Review of Fu, et al., 2022.

This paper shows results from an aircraft field campaign in the Philippines where mostly cumulus – like clouds were sampled and focuses on the retrieval of cloud droplet effective radius (Re) using remote sensing. The aircraft were equipped with both the remote sensing RSP polarimeter instrument and in-situ probes. The latter can directly measure cloud droplet size distributions (and hence Re). The RSP instrument can retrieve Re using both polarimetry and using the bi-spectral method. The latter is similar to the method used by the MODIS satellite instrument. The polarimetry method is thought to be less prone to retrieval errors than the bi-spectral method. The results show that the bi-spectral method produces higher Re values than the polarimetery method. The polarimetery method agrees better with the in-situ values except in some cases (where rain is blamed for increasing the in situ Re). MODIS retrievals that are approximately collocated produce similar values to the bi-spectral RSP method. A correction for MODIS is also applied and this brings the MODIS values close to the in-situ and polarimetery values. The bi-spectral errors are largest for small cloud optical depth values. Some potential reasons for the error using the bi-spectral technique are explored with the data suggesting that some are not likely explanations.

Overall, the paper shows catalogues some nice results. The main results are important and are worthy of publication; namely, that the bi-spectral aircraft RSP retrievals overestimate Re, that the MODIS bi-spectral results agree with the aircraft bi-spectral Re, that the MODIS correction seems to work well and that the bias is worse at low optical depths. The text is also well written and mostly clear, but the number of figures is a little excessive. As mentioned below I would like to see the analysis look more closely at the issue of sub-pixel variability – or at least to discuss it more thoroughly. I would be happy to see it published once the above issues are addressed.

The paper doesn't really get to the bottom of what causes the high values for the bi-spectral retrievals, except that they mainly occur at low optical depths. From previous work (e.g., see Fig. 3d) and e) of Zhang (2016) it seems clear that we might expect large Re retrieval biases at low optical depths due to the non-linear nature of the look-up tables (LUTs) used in the retrievals combined with sub-pixel variability of COD. At low COD values the LUTs get very non-linear making them more susceptible to these errors, and also they become more sensitive to reflectance errors. This should be discussed more in the paper as a possible explanation. Why not examine the effect of cloud heterogeneity on the Re biases using the variability in COT or in 0.86um reflectance (e.g., as used in Liang, 2009 and Zhang, 2016)?

Regarding clear-sky contamination (Fig. 16) using the HRSL-2 lidar – what is the optical depth threshold used to define regions as cloud when estimating the cloud fraction? Is it comparable to that used for the bi-spectral RSP or MODIS retrievals? Perhaps if the HRSL-2 is very sensitive to cloud then its definition of cloud fraction within a cloudy segment is not meaningful for bi-spectral retrievals. What happens if you use a higher optical depth threshold?

The ASTER data (Fig. 12) does not seem to be used except to show that many of the clouds are smaller than 1km in size. Could it be used to estimate the effects of sub-pixel cloud heterogeneity (similar to what was done in Werner, 2018)? Since this could be a cause of the Re biases. Also, can you examine what the MODIS PCL retrievals estimate for Re?

I don't really see any evidence for this statement in the abstract (line 44): "3D radiative pathways appear to be the leading cause for the large positive biases in bi-spectral retrievals.". Where was this shown?

Regarding the bias correction to the MODIS data – do the results here suggest that the lower bound of the correction is most suitable? Could this be added as a recommendation at the end?

Some of the figures seem a little bit redundant and the paper is very long in terms of the number of figures. Perhaps some of them could be removed, or put into an appendix or supplementary section? E.g., Figs. 13 and 14 don't seem to add much beyond what has already been shown. If you want to demonstrate that the CTH variability gets larger with height then there are more direct ways to do this. Fig. 15a seems the same as Fig. 3b and I'm not sure how much the other panels add for Fig. 15. The 4 figures for the different case studies start to get a bit repetitive too. Figures 6 and 7 are useful perhaps since Fig. 7 shows some interesting high Re values from the Lear Jet. But after that the story is similar with higher Re retrievals for the bi-spectral method. Maybe the rest of the case study figures (Figs. 8-11) could be put into an appendix?

Specific comments

Fig. 2 – the caption should say whether the data is for all of flights for which data was captured and for only oceanic liquid clouds only.

L357 – "The samples exhibited a large difference (a factor of ~2) between RSP bi-spectral and polarimetric Re retrievals, which is investigated further in the sections below."

- This sentence seems out of place at the end of a paragraph about radar reflectivity. I would argue that it is not necessary since it is clear by now that the paper is focuses on Re. But if you want to keep this to lead into the focus on Re then it would be better in its own paragraph and would need some rewording.

"Cloud bow COT" – this is used a few times and is only explained in the Results section rather than in the Methods – a short description of how this is done would be better placed in Section 2.1.1 then in the Results section. I also think that just calling it the RSP COT would be clearer (after you have defined what this means). It would then be more aligned with how you describe the Re from the RSP.

Fig. 4h – it's a bit hard to see the CTH dots – would this be better as a separate timeseries and maybe with a line as well as dots? This could perhaps be overlaid on the radar reflectivity plot.

Fig.7 – it's interesting that here the RSP-pol and adjusted MODIS values agree better with the in-situ values at lower altitudes, but at higher altitudes the bispectral and non-adjusted MODIS values do. You should mention this even though you suggest that the Lear jet samples were biased high due to flying through a raining turret (i.e., sampling bias – this could be spelled out a bit more clearly in the text). Perhaps other explanations could be a potential role of cloud top entrainment causing the RSP-pol Re retrievals to be low (since they sample very close to cloud top), whereas deeper in the clouds (in-situ and bi-spec retrievals) the Re values are higher?

Figs. 4, 8 and 10 – the captions should say which flight the plots were were for (RFxxx).

Case study introductory paragraphs – i.e., Sections 3.3.1 – 3.3.4. These should mention the relevant overview figures early on (i.e., Figs. 4,6 8 and 10) when giving the general description of the cases.

Fig. 12 – what happens if you use the PCL retrievals from MODIS?

Figs. 13 and 14 – are these necessary? I'm not sure that they add much beyond what has already been shown. If you want to demonstrate that the CTH variability gets larger with height then there are more direct ways to do this.

Fig. 15a – how is this different to Fig. 3b? Do panels b and c add much more? And would they be better as density maps instead of scatter plots as in Fig. 3?

L743 – "to derive the cloud fraction (CF) for each RSP cloud element as follows: For RSP cloud elements that have HSRL-2 CTH retrievals, the HSRL-2 cloud fraction for a RSP cloud element is defined as the number of valid HSRL-2 CTH retrievals divided by the total number of HSRL-2 CTH retrievals within the RSP cloud element"

- This is a little confusing – do you mean that you divide by the total number of *attempted* HSRL-2 CTH retrievals?

L756 – "there are no samples for CF < 0.5 (hence no red dashed histogram)" – it would be good to mention this in the caption of the figure (16) too.

Typos / grammar

L41 – "RSP bi-spectral Re shows larger relative values compared to RSP polarimetric Re for smaller and optically thinner clouds." – this doesn't quite get across the result that the bias is worse for smaller optical depths. I recommend :- "The overestimate of Re from the RSP bi-spectral method relative to Re from the polarimetric RSP method increased as cloud size and optical depth reduced."

L69 – "(hence, 1-D radiative transfer as the forward model used in this retrieval)," – better as "(hence, 1-D radiative transfer is used as the forward model in this retrieval)," I think.

L142 – "because the overpass time of the latter two sensors occurs in the afternoon when cirrus is more frequent and when the aircraft was returning to base that did not have favourable samplings.". Better as :- "because the overpass time of the latter two sensors occurs in the afternoon when cirrus is more frequent and when the aircraft was returning to base; therefore, the sampling was not favourable."

L174 – "extend its evaluation in cumulus cloud fields" -> "extend its evaluation to cumulus cloud fields"

L179 – "Mean and standard deviations of retrieved quantities belonging to a cloud element is computed." -> "Means and standard deviations of retrieved quantities are computed for cloud elements."

L200 – "Only drop size distribution with" -> "Only drop size distributions with" + "temperature" -> "temperatures"

L211 – "The median differences within 1 µm" – "The median differences were within 1 µm".

L256 – "pixel" -> "pixels".

L268 – "to retrieve COT at MISR 9 view angles" -> "to retrieve COT at MISR's 9 view angles"

L267 – "As a continuation of Liang et al. (2015), fused MISR L1B radiance data and MODIS L2 cloud

Re were used to retrieve COT at MISR 9 view angles.".

Better as :- “As a continuation of Liang et al. (2015), Fu et al. (2019) fused MISR L1B radiance data and MODIS L2 cloud Re to retrieve COT at MISR’s 9 view angles.” (Since otherwise it sounds like this was done in the paper under review here).

L330 – “The median COT is 3.5 for the cloud bow (COT retrieved using total reflectances and polarimetric Re) and 4.2 for the bi-spectral.” – add “retrievals” at the end.

L440 – “over which little overall change in the cloud field” – add “occurs” after this.

L441 – “Here, the Re retrievals were sorted into 250 m CTH bins.” – this makes it sound like you are referring to a figure or a result that has already been introduced. You could just say “We sorted the Re retrievals into 250 m CTH bins.”

L581 – “Apart from these clouds being sub-pixel to MODIS retrievals cannot resolve” -> “Apart from these clouds being sub-pixel to MODIS retrievals so that MODIS cannot resolve them”

L609 – “As mentioned in Sect. 2.2, we acknowledge the difference between the MODIS 2.1 µm channel to the RSP 2.26 610 µm channel, we acknowledge that the differences in the two wavelengths and we do not expect the Re retrieved from MODIS and RSP bi-spectral to have the exact same bias” -> – “As mentioned in Sect. 2.2, we acknowledge the difference between the MODIS 2.1 µm channel to the RSP 2.26 610 µm channel ~~we acknowledge that the differences in the two wavelengths~~ and so we do not expect the Re retrieved from MODIS and RSP bi-spectral to have the exact same bias”

L629 – “that can be” -> “than can be”.

L660 – “A prominent feature in Fig. 13 is the much-improved correlation between RSP polarimetric Re and CTH means, with a linear correlation coefficient of 0.72, compared to the correlation coefficient between RSP bi-spectral Re and CTH means of 0.24.” -> “A prominent feature in Fig. 13 is the much-improved correlation between the RSP polarimetric Re and CTH means (linear correlation coefficient, r, of 0.72) compared to between the RSP bi-spectral Re and CTH means (r=0.24).”

L844 – “Also as noted in Sect. 3, are associated with aircraft penetration of deeper clouds not near the same CTH level that contain drizzle.” -> “Also as noted in Sect. 3, they are associated with the penetration of deeper clouds at altitudes different to the CTH level observed by the remote sensing, with the clouds tending to contain drizzle.”

L846 – “Overall, RSP polarimetric Re and bias-adjusted MODIS Re, the Learjet, P-3

in situ indicated” -> “Overall, Re observations from the RSP polarimetric, the bias-adjusted MODIS, the Learjet in situ and the P-3 in situ techniques indicated…”

L864 – “have closer median Re values within their differences within 1 to 2 µm,” – not clear what you mean by “within their differences”?

References

Liang, L., Di Girolamo, L., & Platnick, S. (2009). View-angle consistency in reflectance, optical thickness and spherical albedo of marine water-clouds over the northeastern Pacific through MISR-MODIS fusion. Geophysical Research Letters, 36, L09811. https://doi.org/10.1029/2008GL037124

Zhang, Z., Werner, F., Cho, H. M., Wind, G., Platnick, S., Ackerman, A. S., et al. (2016). A framework based on 2-D Taylor expansion for quantifying the impacts of subpixel reflectance variance and covariance on cloud optical thickness and effective radius retrievals based on the bispectral method. Journal of Geophysical Research: Atmospheres, 121, 7007–7025. https://doi.org/10.1002/2016JD024837

Werner, F., Zhang, Z., Wind, G., Miller, D., & Platnick, S. (2018). Quantifying the impacts of subpixel reflectance variability on cloud optical thickness and effective radius retrievals based on high-resolution ASTER observations. Journal of Geophysical Research: Atmospheres. 123, 1–20. https://doi.org/10.1002/2017JD027916