A New Temperature-Dependent THM Ice Particle Database and Analyzing Ice Cloud Property Retrieval Results of an Improved MC6 Database

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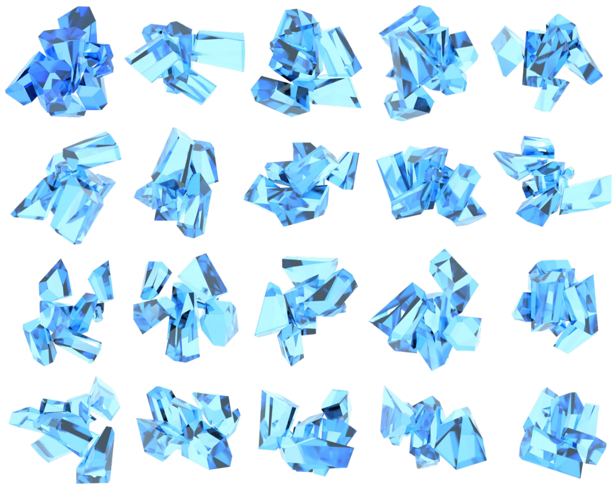
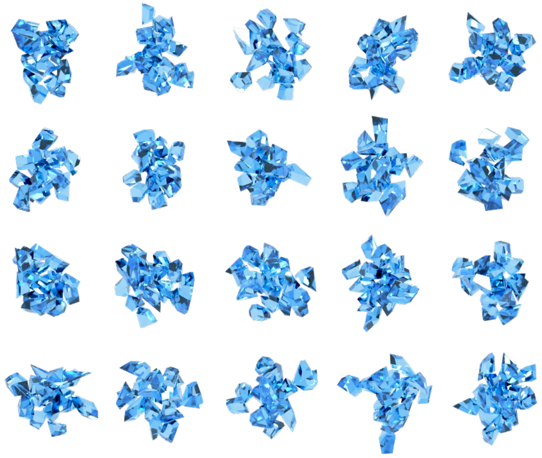
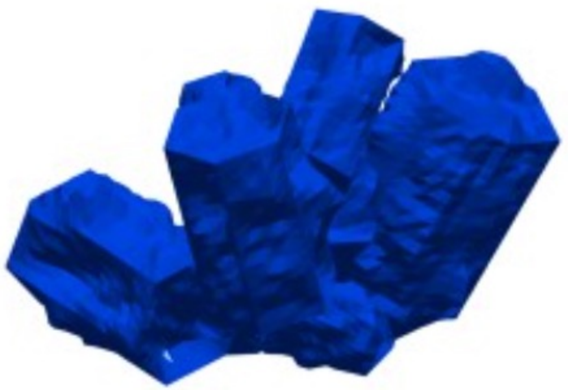
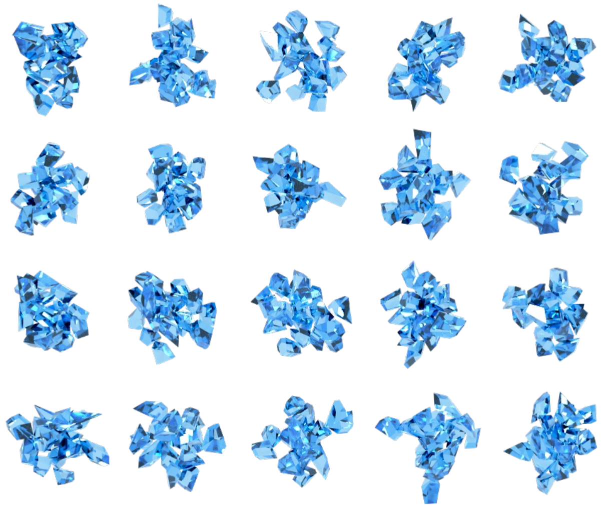


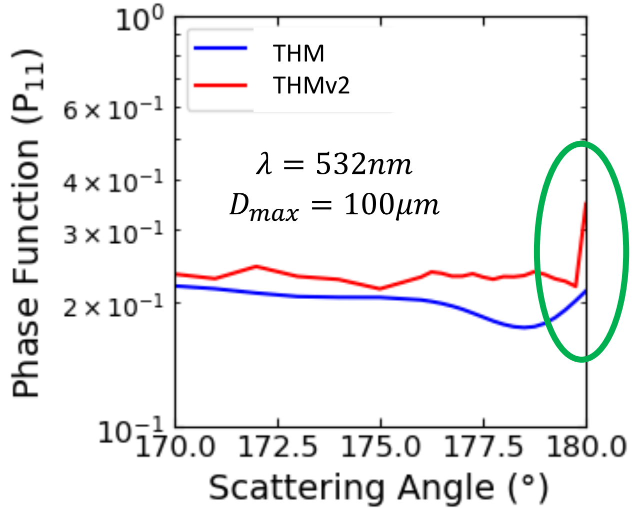


An Improved MODIS Collection 6 Ice Particle Property Database

- Inspired by the recent development of the new Two-Habit Model:
  - Primary goal is to have more accurate scattering phase function backscattering through the use of the Physical Geometric Optics Method (PGOM).
- Cannot simply append improved phase function backscattering calculations to existing MODIS Collection 6 (MC6) database.
  - PGOM incompatible with particles that have small-scale surface roughness.
  - Ensemble-averaged particles of distorted geometry can be optically consistent with roughened counterpart.
  - Optical consistency between the original and new databases needs to be achieved in order to be compatible with existing MODIS ice cloud retrieval algorithm.

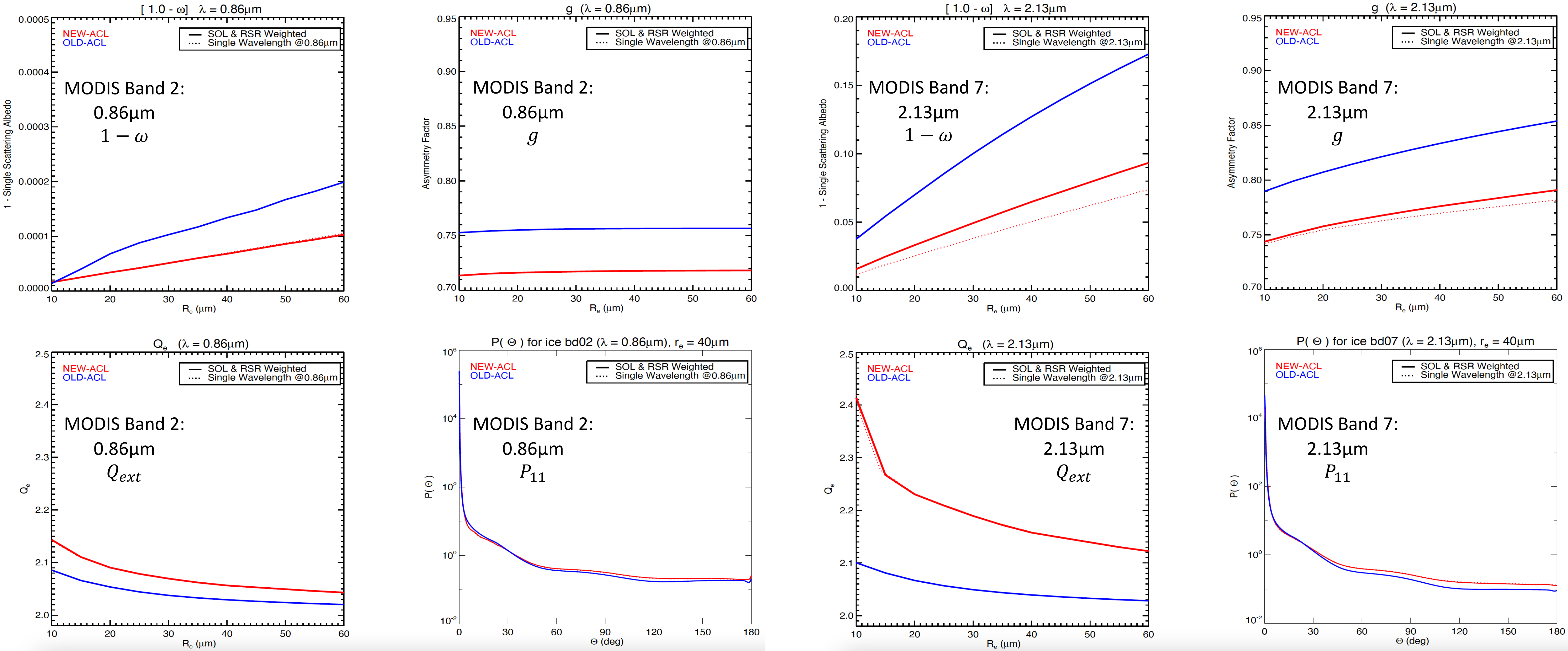






1st Attempt: Distorted 20-Column Aggregate Ensemble

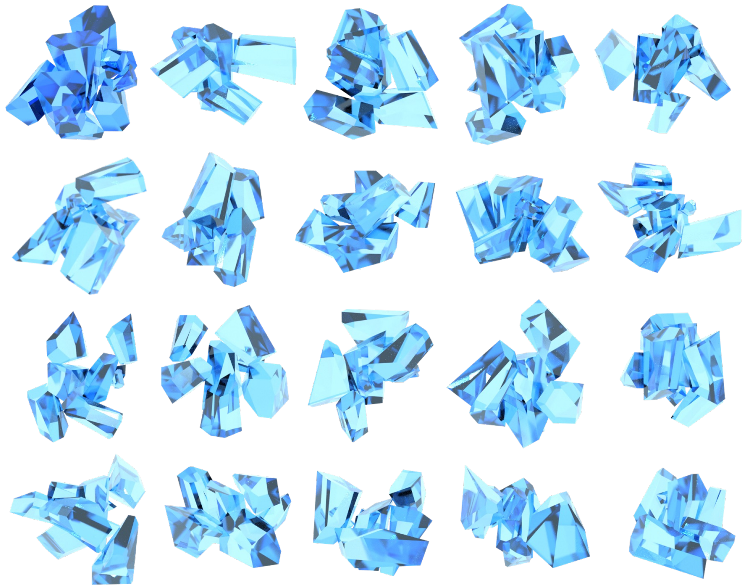
- Initial version of improved MC6 database comprised of randomly distorted 20-column aggregates from the new THM.
  - Resulted in inconsistent single-scattering properties with original MC6 which could significantly impact retrievals.



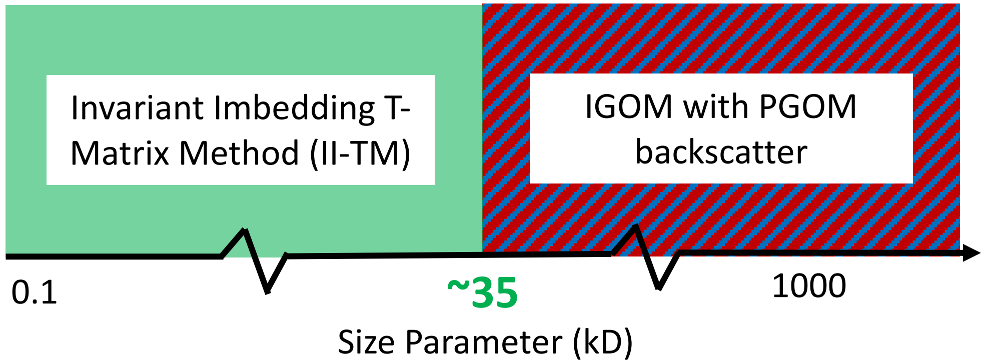
Improved MC6 Ice Particle Optical Property Database (IMC6)

- To achieve optical consistency with original MC6 database, new randomly distorted 8-column aggregates are generated to represent the IMC6 database.
    - Ensemble-averaged optical properties of distorted particles are likely to achieve optical consistency with their roughened, ideally-shaped counterpart (Liu et al. 2014).
- IMC6 database comprised of randomly-distorted 8-column aggregates.
- Wavelength range specifically covers MODIS bands 1-7, 20, 26, and 29-32.
- PGOM backscattering phase matrix computations appended to corresponding Improved Geometric Optics Method (IGOM) computations to preserve computational efficiency.

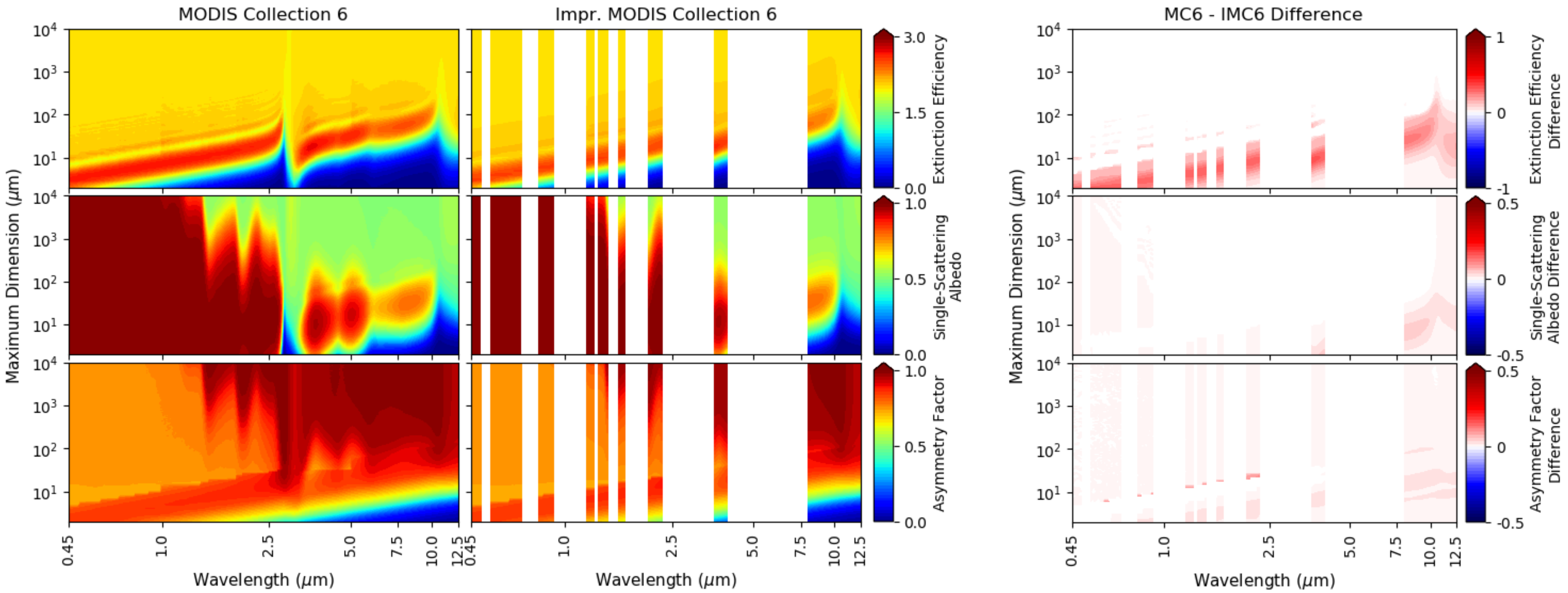
IMC6 Info	
Wavelength	0.43 – 12.5μm
Particle Size	2 – 10000μm



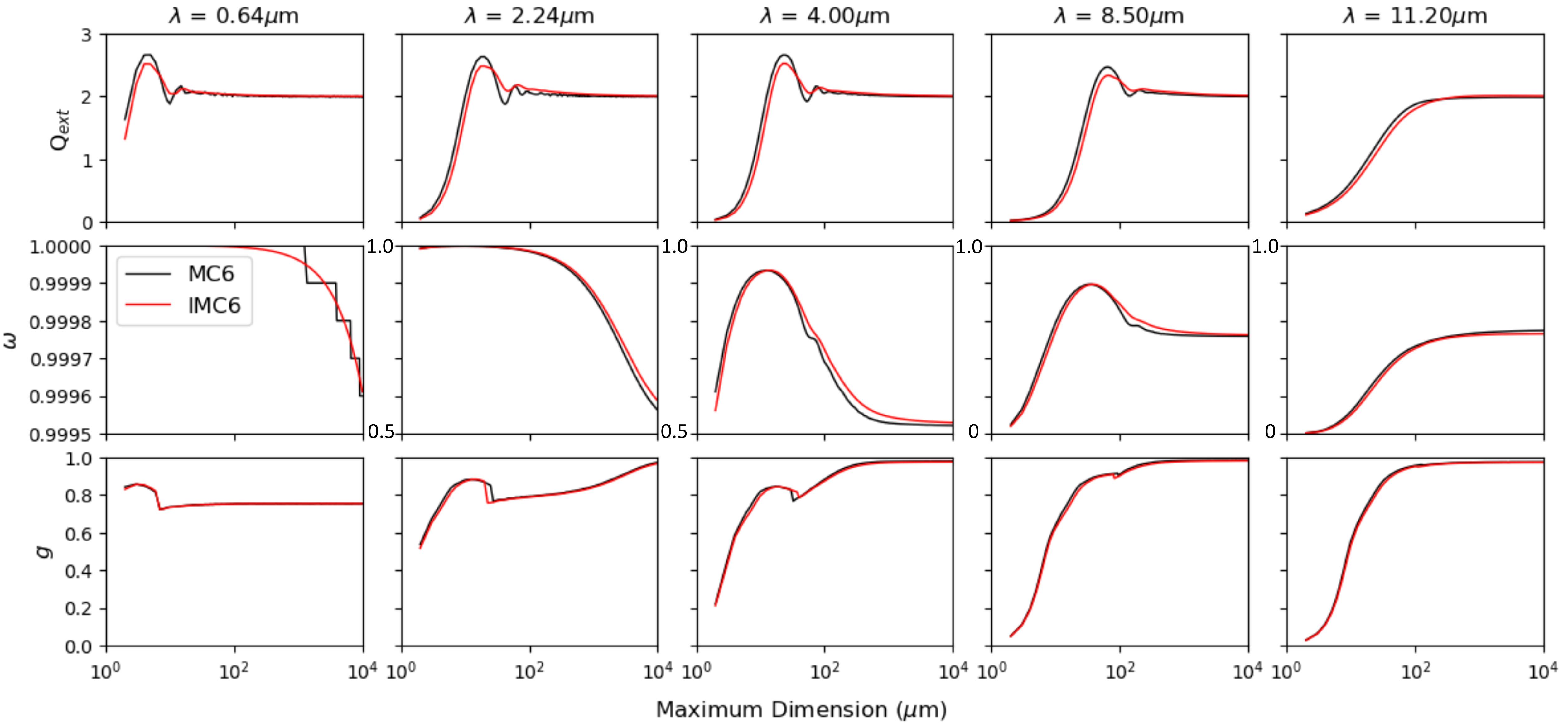
IMC6 Computation Methods



IMC6 Database: Optical Consistency



IMC6 Database: Optical Consistency



IMC6 Database: Nakajima-King Forward Model Consistency

VIS/NIR retrieval inputs	Data source
Band 2 (0.64 μm)	GOES-17
Band 6 (2.24 μm)	GOES–17

- THMv2 LUT inconsistent with IMC6 especially for large effective radii.
- IMC6 LUT fairly consistent with MC6 with slight deviations in optical thickness and very large effective radii.

Forward Model

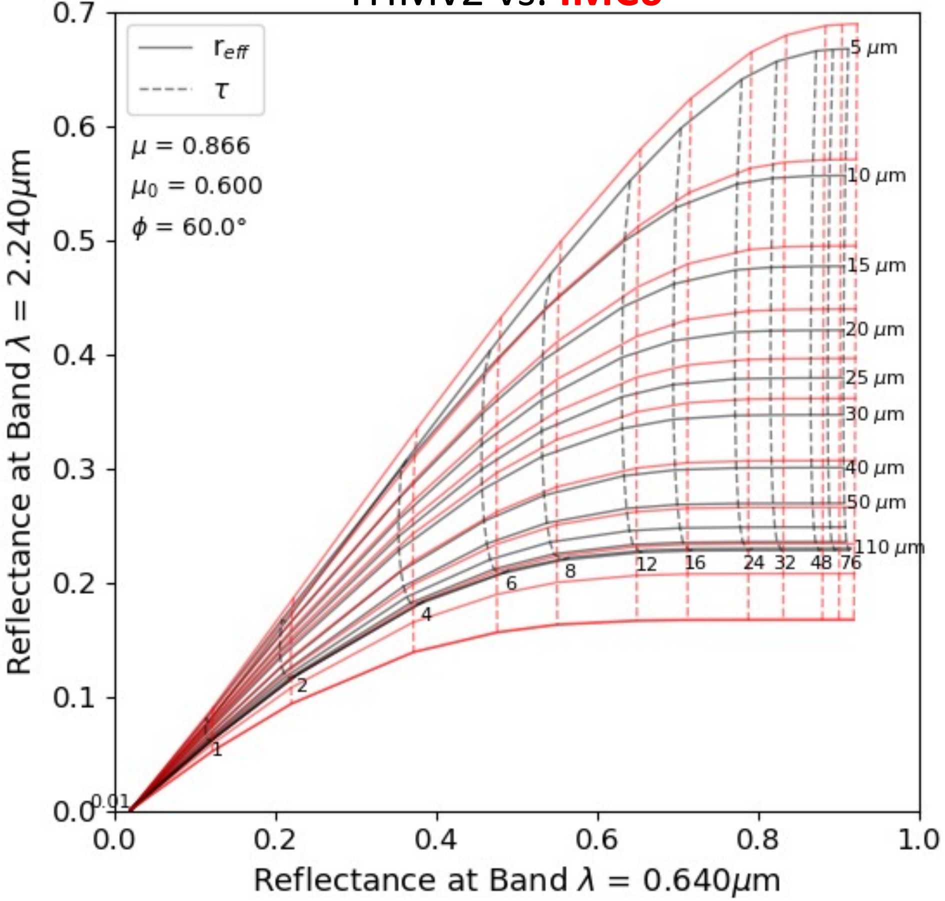
$$y = F(x, b) + e$$

$$x = \begin{pmatrix} \tau \\ r_{eff} \end{pmatrix}$$

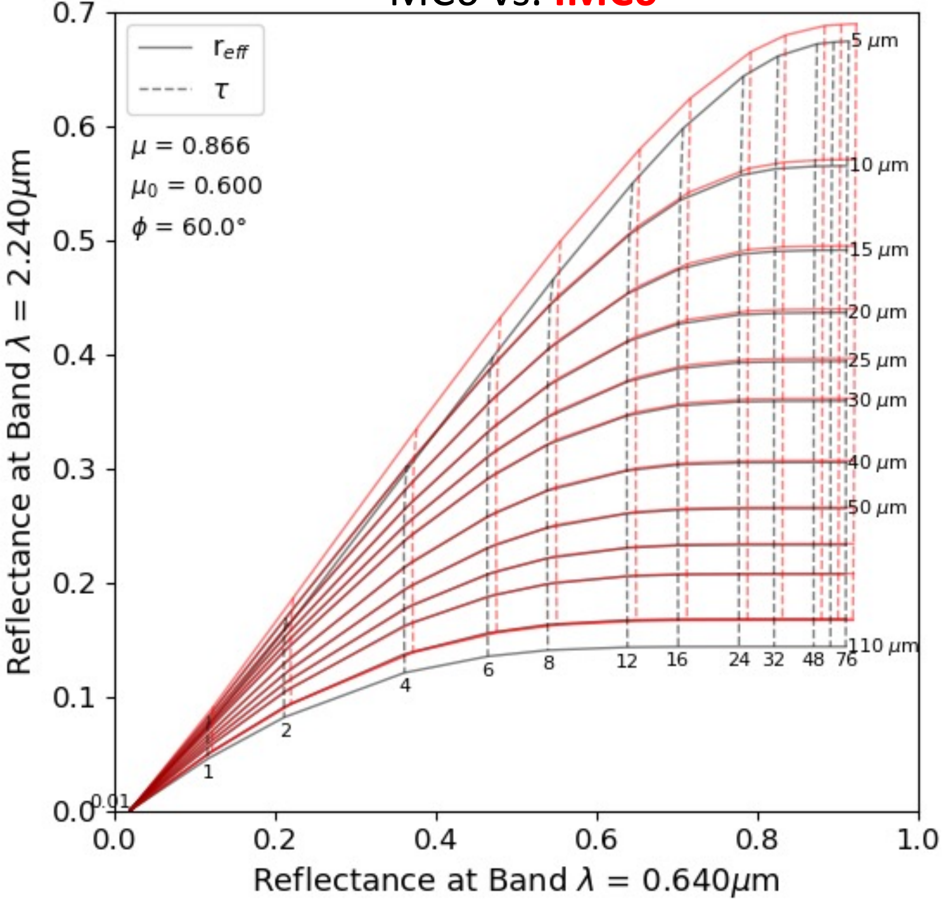
$$y = \begin{pmatrix} R_{band\ 2} \\ R_{band\ 6} \end{pmatrix}$$

$$b = \begin{pmatrix} \mu \\ \mu_0 \\ \phi \\ \alpha_{sfc} \end{pmatrix}$$

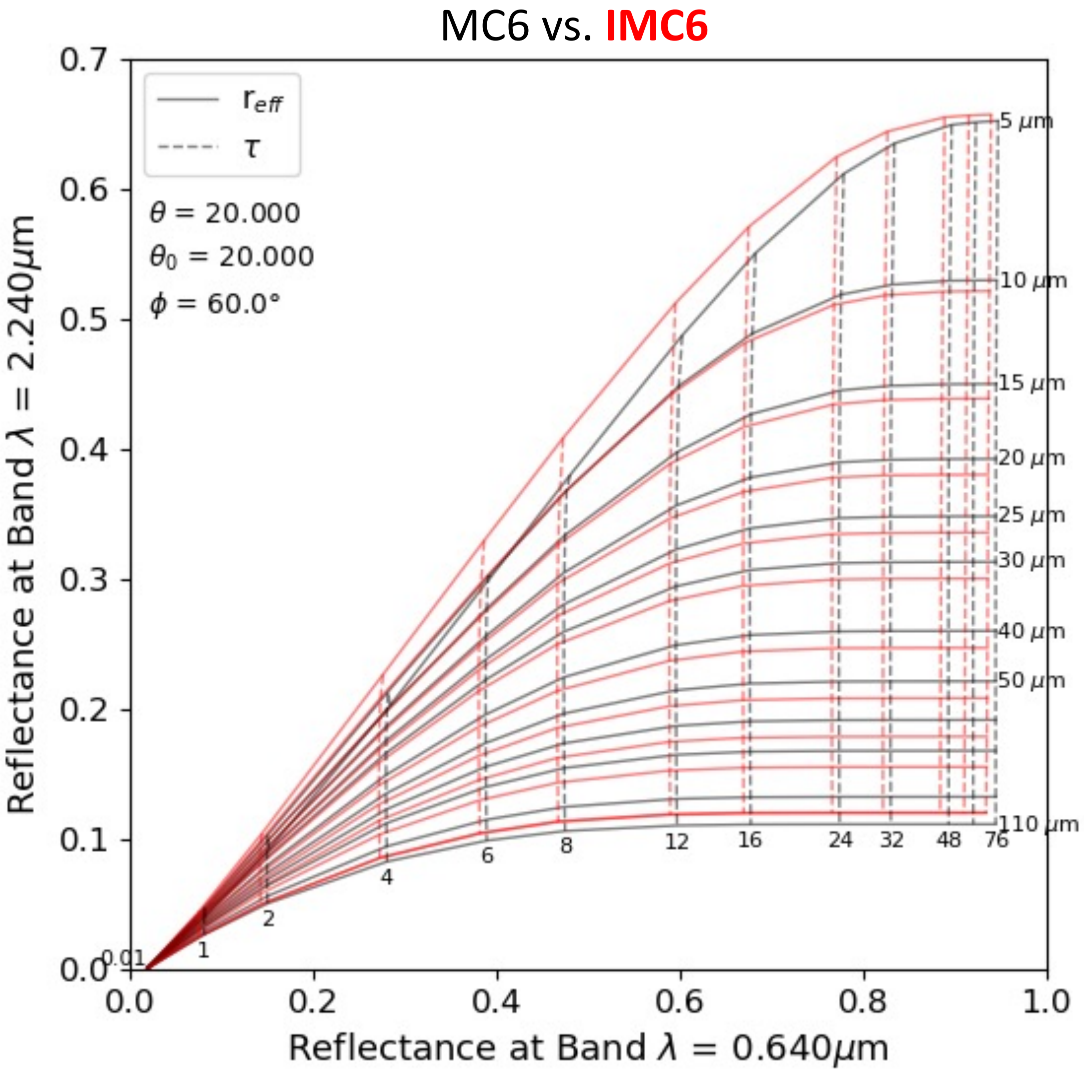
THMv2 vs. **IMC6**

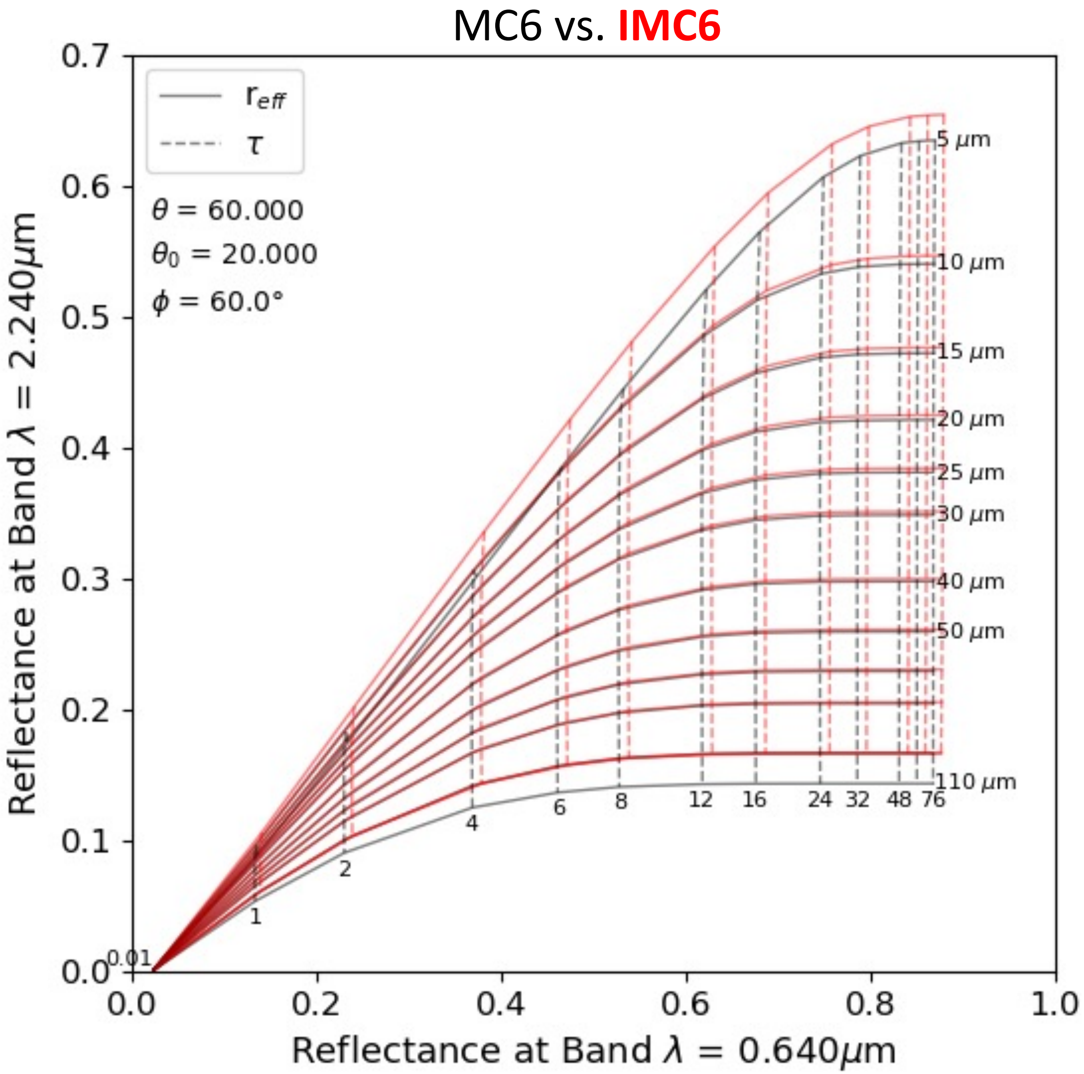


MC6 vs. **IMC6**



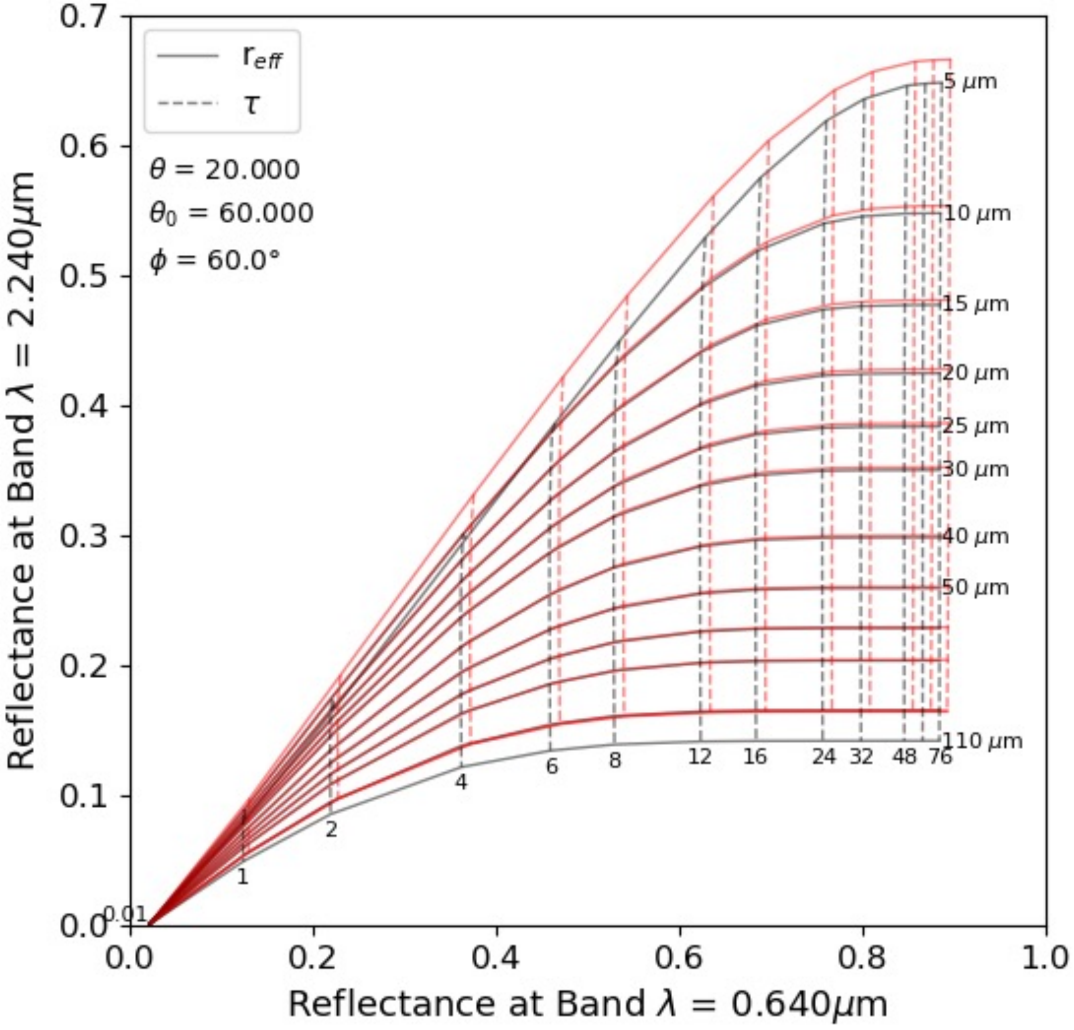
IMC6 Database: Nakajima-King Forward Model Consistency (Extreme Cases) [VZA = $\mathbf{20°}$]



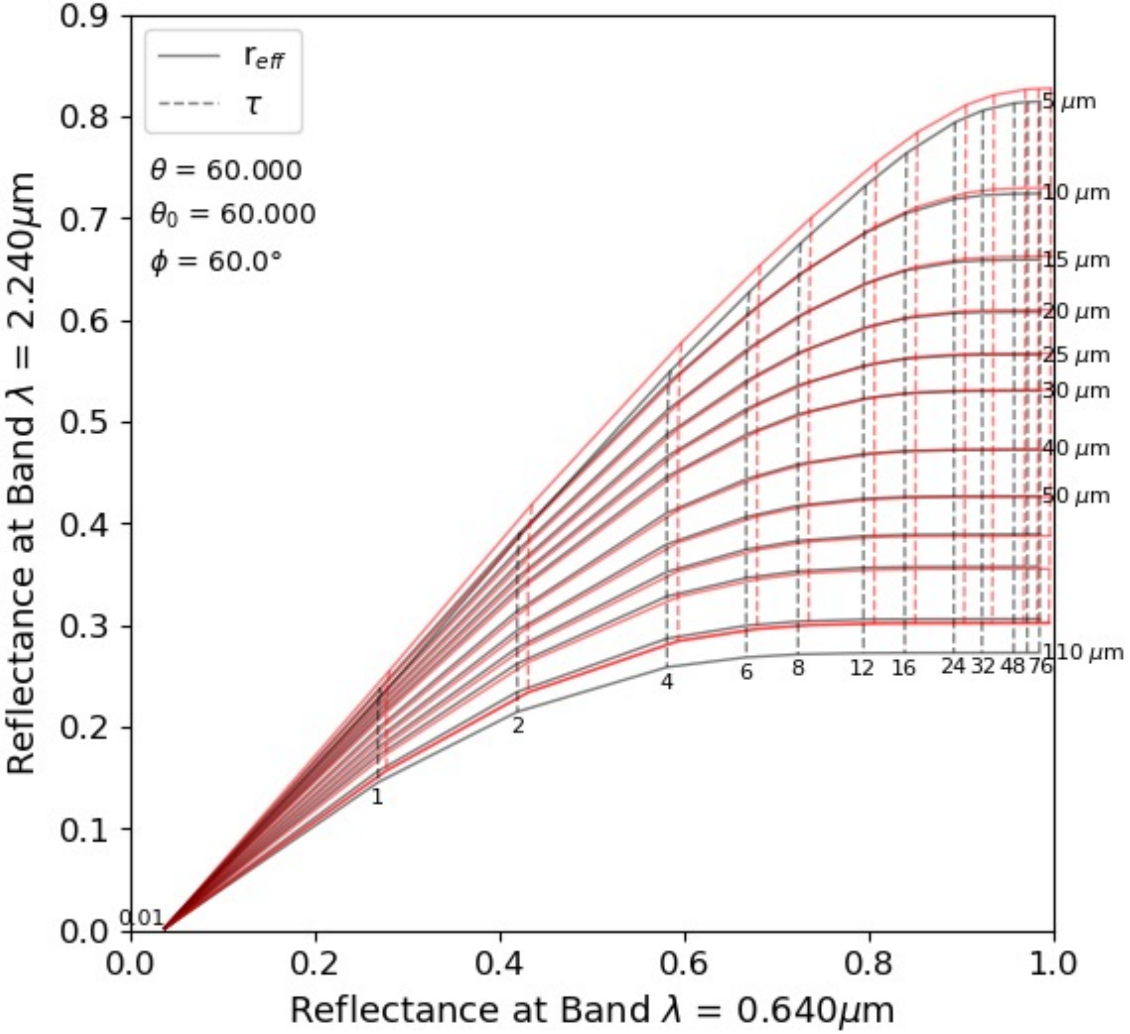


IMC6 Database: Nakajima-King Forward Model Consistency (Extreme Cases) [VZA = $\mathbf{60°}$]

MC6 vs. **IMC6**



MC6 vs. **IMC6**



IMC6 Database: Split-Window Forward Model Consistency

IR retrieval inputs	Data source
$\text{Band}_{11,13,14,15}$ (8.5 μm, 10.3 μm, 11.2 μm, 12.3 μm)	GOES-17
Cloud Top Temp. (CTT)	GOES-17
P_{atm}, w	MERRA-2
Sea Surface Temp. (SST)	JPL PO.DAAC

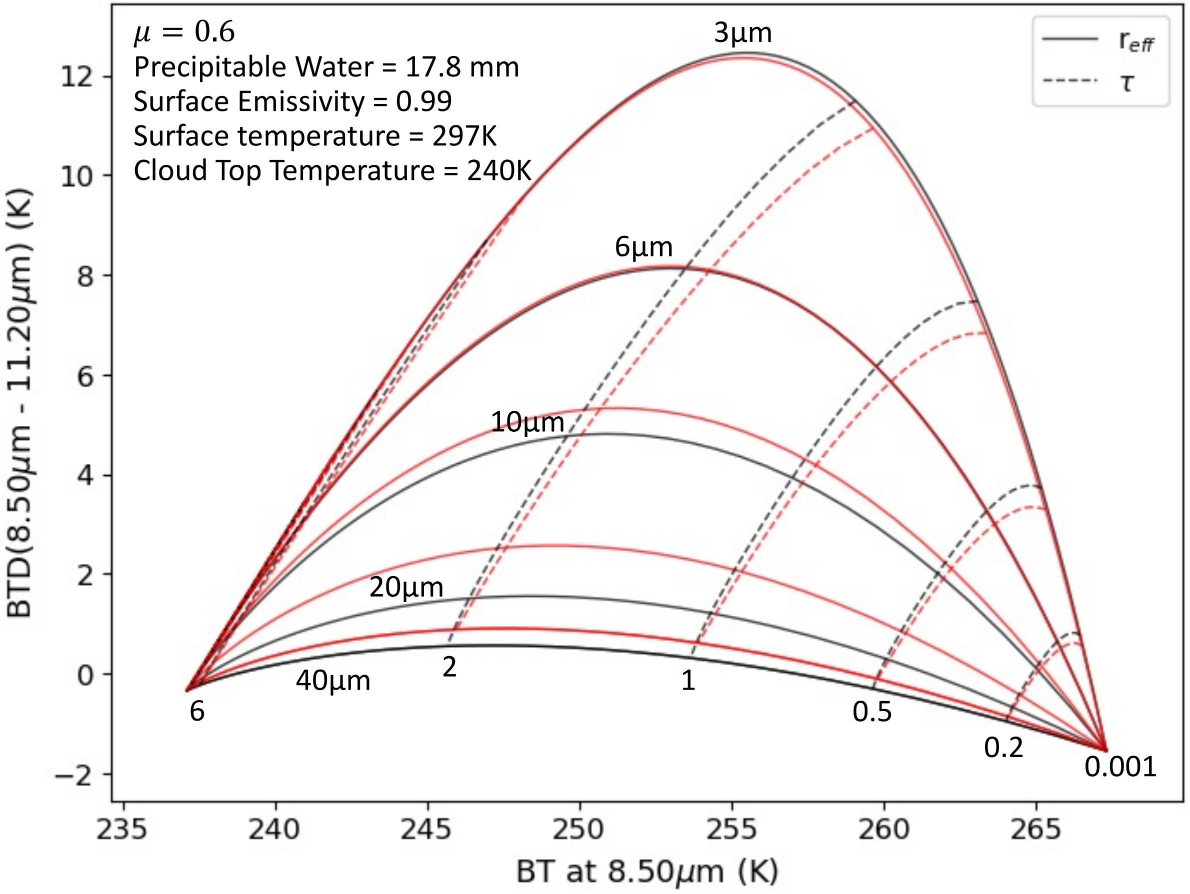
Forward Model

$$y = F(x, b) + e$$

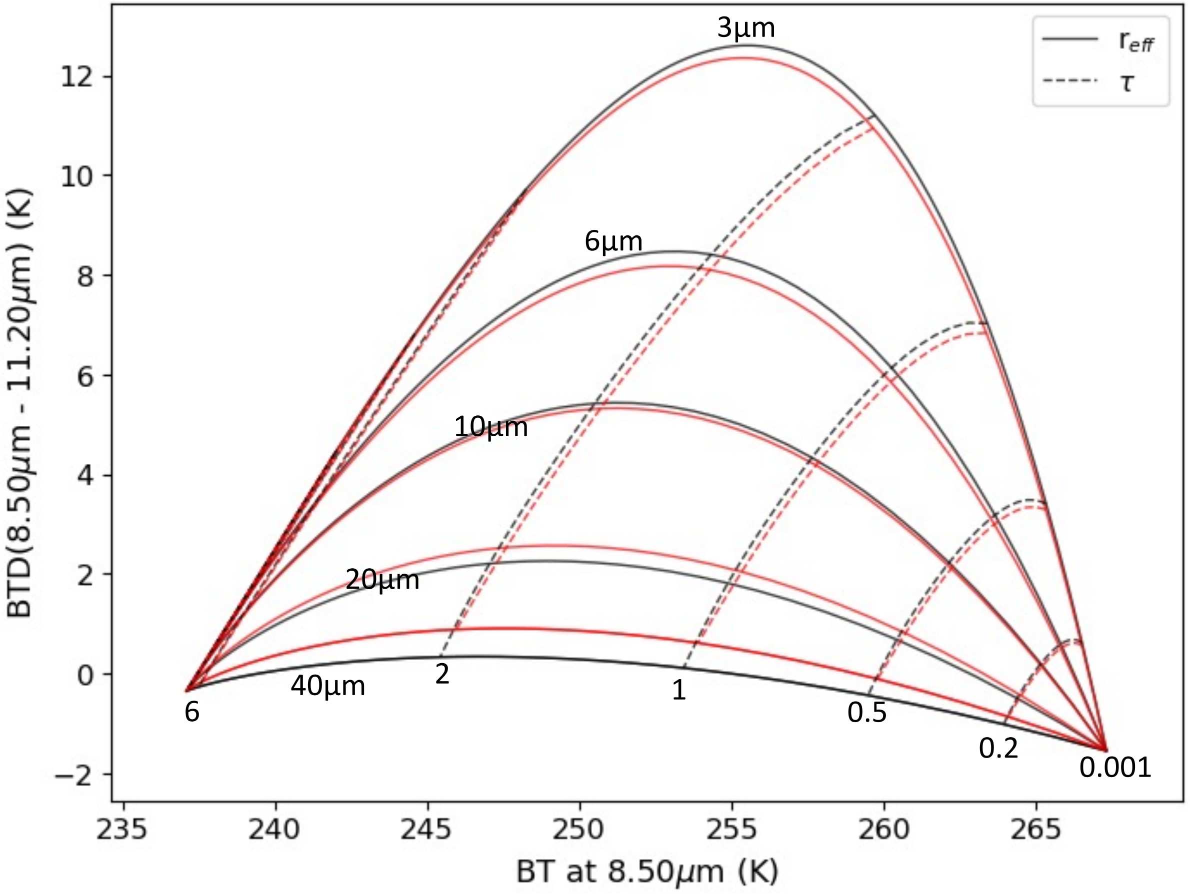
$$x = \begin{pmatrix} COT \\ CER \\ CTT \end{pmatrix}. \quad y = \begin{pmatrix} BT_{band\ 11} \\ BT_{band\ 13} \\ BT_{band\ 14} \\ BT_{band\ 15} \end{pmatrix}. \quad b = \begin{pmatrix} \mu \\ w \\ \varepsilon_{sfc} \\ P_{atm} \\ SST \end{pmatrix}$$

- IMC6 and MC6 are fairly consistent with each other.
- THMv2 inconsistent with IMC6 for small cloud optical thickness and large effective radii.

THMv2 vs. IMC6

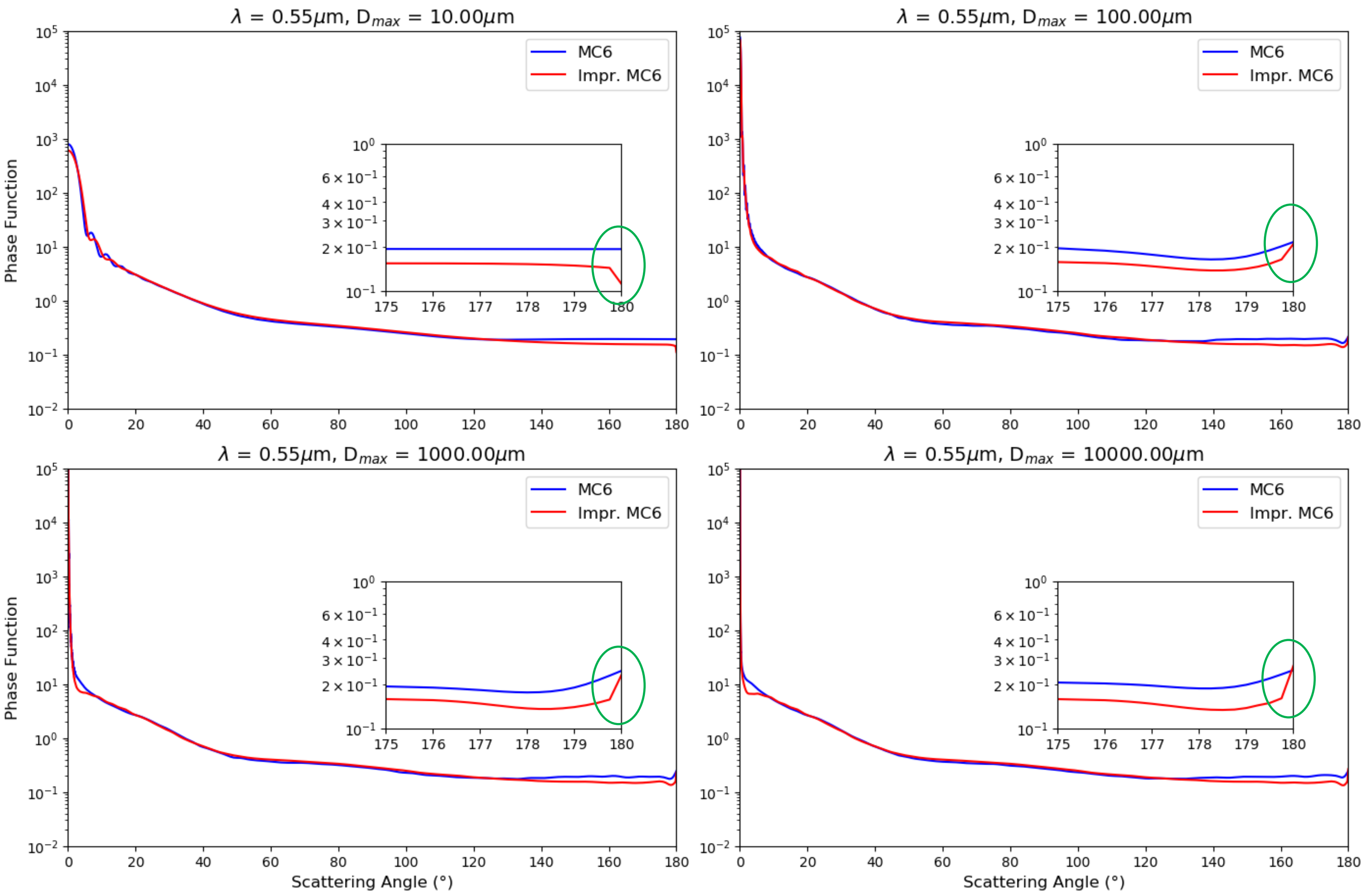


MC6 vs. IMC6



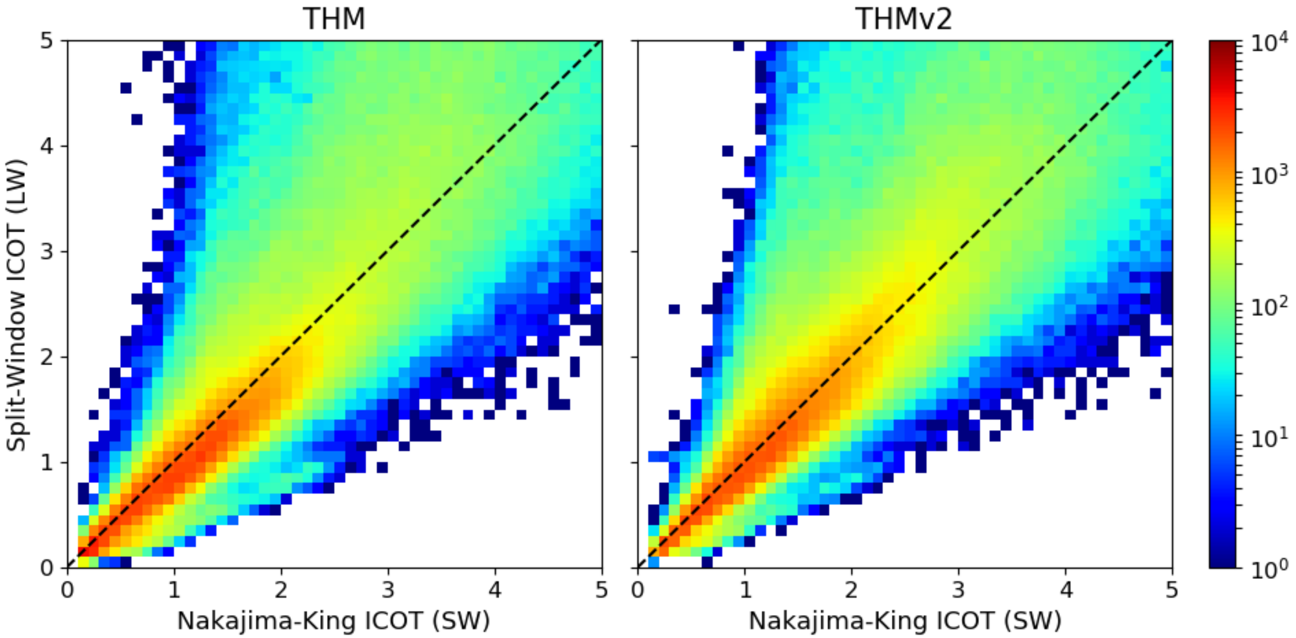
IMC6 Database: PGOM Backscattering Issues

- IMC6 phase function PGOM backscattering appears to only exceed that of MC6 when particles size is very large.
- Distorted aggregates appear to not produce significant backscattering intensity.
  - Random orientation and complex geometrical shape are likely the cause.
  - Not enough random orientations for PGOM calculations could also be the cause.
  - Could possibly incorporate small habit fraction of simplistic particle shape (e.g. columns/plates) to boost backscattering intensity of IMC6.



IMC6 Database: Summary and Future Work

- IMC6 database has been recently developed with the intention to replace existing MC6 ice particle optical property database.
  - IMC6 optically consistent with MC6
  - Phase function PGOM backscattering calculations incorporated into IMC6 but has known to have issues with intensity and will likely need to be corrected/redone.
- Final validation test will involve calculation of LW and SW spectral consistency between IMC6 and MC6 to ensure accuracy of ice cloud retrievals will not change when using IMC6.
- A manuscript based on the optical and spectral consistency between IMC6 and MC6 will eventually be written and submitted to a publication.



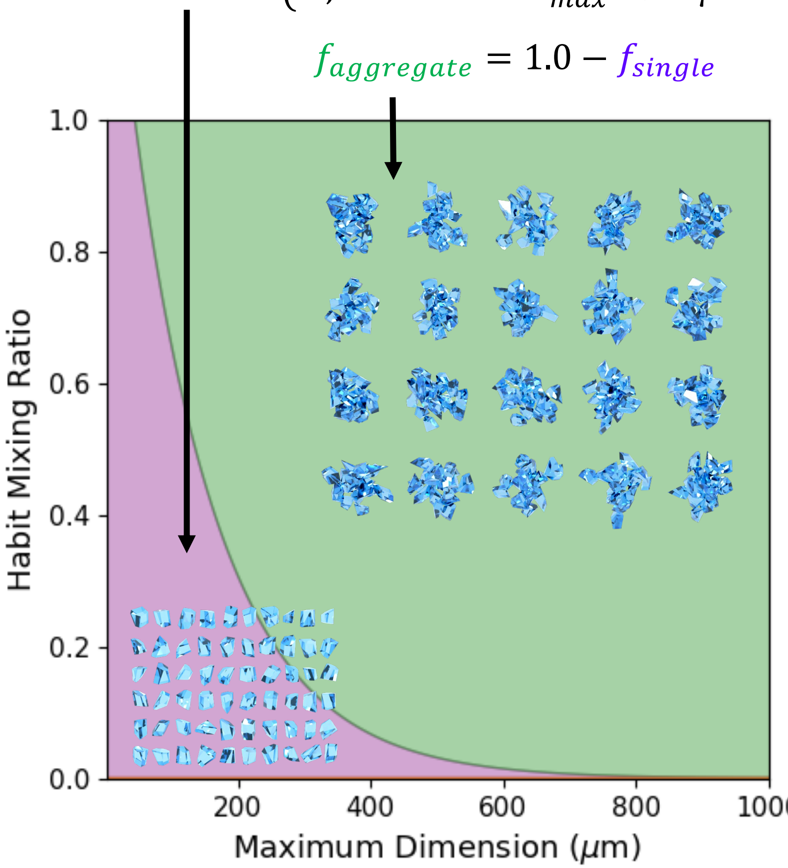
THMv2-TEMP: Temperature Dependent THMv2 Database Development Progress

- THMv2 being expanded to include temperature-dependent single-scattering properties for Far-Infrared (FIR) wavelengths (14 – 200µm).
- To be eventually used for radiative transfer model FIR retrievals of ice cloud properties to be analyzed with the observational data of:
  - Polar Radiant Energy in the Far Infrared Experiment (PREFIRE) (0-54µm) (NASA).
  - Far-infrared-Outgoing-Radiation Understanding and Monitoring (FORUM) (6.25 – 100µm) (ESA).
- THMv2-TEMP developed using only IGOM and IITM computational methods.
  - All IGOM calculations currently completed.
  - 33% of all IITM calculations completed.
    - About 3,800,000 IITM calculations needed to develop database taking <30sec to 1 hour each depending on size parameter.
    - Expected to be completed by early 2025.

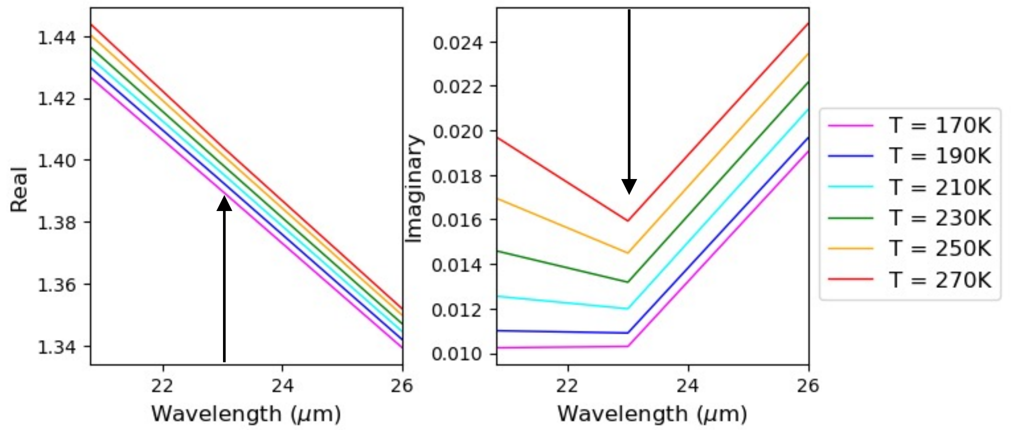
	THMv2-TEMP
Temperature	6 bins **(170 – 270K; 20K increments)**
Wavelength	80 bins **(14.0 – 200µm)**
Size (D_{max})	189 bins **(2.206 – 11031.337µm)**

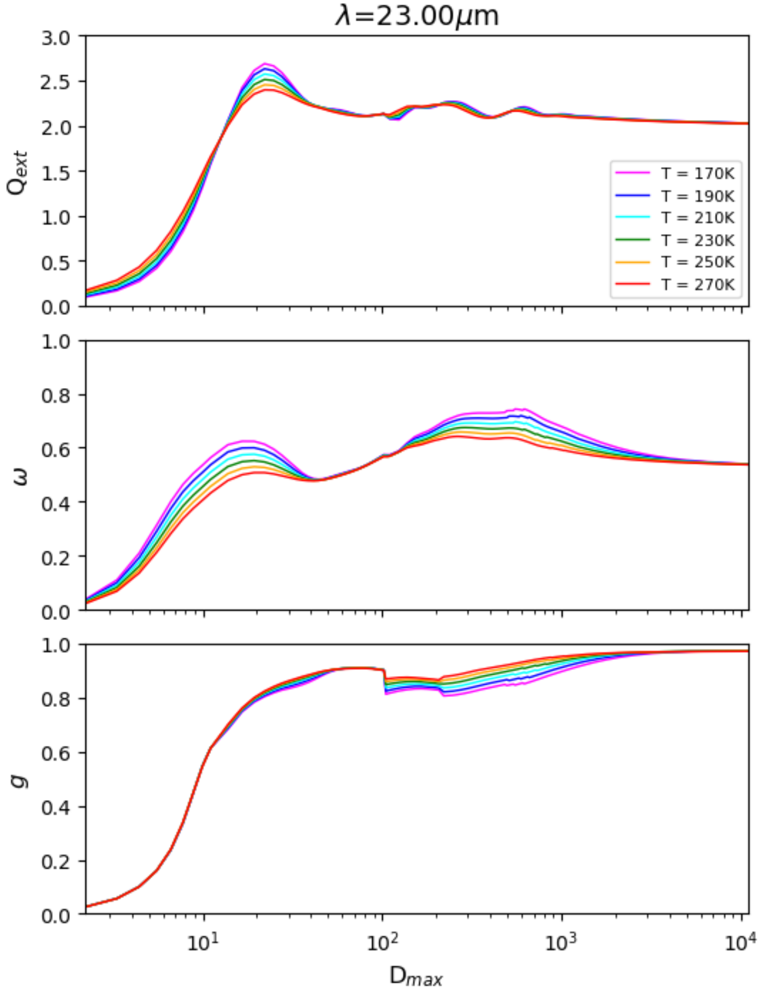
$$f_{single} = \begin{cases} e^{-0.0076(D_{max}-45)}, & D_{max} \geq 45\mu m \\ 1, & D_{max} < 45\mu m \end{cases}$$

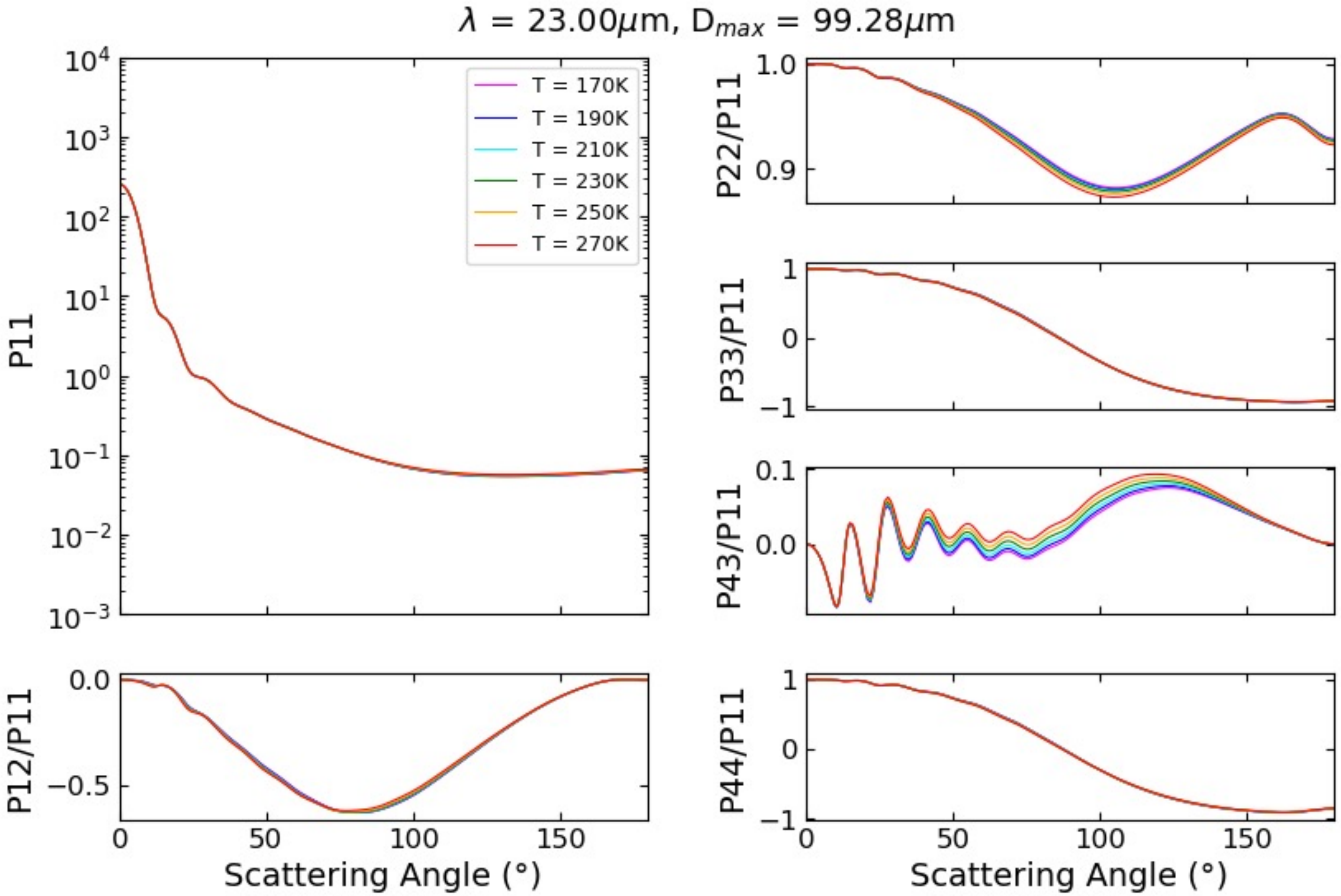
$$f_{aggregate} = 1.0 - f_{single}$$



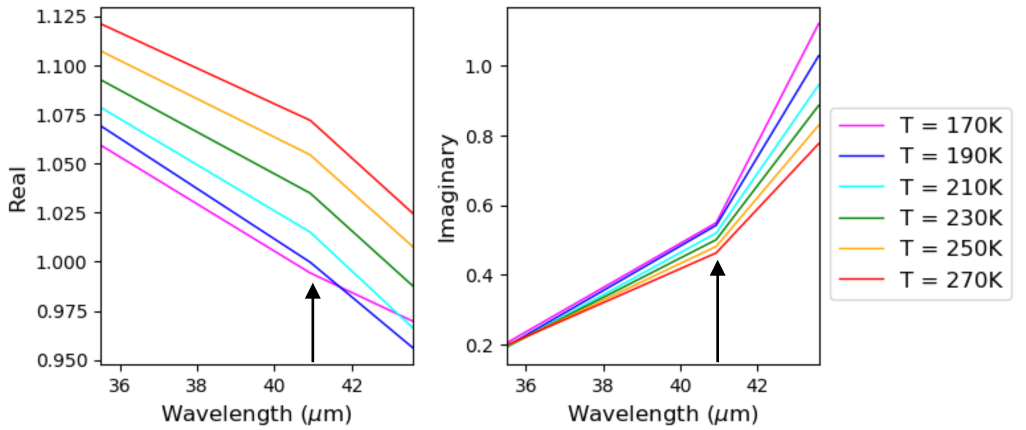
Preliminary Single-Scattering Property Comparisons: 23µm

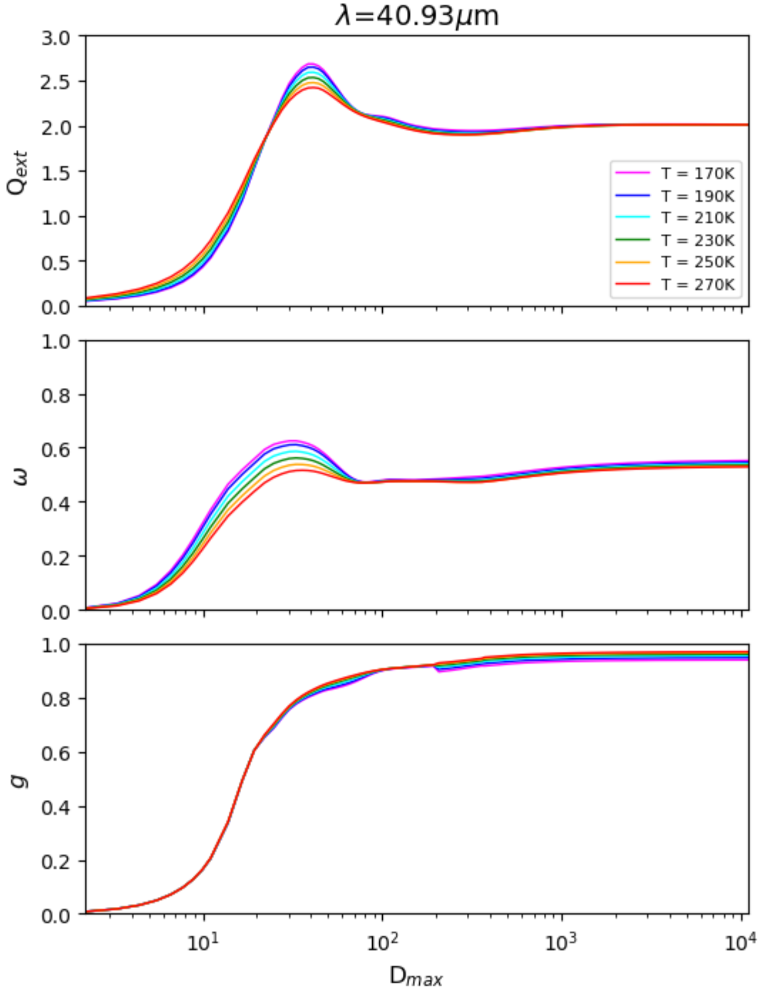


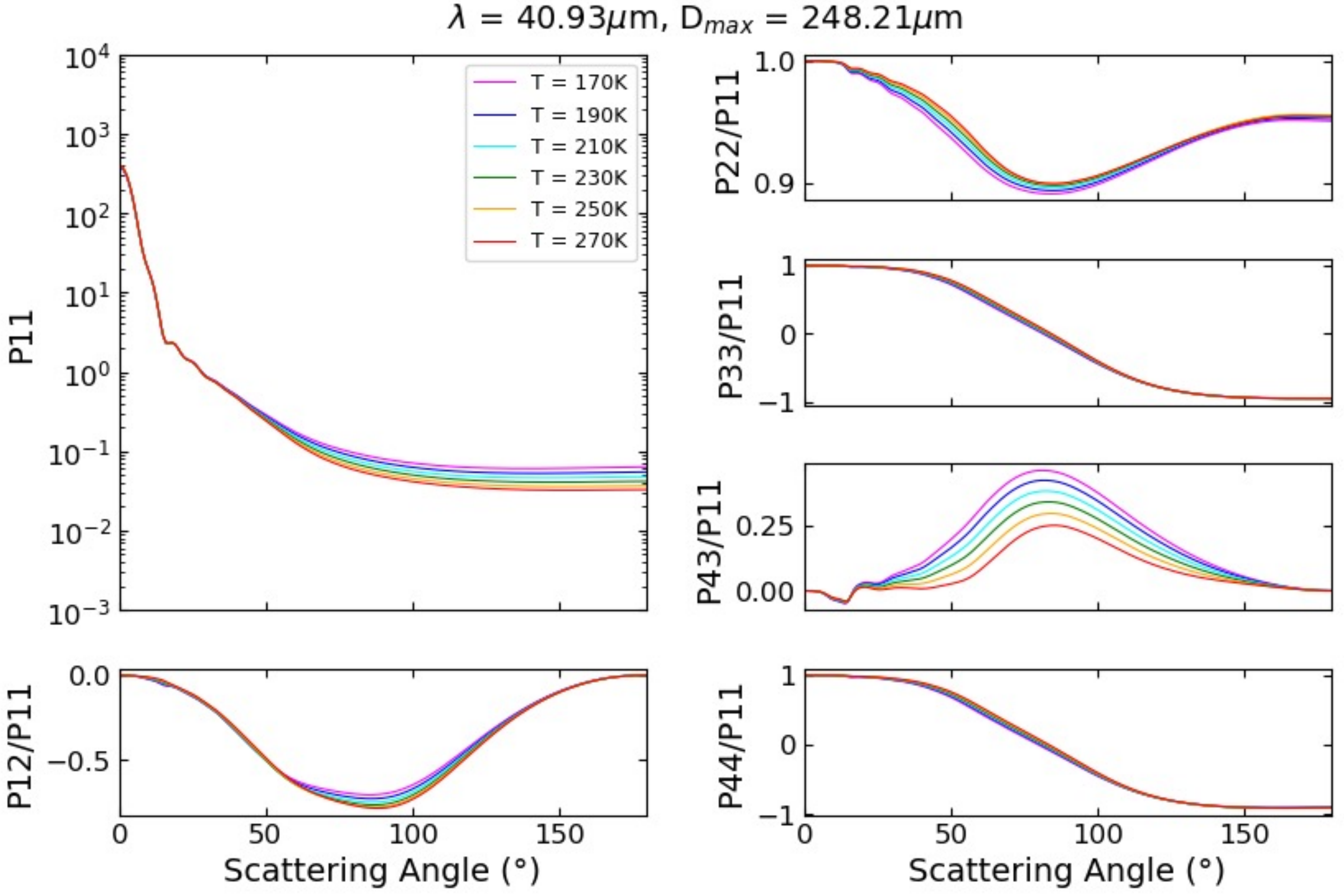




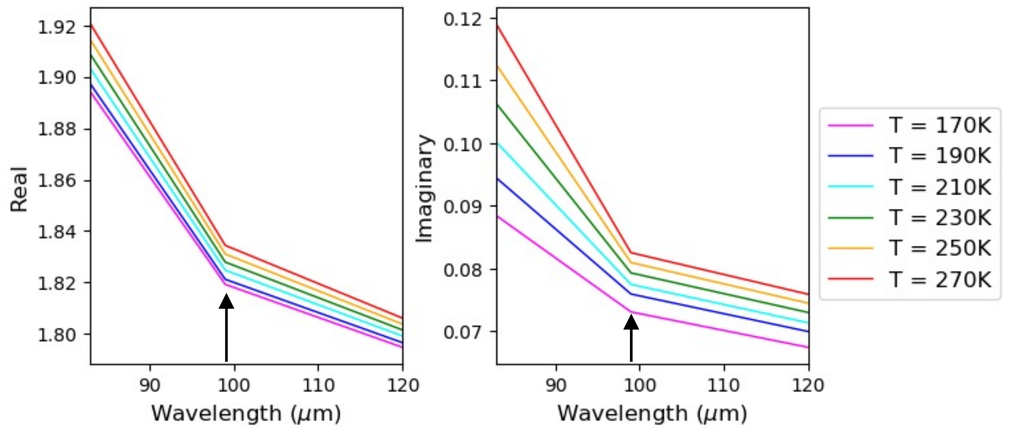
Preliminary Single-Scattering Property Comparisons: 40.93μm

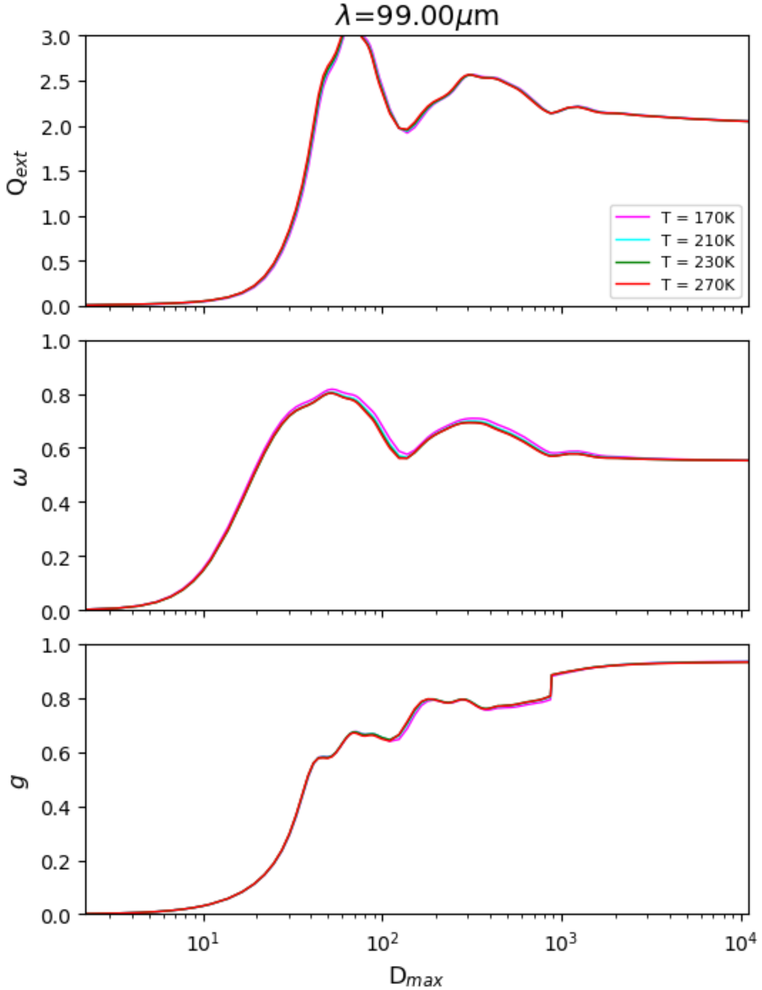


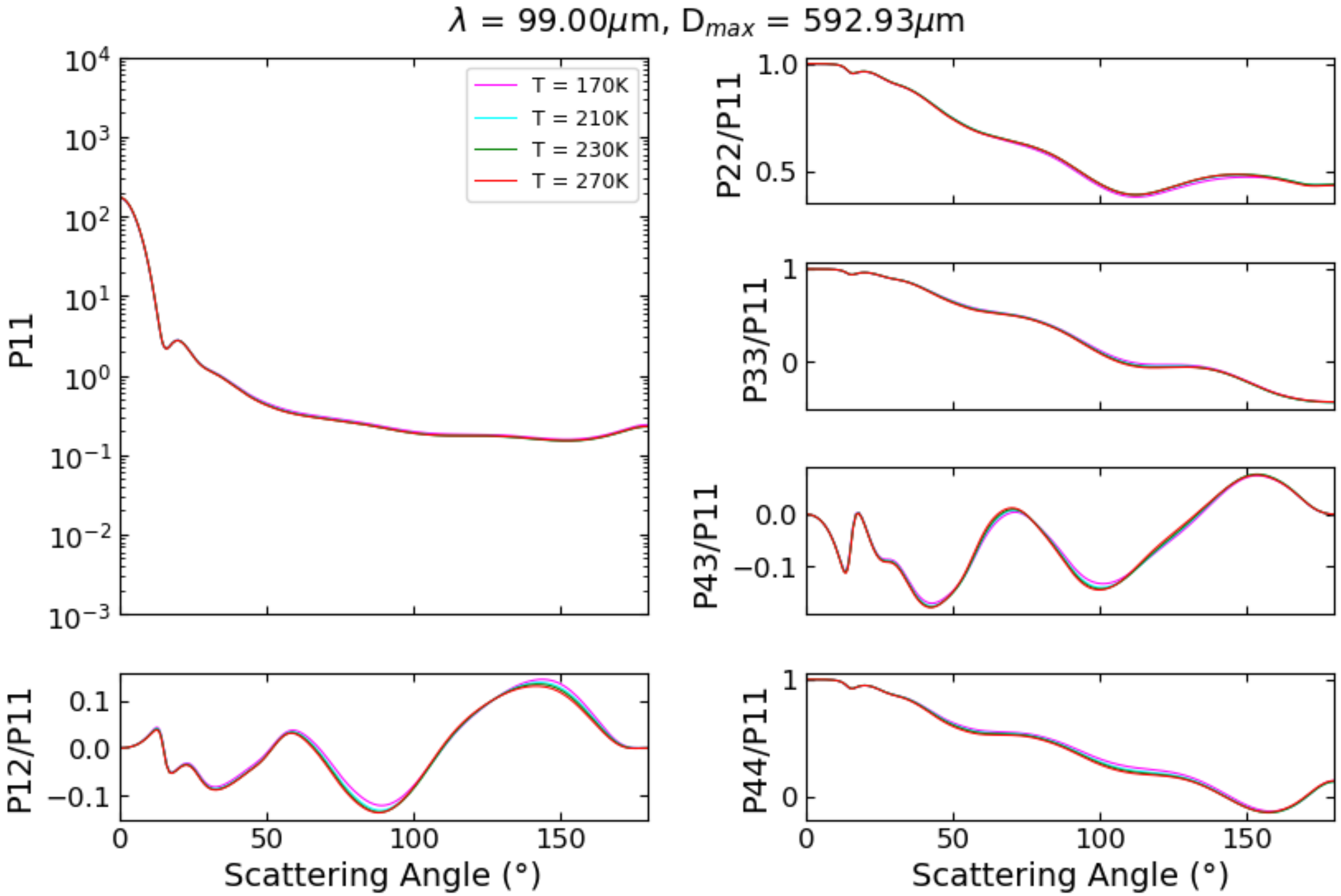




Preliminary Single-Scattering Property Comparisons: 99µm







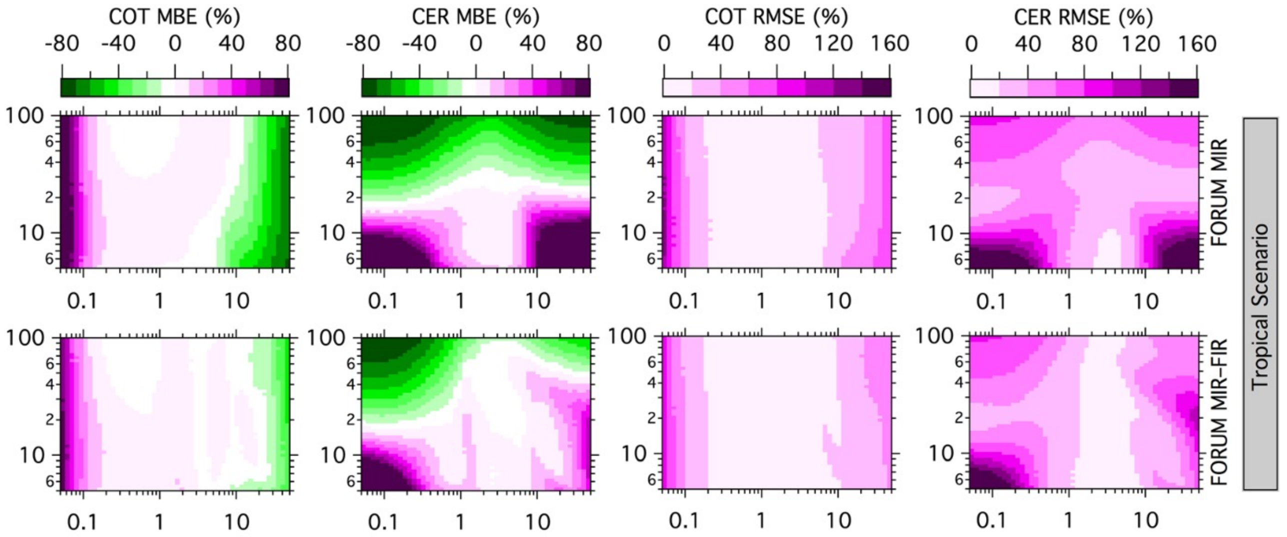
THMv2-TEMP: Future Work

- THMv2-TEMP database will be fully developed before PREFIRE or FORUM data become available.
  - How do we know if the database will be useful for ice cloud retrievals?
- Radiative transfer simulations based on synthetic PREFIRE/FORUM observations could possibly be conducted to test the database.
- Saito et al. 2020 conducted radiative transfer simulations of nighttime ice clouds using temperature-dependent 8-column aggregate database.
  - To evaluate if retrievals would improve if far-infrared ($\lambda > 12\mu m$) retrievals were used synergistically with split-window retrievals (middle-infrared, MIR).
- Synergistic split-window and far-infrared retrievals were shown to have sufficient sensitivity to optically thick ice clouds (0.2 - 30).
- A similar test using THMv2-TEMP could be expected to lead to similar results in order to confirm the database's accuracy.

Retrieval error analysis of cloud optical thickness (COT) and effective radii (CER) showing mean bias error (MBE) and root mean square error (RMSE) for FORUM-like simulations of nighttime ice clouds in a tropical scenario.

Top row are retrieval error results from only MIR simulations.

Bottom row are retrieval error results from synergistic MIR and FIR simulations. (Saito et al. 2020)



References

Liu, C., Panetta R. L., and Yang, P. (2014). The effective equivalence of geometric irregularity and surface roughness in determining particle single-scattering properties. *Optics Express*. **22**, 23620-23627.

Saito, M., Yang, P., Huang, X., et. al. (2020). Spaceborne Middle- and Far-Infrared Observations Improving Nighttime Ice Cloud Property Retrievals. *Geophysical Research Letters.* **47**, e2020GL08749.