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# STOCHASTICALLY BASED WET SNOW MAPPING WITH SAR DATA

*N. Besic*<sup>1,2</sup>, *G. Vasile*<sup>1</sup>, *J. Chanussot*<sup>1</sup>, *S. Stankovic*<sup>2</sup>, *J.-P. Ovarlez*<sup>3</sup>, *G. d'Urso*<sup>4</sup>, *D. Boldo*<sup>4</sup>, *J.-P. Dedieu*<sup>5</sup>

<sup>1</sup> GIPSA lab, CNRS/Grenoble-INP, Grenoble, France, nikola.besic@gipsa-lab.grenoble-inp.fr

<sup>2</sup> University of Montenegro, Podgorica, Montenegro, srdjan@ac.me

<sup>3</sup> ONERA, DEMR/TSI, Palaiseau, France, jean-philippe.ovarlez@onera.fr

<sup>4</sup> EDF, R&D STEP, Chatou, France, guy.durso@edf.fr

<sup>5</sup> LTHE, CNRS/Grenoble-INP, Grenoble, France, jean.pierre.dedieu@ujf.grenoble.fr

## ABSTRACT

This paper proposes the new method for wet snow mapping using SAR data. It represents a modified version of the existing Nagler's mapping method, based on winter/summer image comparison, which is considered as the classic one. Instead of the existing unique threshold, a variable threshold matrix (function of the local incidence angle for each pixel) is proposed, based on dry and wet snow backscattering simulation results. The new membership decision method (with the respect to the dry/snow classes) is introduced. It considers the intensity ratio as a stochastic process: the probability that "the intensity ratio is smaller than the corresponding dry/wet snow determined threshold" is larger than the desired confidence level.

**Index Terms**— SAR, backscattering, wet snow, mapping, stochastic model

## 1. INTRODUCTION

Depending on liquid water content, snow can be considered as dry or wet. Former is defined as snow consisted just of the ice crystals embedded in air, without any liquid water, and its presence is characteristic for temperatures below 0°C. The latter can be found during the melting season, when temperature exceeds 0°C, and it contains certain amount of liquid water, introduced quantitatively through the percentage quantity called wetness ( $w$ ).

Those two snow types, with respect to their dielectric properties, behave like two totally different materials. This is due to the fact that the wet snow contains liquid water with dielectric constant differing significantly from the one of the ice, causing the mixture to have different dielectric properties, also.

Dry snow cover can be characterized with dielectric constant, which is a function of dry snow density only [1] ( $\rho_{ds}$ ):

$$\varepsilon'_{ds} = 1 + 1.9\rho_{ds} = 1 + 1.9\rho_{ice}f_{ice} \quad (1)$$

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where  $\rho_{ds}$  depends on ice volume fraction ( $f_{ice}$ ), with  $\rho_{ice}$  having a value  $917kg/m^3$ . Dielectric constant is purely real, indicating the absence of medium dielectric losses.

On the other side, wet snow dielectric constant is a complex quantity, function of ice volume fraction ( $f_{ice}$ ), wetness ( $w$ ) and frequency ( $f$ ):

$$\varepsilon_{ws} = \varepsilon'_{ws} + j\varepsilon''_{ws} \quad (2)$$

For the frequency range of 3GHz - 15GHz it is [1]:

$$\varepsilon'_{ws} = 1 + 1.83\rho_{ds} + 0.02w^{1.105} + \frac{0.073w^{1.31}}{1 + (\frac{f}{9.07})^2} \quad (3)$$

$$\varepsilon''_{ws} = \frac{0.073\frac{f}{9.07}w^{1.31}}{1 + (\frac{f}{9.07})^2} \quad (4)$$

Unlike the dry snow one, wet snow dielectric constant, being a complex quantity, it has its imaginary part, indicating the presence of the medium absorption losses.

This difference is pointing out to the difference in backscattering mechanisms of those two snow cover types. When estimating snow pack parameters by SAR remote sensing the proper identification of the backscattering mechanism is required. In the first processing step, it is necessary to be able to distinguish between the wet and the dry snow cover [2].

Nagler and Rott [3] proposed a dry/wet snow mapping method, using C band SAR data, founded on the fact that the backscattering coefficient should be smaller in case of a wet snow, due to the presence of the medium absorption. They introduced a single backscattering difference threshold, which allows forming the binary classification map. The latter is obtained in each pixel whenever the difference between a melting season SAR image ( $I_1$ ) and a corresponding SAR summer image ( $I_2$ ) is lower than -3 dB:

$$\frac{I_1(i, j)}{I_2(i, j)} < \frac{1}{2} \quad (5)$$

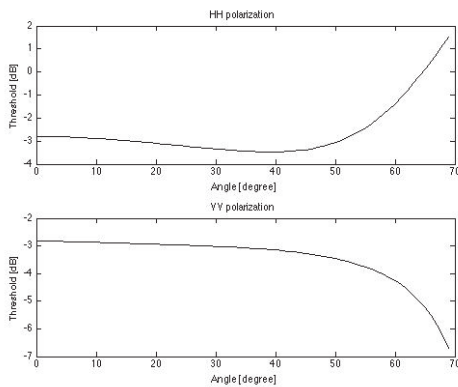
This paper proposes novel method, which introduces a variable threshold value (function of the local incidence

angle ( $\alpha$ ) for every pixel). In our approach, the membership decision of a pixel  $(i, j)$ , with respect to the dry/wet snow classes, is made by considering the intensity ratio as a stochastic process: the probability that the intensity ratio is smaller than the corresponding dry/wet snow determined threshold  $P(\frac{I_1(i, j)}{I_2(i, j)} < T(\alpha(i, j)))$  is larger than the desired confidence level  $C$ .

Although the method verification was performed using X band data, there is an open assumption of its applicability in the C band.

## 2. METHODOLOGY

In our approach, the variable threshold is derived using the snow pack backscattering simulator based on fundamental scattering theories. Integral Equation Model [4] is used for the modelling of both snow surface backscattering and underlying ground backscattering. The Quasi Crystalline Approximation [5] is used for snow volume behaviour modelling through the Radiative Transfer Theory [2]. In case of dry snow the approximation is applied in its basic form, while the wet snow simulator, due to the increase in dielectric contrast between the particles and the host medium, requires application of Quasi Crystalline Approximation with Coherent Potentials [5]. Our simulator gives the total backscattering as the sum of particular backscattering components: snow pack surface component, underlying ground component, volume component and ground volume interaction component [6]. The final threshold value ( $T(\alpha)$ ) given in fig. 1 is obtained by averaging backscattering coefficient over different ground dielectric constant and wetness values, characterizing the French Alps.



**Fig. 1.** Threshold angular distribution for the HH and the VV co-polarizations

This approach assumes that the SAR intensity ratio is modelled by the Fisher probability density function (ratio of two uncorrelated Gamma distributions ( $\Gamma$ )), defined with

three parameters  $m, n$  and  $p$ :

$$p(X|m, n, p) = \frac{\Gamma(n+p)}{\Gamma(n)\Gamma(p)} \frac{n}{mp} \frac{(\frac{nX}{mp})^{n-1}}{(1 + \frac{nX}{mp})^{n+p}} \quad (6)$$

The underlying assumptions are two:

- 1) gaussianity of SAR clutter,
- 2) negligible interferometric coherence.

The algorithm uses the boxcar neighborhood coupled with approximate maximum likelihood estimators, in order to obtain local statistics for each of the areas in the image. The result of this operation are estimated parameters  $m, n$  and  $p$  (eq. 6) for each square neighbourhood in the image, and the mean average value of concerned pixels. This allows defining the corresponding cumulative distribution function (CDF) of the intensity ratio random variable. After having the CDF, it is possible to derive the probability that the ratio between wet snow and dry snow image is smaller then the threshold.

$$i_{out}(i, j) = \frac{1}{\mu} \int_{-\infty}^{T(i, j)\mu} p_{(i, j)}(X) dX \quad (7)$$

The resulting value is considered as wet snow probability. The presented probability map can be transformed into the wet snow binary map by defining the appropriate confidence level  $C$  (for example 0.95) (eq. 8).

$$I_{out}(i, j) = \begin{cases} 1 & \text{if } i_{out}(i, j) \geq C \\ 0 & \text{if } i_{out}(i, j) < C \end{cases} \quad (8)$$

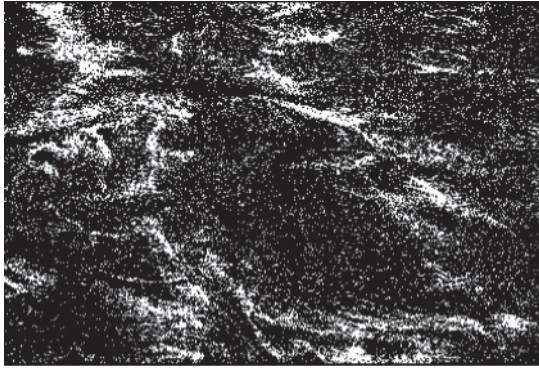
## 3. RESULTS

We illustrate the results obtained with the proposed dry/wet snow-mapping algorithm with 2 TerraSAR-X X-band images acquired in the winter of 2009 over the Grand Rousse massif near Grenoble, France.

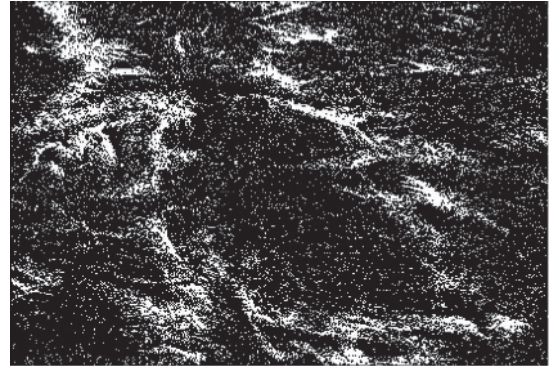
Fig. 2 illustrates the maps computed with TerraSAR-X, between February (08/02/2009) for dry snow and March (02/03/2009) for wet snow. For the purpose of comparison, it also provides corresponding binary maps, based on both single threshold and variable thresholds. The necessary remark would be that the former binary maps can not be exactly classified as the most advanced previously known ones, given that the nonlinear activation function introduced in [2] to account for the influence of underlying media and pixel heterogeneity, was not applied.

## 4. METHOD VALIDATION ON REAL DATA

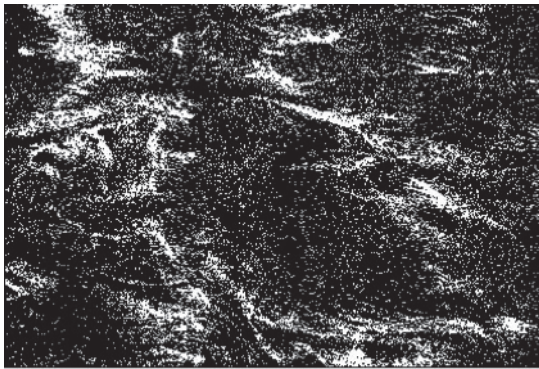
The verification of the proposed method validity is conducted using the local temperature measurements at the ground level. The measurements data, provided by EDF (*Électricité*



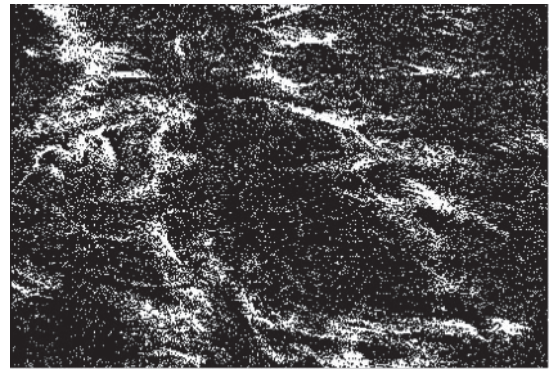
(a) Binary map based on single threshold- HH



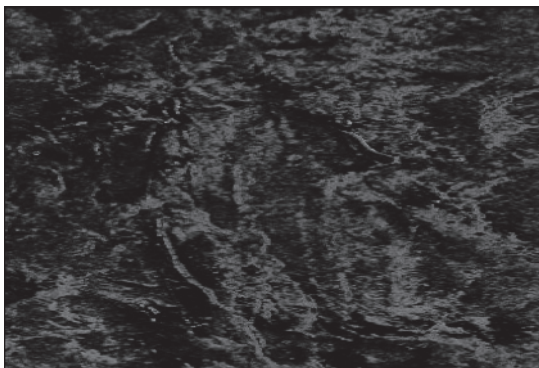
(b) Binary map based on single threshold- VV



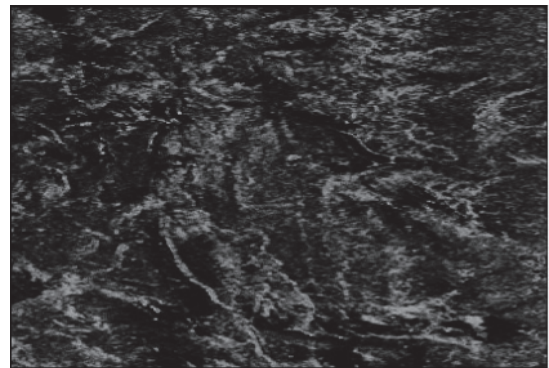
(c) Binary map based on variable threshold - HH



(d) Binary map based on variable threshold - VV



(e) Proposed method probability map - HH



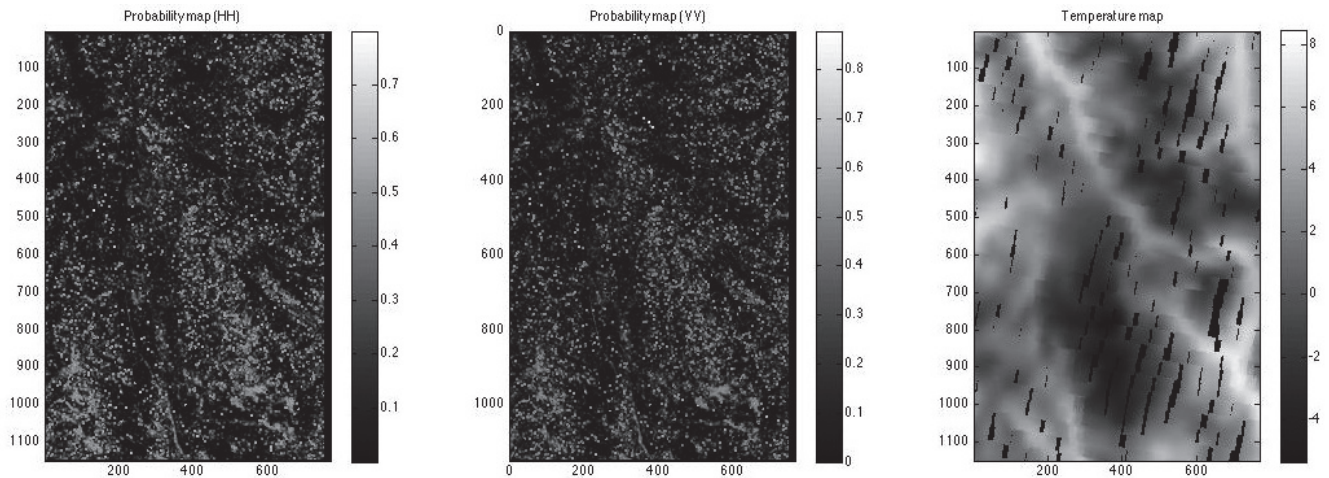
(f) Proposed method probability map - VV

**Fig. 2.** Wet snow mapping

*de France*), are related to the area of interest (Grand Rousse massif) and to the date of interest (03. March 2009.), meaning that comparison with the available SAR images was possible.

The procedure is based on the stated fact that wet snow presence is characteristic for the local temperature above  $0^{\circ}\text{C}$ , while dry snow can be found below  $0^{\circ}\text{C}$ . Using local incidence angle data the temperature measurements are projected

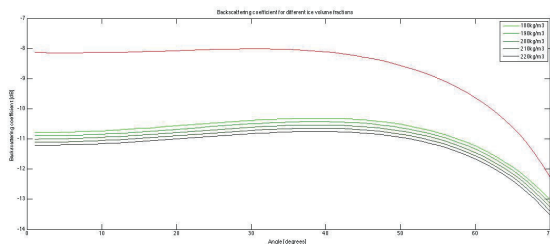
into the slant range and then compared to the result of method application on corresponding winter and melting season - wet snow probability map (fig. 3). The approximate matching between the high temperature regions and the high probability regions, two information sources which could be considered as independent, is pointing to the validity of the proposed method.



**Fig. 3.** Method validation: Wet snow probability map (HH and VV) and temperature map

## 5. CONCLUSIONS

This approach is based on the multitemporal data comparison, just like the classical one proposed in [3]. One improvement consists in the choice of the reference image. Instead of using the bare ground (summer season) image as reference, dry snow image is taken (winter season). According to our backscattering simulator results, the assumption that bare ground and dry snow backscattering difference is always smaller than -3 dB is not valid for the X band (fig. 4). That implies that bare ground and melting season image backscattering coefficient difference bigger than 3 dB is not unambiguously pointing to the wet snow. Therefore, the comparison is made directly between the assumed pure dry snow cover image and the mixed snow cover one. Variable threshold, introducing important local incidence angle influence reinforces the decision validity, while the stochastically based decision method enhances discrimination accuracy, additionally.



**Fig. 4.** Bare ground (red) backscattering and dry snow backscattering for different densities (green)

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