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Indicators for modern and recent climate change in the highest mountain areas of Bulgaria

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Abstract: The highest Bulgarian mountains Rila (2,925 m a.s.l.) and Pirin (2,914 m a.s.l.) provide virgin mountain landscapes, intensive natural processes and a sharp sensitivity on natural and human impacts. The present paper focuses on the existing natural indicators for changes in climate during the last few centuries in the areas around the highest peaks Musala (the Rila Mountains) and Vihren (the Pirin Mountains), and the accent is put on the past and present existence of embryonic glacier forms. Dynamics of perennial ice bodies in the Pirin and the newly found fresh moraine ridge on the bottom of the Ledeno ezero Lake (the highest lake in the Rila Mts.) as well as the data from instrumental and historical records suggest a general trend of warming since the first two decades of the 20th century, especially expressed in the last 30 years. Inter-annual size variations of perennial ice bodies are found to be closely related to fluctuations of air temperature.

Regional comparative studies show that perennial ice bodies in Bulgarian mountains are less sensitive to slight climate fluctuations than some other similar features in the Carpatho-Balkan area. Proper interpretation of these and future research results requires their incorporation in regional studies within the entire Carpatho-Balkan area.

Key words: natural indicators of climate change, embryonic glacier forms, palaeoclimatology, Rila Mts., Pirin Mts.

Introduction

Recently, global climate change has appeared to be probably the most debated problem not only among scientific community but also among whole civil society at planetary scale. As a result, this issue focused on large research efforts and environmental reconstructions registering a rapid progress during the last several years. Although there have been developed whole sets of global climate models and scenarios concerning various past and also future periods, still a serious deficit of regional and local data is observed in this area of knowledge. And here is the very tricky moment in studying the climate – global changes in the state of the atmosphere have a different reflection at every separate place because of the specific combination of topography, biotic environment and human impact in each location

That is why regional and local response to global changes is very hard to predict without knowing in great detail the current regional and local environmental setting, which may be quite specific. This problem has really a pragmatic importance – understanding mechanisms of local response will give us chance to correctly suggest, estimate and evaluate future changes in the environment.

High mountain areas have a key role as places for palaeo-environmental reconstructions, especially in Europe. They provide unique landscapes with harsh environment, maximum topographic contrasts, great rates of geomorphic activity and high sensitivity on climate change and human impacts. Here still can be found nature virgin enough to provide well preserved field evidence for past environmental conditions, and contemporary natural processes occur in a substantially natural mode. This allows for present and past to be compared without a need to specially exclude anthropogenic factor.

The present paper is focused on the study of environmental change during the last several decades in some of the highest areas in Bulgaria made on the basis of existing field indicators.

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Bulgarian highest mountains – a target area for palaeoclimatic research

Bulgaria occupies the eastern and central parts of the Balkan peninsula. Although it is not as mountainous as some of the neighbour countries, here are found some of the highest mountain ranges – most important of them are the Rila Mountains, with Musala peak (2,925 m a.s.l.) – the highest point of all the Balkan region, and the Pirin Mountains (2,914 m a.s.l.), which is third highest (after Mt Olympos in Greece). These two mountain massifs provide remarkable geomorphic traces of past glaciations from the cold phases during the late Quaternary and this namely makes them most appropriate natural objects for palaoclimatic studies.

At present, the interest is focused most of all on the highest areas of both mountains: the cirque of the Ledeno ezero Lake (the Icy lake) at the NE foot of Musala peak (highest in the Rila Mountains) – the uppermost part of the larger Musala cirque, and Golemia Kazan cirque at the NE slopes of Vihren peak (the highest point of the Pirin Mountains) (Fig. 1).

The present research focuses especially on microglaciers – relatively small in size patches of perennial snow (firn), and on the geomorphic traces from their spread in the past. Although not having all characteristics of the real glaciers, microglaciers are an embryonic form of glaciation (Grünewald *et al.*, 2008). They are formed under specific marginal climatic conditions; depending on climate changes they can grow up into classical mountain glaciers or completely disappear (Peev, 1956).

Research activities and results

The cirque of the Ledeno ezero Lake in the Rila Mountains

This is the highest level of the big staircased Musala cirque. The cirque of the Ledeno ezero Lake (the Icy lake) has an area of 0.22 km^2. Lying at the foot of Musala peak, it has an aspect towards NNE (Fig. 1). The cirque is formed in a uniform bedrock – pre-Mesozoic granitoides. The bottom of the cirque is occupied by the Ledeno ezero Lake. The lake has a hexagonal shape, a total area of 1,8 ha, it is 140 m long and 100 m wide (Fig. 2). To the NE the cirque is bordered by a moraine of coarse boulders, through which lake waters drain underground. Situated at 2,709 m a.s.l. the lake is covered by ice from October to mid July. It is fed entirely by precipitation and smowmelt and lake level in fact does not change throughout the year.

The lake was mapped for the first time in 1932 by an Austrian team of students from Innsbruck led by S. Leutelt-Kipke. Their map, published in Issue of the Institute of Hydrology and Meteorology – BAS (vol. XVI, 1964) shows that the deepest part of the lake hollow is located at the eastern side, with a maximum depth of 16, 4 m. In summer 2008, a fieldwork was organized in order to concretize lake morphology in more detail and to make an up-to-date map of the lake bottom 76 years after the first mapping (Gachev *et al.*, 2008).

The newly created map, shown in Fig. 2, was made by probing the depth in 95 locations throughout all the lake basin following a classical approach (a boat and a rope). The mapping was conducted in

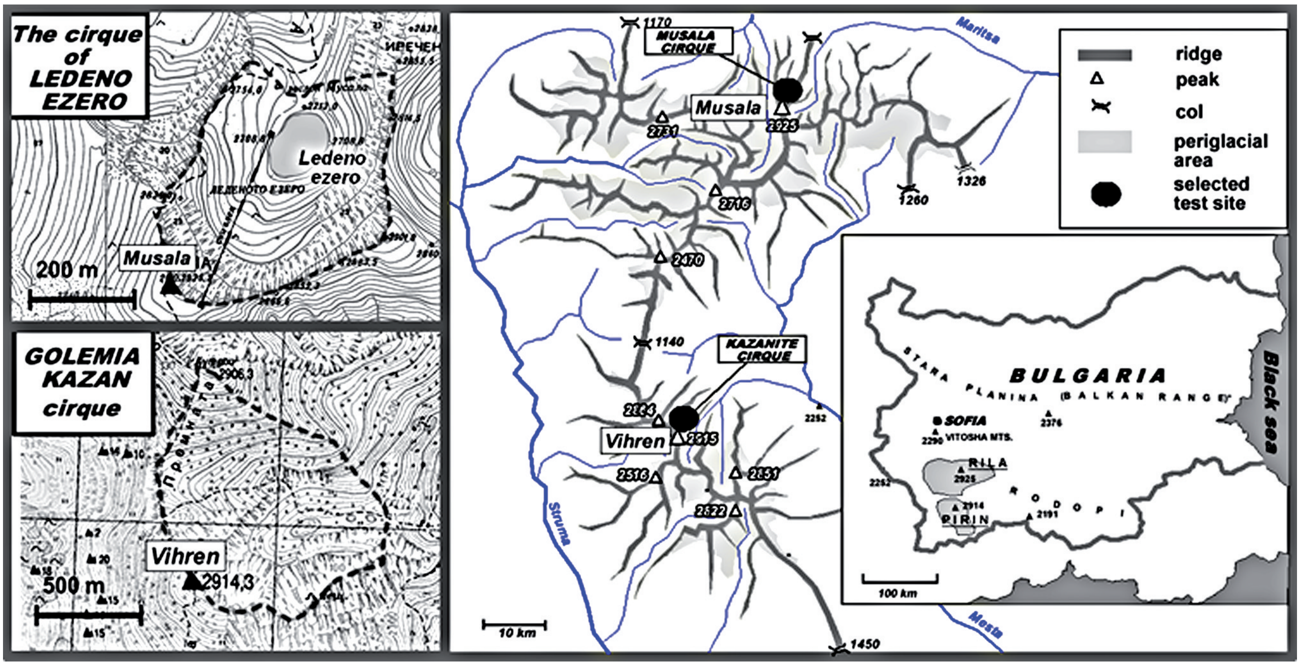

Fig. 1. Location of the key research areas

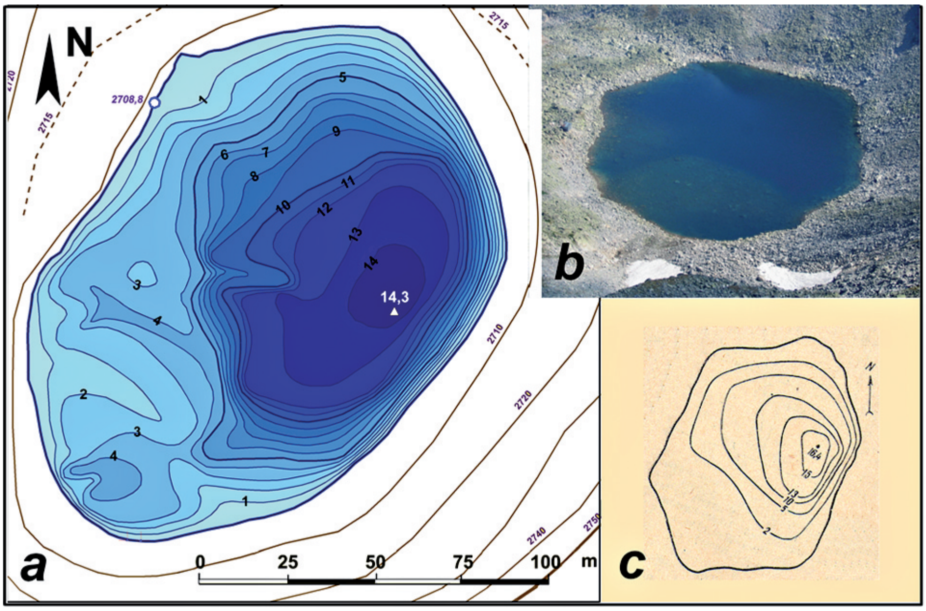

Fig. 2. Bottom morphology of the Ledeno ezero Lake – a) bathymetric map – August 2008 (Gachev *et al.*, 2008); b) the Ledeno ezero Lake seen from the trail to Musala peak; c) the first map made by S. Leutelt-Kipke (1932)

two days in August in a completely calm weather. Some interesting features are evident from the map:

1. An underwater crescent-shaped ridge has been discovered and parameterized in the SW shallow part of the lake. The ridge rises to a depth of 2.1 m, which is about 2 m above the bottom at the shallow SW side. The ridge is not present on the map of S. Leutelt-Kipke (1932), but is quite clearly seen when climbing up the tourist trail from Ledeno ezero refuge to Musala peak (Fig. 2);
2. There is quite a serious difference (2.1 m) in the value of maximum depth, registered during the mappings in 1932 (16.4 m), and 2008 (14.3 m). Differences exist also in the shallow SW part of the lake, where S. Leutelt-Kipke (1932) had given depths below 2 m for all this area, while the present mapping shows a hollow that reaches down to 4 m depth. The accuracy of the last mapping is confirmed by the fact that at more than 20 points at the deepest area of the lake were measured values between 13.9 and 14.3 m (i. e. within a range of 40–50 cm). This suggests that the bottom of the deepest part is flat, probably covered by a layer of silt.

The cirque Golemia Kazan in the Pirin Mountains

This is the deepest cirque in the Pirin Mountains. It lies between the peaks Vihren (2,914 m a.s.l.) and Kutelo (2,908 m a.s.l.) and occupies a total area of about 1,2 m^2. The cirque is formed in karstified marbles at the radial crossing of several tectonic dislocations. The bottom is dry and lies at about 2,400 m a.s.l. The cirque is opened to the east. From the south and west it is surrounded by almost vertical rock walls up to 450 m high, and from the north by the steep slopes of Kutelo peak (Fig. 1). Such topographic conditions favour the existence of a perennial snow patch, categorized by some authors as a microglacier (Grünewald *et al.*, 2008). It is called Snezhnika and lies in a hollow in the western part of the cirque bottom, just below the rock wall of Vihren peak (fig. 3). During the period of minimum ice volume (mid September to mid November) Snezhnika has an area in the range of 0.4 to 1.3 ha (Figs. 4, 6), which varies from year to year in dependence of the balance between snow input and snowmelt.

The Golemia Kazan cirque has been a target for several studies. Vladimir Popov from the Institute of Geography – BAS, performed a 4-year monitoring programme in the period 1957–1961 when he made detailed measurements of seasonal size dynamics of Snezhnika, a geomorphic mapping of the cirque and climatic observations on a stationary basis (Popov, 1962, 1964). Since 1994, a team from the Centre for

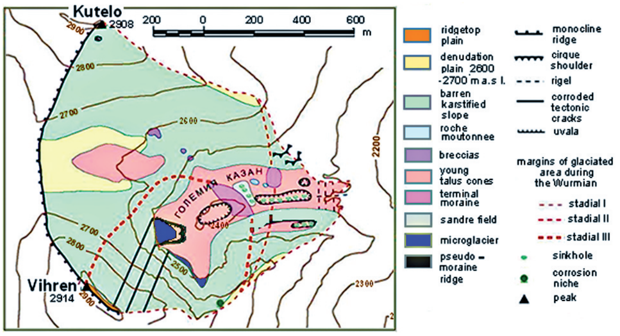

Fig. 3. Geomorphological map of Golemia Kazan cirque (by Popov, 1962)

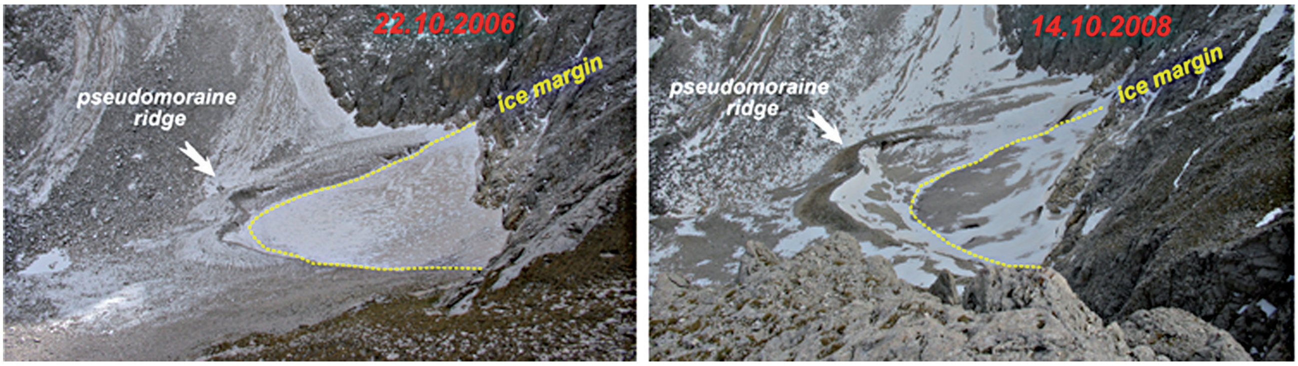

Fig. 4. Inter-annual dynamics of Snezhnika – ice extent in fall 2006 and 2008

Landscape Research in Dresden, led by K. Grünewald has been conducting regular observations of Snezhnika. Besides measurements of inter-annual minimum size (in September), this programme included also ice core drilling and radiocarbon dating of ice samples and primitive soils. Results of these studies till 2006 are available in press (Grünewald & Scheithauer, 2007; Grünewald *et al.*, 2008). The Institute of Geography – BAS, organized fieldworks in Golemia Kazan in 2006 and 2008. They comprised measurements of present geomorphic activity (debris movement in taluses), a size measurement of Snezhnika in fall 2008, and detail geomorphic and land cover mapping. The Snezhnika microglacier is surrounded by a well-outlined moraine ridge situated at some distance far from the present ice margins even in years when the size of the firn body during minimum is relatively high. Two more moraine ridges are clearly distinguished to surround the main cirque bottom to the east (Fig. 3). These provide clear evidence for the larger extent of glaciation in the past.

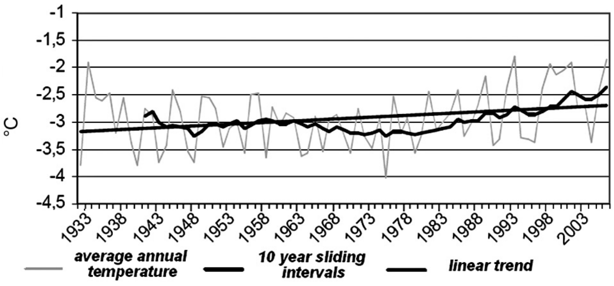

Fig. 5. Temperatures at Musala peak for the period of 1933–2007 (after Nojarov, 2008)

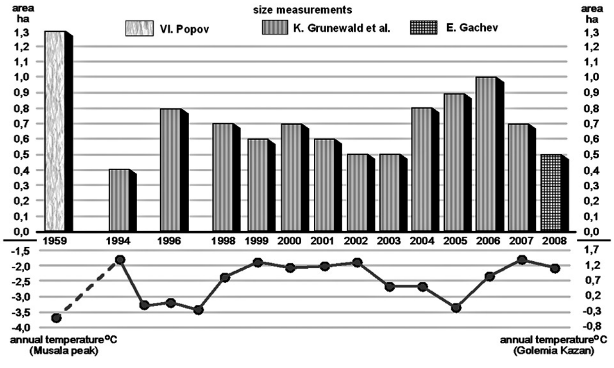

Fig. 6. Variations in the size of Snezhnika in the period of 1959–2008 and their connection to temperature

Discussion

On the basis on what has been observed in the uppermost part of Musala cirque, an hypothesis is raised that the crescent-shaped ridge observed on the bottom of the Ledeno ezero Lake represents in fact a moraine-like feature of relatively young age that was formed by a perennial snow patch or by a small glacier, probably during the Little Ice Age (LIA). Some historical records support this hypothesis. The famous Bulgarian geographer Radev (1920) pointed out the presence of a snow patch “that never disappears”, at the southern part of the Ledeno ezero Lake, at the very slope foot of Musala peak. Louis (1930) reported for 11 microglaciers in Bulgarian mountains at altitudes between 2,650 and 2,925 m a.s.l. This should mean that in the highest areas of the Rila perennial show patches might have existed till the beginning of the last century. Therefore, these features must have had even larger sizes during the LIA. At present, there are no perennial snow bodies in the Rila Mountains, but small patches of last winter snow are observed to survive the summer until the new snowfalls in some years, when climatic conditions are colder and damper than average (such as in 2005–2006). This means that the highest mountain area of the Rila is still in a marginal condition in relation to perennial ice features and a very little drop in temperatures and/or rise of winter precipitation should cause their formation and size increase.

The topographic setting in the deepest N and NE oriented cirques of the northern Pirin Mountains create microclimatic conditions that are more favourable to formation of microglaciers, despite the lower elevation of cirque bottoms compared to Musala area. This is due to the karstified marble bedrock that drains meltwater from snowpatches, the high albedo of white marbles that lowers the insulation, and the smaller amounts of solar radiation because of the high rock walls from the south and west (Peev, 1956, Popov, 1962). However, the configuration of the moraine-like ridge that surrounds Snezhnika suggests that the latter had larger size in the past. Although not precisely dated, the crest should have been formed in its present shape during the LIA. Such an hypothesis is supported by several facts: the state of the lichen cover on the crest (partly but evenly developed) suggests that at present the extent of the snow patch during minimum extension never reaches the crest (no fresh material has been added); and no other moraine ridge is observed further down the cirque bottom – the next ridge in sequence is quite old (weathered, corroded and covered entirely by lichen), with undoubtedly a several thousand year age (most probably Würmian, as firstly stated by Popov, 1962).

Climatic records from instrumental measurements in the highest mountain areas of Bulgaria date from 1932, when the meteorological station at Musala peak was opened. Temperature measurements from this station can be related to the highest region of the Pirin as well, as there is a strong correlation ($R_{xy}=0.99$) between data from Musala peak and those registered in Golemia Kazan cirque in the period 1957–1961 (Nojarov & Gachev, 2007). For the 76 year period of instrumental observation average annual temperatures at Musala peak show year-to-year variation in a range of about 2°C, between – 4°C (1976) and –1.79°C (1994). Clearly expressed cyclic variations in average annual temperatures are observed with duration of 3 to 5 years (Fig. 5). Analyzing 10-year sliding intervals there can be outlined two stages of cooling (in the 1930s – 1940s and in the 1960s – 1970s) and two warming stages (in the 1940s – 1960s and from 1980 to present), while the general trend is towards warming.

When looking at the relation between the size of Snezhnika and the air temperature (Musala peak) on an inter-annual basis, a conclusion can be made that there is quite a close connection between these two parameters (Fig. 6). The firn body reacts with a little delay (about a year), probably in relation to higher (or lower) volumes of ice left from the previous melt season.

What is observed proves the importance of temperature over the regime of perennial ice bodies. A serious problem in analyzing the influence of climatic controls over the size dynamics of Snezhnika is the lack of local precipitation data. Records from Musala peak show a decrease of annual precipitation by 26% in the period 1961–1990 compared to 1933–1985, although values stagnated in the last decade. Despite the strong differences in precipitation regime between Musala peak and the Pirin Mountains, according to Velev (2002) a moisture decrease should be expected to have occurred in the latter as well, because a decrease of annual precipitation in the last 40 years is observed in SW Bulgaria as a whole. Smaller amount of precipitation is most probably a reason for the observed much smaller size of Snezhnika in 1996 and 2005 in comparison to 1959, as it is seen from Figure 5 that the difference in temperature for these years is slight.

Concerning the larger size of the pseudo-moraine crest that surrounds Snezhnika, and also the traces of extinct microglaciers in the highest areas of the Rila, it can be suggested that at some time during the LIA climatic conditions in Bulgarian high mountain zone were much colder, and surely more humid than at present.

An intriguing question rises from the differences in maximum depth registered during the first and the second bathymetry mappings of the Ledeno ezero Lake. Is it possible that lake bottom has risen more than 2 m for several decades if no catastrophic events are known to have been observed in the area, or it is just a matter of a mistake done during the first measurement? A way to properly answer this question is by dating a sample from lake sediments.

Regional interpretation and perspectives

Observations in the cirques Musala and Golemia Kazan show that a few centuries ago microglaciers occupied larger areas of the highest mountain zone of Bulgaria. Most probably such environmental conditions lasted even until the first two decades of the 20th century, although the exact time of maximum spread of perennial ice features during the LIA is still not known.

It is interesting to compare modern and recent temporal dynamics of microglaciers in Bulgaria to those in other areas in the Carpatho-Balkan region. The microglacier Debeli Namet is situated in the Durmitor mountains (Montenegro), in a deep north-facing cirque at 2,150 m a.s.l. The lithology, metamorphosed karstified limestone, is similar to that in the Pirin Mts, although not identical. The climate is humid Mediterranean, with precipitation up to 2,500 mm and average annual temperatures about 0.5°C. Hughes (2007) described a sequence of three clearly defined parallel moraine ridges, situated respectively 1–2, 20–30 and 50 m far from the ice margin of Debeli Namet in fall 2006. Lichenometric dating showed that the lower two of them had been formed at the end of 19th and the beginning of the 20th century. It seems likely that these advances and retreats were in response to slight fluctuations in climate conditions in the very end of the LIA. At the same time only one ridge is formed around

Snezhnika in the Pirin and no traces of such decade-scale dynamics are left in the field. This indicates that Debeli Namet has been much more sensitive to climate changes in the last few centuries than Snezhnika in the Pirin, probably due to the greatest variation of precipitation of the maritime climate. Results of observations of some other microglaciers in the Carpatho-Balkan region show that some of them registered a great size reduction during the last 100 years; Zeleni sneg microglacier in the Julian Alps (Slovenia) has reduced its size 18 times since 1950 and 45 times since 1900 (compared to the size in 2004), Skuta microglacier (the Kamnik Alps, Slovenia) – 3 to 4 times. On the other hand, microglaciers located in the Tatra and Pirin mountains registered much smaller size reduction – for the period 1959–1999 Mięguszowiecki microglacier in the Tatra mountains (Poland) decreased in size by only 5% (Grünewald *et al*., 2008). Size decrease of Snezhnika in Bulgaria is about 2 times (between 1959 and the average for the last 15 years).

These data show that apart from the general tendency towards size reduction, modern and recent changes in microglaciers in our region vary in great extent. This is because the regime of these quite small features is influenced not only by temperature and the complicated local pattern of precipitation, but also from the strong affect of local topography, which should be carefully taken into account when making comparative analyzes.

Conclusions

At present, the highest areas in the Rila and Pirin Mountains have climatic conditions that define them as marginal in relation to the existence of embryonic forms of present glaciation. Slight changes in input climatic parameters will lead to increase of these forms or to their extinction. Latest research in the high mountain zone clearly defined traces of bigger extent of perennial ice bodies in the close past, addressed most probably to the Little Ice Age. However, a comparison with similar areas in the region with a damper climate shows that embryonic glacial features in Bulgarian mountains were and are less sensitive to climatic changes than those in Montenegro and Slovenia for instance. Proper interpretation of these and other results and conclusions requires comparative and synchronized research in the whole Carpatho-Balkan area to achieve a correct regional look on the high mountain climate change.

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