

Response to RC3 of egusphere-2026-4795

We want to thank the referee of our paper for the review and comments. Below are our responses (black) to the general and specific comments of the reviewer (in blue):

This study provides a new algorithm for polarimetric cloud retrievals, though it is based on the same physical basis as Bréon et al.'s parametric retrieval and Alexandrov et al.'s RFT retrieval. The authors describe the similarities and differences and emphasize the advantages of their approach over the others. The paper is well written and shows substantial potential for contributing to and improving the existing body of work. In short, great work. I think that, after addressing the questions and points raised, this work would be an excellent addition to the field.

That said, following are my general comments, followed by some line by line comments,

1. I'd rather see this algorithm described as an extension to parametric fitting. This is because, even in the "recipe" (Fig. 4), the extended, multi-mode retrieval is only performed when the single-mode parametric retrieval suggests a "suspicious quality assessment." This is not a criticism. In fact, I believe it's a smart way to improve existing methods. However, I'd suggest mentioning this appropriately in the abstract, i.e., noting that the multi-mode extension is applied when single-mode retrievals are unreasonable, and the method itself is extension of parametric retrievals, rather than a new technique between parametric and RFT.

Thanks for the comment. We rephrased the beginning of the abstract to

“We present a new method to derive droplet size distributions in clouds consisting of multiple modes using aircraft based polarized measurements of the cloudbow. The retrieval builds onto the existing single mode parametric approach, but allows up to three modes in the droplet size distribution (DSD), where each mode is described by a gamma distribution of effective radius r_{eff} and effective variance v_{eff} . While the DSDs of shallow cumulus or stratiform clouds are often well described by single mode distributions, this does not hold in the presence of drizzle or rain and the measured polarized radiance is not accurately described by a single mode fit. We show that allowing multiple modes in those cases not only improves the fit significantly but also shows good agreement to the Rainbow Fourier Transform (RFT), which derives an arbitrary distribution.”

2. Another important missing part, for me, is how important angular resolution is for performing such retrievals up to very large CER values. When the CER is large, cloudbow features become very narrow. It would be a natural, practical question to ask what the minimal angular resolution would need to be to perform such 3-mode retrievals. I couldn't find any information about the angular resolution of specMACS used here. In addition, a

sensitivity study on the importance of viewing-angle resolution would greatly strengthen the work.

We agree, that the angular resolution might play an important role in resolving particularly the rainbow of larger droplets and performed a first simple analysis based on simulations. While the retrieval of the cloud mode ($r_{\text{eff}} = 10 \mu\text{m}$) works reasonably well for angular resolutions up to about 2° (dependent on the optical thickness ratio between cloud and rain droplets), the retrieval of the rain mode becomes less accurate for angular resolutions less than about 1° . Since this paper, however, deals rather with the general implementation of the multimode retrieval and the demonstration of its capability, we leave a full sensitivity study for future work. Nonetheless, we clarified the section about the resolution of specMACS in the introduction and added the angular resolution on which the retrieval is performed:

“Prior to the EUREC4A campaign the instrument has been extended by two downward looking polarization resolving Phoenix 5.0 MP Polarization Model cameras (Pörtge et al., 2023). In 2024, two more sideward-facing polarization cameras were integrated, providing an overall field of view of about $91^\circ \times 220^\circ$ (along x across track) for the observation of deep convective clouds reaching flight altitudes during the PERCUSION campaign. Each camera covers a field of view of about $91^\circ \times 78^\circ$ and has a resolution of 2448×2048 pixels (along x across track, Weber et al., 2024). Moreover, the cameras provide simultaneous measurements at a frame rate of 5–8Hz resulting in a high temporal resolution. Together, this allows to aggregate the scattered polarization signal from cloud targets at a spatial resolution of about $100 \times 100\text{m}$ and an angular resolution of 0.3° (Pörtge et al., 2023).”

3. Another point I'd argue is that polarimeters only see the top of the clouds. So, is it possible to see big droplets at such high levels? I agree with the point made (around line 356) that it is possible to see raindrops from the side with sufficient angular resolution, or that this kind of method would generally be useful for satellite retrievals. However, in this particular case study shown in Fig. 8, I can't shake the feeling that it's unclear whether we can really see those large droplets in the regions where Fig. 10 shows multi-mode retrievals. Perhaps you could check how the stereographic cloud-top retrievals shown in Fig. 9 (b) can be overlaid on Fig. 8(b), along the track where radar observations are available, and then show the multi-mode retrievals from Fig. 10 on the same figure. In this way, if the multi-mode retrievals coincide with regions where larger droplets are closer to the identified cloud top, it would strengthen the argument that the algorithm is correctly identifying and performing multi-mode retrievals where large droplets exist near the cloud top.

Thank you for this thought. We added a new figure to the manuscript (now Fig. 12), which relates the retrieval results around the radar beam to the radar reflectivity and the optical thickness measured by the WALES lidar, which was also operated onboard the aircraft

during the PERCUSION campaign. We plot the timeline of the effective radius results for the different modes and the corresponding heights of the observed cloud targets, which shows that specMACS indeed penetrates to the areas with enhanced radar reflectivity, while the heights still coincide with the optical thickness measurement of the lidar, i.e. the mean height within the cone is around an optical thickness of one or where the lidar is attenuated.

We added the following description of the figure to the manuscript:

“A remaining question to consider is whether large droplets can really be seen at the higher cloud tops as indicated by Fig. 10 and Fig. 9b. To this end, Fig. 12 combines the cloud targets from specMACS within the 1° cone around the radar beam with the radar measurements and optical thickness measurements of the WAter vapor Lidar Experiment in Space (WALES; Wirth et al., 2009; Wirth and Groß, 2025). In panel (a) we show the radar reflectivity as in Fig. 8b, but this time overlayed with the cloud top heights (mean, minimum, and maximum) of the retrieved targets within the cone. The heights of the specMACS cloud targets are partly well below the radar heights (excluding the cirrus above), i.e. towards the upper left of the deeper convective cloud, which indicates that specMACS is sensitive to targets deeper within the cloud. The optical thickness at 532nm measured by WALES is shown in panel (b) together with the corresponding cloud target heights, illustrating that the mean height of the retrieval points from specMACS is well in line with the attenuation of the lidar at optical thicknesses around one. Thus, this might be evidence that specMACS penetrates into the areas where the radar shows an enhanced reflectivity and large droplets might be present as the optical thickness above is low. In panel (c), we show the corresponding effective radii derived for the up to three modes. The dominant mode depicted in red shows targets with values up to about 100µm around 13:50 UTC, exactly where the mean of the specMACS cloud target heights coincides with the higher radar reflectivity.”

line 5: "Since current look-up tables ..." At this point readers would have no clue what meant by "current" here. I'd suggest avoid doing that.

We changed the respective sentence to “The parametric retrieval fits polarized phase functions derived by Mie theory to the measured polarized radiance, such that, for the retrieval of large droplets, new Mie calculations were performed to include effective radii up to 1000 µm.”

line 40: "phase tables" or "phase function table" ??

We clarified the wording and changed “phase table(s)” to “phase functions table(s)” throughout the whole manuscript.

line 106: "Theoretical basics" or "Theoretical basis"?

We renamed the section to “Theoretical framework”.

line 324: "..., while there is hardly any *overestimation* for ..."

The missing "overestimation" was set in.

line 397: Why do the cloud top height uncertainties matter here? Is it because all observations are mapped to cloud top before performing retrievals? If so, I think this would be a major point worth mentioning explicitly.

The cloud top height is important for the aggregation of the signal, i.e. if one follows a cloud target through multiple images to derive the angularly resolved cloudtop signals. If the cloud top heights were wrong, the aggregated signal would be wrong and potentially contaminated by signals from different cloud parts or the ocean surface. We extended the existing sentence to clarify the role of the cloud top heights:

"A reason for this might be other uncertainties in the aggregation of the measured signal, e.g. due to the development of the cloud, convective movement, which is not captured in the mean wind from ERA5 data used in the single mode retrieval (Pörtge et al., 2023), or potential uncertainties in the cloud top height, which are needed for the correct identification of cloud targets in subsequent images."

line 443: "... RFT is its current implementation only retrieves radii up to 100 μm .." Wouldn't it be possible to extend RFT to those larger CER values, so that we could see whether RFT can also handle them?

Yes, in principle one could extend the RFT to larger radii, however, as we argue in the introduction (l. 90ff. of the original preprint), the current implementation of the RFT is based on an equally spaced database (0.5 μm in radius at an angular resolution of 0.2°), such that a huge database would be required. Further, the oscillations in the phase functions of the individual phase functions increase for larger radii such that it would need to be tested, whether an angular resolution of 0.2° would still be sufficient. Another point that would need to be addressed, are the corrections introduced in Alexandrov et al. (2012) for the original transformation with radii up to 100 μm . Altogether, we agree that it would be very interesting to extend the RFT to larger radii, and will leave it to future work to investigate whether it would be possible.