Response to the reviewer comments on the manuscript:
"Variability and properties of liquid-dominated clouds over the ice-free and sea-ice-covered Arctic Ocean"
[acp-2022-848]

We thank the two anonymous reviewers for diligently reading and carefully reviewing our manuscript and providing us with useful comments and suggestions to improve the quality of the manuscript. A list of all reviewer comments and questions (written in *italics*) as well as our response (written in regular) is given below. Whenever we provide information in which line changes were made we refer to the line numbering of the revised manuscript.

Comments Reviewer 1:

This paper presents a fairly straightforward application of a bispectral retrieval for liquid cloud optical properties from airborne data in the arctic. There is a limited validation of the retreival against in-situ probe data. It is found that the effective radius agrees well with the in-situ data whereas the liquid water path can be overestimated, presumably due ot the presence of ice. The retrieval is applied to two deployments in different seasons and the optical properties from two seasons are contrasted. I have a few minor comments listed below and two more significant comments.

Significant comments:

First, I would like to see the optical depth retreival validated to explain the liquid water path biases.
We appreciate this suggestion to explore the bias caused by ice crystals on the retrieved liquid water path (LWP) in a more quantitative manner. However, we would like to clarify that our study focuses specifically on liquid-phase clouds, and our retrieval method is designed to avoid cloud top sections dominated by ice crystals.
Anyway, we investigated the possibility to include the vertical distribution of ice particles into our libRatran simulations to reduce the bias in the retrieved LWP. The challenge we encountered was that, apart from comparing the results with in-situ measurements, we could not identify the quantity and location of ice particles within the clouds using our passive remote sensing technique for all the measurements conducted during the AFLUX and ACLOUD campaigns. Nevertheless, to ensure transparency in our manuscript and emphasize that the retrieved LWP is solely based on radiative properties, we made the decision to rename it as the retrieved effective liquid water path, LWP_{eff}, throughout the entire document. To convey this change, we modified the following description:
Line 163: "For this reason we use the index eff in LWP_{eff} to make clear that this is an effective parameter based on passive remote sensing measurements, which might be biased by the vertical cloud structure."

Second, I believe there is lidar data for these flights and I would like to see the lidar data compared to bispectral retreivals in addition to the radar since the two instruments together provide a more complete picture of hydrometeor phase throughout the vertical profile.
Thanks for this comment. Regarding your comment we spend some time to look into these data and implemented the data in the analysis. First, we identified the cloud top heights from the AMALi Lidar and the MiRAC Radar measurement and then calculated their relative distance, which can be used as an indicator of the presence or absence of ice crystals in the cloud top layer. To estimate the difference in cloud top height we interpolated the datasets to a time resolution of 1 Hz. The resulting difference in cloud top heights represents the liquid layer thickness at cloud top. Figure 1 (see below) shows two histograms showing the difference of cloud top height (Lidar minus Radar) for the ACLOUD and AFLUX campaign. It is obvious that more ice particles were present close to cloud top during AFLUX (Fig. 1b) than during ACLOUD. This agrees with our previous results written in the manuscript.

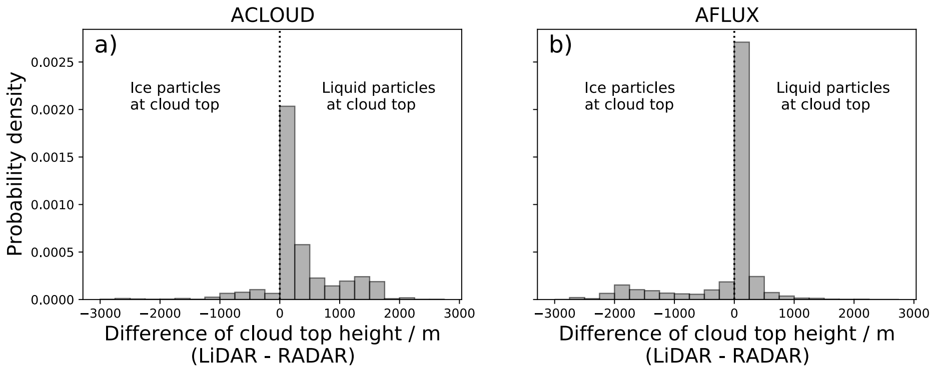

Figure 1: Difference in cloud top height, based on AMALi Lidar and MiRAC Radar measurements for the ACLOUD (a) and AFLUX (b) campaign.

Anyway, to see what difference a consideration of the liquid layer depth at cloud top makes for the retrieval results, we applied it to Figure 9 from in the manuscript and the result is shown here in Figure 2 (see below). Here, we applied a further filter in comparison to the manuscript, considering only retrieval results where the liquid layer at cloud top is larger than 10 m. As comparison, the retrieved parameters from the manuscript are plotted in grey (Fig. 2f-h and j-l). As you can see, the differences are hardly noticeable.
Unfortunately, the lidar and radar are not available for all flights and flight sections covered by the AISA Hawk data set. The combined data set is reduced tremendously. For this reason and in light of the good agreement between the filtering method applied in the manuscript and the Radar/Lidar filter, we decided to use the full data set and not implement the additional filter.

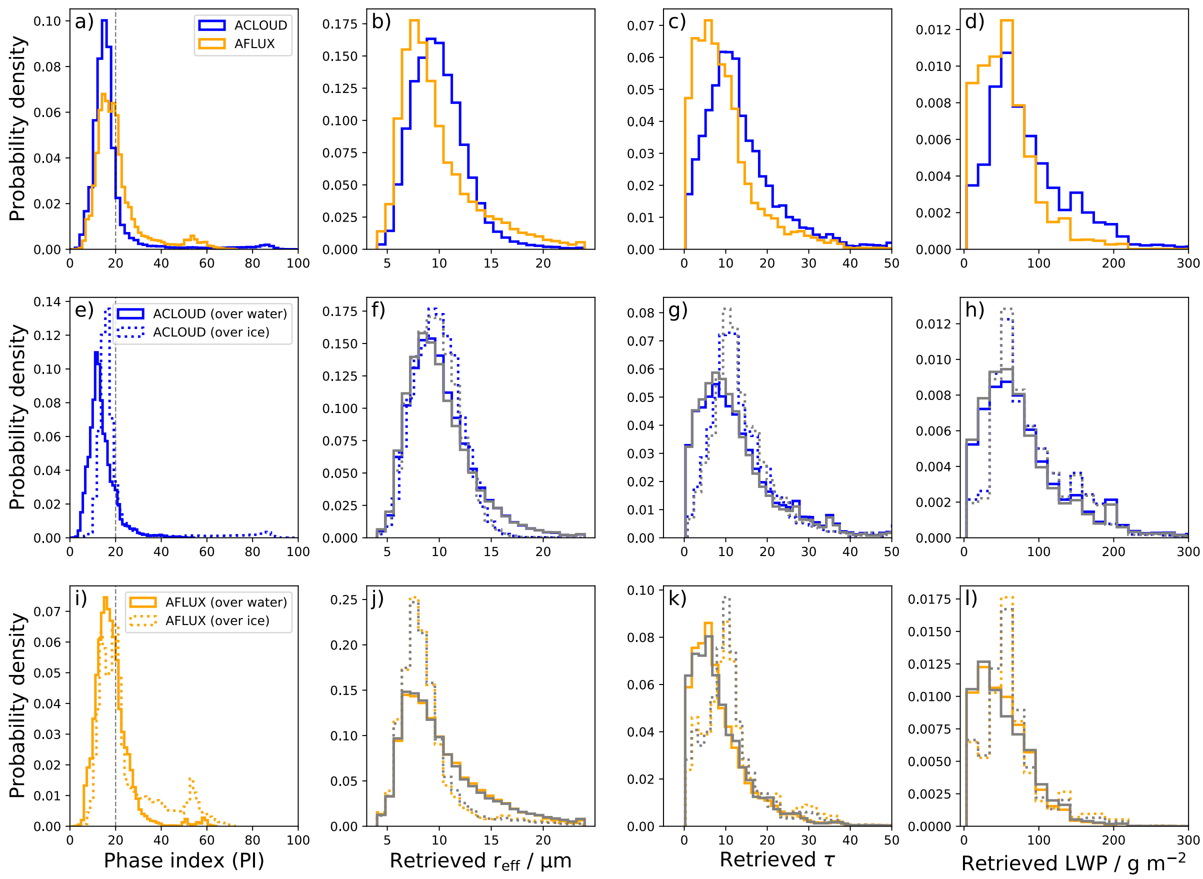

Figure 2: Same as Figure 9 in the manuscript, but with an additional filter. Here, we plot only retrieval results where the liquid layer at cloud top is larger than 10 m. For the retrieved values over ice and water surface (f – h and j – l), we plotted in grey the values from Figure 9 in the manuscript.

Minor comments:

Line 86: please describe the simulations of the spectral flux.

We added following information:

Line 91: "Within libRadtran we used the radiative transfer solver DISORT2 (Discrete Ordinate Radiative Transfer, Stamnes et al., 2000) and performed the simulations of the upward radiance for solar zenith angles between 55° and 69°. Azimuth angles were adjusted depending on measurement time, location and attitude of the research aircraft."

Line 90: Can you provide some estimate of uncertainty in the phase identification either from the references or collocated measurements (e.g. lidar? or in-situ probes). What is the False Alarm Rate, Probability of Detection etc.?

Thanks for this comment. The phase index calculated from spectral reflectivity is not always unambiguous and therefore there is uncertainty in the phase detection. It can become ambiguous when only small ice crystals are present as shown by Ehrlich et al. (2008). However, the observed clouds were clearly liquid dominated, which was indicated by the presence of glories during the flights. Our filtering aims at removing clouds where the ice crystals can significantly affect the retrieval, e.g., the liquid cloud top layer is not present. Such cases can well be identified by the phase index. As demonstrated above for another question, we checked the performance of the phase index filter by radar/lidar observations of the cloud top liquid layer. This showed that the current filtering method is sophisticated enough and an additional filtering based on lidar/radar measurements is not necessary.

Figure 3: you should spell out MIZ in the figure caption.
We changed it.

Line 150: neglection -> neglect
Done.

Line 188: does -> do
Changed.

Line 215: obtains -> results
Thanks, we changed it.

Equation 4: how are zbase and ztop chosen? Is this the entire profile or only the liquid cloud layer at the top of the profile?
You actually can see the chosen part in Fig. 6b and 6c. The top and base of the profiles of the in-situ measured LWC were used for the z_{top} and z_{base}. The gray shaded areas mark only the sections which we considered for the in-situ estimation of r_{eff}. To make that more clear we wrote:
Line 249: "The profiles capture the whole vertical descent and ascent through the clouds, limited only by the minimum flight altitude of 60 m. The top and base altitude of these *LWC* profiles were used for the estimation of z_{top} and z_{base}".

Line 233- 236: This paragraph is not written clearly. Please rewrite it for clarity. What do you mean by both cloud layers? Do you mean that the integral is over the entire liquid water content profile? In lIne 235, what does the 'first section' refer to?
Thanks for pointing that out. You are right that does not make sense. It seems like the sentence is a leftover from an earlier iteration. We removed this sentence.

Section 4.2: You have the measurements to be more quantitative with regard to the bias caused by ice crystals on you retrieved LWP. You should convert the liquid and ice drop size distributions to optical extinctions. Then you can integrate the liquid + ice extinction and compare that with your retrieved optical depths. This will allow you to demonstrate to what extent the scattering by ice crystals is biasing your LWP. You should include profile plots of the calculated liquid and ice extinction.
Because this comment is about the LWP bias as well, we repeat our response regarding your first comment:
We appreciate this suggestion to explore the bias caused by ice crystals on the retrieved liquid water path (LWP) in a more quantitative manner. However, we would like to clarify that our study focuses specifically on liquid-phase clouds, and our retrieval method is designed to avoid cloud top sections dominated by ice crystals.
Anyway, we investigated the possibility to include the vertical distribution of ice particles into our libRatran simulations to reduce the bias in the retrieved LWP. The challenge we encountered was that, apart from comparing the results with in-situ measurements, we could not identify the quantity and location of ice particles within the clouds using our passive remote sensing technique for all the measurements conducted during the AFLUX and

ACLOUD campaigns. Nevertheless, to ensure transparency in our manuscript and emphasize that the retrieved LWP is solely based on radiative properties, we made the decision to rename it as the retrieved effective liquid water path, LWP_{eff}, throughout the entire document. To convey this change, we modified the following description:
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Section 4.3 From what I can tell from Wendisch, 2019 it seems like there was an airborne lidar flying as well. You should be able to get a much more precise idea of cloud top phase using the lidar LDR and backscatter.
We answered that comment already above (second major comment, page 2).

Figure 9: change a-e -> a-d.
Thanks, done.

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