

Referee comment on “Retrieval of cloud thermodynamic phase partitioning from multi-angle polarimetric imaging of Arctic mixed-phase clouds” by Weber et al.

This study presents a novel retrieval method based on multi-angle polarimetry to derive the ice fraction near the cloud top. The method involves simulating polarized signals within the cloudbow and slope ranges of the scattering angle. The retrieval was applied to synthetic cloud scenes representing Arctic mixed-phase clouds, as well as to measurements taken during the HALO-(AC)³ campaign. Uncertainties in the retrieval were attributed to 3D radiative effects and the assumption of a vertical ice fraction profile.

Overall, the authors did a very good job of presenting their new approach. The manuscript is well structured. Some suggestions for improving the content are provided below. I can recommend publication once clarification has been provided.

General Comments

1. Retrieval results for the horizontal distribution of the thermodynamic phase of clouds near the cloud tops have shown systematic features that do not necessarily provide a consistent picture of slope and cloud bow range (see Figures 10a, 10b and 13a). In any case, the spatial variability of the ice fraction is significantly impacted by retrieval uncertainty, both quantitatively and qualitatively. Would it be more accurate to claim that the method works well on average for complete cloud scenes rather than for individual cloud elements?
2. The authors have shown the I and Q components of the Stokes vector for 550 nm to illustrate the sensitivity to the ice fraction. The polarization camera moreover gives I and Q for a broader spectral range (R, G, B channels). How are the spectral signatures affected by this fact? Is there a lower sensitivity when accounting for the spectral resolution of the camera? Which of the three spectral bands (R, G or B) is finally used for retrieval? From the different figures, I guess it is the green channel. Perhaps I missed a discussion about which of these channels is most appropriate.
3. Why is the shadow masking performed after the retrieval of the ice fraction? Would it not be more efficient to mask this data in advance?

Minor/Specific Comments

1. The method is sensitive to the penetration depth of the radiation into the cloud. The retrieved ice fraction corresponds to the upper most cloud layer (optical thickness between 1 and 2). What are realistic values of the optical depth of the liquid layer at cloud top? Could you be more specific in the introduction about what mixed-phase clouds typically look like in the Arctic?
2. P3182: “10 m resolution” → Specify a flight altitude that complies with this resolution.
3. P4 Fig1a: The figure is not discussed in this section, only Fig. 1b.
4. P51121: “Here, cases where the polarization signal is saturated and not saturated are distinguished.” → “Here, cases where the polarization signal of Q is saturated and not saturated are distinguished (see Sec. 3.4).” I found it difficult to understand the meaning of 'saturated' here. This becomes clear in Section 3.4.
5. P61146: “... from the cloudbow range to cover the complete scattering angle range” Maybe add “available” before “scattering angle”
6. P61160: “see Fig. 3b” I would suggest referring to Fig. 1b instead, since Fig. 3b has not yet been introduced.
7. P71163: “In case the geometry does not allow for observing the cloudbow...” This case is not included in Fig. 2. Maybe revise the schematics.
8. P71175: “but the accuracy of the retrieved ice fraction is not affected” Why not?

9. P7I192: "Unknown parameters are the total optical thickness" → "Unknown parameters are the total cloud optical thickness"
10. P8I204: "Thus, the retrieved ice fraction has to be interpreted as an effective ice fraction under the assumption of a homogeneously mixed cloud." Later, the ice fraction is related to the cloud top layer. This statement may give the reader the wrong impression, of what the effective ice fraction provides. It's not representing the whole cloud layer.
11. P8I214: "total intensity I are compared to simulations with a worst-case assumption of $f_{ice} = 1$, since ice clouds are brighter than liquid clouds" I wouldn't call it a worst-case assumption. It's rather an extreme case. Further, add "within this range of scattering angles". Ice clouds are not generally brighter than liquid clouds.
12. P8I221: "I and Q are converted to reflectivity as in Weber et al. (2025)" Do the previous plots show R_I and R_Q (notation from Weber et al., 2025) or I and Q? Which downward irradiance (E_{dw}) is used to calculate the reflectivity? $E_0 \cdot \cos(\theta)$ is only a rough estimate for E_{dw} at flight altitude.
13. P10I249: "there are two possible extreme cases" There are certainly more extreme cases. I suggest to rewrite the sentence. "For the phase partitioning in low-level Arctic mixed-phase clouds, we assume two extreme cases for the vertical profile."
14. P10 Fig4: I am having difficulty understanding the illustration. Assuming the black line represents the ice fraction, Fig. 4b is understandable. However, the horizontal line in Fig. 4a, which is located between the liquid and ice phases, cannot represent the ice fraction. It must be either 0 for the upper liquid part or 1 for the lower part. Please clarify.
15. P11I280: "In addition, there is agreement between the threshold values determined for the two-layer cloud and the profile cloud." Does this refer to Fig. 6b? I wouldn't call it an agreement, given that the threshold values derived for the two cloud profiles differ by around 0.5.
16. P13I313: "A realistic cloud field..." The realistic aspect is the geometry; the cloud microphysics is not.
17. P14I323, I326: I suggest to combine Fig. 7 and Fig. 12 here, as Fig.12 is discussed here already.
18. P14 Fig7: Add "Retrieved" in front of "cloud top height" in the figure caption.
19. P15I355: "The cloudbow range shows a small bias even for the plane-parallel assumption..." Maybe add "mean" in front of bias. Here and elsewhere.
20. P16I369: "reflectance" → "reflectivity"?
21. P17I143: "but smaller standard deviation" Actually, the numbers are almost the same.
22. P18I417: "In the slope range, there seems to be a compensating effect between the influence of 3D cloud geometry and the assumption of the vertical ice fraction profile, ..." I cannot follow the argument here. Compensation may only occur in the 1D case when 3D radiative effects are not considered. However, I think the authors are referring to Fig. 10 d–f and the 3D-based retrieval. Please clarify.
23. P18I420: "In all cases, however, there is a significant contribution of the 3D cloud geometry to the total retrieval error. The influence of the assumption of the vertical ice fraction profile can also not be neglected." It's a quite general statement here. Can you estimate which one has the bigger effect on the retrieval?
24. P20I455: "... IDEFAX demonstrated a better performance ..." It's not completely true for the cloudbow range.
25. P20I456: "before applying the shadow mask" Why does Fig. 13 not show the final result after applying the shadow mask?
26. P21I460: "Evaluation of the angular range between the slope range and the cloudbow range is not possible..." I'm not sure what is meant here. Is there no comparison between the retrieved ice fractions from slope range and cloudbow range possible?

Technical Comments

1. P5l116: "so-called L1C data" → "so-called level1C (L1C) data".
2. P7l187: I suggest to remove "(unknown)"
3. P7l188: "These include ..." Perhaps consider splitting the very long sentence.
4. P21 Fig 13: Number of contour lines are hard to read.