

Reply to RC2: 'Comment on essd-2024-281', Anonymous Referee #2, 27 Oct 2024

Thanks for the detailed and constructive review. The comments of the reviewer have been helpful to improve the manuscript. We are especially thankful for the suggestion to emphasize the data sets of other HALO-(AC)³ activities, which significantly increased the value of the manuscript for potential readers.

Our detailed replies on the reviewers' comments are elaborated below. The reviewers' comments are given in bold, while our replies are in regular roman letters. Citations from the revised manuscript are given in italic fonts.

General comments:

1. Sect. 2.1 of general setup: The authors mentioned the ground-based and balloon-borne observations, however, the associated instrumentation, data processing, archive, and publication are not provided. Could authors provide more information related to these observations?

It is true, that we only mention these data. Indeed, our intention with this paper was to restrict to the aircraft data set, which includes a huge amount of data measured by a multitude of instruments. In the context of HALO-(AC)³ additional observations are available such as ground-based and balloon measurements at AWIPEV. We decided not to include these data and their description in our paper, also because there are plans to publish and present the data sets separately. Combining the aircraft, balloon, and ground-based data would have clearly exceeded the scope of this paper.

However, as suggested by the reviewer, we have added relevant references including those where details on the instrumentation are published and made clearer, which of these references provide the data sets. The corresponding text was changed to:

"The tethered balloon BELUGA (Balloon-born moduLar Utility for profilinG the lower Atmosphere, Egerer et al., 2019) collected vertical profile data in the atmospheric boundary layer and the lower free troposphere from the ground to about 1 km height using sophisticated turbulence, radiation, and aerosol instrumentation (e.g., Pilz et al., 2023). An overview of the balloon-born observations conducted during HALO-(AC)³ is given by Lonardi et al. (2024). During March and April 2022, the frequency of the regular radiosonde launches at AWIPEV was increased to six-hourly intervals. These data are published by Maturilli (2022a, b). A long-term data set of ground-based cloud remote sensing observations at AWIPEV is published by Chellini et al. (2023)."

Chellini, G., Gierens, R., Ebell, K., Kiszler, T., Krobot, P., Myagkov, A., Schemann, V., and Kneifel, S.: Low-level mixed-phase clouds at the high Arctic site of Ny-Ålesund: a comprehensive long-term dataset of remote sensing observations, *Earth System Science Data*, 15, 5427–5448, <https://doi.org/10.5194/essd-15-5427-2023>, 2023.

Lonardi, M., Akansu, E. F., Ehrlich, A., Mazzola, M., Pilz, C., Shupe, M. D., Siebert, H., and Wendisch, M.: Tethered balloon-borne observations of thermal-infrared irradiance and cooling rate profiles in the Arctic atmospheric boundary layer, *Atmos. Chem. Phys.*, 24, 1961–1978, <https://doi.org/10.5194/acp-24-1961-2024>, 2024.

Maturilli, M.: High resolution radiosonde measurements from station Ny-Ålesund (2022-03), PANGAEA, <https://doi.org/10.1594/PANGAEA.944406>, in: Maturilli, M (2020): High resolution radiosonde measurements from station Ny-Ålesund (2017-04 et seq). Alfred Wegener Institute - Research Unit Potsdam, PANGAEA, <https://doi.org/10.1594/PANGAEA.914973>, 2022a.

Maturilli, M.: High resolution radiosonde measurements from station Ny-Ålesund (2022-04), PANGAEA, <https://doi.org/10.1594/PANGAEA.944409>, in: Maturilli, M (2020): High resolution radiosonde measurements from station Ny-Ålesund (2017-04 et seq). Alfred Wegener Institute - Research Unit Potsdam, PANGAEA, <https://doi.org/10.1594/PANGAEA.914973>, 1060, 2022b.

2. Lines 42-43: The authors mentioned that “the HALO-(AC) 3 aircraft campaign was designed to combine different aircraft platforms and aiming for observations in a quasi-Lagrangian approach”. Lines 50-52: The authors also mentioned that “CAOs were characterized in their initial stage close to the sea ice edge with the Polar 5 and Polar 6 research aircraft and in a quasi-Lagrangian perspective jointly with HALO”.

However, in Sect. 3.1.5 and Table 4, the analysis approach and data publication of quasi-Lagrangian matches are described only for HALO aircraft flights. Are quasi-Lagrangian matches analyzed between HALO and Polar 5, or 6 flights? If yes, could authors provide more information related to such as its data publication?

This is correct, the two data sets only account for Lagrangian matches achieved with HALO. We tried to identify the matches including Polar 5 and Polar 6, but for several reasons this turned out to be not useful. (i) The flight patterns of Polar 5 and Polar 6 were designed to be collocated with HALO most of the time, e.g., along the standard leg, for having simultaneous in situ

measurement. That is why, Lagrangian matches from this leg are already covered in the HALO-HALO matches. (ii) Matching observations from HALO and Polar 5 would have the disadvantage that Polar 5 only covered the lowest 3 km of the atmosphere. (iii) Matches between Polar 5 and Polar 6 (without HALO) were also not considered in the flight planning and would only cover small scales, e.g., just a few minutes covering a rather limited area, too limited to observe significant air mass transformation. When searching the quasi-Lagrangian matches, a constraint of a minimum threshold of 1 hour between first and second sampling was applied. This limit was mostly not exceeded by both Polar aircraft.

In the revised manuscript we add this statement:

“For a reasonable analysis of air mass transformations, the data sets include only matches with a minimum threshold of one hour between the first and second sampling. This limits the analysis to HALO flight tracks. The flight tracks of Polar 5 and Polar 6 did not cover such long distances along the trajectories.”

If it is available, could you also provide an example figure of quasi-Lagrangian matches?

Thanks for this suggestion. We agree, that an example figure helps to understand the nature of the quasi-Lagrangian matches. As a representative example, we chose RF03 where a warm air intrusion was captured by HALO (see new Figure 4 below). Here it is obvious, which part of the flight includes the matches and how wind shear affects the vertical distribution of the locations. In the manuscript we added:

“Figure 4 illustrates the horizontal and vertical location of quasi-Lagrangian matches that occurred within the research flight number 3 (RF03) performed on 13 March 2024. All locations where the air mass was sampled the first time (start points) are distributed on the zigzag leg directed northward. On the return flight leg these air masses were sampled a second time (end point). In total, seven quasi-Lagrangian matches (indicated by numbers in Fig. 4) were identified.”

and

“Vertically, trajectories were initialized at all altitudes below HALO with a 5 hPa resolution to consider wind shear, ascend, and descend of air masses (see Wendisch et al., 2024). This is obvious by the distribution of the start/end points in Fig. 4b where the branches of quasi-Lagrangian matches are diffusing and not restricted to a fixed vertical column.”

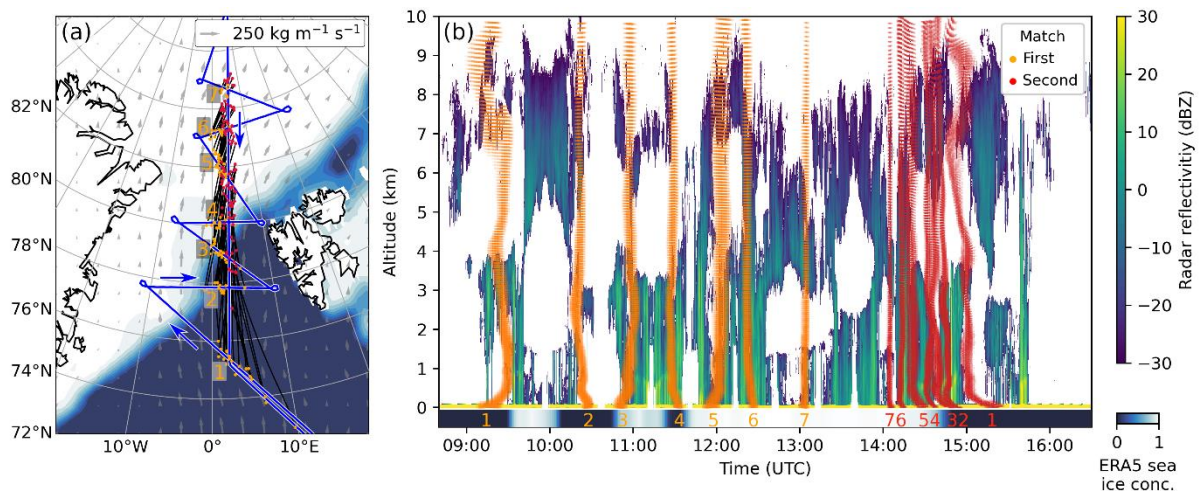


Figure 4. Visualization of quasi-Lagrangian matches for the HALO RF03 on 13 March 2022. The map in a) shows the flight track of HALO overlaid on ERA5 data of sea ice concentration and integrated water vapor transport (gray arrows). In b), a vertical cross section of radar reflectivity is shown. The first sampling location (start points) of matches are indicated in both panels by orange dots, the second location (end points) by red dots. For the map in panel a) these start/end points represent altitudes close to the surface and are connected by the trajectories. Number labels in both panels indicate the individual branches of start/end points.

3. Section 3.5.3: The analysis method of INP filters is not provided in the manuscript, which is an important part of INP filter methodology. Additionally, the publication of the INP dataset is not provided. Could authors provide more information related to INP filters?

The analysis of the INP filter was not included by intention for several reasons. (i) the data prescription is focusing on the primarily measured quantities. In the case of the INP filters, these are physical samples of aerosol particles. These can not be published like all recorded data. (ii) the analysis of the filter is done offline and different methods can be used, e.g., different freezing arrays for INP analysis (e.g., Chen et al. 2018, Hartmann et al. 2019) or scanning electron microscopy for particle morphology analysis (e.g., Seifried et al. 2021) or chemical composition analysis of the filtered particles (e.g., Kwiezinski et al. 2021). In our view, this analysis goes beyond the scope of the data description paper. Similar, other data sets, e.g. remote sensing data, can be postprocessed to derive additional data products afterwards.

To avoid the impression, that INP concentrations are published in the data set, we changed the title of the subsection to “*Polar 6 - Cloud condensation particles measurements and particle filter sampling*” and explained the potential applications of the filter samples:

“The High-volume flow aERosol particle filter sAmpler (HERA, Grawe et al., 2023) was deployed for collecting aerosol particles that can be used in offline laboratory analysis. For example, the samples can be used for deriving the ice nucleating particles (INP) concentrations (e.g., Chen et al., 2018; Hartmann et al., 2019), scanning electron microscopy for particle morphology analysis (e.g., Seifried et al., 2021) or chemical composition analysis of the filtered particles (e.g., Kwiezinski et al., 2021).”

Chen, J., Wu, Z., Augustin-Bauditz, S., Grawe, S., Hartmann, M., Pei, X., Liu, Z., Ji, D., and Wex, H.: Ice-nucleating particle concentrations unaffected by urban air pollution in Beijing, China, *Atmos. Chem. Phys.*, 18, 3523–3539, <https://doi.org/10.5194/acp-18-3523-2018>, 2018.

Hartmann, M., Blunier, T., Brügger, S., Schmale, J., Schwikowski, M., Vogel, A., Wex, H., and Stratmann, F.: Variation of Ice Nucleating Particles in the European Arctic Over the Last Centuries, *Geophys. Res. Lett.*, 46, 4007–4016, <https://doi.org/10.1029/2019GL082311>, 2019.

Seifried, T. M., Bieber, P., Kunert, A. T., Schmale, D. G., Whitmore, K., Fröhlich-Nowoisky, J., and Grothe, H.: Ice Nucleation Activity of Alpine Bioaerosol Emitted in Vicinity of a Birch Forest, *Atmosphere*, 12, 779, <https://doi.org/10.3390/atmos12060779>, 2021.

Kwiezinski, C., Weller, C., van Pinxteren, D., Brüggemann, M., Mertes, S., Stratmann, F., and Herrmann, H.: Determination of highly polar compounds in atmospheric aerosol particles at ultra-trace levels using ion chromatography Orbitrap mass spectrometry, *J. Sep. Sci.*, 44, 2343–2357, <https://doi.org/10.1002/jssc.202001048>, 2021

Specific comments:

Page 7, Line 133: “the cloud microphysical devices was extended...” should be “were extended”.

Thanks! We corrected this.

Page 11, Line 180: It will be nice to provide which flight numbers are not available for the Polar 5 and Polar wind data.

We added the research flight number for which wind data are missing:

“Problems concerned especially data from Polar~5, where we cannot provide wind data from nine flights (RFs 08-16) while from Polar~6 wind data are missing from five flights (RFs 06-08, 12, 16)”

Page 12, Line 215: “where the accuracy of measurements is large” should be “where the uncertainty of measurements is large”.

Thanks! We corrected this.

Page 14, Line 249: “Measurements during HALO-(AC)³ are characterized...” should be “were characterized”.

Thanks! We corrected this.

Page 14, Line 251: “the solar leakage effect of the pyrgeometer effecting the...” should be “affecting the...”.

Thanks! We corrected this.

Page 15, Line 269: the authors mentioned that “Spectrally resolved downward (Polar 5, HALO) and upward (Polar 5 only) solar irradiance were measured using two versions of the Spectral Modular Airborne Radiation measurement system (SMART)”. What are the two versions of the SMART and the corresponding versions for HALO and Polar5? What are the differences between the two versions of the SMART?

Yes, on both planes one system was operated. Maybe the term “versions” was misleading, as the main components are almost identical. We omitted “versions” and added the following sentence:

“The two systems, one installed on HALO and one on Polar 5, utilize identical types of grating spectrometers and optical inlets. They differ only in the implementation of the horizontal stabilization.”

Differences in terms of measured radiative quantities (irradiance/radiance and upward/downward) are listed in Tables 2 and 3.

Page 15, Line 284: The authors mentioned that “the Polar 5 data set was filtered for large SZA and aircraft pitch and roll angle”. Why this filter criteria was not applied to the HALO dataset?

The two systems have different mechanics to actively level the optical irradiance inlets into a horizontal position. On HALO, the performance of this stabilization is easier to obtain because the roll/pitch changes of HALO are weaker compared to Polar 5. HALO flies faster, higher and, therefore, more smoothly. This allows to meaningfully analyze measurements conducted under low Sun conditions. Still, the uncertainty is increased for irradiance measurements with HALO radiometers when flying close to the North Pole with extremely large solar zenith angles. As HALO flew frequently in these conditions, removing the data would reduce the amount of measurements significantly, which is not the case for Polar 5. Thus, we decided to not filter the HALO data beforehand.

In the revised manuscript we clarified this issue:

“HALO data were not filtered because the horizontal stabilization is more accurate and the amount of flight time in the highest latitudes with low Sun was higher.”

Page 15, Line 295: “particle linear depolarization depolarization”, duplicate “depolarization”.

Thanks! We corrected this.

Page 16, Lines 297-298: “The backscatter profiles are extinction-corrected...” should be “were...”.

Thanks! We corrected this.

Page 16, Lines 304-305: The authors mentioned “The data are considered of good quality if no flag is set, i.e., if the flag is zero. Note that for a non-zero flag, the data value itself is not replaced by a fill-value.” What is the recommended treatment for non-zero-flag value? Not reliable to use or?

There is no general recommendation for the treatment of non-zero quality values. It depends on the type of analysis and the objectives of the data user. To keep as many options for analysis as possible, we used the flags and did not remove the data value. Here is one example: E.g. a cloud mask can be produced from less quality WALES data while retrieval of aerosol properties using data of the same quality would be significantly wrong. Similarly, data averaging might overcome these issues. This is only one example. Explaining all possibilities is not possible in the data paper. Instead, we added:

“Note that for a non-zero flag, the data value itself is not replaced by a fill-value because it still can be used for some analysis. Thus, potential users have to make sure to filter the data by help of the flags according to their objectives of the data analysis or retrieval.”

Page 16, Line 308: “at 355 nm and 532 nm wavelength” ---> “wavelengths”.

Thanks! We corrected this.

Page 20, Lines 451-452: The authors mentioned that “Due to the complexity of deriving microphysical properties from OAPs different solutions are included in the data sets, which can be selected depending on the focus of analysis”. What do “different solutions” refer to?

Sorry, we had not been very specific and precise on this important detail! The particle size distributions are provided for different definitions of the particle diameter of ice crystals, which have established in the literature. Due to the irregular shape of ice crystals, different solutions for quantifying the particle size are possible. In the dataset, the diameter for surface equivalent (Deq) and the diameter of a circumscribed circle (Dcc) are provided. As ice crystals may only be partly imaged by the limited sensor width, two solutions, one considering all images (index 0) and one considering only complete ice crystals (index 1) are analyzed. For the 2D-S imaging probe separate analysis of the horizontal and vertical camera are included in the data set.

Similarly, the computation of the effective diameter using the ratio of the moment of order 3 to the moment of order 2 is only correct for spherical particles, thus this formulation cannot be applied to ice crystals. For ice crystals, the ratio of the ice water content to the ice extinction coefficient (related to the total ice crystals cross section surface) needs to be applied but cannot directly measured by 2D imaging probes. Therefore, a mass diameter relationships need to be applied to compute the ice water content and to derive the effective diameter. The published data set provides effective diameter and IWC based on the two mass diameter relationship by Field et al. (2006) and Brown and Francis (1995).

These multitude of data versions, which all are reasonable, allow user to choose the most suitable data processing for their specific objective in the data analysis.

In the revised manuscript, we added this information:

“The 2D-S data are published by Dupuy et al. (2024) and are provided separately for the horizontal and vertical viewing direction. Due to the complexity of deriving microphysical properties from OAPs, different solutions are included in the data sets, which can be selected depending on the focus of analysis. For ice crystal size, the diameter for surface equivalent (Deq) and the diameter of a circumscribed circle (Dcc) are provided. As ice crystals may only be partly imaged by the limited sensor width, two solutions, one considering all images (index 0) and one considering only complete ice crystals (index 1) are analyzed. For the IWC two mass diameter relationship by Field et al. (2006) and Brown and Francis (1995) were applied and both results are included in the data set. The effective diameter was computed based on the ratio of the IWC by the ice extinction which is related to the total ice crystal cross section as in Gayet et al. (2002).”

Page 21, Lines 469-470: “The respective enrichment factor (EF) needs to be applied to every instrument sampling CPRs”. Could authors provide a reference or brief introduction about the calculation method of EF?

We agree that more information is needed for reader to apply the enrichment factor to the data. The revised manuscript now includes the following explanation:

“EF is defined by the ratio of the air volume flow in front of and inside the CVI inlet. The inlet sample flow inside the CVI was measured continuously and depends on the number of instruments connected to the CVI. The in front flow was determined from the aircraft speed relative to the air and the inlet diameter. Since the Polar 6 aircraft speed is rather low, EF values were rather low, ranging between 3 and 6, depending on the sample flow.”

Page 21, Line 490: “the number concentration of particles larger than 10 nm wass” ---> “was”.

Thanks! We corrected this.

Page 24, Line 560: " to investigating potential" ---> "to investigate"

Thanks! We corrected this.

Page 33, Line 726: “cold air outbreaks (COAs)” should be rephrased to “cold air outbreaks (CAOs)”.

Thanks! We corrected this.

Further changes:

We checked and corrected grammar and wording in some instances.

The unified HAMP data set (Dorff et al., 2023) was updated for new calibration coefficients of the passive microwave radiometer. The new data (Dorff et al. 2024) are published as a revised data set on PANGAEA. The reference was exchanges in the manuscript to guide readers directly to the new revised data.

Dorff, H., Aubry, C., Ewald, F., Hirsch, L., Jansen, F., Konow, H., Mech, M., Ori, D., Ringel, M., Walbröl, A., Crewell, S., Ehrlich, A., Wendisch, M., and Ament, F.: Unified Airborne Active and Passive Microwave Measurements over Arctic Sea Ice and Ocean during the HALO-(AC)³ Campaign in Spring 2022 (v2.7), <https://doi.org/10.1594/PANGAEA.974108>, 2024.