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Atmospheric Measurement Techniques Discussions

Interactive comment on "Comparisons of bispectral and polarimetric cloud microphysical retrievals using LES-Satellite retrieval simulator" *by* Daniel J. Miller et al.

Anonymous Referee #1

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1 General remarks

The manuscripts provides a detailed analyses of two well established cloud retrieval methods using passive satellite measurements of solar radiation. Bispectral and polarimetric retrieval of cloud optical thickness, droplet effective radius, and effective variance are compared for cases of liquid maritime clouds. The study is not based on measurements of real clouds. To analyze the limits of the physics behind the retrieval approaches, cloud fields provided by LES model runs are used to generate synthetic radiation measurements by radiative transfer simulation. This approach has the advantage of being independent on different uncertainties introduced by real observations

and that the retrieved quantities can be compared to the truth given by the LES model. It is concluded that the bispectral retrieval shows a higher uncertainty for the retrieval of cloud droplet size compared to polarimetric retrieval while cloud optical thickness agrees between both approaches.

The results presented by this study are of high value for current and future satellite remote sensing. Retrieval uncertainties which originate from the general limitations of the retrieval algorithms are clearly quantified and may help to improve the interpretation of satellite cloud products. In this regard, the manuscript provides an important contribution to current and future research and is worth to be published.

However, in my opinion the manuscript lacks of some major issues which have to be reassessed in detail before publishing the manuscript. By neglecting measurement uncertainties, the retrieval comparison might be only of academic value because it does not reflect the real uncertainties of both retrieval approaches when real satellite observations are considered. Furthermore, new developments of the bispectral retrieval are not considered in the study and limit the conclusions for future satellite employments. The bias of the bispectral retrieval is surprisingly high considering the ideal setup of the study. A more accurate treatment of the vertical weighting function of the bispectral retrievals needs to be applied in order to guaranty the comparability with the LES and the polarimetric retrieval.

Below, I compiled a list of comments which have to be considered in a revised version of the paper. There might be some contradictory statements resulting from my misinterpretation of the text when first reading. I am sure the authors will know how to weight in such cases and how to improve the text to avoid misinterpretations by other readers.

2 Major comments

Neglecting measurement uncertainties

I understand the approach of the authors to use synthetic measurements generated from LES cloud fields and radiative transfer simulations. This approach leaves only a limited number of causes which can explain the difference between both retrieval approaches, such as the complexity of the cloud representation in the radiative transfer model (vertical profile). In this regard, the study provides good insight into the physics of the retrieval approaches. This is worth to be published but might be only of academic value. However, the conclusions on the performance of the retrieval approaches might change when measurement errors are considered. Uncertainties of the spectral radiance measured by the satellite sensors, e.g. radiometric calibration, might propagate differently in both retrieval approaches. An uncertainty of spectral radiance might have larger consequences on retrieved cloud properties compared to uncertainties in the polarimetric measurements. To judge, which retrieval algorithm provides the more accurate cloud properties when applied to real satellite measurements such a propagation of the measurement uncertainty has to be considered and analyzed. This should not replace the current results of the study. Please keep these results. I rather suggest to add an additional exercise with focus on the propagation of measurement uncertainties. On basis of the available data set, this should be easy to realize. The simulated radiances which are the exact synthetic measurement are available. By generating synthetic measurements including a measurement uncertainty and propagating through the retrieval algorithm should already give an estimate of these retrieval uncertainties. Your motivation to use a LES cloud field and IPA simulations would still hold for such a study, as 3D-radiative effect, etc. still can be ruled out. Only the propagation of pure sensor uncertainties will be analyzed.

Vertical weighting functions

As discussed by the authors, the vertical weighting function is essential to compare retrieved cloud properties with the LES model clouds. Therefore, I am wondering why a relative crude assumption for the weighting function of the bispectral retrieval is assumed. The two-way transmittance function is valid for single-scattering only which holds for the polarimetric retrieval where single scattering features are extracted from the measurements. But the bispectral retrieval certainly are effected by multiple scattering. Platnick (2000) clearly shows that the vertical weighting functions significantly extend into the lower cloud layers. Even for 3.7 μm cloud layers at optical thickness larger than $\tau > 2$ contribute to the weighting function while the 2WT weighting already becomes zero for $\tau > 2$.

First, I was surprised by the relative large differences between bispectral retrieval and LES-truth because the setup of the study was chosen well and should not allow large differences. But the treatment of the vertical weighting functions may explain these differences. Considering the idealized setup using the LES clouds and the independent pixel approximation to generate the synthetic measurements, I do not see many sources of error than the vertical distribution of cloud particles and how these are represented in the radiative transfer model. I assume, that the calculation of the synthetic measurements and the calculation of the LUTs use the same radiative transfer code. For the synthetic measurements, the vertical cloud profile is considered, but not for the LUTs of the retrieval. So the radiative transfer code itself is no issue.

The inaccurate treatment of the vertical weighting fits also to the results shown in Figure 3a. The slight shift of the bispectral retrieval to smaller particle sizes compared to the 2WT weighing might result from different vertical weighting function. While the 2WT weighting only considered the larger particles at cloud top, the bi-spectral retrieval is also influenced by smaller particles at lower cloud levels. This could already lead to the observed differences. Therefore, I suggest to use a more realistic vertical weighting function for comparing the bispectral retrieval with the LES model. The weighting function considering multiple scattering can be easily calculated by the method presented by Platnick (2000). As an approximation the weighting functions can be calculated assuming vertically homogeneous clouds as for the retrieval LUTs. With this assumption they can be easily extracted from the LUTs as the slope of reflectance with increasing optical thickness. So all required simulations should be available.

Radiance Ratio Retrieval

The manuscript motivates the study by future satellite missions providing multi-angular polarimetric observations. However, also the classic bispectral observation will profit from continuous improvement of the retrieval algorithms. In recent studies, the radiance ratio retrieval approach has been proposed (actually by one of the co-authors) to reduce some limitations of the bispectral retrieval (Werner el al. 2013, Ehrlich et al. 2017, LeBlanc et al. 2015, Brückner et al. 2014). Using ratios of spectral radiance instead of absolute radiance improves the orthogonality of the LUTs and the impact of measurement uncertainties. Therefore, some limitations discussed for the bispectral retrieval might be improved. E.g. LUTs of radiance ratios are more spread for small cloud optical thickness, the PPH-bias is likely reduced having more orthogonal LUTs (similar to the differences between 2.1 μm and 3.7 μm). This improved retrieval approach should be considered in the manuscript as a third retrieval approach if it aims to be relevant for future satellite observations.

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liquid water cloud and surface snow properties using airborne spectral solar remote sensing, Atmos. Meas. Tech., 10, 3215-3230, https://doi.org/10.5194/amt-10-3215-2017, 2017.

LeBlanc, S. E., Pilewskie, P., Schmidt, K. S., and Coddington, O.: A spectral method for discriminating thermodynamic phase and retrieving cloud optical thickness and effective radius using transmitted solar radiance spectra, Atmos. Meas. Tech., 8, 1361–1383, https://doi.org/10.5194/amt-8-1361-2015, 2015.

Brückner, M., Pospichal, B., Macke, A., and Wendisch, M.: A new multispectral cloud retrieval method for ship-based solar transmissivity measurements, J. Geophys. Res., 119, 11338–11354, https://doi.org/10.1002/2014JD021775, 2014.

Polarimetric Retrieval

How meaningful are the results of the study on effects of the horizontal resolution for the polarimetric retrieval? In the motivation it was mentioned, that for POLDER a footprint of 150 km has to be used to obtain measurements of the cloudbow? This is far from the scales analysed here with the LES clouds. Is the spatial resolution of future spaceborne polarization sensors comparable to the scales analyzed in this study? The results presented in the manuscript suggest, that in the scales analyzed here, polarimetric measurements are not strongly effected by cloud inhomogeneities. Can this conclusion also be transferred to larger spatial scales? These issues should be discussed somehow in the manuscript.

3 Minor comments

P1 L1: Title: The study is limited to three very specific cases of liquid low level cloud over the ocean (trade wind cumulus, stratocumulus). At least "liquid clouds" has to be added in the title. "marine" or similar indicating, that only clouds over water have been analyzed should also be considered. Retrieval of ice clouds will certainly differ from the study presented here. Also results for clouds over land can differ due to surface albedo and the different cloud dynamics over land (vertical profile).

P5 L10: The reflectance at SWIR and VNIR bands both depend on optical thickness and effective radius. It is simply wrong to indicate that the sensitivities are decoupled. The lookup table shown in the manuscript clearly reveal the non-orthogonality especially for small optical thickness. This coupling has different implication on the bispectral retrieval (PPH-bias) which partly are already used to discus the retrieval biases.

P8 L12: The polarized phase function and the modeled polarized reflectance are two different quantities as far as I understood. How these can be fitted to each other? The degree of linear polarization calculated from polarized reflectance would be comparable to P12.

P9 L27: Eq. 4: Wouldn't it be better to use/write the size of the coarser resolution pixel into brackets of the mean value. Instead R(0.865 μm, 50 m) better R(0.865 μm, 800 m)? The mean value is calculated for the coarse resolution pixel and independent on the fine resolution of 50 m.

P10 L11: Is the comparison only done for a specific solar zenith angle or are all simulations mixed? In Sect. 4.2, Fig. 5 it was explicitly mentioned that all cases and geometries are included. Should be done here as well.

P11 L3: Footnote: Why this was written as footnote? The explanation given in the footnote should be presented directly in the main text because it is needed to understand the systematic bias. Putting such parts into a footnote only disturbs the flow of reading.

P14 L5: Figure 8: This comparison has to be done with respect to the LES-truth (see also comment to Figure 5). Only then you can judge which retrieval has a bias and which not. Comparing both retrieval to each other merges effects and does not tell which retrieval is closer to reality. In P 14 L 9 the differences between bispectral

and polarimetric retrieval are rated by assuming the polarimetric retrieval to be the truth. This should be avoided as also the polarimetric retrieval may have caused these differences. You should always refer to the truth solution which is given by the LES cloud fields.

P14 L10: typo: "less" and "lower"

Figure 1: Panel a): Something is wrong because the color codes do not fit to spectral bands! Likely the labeling of x-y axis is switched.

Figure 2: Indicate horizontal scale!

Figure 3: Typo in caption: "or" should be "of"

Figure 5: I do not see a need for these plots. Comparing both approaches separately to the LES-truth already tells where the uncertainties of the individual approaches are. Comparing both to each other makes interpretation only very difficult but does not give any new conclusions. Both retrieval have to be compared to the LES-truth. The comparison in figure 5 also results in some incorrect conclusions (at least when these are only followed from Fig. 5 alone). The polarimetric retrieval has been found to be better compared to the bispectral retrieval. But this conclusion can not come from Fig. 5 because Fig 5 does not compare to the truth values. Therefore, I suggest to remove Fig. 5 or exchange by similar comparisons with the LES-truth. Also the corresponding discussion (P 12 L 20-30) should use the LES-truths as the reference.

Figure 6: Some data does not fit into the LUT. Is this necessary? The range of optical thickness can be extended in your simulations? You should be able to calculate the maximum optical thickess from the LES field in advance. Or is there any other reason why these data does not fit?

Figure 6: What is the range of optical thickness? Can be labeled similar to the particle size.

Figure 7: This figure is also not needed. Both results have already been compared to

the LES-truth.

Figure 8: Very hard do distinguish the color code and circle size. Especially the size of the circles is not visible in the center of the data cloud. Only outliers are visible.

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