Manuscript entitled „Application of holography and automated image processing for laboratory experiments on mass and fall speed of small cloud ice crystals" by M. Weitzel et al.

Once again, we would like to thank the reviewer for the useful comments and suggestions which helped to improve the manuscript. The reviewer's comments and questions were answered in the following; comments or questions are written in bold font, our answers in standard font.

Authors' response to reviewer #3:

"Line 85: Were particles measured in the fall chamber individually matched to the particles collected on the glass slides? It was not clear if the experiment supported this"

Reviewer #2 highlighted a similar point, and the same explanation given to them is appropriate here.

The concept of matching individual velocity measurements to mass measurements was considered during design of the experimental setup. The final setup, however, only allows for the comparison of ensembles of mass measurements to ensembles velocity measurements, as the focus of this study was to maximize the number of individual m(D) and v(D) data points. The connection between our findings for mass and velocity can only be made by comparing the distributions of particle masses and the distribution of fall velocities measured during the same experiment.

This fact has been reemphasized in the corresponding text section of the revised manuscript in Section 3.2, lines 180 and following.

Line 100: What is the estimated positional accuracy in all three directions for particles in the hologram?

The estimated positional uncertainty is $\Delta x = \Delta y = 9$ µm, and $\Delta z = 200$ µm along the optical axis. Since the fall velocity is calculated as the vertical component of the particles' motion, only Δy matters for the uncertainty in w. The resulting velocity uncertainty of $\Delta w_{track} = 0.5$ mm s^{-1} is considered along with the error introduced by residual turbulence (see Section 3.1.4), and a text section has been added in line 111 and the following to elaborate on this aspect.

Line 132: How many particles are in a typical hologram? Was the ice concentration so high that linking particles from one frame to another is difficult?

The most populated holograms contained up to several hundred crystals, which made linking challenging. The median particle number, however, was around 20. For these typical holograms, the third dimension made linking mostly easy.

Line 180: Were the same edge detection methods used for the holographic images as for the slide-captured images?

The detection method for hologram analysis involved a thresholding algorithm in the reconstructed slices. As many two-dimensional slices are reconstructed for each hologram, the signal created by the crystals are visible in several layers along the optical axis. This three-dimensional nature of the detected signal makes particle detection and noise filtering easier than in the case of classical two-dimensional imaging.

In the 2D case of microscope image analysis, thresholding often introduces errors created by incomplete edges or incorrect merging of multiple objects. To improve measurement accuracy, the more sophisticated segmentation methods described in Section 3.2 and the Supplement were implemented and compared.

Line 242 and Figure 5: Were the other power law relationships converted to use a consistent size definition (D_{eq} or D_{sec})? This can sometimes make a large difference.

We agree that the size definition has to be taken into account when applying power law relationships to determine the unknown mass of an ice particle from its size. The definition used plays a major role regarding the applicability and accuracy of parameterizations like the ones determined in this work. The parameterizations depicted in Figure 5 are shown without prior conversion however, as either additional information about the particles at hand or simplifying assumptions would have been required for an accurate conversion in several cases.

Line 243: What are the power law coefficients from this study (a and b), for both Deq and Dsec?

D_{sec}: a = 0.03097, b = 2.13
D_{ae}: a = 0.4972, b = 2.36

The power law relationships including their parameters were added in Section 4.2, line 257 and the following.

Line 245: It is mentioned in the abstract that the other power laws were generally developed on larger particles and have been extrapolated down to the sizes in this study. I think this point needs to be reemphasized here.

A remark has been added in line 279 which reemphasizes that the power law relationships from the literature were determined from measurements of larger ice crystals.

Some discussion behind the observed differences would also be valuable, such as the types of particles (habit, degree of riming, etc.) that were collected in the other studies.

Section 4.2 has been expanded by more detailed descriptions of the origins of the parameterizations shown in Figure 5.

Also, is there a functional form that could bridge the gap between various small/large mass-size parameterizations?

We have not looked into determining a functional form to bridge the gap between several parameterizations. A future review article with the objective of finding such a relationship would be a valuable resource for handling the challenges of parameterizing particle mass.

Line 255: Related to the first comment, is the mass of each particle known, i.e. were the velocity measurements (either by hologram or fallstreak) directly linked to the mass measurement for each individual particle? If not, is m estimated from the power law in Section 4.2 to get D_{hyd}?

This question is mostly answered in our response on the first comment by the reviewer.

m is indeed parameterized from the power law obtained in Section 4.2 for the calculation of D_{hyd}. The errors introduced thereby are discussed in line 298 and the following.

Line 260: What is happening physically when $D_{hyd} > D_{max}$, and do you have any speculations or measurements to indicate why that transition occurs around 100um?

Again, Reviewer #2 asked a similar question, and the explanation given to them is repeated here.

D_{hyd} is calculated from Equation 9. The power law relation given in Section 4.2 is applied to parameterize m on the right side of the equation here, which introduces two sources of error. Firstly, the parameterization is determined for the area-equivalent diameter of the crystal contour, D_{ae}, but applied to the long axis of an ellipse fit around the particle contour D_{maj} and is thus not applicable strictly without erroring this context. Further, the mass parameterization is most strongly determined by ice particles with sizes around 60 µm and, as evident from Fig. 5, mostly overestimates the mass of crystals with D > 100 µm. This overestimation of m also leads to an overestimation of D_{hyd} for those larger crystals. We do not expect that $D_{hyd} > D_{maj}$ would be observed for any crystals in individual measurements, but rather an asymptotical approximation of the fit to $D_{hyd} = D_{maj}$.

The parameterization between D_{hyd} and D_{maj} proposed in this work is thus expected to accurately describe crystals with $D_{maj} < 90$ µm. For larger crystal sizes, more data would be required to either determine a new parameterization or adjust the one given here to be more accurate for all D_{maj}.

The discussion section has been extended in line 297 and the following by a paragraph explaining these considerations.

Line 278: The 3-D holographic track information is highlighted in the abstract and in a few places in the body of the manuscript, but I don't see any data on the lateral movement of the particles presented in this manuscript. Is there significant lateral movement of the particles? Were any tumbling motions observed? I think it would be valuable to add a figure or two to highlight any lateral movement (or lack thereof).

The observed lateral distances covered by the falling particles on their short way through the sample volume was mostly small when compared to the vertical movement. A sample figure showing the three-dimensional track of a falling particle along with the evolution of its measured properties has been added to Section S6 in the supplement. The ratio between lateral and vertical movement of the majority of all sampled crystals is in a similar range.

Line 295: Was there any attempt to measure the size of the particles in the fallstreak analysis, and how does the distribution compare with the holographic method?

The size of particles sampled in the fall streak method was not investigated directly from the streak images. The method was designed with the objective of optimizing the accuracy and quantity of the velocity measurements, which resulted in large errors if particle size were extracted from the width of the streaks. Size and velocity observed in this method can thus only be related through the distribution of the fall velocity (determined from streaks) and size (determined from microscopy afterwards) of ensembles of many crystals.