Creating a global aerosol data time series from MODIS, Suomi-NPP VIIRS and beyond: Dark Target

Robert C. Levy (NASA-GSFC)
robert.c.levy@nasa.gov

And the Dark-target aerosol retrieval team:

Shana Mattoo, Leigh Munchak and Richard Kleidman (SSAI/GSFC)
Lorraine Remer (UMBC/JCET), Falguni Patadia (MSU/GSFC),
Pawan Gupta (USRA/GSFC), Robert Holz (SSEC/UWisc), and others

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Aerosol retrieval from MODIS

What MODIS observes

May 4, 2001; 13:25 UTC
Level 1 “reflectance”

Attributed to aerosol (AOD)

May 4, 2001; 13:25 UTC
Level 2 “product”

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, Bettenhausen, Sayer, …): Previous talk!!!
3. MAIAC (coupled with land surface everywhere; Lyapustin, Wang, Korkin, …)
4. Land/Atmospheric correction (Vermote, …)
5. Ocean color/atmospheric correction (McClain, Ahmad, …)
6. Etc (neural net, model assimilation, statistical, …)
6. Your own algorithm (many groups around the world)
Outline

1. MODIS Collection 6 updates (algorithm wise)
   1. DT ocean
   2. DT land
2. Terra vs Aqua (and calibration and trends)
3. Onward to S-NPP VIIRS and climate data records?
4. Summary, challenges, etc
MODIS Collection 6 updates (Dark target)

- The 10 km standard product (MxD04_L2)

- In addition to improved Deep Blue (DB; previous talk by Andy), there is a DB/DT merge (Sorry, I won’t talk about it).

- And a separate 3 km product (3km: MxD04_3K), aimed at air quality applications (I won’t talk about that, either).
The Dark Target family consists of two separate aerosol optical depth (AOD) retrieval algorithms

**Dark land**
- Spectral surface reflectance relationship, which is function of angle and NDVI_SWIR.
- Aerosol types are prescribed for location/season
- Multispectral inversion using 3 wavelengths (0.47, 0.55 and 2.1 \(\mu\)m) and compared to lookup tables

**Water**
- Surface BRDF including glint, foam, underlight (function of wind speed)
- Aerosol types are not prescribed for season/location
- Multispectral inversion using 6 wavelengths (0.55 – 2.1 \(\mu\)m) and compared to lookup tables

Both report the AOD at 550 nm,
Along spectral AOD and/or fine-mode fraction
Overall changes (C6 vs C5): Aqua, 2008

AOD at 0.55 μm

0.0

0.8

AOD Difference

-0.1

0.0

0.1

DETAILS?? →
MODIS (MxD04) Collection 6!


Focus on Trends/Calibration: Terra versus Aqua

- Same instrument hardware (optical design)
- Same spatial and temporal sampling resolution
- Same calibration/processing teams
- Same aerosol retrieval algorithms
- Identical twins!
Aerosol Trends: If based on Collection 5

Over land, Terra decreased (-0.05/decade), Aqua constant

Terra / Aqua divergence was similar everywhere on the globe!

Like identical human twins, the twin MODIS sensors aged differently.
Tracking MODIS RSB radiometric stability from reflectance trends over CEOS desert sites

1. Collect clear-sky MODIS data over desert sites
2. Develop site-specific BRDF from first 3 years of mission
3. Over time, compare “observed” reflectance with BRDF modeled reflectance, for different view angles
4. Trends in Band #3 (0.47 µm) are consistent with Terra’s AOD trends over LAND!
5. → NEW CALIBRATION METHOD applied to Terra!

![Graph showing normalized reflectance over time for Terra and Aqua](chart.png)
C6 differences AOD: Terra-Aqua

• Terra/Aqua divergence “mostly” removed for C6
• Terra offset by 0.027 land/0.017 ocean), THIS IS >13% of AOD!
• There is still residual trending (Terra-Aqua increasing by ~0.01/decade)
• Bigger-amplitude seasonal cycle to Terra-Aqua after 2011.
“Validation”: 2003-2013, Land

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<th>Sat</th>
<th>N</th>
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<th>Int</th>
<th>R</th>
<th>RMSE</th>
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<tr>
<td>Terra</td>
<td>94.9K</td>
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<td>0.892</td>
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<td>Aqua</td>
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<td>1.01</td>
<td>0.00</td>
<td>0.890</td>
<td>0.104</td>
<td>0.004</td>
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</table>

- EE% > 68%: Both Terra and Aqua meet “expected error (EE)” of ±(0.05 + 15%)
- Some metrics nearly identical: Corr = R=0.89, Slope=M=1.01, RMSE=0.10
- Terra is biased high for all AOD (due to y-intercept)
- \( N_{\text{Terra}} = 95K \) versus \( N_{\text{Aqua}} = 81K \). Why? Calibration? Sampling? AM/PM Clouds? Other?
“Validation”: 2003-2013, Ocean

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<td>Aqua</td>
<td>29.9K</td>
<td>0.97</td>
<td>0.02</td>
<td>0.929</td>
<td>0.066</td>
<td>0.016</td>
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- EE% > 68%: Both Terra and Aqua meet “expected error (EE) ” of ±(0.03 + 10%)
- Some metrics nearly identical: Corr = R=0.93, Y-int=0.02, RMSE=0.07
- Terra is biased high, but due to slope.
- $N_{\text{Terra}} = 34K$ versus $N_{\text{Aqua}} = 30K$. Why? Calibration? Sampling? AM/PM Clouds? Other?
Summary (MODIS C6)

• MODIS aerosol retrieval (“MxD04_L2”) has many upgrades for Collection 6.
• Aqua/Terra level 2 and 3 are available now
• Trending issues reduced with C6 calibration
• But still significant offsets (~0.02). Why?
• Still residual co-trending (<0.01 / decade)

• Next step: Consider applying C6+ calibration

Beyond MODIS?

• Terra just celebrated its 15\textsuperscript{th} birthday!
• At 12+, Aqua ain’t no spring chicken!
• Terra and Aqua MODIS instruments are both >2x original mission lifetimes
• MODIS won’t be here forever
• How do we get to 20+ year aerosol data records?
VIIRS?

Suomi-NPP (and future JPSS) VIIRS
Visible Infrared Imager Radiometer Suite

Can VIIRS “continue” the MODIS aerosol data record?
VIIRS versus MODIS

**Orbit:** 825 km (vs 705 km), sun-synchronous, over same point every 16 days
   Equator crossing: 13:30 on Suomi-NPP, since 2012 (vs on Aqua since 2002)

**Swath:** 3050 km (vs 2030 km); Granule size: 86 sec (vs 5 min)

**Spectral Range:** 0.412-12.2\( \mu \)m (22 bands versus 36 bands)

**Spatial Resolution:** 375m (5 bands) 750m (17 bands): versus 250m/500m/1km

**Aerosol retrieval algorithms:** “Physics” similar, but different strategies

**Wavelength bands (nm) that could be used for DT aerosol retrieval:** 482 (466), 551 (553) 671 (645), 861 (855), 2257 (2113) → differences in Rayleigh optical depth, surface optics, gas absorption.
VIIRS Aerosol Algorithm (NOAA-IDPS)

- Multi-spectral over dark surface
- Separate algorithms used over land and ocean
- 6 km resolution product – an integer multiple of scan lines
- Algorithm heritages
  - over land: MODIS atmospheric correction (e.g. the MOD09 product)
  - over ocean: MODIS aerosol retrieval (MOD04 product)
- Many years of development work:
- Retrives: AOD (at 0.55 μm and spectral), Ångström Exponent (AE), Suspended Matter (aerosol classification), etc
- NOAA CLASS: The Primary Gateway for the VIIRS Data Distribution
- “Validated Stage 2” (published) since 23 Jan 2013.
- Provides data in HDF5 format (compared to HDF4-ish for MODIS)
Aerosol retrieval: Different algorithms

• Differences in wavelengths, cloud masks, pixel selection technique, quality assurance etc.
• Also, not exactly overlapping orbits (note 5 min difference).
• Note, 86 second VIIRS granules aggregated to 5 minutes.

Ocean retrieval algorithm
- “heritage” circa 1997 (Tanré, Kaufman, Remer,...)
- MODIS: C6 assumptions (Levy et al., 2013)
- VIIRS: C5-like assumptions (Remer et al., 2005)

Land retrieval algorithm
- “heritage” circa 1997 (Kaufman, Tanré, Vermote,...)
- MODIS: C6 “dark-target” (Levy et al., 2007, 2013)
- VIIRS: C5 “atmos. correction” (Vermote et al., 2008).

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Monthly mean AOD for Spring 2013 (Mar-May)

MODIS C6 and VIIRS-EDR are similar, yet too different
Developing a MODIS-like algorithm for VIIRS

- The Intermediate file format (IFF) puts MODIS and VIIRS in “same common denominator” (University of Wisconsin)
- MODIS-IFF is 1 km resolution for all bands, VIIRS-IFF is 750 m (no high-resolution bands for either MODIS or VIIRS)
- Use 10 x 10 pixel retrieval boxes (so 10 km for MODIS; 7.5 km for VIIRS).
- Run lookup tables to account for different wavelengths
Same algorithm on both platforms?

- Apply C6-like thresholds for cloud masking, pixel selection and aggregation
- Run “MODIS-like” algorithm on both M-IFF and V-IFF data

→ Much more similar AOD structure
→ Still differences in coverage and magnitude. We are learning why. (Cloud masking/spatial variability thresholds?)
Gridded seasonal AOD (Spring 2013)

Running MODIS-like on VIIRS has reduced global AOD differences and has similar global sampling.

Systematic bias over ocean (VIIRS high by 15%)

Less systematic bias over land (MODIS high by 5%)
Comparing gridded AOD (Spring 2013)

VIIRS_EDR vs MODIS

MODIS-like (VIIRS) vs MODIS

New data
More like MODIS
But 1.15 slope over ocean!
MODIS-like on VIIRS has Angstrom Exponent that looks much more like MODIS
“Validation”: 2013-2014, Land

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</table>

VIIRS vs MODIS (Aqua): March 2013-Feb 2014

- EE% > 68%: Both VIIRS and MODIS-Aqua meet “expected error (EE)” of ±(0.05 + 15%)
- Some metrics nearly identical: Corr = R=0.90, Slope=M=1.01, RMSE=0.10
- VIIRS is has even smaller bias than MODIS (due to y-intercept)
“Validation”: 2013-2014, Ocean

- VIIRS does not quite meet >68% within EE of ±(0.03 + 10%)
- Some metrics nearly identical: Corr = R=0.93, Y-int=0.02, RMSE=0.07
- VIIRS is biased very high, but due to slope.
Calibration? Again?

- **Terra vs Aqua:**
  - Ocean: Terra high by +0.017 or 13%; Driven by slope
  - Land: Terra high by +0.027 or 13%, Driven by y-offset

- **VIIRS vs Aqua:**
  - Ocean: VIIRS high by +0.25 or 20%; Driven by slope
  - Land: VIIRS lower by -0.01 or 5%; Driven by y-offset

- VIIRS reflectance may be >2% high in some bands? (e.g. Uprety et al., 2013)
- 2% high bias can give a 1.17 slope over ocean without the adding bias to land.
- Terra-Aqua differences are smaller, but they also to be calibration-driven.
Retrievability: To retrieve or not to retrieve?

MODIS (Aqua): MAM 2013

1°x1° retrieval fractions provided by the ML_V versus ML_M products during Spring 2013.
Will VIIRS continue MODIS? How would we know?

- **Convergence:** of gridded (Level 3 –like) data
  - For a day? A month? A season?
  - What % of grid boxes must be different by less than X?
    - in AOD? In Angstrom Exponent? Size parameters?

- **Sampling:** Do instruments observe similar conditions?

- **Retrievability:** Do algorithms make same choices?

- **Validation:** Comparison with AERONET, MAN, etc?
A time series (of sorts) so far

0.55 µm AOD, Ocean

0.55 µm AOD, Land

0.55 µm AOD, Ocean

0.55 µm AOD, Land
Greater community-wide VIIRS plans

- Some highlights from the recent “joint” MODIS-VIIRS Science team meeting in Maryland (early May 2015).
  - Our VIIRS-DT processing will be handled by University of Wisconsin
  - Formats will likely be NetCDF4. Level 1 “granule” size will likely be 6 minutes (collocation with CrIS sensor)
  - MODIS-VIIRS “Continuity” cloud mask (MOD35-like) is under development
  - NASA-led “calibration” effort is underway, and will be different than the NOAA-led calibration
  - We are required to post something resembling an ATBD and/or a user guide for VIIRS products.
  - Many more issues to work out. For example, will new products on VIIRS be back-produced on MODIS? What will happen to Level 3?
  - Another issue: retrieval pixel size versus original pixel size: # scan lines
  - Discussions over how algorithms will be implemented after Suomi-NPP (e.g. JPSS 1 and JPSS 2 satellites).

- We will continue to retrieve IFF-based MODIS-like aerosol products, and provide to the ICAP community (please ask) until “official” products are released
Summary

• MODIS-DT Collection 6 –
  – Aqua/Terra level 2, 3 available now;
  – Extended diagnostics, DT/DB merge, science improvements
  – “Trending” issues reduced, but 15% or 0.02 Terra/Aqua offset remains.

• VIIRS-IDPS (MODIS-ish over ocean; not over land)
  – VIIRS is “similar” instrument, yet different then MODIS
  – The NOAA product has similar global EE to MODIS (over ocean).
  – With 50% wider swath, VIIRS has daily coverage

• VIIRS-DT – now,
  – Ensures *algorithm* consistency with MODIS DT.
  – IFF-based granules are being processed now (we are sharing)
  – 20% NPP/Aqua offset over ocean.
  – Paper was submitted May 31 to AMTD! (Some of you may review it?)

• VIIRS-DT - future,
  – We don’t have “continuity” yet.
  – Move towards full resolution (includes I-bands)
  – Discussion here at MODIS-VIIRS Science Team meeting (formats, delivery, ATBDs, documentation, etc...)
Summary (cont)

• Can VIIRS continue the MODIS record?
  – We believe we need to apply the same algorithm
  – Calibration is a concern.
• We still need to define “how similar is good enough”?
• Which statistics must converge?
  – Expected error (validation)
  – Sampling
  – Means/variance
  – At 0.55 µm only? At other wavelengths?
  – Etc
• Keep open discussion with our “super-users” (ICAP modelers, assimilators, etc). What do **YOU** need?
• Improvements for “Collection 7”, which would be a joint MODIS/VIIRS product.
• Web site in development/ATBDs being updated
• Reference for all things “dark target”
  – The algorithms and assumptions
  – Examples
  – Validation
  – Primary publications
  – Educational material
  – FAQ
  – Links to data access
  – Considering a “forum”

http://darktarget.gsfc.nasa.gov