Chapter 25
Research of Field Evidence for Late Quaternary Climate Changes in the Highest Mountains of Bulgaria

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Abstract The highest Bulgarian mountains, Rila (2925 m a.s.l.) and Pirin (2914 m a.s.l.), provide groups of relatively well preserved glacial landforms from late Pleistocene and Holocene cold phases, several small recent perennial ice features, and still well preserved forest ecosystems at the tree limit that can serve as a source for valuable environmental records. Results of our latest studies show that in Rila valley glaciers reached their largest extent during the Last Glacial Maximum (LGM) stage (23,000–19,000 BP), when the Equilibrium Line Altitude of the glaciers was at around 2150–2250 m a.s.l. and the longest glacier tongues went down to 1150–1200 m a.s.l. Traces from several stages of glacier retreat were also found and described.

Another important aspect of environmental change consists of the observation of current environmental phenomena to evaluate local climate change during the past decades and at present. This chapter presents some of the results of research efforts in this field that have been achieved up to the present.

One of the aims of this chapter is to propose incorporation of high mountain environmental change research from all the interested Balkan countries in a network for regional studies and modeling, and, if possible, to establish a workgroup dedicated to this topic.

Keywords Global change • High mountains • Field indicators

25.1 Introduction

Global climate change has recently appeared to be probably the most debated problem not only among the scientific community but also among the entire society at a planetary scale. As a result, environmental reconstructions have registered rapid progress during the past several years. Although entire sets of global climate models

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and scenarios concerning various past and also future periods have been developed, there is still a serious deficit of regional and local data in this area of knowledge. And here is the very tricky moment in studying climate–global changes in the state of the atmosphere that cause quite different local reactions because of the unique combination of specific topography, biotic environment, and human impact at each location (Fig. 25.1). Thus, regional and local response to global changes is very hard to predict without knowing in great detail the current regional and local environmental setting. This problem is of pragmatic importance:–understanding the mechanism of local response will give us the chance to correctly suggest, estimate, and evaluate future changes in our environment.

The present chapter is focused on regional and local environmental change studies in the highest mountains of Bulgaria with the aim of a short review of what has been done and what should be done in the future.

25.2 Bulgarian Mountains: A Target Area for Paleoclimatic Research

The most serious difficulties when trying to reconstruct environmental conditions of the past come from the impacts of human activity. In the context of climate, this is a "vicious circle:" we want to evaluate the changes in climate for some of which we suspect the human factor, and at the same time civilization has destroyed evidence of the natural conditions in the past. This problem is valid for most of Europe, where only in isolated and barely accessible areas is nature sufficiently preserved to tell us what the climate was like in the past. In this aspect the Balkan region has an

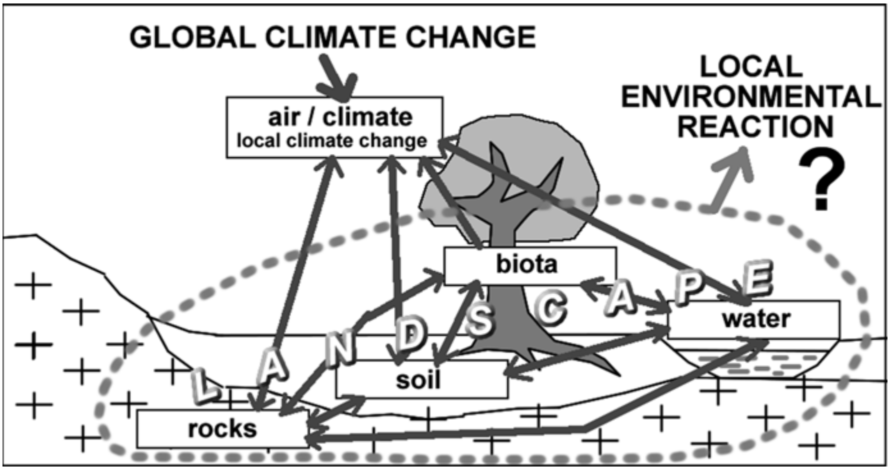

Fig. 25.1 General scheme of the interaction "global change–landscape system"

advantage because here vast areas are occupied by mountains of various height, lithology, and present local climate, and that many of them are still relatively wild in nature.

Although Bulgaria is not as mountainous as some of the neighboring countries, here are found some of the highest mountain ranges, the most prominent being Rila, with Musala peak (2925 m a.s.l.), the highest point of all the Balkan peninsula, and Pirin (2914 m a.s.l.), the third highest after Mt. Olympus in Greece. These two massifs provide remarkable geomorphic traces of past glaciations from the cold phases during the late Quaternary, which makes them very appropriate for paleoclimatic research. Alpine and subalpine areas that are spread above 2200 to 2300 m a.s.l. represent an environment of harsh and marginal nature conditions that is very sensitive and vulnerable to climate changes.

In fact, concerning the diversity of applicable research methods, the target area for environmental change researches in Bulgaria should be broadened to include Rhodope mountains, Central and Western Stara planina, Vitosha, and the mountains along Bulgaria's western border (Fig. 25.2). Evidence from past glaciations at lower elevations is quite rare, but in mid- and low-mountain areas the focus should be on forests as indicators of past natural changes because the Bulgarian mountains host the best preserved forest communities in the country.

Another key aspect of environmental change studies concerns monitoring of the present state of the environment: by this means we can make comparisons to natural states in the past and also directly measure present environmental change, marking the trends in contemporary development of the landscape. Here once again mountains are in a leading position, especially the alpine zone, because of the strong activity of present natural processes, highest sensibility to environmental changes, and still quite limited human impact.

25.3 Types of Indicators and Research Methods

Because of the insufficiency of data from direct climatic measurements in the spatial as well as in temporal aspect, environmental change studies in high mountain areas on a regional and local scale are based most of all on the existence of field evidence that indicates different conditions in the far or near past. According to research methods that have been used at present, such evidence can be summarized in several categories (Fig. 25.3).

Of course, instrumental measurements also are an important part of the studies. The start of climatic records in the high mountain area of Rila date from 1932, when a meteorological station at Musala peak was opened. However, as noted in Table 25.1, the number of climate stations in our country at altitudes above 2000 m a.s.l. is very small.

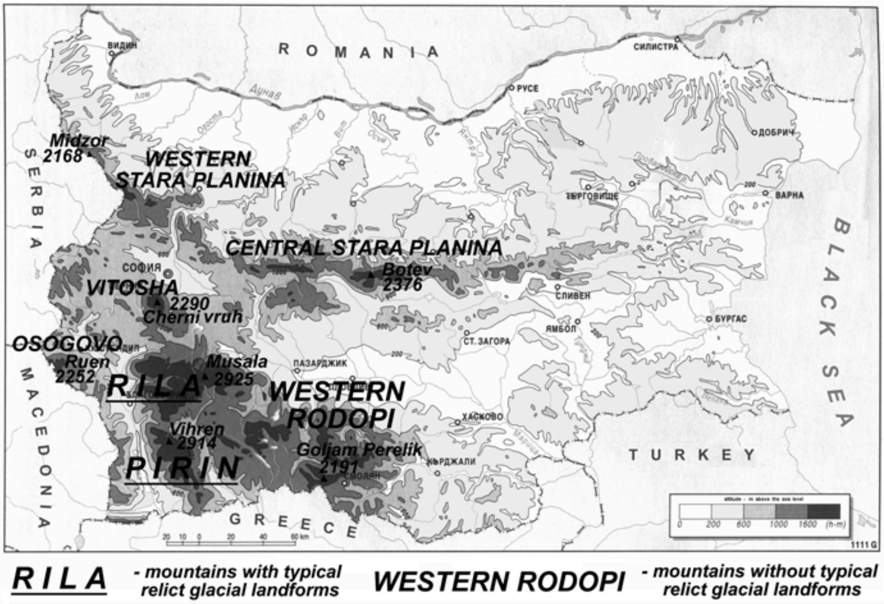

Fig. 25.2 Key mountain areas for environmental change studies in Bulgaria

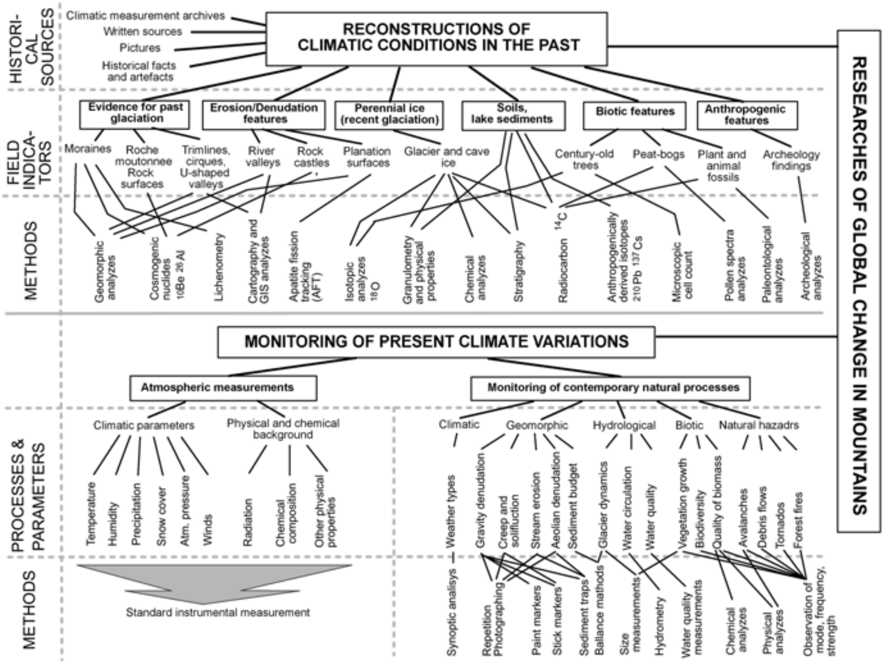

Fig. 25.3 Field evidence for evaluation of environmental change and main methods for research

Table 25.1 Distribution of climatic stations in high mountain areas above 2000 m a.s.l

Station	Altitude (m a.s.l.)	Location	Period of operation
Musala peak	2925	Rila	1933–present
Golemia Kazan	2450	Pirin	1957–1961
Kalin dam	2390	Rila	1956–1975
Musala hut	2389	Rila	1940–1990
Botev peak	2376	Central Stara planina	1940–present
Cherni vruh	2290	Vitosha	1935–present

25.4 Previous Geographic Studies in Rila and Pirin

High mountains have attracted the interests of naturalists since the beginning of nineteenth century AD. The first explorer who made natural descriptions of Bulgarian mountains was Boue (1840). Cvijic (1896, 1908) was the first to describe the relict glacial landforms in Rila, and Louis (1930, 1933) described and analyzed glacial morphosculpture and planation surfaces in the mountains. Leutelt-Kipke (1932), with a team of students from Innsbruck, made the first bathymetry mapping of glacial lakes in Rila (Musala Lakes) and measured water quality (temperature, salinity, ion concentration). In the 1950s and 1960s, studies were carried out by Bulgarian geographers. Ivanov (1954) and Glovnia (1958, 1961, 1962) made detailed descriptions and mappings of relict glacial landforms in Rila massif. Peev studied avalanches in Pirin and mentioned the existence of a "firn glacierette" in Bajuvi Dupki cirque in the northern part of the mountain (Peev 1956). Vladimir Popov from the Institute of Geography–BAS carried out a 4-year monitoring program of the cirque Golemia Kazan in Pirin (1957–1961), which was the most prominent study of this type for its time. Along with the detailed geomorphic mapping, systematic climatic observations were organized in the cirque and a small building was erected. Popov (1962, 1964) was the first to describe and measure Snezhnika, a perennial snow patch that lies at 2400–2450 m a.s.l. He explained the existence of these embryonic glacial features in Northern Pirin with the specific lithology (white karstified marbles) and topography (shading by high vertical rockwalls). In past decades glacial landforms in Rila were studied by Velchev (1995, 1999), Baltackov and Cherkezova (1991), Baltackov (2004), and in Pirin by Choleev (1982). All these authors relied on relative dating of relict landforms based on geomorphic evidence, standing on the position of the occurrence of two main glacial stages: Rissian and Würmian. An important contribution to the issue was the detailed study and mapping of subalpine and alpine grassy vegetation in Rila made by Rusakova (1990), and the palinological researches of peat bogs and lake sediments performed by Bozhilova (1972, 1995), Bozhilova et al. (2002), Bozhilova and Tonkov (2000), Tonkov and Marinova (2005), and Tonkov et al. (2002, 2006), through which the basic changes of the vegetation in Rila and Pirin during the Holocene were shown.

In 1992–1998 a French-Bulgarian project called OM2 came into force in Rila mountain. The project included much monitoring research in different components and characteristics of environment (radiation background, chemical contamination, biodiversity, etc). Results were published in the journal "OM2 series" issued by the Institute of Nuclear Research and Nuclear Energy (INRNE)–BAS. The main result of the project was the opening in 1999 of the Basic Environmental Observatory (BEO) "Musala," a station for complex environmental monitoring situated at 2925 m a.s.l. on the very top of Musala peak. Although the OM2 project was not attended by geographers, the field and instrumental data obtained during its performance served as a good basis for geographic studies. BEO "Musala" is governed and managed by INRNE, and since 2002 has been obtaining climatic and air quality data that are available online (see Stamenov et al., this volume).

In the years since 1994, a team from the Center for Landscape Research in Dresden (Germany) has been conducting systematic environmental observations in Northern Pirin. Some of the main activities of the program have been dendrochronology studies at timberline to evaluate recent changes in tree growth of *Pinus heldreichii* as a result of local climate change, and regular measurements of the size of the glacieret "Snezhnika" in Golemia Kazan cirque (in September, during the stage of annual firn mass minimum), which, for the period of observation, showed variation between 1 ha (2006) and 0.4 ha (1994). In 2006 a group of researchers from Dresden, led by K. Grunewald, in cooperation with specialists from the Institute for Space Research of the Bulgarian Academy of Sciences (BAS), made three core drills in the firn body and took samples for absolute dating and chemical analyses. A drill in the central part of Snezhnika registered 11 m thickness of the ice mass. At this time the moraine ridge that surrounds the snow patch was also studied: layers of primitive soil were found on the crest to date from the early Middle Ages, whereas the formation of the ridge in its present configuration is suggested for the Little Ice Age (LIA; fifteenth to nineteenth centuries AD) when the snow patch must have been quite larger (Grunewald et al. 2008). This monitoring program is still ongoing, and in 2007 two temperature data loggers were installed in the cirque to measure local temperature.

25.5 Review of Achieved Results

25.5.1 Researching Environmental Conditions of the Past: The Glacial Evidence

Although relict glacial landforms, especially in Rila, were subject to numerous studies, still no common interpretation of their distribution has been done for the whole Rila and Pirin mountains, and results obtained about environmental settings of the past have not been summarized on a regional scale, especially by comparison with glacial evidence from adjacent mountain massifs. That is why the Institute of Geography participated in two terrain studies in 2007 and 2008, dedicated to a study of former glaciations in Rila. The first fieldwork was initiated and organized by the Geosciences Institute, University of Tubingen, Germany, and led by Prof. Joachim Kuhlemann. For 9 days all main valleys of Rila mountain were searched and moraine features were described and mapped. Samples were also taken for cosmogenic nuclide dating (^{10}Be) to estimate the absolute age of glacial deposits. Results showed that most terminal moraines in the valleys of the Rila mountains date from 18 to 16 ka BP – the very end of the LGM and the beginning of the Late Glacial. Just for the outermost ridge of the moraine above the Beli Iskar village, an age from the beginning of the LGM (24 ka BP) was obtained (Kuhlemann et al. 2013). The main conclusion from this study is that most landforms from the relict glacial complex are quite new with the oldest moraine features dating from Late Würmian (LGM) and the newest probably from the cold phases during the Holocene. No glacial accumulative landforms were registered from earlier glacials (e.g., Riss or Mindel) as some of the previous authors suggested, although there are geomorphic traces of previous glacial stages, such as parallel trough valley trimlines and some old cirque shoulders.

Analysis of the positions of LGM terminal moraines and of the configuration of trimlines in the analyzed river (for which aerial photographs were also studied), showed that the equilibrium line altitude (ELA) of Rila glaciers during their maximum spread (LGM) had been lying at 2150 to 2250 m a.s.l., with a gradual rise from northwest to southeast. Considering a temperature lapse rate of −0.6 °C/100 m altitude, this should mean that average temperatures during the coldest phase of the LGM were about 6 °C lower than at present. Compared to the Alps and the mountains of the Western and central Mediterranean, the LGM equilibrium line in Rila was situated much higher, and differences between north and south aspects were quite small. These results suggest a considerable smaller moisture supply in Rila Mountain during the LGM and support the hypothesis of a compensatory warm advection from the south in the eastern Mediterranean as a response to the cold northerly advections in Western Europe for this period (Fig. 25.4). Obtained ages of moraines indicate that in the context of prevailing southwest winds during the coldest phase of the LGM, most favorable conditions for glaciation in Rila existed in the beginning and in the end of the cold episode when air mass transition from the NW prevailed, but at lower temperature levels (Kuhlemann et al. 2013).

To study the newest traces of glaciation, a field survey was held in summer 2008: its task was to research the morphology of the bottom of Ledeno Ezero, the highest lake in Rila, situated at 2709 m a.s.l. On the created detailed bathymetry map (second after the one made by the Austrian team of S. Leutelt-Kipke in 1932), a well-outlined crescent-shaped ridge can be identified underwater in the shallow SW part of the lake (Fig. 25.5). The crest rises up to 2 m from the shallow part of the lake bottom, its highest point lying 2.1 m under the water level. Geomorphic indications, meteorology records, and historical sources support the hypothesis that this ridge represents a relatively young moraine feature, formed probably by a perennial snow patch (micro-glacier) during the Little Ice Age (LIA). Today there are no perennial snow patches in Rila, and some small spots of last winter's snow may survive the summer only in years colder than average, but historical sources say that the presence of firn bodies was common in the beginning of the twentieth century.

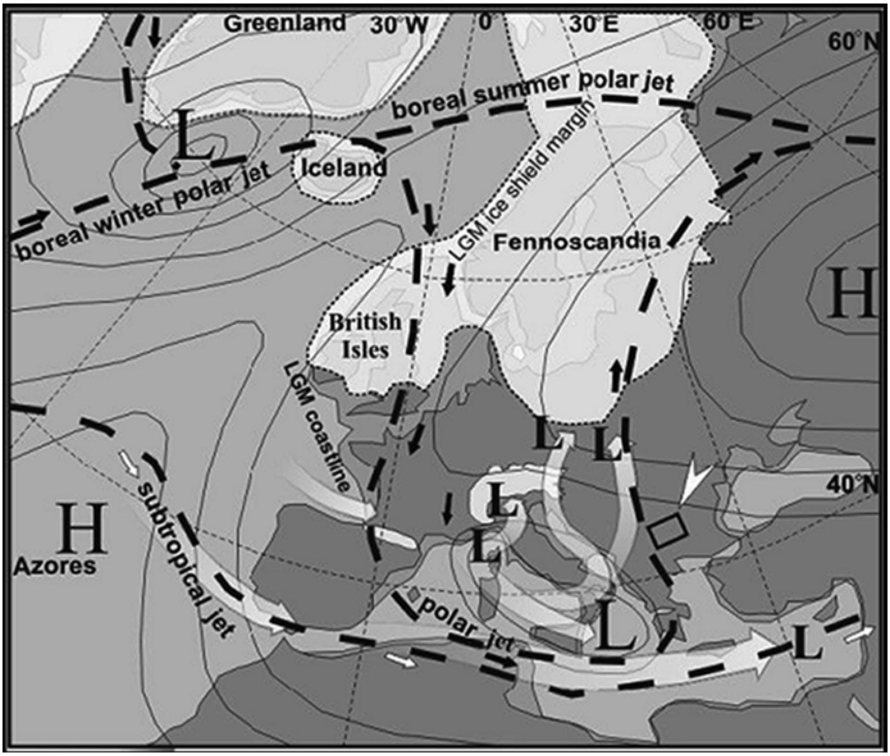

Fig. 25.4 Sketch map of Europe, showing the outline of LGM ice sheets, coastlines, and potential cyclone tracks (*L*) postulated on the base of the new ELA isoline pattern (After Kuhlemann et al. 2008) (*The *hatched line* for a preferential flow of the jet stream in the high troposphere is only a hand-fitted tentative estimate; Mediterranean cyclone tracks are marked in *white*)

Thus, Radev (1920) wrote about "a patch of snow that never disappears at the SW end of Ledeno ezero," that is, just at the location where the ridge was found, and Louis (1930) mentioned "several small glaciers in the high areas of Rila and Pirin." All this information suggests that climatic conditions in the highest cirques of Rila are marginal in relationship to embryonic forms of glaciation (i.e., the present equilibrium line altitude in Rila is not far above the highest peaks), and a small but continuous drop in temperatures will cause their formation. However, for the period of instrumental observation (1933–2008), temperatures at Musala peak were ranging between −1.7 °C and −4.0 °C and showed a general trend of warming, although there was a shift of four contrasting short-term trends, toward a decrease (in the 1930s and 1940s), an increase (in the 1940s–1960s), a decrease (in the 1960s–1970s), and finally a period of sufficient increase (since 1980). Average annual temperatures at Musala have shown a cyclic variations over a range of about 0.5–1.5 °C with a duration of 3 to 5 years. In general, when looking at sliding averages (10-year intervals) it appeared that the rise of temperature for 1998–2008 compared to 1933–1943 has been about 0.5 °C, and for 1998–2008 compared to 1958–1968 was about 1.0 °C (Nojarov 2008).

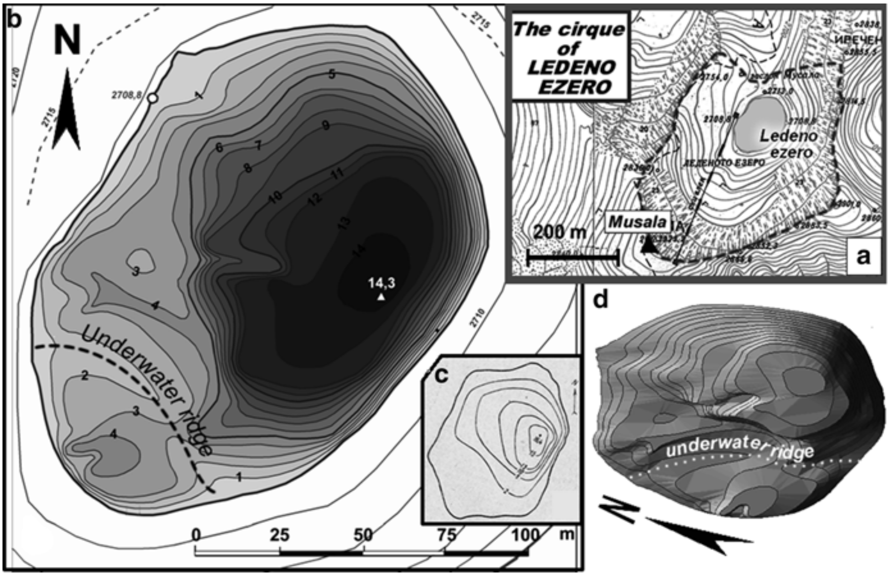

Fig. 25.5 Bathymetry map of Ledeno ezero (the Icy Lake) (Gachev et al. 2008). At the *bottom* on the *right* is the first map made by S. Leutelt-Kipke (1932)

Although there are no measured data in the Bulgarian high mountains before 1933, regional climatic evidence surely indicates that the climate was much colder in about 1910 and suggests that long-term average temperatures were more than 1 °C lower than at present; this should be considered as a maximum temperature for the formation of perennial snow patches in the higher areas of Rila Mountain.

Clear traces of a greater extent of the embryonic forms of glaciation can be observed also in Pirin, in Golemia Kazan cirque. Snezhnika glacieret is surrounded by a well-outlined moraine ridge situated at some distance away from the present ice margins even in years when the size of the firn body during minimum is relatively high. As already mentioned (Grunewald et al. 2008, 2011), the crest should have been formed in its present shape during the LIA. Such a hypothesis is supported by the state of the lichen cover on the crest (partly but evenly developed), which indicates that at present the ice margin during minimum never reaches the crest (no fresh material has been added), and on the other hand no other moraine ridge is observed further down the cirque bottom; the next ridge in the sequence is quite old (weathered, corroded, and covered entirely by lichen), undoubtedly several thousand years in age (most probably Würmian, as first stated by Popov 1962). As in Rila, this larger extent of Snezhnika in the past is a result of climate conditions with lower annual temperatures and probably higher precipitation. The role of each of these climatic factors over the extent of glaciation is hard to differentiate, but it is certain that they both are of great importance. The influence of temperature on the dynamics of perennial snow patches can be clearly seen when comparing the size fluctuations of Snezhnika in the past several decades and air temperature (Fig. 25.7).

25.5.2 Monitoring of Present Geomorphic and Hydrologic Processes

In 2003 the Institute of Geography launched the project “Models of contemporary periglacial morphogenesis,” in which detailed 3-year observations were planned to be carried out on a comparative basis in four key areas: Musala area in Rila Mountain, Vihren area in Pirin Mountain, Livingston Island in the Antarctic, where the Bulgarian Antarctic base is operating, and Spitzbergen Island in the Arctic (Stefanov et al. 2003). The project was carried out in 2004–2007, and because of the severely restricted funding by the Ministry of Education’s Council for scientific research, project activities were carried out to a very limited extent and were concentrated only in the areas of Musala and Vihren peaks. According to the treaty for collaboration signed between INRNE and the Institute of Geography, all research activities in Musala area has become part of the BEO “Musala” observation of terrestrial processes. Activities under this particular project included measurements of water chemistry of Musala lakes, detailed environmental mapping in GIS of Musala cirque, and setting up polygons for monitoring of weathering and slope denudation (solifluction).

An important step forward was the incorporation of Bulgarian research on high mountain geomorphic processes into the global networks of the International Association of Geomorphologists (IAG/AIG). The research team from the Institute of Geography was accepted to participate in the global network SEDIFLUX (sediment source-to-sink fluxes in cold environments). The network aimed to establish worldwide observations and quantitative measurements of contemporary geomorphic processes in Earth’s high latitudes and high altitudes to evaluate current climate fluctuations and trends.

At the fourth science meeting of SEDIFLUX in Trondheim (Norway) in 2006, the Institute successfully promoted Musala area (the upper parts of Musala and Maritsa cirques) for inclusion in the global network for research of present sediment transfer processes in cold environments that should be built up in 2009–2012 under the coordination of the newly established IAG/AIG workgroup SEDIBUD (sediment budgets in cold environments). Now the Musala area is one of the several high-altitude and high-latitude key test sites worldwide (Fig. 25.6), which should contribute to a special global change database for cold environments and where observations should be performed following a unified methodology according to the commonly approved SEDIFLUX Manual (Beylich and Warburton 2007). The Musala area is the only place in Southeastern Europe that is included in the SEDIBUD network of test sites. For now, all sites included in the network must find their own funding for research. Under present conditions this is still a difficult task, so research continues at an insufficient pace.

Since 2008, researchers from the South-West University of Blagoevgrad, Bulgaria, and Bulgarian Academy of Sciences have been performing regular measurements of perennial snow and ice bodies in the Pirin mountains (Gachev et al. 2009; Gachev, 2014) to complete the results obtained by Grunewald et al. (2008).

Fig. 25.6 SEDIBUD global network of test sites (preliminary list, 2008): *1* Cape Bounty (Canada), *2* Botn í Dýrafirði (Iceland), *3* Tindastöll (Iceland), *4* Hrafndalur (Iceland), *5* Örravatnrústir (Iceland), *6* Fnjóskadalur (Iceland), *7* Hofsjökull (Iceland), *8* Austdalur (Iceland), *9* Kangerlussuaq (West Greenland), *10* Mittivakkat-Sermilik (Greenland), *11* Zackenberg (Greenland), *12* Petuniabukta-Sermilik (Spitsbergen), *13* Scottelva-Svalbard (Norway), *14* Moor House, North Pennines (UK), *15* Erdalen (Norway), *16* Kidisjoki (Finland), *17* Latnjavagge (Sweden), *18*Bodalen (Norway) *19* Pasterze (Austria), *20* Musala Area (Bulgaria), *21* East Dabka (India), *22* Godley Valley (New Zealand), *23* Potrok Aike (Argentina)

The area of the Snezhnika glacieret, which is situated at 2400–2450 m a.s.l. under the NW wall of Vihren, was measured in the autumns of 2008–2014 (results presented in Fig. 25.7). The other glacieret in the Pirin mountains, Banski Suhodol, located 2600–2710 m in the cirque with the same name, was studied for the first time in 2009 and has been regularly monitored since then (Gachev and Gikov 2010). In October 2012, fresh glacial striations were found on bedrock surfaces near the glacieret, which were exposed for the first time during the period of observations. This has been the first direct evidence for the presence of a glacier-type dynamic motion for the glacierets in Pirin (Fig. 25.8). The importance of temperature over the regime of perennial ice bodies is well illustrated by the close relationship between air temperature and the size of Snezhnika in periods of minimal ice extent with annual air temperatures (Fig. 25.7). Musala peak is used as a reference parameter for estimating temperature conditions, because there is a strong correlation between temperatures in the highest parts of Rila and Pirin (Nojarov and Gachev 2007), and temperatures in the bottom of Golemia Kazan are about 2.6 °C higher than those at Musala.

The firn body seems to react with a small delay (about a year), probably in relationship to higher (or lower) volumes of ice left from the previous melt season. Sadly, the present analysis excludes the precipitation factor, because there have been no instrumental measurements of climate since 1961 and the great differences in the regime do not allow using precipitation data from Musala peak. If taking into

Fig. 25.7 Variation in interannual size of the Snezhnika micro-glacier and its relation to air temperature

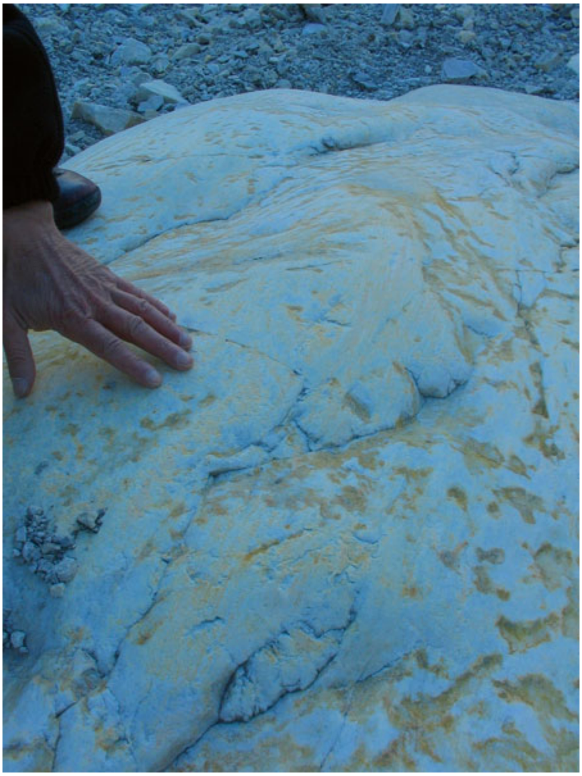

Fig. 25.8 Field measurements of slope gravity processes (Golemia Kazan cirque, Pirin Mountains)

account the fact that a decrease of annual precipitation in the past 40 years is observed in SW Bulgaria as a whole (Velev 2002), a suggestion can be made that the observed much smaller sizes of Snezhnika in 1996 and 2005 in comparison to 1959 (as seen in Fig. 25.7) were caused mainly by the lesser amounts of precipitation, as air temperatures for these particular years differed slightly. The other glacieret in the Pirin mountains, Banski suhodol, located at 2600-2710 m in the cirque with the same name, was studied for the first time in 2009, and has been regularly monitored since then (Gachev and Gikov 2010). In October 2012 fresh glacial striations were found on bedrock surfaces near the glacieret, which were exposed for the first time during the period of observations. This has been the first direct evidence for the presence of a glacier-type dynamic motion for the glacierets in Pirin (Fig. 25.8).

25.6 The Future: Prospects and Expectations

Future activities within the framework "Himont research" should follow the conceptual guidelines of global climate change studies. Research in the Bulgarian mountains needs to be incorporated in a joint effort extending to a regional scale, possibly within the Carpatho-Balkan region. Thus, we recommend initiation and building up of a Balkan workgroup for high mountain environmental studies with a focus on climate change and its local impact on the diverse mountain landscapes of the Balkans. To have a regional look is the only way to properly understand and interpret results from local studies, not only those made in Bulgaria, but elsewhere. Creation of a network of scientists from the Balkan countries will make it possible to elaborate regional climate change models, assessments, and forecasts. For this purpose, a regional mountain environmental change database should also be established.

Priorities in the future development of research in Bulgaria will be placed on a steady broadening of the spatial extent of research and the range of methods used. After 2011, we broadened our study area also including regular monitoring and research of small glaciers in mountains of the western Balkan peninsula: Prokletije (in Albania and Montenegro) and Durmitor (in Montenegro). In particular, ten possible small glaciers were described for the first time in the Albanian parts of Prokletije. During the last years, we have established close contact and collaboration in the field of glacial geomorphology with colleagues from the University of Belgrade (Serbia), the Geographical Institute in Ljubljana (Slovenia), and the Universities of Timisoara and Suceava (Romania).

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25.7 Conclusion

The Bulgarian high mountains Rila and Pirin provide valuable field evidence for estimations of past climatic conditions. Available geomorphic traces from past glaciations suggest that during the coldest phase of LGM average temperatures were at least 6 °C lower than at present, and during the Little Ice Age were 1 to –1.5 °C lower than at present.

Today the alpine zone represents a marginal environment with intensive occurrence of geomorphic processes that can serve as a tool to assess present climate fluctuations. On this basis the Musala area is included in the global network of SEDIBUD test sites for establishment of monitoring these processes following a standardized methodology.

Among the most sensitive field indicators for current environmental changes are perennial snow bodies in Pirin, for which a character of small glaciers was proved (Gachev 2014, Gachev et al. 2015 in press). At present the marginal position of the alpine zone determines an absence of such features in the highest areas of Rila and their presence in Pirin at lower altitudes because of specific lithology and topography. Research in Musala cirque (Rila) and Golemia Kazan cirque (Pirin) shows that very little change toward cooler and damper climate conditions will cause formation of micro-glaciers in Rila, whereas further warming and drying will threaten the existence of perennial snow patches in Pirin.

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