Raindrop Breakup & Coalescence Diagnosed from Raindrop Size Distributions Retrieved from Vertically Pointing Radars

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1. Motivation

Microphysical processes modify the distribution of falling raindrops. Evaporation and accretion modify the total liquid mass. While breakup and coalescence modify how that liquid is distributed between different sized raindrops.

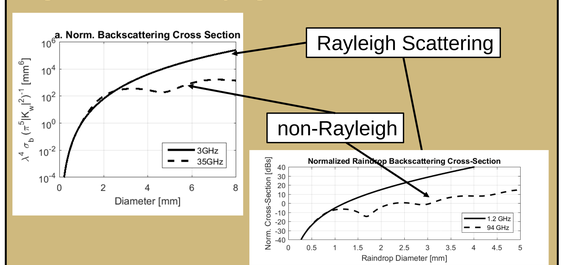
This study uses vertically pointing radar (VPR) observations from Midlatitude Continental Convective Clouds Exp. (MC3E) and GoAmazon field campaigns:
(1) Retrieve profile of raindrop size distributions (DSDs)
(2) Investigate raindrop breakup & coalescence

2. Rayleigh / Non-Rayleigh

Retrieval methodology exploits differences in Rayleigh and non-Rayleigh scattering signatures observed by two VPRs observing same raindrops.

MC3E: Included 3 & 35 GHz VPRs
GoAmazon: Included 1.2 & 94 GHz VPRs

When raindrops larger than 1 mm (35 GHz) or 2 mm (94 GHz) diameter are present, the Rayleigh radar velocity is larger than the non-Rayleigh radar values.



When radar observe the same raindrops, the difference in measured radial velocity is independent of air motion ω:

Rayleigh radar velocity: $\bar{V}_{obs}^{Rayleigh} = \bar{V}_{DSD}^{Rayleigh} - \omega$

Non-Rayleigh velocity: $\bar{V}_{obs}^{non-Rayleigh} = \bar{V}_{DSD}^{non-Rayleigh} - \omega$

Velocity Difference: $\Delta\bar{V}_{obs} = \bar{V}_{obs}^{Rayleigh} - \bar{V}_{obs}^{non-Rayleigh}$

$\overline{\Delta V}_{obs} = \bar{V}_{DSD}^{Rayleigh} - \bar{V}_{DSD}^{non-Rayleigh}$

3. Retrieval Framework

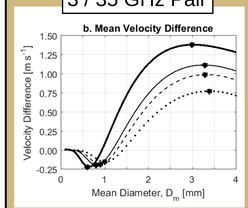
Desire: Estimate 4 unknowns:
3 DSD parameters:
N_t - Total number concentration
D_m - mass-spectrum mean diameter
γ_m - mass-spectrum effective variance $\left(\frac{\sigma_m^2}{D_m^2}\right)$
1 vertical air motion - ω

Input Observations:

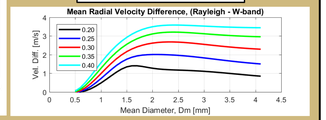
Rayleigh radar reflectivity	(3 / 1.2 GHz)
Rayleigh radar mean velocity	(3 / 1.2 GHz)
Non-Rayleigh radar mean velocity	(35 / 94 GHz)
Non-Rayleigh velocity spectra	(35/ 94 GHz)

Retrieval Steps:
(1) Calibrate Rayleigh VPR to surface disdrometer.
(2) Given an observed velocity difference $\Delta\bar{V}_{obs}$, there is a family of possible solutions, $\boldsymbol{D}_m^{possible}$ and $\boldsymbol{\gamma}_m^{possible}$.

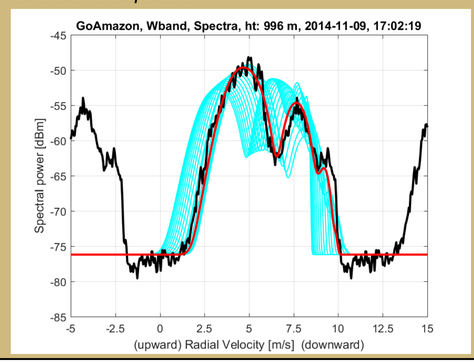
3 / 35 GHz Pair



1.2 / 94 GHz Pair



(3) Estimate possible air motions:
$\boldsymbol{\omega}^{possible} = \bar{\boldsymbol{V}}_{DSD}^{Rayleigh} - \bar{V}_{obs}^{Rayleigh}$.
(1) Forward simulate non-Rayleigh spectra using all possible solutions: $\boldsymbol{D}_m^{possible}$, $\boldsymbol{\gamma}_m^{possible}$ and $\boldsymbol{\omega}^{possible}$
(2) Choose best fit between observed and model spectra.
(3) Estimate N_t from observed Rayleigh reflectivity and $(D_m^{best}, \gamma_m^{best})$.
Solution is best fit between forward simulated spectra and observed spectrum.



4. Reflectivity Decomposition

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

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

Reflectivity in logarithmic units [dB]:

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

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

Meneghini et al., 2003

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

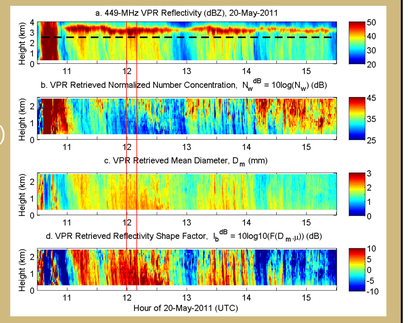
$\Delta\, 1\, dB = \Delta\, 26\%$ $\Delta\, 2\, dB = \Delta\, 58\%$ $\Delta\, 3\, dB = \Delta\, 100\%$

Reflectivity, Z^{dB}

Norm. Number Conc., N_w^{dB}
(Decreasing with decreasing ht)

Mean Diameter, D_m
(Increasing with decreasing ht)

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

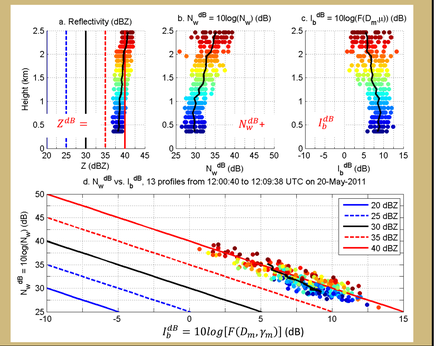


Reflectivity Vertical Decomposition Diagram
(Colors indicate height)

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



5. LWC Decomposition

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

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

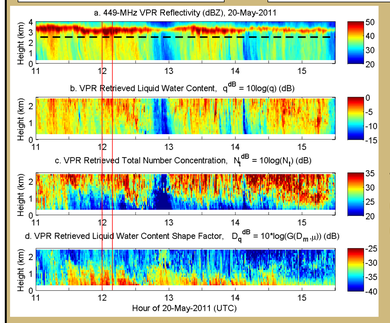
LWC in logarithmic units [dB]:

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

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

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)

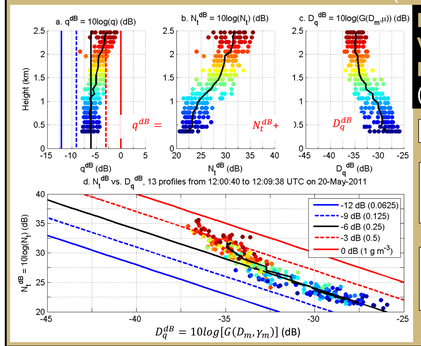


Reflectivity, Z^{dB}

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

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

LWC shape factor, D_q^{dB}
(Increasing with decreasing ht)
(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. 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**

7. References

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