Diagnosing Raindrop Breakup and Coalescence from Vertically Pointing Radar Observations

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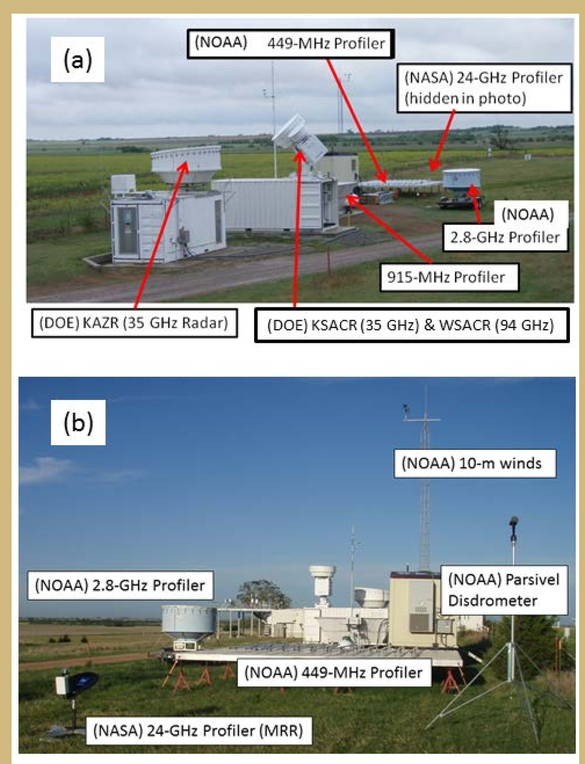
Williams, 2016: Reflectivity and liquid water content vertical decomposition diagrams to diagnose vertical evolution of raindrop size distributions. *J. Atmos. Oceanic Technol.*, **33**, 579-595.

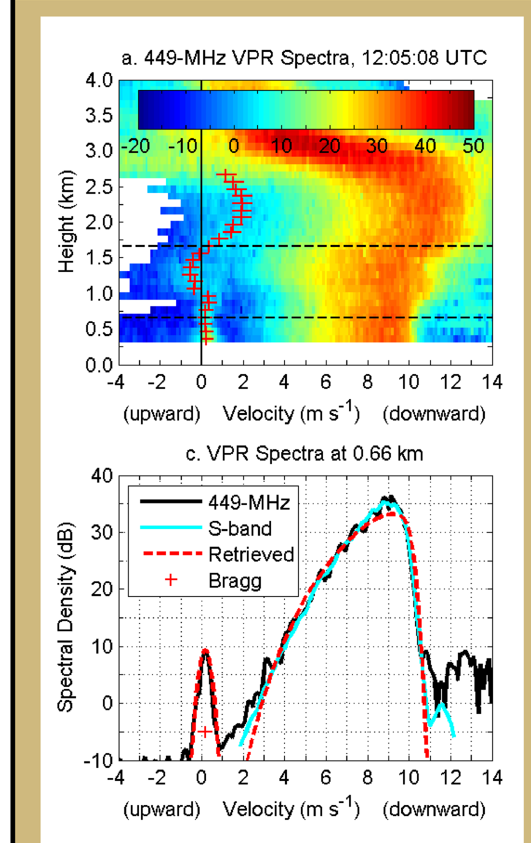
1. Motivation

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, 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):

Normalized raindrop size Distribution (DSD)

$$N(D) = N_w f(D; D_m, \mu) = N_w \left[\frac{6}{4^4}\frac{(\mu+4)^{\mu+4}}{\Gamma(\mu+4)}\right]\left[\frac{D}{D_m}\right]^{\mu} exp\left[-(\mu+4)\left(\frac{D}{D_m}\right)\right]$$

where:

N_w parameter [mm^{-1} m^{-3}]: $$N_w = \frac{4^4}{\pi\rho_w}\left(\frac{q}{D_m^4}\right)$$

q, liquid water content (LWC) [g m^{-3}]: $$q = \frac{\pi\rho_w}{6}\int_0^{\infty} N(D) D^3 dD = \frac{\pi\rho_w}{6} M_3$$

D_m, mean diameter [mm]: $$D_m = \frac{\int_0^{\infty} N(D) D^4 dD}{\int_0^{\infty} N(D) D^3 dD} = \frac{M_4}{M_3}$$

N_w is a 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_w from a normalized parameter to number of drops per unit volume, N_t:

$$N_t = N_w \frac{6}{4^4}\frac{(\mu+4)^3}{(\mu+3)(\mu+2)(\mu+1)} D_m$$

Tapiador et al., 2014

3. Reflectivity Decomposition

Number Concentration: $N(D) = N_w f(D; D_m, \mu)$

Reflectivity [mm^{-6} m^{-3}]: $$z = N_w \sum_{D_i}^{D_{max}} f(D_i; D_m, \mu) D_i^6 \Delta D$$

Reflectivity in logarithmic units [dB]:

$$Z^{dB} = 10log(N_w) + 10log\left(\sum_{D_i}^{D_{max}} f(D_i; D_m, \mu) D_i^6 \Delta D\right)$$

$$Z^{dB} = N_w^{dB} + I_b^{dB}(D_m, \mu)$$

Meneghini et al., 2003

Benefit of logarithmic units – *Change in dB is a percent change*:

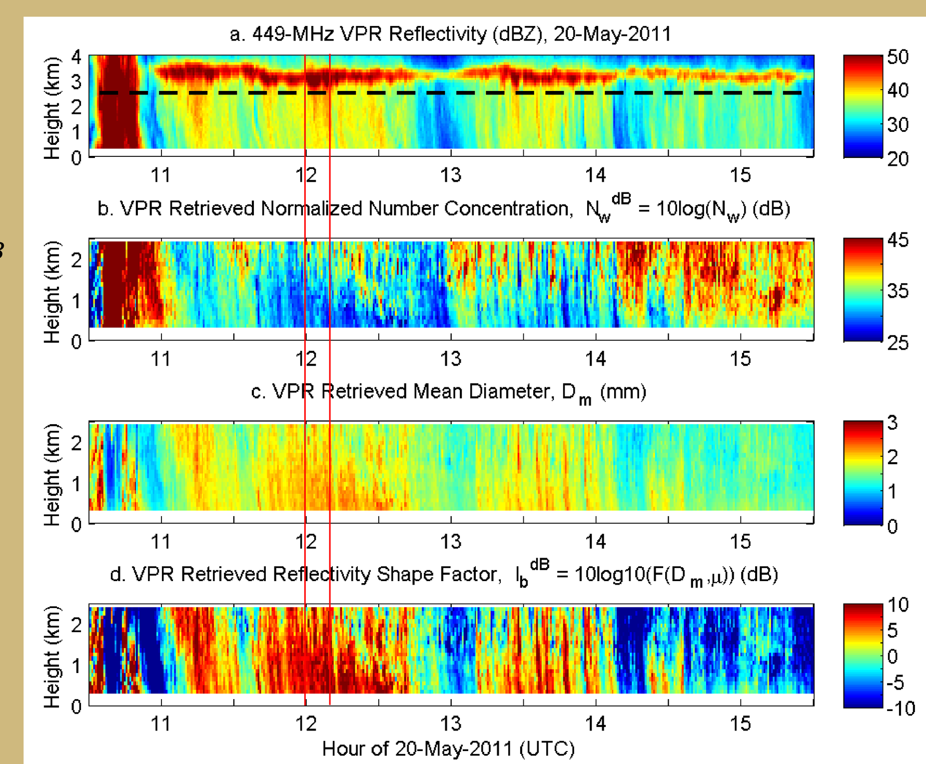
$\Delta\, 1\, dB = \Delta\, 26\%$ $\quad$ $\Delta\, 2\, dB = \Delta\, 58\%$ $\quad$ $\Delta\, 3\, dB = \Delta\, 100\%$

Reflectivity, Z^{dB}

Normalized Number Concentration, N_w^{dB}
(Decreasing with decreasing height)

Mean Diameter, D_m
(Increasing with decreasing height)

Reflectivity shape factor, I_b^{dB}
(Increasing with decreasing height)

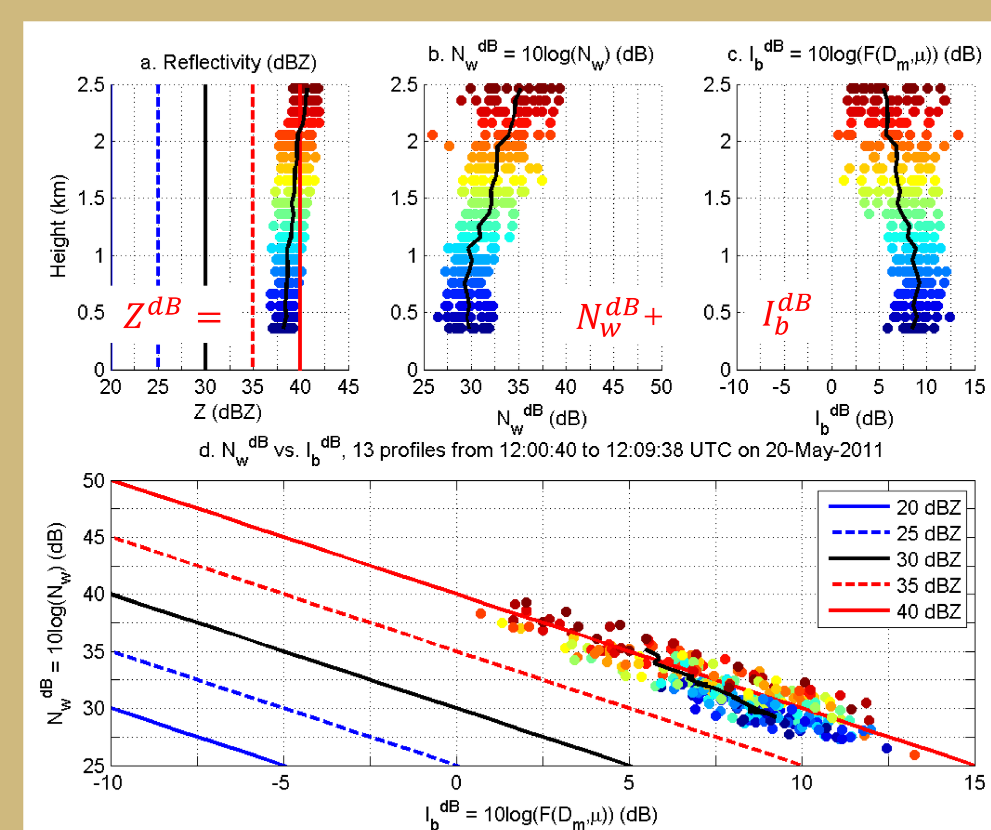


Reflectivity Vertical Decomposition Diagram
(Colors indicate height)

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

As the raindrops fall:
Z^{dB} decreases by ~1 dB
Suggests: Evaporation

N_w^{dB} decreases
I_b^{dB} increases
Suggests: Coalescence



4. LWC Decomposition

Number Concentration: $N(D) = N_t g(D; D_m, \mu)$

Liquid Water Content (LWC) [g m^{-3}]: $$q = N_t \frac{\pi\rho_w}{6}\sum_{D_i}^{D_{max}} g(D_i; D_m, \mu) D_i^3 \Delta D$$

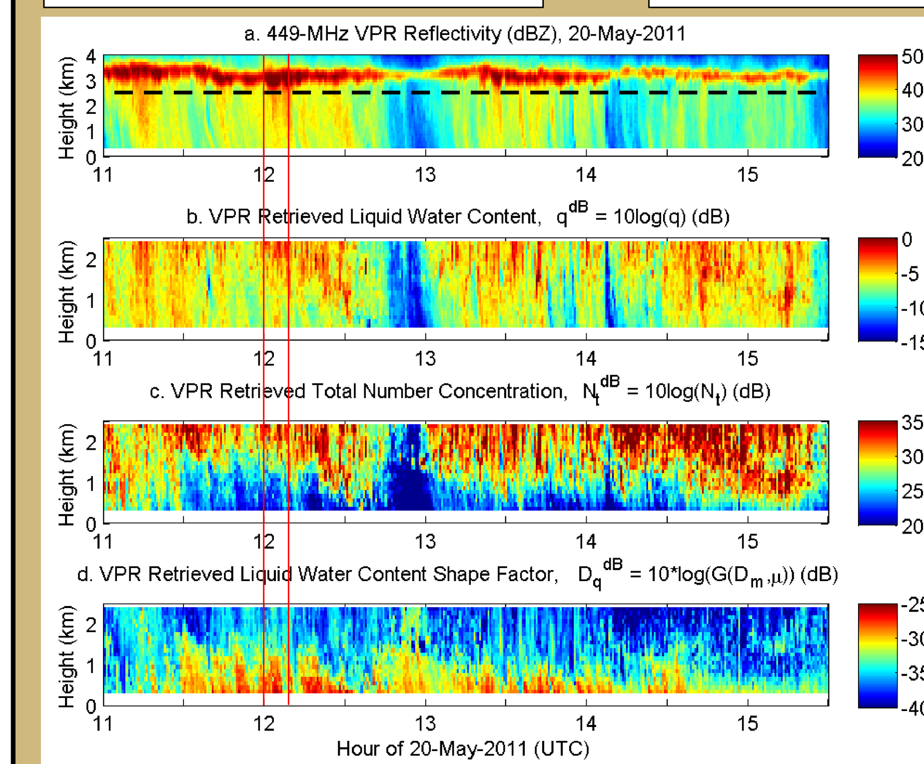
LWC in logarithmic units [dB]:

$$q^{dB} = 10log(N_t) + 10log\left(\frac{\pi\rho_w}{6}\sum_{D_i}^{D_{max}} g(D_i; D_m, \mu) D_i^3 \Delta D\right)$$

$$q^{dB} = N_t^{dB} + D_q^{dB}(D_m, \mu)$$

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

Change in N_t^{dB} and D_q^{dB} related to
Breakup & Coalescence
(Redistribution of mass through number and size)

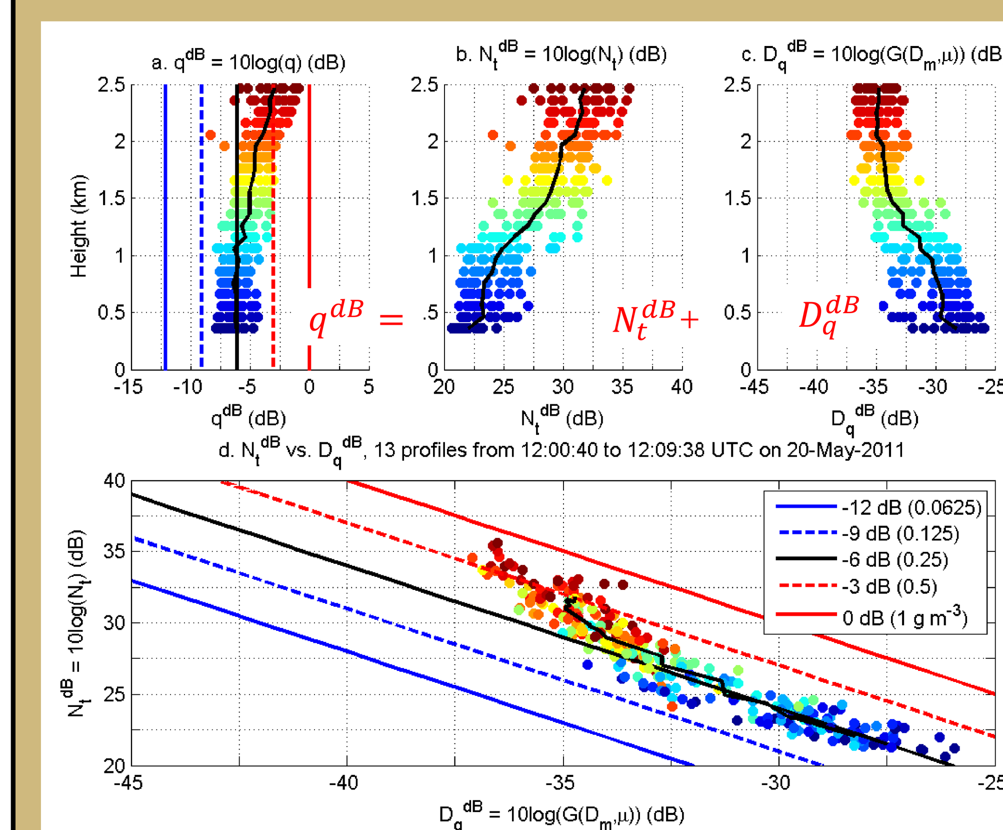


Reflectivity, Z^{dB}

Liquid Water Content, q^{dB}
(Decreasing with decreasing height)
(Evaporation)

Total Number Concentration, N_t^{dB}
(Decreasing with decreasing height)
(Fewer number of raindrops)

LWC shape factor, D_q^{dB}
(Increasing with decreasing height)
(Raindrops are getting bigger)



Liquid Water Content (LWC) Vertical Decomposition Diagram
(Colors indicate height)

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

As the raindrops fall:
q^{dB} decreases by 3 dB over 2 km
Indicates: Evaporation

N_t^{dB} decreases
D_q^{dB} increases
Indicates: Coalescence

6. References

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5. Concluding Remarks

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

$$q^{dB} = N_t^{dB} + D_q^{dB}$$

Changes in q^{dB} with height indicate: **evaporation** or **accretion**
Changes in N_t^{dB} & D_q^{dB} indicate: **breakup** or **coalescence**