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DOCTORAL THESIS

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Analysis of snow cover in Romania and its estimation based on conceptual modeling

PHD THESIS ABSTRACT

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IAȘI,
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Publication of results

A substantial part of the results presented in this part of the thesis has already been published in scientific publications with international visibility. Thus, the results on the climatology of snow cover in Romania, trends of snow indicators, altitudinal dependence and correlations with the main climatic factors (temperature, precipitation) were published in the article: Amihăesei, V.-A., Micu, D.-M., Cheval, S., Dumitrescu, A., Sfîcă, L., & Bîrsan, M.-V. (2024). Changes in snow cover climatology and its elevation dependency over Romania (1961-2020). *Journal of Hydrology: Regional Studies*, *51*, 101637. https://doi.org/10.1016/j.ejrh.2023.101637 https://doi.org/10.1016/j.ejrh.2023.101637

Also, the detailed analysis of the contribution of Mediterranean cyclones to snowfall accumulation in Romania has been developed in a separate paper entitled *"Contribution of Mediterranean cyclones to snowfall accumulation in Romania"*, which has already been submitted for publication to the journal *Atmospheric Research*: Amihăesei, V.-A., Sfîcă, L., S-R., Rubin, Micu, D.-M., Cheval, S. (under review). Contribution of Mediterranean cyclones to snowfall accumulation in Romania. *Atmospheric Research*.

Concerning the use of the SNOW-17 snow model, some of the results obtained have been published in the form of a scientific paper in which the performance of the conceptual SNOW-17 snow model was tested. The paper was published at the international conference "Air and Water - Components of the Environment", held in Cluj-Napoca in 2020, entitled *An Approach on Estimating of Snow Depth and Snow Water Equivalent* (Amihaesei V-A., Apostol L., Dumitrescu A. al., 2020)

Contents of the thesis

Key words: snow cover, snow depth, duration, atmospheric circulation, Mediterranean cyclones, Romania, trends, modeling, SNOW-17, data assimilation.

Introduction

Snow plays a crucial role in the global climate system, with significant impacts on hydrology, ecosystems, and climate. In the context of climate change, the study of snow cover has become crucial, with significant decreases in its duration and thickness observed, especially at low and mid altitudes where the impact of warming is most pronounced.

The snowpack in temperate regions is particularly vulnerable, with clear downward trends confirmed by numerous international studies. These changes are influenced by topography, elevation, vegetation, and regional variability in atmospheric circulation.

An essential factor in the accumulation of snow cover in Romania is the Mediterranean cyclones (MCs), which bring warm and moist air masses that interact with cold air, generating episodes of heavy snowfall. Although their role in precipitation generation is recognized, the contribution of MCs to the snow budget is poorly quantified from a climatological perspective.

Snow cover modeling is essential for climate change impact assessment, water resources estimation and hydrological hazard. There is a wide range of snow models, from empirical (e.g. degree-day) to physical, with varying degrees of complexity. Their performance strongly depends on the parameterization, the studied area and the quality of the input data.

Data assimilation in snow models by integrating observations can improve model estimates. Modern methods such as Ensemble Kalman Filter (EnKF) or Particle Batch Smoother (PBS) have demonstrated significant improvements in model accuracy, especially in the estimation of snow water equivalent. However, the quality of the observed data remains a critical factor in assimilation efficiency.

Hypotheses

The working hypotheses of the thesis are grouped into two main directions: climatological and modeling. On the one hand, it is assumed that the Romanian snow cover has undergone notable transformations in the last decades, characterized by delayed installation, early melting, and a general reduction in duration and thickness, especially in low and medium areas. A significant proportion of snowfall, especially heavy snowfall, is also thought to be associated with Mediterranean cyclone activity. On the other hand, from the modeling perspective, the thesis starts from the idea that conceptual models can realistically simulate the snow cover dynamics in Romania under various climatic conditions. It is also assumed that data assimilation methods, such as PBS, help to reduce errors by aligning simulations with field observations. Furthermore, the implementation of the model in an interactive web application (Shiny) is considered as an efficient solution for calibrating and testing snow model parameters.

Objectives

For **Chapter I, the** objectives focus on the climatological analysis of the snow cover in the period 1961-2020. They are aimed at: detailed characterization of the calculated snow indicators (duration, mean and maximum thickness, date of occurrence/disappearance, number of snow cover days or free snow cover days), identification of spatial and temporal trends and assessment of their significance. The influence of altitude on the changes is also analyzed in order to delineate areas vulnerable to these climate changes. Moreover, it is analysed the role of atmospheric circulation - in particular Mediterranean cyclones - in shaping the snow regime, both through synoptic studies and by quantifying their contribution to snow accumulation and extremes. The chapter thus aims to provide a sound scientific basis for assessing the impact of climate change on the snow regime in South-Eastern Europe.

For **Chapter II**, the overall objective is to build a framework for daily snow cover estimation using the conceptual model SNOW-17. This includes: applying the model to simulate snow depth and snow water equivalent, generating ensembles of simulations to represent uncertainty, integrating observations by the Particle Batch Smoother (PBS) assimilation method, and obtaining *a posteriori* estimates even in the absence of observational data. The model performance is evaluated comparatively (with/without data assimilation) and explores the advantages and limitations of the method in the climatic and geographical context of Romania.

Originality of the thesis

First, the thesis provides an extensive and well-documented climatological analysis of snow cover in Romania, based on a selection of meteorological stations and the use of eight relevant snow indicators. The influence of elevation, significant trends in the duration and snow depth and the role of climatic parameters (temperature and precipitation) were highlighted. The thesis also highlights the contribution of Mediterranean cyclones to the snowfall accumulation, providing for the first time quantitative information on the snow regime attributed to these cyclones.

Second, the thesis makes an original contribution by implementing the conceptual model SNOW-17 for the first time in Romania to simulate the snow depth and snow water equivalent. The model was evaluated for a set of representative stations, and the results were significantly improved by using the Particle Batch Smoother (PBS) method of assimilation of observed data. Thus, the model provided realistic and continuous estimates, including for variables that are not directly measured (e.g. daily snowfall amount or continuous/daily evolution of the water equivalent of the snow cover).

An important element of originality consists in filling in missing data series through simulation and assimilation, thus providing a tool applicable in climate reconstructions and long-term retrospective analyses. Also, the development of an interactive application in R/Shiny, adapted to the stationary use of the model, brings added accessibility and transparency to the exploration of results through real-time user calibration.

I. Snow Cover. Characteristics and evolution

I.1 Data and Methods

The climatological analysis was based on data from 114 meteorological stations in Romania (1961-2020), supplemented with ERA5/ERA5-Land reanalysis products and Mediterranean cyclone trajectories provided by the COST MedCyclones project. Eight relevant snow indicators were calculated. Trends were identified using Mann-Kendall and Theil-Sen tests, and the spatial distribution was modeled by Regression Kriging. All these indicators were analyzed both in relation to Köppen climate types (BSk, Cfa, Cfb, Dfb, Dfc, ET) and by spatial interpolation and aggregation over decades.

I.2 Results

I.2.1 Snow cover climatology (1961-2020)

This section provides a detailed climatological characterization of the snow cover in Romania, based on eight snow indicators calculated for the period 1961-2020. The indicators used are: first snow cover day (FSC), last snow-cover day (LSC), mean annual mean duration (SCD), maximum consecutive snow cover duration (SCDmax), mean snowdepth (SZAmed), maximum snowdepth (SZAmax), number of days with snow cover (SCd) and number of days without snow cover (SFd).

First snow cover day (FSC) shows a clear dependence on elevation and climatic region. In high mountainous areas (ET climate), snow cover generally sets up in October or even September, whereas in lowland and low hilly regions (BSk, Cfa), snow onset is significantly later, on average in December. On a decadal timescale, there is a progressive delay of FSC in almost all extra-Carpathian regions, indicating a postponement of the onset of the snow season.

Last snow cover (LSC) follows the same altitudinal control: in high mountain areas, snow persists until May or even June, while in low areas it frequently disappears before the end of February. The decadal evolution indicates an earlier and earlier melting of the snow in most regions, especially in lowland areas, suggesting a compression of the snow season.

The mean annual duration (SCD) and **maximum consecutive duration (SCDmax)** directly reflect these changes. In ET and Dfc regions, SCD exceeds 200 days per year, whereas in BSk and Cfa areas it rarely reaches 30-50 days. SCDmax follows a similar pattern: above 150 days in the Carpathians and below 20-30 in the lowlands. In the long term, the duration tends to decrease in almost all regions, with a noticeable decrease in continuous snow persistence.

The mean (SZAmed) and **maximum (SZAmax) thickness** highlight the altitudinal and climatic contrast. In ET, SZAmed often exceeds 50-70 cm and SZAmax can locally reach extremes of more than 200-250 cm. In the lowlands and SE, values are very low (below 10-15 cm for SZAmed). The decadal evolution shows a significant decrease in snowdepth in lowland and hilly areas, while in the highlands (ET) values remain stable or even slightly increasing.

The number of days with snow cover (SCd) is maximum in the Carpathians (>180 days/year), medium in the sub-Carpathian regions (80-140 days/year) and low in the Romanian Plain, Dobrogea or Bărăgan (below 50, even 30 days/year). The evolution indicates a clear reduction of SCd in extra-Carpathian areas.

The number of days without snow cover (SFd) is the complement of SCd and shows a steady increase, especially in the lowland regions, suggesting a decrease in the frequency and duration of snow on the ground in cold months.

I.2.2 Trend analysis (1961-2020)

Trend analysis for the period 1961-2020 shows clear signs of a shortening of the snow cover season and a reduction in snow depth, especially in the low and mid-altitude (500-1000 m) areas. The first snow date (FSC) is delayed on average by +1 to +2%/decade and the last snow date (LSC) by -1 to -2%/decade. Consequently, the total season length (SCD) and maximum continuous duration (SCDmax) decrease significantly, especially at altitudes < 1000 m. This decrease is due to an earlier melting rather than a later onset of snow cover. These changes are mainly correlated with warming air, especially in the spring months.

Mean (SZAmed) and maximum (SZAmax) snow depth generally decreases in regions below 1000 m, but in ET (Carpathians > 2000 m) positive trends (up to +10%/decade) are observed, which may indicate an increased input of solid precipitation in the context of global warming. SCd and SFd trends are convergent: days with snow cover decrease and days without increase, especially in Dfb, Cfa and BSk climates.

I.2.3 Altitude dependence of trends

Spatial analysis shows that altitude plays a determinant role in the maintenance of the snow cover - in mountainous areas, the cover persists longer and has higher snow depth, but even here there is a slight shortening of the snow season. In altitude bands, the largest decreases in snow cover duration and thickness are observed below 1000 m. The correlation between altitude and trends in SCD, SCd and SZAmed is significantly positive. Areas above 2000 m are more resilient to change, and in some cases even show slight increases in thickness and duration.

I.2.4 Relationship with the general atmospheric circulation and the role of Mediterranean cyclones

The North Atlantic Oscillation (NAO) significantly influences the snow regime in Romania, especially in the west and northeast of the country. The positive phase of the NAO is associated with warmer winters, shorter snow cover durations and fewer snow days. A key result is the identification of the influence of Mediterranean cyclones on snow cover. For the first time for Romania, a detailed quantification of the contribution of Mediterranean cyclones to snow accumulations is carried out. It turns out that more than 55-60% of the snowfall in the cold season is directly associated with the activity of Mediterranean cyclones, with a significant role especially in the extra-Carpathian regions. For the spring months their contribution can reach more than 90% of the total snowfall. In the northern regions, the influence is smaller, but not insignificant (less than 40%), being mediated by the Atlantic circulation. Over the four decades analyzed, significant trends in the influence of Mediterranean cyclones on snowfall have been observed. In February, there is a decrease of 4-6%/decade in the contribution of Mediterranean cyclones to snow accumulations. In contrast, November and January show increasing trends, especially in northern and central regions.

II. Using and calibrating a snow model to estimate water equivalent and snow depth

Snow cover modeling is an essential component in climatological and hydrological studies because of the direct influence of snow on energy balance, water resources and hydrological risks. Snow models are divided into three main categories: empirical, conceptual and physical.

Empirical models are based on statistical relationships between climatic variables (precipitation, temperature) and snow variables and have the advantage of rapid applicability, but significant limitations in terms of transferability to other regions or climatic conditions.

Conceptual models, such as SNOW-17, provide a balance between complexity and data requirements, being able to describe the major processes (accumulation, melting, refreezing) in a simplified but physically coherent manner. They are suitable in regions with limited meteorological data and can be integrated into broader modeling schemes (e.g. hydrological models).

Physical models are the most detailed and simulate processes in the snowpack based on full energy and mass balance. Although very accurate, they require extensive input data (solar radiation, wind, albedo, etc.) and high computational resources, which limits their use in operational or wide-area applications.

II.1 Data and methods

II.1.1 Data

We used daily mean air temperature and precipitation data from 145 meteorological stations in the national network. In addition, snow cover water equivalent and snow density data were used to assimilate the observations and to correct the snow cover estimation model. It should be noted that the observed water equivalent and snow density data are pentadic and have been available since 2001. Thus, the comparative analysis between modeled and observed values was carried out for a 20-year period from 2001 to 2021, using as reference unit the hydrological year, which starts on September 1 and ends on August 31 of the following year.

II.1.2 Methods

The SNOW-17 conceptual model was used to simulate the daily evolution of the snow cover, with a focus on snow depth and water equivalent estimation. The model was chosen because of its computational efficiency, low input data requirements (daily temperature and precipitation) and its validation in multiple international climate contexts. The SNOW-17 model was completely rewritten and implemented in the R programming language, adapting its structure to the specific Romanian meteorological data.

This version in R allowed the model to be integrated into analysis workflows, tested on multiple stations and run in ensemble to capture parameter uncertainty. This approach made it possible to fill in missing data, generate continuous estimates, and develop an interactive application for visualization and simulation.

To assess the uncertainty associated with the snow cover simulation, the SNOW-17 model was run as an ensemble of simulations (ensemble). Each simulation used a different combination of parameters, selected by controlled perturbations within plausible bounds, to reflect the uncertainties associated with snow accumulation, melting and transformation. In total, 256 simulations (particles) were generated, each representing a possible evolution of the snow cover, keeping the same meteorological input conditions.

To improve model estimates, the Particle Batch Smoother (PBS) method - a data assimilation technique based on Bayesian inference - was applied. In this approach, observations (snow cover thickness and water equivalent) are used to *subsequently* adjust the model estimates, also taking into account uncertainties in the observations.

II.2 Results

II.2.1 Snow model performance assessment

This section presents the results obtained from simulations carried out with the SNOW-17 model, both in open-loop (without data assimilation) and in Post-DA (assimilated, using the Particle Batch Smoother (PBS) method). The analysis focuses on two key snow cover variables: snow depth (cm) and snow water equivalent (mm). Evaluations are carried out at the level of mountain and lowland stations, as well as on a national scale by aggregating the results.

The analysis compared the performance of the simulations before (Prior-DA) and after (Post-DA) assimilation of observed data by the Particle Batch Smoother (PBS) method, mainly looking at estimates of snow cover thickness and its water equivalent.

Results showed a consistent and substantial improvement in model performance after assimilation, both visually and statistically. In all the six mountain stations analyzed (Vf. Omu, Ceahlău Toaca, Iezer, Bâlea Lac, Stâna de Vale, Parâng), the model in the unassimilated regime showed a clear tendency to overestimate the snow cover thickness, sometimes with differences of 70-90 cm from the observations. After assimilation, these errors were significantly corrected, with RMSE being reduced by almost five times in some cases, and the Kling-Gupta coefficient (KGE) increasing from negative or modest values to excellent values of more than 0.90.

The same conclusions were confirmed for stations in low-lying areas such as Iași, Cluj-Napoca, Brasov or Craiova. Even in these regions, where snow is less frequent, the assimilation led to a much better alignment between estimates and observations. For example, at the Iași station, RMSE decreased from 4.3 cm to 1.5 cm and KGE increased to 0.89, indicating a much more realistic fit.

The multi-annual evaluations confirmed the same pattern: the model without assimilation had a systematic tendency to overestimate, with mean differences of more than 30% in snow depth at more than half of the stations. After assimilation, the errors were substantially reduced and in more than 65% of the cases the differences were within a realistic range of ±10%. Error distributions narrowed and re-centered around zero, indicating effective correction for both bias and variability.

As for the snow water equivalent, the Prior-DA model showed the same problems of overestimation, especially during the period of maximum accumulation and in mountainous areas. For example, at Iezer, the model estimated more than 300 mm, while observations indicated only 150 mm. The assimilation corrected this deviation, bringing the estimate to a realistic value, with a reduction in error (RMSE) and a strong increase in KGE (from -2.53 to 0.87). An important aspect corrected by the assimilation was the timing of snow melt: in the simulations without assimilation, the model delayed this timing by 3-4 weeks, while after assimilation, the synchronization with observations was almost perfect.

Overall, the evaluations confirm that data assimilation leads to a significant improvement in SNOW-17 model performance. For snow depth, the correlation coefficient increased from R = 0.85 to R = 0.93, and for SWE from R = 0.83 to R = 0.96. The RMSE almost halved for both variables, and KGE and NSE reached values above 0.90, indicating a very high fit between simulations and observations.

II.2.2 Applicability of the model

The RO-SNOW-17 model developed within the thesis in R programming language and downloadable from the Github platform provides a wide range of simulated variables that considerably extend its applicability in climate, hydrology and water resources management studies. The main outputs include snow depth (SZA), snow water equivalent (ECHIVZAP), solid precipitation (snowfall) and liquid precipitation (rain).

Another important utility of the RO-SNOW-17 model, developed and implemented in this study, is that it allows the generation of a daily time series for the snow cover water equivalent, thus replacing the observed discontinuous series available only at a five-day interval (pentadic). As in Romania, the official observations of the water equivalent are not performed daily, but only once every five days, the simulations provided by the RO-SNOW-17 model, adjusted by assimilating the snow cover thickness observations, provide estimates of the water equivalent of the snow cover at daily resolution, which reflect not only the accumulation but also the snow melt dynamics. Thus, the model bridges the gaps between measured observations, allowing a complete reconstruction of the snow evolution over the whole period analyzed.

II.2.3 Model interactivity through the Shiny application

An interactive application in R Shiny, called **RO-SNOW17_web**, has been developed as part of the thesis. It allows running and visualization of the SNOW-17 model for various locations in Romania, for scientific, educational and application purposes. The need for such a tool resulted from several observations. First, the lack of dedicated applications dedicated to our region for snow cover simulation and the lack of intuitive tools for direct comparison of simulations with existing meteorological observations. Second, the difficulty in using and calibrating SNOW-17 conceptual models, especially by non-programmer users, has limited the applicability of these models in research. The application is hosted online and publicly accessible at https://climall.shinyapps.io/RO-SNOW17_web/ . It consists of several sections organized in tabs.

Source code

In this thesis, open-source software programs were used for the processing and analysis of climate data (climatologies, trends, etc.) as well as for the representation of the results (maps, graphs). Statistical processing, calculation of indicators and plot generation (boxplots, time series, correlation diagrams, etc.) were carried out in the R programming language, using different libraries specialized in data analysis (i.e. climate). In addition, the Climate Data Operators (CDO) command-line processing tool Climate Data Operators (CDO) was used to manipulate NetCDF files and perform basic climatological operations (monthly, multi-year averaging, temporal and spatial selections, clipping by area of interest). This combination of open-source tools allowed a reproducible, efficient and transparent workflow at all stages of the analysis.

The source codes used for the first chapter of the study are publicly available at: https://github.com/vladamihaesei/snow_clim

As for writing the SNOW-17 model in R programming language, it can be found at the following Github address: https://github.com/vladamihaesei/RO-SNOW17

Conclusions

The obtained results provide a detailed insight into the spatial and temporal distribution of snow cover characteristics, recent climate changes and the ability of models to reproduce these phenomena.

The climatological analysis revealed a clear signal of a shortening of the snow season, manifested by delayed snow cover (FSC), earlier melting (LSC), and a decrease in its duration and depth. The most affected areas are lowland and hilly areas, where the snow cover is becoming more discontinuous and ephemeral. On the other hand, in the high mountain regions (ET and Dfc), the persistence of the layer remains significant, and in some cases even slight increases in maximum snow depth are recorded, possibly due to increased solid precipitation.

In terms of modeling, by implementing the SNOW-17 model in the R programming language, the model proved to be able to broadly reproduce the snowpack evolution, but with a systematic tendency to overestimate, especially in mountainous regions and in periods with massive accumulations. This behavior was significantly corrected by applying data assimilation techniques.

Implementation of the Particle Batch Smoother (PBS) method led to a considerable improvement in model performance. In the post-assimilation regime (Post-DA), the estimation errors were reduced and the correlation with observations visibly improved, both for snow depth and snow water equivalent. Assimilation thus played a crucial role in reducing the uncertainties associated with model parameterization and obtaining more robust estimates.

An interactive Shiny application (RO-SNOW17_web) was also developed, which allows to run the model and visualize the results in a publicly accessible way. This facilitates experimentation with model parameters, comparison with real observations and visual exploration of local snow behavior.

Selected bibliography

Amihăesei, V.-A., Sfîcă, L., S-R., Rubin, Micu, D.-M., Cheval, S., 2025 (under assessment). Contribution of Mediterranean cyclones to snowfall accumulation in Romania. *Atmospheric Research*

Amihăesei V.-A., Micu D.-M., Cheval S., Dumitrescu A., Sfîcă L., Bîrsan M.-V., 2024. Changes in snow cover climatology and its elevation dependency over Romania (1961-2020). J Hydrol Reg Stud 51:101637. https://doi.org/10.1016/j.ejrh.2023.101637 https://doi.org/10.1016/j.ejrh.2023.101637

Amihaesei, V.-A., Apostol, L., Dumitrescu, A. (2020) An Approaching on Estimating of Snow Depth and Snow Water Equivalent. 2020 "Air and Water - Components of the Environment" Conference Proceedings, Cluj-Napoca, Romania, p. 201-212, DOI: 10.24193/AWC202020_19.

Anderson EA, 1976. A point energy and mass balance model of a snow cover. NOAA Technical Report, NWS 19, p 150

Anderson EA, 2006. Snow accumulation and ablation model. NWSRFS (National Weather Service River Forecast System) Snow17, 2005. II.2-SNOW-17: HYDRO-17 Snow Model, in User Manual for Release 81.
http://www.weather.gov/oh/hrl//nwsrfs/users_manual/part2/_pdf/22snow17.pdf

Apostol L., 2008. The Mediterranean cyclones-the role in ensuring water resources and their potential of climatic risk, in the east of Romania. Present Environ Sustain Dev 2:143-163

Beck, H.E., Zimmermann, N.E., McVicar, T.R., Vergopolan, N., Berg, A., Wood, E.F., 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution.Sci. Sci. Data 5, 180214. https://doi.org/10.1038/sdata.2018.214

Beniston, M., 2012. Impacts of climatic change on water and associated economic activities in the Swiss Alps. J. Hydrol. 412–413, 291–296. https://doi.org/10.1016/j.jhydrol.2010.06.046

Beniston, M., Stoffel, M., 2014. Assessing the impacts of climatic change on mountain water resources. Sci. Total Environ. 493, 1129–1137. https://doi.org/10.1016/j.scitotenv.2013.11.122

Bîrsan M-V.Niță I-A & Amihăesei V-A., 2024. Influence of large scale atmospheric circulation on romanian snowpack duration, Romanian Reports in Pysics 76, 708 https://doi.org/10.59277/RomRepPhys.2024.76.708 https://doi.org/10.59277/RomRepPhys.2024.76.708

Bîrsan, M.-V., Dumitrescu, A., 2014. snow variability in Romania in connection to large-scale atmospheric circulation: SNOW VARIABILITY IN ROMANIA IN CONNECTION WITH LARGE-SCALE CIRCULATION. Int. J. Climatol. 34, 134-144. https://doi.org/10.1002/joc.3671

Bojariu, R., Gimeno, L., 2003. The role of snow cover fluctuations in multiannual NAO persistence. Geophys. Res. Lett. 30, 2002GL015651. https://doi.org/10.1029/2002GL015651

Caian M, Andrei MD, 2019. Late-Spring Severe Blizzard Events over Eastern Romania: A Conceptual Model of Development. Atmosphere 10:770. https://doi.org/10.3390/atmos10120770 https://doi.org/10.3390/atmos10120770

Dong, C., Menzel, L., 2019. recent snow cover changes over central European low mountain ranges.Hydrol. Process, 34 (2), 321-338. https://doi.org/10.1002/hyp.13586. https://doi.org/10.1002/hyp.13586.

Dumitrescu, A., Bojariu, R., Birsan, M.-V., Marin, L., Manea, A., 2015. recent climatic changes in Romania from observational data (1961-2013).Theor. Appl. Climatol. 122, 111-119. https://doi.org/10.1007/s00704-014-1290-0

Essery, R., Morin, S., Lejeune, Y., B Ménard, C., 2013. A comparison of 1701 snow models using observations from an alpine site. Adv. Water Resour. 55, 131-148. https://doi.org/10.1016/j.advwatres.2012.07.013

Flaounas E, Davolio S, Raveh-Rubin S, 2022. Mediterranean cyclones: current knowledge and open questions on dynamics, prediction, climatology and impacts. Weather Clim Dyn 3:173-208. https://doi.org/10.5194/wcd-3-173-2022 https://doi.org/10.5194/wcd-3-173-2022

Ionițe I, Sfîcă L, 2016. The Black Sea As Contributor To the Precipitation Amount on Moldova Region. in: Physical Geography; Cartography; Geographic Information

Jacobi, H.-W., 2012. Snow: a reliable indicator for global warming in the future? Environ. Res. Lett. 7, 011004. https://doi.org/10.1088/1748-9326/7/1/011004

Margulis, S. A., Girotto, M., Cortés, G., and Durand, M., 2015. A particle batch smoother approach to snow water equivalent estimation, J. Hydrometeorol., 16, 1752-1772, https://doi.org/10.1175/JHM-D-14-0177.1

Micu, D., 2009. Snow pack in the Romanian Carpathians under changing climatic conditions, Meteorol. Atmospheric Phys. 105, 1-16. https://doi.org/10.1007/s00703-009-0035-6

Micu, D.M., **Amihaesei, V.A.**, Milian, N., Cheval, S., 2021a. Recent changes in temperature and precipitation indices in the Southern Carpathians, Romania (1961-2018).Theor. Theor. Appl. Climatol. 144, 691-710. https://doi.org/10.1007/s00704-021-03560-w

Micu, D.M., Dumitrescu, A., Cheval, S., Nita, I., Birsan, M., 2021b. Temperature changes and elevation-warming relationships in the Carpathian Mountains. Int. J. Climatol. 41, 2154-2172. https://doi.org/10.1002/joc.6952

Patriche, C.-V., 2009. Statistical methods applied to climatology. Terra Nostra, Iasi.

Peng, S., Piao, S., Ciais, P., Friedlingstein, P., Zhou, L., Wang, T., 2013. Change in snow phenology and its potential feedback to temperature in the Northern Hemisphere over the last three decades. Environ. Res. Lett. 8 014008. Doi: 10.1088/1748-9326/8/1/014008

Pepin, N., Arnone, E., Gobiet, A., Haslinger, K., Kotlarski, S., Notarnicola, C., Palazzi, E., Seibert, P., Serafin, S., Schöner, W., Terzago, S., Thornton, J.M., Vuille, M., Adler, C., 2021. Climate Changes and Their Elevational Patterns in the Mountains of the World. Reviews od Geophysics. 60(1). https://doi.org/10.1029/2020RG000730

Popova, V., 2007. Winter snow depth variability over northern Eurasia in relation to recent atmospheric circulation changes. Int. Int. J. Climatol. 27, 1721-1733. https://doi.org/10.1002/joc.1489

Raveh-Rubin S, Wernli H., 2015. Large-scale wind and precipitation extremes in the Mediterranean: a climatological analysis for 1979-2012: Mediterranean Large-scale Wind and Precipitation Extremes. Q J R Meteorol Soc 141:2404-2417. https://doi.org/10.1002/qj.2531

Sfîcă, L., Andrei, A., Bărcăcianu, F., Cojocaru, Ș., Enea, A., Hapciuc, O.-E., Iosub, M., Ichim, P., 2013. Analysis of snow-drifting vulnerability. application to Botoșani county. Lucr. Semin. Geogr. Dimitrie Cantemir 36, 43-54.

Sfîcă L, Damian A-D, Grozavu A, et al., 2022. Synoptic Conditions Associated with Floods and Highest Discharges on Lower Danube River (1980-2010). in: Negm A, Zaharia L, Ioana-Toroimac G (eds) The Lower Danube River. Springer International Publishing, Cham, pp 329-355

Sfîcă, L., Minea, I., Hrițac, R., **Amihăesei, V. A.**, & Boicu, D. (2022). Projected changes of groundwater levels in northeastern Romania according to climate scenarios for 2020-2100. *Journal of Hydrology: Regional Studies*, *41*, 101108. https://doi.org/10.1016/j.ejrh.2022.101108 https://doi.org/10.1016/j.ejrh.2022.101108

Voiculescu M., 2009. Snow avalanche hazards in the Fagaras massif (Southern Carpathians): Romanian Carpathians-Management and perspectives, Natural hazards, 51 (3), p. 459-4