

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



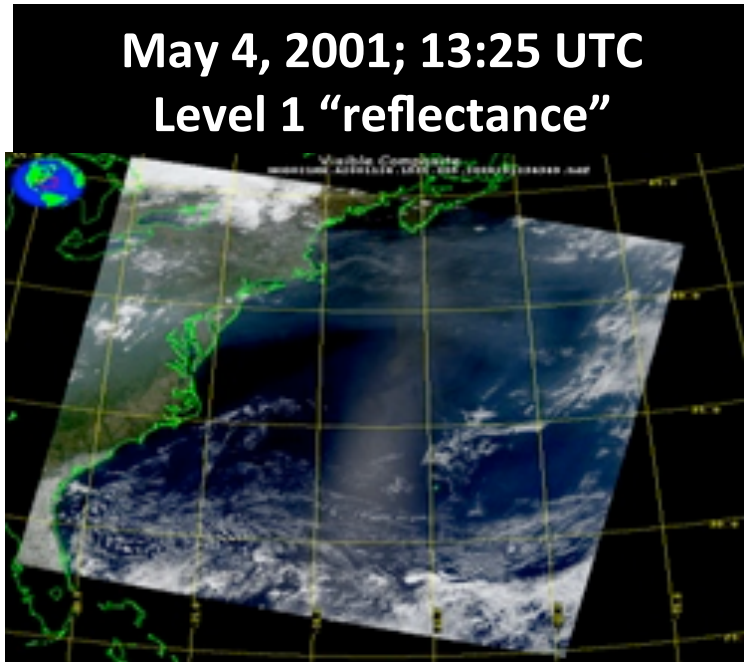
Robert C. Levy (NASA-GSFC)  
robert.c.levy@nasa.gov

And the Dark-target aerosol retrieval team:

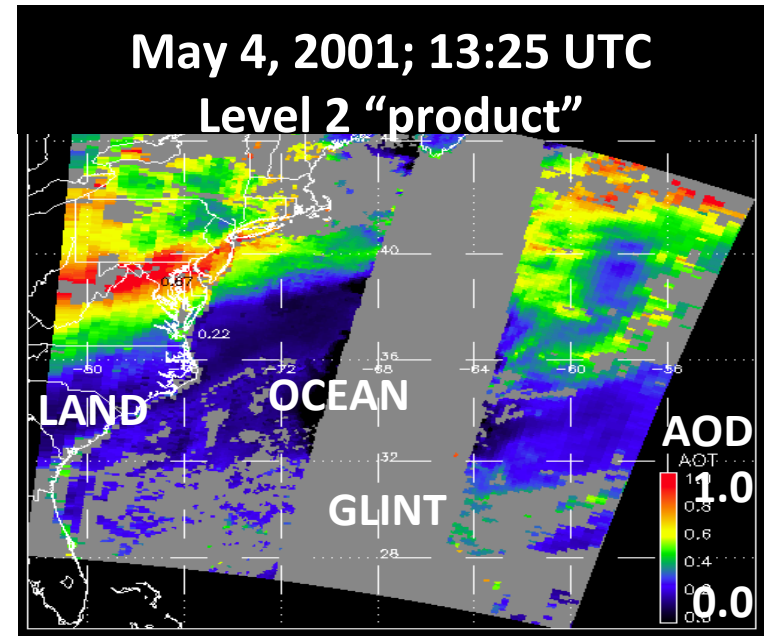
Shana Mattoo, Leigh Munchak and Richard Kleidman (SSAI/GSFC) -  
Lorraine Remer (UMBC/JCET), Falguni Patadia (MSU/GSFC), -  
Pawan Gupta (USRA/GSFC), Robert Holz (SSEC/UWisc), and others

# 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,.. ): 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 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  $\mu\text{m}$ ) and compared to lookup tables



## Water

Surface BRDF including glint, foam, underlight (function of wind speed)

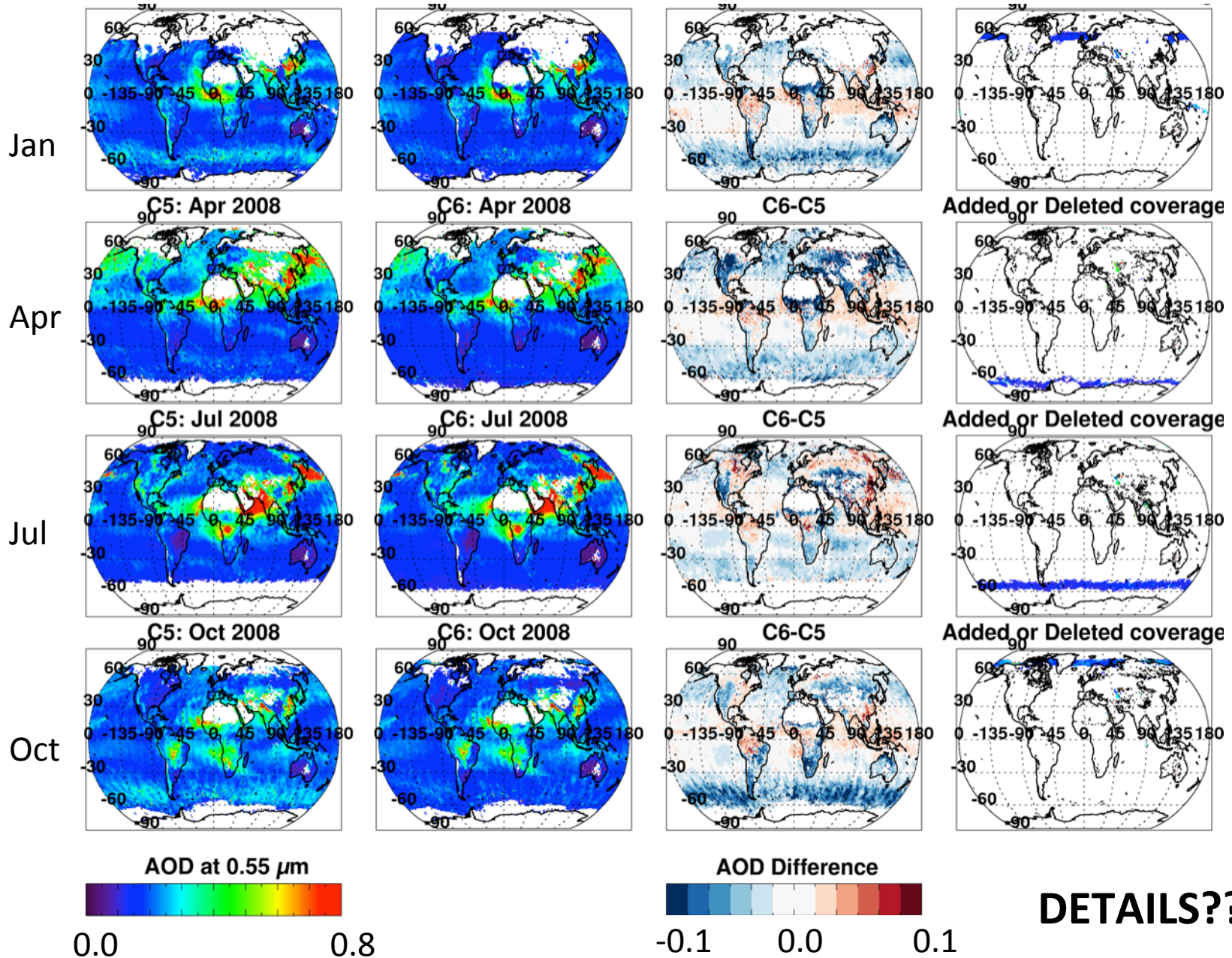
Aerosol types are not prescribed for season/location

Multispectral inversion using 6 wavelengths (0.55 – 2.1  $\mu\text{m}$ ) 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



# 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.

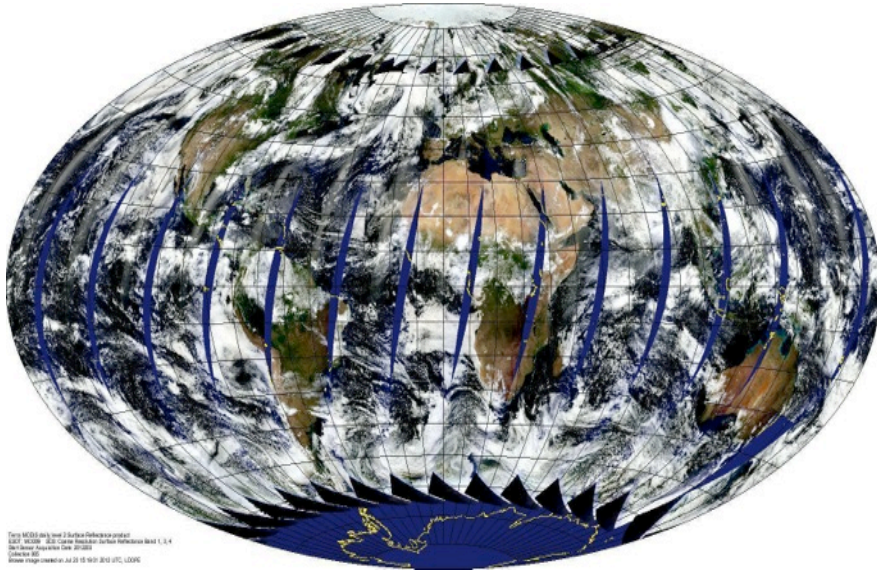
Collection 6 “Webinars”: <http://aerocenter.gsfc.nasa.gov/ext/registration/>

New “dark-target” website: <http://darktarget.gsfc.nasa.gov>

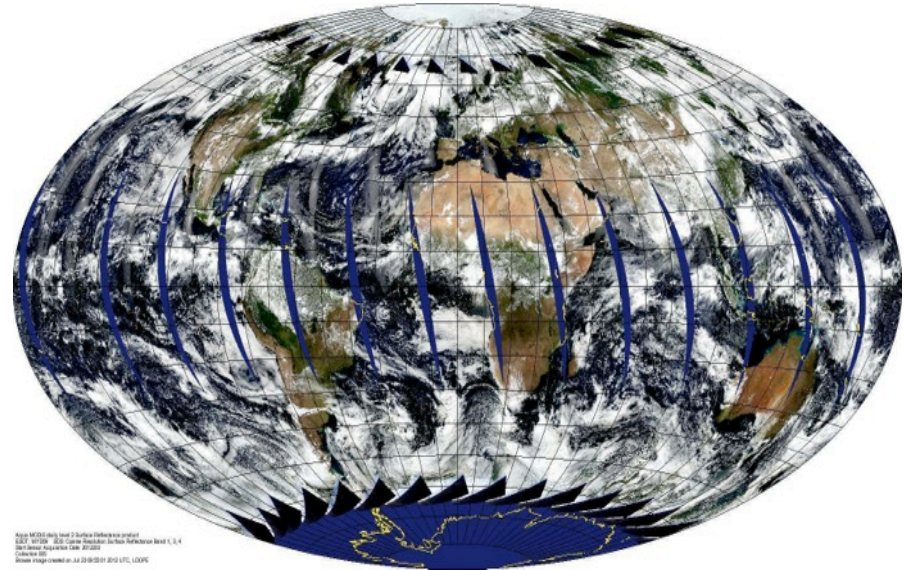
MODIS product website: <http://modis-atmos.gsfc.nasa.gov>

# Focus on Trends/Calibration: Terra versus Aqua

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

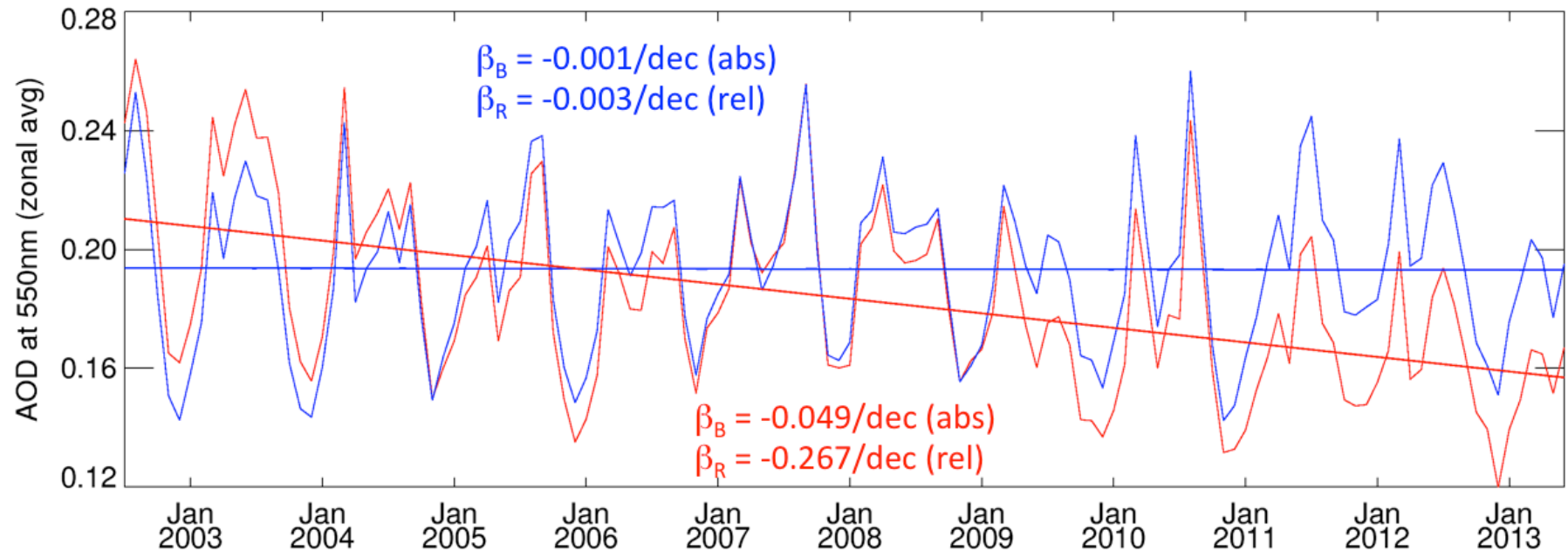
Aqua: JUL, 2002 to JUN, 2013 ; Terra: JUL, 2002 to JUN, 2013

AREA WEIGHTED = YES, PIXEL WEIGHTED = NO

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

Terra  
Aqua

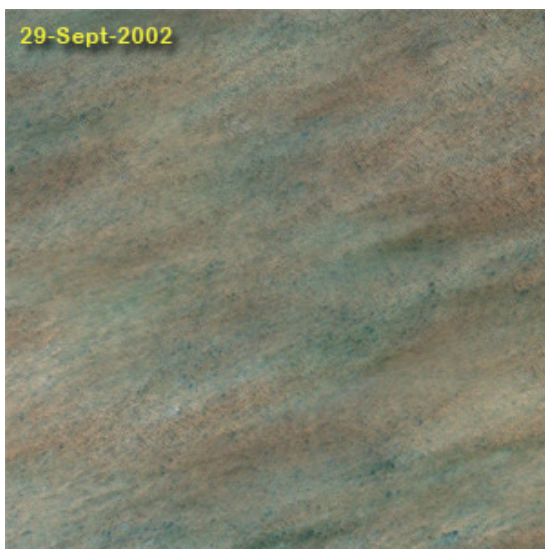
LAND



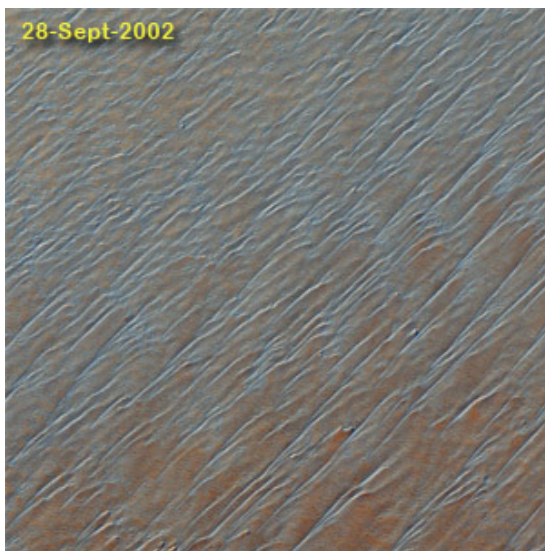
- Over land, **Terra decreased** (-0.05/decade), **Aqua constant**
- **Terra / Aqua** divergence was similar everywhere on the globe!
- Like identical human twins, the twin MODIS sensors aged differently.



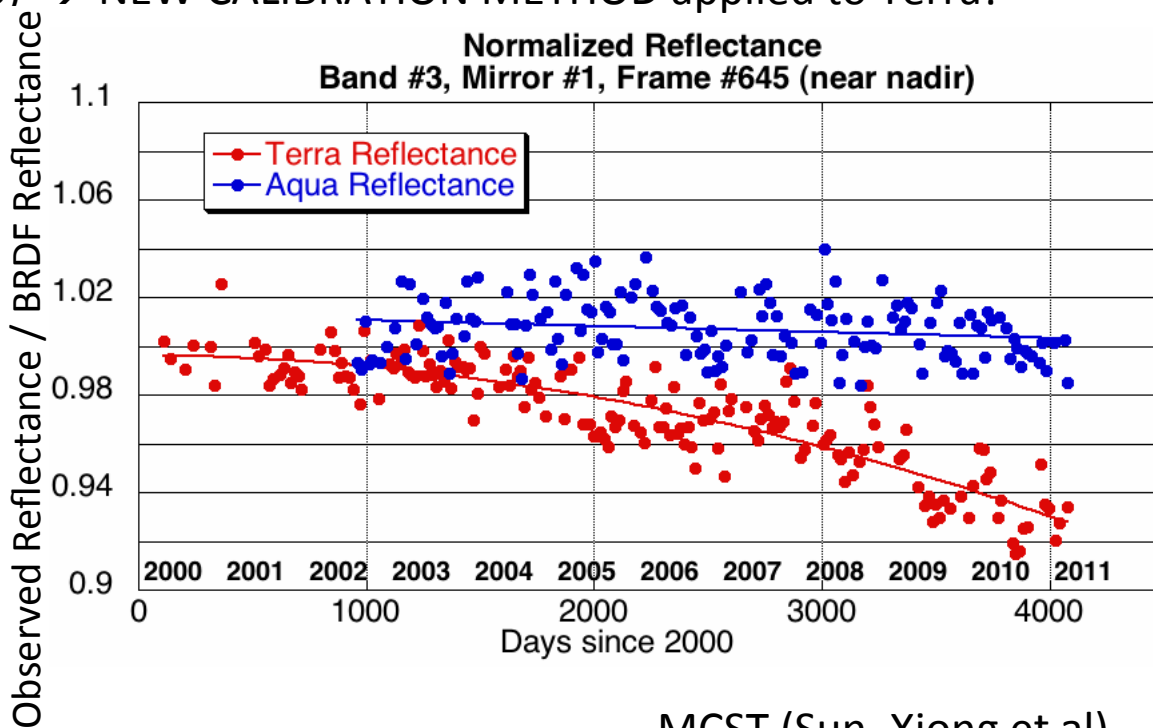
# Tracking MODIS RSB radiometric stability from reflectance trends over CEOS desert sites



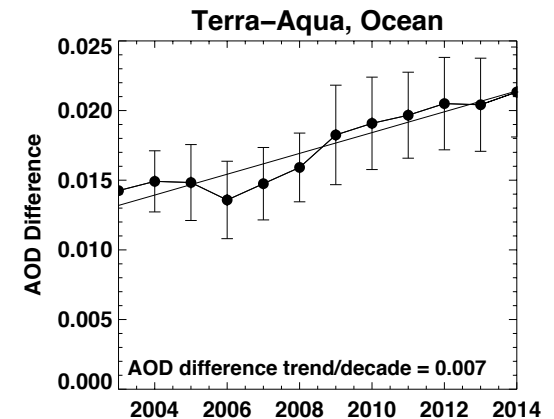
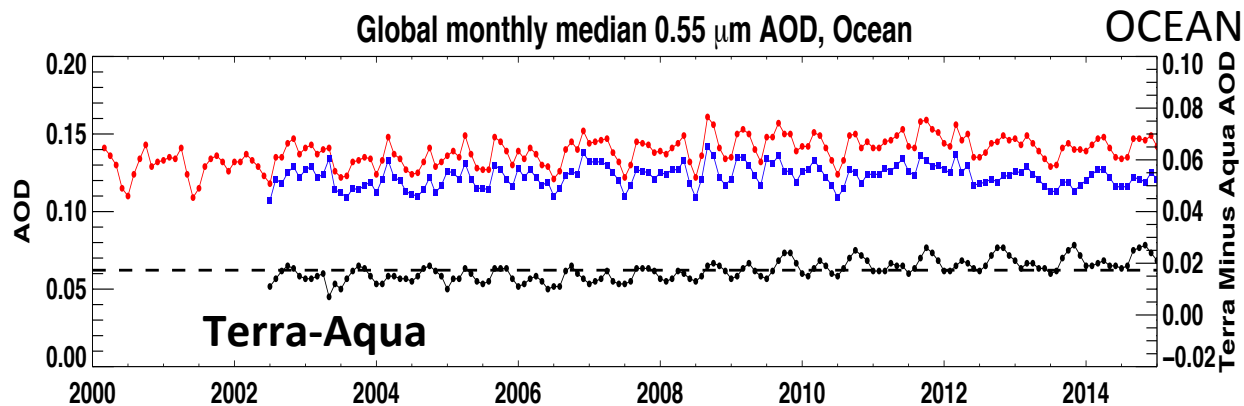
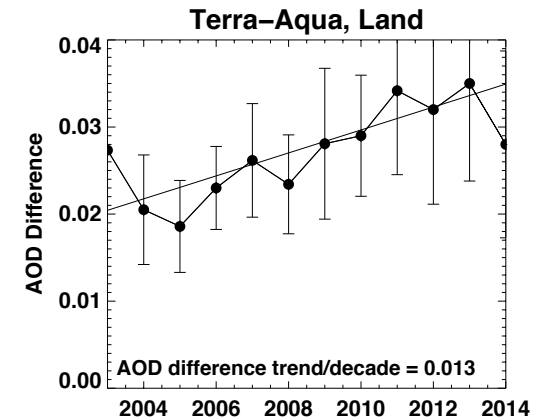
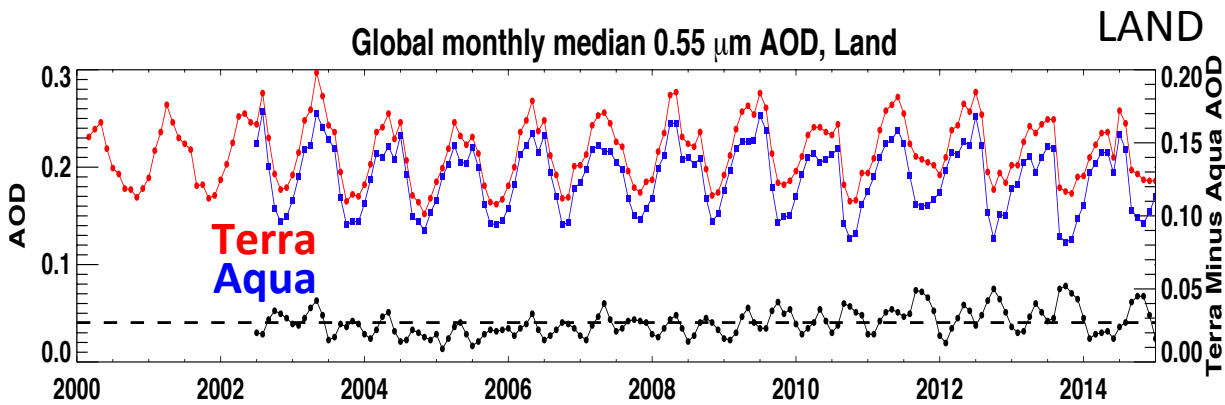
CEOS desert test sites



- (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 ( $0.47 \mu\text{m}$ ) are consistent with Terra’s AOD trends over LAND!
- (5) → NEW CALIBRATION METHOD applied to Terra!

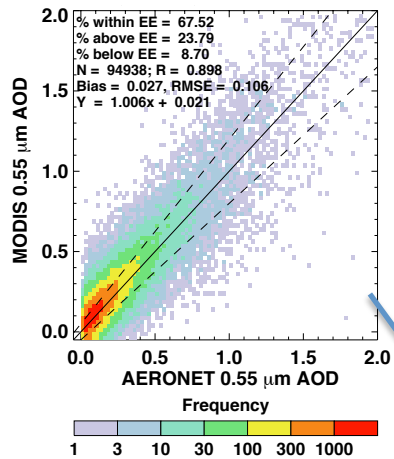


# C6 differences AOD: Terra-Aqua



- 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  $\sim 0.01$ /decade)
- Bigger-amplitude seasonal cycle to Terra-Aqua after 2011.

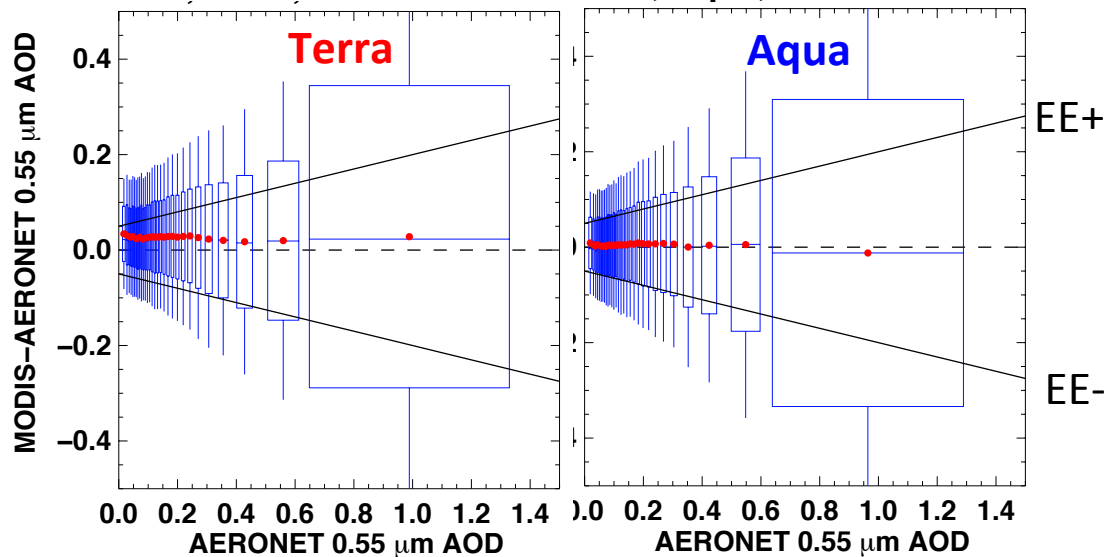
## scatterplots



# “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

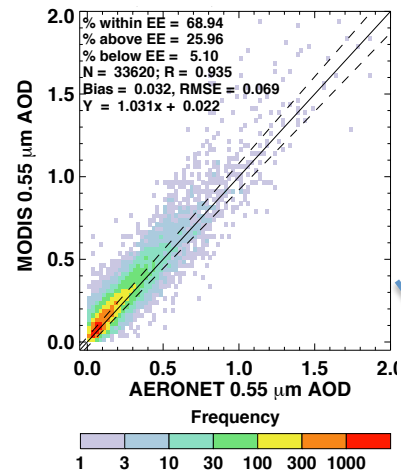
MODIS vs AERONET: Mar 2003-Feb 2013



- EE% > 68%: Both Terra and Aqua meet “expected error (EE)” of  $\pm(0.05 + 15\%)$
- 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**)
- $N_{Terra} = 95K$  versus  $N_{Aqua} = 81K$ . Why? Calibration? Sampling? AM/PM Clouds? Other?

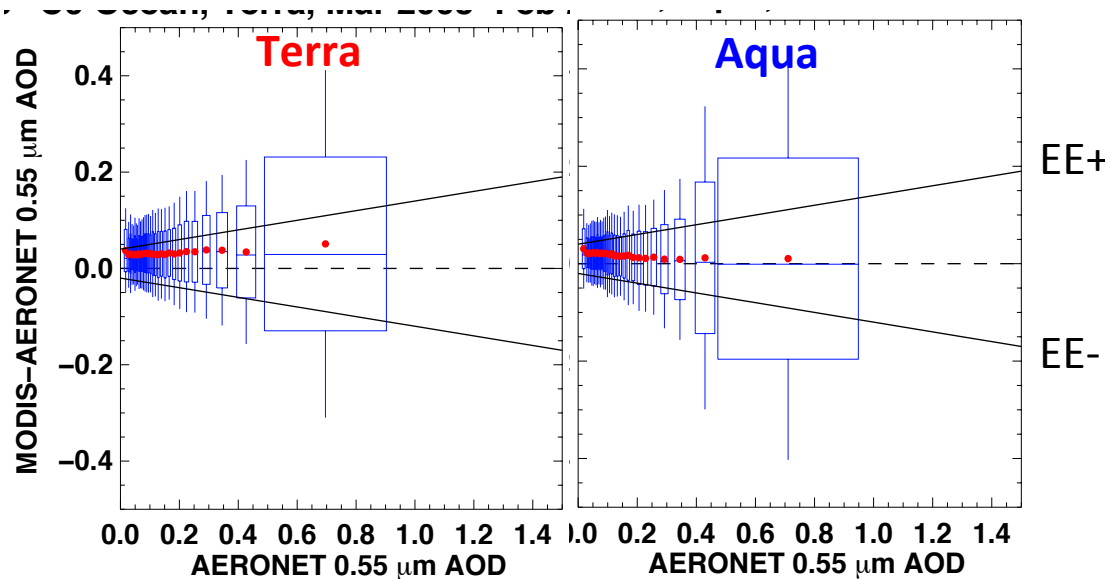
## scatterplots

# “Validation”: 2003-2013, Ocean



Sat	N	slope	Y-int	R	RMSE	Bias
Terra	33.6K	1.04	0.02	0.935	0.069	0.032
Aqua	29.9K	0.97	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  $\pm(0.03 + 10\%)$
- Some metrics nearly identical: Corr = R=0.93, Y-int=0.02, RMSE=0.07
- Terra is biased high, but due to **slope**.
- $N_{\text{Terra}} = 34\text{K}$  versus  $N_{\text{Aqua}} = 30\text{K}$ . Why? Calibration? Sampling? AM/PM Clouds? Other?

# Summary (MODIS C6)

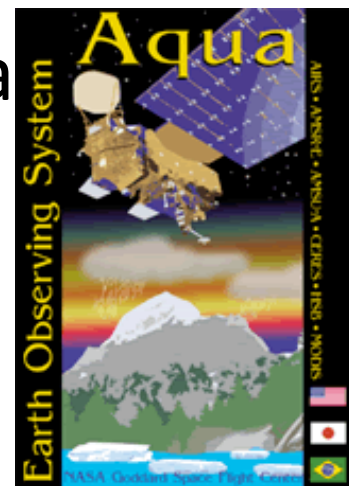
- MODIS aerosol retrieval (“MxD04\_L2”) has many upgrades for Collection 6.
- Aqua/Terra level 2 and 3 are available now
- Trending issues reduced with C6 calibration
- But still significant offsets ( $\sim 0.02$ ). Why?
- Still residual co-trending ( $< 0.01$  / decade)
- **Next step: Consider applying C6+ calibration**

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?

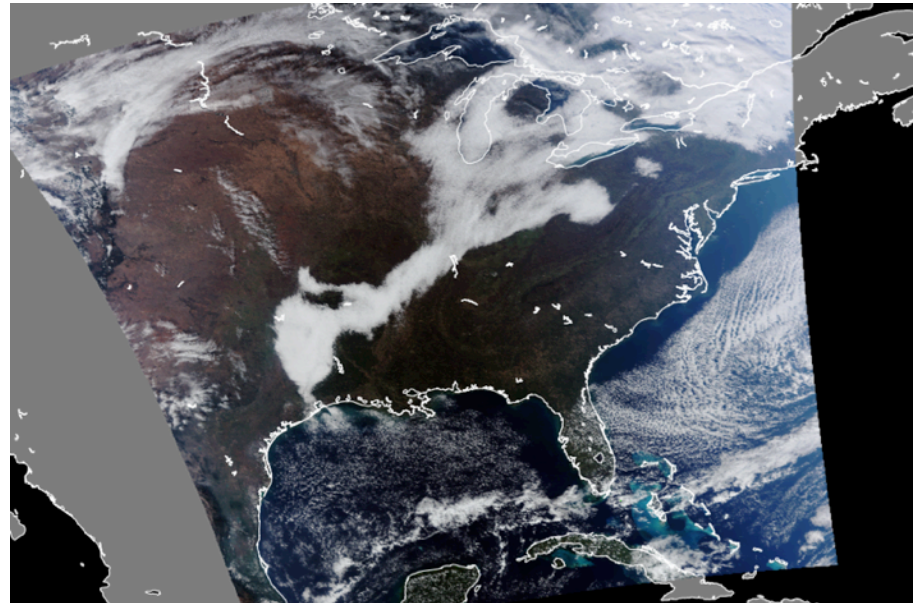
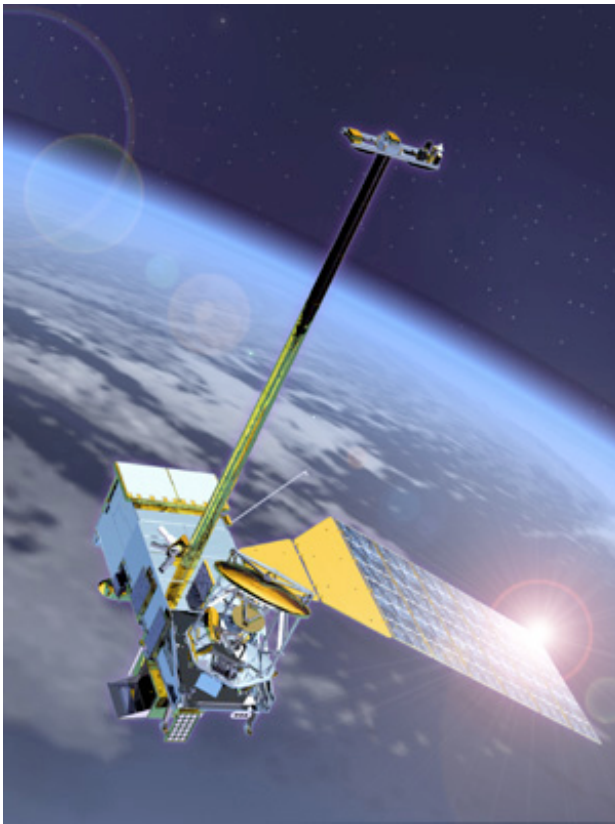


- Terra just celebrated its 15<sup>th</sup> birthday!
- At 12+, Aqua ain't no spring chicken!
- Terra and Aqua MODIS instruments are both >2x original mission lifetimes
- MODIS won't be here forever
- How do we get to 20+ year aerosol data records?



# VIIRS?

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



Can VIIRS “continue” the MODIS aerosol data record?



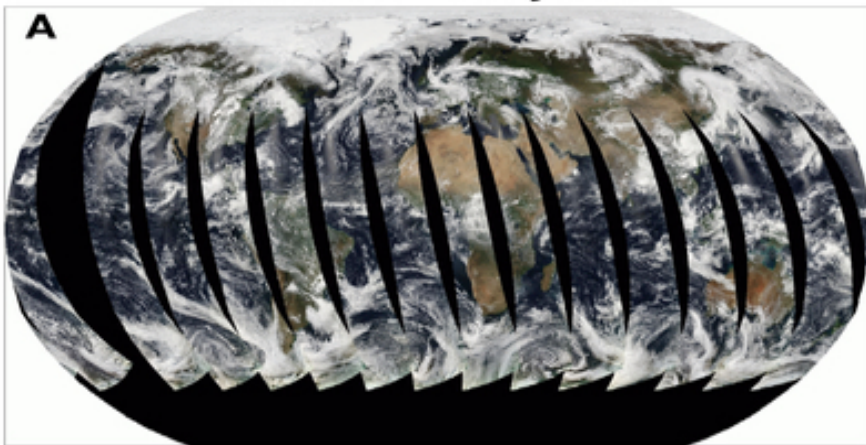
# VIIRS versus MODIS

**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.

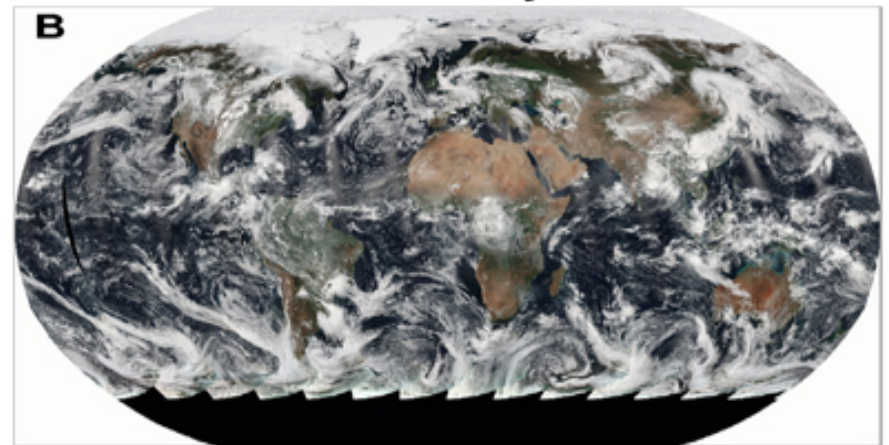
Aqua (13:30 Local Time, 14.6 revs/day)

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

MODIS - 29 May 2013



VIIRS - 29 May 2013

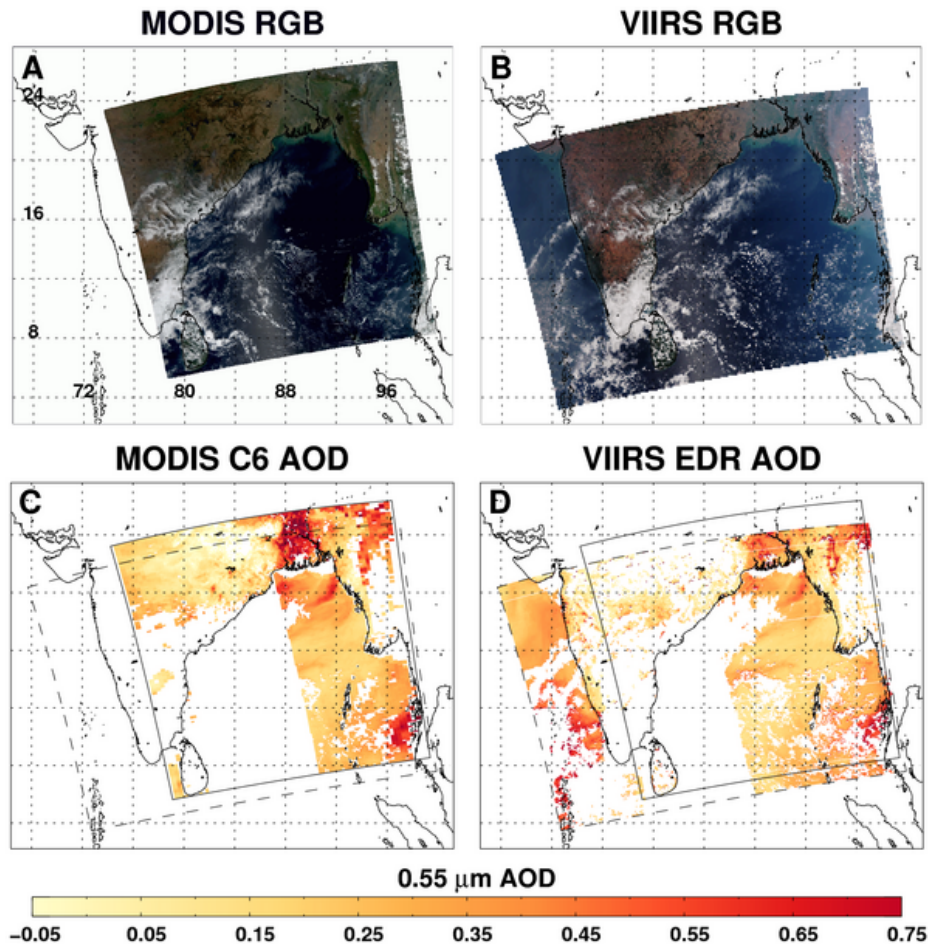


# VIIRS Aerosol Algorithm (NOAA-IDPS)

- Multi-spectral over dark surface
- Separate algorithms used over land and ocean
- 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  $\mu\text{m}$  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

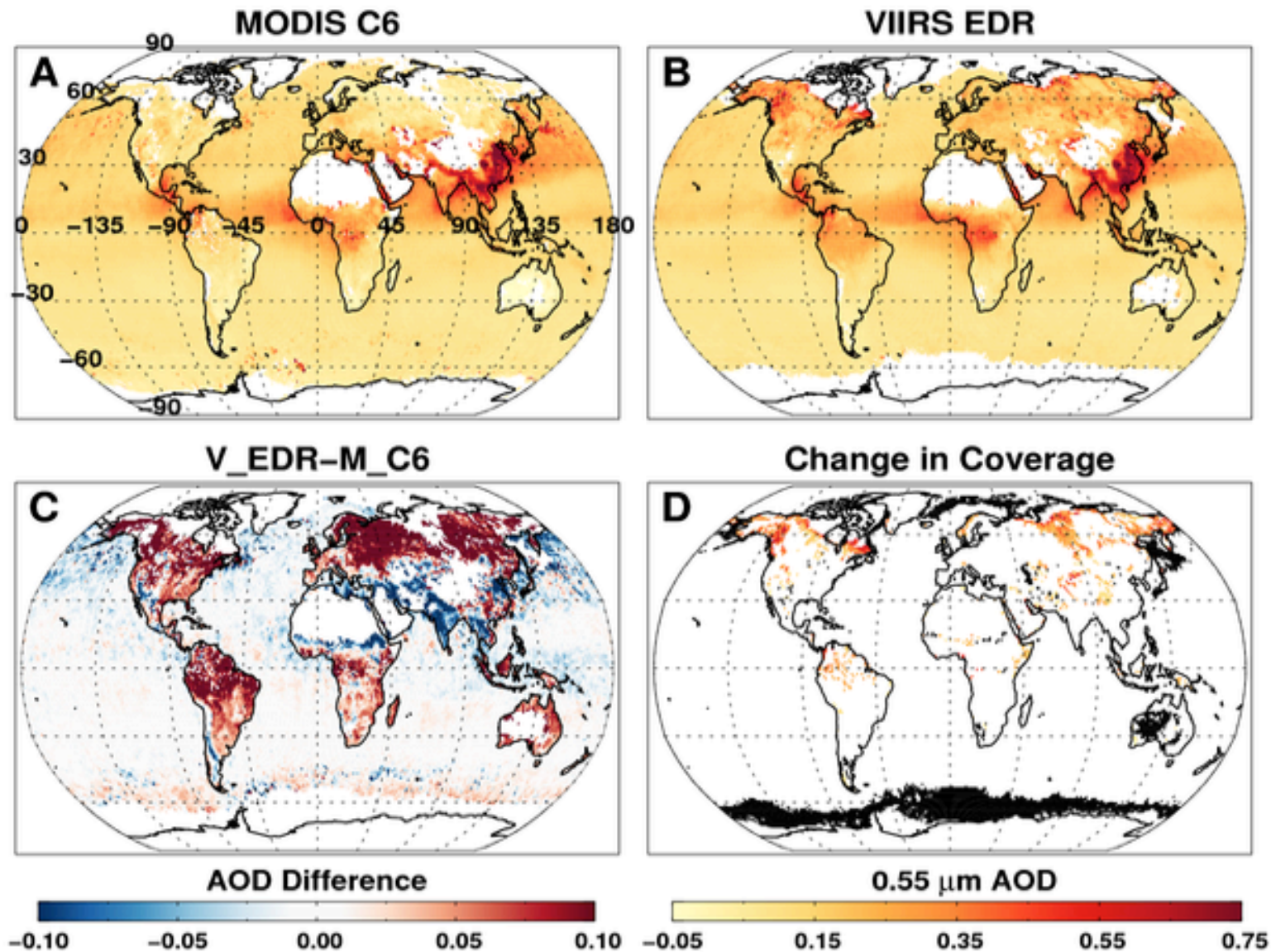
- “heritage” circa 1997 (Tanré, Kaufman, Remer,... )
- MODIS: C6 assumptions (Levy et al., 2013)
- VIIRS: C5-like assumptions (Remer et al., 2005)

## 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.

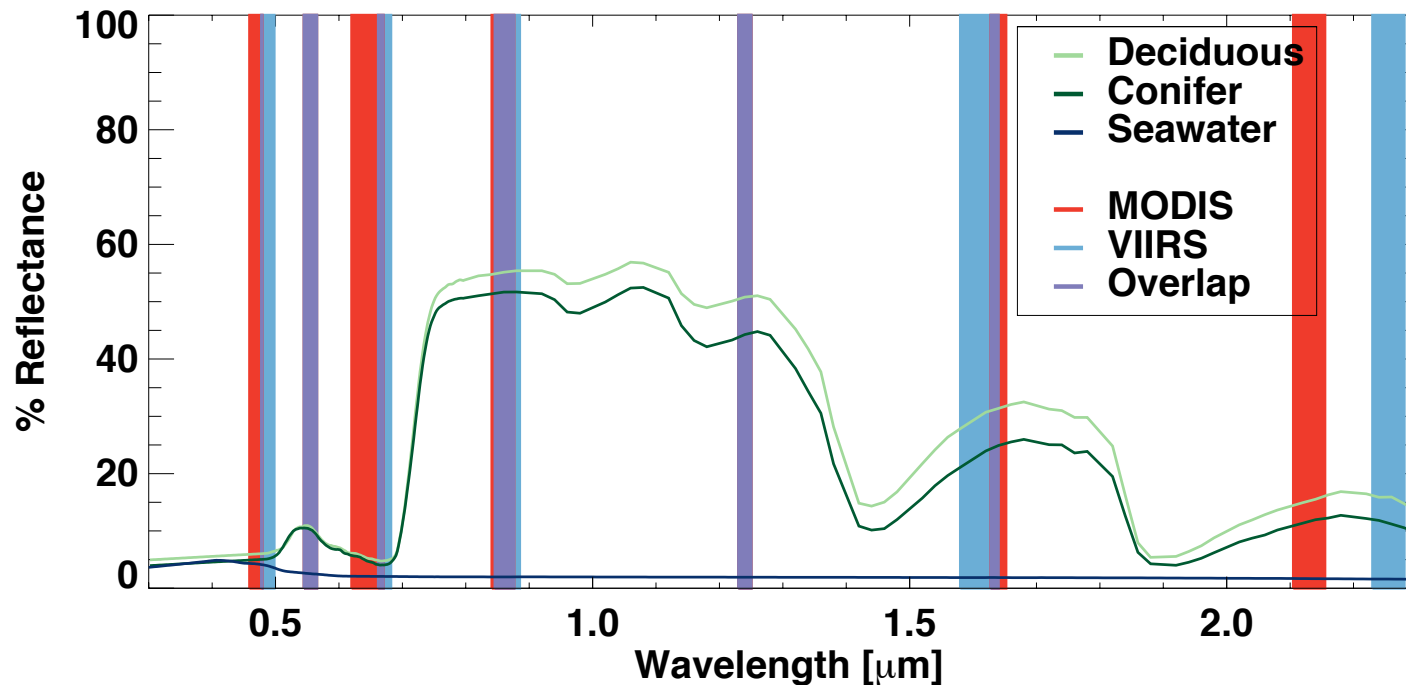
# Monthly mean AOD for Spring 2013 (Mar-May)



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

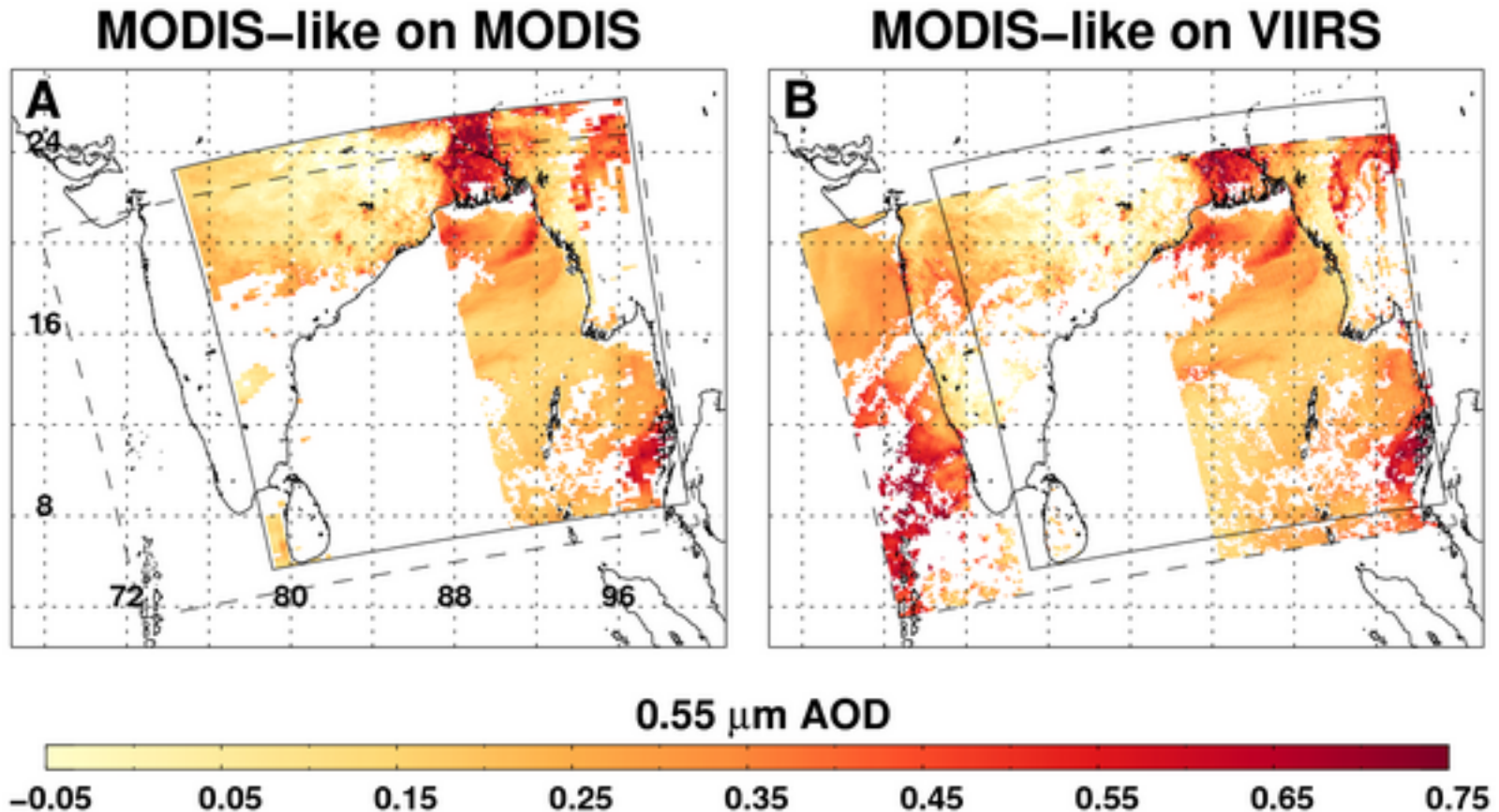
# Developing a MODIS-like algorithm for VIIRS

- 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



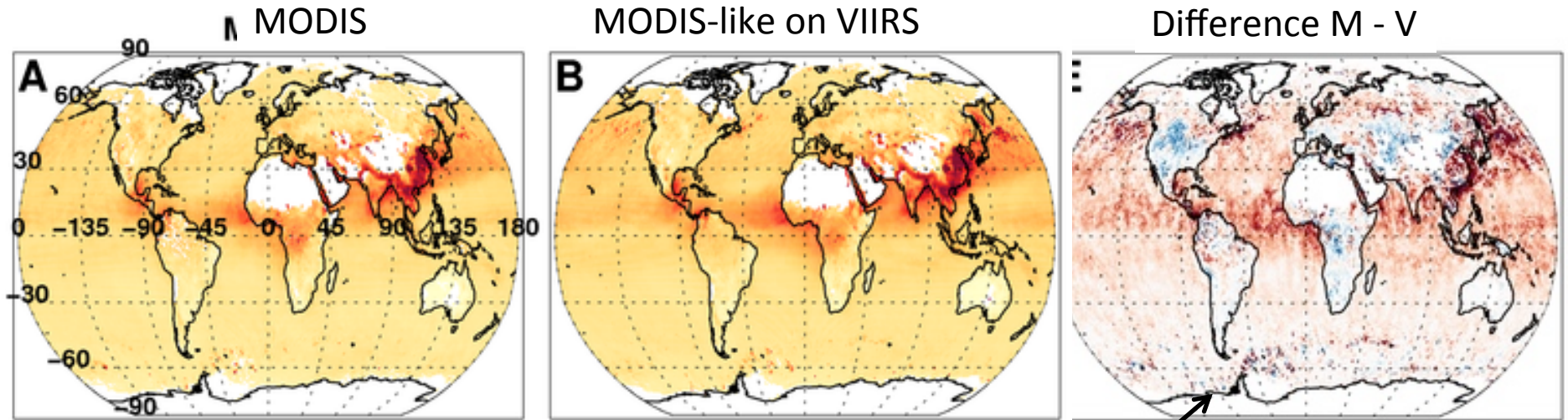
# Same algorithm on both platforms?

- 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)

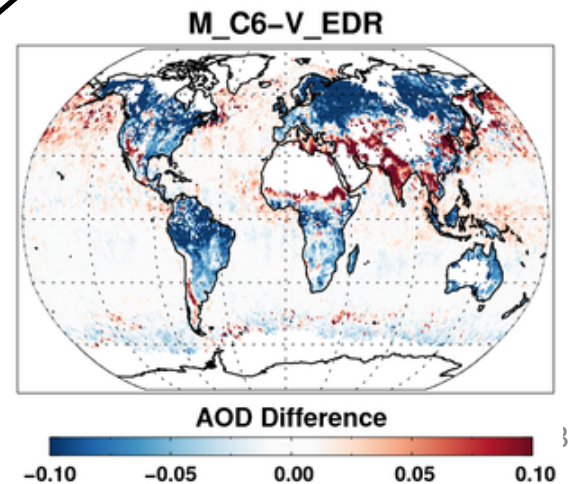


Versus...

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

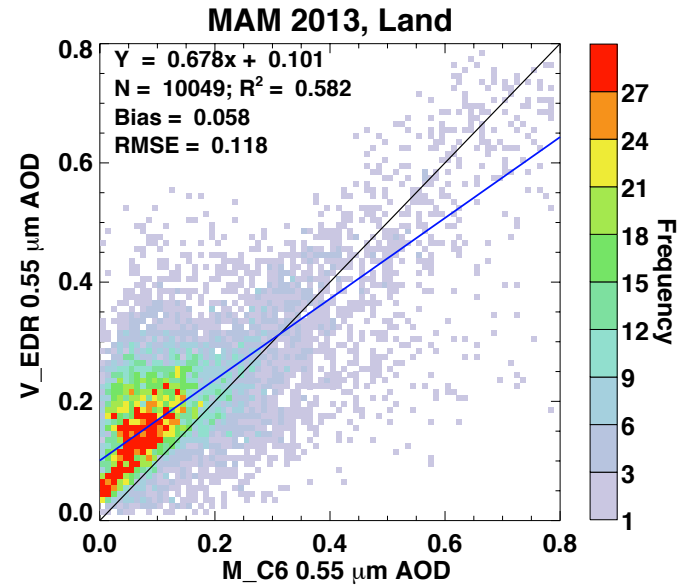
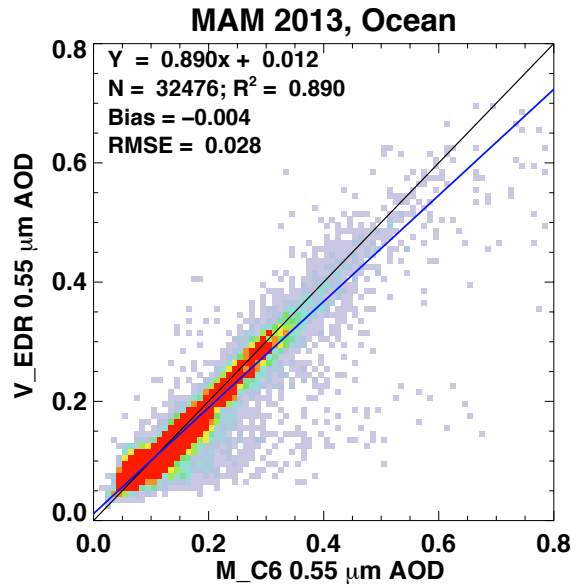
Systematic bias over ocean (VIIRS high by 15%)

Less systematic bias over land (MODIS high by 5%)

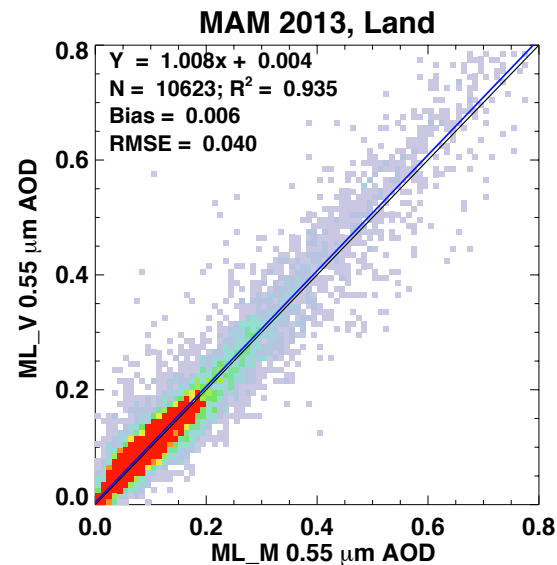
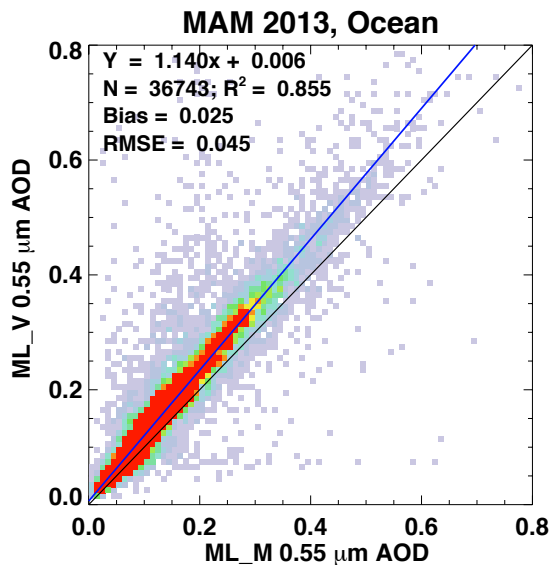


# Comparing gridded AOD (Spring 2013)

VIIRS\_EDR vs  
MODIS



MODIS-like  
(VIIRS) vs  
MODIS



New data  
More like MODIS  
But 1.15 slope  
over ocean!



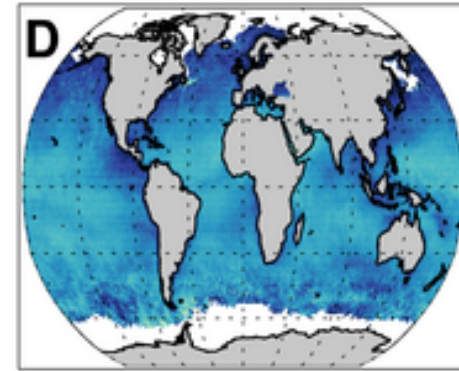
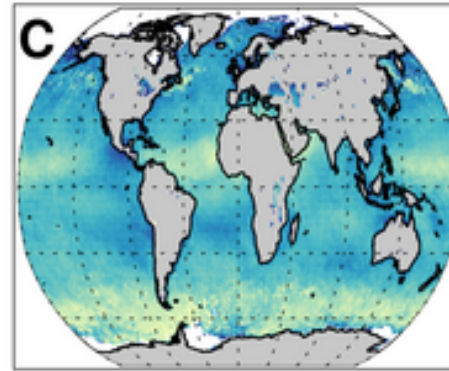
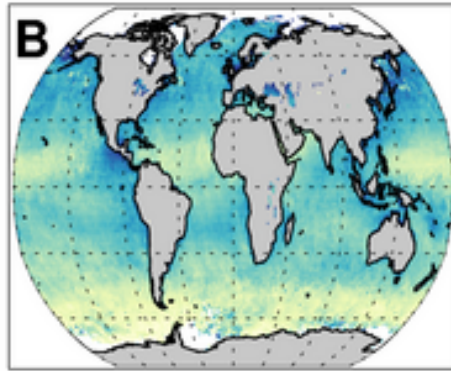
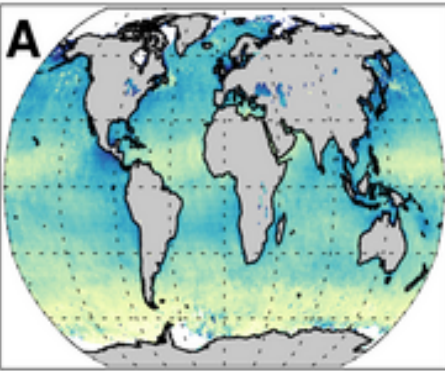
# Angstrom Exponent (0.55 / 0.86 $\mu\text{m}$ )

M\_C6

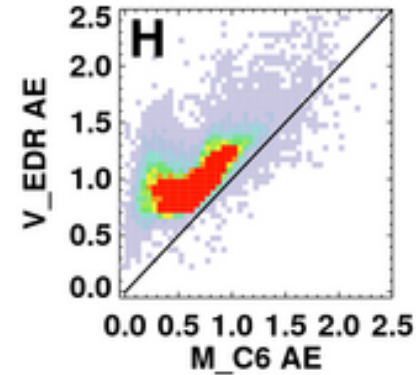
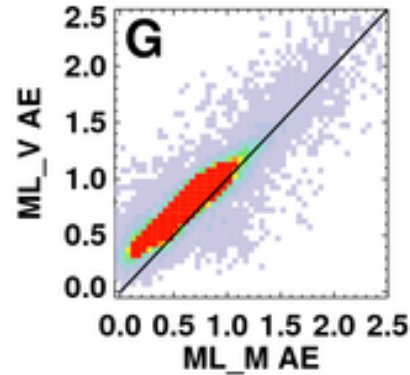
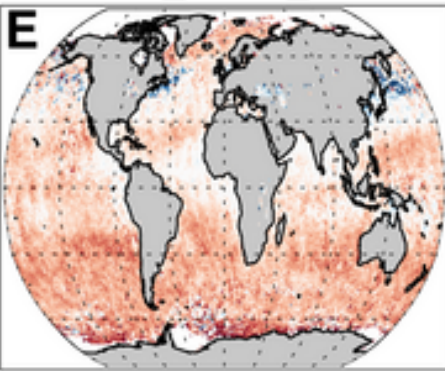
ML\_M

ML\_V

V\_EDR



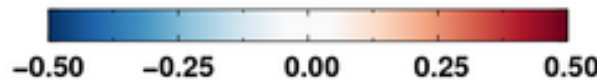
ML\_V-ML\_M



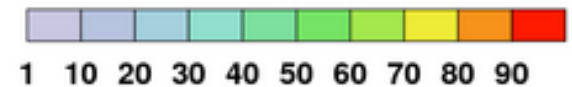
0.55/0.86  $\mu\text{m}$  AE



AE Difference



Frequency



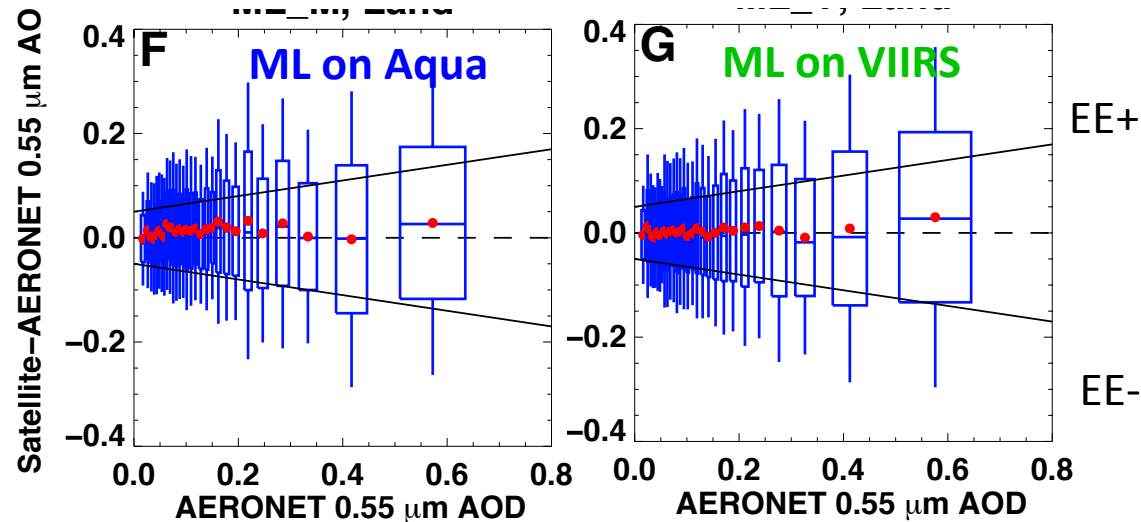
MODIS-like on VIIRS has Angstrom Exponent that looks much more like MODIS

# “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



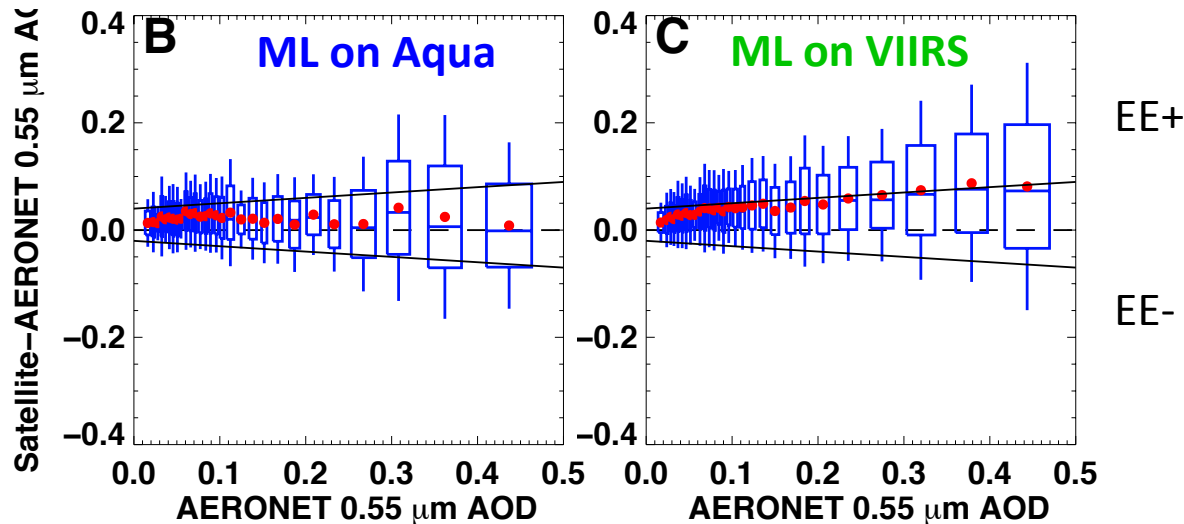
- EE% > 68%: Both VIIRS and MODIS-Aqua meet “expected error (EE)” of  $\pm(0.05 + 15\%)$
- Some metrics nearly identical: Corr = R=0.90, Slope=M=1.01, RMSE=0.10
- VIIRS is has even smaller bias than MODIS (due to **y-intercept**)

# “Validation”: 2013-2014, Ocean

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

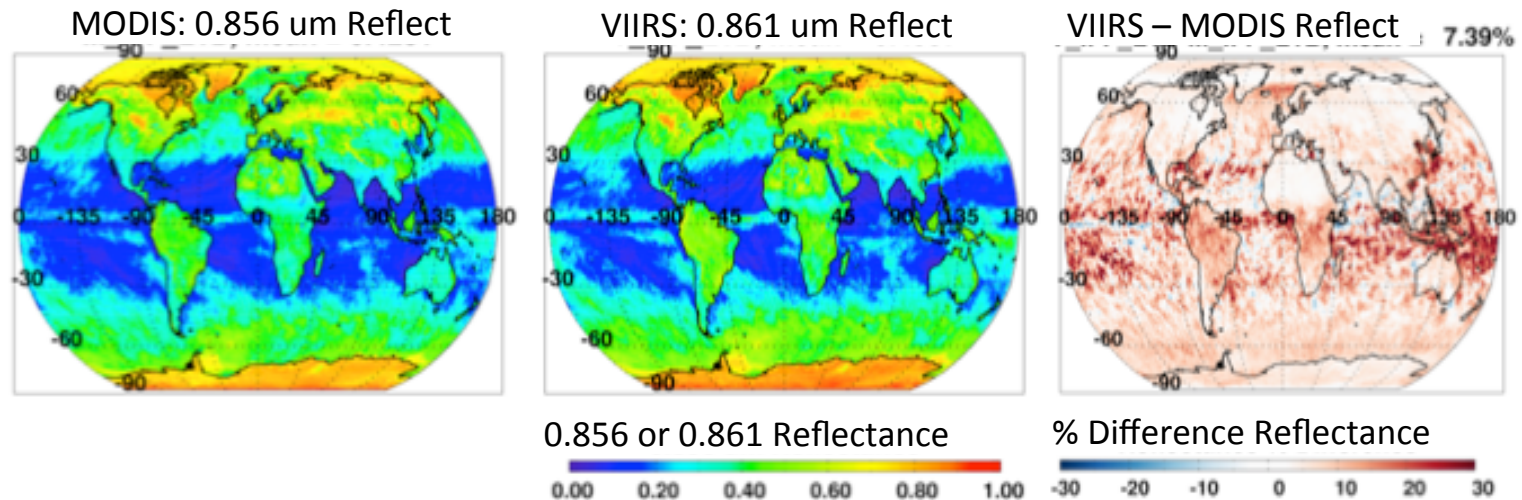
VIIRS vs Aqua: Mar 2013-Feb 2014



- VIIRS does not quite meet >68% within EE of  $\pm(0.03 + 10\%)$
- 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?

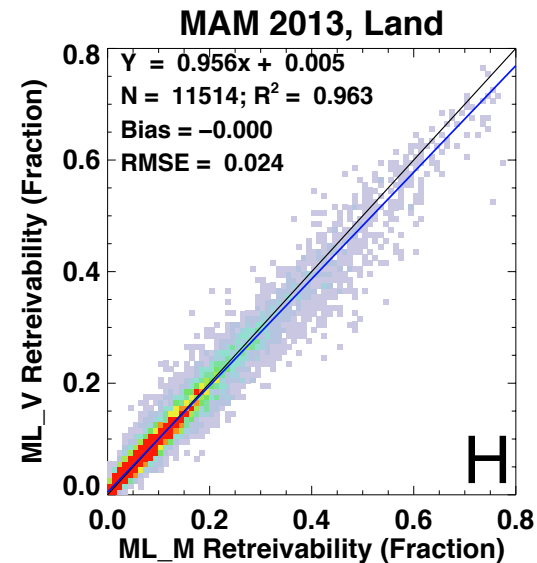
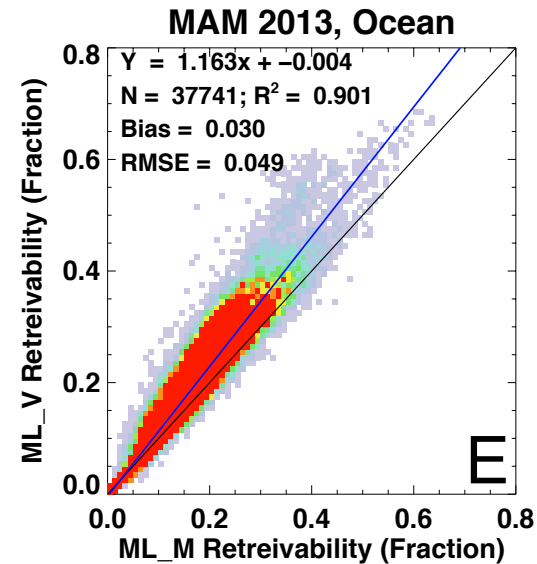
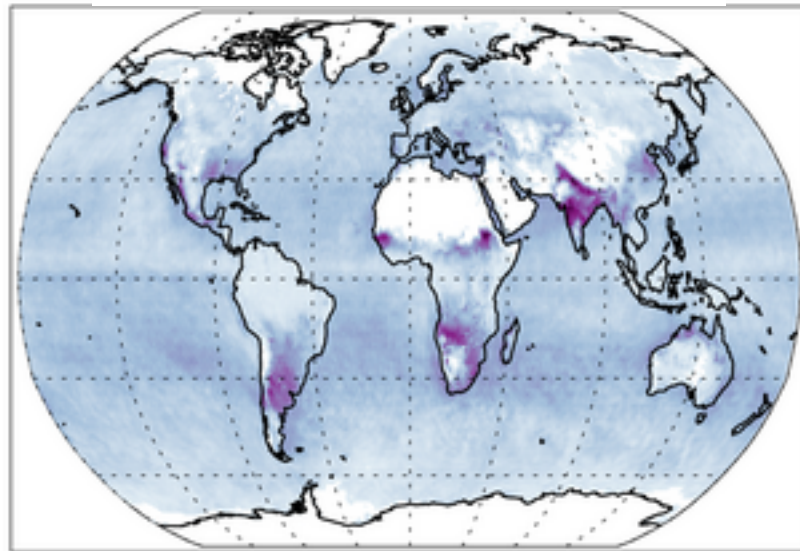
- **Terra** vs **Aqua**:
  - Ocean: Terra high by +0.017 or 13%; Driven by slope
  - Land: Terra high by +0.027 or 13%, Driven by y-offset
- **VIIRS** vs **Aqua**:
  - Ocean: VIIRS high by +0.25 or 20%; Driven by slope
  - Land: VIIRS lower by -0.01 or 5%; Driven by y-offset



- 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.

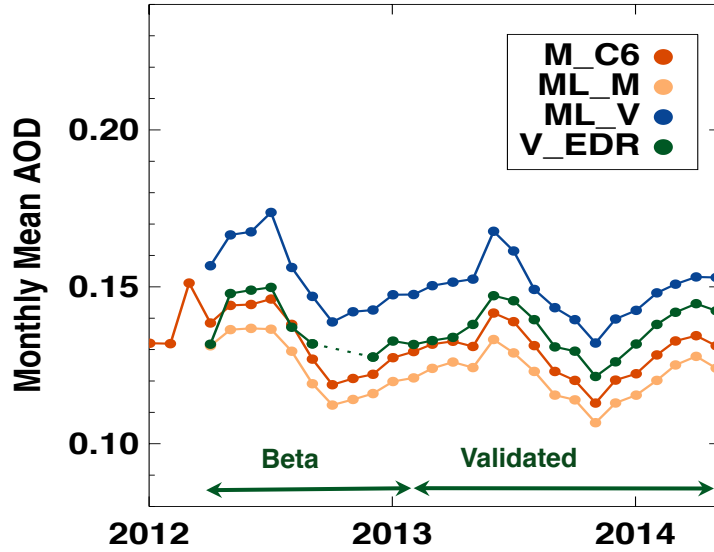
# Will VIIRS continue MODIS?

## How would we know?

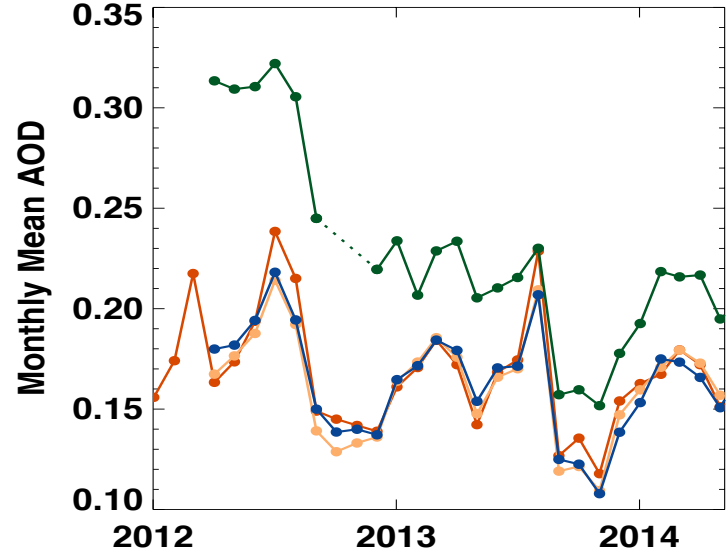
- Convergence: of gridded (Level 3 –like) data
  - For a day? A month? A season?
  - What % of grid boxes must be different by less than X?
    - in AOD?      In Angstrom Exponent?      Size parameters?
- Sampling: Do instruments observe similar conditions?
- Retrievability: Do algorithms make same choices?
- Validation: Comparison with AERONET, MAN, etc?

# A time series (of sorts) so far

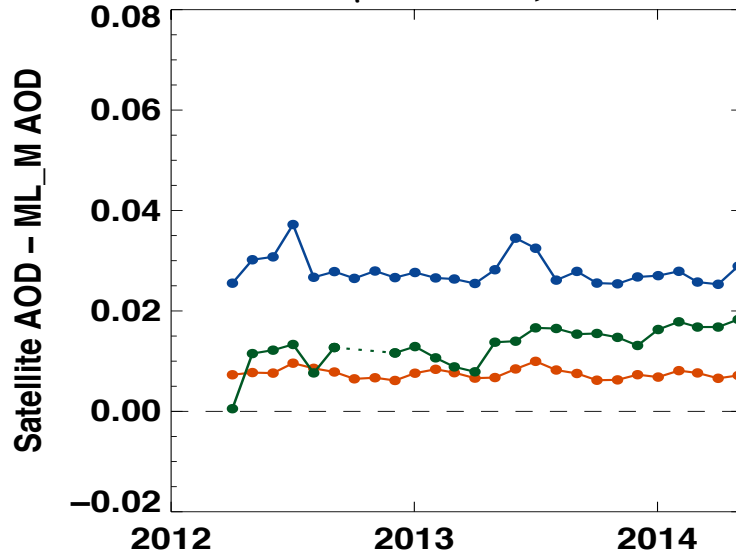
### 0.55 $\mu\text{m}$ AOD, Ocean



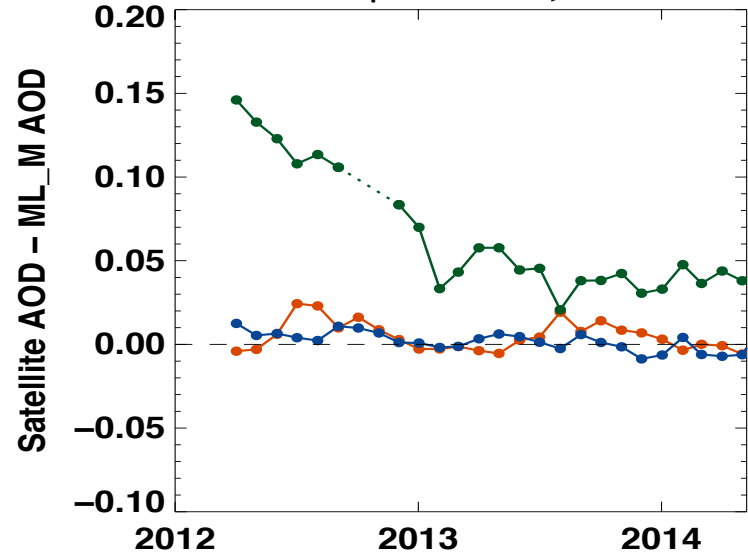
### 0.55 $\mu\text{m}$ AOD, Land



### 0.55 $\mu\text{m}$ AOD, Ocean



### 0.55 $\mu\text{m}$ 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  $\mu\text{m}$  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.



# MODIS Aerosol

Dark-Target Retrieval Algorithm

OUR TEAM

PUBLICATIONS

CLIMATE & RADIATION

Search

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>

