Using ARM Multi-Sensor Datasets to Investigate Precipitation Characteristics and Vertical Variability

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1. Motivation

Microphysical processes modify the distribution of falling raindrops.

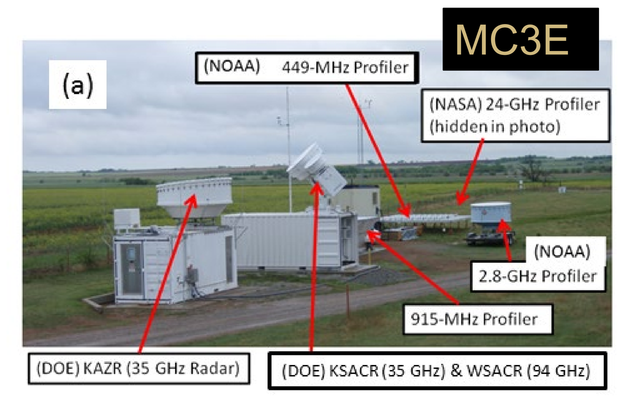
- Evaporation and accretion modify the total liquid mass
- Breakup and coalescence redistribute mass between raindrops

This study uses vertically pointing radar observations to:

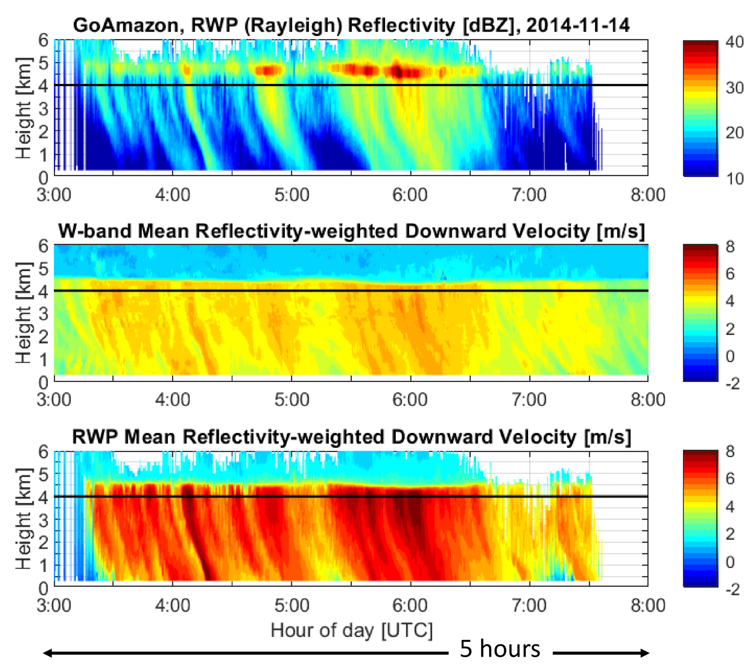
(1) Retrieve profile of raindrop size distributions (DSDs)

(2) Investigate raindrop evaporation, breakup, and coalescence

Midlatitude Continental Convective Clouds Experiment (MC3E)



Example precipitation event from GoAmazon (14-Nov-2019)



1.2 GHz (L-band)
Reflectivity [dBZ]
Dwell: 2 second
Repeat: every 12 seconds

94 GHz (W-band)
Mean Reflectivity Downward Velocity [m/s]
(Positive values are downward)

1.2 GHz
Mean Reflectivity Downward Velocity [m/s]
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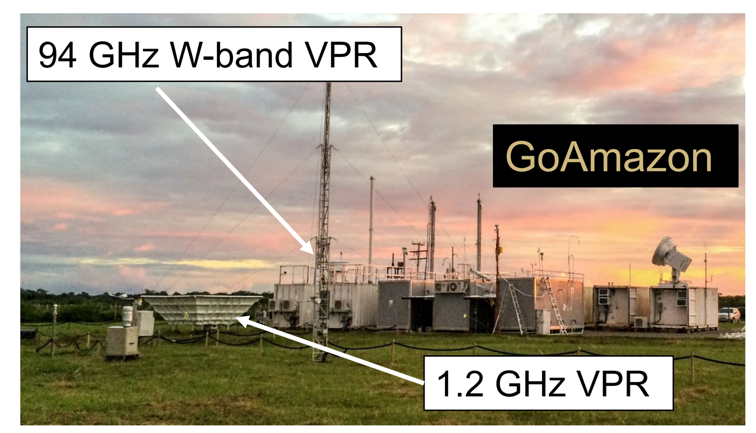
Green Ocean Amazon Experiment (GoAmazon)

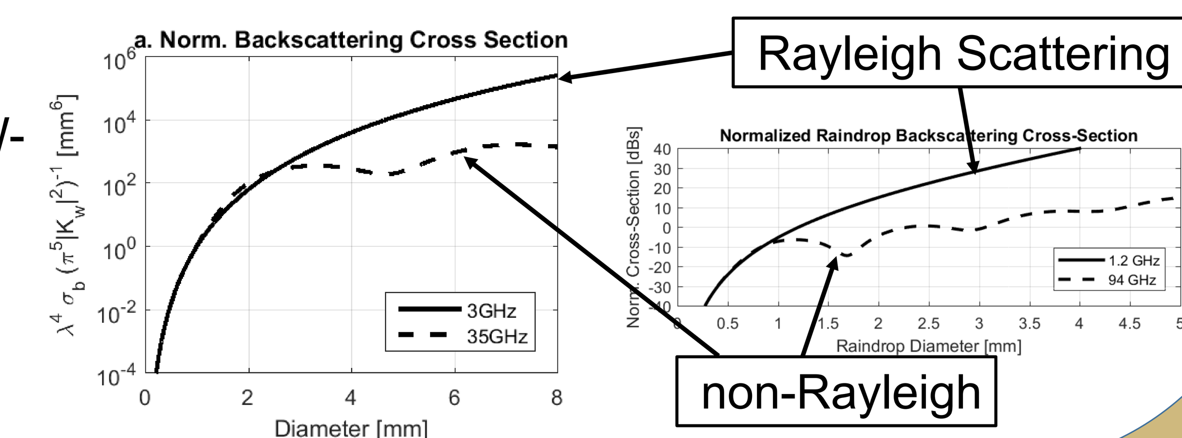


Note the different radar mean radial velocities at L- and W-band because of Rayleigh and non-Rayleigh scattering.

Non-Rayleigh scattering occurs for raindrops larger than:

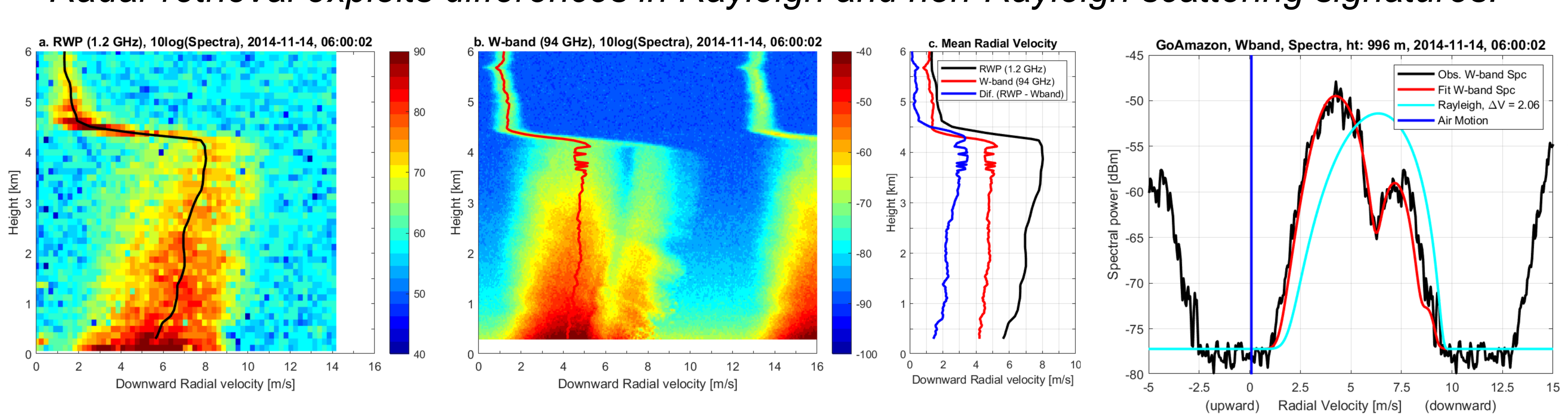
2 mm @ 35 GHz (KAZR)

1 mm @ 94 GHz (W-band)



2. DSD & vertical Air Motion Retrievals

Radar retrieval exploits differences in Rayleigh and non-Rayleigh scattering signatures.



Black line is observed W-band spectra.

Red line is "best" fit relative to observed W-band spectrum.

Blue line is RWP (Rayleigh) spectrum using "best" fit (D_m, μ).

Dark Blue line is estimated vertical air motion.

Gamma DSD distribution using parameters N_t, D_m, μ:

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

$$N(D) = N_t \left[\frac{(\mu+4)^{\mu+1}}{\Gamma(\mu+1)D_m}\right]\left[\frac{D}{D_m}\right]^{\mu} exp\left[-(\mu+4)\left(\frac{D}{D_m}\right)\right]$$

Retrieval Methodology:

1. Vary 3 DSD parameters and vertical air motion.
2. Forward simulate Doppler velocity spectrum at W-band.
3. "Best fit" is relative to observed W-band spectrum.

Liquid Water Content (LWC) [g m^{-3}]:

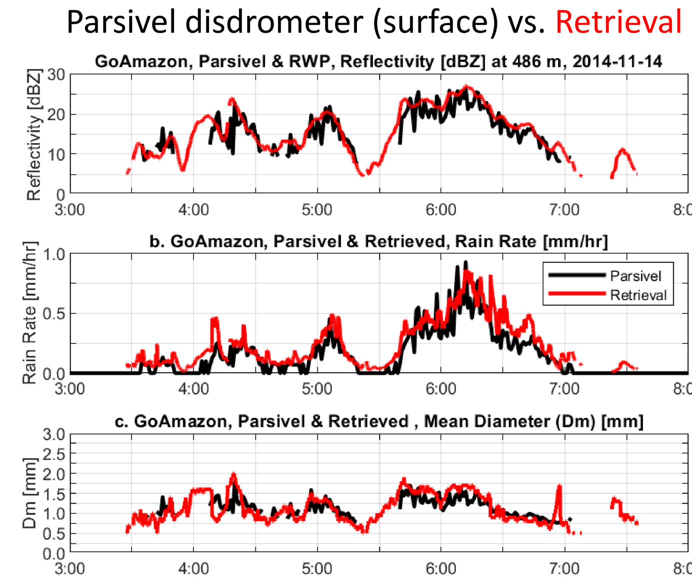
$$q = \frac{\pi}{6}\rho_W \int_0^{\infty} N(D)D^3 dD$$

$$q = N_t \frac{\pi}{6}\rho_W \int_0^{\infty} g(D; D_m, \mu)D^3 dD$$

Mass-weighted mean diameter [mm]:

$$D_m = \frac{\int_0^{\infty} N(D)D^4 dD}{\int_0^{\infty} N(D)D^3 dD} = \frac{M_4}{M_3}$$

Parsivel disdrometer (surface) vs. Retrieval (500 m)



1.2 GHz
Reflectivity [dBZ]

Rain Rate [mm/hr]

Mass-Weighted
Mean Diameter, D_m [mm]

3. Time-Height Cross-Section of Radar Retrievals

Express Liquid Water Content in both natural units and in decibel units:

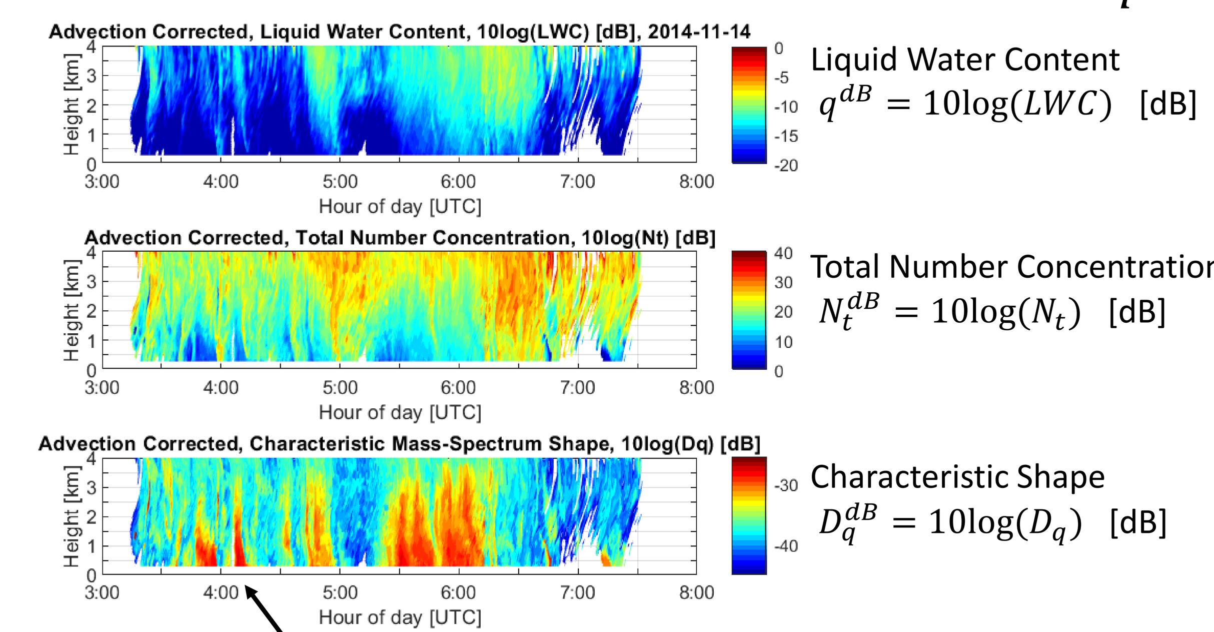
Natural Units [g m^{-3}]

$$q = N_t \frac{\pi}{6}\rho_W \int_0^{\infty} g(D; D_m, \mu)D^3 dD$$

Decibel Units [dB] (1 dB = 26% 2 dB = 58%, 3 dB = factor of 2)

$$10log(q) = 10log(N_t) + 10log\left(\frac{\pi}{6}\rho_W \int_0^{\infty} g(D; D_m, \mu)D^3 dD\right)$$

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



Liquid Water Content
$q^{dB} = 10\log(LWC)$ [dB]

Total Number Concentration
$N_t^{dB} = 10\log(N_t)$ [dB]

Characteristic Shape
$D_q^{dB} = 10\log(D_q)$ [dB]

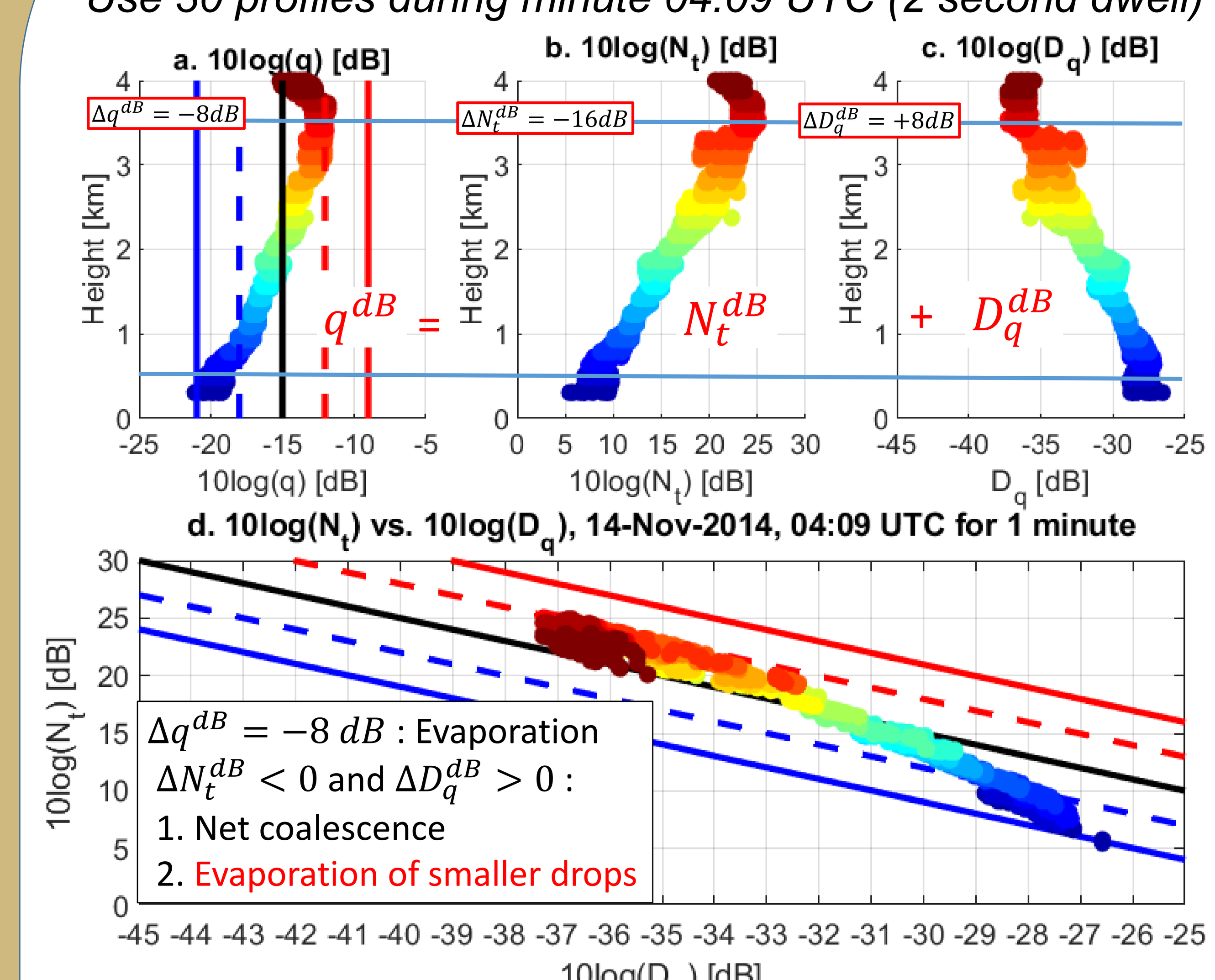
Decrease in LWC with decreasing height implies evaporation through the loss of mass with height.

Decrease in number concentration and increase in characteristic size is consistent with evaporation of smaller drops and redistribution of mass through breakup & coalescence.

4. Vertical LWC Decomposition Diagram

+3 dB is a doubling
–3 dB is a halving

Use 30 profiles during minute 04:09 UTC (2 second dwell)



Decomposition Diagram shows vertical evolution of:

- **Mass**
- **Number of Raindrops**
- **Characteristic DSD Shape**

From 3.5 to 0.5 km:

$\Delta q^{dB} = -8dB$	* Decrease mass
$\Delta N_t^{dB} = -16dB$	* Decrease number count
$\Delta D_q^{dB} = +8dB$	* Increase characteristic shape
$\Delta q^{dB} = \Delta N_t^{dB} + \Delta D_q^{dB}$	* Δ LHS = Δ RHS

- Color of symbols represent height
- Diagonal lines represent constant q^{dB}
- Observations that cross constant q^{dB} lines indicate *evaporation* or *accretion*

5. References

Williams, C.R., 2016: Reflectivity and liquid water content vertical decomposition diagrams to diagnose vertical evolution of raindrop size distributions. *J. Atmos. Oceanic Technol.*, **33**, 579-595, doi: 10.1175/JTECH-D-15-0208.1

Williams, C.R., R.M. Beauchamp, and V. Chandrasekar, 2016: Vertical air motions and raindrop size distributions estimated using mean Doppler velocity difference from 3- and 35-GHz vertically pointing radars. *IEEE Trans. on Geosci. Remote Sens.*, **54**, 6048-6060, doi: 10.1109/TGRS.2016.2580526.

Acknowledgments

ASR Atmospheric System Research

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