“Introducing the Collection 6 MODIS Aerosol products”

Season III
Starring: The “Dark Target” Aerosol Team

Disclaimer: Lorraine is an renegade superhero. She receives no financial contribution from the MODIS aerosol group, and does not in any way "influence the government on this particular matter on behalf of UMBC".

Telling Rob what to do, on a personal level, is perfectly legal. That's just female-male communication.
When we last saw our motley gang of heroes...

(Scenes from Season II)

AeroCenter update: May 2012
... They were promising “final” delivery of Collection 6 algorithms
(imagine camera pans into each office)

- **Rob** was fussing with gas correction
- **Leigh** was fixing the cloud mask
- **Shana** was ordering that Version V6.0.11 was the *final* version
- **Rich** was evaluating DeepBlue/DarkTarget merge
- **Lorraine** was at UMBC, starting AirPhoton
- **Falguni** and **Pawan** had not yet joined the gang.
Now one year later...

(Scene from Season III)
... They are still promising “final” delivery of Collection 6 algorithms

(Imagine camera pans into each office)

- Rob is answering 40 pages of AMTD comments
- Leigh is fixing the coastline mask
- Shana is insisting that Version V6.0.27 is the *final* version
- Rich is re-evaluating DeepBlue/DarkTarget merge
- Lorraine comes to GSFC because she misses the rest of the gang.
- Falguni is fussing with gas correction.
- Pawan is improving urban aerosol retrieval
Introducing the Collection 6 MODIS aerosol products

Subtitle: The art of the MODIS aerosol retrieval

Sub-subtitle: Getting a cat into a carrier
Trying to get C6 into product is like...

Video found on You-Tube
Note: no harm to cat
Aerosol retrieval from MODIS

What MODIS observes

Attributed to aerosol (AOD)

There are many different “algorithms” to retrieve aerosol from MODIS
1. Dark Target (“DT” ocean and land; Levy, Mattoo, Munchak, Remer, Tanré, Kaufman)
2. Deep Blue (“DB” desert and beyond; Hsu, Bettenhousen, Sayer, ...)
3. MAIAC (coupled with land surface everywhere; Lyapustin, Wang, Korkin, ...)
4. Ocean color/atmospheric correction (McClain, Ahmad, ...)
5. Etc (neural net, model assimilation, statistical, ...)
6. Your own algorithm (many groups around the world)
**Generic MODIS-DT retrieval algorithm**

**INPUTS / UPSTREAM PRODUCTS**
- MOD02 = MODIS spectral reflectance pixels (at 500 m resolution)
- MOD03 = geo-location: geometry and surface type (1 km resolution)
- MOD35 = cloud mask, including IR tests. Also has surface type
- Ancillary data: GDAS 1° ozone, water vapor, surface wind speed

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100% water?  What surface are we?  At least 1% land?
Try Ocean retrieval  Coastal?  lakeshore?  Try land retrieval
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- **“Massaging” input data**
  - Cloud masking (MOD35 IR tests + our tests)
  - Perform spectral gas absorption correction
  - Other masking (glint, deserts, sediments, etc)
  - Sort and select valid pixels → one value per N x N

- **The retrieval itself**
  - Compare with pre-computed Lookup tables (LUTs)
  - Decisions about what is a “successful” retrieval
  - Decisions about what to report, and under what conditions

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Aggregate into N x N boxes
= 20x20 for 10 km
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We expected to change these for C6
Last November we submitted Collection 6 overview paper to AMTD


- We thought it would be a service to our users to have paper out when C6 processing began.
- It was a really long paper (100 AMTD pages) describing major updates and effects on the “products”
- It received 40 pages of online criticism and comments
- Then the rug was pulled out from under us.

What happened?
The world changed
(or at least the MODIS-observed view of the world)

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What surface are we?
- 100% water?
  - Try ocean retrieval
- Coastal?
  - No retrieval
- Lakeshore?
  - Try land retrieval
- At least 20% land?

For MOD02: Different decisions about bad/missing pixels, plus calibration
For MOD03: Definitions of land/water/coastal were changed
For MOD35: IR test finding high cirrus clouds was changed
For ozone: Input stream changed from TOAST to GDAS

“Our” changes for C6 needed to be revised

Note: that “our” also refers to ALL MODIS products (clouds, land surface, etc)
“Definitions” of land/coastal/water:

C5: Used MOD35; C6: Use MOD03 (It’s a long story)

This is ARCTAS region in northern Canada.

Land ‘o lakes

Note very little “coastal” in C5.

Clean divide between Green (land) and Yellow (Lakes)

Note much more “coastal” in C6.

Lots of shorelines (lime colored) pixels that would be thrown out.
Now they are promising “final” delivery of Collection 6 algorithms

(Shana will allow NO MORE CHANGES!!!!)

OUTLINE of REST of TALK

• Compensated for upstream changes!!!!!
• Better RT (gas corrections, LUTs)
• Cloud mask and pixel decision-making
• “Science” upgrades
• “Quality assurance” upgrades
• DT products (expected C6 versus C5)
• Other stuff: 3 km, DT/DB merge, etc
Better RT: Gas Corrections

- Gases (H\textsubscript{2}O, O\textsubscript{3}, CO\textsubscript{2}, NO\textsubscript{2}, etc...) absorb radiation, T\textsubscript{gas} < 1.0
- T\textsubscript{gas} varies spectrally and function of gas optical depth:
  - T\textsubscript{gas} \approx 1-\tau_{gas}

- The C5 assumptions were undocumented (circa 1995)
- Used modern RT code and found changes
- Changes for C6 have impacts.
Gas Corrections (cont.)

Gas Optical Depths for Mid Latitude Summer

- Consistent “bias” of $\Delta \rho^* \approx 0.001 \rightarrow$ “bias” of AOD of 0.01.
- Bias is double for $Z=60^\circ$. Quadruple for two-way transmission!
- Something really weird is happening at 1.24 $\mu$m channel (big impact on land retrieval)
- ACE: We want to know global AOD to $\pm 0.01$? Not when we don’t know gas!!!
Radiative Transfer updates (applied to C5)

Jul 2008: Aqua

- Recalculate “center wavelengths” from MODIS filter functions, and spectral Rayleigh optical depths
- Recalculate gas absorption coefficients and optical depths for H₂O, O₃, CO₂, CH₄, O₂, etc
- Extend valid solar zenith angle from 72° to 84°.

Pretty big changes, but they are justified.
Update cloud masking (ocean & land)

- Retrieve more “heavy smoke” cases
- Retrieve fewer “thin cirrus” cases
- Correct assignment of QAC due to clouds
Science: wind speed dependence (ocean)

- Higher wind speeds → more ocean foam and diffused glitter pattern

- Aerosol LUT now calculated for 4 wind speeds (v=2, 6*, 10, 14 m/s)

- Retrieved AOD reduced when v≥6

- Reduces AOD near 40° glint mask edges and in “Roaring 40s” of southern Oceans.
Quality Confidence “definitions”

Old (C5): Quality assurance depends on success of a retrieval solution. If aerosol signal is too small, then do not include in daily/monthly statistics.

New (C6): Sometimes signal is small, but we are confident that it is small. Include in daily/monthly statistics.

- But “major” influence on estimating regional and global mean AOD
Major bug fix: surface reflectance relationship to \text{NDVI}\_\text{swir}

- Coding error from C5 continued to C6
- Surface reflectance dependence on \text{NDVI}\_\text{swir} was reversed
- New: Reduces super-high bias for semi-arid regions.

These labels were reversed Resulting in coding error
New INPUTS

Add wind speed dep.

Fix cirrus bug over land

Degrade coastal QA

Switch NDVI_swir

New GAS and LUT
Results from **ALL** changes

- lower AOD over ocean, but significantly lower over southern oceans
- Higher AOD over most land, but lower in semi-arid regions.
- Changes in decisions to retrieve (see Aral sea).
Preliminary “validation” of C6
6 months testing (on Aqua)

• No dramatic changes, but 10-20% more valid collocations with AERONET
• C6 algorithm has slightly better (68% vs 64%) retrieved over ocean
• C6 will have more of a high bias over land, but slightly better correlation.
C5: Trends Terra ≠ Aqua

- Over land, Terra decreases (-0.04/decade), Aqua constant.
- Terra / Aqua divergence is the same everywhere on the globe!
- Artificial Terra trend traced to degrading of Terra’s calibration.
C6: Impact of New Terra calibration

• Main impacts over land
  – Global increase by 0.02 (for this particular month)

• Impact over ocean is small
  – Global increase by 0.004 (for this particular month)

Jack Xiong, Junqing Sun and MCST
C6: Impact of new calibration on trend?

- 6 months processed with same dark-target aerosol algorithms
- Terra (T) now “in sync” with Aqua (A) time series
- (Terra-Aqua) offset remains 0.01 (ocean) and 0.015 (land)
- **New calibration → Terra/Aqua divergence removed for C006!**
What else for C6 Level 2?
New Diagnostic SDSs

- **Land_Ocean_Quality_Flag**
  - Legend: 0: Poor, 1: Marginal, 2: Good, 3: Very Good

- **Topographic_Altitude_Land**
  - Surface Height [km]

- **Land_Sea_Flag**

- **Wind_Speed_Ncep_Ocean**
  - Wind Speed [m/s]
500 meter resolution cloud mask used in aerosol retrieval. Can be (at times, significantly) different than MOD35

Number of pixels between an aerosol retrieval and the closest cloud. Not thoroughly validated yet.
The Deep/Dark merge

- Dark, bright, and transitional regions are identified by monthly mean NDVI
- In Dark regions, value from dark-target retrieval is used
- In bright regions, deep-blue is used
- In transition regions, AOD is merged, dependent on QA of retrievals

C. Hsu, A. Sayer, C. Bettenhausen, S. Mattoo, L. Munchak, R. Kleidman, et al.
Merging deep blue & dark target produces best global coverage
• Deep blue is land-only; need dark target for oceans
• Deep blue introduces coverage over Australian outback, Sahara desert and Arabian peninsula
• Still no coverage over snow (see: most of Northern Hemisphere).

MERGE LOOKS REASONABLE, BUT NOT VALIDATED YET!!!! (Kleidman et al)
What about C6 Level 3?
Calculating mean AOD

- It depends on the post-processing path
- Many choices for aggregation and weighting
- Accentuate different limitations of original (L2) sampling

Levy et al., TRGS, 2009
Changes to Level 3: monthly

- Pixel weighting for monthly data is removed
- Replaced by “equal day” weighting (assuming at least 5 observations per day).
- Increase monthly mean AOD over land, and ocean
Global → Local

• Nominal resolution (e.g. 10 km) cannot resolve higher scale (e.g. urban, neighborhood) variability

• Air Quality community has been asking (no, *pleading!* for higher resolution data

• We have been afraid to lose the advantage (pixel statistics) of the 10 km.
3 km algorithm

In two AMT-Discussion Papers (in revision for AMT)


MODIS 3 km product over suburban (MD) landscape (summer 2010)

- 3 km mirrors 10 km product (pattern and magnitude)
- 3 km introduces noise, but also can reduce spatial impact of outliers
MODIS vs DRAGON
July 21, 2011

**AOD (AERONET: DRAGON)**

- DRAGON = Many AERONET over Maryland during DISCOVER-AQ experiment, July 2011
- For MODIS plots, QA=3 only
  - Circle Center = AERONET ±2 hours
  - Circle Outer = MODIS 5 x 5 box
- 3km (bottom) resolves Baltimore maxima
- Gray is MODIS-Aerosol cloud mask
- 3km also resolves aerosol over Ches. Bay

L. Munchak
MODIS 3 km product (operational for C006)

- Algorithm structurally identical to standard “10 km” retrieval
- Results will be in new files, ‘MOD04_3K’
- Over land and ocean, (but no Deep Blue yet).
- Both MOD04_L2 and MOD04_3K will be available

S. Mattoo, L. Munchak, M. Martins, L. Remer, B. Holben, et al
Summary (1)

- Dark-target algorithm/products are updated for C6, but only “modest” changes (no major science updates).
- “Modest” is relative... Many difficult decisions about seemingly small things that actually were significant. (e.g. Gas Correction, Cloud Mask, Quality Assurance etc).
- Upstream changes (L1B and MOD35) meant we had to re-analyze, over and over.
- Not superhero like, but there were mistakes (bugs carried over from C5) that needed re-analysis.
- Dark-target and Deep-blue products are merged, leading to more global coverage.
Summary (2)

• MODIS aerosol retrieval was intended for *global* climate applications
  – Air quality events are sometimes on urban and local scales
  – Aerosol properties change near clouds
  – The MODIS dark-target team is offering 3 km operational aerosol data.
  – Issues in land/sea/coastal are ACCENTUATED!
Trying to get C6 into product is like...

... Being Sisyphus

Hopefully, there will be no season IV for “Introducing Collection 6 products”
On towards Collection 7!

At the Yoram memorial tree outside of Bldg #33

- Proper per-pixel error products
- Better urban retrievals
- Use IR information for dust detection
- Etc: It’s proposal season!

THANK YOU FOR YOUR ATTENTION !!!