Effects of Vegetation on the Retrieval of Snow Parameters from Backscattering Measurements at the X- and Ku-Bands

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Abstract

In preparation of the satellite mission CoReH2O, one of the six missions which has been selected for scientific and technical feasibility studies within the Earth Explorer Programme of the European Space Agency, experimental and theoretical studies started in order to investigate backscatter properties and improve the methods for retrieval of snow physical properties from SAR data. The aim of this paper is to investigate the impact of vegetation in the retrieval of snow parameters from backscattering measurements at the X- and Ku-bands. First the key vegetation types found in snow covered regions were identified on the basis of available global scale data base. A model able to simulating scattering from a vegetated snow-covered terrain was then developed and implemented. Lastly, a sensitivity analysis to vegetation parameters was conducted on sparse vegetation and coniferous forest.

1. Introduction

For quantifying the interactions between the major components of the Earth system, namely the atmosphere, the hydrosphere, the cryosphere, the land surfaces and the biosphere, and for assessing anthropogenic impacts on climate and ecosystems, it is necessary to develop realistic models and parameterisation schemes for the main sub-systems and processes. These models are also essential for assessing the present availability and expected climate-induced changes of vital resources such as fresh water. Though understanding of climatic and environmental processes has advanced during the last years, there is still significant need for more complete characterization of dominant processes and feedbacks. Both IGOS Cryosphere [1] and the IGOS/Water Cycle [2] reports have stressed the importance to fill the large gaps in present observations of snow and ice masses and in the treatment of cryospheric processes in climate models.

The satellite mission COld REgions Hydrology High-resolution Observatory (CoReH2O) is one of the six missions which has been selected for scientific and technical feasibility studies within the Earth Explorer Programme of the European Space Agency. The mission aims at closing major gaps in present snow and ice observations. The focus of the mission is on spatially detailed repeat measurements of snow and ice properties in order to advance the understanding of the role of the cryosphere in the climate system and to improve the knowledge and prediction of water cycle variability and changes. CoReH2O will provide spatially detailed observations of extent, water equivalent and melting state of the seasonal snow cover, of snow accumulation and diagenetic facies on glaciers, of permafrost features, and of sea ice properties with emphasis on new ice formation and snow burden. Two different observation phases are proposed for the mission. For the first two years a three day repeat cycle with limited spatial coverage is suggested, in order to match the time scale of meteorological forcing, particularly addressing cryosphere-atmosphere exchange and the parameterization of snow and ice processes. The second mission phase shall provide near complete observations of the global cryosphere at about 15 day repeat cycle. As sensor a dual frequency SAR is proposed, operating at X-band (9.6 GHz) and Ku-band (17.2 GHz), VV and VH polarizations, with a swath width of about 100 km. Ku-band is more sensitive to shallow snow, whereas X-band provides greater penetration for sensing deeper snow. In preparation of this mission experimental and theoretical studies started in order to investigate backscatter signatures in dependence of target properties and improve the methods for retrieval of snow physical properties from SAR data.

The aim of this paper is to investigate the impact of vegetation on the retrieval of snow parameters from backscattering measurements at the X- and Ku-bands.

2. The Vegetation Model

The identification of key vegetation types found, on a global scale, in snow covered regions is fundamental for the development of the algorithm for the retrieval of snow properties on vegetated area. Various projects, promoted by national and international organizations, have been aimed at developing methods and maps for the classification of vegetation at global and regional scales. A summary of the on-line vegetation and plant distribution maps can be found in http://www.lib.berkeley.edu/EART/vegmaps.html. Among these models we selected the ECOCLIMAP [3] data-base 0 for our analysis. The advantages of this data set is that it provides land classification of the Earth at a very high spatial resolution (1 Km) and that it is accessible (e.g. software and data are free of charge distributed) and relatively easy to use. Maps of different types of vegetation were produced and analyzed. Computations were then performed on an area between latitude of 40° and 88° which was the area containing the largest parts of the cryosphere of the globe and was therefore most interesting for the CoReH2O mission. From the analysis we could conclude that, for about 40 % of the interested area, the effect of vegetation in the retrieval of snow parameters can be ignored. Furthermore, herbaceous vegetation, which covers a large part of the remaining area (around 54%), and coniferous forests are the most interesting vegetation types and their effect on σ^0 will have to be considered in the definition of the retrieval algorithms of snow parameters that will be developed for the COREH2O mission. The model analysis focuses mainly on the effect of these vegetation types.

In order to simulate the scattering from a vegetated snow-covered terrain we need to combine a model for a snow-covered terrain with a model for vegetation. Among the possible models a model similar to MIMICS [4], which was originally developed at IFAC for the simulation of agricultural crops and then modified for forest vegetation, was selected. The main advantages of this model are that it can be combined with the snow model that was developed and tested within the CoReH2O activities and which was used to investigate on sensitivities to snow parameters at X and Ku band. The model was developed for the simulation of both agricultural and forest vegetation and inputs are related to measurable vegetation parameters.

The scattering from snow was computed by a single layer DMRT model, which considers snow parameters (grain size and shape, snow depth and density) as inputs. The total backscatter is composed of the individual scattering contributions at the air/snow interface, snow/ground interface (attenuated by the snow pack), snow volume, and snow/ground and ground/snow interactions. For the medium below the homogeneous half space (e.g frozen or unfrozen soil) is assumed, whose backscattering contribution can be modelled by surface scattering. The snow volume is modelled as a dense medium of ellipsoidal or cylindrical ice particles characterized by an effective grain size. The surface soil scattering was computed by the AIEM model.

In the vegetation model, the canopy is divided into a certain number of horizontal layers over a snow-covered terrain. Each layer contains different groups of scatterers, and each group is assumed to be composed of identical scatterers that are uniformly distributed in the azimuth direction and with a certain density (number of elements m^3). Moreover, the scatterers are randomly oriented in elevation, with a distribution described by their probability density function. The number of layers, as well as the thickness of each layer, depends on the vegetation type. For example, agricultural vegetation can be represented as a single layer, while two or three layers are used for forest. The scatterers are then characterized, as extinction and scattering properties, as a function of shape and size using different approaches. Moreover the scattering was computed for both close and sparse canopies. In this last case (e.g. the case of boreal forest) the cover fraction factor is introduced and total contribution was represented as a sum of forested area, snow area and the interaction between the forest-free area and the forested area.

Due to the lack of contemporaneous acquisitions of SAR and ground data (of both snow and vegetation) the validation at Ku and X band of the complete model (snow+vegetation) so far has been unfeasible. Nevertheless the model was validated at C-band by using the data set presented in recent papers. Further validation is planned with coincident Ku and X band backscatter data sets that have been acquired during field experiments in the Alps and in Alaska in winter 2007/08.

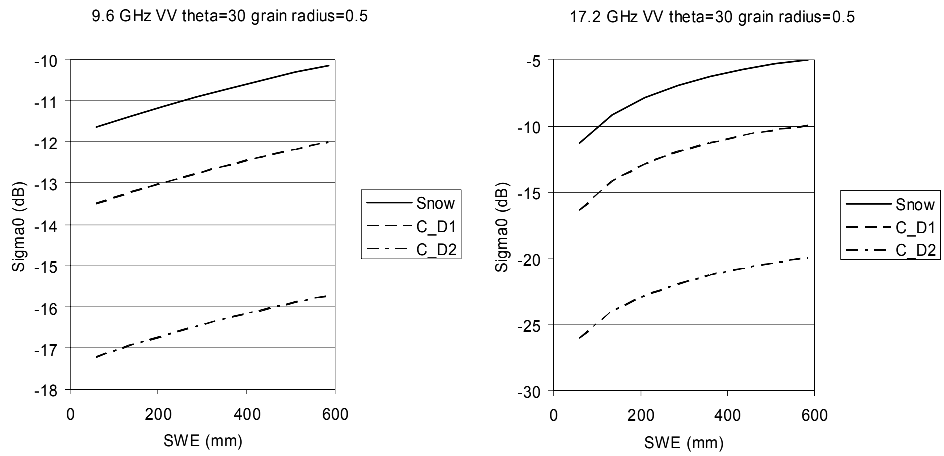

Figure 1. Simulated backscattering coefficient at 9.6 (left) and 17.2 (right) GHz at VV polarization, Incidence Angle 30°, as a function of SWE. Continuous line = snow, Dashed line = snow + vegetation (density 1); Dotted –Dashed line = snow + vegetation (density 2).

The sensitivity analysis to vegetation parameters was conducted on both sparse vegetation (shrubs or natural herbaceous) and coniferous forest. For these crop types the backscattering coefficient was simulated at the CoReH2O configuration: frequencies 9.6 and 17.2 GHz, polarization VV and HV, incidence angle between 30 and 40 degrees. The ground under the vegetation was assumed to be covered with dry snow having a SWE value between 20 and 200 mm. The simulations were conducted for two to three different grain sizes and two different soil roughness. As an example of herbaceous vegetation the backscattering as a function of SWE for two density canopy values (1000 and 3000 n/m^3 respectively, that corresponds to a biomass value of 28 m^3/ha and 84 m^3/ha) is represented in Figure 1. The snow was dry, with a grain diameter of 0.5 mm and a volume fraction of 0.3. From the figure we can observe that, at both frequencies and polarizations, the presence of vegetation attenuated the backscattering signal. The attenuation increased when the vegetation density increased and was higher at 17.2 GHz than at 9.2 GHz and at VV than at HV polarization. This last effect was due to the fact that the vegetation was simulated as vertical cylinders. For the same reason, and as expected, the results obtained at HH polarization showed a lower attenuation of the σ^0. The investigation on coniferous forest was conducted on Black spruce, which is typical of subarctic areas, using the geometrical and biophysical properties described in [5] as input for electromagnetic model. Starting from this description and using allometric equations other examples of forest (of the same specie), that had a different forest biomass in the 50 – 250 m^3/ha range, were realized. Moreover the cover fraction effect was also considered. The sensitivity to woody volume, in snow- free conditions, in the 0 – 250 m^3/ha range was firstly simulated. The results obtained at an incidence angle of 30°, shows that, at both frequencies and at all polarizations, the σ^0 rapidly increased when woody volume increased from 0 to 100-150 m^3/ha. After this value, the signal exhibited a fairly flat trend. The increase was higher at HH than VV polarization and at 17.2 GHz than at 9.6 GHz. Snow was then introduced in the model as a uniform single layer above ground. An analysis of sensitivity to snow parameters was carried out that showed the σ^0, at an incidence angle of 30°, as a function of SWE for two woody volume values (60 m^3/ha and 110 m^3/ha respectively) (Figure 2). In the figure the backscattering of non vegetated terrain, using the same snow conditions is also represented as a reference. The cover fraction is 100% (closed canopy). The figure shows that the presence of vegetation results in a different contribution to snow signature, depending on the SWE value. For example, at a low SWE value (lower than 100-150 mm) the σ^0 for vegetated terrain was in general higher than for non-vegetated terrain; when SWE increased the signal could be higher or lower than non-vegetated terrain, depending on polarization, frequency and vegetation woody volume (e.g. it was higher at 9.6GHz at HH and HV and lower at VV). This variability strongly depended on the input parameters that we used in the snow model and then on the complex scattering mechanisms between snow and vegetation, such as the attenuation of snow signal from vegetation and contributions of volume scattering from vegetation. Among the snow parameters, grains size had the strongest impact on σ^0 signature. Other tests were performed as a function of snow grains size, soil roughness, vegetation parameters and cover fraction.

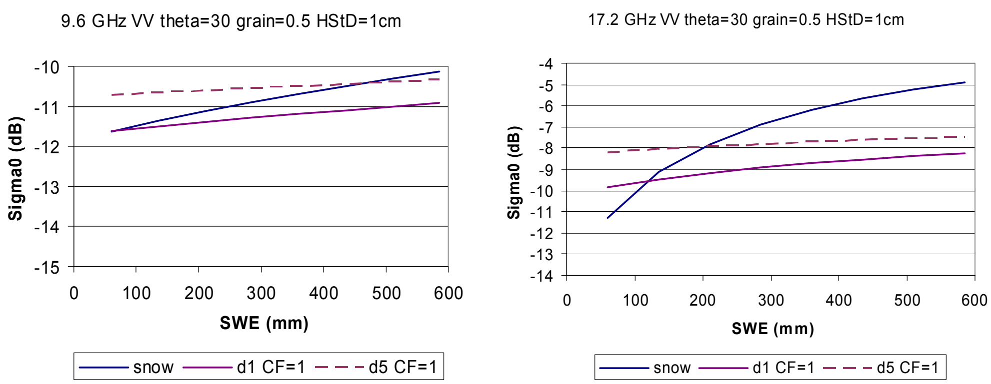

Figure 2. Simulated backscattering coefficient of forest canopy and snow as a function of SWE at 9.6 (left) and 17.2 (right) GHz at VV polarization, incidence angle 30°. Blue line = snow (non vegetated); Solid purple line = Forest woody volume 1; Dashed purple line = Forest woody volume 2.

3. Conclusions

The paper evaluates the impact of vegetation on the retrieval of snow parameters from backscattering measurements at the X- and Ku-bands. A radiative transfer model, able to represent the scattering from snow covered vegetated terrain was developed and validated. The sensitivity analysis was conducted for two vegetation types: homogenous vegetation and coniferous forests. The analysis conducted on herbaceous vegetation confirmed that the presence of sparse vegetation attenuates the σ^0 of snow but does not affect the sensitivity to SWE. Nevertheless, since the influence of vegetation on the σ^0 of snow signature can be very high, the knowledge of vegetation type is fundamental in order to correctly retrieve snow properties from SAR data. As expected the attenuation is higher at 17.2 GHz than 9.6 GHz and at an incidence angle of 40° than at 30°. The results obtained for coniferous forest demonstrated that for relative low woody volume value (<= 110 m^3/ha) σ^0 of vegetated snow-covered areas was influenced by the snow and soil properties (grain size, SWE, soil roughness, etc.). Among the snow parameters, grain size had the strongest impact on σ^0 signature. The cover fraction (CF) is another important parameter that influenced the σ^0 signature. In fact, also at low woody volume value, the sensitivity to SWE was strongly reduced if CF was higher than 0.5. Furthermore, when the when woody volume was higher than 200 m^3/ha, and CF was higher than 0.25, the sensitivity to snow properties disappeared at all frequencies and polarizations. In this case the σ^0 trend (as a function of SWE) was quite flat and the retrieval of snow properties was not feasible.On the basis of these results proposals to take into account these effects in the development of the algorithm for the retrieval of snow properties on vegetated area are illustrated.

4. References

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