General Comments

This work demonstrates a legacy polarimetric cloud retrieval algorithm on data from a new dual-imaging polarimeter instrument, specMACS. specMACS is a wide-field, division of focal plane polarimeter. 3-band VIS wavelength selection is done using a Bayer-filter-like scheme at the detector. The polarimeter has two identical cameras looking slightly off-nadir such that their FOVs have a significant overlap. This design produces an effective FOV larger than both cameras alone.

specMACS co-registered, multi-angle data over large stratiform clouds and trade wind cumulus were used to explore cloud information content at scales ~100m. These retrievals were done over a wide spatial field, in the overlap region between both cameras. This work is a spiritual successor to McBride et al. (2020), which was the first to do a similar study using cloud measurements from the AirHARP polarimeter. This work improves on that study in several ways: (1) a stereo cloud height is determined for each cloud pixel, and (2) the authors claim retrieval sensitivity in effective radius (r_{eff}) up to 40um and at a spatial resolution two times smaller than results in the McBride paper, and (3) an application to small cumulus clouds is shown. These factors and others may provide new opportunities to tease out cloud processes with specMACS data.

As polarimetric instrument development continues, papers like these help track the state of the field. They will be used to inform new instrument designs, missions, and algorithms. Therefore, I recommend this exciting paper for publication in AMT. However, I suggest a mix of specific and minor revisions.

Specific Comments

(1) The opening paragraph needs more discussion on the current state of cloud and climate science: their non-uniform global distribution, both vertically and horizontally, thermodynamic phase differences (ice vs. water), and current challenges in comparing remote sensing/in-situ measurements/retrievals, cloud simulations, and global climate models. These are just examples, but please add a few extra sentences that put the paper in stronger context with the field.

The connection between aerosols and clouds and the potential benefit of using polarmetric measurements in aerosol-cloud studies is missing in the Introduction. This is a hot field of current cloud research and polarimeters like specMACS are highly relevant to this topic. Please add a few sentences about this.

(2) One of the major results of this paper is the ability to retrieve r_{eff} ~40um from specMACS cloud data. This capability is highly attractive for future climate applications and missions. This can be a challenge for some polarimeters and retrievals done on their data. For this kind of retrieval, some polarimetric instruments are capped in the upper bound of retrieved r_{eff} due to limitations in view zenith angle density (Miller et al. 2018, citation below). specMACS may get around this limitation with its dual-camera design and access to a second set of retrievable pixels and geometry for the same cloud target. This is important to mention. Also, more details about how the specMACS design and sampling directly compares to other, similar cloud measuring instruments (specifically AirHARP and RSP) would be valuable.

Miller, D. J., Zhang, Z., Platnick, S., Ackerman, A. S., Werner, F., Cornet, C., and Knobelspiesse, K.: Comparisons of bispectral and polarimetric retrievals of marine boundary layer cloud microphysics: case studies using a LES–satellite retrieval simulator, Atmos. Meas. Tech., 11, 3689–3715, https://doi.org/10.5194/amt-11-3689-2018, 2018.

This paper would also benefit from a short, quantitative discussion of retrieval uncertainty (Qual and RMSE). How well can one use specMACS data to reliably retrieve large r_{eff} and v_{eff}? An accompanying sub-figure similar to Figure 7a and b that shows the spatial distribution of the best-fit RMSE may support this discussion.

(3) In many areas, this paper has colons (:) when a period would be more effective. Please look through the document and make revisions as needed.

<u>Technical Corrections</u>

Abstract

Please put the conclusion of this paper at the end of the abstract.

Section 1

Line 21: What is “extreme precipitation”?
Line 22: “future temperature changes” is vague. The IPCC AR6 is specific in defining how future climates may be influenced by changes in sea surface temperature, global mean air surface temperature, or other similar measures. Please be specific.

Line 39: Large phrases like “droplet size distribution” can be reduced to conventional acronyms, like DSD. Also, since effective radius and effective variance are defined as r_{eff} and v_{eff} in Lines 43/44, please can use these abbreviations going forward in the paper. Other phrases can be simplified too - like “degree of linear polarization” to DOLP.

Lines 42 and 97: Remove the “e.g.”

Line 51: “it has some difficulties which are mainly related to 3-D effects occurring especially in inhomogeneous cumulus cloud fields” should change to “has known biases in the presence of 3-D effects and spatial inhomogeneity.” Spatial inhomogeneity impacts the retrieval at some level for all cloud types, and those biases aren’t always related to 3-D effects.

Line 53: “Furthermore, retrieving the effective variance of the cloud droplet size distribution is not possible.” Please add a citation and/or elaborate.

Line 58, 134, 239, 292, 345: please remove “so-called” in all instances. In most cases, these techniques actually go by these names (i.e. scattering matrix is the name of that matrix, wire-grid polarizer is the official term for that kind of polarizer). In Line 59, it would be a stronger sentence as “Based on polarized observations of the cloudbow, a new kind of DSD retrieval was developed.”

Line 73: The following two sentences are somewhat redundant. Something like "Furthermore, the v_{eff} of the cloud DSD is derived in the polarimetric retrieval. This parameter may be directly linked to entrainment and mixing processes at the cloud top." would be stronger.

Line 91: The ~2um r_{eff} bias between the MODIS bi-spectral and polarimetric DSD techniques was found in other earlier studies as well, largely due to information content differences in location of the cloud DSD creating the signal, retrieval resolution, inhomogeneity in the pixel, and choice of SWIR band used in the bi-spectral retrieval. Please cite as necessary:

Alexandrov et al. (2015, 2016)
Breon and Doutriaux-Boucher (2005)
and

Di Noia, A., Hasekamp, O. P., van Diedenhoven, B., and Zhang, Z.: Retrieval of liquid water cloud properties from POLDER-3 measurements using a neural network ensemble approach, Atmos. Meas. Tech., 12, 1697–1716, https://doi.org/10.5194/amt-12-1697-2019, 2019.

Line 97: Please re-word this sentence for clarity, something like "RSP data can provide a bi-spectral and a polarimetric r_{eff} from the same cloud target, due to spectral coverage from VIS to SWIR and along-track, co-located multi-angle sampling."

Section 2

Line 133 (and Figure 1). I appreciate the relative spectral response figure added to the manuscript. It would be helpful to also include the center wavelength and bandwidth (FWHM) of the three filters in the text itself. The typical convection is to write it as wavelength (bandwidth), like 440 (15) nm.

Line 142: Please reword this statement - the degree of linear polarization (DOLP) describes the fraction of the incoming light that is linearly polarized. Q and U also quantitatively describe the linear polarization.

Line 152: Remove the comma between "advantage, that"

Line 156: "For further analysis, each measured Stokes vector is rotated into the scattering plane (Hansen and Travis, 1974) and we only evaluate Q." Although this work focuses on solar principal plane (SPP) geometries (typically a narrow line of pixels in an observation), there will likely be non-zero U values for cloud targets located off the SPP in the spatial field retrieval. Were there cloud targets with non-negligible U values? If so, how does that contribute to the interpretation of the retrieval results?

Figure 2 caption: Please reword for clarity - "The primary bow of the cloudbow is visible in the degree of linear polarization as a bright ring at a scattering angle of about 140°"

Section 3

Line 173: “This method can easily be applied to any cloudbow observations, including those from commercial cameras, but it requires averaging over a large area.” Please describe why is this less desirable than the co-located, along-track method presented in this paper.

Line 175: Please change “we fly over it” to “specMACS images the scene”.

Line 181: “In a final step, a look-up table (LUT) of cloudbow signals for different cloud droplet size distributions..” Please be specific that a simulated Mie LUT is used for this comparison.

Figure 3: The alpha angle in the figure is missing a zenith line coming directly from the plane, please add this in.

Figure 4: The colorbar is very large and doesn’t apply to (d), so it would be cleaner visually if it was condensed and placed under (c). The caption would need to reflect this change as well. Please adapt Figure 10 similarly.

Line 240: Please remove the (single scattering). This is redundant with line 239.

Line 241: The polarized phase function is directly proportional to the measured polarized radiance Q, under the assumption of single scattering. P_{12} is not an approximation of Q. Please revise.

Line 245: Effective variance determines the amplitude of the secondary maxima/minima (see Figure 5b), which is where the information content lies (not number of peaks). Please revise this sentence.

Line 254: Please add the word unimodal or monomodal before “gamma distribution”.

Line 280 and 287: Thanks for changing Eq. (6) and (8) to the typical/original convection!

Line 284: It has also been shown in Alexandrov et al. (2012a) that increasing cloud and/or aerosol optical thickness can impart a linear slope on Q. Reidi et al. (2010) shows that cirrus ice polarization signal is approximately linear in the rainbow region, too. These contaminations can also be accounted for by B and C terms in Eq. (6).

Riedi, J., Marchant, B., Platnick, S., Baum, B. A., Thieuleux, F., Oudard, C., Parol, F., Nicolas, J.-M., and Dubuisson, P.: Cloud thermodynamic phase inferred from merged POLDER and MODIS data, Atmos. Chem. Phys., 10, 11851–11865, https://doi.org/10.5194/acp-10-11851-2010, 2010.

Figure 6: The presentation of the “number of measurements” is a little confusing. In the plots, it almost looks like an uncertainty but it’s a bit more complex than that and it blurs the overall message in my view. When the slope of the Q_fit signal is large in a small scattering angle range (see 6a between 142-147 degrees), it is hard to differentiate the box values from the measurement/fit lines.

I recommend to replace the “number of measurements” pixels in the plots with errorbars that correspond to the angular measurement. This goes for Figures 9 and 15 as well.

Section 4

Line 376: Please remove the comma between “example, to”

Line 378: Please remove the e.g. and commas.

Line 380: Please change to “In the case of small cumulus clouds, a precise geolocalization is important for image-to-image tracking.”

Line 393: Please define 100m as a “target unit” here. This is definition referenced later in Line 401, but in an indirect way and was confusing on a blind read.

Figure 10: See comment for Figure 4.

Figure 10c: Why does the interpolation at the bottom right look artificial? Since it is not discussed in the text, I recommend to screen out this data and leave it unassessed (i.e. as it looks in 10a).

Line 423: If the error due to incorrect geolocalization is yet be estimated quantitatively, how is it that the cloudbow retrieval is “affected [by it] to a much lesser degree”? This is confusing. Please elaborate.

Line 433: It is clear in 12b that the majority of 0.3+ veff values are “tracing” the lower boundary of the overlap between polA and polB cameras. 12f shows a big spike at the 0.32 v_{eff} bin, which is the very edge of the Mie LUT described on Line 269. This together suggests that these retrievals are artificially converging (either due to noise or errors in geolocalization) and may not be valid, even if they pass the Qual and RMSE. I suggest removing this v_{eff} bin from the Figure 7f and 12f plots (and corresponding data points from the 7b and 12b maps) to focus the discussion on the valid larger v_{eff} that do exist in the data.

Line 458: McBride et al. (2020) was also careful to note that the subpixel r_{eff} and v_{eff} distribution that contributed to their larger-scale wide DSD result could also be impacted by cloud height geo-registration (they used a granule-wide average, not pixel-by-pixel as in this study). I suggest to change the “does” to “may” in this sentence.

Section 5

Line 468: Remove the comma between “cloud, that” and change “are” to “may be”. This has not been shown in this study, only suggested.

Line 470: Add a comma between “layer very”