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Present state of Bulgarian glacierets

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Abstract: The present article makes a revision of the recent studies related to Bulgarian glacierets, all located in the northern part of the Pirin Mountains, as well as presents some latest results from field measurements of firn size and morphology descriptions. This has been the first scientific study of Banski suhodol glacieret, which at present is the largest in Bulgaria.

Data gained until now indicates differences between the Pirin and the High Tatras concerning the driving factors of glacieret inter-annual dynamics, as for Bulgarian glacierets air temperature appears to be one of the most sufficient controls.

Key words: Pirin Mountains, glacierets, inter-annual dynamics, climate fluctuations

Introduction

Small firn patches are an important indicator for present day climate fluctuations in the marginal environments of the presently non-glaciated high mountains of the middle latitudes. Glacierets are one of the most representative features of such type. According to Grünewald et al. (2006) a *microglacier*, or *glacieret*, is a permanently existing firn body (at least since the Little Ice Age, i.e. since 1850 AD), with density of firn above 0.6 g/cm^3 (at the bottom over 0.8 g/cm^3), with presence of stratified annual layers, and with sufficient dimensions (area at least 1,000 m^2 and several meters firn thickness). Glacierets are in fact an embryonic form of present mountain glaciation, which exists below the present snow line due to the specific setting of local environmental conditions at the places they are located. Usually these conditions include deep relict glacial cirques with northerly exposition, high rock walls to ensure strong shading for almost whole year, and a big accumulation of avalanche snow at the spot. Existence of glacierets in Bulgaria is also favoured by karstified carbonate bedrock (marble), which drains bottom meltwaters from the snow patches (Popov 1962).

Bulgarian glacierets – an overview of geographical location

In Bulgaria favourable conditions for the formation of glacierets exist only in the highest parts of the Pirin Mountains, in the northern marble section of the main ridge (Vihren area). Two glacierets are known to have classical morphological setting, sufficient size of firn area (in a range of 0.5–1.5 ha) and proven persistence during the last several decades. These are: Snezhnika, located in Golemia Kazan cirque at the NE foot of Vihren peak (2,914 m a.s.l., the highest point of the Pirin), and Banski suhodol, situated in the highest part of the central section of Banski suhodol cirque, just below the rockwall of Koncheto crest. Some smaller and less persistent features exist elsewhere in the vast Banski suhodol cirque as well as in the other N exposed cirques in the marble part – Kutelo and Bajuvi dupki (Fig. 1). All features are found in end parts of cirque bottoms, at altitudes between 2,400 and 2,750 m a.s.l.

In fact, at present Bulgaria hosts the most southerly located glacierets in Europe (Grünewald & Scheitchauer 2008).

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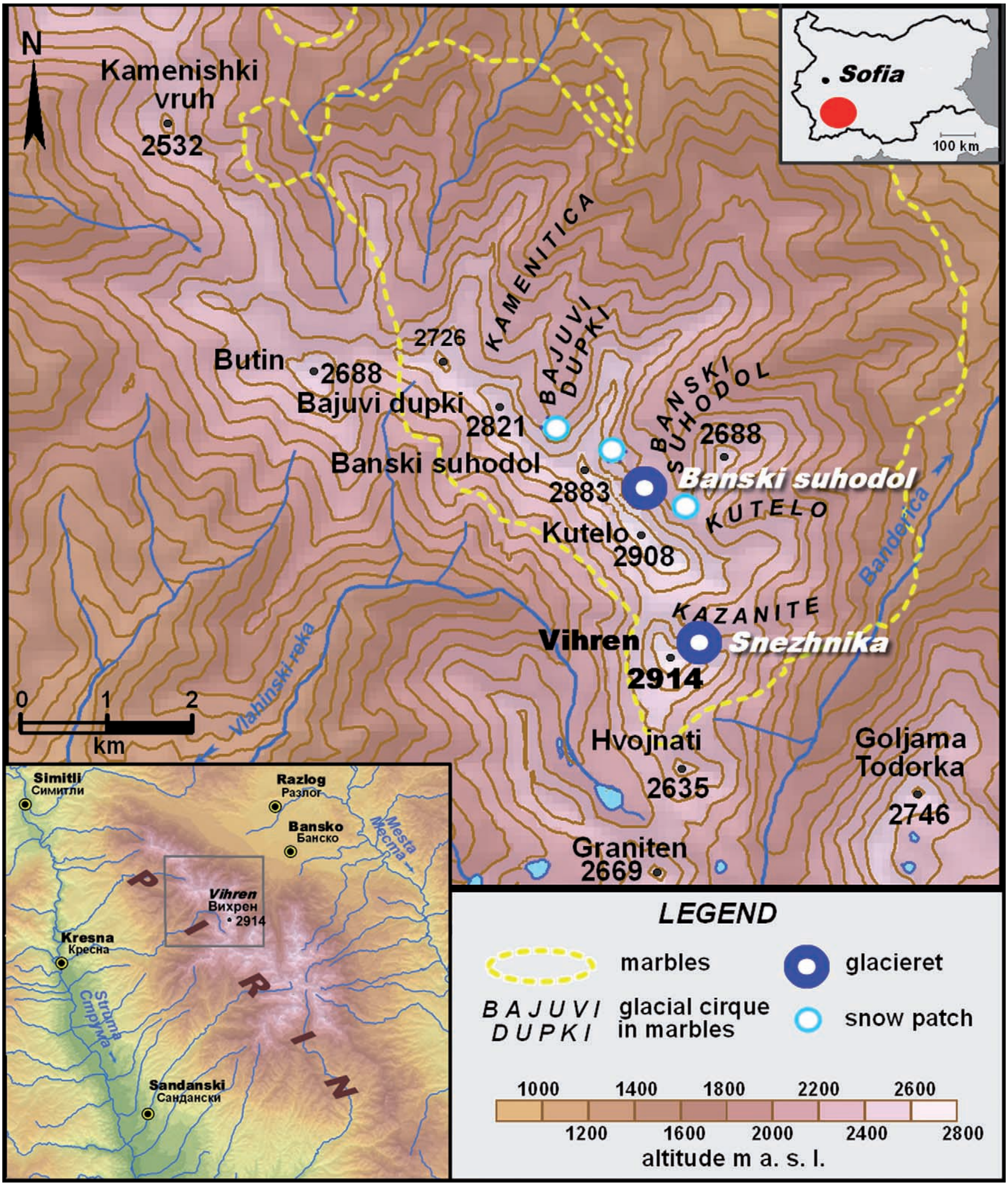

Fig. 1. Glacierets and snow patches in Vihren area (the Northern Pirin)

Snezhnika glacieret

By no doubt Snezhnika is the most famous and the best explored glacieret in Bulgaria, mainly because of its appropriate location at one of the main tourist routes in the Pirin Mountains (the trail from Bunderica cottage to Vihren peak) and an easy access (1 hour and a half away from the high mountain asphalt road in Bunderica valley).

Snezhnika is situated at 41°46'09"N and 23°24'10"E in Golemia Kazan cirque – in fact the deepest glacial cirque in the Pirin Mountains. The cirque is 1.25 km long, 1.2 km wide and 520 m deep. It is opened to the east and bordered by the main

Fig. 2. Snezhnika glacieret – a photo from October 2009

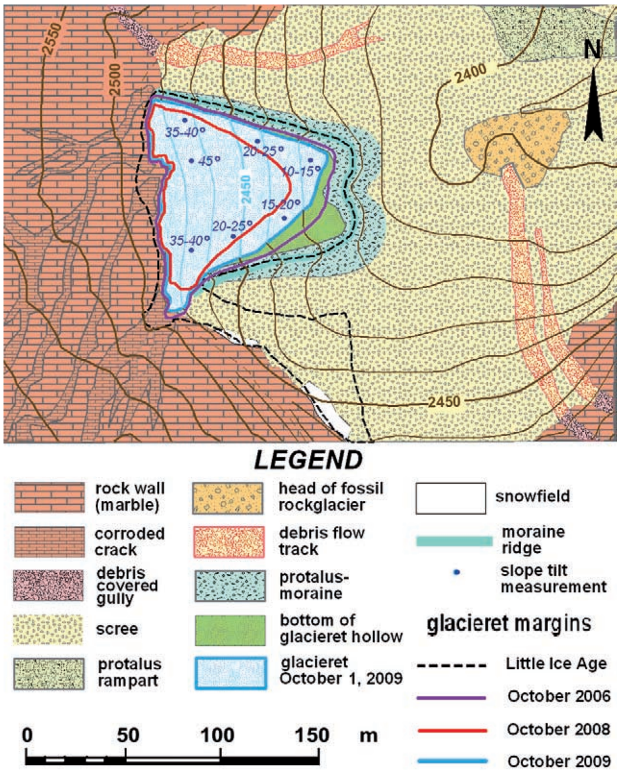

Fig. 3. Geomorphological map of the area around Snezhnika

ridge of the Northern Pirin with the highest peaks in the mountain – Vihren (2,914 m a.s.l.) and Kutelo (2,908 m a.s.l.). The extraordinary depth of the exaration, which took place mainly during the Wurmian, is explained by the fact that the cirque is located on the crossing point of three faults with an azimuth of 20°, 55° and 130°. This topographic setting results in a strong shading in the NE foot of Vihren peak, thus making conditions favourable to a formation of a glacieret. Main topographic and geomorphic characteristics of this cirque were published previously (Gachev 2009a).

Snezhnika lies at the westernmost part of the cirque bottom. Its base is at about 2,425 m a.s.l., western high part reaching 2,480 m a.s.l. In general the glacieret has a trapezoid shape and lies in a well formed nival hollow. It is surrounded by a well developed protalus-moraine ridge with an overall length of ca. 270 m. The glacieret hollow, outlined by the moraine ridge is approx. 100 m long (real size from west to east) and 108 m wide (in the uppermost part). Behind the glacieret lies the NE rockwall of Vihren peak made of corroded and weathered marble. The overall height of the wall is 420 m. The lower part is almost vertical, tilted up to 65–75° (Popov 1962), and the upper section known as “Funiata” (the Funnel) is 45–60° steep. Two parallel systems of deep cracks serve as main avalanche tracks, through which comes the main snow feed of the glacieret (Figs. 2, 3).

Snezhnika glacieret was studied in detail for the first time in 1957–1961 by Vladimir Popov (1962, 1964) and for the second time in the period of 1994 – 2007 by a team from the Landscape Research Centre in Dresden, Germany, led by Karsten Grunewald (details presented by Gachev 2009a). Three drillings were made, the deepest reaching the bottom at 11 m. Radiocarbon dating showed that the firn at the base of the glacieret is at least 150 years old, i.e. it dates back to the Little Ice Age. The moraine ridge surrounding Snezhnika is also considered to be formed in its present shape during the LIA (Grünewald et al. 2006, Grünewald & Scheithauer 2008, Grünewald et al. 2008a) probably as a result of glacial reworking of previously existing protalus rampart. Exact size measurements in the autumns of 2008 and 2009 were made by the authors of the present study (Gachev 2009b in press, see Fig. 3).

Glacieret firn mass balance is expressed with the equation:

$$M = (I_s + M_p) - (F_i + F_m), \quad (1)$$

where

- M is the current firn mass,
- I_s is the ice income from snowfalls and avalanches during the winter season,
- M_p is the firn mass from the previous year (after the melting season),
- F_i is the firn mass melted or ablated by insolation during the period with air temperatures above 0°C, and
- F_m is the firn mass melted away by rain precipitation during the summer.

Fig. 4. Measurements in autumn 2009 (left and right)

Glacierets have a well expressed annual regime of snow mass, related to the periods of snowfall and melting. Each year they reach their minimum mass in autumn, after the end of the melting season (in most years in October). This period should be accepted as the end of the annual cycle, and is the most appropriate for measurements of firn area and mass. As firn volume is hard to measure, a common practice in glaciology is to measure glacier length or glacial area. As Snezhnika does not have an elongated shape, it is most appropriate to measure the total glaciated area. Results obtained from measurements in autumns of 1994–2007 (Grünewald et al. 2008a), and 2008–2009 show an inter-annual fluctuation in the range of 0.75 to 0.30 ha. Taking into account the overall size of glacieret hollow this should correspond to 82% and 33% respectively of the suggestible LIA area of the glacieret (Fig. 3). Figure 7 of Gachev (2009a), with the addition of the newest value measured on October 1, 2009 – 0.67 ha (Fig. 4), shows that no special long-term trend was observed in the inter-annual size dynamics of Snezhnika during the last 16 years. According to the calculations of Grünewald et al. (2008a), the area recorded by Popov in fall 1959 was slightly bigger than of 2006, but the slight difference with the LIA area (represented by the size of the glacieret hollow) proves that the 20th century warming has had a little affect on glacieret area. On the other hand, the firn area is not a strict criterion for evaluation of firn mass and volume at a long-term scale because it does not take into account firn thickness – 18% decrease of area for 2006 compared to LIA may

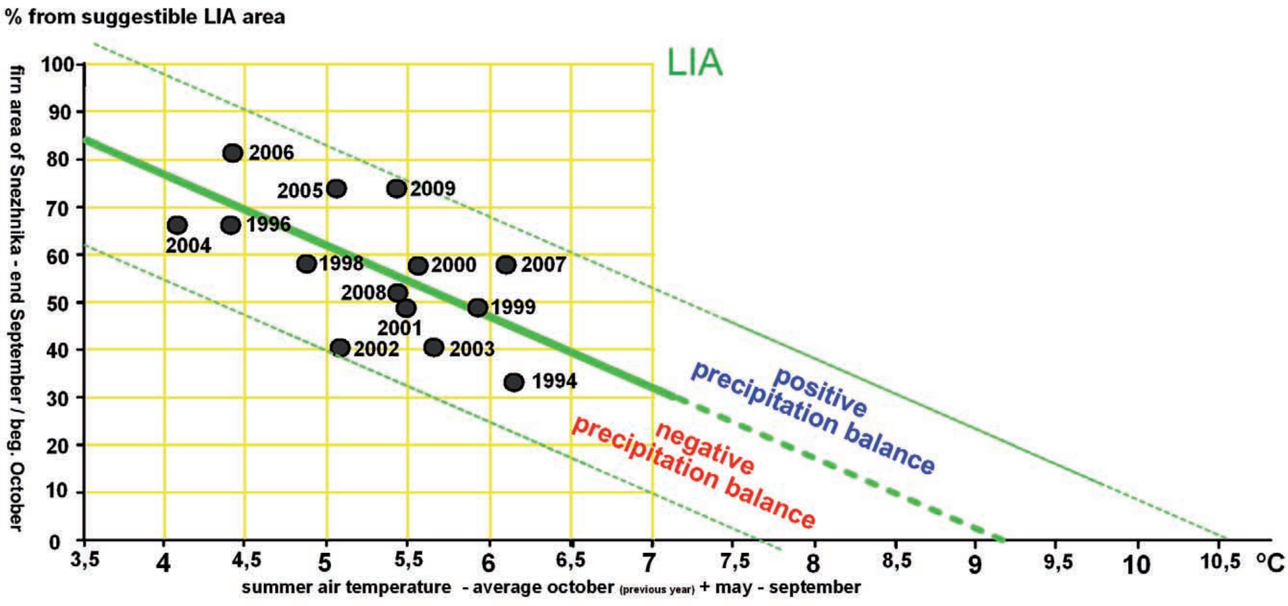

Fig. 5. Relation between the size of Snezhnika and summer air temperature

correspond to 50% loss of firn mass. In this aspect more research is needed.

It is quite difficult to analyze relations between the size dynamics of Snezhnika and environmental controls due to serious lack of data on the local climate. Temperature conditions in Golemia Kazan cirque were discussed in the works of Popov (1964), Nojarov & Gachev (2007) and Grünewald et al. (2008b). It was found that air temperatures in the cirque are in a very close correlation to temperatures measured at Musala peak ($R_{xy} = 0.99$), so the latter can be used for estimations of temperatures under the condition that Golemia Kazan (at 2,400 m a.s.l.) is about 2.2°C warmer than Musala peak (2,925 m a.s.l.).

As a result of the analysis it has been discovered that the inter-annual size and mass dynamics of Snezhnika are mainly related to thermal fluctuations, and in particular to summer temperatures, recorded from May to October which in general are above zero (Fig. 5). Points on the figure are situated above or below the trend line in dependence of precipitation conditions for each particular year in combination with the value of firm mass from the previous year. Precipitation factor is really hard to evaluate because local data is available only from the measurements of Popov (1964), and there the precipitation is measured in total for annual periods. Precipitation patterns can probably be suggested by comparison to the stations in Bansko (11 km to NE) and Sandanski (25 km to SW). These initial results give the first chance to estimate, even quite uncertainly, the threshold values of average summer temperature (9.2°C), beyond which the glacieret will survive only in favourable precipitation conditions, as well as the marginal temperature (10.6°C), beyond which a snow patch can never survive the summer. More reliable results can be obtained while measuring not the firn area, but the firn mass.

Banski suhodol glacieret

This is the largest glacieret in Bulgaria in respect to surface area and firn volume. It is located at 41°46'54''N and 23°23'40''E in the highest southern part of the biggest cirque in the Northern Pirin – Banski suhodol (Fig. 6).

Banski suhodol is the largest cirque in the marble part of the Northern Pirin. In general it has a rhomboid shape and aspect towards NNE. To the south it is bordered by the main ridge of the Pirin in the section between peaks Kutelo II and Banski suhodol II, and to the north-east it reaches the main rigel at 2,300 m a.s.l. The altitude ranges from 2,908 m a.s.l. at Kutelo I peak to 2,226 m a.s.l. at the lowest part of cirque bottom. The cirque has an overall area of about 2.3 km^2, it is 2.4 km long and 1.5 km wide.

Morphology of the cirque combines elements of glacial and karstic characteristics. The cirque bottom is a labyrinth of sinkholes, hills and low ridges. The main sinkhole, where the lowest point is located, is found in the northern part near the rigel. In its upper part the vast cirque is divided into three sections, separated by short but sharp ribs. Each section has a shape of a separate cirque, ending with a sinkhole. The largest is the eastern section – it includes a small intra-cirque U-shaped valley with a strip of sinkholes on its bottom, which ends in the main sinkhole of the cirque.

Although mentioned in some previous works (Grünewald et al. 2008a and others), Banski suhodol had remained uninvestigated until October 2009 when the first mapping and size measurement were done by the authors of the present publication. The glacieret is situated in the middle section, which, although smallest in area, has the largest cirque catchment zone. Here the rockwall, bordering the cirque to the south, reaches its greatest steepness with tilts up to 65–70°. The glacieret is located just below the northerly exposed rockwall, known also as Koncheto saddle, or crest. The crest is linking Kutelo I peak (2,908 m a.s.l.) and Banski suhodol I peak (2,886 m a.s.l.), reaching at its lowest section not less than 2,829 m a.s.l. The height of the wall above the glacieret is 110–150 m to the west to about 200 m below Kutelo peak.

The glacieret has its base at 2,610–2,640 m a.s.l., and reaches up to 2,700–2,740 m a.s.l. Its altitude is in fact about 200 m higher than Snezhnika in Golemia Kazan cirque. Banski suhodol glacieret lies in a well shaped deep hollow in the rockwall (Fig. 7), which, as indicated by the lighter coloring of the rocks in the vicinity of the glacieret, during the winter is filled with snow up to 10–12 m above the glacieret surface at the end of the melting season. The glacieret hollow is fed with an avalanche snow mainly through three large and several smaller cracks which form a radiative convergent pattern (Fig. 8).

Measurements made on October 2, 2009 showed a total surface area of 1.2 ha (real, not projected surface), i. e. a size 1.8 times bigger than that of Snezhnika for the fall of this year. Measured dimensions are shown on Fig. 8. Surface tilts are similar to those at Snezhnika. There is no data about ice thickness. As at Snezhnika, a well shaped backside crack is observed to depths of 2 to 4 m. A natural outcrop of the firn mass was observed in the uppermost part of the glacieret, where the firn body was exposed from the side to the depth of 4.5–5 m. There a stratification of the glacieret was observed. Above lied a layer of white snow with a thickness of 2–2.5 m. Below followed a thin layer of 10–20 cm hard transparent ice, and next – a compact mass of glass glacier ice with milky-gray patterns.

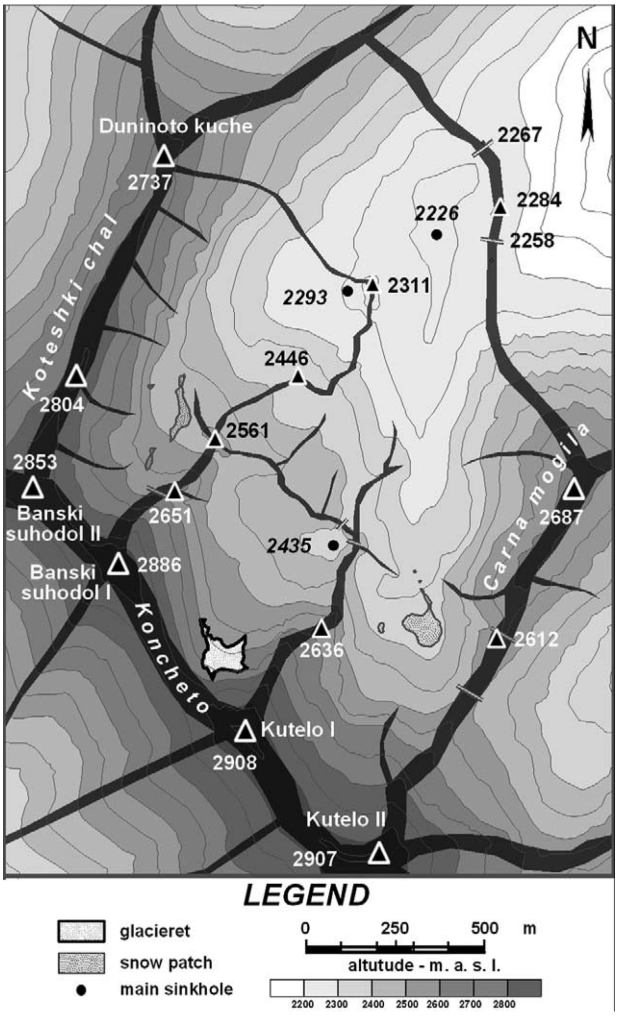

Fig. 6. A map of Banski suhodol cirque

Like at Snezhnika, here as well a protalus-moraine ridge is formed at glacieret base (at 2,640 m a.s.l.), but only in the middle part (Fig. 8). Both end sections have shape of gullies and traces of debris flow activity are observed there, so rock material is taken away. Considering the state of lichen cover and the initial formation of primitive soils this moraine ridge can be paralleled to the ridge around Snezhnika and addressed to LIA period of formation. What is different from Golemia Kazan is that here a small second ridge is formed on the upper side and the two parallel ridges are separated by a small trench. This second ridge is made of fresh rock and seems to be recent in age – probably formed during the cooling in the 70s of the last century.

Further down the cirque a well-shaped moraine ridge can be traced as a strip crossing the cirque bottom at 2,470–2,480 m a.s.l. (Fig. 8). Taking into account its elevation and appearance this can be accepted as an analogue of the crescent shaped moraine in the eastern part of Golemia Kazan, and should be probably addressed to the Younger Dryas cooling stage.

Fig. 7. Banski suhodol glacieret – a photo from October 2, 2009

Other features of perennial ice

Except the two glacierets, several other firn features are found in the marble part of the Northern Pirin, which, although not so permanent and well expressed, are more or less persistent through time. Most of them fall into the category of 'snow patches'. In the mid 50s Peev studied a small ice feature in the cirque Bajuvi dupki, which he categorized as "a small firn glacieret" of a talveg type (Peev 1956). It occupied the bottom of the cirque and had the shape of a narrow strip, starting at 2750 m a.s.l. and reaching down to 2,450 m a.s.l. The length of the glacieret was about 1,000 m and the width at the lower section in the range of 25–40 m (Peev 1956). The author reported a total firn thickness up to 8–9 m, the lowest 2–3 m being of the firn ice. He explained the existence of this talveg glacieret with the strong avalanche feed from the high periphery of the cirque. Peev (1956) was criticized by Popov (1964), who reported that still in the year 1957 the "small firn glacieret" had been scattered into several small patches. The same condition is observed on the Google Earth image of August 2007 but a detail study at the spot for several years is necessary to obtain a reasonable explanation of this feature and its dynamics.

Another form that is quite similar to the one just mentioned is found in the eastern section of Banski suhodol cirque – a firn spot of an almost round shape with an elongated outlet, looking like a very small glacier tongue, which ends in a sinkhole (Fig. 9).

The dark coloring of ice indicates that this feature survived at least two summers, but due to the absence of long-term observations it is hard to evaluate the marginal conditions for its existence. Although at the beginning of October 2009 it covered a sufficient area, the bed morphology of this snow patch suggests

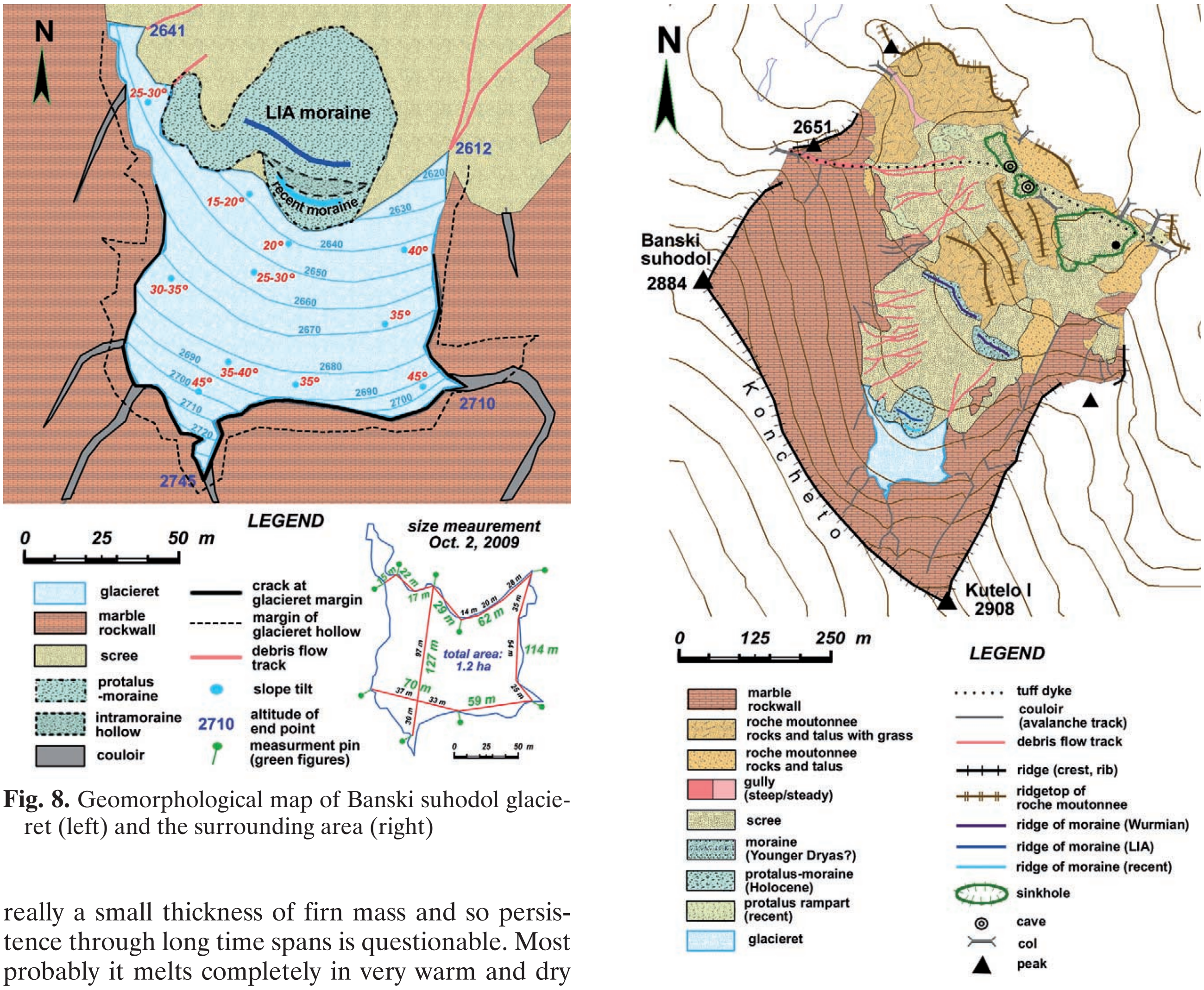

Fig. 8. Geomorphological map of Banski suhodol glacieret (left) and the surrounding area (right)

really a small thickness of firn mass and so persistence through long time spans is questionable. Most probably it melts completely in very warm and dry years. Some smaller similar features are also found in the western section of Banski suhodol cirque, and also in Kutelo cirque, lying between Kazanite and Banski suhodol.

Discussion

It is interesting to fit observations in the Pirin Mountains (Bulgaria) in a regional outlook of history and dynamics of glacierets in Southeastern Europe (Carpatho-Balkan and Adriatic regions). Existence of at least 10 such features is registered within this broadened area (Fig. 10). Some of them were being monitored for different periods during the last 100 years.

Results of several studies focused on glacierets in Bulgaria show that Snezhnika (and probably also Banski suhodol), have been quite stable at least during the last 100–150 years. The same is reported for glacierets in the High Tatra Mountains, whose existence was documented already from 17th to the 19th century (Gądek 2008). At the same time research in the High Tatras shows that glacierets there have a different nature of dynamics – the main factor for their size and mass fluctuations appear to be precipitation, and most of all winter snowfall (positive factor) and summer rainfalls (negative factor). This is due to the much wetter climate – total annual precipitation in the High Tatra Mountains is about 2000 mm and often even more. According to Gądek (2008) the three largest glacierets in the Rybny Potok Valley (the Polish Tatra Mountains) have sufficiently different patterns of inter-annual variations, which are in general not related to temperature conditions. As a main factor for increase and decrease of glacieret size the same author points out the development and subsequent destruction of subglacial tunnels that drain meltwaters in spring and abundant rain waters in summer. In comparison, Pirin receives much lower amounts of precipitation, especially in summer due to the sufficient Mediterranean climatic influences (total amounts are around 1,000–1,200 mm/y, nearly 60% of which fall in the period of November–April). Summer is relatively dry – that is why the main factor for the firn loss during this period is temperature. Something more – karstified bedrock causes almost a lack of surface water flow, so subglacial tunnels do not develop in Bulgarian glacierets, and this appears to be

Fig. 9. The firn patch in the eastern section of Banski suhodol cirque

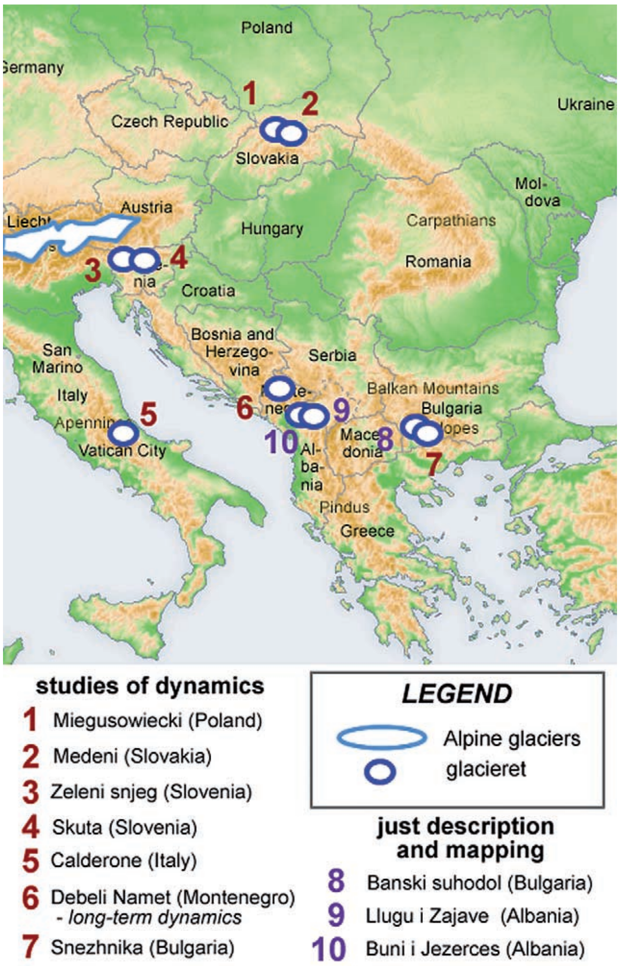

Fig. 10. Glacierets in the mountains of Southeastern Europe

the main morphological difference in relation to glacierets in the Tatras. Although still not continuously measured, the pattern of size fluctuation of Banski suhodol is expected to be quite similar to that of Snezhnika in Golemia Kazan.

Other differences appear when comparing Bulgarian glacierets to those in the central Mediterranean areas of Europe, namely the mountains around the Adriatic Sea. Measurements of Calderone glacieret (Abruzzi Range, Italy), and Zeleni snjeg glacieret (Triglav massif, Slovenia) have shown a rapid and continuous shrinkage of firn area and mass during the last 8–9 decades – a phenomenon that is typical neither for the Pirin Mountains nor for the High Tatras. According to the revisions of Grünewald et al. (2008a) Triglav glacieret had decreased its size 18 times since 1950 and 32 times since 1920 and Skuta glacieret in the Kamnik Alps (Slovenia) became 3–4 times smaller than 50 years ago. What appears especially interesting is the fact that in the autumn of 2009 Calderone glacieret was so small that it was scattered in two parts (photo sent by K. Grünewald) – at the same time glacierets in the Pirin (which are situated at the same latitude and similar topographic and lithology conditions), and also glacierets in the High Tatras, were 'in good health' – with area slightly larger than usual. Another prominent small glacier – Debeli Namet in the Durmitor Mountains (Montenegro) was also proved to have been retreated since the first decades of the 20th century (Hughes 2007), but the total size decrease is much smaller than of Zeleni snjeg and Skuta glacierets.

Although the existence of glacierets is highly dependant on local topographic factors, the driving mechanism for their dynamics and evolution through time appear to show regional patterns, which are a consequence of differences in regional climate. From the made comparisons it becomes evident that glacierets in the Pirin are more stable than those in the Adriatic area in long-term aspect, more stable and than those in the High Tatras in terms of inter-annual variations, but probably less stable than the latter in a long-term context. Firn size and mass of Bulgarian glacierets are related to air temperature, which means that they are also threatened by the global warming. The fact that glacierets in the High Tatras are not directly dependent on thermal conditions may make them more resistant to temperature rise. At the same time they might come to a shrink if overall warming is accompanied by an increase of summer precipitation.

Conclusions

The studies carried out so far in the Pirin Mountains prove the persistence of two glacierets in the marble part of the massif – Snezhnika and Banski suhodol, and their relative stability (a small decrease) since the Little Ice Age. The 16-year continuous observations of Snezhnika glacieret show that contrary to the similar features in the High Tatras, inter-annual size and mass fluctuations of Bulgarian glacierets are mainly related to variations in temperature, in particular in the summer period (from May to October), while precipitation plays a secondary role. The newest size measurements carried out at the beginning of October 2009 show a good condition of the glacierets in the Pirin Mountains and size above the average for the last 2 decades.

Comparisons with other parts of Southeastern Europe show that glacierets in the eastern part of the Balkan Peninsula, in the High Tatras and in the Adriatic area have at least three specific modes of development, determined by the differences in regional climate in terms of inter-annual fluctuations and long-term change. Each mode has its own scenario for future development, and trends in the different regions may be even controversial. In a long-term sense Bulgarian glacierets are expected to keep relative stability of size and mass with a slow trend towards decrease, related to the rise of air temperature.

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