Referee Report for ACP
ACPD article title: Mass of different snow crystal shapes derived from fall speed measurements
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2nd review

General Comments:

The authors have done an excellent job addressing my review comments and have advanced the science of ice particle fall velocities by adding Appendix C. Most of my comments address Appendix C, followed by a few other specific comments.

Appendix C in this paper demonstrates for the first time (as per my knowledge) that characteristic length L* is superior to the ice particle maximum dimension D for estimating ice particle fall speeds (v). Since Reynold's number Re and Best number X are related through boundary layer theory, this is expected, but this has not been experimentally demonstrated until now. For this reason, I consider Appendix C as seminal work in the field of cloud physics.

As noted in Heymsfield and Westbrook (2010; henceforth HW2010), the Best number X was derived by equating the drag and gravitational forces, where $X = C_d Re^2$, with C_d = drag coefficient. The dimension employed in describing this balance of forces would seem to be related to the particle's boundary layer rather than D. But the method for calculating ice fall speeds in HW2010, as well as other ice fall speed methods, employs D rather than L*. This is natural since L* = A/P where A = total surface area of particle and P = particle perimeter projected to the flow, which are both difficult to measure. Perhaps what is needed in future studies is an expression relating L* to D for each shape category (assuming A and P could be measured somehow).

Appendix C is rich in scientific knowledge that might be missed as it is written. The following clarifications/questions are offered to bring out this knowledge better:

1) The closure experiment consisting of the magenta data points and curve, along with the blue data points, follow a theoretical treatment that demonstrates the superiority of L* over D.
2) The closure experiment consisting of the green data points and curve demonstrates better closure is obtained by using X* rather than X, where $X^* = X A_r^{½}$, where X and Re are based on L* and A_r = area ratio. There is no theoretical reason (so far) for multiplying X by $A_r^{½}$.
3) The HW2010 scheme was derived in terms of D; not L*. Moreover, the limiting value of the pressure drag coefficient, C_0, is 0.35, which is not supported by lab experiments.

Perhaps a more theoretical (i.e., first principle) treatment of ice fall speeds may be possible using L* (given that correcting potential overestimates in m_{geom} might produce better agreement with the Re-X (Eq. 5) relationships).

4) What happens when the green data points are based on X* calculated from m_{geom}, A, D and A_r and Re is calculated from D and v (as done in HW2010)? Is similar closure obtained? What can this tell us about the viability of the HW2010 scheme?

Specific Comments:

Author's response to major comments 3 & 4 (relating to lines 220-229): This may be a minor point but is something I feel the authors should be aware of. Regarding the subset of 75 particles in shape group 3 (hexagonal columns), the authors response states that when width (column diameter) is used instead of column length (i.e., D_{max}), the m-D power law exponent b_D is 2.4. They note this appears consistent with the b_D in Mitchell et al. (1990) for hex-columns, which was 2.6, but also acknowledge the latter b_D depends on D_{max}. However, the columns in M1990 having $b_D = 2.6$ are short, nearly isometric hex-columns, that are much different than the columns shown in Fig. C1 (i.e., the hex-column subset used in Appendix C). M1990 also features "long columns" (Figs. 1-3) that are comparable with the columns in V-M et al. Fig. C1.

Moreover, the mass-width relationship for columns obtained by the authors; $m = a\,W^{2.4}$, where W = column width, can be converted into a mass-D_{max} relationship by substituting the width-length relationship for columns from Auer & Veal (1970, JAS). From Auer & Veal, $W = 11.3\,L^{0.414}$ for L > 200 um, where L = length and units are in microns. Substituting into the V-M et al. relationship gives:
$m = a\,W^{2.4} = a\,(11.3\,L^{0.414})^{2.4} = a'\,L^{0.994}$. Thus, a quasi-linear dependence is found between m & L, similar to $b_D = 1.1$ for columns in Table 1 of V-M et al., but this time derived from column width. This also demonstrates consistency with the Auer and Veal measurements.

Line 448: Please define L* as A/P where A = total surface area and P = particle perimeter projected to the flow.

Technical Comments:

Line 115: Needs a "period" at the end.