Monitoring Snow Parameters in Boreal Forest Using Multi-Frequency SAR data

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Abstract

The northern hemisphere is characterized by the presence of boreal forest, a nearly continuous belt of coniferous trees across North America and Eurasia. This region is characterized by a subarctic and cold continental climate, showing severe winters and short summers. Precipitation varies, from about 20 cm of precipitation per year to over 200 cm and for the higher percentage is in the form of snow. Recent studies, which were carried out within the framework of ESA's CoReH2O Phase-A mission, demonstrate that multi-frequency SAR data are able to quantify the amount of snow mass (SWE) on land or glaciers. On the other-hand the presence of forest has a significant impact on the propagation of the radar signal, depending on its structure, biomass, water content and cover fraction. In particular for dense forest scattering of vegetation strongly hides the signal from snow and, consequently, compromises the sensitivity to snow parameters. A method to compensate the vegetation effect and then to retrieve snow in forested areas is presented here. The method is based on the development of an e.m. model for a snow-covered vegetated terrain and the availability of some ancillary data about forest characteristics. An example of the SWE retrieval is provided using SAR airborne data collected over a boreal test site in Finland.

1. Introduction

In preparation for the CoReH2O satellite mission, one of the three missions were selected for Phase-A within the Earth Explorer Programme of the ESA, experimental and theoretical studies were conducted in order to improve methods for the retrieval of snow physical properties from SAR data [1]. The principal objective of the CoReH2O mission was to carry out the frequent spatially-detailed measurements of snow and ice in order to advance our knowledge and prediction of the water cycle in cold regions. The sensor proposed was a dual frequency SAR, operating at Ku-band (17.2 GHz) and X-band (9.6 GHz), VV and VH polarizations. The principal products expected from the mission were the snow water equivalent (SWE) and the snow accumulation on glaciers. It was expected that the product was delivered at a global scale and, in the development of a retrieval algorithm able to derive SWE from SAR measurements, particular attention was devoted to boreal forested areas which occupy a large portion of the northern hemisphere. In fact, the presence of vegetation has a significant impact on the propagation of the radar signal, depending on its structure, biomass, water content and cover fraction. In particular for dense forest scattering of vegetation strongly hides the signal from snow and, consequently, compromises the sensitivity to snow parameters [2]. In particular a method to compensate the vegetation effect and then to retrieve snow in forested areas was developed. The method is based on the possibility to separate the scattering contribution from soil and vegetation from the data itself with the additional information of ancillary data, and using it for the vegetation correction. The proposed method was tested using airborne SAR data were collected in Finland.

2 The retrieval algorithm

During the CoReH2O study a processing line for retrieval of the Level-2 parameters was developed and implemented [3] staring from Level-1 data. The first step (after geocoding and atmospheric correction) relies in the segmentation of SAR image into classes for further processing (dry snow on land, glaciers) and into areas (dense forest, wet snow) where retrieval of SWE cannot be performed. The segmentation is based on auxiliary data (land cover maps) and on measured backscatter data in the four channels, applying change detection technique. For retrieval of SWE a constrained minimization approach is applied, matching forward computed and measured backscatter values. Iteration is performed for two free parameters, SWE and effective grain radius, RE, using the following cost function:

$$F = \sum_{i=1}^{4} \frac{1}{2\,\mathrm{var}_i} \left[\Phi_i\left(x_1, x_2; c_1, \ldots, c_r\right) - \sigma_i^0 \right]^2 + \sum_{j=1}^{2} \frac{1}{2\lambda_j^2} \left(x_j - x'_j \right)^2 \qquad (1)$$

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The index i refers to the measurement channel (KuVV, KuVH, XVV, XVH). x_1,x_2 are the free model parameters (SWE, RE). $c_1,\ldots,c_i$ are configuration parameters: snow density, snow temperature, rms-height of air/snow interface. σ^0_i are the measured backscatter coefficients, and var_i is the measurement noise. The second sum represents the regularization functional, based on a-priori information of the two free parameters (SWE, R_E) with the mean value x'_j and standard deviation λ_j. Besides the configuration parameters of the snowpack, an estimate of the backscatter signal of the ground below the snow pack, σ_G, is needed as input to the forward model Φ. σ_G is obtained from backscatter data of the pre-snowfall period. In case of forested area the presence of vegetation is included in the forward model, and related to the total backscattering as follows:

$$\sigma^\circ_{tot\text{-}pq} = C_f\,(\sigma^\circ_{tot\text{-}veg\text{-}pq} + \sigma^\circ_{snow\text{-}pq}\,L) + (1-C_f)\,((1-C_s)\,\sigma^\circ_{snow\text{-}pq} + C_s\,\sigma^\circ_{snow\text{-}pq}\,L) \qquad (2)$$

where: $\sigma^{o}_{snow\text{-}pq}$ = direct scattering from snow-covered terrain, $\sigma^{o}_{tot\text{-}veg\text{-}pq}$ = direct scattering from vegetation, L=two ways attenuation factor, C_f = percentage of pixel covered by vegetation and C_s = area shaded by the canopy [2]. Vegetation correction follows through to the estimation of the volume scattering from the canopy $\sigma^\circ_{tot\text{-}veg\text{-}pq}$ and its transmissivity L. An innovative technique was recently studied and implemented for the estimation of $\sigma^\circ_{tot\text{-}veg\text{-}pq}$ and for the monitoring of the direct contribute from soil $\sigma^{o}_{snow\text{-}pq}$ during the pre-snowfall season starting from SAR data. The procedure starts with a degradation of the resolution and on the fact that, because we analyze a sparse forested area, in the low resolution pixel is possible to find not-vegetated high resolution pixels. Because of the capability to infer information to the image itself, the proposed procedure can be applicable at global scale to any specie of low density forest, and doesn't need a-priori information on the canopy structure or soil characteristics. Accurate auxiliary data on the canopy cover and the tree height are needed to provide a better vegetation correction and reliable retrieval results.

3. Experimental data

3.1 SAR data

In order to test the CoReH2O SWE retrieval algorithm, a multi-frequency airborne SAR sensor (SnowSar), was developed. SnowSAR instrument consists of a dual-frequency, dual polarization X- and Ku-band mini-SAR airborne system, left side looking with a swath width of about 400m. Two campaigns were successfully performed in 2010-11 and 2011-12 winter seasons in Sodankylä, Finland. The purpose of the campaign was to provide a continuous time series of SAR observations of snow cover in a representative location of the arctic boreal forest area, covering the whole winter seasons. The outline of the campaign aims at repeated measurements over the chosen test site at regular intervals, matching closely the 15 day repeat pass period of CoReH2O. The flight lines and data acquisitions are designed so that these cover the most common land cover types typical for the Northern Boreal Forest region. Flight trajectories have been designed taking into account as direction of observation the descending path, right looking TerraSAR X acquisition mode, resulting into 25 SSW-NNE (14°) flight lines, 8 Km long, 400 m apart and allowing to reconstruct an image of the entire study area.

3.1 The Test Site

The study area is located in Sodankyla (67.4N, 26.6 E) in Northern Finland. It's a typical low-relief northern boreal forest area with pine as a dominant tree type. It's worth noticing that forests are characterized by sparsely distributed trees and low aboveground biomass (i.e. lower than 200 m^3/ha), thus the possibility to correct the effect of vegetation and to retrieve the snow parameters. Moreover, because of the abundance of ground data (e.g. tree height, meteo data, stem volume, snow depth) this site is suitable for an accurate algorithm's validation. Forestry data were provided by the Finnish Environment Institute (SYKE) through the Corine 2000 survey. The produced forestry information consists of data in raster format, including canopy cover of trees (%) and the trees average height (m). Snow measurements were routinely carried out during the winter period. Manual snow course observations monitor the distribution of snow depth and density at fixed locations. The longest course covers a track of 4 km; 80 samples of snow depth and 8 samples of density (SWE) are measured twice a month from the course. The course track covers the main land cover types typical for the area (boreal coniferous forest on mineral soil of varying density and peatbogs), enabling the establishment of statistical relations of snow characteristics depending on land cover.

4. Results

Starting from a set of σ^0 SnowSAR acquisitions (i.e. geocoded and geo-referenced) the developed algorithm was validated using ground truths data. The original 2m resolution was resampled to 100m to have a more accurate estimation of

soil and vegetation components and achieve the forward model requirements of homogeneity. Moreover, model simulations and data analysis prove that in case of forested areas, the sensitivity to SWE disappears at both X and Ku bands and VV-VH polarizations for biomass greater (of more) than 150 m^3/ha and CF of more than 0.3-0.4 [2]. Segmentation is applied to select areas which fulfill this condition and to exclude denser forests from the retrieval. The retrieval is computed as specified in section 2 including the module for the vegetation correction. Examples of retrieved SWE values are presented in Figure 1 which shows a map of SWE (mm) for the SnowSAR acquisition of 26/2/2012 in a heterogeneous strip in the observed area. Results highlight the different snow accumulation in open land rather than in sparsely forested areas, while the denser forest is masked out. SWE retrieved values are then validated using in situ measurements for the same date, see Figure 2. Retrieved values are in a good agreement with ground truth and respect the CoReH2O requirements.

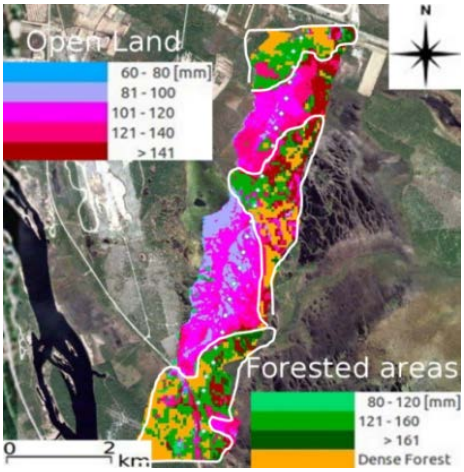

Figure 1: Retrieved values of SWE (mm) for a SnowSAR acquisition on 26/2/2012 in the nearby of Sodankvla.

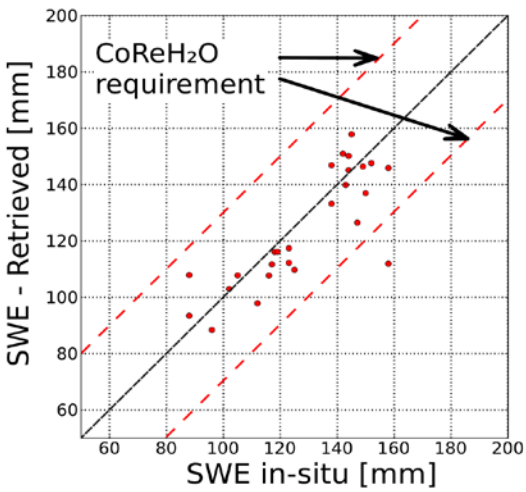

Figure 2: SWE retrieved as a function of SWE measured (mm).

5. Conclusions

With the purpose of investigating on the capability of SWE retrieval developed during Phase-A of the CoReH2O mission in vegetated areas, an innovative procedure for the retrieval of SWE in presence of sparse forests was developed and validated using ground truth.For retrieval of SWE a constrained minimization approach is applied, matching forward computed and measured backscatter values. In presence of forested area the vegetation is included in the forward model and estimated using an iterative method. The method is able to decompose the backscattering of a forested area in soil and vegetation contributions and then follow the evolution of them during the season. Moreover, the proposed approach is capable to infer information on vegetation scattering contribution from the data itself and thus it is not related to a semi-empirical model or a priori information on the forest structure. It's worth noting that the retrieval of SWE is possible in sparse forest, where the sensitivity to SWE still exist dealing with cover fraction lower than 35-40%. Instead, for denser forest the applicability of this method is questionable. Examples of SWE retrieval were computed using the SnowSAR data were acquired on the test site of Sodankyla. Results pointed out the possibility to retrieve SWE on sparsely forested areas, the values are in a good agreement with the ground truth and respect the CoReH2O requirements.

6. References

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