MODIS Atmosphere Team Webinar Series #9: Overview of Collection 6 Cloud Optical Properties

Steven Platnick et al.
NASA Goddard Space Flight Center, Greenbelt, MD

17 Sept. 2014
The Story So Far …
Atmosphere Team
Webinar Schedule

http://aerocenter.gsfc.nasa.gov/ext/registration/

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<td>MODIS Dark Target Global 10 Km Product</td>
<td>Rob Levy</td>
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<td>MODIS Aerosols Deep Blue</td>
<td>Andy Sayer</td>
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<td>MODIS Aerosols Merged Dark Target: Deep Blue Product</td>
<td>Rob Levy / Andy Sayer</td>
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<td>Materials to Follow.</td>
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<td>Steve Platnick / Bill Ridgway</td>
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<td>Giovanni Aerosols Express</td>
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<td>Materials to Follow.</td>
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<td>MAIAC 1 Km Aerosol Product</td>
<td>Alexei Lyapustin</td>
<td>15-Oct-14</td>
<td>Materials to Follow.</td>
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Atmosphere Team Product Organization and PIs

**MODIS**

**Atmosphere Team**

**C6**

**Webinar #9**

**L1B MOD/MYD02,03**

**Ancillary Data**

**MOD35/MYD35 Cloud Mask**

- **S. Ackerman** (U. Wisconsin)  
  - **MOD35/MYD35 Cloud Mask**
    - **S. Ackerman**
      - **06 Cirrus Reflectance**
      - **07 Clear-Sky Profiles**
    - **06 Cloud-Top Properties**
      - **S. Ackerman**
    - **06 Cloud Optical Properties**
      - **S. Platnick**
  - **B.-C. Gao (no longer supported)**

**04 Aerosol (“Dark Target”)**

- **R. Levy (GSFC)**

**04 Aerosol (“Deep Blue”)**

- **C. Hsu (GSFC)**

**05 Near-IR PW**

- **S. Ackerman**

**05 IR PW**

- **S. Platnick**

**06 Cloud-Top Properties**

**06 Cloud Optical Properties**

**07 Clear-Sky Profiles**

**08 Daily, 8-day, & monthly aggregations**

**ATML2 (joint sampled product)**

**S. Platnick**

**Level-3**

**Level-2**
Atmosphere Team Product Organization and PIs

MODIS Atmosphere Team C6 Webinar #9
Atmosphere Team Collection 6 Production Status
(as of 17 Sept. 2014, see modis-atmos.gsfc.nasa.gov/validation.html)

- Cloud Mask (MOD/MYD35) and Atmospheric Profile (MOD/MYD07) Terra/Aqua reprocessing started in 2012. Both reprocessed after L1B Band 5 trend correction implemented.
- Reprocessing of other L2 products from Aqua MODIS started on 6 December 2013. Was completed in spring 2014 but …
  - MYD07/MYD05 IR PW: reprocessed all nighttime granules due to ancillary issue
  - MYD06 Cloud Optical Properties being reprocessed from 1 January 2013 forward with updated gap-filled surface spectral albedo files
  - MYD05 NIR PW: entire record reprocessed w/non-reaggregated L1B files
- Aqua L3 (MYD08) starting this week!
- Terra reprocessing code finalized. Start after completion of Aqua L3.
Outline

1. Who’s who
2. What are the MODIS L2 Cloud Optical Property Datasets?
3. “Quick Guide” to the Physical Basis of the Algorithm
4. Retrieval Challenges
5. What’s new? Major Collection 6 (C6) Changes and Example Results
## Cloud Optical/Microphysical Properties

<table>
<thead>
<tr>
<th>Steve Platnick</th>
<th>Bob Holz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michael King</td>
<td>Zhibo Zhang</td>
</tr>
<tr>
<td>Gala Wind</td>
<td>Paul Hubanks</td>
</tr>
<tr>
<td>Kerry Meyer</td>
<td>Bill Ridgway</td>
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<tr>
<td>Nandana Amarasinghe</td>
<td>Jerome Riedi</td>
</tr>
<tr>
<td>Ben Marchant</td>
<td>Ping Yang</td>
</tr>
<tr>
<td>Tom Arnold</td>
<td>Andy Heidinger</td>
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## Cloud-Top Properties

- Steve Ackerman
- Rich Frey
- Paul Menzel
- Bryan Baum
## Cloud Optical Property Datasets

<table>
<thead>
<tr>
<th>Terra MODIS:</th>
<th>MOD06_L2.AYYYYDDD.HHMM.CCC.YYYYYDDDHHHMSS.hdf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqua MODIS:</td>
<td>MYD06_L2.AYYYYDDD.HHMM.CCC.YYYYYDDDHHHMSS.hdf</td>
</tr>
</tbody>
</table>

*Science Data Set: An individual dataset within an HDF file (HDF4)*
Cloud Optical Property Datasets

- MODIS L2 Cloud Optical Property datasets are part of the MOD06/MYD06 files along with cloud-top property datasets.  

| Science Data Set | Terra MODIS: MOD06_L2.AYYYYDDD.HHMM.CCC.YYYYDDDHMMSS.hdf | Aqua MODIS: MYD06_L2.AYYYYDDD.HHMM.CCC.YYYYDDDHMMSS.hdf |

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- Included SDSs*: 1km (nadir), daytime ($\mu_0 > 0.15$), global (all surface types), ice and liquid water phases

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  - Cloud Optical Property Retrieval Phase (≠ IR phase)
  - Cloud Optical Thickness (COT)

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  – Cloud Effective Radius (CER)

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  - Uncertainty SDS for all COT, CER, WP retrievals

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  – Retrieval Fractions

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  - Cloud Effective Radius (CER)
  - Cloud Water Path (LWP, IWP)
  - Uncertainty SDS for all COT, CER, WP retrievals
  - Retrieval Fractions
  - Diagnostic datasets, QA, etc.

*Science Data Set: An individual dataset within an HDF file (HDF4)
Cloud Optical Property Datasets

User Guide - Appendix A Highlighted Rows

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<tr>
<th>SDS name</th>
<th>Long Name</th>
<th>Dataset resolution (if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above_Cloud_Water_Vapor_094</td>
<td>Above-cloud water vapor amount from 0.94μm channel, ocean only, tau &gt; 5</td>
<td>1 km</td>
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<tr>
<td>Asymmetry_Parameter_Ice</td>
<td>Ice Asymmetry Parameter from the phase functions used to generate the forward lookup tables</td>
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</tr>
<tr>
<td>Asymmetry_Parameter_Liq</td>
<td>Liquid Asymmetry Parameter from the phase functions used to generate the forward lookup tables</td>
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<tr>
<td>Atm_Corr_Refl</td>
<td>Atmospherically corrected reflectance used during cloud optical and microphysical properties retrieval</td>
<td>1 km</td>
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<tr>
<td>Band_Number</td>
<td>Band Number</td>
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<tr>
<td>Brightness_Temperature</td>
<td>Observed Brightness Temperature from Cloudy Averaged Radiances in a 3x3 1-km Pixel Region</td>
<td>5 km</td>
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<td>Cirrus_Reflectance</td>
<td>Cirrus Reflectance</td>
<td>1 km</td>
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<tr>
<td>Cirrus_Reflectance_Flag</td>
<td>Cirrus Reflectance Flag</td>
<td>1 km</td>
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<tr>
<td>Cloud_Effective_Emissivity</td>
<td>Cloud Effective Emissivity from Cloud Top Pressure Retrieval</td>
<td>5 km</td>
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<tr>
<td>Cloud_Effective_Emissivity_Day</td>
<td>Cloud Effective Emissivity from Cloud Top Pressure Retrieval, Day Only</td>
<td>5 km</td>
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<tr>
<td>Cloud_Effective_Emissivity_Nadir</td>
<td>Cloud Effective Emissivity from Cloud Top Pressure Retrieval for Sensor Zenith (View) Angles &lt;= 32 Degrees</td>
<td>5 km</td>
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<tr>
<td>Cloud_Effective_Emissivity_Nadir_Day</td>
<td>Cloud Effective Emissivity from Cloud Top Pressure Retrieval for Sensor Zenith (View) Angles &lt;= 32 Degrees, Day Only</td>
<td>5 km</td>
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<tr>
<td>Cloud_Effective_Emissivity_Nadir_Night</td>
<td>Cloud Effective Emissivity from Cloud Top Pressure Retrieval for Sensor Zenith (View) Angles &lt;= 32 Degrees, Night Data Only</td>
<td>5 km</td>
</tr>
<tr>
<td>Cloud_Effective_Emissivity_Night</td>
<td>Cloud Effective Emissivity from Cloud Top Pressure Retrieval, Night Only</td>
<td>5 km</td>
</tr>
<tr>
<td>Cloud_Effective_Radius</td>
<td>Cloud Particle Effective Radius two-channel retrieval using band 7(2.1μm) and either band 1(0.65μm), 2(0.86μm), or 3(1.2μm)</td>
<td>1 km</td>
</tr>
<tr>
<td>Cloud_Effective_Radius_PCL</td>
<td>Cloud Particle Effective Radius two-channel retrieval using band 7(2.1μm), 2(0.86μm), or 3(1.2μm)</td>
<td>1 km</td>
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<tr>
<td>Cloud_Effective_Radius_16</td>
<td>Cloud Particle Effective Radius two-channel retrieval using band 6(1.6μm) and either band 1(0.65μm), 2(0.86μm), or 3(1.2μm)</td>
<td>1 km</td>
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<tr>
<td>Cloud_Effective_Radius_16_PCL</td>
<td>Cloud Particle Effective Radius two-channel retrieval using band 6(1.6μm), 2(0.86μm), or 3(1.2μm)</td>
<td>1 km</td>
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<tr>
<td>Cloud_Effective_Radius_1621</td>
<td>Cloud Particle Effective Radius two-channel retrieval using band 7(2.1μm) and band 6(1.6μm)</td>
<td>1 km</td>
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<tr>
<td>Cloud_Effective_Radius_1621_PCL</td>
<td>Cloud Particle Effective Radius two-channel retrieval using band 7(2.1μm) and band 6(1.6μm)</td>
<td>1 km</td>
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<td>Cloud_Effective_Radius_37</td>
<td>Cloud Particle Effective Radius two-channel retrieval using band 20(3.7μm) and either band 1(0.65μm), 2(0.86μm), or 3(1.2μm)</td>
<td>1 km</td>
</tr>
<tr>
<td>Cloud_Effective_Radius_37_PCL</td>
<td>Cloud Particle Effective Radius two-channel retrieval using band 20(3.7μm), 2(0.86μm), or 3(1.2μm)</td>
<td>1 km</td>
</tr>
<tr>
<td>Cloud_Effective_Radius_Uncertainty</td>
<td>Cloud Effective Particle Radius from band 7(2.1μm) Relative Uncertainty (Percent)</td>
<td>1 km</td>
</tr>
<tr>
<td>Cloud_Effective_Radius_Uncertainty_16</td>
<td>Cloud Effective Particle Radius (from band 6(1.6μm) Relative Uncertainty (Percent))</td>
<td>1 km</td>
</tr>
<tr>
<td>Cloud_Effective_Radius_Uncertainty_1621</td>
<td>Cloud Effective Particle Radius Relative Uncertainty (Percent) using band 7(2.1μm) and band 6(1.6μm)</td>
<td>1 km</td>
</tr>
<tr>
<td>cloud_emiss11_1km</td>
<td>11 micron Cloud Emissivity at 1-km resolution from LEOCAT for All Clouds</td>
<td>1 km</td>
</tr>
<tr>
<td>cloud_emiss12_1km</td>
<td>12 micron Cloud Emissivity at 1-km resolution from LEOCAT for All Clouds</td>
<td>1 km</td>
</tr>
</tbody>
</table>
Algorithm “Quick Guide”

• 2-Channel reflectance algorithm. Retrieval datasets include:
  – 1 nominally non-absorbing band: 0.65 (land), 0.86 (ocean), 1.2 µm (snow/ice) + each of the following absorbing bands: 1.6, 2.1, 3.7 µm ⇒ 3 τ, 3 re retrievals
  – 2.1 µm combination has been the “primary” retrieval in previous collections
  – additional 1.6 & 2.1 µm band combination retrievals provided over snow/ice and water surfaces

• Look-Up Tables: Spectral bidirectional reflectance, effective emittance, flux reflectances/transmittances, clear sky transmittances

• Ancillary data: cloud mask, cloud-top pressure/temperature, NCEP GDAS, global spectral albedo maps, emissivity maps, snow/ice maps, …
Algorithm “Quick Guide”

Example COT, CER solution space: water clouds over snow/ice surface

Fig. 1.2-1/-2. Theoretical relationship between the liquid water cloud reflectance function over a snow/ice surface at 1.24 and 2.13 μm (left panel) and 1.64 and 2.13 μm (right panel). COT and CER contours are indicated by the dashed and solid lines, respectively. Data from MODIS arctic observations is superimposed on the figures.
Algorithm “Quick Guide”
Example Retrievals

2 July 2008, MODIS Aqua, 2105 UTC
Algorithm “Quick Guide”
Example Retrievals

2 July 2008, MODIS Aqua, 2105 UTC
Algorithm “Quick Guide”

Example Retrievals

CER_2.1 µm

COT

Ice

Liquid Water

COT

CER (µm)
Algorithm “Quick Guide”
Example Retrievals

CER_2.1 µm

CER_3.7 µm (new C6 SDS)
Challenges

- What is a cloud? What constitutes a cloudy FOV appropriate for a retrieval? What does it mean if a retrieval ‘fails’?

- What is the thermodynamic phase?

- Choice of forward radiative cloud model (e.g., ice radiative models)?

- Assigning retrieval uncertainties? How to account for above three items?

- How to use Quality Assessment (QA) bit assignments or related information to filter L3 retrievals?
  - discrepancies from different spectral channel pairs
  - partly-cloudy FOVs
  - multiphase/multilayer scenes (MODIS has a multilayer flag)

Subjectivity always comes into play. Sometimes it’s explicit (developer says “I am making a choice”), sometimes it’s implicit.
Challenges

- What is a cloud? What constitutes a cloudy FOV appropriate for a retrieval? What does it mean if a retrieval ‘fails’?

- What is the thermodynamic phase?

- Choice of forward radiative cloud model (e.g., ice radiative models)?

- Assigning retrieval uncertainties? How to account for above three items?

- How to use Quality Assessment (QA) bit assignments or related information to filter L3 retrievals?

Don’t Bother! No QA-filtering in C6 L3. Provide separate SDSs for various pixel populations.

Subjectivity always comes into play. Sometime’s it’s explicit (developer says “I am making a choice”), sometimes it’s implicit.
What is a cloud mask ‘cloudy’ FOV?

ideal ‘pixel’ doesn’t exist!
What is a cloud mask ‘cloudy’ FOV?

Ideal ‘pixel’ doesn’t exist!

1 km

Cloud

Clear

Satellite Cloud Mask (likelihood of “Not Clear”)

possibly identified w/250 m spectral tests
What is a cloud mask ‘cloudy’ FOV?

ideal ‘pixel’ doesn’t exist!

Cloud

Overcast

Clear

Partly Cloudy

Clear Sky

1 km
What is a cloud mask ‘cloudy’ FOV?

Pixel Categories Assigned by Clear Sky Restoral (CSR) Algorithm

ideal ‘pixel’ doesn’t exist!

New C6 SDS Category: `<parameter name>_PCL` (e.g. `Cloud_Effective_Radius_37_PCL`)

Standard SDS naming convention: `<parameter name>` (e.g. `Cloud_Effective_Radius_37`)

ideal ‘pixel’ doesn’t exist!
Uncertainties: Measurement and Model

0.86 & 2.1 µm channel combination

θ₀ = 30.0°, θ = 30.0°, Δφ = 100.0°

liquid water cloud

ice cloud ("Collection 6")
Uncertainties: Measurement and Model

0.86 & 2.1 μm channel combination

liquid water cloud

ice cloud (“Collection 6”)

MODIS Atmosphere Team C6 Webinar #9
Uncertainties: Measurement and Model

0.86 & 2.1 \mu m channel combination

\begin{align*}
\theta_0 &= 30.0^\circ, \ \theta = 30.0^\circ, \ \Delta\phi = 100.0^\circ \\
\end{align*}

\begin{align*}
\text{liquid water cloud} & \quad \text{COT} \\
\text{ice cloud ("Collection 6")} & \quad \text{CER}
\end{align*}

\begin{align*}
\text{retrieval uncertainty} \\
\text{retrieval error covariance} &= \left( \mathbf{K}^T \mathbf{S}^{-1} \mathbf{K} \right)^{-1} \\
\text{where} \quad S &= S_y + \mathbf{K}_m S_m \mathbf{K}_m^T \\
y \ (\text{refl.} \ \text{meas.}) \ \text{uncertainty} & \quad \text{maps Model uncertainty into cloud-top reflect.} \ \text{uncertainty}
\end{align*}
Uncertainties: Measurement and Model

0.86 & 2.1 µm channel combination

\[
\theta_0 = 30.0^\circ, \theta = 30.0^\circ, \Delta\phi = 100.0^\circ
\]

liquid water cloud

\[\text{COT}\]

ice cloud ("Collection 6")

\[\text{CER}\]

retrieval uncertainty

\[\text{retrieval error covariance} = (K^T S^{-1} K)^{-1}\]

where \[S = S_y + K_m S_m K_m^T\]

\[y\ (\text{refl. meas.})\]

uncertainty maps Model uncertainty into cloud-top reflect. uncertainty

MODIS Atmosphere Team C6 Webinar #9
Uncertainties: Measurement and Model

0.86 & 2.1 µm channel combination

re = \frac{T_S}{T_S - 1}

where \( S = S_y + K_m S_m K_m^T \)

retrieval error covariance = \((K^T S^{-1} K)^{-1}\)

retrieval uncertainty

y (refl. meas.) uncertainty

maps Model uncertainty into cloud-top reflect. uncertainty
Uncertainties: Measurement and Model

0.86 & 2.1 µm channel combination

liquid water cloud

0.86 µm channel cloud-top reflectance

ice cloud ("Collection 6")

cot

retrieval uncertainty

retrieval error covariance \( = (K^T S^{-1} K)^{-1} \)

where \( S = S_y + K_m S_m K_m^T \)

maps Model uncertainty into cloud-top reflect. uncertainty

"Failed" Retrieval

\( (\text{Retrieval\_Failure\_Metric}_*: \text{new SDS for C6}) \)
What’s New?
Major Categories

- Radiative Transfer
- Algorithm
  - Retrieval Science
  - QA and pixel-level filtering
  - Pixel-level uncertainty
- L1B characterization/trend corrections
# Overview of Major C6 Changes

See Appendix G User Guide

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<th>Category</th>
<th>Collection 5</th>
<th>Collection 6</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Radiative Transfer</td>
<td></td>
<td></td>
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</table>
| Cloud Model: all phases         | Combined discrete ordinate LUT (small COT) + asymptotic theory parameters (large COT) | Full reflectance, flux, and emissivity LUTs across retrieval space/geometry. LUT entries provided for multiple scattering component only; phase function provide in file for direct calculation of single scattering component. | • Single approach (LUT) => easier retrieval code maintenance.  
• LUT grid designed to limit median linear interpolation error to << 1%.  
• Separation of single scattering component => fewer LUT grid points and interpolations during processing.  
• Required DISORT code mod to improve efficiency for BRF-specified surfaces. |
| Ice Cloud Model                 | Variable habit (smooth) vs. size/ empirical distributions. Relatively large asymmetry parameter (g) and highly dependent on CER. | Single habit (severely roughened aggregated columns) w/analytic distribution (gamma, _ | • Smaller g reduces COT & provides closure with non-opaque IR COT retrievals.  
• Constant g vs. CER.  
• SWIR/MWIR particle absorption decreases => larger retrieved CER. |
| Surface Ancillary Datasets      | Team-designed nominal annual gap-filled spectral albedo dataset using Terra C5 product MOD43. | New dynamic gap-filled spectral albedo dataset derived from Aqua+Terra C5 MCD43B3. Emissivity dataset from MOD06 CT product for spectral consistency. | • C6 albedo dataset provided higher temporal resolution than C5 (8 day interval, 16 day average).  
• Sea-ice spectral albedo dataset same as for C5. |
| Ocean Surface BRDF              | Lambertian (5%)                                                             | Cox-Munk BRDF for 3 wind speeds (3, 7, and 15)                                | • Independent ocean LUTs with Cox-Munk explicitly modeled. |
| Incorporation of Model Error Sources | N/A                                                                         | LUT includes sensitivity datasets for and Cox-Munk wind vector.               | No explicit model error sources used in C5 uncertainty calculations. |
## Overview of Major C6 Changes

See Appendix G User Guide

<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Radiative Transfer</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Cloud Model: all phases               | Combined discrete ordinate LUT (small COT) + asymptotic theory parameters (large COT) | Full reflectance, flux, and emissivity LUTs across retrieval space/geometry. LUT entries provided for multiple scattering component only; phase function provide in file for direct calculation of single scattering component. | • Single approach (LUT) => easier retrieval code maintenance.  
• LUT grid designed to limit median linear interpolation error to << 1%.  
• Separation of single scattering component => fewer LUT grid points and interpolations during processing.  
• Required DISORT code mod to improve efficiency for BRF-specified surfaces. |
| Ice Cloud Model                       | Variable habit (smooth) vs. size/ empirical distributions. Relatively large asymmetry parameter ($g$) and highly dependent on CER. | Single habit (severely roughened aggregated columns) w/analytic distribution (gamma, _ ) | • Smaller $g$ reduces COT & provides closure with non-opaque IR COT retrievals.  
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| Incorporation of Model Error Sources | N/A                                                                         | LUT includes sensitivity datasets for and Cox-Munk wind vector.             | No explicit model error sources used in C5 uncertainty calculations. |
Ice Cloud Radiative Models
(P. Yang et al.)

Ice and Liquid Scattering Properties vs. CER are reported in MOD06 as attributes (e.g., \textit{Asymmetry\_Parameter\_Ice})
Ice Cloud Radiative Models
(R. Holz et al.)

IR COT Retrieval Closure Studies

C5 Models
(variable habit distribution)

C6 Models
(severely roughened aggregated columns)
Ice Phase Cloud C6 vs. C5 Results

(derived from histograms w/common COT_{max}=100)
Ice Phase Cloud C6 vs. C5 Results

(derived from histograms w/common COT\textsubscript{max}=100)

**LAND ONLY (FROM HISTOGRAM COUNTS)**

\[ \beta_{C51} = -0.029 \text{ per dec (rel)}, \quad \beta_{C6} = -0.032 \text{ per dec (rel)} \]

**OCEAN ONLY (FROM HISTOGRAM COUNTS)**

\[ \beta_{C51} = -0.028 \text{ per dec (rel)}, \quad \beta_{C6} = -0.012 \text{ per dec (rel)} \]

\[ \text{AREA WEIGHTED = YES, PIXEL WEIGHTED = YES} \]

DATA: C51 (JUL, 2002 to JUN, 2014) AND C6 (JUL, 2002 to JUN, 2014)
Ice Phase Cloud C6 vs. C5 Results


**LAND ONLY**

\[
\beta_{\text{C5}} = 0.003 \text{ per dec (rel)}, \quad \beta_{\text{CSR}=0} = -0.003 \text{ per dec (rel)}, \quad \beta_{\text{CSR}=0,1,3} = -0.003 \text{ per dec (rel)}
\]

**OCEAN ONLY**

\[
\beta_{\text{C5}} = -0.004 \text{ per dec (rel)}, \quad \beta_{\text{CSR}=0} = 0.001 \text{ per dec (rel)}, \quad \beta_{\text{CSR}=0,1,3} = 0.002 \text{ per dec (rel)}
\]
Ice Phase Cloud C6 vs. C5 Results

LAND ONLY

\[
\begin{align*}
\beta_{C51} &= 0.003 \text{ per dec (rel)}, \\
\beta_{CSR=0} &= -0.003 \text{ per dec (rel)}, \\
\beta_{CSR=0,1,3} &= -0.003 \text{ per dec (rel)}
\end{align*}
\]

\[+32\%\]

C51
C6 CSR=0

OCEAN ONLY

\[
\begin{align*}
\beta_{C51} &= -0.004 \text{ per dec (rel)}, \\
\beta_{CSR=0} &= 0.001 \text{ per dec (rel)}, \\
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\end{align*}
\]

\[+29\%\]
# Overview of Major C6 Changes

## Level-1 Analysis/Corrections

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<td>N/A</td>
<td>COT monthly anomaly trend analysis</td>
<td>Used to justify MCST work with desert site response-vs-scan angle corrections.</td>
</tr>
<tr>
<td>Aqua Band 1,2 250m–&gt;1km aggregation</td>
<td>N/A</td>
<td>Used to improve known Aqua VNIR focal plane mis-registration w/SWIR, MWIR, and IR focal planes</td>
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## Algorithm - Retrieval Science

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<td>Full retrievals reported separately for as many as 4 spectral channel pairs.</td>
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<tr>
<td>Cloud-Top (CT) Pressure/Temperature</td>
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<td>Uses new 1km MOD06 CT product. Incorporates non-unity cloud emissivity from optical retrieval into low cloud CT retrievals that use IR window channel.</td>
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<td>Thermodynamic Phase</td>
<td>Used SWIR/VNIR ratio tests as a proxy for particle size that was then used to indicate phase.</td>
<td>SWIR/VNIR ratio tests replaced w/ separate ice and liquid retrievals. Uses new tri-spectral IR phase product. Eliminates use of individual cloud mask tests. Weights applied to various tests in lieu of strict logical approach.</td>
<td>• Algorithm tests/weights validated against CALIOP, POLDER products. • Significant skill improvement seen for most regions (e.g., land, ocean, snow/ice) though still limited by available spectral bands.</td>
</tr>
<tr>
<td>Misc.</td>
<td>N/A</td>
<td>Numerous science and code infrastructure performance improvements.</td>
<td>• Improved processing efficiency. • Easier code maintenance, porting to other sensors.</td>
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Cloud Retrieval Phase  
(B. Marchant et al.)

Figure 2.4-2. Global thermodynamic phase evaluation of the MODIS Aqua C5 and C6 algorithms vs. CALIOP over all surface types during January 2008. The population is from all colocations where CALIOP observed a single phase in the column. The overall Probability of Phase Agreement (PAF) skill score increases by ~10% for C6.

SDS name: *Cloud_Phase_Optical_Properties*
Cloud Retrieval Phase

Figure 2.4-3. Global thermodynamic phase evaluation of the MODIS Aqua C5 and C6 algorithms vs. CALIOP for a variety of surface types during January 2008. The population is from all collocations where CALIOP observed a single cloud phase throughout the column. The bar plots to the left are for scenes where the lidar was not completely attenuated by the cloud layers (COT less than about 3); bars to the right are for scenes where the lidar was completely attenuated (no ground return).
Figure 2.4-7 Example C5 and C6 phase retrievals for an Aqua data granule showing low marine clouds through much of the central/eastern portion of the image (RGB composite in panel a). Cloud-top temperatures from MYD06 are shown in panel b, while C5 and C6 phase are in panel c and d, respectively. An area with substantial broken clouds is shown in the bottom two panels (e and f) indicating less ice cloud retrievals for the C6 phase algorithm.
Global Changes in Cloud Retrieval Phase
Successful Retrieval Fraction by Collection (CSR=0 for C6)

C6 Liquid

C6 – C5 Liquid

C6 Ice

C6 – C5 Ice

MODIS Atmosphere Team C6 Webinar #9
# Overview of Major C6 Changes

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<td>Updated ‘Clear Sky Restoral’ (CSR) algorithm</td>
<td>N/A</td>
<td>Improve discrimination between heavy aerosol (smoke/dust) and glint from low uniform cloud population.</td>
<td>Added explicit aerosol model tests. Replaced 1.38 µm cloud height discrimination tests w/CT 'method' flags.</td>
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<tr>
<td>Pixels identified as not-overcast and/or cloudy FOV by CSR algorithm</td>
<td>Do not retrieve CSR-identified pixels</td>
<td>Attempt retrievals on CSR-identified pixels and, if successful, write results to separate dataset (SDS).</td>
<td>Separate SDS allows for analysis of CSR population w/out need to read/interpret QA assignments.</td>
</tr>
<tr>
<td>Failed Retrieval Metrics (‘failure’ defined as the simultaneous COT, CER solution being outside of LUT space)</td>
<td>No failure metrics reported</td>
<td>The following metrics are reported: nearest COT, nearest CER, relative distance from 2D measurement point to nearest LUT solution point.</td>
<td>Allow users to understand failure mode (e.g., large CER, small COT) for cloudy FOVs not meeting 1D fwd. model assumptions. Potentially useful for radiative studies, comparison with other observational datasets, and high resolution LES models.</td>
</tr>
<tr>
<td>Retrieval Confidence QA</td>
<td>2-bit assignment</td>
<td>Not actively assigned. Superseded by pixel-level uncertainty SDS.</td>
<td></td>
</tr>
<tr>
<td>Sub-pixel Heterogeneity</td>
<td>N/A</td>
<td>Bands 1 &amp; 2 250 m reflectance heterogeneity included in MOD35 and MOD06 dataset.</td>
<td>Heterogeneity partial predictor for marine liquid water cloud spectral differences.</td>
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<td>Retrieval Confidence QA</td>
<td>2-bit assignment</td>
<td>Not actively assigned. Superseded by pixel-level uncertainty SDS.</td>
<td>QA assignments confusing to users, lack of consistency across products. L3 users directed to “Uncertainty of Mean” SDS derived from pixel-level uncertainties.</td>
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<td>Bands 1 &amp; 2 250 m reflectance heterogeneity included in MOD35 and MOD06 dataset.</td>
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Clear Sky Restoration (CSR) QA bits in Quality_Assurance_1km
(K. Meyer et al.)

2 July 2008, MODIS Aqua, 2105 UTC
Clear Sky Restoral (CSR): “Partly Cloudy” vs. “Overcast”

Cloud Optical Thickness Histograms

COT for PCL pixels have very small mode as expected
Figure 2.8-3. Monthly fraction of MYD35 “not clear” pixels identified as CSR = 2 (a) and MYD35 cloud fraction (b) for April 2005 Aqua MODIS.
Clear Sky Restoral (CSR): Not Cloudy Determinations

Figure 2.8-3. Monthly fraction of MYD35 "not clear" pixels identified as CSR=2 (a) and MYD35 cloud fraction (b) for April 2005 Aqua MODIS.
Clear Sky Restoral (CSR): Not Cloudy Determinations

Figure 2.8-3. Monthly fraction of MYD35 “not clear” pixels identified as CSR=2 (a) and MYD35 cloud fraction (b) for April 2005 Aqua MODIS.

- Sun glint
- Desert dust
- Dust and sun glint

April 15, 2014
## Overview of Major C6 Changes

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| Misc.                            | N/A          | Numerous science and code infrastructure performance improvements. | • Improved processing efficiency.  
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## Overview of Major C6 Changes

### Level-1 Analysis/Corrections

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| Misc.                          | N/A           | Numerous science and code infrastructure performance improvements. | • Improved processing efficiency.  
• Easier code maintenance, porting to other sensors. |
Spectral CER and Sensitivity to PCL
Aqua MODIS April 2005

Figure 2.5-4. Aqua MODIS monthly (April 2005) mean 1° gridded effective radius for three separate SWIR/MWIR spectral channel combinations, filtered for liquid water pixels with cloud-top temperatures greater than 270K. Panels on the left are aggregated from pixels that the clear sky rostral (CSR) algorithm identifies as “overcast”; panels to the right are identified as “partly cloudy”.

MODIS Atmosphere Team C6 Webinar #9
Figure 2.5-5. Same as Fig. 2.5-4 but for the right panels showing the difference CER calculated as the mean for overcast pixel population minus the mean for the total (overcast + partly cloudy) population.
What Does CER_2.1 >> CER_3.7 Mean?

- CER_2.1 more sensitive to **3-D radiative effects** than CER_3.7 (LES studies) and CER_2.1>>CER_3.7 associated with larger 250m **horizontal heterogeneity** (empirical studies) [Zhang and Platnick, 2011; Zhang et al., 2012]

- CER_2.1>>CER_3.7 associated with **drizzle** (CloudSat) [Lebsock et al., 2011]
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<td>Combined with model error sources and fixed at 5% relative</td>
<td>Uses L1B scene-dependent pixel-level spectral uncertainty indices (improved for C6)</td>
<td>reduces combined uncertainty in many cases.</td>
</tr>
<tr>
<td>Instrument Calibration</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Model Errors</td>
<td></td>
<td>See LUT above for details.</td>
<td></td>
</tr>
<tr>
<td>3.7 µm Emission Error Sources</td>
<td>Not included</td>
<td>Accounts for effective cloud and surface emissivity including dependence on ancillary water vapor field.</td>
<td>More realistic (larger) 3.7 µm channel CER and water path uncertainties.</td>
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Pixel-Level Error Sources **Explicitly Included** in C6 Uncertainty Calculations

cloud retrievals (1km): COT, CER_1.6, CER_2.1, CER_3.7, CER_1.6/2.1, WP_1.6, WP_2.1, WP_3.7, WP_1.6/2.1

*surface spectral reflectance/emission*

Plane-Parallel Fwd. Model

cloud masking, cloud-top pressure provided through separate algorithm team (S. Ackerman et al.)
Pixel-Level Error Sources **Explicitly Included** in C6 Uncertainty Calculations

MODIS

- instrument calibration (pixel-level, L1B file)
- atmospheric corrections: $q$ (fwd. model LUT), $O_3$
- cloud model: droplet size distribution $v_{eff}$
- Surface reflectance –
  - Ocean: Cox-Munk wind speed/direction
  - Land: MODIS-derived gap-filled product
  - Snow/ice: MODIS-derived gap-filled database
- 3.7 µm retrievals: $T_{sfc}$, low cloud $T_c$ retrievals, $F_0$

cloud retrievals (1km): COT, CER_1.6, CER_2.1, CER_3.7, CER_1.6/2.1, WP_1.6, WP_2.1, WP_3.7, WP_1.6/2.1

**surface spectral reflectance/emission**

Plane-Parallel Fwd. Model

cloud masking, cloud-top pressure provided through separate algorithm team (S. Ackerman et al.)
Pixel-Level Error Sources **Not Included** in C6 Uncertainty Calculations

cloud retrievals (1km): COT, CER_1.6, CER_2.1, CER_3.7, CER_1.6/2.1, WP_1.6, WP_2.1, WP_3.7, WP_1.6/2.1

*surface spectral reflectance/emission*

Plane-Parallel Fwd. Model

cloud masking, cloud-top pressure provided through separate algorithm team (S. Ackerman et al.)
Pixel-Level Error Sources **Not Included** in C6 Uncertainty Calculations

MODIS

- long-term radiometric bias/drift

cloud retrievals (1km): COT, CER_1.6, CER_2.1, CER_3.7, CER_1.6/2.1, WP_1.6, WP_2.1, WP_3.7, WP_1.6/2.1

- cloud model: vertical and horizontal heterogeneity (3-D radiative effects)

More egregious cases accounted for by flagging obvious partly cloudy pixels

- cloud masking, cloud-top pressure provided through separate algorithm team (S. Ackerman et al.)

**surface spectral reflectance/emission**

Plane-Parallel Fwd. Model
Pixel-Level Retrievals
2 July 2008, MODIS Aqua C6, 2105 UTC
(best quality pixels only, CSR=0)
Pixel-Level Retrieval Uncertainties
2 July 2008, MODIS Aqua C6, 2105 UTC
(best quality pixels only, CSR=0)

ΔCOT (%)
ΔCER_2.1 (%)
ΔCER_3.7 (%)
Uncertainties in Aggregated Means: Daily

Daily Means for Liquid Water Clouds

Single Day Uncertainty (1 April 2005) w/pixel-to-pixel error correlation = 1
Uncertainties in Aggregated Means: Monthly

Monthly Means for Liquid Water Clouds

CER_2.1 (µm)

Monthly Uncertainty (April 2005) w/day-to-day error correlation = 0

ΔCER_2.1 (%)

ΔCOT (%)

Monthly Means for Liquid Water Clouds

Uncertainties in Aggregated Means: Monthly
Cloud Optical Properties Summary

• Significant changes/enhancements throughout C6

• MOD06 COP is portable!
  – Runs on VIIRS, SEVIRI (ICARE), airborne (eMAS, MASTER, AMS)

• Useful links/references
  – Known problems page: modis-atmos.gsfc.nasa.gov/validation.html