

Creating a global aerosol data time series from MODIS, VIIRS and beyond



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Presented to MODIS meeting - 19 May 2015 @ Silver Spring, MD

Aerosol Climate Data Records (CDRs)?

“A time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change.”



Some requirements

- Measurements sustained over decades
- Measurement of measurement performance (e.g. calibration, stability)
- Acquired from multiple sensors / datasets

aerosols in the climate system

- Understanding climate requires accurate and complete aerosol characterization
- ... which requires accurate and complete global aerosol data
- ... which requires global observations.
- ... which requires high quality techniques to retrieve aerosol properties
- ... which requires accurate global measurements
- ... which requires **detailed characterization of the sensors and algorithms** being used

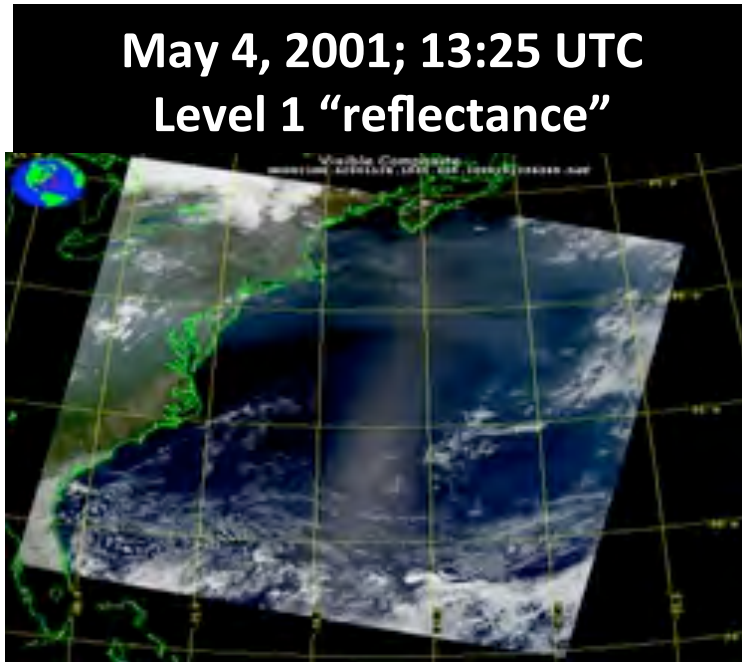
MODIS is 15+ years, how do we extend across decades?

Outline

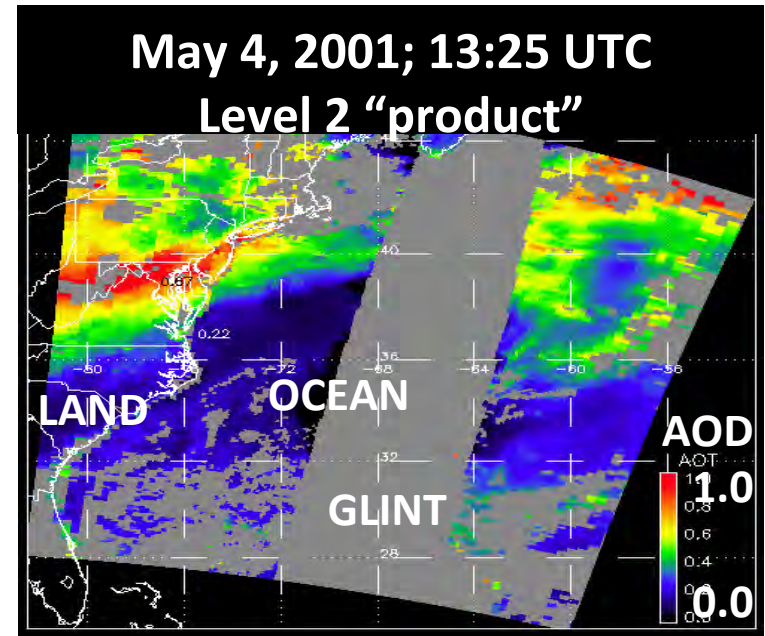
1. MODIS Collection 6 updates (algorithm wise)
 1. DT ocean
 2. DT land
2. Terra vs Aqua (and calibration and trends)
3. Onward to S-NPP VIIRS and climate data records?
4. Summary, challenges, etc

Aerosol retrieval from MODIS

What MODIS observes



Attributed to aerosol (AOD)



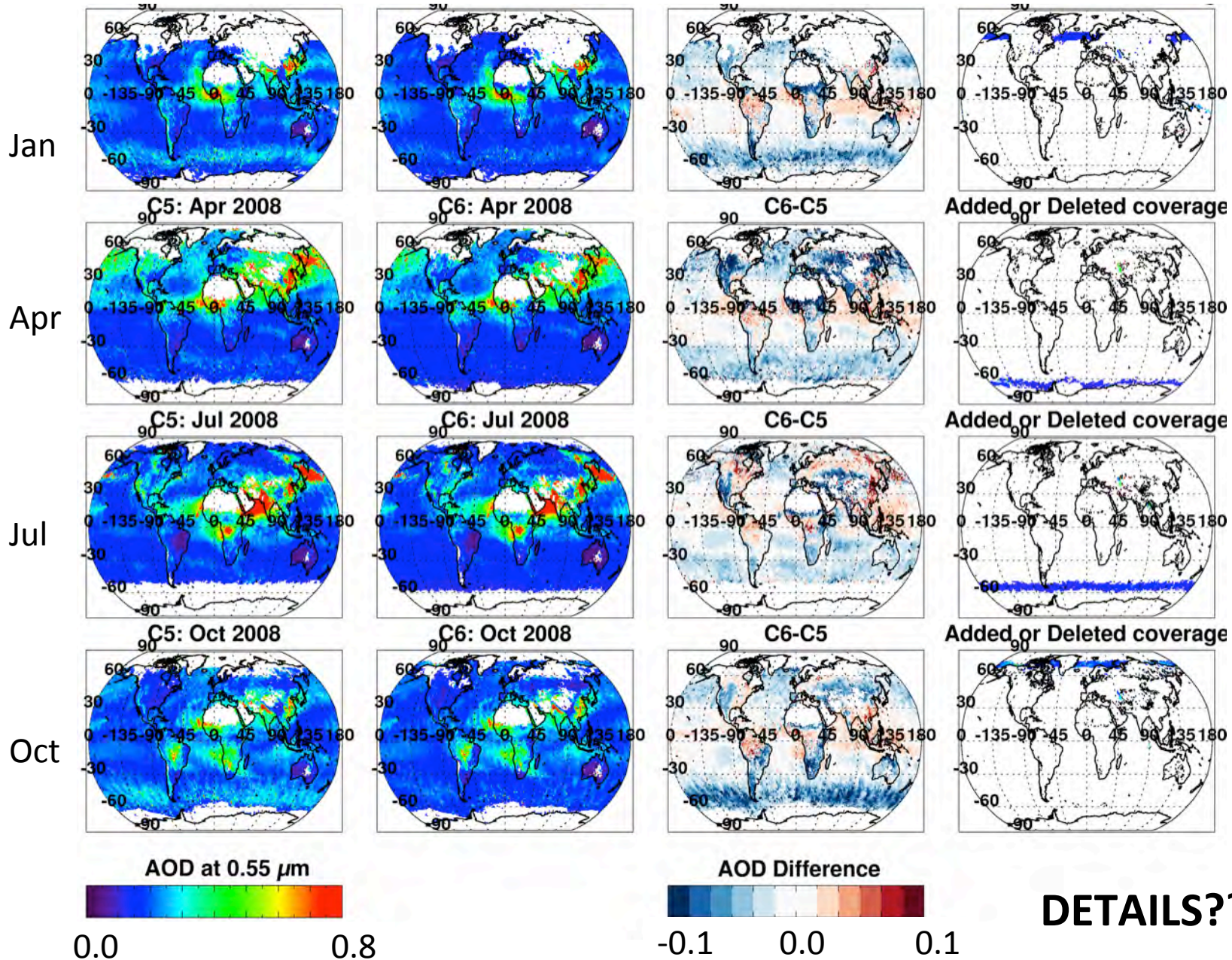
There are many different “algorithms” to retrieve aerosol from MODIS

1. Dark Target (“DT” ocean and land; Levy, Mattoo, Munchak, Remer, Tanré, Kaufman)
2. Deep Blue (“DB” desert and beyond; Hsu, Bettenhausen, Sayer,..)
3. MAIAC (coupled with land surface everywhere; Lyapustin, Wang, Korokin,...)
4. Land/Atmospheric correction (Vermote, ...)
5. Ocean color/atmospheric correction (McClain, Ahmad, ...)
5. Etc (neural net, model assimilation, statistical, ...)
6. Your own algorithm (many groups around the world)

MODIS Collection 6 updates (Dark target)

- Specifically, the 10 km standard product (MxD04_L2)
- There is also a higher resolution product (3km: MxD04_3K), aimed at air quality applications.
- There is also a new Deep Blue/ Dark-target “merge” product
- and Deep Blue is improved greatly everywhere (Next talk!)

Overall changes (C6 vs C5): Aqua, 2008



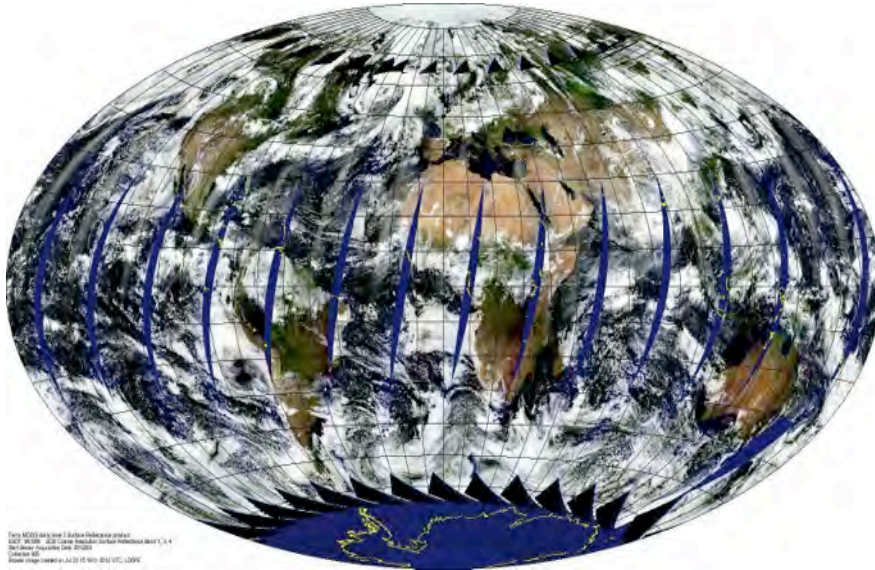
MODIS (MxD04) Collection 6!

- Levy, R. C., Mattoo, S., Munchak, L. A., Remer, L. A., Sayer, A. M., Patadia, F. and Hsu, N. C.: The Collection 6 MODIS aerosol products over land and ocean, *Atmos Meas Tech*, 6(1), doi:10.5194/amt-6-2989-2013, 2013.
- Sayer, A. M., Munchak, L. A., Hsu, N. C., Levy, R. C., Bettenhausen, C. and Jeong, M. J.: MODIS Collection 6 aerosol products: Comparison between Aqua's e-Deep Blue, Dark Target, and 'merged' data sets, and usage recommendations, *J Geophys Res-Atmos*, doi: 10.1002/2014JD022453, 2014.
- Munchak, L. A., Levy, R. C., Mattoo, S., Remer, L. A., Holben, B. N., Schafer, J. S., Hostetler, C. A. and Ferrare, R. A.: MODIS 3 km aerosol product: applications over land in an urban/suburban region, *Atmos Meas Tech*, 6(1), doi: 10.5194/amt-6-1747-2013, 2014.
- Remer, L. A., Mattoo, S., Levy, R. C. and Munchak, L. A.: MODIS 3 km aerosol product: algorithm and global perspective, *Atmos Meas Tech*, 6(7), doi:10.5194/amt-6-1829-2013, 2013.

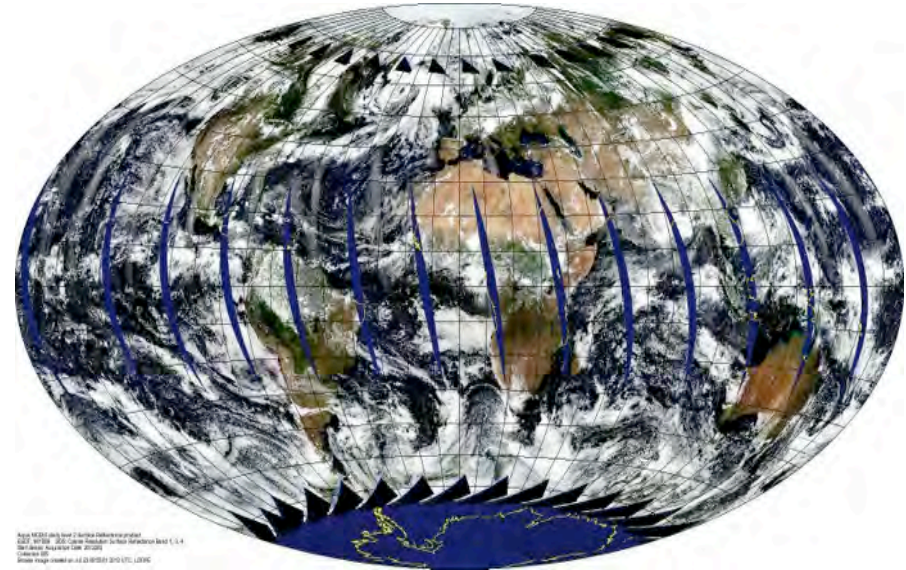
Collection 6 “Webinars”: <http://aerocenter.gsfc.nasa.gov/ext/registration/>
New “dark-target” website: <http://darktarget.gsfc.nasa.gov>
MODIS product website: <http://modis-atmos.gsfc.nasa.gov>

Focus on Trends/Calibration

Terra (since spring 2000)



Aqua (since summer 2002)



- 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

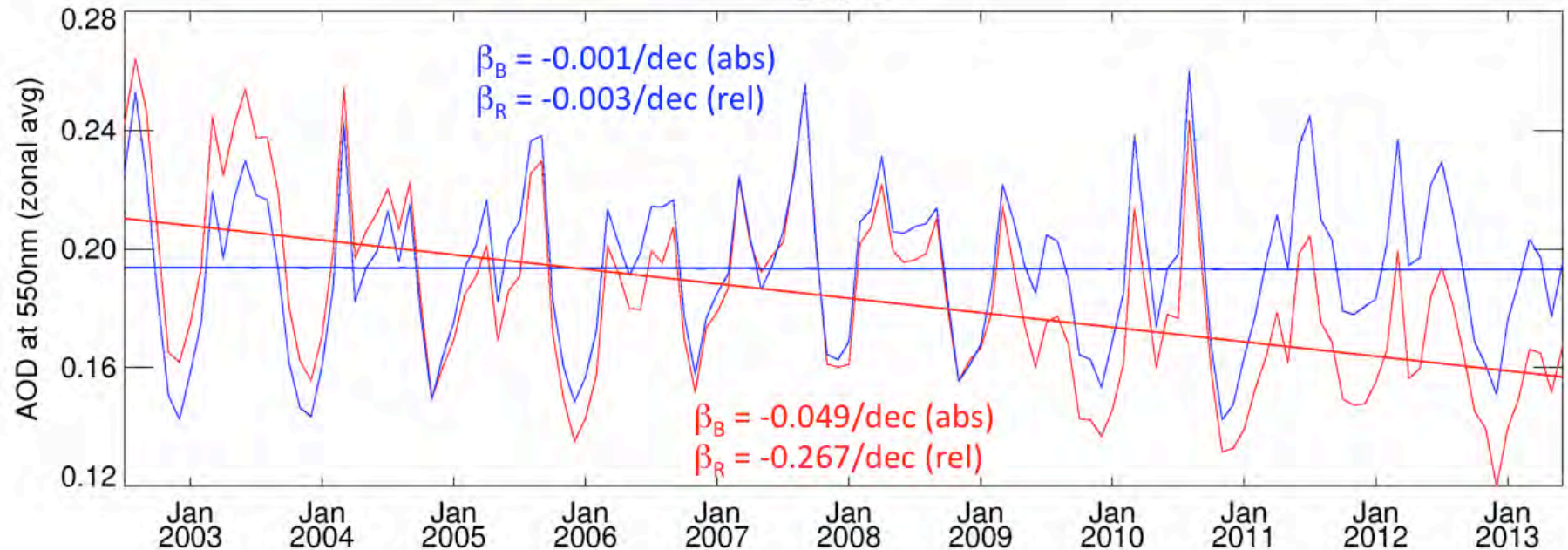
Aqua: JUL, 2002 to JUN, 2013 ; Terra: JUL, 2002 to JUN, 2013

AREA WEIGHTED = YES, PIXEL WEIGHTED = NO

C5(Aqua & Terra) AOD zonal avg [60S, 60N]

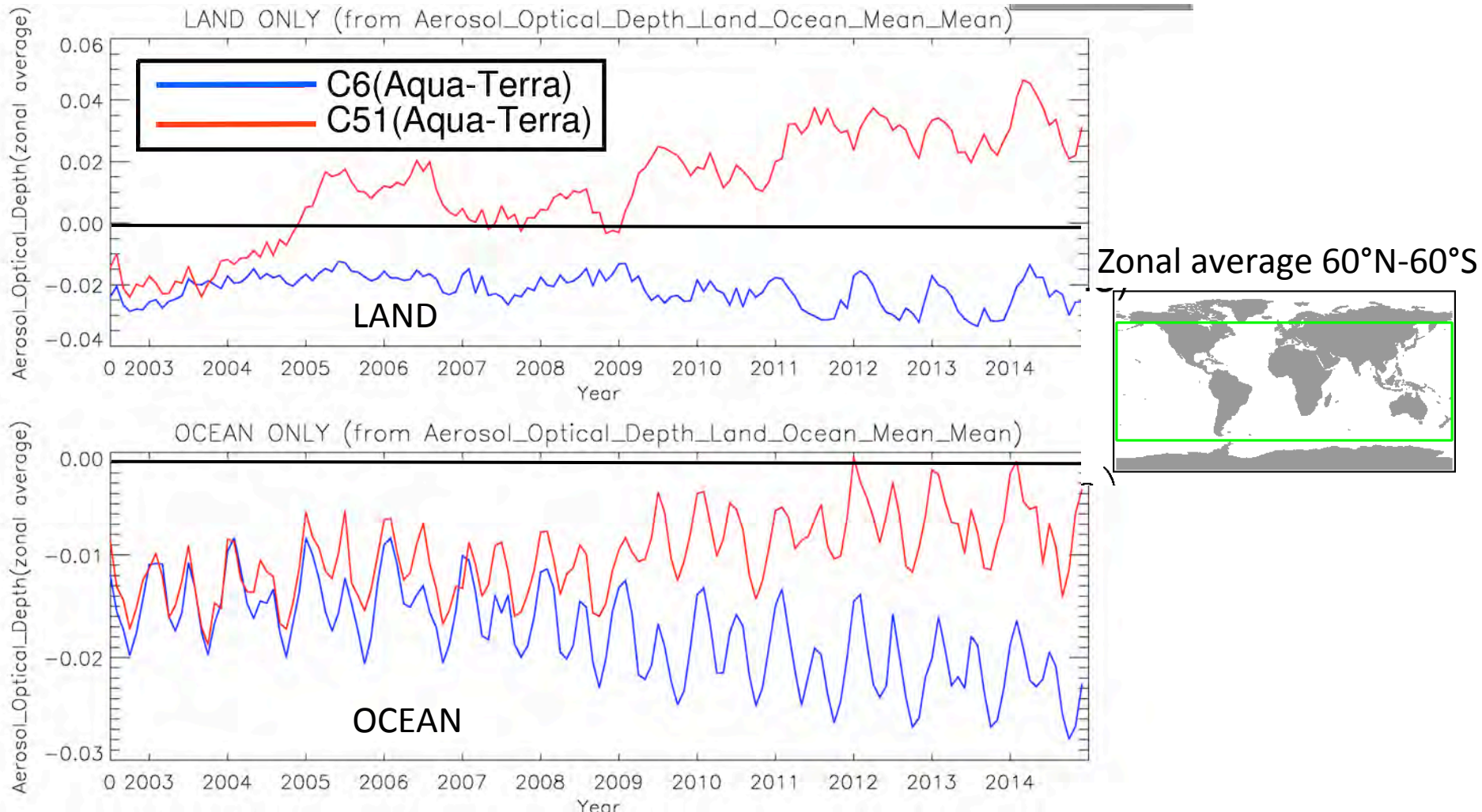
Terra
Aqua

LAND



- 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.

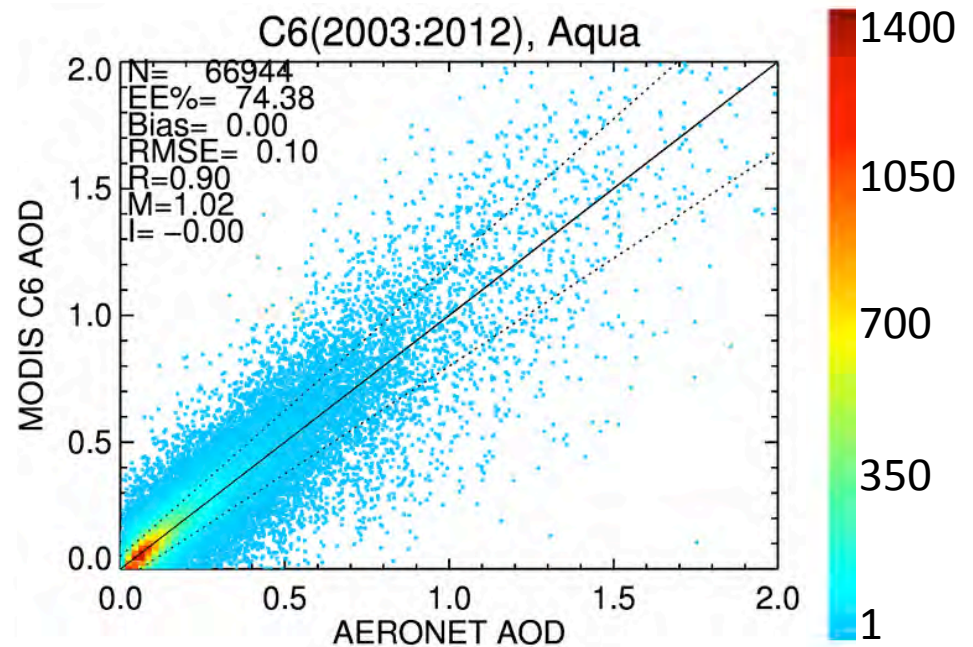
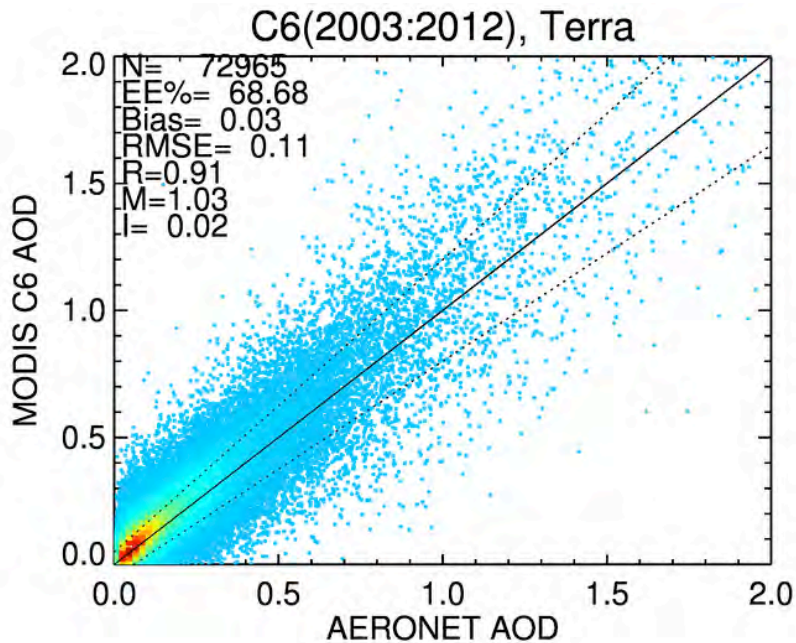
Impact of new calibration on C6 Aqua-Terra AOD



- Terra/Aqua divergence “mostly” removed for C6
- Terra offset by 0.02 (both land and ocean), THIS IS >10% of AOD!
- There is still residual trending
- Something seasonal after 2011 over land.

Figure by:
Vani Starry Manoharan

Some “validation” (2003-2012): Land



- AOD compared with AERONET (2003-2012, overlapping periods).
- EE% > 68%: Both Terra and Aqua meet “expected error” of $\pm(0.05 + 15\%)$
- Many metrics nearly identical:
 - Corr = R=0.91, Slope=M=1.02, RMSE=0.10
- Terra is biased high by 0.03 (intercept = 0.02 vs 0.00)
- $N_{\text{Terra}} = 73\text{K}$ versus $N_{\text{Aqua}} = 67\text{K}$. Why?
- Not “proof” that Terra is biased high, but that Terra is biased compared to Aqua.

Summary (MODIS C6)

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

Lyapustin, A., Wang, Y., Xiong, X., Meister, G., Platnick, S., Levy, R., Franz, B., Korkin, S., Hilker, T., Tucker, J., Hall, F., Sellers, P., Wu, A. and Angal, A.: Scientific impact of MODIS C5 calibration degradation and C6+ improvements, *Atmos Meas Tech*, 7(12), 4353–4365, doi:10.5194/amt-7-4353-2014, 2014.

Beyond MODIS?

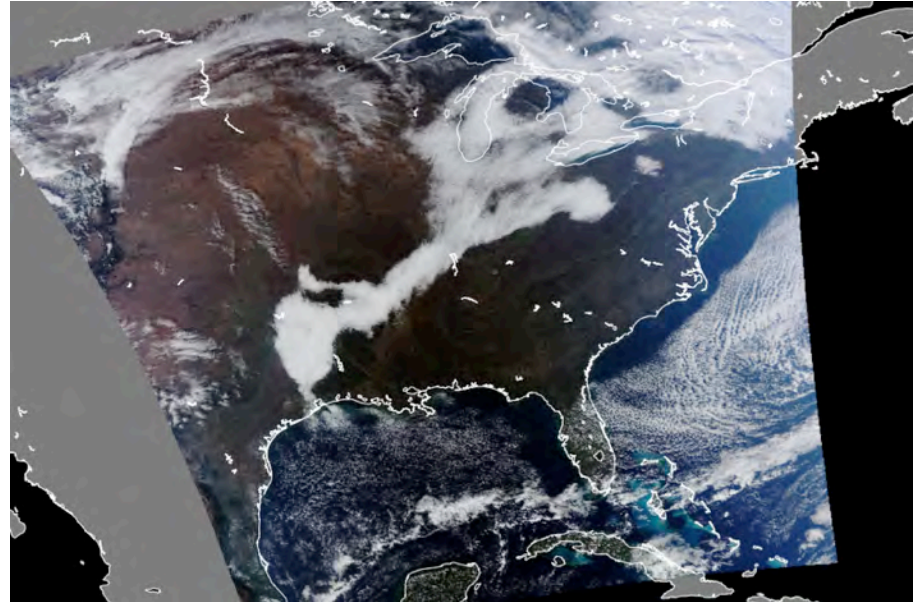
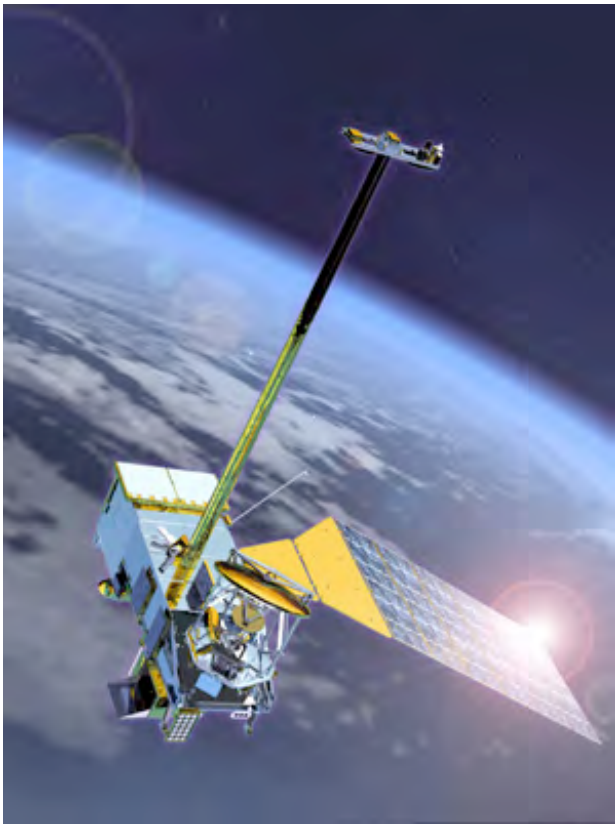


- Terra just celebrated its 15th birthday!
- At twelve - Aqua ain't no spring chicken!
- Terra and Aqua MODIS instruments are both 3x original mission lifetimes
- MODIS won't be here forever
- How do we get to 20+ year aerosol data records?



VIIRS?

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



Can VIIRS “continue” the MODIS aerosol data record?

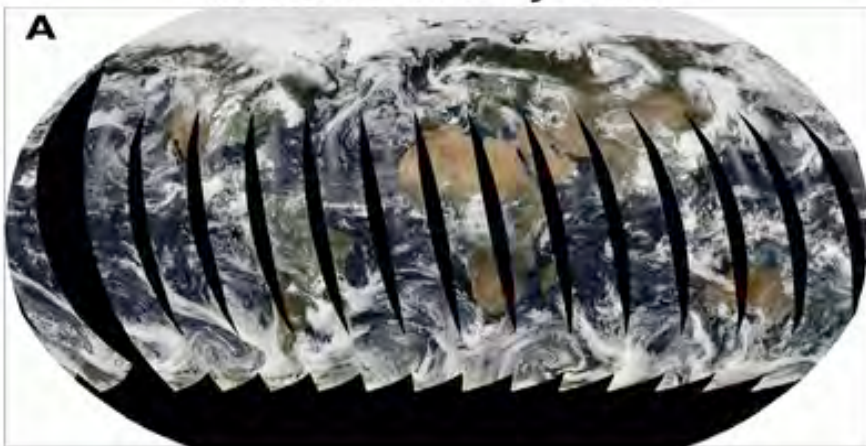
VIIRS versus MODIS

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 μ 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) \rightarrow differences in Rayleigh optical depth, surface optics, gas absorption.

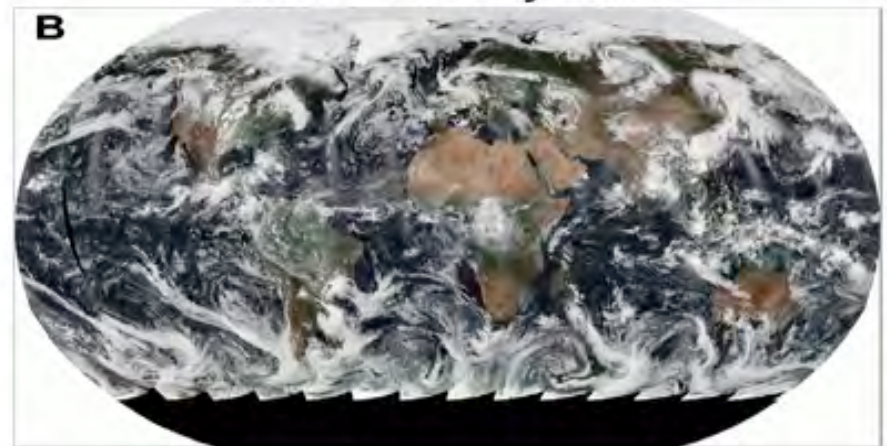
Aqua (13:30 Local Time, 14.6 revs/day)

Suomi-NPP (13:30 Local Time 14.1 revs/day);

MODIS - 29 May 2013



VIIRS - 29 May 2013

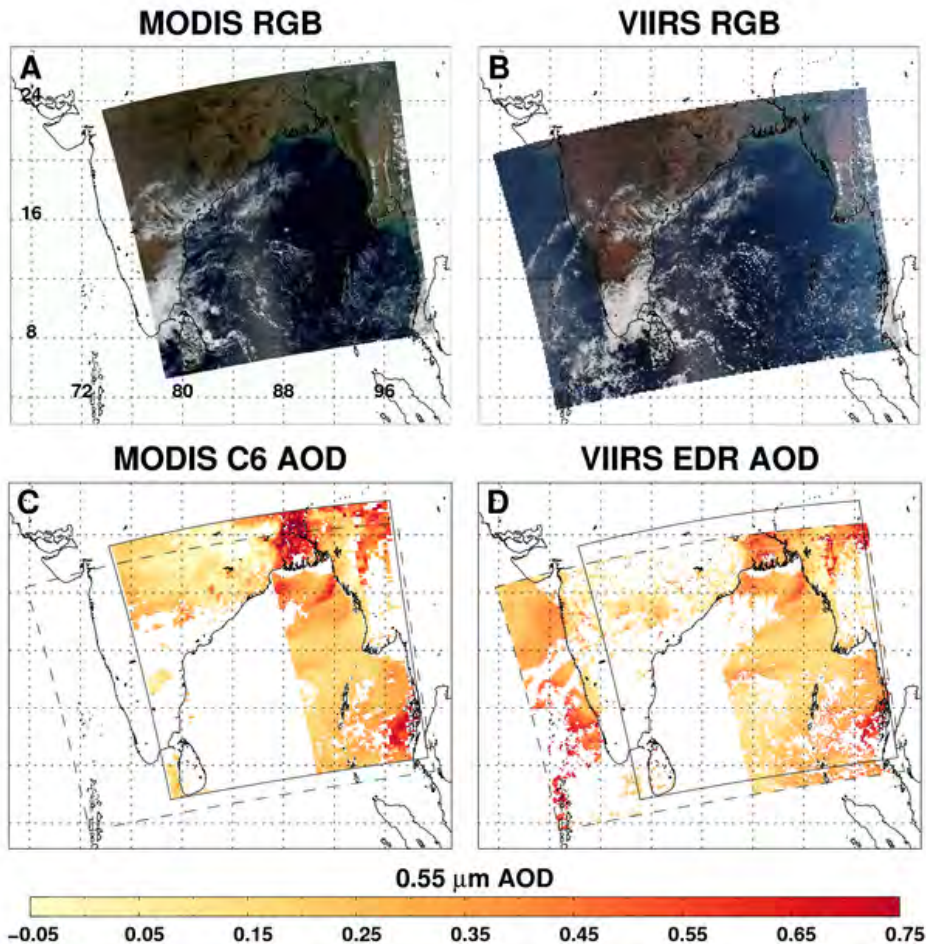


VIIRS Aerosol Algorithm (NOAA-IDPS)

- Multi-spectral over dark surface
- Separate algorithms used over land and ocean
- Algorithm heritages
 - over land: MODIS atmospheric correction (e.g. the MOD09 product)
 - over ocean: MODIS aerosol retrieval (MOD04 product)
- Many years of development work:
- Retrieves: 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

Granules over India (Mar 5, 2013, 0735/0740 UTC)



Ocean retrieval algorithm

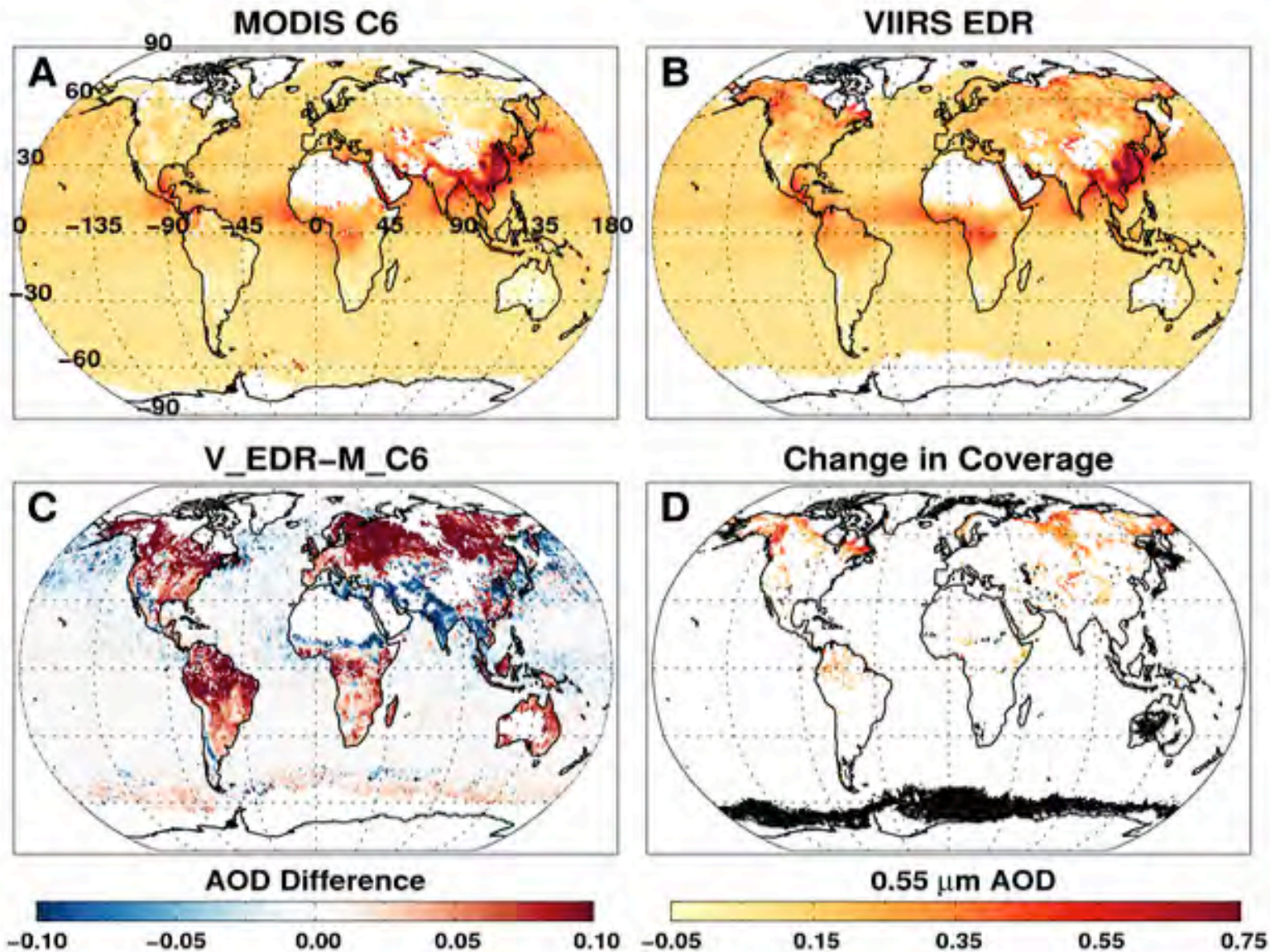
- “heritage” circa 1997 (Tanré, Kaufman, Remer,...)
- MODIS: C6 assumptions (Levy et al., 2013)
- VIIRS: C5-like assumptions (Remer et al., 2005)

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).

- 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.

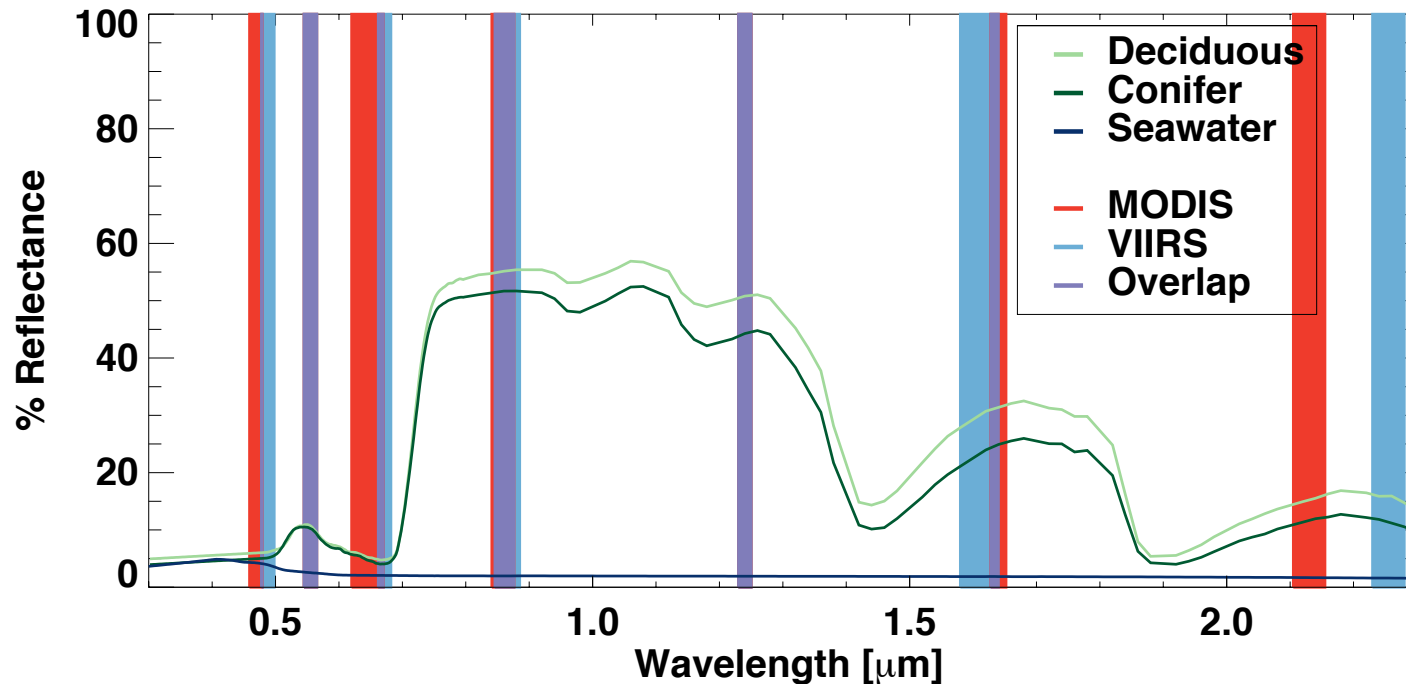
Monthly mean AOD for Spring 2013 (Mar-May)



MODIS C6 and VIIRS-EDR are similar, yet different

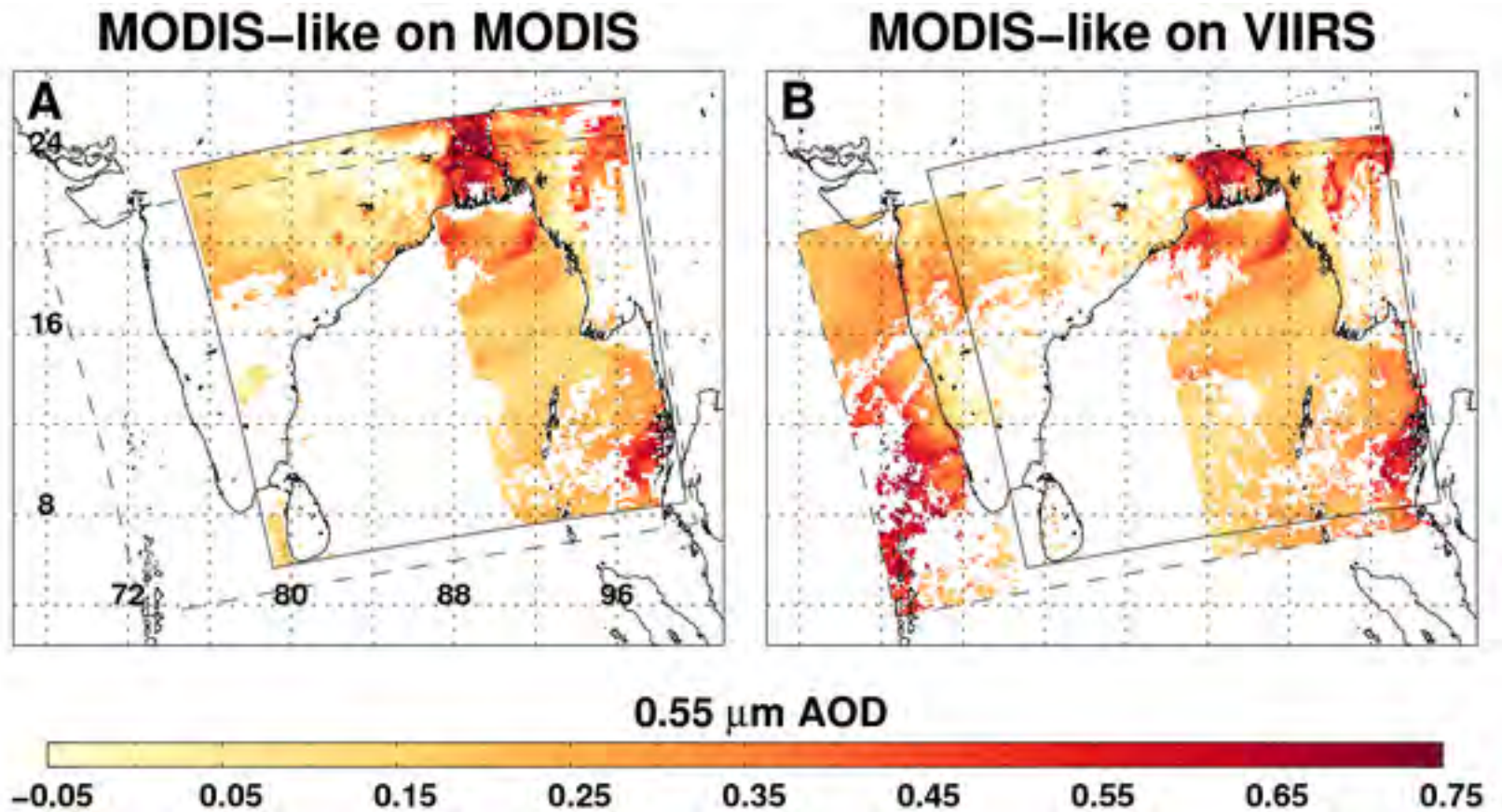
Create a MODIS like algorithm for VIIRS?

- 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



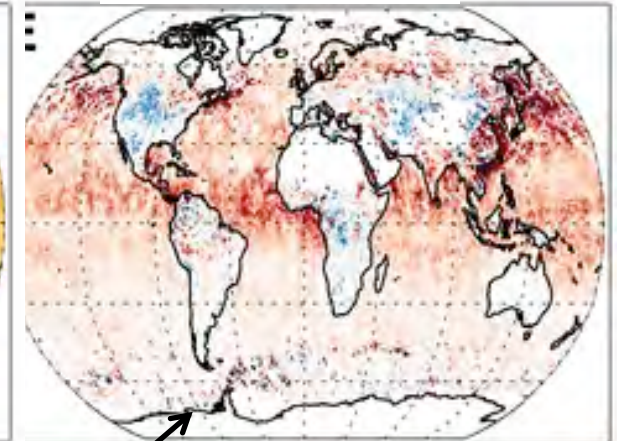
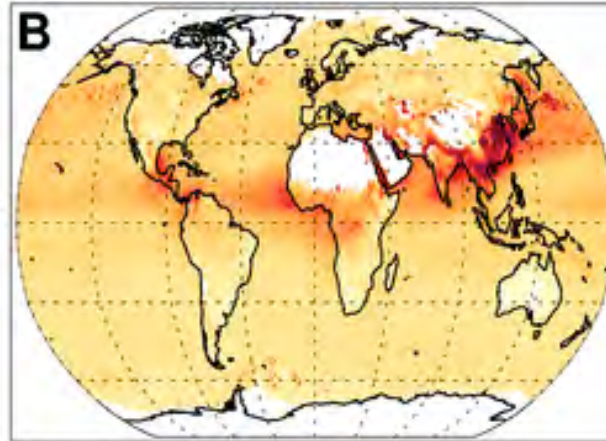
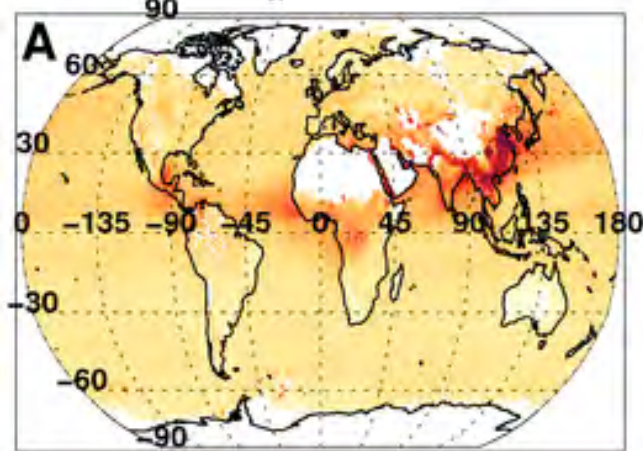
- Much more similar AOD structure
- Still differences in coverage and magnitude. We are learning why. (Cloud masking/spatial variability thresholds?)

Gridded seasonal AOD (Spring 2013)

MODIS

MODIS-like on VIIRS

Difference M - V



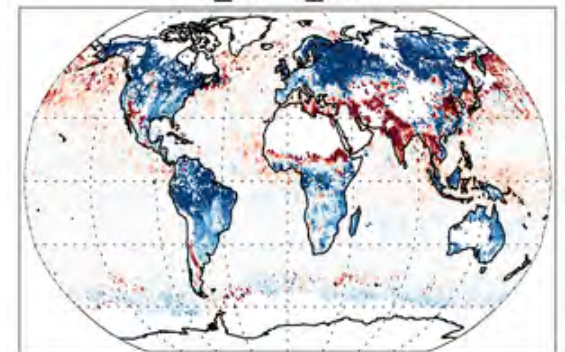
Versus...

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

Systematic bias over ocean (VIIRS high by 15%)

Not systematic bias over land (MODIS high by 5%)

M_C6-V_EDR

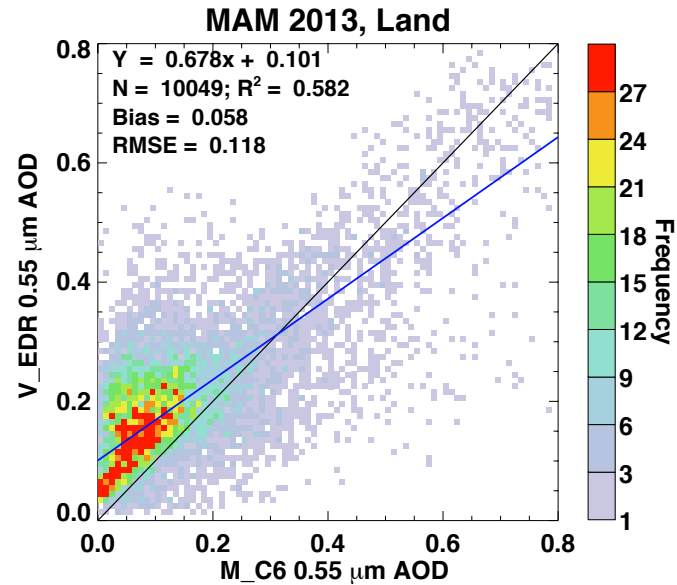
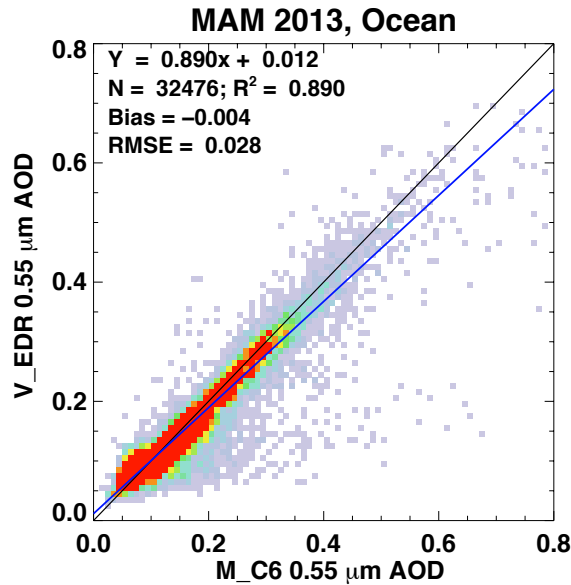


AOD Difference

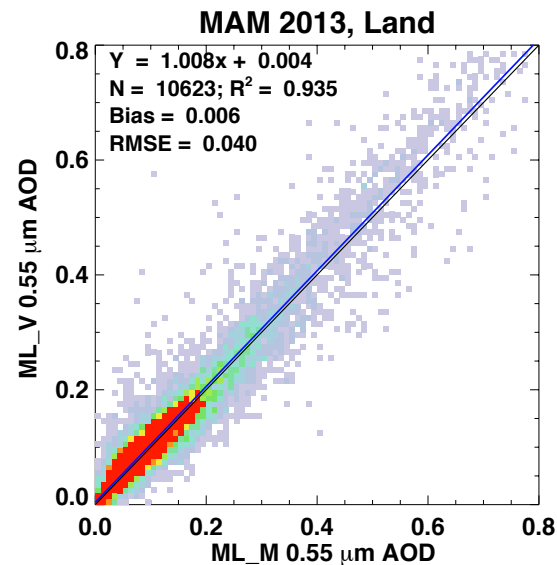
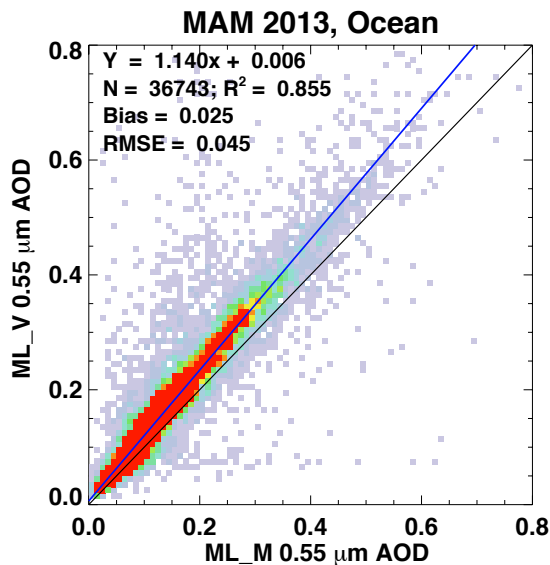
-0.10 -0.05 0.00 0.05 0.10

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!

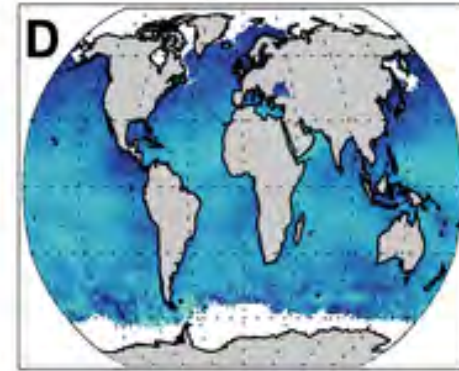
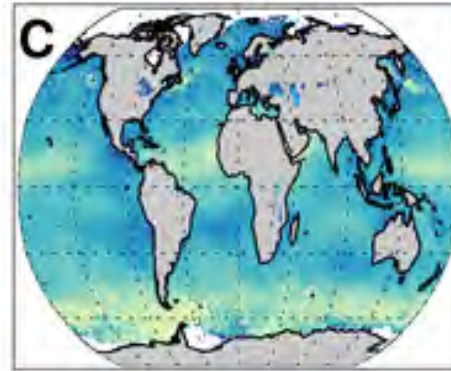
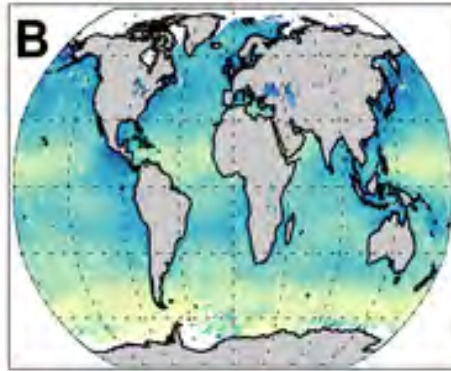
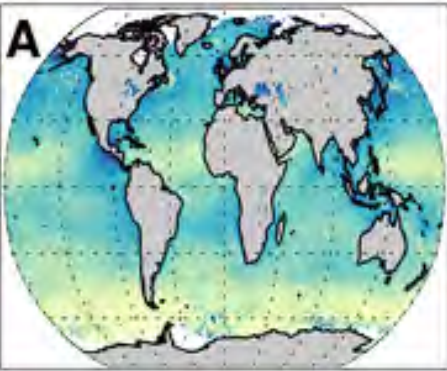
Angstrom Exponent (0.55 / 0.86 μm)

M_C6

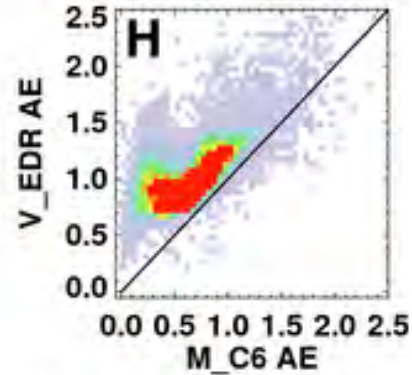
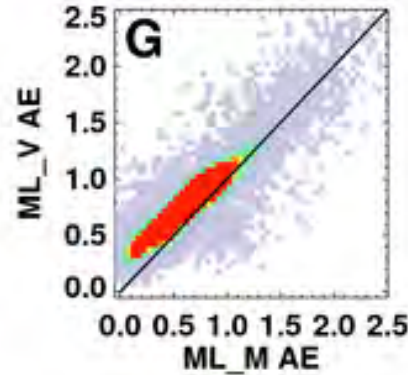
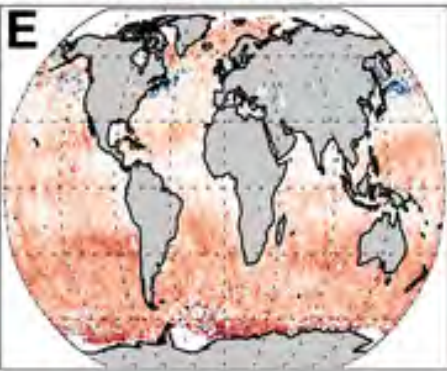
ML_M

ML_V

V_EDR



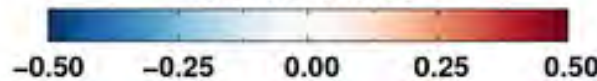
ML_V-ML_M



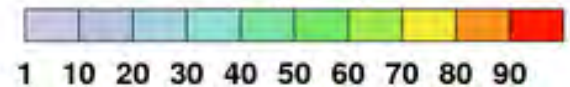
0.55/0.86 μm AE



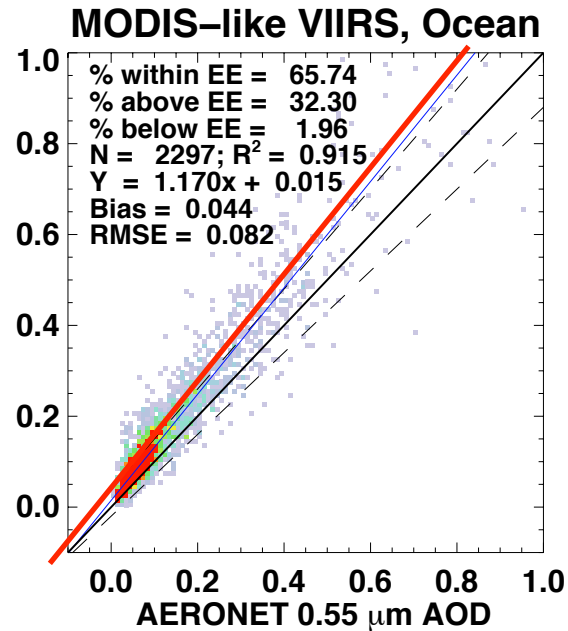
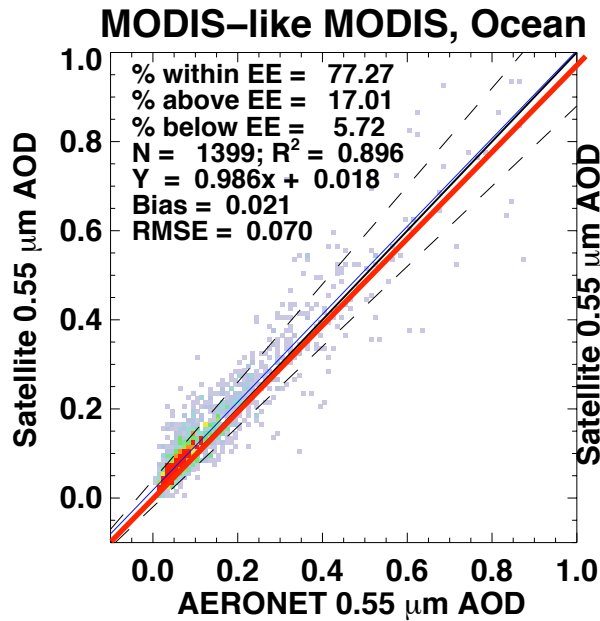
AE Difference



Frequency

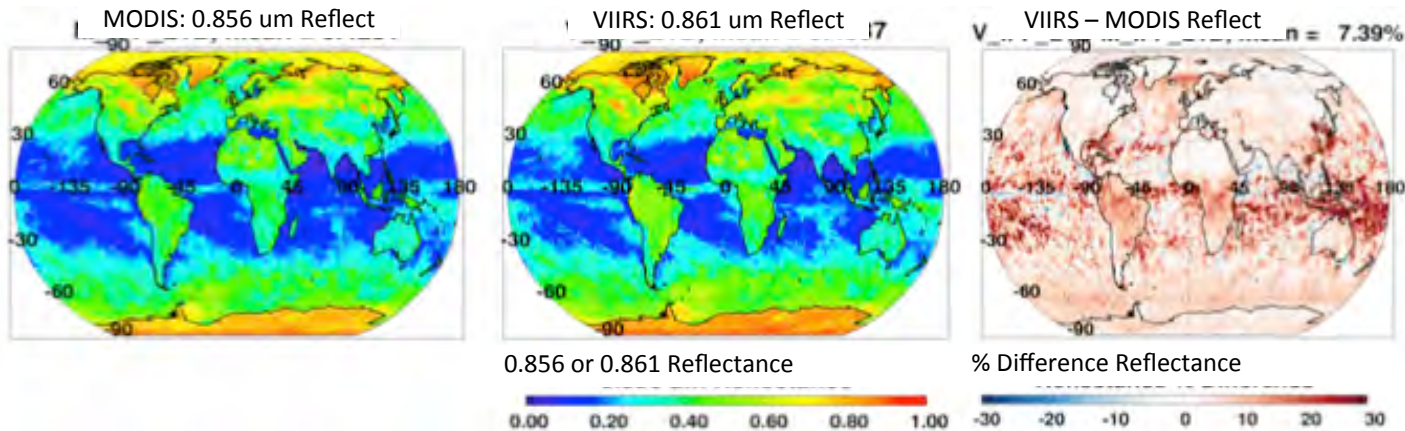


MODIS-like on VIIRS has Angstrom Exponent that looks much more like MODIS



Comparing to
AERONET and
calibration (2013)

- MODIS-like on VIIRS has great correlation ($R^2 > 0.9$) but 1.17 slope!
- 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.



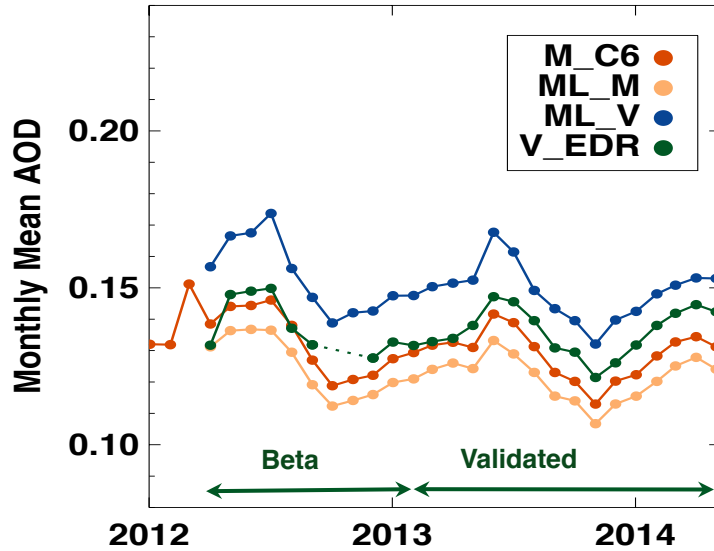
Will VIIRS continue MODIS?

How would we know?

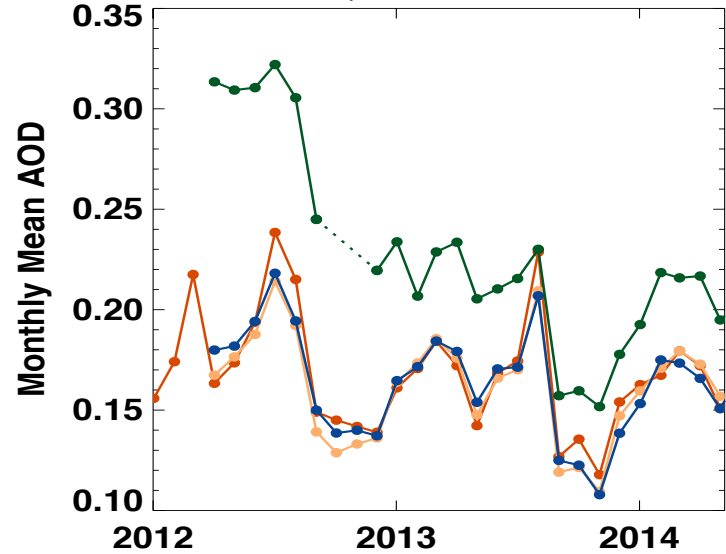
- Convergence of gridded (Level 3 –like) data?
 - For a day? A month? A season?
 - What % of grid boxes must be different by less than X?
 - in AOD? In Angstrom Exponent?
- What about “sampling”?
 - Even if the mean, histograms and gridded data looked similar, what about the “retrievability?”
 - Fraction of retrieved pixels / total pixel
- Comparison (validation) with AERONET?

A time series (of sorts) so far

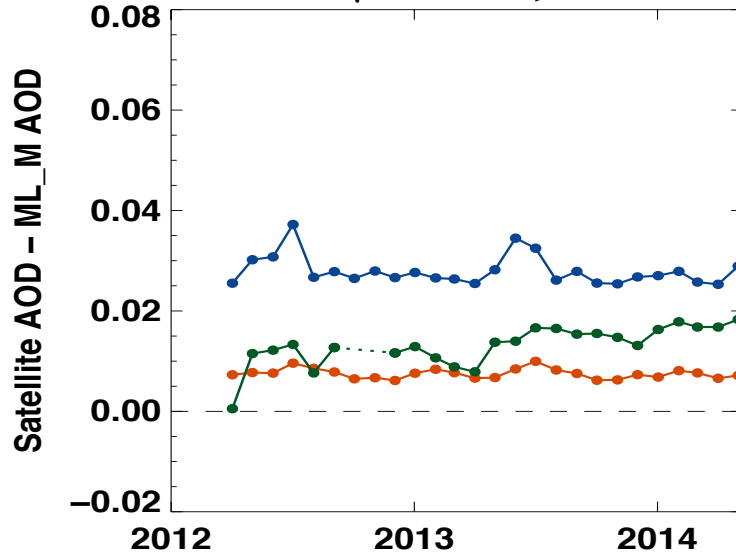
0.55 μm AOD, Ocean



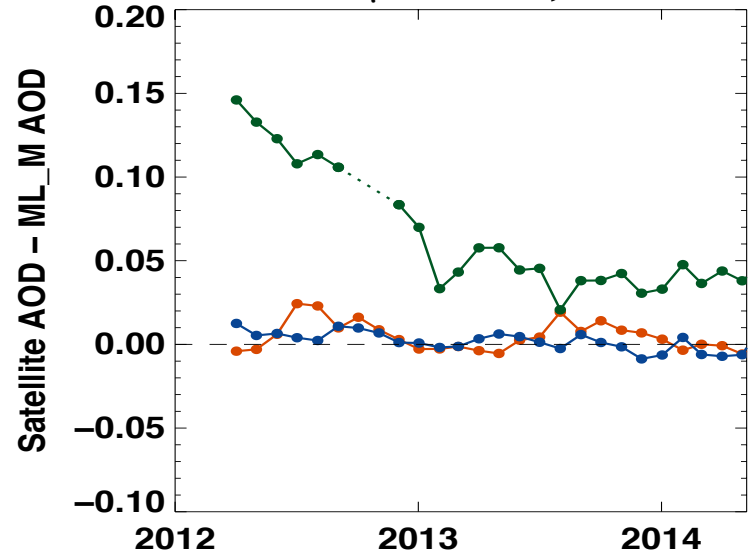
0.55 μm AOD, Land



0.55 μm AOD, Ocean



0.55 μm AOD, Land



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 will be submitted by end of May!
- 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” (modelers, assimilators, CERES team, etc). What do they need?



MODIS Aerosol

Dark-Target Retrieval Algorithm

OUR TEAM

PUBLICATIONS

CLIMATE & RADIATION

ALGORITHM

PRODUCTS

VALIDATION

REFERENCE

FAQ

LINKS

- 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>

