Uncertainties in In-Situ Observations of Cloud Microphysics

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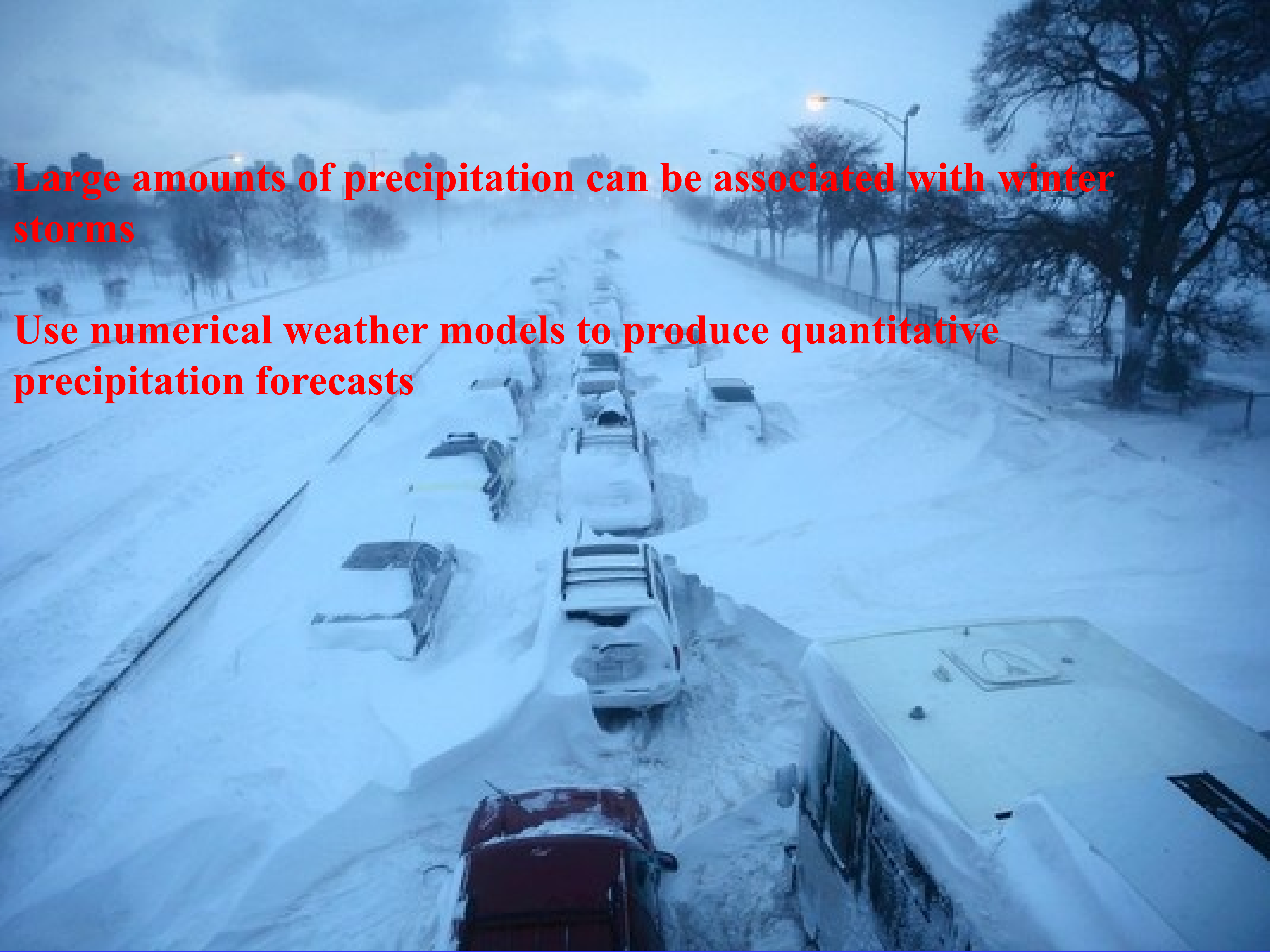
Uncertainty in Radar Retrievals, Model Parameterizations, Assimilated Data and In-Situ Observations: Implications for the Predictability of Weather

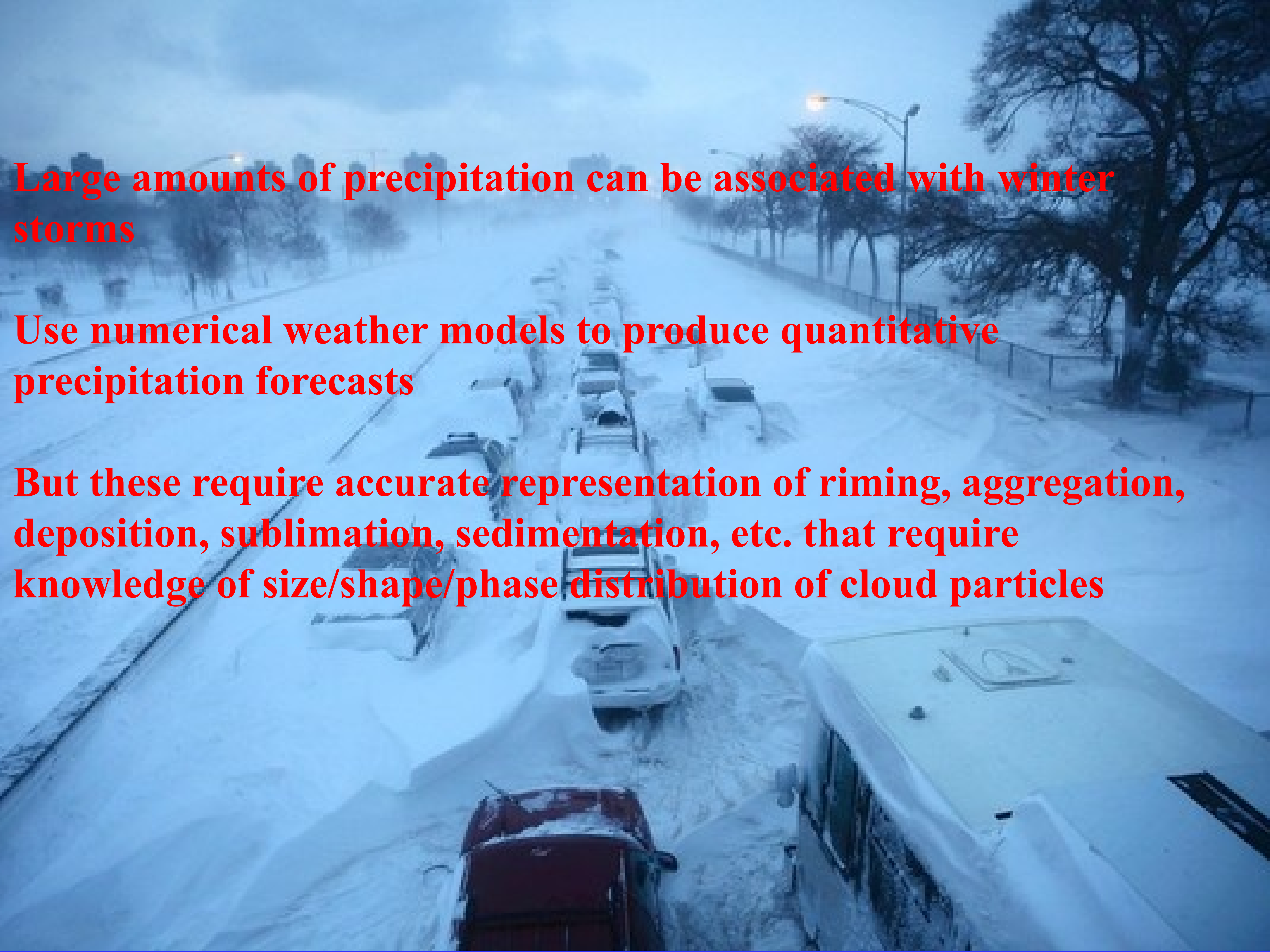
31 October 2018

Large amounts of precipitation can be associated with winter storms



Large amounts of precipitation can be associated with winter storms

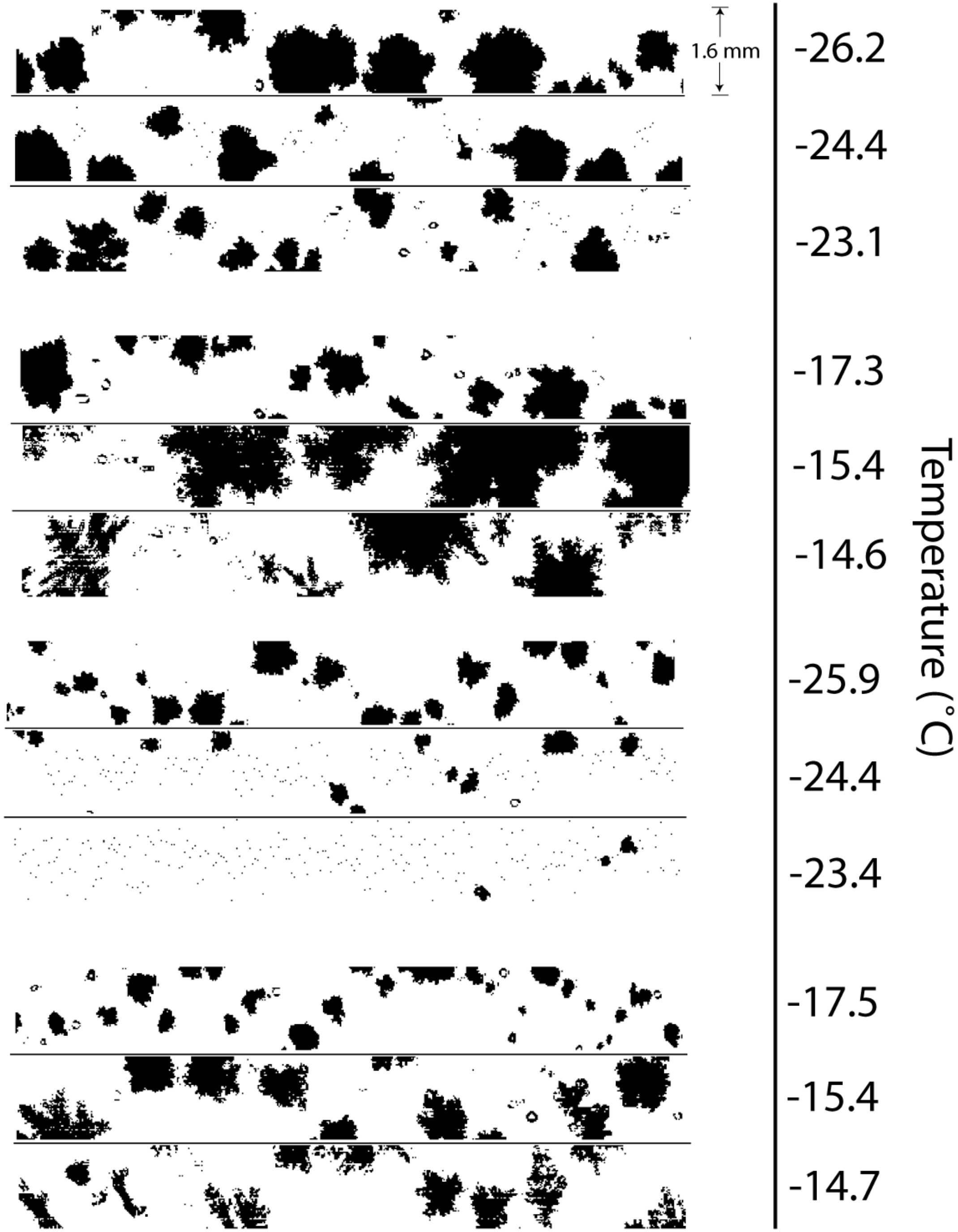
Use numerical weather models to produce quantitative precipitation forecasts



Large amounts of precipitation can be associated with winter storms

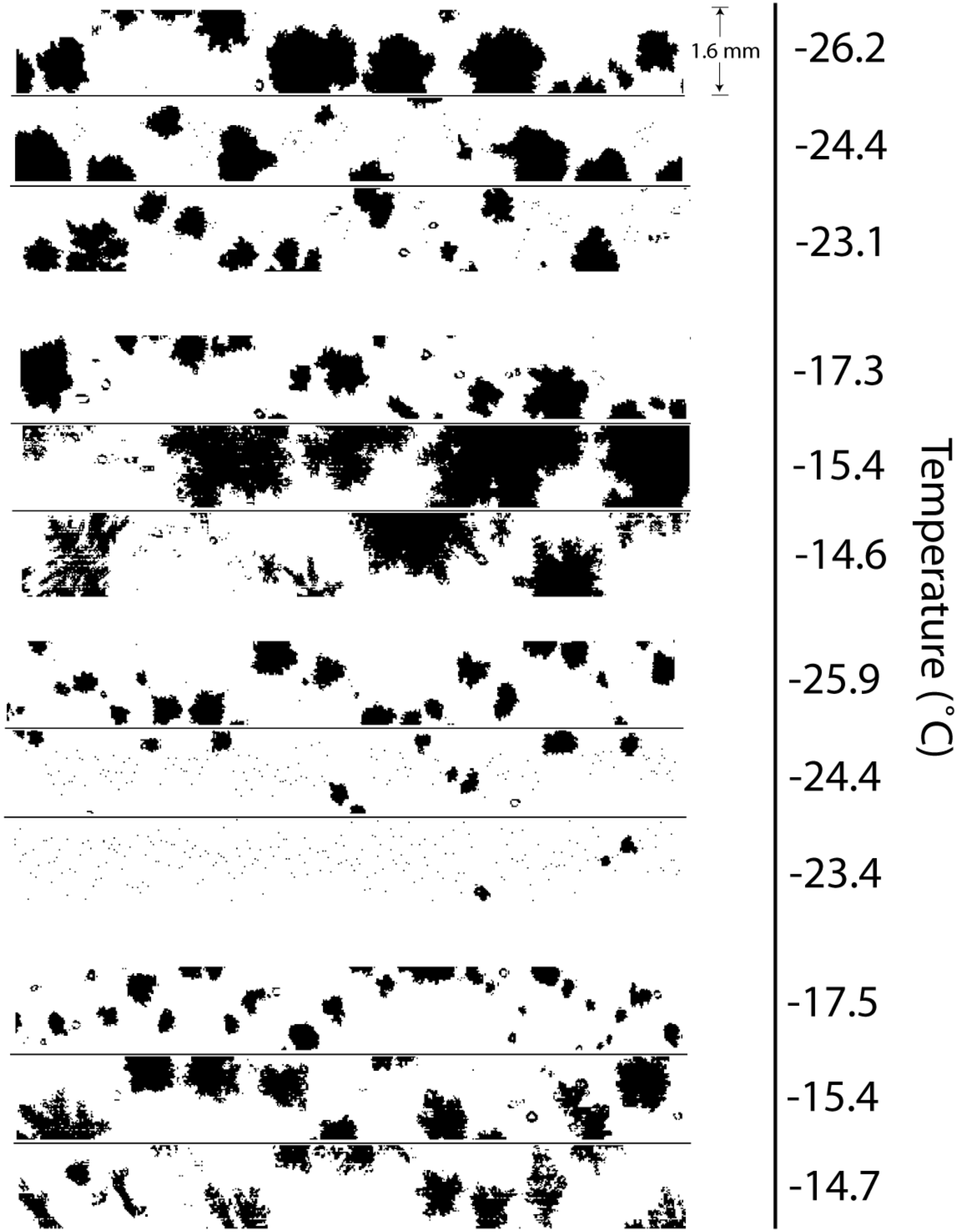
Use numerical weather models to produce quantitative precipitation forecasts

But these require accurate representation of riming, aggregation, deposition, sublimation, sedimentation, etc. that require knowledge of size/shape/phase distribution of cloud particles



Images of ice crystals & water droplets obtained in winter storms

Plummer et al. 2014



Images of ice crystals & water droplets obtained in winter storms

How do these images give us information about how processes occurring in clouds?

Plummer et al. 2014

Overview

Motivation

- Uncertainties in microphysics observations → uncertainty in cloud processes & model representation

In-situ measurement techniques

- Hot wire, scattering and optical array probes

Quantifying Sources of Error

- Counting, variability & measurement

Representation in Models

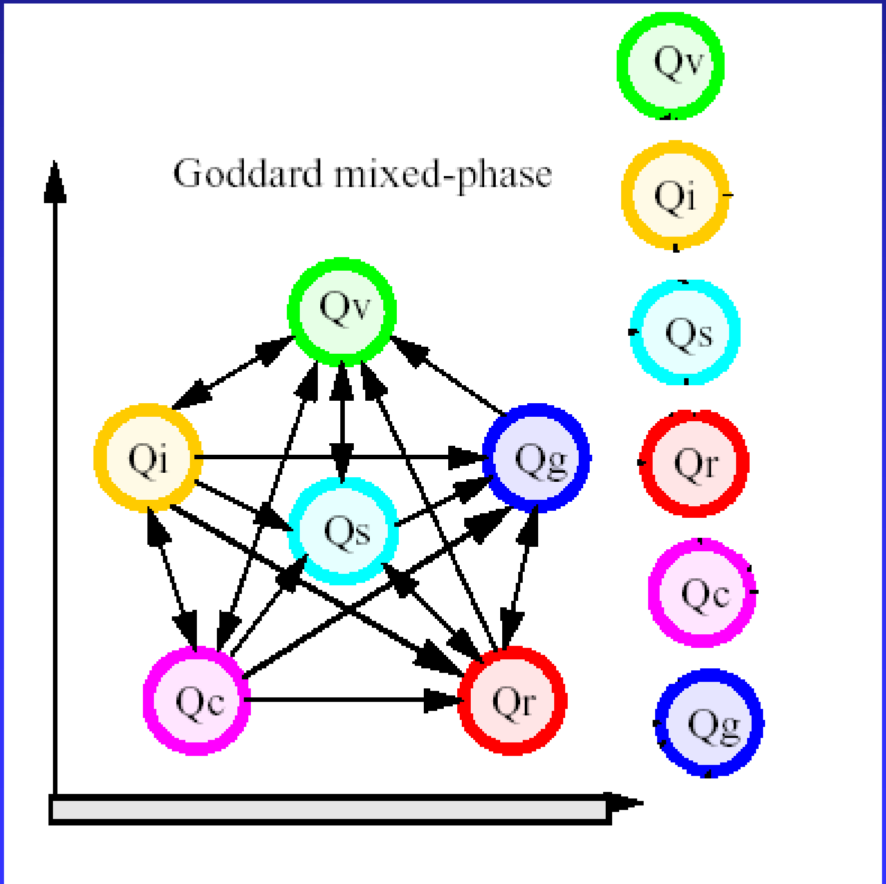
- Stochastic Parameterizations for m-D relations

Summary and Conclusions

- Recommendations for future studies

What do models need from in-situ data?

- Most cloud parameterization schemes predict 1- or 2- moments of a size distribution for a # of hydrometeor categories
- These schemes require some information about cloud microphysics to calculate conversion rates between species



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Most cloud parameterization schemes predict 1- or 2- moments of a size distribution for a # of hydrometeor categories

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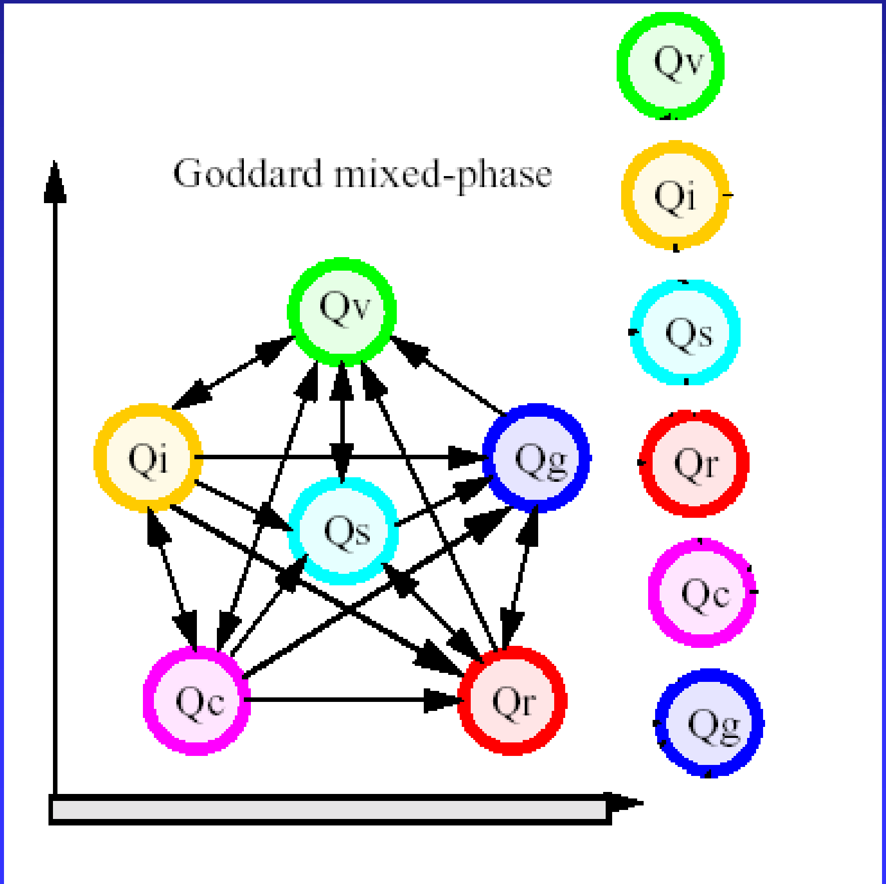
$N(D) = N_0 D^{\mu} e^{-\lambda D}$
(size distribution)

$m = \alpha D^{\beta}$ (mass)

$V = aD^{b}$ (fall speed)

$g, \omega_0 = f(T, IWC, r_e)$
Scattering properties



Different measurement techniques

- **Size distributions:**

Different measurement techniques

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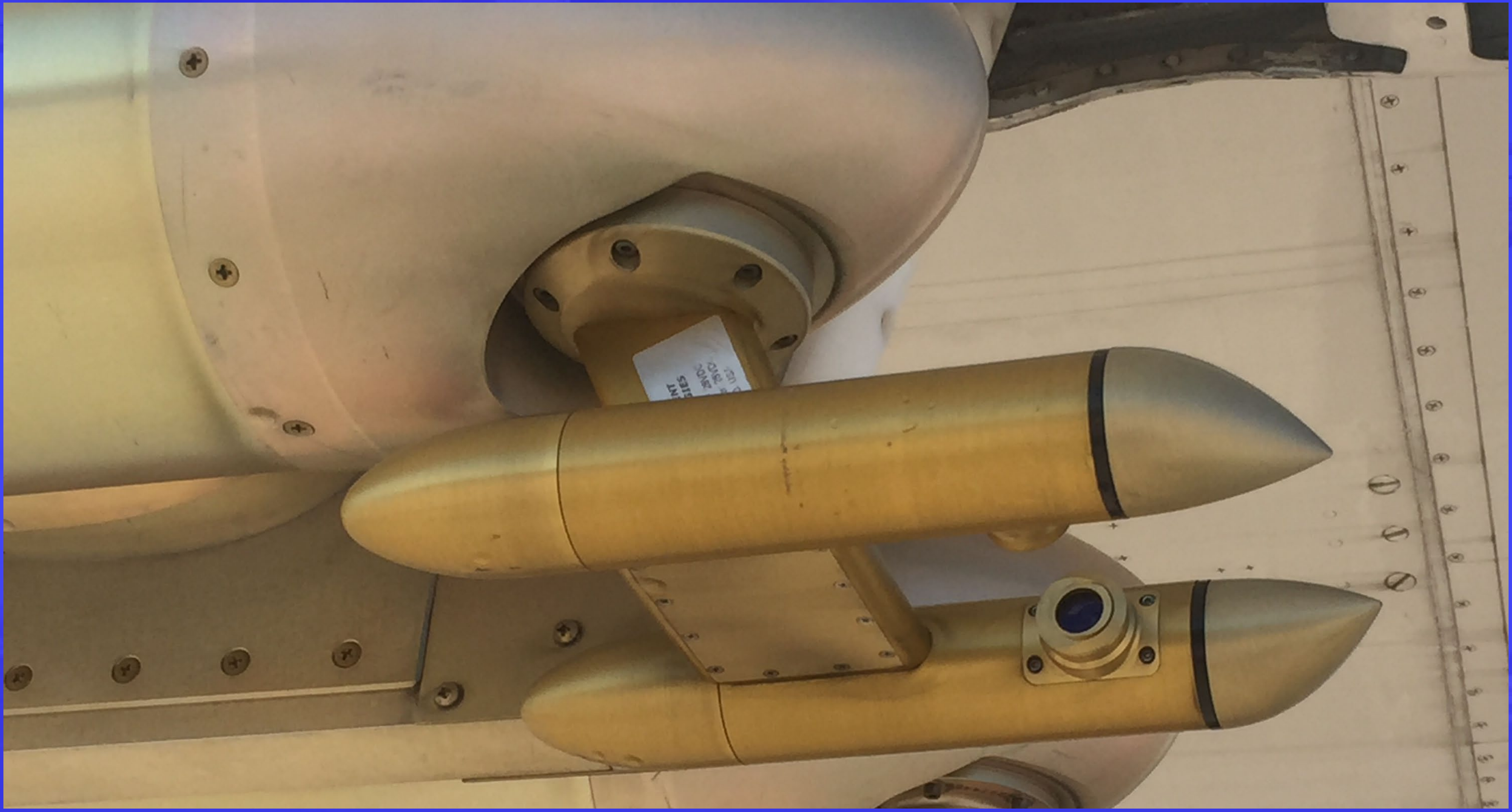
  - Forward scattering probes convert forward scattered light to particle size ($1 < D < 50$ μm)



Different measurement techniques

- **Size distributions:**
  - Forward scattering probes convert forward scattered light to particle size ($1 < D < 50\ \mu m$)
  - Optical array probes use fast response photodiode arrays to get 2-d particle images ($50\ \mu m < D < 10$ mm)

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- **Bulk parameters**
  - Bulk liquid water and total water
  - Bulk extinction
  - Flag for presence of supercooled water

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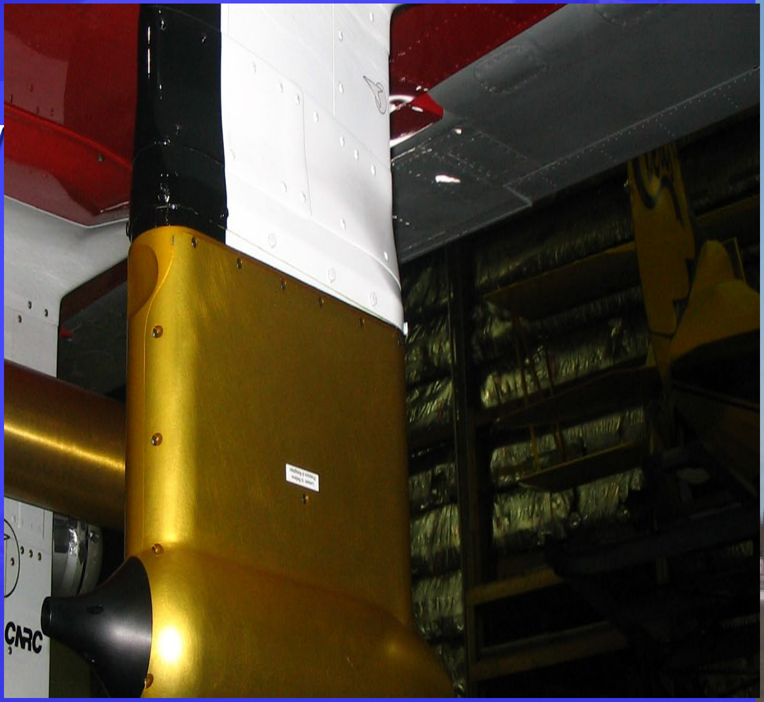

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- **Bulk parameters**
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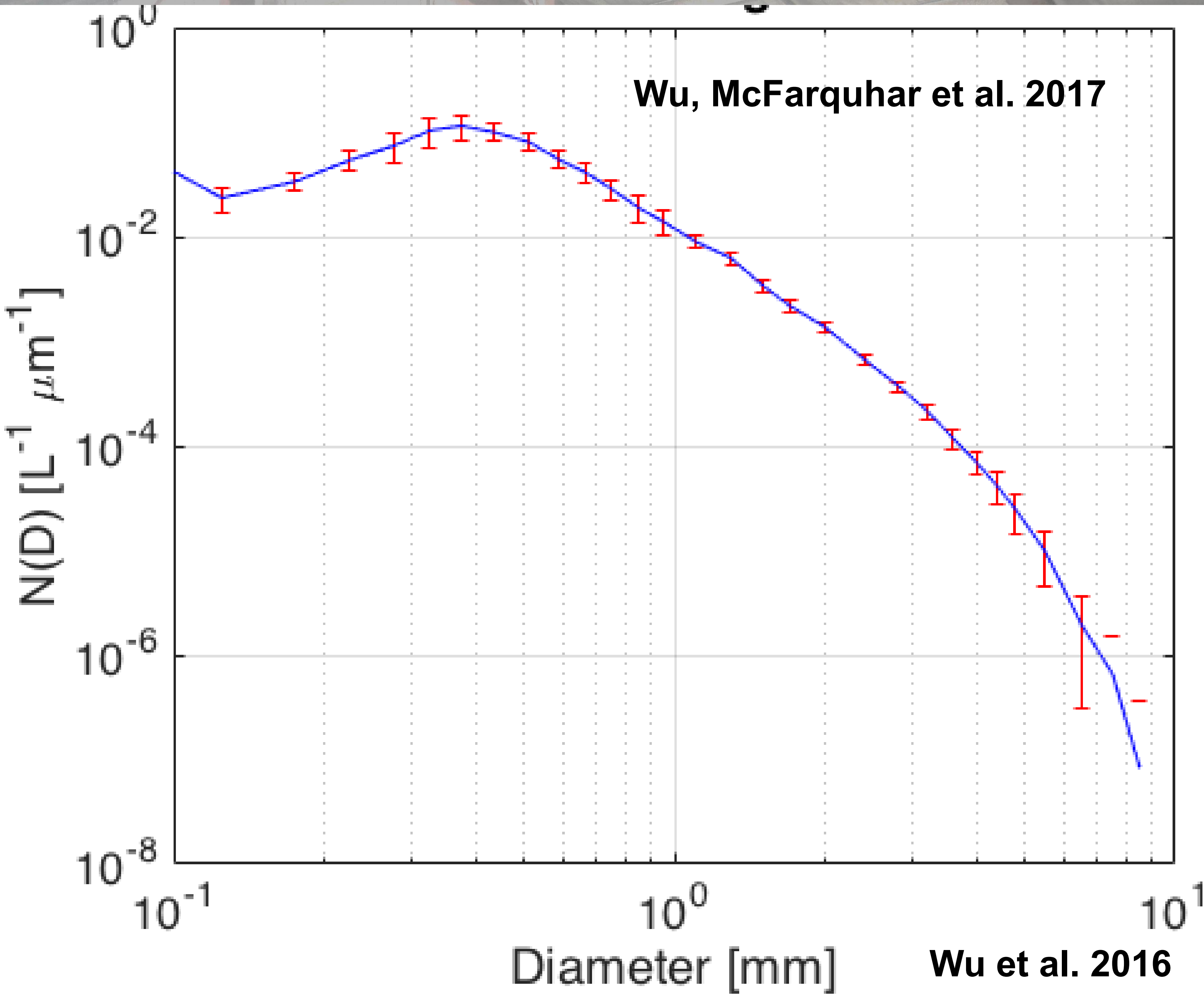
  - Flag for presence of supercooled water
- **Redundancy key to microphysical measurements**
  - assess consistency & performance of multiple probes through closure tests (extinction & mass)

Sources of Uncertainty

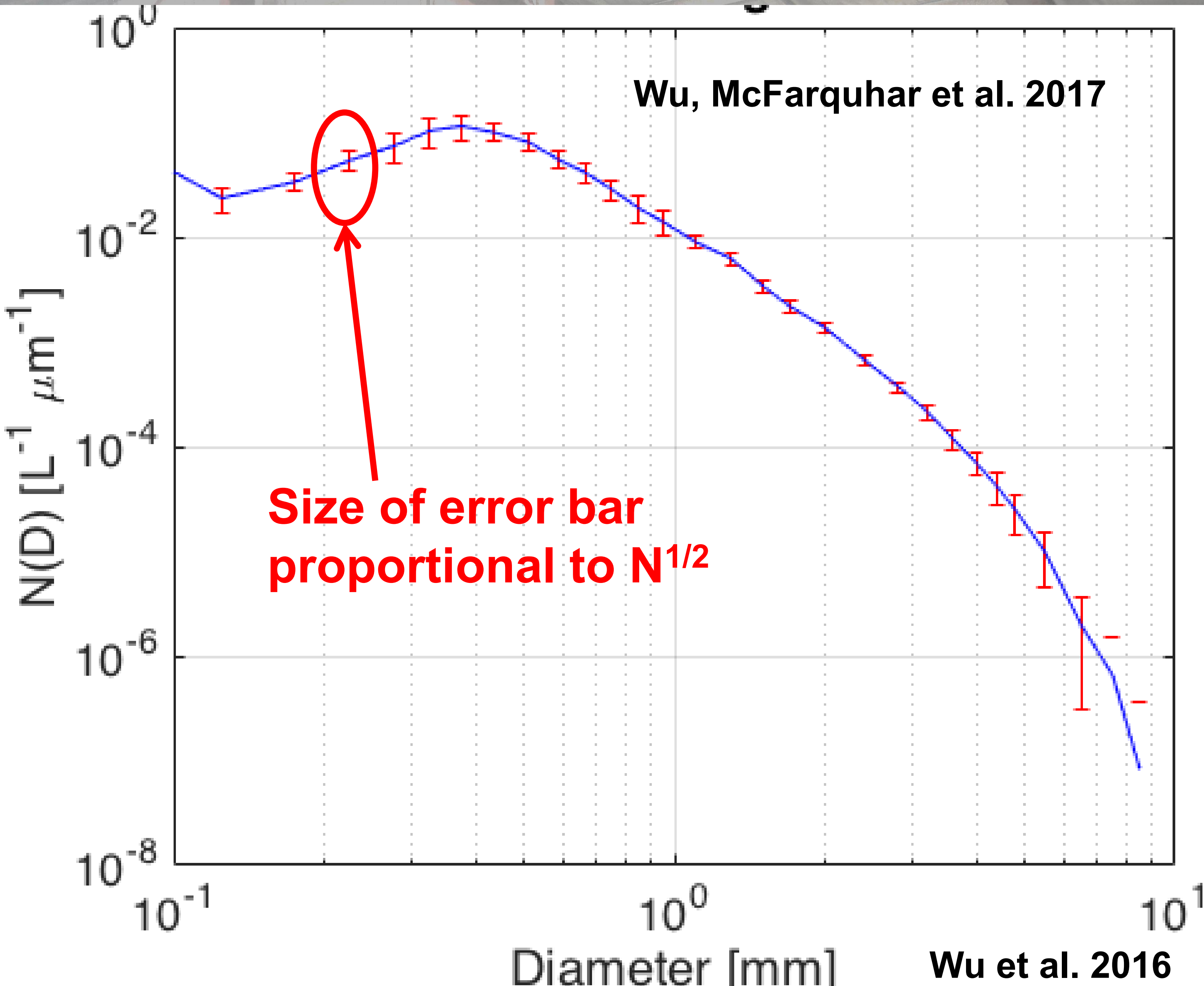
- EC: Counting statistics error of particles
- EV: Variability in microphysics for given conditions
- EM: Measurement errors

Sources of Uncertainty: EC



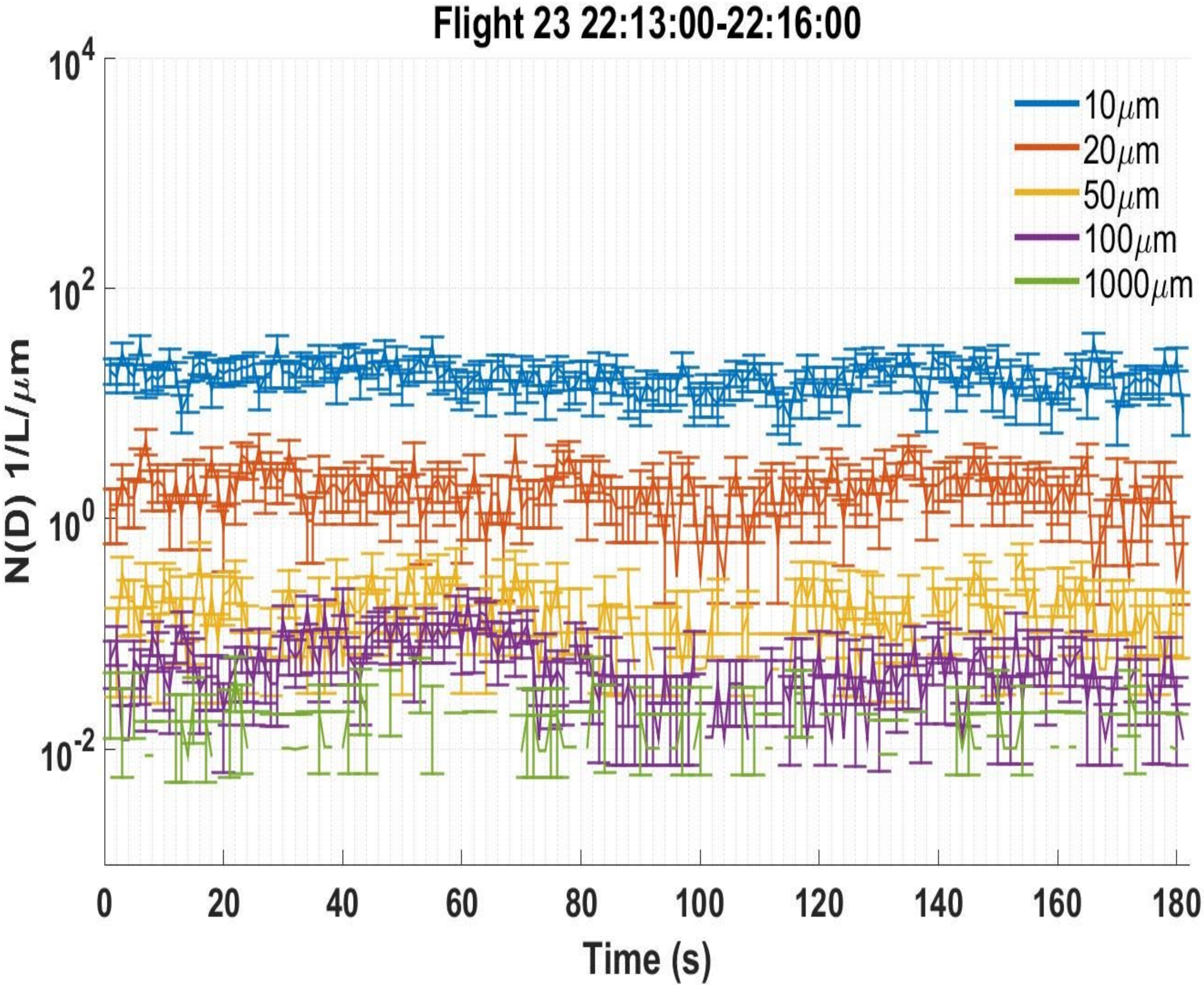
Wu et al. 2016

Sources of Uncertainty: EC

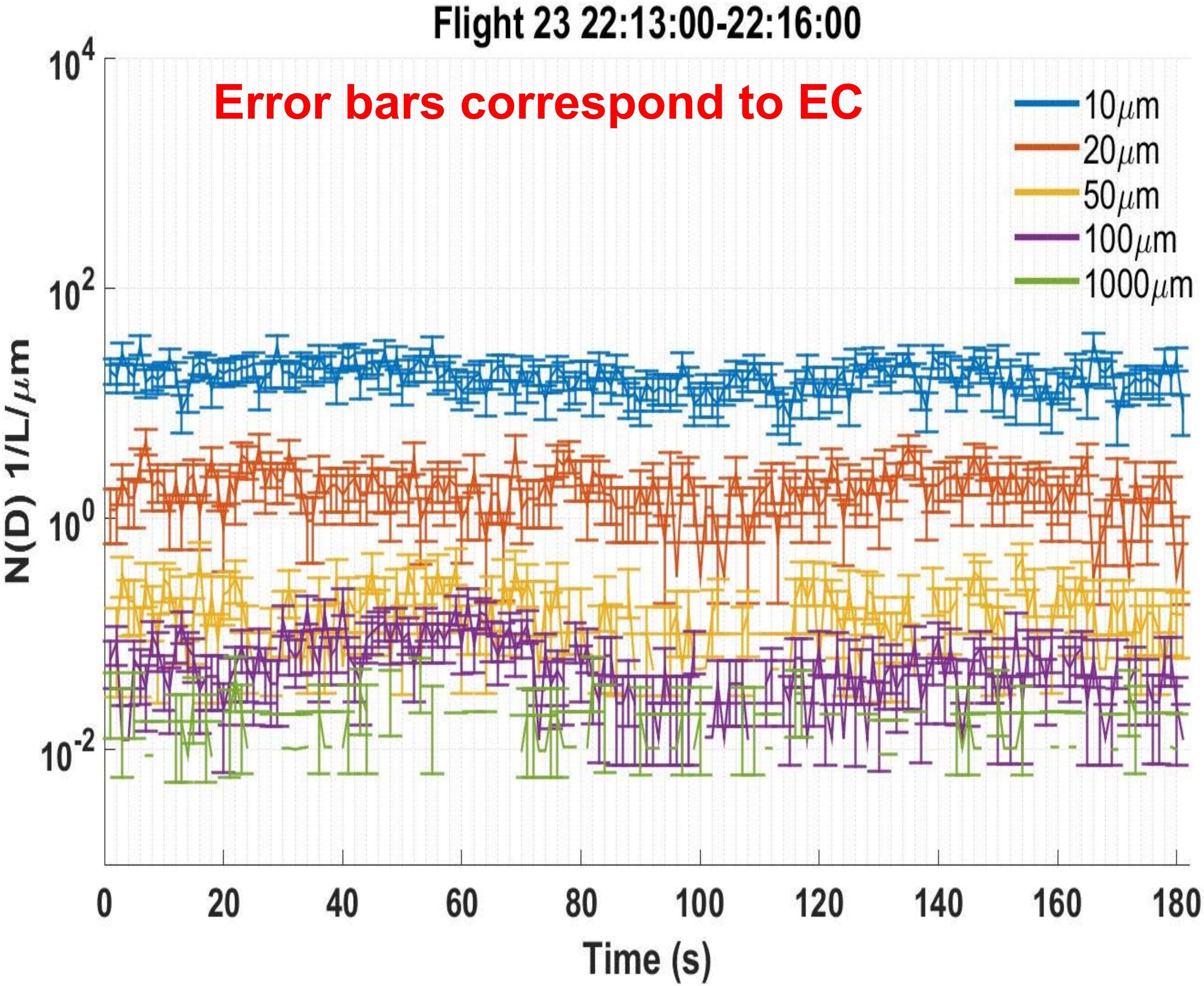


Wu et al. 2016

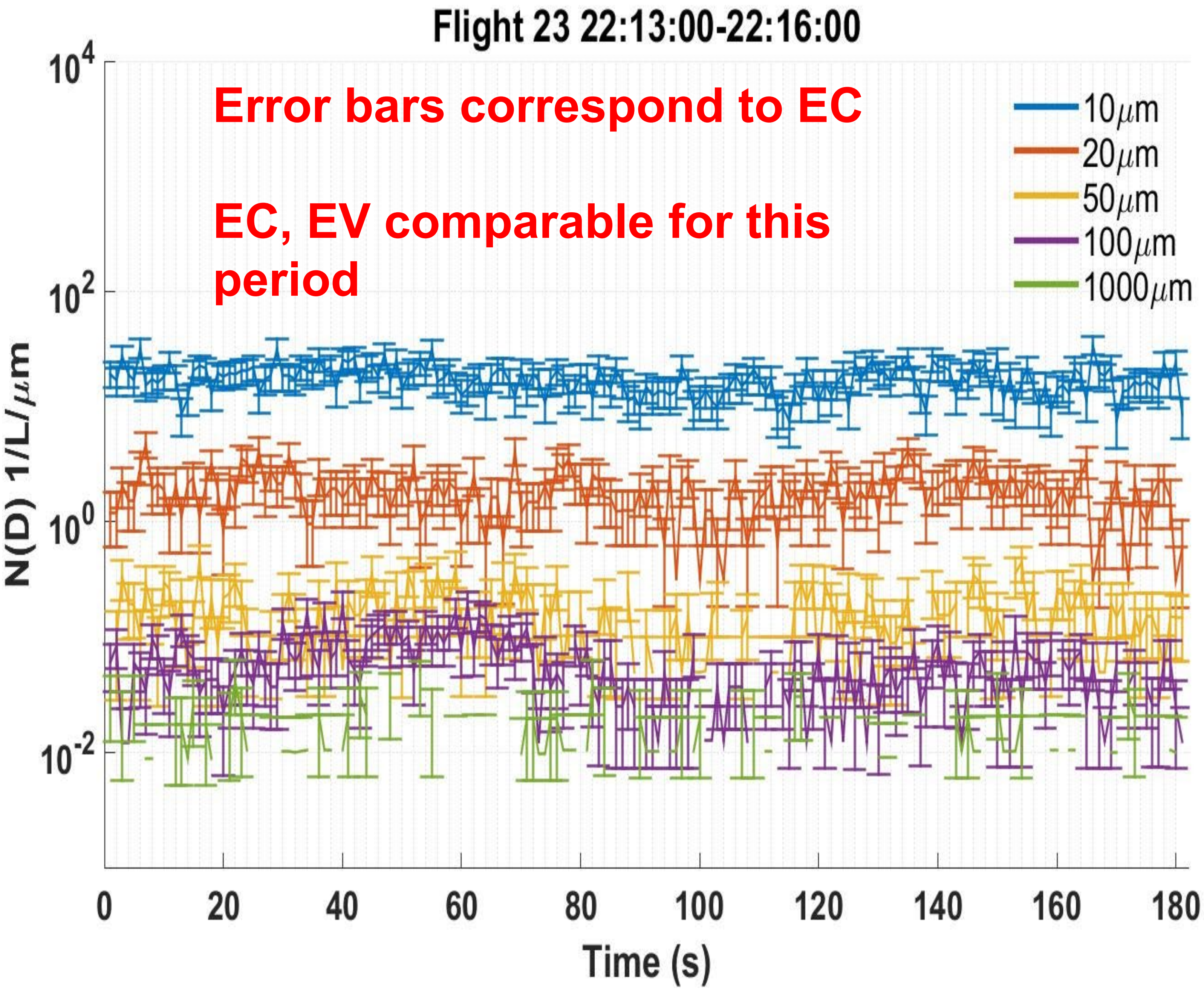
McFarquhar et al. 2018



McFarquhar et al. 2018

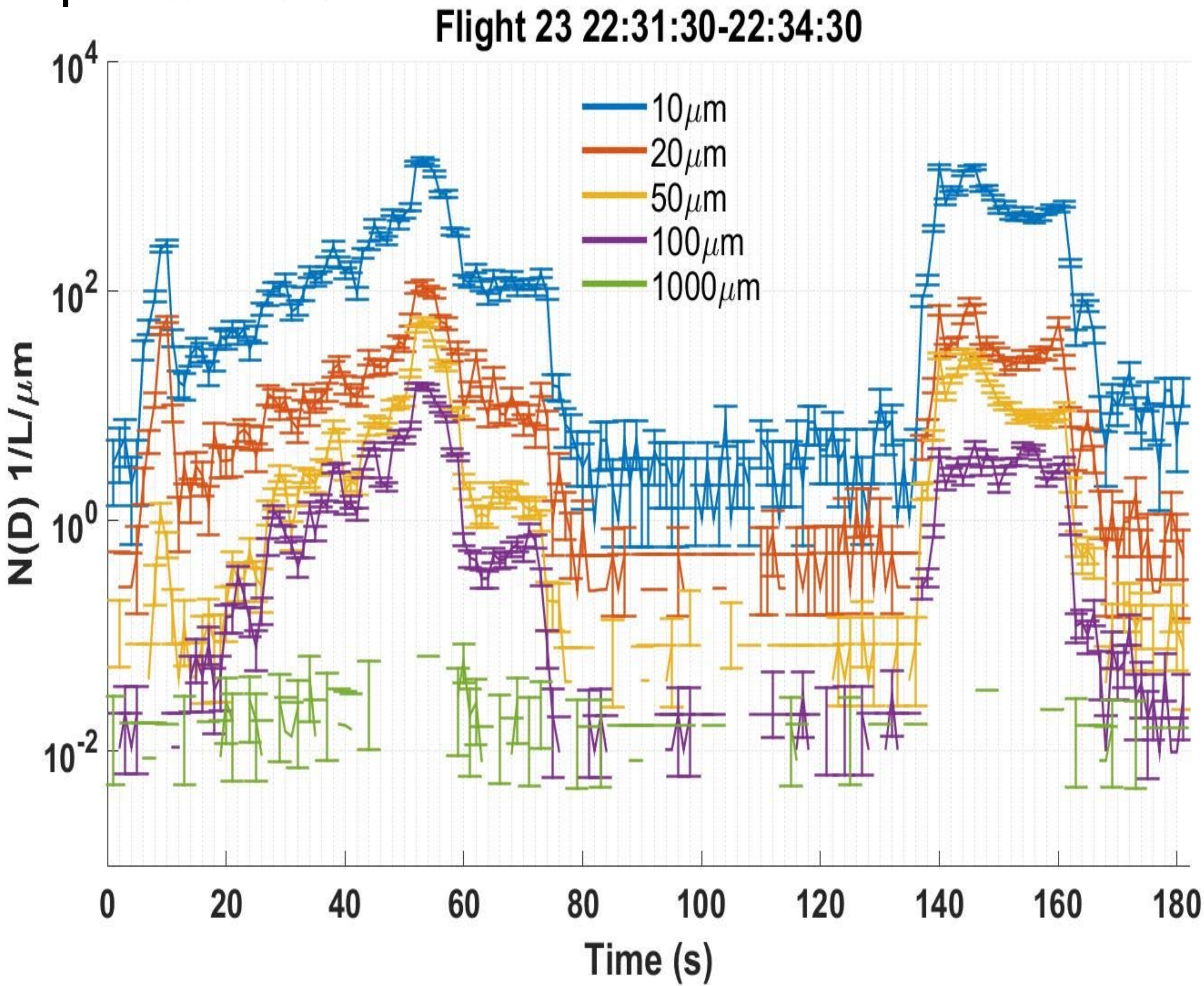


McFarquhar et al. 2018



But, EC smaller than EV for period with higher IWC

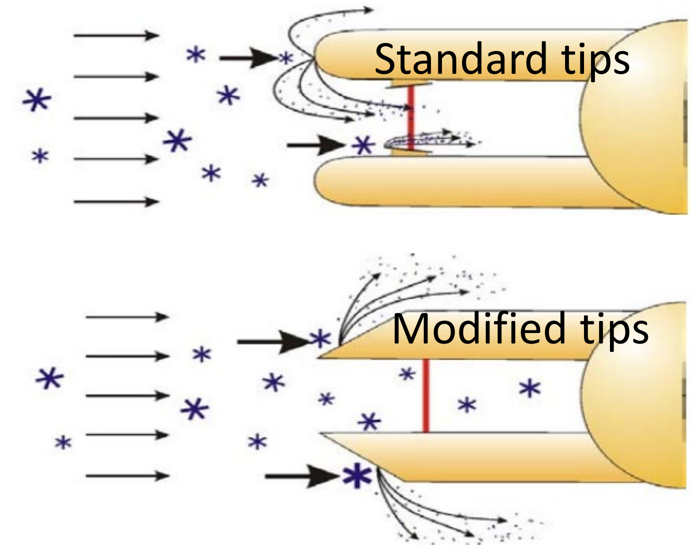
McFarquhar et al. 2018

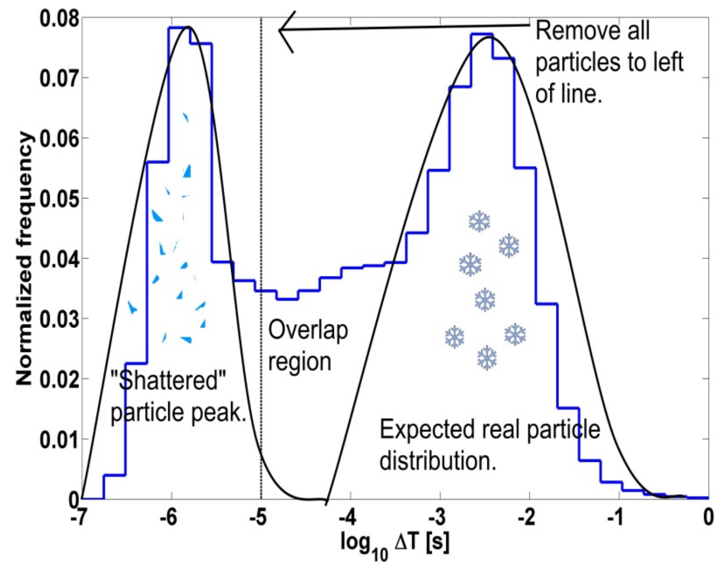


Measurement Error: Shattering

- Measured ice crystal size distributions (SDs) from cloud probes may be biased by shattering on tips of probes

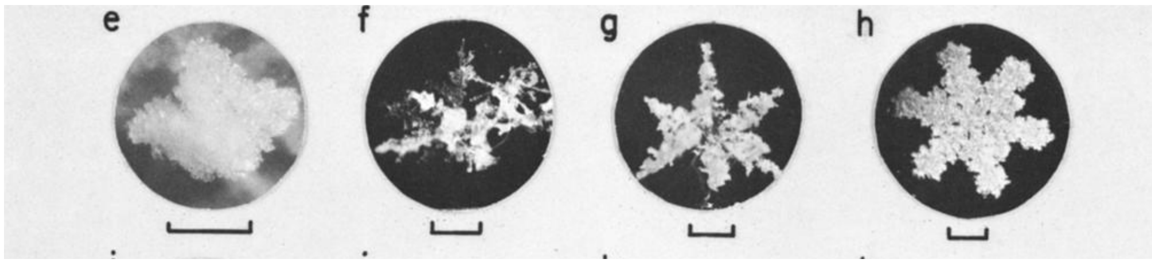
- Modified tips for OAPs & varying processing techniques based on particle interarrival distance (time) have been used to correct for artifacts





Korolev and Isaac (2006)

Mass-dimensional (*m-D*) Relations



$m = a\,D^b$ commonly used to represent mass of ice crystals

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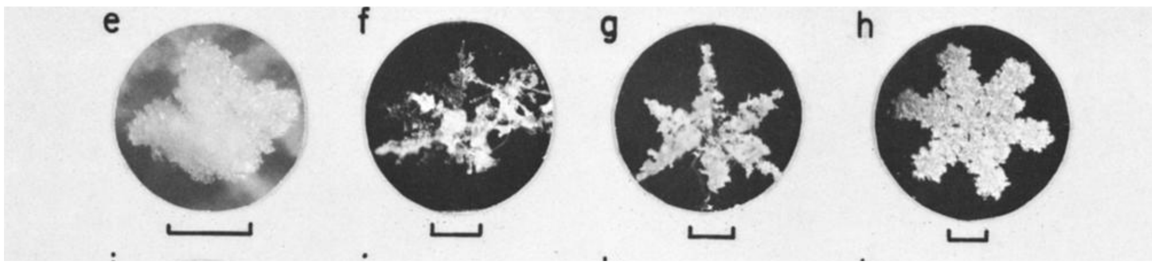

$m = a D^b$ commonly used to represent mass of ice crystals

Representation of a and b affects model simulated properties

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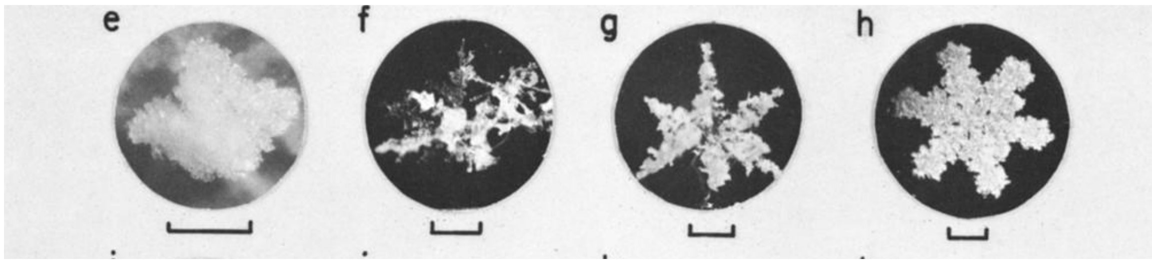

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Representation of a and b affects model simulated properties

Many studies give different a and b coefficients

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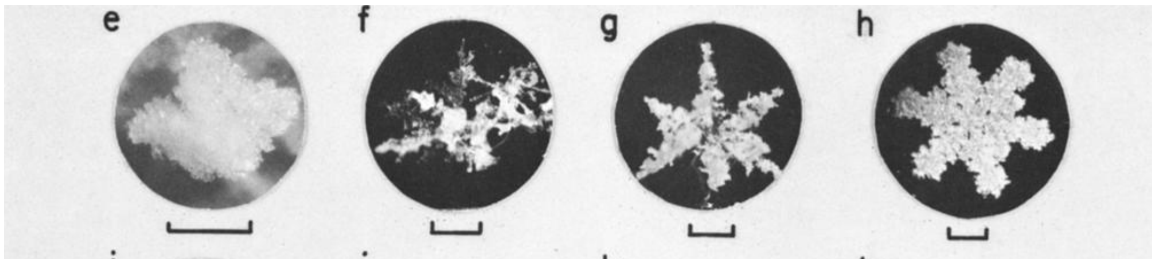

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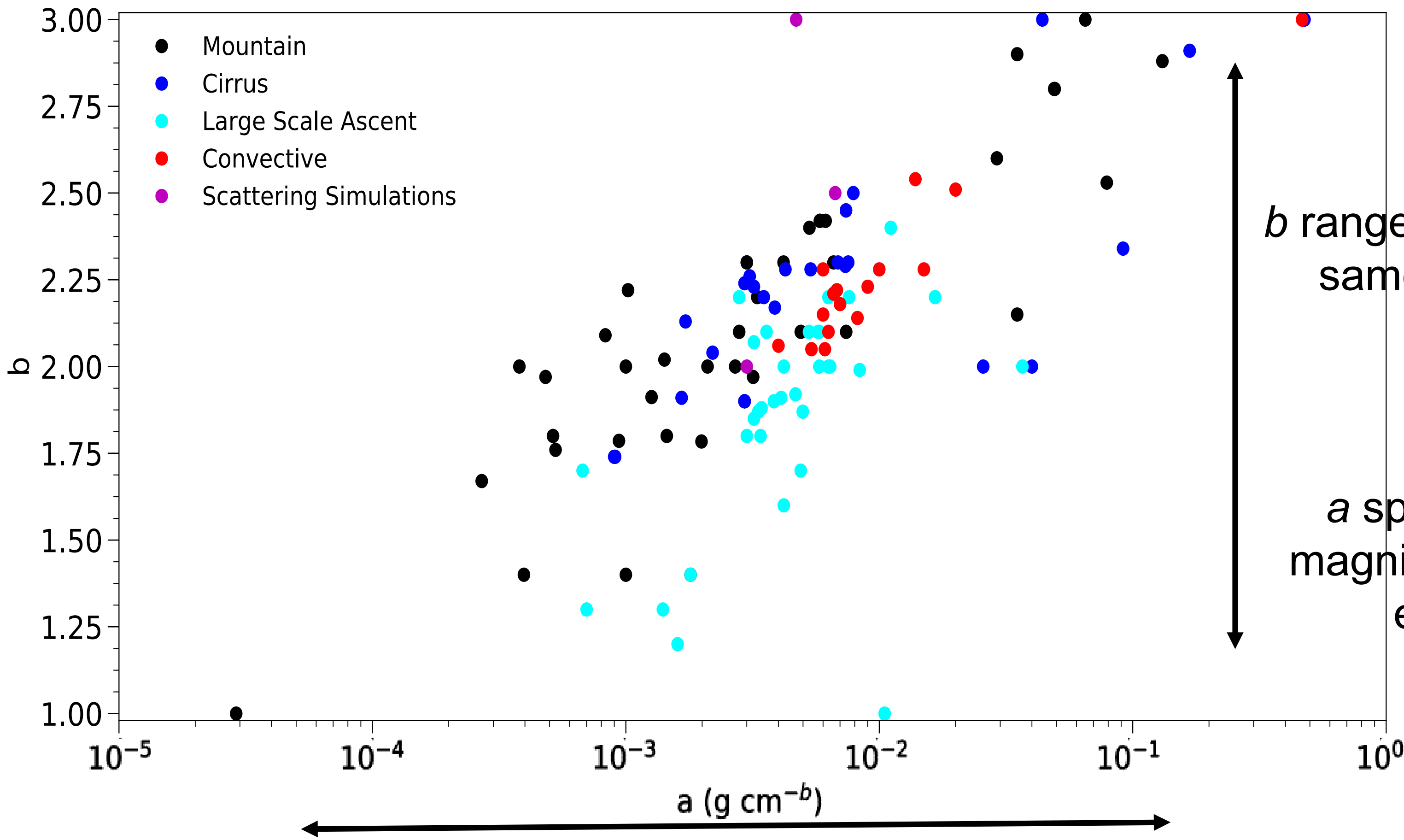
What do a and b depend on?

Empirical mass-Dimension Relationships



b ranges from 1-3 within same environment

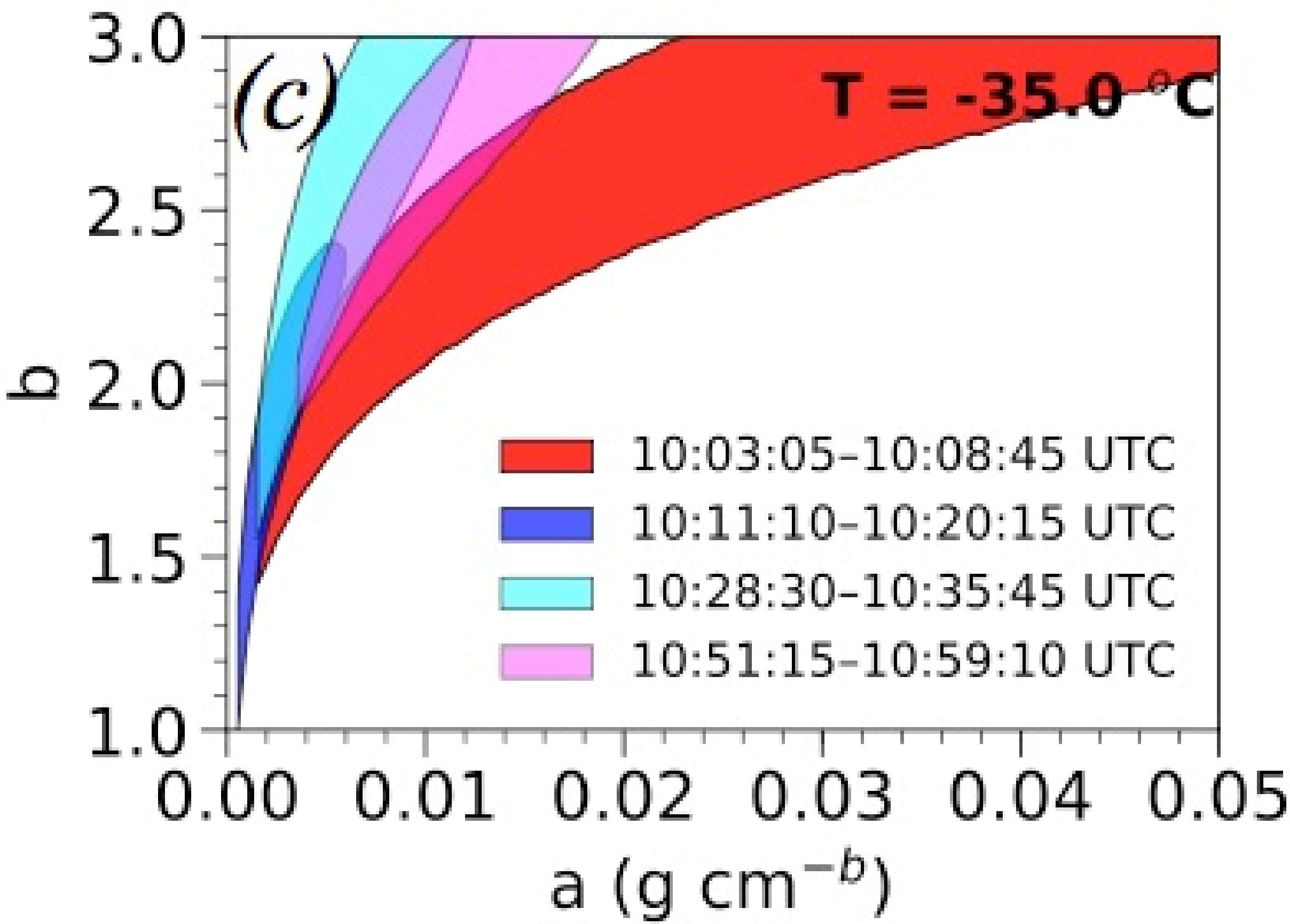
a spans 3 orders of magnitude within same environment

Future of Microphysical Parameterizations

- **Current state:** Single, fixed *a & b* coefficient used
  - Cannot adequately represent ensemble-retrieved *m-D* variability of observed cloud conditions
  - Considering a <u>range</u> of *a,b* coefficients may be more applicable
- **Future trend:** Stochastic framework within microphysical schemes
  - Range of *a,b* coefficients can be represented as PDF
  - Progress toward stochastically resolving *m-D* parameters in P3 scheme

Equally realizable *a/b* Coefficients

Finlon et al. 2018



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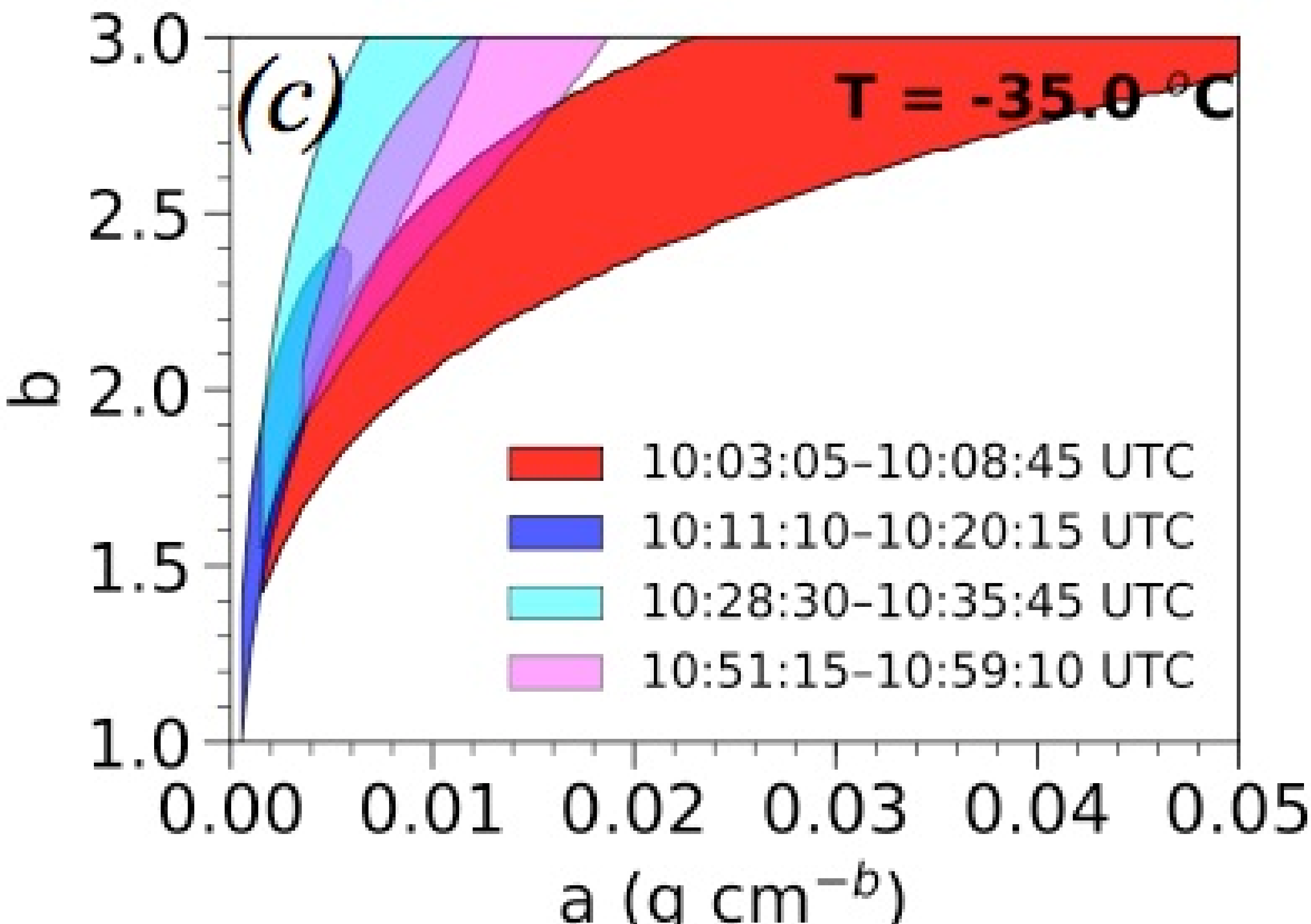

Range of values a and b generated by forcing agreement from bulk reflectivity and that computed from SDs from MC3E project

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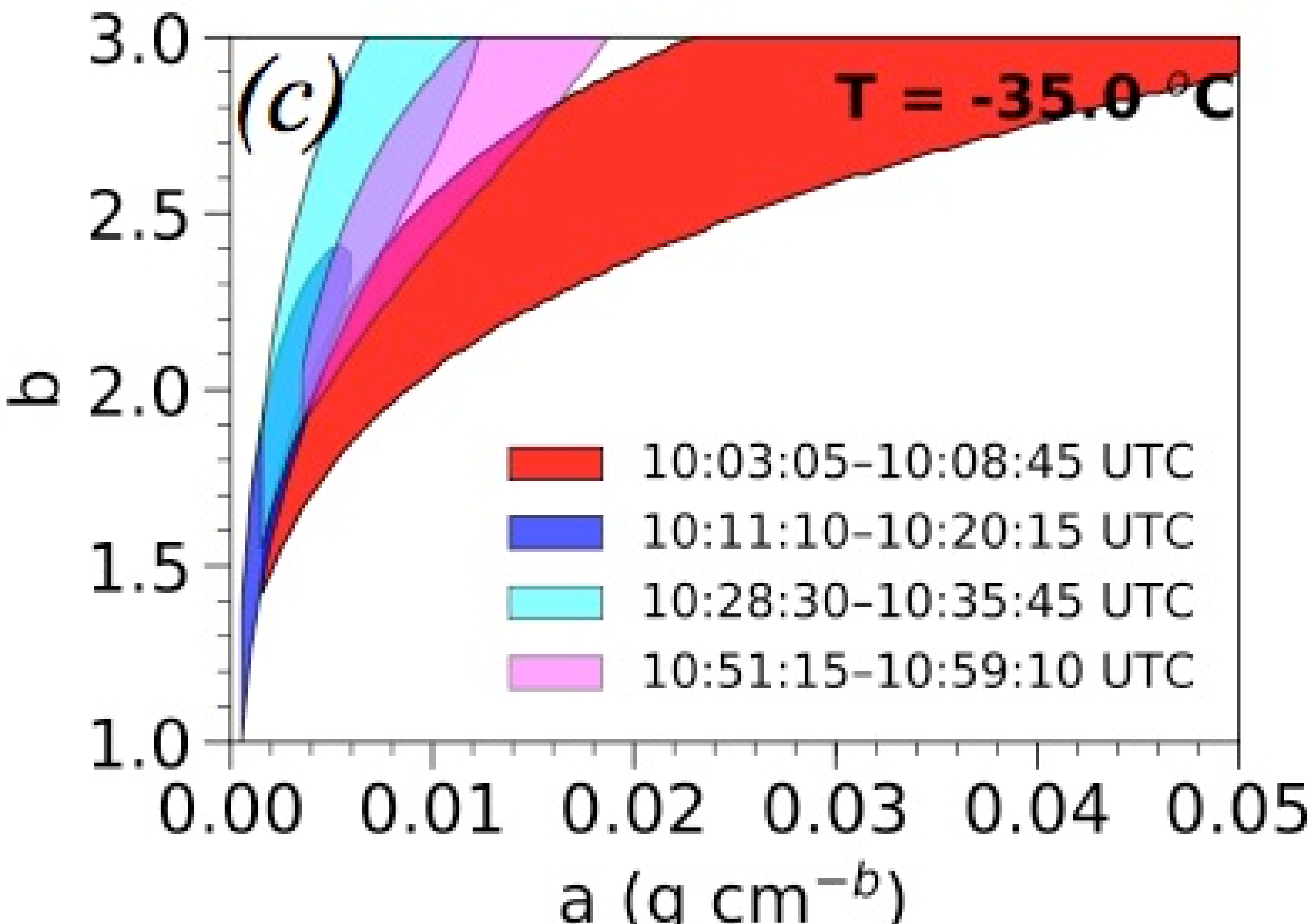
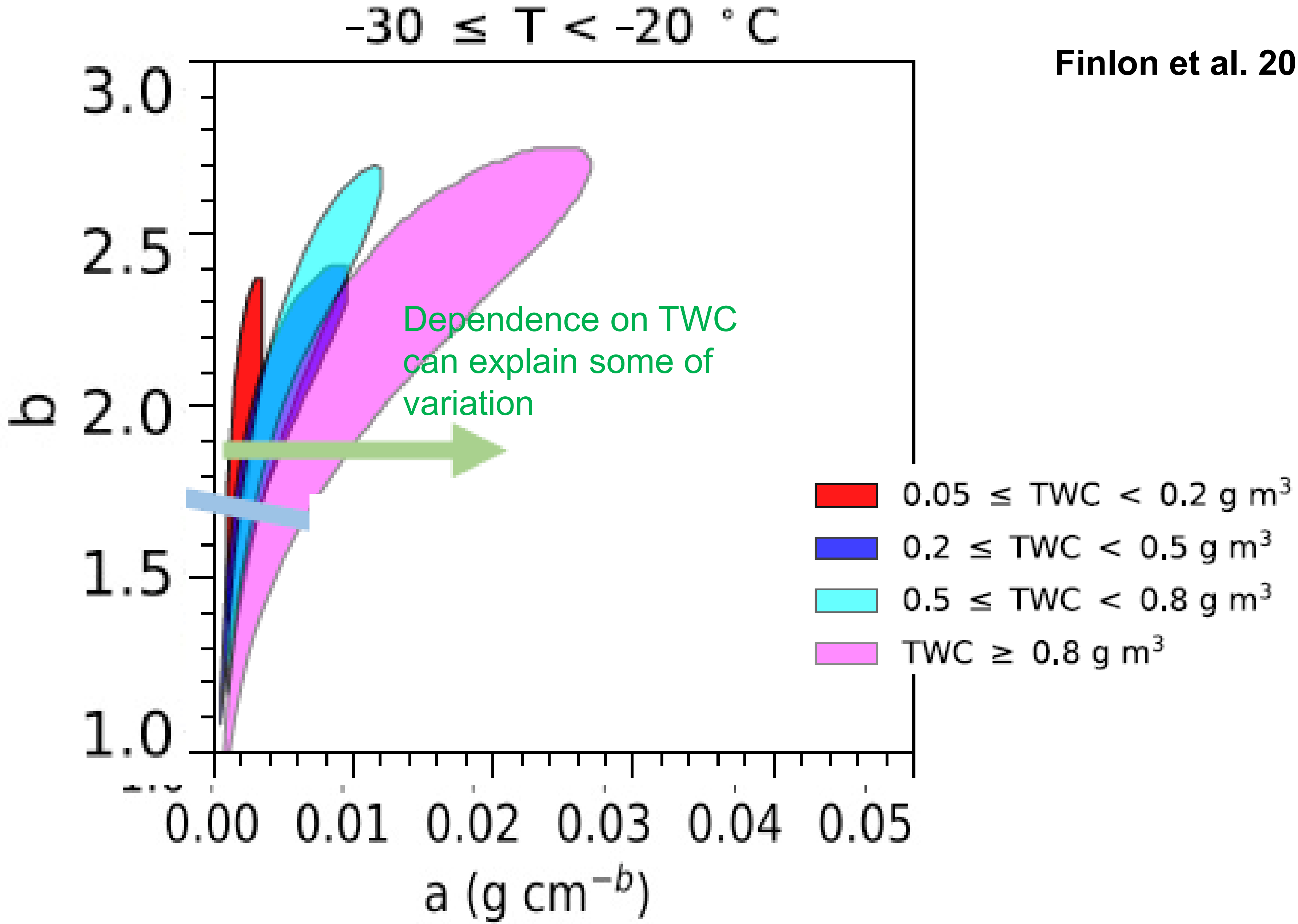


Can be variation in surfaces even for legs flown at similar T!



Finlon et al. 2018

Parameterizations of SDs

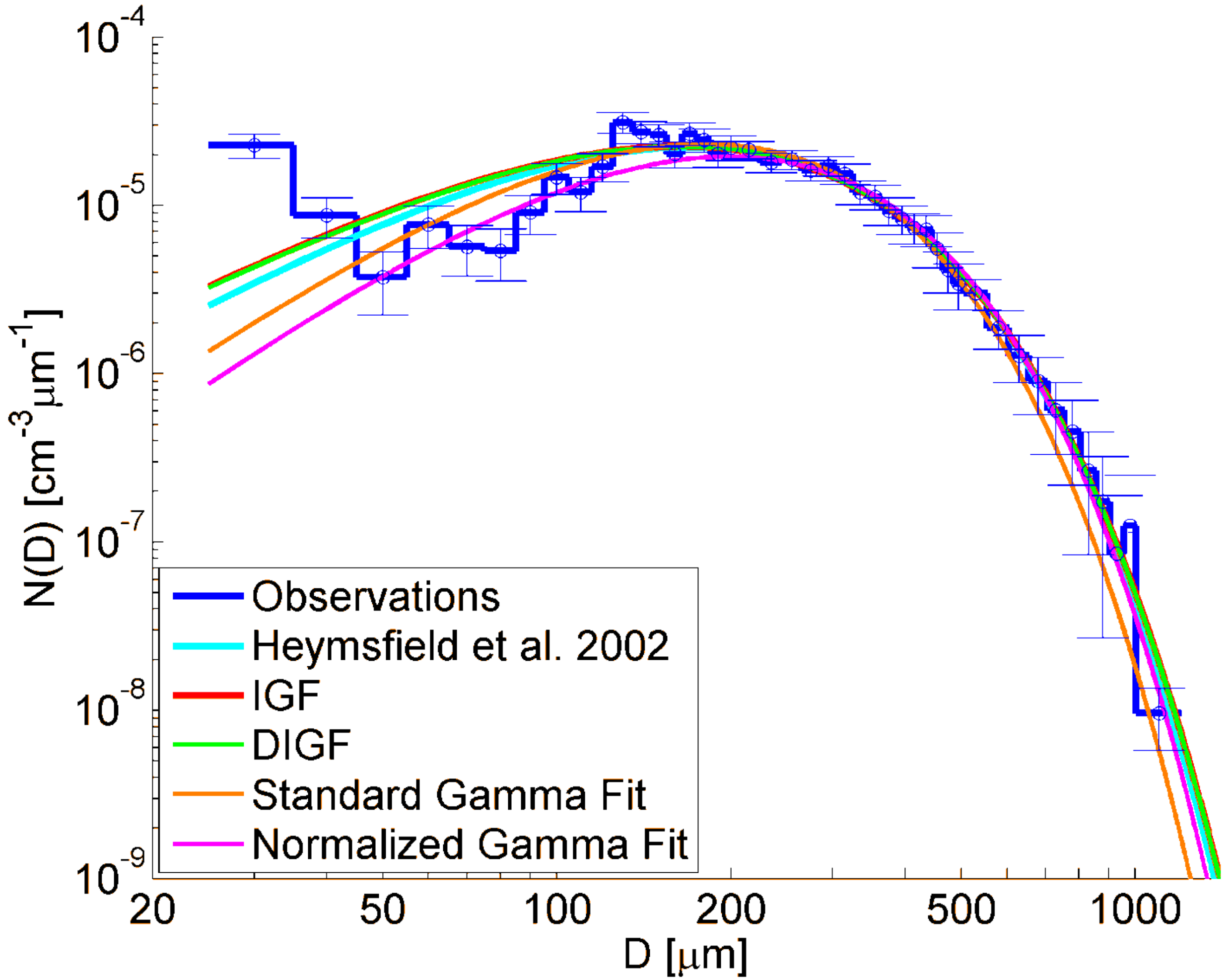
- **Gamma functions used to characterize N(D)**

$$N(D) = N_0 \ D^{\mu} \exp(-\lambda D)$$

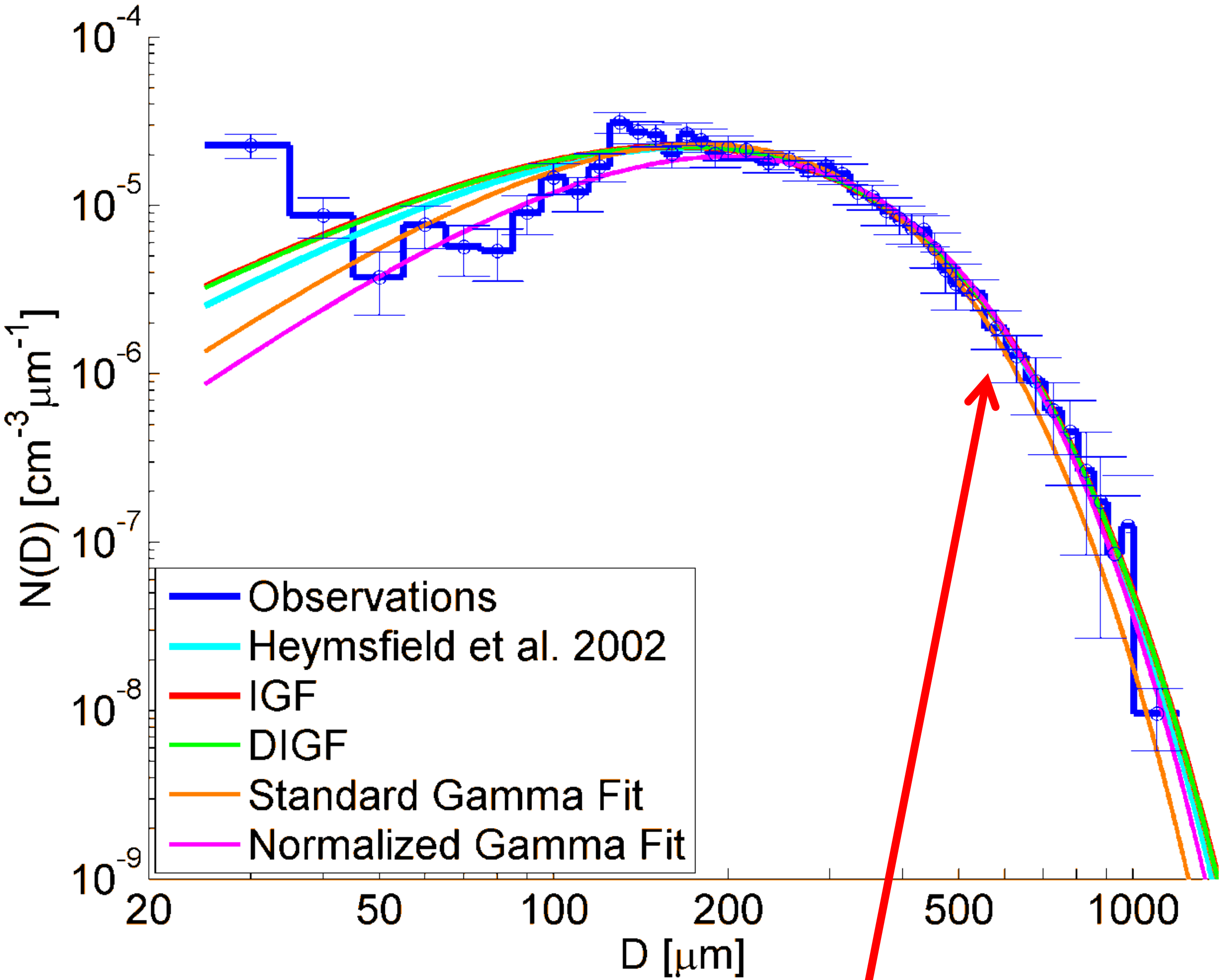
with N_0 intercept, λ slope and μ shape

- **Determine (N_0,μ,λ) by minimizing χ^2 difference between observed and fit moments**
- **Any (N_0,μ,λ) within $\Delta\chi^2$ of minimum χ^2 regarded as equally realizable solutions**

McFarquhar et al. 2015

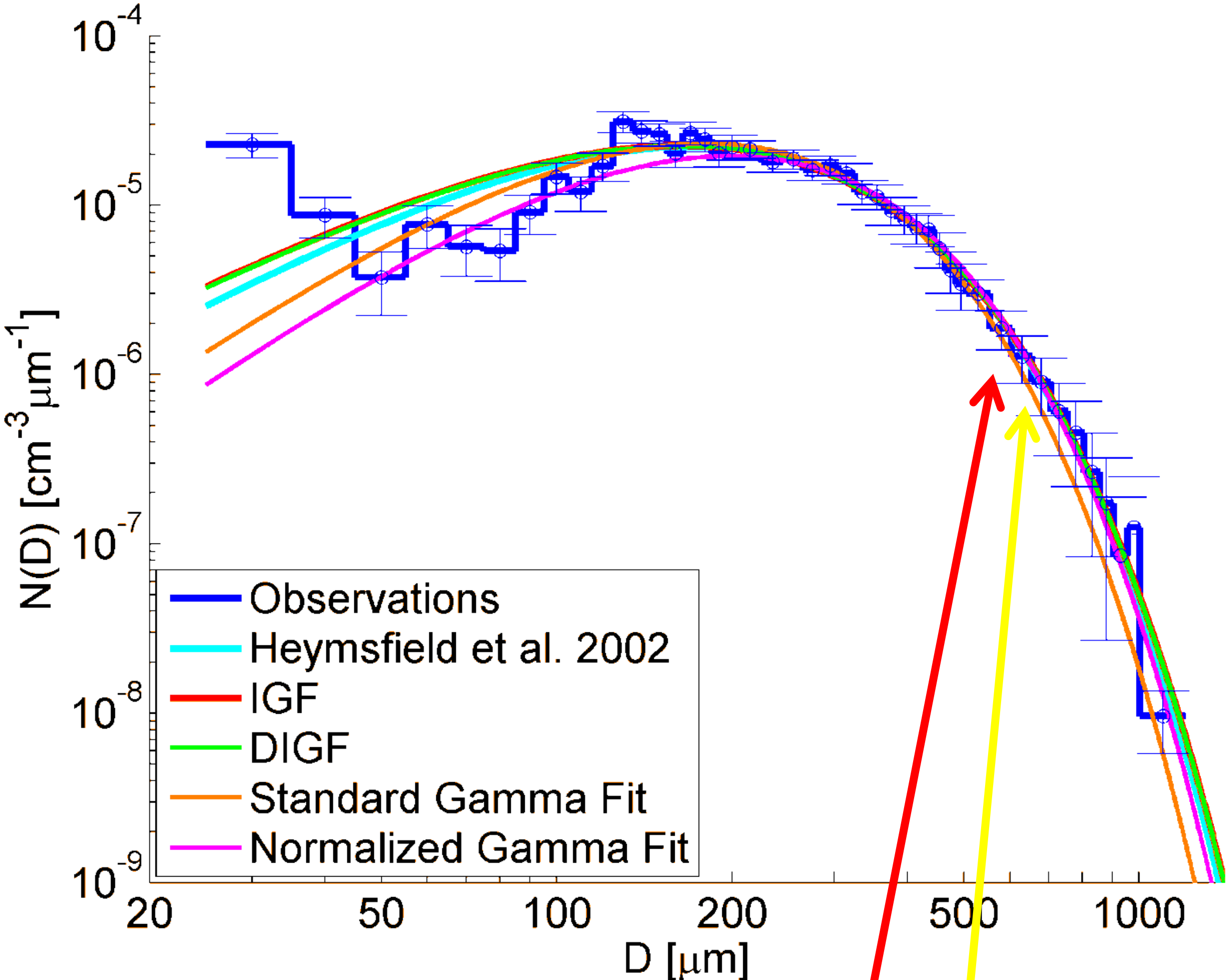


Even though fits all look quite good, there can be huge range in N_0, λ and μ



Even though fits all look quite good, there can be huge range in N_0, λ and μ

IGF: N_0 9.9×10^{-2} cm^{-3}μm^{-1} μ=1.62; λ =1.0×10^{-2} μm^{-1}



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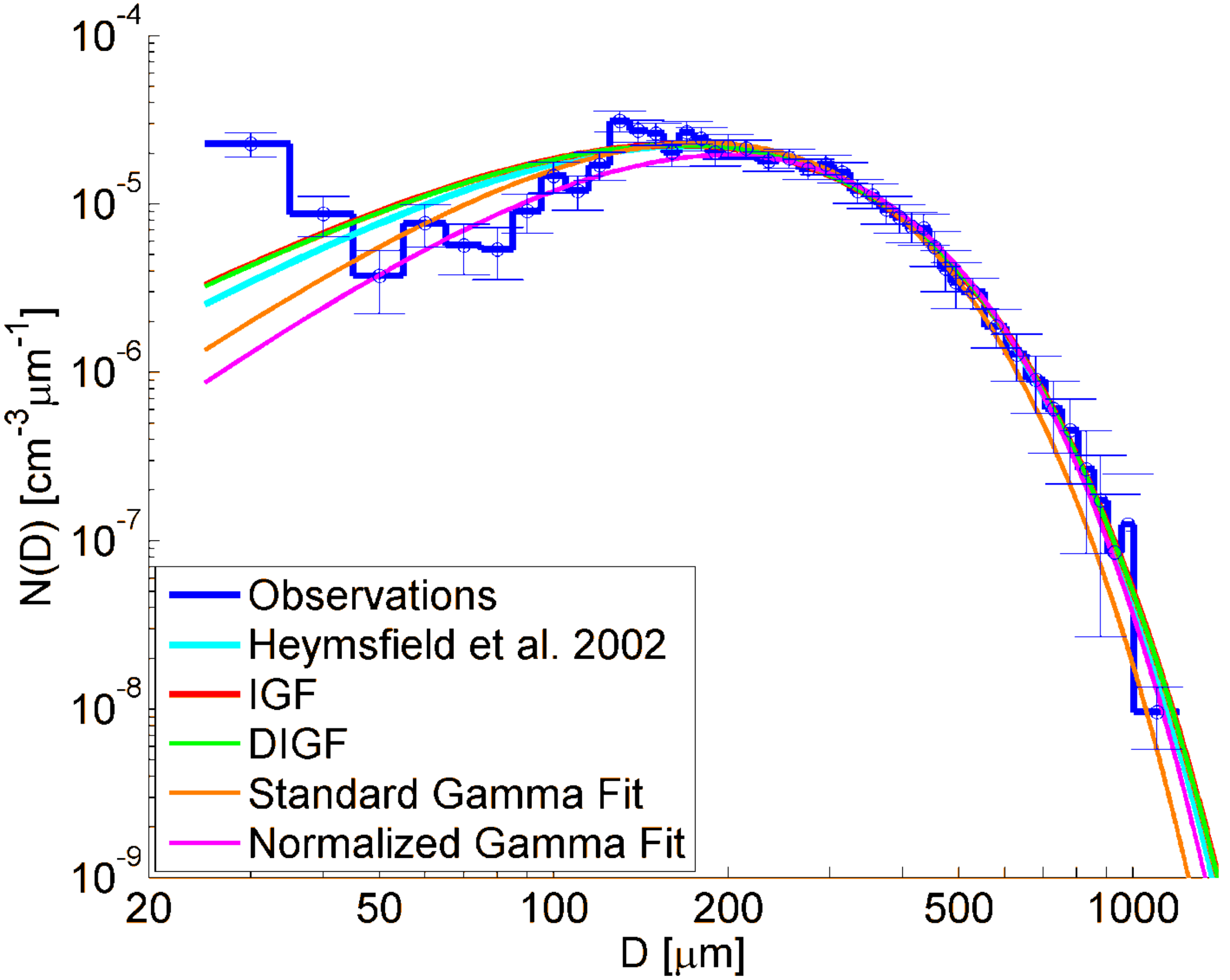
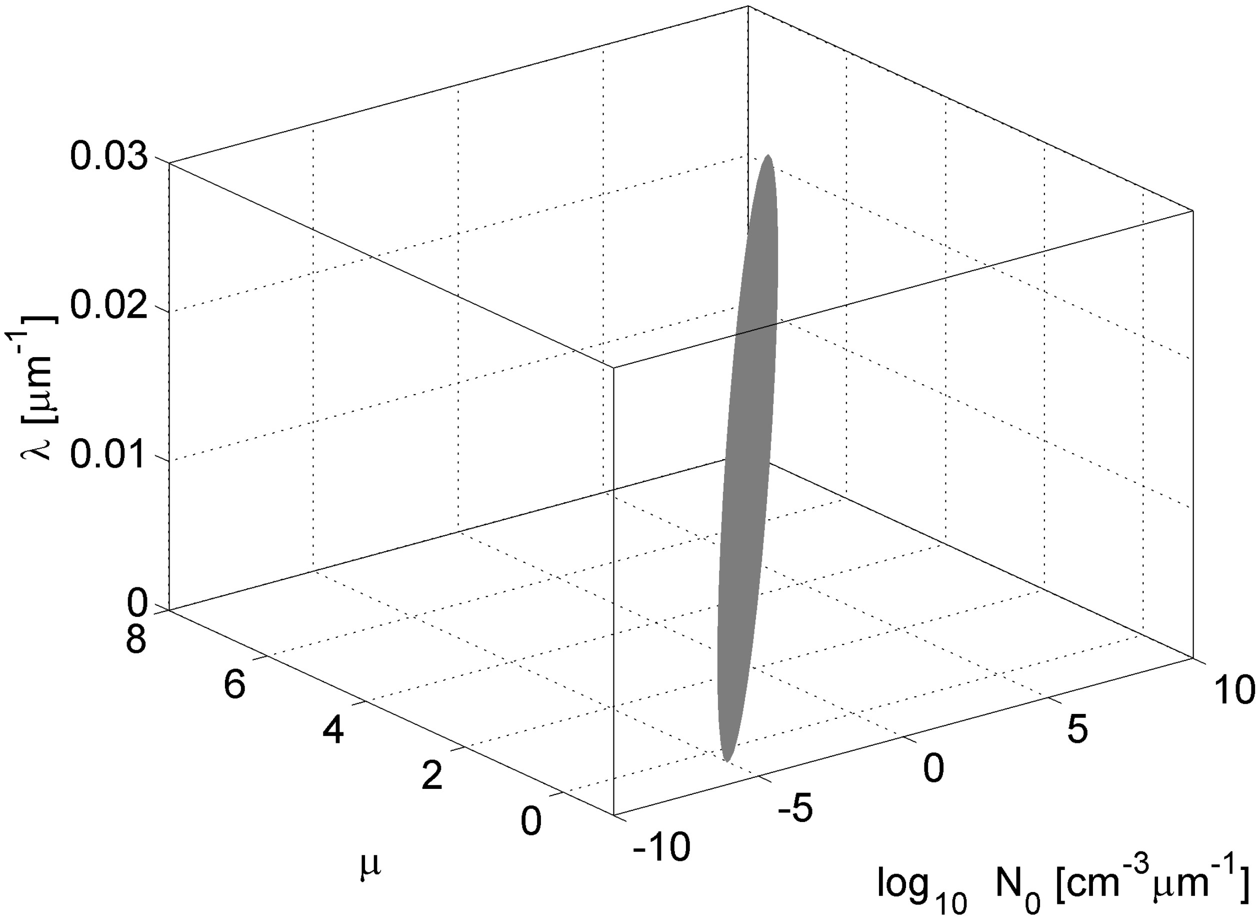
St.: N_0 7.8x10^{0} cm^{-3}μm^{-1} μ=2.54; λ =1.4x10^{-2} μm^{-1}



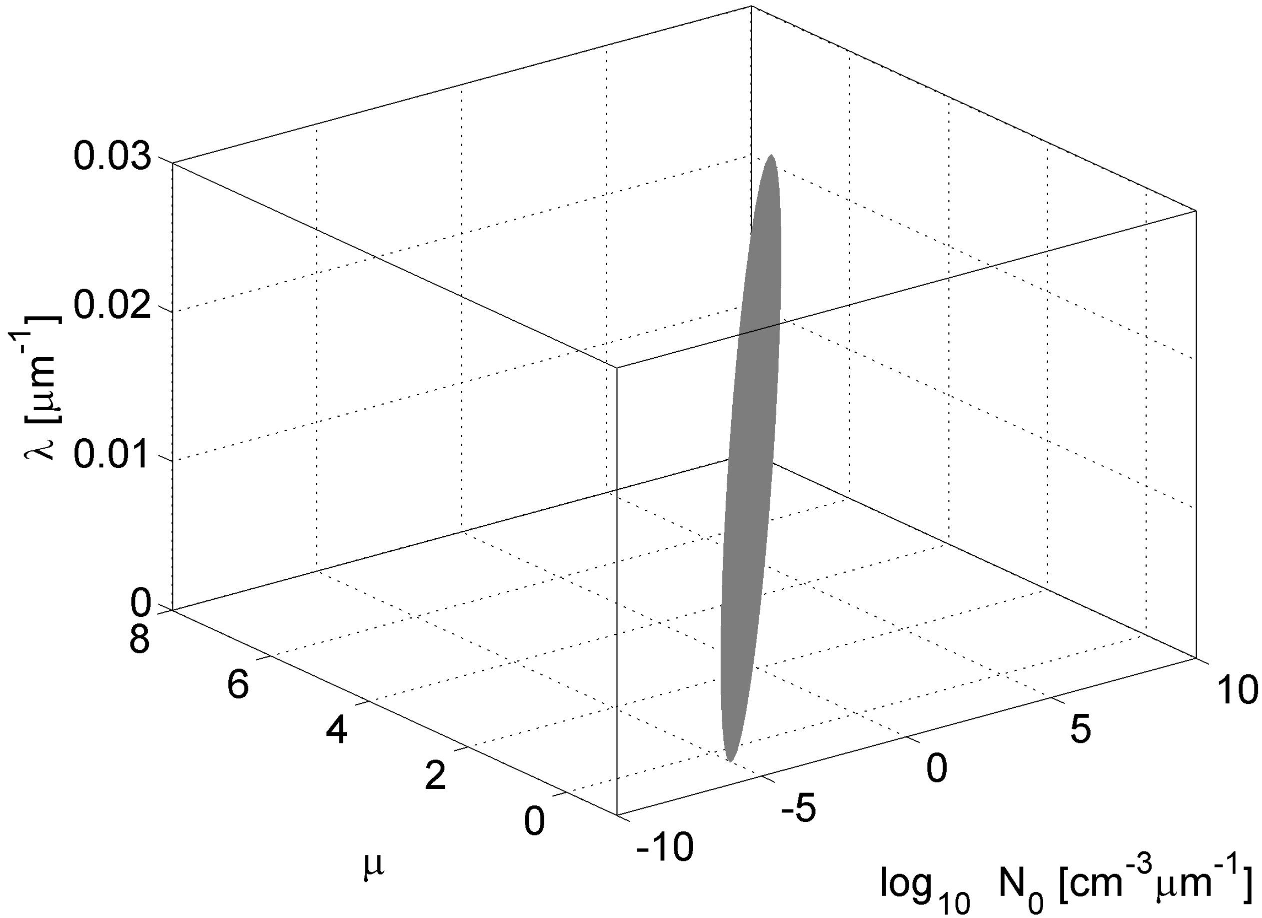
There is broad range of $N_0/\mu/\lambda$ that fit SD well

$N_0/\mu/\lambda$ determined depend on tolerance allowed

→ Can't represent by single $N_0/\mu/\lambda$ value



There is broad range of $N_0/\mu/\lambda$ that fit SD well
→ Range determined by IGF technique that allows derived/observed moments to differ by $\Delta\chi^2$
→ Can't represent by single $N_0/\mu/\lambda$ value



But how big is $\Delta\chi^2$?

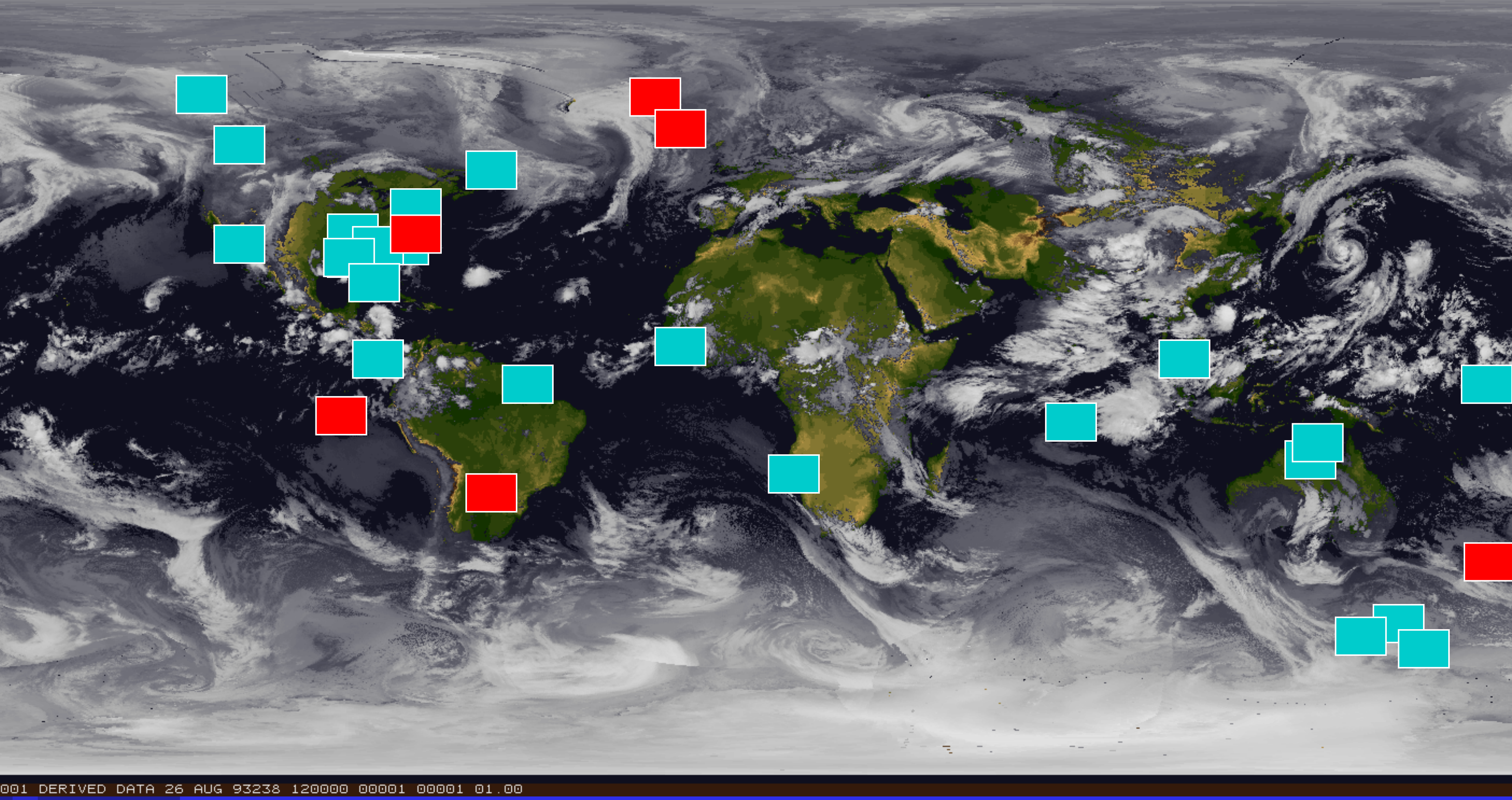
$N_0/\mu/\lambda$ determined from uncertainty in PSD

Summary

- Stochastic parameterizations of ice microphysics take into account different sources of uncertainty
  - measurement, statistical, variability
  - developed for size distributions and mass relationships
- Observations used to determine whether microphysical properties vary with environmental conditions within range of measured uncertainties
  - can be applied in models
  - can be used to evaluate remote sensing retrievals

Future

- **Observations in more regimes to learn more about processes affecting cloud properties (including aerosol-cloud interactions)**
  - **analyze data in a consistent manner because of varying error characteristics**
  - **Separate dependence on environmental conditions from variability & uncertainty**
- **Apply stochastic parameterizations in models to determine their impact**
  - **How do uncertainties in measured microphysics cascade up to model predicted fields?**



Cloud properties vary depending upon formation mechanism, height and geographic location

Need observations in variety of locations!! Projects have sampled and will sample clouds in a variety of locations

Empirical mass-Dimension Relationships

Particle Type	Mass-Size Relationship
Lump graupel	$M = 0.042D^{3.0}$, $N = 35$, $r = 0.98$
Lump graupel	$M = 0.078D^{2.8}$, $N = 58$, $r = 0.93$
Lump graupel	$M = 0.14D^{2.7}$, $N = 17$, $r = 0.98$
Conical graupel	$M = 0.073D^{2.6}$, $N = 26$, $r = 0.91$
Hexagonal graupel	$M = 0.044D^{2.9}$, $N = 31$, $r = 0.93$
Graupellike snow of lump type*	$M = 0.059D^{2.1}$, $N = 17$, $r = 0.91$
Graupellike snow of hexagonal type†	$M = 0.021D^{2.4}$, $N = 22$, $r = 0.72$
Densely rimed columns	$M = 0.033L^{2.3}$, $N = 13$, $r = 0.78$
Densely rimed dendrites†	$M = 0.015D^{2.3}$, $N = 9$, $r = 0.90$
Densely rimed radiating assemblages of dendrites*	$M = 0.039D^{2.1}$, $N = 13$, $r = 0.92$

Locatelli & Hobbs (1974)

VERY LOW REPRESENTATIVE SAMPLE

CANNOT RESOLVE VARIATION IN PARTICLE MASS