Simulation of the Radiative Properties of Ice Clouds, Snow, and Dust Aerosol in Support of CERES

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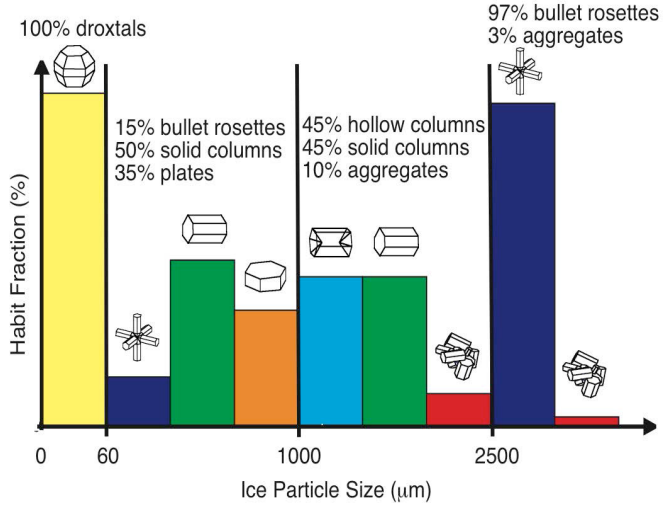
Stephens, G. L., S.-C. Tsay, P. W. Stackhouse Jr., and P. J. Flatau, 1990: The relevance of the microphysical and radiative properties of cirrus clouds to climate and climatic feedback. J. Atmos. Sci., **47**, 1742–1754.

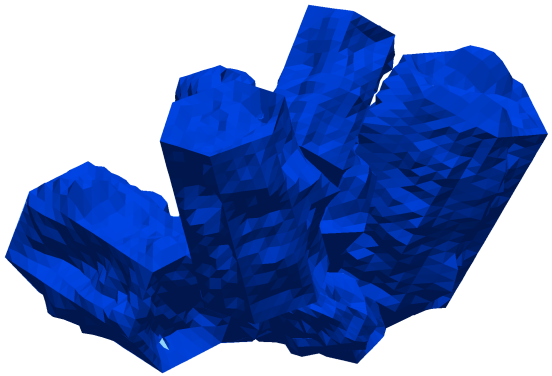
- "The asymmetry parameter had to be adjusted from the broadband Mie value of g=0.87 for the size distribution chosen to a lower value of g=0.7 in order to bring the observations and theory into broad agreement."
- "Cirrus clouds characterized by g=0.87 warmed approximately twice as much as cirrus clouds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

MODIS C5 (Baum et al. 2005) and MODIS C6 (Platnick et al. 2017) Ice Models

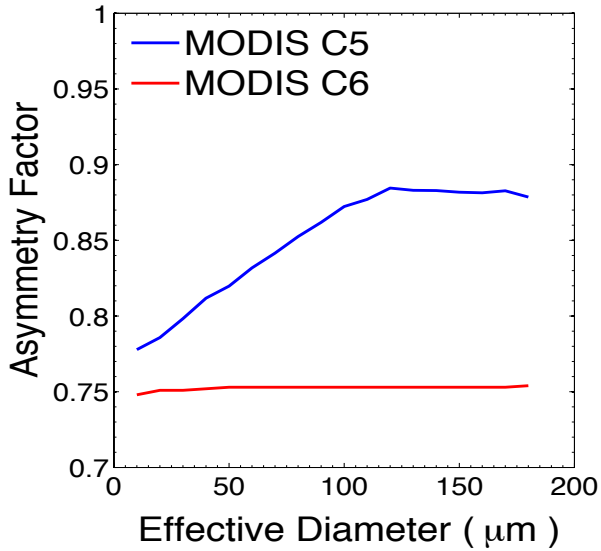
a. MODIS Collection 5



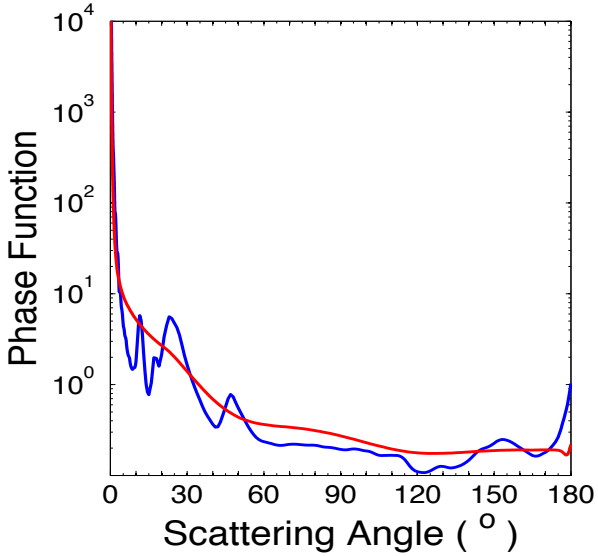
b. MODIS Collection 6



c.

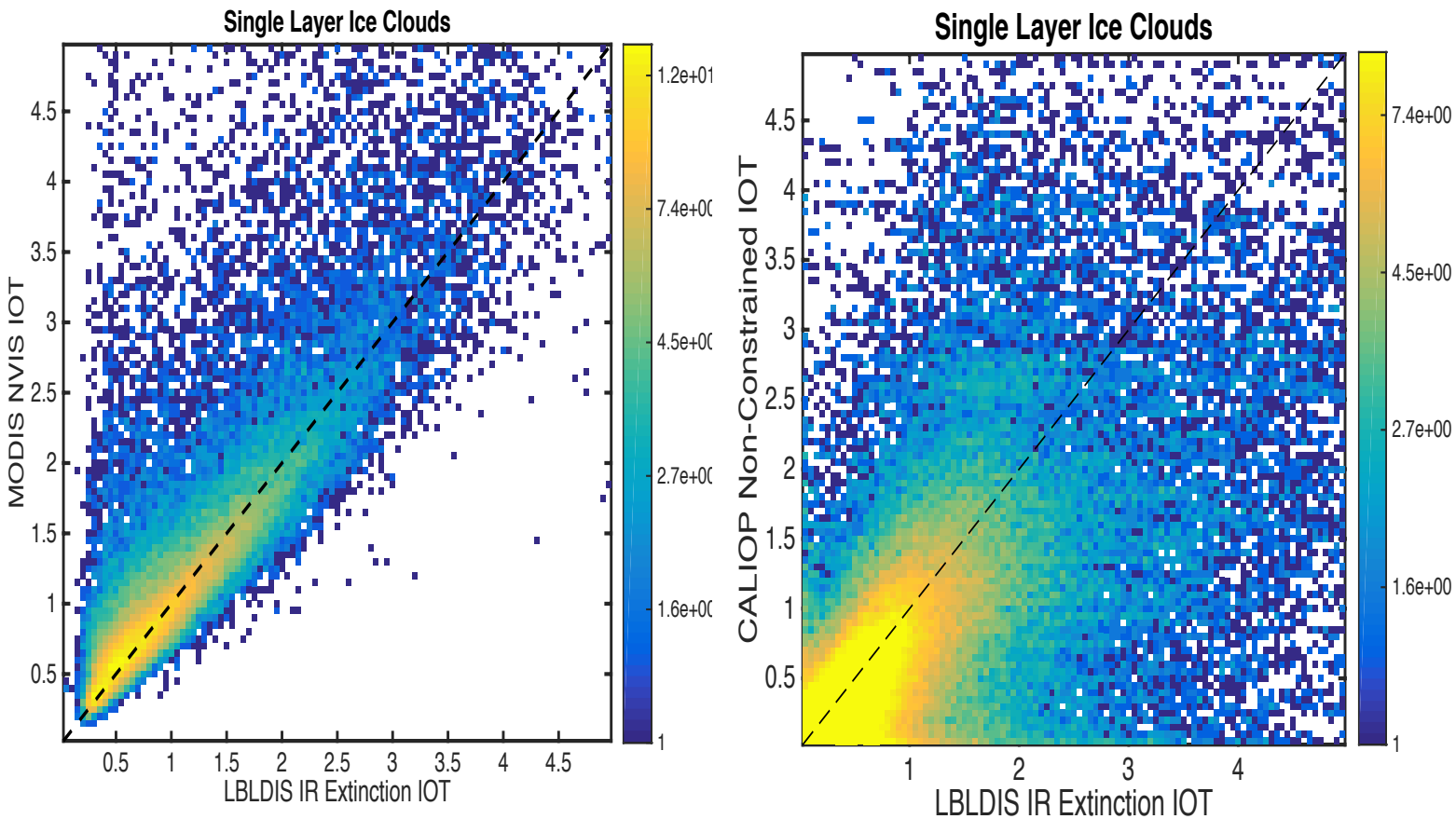


d.



MODIS C6 versus CALIPSO Ice Cloud Optical Thickness (IOT)

Holz et al., 2015

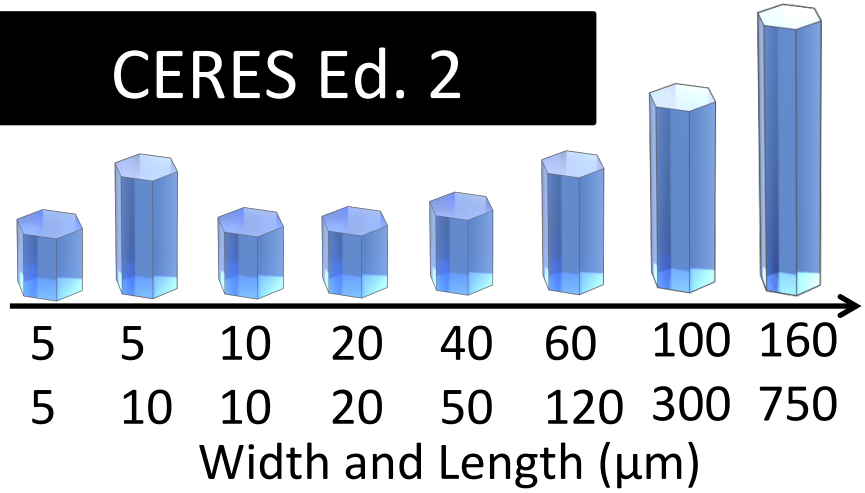


Left: the joint histogram comparing the MODIS C6 ice optical thickness (IOT) with the reference IR IOT retrieval. Right: the CALIOP non-constrained IOT using a modified lidar ratio of 32 is compared to collocated IR MODIS retrieved IOT.

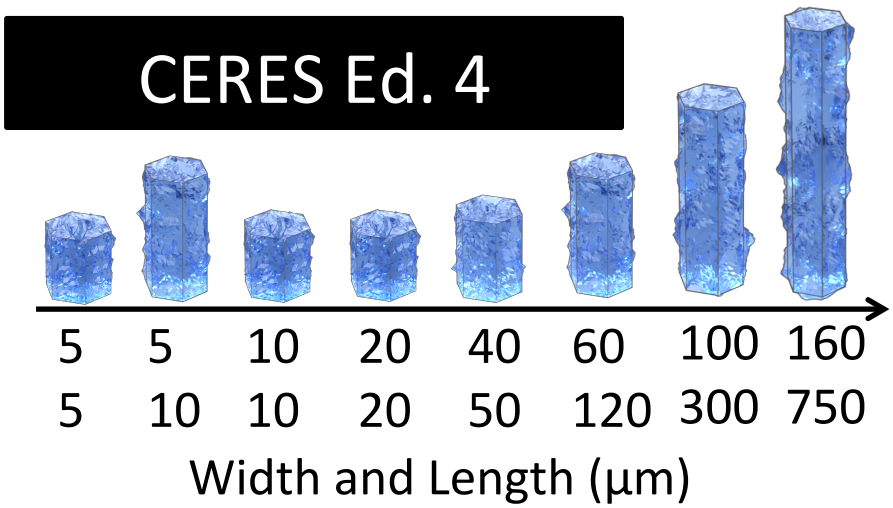
Ice Cloud Simulations

Particle Shapes and Mixing Ratios

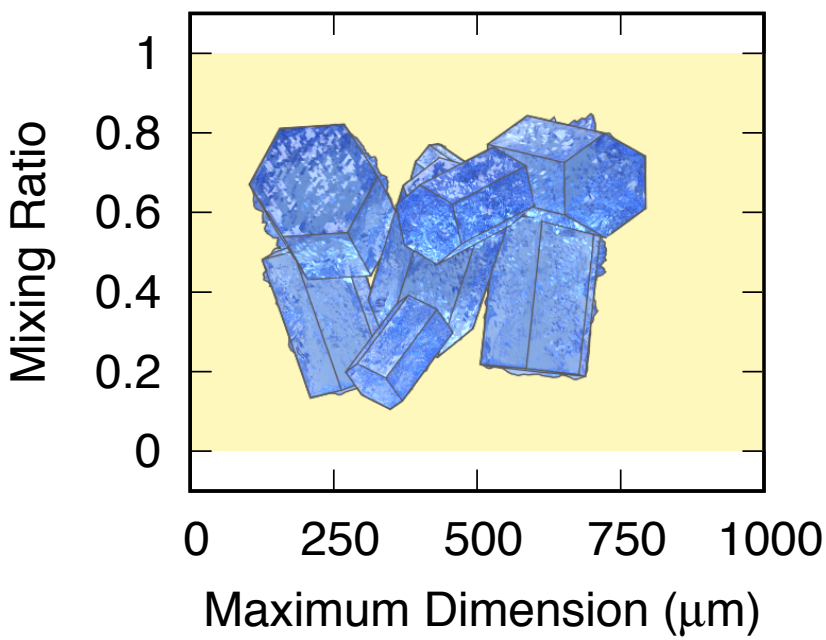
CERES Ed. 2



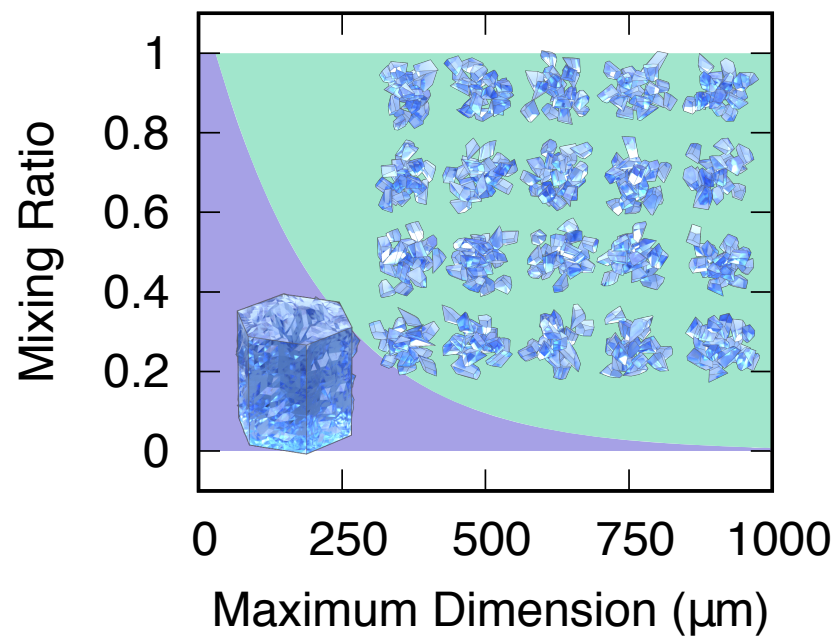
CERES Ed. 4



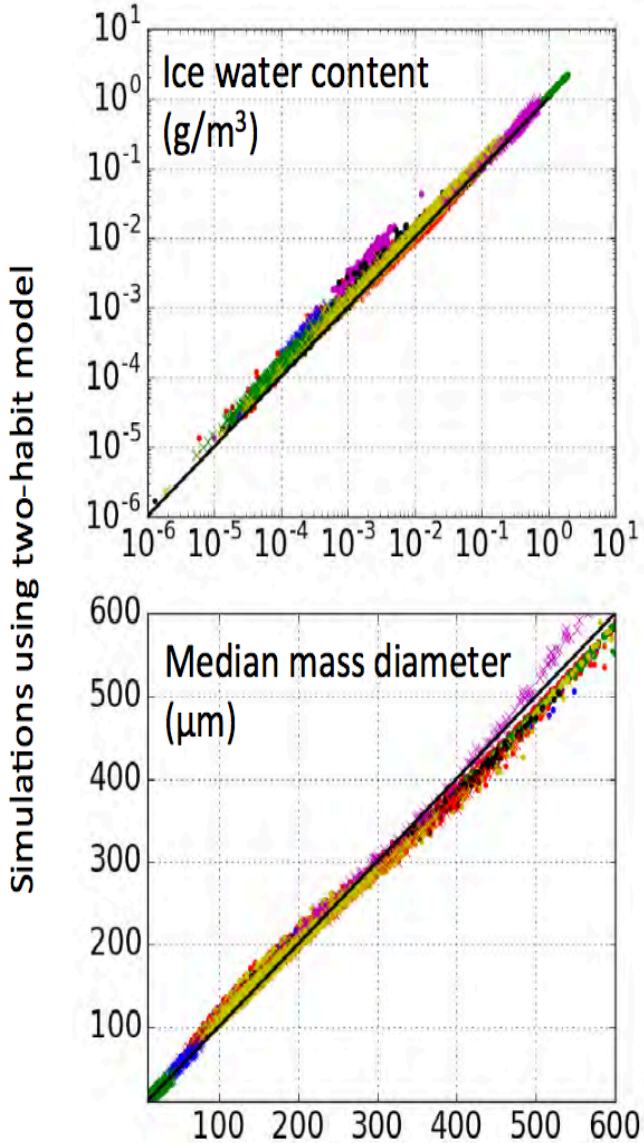
MODIS Collection 6



Two-habit



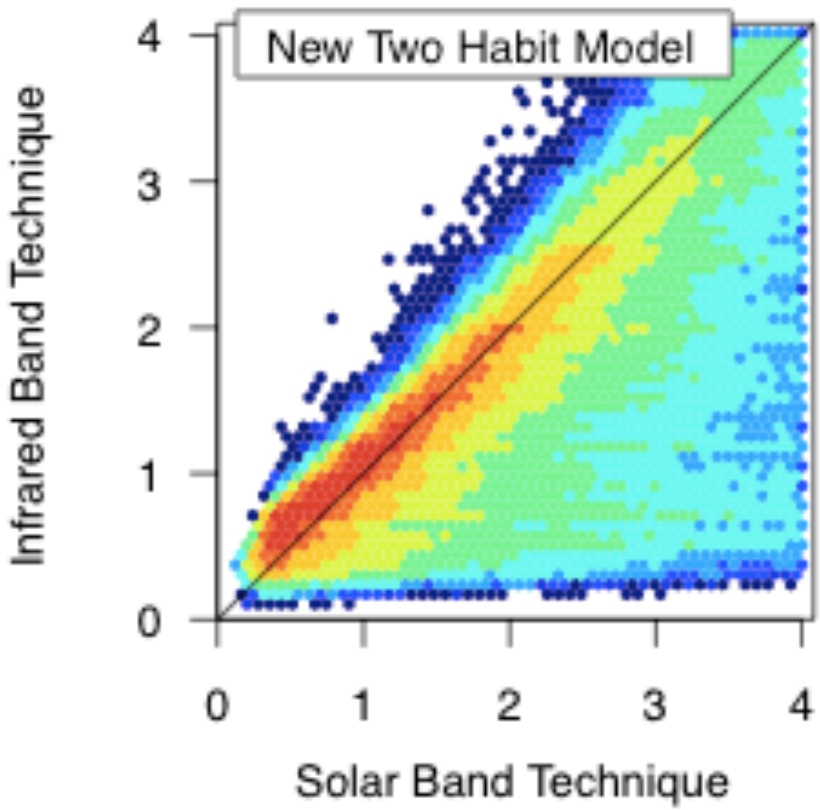
Consistency of THM with in-situ microphysics measurement



- ACTIVE Hector
- ACTIVE Monsoon
- ACTIVE SquallLine
- ARM-IOP
- CRYSTAL
- MIDCIX
- MPACE
- preAVE
- SCOUT
- TC4
- TRMM

Spectral consistency

Comparison between the the cloud optical thickness retrieved by the solar band technique and that by the infrared band technique



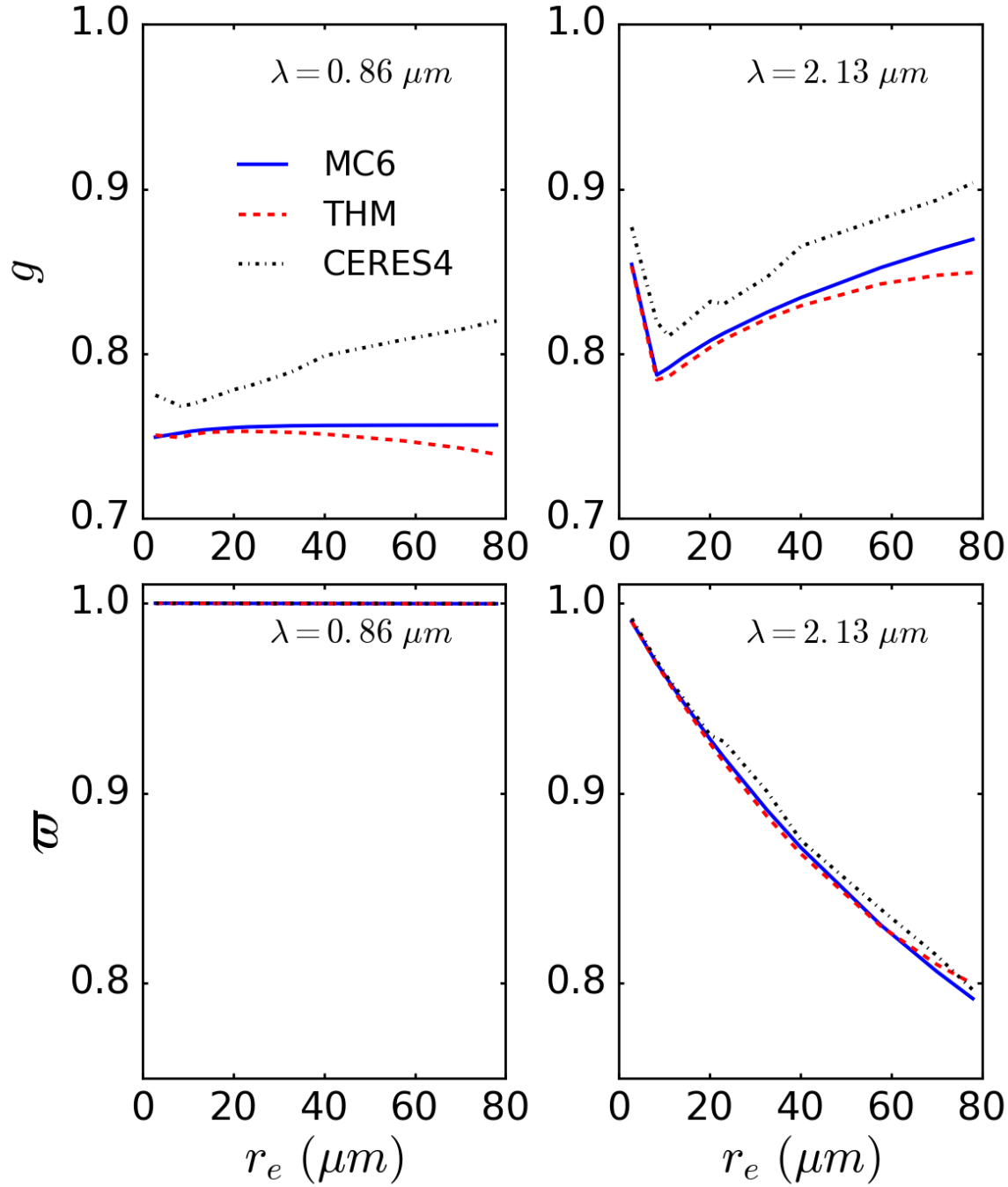
Ice Cloud Simulations

Asymmetry Parameter

The THM has smaller asymmetry parameter than the CERES 4 model

Single Scattering Albedo

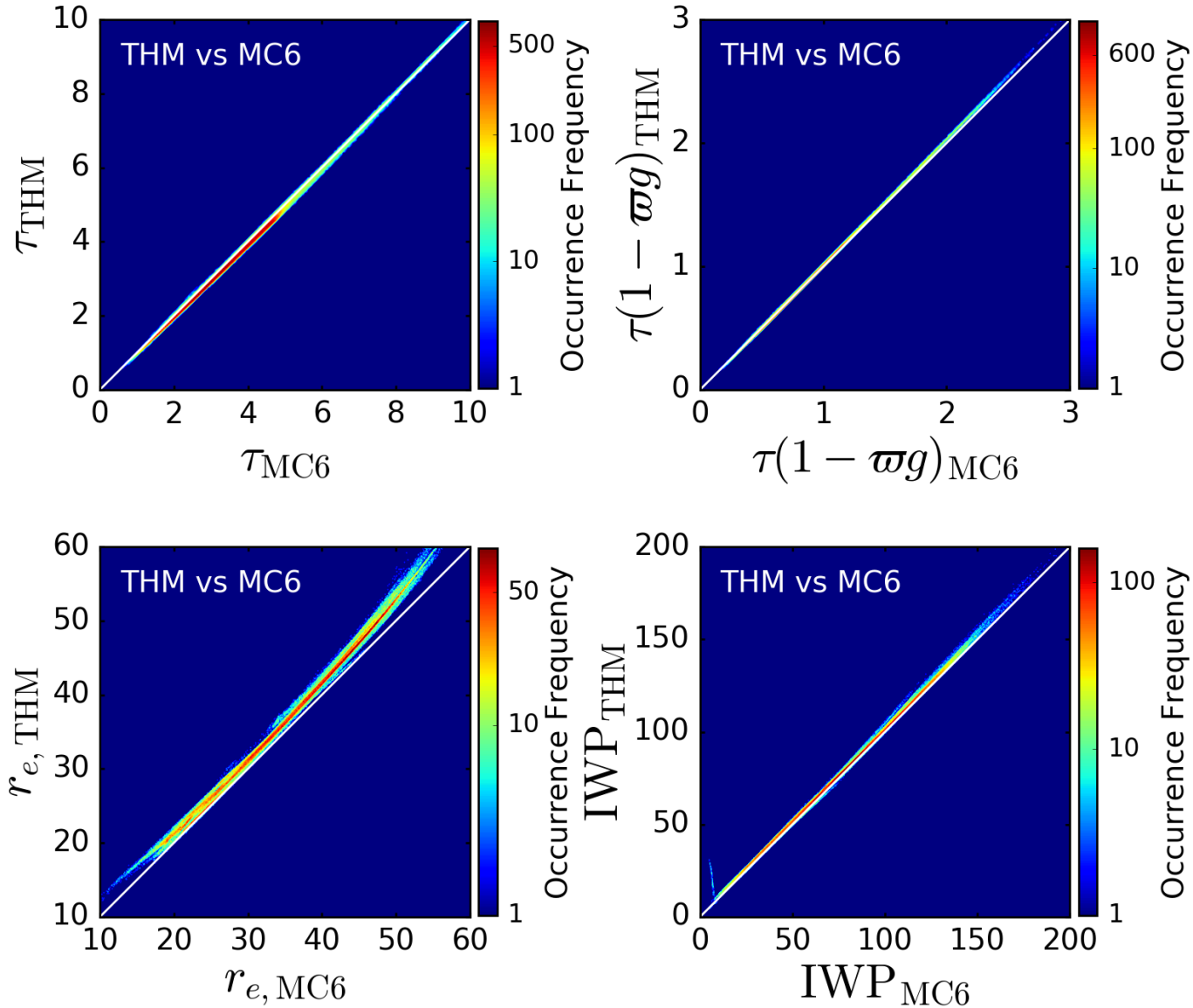
The THM has slightly smaller single scattering albedo than CERES 4 model at 2.1 µm Channel



Ice Cloud Simulations

THM: Two-habit
MC6: MODIS Collection 6

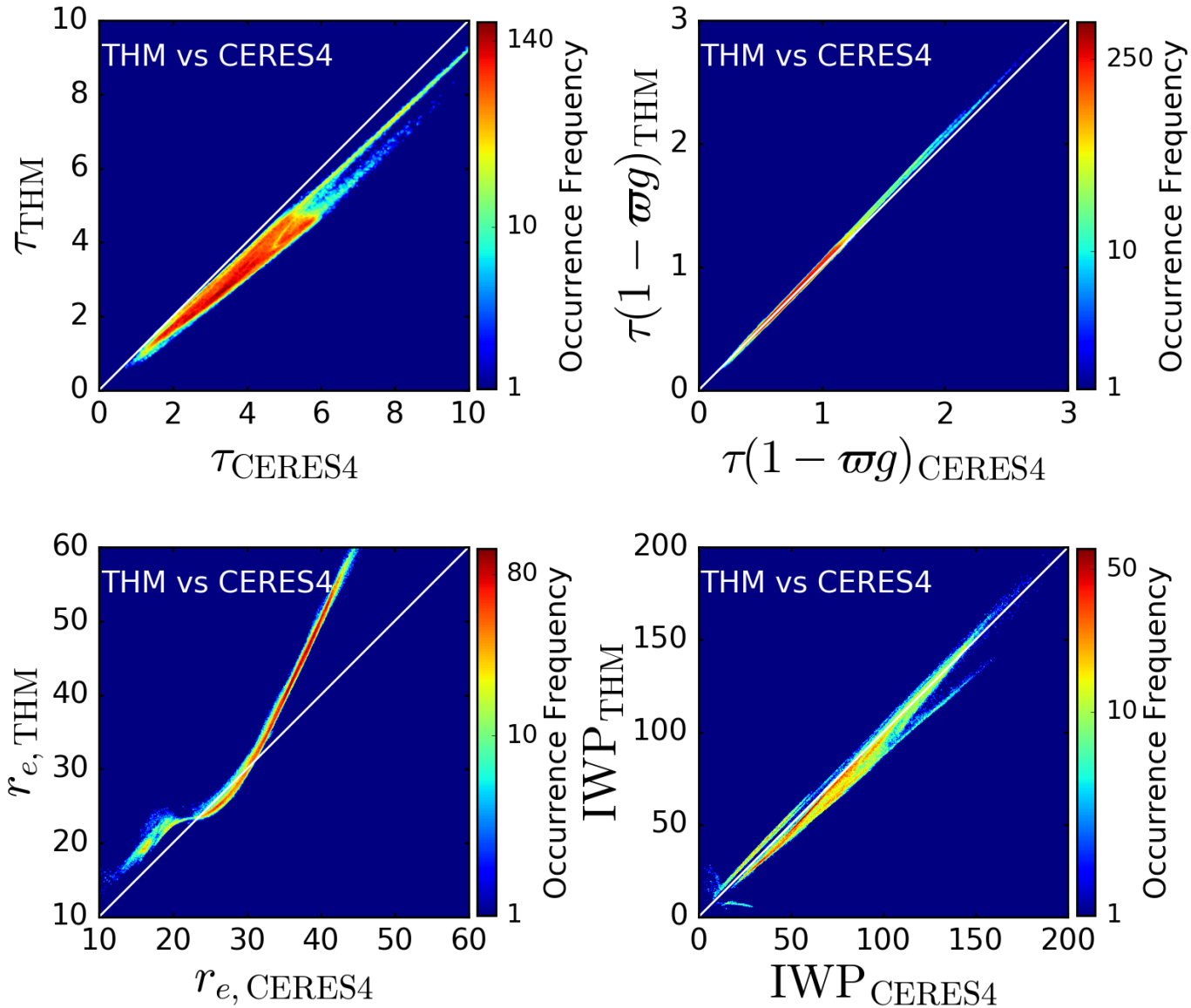
Retrieved ice cloud optical thickness (τ), effective optical thickness $\tau(1\text{-}\varpi g)$, effective radius (r_e), and ice water path (IWP) from MODIS Level 1B radiance



Ice Cloud Simulations

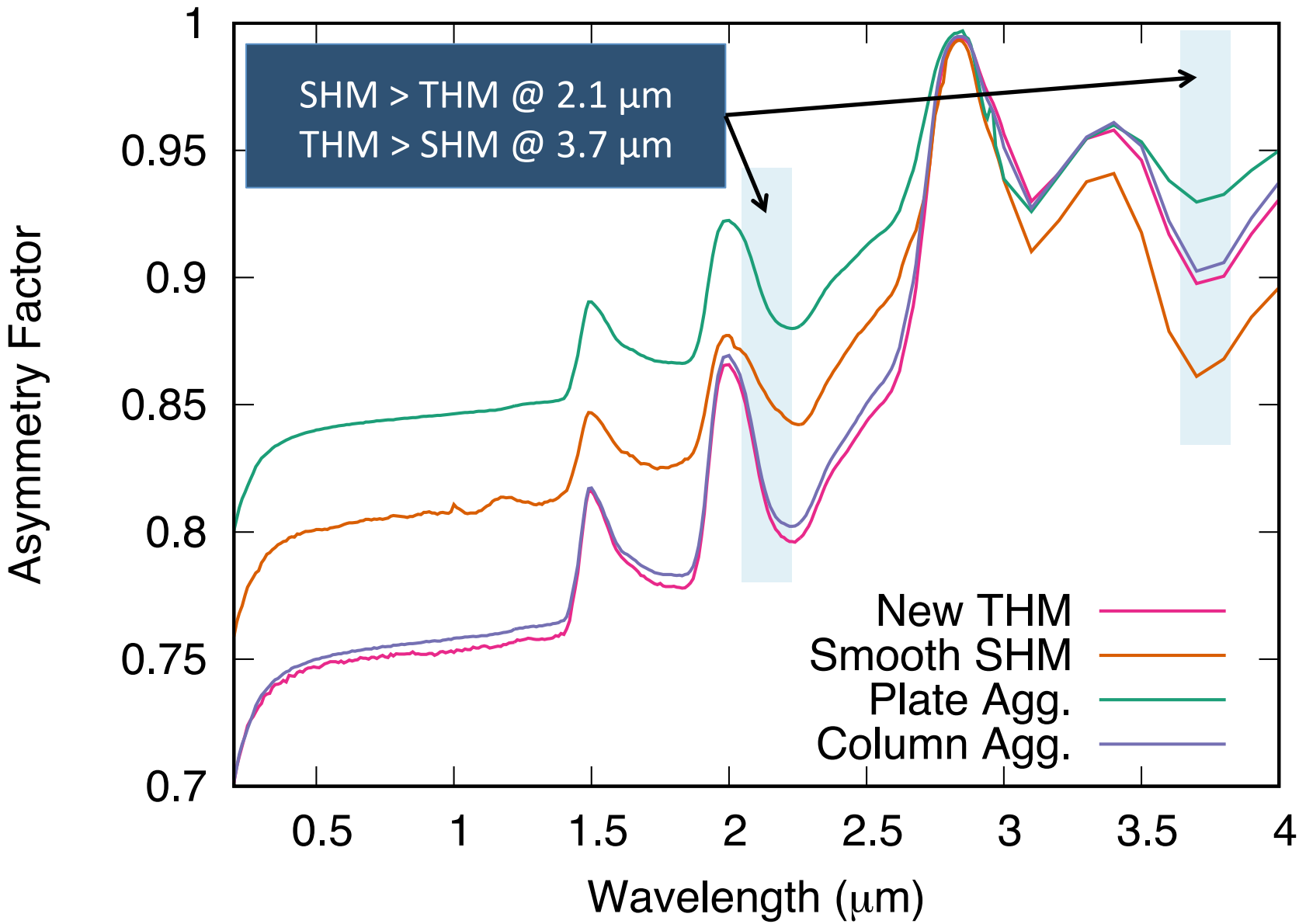
THM: Two-habit
CERES4: CERES Edition 4

Retrieved ice cloud optical thickness (τ), effective optical thickness $\tau(1\text{-}\varpi g)$, effective radius (r_e), and ice water path (IWP) from MODIS Level 1B radiance



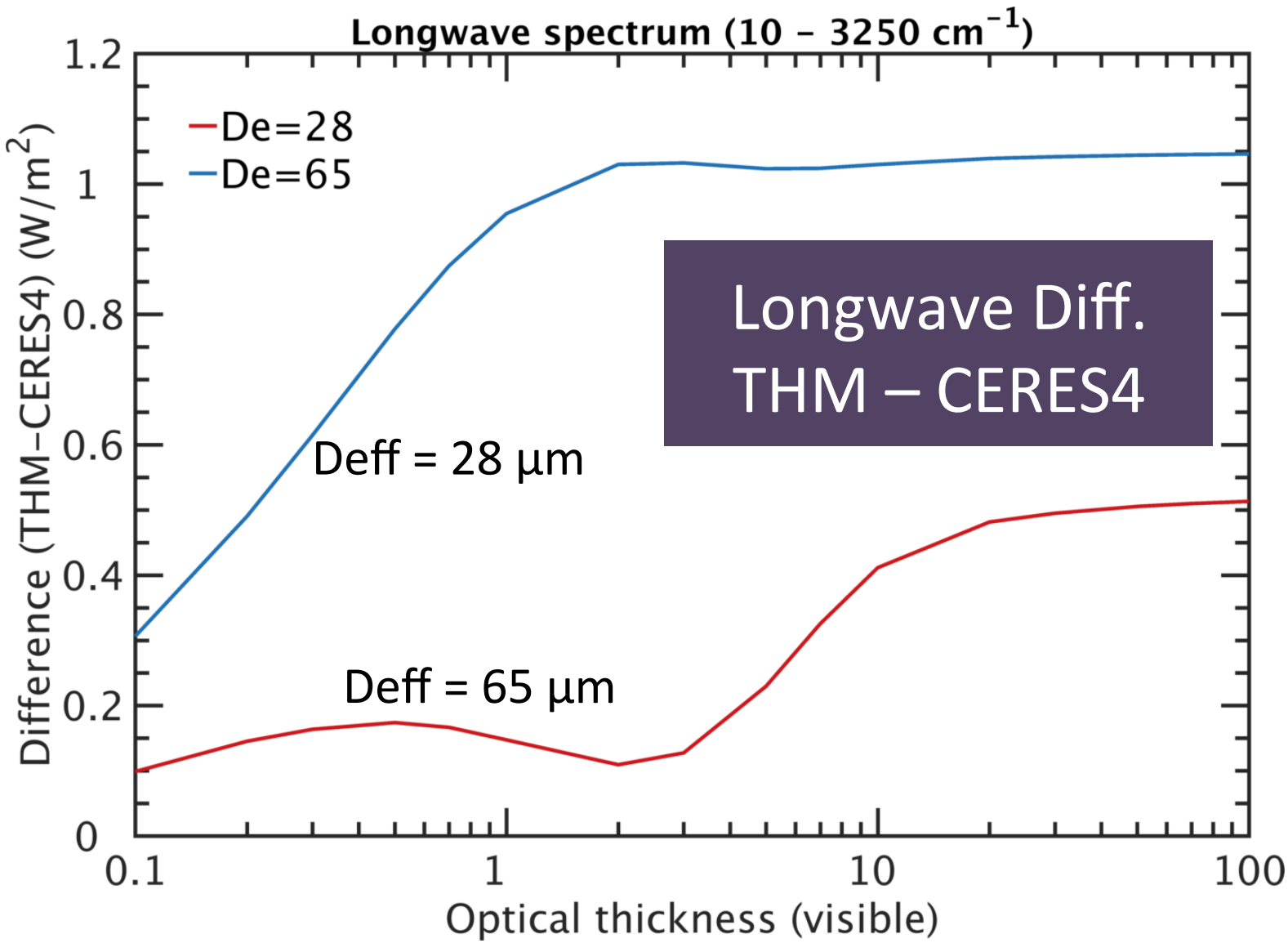
Ice Cloud Simulations

Particle Size Retrieval with 3.7 µm channel



Ice Cloud Simulations

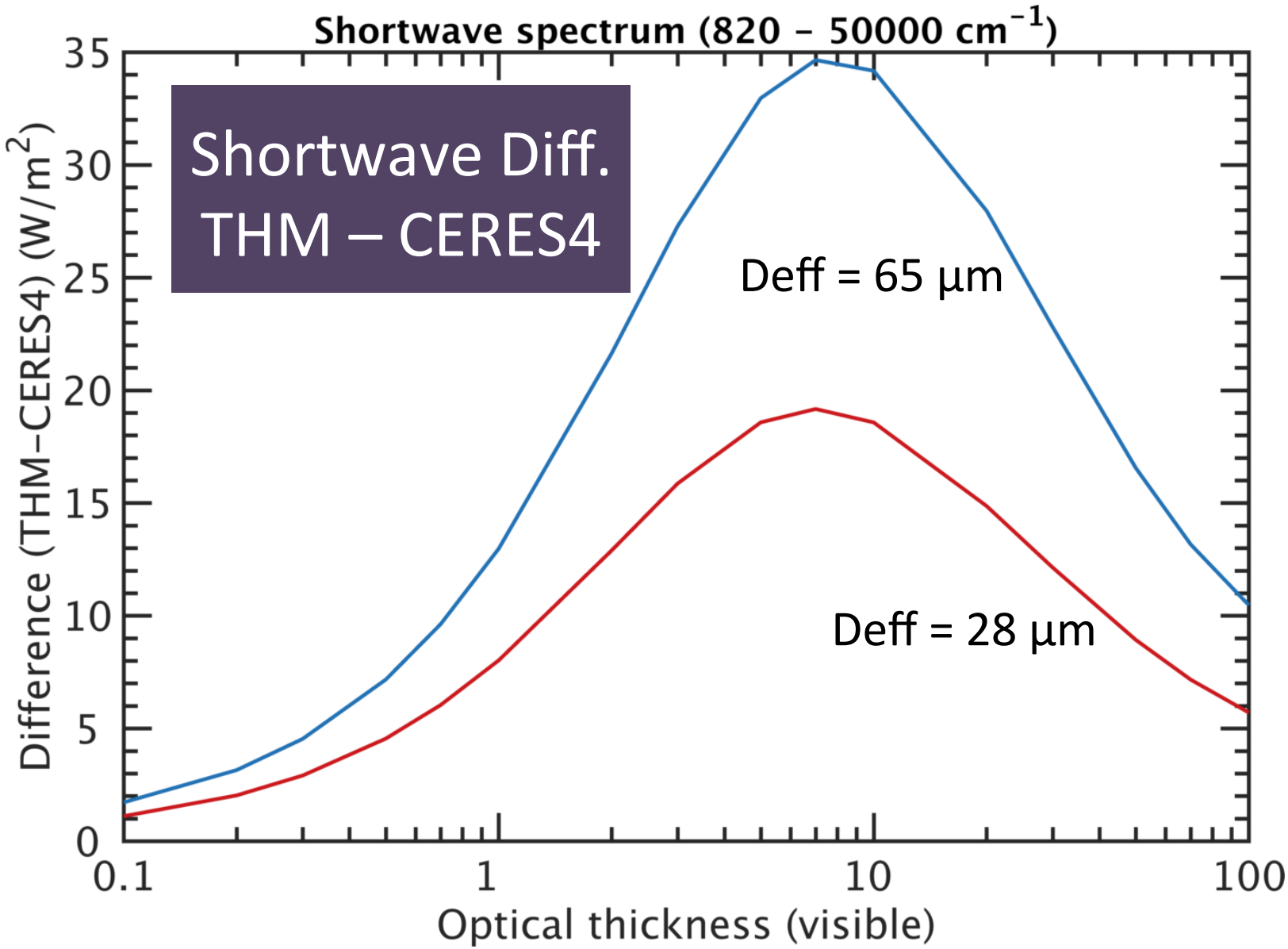
LW Upward flux **difference** at the TOA



RRTM (16 stream DISORT), Vertical profile: Midlatitude summer

Ice Cloud Simulations

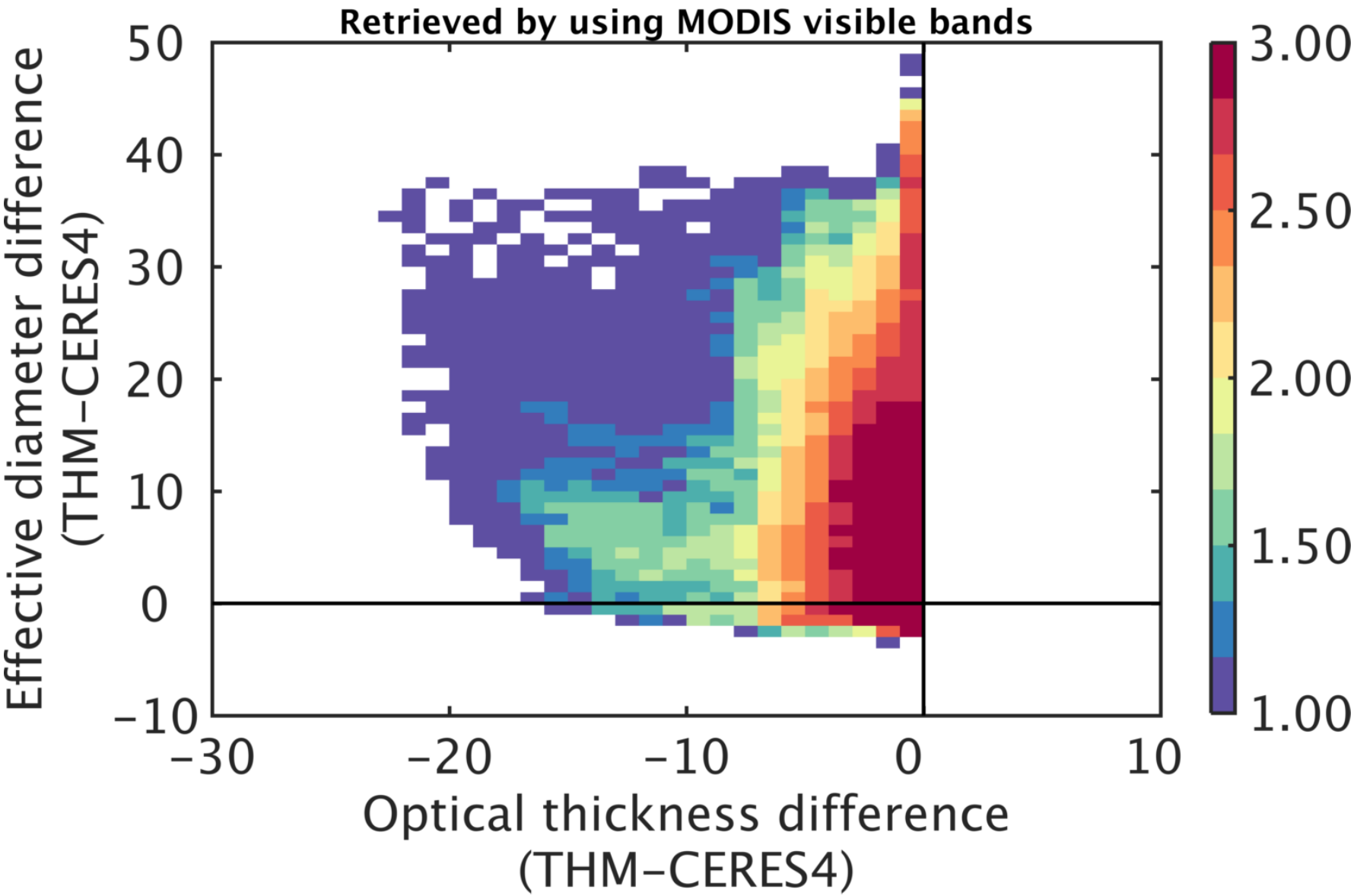
SW Upward flux **difference** at the TOA



RRTM (16 stream DISORT), Vertical profile: Midlatitude summer

Ice Cloud Simulations

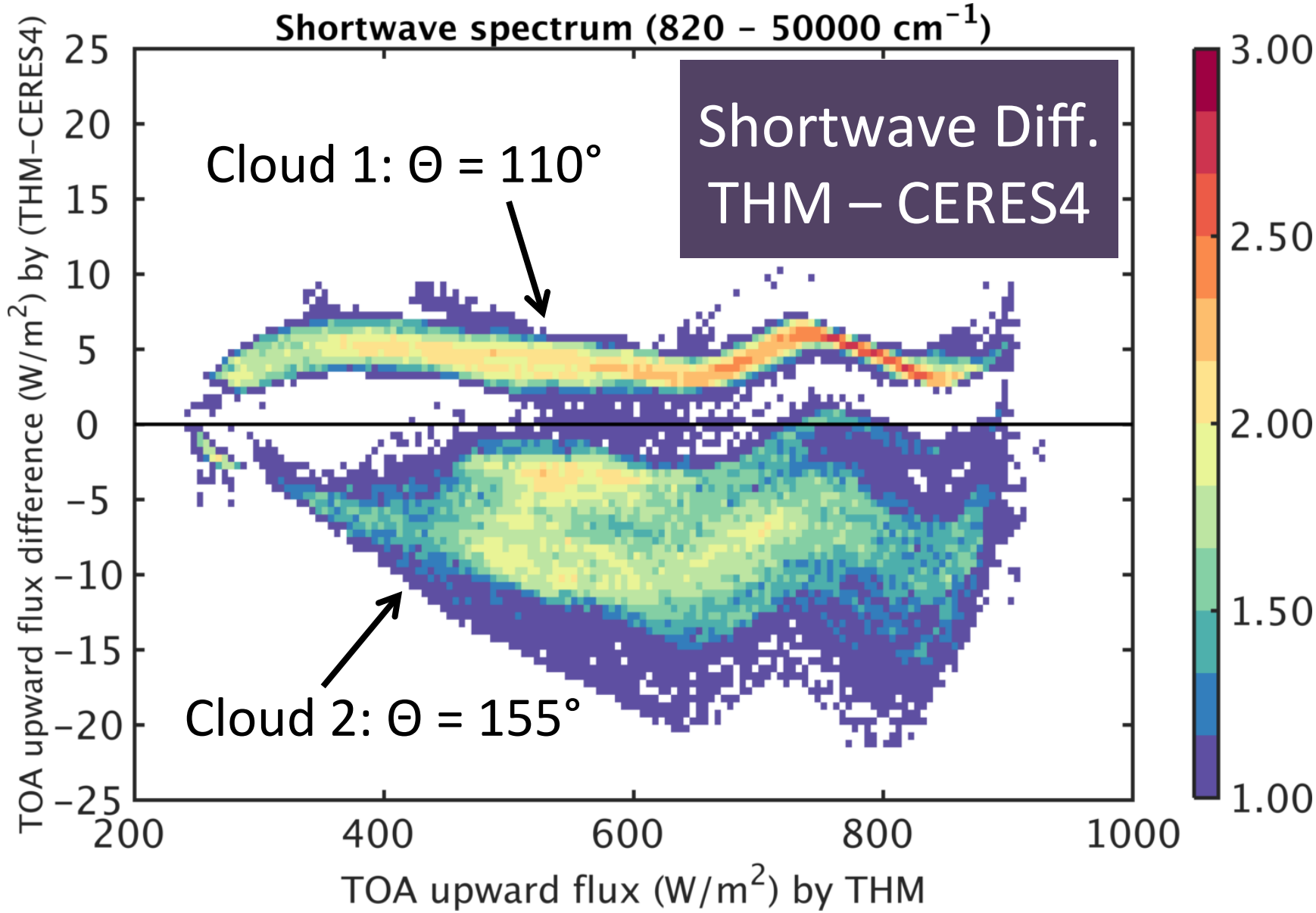
Retrieved Optical Thickness and Size



Granule: Terra 2013258.0100, Band 2 (0.865 µm) and Band 7 (2.13 µm)

Ice Cloud Simulations

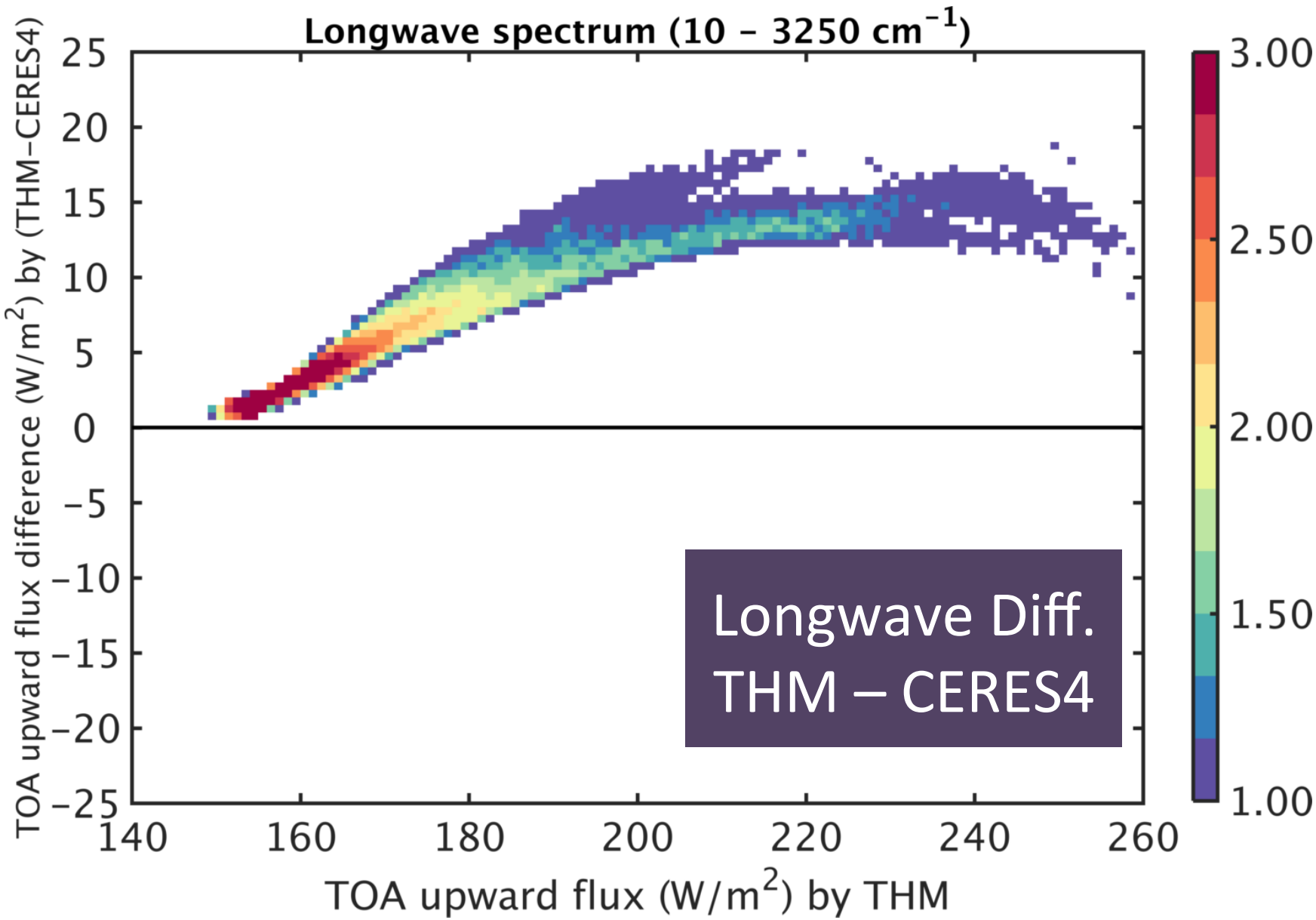
Shortwave Flux Difference at the TOA



Granule: Terra 2013258.0100, Band 2 (0.865 µm) and Band 7 (2.13 µm)

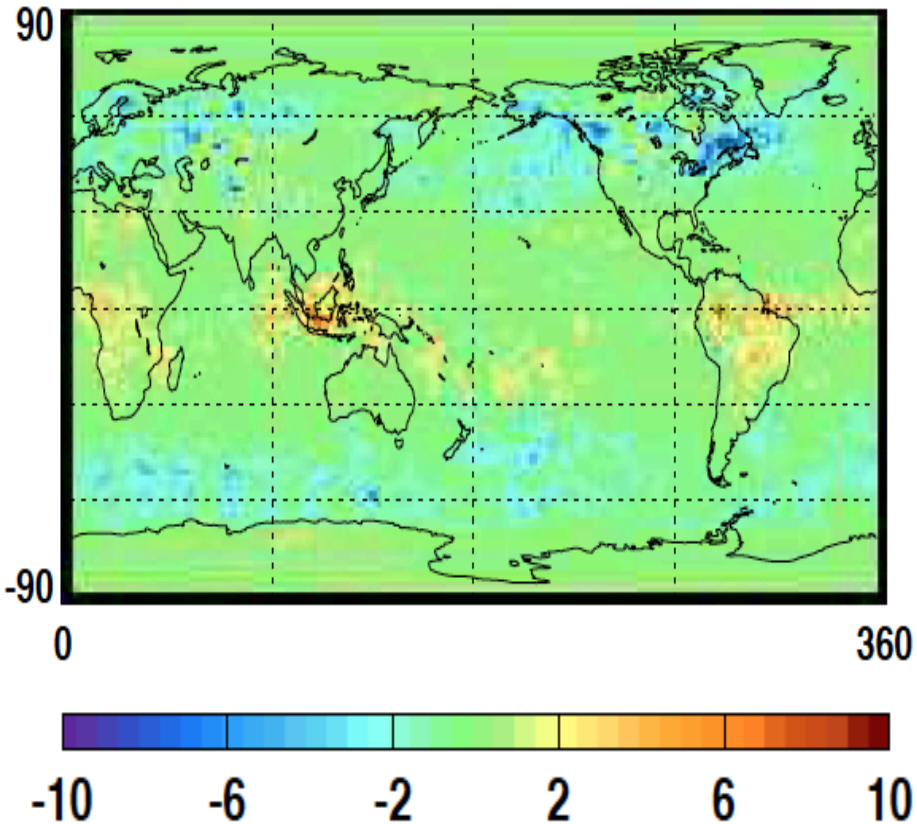
Ice Cloud Simulations

Longwave Flux Difference at the TOA

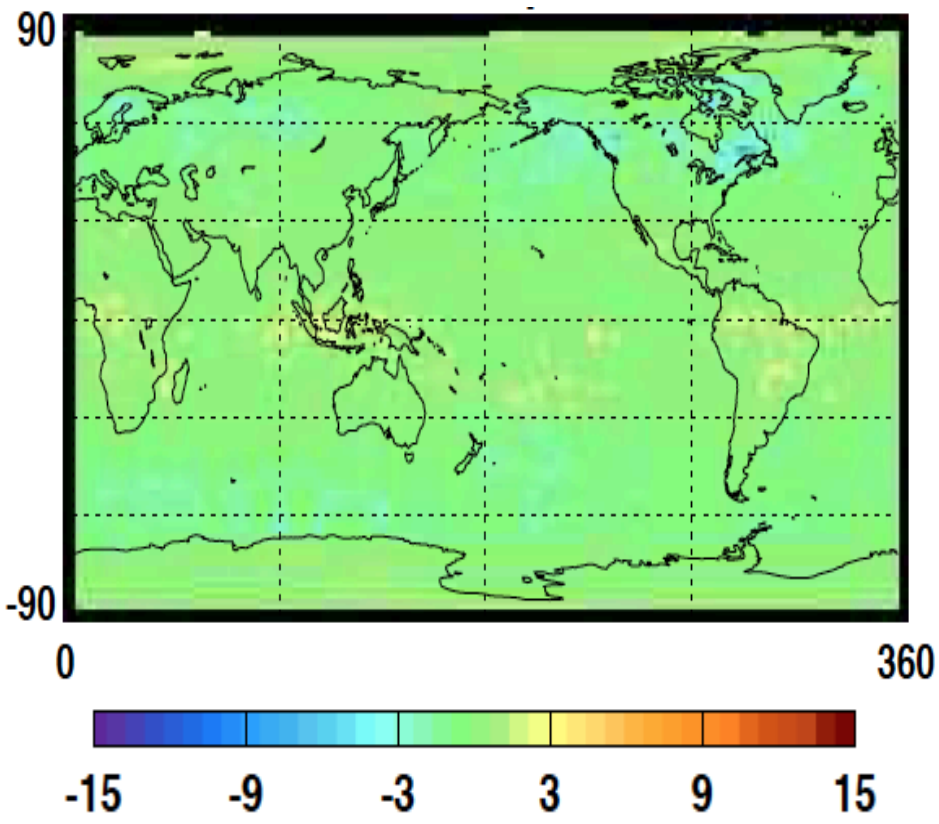


Granule: Terra 2013258.0100, Band 2 (0.865 µm) and Band 7 (2.13 µm)

SW TOA Flux Difference at Aqua Overpass Time
(THM(Ret)/THM(Fwd) minus Smooth(Ret)/Smooth(Fwd))



Difference (Wm^{-2})

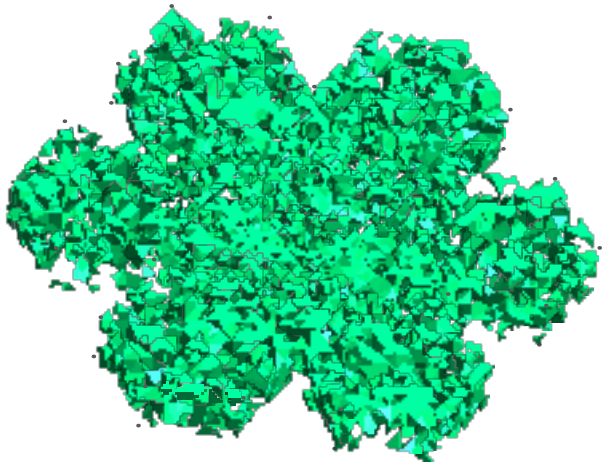


Difference (%)

- Overall regional RMS difference is ~1%. However, in some locations regional differences reach 3%.
- Differences tend to be positive in tropics and negative in midlatitudes.

N. Loeb et al. (2016)

Bicontinuous medium technique (Xu and Tsang, 2012) for snow particles

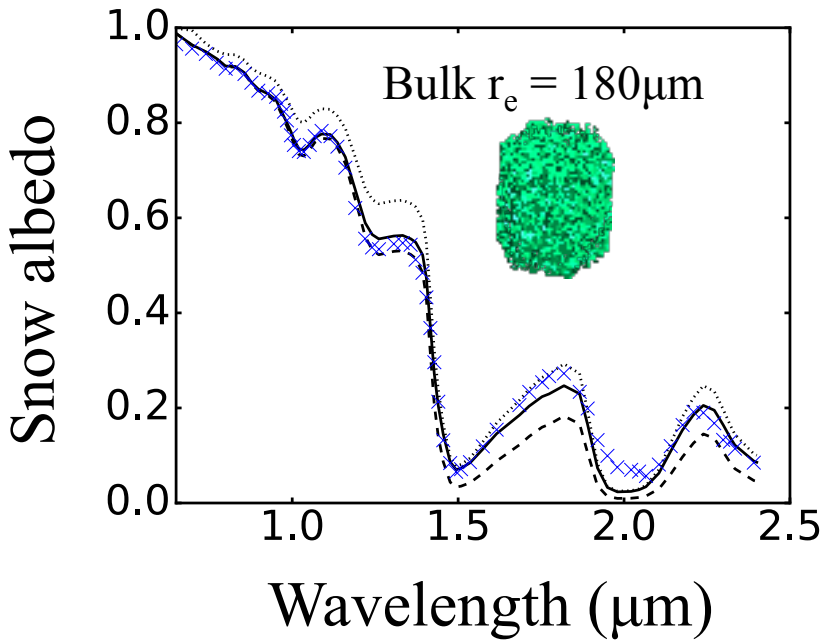


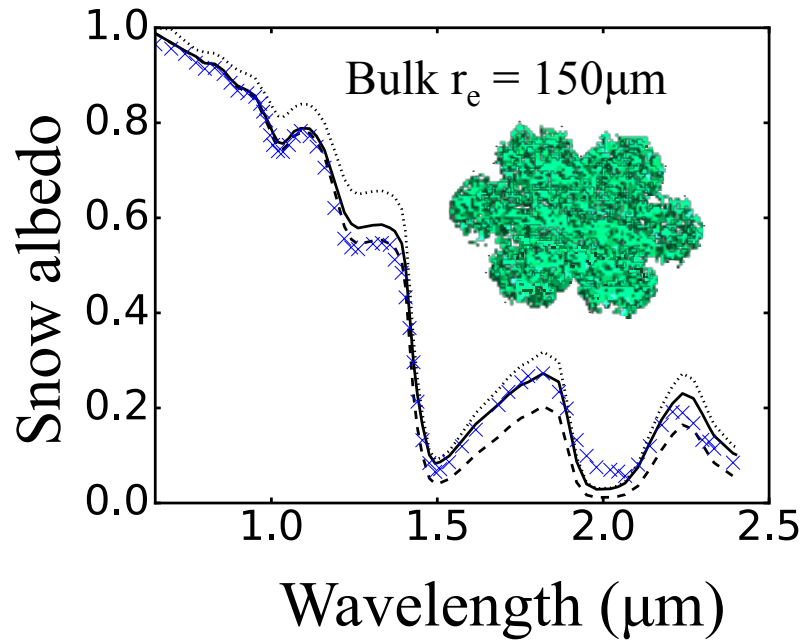
Courtesy of K. G. Libbrecht

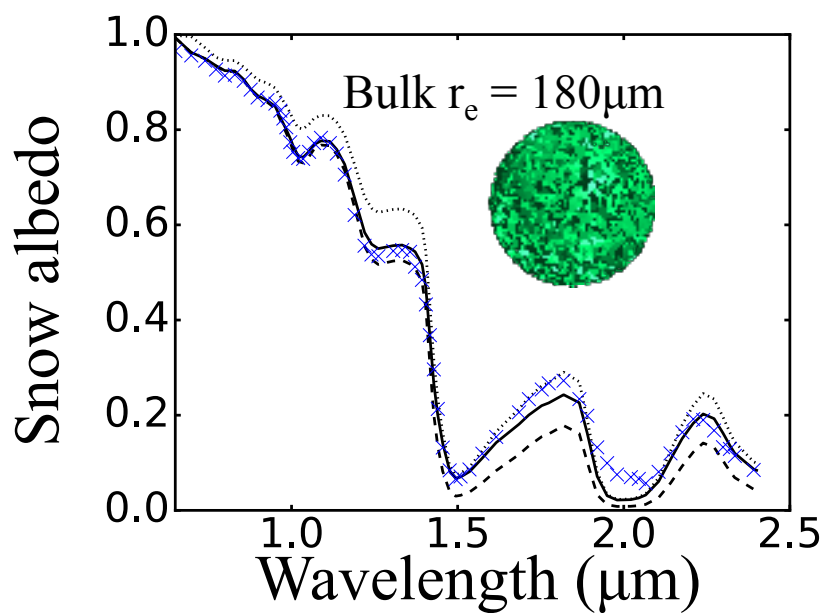
$$S(\overline{r}) = \frac{1}{\sqrt{N\langle A^2\rangle}} \sum_{n=1}^{N} A_n \cos(\overline{k}_n \cdot \overline{r} + \phi_n)$$

$$\Theta_\alpha\left(S(\overline{r})\right) = \begin{cases} 1 & for\ S(\overline{r}) > \alpha \\ 0 & otherwise \end{cases}$$

Snow albedo (diffuse illumination) simulation



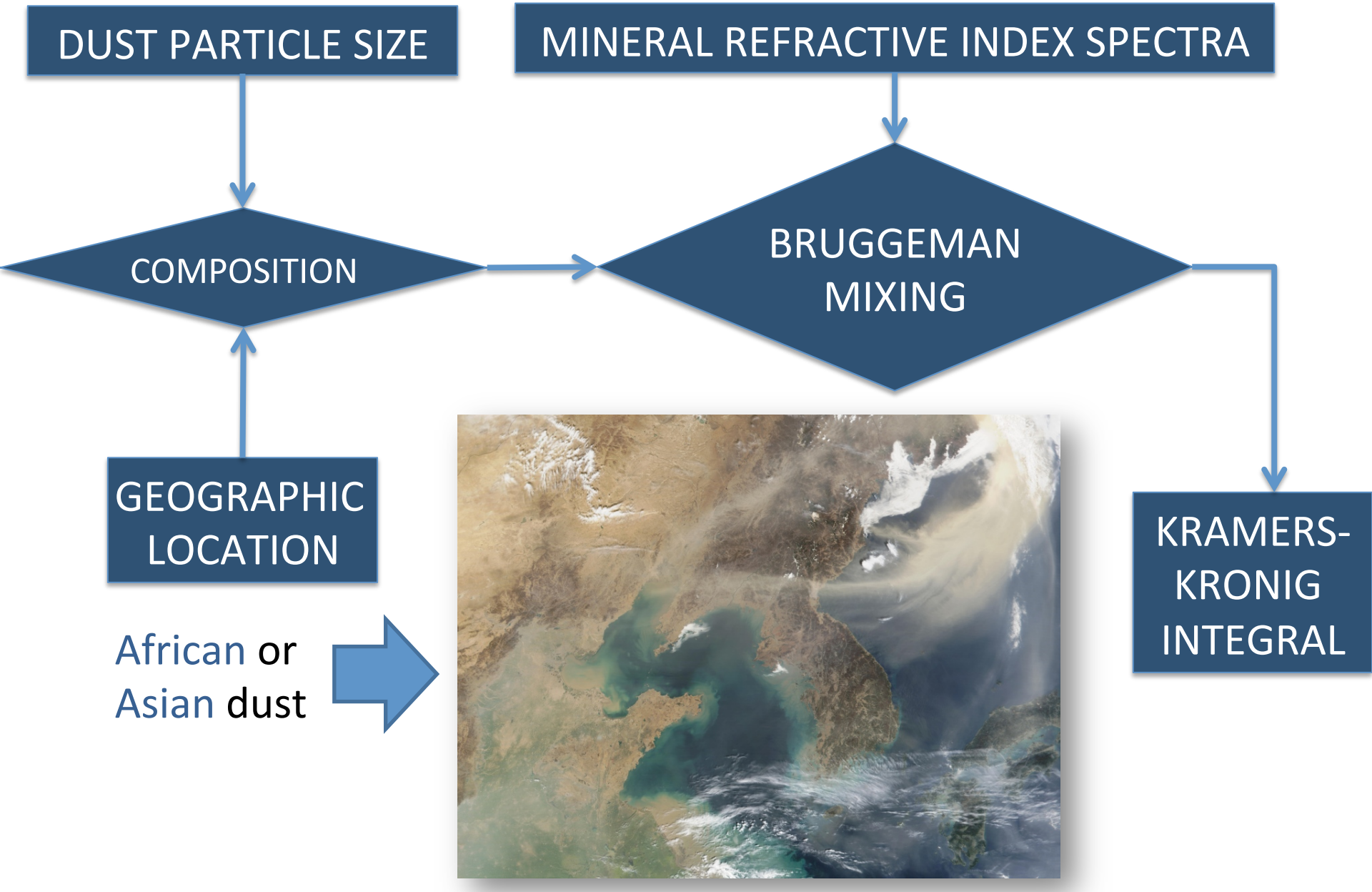




Density = $0.2\rho_{ice}$
Density = $0.5\rho_{ice}$
Density = $0.2\rho_{ice}/0.5\rho_{ice}$
Observation (Hudson 2006)

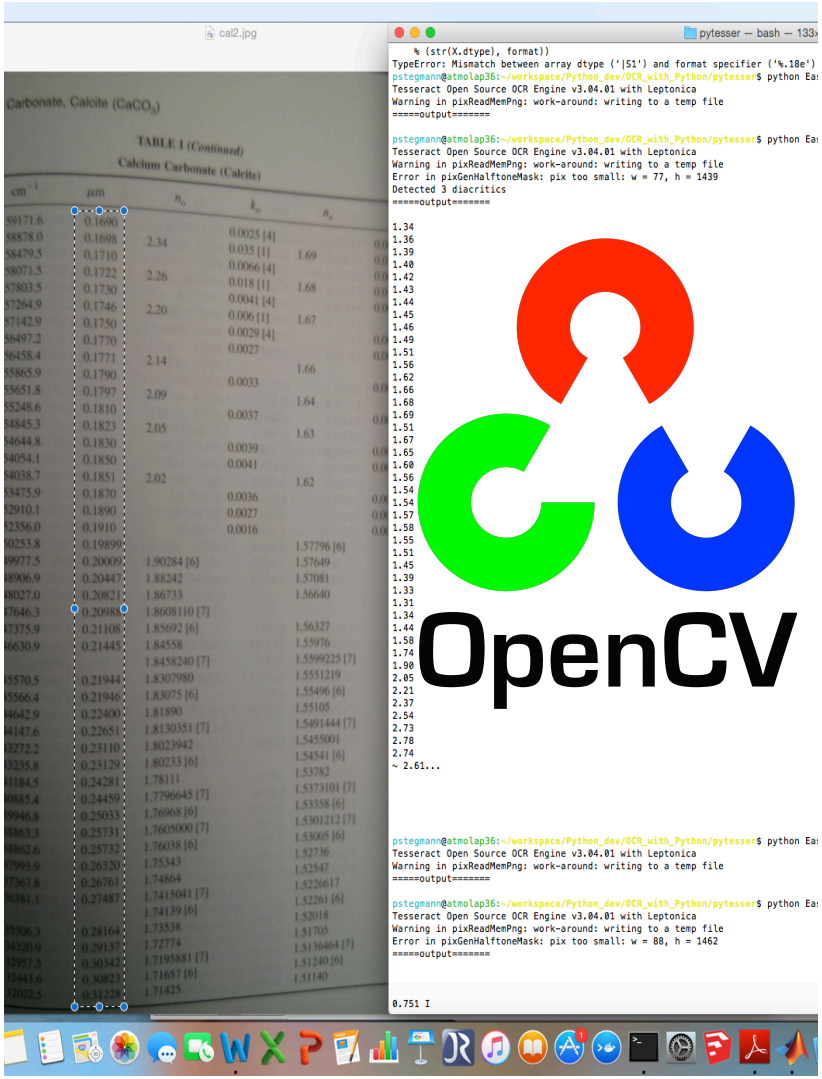
Dust Simulations

DUST MODEL OVERVIEW



Dust Simulations

METHODOLOGY



46 Journal Articles
3 Reference Books

↓

Optical Character Recognition Program

↓

Digital Data

The Kramers-Kronig relation for the index of refraction (the real part and imaginary part are NOT independent)

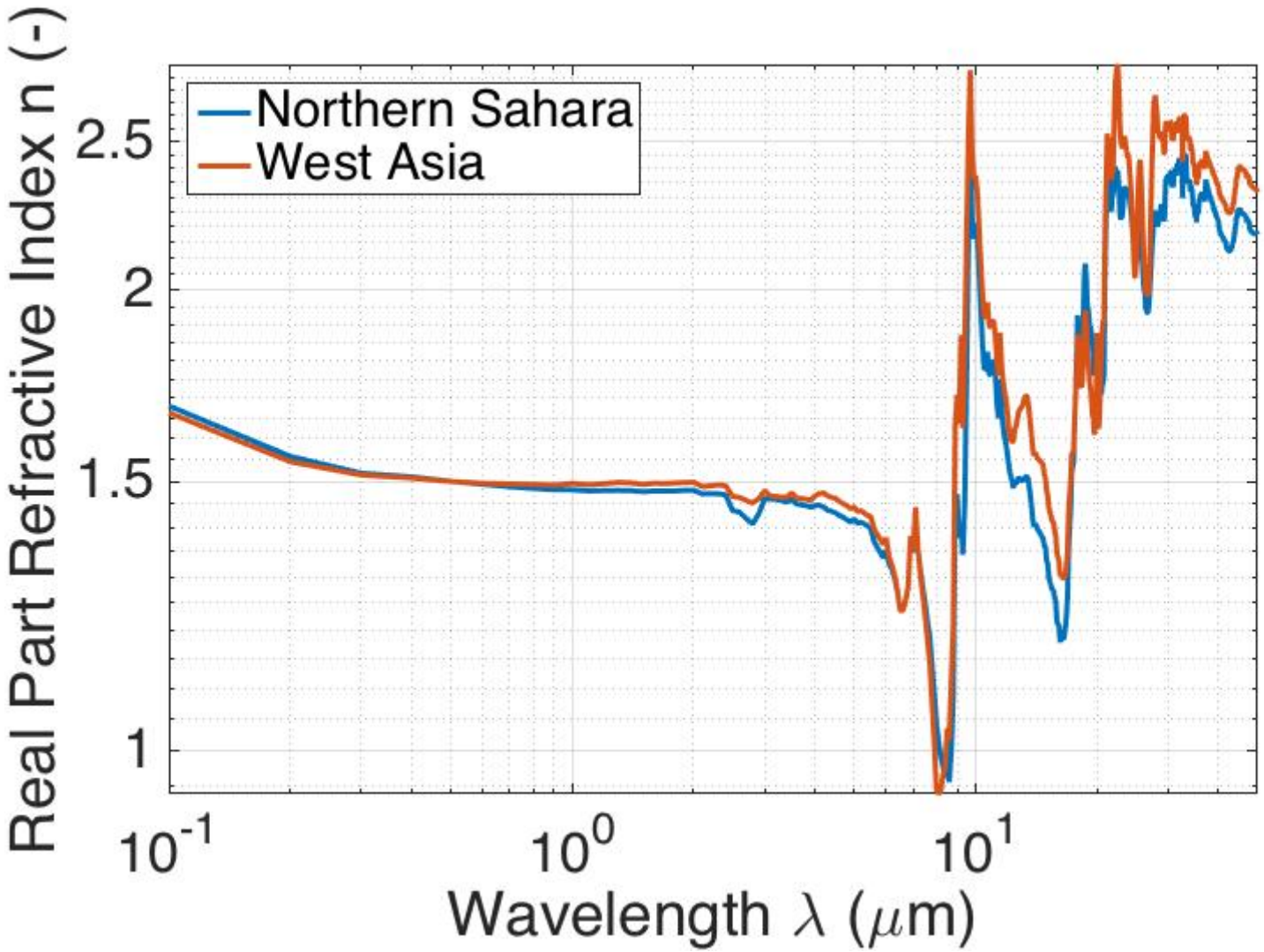
$$\mathrm{Re}\left[\varepsilon(\nu)\right] = 1 + \frac{2}{\pi}\mathrm{P}\int_0^\infty \frac{\nu'\mathrm{Im}\left[\varepsilon(\nu')\right]}{\nu'^2 - \nu^2}d\nu',$$

$$\mathrm{Im}\left[\varepsilon(\nu)\right] = -\frac{2\nu}{\pi}\mathrm{P}\int_0^\infty \frac{\mathrm{Re}\left[\varepsilon(\nu')\right] - 1}{\nu'^2 - \nu^2}d\nu',$$

Dust Simulations

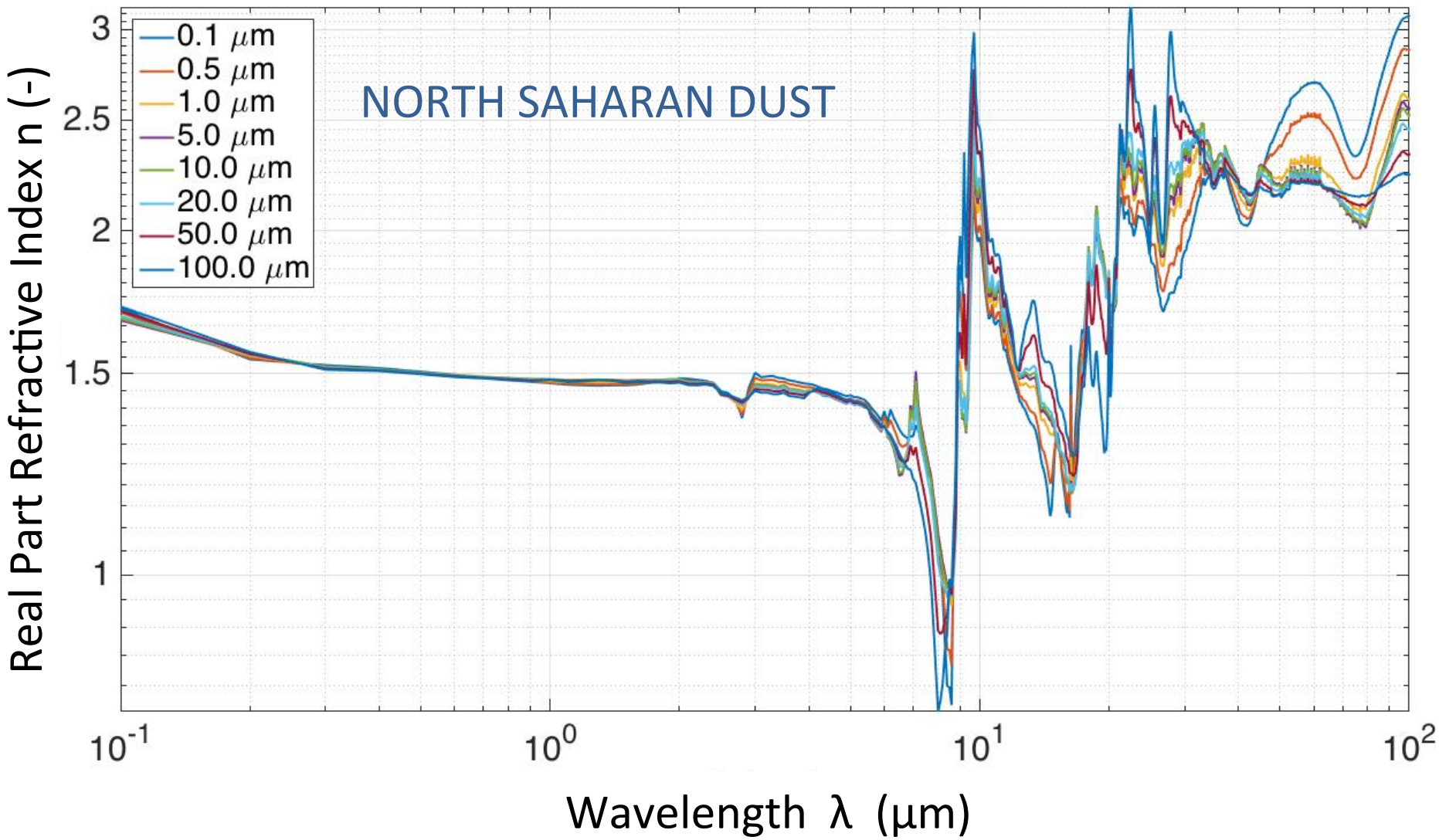
VARIATION WITH LOCATION (AFRICA / ASIA)

Computed refractive index of dust from the Northern Sahara, and West Asia (Gobi desert). The particle size is 15 µm.



Dust Simulations

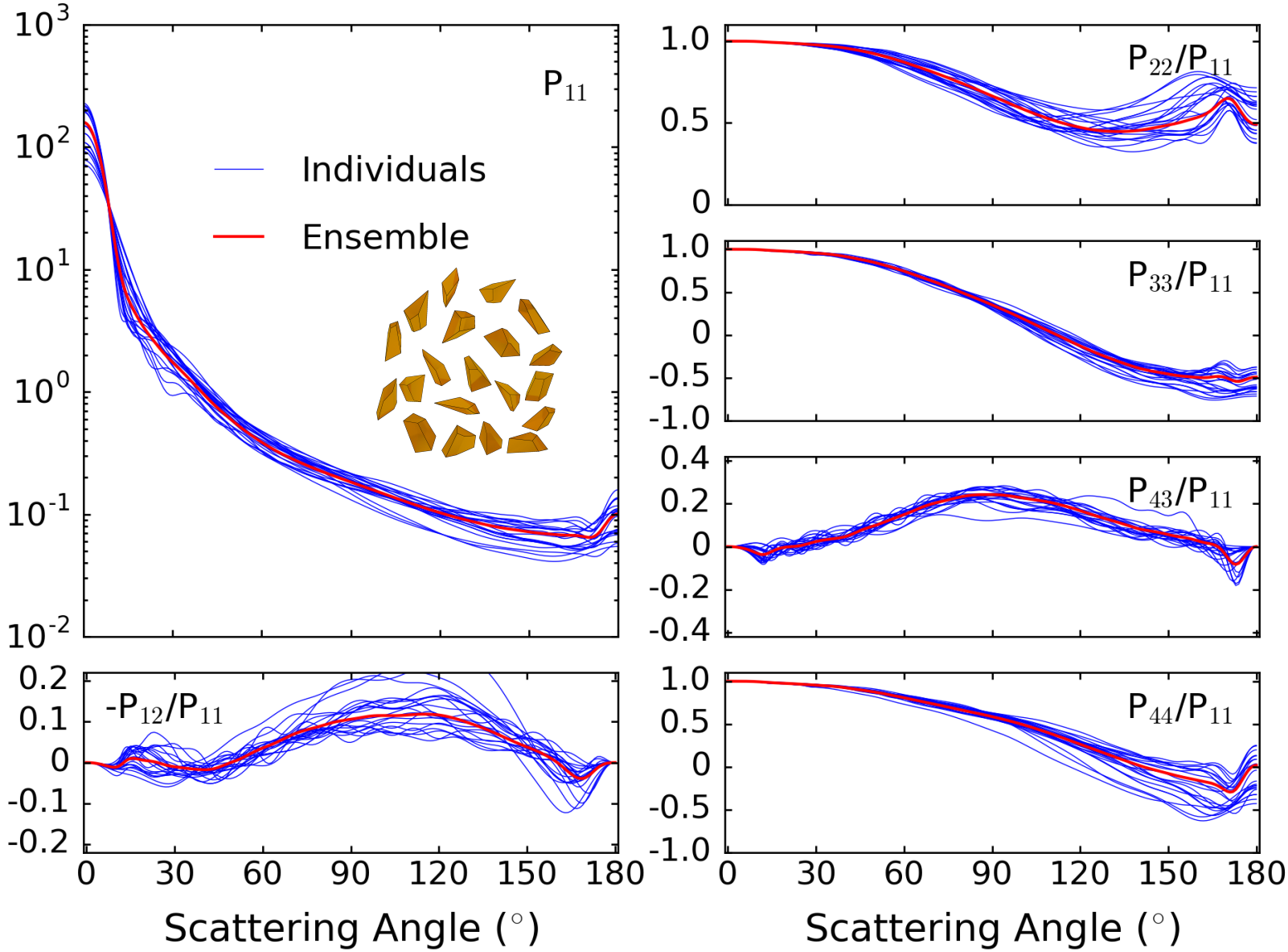
VARIATION WITH GRAIN SIZE

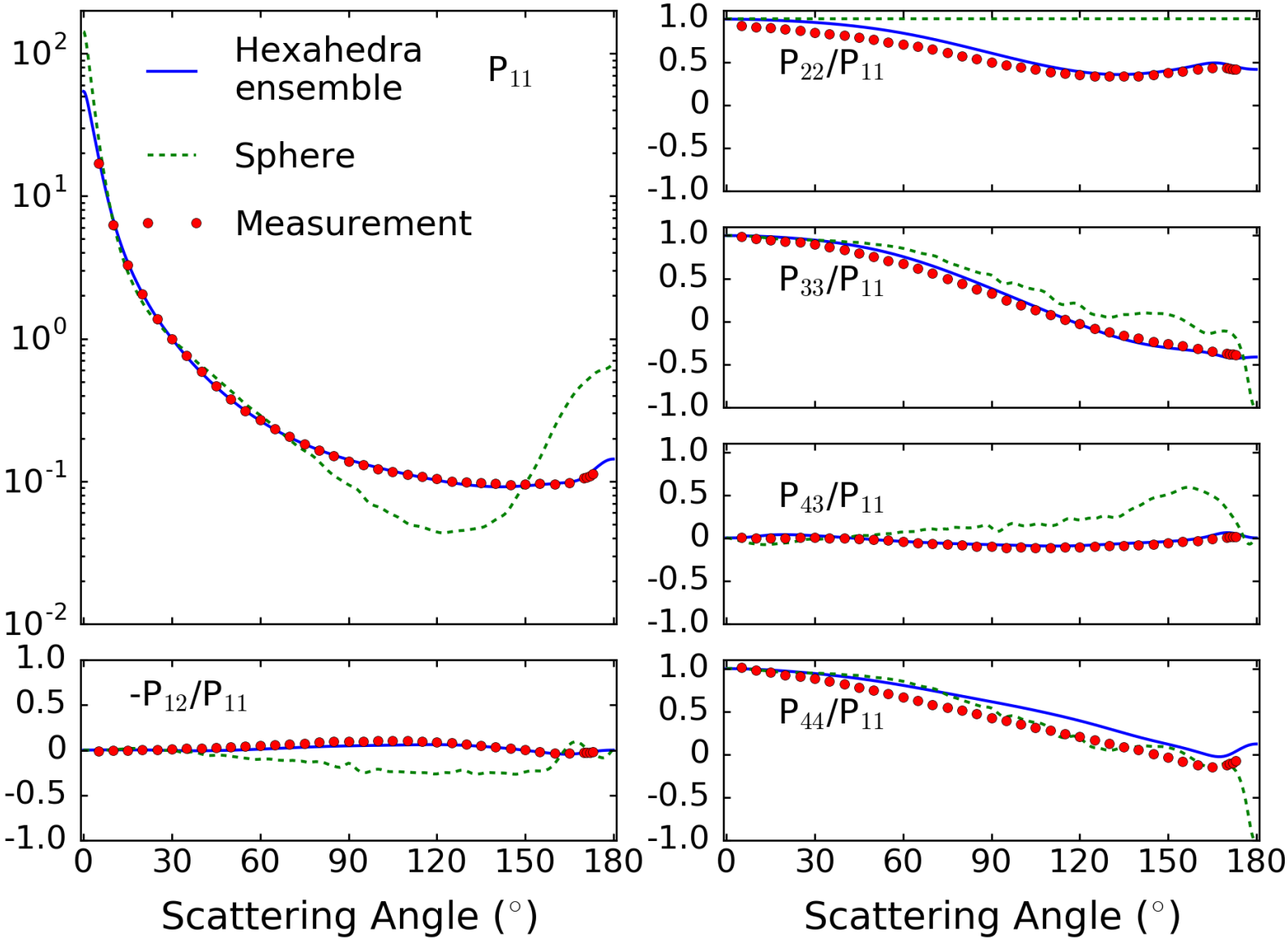


Dust Simulations

The phase matrix of modeled dust particle

maximum dimension = 8.6 μm, wavelength = 0.55 μm



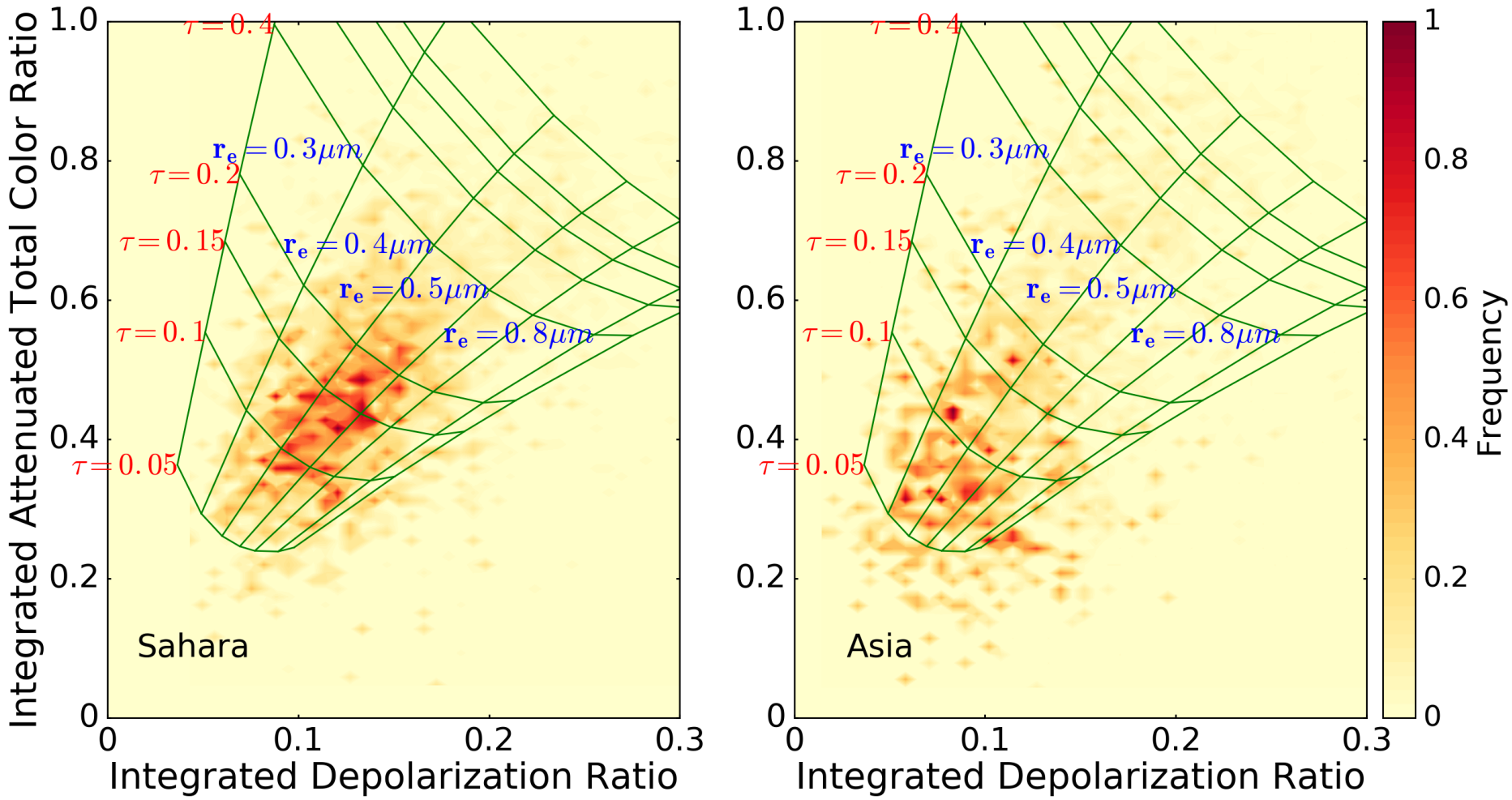


Phase matrices at 632.8 nm of **hexahedra ensemble** and **sphere** models compared with **olivine measurement** in Amsterdam light scattering database

Dust Simulations

Asia / Sahara differences

Comparison of Integrated depolarization ratio (IDR) and integrated color ratio (ICR) relations between **CALIOP data (contour)** and **simulation (green curve)** for various AOT (τ) and effective radius (r_e). **Left:** Saharan dust; **Right:** Asian dust



Summary

- The overall performance of the new two-habit model (THM) for ice clouds is similar to that of the MODIS C6 model.
- Significant progress has been made in modeling the optical properties of surface snow by using the bi-continuous medium technique, which will be incorporated into the Langley radiation model.
- A new database of the optical properties of African and Asian dust is under development.