Predicting Deposition Coefficients in a Bulk Adaptive Habit Microphysical Model and Comparison to In-situ Measurements

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Introduction and Motivation

- The deposition coefficient (α) is a critical term in the prediction of atmospheric ice crystal growth.
- **Often α set to 1.0 and ice crystals often grown as reduced density spheres where ice particle capacitance is equal to its radius.**
- However, accurate prediction of α for each crystal facet is crucial for modeling vapor flux (here, **F**), and thus nonspherical growth, of ice crystals.
- Here, we capture nonspherical growth of ice crystals by modeling ice particles as **oblate** or **prolate spheroids** (Fig 1).
- Single-particle framework based on the Adaptive Habit model pioneered by Chen and Lamb (1994).
- Deposition coefficient prediction uses a bulk PSD modification of the method used by Zhang and Harrington (2014, 2015) in their Kinetically Limited Adaptive Habit (KLAH) bin model, using the radius 2nd moment.
- Bulk PSD frameworks from Harrington et al. (2009) and Harrington et al. (2013).

Maxwell's Growth Equation for Single Ice Particles

$$\frac{dm_p}{dt} = 4\pi\rho_i C(a,c) G_i'(P,T,\alpha_c,\alpha_a) s_{u,i}$$

Adaptive Habit Size Spectrum (based on a-axis)

$$n(a) = \frac{N_i}{\Gamma(\nu)}\left(\frac{a}{a_n}\right)^{\nu-1}\frac{1}{a_n}\exp\left(-\frac{a}{a_n}\right)$$

Total ice mass (integrating across size spectrum)

$$\frac{dM}{dt} = \int_{a=0}^{\infty}\frac{dm_p}{dt}n(a)da$$

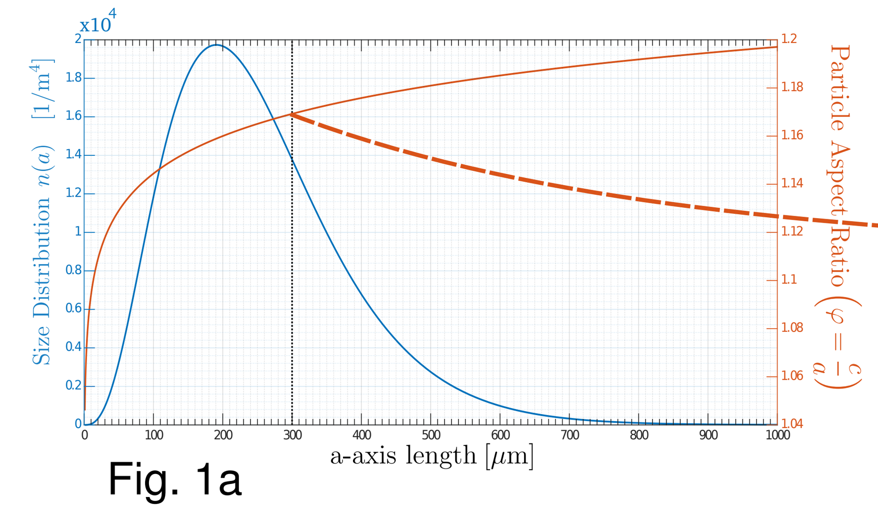


Fig. 1a

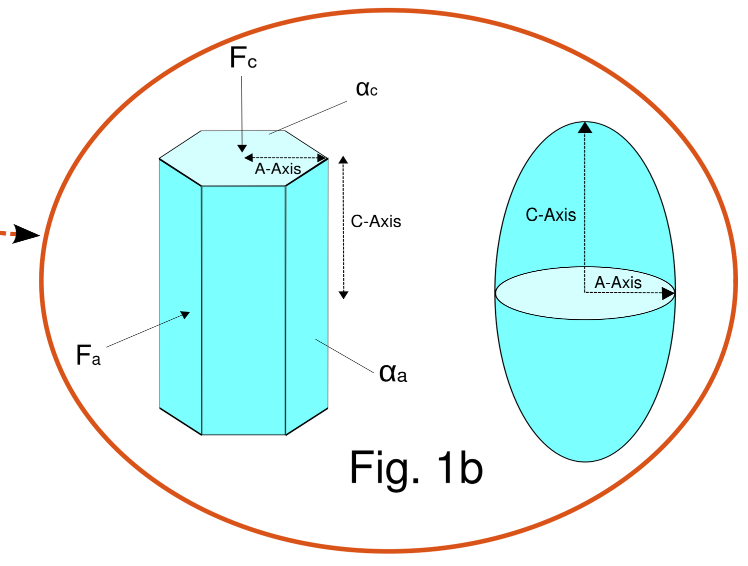


Fig. 1b

1.) How well does α prediction in a bulk model compare to that of a bin approach?
2.) Does the adaptive habit bulk model predict realistic ice particle shapes?

Two nonlinear links for nonspherical evolution:
1.) C(a,c) = Capacitance (shape) of ice crystal
2.) G_i' = Effective Diffusivity (Mass and Thermal)

α Prediction and Model Test Framework

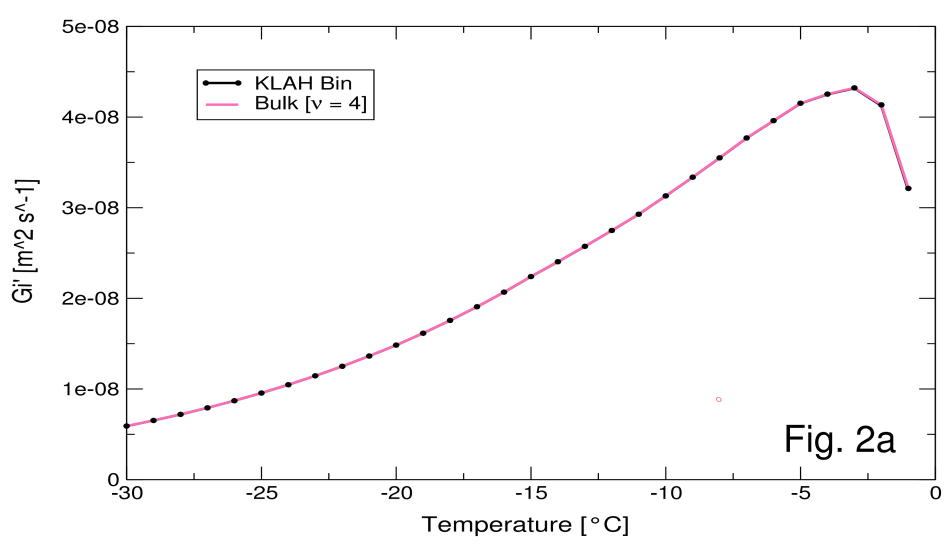


Fig. 2a

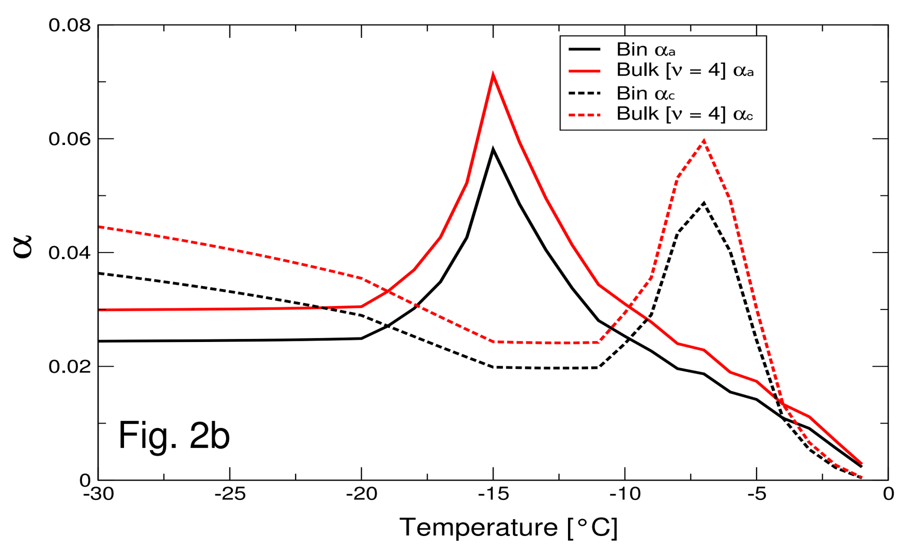


Fig. 2b

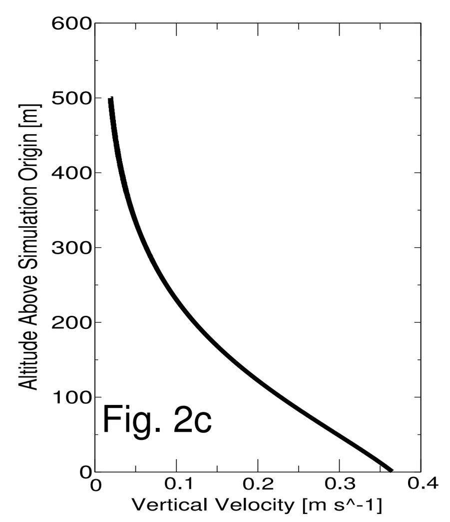


Fig. 2c

- Tests included modeling bin and bulk PSD evolution within a Lagrangian parcel model framework.
- This model conserves total water mass between the vapor and ice phases, and advects the PSD vertically within an environment that changes with height (with the vertical velocity profile depicted in Fig. 2c.
- Bulk instantaneous growth calculations are virtually indistinguishable from Zhang and Harrington's KLAH bin framework.
- Gi' is identical (Fig. 2a), and α prediction for each axis is very close, with bulk slightly overpredicting bin (Fig. 2b).

Results and Analysis (Parcel Model)

Fig. 3a: -15 °C (Platelike Growth Case)

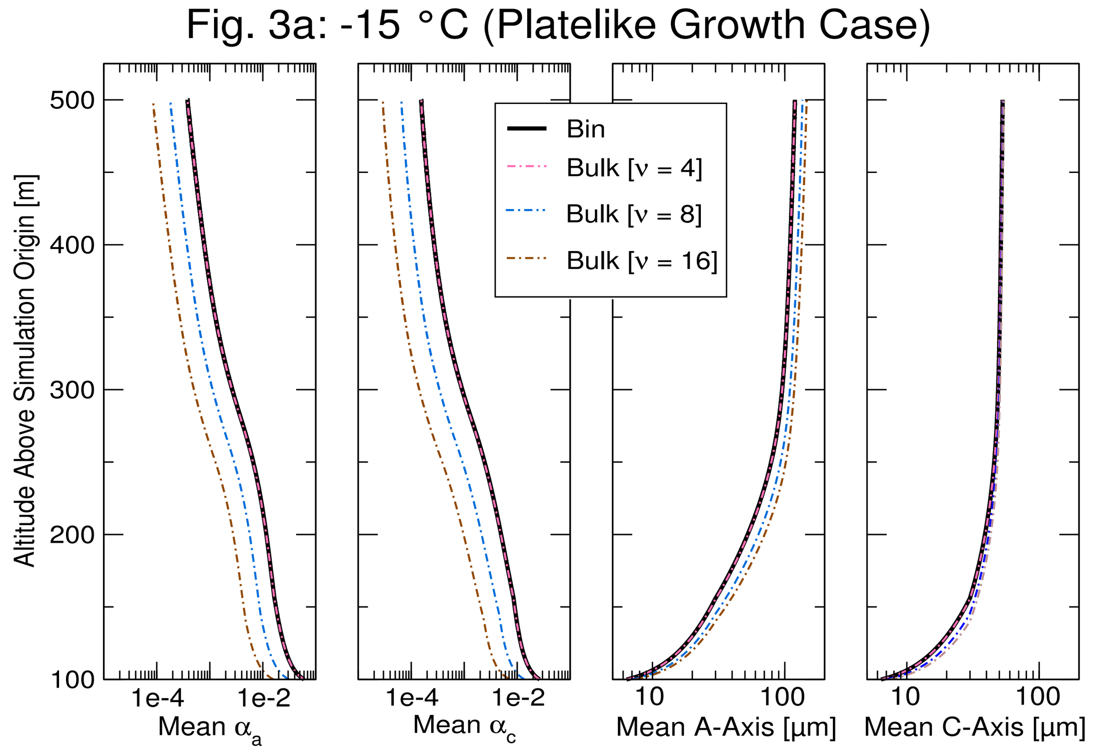
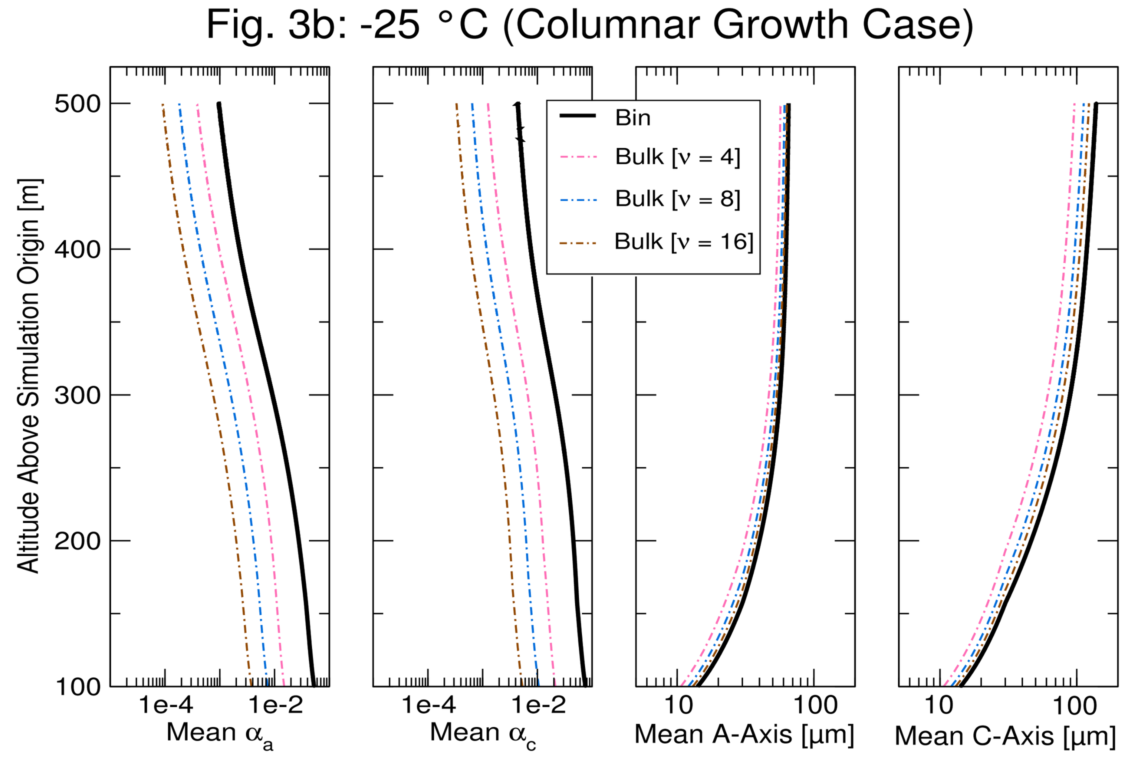


Fig. 3b: -25 °C (Columnar Growth Case)



- Evolution with height consistent between different ν
- Strong agreement for every variable except deposition coefficient, particularly for higher shape factors

- Evolution with height consistent between different ν
- Agreement not as strong as platelike case, but still quite good overall

Acknowledgments

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Comparison of Predicted Aspect Ratios with In-situ Projections

- One way to test predicted model aspect ratios is to compare with in-situ 2-D ellipse fit projections.
- However, spheroidal aspect ratios do not necessarily correspond to 2-D projected ellipse aspect ratios derived from in-situ probes (Jiang et al. 2016).
- Therefore, we extend the approach of Jiang et al. (2016) for particles predicted by the **ISHMAEL** WRF microphysics scheme described in Jensen et al. (2017).
- Ratio of deposition coefficients determined by temperature *a priori* following Chen and Lamb (1994) such that: $\Gamma(T) = \frac{\alpha_c}{\alpha_a}$
- The choice of this **inherent growth ratio parameterization** (Fig 4a) can drastically affect the formation and structure of mesoscale convective systems (MCSs) as shown in a **comparison of model surface rain reflectivity** (Fig 4b) at various times.
- **Old ISHMAEL** scheme reduces ice number concentrations during aggregation but **new ISHMAEL** scheme **includes aggregate category**.
- 2D-C optical array probe (OAP) images fit with ellipses following approach by Welzl 1991.
- Ice particles taken from the stratiform region in the new and old ISHMAEL at 6 hours (Fig 5a) are projected by calculating ellipse conic sections based on particle orientations.
- Fig 5b is a joint PDF of the 2-D ellipse fit aspect ratio and major dimensions of these projections for observations and for these two model runs.

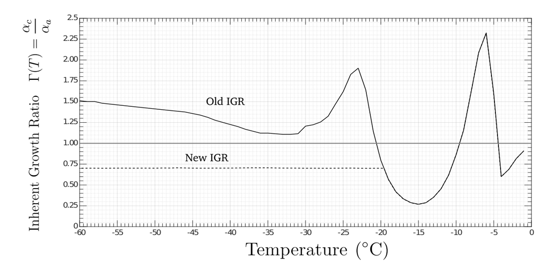

Fig. 4a

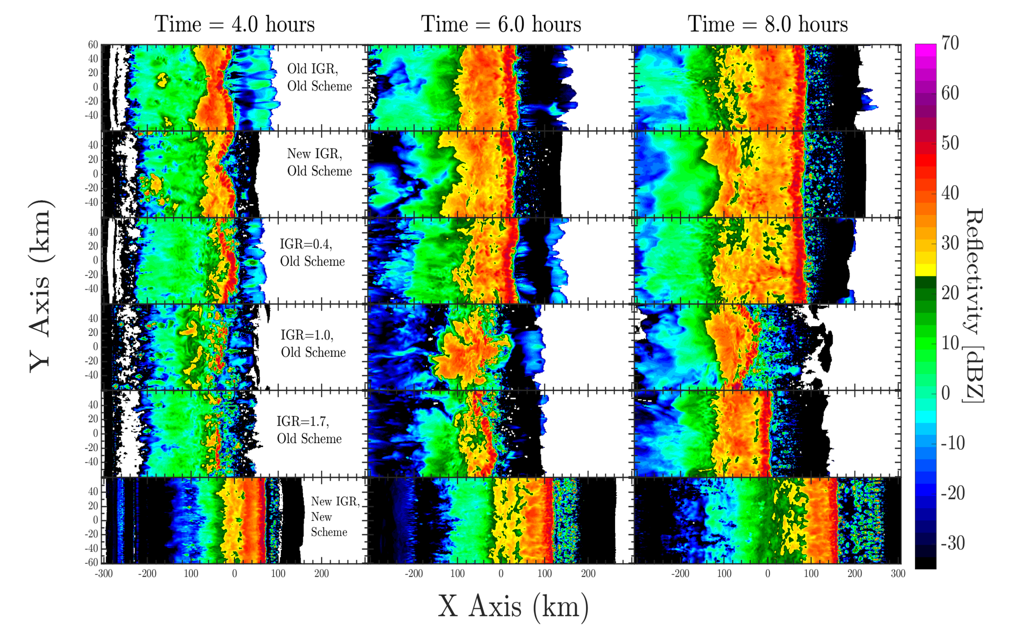

Fig. 4b

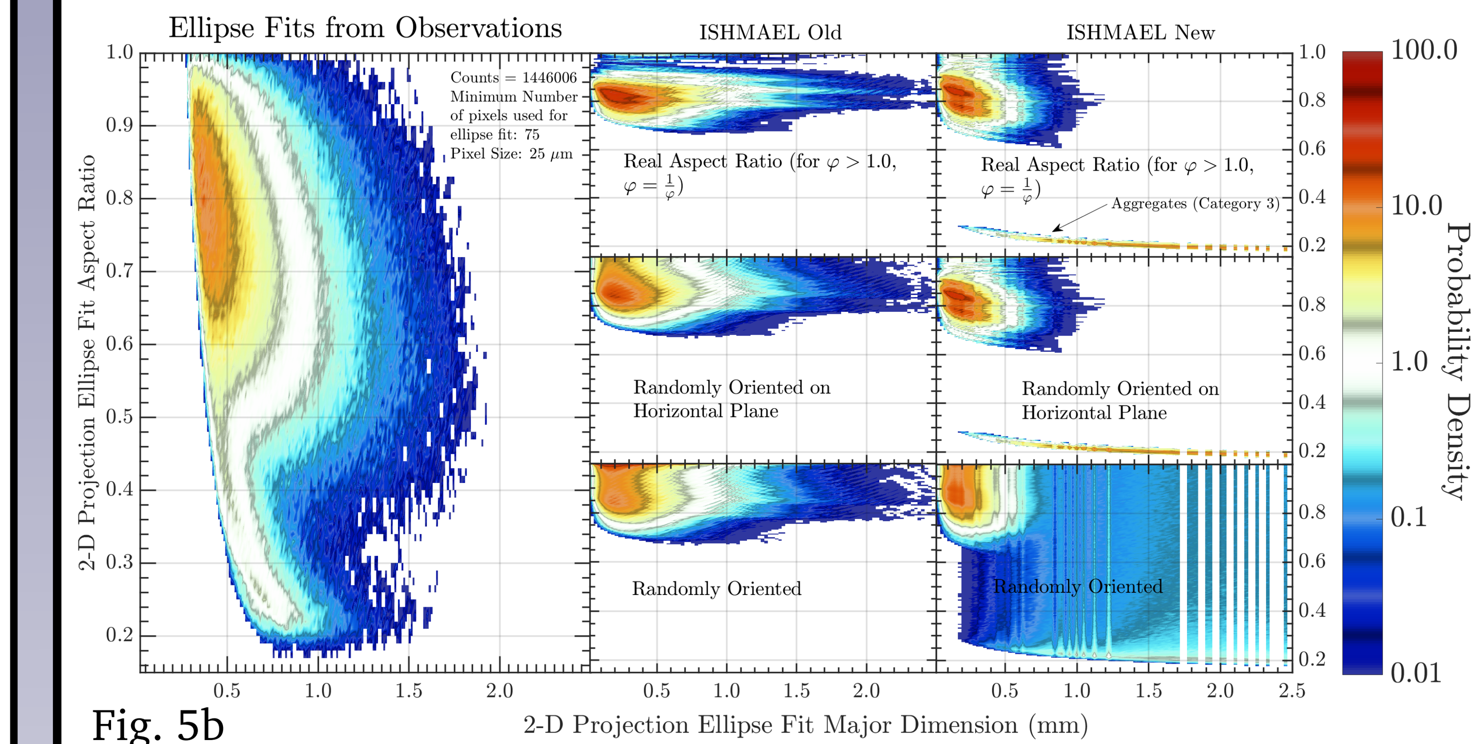

Fig. 5b

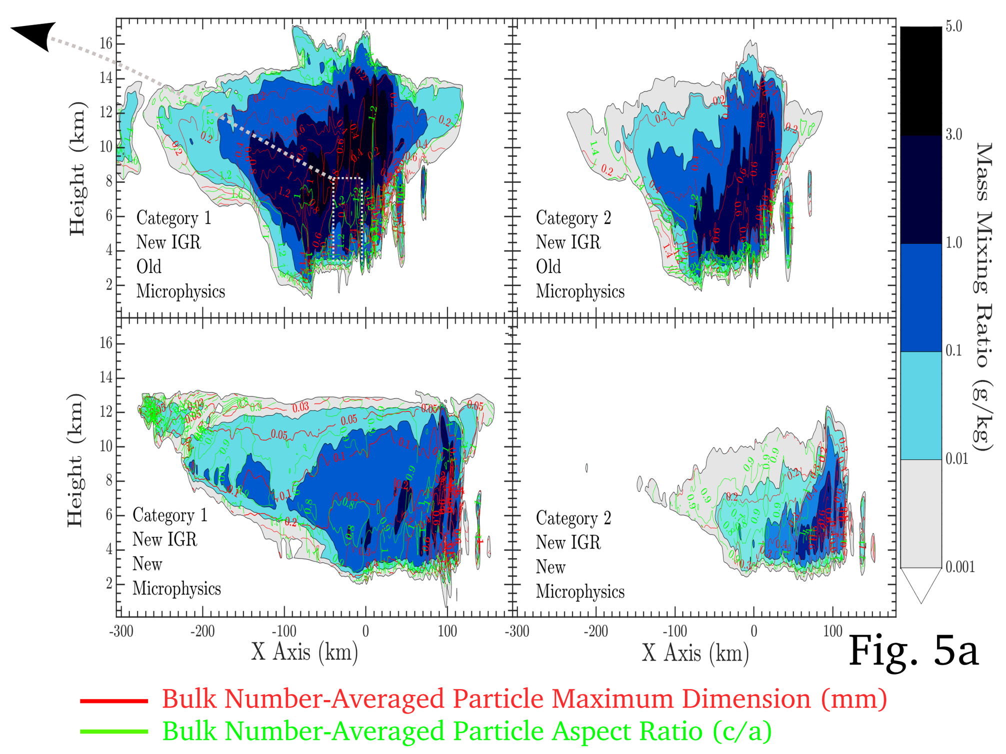

Fig. 5a

- Random orientations of spheroids act to shift projected aspect ratios toward unity.
- Particle shape changes using the adaptive habit model for these ideal model runs do not reach the lowest calculated ellipse fit aspect ratios from OAP projections.
- It is not clear what size/pixel threshold to use for this comparison. More tests are required.
- This approach will allow us to constrain process rates that govern changes in aspect ratio.