How does riming influence the observed spatial variability of ice water in mixed-phase clouds?

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Original Referee comments are in italic

> manuscript text is indented, with added text underlined and ~~removed text crossed out.~~

We revised the manuscript and responded to all of the reviewer's comments.

Reviewer I

The revised manuscript is far improved in its readability and overall quality, and the authors addressed most of my points. However, I still have minor comments which need addressing. Line numbers are in reference to the tracked changes document.

We thank the reviewer for taking the time to review our manuscript for a second time. Thank you for the constructive comments, which helped to improve the manuscript.

Major comment

I have still found a significant number of grammatical and punctuation issues. I sincerely urge the authors to take time diligently proofreading the manuscript and editing appropriately.

Thank you for addressing this issue. We carefully proofread the manuscript and corrected all grammatical and punctuation issues we could find. We also deployed the help of writing assistance tools.

Additional comments

Figure 11: you should move it up before the conclusion section.

There is an issue with the LaTeX diff tool that we used to compile the author's tracked changes document. In the revised version of the manuscript (without tracked changes), the figure appears before the conclusion.

Line 72-75: Are you saying there is no method to obtain the mass of an ice PSD beyond utilizing Dmax and Nice? There have been efforts made to quantify ice particle mass accounting for their habit (e.g., McFarquhar et al. 2019; University of Illinois OAP software). In fact, you mention that am and bm can be modulated as a function of particle habit (line 284-285). Perhaps I'm misunderstanding.

No, we intended to make the argument that with no further information expect the PSD (so no information about particle shape, IWC, etc.), it is not possible to derive particle density. In retrospect, this argument does not make much sense, because most (if not all) cloud probes that derive PSDs also provide particle images. We rephrased to:

> relationship. Because it is difficult to derive size-resolved ice particle densities from in situ ~~PSD aloneis not possible yet (to our knowledge)~~observations alone, Deng et al. (2024) used constant mass-size ~~parameter~~ parameters from Heymsfield et al. (2010).

Line 123: You deleted where you introduced MCAO. In fact, this occurs for multiple acronyms in the paper (including NASA and DFG). Please thoroughly proofread and write out terms for every acronym.

Thank you. We added:

> The main objective of the HALO-(AC)^3 campaign was ~~studying~~ to study Arctic air mass transformations during warm air intrusions and marine cold air outbreaks (MCAOs).

Also for DFG and NASA:

> The ~~DFG-funded~~ German Research Foundation (DFG) funded field campaign HALO-(AC)^3 ...

> The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening

> Snowstorms (IMPACTS, McMurdie et al., 2022) campaign was a ~~NASA-sponsored~~ National Aeronautics and Space Administration (NASA) sponsored field campaign ...

We also wrote out CMIP6, HALO-(AC)^3, LWP, and MODIS:

> ... Coupled Model Intercomparison Project version 6 (CMIP6) ...

> ... HALO-(AC)^3 (Wendisch et al., 2024; HALO, High Altitude and Long Range Research Aircraft – (AC)^3 Project on Arctic Amplification Climate Relevant Atmospheric and Surface Processes and Feedback Mechanisms; see https://halo-ac3.de/, last access: 8 October 2024)...

> During HALO-(AC)^3, brightness temperature T_B measurements at 89 GHz were collected and are used to derive the ~~LWP~~liquid water path (LWP).

> According to the level-2 ~~MODIS~~ Moderate-resolution Imaging Spectroradiometer (MODIS) ...

Line 121-124: Correct the numbering of these bullet points.

This is again an issue with LaTeX diff that does not occur in the revised manuscript (without tracked changes).

Line 141-143: Be consistent in "Section" vs "Sect."

Done.

195-197: Why did you set a threshold of -1C degree to account for kinetic heating of the aircraft allowing for the ability to avoid de-icing and thus sampling these large drops? This heating can occur at a few degrees below zero (perhaps include a source). Otherwise, why even include this threshold? Since you said you looked through the in situ particle imagery.

Because we wanted to avoid partially melted ice particles, which would not be represented well in our scattering simulations, we had to set a temperature threshold to sort out all flight segments with too warm temperatures. We thought this threshold would be sufficient. However, further inspection of in situ images during the remaining flight segments showed that some segments with large drops were still left. We removed these segments from the analysis. Setting no temperature threshold would mean unnecessary additional work, i.e. looking through images for segments with temperatures larger 0°C.

We added:

> As in Maherndl et al. (2024), we only include data up to -1 °C to avoid melting ~~effects~~ice particles, which are not represented well in the scattering

simulations that we perform. In addition, we manually looked through in situ images of all ~~analyzed~~ remaining flight segments ...

Line 203: Here and I believe other places you say "typical" with quotation marks. Remove them.

Done.

Line 276-277: I'm unsure why you're introducing this in situ method only to show it in the case studies? Why include this at all? I also ask this, since in the case studies you reference it but you never say why you don't use it versus the dual platform method. Why not use this method and avoid the uncertainties associated with collocating the remote sensing observations?

We introduced the in situ method for reference and rough uncertainty estimation. We believe that showing results for both methods in the case studies and in the overview in Appendix A gives more credit to the combined method M that we use in the further analysis. It also helps to better show the uncertainty of our riming product. We trust the combined method results more than the in situ method because the former uses the full PSD. For the in situ method we are left with a size gap where M cannot be derived due to instrument resolution. This can be problematic if there are heavily rimed particles that occur exactly in this size range (see Maherndl et al., 2024, for an example of such a case).

Because this was not explained well in the text, we added:

> Only a subset of ice particles can be used to derive M with the in situ method, because particles cannot touch edges to derive P and ~~need to~~ must be large enough to derive meaningful χ. ~~We therefore assume~~ Because of these two criteria, ice particles with D_{max} in the range of about 1.0-1.4 mm and 2.0-6.0 mm are neglected by the in situ method when using the HALO-(AC)³ and IMPACTS particle probes, respectively. Therefore, we assume that the combined method—which uses the full PSD—gives more reliable results ~~when~~ if the aircraft are reasonably collocated~~. In situ method results are therefore only shown~~ , as shown in Maherndl et al. (2024) for HALO-(AC)³. We use M derived with the combined method for all further analysis steps. For reference and uncertainty estimation, we show the in situ method M results are in Sect. 4.1.1 and 4.1.2 ~~as references and the combined method is used in all further analysis steps~~and in Appendix A.

Line 313: Perhaps I missed it, but what are the radar sensitivity limits? Include them.

We included:

> EXRAD, HIWRAP Ku-band, HIWRAP Ka-band, and CRS have sensitivity

> limits of -15 dBZ, 0 dBZ, -5 dBZ, and -28 dBZ at 10 km range, respectively. ... MiRAC-A has a sensitivity limit of about -40 dBZ at 3 km range.

Line 403: This should not be titled Campaign overview. It is not that. Call it something like "Additional riming product discussion"

We changed the title of this section to "Riming product statistics and discussion".

Line 411: This seems out of nowhere. I don't know what x is.

We rephrased the paragraph so that the size parameter x is properly introduced:

> For IMPACTS, the ~~disagreement of~~ discrepancy between the W-band results ~~to~~ and the other frequency bands is due to the ~~occurrences~~ occurrence of large ice particle sizes. ~~Due to saturation effectsfor Z_e values associated with large particles at 94 GHz~~Because of saturation effects, the riming-dependent parameterization (Maherndl et al., 2023) ~~used here~~ has a positive Z_e bias for ~~size parameters $x = 2\pi\alpha_e D_{max}/\lambda > 4$ where $x > 4$. Here~~ large relative sizes of scattering particles. The relative size of a scattering particle is defined by its size parameter $x = 2\pi\alpha_e D_{max}/\lambda$, where α_e is the ~~ice particle's~~ effective aspect ratio of the ice particle, and λ the radar wavelength. Positive biases occur for $x > 4$. The positive Z_e bias for $x > 4$ results in a positive bias of M.

Line 418-419: I don't get how this further motivates your study. It seems this is showing the range of expected M and associated Ze. If so, rewrite this introductory sentence accordingly.

We agree that the phrasing was not ideal. We changed to:

> To ~~motivate our further analysis~~ show the effect of expected M on Z_e and to evaluate whether the retrieved amounts of riming significantly impact IWC, we conduct a sensitivity study.

Line 515-518: In the comments to the reviewers, you confirm resampling with replacement. State this in the manuscript.

We added:

> This is repeated 100 times and the average η over all (sub)segments of the respective campaign is calculated. In principle, parts of sub-segments can be resampled. However, the sampling process is random. To perform the averaging, ...

Line 569: "convective cells"

Done.

Line 570-571: "liquid condensation" change to "condensational growth"

Done.

Line 600-601: Rewrite sentence.

We rephrased to:

> During IMPACTS, ~~maximum~~ the maximum spatial scales of N_i, IWC~~and LWC cluster spatial scales~~, and LWC clusters inside clouds are 0.6-3 km for distances of ~~2~~ 2-15 km~~and increase to about 3 for distances of 15~~.

Line 621: "models' representations of MPCs".

Done.