SWE retrieval in Alpine areas with high-resolution COSMO-SkyMed X-band SAR data using Artificial Neural Networks and Support Vector Regression techniques

Emanuele Santi(1), Simonetta Paloscia* (1), Simone Pettinato(1), Ludovica De Gregorio(2), Giovanni Cuozzo(2), Alexander Jacob(2), Claudia Notarnicola(2), Francesca Cigna(3), and Deodato Tapete(3)
(1) Institute of Applied Physics, National Research Council – CNR-IFAC, Florence 50019, Italy
(2) EURAC Research, viale Druso, 1-39100 Bolzano, Italy
(3) Italian Space Agency – ASI, Via del Politecnico s.n.c., 00133 Rome, Italy

Abstract

The potential of satellite Synthetic Aperture Radar (SAR) sensors for Snow Water Equivalent (SWE) retrieval in Alpine areas is assessed in this study. X-band HH-polarized SAR backscatter from 2012-2015 images acquired by the COSMO-SkyMed constellation over the South Tyrol province in northern Italy is compared with SWE in-situ measurements and nivo-meteorological station records. The resulting relationship is compared with simulations based on the Dense Media Radiative Transfer – Quasi Mie Scattering (DMRT – QMS) model. Artificial Neural Networks (ANN) and Support Vector Regression (SVR) machine learning techniques are trained and used for SWE retrieval from COSMO-SkyMed data. Good accuracy and small computational cost are observed for both ANN and SVR. The resulting SWE maps agree with snow conditions measured in-situ.

1 Introduction

Synthetic Aperture Radar (SAR) constellations nowadays provide long stacks of C- and X-band data consistently acquired over Alpine areas. However, signal penetration through the snowpack is high in dry snow and very low in wet snow, therefore the estimation of Snow Water Equivalent (SWE) is challenging. Recent research proved that while C-band does not allow the detection of snow cover, the use of X-band SAR imagery can support the estimation of snow physical parameters [1, 2].

The geographic focus of the experiments presented in this paper is the ~7,400 km^2 wide province of South Tyrol in northern Italy, where terrain elevation spans between 200 and over 3,900 m a.s.l. In this region, the snow season typically lasts from November to May, and snow parameters such as density, depth, wetness, temperature, radius size and shape, are regularly measured in-situ and at nivo-meteorological stations by the Avalanche Office of the Province of Bolzano. The area is covered by the nation-wide X-band SAR acquisition plan called MapItaly, a project aimed to provide a full interferometric mapping of the whole Italian territory with COSMO-SkyMed StripMap HIMAGE HH-polarized ascending and descending scenes (3 m resolution; 16 day revisit time) [3]. SAR imagery from this plan was used as input for the development and testing of two machine learning techniques for SWE retrieval, namely Support Vector Regression (SVR) and Artificial Neural Networks (ANN), both increasingly exploited in the field of remote sensing, e.g. [4,5]. The former are supervised nonparametric statistical learning models used for regression problems, while the latter are statistical minimum variance computing approaches inspired by biological neural networks and capable to represent input-output relationships.

This work is carried out in the framework of the collaborative research project ALGORITHMS (2019-2021) between the Italian Space Agency (ASI) and the Institute of Applied Physics of the National Research Council of Italy (IFAC-CNR), in collaboration with the Institute for Applied Remote Sensing of EURAC Research. The project aims to develop innovative algorithms to estimate geophysical parameters which feed into the hydrological cycle (e.g. soil moisture content, vegetation properties, snow depth and SWE) [6].

2 Results

Initial analysis of the sensitivity of the COSMO-SkyMed X-band HH-polarized SAR backscatter to SWE showed better correlation for satellite data acquired in ascending mode at dawn, than for data acquired in descending mode at dusk, due to a potentially wetter snowpack in the latter condition caused by surface snow melting occurred during the course of the day [7]. The sensitivity to dry snow was exploited by using an electromagnetic model based on the coupling of the Oh model and the Dense Medium Radiative Transfer theory under the Quasi-Crystalline Mie Scattering (DMRT-QMS) approximation [8]. The snowpack was considered as a single layer of identical scatterers, and the differences between modelled and measured backscatter as a function of the grain diameter (0-0.3 mm) and stickiness (0.1-0.4) were minimized. Frozen and unfrozen soil conditions were simulated, and the model showed capability to simulate excellently the experimental data in both conditions (Fig.1), with Pearson correlation coefficient R of nearly 1, root mean square error (RMSE) of 0.2 (frozen) and 0.4 (unfrozen) dB, and bias of -0.01 (frozen) and -0.06 (unfrozen) dB.

45 sets of COSMO-SkyMed backscatter, local incidence angle and SWE were used as the test set, while 4,500 sets from DMRT model simulations with pseudo random inputs mimicking the experimental data were used as the training set (Fig.2). The latter allowed the generation of a set of adequate size to robustly train the ANN and SVR.

The ANN was trained via back propagation learning, and its architecture and the transfer function employed were optimized. The "early stopping" rule was used for neural network regularization, and the tangent sigmoid (tansig) as activation transfer function. The SVR training was repeated 100 times, by resetting initial conditions, and the SVR returning the highest R was selected.

Fig.3 compares estimated and target SWE values from the ANN and SVR implementations, resulting in similar values of R of 0.8-0.9, RMSE of 85.6 (ANN) and 81 (SVR) mm, and bias of -3.6 (ANN) and 1.7 (SVR) mm. The SWE map resulting from the use of the ANN to estimate SWE based on the COSMO-SkyMed HH-polarized SAR scenes acquired on 17/01/2013 and the SWE values distribution are shown in Fig. 4. The results agree with the snow conditions at the date of the COSMO-SkyMed acquisition and with the available in-situ information, thus proving the promising performance of the ANN.

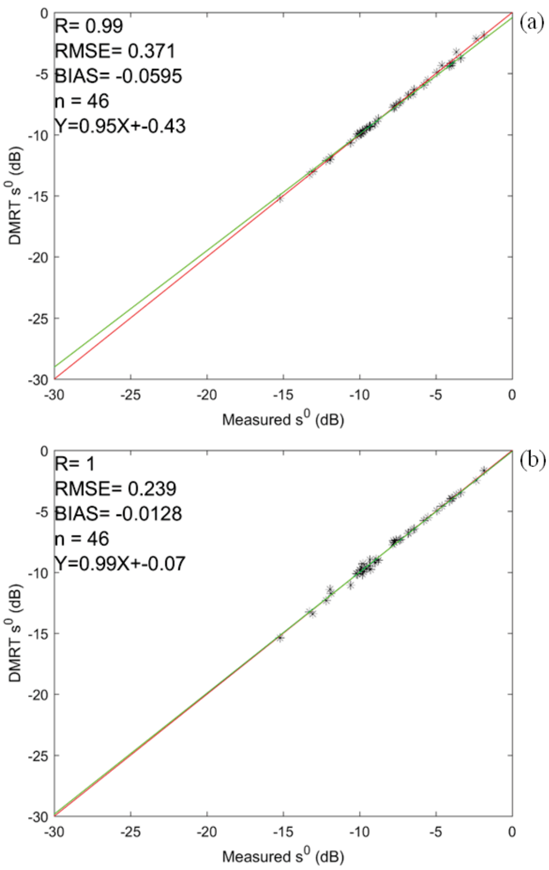

Figure 1. Comparison of modelled and measured COSMO-SkyMed X-band HH-polarized SAR backscatter for (a) unfrozen and (b) frozen soil.

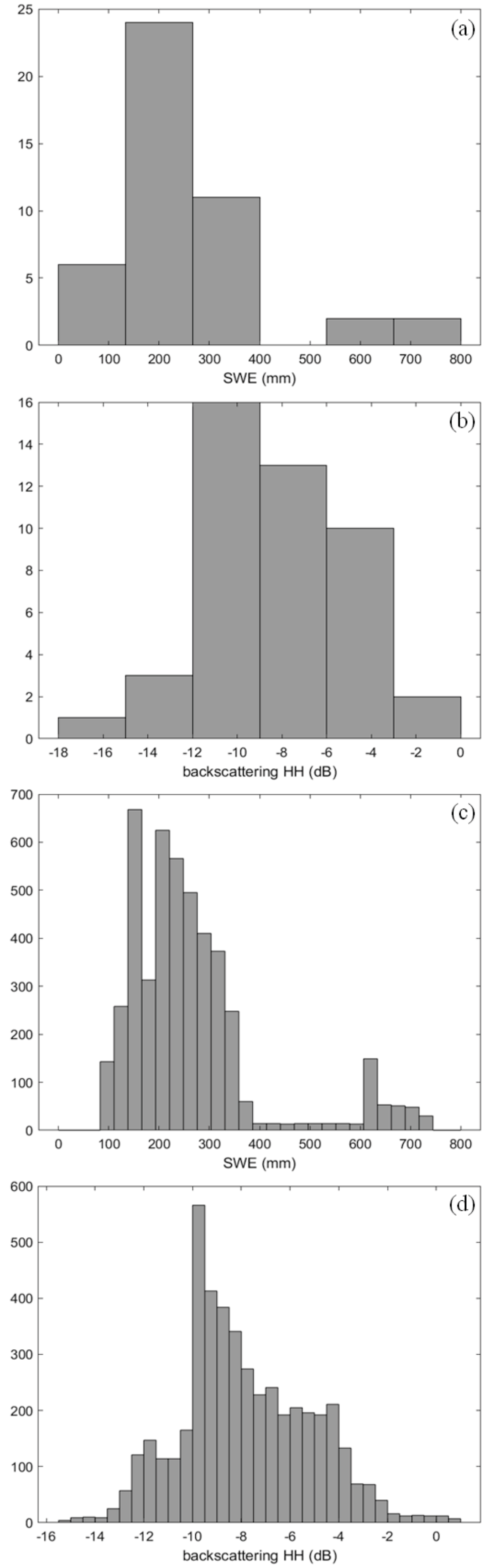

Figure 2. Distribution of measured (a) SWE and (b) COSMO-SkyMed HH-polarized SAR backscatter for the test set, and modelled (c) SWE and (d) backscatter in the training set.

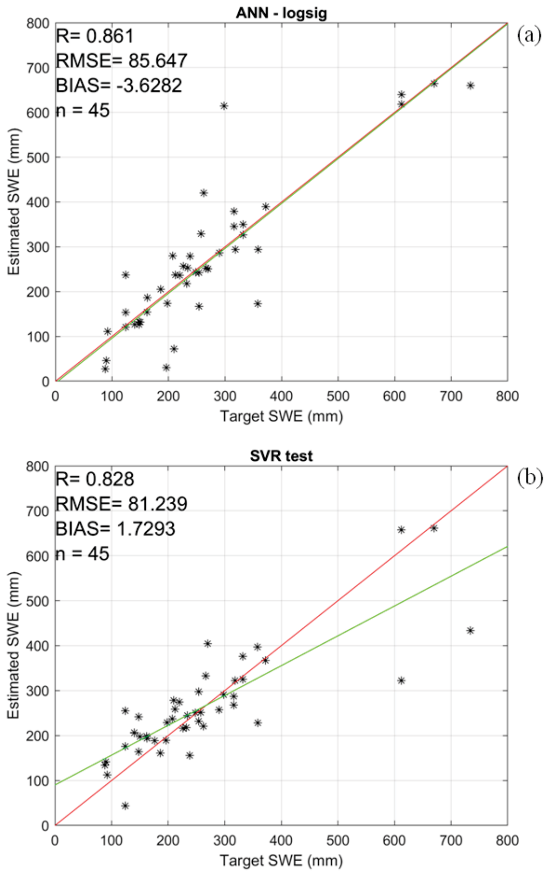

Figure 3. Comparison of SWE from in-situ measurements (target) and estimated SWE values using (a) ANN and (b) SVR with COSMO-SkyMed HH-polarized data.

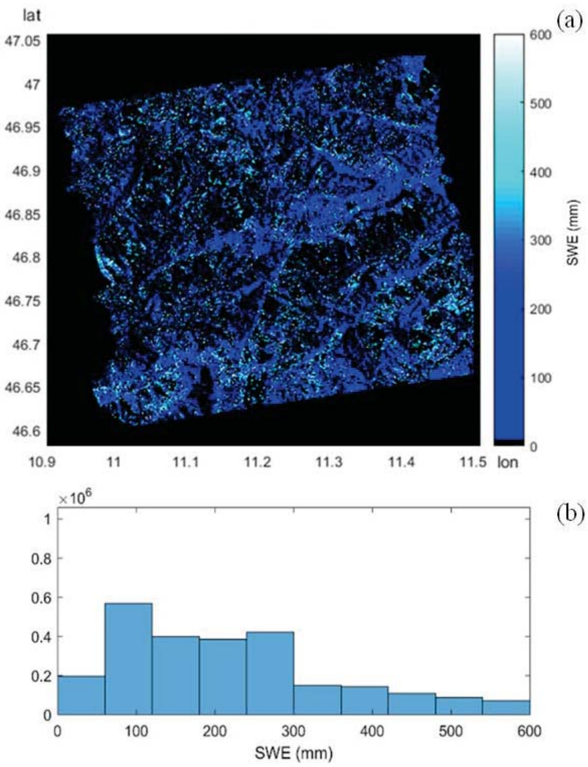

Figure 4. (a) SWE map based on ANN applied to COSMO-SkyMed HH-polarized image acquired on 17/01/2013, and (b) associated SWE distribution.

3 Conclusions

In this work, COSMO-SkyMed HH-polarized backscattering was compared with in-situ measurements of snow parameters in South Tyrol, to assess its sensitivity to SWE in dry snow conditions. The experimental relationships were validated by DMRT-QMS model simulations for frozen and unfrozen soil. SWE retrieval was attempted by using two machine learning methods, namely ANN and SVR trained by DMRT-QMS and tested on the experimental data. No significant differences between SVR and ANN were found in terms of both accuracy and computational cost. The latter was found fairly small, especially compared to that of DMRT-QMS modeling. The trained ANN and SVR algorithms were applied to the available COSMO-SkyMed scenes to generate SWE maps, which showed general agreement with snow conditions recorded in-situ.

Future work will focus on algorithm improvement and robust validation to ensure exportability to other Alpine areas. Moreover, additional tests will be carried out to train and assess the performance of the algorithms using dual-polarization HH/VV SAR data at 15 m resolution that are currently being acquired since May 2019 as part of a bespoke COSMO-SkyMed campaign in StripMap PingPong mode over the site of Val Senales in north-western South Tyrol [6].

4 Acknowledgements

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