A Stochastic Approach for Representing Ice Cloud Microphysical Processes in Models

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1. Motivation

- Model parameterizations use varying hydrometeor categories defined by prescribed characteristics (e.g., mass (*m*) –dimension (*D*), area (*A*)-*D*, perimeter (*P*)-*D* and fall velocity (*V*)-*D* relations)
  - Empirical parameters defining these relations derived from in-situ data & held fixed in models
- Various studies have derived different empirical parameters, but none have characterized parameter variability
- Here parameters characterizing *A-D* & *m-D* relations derived as volume of equally realizable solutions (McFarquhar et al. 2015) so that parameters can be chosen stochastically in models
  - *A-D* & *m-D* relations need to be consistent since both used to compute *v-D* relation

2. Prior Relations

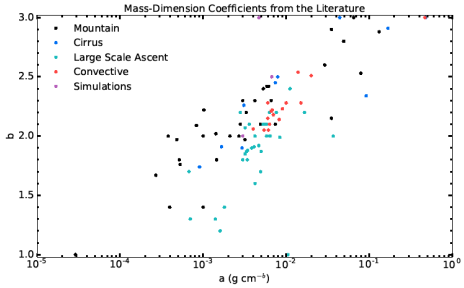


Fig. 1 Parameter b as a function of parameter a characterizing m-D relations that have been derived in previous studies, where m=aD^b. Different colors represent the varying meteorological conditions where parameters have been derived.

- Substantial variability in *a-b* relations from prior studies; co-variability between parameters also exists
- Variability/uncertainty in *a-b* from each study not known: this must be determined to quantify dependence on environmental conditions

3. Data

- **Mid-Latitude Continental Convective Cloud Experiment (MC3E):** Studied convective clouds in vicinity of SGP site in 2011 using UND Citation

Probe	2DC	CIP	HVPS
Resolution	30 μm	25 μm	150 μm
Diodes #	32	64	128
Range	30 - 960 μm	25 – 1600 μm	150 - 19200 μm
Photos			

Table 1. MC3E probes used to derive size-shape distributions of cloud particles

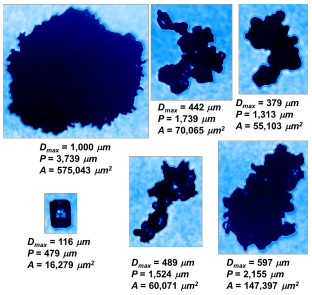
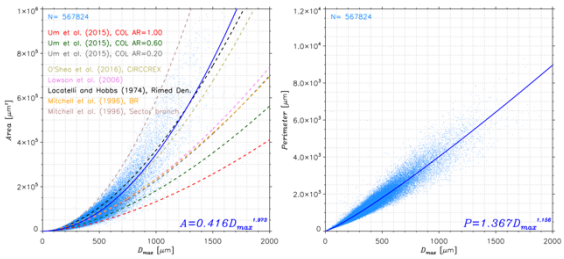


Figure 2. Example images of ice crystals obtained by cloud particle imager (CPI) on 23 May during MC3E. Maximum dimension (D_{max}), perimeter (P), and area (A) of each ice crystal are embedded. Majority of ice crystals had highly rimed irregular shapes.

4. Consistent *A-D* and *P-D* Relations



Best fit relationships of *A-D* (left) and *P-D* (right) derived from CPI images; future work will determine uncertainty estimates on *A-D*/*P-D* coefficients

Fig. 3: A-D and P-D relations derived from 567,824 CPI images obtained during MC3E; solid blue lines demonstrate best fit to data, other lines represent relations from previous studies.

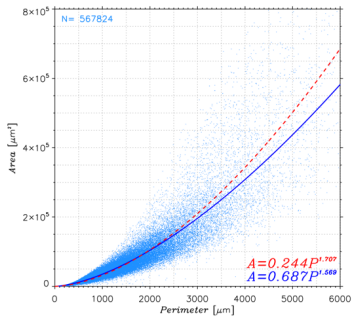


Fig. 4: A versus P for individual CPI images from MC3E; blue line shows best fit to data, red line derived from A-D and P-D relations

A-P relation derived from *A-D* and *P-D* relation is not consistent with that derived from images directly

Future work will determine if different relations equivalent within uncertainties

Such inconsistencies can be problematic if also present in *A-D* and *m-D* relations since they are used to derive *V-D* relations

5. Stochastic *m-D* Relations

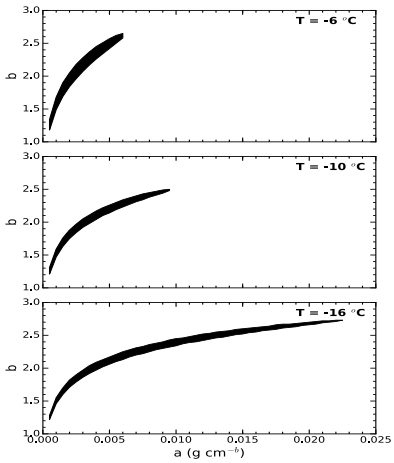


Fig. 5: Volume of equally realizable solutions for m-D relations in a/b phase space determined for 3 different temperature ranges using MC3E data acquired on 20 May 2011. Statistical uncertainty and variability considered in development of relations by minimizing difference between mass and reflectivity derived from N(D) and that directly measured.

Bulk mass measured by Nevzorov probe during MC3E

Radar reflectivity obtained by Vance Air Force Base, OK S-band (λ = 10 cm) radar matched to location of aircraft using Airborne Weather Observation Toolkit radar matching algorithm

Most likely (*a*,*b*) derived by minimizing χ^2 difference between sum of observed/fit mass and observed/fit reflectivity

All χ^2 within $\Delta\chi^2$ of minimum χ^2 are equally realizable solutions, $\Delta\chi^2$ determined by variability and statistical uncertainty

Solutions can be implemented in stochastic model (see poster of Morrison et al.)

6. Future Work

1. Ensure that derived *m-D* and *A-D* relations are consistent so that *V-D* relations appropriate for models can be derived
2. Better quantify uncertainty surfaces for *m-D* and *A-D* relations so that dependence on environmental conditions can be isolated from variability.

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