SNOW PACK IN THE ROMANIAN CARPATHIANS UNDER CHANGING CLIMATIC CONDITIONS

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Abstract:
Snow pack characteristics and duration are considered key indicators of climate change in mountain regions, especially during the cold season (November 1 – April 30). Deviations in the regime of the main climatic factors (temperature and precipitation) offer useful information on snow pack variability, in the conditions of the winter warming trend already seen in many areas of the Romanian Carpathians. The present work focuses on changes and trends in snow pack and related parameters, registered at the 15 weather stations located in the alpine, subalpine and forest belts (>1,000 m), changes due to the modifications of temperature and precipitation, detected mostly at the end of the 20th century. A winter standardized index was calculated in order to group winters over the 43-years of meteorological observations (1961-2003) into severity classes and detect the respective changes. Negative and weak correlations were found over the December – March interval, between the number of snow days and the NAO index. The general results show large regional and altitudinal variations and the complex character of climate in the Romanian Carpathians. The Mann-Kendall statistical test has been used in order to quantify the significance of trends in the studied snow pack-related parameters.

Keywords: *snow pack, snow depth, snowfall, winter, variability, trends.*

1. INTRODUCTION

A great deal of interest has focused on climatic variations and changes in the mountain regions of the Earth, and on the effects of such changes. Many studies (e.g. Beniston, 2000, Keller, 2000, Diaz, Graham, 1996, Diaz, Bradley, 1997) demonstrate that the alpine zone can be quite sensitive to large-scale climate change, so that regional indices often show larger amplitudes relative to hemispheric or global averages. The potential for significant changes in the timing of snowmelt in the alpine regions, including a widespread retreat of mountain glaciers from the non-polar regions is also considered (e.g. Dettinger, Cayan, 1995; Swetnam, Betancourt, 1998; Dyurgerov, Meier, 2000; Cayan et al., 2001; Dey, 2002).

According to the IPCC Report (2001) deviations in global temperature and precipitation in the late part of the 20th century resulted in an evident reduction (-10%) of the Northern Hemisphere snow cover area, beginning with the late 1960s and especially in the 1974-1994 interval, as indicated by monthly temperature and precipitation variability during winter. In the Alps, a trend in winter weather to gradually grow from cold and humid to milder and humid/dry was reported by Beniston (1997, 2003). Also, it was estimated that snow pack duration in winter decreases at a rate of 15-20 days with every +1°C during winter.

2. DATA

The analyses were based on snow pack duration, snow depth and snowfall series yielded by daily measurements made at 15 weather stations located in the three branches of the Romanian Carpathians, at above 1,000 m altitude, as part of the meteorological observation network of the National Administration of Meteorology (fig. 1). Additionally, parameters related to snow pack (e.g. snow onset/melting dates, number of days with specific snow depth thresholds, number of snow days, snowfalls and local temperature) were also taken into account in order to provide a background for snow pack variability patterns in the conditions of warmer and drier winters, a trend already evident in some areas of the Romanian Carpathians. The selection of weather stations was based on three main criteria: continuous and homogeneous data sets and representative lengths of meteorological observation periods (40-to-43 year period between 1961 and 2000-2003).

3. PARAMETERS AND METHOD

In this study, the winter season is considered to last from November 1 to April 30. Snow pack and snowfall durations and onset/melting dates of snow pack and snowfall have been substantially followed. The

seasonal duration of intervals with snow depth higher than specific thresholds (10, 20, 50 and 70 cm) has also been determined in order to reveal the years with high and low snow amounts and detect their occurrence trends as a function of snowfall variability. Shifts in the snow pack patterns induced by temperature and precipitation variability, mainly during the winter season, have also been studied. Calculations and correlations were performed with SPSS 14.0 software, the Mann-Kendall statistical test being used to determine the significance of the corresponding trends (>90% significance level).

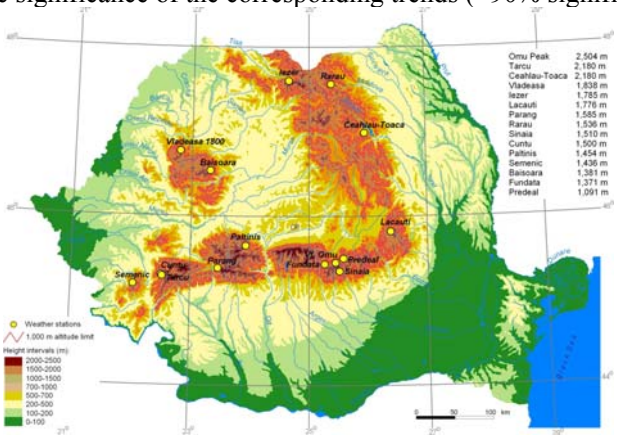

Fig. 1. Spatial distribution of the 15 weather stations in the Romanian Carpathians (above 1, 000 m altitude).

4. RESULTS

4.1. Trends in maximum snow depth

A winter-to-winter variability of maximum snow depth (MSD) occurrence was computed and the relative deviation of the 10-year mean of MSD was compared with the 43-year average. Despite the few measurement sites very much 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 for the Western Carpathians, at Băişoara and for the Eastern Carpathians, at Rarău, both stations located in the forest belt. The only significant positive trend appeared at Lăcăuți station, located in the lower subalpine belt of the Eastern Carpathians.

Winter variability of maximum snow depth 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).

4.2. Trends in snow pack duration and related parameters

Snow pack duration and its related parameters are closely and significantly correlating with altitude, which induces obvious differences. In terms of intensity, frequency and amount of snowfall, which also tend to increase with altitude, and of the frequent occurrence of related variables beyond winter months, the winter season may last up to the end of spring and early summer. The percentile approach shows an evident change of snow pack duration with height (r^2>0.90). The best correlations with altitude were given by "moderately long" (P50) and "lengthy" snow pack intervals (P95), with r^2 values of 0.80-0.90, while "short" ones exhibited weaker correlations (0.73).

In terms of annual snow pack duration trends, statistically significant values, at least for the 90% significance level, occurred at only 20% of the weather stations. The results indicate a longer snow season in the alpine realm (Țarcu station) and a shorter one in two forest stations below 1,500 m altitude (Sinaia and Fundata). 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, in 60% of the weather stations,

mainly 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 positive deviation cases were noticed only at the forest belt weather stations, in the early-to-mid interval. During the 1970s, positive deviations were dominant in the early interval, mainly in the forest-to-lower subalpine belts, they being more scattered in subalpine and alpine stations, in the mid and late intervals. Isolated negative deviations were determined at Semenic, Băişoara and Ceahlău-Toaca stations. The 1980s displayed an equal distribution between positive and negative deviations (47% each), with more evident shorter durations 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 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 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 and significantly earlier onsets were recorded at the Omu Peak, Țarcu and Băişoara stations. Some exceptions (later onsets) were found at Sinaia and Fundata stations. Negative snowmelt deviations are concentrated mainly after 1998, sustaining the idea of an ongoing warming process. Significant earlier snowmelt occurred at Parâng, Cuntu, Păltiniş, Semenic, Băişoara and Fundata stations.

The number of days with specific snow depth thresholds (10, 30, 50 and 70 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, as a result of shifts in precipitation regime. Statistically significant returns do not suggest any uniform trend over the whole period. A tendency towards snow days decreasing was found at Băişoara (with all thresholds), Rarău (10, 30 and 50 cm), Sinaia (30 cm) and Iezer (50 cm), increasing trends being recorded at Păltiniş (10 and 30 cm), Sinaia (10 cm), Lăcăuți (10, 30 and 50 cm) and Ceahlău-Toaca (50 cm).

Against the background of winter temperature variability (November – April), a general increase in minimum temperatures over the 1961-2003 period for 11 out of the 15 weather stations was found, but the statistical significance was determined only for Parâng and Cuntu stations (>95% significance level). The results remain valid because minimum winter temperatures play an important role in snow accumulation and snow pack duration (Jungo, Beniston, 2002, Beniston, 2006) even if the correlation between them stays negative and weak (<-0.3). Maximum winter temperature indicates significant positive trends for the same areas (including also, Băişoara station), with the exception of the highest altitude station where trends were significantly negative (Omu Peak).

In order to classify winters in terms of thermal characteristics and detect their variability trends a winter standardized index – WSI was calculated for each of the 15 weather stations in the Romanian Carpathians (Tuinea et al., 1997). The results show that “normal” winters dominated the 1961-2003 period (40-50% cases), with “ warm” and “cold” ones being less frequent (20-30% cases); extreme winters occurred in less than 10% cases over the whole period of observations. WSI variability showed rising values at 14 out of the 15 weather stations, supporting the idea of winters tending to become gradually milder. The Mann-Kendall test revealed significant positive trends at 6 weather stations. A single case in which the trend showed a decrease was found at Ceahlău-Toaca station, but no statistical significance was attached to it.

4.3. Trends in snowfall days

The great variability in the number of snowfall days in winter (November to April) also depends to a great extent on altitude, so above 2,000 m, snowfalls may occur throughout the year. A general and significant decrease in the variability of winter snowfall days was observable across the whole Romanian Carpathian territory.

A close decadal investigation into the winter deviations of snowfall days from the long-term average indicates similarities with the winter maximum snow depth only at the beginning and at the end of the observation period. Winter snowfall days showed higher positive and negative deviations than winter

maximum snow depth, during the 1960s and the 1990s, respectively. From 1960 to 1980 the number of snowfall days was above-average (from 33 days at Vlădeasa 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.

The considerable decrease in the incidence of snowfalls is due to the same variability patterns shaped by winter precipitation amounts. Large areas of the Romanian Carpathians experience significant decreasing trends in the alpine (Omu Peak and Țarcu stations) and subalpine belts (Vlădeasa, Iezer and Lăcăuți stations), as well as in the forest belt (Parâng, Sinaia, Semenic and Predea stations). The lower frequency of precipitation/snowfall events at high-altitude and low-altitude sites partly explains the changes in snow pack parameters, even if the correlation between them is rather weak.

4.4. NAO influence on snow pack duration and number of snow days

The influence of the NAO index on snow pack duration and number of snow days in Romania, including the mountain area, was already studied (Cazacioc, Cazacioc, 2006, Bojariu, Gimeno, 2003). The results show that the correlation between the NAO index and the number of snow days for the Romanian territory, over the December – March interval, is negative and weak for the Romanian Carpathians, with values between 0.0 and -0.40. The snowiest interval/year is February to March, when more than 25 days/month are recorded, 7 months/year in the alpine belt, 5 to 7 months/year in the subalpine belt and 4 to 5 months/year in the forest belt. The relation between snow pack duration, number of snow days and the NAO index seems to be stronger in the positive phase of the index than in the negative one.

5. CONCLUSIONS

There is high winter snow pack variability in the Romanian Carpathians, given the very complex climate of this region. 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, none of the snow pack parameters indicated a significant widespread trend in this respect over the 1961-2003 period. Observations have shown some changes in terms of station location, changes of snow pack-related parameters that were milder in the alpine belt than in the subalpine and forest belts 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 (Martin, Durand, 1998). The forest belt weather stations indicate a more significant climate variation response because the snow season starts later (Sinaia and Fundata stations) and ends up earlier, a situation seen mainly after 1998 (Parâng, Cuntu, Păltiniş, Semenic, Băişoara and Fundata stations).

Winter snowfall/precipitation events having the greatest expansion in the territory, support the idea of a general trend in the Romanian Carpathians (above 1,000 m altitude) towards drier winters with every fewer snowfalls. No obvious links were noticed between the number of snow days and snow pack duration variability, on the one hand and NAO index values on the other, negative and weak correlations being recorded mostly over the December-to-March interval.

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