Exploitation of X-band SAR images and ground data for SWE retrieval through a machine learning technique

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Background

The current methods for retrieving SWE from space rely on passive microwave sensors. However, the use of these sensors for snow properties detection is limited by the poor spatial resolution that implies difficulty in considering mixed pixel effects over heterogeneous landscapes, such as in mountainous areas. The use of Synthetic Aperture Radar (SAR) has been suggested as a potential observation method to overcome the coarse resolution of passive microwave sensors [1,2,3].

Objective

To exploit the strengths of the Support Vector Regression (SVR) technique to obtain an estimate of the SWE starting from information derived from X-band SAR images together with ground measurements of SWE.

- *Case study 1*: To achieve the above objective, the information derived from the X-band SAR imagery acquired by the COSMO-SkyMed constellation in StripMap HIMAGE mode at 3 m ground resolution with HH polarization together with the manual ground measurements of SWE have been exploited.
- *Case study 2*: For retrieving snowmelt areas, especially in regions with steep topography, the added value of cross-polarized data is significant, because of the good separability of wet snow and snow-free surfaces that this data offer [4]. For this reason, in the second phase we also consider these data, namely the COSMO-SkyMed constellation in StripMap PINGPONG mode (dual polarization- VV/VH).

Outline

✓ Study area

✓ Data

✓ Case study 1: SWE retrieval with COSMO-SkyMed in HIMAGE mode (HH polarization)

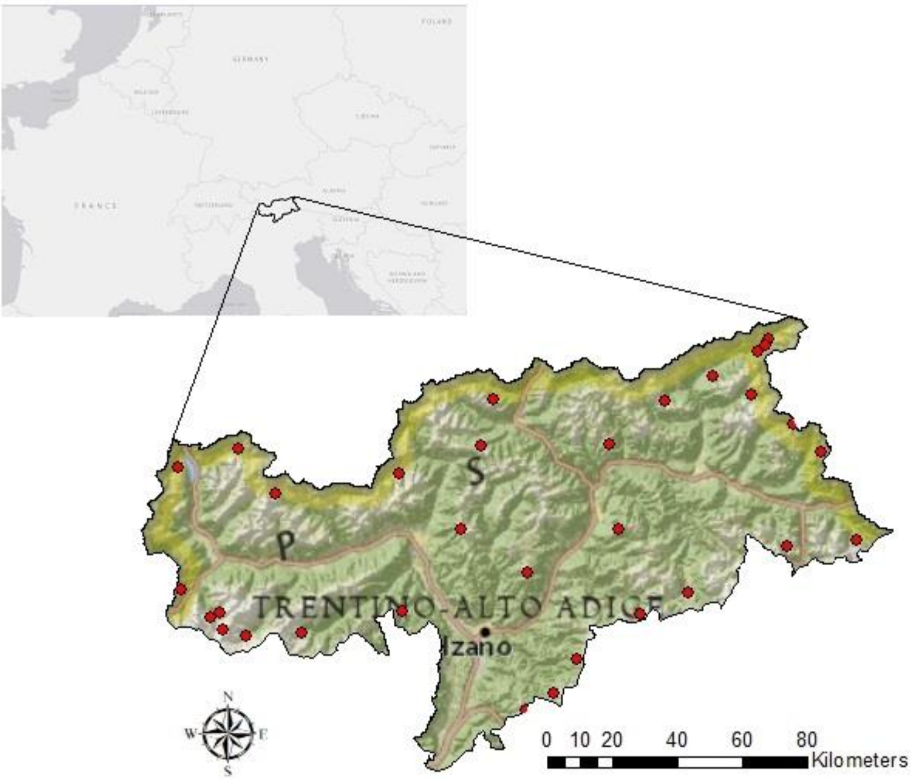
- Method
- Results
- Discussion and remarks

✓ Case study 2: use of COSMO-SkyMed in PINGPONG mode (dual polarization – VV/VH) → ongoing developments and future steps

- Increase of the dataset
- Verification of the “dry snow condition” assumption
- Multilayers snowpack structure in the simulations with e.m. model

Study area

The study area is the Alpine region of South Tyrol (~7,400 km²), in north-eastern Italy. The area is almost entirely mountainous and the altitude ranges between 200- and 3905-meters a. s. l. The wide altitude range implies a great variation in snow condition and snow cover duration in the period between November and May. The mountain ridges act as a natural obstacle on which larger-scale weather system can be deflected or modified.



Data

Ground data

Ground measurements of SWE in the first part, Test 1, and of snow depth (SD) in the second part, Test 2, are used as reference samples for SWE retrieval.

- SD daily from automatic station network
- SWE every 2 weeks, through manual measurements performed by the foresters and operators of the Avalanche Office of the Province of Bolzano. Through the average density (ρs) and the depth of the snowpack (SD) measures during the field campaigns, it is possible to estimate the SWE with the following formula:

$$SWE\ (mm) = \mathrm{SD} \cdot \rho s$$

Satellite data

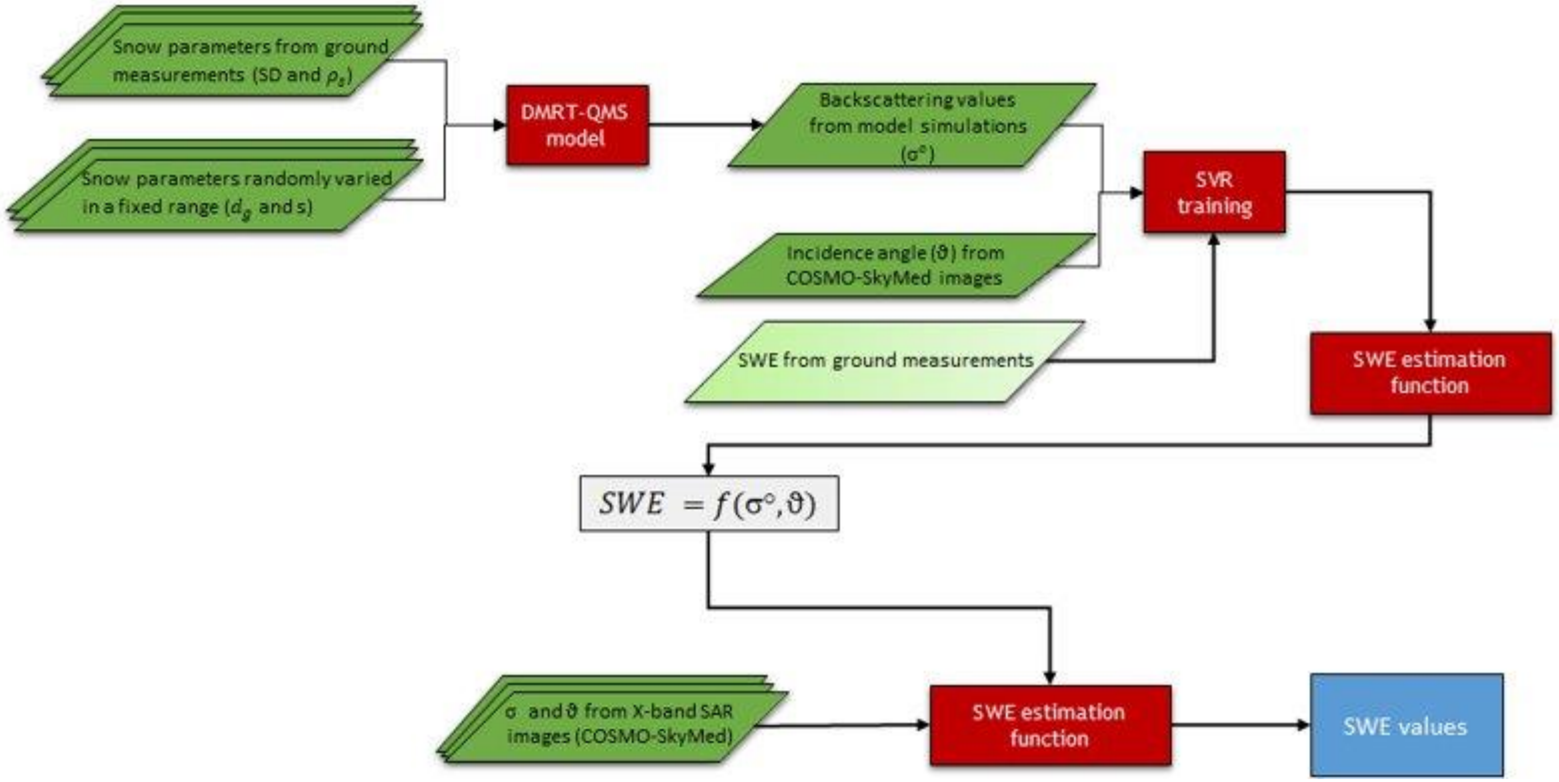
The satellite data used in this work involve the COSMO-SkyMed mission that consists of a constellation of four sun-synchronous, near-polar and low-Earth orbiting midsize satellites, each equipped with a multimode high-resolution SAR operating at the X-band (9.6 GHz frequency; 3.1 cm wavelength). The SAR instruments can be operated using different beam modes and we exploited the StripMap mode:

- HIMAGE: wide swath imaging , single polarization imaging mode with 40 km swath and 3 m ground resolution (Case study 1). In this study the images have been preprocessed to obtain a 20 m spatial resolution.
- PINGPONG: medium swath imaging, two radar polarization's selectable among HH, HV, VH and VV, a spatial resolution of 15 meters on a swath ≥30 km (Case study 2).

Case study 1: SWE retrieval with COSMO-SkyMed in HIMAGE mode (HH polarization)*

*This case study has been published in “De Gregorio, L., Cigna, F., Cuozzo, G., Jacob, A., Paloscia, S., Pettinato, S., Santi, E., Tapete, D., Bruzzone, L., and Notarnicola, C. (2019, October). SWE retrieval by exploiting COSMO-SkyMed X-band SAR imagery and ground data through a machine learning approach. In *Active and Passive Microwave Remote Sensing for Environmental Monitoring III* (Vol. 11154, p. 111540M). International Society for Optics and Photonics“

Method



(σ^0 indicates the backscattering value derived from model simulation, while σ and ϑ are the backscattering value and the incidence angle extracted by the satellite images, respectively.)

Step1: Simulation of backscattering coefficients with a model based on the Dense Media Radiative Transfer theory - Quasi-crystalline approximation Mie scattering of Sticky spheres (DMRT-QMS) [4] ⟶ generation of training dataset for the Support Vector Regressor (SVR) algorithm.

Step2: Training of the SVR by using simulated backscattering coefficients as input and SWE values from ground measurements as reference.

Step3: Testing of the SVR on observed data of backscattering (from COSMO-SkyMed images).

Results

The dataset composed of about 1000 samples obtained from the electromagnetic model simulations has been divided in a training dataset and a test dataset (used to verify that no overfitting episodes had occurred and to test the reliability of the model created):

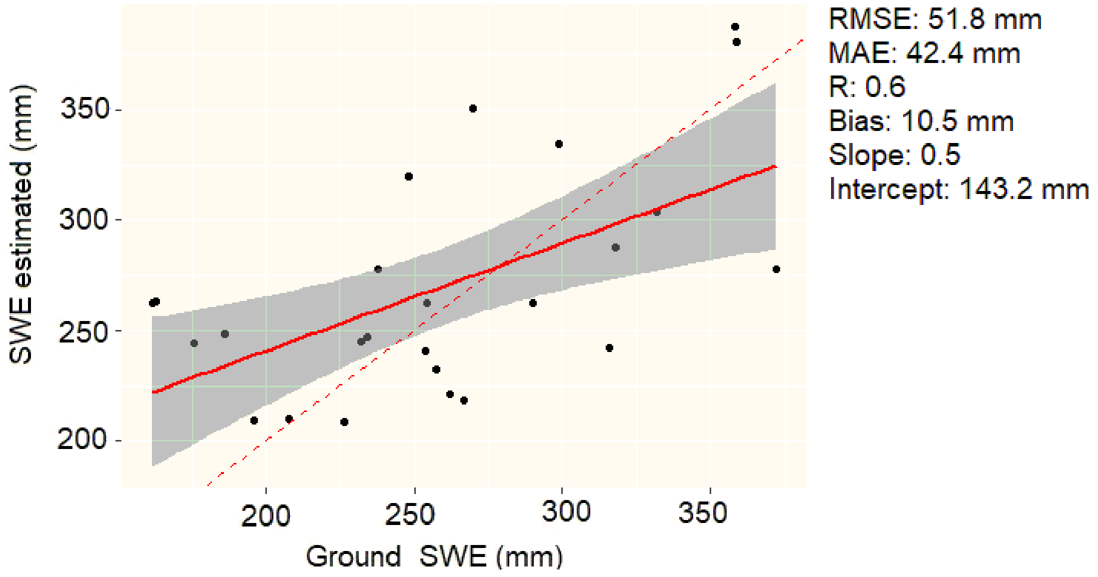
Training dataset= 70%, i.e. about 700 samples

Test dataset = 30%, i.e. about 300 samples

Dataset	RMSE (mm)	MAE (mm)	R	Bias (mm)
Training	61.2	49.1	0.5	0.8
Test	65.5	53.9	0.6	3.8

Then the regressor has been applied to the backscattering values extracted from the satellite images and corresponding ground measurements.
The performance are shown in the scatterplot, where the regression line is between estimated and measured SWE values. The dashed line represents the 1:1 line.

Results from the application on COSMO-SkyMed images



Discussion and remarks

The results obtained by applying the presented approach to the satellite images and by comparing the estimated and the measured SWE values are not completely satisfactory, by showing a correlation coefficient of only 0.6, a bias value of 10.5 mm and a slope and intercept value of the regression line of 0.5 and 143.2 mm, respectively.

Possible reasons for these performances and further aspects to investigate are:

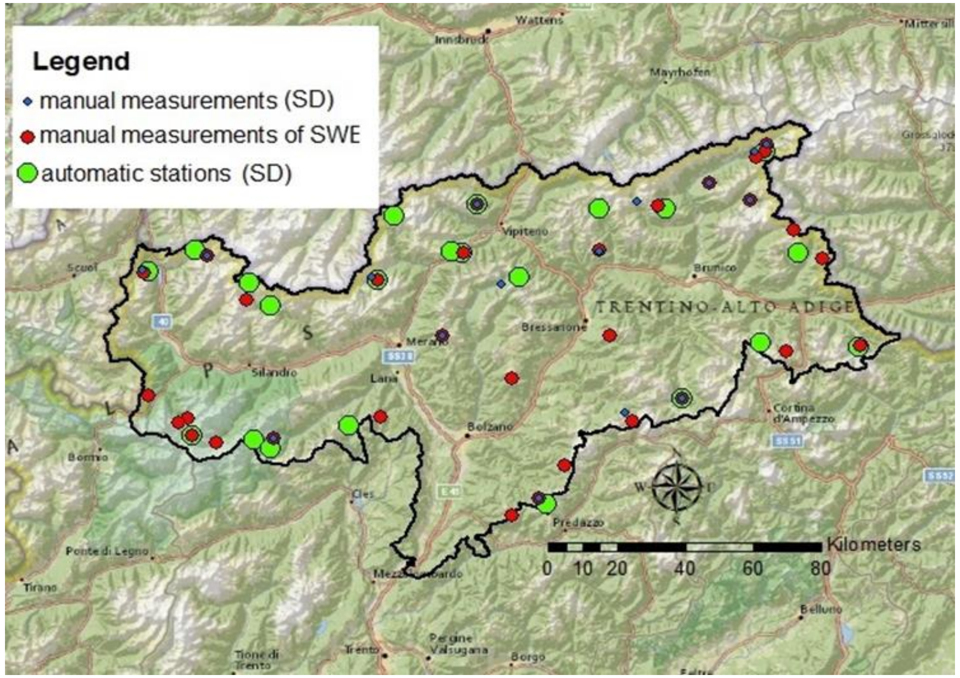
- The increase of the dataset through an increasing number of available ground measurements.
- The use of HH polarization images. To increase the sensitivity, dual polarization data should be considered, such as images in VV/VH polarization.
- The assumption at the basis of this work is that the snowpack is dry: the selected ground data, and the corresponding satellite images, have been collected in a typical dry period for alpine regions, i.e. in January and February. However, this assumption should be supported and verified.
- A possible improvement could be to consider the multilayer snowpack structure, by extracting the real snow grain diameters for each layer and using them for implementing the model and generating more realistic and representative backscattering coefficients to train the SVR

In the case study 2 we address these points by proposing solutions to improve SWE estimation!

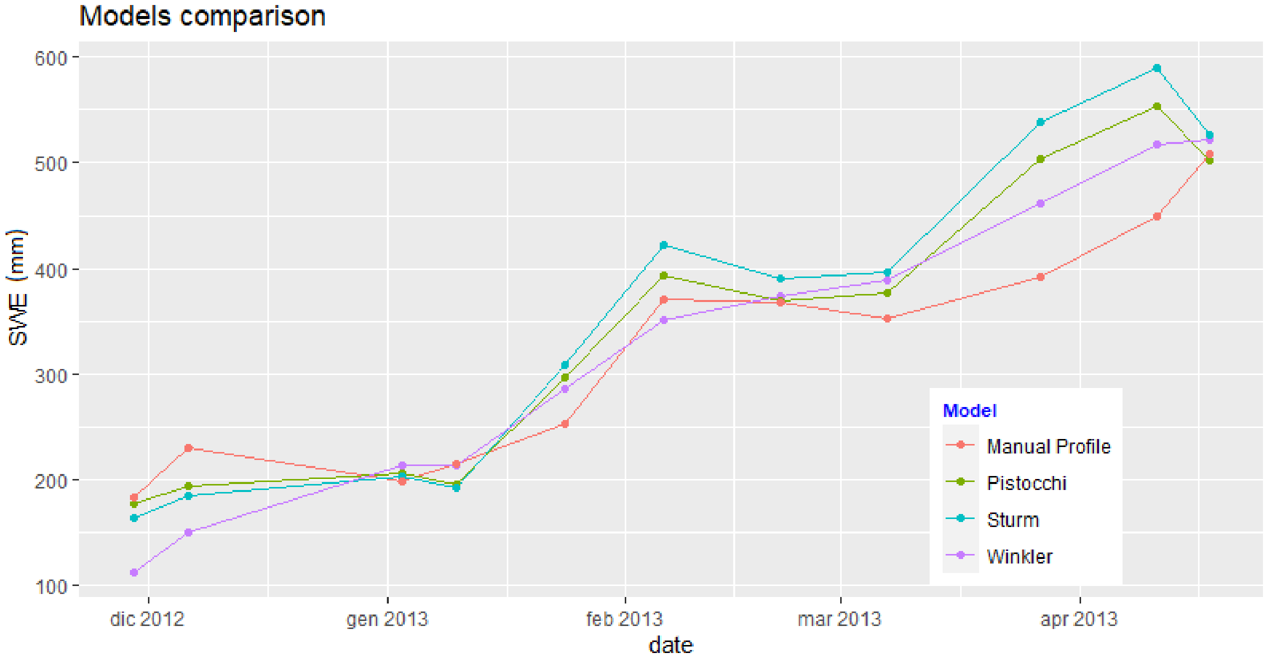
Case study 2: use of dual polarization data → ongoing developments and future steps

Ongoing developments - number of available ground measurements (1)

- To increase the number of available ground measurements, two solutions have been considered:
  - ➢ The exploitation of snow depth (SD) continuous measurements from automatic stations. These data are daily available and could be used as they are or to calculate the SWE using snow models.



Location of the manual measurement sites of SD and SWE (blue and red points, respectively) and of the automatic stations (green points) in the South Tyrol area. All these measurement sites are maintained by the Autonomous Province of Bolzano.

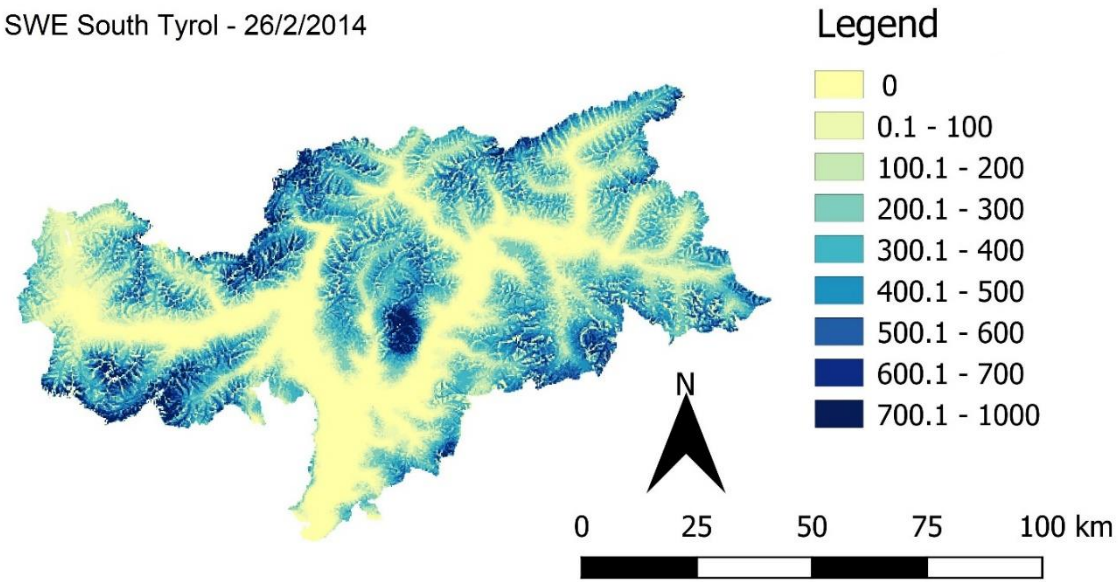


Example of SWE retrieval starting from the continuous time series of SD. Different snow models have been tested and then they have been compared with the available ground measurements-derived SWE values.

Ongoing developments - number of available ground measurements (2)

However, the number of SWE obtained by snow models is again spatially limited to the measurement sites and they do not cover the whole study area, by allowing a limited exploitation of the satellite images. The second approach, to obtain spatialized SWE values, is the following:

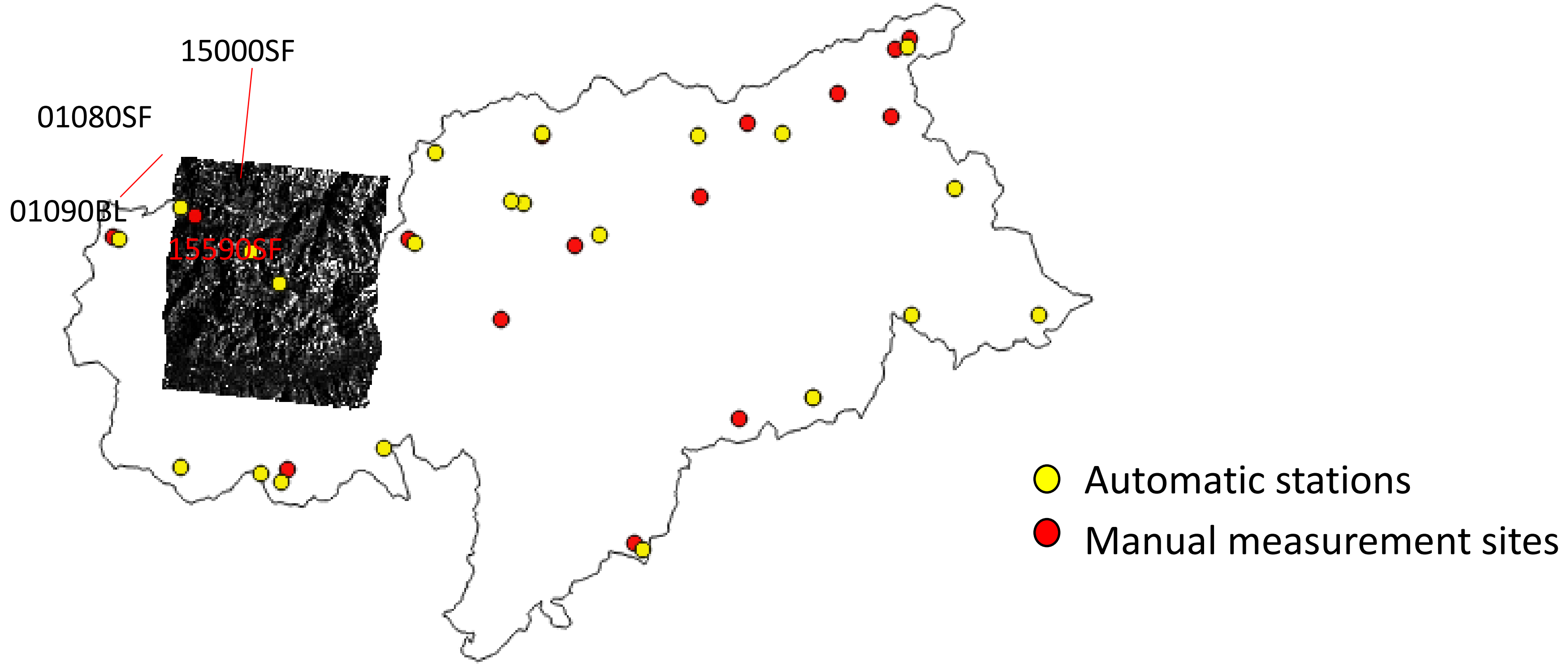
- The exploitation of the SWE maps as derived with the approach described in De Gregorio et al. [5], by correcting the snow model AMUNDSEN.



Example of a SWE map created by correcting the AMUNDSEN model [5].

Ongoing developments – dual polarization data

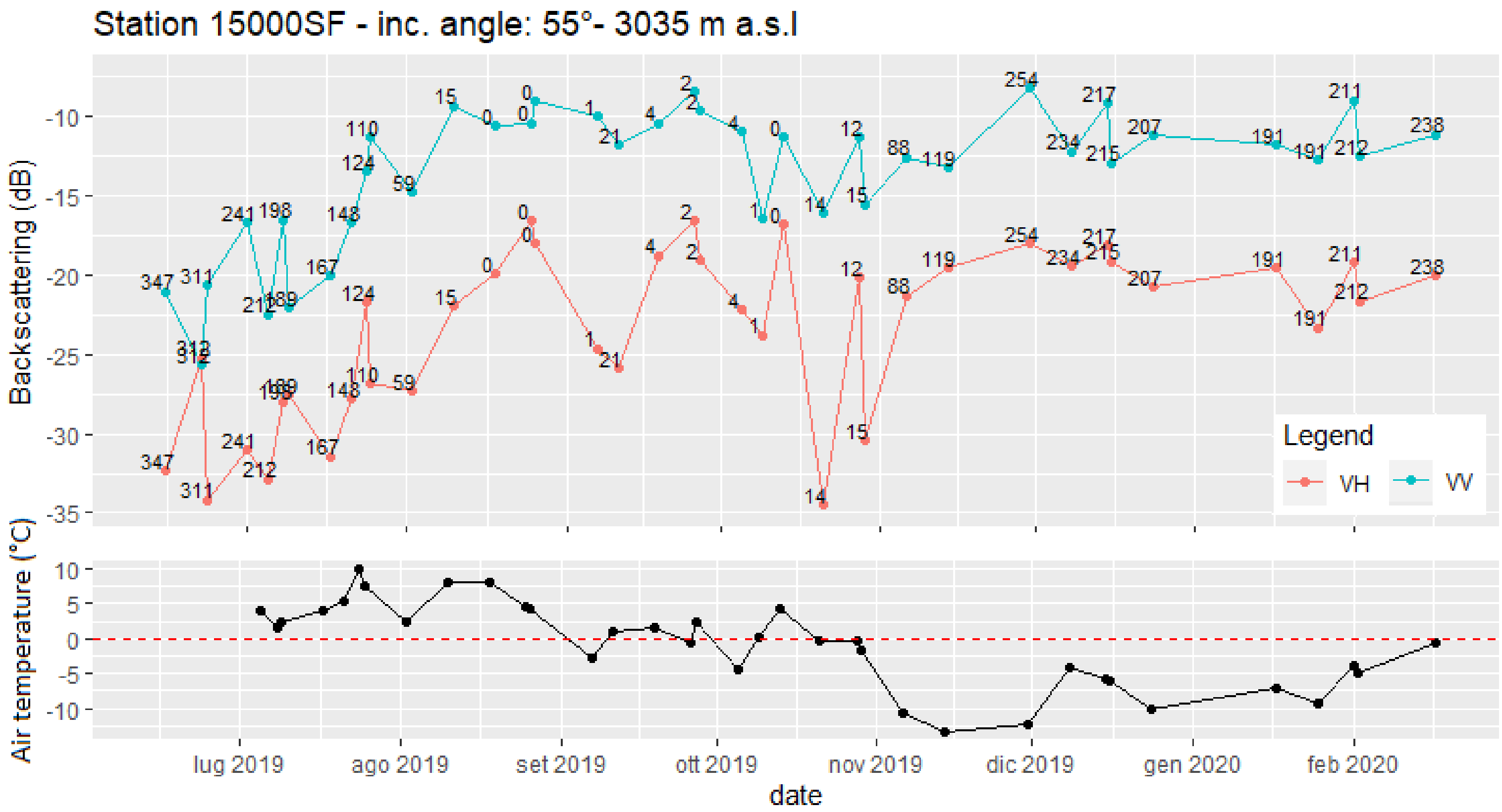
- Exploitation of COSMO-SkyMed constellation in StripMap PINGPONG (PP) mode (dual polarization- VV/VH) in the area of Val Senales – South Tyrol. The images have been preprocessed to obtain a 50 meters resolution. In the figure the area and both the automatic stations and the manual measurement sites are shown. The analysis was carried out by extracting the backscattering values from the satellite images at these measurement sites and considering all the images available from June 2019 until March 2020.



COSMO-SkyMed PingPong on 25/01/2020 (VH). The images include 3 automatic stations (yellow points) and 1 manual measurements site (red point).

Ongoing developments – dual polarization data: temporal analysis

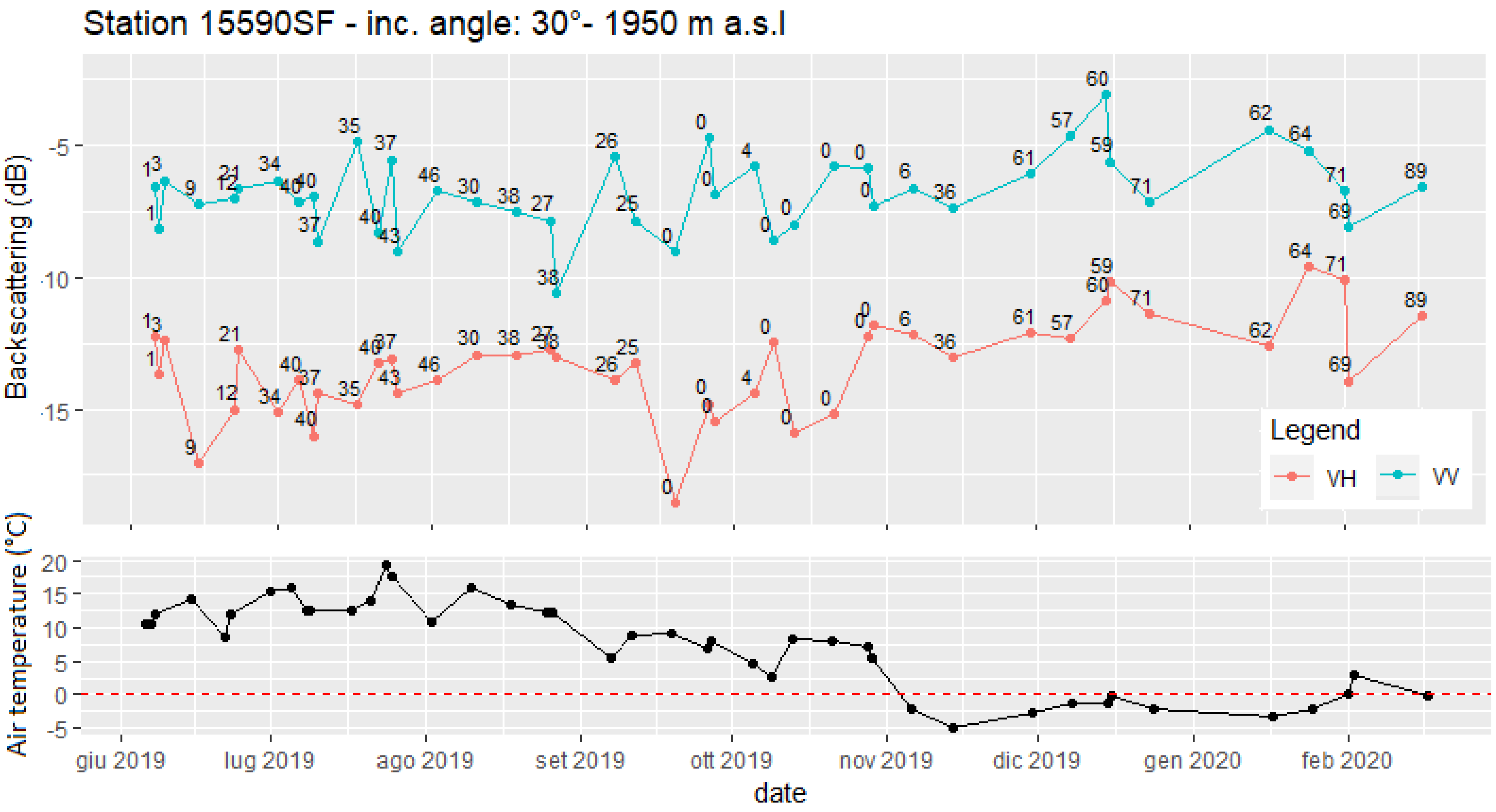
- The temporal behavior of the backscattering values extracted from PP images has been firstly analyzed in correspondence of both automatic and manual measurement sites. In this figure the behavior for the station 15000SF is shown. The high altitude of the station causes the presence of snow even at the beginning of summer season, as demonstrated by the high values of SD in June 2019. However, the air temperature in this period of the year is above the 0°C and this results in wet snow, as highlighted by the backscattering value, lower than in the case of snow free or dry snow conditions.



COSMO-SkyMed PingPong temporal analysis in correspondence of the automatic station 15000SF located at 3035 meters a.s.l.. The label shown for each point represent the SD recorded from the instrument in the station.

Ongoing developments – dual polarization data: temporal analysis

- The same analysis has been performed for the automatic station 15590SF, located at 1950 meters a.s.l. In this case the behavior is less pronounced than in the previous case, but you can still see an increase in backscattering values in the winter period when the snow is theoretically drier and when the air temperature is below 0°C (from mid-November).
- However, further analysis, including updated points in spring 2020, will be done to have a more consistent dataset and verify the behavior in presence of wet snow during the melting season.



COSMO-SkyMed PingPong temporal analysis in correspondence of the automatic station 15590SF located at 1950 meters a.s.l.. The label shown for each point represent the SD recorded from the instrument in the station.

Future steps

- *Discrimination between wet and dry snow* - The next step will involve the approach described in [6] and [7] to discriminate the wet from the dry snow. The method is based on the comparison of the backscattering coefficients of snow-covered areas with a *reference image* representing snow-free conditions.
- *Multilayer snowpack structure* - During the field campaigns, the operators collect several information regarding the single layers of the snowpack, such as the snow layer temperature, the snow density, the snow grain size and shape and so on. Further improvements could be made by providing all these information as input to the theoretical model in order to improve the performance and obtaining more realistic and reliable backscattering values used in the training phase of the regressor (see the method presented in Case study 1).

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Thank you for your attention

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