Ice size distribution evolution:
A perspective from bin microphysics modeling of mixed-phase clouds

Ann Fridlind • NASA/GISS

many thanks to

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Ice in DHARMA:
A model for observation-constrained case studies

- CARMA in DHARMA applied to CRYSTAL-FACE [Fridlind et al. 2004]
  - single ice class, spheres with prescribed mass-dimension relations, density decreasing with increasing size
  - Hall collision-coalescence kernel developed for liquid phase
  - Lorenz-Mie radiative scattering

Garrett et al. (2006)

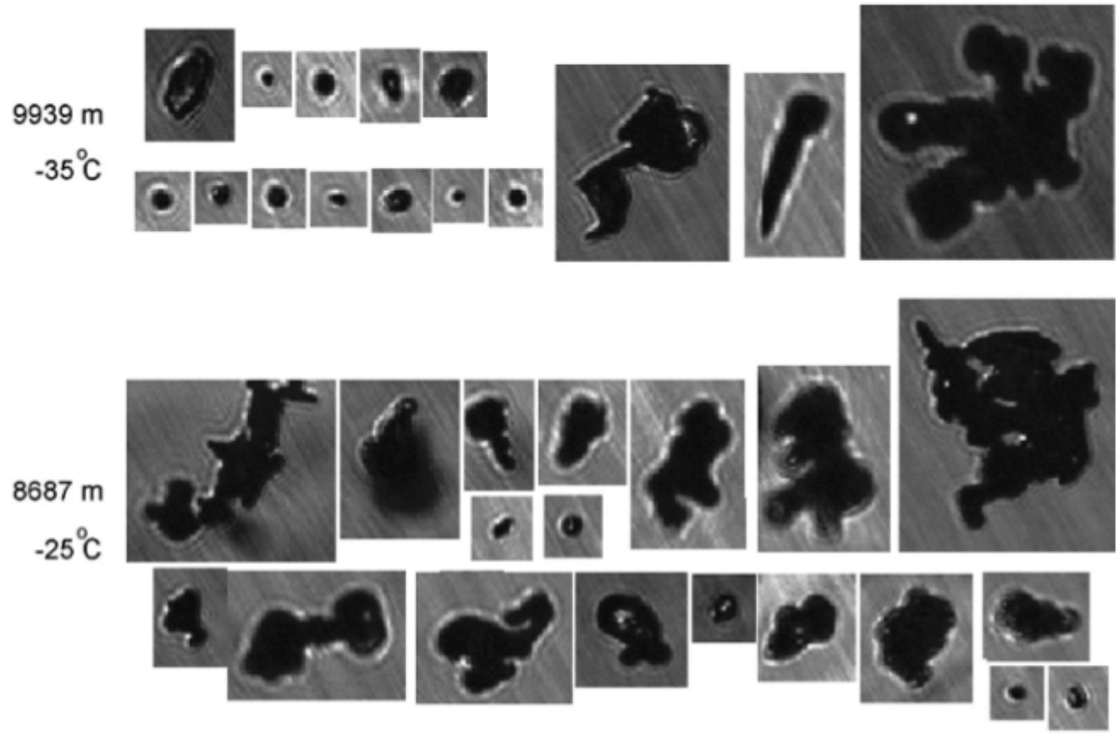
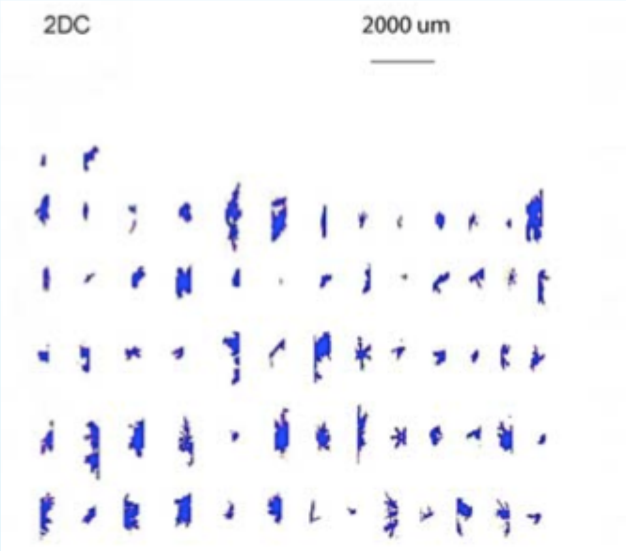
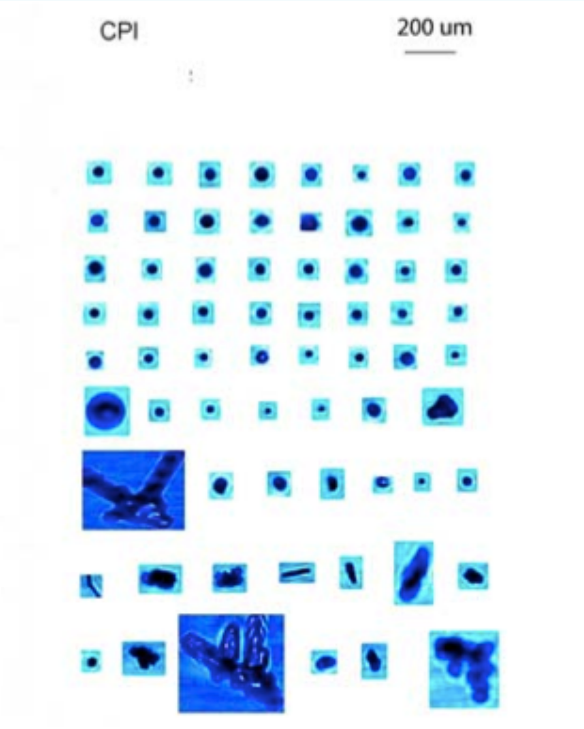


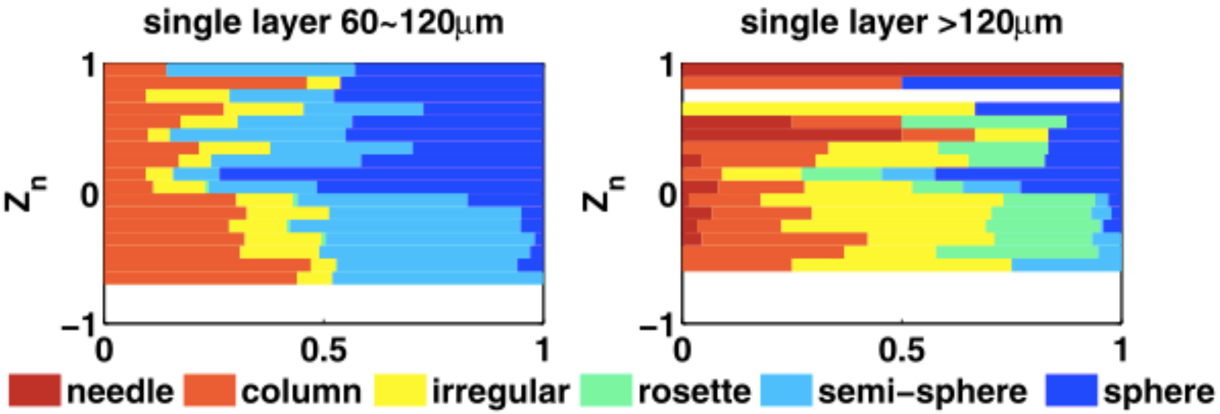
FIG. 7. CPI images showing the crystal habits encountered during the Citation vertical profile within the anvil.

Ice in DHARMA:
A model for observation-constrained case studies

- CARMA in DHARMA applied to M-PACE [Fridlind et al. 2007]
  - sensitivity test with prescribed mass-dimension relations, density decreasing with increasing size







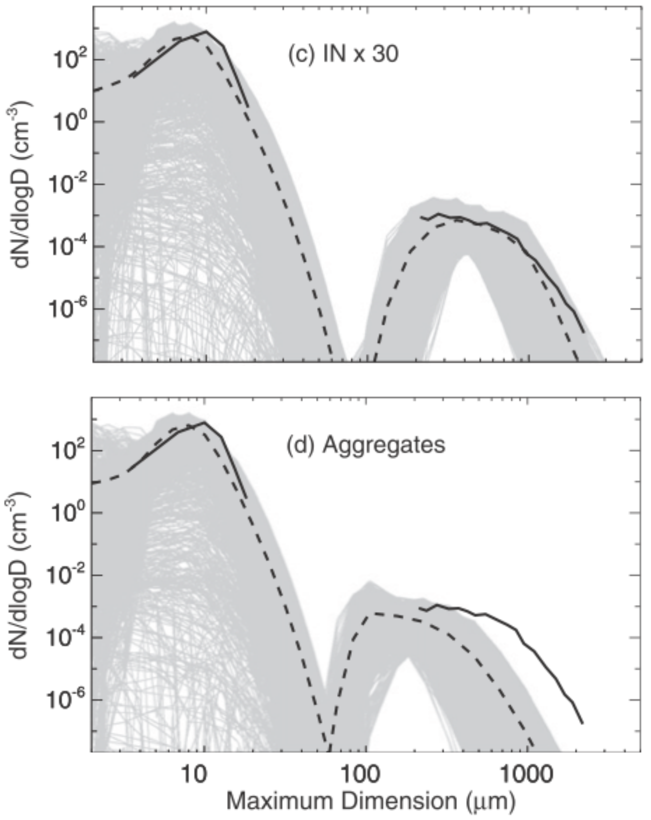
McFarquhar et al. (2007)

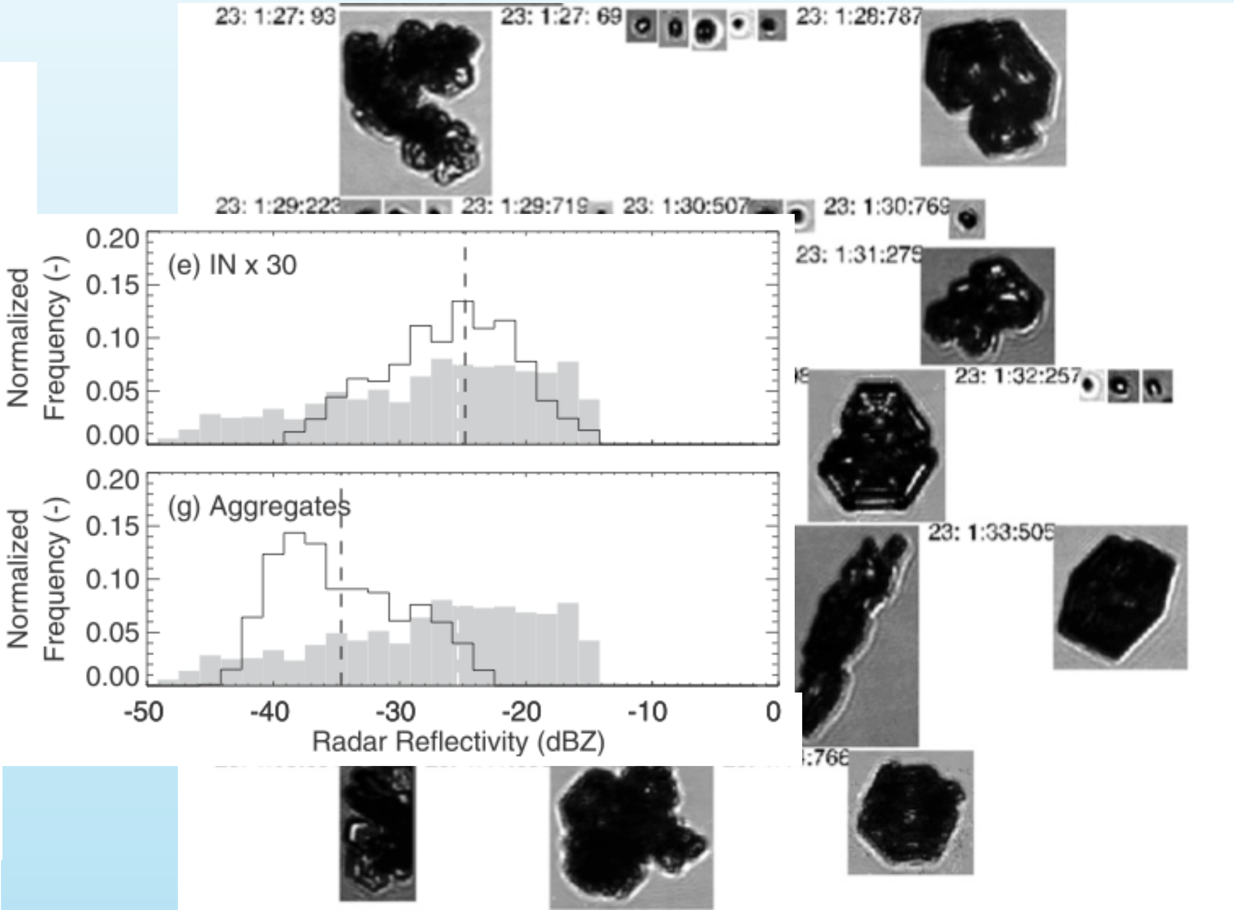
Ice in DHARMA:
A model for observation-constrained case studies

- One way: one or more non-spherical ice classes with fixed habits
  - SBM–Fast (Lynn et al. 2005a, 2005b, 20005c)
    - original six ice classes (columns, plates, dendrites, snowflakes/aggregates, graupel, hail/frozen drops) reduced to three (dendrites/snowflakes/aggregates, plates/hail, columns/graupel)
    - mass-doubling bins 1–16 for ice < 100-μm melted radius
    - ice-water and ice-ice kernels account for ice shape and dispersion of fall speeds within single mass bins
- Another way: one or more non-spherical ice classes with fixed properties
  - Böhm (1992a, 1992b, 1992c, 1999, 2004)
    - specify mass, maximum dimension, aspect ratio, projected area
    - theoretical development of fall speeds, at GISS adjusted after Heymsfield and Westbrook (2010) [Avramov et al. 2011]
    - theoretical development of collision efficiencies for any combination of particles
  - positive features
    - permits direct observational constraint of ice properties without requiring habit
    - permits fine-tuning of ice properties over continuous range
- Third way: one or more ice classes with predicted, evolving properties (see Harrington talk)

Ice in DHARMA:
A model for observation-constrained case studies

- DHARMA applied to SHEBA [Fridlind et al. 2011]
  - single ice class, prescribed Böhm mass–maximum dimension and mass–projected area relations based on radiating plate habit, and aspect ratio
  - Böhm collision-coalescence kernel developed for ice-ice and ice-liquid pairs
  - Lorenz-Mie radiative scattering (still reduced-density spheres)



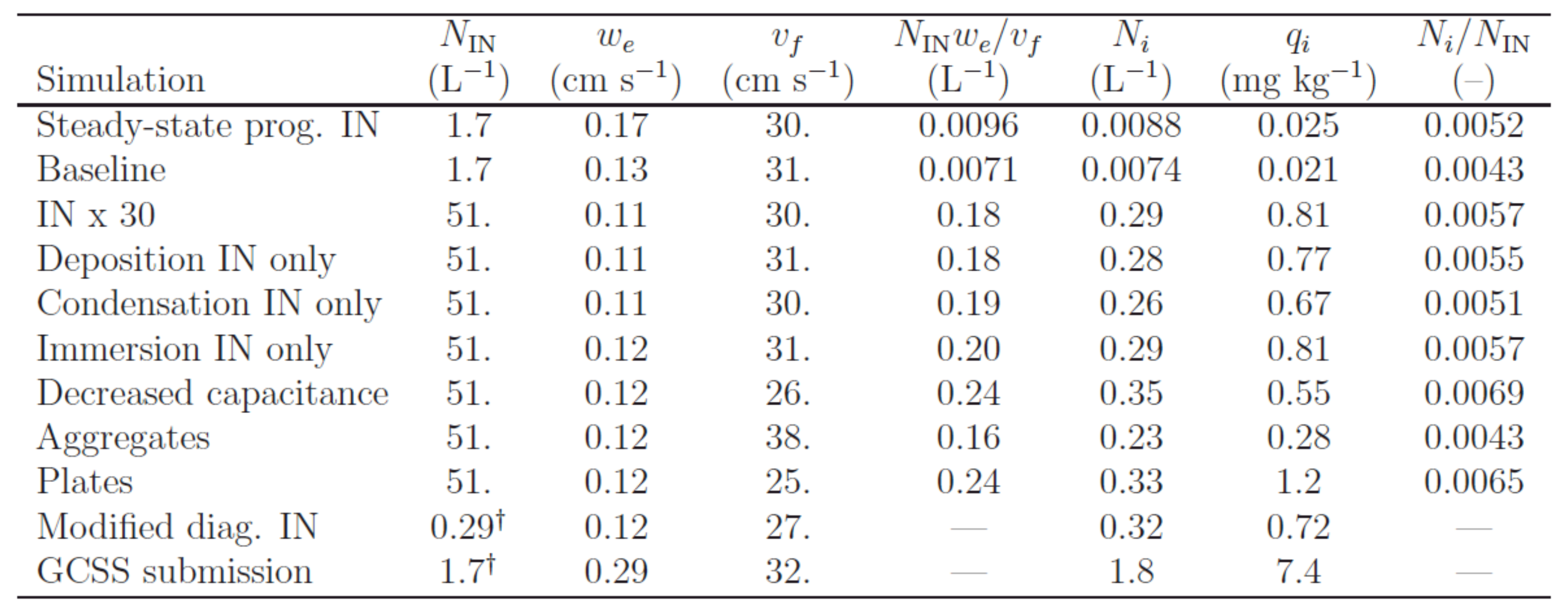


Ice in DHARMA:
A model for observation-constrained case studies

- DHARMA applied to SHEBA [Fridlind et al. 2011]
  - rapid quasi-equilibrium following Lilly (1968)

$$H\,\cancel{dN_i/dt} = w_e N_{IN} - (v_f + \cancel{w_e}) N_i$$

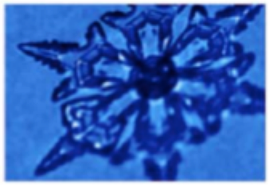
$$N_i/N_{IN} = w_e/v_f \ll 1$$

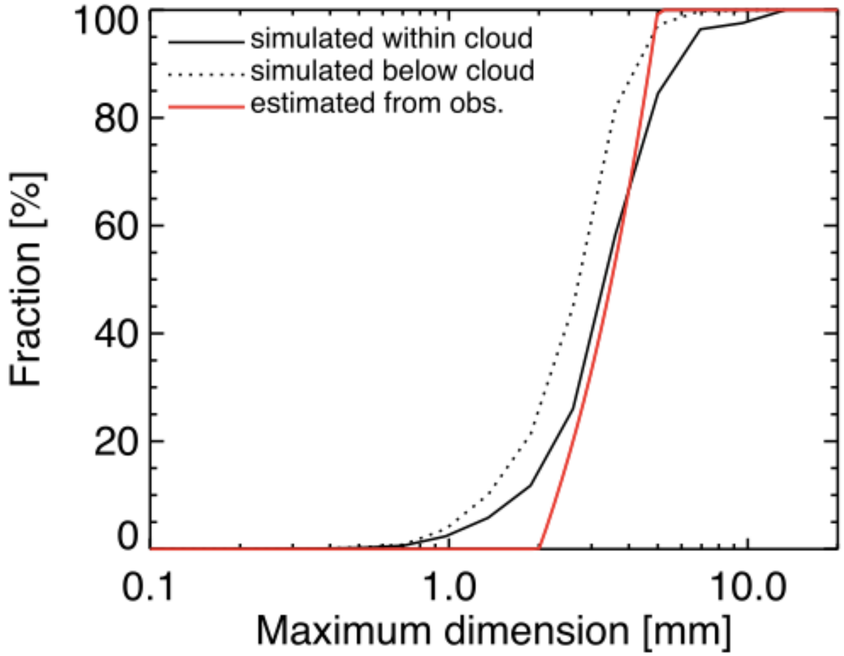


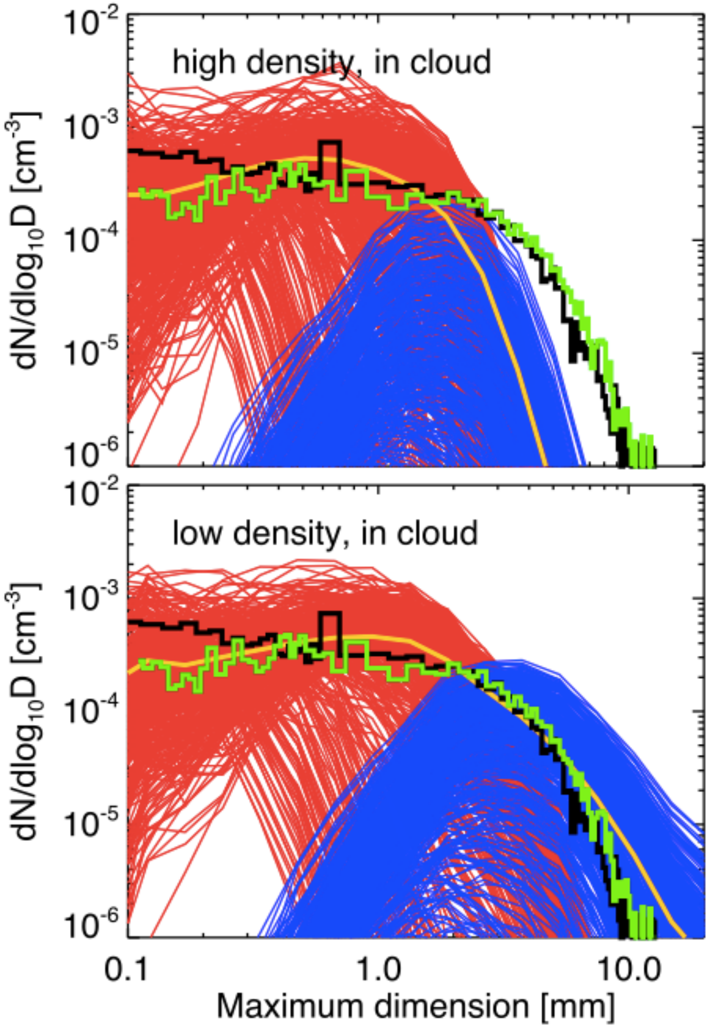
Simulation	N_{IN} (L^{-1})	w_e ($\mathrm{cm\ s}^{-1}$)	v_f ($\mathrm{cm\ s}^{-1}$)	$N_{\mathrm{IN}}w_e/v_f$ (L^{-1})	N_i (L^{-1})	q_i ($\mathrm{mg\ kg}^{-1}$)	N_i/N_{IN} (–)
Steady-state prog. IN	1.7	0.17	30.	0.0096	0.0088	0.025	0.0052
Baseline	1.7	0.13	31.	0.0071	0.0074	0.021	0.0043
IN x 30	51.	0.11	30.	0.18	0.29	0.81	0.0057
Deposition IN only	51.	0.11	31.	0.18	0.28	0.77	0.0055
Condensation IN only	51.	0.11	30.	0.19	0.26	0.67	0.0051
Immersion IN only	51.	0.12	31.	0.20	0.29	0.81	0.0057
Decreased capacitance	51.	0.12	26.	0.24	0.35	0.55	0.0069
Aggregates	51.	0.12	38.	0.16	0.23	0.28	0.0043
Plates	51.	0.12	25.	0.24	0.33	1.2	0.0065
Modified diag. IN	0.29†	0.12	27.	—	0.32	0.72	—
GCSS submission	1.7†	0.29	32.	—	1.8	7.4	—

Ice in DHARMA:
A model for observation-constrained case studies

- DHARMA applied to ISDAC [Avramov et al. 2011]
  - two ice classes (dendrites and aggregates), prescribed mass–maximum dimension and mass–projected area relations based on radiating plate habit, and aspect ratio (theoretical relations)

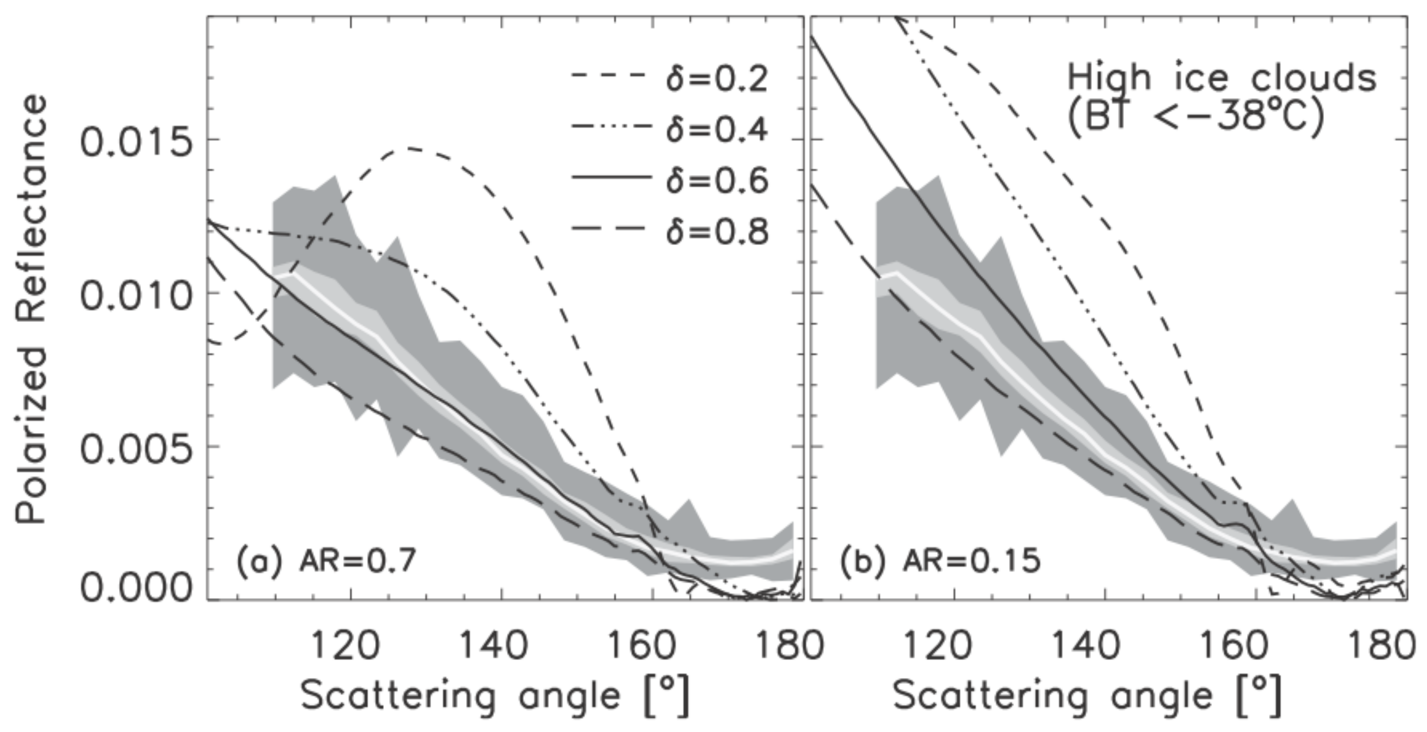






Ice in DHARMA:
A model for observation-constrained case studies

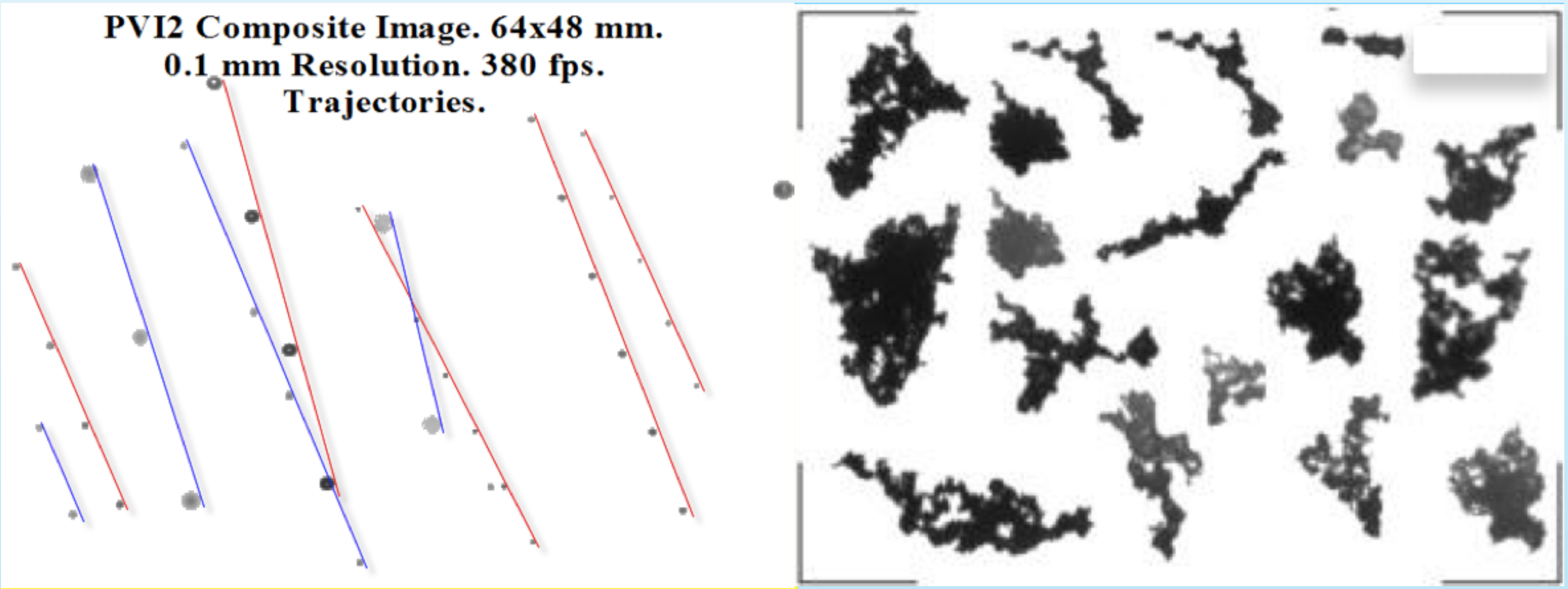
- DHARMA applied to TWP-ICE [van Diedenhoven et al. 2012]
  - two ice classes, both with prescribed mass–maximum dimension and mass–projected area relations, aspect ratio
  - Böhm collision-coalescence kernel (still new)
  - equal-volume-area spheres [Neshyba et al. 2003] (then new, now improved)



van Diedenhoven et al. (2012)

Summary and needs

- Modeling
  - Individual ice crystal properties have been insufficiently quantified to specify in models
  - Relatively small changes in ice crystal properties can be responsible for large changes in ice crystal size distribution evolution (especially if ice nucleation is treated prognostically)
  - Model uncertainties in collision and coalescence processes are neglected
  - Integrating ice crystal physical and radiative properties is an objective that is not sorted
- Suggested directions for programmatic research
  - Characterize individual ice crystal properties (physical description, fall speed, mass)



Source: Walt Peterson and Larry Bliven

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  - Integrating ice crystal physical and radiative properties is an objective that is not sorted
- Suggested directions for programmatic research
  - Characterize individual ice crystal properties (physical description, fall speed, mass)
  - Characterize ice optical properties (connection to physical properties, roughness)
  - Remote-sensing approaches sensitive to shape or properties of ice particle populations (Matrosov/scanning radar, Eloranta/profiling HSRL and Doppler spectra)
  - Establishing importance of measured ice property variably in global modeling framework (prognostic IN conditions, overall importance to relevant processes, radiative fluxes, hydrologic cycle)