PROGRESS IN THE ANALYSIS OF ANTARCTICA AS A TARGET FOR MULTIFREQUENCY CROSS-CALIBRATION BETWEEN ASCAT AND NSCAT

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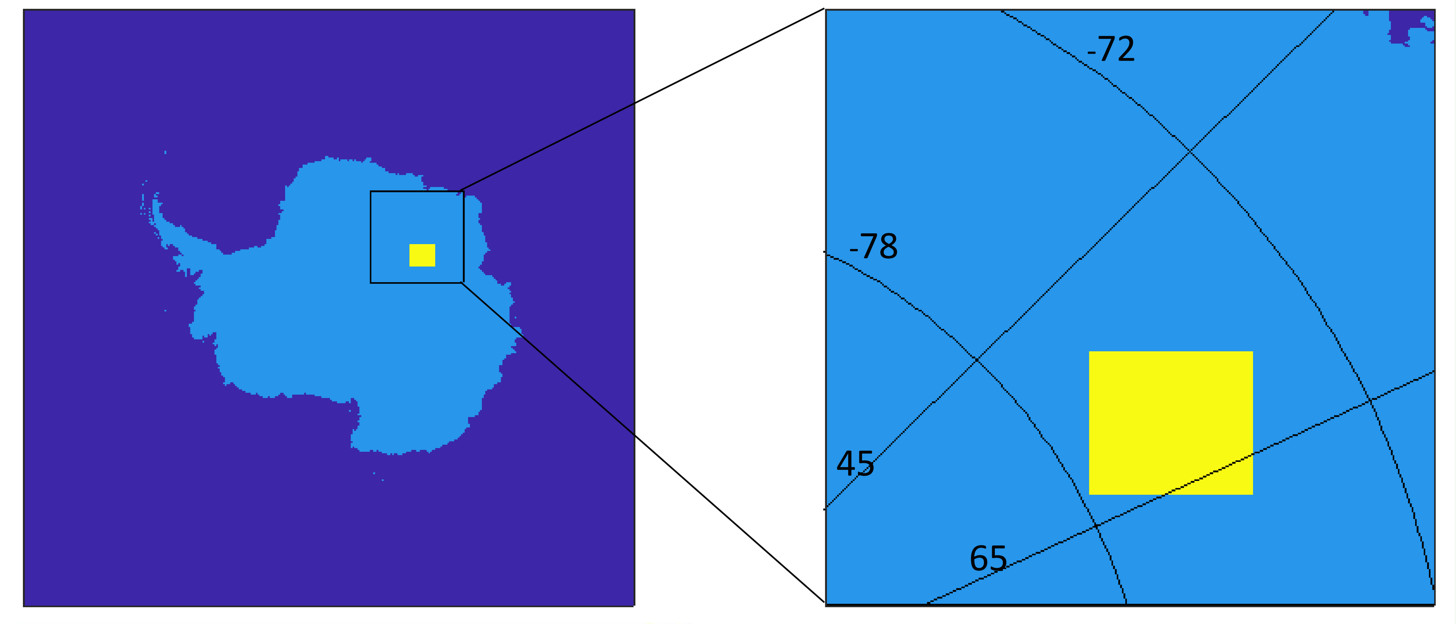
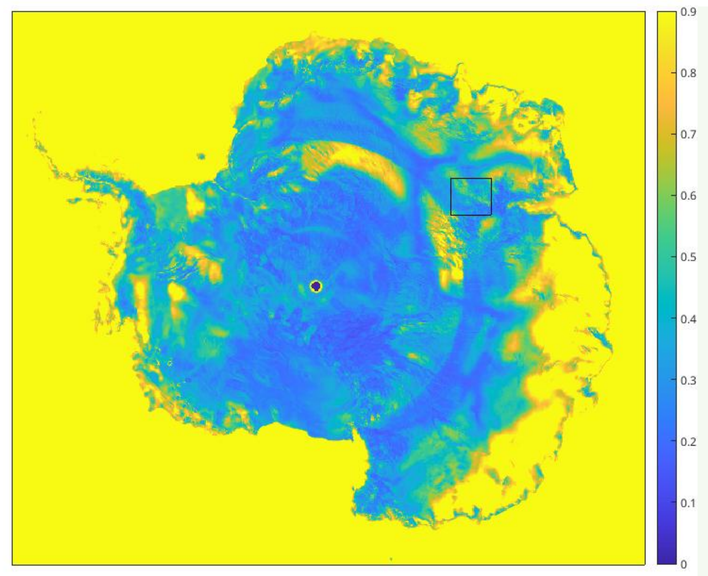
Summary

Variations in incidence angle, frequency, beam pattern, and time periods complicate efforts to cross-calibrate data from different sensors and make it difficult to create a homogenous data set to support long-term studies. Land calibration targets with little seasonal variation and significant volume scattering characteristics help to mitigate some of these differences, thus enabling cross-calibration of the various sensors [1][2][3]. Having shown that regions of Antarctica exhibit long-term stability and volume scattering effects we examine the characteristics of a study area near the Amery ice shelf in what is known as a 'wind glaze' region, an area characterized by near-zero snow deposition rate and an ice surface layer over coarse refrozen ice grains [4], as a calibration target.

A simultaneous azimuth and incidence angle correction is used to predict and remove azimuth modulation [5]. The correction model assumes that the calibration offset is multiplicative to the sum of the volume and surface components. We predict the volume scattered component with a single scattering model, the surface scattering with the I2EM model, and subtract those values from the azimuth corrected measured backscatter to get the calibration offset [6]. Parameters in the models include particle size, surface RMS height, surface correlation length, and dielectric constant, which should all either remain constant for each scatterometer or vary predictably with frequency [6]. Data from SMAP (1.4 GHz), ASCAT (5.3 GHz) and NSCAT (13.995 GHz) are used in the model to evaluate the scattering behavior of the region. Because different frequencies exhibit different levels of volume and surface backscatter, using data from the two instruments enables better parameter estimates and a more accurate model. The modeled fit follows the mean of the data to within 0.5 dB

Several advancements have been made in firn backscatter modeling. Improvements to the model include incorporating the effect that the surface ice density has on the surface component of the backscatter, inclusion of a particle size gradient parameter, and research into firn structure as a mechanism to explain the azimuth modulation observed in Antarctic firn.

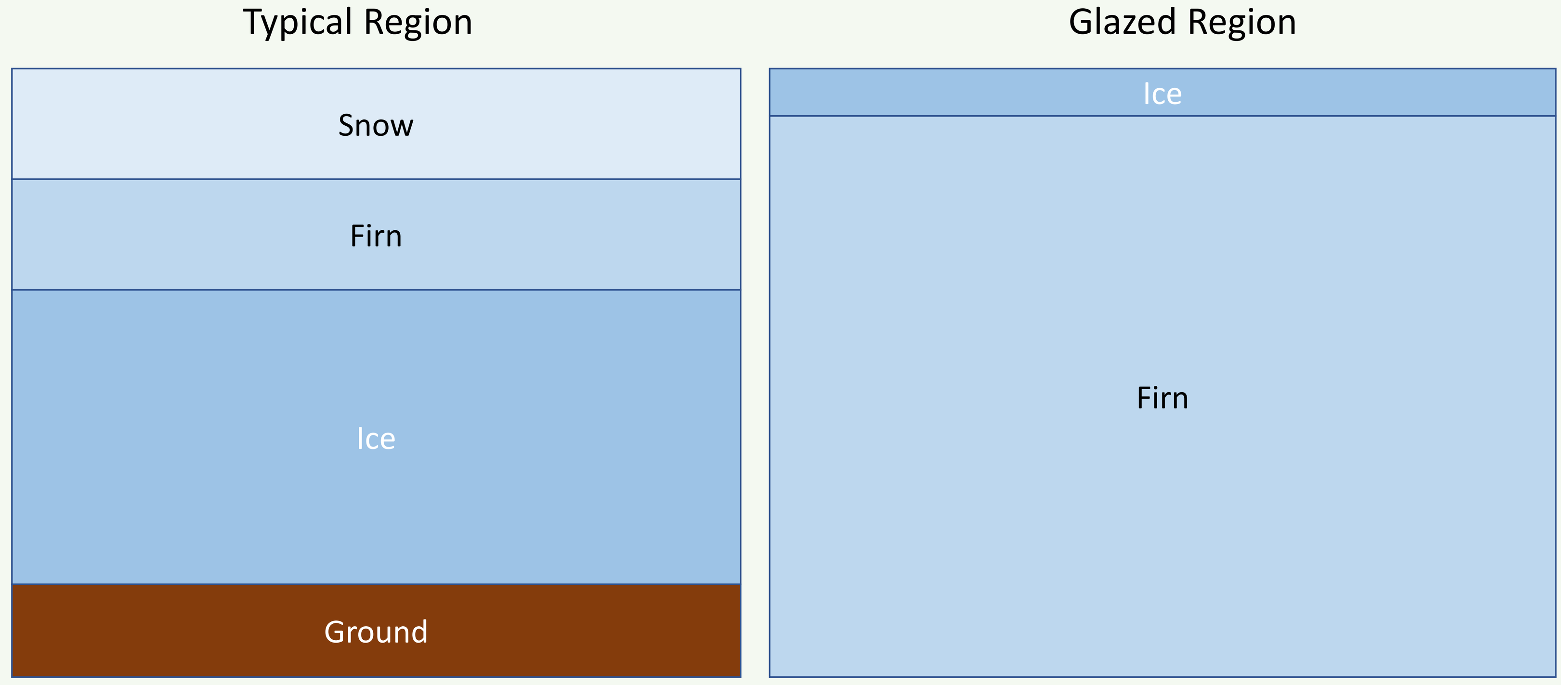




Study Region

(top row) Study region location inland of the Amery Ice Shelf. This region was chosen because of its location inside the section of Antarctica with coverage from all beams of the fan beam scatterometers and the consistency of its backscatter at 5.3 GHz and 13.5 GHz. (left) map of the 3-year standard deviation in the daily pixelwise mean difference between ASCAT and QuikSCAT SIR σ_0 data (in dB). The region of interest outlined in black, has low standard deviation

The backscattering consistency of this and similar areas is likely due to the areas being low accumulation regions known as glaze regions. These regions have a different layered structure than most snow-covered regions as outlined in the figure below. The main takeaway from a backscattering perspective is that glazed regions have fewer layering effects that complicate modeling of the backscatter, and the ground is far enough away that we ignore ground reflections.



Glaze Region Backscatter Model

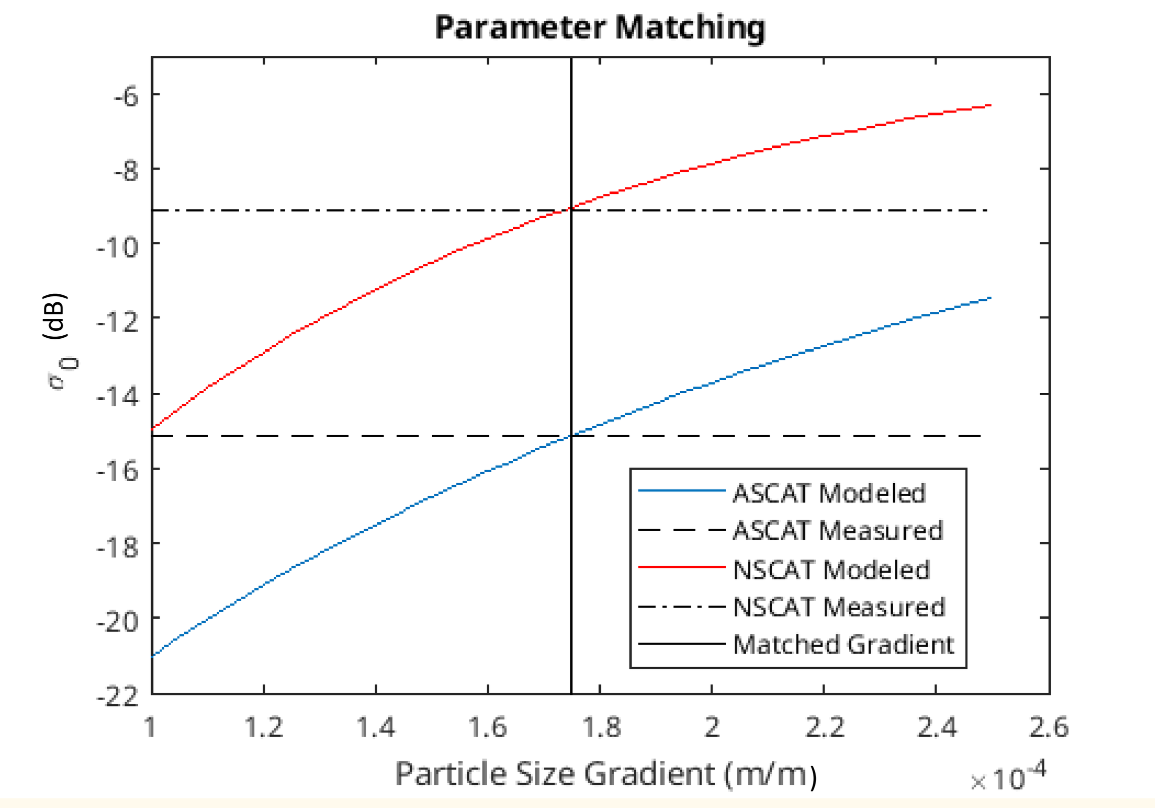
Volume Component — Surface Component

$$\sigma_0 = 10\log_{10}[\sigma_v(\theta_i)M_v(\theta_a) + \sigma_s(\theta_i)M_s(\theta_a)] + C$$

- σ_0 : Reported measurement
- σ_v: Volume return
- θ_i : Incidence angle
- θ_a : Azimuth angle
- σ_s : Surface return
- M_v : Volume azimuth modulation
- M_s : Surface azimuth modulation
- C : Calibration offset

The semi-empirical calibration model equation consists of three parts: volume and surface backscatter, volume and surface modulation, and a calibration constant, C. It estimates the azimuth modulations using an approximation from the data but predicts the volume backscatter using a single scattering physics model, and the surface backscatter using the I2EM model. The surface component in high incidence NSCAT and ASCAT data is negligible, so this data is used to estimate the volume scattering variables, and low incidence data is used to estimate the surface scattering variables. SMAP data is only taken at a narrow range of incidence angles and has significant contribution from both surface and volume scattering, so this data is only used to confirm the other estimates.

Firn Gradients



The volume model uses information about particle shape and dielectric constant to estimate the volume contribution to σ_0. Both parameters vary with depth, and particle size has the dominant effect on σ_0.

The dielectric constant is determined by the density of the firn. The formula used for the density prediction is the Herron and Langway firn densification model. Density increases steeply in the first 20 meters and then approaches 0.91 g/cm³.

Particle shape is modeled as a triaxial ellipsoid, and this shape is governed by three parameters: surface particle height, semi-axis (a/b) ratio, and depth gradient. The initial approach uses constant a/b ratios and depth gradients, meaning the gradient does not change with depth, nor does the a/b ratio. The implementation of a particle size depth gradient enables parameter matching between ASCAT and NSCAT, meaning that the model can use the same parameters to accurately predict the measured backscatter from two different frequencies. This is a major step towards completing the multifrequency scattering model of Antarctic0 firn.

The figure to the left shows the measured and modeled σ_0 with respect to the particle size gradient. The gradient value at which the modeled and measured lines intersect for a given scatterometer is the effective gradient value. Because the vertical line passes through both intersections, we have an agreement on model parameters that persists across frequencies.

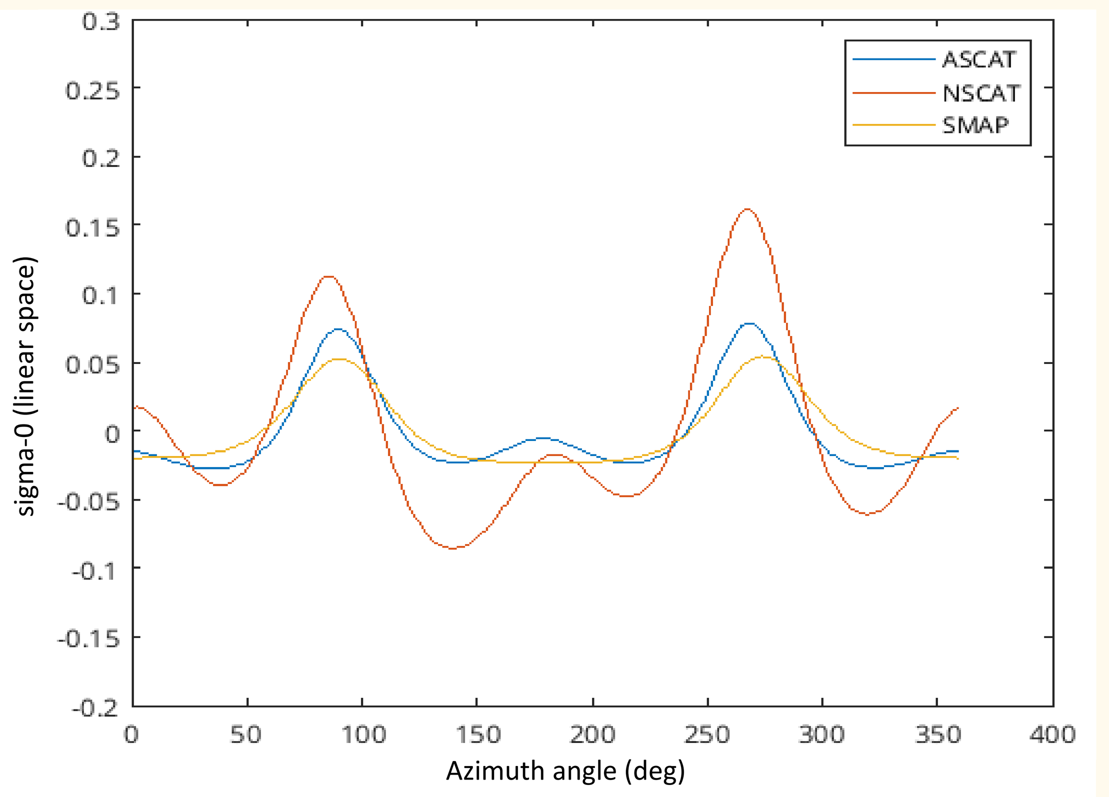
Volume Scattering

$$\sigma_v = \int_{-d}^{0} \sigma_v^{back} e^{2\kappa_e z \sec(\theta_i)} dz$$

- κ_e: extinction coefficient
- σ_v^{back}: backscatter from a single particle
- z: depth in the firn

The volume model employs a single scattering method to predict the volume contribution. The single scattering equation is used in its integral form so that the appropriate dielectric constant and particle size can be applied at every depth increment. This leads to a volume calculation that is very similar at high frequencies but differs by up to 2 dB from the non-gradient model method at lower frequencies. This matches with expectations because lower frequencies penetrate deeper into the ice and thus interact with a greater range of firn properties.

Azimuth Modulation



Azimuth modulation for ASCAT (blue), NSCAT (orange), and SMAP (yellow). Note that the main peaks are aligned with each other within 3 degrees. The data shown is adjusted to have zero mean and is displayed in normal space to more accurately compare examples of modulation that occur with a separation of several dB in dB space. Because the modulations are similar, we conclude that the cause of azimuth modulation in the glaze region is not sensitive to frequency.

Azimuth modulation is present to some degree at all incidence angles. Surface contribution to backscatter is negligible at high incidence angles, implying that the most widely accepted mechanism for azimuth modulation, sastrugi on the surface of the ice, might not explain the entirety of the effect.

A new mechanism for azimuth modulation is proposed. Literature on ice particle growth suggests that ice crystals preferentially grow in the vertical direction [7]. This implies that the spherical model for ice particles is flawed, and that an ellipsoidal model could be more accurate. The same study also suggests that the major semi-axes of the ice particles are not oriented perfectly vertically. The hypothesis is that preferential growth directions and/or tilting of the non-spherical particles results in the bulk azimuth modulation effect observed in Antarctic firn. Preliminary results indicate that modeled particles with reasonable dimensions can cause an azimuth modulation with the same shape and magnitude as the modulation observed in Antarctic firn.

Parameter Values

Parameter	Component	Effect	Value Range
Surface Volume Fraction	Surface	Magnitude Offset	45 - 60 (%)
Correlation Length	Surface	Initial Shape	0.1 - 0.4 (m)
RMS Height	Surface	Rolloff	0.01 - 0.03 (m)
Particle Height	Volume	Magnitude Offset	0.125 - 0.2 (mm)
Particle a/b and a/c ratios	Volume	Azimuth Modulation	2 - 1.2 (ratio)
Particle Depth Gradient	Volume	Frequency Matching	0.001 - 0.003 (mm/m)

The surface and volume sections of the model rely on 6 parameters, outlined in the table above. Major new contributions include an increased understanding of the effects of surface volume fraction on the surface component, an implementation of a particle size depth gradient that enables parameter matching between frequencies, and exploration of a novel mechanism for azimuth modulation.

References

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