Improved snow water equivalent estimation methodology, for better hydrological warnings and forecasting

Marius Mătreaţă, Simona Mătreaţă, Bogdan Agiu
National Institute of Hydrology and Water Management

SnowBall project Final Conference,
27 April 2017, Bucharest, Romania

Introduction

- Snow represent one of the important component of the hydrological cycle, and is a major source of the runoff volume for the main River Basins in Romania, especially during spring period.
- Moreover, the intensification in recent years of the floods events, generated by snowmelt contribution combined with liquid precipitations, even during winter season, justifies the need for more accurate estimation of the snow water equivalent.

Introduction

- The main parameters for the snow layer **(snow layer depth, water equivalent)** have a particularly high spatial and temporal variability, which generate a very high degree of uncertainty in estimating these parameters at river basin level using only observations from the national monitoring networks.

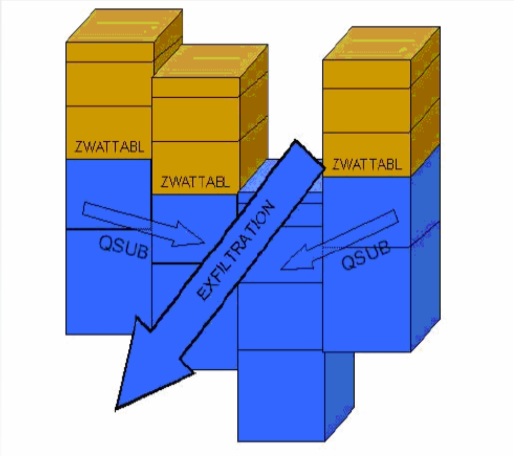
- Estimating the spatial distribution of snow water equivalent (SWE) in mountainous terrain, characterized by high elevation and spatially varying topography, is currently the most important unsolved problem in snow hydrology (Dozier, 2016).

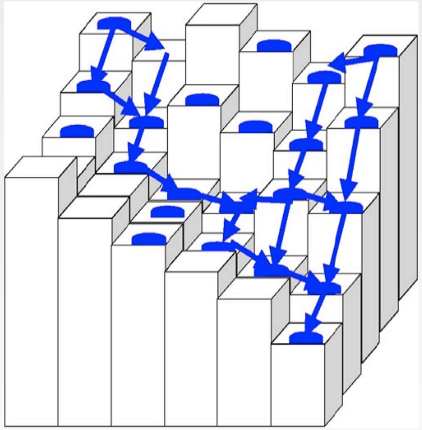
Introduction

- The observations on snow covered area can be obtained from direct measurements at ground level or by remote sensing / satellite products.
- In order to reduce the errors associated with the estimation of the snow water equivalent, we designed and implemented within SNOWBALL Project a specific data fusion type approach using:
  - snow water equivalent simulations performed with a distributed hydrological model;
  - observations of the snow layer from the national monitoring networks;
  - satellite products for the snow cover extent.

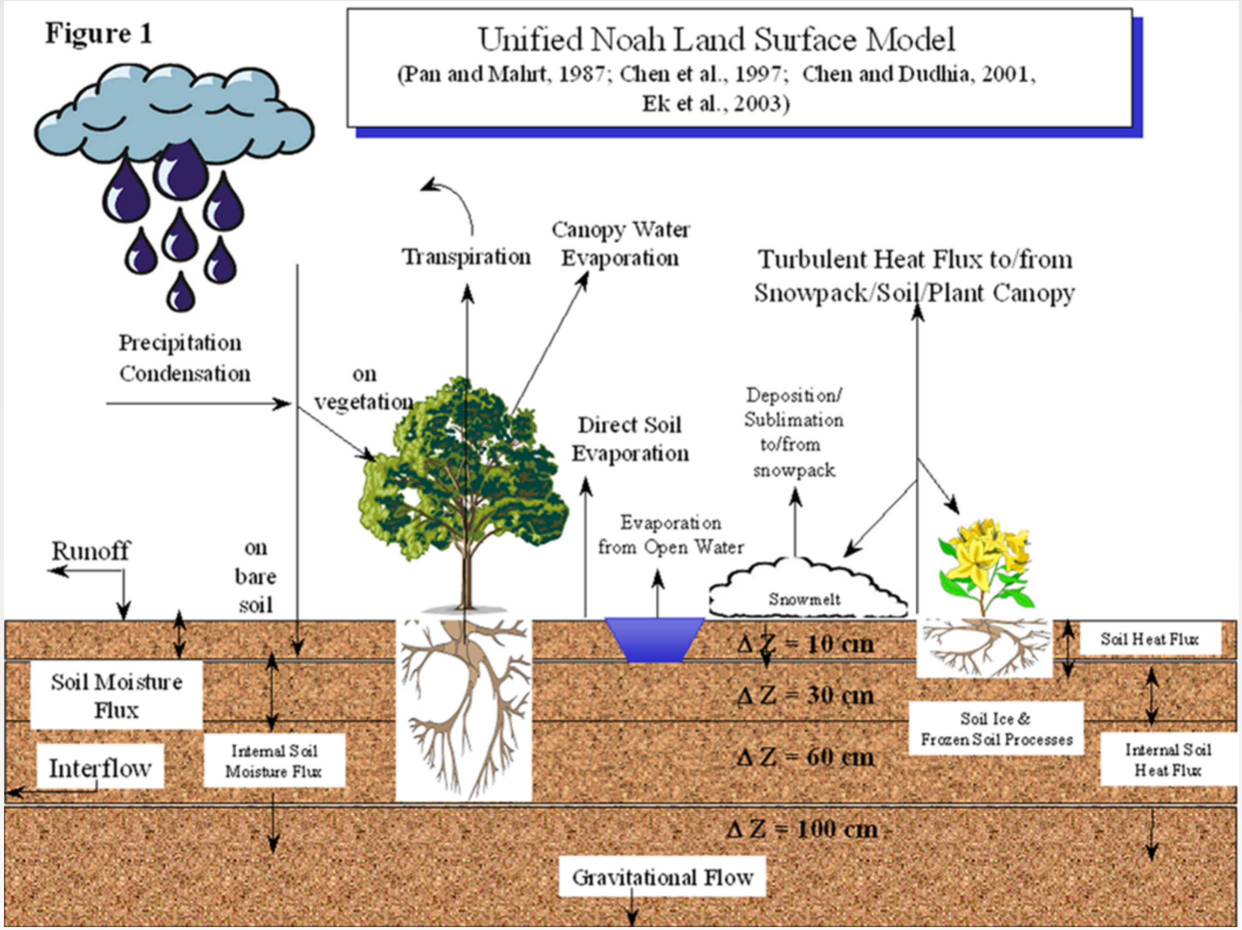
Distributed hydrological model simulation

- Simulations of the evolution of snow layer necessary for the implementation of this procedure is provided by the hydrological model with distributed parameters NOAH-R, one of the hydrological models currently being used in operational activities for the development of hydrological forecasts and warnings.
- NOAH-R model, runs at the radar-scale (1km) for the rainfall-runoff processes, and the overland and channel routing model at 100m resolution.



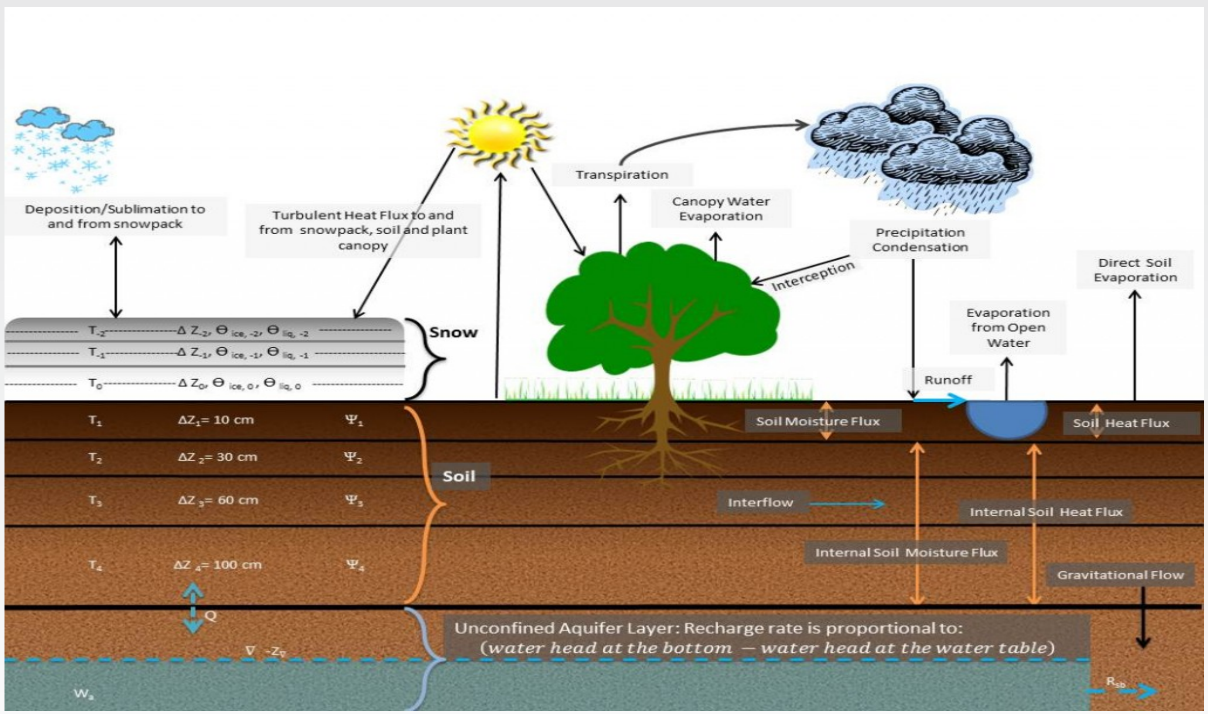


Distributed hydrological model simulation



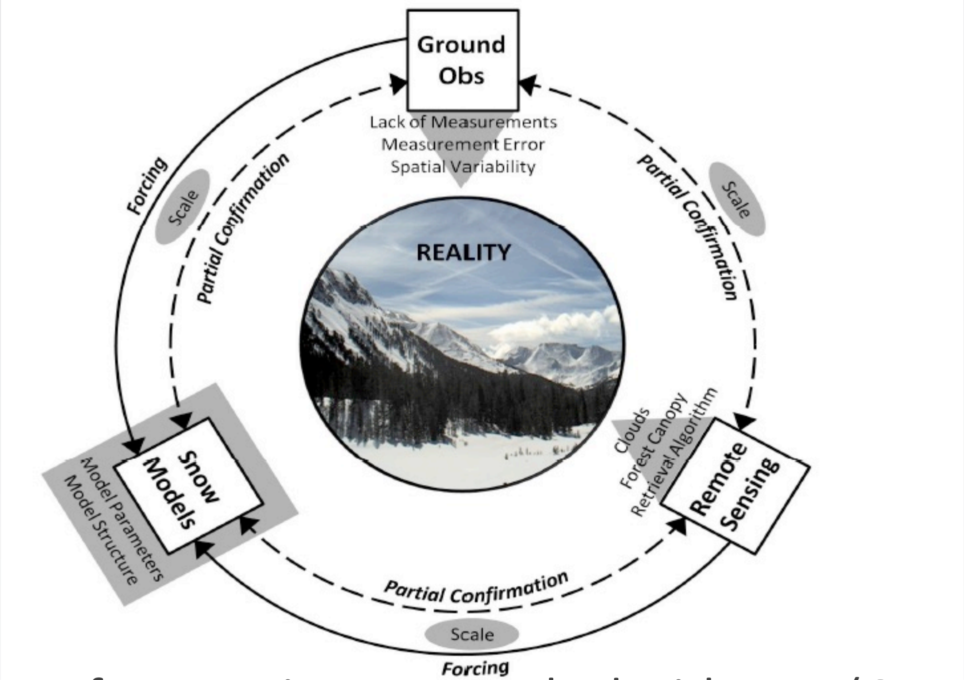
Distributed hydrological model simulation

- The distributed snow model module of NOAH-R model was improved based on the new developments on NOAH – MP (Noah Land Surface Model with Multi-Physics options - http://www.jsg.utexas.edu/noah-mp/)
- More realistic snow physics: a thin surface layer, liquid water retention and refreezing, and snowpack densification (Yang and Niu, 2003)



Data fusion methodology for estimating the SWE

- Due to the relatively high degree of uncertainty associated with different categories of input data within the methodology, we used methods based on fuzzy logic systems, and the overall processing stage use a cellular automata approach with variable neighborhood.



The major sources of uncertainty are marked with gray (Oreskes et.al., 1994)

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Data fusion methodology for estimating the SWE

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

Data fusion methodology for estimating the SWE main processing steps:

Automatic quality check of all the input data.

- Point observation and grid cell values (model simulation or satellite products).
- As output of this step, all the available data are categorized on 3 classes, based on their estimated quality (very good, good, acceptable), and all the observation not passing the tests are set to missing.
- The snow satellite products, 24 hours precipitation and air temperature data are used as input data for quality check of station data and model simulation.
- The quality check algorithm analyze/check not only the last values but also the variation from the previous estimation (previous day).
- For each cell a history/time series data is stored in a local database, to be used in a second phase, to further improve the quality checks algorithms.

Data fusion methodology for estimating the SWE main processing steps:

First general data fusion processing step – objective: establish/determine the most probable value for each cells:

- Analyze the cells with at least one data source in the category “very good”, and compute for each cell the most probable value.
- Interpolate the values using the values from the first class of cells.
- Validate and adjust the interpolation results using the cells with at least one data source in the category “good”, and the other data source values in the same category, “acceptable” category or missing.
- Validate and adjust the interpolation results using the cells with at least one data source in the category “acceptable”, and the other data source values in the same category or missing.

Data fusion methodology for estimating the SWE main processing steps:

Second general data fusion processing step – objective:

- o final determination of the cells without snow (SWE = 0), using satellite snow cover extent product and station data, as a final adjustment of the interpolated field.

The entire processing steps take into account also the topographical and land use / land cover controlling factors for the snowpack evolution, especially during snowmelt period.

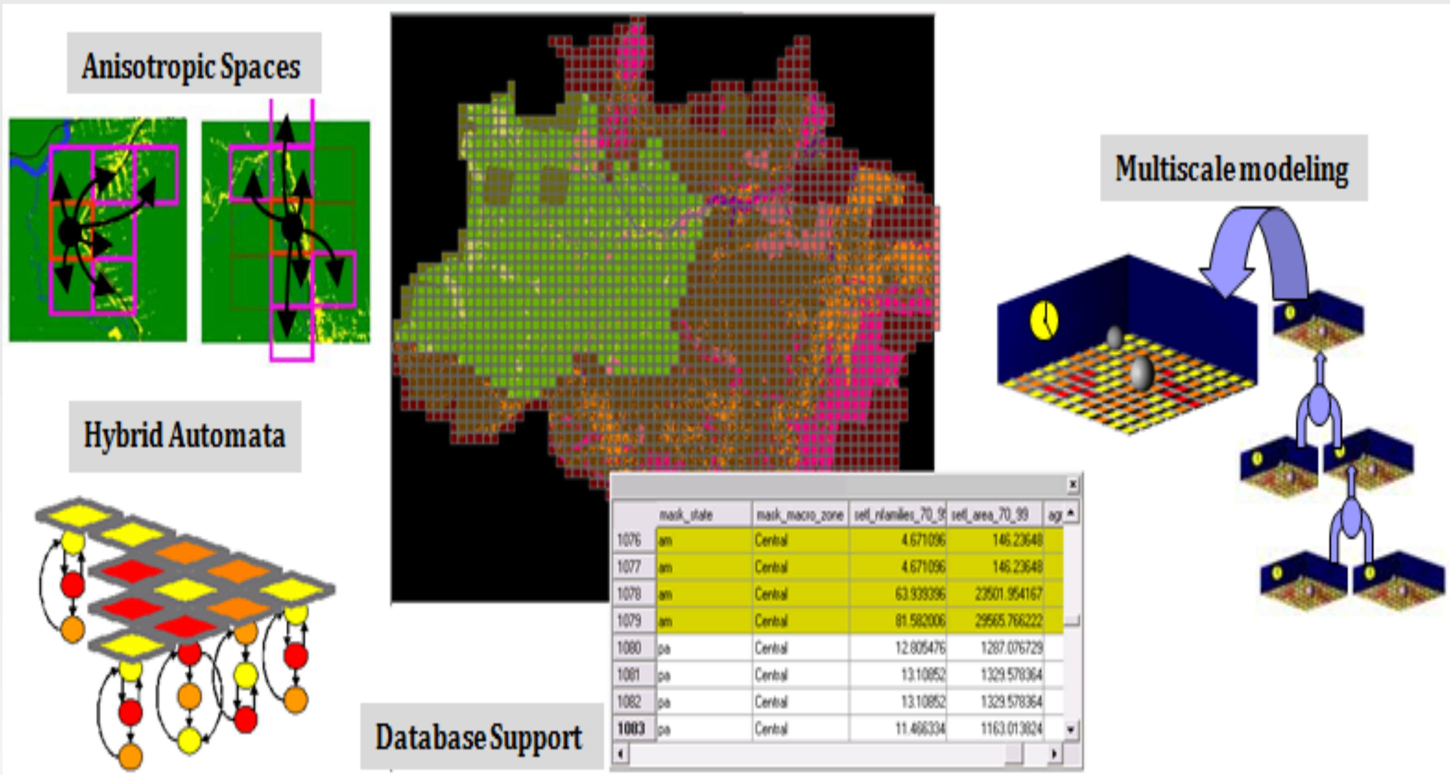
This is mainly based on results from the previous research done within the National Institute of Hydrology and Water Management, using the data from representative basins.

Data fusion methodology for estimating the SWE – Software implementation:

- The software implementation was also done using a modular approach, flexible and easy adapted configuration, based on the following stable open source components:
  - Use Java and R custom program mainly for data interfaces with existing systems.
  - Use R and TerraME (http://www.terrame.org/doku.php) custom scripts for main processing and data analysing steps.
  - Use OddJob (http://rgordon.co.uk/oddjob/index.html) scheduler for processing workflow control.

- TerraME is a programming environment for spatial dynamical modelling, supporting cellular automata, agent-based models, and network models running in 2D cell spaces.

Data fusion methodology for estimating the SWE – Software implementation:



General TerraME environment modelling functionalities

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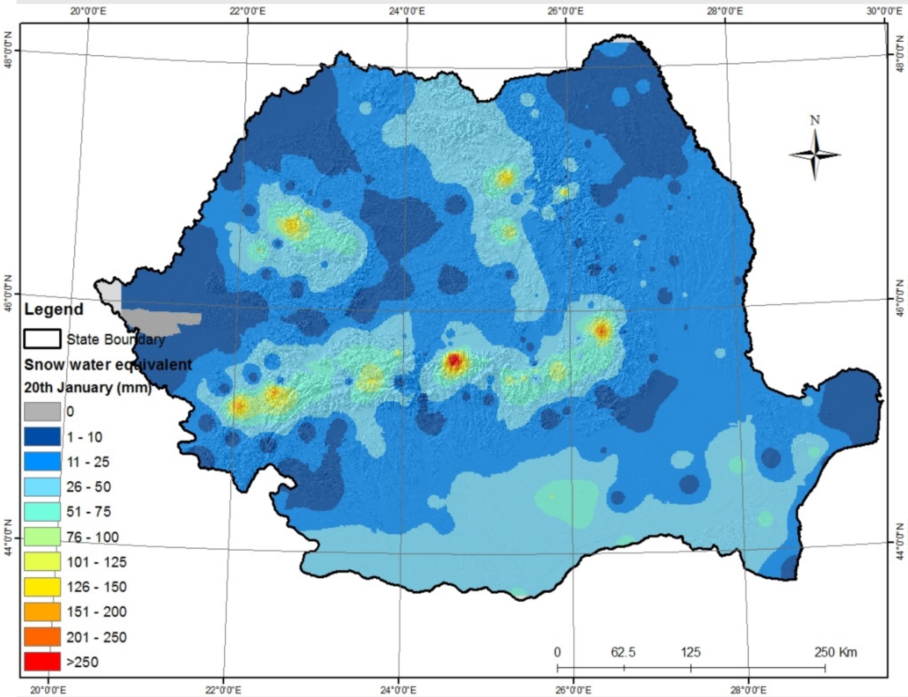
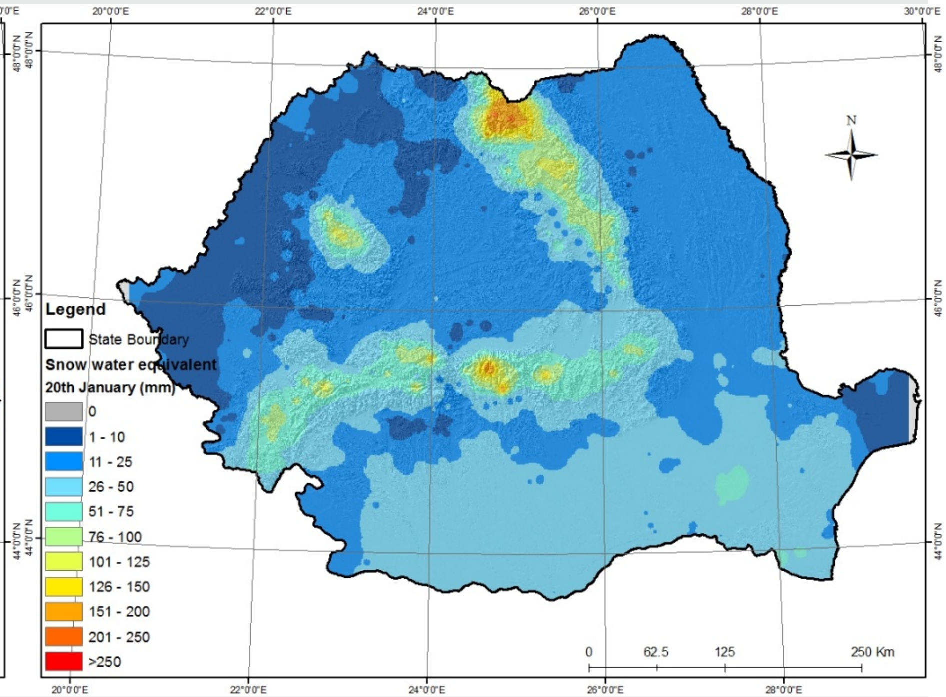
Data fusion methodology for estimating the SWE – example products:





Station data interpolation – 20.01.2017

Data fusion – 20.01.2017

Assimilation of snowpack parameters in the National Flood Forecasting and Warning System

- One of the main application of the improved detailed estimations of the snow water equivalent, is to update this important state parameter in the operational hydrological forecasting models.
- The Romanian National Hydrological Forecasting and Modelling System is composed by specialized hydrological modelling modules, adequate for the real-time simulation and forecasting of hydrological processes at different spatial and temporal scales:
  - A conceptual lumped hydrological modelling system based on a specific NWSRFS implementation.
  - A distributed modelling component, which is mainly based on the NOAH-R model.
  - A Flash-Flood Guidance component, which is an adaptation of the HRC Flash Flood Guidance System.

Assimilation of snowpack parameters in the National Flood Forecasting and Warning System

- Taking into account that the gridded SWE product generated using the data fusion approach represent the best estimate of this parameter, using detailed model simulation, satellite products and ground observation, the direct insertion method is used as data assimilation approach.
- This approach makes the explicit assumption that the models simulations have no supplemental useful information, other than the information used to derive the data fusion product.
- The state SWE parameters in the NOAH-R distributed hydrological model are updated based on the adjusted gridded SWE output product, from the data fusion methodology, which have the same spatial resolution (1Km).

Assimilation of snowpack parameters in the National Flood Forecasting and Warning System

- The other two important hydrological forecasting systems (NWSRFS and ROFFG) are using the same conceptual model SNOW-17, for simulating the snowpack evolution.

- The adjusted gridded SWE product, output from the data fusion methodology, is used to compute the mean SWE for the sub-basins configured within the NWSRFS and respectively ROFFG operational models implementation.

- Taking into account the uncertainty related to the real time data, the mean sub-basin SWE from the model will be adjusted only if the difference is > 10 %.

Conclusions

- 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.

Conclusions

- Also the algorithms of automatic control of quality and interpolation that are used for the implementation of the data fusion methodology, also take 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.
- 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).

Thank you very much for your attention!

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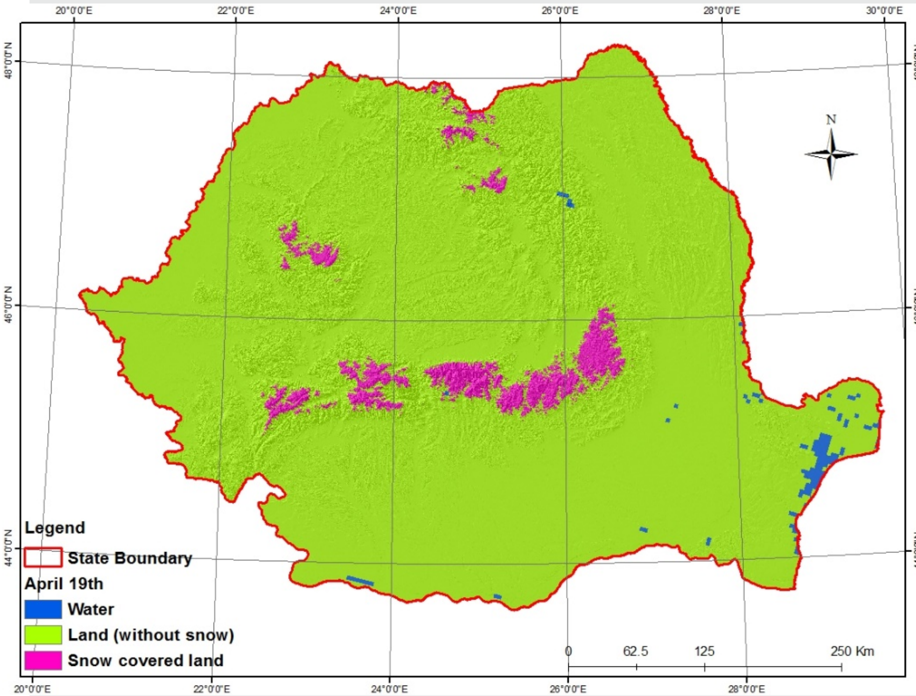
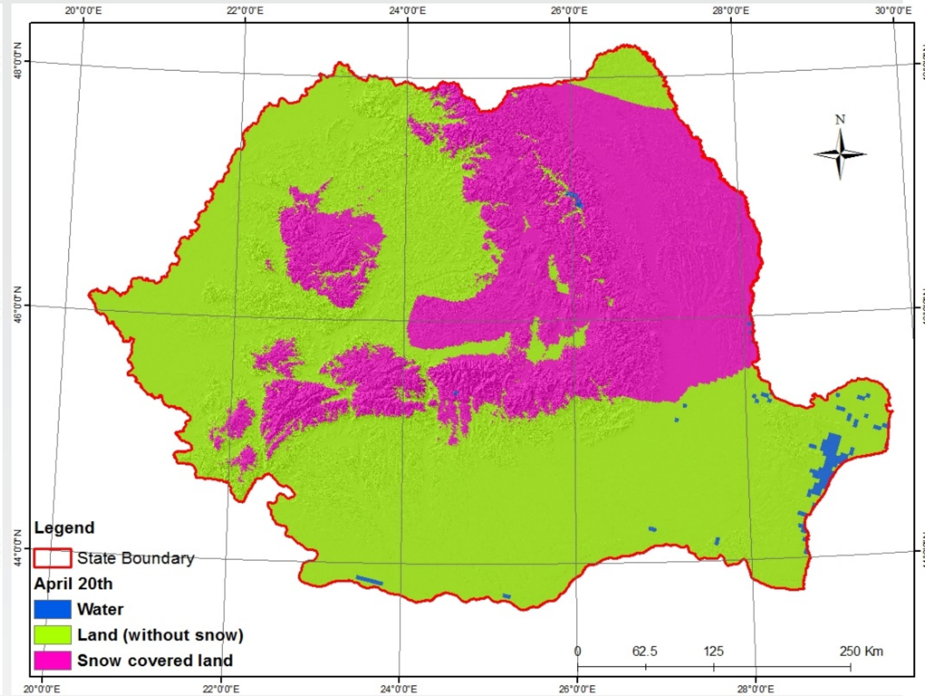
Data fusion methodology for estimating the SWE – example products:





SCE – 19.04.2017

SCE – 20.04.2017

Satellite snow cover extent – daily operational products

Source: National Ice Center. 2008, updated daily. IMS daily Northern Hemisphere snow and ice analysis at 1 km, 4 km, and 24 km resolutions. Boulder, CO: National Snow and Ice Data Center. Digital media.

Data fusion methodology for estimating the SWE – example products:

Characteristics of selected NWSRFS sub-basins

No.	Basin	River	Hydrometric Station at basin outlet	Area (km^2)	Minimum Altitude (m)	Maximum Altitude (m)
1	MUREŞ	Mureş	Topliţa	1070	651	1683
2	MUREŞ	Gurghiu	Ibăneşti	407	455	1760
3	JIU	Jiul de Est	Livezeni	440	561	2477
4	OLT	Caşin	Ruseni	483	547	1449
5	OLT	Covasna	Boroşneu Mare	232	519	1466
6	SIRET	Bistricioara	Tulgheş	410	637	1669
7	SIRET	Bistriţa	Cârlibaba	360	928	2227
8	SIRET	Moldova	Fundu Moldovei	325	723	1565
9	SIRET	Uz	Cremenea	340	548	1630
10	SIRET	Cracău	Slobozia	438	269	1206
11	SIRET	Nişcov	Izvoru	130	165	737
12	SIRET	Slănic	Cernăteşti	415	144	1355

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Data fusion methodology for estimating the SWE – example products:

Mean basin SWE for selected NWSRFS sub-basins – 20th January 2017

No. Crt.	River	Hydrometric Station	SWE IDW (mm)	SWE Data fusion (mm)
1	Mureş	Topliţa	28	43
2	Gurghiu	Ibăneşti	49	21
3	Jiul de Est	Livezeni	61	61
4	Caşin	Ruseni	21	30
5	Covasna	Boroşneu Mare	55	38
6	Bistricioara	Tulgheş	24	88
7	Bistriţa	Cârlibaba	29	170
8	Moldova	Fundu Moldovei	22	83
9	Uz	Cremenea	12	53
10	Cracău	Slobozia	12	12
11	Nişcov	Izvoru	9.3	28
12	Slănic	Cernăteşti	20	27