Use of SPARTICUS ice crystal image analysis to develop internally consistent representations of ice physical and optical properties for a size-resolved microphysics model

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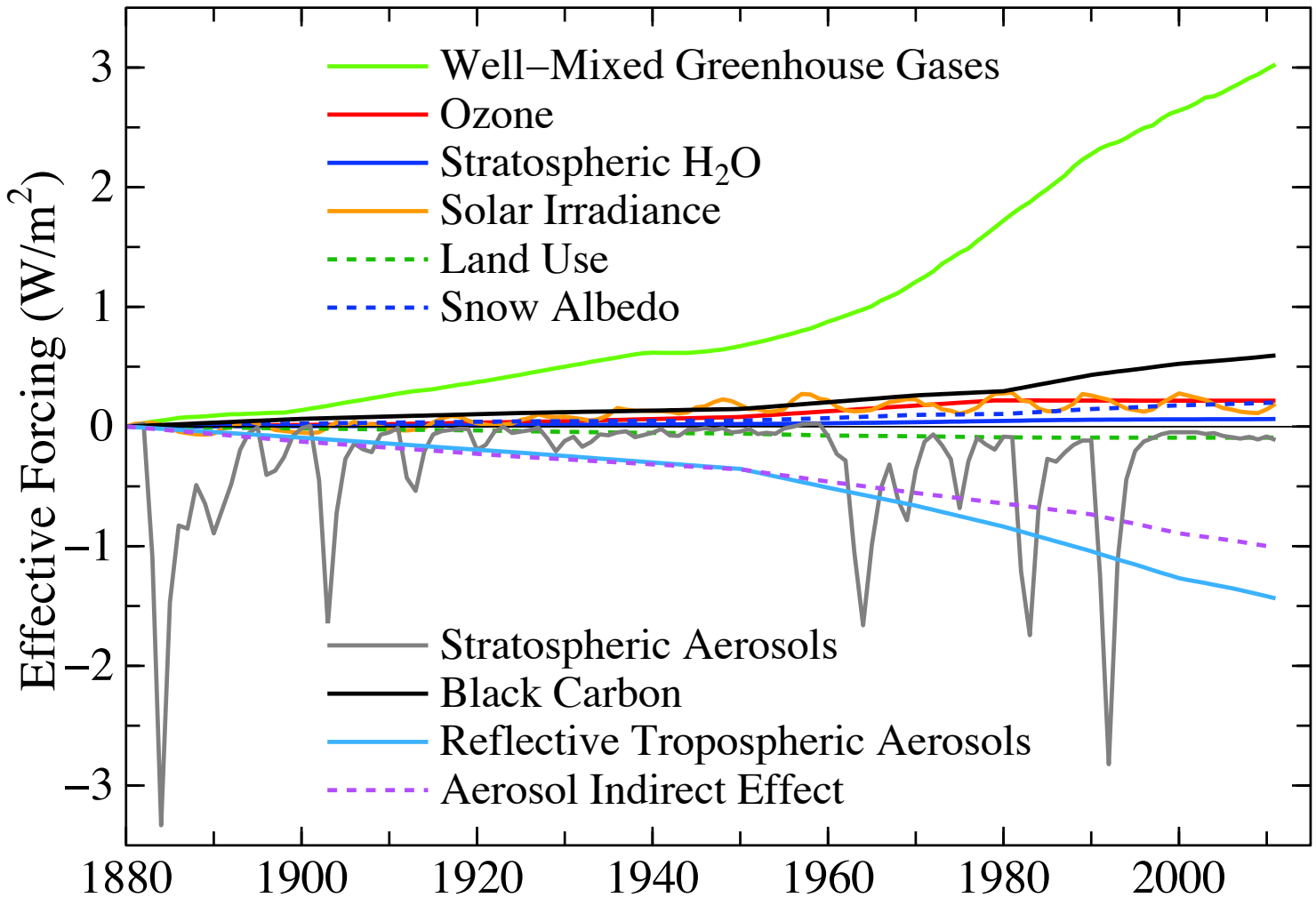
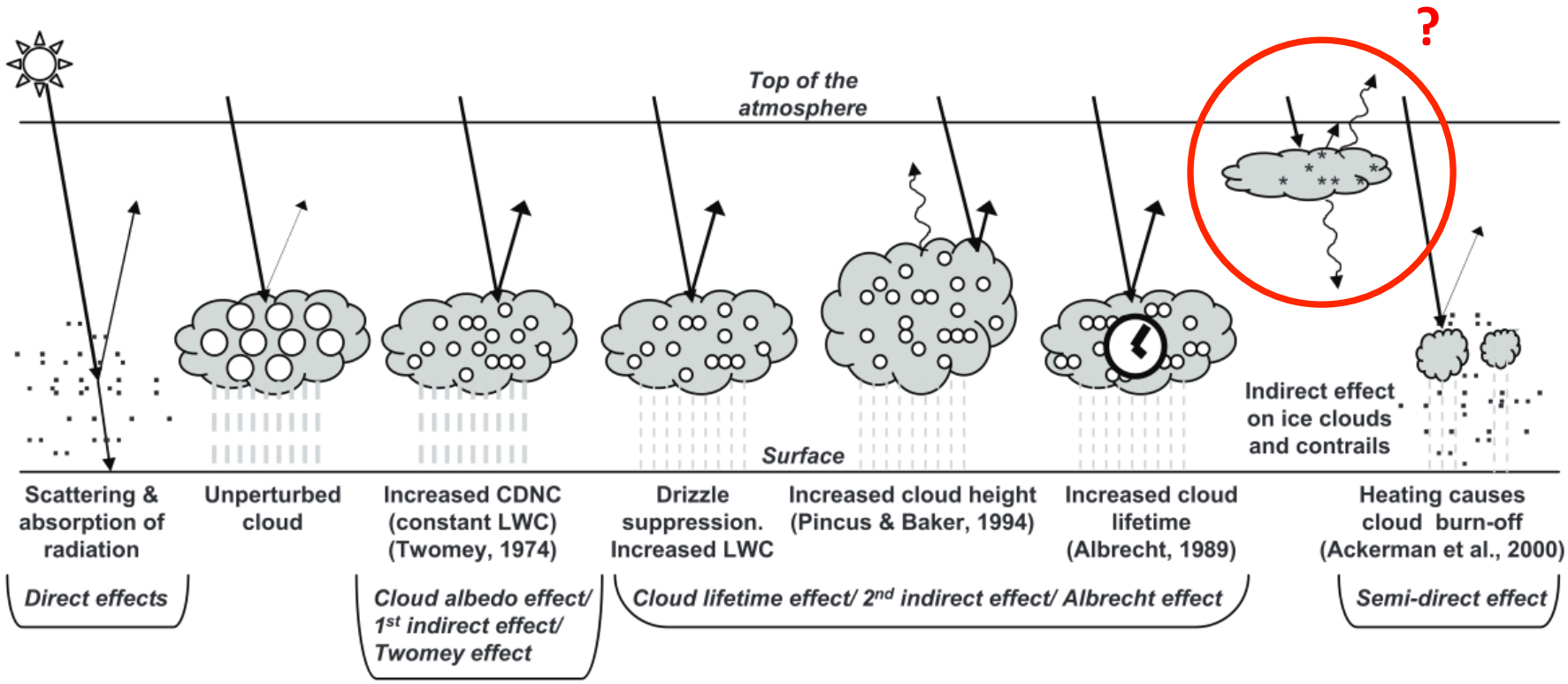
Aerosol indirect effects on radiative fluxes



http://data.giss.nasa.gov/modelforce/RadF.pdf

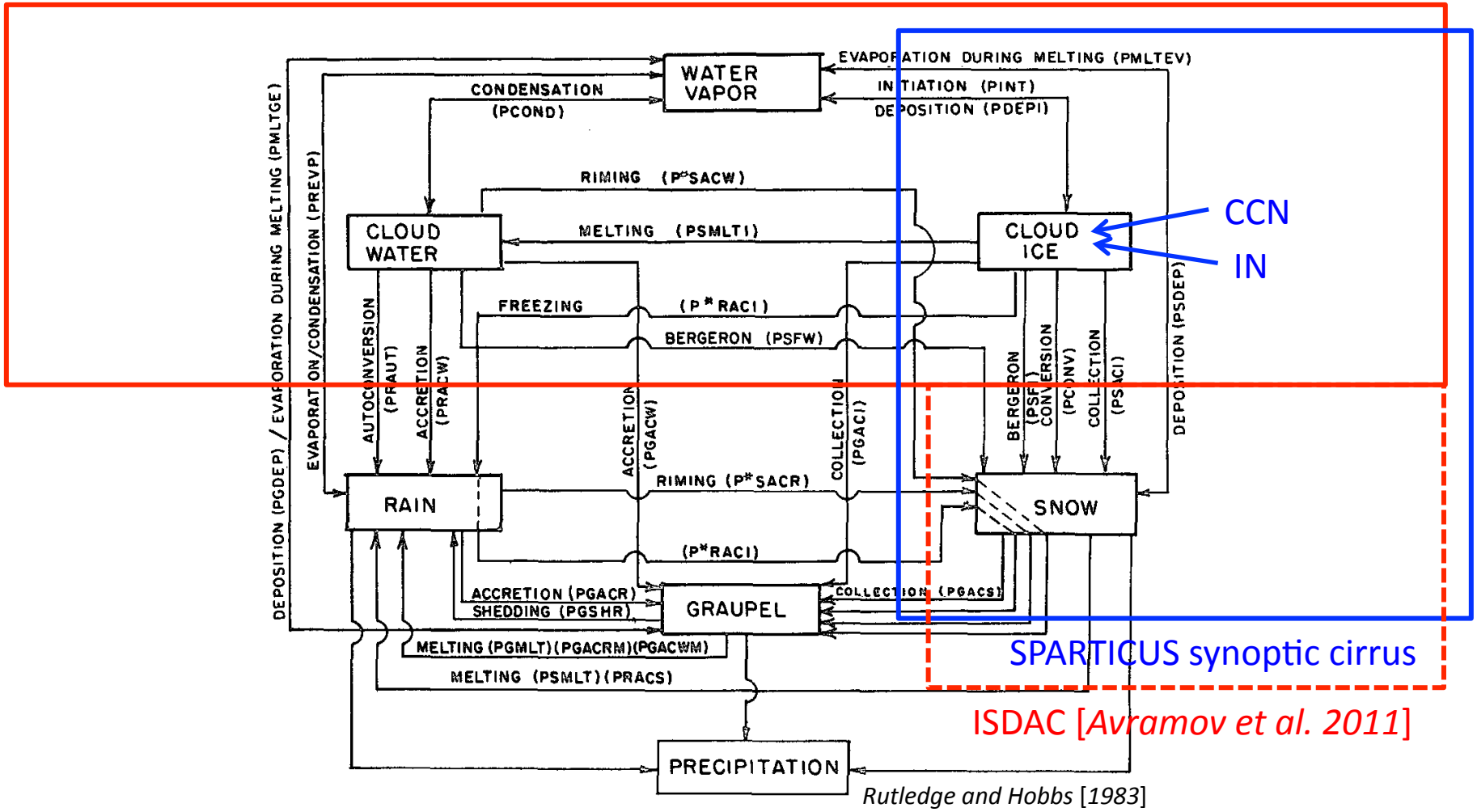
Aerosol indirect effects on radiative fluxes

- Fig. 2.10 from *Climate Change 2007: The Physical Science Basis* [IPCC WG1, 2007]

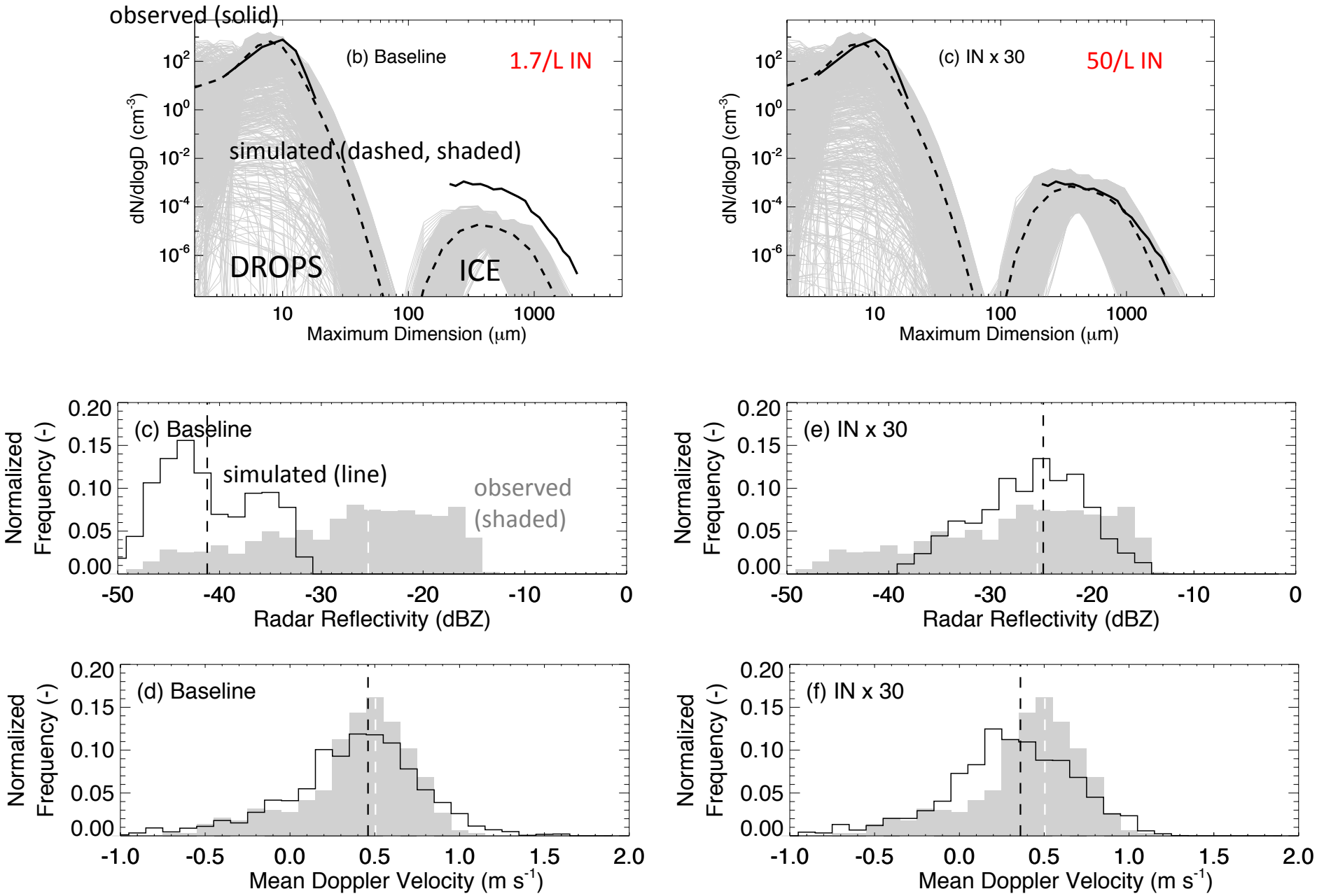


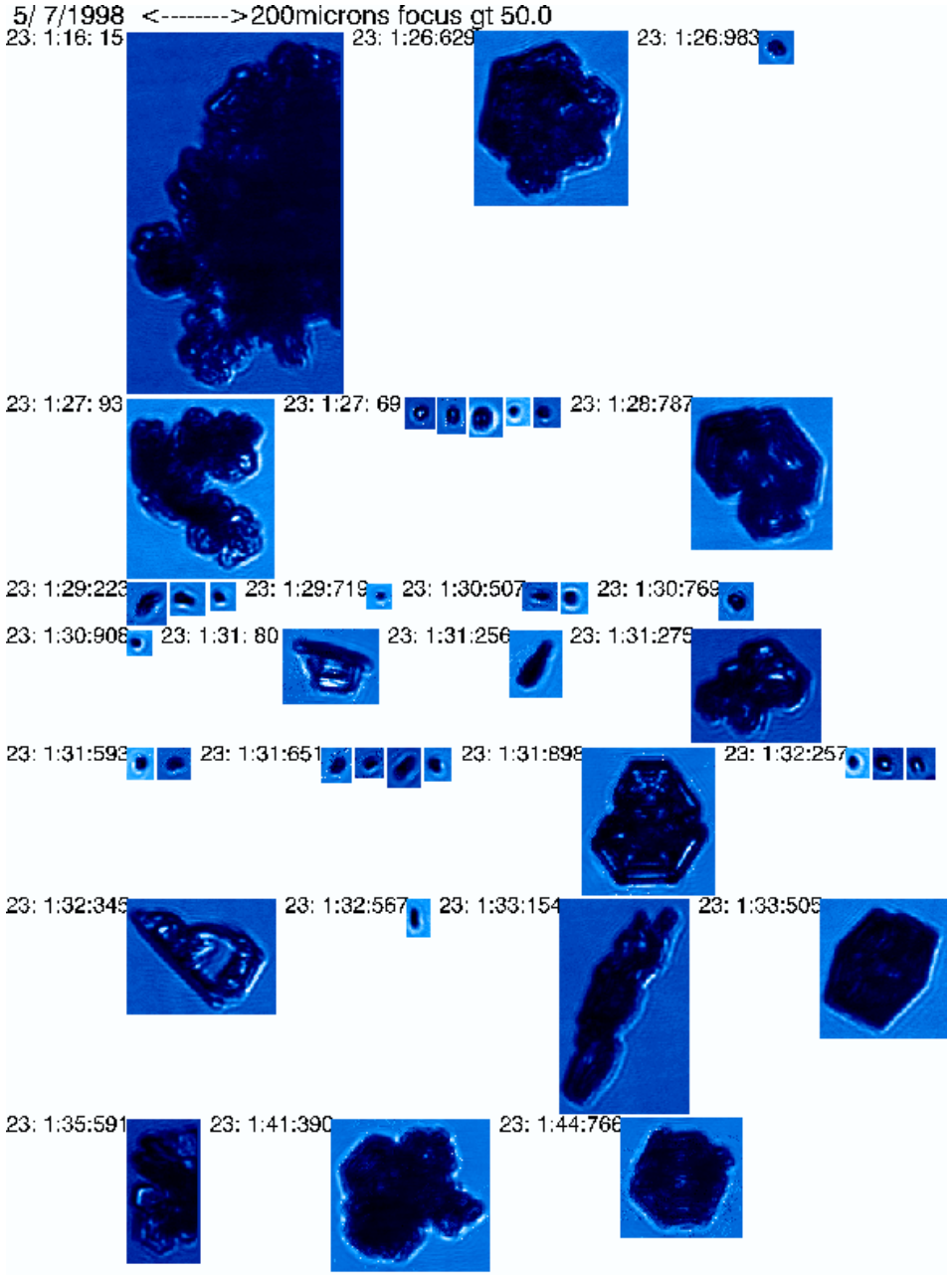
Field experiment conditions

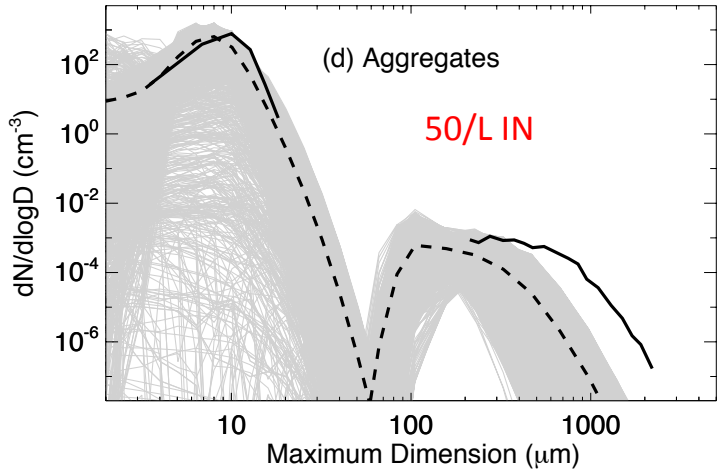
SHEBA boundary-layer stratus [*Morrison et al., JAMES, 2011; Fridlind et al., JAS, 2012*]

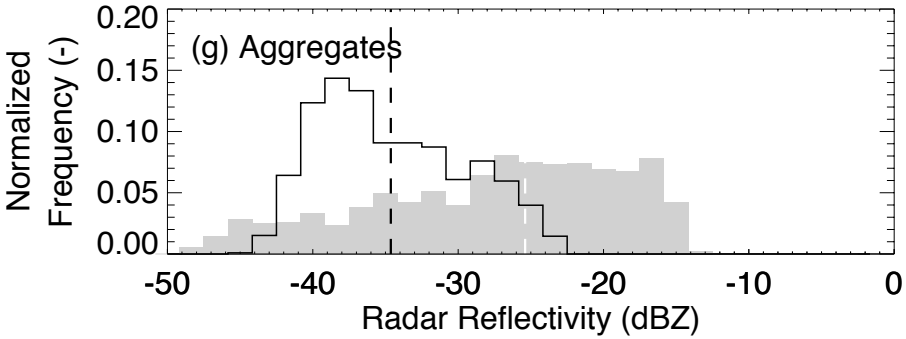


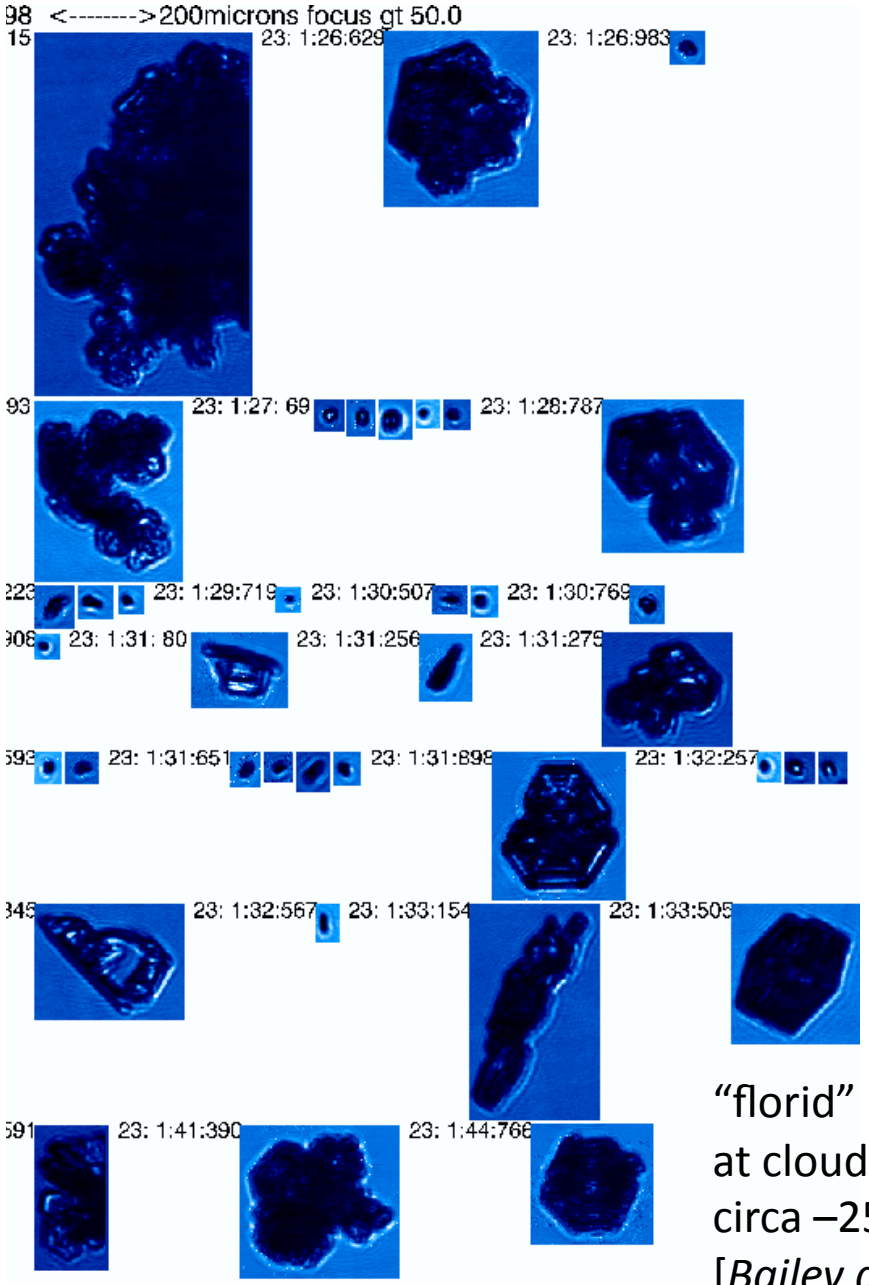
Rutledge and Hobbs [*1983*]


observed (solid)
(b) Baseline
1.7/L IN
simulated (dashed, shaded)
DROPS
ICE
dN/dlogD (cm-3)
Maximum Dimension (μm)
(c) IN x 30
50/L IN
(c) Baseline
simulated (line)
observed (shaded)
Normalized Frequency (-)
Radar Reflectivity (dBZ)
(e) IN x 30
(d) Baseline
Mean Doppler Velocity (m s-1)
(f) IN x 30


5/ 7/1998 <-------->200microns focus gt 50.0
23: 1:16: 15
23: 1:26:629
23: 1:26:983
23: 1:27: 93
23: 1:27: 69
23: 1:28:787
23: 1:29:223
23: 1:29:719
23: 1:30:507
23: 1:30:769
23: 1:30:908
23: 1:31: 80
23: 1:31:256
23: 1:31:279
23: 1:31:593
23: 1:31:651
23: 1:31:898
23: 1:32:257
23: 1:32:345
23: 1:32:567
23: 1:33:154
23: 1:33:505
23: 1:35:591
23: 1:41:390
23: 1:44:766


(d) Aggregates
50/L IN
dN/dlogD (cm^{-3})
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10
100
1000
Maximum Dimension (μm)


(g) Aggregates
Normalized Frequency (-)
0.20
0.15
0.10
0.05
0.00
-50
-40
-30
-20
-10
0
Radar Reflectivity (dBZ)



Bohm [*AR, 1989*]

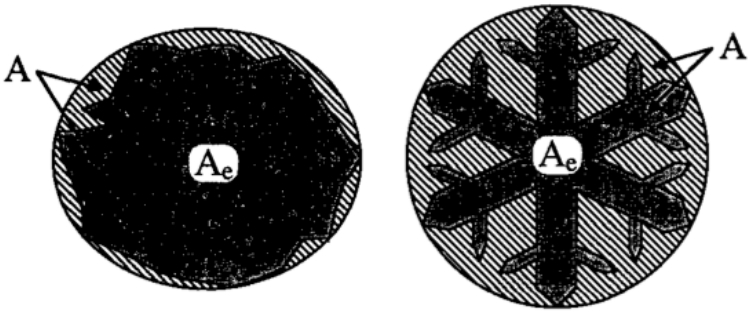
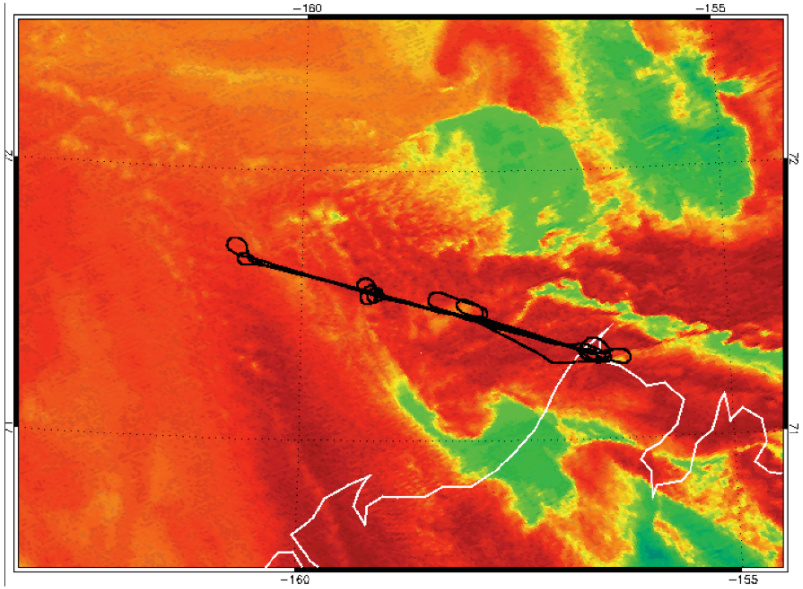


FIG. 1. Definition of cross sectional areas A_e and A. A includes the hatched and shaded areas. See text for explanations.

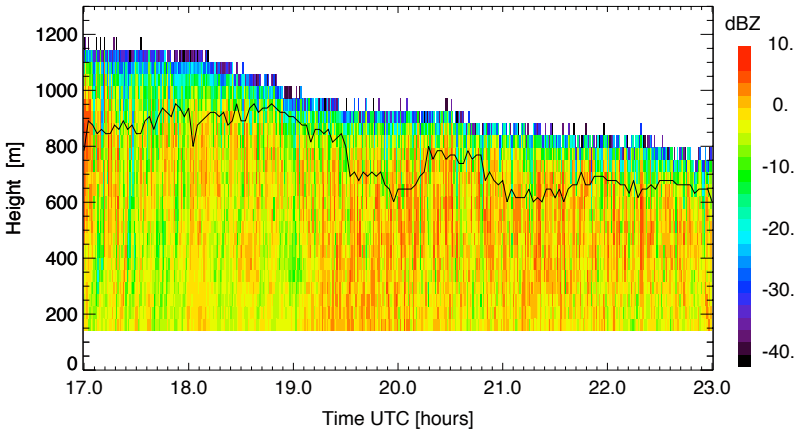
Ice fall speeds and collision-coalescence based on specified ice properties (not "habit")
[*Böhm et al. 1989, 1999, 2004; Heymsfield and Westbrook 2010*]
— mass (fundamental property)
— maximum dimension [*Mitchell et al. 1990*]
— projected area [*Mitchell et al. 1996*]
— aspect ratio [*Korolev and Isaac 2003*]

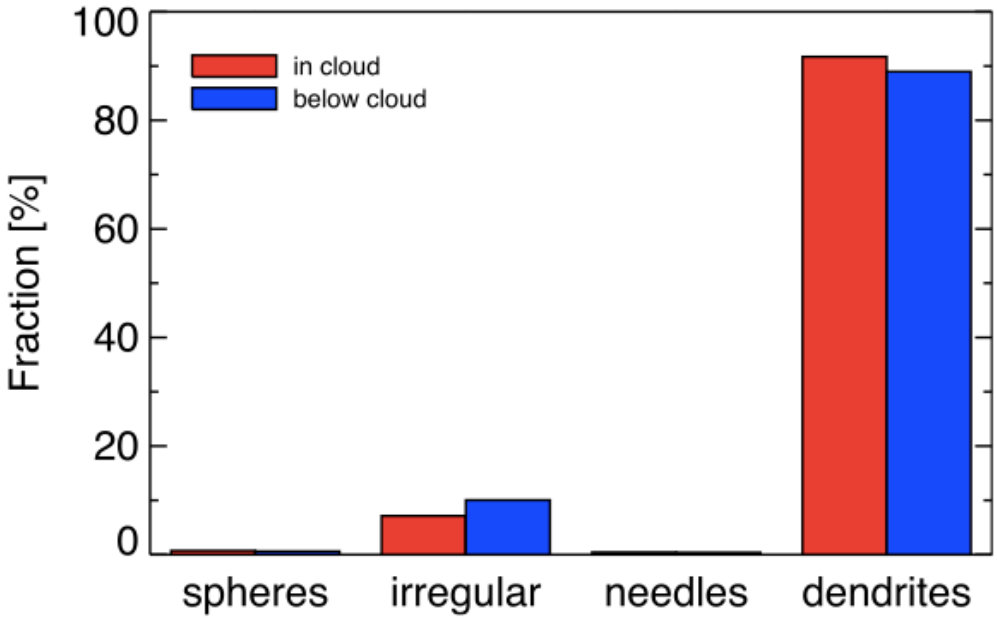
"florid" radiating plates
at cloud top temperature
circa –25°C (high RH wrt ice)
[*Bailey and Hallett JAS 2004*]

ISDAC: Dendrites and aggregates



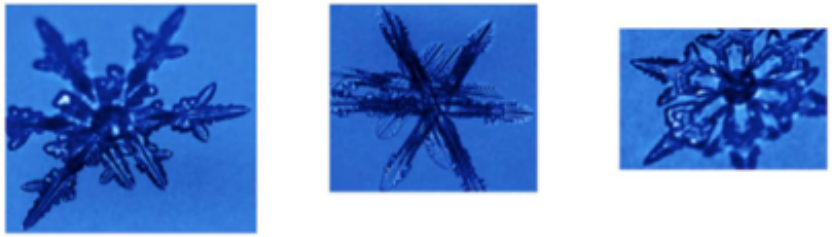
MODIS 3.7-µm

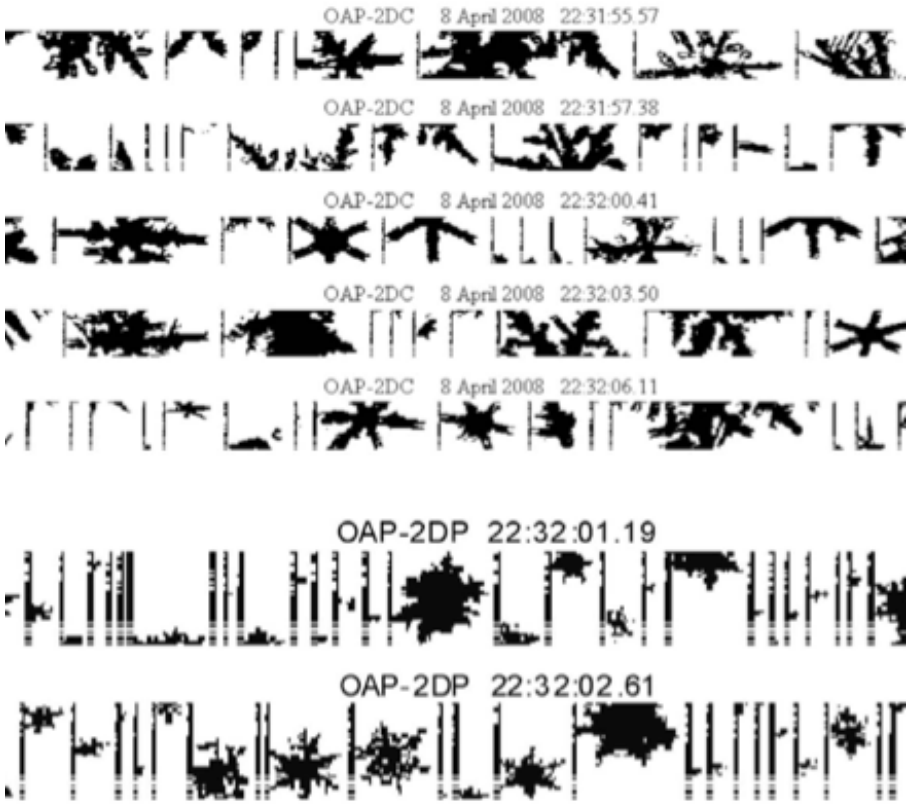




Avramov et al. [*JGR 2011*]

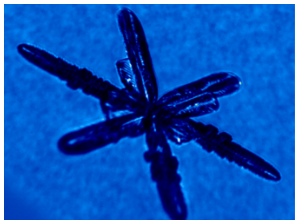
ISDAC: Dendrites and aggregates





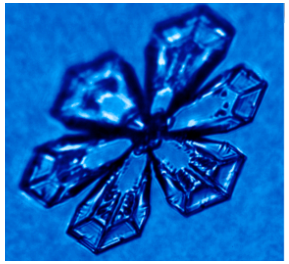
"low density" P1d stellar dendrite

~1 mm



"high density" P1c broad arm dendrite

~1 mm

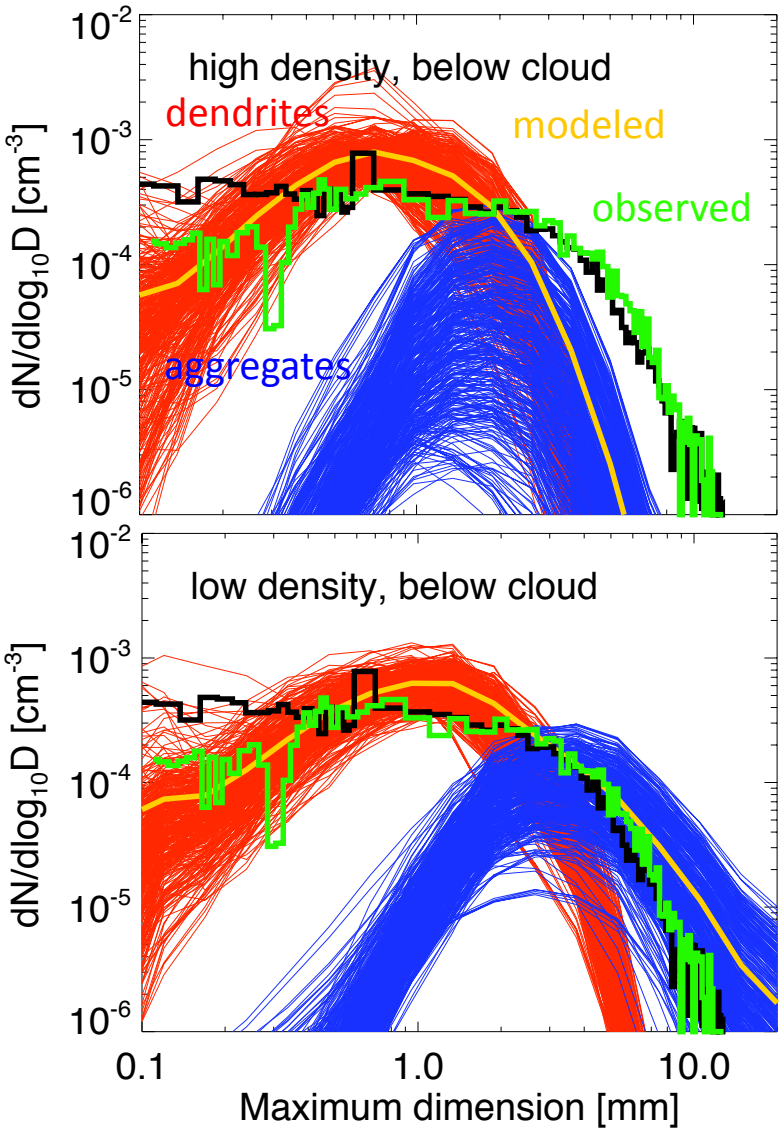


aggregates of dendrites

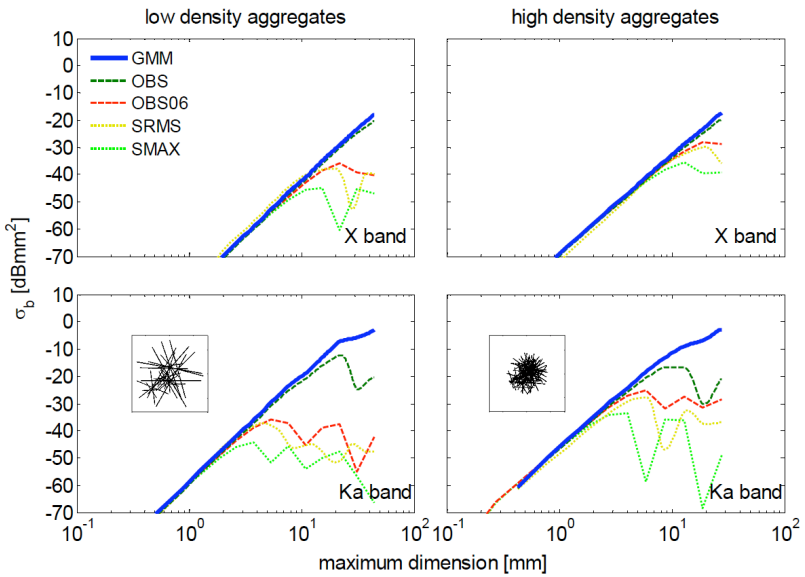
0.8 mm

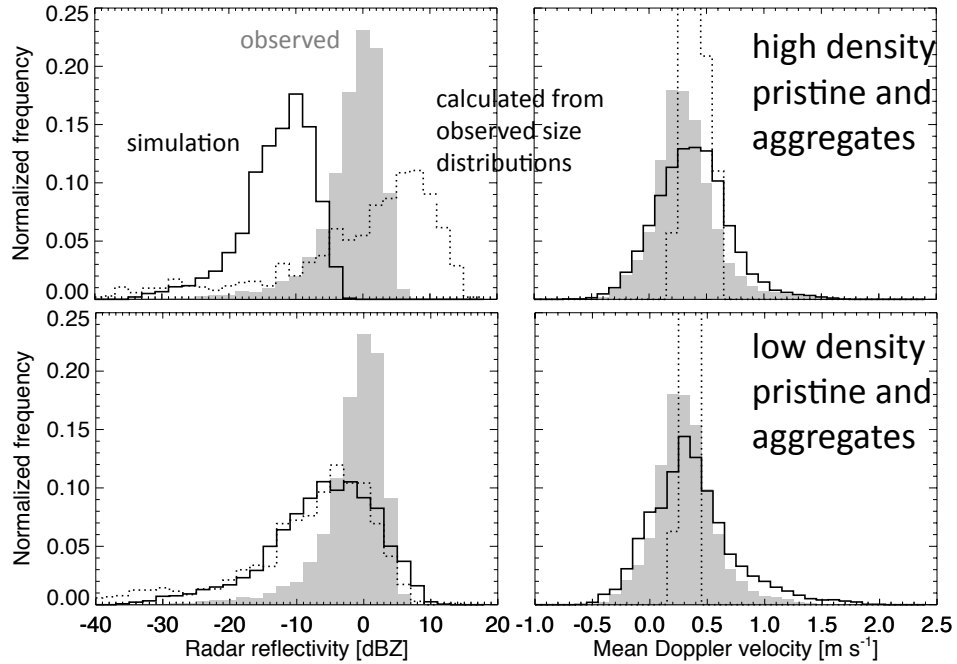
Avramov et al. [*2011*]

ISDAC: Ka-band reflectivity

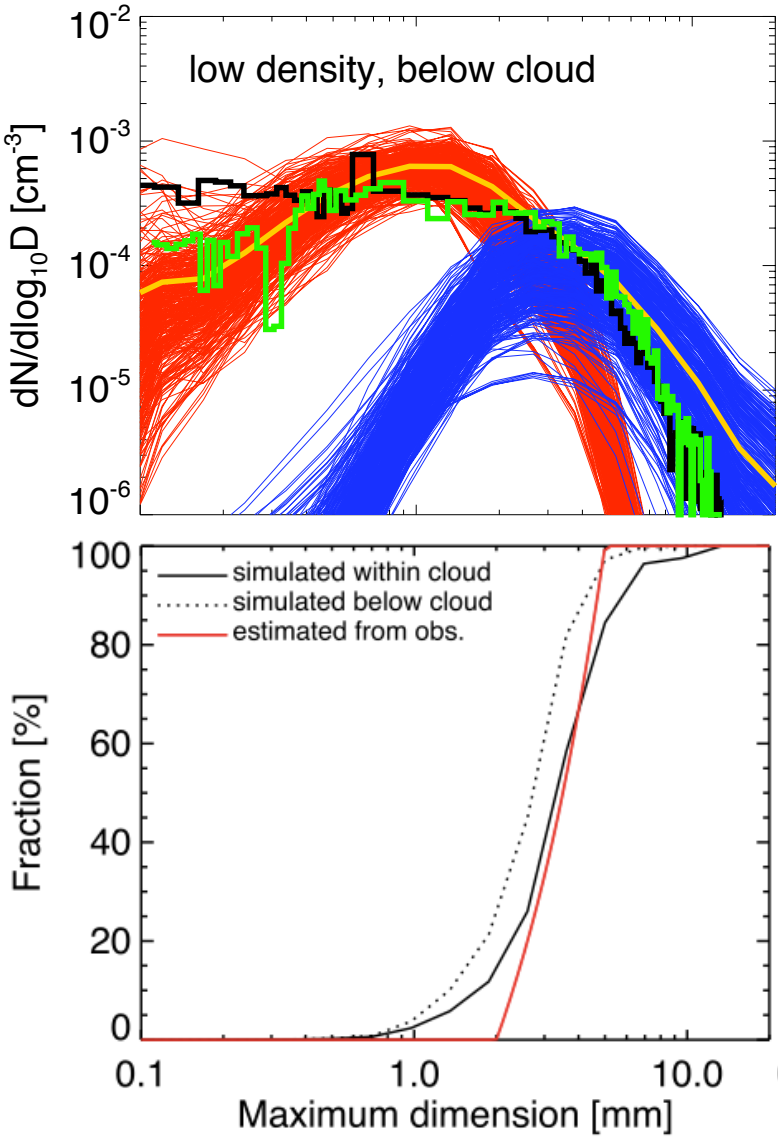


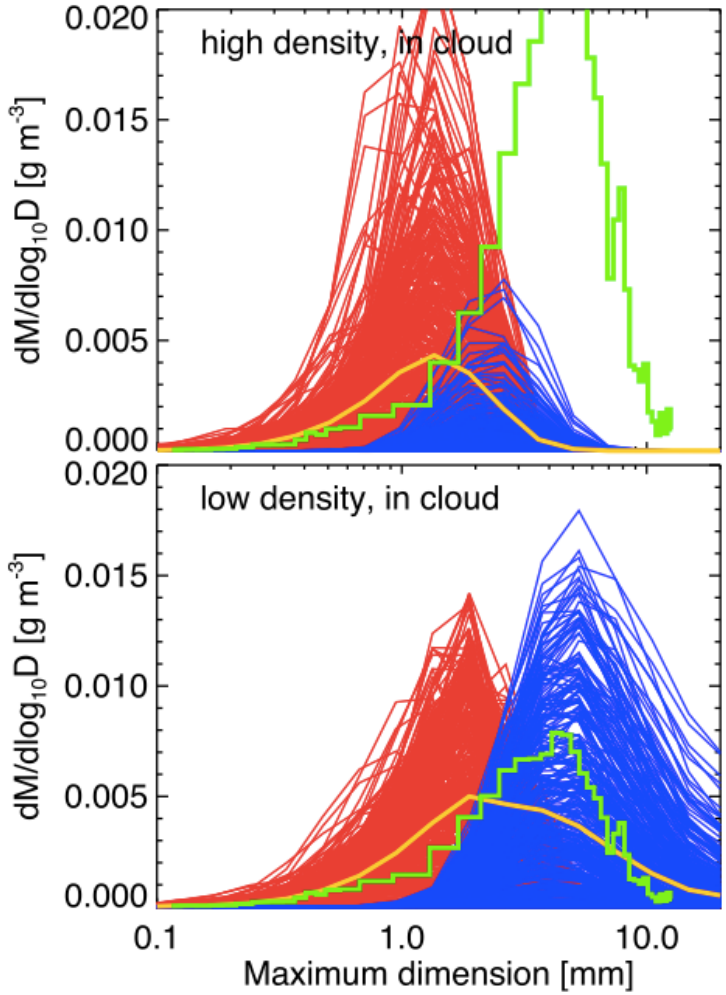
Botta et al. [2011]





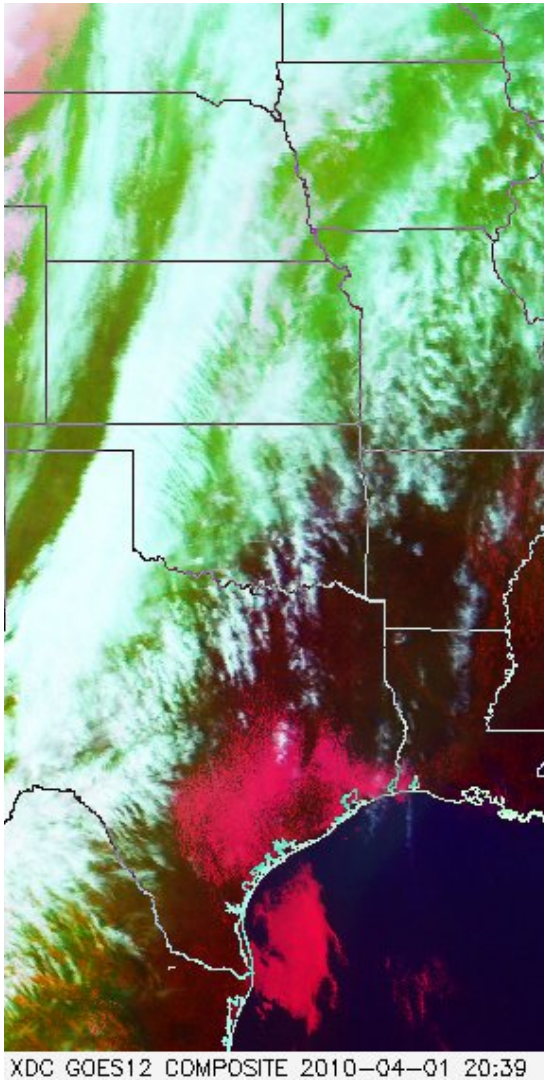
Ice aggregation during ISDAC

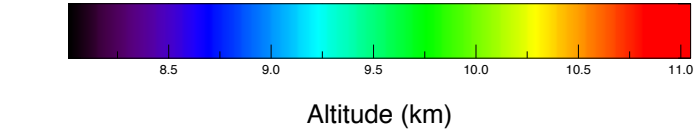


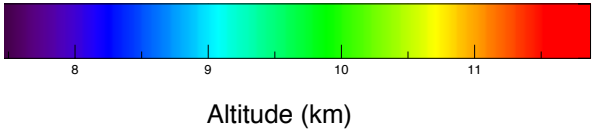


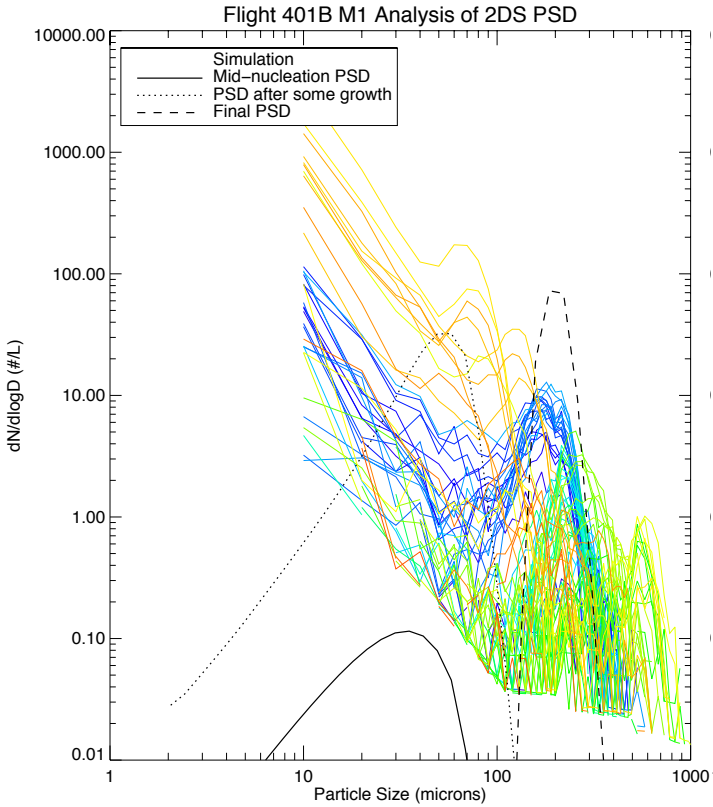
Avramov et al. [*JGR 2011*]

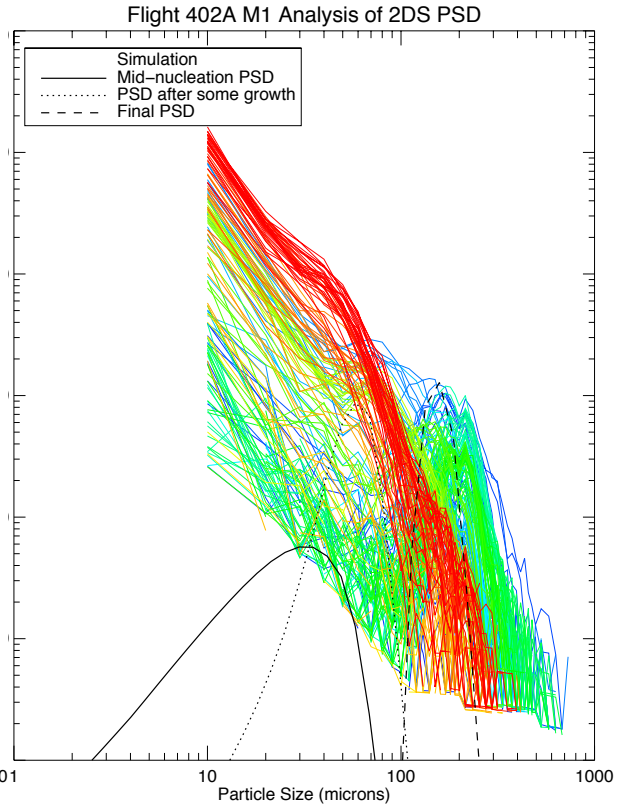
SPARTICUS

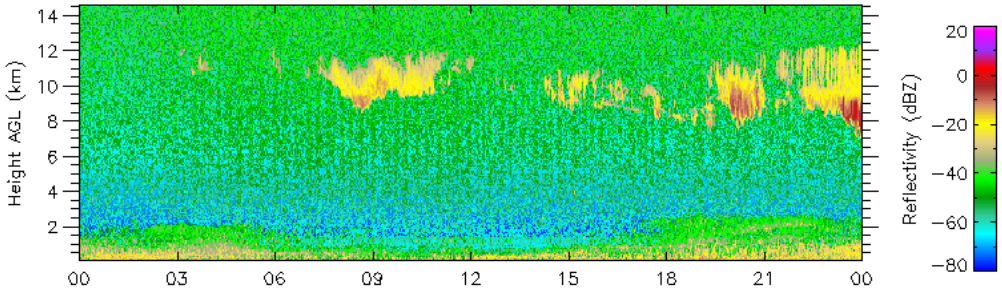

XDC GOES12 COMPOSITE 2010-04-01 20:39


8.5
9.0
9.5
10.0
10.5
11.0
Altitude (km)

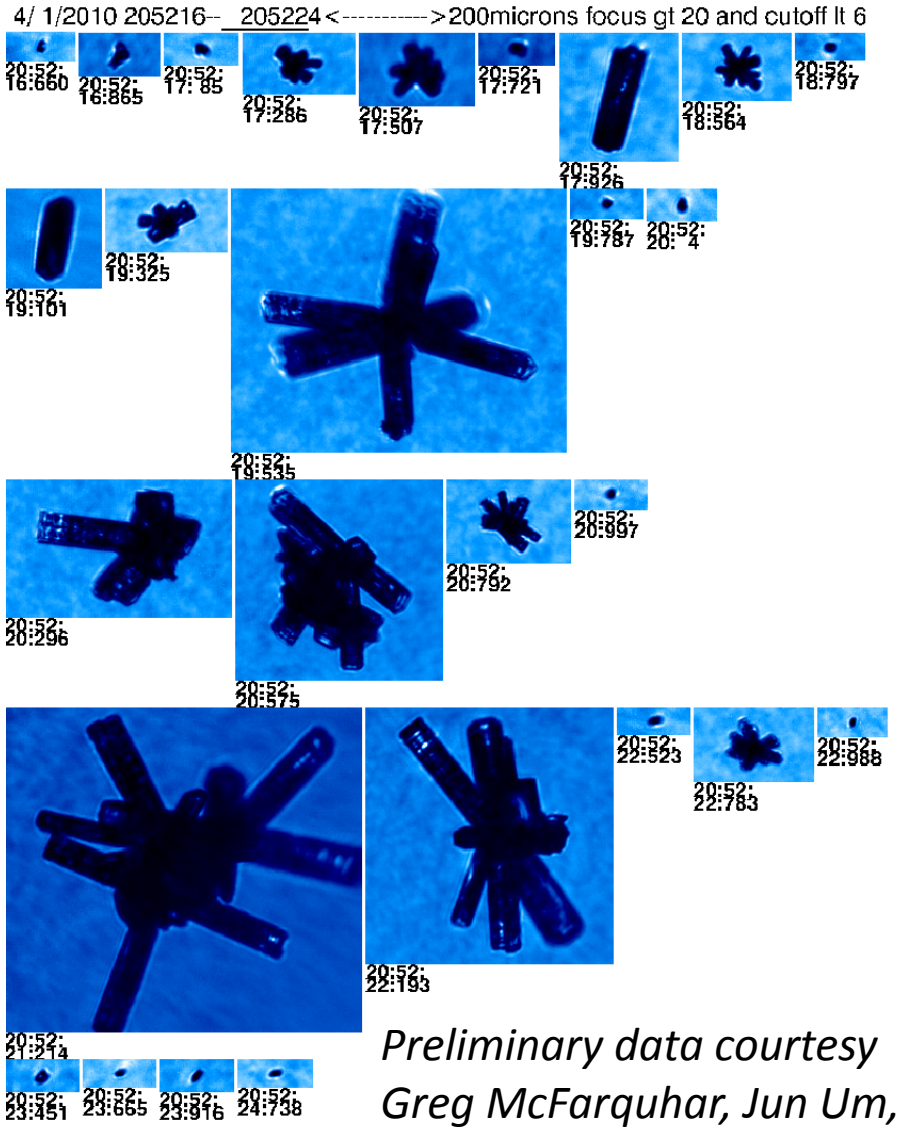

8
9
10
11
Altitude (km)

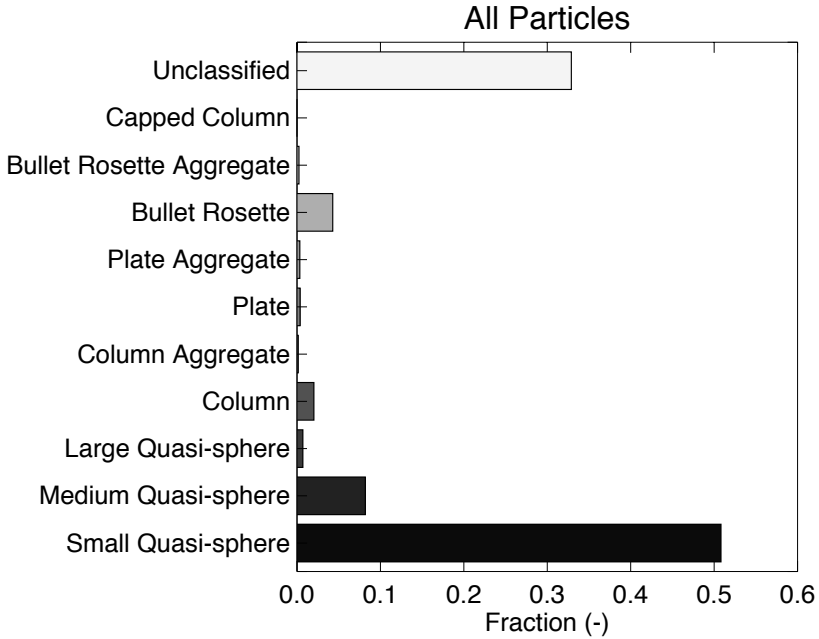

Flight 401B M1 Analysis of 2DS PSD
Simulation
Mid-nucleation PSD
PSD after some growth
Final PSD
dN/dlogD (#/L)
10000.00
1000.00
100.00
10.00
1.00
0.10
0.01
1
10
100
1000
Particle Size (microns)

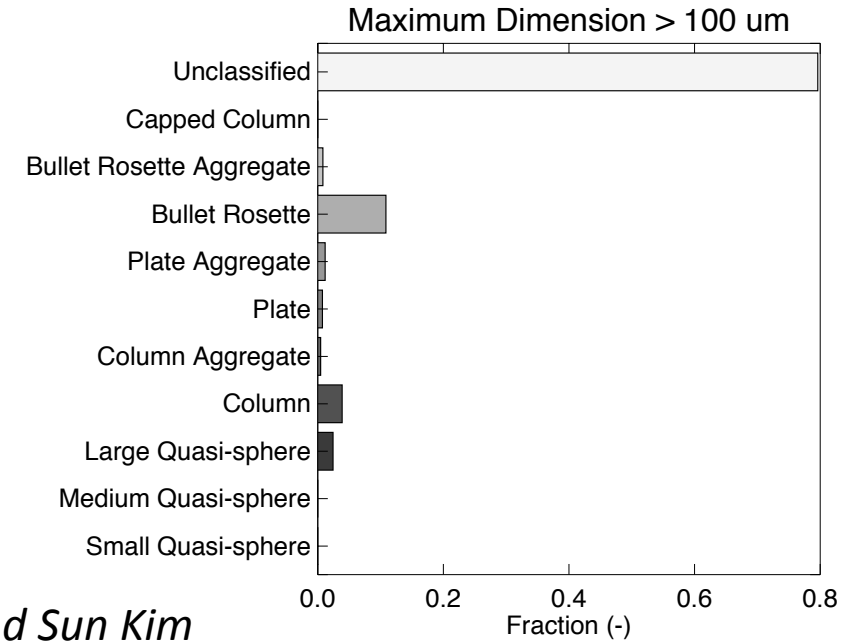

Flight 402A M1 Analysis of 2DS PSD
Simulation
Mid-nucleation PSD
PSD after some growth
Final PSD
1
10
100
1000
Particle Size (microns)


Height AGL (km)
14
12
10
8
6
4
2
00
03
06
09
12
15
18
21
00
Reflectivity (dBZ)
20
0
−20
−40
−60
−80

SPARTICUS





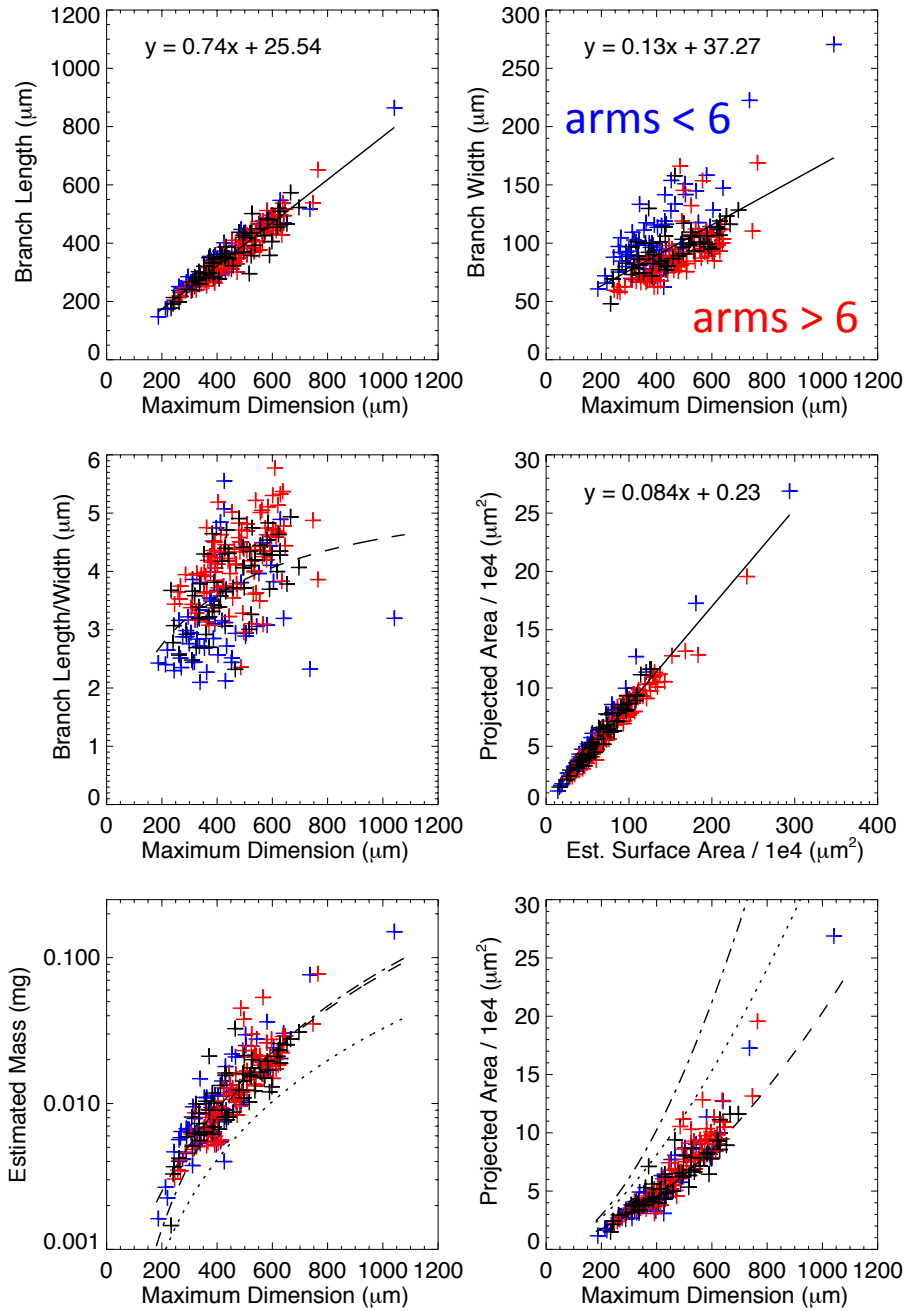


Preliminary data courtesy
Greg McFarquhar, Jun Um, and Sun Kim

SPARTICUS

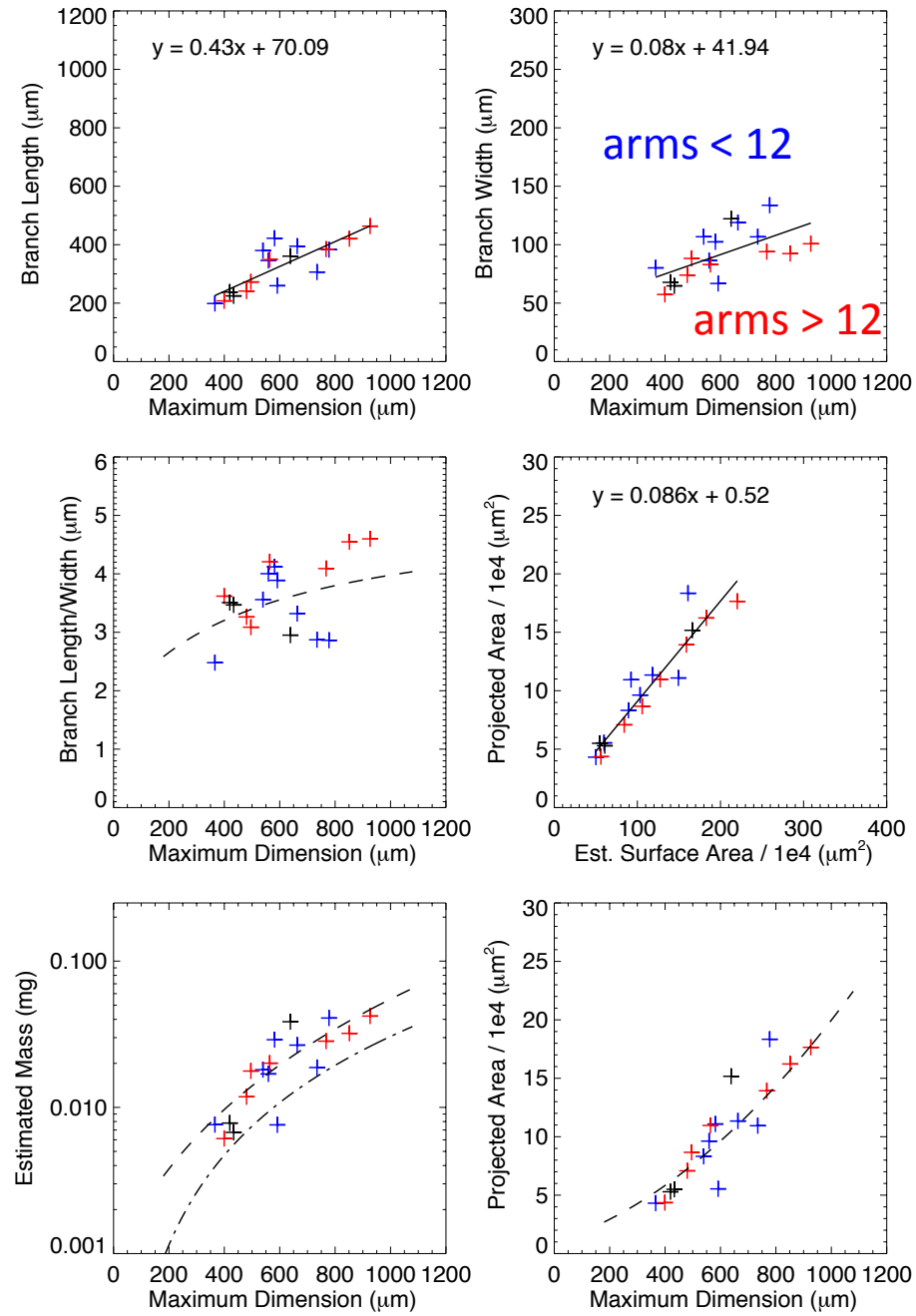
- Bullet rosettes
  - mean and median arms = 6
  - branch width wider (thinner) with fewer (more) arms
  - surface area estimated from arms ~ measured projected area (less than one-fourth)
  - mass-dimension and area-dimension relations compared with Mitchell et al. [1996] (dotted) and Heymsfield et al. [2002] (dash-dotted) assuming standard bulk density of ice

Preliminary data courtesy
Greg McFarquhar, Jun Um, and Sun Kim



SPARTICUS

- Bullet rosette aggregates
  - mean and median arms = 12
  - all the same conclusions as for single crystals
  - mass-dimension relation compared with Heymsfield et al. [2002] (dash-dotted line)



Preliminary data courtesy
Greg McFarquhar, Jun Um, and Sun Kim

SHEBA Arctic stratus

TABLE 1. Mass- and area-dimensional power laws used in simulations and radar reflectivity calculations.

Habit	D (cm)[a]	a[b]	b[b]	c[b]	d[b]	Source[c]
Spheres	0.0002–0.0005	0.480 14	3.00	0.785 40	2.00	—
Transitional	0.0005–0.012	0.023 06	2.61	0.175 96	1.82	—
Radiating assemblages of plates	>0.012	0.002 40	2.1	0.228 50	1.88	LH74, MZP90, M96, BL06
Aggregates of unrimed radiating assemblages of plates, side planes, bullets, and columns	>0.012	0.002 94	1.9	0.228 50	1.88	LH74, M96
Plates with sectorlike branches	0.001–0.016	0.006 14	2.42	0.24	1.85	M96
	>0.016	0.001 42	2.02	0.55	1.97	M96
Hexagonal plates	>0.012	0.007 39	2.45	0.65	2.00	M96

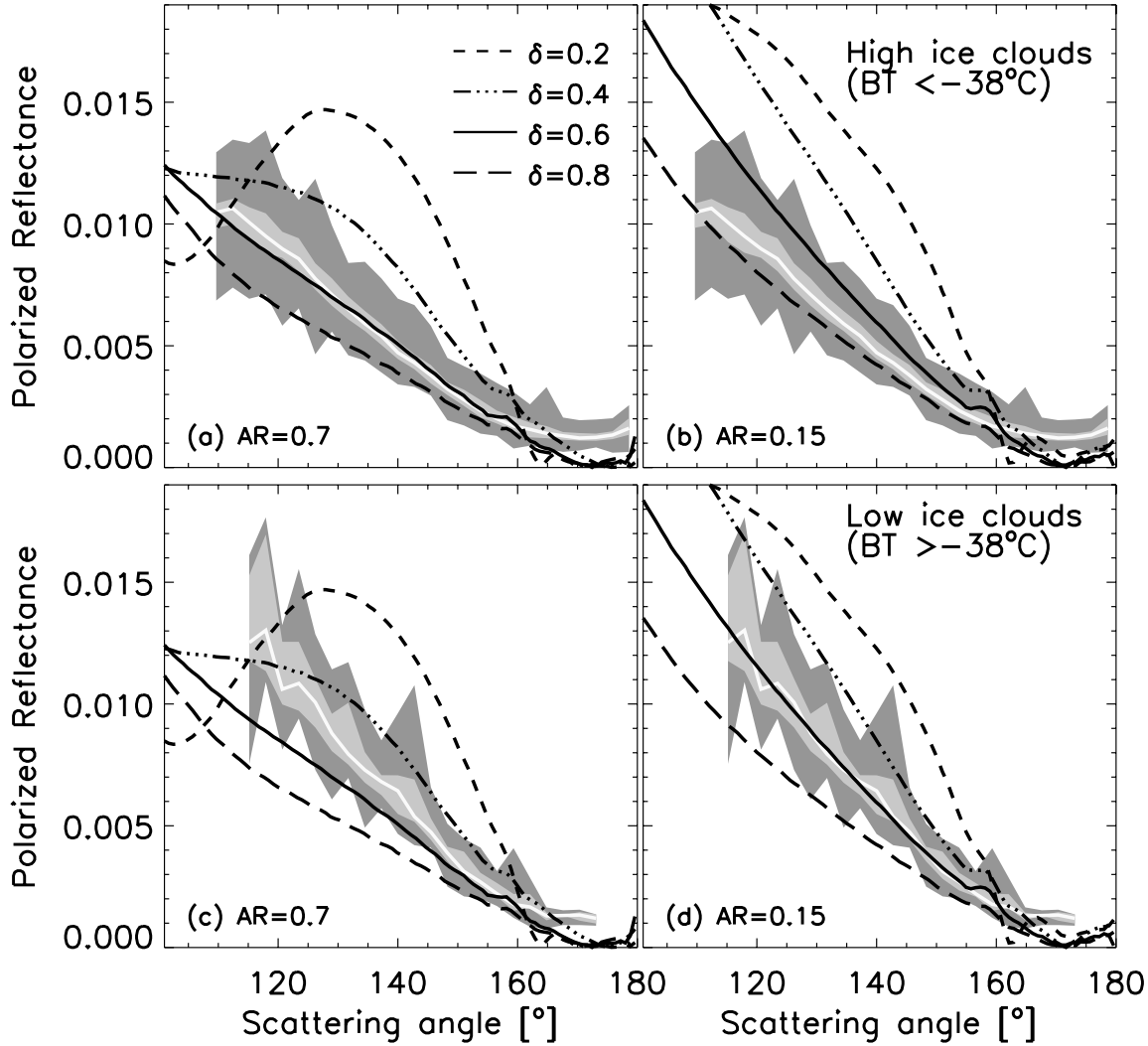
Fridlind et al. [*JAS 2012*]

Radiative transfer consistent with microphysics

- Optical properties cannot be directly calculated for irregular ice
- Use *2 sets* of hexagonal columns which reproduce CRM's assumptions on
  1. projected area and volume (mass) for scattering and absorption (σ, ω_o)
  2. projected area and aspect ratio for scattering phase matrix (e.g., g) (see Fu, *J. Clim*, 1996; Fu, *JAS* 2007)
- Crystal surfaces roughened to obtain featureless phase functions (Macke et al., *JAS* 1996; Baran & Labonette, JQSRT, 2006)
- Habit mixtures do not allow volume and projected area to be chosen independently

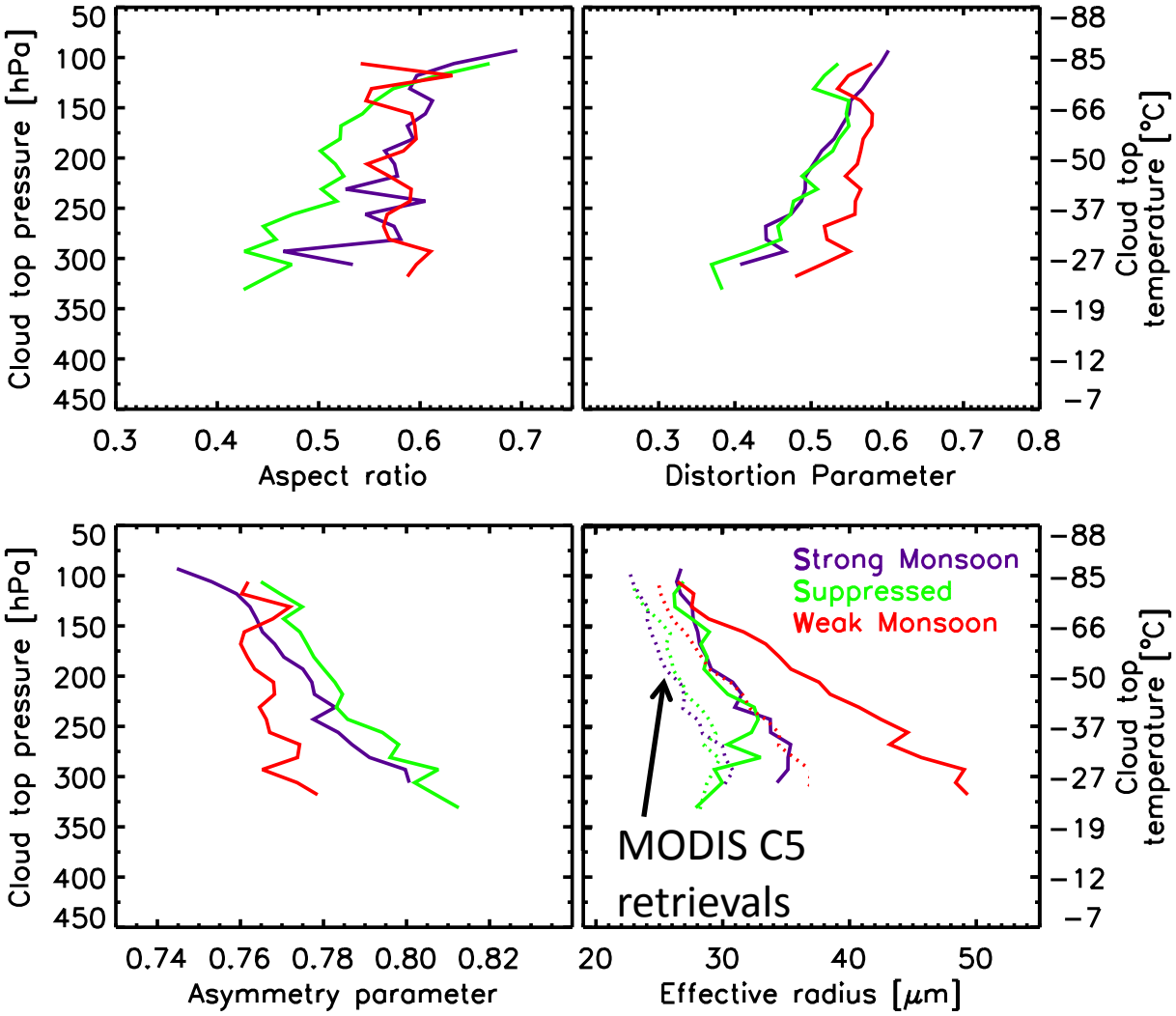
POLDER/MODIS ice aspect ratio, roughness

- Constrain *roughness* using 0.86-µm polarized reflectance with scattering angle [*van Diedenhoven et al. JAS 2012*]



POLDER/MODIS ice effective radius

- Preliminary retrieved r_{eff} [*van Diedenhoven et al., in prep.*]



Summary

- ice size distribution evolution cannot be evaluated or understood in the absence of *quantitative* characterization of ice single-particle properties (mass, shape) as a function of size
- non-spherical ice microphysical (and optical) properties are not quantitatively constrained by existing habit ID methods
- non-habit-specific bin model approach in DHARMA (following Böhm) provides internally consistent fall speeds, collision kernels, and optical properties (growth rates currently spheroids, to be integrated)
  - mass
  - maximum dimension and projected area (no analytic relations required)
  - aspect ratio
  - roughness
- neither airborne nor surface-based measurement suites currently provide direct measurement of single-particle mass
  - "holy grail"? —David Wolff/GPM team
- SPARTICUS case studies
  - large bullet rosettes and their aggregates and likely precursors
  - irregular particles (the 90%?)
  - model should reflect what is really out there (e.g. informing growth rate integration)