Review of “Validation of cloud macrophysical properties from the ATLID Level 2a products A-TC, A-FM, A-CTH using airborne lidar observations during the HALO missions PERCUSION, ASCCI and NAWDIC”

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Response to Reviewer #2:

The manuscript “Validation of cloud macrophysical properties from the ATLID Level 2a products A-TC, A-FM, A-CTH using airborne lidar observations during the HALO missions PERCUSION, ASCCI and NAWDIC” by Krüger et. al. presents an independent validation of three ATLID single-sensor Level 2 products using a comprehensive multi-campaign dataset of airborne high spectral resolution lidar (HSRL) backscatter ratio (BSR) measurements. The results are relevant and useful for the EarthCARE community. Overall, the manuscript is well written and suitable for publication in ACP, after some comments detailed below in my review.

We greatly appreciate the reviewer’s positive assessment of the manuscript and its relevance to the EarthCARE community, as well as the recommendation for publication in AMT after revision. We also thank the reviewer for the careful evaluation of our work and for the constructive comments. These have provided valuable guidance and helped us to further improve both the manuscript and the presentation of our results.

We have addressed all of your comments and provide a point-by-point response below. Our responses are given in bold italics, and all changes to the manuscript are marked in bold italics and blue.

<u>**General comments**</u>

The results are presented in Section 4 and discussed in Section 5. However, some parts of the discussion, especially in Section 5.1, repeat the results rather than providing further interpretation. Consider incorporating the relevant discussion directly into the corresponding results sections to improve clarity and readability.

We acknowledge that the “Discussion” and “Summary” sections could be further condensed, as noted in Comment 26 from the other reviewer. To improve the clarity of the discussion and better highlight the key findings, we have revised Section 5 accordingly. In particular, we have reduced unnecessary repetition of the results and placed greater emphasis on their implications. Please find the adjustments to Sect. 5 in the track changes document, or in the revised manuscript.

L89-L112: The information provided in this part would fit better in Section 2.1, where the WALES lidar system is described. Consider moving the detailed description to that section while retaining only the relevant introductory information in the Introduction.

We decided to retain the aerosol- and cloud-related content of this paragraph, as we consider it important for strengthening the motivation. However, we agree with the reviewer that the non-aerosol/cloud-related

content would fit better in Sect. 2.1. We have therefore revised and condensed L89–L112 accordingly: Hence, we adjusted ll.89-ll.112 to make it more concise:

"The WALES HSRL and depolarization measurements have been extensively applied in numerous cloud- and aerosol-studies, including the characterization of aerosol optical properties and the development of aerosol classification schemes (Groß et al., 2013), as well as investigations of ice cloud properties (e.g., Groß et al., 2014; Urbanek et al., 2018; Dekoutsidis et al., 2024). Previous studies demonstrated that the WALES backscatter ratio can be used to reliably identify liquid clouds in the tropics (Gutleben et al., 2019) and ice-phase clouds in the extratropics (Urbanek et al., 2017; Dekoutsidis et al., 2024). Building on these findings, we use the backscatter ratio to generate ATLID-like cloud products, from which macrophysical properties such as cloud fraction and cloud-top height are derived and compared with the ATLID Level 2 products A-FM, A-TC, and A-CTH."

Accordingly, we changed ll.163-165. In Sect 2.1. which now reads as follows:

"Its DIAL observations have been used to investigate water vapor and ozone distributions and transport processes across the tropopause in numerical weather prediction models (e.g., Schäfler et al., 2021; Krüger et al., 2022). In addition, its HSRL and depolarization measurements are well established for aerosol and cloud studies, enabling the characterization of aerosol optical properties (e.g., Groß et al., 2013) and cloud structures (e.g., Groß et al., 2014)."

Specific comments

Figure 7: The authors present the correlation between WALES and A-CTH cloud-top altitudes. While the scatter plot visually indicates that most points cluster around the 1:1 line as written, I recommend including values to support this assessment. Statistics such as the mean bias, median bias, RMSE, and correlation coefficient would provide a better evaluation of the agreement between the two datasets.

We note that this point was also raised by the other reviewer. As discussed in our response to Comment 25 of Reviewer 1, we found that a simple correlation would not be an adequate statistical metric for capturing the overall performance of A-CTH. While the overall correlation would be approximately 0.99 when outliers, e.g., those associated with cloud edges, are removed, this value would not adequately reflect the systematic differences between the distributions we find for the different cloud clusters in Fig.7. Instead, we decided to retain the analysis of the distributions, as shown in Fig. 8, which provides a more meaningful basis for evaluating the performance of A-CTH across different cloud types.

Figure 10: Figure 10c: Could the authors also include the number of cloud tops detected by WALES for each cloud class and present the differences relative to the A-CTH different baselines? This comparison may help explain the discrepancies observed in Fig. 10b.

The number of cloud-top pixels detected by WALES remains constant for all cloud classes, as the WALES observations provide the reference for the comparison. Since the number of A-CTH cloud-top detections changes (and generally decreases) between the different baselines shown in panel (c), this information is already implicitly contained in the figure c).

As suggested by the reviewer, the improvement for liquid-cloud tops from BA to proto-CA is primarily caused by the systematic removal of false detections over the ocean. To better clarify this, we have revised the corresponding discussion in Sect. 5.1 which reads as follows:

"The evaluation of cloud top differences for distinct clouds regimes shows a consistent overestimation (median between 260-300 m) in A-CTH for mixed-phase and ice clouds (Fig. 8), indicating that this bias is likely not related to the different temperatures and altitude of these cloud types. In contrast, the cloud top differences for low-level (liquid) clouds show a bimodal distribution, with distinct cluster indicating over-

and underestimations of cloud tops. While the overestimation cluster (about 300 m) is consistent with findings in mixed-phase and ice-phase clouds, the underestimations are related to occasionally strikingly low cloud tops of about < 200 m in A-CTH. These very low clouds are found in tropical and extratropical frames predominantly over ocean but also occasionally above landmasses, and it is noted that they can occur in cases where no cloud could be detected by WALES, or indicated by A-TC/A-FM. These underestimations occur due to a known bug that occasionally led to misidentified surface return which should be resolved from Baseline BB onwards (see: ESA, 2026b)."

Typos, wording and requests for clarification

L103, L164: "water vapour". Water vapor is used elsewhere through the manuscript. Please select one terminology.

We now use "water vapor" consistently throughout the revised version of the manuscript.

L156, L303: "depolarisation", Depolarization is used elsewhere through the manuscript. Please select one terminology.

Changed to "depolarization" in the revised manuscript.

L161: "airborne field campaigns." Is there any bibliography for these previous campaigns?

Due to the large number of campaigns, we decided not to list all campaigns in which WALES participated. An overview of the HALO campaigns can be found at: https://www.halo-spp.de/Missions/ (last access 26.08.2026). We decided to add three references for field campaigns roughly spanning the HALO era, and for which WALES HSRL data were applied to study clouds.

NAWDEX: Schäfler et al., 2018

Schäfler, A., Craig, G., Wernli, H., Arbogast, P., Doyle, J. D., McTaggart-Cowan, R., Methven, J., Rivière, G., Ament, F., Boettcher, M., Bramberger, M., Cazenave, Q., Cotton, R., Crewell, S., Delanoë, J., Dörnbrack, A., Ehrlich, A., Ewald, F., Fix, A., Grams, C. M., Gray, S. L., Grob, H., Groß, S., Hagen, M., Harvey, B., Hirsch, L., Jacob, M., Kölling, T., Konow, H., Lemmerz, C., Lux, O., Magnusson, L., Mayer, B., Mech, M., Moore, R., Pelon, J., Quinting, J., Rahm, S., Rapp, M., Rautenhaus, M., Reitebuch, O., Reynolds, C. A., Sodemann, H., Spengler, T., Vaughan, G., Wendisch, M., Wirth, M., Witschas, B., Wolf, K., and Zinner, T.: The North Atlantic Waveguide and Downstream Impact Experiment, B. Am. Meteorol. Soc., 99, 1607–1637, https://doi.org/10.1175/BAMS-D-17-0003.1 , 2018.

NARVAL: Stevens et al., 2019.

Stevens, B., Ament, F., Bony, S., Crewell, S., Ewald, F., Gross, S., Hansen, A., Hirsch, L., Jacob, M., Kölling, T., Konow, H., Mayer, B., Wendisch, M., Wirth, M., Wolf, K., Bakan, S., Bauer-Pfundstein, B., Brueck, M., Delanoë, J., Ehrlich, A., Farrell, D., Forde, M., Gödde, F., Grob, H., Hagen, M., Jäkel, E., Jansen, F., Klepp, C., Klingebiel, M., Mech, M., Peters, G., Rapp, M., Wing, A. A., and Zinner, T.: A High-Altitude Long-Range Aircraft Configured as a Cloud Observatory: The NARVAL Expeditions, B. Am. Meteorol. Soc., 100, 1061–1077, https://doi.org/10.1175/BAMS-D-18-0198.1 , 2019.

Cirrus-HL: Jurkat-Witschas et al., 2025.

Jurkat-Witschas, T., Voigt, C., Groß, S., Kaufmann, S., Sauer, D., De la Torre Castro, E., Krämer, M., Schäfler, A., Afchine, A., Attinger, R., Bartolome Garcia, I., Beer, C. G., Bugliaro, L., Clemen, H., Dekoutsidis, G., Ehrlich, A., Grawe, S., Hahn, V., Hendricks, J., Järvinen, E., Thomas, K., Krüger, K., Ovid, K., Lucke, J., Luebke, A. E., Marsing, A., Mayer, B., Mayer, J., Mertes, S., Moser, M., Müller, H., Nenakhov, V., Pöhlker, M., Pöschl, U., Pörtge, V., Rautenhaus, M., Righi, M., Röttenbacher, J., Rubin-Zuzic, M., Schaefer, J., Schnaiter, M., Schneider, J., Schumann, U., Spelten, N., Stratmann, F., Tomsche, L., Wagner, S., Wang, Z., Weber, A.,

Wendisch, M., Wernli, H., Wetzel, B., Wirth, M., Zahn, A., Ziereis, H., and Zöger, M.: CIRRUS-HL: Picturing high- and mid-latitude summer cirrus and contrail cirrus above Europe with airborne measurements aboard the research aircraft HALO, Bulletin of the American Meteorological Society, https://doi.org/10.1175/BAMS-D-23-0270.1 , 2025.

L214: "Liu et. al., 2004." Please verify the year of the citation, as it appears to be 2024 in the reference list.

Thanks for pointing to this inconsistency. Liu et al., 2024 is correct. Updated.

L243: 1 s.

Corrected. Also corrected in l.196.

L273: "consistent with the generally reduced cirrus altitudes expected at higher latitudes and during spring or winter conditions". Please cite relevant studies.

We included Stubenrauch et al. (2017), which shows the seasonal variability of cloud altitudes across the tropics, midlatitudes, and polar regions.

Figures 3 and 4: Consider placing the panel labels (a), (b), etc. outside the plotting area, as done in most of the other figures, to improve consistency throughout the manuscript. In Figure 4, some panel labels also appear to be partially clipped.

We revised the labelling Fig. 3 and Fig. 4, and Fig. 9 to place the panel labels consistently throughout the manuscript.

L388: The date and campaign are missing. I suggest revising the sentence to: "A second case study is presented to illustrate an EarthCARE underflight on 31 March 2025 during the ASCCI campaign under extratropical conditions."

Corrected as suggested by the reviewer.

L395: Fig. 3

We think that "Fig. 3" is technically correct here. However, later in the sentence, we changed "Fig. 3c" and "Fig. 3d" to "Fig. 4c" and "Fig. 4d," respectively (according to the suggestion by reviewer 1).

L397: "near the approx. constant tropopause …". Consider writing out approximately.

We changed the wording from "approx." to "roughly" to avoid repeated use of "approximately."

L440: "(factor of >2 increase)". I would recommend rewriting it for clarity

We agree that this sentence could be more concise and have rewritten the full sentence as follows:

"A small number of flights (6 in A-TC, 3 in A-FM) have a substantially higher number of pixels (by a factor of >2) compared to WALES, but these are cases in which generally fewer cloud pixels were observed."

L466: Fig. 1.

Corrected.

L544: consider expressing the entire altitude range in the same units, e.g., "from approximately 0.2 to 9 km."

Updated as suggested.

L585: Fig. 4

Corrected.

L616: comparable to Fig. 8.

Corrected as suggested.

L675: Fig. 3e

Corrected, also for the following "Fig. 4e".

L747: Fig. 8

Corrected.

L814: ... below.

Corrected.

L867: Fig. 6

Removed "Fig. 6" as Figure 6 appears already in the same sentence.

L918-L920: This reference is not cited in the manuscript text. Please check.

Included now in the text.

L966-L968: This reference is not cited in the manuscript text. Please check.

We thank the reviewer for pointing this out. The reference is indeed cited in the manuscript; however, the authors' names were spelled differently as "Gloeckner" and "Glöckner," which may have caused confusion. We have corrected the spelling in the manuscript.

L1071-L1073: This reference is not cited in the manuscript text. Please check.

Corrected. 2018 is the correct year of this cited publication that also appear in the manuscript.

L1116-L1117: This reference is not cited in the manuscript text. Please check.

Included now in the text.