# Sensitivity analysis of microwave backscattering and emission to Snow Water Equivalent: Synergy of dual sensor observations


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## Abstract


An accurate sensitivity analysis of microwave emission and scattering to snow water equivalent (SWE) is performed by using a two layer Dense Medium Radiative Transfer Model implemented for both active and passive case. In order to evaluate the potential of the recent Cosmo-Skymed and TerrasarX missions , the study is mainly focussed on X band sensors . Model simulations have shown that an appreciable sensitivity of X-band backscattering and emission to dry snow can be found for Snow Water Equivalent higher than 70-100 mm and relatively high values of snow density and crystal dimensions. These results have been confirmed by experimental data taken from Cosmo Skymed mission and ground based multifrequency radiometers on a test site in the Italian Alps.


## 1. Introduction

Remote sensing of snow cover, and in particular the monitoring of snow water equivalent, is crucial to the study of global climate changes, for water resource management, as well flood and avalanche risk prevention. Indeed, snow cover is the major component of the cryosphere and plays a significant role in the global water cycle and the climate system. The sensitivity of microwave emission and scattering to snow type and water equivalent (SWE) has been pointed out in several theoretical and experimental studies, all of which have demonstrated some potential of microwave sensors in monitoring snow parameters and seasonal variations in snow cover. Due to the high transmissivity of dry snow at wavelengths longer than 2-3cm (frequencies lower of about 10-15 GHz) the estimation of SWE with the present available satellite SAR systems (C-X- band) is a challenge. Microwave radiometers, that can operate up to millimeter band do not have such a problem, although their effectiveness in operational use can be limited by the coarse spatial resolution.

Preliminary model and experimental investigations have shown that C-band data are not able to separate dry snow from snow free areas but can detect wet snow because, in this case, the backscattering is of about 2-3 db lower than that of bare soil and wet snow areas can be detected by using a change detection approach. With the launch of the new X-band SAR systems (ASI/Cosmo-Skymed and DLR/TerraSAR-X) some improvements are expected. The aim of this paper is to perform an accurate sensitivity analysis of microwave sensors to snow water equivalent (SWE). The analysis is performed by using a two layer Dense Medium Radiative Transfer Model implemented for both active and passive case and is mainly focussed on X band emission and backscattering . Theoretical results are also compared with experimental data taken from Cosmo Skymed mission and ground based radiometers realized and operated by the Institute of Applied Physics (IFAC-CNR).

## 2. The theoretical model

The model developed for this study includes two layers of snow upon a rough soil. Emission and scattering are computed by using the Dense Medium Radiative Transfer Theory (DMRT). The basic physical idea is that because the particles are randomly distributed, the phases of the scattered fields are random, so that the products of scattered fields generally average to zero except those terms in the multiple scattering equations that result in constructive interference. The mathematical approach is to identify and retain only the constructive interference terms in the correlated ladder approximation. The extinction rate, albedo, and phase matrix of the DMRT equation are expressed in terms of the

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

physical parameters of the medium. DMRT takes the following into account: 1) Scattering by correlated scatterers; 2) the pair distribution function of scatterer positions; and 3) the effective propagation constant of a dense medium. The improved equations also preserve the advantages of the conventional radiative transfer equations: a) Multiple scattering of the incoherent intensities is included; b) energy conservation and reciprocity are obeyed; and c) the form of the equations remains the same as the conventional radiative transfer equations so that numerical solutions are calculated in the same manner. For this case of two-layer model the radiative transfer equations (two for each layer and quadrature angle) are coupled and needs to be solved simultaneously

## 3. Experimental data

Experimental X band data from Cosmo-Skymed (CSK) and Terrasar X satellites and from ground based multi-frequency (C-, X, Ku and Ka band) radiometers were collected in winter 2010-2011 on a test site (Cordevole Watershed) on the Italian Alps. Simultaneously to remote sensing data ground measurements of all the most important snow parameters (depth, density, grain size, and wetness) were performed. Microwave radiometers observed continuously 24h/day from November 2010 to March 2011. In the same time interval a conspicuous number of images were collected with SAR of Cosmo-Skymed mission.

## 4. Results

Model analysis made it possible to quantify the sensitivity of backscattering and brightness temperature to snow parameters. Several configurations of dry and wet snow-pack with different values of depth, density, and crystal dimension were tested.
As a preliminary example Fig.1 shows the total backscattering coefficient of a layer of dry snow upon a smooth soil for three classes of ice crystal dimensions. In each diagram, the contributions of soil and snow layer are represented together with the total backscattering; the spread of data is due to a parameterization of soil parameters (moisture, roughness) and snow density in a range of expected average values.

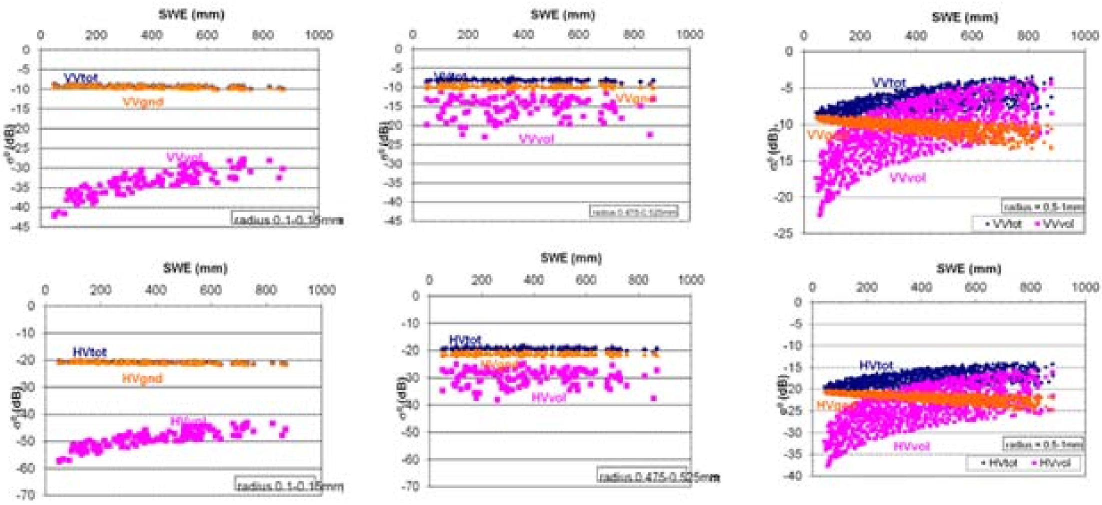


Fig. 1. X band backscattering as a function of SWE for three ranges of ice crystal dimensions (Pink: contribution of the snow layer, Orange: contribution of soil, Blue: total contribution)

The model sensitivity of the brightness temperature Tb to the Snow Water Equivalent is depicted in Fig.2 for the X, Ku- and Ka-band. In these simulations we kept the grain diameter fixed at 1mm. We can see that at X band the sensitivity is quite low while increases significantly at the higher frequencies. The trend of Tb at 19 GHz is almost linearly and decreases with a rate of -0.12K/mm SWE for the V pol and -0.09 K/mm SWE for the H pol. Instead, the trend of Tb at 37 GHz shows a saturation at relatively low values of SWE (around 75mm SWE); its sensitivity before saturation is -0.83 K/mm SWE for the V pol and -0.5 K/mm SWE for the H pol.

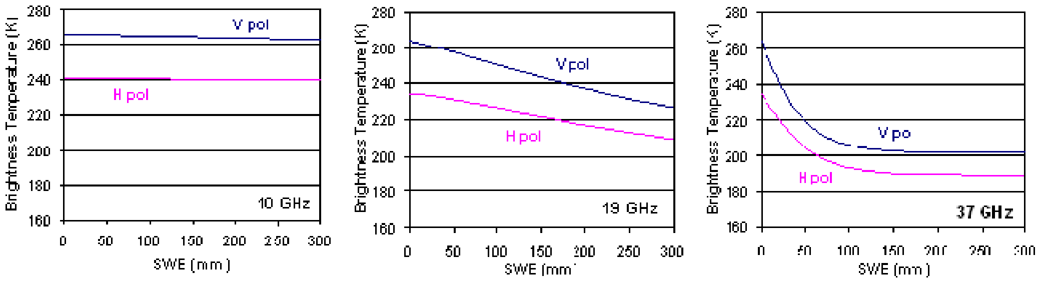


Fig. 2: Model sensitivity to the Snow Water Equivalent of the brightness temperature at 10, 19, and 37 GHz( Blue = Vertical Pol. Magenta = Horizontal Pol. ) Grains radius = 0.5 mm

## 5. Conclusion

Model simulations confirmed the high sensitivity of microwave emission and scattering to grain size and snow density. X-band backscattering and emission exhibit a modest but appreciable sensitivity to dry snow for Snow Water Equivalent higher than 70-100 mm and relatively high values of snow density and crystal dimensions. A much higher sensitivity is possible by using higher frequencies that, at present ,are available from space on passive sensors only. The latter, on other hand, are penalized by the coarse ground resolution. Thus, for operational use, we propose a synergetic observation based on a wide swath low ground resolution multifrequency radiometer, such as the AMSR-E, combined with high resolution X-band SAR such as COSMO-Skymed.