The Vertical Structure of Liquid Water Content in Shallow Clouds as Retrieved from Dual-wavelength Radar Observations

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ASR
Atmospheric
System Research

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RADAR SCIENCE

Stony Brook University
School of Marine and Atmospheric Sciences

Motivation

How to retrieve LWC in warm cloud?

- Radar

$$Z = 0.048 * LWC^2$$

[Atlas, 1954]

-Microwave Radiometer & Radar

$$LWC_i = \frac{QZ_i^{0.5}}{\sum_{i=1}^{M} Z_i^{0.5} \Delta h}$$

[Frisch et al., 1998]

Limited to reflectivity accuracy and drizzle occurrence

- Dual-wavelength technique

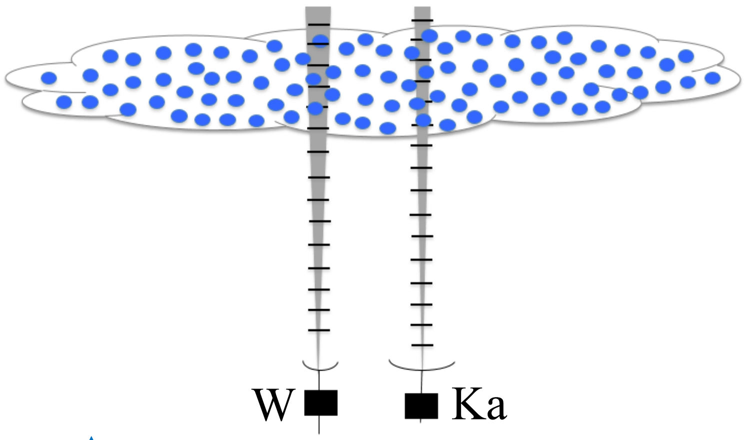
No priori assumption of LWC distribution

Not affected by radar calibration

Not affected by drizzle occurrence

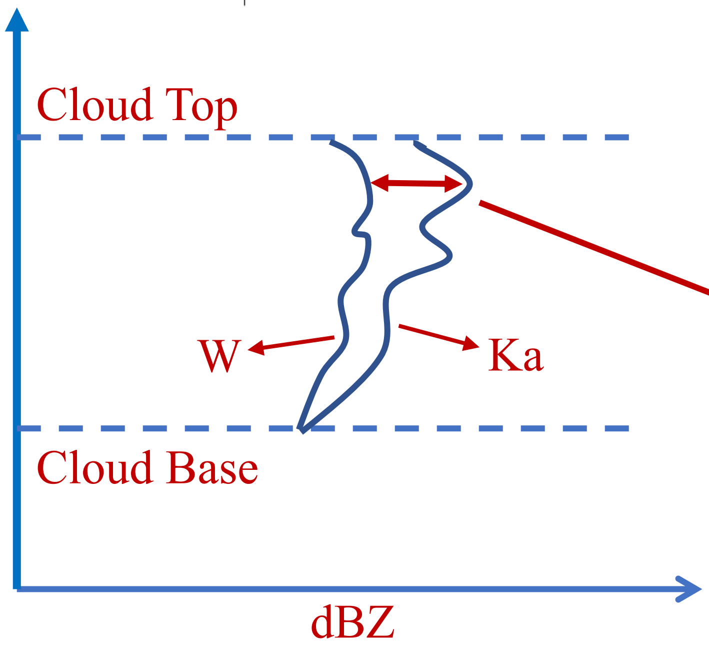
[Hogan et al., 2005]

Methodology



$$Z_f = Z_0 - 2\int_0^h (\alpha_f + \kappa_f LWC)\,dh$$

Observed
Unattenuated
Two way
Gas
Liquid



$$DWR_h(dB) = Z_{Ka}(h) - Z_W(h) = -2\int_0^h [\alpha_{35} - \alpha_{94} + (k_{35} - k_{94})LWC]\,dh$$

Known

[Hogan et al., 2005]

Methodology

Well matched radar observation in beam width, range resolution and sampling time

Ka/W-SACR2 operating on ENA site provide us a best opportunity to apply DWR technique

Jun 21- Oct 15, 2016

Constrain random observational uncertainty

$$\Delta Z_f = \frac{4.343}{\sqrt{\Delta t PRF_f M}} \left(\frac{\lambda PRF_f}{4\pi^{\frac{1}{2}} \sigma_{w,f}} + \frac{1}{SNR_f^2} + \frac{2}{SNR_f} \right)^{\frac{1}{2}}$$

$$\Delta LWC = \frac{(\Delta Z_{f1}^2 + \Delta Z_{f2}^2)^{\frac{1}{2}}}{\sqrt{2}(k_{f1} - k_{f2})\Delta h}$$

Averaging profiles in time and considering a vertical window to account for more observation to reduce error

$\Delta Z_f \sim 0.2$ dB

$\Delta t = 2s$
$\Delta h = 12.5m$

$\Delta LWC \sim 4$ g m^{-3} !!

Need to reduce random error

[Hogan et al., 2005]

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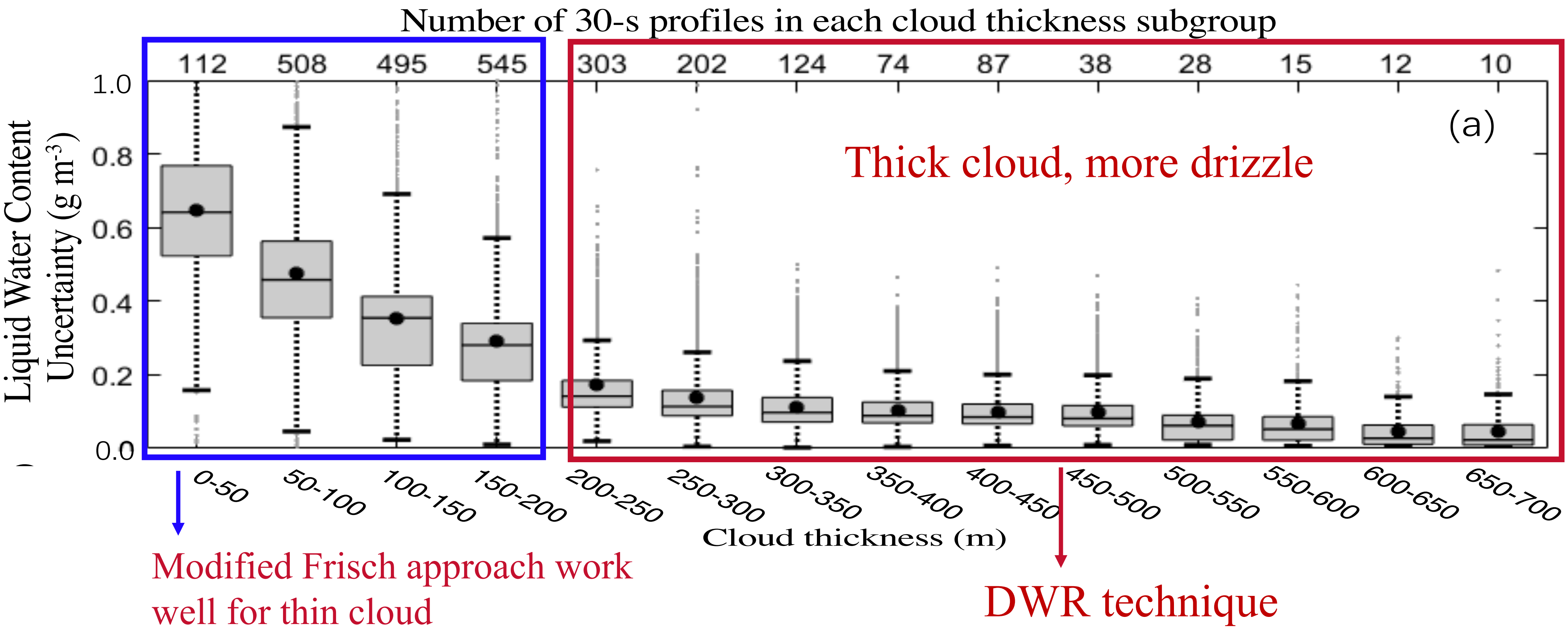
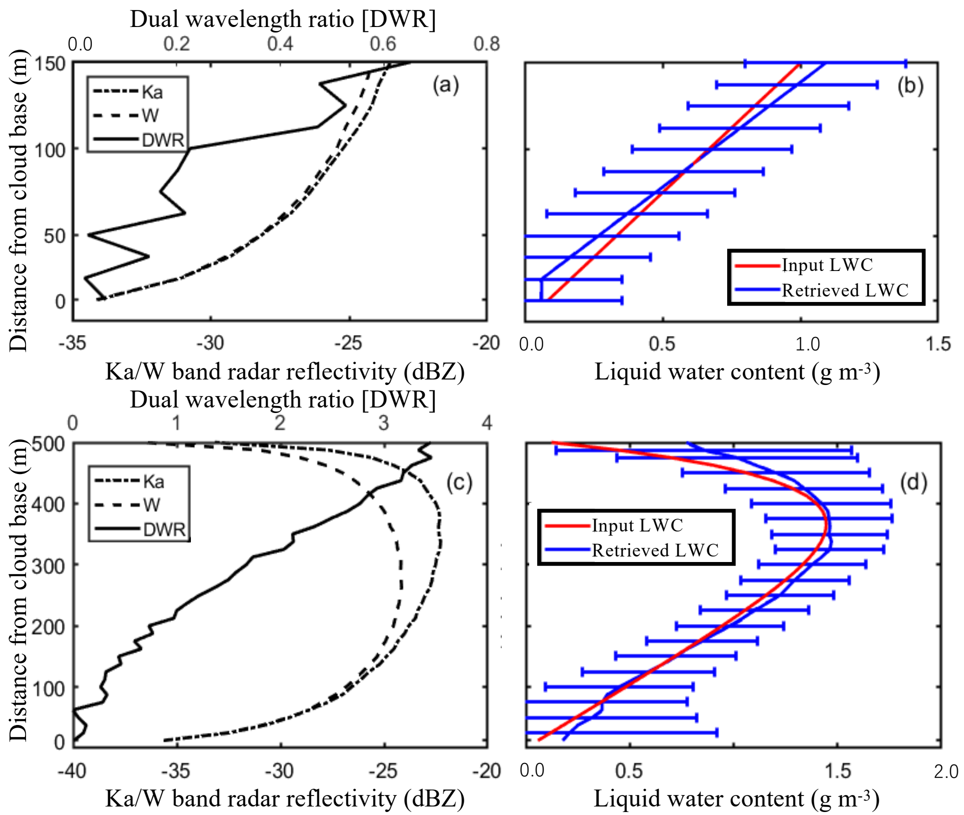
Uncertainty Estimation



[N. Küchler.,2018]

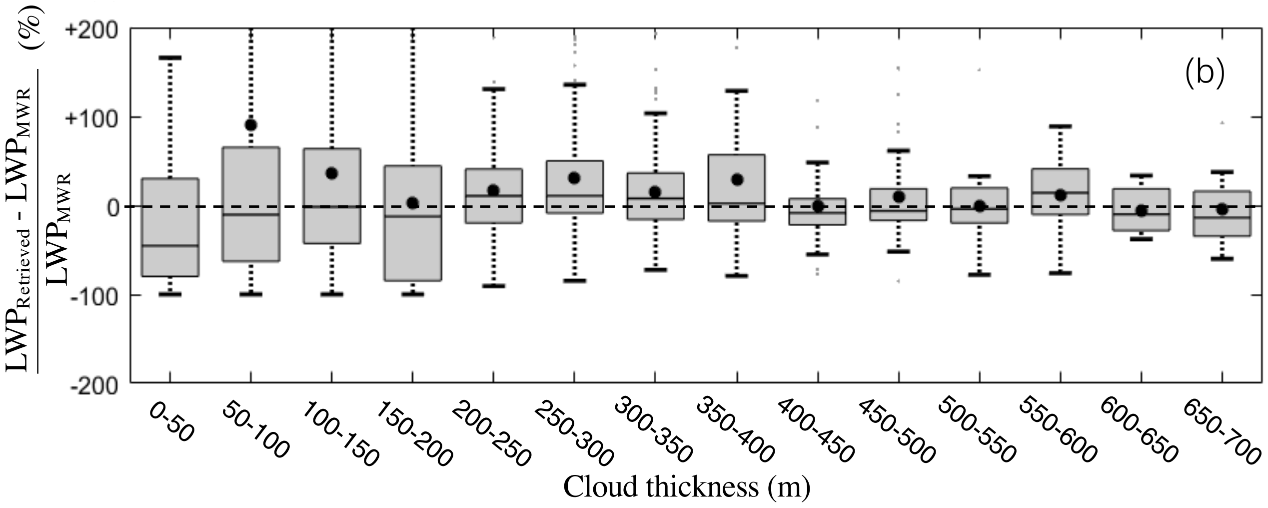
Retrieval Evaluation

Observing System Simulation Experiments (OSSEs)



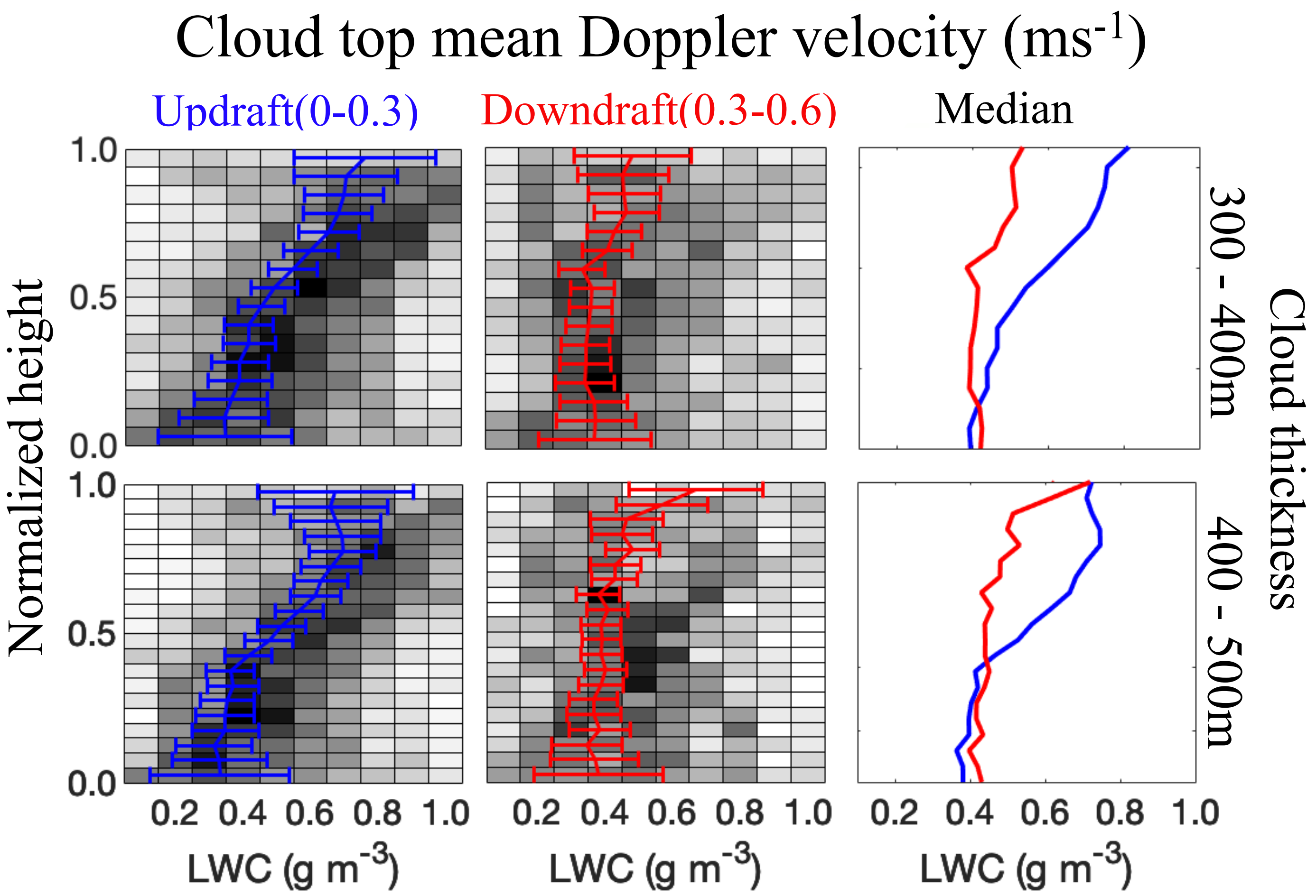
The proposed technique can capture the shape for both linear and nonlinear LWC distribution

Comparison with MWR- retrieved LWP



LWP comparison with MWR indicates no systematic bias of the retrieval

Impact of Dynamics on Vertical Distribution of LWC

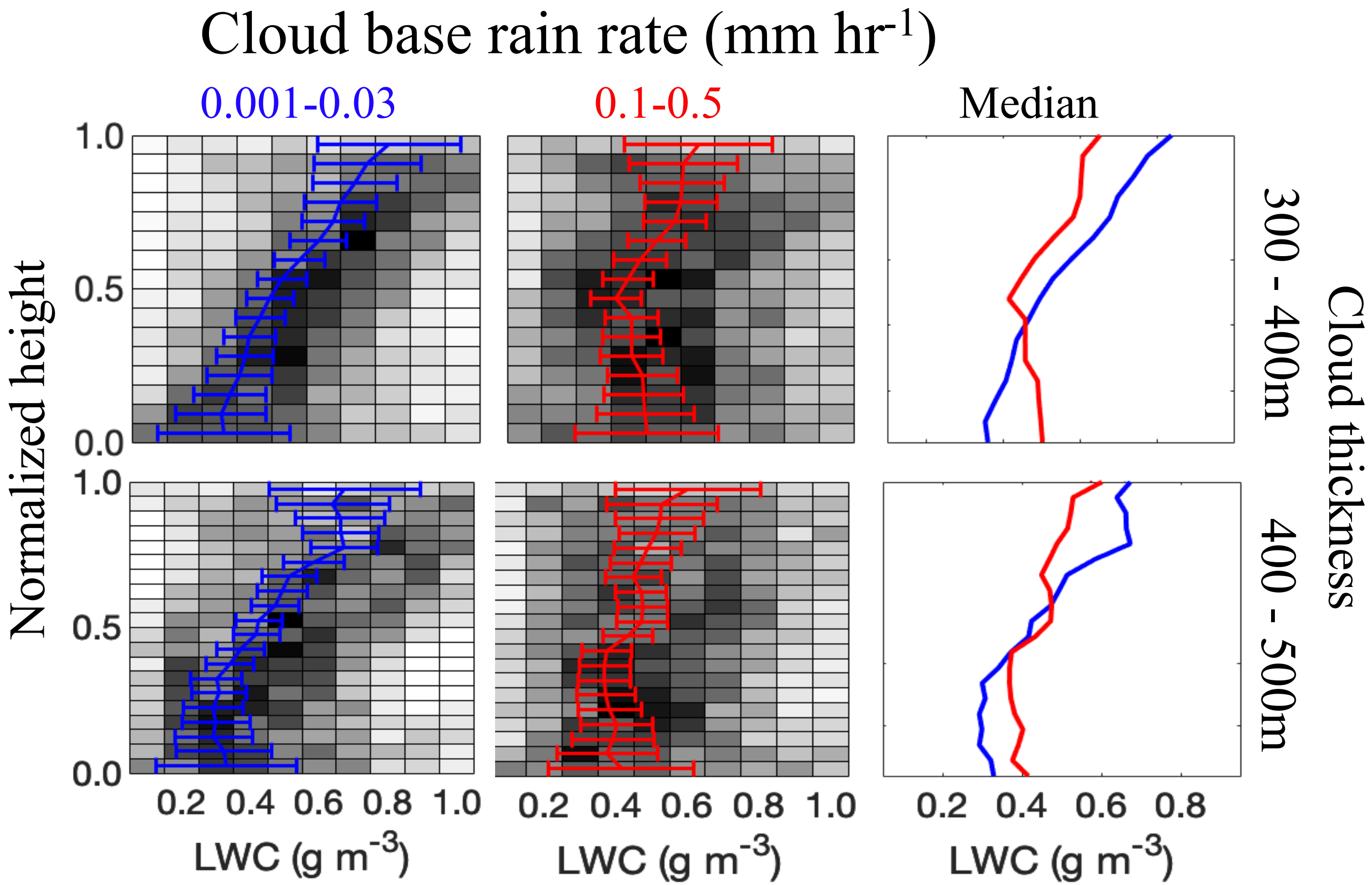


Downdraft velocity at cloud top

Entrainment ?

Lower LWC in the upper part of the cloud

Impact of Rain Rate on Vertical Distribution of LWC



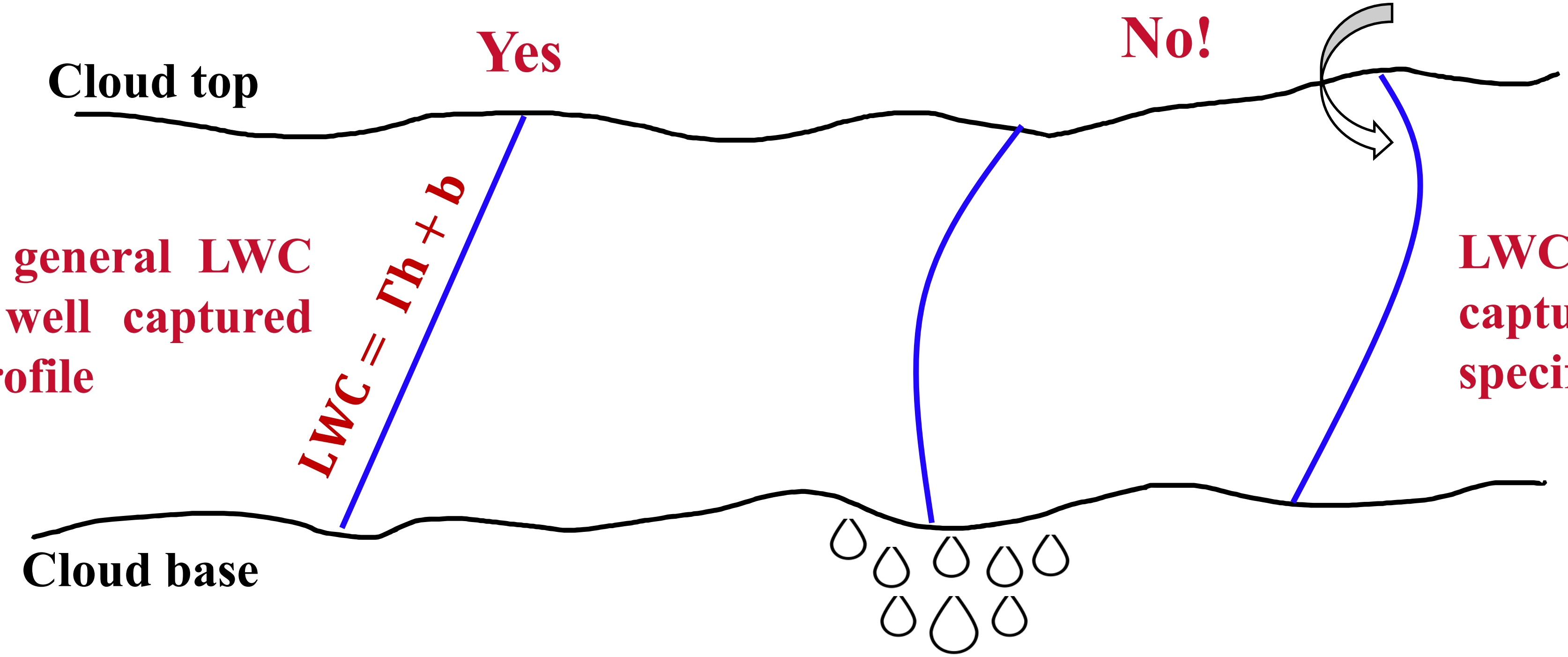
Increasing rain rate at cloud base

More liquid water in the lower part of the cloud

LWC Profile Linearity

Can LWC profile be represented linearly within cloud ?

On average, general LWC profiles are well captured by a linear profile



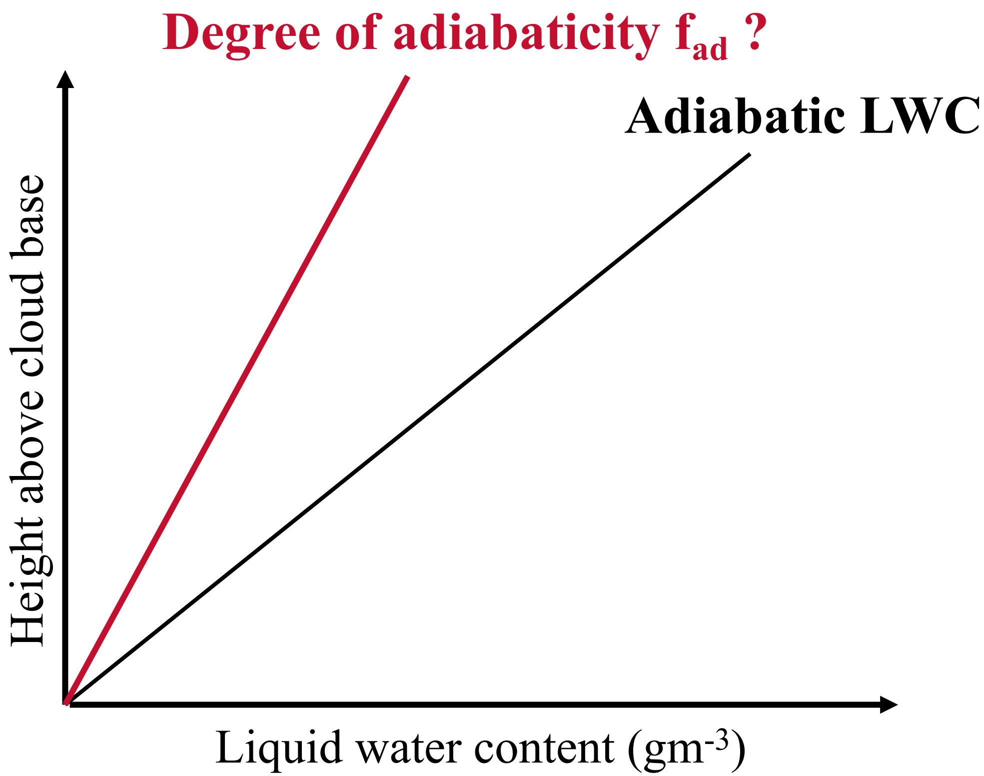
LWC distribution is poorly captured by linear for some specific process

**More details see Zeen Zhu, Katia Lamer, Pavlos Kollias, Eugene E. Clothiaux, 2019: The Vertical Structure of Liquid Water Content in Shallow Clouds as Retrieved from Dual-wavelength Radar Observations.*

LWC Profile Adiabaticity

$$\mathrm{LWC}(z) = f_{ad}\Gamma_{ad}z$$

[Wood., 2006]



Cloud thickness(m)	Degree of adiabaticity
200-300	f = 0.66
300-400	f = 0.55
400-500	f = 0.4
500-600	f= 0.22

Decrease

Conclusion & Future work

The shape of the LWC profile in clouds is affected by cloud dynamics and precipitation rate.
Can high-resolution models reproduce this behavior?

The degree of adiabaticity decreases with cloud thickness.
Is this a response to stronger dynamics and turbulence?

We are currently working on joint vertical air motion and LWC retrievals in cumulus clouds

We plan to release the retrievals for ACE-ENA.

Zeen Zhu, Katia Lamer, Pavlos Kollias, Eugene E. Clothiaux, 2019: The Vertical Structure of Liquid Water Content in Shallow Clouds as Retrieved from Dual-wavelength Radar Observations . submitted.

LWC Profile Linearity

Depth (m)	LWP (gm^{-2})	All	Cloud top velocity ($m\ s^{-1}$) Updraft 0.0 to 0.3		Cloud top velocity Downdraft 0.0 to 0.3		Cloud base velocity ($m\ s^{-1}$) Updraft 0.0 to 0.3		Cloud base velocity Downdraft 0.0 to 0.3		Rain rate ($mm\ hr^{-1}$) at cloud base 0.001 to 0.03		
			0.0 to 0.3	0.3 to 0.6	0.0 to 0.3	0.3 to 0.6	0.0 to 0.3	0.3 to 0.6	0.0 to 0.3	0.3 to 0.6	0.001 to 0.03	0.03 to 0.1	0.1 to 0.5
100-200	93+45	0.38 0.27 **0.97** *510*	0.48 0.29 **0.97** *121*	~~-0.61~~ ~~0.97~~ ~~**0.60**~~ ~~*8*~~	0.43 0.24, **0.97** *292*	0.29 0.32 **0.92** *73*	0.50 0.18 **0.95** *62*	~~0.05~~ ~~0.43~~ ~~**-0.04**~~ ~~*28*~~	0.33 0.32 **0.93** *156*	0.40 0.27 **0.93** *116*	0.36 0.27 **0.96** *296*	0.50 0.22 **0.96** *149*	0.35 0.33 **0.93** *72*
200-300	137+57	0.33 0.31 **0.97** *901*	0.41 0.27 **0.97** *203*	~~0.31~~ ~~0.34~~ ~~**0.66**~~ ~~*520*~~	0.33 0.31 **0.96** *520*	0.27 0.32 **0.89** *131*	0.37 0.29 **0.97** *128*	0.31 0.28 **0.92** *67*	0.32 0.32 **0.89** *328*	0.34 0.30 **0.98** *198*	0.38 0.28 **0.95** *493*	0.34 0.30 **0.97** *253*	0.19 0.37 **0.80** *147*
300-400	196+67	0.39 0.32 **0.89** *608*	0.47 0.30 **0.90** *113*	0.62 0.18 **0.90** *14*	0.40 0.32 **0.84** *321*	~~0.13~~ ~~0.37~~ ~~**0.64**~~ ~~*91*~~	0.39 0.33 **0.91** *120*	0.37 0.26 **0.94** *38*	0.40 0.31 **0.85** *216*	0.36 0.34 **0.82** *125*	0.51 0.26 **0.97** *187*	0.46 0.29 **0.89** *199*	~~0.17~~ ~~0.42~~ ~~**0.49**~~ ~~*212*~~
400-500	265+102	0.35 0.33 **0.94** *390*	0.48 0.28 **0.90** *113*	~~0.56~~ ~~0.30~~ ~~**0.51**~~ ~~*7*~~	0.31 0.34 **0.92** *187*	~~0.17~~ ~~0.37~~ ~~**0.66**~~ ~~*47*~~	0.38 0.30 **0.92** *77*	0.45 0.28 **0.94** *33*	0.32 0.34 **0.89** *141*	0.28 0.33 **0.93** *65*	0.46 0.25 **0.89** *73*	0.50 0.28 **0.98** *131*	~~0.18~~ ~~0.39~~ ~~**0.76**~~ ~~*176*~~
500-600	347+183	0.25 0.35 **0.96** *219*	0.32 0.34 **0.87** *49*	~~0.60~~ ~~0.20~~ ~~**0.65**~~ ~~*5*~~	0.24 0.33 **0.84** *106*	~~0.21~~ ~~0.40~~ ~~**0.54**~~ ~~*31*~~	~~0.26~~ ~~0.34~~ ~~**0.72**~~ ~~*39*~~	~~0.41~~ ~~0.33~~ ~~**0.66**~~ ~~*23*~~	0.30 0.27 **0.85** *57*	~~0.15~~ ~~0.40~~ ~~**0.69**~~ ~~*52*~~	0.51 0.22 **0.89** *26*	0.48 0.23 **0.96** *66*	~~0.09~~ ~~0.42~~ ~~**0.73**~~ ~~*111*~~

Table 1. Parameters of the linear fits LWC = a H + b. Within each cell (i.e., shaded row) the slope parameter a, the intercept b, the R^2 value (in bold) of the fit to the median, the number of 30-s profiles used in the fit (in italics) are presented in order from top to bottom. Results with R^2 less than 0.8 are crossed-out.