Diagnosing Raindrop Breakup and Coalescence from Vertically Pointing Radar Observations

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1. Motivation

Microphysical processes act on the distribution of falling raindrops such that evaporation and accretion modify the total liquid mass while breakup and coalescence modify how that liquid is distributed between different sized raindrops. This study uses Midlatitude Continental Convective Clouds Experiment (MC3E) observations to first retrieve raindrop size distributions (DSDs) from vertically pointing radars. Then, it defines Vertical Decomposition Diagrams which are used to diagnose evaporation / accretion processes and breakup / coalescence processes.

2. DSD Retrieval

The DSD profiles were estimated in two steps. First, the vertical air motion was estimated using the Bragg scattering signal in the 449-MHz vertically pointing radar (VPR) (Williams 2012). Second, the DSD was retrieved by fitting a modeled Doppler velocity spectrum to each observed 2.8-GHz (S-band) VPR spectrum using a normalized DSD (see Williams 2016 for retrieval details):

\[ N(D) = N_0 f(D; D_m, \mu) \]

where:

- \( N_0 \): normalized parameter defined as the intercept parameter of an exponential distribution (aka, \( N_0 \) with the same liquid water content \( q \) and mean diameter \( D_m \) of the original DSD (Testud et al. 2001).

Convert \( N_0 \) from a normalized parameter to number of drops per unit volume, \( N_t \):

\[ N_t = N_0 \frac{6}{\pi} \left( \frac{\rho_w}{\rho_r} \right) \left( \frac{4}{9} \right) \frac{(D_m)^3}{D_{\max}^3} \]

\( \rho_w \): liquid water content (LWC) [g m\(^{-3} \)]

3. Reflectivity Decomposition

Reflectivity [mm\(^6\) m\(^{-3} \)]:

\[ z = \int_0^{D_{\max}} f(D; D_m, \mu) D^2 \text{d}D \]

Reflectivity in logarithmic units [dB]:

\[ Z_{dB} = 10 \log(N_w) + 10 \log \left( \sum_{D=0}^{D_{\max}} f(D; D_m, \mu) D^2 \text{d}D \right) \]

\[ Z_{dB} = N_t^{dB} + \mu D_{\max}^{dB} \]

Benefit of logarithmic units – Change in \( dB \) is a percent change:

- \( \Delta 1 \text{ dB} = \Delta 25\% \)
- \( \Delta 2 \text{ dB} = \Delta 50\% \)
- \( \Delta 3 \text{ dB} = \Delta 100\% \)

Reflectivity, \( \mu \)

Normalized Number Concentration, \( N_t^{dB} \)

(Decreasing with decreasing height)

Mean Diameter, \( D_m \)

(increasing with decreasing height)

Reflectivity shape factor, \( \mu \)

(increasing with increasing height)

Reflectivity Vertical Decomposition Diagram

10-minute interval: 12:00-12:10

4. LWC Decomposition

Liquid Water Content (LWC):

\[ q = \frac{N_t}{\rho_w} \int_0^{D_{\max}} f(D; D_m, \mu) D^2 \text{d}D \]

LWC in logarithmic units [dB]:

\[ q_{dB} = 10 \log(N_w) + 10 \log \left( \sum_{D=0}^{D_{\max}} f(D; D_m, \mu) D^2 \text{d}D \right) \]

\[ q_{dB} = N_t^{dB} + \mu D_{\max}^{dB} \]

Change in \( q_{dB} \) related to Evaporation / Accretion (loss / gain of mass)

Reflectivity, \( Z_{dB} \)

Liquid Water Content, \( q_{dB} \)

(Decreasing with decreasing height) (Evaporation)

Total Number Concentration, \( N_t^{dB} \)

(Decreasing with increasing height)

(Fewer number of raindrops)

LWC shape factor, \( \mu_{DB} \)

(Increasing with decreasing height)

(Raindrops are getting bigger)

5. Concluding Remarks

By expressing DSD parameters in logarithmic units, total liquid water content is a linear function of raindrop number and size:

\[ q_{dB} = N_t^{dB} + \mu_{DB} \]

Changes in \( q_{dB} \) with height indicate: evaporation or accretion

Changes in \( N_t^{dB} \) & \( D_{\max}^{dB} \) indicate: breakup or coalescence

6. References

Maneghin, R., S.W. Bidwell, L. Liao, R. Rincon, and G.M. Heymsfield, 2003: Differential-frequency Doppler velocity spectrum to each observed 2.8-GHz (S-band) VPR spectrum using