C Band Sentinel 1 Remote Sensing Of SWE with Roughness Effects And Snow Wetness.

ELECTRICAL ENGINEERING AND COMPUTER SCIENCE
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ABSTRACT

Sentinel-1 C band satellite gives us a global coverage of snow which is essential in studying the properties of snow like SWE, snow wetness etc. Researchers in the past have thought that at C band, there is no volume scattering from snow. But the Sentinel-1 data at very deep snow depths shows that the cross-pol and the ratio of cross- to co-pol is sensitive to snow depth. Whereas co-pol alone shows little sensitivity to snow depth as shown in figure 1.

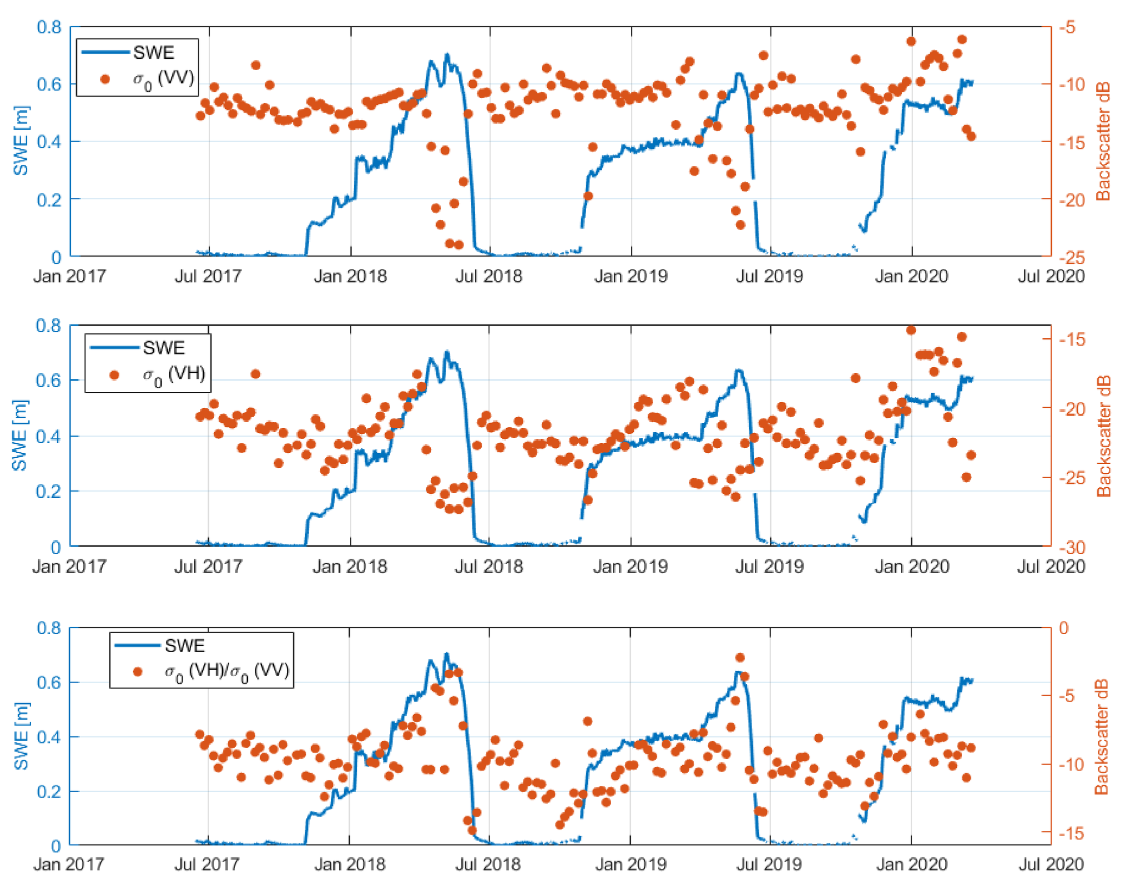


Figure 2: Backscatter and SWE time series at an Alps location. The top, middle and bottom figure correspond to the co-pol, cross-pol and the ratio of cross- to co-pol, respectively.

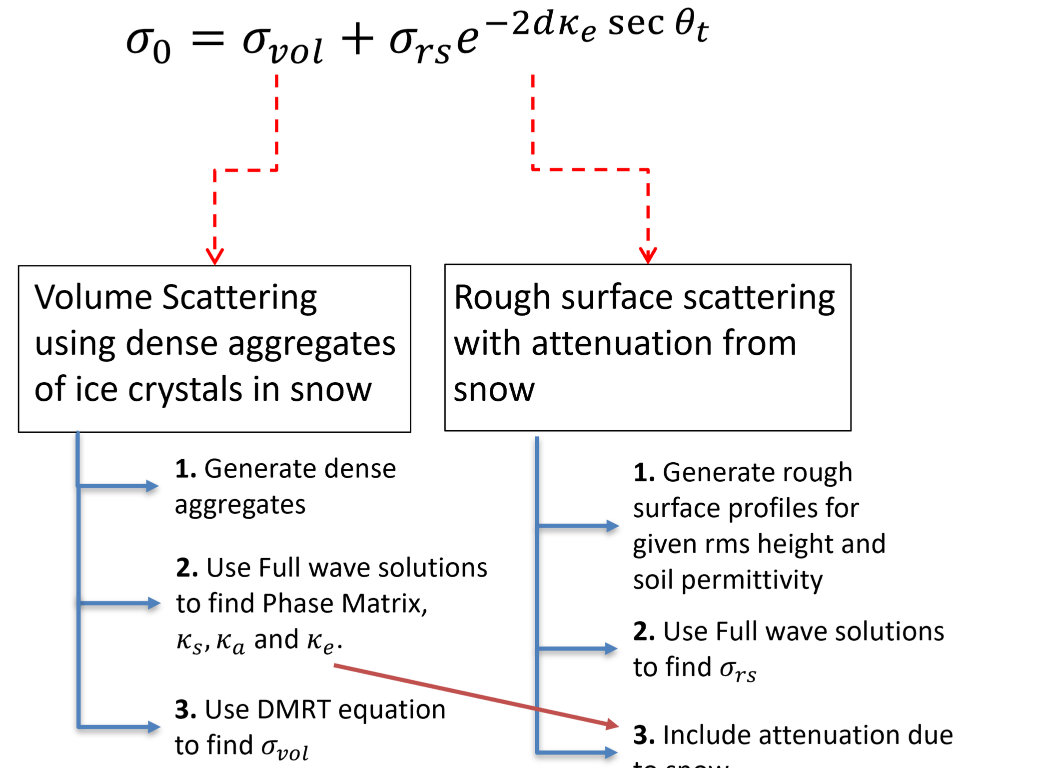
In this work, we study the retrieval of deep snow SWE using-

1. The volume scattering of snow using the dense aggregate model to account for the high cross-pol in the Sentinel-1 data.
2. We include the rough surface contribution from the snowpack below to study the combined volume surface contribution in the Sentinel-1 data.
3. We also study the effect of snow wetness in the Sentinel-1 data.

Physical Modelling of Snow and Rough Surface

- The backscatter from snow and rough surface is given by-

$$\sigma_0 = \sigma_{vol} + \sigma_{rs} e^{-2d\kappa_e \sec\theta_t}$$



Volume Scattering of Snow: Dense Aggregate

- Dense aggregate scattering is based on bi-continuous (two phase) random media governed by pdf-

$$p(\zeta) = \begin{cases} a\exp\left(-\frac{\zeta_j}{\zeta}\right), & \text{for } \zeta \le \zeta_j \\ \frac{(b+1)^{b+1}}{\Gamma(b+1)<\zeta>}\left(\frac{\zeta}{<\zeta>}\right)^b \exp\left(-(b+1)\left(\frac{\zeta}{<\zeta>}\right)\right), & \text{for } \zeta > \zeta_j \end{cases}$$

- <ζ> controls ice grain size (Inverse of grain size)
- b controls the aggregation of ice grains

$b < 1 \rightarrow$ dense ice crystal aggregate
$b > 1 \rightarrow$ distributed ice crystals

- Based on b, snow can be generated as a bi-continuous media of dense or distributed ice crystals:

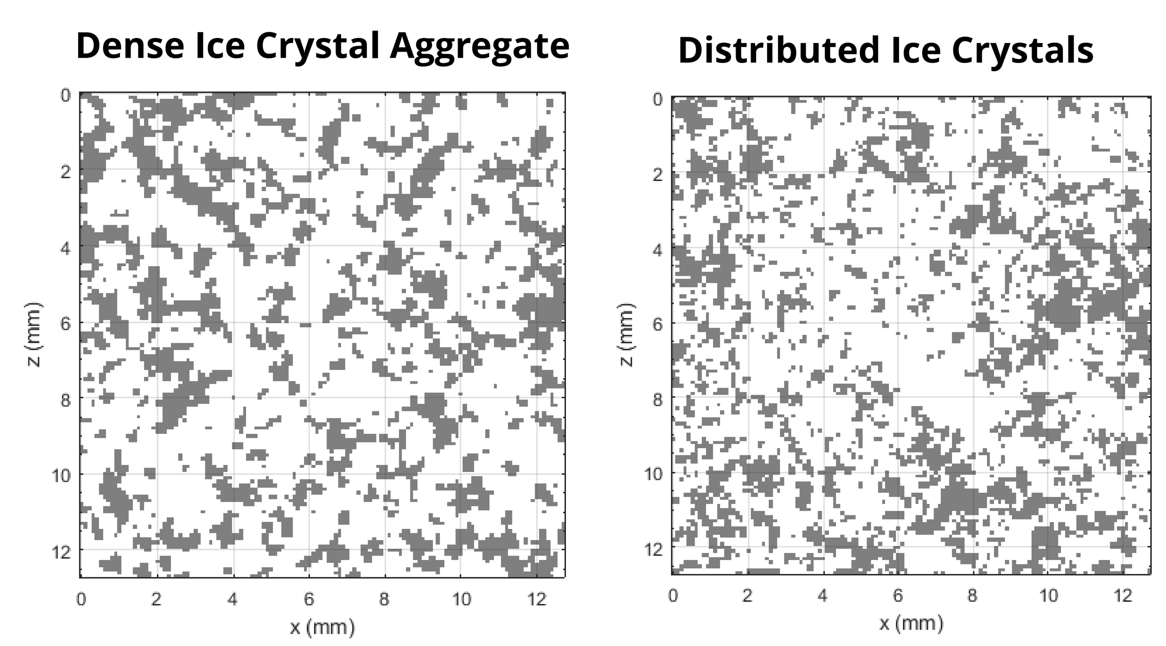


Figure 2: Bi-continuous media for dense aggregate (left; b=0.4) and distributed ice crystals (right; b=1.2).

- Once dense aggregate media has been generated, Full wave simulations with discreet dipole approximation (DDA) to find phase matrix, and κ_e and find σ_{vol}.

Rough Surface Scattering

- The volume scattering depends on SWE while the snow-soil roughness interface scattering does not.
- But contribution of rough surface scattering increases the overall backscatter.
- We perform NMM3D full wave simulations of rough surface scattering at C band to find σ_{rs}.

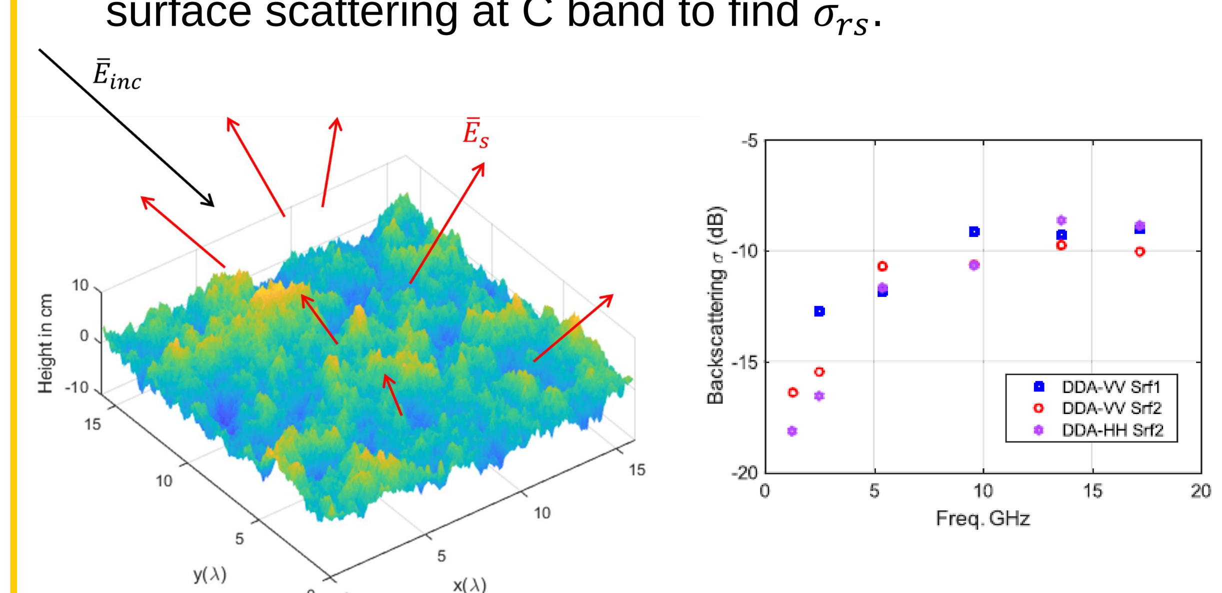


Figure 3: NMM3D simulation of random rough surface (left). Backscattering as a function of frequency using NMM3D Volume Integral Equations (right).

Combined Effect of Volume and Rough Surface Scattering at Deep Snow

At higher snow depths:

- C band co-pol volume and surface scattering are comparable.
- C band cross-pol volume scattering much larger than surface scattering.
- This is shown in Table 1 and figure 4.

Table 1: Comparison of co-pol and cross-pol backscatter at shallow and very deep snow depths.

	Snow Depth	Volume Scattering (dB)	Surface scattering (dB)
Co-pol VV	50 cm	-15.2	-8.8
	200 cm	-9.4	-10
Cross-pol VH	50 cm	-24.3	-19.1
	200 cm	-15	-20.2

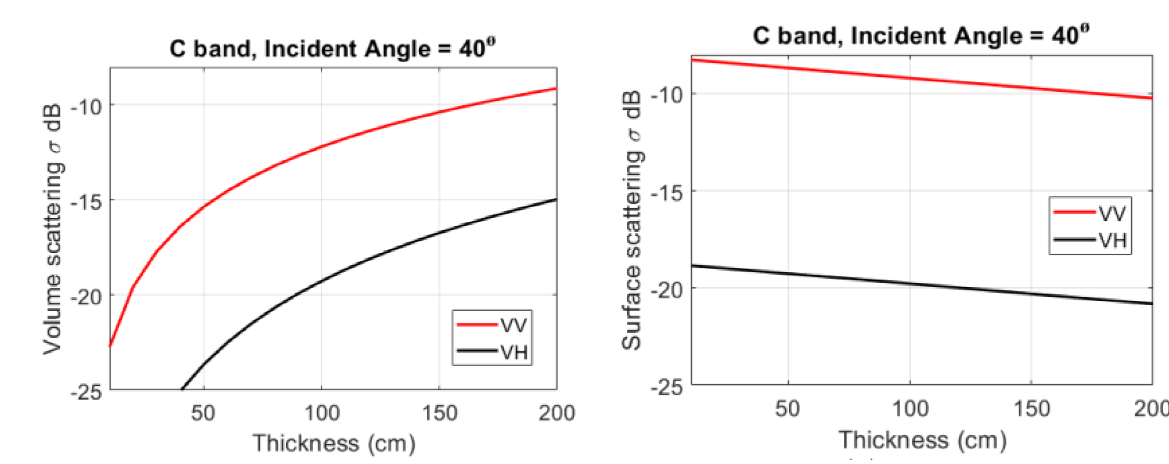


Figure 4: Volume scattering (left) and surface scattering (right) as a function of thickness for a layer of dense aggregates.

Sentinel-1 Time Series Data Analysis with Volume and Surface Scattering

- We analyze the winter season of 2017-18 for one location, that is from 15 June 2017 till 21 March 2018.
- The forward model shows that at small snow depths, rough surface scattering dominates for both co-pol and cross-pol.
- At deeper snow, the volume and surface scattering of co-pol becomes comparable and starts compensating one another, resulting in no sensitivity to SWE. The cross-pol volume scattering is much larger than cross-pol surface scattering at deep snow, which results in cross-pol signal of Sentinel-1 to increase with SWE.

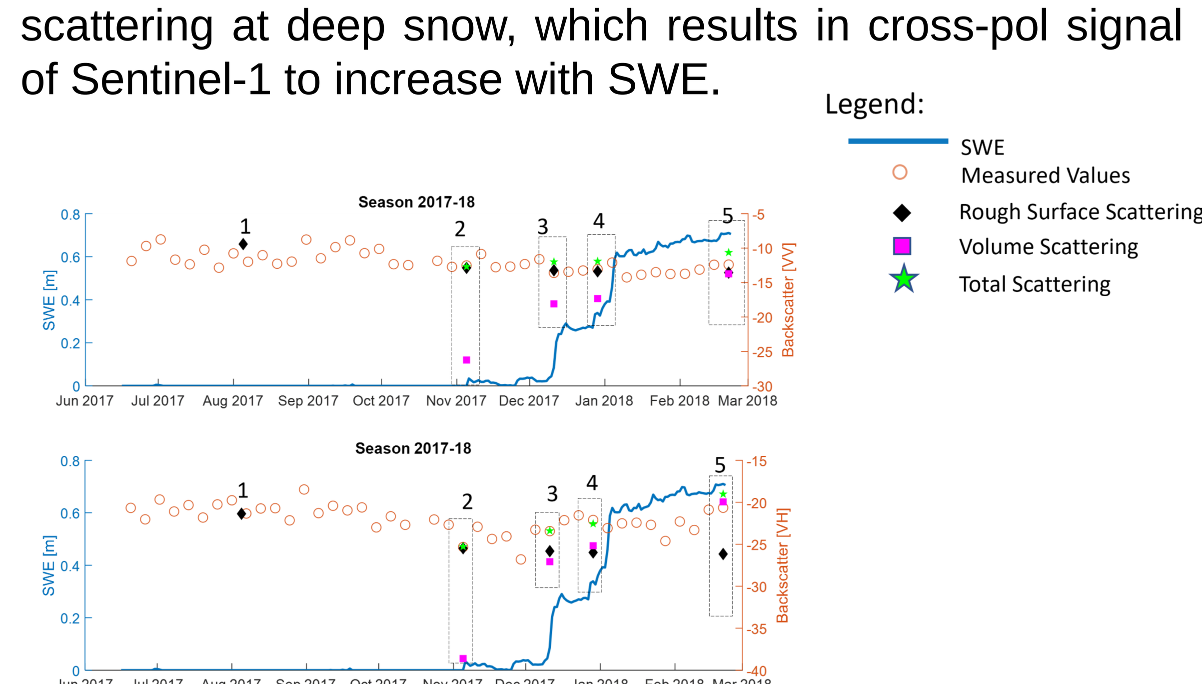


Figure 5: Contribution of volume, rough surface and total scattering compared to the measured Sentinel-1 data. .

- Parameters are varied based on seasonal change-
  - Rms height remains constant.
  - Soil Moisture decreases as snow increases.
  - Density increases as snow accumulates.
  - Grain size variation is based on the best match to the data.
- We extend the five-point analysis to the full season to show the time-series variation of Sentinel-1 signal at both polarizations.

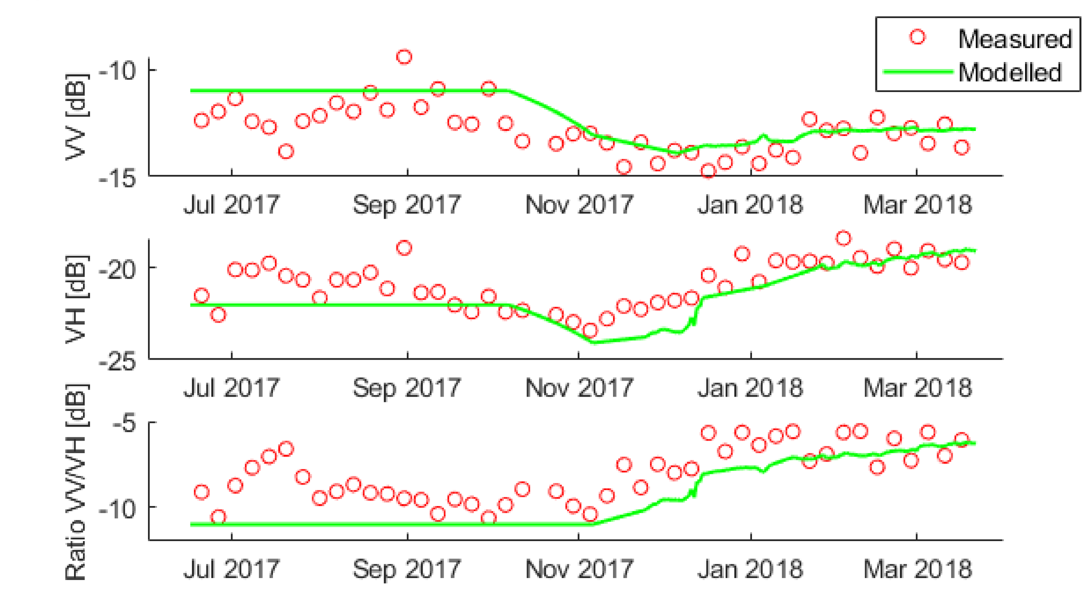


Figure 6: Modelled data compared to measured Sentinel-1 data over the entire season for an Alps location.

Snow Wetness from C-band Sentinel-1 Data

- For wet snow at C band the scattering contributions are from (i) the snow volume, (ii) the rough soil surface below and (iii) the air/snow interface at the top. The backscatter is-

$$\sigma_0^C = \sigma^{as} + |T|^2(\sigma^{vol} + \sigma^{rs} e^{-2\kappa_e d \sec\theta_t})$$

- We use full wave simulations to calculate the scattering and absorption coefficients, κ_s and κ_a and then σ^{vol} and $\sigma^{rs} e^{-2\kappa_e d \sec\theta_t}$.
- Preliminary results show that the attenuation in C band is high, and the wetness can only be measured for SWE up to 150mm and wetness up to 8%.

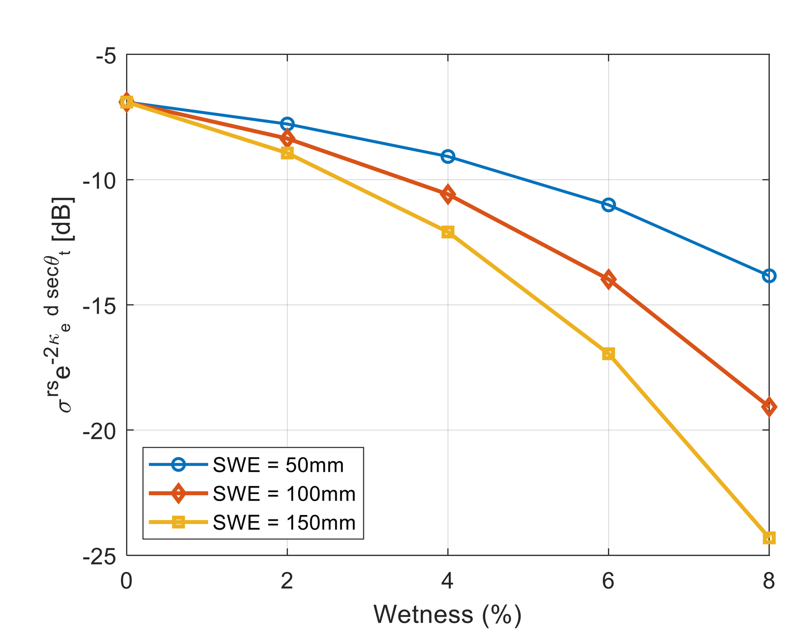


Figure 7: Rough surface contribution of σ_0^C versus snow wetness for different snow depths (SWE)..

REFERENCE

Borah, F. K., Jans, J.-F., Huang, Z., Tsang, L., Lievens, H., and Kim, E.: Time Series Analysis of C-Band Sentinel-1 SAR Over Mountainous Snow with Physical Models of Volume and Surface Scattering, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-1825, 2024.