MODIS Cloud Optical Properties: Exec. Summary of Collection 6 Level-2 Optical Property Changes for MOD06/MYD06

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This brief summary document describes essential algorithm updates for the Collection 6 (C6) cloud optical property datasets that are contained within the MOD06 (MODIS Terra) and MYD06 (MODIS Aqua) product files. **An extensive user guide is under development** and will provide details on changes relative to the Collection 5.1 (C51) algorithm, the structure and content of the MODIS cloud product (including the science data sets, metadata, and quality assurance), and frequently asked questions. We will post a draft version when it is available. For conciseness, we abbreviate cloud optical thickness, effective radius, and water path as COT, CER, and CWP, respectively. Note that the MODIS Terra and Aqua algorithms are essentially identical.

Recent Collection Overview

Collection 6 (C6) efforts have been extensive. While a detailed summary of the major algorithm work is given in the table below, key highlights include the following:

- **Radiative transfer/Look-up Tables (LUTs)**: eliminated use of asymptotic parameter radiative transfer code (reduces code complexity/maintenance); generated precomputed LUTs with separate single and multiple scattering components to reduce the number of angular grid points and linear interpolation errors (median errors typically ≪ 1% across the solution domain).
- **Thermodynamic retrieval phase**: improved algorithm using a variety of separate tests with

assigned weights (MOD06 IR phase product (*Baum et al.*, 2012), microphysical retrievals for each phase, cloud-top temperature, and the 1.38 µm channel reflectance). Comparisons against CALIOP and POLDER phase products show a substantial improvement in the overall global skill.

- **Ice radiative models**: now use a single habit, severely roughened aggregated columns (Y*ang et al.*, 2013), that provides closure with global cirrus COT from IR methods and the upcoming CALIOP lidar ratios (*Holz et al.*, 2012).
- **Spectral retrievals**: In C5, the 1.6 and 3.7 µm CER retrievals were provided as differences with respect to the 2.1 µm CER retrieval. In C6, all spectral retrievals are now reported as separate SDSs (i.e., separate absolute COT, CER, and WP retrievals for band combinations that include the 1.6, 2.1, and 3.7 µm bands). The 1.6 and 3.7 µm retrievals are found in SDS names <*parameter name*>_16 and <*parameter name*>_37, respectively; the legacy 2.1 µm C5 retrieval SDS is not appended with a band designation qualifier.
- **Retrieval failure metrics**: provided for those pixels where the observations fall outside the LUT solution space (Retrieval_Failure_Metric SDS).
- **Quality Assessment (QA)**: provide separate SDSs for lower quality scenes derived from C5-like Clear Sky Restoral algorithms (e.g., *Zhang and Platnick*, 2011) that flag pixels not expected to be overcast (referred to as 'Partly Cloudy' retrievals and found in SDSs <*parameter name*>_PCL), a 1 km sub-pixel 250 m reflectance heterogeneity index (Cloud_Mask_SPI), and an updated multilayer detection (*Pavolonis and Heidinger*, 2004; *Wind et al.*, 2010; *Joiner et al.*, 2010).
- **Quantitative pixel-level uncertainty**: Provided for all spectral optical/microphysical retrievals (*Platnick et al.*, 2004) and updated to include scene-dependent L1B uncertainties (*Sun et al.*, 2012), cloud model and surface albedo error sources (cloud effective variance, ocean surface wind speed and direction), and 3.7µm emission error sources. Does not include estimates of 3D radiative transfer biases or ice habit model error sources. Provided in SDS names <*parameter name*>_Uncertainty_<*band channel/pair designation* (if appropriate)>.
- **Water surfaces**: Wind-speed interpolated bidirectional reflectance properties (Cox-Munk model) of water surfaces.
- **Surface ancillary datasets**: new dynamic 8-day sampling surface spectral albedo dataset derived from gap-filled C5 Aqua+Terra MODIS data (MCD43B3, *Schaaf et al.,* 2011), and adoption of land spectral emissivities consistent with cloud-top property code (*Seemann et al.*, 2008).

Details on individual C6 science tests and accompanying browse imagery are available at *link*; other algorithm enhancement details and draft Level-2 Quality Assurance (QA) information are at *link*.

Tabular summary of MOD06 Cloud Optical Properties Collection 6 Efforts

The following table provides a summary of the key Collection 6 MOD06 optical/microphysical algorithm development efforts. The symbol ▵ denotes the main evaluation and refinement activities that are expected to continue subject to future support.

Category	Collection 5	Collection 6	Notes
Radiative Transfer			
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 provided 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	Single habit (severely roughened aggregated columns) w/analytic distribution (gamma, _	• Smaller *g* reduces COT & provides closure with non-opaque IR COT retrievals. • Nearly constant • SWIR/MWIR particle absorption decreases => larger retrieved
Surface Ancillary Datasets	Team-designed nominal seasonal gap-filled spectral albedo dataset using Terra C4 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 provides higher temporal resolution than C5 (8 day interval, 16 day average). • Snow and 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 wind vector.	No explicit model error sources used in C5 uncertainty calculations.
Level-1 Analysis/Corrections			
▵ Band 1,2 trend detection/correction	N/A	COT monthly anomaly trend analysis	Used to justify MCST work with desert site response-vs-scan angle corrections.

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ᐞ Aqua Band 1,2 250 m⇒1 km aggregation	N/A	Used to improve known Aqua VNIR focal plane mis-registration w/SWIR, MWIR, and IR focal planes	Impacts Aqua COT and statistics in heterogeneous low cloud regions.
Algorithm - Retrieval Science			
Retrieval channel pairs	r_e differences for VNIR-SWIR/MWIR channel pairs (relative to standard VNIR-2.1 µm).	Full retrievals reported separately for as many as 4 spectral channel pairs.	• Doesn't filter alternate channel pair retrievals by success of standard retrieval. • Allows for separate evaluation/aggregation of all channel pairs.
Cloud-Top (CT) Pressure/ Temperature	Used 5 km MOD06 CT product.	Uses new 1km MOD06 CT product. Incorporates non-unity cloud emissivity from optical retrieval into low cloud CT retrievals that use IR window channel.	
ᐞ Thermodynamic Phase	Used SWIR/VNIR ratio tests as a proxy for particle size that was then used to indicate phase.	SWIR/VNIR ratio tests replaced w/separate ice and liquid retrievals. Uses new tri-spectral IR phase product. Eliminated use of individual cloud mask tests. Weights applied to various tests in lieu of strict logical approach.	• 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.
ᐞ Misc.	N/A	Numerous science and code infrastructure performance improvements.	• Improved processing efficiency. • Easier code maintenance, porting to other sensors.
Algorithm - Pixel Quality Assessment (QA)/Filtering			
ᐞ Updated 'Clear Sky Restoral' (CSR) algorithm	N/A	Improve discrimination between heavy aerosol (smoke/dust) and glint from low uniform cloud population.	Added explicit aerosol model tests. Replaced height/phase discrimination test w/CT 'method' flags.
Pixels identified as not-overcast and/or cloudy FOV by CSR algorithm	Do not retrieve CSR-identified pixels	Attempt retrievals on CSR-identified pixels and, if successful, write results to separate dataset (SDS).	Separate SDS allows for analysis of CSR population w/out need to read/interpret QA assignments.
Failed Retrieval Metrics ('failure' defined as the simultaneous COT, r_e solution being outside of LUT space)	No failure metrics reported	The following metrics are reported: nearest COT, nearest from 2D measurement point to nearest LUT solution point.	Allow users to understand failure mode (e.g., large 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.

Category	Collection 5	Collection 6	Notes
Multilayer cloud detection	*Wind et al.* (2010)	Updated multilayer detection using additional tests from *Pavolonis and Heidinge*r (2004).	
Retrieval Confidence QA	2-bit assignment	Not actively assigned. Superseded by pixel-level uncertainty SDS.	QA assignments confusing to users, lack of consistency across products. L3 users directed to “Uncertainty of Mean” SDS derived from pixel-level uncertainties.
Sub-pixel Heterogeneity	N/A	Bands 1 & 2 250 m reflectance heterogeneity included in MOD35 and MOD06 dataset.	Heterogeneity partial predictor for marine liquid water cloud spectral differences.
Algorithm - Pixel Level Uncertainty			
Instrument Calibration	Combined with model error sources and fixed at 5% relative	Uses L1B scene-dependent pixel-level spectral uncertainty indices (improved for C6)	Reduces combined uncertainty in many cases.
$^{\Delta}$ Model Errors		See LUT above for details.	
$^{\Delta}$ 3. Error Sources	Not included	Accounts for effective cloud and surface emissivity and retrieved dependence on ancillary water vapor field.	More realistic (larger) 3.7 µm channel uncertainties.

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