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THE DEBELI NAMET GLACIER FROM THE SECOND HALF OF THE 20TH CENTURY TO THE PRESENT

LEDENIK DEBELI NAMET OD DRUGE POLOVICE 20. STOLETJA DO DANES

Predrag Djurović

Debeli Namet is one of Europe's southernmost glaciers (July 28, 2007).
Debeli namet je eden od najjužnejših evropskih ledenikov (28. julija 2007).

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ABSTRACT: The Debeli Namet glacier is one of two recent glaciers located in the south western Balkans, located on Durmitor Mountain in the south eastern Dinarides mountain range in Montenegro and is considered to be a small glacier. The size of the glacier from 1954 to 1981 was estimated based on aerial photographs. According to glaciological research, geomorphologic studies of the nearby relief and analyses of climate change (temperature and precipitation) within the last 50 years, new data on the glacier have been obtained. The Debeli Namet glacier is reducing at a rate slower than that of other southern European glaciers. The Debeli Namet glacier did not significantly fluctuate in size (surface and thickness) in response to temperature increases that occurred at the end of the 20st and at the beginning of the 21st centuries. Here, we present partially revised data accompanied by recent results related to the glacier's recent behaviour, its surroundings and its associated climate.

KEY WORDS: geography, glaciology, glacier, Debeli Namet, climate change, Durmitor, Dinarides, Montenegro

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Contents

1 Introduction

Abundant evidence of Pleistocene glaciation has been discovered and studied in the high mountain areas of southern Europe and the broader Mediterranean (Messerli 1967; Hughes and Woodward 2008). During the Holocene era, glaciers almost completely retreated from these areas and remained only on particular mountains (Messerli 1980; Grünewald and Scheithauer 2010). Compared to their size during the Pleistocene, glacier sizes have been greatly reduced. They display similar characteristics: small spatial extents, underdeveloped tongues and widths commonly exceeding their lengths. They have been described as the Pyrenean type (Meccerli 1967) and were studied in the Pyrenees (Grove and Gellatly1995; Grove 2004), in the Sierra Nevada (Gómez et al. 2003), in Picos de Europa (González-Trueba 2004) in Spain, in the Alpes Maritimes in France (Federici and Stefanini 2001), in the Italian Apennines (D'Orefice et al. 2000; Dramis et al. 2002; D'Alessandro et al. 2003; Pecci 2006; Pecci et al. 2008), in the Slovenian Alps (Šifrer 1976; Tintor 1993; Gams 1994; Gabrovec 1998; Pavšek 2007; Triglav Čekada et al. 2012), in Durmitor Mountains in Montenegro (Djurović 1996; 1999; 2008; Hughes 2007; 2008; 2010), in Prokletije Mountains in Albania (Milivojević et al. 2007; Hughes 2008), in Pirin Mountains in Bulgaria (Grünewald et al. 2008; Gachev 2009; Gachev et al. 2009; Grünewald and Scheithauer 2010) and elsewhere. Several smaller glaciers existed beyond the Debeli Namet glacier during the LIA on Durmitor Mountain but subsequently disappeared (Hughes 2010).

Glaciers are located at lower altitudes in response to the recent equilibrium-line altitude (ELA) in these areas (Hughes and Woodward 2009). Small mountain glaciers have responded rapidly to climate changes at the end of 20th and beginning of the 21st centuries. Comprehensive studies of glaciers have been carried out to examine these changes and the possibility of glaciers retreating and/or disappearing (Meier et al. 2003). Data collected on the Debeli Namet glacier contribute to a better understanding of one of the southernmost and the lowest altitude southern European glaciers.

The Debeli Namet glacier is located along the western part of the Balkan Peninsula on Durmitor Mountain, which is part of the Dinarides mountain chain (Figure 1). Durmitor Mountain is primarily composed of

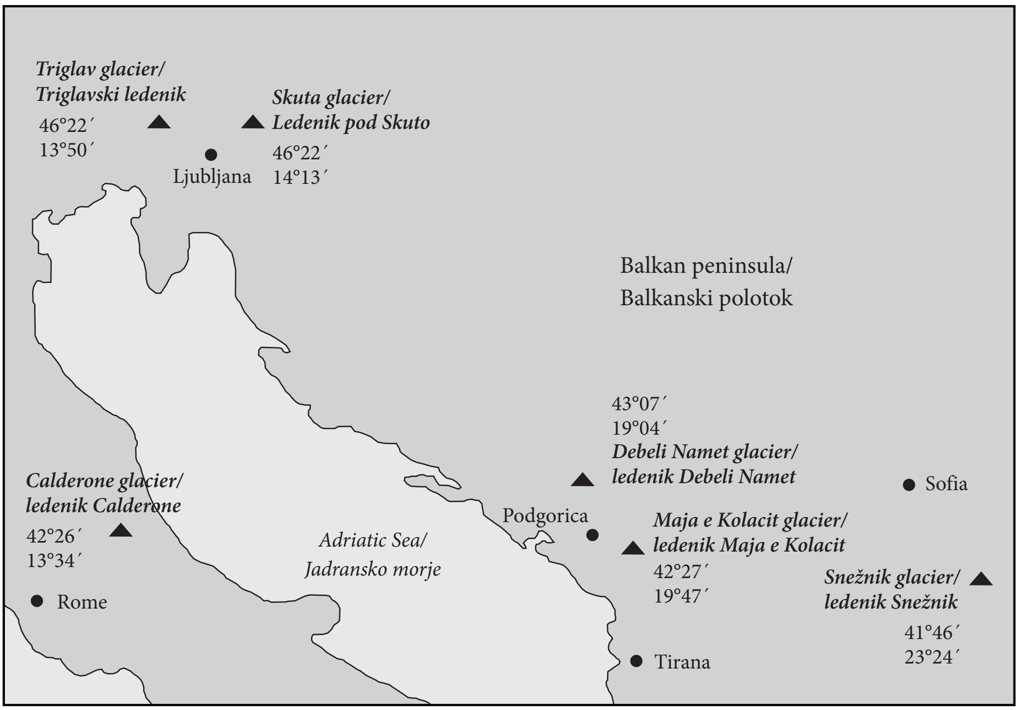

Figure 1: Geographic position of Durmitor Mountain and the modern glaciers in its vicinity.

Cretaceous carbonaceous rocks and Eocene carbonaceous flysch (Mirković 1983). Recent karst formations dominate its relief (Djurović 1996; 2010). Whereas numerous glaciers were present on Durmitor Mountain during the Pleistocene era, the Debeli Namet glacier is the only one that has persisted through time (Cvijić 1889; Milojević 1937; Marović and Marković 1972; Djurović 1996; 2002; 2009).

2 Methodology

Research on the Debeli Namet glacier has included glacier studies, geomorphological investigations and analyses of the glacier's main climatic elements. The size of the glacier was estimated according to analyses of aerial photographs taken prior to this research.

Geomorphic studies included quantitative and qualitative relief analyses. The result of these studies was a geomorphologic map (scale of 1 : 25,000) accompanied by characteristic cross-sections. Because the geomorphologic map was created regarding the genetic principles, all morphological forms and occurrences were classified based on dominant morphogenetic processes (Djurović and Menković 2004; Smith et al. 2006; Baumann et al. 2009).

The glacier was measured with a geological compass (accuracy 1°), a manual GPS, a measuring strip and a laser remote sensor. By comparing results obtained with the GPS with reference points located in the field, some errors that exceeded the limit of predicted tolerance were recognised. Most errors were most likely caused by high mountain ridges around the glacier that hindered our ability to obtain a good quality signal. Glacier length was measured with a measuring strip and a geological compass instead of the laser remote sensor because of frequent foggy weather above the glacier.

To determine fluctuations in glacier length, a reference point was placed at the end of the frontal moraine (i.e., near the glacier's tongue).

Past glacier size was obtained trough to aerial photographs taken in 1954, 1971 and 1981 (scale of 1 : 25,000). Photographs were taken during the first half of August and were analysed with remote sensing techniques (Elachy and Zyl 2006; Schowengerdt 2007).

Cirque margins were determined using aerial photographs (scale of 1 : 25,000). The same photographs were used to determine the area of the surface fed by snow avalanches. The utilisation of aerial photographs was more accurate than the utilisation of topographic maps at the same scale the aerial extents of the glacier were established trough photogrammetric methods (Fox and Nuttall 1997; Sanjosé et al. 2007)

The glacier's volume was calculated with an empirical formula. Measurements performed on 63 glaciers allowed for the ratio between the surface area and the glacier's mass to be estimated (Chen and Ohmura 1990):

$$V = 28.5\, S^{1.357}$$

where V is glacier volume (10^6 m^3) and S is glacier surface area (10^6 m^2).

The main climatic elements were analysed according to data collected by the Žabljak meteorological station from 1958–2010 (Republic Hydro-Meteorological Service of Montenegro). The vertical temperature gradient was calculated from data collected by the Žabljak (1450 m a.s.l.), the Pljevlja (784 m a.s.l.), the the Bijelo Polje (560 m a.s.l.) and the Kolašin (943 m a.s.l.) meteorological stations from 1961–1985. The linear correlation between the altitudes of these stations and their air temperatures was 0.95.

3 Previous research

The earliest data regarding the existence of a glacier on Durmitor Mountain was collected during the second half of the 1960s (Nicod 1968). Later, complex geomorphological research was carried out to estimate the influences of glacial, periglacial and karst processes on recent relief on Durmitor Mountain. This research confirmed the existence of a glacier (Djurović 1996). In the summer of 1993, the snow and the firn over the glacier started to melt (Djurović 1996; 1999) producing three small streams which carved up to 1 m deep and from 50 to 70 m long channels in the upper, concave part of the glacier. The convex part of the glacier transverse crevasses that were approximately 0.1 m wide and 10 m long. The streams disappeared into these crevasses producing three up to 8 m deep pits by melting the ice (Djurović 1996; 1999). This depth corresponds to the thickness of the Debeli Namet glacier.

The glacier area was completely and uniformly covered with a 0.1 to 0.3 m thick layer of debris) representing the vertical boundary between the glacier's ice and the overlying firn and snow. In August 1997, the boundary layer of debris was discovered when drilling through the glacier. The boundary layer was approximately 1 m beneath the thick firn layer. By mistake, the firn thickness was interpreted as the glacier thickness, and the debris layer was interpreted as the glacier's bedrock (Veselinović et al. 1997).

Intensive research has been carried out since then. The ice has been analysed to estimate its radioactivity and heavy metal content (Veselinović et al. 1997). Additionally, the natural and anthropogenic influences that may threaten the pits in the glacier have been examined (Djurović 1999). Radiochemical methods, specifically γ-spectrometry (^{137}Cs) and β-activity measurements (^{3}H concentration by liquid scintillation counting technique), were applied to the ice (Kern et al. 2006). The age of the Debeli Namet glacier moraines was determined by the lichenometric method accompanied by variable morphometric parameters (Hughes 2007). Comparative analysis of moraines on Durmitor and alluvial fans surrounding area adjacent highlighted errors of their determination and consequences (Djurović 2007). The influence of extreme summer temperatures during 2003–2007 on the Debeli Namet glacier was examined (Hughes 2008). Grünewald and Scheithauer (2010) analysed and predicted the current and future status of the southern European glaciers, including the Debeli Namet glacier, in terms of regional climate change.

4 Recent research in the Durmitor Mountain

4.1 Recent climate of the Durmitor Mountain

Stationary and permanent meteorological measurements are not taken on the Durmitor Mountain. Therefore, we used data obtained in the period from 1958 to 2010 at the Žabljak meteorological station (1450 m a.s.l.)

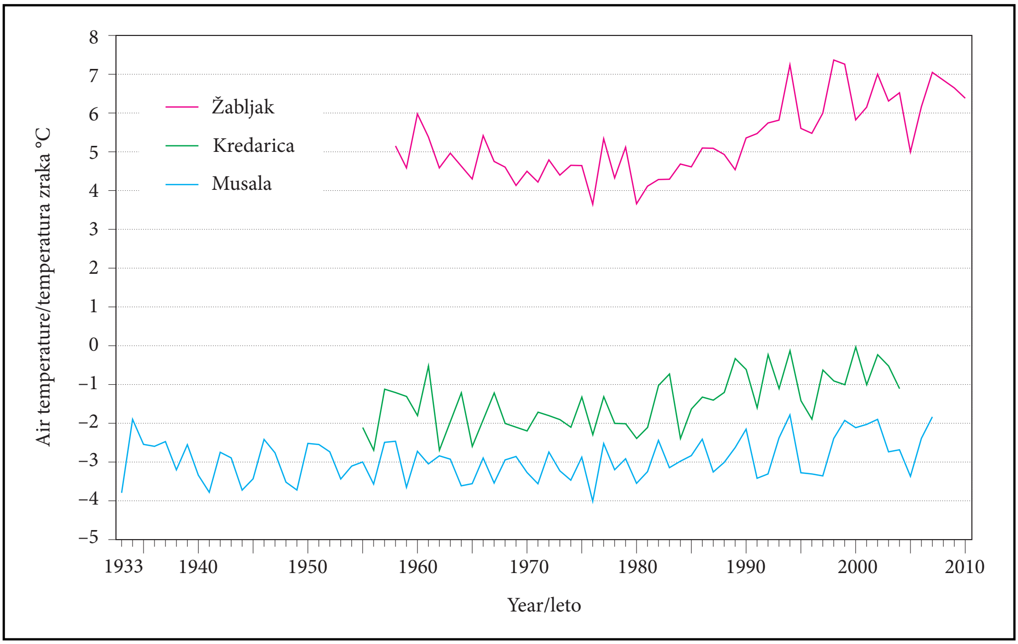

Figure 2: Comparative analyses of the average annual temperatures at the Žabljak (Montenegro), Kredarica (Slovenia) and Musala (Bulgaria) meteorological stations.

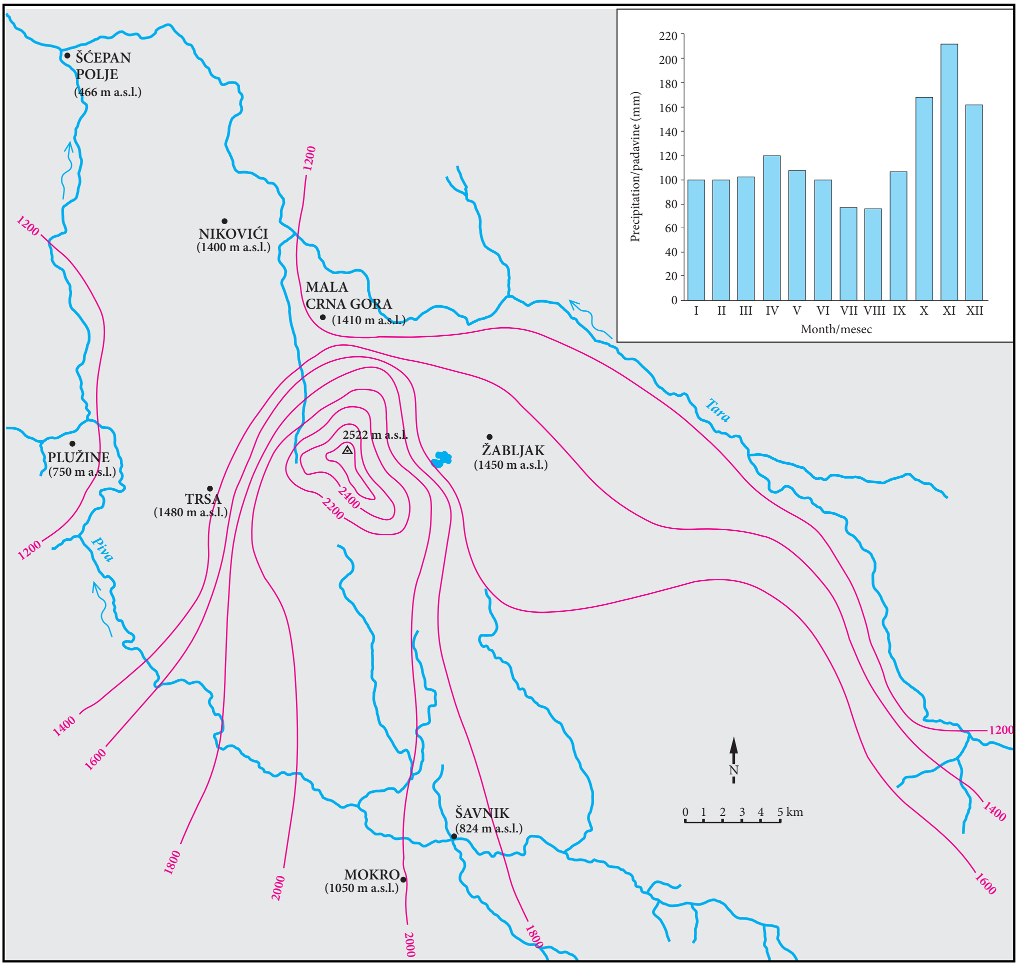

Figure 3: Isohyetal map of Durmitor Mountain with monthly precipitation rates.

as well as data collected from eight precipitation stations distributed over the mountain (at elevations ranging from 446 to 1280 m a.s.l.) to highlight the contemporary climatic conditions of this mountain.

Average annual temperature in Žabljak was 4.7 °C during 1961–1990 and 5.3 °C during 1958–2010. Since 1980', the temperature has been gradually and continuously increasing. The last two decades have been marked with further increases in temperatures but with significant annual deflections. Comparative analyses between the Žabljak meteorological station, the Kredarica meteorological station (Triglav glacier, Julian Alps, Slovenia, 2544 m a.s.l.; Cengar and Rokšar 2004), and the Musala meteorological station (Bulgaria, Rila Mountain, 2925 m a.s.l.; Nožarov 2008) show that average annual temperature trends among these three meteorological stations are in close agreement (Figure 2), which suggests that these changes are regional.

Annual precipitation rates in Žabljak vary significantly with an average 1450 mm/yr (1948–1993). The approximately perpendicular position of the mountain in relation to the direction of moist air currents from the Mediterranean area significantly contributes to precipitation rates in this region. Precipitation rates on the southwestern slopes are approximately 60 to 70% higher than precipitation rates on the north-eastern slopes (Figure 3). The annual precipitation rate calculated for the central part of Durmitor Mountain (areas above 2000 m a.s.l.) is approximately 2600 mm.

4.2 Geomorphological studies

Through qualitative geomorphological analyses (Djurović 2009), glacial, colluvial and karst landforms were distinguished (Figure 4 and 5): glacial landforms are represented by recent moraines, the most common colluvial landforms are clefts and taluses, while karst landforms are represented by dolines and karrens.

The Debeli Namet glacier is located on the highest part of the Pleistocene Velika Kalica cirque (Figure 6). Five moraines have been observed in this cirque (Djurović 1996). Four of them were formed under successive glacier retreat, and one is a recent moraine. The age of moraine IV was estimated according to the secondary calcite cement to be 605 ± 193 years using U-series10, and the age of moraine III was estimated to be 9575 ± 836 years (Hughes and Woodward 2008).

Thus defined recent cirque with a bottom and with sides covers the area (approximately 0.056 km^2). The drainage area of the cirque, caused by snow avalanches feeding the Debeli Namet glacier, is 0.144 km^2, with the surface of glaciers total of 0.2 km^2. Horizontal and vertical asymmetry was observed in the moraine (Figure 5). According to weak morphological differentiation and to the colour of moraine material, three banks were distinguished in the moraine (Djurović 1993; Hughes 2007). Two higher banks were visible from the outer side of lateral moraines, whereas banks were missing in the frontal moraine. The lichenometric method inferred that these two moraines were formed in years 1887 and 1903. These banks were not colonised by lichens and were considered to be less than 11 years old (Hughes 2007). Intensive cryogenic

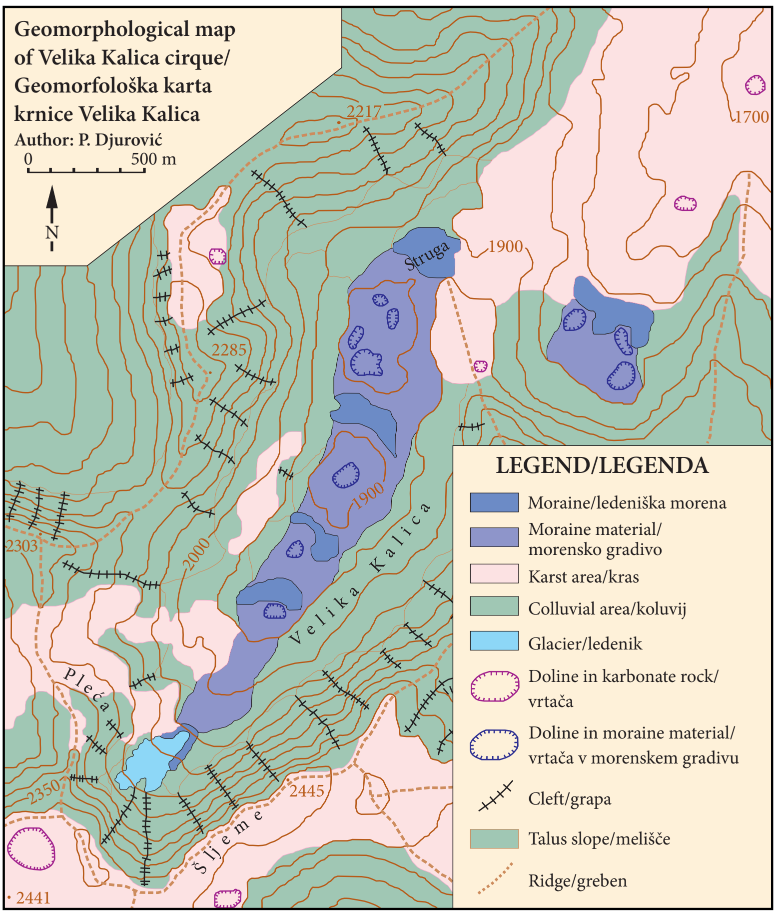

Figure 4: Geomorphological map of the Velika Kalica cirque.

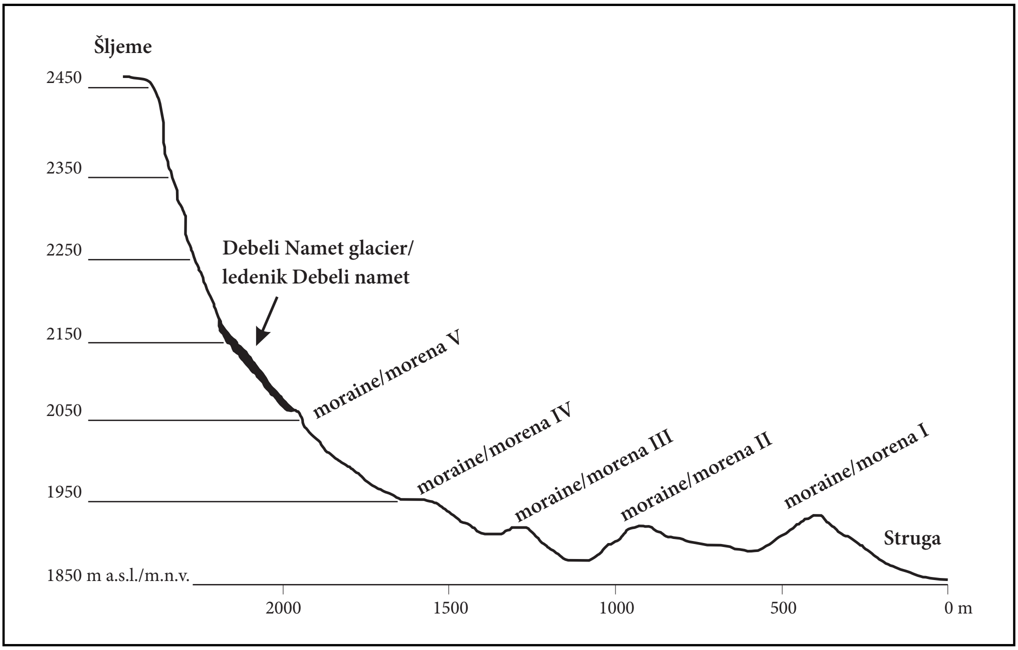

Figure 5: Profile of the Pleistocene cirque in Velika Kalica.

process derived colluvial forms with considerable dimensions: clefts and talus slope (Figure 4). Taluses are also common here, and debris travels until it reaches the right lateral moraine.

Since the geomorphological influence of low temperatures and snow accumulation prevail, karst forms are rare in the area. However, a few places with karren occurrences were recognised and studied near the glacier. Karrens enable the determination of the spatial boundary between cryo-nivation and karst processes. The first group of 5–10 cm wide and 5 cm deep karrens occurred on a vertical limestone wall located just above the glacier and to the left of the lateral moraine. Karrens did not reach the end of the rocky wall and ended at approximately 3 to 5 m above the left lateral moraine. This height represents the qualitative boundary of prevailing dominant influences of two geomorphological processes: karst processes take part above this height, and cryo-nivation process take part beneath it. Another group of karrens was found on rocky cascades just above the south-eastern part of the glacier. The vertical sides of the cascades have intersecting shallow karrens that are up to 2 m long. Despite the pronounced duration of yearly snow, there was sufficient time for development of karrens.

4.3 Glaciological studies

According to the generally accepted idea that a glacier is a compact ice mass that is in motion and is being deformed by this motion (UNESCO/IACH 1970), the Debeli Namet glacier can be considered to be a contemporary glacier rather than a snow patch (Djurović 1996; Hughes 2007).

The longitudinal glacier section could be distinguished into its three distinct parts: lower, shorter and concave parts (from the glacier's front to 90 m), convex parts (90–120 m) and upper, longer concave parts (120–330 m).

The glacial tongue is bordered by frontal and lateral moraines (Figure 7). The medium convex part is the most dynamic part of the glacier, while the upper, concave part of the glacier represents the zone of snow accumulation and its transformation to glacier ice. This part is subdivided in two segments: the south-western segment is the highest part of the glacier, and it ends beneath the limestone cliff of the Pleća ridge; the south-eastern segment is a wide, snow-firn mass that has accumulated on rocky cascades that

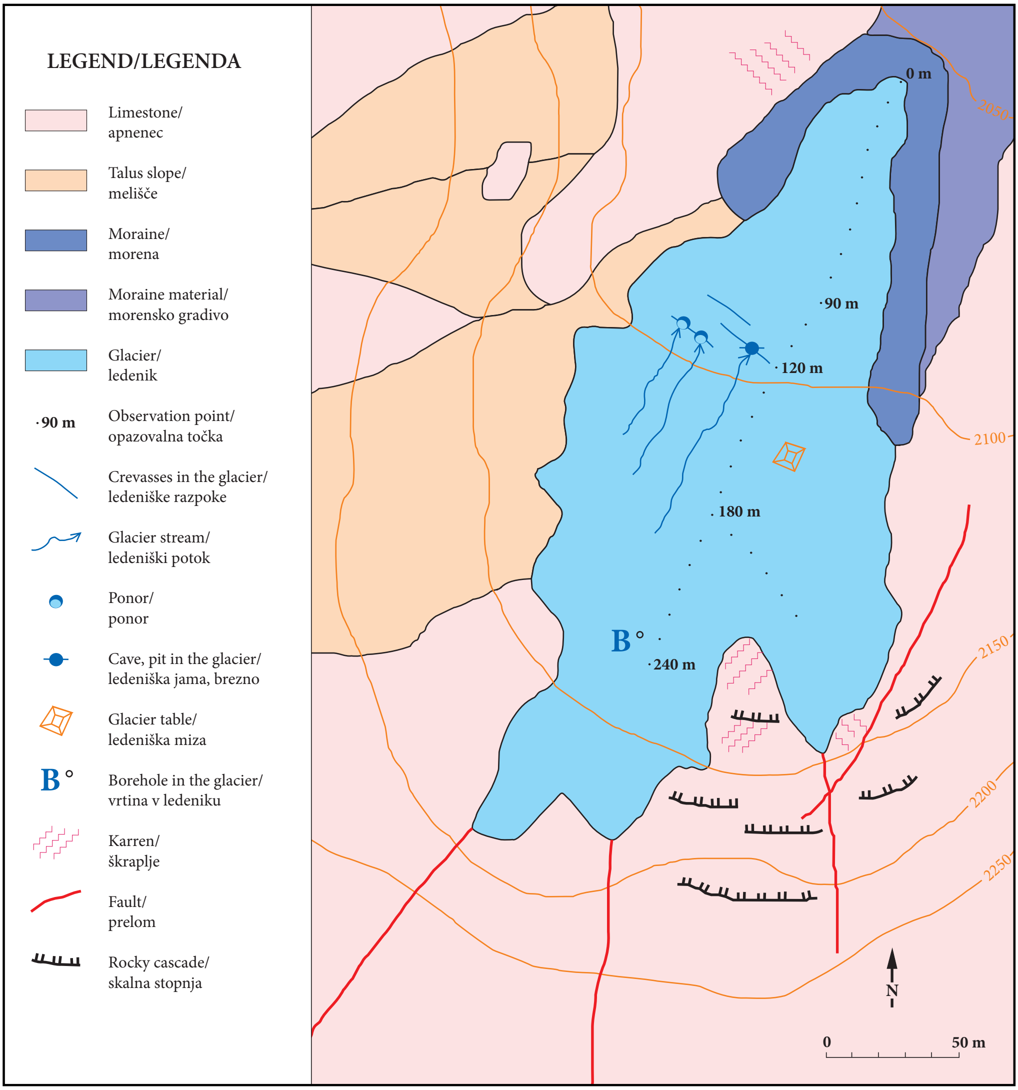

Figure 6: Geomorphological map of the cirque and the Debeli Namet glacier.

descend to the base of the cliff from the Šljeme ridge. This part of the glacier is exposed to large annual fluctuations in size.

Complete melting of snow and firn from the glacier surface did not occur between 1993 and 2010. The glacier was drilled in the upper, concave part in October 2008. The thickness of the firn was estimated from the drilling to be 6 m at a minimum. Drilling was thereafter cancelled as a result of technical problems.

The lowest point on the glacier at the end of glacier tongue at an average altitude of 2050 m a.s.l. Fluctuations at this altitude were measured according to a reference point in the middle of the frontal moraine. The glacier descended up to the recent lateral moraine during the observation period. Horizontal migrations (ranging from 4 to 6 m) and minimal vertical movement (within the range of 2 m) were estimated.

The highest glacial point experiences greater seasonal changes than the rest of the glacier. The fewest changes occur on the south-western part of the glacier (5 to 10 m vertically and approximately 20 m horizontally) (i.e., on average, ranging from 2160 to 2170 m a.s.l.). Seasonal changes on the south-eastern part

Figure 7: The Debeli Namet glacier on October 18, 2006.

of the glacier are greater (20 to 30 m vertically and approximately 70 m horizontally). Along the long axis, from the lowest point on the glacier tongue to the highest point in the southwest, the glacier length is a minimum of 320 m and a maximum of 350 m. These values along the short axis, from the lowest point on the glacier tongue to the highest point on the south-eastern part of the glacier, are a minimum of 260 m and a maximum of 330 m. Glacier size has been measured only a few times in the last 20 years (Table 1).

Table 1: Spatial extent and volume of the Debeli Namet glacier.

Year	Glacier area (km^2)	Glacier volume (m^3)	Source of data
August 1954	0.022	160 500	Djurović, according to Belgrade Military Geographical Institute aerial photographs
August 1971	0.036	313 000	Djurović, according to Belgrade Military Geographical Institute aerial photographs
August 1981	0.043	398 500	Djurović, according to Belgrade Military Geographical Institute aerial photographs
August 7, 1993	0.017	113 000	Djurović, 1996
August 6, 1997	0.024	180 500	Djurović, unpublished
2003	0.018	122 250	Hughes, 2008
2005	0.041	373 500	Hughes, 2008
2006	0.050	489 000	Hughes, 2008
October 18, 2006	0.029	233 500	Djurović, unpublished
2007	0.037	325 000	Hughes, 2008
September 25, 2008	0.034	289 750	Djurović, unpublished
October 17, 2009	0.026	201 250	Djurović, unpublished
September 22, 2010	0.033	278 250	Djurović, unpublished


PREDRAG DJUROVIĆ

Figure 8: A glacier table (October 24, 2010).

Glacier tables have been observed on this glacier. In 1993, one of the largest glacier tables was formed. This table was made of rock boulders and had 3 m in length and 1 m width (Djurović 1996). In 1994, this glacier table was covered with snow and firn and was no longer recognisable. Glacier tables vary in size, and the last large glacier table was observed in 2010 (Figure 8).

The Debeli namet glacier is fed with snow directly precipitated in cirque, snow transported by avalanching as well as with wind-drifted snow. Based on monthly precipitation rates estimated for Žabljak, the percentage of the total precipitation accounted for by months with negative average air temperature values (November–April) at an altitude of 2150 m were calculated. During this period, approximately 55 % (1430 mm) of the total annual snow (2600 mm) falls. The amount of snowfall on the avalanche drainage area was calculated as a product of the area (0.144 km^2) multiplied by the annual snow precipitation rate (1430 mm). Dividing this value by the cirque size (0.056 km^2) gave an accumulation rate of 3677 mm. When this value is added to the directly precipitated snow value in the cirque, the total amount of snow feeding the glacier is estimated to be 5107 mm.

Because glacier motion velocity measurements began in 2009, these values are still unknown. However, according to some indicators, it is possible to deduce the approximate value of the glacier motion velocity. A limestone block that represented the glacier table in 1993 was visible again at the end of the terminal moraine on October 16, 2006. During this period it was not exposed on a glacier surface but within it and covered by icy-snow mass. Therefore the motion velocity of the block is supposed to be the same as that of glacier. It is unknown whether that block was brought into that position in 2006, as the glacier tongue thickness was previously greater than 2 m. The block migrated approximately 150 m over 13 years and thus had a minimum velocity of 11 m/yr. This finding, along with the understanding that the glacier does not retreat or advance along with its maximal obtained length of 350 m, suggests that it would take more than 30 years for the ice mass of the Debeli Namet glacier to recover.

4.4 Results of glacier reconstruction

The glacier's size was estimated before direct field observations were made based on aerial photographs (Figure 9). Because observations were made during the first half of August, these photographs represented the glacier pattern in middle of the ablation season. Although these photographs do not illustrate the glacier pattern at the end of the ablation period, they offer significant information regarding fluctuations in glacier size.

The current glacier size at the end of the ablation period (November) corresponds to the glacier size in August 1954. Glacier sizes in August 1971 and 1981 represent the beginning of the ablation season (i.e., they refer to enlarged glacier areas present during the last decade). In 1953, the snow precipitation rate was

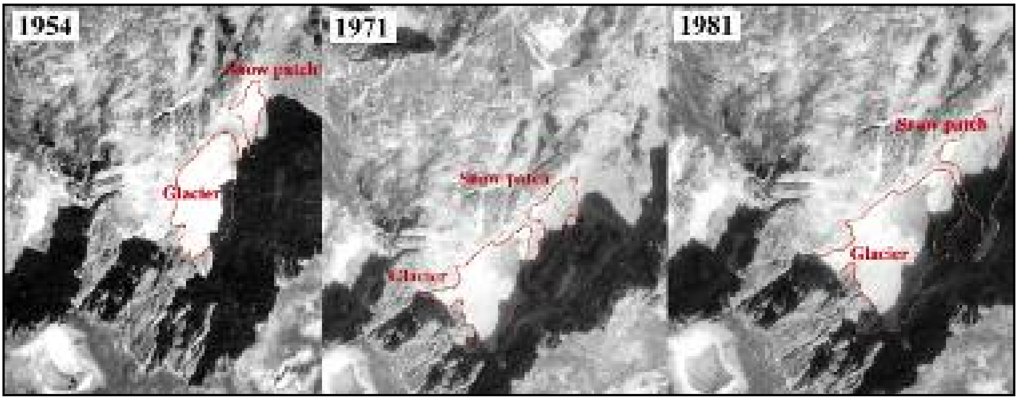

Figure 9: Aerial photographs of the Debeli Namet glacier (Archive of the Military Geographical Institute, Belgrade).

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Figure 10. The Debeli Namet glacier at the end of the ablation period (September, 1981).

only 43% of the average annual rate (1450 mm). Significant decreases in precipitation rates were accompanied by significant increases in air temperatures in 1954. As a consequence, both the glacier area and the area of adjacent snow patches were reduced. From the middle of the 1970s to the middle of the 1980s, considerable increases in precipitation rates were observed. During the same period, the air temperature dropped considerably. This resulted in an enlargement of the glacier area, including the area of adjacent snow patches (Figure 10).

5 Discussion

Differences in previously reported data regarding the position and size of the glacier can lead to different conclusions regarding the dynamics of the Debeli Namet glacier. The first measurement of the lowest point on the glacier was 2050 m a.s.l. (Djurović 1996; 1999). The altitude of the glacier has also been determined to be at various levels: 2100–2200 m a.s.l. (Hughes 2007), ranging between 2050–2300 m a.s.l. (Hughes 2008; 2009) and between 2000–2200 m a.s.l. (Hughes 2010). Differences in altitude values could reflect the glacier's motions or the varying vertical extent of the glacier (e.g., 100 m, 250 m and 200 m) (Hughes 2007; 2008; 2010). The lowest point of the glacier (at the end of the glacier tongue) has been displaced within the vertical range of 2 m since the middle of 20th century (note that data prior to the middle of the 20th century are missing). Thus, the lowest point of the glacier has been at an approximate altitude of 2050 m a.s.l. for more than a half century. The highest point of the glacier has moved more, having moved on average from an altitude of 2160 to 2170 m a.s.l. According to the position of the lowest and highest points of the glacier it was estimated that the Debeli Namet glacier is located at an altitude ranging between 2050 m a.s.l. and 2160–2170 m a.s.l. Therefore, its vertical extent (its height) is approximately 110–120 m and its length is 320–350 m.

The area of the glacier has been calculated to be the sum of the glacier ice area and the snow-firn area. The maximum area extent (0.056 km^2) was estimated using the area of the glacier's bottom and the sides of the cirque. This is the area that the glacier attains at the end of the accumulation season (November–April). During the ablation season (May–October), the marginal parts of the glacier melt, leading to a reduction of glacier size and thickness. Aerial vales for 2005 (0.05 km^2) and 2006 (0.041 km^2) (Hughes 2007; 2008) represented 91% and 73%, respectively, of the glacier area at the beginning of the ablation period. However, measurements and observations recorded on October 18, 2006 (Figure 8) resulted in different glacier area values at the end of the ablation period (Table 1).

During these years, significant variations in air temperatures and precipitation rates that could cause an increase in glacier size were not observed. Therefore, these data do not represent the real values of glacier size reported in the cited period.

Literature data related to climate conditions on Durmitor, as one of the most important impacts to the glacier Debeli namet, are mutually differing. The values that have been reported for the average annual temperatures in Žabljak are significantly different: 0 °C (Cerović 1986; Hughes 2007), 4.7 °C (1961–1990) (Djurović 1996), 5.1 °C (Ćurić 1986; Hughes 2008; 2010) and 5.3 °C (1958–2010). Values for the mean annual air temperature, without a specified period of time as the related can not be correlated. Their use for calculation could lead to considerable differences in derived estimates that may not be related to climate changes. For example, the temperature calculated for the altitude of 2150 m (0.9 °C) (Hughes 2008) is for 0.7 °C lower than the temperature calculated for the period 1961–1990 and much lower (1.3 °C) than for period 1958–2010.

According to topographic map, the average altitude of snow and ice transition is 2150 m (Hughes 2007). This altitude is actually the upper border of the glacier. The equilibrium line altitude (ELA) was determined according to direct measurements made on the glacier, drillings in the firn, analyses of the longitudinal section through the glacier and results of the performed qualitative analyses. The ELA is 58 m higher the glacier tongue, at an approximate altitude of 2100 m a.s.l. With this correction, the ELA was reduced by 50 m to its true altitude.

The average value of snow accumulation available for glacier feeding that we calculated (5107 mm/yr) suggests that the Debeli Namet glacier has a satisfactory amount of snow to retain its equilibrium balance. The value we calculated is comparable to the theoretically obtained value of 5000 mm of snow (Hughes 2008). The short time reduction of the precipitation rate did not significantly affect the glacier size, and it compensated for itself rapidly thereafter. The increase in precipitation rates by 44% in the 1980s in Žabljak led to 7353 mm of snow being fed to the Debeli Namet glacier in 1980s.

According to lichenometric data, the outer part of the moraine was formed in approximately 1878 AD, while its middle part was formed in 1904 AD. Because the interior moraine lacks lichen, it was formed within the last 11 years as the result of either glacier stabilisation or glacier advancement (Hughes 2007). However, the estimated age of lichens on the outer side of the moraine could represent the time since the moraine remained without snow long enough to enable lichen colonies to be established. This was confirmed by observing how long the snow cover lasted on the cirque. The highest parts of the moraine are covered with snow 250 days annually. For the southern Balkans was established that since 1865th to 1984th was the highest precipitation in the period from 1875 to 1884 (Katsoulis and Kambetzidis 1989).

In this period, the moraine was covered with snow much longer than it had been in the last two decades. Lichen colonisation was possible during longer periods of the absence of snow cover. The moraine experienced a long period of snow cover in 1981. The snow started to melt on the moraine in the middle of August; the moraine had been covered with snow for approximately 300 days. Such micro-ecological changes either slow down lichen growth or lead to their extirpation (Bradwell 2001). Dating of moraines of the Snežnik glacier (Bulgaria) gave higher values for its age (AD 330–610 and AD 1150–1270) (Grünewald and Scheithauer 2010). Moraine material between the contemporary moraine and moraine IV in the cirque (Figure 5) was not colonised by lichens. Thus, its age would coincide with the age of the inner moraine in the Debeli Namet glacier. It has been determined that the inner moraine was generated within the last 11 years (Hughes 2007). Direct field observations suggest that little moraine material has accumulated within the last 30 years (i.e., the moraine accumulated before 1981). Noted example confirms the uncertainty of the data collected by lichenometric methods.

The nearest glacier to the Debeli Namet glacier is located in Albania in the Prokletije Mountains northeast of the Maja e Kolacit summit (2490 m a.s.l.) (Milivojević et al. 2008; Hughes 2009).

The aerial extent of the Triglav glacier (Slovenia) varied from 1946–1973 from 0.11 to 0.17 km^2 (Gams 1994) and was reduced to 0.03 km^2 by the end of 1995 (Gabrovec 1998: Gabrovec and Zakšek 2007; Triglav Čekada et al. 2011; 2012). Similar trend of steadily decreased area extent has been noted within the three remained glaciers on Julian Alps (Tintor 1993) and at the Lednik pod Skuto (Slovenia) glacier which has decreased in size from 2,8 ha in 1950 to 0,73 ha in 2003 (Šifrer 1976; Pavšek 2004; Pavšek 2007).

The Snežnik glacier (Bulgaria), during the period of the smallest ice volume (September–November), covered an area ranging from 0.4 to 1.3 ha. Observations since the 1980s suggest that these two glaciers are relatively stable (Gachev 2009; Gachev et al. 2009). The thickness of the glacier in September 2006 was 7.8 m, 10.9 m and 11 m (Grünewald and Scheithauer 2008).

The Ghiacciaio del Calderone glacier in the central Apennines is west of the Debeli Namet glacier. Its estimated mass balance (1920–1994) was permanently negative (except in late 1950s and early 1960s). In 2000, the glacier split into two pieces (Dramis et al. 2002; D'Alessandro et al. 2003; Pecci 2006).

6 Conclusion

The Debeli Namet glacier is a small glacier located between an altitude range of 2050 and 2160–2170 m a.s.l. and has an altitude difference between 110–120 m. The glacier covers an area of approximately 0.025 to 0.032 km^2. The minimum ice thickness is 8 m. Although the ice thickness of the Debeli Namet glacier is steadily shrinking, the glacier's aerial extent is not being reduced. The glacier has three sides surrounded by high ridges, which represent the avalanche drainage area for the additional feeding of ice. The average annual rate of snow precipitation is approximately 5000 mm but occasionally exceeds 7000 mm. Through these occasional large snowfall years, the negative influences caused by temperature increases are mitigated, and equilibrium is preserved. The Debeli Namet glacier did not significantly fluctuate in size within the last 50 years, and it has become one of the largest glaciers in southern Europe.

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8 References

Baumann, S., Winkler, S. and Andreassen L. M. 2009: Mapping glaciers in Jotunheimen, South-Norway, during the »Little Ice Age« maximum. The Cryosphere 3-2. Göttingen.

Benedict, J. B. 1991: Experiments on lichen growth II. Effects of a seasonal snow cover. Arctic and Alpine Research 23-2. Boulder.

Bradwell, T. 2001: Glacier fluctuations, lichenometry and climatic change in Iceland. PhD thesis, University of Edinburgh. Edinburgh.

Cerović, B. 1986: Durmitor and the Tara Canyon. Beograd.

Cengar, T., Roškar, J. 2004: Meteorološka postaja Kredarica: 1954–2004. Ljubljana.

Chen, J., Ohmura, A. 1990: Estimation of Alpine glacier water resources and their change since the 1870s. Hydrology in Mountainous Regions. International association of hydrological sciences 193. Lausanne.

Ćurić, M. 1986: Klima Nacionalnog parka Durmitor. Posebna izdanja 8. Beograd.

Cvijić, J. 1889: Glacijalne i morfološke studije o planinama Bosne, Hercegovine i Crne Gore. Glas SKA 57-21. Beograd.

Elachy, C., Zyl, J. 2006: Introduction to the physics and techniques of remote sensing. Hoboken.

D'Alessandro, L., De Sisti, G., D'Orefice, M., Pecci, M., Ventura, R. 2003: Geomorphology of the Summit Area of the Gran Sasso d'Italia (Abruzzo Region, Italy). Geografia Fisica e Dinamica Quaternaria 26. Torino.

Djurović, P. 1996: Visokoplaninski kras Durmitora – geomorfološka studija. PhD thesis, Geografski fakultet. Beograd.

Djurović, P. 1999: Natural and anthropogenic influences as threats to pits in the Debeli Namet glacier Durmitor National park. Montenegro. Contribucion del estudio cientifico de las cavidades karsticas al conocimiento geologico. Malaga.

Djurović, P. 2002: New Approach in study of the extent of Pleistocene glaciation in the southwest part of Balkan peninsula. International scientific conference in memory of prof. Dimitar Jaranov. Varna.

Djurović, P. 2007: Prilog rešavanju problema determinisanja morena i plavina. Zbornik radova 55. Beograd.

Djurović, P. 2009: Reconstruction of the pleistocene glaciers of mount Durmitor in Montenegro. Acta geographica Slovenica 49-2. Ljubljana. DOI: 10.3986/AGS49202

Djurović, P. 2010: The overall impact of Pleistocene glaciation on morphological diversity at Durmitor and Žijovo. Glasnik Srpskog geografskog društva 90-1. Beograd.

Djurović, P., Menković, Lj. 2004: Remote Sensing in Geomorphological Mapping. First mediterranean conference on earth observation – remote sensing. Belgrade.

D'Orefice, M., Pecci, M., Smiraglia, C., Ventura, R. 2000: Retreat of Mediterranean glaciers since the Little Ice Age: case study of Ghiacciaio del Calderone, Central Apennines, Italy. Arctic, Antarctic and Alpine Research 32. Boulder.

Dramis, F., Fazzini, M., Pecci, M, Smiraglia, C. 2002: The Geomorphological Effects of Global Warming in the Calderone Glacier Area (Central Apennine, Italy). Extended Abstracts of the International Conference: Climate Changes, Active Tectonics and Related Geomorphic Effects in High Mountain Belts and Plateaux. Addis Abeba.

Fox A. J., Nuttall, A. M. 1997: Photogrammetry as a research tool for glaciology. The photogrammetric record 15-89. Oxford. DOI: 10.1111/0031-868X.00081

Federici, P. R., Stefanini, M. C. 2001: Evidences and chronology of the Little Ice Age in the Argentera Massif Italian Maritime Alps. Zeitschrift für Gletscherkunde und Glazialgeologie 37. Innsbruck.

Gabrovec, M. 1998: The Triglav glacier between 1986 and 1998. Acta geographica 38. Ljubljana.

Gabrovec, M., Zakšek, K. 2007: The shrinking of the Triglav glacier in the light of Solar irradiance. Dela 28. Ljubljana.

Gachev, E. 2009: Indicators for modern and recent climate change in the highest mountain areas of Bulgaria. Landform Analysis 10. Katowice.

Gachev, E., Gikov, A., Zlatinova, C., Blagoev, B. 2009: Present state of Bulgarian glacierets. Landform Analysis 11. Katowice.

Gams, I. 1994: Changes of the Triglav Glacier in the 1955-94 period in the light of climatic indicator. Acta geographica 34. Ljubljana.

Golledge, N. R., Everest, J. D., Bradwell, T., Johnson, J. S. 2010: Lichenometry on Adelaide Island, Antarctic Peninsula: size-frequency studies, growth rates and snowpatches. Geografiska Annaler A 92-1. Oxford. DOI: 10.1111/j.1468-0459.2010.00381.x

Gómez, A., Palacios, D., Luengo, E., Tanarro, L. M., Schulte. L., Ramos, M. 2003: Talus instability in a recent deglaciation area and its relationship to buried ice and snow cover evolution (Picacho del Veleta, Sierra Nevada, Spain). Geografiska Annaler A 85-2. Oxford. DOI: 10.1111/1468-0459.00196

González-Trueba, J. 2004: Topoclimatical factors and very small glaciers in Atlantic mountain of SW Europe: the little ice age glacier advance in Picos de Europa (NW Spain). Zeitschrift für Gletscherkunde und Glazialgeologie 39. Innsbruck.

Grove, J. 2004: Little Ice Ages: Ancient and Modern. London.

Grünewald, K., Scheithauer, J., Gikov, A. 2008: Mikrolednik na planina Pirin. Problems of geography 1–2. Sofia.

Grünewald, K., Scheithauer, J. 2008: Bohrung in einen Mikrogletscher. Zeitschrift für Gletscherkunde und Glazialgeologie 42-1. Innsbruck.

Grünewald, K., Scheithauer, J. 2010: Europe's southernmost glaciers: response and adaptation to climate change. Journal of glaciology 56-195. Cambridge. DOI: 10.3189/002214310791190947

Hughes, P. H. 2007: Recent behaviour of the Debeli Namet glacier, Durmitor, Montenegro. Earth surface processes and landforms 32. Chicester. DOI: 10.1002/esp.1537

Hughes, P. D. 2008: Response of a Montenegro glacier to extreme summer heatwaves in 2003 and 2007. Geografiska Annaler A 90-4. Oxford. DOI: 10.1111/j.1468-0459.2008.00344.x

Hughes, P. H. 2010: Little Ice Age glaciers in the Balkans: low altitude glaciation enabled by cooler temperatures and local topoclimatic controls. Earth surface processes and landforms 35. Chicester. DOI: 10.1002/esp.1916

Hughes, P. D., Woodward, J. C. 2008: Timing of glaciation in the Mediterranean mountains during the last cold stage. Journal of Quaternary science 23. Chicester. DOI: 10.1002/jqs.1212

Hughes, P. D., Woodward, J. C. 2009: Glacial and periglacial environments. The Physical Geography of the Mediterranean Basin. Oxford.

IASH-UNESCO, 1970: Perennial ice and snow masses: a guide for compilation and assemblage of data for a world inventory. Technical Papers in Hydrology 1. Paris.

Katsoulis, B. D., Kambetzidis, H. D. 1989: Analysis of the long-term precipitation series at Athens, Greece. Climatic change 14. Dordrecht. DOI: 10.1007/BF00134966

Kern, Z., Surányi, G., Molnár, M., Nagy, B., Balogh, D. 2006: Investigation of natural perennialice deposits ice of Durmitor Mts, Montenegro. Proceedings of the 2nd international workshop on ice caves. Demänovská dolina.

Maas, G. S., Macklin, M. G. 2002: The impact of recent climate change on flooding and sediment supply within a Mediterranean mountain catchment, southwestern Crete, Greece. Earth surface processes and landforms 27. Chicester. DOI: 10.1002/esp.398

Maisch, M., Wipf, A., Denneler, B., Battaglia, J., Benz, C. 1999: Die Gletscher der Schweizer Alpen. Gletscherhochstand 1850 – Aktuelle Vergletscherung – Gletscherschwund-Szenarien 21. Zürich.

Marović, M., Marković, M. 1972: Glacijalna morfologija šire oblasti Durmitora. Geološki anali Balkanskog poluostrva 37-2. Beograd.

Meier, M. F., Dyurgerov, M. B., McCabe, G. J. 2003: The health of glaciers: recent changes in glacier regime. Climatic change 59. Dordrecht.

Milivojević, M., Menković, L., Ćalić, J. 2008: Pleistocene glacial relief of the central part of Mt. Prokletije (Albanian Alps). Quaternary international 190. Oxford.

Milojević, B. Ž. 1937: Visoke planine u našoj Kraljevini. Beograd.

Mirković, M. 1983: Geološki sastav i tektonski sklop Durmitora, Pivske planine i Volujka. Glasnik 5. Titograd.

Messerli, B. 1967: Die eiszeitliche und die gegenwärtige Vergletscherung im Mittelmeeraum. Geographica Helvetica 22-3. Egg.

Messerli, B. 1980: Mountain glaciers in the Mediterranean Area and in Africa. World glacier inventory. IAHS 126. Riiederalp.

Nicod, J. 1968: Premières recherches de morphologie karstique dans le massif du Durmitor. Meditérranée 3. Aix-en-Provence.

Nožarov, P. 2008: Air temperature variability and change at peak Moussala for the period 1933–2007, Geografija globalnih promeni 2. Sofia.

Pavšek, M. 2004: Lednik pod Skuto. Geografski obzornik 51. Ljubljana.

Pavšek, M. 2007: The Skuta glacier as in indicator of climate changes in Slovenian part of the Alps. Dela 28. Ljubljana.

Pecci, M. 2006: Il Ghiacciaio del Calderone (Abruzzo settentrionale). Testimoni di una montagna scomparsa. Quaderno della Montagna 8. Bologna.

Republic hydro-meteorological service of Montenegro 1948–2010: Meteorological Annuals. Podgorica

Sanjosé, J. J., Atkinson, A. D. J., Franch, F. S., Ortiz A. G., Bejarano J. M. 2007: Geodesic and photogrammetric techniques for the cartographic production and the observation of the geomorphic dynamic of the »Corral del Veleta« active rock glacier (Sierra Nevada – Spain). Grazer Schriften der Geographie und Raumforschung 43. Graz.

Schowengerdt, R. A. 2007: Remote sensing: models and methods for image processing. San Diego.

Smith, M. J., Rose, J., Booth, S. 2006: Geomorphological mapping of glacial landforms from remotely sensed data: An evaluation of the principal data sources and an assessment of their quality. Geomorphology 76-17–2. Amsterdam. DOI: 10.1016/j.geomorph.2005.11.001

Šifrer, D. 1963: Nova geomorfološka dognanja na Triglavu. Triglavski ledenik v letih 1954–1962. Acta geographica 8. Ljubljana.

Šifrer, M. 1976: Nova dognanja na Triglavskem ledeniku in ledeniku pod Skuto. Acta geographica 15. Ljubljana.

Šifrer, M. 1986: Triglavski ledenik v letih 1974–1985. Acta geographica 27. Ljubljana.

Tintor, W. 1993. Die Kleingletscher der Julischen Alpen. Carinthia II 183-103. Klagenfurt.

Triglav Čekada, M., Radovan, D., Gabrovec, M., Kosmatin F. 2011: Acquisition of the 3D boundary of the Triglav glacier from archived non-metric panoramic images. The photogrammetric record 26-133. Oxford. DOI: 10.1111/j.1477-9730.2011.00622.x

Triglav Čekada, M., Zorn, M., Kaufmann, V., Lieb, G. K. 2012: Measurements of small glaciers: examples from Slovenia and Austria. Geodetski vrstnik 56–3. Ljubljana.

Veselinović, D., Kovačević, D., Marković, D., Vukmirović, Z., Rajšić, S., Stanković, S., Stanković, A., Djordjević, D. 1997: Sadržaj metala i radioaktivnost leda sa ostataka lednika Debeli namet na Durmitoru. Niš.

Ledenik Debeli Namet od druge polovice 20. stoletja do danes

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IZVLEČEK: Ledenik Debeli Namet je eden izmed dveh sodobnih ledenikov v jugovzhodnem delu Balkanskega polotoka, v Črni gori. Leži na gori Durmitor, ki pripada planinskemu vencu Dinaridi. Sodi v skupino malih ledenikov. Z uporabo aerofoto posnetkov je rekonstruirana velikost ledenika v obdobju od 1954 do 1981. Na podlagi glacioloških študij, geomorfoloških raziskovanj reliefa bližje okolice in analize osnovnih podnebnih elementov v zadnjih 50 letih (temperature in padavine) so podana nova dejstva o ledeniku. Ugotovljene spremembe velikosti Debelega Nameta niso v takšnem obsegu, kot je to v primeru drugih ledenikov južne Evrope. Debeli namet predstavlja primer ledenika, v katerem povišanje temperature zraka s konca 20. in začetka 21. stoletja ni izzvalo pomembnih sprememb velikosti. Prikazani rezultati predstavljajo delno revizijo dosedanjih spoznanj o ledeniku, njegovi okolici in sodobni klimi okoli ledenika.

KLJUČNE BESEDE: geografija, glaciologija, ledenik, Debeli Namet, klimatske spremembe, Durmitor, Dinaridi, Črna gora

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Vsebina

1 Uvod

Na visokih gorah južne Evrope in širšega prostora Mediterana so preučeni številni sledovi pleistocenske glaciacije (Messerli 1967; Hughes in Woodward 2008). V holocenu so ledeniki iz teh gora skoraj popolnoma izginili (Messerli 1980; Grünewald in Scheithauer 2010), preostali pa so precej manjših dimenzij kot pleistocenski ledeniki. Te ledenike odlikujejo podobne lastnosti: so majhnih površin, nimajo razvitega ledeniškega jezika in pogosto je širina večja kot dolžina. Opisani so kot pirenejski tip ledenika (Meccerli 1967). Preučeni so v Pirenejih (Grove in Gellatly 1995; Grove 2004.), Siera Nevadi, Španija (Gómez in ostali 2003), Picos de Europa (González-Trueba 2004), na Primorskih Alpah (Federici in Stefanini 2001), Apeninih (D'Orefice in ostali 2000; Dramis in ostali 2002; D'Alessandro in ostali 2003; Pecci 2006; Pecci in ostali 2008), Slovenskih Alpah (Šifrer 1976; Gams 1994; Gabrovec 1998; Pavšek 2007; Triglav Čekada in ostali 2012), na Durmitorju (Djurović 1996, 1999, 2008; Hughes 2007, 2008, 2010), na Prokletijah (Milivojević in ostali 2007; Hughes, 2008) in na Pirinu (Grünewald in ostali 2008; Gachev 2009; Gachev in ostali 2009; Grünewald in Scheithauer 2010). V mali ledeni dobi so na Durmitorju, razen ledenika Debeli namet obstajali številni majhni ledeniki, ki so pozneje izginili (Hughes 2010).

Ti ledeniki so ležali na dosti manjši višini, kot je višina sodobne ravnovesne meje ELA (ang. *equilibrium line altitude*; Hughes in Woodward 2009). Majhni gorski ledeniki hitro reagirajo na podnebne spremembe na koncu 20. in na začetku 21. stoletja. Zaradi dramatičnih sprememb in možnosti za njihovo popolno taljenje in izginotje (Meier in ostali 2003), so se začele številne, obsežne in raznovrstne raziskove teh ledenikov. Rezultati raziskovanj ledenika Debeli namet predstavljajo prispevek k boljšemu razumevanju enega najjužnejših in najnižjih ledenikov južne Evrope.

Ledenik Debeli namet leži v zahodnem delu Balkanskega polotoka, na gori Durmitor, ki pripada planinskemu vencu Dinaridi (slika 1). Gora je večinoma sestavljena iz krednih karbonatnih kamnin in eocenskega karbonatnega fliša (Mirković 1983). Na njej dominira sodobni kraški relief (Djurović 1996; 2010). V pleistocenu so bili na gori številni ledeniki (Cvijić 1889; Milojević 1937; Marović in Marković 1972; Djurović 1996; 2002; 2009), danes je na njej le eden.

Slika 1: Geografski položaj Durmitorja in sodobnejših ledenikov iz okolice.
Glej angleški del prispevka.

2 Metodologija

Preučevanje ledenika Debeli Namet obsega glaciološke in geomorfološke raziskave ter analizo podnebnih elementov. Za obdobje pred neposrednimi raziskovanji je opravljena rekonstrukcija velikosti ledenika na podlagi analize aerofoto posnetka.

Geomorfološka preučevanja so zajela kvantitativno in kvalitativno analizo reliefa. Končni rezultat geomorfoloških raziskovanj je geomorfološka karta v merilu 1 : 25000 s spremljajočimi značilnimi profili. Geomorfološka karta je zasnovana po genetskem principu, zato so vse oblike in pojavi klasificirani po prevladujočem morfogenetskem procesu (Djurović in Menković 2004; Smith in ostali 2006; Baumann in ostali 2009).

Pri glacioloških raziskavah z namenom merjenja ledenika so uporabljeni geološki kompas (z natančnostjo 1°), ročna GPS naprava, merilni trak in laserski daljinomer. S primerjanjem rezultatov, dobljenih z GPS napravo z referenčnimi točkami na terenu smo ugotovili napake, ki presegajo mejo tolerance. Verjetno do napak prihaja zaradi visokih grebenov, ki obdajajo ledenik in onemogočajo kakovosten sprejem signala. Če so bile zaradi pogostih meglic nad ledenikom meritve večjih dolžin z laserskim daljinomerom nenatančne, smo merili s pomočjo merilnega traku in geološkega kompasa.

Za ugotavljanje sprememb dolžine ledenika smo vzpostavili referenčno točko na najnižjem delu čelne morene, to je blizu ledeniškega jezika oziroma konca ledenika.

Pri rekonstrukciji velikosti ledenika smo obravnavanl aerofoto posnetki iz različnih obdobij: 1954, 1971 in 1981 v merilu 1 : 25.000. Snemali smo v prvi polovici avgusta. Med analizo aerofoto posnetkov so uporabljane metode daljinske detekcije (Elachi in Zyl 2006; Schowengerdt 2007).

Za določanje meje sodobne krnice ledenika Debeli namet smo uporabili aerofoto posnetke v merilu 1 : 25.000. Te posnetke smo uporabili tudi za ugotavljanje meja dosega snežnih plazov. Aerofoto posnetki so izkazali precej natančnejši kot topografske karte v istem merilu. Površine smo izračunali s standardnimi fotogrametrijskimi metodami, prostornino ledenika pa z empiričnim obrazcem. Na podlagi meritev, opravljenih na 63 ledenikih, je ugotovljeno razmerje med površino ledenika in njegovo maso (Chen in Ohmura 1990):

$$V = 28.5\,S^{1.357}$$

kjer je V prostornina ledenika (km^3), S pa njegova površina (km^2).

Za analizo podnebja smo uporabili podatke meteorološke postaje Žabljak za obdobje od 1958 do 2010, za izračun navpičnega temperaturnega gradienta pa podatke meteoroloških postaj Žabljak (1450 m n. v.), Pljevlja (784 m n. v.), Bijelo Polje (560 m n. v.) in Kolašin (943 m n. v.) za obdobje od 1961 do 1985. Linearni korelacijski koeficient med višinami in temperaturami zraka izbranih postaj je 0,95.

3 Dosedanja raziskovanja

Prve navedbe o ledenik na tej gori so s konca šestdesetih let preteklega stoletja (Nicod 1968). V okviru kompleksnih geomorfoloških raziskovanj o vplivu glacialnih, periglacialnih in kraških procesov na nastanek sodobnega reliefa Durmitorja (Djurović 1996) so nedvoumno ugotovili obstoj ledenika. Med poletjem leta 1993 sta se z največjega dela ledenika otopila sneg in firn (Djurović 1996; 1999). V vbočenem delu ledenika so nastali trije manjši vodotoki globine okoli 1 m in dolžine od 50 do 70 m. V izbočenem delu ledenika so bile razkrite razpoke široke okoli 0,1 m in dolge okoli 10 m, v katere je odtekala voda z ledenika, ki je pri tem oblikovala tri osemmetrske jame (Djurović 1996; 1999). Globina jam je enaka debelini ledenika.

Celotno površino ledenika je prekrivala plast drobirja debeline od 0,1 do 0,3 m, ki predstavlja navpično mejo ledeniškega ledu ter firna in snega. Avgusta 1997 so z vrtanjem ledenika ponovno odkrili mejno plast iz drobirja. Ležala je pod 1 meter debelo plastjo firna. Njihova domneva, da je takšna debelina ledenika in da drobirski material predstavlja skalno podlago, na kateri leži ledenik, je napačna (Veselinović in ostali 1997).

Po prvih raziskavah je prišlo obdobje njegovega intenzivnega preučevanja: opravljena je bila analiza radioaktivnosti in vsebine težkih kovin v ledu (Veselinović in ostali 1997) ugotavljali so naravne in antropogene vplive jam in ledenika (Djurović 1999) ter led preučevali z radiokemijsko metodo, imenovano γ-spektometrija (^{137}Cs izotop) in meritve aktivnost β (^{3}H koncentracija v LSC tehniki) (Kern 2006). Z lihenometrijsko metodo so ugotovili starost morene in merili različne morfometrijske parametre ledenika (Hughes 2007). Primerjalna analiza moren na Durmitorju in aluvialnih naplavin v okolici je izpostavila napake, ki so nastale ob predhodnem določanju starosti sedimentov (Djurović 2007). Analiziran je bil vpliv ekstremnih poletnih temperatur za obdobje od 2003 do 2007 (Hughes 2008) in bile so podane napovedi za preživetje ledenikov v južni Evropi s stališča regionalnih podnebnih sprememb (Grünewald in Scheithauer 2010).

4 Sodobne raziskave

4.1 Sedanje podnebne razmere na Durmitorju

Na Durmitorju ni stacionarnih in stalnih meteoroloških meritev, zato temelji opis sodobnih podnebnih razmer na Durmitorju na podatkih meteorološke postaje Žabljak (1450 m n. v.) za obdobje od 1958 do 2010. Za analizo padavin pa smo poleg podatkov z meteorološke postaje Žabljak uporabili podatke iz osmih padavinskih postaj (na višinah od 446 do 1280 m n. v.).

Srednja letna temperatura zraka v Žabljaku v obdobju 1961–1990 je bila 4,7 °C, v celotnem opazovalnem obdobjue (1958–2010) pa 5,3 °C. Do začetka 80-tih let preteklega stoletja je imela srednja letna temperatura zraka v Žabljaku trend upadanja, potem pa postopnega in stalnega naraščanja. V zadnjih dveh desetletjih je značilen trend nadaljnjega povišanja temperature zraka, čeprav s pomembnimi letnimi odstopanji.

Slika 2: Primerjalna analiza srednjih letnih temperatur zraka na meteoroloških postajah Žabljak (Črna Gora), Kredarica (Slovenija) in Musala (Bolgarija).

Glej angleški del prispevka.

Primerjalna analiza srednjih letnih temperatur zraka med meteorološkimi postajami Žabljak, Kredarica (Triglavski ledenik, Julijske Alpe, Slovenija, 2544 m n. v.) in Musala (Rila, Bolgarija, 2925 m n. v.) (Nožarov 2008) kaže enak trend, kar ponazarja spremembe regionalnega značaja (slika 2).

Na Žabljaku se letna količina padavin spreminja, njihova povprečna vrednost je 1450 mm (1958–1993). Količina padavin je v prvi vrsti odvisna od prečnega položaja gore v razmerju do smeri gibanja vlažnih zračnih gmot iz Sredozemlja, zato je na jugozahodnih pobočjih za okoli 60 do 70 % več padavin kot na severovzhodnih (slika 3). Preračunana letna količina padavin za osrednji Durmitor (nad 2000 m n. v.) je okoli 2600 mm.

Slika 3: Izohietna karta Durmitorja z mesečno količino padavin.
Glej angleški del prispevka.

4.2 Geomorfološka raziskave

S kakovostno geomorfološko analizo (Djurović 2009) smo reliefne oblike razvrstili glede na način nastanka: ledeniške, koluvialne in kraške (sliki 4 in 5). Ledeniške oblike so v obliki morene, koluvialne tvorijo melišča in nasipe, med kraškimi pa so najpogostejše vrtače in škraplje.

Slika 4: Geomorfološka karta Velike Kalice.
Glej angleški del prispevka.

Slika 5: Vzdolžni prerez skozi pleistocensko krnica Velika Kalica.
Glej angleški del prispevka.

Ledenik Debeli Namet leži v najvišjem delu pleistocenske krnice Velika Kalica (slika 6). V krnici Velika Kalica je pet moren (Djurović 1996). Prve štiri so nastale s sukcesivnim umikanjem pleistocenskega ledenika, medtem ko je peta sodobna. Na podlagi sekundarnega kalcitnega cementa z U-serijo je starost morene IV. 10.605 ± 193 let, in starost morene III. 9575 ± 836 let (Hughes in Woodward 2008).

Slika 6: Geomorfološka karta cirka in ledenika Debeli namet.
Glej angleški del prispevka.

Tako opredeljena sodobna morena z dnom in stranmi ima površino 5,6 ha. Površina drenažnega območja, s katerega snežne padavine v obliki plazov lahko hranijo ledenik, je 14,4 ha, kar je s površino ledenika skupaj 20 ha.

Na moreni je opazna vodoravna in navpična asimetričnost (slika 5) in na podlagi šibke morfološke razčlenjenosti in barve gradiva smo v moreni izločili tri nasipine (Djurović 1993; Hughes 2007). Dve večji nasipini sta na zunanji strani bočnih moren, medtem ko jih v čelnem delu morene ni. Z lihenometrijsko metodo so ugotovili, da so nastale v letih 1903 oziroma 1887 (Hughes 2007). Razen teh je na notranji strani morene še serija manjših nasipin, ki jih ne poraščajo lišaji in zato sklepajo, da so mlajše od 11 let (Hughes 2007).

Z intenzivnimi kriogenimi procesi so nastale velike koluvialne oblike: grape in melišča (slika 4). V tem delu krnice so pogosti tudi podori, podorno gradivo pa se nalaga ob desni bočni moreni.

Na širšem prostoru ledenika prevladujejo vplivi nizkih temperatur in snega, zato so kraške oblike precej redke. Vendar so na več mestih v neposredni bližini ledenika nastale manjše površine s škrapljami, ki so dober indikator za določanje meje med krionivacijskimi in kraškimi procesi. Prva skupina škrapelj je na navpični apnenčasti skali neposredno nad ledenikom in levo bočno moreno. Škraplje ne sežejo do konca skalnatega zidu, temveč se končujejo 3 do 5 metrov nad levo bočno moreno. Ta višina je kvalitativna meja prevladujočega delovanja geomorfnih procesov: zgoraj prevladujejo kraški, spodaj pa krionivacijski procesi. Druga skupina škrapelj leži na skalnih stopnjah nad jugovzhodnim delom ledenika, v katere so vrezane plitve škraplje dolžine do 2 m.

4.3 Glaciološke raziskave

Če izhajamo od splošno sprejete opredelitve, da kot ledenik razumemo kompaktno ledeno maso, ki se premika in je deformirana zaradi premikanja (UNESCO/IACH, 1970), lahko Debeli Namet uvrstimo med sodobne mikroledenike, ne pa med snežnike (Djurović 1996; Hughes 2007).

Na vzdolžnem profilu ledenika lahko izločimo tri dele: spodnji vbočeni del (od ledeniškega čela do 90 m), izbočeni del (90 do 120 m) in zgornji izbočeni del (120 m do 330 m).

Ledeniški jezik ograjujejo čelna in bočne morene (slika 7). Osrednji, vbočeni del je najbolj dinamičen del ledenika, zgornji del je območje akumulacije snega in njegove transformacije v ledeniški led. Razdeljen je na dva segmenta. Jugozahodni segment je najvišji del ledenika, ki se konča pod apnenčastim odsekom grebena Pleća. Jugovzhodni segment je široka snežno-firnska gmota, ki leži na skalnih stopnjah pod grebenom Šljemena. Ta del ledenika je izpostavljen velikim letnim spremembam.

Slika 7: Ledenik Debeli namet 18. oktobra 2006.
Glej angleški del prispevka.

Med letoma 1993 in 2010 se sneg in firn na površju ledenika nista stalila. Oktobra 2008 smo vrtali v zgornjem vbočenem delu ledenika in ugotovili, da je firn debel 6 m. Vrtanje smo prekinili zaradi tehničnih težav.

Najnižja ledeniška točka je na koncu ledeniškega jezika na višini 2050 m. Spremembe višine smo določali glede na reperno točko v osrednjem delu čelne morene. V opazovalnem obdobju je ledenik nenehno segal do sodobne čelne morene, vodoravna premikanja so bila v razponu 4–6 m, minimalni navpični premiki pa v intervalu 2 m.

Najvišje točke ledenika kažejo precej večje sezonske spremembe. Te so najmanjše v jugozahodnem delu ledenika (navpično 5 do 10 m, vodoravno pa okoli 20 m), povprečno od 2160 do 2170 m n. v. Spremembe v jugovzhodnem delu ledenika so večje (navpično 20 do 30 m, vodoravno pa okoli 70). Po daljši osi, od najnižje točke ledeniškega jezika do najvišje točke v jugozahodnem delu, je ledenik dolg najmanj 320 m in največ 350 m. Po krajši osi, od najnižje točke ledeniškega jezika do najvišje točke v jugovzhodnem delu, je ledenik dolg najmanj 260 m in največ 330 m. V zadnjih dveh desetletjih so bile opravljene večkratne meritve velikosti ledenika (preglednica 1).

Preglednica 1: Površina in prostornina ledenika Debeli namet.

leto	površina ledenika (km^2)	prostornina ledenika (m^3)	vir podatkov
avgust 1954	0,022	160 500	Djurović, po aerofotografskih posnetkih Beograjskega Vojno-geografskega inštituta
avgust 1971	0,036	313 000	Djurović, po aerofotografskih posnetkih Beograjskega Vojno-geografskega inštituta
avgust 1981	0,043	398 500	Djurović, po aerofotografskih posnetkih Beograjskega Vojno-geografskega inštituta
7. avgust 1993	0,017	113 000	Djurović, 1996
6. avgust 1997	0,024	180 500	Djurović, neobjavljeno
2003	0,018	122 250	Hughes, 2008
2005	0,041	373 500	Hughes, 2008
2006	0,050	489 000	Hughes, 2008
18. oktober 2006	0,029	233 500	Djurović, neobjavljeno
2007	0,037	325 000	Hughes, 2008
25. september 2008	0,034	289 750	Djurović, neobjavljeno
17. oktober 2009	0,026	201 250	Djurović, neobjavljeno
22. september 2010	0,033	278 250	Djurović, neobjavljeno

Na ledeniku nastajajo ledeniške mize. Ena največjih je nastala leta 1993 pod skalnim blokom, ki je meril 3 m v dolžino in 1 m v širino (Djurović 1996). Naslednje leto sta mizo prekrivala firn in sneg. Mize so različnih velikosti, zadnja večja pa je bila opažena 2010 (slika 8).

Slika 8: Ledeniška miza 24. oktobra 2010.
Glej angleški del prispevka.

Ledenik Debeli namet hrani sneg, ki se izloči neposredno na površino krnice, sneg, ki ga prinesejo snežni plazovi, kakor tudi sneg, ki ga prinese veter.

Na postaji Žabljak pade v mesecih, ki imajo negativno srednjo mesečno temperaturo zraka (november–april) 55 % letne količine padavin. To pomeni, da se v obliki snega izloči 1430 mm. Skupno količino snega na drenažnem prostoru snežnih plazov smo izračunali z množenjem površine drenažnega prostora snežnih plazov (0,144 km^2) in letne količine padavin v obliki snega (1430 mm), ki smo jo delili s površino cirka (0,056 km^2) in dobili vrednost 3677 mm. Skupaj s količino snega, ki se neposredno izloči v krnico, dobimo 5107 mm snega, ki letno hrani ledenik.

Spremljanje hitrosti premikanja ledenika z reperji smo začeli leta 2009 tako, da končne rezultati šele pričakujemo. Na podlagi določenih kazalcev je mogoče približno ugotoviti hitrost premikanja ledenika. Apnenčasti blok, ki je 1993 gradil ledeniško mizo, je smo ponovno opazili na čelu morene 16. oktobra 2006. V tem obdobju skalni blok ni bil izpostavljen na površju in je bil pokrit z ledom oziroma snegom, zato je hitrost njegovega premikanja enaka hitrosti premikanja ledenika. Sicer ne moremo z gotovostjo trditi, da je blok prišel do čela morene leta 2006, ker je bila v predhodnih letih debelina ledeniškega jezika večja za približno 2 m. Blok se je v obdobju 13 let premaknil za okoli 150 m, kar pomeni, da se je ledenik premikal z minimalno hitrostjo okoli 11 m letno. Na podlagi hitrosti premikanja ledenika in dejstva, da ne prihaja do umikanja ali napredovanja ledenika ter da je njegova maksimalna dolžina 350 m, smo ugotovili, da je treba več kot 30 let, da se ledena gmota Debelega nameta popolnoma obnovi.

4.4 Rezultati rekonstrukcije ledenika

Velikost ledenika smo za obdobje pred neposrednimi terenskimi opazovanji rekonstruirali z uporabo aerofoto posnetkov (slika 9). Snemanja smo izvajali v prvi polovici avgusta, tako da posnetki ponazarjajo sredino obdobja ablacije, ne pa njegovega konca. Kljub temu posnetki ponujajo pomembne informacije o spremembah velikosti ledenika.

Slika 9: Aerofotografski posnetki ledenika Debeli namet (Arhiv beograjskega Vojno-geografskega instituta).
Glej angleški del prispevka.

Trenutna velikost ledenika na koncu obdobja ablacije (november) ustreza velikosti ledenika iz avgusta 1954. Avgusta 1971 in 1981 je bil ledenik večji od povprečne velikosti ledenika sredi obdobja ablacije v zadnjem desetletju.

Leta 1953 so snežne padavine znašale le 43 % padavin povprečne letne količine (1450 mm). Pomembno zmanjšanje količine padavin v predhodnem letu je spremljalo povišanje temperature zraka leta 1954. Posledica je bilo zmanjšanje površine ledenika in sosednjih snežnih ploskev. V obdobju od sredine 70-ih do sredine 80-ih let se je pomembno povečala količina padavin temperature zraka pa se je znižala, zaradi česar se je povečala površina ledenika in okoliških snežnih ploskev (slika 10).

Slika 10: Ledenik Debeli namet na koncu obdobja ablacije septembra 1981.
Glej angleški del prispevka.

5 Diskusija

Dosedanje raziskave so privedle do določenih razlik v številčnih podatkih o položaju in velikosti ledenika, ki nas lahko pripeljejo do različnih sklepanj o dinamiki ledenika Debeli namet. Ob prvih meritvah ledenika (Djurović 1996; 1999) je ugotovljena višina najnižje točke ledenika 2050 m n. v. Pozneje je bila določena višinska cona, na kateri leži ledenik, in sicer na okoli 2100–2200 m n. v. (Hughes 2007) oziroma med 2050 in 2300 m n. v. (Hughes 2008; 2009) in med 2000 in 2200 m n. v. (Hughes 2010). Različne vrednosti nadmorskih višin nas napeljujejo k sklepanju, da se ledenik v različnih časih premika na različne višine. Prav tako so opredelili tudi različno višinsko razvitost ledenika od 100 m do 200 m oziroma 250 m (Hughes 2007; 2008; 2010). Po naših ugotovitvah, se najnižja točka ledenika na koncu ledeniškega jezika od srede 20. stoletja (za prejšnje obdobje ni podatkov) premikala v zanemarljivo majhnem navpičnem intervalu: 2 m. To pomeni, da je bila najnižja točka ledenika v obdobju, daljšem od pol stoletja, na višini okoli 2050 m n. v. Najvišja točka ledenika je izraziteje nihala in je bila povprečno med 2160 in 2170 m n. v.

Na podlagi teh dveh parametrov lahko ugotovimo, da ledenik Debeli namet leži v višinski coni med 2050 in 2160–2170 m, je višinsko razvit med 110 in 120 m in je dolg med 320 in 350 m.

Površina ledenika je zmeraj predstavljena kot seštevek površine ledeniškega ledu in snežno-firnskega območja. Največjo površino ledenika smo določili s površino dna in strani sodobne krnice, ki znaša 0,056 km^2. To površino ledenik doseže na koncu obdobja akumulacije (november–april). V obdobju ablacije (maj–oktober) se zaradi taljenja obodnih delov ledenika zmanjšata njegova površina in debelina.

Za leti 2005 (0,05 km^2) in 2006 (0,041 km^2) je Hughes (2007; 2008) izračunal, da površina ledenika obsega 91 % oziroma 73 % površine ledenika na začetku ablacijske dobe. Toda naše meritve in opazovanja z 18. 10. 2006 so podale povsem drugačne podatke o velikosti ledenika na koncu ablacijske dobe (preglednica 1). Ker v navedenem obdobju nismo zasledili pomembnejših sprememb temperatur zraka in količine padavin, ki bi lahko vplivale na tako opazno povečanje velikosti ledenika, sklepamo, da zgoraj omenjene meritve ne dajejo realne podobe velikosti ledenika v letih 2005 in 2006.

Tudi objavljeni rezultati o podnebja kot enem pomembnih vplivnih dejavnikov ledenika Debeli namet se razlikujejo. Srednje letne temperature zraka za Žabljak so po različnih virih: 0 °C (Cerović, 1986; Hughes, 2007), 4,7 °C (1961–1990) (Djurović 1996), 5,1 °C (Ćurić 1986; Hughes 2008; 2010) in 53 °C (1958–2010). Ker srednjih letnih temperatur zraka brez natančnega časovnega obdobja, na katerega se nanašajo, ne moremo primerjati, privede njihova uporaba v računih do precejšnjih razlik, ki pa niso posledica podnebnih sprememb. Tako je na podlagi nekaterih virov (Hughes 2008) preračunana temperatura za višino 2150 m 0,9 °C za 0,7 °C nižja od povprečne temperature za obdobje 1961–1990 ter nižja celo za 1,3 °C za povprečno temperaturo v obdobju 1958–2010.

Srednja višina prehoda med snegom in ledom, ocenjena na podlagi topografske karte 1 : 25 000, naj bi bila na višini 2150 m (Hughes 2007). Ta višina je v realnem prostoru zgornja meja ledenika. Na podlagi neposrednih meritev na ledeniku, vrtanja firna, analize vzdolžnega profila ledenika in kvalitativne analize ledenika je bila določena višinska ravnovesna meja (ELA), ki je 58 m nad ledeniškim jezikom in leži na okoli 2100 m n. v. S to korekcijo je ELA znižana za 50 m glede na njeno realno višino.

Izračunana povprečna vrednost 5107 mm letne količine snega, ki hrani ledenik, kaže, da dobi ledenik Debeli namet zadostno količino snega za vzdrževanje ravnovesne bilance ledenika. Dobljena vrednost se ujema s teoretičnim izračunom – 5000 mm snega (Huges 2008). Kratkoročno zmanjšanje količine padavin ne more bistveno vplivati na velikost ledenika, ker lahko padavine zmanjšanje zelo hitro nadomestijo. Če v odstotkih izraženo povečanje količine padavin (44 %), ki smo ga izmerili v osemdesetih letih preteklega stoletja v Žabljaku, prenesemo na prostor Debelega nameta, dobimo 7353 mm snega, ki je v tem času letno hranil ledenik.

Na podlagi lihinometrijskih raziskovanj so ugotovili, da naj bi zunanji del morene nastal okoli 1878 AD, osrednji pa leta 1904. Notranja morena je brez lišajev, kar naj bi pomenilo, da je nastala v zadnjih 11 letih kot odgovor na stabilizacijo ali napredovanje ledenika (Huges 2007). Ugotavljamo, da starost lišajev na zunanji strani morene ne more nujno nakazovati časa nastanka morene. Pokaže lahko čas, ko je bila morena dovolj dolgo brez snežne odeje oziroma pove, kdaj so bili ustvarjene razmere za kolonizacijo lišajev. Dokaz za to so opazovanja trajanja snežne odeje v krnici. Najvišje dele morene sneg pokvira več kot 250 dni letno. Na južnem Balkanu je bilo v obdobju od 1865 do 1984 največ padavin med letoma 1875 in 1884 (Katsoulis in Kambetzidis 1989). Takrat je sneg moreno prekrival precej dlje kot v zadnjih dveh desetletjih. Lišaji so se lahko naselili šele kasneje, ko se je podaljšalo obdobje brez snežne odeje. Kot primer izjemno dolgega obdobja pokritosti morene s snegom je leto 1981, ko se sneg na moreni ni dokončno stalil do srede avgusta. To pomeni, da je sneg moreno prekrival okoli 300 dni. Takšne mikroekološke spremembe pripeljejo ne le do upočasnjene rasti lišajev, temveč tudi do njihovega izginotja (Bradwell 2001). Datiranje starosti morene sodobnega ledenika Snežnik v Bolgariji je dalo precej večjo starost: AD 330–610 in AD 1150–1270 (Grünewald in Scheithauer, 2010). Morensko gradivo, ki leži med sodobno moreno in moreno IV. v krnici Velika Kalica (slika 5), ni kolonizirano z lišaji. Njegova starost bi ustrezala starosti notranje morene Debelega nameta, za katero je ugotovljeno, da naj bi se oblikovala v zadnjih 11 letih (Hughes 2007). Na podlagi neposrednih raziskav pa smo ugotovili, da v zadnjih 30 letih ni bilo akumulacije morenskega gradiva oziroma da je gradivo starejši od leta 1981. Navedeni primeri potrjujejo dvom, da je z lihenometrijsko metodo ugotovljena starost pravilno določena oziroma je dala bistveno mlajši čas nastanka morene od resničnega.

Debelemu nametu je najbližji ledenik v albanskem delu Prokletij, severovzhodno od vrha Maja e Kolacit (2490 m n.v) (Milivojević in ostali 2008; Hughes 2009). Površina Triglavskega ledenika (Slovenija) je v obdobju 1946–1973 nihala med 0,11 in 0,17 km^2 (Gams 1994) in se je zmanjšala na 0,03 km^2 ob koncu 1995

(Gabrovec 1998; Gabrovec in Zakšek 2007; Gabrovec in drugi 2007; Triglav Čekada in ostali 2011). Podoben trend zmanjševanja površine kažejo tudi ostali trije ledeniki v Julijskih Alpah (Tintor 1993), kakor tudi ledenik pod Skuto (Slovenija), ki ima stalni trend zmanjševanja površine, in sicer od 2,8 ha med letom 1950, do 0,73 ha med letom 2003 (Šifrer 1976; Pavček 2004; 2007).

Ledenik Snežnik (Bolgarija) v obdobju z najmanjšo prostornino ledu (september–november) ima površino med 0,4 in 1,3 ha. Nenehno spremljanje ledenika od srede 80-tih let preteklega stoletja kaže na njihovo relativno stabilnost (Gachev 2009; Gachev in ostali 2009). Debelina ledenika je bila septembra 2006 7,8 m, 10,9 m in 11 m (Grunewald in Scheithauer 2008).

Zahodno od ledenika Debeli namet leži ledenik Ghiacciaio del Calderone v osrednjem delu Apeninov. Rekonstruirana mas balanca (1920 do 1994) je bila nepretrgoma negativna (razen ob koncu 1950-ih in v času zgodnjih 1960-ih let). Ledenik je doživel največjo spremembo na začetku 21. stoletja, ker se je leta 2000 razdelil na dva dela (Dramis in ostali 2002; D'Alessandro in ostali 2003; Pecci 2006).

6 Sklep

Ledenik Debeli namet leži v višinski coni od 2050 do 2160/2170 m n. v., oziroma ima višinsko razvitost od 110 do 120 m ter površino od 0,025 do 0,032 km^2. Minimalna debelina ledu je 8 m. Opažamo zmanjševanje debeline ledu, ne pa tudi zmanjševanja njegove površine. Ledenik s treh strani obdajajo visoki grebeni, ki predstavljajo drenažni prostor snežnih plazov, ki hranijo ledenik. Prispevno območje ledenika povprečno letno dobi okoli 5000 mm padavin v obliki snega, v posameznih letih pa tudi čez 7000 mm. Viški nadomestijo negativen vpliv povišane temperature zraka in omogočajo vzdrževanje ravnovesnega stanja ledenika. Zato ledenik Debeli Namet v zadnjih 50 letih ni utrpel pomembnejših sprememb velikosti in je postal eden največjih ledenikov južne Evrope.

7 Zahvala

Avtor se zahvaljuje vsem kolegom, ki so mu v zadnjih 20 letih pomagali pri raziskovanju Durmitorja.

8 Literatura

Glej angleški del prispevka.