SnowBall project – Outcomes and challenges

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Introduction

- Snow significantly affects daily life and economy in many European countries. Heavy seasonal snow affects transport and every day life, changes in snow precipitation having an considerable impact on water provision, hydroelectric power supplies, agriculture, tourism and recreational activities.
- Moreover, snow also plays an important role in Earth's climate regulation by being an important element of the water cycle, by reflecting incident solar radiation back out to space and by acting as a thermal insulator. Thus, it is of greatest importance to monitor changes in the extent, duration and properties of snow over both land and ice.
- The **EU Copernicus Program** goal is to develop information services based on a strong satellite and in situ observation capability which has to be used for operational modelling.
- The **Sentinel satellites** are developed for the specific needs of the Copernicus Program. The Sentinel Program is a joint effort between the ESA and the EC to replace and/or continue existing older Earth Observation missions ensuring there are no data gaps in the global monitoring of the environment and security.
- The EC is currently analyzing the user requirements on **snow parameters monitoring** using satellite, in-situ and model data for the **next generation of the Copernicus Space Component**.
- The envisaged **COPERNICUS contribution for snow and ice monitoring** is related to:
  - Increase stakeholder awareness of satellite-based snow monitoring services;
  - Facilitate access to snow information products for stakeholders;
  - Train stakeholders to use satellite-derived snow products;
  - Encourage the expansion of services for cross-regional applications.

Project summary (1)

The **SnowBall** project („Remote sensing, model and in-situ data fusion for snowpack parameters and related hazards in a climate change perspective") was implemented in the framework of the "Research within Priority Sectors" Program, funded by the Financial Mechanism of the European Economic Area (SEE), 2014-2017.
The "Research within Priority Sectors" main goal is to reduce the economic and social disparities, strengthen the bilateral relations through increased cooperation between scientific communities in Romania, Norway, Iceland and Liechtenstein, as well as fostering long-term cooperation through building partnerships between the research entities.

Project Promoter: The National Meteorological Administration, Bucharest, Romania.

Project Partners:

- Norsk Regnesentral Stiftelse (Norwegian Computing Center), Oslo, Norway.
- Technical University of Civil Engineering Bucharest – Groundwater Engineering Research Center, Bucharest, Romania.
- National Institute of Hydrology and Water Management, Bucharest, Romania.
- West University of Timisoara – Faculty of Chemistry, Biology and Geography, Timisoara, Romania.

Budget: 1.199.000 Euro

Duration: 34 months (30.06.2014 – 30.04.2017)

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Project summary (2)

The overall *SnowBall* project objective is to explore and develop a methodology supporting the vision of a future service providing national authorities in Romania with hind-cast and real-time snow and avalanche information retrieved from Earth Observation data.

Objectives:

- Improve the **spatial and temporal resolution of in-situ snowpack parameters measurements**.
- 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.
- Define and test a reliable methodology for the **snowmelt infiltration component of the hydro-geological cycle**.
- Assess the **impact of snow under present and future climate conditions** on flash flood statistics due to snowmelt contributions, avalanche statistics and groundwater.
- Develop and implement a data assimilation procedure for adjusting the snowpack related state parameters within the **snow module of the hydrological forecasting models**.
- Develop methods for **avalanches detection, modelling, and hazard assessment**.

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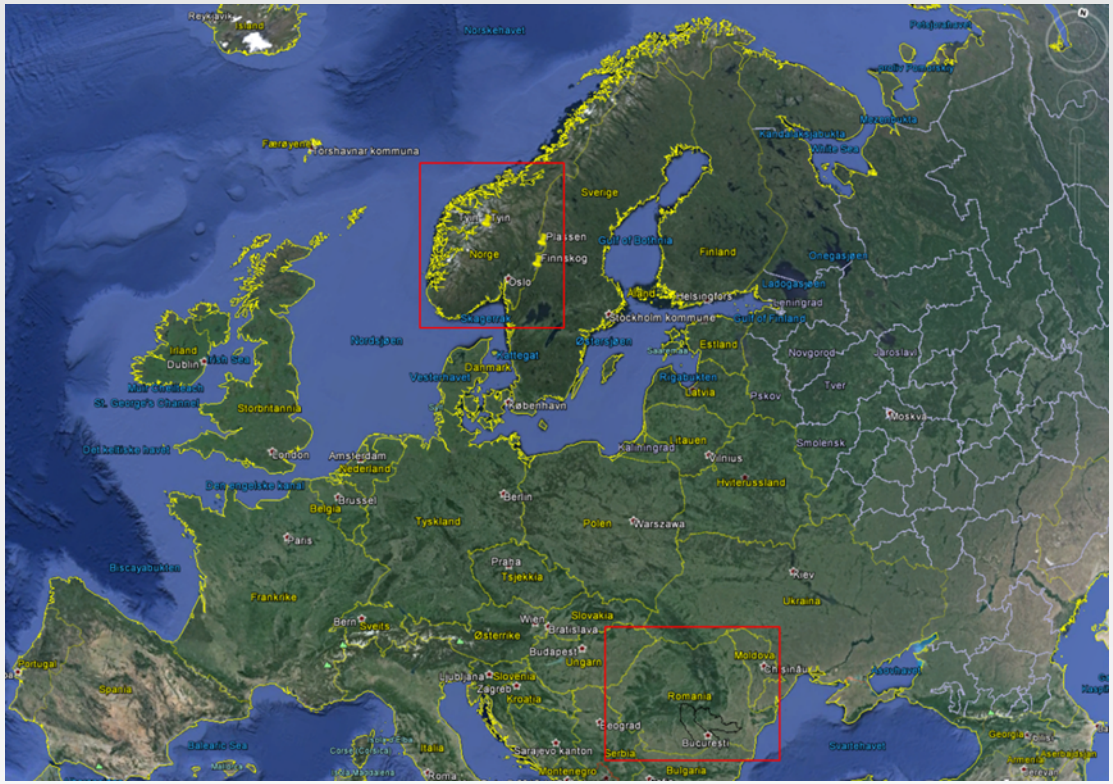
eea grants

norway grants

The study areas in Romania and Norway



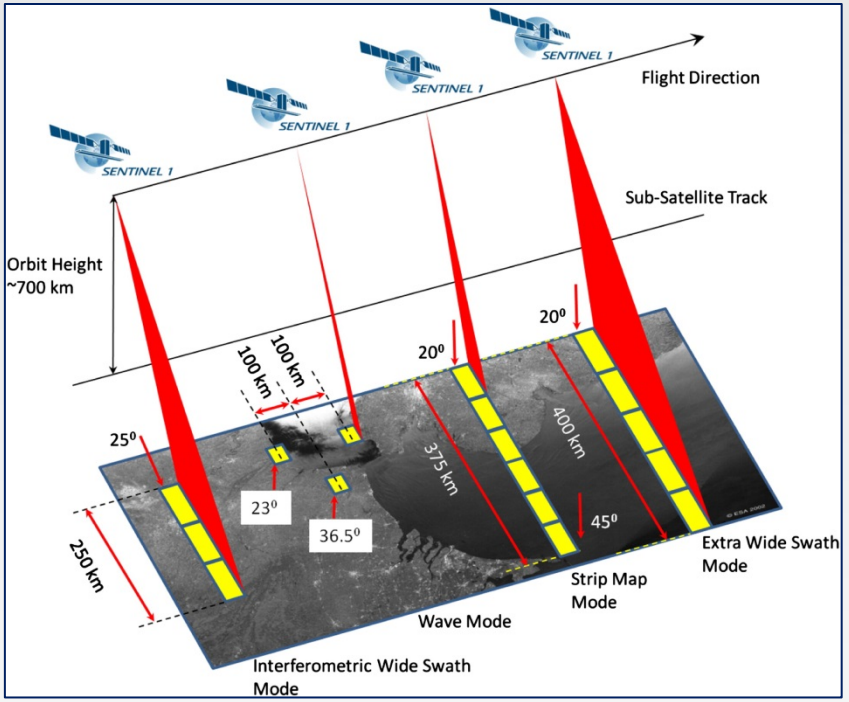
Satellite data used

- **Sentinel-1A** (launched on 3 April 2014) and **Sentinel-1B** (launched on 25 April 2016).
  - ✓ well-suited to detect regional snowmelt processes by providing:
  - ✓ global coverage;
  - ✓ ground resolution of 5m x 20 m;
  - ✓ frequent revisit time;
  - ✓ quick data delivery;
  - ✓ coherent, reliable information;
  - ✓ all-weather radar day-and-night cloud-free imagery.
- **Sentinel-2A** (launched on 23 June 2015) and **Sentinel-2B** (on 7 March 2017).
  - ✓ provides high-resolution optical imagery for land services.
- **Sentinel-3A** (launched on 16 February 2016) and Sentinel-3B is scheduled for launch in 2017;
  - ✓ provides high-accuracy optical, radar and altimetry data for marine and land services.
- **Terra MODIS**;
- **Suomi NPP VIIRS** as backup.

Satellite data used

Sentinel-1A and Sentinel-1B

- The SENTINEL-1 mission is designed to provide enhanced revisit frequency, coverage, timeliness and reliability for operational services and applications requiring long time series.
- The SENTINEL-1 SAR instrument and short revisit time will greatly advance users' capabilities and provide data routinely and systematically for maritime and land monitoring, emergency response, climate change and security.



SENTINEL-1 Modes

Satellite data used

❖ **Sentinel-2A** and **Sentinel-2B**

- The Sentinel-2 satellites caries a single multi-spectral instrument (MSI) with 13 spectral channels in the visible/near infrared (VNIR) and short wave infrared spectral range (SWIR).
- The spatial resolution range is: 10 m ÷ 60 m.

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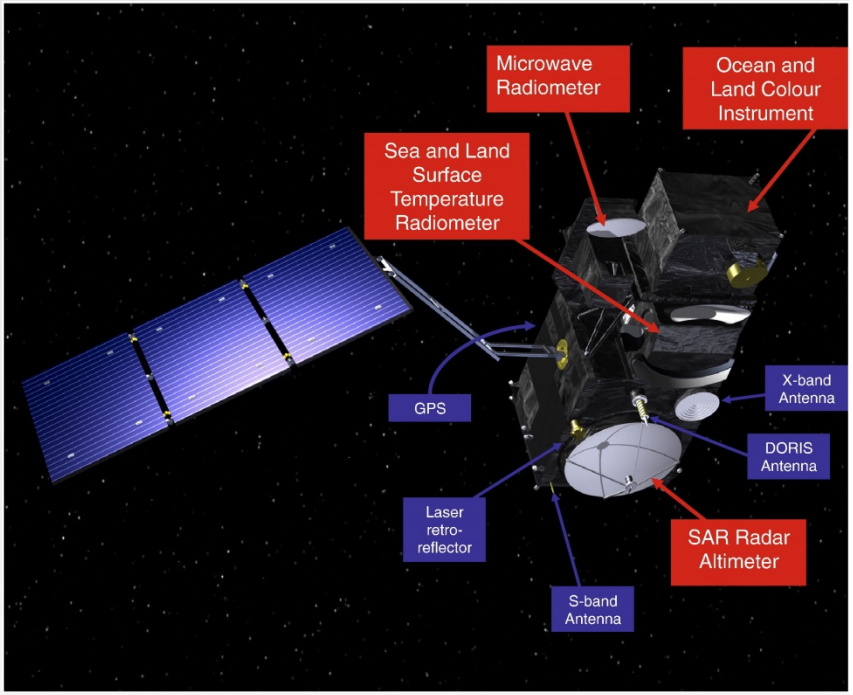
Sentinel-2

Satellite data used

❖ Sentinel-3

The Sentinel-3 satellites caries the following payload instruments:

- ✓ A push-broom imaging spectrometer instrument (Ocean and Land Colour Instrument - OLCI) – spatial resolution **300 m**;
- ✓ A dual view conical imaging radiometer (Sea and Land Surface Temperature Radiometer - SLSTR) – spatial resolution **500 m** (visible and shortwave infra-red) - **1 km** (thermal infra-red channels);
- ✓ A dual-frequency SAR altimeter (SAR Radar ALtimeter - SRAL;
- ✓ A Microwave Radiometer (MWR) instrument;
- ✓ A Precise Orbit Determination package including a Global Navigation Satellite Systems (GNSS), a Doppler Orbit determination and Radio-positioning Integrated on Satellite (DORIS) instrument and a Laser Retro-Reflector (LRR).



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Sentinel-3

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The project practical relevance

- The SnowBall project addresses a problem of **national interest**, namely the accurate and timely knowledge of the seasonal snow distribution and characteristics. The socio-economic impact of snow is significant, ranging from water management and hydropower, to agriculture, transport, tourism, urbanism and emergency situations management.
- The monitoring of ice and snow is **very important for the management of extreme events prediction** such as **snowmelt floods**, **avalanches** and the **impact of global warming**.
- The project has developed a **novel wet snow cover product** based on a multi-sensor/multi-temporal combination of the new Sentinel-1 and Sentinel-3 satellite data.
- Observations of snow pack parameters provide a reliable source of information for **long term hydrological prediction in spring season**; the SWE (Snow Water Equivalent) observations are essential to update the model simulated snow pack conditions, to ensure that hydrological forecasts are reliable.
- Accurate observations of SCE (Snow Cover Extent) area and the physical properties and state of the snow are of **great interest for climate change research**.
- In the perspective of climate change, surface water resources are becoming more vulnerable, and **groundwater needs special attention**. In this regard a better knowledge of the snow parameters spatial and temporal distribution can enhance and **improve the groundwater resources assessment**.
- The combined use of satellite based snow parameters and weather station data for snow modelling, are able to provide **better snow avalanche warning and forecasting**.

Project outcomes (1)

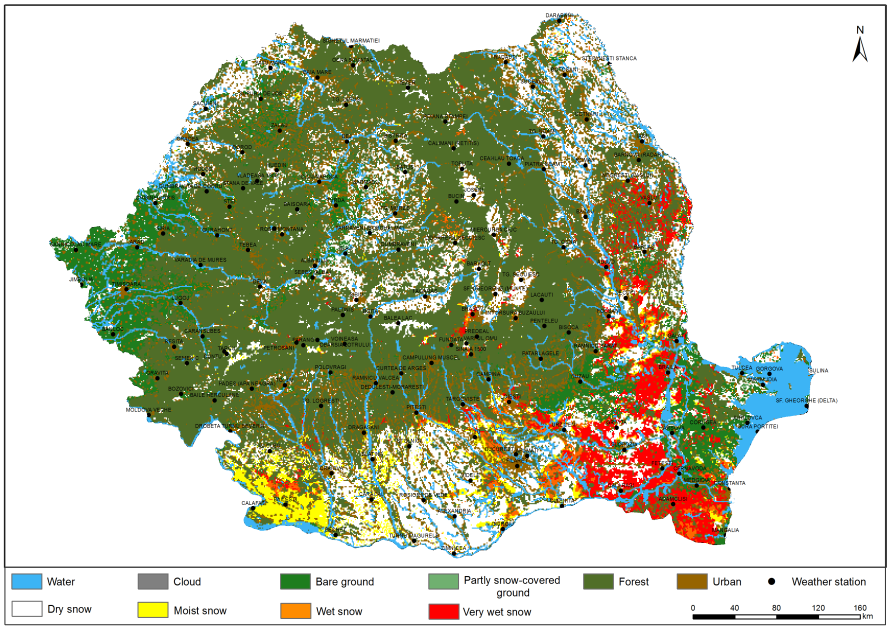
A reliable ground truth data to improve the snow parameters assessment and monitoring as well as for the validation of EO derived snow products, as a result of data collection from a denser in-situ snow measurement network and from the field campaigns.

- Snow parameters measuring devices (depth, snow water equivalent, temperature profile) were designed, assembled and tested.
- A portable spectrometer (750 – 1400 nm) for measuring shaped snow reflectance spectral data (new powder or wet snow, older deep snowpack, thin water films and ice) was acquired, laboratory and in field tested and programmed.
- A spatial database managed by dedicated GIS software was designed and set-up.

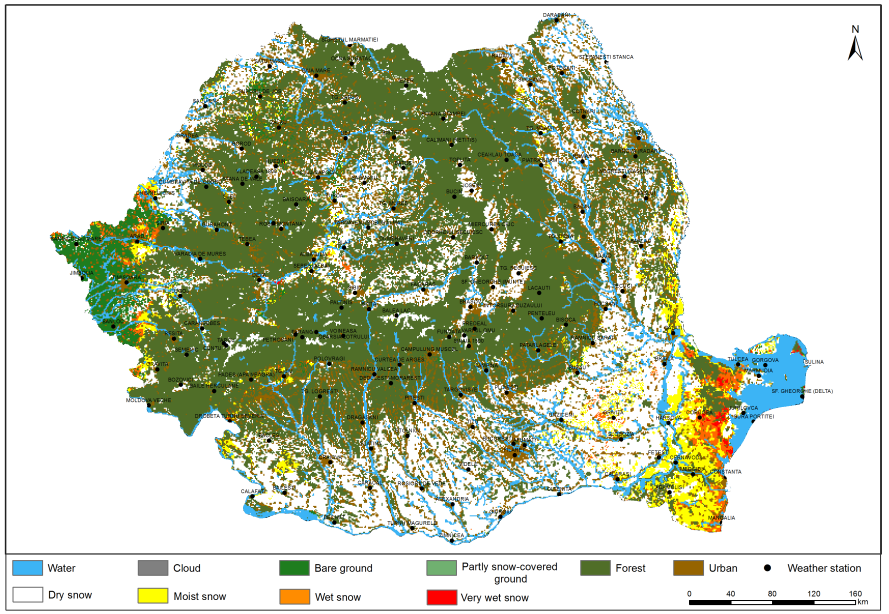
Project outcomes (2)

A set of high performance algorithms and prototype processing chains for EO (Sentinel 1/3) and hydrological modelling snowpack parameters retrieval, including elements of an pre-operational snow service.

- For the wet snow mapping, a novel model based on multi-sensor/multi-temporal wet snow (MWS) algorithm fusing optical (Sentinel 3) and SAR data (Sentinel 1) was elaborated and tested.



MWS map for 4 February 2017

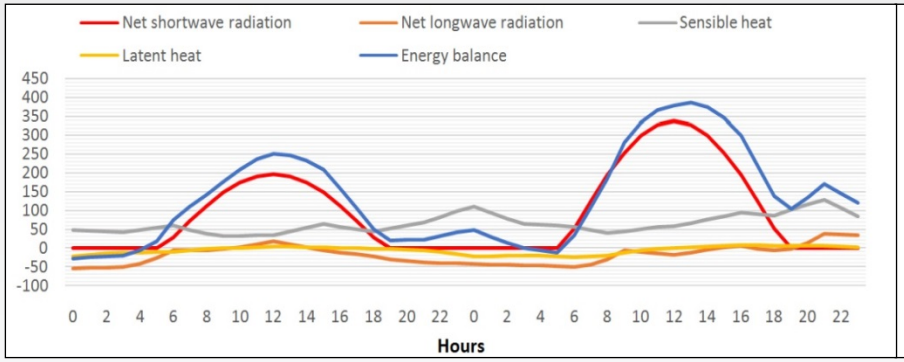


MWS map for 15 January 2017

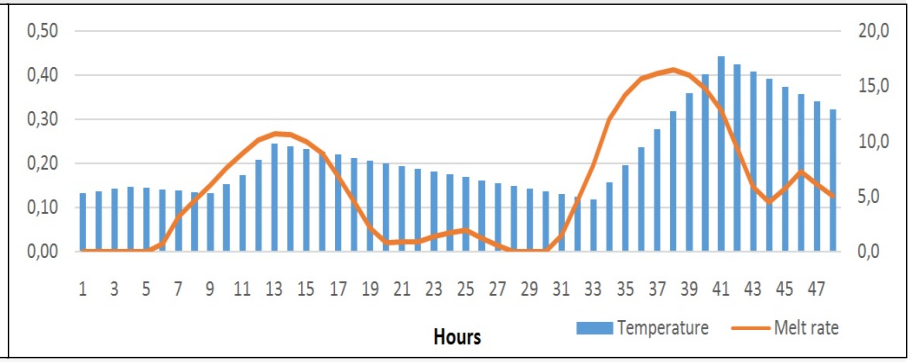
Project outcomes (3)

Quantitative estimations of the snowmelt contribution to the aquifer replenishment.

- In order to develop and test a new methodology to estimate the aquifer recharge from snowmelt 3 test sites were selected (Prahova-Teleajen Cone, Ialomita Upper River Basin and Bucharest City) and for each a hydro-geological conceptual model was develop.
- A TDR (Time Domain Reflectometry) based equipment was acquired for the in-situ measurements of soil water content.
- A numerical flow model for the unsaturated zone was developed for the Ialomita Upper River Basin.



Energy flux density

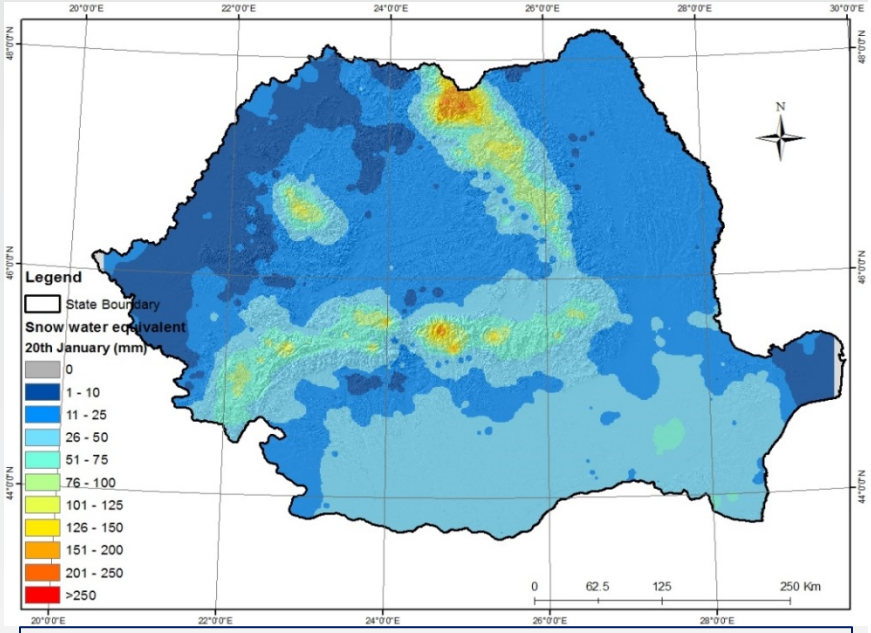


Temperatures and melt rates

Project outcomes (4)

More accurate snowmelt runoff forecasts based on higher temporal and spatial resolution of the snowpack parameters derived from EO data.

- Design of data fusion methodology for estimating the SWE, as a gridded product 1 km spatial resolution, using distributed snow model simulations, ground observations and satellite products.
- Design of the algorithms and methodology for data assimilation of snow pack parameters in the main operational hydrological forecasting models.

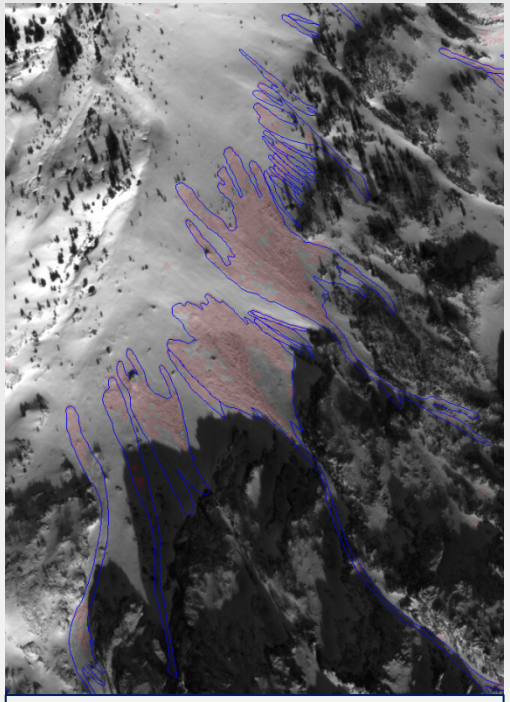


SWE computed using data fusion method the 20th January 2017

Project outcomes (5)

More accurate snow avalanche detection, prediction and hazard assessment using higher spatial and temporal resolution in-situ and EO based snow data, supporting a future service providing hind-cast and quasi real-time snow and avalanche information.

- Pattern recognition techniques to detect and map the outline of avalanches, in very high resolution optical satellite data.
- Change-detection algorithms of land and snow cover, caused by avalanches in high resolution satellite data (Sentinel 1 and 2).
- Avalanche inventory and the associated geodatabase regarding morphometric parameters and snow characteristics.
- Apply and calibrate the numerical avalanche simulation tool RAMMS (RApid Mass Movement Simulation) to model the avalanche trajectories based on DEM's release areas and friction parameters.



Făgăraș Mountains. Red areas correspond to detected avalanches areas.

Project outcomes (6)

Knowledge of the impact of climate change on the snow-related water resources and hazards.

- Detailed assessment of snow and other related atmospheric and hydrologic variable over the domains of interest, under present (1981-2010) and future climate scenarios (2021-2050 and 2070-2099) and the associated impact, based on 6 regional climatic EURO-CORDEX models using 2 representative Concentration Pathways Scenarios (RCP 2.6 and RCP-8.5).

The SnowBall project generated and is able to deliver a portfolio of products to end-users operating in various application fields: meteorology, hydrology, water management, agriculture, energy, emergency situations, tourism, media.

- The products include: the extent of seasonal snow cover, the snow surface wetness (optical and SAR wet snow, multi-sensor/multi-temporal wet snow maps), snow water equivalent estimations at high spatial resolution for drainage basins, evaluation of the infiltration and run-off processes from the snowmelt for groundwater recharge assessment, automatic detection of avalanches in VHR optical satellite images, snow avalanche inventory and hazard assessment in Southern Carpathians, assessment of snow-related hazards in Romania based on climate change scenarios for the time horizons 2022–2050 and 2072–2100.

Project outcomes (7)

7 peer-reviewed journal publications.

35 conferences, seminars presentations:

- International Conference on "Air and Water Components of the Environment", 25-27 March 2016, Cluj Napoca, Romania;
- The 2016 ESA Living Planet Symposium, Prague, Czech Republic, 9-13 May 2016;
- The International Geostatistics and Machine Learning, Applications in climate and environmental sciences, 21-24 June 2016, Belgrade, Serbia;
- The 36th EARSeL Symposium (Frontiers in Earth Observation), 20-24 June 2016, Bonn, Germany;
- The 73rd Eastern Snow Conference, 14-16 June 2016, Columbus, Ohio, USA;
- The Geoscience and Remote Sensing Symposium (IGARSS), 10-15 July 2016, Beijing, China
- The 5th COPERNICUS Conference for the Eastern European Copernicus users and service providers. The future of COPERNICUS: Extension and Expansion, Bucharest , 5 – 6 October 2016;
- The 2nd Workshop on Geoinformatics in the framework of SYNASC 2016: 18th International Symposium on Symbolic and Numeric Algorithms for Scientific Computing, Timisoara, Romania, 27September 2016;
- Workshop on „Communication and Publicity" Program RO14 "Research within Priority Sectors", 25 May 2016, Sibiu;
- Air and Water Components of the environment, 25-27 March 2017, Cluj Napoca, Romania;
- The 8th EARSeL Workshop on Land Ice and Snow, 7-9 February 2017, Bern, Switzerland;
- International Symposium on Polar Ice, Polar Climate, Polar Change: Remote sensing advances in understanding the cryosphere, 14-19 August 2017, Boulder, Colorado, USA.

Conclusions and way forward (1)

- The project addresses a challenge of national interest: accurate and timely knowledge of the seasonal snow distribution and characteristics.
- The project supports the public priorities: emergency situations and water management, transport and tourism.
- The most important novelty of the project is related to the use of Sentinel satellites for the snow monitoring and assessment. These satellites open up new approaches, in particular with respect to multi-sensor and multi-temporal applications.
- The partnership between Romania and Norway institutions contributed to technology transfer in the areas of:
  - satellite remote sensing, data fusion and modelling of snow parameters;
  - methodology for snow water equivalent estimation using data fusion of model simulations, ground observations and satellite products;
  - snow avalanche detection from high-resolution satellite images;
  - instrumentation for snow parameters field measurements.

Conclusions and way forward (2)

Plans for continuation of collaboration beyond this project in the framework of future R&D programs (e.g.: H2020, EEA grants):

- Extending the aim of SnowBall to a pre-operational snow service over the entire Romanian and Norwegian territory, taking full advantage of the operational Sentinel-1/2/3 satellites and the tested algorithms and processing lines and experience gained in the SnowBall project.
- Hydropower production and energy trading (optimizing hydroelectric power production, regulating dam levels and setting electricity prices);
- Remote sensing and big data analysis for environmental applications which require high performance computing by using the High Performance Computing.
- Monitoring and estimating the evolution of ice phenomena on rivers.

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