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Observed hotspots of changing snow depth and snowfall in European mountain regions

Dana-Magdalena Micu[1], **Vlad-Alexandru Amihaesei**[1], Gabriele Quinti[2], Kirsten Halsnæs[3], Shreya Some[3], Monica-Gabriela Paraschiv[1], Alexandru Dumitrescu[1], and Sorin Cheval[1]

[1]National Meteorological Administration, Climatology, Bucharest, Romania (dana.micu@meteoromania.ro)
[2]Conoscenza e Innovazione, Roma, Italy (quinti@knowledge-innovation.org)
[3]Danmarks Tekniske Universitet, Copenhagen, Denmark (khal@dtu.dk)

Mountain regions are particularly vulnerable to natural hazards, such as snow avalanches, landslides, or flash-flooding, which are increasingly exacerbated by climate warming and changing climate patterns. This paper leverages the Copernicus Regional ReAnalysis for Europe (CERRA) dataset, with 5 km x 5 km spatial resolution, from the Copernicus Climate Change Service (C3S), covering the period 1985–2020, to analyse the changing of the seasonal patterns of snow depth and snowfall in two major European mountain ranges: the Alps and the Carpathians. More specifically, the study aims to identify the mountain areas with persistent and statistically significant increases or declines in snowfall and snow depth, referred to as "hotspots". The focus of the study is on four key snow depth and snowfall-related indicators including (i) total snow depth, (ii) number of snow cover days, (iii) days with snow depth exceeding 30 cm, and (iv) snowfall water equivalent. The hotspots are identified based on local spatial auto-corelation methods (the Getis and Ord G statistic), using the estimated Mann-Kendall trends of the four snow indicators as inputs. A positive Gi value signifies that a feature and its surrounding neighbours exhibit high values, whereas a negative Gi value indicates low values in the feature and its neighbours. The magnitude of the Gi value reflects the intensity of the clustering.
The results indicate widespread hotspots characterised by significant declines in both snow depth and snowfall indicators, in all seasons, especially at low and mid-elevations in both mountain regions. The observed shifts are particularly pronounced during winter (December-January-February) and spring (March-April-May). The location of identified hotspots carries multiple implications for the distribution and availability of water resources, ecosystem services, infrastructure and tourism activities, and so for the livelihood of mountain communities. These findings provide critical insights into the shifting snow avalanche hazard and their socio-economic impacts at NUTS3 level and in specific areas where historical snow avalanche events have significantly impacted three key socio-economic sectors—tourism, infrastructures, and forestry. They also could underscore the ongoing challenges in the mountain risk management under a changing climate.
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