Report no. 4

Project Title: Remote sensing, model and in-situ data fusion for snowpack parameters and related hazards in a climate change perspective (SnowBall)

Table of Content

1. Generale Objective …………………………………………………………………………………………………… 3

2. Objectives of the 2017 reporting period ………………………………………………………………………… 3

3. Summary ……… 5

4. Scientific and Technical Description …………………………………………………………………………… 9

5. Annexes ……… 45

6. Conclusions ……………………………………………………………………………………………………… 49

7. References …… 53

List of Acronims 56

1. GENERALE OBJECTIVE

Overall project objective:

Explore and develop methodology supporting the vision of developing a future service providing national authorities with hind-cast and real-time snow and avalanche information retrieved from earth observation data.

SnowBall is aiming at providing and demonstrating the methods required for a snow service to deliver geospatial products on the seasonal snow cover derived from satellite data, to the scientific community in Romania, policy makers, users of snow information and the public.

To meet its overall objective, SnowBall has identified 6 key project objectives. These key objectives and the related sub-objectives are directly mapped onto the tasks undertaken in each of the work packages.

Project objectives:

- Improve the spatial and temporal resolution of in-situ snowpack parameters measurements (WP2).
- Development of algorithms and implementation of a prototype snow monitoring system combining Sentinel-1/-3 satellite data, weather station data, and hydrological modelling for snowpack parameters estimation (WP3).
- Assess the impact of climate change on the snow-related resources and hazards (WP4).
- Define and test a reliable methodology for the snowmelt infiltration component of the hydrogeological cycle (WP5).
- Develop and implement a data assimilation procedure for adjusting the snowpack related state parameters within the snow models module of the hydrological forecasting models (WP6).
- Develop methods for avalanche detection, modelling, and hazard assessment (WP7).

2. OBJECTIVES of the 2017 reporting period

WP1 Management
Activity 1.1. Project Management

WP2 In-situ snow parameters measurements
Activity 2.2. Snowpack parameters observation and measurements (completition degree 100%);
Activity 2.4. Elaboration of spatial products using the spatial database (completition degree 100%).

WP3 Satellite remote sensing, data fusion and modelling of snow parameters
Activity 3.2. MWS algorithm and product (completition degree 100%);
Activity 3.3. New multilayer snow model module in NOAH (completition degree 100%).

WP4 Climate change impact on snow-related hazards
Activity 4.1. Snow-related climate variability and change and associated impact (completition degree 100%);
Activity 4.2. Variability and change in flash floods with snow melt contribution (completition degree 100%);
Activity 4.3. Variability and change in avalanche statistics (completition degree 100%).

WP5 Aquifer replenishment modelling from snowmelt infiltration
Activity 5.2. Aquifer modelling

Activity 5.3. Pattern matching and climate scenarios (completition degree 100%)

WP7 Avalanche inventory, release and hazard mapping
Activity 7.2. Change-detection algorithm for Sentinel-1 and Sentinel-2 (completition degree 100%);

Activity 7.3. Avalanche simulation (completition degree 100%).

WP8 Promotion and Dissemination
Activity 8.1. Project website (completition degree 100%);
Activity 8.3. Dissemination and training actions (completition degree 100%).

3. SUMMARY

WP1 Management
Activity 1.1. Project Management

The project management activity was developed by the Romanian National Meteorological Administration, as project promoter, unfolding throughout 2017. The activity encompassed the research, administrative and financial activities, too, also the communication with the National Authority within the Ministry of Research and Innovation, as well as for the exploitation of the obtained results.
On 6 February 2017 a work session took place via Skype with the project partners. The meeting agenda contained mainly the preparation of the 2016 and 2017 Annual Reports, as well as the project Final Report, according to the project Management Plan and the Addendum no. 6 of 1 November 2016.
The final workshop of SnowBall project was organized according to the project fulfilment Plan (Work Package 8; Promotion and Dissemination), taking place in Bucharest, at Marshal Garden Hotel, in Bucharest, on 27 April 2017.
The final workshop was attended by representatives of users of the project's results from: the Ministry of Research and Innovation, Ministry of Environment, Ministry of Water and Forests, General Inspectorate for Emergency Situations, National Administration "Romanian Waters", Romanian Space Agency, University of Agronomic Sciences and Veterinary Medicine, Institute of Geography of the Romanian Academy, Faculty of Geography in Bucharest, Technical University of Cluj-Napoca, Faculty of Automation and Computer Sciences, Computers Department- National Company of Road Infrastructure Management, Military Topographic Directorate etc. There was peculiar importance highlighted of the implementation in the National Meteorological Administration of the snow monitoring prototype system, which combines the daily data supplied by Sentinel-1, Sentinel-2 and Sentinel-3 satellites with in-situ observations from the weather stations and with the most modern climatic modelling techniques of the snow layer.
The third Annual Meeting (2017) in the SnowBall project took place in Bucharest at Marshal Garden Hotel, on 28 April 2017. Participation was from representatives of the partner institutions from Romania and Norway in the implementation of the project.
Brief reports were presented on the final stage of the budget implementation and the budget execution for the 2016 – 2017 period.
During the meeting there were discussions connected to the elaboration of the technical-scientific and financial Reports for 2016 and 2017 as well as of the final Report of the project. Great attention was paid to the planned/achieved indicators in the project and to aspects connected to the dissemination activities.
Participants from partner institutions discussed in view of the identification of new application domains, potential new users and opportunities to obtain contracts for turning to good account the results yielded in SnowBall project.

WP2 In-situ snow parameters measurements
Activity 2.2. Snowpack parameters observation and measurements

Snow spectral reflectance data sets
In 2017, the spectral data collection continued with two field campaigns in Sinaia (Vârful cu Dor – Valea Dorului) and Babele (Babele – Pestera), with more than 100 new, high quality snow spectra in the visisble and infrared collected using the DSR (StellarNet) portable spectro-radiometer.
Measuring methodology of the snow liquid water content (SLW) with the dielectric constant sensor
The automated snow stations have been providing snow depth, snow temperature and snow dielectric permitivity measurements during the winter 2016-2017. The dielectric permitivity of snow has been successfully used to calculate the snow liquid water content using both the Denoth and Topp equations.

Activity 2.4. Elaboration of spatial products using the spatial database

The daily gridded data sets of air temperature (minimum, mean and maximum), precipitation, snow depth and snow water equivalent have been updated over the period 1 October 2005 – 30 April 2017 at 1000 m × 1000 m spatial resolution.

WP3 Satellite remote sensing, data fusion and modelling of snow parameters

Activity 3.2. MWS algorithm and product

The aim of the work in this period has been to test and validate the use of the SLSTR sensor aboard the recently launched Sentinel-3A satellite. Necessary adaptations had to be done to adapt algorithms to this sensor compared to what we developed previously using MODIS. More experience with the novel multi-sensor/multi-temporal wet snow (MWS) algorithm and the products in two versions based on Sentinel-1 combined with MODIS and Sentinel-1 combined with SLSTR gave substantially more data and experience underpinning the work on algorithm improvements and training based on ancillary data.
The products have been demonstrated, studied and evaluated for the general quality over the whole product domains, Romania and southern Norway. The general behaviour of the product could be reasonably well assessed against the temporal development of the air temperature from the respective national networks of weather stations. Nine weather stations operated by the Norwegian Meteorological Institute (MET Norway) were chosen for product validation in Norway. Fourteen weather stations operated by the Romanian National Meteorological Administration (NMA) were chosen for Romania.

Activity 3.3. New multilayer snow model module in NOAH

The data fusion methodology for estimation of snow water equivalent, as a gridded product with 1 km spatial resolution, at national level, implemented in a first version in the previous reporting period, was applied experimentally during the period January – March 2017, in order to test, correct and improve the algorithms and data processing workflow.
The results were also compared with a reference interpolation method, respectively with the IDW method, computed using the available snow water equivalent observations from the stations networks.
The main improvement of the algorithms for automatic control of data quality and data interpolation that are used within the data fusion methodology, was done by considering also the influence of the slopes exposure and the vegetation covering on the snow layer evolution, which is an important one especially during the snow layer melting period.
This interdependency configuration was based on results from the previous research done using the data from representative basins in Romania, and the implementation was done using the fuzzy logic system approach, in order to be able to incorporate this dependency, in a robust way in the data fusion methodology.

WP4 Climate change impact on snow-related hazards
Activity 4.1. Snow-related climate variability and change and associated impact

The main work was dedicated to synthesize the results on impact of climate change for snow-related resources (e.g. snow water equivalent snow contribution to aquifer) and associated hazards (e.g. flash floods with snow melt contribution, avalanche statistics).

Activity 4.2. Variability and change in flash floods with snow melt contribution

The activities in 2017 was to complete the analysis of variability and change in maximum discharges determining flash floods with snow melt contribution for the sub-basins of Ialomita River (Activity 4.2). The results of the hydrologic model (CONSUL) indicate, like in the case of sub-basins of Arges

River, that multiannual averages of maximum discharges during the interval from November to April show increases compared with present climate (1981-2010) under best (RCP 2.6) and worst (RCP 8.5) climate change scenarios. Also, for sub-basins with larger areas, the increases are systematically larger under the worst scenario compared to those under the best one showing how the climate change signal overcomes the noise beyond specific spatial scales of river basins. We have also analysed the common statistics for all sub-basins in our area of interest and the above mentioned conclusions are the same.

Activity 4.3. Variability and change in avalanche statistics

The activity was concentrated to elaborate the GIS-enhaced files and avalanche statistics.

WP5 Aquifer replenishment modelling from snowmelt infiltration

Activity 5.2. Aquifer modelling

In 2017, whithin the activity 5.2 Modeling of aquifers, the calculation methodology was calibrated, as well as the extrapolation for climatic scenarios. Snow melting is a major component of the hydrological cycle closely linked to aquifers and surface waters. Aquifers act as natural reservoirs that can be used as sources of drinking water and / or irrigation. Estimation of snow melt is also important for flood forecasts in hydrological modeling of river basin processes (surface runoff, overexploitation, sediment transport, nutrient transport, frozen soil depth) in general design projects (highways, bridges, sewers , Etc.) in safety and recreation projects (avalanche warnings, ski conditions and expected road conditions) (Voight, S., 2003).

Activity 5.3. Pattern matching and climate scenarios

Pattern matching and climate scenarios was represented in climate projections in modeling water infiltration patterns in aquifers. Climate scenarios are alternative ways, where the future can take place. Climate scenarios have evolved from stylized representations of annual percentage increases in global GHG concentrations to advanced GHG representations that affect the climate based on detailed socio-economic and technological hypotheses. Climate scenarios based on emission estimates are used to explore the anthropogenic influences that could contribute to future climate change, given the uncertainties of factors such as population growth, economic development and the development of new technologies. RCPs are the latest generation of scenarios that provide information on climate models. Scientific advances and increasing interest in exploring different approaches to achieving specific climate change objectives (such as limiting change to 2° C) and increasing interest in a "risk management" approach combining emission reductions and adaptation to reduce The damage caused by climate change also dictated the need for new scenarios (van Vuuren DP et al., 2011).

WP7 Avalanche inventory, release and hazard mapping

Activity 7.2. Change-detection algorithm for Sentinel-1 and Sentinel-2

The activity related to change detection of snow cover caused by avalanches has been finalized. The winter images from the Sentinel-1 archive have been analyzed and several images have been selected to identify changes in the upper limit of the forest generated by avalanches, using an object-based detection algorithm.

Activity 7.3. Avalanche simulation

In this stage of the project, the activity related to the avalanche simulation for different values of snow parameters, magnitude and frequency scenarios has been completed. The release areas bave been extracted and selected based on morphometric parameters (slope, plan curvature and ruggedness) and different snow depth values have been tested in simulation scenarios for the central area of Făgăraș Mts.

The maps of snow extent, snow height and pressure have been generated for large, medium and small magnitude scenarios for the test areas. The avalanche hazard map for the central Făgăraș Mts. has been generated using a combination of topografic-statistic and dinamic models.

WP8 Promotion and Dissemination

Activity 8.1. Project website

The project website (http://snowball.meteoromania.ro) was updated on a continuous base.

Activity 8.3. Dissemination and education activities

The dissemination and education actions have been conducted according to the project dissemination strategy included in the Publicity Plan: awareness of the user community about the opportunities offered by the Snowball project; communication of the results achieved in the project; preparation of the support materials for the products created within the project (eg. documentations, flyers, posters, etc.); ensuring project visibility at national and international level.
Members of the research teams of the Snowball consortium has participated with oral presentations and posters at relevant events for the topics addressed in the project. There have also been submitted some articles for publication in relevant national and international journals for the project objectives.
At the end of the project, on April 27, 2017 in Bucharest, at Hotel Marshal Garden was organized the final conference dedicated to the presentation of the results obtained within the project.
The project book „Remote sensing, model and in-situ data fusion for snowpack parameters and related hazards in a climate change perspective" (Gheorghe Stancalie coordinator, Anisoara Irimescu editor, ISBN 978-606-23-0733-2, ed. PRINTECH, 163 pag.), was presented and distributed to the participants.
The third newsletter (e-format) was elaborated and uploaded to the project site and distributed to the SnowBall end-user list.

4. SCIENTIFIC AND TECHNICAL DESCRIPTION

4.1. WP1 Management

*4.1.1. **Activity 1.1** Project Management*

In view to ensure fulfilment of the project's objectives, meetings took place of the work groups, along with close communication between the partners via Internet.

The project management activity was developed by the Romanian National Meteorological Administration, as project promoter, unfolding throughout 2017. The activity encompassed the research, administrative and financial activities, too, also the communication with the National Authority within the Ministry of Research and Innovation, as well as for the exploitation of the obtained results.

On 6 February 2017 a work session took place via Skype with the project partners. Table 4.1.1 renders the participants in the work meeting.

Table 4.1.1: List of participants in the work session via Skype on 6 February 2017.

Name	Institution	E-mail address
Gheorghe Stancalie	Project Manager National Meteorological Administration Bucharest	gheorghe.stancalie@meteoromania.ro
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Roxana Bojariu	National Meteorological Administration Bucharest	bojariu@meteoromania.ro
Narcisa Milian	National Meteorological Administration Bucharest	narcisa.milian@gmail.com
Anisoara Irimescu	National Meteorological Administration Bucharest	anisoara.irimescu@meteoromania.ro
Denis Mihailescu	National Meteorological Administration Bucharest	denis.mihailescu@meteoromania.ro
Arnt-Borre Salberg	Norwegian Computing Center, Oslo	arnt-borre.salberg@nr.ro
Rodica Mic	National Institute of Hydrology and Water Management, Bucharest – P3	Rodica.mic@hidro.ro
Ciprian Corbus	National Institute of Hydrology and Water Management, Bucharest – P3	ciprian.corbus@hidro.ro
Dragos Gaitanaru	Technical University of Bucharest /CCIAS – P2	dragos.gaitanaru@gmail.com
Florina Ardelean	West University of Timișoara, Geography Department – P4	florina.ardelean@e-uvt.ro

The meeting agenda contained:

- Preparation of the 2016 and 2017 Annual Reports, as well as the project Final Report, according to the project Management Plan and the Addendum no. 6 of 1 November 2016;
- Preparation of the 2017 annual meeting and of the final workshop and establishment of the detailed plans for associate activities;
- Administrative and organizing activities;
- Financial reports;
- Project delivrables;
- Project indicators;
- Project results dissemination activities: blog article, leaflets, brochures, scientific papers to be published in magazines with an impact factor, papers to be presented in conferences/sessions.

It was decided to elaborate a book of 120 – 130 pages comprising the main results obtained in the project, mainly addressing users in meteorology, climatology, surface and ground water hydrology, water management, emergency situations management (flood, snow avalanches), tourism, media.

There was a discussion via E-mail on 20-30 March 2017 with the project partners about the updated list and the content of the promotional materials: *Project brochure – version 2 / in Romanian; Project leaflet - in Romanian; Newsletter 2, in Romanian; Newsletter 3, in Romanian; Project brochure – version 2 / in English; Project leaflet – in English; Newsletter 2, in English; Newsletter 3, in English; Blog article.*

On 10 May 2017 the contracting Authority was sent the links where the promotion materials can be downloaded, as achieved in SnowBall project (most of which are posted on the project's webpage: http://snowball.meteoromania.ro/gallery-ro/gallery-ro)

The final workshop of SnowBall project was organized according to the project fulfilment Plan (Work Package 8; Promotion and Dissemination), taking place in Bucharest, at Marshal Garden Hotel, in Bucharest, on 27 April 2017. The final seminar agenda is rendered in Annex 1.

The final workshop was attended by representatives of users of the project's results from: the Ministry of Research and Innovation, Ministry of Environment, Ministry of Water and Forests, General Inspectorate for Emergency Situations, National Administration "Romanian Waters", Romanian Space Agency, University of Agronomic Sciences and Veterinary Medicine, Institute of Geography of the Romanian Academy, Faculty of Geography in Bucharest, Technical University of Cluj-Napoca, Faculty of Automation and Computer Sciences, Computers Department- National Company of Road Infrastructure Management, Military Topographic Directorate etc.

There also participated representatives of the partner institutions: National Meteorological Administration, Norwegian Computing Center Oslo, Technical Construction University – Research Centre Groundwater Engineering Bucharest, National Institute of Hydrology and Water Management Bucharest and West University – Faculty of Chemistry, Biology and Geography, Timişoara.

During the seminar there were presented ad discussed the main achievements in the project.

The main aim of the project was to develop a new service able to provide the national authorities and the large public with meaningful information in quasi-real time, for the monitoring of the spatio-temporal characteristics of the snow layer and of the associated hazards (floods caused by the sudden snowmelt and snow avalanches), in present and future climate conditions, on the grounds of observation data measured in-situ and of those supplied by satellites.

There was peculiar importance highlighted of the implementation in the National Meteorological Administration of the snow monitoring prototype system, which combines the daily data supplied by Sentinel-1, Sentinel-2 and Sentinel-3 satellites with in-situ observations from the weather stations and with the most modern climatic modelling techniques of the snow layer.

Representatives of the various organisms and institutions praised the immediate applicability in operational and research activities of the presented results, like: hydrological modelling, warning for the occurrence of fast floods through snowmelt and warning for snow avalanches occurrence. Participants were very interested in the possibilities to assess the snow impact in the present and

future climate conditions on the statistics of the fast floods occurred with the contribution of snowmelt, as well as on the statistics of snow avalanches and ground waters respectively.
The third Annual Meeting (2017) in the SnowBall project took place in Bucharest at Marshal Garden Hotel, on 28 April 2017. Participation was from representatives of the partner institutions from Romania and Norway in the implementation of the project. The agenda of the final seminar is rendered in Annex 2.
Brief reports were presented on the final stage of the budget implementation and the budget execution for the 2016 – 2017 period.
During the meeting there were discussions connected to the elaboration of the technical-scientific and financial Reports for 2016 and 2017 as well as of the final Report of the project. Great attention was paid to the planned/achieved indicators in the project and to aspects connected to the dissemination activities.
Participants from partner institutions discussed in view of the identification of new application domains, potential new users and opportunities to obtain contracts for turning to good account the results yielded in SnowBall project.
Using the experience acquired during project implementation and the excellent cooperation relationships between the Romanian and the Norwegian researchers, peculiar attention was paid to preparing new projects in the frame of the research-development programs which will be initiated in the near future (SEE, ESA, H2020).
Those responsible for activities have been established their teams to achieve the proposed objectives. Also have been nominated the responsible for deliverables for the reported period (Table 4.1.2).

Table 4.1.2: List of Deliverables for 2017

LIST of DELIVERABLES - 2017					
Del. no.	**Deliverable Name**	**WP no.**	**WP Leader**	**Delivery date**	**Responsable**
1	D1.2. Annual project reports	1	CO	Each year	Gheorghe Stăncălie
2	D2.4 SD and SWE data sets	2	CO	33	Andrei Diamandi
3	D2.6 Reflectance spectral data sets of the snow – Version 2	2	CO	33	Andrei Diamandi
4	D2.10 Snowpack parameters data sets – Version 2	2	CO	33	Vasile Crăciunescu
5	D2.14 Snow related in-situ data sets and historical meteorological and hydrological data – Version 2	2	CO	33	Vasile Crăciunescu
6	D2.16 Mapping products derived from the spatial database (SD, SWE, precipitation, etc.) – Version 2	2	CO	33	Alexandru Dumitrescu
7	D3.7 Gridded SWE prototype products generated using data fusion methodology – Version 2	5	P3	34	Marius Mătreaţă
8	D4.4 Assessment of climate change impact (2021-2050 vs. 1981-2010) on flash floods with snow melt contribution from winter to spring transition period in the upper part of Arges - Ialomita river basins	4	P3	31	Roxana Bojariu Rodica Mic Ciprian Corbuş
9	D4.5 Public report on the impact of climate change for snow-related resources (snow contribution to aquifer) and hazards (flash floods with snow melt contribution,	4	P2	34	Roxana Bojariu Radu Gogu

	avalanche statistics)				
10	D4.6 GIS-enhanced maps of changes from present to future climate for snow water equivalent, statistics of flash floods with snow melt contribution, avalanche statistics, and snow contribution to aquifer over area of interests	4	CO	34	Roxana Bojariu
11	D5.3 Groundwater resources in the climate change framework: Based on the achievements of the WP4 (Climate Change) regarding the different climate change models and scenarios a holistic study for groundwater resources in correlation with snowmelt infiltration will be developed	5	P2	31	Radu Gogu
12	D7.3 Avalanche hazard maps	7	P4	34	Mircea Voiculescu
13	D8.6. Visibility products (banners, posters etc.)	8	CO	Each dissemination session	Denis Mihăilescu
14	D8.7. Conference project presentation package	8	CO	Each dissemination session	Vasile Crăciunescu
15	D8.8. Dissemination action report	8	CO	Each year	Oana Nicola
16	D8.9. Project newsletter (e-zine) - digital form	8	CO	Each year	Vasile Crăciunescu
17	D8.5 Project overall report	8	CO	34	Gheorghe Stăncălie

4.2. WP2 In-situ snow parameters measurements

4.2.1. Activity 2.2. Snowpack parameters observation and measurements

Snow spectral reflectance data sets

In 2017, the spectral datat collection continued with two field campaigns in Sinaia (Vârful cu Dor – Valea Dorului) and Babele (Babele – Pestera), with more than 100 new snow spectra in the visisble and infrared collected using the DSR (StellarNet) portable spectro-radiometer (examples in Figures 4.2.2 – 4.2.3). In Figure 4.2.1, the DSR spectro-radiometer setup for spectral data acquisition is shown at one of the sites on the measurement path Babele - Pestera.

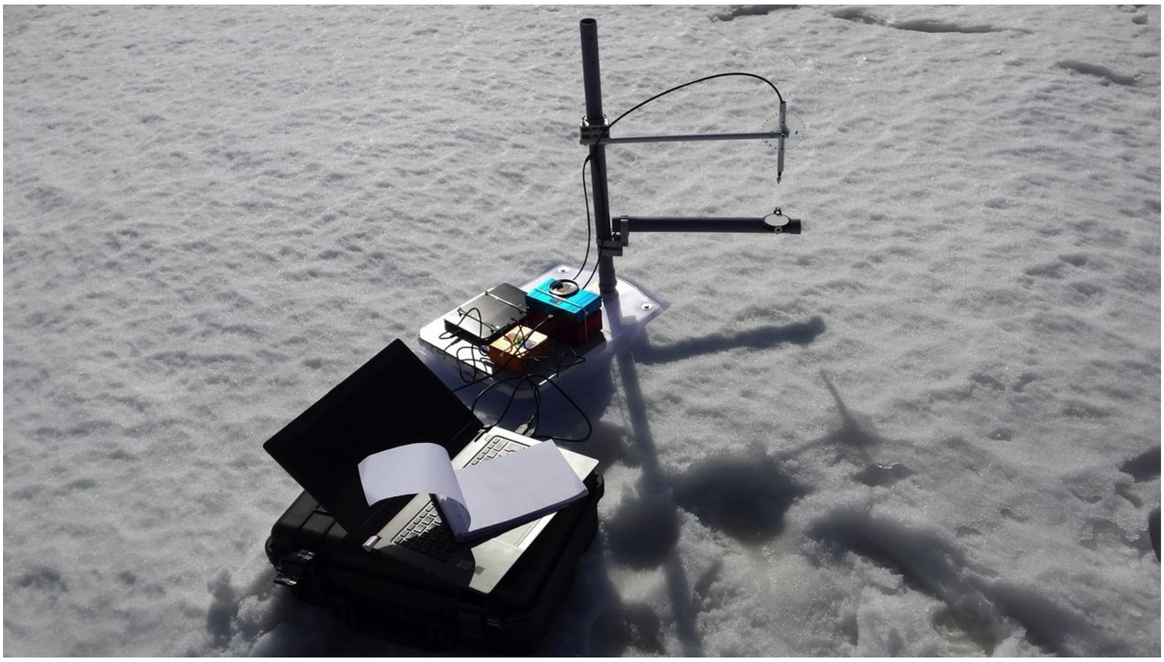

Figure 4.2.1: The DSR spectro-radiometer ready for snow spectra data acquisition, Babele 2017.

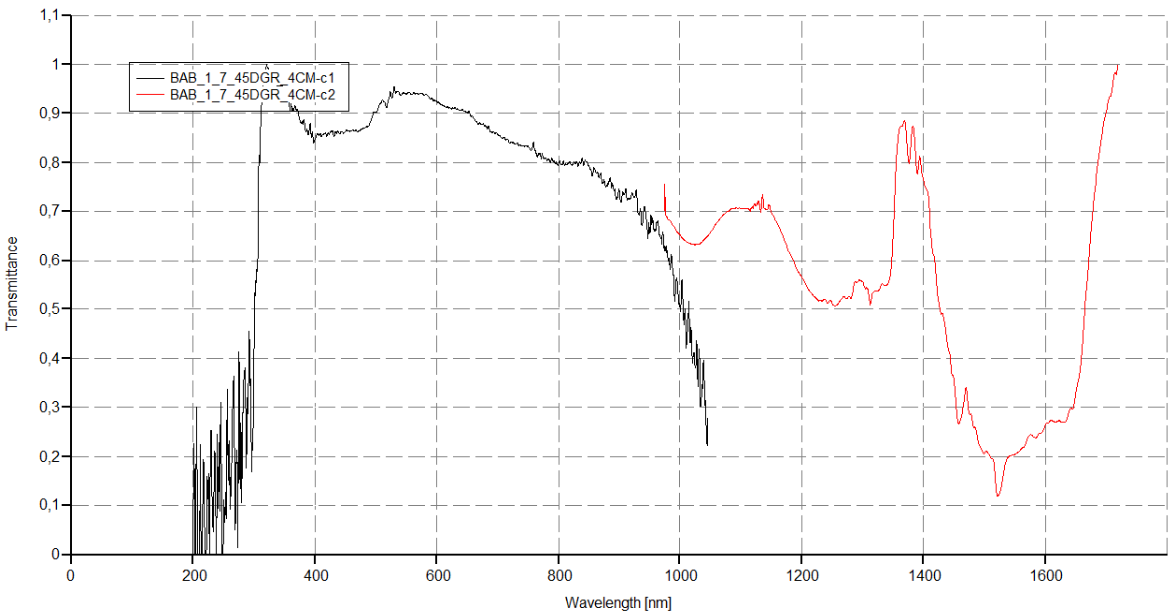

Figure 4.2.2.: Transmittance snow spectra, Babele, 01/02/2017 11:34.

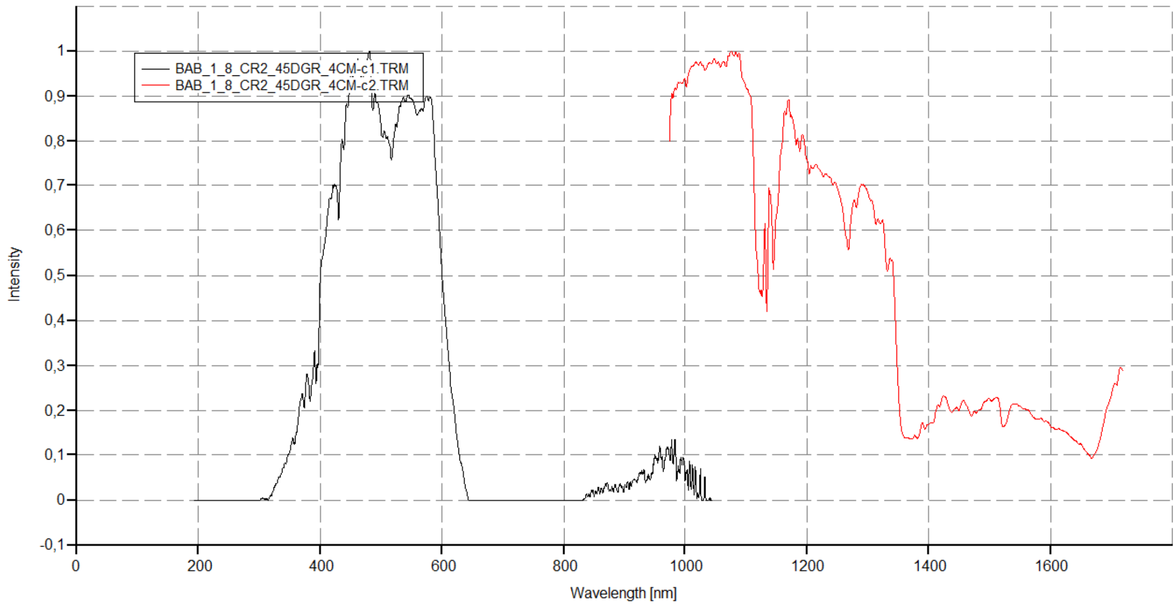

Figure 4.2.3: Irradiance snow spectra, Babele, 01/02/2017 11:50.

One can observe on the selection of snow spectra presented in Figures 4.2.2 – 4.2.3 the minima at 1 µm and 1.5 µm, confirming the quality of the data acquisition. The data set obtained so far is covering a wide range of weather and snow conditions (sun angles, spectro-radiometer viewing angles, air temperature, illumination, etc).

Measuring methodology of the snow liquid water content (SLW) with the dielectric constant sensor

The Decagon 5TM sensors has been selected for capacitive snow wetness mesurements in the SnowBall project. The probes were deployed at the Joseni and Targu Secuiesc cal/val stations and at 7 weather stations withing the project test area: Sinaia 1500, Varfu Omu, Predeal, Curtea de Arges, Fundata, Balea Lac si Salvamont Cota 2000 (Valea Argesului).
The snow water liquid content (SWE) has been derived from the snow permittivity measurements using the Denoth (1) and Topp equations (2):

$$\varepsilon = 1 + 1.92\,\rho + 0.44\,\rho^2 + 0.187\,SWE_{Denoth} + 0.0045\,(SWE_{Denoth})^2 \quad (1)$$

$$SWE_{Topp} = 4.3 * 10^{-6}\,\varepsilon^3 - 5.5 * 10^{-4}\,\varepsilon^2 + 2.92 * 10^{-2}\,\varepsilon - 5.3 * 10^{-2} \quad (2)$$

where: ε is the real part of the snow dielectric permittivity measured with the Decagon 5TM sensor, ρ is the snow density and SWE_{Denoth} and SWE_{Topp} the volumetric water content.
An example of snow liquid water content calculated with Denoth and Topp formulas is given in Figure 4.2.4. Denoth SWC graph follows very well the SWC calculated with Topp's formula.

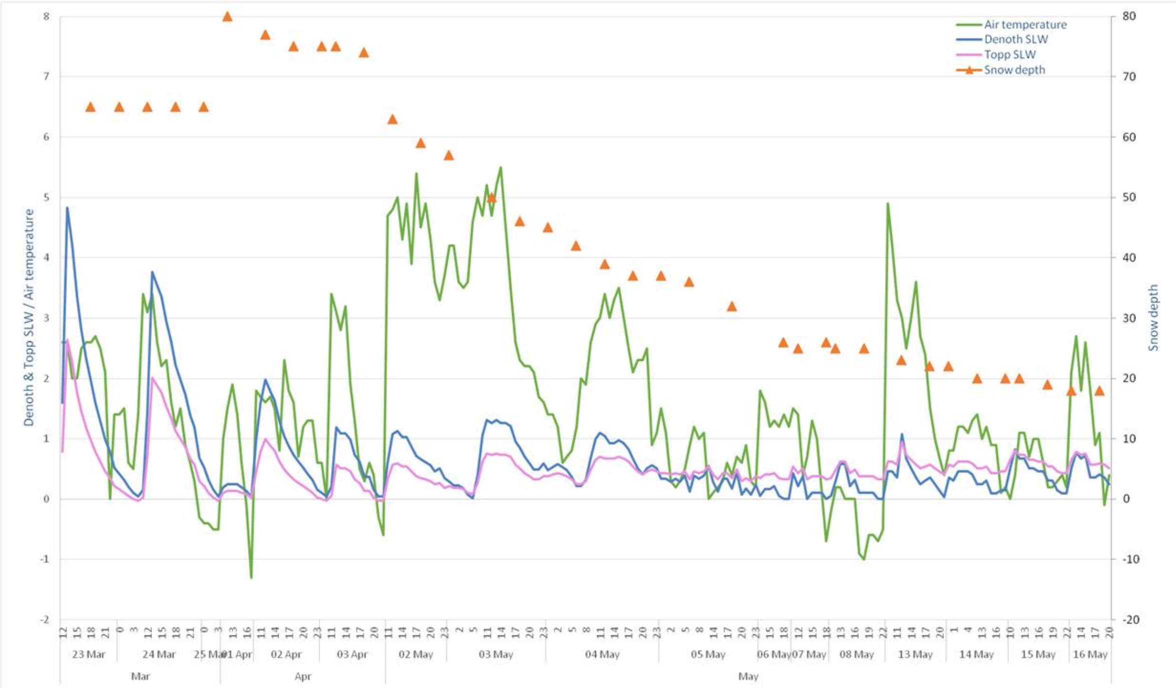

Figure 4.2.4: Vf. Omu Denoth and Topp SWC, air temperature and snow depth diurnal variation, March-May 2017.

More details are presented in the deliverable D2.6: „Reflectance spectral data sets of the snow – Version 2”.

*4.2.2. **Activity 2.4.** Elaboration of spatial products using the spatial database*

The spatial interpolation procedure of the weather stations data was achieved through three steps, as follows:

(1) Spatial interpolation (at 1 km × 1 km resolution) of the mean multiannual values corresponding to each month, computed from data extracted from the climatological database;

(2) The daily, 5-day and yearly deviations against the multiannual monthly mean were computed for each day, 5-day and 1-year periods, respectively, over 2005-2017, together with their spatial interpolation;

(3) The spatio-temporal datasets were obtained by merging the two surfaces obtained in the aforementioned stages.

To choose the optimum method applied in spatializing deviations, three interpolation methods were tested through the cross validation procedure: Multiquadratic Kriging (MQ), Ordinary Kriging (OK) and Inverse Distance Weighting (IDW).

Validation methods

A number of interpolation methods were tested in order to choose –by a **cross validation** procedure – the optimum interpolation method of daily anomalies against the multiannual means: Inverse Distance Weighting (IDW), Multiquadratic (MQ) and Ordinary Kriging (OK). The cross validation procedure implies eliminating, one by one, the values from the set of observed values and determining the value of the point excluded on the basis of the other observed data. The difference between the P estimated data and the O measured ones represents the ε experimental value:

$$\varepsilon_i = P(s_i) - O(s_i)$$

Quantification of differences between estimations and observed data was performed with the help of the the following error measurement indicators: mean error (ME), mean absolute error (MAE), root mean square error (RMSE). Box-plot diagrams and Taylor-type diagram were also used. For all analysed parameters, the cross validation procedure was applied to the anomalies computed over the 2005-2017 interval.
The cross validation procedure was applied to the anomalies computed over the 2005-2017 interval for all analysed parameters. Given that both validation methods of the interpolation procedures highlight the good results obtained by MQ, this method was selected for the spatial interpolation of anomalies. By summing the maps displaying the minimum temperature daily anomalies and the maps displaying the climatological normals, the daily minimum air temperature maps at 1 km × 1 km spatial resolution were built.

Minimum air temperature

The minimum monthly air temperature was computed recorded in the October 2005 – April 2017 interval (Figure 4.2.5) using daily minimum air temperature gridded data. The lowest temperatures were recorded in January and February, when those were lower than -30˚C in the inter-mountainous depressions from eastern Transylvania, where the thermal inversion phenomenon frequently occurs in the cold season.

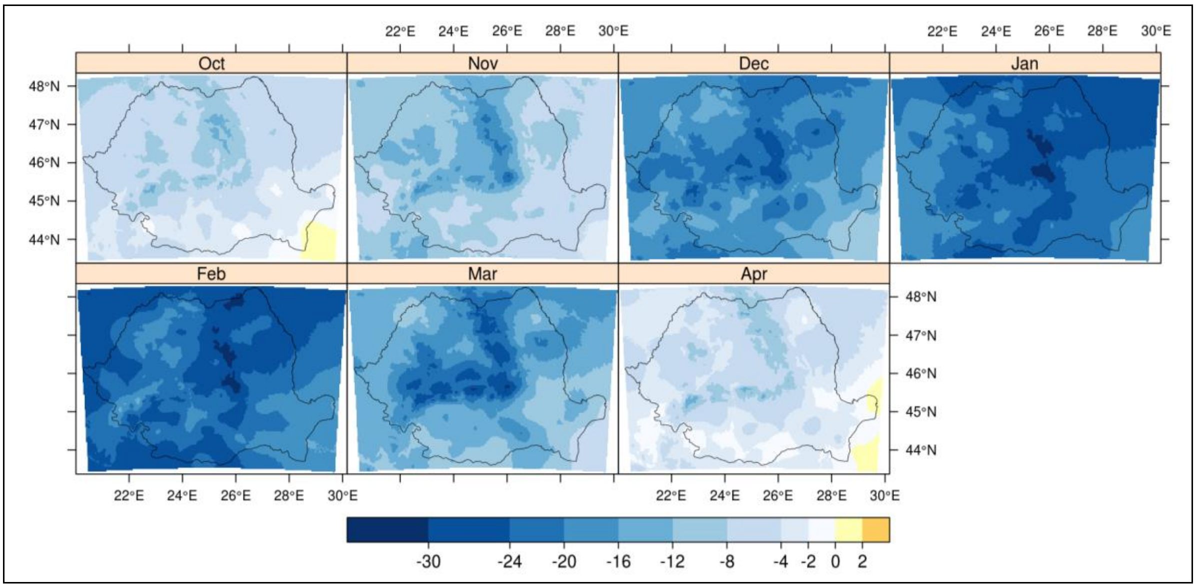

Figure 4.2.5: Monthly minimum air temperatures (°C) recorded in the 2005-2017 period.

Maximum air temperature

The maximum air temperatures maps obtained from the gridded daily datasets are presented in Figure 4.2.6. The highest maximum air temperatures are over 30°C, being recorded in October and April in the low areas from the Romanian Plain and Western Plain. In all analysed cases, the monthly maximum temperatures are above 0°C.

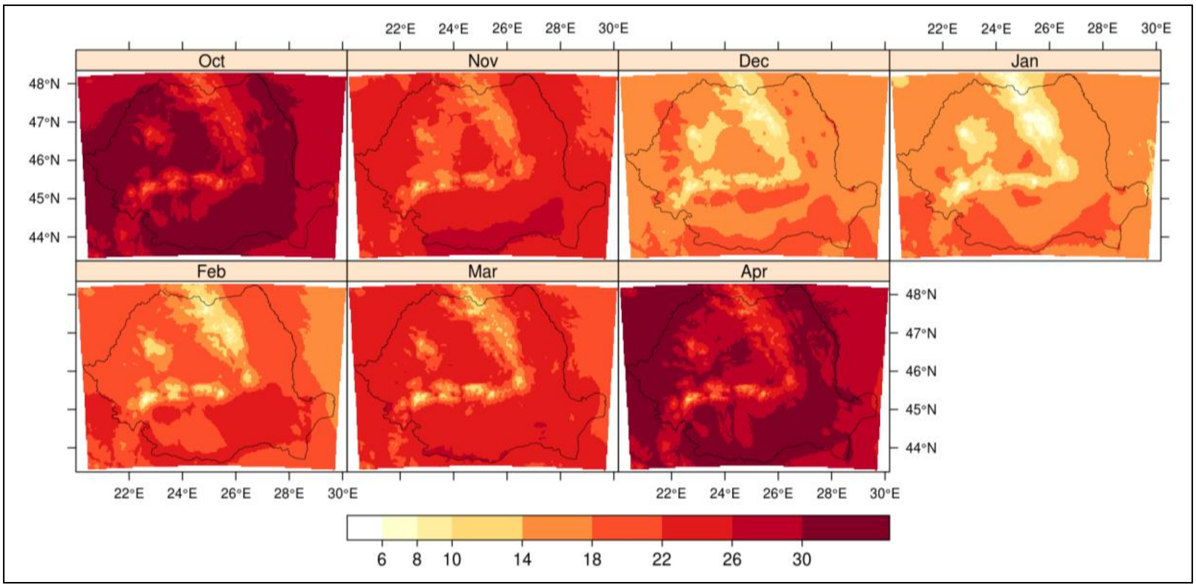

Figure 4.2.6: Maximum annual air temperatures (°C) recorded in the 2005-2017 period.

Snow depth

By means of daily gridded snow depth data, the monthly maximum snow depth was computed for every grid point (Figure 4.2.7). The highest values of this parameter correspond to the high mountain areas (more than 200 cm starting from January), persisting till April due to the negative mean temperatures. A considerable snowpack (deeper than 50 cm) can also be found in the extra-Carpathian areas as a consequence of the blizzard episodes that are specific to the first two months of the year.

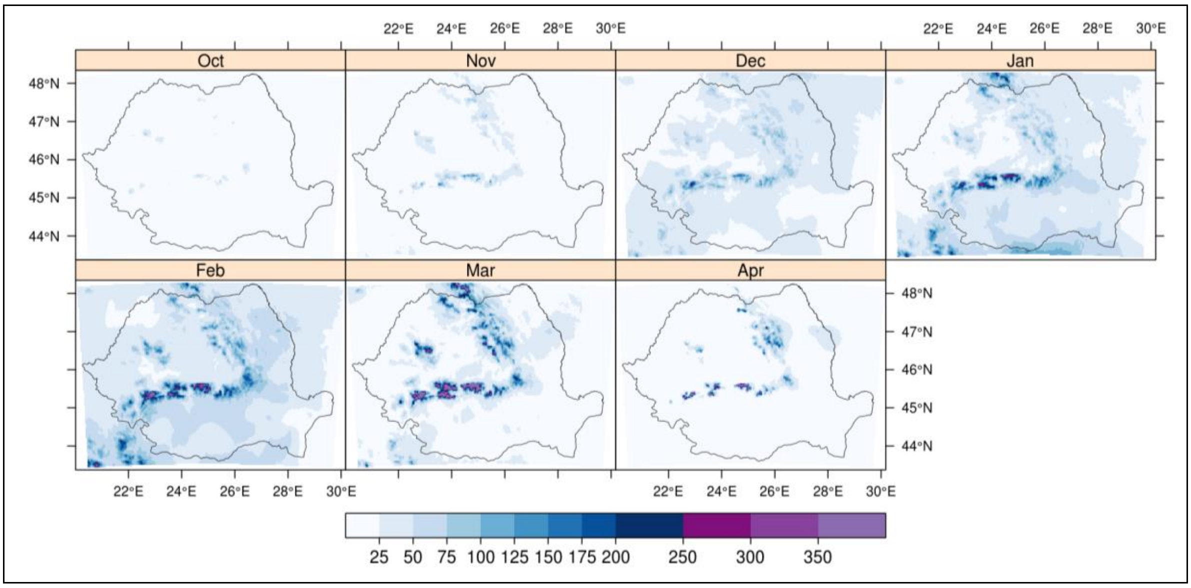

Figure 4.2.7: Maximum snow depth (2005-2017).

Snow water equivalent

The spatio-temporal distribution of the maximum values of the snow water equivalent computed from gridded daily data is very similar to the snow depth distribution, the largest values persisting until April in the high mountain areas (Figure 4.2.8).

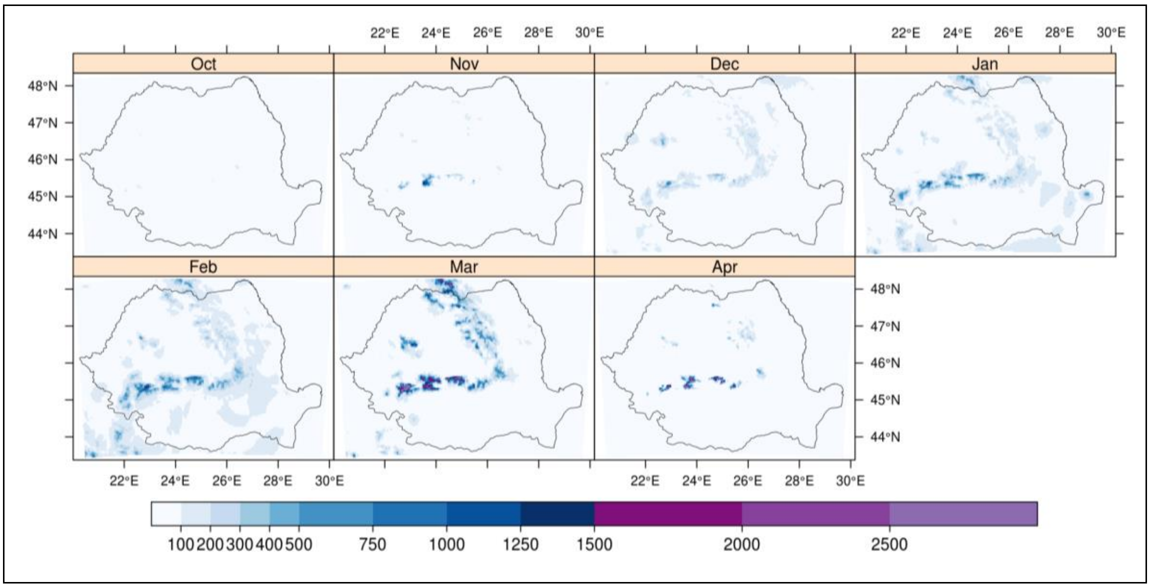

Figure 4.2.8: Maximum snowpack water equivalent (cm) (2005-2017).

More details are presented in the deliverable D2.16: „Mapping products derived from the spatial database (SD, SWE, precipitation, etc.) – Version 2”.

4.3. *WP3 Satellite remote sensing, data fusion and modelling of snow parameters*

4.3.1. Activity 3.2. MWS algorithm and product

The original objective of this activity was to develop a multi-temporal multi-sensor snow wetness algorithm using Sentinel-1 and Sentinel-3 data. As the Sentinel-3 satellite launch was delayed, we had to follow the contingency plan and use Terra MODIS data in the first two project years. Sentinel-3A was finally and successfully launched on 16 February 2016. The commissioning phase was completed summer 2016 and a ramp-up phase took place autumn 2016. From mid-November 2016 data started to become available for users of the satellite.

With the release of Sentinel-3 SLSTR data we could start testing and final adaptation of algorithms and software for this sensor. The snow-rich winter 2016/2017 in Romania made a perfect situation for extensive validation of both lowland and mountainous snow. Also calibration/validations sites were well covered with snow and gave valuable data for the final algorithm work and validation.

Sentinel-3 SLSTR

Sentinel-3A is primarily a mission to support services related to the marine environment, with capability to serve numerous land-, atmospheric- and cryospheric-based application areas. The Sea Land Surface Temperature Radiometer (SLSTR) is based on the heritage from ENVISAT's Advanced Along-Track Scanning Radiometer (AATSR). The SLSTR uses a dual-viewing technique and operates across eight wavelength bands providing better coverage than AATSR because of a wider swath width (1675 km for the nadir view angle). The sensor has three bands in the visual and near-infrared (555, 659 and 865 nm), three in the mid-infrared (1.38, 1.61 and 2.25 µm) and three in thermal infrared (3.74, 10.85 and 12 µm). The spatial resolution is 500 m at visible and infrared wavelengths and 1 km at thermal wavelengths.

Calibration of Sentinel-3 SLSTR data for the optical component of MWS

The snow grain size was in the original OWS (optical wet snow) algorithm estimated from MODIS data by using bands 2 (841-876 nm) and 7 (2105-2155 nm). SLSTR band 3 (855-875 nm) corresponds to MODIS band 2. However, for SLSTR, there is no band corresponding to MODIS band 7. Band 7 includes an absorption band making it insensitive for snow grain size. It is used together with band 2 in a snow grain size index. A band of similar characteristics to MODIS band 7 is SLSTR band 5 (1550-1670 nm). In order to limit the impact of the band change from MODIS to SLSTR, we determined a linear regression between the original and the new snow grain size index to obtain similar performance as previously.

An initial regression was made based on one date, 9 January 2017 (Figure 4.3.1).

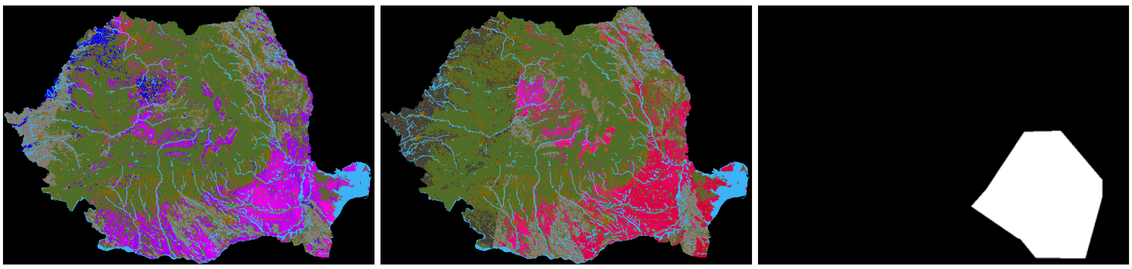

Figure 4.3.1: Left: SGS estimated from MODIS, assumed to be correct for the purpose of calibrating SLSTR estimates. Middle: SGS estimated from SLSTR by simply replacing MODIS bands 2 and 7 with SLSTR bands 3 and 5. Right: Digitized mask of snow covered area, to be used for initial regression.

For all pixels inside the manually digitized mask (Figure 4.3.1, right) that had valid SGS observations in both images, i.e., excluding cloud cover, water mask, forest mask and urban mask, a linear regression was applied. This included 16604 pixels at 1 km grid spacing. The scatter plot (Figure 4.3.2) shows a linear trend.

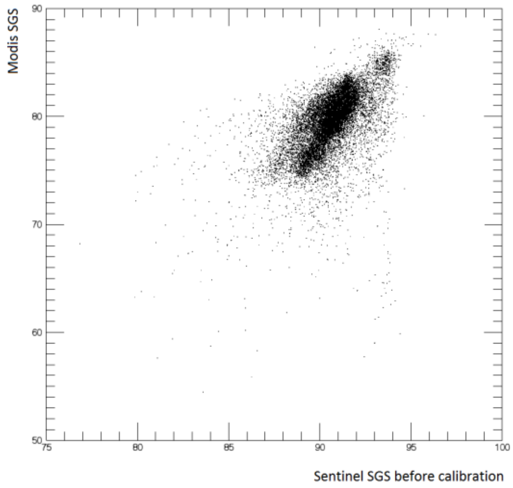

Figure 4.3.2: Scatter plot for initial SGS regression.

Based on this initial calibration of SGS for SLSTR, OWS was estimated for the entire time series 17 November 2016 – 28 March 2017. By visual inspection of the OWS results, ten dates were picked for a new regression, including a variety of OWS classes occurring at different elevations and geographic areas.

Refinements of the multi-temporal multi-sensor snow wetness algorithm

The multi-temporal multi-sensor snow wetness algorithm is based on fusion of SWS (SAR wet snow) and OWS (optical wet snow) products. The Sentinel-1 C-band SAR can be used to detect wet snow, as the backscatter drops significantly. With C-band SAR however, it is difficult to determine how wet the snow is. It can also be difficult to distinguish bare ground from dry snow cover. Optical sensors such as Sentinel-3 SLSTR on the other hand, through monitoring of the temperature and snow grain size, can be used to estimate the degree of wetness. However, optical data, are limited by cloud cover. Earlier in the SnowBall project we developed an approach for merging these two products in a multi-temporal multi-sensor snow wetness product (see Annual Technic & Scientific Report for 2016).
Our approach makes use of a hidden Markov model (HMM) to describe the different states the snow goes through during the melting season, and the possible transitions between these states. The original states included dry snow, “moist snow”, “wet snow”, “very wet snow”, “soaked snow cover” and “temporary snow cover”. This model is combined with the available optical and SAR snow wetness products and used to estimate the state of the snow for every 1 km grid cell. The Viterbi algorithm is used to produce the most likely sequence of snow states, given the observations. The result of the method is daily multi-sensor snow wetness products, providing the best estimate for each grid cell for every day.
From more extensive experience with data from the previous years of the SnowBall project we found that the state “soaked snow cover” is very rare. This resulted in very little data for establishing the necessary statistics for training. We therefore included the state in “very wet snow” by extending the snow-liquid-water range of this state.
Furthermore, we made some changes in the allowed transitions. The wet snow states may now transition directly to the “depletion” state (Figure 4.3.3). This is more in agreement with what is seen in the data.

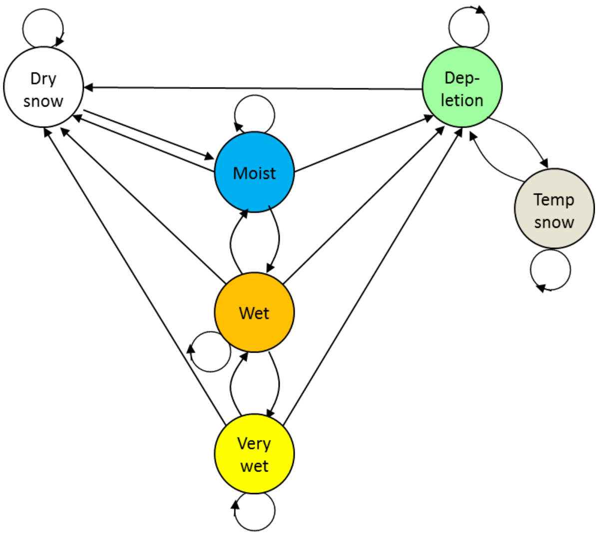

Figure 4.3.3: The snow states and the allowed transitions in the updated hidden Markov model.

The training of the HMM has been improved by use of prior data for Norway and Romania. Per time unit throughout the season (day) we would like to establish estimates of the likelihood of each state and the transition probabilities. For Norway, we used a 15-year daily time series (2000-2015) of a 1-km snow surface state product based on a model where data from meteorological stations and numerical weather prediction is combined into a national-wide product provided through the seNorge web portal (Saloranta 2012). Previously, the different transition probabilities have been modelled from a single estimated "wetness probability". This data set, however, allowed us to directly train each of the individual state transitions.
The data set was also used to train a model for estimating the transition probabilities from air temperature. For Romania we estimated climatology from a 10-year time series (2005-2015) with re-analysis of snow depth and temperature at a 1-km grid resolution (Dumitrescu et al. 2015).

Validation Results

The algorithm validation results are presented for the test sites in Norway and Romania. The validation is based on data from the winter season 2016-2017. Products based on both MODIS and Sentinel-3 SLSTR were included in the study to establish the consistency between the two versions of the products.

Norway

In the following, validation against weather stations for a time series of multi-sensor wet snow (MWS) products for southern Norway is shown for the winter season 2017. Nine weather stations operated by the Norwegian Meteorological Institute (MET Norway) have been used in this study. The stations' locations and names are indicated in Figure 4.3.4.
Table 4.3.1 provides the weather stations' daily mean temperatures for the days of satellite data acquisitions.

Table 4.3.1: Mean daily temperatures (in degrees Celsius) for the MET Norway weather stations applied in this study.

Date	Beitostølen	Dombås	Filefjell	Finse	Hjerkinn	Juvasshøe	Møsstrand	Sirdal	Skåbu
13 February	-2.2	-4.2	-4.3	-3.7	-1.7	0.9	-4.7	-8.5	-1.7
25 March	2.9	5.5	2.1	-4.4	3.5	-2.0	2.7	2.5	3.5
26 March	5.5	6.5	4.4	2.8	5.2	0.7	5.6	4.6	5.9
29 March	-3.7	-3.5	-3.4	-1.8	-6.8	-8.0	0.6	2.7	4.2
30 April	-1.9	1.3	-3.1	-5.1	-2.1	-7.2	-1.8	3.4	-0.9

Winter 2016/17 started rather late due to unusual warm weather in 2016 and early 2017. Significant snow accumulation started very late, typically between December 2016 and February 2017, depending on altitude and regional climate. From February, the temperatures usually kept low until

the end of the project period. Two distinct mild weather periods with snowmelt at also high elevations took place in late March and beginning of April (25 March – 2 April), and from 29 April.
As the project period ended 30 April 2017 and the winter and accumulation period in the mountains took place almost until the end of the period, we mainly missed the melting season for 2017. We therefore focus on the mild weather events in this validation study.

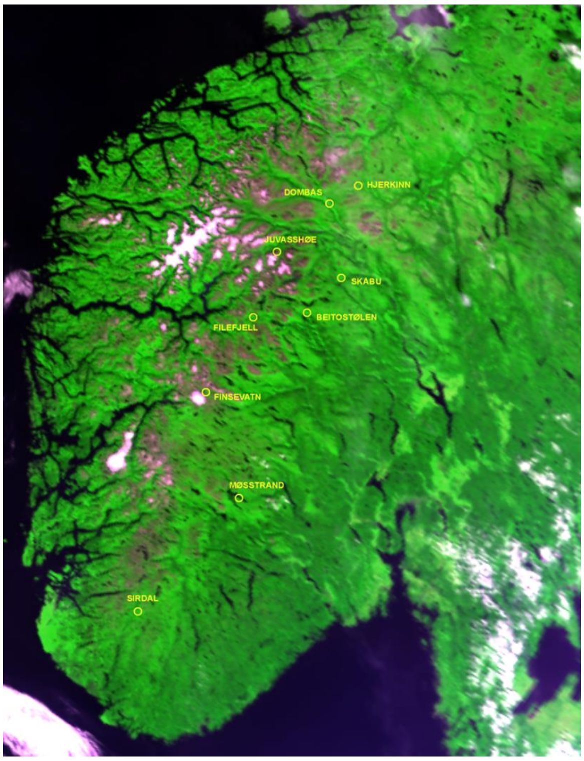

Figure 4.3.4: The locations of the weather stations (circles) applied. The background image is acquired by MODIS.

Figure 4.3.5 shows MWS maps for 13 February 2017. We see that the maps including Terra MODIS and Sentinel-3 SLSTR are almost identical. Both map versions show dry snow all over except for a few, small areas. The weather station data in Table 1 show freezing temperatures for all stations except for Juvasshøe. This station is the highest of all at 1844 m.a.s.l. indicating high-altitude mild air. A closer look at the map shows some scattered pixels of moist snow. However, the highest density of moist snow pixels is east of Oslo, in agricultural fields. Agricultural fields is a known source of noise in the SWS maps, and a check of the corresponding SWS map for this day and the days before confirm the problem. The corresponding OWS maps do not show any wet snow.

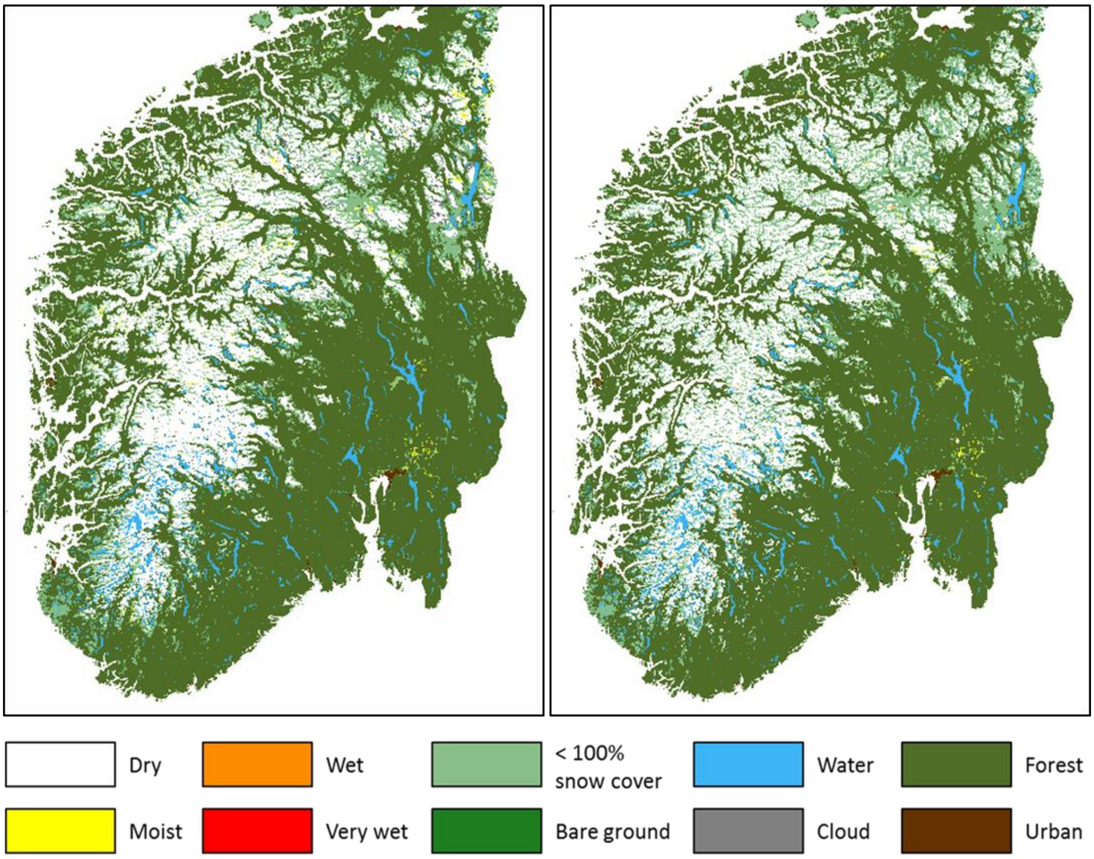

Figure 4.3.5: MWS maps for southern Norway based on Terra MODIS (left) and Sentinel-3 SLSTR (right) for 13 February 2017.

Figure 4.3.6 shows MWS maps for 25 March 2017, at the time of the start of a few days of mild weather in general, also resulting in wet snow at high altitudes in the mountains when the weather was at the warmest. The general pattern is similar in the map versions including Terra MODIS and Sentinel-3 SLSTR. There is moist snow in the southern part, the Hardangervidda mountain plateau, with some wet snow at lower altitudes around Hardangervidda. There is also moist snow at the lower part of the Scandinavian Mountains around the south-eastern Norway. The SLSTR-based version shows wet snow in areas the MODIS-based version shows moist snow in the north east. The difference in acquisition time was 7 minutes this day, so this does not explain the differences between the maps. However, the differences might very well be that the actual liquid water content of the snow was close to the transition zone between the two classes. The highest stations, Juvasshø and Finse (1203 m.a.s.l), show negative temperatures confirming dry snow in the high mountains. Otherwise, all stations show positive temperatures.

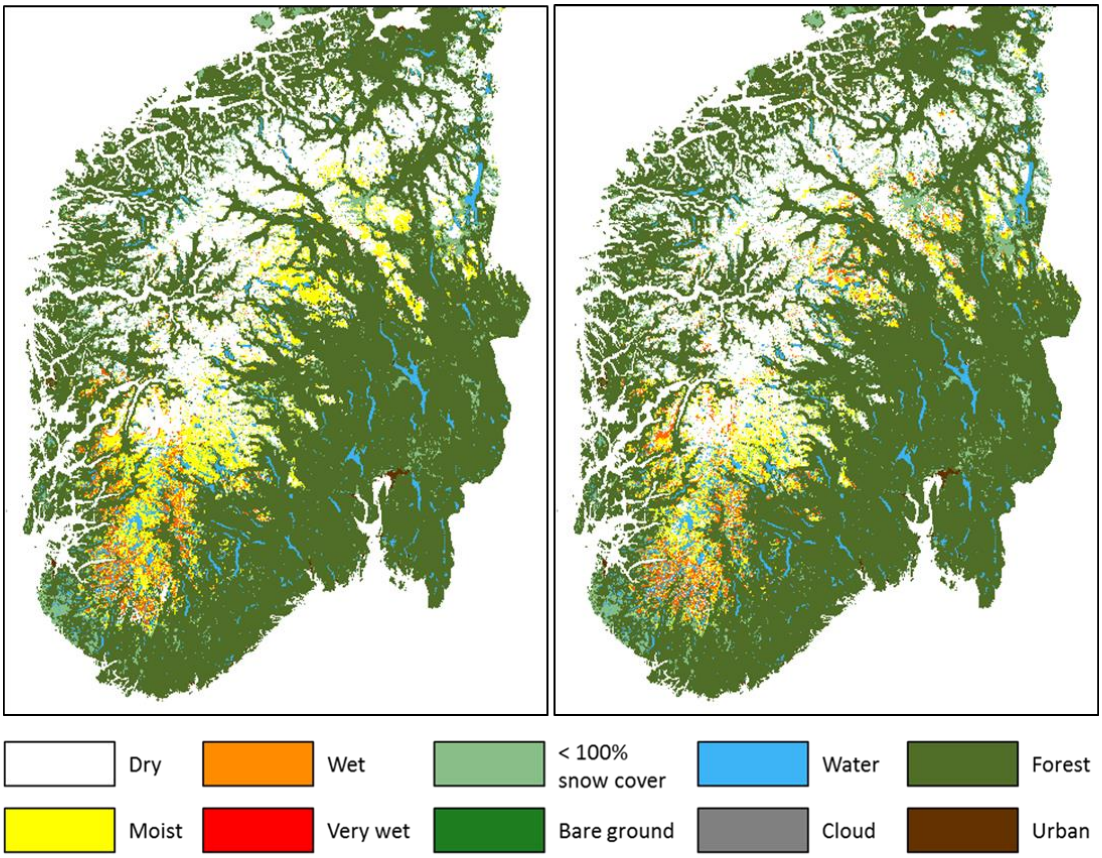

Figure 4.3.6: MWS maps for southern Norway based on Terra MODIS (left) and Sentinel-3 SLSTR (right) for 25 March 2017.

Figure 4.3.7 shows MWS maps for 26 March 2017, the following day of the previous maps. Mild weather has influenced almost all the mountains in southern Norway, except for some areas in northeast and a region in the northern part of Hardangervidda. In this case the MODIS version tends to show somewhat wetter snow than the SLSTR version. However, the overall pattern is similar in both maps. All weather stations show positive temperatures. The lowest temperatures are at Juvasshø (0.7°C) and Finse (2.8°C). For the Jotunheimen region, where Juvasshø is situated, the snow maps indicate dry snow above about 2000 m.a.s.l. This seems to agree well with the temperature at Juvasshø at 1844 m.a.s.l. The region just south of Finse at Hardangervidda also shows dry snow in both maps. Surprisingly, this is in the transition zone between wet snow in the south and moist snow in the north. The highest part of the mountains in Hardangervidda is just north of this dry-snow area, so it might be that the local topography has blocked the mixing of air between north and south, including protecting a dry-snow zone.

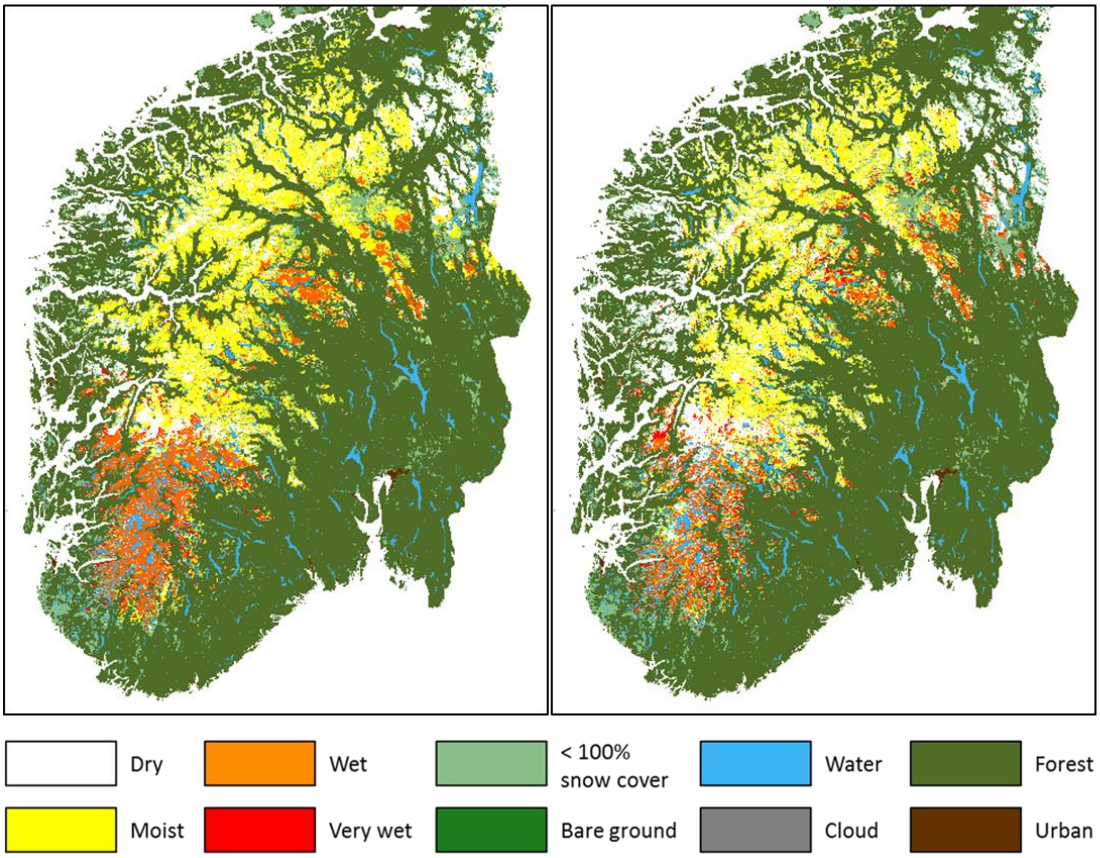

Figure 4.3.7: MWS maps for southern Norway based on Terra MODIS (left) and Sentinel-3 SLSTR (right) for 26 March 2017.

Figure 4.3.8 shows MWS maps for 29 March 2017. The mild weather period is now diminishing and the highest parts of the mountains show dry snow in general. There is still moist or wet snow at lower elevations in several regions. However, parts of the two snow maps are quite different. There is a wet snow region in the northern part of Hardangervidda in the version where MODIS is used, while the same region is shown as dry snow in the version where SLSTR is used. There is also more wet snow in the northern part at lower altitudes. Checking the OWS maps, we see that most of southern Norway is cloudy this day. There is also no SWS map this day (no SAR observation). This means that the MWS maps are entirely based on the model using data from previous days only. The previous days had partly cloudy conditions, with more clouds in the SLSTR-based map. Wet snow was indeed observed by MODIS the previous day in northern Hardangervidda, which is the origin of a similar region on 29 March. This region was, however, partly cloudy in the SLSTR observations. The moist and wet snow in the lower elevation mountain regions in the north is harder to explain. The regions are partly observed by SLSTR, which show dry snow. The weather station data show negative temperatures except for three stations. Møsstrand shows 0.6°C, and both maps show moist snow for this region. Sirdal shows 2.7°C, and both maps shows wet snow. Skåbu shows 4.2°C, and there is wet snow in both maps. All the stations showing negative temperatures correspond with dry snow in both versions of the MWS maps. This indicates that the maps are describing the current snow state quite well despite regions of anomalies shown as differences between the maps.

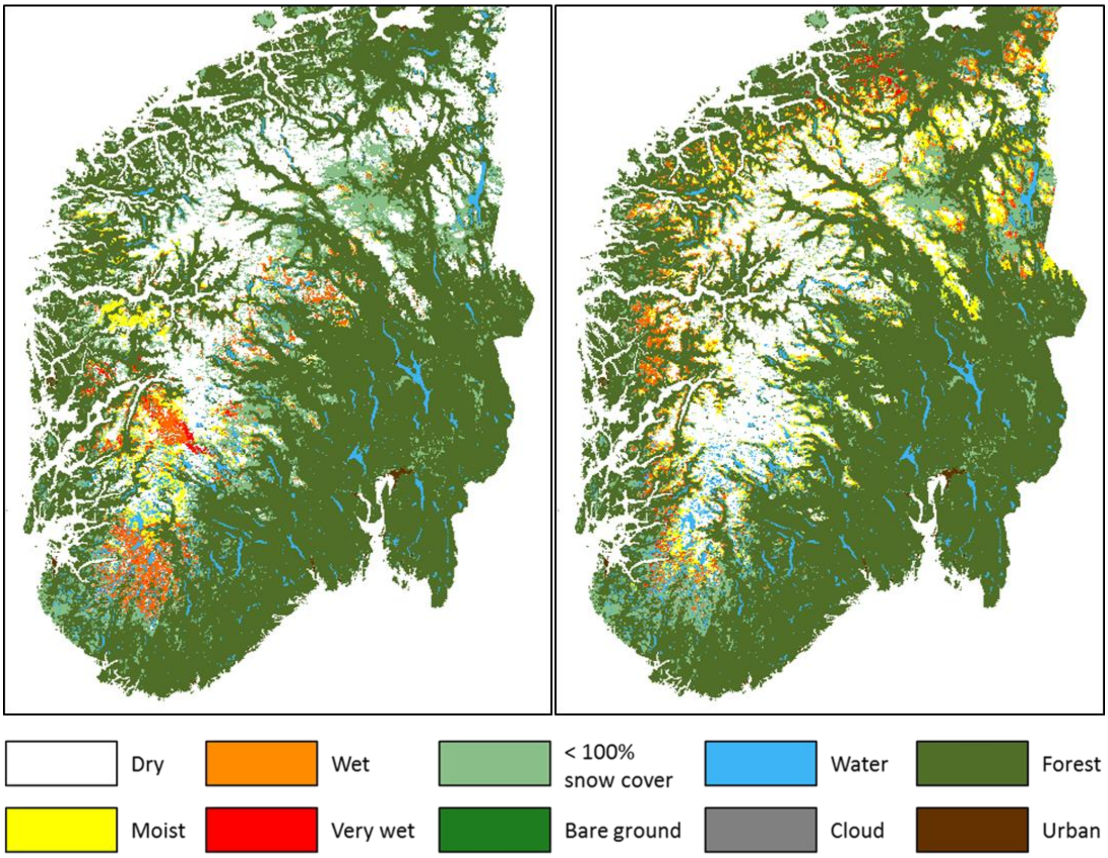

Figure 4.3.8: MWS maps for southern Norway based on Terra MODIS (left) and Sentinel-3 SLSTR (right) for 29 March 2017.

Figure 4.3.9 shows MWS maps for 30 April 2017, just the starting point of the spring melt. We see that the maps from Terra MODIS and Sentinel-3 SLSTR are quite similar. The situation is typical for calm weather and an adiabatic thermal situation. All, except for two, weather stations show negative temperatures. Sirdal (3.4°C) and Dombås (1.3°C) are both in a wet-to-very-wet zone in both snow maps. Beitostølen (-1.9°C) is close to the transition zone between moist and dry snow. Skåbu (-0.9°C) and Møsstrand (-1.8°C) show moist snow in both maps, but both stations are close the transition zones between moist and dry snow. The remaining stations are all high altitudes showing negative temperatures and located within larger regions of dry snow.

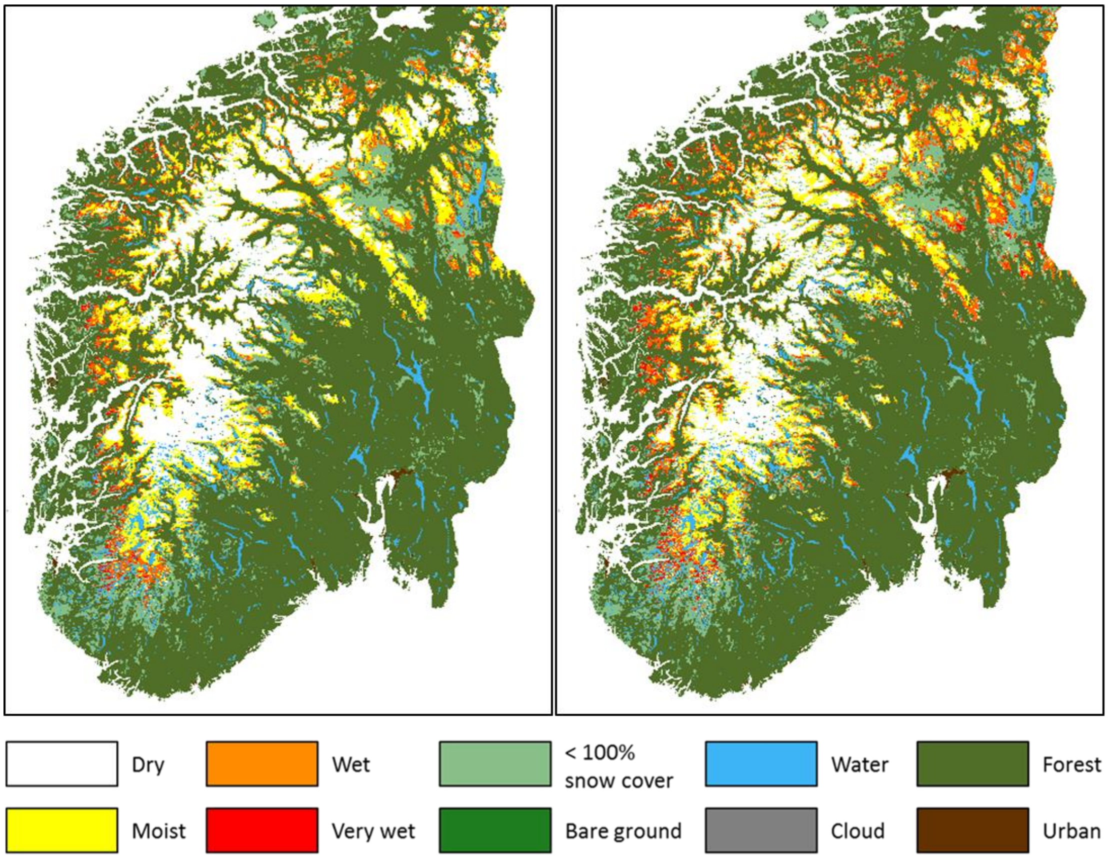

Figure 4.3.9: MWS maps for southern Norway based on Terra MODIS (left) and Sentinel-3 SLSTR (right) for 30 April 2017.

Romania

The validation analysis of multi-sensor wet snow (MWS) products for Romania for the winter season 2016 - 2017 is presented below. The measurements of air temperature, snow cover and snow depth recorded at national weather stations have been used in this study. The stations' locations and names are indicated in Figure 4.3.10.

In same cases, because the weather stations are located very close to the urban areas (specially the weather station located in lowlands) or very close to the forested areas (for the weather stations located in the mountains), the surrounding pixels are considered, in order to classify the snow wetness.

For the analysed cases the maps from Terra MODIS and Sentinel-3 SLSTR are quite similar. Some exceptions are related to the cloud cover in one image.

Below are presented examples for Romania, based on MWS products obtained from Sentinel-3 SLSTR and Sentinel-1 data.

Figure 4.3.10: Romanian weather stations network.

First case presented is the MWS map from December 27, 2016 (Figure 4.3.11), where it can be observed that snow wetness varies from “dry” to “very wet”. Comparing the MWS product with OWS product from the same day, it can be observed that the optical snow product presents a huge area covered by clouds, excepting the pixels representing moist, wet and very wet snow, and some pixels representing dry snow in the Eastern Carpathians. This was the first snowmelt episode of the 2016 - 2017 winter season located in the central and South-East of Romania. The clasification is well correlated with the meteorological conditions that indicate no snow cover and positive air temperatures.

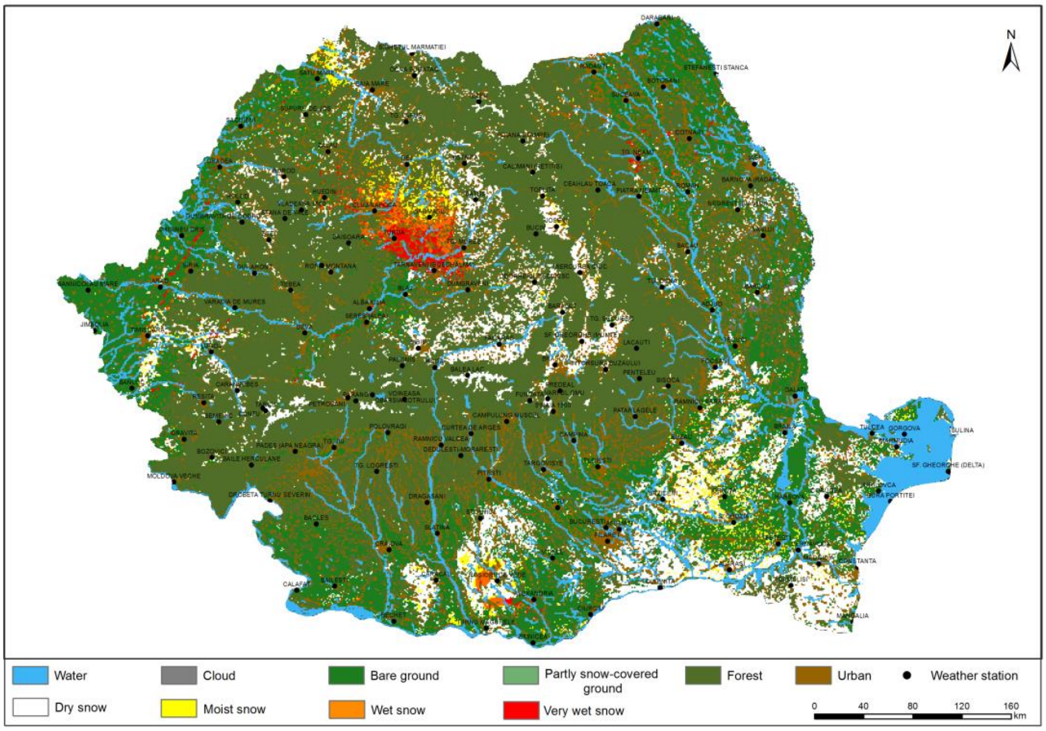

Figure 4.3.11: Multi-sensor snow wetness based on Sentinel-3 and Sentinel-1 for 27 December 2016.

Starting in the second decade of January 15, 2017, there have been significant snow falls, which has materialized in considerable snow accumulations in almost all regions of the country (Figure 4.3.12). Most of the pixels are classified as "dry" snow that is in good correlation with the daily temperature profile. In some cases (especially the weather stations situated in the plain regions), even the temperature has positive values in the second part of the day, the snow appear dry on the map (Bailesti, Bechet, Blaj, Bucuresti, Calarasi, Craiova, Tragoviste, Titu, Tg. Neamt, Turnu Magurele, Tecuci, Zimnicea weather stations). A possible explanation could be the difference between the time acquisition of optical satellite image (in the morning) and the acquisition of the SAR image (in the afternoon). A possible explanation is related to the weather cooling during the night and the previous day that would contribute to slow down the snow melting for some time, even if the air temperatures were positive.
Most of the "moist", "wet" and "very wet" pixels are located in the Dobrugea region and in the Western part of the country. There is a strange situation in the case of the Corugea weather station: the snow appears to be "wet", even the air temperature had negative values during all day.

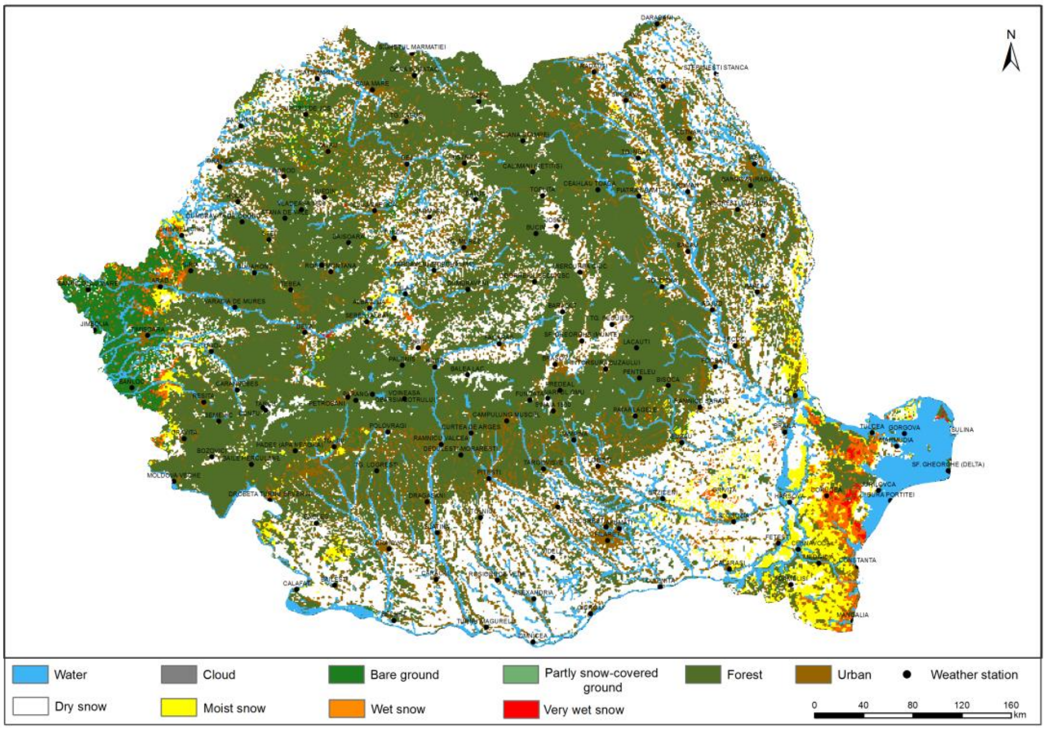

Figure 4.3.12: Multi-sensor snow wetness based on Sentinel-3 and Sentinel-1 for 15 January 2017.

The Figure 4.3.13 shows the situation of the snow wetness from February 4, 2017. It is the second snowmelting period and it can be observed that the "very wet" snow pixels are concentrated in the South-Eastern part of the country. Also, the pixels representing "moist" snow can be found in the Oltenia region in the south of Romania. This is the result of the melting period from the end of January and beginning of February 2017. The results highlighted by the map are in good correlation with climatic conditions, with some exceptions:

- Radauti, Sarmasu, Stefanesti Stanca, Suceava, Tg. Neamt weather stations are located in an urban areas, so to classify the snow wetness it was necessary to take into account the surrounding pixels. On the MWS map, the surrounding pixels appear to be "dry" snow. The weather stations indicate positive air temperature values and snow patches. In this context, the pixel corresponding to these weather stations were classified as "partly snow-cover ground";
- At Tarnaveni, Joseni and Miercurea Ciuc weather stations the MWS map shows "dry" snow. The weather parameters indicate: in the morning the snow cover depth measured few centimeters and after the temperature increased, during the day, the snow melted, leaving

only snow patches. The difference between acquisition time of both satellite images (optical and SAR) explains those discrepancies;

- In case of Holod and Sacuieni weather stations, the snows, on the MWS map is dry, while the meteorological observations indicate no snow cover; in this situation, the corresponding pixels are classified as “bare ground”.

In same cases (located in North of Romania and Central-South), the “dry” snow is present even the air temperature has positive values. The situation can be explained by the very low negative temperatures from the previous days that have allowed the snow to resist to the melting.

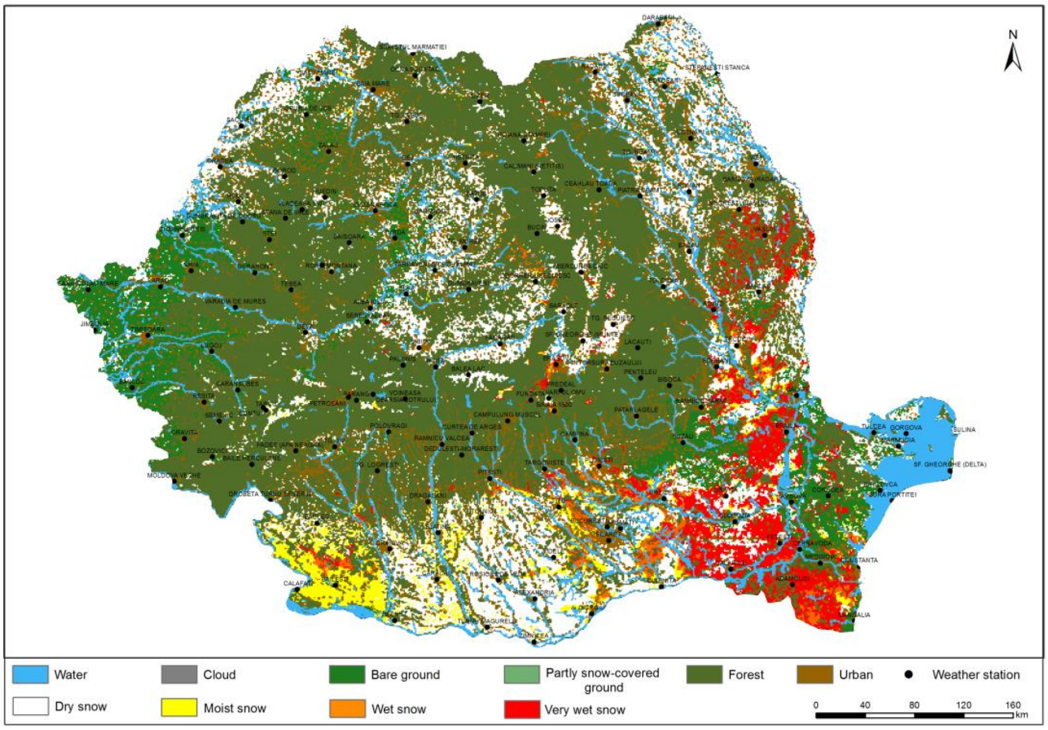

Figure 4.3.13: Multi-sensor snow wetness based on Sentinel-3 and Sentinel-1 for 4 February 2017.

More details are presented in the deliverable D3.4bis: „MWS prototype products for flood and avalanche warnings – Version 2”.

*4.3.2. **Activity 3.3.** New multilayer snow model module in NOAH*

During this phase, was tested, adjusted and further improved the first version of the methodology for estimating the snow water equivalent, by data fusion approach, using the distributed model NOAH simulations, ground observations and satellite products (was elaborated the deliverable D3.7.).

Within the methodology, the diferrent type of data and information are analyzed and compared, using a series of automatic cross-validation algorithms, and then the snow water equivalent is estimated in grid format, at spatial resolution of 1 km, by multiple succesive steps of interpolations and adjustments, depending on the degree of uncertainty associated with different type of data.

The algorithms of automatic control of quality and interpolation that are used for the implementation of the data fusion methodology, were improved by taking into consideration the influence of the slopes exposure and the vegetation covering on the snow layer evolution, which is an important factor especially in the snow layer melting period.

This interdependency is mainly based on results from the previous research done within the National Institute of Hydrology and Water Management, using the data from representative basins. The relations derived from the representative basins data were converted to an adequate fuzzy sets representation using the fuzzy logic system approach, in order to be able to incorporate this dependency, in a robust way in the data fusion methodology.

The data fusion methodology for estimation of snow water equivalent, as a gridded product with 1 km spatial resolution, at national level, was applied experimentally during the period January – March 2017, in order to test, correct and improve the algorithms and data processing workflow.
The results were compared with a reference interpolation method, respectively with the IDW method, computed using the available snow water equivalent observations from the stations networks (Figures 4.3.14 and 4.3.15).

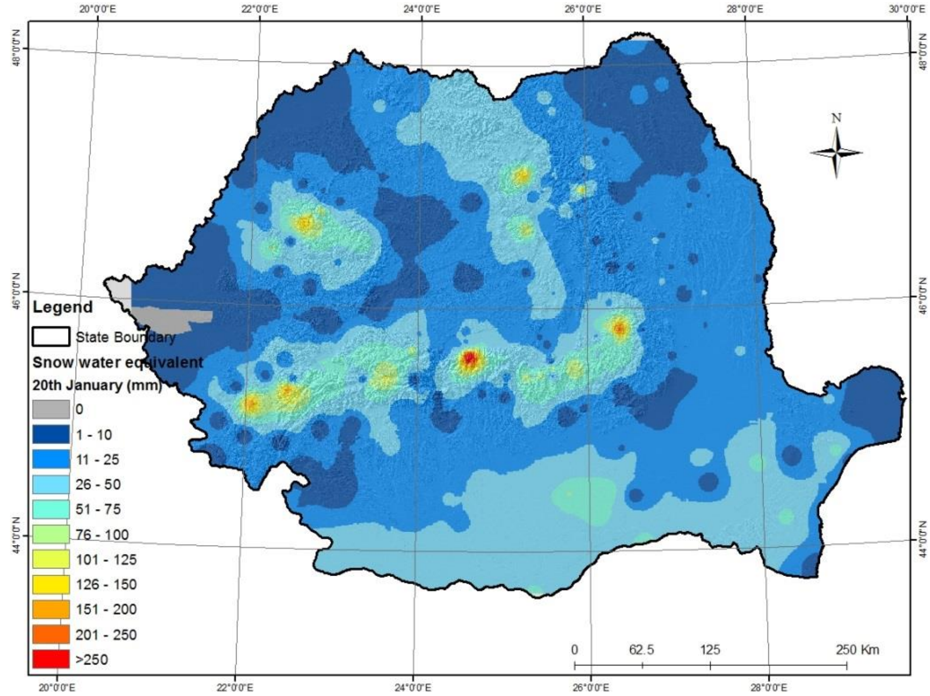

Figure 4.3.14: SWE computed using IDW method – 20th January 2017

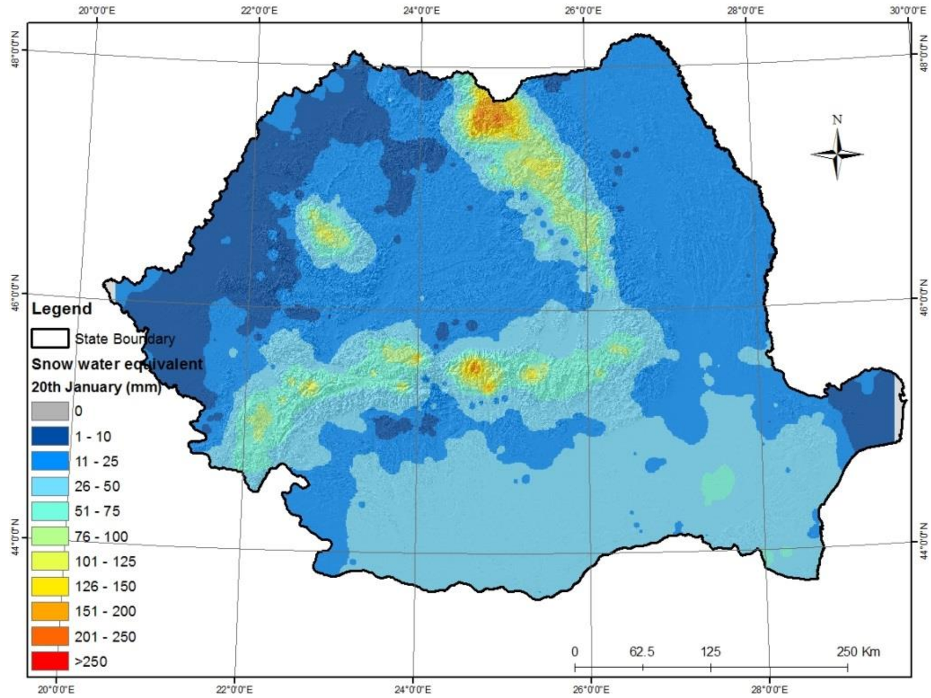

Figure 4.3.15: SWE computed using data fusion method – 20th January 2017

More details are presented in the deliverable D3.7: „Gridded SWE prototype products generated using data fusion methodology – Version 2".

4.4. WP4 *Climate change impact on snow-related hazards*

4.4.1. Activity 4.1. Snow-related climate variability and change and associated impact

The main activities in 2017 were to synthesize the results on impact of climate change for snow-related resources (e.g. snow contribution to aquifer) and hazards (e.g. flash floods with snow melt contribution, avalanche statistics) and make GIS-related maps (Activity 4.1), (e.g. Figures 4.4.1 and 4.4.2).

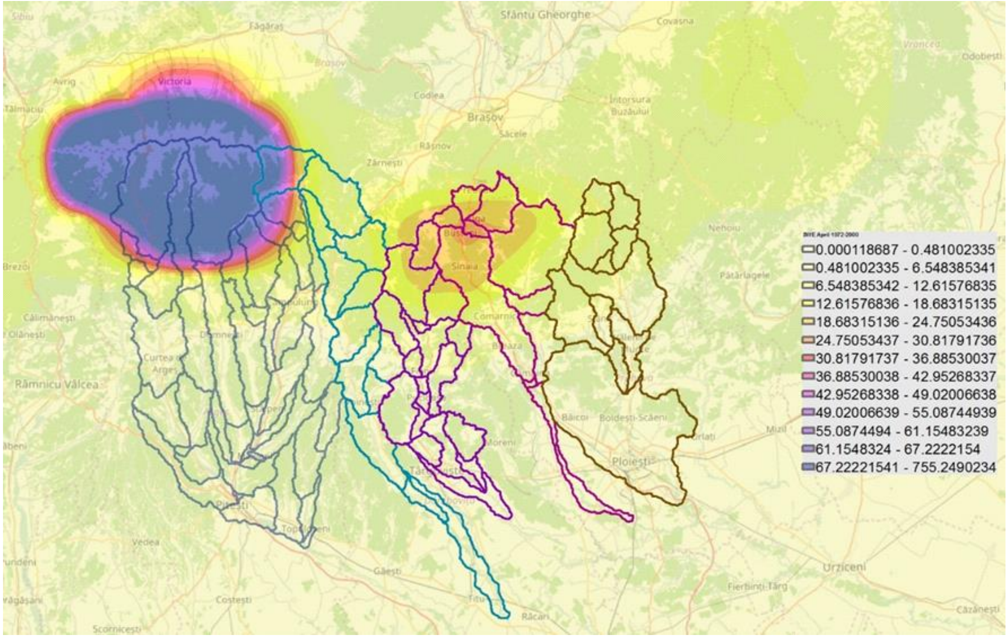

Figure 4.4.1: Snow water equivalent (in mm) for April months from the time interval 1981-2010 simulated by the RCA4 regional climate model. Colored lines are the sub-basins of Arges and Ialomita Rivers.

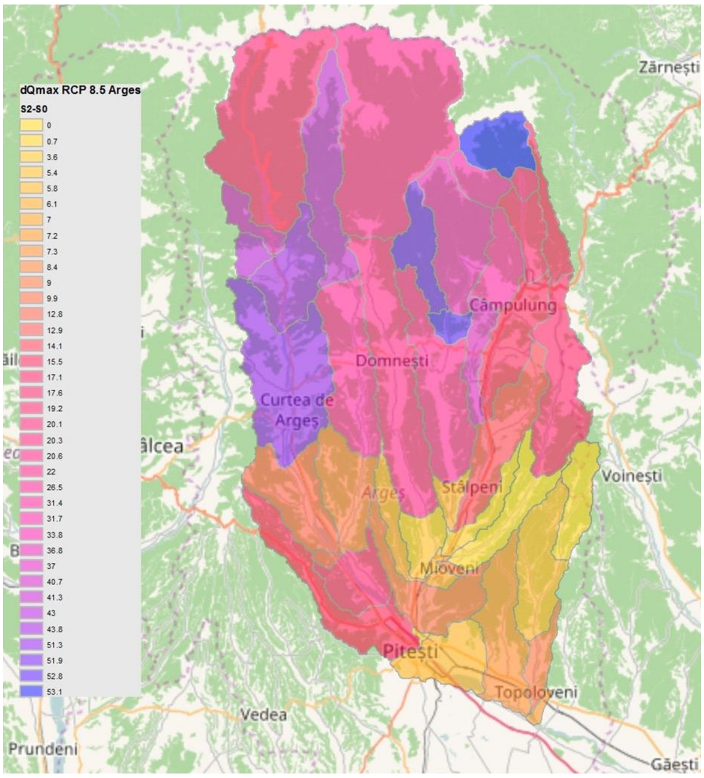

Figure 4.4.2: Changes in the maximum streamflow (in %) in the sub-basins of Arges and Ialomita in the time interval 2021-2050 vs. 1981-2010 under the climate change scenario RCP 8.5. Blue and magenta areas show sub-basins with higher changes.

More details are presented in the deliverable D4.5: „Public report on the impact of climate change for snow-related resources (snow contribution to aquifer) and hazards (flash floods with snow melt contribution, avalanche statistics)".

*4.4.2. **Activity 4.2.** Variability and change in flash floods with snow melt contribution*

The activity consists in: (1) to synthesize the results on impact of climate change for snow-related resources (e.g. snow contribution to aquifer) and hazards (e.g. flash floods with snow melt contribution, avalanche statistics) and elaborate the GIS-related maps; (2) to complete the analysis of variability and change in flash floods with snow melt contribution for the sub-basins of Ialomita River. The research was done applying the hydrologic model CONSUL to the sub-basins located mainly in mountain areas, to add more local details about the maximum discharge and flood statistics (Corbus et al., 2011). The results of the hydrologic model (CONSUL) indicate, like in the case of sub-basins of Arges River, that multiannual averages of maximum discharges during the interval from November to April show increases compared with present climate (1981-2010) under best (RCP 2.6) and worst (RCP 8.5) climate change scenarios. Also, for sub-basins with larger areas, the increases are systematically larger under the worst scenario compared to those under the best one showing how the climate change signal overcomes the noise beyond specific spatial scales of river basins (Figure 4.4.3). However, when very rare events (less than 2 % probability) are taken into consideration, the two climate scenarios do not exhibit significant differences in terms of maximum stream flow. We have also analyzed the common statistics for all sub-basins in our area of interest and the above mentioned conclusions are the same.

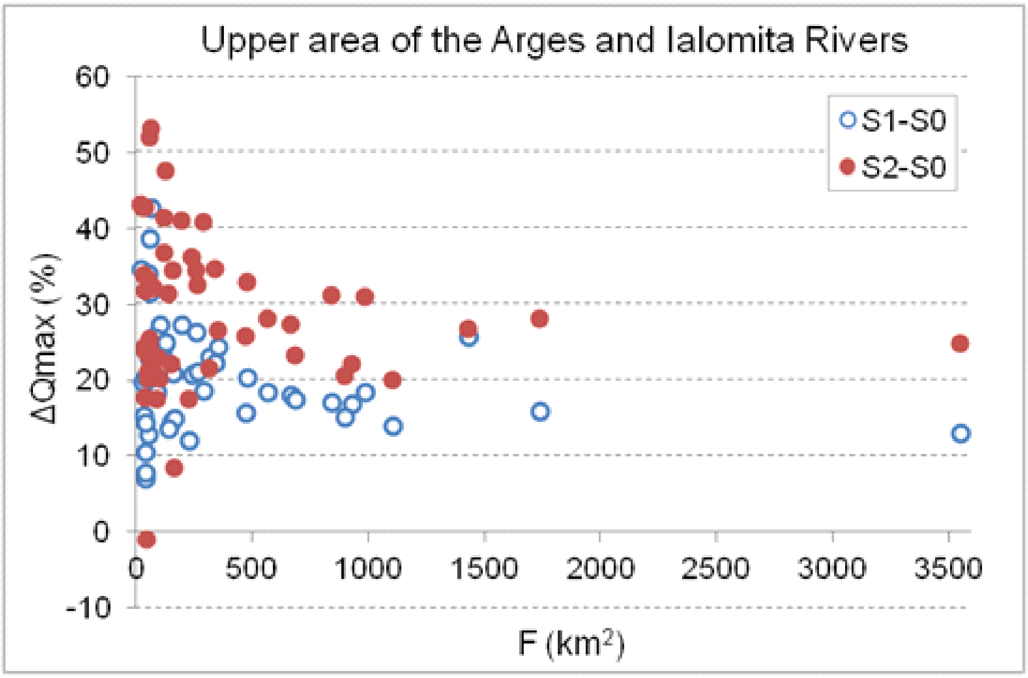

Figure 4.4.3: Relative deviations (%) of the maximum discharges during November to April, multiannual averages, for S1 and S2 scenarios compared to S0 scenario, at hydrometric stations from upper area of the Argeş and Ialomiţa Rivers. Scenarios S1 (RCP 2.6) and S2 (RCP8.5) cover the time interval 2021-2050. Scenario S0 covers the historical period 1981-2010.

More details are presented in the deliverable D4.4: „Assessment of climate change impact (2021-2050 vs. 1981-2010) on flash floods with snow melt contribution from winter to spring transition period in the upper part of Arges - Ialomita river basins".

*4.4.3. **Activity 4.3**. Variability and change in avalanche statistics*

In the framework of the Activity 4.3, GIS-enhanced files and avalanche statistics were built (Figure 4.4.4).

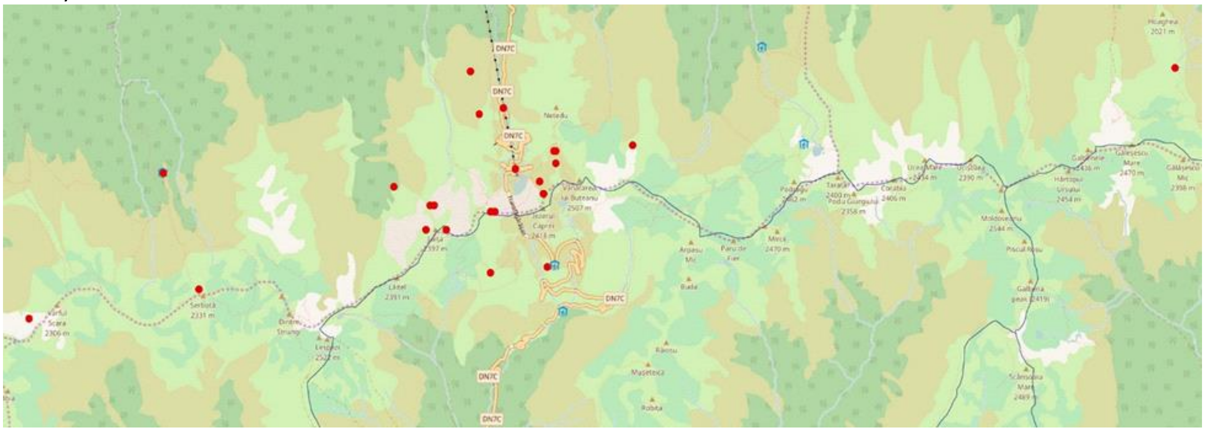

Figure 4.4.4: Locations of recorded avalanches in the Fagars Massiff (Bilanţul nivologic al sezonului de iarnă, 2004-2016; http://www.dinumititeanu.blogopedia; Gaspar and Munteanu, 1968; Milian N. et al., 2010; Milian and Stăncescu, 2012; Moţoiu, 2008).

More details are presented in the deliverable D4.6: „GIS-enhanced maps of changes from present to future climate for snow water equivalent, statistics of flash floods with snow melt contribution, avalanche statistics, and snow contribution to aquifer over area of interests”.

4.5. WP5 *Aquifer replenishment modelling from snowmelt infiltration*

4.5.1. Activity *5.2. Aquifer modelling*

The modeling of surface leakage resulting from the melting of snow in a mountain watershed is perceived as difficult due to the complexity of the simulation, but also because of the difficulty in specifying the model parameters and the absence of a theory explaining the surface leakage mechanism resulting from the melting of the snow. It is still controversial how to incorporate temperature changes into the snow melting pattern, but also the leakage from a mountain basin.
Two approaches are used to quantify the melting phenomenon of snow (USDA, 2004):

- Empirical use of temperature index models with a limited number of parameters. The most common method in this approach is the "day-to-day" method, where air temperature is used to index all flows energy.
- Physics-based process, which requires a more detailed description of the mass or energy balance

Temperature-index methods are commonly used, under the assumption that process-based models require too much input.To test this, we used a process-based physical model to simulate snow melting using air temperature, relative air humidity, wind speed and nebulosity as input data.
To estimate the snow melt infiltration, you can use the Hydrus 1D program based on the finite element method. Hydrus does not work with the thickness of the snow layer but with the equivalent of snow water (SWE). In order to assess the accumulation of the snow layer it is necessary to introduce the air temperature, considering that conditions at the upper limit of atmospheric conditions. The Hydrus program used to estimate the snow layer's evolution uses the flow modulus that solves the Richards equation for water flow in saturated and unsaturated zones and the heat transfer module by solving the convection-dispersion equation.
If the direct problem is a simulation model in which the hydraulic loads are calculated, the inverse problem is to determine the soil parameters for which the modeling error between the calculated values and the observed values is minimal.

4.5.2. Activity 5.3. *Pattern matching and climate scenarios*

The way climate change influences the melting rates during the spring defrost in the Bucegi Mountains, the Padina area has been evaluated for the RCP 2.6 and 8.5 scenarios in terms of snow thickness, melting snow for the 2015-2050 period and the evolution of the mean snow water equivalent (SWE).
Infiltrations associated with snow melting depend not only on soil properties but also on many other factors such as water equivalent of snow cover, snow melting rate, transport and storage properties of snow water and soil type: frozen or not frozen.
Snow runoff can occur in various ways: (Dingman, S. L 2002)

I. Depending on the rate of melting of snow and the soil infiltration capacity
II. If the melting rate is low and the soil infiltration capacity will not be exceeded, the entire amount infiltrates
III. If we have rapid melting times and the soil infiltration capacity will be exceeded, the whole of the resulting amount will flow on the surface of the soil
IV. Depending on the type of soil (frozen or not frozen)

1. Non-frozen soil
If the soil is not frozen, the aquifer is deep and the top soil is unsaturated then the whole quantity infiltrates being governed by the flow laws in the unsaturated zone. Thus the flow can take place in a permanent or non-permanent regime.
2. Frosen soil
If the soil is frozen, the infiltration is limited (infiltration rate is lower than the melting rate) and a saturated area appears at the base of the snow layer from which water can flow at the surface to surface waters.

In the case of frozen soil, it becomes impermeable and severely restricts the infiltration of water from the snow. Infiltrations in frozen soils represent a complex phenomenon involving mass and heat transport in a porous environment.

It has been established by numerous case studies that there is an inverse proportionality between the infiltrations and the total water content (water + ice) of the frozen soil at thaw in Alaska (Kane and Stein, 1983) and Canada (Granger et al. Gray et al., 1985). Also the presence of ice in the soil reduces the effective porosity as well as the hydraulic conductivity of the soil (Gray and Granger, 1987).

Granger et al. (1984) also showed that soil moisture in the 0-30 cm is important because at this depth there is most of the infiltrated water during the melting of the snow.

Following in-situ observations, Gray et al. (1985) proposed a classification of frozen soils of Canadian lands depending on the infiltration capacity:

A) Unlimited capacity for soils containing large, surface-bounded and air-filled portions (e.g., cracks) that allow total / about total water infiltration of snow melting.

B) Limited capacity: mainly dependent on the water equivalent of the snow layer and the water / ice content in the first 30 cm of soil during melting.

C) Restricted capacity: where infiltration is prevented by an ice lens located above the ground or at a low depth. In this category, the infiltrations are negligible and the water resulting from the melting of snow is totally redirected to surface leakage and evaporation.

More details are presented in the deliverable D5.3: „Groundwater resources in the climate change framework: Based on the achievements of the WP4 (Climate Change) regarding the different climate change models and scenarios a holistic study for groundwater resources in correlation with snowmelt infiltration will be developed”.

4.6. WP7 Avalanche inventory, release and hazard mapping

4.6.1. ***Activity 7.2.*** *Change-detection algorithm for Sentinel-1 and Sentinel-2*

In the Sentinel archive 56 images for the interval January 1st – May 1st 2017 have been identified. Only one image was useful (January 29, 2017) due to high cloud cover percentage, that dominated the test area in winter optical images.

Since the use of Sentinel-2 images has proved to be inefficient for the small and medium size avalanches characteristics for the Southern Carpathians (because spatial resolution is too coarse and limited spertral resolution of band 8-NIR), we tried to detect the changes caused by avalanches.In the study area the changes in the forest cover (especially in the upper limit) might be visible, mainly in the areas where avalanches caused damage to forest. Thus we used a reference image to compare the results. The image from January 29 was used as reference image to identify the forest cover, while in the winter images all the other vegetation types are covered by snow and forest is visible and can be delineated (Figure 4.6.1).

Figure 4.6.1: Comparison of Sentinel-2 images from January 29th, 2017 (left) and Aprilie 4th, 2017 (right). The upper limit of the forest cover can be better distinguished in the first image, while in tthe right image the snow cover started to melt and other types of vegetation are also visible.

We used and algorithm for forest detection in an object-based environment, while its condifered to have better results as compared to pixel-based methods (Blaschke, 2010). For processing we used eognition Developer and the image segmentation was based on NDVI and Brightness values (Figure 4.6.2). The obejects classified as forest have been validated using aerial photos. The resulted image is considered the reference image and ca be used for comparison in order to detect the potential changes of forest cover induced by avalanches. Due to high cloud cover percentage in the analized images, other types of images need to be idetified for the detection of changes.

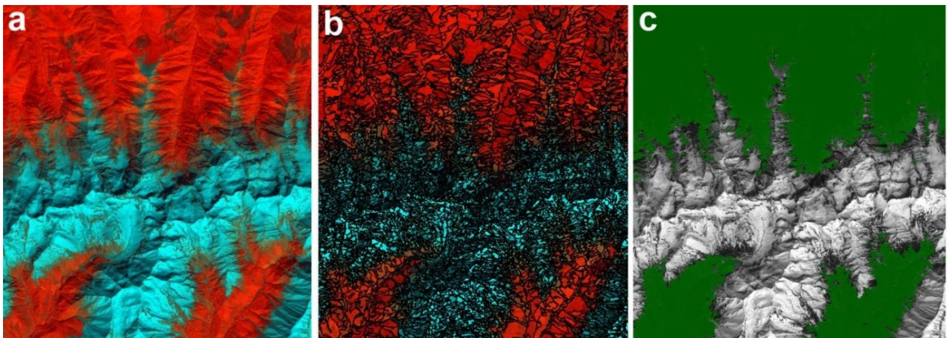

Figure 4.6.2: Forest detection in eCognition: a) originla image (composite Green, red and NIR); b) objetcts resulted from segmentation; c) forest cover areas.

4.6.2. ***Activity 7.3.*** *Avalanche simulation*

4.6.2.1. Analysis of past documented snow avalanche events in central* Făgăraș *Mts. and impact on environment

The development of winter tourism infrastructure in mountain areas in Romania with a high number of skiers and climbers have increased the demand for accurate snow monitoring in relation to both climate change and hazard assessment. In Romania, in the last 10 years, more than 500 avalanches with 7 deaths have occurred in Southern Carpathians and almost 300 events only in Făgăraș Mountains.

Between 1963 to 2015, 27 avalanche accidents were recorded in the interval November-June in the Făgăraş massif resulting in 76 fatalities and 50 burials/injuries (Voiculescu et al., 2016a). Most of the injuries and fatalities caused by past events were located in the alpine domain of the study area and triggered by victims in favorable topographic and snow layer, after an increase in temperature followed by a heavy snowfall. In Făgăraș Mountains, avalanche events are one of the major disturbance factor at the sub-alpine level and at the contact zone with the timberline (Voiculescu and Ardelean, 2012; Voiculescu et al., 2011).

In Romania, the current snow in-situ observation network (4 weather stations above 2000 m and 19 between 1000-2000 m) cannot provide the information needed, thus the satellite imagery and GIS techniques might overcome this shortcoming.

Thus to analyze the snow avalanche hazard in the potential affected mountain areas, the existence of snow avalanche databases with historical records of past avalanche events related to the triggering factors, extent and volume, regular observations are very important (Bourova et al., 2016).

For avalanche monitoring and hazard assessment, an important category of factors is related to snow parameters. For snow avalanche hazard monitoring, the most important input parameters refer to the snow characteristics. Satellite based products, for monitoring of snow parameters (snow cover extend, snow wetness, avalanche tracks, avalanche hazard assessment and so on), provide an overview on the high mountain areas, hard to be reach with other tools.

The avalanche mapped using GeoEye-1 satellite images and orthophotos acquired from drone are important spatial databases that was used to extract quantitative and qualitative information related to morphology, spatial distribution and frequency. The high number of avalanches (more than 1400) detected based on the available images mentioned earlier proved that this is the most important natural hazard in winter season that are specific for the alpine and subalpine domains of Southern Carpathians.

Avalanche characteristics exhibit a particular pattern for Southern Carpathians (Table 4.6.1). Most of the avalanches mapped in the test areas were small and medium size (less than 1000 m length). This pattern is related to a morphology constraint.

Table 4.6.1 Avalanche characteristics extracted from the spatial database

Avalanche dimension	**GeoEye-1 11.04.2012**	**Drone image 12.04.2016**
Mean length (m)	178	159
Min. length (m)	12	12
Max. length (m)	1165	789
Mean width (m)	26	32
Min. width (m)	2.5	2.5
Max. width (m)	254	244
Mean area (m^2)	2166	2743
Min. area (m^2)	29	23
Max. area (m^2)	29037	55395
Mean elongation ratio	0.85	0.78
Min. elongation ratio	0.37	0.09
Max. elongation ratio	0.96	0.95

Most of the avalanches mapped in the study area have widths less than the mean values (26 m), and this proves that most these events were constrained by morphology (along avalanche tracks).
The elongation ratio (E) has been calculated using the formula:

$$E = 1 - S / L$$

where: S is width, L – length of the bounding box (rectangular shape) outside the avalanche polygon (Figure 4.6.3).

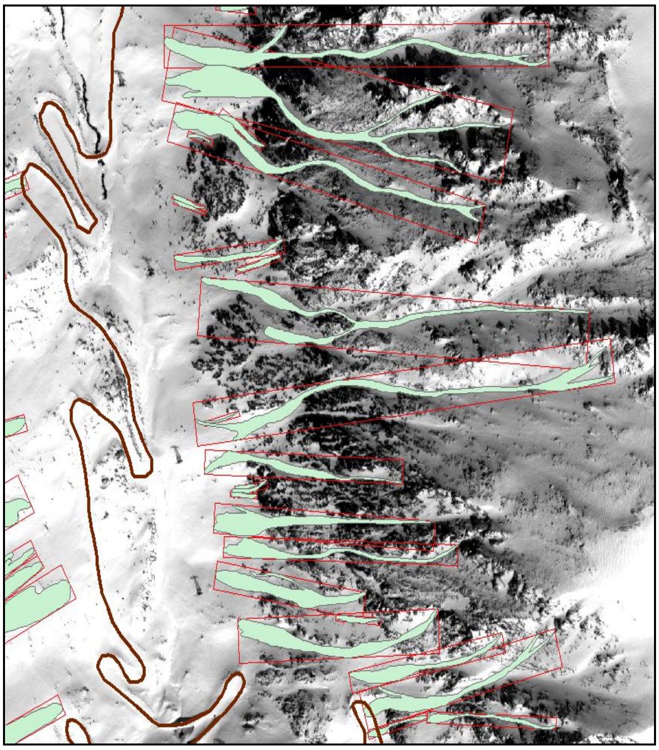

Figure 4.6.3: Avalanches with elongation ratio values higher that 0,8 in the area of avalanche tracks, near Transfăgărășan, Bâlea valley.

In the same time, in the context of hazard assessment, a database with avalanche frequency on same trajectories, and for the areas with high number of events, higher marks were attributed, even though the extent was not the same (Figure 4.6.4).

Figure 4.6.4: Avalanche events mapped for different years in the same area of Transfăgărășan highway on southern slope.

Past avalanche events with impact on the environment causing injuries, fatalities, infrastructure and forest damages are important for magnitude scenarios in hazard analysis. Several documented events have been selected from years 1974 and 1977, 2005, 2008, 2009, 2012, 2013 și 2016, to evaluate the extent of these areas.
Although the avalanches occuring in Southern Carpathians are smaller than in the Alps, these events caused damages – i.e. altitude roads, deciduous and coniferus forest, especially on southern slopes. An example can be observed in the Figure 4.6.5 (the avalanche in Paltinu-Călțun area, 2009, on southern slopes).

Figure 4.6.5: Avalanche in Paltinu-Călțun area, southern slope, 2009 event (left) forest damages (right).

4.6.2.2. Hazard assessment and mapping

Snow avalanche hazard assessment is a complex approach characterized by a multivariate nature and usually is based on high return periods of the reference events (Eckert et al., 2012).
The avalanche hazard areas have been traditionally defined in relation with return period and impact pressure (Mears, 1992). The methodology is usually based on zoning the terrain usually in three classes, as high, medium and low hazard areas (Salm et al., 1990).
The approaches for identification of hazard prone areas can be divided into two types of models - topographic-statistical models and dynamic models (Jamieson et al., 2008). Currently in the Alps, the avalanche hazard zoning guidelines are based on avalanche dynamics simulations (Jamieson et al., 2008). However these are highly dependent on the existence and quality of the of the input data (McClung and Schaerer, 2006). In Romania few studies analyzed snow avalanche hazard on small areas and were based mainly on a multicriteria analysis of topographic factors (Simea, 2012; Voiculescu et al., 2011). A combination of topographic, statistic and dynamic models to generate avalanche hazard maps have been applied with good results in mountain areas similar to Southern Carpathians, as in Tatra or Krkonose Mts. (Blahut et al., 2017; Chrustek et al., 2013).

Avalanche release area

Most of the avalanches have starting areas in the upper part of the slopes, close o the ridges. The release areas are represented in most cases by the upper part of an avalanche track. The altitude in the area of these paths is above 1700 m and steep slope values are characteristic.
Areas with high potential for avalanche release, might became unstable function of snow conditions. From the topographical factors favoring snow avalanches release areas, slope in the most important, with a values between 25-60 degrees being susceptible for triggering avalanches along the slope profile (Bühler et al., 2013; McClung and Schaerer, 2006). Other factors influencing the release areas used in analysis were plan curvature, roughness, flow direction, forest cover (Bühler et al., 2013; Chrustek et al., 2013; Gruber, 2001; Gruber and Bartelt, 2007; Maggioni, 2005).
For the central area of Făgăraș Mts., based on morphometric data and avalanche statistic, several release areas have been tested in simulations (Figure 4.6.6)

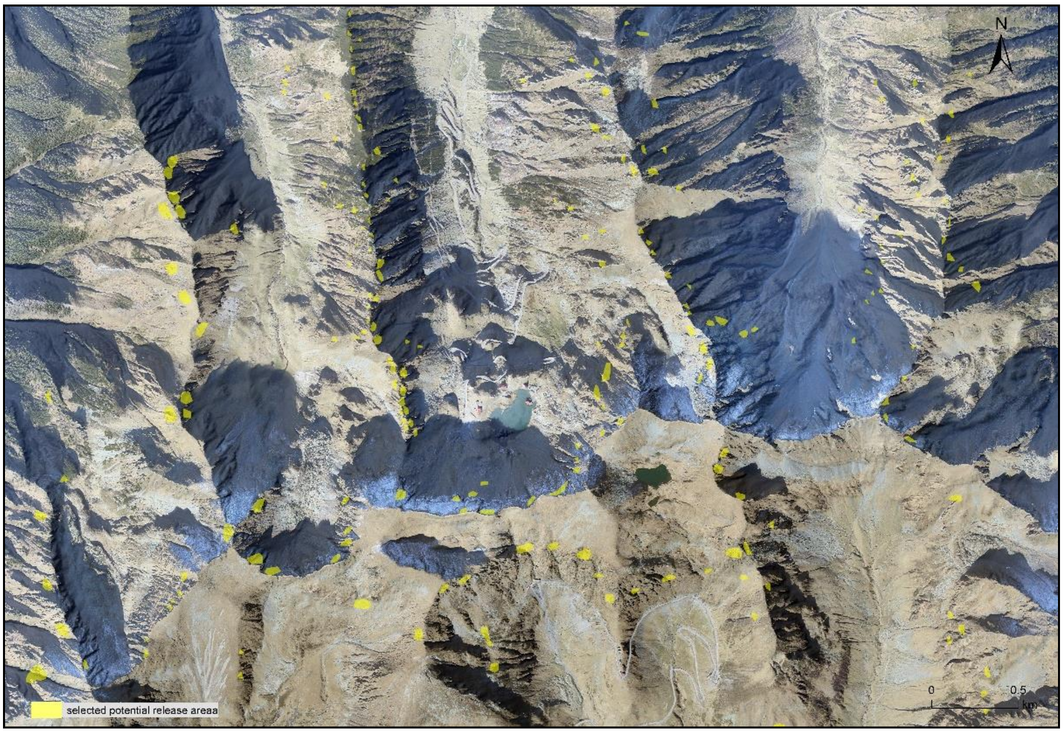

Figure 4.6.6: Exemple of selected release areas related to the past avalanche events (in yellow) near Transfăgărășan.

The compact forest area have been excluded from the analysis of potential release areas. We used as input slope, plan curvature and terrain ruggedness. Slope values of 25-60 are considered favorable for potential release areas.

Simulation of avalanche trajectories, snow height and pressure

Simulation of avalanche trajectories is considered an important step in hazard analysis and has an important influence on the separation of hazard levels. The simulations were tested with RAMMS (Christen et al., 2010) in the area surrounding the Transfăgărășan highway, this being the most affected by snow avalanche events, that caused damages, as are mentioned in the records. The friction parameters (Bartelt et al., 1999; Salm et al., 1990) as input variables were calculated using the automatic procedure implemented in this model. The procedure classifies terrain parameters, altitude, slope gradient, and plan curvature, in types like flat terrain / open slope, channelled / gully and forested or non-forested areas (Bartelt et al., 2013).
Calculation and classification of friction parameters is based on DEM derived data (altitudine, slope, curvature), forest cover and global parameters (volume and return period). For the estimation of the return period of avalanches in the areas, data from dendrochronologic reconstructions (Voiculescu et al., 2016b) from other studies have been used (with values of 10 and 30). For the size of the

avalanches, small and medium size events were used as resulted from the database calculations(Greene et al., 2010).Trajectories simulation have been tested on several high impact past avalanches identified in statistics. The avalanche trajectories, depth, velocity, pressure and spatial extent of the snow deposits.

Hazard level mapping

The processing steps for hazard evaluation and mapping included:

- Avalanche inventory and analysis
- Statistic analysis of past documented events
- Morphometric and snow depth analysis
- Identification of potential release areas
- Simulation of avalanche trajectories and calculation of snow height and pressure for several magnitude scenarios
- Hazard level classification by integrating frequency and simulation results.

The map of hazard level (very high, high, moderate) for the cetral area of Făgăraș Mts. near, Transfăgărășan highway (Figure 4.6.7) indicate that high level of hazard areas are located on steep slopes in the alpine domain and for high magnitude events will frequently damage the road and forest on extended areas, mainly on southern slopes.

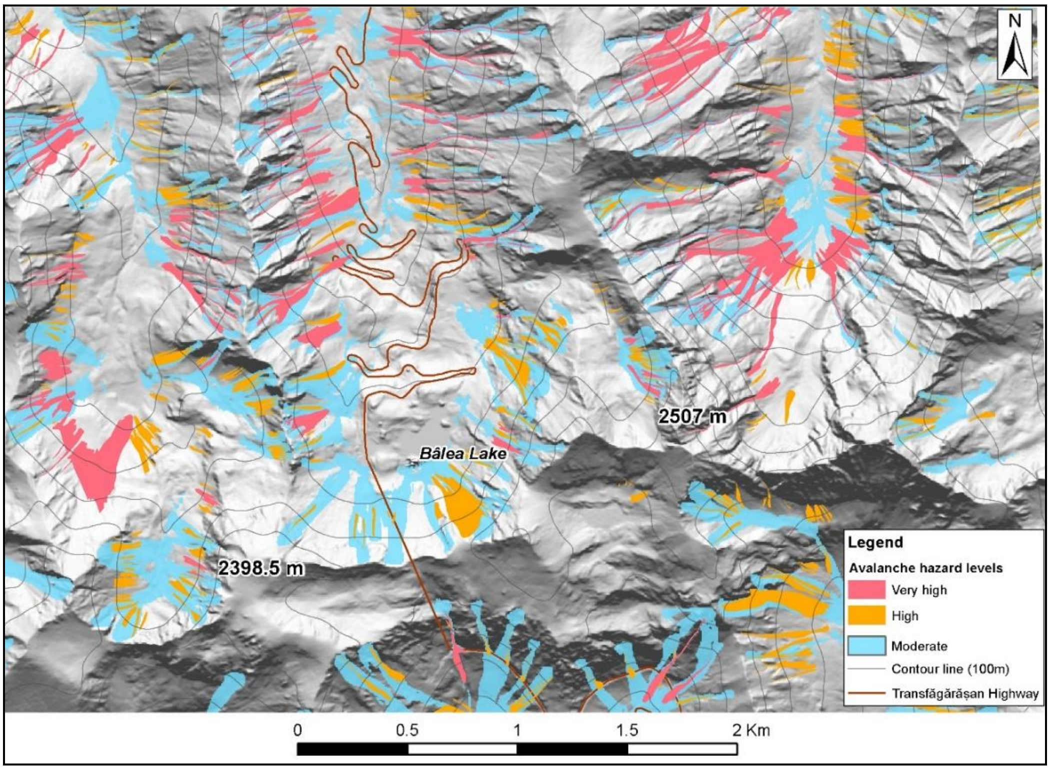

Figure 4.6.7 Hazard map of the central area of Fagaras Mts., near Transfăgărășan highway

More details are presented in the deliverable D7.3: „Avalanche hazard maps”.

4.7. *WP8* Promotion and Dissemintion

*4.7.1. **Activity 8.1.** Project website*

There was updated the project website (http://snowball.meteoromania.ro), being included information about the Snowball consortium activity for the current stage of the project: obtained results, meetongs, disseminations, etc (figure 4.7.1). Also, have been realised the Romanian version of the website.

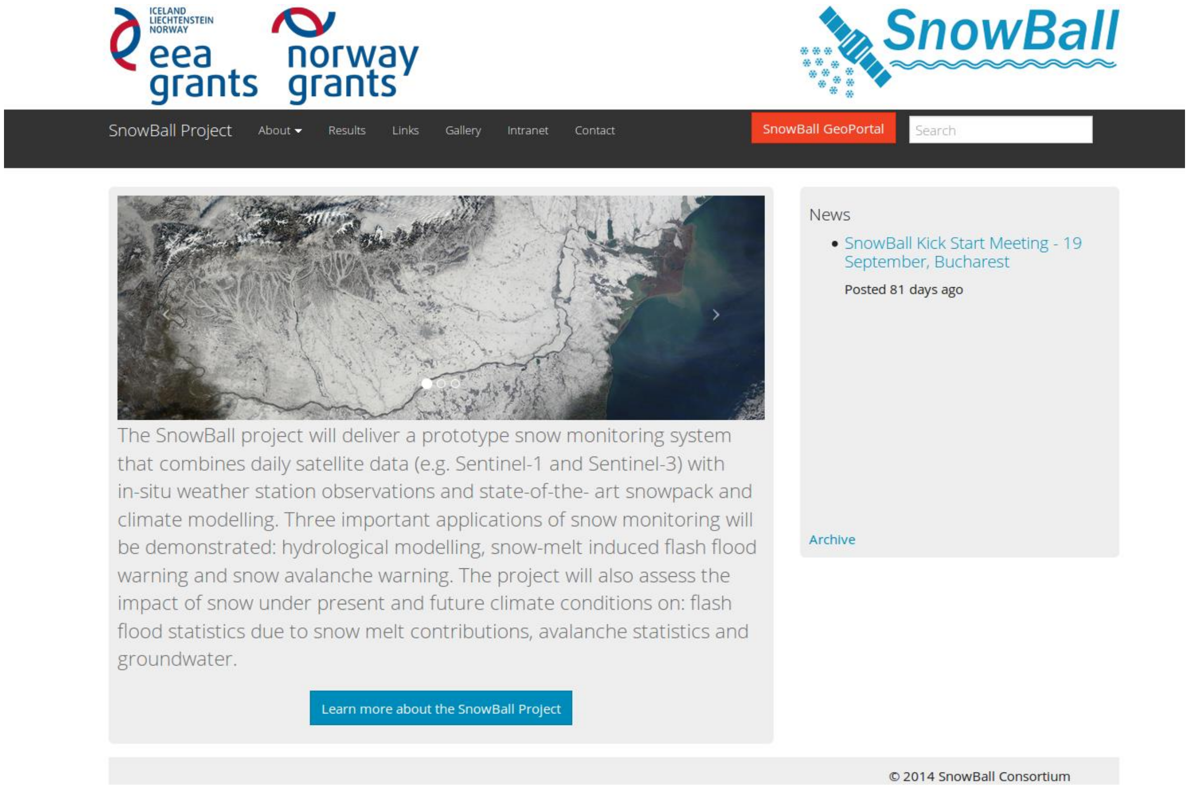

Figure 4.7.1: The web page of the project SnowBall

4.7.2. Activity 8.3. Actions of dissemination and education.

The dissemination and education actions have been conducted according to the project dissemination strategy included in the Publicity Plan: awareness of the user community about the opportunities offered by the Snowball project; communication of the results achieved in the project; preparation of the support materials for the products created within the project (eg. documentations, flyers, posters, etc.); ensuring project visibility at national and international level.
The following outlines are followed for each dissemination activity:

- Consistent visual identity;
- The project logo has to be visible;
- Mention of partners and financiers;
- All documents have to include a standard paragraph that mention the name and the indicative of the project, the financier..

Attending national and international conferences

One of the best appropriate ways to disseminate the scientific results of the project SnowBall is the scientific conferences message. Snowball consortium has participated with oral presentations and posters at relevant events for the topics addressed in the the project. There have also been submitted some articles for publication in relevant journals for the project objectives. At the end of the project, on April 27, 2017 in Bucharest, at Hotel Marshal Garden was organized the final conference dedicated to the presentation of the results obtained within the project.

The project book „Remote sensing, model and in-situ data fusion for snowpack parameters and related hazards in a climate change perspective” (Gheorghe Stancalie coordinator, Anisoara Irimescu editor, ISBN 978-606-23-0733-2, Ed. Printech, 163 pag.), was presented and distributed to the participants.

The project brochure

The brochure contains information about the the project objectives and results structured in an attractive manner and in non-technical language, understandable by the general public. The final version was distributed before the official end of the project.

Newsletter

The tird e-newsletter (electronic format) was elaborated and downloaded on the project website and distributed to the end-users of the project SnowBall.

More details are presented in the deliverables D8.6: „Visibility products (banners, posters etc.)”, D8.7: „Conference project presentation package”, D8.8: „Dissemination action report”, D8.9: „Project newsletter (e-zine) - digital form”.

5. ANNEXES

- **Annex 1. Agenda of the Annual Progress Meeting (2017);**
- **Annex 2: Agenda of the 3rd Annual Progress Meeting (2017)**

Annex 1

SnowBall – Remote sensing, model and in-situ data fusion for snowpack parameters and related hazards in a climate change perspective

Final Workshop AGENDA
Date: 27 April 2017
Venue: Hotel Marshal Garden, Bucharest, Romania

8:30 – 9:00	Participant's registration
9:00 – 9:20	Welcome addresses Round Table - Introduction of Participants
	SnowBall project results presentations
9:20 – 9:40	**Snowball project – outcomes and challenges** Gheorghe Stăncălie
9:40 – 10:05	**Measuring snow from space starts at the ground: from new station designs to collecting snow truth data** Andrei Diamandi, Cătălin Dumitrache, Adrian Rădulescu, Oana Nicola, Eduard Luca, Robert Chiriţescu, Narcisa Milian, Adrian Alin Paşol, Cristian Lucian Grecu, Anişoara Irimescu, Denis Mihăilescu Speaker: Andrei Diamandi
10:05 – 10:30	**Satellite remote sensing of snow wetness in Romania and Norway** Rune Solberg, Øystein Rudjord, Arnt-Børre Salberg, Øivind Due Trier, Gheorghe Stăncălie, Anişoara Irimescu, Andrei Diamandi, Vasile Crăciunescu Speaker: Rune Solberg
10:30 – 11:00	**Coffee break**
11:00– 11:25	**Climate change impact on snow-related processes** Roxana Bojariu, Ciprian Corbuş, Rodica Mic, Marius Mătreaţă, Vasile Crăciunescu, Narcisa Milian, Alexandru Dumitrescu, Marius-Victor Bîrsan, Sorin-Ionuț Dascălu, Mădălina Gothard, Liliana Velea, Roxana Cică, Cristian Lucian Grecu, Adrian Alin Paşol, Speaker: Roxana Bojariu
11:25 – 11:50	**Quantitative assessment of aquifer recharge from snowmelt** Dragos Găitănaru, Roxana Holban, Radu Gogu Speaker: Dragos Găitănaru
11:50 – 12:15	**Avalanche detection in very high resolution optical satellite images** Arnt-Børre Salberg, Florina Ardelean, Marcel Török-Oance Speaker: Arnt-Børre Salberg
12:15 – 12:40	**Improved snow water equivalent estimation methodology, for better hydrological warnings and forecasting** Marius Mătreaţă, Simona Mătreaţă, Bogdan Agiu Speaker: Marius Mătreaţă

12:40 – 14:10	**Lunch break**
14:10 – 14:35	**Change-detection based mapping of avalanches in Sentinel-1 images** Arnt-Børre Salberg, Jarle H. Reksten, Florina Ardelean Speaker: Arnt-Børre Salberg
14:35 – 15:00	**Snow avalanche inventory and hazard assessment in Fagaras Mountains** Marcel Török-Oance, Florina Ardelean, Mircea Voiculescu, Narcisa Milian, Arnt-Børre Salberg Speaker: Marcel Török-Oance
15:00 – 15:25	**River ice monitoring using remote sensing data. Case studies: Romania, winter season 2016-2017** Denis Mihăilescu, Vasile Crăciunescu, Gheorghe Stăncălie, Ştefan Constantinescu, Anişoara Irimescu, Claudiu Angearu Speakers: Denis Mihăilescu, Vasile Crăciunescu
15:25 – 16:00	**Coffee break**
16:00 – 16:35	**Discussions between end-users / stakeholders and project partners**
16:35 – 17:00	**First day conclusions**
18:30	**Dinner at Hotel Marshal Garden**

Annex 2

SnowBall – Remote sensing, model and in-situ data fusion for snowpack parameters and related hazards in a climate change perspective

Annual Progress Meeting (2017) - AGENDA
Date: 28 of April 2017
Venue: Hotel Marshal Garden, Bucharest, Romania

28th of April 2017 (3rd Annual project meeting)

9:00 – 9:45	Discussions to identify additional potential application fields, customers and business opportunities based on the reactions to the project results dissemination activity.
9:45 – 10:30	Discussions about potential project proposals in the frame of future Program Calls.
10:30 – 11:00	**Break**
11:00 – 11:45	Final project implementation stage and budgetary execution
11:45 – 12:30	Planned project indicators
12:30 – 14:00	**Break**
14:00 – 15:30	Scientific and Financial Final Reporting
15:30 – 16:00	**Break**
16:00 – 17:00	Dissemination aspects (web page, articles, reports etc.)
17:00 – 18:00	Final conclusions

6. CONCLUSIONS

This report presents the results obtained during 2017 in implementing the objectives of the Snowball project, according to the work plan, broken down by work packages, activities and related deliverables.

WP1 Management

Activity 1.1. Project Management

The project management activity was developed by the Romanian National Meteorological Administration, as project promoter, unfolding January – April 2017 period. The activity encompassed the research, administrative and financial activities, too, also the communication with the National Authority within the Ministry of Research and Innovation, as well as for the exploitation of the obtained results.
In view to ensure fulfilment of the project's objectives, meetings took place of the work groups, along with close communication between the partners via Internet.

WP2 In-situ snow parameters measurements

Activity 2.2. Snowpack parameters observation and measurements

The spectral data set obtained so far (more than 100 spectra) is covering a wide range of weather and snow conditions (sun angles, spectro-radiometer viewing angles, air temperature, illumination, etc). Close examination of the snow spectra shows all the known features associated with the snow spectral characteristics for different conditions and confirm therefore the quality of the acquired data.
The diurnal variation of the snow liquid water content derived from both Denoth and Topp equations are showing a good correlation with the air temperature. Comparing the Denoth and Topp SWC's, they are quite similar with the exception of an offset. In the absence of a "truth" measurement (e.g. SWC measured with either a Denoth instrument or a Snow Fork, it is difficult to assess which of the 2 equations is comes closer to the real SWC. However, both calculations can be used to evaluate the melt/freeze state of the snow, which is a useful information.

Activity 2.4. Elaboration of spatial products using the spatial database

Daily gridded data sets of air temperature (minimum, mean and maximum), precipitation, snow depth and snow water equivalent were realized over the period 1 October 2005 – 30 April 2017 at 1 km × 1 km spatial resolution.
An interpolation procedure implying three stages was used. The first stage regards the multiannual monthly means of the parameters of interest, where maps were created by a multivariate (RK) interpolation method, which can use one or more predictors derived from the digital elevation model within the spatialization process. In order to choose the optimum combination of potential predictors, the stepwise regression was used for each paramenter and month.
The second stage implied spatial interpolation of the daily deviations against the monthly normals. In order to choose the optimum interpolation method, three approaches were tested in this study, and the selection was made three error indicators. The best estimates were obtained by MQ, which was used to interpolate the anomalies.
The gridded data sets for the six analysed parameters were obtained by combining the maps with daily anomalies with those of the monthly normals.
By means of daily gridded data, other parameters can be computed, like: the number of days with snowpack, the first and last day with snowpack, the maximum snowpack depth, maximum precipitation fallen in 24 hours a.o. To exemplify, in section 3.3 there were computed a number of significant parameters for each analysed variable.
In certain areas where peculiar climatic conditions are specific and where no meteorological measurements are performed, it is recommended to achieve detailed studies regarding the spatio-

temporal variability of the meteorological variables stressing the local / regional meteorological particularities.

WP3 Satellite remote sensing, data fusion and modelling of snow parameters

Activity 3.2. MWS algorithm and product

The snow wetness maps seem in general quite consistent with the air temperatures. In most cases retrieval results of dry snow correspond with air temperatures below freezing point, and retrieval results of one of the wet-snow classes with air temperatures above freezing point. The highest temperatures usually gave the wettest snow classes. When inconsistencies were identified, most could be well explained with transitions from cold and dry conditions during the night to short periods of air temperatures above 0°C during daytime. If air temperatures above 0°C have lasted for only a few hours, the snow surface may not necessarily become wet. What happens when the air temperature is above freezing point depends very much on the wind. The melting intensity strongly increases with wind speed for air temperatures above 0°C.

Furthermore, the MWS maps are usually internally consistent in the way that the content follows the topography and local climate well. The temporal transitions are similar in the way that increasing temperatures gives increasing wetness. Also, the classes follow the topography logically (canonically) with wettest snow at lower altitudes and reduced wetness with altitude.

The inclusion of SAR indeed improves the observational capacity when optical observations are obscured under clouds. But SAR gives less information than optical (can only discriminate between dry and wet snow), and it is prone to noise showing false wet snow in agricultural areas. This is a well-known problem in the snow SAR community, but not fully understood. Ploughed fields give high backscatter when the ground is wet, and it might be that there are cases with wet soil under a layer of dry snow. However, fields might also give false snow in the summer. So, the problem is more complex and probably related to the use of reference data in the algorithms that might result from a mixture of soil tillage in the reference data giving significant variation in the backscatter properties of some fields.

The main added value of the MWS maps is that there is a new map every day, independent of observations that day. Sharp weather shifts would certainly not be included without any observations, but otherwise the approach seems to produce useful estimates of the current conditions. However, it is important to stress that the Hidden Markov Model that is used in the retrieval algorithm is not a forecasting model – it is a data fusion model. Therefore, snow wetness maps from days with few or no observations have necessarily high uncertainty.

As an overall conclusion, the analysis of the novel multi-sensor/multi-temporal wet snow maps has confirmed that the approach of fusing temporal optical and SAR observations to make an estimate of the daily snow surface wetness state seem to work well in general. The project reached the originally goal of developing a fusion algorithm for optical and SAR data, and to tailor it to and validate and demonstrate it on Sentinel-1 SAR and Sentinel-3 optical data utilising the operational capability in earth observation established by the Copernicus programme.

Activity 3.3. The new module of the multilayer model for snow in NOAH

The implemented data fusion methodology for snow water equivalent estimation, represent a state-of-the-art approach, to cope with the high degree of uncertainty of snowpack parameters evolution.

It is expected that the use of these improved snow water equivalent estimations, at high spatial resolution of 1 km, to update 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.

From computational point of view, the cellular automata approach, is a very flexible option, that will facilitate the incorporation in the future of more complex interpolation rules, and other type of input data (e.g. other satellite snow products).

Was finalized the deliverable D3.7. “Gridded SWE prototype products generated using data fusion methodology – Version 2”.

WP4 Climate change impact on snow-related hazards

Activity 4.1. Snow-related climate variability and change and associated impact

The main results in 2017 for Activity 4.1 were to synthesize the results on impact of climate change for snow-related resources.

Activity 4.2. Variability and change in flash floods with snow melt contribution

The results of the hydrologic model (CONSUL) indicate that multiannual averages of maximum discharges during the interval from November to April show increases compared with present climate (1981-2010) under best (RCP 2.6) and worst (RCP 8.5) climate change scenarios in our area of interest. Also, for sub-basins with larger areas, the increases are systematically larger under the worst scenario compared to those under the best one showing how the climate change signal overcomes the noise beyond specific spatial scales of river basins.

Activity 4.3. Variability and change in avalanche statistics

The main results achived in 2017 for Acticity 4.3 were to synthesize the results on impact of climate change for hazards.

WP5 Aquifer replenishment modelling from snowmelt infiltration

Activity 5.2. Aquifer modelling

To quantify the amount of water resulting from the snow melting, two methods are used, namely: the energy balance method consisting of measuring or estimating each term in the equation (short wave short wave and long waves, latent heat by sublimation and condensation, sensible heat, ground heat and ground level between the ground interface and snow layer), also taking into account the degree of coverage of the land (with forests, vegetation, building, etc.) as well as exposure to wind, and the "grade-day" method, which consists of indexing all energy flows in the snow layer with air temperature.

Knowledge of the amount of snowfall, amount of snow accumulation on the ground, spatial distribution along the area of interest, water frequency and volume resulting from snow melting as well as factors and processes contributing to the melting process are essential to perform models to determine the amount of water infiltrated into the soil from snow melting.

Activity 5.3. Pattern matching and climate scenarios

The series of average air temperature and snow thickness for April in the Padina area, obtained from the simulations using the RCP 2.6 and RCP 8.5 scenarios, were analyzed and the following changes were made as compared to 2005 as the reference year.

Compared to the average temperature of April 2005 that was 3.57 °C = 276.73 K, for April 2050, for the RCP 2.6 scenario the average temperature dropped by 77.4% reaching a value of 0.8 °C = 273.96 K and increased by 51.5% for RCP 8.5 scenario reaching 5.4 °C = 278.56 K.

Compared to the average thickness of the snow thickness in April 2005, which was 36.1 mm, for April 2050, for the RCP scenario 2.6 the average snow thickness increased by 18.4% to 42.6 mm and decreased by 40% for the RCP 8.5 scenario reaching 21.6 mm.

The melting process is determined by the net energy flow of the snow layer. To simulate snow melting based on an energy model, air temperature, relative air humidity, wind speed, nebulosity and net radiation were used as input (daily) data. The model is built in Microsoft Excel and uses adapted formulas from Dingman, L., 2002; Sung, C.T.B., 2015; Strasser, U., Marke, T., 2010; Walter, M.T. 2005.

For the April 2008 scenario, the RCP 2.6 scenario has highlighted the following (as compared to the 2005 reference year): a decrease in temperature of approximately 2.7 °C to close to freezing limit 0.8 °C, mean thickness thickness of a increased by 18.4%, melting rate decreased by 52%, and mean SWE

decreased by 27%, and infiltration may be limited by ice content in the soil, decreasing with the decrease in SWE.
For the RCP 8.5 scenario for April 2050, the following (compared to the 2005 reference year) were highlighted: an increase in temperature of about 1.8 ℃, the average thickness of the snow decreased by 40%, the melting rate decreased with 45.5% and the average SWE weight decreased by 11%. Given the net positive temperatures, if the soil is not saturated, the entire amount, which decreases with the SWE drop and melting rates, will infiltrate. If the soil is saturated, the amount of water resulting from the melting of snow will flow down the slope as a surface flow.

WP7 Avalanche inventory, release and hazard mapping
Activity 7.2. Change-detection algorithm for Sentinel-1 and Sentinel-2

The activity related to change detection of snow cover caused by avalanches has been finalized. The winter images (2017) from the Sentinel-1 archive have been analyzed and several images have been selected to identify changes in the upper limit of the forest using an object-based detection algorithm. An object-based detection algorithm was used to detect the forest cover based on reference image.

Activity 7.3. Avalanche simulation

Simulation of avalanche trajectories is considered an important step in hazard analysis and has an important influence on the separation of hazard levels. An important factor that drives the simulation results is related to the existence of databases with past documented events and identification of potential release areas. The hazard map integrated a combination of topographic-statistic and dinamic models and exhibit the pattern of past and recent events for the central area of Făgăraș Mts. The simulation of potential level of hazard showed that for high magnitude events, the altitude road infrastructure and forested areas will be damaged, especially in the southern slopes of the mountains.

WP8 Promotion and Dissemination
Activity 8.1. Project website

The project web site (http://snowball.meteoromania.ro) has been updated. There were included information concerning the Snowball consortium activity in the current stage: results, meetings, dissemination, etc. It has also been performed the Romanian version of the website.

Activity 8.3. Dissemination and training actions

The dissemination and training actions have been conducted according to the project dissemination strategy included in the Publicity Plan.
Members of the research teams of the Snowball consortium has participated with oral presentations and posters at scientific events for the topics addressed in the project. There have also been submitted some articles for publication in relevant national and international journals for the project objectives.
At the end of the project, on April 27, 2017 in Bucharest, at Hotel Marshal Garden was organized the final conference dedicated to the presentation of the results obtained within the project.

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LIST of ACRONIMS

ANCSI	National Authority of Scietific and Inovation Research
ASAR	Advanced Synthetic Aperture Radar
CMIP5	Coupled Model Intercomparison Project Phase 5
DEM	Digital Elevation Model
EEA	European Economic Area
EO	Earth Observation
ESA	European Space Agency
FSC	Fractional Snow Cover
GIS	Geographic Information Systems
GPS	Global Positioning System
HR	High Resolution
HRLDAS	Data Assimilation System for High Resolution
IR	Infrared
LC/LU	Land Cover / Land Use
LSM	Land Surface Model
MODIS	Moderate Resolution Imaging Spectroradiometer
MWS	Multi-Sensor/Multi-Temporal Wet Snow
NASA	National Aeronautics and Space Administration
NIHWM	National Institute of Hydrology and Water Management
NIR	Near-infrared
NMA	National Meteorological Administration
NR	Norsk Regnesentral
NWSRFS	National Weather Service River Forecast System
OLCI	The Ocean Land Colour Instrument
OWS	Optical Wet Snow
PSC	Project Steering Committee
RCPs	Representative Concentration Pathways
ROFFG	Romanian Flash Flood Guidance System
RS	Remote Sensing
SAR	Synthetic-Aperture Radar
SCE	Snow Cover Extent Area
SGEM	International Multidisciplinary Scientific GeoConferences
SGS	Snow Grain Size
SLSTR	Sea Land Surface Temperature Radiometer
SPOT	Satellite for observation of Earth
SSW	Snow Surface Wetness
STG	Scientific and Technical Group
STS	Snow Surface Temperature
SW	Snow Wetness
SWCC	Soil Water Characteristic Curve
SWE	Snow Water Equivalent
SWS	SAR Wet Snow
TDR	Time-Domain Reflectometer
USGS	U.S. Geological Survey
UTCB	Technical University of Civil Engineering
UTM	Universal Transverse Mercator
VHR	Very-High Resolution
WUT	West University of Timisoara