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Interactive comment

Interactive comment on "Shape dependence of snow crystal fall speed" *by* Sandra Vázquez-Martín et al.

Anonymous Referee #1

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As an overview, this paper presents what I think is an informative analysis of snow particle fall speed and its dependence on particle shape, maximum dimension and area ratio. The observations were collected using in situ imaging during winter seasons over a five-year period, giving fairly robust sampling for a number of particle shapes. Aside from the concerns I mention below, the results are well-supported by the analysis and interpretation. I have several more substantial concerns that I've described in my general comments below. These are followed by more specific comments. Overall, I think the work is valuable, with application to microphysical parameterization, process studies and remote sensing. I think the content is suitable for ACP and likely publishable after comments are addressed.

General comments

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Discussion paper

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One of the most interesting aspects of this paper is the examination of whether v vs. D_max or v vs. A do a better job of predicting particle fall speeds, but this aspect of the work isn't highlighted in the abstract or introduction. I'd suggest adding this.

It is unclear to me how the method used to analyze images for fall speed in this work differs from the method presented in Kuhn and Vazquez-Martin (2020). The description in this paper (e. g., around lines 106 - 125) seems to suggest that an automated method is used when side-viewed particle exposures do not overlap, but a manual method is used when they do overlap. For example, at lines 109 - 110: "...whereas, in Fig. 1b, the particles are partly overlapping, which poses a limitation for an automated fall speed determination." But Kuhn and Vazquez-Martin (2020) say that fall speed determination is done using a manual method. It would be helpful to clarify (maybe succinctly describe the Kuhn and Vazquez-Martin (2020) method, then describe what is different in this work).

The paper lacks some essential detail about how the power law fits were performed, stating for example, simply that the parameters are "determined from linear fits to the data expessed as ...". I assume the data were log-transformed, then a linear least-squares fit was applied. How were uncertainties in the data treated? See my comment for lines 187-190, in particular.

Starting in the paragraph just before section 3.2.3 and within section 3.2.3 itself, there seems to be some confusion and lack of clarity about the meaning of (Rˆ2)_a and (Rˆ2)_b when compared to how they are shown in Tables 3 and 4. This affects the interpretation of the results. Perhaps consider reorganizing this section to discuss separately the effects on Rˆ2 of binning and the effects on Rˆ2 of using D_max or A as the independent variable for fall speed parameterization.

Specific comments

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Lines 2-3: Note that the influence of shape depends strongly on radar wavelength, with precipitation radar reflectivities (at S- and C-band) being much less sensitive to shape than are cloud radars (at W- and Ka-band).

Line 6: It is unclear what "They" is referring to.

Line 7-8: This seeems to repeat the earlier statement at lines 2-3. Perhaps this should be removed?

*Lines 15-17: Not sure that these methodology details belong in the abstract. Maybe focus more on principal results.

Line 93: It's not clear to what number the 23% reduction applies. The previously-mentioned count was 10,000 particles, and a 23% reduction would leave 7,700 particles.

Lines 104-105: It may not be apparent to the general reader why these quantities are more relevant (and more relevant to what?) when observed from a vertical rather than horizontal viewing geometry.

Lines 106-110: Are multiple particles ever side-view imaged? I'm wondering how the automated fall speed method deals with this. Since that could be a source of error to fall speed determination, it would probably be relevant to discuss that briefly.

Lines 112-113: And for the automated fallspeed method, how does the method find these matching points? This question ties back to my initial comments.

Line 125: How much impact did this have on the previously-mentioned (line 93) sample size of 2,461 particles?

Line 145-147: It seems like "shape" is being used somewhat inconsistently here. The "shape groups" mentioned in line 145 refers to the 3-dimensional characteristics of the particle, I think. But when it is said here (line 147, "shape does not change with size"), I think it's describing a 2-D property of the particle (the particle's projected area and area ratio). I suggest being more precise with the term - a particle shape can change with size while the area ratio remains constant.

Table 1: It would be useful to also know the RMS error of the fitted line versus the measured area ratios for each shape group. This would be useful, for example, for assessing uncertainties in fallspeed parameterizations that use area ratios. Could these be added to Table 1?

Line 152: This is more of a writing style comment, but I think it's usually not necessary to open with a statement of what the section contains. It's more engaging to proceed directly into the content (see for example, how you opened section 3.1).

Lines 152-156: These four lines mostly restate information already provided in the caption for Figure 5. Perhaps this could be made more succinct with something like "Analysis of the shape dependence of fall speed (Fig. 5) shows that shape groups (7) Bullet rosettes ...". Also, note that the sentence "Followed by shape groups (4) ..." is an incomplete sentence.

Figure 3 and 4 captions: Should be "length of the fit lines", I think.

Line 183: It would be useful to comment on the source for this randomness in determining the fall speed of individual particles, either here or (mabye better) in the discussion section. Is it due to errors in determining matching points in the particle images? Air currents within the device? Variations in particle orientation that cause the horizontally-projected area to vary?

Lines 187-190: Does this method of fitting use the scatter of fall speeds within each bin as an uncertainty for the bin fall speed (the median value)? It seems with such significant scatter in the individual data points, it would be important to de-emphasize bins with a lot of scatter when fitting. Also, if the bin widths become large (e. g., due to the requirement that all bins contain equal numbers of particles), it may be necessary to also treat scatter in the particle sizes within each bin as an uncertainty on the median particle size for each bin. In cases with uncertainties in both the x- and y-values to be fitted, a method such as orthogonal distance regression is needed.

Lines 191-193: I'm not sure I agree completely with this assertion. Imagine an extreme case of fitting using M_b with only two bins. I wouldn't expect the results to match those from an M_a fit. Is there a reason that 10 bins were selected?

Line 201-208: This is saying that $(R^2)_a$ is for v vs. D_{max}, and $(R^2)_b$ is for v vs. A. Is this what is intended? That doesn't seem consistent with what is shown in Tables 3 and 4. Instead, Tables 3 and 4 show that $(R^2)_a$ corresponds with M_a, and $(R^2)_b$ corresponds to M_b. My understanding, then, is that you want $(R^2)_b$ to be better than $(R^2)_a$ in order to believe that M_b provides a vaild fit. Or do you want both correlations to be high? I think it is necessary to review the discussion in these lines to make sure it says what you intended. See my opening comments.

Line 211-212: Given the data in Tables 3 and 4, it's not clear to me how binning improved both $(R^2)_a$ and $(R^2)_b$ for capped columns. $(R^2)_a$ doesn't represent binned fits. See my opening comments.

Lines 213-214: Similarly here, binning doesn't impact $(R^2)_a$, so I'm not sure what is meant by "improved their correlation coefficients $(R^2)_a$...". See my opening comments.

Line 223: Isn't cross-sectional area an aspect of particle size? Do you mean that fall speed depends more strongly on cross-sectional area than on maximum dimension?

Figure 7 caption: Again, this usage of $(R^2)_a$ and $(R^2)_b$ seems inconsistent with how they are represented in Tables 3 and 4.

Lines 242: Does the "(15) Spherical" shape group then represent solid ice spheres?

Lines 272-274: For me, the most interesting aspect of this is that the vertically-oriented particles do not fall *much* faster than the horizontally-oriented particles. Per, for example, Mitchell and Heymsfield (2005), fallspeed should depend on the ratio of mass to horizontally-projected area. It would be interesting to see the comparisons shown in Figure 11, but resolved by particle shape. Do vertically-oriented plates fall faster than horizontally-oriented plates of the same D_max? I'm not suggesting that this be included in this paper, of course, but perhaps for future work.

Line 285: I'm not sure what is meant by "overlapping somewhat in D_max and A".

Lines 293-319: This analysis is highly interesting, but it took several read-throughs to follow the development. Since mass, area and area ratio can all be expressed succinctly using power laws as functions of D_max, I wonder if it might be clearer to develop, for example, the resulting power law relationships for mass and area as functions of area ratio then show, by substituting in the appropriate exponents for elongated particles, that mass increases more rapidly than does A as A_r increases. Is there a reason this approach wasn't used?

Lines 308-311: If I look at prior studies like Mitchell (1996), it seems more common for other shapes to have mass power laws where the exponents are in the range of 1.7 to 2.4, rather than 3. Does this alter the interpretation presented here?

Figure 13 caption: Please also describe the purpose of the numbers labeling each line.

Table 6: For comparison purposes, I suggest that you consider converting all the relationships reported here to consistent units. I know it will affect only the leading coefficients, but it would make it easier to quantify the differences between the relationships.

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