



## Snow line analysis in the Romanian Carpathians under the influence of winter warming

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The Romanian Carpathians are subject to winter warming as statistically proved by station measurements over a 47 year period (1961-2007). Herein, the snow season is considered to last from the 1st of November to the 30th of April, when snowpack usually reaches the highest stability and thickness. This paper investigates the signals of winter temperature and precipitation change at 17 mountain station located above 1,000 m, as being considered the main triggering factors of large fluctuations in snow amount and duration in these mountains. Fewer snowfalls were recorded all over the Romanian Carpathians after the mid 80s and over large mountain areas (including the alpine ones) the frequency of positive temperature extremes became higher (e.g. winter heat waves). Late Fall snowfalls and snowpack onsets (mainly in mid elevation areas, located below 1,700 m) and particularly the shifts towards early Spring snowmelts (at all the sites) were statistically proved to explain the decline of snow cover duration across the Carpathians. However, the sensitivity of snow cover duration to recent winter warming is still blurred in the high elevation areas (above 2,000 m). The trends in winter climate variability observed in the Romanian Carpathians beyond 1,000 m altitude are fairly comparable to those estimated in other European mountain ranges from observational data (e.g. the Swiss Alps, the French Alps and the Tatra Mts.). In relation to the climate change signals derived from observational data provided by low density mountain meteorological network (of about 3.3 stations per km<sup>2</sup> in the areas above 1,000 m), the paper analysis the spatial probability and evolution trends of snow line in each winter season across the Romanian Carpathians, based on Landsat satellite data (MSS, TM and ETM+), with sufficiently high spatial (30 to 60 m) and temporal resolutions (850 images), over the 1973-2011 period. The Landsat coverage was considered suitable enough to enable an objective statistical assessment of snow line and snow cover change across the Carpathians, providing results obtained for the first time in the national specialist literature on this topic. The satellite images were bulk processed for calibration to radiance and reflectance and the Normalized Difference Standardized Index (NDSI) and Land Surface Temperature (LST) have been extracted (the latter, only for TM and ETM+) and validated with ground meteorological measurements. All NDSIs and LSTs were merged into distinct monthly images covering the entire mountain range for each 38 winters in the study period. A quantitative analysis of snow line elevation change in relation to the variability of freezing level has been conducted. The snow line change across the Romanian Carpathians derived from satellite imagery has been used as a proxy for local response of the Carpathian climate to the warming process also observed in other mountain regions of Europe. The winter warming observed in the last decades caused an upward shift of the snow line and freezing level, associated to a shrinking of snow cover area all over the Carpathians, particularly after 2000. The paper's findings explain partially the difficulties that winter tourism industry in Romania has been facing in the last years due to the lack of snow or poor snow coverage, particularly in the low elevation ski domains located below the snow reliability line