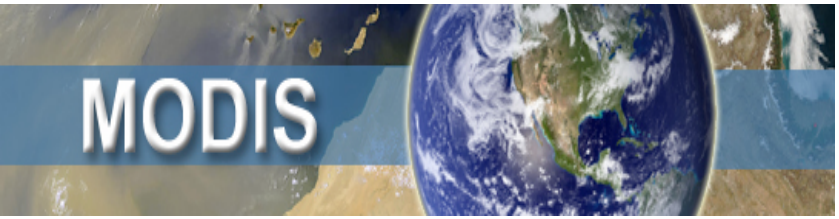
Retrieval of aerosol properties from MODIS-Terra, MODIS-Aqua, and VIIRS-SNPP: Calibration focus

Robert C. Levy (NASA-GSFC)



Shana Mattoo, Virginia Sawyer* and Richard Kleidman (SSAI/GSFC)
Falguni Patadia and Yaping Zhou* (Morgan State U / GSFC)
Pawan Gupta and Yingxi Shi* (USRA/GSFC)
Lorraine Remer (UMBC/JCET), Robert Holz (SSEC/UWisconsin)

* New people in 2016.

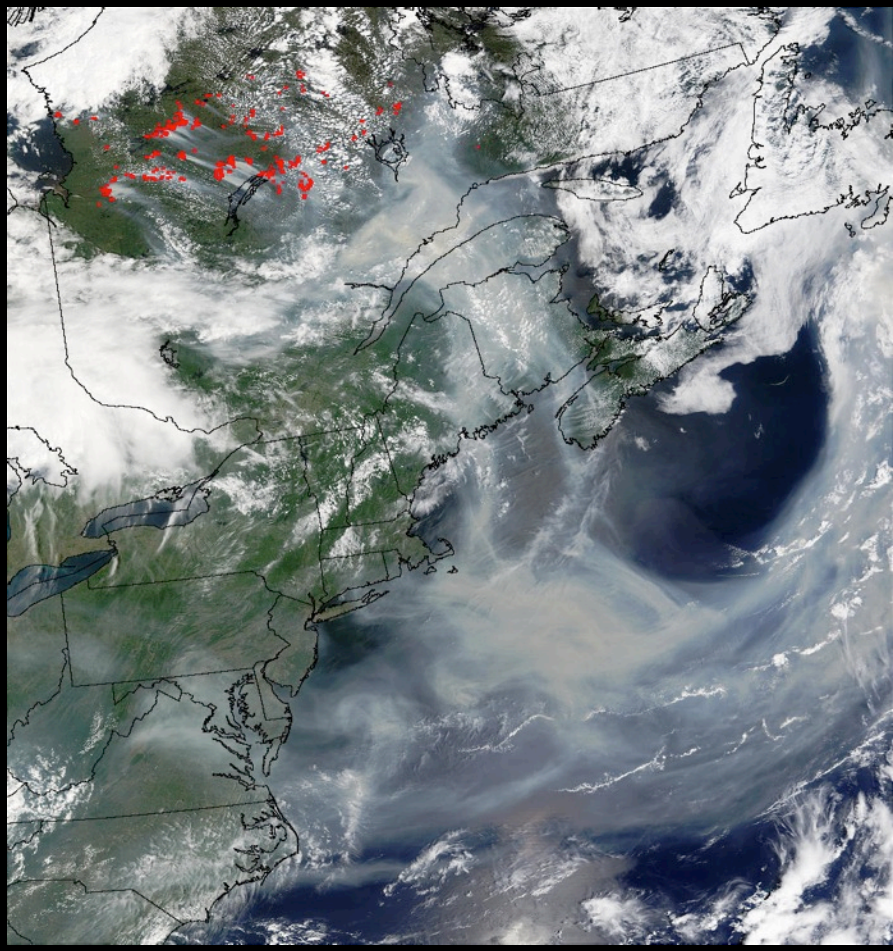
And many, many, many others

MODIS/VIIRS Science Team Meeting: June 2016

Aerosol from space

- Aerosol optical depth (AOD or τ)
- "Essential Climate Variable" (ECV)
  - Requires accuracy <±0.02
  - Measured over multi-decades
- Yet, mostly a "regional" problem.
- Required uncertainty (per pixel) = <15%.

- A 2% uncertainty in measuring reflectance (low light levels) can lead to 20% uncertainty in AOD



Smoke transported over Eastern Canada/USA (8 July 2002)

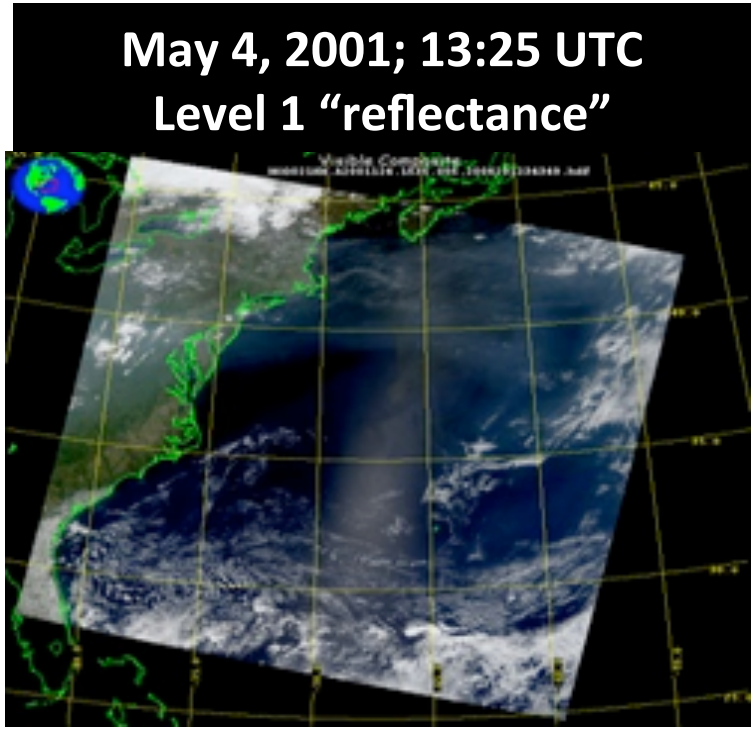
http://earthobservatory.nasa.gov/

Outline

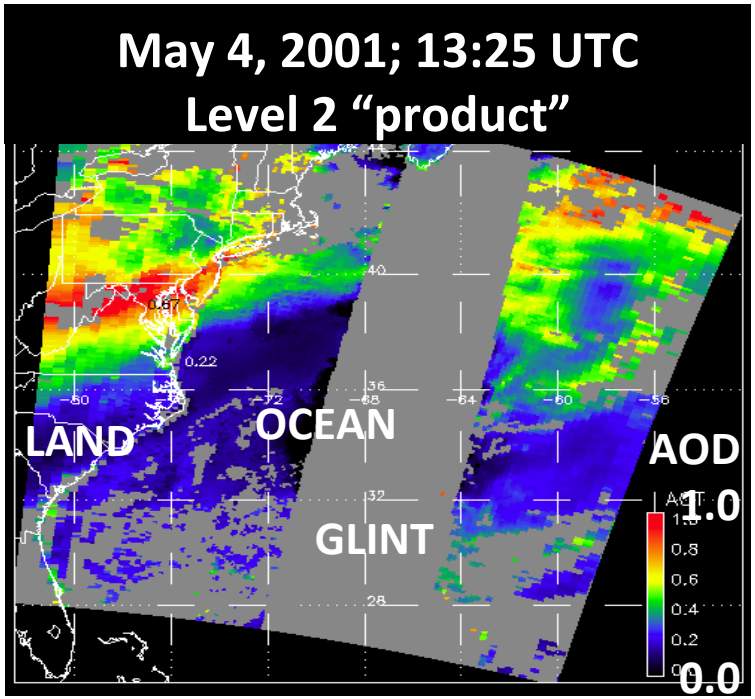
1. “Dark-target” (DT) remote sensing
2. Terra vs Aqua
3. VIIRS vs Aqua (using Wisconsin and IFF)

Dark Target Aerosol Retrieval

What sensor observes



Attributed to aerosol (AOD)



There are many different "algorithms" to retrieve aerosol

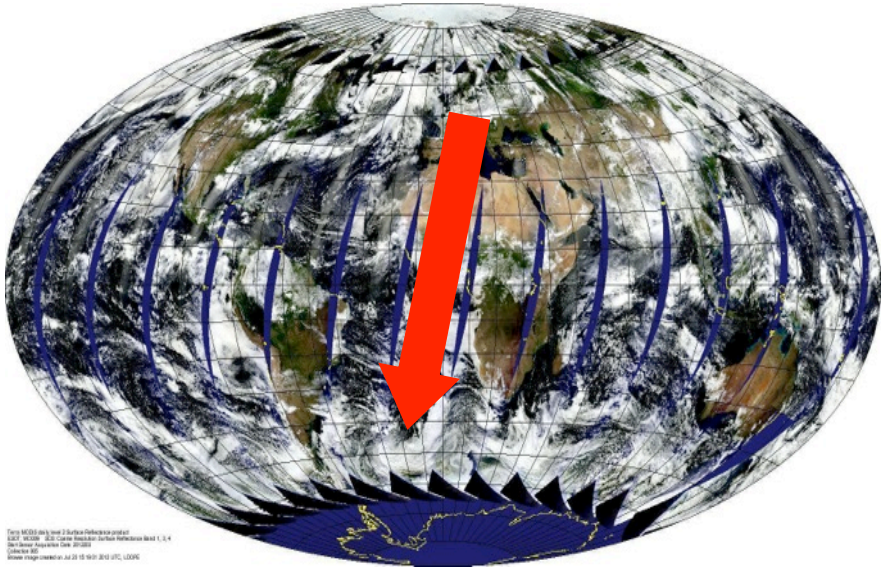
Ours is **Dark Target (DT)**; "Established 1997" by Kaufman, Tanré, Remer, etc)

Separate algorithms: Ocean and Land
Both are multi-channel inversions
Products = AOD at 0.55 μm, spectral AOD, diagnostics

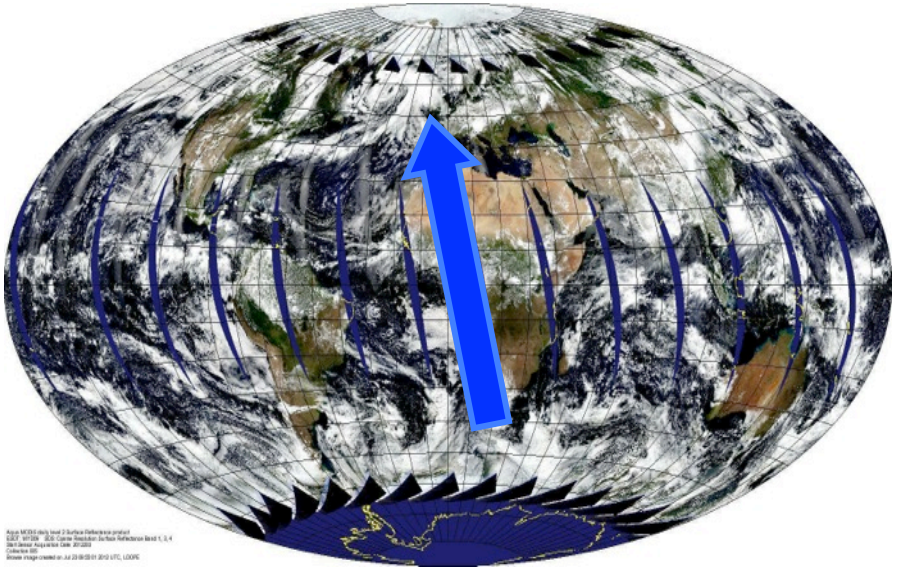
MODIS on Terra and Aqua
Do they represent the same world?

- 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!

Terra (10:30, Descending)



Aqua (13:30, Ascending)

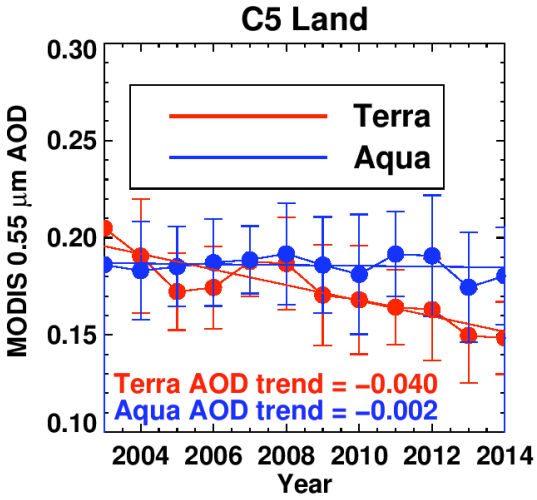


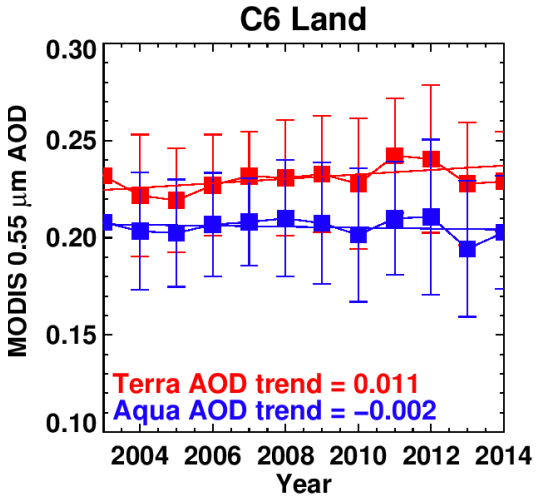
Twins! And they behave like twins, meaning not exactly the same

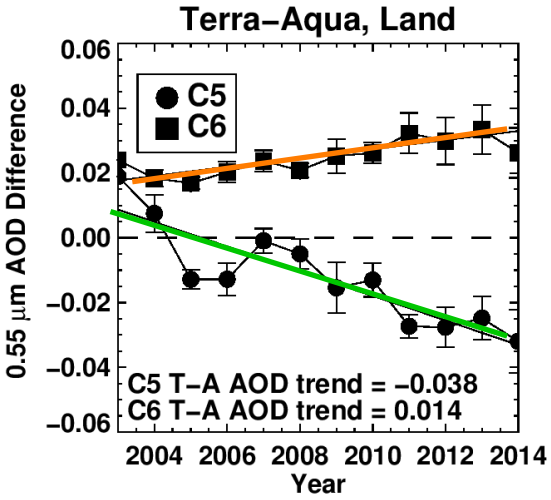
Time series of MODIS-derived AOD

$\Delta\tau$ = Terra - Aqua

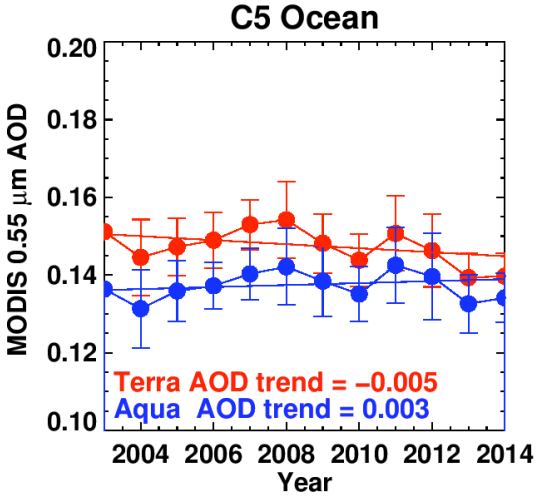
LAND

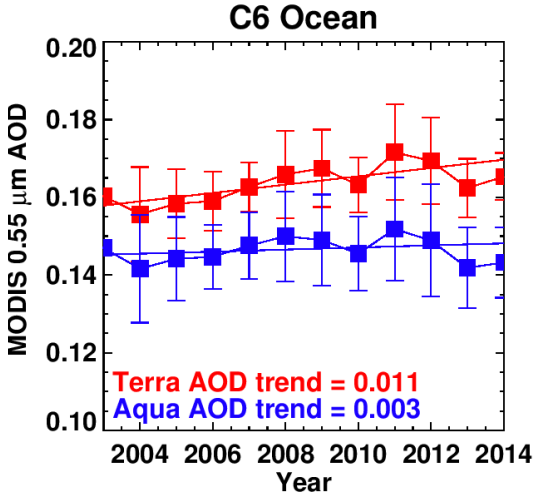


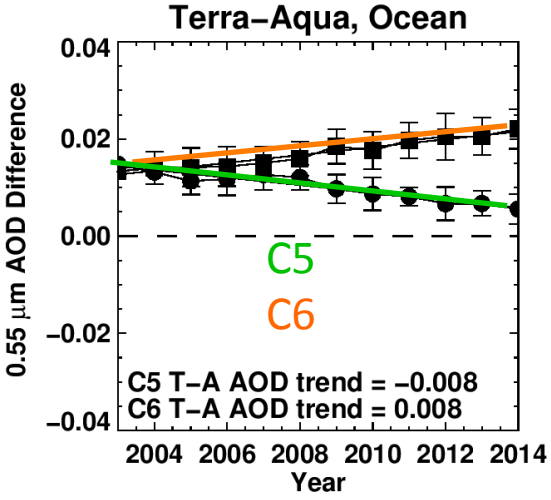




OCEAN



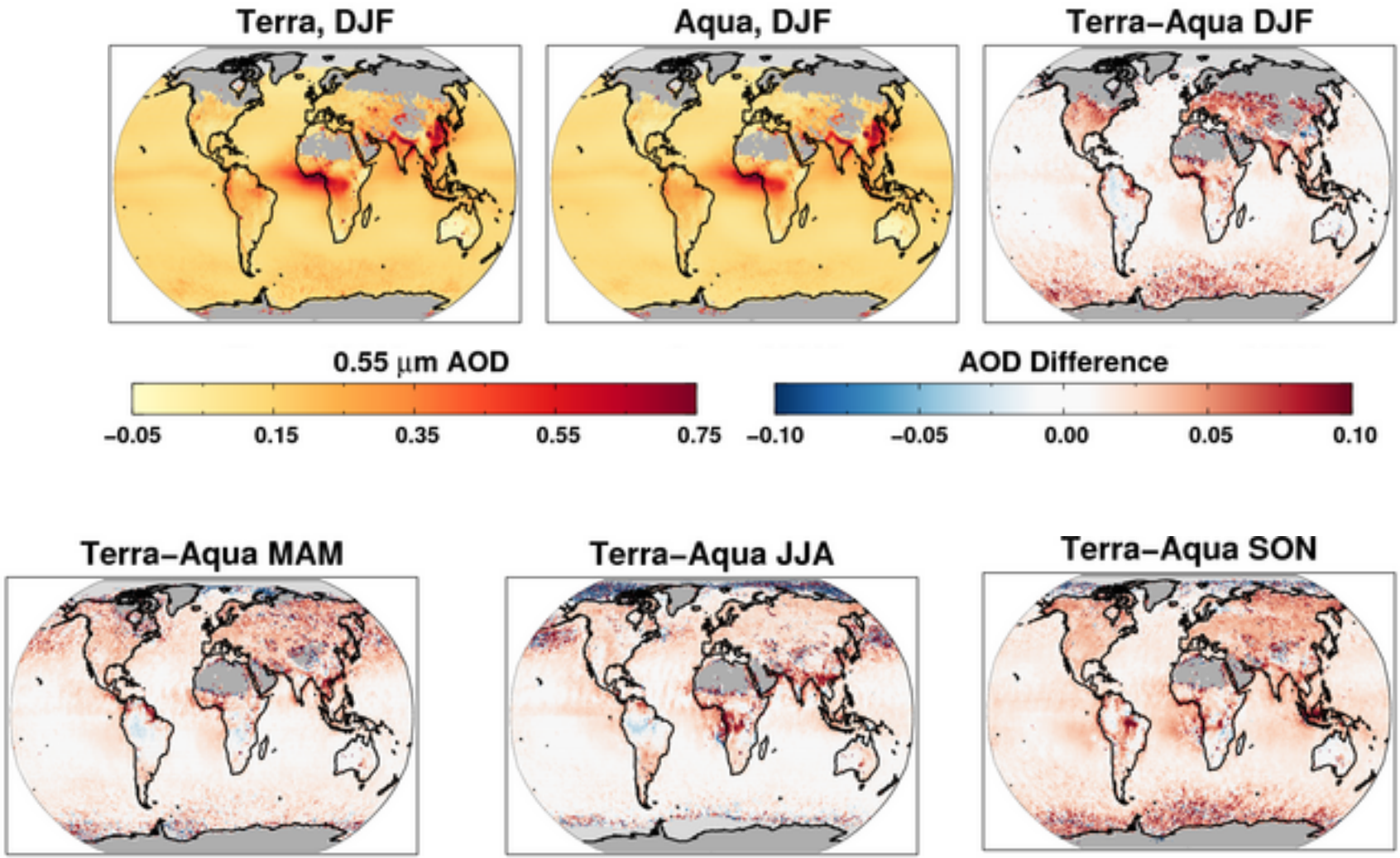




Good news: Strong $\Delta\tau$ negative "trending" is reduced in C6

Bad news: 1) $\Delta\tau$ offset increases, and 2) there is now a positive trend

$\Delta\tau > 0$: everywhere and for all seasons



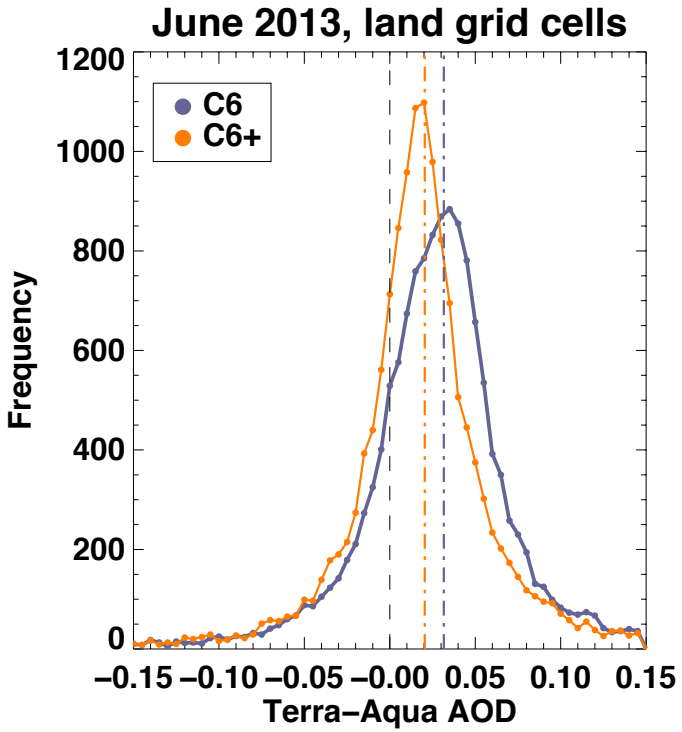
This can't be right…..

MODIS C6 (and calibration adjustments?)

- Trending issues reduced with C6 product, but:
  - Still significant offsets (13%) and
  - Still residual co-trending (<0.01 / decade)
- Why? Sampling? diurnal cycles? Cloud masking?

- Calibration?
  - Test different options
  - "C6+" of Alexei Lypustin et al.,
  - Ocean vicarious corrections
  - Many others
  - Me, playing on my own.
  - Etc.

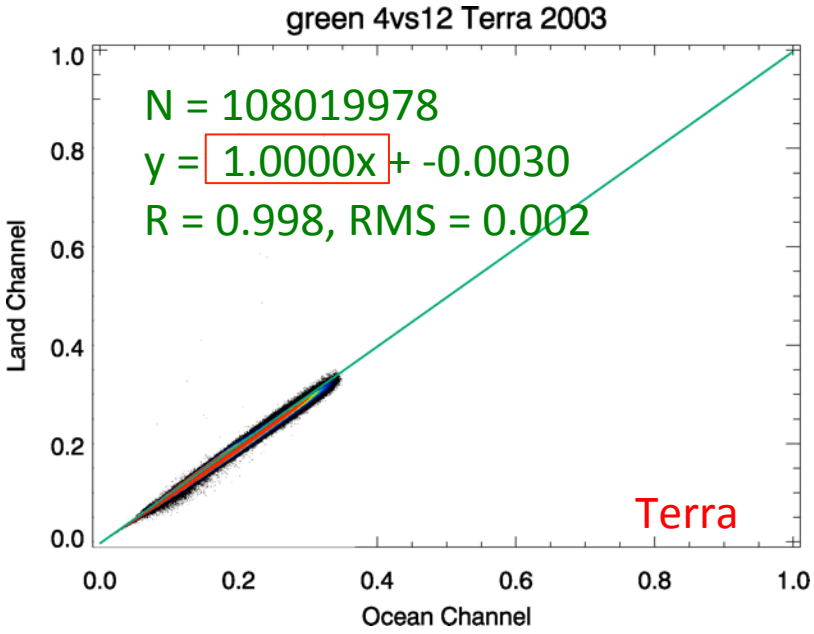
- Still working on problem

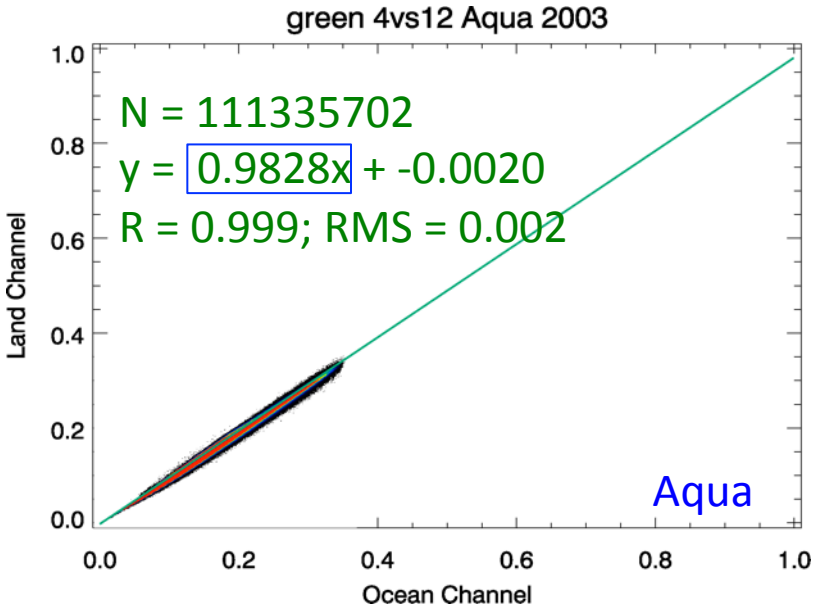


TBD author et al., (in prep)

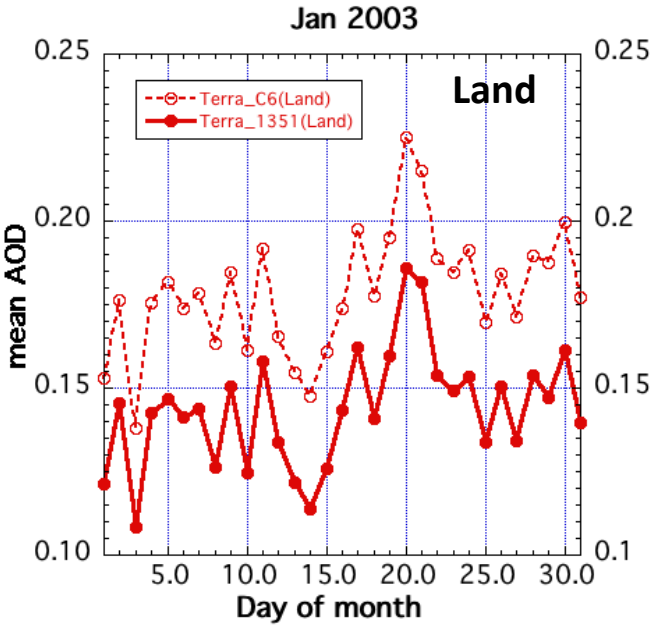
Me playing on my own: Land vs Ocean bands

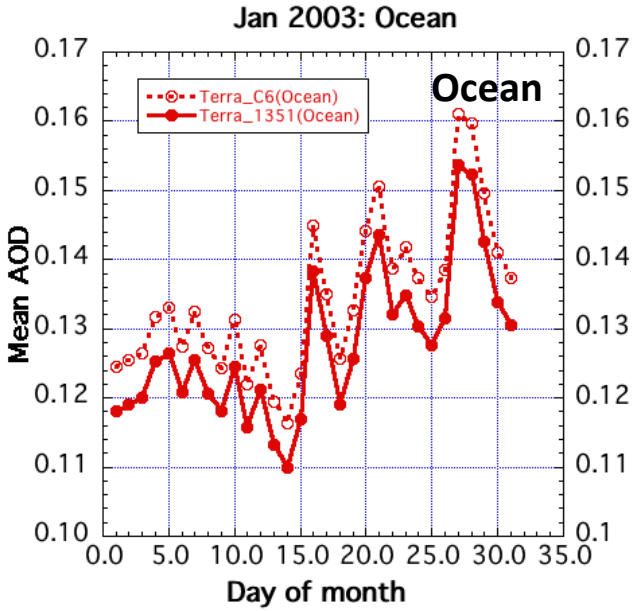
- For aerosol retrieval, we generally operate in the lower reflectance regime (as compared to clouds or ice/snow retrievals)
- Some “land” bands (#3,4,1 & 2 = 0.47, 0.55, 0.65, & 0.86) have counterpart “ocean” bands (#10,12,13 & 16 = 0.48, 0.55, 0.67 & 0.87)
- Make scatterplots of land vs ocean band reflectance, stratified by sensor, and by year. Ignore angle/detector dependencies. Note slope and offset





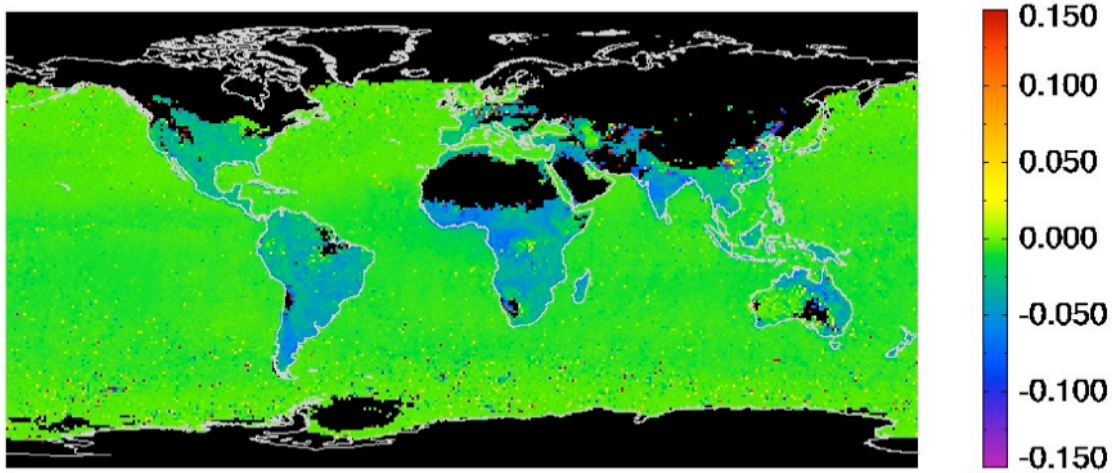
For green, there is a 2% difference in slope! Do same for other pairs.





Apply "corrections" (e.g. make Terra look like Aqua): Jan 2003; Terra

Jan 2003 Gridded AOD: Test1351 – C6

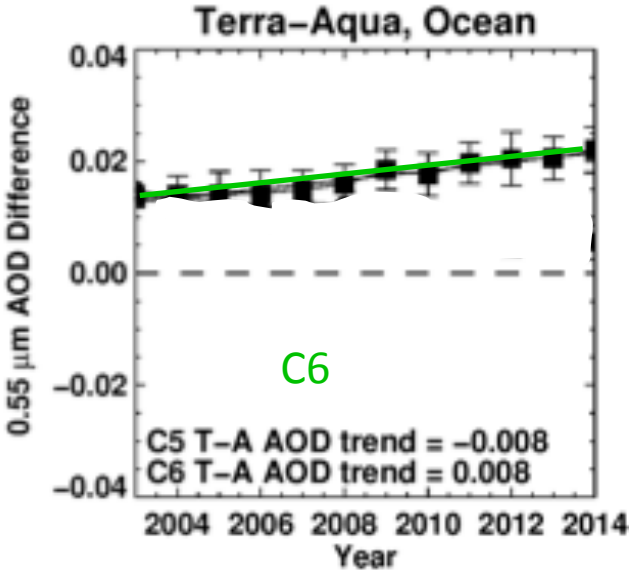


With the gain correction factors:
- Land reduced by 0.027
- Ocean reduced by 0.007

Recall: $\Delta\tau$ = Terra – Aqua in 2003
- Land offset by 0.024
- Ocean offset by 0.015

MODIS: Terra vs Aqua

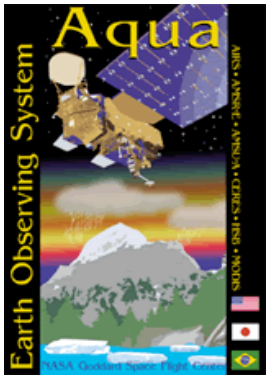
- Trending issues reduced with C6 product, but:
  - Still significant offsets (13%) and
  - Still residual co-trending (<0.01 / decade)
- Why? Sampling? diurnal cycles? Cloud masking?
- Calibration?
  - Test different options



- Aerosols are hard: We retrieve in a range from near black to fairly bright.

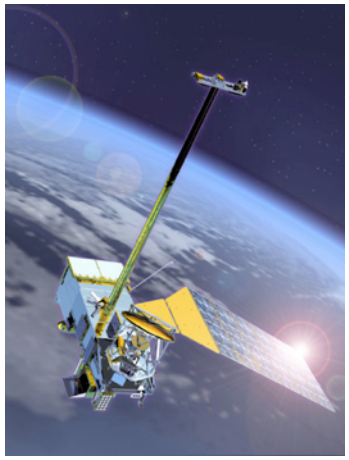
TBD author et al., (in prep)

Beyond **MODIS**



- Terra (16 years old) is driving in Maryland
- Aqua (14) “seems” well behaved, but is a teenager
- Both have well-exceeded their planned mission lifetimes
- Calibration continues to get trickier, and there are end-of-lifetime plans

How do we make AOD climate data record? (20+ years of global AOD)?



VIIRS?

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

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)

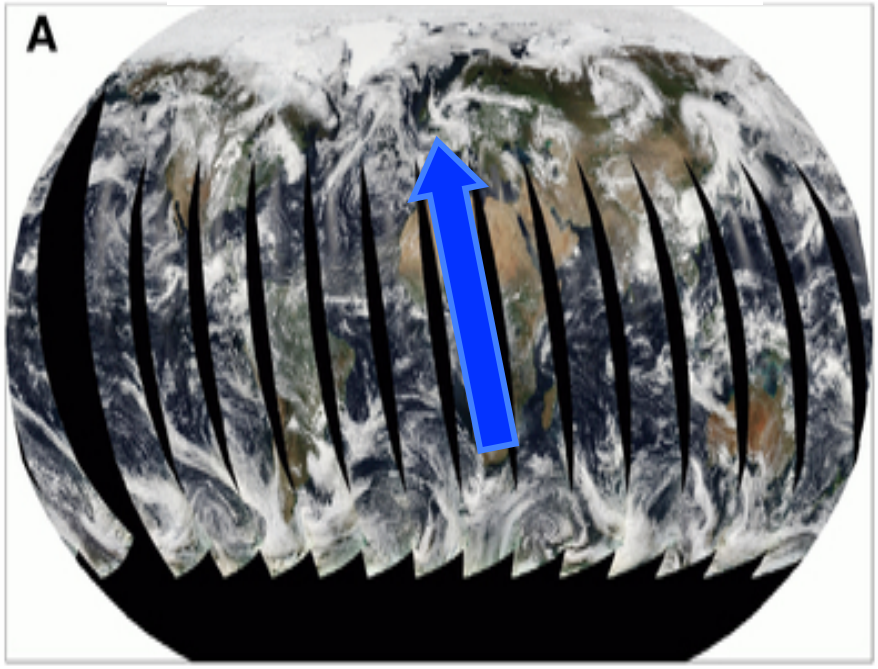
Spectral Range: 0.412-12.2μm (22 bands versus 36 bands)

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

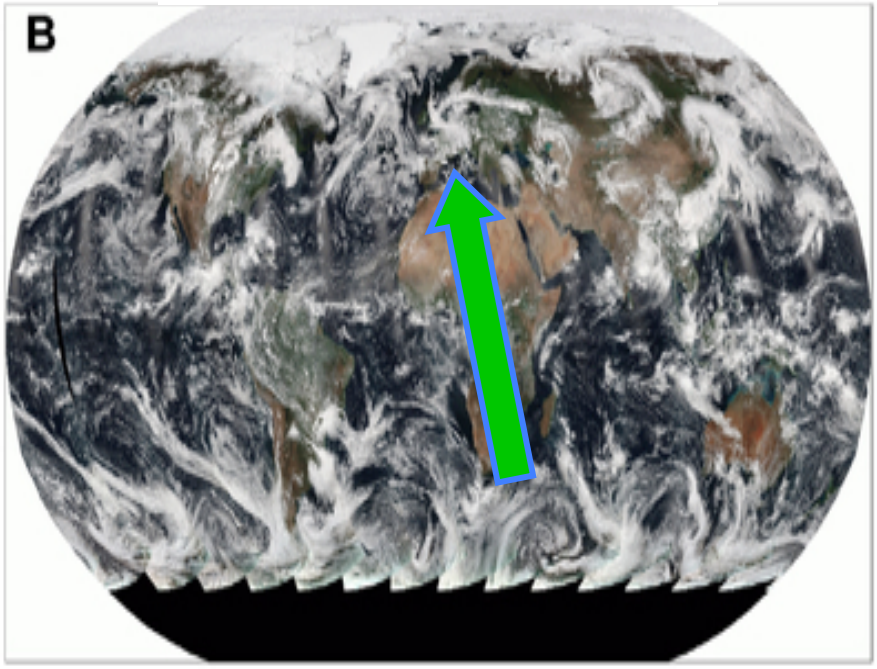
Aerosol retrieval algorithms: "Physics" similar, but different strategies

Wavelength bands (nm) / DT aerosol retrieval: 482 (466), 551 (553) 671 (645), 861 (855), 2257 (2113) → differences in Rayleigh optical depth, surface optics, gas absorption.

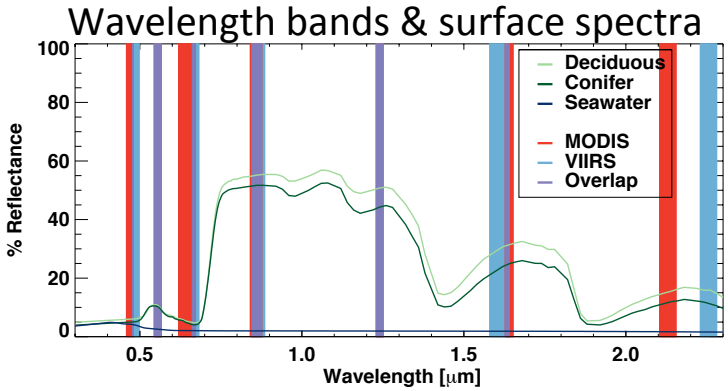
MODIS-Aqua – 29 May 2013



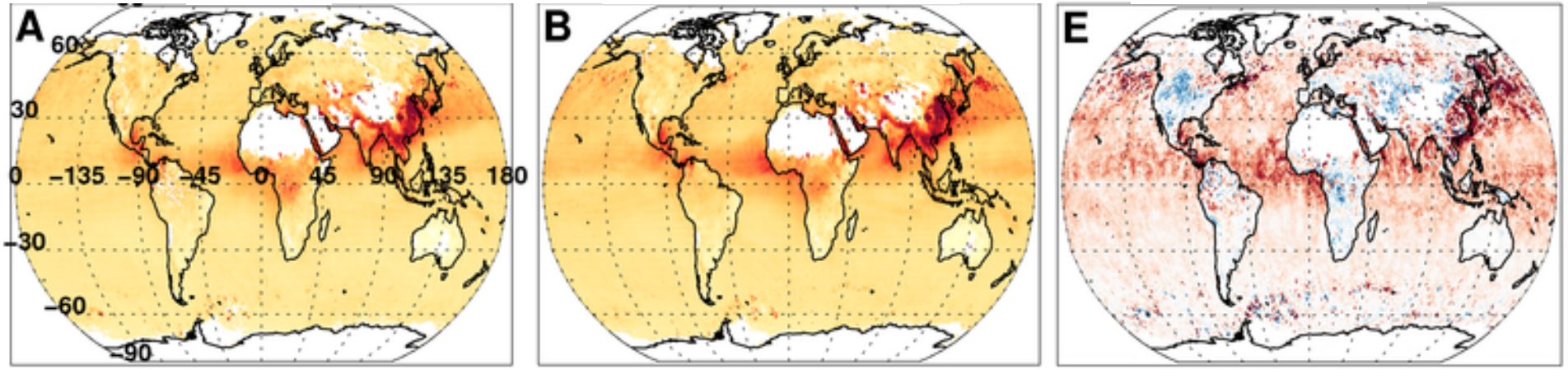
VIIRS-SNPP – 29 May 2013



We want continuity?
Port the DT algorithm!



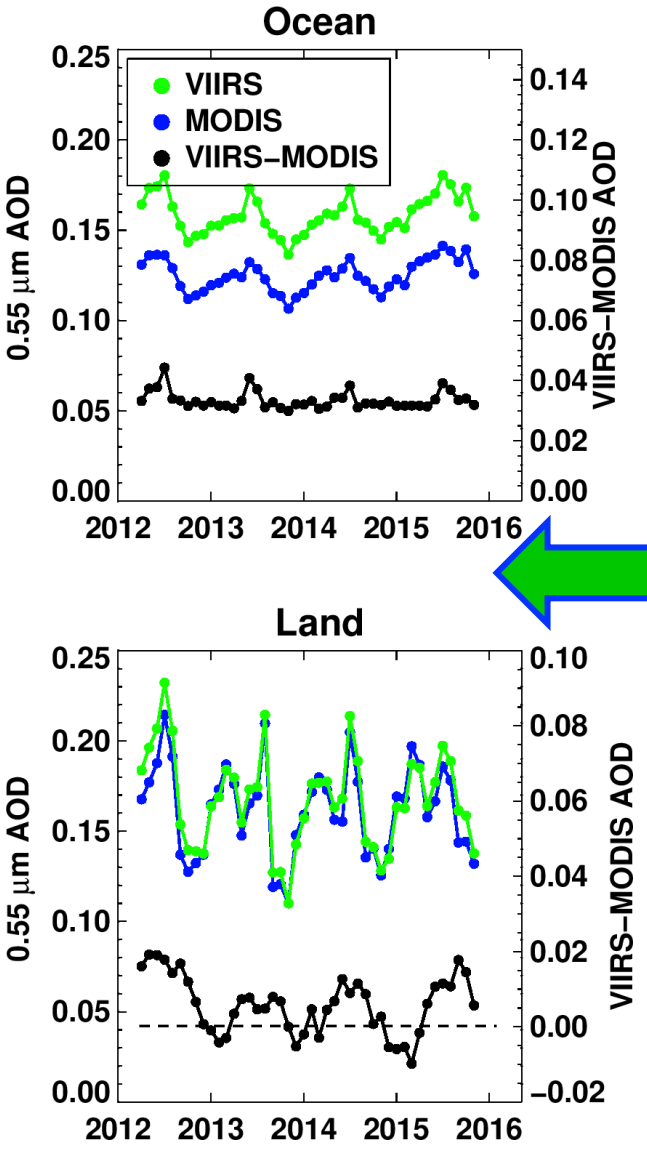
MODIS | MODIS-like on VIIRS | Difference M - V



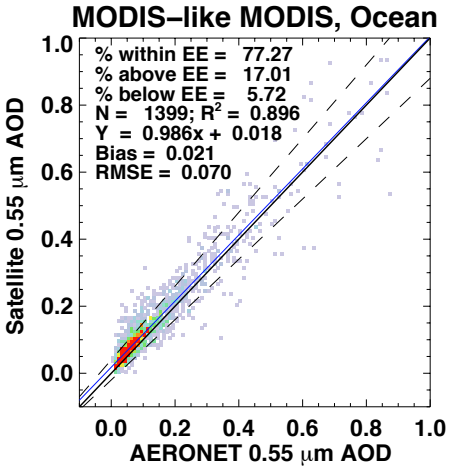
- We use Intermediate File Formats (IFF) and tools developed at the "Atmosphere-SIPS", at the University of Wisconsin
- Results of MODIS-like on VIIRS include:
  - Reduced global AOD differences and more similar global sampling
  - Now a systematic bias over ocean (VIIRS high by 20%).
  - Déjà vu? Terra versus Aqua? (Terra high by 13%)
  - → VIIRS also needs calibration study?

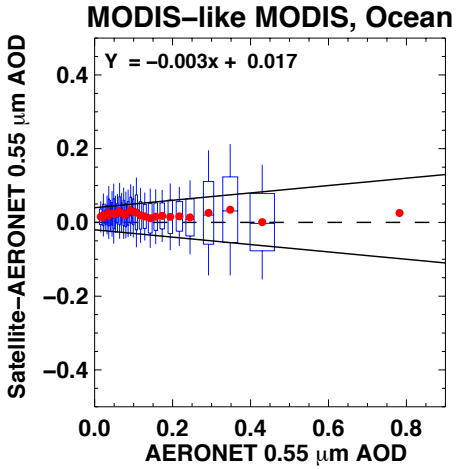
Levy et al., 2015

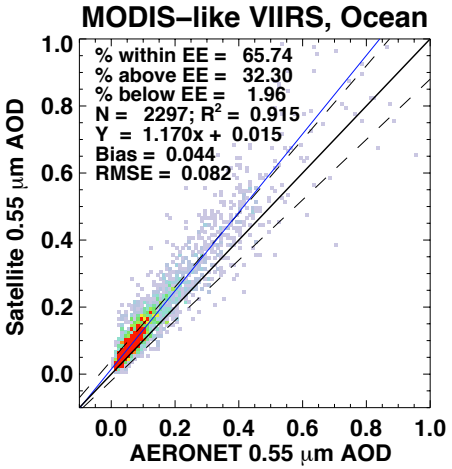
MODIS – VIIRS overlap with the IFF

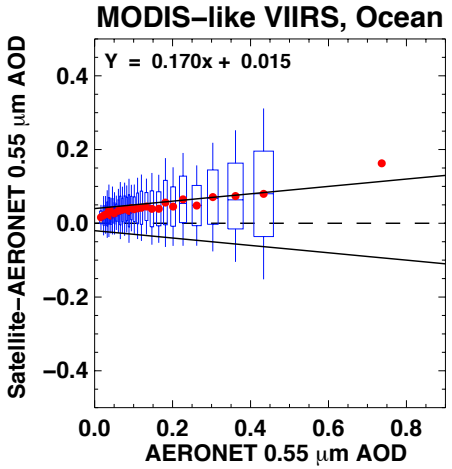


- 2012-2015.
- Ocean: Consistent offset = 0.03 (20%) with spikes in summer
- Land: Average offset is near zero, but seasonal dependence







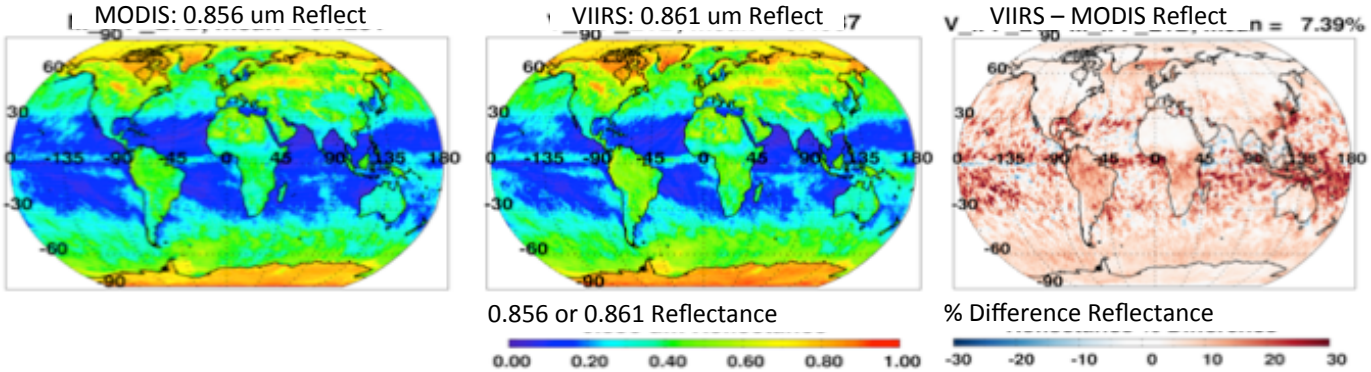


Comparing to AERONET and calibration

MODIS-like on VIIRS has great correlation but 1.17 slope!

Studies such as Uprety et al., (2013) do radiometric comparisons between VIIRS and MODIS and find that VIIRS may be 2% high in some bands.

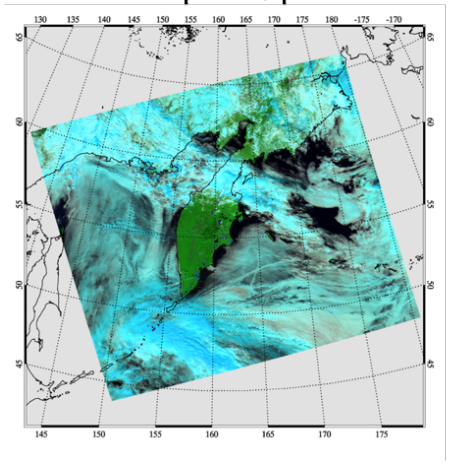
2% high bias is sufficient to give a 1.17 slope over ocean without the adding same bias to land.



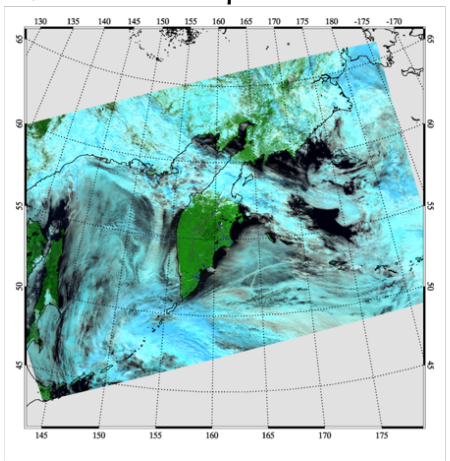
Calibration: Match files

- Can we "prove" calibration differences? It's hard!
  - Slight differences in orbit → no true matches inside ±70° latitude
  - Common geometry is very limited
  - University of Wisconsin is creating "match" files for us to look at

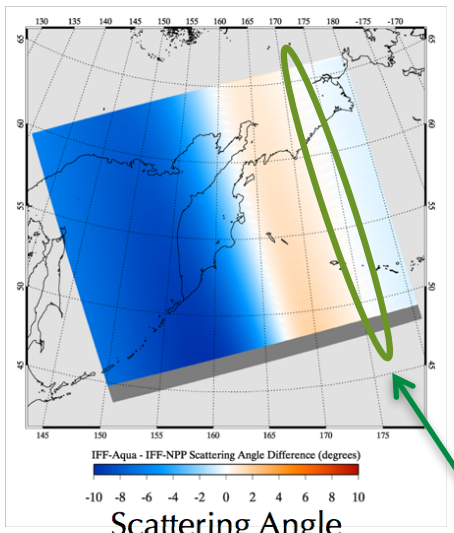
Close overpass (space and time) between Aqua and SNPP near the Kamchatka Peninsula and surrounding waters.



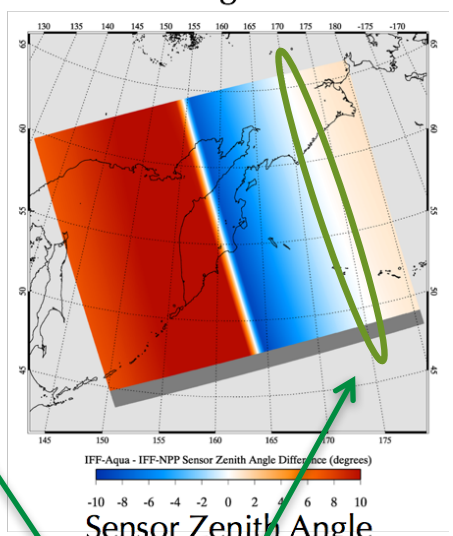
MODIS False Color
(Bands 7, 2, 1)



VIIRS False Color
(M11, M7, M5)



Scattering Angle
Difference



Sensor Zenith Angle
Difference

6 July 2014

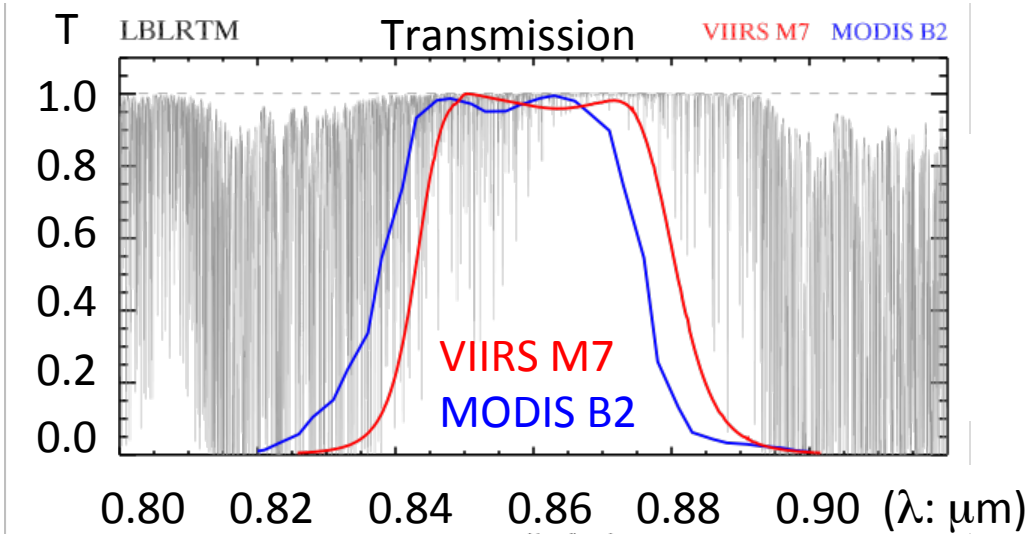
From Steve Platnick

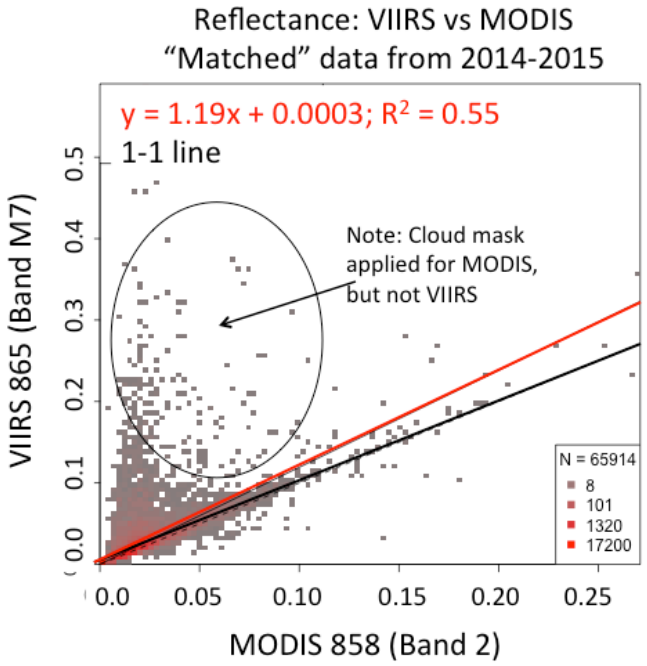
"common" geometry/angles

Calibration: Wavelength issues

- Slight differences in wavelength → no true matches
- Slight differences in Rayleigh optical depths,
- Sometimes major differences in gas absorptions
- With of lack of spatial overlap, hard to find mutual cloud free.
- And so far, both datasets are not cloud-masked equally.

Example: 0.86 μm channel over "clear" sky

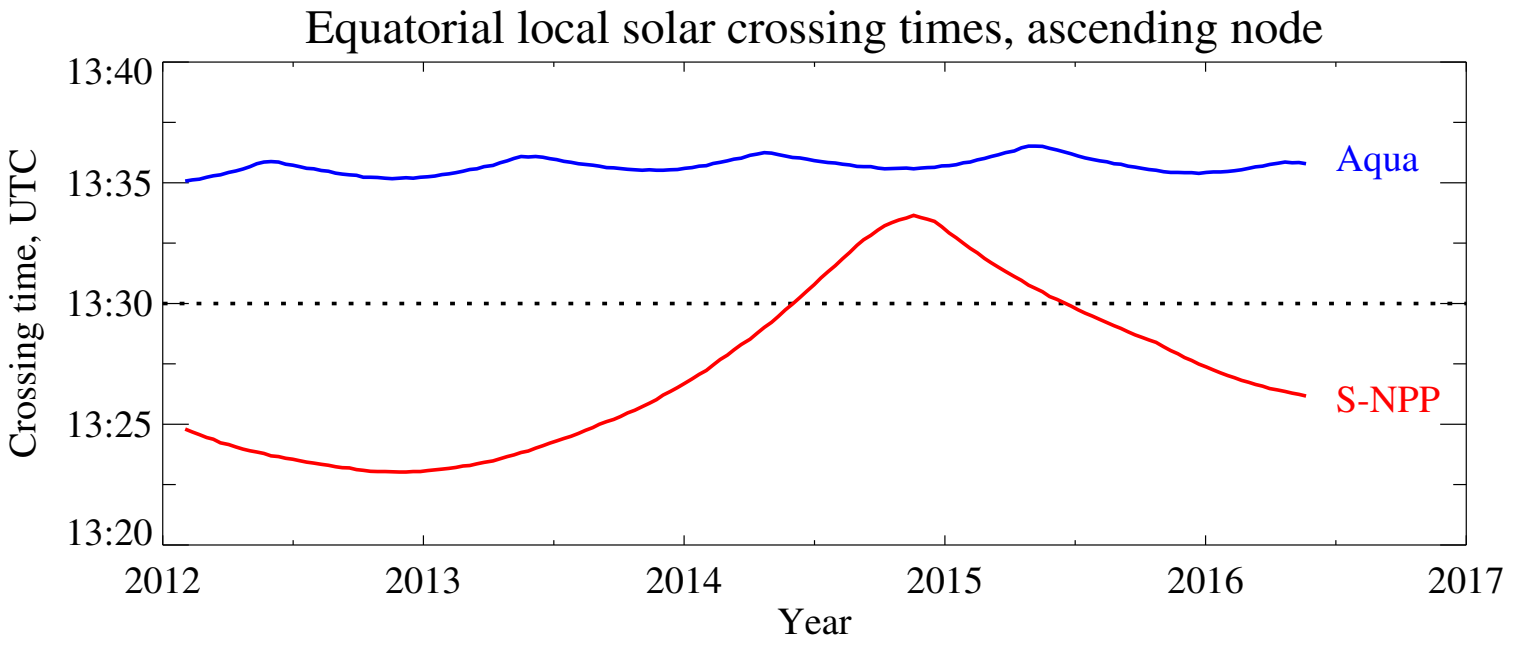




See Virginia Sawyer poster:

Calibration: Timing issues

- Drifting orbits: varying equatorial overpasses
- Defining a max time difference (e.g. 10 mins) may not work



Plot drawn by Andy Sayer (GSFC), source data from Greg Quinn at SSEC Wisconsin.

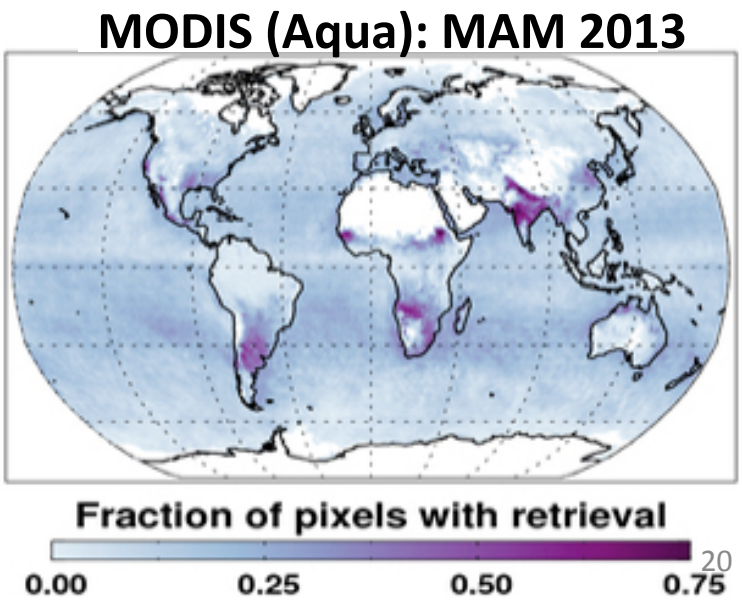
What is good enough?

- 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?

- Validation: Comparison with AERONET, etc?

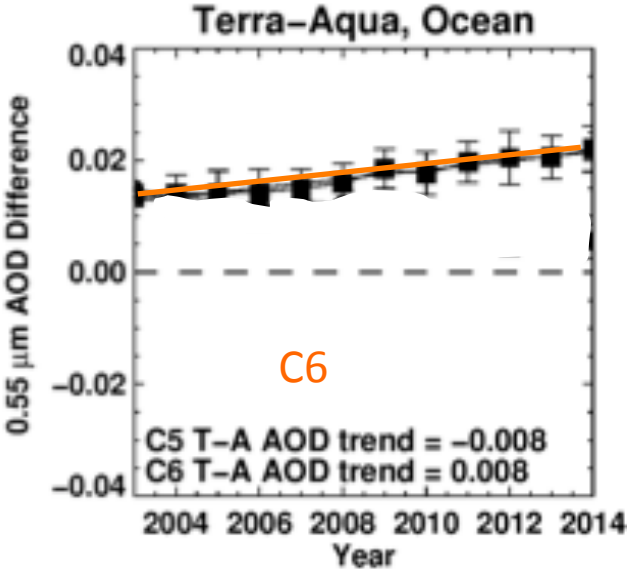
- "Retrievability": Do algorithms make same choices under same conditions?

- Other metrics?

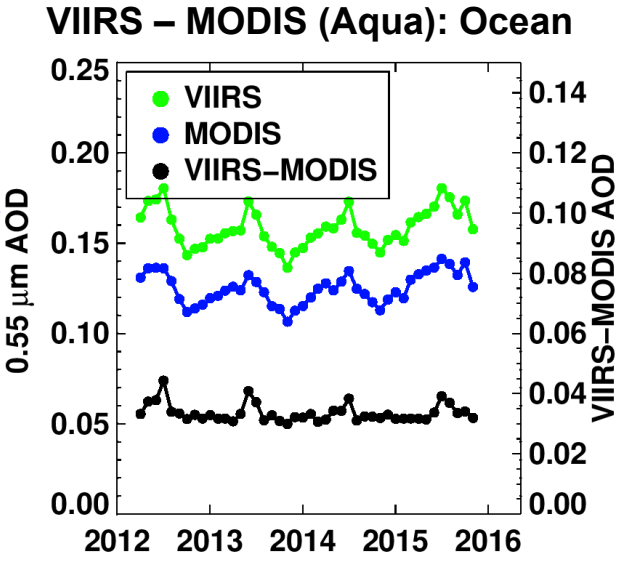


Summary (MODIS →VIIRS)

- MODIS-DT Collection 6
  - Aqua/Terra level 2, 3; entire record processed
  - "Trending" issues reduced
  - Still a 15% or 0.02 Terra vs Aqua offset.
  - Terra/Aqua convergence improved with C6+, but bias remains.
  - Other calibration efforts yield mixed results



- VIIRS-DT in development
  - VIIRS is similar, yet different then MODIS
  - With 50% wider swath, VIIRS has daily coverage
  - Ensures *algorithm* consistency with MODIS.
  - Currently: 20% NPP vs Aqua offset over ocean.
  - Only small bias (%) over land (2012-2016)
  - Can VIIRS/MODIS create aerosol CDR?



- Calibration for MODIS – VIIRS continues to fundamentally important.
- It's not just Terra, or just Aqua, or just NPP-VIIRS, I really want to push synergistic calibration.