

The authors demonstrate a differential absorption technique that combines coincident G-band and Ka-band radar observations to obtain vertical profiles of liquid water content (LWC) in shallow clouds. Compared to previous studies using W-band and Ka-band, the new technique results in lower uncertainties due to the increased frequency separation. The improvement due to the use of G-band data is shown both theoretically and from observations. The latter come from about 100 minutes of consecutive measurements of a shallow warm cloud of varying thickness observed during the Eastern Pacific Cloud Aerosol Precipitation Experiment (EPCAPE). The retrieved LWC profiles are compared with single-frequency retrievals as well as microwave radiometer measurements of liquid water path (LWP) and their adiabaticity is analyzed.

The paper is well written and easy to follow. The described technique combining Ka-band and G-band is novel and offers significant advantages over previous efforts in clouds with low LWP. It therefore clearly falls within the scope of AMT. However, I have several concerns that need to be addressed first. I recommend major revision.

Major comments

1. It is not clear to me why the Ka- and W-band components from CloudCube are not used in this study. In Sect. 7 the LWC retrieval using Ka-W vs. W-G vs. Ka-G is discussed theoretically. However, I wonder why this was not also investigated using the CloudCube observations? Applying the same retrieval as for Ka-G to Ka-W and W-G and deriving uncertainties should clearly show the improvement using Ka-G band. The authors state in line 436 that a “triple-frequency system can be used to identify Mie scattering regions if Doppler is not available, and to facilitate the removal of biases and isolate sporadic instrument artifacts”. I wonder, why is this not done in this study? If the Ka and W-band CloudCube products are not operational yet or had data issues during this period, please say so in the manuscript.

2. I worry that presenting just one case study makes it easy to question the robustness of the results. To me, stating that LWC was retrieved from more than 15000 vertical profiles is questionable, because the retrieval was done for 60 s averages, if I understood correctly. Therefore, LWC was retrieved for 100 profiles, right? Reading the number 15000 feels artificially inflated to me, especially considering that the KAZR data was interpolated. (I want to make clear here that I don't think this was done on purpose out of malicious intent or so.) I recommend including more cases (at least one more) such that the results are more robust. Maybe a case with lower drop concentration according to MODIS would add value to the discussion in Sect. 4?

3. In my opinion, a greater effort to validate the LWC retrieval product not only in terms of column integrated values but also in terms of vertical structure could be taken. The authors could perform (microwave) radiative transfer simulations and forward simulate radar reflectivities given the retrieved amount of liquid water and the assumed drop distribution from Sect. 4. Radar simulators that are flexible in terms of instrument specifications and hydrometeor input are freely available, so I think this could be done without causing too much workload.

4. The authors often use qualitative descriptions, such as “small” or “low” without specifying what they mean quantitatively. This should be clarified in the revision.

5. To my knowledge, figure captions should be limited to describing the figure and only include information necessary to read the figure. Discussion of the figure should be limited to the text. I recommend, the authors have a look at their figure captions again and rewrite where necessary. Also, I suggest writing out any abbreviations used in the figure for readers who only take a look at the figures without reading all of the text.

Additional comments

Line 15: Theoretically, ...

Line 18: Did you mean “remote sensing”?

Line 20: Please specify what “small” amounts of LWC means in terms of numbers.

Line 23: Please specify what “low” LWP range means.

Line 32: To my knowledge low clouds over the subtropical oceans are one of the largest contributors to uncertainty in climate predictions. This could be stated more explicitly in this paragraph.

Line 33/34: I don't follow the logic here. To me, “difficult to model in simulations” does not necessarily lead to “inaccurate parameterizations”. Also “model in simulations” is a bit of a tautology. Maybe you can rephrase this sentence.

Line 34: 2013 is quite a while ago. Are there more recent studies?

Line 35: It should be their, right?

Line 35/36: You have not mentioned remote sensing yet, so I think “range gates” is too specific. I suggest “vertical profile” instead.

Line 38: What do you mean with usual small amounts? Please include typical amounts.

Line 44: Do you mean “profile”?

Line 54: Using the term “new frontier” and citing a ten year old paper feels a bit iffy to me. I am aware (and appreciate) that you give a nice overview of recent studies in the following. Maybe just place the citation differently, e.g. after G-band radar instruments?

Line 66&71: It is not clear to me why you use KAZR instead of the Ka-band component of CloudCube. Please specify.

Line 71: Please specify the temporal resolution.

Line 74: I would recommend you insert references to the corresponding section here.

Line 86/87: If I am not mistaken, you do not specify the instrument model of the used ceilometer and radiometer. Please do so and include references.

Line 88: Please either specify what periodical means or just write “radiosonde data have also been considered”.

Figure 1: To me the figure looks rather low quality, especially the white text.

Line 108/109: “based on criteria” sounds very vague, please specify.

Line 112: Remove “in”

Line 115: Since you average your data before performing the LWC retrieval, I don't think you can claim you retrieve LWC from more than 15000 vertical profiles.

Line 120: How did you detect regions with precipitating drizzle from the ceilometer? Please specify.

Line 123: please specify which parameters you use (temperature, relative humidity, pressure?)

Line 125/126: Please quantify what you mean with “small”.

Line 127: Again, please quantify what “small percentage” means.

Line 133: Also here (small amounts of LWC and LWP). It’s also ok if you specify somewhere (for example in the introduction) that you refer to LWC below xx / LWP below yy as small.

Line 136: Please specify the instrument model and how cloud base height is determined (it is sufficient to state “the internal ceilometer cloud base detection algorithm was used” if that’s the case). Also please include the observation frequency, range resolution and uncertainty estimate (probably the range resolution?).

Line 137: I don’t think you have mentioned yet, how the correction was done (Rosenkranz?).

Figure 2: I am not a fan of rainbow colormaps and would highly recommend switching to a more color blind friendly colormap (e.g. the python colormaps viridis or plasma). Using a color blindness simulator I found the digital version is not ideal but ok (because the green is lighter than the red tone). However, the printed version of this plot is not readable for people with red-green vision deficiency.

Figure 2: Please mention in the figure caption, if positive or negative doppler velocities mean towards the radar.

Line 182: How rare? Please include percentage values or similar.

Line 192/193: “This is the two-way hydrometeor attenuation in the cloud depth.” sounds awkward, can you maybe rephrase?

Line 196: “most of the cases” or “most cases”

Line 198/199: Please specify that you mean 210-270 m above cloud base.

Figure 3 & 5: I suggest you plot the relative uncertainty as well.

Figure 3: Note what the arrow means in the figure caption.

Line 221: “about” sounds awkward to my non-native speaker ears, but maybe that’s just me.

Line 221: What does “short” mean? Please be more specific here.

Line 240: What is the optical length determined in Zhu et al. (2019)? Please include it here.

Line 254/255: Please state how many values are 0 within uncertainty ranges and how many negative results remain.

Line 265: Please motivate why you jump from your DFR retrieval to a reflectivity-based approach (for validation? for evaluation which is better? etc)

Line 276: Be specific and state which cases (Miles and Matrosov? Just Miles?)

Line 280-282: “The drop concentration and distribution width in Miles et al. (2000) were $N_o = 75 \text{ cm}^{-3}$ (for maritime clouds) or $N_o = 280 \text{ cm}^{-3}$ (for continental clouds) and $\sigma = 0.38$ (for both cases), respectively.” -> awkward sentence, can you rephrase it?

Line 289: Do you mean realistic?

Line 294: I don’t get the reasoning. Why don’t you use the 400 cm^{-3} from MODIS?

Eq 6: I don’t see a good correlation with your retrieval. Is there a physical reason why b must be 0.5?

Line 300: liquid water content -> LWC

Line 314: Same as for the ceilometer. Please specify which instrument was used and which algorithm to retrieve LWP.

Line 322: How much does this depend on the drop concentration? How does it look for 200 or 400 cm^{-3} ? (Is this the reason why you chose 300 cm^{-3} ?)

Line 343: To me, the spread in RMS highlights why this study would benefit from more cases.

Figure 9: Can you include uncertainties for MWR and KAZR-CloudCubeG LWP? Maybe also for Eq. 9 using a realistic range of drop concentrations?

Line 360-362: Very long sentence, maybe split in two for better readability?

Line 375/376: What do you mean with the same thickness? Same within +/- 30 m?

Line 377: I know this will be typeset later, but how the unit is split is ugly.

Figure 10: Can you include standard deviation as shaded areas?

Line 405: I suggest adding "to our knowledge"

Line 451/452: Include references here.

Line 456: Where did you demonstrate this? → Add references to the respective figure(s) or section(s).

Line 462: Please state more clearly that the 15000 profiles are from one case study. (Also I'm still not convinced you can claim you use 15000 profiles to retrieve LWC).

Line 470: I suggest you write out abbreviations at least once in the conclusions. Many people will only read abstract and conclusions.

Line 478: The "very" is not necessary, I think "valuable" is convincing enough.