Arctic Cloud-Base Ice Precipitation Properties for Constraining Models Retrieved Using a Bayesian Inference Method

Israel Silber
Pacific Northwest National Laboratory

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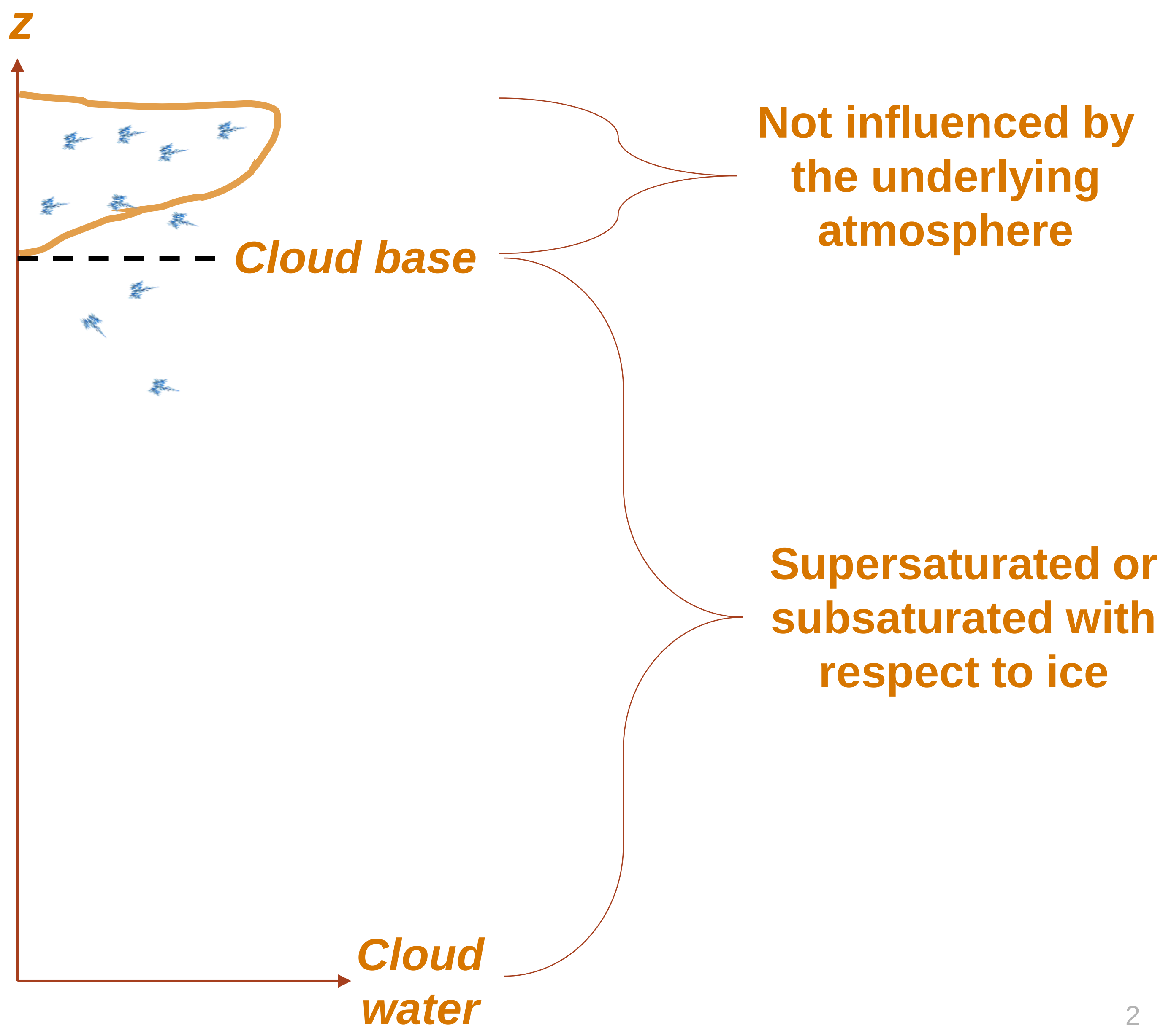
Why Focus on Cloud Base Ice Precipitation?

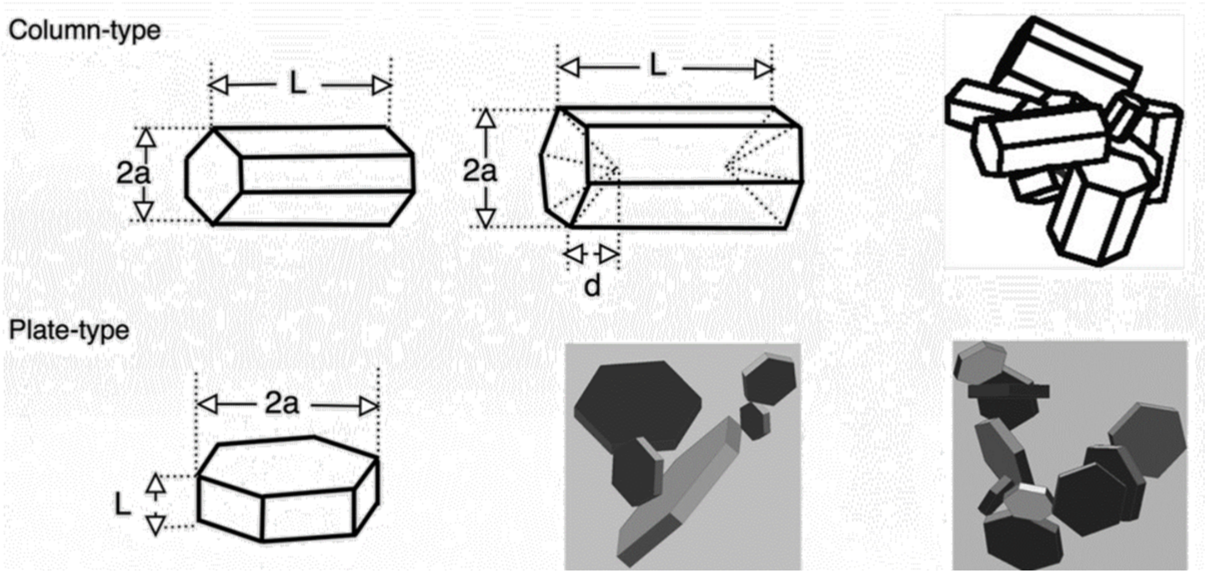
- Liquid cloud base precipitation can serve as the dominant cloud moisture sink
- The atmosphere underlying an ice-generating cloud can be super- and/or sub-saturated
- This could result in inconsistencies when comparing ESM output to observations
- Cloud base precipitation statistics provide observational process constraints for models
- Ground-based measurements provide an unmatched sensitivity and range gate separation



Method

- Markov Chain Monte Carlo (MCMC) algorithm
- The algorithm samples from distributions of Gamma PSD parameters and different ice habit mixtures, among other sampled variable distributions
- KAZR and HSRL observations from the ARM North Slope of Alaska site spanning more than 7 years

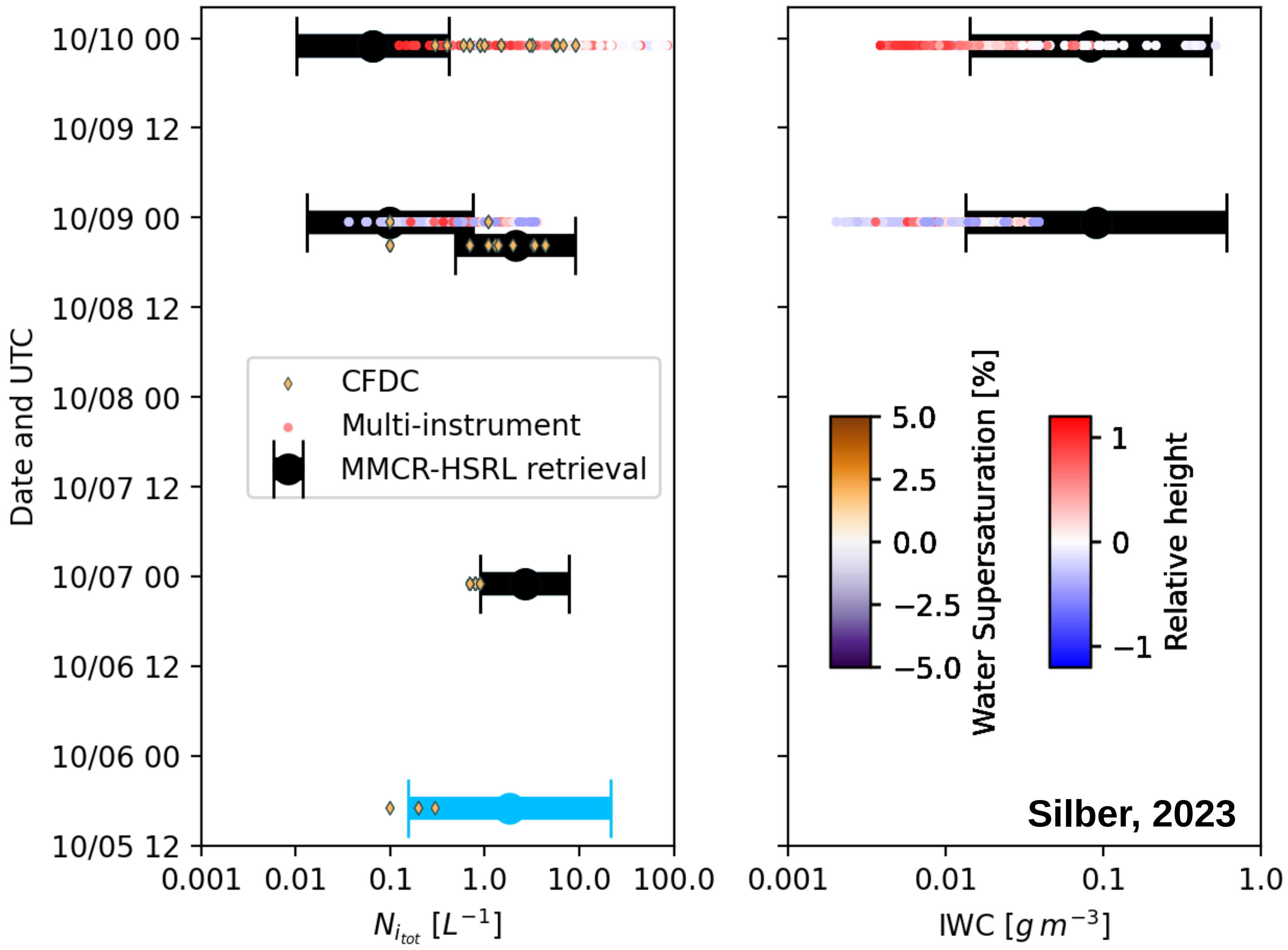
$$N_i(D) = N_0(\frac{D}{D_0})^{\mu} e^{-\lambda D}$$



Yang et al., 2013

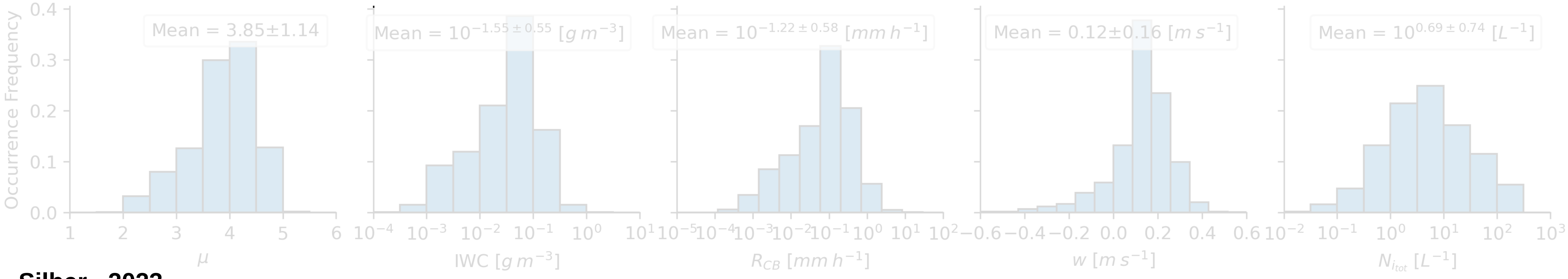
Evaluation

- Using in-situ measurements and retrievals from several M-PACE flight legs
- Equivalent co-located ground-based instrument suite
- IWC and total ice number concentration (Ni_{tot}) Measurements are within range of retrieval output



Cloud Base Precipitate Rates

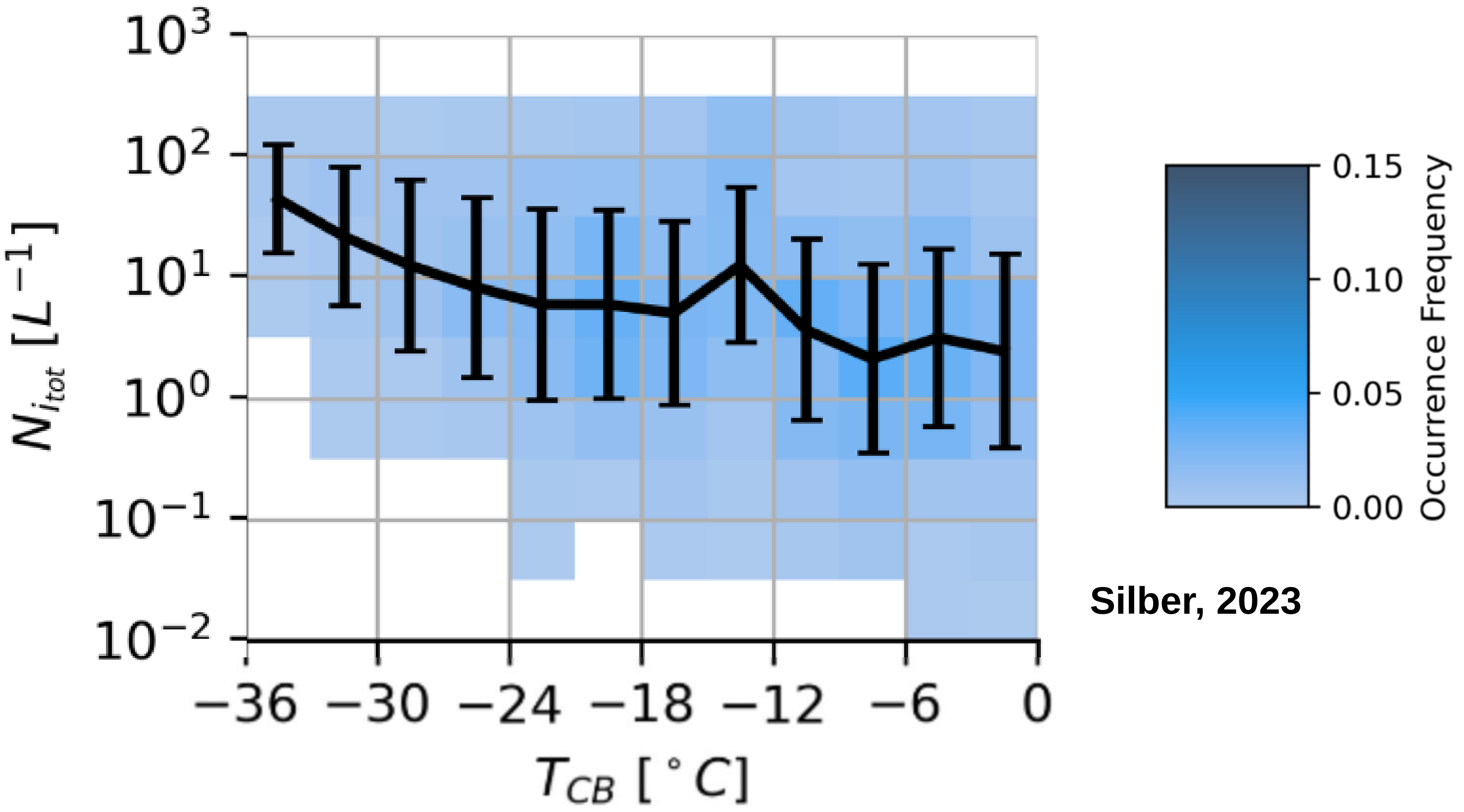
- Ice PSD shape parameter μ averages at ~4
- Mean IWC of ~0.03 g m^{-3} (factor of 3 uncertainty)
- Cloud base ice precipitation rate (R_{CB}) averages at ~0.06 mm h^{-1}
- Mean cloud base updrafts of 12 cm/s, significantly smaller than previous estimates
- Cloud base total ice number concentration N_{itot} range 0.01 to more than 100 L^{-1}



Silber , 2023

N_{itot} and Cloud Base Temperature

- Exponential increase in N_{itot} with decreasing cloud base temperature (T_{CB}) as expected from primary ice nucleation
- Local N_{itot} enhancements around -15 and -5 C, suggesting potential secondary ice production signatures



Silber, 2023

A Habit Effect?

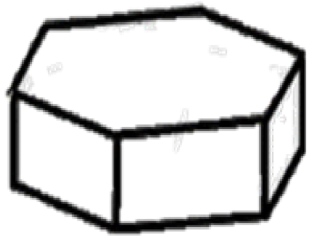
- What if the implemented habits used here do not have sufficiently extreme aspect ratios?
- *N_{itot}* enhancement around -15 C is likely exaggerated
- Direct implications on studies relying on radars and/or lidars without consideration of extreme ice habits (e.g., via mass-dimensional relationships)

Observed

Falling slower

Larger surface area

Used in model



Falling faster

↓

Ameliorate with stronger updrafts

Smaller surface area

↓

Ameliorate with broader ice PSD

←

Ameliorate with weaker shear and turbulent broadening terms

Summary

- Total cloud base ice number concentration (N_{itot}) enhancements around -15 and -5 C could be the result of SIP
- N_{itot} values around these temperatures are likely overestimated (potentially significant implications on SIP event occurrence and intensity suggested by studies relying only on active remote sensing measurements)
- A Gamma distribution shape parameter μ value of 4 is suggested as a suitable value for mono-modal ice PSD fits; for example, in ice microphysics schemes
- Arctic cloud base precipitation rates average at ~0.06 mm h^{-1} and generally increases with cloud depth
- **Future direction:** this retrieval will be applied to sub-cloud profiles at multiple ARM sites to produce an ARM dataset that will be made available to the community

Published manuscript:

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Acknowledgments:

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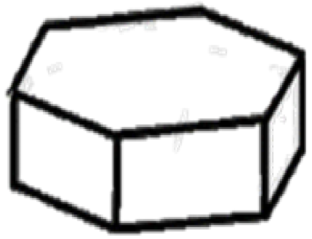
A Habit Effect?

- What if the implemented habits used here do not have sufficiently extreme aspect ratios?
- ***Equivalent reflectivity Z_e*** ∝ **Σ(volume²)**
- **Lidar extinction and backscatter** ∝ **total projected area**
- **Mean Doppler velocity** **(terminal velocity + air motion)**
- **Spectral width** **(Microphysical + beamwidth + turbulent + shear)**

Observed	Used in model
	
Falling slower	Falling faster
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	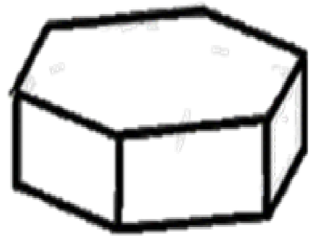
Falling slower	**Falling faster**
	✓ **Ameliorate with stronger updrafts**
Larger surface area	**Smaller surface area**
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✓ **Ameliorate with weaker shear and turbulent broadening terms**

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Observed

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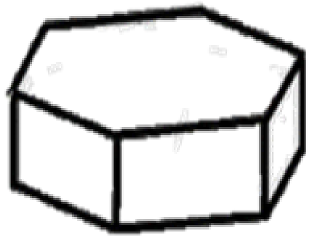

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