

Atmos. Meas. Tech. Discuss., referee comment RC3  
<https://doi.org/10.5194/amt-2022-3-RC3>, 2022  
© Author(s) 2022. This work is distributed under  
the Creative Commons Attribution 4.0 License.

## Comment on amt-2022-3

Anonymous Referee #3

---

Referee comment on "Climatology of estimated liquid water content and scaling factor for warm clouds using radar–microwave radiometer synergy" by Pragya Vishwakarma et al., Atmos. Meas. Tech. Discuss., <https://doi.org/10.5194/amt-2022-3-RC3>, 2022

---

Climatology of estimated LWC and scaling factor for warm clouds using radar - microwave radiometer synergy

by

Pragya Vishwakarma, Julien Delanoë, Susana Jorquera, Pauline Martinet, Frederic Burnet, Alistair Bell and Jean-Charles Dupont

AMT-2022-3

General comments

This manuscript combines cloud radar and microwave radiometer observations using a variational framework in order to estimate the liquid water content profile of warm liquid water clouds. Reliable quantification of uncertainties (both instrument and retrieval uncertainties) is a major goal of the profiling community, so the use of optimal estimation in the retrieval methodology is an attractive approach as it enables multiple error sources to be included and provides the uncertainties directly within the retrieval framework.

The manuscript is relatively well written but would benefit from some editing as there are a number of mistakes. The figures are relevant and clear. The explanation of the methodology is clear but could be much more concise in some sections.

A reliable method of retrieving the profile of liquid water content from remote sensing observations is of clear interest to the community. However, the initial assumption that a power law is suitable for deriving liquid water content from radar reflectivity should be examined more closely. The authors try to solve this by varying the exponent  $a$  in the power law relationship between radar reflectivity and liquid water content to account for the presence of drizzle, but it seems of more benefit if the authors used this need to modify the exponent as an indication that drizzle is present and that maybe another retrieval method should be used.

Validation of the retrieved profile of liquid water content has historically proved somewhat challenging, with mostly aircraft-based observations being used for validation. Obtaining the vertical profile of liquid water content from aircraft observations usually requires significant averaging in time and space. There is clear potential shown here for validating the retrievals using balloon-borne in situ measurements, and the case study shows that retrievals in non-drizzling clouds match well, whereas those in drizzling situations are not so good. Investigating if these aspects within the retrieval methodology are robust would be novel and of interest. The manuscript requires some major revisions.

#### Specific comments and questions

If drizzle is present, then the measured radar reflectivity is essentially responding to the drizzle droplets and not the cloud droplets, hence the wide spread seen in the power law relationships given in the literature. This problem has been discussed previously in numerous articles (which have also been referenced in this manuscript) and nicely summarised in Löhnert et al. (2008, <https://doi.org/10.1175/2007JTECHA961.1>).

One issue with the approach taken in this manuscript is the retrieval of liquid water content profiles for drizzling cloud cases. While there likely is a relationship between the amount of drizzle and the cloud liquid water content or cloud liquid water path, it no longer follows that the shape of the profile of reflectivity in drizzle should necessarily match the shape of the profile of cloud liquid water content; it will match the shape of the profile of drizzle water content, which can extend far below the liquid cloud base.

If the drizzle situations can be identified using the fact that the scaling parameter in the power law relationship has had to be adjusted to match the measured liquid water path, then this does provide additional information. Do the uncertainties in the retrieval increase when the scaling parameter changes?

Lines 61-63: I'm not sure - depends on how you define spectrum shape - its more that any variation in the largest sizes will make much more of a difference to  $Z$  than for LWC.

Lines 118-124: It's not clear which range-resolution mode is used here (highest

resolution?), or is it a merged product? If it is the merged product, at what range does the range resolution change? Presumably, although not stated, the range resolution in fog is 12.5 m?

Section 3.1: Much of this section could be condensed considerably and combined with section 3.2

Section 3.3.1: There are a number of recent papers (summarised neatly e.g. in Tridon et al., 2020, <https://doi.org/10.5194/amt-2020-159>) discussing the uncertainties in models of the attenuation by liquid droplets, particularly with respect to temperature. The radiative model used for generating the gaseous absorption should also be stated and referenced. Is -17 dBZ an appropriate threshold for discriminating between cloud and drizzle droplets? Especially since it would be expected that cloud droplets would dominate the attenuation; drizzle droplets can dominate the reflectivity while contributing negligible amounts of attenuation.

Section 3.5.1: The case study shows an example where the cloud base is not known, particularly during the first four hours of the day (and for the last 30 minutes of the day). The clear presence of drizzle during the first four hours suggests that the cloud base is probably around 800 m at 0000 lowering to 250 m by 0330. Periods from 0430 to 2330 look most appropriate for the retrieval methodology described in this manuscript. Why not include cloud base information from the co-located ceilometer at SARTA to determine this. Then investigate the different  $\ln a$  values suggested by the retrieval. Which ones suit drizzle-free periods, and which ones suit drizzling clouds?

Section 5.2: This case study shows the impact of drizzle on the retrievals. Figure 9b shows the heterogeneous nature of the drizzle increasing the reflectivity by significant amounts in some regions. Indeed, the two panels in Figure 10 are very reminiscent of the figures presented in Krasnov and Russchenberg (2002, 2006) and in Löhnert et al. (2008, <https://doi.org/10.1175/2007JTECHA961.1>) which show two populations with their own relationships, one for drizzle and one for drizzle-free clouds. With very different Z-LWC relationships for drizzle and for liquid droplets, it is not surprising that CDP-calculated reflectivities don't always match observed reflectivities. This is quite obvious in Figure 8, where the two measurements for the non-drizzling time period from about 0430 onwards seems to agree very well, but the agreement for the drizzling time period beforehand is not so good.

Section 6: It may be safer to remove the discussion on vertical velocity relationships. Correcting Doppler velocity for the vertical air motion is a challenge, and without this correction, some of the statements are difficult to corroborate. The typical air motion in low-level liquid clouds can easily exceed  $\pm 1 \text{ m s}^{-1}$  in turbulent situations, so using Doppler velocity alone to discriminate between drizzle and liquid droplets requires care.

Technical comments

The variable  $\ln a$  needs a clear introduction and description. I assume it is  $\log(a)$ ?

Line 28: Replace 'net radiative forcing in earth's radiation' with 'the net radiative forcing in the Earth's radiation'.

Line 34: Not sure that fog and haze are always 'disastrous'.

Line 43: Replace 'longer' with 'larger'. Suggest adding that droplets larger than this size have appreciable terminal velocity and fall out of the cloud, and are termed drizzle droplets.

Line 45: Replace 'spectrum and whereas, LWC' with 'spectrum, whereas LWC'.

Line 68: Would be clearer if LWC and LWP are defined together. Then line 71 should not start as a new paragraph but follow the sentence introducing the Frisch algorithm.

Line 76: Should state why the presence of drizzle causes problems for the retrievals (a few drizzle droplets dominate the reflectivity without contributing much to LWC).

Line 80: There are some LWC profile retrievals in the literature that are applicable to both precipitating and non-precipitating clouds, although they may have their own drawbacks. It's worth stating here that the issues for fog retrievals have historically been due to the cloud radar blind zone, which can now be mitigated for FMCW radars.

Lines 112-113: Suggest using 'range-resolution modes' rather than 'resolution modes' both here and elsewhere in this paragraph. Include the minimum range for the 12.5 m range-resolution mode.

Line 128: How many channels in the water vapor absorption band? What is the frequency range?

Line 137: The statement starting on this line is not strictly true, suggest revising.

Line 141: For a column containing a single liquid layer, MWR provides the LWP for the cloud layer.

Line 145: This uncertainty is also due to uncertainty in the microwave radiative transfer model.

Table 2: How many size bins does the CDP have?

Lines 172-174. Sentence needs revising

Line 264: To be consistent, can use the same size limit as stated in line 44.

Lines 288-289: This statement is not strictly true. Some of the liquid water attenuation estimates were calculated for a wide range of liquid cloud microphysical properties.

Lines 327-329: Why choose a hard limit of 2.5 km? Why not use a temperature profile (e.g. from MWR, NWP model, or nearby radiosonde) to select an appropriate freezing level for each day, since you state later on in the paragraph that it changes from day to day.

Lines 519-521: This statement is not true, calculations for all types of liquid clouds have been examined in the literature.

Lines 574-575: Is this true if the CDP is limited to sizes less than 50 microns? A few drizzle droplets (e.g. 100-500 microns in diameter) will immediately increase the radar reflectivity far above that calculated from the CDP.

Lines 583-584: The standard term for PPI is Plan Position Indicator.

Lines 772-779: Most liquid clouds, by their very nature, are unlikely to be homogeneous in the sense suggested as suitable here. Maybe a more statistical approach is necessary for some aspects of the retrieval comparisons.

References: Some references are not complete