Impact of Drizzling on the CERES-MODIS MBL Cloud Microphysics Retrievals During MAGIC and Azores IOPs

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1) Dong, X., B. Xi, A. Kennedy, P. Minnis and R. Wood, 2014: A 19-month record of Marine Aerosol-Cloud-Radiation Properties derived from DOE ARM AMF deployment at the Azores: Part I: Cloud Fraction and Single-layered MBL cloud Properties. J. Clim. DOI: 10.1175/JCLI-D-13-00553.1

2) Xi, B., X. Dong, P. Minnis, and S. Sun-Mack, 2014: Validation of CERES-MODIS Edition 4 Marine Boundary Layer Cloud Properties using DOE ARM AMF Measurements at the AZORES. Submitted to JGR.

3) Tian, J., X. Dong, B. Xi, S. Giangrande, and T. Toto, 2014: Retrievals of cloud microphysical properties of DCS using ARM ground-based and aircraft in situ measurements. Part I: Ice-phase layer. Submitted to JGR.

4) Qiu, S., X. Dong, and B. Xi., 2014: Detection of Arctic Clouds and Determination of Cloud Base Height from MPL and Ceilometer Measurements at the ARM NSA Site. Submitted to GRL.

5) Stanfield, R., X. Dong, B. Xi, A. Gel Genio, P. Minnis, and J. Jiang, 2014a: Assessment of NASA GISS CMIP5 and post-CMIP5 Simulated Clouds and TOA Radiation Budgets Using Satellite Observations: Part I: Cloud fraction and properties. J. Clim. doi:10.1175/JCLI-D-13-00588.1

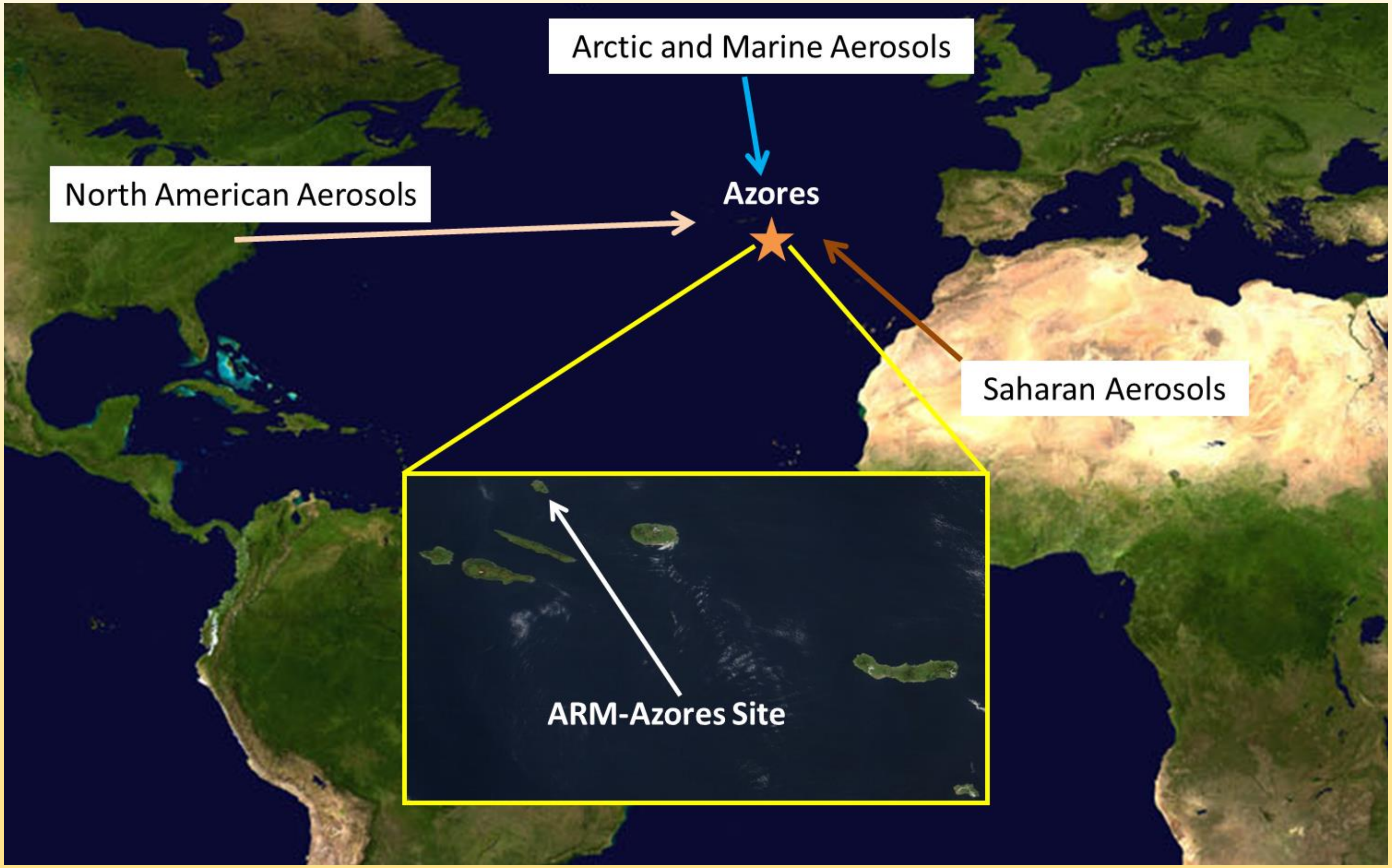
6) Stanfield, R., X. Dong, B. Xi, A. Gel Genio, P. Minnis, D. Doelling, and N. Loeb, 2014b: Assessment of NASA GISS CMIP5 and post-CMIP5 Simulated Clouds and TOA Radiation Budgets Using Satellite Observations. Part II: TOA Radiation Budgets and Cloud Radiative Forcings. Submitted to J. Clim.

7) Dolinar, E., X. Dong, B. Xi, J. Jiang and H. Su, 2014: Evaluation of CMIP5 simulated Clouds and TOA Radiation Budgets using NASA satellite observations. Climate Dynamics (In press).

Motivation

- **How often drizzles occur in MBL clouds and why do we care about drizzling underneath the MBL clouds?**
- **Can we distinguish the drizzle AND non-drizzle clouds using particle size? What percentages of drizzle LWP_d to MWR-retrieved entire column LWP_t?**
- **Do drizzles affect both ARM and satellite cloud microphysics retrievals?**

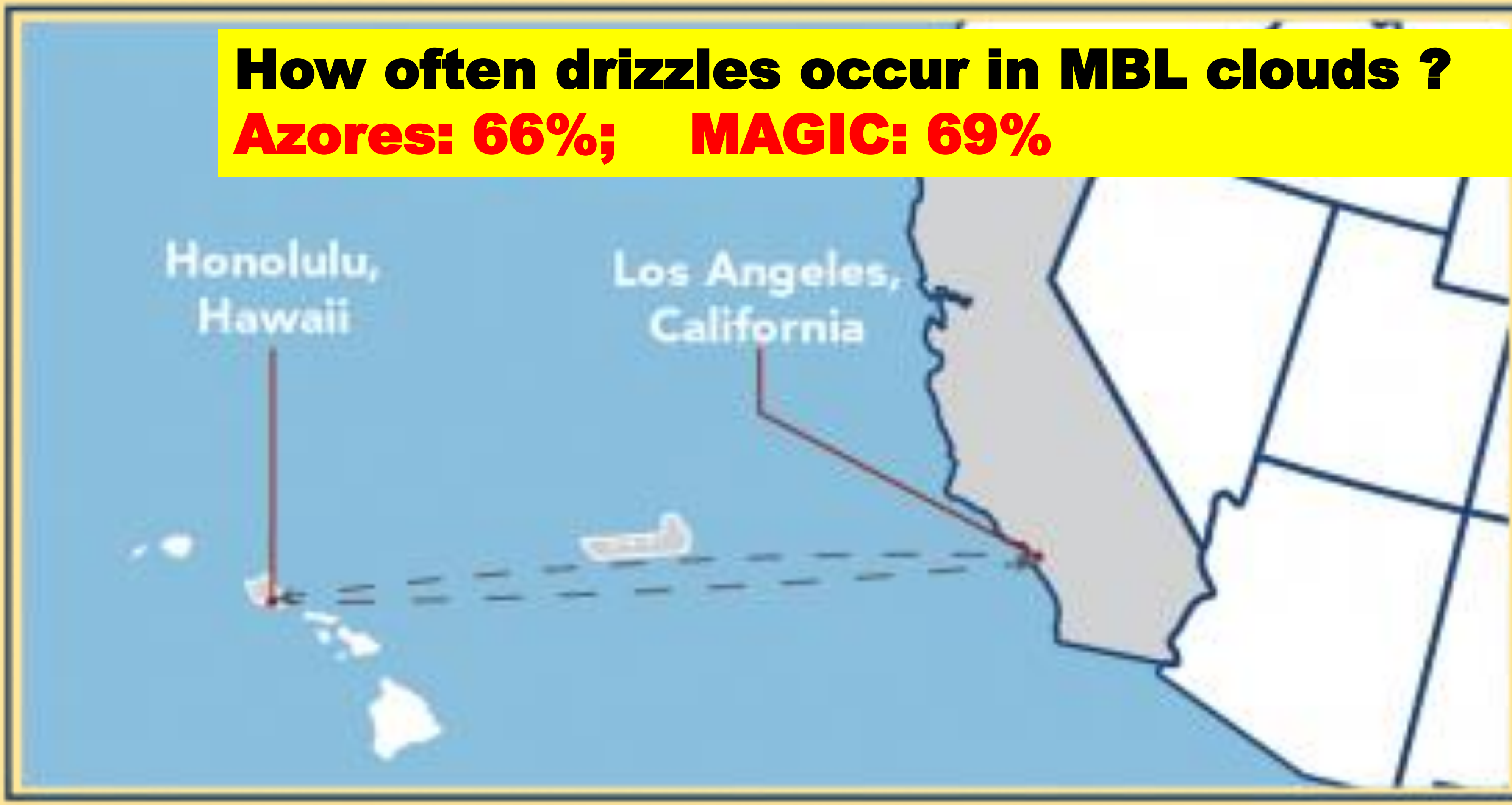
Data and Methods



ARM Azores-AMF data and retrievals are available from 200906 to 201012 (Dong et al. 2014, J. Clim; Xi et al. 2014, JGR)

Marine ARM GPCI Investigation of Clouds (MAGIC) IOP

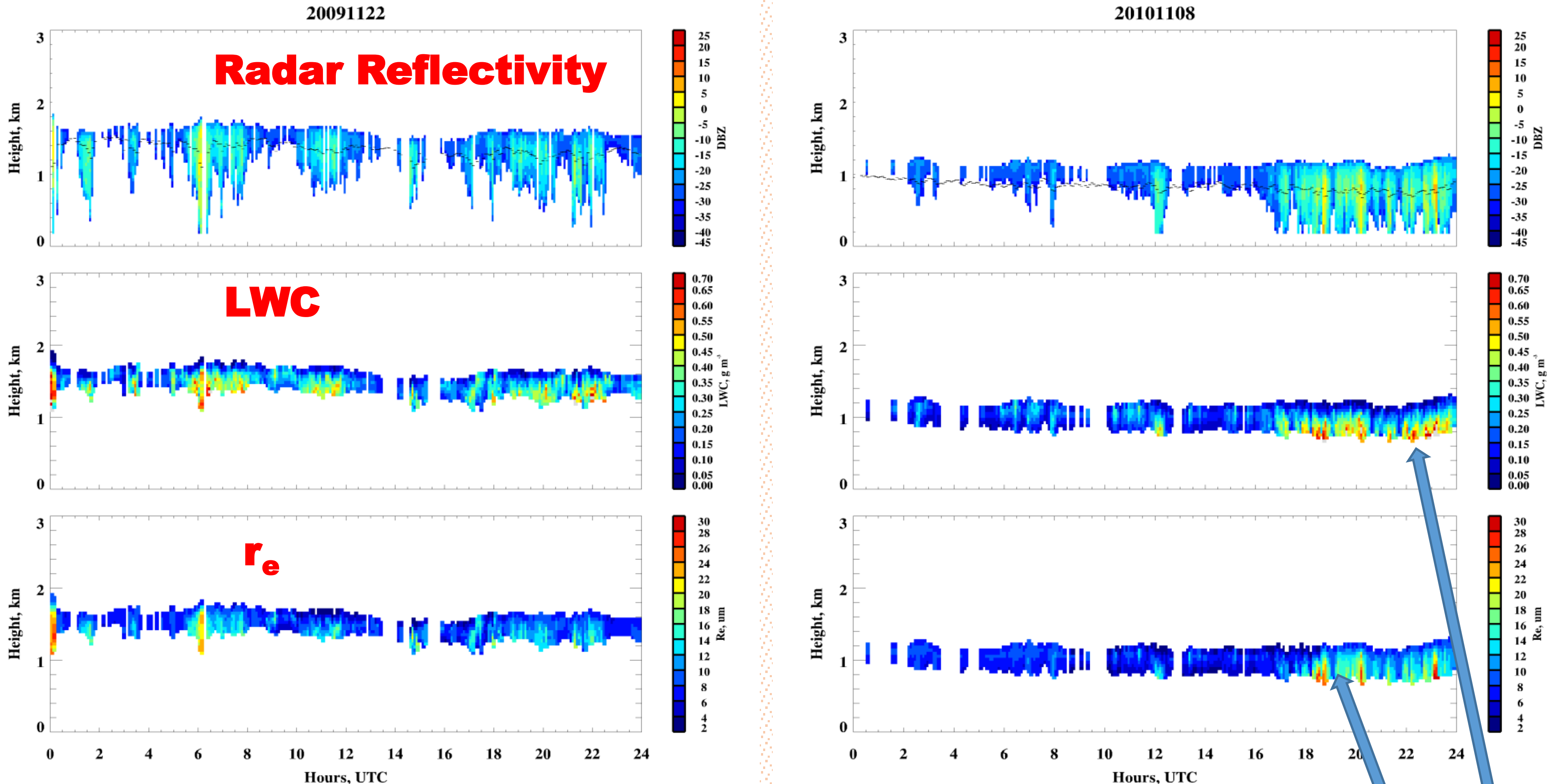
How often drizzles occur in MBL clouds ?
Azores: 66%; MAGIC: 69%



From 201210 to 201309, the DOE AMF2 was carried by the Horizon Line cargo ship Spirit traversing the route between Los Angeles, CA and Honolulu, HI

Why do we care about drizzling underneath the MBL clouds?

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



<u>Definition of drizzling:</u> particles falling out of cloud base are called 'drizzles' in this study. Due to their large size, a few drizzles will lead to large radar reflectivity (~ D^6/λ^4), which may result in overestimation of cloud LWC and re retrievals near the cloud base.

Retrieval method

Drizzle microphysics

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

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

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 α=$S\beta$, where S is termed of lidar ratio and can be estimated using Mie theory.

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

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

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 N_d as follows:

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

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

The ratio(R) of drizzle LWP_d to total LWP_t (retrieved by MWR) is

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

The uncertainties of D_0 and LWC_d are 14% and 10%, respectively.

Retrieval method

Cloud microphysics

Dong (1998) parameterized the retrieval process using the LWP, solar transmission, and cosine of solar zenith angle as

$\overline{r_e} = -2.07 + 2.49LWP + 10.25\gamma - 0.25\mu_0 + 20.28LWP\gamma - 3.14LWP\mu_0$ **(6)**

Profile of r_e can be written as

$$r_e(h) = \overline{r_e}\left[\frac{\Delta H}{\Delta h}\frac{Z^{1/2}(h)}{\sum_{base}^{top} Z^{1/2}(h)}\right]^{1/3} \quad (7)$$

ΔH is cloud thickness

$r_e(h)$ derived from (7) is independent of the radar calibration similar to the independence

Assuming the cloud-droplet number concentration and lognormal size distribution are constant with height, radar reflectivity can be written as

$$Z(h) = 2^6 N\langle r^6(h)\rangle = 2^6 N {r_e}^6(h) exp(3{\sigma_x}^2) \quad (8)$$

Take $10log_{10}$ of both side,

$$dBZ(h) = 10\left[1.806 - 12 + 0.4343lnN + 2.606lnr_e(h) + 1.303{\sigma_x}^2\right]$$

Solve for $r_e(h)$

$$r_e(h) = \frac{\exp(3.912 - 0.5{\sigma_x}^2)}{N^{0.167}}\exp[0.0384dBZ(h)]$$
$$= a\ exp[0.0384dBZ(h)] \quad (9)$$

Get empirical coefficients between dBZ and r_e from daytime dBZ at Azores, then apply this formula to MAGIC.

After eliminating drizzle LWP (LWP_d), we use

$LWP_c = LWP - LWP_d$ instead of LWP in (6),

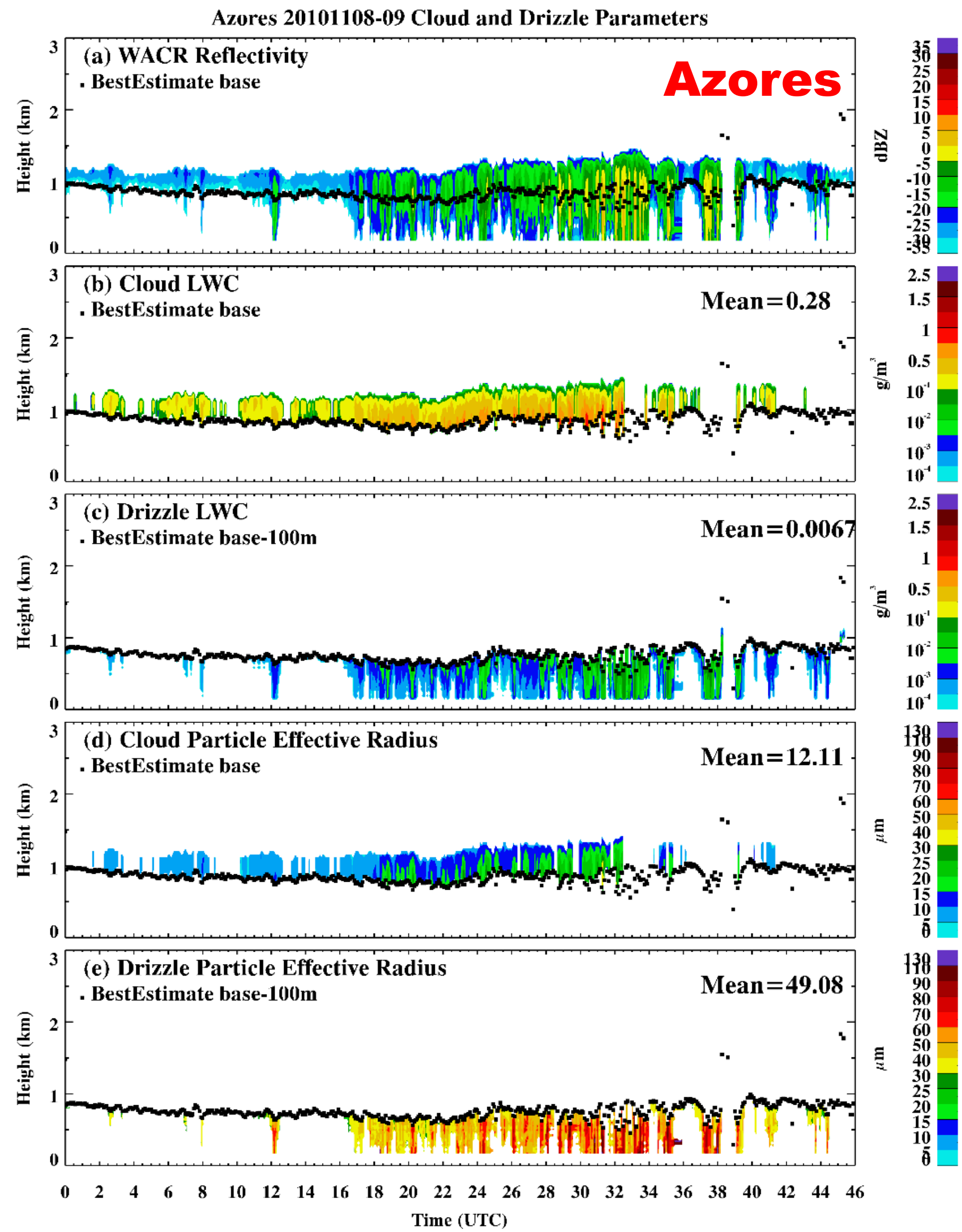
$\overline{r_{e_c}} = -2.07 + 2.49LWP_c + 10.25\gamma - 0.25\mu_0 + 20.28LWP_c\gamma - 3.14LWP_c\mu_0$ **(10)**

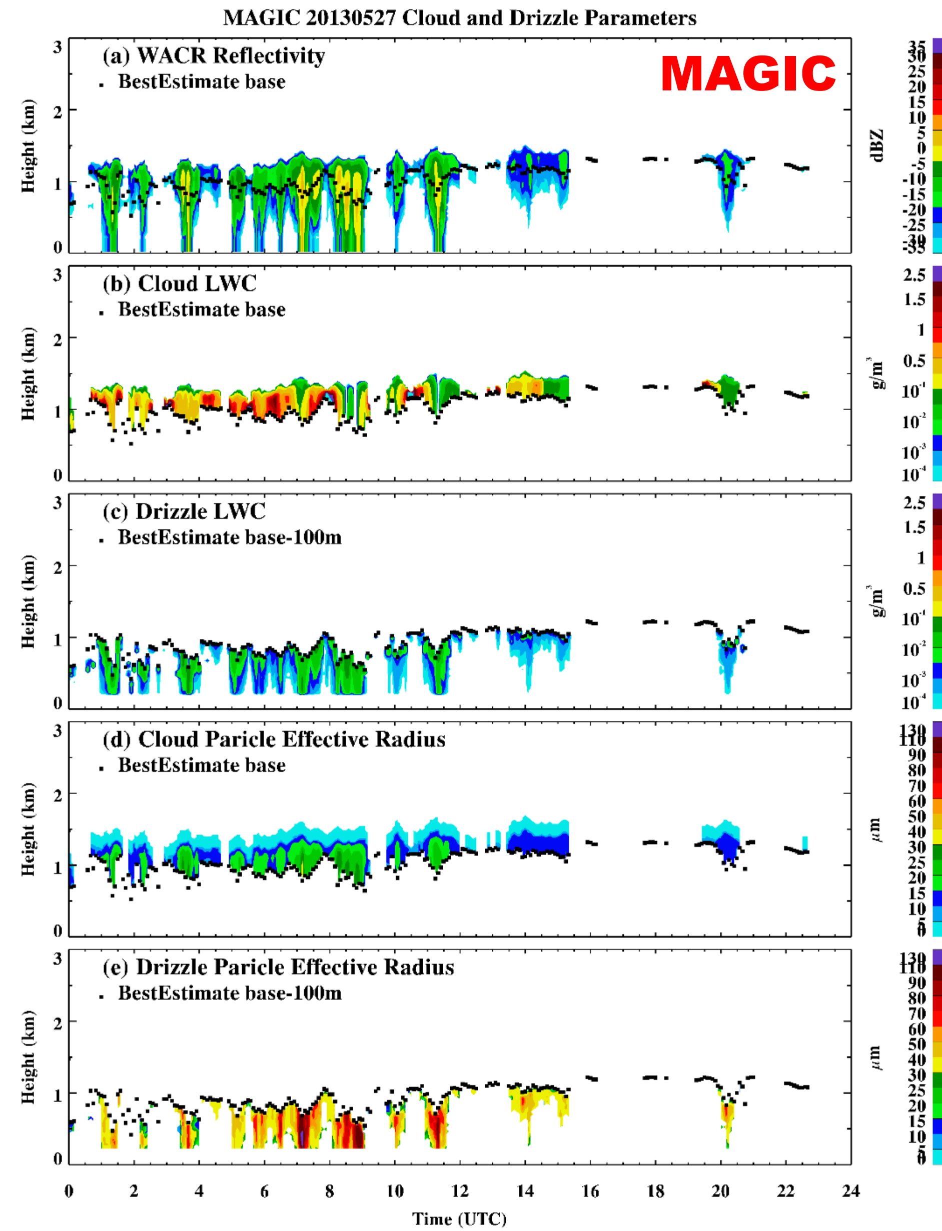
Profile of r_e can be written as

$$r_{e_c}(h) = \overline{r_{e_c}}\left[\frac{\Delta H}{\Delta h}\frac{Z^{1/2}(h)}{\sum_{base}^{top} Z^{1/2}(h)}\right]^{1/3} \quad (11)$$

ΔH is cloud thickness

$r_e(h)$ derived from (7) and (11) is independent of the radar calibration similar to the independence



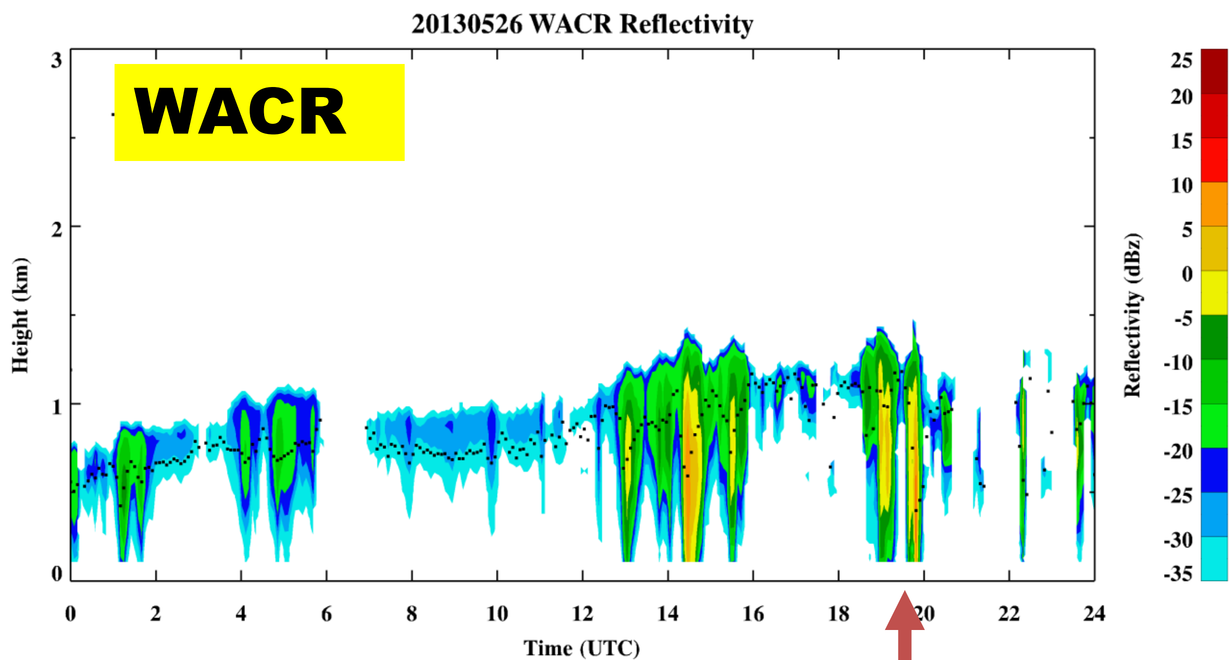


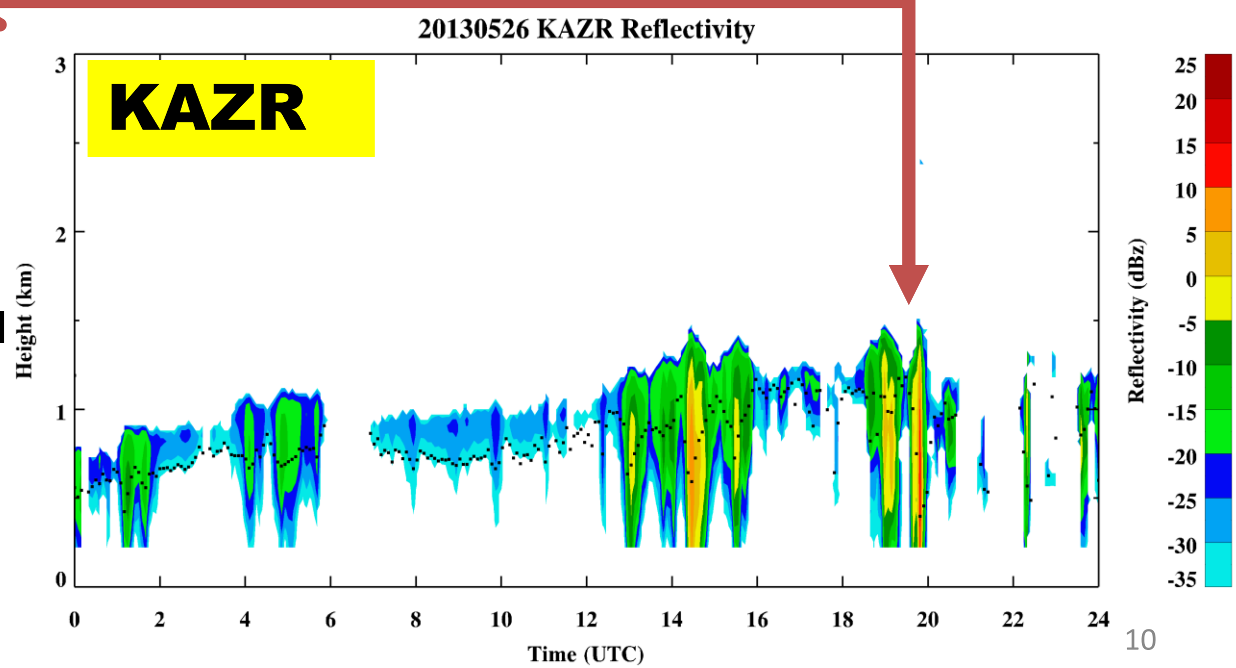
Although drizzle r_e (49 μm) is 4 times of cloud droplet radius r_e (12 μm), its LWC (0.007 gm^{-3}) is three order magnitude lower than cloud LWC (0.28 gm^{-3}) due to its much lower N_d than cloud N_c.

Rain period

May 26, 2013
19:47:00 UTC
TSI Images

20130526-19:47:00, Rain reached TSI



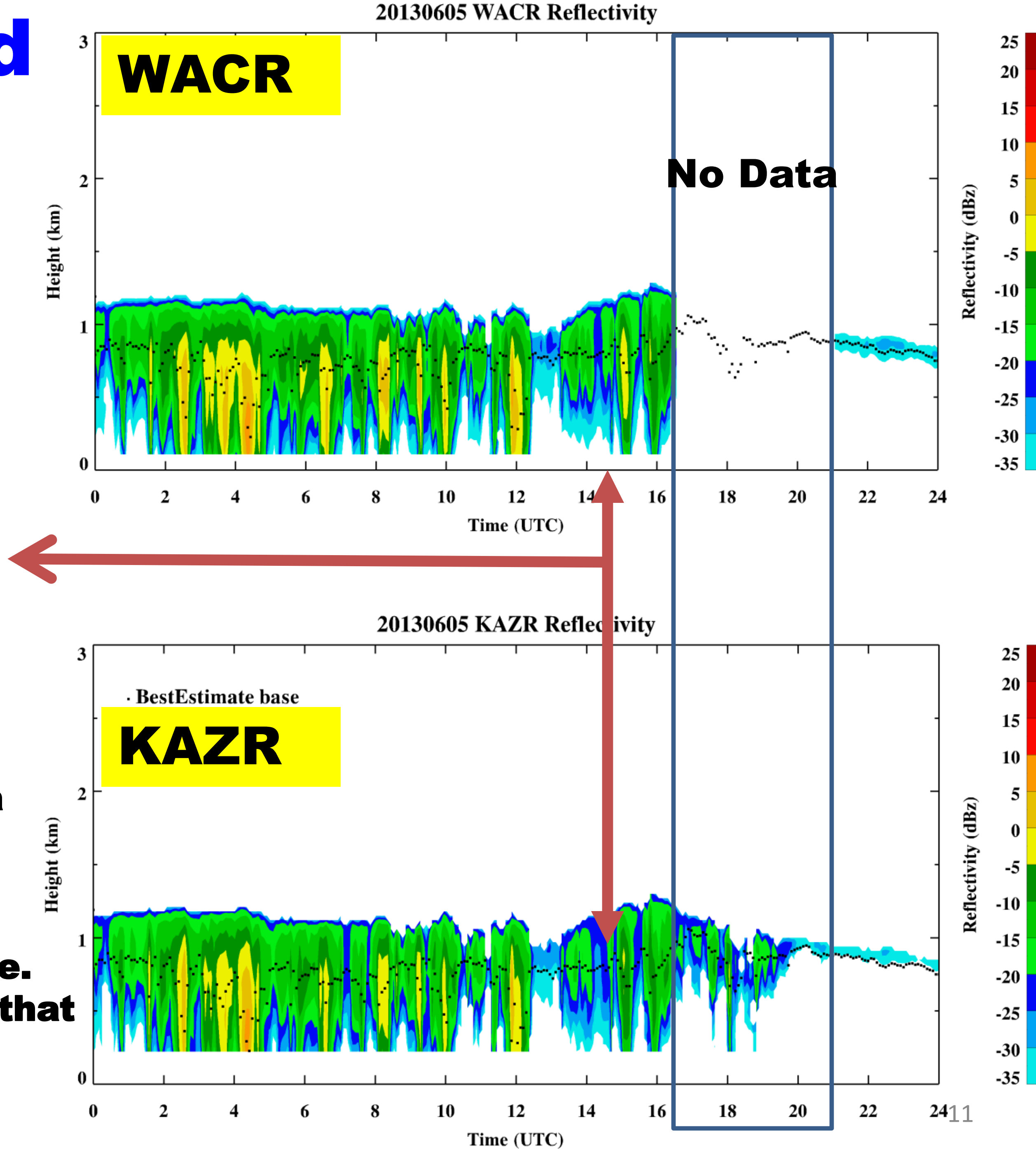


1) Both WACR and KAZR reflectivity have confirmed drizzling underneath the cloud base.
2) From TSI, the rain droplets reach the ground, which defines as "Rain period'.

Virga period

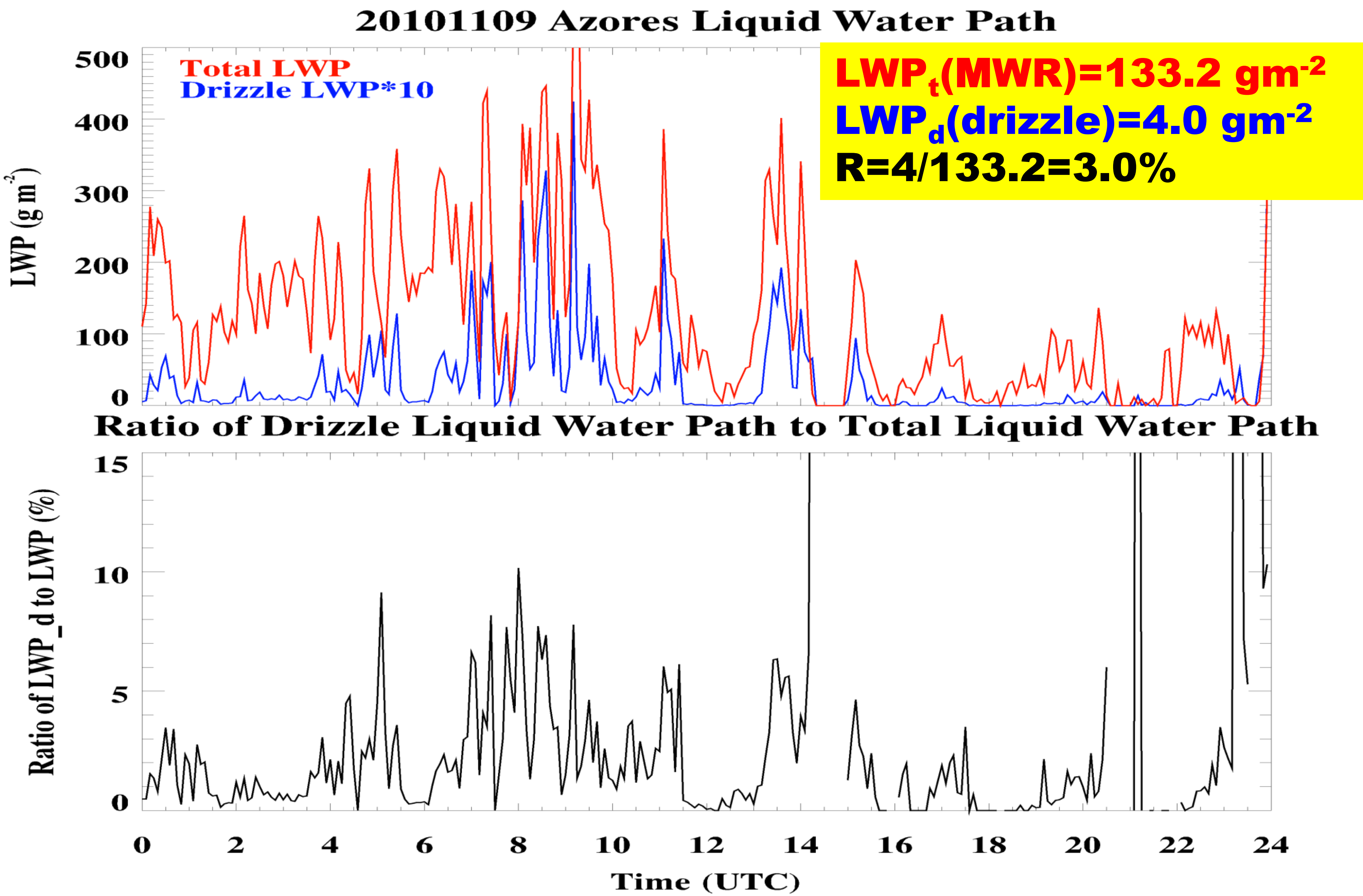
June 5th, 2013
14:30:00 UTC
TSI Images

20130605-14:30:00, Virga

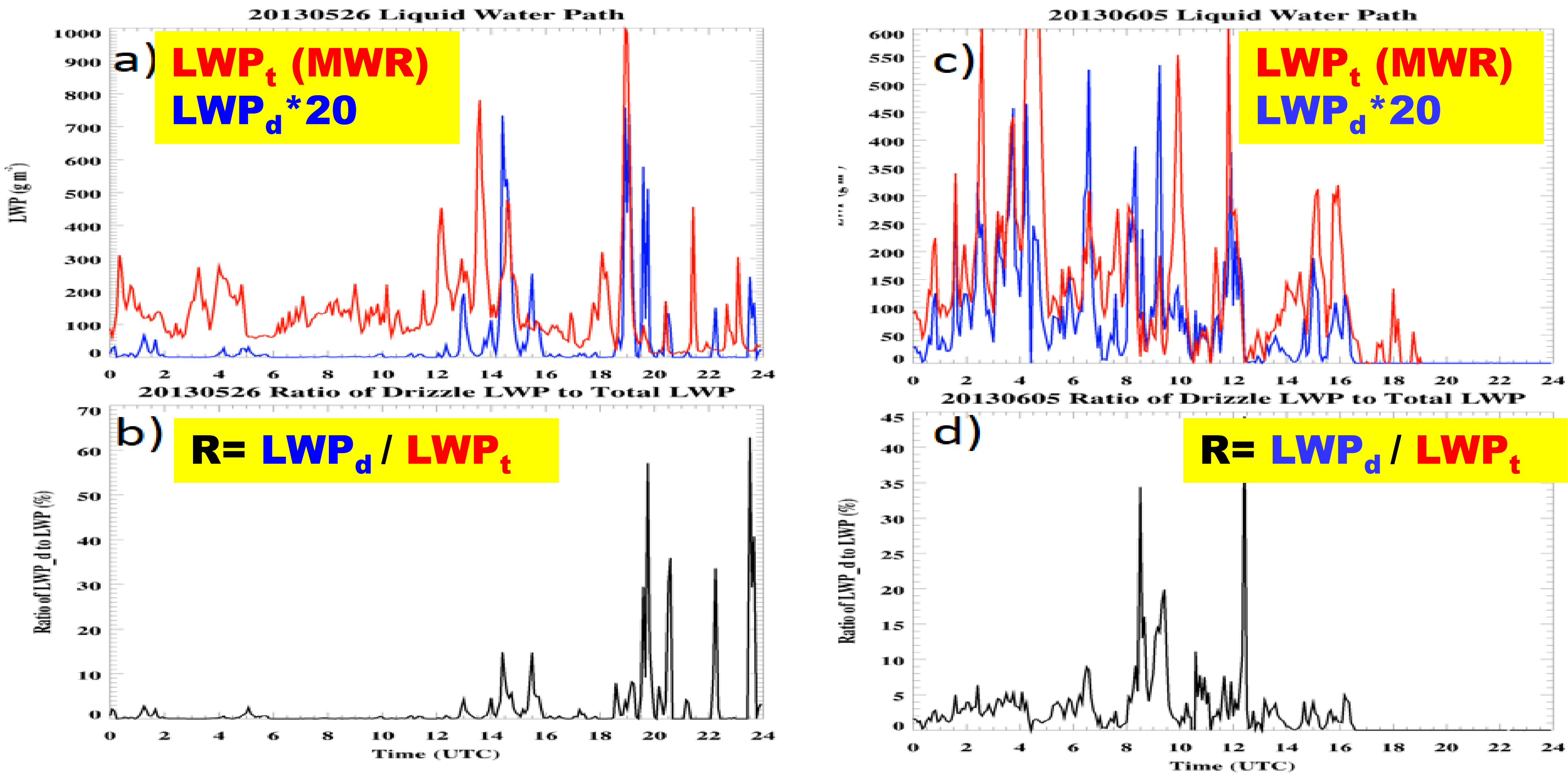


(1)KAZR added more data when WACR did not work
(2) Both radars have confirmed drizzling underneath the cloud base. But TSI image confirmed that drizzles did not reach the ground, which defines as 'Virga period'.

What percentages of drizzle LWP to MWR-retrieved entire column LWP?

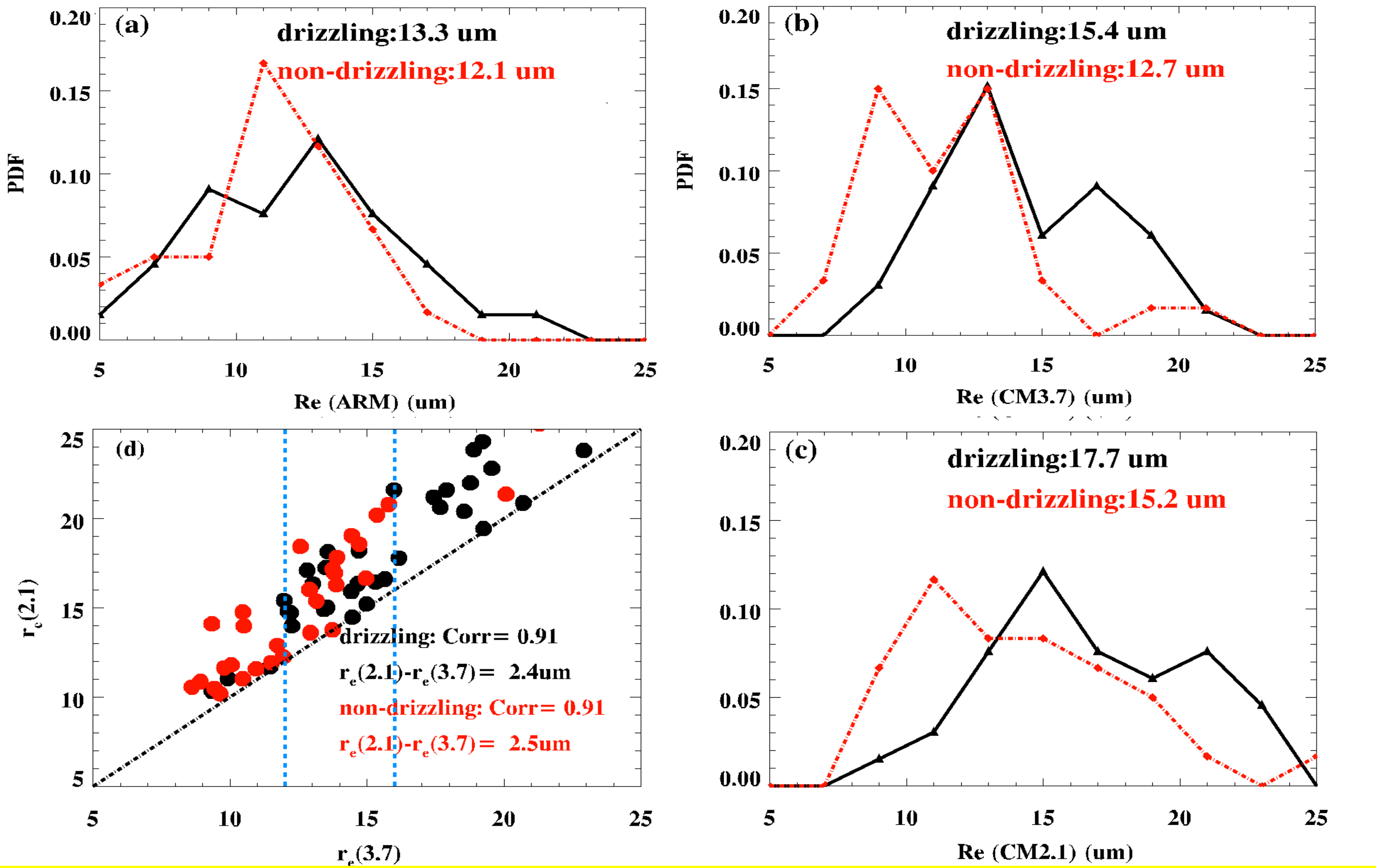


MAGIC: Comparisons between calculated LWP_d and LWP_t retrieved by MWR



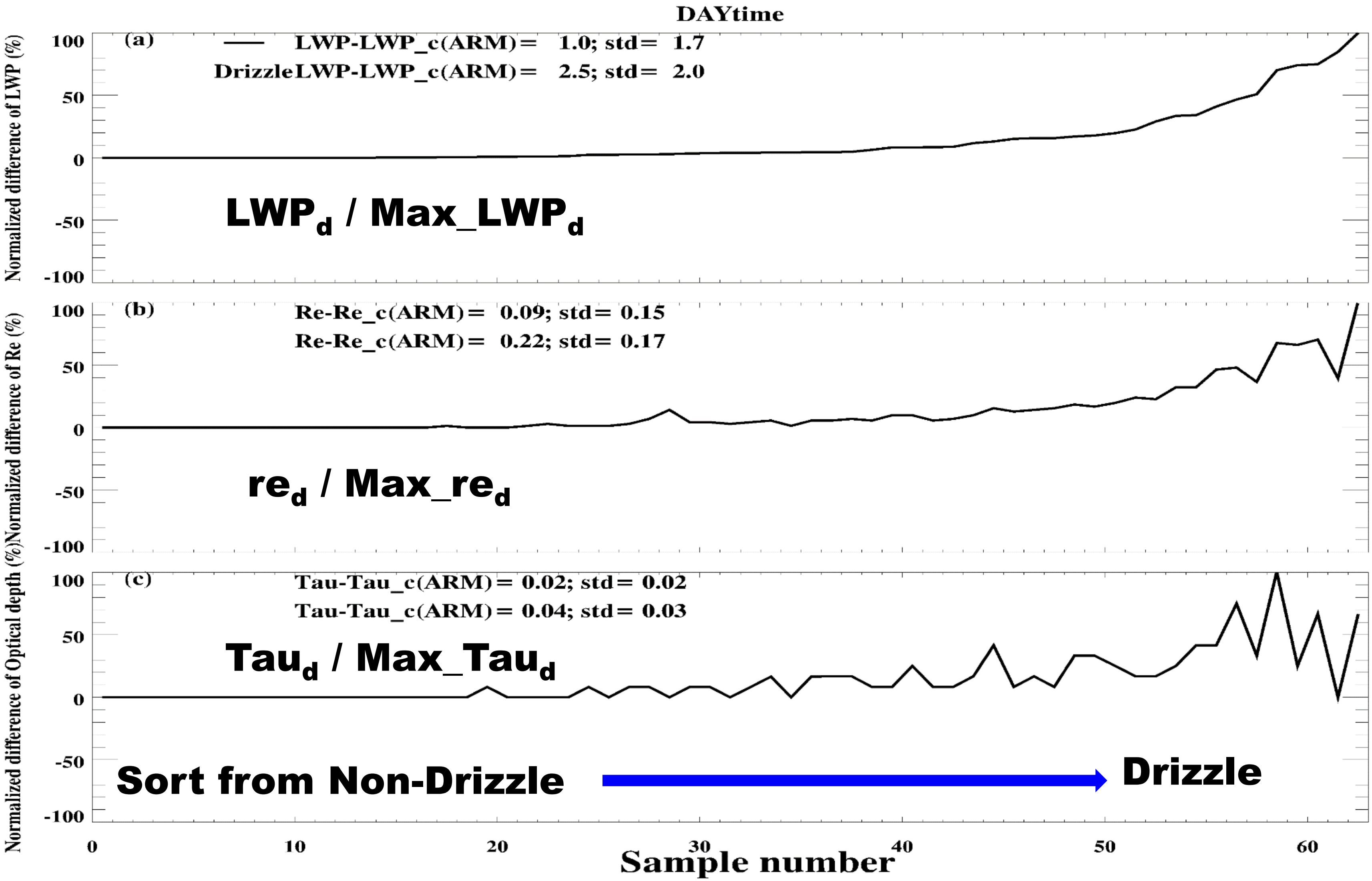
During the MAGIC IOP, the averaged LWPd, LWPt and Ratio are
LWP_d(Virga)=1.71 gm^{-2}, LWP_t(MWR)=87.1 gm^{-2}, R=2%
LWP_d(Rain)=22.4 gm^{-2}, LWP_t(MWR)=252.9 gm^{-2}, R=9%
But for some rain cases, drizzle LWP_d can be up 50%.

Can we distinguish drizzle and non-drizzle clouds only using r_e?



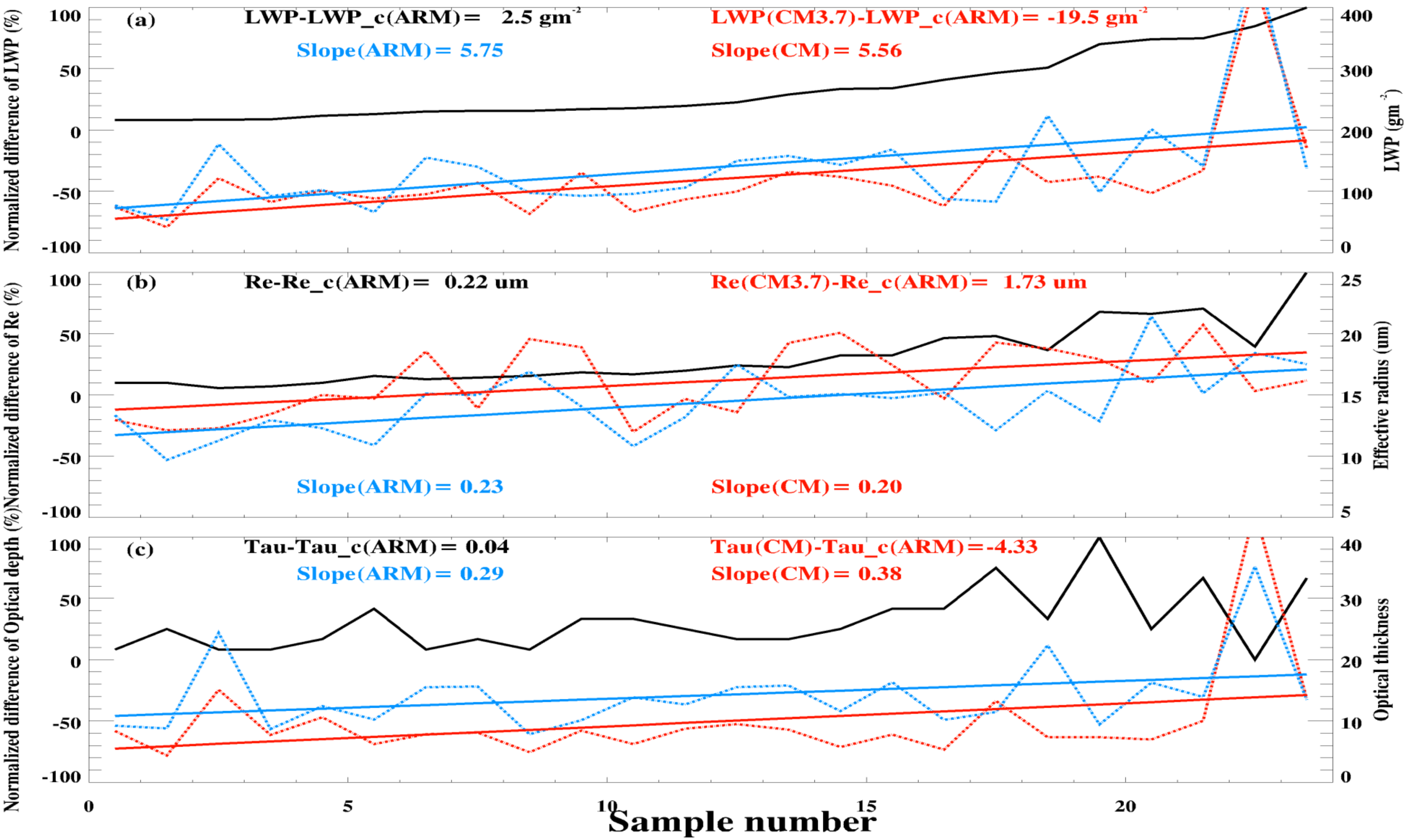
Yes, we can. As illustrated in Fig. d, there are little drizzle cases for $r_e(3.7) < 12$ μm, large overlap in the drizzle and non-drizzle size distributions for 12 μm < $r_e(3.7) < 16$ μm, and very high confidence for drizzle events for $r_e(3.7) > 16$ μm. (Figure 11 of Xi et al. 2014)

Do drizzles affect ARM cloud microphysics retrievals?



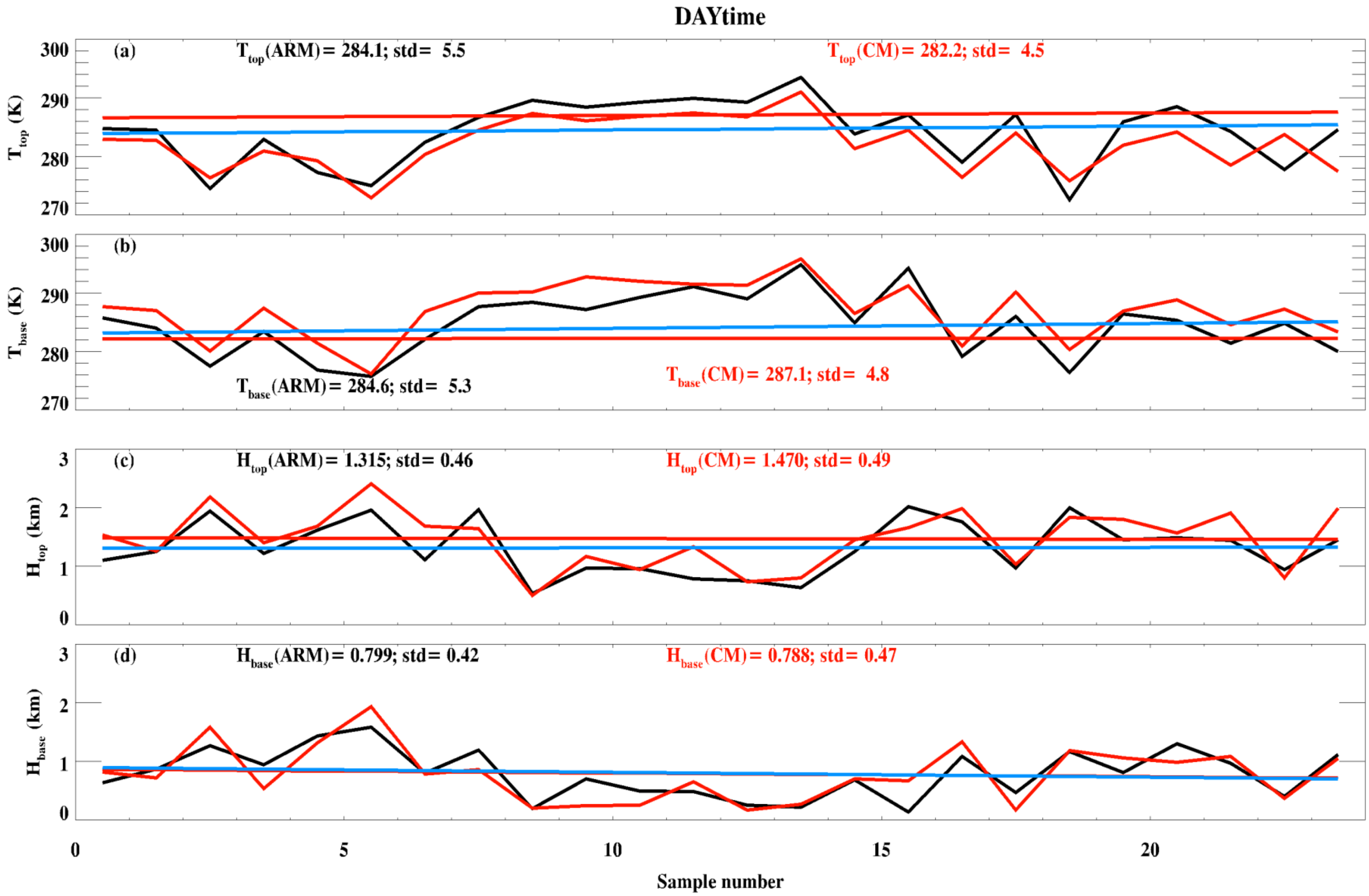
On average, the impact of drizzles on LWP, re, and tau retrievals (1.0 g/m^2, 0.09 um, and 0.02) is negligible. However, for some rain cases, drizzle effect can be significant (2.5 g/m^2, 0.22 um, and 0.04).

Any relations between cloud microphysics retrievals and drizzles?
For selected drizzle cases only here!



Following the sorted drizzle cases (solid black lines), both surface and satellite LWP/r_e/tau retrievals increase with increased drizzling underneath the cloud base, and their slopes are similar to each other.

Any relations between cloud height and temp with drizzles?
For selected drizzle cases only here!



The cloud macrophysical properties have NO response to the drizzling underneath the cloud base.

Summary

1) The drizzling is common underneath the MBL clouds: There is no significant difference between the Azores (66%) and during MAGIC (69%).

2) Based on a total of 19 months of Azores data, Xi et al. (2014) found
   a) there are little drizzle cases for $r_e(3.7) < 12$ μm,
   b) large overlap in the drizzle and non-drizzle size distributions for 12 μm $< r_e(3.7) <$ 16 μm, and
   c) very high confidence for drizzle events for $r_e(3.7) > 16$ μm.

3) What percentages of drizzle LWP_d to MWR-retrieved LWP_t?

- During the MAGIC IOP, the averaged LWP_d, LWP_t and Ratio are
- LWP_d(Virga)=1.71 gm^{-2}, LWP_t(MWR)=87.1 gm^{-2}, R=2%
- LWP_d(Rain)=22.4 gm^{-2}, LWP_t(MWR)=252.9 gm^{-2}, R=9%
- But for some rain cases, drizzle LWP_d can be up 50%.

4) Any relations between cloud microphysics retrievals and drizzles? Both surface and satellite LWP/r_e/tau retrievals increase with increased drizzling underneath the cloud base, and their slopes are similar to each other.