Comment on:

The Arctic Low-Level Mixed-Phase Haze Regime and its Microphysical Differences to Mixed-Phase Clouds

by Moser et al. (2025)

The manuscript of Moser et al. (2025) (Moser-25, hereafter) is a very nice and interesting study that presents new insights into the formation of different particle size distributions (PSDs) of Arctic low-level mixed-phase clouds.

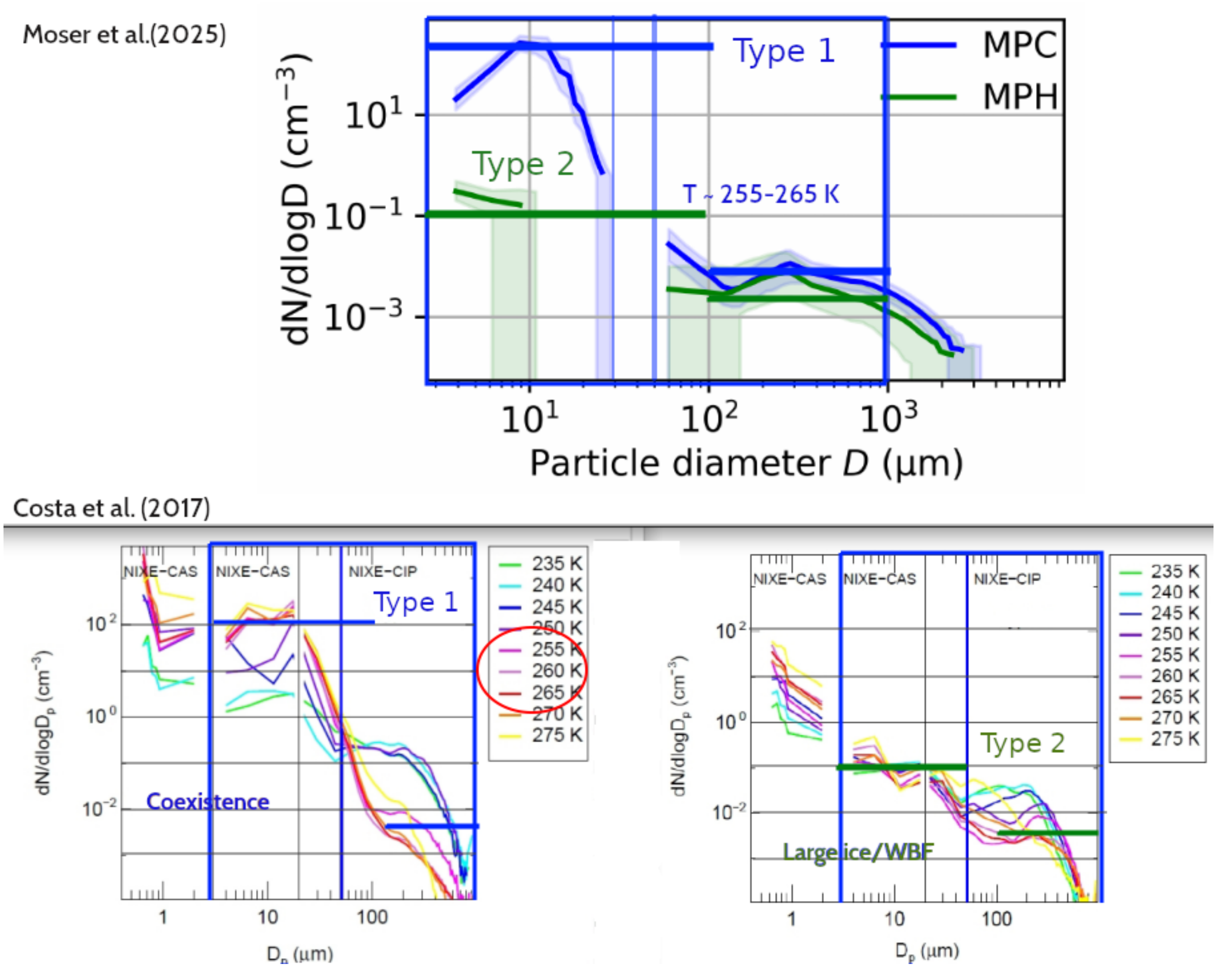
This commentary compares the study with that of Costa et al. (2017) (Costa-17, hereafter), who investigated PSD types occurring in mixed-phase clouds from five airborne campaigns in Arctic, mid-latitude and tropical regions within the temperature range 235 to 275 K. Costa-17's study is mentioned by Moser-25, but the results were not compared in detail - which I think is worth doing.

Comparison of mixed-phase cloud PSDs in Moser-25 and Costa-17

The measurements of Costa-17 were performed with almost identical cloud instrumentation and are therefore well comparable (see caption of Figure 1).

Moser-25 identified two types of mixed-phase clouds (see upper panel of Figure 1) in the temperature range 255-265 K, which they call MPC (mixed-phase clouds, blue) and MPH (mixed-phase haze, green). Costa-17 also found two mixed-phase cloud types (middle panels of Figure 1), named as 'Coexistence' (blue) and 'Large ice/WBF' (green) mixed-phase clouds. They show the PSDs in 5K temperature intervals, the range in which the Moser-25 measurements are located is circled in the legend (purple-reddish colors).

Comparison of the Moser-25 and Costa-17 PSDs in the overlapping temperature range shows the same features in both mixed-phase cloud types. Moreover, the MPC | 'Coexistence' (Moser-25 | Costa-17) and the MPH | 'Large ice/WBF' (Moser-25 | Costa-17) PSDs are very similar, which can be seen when comparing the blue and green horizontal lines, drawn to guide the eye. The reason why the largest ice crystals of Costa-17 are smaller than that of Moser-25 is that Costa-17 used 'area equivalent diameter' as size measure and Moser-25 used 'maximum dimension', and also that the sizerange of Costa-17 had no PIP on board and is therefore limited to 1000 µm
Notable is that the Costa-17 PSDs include not only Arctic, but also mid-latitudes and tropical clouds. This means that the observed structures in the PSDs depend not on geography but on temperature and environmental conditions.



	PSD		Aspherical fraction for Dp 20-50 µm	Particles Dp > 50 µm	Dominant mass mode
Mostly liquid	Type 1	a	Zero	Drizzle drops/few ice crystals possible	Dp < 50 µm
Coexistence		b	Low	Glaciated	Dp < 50 µm
Secondary ice		c	High	Glaciated	Dp < 50 µm
Large ice/ WBF	Type 2		High	Glaciated	Dp > 50 µm

Figure 1

Particle size distributions (PSDs) of mixed- phase clouds, measured by Moser-25 (upper panel) and Costa-17 (middle panels). The bottom panel shows the mixed-phase cloud type classification of Costa-17 (their Table 15).

Moser-25 and Costa-17 both found two mixed-phase cloud types:

Type 1: MPC | 'Coexistence' (Moser-25 | Costa-17),
Type 2: MPH | 'Large ice/WBF' (Moser-25 | Costa-17).

The PSDs are very similar, which can be seen when comparing the blue (Type 1) and green (Type 2) horizontal lines, drawn to guide the eye.

Instruments used for the measurements: Costa-17: CAS-DPol, CIP; Moser-25: CDP, CIP, PIP; all instruments were manufactured by DMT, Boulder, CO, USA. For more information seey Costa-17 and Moser-25.

The interpretation of PSDs of *Type 1* (MPC | 'Coexistence' clouds; Moser-25 | Costa-17), is that:
– the many small (< 50 µm) cloud particles are liquid droplets and the larger ones are ice crystals. Moser-25 proves this with measurements that show saturation/supersaturation with respect to water of the ambient air; Costa-17 explained this in the same way, but could not prove it due to a lack of humidity measurements. Instead, they used depolarization measurements in this size range to show that the cloud particles were spherical (see the Table at the bottom of Figure 1: the aspherical fraction of the small cloud particles is low for 'Coexistence' clouds).
– for the larger cloud particles, Moser-25 assumes that they are frozen based on their size; Costa-17 shows this by determining the asphericity of the cloud particles.

The PSDs of *Type 2* (MPH | 'Large ice/WBF' clouds; Moser-25 | Costa-17) are interpreted as completely glaciated mixed-phase clouds in both studies. These clouds are found in ambient air that is subsaturated with respect to water and saturated/supersaturated with respect to ice. All small liquid droplets have evaporated, and the larger ice crystals have grown due to the released water vapour - this is called the Wegener-Bergeron-Findeisen (WBF) process.
However, in both studies, particles are still present in the size range < 50 µm, though Costa-17 found these small particles up to ∼20 µm, while Moser-25 the did not detect particles larger than 6 µm. This may be due to the smaller data base of Moser-25 (Costa-17: 38.6 h, Moser-25: 19.4 h). Costa-17 reported that PSDs without small particles where detetcted, but not frequently. Note that these particles are present at similar concentrations across all temperature ranges in the Costa-17 dataset.
Moser-25 identified these particles as dissolved sea salt particles. Costa-17 did not explain the occurrence of these particles, but showed that they contain a high fraction of aspherical particles. The measurement of the asphericity of the particles fits very well with the results of the new study.

Summary of the comparison

Overall, Moser-25's study confirms Costa-17's findings for the two types of mixed-phase Arctic low level clouds (between 255 and 265 K).

Since Moser-25 investigate Arctic mixed-phase clouds and Costa-17 a mixture of Arctic, mid-latitude, and tropical clouds, the similarity of the PSDs shows that their structures depend not on geography but on temperature and environmental conditions. The dependence on temperature means that clouds are found at different altitudes, lowest in the Arctic and highest in the tropics.

A new result of Moser-25 is that the smaller particles (< 6 µm) present in mixed-phase clouds that are completely glaciated by the WBF process (*Type 2*) are dissolved sea salt particles (haze particles). This result is obtained by Moser-25 and confirmed by Costa-17's aspherity measurements, but the Costa-17 PSDs range up to ∼20 µm.

Recommendations

1. To contextualize the study within the broader landscape of existing research, I recommend to include the comparison with Costa-17 into the manuscript, in particular to point out

   a the similarity of the PSDs found by Moser-25 and Costa-17,

   a-1 indicating that the structures of the PSDs depend not on geography but on temperature and environmental conditions.

   b that the finding that the small mode particles (< 6 µm) are dissolved sea salt particles is confirmed by the asphericity measurements of Costa-17, and to discuss that Cost-17 found small aspherical particles up to ∼20 µm.

2. I also recommend reconsidering the names of the mixed-phase cloud types.

   Often, the -well known- two types of mixed-phase clouds are summarized under the acronym MPC. In Moser-25, MPC only includes the cloud type in which small liquid droplets coexist with large ice crystals.

   For the completely glaciated mixed-phase clouds the, term MPH (mixed-phase haze) is introduced. This is somewhat misleading because 'haze' (in particular Arctic haze) refers commonly to a size spectrum of grown aerosol particles, not to a cloud. However, this type of completely glaciated cloud is usually considered as glaciated mixed-phase cloud with a very low concentration of large ice crystals, which, however, represent the dominant mass mode (see Figure 1, bottom panel) .

   Therefore, I would recommend names that make it clear that both types are clouds, maybe MPC_coex for the Type 1 and MPC_haze for the second?

With kind regards, Martina Krämer

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Reference:

- **Costa, A.**, Meyer, J., Afchine, A., Luebke, A., Günther, G., Dorsey, J. R., Gallagher, M. W., Ehrlich, A., Wendisch, M., Baumgardner, D., Wex, H., and Krämer, M.: Classification of Arctic, midlatitude and tropical clouds in the mixed-phase temperature regime, Atmos. Chem. Phys., 17, 12219–12238, https://doi.org/10.5194/acp-17-12219-2017, 2017.