Development of Ice Cloud Microphysical and Optical Models for a Variety of Imagers and Interferometers

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Bulk Ice Scattering Models

Incorporate

- latest computational light scattering research
- *in situ* data from multiple field campaigns

Develop a more comprehensive set of ice scattering models

Develop similar models for a variety of imagers, interferometers, and other sensors

Facilitate intercomparison of retrieved ice cloud properties from multiple sensors

Recent articles awaiting final decision at the *Journal of Applied Meteorology*

Baum, B. A., A. J. Heymsfield, P. Yang, and S. Thomas: Bulk scattering models for the remote sensing of ice clouds. 1: Microphysical data and models.

Baum, B. A., P. Yang, A. J. Heymsfield, S. Platnick, M. D. King, Y.-X. Hu, and S. Thomas: Bulk scattering models for the remote sensing of ice clouds. 2: Narrowband models.

Particle Size Distributions

Gamma size distribution* has the form:

$$N(D) = N_o D^{\mu} e^{-\lambda D}$$

where D ***= max diameter***

N_o ***= intercept***

μ ***= dispersion***

λ ***= slope***

The intercept, slope, and dispersion values are derived for each PSD by matching three moments (specifically, the 1st, 2nd, and 6th moments)

Note: when $\mu = 0$***, the PSD reduces to an exponential distribution***

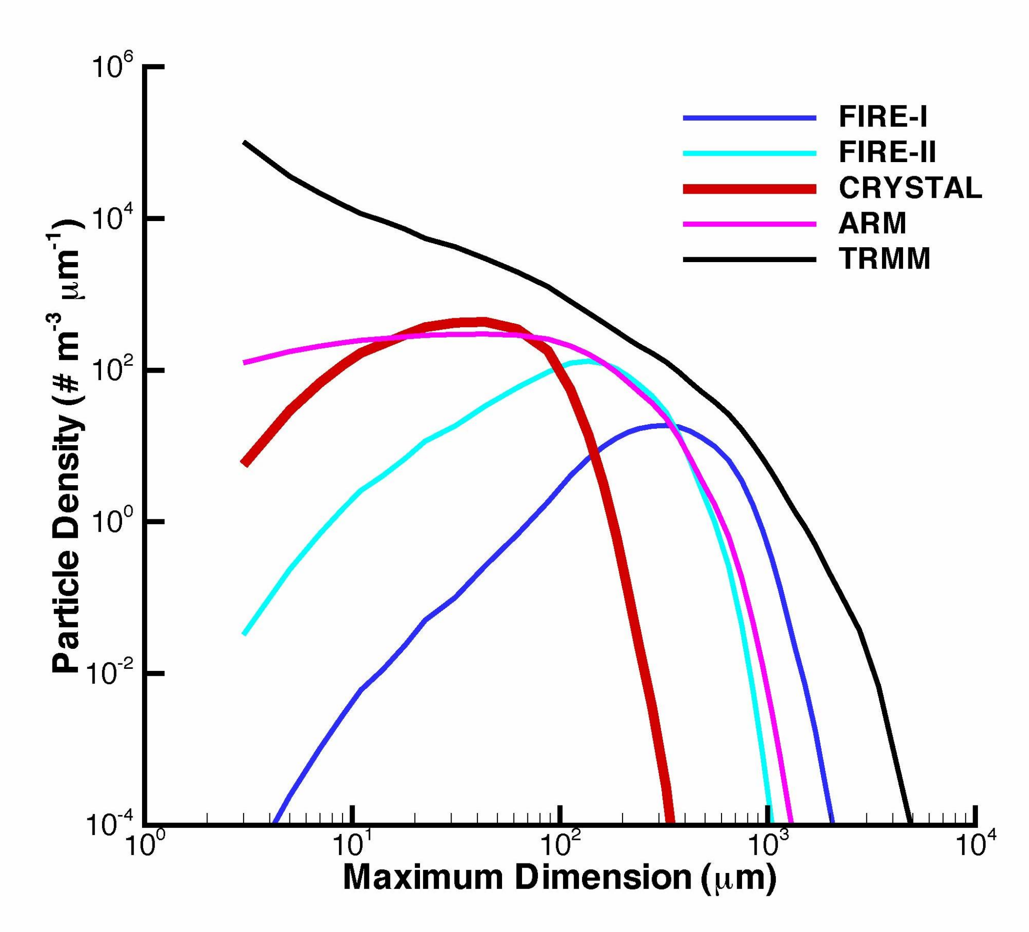
******Heymsfield et al., Observations and parameterizations of particle size distributions in deep tropical cirrus and stratiform precipitating clouds: Results from in situ observations in TRMM field campaigns. J. Atmos. Sci., 59, 3457-3491, 2002.*

Field Campaign Information

Field Campaign	***Location***	***Instruments***	***Number of PSDs***
FIRE-1 (1986)	Madison, WI	2D-C, 2D-P	246
FIRE-II (1991)	Coffeyville, KS	Replicator	22
ARM-IOP (2000)	Lamont, OK	2D-C, 2D-P, CPI	390
TRMM KWAJEX (1999)	Kwajalein, Marshall Islands	2D-C, HVPS, CPI	418
CRYSTAL-FACE (2002)	Off coast of Nicaragua	2D-C, VIPS	41

Probe size ranges are: 2D-C, 40-1000 μm; 2D-P, 200-6400 μm; HVPS (High Volume Precipitation Spectrometer), 200–6100 μm; CPI (Cloud Particle Imager), 20-2000 μm; Replicator, 10-800 μm; VIPS (Video Ice Particle Sampler): 20-200 μm.

Particle Size Distributions



Midlatitude cirrus characteristics

- ***Size sorting more pronounced***
- ***Small crystals at cloud top***
- ***More often find pristine particles***

Tropical cirrus anvil characteristics

Form in an environment having much higher vertical velocities

- ***Size sorting is not as well pronounced***
- ***Large crystals often present at cloud top***
- ***Crystals may approach cm in size.***
- ***Habits tend to be more complex***

- Note that CRYSTAL distributions tend to be the narrowest overall

Library of Scattering Properties In 0.4-13 μm Spectral Region

Ice particle habits:

Hexagonal plates
Solid and hollow columns
Aggregates
Droxtals
3D bullet rosettes

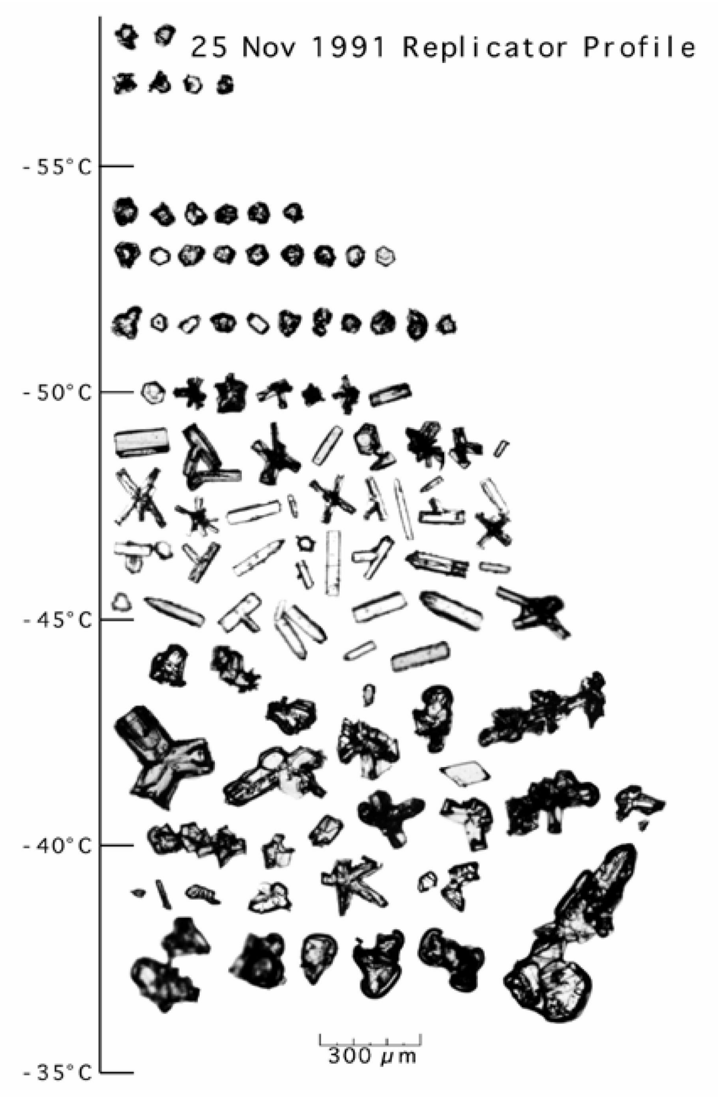
45 size bins ranging from 2 to 9500 μm

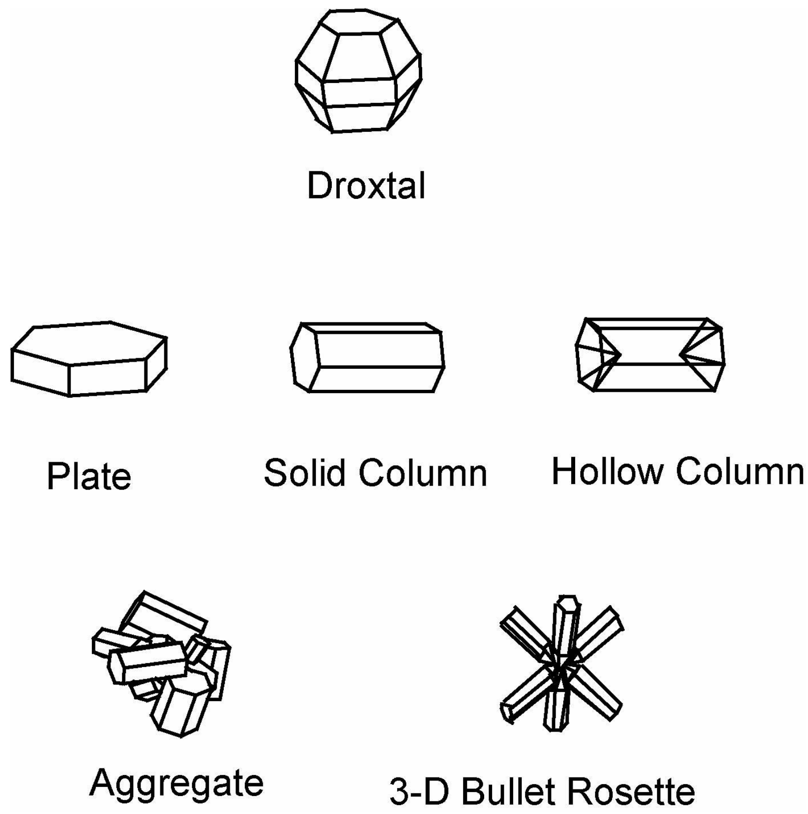
Spectral range:

0.4 to 1.00 μm at 0.01-μm resolution
1.20 to 1.70 μm at 0.01-μm resolution
1.80 to 1.95 μm at 0.01-μm resolution
2.05 to 2.20 μm at 0.01-μm resolution
3.45 to 4.05 μm at 0.05-μm resolution
8.10 to 8.95 μm at 0.05-μm resolution
10 to 13 μm at 0.05-μm resolution

Properties for each habit/size bin include volume, projected area, maximum dimension, single-scattering albedo, asymmetry factor, scattering phase functions, and scattering/extinction cross sections

Replicator Particle Habits | *Simulated Particle Habits*





Ice Particle Habit Distribution

At this point, we have

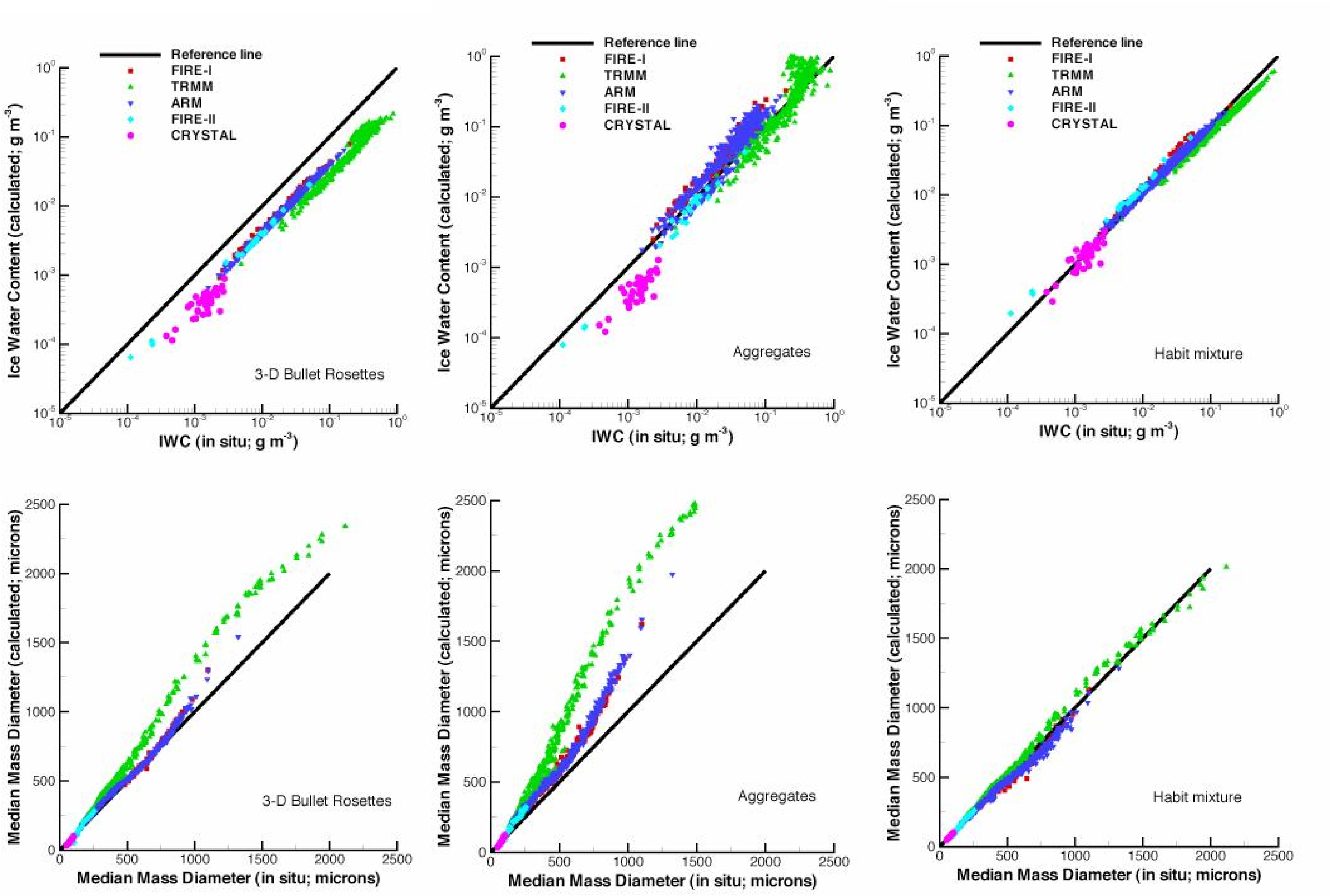
- **ice particle scattering library**
- **wealth of microphysical data for ice clouds (1117 PSDs)**

Next issue: develop a ice particle habit distribution that makes sense

Note: each idealized ice particle has a prescribed volume, and hence mass

Compare *IWC* and D_m computed from integrating over the habit and size distributions to those values estimated from techniques developed by Heymsfield and colleagues from analyses of their *in situ* data

Ice Water Content and Median Mass Diameter



Ice Particle Habit Percentages Based on Comparison of Calculated to In-situ D_m and *IWC*

Guidelines

4 size domains defined by particle maximum length

Droxtals: used only for smallest particles

Aggregates: only for particles > 1000 μm

Plates: used only for particles of intermediate size

Proposed ice particle habit mixture

Max length < 60 μm
100% droxtals

60 μm < Max length < 1000 μm
15% bullet rosettes
35% hexagonal plates
50% solid columns

1000 μm < Max length < 2500 μm
45% solid columns
45% hollow columns
10% aggregates

Max length > 2500 μm
97% bullet rosettes
3% aggregates

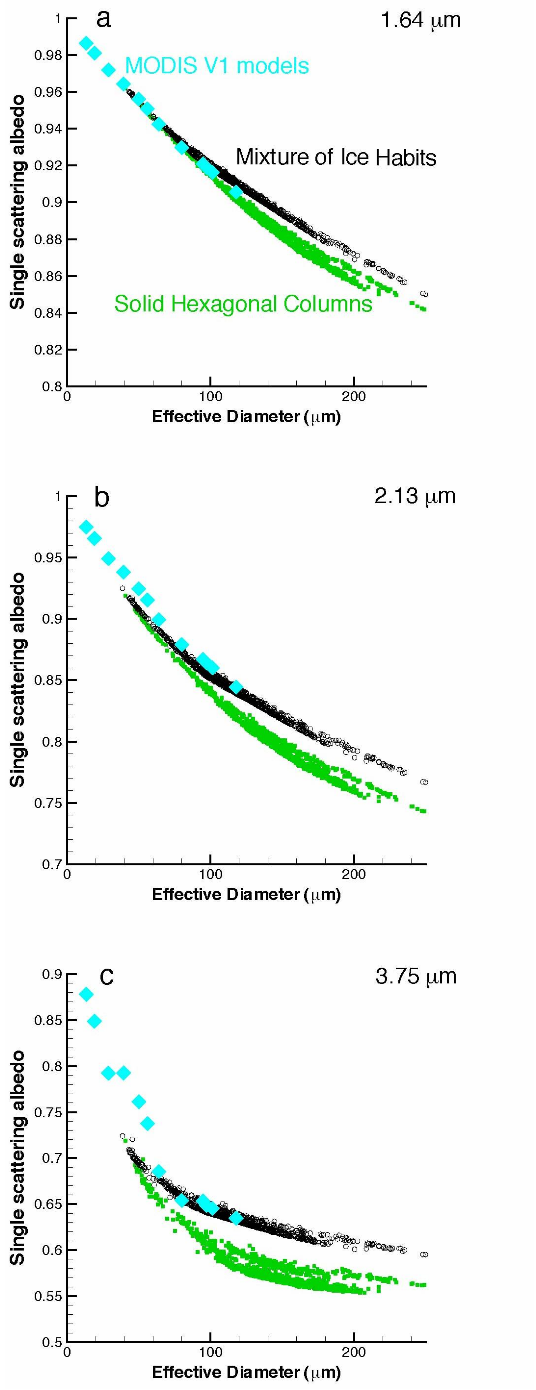
Band-averaged Scattering Properties

The following calculations are now based on integration over

a. PSD

b. habit distribution

c. spectral response function



MODIS Band-averaged Single Scattering Albedo

For 3 MODIS bands, comparing

- MODIS V1 models

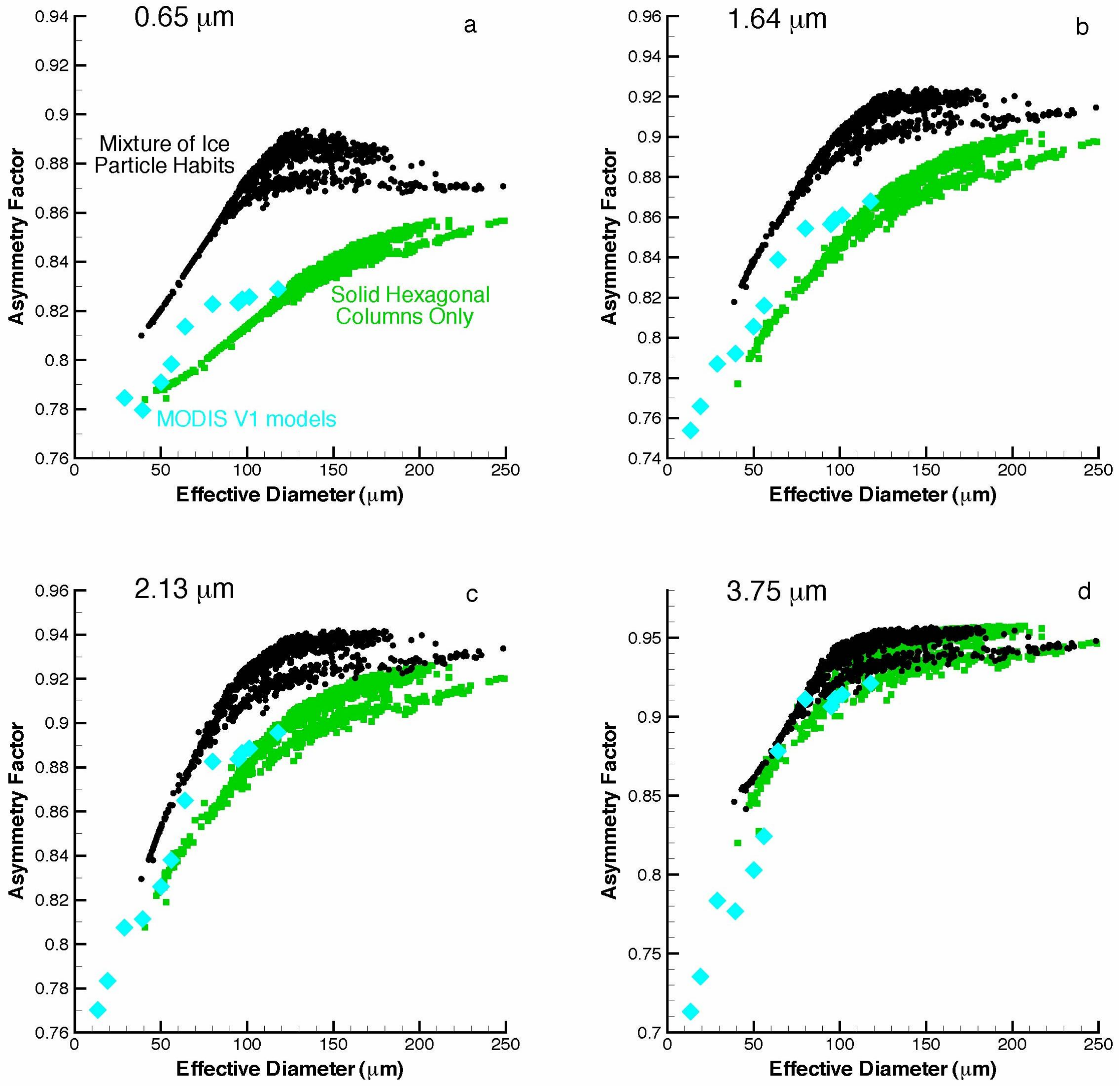
- Single habit assumption of solid hexagonal columns

- Habit mixture

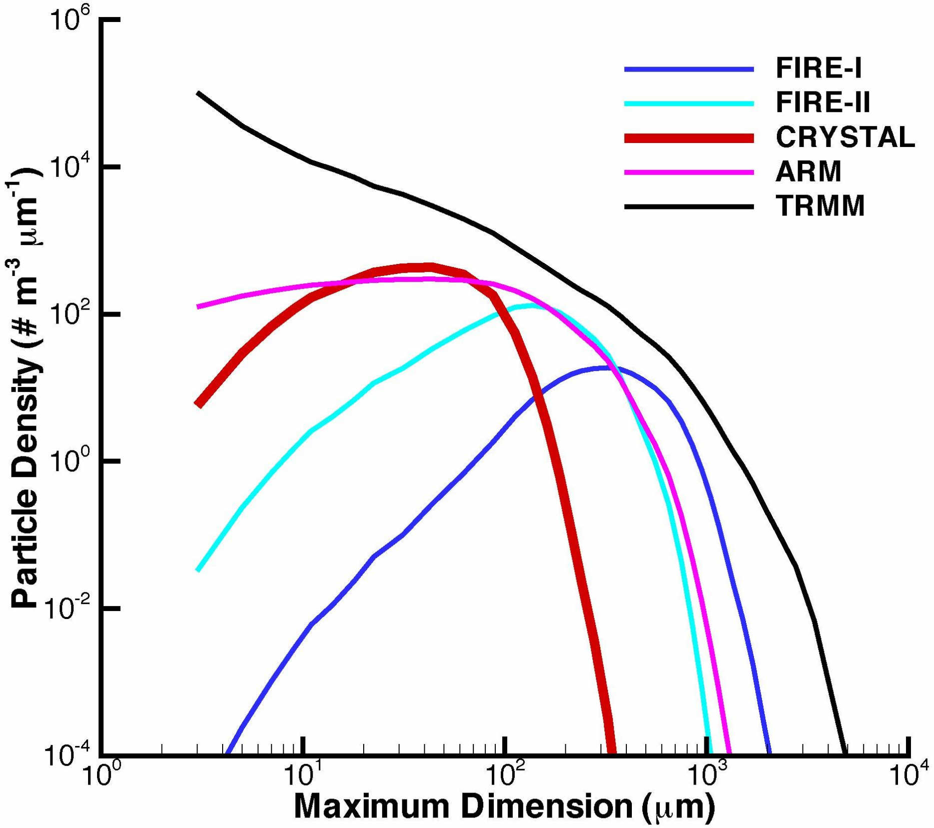
Habit does not seem to be a factor for smaller D_{eff} but does for larger D_{eff}

Several MODIS V1 models are out of range

MODIS Band-averaged Asymmetry Factor

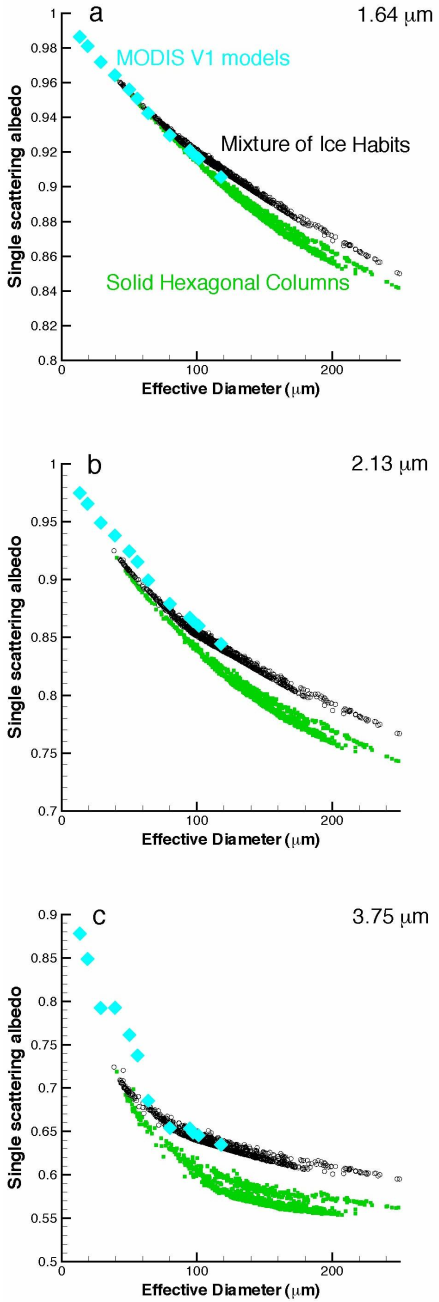


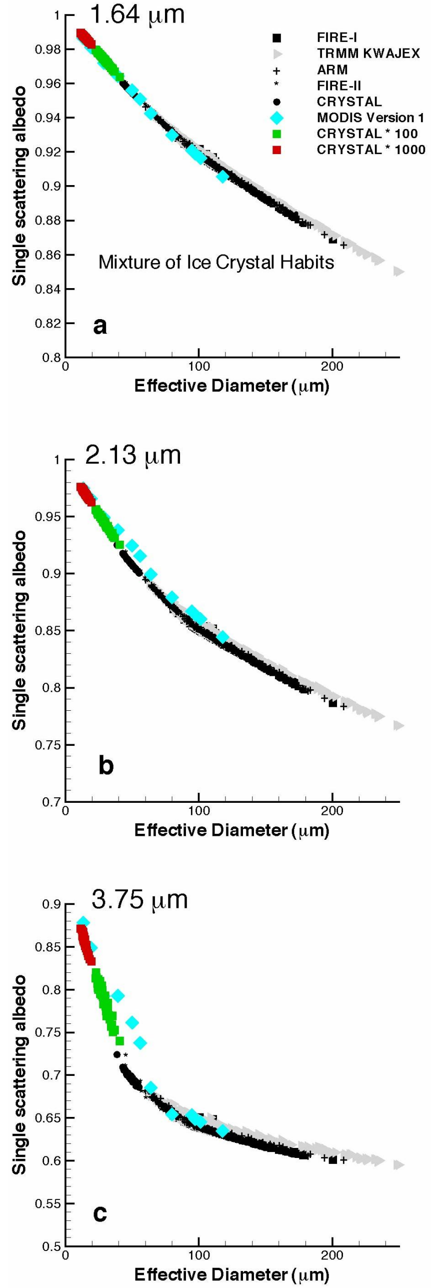
Small Particle Sensitivity Study

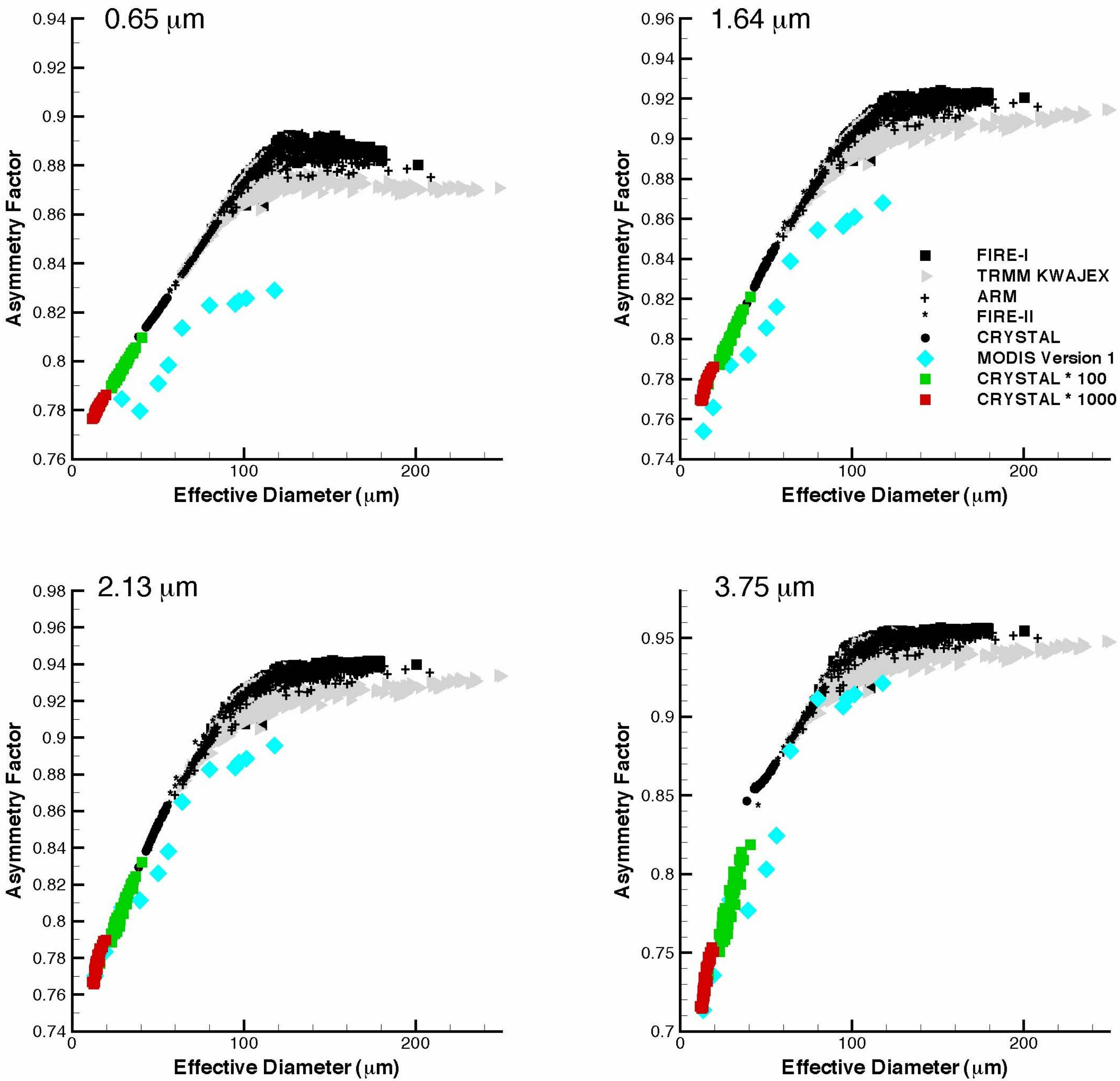


Note that CRYSTAL distributions tend to be the narrowest overall

For all 41 CRYSTAL size distributions, increase the number of particles with $D_{max} < 20$ μm by a factor of 100 or 1000


a
1.64 μm
MODIS V1 models
Mixture of Ice Habits
Solid Hexagonal Columns
b
2.13 μm
c
3.75 μm
Single scattering albedo
Effective Diameter (μm)

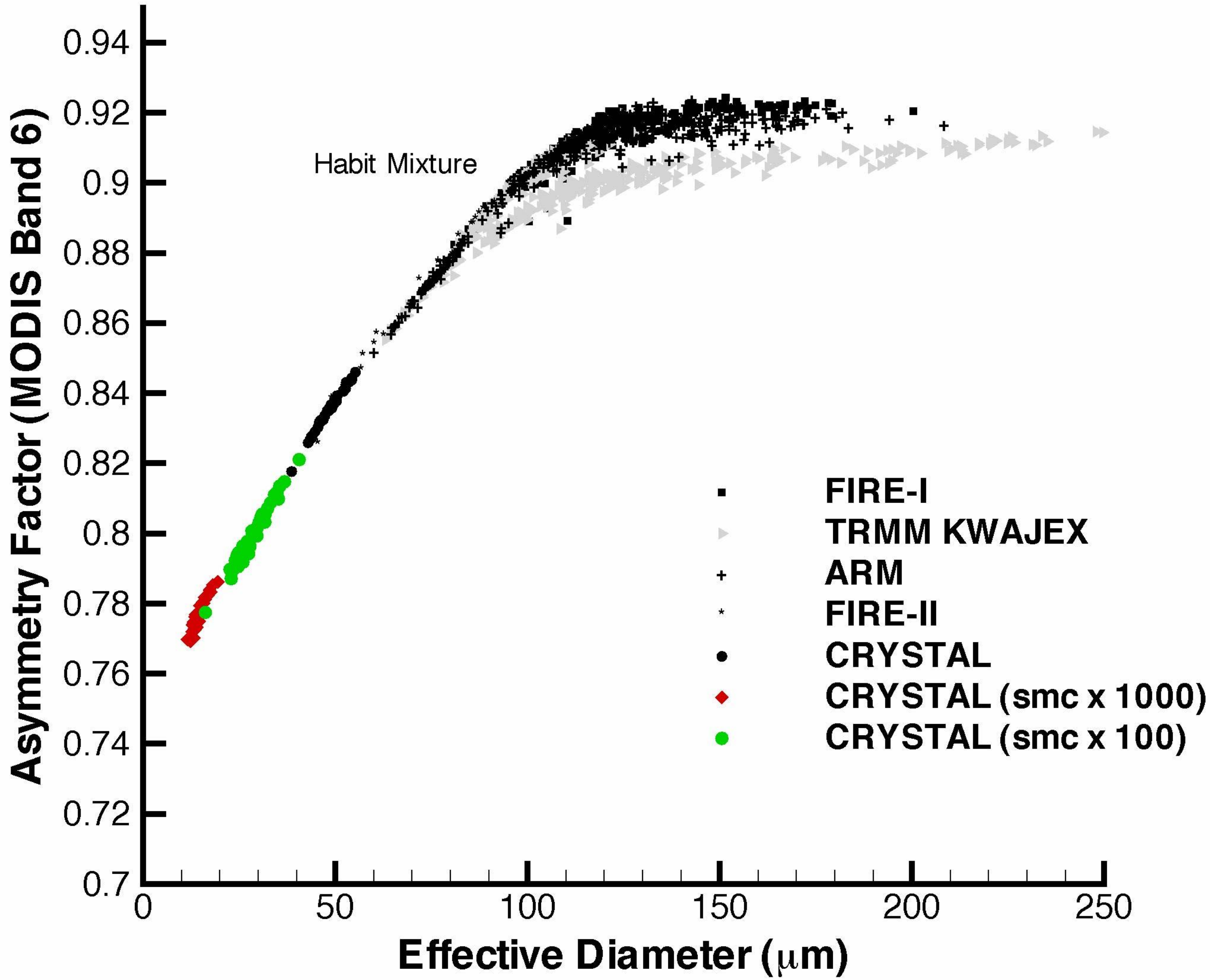

1.64 μm
FIRE-I
TRMM KWAJEX
ARM
FIRE-II
CRYSTAL
MODIS Version 1
CRYSTAL * 100
CRYSTAL * 1000
Mixture of Ice Crystal Habits
a
2.13 μm
b
3.75 μm
c
Single scattering albedo
Effective Diameter (μm)


0.65 μm
1.64 μm
2.13 μm
3.75 μm
Asymmetry Factor
Effective Diameter (μm)
0
100
200
FIRE-I
TRMM KWAJEX
ARM
FIRE-II
CRYSTAL
MODIS Version 1
CRYSTAL * 100
CRYSTAL * 1000

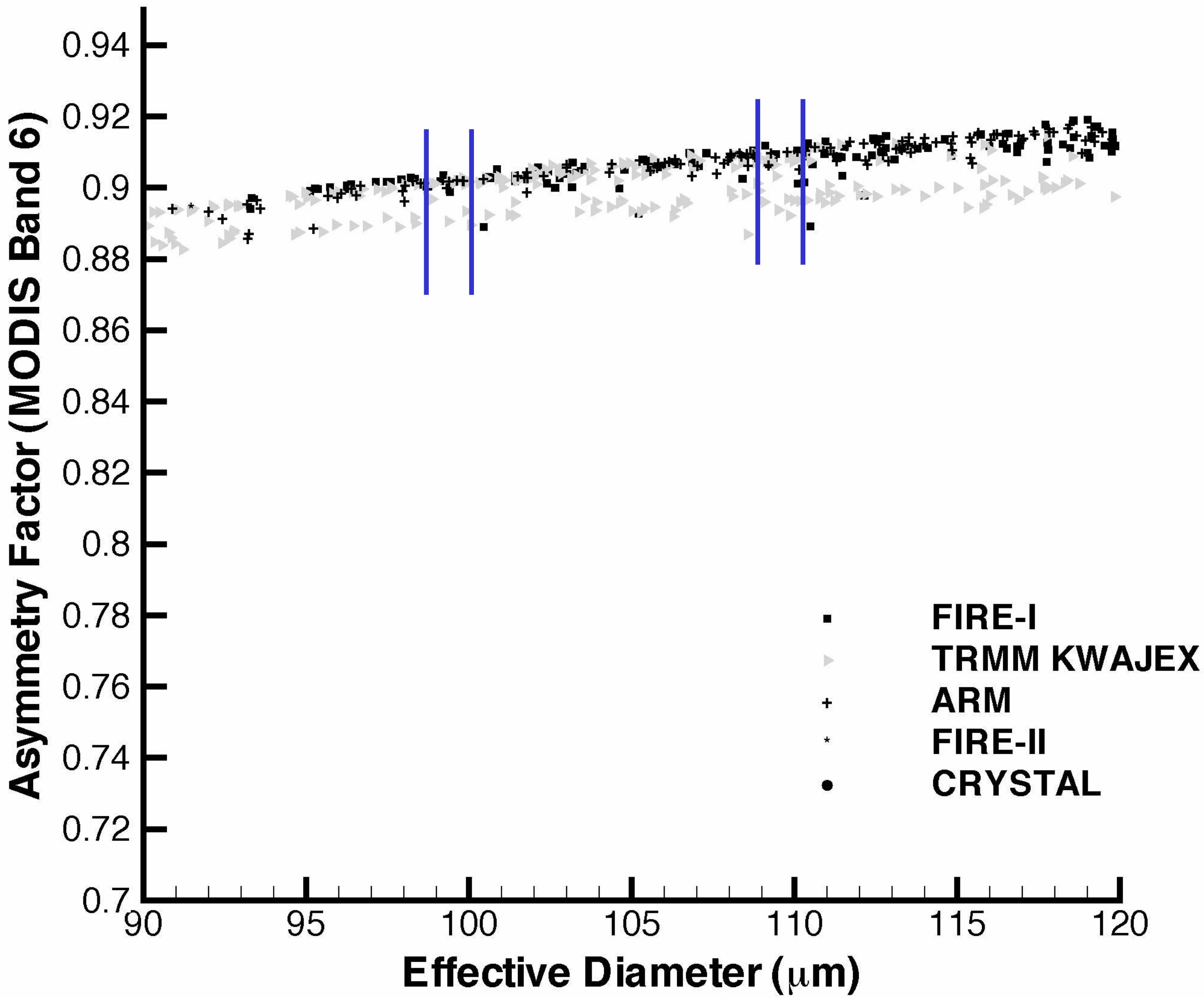
Development of Band Models

Need discrete set of scattering models upon which to base look-up table and associated radiative transfer calculations

Suggestion that models be evenly spaced in effective diameter



Asymmetry Factor (MODIS Band 6)
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0.78
0.76
0.74
0.72
0.7
0
50
100
150
200
250
Effective Diameter (μm)
Habit Mixture
FIRE-I
TRMM KWAJEX
ARM
FIRE-II
CRYSTAL
CRYSTAL (smc x 1000)
CRYSTAL (smc x 100)



Asymmetry Factor (MODIS Band 6)
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0.78
0.76
0.74
0.72
0.7
90
95
100
105
110
115
120
Effective Diameter (μm)
FIRE-I
TRMM KWAJEX
ARM
FIRE-II
CRYSTAL

Ice Scattering Models Currently Available

Provide microphysical and scattering properties (mean and std. dev.) at D_{eff} from 10 μm to 180 μm, in increments of 10 μm, for

IWC	D_m
Volume	*Projected area*
asymmetry factor	*scattering phase function (498 angles)*
single scattering albedo	*extinction efficiency / cross section*

Models available at ***http://www.ssec.wisc.edu/~baum*** for

Narrowband imagers:

MODIS	AVHRR	MISR
AATSR	MAS	VIRS

GOES-R Advanced Baseline Imager (ABI)

MSG SEVIRI (Spinning Enhanced Visible InfraRed Imager)

MWIR/IR/FarIR models: 100 cm^{-1} to 3250 cm^{-1} at 1 cm^{-1} resolution

Models with full phase matrix (for polarization measurements) available at 7 wavelengths from 0.35 μm to 2.1 μm