

The SnowBall project has successfully managed to improve the monitoring and impact assessment of snow in Romania under present climate and future climate scenarios.

The project implemented innovative approaches based on satellite, in-situ and modelling data for snow monitoring and risk assessment of climate related changes in rapid snowmelt and avalanches hazards.

PROJECT OUTCOMES

- › A denser, operational, in-situ snow measurement network in the test zone. An usable ground truth dataset for the validation of satellite derived snow products, as a result of in situ data collection;
- › Development and implementation of a prototype for snow monitoring system, combining Sentinel-1/-3 satellite data, weather data and hydrological modelling for snowpack parameters estimation;
- › A data assimilation procedure for adjusting the snowpack related state parameters within the snow models module of the hydrological forecasting models;
- › Quantitative estimations (for the first time in Romania) of the snowmelt contribution to the aquifer replenishment;
- › Development of methods and models (e.g. satellite image texture segmentation approaches, numerical avalanche simulation tool, Snowpack and Rapid Mass Movement System models) for avalanche detection and related hazard assessment;
- › Output of climate model generation (CMIP5) runs will be downscaled and tuned on regional and local scales to assess climate change impact on snow water resources and hazards over the study area in Romania.



Project website: snowball.meteoromania.ro

www.norwaygrants.org



REMOTE SENSING, MODEL AND IN-SITU DATA FUSION
FOR SNOWPACK PARAMETERS AND RELATED
HAZARDS IN A CLIMATE CHANGE PERSPECTIVE-
SNOWBALL



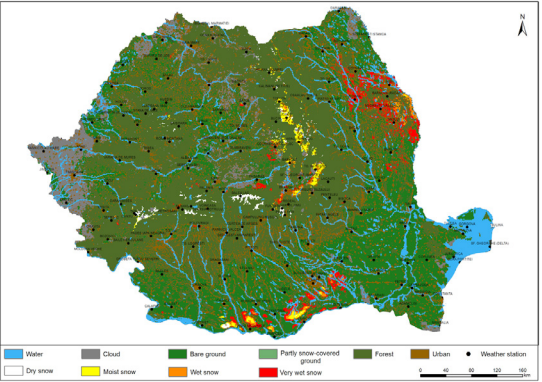
The overall project goal is to develop methodology supporting the vision of a snow service providing national authorities and the general public with consistent information in cvasi-real time, of the snow cover spatio-temporal characteristics and of associated hazards (floods caused by sudden melting of snow and avalanches), in conditions of present and future climate, based on in situ measured data and satellite information.

RESULTS

› **Developing algorithms for snow parameter estimation from satellite data.**

Methods and algoritms have been developed in order to achieve the snow parameters from satellite data for optical and radar spectral domain and for each specific parameter.

The Multi-sensor/multi-temporal Wet Snow (MWS) algorithm is novelty of this project, and fuses optical and SAR data to map the wet-snow area. The idea was to combine multi-temporal observations of optical and SAR wet snow in a fusion model to generate improved coverage in space and time. The developed algorithm fuses the optical and SAR observations using a Hidden Markov Model (HMM) approach. The snow map includes four thematic snow



classes, based on international standard classes (dry snow, moist snow, wet snow and very wet snow) obtained from Sentinel-1 (radar) and Sentinel-3 (optical) satellite data. The validation results are very promising and the quality and temporal resolution of the products increased from 2015 with the launch of European satellites Sentinel-1B and Sentinel-3.

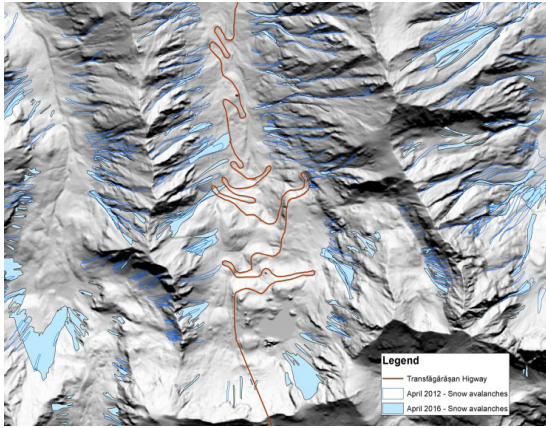
› **Snow avalanche activity assessment and avalanches inventory derived from Very High-Resolution Satellite (VHR) and drone based images analysis.**

Avalanche detection was manually performed in this step, using various band combinations, principal component analysis and normalized differentiation indices for a better visual analysis and delineation of avalanches. A total of 1069 avalanches were detected on the satellite image and 374 avalanches on the drone – based image. Most avalanches are of small or medium size, less than 1000 m long. The results showed that in the Romanian Carpathians the avalanches are much more numerous and their activity is much more intense than previously thought. They are the main natural hazard for the Carpathians in winter.

• **Avalanches simulation and hazard assessment.**

Hazard assessment was based on a topographic-statistic model combined with simulation results to identify areas with favorable conditions for snow avalanche release areas and separate levels of potential danger based on snow pressure derived from the simulation of avalanche extent and pressure.

The hazard being expresses as the probability of occurrence of a given process, in the case of snow avalanche assessment, the release areas and runout distances for several magnitude



classes have been determined. A combination of topographic factors to identify the potential release areas and simulation of avalanche pressure and volume based on past events with maximum extent has been applied for central part of Făgăraș Mts.

› **Improved hydrological warnings and forecasts during winter and spring periods.**

In order to reduce the errors and the uncertainty associated with the estimation of the snow water equivalent, we designed and implemented a specific data fusion type approach using: snow water equivalent simulations performed with a distributed hydrological model, observations of the snow layer from the national monitoring networks, and satellite products for the snow cover extent. The implementation of the methodology was done based on the following general design principles:

- Adaptive – use all the data available in real-time, from different sources, adapting the processing workflow in function of data availability.
- Automated procedure, non-interactive, having as final target operational daily run.
- Specific adequate processing approach, taking into account the relative high uncertainty associated with all the type of input data (approach based on a combination of Cellular Automata and Fuzzy Logic System).

It is expected that the use of these improved snow water equivalent estimations, at high spatial resolution of 1 km, for updating the snow state parameters in the main operational hydrological forecasting models, will significantly contribute to the improvement of the hydrological warnings and forecasts during winter and spring periods.

› **Climate variability and climate change impact on the snowcover and associated hazards.**

The hydrologic modelling applied to the sub-basins corresponding to the rivers Argeș and Ialomița, located mainly in mountain areas, supports the previous findings from the analysis of EURO-CORDEX results and add more local details about the maximum discharge and flood statistics. The results of the hydrologic model (CONSUL) indicate that multiannual

averages of maximum discharges during the interval from November to April 2021-2050 show increases compared with present climate (1981-2010) under stabilization (RCP 2.6) and worst (RCP 8.5) climate scenarios. For sub-basins with larger areas, the increases are systematically larger under the worst scenario compared to those under the stabilization one showing how the climate change signal overcome the noise beyond specific spatial scales of river basins.

› **Evaluation of snowmelt water infiltration in unsaturated zone for aquifers refilling.**

Prediction of groundwater recharge from snowmelt is critical to assess water resources necessary for agricultural, economical and ecological activities.

Infiltration of melt water during spring thaw is a complex process that involves coupled heat transport and mass flow with phase changes. Many studies have shown that seasonal infiltration is inversely related to the total moisture content (water and ice) of a frozen soil at the time of melt.

In the context of future climatic changes, the snowpack, the snow water equivalent and thus the aquifer recharge will be influence. Assessing and knowing this changes will improve the future of water management and the economic challenges.