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Characterisation of contemporary local climate change in the mountains of southwest Bulgaria

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Abstract The Pirin Mountains in southwest Bulgaria spatially mark a transition between the Mediterranean and temperate climate zones. Therefore they are also particularly relevant for research on high mountain climate and the effect of landscape transformation. Historical climate records gathered in the area have been researched, checked and statistically examined. The mountainous climate has been characterised and trends in the evolution of temperature and precipitation since 1931 have been outlined. There are objective evidences for an increasing annual mean temperature, longer vegetative periods and local droughts in spring and autumn. Significant changes also appear in climatic threshold values such as the number of frost change days. This last parameter is very important for the sustainability of mountainous ecosystems.

1 Introduction

Spatial factors such as the geographical latitude or the landmass continentality influence a region's climate. Further, mountain ranges mark and regulate regional climate processes. The Rhodope massif along with the Pirin and Rila Mountains constitute a disruptive element in the atmospheric circulation over southeast Europe. The climate of these high mountains differs significantly from the climate of the surrounding plains, basins and valleys due to the vertical gradient of the atmospheric parameters. Mountains intensify spatial climate contrast from valleys to valleys and

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disparity of climate temporal regimes (Böhm 2004). They can be seen as a vertical stack of horizontal climate zones. In Bulgaria, for instance, a distance of only 100 km separates the coldest place (Musala Peak in Rila Mountains) from the warmest place (Sandanski in Pirin Mountains). This means that polar and subtropical–Mediterranean climate characteristics can be found very close to each other in the area of study.

Southeast Europe is constituted of a mosaic of several small mountain regions and countries (Fig. 1). This strong internal differentiation generates a wide diversity of local physic-geographical and socio-economic situations. On the one hand, high mountain regions such as the Rila Mountains receive ample precipitation and experience permanently low temperatures. On the other hand, the southern peripheral areas, either highlands or lower areas are dry and warm (for instance in northern Greece). Consequently, this strong local geographic diversity offers limited options for extended land use but in the contrary offers a high potential for nature conservation and recreation areas. However, even two decades after the political change, the long-term national isolation due to the former eastern block political regime as well as the legacy of the Balkan historical complexity have left their mark on the region. Systematic environmental screening is still an exception in this area of Europe (Alitchkov and Kostova 1996; Grunewald et al. 2007). In addition, there is a considerable lack of knowledge regarding the dynamic of weather and climate (time and space), the water supply (snow, lakes), and the water availability (where and when) at the regional level.

Climate predictions for mountain regions are very uncertain because of the effect of regional variability and heterogeneity as well as because they are monitored by an insufficient number of weather stations. This paper is aimed a detailed analysis of available meteorological data series for south-western Bulgaria followed by a discussion of the possible climate trends for this mountainous region. These results are relevant to ecological and environmental issues linked to the sustainable development of forestry and agriculture in the area as well as that of tourism and health care.

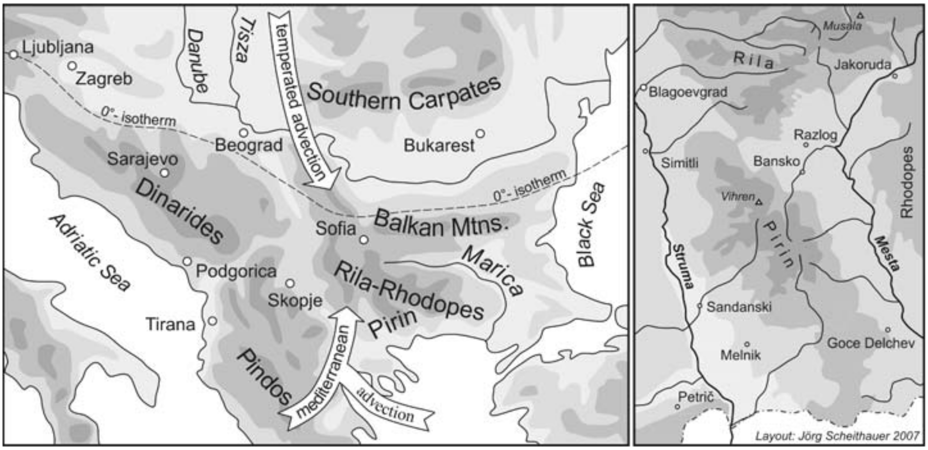


Fig. 1 The Balkans—major mountains, rivers and cities (*left map*, 0°C-isotherm in January according to Altemüller 1989), zoom in southwest Bulgaria (*right map*)

2 Analysis of meteorological observations

In south-western Bulgaria, climate data has been acquired since the beginning of the twentieth century. Monthly temperature and precipitation measurements are available for the stations of Musala Peak (Rila Mountains) and Bansko (northern Pirin Mountains foothills) since 1931. Petkova et al. (2004) reconstructed trends of snow cover for Bulgarian mountains over the same period. Several other stations located in the Bulgarian lowlands started measuring and recording climate data around 1900 (Alexandrov and Genev 2003). Thus, compared to similar time series available for the Alps (Böhm 2004), climatological measurement started in Bulgaria some 100–170 years later (Sharov et al. 1999, p. 55).

Table 1 shows the vertical distribution of the 25 weather and climate stations available in the Pirin Mountains and adjacent areas. They extend over the 6,500 km^2 of Blagoevgrad district which means that on the average there is one station per 260 km^2.

Although the measuring network seems well distributed both spatially and vertically, its technology is presently outdated and data quality in particular such as that of precipitation measurements is uncertain. Many stations have been used temporary only or even dilapidated since the political change which occurred in 1990. It is only at Musala Peak that a modern monitoring station has been established with the help of France (Stamenov et al. 2001). The stations of Musala Peak, Bansko, Vihren Hut and Sandanski supply well populated time-series. However, other stations often provide data on the basis of monthly mean values sometimes based on historical series of measurements (1930–1970; Anonymous 1977).

Climate data administration in Bulgaria is under the responsibility of both the Bulgarian Academy of Sciences (BAN) and the National Institute of Meteorology and Hydrology (NIMH) in Sofia. However, since data pricing often exceeds usual research projects budgets, other sources such as reports, statistics and the open-access data on internet are usually used as well. For our study, most of these alternate sources have been used to the exception of GCM grid-data which did not show enough consistency with local observations in the area of study.

Climate variability assessment must be based on carefully examined and standardised instrumental time series (Auer et al. 2001). In our case, monthly mean temperature and precipitation values were submitted to significance tests and *t*-tests, statistical screening and stations were also compared to each other (Schönwiese 2000).

Table 1 Vertical distribution of climate stations in southwest Bulgaria

Geographical unit	Altitude (masl)	Share of the unit of the district Blagoevgrad (%)	Number of stations
Lowland	< 200	4.8	3
Basins/hilly	200–600	18.4	4
Lower mountain zone	600–1,000	26.8	7
Middle mountain zone	1,000–1,600	36.3	4
Upper mountain zone	1,600–2,200	10.3	4
Alpine zone	$> 2,200$	3.4	3

It is common knowledge that measurements of precipitation in high mountain regions generally include high discrepancies due to relief effect, velocity of wind and high snow rates. According to Veit (2002), the error rate is about 15% in the case of rain and as high as 50% in the case of snow. These error rates are often underestimated, may increase with altitude and bias annual values. Therefore, precipitation statistics gathered in the Pirin Mountains should be taken with precaution as the small number of available stations is not sufficient to capture the full precipitation's spatial and temporal heterogeneity.

3 Regional climate aspects

Due to their latitude, most parts of Bulgaria are influenced by the Azores anticyclones. According to the Lauer/Frankenberg classification, a warm temperate, continental, semi-humid climate dominates which is classified as C*fb* following W. Köppen (Weischet 2002).

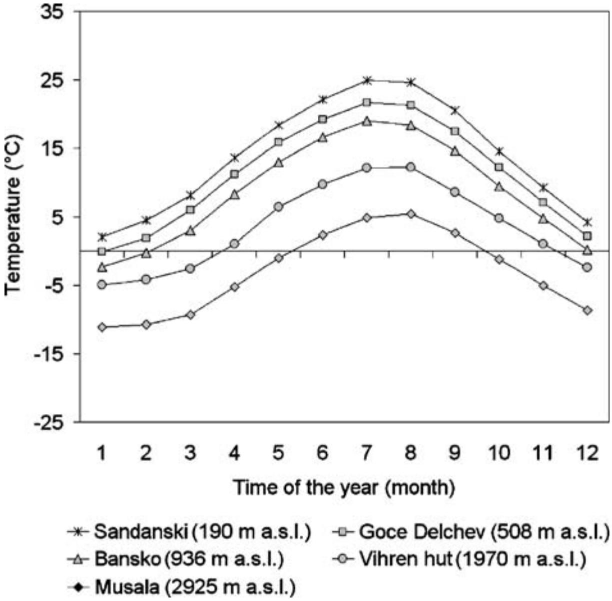
The climatic regimes display a transitional character between the continental influences coming from Europe, West Asia and to some extent North Africa, and the maritime influences of the Atlantic Ocean, Black Sea and the Mediterranean Sea. At local level, orographic factors from the main mountains relief (Stara Planina, Dinarides, Rhodopes) determine climate characteristics. Recent suspected shifts in global pressure systems and wind belts also bring subtropics influences which become noticeable in south Bulgaria (Velev 1990; Grunewald and Stoilov 1998).

Our area of interest in southwest Bulgaria covers two typical climatic regions, namely: the Mediterranean transitional climate and the mountainous climate (Dimitrov 1996). The former region is under the influence of warm air coming from the Aegean Sea region and which mostly affects the southern valleys of the Struma and Mesta rivers (Fig. 1). The beech-fir-forest belt (above 900–1,400 m of altitude in southwest Bulgaria) marks the transition to the mountainous climate. Vertical layering of temperature and local relief influence the climate and often lead to thermal inversions sites. Therefore, the climate in the Pirin Mountains and adjacent areas shows a strong differentiation driven by a variety of influences: air stream, solar radiation, lee- and windward effect, mountain wind, vertical distribution of temperature and precipitation.

3.1 Temperature

Figure 2 displays the mean monthly temperatures of selected stations and gives an overview of the regional temperature range and the spread of annual mean temperature. It is to notice that at alpine altitude, the mean temperature values were below 0°C during the twentieth century. The values vary according to altitude and are modified by the N–S-location. Temperature decrease with altitude is more developed in summer and this may be the reason for smaller annual temperature amplitudes in comparison to what happens in nearby valleys (Koleva 2003). January is the coldest month and average temperature difference between the highest northern station (Musala Peak with −11.1°C) and the lowest southern station (Sandanski with +2.1°C) is 13°C. This difference is even higher with about 20°C during the

Fig. 2 Mean monthly temperatures in south-western Bulgaria in the period 1931–1970 (data base: Anonymous 1977; Musala Peak added)



warmest months of July and August. Rashev and Dinkov (2003) classified the area near Sandanski as Mediterranean climate with cold winters.

Threshold values have been calculated using the measured daily temperatures at Musala Peak station (2,925 m) from 1973 until 2006 which amount to about 12,000 single measurements. These values were extrapolated to the areas of the timberline and the kars in the nearby northern Pirin Mountains (Kar Golemija Kasan, 2,500 m; Kar Malkija Kasan, 2,200 m and Vihren Hut, 1,970 m) as well as for the town of Bansko (936 m). Tables 2, 3, and 4 summarise the results and clearly show the influence of altitude.

Most days in the upper mountainous region can be considered as “cold days” (above 1,970 m) while “summer days” are very rare (Table 4). However, the number of days with frost varies strongly from year to year. The limits of tree-growth depend heavily upon temperature (100 days with more than 5°C) and hence timberline is situated between 2,000 and 2,400 m. The vegetative period characterised by temperatures of more than 5°C can help in categorising the stations as follows (cf. Anonymous 1977, 2003):

1. lower and middle altitude: from mid-April until the beginning of November (180–215 days)
2. upper altitude: from the beginning of May until October (120–160 days)
3. highest altitudes, summits: less than 100 days

A specific characteristic in mountainous regions is the frost change climate. A “frost change day” is a day on which one or more movements through 0°C occur (Geiger et al. 2003). The number of frost changes occurring on a *frost change day* is an indicator for thawing–freezing-cycles. The average number of frost change days per year ranges from 89 to 92 days at the timberline in the study area (Table 4) and is

Table 2 Statistic of daily temperatures in the period 1973–2006

	Musala			Golemija Kasan			Malkija Kasan			Vichren hut			Bansko		
	$T_{\emptyset}$	$T_{\max}$	$T_{\min}$	$T_{\emptyset}$	$T_{\max}$	$T_{\min}$	$T_{\emptyset}$	$T_{\max}$	$T_{\min}$	$T_{\emptyset}$	$T_{\max}$	$T_{\min}$	$T_{\emptyset}$	$T_{\max}$	$T_{\min}$
Mean	−2.8	0.2	−5.4	−0.6	2.5	−3.2	1.0	4.1	−1.6	2.9	6.0	0.3	8.4	11.4	5.8
Max.	15.3	25.0	12.5	17.5	27.2	14.7	19.1	28.8	16.3	21.0	30.7	18.2	28.3	38.0	25.5
Min.	−29.6	−26.4	−31.6	−27.5	−24.3	−29.5	−26.0	16.3	−28.0	−24.1	−20.9	23.0	−19.2	−15.7	−22.6

Table 3 Threshold values of temperature based on daily averages (mean number of days per year in the period 1973–2006)

Station	Altitude (masl)	$< -5°C$	$> -5°C$ to $<0°C$	$>0°C$ to $<5°C$	$>5°C$ to $<10°C$	$>10°C$
Musala	2,925	137	89	86	46	5
Golemija Kasan	2,500	96	90	88	71	18
Malkija Kasan	2,200	70	88	86	83	35
Vichren hut	1,970	47	77	88	88	64
Bansko	930	20	37	70	67	168

lower both in summit areas and in the lower mountain zone (77 days at Musala Peak, 62 days in Bansko) where lengths of ice days or warm days are more important.

The number of frost change days per month in Bansko shows only one maximum in winter while days with frost change do not occur in the summer. For higher stations situated near the timber line such as the Vihren Hut and the Kar Malkija Kasan, there are maxima in April as well as during the winter in November and December. However, frost change days are rare at this altitude from June until September. For the summit station of Musala Peak, two maxima (May and October) and two minima (winter and summer) are observed (Fig. 3). This behaviour is close to the one observed in the Eastern Alps (Veit 2002).

3.2 Precipitation

Precipitation patterns are strongly determined by relief (altitude, lee-/windward effects), atmospheric circulation, and the humidity of circulating air masses. In the upper mountain regions of south-western Bulgaria, the average annual precipitation ranges from 1,000 up to 1,300 mm/year in isolated areas (on north-facing slopes and/or summits). In the lower and middle mountain regions (Anonymous 1977) it lowers to 700–1,000 mm/year. Some intra-mountainous basins and particularly the southern valleys are relatively dry with an annual precipitation between 400 and 700 mm and high evapotranspiration.

Figure 4 compares the distribution of annual precipitation values for the stations of Bansko and Musala Peak during years 1973 until 2005. In the town of Bansko,

Table 4 Threshold values based on daily minimum and maximum temperatures (mean number of days per year in the period 1973–2006)

Station	Frost changing days ($T_{min} < 0°C$/ $T_{max} > 0°C$)	Frost days ($T_{min} < 0°C$)	Ice days ($T_{max} < 0°C$)	Cold days ($T_{max} < 10°C$)	Summer days ($T_{max} > 25°C$)
Musala	77	261	175	325	0
Golemija Kasan	89	222	133	300	0
Malkija Kasan	91	199	108	279	0
Vichren hut	92	166	74	247	0
Bansko	62	94	32	155	15

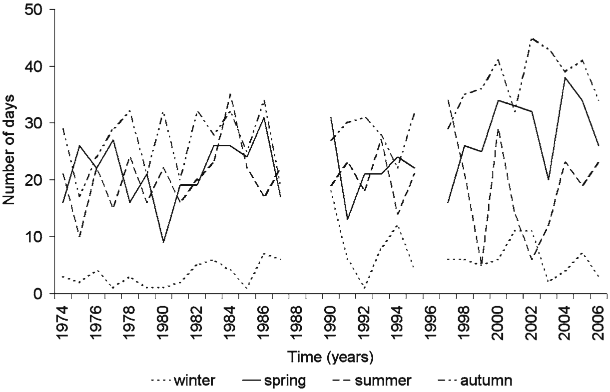


Fig. 3 Average number of frost change days per season during the period 1974–2006 (Musala Peak)

precipitation rates range between 500 and 700 mm during two thirds of the observed period. The variation spread is higher for Musala Peak where precipitation rates vary between 600 and 1,000 mm/year. At this high altitude, the monthly precipitation rate is often over 50 mm. In general, monthly precipitations in mountain regions display a high inter- and intra-annual variability. At Musala Peak for instance, a high of 304 mm was observed in April 1997 while precipitation dropped as low as 6 mm in July 2000.

Figure 5 displays the annual variation of average monthly precipitation at selected stations. In Bansko and at Musala Peak most precipitations occur between March and June which can be explained by the fact that W–NW-weather conditions being typical, particularly in spring (Koleva 2003), this leads to orographic rainfalls in the Rila and Pirin Mountains. The lowest amount of precipitation occurs in February and from August until November. Therefore, a humid surplus in spring and a deficit in late summer can be expected.

The southern valley station of Sandanski shows a distinctive November–December precipitation maximum due to the impact of cyclonic systems coming from the Mediterranean area. Sandanski is further characterised by another maximum

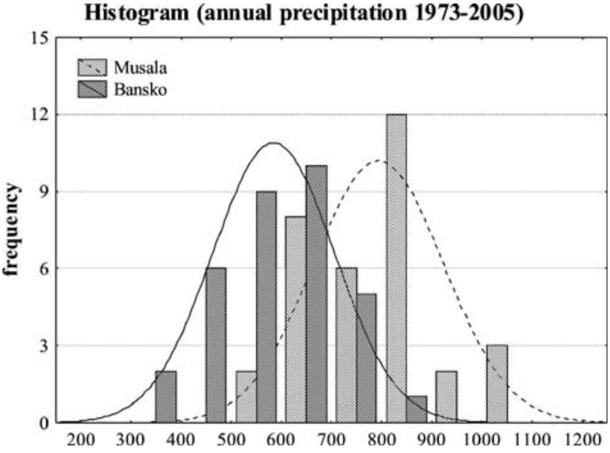


Fig. 4 Histograms of the annual precipitation in Bansko and at Musala Peak [mm]

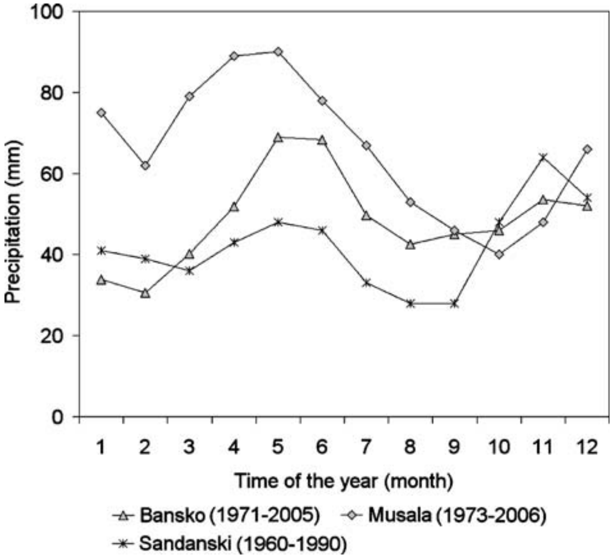


Fig. 5 Distribution of the average (mean) monthly precipitation

in spring. As the Pirin Mountains are situated between Bansko and Sandanski, they probably experience an intermediate pattern for the annual distribution of precipitation.

Mountains are also known as "water towers" due to the high amount of precipitation that they receive and their retention of water in the form of snow. The release of water during the thawing period is vital to their environment and to the people living in the downstream plains (Andreeva et al. 2003; Grunewald et al. 2007). The observations clearly show that solid precipitation (snow, frost, fog) amounts from 70% to 90% of the total precipitation received by both the Pirin and the Rila Mountains. These massifs are covered by snow during more than half of the year. Table 5 presents the snow average thickness and the duration of snow cover for south-western Bulgaria. The maximal snow thickness ranges between 3.6 and 4.7 m in Rila and Pirin Mountains while an overall maximum of 4.72 m was measured at the Vihren Hut on the 5th April 1963 (Nikolova and Jordanova 1997). Wind, avalanches, solar radiation and exposition also affect locally the depth and duration of snow cover.

A further parameter to evaluate the dynamics of precipitation is the number of days with snowfall. While at Musala for the period from 1973 to 2006 solid precipitation was recorded on more than 120 days per annum (Table 6), in Sandanski

Table 5 Characteristics of snow cover for southwest Bulgaria (Anonymous 1977; Vekilska 1995)

Altitude (masl)	Days with snow cover	Mean max. of snow depth in winter (cm)
$< 1,000$ (southern basins)	15–20	3–5
1,000	50–60	80–90
2,000	ca. 160	100–200
$> 2,400$	ca. 250	$>$ 200

Table 6 Descriptive statistic and trend analysis of number of days with snowfall at Musala Peak (1973–2006)

	n	Mw	Median	Min	Max	uQ	oQ	SD	Variance	QA	Trend
Year	33	126	122	87	169	114	139	19	348	25	−0.45*
Winter	31	47	48	30	66	39	54	9	84	15	−0.18
Spring	32	50	50	36	72	44	55	9	88	11	−0.31
Summer	31	7	7	0	15	4	11	4	14	7	−0.47*
Autumn	33	23	23	13	35	19	25	6	39	6	−0.35*

*$p < 0.05$; significant trend (rR)

only 10 days with snowfall occurred, however the recordings here refer to the period from 1961 to 1990 (Rashev and Dinkov 2003).

4 Climate change and climate trend

According to the Intergovernmental Panel on Climate Change (IPCC) our world is experiencing global warming and the global average annual temperature has increased by 0.74°C since 1990. The last decade was globally the hottest since the beginning of worldwide temperature measurement during the nineteenth century. Further global warming of ranging between 1.4°C and 5.8°C is expected by the end of the twenty-first century (IPCC 2007). This could also lead to an increase in temperature extremes as well as the frequency of heavy rainfalls and droughts.

Through the existing meteorological records it is worth studying how these global climate trends reflect locally in Bulgaria and particularly in the mountains of its south-western region. Different sources: Anonymous (1997), Sharov et al. (1999), Alexandrov and Genev (2003) and Topliiski (2004) have already presented comprehensive studies on climate change in Bulgaria. They describe the main evolution of climate in the twentieth century as follows:

- three periods with minimal annual air temperature (1905–1914, 1941–1945, 1972–1981) and three with higher temperatures than normal (1922–1931, 1945–1954, 1984–1993),
- a temperature decrease in the 1970s and a temperature increase in the 1990s,
- a cyclic evolution of precipitation: 1897–1901: humid; 1902–1909: dry; 1910–1934: normal to dry; 1935–1944: humid; 1945–1953: dry; 1954–1984: humid; 1985–1994: dry.

The data analyses need to be further refined when dealing with Pirin, Rila and Rhodope Mountains scrutinised due to the scarcity of existing stations in these zones, the dominance of orographic influences and the close vicinity of the Mediterranean Sea. Through existing dedicated analyses of the area by Bulgarian scientists, the main climate evolutions as compared with the situation at the beginning of the twentieth century are mainly a decrease of precipitation by 5–10% and a small increase in temperature (Sharov et al. 1999; Alexandrov and Genev 2003; Andreeva et al. 2003; Zlatunova and Slaveykov 2004).

These climate change features can be better scrutinised through the analysis of the meteorological data series available for the stations of Bansko and Musala Peak between 1931 and 2006. On the basis of mean decade values, the monthly and annual averages at Musala Peak from the 1930s until the 1980s show that temperature deviates only by ±0.2°C from long-term average (−3.0°C). An increase in temperature is however observed in the 1990s (2.7°C) and since 2001 (2.5°C).

In Bansko, mean decade periods 1931–1970 and 1981–1990 experience an average annual temperature of 8.3–8.5°C which can be considered as being "normal". In comparison, the 1970s were relatively colder (average 8.1°C), and temperature has distinctly increased since 1990 (1991–2000, 9.1°C; and since 2001, 9.6°C). Colder years with an average temperature below 8.0°C have occurred periodically between 1931 and 1980, but there was only one such cold year since 1981. Between 1998 and 2001, average temperatures were above 10.0°C, and hence these years are considered as the warmest of the observed period. A trend toward temperature increase in southwest Bulgaria since the 1990s can also be verified when looking at the temperature time series from Bansko and Musala Peak (Fig. 6). It would tend to indicate an evolution in the temperature regime, particularly for period 1998–2002.

Although a fairly good linear correlation does exist between the annual temperature series of Musala Peak and Bansko ($r_R = 0.72$), a significant linear warming trend could only be detected for Bansko over the 1931–2006 period. A seasonal analysis has also been conducted using average monthly temperature values of predetermined periods (winter: December of the previous year–February; spring: March–May; summer: June–August; autumn: September–November). A little increase in warming trends can only be significantly observed for the summer temperatures in Bansko. However, restricting the analysis to the last 30 years, a significant modification of temperature regimes at summit level and in the basins can be characterised through the study of typical threshold values (frost change or vegetative period) and extremes. If one considers the station of Musala Peak over the 1973–2006 period (Fig. 7), the main features are:

- a significant shifting from cold to warm days,
- an increase of days with frost change, especially in April and September/October,
- a general decrease of days with temperatures below 0°C,
- a significant longer vegetative period (>5°C),
- the tendency to shorter winters and longer summers.

These changes should affect the morphological stability of this alpine area, the development of soils, micro-organisms, vegetation or species composition, as well

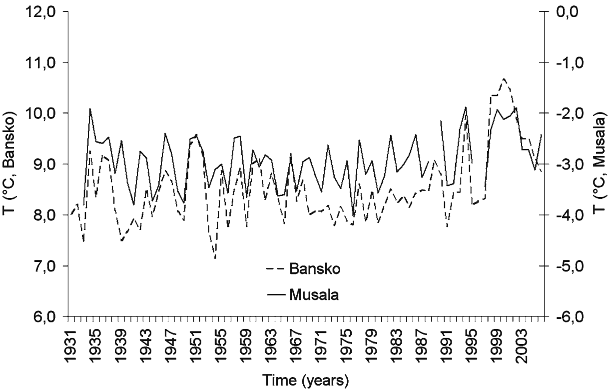
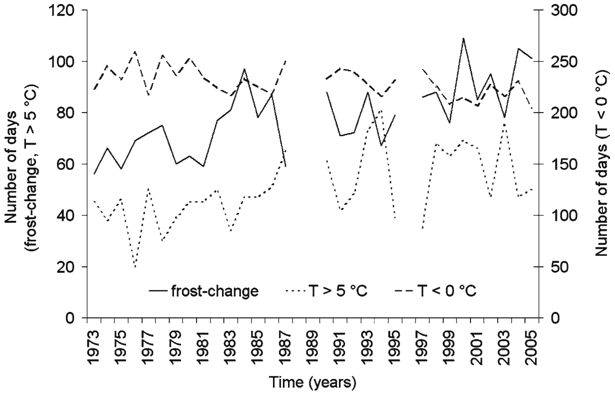


Fig. 6 Evolution of annual mean air temperature in Bansko and at Musala Peak for the period 1931–2006

Fig. 7 Change in temperature threshold values at the Musala Peak



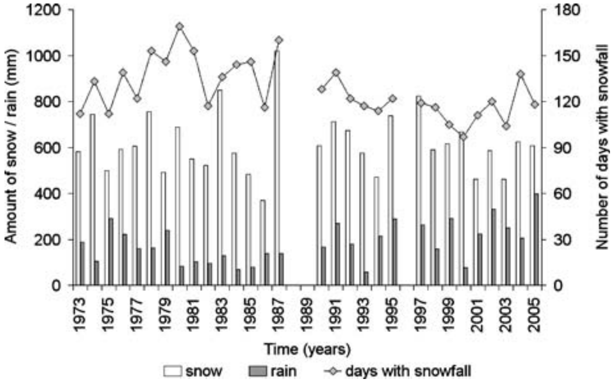
as the water retention capacity and snow cover period suitable for winter tourism (e.g. Veit 2002; Koleva-Lizama and Rivas 2003).

When looking at precipitation measurements, a trend could not be detected for long-term series. Humid and dry years alternate on a relatively frequent basis. Year periods 1990–1995 and 1998–2002 were characterised by high temperatures and low precipitations. The analysis of monthly precipitation reveals possible trends for June (decrease during the first vegetation period) and September (increase), but statistical significance of these trends are fairly low.

The statistical evaluation of the precipitation data for Bansko resulted in significant trends for the period from 1955 to 1995. A decrease of annual precipitation was observed ($r_R = -0.50$) which, with the exception of summer, is as well reflected seasonally. On a monthly basis only September was significantly declining.

Petkova et al. (2004) investigated the change in snow cover duration over Bulgarian mountains during the period of 1931–2000 using 15 mountain weather stations. However, they could not characterise a variation in the beginning of the thawing period in spring nor could they find a significant influence of the recent global warming. Due to the lack of consistent data we could not clarify whether these insufficiently significant changes in snow cover regime in the beginning of the thawing

Fig. 8 Days with snowfall and snow–rain-balance at the Musala Peak



period, presented in Petkova et al. (2004), are mostly caused by an increase of solid precipitation totals during the observed winter seasons.

A global correlation between winter precipitation variability in the Alps and the Northern Atlantic Oscillation (NAO) has been recently documented (Beniston et al. 1997; Petkova et al. 2004). This would cause a later start of the snow period in the mid-mountain region between 1,000 and 1,500 m. Consequently, this would lead to a shorter annual snow cover period. This type of hypothesis has been tested through the analysis of the number of days with/without snowfall at Musala Peak station during the 1973–2006 period. It showed that the annual number of days with snowfall decreases over time as well as for the summer and autumn periods (Table 6). Comparatively, rainfall and temperature have significantly increased (Fig. 8).

5 Conclusions and outlook

Climatic conditions in south-western Bulgaria are typical for the Balkan region with its mosaic of mountains and plains. Its transitional character between the temperate and Mediterranean zone is reflected in its intra-annual distribution of temperature and precipitation. Dry and warm summers are in contrast with cool and wet winters. Climate and weather were subject to significant changes in the last decades, possibly in response to global influences. A seasonal temperature increase, longer vegetative periods, and shorter, warmer winters with less snow were observed. Furthermore, the intra-annual variability of precipitation has shifted. There is also a decreasing trend of the snow–rain ratio.

The illustrated change could have a long-term effect on the eco-systems. Warming leads to a change in the vertical distribution of the vegetations altitudinal zones which can be the case of the Mountain Pine (*Pinus mugo*) which presently spreads out vertically. The increase in the number of days with frost change could also increase the erosion processes in high mountain parts. Generally, it is expected that under such climate modifications the stability of mountain eco-systems could change, as it is already happening in the Alps (Beniston et al. 1997; Anonymous 2002; Beniston 2003). These climate evolutions have been confirmed in the Pirin Mountains by the examination of a micro-glacier and by the record of growth rings from centuries old coniferous trees (Grunewald et al. 2006; Grunewald and Scheithauer 2008). This type of climate change could also have socio-economical consequences, such as the reliability of snow cover in the Bulgarian ski resorts and the sustainability of the water supply in the currently booming Bansko ski resort, situated at the foot of the northern Pirin Mountains. Being a regional "water tower", a significant modification in the south-western Bulgarian mountains water resources would also have a far-reaching impact on the water reservoirs and the irrigated agriculture in northern Greece (Grunewald et al. 2007).

The reliability of meteorological data is limited due to the region's few operating stations and the inherent uncertainty in high mountain regions climate (extreme topographical conditions). Nevertheless, significant trends can be determined over the available 70-year-old climate measurement series which have been significantly complemented by dendrochronology and isotope analysis (modern climate reconstruction). This is necessary in order to increase the reliability of local climate predictions.

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