Quantifying the relative impact of model microphysics parameterizations and scattering models in simulating synthetic radar and microwave radiometer observations

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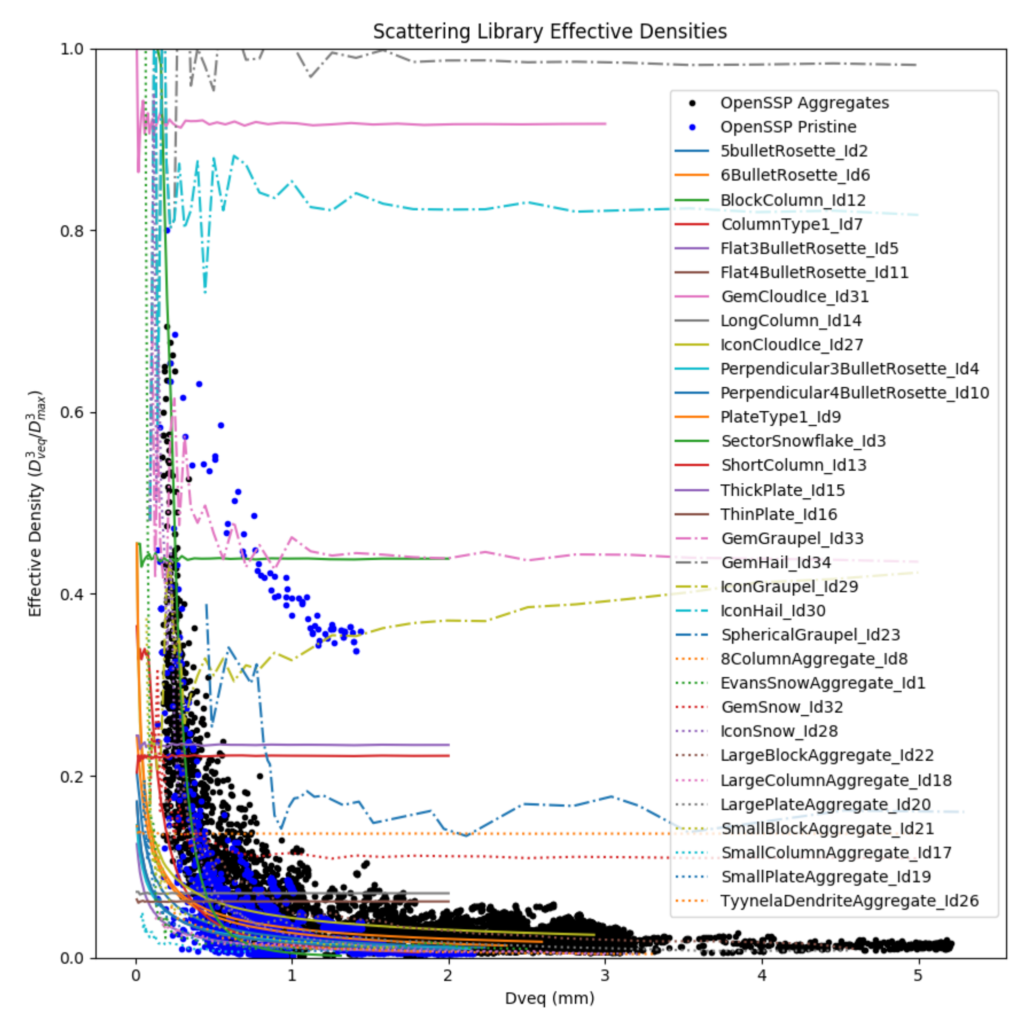
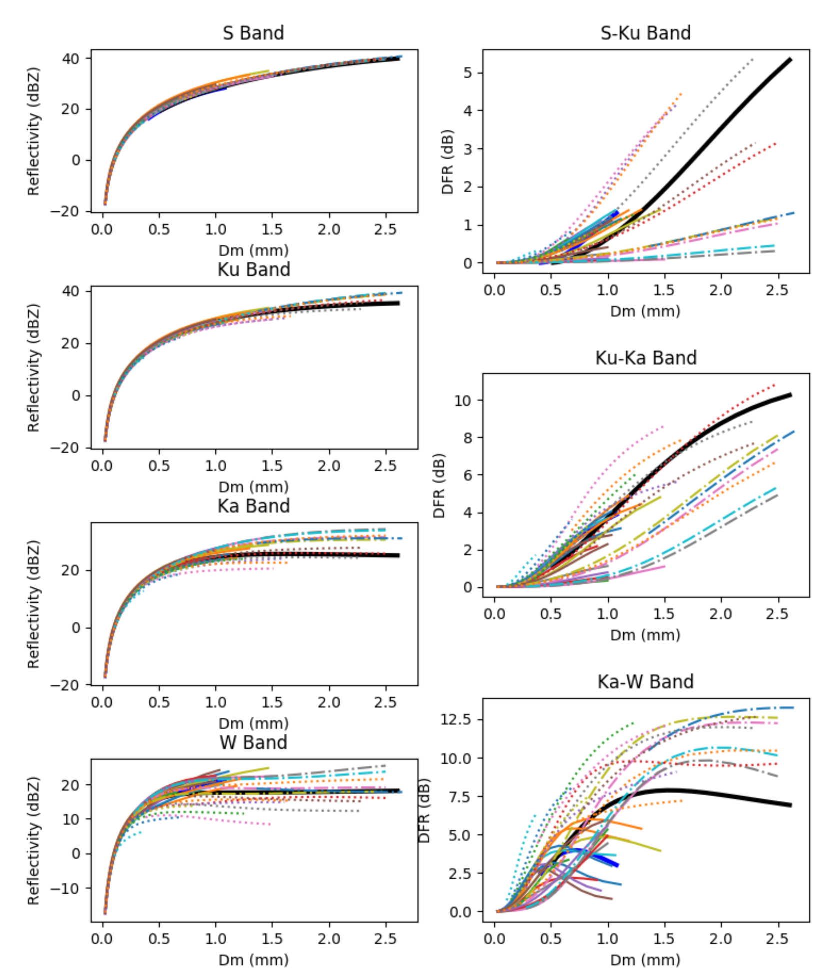
Introduction

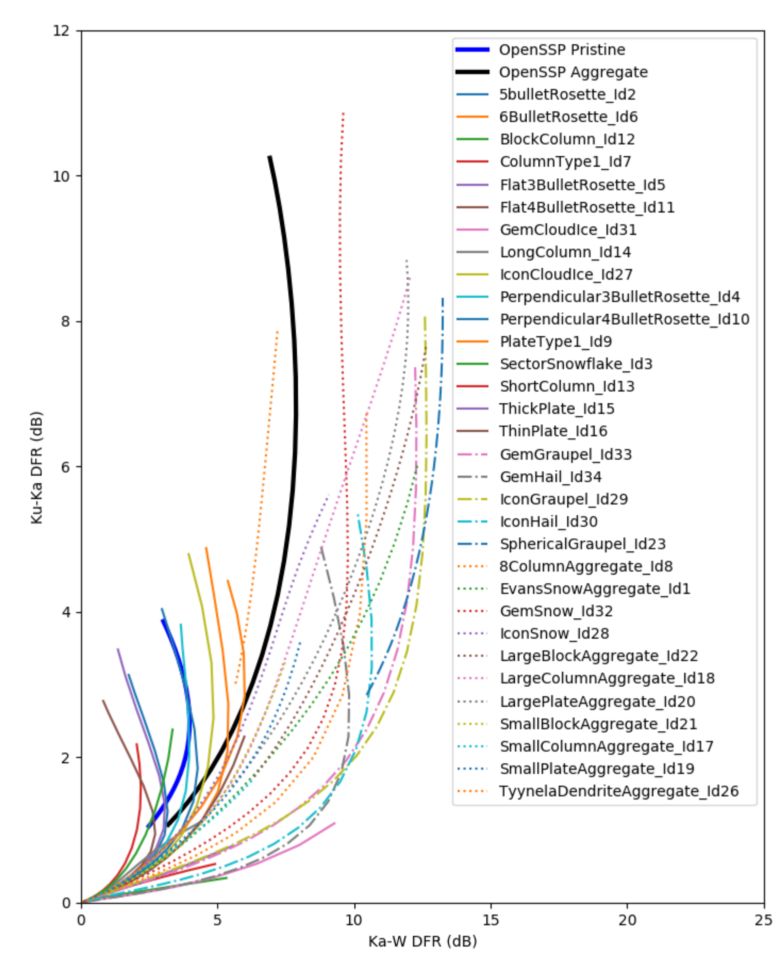
Output from numerical weather models is often used to simulate observations from remote sensing instruments, for purposes ranging from data assimilation, synthetic retrievals of geophysical quantities, and optimization of observing systems. However, when hydrometeors are present, the level of detail provided by the weather model is generally insufficient to fully constrain the input to the radiative transfer model (RTM), and further assumptions must be made by the RTM user in order to produce synthetic observations. Using a hierarchy of cloud-resolving models including double-moment, bin microphysical, and ice-habit predicting models, along with scattering properties from the OpenSSP, Atmospheric Radiative Transfer Simulator (ARTS) databases, as well as relatively simple geometries (e.g., cylindrical plates and columns), we demonstrate the spread in synthetic observation output and the extent to which it is reduced when microphysics is more strongly constrained by the model.

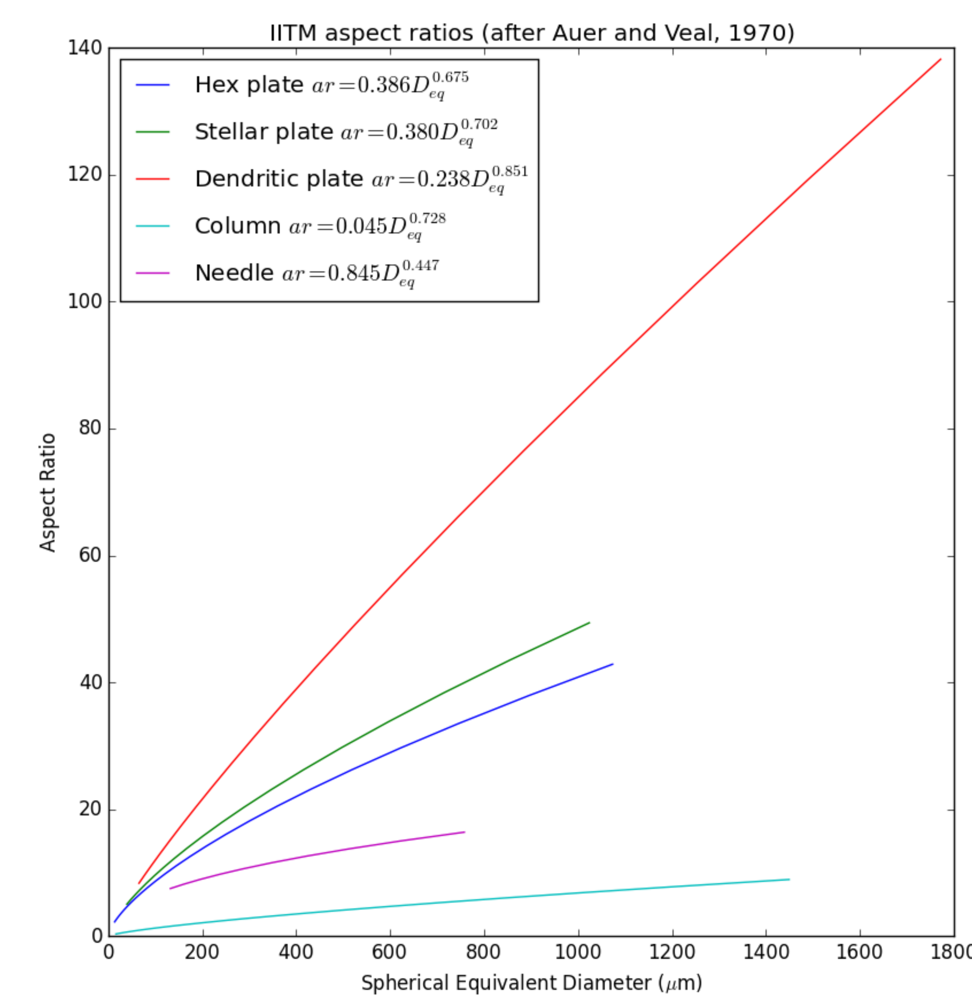
Scattering Libraries

	ARTS SSP 1.0	OpenSSP	T-Matrix (EBCM)	T-Matrix (IITM)
Frequency Range (GHz)	1-886	10.65-191	3-880	10-880
Size Range (D_{veq}, mm)	0.01-5.293	0.17-5.21	0.2-3.9	0.1-0.9
Phase matrix elements	S11, S12, S22, S33, S34, S44	S11, S12, S21, S22, S31, S41	all	all
Aligned Particles?	No	No	Yes	Yes
Geometric limitations	None (uses ADDA)	None (uses DDSCAT)	Rotational symmetry required; does not converge for aspect ratio > 6 (frequency dependent)	Rotational symmetry required



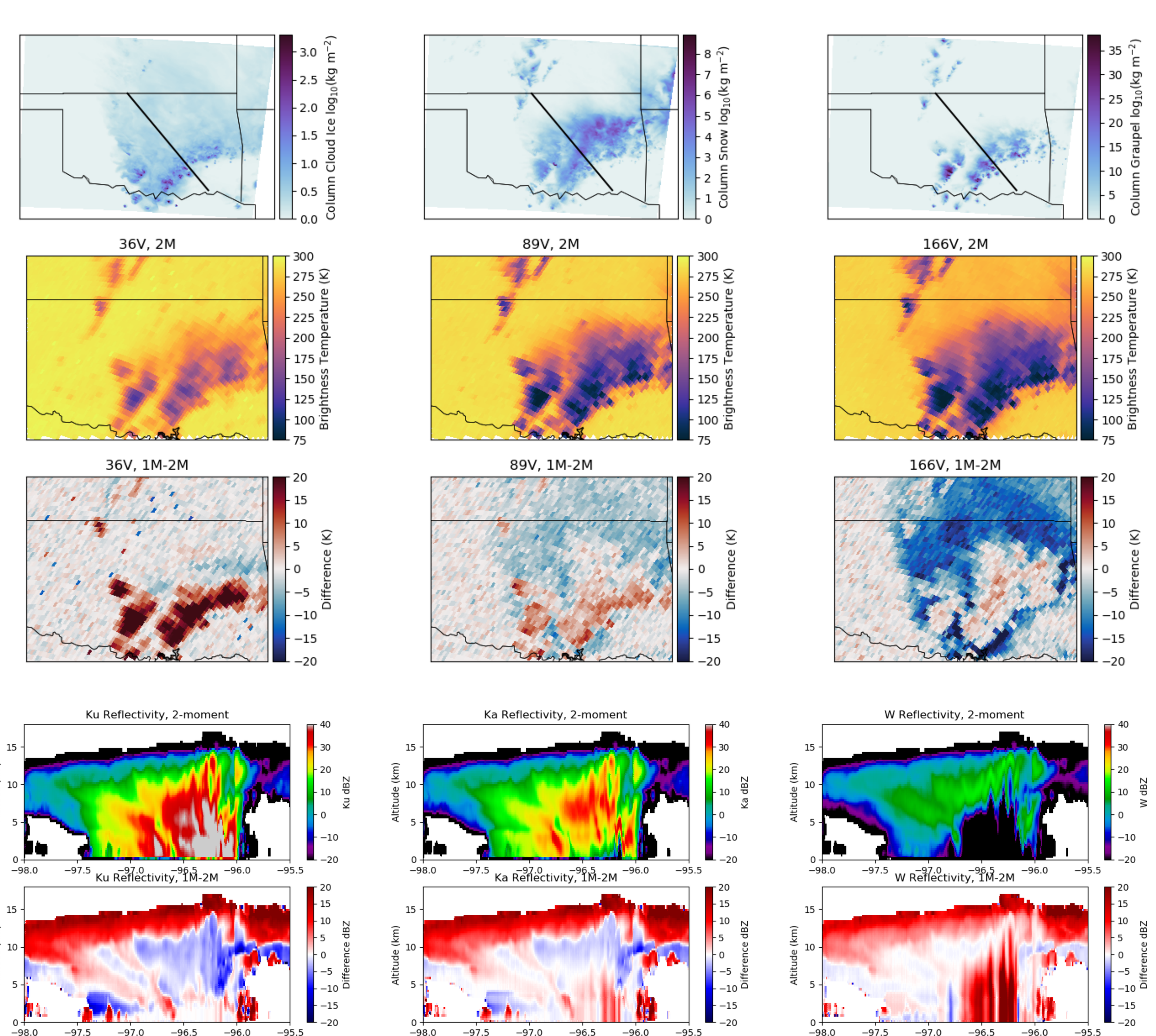


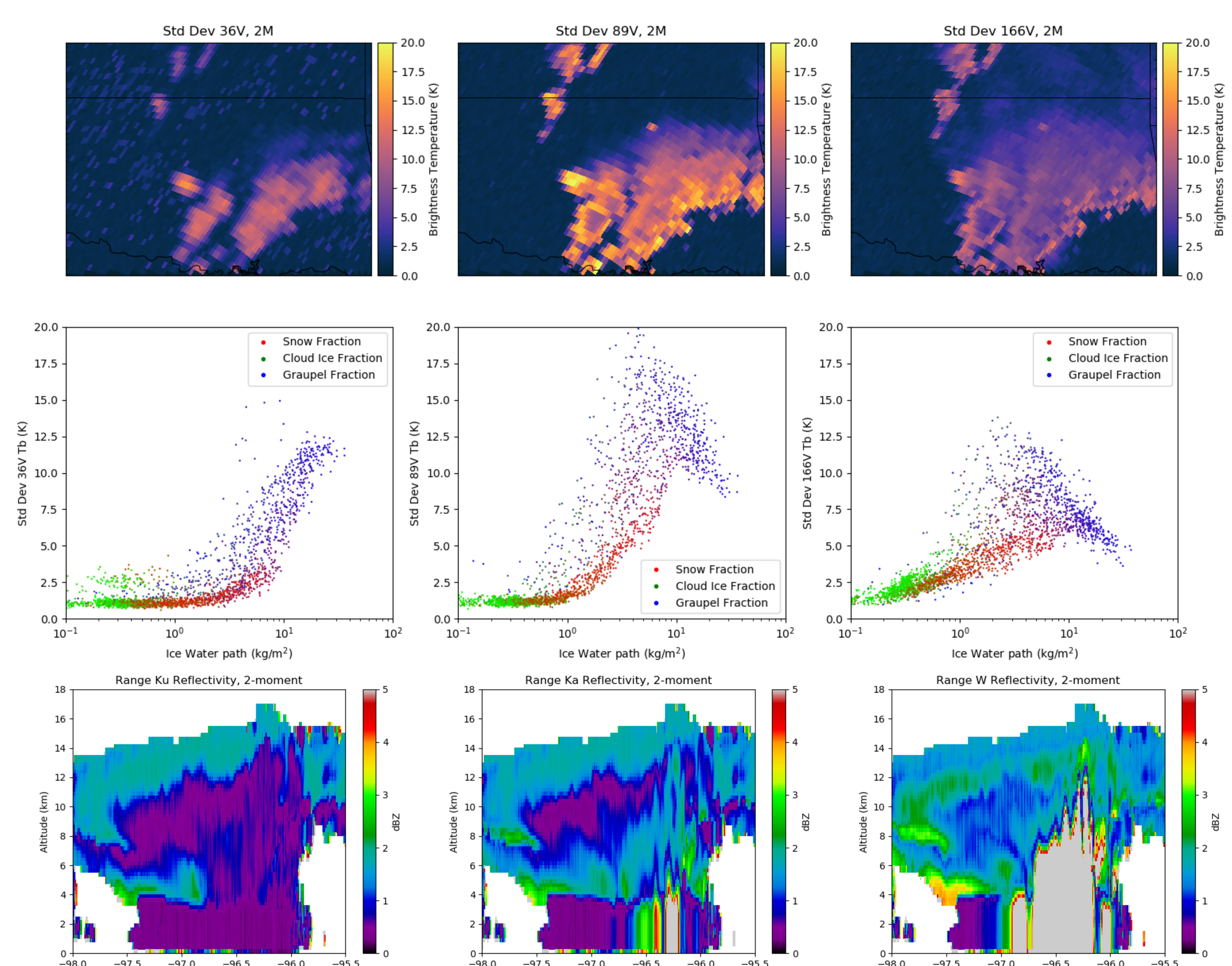




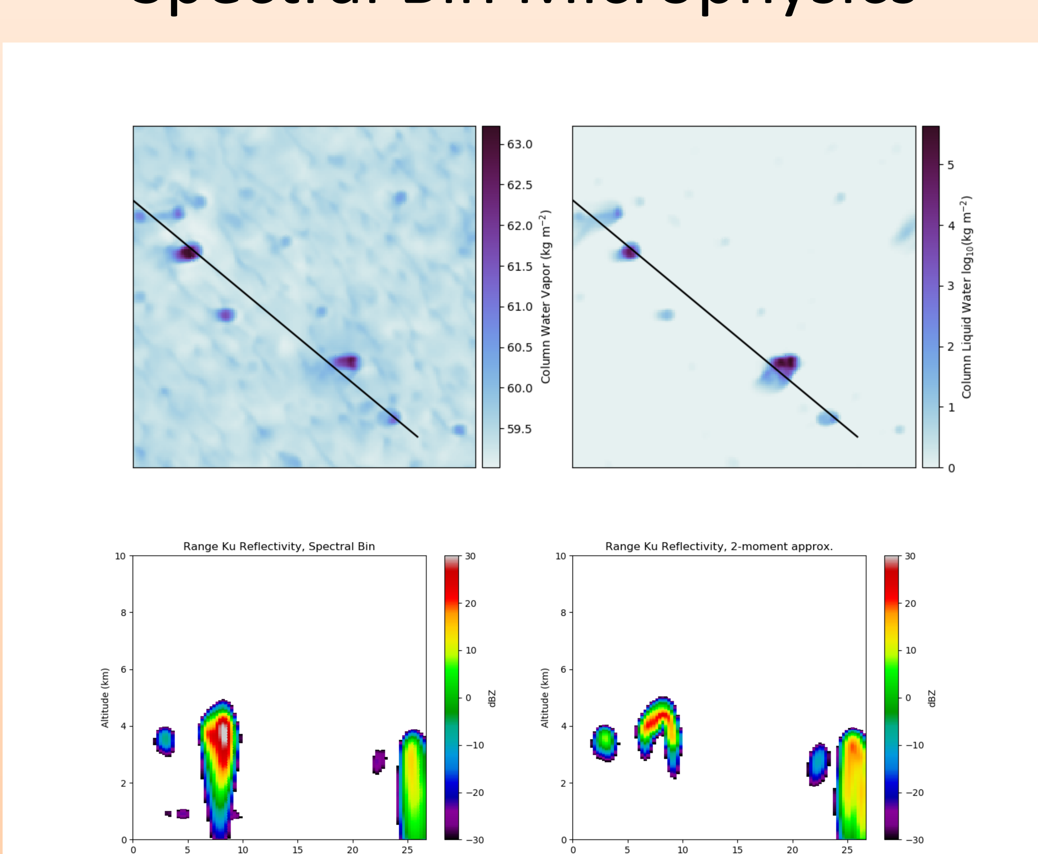
One- and Two-Moment Schemes

Bulk microphysical schemes predict one or more moments of the hydrometeor size distribution, typically mixing ratio and/or number concentration. In this experiment we took output from a WRF simulation of mesoscale convection from MC3E on 20 May 2011 using the Morrison et al. (2009) 2-moment microphysics scheme. Simulations of 36-, 89-, and 166-GHz brightness temperature from the GMI viewing geometry as well as airborne radar at Ku, Ka, and W bands were performed on the 2-moment data and a 1-moment conversion using temperature-dependent relationships between mixing ratio and number concentration. Significant differences are noted in different regions and at different frequencies, highlighting the inability of single-moment fits to represent the diversity of microphysics in this simulation.



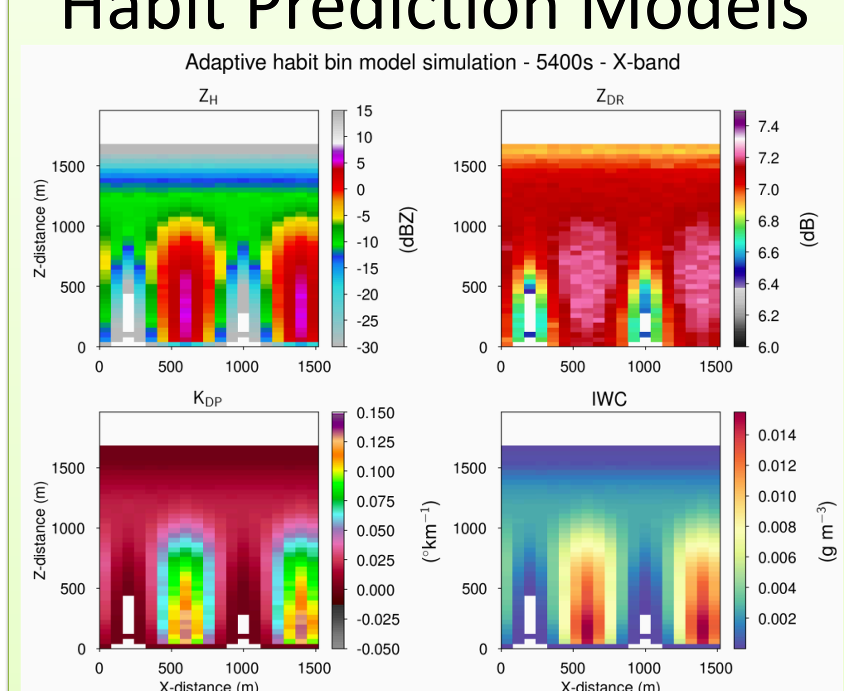


Spectral Bin Microphysics



Spectral bin microphysical models can simulate the evolution of particles in discrete bins and for discrete ice species (e.g., Khain et al., 2000). Because of the high computational cost, domain size is often limited (the above simulation covers 25 x 25 km), but these models can serve to tune lower-moment parameterizations. The impact on simulated radar reflectivity can be substantial, as shown above, owing to the strong dependency of the radar reflectivity on the distribution of the largest particles, which may not be adequately captured by a two-moment model.

Habit Prediction Models



Adaptive habit models (e.g., Jensen et al., 2017) explicitly predict the evolution of ice particle shape and density as a function of environmental conditions. These models remove the somewhat arbitrary distinction between classes in bulk models and provide more constraint on the scattering models that may be used to simulate remote sensing observations, but still leave some parameters (e.g, orientation distribution) to the discretion of the forward model. The initial temperature and humidity profile from the case shown above (Schrom and Kumjian, 2019) are from an Arctic, vapor-growth dominated cloud case; this simulation has no riming or aggregation so the ZDR is relatively high, similar to the observations.

Sensitivity to Scattering Model

Using the 2-moment MC3E case WRF output with 3 ice species (cloud ice, snow, and graupel), sensitivity to scattering models was testing by simulating brightness temperatures and radar reflectivity with 3 different scattering models from the ARTS SSP for each species:

- Cloud ice: Gem Cloud Ice, Icon Cloud Ice, Flat 3-Bullet Rosette
- Snow (aggregates): Gem Snow, Large Block Aggregate, Large Plate Aggregate
- Graupel: Gem Graupel, Gem Hail, Spherical Graupel

Significant sensitivity in terms of brightness temperature standard deviation is noted at all 3 frequencies but is highest at 89 GHz. For a given ice water path, the simulated brightness temperatures are most sensitive to the choice of graupel scattering model at all frequencies. Meanwhile, the range of reflectivity is within 2-3 dB between all combinations of scattering models. Sensitivity to attenuation differences are noted at Ka- and W-band.

References

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