We thank both referees for taking the time to read the manuscript. Their comments will help us improve it. The reviewer's points are in black, our replies are in blue, and new text in the revised manuscript is in red.

General comment from the authors:

Due to a bug in data processing routines, the N_{ice} and $\overline{R}_{ice}$ data of the ATTREX and POSIDON campaigns were not correct. This affected Figure 8, Table 3 and Figure A3 of the manuscript, which were replaced in the revised manuscript by the corrected versions. However, the statements in the manuscript do not change.

Responses to Reviewer#1

General Comments

This manuscript represents the third instalment in a well-established series providing a comprehensive microphysical perspective on cirrus clouds. Building upon the foundational work in Cirrus Guides I and II, this paper o@ers a novel and highly valuable exploration of cirrus particle size distributions (PSDs), leveraging an unprecedentedly large data set (∼975,000 PSDs over 270 flight hours) from 11 field campaigns. The authors have developed a unique heat map-based visualization methodology, supported by in situ measurements and model simulations, to uncover occurrence patterns of cloud particle sizes under various thermodynamic regimes.

The manuscript is scientifically robust, methodologically sound, and clearly written. It successfully connects microphysical processes with observed PSD features across temperature and IWC regimes, offering insights relevant to both process understanding and climate modeling. Particularly notable is the classification of PSD behavior into nucleation/sublimation, overlap, and uplift/sedimentation size regimes, and the differentiation between in situ- and liquid-origin cirrus using a physically motivated threshold based on simulations.

The integration of measurements, theory, and model results is a major strength. This paper provides not only a valuable resource for the community but also a reference data set that could serve as a benchmark for global models and remote sensing retrievals. The figures are generally informative, and the inclusion of synchronized PSDs enhances the coherence of multi-instrument data.

Reply **G1:** Thank you for the positive evaluation of the manuscript.

However, while the depth of analysis is commendable, some sections (notably in Section 5) could benefit from more concise summarization to maintain focus. Clarifications are also needed regarding the transition between cloud types and the uncertainties involved in origin attribution.

Reply **G2:** See *Reply* **S1**.

I am also concerned about the lack of the key mechanism of ice crystal aggregation in the model, and would like to be more convinced that comparing Dmax between model and observation is a sound metric for liquid vs in situ origin. The densities, shape factors and growth rate descriptions for ice crystals need a more thorough description for the modelling.

Reply **G3:** See *Reply* **S1** and **S3-b**.

Specific Comments

1. Section 2.3 (Simulations of in situ-origin ice particle sizes):
   In the modelling description of MAID you say that you consider diffusional growth, sublimation and sedimentation. But you don't mention aggregation, which can have a very important effect on Dmax, even for in-situ cirrus clouds. Maybe you could comment on this, and how it might affect your findings.

   Reply **S1:** We mentioned aggregation in a paragraph at the **end of Section 2.3.3**:

   'Aggregation of the in situ-origin ice crystals could produce larger crystals, but this process plays a -minor- role only at the warmest cirrus temperatures (Spichtinger, 2023; Sölch and Kärcher, 2010) and a large role for ice crystals falling from this altitudes into warmer saturated or supersaturated regions, that we do not consider in this study.'

   We extended this paragraph, and the new text reads as follows:

   'Aggregation of the in situ-origin ice crystals could produce larger crystals, but this process plays a -minor- role only at the warmest cirrus temperatures (Spichtinger, 2023; Sölch and Kärcher, 2010), because aggregation has a strong dependence on the ice particle size and weakens with ice mass, number concentration and temperature. Therefore, aggregation occurs mainly in fall streaks, i.e. at temperatures that are usually higher than those considered here, where the ice particles are large. This can also be seen in Gallagher et al. (2005), where aggregation is observed in fall streaks at temperatures between about 230 and 240 K, and is also discussed in a modelling study by Sölch and Kärcher (2010).

   Further, the maximum ice crystal sizes from the MAID simulations are supported by observations of Wolf et al. (2018), which are now mentioned in the revised manuscript:

   'The maximum ice crystal sizes of ice from the MAID simulations are supported by observations of Wolf et al. (2018), who found an average maximum size of $\sim$ 140 µm in their measurements in in situ-origin cirrus.'

   However, we agree that we cannot completely rule out the possibility that aggregation might occur in the warmest temperature interval (220-235 K), in particular at high IWCs. In such cases, the limiting size for in-situ ice particles might be larger. We changed the manuscript accordingly at the end of Section 2.3.3:

   'Overall, a conservative estimate from the simulations is that in the three temperature ranges $\sim$190, 210, and 230 K, ice crystals formed in situ do not grow larger than 60, 120, and 230 µm, respectively. However, we cannot rule out that at $>$ 230 K , in situ-origin ice particles larger than D_{ice}^{max} may also occur, resulting from aggregation.'

   and at the beginning of Section 5.3:

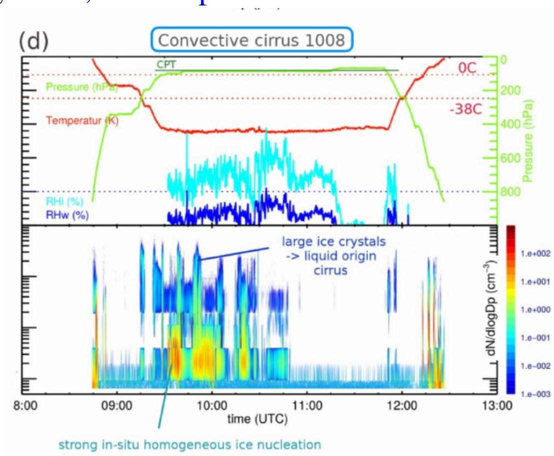
   'Due to the highest amount of available water to grow the ice particles (100-500 ppmv), the in situ D_{ice}^{max} is largest ($\sim$230 µm). Additionally, at temperatures $>$ 230 K, in situ-origin ice particles larger than D_{ice}^{max} may also occur due to aggregation (see Section 5.3.')

2. Distinction between in situ- and liquid-origin cirrus:
   You are using simulated Dmax to discriminate between in situ or liquid formed cirrus clouds. But you are missing aggregation, which may be a key mechanism. A discussion on the robustness of this attribution in mixed or transitional conditions would be valuable.

   Reply **S2-a:** See response to point 1.

   Is Dmax the best metric? Maybe the shape of the distribution would be more statistically significant? How well does the model reproduce the shape of the distribution? Knowledge of this would allow the reader to assess the methodology.

   Reply **S2-b:** That's a good point—we also thought first we could use the shape of the size distribution. The idea was that, on average, in-situ origin cirrus have a unimodal size distribution, while liquid origins have two modes. However, that turned out not to be true. In-situ origin cirrus often also have two modes, since heterogeneous freezing occurs first, followed by homogeneous freezing.
   From the observations it became clear that size is the most valid distinguishing feature, as can be seen from Figure 1d, bottom panel:



   The best possible way to determine the origin of cirrus is to calculate air mass backward trajectories, as done by Wernli et al. (2016) and Luebke et al. (2016). However, this is very time-consuming for such a large data set and also not free from uncertainties.
   We believe that sorting by size, although imperfect, is a robust method to determine the origin of cirrus clouds.

   We did not check whether the simulated distributions matches the measured, since we did not know the history of the observed PSDs. However, Figure 1 shows an example of the time evolution of a cirrus PSD in the temperature range $<$190K (left panel) and the heat map of the observations in the same temperature range (Figure 7a) and low IWC, to exclude liquid origin cirrus as good as possible.

   The simulated PSD has the peak size at a bit larger sizes and lower concentrations than median of the heat map, because of the very slow updraft and low INP number (the PSDs are from purely heterogeneous freezing). Nevertheless, this comparison shows that the PSDs are well represented by the model.

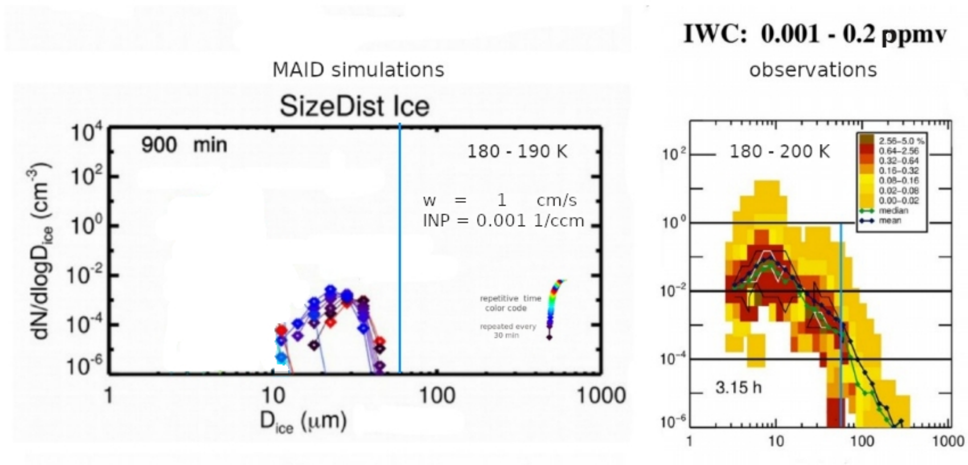


Figure 1: left: MAID simulation, right: observations (Figure 7a)

3. Figures 7 & 8:
These figures are central to the paper's conclusions. At the higher temperature the threshold size for in situ cirrus is 230 micron, but we regularly see that in situ cirrus produce much larger particle sizes, due to aggregation – e.g. see the paper by `https://rmets.onlinelibrary.wiley.com/doi/epdf/10.1256/qj.03.138`.

Reply **S3-a:** As you rightly point out, the large ice crystals formed by aggregation are usually found at warmer temperatures in fall streaks, often above the temperatures we are considering here (see also *Reply* **S1**). So our largest IWC-T interval (Figure 7i and Figure 8c) may also contain ice crystals formed by aggregation. This is mentioned now at the beginning of Section 5.3:

'Due to the highest amount of available water to grow the ice particles (100-500 ppmv), the in situ D_{ice}^{max} is largest (∼230 μm). Additionally, at temperatures > 230 K, in situ-origin ice particles larger than D_{ice}^{max} may also occur due to aggregation (see Section 5.3.')

In addition what growth rates, shape factors and densities were used when modelling diffusional growth – since this is key for calculating Dmax.

Reply **S3-b:** The ice particle growth is calculated from the difference between the partial pressure of the corresponding trace gas in the bulk and its vapor pressure at the particle surface (see Bunz et al., 2008). The particles are assumed to be spherical$^{(\star)}$ with an accommodation coefficient of 1 for water molecules and the density of ice crystals is set to 0.91 g/cm^3.
($\star$): This assumption can be made for the size range of in situ-origin cirrus clouds. Very different shapes are only found in liquid-origin cirrus clouds, as these evolved at warmer temperatures and with a higher water content in the air (see Wolf et al., 2018).

4. Table 3 (Median Nice, Rice, RHice):
This table could benefit from a clearer explanation of how these median values were derived from the climatologies in Cirrus Guide II. Were percentile bounds applied uniformly across all IWC-T tiles?

Reply **S4:** We have changed the corresponding text in the caption of Table 3 to

'Cirrus median N_{ice}, $\overline{R}_{ice}$ and $RH_{ice}^{(\star)}$ in nine IWC-T (Ice Water Content - Temperature) intervals, calculated from the combination of all flights shown in Krämer et al. (2020) (their Figure 6) within the respective IWC and temperature intervals. ...'

And yes, the percentile limits were applied uniformly to all IWC-T tiles.

5. Cirrus cloud classification terminology:
The paper uses terms like "thin," "median thick," and "thick" cirrus. It would be helpful to define these in absolute IWC terms earlier in the paper, perhaps when the IWC-T matrix is first introduced.

   Reply **S5:** We introduce the names for the temperature and IWC ranges at the beginning of Section 5, where the IWC-T matrix appears for the first time. To make them easier to find at any time, we have now defined them in Figure 7 and the corresponding caption. We hope this makes things clearer.

6. Potential for model validation and satellite application:
The final paragraph of the conclusions alludes to validation of climate models and remote sensing products. It would strengthen the impact of the paper to expand briefly on how the data set might be practically used for these purposes (e.g., specific satellite retrieval algorithms or GCM parameterizations).

   Reply **S-6:** You are right that such a statement for specific models and satellite retrieval would strengthen the impact of the paper, but since this is not so easy to say and might be different for differing models / algorithms, we have formulated this sentence in a somewhat more general way:

   '... Furthermore, these occurrence patterns represent a valuable data set to compare the representation of especially ice clouds in global climate models and in satellite-based remote sensing observations.'

Technical Corrections

- Start "Correspnodence" → "Correspondence"
  Reply **T-1:** Done.
- Line 66: "perfom" → "perform"
  Reply **T-2:** Done.
- Line 67: "scienfic" → "scientific"
  Reply **T-3** Done.
- Line 212: "agreemenent" → "agreement"
  Reply **T-4:** Done.
- Line 147: "liekly" → "likely"
  Reply **T-5:** Done.
- Line 551: "prepartion" → "preparation"
  Reply **T-6:** Done.

- In situ is a Latin phrase meaning “in its original place,” and as such, it should be italicised especially in scientific contexts.
  Reply **T-7:** I had a long discussion with Copernicus about the notation of in situ origin (and liquid origin), and the one used here is what we agreed on in Krämer et al. (2016). Therefore, I think it’s consistent to keep it this way.

- “Database” is a compound noun that has long since been accepted as a single word in both technical and general usage.
  Reply **T-8:** Changed.

References

Bartolomé García, I., Sourdeval, O., Spang, R., and Krämer, M.: Technical note: Bimodal parameterizations of in situ ice cloud particle size distributions, Atmospheric Chemistry and Physics, 24, 1699–1716, https://doi.org/10.5194/acp-24-1699-2024, 2024.

Baumgardner, D., Abel, S. J., Axisa, D., Cotton, R., Crosier, J., Field, P., Gurganus, C., Heymsfield, A., Korolev, A., Krämer, M., Lawson, P., McFarquhar, G., Ulanowski, Z., and Um, J.: Cloud Ice Properties: In Situ Measurement Challenges; Chapter 9 of 'Ice Formation and Evolution in Clouds and Precipitation: Measurement and Modeling Challenges', Meteorol. Monographs, https://doi.org/10.1175/AMSMONOGRAPHS-D-16-0011.1, 2017.

Bunz, H., Benz, S., Gensch, I., and Krämer, M.: MAID: a model to simulate UT/LS aerosols and ice clouds, Envir. Res. Lett., 3, 035 001 (8pp), https://doi.org/10.1088/1748-9326/3/3/035001, 2008.

Gallagher, M. W., Connolly, P. J., Whiteway, J., Figueras-Nieto, D., Flynn, M., Choularton, T. W., Bower, K. N., Cook, C., Busen, R., and Hacker, J.: An overview of the microphysical structure of cirrus clouds observed during EMERALD-1, Quarterly Journal of the Royal Meteorological Society, 131, 1143–1169, https://doi.org/https://doi.org/10.1256/qj.03.138, 2005.

IPCC: Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2023.

Krämer, M., Rolf, C., Spelten, N., Afchine, A., Fahey, D., Jensen, E., Khaykin, S., Kuhn, T., Lawson, P., Lykov, A., Pan, L. L., Riese, M., Rollins, A., Stroh, F., Thornberry, T., Wolf, V., Woods, S., Spichtinger, P., Quaas, J., and Sourdeval, O.: A microphysics guide to cirrus – Part 2: Climatologies of clouds and humidity from observations, Atmospheric Chemistry and Physics (highlight article), 20, 12 569–12 608, https://doi.org/10.5194/acp-20-12569-2020, 2020.

Krämer, M., Rolf, C., Luebke, A., Afchine, A., Spelten, N., Costa, A., Meyer, J., Zoeger, M., Smith, J., Herman, R. L., Buchholz, B., Ebert, V., Baumgardner, D., Borrmann, S., Klingebiel, M., and Avallone, L.: A microphysics guide to cirrus clouds - Part 1: Cirrus types, Atmospheric Chemistry and Physics, 16, 3463–3483, https://doi.org/{10.5194/acp-16-3463-2016}, 2016.

Luebke, A. E., Afchine, A., Costa, A., Grooss, J.-U., Meyer, J., Rolf, C., Spelten, N., Avallone, L. M., Baumgardner, D., and Krämer, M.: The origin of midlatitude ice clouds and the resulting influence on their microphysical properties, Atmospheric Chemistry and Physics, 16, 5793–5809, https://doi.org/{10.5194/acp-16-5793-2016}, 2016.

Spichtinger, P.: Aggregation of ice crystals in a cirrus cloud model, by Kienast-Sjögren, E., Spichtinger, P. and K. Gierens, EGU 2011, personal information, 2023.

Sölch, I. and Kärcher, B.: A large-eddy model for cirrus clouds with explicit aerosol and ice microphysics and Lagrangian ice particle tracking, Quarterly Journal of the Royal Meteorological Society, 136, 2074–2093, https://doi.org/https://doi.org/10.1002/qj.689, 2010.

Wernli, H., Boettcher, M., Joos, H., Miltenberger, A. K., and Spichtinger, P.: A trajectory-based classification of ERA-Interim ice clouds in the region of the North Atlantic storm track, Geophysical Research Letters, 43, 6657–6664, https://doi.org/10.1002/2016GL068922, 2016.

Wolf, V., Kuhn, T., Milz, M., Voelger, P., Krämer, M., and Rolf, C.: Arctic ice clouds over northern Sweden: microphysical properties studied with the Balloon-borne Ice Cloud particle Imager B-ICI, Atmospheric Chemistry and Physics, 18, 17 371–17 386, https://doi.org/10.5194/acp-18-17371-2018, 2018.