MODIS Collection 6 Ice Model Assessments with POLDER and CALIPSO

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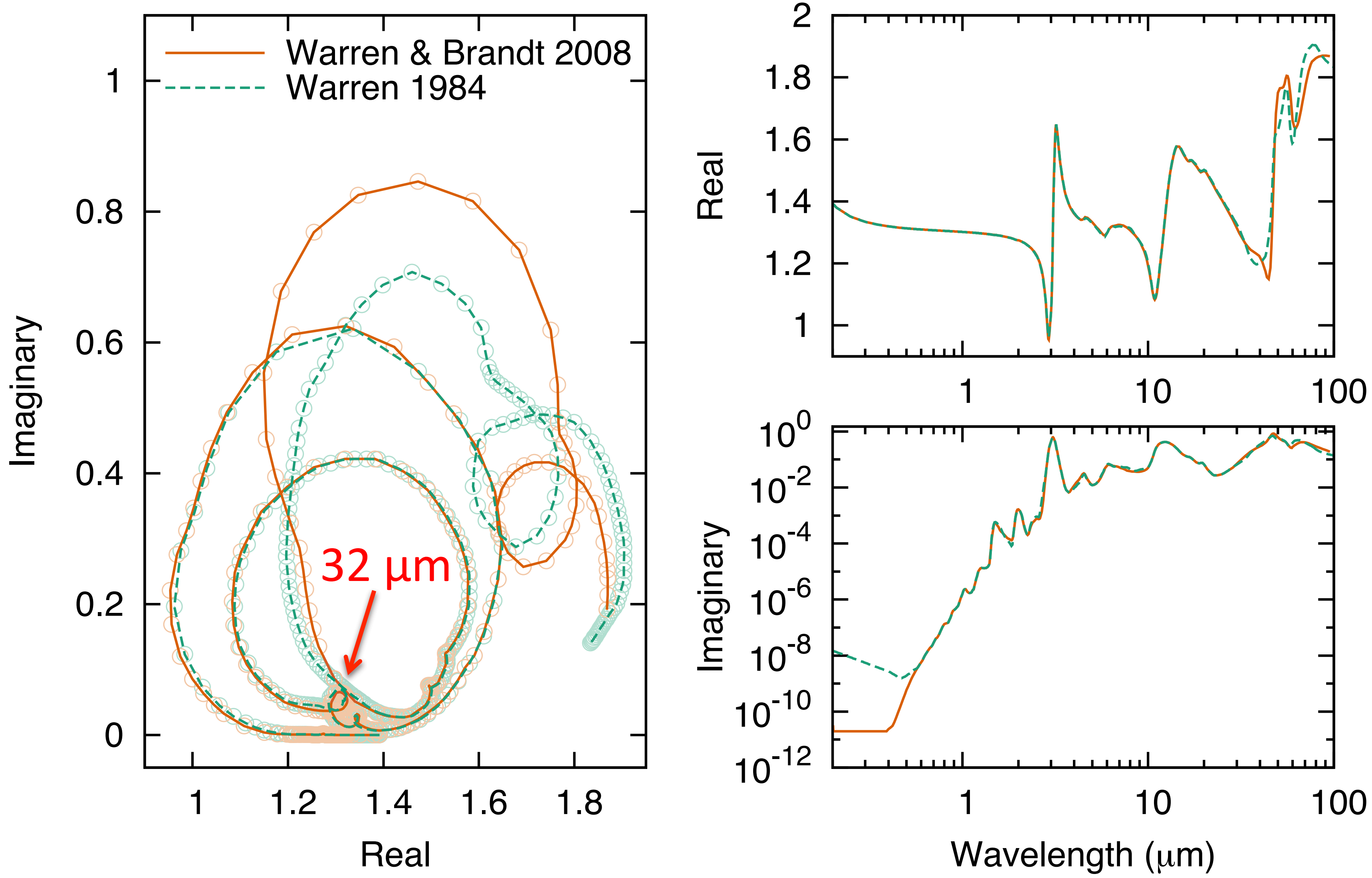
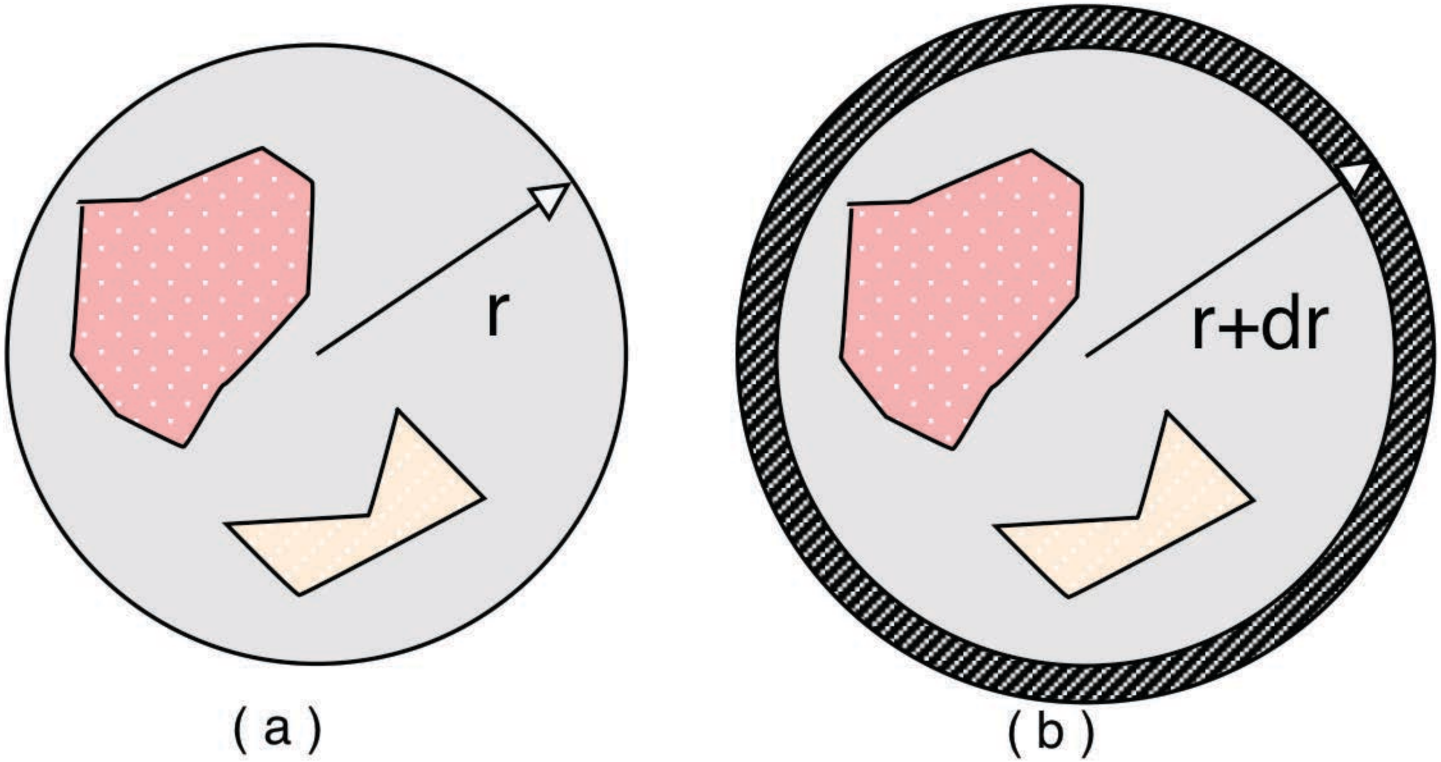
Ice Refractive Index



Novel Invariant Imbedding T-Matrix Method



$$\vec{E}(\vec{r}) = \vec{E}_{inc}(\vec{r}) + k^2 \int \left(m^2 - 1\right) \overleftrightarrow{G}(\vec{r} - \vec{r}\,') \cdot \vec{E}(\vec{r}\,') d^3\vec{r}\,'$$

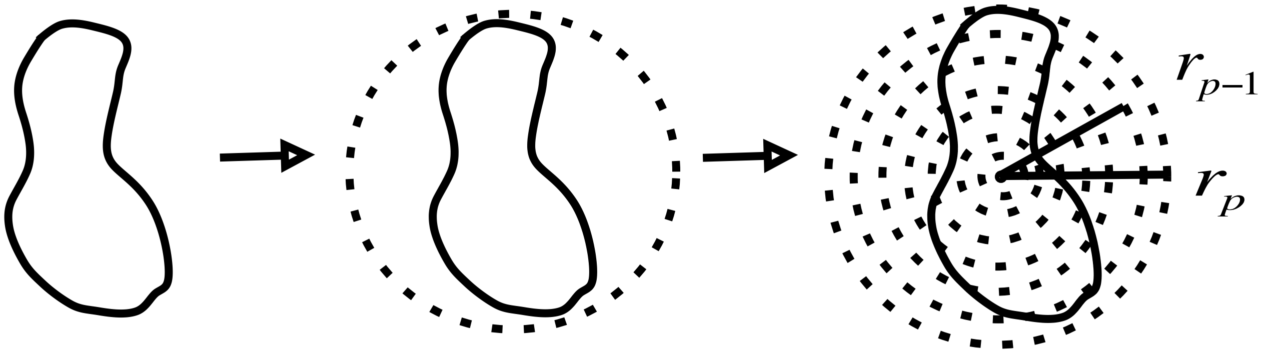
↓

$$T_{mnmn'}(r+dr) = Q_{11}^{m}(r+dr) + \left[\mathbf{I} + Q_{12}^{m}(r+dr)\right]\left[\mathbf{I} - T_{mnmn'}(r) Q_{22}^{m}(r+dr)\right]^{-1} T_{mnmn'}(r)\left[\mathbf{I} + \tilde{Q}_{12}^{m}(r+dr)\right]$$

Johnson (1988); Bi, Yang, Kattawar, and Mishchenko (2013), Bi and Yang (2014)

What is a nonspherical particle?

A nonspherical particle is <u>a certain distribution of the refractive index within a spatial domain of interest</u>.

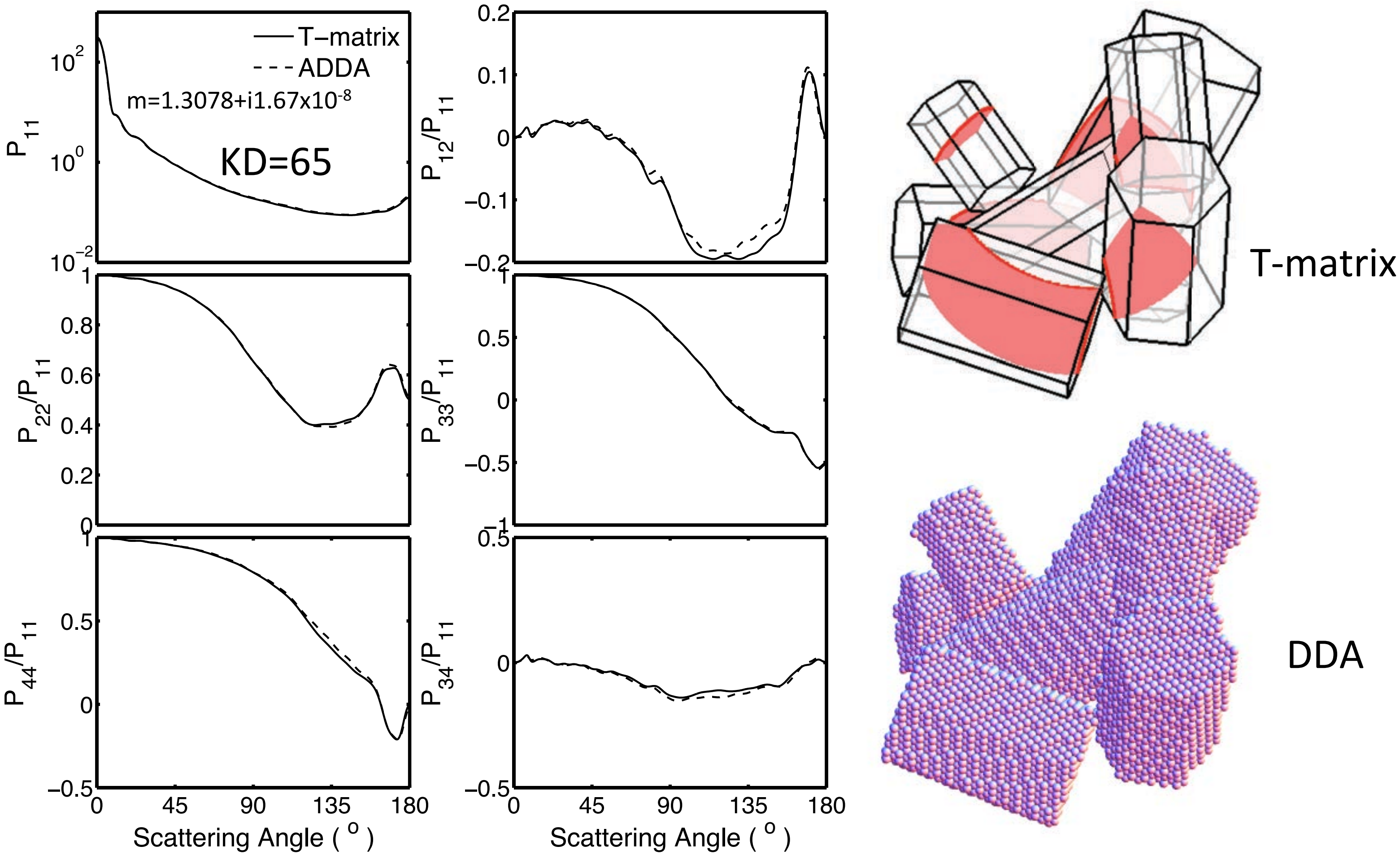


A nonspherical particle = an inhomogeneous sphere

= a multi-layered sphere

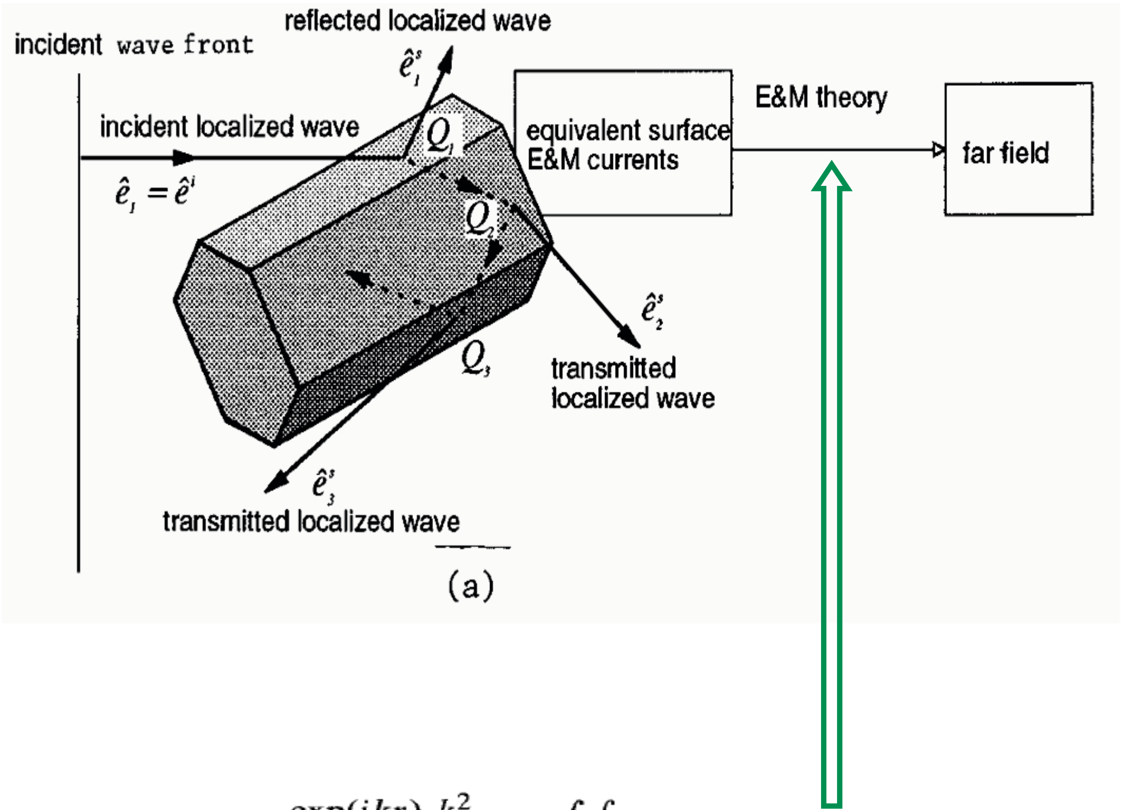
Note that the T-matrix corresponding to r=0 is zero.

Comparison between II-TM and ADDA (Bi and Yang, 2014)



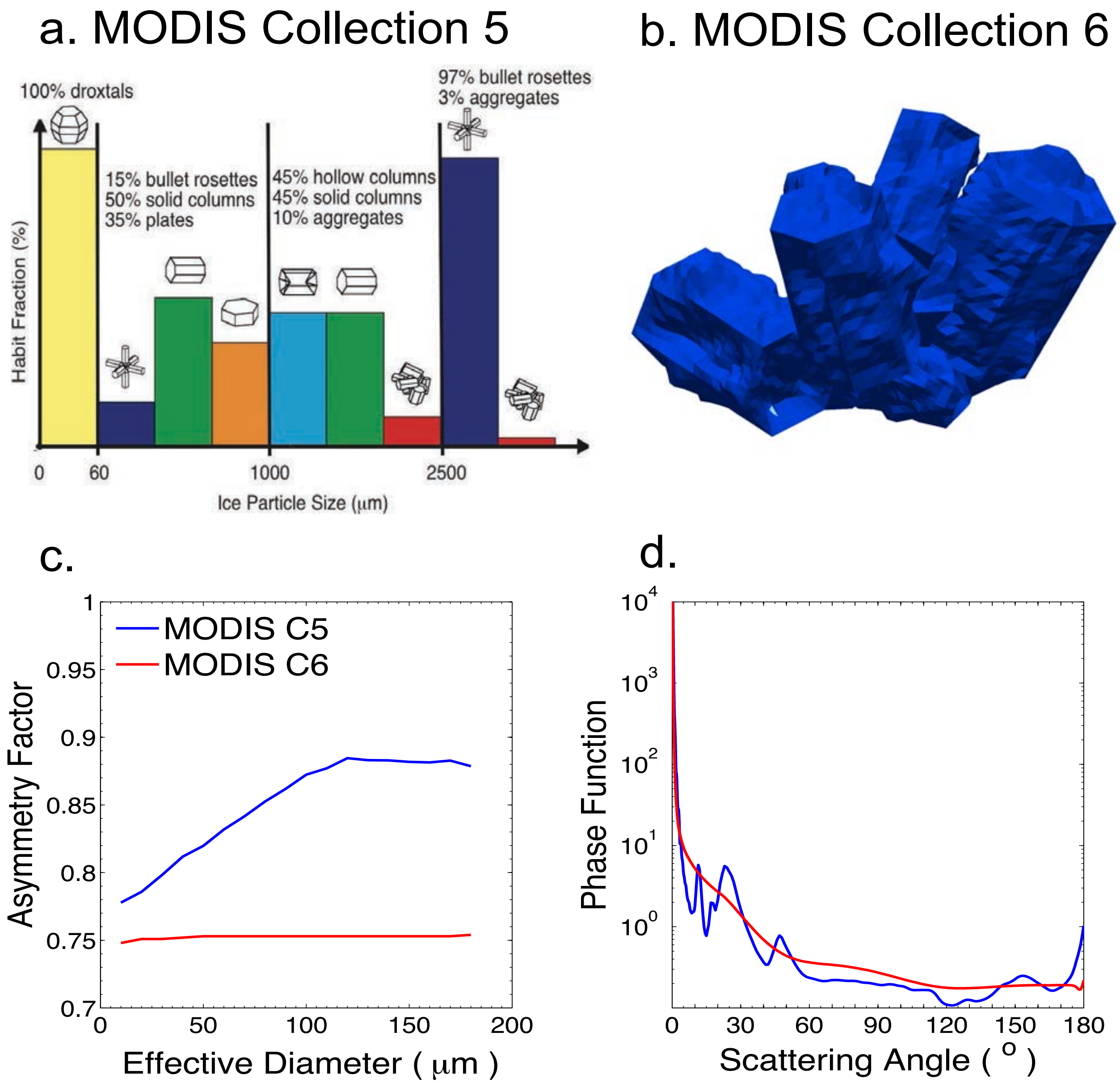
In the Discrete-dipole-approximation(DDA)simulation, 1056 orientations with 128 scattering planes are set to achieve the randomness. ADDA is a public DDA software developed by Yurkin and Hoekstra.

Yang and Liou (1996)



$$\mathbf{E}_s(\mathbf{r})|_{kr\to\infty} = \frac{\exp(ikr)}{-ikr}\frac{k^2}{4\pi}\mathbf{n}\times\iint_S\{\mathbf{n}_S\times\mathbf{E}(\mathbf{r}') - \mathbf{n}\times[\mathbf{n}_S\times\mathbf{H}(\mathbf{r}')]\}$$
$$\times\exp(-ik\mathbf{n}\cdot\mathbf{r}')\,d^2\mathbf{r}',$$

MODIS C5 (Baum et al. 2005) and MODIS C6 (Platnick et al. 2014) Ice Models



G. L. Stephens, S.-C. Tsay, P. W. Stackhouse Jr., and P. J. Flatau, 1990: The relevance of the microphysical and radiative properties of cirrus clouds to climate and climatic feedback. *J. Atmos. Sci.*, **47**, 1742–1754.

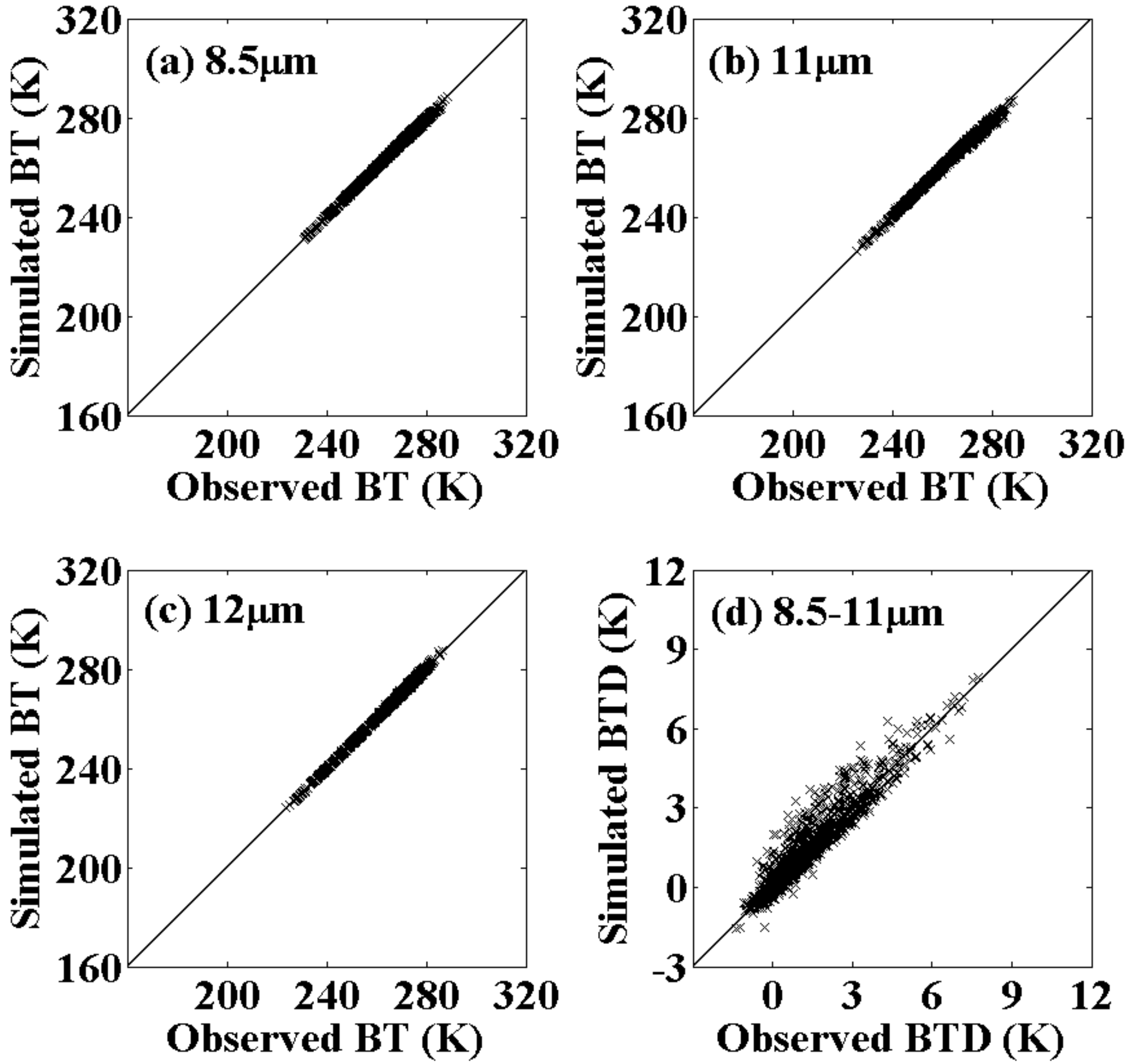
- “The asymmetry parameter had to be adjusted from the broadband Mie value of g=0.87 for the size distribution chosen to a lower value of g=0.7 in order to bring the observations and theory into broad agreement.”
- “Cirrus clouds characterized by g=0.87 warmed approximately twice as much as cirrus clouds modeled with g=0.7.”

Consistency of spectral retrievals

- MODIS operational retrieval algorithm (Nakajima and King, 1990)

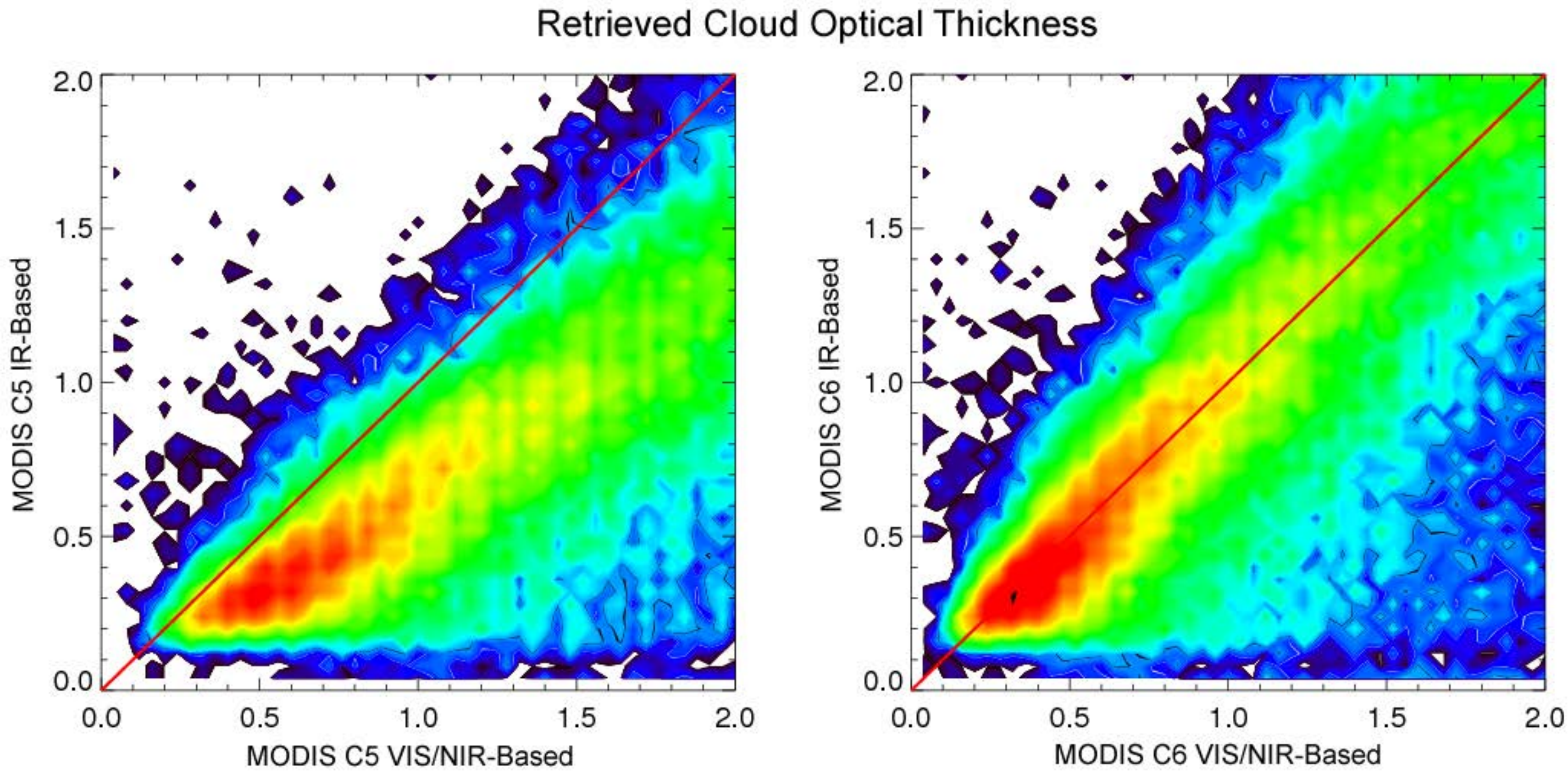
- Infrared techniques: 8.5 µm, 11 µm, and 12 µm (e.g., Wang et al. 2011)

- The cloud property retrievals based on the two techniques should be consistent.

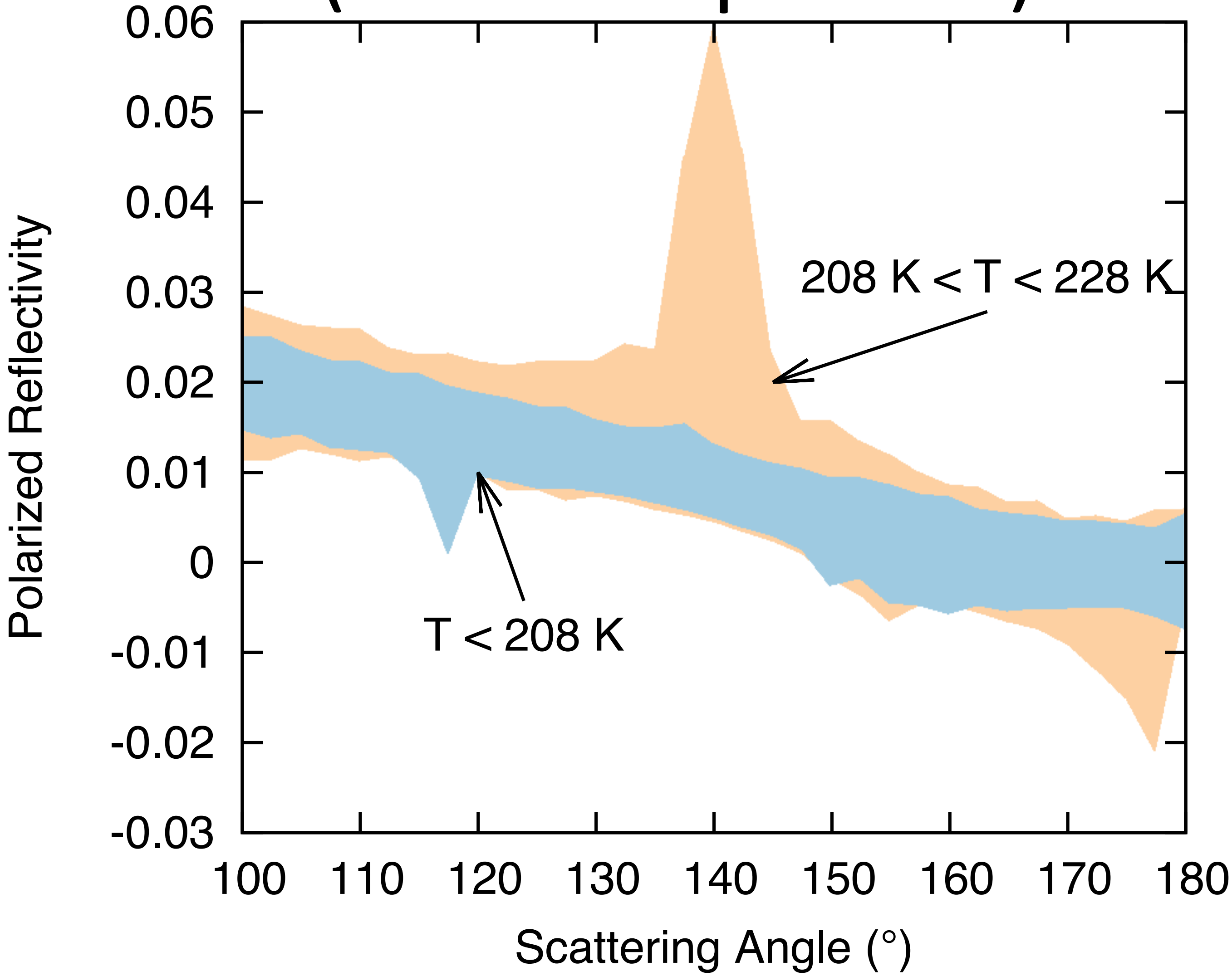


Scatter plots of MODIS observed TOA BTs and BTD (8.5-11mm) vs. simulated BTs and BTD by using the optimal t and D_{eff} (after Wang et al. 2011).

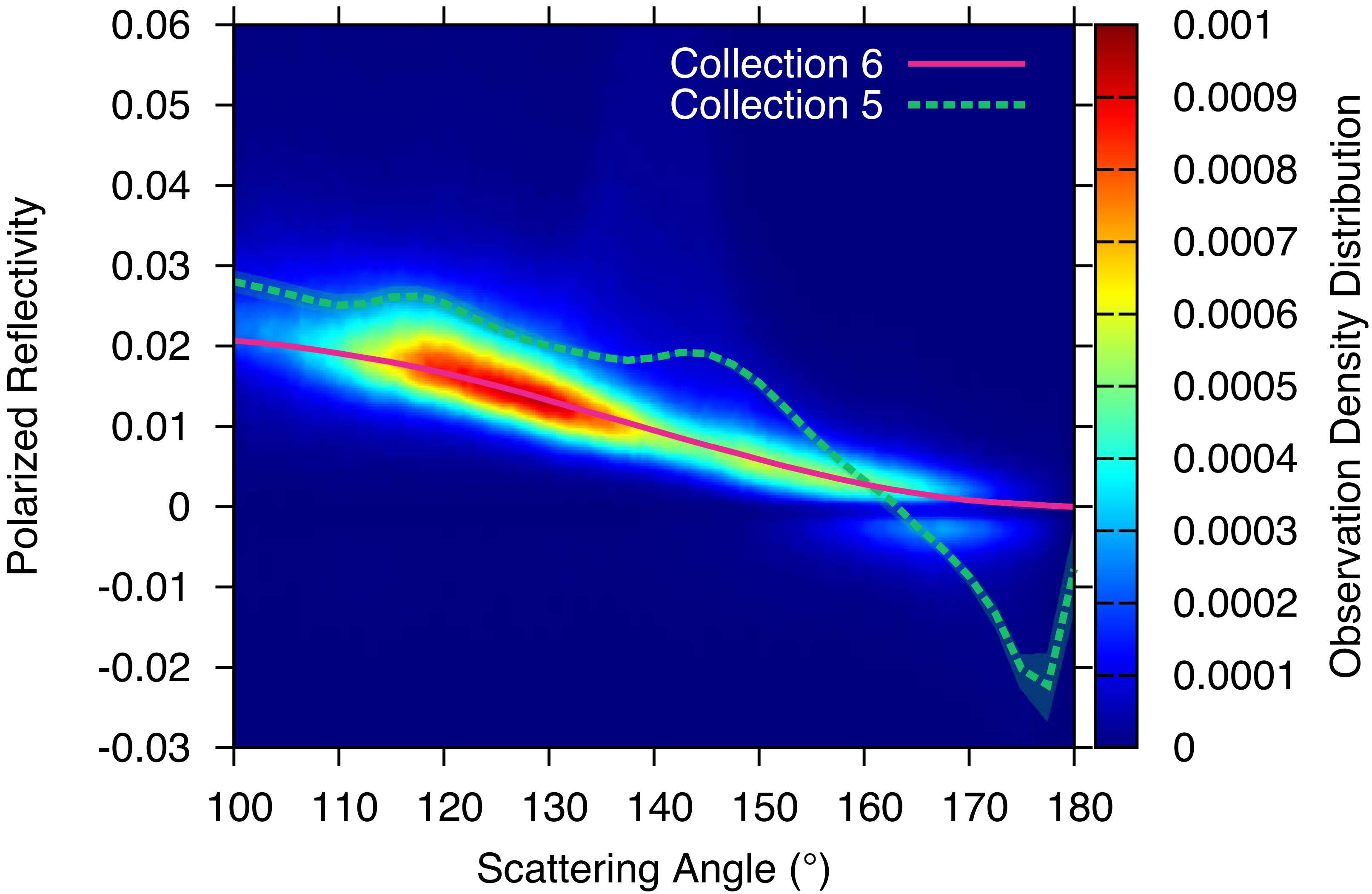
Spectral Consistency: MODIS C5 versus MODIS C6

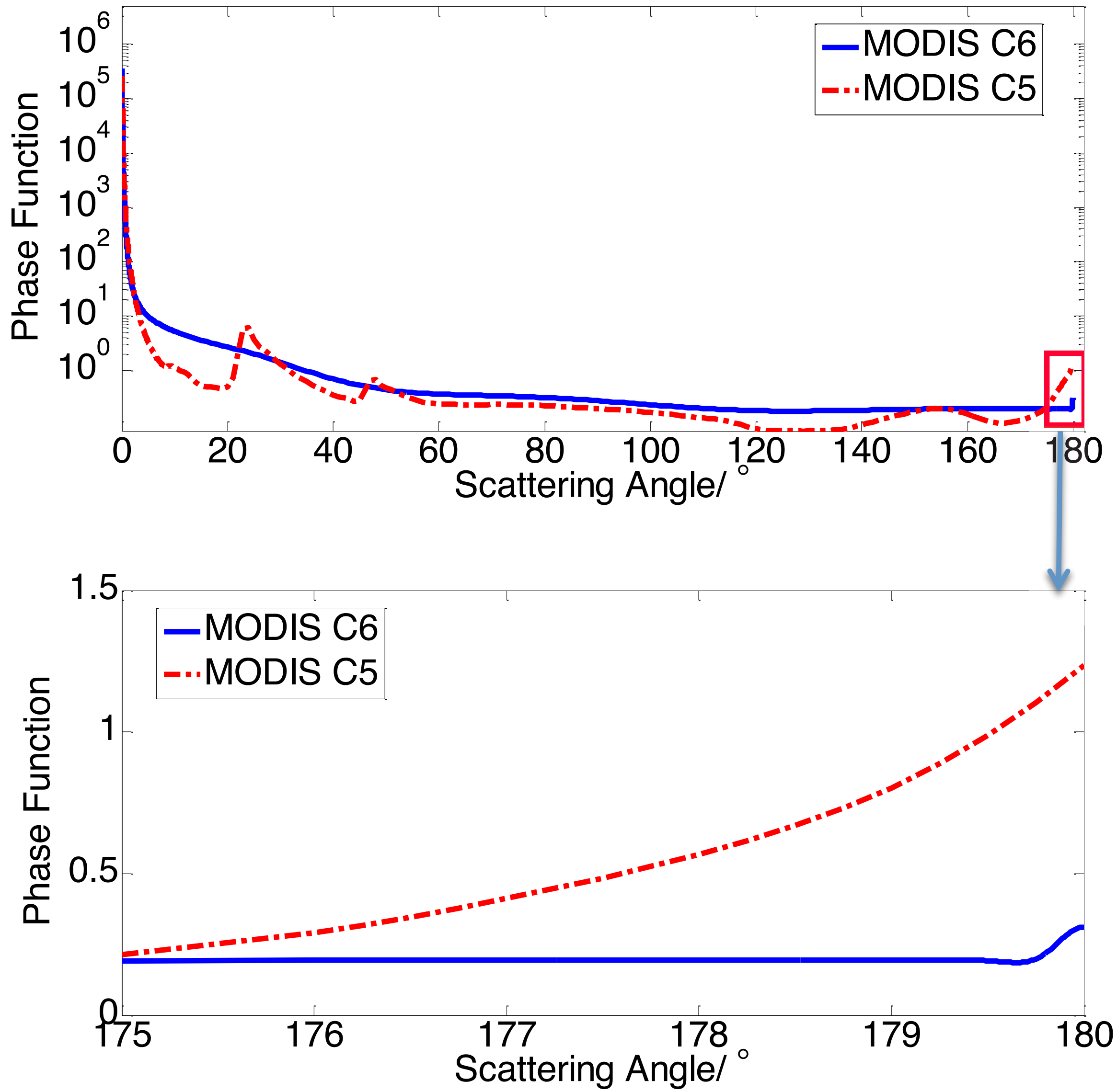


Ranges of POLDER Observations (5%-95% quantile)



Polarimetric property consistency: POLDER observations (color contour) versus simulations (lines) with D_e=60 μm



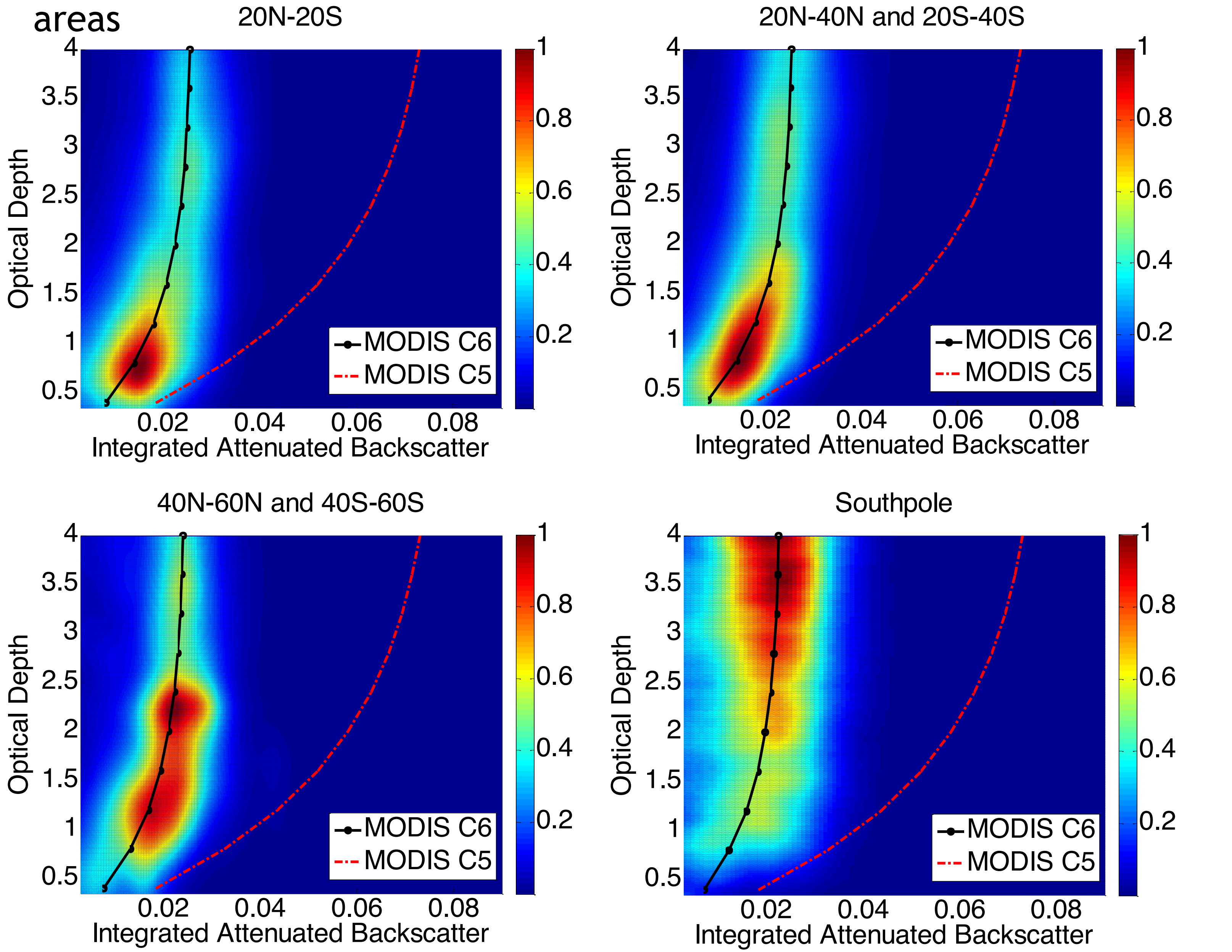


Enhanced backscatter for roughened particles (Zhou and Yang 2015):

$$\zeta = 1 + \frac{\sin\delta_c}{\delta_c} R$$

where $0.3 < R < 0.7$ and $\delta_c = 2\pi D(\pi - \theta)/\lambda$.

Comparison of Integrated Attenuated Backscatter-Optical Depth relations of MODIS C5 and MODIS C6 model ice particles in different latitudinal areas



Conclusions

- With the newly developed MODIS C6 ice cloud optical property model, improvements have been achieved from several perspectives:
  - ➢ Spectral consistency in cloud property retrieval (VIS/NIR vs IR)
  - ➢ Polarimetric property consistency: POLDER observations vs simulations
  - ➢ Consistency in a combination of passive (MODIS) and active (CALIPSO) observations.
- MODIS C6 ice cloud optical property model has been extended to the generation of ice cloud properties in the Community Radiative Transfer Model (CRTM)
- Will apply the MODIS C6 model to RT models in GCMs (e.g., CESM).