The Impact of Raindrop Collisional Processes on the Polarimetric Radar Variables

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Introduction

We investigate how the raindrop collisional processes in warm rain (coalescence, breakup) affect the radar reflectivity factor at horizontal polarization Z_H, differential reflectivity Z_{DR}, and specific differential phase K_{DP}.

The fingerprint of each microphysical process is quantified individually and in combination for a variety of DSD shapes and nominal rainfall rates using a spectral bin model and electromagnetic scattering calculations. These fingerprints are compared to disdrometer and radar observations.

Methods

The 1-D version of the explicit bin microphysical model of Prat et al. (2012) is initialized with various DSDs and rainfall rates at the top of the model domain.

The DSD is allowed to evolve under the influence of selected microphysical processes: **size sorting/settling**, **coalescence**, **collisional breakup**, **aerodynamic breakup**.

The predicted DSDs are converted into vertical profiles of Z_H, Z_{DR}, and K_{DP} using T-Matrix scattering calculations (details of the parameters can be found in Kumjian and Ryzhkov 2012).

Evolution of Profiles

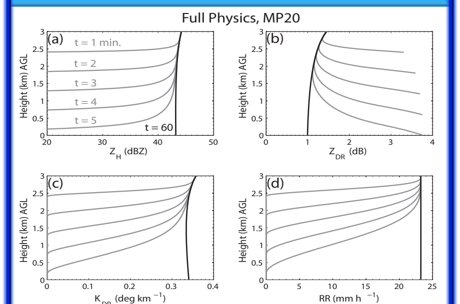
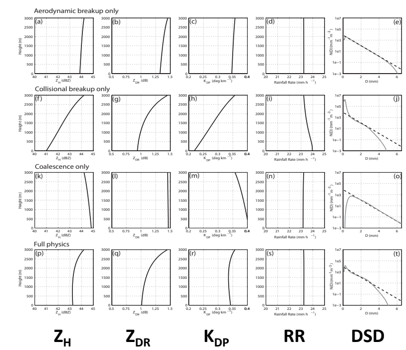


*Fig. 1: Evolution of the vertical profiles of (a) Z_H, (b) Z_{DR}, (c) K_{DP}, and (d) rainfall rate RR for a full-physics simulation over the first 5 minutes (gray curves) and after one hour (black curve). The initial impact of **size sorting** is evident by the large decreases in Z_H, K_{DP}, and RR coincident with a large increase in Z_{DR}.*

Microphysical Fingerprints



Aerodynamic breakup only: slight decrease towards the ground in Z_H, Z_{DR}, and K_{DP} owing to the breakup of large (D > 5 mm) drops.

Collisional breakup only: large decreases in Z_H, Z_{DR}, and K_{DP} owing to the breakup and depletion of medium and large (D > 3 mm) drops; large production of tiny (D < 0.5 mm) drops.

Coalescence only: slight increases in Z_H, Z_{DR}, and K_{DP} owing to the redistribution of mass from small (D < 1 mm) drops to larger drops.

Full physics: decreases in Z_H and Z_{DR}. K_{DP} initially decreases, owing to the breakup of large drops aloft, then increases as small drops 0.6 < D < 1.7 mm coalesce, leading to an increase of drops 1.7 < D < 3.1 mm.

Fig. 2: Fingerprints of individual microphysical processes (first three rows) and full physics (bottom row) in vertical profiles of (1st column) Z_H, (2nd column) Z_{DR}, (3rd column) K_{DP}, and (4th column) RR. The last column shows the initial DSD aloft (dashed curves) and the final, steady-state DSD at the ground (gray curves). Initial DSD aloft is a Marshall-Palmer type with nominal rainfall rate RR = 20 mm h^{-1}. Calculations here are for S band.

The impact of radar wavelength:
Changes in Z_H are largest in magnitude at X band; changes in Z_{DR} are largest at C band. Note the nonmonotonic behavior of the K_{DP} profiles at all 3 wavelengths; K_{DP} increases to larger than the value aloft at X band.

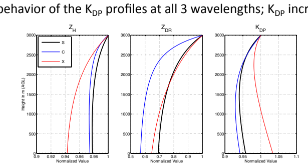


*Fig. 3: Normalized vertical profiles of (a) Z_H, (b) Z_{DR}, and (c) K_{DP} for a full-physics simulation initialized with a Marshall-Palmer DSD with nominal rainfall rate of 20 mm h^{-1}. Profiles are shown for **S band**, **C band**, and **X band**.*

The impact of different initial DSDs:
Full-physics simulations of the collisional processes show that the polarimetric fingerprints can occupy various regions in the ΔZ_H-ΔZ_{DR} and ΔZ_{DR}-ΔK_{DP} parameter space (Fig. 4). For example, ΔZ_H, ΔZ_{DR}, and ΔK_{DP} are positive when coalescence dominates and negative when breakup dominates. However, for the whole range of initial DSD shapes and RR, the fingerprint identified for evaporation (ΔZ_H and $\Delta K_{DP} < 0$, $\Delta Z_{DR} > 0$; Kumjian and Ryzhkov 2010) is distinct from those produced by the collisional processes.

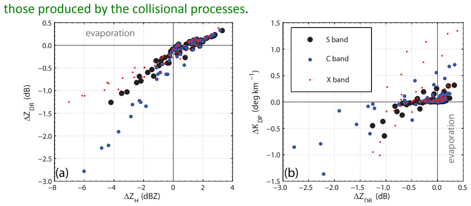


*Fig. 4: (a) Changes in Z_H vs. changes in Z_{DR} (b) changes in Z_{DR} vs. changes in K_{DP} over the 3-km domain for full-physics simulations initialized with a variety of DSDs of varying rainfall rates. Markers indicate **S band**, **C band**, and **X band**.*

Comparison with Observations

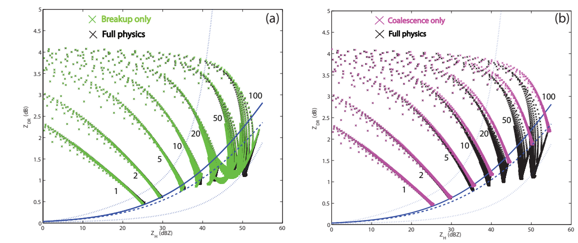


*Fig. 5: Evolution of the Z_H-Z_{DR} pairs for the DSD at each time and each height level for the **full physics** simulations, and (a) **breakup only**, (b) **coalescence only**. The numbers represent the rainfall rate aloft. Comparison with disdrometer observations collected in Oklahoma (blue solid curve: Cao et al. 2008), Florida (blue dashed curve: Zhang et al. 2006), and the envelope of observations in Florida (dotted blue curves: Brandes et al. 2004).*

The full-physics simulations for large RR produce negatively biased Z_{DR}, indicating over-aggressive breakup of drops and production of too many small drops. In contrast, simulations where only coalescence is permitted better match the disdrometer observations.

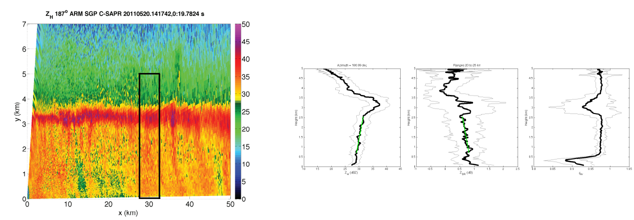
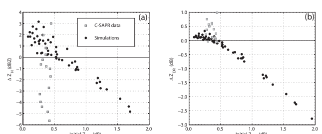


Fig. 6: (left) Field of Z_H in an RHI taken by the CSAPR at the DOE ARM Southern Great Plains site on 20 May 2011. The rectangle shows the window used for the averaging in the right panel. (right) Average vertical profiles of Z_H, Z_{DR}, and ρ_{hv} (black curves) with ±1 standard deviation shown (gray curves). The linear fit to the mean profiles is shown in green.

Fig. 7: (a) Change in Z_H vs. initial Z_H in simulations (black dots) and CSAPR observations (gray squares). (b) as in (a), except showing change in Z_{DR} vs. initial Z_{DR}. Note the strong signal for evaporation in the observations (i.e., negative changes in Z_H and positive changes in Z_{DR}).



Conclusions

-Each individual microphysical process (size sorting, breakup, coalescence, evaporation) produces a distinct fingerprint in vertical profiles of Z_H, Z_{DR}, and K_{DP}. This can allow for identifying the dominant process in rainfall.

-These polarimetric fingerprints are dependent on radar wavelength.

-Comparisons with disdrometer and radar observations suggest that the accepted parameterizations of drop breakup are too aggressive for the largest rainfall rates, resulting in very "tropical" DSDs heavily skewed towards smaller drops.

-Polarimetric radar observations in rain may be used to improve such parameterizations via inverse modeling techniques.

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