Retrieval Algorithm of Snow Water Equivalent using SnowSAR and Scatterometer Backscatters with both Co- and Cross-Polarizations

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ABSTRACT

A microwave volume scattering based retrieval algorithm is presented to invert a snow water equivalent (SWE) based on dual frequency (X- and Ku- bands—10 and 17 GHz) and single polarization (VV-polarization) radar measurements. The validation of this algorithm used 3 sets of airborne SnowSAR data (including 2011 and 2012 campaigns in Finland; 2013 campaign in Canada). The retrieval performance achieved a root-mean-square error (RSME) below 30 mm of SWE and a correlation coefficient above ~0.64. In the retrieval, the uncertainty associated with the lower boundary of the snowpack is reduced by predictions from scattering model of soil surface. Based on original dual band retrieval method, we also investigate the potential addition of lower Ku band (13 GHz) for SWE retrieval, which is less affected by this background scattering. Then, this combination with X-, Ku-, and lower Ku- bands is consistent with the SWE mission concept proposed by the Canadian Space Agency (CSA). While observations at cross-polarization provide sensitivity to handle thick snowpacks, this study shows the higher Ku band co-polarization backscatter may saturate when the snowpack is deeper than 4 meters. The proposed retrieval scheme thus forms a three-frequency and dual polarization radar SWE algorithm. Validations of the proposed algorithm is followed with the airborne SnowSAR data from Canada campaign 2013. The performance of the lower Ku band and cross-polarization for retrieval is cross-checked with the scatterometer data from Finland (ESA NoSREx; 2009-2013) and compared with previous results.

Keywords: bicontinuous dense media radiative transfer (Bic-DMRT), retrieval algorithm, snow water equivalent (SWE), lower Ku band (13 GHz), cross-polarization, SnowSAR, scatterometer

RESULTS

The SnowScat data were collected in Nordic snow radar experiment campaign (NoSREx) to support Earth Explorer mission CoReH2O. The data were measured by SnowScat at Sodankylä, Finland during the winter of 2010~2011. The instrument is three frequency, X-, low and high Ku-bands, dual polarization (VV & HV) ground-based scatterometer system.

In retrieval, a least-squares algorithm by a priori constrained by $\bar{\omega}_X$ is applied to fit the forward model results into radar observations. The cost function is given as:

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$$F = \min_{\omega_X,\tau_X} \left\{ \frac{\left(\sigma_1^{obs} - \sigma_1^{model}(\omega_X, \tau_X)\right)^2}{2s_1^2} + \frac{\left(\sigma_2^{obs} - \sigma_2^{model}(\omega_X, \tau_X)\right)^2}{2s_2^2} + \frac{(\omega_X - \overline{\omega}_X)^2}{2s_{\omega_X}^2} \right\} \quad (1)$$

where σ_1^{obs} and σ_2^{obs} are the two channel radar observations chosen for the class after subtraction background scattering, and σ_1^{model} and σ_2^{model} are the corresponding backscattering prediction by parameterized forward model. s_1 and s_2 are the expected error standard deviation of the measurements which is also regarded as the variance of speckle in a SAR image. In retrieval, we set $s_1 = s_2 = 0.5$ dB, $\overline{\omega}_X$ is the a priori value for albedo, and $s_{\omega_X} = 0.1$ act as the standard deviation of the priori constraint. The contribution from each term in cost function is normalized by assuming a Gaussian distribution. ω_X and τ_X are the two parameters we need to solve from this equation. With cost function, we find the best fit ω_X and τ_X for each set of σ_1^{obs} and σ_2^{obs}.

In Figure 1 (a), (b) and (c), the performance of SWE retrieval for co-polarization Finland SnowScat data 2010-2011 based different frequency sets are inter-compared. In Table 1, we list the detail statistical results. We find retrievals based on all three frequency sets achieves RMSE less than 200mm and correlation above 0.85 which satisfy with the SCLP requirements. The combination of three frequency band retrieval gives best results showing that the low Ku band improves the retrieval especially for thin snow. In Figure 2 (a) and (b), the comparison of retrieval performance based on co-pol and cross-pol for thick snow is illustrated. In Table 2, we list the detail statistical results. The retrieval performance is improved for thick snow by introducing cross-polarization. RMSE and correlation are become better by using the cross-polarization.

Table 1. Performance of SWE retrieval for co-polarization Finland SnowScat data 2010-2011.

Co-pol channel	**Correlation coefficient**	**RMSE (mm)**	**Bias (mm)**
X and Ku high	0.854	14.63	6.81
Ku low and high	0.871	13.28	-5.41
Ku low and high for SWE < 60 mm X and Ku high for SWE > 60 mm	**0.913**	**11.54**	**1.66**

Table 2. Performance of SWE retrieval for co- and cross-pol Finland SnowScat data 2010-2011.

Channel	**Correlation coefficient**	**RMSE (mm)**	**Bias (mm)**
X and Ku co-pol	0.756	20.60	11.87
X and Ku cross-pol	**0.787**	**10.80**	**-2.66**

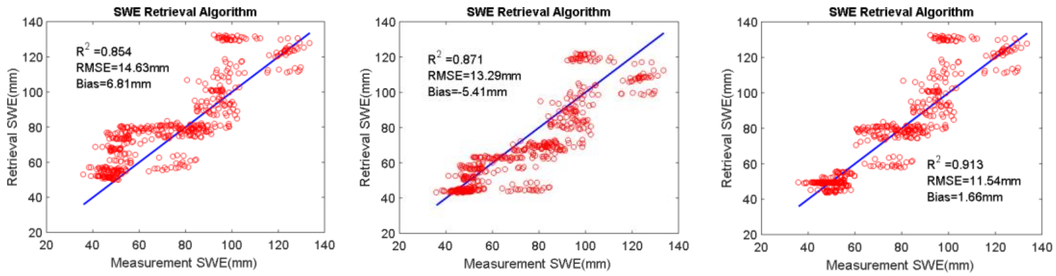

Figure 1. Comparison of SWE retrieved with SWE measured for co-polarization Finland SnowScat data 2010-2011. (a, left) retrieval based on co-pol X and high Ku band, (b, middle) retrieval based on co-pol two Ku band, and (c, right) retrieval based on combination of X-, low and high Ku-band.

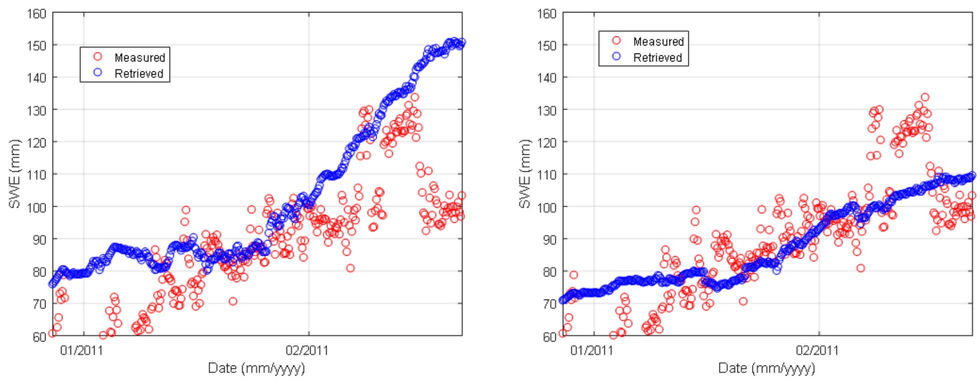

Figure 2. Comparison of SWE retrieved with SWE measured for Finland SnowScat data 2010 with SWE above 60 mm. (a, left) retrieval based on X and Ku-band co-pol, and (b, right) retrieval based on X and Ku band cross-pol.

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