SAR BACKSCATTER INVERSION MODEL FOR ESTIMATION OF SNOW PROPERTIES

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Abstract: This paper presents an inverse model for SAR backscatter X - band designed to snow and ice surfaces. The model inversion enables estimating the morphological characteristics of snow cover from SAR data. X Cosmo-Skymed sensor data was used in the experiment tested here for the region of Union Glacier - Antarctica. We observed a precision in determining the estimated size of snow grains about 94%. This result depicts the applicability of the analyzed model as an alternative way for extracting information from X-SAR data.

Index Terms— SAR-X, backscatter, inverse model, snowpack, Union Glacier

1. INTRODUCTION

Synthetic Aperture Radar (SAR) image data is an important tool for monitoring snow and ice covers being recognized as one of the main techniques used in glaciology studies (Yurchak, 2009). In this context, the modeling of the backscattering presented by SAR signals has shown valuable for extracting information from snow and ice surfaces like snow particle size and density, snow depth, and others characteristics (Jinyang, et al, 2010). The development of models for SAR backscattering and the application of the inverse problem to SAR signals allow understanding the value connected to the structure and the dynamics of the snow surfaces (e.g. snow depth, equivalent of water, liquid water content) (Root et al, 2008). Broadly speaking, most of the description models of SAR backscattering are mathematically complex preventing their complete understanding and its using (Root, et al, 2008; Siqueira et al, 1995). This complexity is perhaps necessary to correctly describe the interaction between radiation and land targets. The backscattering of SAR signals on snow or ice can be effectively modeled by three factors: (a) the parameters of the satellite sensor, which include the frequency, polarization and geometry of the incidence; (b) the parameters of the snow pack or ice, which include snow density, snow particle size and variation in size, content of the free liquid water, characteristics about the spatial distribution of the particles, viscosity and the stratification; and (c) the parameters of the subsurface, which include the dielectric characteristics of the material, roughness in the soil-snow and ice-snow interface. According to SHI and DOZIER (2000), substantial progress in the backscatter models of SAR signals in masses of snow and ice is made by employing physical parameters of the signal dispersion. The MTR takes into account the interactions between consistent waves as function of the distribution and the position of target particles which interact with this wave. This work aims at employ inverse modeling of SAR interaction with snow and ice in order to better describe the backscattering presented by the snow pack of Union Glacier, Antarctica. To this end, we propose to perform an inversion of the SAR backscatter model in order to evaluate the stratigraphy of the snow pack. This model considers multiple backscatters for the dry snow layers based on theoretical advances in the field, bringing new information about the effects of the multiple backscatters on snow particles (grains) and on the shape of the snow. We expect the present study can bring a more comprehensive description about the natural snow.

2. PROPOSED METHODOLOGY

The methodology starts by performing pre-processing steps with the free software NEST®. The steps intend to (a) calibrate the pixel values from digital number (DN) to values of backscatter coefficient in the decibel scale; (b) reduction of the speckle noise by applying a medians filter with 5x5 pixels size window; (c) orthorectification of the SAR image data with the corresponding digital elevation model obtained in GDEM_2 ASTER base; and (d) conversion of the image data to a new format (*GeoTiff*). These initial processing steps are essential to allow extracting relationships between image data and field data, which is the basis of the comparison among the backscatter models discussed here.

The analytical form of the first order solution of the radiant transfer equation is used as the base model, which is also a function of optical thickness and snow. The development of the model brings its three parts built up by the expressions (A-C). They respectively stand for the backscatter components produced in the snow-air interface (A), the component formed by backscattering interaction between microwave radiation and volume (B), and the portion of the backscatter composed by interaction between microwave radiation and snow-ice interface or snow-soil (C).

$$\left.\begin{aligned}
\sigma_{v_pp} &= C_v \cdot 0.75 \cdot T_{pp}^2 \cdot \omega \cdot \mu \cdot [1 - \exp(-2\tau/\mu)] \\
C_{v_pp} &= m_1 + (1.0 - \exp(-\tau/\mu)) \cdot m_2 \cdot \omega \\
\log(\sigma_{v_pq}) &= m_3(rt) \cdot \exp\left(\log(\sigma_{v_pp}) / m_4(rt)\right) + m_5(rt)
\end{aligned}\right\} A$$

$$\left.\begin{aligned}
\sigma_{vs_hh} &= C_{vs_hh} \cdot T_{pp}^2 \cdot \omega \cdot (1.0 - \exp(-\tau/\mu)) \cdot \exp(-\tau/\mu) \cdot R_h \\
C_{vs_hh} &= n_1 \cdot \exp^2(-\tau/\mu) + n_2 \cdot \exp(-\tau/\mu) + n_3 \cdot R_h + n_4 \cdot R_h^2 + n_5 \\
\log(\sigma_{vs_vv}) &= n_6 \cdot \log(\sigma_{vs_hh}) + n_7 \cdot \log(R_v/R_h) + n_8 \\
\log(\sigma_{vs_vh}) &= n_9 \cdot \log(\sigma_{vs_hh}) + n_{10} \cdot \log(R_v/R_h) + n_{11} \\
R_p &= R_{p_co} \cdot \exp\left(-(2 \cdot ks \cdot \mu)^2\right) + \int R_{p_inco} d\Omega
\end{aligned}\right\} B$$

$$\left.\sigma_{s\_pq} = T_{pp}^2 \cdot \exp(-2\tau/\mu) \cdot \sigma_{g\_pq}\right\} C$$

In each of the equations, Cv_pp and Cvs_pp are the correction factors, ω is the albedo, τ is the optical thickness, T is the transmissibility at the air-snow interface, μ is the angle of propagation, and Rp is the effective reflectivity. Subscripts p and q denote the indices for different polarizations, n is the regression coefficients/setting listed in (Jinyang et al, 2010). This model considers the presence of multiple scattering and the effects of the scattering volume. Moreover, equations are considered for the elliptical scattering, which approximates more accurately the model to the reality since there is no absolute uniformity of particle snow.

3. EXPERIMENT AND ANALYSIS

In this paper, we consider a set of field data collected in summer 2011-2012 formed by stratigraphic data from the snow pack (i.e., snow temperature, limits between layers, average size and form of snow grains and average density of snow pack). These data were obtained through the excavation of snowpits over an area covered by a *Cosmo-Skymed* Sensor/Orbit CSKS2/Scion21378 (X-band) scene acquired approximately at Dec/2011. Fig 1 depicts the scene used here.

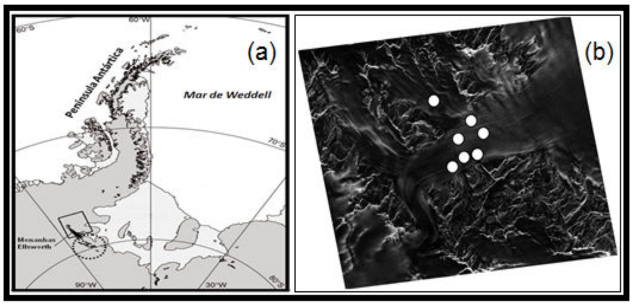

Figure 1: Study area (a) - Adapted from Gudmundsson e Jenkins [6], with the dots indicating the region of Union Glacier; Image Cosmo-Skymed used in this study (b). White dots depict the snowpits.

The evaluation of the model was performed by computing the R^2 index by comparing the ground truth and data obtained by the model. Tab. 1 summarizes the results for estimating the thickness of the snowpack, the average grain size, and average density of the snowpack.

Tab.1: Statistical determination coefficient R^2 - Comparison between field data and model estimates

	Average grain size	Thickness of the snow pack	Average density of the snow pack
R^2 - Reversal of a model backscatter	93,52%	92,23%	71,223%

The experiments show better results for the thickness and the average size of the grains, and correlated linear behavior in comparison with the values obtained in the SAR backscatter – X band. As an example, Fig. 2 displays the correlation between field data (snowpit) and modeled data for the thickness of the snow pack layer.

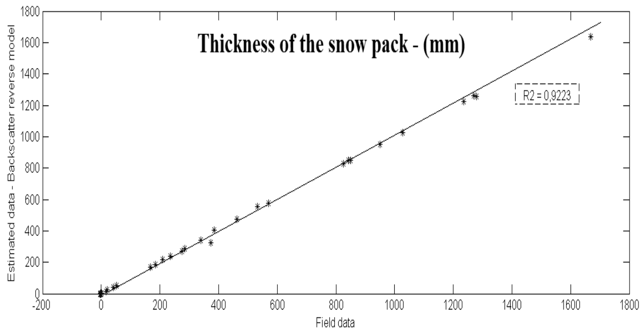

Fig. 2: linear regression between field data (snowpit) and modeled data.

Once the using of this inverse model approach of SAR signals allows estimating stratigraphic parameters for extended areas imaged by SAR sensors, and also considering the difficulties to rely on field data for stratigraphic snow, the proposed methodology is a valuable tool. The use of inverse backscattering models showed promising for estimating the stratigraphy of the snow pack of large areas. These estimates are very important for evaluating mass balance and thermodynamic equilibrium of areas marked by snow and ice.

4. CONCLUSIONS

The experimental results indicate the soundness of inverse backscattering models. The method allows us to estimate parameters of snow stratigraphy snow pack from the using X-band SAR data X band. However, experiments with other images and in different areas are needed to state more consistent conclusions.

5. REFERENCES

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