Comments in response to amt-2024-106-ATC3 and amt-2024-106-author_response-version3

Thank you for your careful responses and revisions of the manuscript. I have checked them and still found a few points I would like to highlight.
In the following I will first point out a few issues that can be easily fixed followed by a few points that I think need further discussion and/or need more than an easy fix.
I am referring to numbers in the revised manuscript (version4), in particular line numbers as, for example, “L100” for line 100 in that manuscript version.

Easily fixed issues

Pu et al 2021

The new reference to Pu et al. 2021 (L29) is about snow darkening and melting as a consequence of it. As such it is not suitable as reference for “importance of snowflake shapes for our understanding of atmospheric science.

Fig 2

The beams extending from the four cameras in Fig 2 are confusing. They are not mentioned neither in the sentence (L104) referring to Fig 2, nor in the caption of Fig 2.
Fig 2 shows also the high-speed camera Cam3, apparently with a conical beam extending from it. That camera is not mentioned in L104.
For clarity, I would add labels in Fig 2 pointing to the three telecentric lenses, the high-speed camera or lens, and the LED light beams. If you still want to keep the additional beams extending from the lenses, then I would mention them somehow in the caption.

Three dimensions of OV

The sentence in L104-106 has several issues and should be rephrased. The “three dimensions … is a x b x d” is grammatically and mathematically wrong. The three dimensions are a, b, and d, not a x b x d. The previous issue is better fixed with using the appropriate term instead of “interior rectangle”. I think “cuboid” would be correct here (OV of one camera is a cuboid defined by the three dimensions …).

Da vs Dp

Thank you for adopting this way of showing results of ceramic spheres.
Remove sentence L209-210 which doesn’t apply anymore.

Size-dependent OV

The new Eq (10) to calculate the effective OV as a function of snowflake size seems wrong to me. At each border or edge only D/2 needs to be removed. If a particle of size D is at least D/2 away from the border (distance between particle centre and border), then it will not touch it. So: Vi = (a-Di)(b-Di)*d

Further discussions

REVISED Sec. 3.2 Estimation of pixel resolution (previously Calibration of image binarization) and NEW Sec. 3.3 Calibration of image binarization

For me the estimation of pixel resolution comes too early (before image processing) and requires image binarization (so that that is done twice). Image binarization is optimized, not calibrated.

In your response you try to justify why spherical targets are better than planar micrometer scales, where there would be an issue with orienting them perfectly. The disadvantage of the spherical targets is the necessity to do a manual binarization in addition to the adaptive thresholding. The apparent size of spherical objects depends on any binarization. I believe that this is introduces a larger uncertainty than what would be related to imperfect alignment of a micrometer slide. Some more detailed comments below:

Image processing is described in separate sections (3 and 4):
The image binarization (now described in the new Sect 3.3) is for me not a "calibration" as the title of the subsection suggests (but the determination of optimal binarization).
I would consider image binarization as one of the steps in image processing.
Subsection 4.1 is now called "Image processing" and describes the steps of noise removal and segmentation.
It would be a clearer structure to first describe the complete image processing and only then results (pixel resolution) and algorithms that use this image processing. Sect 3.3 should be part of image processing (Sect 4.1).

For doing the above, you would need to do the binarization only once (with adaptive thresholding). Now it is done twice:
In Sect. 3.2, Dp is "counted manually" to determine pixel resolution, which means that a manual binarization is done. Then, in Sect 3.3, binarization is done again with adaptive thresholding. The "optimal" sensitivity coefficient c is effectively the coefficient where adaptive thresholding approximates closest the manual binarization from Sect 3.2.

(It is understandable and fine that you will not change from your spheres to anything else now. But consider the following:)

It would be more transparent to find “manually” the best sensitivity coefficient c (i.e. decide visually what looks to be a good binarization) and make this part of the description of image processing. Then the estimation of pixel resolution could be done with images processed according to that image processing. That would also avoid having twice similar analyses (related to 6b and 7c/d).

MTF method to determine the depth of field

I appreciate the details on how you determined the depth of field and that you checked and corrected it.
There are two things I didn’t understand though:

- What are “different spatial frequencies”? This is probably a minor thing or me not understanding.
- How are snowflakes below the MTF threshold “deemed fuzzy and considered
- outside the depth of field”? You claim that, consequently, your “algorithm effectively excludes these particles from identification”. How does this work? Snowflakes are detected/identified if they are binarized as a connected region of more than 20 pixels. What is the relation to the MTF threshold?

Description of image binarization Sec. 3.3

I appreciate the added details about the binarization method (adaptive thresholding). However, I have some questions and see a few issues:

- Could you cite some description of this method in the literature? Without that I think that I need some more information.
- L221 and Eq (6): what is the “local mean $\mu(u,v)$”? Mean of what? How is it calculated? What is the specified neighborhood? How is that adjusted by the sensitivity coefficient C?
- MRE defined by Eq (7): this seems to be the average of the two means of the absolute relative errors. Being based on absolute values it is always positive.
    - Later you refer to the “MRE of Dmax” (L243) and “MRE of Deq” (L244). According to Eq (7) there is only one MRE, which is based on both Dmax and Deq.
    - Then, you also refer to “relative errors” of Dmax and Deq. These are not absolute values but positive or negative. From Fig 7 I assume that they are determined as (Dmaxi-Dai)/Dai, which is different from what Eq (7) would suggest ((Dai-Dmaxi)/Dai).
    - If the worst relative error is -7% then it is strictly speaking wrong to call that the “maximum relative error”, which would be +2% in case of Deq (Fig 7f).
- The definition of Dmax (L231) is different from the definition of Dmax later used in Sect. 5.2 (L397). The definition in L397 is the one I would expect here. I would call Dmax “maximum dimension” not “maximum size” as doen in Sect 5.2.

- The definition of Deq (L232) is linguistically wrong (a circle cannot be equal to an area).

Pixel noise (L274-275)

Referring to detected regions with less than 20 connected pixels as “pixel noise (no larger than 20 pixels)” is now clearer than “small noises” previously. It implies that all regions with less than 20 connected pixels are indeed noise, i.e. not related to actual snowflakes. I am not sure this is true in general. Could these “noise” features be caused by snowflakes that are outside the depth of field, or by small snowflakes that are too small to be detected by 3D-PPI? So, rather than and/or in addition to “prevent these noises from being mistakenly detected as small snowflakes” it should say “exclude features of small snowflakes that cannot be detected from analysis”?

2-mm gap criterion

Your new criterion for joining regions is better than the previous one. It, however, still allows that small regions would be joined across a gap that can be larger than these regions. A 20-pixel region has about 14 to 5 pixels across, and a 2-mm gap corresponds to almost 50 pixels. I.e., two 5-pixel regions could be joined even if they are separated by a about ten times larger gap. I think two such regions should rather be excluded. Would they indeed be belonging to the same snowflake, then that would mean that a large part of this snowflake would have been missed (not been detected by binarization) likely due to being out of depth of field.