Validation of cloud macrophysical properties from ATLID Level 2a products A-TC, A-FM, A-CTH using airborne lidar observations

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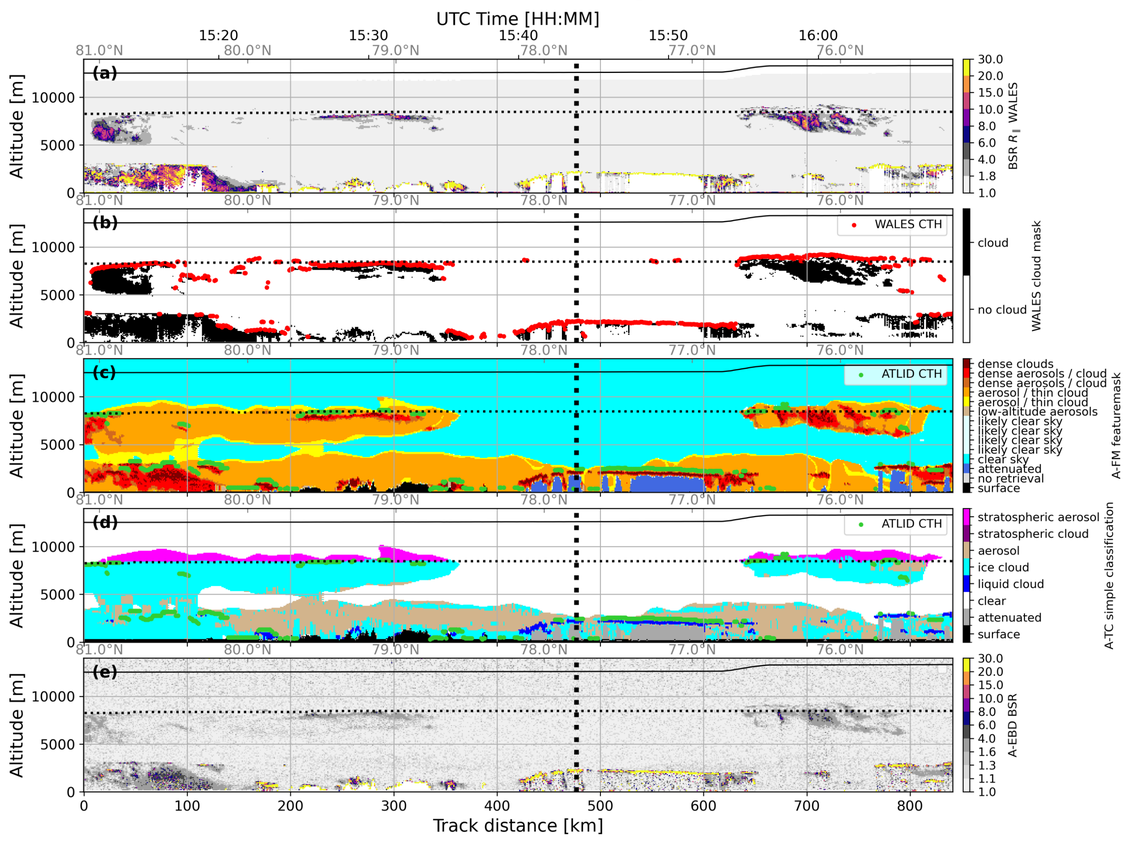
Validation of EarthCARE cloud products

- **Earth Cloud Aerosol Radiation Explorer (EarthCARE)** aims to improve understanding of cloud-aerosol-radiation interactions, with its ATmospheric LIDar (ATLID) playing a crucial role to reaching this goals.
- ATLID-derived Level 2a provide important information to study cloud macrophysical properties such as cloud distribution of liquid/ice clouds, cloud lengths or cloud top heights.
- **Validation of cloud-related parameters** from three ATLID Level 2a products: The **'feature mask'** from the Feature Mask product **(A-FM[1])**, the **'simple classification'** from the Target Classification product **(A-TC[2,3])** and the **'cloud top height'** from the Cloud top Height product **(A-CTH[4]).**

Case study: cross section of the WALES and the ATLID Level 2a products

Baseline BA

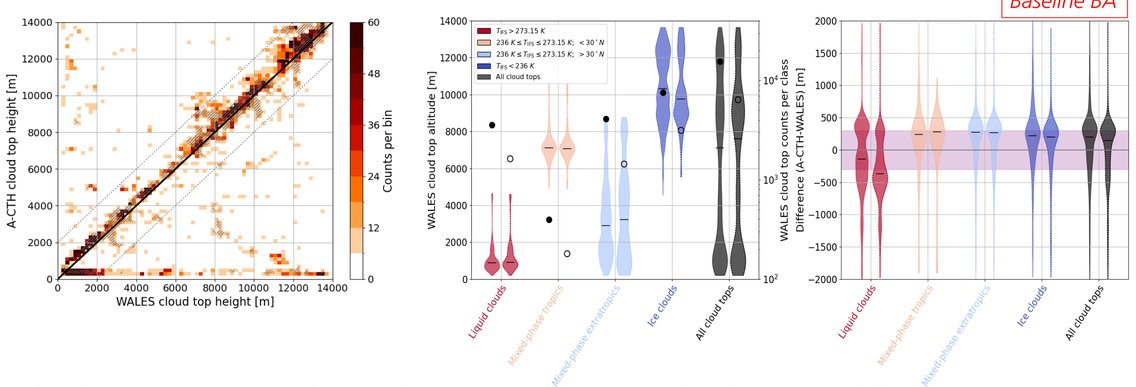


Time-altitude cross sections on the 31 March 2025 for an example underflight between Iceland and Svalbard in the Arctic of (a) the WALES BSR, (b) the WALES cloud mask and cloud top altitude (red dots), (c) the A-FM 'feature mask', (d) the A-TC 'simple classification', (e) the ATLID BSR from A-EBD. The 'cloud top height' of the uppermost cloud from A-CTH is shown as green dots in (c) and (d). The vertical dashed black line marks the location of the satellite overpass, and the solid horizonal lines the altitude of HALO. The solid black line (a)-(e) shows the flight altitude of the HALO aircraft, and the dashed black line illustrates the A-EBD tropopause.

- **Similar cloud pixel distributions and top heights in WALES & ATLID products.**
- **Features associated with ice clouds** appear as too spread compared to the patchy structure in WALES. A-EBD Level 2 BSR is able to reflect this patchy structure.
- **Strong agreement** between WALES/A-TC/A-FM for **features associated with liquid clouds.**
- Misclassifications near tropopause (ice cloud/strat. aerosol) and near feature edges (ice cloud/aerosol).
- **A-CTH cloud top heights agree** well with WALES for A-TC liquid clouds, stronger deviations for ice clouds or at very low altitudes.

Validation of cloud top heights from A-CTH

Baseline BA

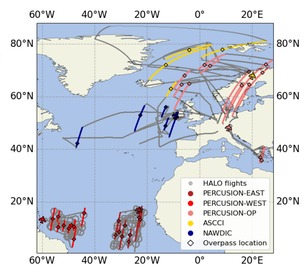


Left panel: Binned correlation (100 m bins) of WALES cloud top height and A-CTH cloud top heights for the full dataset color-coded by pixel count per bin. Middle panel: Cloud top height distributions from WALES BSR-derived clouds and (right panel) differences compared to A-CTH cloud top heights as violin plots. In both panels, the left violins show the distributions for the whole data set, and the right violins (dashed) for a data subset of all clouds with 10 min. / 138 km to the underpass.

- **Good correlation between WALES/A-CTH cloud tops** for most observations, isolated outliers typically related to strong mismatch or cloud edges.
- Systematic for mixed-phase and ice clouds, **overestimation of A-CTH cloud tops (~280 m)** bimodal differences for liquid clouds through misinterpreted surface return.

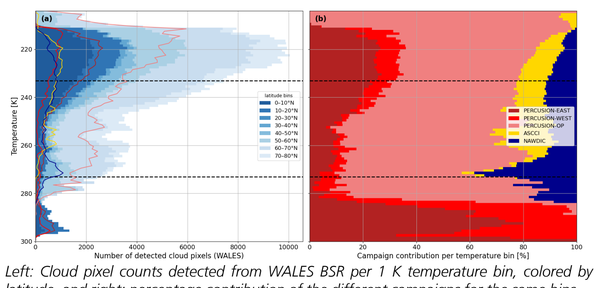
Airborne observations with HSRL WALES

- High-spectral resolution-lidar (HSRL) observations aboard the High Altitude Long Range (HALO aircraft.
- Water Vapor Lidar Experiment in Space (WALES[5]; **backscatter ratio**; 532 nm) → **used to develop a cloud mask.**
- Three field campaigns (08/2024 to 02/2026) with EarthCARE underflights: **PERCUSION[6], ASCCI, NAWDIC.**



HALO tracks during PERCUSION, ASCCI, and NAWDIC. Colors highlight the EarthCARE underflight segments.

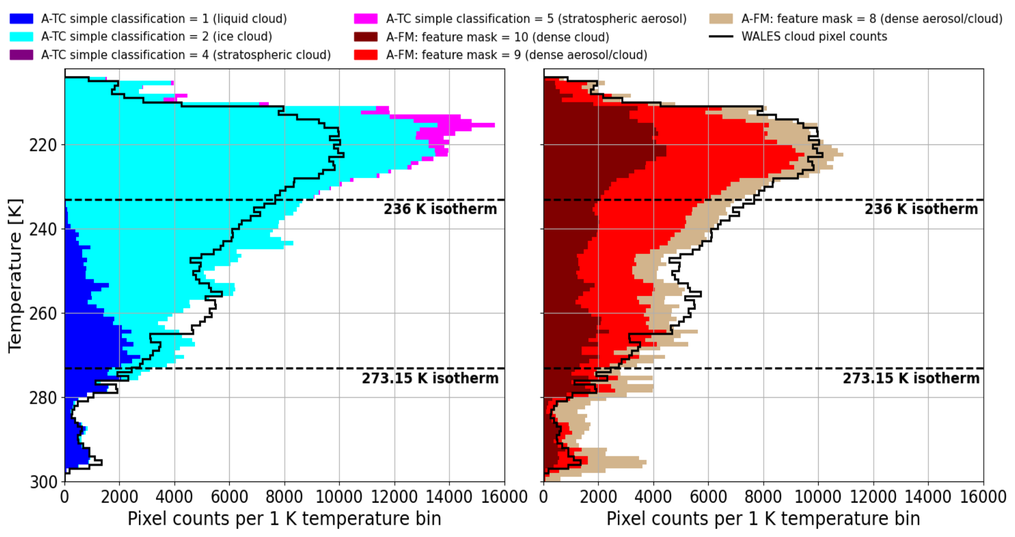
- 35 research flights, 40 EarthCARE underflights.
- Variety of aerosol/cloud conditions in the tropics and the extratropics.
- High frequency of ice clouds covered.



Left: Cloud pixel counts detected from WALES BSR per 1 K temperature bin, colored by latitude, and right: percentage contribution of the different campaigns for the same bins.

Validation of cloud pixels in A-TC and comparison to A-FM

Baseline BA



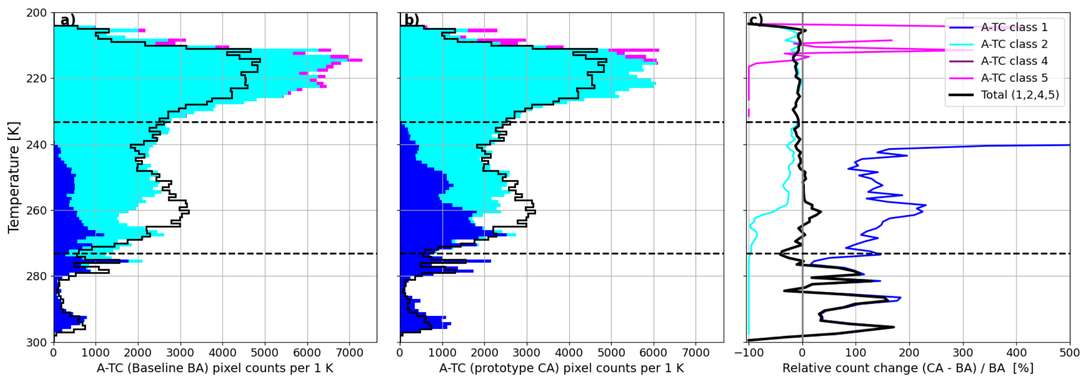
Histogram of cloud pixels in 1K temperature bins shown for the WALES cloud mask (black), combined with (left panel) the classified targets in the A-TC 'simple classification' and (right panel) the 'feature mask' of the A-FM product (see legend).

- **Ice cloud regime (T<236 K):** Cloud pixel overestimation by A-TC (about 30 %); stratospheric aerosols (likely misclassification due to a unambiguous tropopause).
- **Mixed-phase cloud regime (236K < T < 273 K)**
  - Increasing overestimation with decreasing temperature (share of ice increases)
  - Misclassified ice clouds in dense aerosol layers (265-270 K).
- **Liquid cloud regime (T > 273 K):** Strong agreement between WALES and A-TC, and A-FM (dense features of value 9,10).

First results of A-TC in the proto-CA Baseline

12 research flights with a prototype version 'CA'

Baseline BA, proto-CA



Histogram of cloud pixels in 1K temperature bins shown for the WALES cloud mask (black), and A-TC (colors) for 12 research flight for (a) Baseline (BA), (b) Baseline (proto-CA), and (c) relative change in counts from BA to proto-CA.

Comparison of Baseline BA → proto CA

- A-TC **ice cloud counts slightly reduced**, **but still overestimated** in proto-CA. ✓
- **Removal of stratospheric aerosol detections** above T >216 K. ✓
- **Removal of ice clouds above freezing level.** ✓
- More **consistent separation of liquid/ice clouds.** ✓

Conclusion

- **A-TC/A-FM/A-CTH are able to reproduce key cloud macrophysical properties** (distribution, top altitude) consistent with WALES →ready for scientific applications.
- **Some limitations** identified for Baseline BA (A-TC ice cloud overestimation, A-CTH cloud top overestimation), **but improvements confirmed for BC and anticipated for proto-CA.**
- Preprint associated with this study: Krüger et al., 2026

References

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2: **A-PRO product**: Donovan et al., 2024: The EarthCARE lidar cloud and aerosol profile processor (A-PRO): the A-AER, A-EBD, A-TC, and A-ICE products, AMT, https://doi.org/10.5194/amt-17-5301-2024.
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