Uncertainty of Passive Imager Cloud Optical Property Retrievals to Instrument Radiometry and Model Assumptions: Examples from MODIS

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Outline

1. MODIS Solar Reflectance Optical Property Retrievals and Uncertainties
   - challenge: choosing a subset of error sources that can be quantified and are operationally viable

2. Pixel-Level Uncertainties: MODIS Level-2 Example

3. Uncertainties in Aggregated Means: MODIS Level-3 Example
MODIS Collection 6 Cloud Retrieval (MOD06)

Error Sources Explicitly Included in Collection 6 Uncertainty Calculations

- Instrument calibration (pixel-level, L1B file)
- Atmospheric corrections: q (fwd. model LUT), O₃
- 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.)

Platnick et al., AGU 2013
MODIS Collection 6 Cloud Retrieval (MOD06)

Error Sources NOT Explicitly Included in Collection 6 Uncertainty Calculations

- long-term radiometric bias/drift
- above-cloud aerosol [added later, not in original talk]

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.)
Other Error Sources Not Accounted for: Discrete Choices

- What is a cloud? What constitutes a cloudy FOV appropriate for a retrieval? [A44-03, Ackerman et al.]
- How to account for thermodynamic phase retrieval uncertainty?
- Choice of forward radiative cloud model (e.g., ice radiative models [A44B-07, van Diedenhoven et al.])?
- How to use Quality Assessment assignments (common in EOS and other products) or related information.
  - multiphase/multilayer scenes (MODIS has a multilayer flag)?
  - accounting for discrepancies from different spectral channel pairs? [A44B-08, Zhang et al.]

Subjectivity always comes into play. Sometime’s it’s explicit (developer says “I am making a subjective choice”), sometimes it’s implicit.
Example MODIS Cloud Optical Thickness (COT) & Effective Radius (CER) Retrieval Solution Space

0.86 & 2.1 µm channel retrieval combination

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

retrieval error covariance

\[
\left( K^T S_y^{-1} K \right)^{-1} \text{ refl. meas. unc.}
\]

\[
+ \left( K^{-1} K_b \right) S_b \left( K^{-1} K_b \right)^T \]

maps model uncertainty into cloud-top reflect. uncertainty
Pixel-Level Uncertainty Example
2 July 2008, MODIS Aqua
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 (%)

ice 1 10 100 1 10 100
liquid water

Platnick et al., AGU 2013
Mean Uncertainty vs. COT, CER
Liquid Water Pixels

2 July 2008, MODIS Aqua

(MODIS Aqua C6, best quality pixels only, CSR=0)
Pt. 3

Uncertainties in Aggregated Means: Correlations?

Daily Means for Liquid Water Clouds

CER_2.1 (µm)

MODIS Aqua C6, best quality pixels only, CSR=0

Platnick et al., AGU 2013
Uncertainties in Aggregated Means: Correlations?

Daily Means for Liquid Water Clouds

Single Day Uncertainty (1 April 2005) w/pixel-to-pixel error correlation = 1

Platnick et al., AGU 2013

(MODIS Aqua C6, best quality pixels only, CSR=0)
Uncertainties in Aggregated Means: Correlations?

Monthly Means for Liquid Water Clouds

CER_2.1 (µm)

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

ΔCER_2.1 (%) (MODIS Aqua C6, best quality pixels only, CSR=0)

ΔCOT (%) (MODIS Aqua C6, best quality pixels only, CSR=0)

Platnick et al., AGU 2013
Uncertainties in Aggregated Means: Correlations?

Monthly Means for Liquid Water Clouds

CER_2.1 (µm)

Monthly Uncertainty (April 2005)

w/day-to-day error correlation = 0

(modis Aqua C6, best quality pixels only, CSR=0)

Platnick et al., AGU 2013
Uncertainties in Monthly Aggregated Means - Sensitivity

Monthly Unc. Liquid Water Clouds
Best Quality Pixel Aggregation

ΔCER_2.1 (%)

ΔCER_3.7 (%)

Monthly Unc. Liquid Water Clouds
“Partly Cloudy” Pixel Aggregation

ΔCER 2.1 (%)

ΔCER_3.7 (%)

Platnick et al., AGU 2013
(CSR=0 vs. CSR=1, 3 population)
Summary

- MODIS Collection 6 provides pixel-level COT, CER, and WP retrieval uncertainty estimates for the various spectral channel combinations
  - error sources: L1B spectral radiometric uncertainty assignments, atmospheric corrections (q, O₃), surface albedo/temperature, effect of temperature errors on 3.7 µm CER retrievals, limited cloud model parameters (effective variance, Cox-Munk wind vector)

- Issues:
  - How to quantify the impact of Algorithm Discrete decisions (cloud detection, phase) and Quality Assurance choices (pixel screening)?
  - Uncertainties in gridded statistics requires understanding pixel-to-pixel space/time correlations among the error sources!

- Cloud retrieval uncertainties cannot include all error sources (known and unknown unknowns) but should still be useful as a baseline estimate

- Data presented here is from the final Collection 6 algorithm. Aqua L2 reprocessing just started. Terra reprocessing will follow completion of Aqua.