Reply to RC1: 'Comment on essd-2024-281', Anonymous Referee #1, 30 Jul 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 pointing at the missing links to the accompanying studies and 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.

Some general remarks:

A brief overview of the prevailing meteorological conditions in the Atlantic Arctic during spring 2022 would enhance the paper's context. Was that year exceptional or "on average" with respect to temperatures, occurrence of CAOs and WAIs? (I didn't find such a description in Wendisch et al., 2024 or elsewhere. If I overlooked, please provide a corresponding reference.) It could be easily introduced towards the end of chapter 1 or as a dedicated paragraph in chapter 2.

> Thanks for identifying this gap in our paper. Indeed, there is a third overview paper for the HALO-(AC)³ campaign (Walbröl et al., 2024) that puts the campaign into a climatological context. Walbröl et al. (2024) also describes the general synoptic conditions during the research flights. Reanalysis data and continuous ground-based observations were analyzed for this purpose.
>
> In the revised manuscript we explicitly referred to this synoptic overview paper. We have implemented the following text:
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> > *"These synoptic events, the general meteorological conditions, and the sea ice distribution during HALO-(AC)³ are summarized and compared to the long-term climatology by Walbröl et al. (2024). They found that two WAI events were associated with an extraordinary strong moisture transport that led to record- breaking near-surface air temperatures and precipitation rates in Svalbard. Although these WAI events were followed by one of the longest CAO event on record, the entire campaign period was warmer than the climatological mean."*
> >
> > *"To identify how the flights were affected by the general meteorological and sea ice conditions during HALO-*(AC)³*, the reader is referred to Walbröl et al. (2024)."*

Walbröl, A., Michaelis, J., Becker, S., Dorff, H., Ebell, K., Gorodetskaya, I., Heinold, B., Kirbus, B., Lauer, M., Maherndl, N., Maturilli, M., Mayer, J., Müller, H., Neggers, R. A. J., Paulus, F. M., Röttenbacher, J., Rückert, J. E., Schirmacher, I., Slättberg, N., Ehrlich, A., Wendisch, M., and Crewell, S.: Contrasting extremely warm and long-lasting cold air anomalies in the North Atlantic sector of the Arctic during the HALO-(AC)^3 campaign, Atmos. Chem. Phys., 24, 8007–8029, https://doi.org/10.5194/acp-24-8007-2024, 2024.

This paper describes the data collected from the three aircraft. Ground based observations from the AWIPEV base are mentioned in line 75 to 82, but no further reference to data sets is given, except for the radiosonde observations. It would be useful to add further references, at least for the mentioned tethered balloon data and the ground based remote sensing data sets.

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-$(\mathcal{AC})^3$ 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 providing information on these additional 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–$(\mathcal{AC})^3$ 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.

An essential part of the project is the data set of lagrangian matches of air mass trajectories, which have been probed twice, thereby allowing to determine the temporal air mass development. To my understanding the data sets Kirbus et al. 2024a and Kirbus et al. 2024b provide matches of air masses probed by the HALO aircraft only. Wouldn't it by useful to have also matches between air masses probed by HALO and Polar 5, or 6, at least for the drop sonde data? If not, this should be more clearly mentioned in chapter 3.1.5 and especially in the conclusions (line 730f)

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."*

A minor remark on chapter 5.3, line 700:

"Can be applied to validate satellite products" is only a very general statement. Could you give an example, or a reference, of what could be learned from this combination of passive sensors data?

That's true, we had not been very specific here. What we have in mind here is, that satellite products based on passive remote sensing observations typically rely on a combination of data from solar and thermal-infrared spectral channels (e.g., visible channels for cloud optical thickness, near-infrared channels for cloud effective radius and cloud phase, and thermal-infrared channels for cloud top altitude). With the combination of instruments operated on HALO and Polar 5, we can mimic such typical satellite observations in all relevant spectral bands. As an example, we currently apply the retrieval algorithm of the EarthCARE multispectral imager (MSI) to airborne observations from HALO-(AC)^3. Using the high spatial resolution of the airborne observations, we can learn how the coarser spatial resolution of the satellite measurements affect the retrieved cloud properties. Similar studies using active radar remote sensing observations to evaluate CloudSat retrieval products have been published by Schirmacher et al. (2023). Passive microwave of sea ice emissivity from airborne and satellite observations are investigated by Risse et al. (2024)

In the revised manuscript we are more specific with the aspects of satellite remote sensing:

> *"By combining data from these different spectral ranges, the airborne observations can mimic the most common satellite imaging spectrometers with a superior spatial resolution. Satellite retrieval algorithms can then be applied to the airborne data to quantify the impact of spatial averaging on the satellite products of surface and cloud properties."*

Schirmacher, I., Kollias, P., Lamer, K., Mech, M., Pfitzenmaier, L., Wendisch, M., and Crewell, S.: Assessing Arctic low-level clouds and precipitation from above – a radar perspective, Atmos. Meas. Tech., 16, 4081–4100, https://doi.org/10.5194/amt-16-4081-2023, 2023.

Risse, N., Mech, M., Prigent, C., Spreen, G., and Crewell, S.: Assessing sea ice microwave emissivity up to submillimeter waves from airborne and satellite observations, The Cryosphere, 18, 4137–4163, https://doi.org/10.5194/tc-18-4137-2024, 2024.

Line 109 / Figure 2: Figure 2 could be omitted as the main information is well described in the text. Relative flight duration given in % does not seem to be very meaningful to this reviewer.

We decided to keep Figure 2 as it includes additional useful information than stated in the text. Also, visual comparison of the contribution by the individual surface types helps the reader to remember these important numbers without searching in the text. The relative flight duration in % was chosen to make the data of the three aircraft comparable. HALO has an almost three times longer endurance compared to Polar 5 and Polar 6. Thus, absolute hours would have mostly shown this mismatch. The total flight hours are presented in the figure legend. That's why we think, it is easy to convert into flight hours if needed.

Some specific remarks and suggestions:

Author list: C. Lüpkes is of AWI not LIM ?

Of course, he is! Sorry for this typo and thanks for your careful reading.

Line 63: wording of "balloon-borne observations in area around Svalbard"

Was changed by adding a "the".

Line 74: wording of "… during one single and along successive flights"

Was changed into:

"HALO providing the large scale view following air masses with a quasi-Lagrangian flight strategy."

Line 83 and 84: any references available to descriptions of the ISLAS and ACAO campaigns?

There are no general campaign overviews of ISLAS and ACAO available yet. However, for ISLAS we included a corresponding doi-citable webpage, where project reports and publications are available. For ACAO, a recent study also providing a brief overview of the measurements is now included in the revised text of our paper.

Sodemann, H.: Isotopic links to atmospheric water's sources - ISLAS, European research council, Grant agreement ID: 773245, https://doi.org/10.3030/773245, 2018.

Raif, E. N., Barr, S. L., Tarn, M. D., McQuaid, J. B., Daily, M. I., Abel, S. J., Barrett, P. A., Bower, K. N., Field, P. R., Carslaw, K. S., and Murray, B. J.: High ice-nucleating particle concentrations associated with Arctic haze in springtime cold-air outbreaks, EGUsphere, 2024, 1–38, https://doi.org/10.5194/egusphere-2024-1502, 2024.

Line 94 should read "between two fixed waypoints"

Thanks! We corrected this.

Line 131,132: wording "were operated almost identical setup"

Thanks! We corrected this.

Line 133: should read "devices were extended"

Thanks! We corrected this.

Line 215: I think you want to say that in the stratosphere the accuracy of humidity measurements is low.

Thanks! We corrected this.

Line 269: "two versions of SMART": what kind of 2 versions are these? One for each plane? What is their difference? See also line 275 where a 1-2 sentence description of SMART would be helpful.

Yes, on both planes one system was operated. Maybe "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."

Line 275: "two types of grating spectrometers": which 2 types are these? see comment in line 269

Thanks for pointing at this missing information. However, to avoid going into do many details of the system, we decided to remove “two types”. The specifications of the final data set are described, what we think is sufficient here. More details are not necessary to understand the published data. Those who are interested in these details can use the provided references.

Lines 278 and 279: should read “wavelengths”

Thanks! We corrected this.

Line 295: double word “depolarization”

Thanks! We corrected this.

Line 412ff: there are two Moser et al. 2023 references in the literature section. Please be specific, which reference is used where (should be 2023a and 2023b)

Thanks! We solved this bibtex problem.

Line 480: double word “to”

Thanks! We corrected this.

Line 535: “N. and Y., 2010” as well as in reference list: this should be the reference “Moteki and Kondo, 2010” You also need to correct it in the reference list.

Thanks! We solved this bibtex problem.

Line 547: wording “which not always sufficient,”

Thanks! We corrected this.

Line 560: wording “to investigating”

Thanks! We corrected this.

Line 603: wording: “With the exception of some instruments available in compressed ASCII format, ”

Thanks! We corrected this.

Figure 6 (before Line 680): Please add in the figure caption something like: "Blue line in panel (b) gives flight altitude of Polar 6 for in situ sampling."

Thanks! We added this.

Line 731: please write “the meteorological data transferred to GTS”

Thanks! We added 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.