

Assessment of Dual-Frequency Radar for Retrieval of Snow Properties

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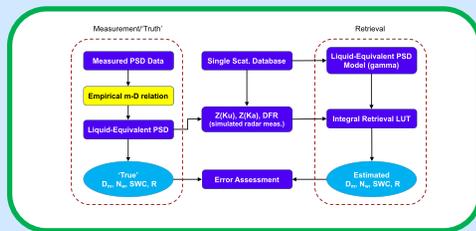
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Introduction

The objective of present study is to evaluate performance of the standard technique, which uses the differential frequency ratio (DFR), defined as the difference of radar reflectivities between two wavelengths, for the estimation of snow parameters. Although the DFR-based technique is effective in obtaining snow properties, its retrieval accuracy depends on parameterization of particle size distribution (PSD) and radar scattering model. Understanding the uncertainties resulting from these model assumptions in snow estimation is important in evaluating the overall performance of dual-frequency retrieval techniques. Furthermore, separation of the uncertainties associated with the PSD models and the scattering models and their respective contributions to overall uncertainties are useful for gaining insight into ways to improve the retrieval methods.

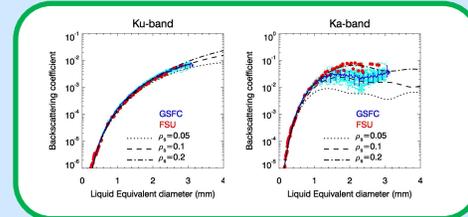
In this study, our focus is on assessment of the uncertainties in snow estimates arising from PSD parameterization, or more specifically, model of particle liquid-equivalent size distribution mass spectrum. To achieve this, observed PSD data are employed. The liquid-equivalent size spectra, which can be converted from measured PSD using an empirical mass-size relation, are used to obtain PSD parameters, e.g., the mass-weighted diameter (D_m) and the normalized intercept of a gamma PSD (N_w), and the snow bulk parameters, such as snow liquid water content (SWC) and snowfall rate (R) if fall velocity is known. Coupling the measured PSD with the particle scattering model, radar measurements are simulated, which are subsequently used as inputs to the standard dual-frequency algorithm. An evaluation of the retrieval accuracy is actually conducted by comparing the radar estimates of D_m , N_w and SWC and R with the same quantities directly computed from the PSD spectra or 'truth'. The scattering databases developed in NASA/GSFC (Kuo et al. 2016) and Florida State University (FSU) (Nowell et al. 2013) are employed in this study.

Approach



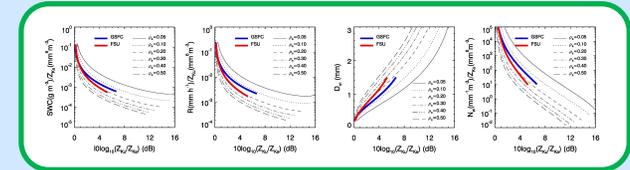
Flowchart that shows the procedures in assessment of uncertainties associated with the PSD model assumed in the dual-frequency radar technique. The left block provides snow parameters that are directly computed from measured PSD using an empirical mass-size relation, which are therefore regarded as 'truth'. The right block shows the way to infer snow parameters based on gamma PSD model. The measured reflectivities simulated from the measured PSD (middle block) are the input to the retrieval algorithm. Same scattering database is used for generating measurements of radar reflectivities and for snow retrieval. The differences of snow parameters between estimates and true values are attributed to the uncertainties associated with the PSD model assumed for retrieval.

Scattering Model



Backscattering coefficients of snow at Ku- (left) and Ka-band (right) obtained from NASA/GSFC (blue) and FSU (red) scattering databases. Green dots represent the results of pristine crystals and aggregates provided by the GSFC database. The blue solid heavy line is their mean and vertical blue lines denote two-time standard deviations of the data. For reference, the data from simple spheroidal model with constant snow densities (ρ_s) of 0.05, 0.1 and 0.2 g/cm³ given in black dotted and dashed curves.

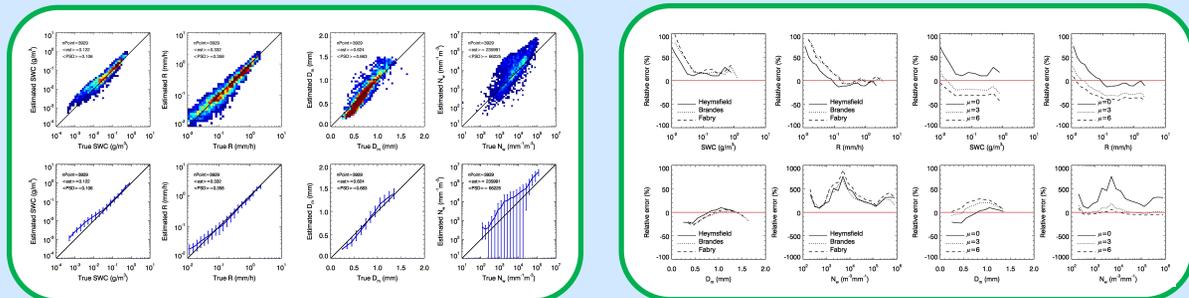
Look-up Tables



The look-up tables (LUT) for estimates of the snow water content (SWC), snowfall rate (R), D_m and N_w , in which DFR is expressed along the abscissa and the snow parameter, normalized by the Ku-band radar reflectivity, is given along the ordinate. The results from the GSFC and FSU are given in blue and red curves, respectively. The black curves correspond to those derived from spheroidal model with fixed densities varying from 0.05 to 0.5 g/cm³. All of the computations are made under the assumption that the snow particles are randomly-oriented and their liquid-equivalent sizes follow gamma distribution with the shape factor $\mu=0$. Note that the largest snow-particles included in both GSFC and FSU databases are up to liquid-equivalent diameters around 3 mm, leaving DFR less than 8 dB. Similar LUT can be created at different μ .

Comparisons between Estimated and True Values

To assess snow retrieval accuracy, SWC, R, D_m and N_w derived from the standard dual-frequency technique via the LUT as illustrated above, are compared with the same quantities obtained from the measured PSD (truth) assuming a mass-size relation (m-D). Three mass-size relations, i.e., Heymsfield et al. (2010), Brandes et al. (2007) and Fabry et al. (1999), are tested. Illustrated below in the left block is an example of snow comparisons: The top row provides the scatterplots (in terms of 2-dimensional pdf) of the estimated and true values while the bottom row presents their mean values (heavy solid lines) and two-time standard deviations (thin vertical bars) as the Heymsfield's m-D relation is used and gamma PSD with $\mu=0$ is assumed for retrieval. The relative errors of the estimates to their true values are provided in the right block, in which the left 4 panels show the results obtained from 3 different m-D relations. For the retrieval, the LUT of $\mu=0$ is used. The right 4 panels display the relative errors for μ values of 0, 3 and 6.



Remarks

- As snow is assumed to obey a gamma distribution, retrieval accuracy has been assessed using measured snowflake size spectra converted to mass spectra by using empirical m-D relations. In the evaluation procedure, the same scattering database is employed to simulate radar reflectivities and to infer snow properties. It is found that: 1) Retrieval accuracy is not sensitive to the m-D relation chosen, which is encouraging from the perspective of the retrieval because the m-D relations are highly variable, depending on snowflake types; 2) Values of μ have various impacts on snow retrieval, e.g., there is less bias in estimates of snowfall rate when $\mu=0$ while better agreement of N_w with their true values (PSD directly derived) is achieved when $\mu=3$; 3) Less than 10% and 30% negative biases in R estimates are obtained when $\mu=0$ and 3, respectively.
- Above findings are not affected by the scattering databases (GSFC/FSU) selected as long as same scattering tables are used for generating radar parameters and for snow retrieval.