# WINTER TEMPERATURE TRENDS IN THE ROMANIAN CARPATHIANS - A CLIMATE VARIABILITY INDEX

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The paper deals with frequency changes in winter temperatures in terms of specific thresholds and trends by using average, minimum and maximum daily temperature data registered at 15 weather stations situated at over 1,000 m altitude in the Romanian Carpathians. The multiannual mean temperature during the winter season and standard deviation values were determined in order to group wintertime into severity classes over 43 years of meteorological observations (1961-2003). Winters were characterized not only by temperature regime, but also by other climatic parameters in order to better reflect the local climatic conditions (e.g. number of days with certain negative temperature thresholds, snow cover onset/melting dates, snow cover duration). The main results show that winters became milder where there was a general increase of temperature, a trend showing some regional differences due to altitude and slope aspect against the circulation of the main air masses.

**Key words:** temperature, severity classes, winter, Romanian Carpathians.

## Introduction

Many studies elaborated in the last 20 years focus on the climatic variations and changes in the mountain regions of the Earth, and on the effects of such changes on water resources, economic development, and the health of the ecosystems (Beniston, 1994; Beniston *et al*., 1997; Messerli, Ives, 1997; Mountain Agenda, 1998). Studies by Diaz and Graham (1996) and Diaz and Bradley (1997) demonstrate that the alpine zone can be quite sensitive to large scale climatic change, so that regional indices often show higher amplitudes relative to hemispheric or global averages. These and other studies (e.g. Dettinger, Cayan, 1995; Swetnam, Betancourt, 1998; Dyurgerov, Meier, 2000; Dey, 2002) indicate 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.

The IPCC projected trends outlined in several assessment reports (IPCC, 1990, 1996, 2001) show changes of climate as a consequence of the significant increases of greenhouse-gases in the atmosphere due to human activity. In response to global temperature and precipitation deviations in the latter half of the 20$^{th}$ century, the IPCC Reports (2001) indicated an evident trend of snow area shrinkage in the Northern Hemisphere (-10%), as from the late 1960s and especially the 1974-1994 interval, shown in the monthly temperature and precipitation variability in winter. Beniston (1997, 2003) reported a gradual transformation trend of winter characteristics in the Alps, from cold and humid to milder and humid/dry. Also, the rate of snow cover duration was estimated to decrease in winter by 15-20 days with every +1°C.

The major goal is to present present temperature trends in winter is the central objective of the present study, moreover so, as the IPCC indicates accelerated temperature increases in the 21$^{st}$ century, that can lead to a climate warming of 1.5-1.8°C by 2100 (IPCC, 2001). In this context, mountain regions will become by some 1°C warmer, hence the snowline will rise by about 150 m (Haerbeli, Beniston, 1998).

## Data and methodology

Climatological data were registered at 15 weather stations situated at 1,000 m above sea level and covering the whole territory of the Romanian Carpathians (fig. 1). The spatial and altitudinal spread of these is not uniform, most of them being situated between 1,500 and 1,800 m altitude (6), while 8 out of the 15 stations are located in the Southern Carpathians. The daily temperature and snow cover data used, refer to the 1961-2003 interval for most of the weather stations, except for Rarău and Ceahlău-Toaca (1961-2000).

The focus of the study was to determine the minimum and maximum below and above the mean winter values of each weather station, as an indicator of the specific temperature of some winters. The trends linear regression of different winter parameters over the 1961-2003 period were analysed and their statistical significance was assessed by the Mann-Kendall test (>90% level of significance). Shifting years in variability were identified based on the *Regime Shift Index* (RSI) (Rodionov, 2004).

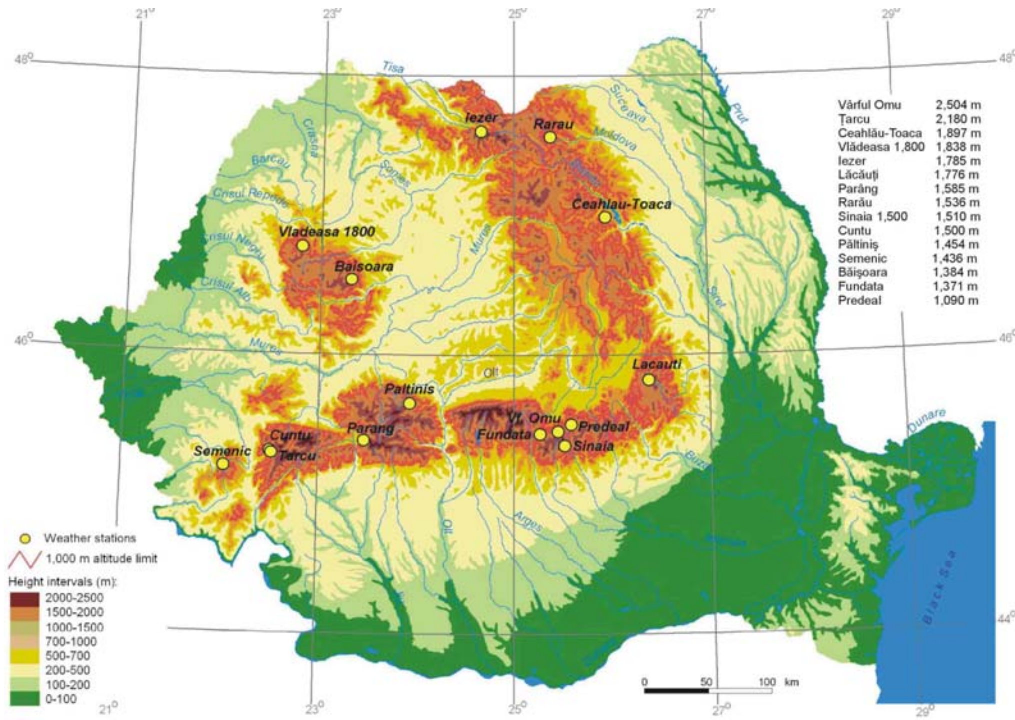


Fig. 1. The location of the 15 weather stations in the Romanian Carpathians.

**Characteristics of temperature distribution in the Romanian Carpathians**

The Romanian Carpathians exhibit temperature characteristics of continentality and latitude. Altitude significantly controls the mountain climate, being the most relevant and fundamental characteristic. As a result, the low heat capacity of the atmosphere at high altitude explains temperature decreases with height. This change is revealed by the mean vertical gradient of 0.5-0.6°C/100 m, even if this relationship is not constant within the three branches of the Romanian Carpathians (0.62°C/100 m in the Southern Carpathians, 0.53°C/100 m in the Eastern Carpathians and 0.47°C/100 m in the Western Carpathians). Temperature differences between the foot and the top of mountains by multianual means reach the highest values (7.3°C) in the Southern Carpathians (6.8°C in the Western Carpathians and 6.2°C in the Eastern Carpathians).

There is an obvious general trend of temperature decrease from west to east (as the degree of continentalism increases) and from north to south (as a result of large latitudinal extension). Since Vârful Omu (the Omu Peak) is the highest weather station in the Romanian Carpathians (2,504 m), and the long-term temperature mean (1961-2003) there is negative (-2.4°C), the important role of altitude in the distribution of temperature values becomes obvious.

The influence of altitude on temperature is also highlighted by the length of negative monthly mean temperatures (106-213 days/year) for 7 months a year at heights above 1,800 m, 5 months between 1,500 and 1,800 m and 4 months between 1,000 and 1,500 m.

Other important aspects related to temperature distribution in the Romanian Carpathians were also considered in order to define temperature regime characteristics. For most of the measurement sites, January is the coldest month of the year (80% cases), with only 20% cases in February. Long-term averages over a 43-year dataset range between -5.0°C (Vârful Omu) and -1.8°C (Băişoara) minimum temperatures, and 0.9°C (Vârful Omu) – 10.5°C (Predeal) maximum temperatures. The distribution of minimum temperature absolute values indicates a difference of 6.5°C between the three Carpathians branches, with the lowest value in the Southern Carpathians (-35.5°C/February 20, 1985 at Vârful Omu); (-29.0°C/February 6, 1965 at Iezer in the Eastern Carpathians and -30.0°C/January 16, 1963 at Vlădeasa 1,800 in the Western Carpathians). The absolute minimum temperature in winter showed differences of 8.4°C between the three winter months, all in the Southern Carpathians (-27.1°C/December 21, 1967 at Vârful Omu; -34.4°C/January 3, 1979 at Țarcu; -35.5°C/February 20, 1985 at Vârful Omu).

At most of the weather stations, the 43-year annual temperature records marked the dominance of "warm" anomalies (53%) comparatively with the "cold" ones (47%), indicating *a rising trend in winter temperatures*, especially after the 1990s. Also, at 12 out of the 15 weather stations, positive deviations were concentrated especially in the last three years of the 1961-2003 period, 50% of the cases occurring in 2000 and 42% in 2002.

An analysis of temperature variability in each and every winter (DJF months) was done on a daily basis, targeting the average, minimum and maximum temperatures series of each weather station. Warmer temperatures were highlighted by a dominance of positive deviations both at low and high altitude weather stations (54%), especially after the 1990s. Cuntu station marked the highest positive deviation in the 2001-2002 winter (6.1°C deviation of mean temperatures), with the lowest negative one at Fundata in the 1984-1985 winter (-4.0°C minimum temperatures deviation). Winters with the highest positive deviations were 1989-1990 and 2000-2001, negative deviations 1962-1963 and 1984-1985, both situations in more than 40% cases.

**The long-term variability for days with different negative temperature characteristics during the winter months** indicated the same pattern. Analysing the trend of winter days by the Mann-Kendall test (Tmax≤0°C), frosty nights (Tmin≤-10°C) and freezing days (Tmin≤0°C) over the 1961-2003 period, has revealed the following trends:

- a general decrease at most of the weather stations (for all types of days) (in up to 94% cases);
- a general increase for a weather station situated in the Eastern Carpathians – Ceahlău-Toaca (with all types), without any obvious statistical significance; at Rarău station, a positive trend was also found for winter days, but without any statistical value.

**Daily minimum temperature data below the -10°C threshold** has been averaged for each winter over the 1961-2003 period, in order to outline the extent of severity or mildness. Most of the weather stations indicate a lower frequency of such days in winter after 1990 (fig. 2). The rising temperature trend in winter months is also shown by minimum deviations, more numerous after 1990. The lowest minimum deviation value was found at Rarău during the mild 1993-1994 winter (24 days below average) and it determined also minimum deviation values at 10 out of the 15 weather stations. The highest maximum deviation was registered at Predeal during the cold winter of 1984-1985 (27 days above average), which also induced maximum deviations at 13 out of the 15 weather stations.

Most of the weather stations presented negative trends with this parameter (except for Ceahlău-Toaca station, which registered positive). At most of the analysed stations, except for Parâng and Cuntu, the Mann-Kendall test returns showed no significant behaviour.

The winter temperature is not always related to the wealth or scarcity of snow fact that happens also in the Romanian Carpathians. Thus, the severity or mildness of winters is not associated with specific snow cover duration. The minimum temperature threshold of -10°C indicates the extreme character of some winters with positive or negative deviations. Together with the 0°C threshold, they are considered as relevant indicators of winter climate variability, when such days reach the highest annual frequency. In both cases, most of the weather stations showed decreasing trends, more or less significant, but generally indicating a gradual transformation of the thermal characteristics towards a less severe or even mild wintertime.

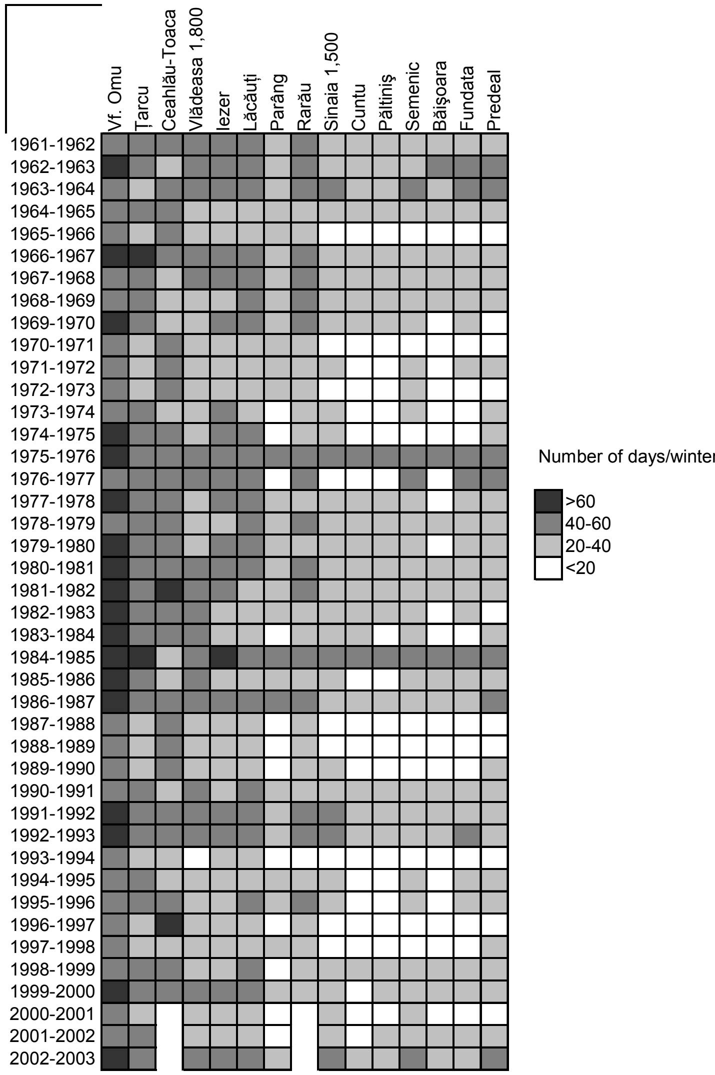


Fig. 2. Variability in the number of days with minimum winter temperature below -10°C.

**Winter types by temperature percentile values**

In order to investigate the behaviour of winter temperatures in terms of mean winter conditions, the 5 (“cold”), 50 (“moderate”) and 95 (“mild”) percentiles of the DJF mean temperature distributions have been used. The general increase with altitude is similar in all winter temperature data sets (fig. 3). The correlation with altitude has shown higher coefficients for the mean (0.75-0.81) and maximum temperature changes (0.61-0.81) than for minimum temperature (0.64-0.76) (fig. 3). In terms of mean and maximum temperatures of cold winters on the one hand, and of maximum temperatures of moderate winters, on the other, the temperature-altitude gradient is higher, e.g. r=0.81.

Above 2,000 m, mean winter temperatures ranged from <-12°C/winter (for minimum temperature), <-9°C/winter (for mean temperature) and <-7°C/winter (for maximum temperature) during “cold” winters to -8°C/winter, -8°C/winter and -3°C/winter in “warm” winters (table 1). The high dependence of temperature on altitude is also shown by the average winter temperatures at 1,000 m, which vary from -4.0°C/winter (for mean temperature) and -7.0°C/winter (for minimum temperature) in “cold” winters to 1.5°C/winter and -5.0°C/winter respectively, in “warm” winters.

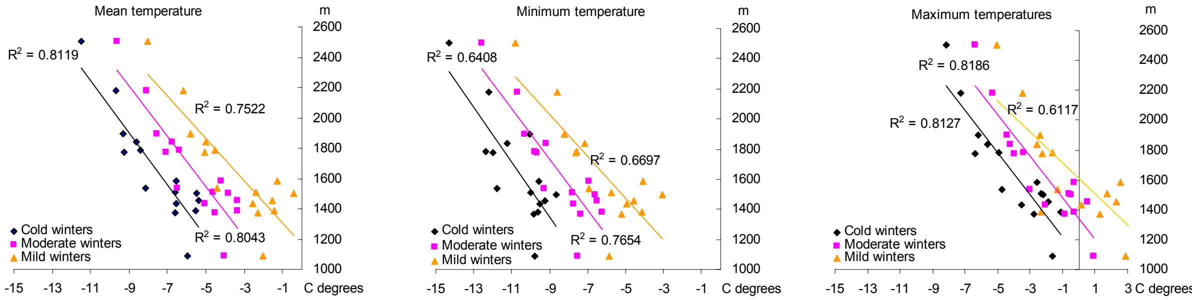

Fig. 3. Temperature changes with altitude for "cold" (P5), "moderate"(P50) and "mild" (P95) winters.

Tabel 1. Percentile value range by winter types.

| Winter types | Percentile value range for minimum temperature | Percentile value range for mean temperature | Percentile value range for maximum temperature |
|---|---|---|---|
| Cold | -14.3° (Vârful Omu) … -8.6° (Cuntu) | -11.4° (Vârful Omu) … -5.4° (Păltiniş) | -8.2° (Vârful Omu) … -1.1° (Băişoara) |
| Moderate | -12.6° (Vârful Omu) … - 6.5°C (Păltiniş) | -9.2° (Vârful Omu) … - 3.3°C (Păltiniş) | -6.3° (Vârful Omu) … - 0.3°C (Băişoara) |
| Mild | -10.8° (Vârful Omu) … -3.1° (Cuntu) | -8.5° (Vârful Omu) … -0.4° (Cuntu) | -5.3° (Vârful Omu) … -0.1° (Semenic) |

The percentile approach showed the same evident change with altitude of snow cover duration, as a function of winter type. "Lengthy" snow cover situations (200 to more than 300 days) are specific to the stations situated above 2,000 m. Below 1,500 m, P5 lasts <150 days, while the opposite is true for P95 (up to 250 days/year). The best correlations with altitude were given by the "moderately long" snow cover intervals (P50) with $r^2$>0.90 and by "long" intervals (P95) with $r^2$>0.80 (fig. 4). As a result of the intensity, frequency and amount of snowfall which also tended to increase with altitude and the frequent occurrence of these variables beyond winter months, the winter season may last up to the end of spring and early summer even so that at top altitudes (e.g. Vârful Omu 350 days, Ţarcu 356 days, Vlădeasa 1,800 310 days, maximum snow cover duration).

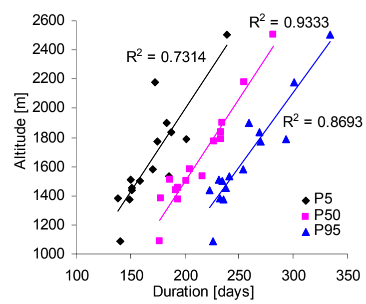

Fig. 4. Changes of snow cover duration with altitude for "short" (P5), "moderately long" (P50) and "long" (P95) snow cover intervals.

**Shifts in the snow season**

According to the thermal characteristics of winter, snow cover onset/melting dates last, basically from December 1 to February 28. *The earliest autumn date of snow onset* was recorded at Ţarcu station, on August 2, 1989, while *the latest spring snowmelt* was July 29, 1979, at Vârful Omu station. The warmer character of some winter months determined an evident reduction in the number of snow cover days, marked by early snow melting (e.g. February 2, 2002 at Cuntu). The lowest negative deviation value was registered in the winter of 2000-2001 at Băişoara, in the Western Carpathians (-17 days), as a result of a warm December month (about 8 consecutive days with maximum temperature above 10°C) and the low incidence of snowfalls during December and January (only 7 days) (fig. 5).

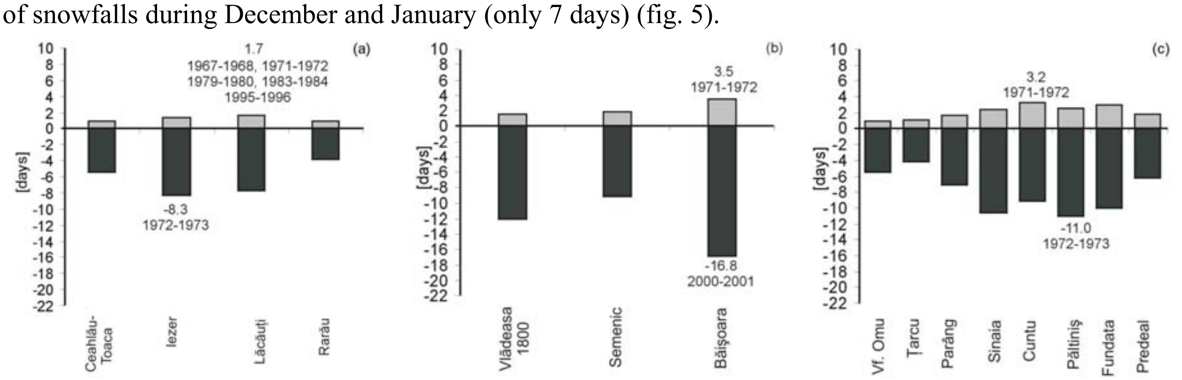

Fig. 5. Deviations from the 1961-2003 average of the mean number of days with snow cover in winter.

No specific trends in snow cover onset dates were found for 10 out of the 15 weather stations (e.g. Ceahlău-Toaca, Vlădeasa 1,800, Iezer, Lăcăuți, Parâng, Rarău, Cuntu, Păltiniş, Semenic and Predeal). Negative deviations dominated the last 10 years of the 1961-2003 period with values ranging from 23 (Vârful Omu) to 64 days (Cuntu) below the long-term average (fig. 6). The idea is supported also by statistics performed with the Mann-Kendall test which indicates earlier dates of snow cover onset at Vârful Omu, Țarcu and Băişoara stations (by more than 1 month). Some exceptions exist, because the same test indicates later dates at Sinaia 1,500 (up to 55 days from the long-term average date) and Fundata stations (up to 41 days).

In terms of snowmelt dates, no evident changes were found at 9 weather stations (e.g. Vârful Omu, Țarcu, Ceahlău-Toaca, Vlădeasa 1,800, Iezer, Lăcăuți, Rarău, Sinaia 1,500 and Predeal). Negative deviations are concentrated mainly after 1998 (82 days below long-term average, at Cuntu in 2002) sustaining the warming process view (fig. 6). The statistics showed earlier snowmelt dates at Parâng, Cuntu, Păltiniş, Semenic, Băişoara and Fundata (up to 1 month or more[*]).

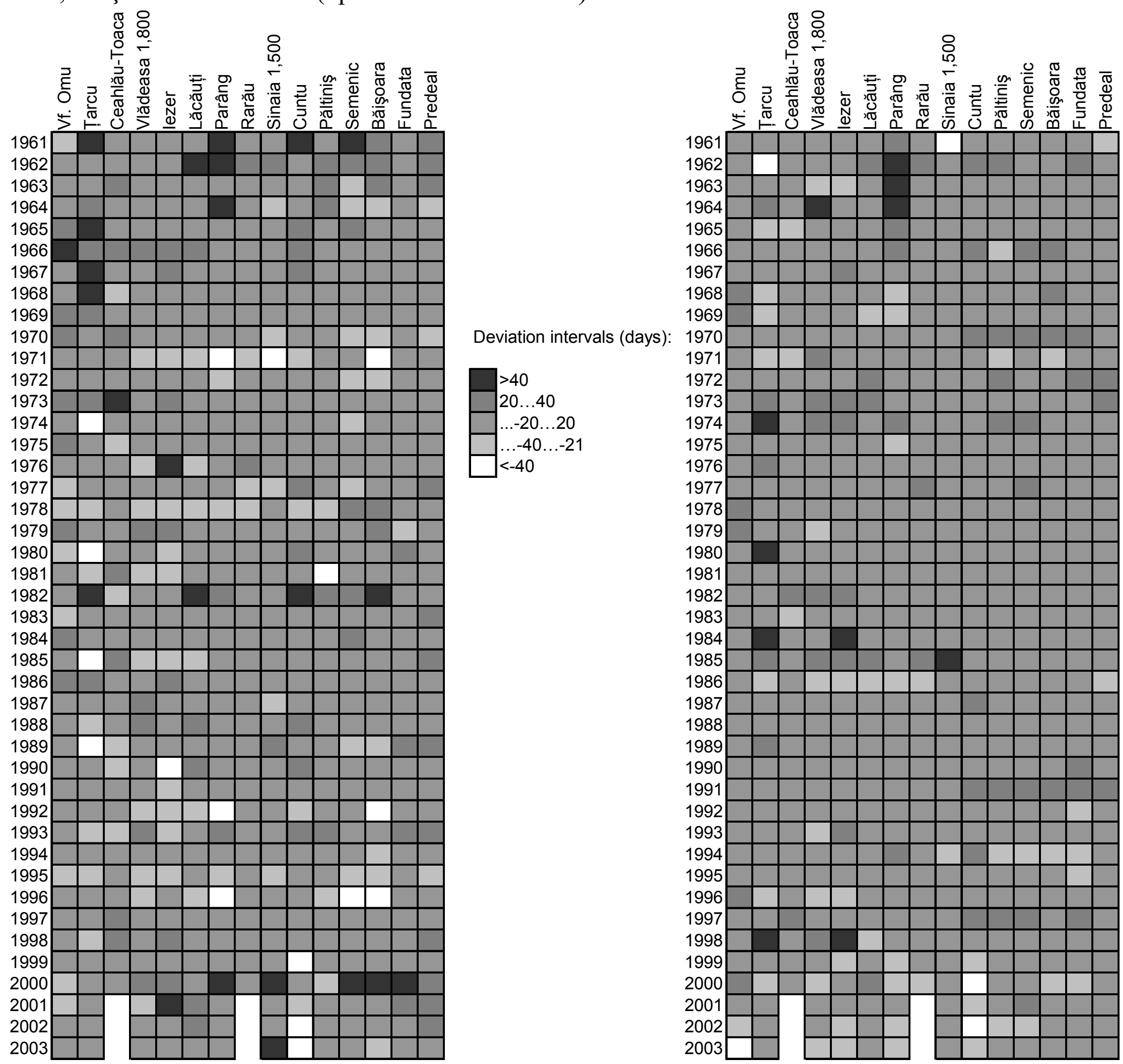


Fig. 6. Deviations from the 1961-2003 average dates of snow cover onset (left) and melting (right) in the Romanian Carpathians.

**Severity of winters**

The winter temperature value distribution is strongly influenced by the general atmospheric circulation associated with altitude. Generally, the influence of Atlantic and Mediterranean air masses from west and south-west makes milder winters with heavy snowfalls (mainly on the western slopes of the Western and Southern Carpathians), while exposure to the Arctic air masses from north-east and east

[*] 82 days deviation from the long-term average date of snow melt at Cuntu, in 2002.

determines severe winters and hard frosts (on the eastern slopes of the Eastern Carpathians). Some peculiarities of the atmospheric circulation helped us single out warmer or colder winter months.

The severity of winters can be measured in different ways, but in the present study a temperature-based approach was chosen (*Winter standardized index* – WSI). In order to classify them, the mean temperature of each winter ($t_i$), the multianual temperature winter means of the 1961-2003 period and the standard deviations were used (t) (table 2) (Tuinea *et al*., 1997).

$$Is = \frac{t_i - t_{med}}{\sigma}$$

where, $t_i$ = mean winter temperature (°C);
$t_{med}$ = multiannual temperature winter mean (°C);
$\sigma$ = standard deviations.

Tabel 2. Winter classification grid

| Winter type | Mean winter temperature (°C) | Winter standardized index values |
|---|---|---|
| Very warm | >0.5 | >1.5 |
| Warm | -1.3 … 0.5 | 0.5 – 1.5 |
| Normal | -3.1 … -1.3 | -0.5 … 0.5 |
| Cold | -4.9 … -3.1 | -1.5 … -0.5 |
| Very cold | <-4.9 | <-1.5 |

The WSI values at each of the 15 weather stations have been calculated for the 1961-2003 period. Results have shown high frequencies of "normal" winters (40-50%) while "warm" and "cold" winters represented 20-30% cases (fig. 7, right). Extreme winter types indicate under 10% cases over the whole period of observation:

- highest frequencies of 4 winters/period in "very warm" winters (Vârful Omu, Iezer, Parâng and Sinaia 1,500) and "very cold" winters (Lăcăuți);
- lowest frequencies of only 1 winter/period in "very warm" winters (Țarcu, Ceahlău-Toaca and Rarău) and "very cold" winters (Ceahlău-Toaca and Cuntu).

In terms of maximum and minimum WSI values, deviations below the -1.5 WSI threshold are higher (>1.0 WSI unit in 53% cases) than those above +1.5 WSI threshold (<1.0 WSI unit in most cases). Cuntu weather station is considered an exception in both cases (fig. 7, left).

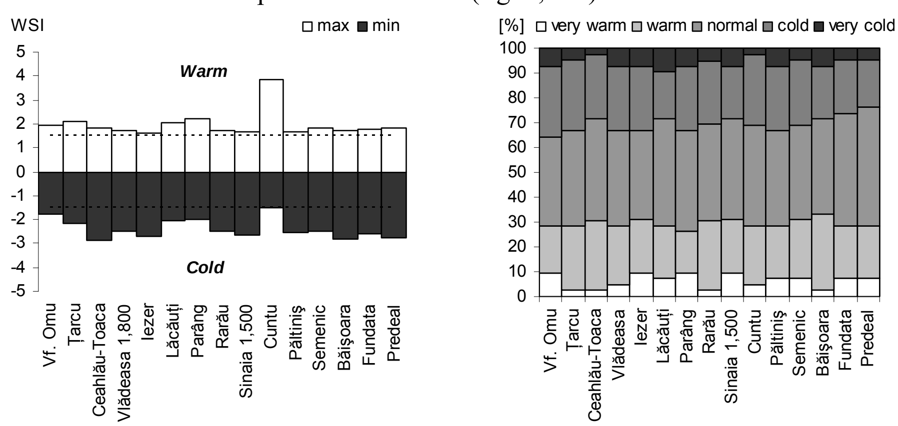


Fig. 7. The warmest and coldest winters (left) and winter type frequencies based on WSI values (right).

A lower number of consecutive winter types was registered both with "warm" and "cold" winter types (3 up to 5 consecutive winters). In terms of "warm" winters, increased frequencies were apparent (isolated occurrences of "very warm" winters) mainly after 1990 (under 2 consecutive winters). *The warmest winters* identified over the 1961-2003 period were: 1989-1990 (5 cases), 1993-1994 (1 case), 1997-1998 (1 case), 2000-2001 (6 cases) and 2001-2002 (1 case) (table 3). Increased frequencies of "cold" winters were found especially between 1962 and 1969, their succession being higher than in the case of "warm" winters (4 to 6 consecutive winters). *The winters* followed over the analysed period (1962-1963 – 3 cases, 1981-1982 –1 case and 1984-1985 – 11 cases) featured as *"very cold"*.

Tabel 3. The warmest and coldest winters in the Romanian Carpathians registered over the 1961-2003 period.

| ***Warmest winters*** | | | | ***Coldest winters*** | | |
|---|---|---|---|---|---|---|
| Position | Weather stations | Winters | WSI values | Weather stations | Winters | WSI values |
| 1. | Cuntu | 2001-2002 | 3.88 | Ceahlău-Toaca | 1981-1982 | -2.86 |
| 2. | Parâng | 1989-1990 | 2.22 | Predeal | 1984-1985 | -2.78 |
| 3. | Ţarcu | 1989-1990 | 2.10 | Iezer | 1984-1985 | -2.68 |
| 4. | Lăcăuţi | 2000-2001 | 2.06 | Sinaia 1,500 | 1984-1985 | -2.63 |
| 5. | Vf. Omu | 2000-2001 | 1.93 | Fundata | 1984-1985 | -2.62 |
| 6. | Semenic | 1989-1990 | 1.84 | Păltiniş | 1984-1985 | -2.55 |
| 7. | Ceahlău-Toaca | 1997-1998 | 1.82 | Cuntu | 1962-1963 | -1.52 |
| 8. | Fundata | 2000-2001 | 1.80 | Vlădeasa 1,800 | 1984-1985 | -2.51 |
| 9. | Predeal | 1993-1994 | 1.80 | Băişoara | 1984-1985 | -2.48 |
| 10. | Vlădeasa 1,800 | 2000-2001 | 1.74 | Semenic | 1984-1985 | -2.47 |
| 11. | Băişoara | 2000-2001 | 1.72 | Rarău | 1984-1985 | -2.46 |
| 12. | Rarău | 1989-1990 | 1.71 | Ţarcu | 1984-1985 | -2.14 |
| 13. | Sinaia 1,500 | 1989-1990 | 1.67 | Lăcăuţi | 1984-1985 | -2.03 |
| 14. | Păltiniş | 2000-2001 | 1.64 | Parâng | 1962-1963 | -2.02 |
| 15. | Iezer | 1993-1994 | 1.60 | Vf. Omu | 1962-1963 | -1.76 |

WSI variability over 1961-2003 showed an increasing value trend at 14 out of the 15 weather stations, which indicates that winters tend to grow generally milder. The Mann-Kendall test returns revealed significant increases only for 6 weather stations, statistical figures covering the interval between 1.90 and 2.92 (Vlădeasa 1,800, Iezer, Parâng, Cuntu, Semenic and Băişoara). The only single WSI decreasing trend was registered at Ceahlău-Toaca, but no statistical significance was attached to it.

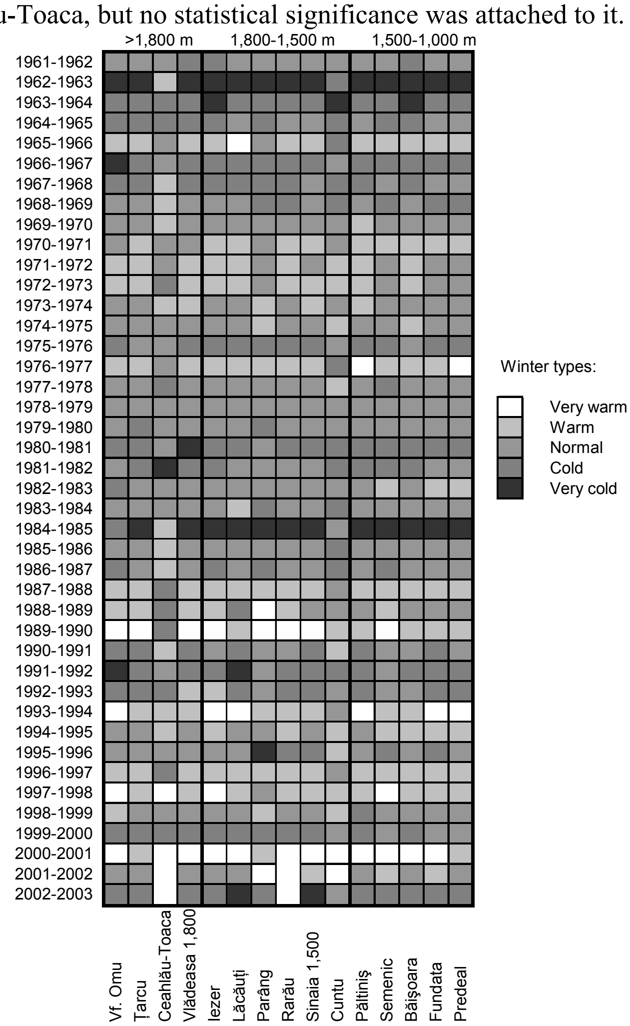


Fig. 8. Variability of winter types in the Romanian Carpathians over the 1961-2003 period.

Warming and cooling intervals are an indicator of the WSI trend during the 43-year period considered within this study. Shifting winters were determined according to the occurrence of warm and cold intervals based on the RSI values (table 4). RSI statistics showed two main warming intervals e.g. the early 1970s and the late 1980s and one main cooling interval (2002-2003 winter), both inducing the same types of winters at most of the weather stations. The winters of 1993-1994 and 2000-2001 led to positive changes in WSI values but frequencies were low.

Tabel 4. Shifting winters in the Romanian Carpathians over the 1961-2003 period.

| Weather stations | Shifting winters and the sign of change |
|---|---|
| Vf. Omu | 1969-1970 (+), 1993-1994 (+), 2002-2003 (-) |
| Ţarcu | 1970-1971 (+), 1978-1979 (-), 1987-1988 (+), 2002-2003 (-) |
| Ceahlău-Toaca | 1999-2000 (-) |
| Vlădeasa 1,800 | 1970-1971 (+), 2002-2003 (-) |
| Iezer | 1970-1971 (+), 2002-2003 (-) |
| Lăcăuţi | 2002-2003 (-) |
| Parâng | 1987-1988 (+), 2000-2001 (+) |
| Rarău | 1970-1971 (+), 1999-2000 (-) |
| Sinaia 1,500 | 2002-2003 (-) |
| Cuntu | 1971-1972 (+), 1980-1981 (-), 1988-1989 (+), 2000-2001 (+) |
| Păltiniş | 1970-1971 (+), 2002-2003 (-) |
| Semenic | 1970-1971 (+), 2002-2003 (-) |
| Băişoara | 1970-1971 (+), 2002-2003 (-) |
| Fundata | 2002-2003 (-) |
| Predeal | 2002-2003 (-) |

**Conclusions**

The variability of winter temperatures in the Romanian Carpathians highlights the heterogeneous character of mountain climate patterns. Altitude and the general atmospheric circulation play a very important role in the distribution of temperature values shaping winter characteristics.

The above conclusions reflect winter temperature variability patterns at certain measurement sites, therefore generalising the results over the whole Carpathian area is risky (large study area, few weather stations unevenly spread throughout the Carpathians, very complex active surface).

Winter temperature variability indicates a general increase in maximum, average and minimum temperatures which is statistically significant only in 40% of the cases (table 5). The most important warming interval occurred at the end of the 1961-2003 period (after 1990) characterized by winter temperatures increases around 3°C as against long-term average, in the locations recording significant positive trends. The same warming interval was also observed in the Alps (Jungo, Beniston, 2002, Beniston, 2006) being considered partly a consequence of the North Atlantic Oscillation, that showed positive index values (when alpine climates respond by lower-than-average precipitation and higher-than-average temperatures).

The number of days with different negative temperature characteristics in winter showed a general decrease at most of the weather stations (80-90% of the cases), but the Mann-Kendall test returns were significant in only 33% of the cases. An exception makes the Ceahlău-Toaca station where an increasing trend was found without statistical test returns being significant.

Shifts in snow seasons were determined in terms of snow cover onset and melting dates. Statistical test returns indicated earlier onset at Vârful Omu, Ţarcu and Băişoara stations and later onset at Sinaia 1,500 and Fundata stations. Important shifts in snow seasons were also determined in 40% of the stations, where statistics showed earlier snowmelt at Parâng, Cuntu, Păltiniş, Semenic and Băişoara stations.

Despite the strong interannual variability in snow cover duration, the overall quantity of snow has not changed substantially, so snow still falls during winter months at most of the weather stations (table 5). The Mann-Kendall test provided significant changes only at 3 out of the 15 weather stations situated in the Southern Carpathians:

- decreases in the duration of the snow season below 1,600 m altitude, at Sinaia 1,500 and Fundata stations (up to 70 days fewer than the long-term average, after 1990);
- increases, above 2,000 m, at Ţarcu (up to 67 days more than the long-term average, in the early 1980s).

Tabel 5. Variability trends in winter temperatures and yearly snow cover duration in the Romanian Carpathians. Statistical significant cases provided by the Mann-Kendall statistics (bold print).

| Weather stations | Maximum temperatures | Mean temperatures | Minimum temperatures | Snow cover duration |
|---|---|---|---|---|
| Vf. Omu | positive | positive | positive | positive |
| Ţarcu | positive | positive | positive | **positive** |
| Ceahlău-Toaca | negative | negative | negative | positive |
| Vlădeasa 1800 | positive | **positive** | **positive** | negative |
| Iezer | positive | **positive** | **positive** | positive |
| Lăcăuţi | positive | positive | positive | negative |
| Parâng | **positive** | **positive** | **positive** | negative |
| Rarău | positive | positive | positive | negative |
| Sinaia 1500 | **positive** | positive | positive | **negative** |
| Cuntu | **positive** | **positive** | **positive** | negative |
| Păltiniş | **positive** | positive | positive | negative |
| Semenic | **positive** | **positive** | **positive** | negative |
| Băişoara | **positive** | **positive** | **positive** | positive |
| Fundata | positive | positive | positive | **negative** |
| Predeal | positive | positive | positive | negative |

The 43-year observation period showed a dominance of "normal" winters, which is a situation representative for the latitudes of the Romanian Carpathians, with not very low temperatures and a continuous, fairly thick snow cover suitable to the practice of winter tourism. The frequency of extreme winter classes is reduced (under 10%). There is a high degree of simultaneity in the occurrence of winters with similar characteristics (especially below 1,800 m altitude in cold winters), but such intervals are not lasting very long (3 to 5 consecutive winters).

*Above 2,000 m*, as a consequence of the strong influence of altitude, climate warming is rather poor and temperatures do not rise above the freezing threshold. The climate factors controlling the snow amount, accumulation and duration are not only temperature but also winter precipitation (mainly snow) (Martin, Durand, 1998). *Below 2,000 and at medium-to-low elevations (1,500 m)*, the onset of the snow cover and its persistence seem to be more sensitive to long-term variations of winter temperature and precipitation.

Over the 1961-2003 period, winters became warmer at 6 of the 15 meteorological sites where the Mann-Kendall test returns indicated significant changes (Vlădeasa 1,800, Iezer, Parâng, Cuntu, Semenic and Băişoara).

The results of this study show that shifts in temperature regimes are significantly modifying the character of winters and the behaviour of the mountain snow pack. We assume that a persistent and a more intense temperature increase in the future will lead to the expansion of positive trends in high areas too (above 2,000 m). If present trends (more evident in some areas) maintain their characteristics, winter will become warmer and drier than they are today.

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