Western Canin glacier in 1957 (Di Colbertaldo, 1959) and in 1970s (1970+ enlarged, 1970++ even more enlarged area) presented on a 2011 shaded relief map with contour lines at 20-meter intervals. The bold black line marks the glacier boundary in 1908.

The photos in Figure 12 show the Canin glaciers during the 1970s (probably in 1976). The photos were most likely taken at the same time. The top photo shows all of the Western Canin glacier and the bottom one shows additional parts of the Eastern Canin glacier, which is hidden behind the relief in the top photo. Unfortunately, the bottom photo does not show all of the Eastern Canin glacier; part of it is hidden behind Mount Ursic. In this case, we again used an approximation for the Eastern Canin glacier, as we encountered the same problem as with the photo taken before 1934 (Figure 8); the upper glacier boundaries are hidden by shade, which makes it more difficult to interpret, but still not as difficult as in Figure 8.

Figure 11 shows only the major central parts of the glaciers; we did not draw individual smaller snowfields under Carnizza Peak (Ital. *Picco di Carnizza*, Slo. *Vrh Krnice*) visible in the top photo of Figure 12 because they are mostly smaller than 0.4 ha. The determined areas of the Eastern and the Western Canin glaciers were 5.1 ha and 10.1 ha, respectively. The total area of the Eastern Canin glacier is obtained by approximating the lower glacier boundary to the contour line. In this way, the medium-gray section in Figure 11 marked 1970+ covering 0.4 ha can be added to the basic area. Being even more optimistic, by drawing the lower boundary along the contour line to which the lower glacier boundary extends in the lower photo in Figure 11 marked 1970++, the glacier area is increased by a further 0.9 ha. Both approximations add a total of 1.3 ha to the Eastern Canin glacier. Table 2 includes the area determined after the first approximation (5.5 ha) on Figure 11 marked 1970+.

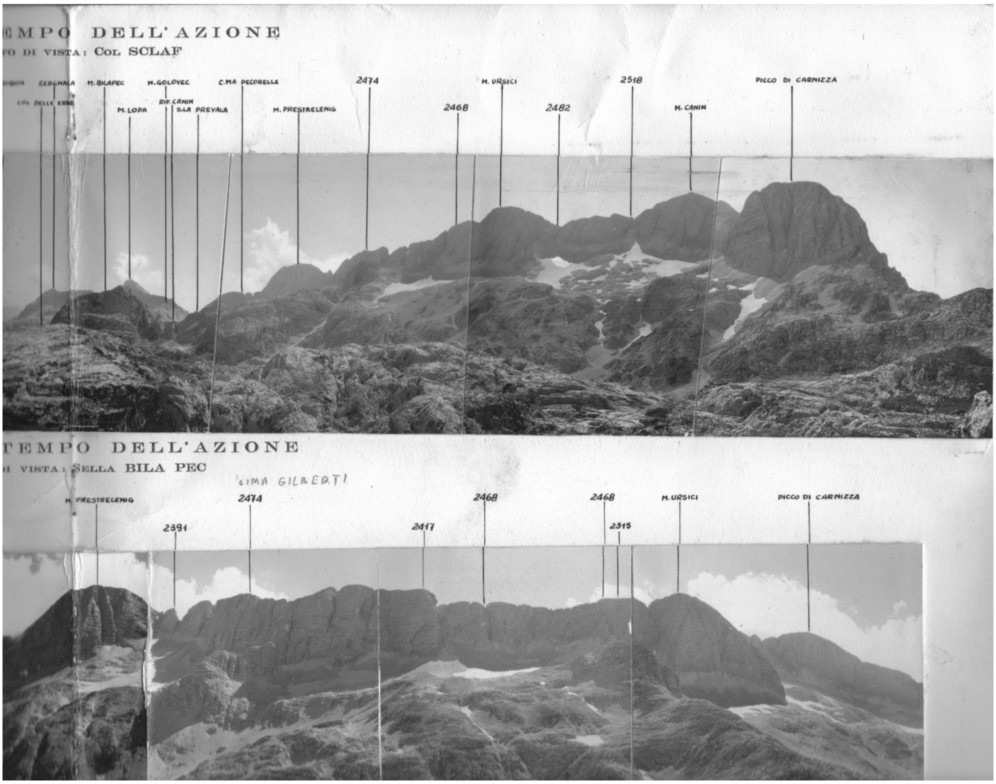


Figure 12: Eastern and Western Canin glaciers during the 1970s (Photo courtesy: Manlio Roseano).

The glaciers sizes in 2000 and 2011 were determined using images produced as part of the cyclical aerial photogrammetric measurements of Slovenia[1] (CAS) conducted by the Slovenian Surveying and Mapping Authority (GURS, 2013). The CAS images were used to produce orthophotos covering an area that extends 250 m across the Slovenian border and therefore the two glaciers are not included in them.

[1] *Slovenia is covered with aerial photogrammetric measurements periodicaly every 3-4 years since 1970ies*

However, they are included on the original CAS photos. Because the Canin glaciers can be found on the CAS photos only occasionally and mostly on the last image, a stereo pair is often not available. Therefore, we also oriented these individual images through the method of interactive orientation with aerial laser scanning DTM. However, this time the summits and ridges were used as the main orientation and not as previously the relief forms in the mountain walls (Figure 13).

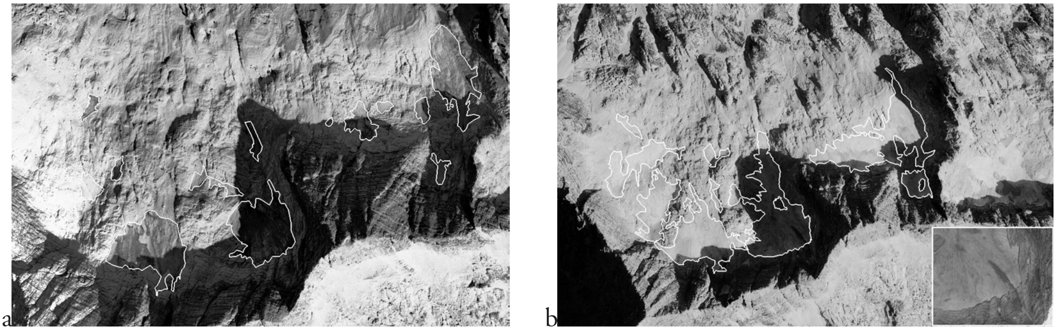


Figure 13: Sections from the CAS images: a) 18 August 2000 and b) 18 August 2011. The glacial remnants are outlined with a white line. The image section from 2011 features the enlarged eastern part of the Western Canin glacier with a clearly visible debris deposit remaining after rock fall of 16 and 18 July 2011.

The two CAS images do not enable a good photo-interpretation. The parts of glaciers hidden in the shade of the mountain ridges are clearly visible, but the parts out in the open are overexposed and so it is very difficult to distinguish snow from talus. Therefore, we first edited the two images; specifically, we increased the contrast in the overexposed sections (Figure 13). An additional problem concerning interpretation is that the remnants of the Canin glaciers are often covered by debris (detail in Figure 13b). Thus it is difficult to distinguish between the glacial remnants and the rock slope. This is especially true for the CAS 2000 images, in which the glaciers were completely snow uncovered. The 1.7 ha eastern part of the Eastern Canin glacier labeled 4 in Figure 14 is heavily covered by debris. In the upper part of this section ice/snow can still be identified, but it is impossible to determine its lower boundary. We interpreted the image by relying on what we knew about this area. We were able to identify other sections, such as the part of the Eastern Canin glacier labeled 3 in Figure 14, relatively easily because they largely lay in the shadow (this section covers 0.5 ha). The largest sections of the Eastern Canin glacier have a total area of 2.2 ha. The four smaller remnants, each covering less than 0.2 ha, add another 0.5 ha to the overall glacier area. The total area of the Eastern Canin glacier provided in Table 2 is thus 2.7 ha. The eastern part of the Western Canin glacier (labeled 2 in Figure 14) covers 2.4 ha and its largest neighbour (labeled 1) covers 2.5 ha. Adding the five small parts, each covering less than 0.3 ha, total area of the West Canin glacier is 5.9 ha.

The CAS image made in 2000 shows the minimum area of completely uncovered glaciers, whereas the 2011 image (both the 2000 and the 2011 image were taken on 18 August) shows a completely snow-covered glacier. On 29 September 2011 (labeled LIDAR2011 in Figure 14) most of the glaciers remained still covered by snow.

The largest part of the Eastern Canin glacier, measured from the 2011 CAS, covers 5 ha (sections 3 and 4 in Figure 14). Less than a month later (Figure 6 below) this part covered only 1.2 ha, and the area measured from the aerial laser scanning, taken at the end of September, covers 2.5 ha. The section labeled 4 in Figure 14 covered 1.9 ha at the end of September 2011, which means that the total area of sections 3 and 4 decreased by 4.4 ha. Table 2 shows the areas of the Eastern and the Western Canin glaciers including the snow-covered sections measured from the CAS and aerial laser scanning. In mid -August 2011 the largest section of West Canin glacier (labeled 2) covered 4.7 ha; it is not visible in the photo taken in early September, and at the end of September it covered 3.6 ha. The second-largest section (labeled 1) covered 3.0 ha in August, only 0.6 ha in early September, and 2.3 ha at the end of September. This unusual increase in size is connected to the fact that part of the glaciers in Figure 6 below is hidden behind the terrain.

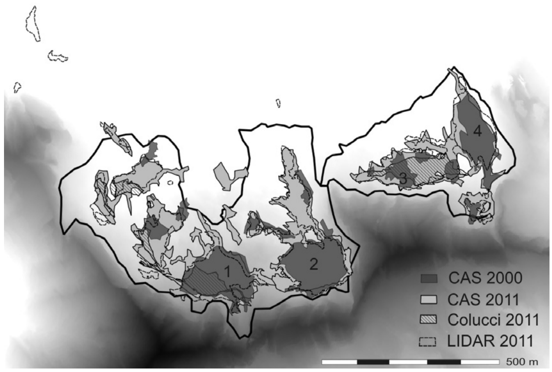


Figure 14: The Canin glaciers based on CAS: 18 August 2000 and 18 August 2011. The size of the glaciers measured from the photo in Figure 6 below taken in 2011 is added. The glaciers are presented on a 2011 shaded relief map. The bold black line marks the glacier boundary in 1908.

While processing the data obtained from CAS images, we realized that small errors in the interactive orientation can quickly lead to 20 to 40 m differences in the glacier location, especially in the east-west direction. We rectified these problems before displaying the information.

Table 2: Area of the Canin glaciers based on archive non-metric images, images produced as part of the cyclic aerial photogrammetric measurements of Slovenia (CAS), and aerial laser scanning (*size of the largest section of the Western Canin glacier).

Image date	**Author and source**	**Western Canin Glacier (ha)**	**Eastern Canin Glacier (ha)**
30 July 1893	Arturo Ferrucci (Marinelli, 1910)	28	13
1908 (map)	Olinto Marinelli (Marinelli, 1909)	30.1	12.9
before 1934	Wilhelm Dronowicz (Kugy, 1934)	23.6	12.1
10 Sept. 1957	Dino Di Colbertaldo (Di Colbertaldo, 1959)	7.6 (*5.0)	
1970s	Photo courtesy Manlio Roseano	10.1	5.5
18 Aug. 2000	CAS	5.9 (*2.4)	2.7
18 Aug. 2011	CAS	14.6 (*4.7)	6.4
8 Sept. 2011	Renato R. Colucci	1.3 (*)	1.2
29 Sept. 2011	2011 aerial laser scanning	8.8 (*3.6)	4.7

5.2 Triglav Glacier between 1897 and 1976

We used the same image processing method for the old images of the Triglav glacier. It makes sense to compare the Canin and the Triglav glaciers because the images used were taken at approximately the same time. The oldest boundary determination is based on a color postcard from or even before 1897 (Figure 15a), previously published in Triglav Čekada and Gabrovec (2008, 509). The photo of the Triglav glacier was taken approximately from the direction of Mount Begunjski vrh. Unfortunately, the lower section of the glacier under the hump Glava (Eng. *Head*) is hidden behind the relief in the front of the photo, which makes it impossible to directly measure the entire glacier area. However, as with the Canin glaciers, its area can be measured based on the contour line of its lower boundary visible in the lower right corner of the photo. Without enlargement, the size of the central part of the glacier is 19.5 ha, and the area of its upper snowfield below the summit of Mount Triglav, which is not considered part of the glacier, is 2.7 ha. If the glacier is enlarged based on the contour line, the total area of the central section is 22 ha (Table 3, Figure 16), but we presumed that part of the glacier also lies under the extended lower boundary. In 1897 the glacier was also much thicker, reaching almost to the summit of Glava. Only five years before that, the Western Canin glacier covered 28 ha.

Figure 15: Triglav Glacier: a) postcard probably before 1897 (photo: R. Konviczka), b) before 1934 (photo: Janko Skerlep (Kugy, 1934)).

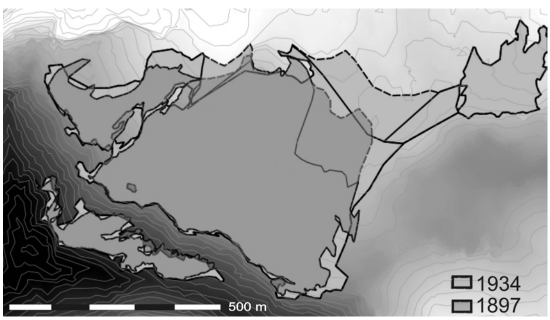
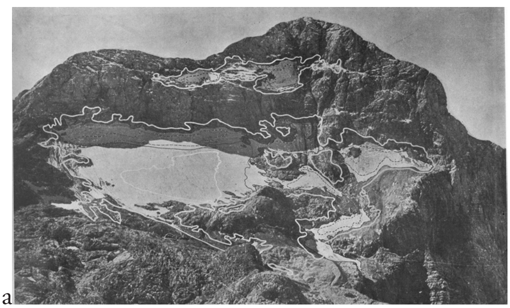


Figure 16: Triglav glacier in 1897 (dark gray) and before 1934 (light gray). The dashed lines mark the approximated area. The glacier is presented on a shaded relief map with contour lines at 20-meter intervals produced from 2012 aerial laser scanning data.

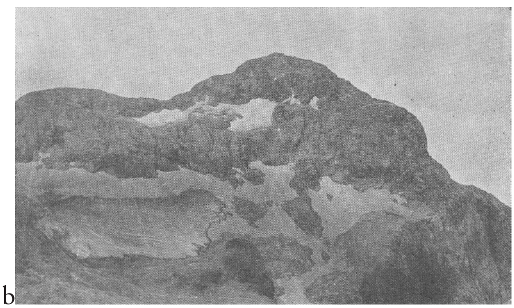
Next image used in the analysis of the Triglav glacier (Figure 15b) was made in the late 1920s or early 1930s. Triglav glacier was photographed from a location close to today's Stanič hut (Slo. *Dom Valentina*

Staniča). This is the same period as the image of the Canin glaciers (Figure 8). The area surrounding the Triglav glacier was still heavily snow-covered and therefore it can be concluded that the glacier's photo was not taken at the end of the melting season like the photo of the Canin glaciers published in the same book (Kugy, 1934). However, the central section around Glava is already uncovered, showing clearly visible transverse crevasses. Hence it can be assumed that the photo was taken some time during the first half of August. The size of the glacier's central section on Figure 15b measures 23.8 ha, and the size of the upper snowfield below the summit of Mount Triglav is 2.7 ha. The largest snowfield in the left part of the photo in Figure 15b, which probably cannot be regarded as part of the glacier, covers 2.6 ha. This snowfield was already there in 1897 because it can be partly seen in Figure 15a. As in the 1897 photo, the lower section of the glacier below Glava is hidden behind the rocks at the front and therefore we enlarged the glacier according to the contour lines of its lower boundary. The size of the glacier below Glava and its spatial position can partly be concluded from Figure 4b (Kugy, 1969). By taking into account these facts, the size of the glacier central section increases to 27.6 ha (Table 3, Figure 16), which means that it was larger than Western Canin glacier.

One of the smallest size of the Triglav glacier during the 1950s was recorded in 1954; the greatest retreat is evident in the part to the right of Glava (marked with a dashed line in Figure 17a; Šifrer, 1963). Unfortunately, the main part of the glacier in 1954 is not marked in full in this photo. In order to compare it to the size of the Western Canin glacier in 1957, we also processed the photo presented in Figure 17b (Šifrer, 1963), showing the Triglav glacier in late September 1956. Both photos (Figure 17) were taken from Mount Begunjski vrh. The distortions were not taken into account in interactive orientation of the 1956 photo. On the contrary, the distortions were accounted for when using the 1958 photo in order to correctly align the details on the left edge of the photo. Despite the rocks extending out of the right side of the glacier, the 1956 glacier can still be treated as a single glacier covering a total of 14.4 ha (Figure 17b). The central section of the snowfield below the peak of Mount Triglav covers 1.3 ha, and the small section on its right covers only 0.06 ha (Table 3). The snowfield below the Mount Triglav peak is not considered as part of the glacier.



a



b

Figure 17: Triglav glacier: a) in 1958 with white lines marking its size in 1962 and dashed lines showing its size in 1954, b) in 1956 (Šifrer, 1963).

At the end of September 1958 the glacier was the smallest in size. A central section covering 12 ha can be distinguished from the glacial remnants to the right side of the Glava, of which the largest covers 1.1 ha and the smallest 0.6 ha. When all three sections are summed, the total glacier area amounts to 13.7 ha (Table 3). The snowfield below Mount Triglav peak is also divided into two remnants covering

0.8 and 0.5 ha. An interesting detail is the snowfield on the left side of the photo, the size of which was measured in the photo taken before 1934 (Figure 15b) and is still there on the 1958 photo (Figure 17a).

In late September 1962, the sections of the Triglav glacier to the right side of the Mount Glava were again connected into a single glacier covering 21.5 ha. The snowfield below Mount Triglav peak covered 2.7 ha.

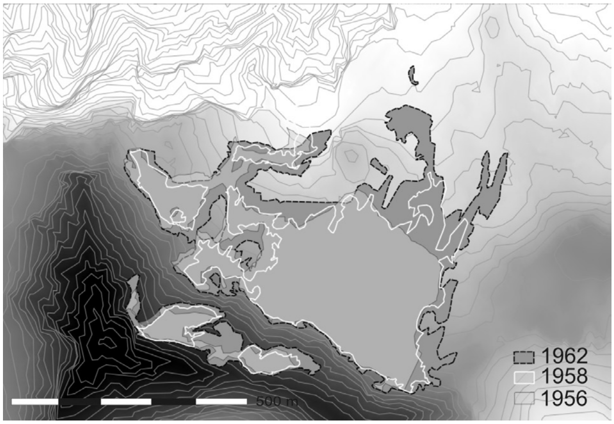


Figure 18: Triglav glacier in 1956, 1958, and 1962. The glacier is presented on a shaded relief map with contour lines at 20-meter intervals produced on the basis of 2012 aerial laser scanning data.

Table 3: The area of the Triglav glacier based on archival images taken between 1897 and 2000, and the 2012 aerial laser scanning (*snow-covered glacier, **glacier's central section, ***detailed analysis showed that at the end of the 2012 melting season the glacier covered only 0.6 ha).

Image date	Author and source	Triglav Glacier (ha)	Snowfield below Mount Triglav summit (ha)
1897	A. Beer (Il Turista)	22.0	2.7
before 1934	Janko Skerlep (Kugy, 1934)	27.6	2.7
23 Sept. 1956	Milan Šifrer (Šifrer, 1963, 185)	14.4	1.3
28–30 Sept. 1958	Milan Šifrer (Šifrer, 1963, 201)	13.7	1.3
16 Sept. 1962	Milan Šifrer (Šifrer, 1963, 201)	21.5	2.7
13 Aug. 1976	Horizont (Triglav Čekada & Gabrovec, 2013)	18.0	
26 Aug. 1977	Horizont (Triglav Čekada & Gabrovec, 2013)	22.3	
15 Aug. 1979	Horizont (Triglav Čekada & Gabrovec, 2013)	24.1	
12 Sept. 2000	Horizont (Triglav Čekada & Gabrovec, 2013)	1.1	
13–14 Sept. 2011	Field measurements	2.4*	
18 Sept. 2012	Aerial laser scanning	1.0 (0.8**) [0.6***]	

The sizes of the Triglav glacier in the 1970s provided in Table 3 are measured from panoramic Horizont camera images using the same method (Triglav Čekada & Gabrovec, 2013). In the 1970s, Triglav glacier was covered by deep snow, therefore it is larger in size than in the previous period. It should be noted that the snowfield below Mount Triglav peak can also be seen on the Horizont photos, but was not measured.

Western Canin glacier (Table 2) also grew larger in this period compared to the size in the 1950s. In the mid-1970s, the Western Canin glacier covered 10.5 ha and in 1976 the Triglav glacier covered 18 ha.

6 CONCLUSION

This paper presents the application of archive images to determine changes in the sizes of glaciers. Non-metric images of the Eastern and Western Canin glaciers and the Triglav glacier, taken from 1893 onwards, were processed using an interactive orientation method. This method employs a detailed digital terrain model to determine the best fit between the DTM superimposition and the image. In the process also radial distortion had to be removed several times, due to the details intended for extraction lying on the edges of the images, where the greatest distortion can occur. However, because mainly it was unknown whether the images show the entire photo or only part of it, radial distortion is taken into account in the digital terrain model superimposition (projection) and not for the resampling of the image. This makes it possible to orient and measure the glacier boundaries in a global coordinate system and consequently compare the glacier sizes over a period of more than a century.

In the studied period the Canin and Triglav glaciers behaved in a similar manner and also had similar sizes. At the end of the nineteenth century, the Western Canin glacier covered 28 ha, the Eastern Canin glacier 13 ha, and the Triglav glacier 22 ha. By the mid-twentieth century, the glaciers had already broken up into several parts. The Western Canin glacier covered 7.6 ha in 1957 and the Triglav glacier covered 13.7 ha in 1958. This was followed by a period of growth. The Western Canin glacier covered 10.1 ha in the 1970s, and Triglav glacier covered 18 ha in 1976. The 1980s saw an accelerated glacier retreat. In 2000, the eastern (largest) part of the Western Canin glacier and the Triglav glacier measured 5 ha and 1.1 ha respectively. The end of the 2010s saw several winters with abundant snow that protected the glaciers. Accordingly, the 2011 aerial laser scanning of the Canin glaciers revealed its larger size as a decade earlier. The 2012 aerial laser scanning of the Triglav glacier was conducted after a winter without abundant snow cover and, accordingly, the smallest size was recorded; its central section covered 0.8 ha. The values presented correspond to the global trend of glacier retreat (Triglav Čekada et al., 2012).

This study showed that older mountaineering literature, in this case books of Julius Kugy, represent an important source of data for the glacier size reconstruction. Old measurements such as Marinelli's 1908 map of the Canin glaciers produced on the basis of terrestrial photogrammetry are also of great help. This map served as an important reference in identifying the sections of the Canin glaciers that were hidden in the photos. This paper focuses on measuring the glacier area from archive images, whereas further studies may also help to determine the changes in the glaciers' thickness.

7 ACKNOWLEDGMENTS

This study was partly funded by the post-doctoral project Z2-4182 (B) and research program P6-0101 of the Slovenian Research Agency (ARRS), the project "MONICA" (*Finanziamento di Ateneo per progetti di ricerca scientifica* - FRA-2012 grant) and the *Unione Meteorologica del Friuli Venezia Giulia*. We would also like to thank Roberto Kostka and Viktor Kaufmann for helping us in identifying Olinto Marinelli's 1908 photogrammetric instrument.

References

Baroni, C. (2012). The Italian Glaciological Committee: Over a century of Italian glaciers monitoring. »From Glaciers to Climate: Euro-Asian perspectives in cryospheric sciences«, Abstracts, July 9–10, Beijing.

Benn, D. L. , Evans, D. J. A. (2010). Glaciers and Glaciations, 2nd edition. London: Hodder Education.

Brunner, K., Welsch, W. (2002). High-mountain cartography of German and Austrian Alpine Clubs. ISPRS Journal of Photogrammetry & Remote Sensing, 57, 126–133. DOI 10.1016/S0924-2716(02)00108-9

Colucci, R. R., Finocchiaro, F., Forte, E., Guglielmin, M., Moro, D. (2011). The cryospere in the Julian Alps (Friuli Venezia Giulia, Italy): The case study of Monte Canin Massif. Poster on »Geoitalia 2011«, September 19–23, Torino.

Colucci, R. R., Forte, E., Guglielmin, M. (2012). Underground cryosphere in the Monte Canin Massif, Alpi Giulie (Italy). »5th International Workshop on Ice Caves (IWIC-V)«, Volume of Abstracts, September 16–23, Barzio.

Desio, A. (1927). Le variazioni dei ghiacciai del Canin nell'ultimo quarantennio. In Alto, 39, 1–12.

Di Colbertaldo, D. (1959). Alpi Giulie. Bollettino del comitato glaciologico Italiano, 8, 322–328.

Erhartič, B., Polajnar Horvat, K. (2010). Slovenia's Triglav glacier as an indicator of climate change. Bulgarian Journal of Meteorology and Hydrology, 15 (1), 3–8.

Forte, E., Pipan, M., Colucci, R. R. (2012). GPR velocity and amplitude analyses to characterize stratigraphy and estimate ice density: Eastern Glacier of Mt. Canin, Italy. »14th International conference on Ground Penetrating Radar (GPR 2012)«, June 4–8, Shanghai, 646–652.

Forte, E., Dossi, M., Colucci, R. R., Pipan, M., (2013). A new fast methodology to estimate the density of frozen materials by means of common offset GPR data, Journal of Applied Geophysics, 99, 135-145. DOI 10.1016/j.jappgeo.2013.08.013

Gabrovec, M., Ortar, J., Pavšek, M., Zorn, M., Triglav Čekada, M. (2013). The Triglav glacier between 1999 and 2012. Acta geographica Slovenica, 53 (1), 257–293. DOI 10.3986/AGS53202

Kaufmann, V. (2012). The evolution of rock glacier monitoring using terrestrial photogrammetry: the example of Äusseres Hochebenkar rock glacier (Austria). Austrian Journal of Earth Sciences, 105 (2), 63–77.

Kugy, J. (1934). Die Julischen Alpen in Bilde. Graz: Leykam.

Kugy, J. (1938). Funf Jahrhunderte Triglav. Graz: Leykam.

Kugy, J. (1968). Iz življenja gornika. Maribor: Založba Obzorja.

Kunaver, J. (1998). Julijske Alpe. In: Slovenija pokrajine in ljudje. Ljubljana: Mladinska knjiga, 54–70.

Lipovšek, M. (1955). Kanin in sedem jezer. Planinski vestnik, 55 (3), 97–105.

Marinelli, O. (1909). Il limite climatico delle nevi nel gruppo del M. Canin (Alpi Giulie). Zeitschrift für Gletscherkunde, 3 (5), 334–345.

Marinelli, O. (1910). I ghiacciai delle Alpi Venete. Memorie geografiche, 4 (11), 5–289.

Melik, A. (1954). Slovenski alpski svet. Ljubljana: Slovenska matica.

Messerli, B. (1967). Die eiszeitliche und gegenwärtige Vergletscherung im Mittelmeerraum. Geographica Helvetica, 22 (3), 105–228. DOI 10.5194/gh-22-105-1967

Nadbath, M. (1999). Triglavski ledenik in spremembe podnebja. Ujma, 13, 24–29.

Pavšek, M. (2007). Ledenik pod Skuto kot pokazatelj podnebnih sprememb v slovenskem delu Alp. Dela, 28, 207–219.

Prešern, J. (1954). S poti na Kanin. Planinski vestnik, 54 (5), 236–244.

Serandrei Barbero, R. (2001). Gli ultimi ghiacciai delle Alpi Giulie. Le Alpi Venete, 55 (1), 91–93.

Serandrei Barbero, R., Rabagliati, R., Zecchetto, S. (1989). Analisi delle misure alle fronti dei ghiacciai delle Alpi Giulie e correlazioni con i dati climatici. Geografia Fisica e Dinamica Quaternaria, 12, 139–149.

Serandrei-Barbero, R., Rabagliati, R., Binaghi, E., Rampini, A. (1999). Glacial retreat in the 1980s in the Breonie, Aurine and Pusterei groups (eastern Alps, Italy) in Landsat TM images. Hydrological Sciences Journal, 44 (2), 279–296. DOI 10.1080/02626669909492222

Šifrer, M. (1963). Nova geomorfološka dognanja na Triglavu, Triglavski ledenik v letih 1954–1962. Geografski zbornik, 8, 159–210.

Tintor, W. (1993). Die Kleingletscher der Julischen Alpen. Carinthia II, 183 (103), 405–424.

Triglav Čekada, M., Gabrovec, M. (2008). Zgodovina geodetskih meritev na Triglavskem ledeniku. Geodetski vestnik, 52 (3), 508–519.

Triglav Čekada, M., Radovan, D., Gabrovec, M., Kosmatin Fras, M. (2011). Acquisition of the 3D boundary of the Triglav glacier from archived non-metric panoramic images. The Photogrammetrical Record, 26 (133), 111–129. DOI 10.1111/j.1477-9730.2011.00622.x

Triglav Čekada, M., Zorn, M., Kaufmann, V., Lieb, G. K. (2012). Measurements of small Alpine glaciers: examples from Slovenia and Austria. Geodetski vestnik, 56 (3), 462–481.

Triglav Čekada, M., Gabrovec, M. (2013). Documentation of Triglav glacier, Slovenia, using non-metric panoramic images. Annals of Glaciology, 54 (62), 80–86. DOI 10.3189/2013AoG62A095

Tuma, H. (2000). Imenoslovje Julijskih Alp. Ljubljana: Tuma.

GURS (2013). Zbirke prostorskih podatkov GURS, Ciklično aerofotografiranje Slovenije. http://prostor.gov.si/cepp/GURS_izpisvse.jsp?ID={8CEB4A50-57AF-4F7F-B75A-266621A6E01F}#p3 (accessed June 4, 2013).

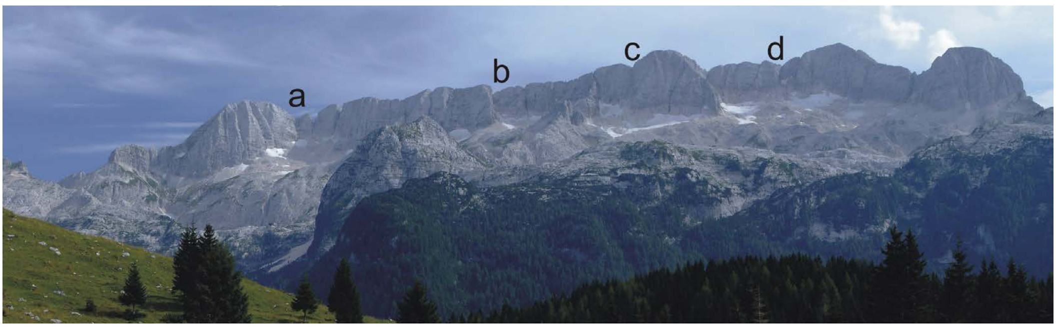
Triglav Čekada M., Zorn M., Colucci R. R. (2014). Changes in the area of the Canin (Italy) and Triglav glaciers (Slovenia) since 1893 based on archive images and aerial laser scanning. Geodetski vestnik, 58 (2): 274–313.

POVRŠINA KANINSKIH IN TRIGLAVSKEGA LEDENIKA OD LETA 1893, DOLOČENA NA PODLAGI ARHIVSKIH POSNETKOV TER AEROLASERSKIH PODATKOV

OSNOVNE INFORMACIJE O ČLANKU:
GLEJ STRAN 274

1 UVOD

Majhni alpski ledeniki so dragocena naravna dediščina. Pomembni so tudi za preučevanje podnebnih sprememb (npr. Nadbath, 1999; Pavšek, 2007; Erhartič in Polajnar Horvat, 2010). Metode za spremljanje njihovih sprememb so se razvijale od začetnih meritev z merskim trakom do poznejših geodetskih metod izmere (Triglav Čekada in sod., 2012). V zadnjih nekaj desetletjih so se za spremljanje ledenikov uveljavile različne metode daljinskega zaznavanja: od fotogrametričnih in satelitskih snemanj do laserskega skeniranja (Gabrovec in sod., 2013).



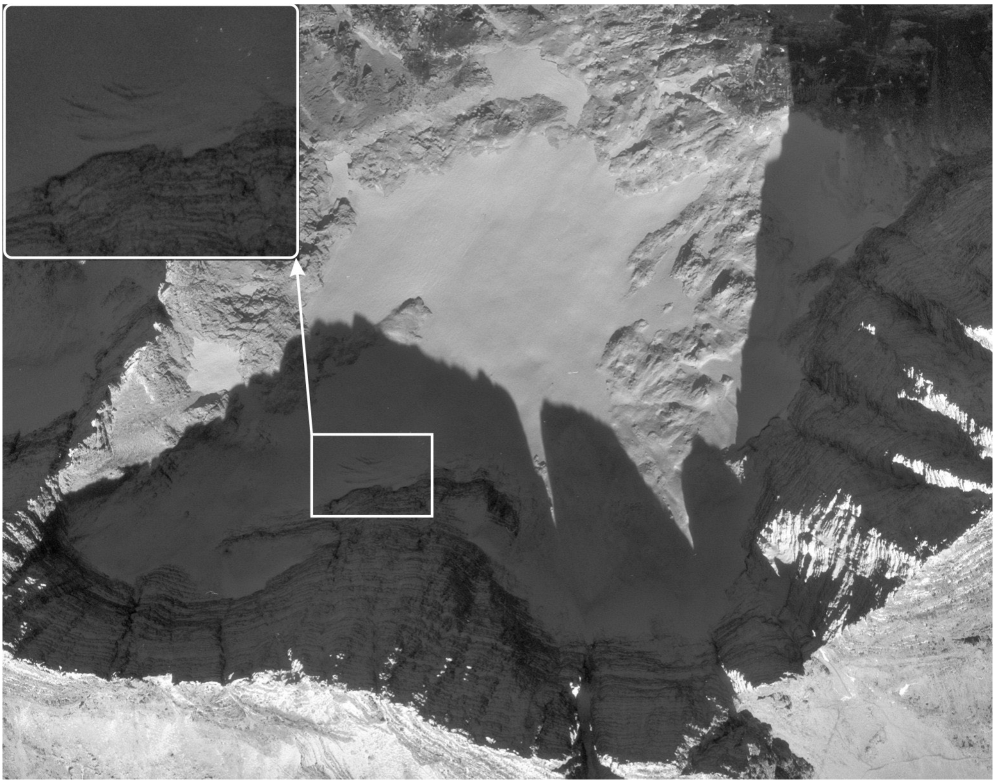
Slika 1: Prestreljeniški ledenik (a), Vršiški ledenik (b), Vzhodni (c) in Zahodni Kaninski ledenik (d) 29. avgusta 2011 (fotograf: Renato R. Colucci).

V prispevku se osredotočamo na obdelavo arhivskih posnetkov za preučevanje sprememb površine ledenikov. Najstarejši posnetki so s konca 19. stoletja in prikazujejo tri ledenike v Julijskih Alpah: Triglavski ledenik ter dva Kaninska ledenika[1]: Vzhodni in Zahodni Kaninski ledenik (tudi Kaninski led[2]). Poleg navedenih dveh med Kaninske ledenike prištevamo še Vršiški ledenik in Prestreljeniški ledenik[3] (tudi Prestreljeniški led[4]) (slika 1). Trije izmed njih (Vzhodni, Zahodni Kaninski in Vršiški ledenik) so bili v mali ledeni dobi povezani v enovit ledenik. Skupaj je sredi osemdesetih let preteklega stoletja v Julijskih Alpah obstajalo osem majhnih ledenikov (Serandrei Barbero, 2001): poleg štirih Kaninskih ledenikov

1 *Zemljepisno ime Kaninski ledenik uporabi Tuma (2000, 17) v knjigi Imenoslovje Julijskih Alp, ki je prvič izšla leta 1929.*
2 *Julijske Alpe: planinska karta; Ljubljana: Planinska zveza Slovenije, 1969.*
3 *Tuma (2000, 17).*
4 *Julijske Alpe: planinska karta; Ljubljana: Planinska zveza Slovenije, 1969.*

ter Triglavskega ledenika, še trije ledeniki pod Montažem (Poliški Špik/Jôf di Montasio): Vzhodni, Zahodni in Mali Montažev ledenik. Njihova italijanska poimenovanja najdete v preglednici 1. Izmed teh lahko danes v Zahodnih Julijskih Alpah med male ledenike štejemo le še Vzhodni in Zahodni Kaninski ledenik ter Zahodni Montažev ledenik, na območju preostalih pa obstajajo le občasna snežišča (Serandrei Barbero in sod., 1989; Serandrei Barbero, 2001).

Ledenike med Kaninom in Prestreljenikom uvrščamo med ledenike, in ne med snežišča, zaradi nekaterih značilnosti, ki so jih imeli v preteklosti. Tako na primer ledeniške razpoke Prestreljeniškega ledenika, ki so vidne na izseku aeroposnetka posebnega fotogrametričnega snemanja Slovenije iz leta 1976 (slika 2), dokazujejo, da se je ledenik v tistem obdobju še premikal. Ker je bil Prestreljeniški ledenik vseskozi manjši od obeh pod Kaninom, lahko na podlagi tega sklepamo, da sta se v tistem obdobju premikala tudi njegova večja soseda.



Slika 2: Prečne ledeniške razpoke na Prestreljeniškem ledeniku, posnete 20. septembra 1976 (vir: aeroposnetki, Geodetska uprava Republike Slovenije).

V članku obravnavamo ledenik kot zasneženo območje, ki ga lahko interpretiramo na podlagi posnetka. Zgodovina izmer na Triglavskem ledeniku je že bila predstavljena v Triglav Čekada in sod. (2012), zato se bomo osredotočili le na opis zgodovine izmer Kaninskih ledenikov. Nadaljevali bomo z obdelavo arhivskih amaterskih posnetkov Kaninskih in Triglavskega ledenika ter primerjavo rezultatov.

2 LEDENIKI JULIJSKIH ALP

Italijanski ledeniki v Julijskih Alpah pomenijo le majhen delež vseh italijanskih ledenikov. V obdobju 1988–1989, ko so izvedli njihovo zadnjo aerofotogrametrično inventarizacijo, so našteli 787 ledenikov, večjih od 5 ha. Skupno so pokrivali prek 474 km^2, kar je približno 20 % vseh ledenikov v Alpah. Pri tem Italijanska glaciološka komisija (it. *Comitato Glaciologico Italiano*) redno spremlja umikanje ledenikov od kontrolnih točk na približno 150 ledenikih. Le na nekaj največjih merijo tudi gostoto ledu za ugotavljanje njihove masne bilance (Serandrei-Barbero in sod., 1999; Baroni, 2012). V preglednici 1 primerjamo površine ledenikov v Julijskih Alpah in njihovo srednjo nadmorsko višino leta 1985. Za primerjavo je podan še soroden Ledenik pod Skuto (Pavšek, 2007) v Kamniško-Savinjskih Alpah. Iz preglednice je razvidno, da imajo Kaninski ledeniki največjo površino med vsemi v Julijskih Alpah, ležijo pa približno dvesto metrov nižje kot Triglavski ledenik. To je verjetno povezano z lokalnimi podnebnimi dejavniki. Čeprav zračna razdalja med Triglavom in Kaninom znaša le približno 30 km so padavine v južnem in zahodnem delu Julijskih Alp, še zlasti pa v Kaninskem pogorju, zaradi vpliva Sredozemlja in privetrnosti višje kot v osrednjem delu gorovja s Triglavom (Kunaver, 1998).

Montaževi ledeniki so glede na velikost in nadmorsko višino primerljivi z Ledenikom pod Skuto. Meritve umikanja čela ledenika od kontrolnih točk z merskim trakom na Kaninskih in Montaževih ledenikih redno potekajo vsaj od 20. let prejšnjega stoletja naprej. Najdlje opazujejo Kaninske ledenike. Prve omembe meritev Zahodnega Kaninskega ledenika segajo v leto 1880, Vzhodnega Kaninskega ledenika pa v leto 1896; meritve na Vršiškem ledeniku se prvič omenjajo leta 1901 (Serandrei Barbero in sod., 1989).

Preglednica 1: Površina ledenikov in njihova srednja nadmorska višina leta 1985. Podatki za italijanske ledenike so povzeti po Serandrei Barbero in sod. (1989), površina Triglavskega ledenika je bila ugotovljena na podlagi arhivskih Horizontovih posnetkov (Triglav Čekada in Gabrovec, 2013), površina Ledenika pod Skuto pa je bila izmerjena z merskim trakom leta 1989 (Triglav Čekada in sod., 2012).

Ledenik (slovensko ime)	Ledenik (italijansko ime)	Površina [ha]	Srednja nadmorska višina [m]
Mali Montažev ledenik	Ghiacciaio Minore di Montasio	1	1850
Vzhodni Montažev ledenik	Ghiacciaio orientale di Montasio	7	1920
Zahodni Montažev ledenik	Ghiacciaio occidentale di Montasio	8	1940
Prestreljeniški ledenik	Ghiacciaio del Prestreljenik	3	2200
Vršiški ledenik	Ghiacciaio dell'Ursic	9	2240
Vzhodni Kaninski ledenik	Ghiacciaio orientale del Canin	15	2220
Zahodni Kaninski ledenik	Ghiacciaio occidentale del Canin	27	2250
Triglavski ledenik	Ghiacciaio del Tricorno	10	2480
Ledenik pod Skuto	–	1	2070

Omembe Kaninskih ledenikov najdemo v starejši slovenski geografski literaturi, saj so le streljaj od slovensko-italijanske meje. Melik (1954, 304) je zapisal: »… *vendar so se prav tukaj razvili trije pobočni ledeniki, podobni triglavskemu, in sicer na severno stran ob glavnem grebenu med Kaninom in Prestreljenikom. […] Pravi kaninski ledenik sestoji iz dveh delov, ki se slabo držita skupaj; zahodni kaninski ledenik je od vseh treh največji s svojimi 30 ha površine, medtem ko meri vzhodni kaninski ledenik 13 ha. Tretji ledenik je v* *severnem bočju Vršiča in je od prvih dveh ločen po vmesnem skalnatem grebenu, a je s svojimi 8 ha površine najmanjši* …« Melik (1954) pri teh navedbah citira italijanska dela iz dvajsetih let 20. stoletja, na primer Densia (1927). Zanimivo je, da površine niso veliko večje od tistih, ki jih omenjajo Serandrei Barbera in sod. (1989) za leto 1985 (preglednica 1).

V avstrijski strokovni literaturi Kaninska ledenika, Montažev ledenik in Triglavski ledenik obravnava Tintor (1993). Za velikost Kaninskih ledenikov leta 1908 citira Marinellija (1909), ki za Zahodni Kaninski ledenik navaja površino 30 ha, za Vzhodni Kaninski ledenik pa 13 ha. Površino za leto 1950 je Tintor (1993) določil na podlagi italijanskih topografskih zemljevidov (*Carta d'Italia* 1 : 25.000), in sicer 21,2 ha za Zahodni in 10,6 ha za Vzhodni ledenik. Za površini v začetku 60. let 20. stoletja Tintor (1993) citira Messerlija (1967, 178), po katerem je Zahodni Kaninski ledenik meril le še 9,0 ha, Vzhodni pa 9,5 ha.

Kaninski ledenik je omenjen tudi v starejših izdajah Planinskega vestnika: leta 1954 je tako omenjena njegova razpokanost (Prešern, 1954, 243), leto pozneje pa njegova »*prostranost*« (Lipovšek, 1955, 102). Med gorniško leposlovno literaturo izpostavimo Kugyja (1968, 176), ki je ledenik obiskal leta 1895 in zapisal, da je Kanin »… *edina gora v Julijskih Alpah, na katero vodi vzpon prek resničnega ledenika*«. Leta 1902 je obiskal tudi Zahodni Montažev ledenik oziroma, kot piše, »… *strmi ledeniški trikot* [takšne oblike je še danes, op. a.] …«, ki ima »… *vrsto značilnosti majhnega ledenika in često, zlasti poleti, sem ga videl v takem stanju, da sem si mislil: to bi bil pravi tretji ledenik v Julijskih Alpah, če bi mu bile dane boljše možnosti za razvoj*« (Kugy, 1968, 200–201).

3 IZMERE KANINSKIH LEDENIKOV

Prve meritve Zahodnega Kaninskega ledenika segajo v leto 1880; izvedel jih je Giacomo Savorgnano di Brazzà s pomočjo lokalnega vodnika Antonia Siega. Meritve niso bile vsakoletne, temveč občasne. Prva serija vsakoletnih meritev umikanja čela Zahodnega in Vzhodnega Kaninskega ledenika na podlagi kontrolnih točk z merskim trakom je potekala med letoma 1893 in 1909; izvajala sta jih Giovanni in Olinto Marinelli (Marinelli, 1909; Serandrei Barbero, 2001). Geograf Olinto Marinelli je že leta 1908 izvedel terestrično fotogrametrično izmero Zahodnega in Vzhodnega Kaninskega ledenika ter Vršiškega ledenika, s katero je poskusil določiti višino snežne meje ter oceniti debelino in starost ledenikov. Marinelli je terestrično fotogrametrično izmero izvedel s fototeodolitom Finsterwalder (Marinelli, 1909), pri katerem se uporabljajo steklene plošče velikosti 12 cm × 16 cm. To je bil predhodnik bolj pogostih instrumentov TAF (nem. *Terrestrische Ausrüstung Finstewalder*) – lahkih terestričnih fototeodolitov. Približno desetletje zatem so jih začeli izdelovati v podjetju Carl Zeiss iz Jene (Nemčija), uporabljali so jih za preučevanje ledenikov in visokogorsko kartografijo, za kar so skrbele kartografske sekcije planinskih društev (Brunner in Welsch, 2002; Kaufmann, 2012). Marinellijev fotogrametrično izdelan načrt ledenika iz septembra 1908, ki je bil originalno izdelan v merilu 1 : 25.000, smo uporabili tudi v naši raziskavi (slika 5). Kot zanimivost omenimo, da se je Marinelli že leta 1909 spraševal, ali bodo ledeniki kmalu popolnoma izginili, saj so se v njegovem 15-letnem obdobju meritev hitro zmanjševali (Marinelli, 1909).

Giovanni Battista De Gàsperi je v letih 1910 in 1911 poskušal meriti hitrost premikanja Vršiškega ledenika. V ta namen je nanj položil kontrolne točke v obliki nekakšnih »signalov« (merilnih točk). Žal je De

Gàsperi padel v prvi svetovni vojni, do začetka naslednjih vsakoletnih meritev na Kaninskih ledenikih leta 1920 pa so se njegove merilne točke že izgubile (Serandrei Barbero, 2001).

Leta 1920 so ponovno začeli z vsakoletnimi meritvami umikanja Kaninskih ledenikov z merskim trakom in jih od takrat izvajajo bolj ali manj nepretrgoma. Danes potekajo pod okriljem Italijanske glaciološke komisije. Ardito Desio, ki je po prvi svetovni vojni prvi meril ledenike, naj bi našel nekaj merilnih točk iz prve serije meritev; uporabil jih je za stabilizacijo novih kontrolnih točk. Med drugo svetovno vojno so meritve deloma zastale, a za to obdobje obstajajo osebna opažanja Bruna Martinisa (Serandrei Barbero, 2001). Po letu 1920 so za daljša obdobja ročnih meritev na Kaninskih ledenikih skrbeli: Ardito Desio, Arrigo Giovanni Tonini, Egidio Feruglio in Manfredi Mazzocca, in sicer do druge svetovne vojne, po drugi svetovni vojni pa Dino Di Colbertaldo, Giancarlo Di Colbertaldo, Rossana Serandrei Barbero, Alberto Beinat, G. C. Rossi, Carlo Pohar in Claudio Pohar.

Tako lahko od leta 1920 naprej spremljamo umikanje Kaninskih ledenikov na podlagi meritev razdalje med čelom ledenika in stalnimi kontrolnimi točkami. Na Zahodnem Kaninskem ledeniku vseskozi uporabljajo devet istih kontrolnih točk, na Vzhodnem Kaninskem ledeniku pa sedem (Serandrei Barbero in sod., 1989). Z meritvami spremljajo umikanje Kaninskih ledenikov in preučujejo vplive različnih podnebnih dejavnikov nanje. Serandrei Barbero in sod. (1989) so določili dvoletni odzivni čas ledenikov na spremembe podnebnih dejavnikov v obdobju 1921–1989. Izpostavili so, da je najpomembnejši podnebni dejavnik, ki vpliva na umikanje Kaninskih ledenikov, sprememba poletne temperature, deloma tudi najvišja snežna odeja v zimski sezoni. Pomembnost slednje je bila ugotovljena tudi za umikanje Triglavskega ledenika (Triglav Čekada in Gabrovec, 2013), pri katerem smo ugotovili, da je na nazadovanje med letoma 1976 in 2011 najbolj vplivala prav višina snežne odeje v juniju.

V zadnjih nekaj letih na Kaninskih ledenikih izvajajo tudi bolj podrobne geodetske in geofizikalne meritve za preučevanje masne bilance ledenikov v okviru projektov Kriosfera Furlanije-Julijske krajine (it. *Progetto criosfera FVG*), MONICA in Climaparks, v katerih sodelujejo Deželni naravni park Julijskih Predalp (it. *Parco Prealpi Guilie*), Oddelek za matematiko in geoznanosti Univerze v Trstu, Univerza Insubria ter Lavinska služba Avtonomne pokrajine Furlanije-Julijske krajine. Nekateri rezultati projekta so predstavljeni v Colucci in sod. (2011; 2012) ter Forte in sod. (2012; 2013). V okviru regijskega laserskega skeniranja dežele Furlanije-Julijske krajine, ki se je izvajalo med letoma 2006 in 2009, so bili Kaninski ledeniki prvič aerolasersko skenirani. Prvo podrobno aerolasersko snemanje (hkratno lasersko skeniranje in aerofotografiranje), namenjeno preučevanju Vzhodnega in Zahodnega Kaninskega ledenika, je potekalo 29. septembra 2011 po naročilu Meteorološkega združenja Furlanije-Julijske krajine (it. *Unione Meteorologica del Friuli Venezia Giulia*). Izvedli so ga s povprečno gostoto 4 točke/m^2 in laserskim skenerjem z valovno dolžino 1047 nm. Na njegovi podlagi so izdelali DMR z velikostjo osnovne celice 1 m × 1 m, ki smo ga uporabili tudi v naši raziskavi.

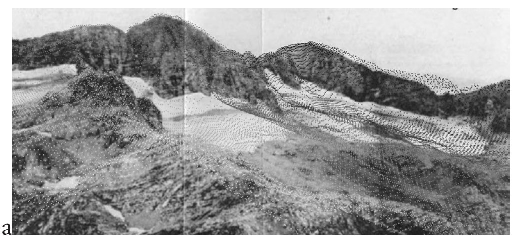
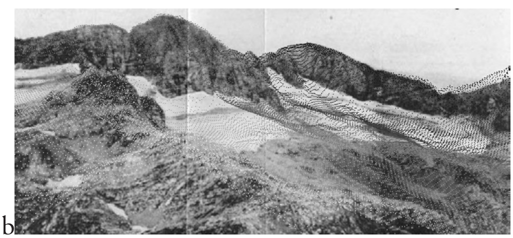
Le nekaj dni po laserskem snemanju, 4. oktobra 2011, so na Vzhodnem Kaninskem ledeniku izvedli prve georadarske meritve (GPRS-meritve) debeline ledu in snega. Uporabili so anteno s frekvenco 250 MHz (Forte in sod., 2012). V juniju 2012 so georadarske meritve debeline ledu in snega izvedli še na vzhodnem delu Zahodnega Kaninskega ledenika. Za potrebe georadarskih meritev so izvedli tudi meritve navezovalnih točk z meritvami globalnih navigacijskih satelitskih sistemov (GNSS-meritev). Ker pa z GNSS-meritvami težko izmerimo objekte pod strmimi severnimi stenami (preslaba vidnost satelitov za zadovoljivo točnost meritev), kjer ležijo Kaninski ledeniki, so georadarske meritve umestili v prostor s klasičnimi tahimetričnimi meritvami, ki so jih izvedli z navezovalnih točk. Georadarske meritve in aerolasersko skeniranje so uporabili tudi za določitev debeline in volumna ledenika. S kopanjem snežnih profilov so določili še gostoto ledu na ledeniku; tovrstni podatki omogočajo izračun masne bilance ledenikov (Forte in sod., 2013).

4 OBDELAVA ARHIVSKIH POSNETKOV

4.1 Interaktivna metoda orientacije

Obod Kaninskih in Triglavskega ledenika smo iz arhivskih posnetkov izmerili z interaktivno metodo absolutne orientacije posnetka na podlagi DMR-ja. To je enoslikovna metoda izmere, ki omogoča zajem 3D-podatkov že na podlagi enega posnetka. Temelji na iskanju najbolj ujemajoče projekcije točk DMR-ja na prikazano vsebino na posnetku, pri čemer z vizualnim iskanjem najboljšega ujemanja iščemo parametre zunanje orientacije posnetka (tri koordinate projekcijskega centra fotoaparata, tri kote zasukov in merilo projiciranega modela). Metoda je interaktivna in temelji na operaterjevem dobrem poznavanju podrobnosti na posnetku ter ujemanju posnetka s projekcijo točk DMR-ja. Pri analizi arhivskih posnetkov ledenikov predpostavimo, da se površje pod ledenikom v obdobju med nastankom posnetka ter časom snemanja osnovnih podatkov za izdelavo DMR-ja ni bistveno spremenilo. Torej lahko rob ledenika iz preteklosti prikažemo na sedanjem DMR-ju (Triglav Čekada in sod., 2011). Tako lahko določamo obseg ledenikov tudi na podlagi zelo starih posnetkov. Predpostavka za Kaninske in Triglavski ledenik drži, saj v zadnjih 120 letih večje geomorfološke spremembe (na primer podori) na njihovih ožjih območjih niso bile opažene, manjše premike pa lahko zanemarimo.

Postopek interaktivne orientacije temelji tudi na predpostavki, da je posnetek v centralni projekciji in so na njem odstranjene napake (predvsem distorzija). Pri zelo starih posnetkih, recimo sto ali več let, ki so bili najdeni kot izseki iz originalnih fotografij, pa podatka o napakah posnetka žal nimamo. Stari posnetki ledenikov imajo še dodatno slabost, saj prikazujejo visokogorje, kjer ni antropogenih ravnih linij (cest, poti), na podlagi katerih bi lahko ocenili napake posnetka.

a  b 

Slika 3: Rezultati interaktivne orientacije Kaninskega ledenika na desnem delu fotografije iz leta 1893 (fotograf: Arturo Ferucci (Marinelli, 1910)). Projekcija DMR-ja je glede na oddaljenost od stojišča obarvana od bele proti črni. Projekcija DMR-ja: a) z radialno distorzijo, b) z odstranjeno radialno distorzijo.

Težavam smo se poskusili izogniti tako, da smo pri starih posnetkih, na podlagi znanega približnega stojišča fotoaparata (na približno 500 metrov), poskusili poiskati najboljše ujemanje med posnetkom in projekcijo DMR-ja (slika 3a). Ker to večinoma ni zadostovalo, predvsem pri preučevanju vsebin na robovih posnetkov, kjer na splošno lahko pričakujemo največje napake, smo pri projekciji DMR-ja na posnetek upoštevali še popravke zaradi radialne distorzije (slika 3b). Torej so bile pri projekciji DMR-ja na posnetek uporabljene enačbe centralne projekcije z dodanimi popravki zaradi radialne distorzije. Parametre radialne distorzije smo interaktivno spreminjali. Tako popravkov zaradi distorzij nismo uporabili za predhodno transformacijo posnetkov v centralno projekcijo brez distorzij, kot pri panoramskih posnetkih Horizont pri analizi Triglavskega ledenika (Triglav Čekada in Gabrovec, 2013). Točnost metode je podrobno opisana v Triglav Čekada in sod. (2011).

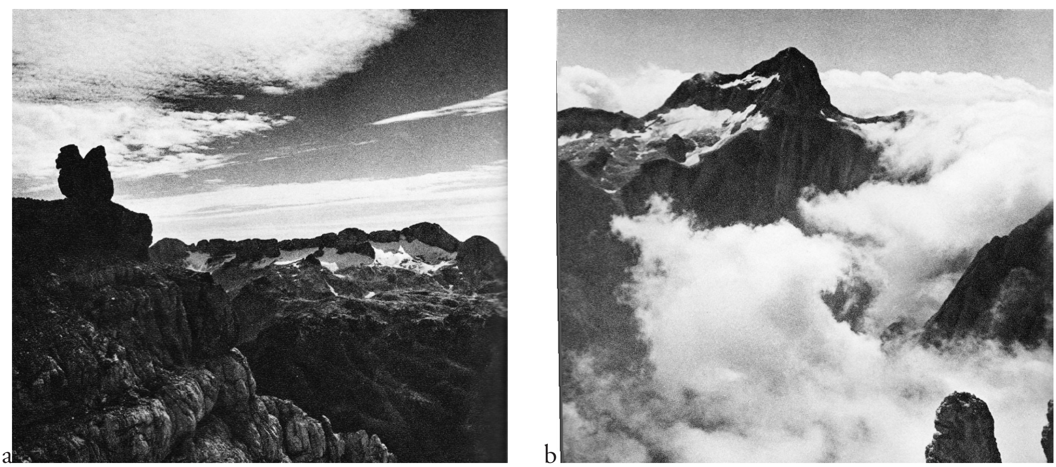
4.2 Podatki aerolaserskega skeniranja Kanina in Triglava

Uspešnost interaktivne metode orientacije je zelo odvisna od ločljivosti uporabljenega DMR-ja. V raziskavi smo za vse tri ledenike uporabili DMR z velikostjo celice 1 m × 1 m, izdelan na podlagi podatkov aerolaserskega skeniranja. Kaninski aerolaserski podatki prikazujejo samo območje Vzhodnega in Zahodnega Kaninskega ledenika ter so zapisani v italijanskem koordinatnem sistemu Gauss-Boaga; snemanje je bilo izvedeno konec talilne dobe 2011. Predhodno zimo je bilo obilo padavin, zato podatki ne ponazarjajo najmanjšega stanja ledenikov. Podatki Triglavskega ledenika so zapisani v slovenskem Gauss-Krügerjevem koordinatnem sistemu (D48).

Aerolasersko skeniranje je bilo izvedeno 18. septembra 2012, in sicer z valovno dolžino 1550 nm. Povprečna gostota laserskih točk je bila 8 točk/m^2. Snemanje je bilo sicer izvedeno konec talilne dobe in po zelo slabi predhodni zimi, zato rezultati kažejo skoraj najmanjše stanje ledenika, saj je le nekaj dni pred snemanjem zapadel prvi jesenski sneg.

5 REZULTATI

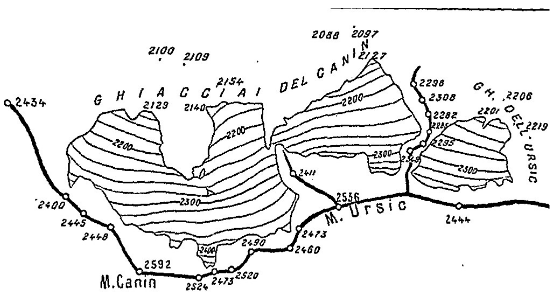
K primerjavi Kaninskih ledenikov in Triglavskega ledenika sta nas spodbudili fotografiji (slika 4), objavljeni v slovenski izdaji Kugyjeve (1968) knjige Iz življenja gornika. Žal posnetka nimata letnice, zato ne vemo, kdaj natančno sta bila posneta ter ali prikazujeta ledenike konec talilne dobe. Tako slika 4a prikazuje združena Kaninska ledenika, pri čemer Zahodni Kaninski ledenik skupaj s snežišči meri 31,2 ha in Vzhodni 11,5 ha, slika 4b pa Triglavski ledenik, ki meri 23 ha, snežišče pod vrhom Triglava pa 2,3 ha.


a
b

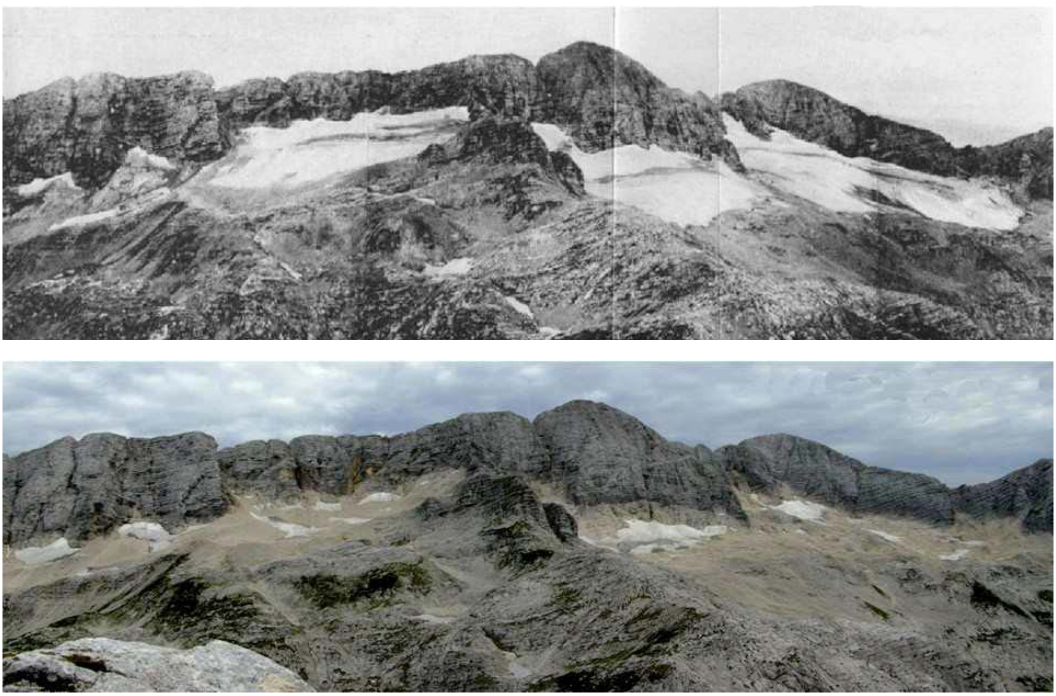
Slika 4: Posnetka iz Kugyjeve knjige (1968): a) Kaninski ledeniki (fotograf: L. Dolhar) in b) Triglavski ledenik (fotograf: J. Čop).

5.1 Kaninska ledenika po letu 1893

Kot je bilo že navedeno, smo georeferencirali Marinellijev fotogrametrično izdelani načrt Kaninskih ledenikov iz leta 1908 (slika 5). K sreči so na njem zelo dobro izrisane lomne linije grebenov, ki omogočajo umestitev v prostor z aerolaserskim DMR-jem. Treba je bilo le spremeniti merilo, da se je načrt vizualno popolnoma prilegal DMR-ju v Gauss-Boagovem koordinatnem sistemu. Načrt je bil tudi referenca za dopolnjevanje vsebin, ki se na arhivskih fotografijah niso (dobro) videle. Po georeferenciranju smo spet določili površini Vzhodnega in Zahodnega Kaninskega ledenika iz načrta iz leta 1908 (preglednica 2). Površini se ujemata z vrednostmi, ki ju je določil Marinelli (1909): 30 ha za Zahodni in 13 ha za Vzhodni Kaninski ledenik.



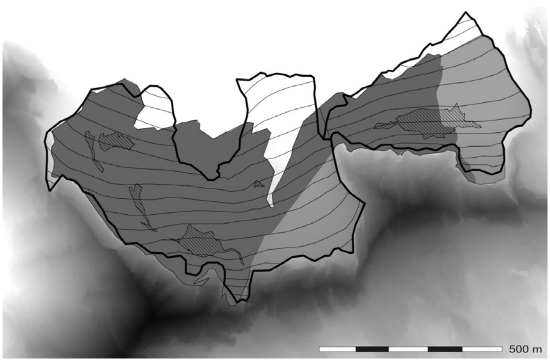
Slika 5: Marinellijev načrt Kaninskih ledenikov iz leta 1908, izdelan na podlagi terestrične fotogrametrične izmere (Marinelli, 1909).



Slika 6: Vršiški ledenik (levo) ter Vzhodni in Zahodni Kaninski ledenik (desno) 30. julija 1893 zgoraj (fotograf: Arturo Ferrucci (Marinelli, 1910)) in 8. septembra 2011 spodaj (fotograf: Renato R. Colucci).

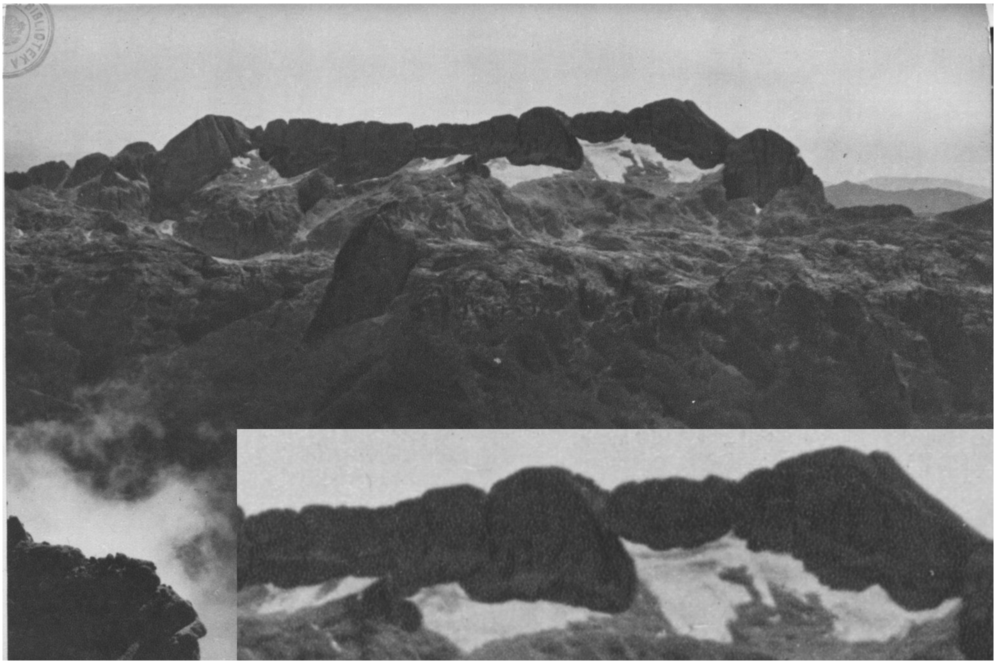
Sledila je obdelava najstarejše fotografije Kaninskih ledenikov (slika 6 zgoraj), ki jo je njen avtor Arturo Ferucci posnel z vrha Bele Peči 30. julija 1893. Posnetek sicer prikazuje tudi Vršiški ledenik, a ker ga DMR iz leta 2011 ne pokriva, njegovega obsega nismo ugotavljali. Skoraj z istega stojišča so bili Kaninski ledeniki spet posneti 8. septembra 2011, kar omogoča neposredno primerjavo (slika 6 spodaj). V 118 letih je opaziti občutno zmanjšanje in stanjšanje vseh treh ledenikov. Leta 1893 je bil na primer zgornji rob Vzhodnega Kaninskega ledenika od 35 do 58 metrov višje ob strmem pobočju Srednjega Vršiča kot leta 2011. Nekdanji zgornji rob ledenika lepo vidimo na sliki 6 spodaj kot ločnico med temnejšo in svetlejšo skalo.

Pri interaktivni orientaciji obeh posnetkov smo v obeh primerih upoštevali še radialno distorzijo (slika 3). Ta najbolj vpliva na zahodni del Zahodnega Kaninskega ledenika, če je namreč na primeru iz leta 1893 ne upoštevamo, dobimo rezultat, v skladu s katerim je zahodni del Zahodnega Kaninskega ledenika manjši za 2 ha. Pri določitvi celotnega obsega ledenika v letih 1893 in 2011 je težava tudi v tem, da sta največji del Zahodnega Kaninskega ledenika ter vzhodni del Vzhodnega Kaninskega ledenika skrita za grebenom Srednjega Vršiča. Celoten obseg Zahodnega Kaninskega ledenika leta 1893 lahko določimo ob predpostavki, da je njegov zgornji rob na približno isti nadmorski višini oziroma je razlika med nadmorsko višino zgornjega robu ledenika med letoma 1893 in 1908 približno enaka na celotnem zgornjem robu ledenikov. Leta 1893 je bil zgornji rob najmanj 20 metrov višje kot leta 1908 na Marinellijevem načrtu (slika 7). V tem primeru ne naredimo prevelike napake, če del ledenikov, ki nista vidna na fotografiji iz leta 1893, aproksimiramo z robom ledenika leta 1908. Tako dobimo najverjetnejšo površino ledenikov za leto 1893 (preglednica 2). Površine, ki bi jih določili brez te predpostavke, bi bile na Zahodnem ledeniku manjše za 4,5 ha, na Vzhodnem Kaninskem ledeniku pa za 6,5 ha.



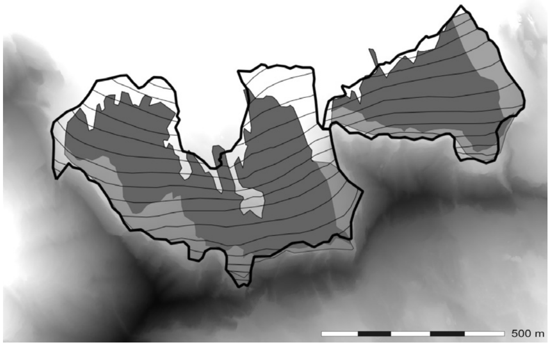
Slika 7: Kaninska ledenika leta 1893 in 1908, predstavljena na senčenem reliefu iz leta 2011. Temno siva površina predstavlja površino ledenika, zajeto neposredno s posnetka iz 1893., svetlo siva pa povečano površino glede na opisane predpostavke. Debela črna črta pomeni rob ledenika, tanjše črne črte pa plastnice z ekvidistanco 20 metrov z Marinellijevega načrta iz leta 1908 (slika 5). Šrafirano območje predstavlja ostanke ledenikov, izmerjene na podlagi slike 6 spodaj, posnete leta 2011.

Na sliki 7 lahko tudi neposredno primerjamo površine iz let 1893 in 2011. Od Zahodnega Kaninskega ledenika so 8. septembra 2011 ostale le ločene zaplate. S posnetka (slika 6 spodaj) žal ne moremo videti največjega vzhodnega dela Zahodnega Kaninskega ledenika. Ledeniški ostanki, ki so vidni, merijo skupaj 1,3 ha. Tudi pri Vzhodnem Kaninskem ledeniku je najbolj vzhodni del ledenika skrit, tako slika 6 spodaj tudi pri tem ne omogoča zajema celotnega ledenika; vidna ledena površina meri 1,2 ha (preglednica 2).

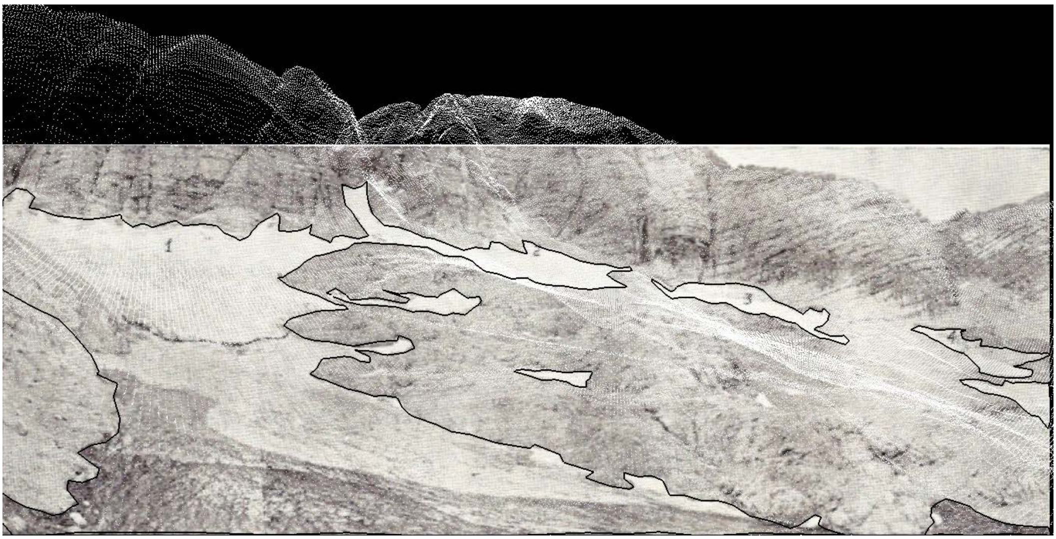


Slika 8: Prestreljeniški ledenik (levo), Vršiški ledenik, Vzhodni in Zahodni Kaninski ledenik pred letom 1934 (fotograf: Wilhelm Dronowicz (Kugy, 1934)).

V knjigi Die Julischen Alpen in Bilde (Kugy, 1934) je bil leta 1934 poleg posnetka Kaninskih ledenikov (slika 8) objavljen tudi posnetek Triglavskega ledenika (slika 15b). Na podlagi Kugyjevih zapisov lahko sklepamo o približni starosti posnetkov. Omenjena posnetka sta domnevno nastala konec 20. oziroma v začetku 30. let 20. stoletja. Kugyjev (1934) posnetek (slika 8) Kaninskih ledenikov je tako kot slika 6 zgoraj posnet približno iz smeri Montaža. K sreči Kaninska ledenika nista na robu posnetka, tako da ni bilo treba odstraniti radialne distorzije. Zaradi senc, ki jih mečejo vrhovi, pa je bilo določanje zgornjega robu ledenikov precej težavno. Najprej smo določili osončen del, potem smo na podlagi rahlih sprememb v sivini slike določili zgornji rob ledenikov. Razlike v sivini so vsaj ponekod dale slutiti, da lahko v senci prepoznamo dva zgornja robova: dejanski zgornji rob in nekdanji zgornji rob, ki ga lepo vidimo na sliki 6 spodaj. Razliko zlahka opazimo pri Vršiškem ledeniku na povečavi fotografije v spodnjem kotu slike 8. Na delih, kjer je bilo na podlagi slike mogoče z zadovoljivo točnostjo določiti zgornji rob ledenikov, se ta rob lepo ujema z zgornjim robom ledenikov iz leta 1908 (slika 9). Zato smo pri celotni dolžini predpostavili, da se zgornji rob ledenika na sliki 8 ujema z zgornjim robom iz leta 1908. Osončeni del Vzhodnega Kaninskega ledenika meri 8,4 ha, Zahodnega pa 18,3 ha. Ko dodamo še osenčeni del ledenika, se površina Vzhodnega Kaninskega ledenika poveča za 1,7 ha, Zahodnega pa za 4,1 ha. Dela obeh ledenikov sta, enako kot pri posnetku iz leta 1893, skrita za pobočji Srednjega Vršiča. Iz zgornje predpostavke, da se zgornji rob ujema z robom iz leta 1908, smo tudi dele ledenikov, ki se na sliki 8 ne vidijo, aproksimirali s stanjem iz leta 1908. Tako dobimo končne površine, zapisane v preglednici 2. Na sliki 9 vidimo, da sta se ledenika glede na stanje iz leta 1908 zmanjšala, na kar nakazuje že njun spodnji rob. Ta opisuje podobno obliko, kot sta jo imela leta 1908, le da se je horizontalno umaknil za od 20 do 40 metrov.

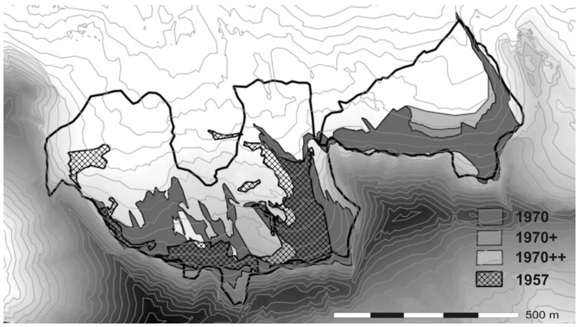


Slika 9: Kaninska ledenika pred letom 1934 in leta 1908, predstavljena na senčenem reliefu iz leta 2011. Temno siva površina predstavlja zajeto osončeno površino ledenika neposredno s fotografije, nastale pred 1934., svetlo siva pa povečano površino glede na opisane predpostavke. Debela črna črta pomeni rob ledenika, tanjše črne črte pa plastnice z Marinellijevega načrta iz leta 1908.



Slika 10: Zahodni Kaninski ledenik 10. septembra 1957: bele pike DMR-ja in zajeti robovi snega, označeni s črno črto (fotograf: Dino Di Colbertaldo (Di Colbertaldo, 1959, 324)).

Interaktivna orientacija Di Colbertaldovega posnetka (slika 10) Zahodnega Kaninskega ledenika iz leta 1957 (Di Colbertaldo, 1959) je pomenila svojevrsten izziv. Na sliki vidimo zelo majhen del severnega ostenja Kanina, kjer se za natančno orientacijo posnetka lahko opremo na le malo reliefnih oblik (grabne, jarke, kamine). Slika je bila posneta izpred Zahodnega Kaninskega ledenika. Končni rezultat interaktivne orientacije se opira na prikaz šestih žlebov v ostenju Kanina in splošni videz ledeniških grbin v ospredju slike (slika 10). Po zagotovitvi razmeroma dobrega ujemanja, smo za boljše ujemanje DMR-ja s posnetkom uvedli tudi popravke zaradi radialne distorzije. Zaradi slabe orientacije sta robova največjega dela Zahodnega Kaninskega ledenika iz let 1957 in 1970 (slika 11) premaknjena v smeri vzhod–zahod za od 20 do 40 metrov. Žal slika 10 ne prikazuje celotnega Zahodnega Kaninskega ledenika, saj manjkata njegov najbolj vzhodni in spodnji del. Pri ugotavljanju površine smo morali biti pozorni na dve barvi snega: bel sneg prikazuje odkrit ledenik, temen sneg, ki ga lepo vidimo v ospredju slike, pa sneg zadnje zime (srenjec). Temnejši sneg zadnje zime povezuje tudi dve beli zaplati (označeni s številko 4 na sliki 10). Ker je leto 1957 približno na sredini med letoma 1908 in 2011, za kateri imamo najbolj zanesljive podatke o celotnem obsegu ledenika, žal ledenika ne moremo povečati z aproksimacijo. Skupno na sliki 11 vidimo 7,6 ha, največji ostanek Zahodnega Kaninskega ledenika, označen s številko 1 na sliki 10, obsega 5,0 ha (preglednica 2). Del, označen z 2 na sliki 10, meri 1,4 ha, ostali oštevilčeni deli pa merijo približno 0,5 ha. Dela 2 in 3 sta deloma skrita za grbino, zato sta morala biti v resnici večja. Sklenemo lahko, da Di Colbertaldov posnetek prikazuje minimalen obseg ledenika v petdesetih letih prejšnjega stoletja. To se ujema s trditvijo Messerlija (1967), da sta v začetku 1960. let Vzhodni in Zahodni Kaninski ledenik merila vsak po približno 9,0 ha.

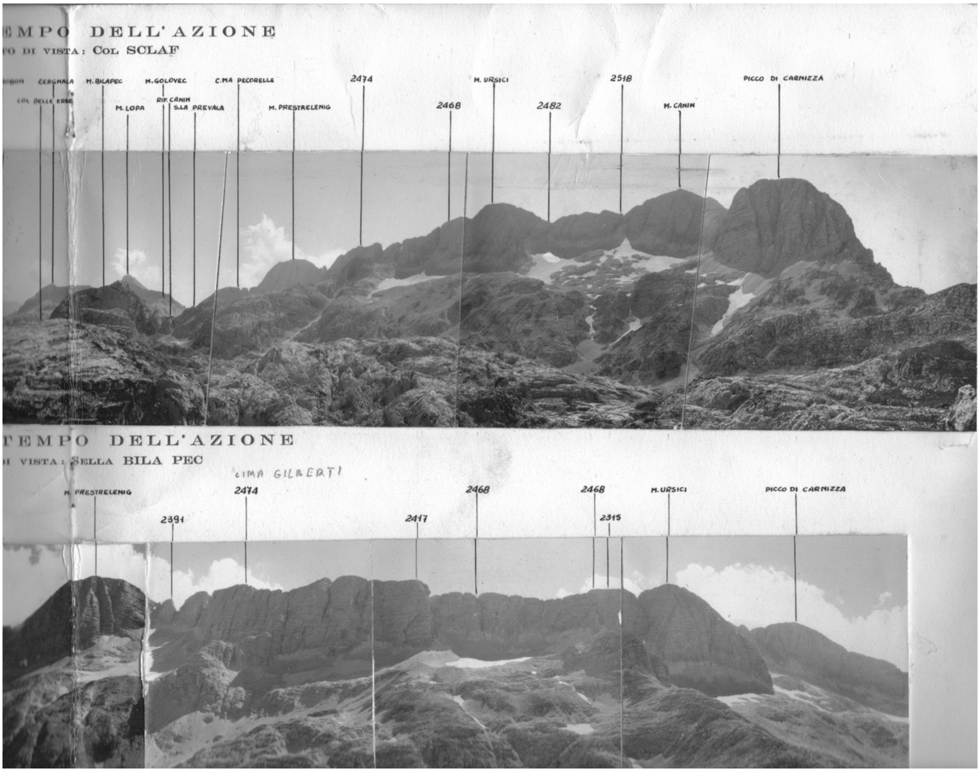


Slika 11: Kaninska ledenika leta 1957 (Di Colbertaldo, 1959) in v 70. letih 20. stoletja (1970+ povečana površina, 1970++ še bolj povečana površina), predstavljen na senčnem reliefu in plastnicah z ekvidistanco 20 metrov iz leta 2011. Debela črna črta predstavlja rob ledenika leta 1908.

Posnetka na sliki 12 prikazujeta Kaninske ledenike v 1970. letih (verjetno leta 1976). Predpostavljamo, da sta bili posneti približno istočasno. Zgornja slika omogoča zajem celotne površine Zahodnega Kaninskega ledenika, spodnja pa dopolnitve Vzhodnega, ki je na zgornji sliki večinoma skrit za grbino. Žal tudi spodnji posnetek ne prikazuje celotnega Vzhodnega Kaninskega ledenika, saj je deloma skrit za delom Srednjega Vršiča. Naleteli smo na isto težavo kot pri posnetku, narejenem pred letom 1934 (slika 8), zaradi česar je bilo treba izvesti aproksimacijo Vzhodnega Kaninskega ledenika; zgornji robovi ledenikov so skriti v senci, zato je njihova interpretacija slabša, a ne tako zahtevna kot pri sliki 8.

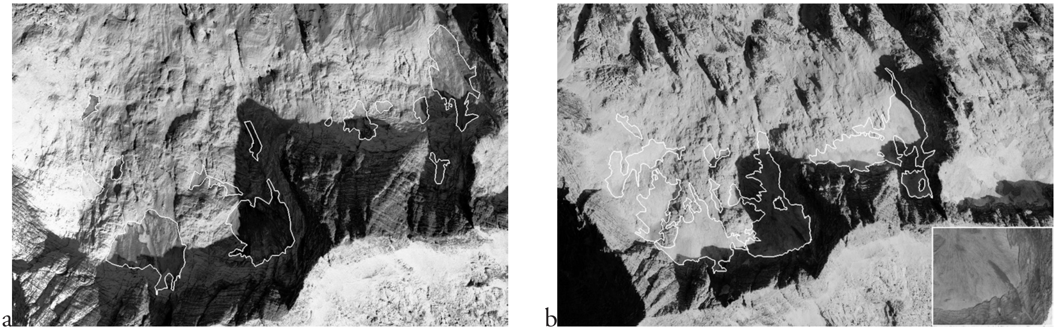
Na sliki 11 sta prikazana le osrednja in največja dela ledenikov, posameznih manjših snežišč, ki jih na zgornji sliki 12 vidimo pod Vrhom Krnice/Picco di Carnizza, pa nismo izrisali, saj so večinoma manjša od 0,4 ha. Površina, določena na tej podlagi, je 5,1 ha ha za Vzhodni in 10,1 ha za Zahodni Kaninski ledenik. Celotno površino Vzhodnega Kaninskega ledenika dobimo z aproksimacijo spodnjega robu ledenika po plastnici. Tako lahko osnovni površini dodamo srednje sivo površino, na sliki 11 označeno z 1970+, ki meri 0,4 ha. Če smo še bolj optimistični in izrišemo spodnji rob po plastnici, do katere sega najnižji spodnji rob ledenika (na zgornji sliki 11 označeni z 1970++), povečamo ledenik še za 0,9 ha. Obe aproksimaciji dodata skupno 1,3 ha površine k Vzhodnemu ledeniku. V preglednici 2 je zapisana površina po prvi aproksimaciji (5,5 ha), na sliki 11 označena z 1970+.

Velikost ledenikov za leti 2000 in 2011 smo določili na podlagi posnetkov cikličnega aerofotografiraja Slovenije (CAS) Geodetske uprave Republike Slovenije (GURS, 2013). Iz posnetkov CAS so narejene ortofotografije, ki sežejo 250 metrov prek slovenske meje, zato ledenika na njih nista prikazana. Vidna pa sta na originalnih aerofotografijah CAS. Če bi imeli stereopar, bi ledenika lahko izvrednotili stereofotogrametrično. Ker Kaninska ledenika na CAS najdemo le občasno, in to večinoma na zadnjem posnetku, stereopara največkrat nimamo. Zato smo tudi te posamične posnetke orientirali z interaktivno metodo orientacije z aerolaserskimi podatki. Tokrat glavne orientacijske točke v prostoru niso bile stenske reliefne oblike, temveč potek vrhov in grebenov (slika 13).



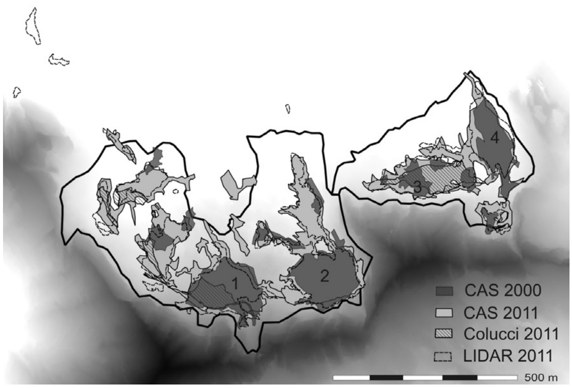
Slika 12: Vzhodni in Zahodni Kaninski ledenik v 1970. letih (foto: arhiv Manlia Roseana).

Posnetka CAS ne omogočata najboljše fotointerpretacije. Deli ledenikov, ki so skriti v sencah grebenov, se vidijo, deli na odprtem pa so presvetljeni, zato na njih težko določimo, kaj je sneg in kaj melišče. Tako smo pred uporabo oba posnetka še obdelali in povečali kontrast na slabo vidnih presvetljenih območjih (slika 13). Dodatna težava pri interpretaciji je, da so ostanki Kaninskih ledenikov mnogokrat zasuti z gruščem (izsek na sliki 13b), zaradi česar je težko ločiti med ostanki ledenika in meliščem. To še posebej velja za posnetke CAS 2000, ko so bili ledeniki povsem razkriti. Najbolj problematičen je vzhodni del Vzhodnega Kaninskega ledenika (na sliki 14 označen s številko 4), kjer smo zajeli močno zasuto območje velikosti 1,7 ha. Tu na zgornjem delu še lahko prepoznamo led, spodnje meje pa ne moremo določiti. Pri interpretaciji smo se oprli na poznavanje območja. Nekatera druga območja, na primer del Vzhodnega Kaninskega ledenika, na sliki 14 označen s 3, pa relativno enostavno prepoznamo, ker so večinoma v senci; ta del meri 0,5 ha. Največja dela Vzhodnega Kaninskega ledenika skupaj merita 2,2 ha. Štirje manjši ostanki, pri katerih posamezen del ni večji od 0,2 ha, pa dodajo še 0,5 ha. V preglednici 2 je navedena skupna velikost Vzhodnega Kaninskega ledenika 2,7 ha. Vzhodni del Zahodnega Kaninskega ledenika (na sliki 14 označen z 2) meri 2,4 ha, njegov največji sosed (na sliki 14 označen z 1) pa 2,5 ha. Če prištejemo še pet manjših delov, kjer posamezen ne meri več kot 0,3 ha, je skupna velikost Zahodnega Kaninskega ledenika 5,9 ha.



Slika 13: Izseka iz posnetkov CAS: a) 18. 8. 2000 in b) 18. 8. 2011. Ostanki ledenikov so občrtani z belo črto. Izsek posnetka iz leta 2011 prikazuje povečavo vzhodnega dela Zahodnega Kaninskega ledenika, kjer se dobro vidi nanos grušča, ki je ostal za podoroma 16. in 18. julija 2011.

Posnetek CAS iz leta 2000 prikazuje najmanjši obseg povsem razkritih ledenikov, nasprotno pa posnetek CAS iz leta 2011 (oba sta bila posneta 18. avgusta) prikazuje še popolnoma zasnežen ledenik. Tudi 29. septembra 2011, ko je potekalo aerolasersko snemanje (na sliki 14 označeno z LIDAR 2011), so ledeniki večinoma še pod snegom.



Slika 14: Kaninska ledenika na podlagi CAS: stanje 18. 8. 2000 in 18. 8. 2011. Dodan je obseg, izmerjen na podlagi slike 6 spodaj iz leta 2011. Ledenika sta predstavljena na senčenem reliefu iz leta 2011. Debela črna črta pomeni rob ledenika leta 1908.

Največji del Vzhodnega Kaninskega ledenika, izmerjen na podlagi CAS 2011, meri 5,0 ha (območji 3 in 4 na sliki 14). Slab mesec zatem (slika 6 spodaj) je ta del meril le še 1,2 ha, med aerolaserskim snemanjem konec septembra pa 2,5 ha. Del, označen s 4 na sliki 14, je konec septembra 2011 meril 1,9 ha, tako da sta se dela 3 in 4 skupaj zmanjšala na 4,4 ha. V preglednici 2 so prikazane površine Vzhodnega in Zahodnega Kaninskega ledenika skupaj z zasneženimi deli, izmerjenimi na podlagi CAS in aerolaserskih podatkov. Največji del Zahodnega Kaninskega ledenika (oznaka 2) je sredi avgusta 2011 meril 4,7 ha;

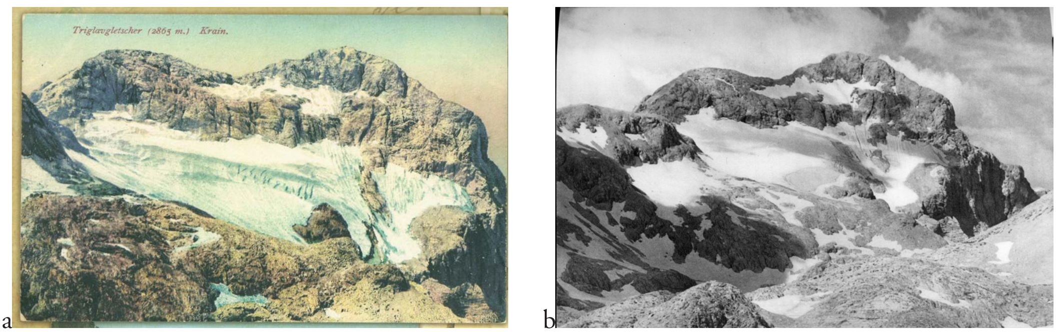
na fotografiji z začetka septembra ni viden, konec septembra pa je meril 3,6 ha. Drug največji del (oznaka 1) je avgusta meril 3,0 ha, v začetku septembra le 0,6 ha, konec septembra pa 2,3 ha. To neobičajno povečanje je povezano s tem, da je del ledenikov na sliki 6 spodaj skrit za reliefom.

Med urejanjem podatkov, pridobljenih iz posnetkov CAS, smo ugotovili, da majhne napake v interaktivni orientaciji lahko hitro pomenijo spremembe v položaju ledenikov za od 20 do 40 metrov, predvsem v smeri vzhod–zahod. Pred prikazom smo te pomike odstranili.

Preglednica 2: Površina Kaninskih ledenikov na podlagi arhivskih nemerskih posnetkov, posnetkov cikličnega aerofotografiraja Slovenije (CAS) in aerolaserskega snemanja (*največji del Zahodnega Kaninskega ledenika).

Leto posnetka	Avtor in vir	Zahodni Kaninski ledenik [ha]	Vzhodni Kaninski ledenik [ha]
30. 7. 1893	Arturo Feruci (Marinelli, 1910)	28	13
1908 (načrt)	Olinto Marinelli (Marinelli, 1909)	30,1	12,9
pred 1934	Wilhelm Dronowicz (Kugy, 1934)	23,6	12,1
10. 9. 1957	Dino Di Colbertaldo (Di Colbertaldo, 1959)	7,6 (*5,0)	
v 1970. letih	Manlio Roseano	10,1	5,5
18. 8. 2000	CAS	5,9 (*2,4)	2,7
18. 8. 2011	CAS	14,6 (*4,7)	6,4
8. 9. 2011	Renato R. Colucci	1,3 (*)	1,2
29. 9. 2011	aerolasersko snemanje 2011	8,8 (*3,6)	4,7

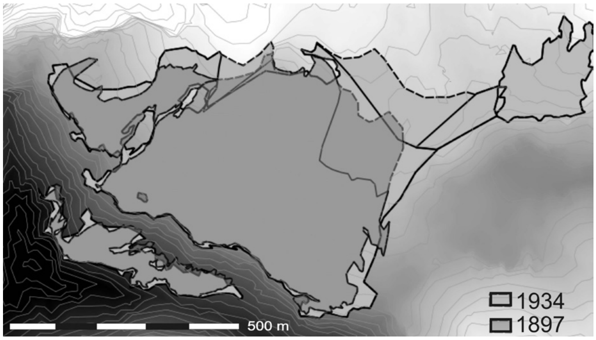
5.2 Triglavski ledenik med letoma 1897 in 1976



a b

Slika 15: Triglavski ledenik: a) na razglednici iz leta 1897 domnevno posneti prej (fotograf: Alois Beer), b) pred letom 1934 (fotograf: Janko Skerlep (Kugy, 1934)).

Isto metodo obdelave posnetkov smo uporabili za Triglavski ledenik. Primerjava med Kaninskimi in Triglavskim ledenikom je smiselna, ker so uporabljeni posnetki iz približno istih obdobij. Najstarejša izmera temelji na barvni razglednici iz leta 1897 (slika 15a), ki smo jo poobjavili že v Triglav Čekada in Gabrovec (2008, 509). Triglavski ledenik je bil posnet približno iz smeri Begunjskega vrha. Žal je njegov spodnji del pod Glavo skrit za grbinami v ospredju slike, zato celotne površine ne moremo neposredno izmeriti. Lahko pa, podobno kot pri Kaninskih ledenikih, njegovo površino povečamo po plastnici spodnjega roba, vidnega v spodnjem desnem delu posnetka (slika 16). Brez povečanja je velikost osrednjega dela ledenika 19,5 ha, zgornje snežišče pod vrhom Triglava, ki ga ne štejemo več k ledeniku, meri 2,7 ha. Če pa ledenik povečamo po plastnici, je skupna površina osrednjega dela 22,0 ha (preglednica 3), vendar domnevamo, da del ledenika leži pod razširjeno spodnjo mejo. Ledenik je bil leta 1897 tudi veliko debelejši, saj je segal skoraj do vrha Glave. Zahodni Kaninski ledenik je le pet let pred tem meril 28 ha, zato lahko rečemo, da sta bila takrat podobno velika.

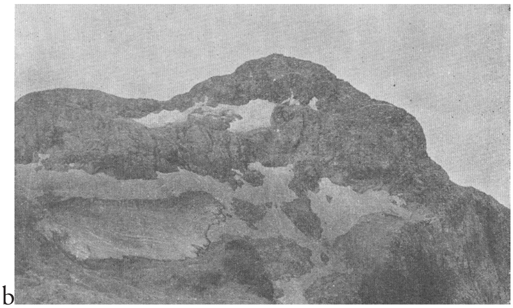


Slika 16: Triglavski ledenik leta 1897 (temno siva) in pred letom 1934 (svetlo siva). Črtkani robovi prikazujejo aproksimirano površino. Ledenik je predstavljen na senčenem reliefu in plastnicah z ekvidistanco 20 metrov iz aerolaserskih podatkov leta 2012.

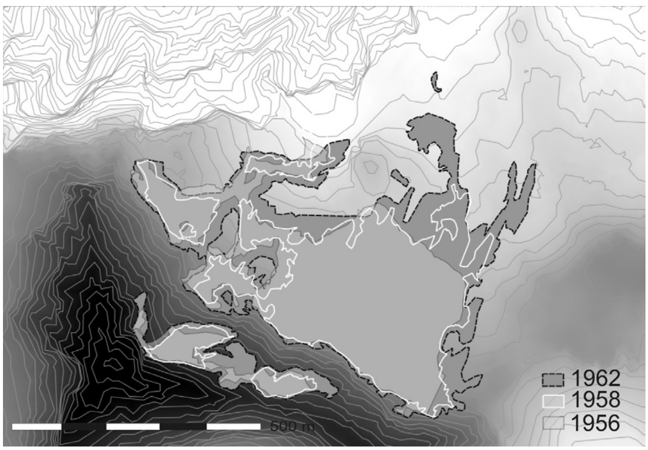
Posnetka Kaninskih ledenikov (slika 8) in Triglavskega ledenika (slika 15b) sta nastala konec 20. oziroma v začetku 30. let 20. stoletja. Triglavski ledenik je bil posnet iz bližine današnje Staničeve koče. Njegova okolica je še zelo zasnežena, zato lahko sklepamo, da ni bil posnet čisto ob koncu talilne sezone kot Kaninska ledenika, objavljena v isti knjigi (Kugy, 1934). Vendar pa je osrednji del okoli Glave že razkrit, saj se na njem lepo vidijo tudi prečne ledeniške razpoke. Iz tega lahko domnevamo, da je fotografija nastala nekje v prvi polovici avgusta. Osrednji del ledenika, izmerjen na podlagi slike 15b, je velik 23,8 ha, zgornje snežišče pod vrhom Triglava pa 2,7 ha. Največje snežišče v levem delu slike 15b, ki ga pa verjetno ne moremo več šteti k ledeniku, meri 2,6 ha. To snežišče je obstajalo tudi leta 1897, saj je delno vidno na sliki 15a. Kot pri posnetku iz leta 1897 nam spodnji del ledenika pod Glavo zakrivajo grbine v ospredju posnetka, zato smo tudi pri tem posnetku ledenik približno povečali po plastnicah spodnjega robu. O obsegu ledenika pod Glavo in njegovi umestitvi v prostor lahko deloma sklepamo tudi na podlagi slike 4b (Kugy, 1969). Osrednji del ledenika se ob upoštevanju teh dejstev poveča na 27,6 ha (preglednica 3), kar pomeni, da bi bil večji od Zahodnega Kaninskega ledenika.

Obseg Triglavskega ledenika je bil v 1950. letih med najmanjšimi leta 1954; zmanjšanje je najbolj vidno desno od Glave (črtkano na sliki 17a; Šifrer, 1963). Žal glavni del ledenika iz 1954. na tej sliki ni označen v celoti. Da bi imeli najbližjo primerjavo s stanjem Zahodnega Kaninskega ledenika leta 1957, smo obdelali še sliko 17b (Šifrer, 1963), ki prikazuje Triglavski ledenik konec septembra 1956. Obe fotografiji (slika 17) sta bili posneti z Begunjskega vrha. Pri interaktivni orientaciji posnetka iz leta 1956 nismo upoštevali distorzij, pri posnetku iz leta 1958 pa smo bili v to primorani, če smo hoteli pravilno poravnati vsebino na levem robu slike. Kljub skalam, ki na desnem delu ledenika gledajo iz njega, lahko leta 1956 ledenik še vedno obravnavamo kot enovit, s skupno površino 14,4 ha (slika 17b). Osrednji del snežišča pod vrhom Triglava meri 1,3 ha, majhen del na njegovi desni strani pa je velik le 0,06 ha (preglednica 3). Snežišče pod vrhom Triglava obravnavamo ločeno od ledenika.

Konec septembra 1958 je bil ledenik najmanjši. Ločimo njegov osrednji del, ki meri 12,0 ha, in ostanke desno od Glave, od katerih največji meri 1,1 ha, spodnji pa 0,6 ha. Ko vse tri dele seštejemo, dobimo skupno površino ledenika 13,7 ha (preglednica 3). Tudi snežišče pod vrhom Triglava je ločeno na dva večja ostanka, ki merita po 0,8 in 0,5 ha. Kot zanimivost omenimo še snežišče na levi strani fotografije, ki smo ga izmerili na posnetku pred letom 1934 (slika 15b) in je še vedno vidno tudi na posnetku iz leta 1958 (slika 17a). Sklepamo lahko, da je obseg Kaninskih ledenikov leta 1957 in Triglavskega ledenika leta 1958 najmanjši v tem desetletju. Konec septembra 1962 (sliki 17a, 18) so deli Triglavskega ledenika desno od Glave spet povezani v enovit ledenik, ki meri 21,5 ha. Snežišče pod vrhom Triglava meri 2,7 ha.

a  b 

Slika 17: Levo Triglavski ledenik leta 1958 z dodanimi belimi črtami, ki označujejo stanje leta 1962, in črtkanimi črtami, ki prikazujejo stanje leta 1954. Desno Triglavski ledenik leta 1956 (Šifrer, 1963).



Slika 18: Triglavski ledenik leta 1956, 1958, 1962. Predstavljen je na senčenem reliefu in plastnicah z ekvidistanco 20 metrov, izdelanih iz aerolaserskih podatkov 2012.

Za 1970. leta so v preglednici 3 podane vrednosti, izmerjene na podlagi arhivskih panoramskih posnetkov fotoaparata Horizont, pridobljenih z isto metodo (Triglav Čekada in Gabrovec, 2013). V tem obdobju je bil Triglavski ledenik prekrit z debelo snežno odejo. Omeniti velja, da na Horizontovih posnetkih vidimo tudi snežišče pod vrhom Triglava, a ga nismo merili. Tudi Zahodni Kaninski ledenik (preglednica 2) se je v tem obdobju povečal glede na obseg, izmerjen v 1950. letih. Zahodni Kaninski ledenik je sredi 1970. let meril 10,5 ha, Triglavski ledenik pa leta 1976 18,0 ha.

Preglednica 3: Površina Triglavskega ledenika na podlagi arhivskih posnetkov v obdobju 1897–2000 in aeroloaserskega snemanja leta 2012 (*ledenik, pokrit s snegom, **osrednji del ledenika, ***natančnejša preučitev je pokazala, da je bil ledenik ob koncu talilne sezone leta 2012 velik le še 0,6 ha).

Leto posnetka	Avtor in vir	Triglavski ledenik površina [ha]	Snežišče pod vrhom Triglava [ha]
1897	A. Beer (Il Turista)	22,0	2,7
pred 1934	Janko Skerlep (Kugy, 1934)	27,6	2,7
23. 9. 1956	Milan Šifrer (Šifrer, 1963, 185)	14,4	1,3
28.–30. 9. 1958	Milan Šifrer (Šifrer, 1963, 201)	13,7	1,3
16. 9. 1962	Milan Šifrer (Šifrer, 1963, 201)	21,5	2,7
13. 8. 1976	Horizont (Triglav Čekada in Gabrovec, 2013)	18,0	
26. 8. 1977	Horizont (Triglav Čekada in Gabrovec, 2013)	22,3	
15.8. 1979	Horizont (Triglav Čekada in Gabrovec, 2013)	24,1	
12. 9. 2000	Horizont (Triglav Čekada in Gabrovec, 2013)	1,1	
13.–14. 9. 2011	terenska izmera	2,4*	
18. 9. 2012	aerolasersko snemanje 2012	1,0 (0,8**) [0,6***]	

6 SKLEP

V članku je prikazana uporaba arhivskih posnetkov za ugotavljanje sprememb velikosti ledenikov. Obdelani so bili nemerski posnetki Vzhodnega in Zahodnega Kaninskega ledenika ter Triglavskega ledenika, začenši z letom 1893. Obdelani so bili na podlagi interaktivne metode orientacije, pri kateri uporabimo natančen digitalni model reliefa za iskanje najboljšega ujemanja med njim in posnetkom. Zaradi vsebine na robovih posnetkov, kjer so napake lahko največje, smo morali večkrat odstraniti radialno distorzijo. Ker večinoma ne vemo, ali uporabljeni posnetki prikazujejo celotno fotografijo ali le njen del, radialno distorzijo upoštevamo pri projekciji digitalnega modela reliefa in ne pri samem posnetku. Tak način nam omogoča orientacijo in izmero obodov ledenikov v globalnem koordinatnem sistemu, ter posledično primerjavo njihove površine v časovnem razponu, daljšem od sto let.

Rezultati kažejo, da so se Kaninska ledenika in Triglavski ledenik v obravnavanih letih »obnašali« podobno, bili so tudi podobno veliki. Konec 19. stoletja je Zahodni Kaninski ledenik meril 28 ha, Vzhodni Kaninski ledenik 13 ha in Triglavski ledenik 22 ha. Sredi 20. stoletja so ledeniki že razpadli na več delov. Zahodni Kaninski ledenik je leta 1957 meril 7,6 ha, Triglavski pa leta 1958 13,7 ha. Sledilo je obdobje rasti. Zahodni Kaninski ledenik je v 1970. letih meril 10,1 ha, Triglavski ledenik pa leta 1976 18,0 ha. V 1980. letih se začne pospešeno zmanjševanje. Leta 2000 je vzhodni (največji) del Zahodnega Kaninskega ledenika meril 5,0 ha, Triglavski ledenik pa 1,1 ha. Konec zadnjega desetletja je sledilo nekaj s snegom obilnejših zim, ki so ledenike zaščitile. Zato je aerolasersko snemanje Kaninskih ledenikov leta 2011 pokazalo večji obseg kot desetletje pred tem.

Aerolasersko skeniranje Triglavskega ledenika leta 2012 je sledilo manj snežni zimi, zato je bil posnet njegov najmanjši obseg; osrednji del je meril 0,8 ha. Vrednosti ustrezajo globalnemu trendu zmanjševanja ledenikov (Triglav Čekada in sod., 2012).

Raziskava je pokazala, da je starejša gorniška literatura, v našem primeru knjige Juliusa Kugyja (1858–1944), pomemben vir podatkov o stanju ledenikov v preteklosti. V veliko pomoč so nam tudi starejše izmere, v našem primeru Marinellijev načrt Kaninskih ledenikov iz leta 1908, izdelan na podlagi terestrične fotogrametrije. Bil je pomembna referenca pri opredelitvi na posnetkih zakritih delov Kaninskih ledenikov. V članku se osredotočamo predvsem na izmero površine ledenikov, nadaljnja obdelava istih posnetkov pa nam lahko omogoči tudi ugotavljanje sprememb v njihovi debelini.

7 ZAHVALA

Delo je bilo delno financirano v okviru podoktorskega projekta Z2-4182 (B), raziskovalnega programa P6-0101 Javne agencije za raziskovalno dejavnost Republike Slovenije (ARRS) in projekta MONICA (FRA-2012 grant) ter Meteorološkega združenja Furlanije-Julijske krajine. Zahvalili bi se še Robertu Kostki in Viktorju Kaufmannu za pomoč pri prepoznavanju fotogrametričnega instrumenta Olinota Marinellija iz leta 1908.

Literatura in viri

Glej literaturo na strani 294.

Triglav Čekada M., Zorn M., Colucci R. R. (2014). Površina kaninskih in triglavskega ledenika od leta 1893, določena na podlagi arhivskih posnetkov ter aerolaserskih podatkov. Changes in the area of the Canin (Italy) and Triglav glaciers (Slovenia) since 1893 based on archive images and aerial laser scanning. Geodetski vestnik, 58 (2): 274–313.

dr. Mihaela Triglav Čekada, univ. dipl. inž. geod.
Geodetski inštitut Slovenije,
Jamova cesta 2, SI-1000 Ljubljana
e-naslov: mihaela.triglav@gis.si

doc. dr. Matija Zorn, univ. dipl. geog. in prof. zgod.
Geografski inštitut Antona Melika,Znanstvenoraziskovalni center
Slovenske akademije znanosti in umetnosti
Gosposka ulica 13, SI-1000 Ljubljana
e-naslov: matija.zorn@zrc-sazu.si

dr. Renato R. Colucci, mag. geol.
Dipartimento Scienze del Sistema Terra e Tecnologie per l'Ambiente
Consiglio nazionale delle ricerche (CNC)
Instituto di Scienze Marine (ISMAR)
Viale R. Gessi 2, IT-34123 Trst, Italija
e-naslov: r.colucci@ts.ismar.cnr.it

Mihaela Triglav Čekada, Ph. D. in Geodesy, B. Sc. in Geodesy
Geodetic Institute of Slovenia
Jamova cesta 2, SI-1000 Ljubljana, Slovenia
e-mail: mihaela.triglav@gis.si

Matija Zorn, Ph. D. in Geography, B. Sc. in Geography and History, Assist. Prof.
Anton Melik Geographical Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts
Gosposka ulica 13, SI-1000 Ljubljana, Slovenia
e-mail: matija.zorn@zrc-sazu.si

Renato R. Colucci, Ph. D. in Environmental Sciences, M. Sc. in Geological Sciences
Department of Earth System Science and Environmental Technologies
National Research Council (CNR)
c/o Marine Science Institute
Viale R. Gessi 2, IT-34123 Trieste, Italy
e-mail: r.colucci@ts.ismar.cnr.it