Abordări conceptuale şi metodologice

TRENDS AND VARIABILITY OF THE SIGNIFICANT PARAMETERS OF SNOW PACK REGIME IN THE ROMANIAN CARPATHIANS

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ABSTRACT. – Trends and variability of the significant parameters of snow pack regime in the Romanian Carpathians. Snow pack characteristics and duration are considered key indicators of climate change in mountain regions, especially during the season of highest snow consistency (considered to last from November 1 to April 30). The paper focuses on trends and variability of the significant parameters of snow pack regime, registered at 15 weather stations (located above 1,000 m), over the 1961-2003 period. The Mann-Kendall non-parametric test was used to determine the statistical significance of trends observed in the snow pack regime. The general results show large regional and altitudinal variations, leading to the idea of an ongoing warming process (mostly affecting areas below 1,600-1,700 m) and a lower incidence of snow.

Key words: snow pack, winter, trends, Romanian Carpathians.

1. Introduction

As many scientific studies focused on climatic variations and changes in the mountain regions showed (e.g. Frei and Robinson, 1999; Diaz and Bradley, 1997), mountain regions can be quite sensitive to large-scale climate change.

The signals of warmer atmosphere trends became evident in alpine regions before 1990s, in terms of the potential for significant changes in the timing of snowmelt snow and of a widespread retreat of mountain glaciers located in the non-polar regions (IPCC, 1990). Currently, in the Northern Hemisphere, snow cover observed by satellite over the 1966-2005 period, decreased in every month (except for November and December), with 5% in the annual mean since the late 1980s (Lemke *et al*., 2007).

Snow pack is one out of the climate elements upon which possible climate changes may have a certain impact as a function of temperature and precipitation changes. Snow is an important resource of commercial and social value for the Romanian Carpathians (tourism, drinking water reservoir, hydro-electricity), but it may also unleash significant hazards (avalanches and road closures), as in the case of the Swiss and the French Alps (Moțoiu *et al*., 2005a, 2005b; Voiculescu, 2002; Beniston *et al*., 2003; Elsaser and Messerli, 2001; Scherrer and Appenzeller, 2004). The change in seasonality and snow quantity will have direct and indirect implications for the mountainous environment (rivers and ecosystems) and also economic consequences (e.g. winter tourism industry).

2. Data and methods

Daily snow depth, snowfall, temperature and precipitation series from the National Meteorology Administration were used here in. The analyses were based on the meteorological measurements made at 15 weather stations, located in the three branches of the Romanian Carpathians, between 1,090 and 2,504 m (fig. 1), covering the 1961-2003 period.

This present study focuses on an extended winter season, being considered to last from November 1 to April 30, when snow pack is the most stable and reaches the highest consistency. In order to detect and to determine the significance of the identified trends in the winter time series, the Mann-Kendall statistical test was resorted to. The selection of the significance of the corresponding trends was done based on the >90% significance level threshold.

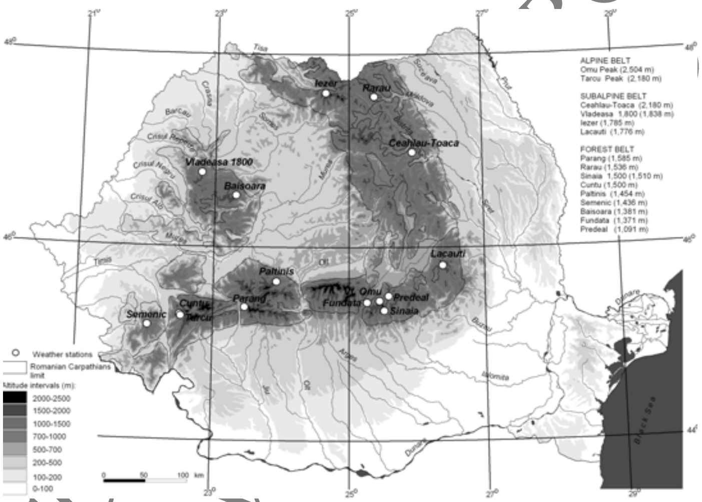

Fig. 1. Spatial distribution of the 15 weather stations in the Romanian Carpathians (above 1, 000 m altitude).

3. Results

3. 1. Trends in snowfall days

A great spatial variability in the number of snowfall days (SD) during the winter season (November to April) was revealed, due to the topography characteristics of the Romanian Carpathians. The parameter's distribution values depend on a great extent on altitude. Thus above 1,500 m and especially, over 2,000 m, snowfalls may occur throughout the year (Bogdan, 2008). The SD deviations between -25% and +25% are generally describing normal snowfall days conditions, with no major oscillation from the 43-year period mean. These deviations have higher negative values and less frequent than the positive values (fig. 2). A general and significant decrease of winter snowfall days was observable across the whole Romanian Carpathian territory (a statistical significance being attached at all the 15 weather stations), more visible at the end of the analysed time-period, suggesting the idea of less snow available for snow pack to form and last.

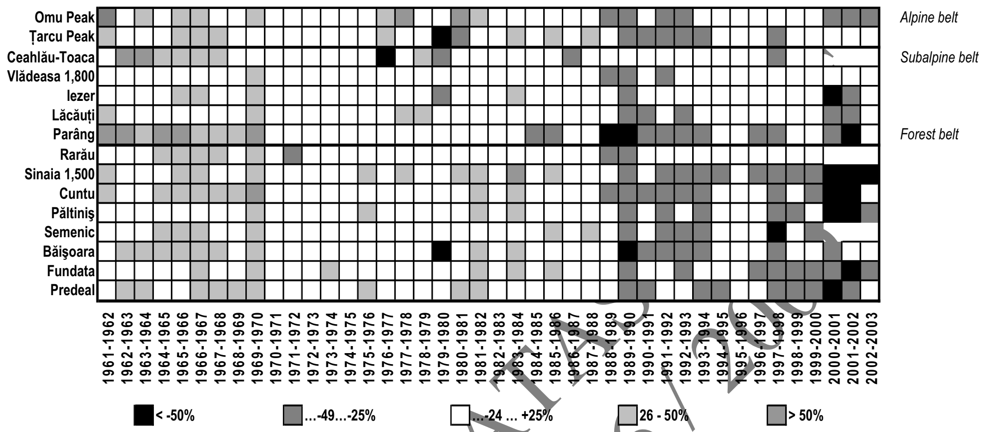

Fig. 2. Relative snowfall days deviation (%) from the long-term mean in the Romanian Carpathians during November-April interval.

A close decadal investigation into the winter deviations of SD from the long-term average indicates similarities with the MSD only at the beginning and at the end of the observation period (fig. 2). This situation would indicate that winters with few snow days, increased with decreasing altitudes. Winter snowfall days showed higher positive and negative deviations than maximum snow depth, during the 1960s and 1990s winters, respectively. From 1960 to 1980 the number of snowfall days was above-average (from 33 days at Vlădeasa 1,800 to 75 days at Parâng, both in the winter of 1969-1970) followed by below-average values, from 1990 to the end of the observation period (from -81 day/2001-2002 at Cuntu to -35 days/1989-1990 at Rarău).

However, the most evident decline was noticed at the end of the observation period, after the 1990s. Based on the statistical test returns the SD rate of changes over the 43-year period were estimated for each weather station, varying from: -48 days/period (Omu Peak) to -26 days/period (Ţarcu Peak), in the alpine belt; -33 days/period (Ceahlău-Toaca and Lăcăuţi) to -29 days/period (Vlădeasa 1,800) in the subalpine; -59 days/period (Parâng) to -32 days/period (Rarău and Băişoara).

3.2. Trends in snow pack duration and its related parameters

Snow pack duration and its related parameters are closely correlating with altitude. The percentile approach shows an evident change of snow pack duration with height (r^2>0.90). In order to show changes in snow pack duration with altitude (fig. 3), the specific snow pack duration percentiles have been selected as a function of winter types. The best correlations with altitude were given by "moderately long" (percentile 50) and "lengthy" snow pack intervals (percentile 95), with r^2 values of 0.80-0.90, while "short" snow pack intervals exhibited weaker correlations (0.73).

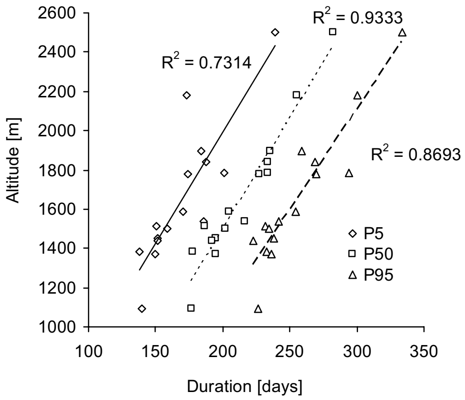

Fig. 3. Changes of snow cover duration with altitude for "short" (P5), "moderately long" (P50) and "long" (P95) snow pack intervals.

In terms of *annual snow pack duration* trends, statistically significant values occurred at only 3 out of the 15 weather stations. The results indicate a longer snow season in the alpine realm (Ţarcu Peak, with an estimated rate of up to +46 days/period) and a shorter one at two forest stations, below 1,500 m altitude (Sinaia 1,500 and Fundata, with estimated rates from -27 days down to -34 days/period, respectively).

A closer decadal investigation reflects that the annual snow pack duration shows average deviations, the positive/negative ones being rather scattered and usually not exceeding the +/-50% threshold.

The 1960s are characterized by a decrease, more evident in the early interval, at 60% of the weather stations (mainly located in the forest and low subalpine belts). Isolated cases of shorter duration were more numerous in the mid-to-late interval of the same decade, mainly in the alpine and subalpine belts. Some cases of positive deviation in the early-to-mid interval were noticed only at the forest belt weather stations. During the 1970s, positive deviations were dominant in the early interval, mainly in the forest-to-lower subalpine belts, being more scattered in mid and late intervals at the subalpine and alpine stations. Isolated cases of negative deviations were found at Semenic, and Băişoara stations located in the forest belt and at Ceahlău-Toaca station, in subalpine belt. The 1980s displayed an equal distribution between positive and negative deviations (47% each), with shorter durations more evident in the winter of 1982-1983 at most of the stations located in the forest belt and at fewer ones in the low subalpine and alpine belts. Longer durations were recorded only in isolated cases during the whole decade. The 1990s exhibited almost the same pattern in terms of shorter durations, which characterize the same forest belt stations, in the early-to-mid interval. However, above-average durations seem to be more frequent during this decade (57% cases), scattered in the early interval and more clustered in the late one. The last part of the 1961-2003 period had a pregnant below-average character due to the incidence of the warmest winters (e.g. 2000-2001, 2001-2002), which affected snow pack durations from the low forest areas to the high subalpine ones.

According to the thermal characteristics of each individual winter, *snow pack onset/melting* dates last basically from September 19 to June 25 in the alpine belt, from October 1 to May 25 in the subalpine belt and from September 14 to May 15 in the forest belt. Negative snow pack onset deviations dominated the last 10 years of the 1961-2003 period, significantly earlier onsets being recorded at the Omu Peak, Ţarcu Peak and Băişoara stations, at a rate between -26 days/period, at Băişoara and -40 days/period, at Ţarcu Peak over the 43-year period. Some exceptions (later onsets) were found at Sinaia 1,500 and Fundata stations (at a rate of 21-22 days/period). At high-altitude stations the snow pack tends set on earlier and slight insignificant changes observable at the subalpine belt stations. At the forest belt mid-altitude stations the snow pack tends to start later, a situation particularly evident in the last years, especially in the late 1990s and after 2000. The onset data were relatively constant, without major deviations, from the late 1960s to the early 1990s for most of the weather stations.

The number of days with different snow depth thresholds (10, 30 and 50 cm) has shown that under the influence of large-scale atmospheric circulation patterns and local geographical conditions snow amounts can vary widely in time and space, mainly due to shifts in the precipitation regime. The statistically significant returns do not suggest any uniform trends. Generally, the days with large amount of snow (>30 cm) started to be less frequent, especially more evident in the early 1990s and after the 2000, showing a more pregnant decline at the forest belt stations than at the higher altitude ones.

3.3. Trends in maximum snow depth

A winter-to-winter variability of maximum snow depth (MSD) occurrence was computed and the relative deviation of MSD was compared with the 43-year period mean. Despite the few measurement sites significantly scattered with altitude and space, some aspects were nevertheless obvious. In most cases statistics indicated a slight dominance of negative trends (53%) over the positive ones (47%). Even so, significant negative trends were found, only at Băişoara, for the Western Carpathians, often affected by foehn processes and at Rarău, for the Eastern Carpathians, both stations being located in the forest belt. A significant positive trend was revealed only at Lăcăuți station, in the lower subalpine belt of the Eastern Carpathians.

Winter variability of MSD by decades has shown that in the 1960s the snow pack was generally above-average (except for subalpine belt stations), in 4.6 to 5.5 winters/decade. In the 1970s and 1980s, MSD was mostly below-average, in 5.9 to 9.3 winters/decade and in 4.9 to 7.3 winters/decade, respectively. Starting with the 1990s there followed several winters with above-average MSD (except for the forest belt stations), in 6.0 to 6.5 winters/decade for the alpine and the subalpine belts, while at the beginning of the 2000s MSD was below-average both at the alpine and the forest belt stations (except for Vlădeasa and Lăcăuți, in the subalpine belt). Snow conditions prevailed mainly in the 1960s and 1990s, while less snow fell mostly during the 1970s and 1980s.

Surprisingly, in terms of the thermal character of winters, the 1990s marked the beginning of a more evident warming process at most of the Romanian Carpathian weather stations, not exactly related to a lower incidence of snow (registered only in the early 1990s). The late 1990s and post-2000 years were featured with greater quantities of snow at most of the stations (with few exceptions in some winters), even if these intervals included two very warm winters: 2001-2002 for the forest belt (only at Cuntu station) and 2000-2001 for all the three vegetation belts.

These results might lead to three main assumptions: 1) the degree of snowiness is not closely related to the thermal character of winters; 2) the periods with less or more snow than the long-term mean do not cover large areas and no pronounced clusters of successive winters with similar MSD relative deviation patterns were determined (maximum 3 successive winters), highlighting the increased spatial variability of the snow pack in mountain regions; 3) the differences induced by altitude within the same Carpathian branch are not very evident by MSD deviation values.

4. Conclusions

There is high winter snow pack variability in the Romanian Carpathians, induced by the very complex climate characteristics of this region. As Bojariu and Dinu (2007) stated, the local and regional factors seems to play a more important role in snow pack variability in the Romanian Carpathians, than in other mountain regions (e.g. Swiss Alps).

The general trend towards warmer and drier winters, caused by deviations in the precipitation and temperature regime, is already visible in many areas of the Romanian Carpathians and it can lead to changes of snow amount and duration. However, most of the snow pack parameters didn't indicate a significant widespread trend in this respect over the 1961-2003 period. Observations have shown several spatial differences in terms of station location. Changes of snow pack-related parameters indicated milder winter conditions in the subalpine belt and especially, in forest one, where significant modifications were usually noticeable. This could be explained by the fact that at high altitudes, the process of climate warming cannot induce temperature increases above the freezing point, suggesting that precipitation and not temperature acts as the main control factor in winter in terms of snow accumulation. A similar pattern has been emphasized also for the French Alps (Martin and Durand, 1998). The forest belt weather stations indicate a more significant climate variation response because the snow season starts later (Sinaia 1,500 and Fundata stations) and ends up earlier, a situation seen mainly after 1998 (Parâng, Cuntu, Păltiniş, Semenic, Băişoara and Fundata stations).However, winter snowfalls showed one of the most homogenous variability signals, supporting the idea of a general transition towards drier winters with every fewer snowfalls.

Since the records included in the 43-year long period for the Romanian Carpathians region is relatively short (less than 50 years), the snow pack trends revealed are likely to be influenced by winter climate variability, as well as by the warming process, more pregnant in the last part of the analysed period. Against this background, the manifestation of extreme phenomena indicates that warm winters have become more frequent, especially after the 1990s, affecting the snow pack regime mainly at altitudes below 1,600-1,700 m. Significant fluctuations, without some uniform snow pack and related parameters evolution trends being identified were noticed above 2,000 m altitude due to the marked atmospheric dynamics at this height, which restricts the warming process more pregnant al lower altitudes, and to wind which may distort the real distribution of this variable at such heights.

The weather stations studied, except for those in the alpine belt (Ţarcu Peak and Omu Peak) do not lie at very high altitudes (under 2,000 m). However, as regards the mountain climate warming process the results obtained are largely comparable with those of the Swiss Alps. Obviously, local geographical conditions, which exert a significant influence, might induce sharp differences. The results hold for low and medium altitude weather stations being comparable with those yielded by the pilot stations of the mountain alpine system (e.g. Laternser and Schneebli, 2003; Beniston, 1997, Beniston *et al*., 2003).

It can be assumed that if the 43-long period trends (more evident in certain areas) maintain their characteristics, winters will become gradually milder and drier than they are today.

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