Improving the Ice Optics in CAM5 : Treatment of the Asymmetry Parameter

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Treatment of the Asymmetry Parameter: Conceptual Framework

A number of studies show that asymmetry parameter g is primarily a function of:

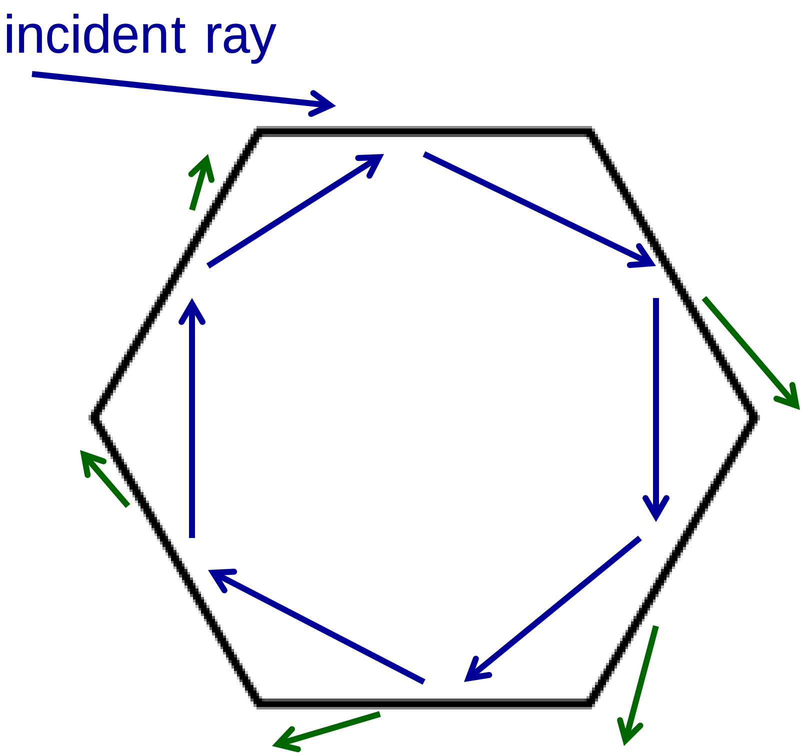
1. Aspect ratio for pristine ice crystals or representative component for complex ice crystals or aggregates

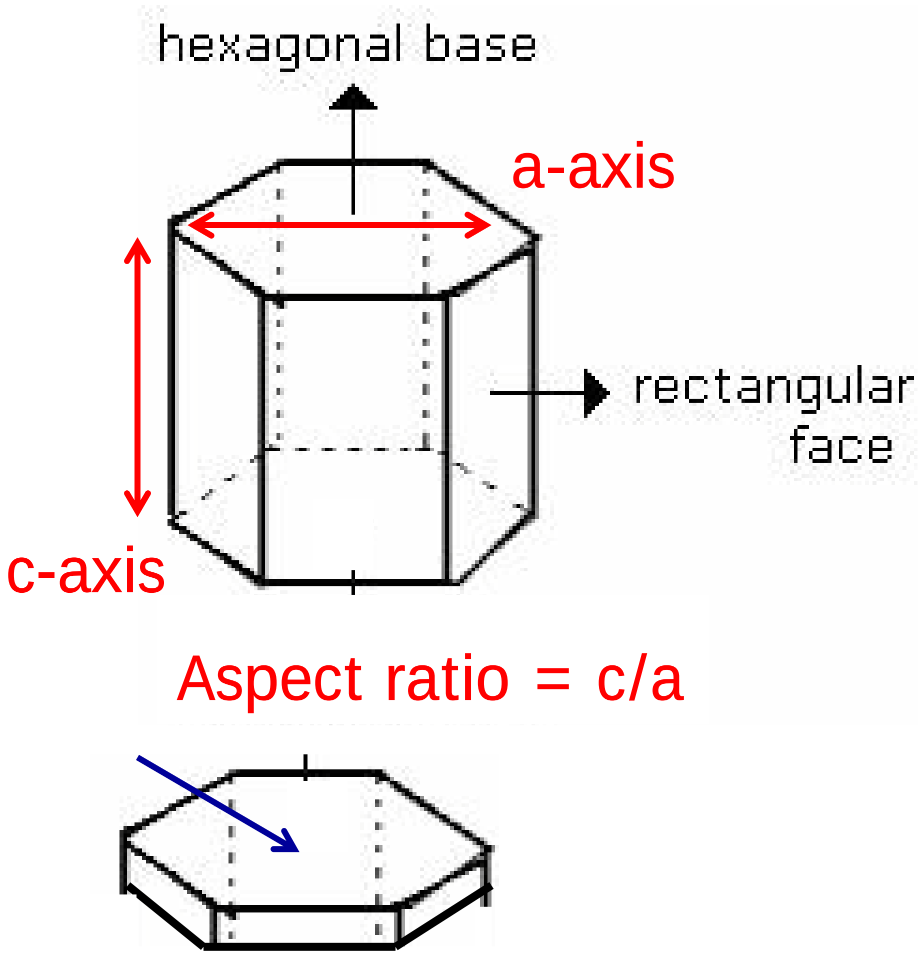
2. Microscale surface roughness

Thus ice cloud optical properties depend on aspect ratio (for a given surface roughness) in addition to effective size.

The g-parameterization of Fu (2007, JAS) incorporates this functionality in an elegant and physically realistic manner.

Light can be redirected in more directions when ice crystal aspect ratio is near unity





Light redirected in fewer directions

From van Diedenhoven et al., AMTD, 2012

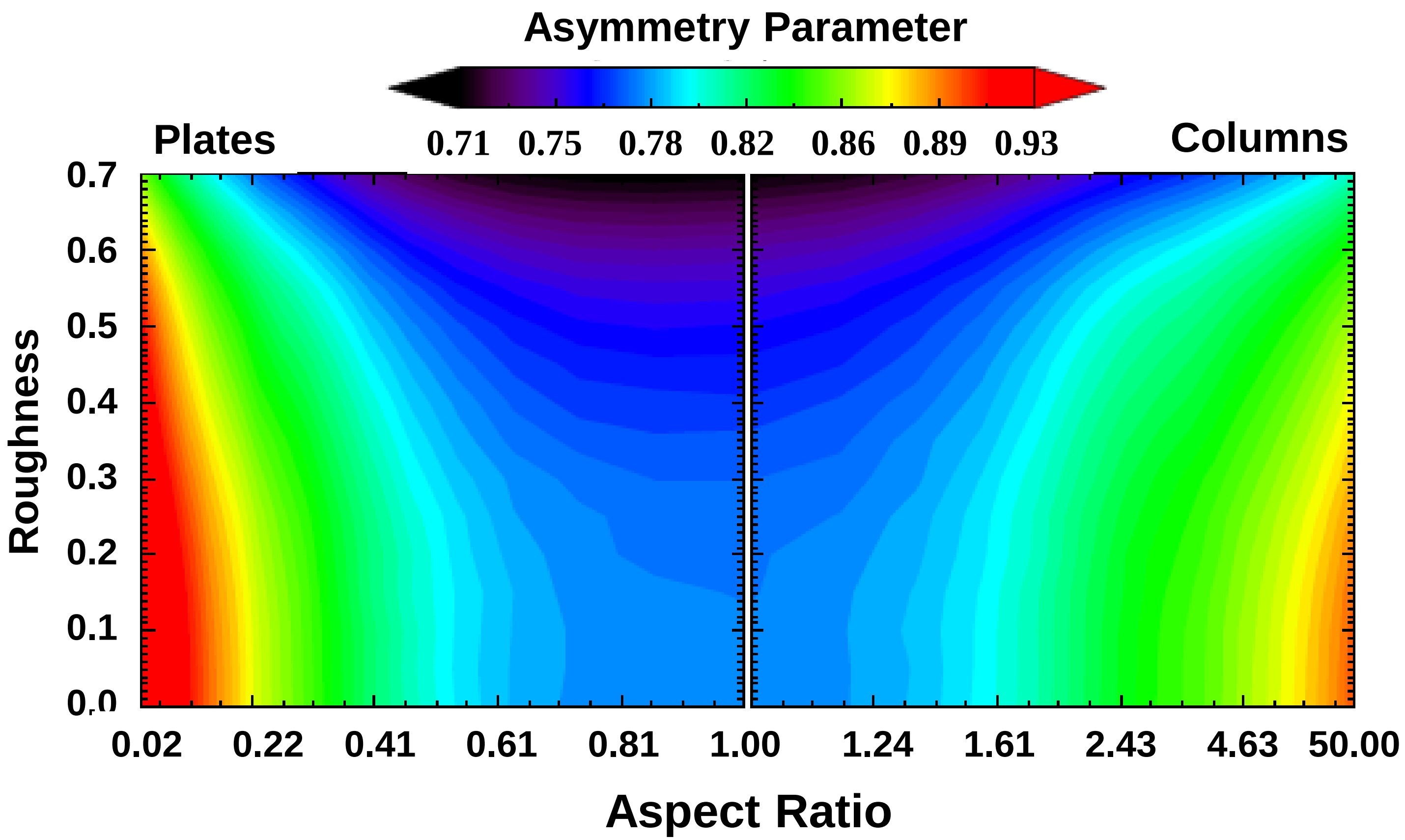


Fig. 1. Asymmetry parameters of plates and columns at 864 nm as a function of their aspect ratio and microscale roughness.

Results from van Diedenhoven et al., AMTD, 2012

1. Research Scanning Polarimeter (RSP) was flown above anvil cirrus during the CRYSTAL-FACE campaign in 2002. The RSP makes multi-directional polarized reflectance measurements from +45° to -75° viewing angle. Corresponding look-up tables of simulated polarized reflectance as a function of hexagonal column and plate aspect ratio and ice crystal surface distortion (proxy for microscale surface roughness) were used to retrieve these properties and g by minimizing differences between measured and simulated reflectances. Retrievals relevant near cloud top.

2. Retrieved g was compared with corresponding CIN measurements of g. Regarding 4 flight cases, retrieved median g ranged from 0.76 to 0.78, exceeding measurement values by 0.01 in 2 cases and by 0.03 to 0.05 in 2 other cases. To constrain SW fluxes within 5%, must know g within 0.02 to 0.04 in absolute terms.

3. Retrieved effective aspect ratios in 3 cases ranged from 0.9 to 1.6, while other case was ~ 0.3, indicating compact ice particles near cloud top. Retrieved surface roughness was relatively high.

Treatment of g based on Fu (2007, JAS):

$$g = g_{dif} + g_{ref}$$

Fraction of diffracted rays = $\delta = 1/ (2\ \omega_o)$

$$g = \delta\ g_{dif} + (1 - \delta)\ g_{ref}$$

Since $g_{dif} \approx 1.0$,

$$g \approx \frac{1}{2\ \omega_o} + \left(1 - \frac{1}{2\ \omega_o} \right) g_{ref}$$

where ω_o is calculated from MADA ice optics.

Treatment of surface roughness:

Ice particles with rough surfaces should not have the delta transmission associated with rays passing through parallel planes of ice crystals at normal angles of incidence. Thus the delta transmission contribution to g, f_d , is removed:

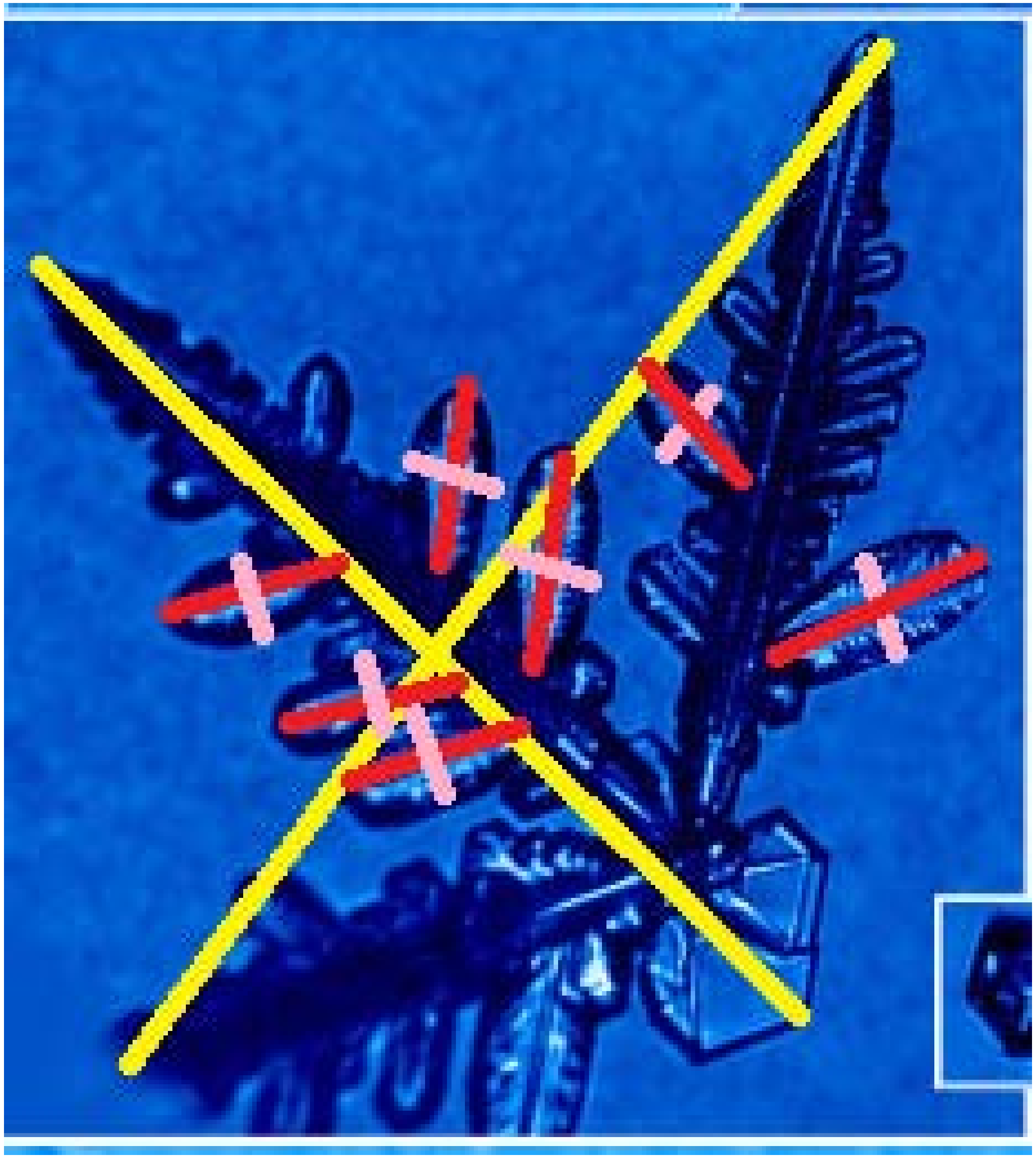
$$g_r = \frac{g_s - f_d}{1 - f_d}$$

where g_r is for rough crystals, g_s is for smooth crystals. Using geometric ray tracing to calculate g_r , g_r is then parameterized in terms of the effective aspect ratio (AR) of the ice particle size distribution N(D), where

$$AR = \frac{\int AR_c \, A(D) \, N(D) \, dD}{\int A(D) \, N(D) \, dD}$$

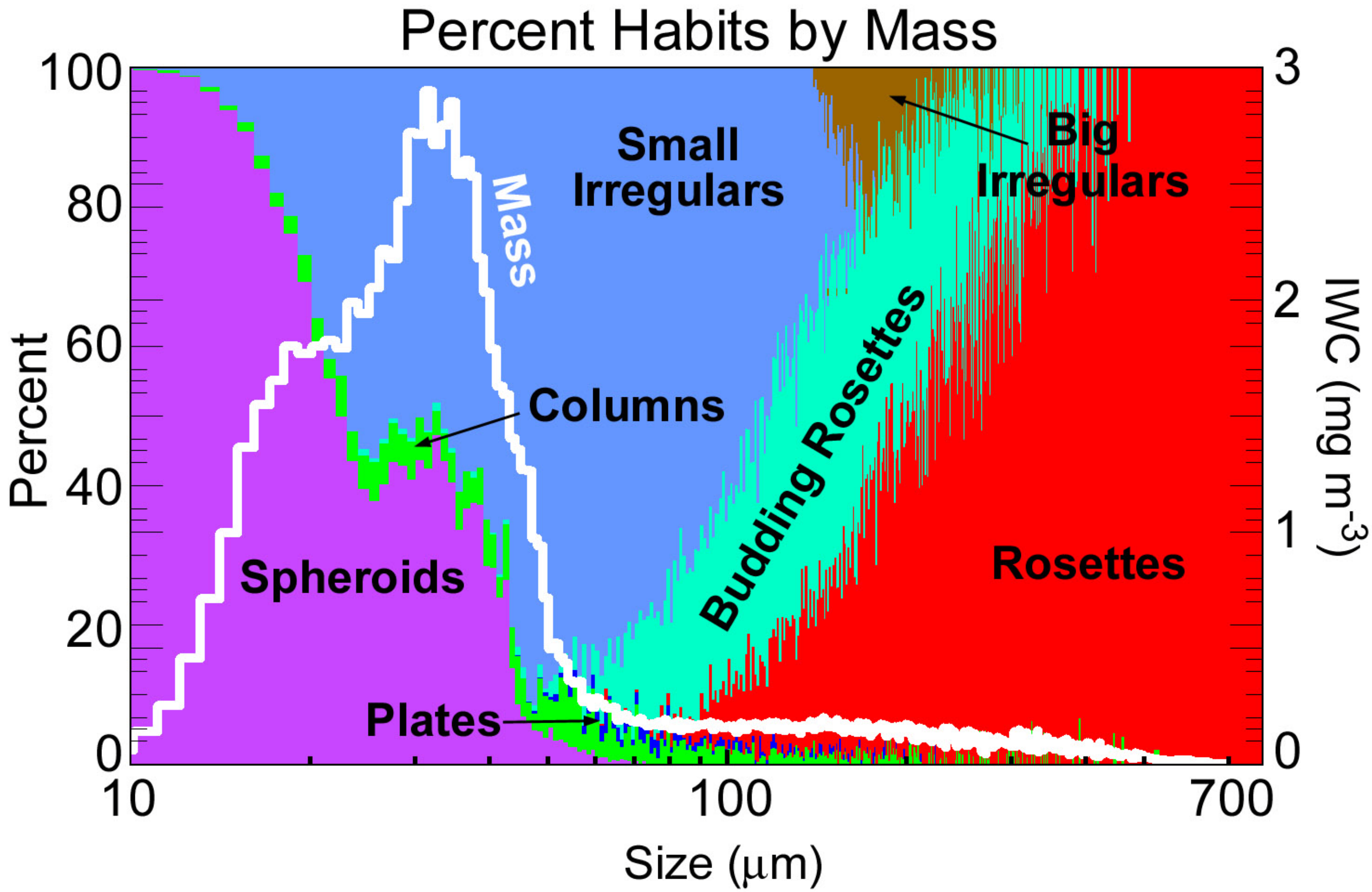
where AR_c is the ice crystal aspect ratio (or AR_c of representative component of a complex crystal or aggregate) and A(D) = ice particle projected area.

Example: Treatment of Aspect Ratio for Dendrite Components



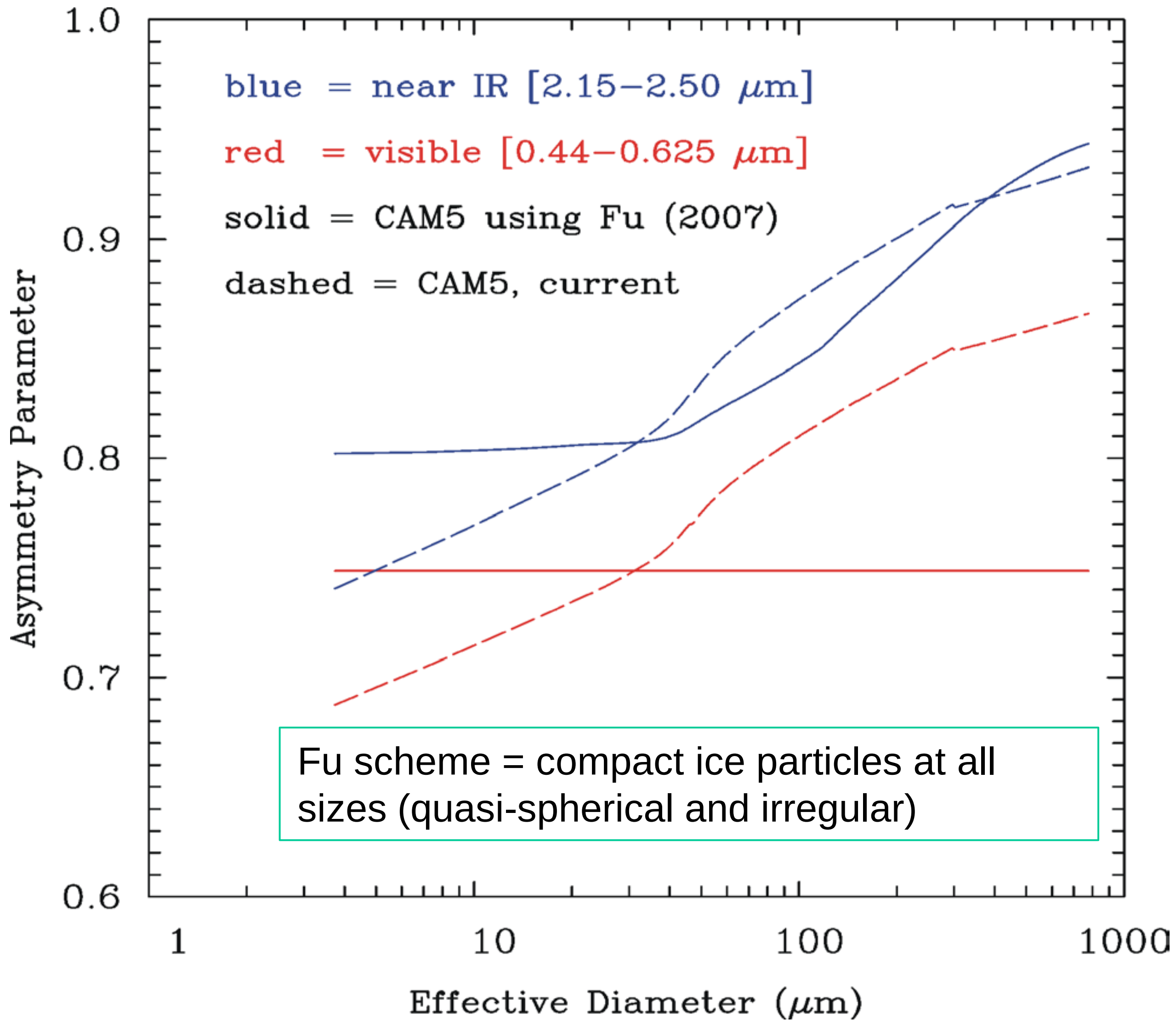
Effective aspect ratio for dendrites can be estimated by taking average of pink and red lines to characterize the planar surface dimension, Dp. From Dp, calculate the component thickness using relationship from Auer & Veal (1970) for dendrites. By ratioing Dp with the dendrite maximum dimension Dmax (yellow lines), Dp can be estimated for any Dmax.

Application of the Fu Scheme to CAM5

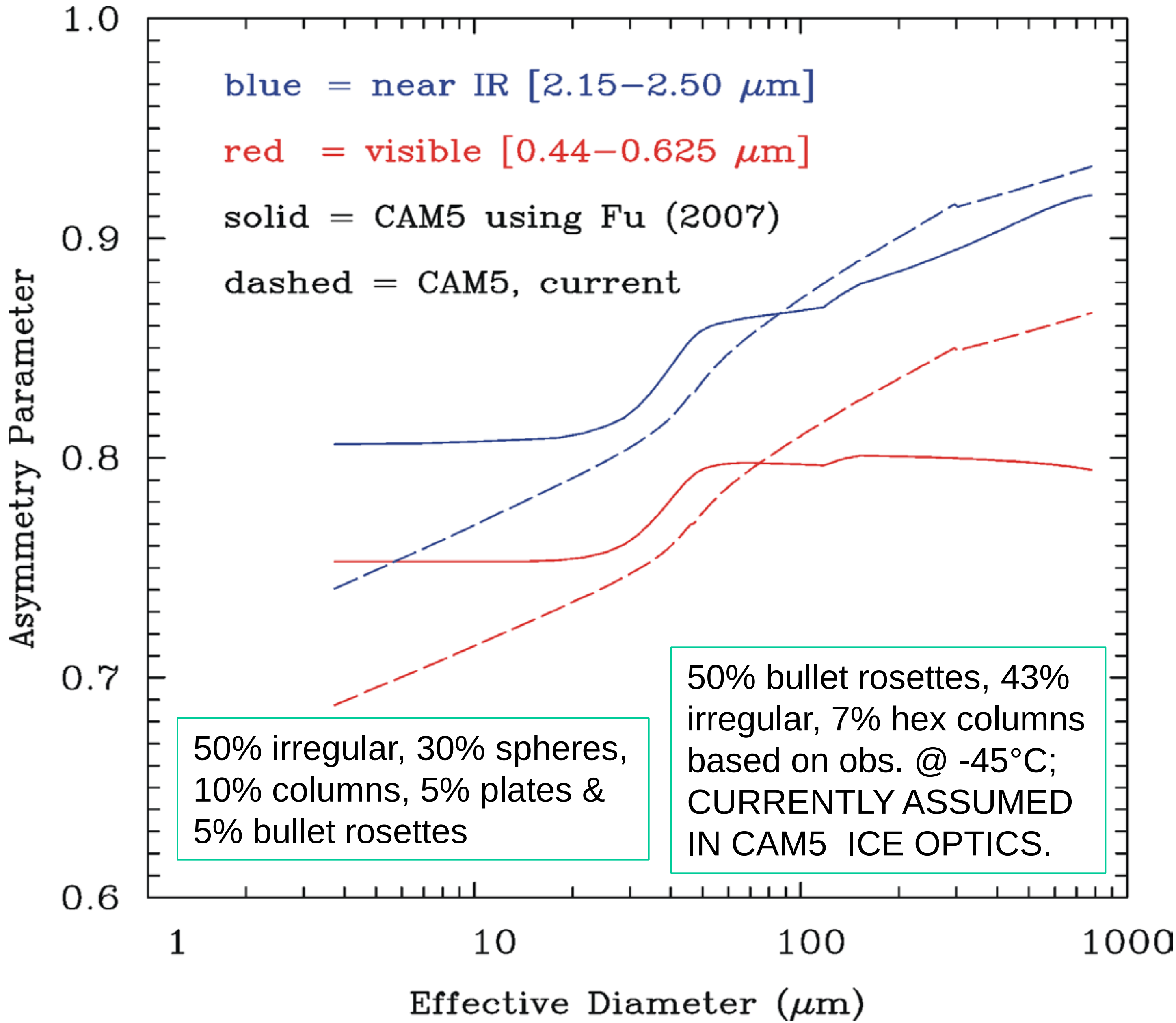


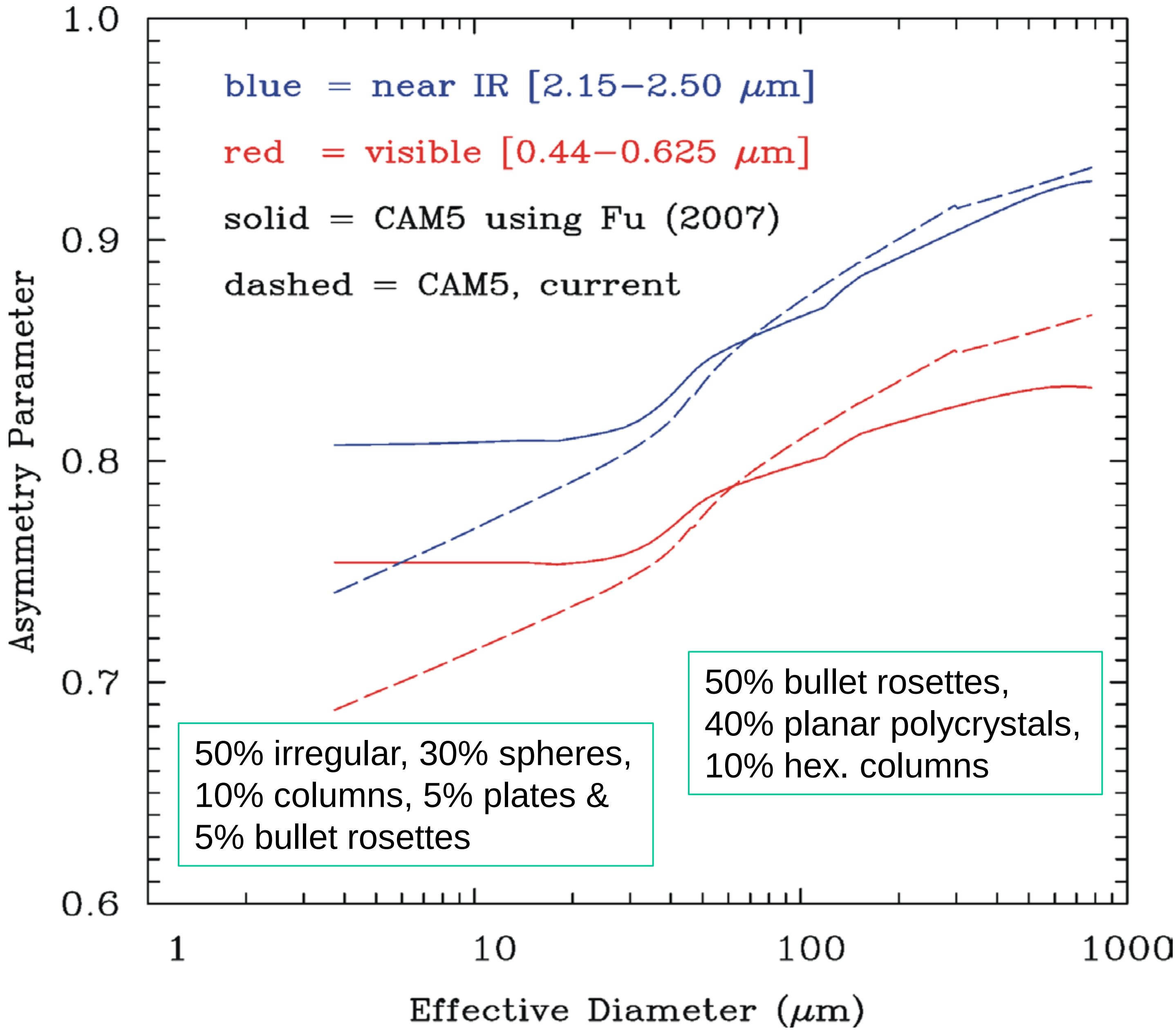
Mass percentage of ice particle habits as a function of particle size.
From Lawson et al. 2006, J. Atmos. Sci.

Comparing g from Fu and CAM5 where ice crystal shape is constant across the PSD for the Fu scheme



Comparing g from Fu and CAM5 where shape varies across PSD




blue = near IR [2.15–2.50 μm]
red = visible [0.44–0.625 μm]
solid = CAM5 using Fu (2007)
dashed = CAM5, current
50% bullet rosettes,
40% planar polycrystals,
10% hex. columns
50% irregular, 30% spheres,
10% columns, 5% plates &
5% bullet rosettes
Asymmetry Parameter
1.0
0.9
0.8
0.7
0.6
1
10
100
1000
Effective Diameter (μm)

Attributes of Fu Scheme

1. Expresses g in terms of aspect ratio and surface roughness. Ice cloud optical properties should depend on both D_e and aspect ratio.

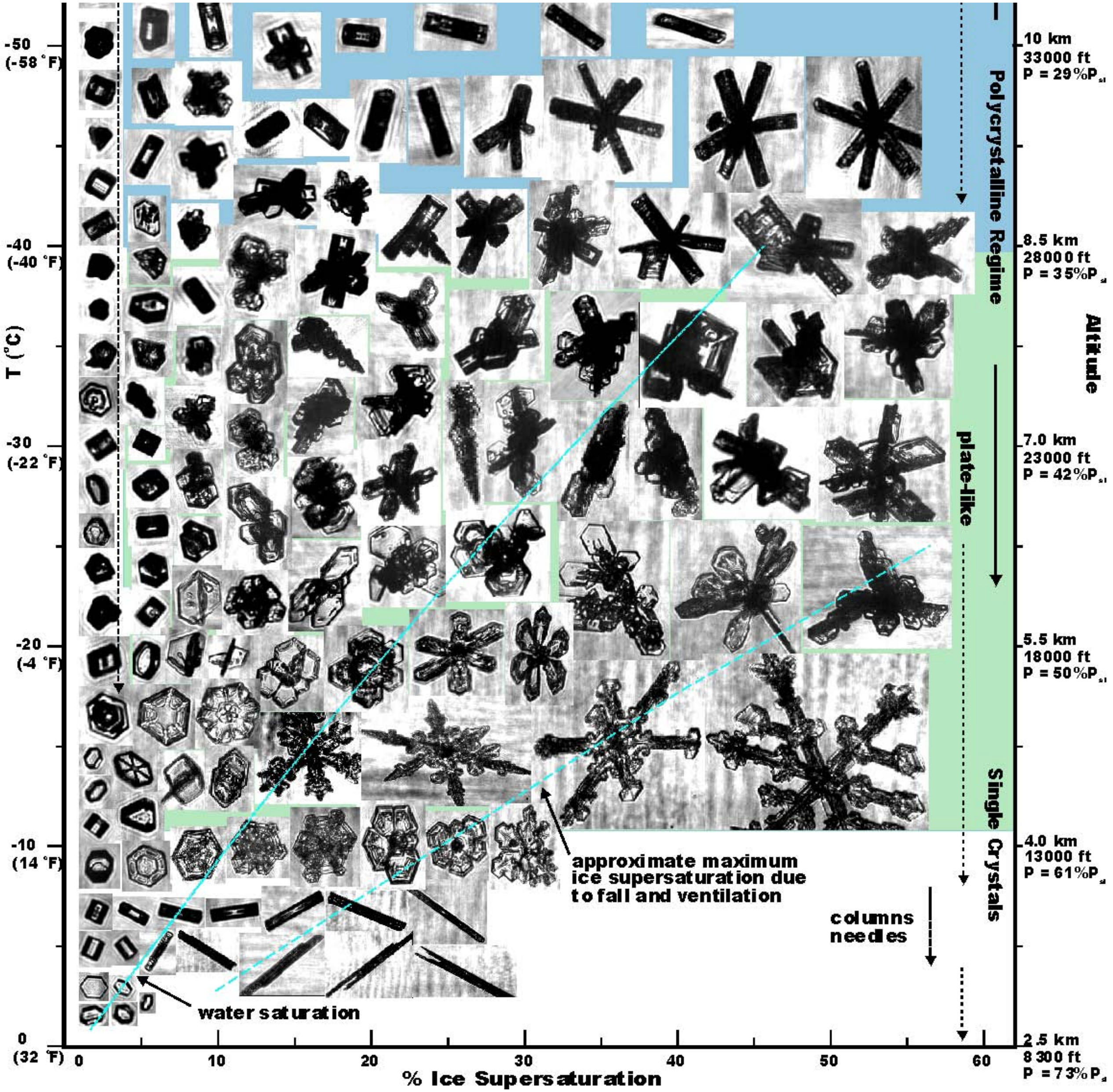
2. Using ice particle shape mixtures representative of cirrus clouds, it yields g values consistent with retrieval measurements of g but slightly higher than in situ measurements of g. It also appears fairly consistent with the current formulation for g in CAM5 that uses a fixed ice crystal shape recipe.
   - To accurately calculate g, it appears necessary to vary the ice particle shape across the size distribution, based on the Fu scheme and the observed size-dependence of ice crystal shape.

3. Makes ice optics more elegant theoretically and computationally

4. Can be generalized to most particle shapes, including complex shapes

5. Could increase coherence between CAM5 microphysics and radiation
   - Could add scheme as research option
   - Would need to pass ice particle shape info to radiation module, possibly using multiple look-up tables

Bailey and Hallett 2009, J. Atmos. Sci.



Complex shapes are common in cirrus clouds. In such cases, the aspect ratio of the crystal component is used.

Laboratory work shows ice crystal shapes vary with temperature, indicating g should also vary with temperature.