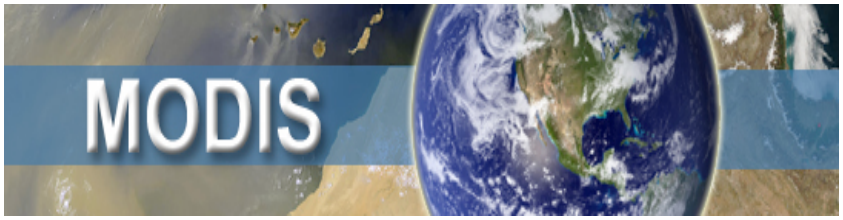
Creating a global aerosol data time series from MODIS, Suomi-NPP VIIRS and beyond: Applying the MODIS Dark Target algorithm





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

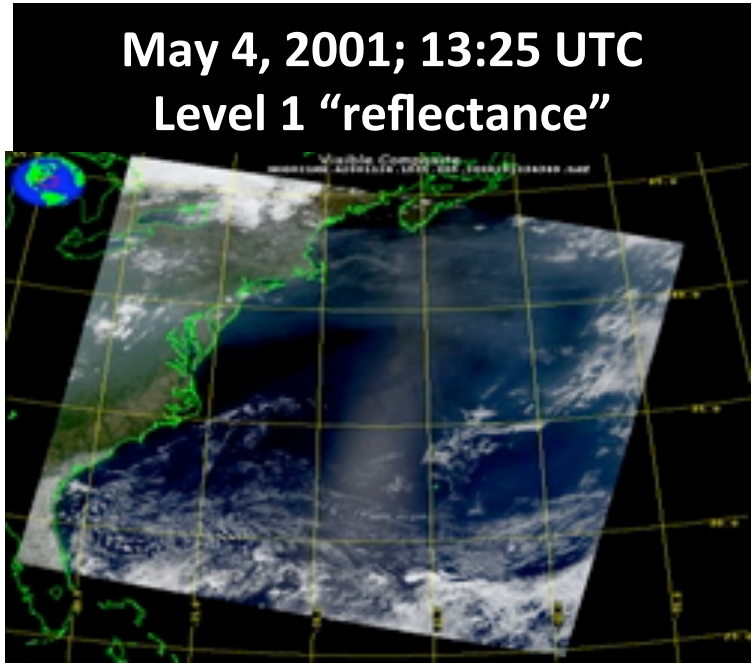
And the Dark-target aerosol retrieval team:

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

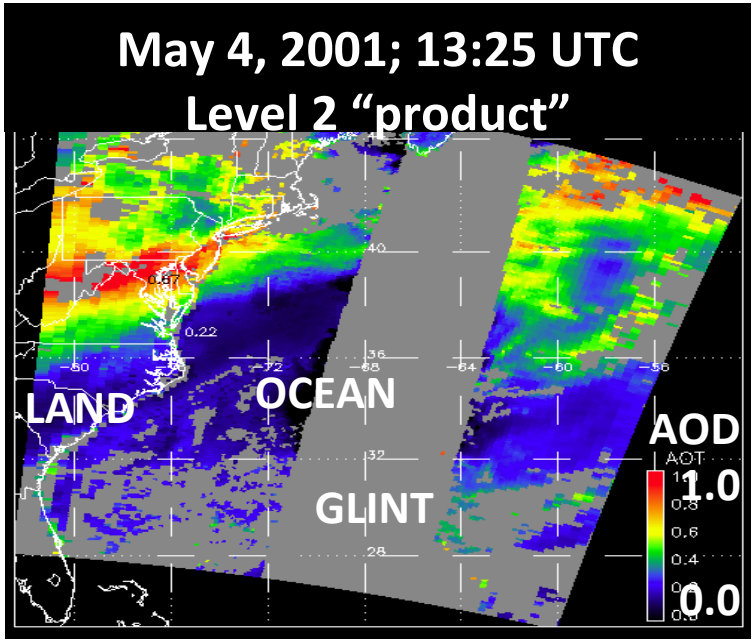
JPSS meeting, College Park, 27 Aug 2015

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,..): Previous talk!!!
3. MAIAC (coupled with land surface everywhere; Lyapustin, Wang, Korkin,…)
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)

Outline

1. MODIS Dark-target (DT) for Collection 6
2. Terra vs Aqua (and calibration and trends)
3. Onward to S-NPP VIIRS (and calibration and trends)
4. Summary, challenges, etc

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

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 μm) 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 μm) and compared to lookup tables

Both report the AOD at 550 nm,
Along spectral AOD and/or fine-mode fraction

Slide stolen and modified from A Sayer – ICAP 2015

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.

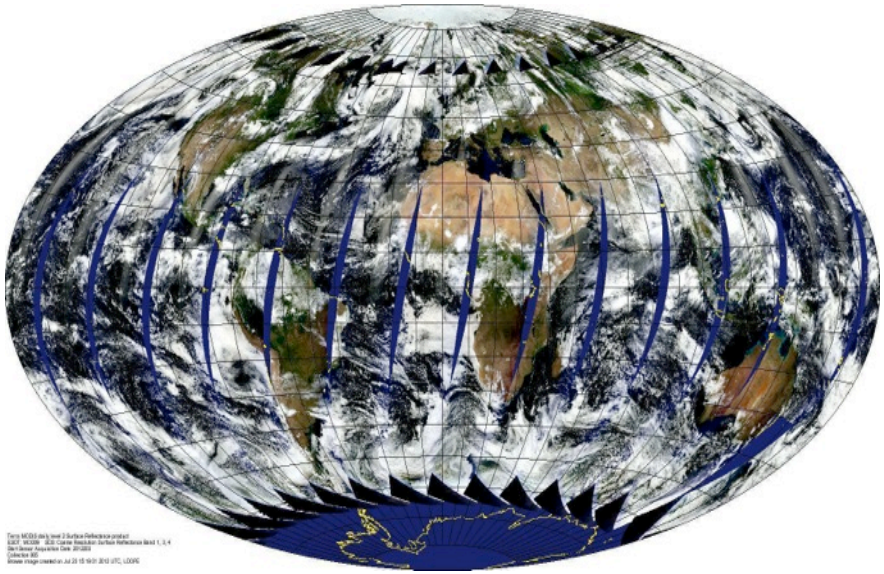
Collection 6 "Webinars": http://aerocenter.gsfc.nasa.gov/ext/registration/

New "dark-target" website: http://darktarget.gsfc.nasa.gov

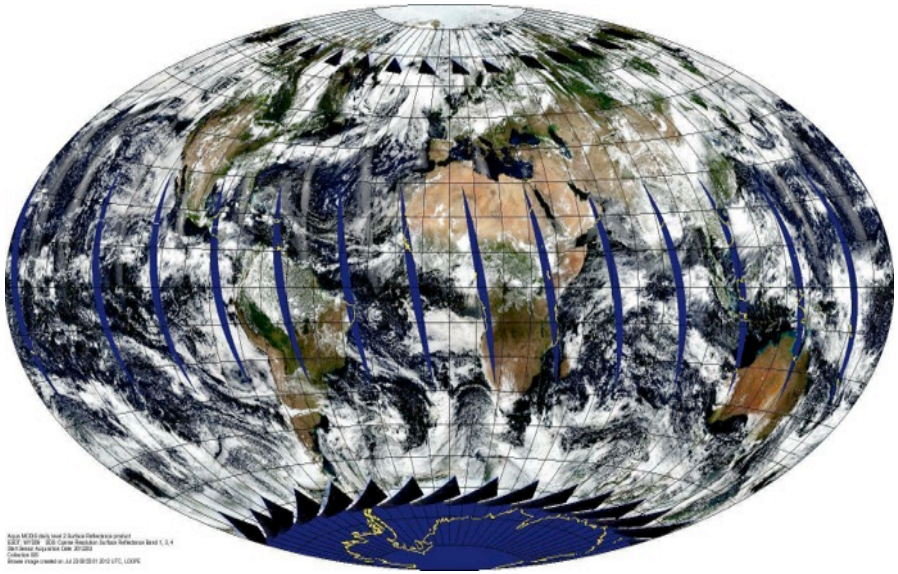
MODIS product website: http://modis-atmos.gsfc.nasa.gov

Terra vs Aqua: Focus on Trends/Calibration

Terra (since spring 2000)



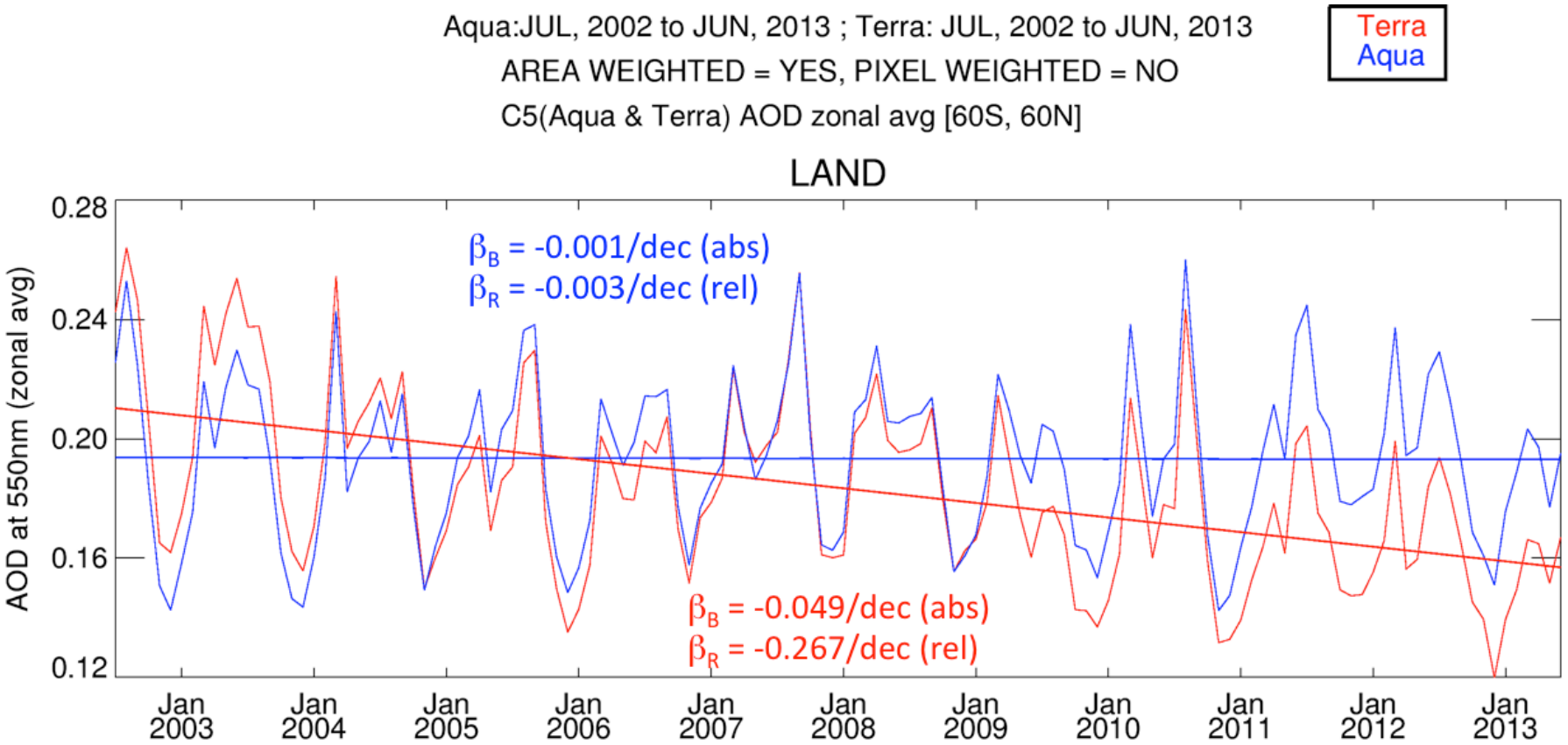
Aqua (since summer 2002)



- Same instrument hardware (optical design)
- Same spatial and temporal sampling resolution
- Same calibration/processing teams
- Same aerosol retrieval algorithms
- The two MODIS instruments are Identical twins!

How do they behave?

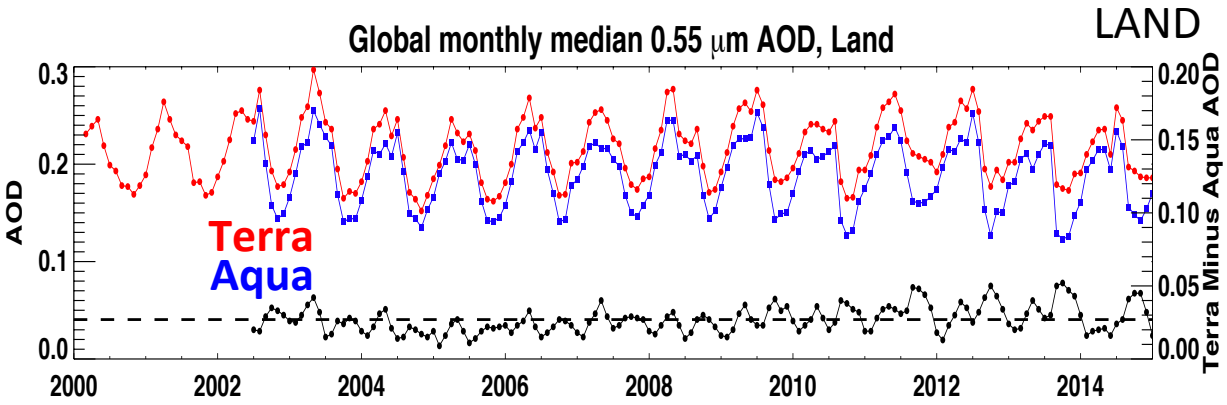
Aerosol Trends: If based on Collection 5

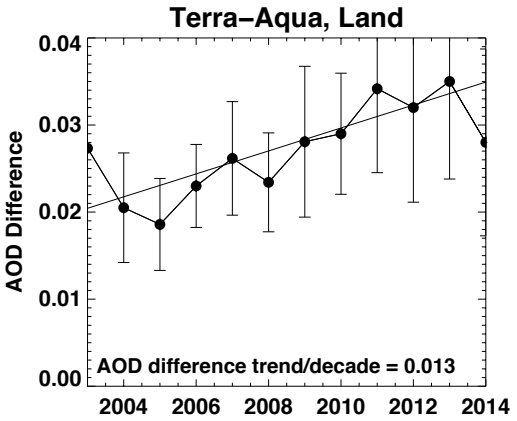


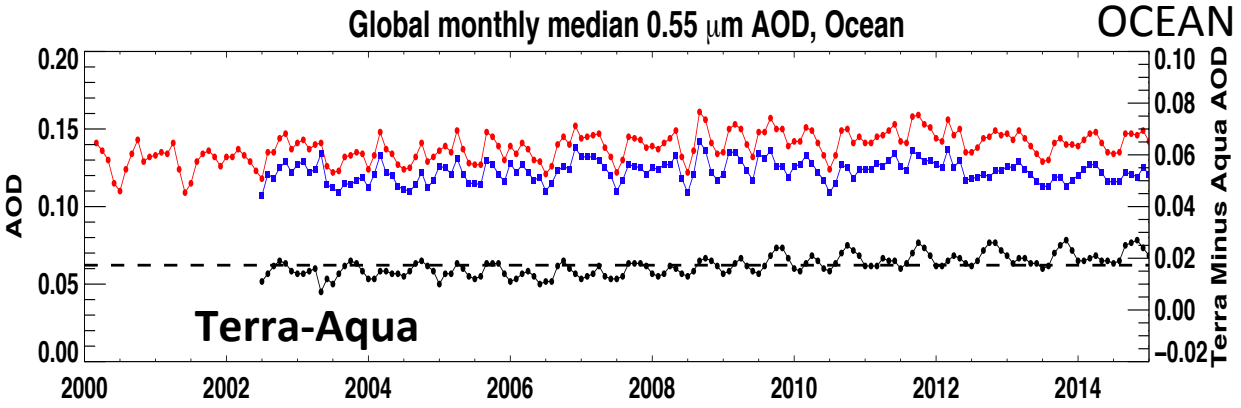
- Over land, Terra *decreased* (-0.05/decade), Aqua *constant*
- Terra / Aqua divergence was similar everywhere on the globe!

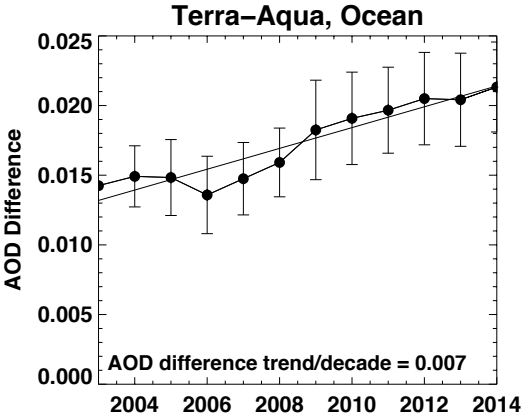
- Like identical human twins, the twin MODIS sensors aged differently.
- New calibration approach for Collection 6, using desert targets

C6 differences AOD: Terra-Aqua



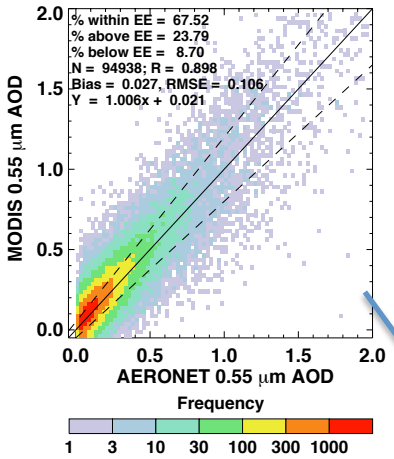






- Terra/Aqua divergence “mostly” removed for C6
- Terra offset by 0.027 land/0.017 ocean), THIS IS >13% of AOD!
- There is still residual trending (Terra-Aqua increasing by ~0.01/decade)
- Bigger-amplitude seasonal cycle to Terra-Aqua after 2011.

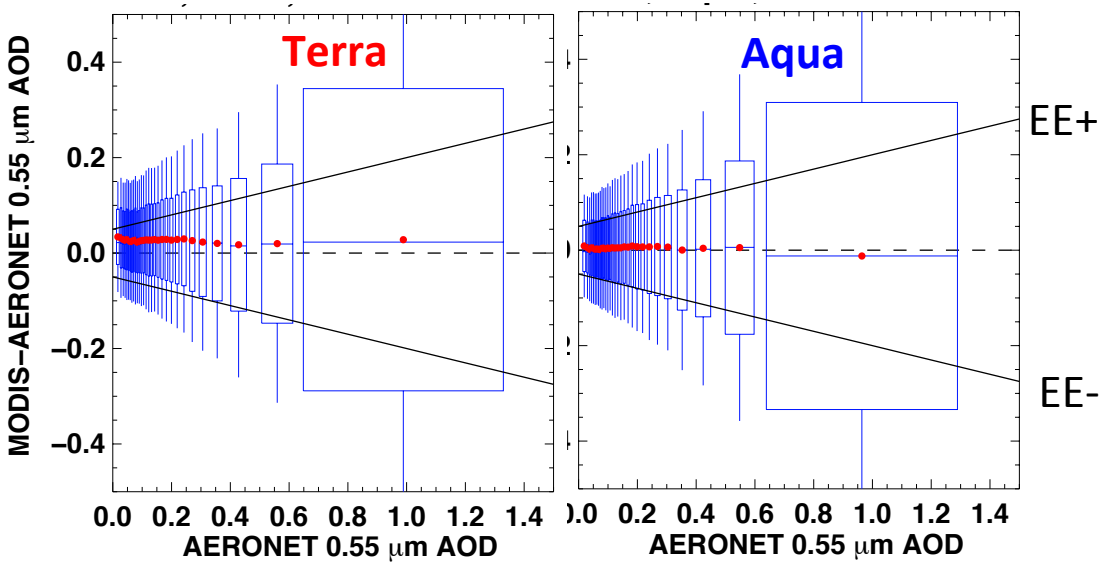
scatterplots



"Validation": 2003-2013, Land

Sat	N	Slope	Int	R	RMSE	Bias
Terra	94.9K	1.01	0.02	0.892	0.106	0.027
Aqua	80.5K	1.01	0.00	0.890	0.104	0.004

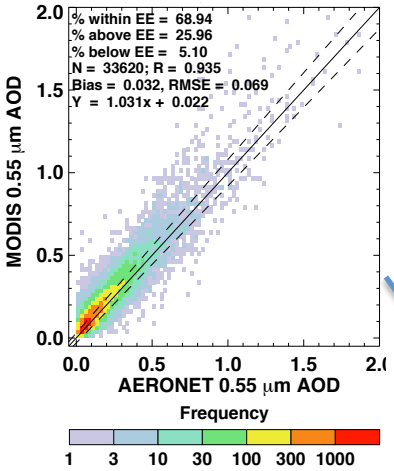
MODIS vs AERONET: Mar 2003-Feb 2013



- 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 of 0.02**)
- N_{Terra} = 95K versus N_{Aqua}=81K. Why? Calibration? Sampling? AM/PM Clouds? Other?

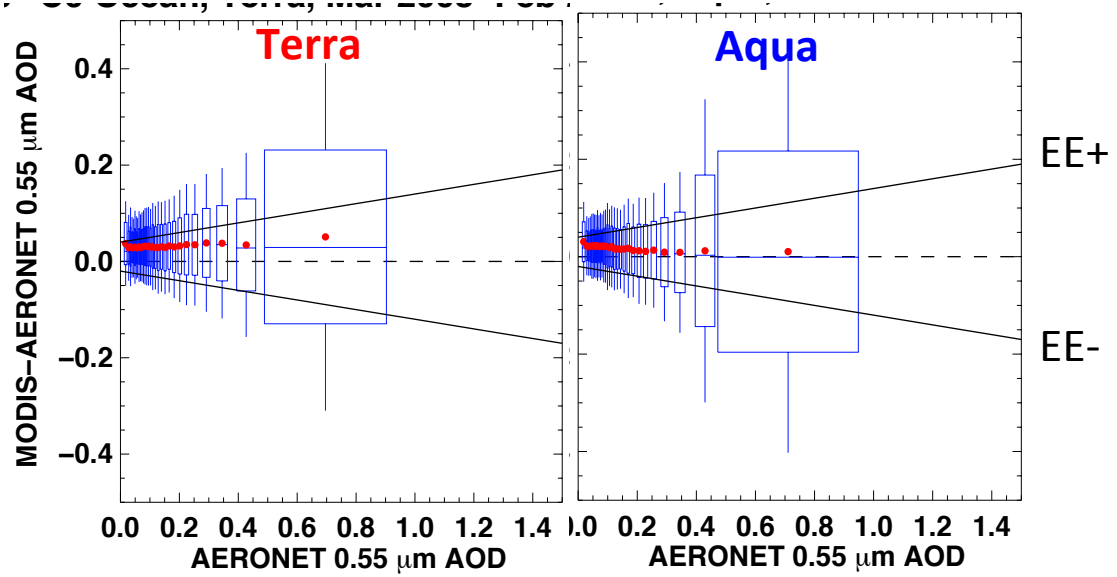
“Validation”: 2003-2013, Ocean

scatterplots



Sat	N	slope	Y-int	R	RMSE	Bias
Terra	33.6K	1.04	0.02	0.935	0.069	0.032
Aqua	29.9K	0.98	0.02	0.929	0.066	0.016

MODIS vs AERONET: Mar 2003-Feb 2013



- 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 = 1.04 versus 0.98**.
- N_{Terra} = 34K versus N_{Aqua}=30K. Why? Calibration? Sampling? AM/PM Clouds? Other?

Summary (MODIS C6)

- MODIS dark-target (DT) aerosol retrieval ("MxD04_L2") is updated for Collection 6.
- Trending issues reduced with C6 calibration
- But still significant offsets (~0.02). Why? Sampling? diurnal cycles? Cloud masking?
- Still residual co-trending (<0.01 / decade)
- Calibration is suspect, trying different alternatives

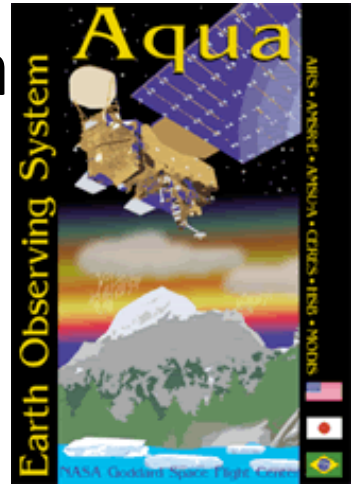
Lyapustin, A., Wang, Y., Xiong, X., Meister, G., Platnick, S., Levy, R., Franz, B., Korkin, S., Hilker, T., Tucker, J., Hall, F., Sellers, P., Wu, A. and Angal, A.: Scientific impact of MODIS C5 calibration degradation and C6+ improvements, Atmos Meas Tech, 7(12), 4353–4365, doi:10.5194/amt-7-4353-2014,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

Doelling, D.R.; A.Wu; X. Xiong; et al: The Radiometric Stability and Scaling of Collection 6 Terra- and Aqua-MODIS VIS, NIR, and SWIR Spectral Bands," IEEE-TGARS , 53, 8, 4520-4535, doi: 10.1109/TGRS.2015.2400928, 2015.

Beyond MODIS?

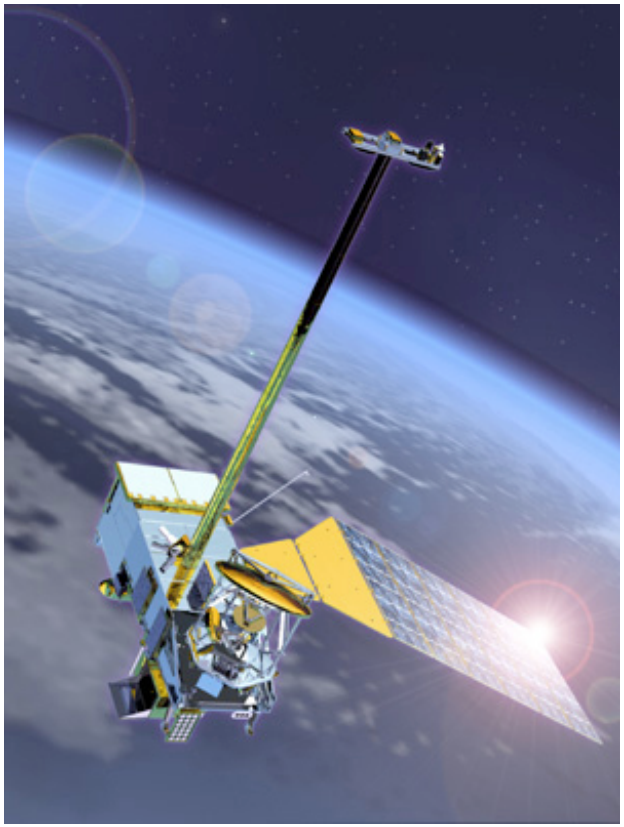


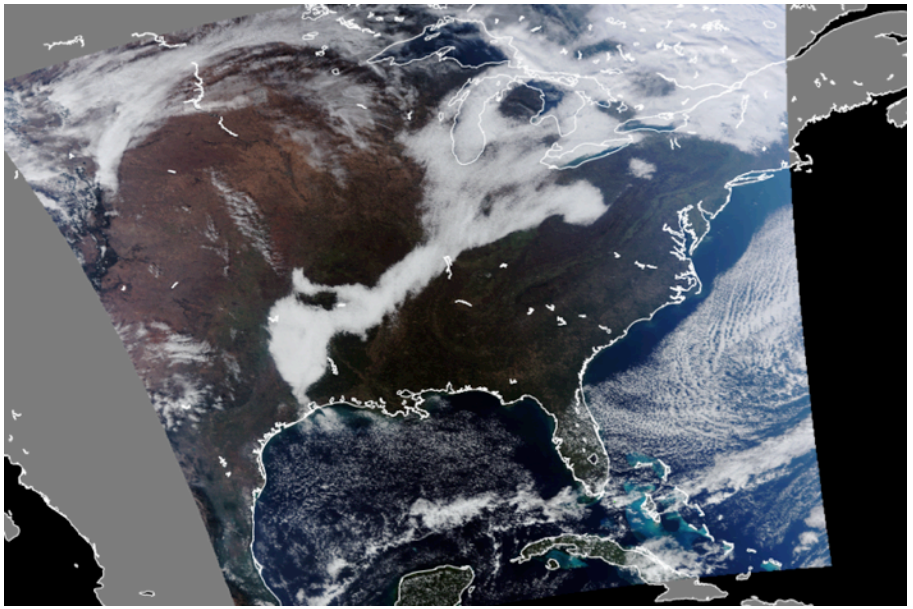
- Terra just celebrated its 15th birthday!
- At 13+, Aqua ain't no spring chicken!
- Terra and Aqua MODIS instruments are both >2x original mission lifetimes
- MODIS won't be here forever
- How do we get to 20+ year aerosol data records?



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)

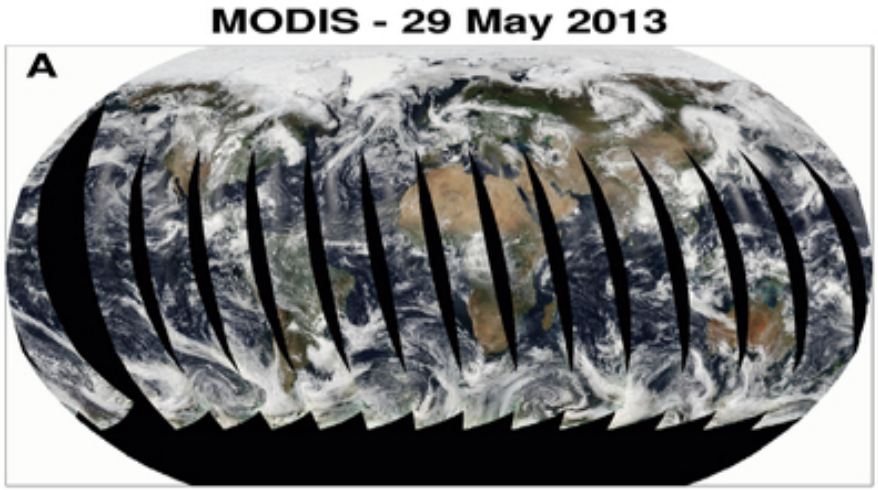
Spectral Range: 0.412-12.2μm (22 bands versus 36 bands)

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

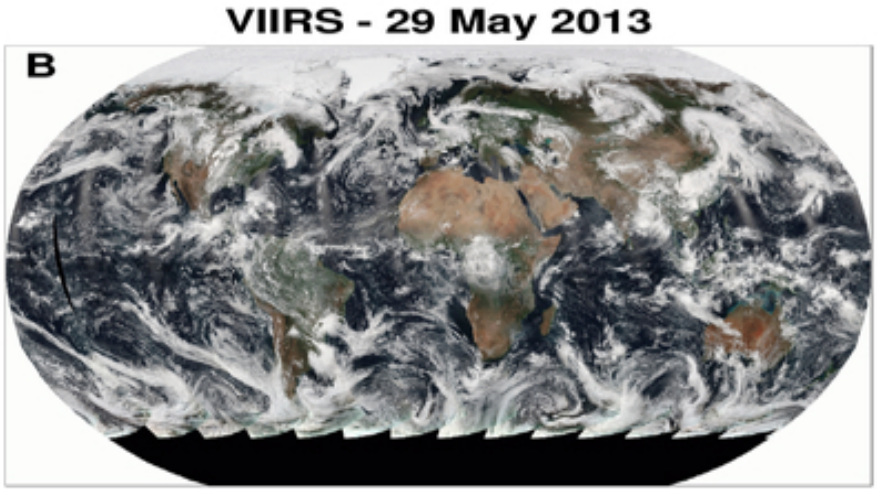
Aerosol retrieval algorithms: "Physics" similar, but different strategies

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.

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



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

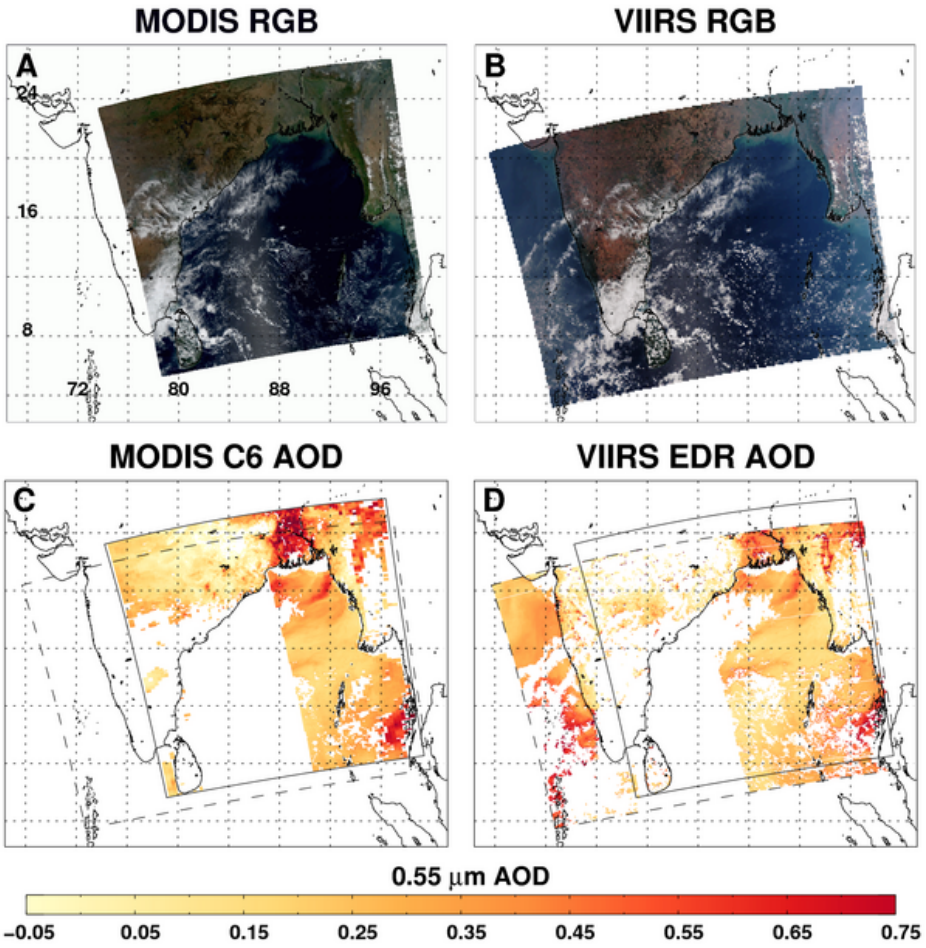


VIIRS Aerosol Algorithm (NOAA-IDPS)

- 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:
- Retrieves: AOD (at 0.55 μm and spectral), Ångström Exponent (AE), Suspended Matter (aerosol classification), etc
- Provides data in HDF5 format (compared to HDF4-ish for MODIS)
- "Validated Stage 2" (published) since 23 Jan 2013. It is a "good" product, with similar error budgets as MODIS DT product.

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)

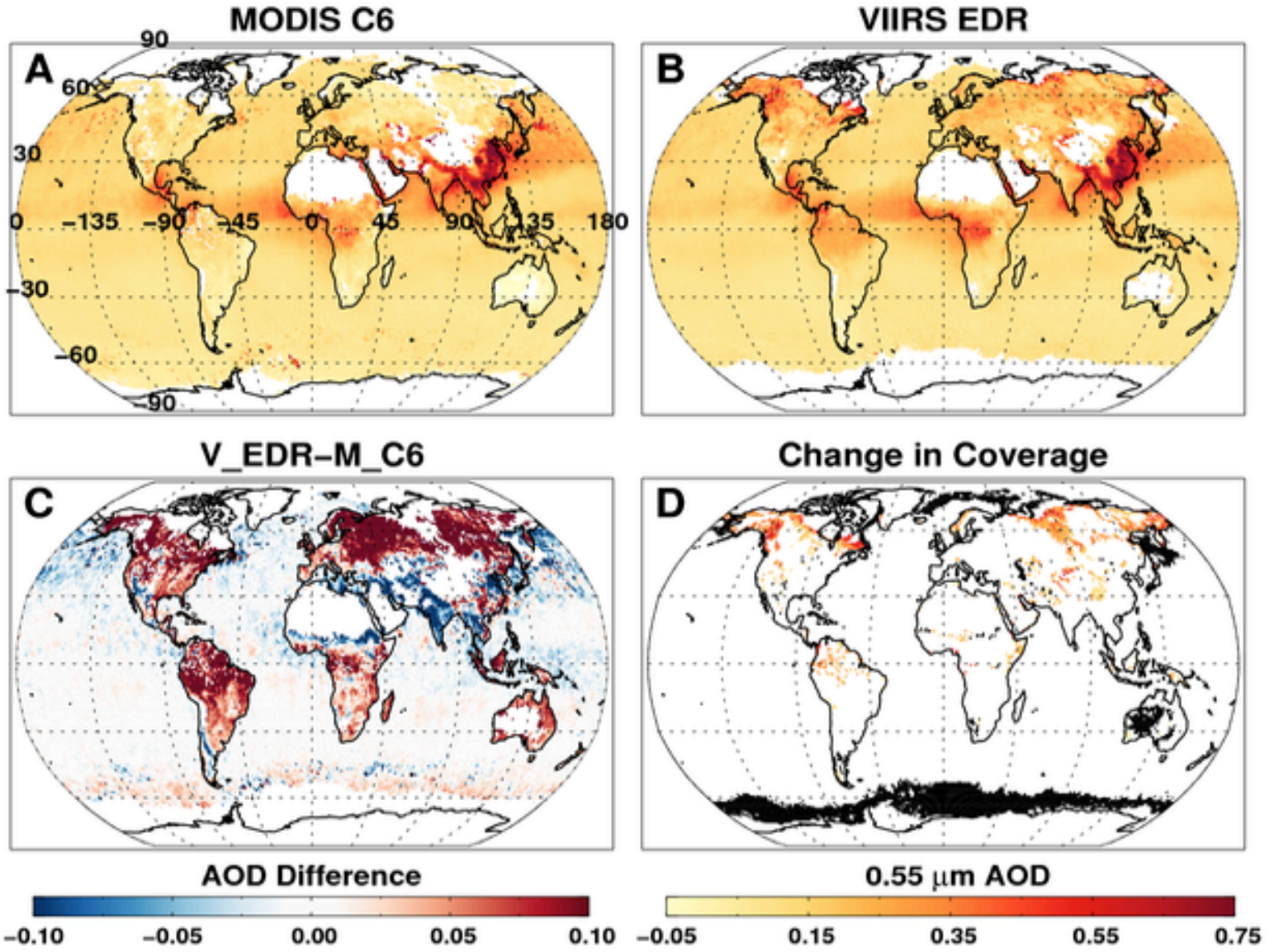
Land retrieval algorithm

- "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.

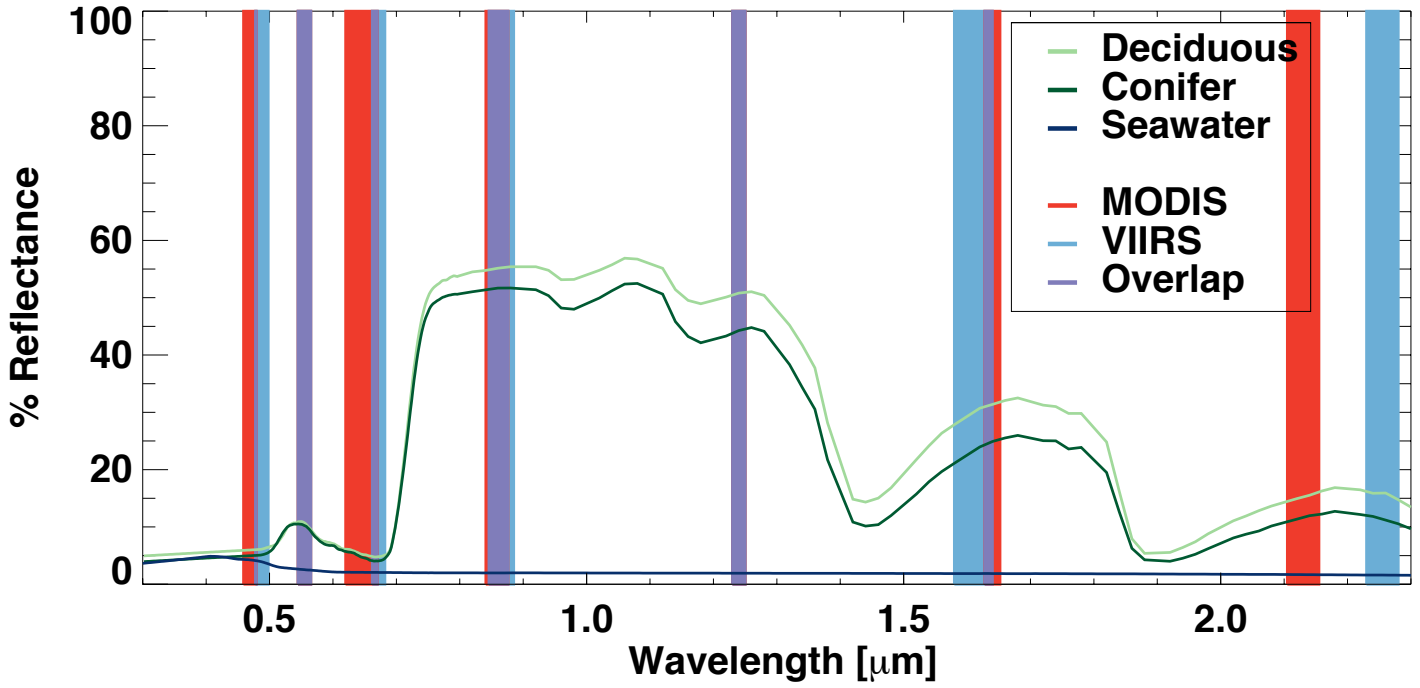
Monthly mean AOD for Spring 2013 (Mar-May)



MODIS C6 and VIIRS-EDR are similar, yet too different

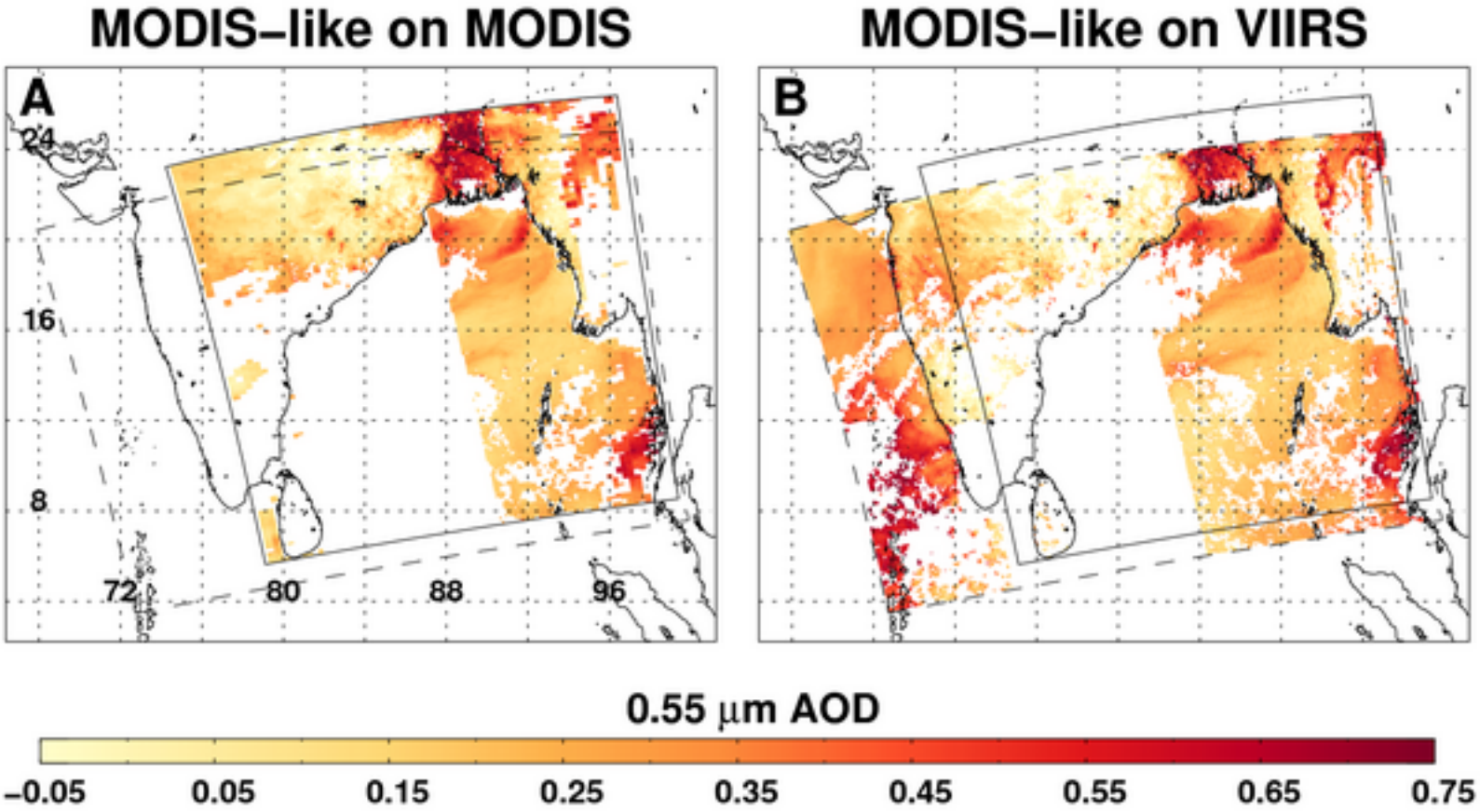
Developing a MODIS-like algorithm for VIIRS

- 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

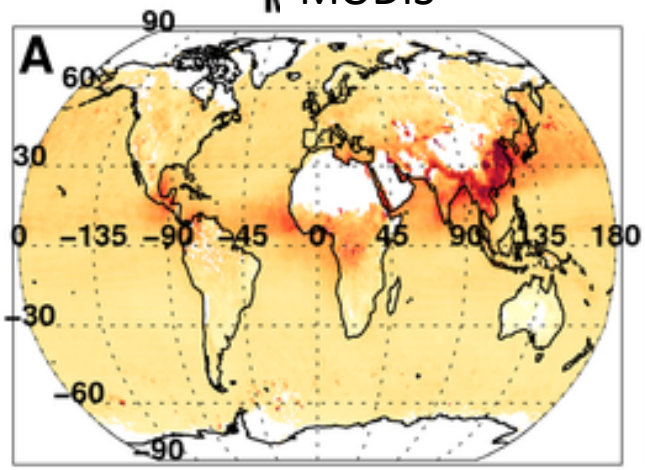


→ Much more similar AOD structure

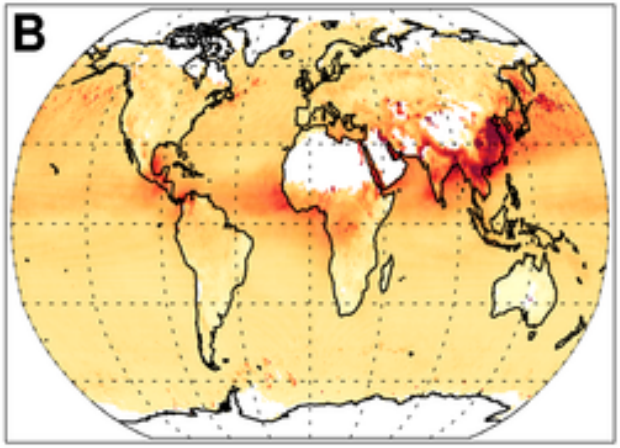
→ Still differences in coverage and magnitude. We are learning why. (Cloud masking/spatial variability thresholds?)

Gridded seasonal AOD (Spring 2013)

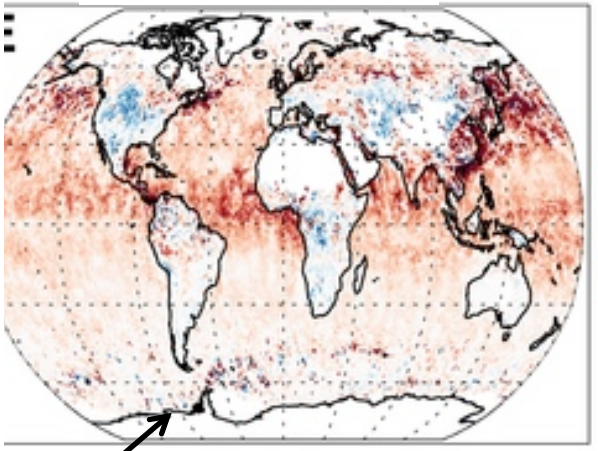
MODIS



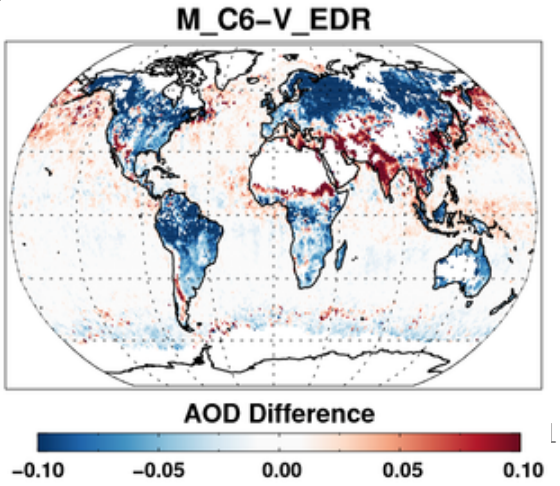
MODIS-like on VIIRS



Difference M - V



Versus…



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

Systematic bias over ocean (VIIRS high by 15%)

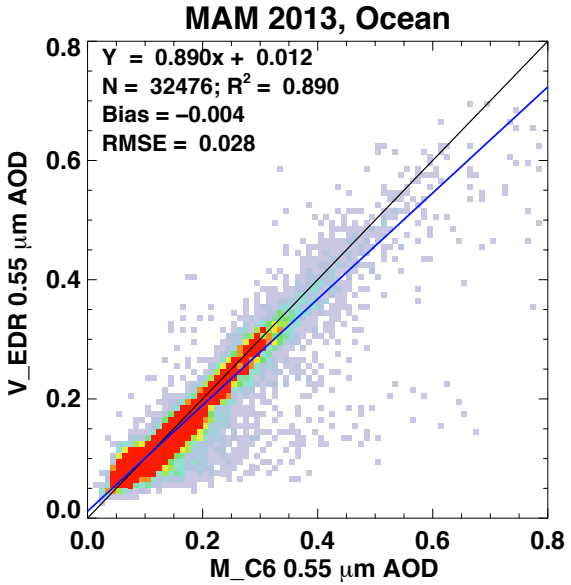
Not systematic bias over land (VIIRS low by 5%)

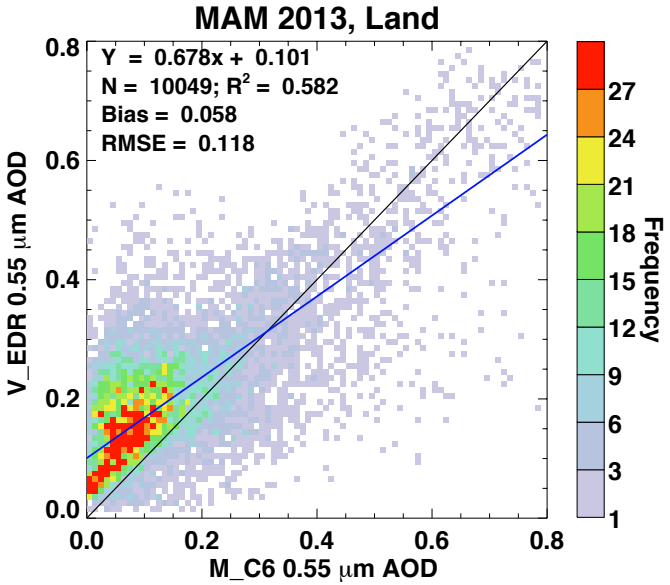
Comparing gridded AOD (Spring 2013)

OCEAN

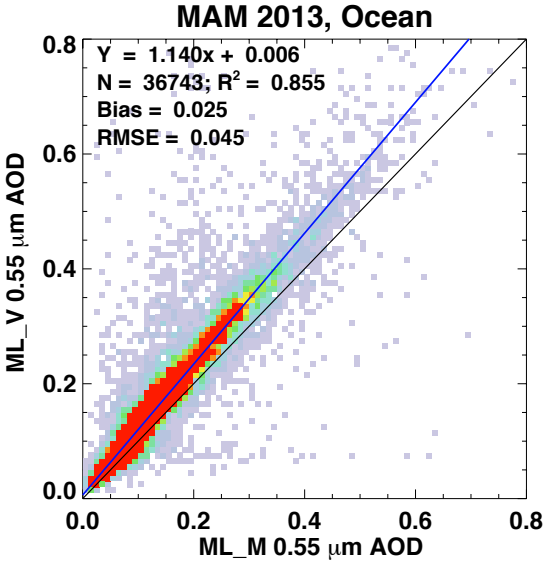
LAND

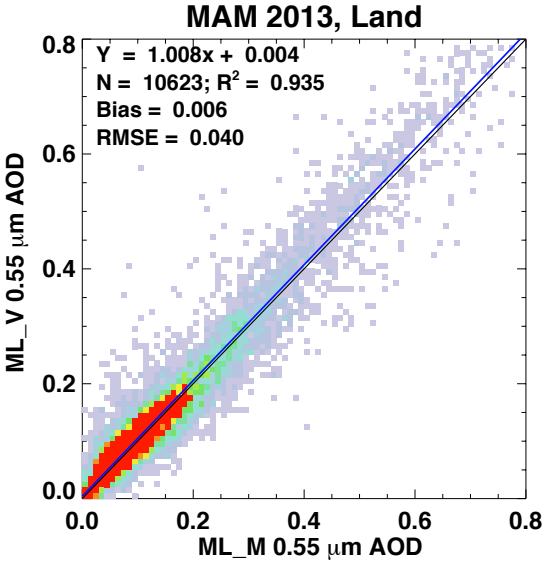
VIIRS_EDR vs MODIS





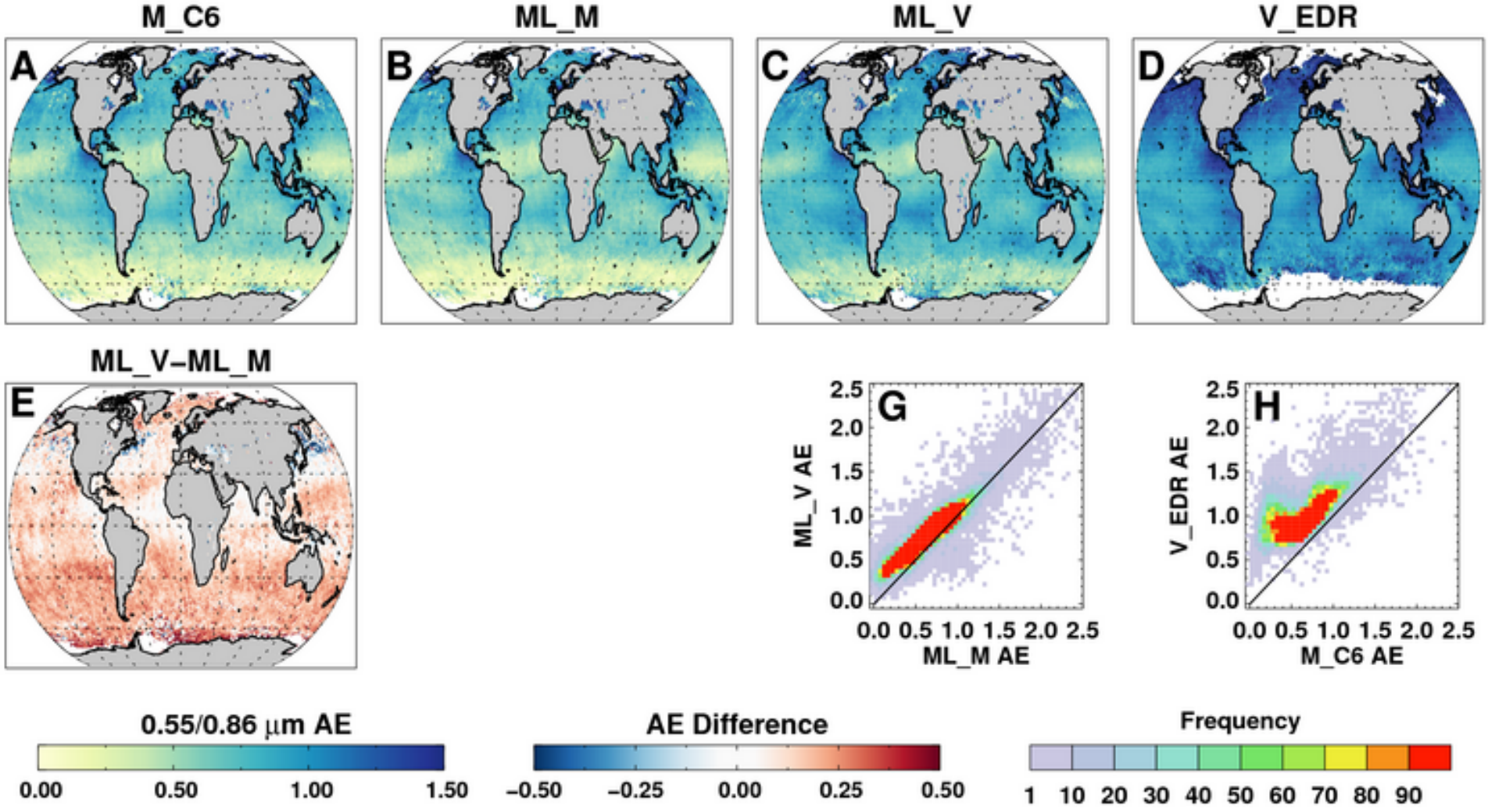
MODIS-like (VIIRS) vs MODIS





New data
More like MODIS
But 1.15 slope over ocean!

Angstrom Exponent (0.55 / 0.86 μm)



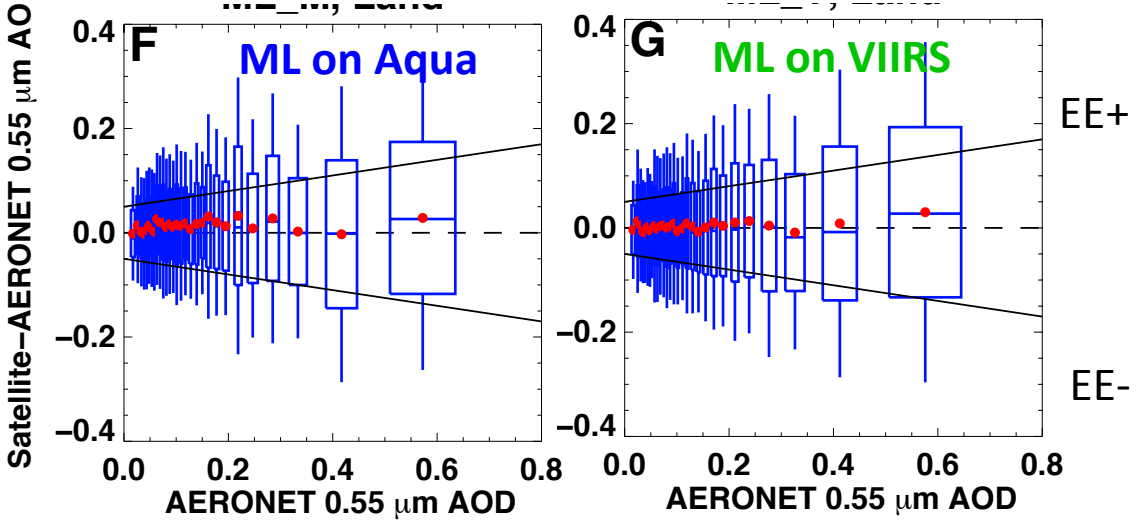
MODIS-like on VIIRS has Angstrom Exponent that looks much more like MODIS
Note: AE is calculated offline (from spectral AOD), and wavelengths are consistent

“Validation”: 2013-2014, Land

scatterplots

Sat	N	slope	Y-int	R	RMSE	Bias
ML-M	4128	1.00	0.003	0.901	0.101	0.012
ML-V	4989	1.01	-0.007	0.902	0.111	0.005

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



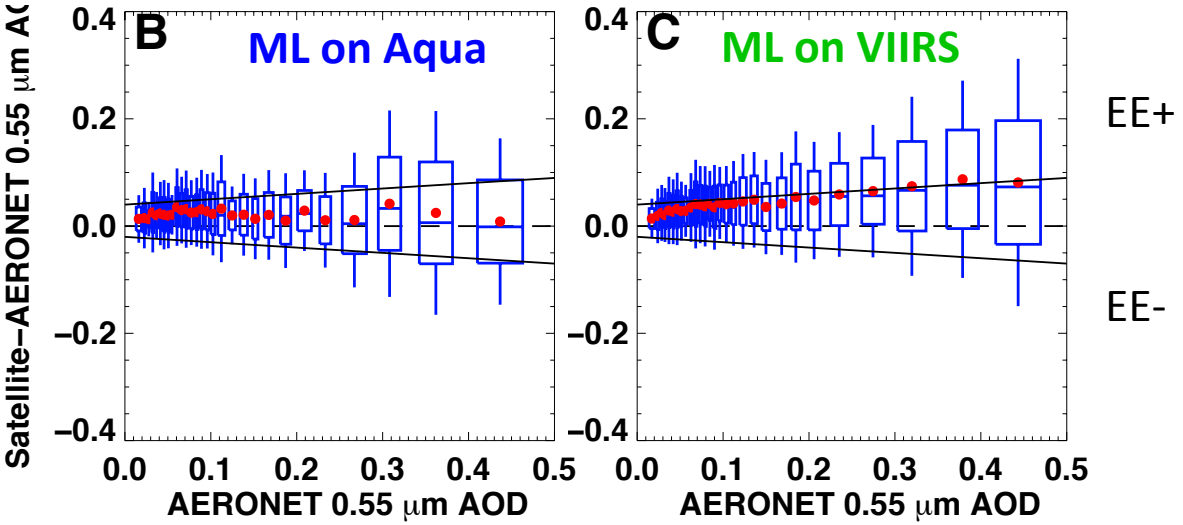
- EE% > 68%: Both VIIRS and MODIS-Aqua meet “expected error (EE) ” of ±(0.05 + 15%)
- Some metrics nearly identical: Corr = R=0.90, Slope=M=1.01, RMSE=0.10
- VIIRS is has even smaller bias than MODIS (due to negative **y-intercept**)

“Validation”: 2013-2014, Ocean

scatterplots

Sat	N	slope	Y-int	R	RMSE	Bias
ML-M	1399	0.98	0.02	0.931	0.070	0.021
ML-V	2297	1.17	0.02	0.949	0.078	0.044

VIIRS vs Aqua: Mar 2013-Feb 2014

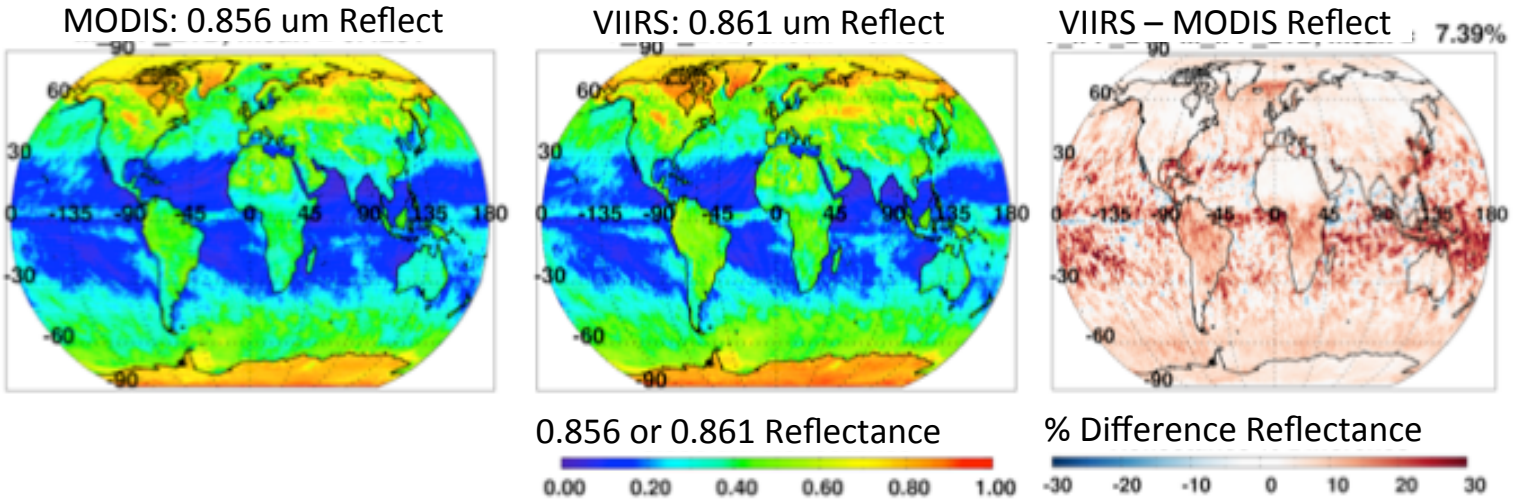


- VIIRS does not quite meet >68% within EE of ±(0.03 + 10%)
- Some metrics nearly identical: Corr = R=0.93, Y-int=0.02, RMSE=0.07
- VIIRS is biased very high, but due to **slope = 1.17 versus 0.98**.

Calibration? Again?

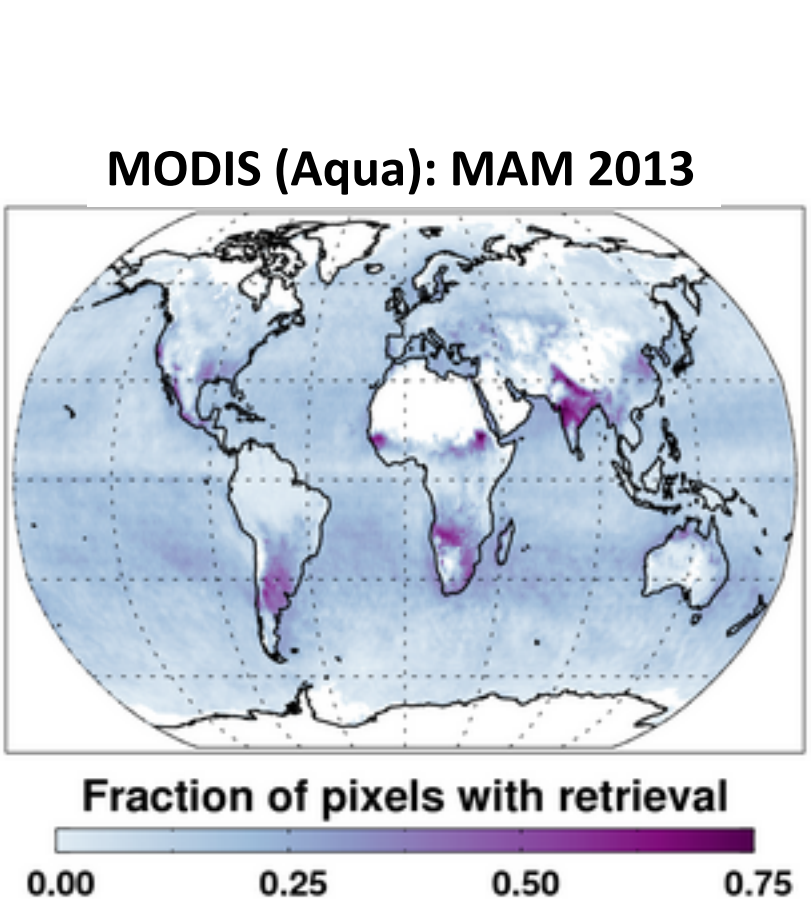
- Terra vs Aqua:
  - Ocean: Terra high by +0.017 or 13%; Driven by slope
  - Land: Terra high by +0.027 or 13%, Driven by y-offset

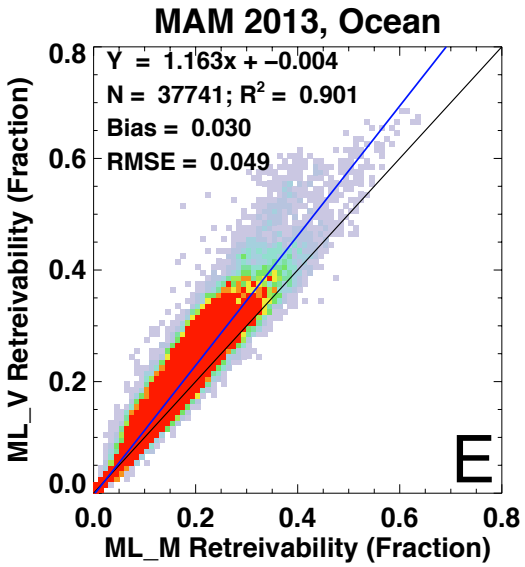
- VIIRS vs Aqua:
  - Ocean: VIIRS high by +0.25 or 20%; Driven by slope
  - Land: VIIRS lower by -0.01 or 5%; Driven by y-offset

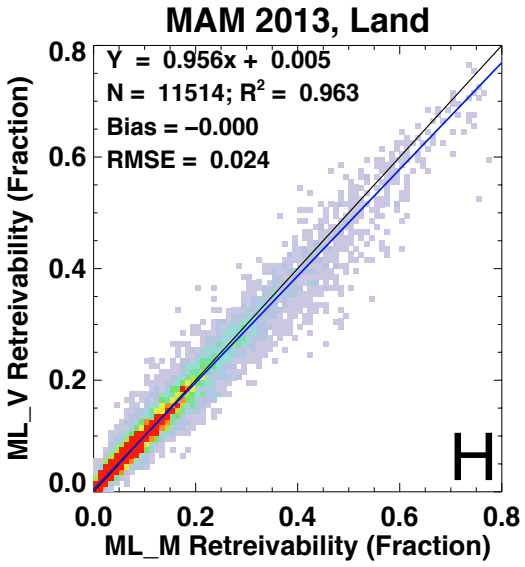


- VIIRS reflectance may be >2% high in some bands? (e.g. Uprety et al., 2013)
- 2% high bias can give a 1.17 slope over ocean without the adding bias to land.
- Terra-Aqua differences are smaller, but they also to be calibration-driven..

Retrievability: To retrieve or not to retrieve?







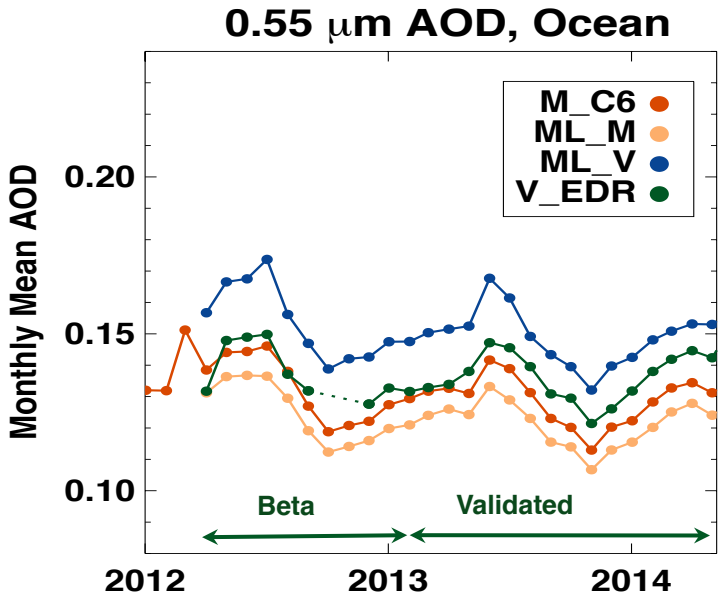
1°x1° retrieval fractions provided by the ML_V versus ML_M products during Spring 2013.

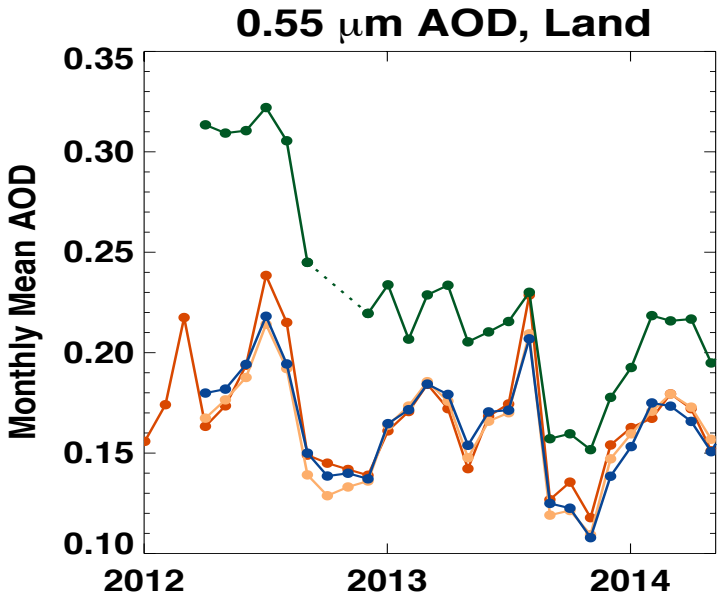
Will VIIRS continue MODIS? How would we know?

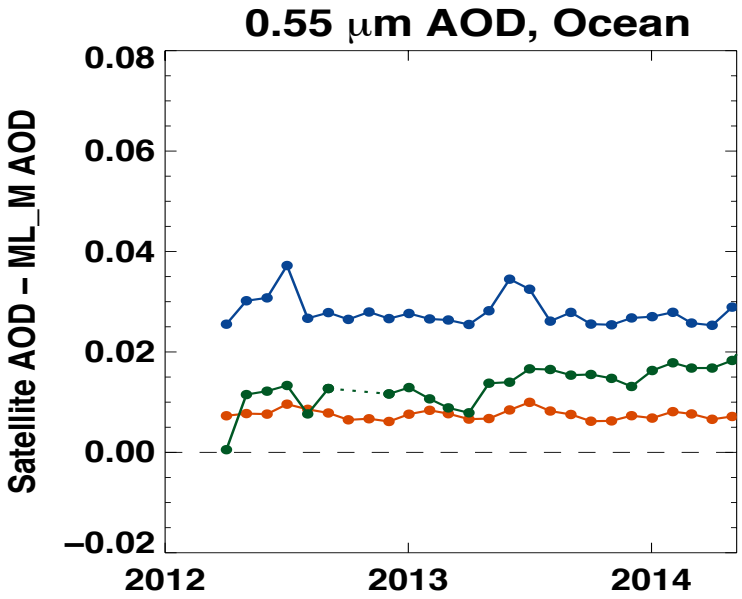
- Convergence: of gridded (Level 3 –like) data
  - For a day? A month? A season?
  - What % of grid boxes must be different by less than X?
    - in AOD? In Angstrom Exponent? Size parameters?

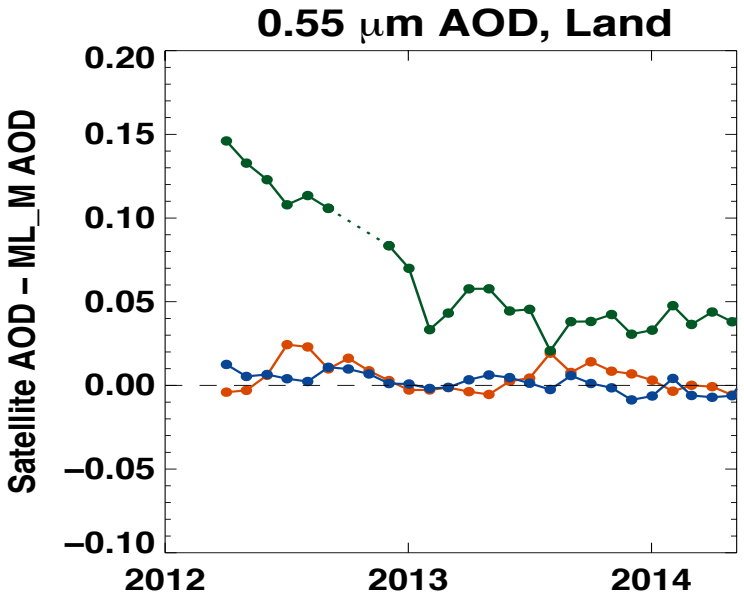
- Sampling: Do instruments observe similar conditions?
- Retrievability: Do algorithms make same choices?
- Validation: Comparison with AERONET, MAN, etc?

A time series (of sorts) so far









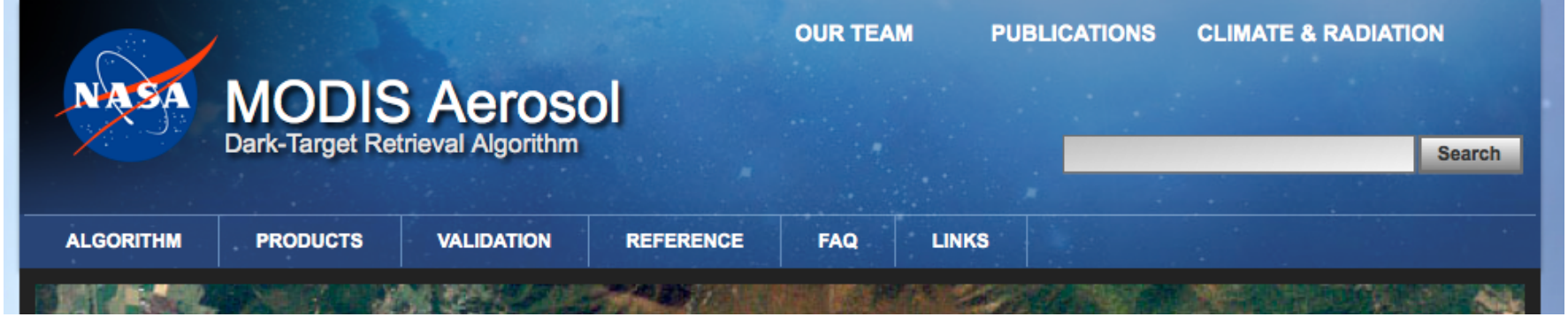
Summary

- 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 under review for AMT ! (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
- Improvements for "Collection 7"? which would be a joint MODIS/ VIIRS product.

- Thank you Shobha for the invitation today.



- Web site /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

