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MBL Drizzle Properties and Their Impact on Cloud Property Retrievals

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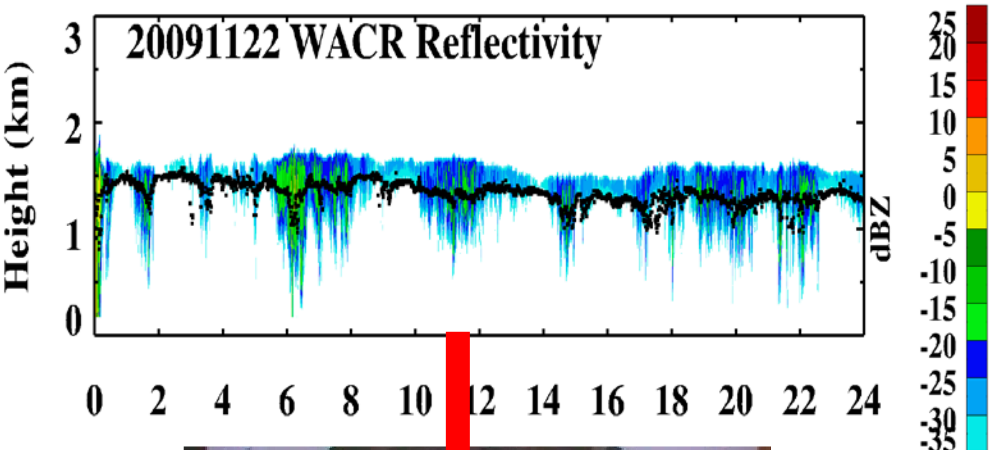
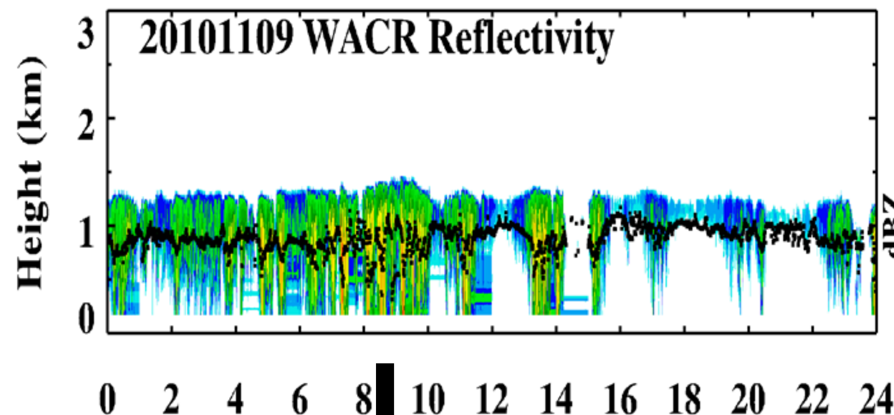
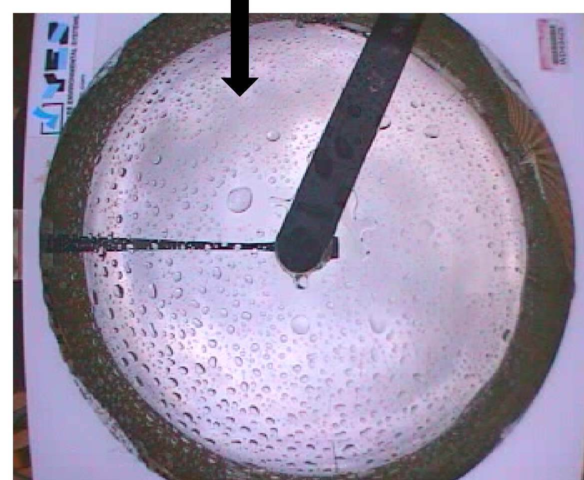
Different types of Drizzles below Cloud Base

Virga: wisps or streaks of water particles falling out of a cloud layer but evaporating before reaching the earth's surface as precipitation. (AMS, 2014)

Rain: drizzle particles falling to the surface as precipitation







Separate virga/rain periods

Given the absence of disdrometer measurements at the Azores, we use a similar method as described in *Rémillard et al*. [2012] to identify virga and rain. (daytime low level clouds only)

Precp. Type	Echo Base	Base Reflectivity
virga	> 200 m	≥ -37 dBZ
rain	< 200 m	≥ -37 dBZ

Scientific Questions:

(1) What are the microphysical properties of drizzle below MBL cloud base during virga/rain periods?

(2) How much can drizzle particles underneath MBL clouds affect the cloud microphysical property retrievals?

To answer above questions, we

(1) retrieved the microphysical properties of virga and rain drizzle under cloud base (case studies and statistical results will be shown)

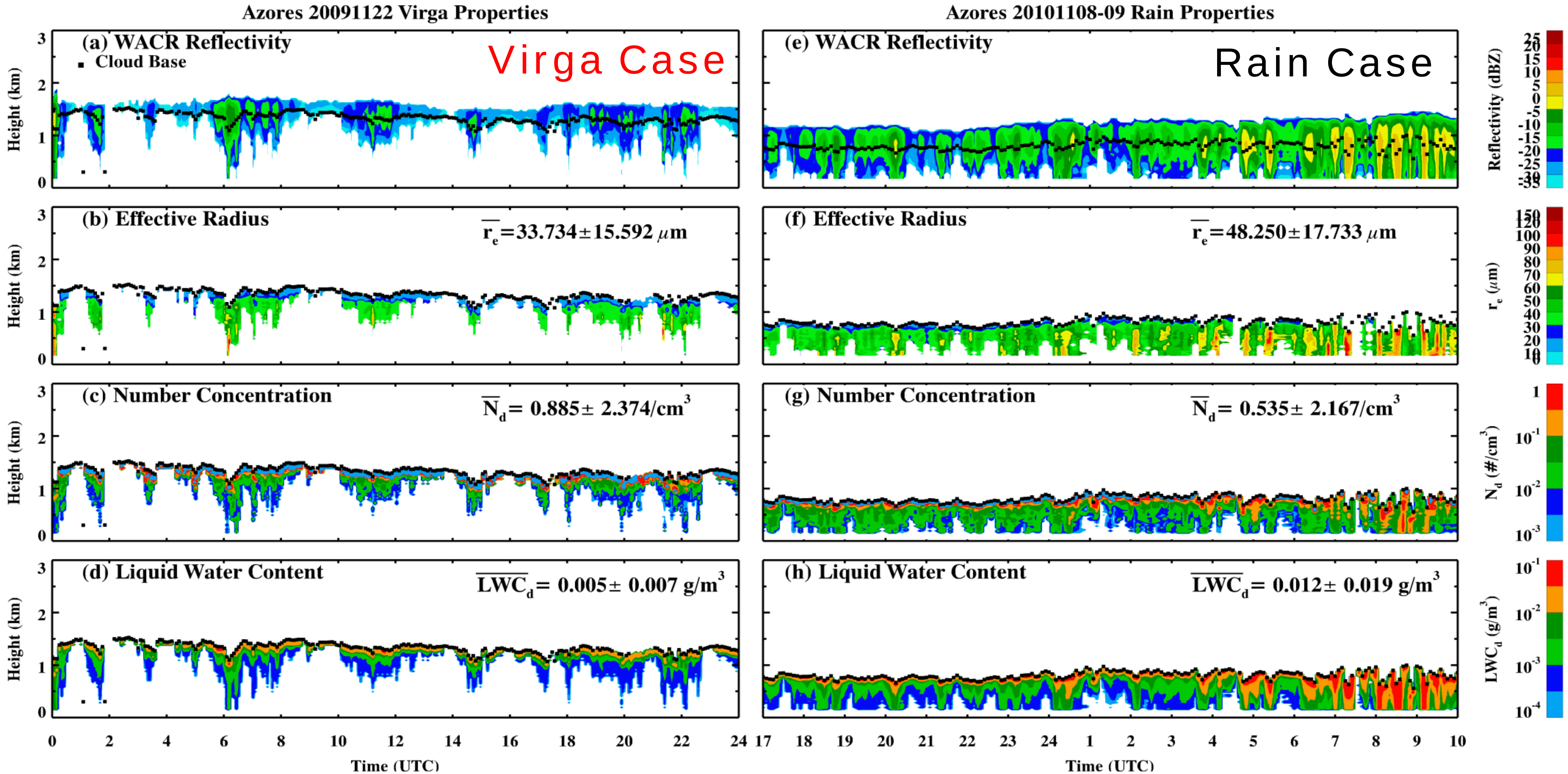
(2) quantitatively estimated the impact of drizzle on cloud property retrievals.

Retrieval Methods

- **Drizzle**: follow O'Connor et al., [2005], normalized gamma distribution, basic equation:
- $$\frac{Z}{\beta} = \frac{2}{\pi}\frac{\Gamma(7+\mu)}{\Gamma(3+\mu)}\frac{S}{(3.67+\mu)^4} {D_0}^4$$
- Z: WACR reflectivity, β: lidar backscatter coefficient
  μ: shape parameter, S: lidar ratio, D_0: median diameter

- **Cloud**: follow Dong et al., [1998], lognormal distribution, $\overline{r_c}$ during the daytime was parameterized as :
- $$\overline{r_c} = -2.07 + 2.49LWP_c + 10.25\gamma - 0.25\mu_0 + 20.28LWP_c\gamma - 3.14LWP_c\mu_0$$
- LWP_c: cloud liquid water path, γ: solar transmission ratio,
  μ_0: cosine of solar zenith angle

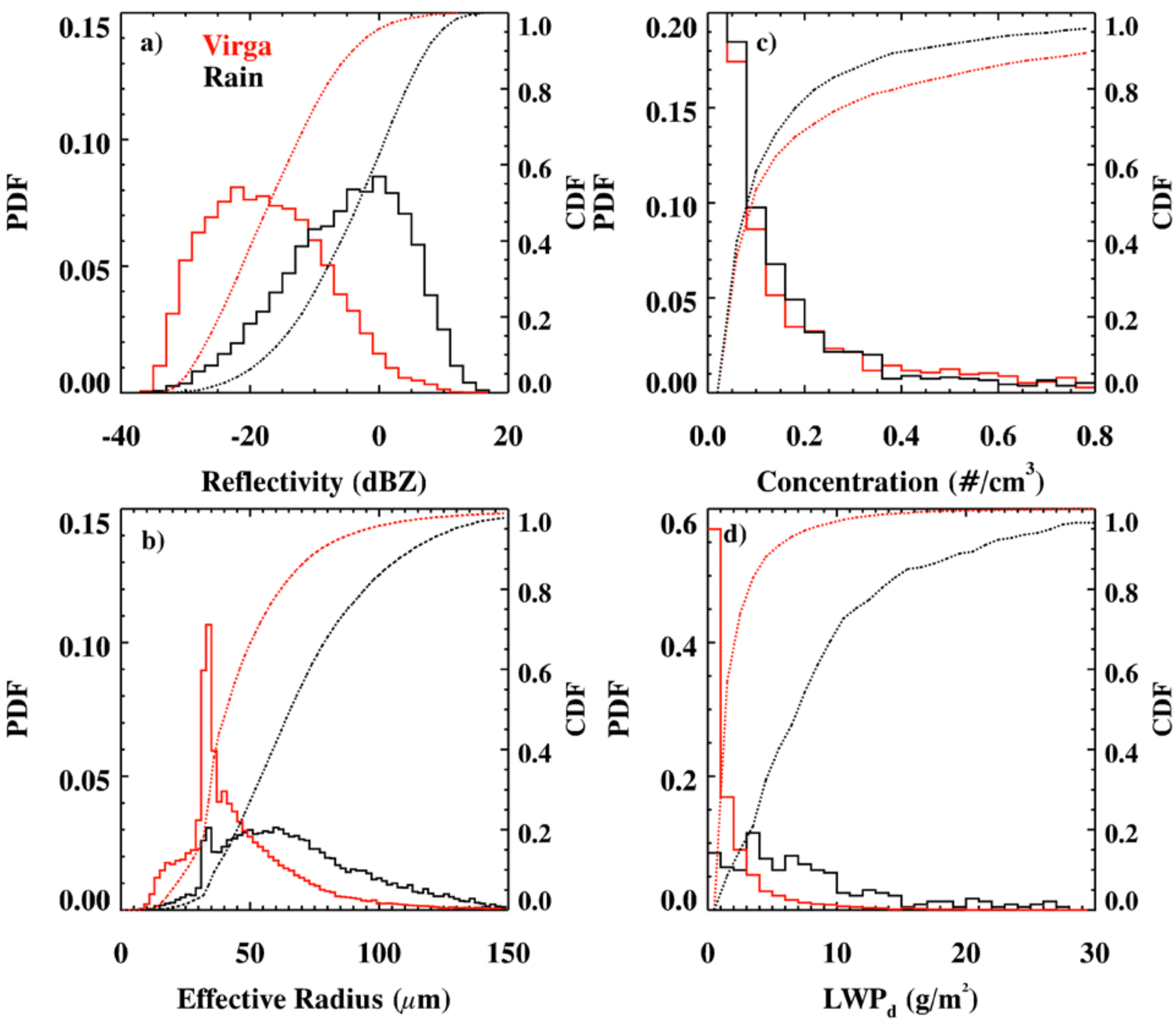
Drizzle Properties-cases



$\overline{r_d}$ in both Cases are nearly 3-4 times larger than $\overline{r_c}$ of MBL cloud-droplet at the Azores (12.5-12.9 mm, *Dong et al.*, 2014a and 2014b).

$\overline{N_d}$ in both cases are two orders of magnitude lower than $\overline{N_c}$ of MBL at the Azores (66-82.6 cm^{-3}, *Dong et al.*, 2014a and 2014b)

Drizzle Properties-statistics



	rain	virga
Z	higher	lower
Mode	0 dBZ	-20 dBZ

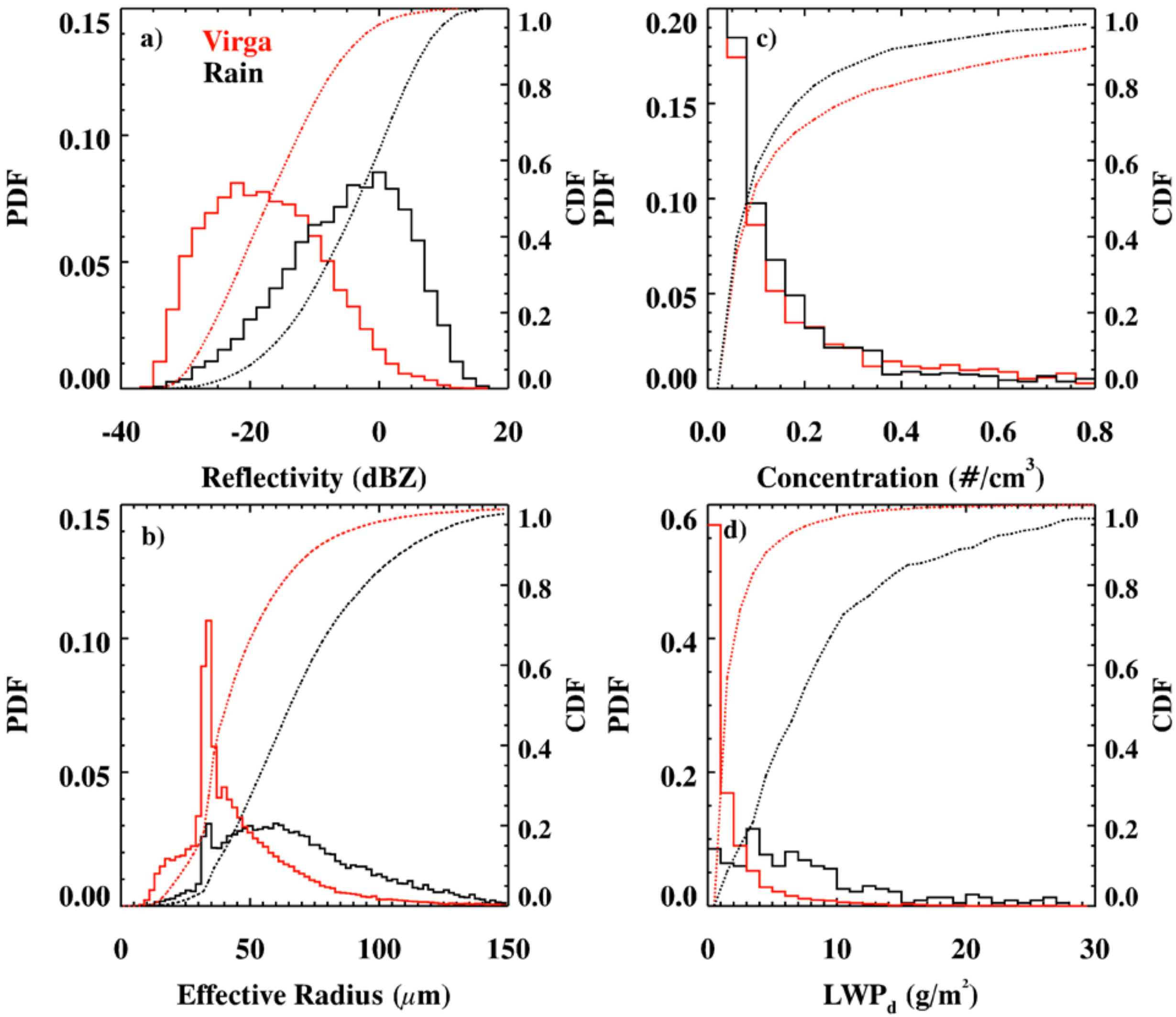
consistent with the definition of intense precipitation type in *Rémillard et al*. [2012]

55% of the virga and 13% of rain samples are less than -15 dBZ

37% of the virga and 6% of the rain samples are less than -20 dBZ

~45% of the drizzle samples would be missed if using a threshold of -15 dBZ, and ~30% for -20 dBZ

Drizzle Properties-statistics



	rain	virga
r_d	larger	smaller
Mode	30-150 μm	30 μm

Both with long tail towards large values

Most of the N_d values for both virga and rain samples are located at the tail end with nearly 70-80% less than 0.2 cm^{-3} and slightly more virga samples for large values

Almost all virga LWP_d values are less than 10 g m^{-2} and ~80% less than 3 g m^{-2}, while only 18% of the rain samples are less than 3 g m^{-2}

New Cloud Properties

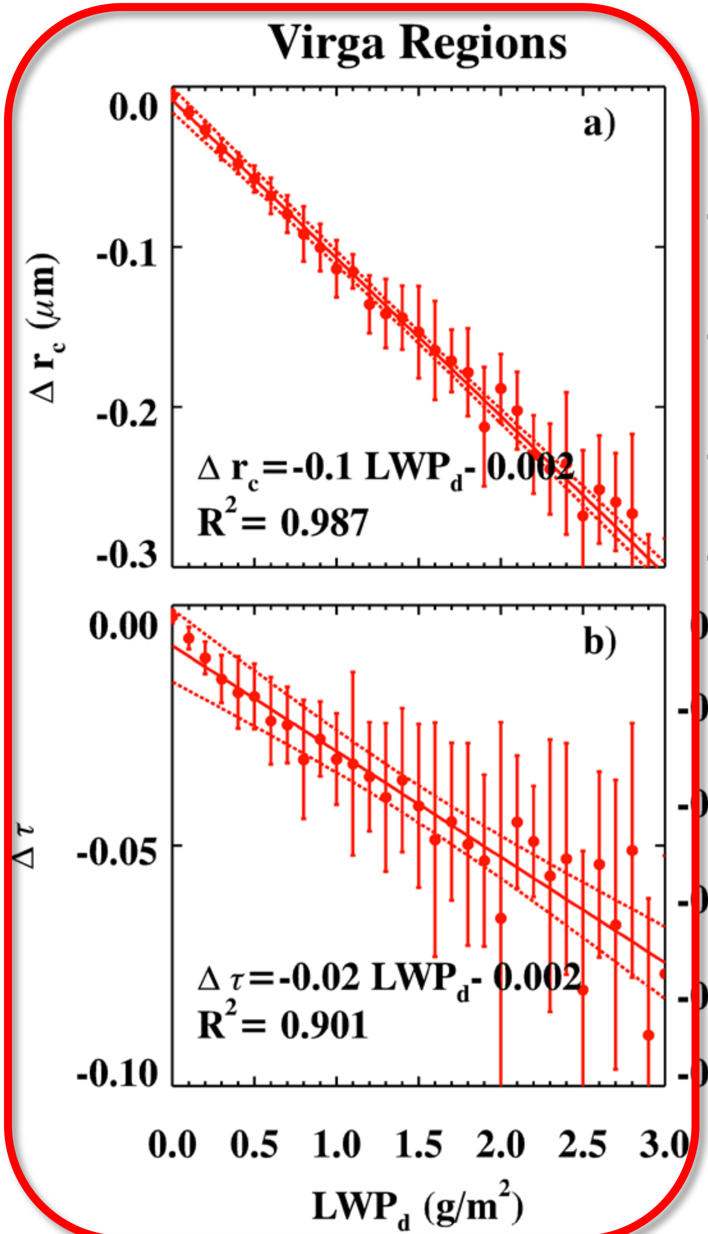
$$\overline{r_c} = -2.07 + 2.49LWP_c + 10.25\gamma - 0.25\mu_0 + 20.28LWP_c\gamma - 3.14LWP_c\mu_0$$

Dong98: LWP_c= LWP_{MWR}

New : LWP_c= LWP_{MWR}-$LWP_{drizzle}$

These newly retrieved cloud properties (r_c´, N_c´, τ´) are then compared with the original retrievals in *Dong et al.* (2014a)

Drizzle Impact on Cloud Property Retrievals



Δ = new - original

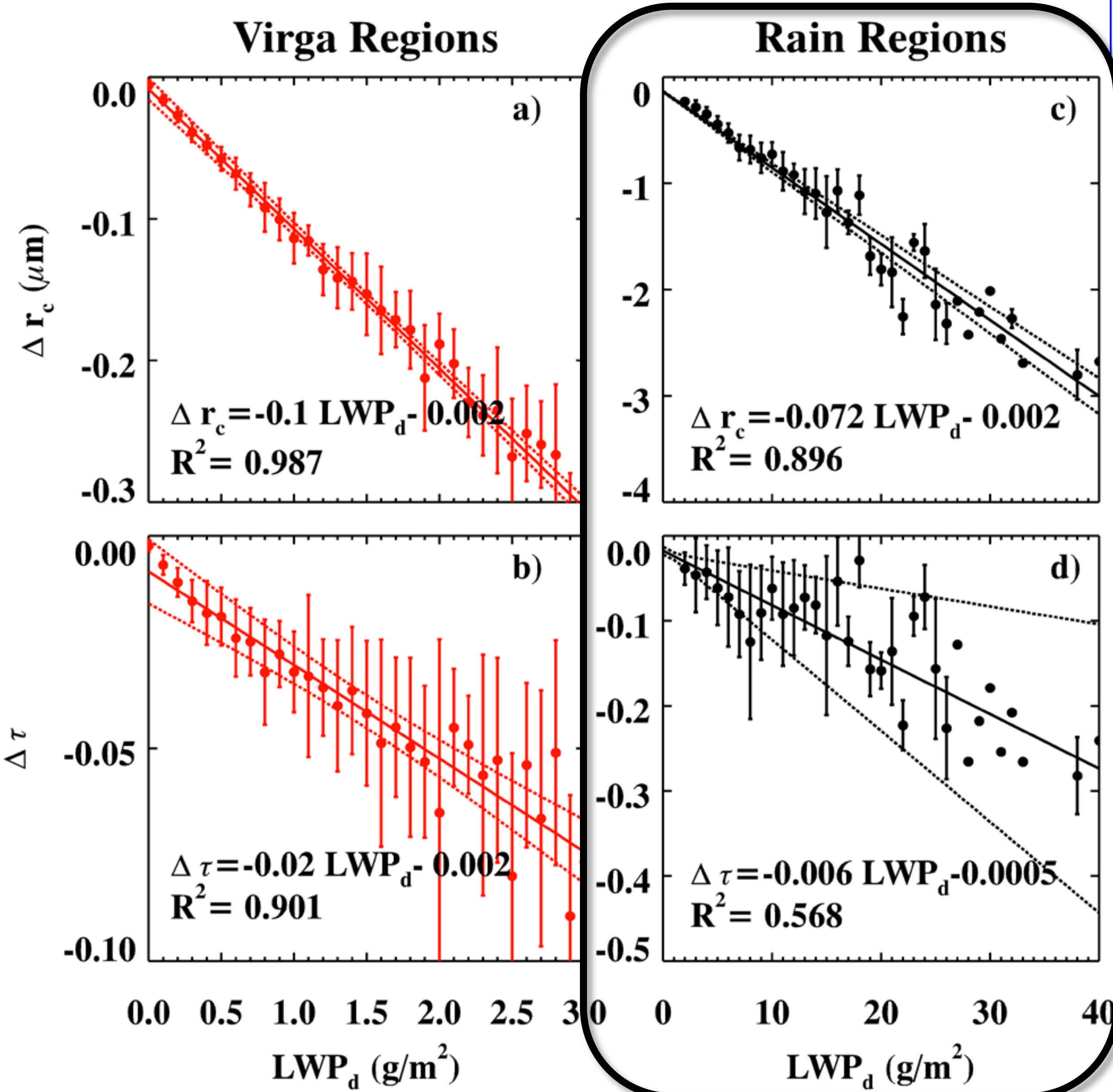
***LWP_d* increase 1 g m^{-2}**

r_c decrease 0.1 μm

***r_c* decrease by up to 0.3 μm in virga regions, which is within the uncertainty (10%)(*Dong et al.,* 2014a)**

The impact of drizzle on τ retrieval (panel b) is similar to that of *r_c* with a slope of -0.02 and R^2 of 0.901

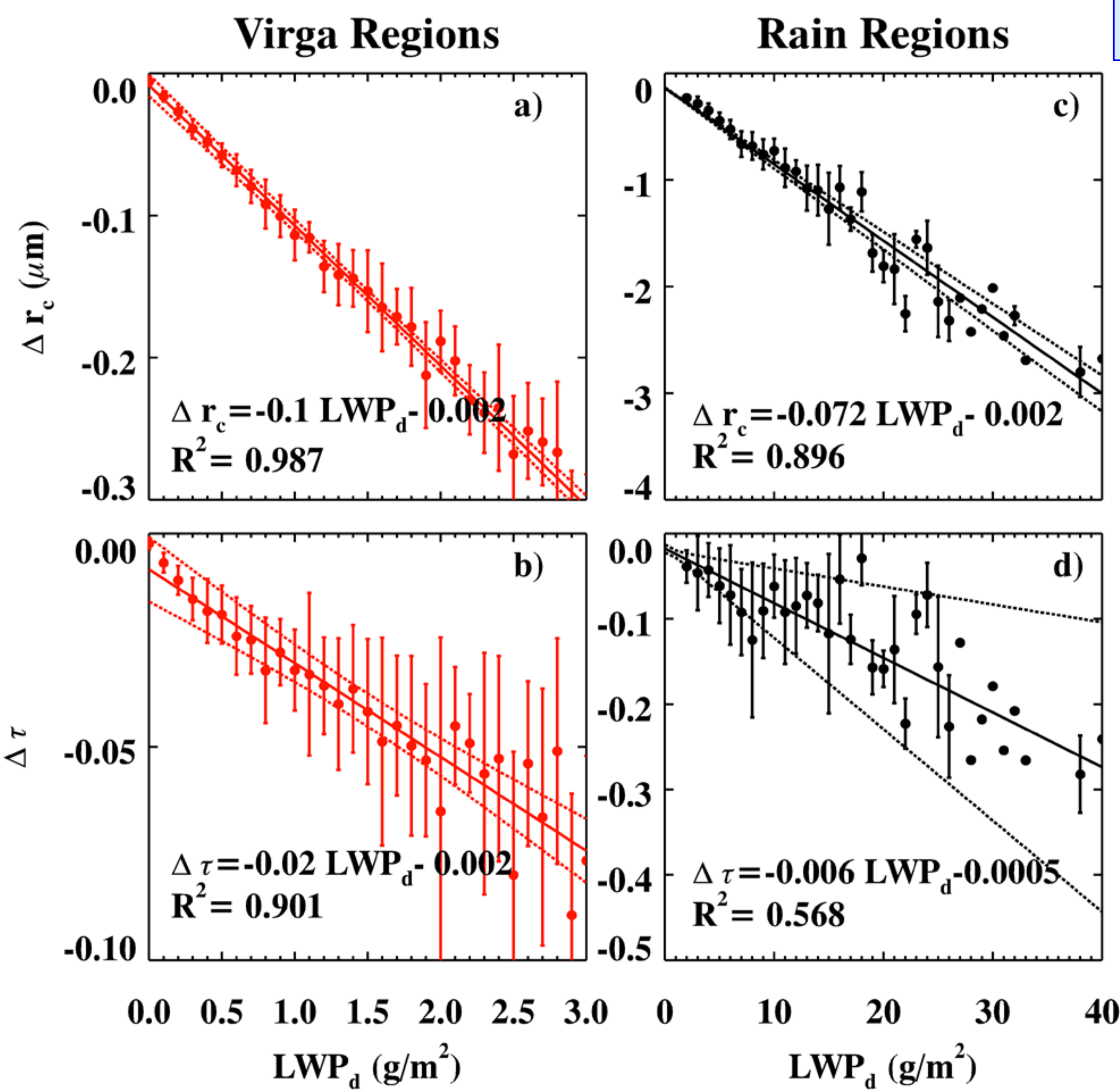
Drizzle Impact on Cloud Property Retrievals



Δ = new - original

rain samples: the slope is -0.07 and the correlation is 0.896 (panel c). The r_c values can be reduced 2~3 mm with an increase of 40 g m^{-2} in LWP_d and relatively larger fluctuation than for the virga samples. The impact of LWP_d on cloud optical depth retrieval is weak with a R^2 of 0.568.

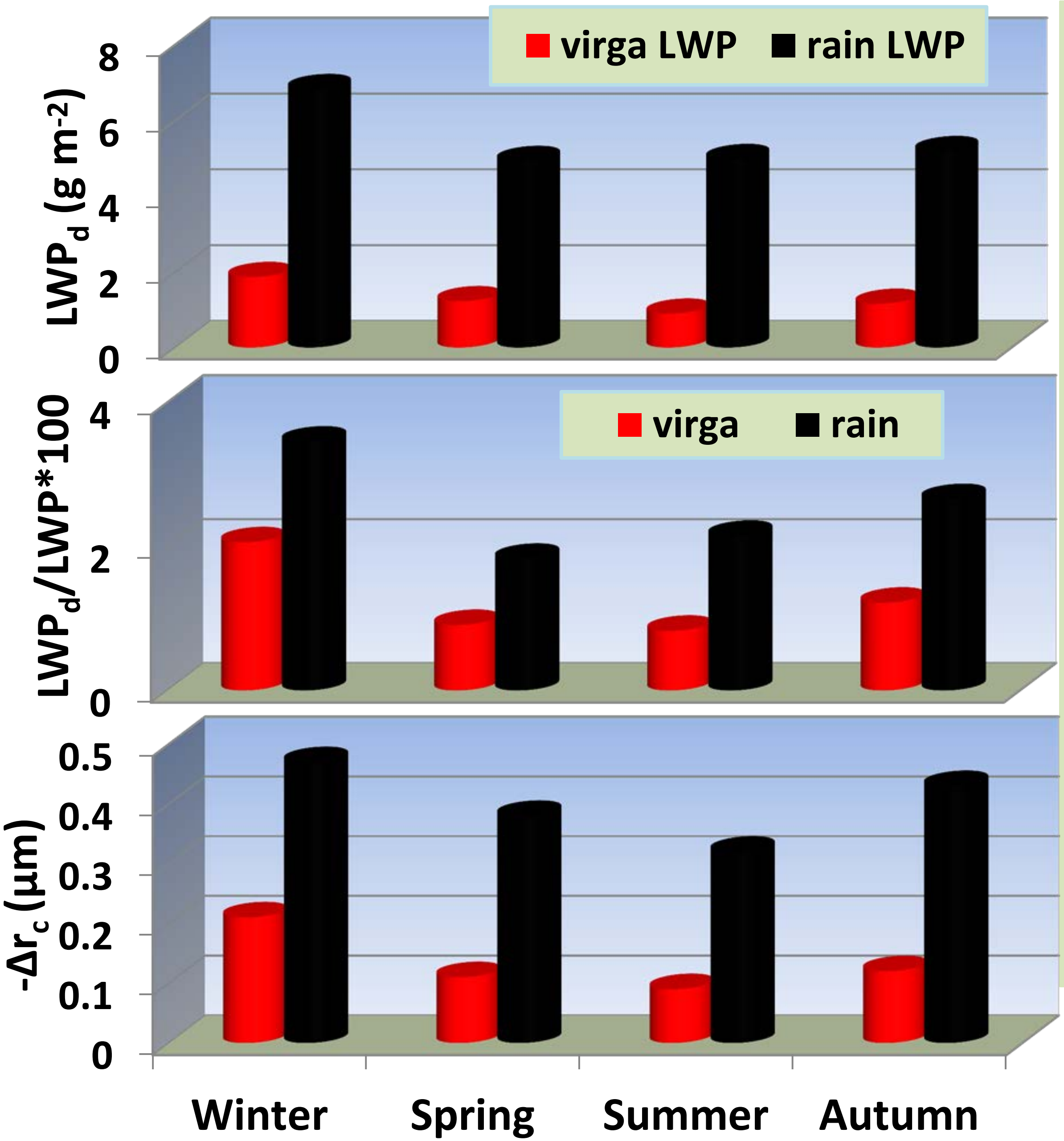
Drizzle Impact on Cloud Property Retrievals



Δ = new - original

Dash lines: 95% confidence interval, true best-fit line for the samples have 95% probability to fall within the intervals. The narrow intervals for panel (a), (b), and (c) suggest high reliability of the regression, whereas for the broad interval in panel (d) indicates relatively large uncertainty of the regression

Seasonal Variations



rain $LWP_d \approx$ 4*virga LWP_d

seasonal mean LWP_d < 4%*LWP.

The seasonal differences fall within the cloud property retrieval uncertainty (~10%). Therefore, their impact on cloud property retrievals is insignificant except for some individual cases which has relatively intense precp.

Summary

- Drizzle occurrence is 42.6% for the selected samples.

	LWP_d (g m^{-2})	r_d (μm)	N_d (cm^{-3})
virga	1.29	39.5	0.14
rain	5.48	68.7	0.38

- The annual mean differences of r_c are 0.12 and 0.38 μm for the virga and rain samples, respectively. These differences fall within the cloud property retrieval uncertainty (~10%). The impacts of drizzle on cloud-droplet number concentration (optical depth) are also small, presumably due to small changes in both LWP_c and r_c. Therefore, we can conclude that the impact of drizzle on cloud property retrievals is insignificant.

THANK YOU FOR YOUR ATTENTION!

QUESTIONS?

Drizzle Retrieval Algorithm

Method for Calculating the drizzle microphysical properties:

- **The ratio of radar reflectivity to lidar backscatter is proportional to the fourth power of drop size***(O'Connor et al. 2005***), assume size distribution as normalized gamma distribution of the form:**

$$n(D) = N_W f(\mu) \left(\frac{D}{D_0}\right)^{\mu} exp\left[\frac{-(3.67+\mu)D}{D_0}\right] \qquad (1)$$

where N_W is the concentration normalized, D_0 is median diameter, μ is shape parameter, $f(\mu) = \frac{6}{3.67^4}\frac{(3.67+\mu)^4}{\Gamma(\mu+4)}$

- **Lidar extinction coefficient is defined as $\alpha = \frac{\pi}{2}\int_0^{\infty} n(D)D^2 dD$. Lidar backscatter coefficient, β is given by $\alpha=S\beta$, where S is termed of lidar ratio (extinction-to-backscatter ratio) and can be estimated using Mie theory.**

O'Connor, Ewan J., Robin J. Hogan, Anthony J. Illingworth, 2005: Retrieving Stratocumulus Drizzle Parameters Using Doppler Radar and Lidar. J. Appl. Meteor., 44, 14–27.

Retrieval algorithm (cont')

- **The ratio of radar reflectivity to lidar backscatter can be derived as:**

$$\frac{Z}{\beta} = \frac{2}{\pi}\frac{\Gamma(7+\mu)}{\Gamma(3+\mu)}\frac{S}{(3.67+\mu)^4}{D_0}^4 \quad \textbf{(2)}$$

- **First assuming** μ**=0 and** D_0 **can be estimated, refine the estimation by comparing calculated spectral width with radar observed spectral width, adjusting** μ **and computing until convergence. Then** N_W **can be calculated from radar reflectivity.**
- **Now we can calculate drizzle LWC and number concentrations Nd as follows:**

$$\mathrm{LWC_d} = \rho_l \frac{\pi}{6}\int_0^\infty \mathrm{n(D)D^3}\,d\mathrm{D} \quad \textbf{(3)}$$

$$N_d = \int_0^\infty \mathrm{n(D)\,dD} \quad \textbf{(4)}$$

- **The ratio(R) of drizzle LWP to total LWP is**

$$R = \frac{LWP_d}{LWP_t} \quad \textbf{(5)}$$

where LWP_t **is the liquid water path(cloud plus drizzle) measured by microwave radiometer.**

Effect of drizzle on cloud

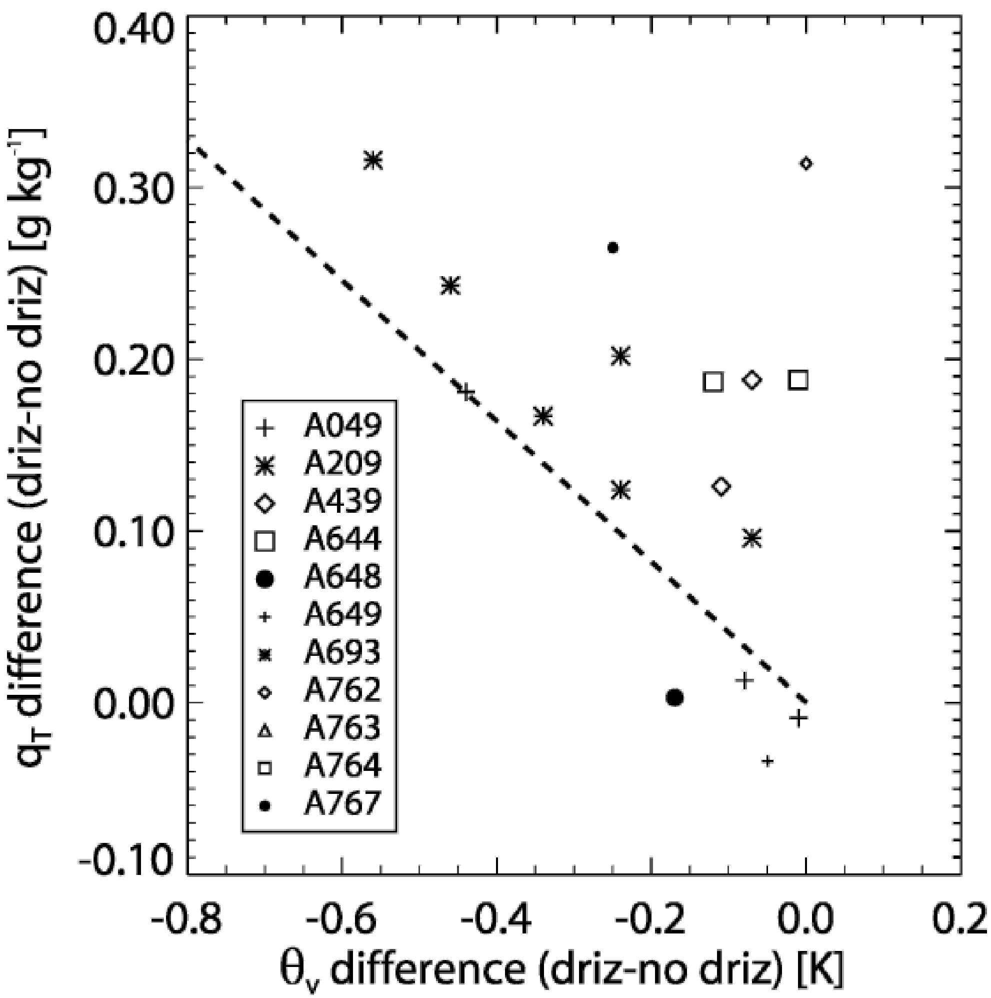


FIG. 11. Difference between the mean subcloud virtual potential temperature (θ_v, abscissa) and mean total water (q_T, ordinate) in drizzle regions and drizzle-free regions for suitable subcloud runs. The dashed line corresponds to differences caused purely by evaporation.

***Wood* (2005) found that the sub-cloud layer with drizzle is generally cooler and wetter than drizzle-free region, which is a result of evaporation cooling and suggest a possible evaporative dynamic feedback.**

Table 1. Nine Ground-Based Cloud Retrieval Products at Five ARM Sites Along With Their Primary Microphysical Products, PI Contact Information and References[a]

Products	Microphysical Products	Contact PIs	Affiliations	Sites	Clouds	References
MICROBASE	LWC, liquid r_e IWC, ice r_e	Mike Jensen; Maureen Dunn	Brookhaven National Lab	All 5 sites	Liquid	*Liao and Sassen* [1994]; *Frisch et al.* [1995]
					Ice	*Liu and Illingworth* [2000]; *Ivanova et al.* [2001]

Table 2. Approximate Uncertainties in the Major Cloud Microphysical Properties Derived From Different Retrievals in Nine Cloud Products Based on Literature[a]

even in COMBRET, they only classify drizzle and do not investigate the impact of drizzle on cloud property retrievals. So far, none of the studies have quantitatively investigated the extent will drizzle impact cloud property retrievals

		Cloud Property Uncertainties From Literature				
Products	Clouds	LWP	LWC	Liquid r_e	IWC	Ice r_e
MICRO						
MACE						
						%
CLOUD						
	Ice part	-	-	-	~30–50%	-
DENG	Ice	-	-	-	~85%	~35%
SHUPE_ TURNER	Pure liquid clouds	~20–30%	~10–50%	~10%	-	-
	Liquid and ice in optical thin clouds	~20–30%	~40–70%	~20–30%	~60–100%	~20–50%
	Ice in other clouds	-	-	-	~60–100%	~20–50%
WANG	Mixed	~18%	~18%	~18%	~10–100%	~10–30%
COMBRET	Liquid (radar)	Same as MICROBASE				
	Ice (Z_e and σ_{ext})	-	-	-	~10–100%	~10–30%
	Ice (Z_e)	-	-	-	~30–50%	NG
	Ice (σ_{ext})	-	-	-	NG	NG
	Drizzle and Rain	-	-	-	NG	NG
RADON	Ice	-	-	-	~30–40%	~15%
VARCLOUD	Ice	Uncertainties are dependent on errors in measurements and accuracy in forward models				

[a]"NG" indicates that the uncertainty is not given in the literature and "-" denotes that the variable does not exist or is not retrieved for the specific cloud type.

Zhao et al., JGR, 2012