Snow Retrieval by Ku- and Ka-band Dual-Frequency Radar

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Introduction

Accurate estimates of snow microphysical properties and its bulk parameters have been a great challenge to active and passive microwave sensors because of the complex geometric shapes and composite structures and also because of the variability in snow particle size/mass distributions (PSD). To develop an effective snow retrieval algorithm, it is important to know the uncertainties associated with the scattering properties of individual particles and the PSD models. The degree of the retrieval accuracy, however, depends on the methods used and sensor frequencies employed. The aim of this study is to explore a suitable scattering model and a proper PSD assumption in estimates of snow micro/macro-physical properties for the Dual-frequency Precipitation Radar (DPR) aboard the Global Precipitation Measurement (GPM) core satellite.

Although a few scattering databases are available to provide the scattering properties of snow aggregates, they are often limited to small-to-moderate particle sizes for a limited set of frequencies. To develop an operational-type radar algorithm for the DPR snow retrieval, it is desirable to have a scattering model that enables efficient computation at an arbitrary frequency over a large range of particle sizes. Comparisons of the scattering results from simple to complicated snow models indicate that the scattering properties of aggregates at the DPR frequencies are fairly well reproduced by randomly-oriented ellipsoidal particles if the effective mass density of snow is constant with size and takes on a value between 0.2 and 0.3 g/cm³. By taking advantage of both developed scattering databases and simple scattering models, we will employ the scattering results of the aggregates for small to moderate particle sizes and use the results from the simple scattering (ellipsoidal) models for large particles to cover the full range of particle sizes for characterizing snow scattering property.

A study of the dual-wavelength technique will be carried out for snow estimates. An analysis of the retrieval uncertainties associated with the PSD model and the particle scattering model will be performed. To aid in the development of the dual-wavelength radar technique and to further evaluate its performance, measurements of the snow size distribution and fall velocity acquired from the Particle Image Probe (PIP) will be used in our study.

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Scattering Model

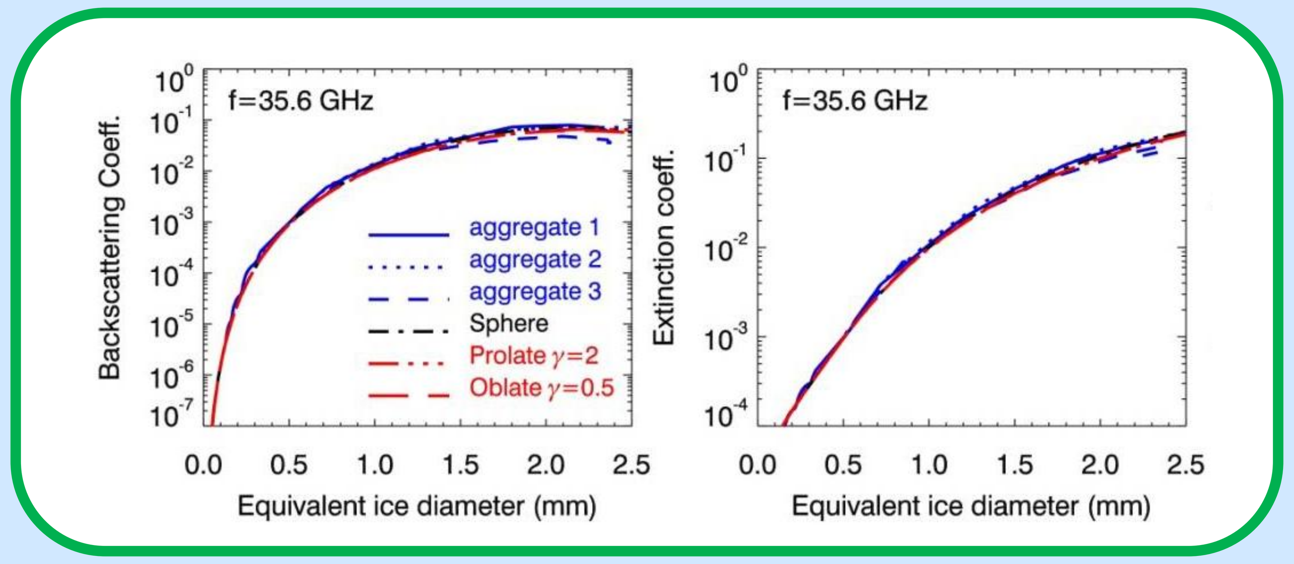

Fig.1 Comparisons of backscattering (left) and extinction (right) coefficients of 3 snow aggregates with the results from the sphere, oblate and prolate spheroids at a frequency of 35.6 GHz in terms of equivalent ice diameter. A constant snow density of 0.2 g/cm³ is assumed for all spherical and spheroidal particle models. The oblate and prolate spheroids are randomly oriented with aspect ratios (γ) of 0.5 and 2, respectively.

PSD Data

Snow measurements were carried out from 8 snow events during winter of 2014 at the NASA Wallops Flight Facility using the Snow Video Imager/Particle Image Probe (SVI/PIP). Shown in Fig.2 are examples of measured snow particle size spectra in time series (top), the liquid-equivalent snowfall rate (middle) and mass-weighted diameter (bottom) as derived from the mass spectra converted from measured PSD using the density-size relation reported by Heymsfield et al. (2004).

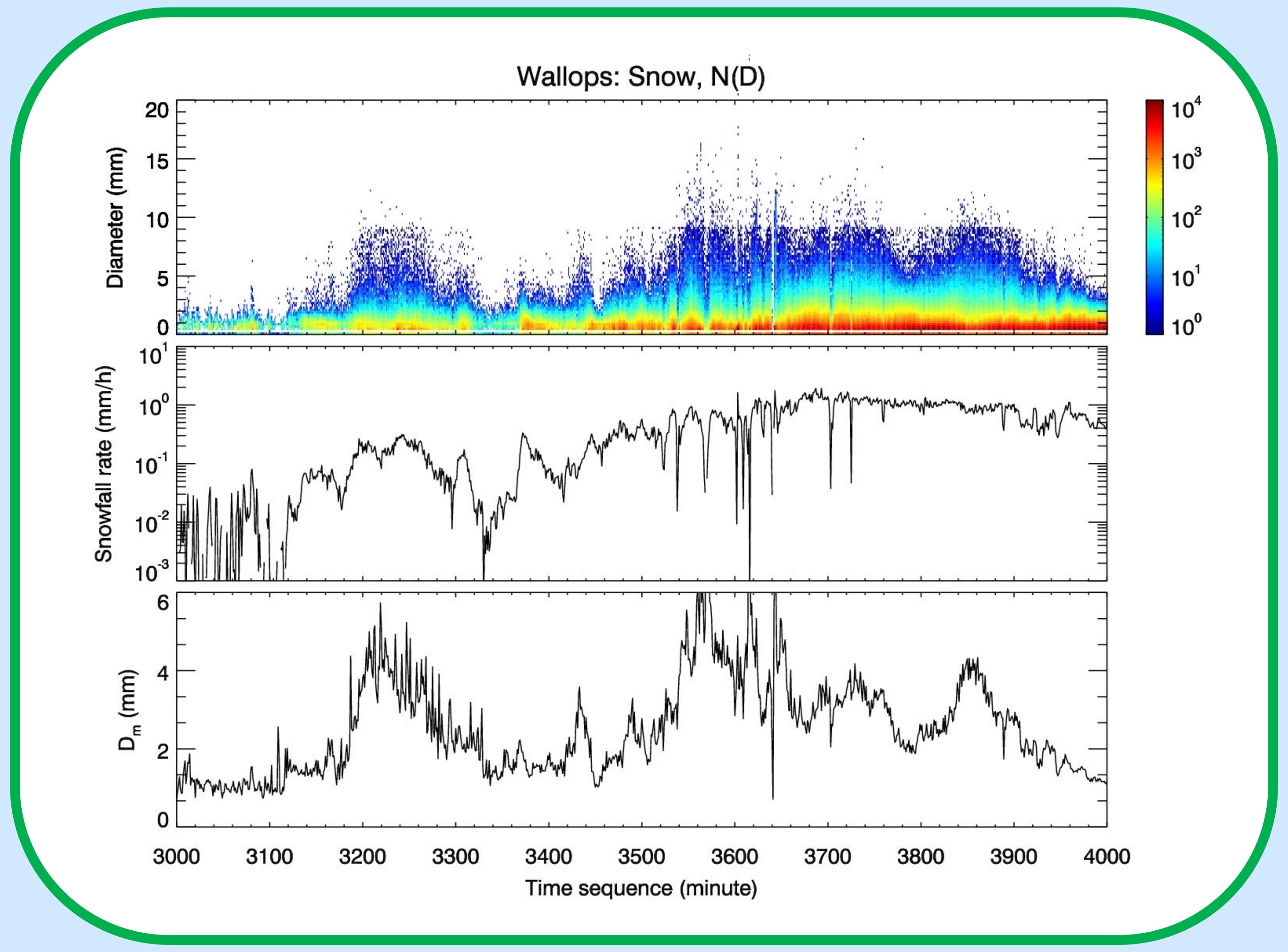

Fig.2 Measured snow particle size spectra (top) and corresponding snowfall rate (middle) and mass-weighted diameter (bottom) in the Wallops from the SVI/PIP during the winter of 2014.

Impacts on Retrieval

Shown in Fig.3 is the DFR plotted as a function of the equivalent-liquid median mass diameter D_m using a randomly-oriented, fixed density spheroidal particle model. The left plot shows the variations in the DFR-D_m relation resulting from different effective snow densities (ρ_s). The center plot shows the effects of particle shape where a γ value of 1 corresponds to a sphere while γ values less than 1 correspond to an oblate spheroid. The plot on the right shows the effect of changing μ. The results indicate that particle shape and μ value have only a small effect on altering the DFR-D_m relation. On the other hand, DFR-D_m relation has a strong dependence on the effective snow density.

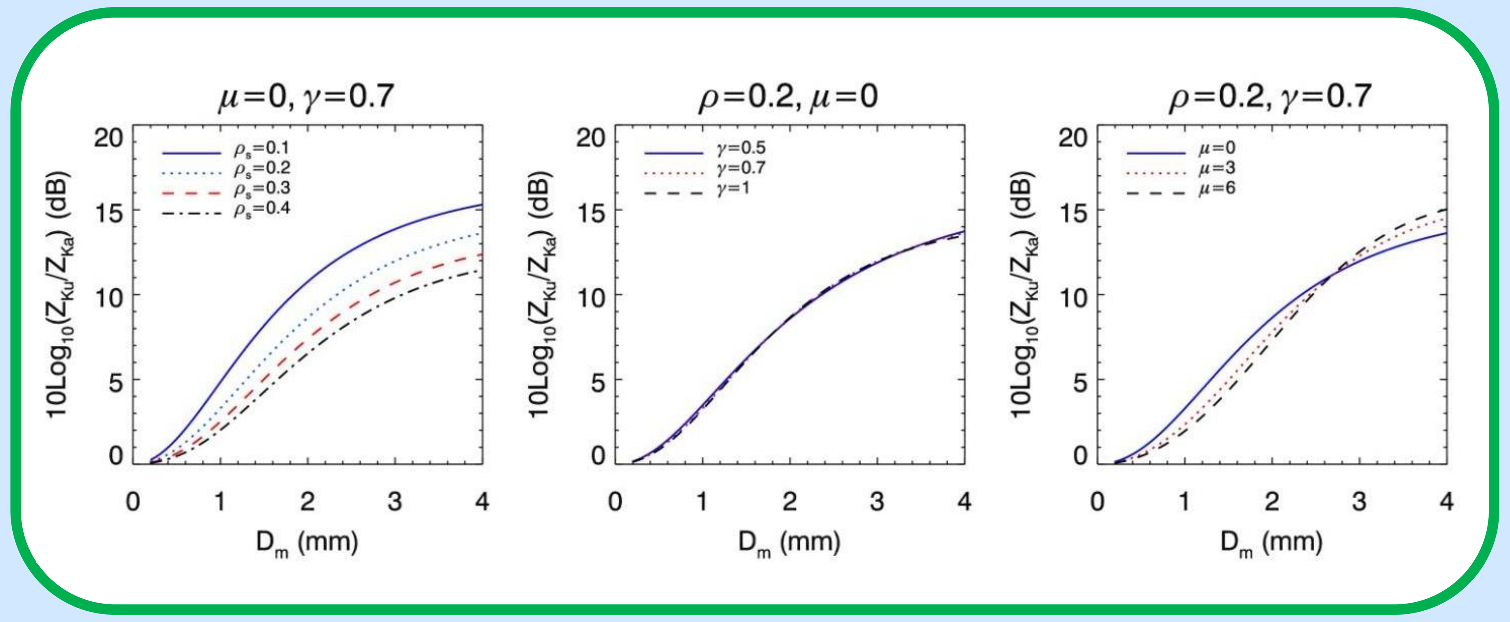

Fig.3 The differential frequency ratio (DFR=10LOG$_{10}$(Z_{Ku}/Z_{Ka})) as a function of equivalent-liquid median mass diameter D_m.

Retrieval LUT

1. Examples of LUT

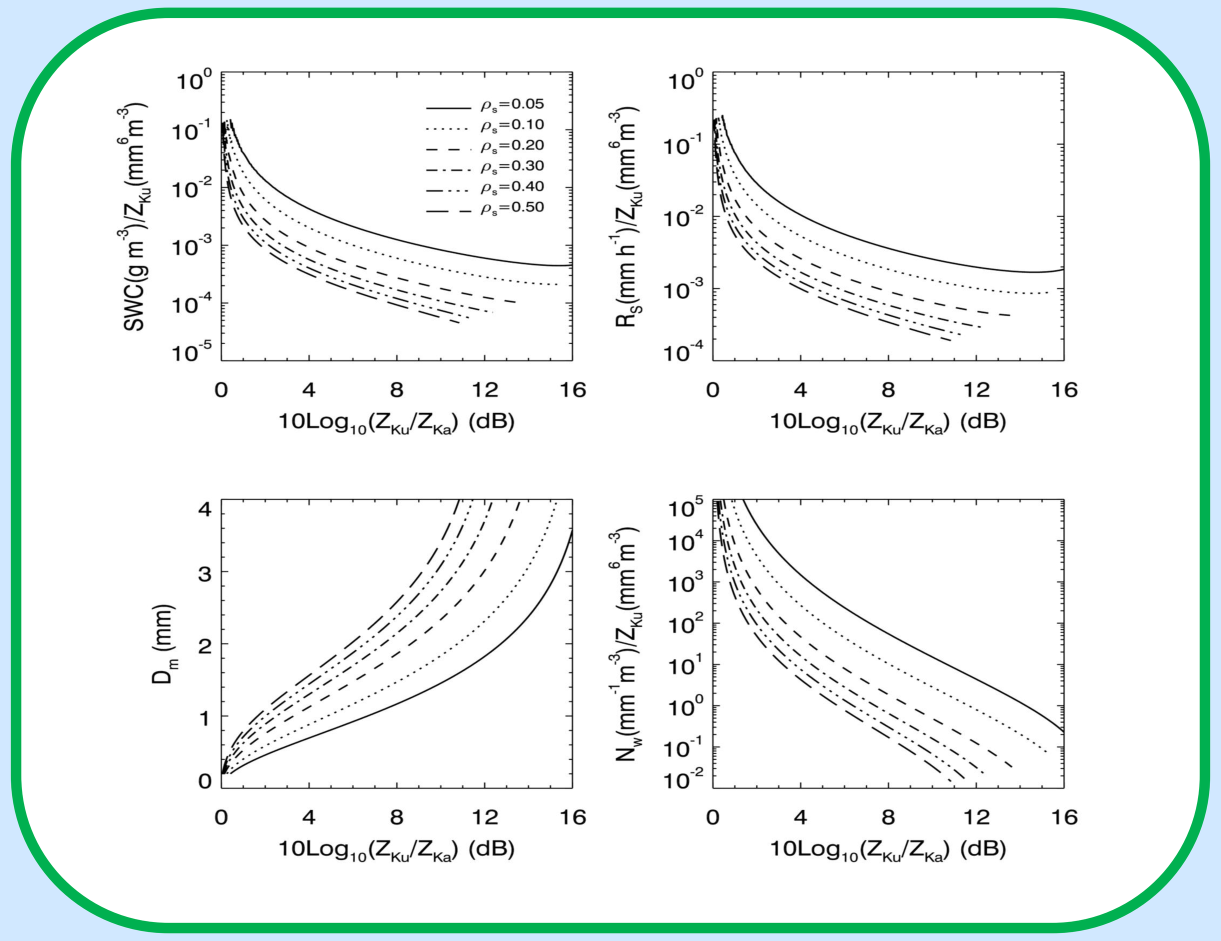

Fig.4 Examples of the LUT for estimates of the snow water content (SWC), snowfall rate (R_S), D_m and N_w, in which DFR of the Ku- and Ka-band radar is expressed along the abscissa and the bulk snow parameter, normalized by the Ku-band radar reflectivity, is given along the ordinate. The results are computed under the assumption that the snow particles are fixed-density, randomly-oriented oblate spheroids with an aspect ratio of 0.7 that follow an exponential particle size distribution.

2. Evaluation through PSD

In order to obtain the snow mass spectra needed for computing the radar reflectivities and snow bulk parameters, the empirical density-size relations reported by Heymsfield et al. (2004) and Brandes et al. (2007) are used. Superimposed in Fig.5 are the scatter plots computed from the measured PSD (red dots) when the effective snow density of 0.2 g/cm³ is assumed and the randomly-oriented spheroid model with an aspect ratio of 0.7 is used.

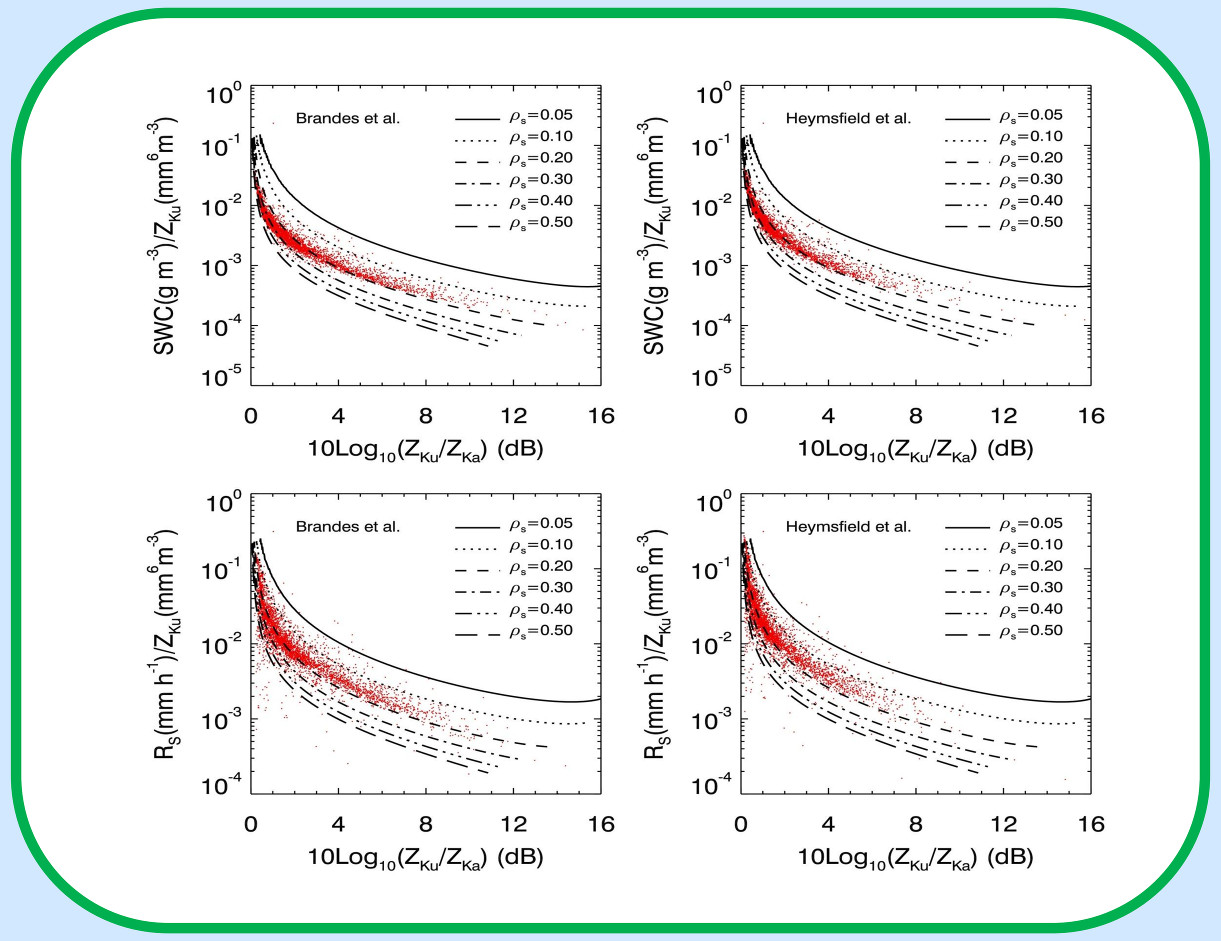

Fig.5 Same as in Fig.4. The scatter plots (red dots) are the results derived from the measured PSD that were collected by the SVP/PIP from 8 snow events in the winter of 2014 at the NASA Wallops Flight Facility. Comparisons of SWC and RS are made when Brandes et al. (2007) (left panels) and Heymsfield et al. (2004) (right panels) density-size relations are used to derive snow mass spectra from the PSD.