Comparison between simulated cloud radiative forcing and CERES measurements

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In collaboration with

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Improved Light Scattering Computational Capabilities

- Small to moderate size parameters: the invariant imbedding T-matrix method (II-TM)
- Large size parameters: the Improved Geometric Optics Method (IGOM) with the incorporation of improvements of inhomogeneous waves inside ice crystals at infrared wavelengths
- Incorporation of the Edge effect (photon tunneling) in the transition from the II-TM to IGOM results
To all the happy ice crystals in planetary atmospheres.

Let there be light.
Let there be beautiful ice crystals in the air and mountain ranges.
And here come the reindeers and Santa Claus carrying Maxwell’s equations, and light rays are shining in the wonderlands.
Let the glory of Geometric Optics for ice crystals, Newton’s optics, and sun’s light rays rise again from the horizon.
Let ice crystals’ old friends - black carbon and dust - be not forgot for Auld Lang Syne.
And ice crystals are carried by the ceaseless winds; and
After travelling thousands of miles up and down, the sky looks very blue.
Let there be space missions to tender ubiquitous light rays in the sky,
And all things considered, let light scattering by ice crystals in remote sensing and climate change be a delight.

-- Liou & Yang
Ice Particle Optical Property Simulation
Ice models in MODIS Collection 5 and 6

MODIS Collection 5
Mixture of Smooth Particles

MODIS Collection 6
100 % Column Aggregate

- $2500 \mu m < D_{\text{max}}$
- $1000 \mu m < D_{\text{max}} < 2500 \mu m$
- $60 \mu m < D_{\text{max}} < 1000 \mu m$
- $0 \mu m < D_{\text{max}} < 60 \mu m$

Habit Fraction

0.0 0.2 0.4 0.6 0.8 1.0
Left: RGB image of Aqua MODIS Level 1B reflectance data (MYD021KM.A2016146.0100.006.2016147144107)
Right: Distribution of cloud phases (from MODIS C6 Level 2 data) in the granule overlapped on band 2 gray-scale image (courtesy of J. Ding)
Comparison of C5 and C6 ice cloud optical thickness at 0.55 $\mu m$ wavelength. The white straight line is the one-to-one ratio line (courtesy of J. Ding)
Comparison of $\tau(1-\omega g)$ for C5 and C6 ice cloud optical thickness data in MODIS Level 2 Cloud Products. The white straight line is the one-to-one ratio line (courtesy of J. Ding).
The New Two-habit Model

Roughened Single Column

Aggregate of Distorted Columns
The New Two-habit Model
The New Two-habit Model

Roughened Single Column

20 Aggregates of 20 Distorted Columns
The new Two-habit Model

has 189 size bins and compatible with various particle size distributions
The new Two-habit Model

has 189 size bins and compatible with various particle size distributions

Size distributions used in the retrieval

Predetermined size distributions
Validation with in-situ Measurements

Simulations using two-habit model

- Ice water content (g/m$^3$)
- Median mass diameter (μm)

In-situ Measurements

Particle Size Distributions

The New Two-habit Model

- Ice Water Content
- Median Mass Diameter

In-situ Measurements (Heymsfield et al, 2013)
Shortwave Retrieval Test

• Three Particle Shapes
  – Column Aggregate
  – Single Habit Model
  – Two-habit Model

• One-day of MODIS Terra Data
  – September 15, 2013
  – Level 2 Reflectivity with Atmospheric Correction

• Shortwave Bi-spectral Retrieval
  – Band 2 (0.86 µm) + Band 7 (2.13 µm)
  – Optical thickness + Effective diameter
Optical thickness and effective diameter are both consistent with retrievals using column aggregate model.
Shortwave Retrieval Test

Lower optical thickness than single habit model (SHM)
Fluctuating, smaller effective diameter at populated sizes

Smaller Optical Thickness

A Strange Blob
Fluctuation
Smaller Optical Thickness

The two-habit model has consistently lower asymmetry parameter.

Asymmetry Parameter (0.86 µm) vs Effective Diameter (µm)

- One-habit
- Two-habit

stronger backscattering

smaller optical thickness
Shortwave Retrieval Test

Lower optical thickness than single habit model (SHM)
Fluctuating, smaller effective diameter at populated sizes
Shortwave Retrieval Test

Lower optical thickness than single habit model (SHM)
Fluctuating, smaller effective diameter at populated sizes

Fluctuation
A Strange Blob

Optical Thickness (THM)
Effective Diameter (THM)
Optical Thickness (SHM)
Effective Diameter (SHM)
Fluctuating Effective Diameter

Reflectivity Product $R (2.1 \mu m)$

Spherical Albedo

Effective Diameter ($\mu m$)

Bicubic spline interpolation

Original points

SZA = 32.3°

VZA = 39.0°

RZA = 63.6°
Fluctuating Effective Diameter

Reflectance Product (2.1 µm) vs. Effective Diameter (µm)

- Interpolation
  - Two-Habit
  - One-Habit

Single habit model shows fluctuating reflectivity
Fluctuating Effective Diameter

Due to variable aspect ratio in SHM

Single habit model shows fluctuating single scattering albedo

Single Scattering Albedo (2.1 µm) vs. Effective Diameter (µm)

One-habit
Two-habit

0.75 0.8 0.85 0.9 0.95 1
0 20 40 60 80 100 120 140 160 180 200
Shortwave Retrieval Test

Lower optical thickness than single habit model (SHM) Fluctuating, smaller effective diameter at populated sizes.
Shortwave Retrieval Test

Lower optical thickness than single habit model (SHM)
Fluctuating, smaller effective diameter at populated sizes

- Lower Optical Factor
- Asymmetry Factor
- Optical Thickness (THM)
- Effective Diameter (THM)
- A Strange Blob
- Fluctuating Aspect Ratio
- Color Scale: 86160, 27656, 8877, 2850, 915, 295, 95, 31, 11, 4, 1
**Local Minima**

Bicubic spline interpolation

Original points

SZA = 32.3°

VZA = 39.0°

RZA = 63.6°

Reflectivity Product $R (2.1 \, \mu m)$
Shortwave Retrieval Test

Lower optical thickness than single habit model (SHM)
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Shortwave Retrieval Test

Lower optical thickness than single habit model (SHM)
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- Lower optical thickness
- Asymmetry Factor
- Fluctuating effective diameter
- Aspect Ratio
- Local Minima
### Delivery of Ice Cloud Models (A&M)

**As of October 21, 2016**

<table>
<thead>
<tr>
<th>Habit Models</th>
<th>SW BRDFs + Bulk Prop. (VIIRS)</th>
<th>IR Bulk Properties (VIIRS)</th>
<th>SW BRDFs + Bulk Prop. (MODIS)</th>
<th>IR Bulk Properties (MODIS)</th>
<th>Spectral Scattering Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS Collection 6 (r050_c8)</td>
<td>Delivered May 7, 2016</td>
<td></td>
<td></td>
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<tr>
<td>One-Habit (Roughened) (CERES4, 1H-PM, shm1_yx)</td>
<td>Previous LUT</td>
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<tr>
<td>Old Two-Habit (2H-PM, thm1_cl)</td>
<td>Delivered Apr. 27, 2015</td>
<td></td>
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</tr>
</tbody>
</table>

Red: Habit names by CERES team (Dr. Gang Hong)  
Blue: Habit names used by Souichiro Hioki  

RSR of VIIRS is from Dr. Hong, and RSR of MODIS is that of Aqua.
Progress of broadband calculations

74% Completed as of October 24

Bright Color: Finished calculations

Green: Calculations by IGOM

Magenta: Calculations by IITM
Conclusions

• Scaling optical thickness by \((1 - \omega_g)\) gives **consistent results with both** MODIS Collection 6 particle model and MODIS Collection 5 model

• **The shortwave retrieval** with the **new two-habit model** is **consistent** with MODIS Collection 6

• Compared to the current **single habit model**, the **new two-habit model** retrieves
  – Smaller optical thickness
  – Smaller effective diameter at populated sizes

• Broadband calculation of the **new two-habit model** is **in progress**