Development of Ice and Mixed-phase Precipitation Parameterizations for GPM Combined Radar-Radiometer Algorithm Applications

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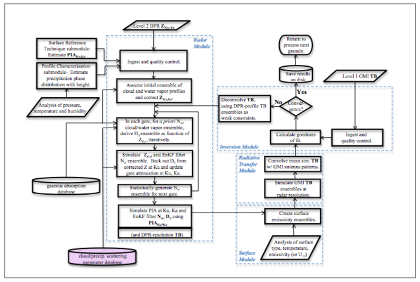


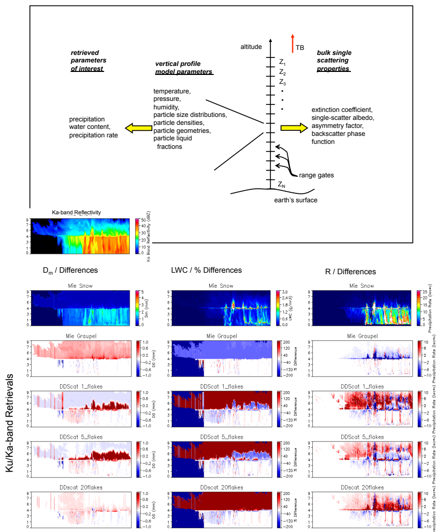
Why? **to improve the physical / statistical models used in GPM radar and combined radar-radiometer precipitation retrieval algorithms.** At left is a schematic of the prototype GPM combined radar-radiometer precipitation estimation algorithm. This algorithm uses input radar reflectivities from the Dual-wavelength Precipitation Radar (DPR) and microwave brightness temperatures from the GPM Microwave Imager (GMI) to deduce profiles of precipitation in all phases (liquid, ice, and mixed-phase). The accuracy of these precipitation estimates depends not only on the validity of the input data, but also on the realism and representativeness of the physical profile models used to fit the input data. In the figure at left, the microwave electromagnetic scattering properties of precipitation particles are tabulated in the purple static file. These tabulated scattering properties are functions of the assumed particle phase (temperature), particle size distribution, density distribution (for ice and mixed-phase), habit, and meltwater fraction. In addition to the tabulated scattering properties, for algorithm applications it is also important to prescribe the statistical behavior of precipitation particle size distributions; e.g., the covariance of particle size distribution parameters as a function of altitude. The objective of this work is to develop better parameterizations of the physical and statistical properties of ice and mixed-phase precipitation for algorithm applications.

Modeling of Ice/Mixed-Phase Precipitation in Algorithms

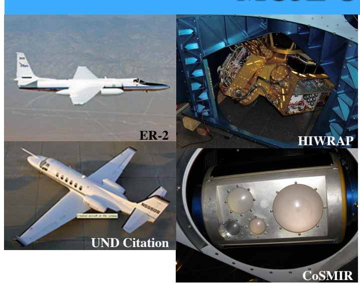
Descriptions of the vertical profiles of cloud, precipitation, atmospheric gases, temperature and pressure are needed to compute the profiles of bulk single-scattering properties of atmospheric layers and ultimately, the radar reflectivities and upwelling microwave brightness temperatures associated with those profiles. A complete description of all of the atmospheric properties in a vertical column is called a "vertical profile model", and a schematic of such a model suitable for combined radar-radiometer algorithm applications is shown at right, with atmospheric properties specified in each range gate of the DPR.

The standard vertical profile models developed during the TRMM era assumed that all precipitation-sized particles were spherical, due to the simplicity of computing the single-scattering properties of spherical particles. However, it is known that larger raindrops are better approximated by oblate spheroids, and ice-phase precipitation particles exhibit a variety of complicated particle geometries. The focus of our investigation will be to see if we can find reasonable parameterizations of ice- and mixed-phase precipitation particle size distributions and habits that produce bulk scattering properties which are consistent with simultaneous radar, radiometer, and *in situ* microphysics probe observations from the GPM field campaigns.

To test the consistency of ice- and mixed-phase precipitation parameterizations, tables of their bulk scattering properties will be included in a versatile retrieval algorithm that can be applied to simultaneous airborne radar and radiometer data. At right is an application of the algorithm applied to Ku- and Ka-band nadir-view reflectivity data from the dual-frequency Airborne Precipitation Radar (APR-2), collected during the GRIP field campaign. The panels in each row represent different assumptions regarding the physics of the assumed ice-phase precipitation; the top row is the precipitation field retrieved assuming spherical snow particles above the freezing level, and the subsequent rows show differences relative to the snow retrieval due to alternative assumptions regarding ice particle density and geometry.

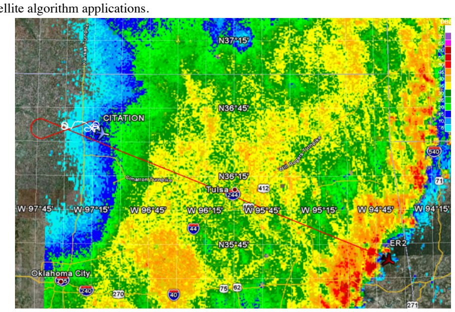


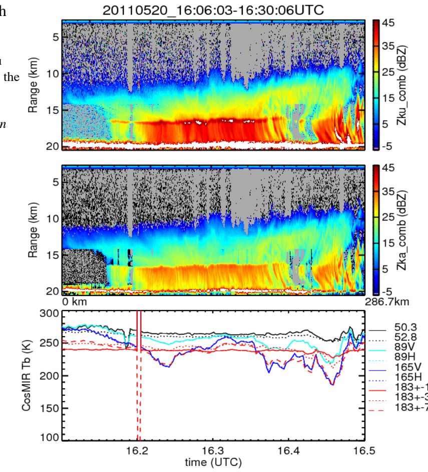
MC3E Observations for Testing



Although radar observations from GRIP were useful for testing the sensitivity of precipitation estimates to different precipitation particle assumptions, simultaneous radiometer and *in situ* observations are needed to better constrain the range of particle parameterizations and vertical structure models incorporated in retrieval algorithms. During the Midlatitude Continental Convective Cloud Experiment (MC3E), the ER-2 aircraft carried both the High-altitude Wind and Rain Profiling Radar (HIWRAP) and the Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR), which simultaneously viewed vertical columns of the atmosphere at nadir view. The HIWRAP radar operates at 14 GHz (Ku band) and 35 GHz (Ka band), while the CoSMIR senses upwelling microwave radiances from 50 to 183 GHz. The specific channels selected for HIWRAP and CoSMIR mimic the channels of the GPM DPR and GMI, respectively. Also during MC3E, the University of North Dakota Citation aircraft provided *in situ* microphysics probe measurements of precipitation in underflights of the ER-2.

At above right are the flight tracks of the ER-2 and Citation just prior to 1630 UTC on 20 May, 2011, superimposed on radar imagery of the observed squall line in the vicinity of Tulsa, OK. The stratiform region behind the convective line is of particular interest, since the horizontally-uniform precipitation structure of this region is simpler to model than more complex structures, providing a convenient testbed for evaluating precipitation parameterizations. At right are the Ku and Ka band reflectivities from HIWRAP and brightness temperature traces from CoSMIR during the flight leg. Our next step will be to apply the algorithm, described previously, to these data using different vertical structure models and precipitation parameterizations. The degree to which such models will fit the data, and the degree to which the estimated precipitation characteristics fit the *in situ* observations, will help to discriminate models and indicate which should be considered for satellite algorithm applications.





Modeling Particle Structure and Scattering Properties

from Kenneth Libbrecht; snowcrystals.com

from Ron Stewart; McGill University

simulated dendrite

simulated aggregate

For each particle size in any prescribed particle size distribution, the mass (or density) of the particle, its structure or habit, and the meltwater fraction of the particle must be specified. Starting with purely ice-phase precipitation, we have examined the properties of both pristine crystals (plates, columns, dendrites) as well as aggregates of crystals. At left, top are photographs of a single dendrite and an aggregate of dendrites. Aggregate ice particles are particularly important because they tend to be the dominant particle type among particles of relatively large size, and they also produce high reflectivities at the onset of melting. The figures below the photographs show silhouettes of dendrite and aggregate particles that have been simulated- the dendrite was simulated using a 2-D growth model, and the dendrite aggregate was constructed using a simple random process to sequentially collect modeled dendrites with different spatial orientations.

Once ice particles are constructed on a three-dimensional grid, microwave single-scattering properties are computed using the discrete dipole approximation (DDA; see Draine and Flatau, 2003). In the DDA, a particle is represented by a grid of dipoles; each dipole interacts with an incoming electromagnetic wave as well as the scattered waves from all other dipoles in the particle. Below are curves of particle extinction, single-scattering albedo, asymmetry parameter, and backscatter efficiency at 89 GHz vs. particle size parameter $x = \pi D / \lambda$. The computations include both spherical (random ice/air distributions within a spherical volume) and nonspherical (collections of dendrites with 1 to 20 members) particles.

We have also implemented a 3-D growth model for pristine crystals and a pseudo-gravitational collection model to create aggregate particles. The constructed particles are filtered to represent different observed size-mass relations. A large number of ice particles have been simulated using this method, ranging from single-crystal particles to multi-crystal aggregates. Subsequently, production runs of DDA calculations at the TRMM channel frequencies have been performed on a majority of these particles using parallel computing methods. The table below indicates status of the DDA calculations as a function of mass-equivalent diameter. Because of limitations of the DDSCAT numerical procedure, DDA computations for the larger aggregates are not always successful; nevertheless, the single-scattering properties of a large sample of aggregates has already been simulated.

Diameter[1] Category	No. Aggregates	No. Freq's[2]	No. Runs	Yield Rate[3]	Useable No. Particles
< 1 mm	246	× 7	1722	100%	246
1 – 2 mm	1715		12005	73%	1258
2 – 3 mm	3540		24780	58%	2053
3 – 4 mm	412		2884	28%	115
Total	5913	× 7	41391	71%	3672

Melting of individual aggregates will be simulated using a heuristic model, and these melting aggregates will be "mapped" to particles with the same size, mass, and meltwater fraction from a 1-D thermodynamic melting model; see Olson et al., *J. Appl. Meteor.* (2001).