Anonymous Referee #2

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This is a review of the manuscript titled "Comparisons of bispectral and polarimetric cloud microphysical retrievals using LES-Satellite retrieval simulator" submitted to AMTD by Miller et al. The paper discusses the biases in retrieved drop effective radius and cloud optical thickness using two independent approaches, namely the bi-spectral approach and the polarimetric approach. Both methods are evaluated using simulated measurements based on large eddy simulations and 2D radiative transfer. Biases in retrieval products caused by vertical and horizontal inhomogeneity are evaluated. The work follows previous work by the same authors, especially that published in Miller et al. (2016) and Zhang et al. (2012). Those previous papers lacked the focus on polarimetric retrievals, so this paper is a useful addition to those studies. The polarimetric method is the more robust method, as also shown here, but requires multi-view polarization measurements at specific viewing geometries, which makes it not applicable everywhere. The polarimetric method is often seen as a means to validate the bi-spectral retrievals. Therefore, this comparison of the two methods is useful to better understand such comparisons. However, in my opinion, some of the means of presentation are difficult to interpret and not very effective. Also, while focus is on the effective radius retrievals, the optical thickness retrievals are also evaluated, but some rather surprising outliers in the optical thickness retrievals are not explained. Finally, the authors should provide more references in the results section to put their results in perspective to other relevant papers. Below I will provide more details to these major comments and will follow with some minor comments

Major comments:

1. The conclusions about polarimetric and bi-spectral retrievals are not new. As mentioned in the paper, the bispectral method is already well studied by several papers, including Miller et al. (2016) and Zhang et al. (2012). The polarimetric results are consistent with those by, for example, Alexandrov et al. (2012) and Shang et al. (2015). All of the papers mentioned above are referenced in the manuscript, but mostly in the introduction or conclusions. The authors should provide more references in the results section and put their results in perspective to the 4 papers mentioned above, and other relevant papers. For example, the reduced sensitivity of effective variance at high values, the effects of vertical variation and insensitivity of the approach to optical thickness are all discussed by Alexandrov et al. (2012). The sensitivity to sub-pixel inhomogeneity in the polarimetric approach is discussed by Shang et al. (2015). Retrieval biases in the bi-spectral approach is discussed by Miller et al. Specifically, Miller et al. conclude that biases are especially large in "transition zone" at the cloud edges. I find it surprising that this is not mentioned here at all. In summary, when discussing the results, please also discuss the appropriate references to set these results in context with these previous studies.

   a. Sure, I can integrate more references into the results and discussion sections.

2. *The optical thickness retrievals are also evaluated in this study, but hardly discussed. I find it rather surprising that even at large optical depths, large biases occasionally occur. As mentioned, the optical depth retrievals are similarly biased using the polarimetry size retrievals. Looking at equation 4, I am curious what could cause these optical depth biases if not errors in assumed size distribution? It would be informative to further explore this bias in the paper.*
   a. The droplet size distributions (DSD) of the LES are not exactly gamma-distributed, as assumed by the bispectral and polarimetric retrievals. The LES distributions sometimes have multiple distribution modes. As a consequence, the size distribution differences reduce the cross section distribution (second moment of the DSD) that is used to define τ_{tot}. This difference in size distribution becomes even more severe for the distributions that are clearly non-gamma with ve>0.3. This is demonstrated by the figure below depicting the median DSD's and cross section distributions for each LES case. The results highlight that the cross section distribution has a reduced peak relative to the expected gamma-distribution. This largely stems from the increased number of droplets in small bins (relative to gamma) as well as an increased number of droplets in the larger bins. Surprisingly, the area and volume distributions of these populations are similar in a relative sense, resulting in values of r_e that are consistent, but low biasing τ_{tot}.

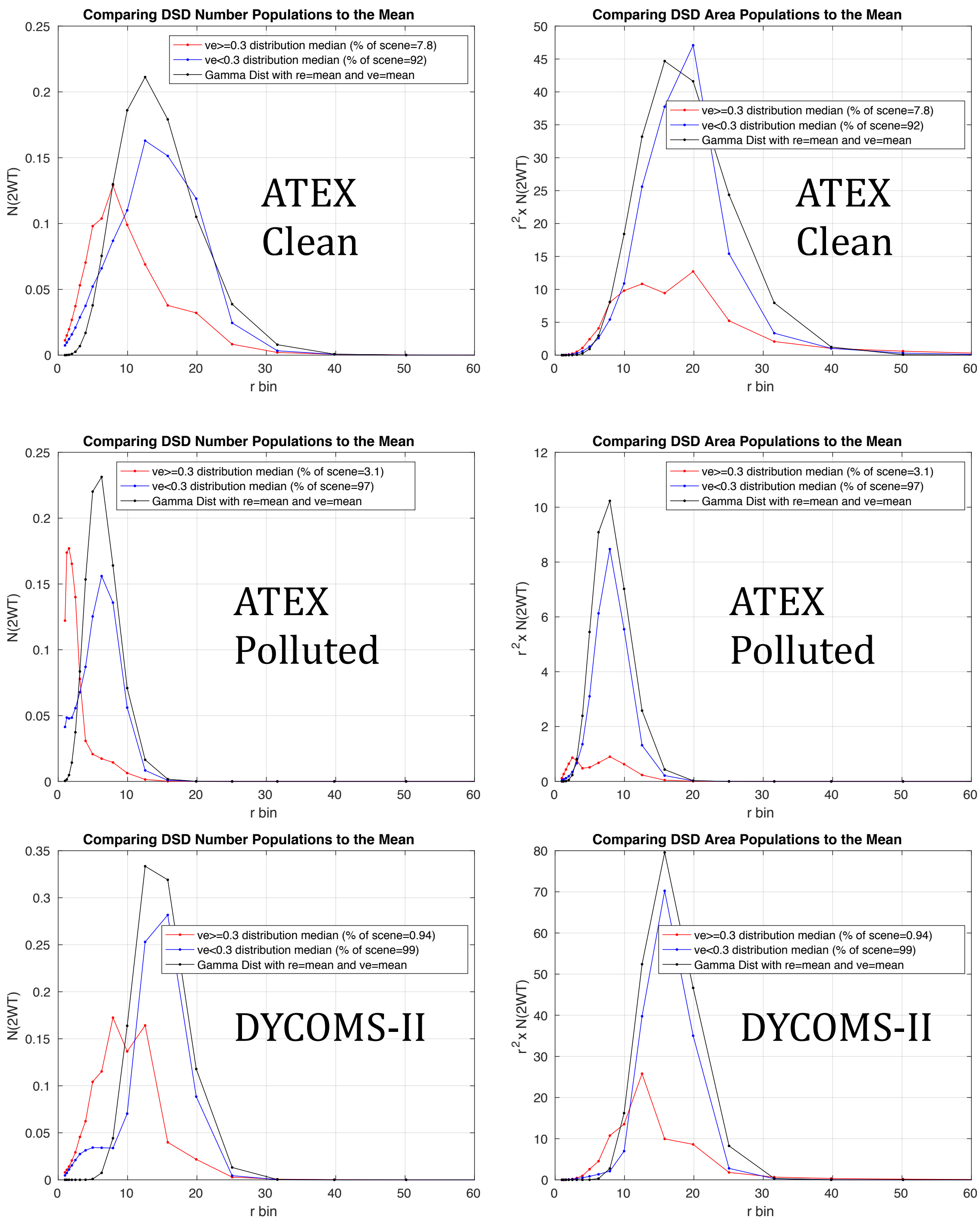

Figure 4: The panels on the left depict droplet size distributions for different populations of each LES case. The red curves denote distributions with non-gamma v_e>0.3, and the blue curves indicate the population with v_e<0.3. The black curves indicate the gamma distribution corresponding to the scene average r_e and v_e combination. The panels on the right are area distribution populations derived from the DSD's on the left.

b. Biases can also be associated with the vertical profile assumption in the LUT. The vertical distribution of the extinction coefficient is not homogeneous as conventionally assumed in the formulation of the bispectral LUT. In the adiabatic model the cloud top r_e is functionally defined with respect to τ_{tot}, indicating that it might be possible that biases in retrieval of one would impact the other.

c. I don't know if there is a lot that can be done regarding these limitations in the context of the two retrieval approaches discussed in this study. Creating retrieval LUT that assumes all clouds are vertically adiabatic is problematic. And the addition of more complicated size distribution assumptions isn't easily implemented in either of these techniques in a practical sense. However, for the droplet size distribution shape assumption, we can perhaps further highlight the Rainbow Fourier Transform method of Alexandrov et al. (2012). for evaluating the droplet size distribution shape and it's impact on retrieval techniques that assume gamma distributions.

3. *In figure 5, the effect of the fixed variance of 0.1 on the bispectral retrievals are evaluated. This is done by coupling the bispectral retrievals to the variance retrieved with the polarimetric approach. However, you showed that this retrieved variance often significantly differs from the true value. It performs best in the case around a value of 0.1, which is the value assumed for the bispectral method. So, in this test, often still a 'wrong' variance is used. It is difficult, if not impossible, to deduce solid conclusions from the present results. The authors should couple the bispectral retrievals to the true (2WT) value of variance for each gridbox for this evaluation.*

a. This can be easily changed, but the results will be quite similar because the polarimetric retrieval of v_e behaves quite well below v_e=0.15, which is comparison is shown.
b. One of the reasons why we coupled to the v_e(pol) retrieval was to highlight how the bispectral and polarimetric retrievals could compliment one another. It is essentially a more formalized comparison of the argument first presented in figure 9 and 10 of Miller et al. (2016). Also note that taking into account this additional information has almost very little impact on the quality of the bispectral 2.13 μm retrieval.

4. *Figure 8 convolves a lot of information and is therefore hard to interpret. The aim is to show the effect of pixel size and inhomogeneity on the bi-spectral and polarimetric technique. Here the two methods are compared, making it impossible to tell which technique is biased where and how. The authors concluded that "it is evident that as the spatial retrieval footprint reaches 800 m the sub-pixel inhomogeneity tends to increase and the re(2.13 μm) retrieval suffers from an increasingly high bias relative to the polarimetric retrieval." I do not get this from looking at this figure. Using the colors and open circles of*

different sizes produces a pretty colorful blob, but individual circles are impossible to spot mostly. I see some large circles with high biases, but have the impression that most are hiding in the colorful blob. The conclusions and abstract state that the methods compare well for high resolutions, but biases appear at coarser resolution. This conclusion appears to be based on this figure. Looking at figure 5, I see some very large differences between the methods for some cases, so the bispectral method also has issues at these fine resolutions, if not more. Also, the abstract and conclusion states "This bias largely stems from differences related to sensitivity of the two retrievals to unresolved inhomogeneities in effective variance and optical thickness." This suggests that the polarimetric retrievals also have sensitivity to the spatial resolution. They probably have somewhat (as concluded by Shang et al.), but this is not at all evident from this figure and analysis. Please produce figures that more clearly and systematically support these conclusions (or other conclusions). I suggest producing separate plots showing biases from true effective radius values in bi-spectral and polarimetric techniques as a function of H. Possibly the resolution can be on the y-axis and biases can be color coded?

a. One of the biggest problems with the original figure, as you point out, is that the spatial resolution information is hard to display simultaneously with the retrieval comparison. Also, because H_σ is the only variable that has a physical dependence on spatial resolution, showing their correlations separately actually makes more sense. We have attempted to deconvolve this plot further by breaking it into multiple parts. First of all, the following figures focus on the ATEX cases because there are more broken and inhomogeneous clouds in these two scenes than in DYCOMS-II.
b. The first part (in Figure 5) demonstrates the increasing population of inhomogeneous observations at coarser spatial resolutions by displaying the change in the histogram of H_σ as a function of resolution. This drives home the point that at coarse resolutions there is more inhomogeneity.
c. The second part (in Figure 6) displays joint histograms of retrieval bias (relative vertically weighted LES properties) and H_σ for the ATEX cloud cases. Note that these figures amass all of the data from the coarse resolution (100 to 800 m) ATEX cases because they have the most diversity in terms of H_σ.
d. I think that these figures provide a more detailed perspective than the previous versions so we will be modifying the manuscript to include them. Mixing all of the coarse spatial resolutions together for the joint histograms is a valid exercise because the primary difference between a joint histogram of a single coarse resolution and all of them is largely just the sampling of the H_σ distribution.

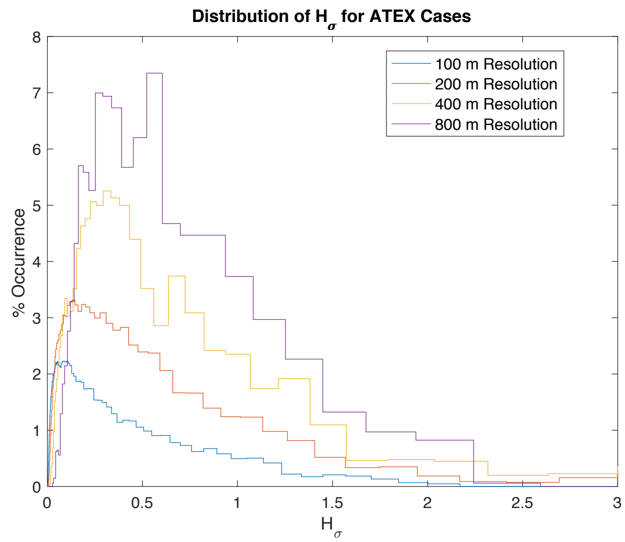

Figure 5: Distributions of H_σ for the ATEX polluted and clean cases at all coarsened spatial resolution (100, 200, 300, 400, 800 m).

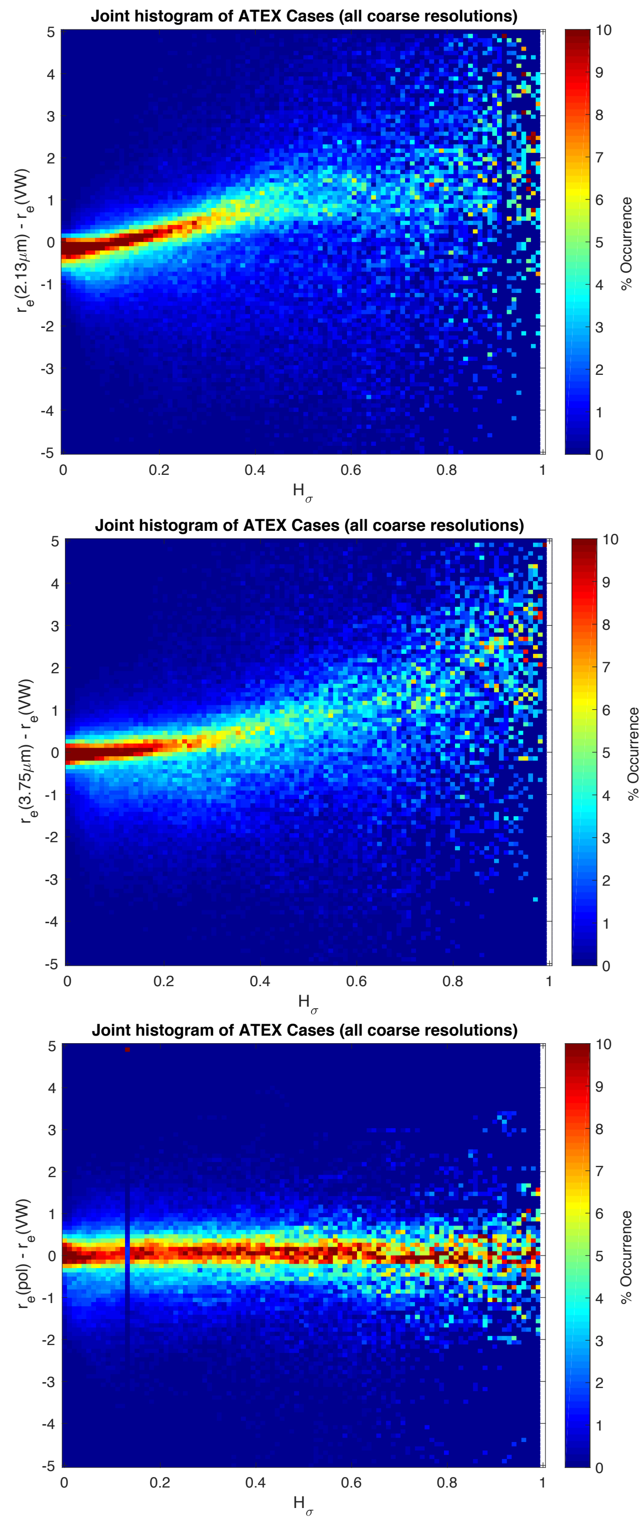

Figure 6: Joint histograms of retrieval biases (relative to VW) with respect to H_σ for the ATEX clean and polluted cases under all observation geometries at coarsened spatial resolution (100, 200, 300, 400, 800 m). The color bar indicates percent occurrence.

Minor comments:

1. *In figure 3, the cases with tau<3 are removed, revealing a better result. However, I am wondering how the 2D histogram for tau<3 looks like. Do the bulk of these retrievals still perform well, or are they all biased? That is not clear from these plots.*
    a.
2. *Figure 4 shows that the uncertainty in the retrievals of effective variance is rather high. Firstly, please relate your findings with those found by Alexandrov et al. (2012). Secondly, please discuss the appropriateness of the assumption of a gamma distribution for these LES fields. Is the model producing size distributions that can be well described by a gamma distribution? If not, this could explain part of the spread found in your results. Also, please discuss the possibility of non-parametric size distributions from polarimetry, as presented by Alexandrov et al. (2012; J. Quant. Spectrosc. Radiat. Transfer, 113, 2521-2535, doi:10.1016/j.jqsrt.2012.03.025.)*
    a. I will put further effort into discussing this topic in the paper.

3. *Figure 9 shows the variation in polarization measurements for sub-pixels in a 800m pixel. For the case including the thin cloud parts, there appears to be a substantial spread, but this is mostly in absolute magnitude. Please note in the text that the polarimetry technique is not sensitive to the absolute magnitude of the measurements, and these variations are therefore not an issue for this technique.*
    a. I will change this to indicate something to that effect.

<u>Minor text edits:</u>

1. *Page 2, line 9: add "which" before "simultaneously"*
2. *Page 2, line 13: Add "Suomi" in front of "National" (and NPP)*