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

Comment Reviewer 1:

I do not feel the authors adequately addressed my comment regarding the optical depth. Perhaps I did not explain my thoughts thoroughly enough.
I suspect that while the retrieved liquid water path is biased high relative to the in-situ data, the optical depth retrieval probably agrees relatively well with the combined (liquid+ice) optical depth.
You should be able to calculate the in-situ extinction coefficient for both ice and liquid using the measured drop size distributions and then integrate vertically to estimate the combined optical depth.
This is a simple calculation - I don't think there is any need to add ice particles to your look up tables and include them in the bi-spectral retrieval.
If you perform this comparison of measured optical depth and in-situ optical depth and they agree, then this provides some physical justification for the assertion that the presence of ice is the primary cause for the biases in the retrieved liquid water path. This would greatly strengthen the paper.

Thanks for the detailed question. We have put some effort in your suggested calculation and present the results in the following.

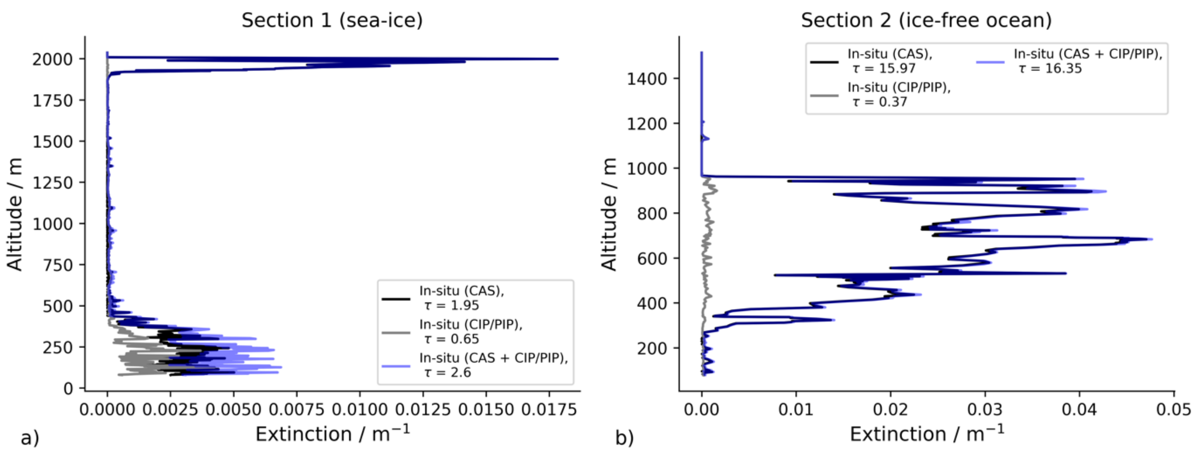

Figure 1: Profiles of the extinction coefficient over sea-ice (a) and ice-free ocean (b). Both plots show the extinction coefficients for in-situ measurements from CAS and CIP/PIP. The total optical depth is provided in the legend.

Your suggestion to compare the optical thickness, τ, of the retrieved and in-situ measurements is great. To do so, we first looked up the retrieved optical thickness for the two cases presented in Figure 6 in the manuscript, which are:

Section 1 (over sea-ice): $\tau_{retr.(sea-ice)}$ = 13.2
Section 2 (over ice-free ocean): $\tau_{retr.,(ocean)}$ = 16.1

The goal is to show if the retrieved optical thickness matches the in-situ measurements. If they agree, then it would provide a physical justification that the presence of ice is the primary

cause for the biases in the liquid water path, like you suggested.
To calculate $\tau_{in-situ}$ we use

$$\tau_{in-situ} = \int_{z=0}^{h} b_{ext}(z)\, dz \qquad (1)$$

with $$b_{ext}(z) = \frac{3}{2} \frac{CWC(z)}{\rho\, r_{eff}(z)} . \qquad (2)$$

The parameter ρ describes the density of water (for CAS, ice for CIP/PIP). The CWC is either the LWC or the IWC, depending on the in-situ instrument. CWC and r_{eff} result from the vertical profiles of the in-situ measurements.

For the single layer cloud of section 2, over the ice-free ocean, the optical thickness between retrieved and in-situ data almost perfectly match with $\tau_{retr.,(ocean)}$ = 16.1 and $\tau_{in-situ} = 16.35\ (CAS + CIP/PIP)$. This result shows clearly that in this case the ice particles do not significantly contribute to the total optical thickness. A bias in in-situ observed and retrieved LWP_{eff} results mainly from the retrieval assumption of a homogenous cloud. This confirms your assumption. Thanks again!

For section 1, the comparison does fail due to the mismatch of the cloud location. This is obvious in the radar reflectivity which significantly increases after the remote sensing measurements and while starting the in-situ profile (see Figure 6 in the manuscript).

Of course, we want to mention this result in the manuscript and therefore we changed section 4.2 in the manuscript (see track-changes file) and added the following paragraph (line 265 to 276):

"To constrain the impact of ice particles on the retrieval biases, the in-situ measurements are converted into extinction profiles of liquid and ice particles following the theory of Eq. 3. The profiles are integrated to the in-situ cloud optical thickness for total, liquid and ice particles. If the extinction by ice particles is low and the extinction by liquid droplets matches the retrieved τ, the observed bias of LWP_{eff} is mostly due to the assumption of homogeneous clouds. This is the case for the second cloud section, where cloud optical thicknesses of 16.1 (retrieved), 16.35 (in-situ total), 15.97 (in-situ liquid) and 0.37 (in-situ ice) were derived. For section 1, the comparison does fail (13.2 (retrieved), 2.6 (in-situ total), 1.95 (in-situ liquid, 0.65 (in-situ ice)) due to the mismatch of the cloud location. This is obvious in the radar reflectivity, which significantly increases after the remote sensing measurement and while starting the in-situ profile. The high radar reflectivity agrees with the high amount of IWC measured in-situ. During the AISA Hawk measurements, the radar reflectivity was still lower indicating a more liquid dominated cloud. Unfortunately, this makes a comparison of the LWP_{eff} and optical thickness impossible for this section. However, the agreement in retrieved and in-situ r_{eff}, at least indicates, that the liquid cloud top layer did not significantly changed."