MODIS Dark Target products
Collection 6 and onward to Collection 7

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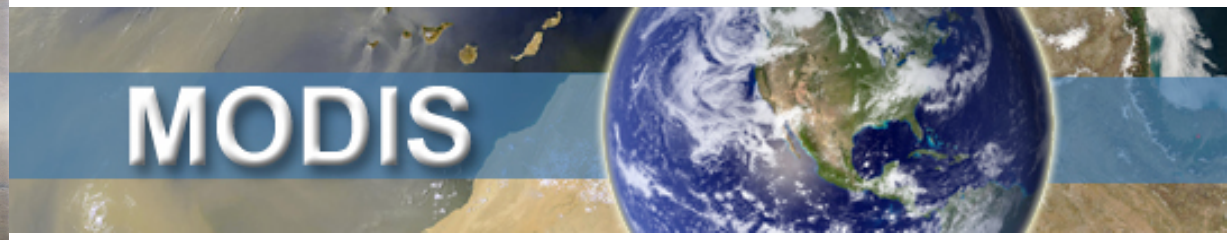
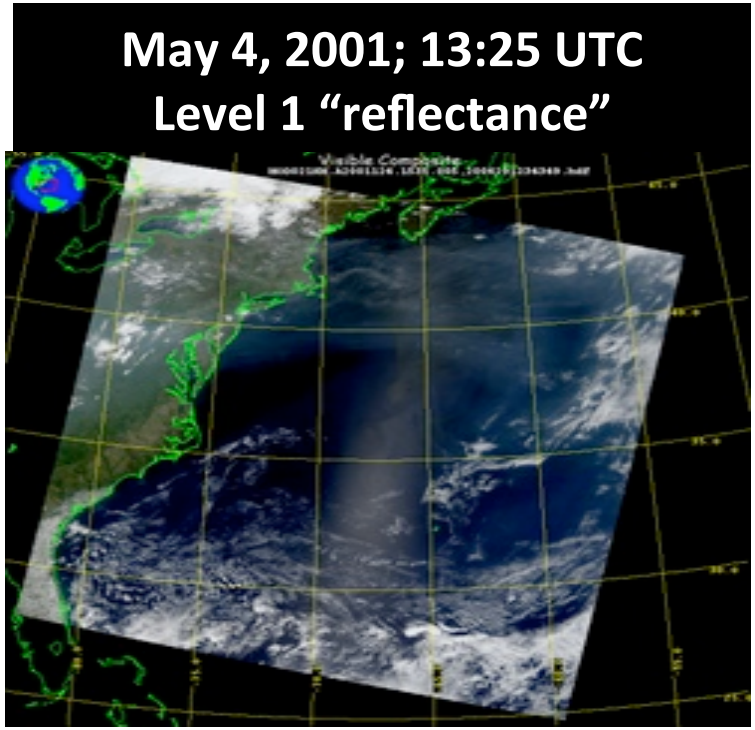
Pawan Gupta (GESTAR/USRA @ NASA-GSFC)

Lorraine Remer (JCET-UMBC)

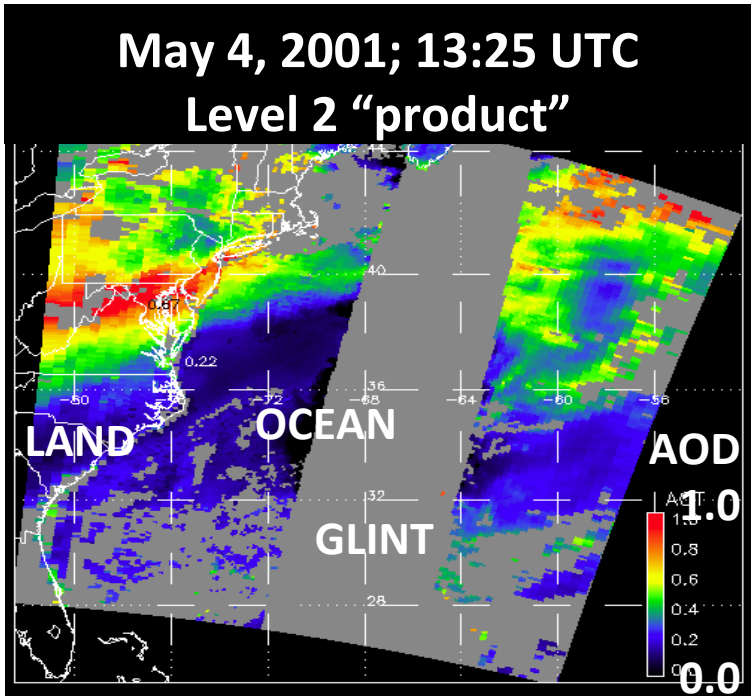


Aerosol retrieval from MODIS

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

Outline

- Collection 6 (C6) in production
  - Differences from C5 (Level 2)
  - Some preliminary validation (for Aqua)
  - Terra versus Aqua and calibration
  - Level 3 protocol
  - Higher resolution 3 KM product
- Maintenance proposal accepted: Towards C7?
  - Corrections of urban surfaces
  - New Uncertainty products (per-pixel)
  - Consistency between Terra and Aqua, and continuation onto VIIRS
- Dark target web page

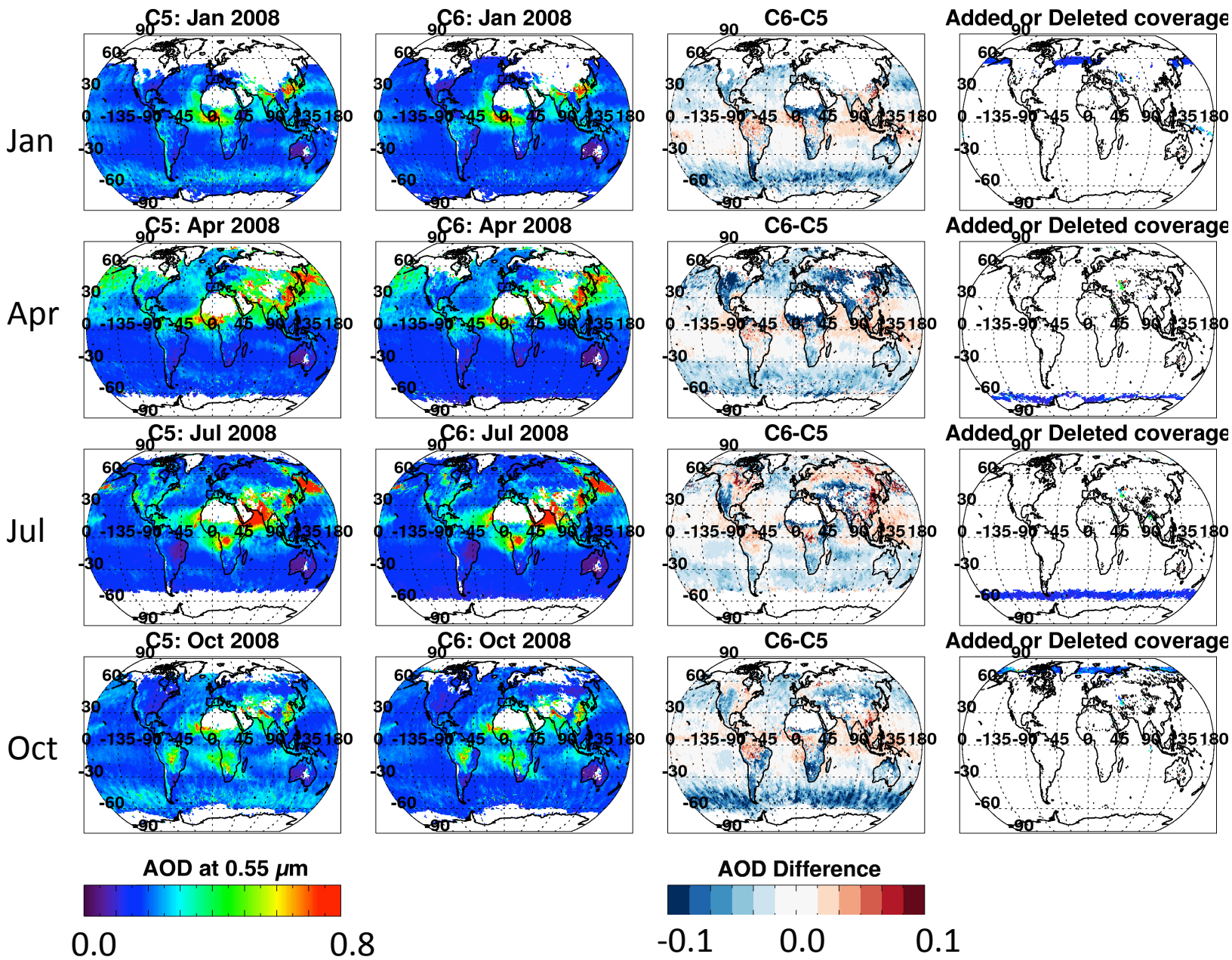
MODIS Collection 6: Introduction

Published in AMT

- 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, 2989-3034, doi:10.5194/amt-6-2989-2013, 2013.

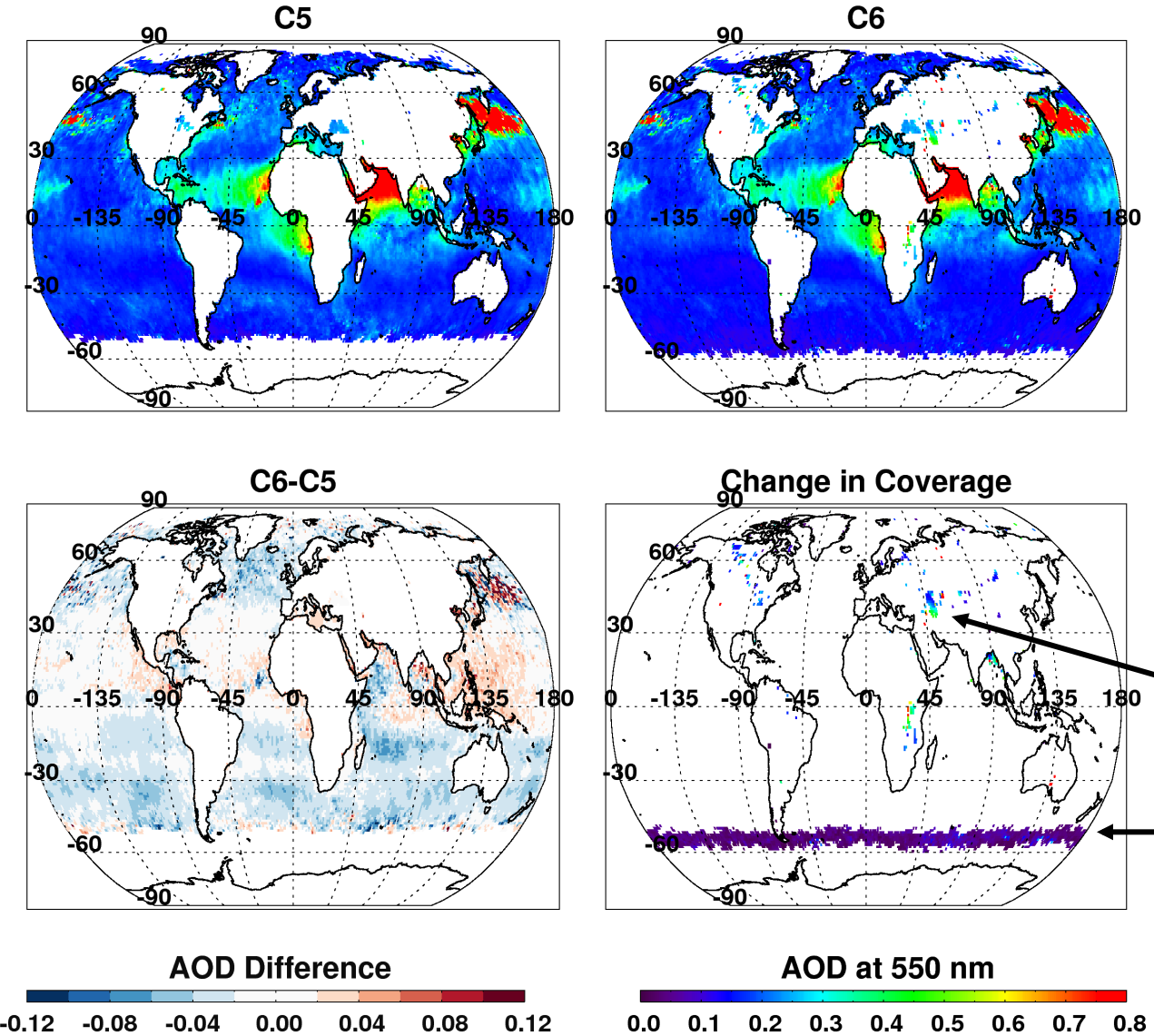
http://www.atmos-meas-tech.net/6/2989/2013/

Overall changes (C6 vs C5): Aqua, 2008



Aerosol over ocean

Dark target over ocean
Overall changes to products (Aqua, Jul 2008)



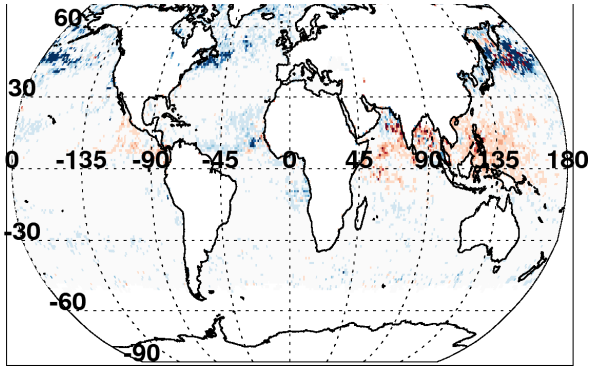
- Overall decrease of AOD in mid-latitudes
- Strong decrease in "roaring 40s" (even stronger in other months)
- Overall increase in tropics

- "New" coverage over inland lakes
- Increase in coverage toward poles

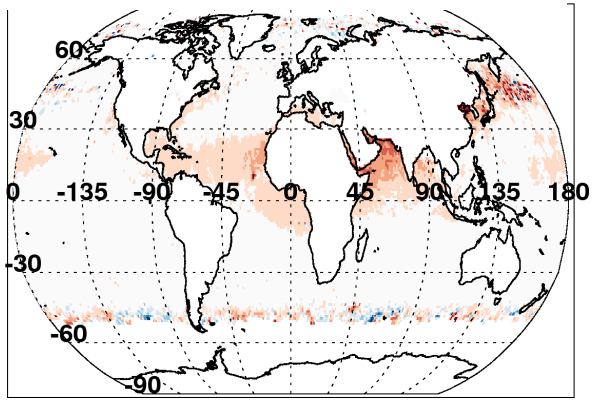
Why the changes?

C6-C5 ocean: Due to many incremental changes (Aqua, July 2008)

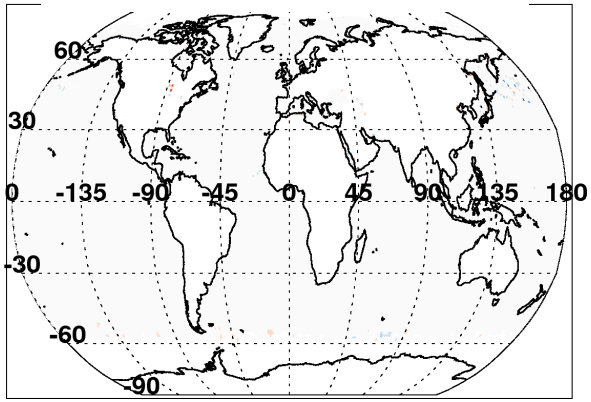
New reflectance, geo-location inputs, Wisconsin cloud mask



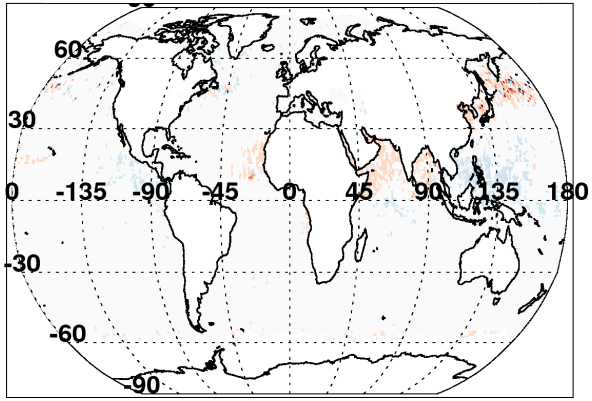
Updated radiative transfer



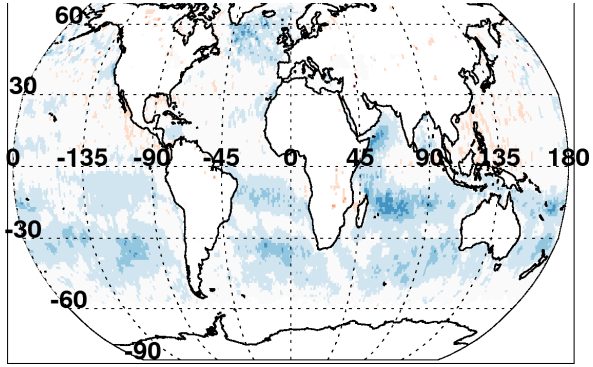
Re-define land and sea

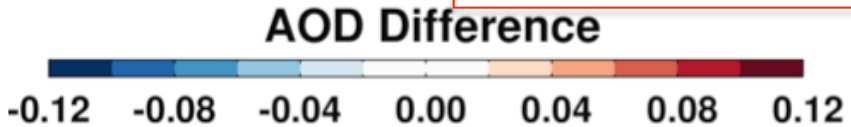


Improved cloud mask



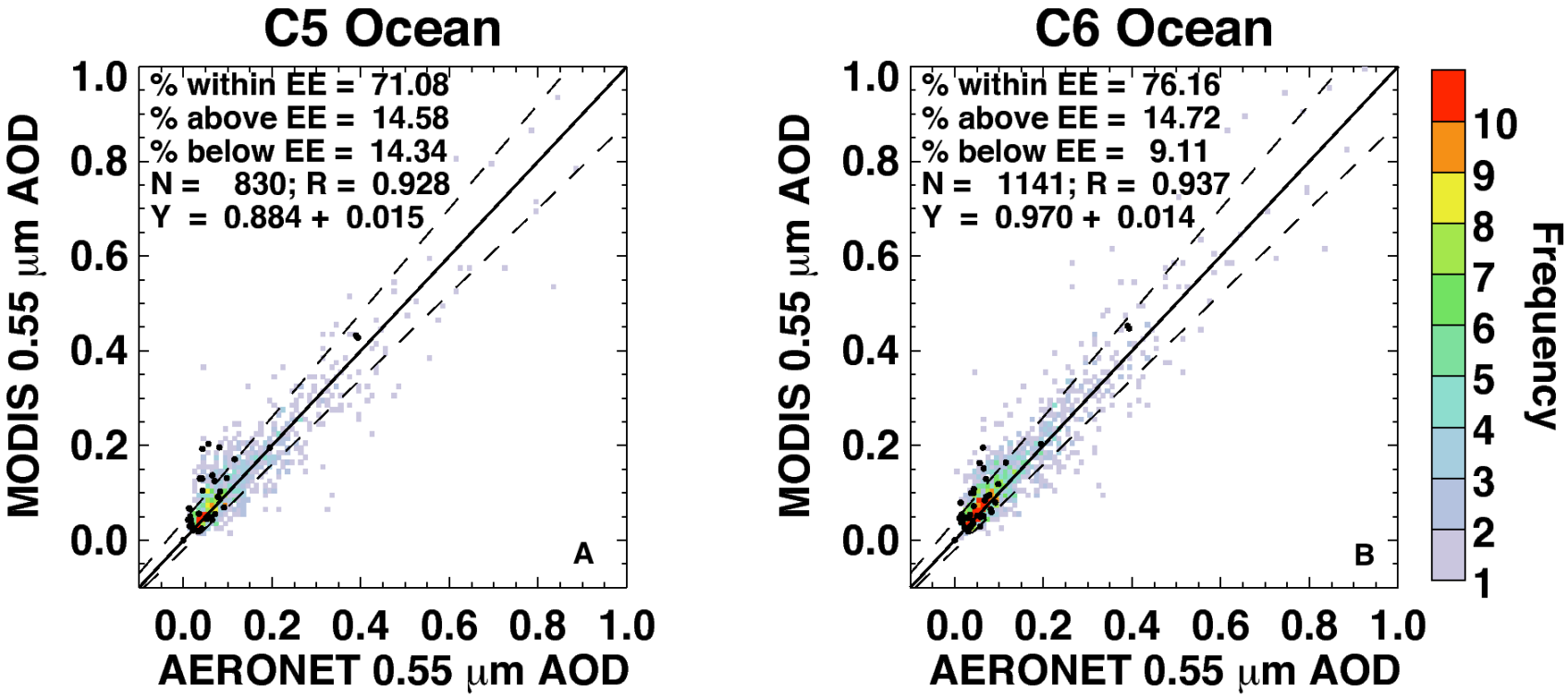
Account for wind speed impact on surface





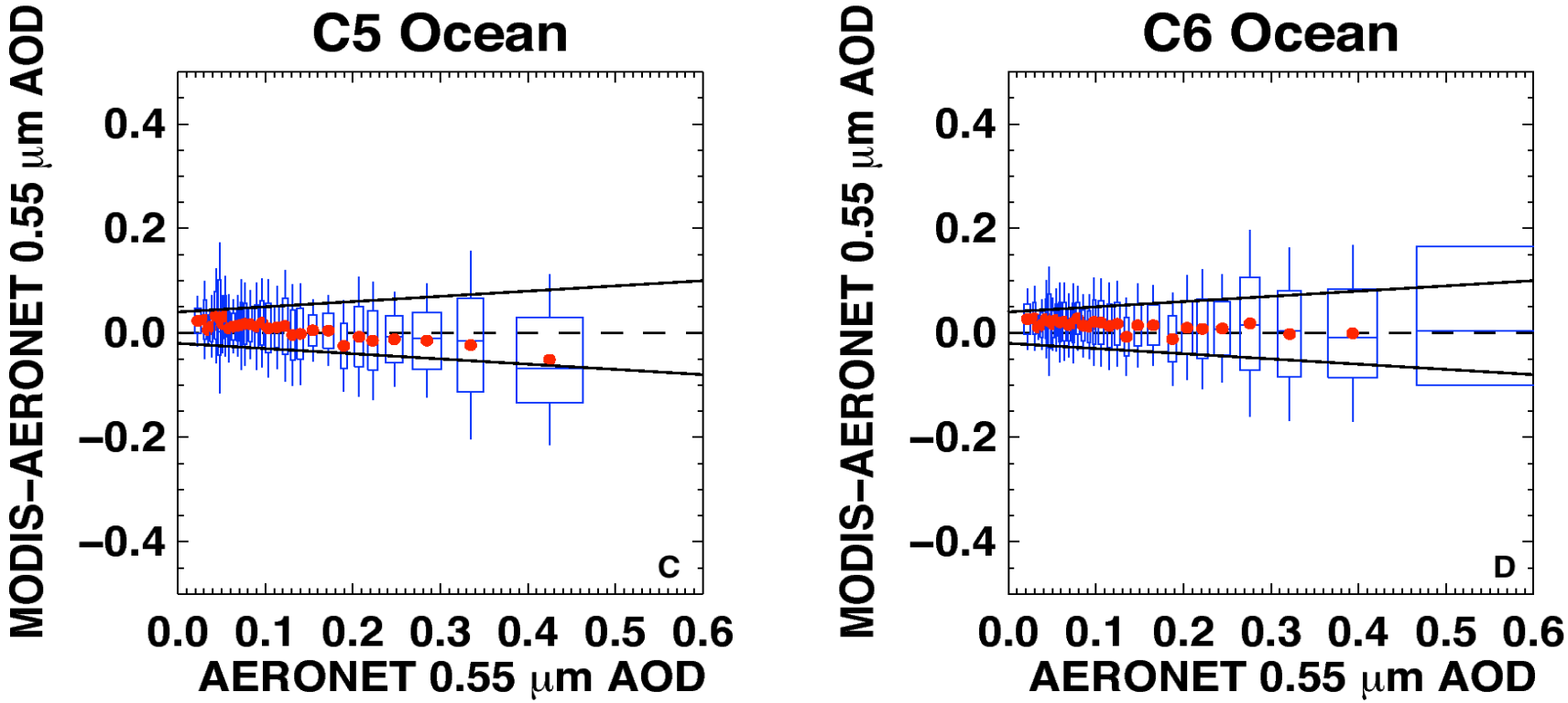
- Also changed "Quality Assurance" Filtering
- Changed aerosol definitions of land and sea
- Etc

Comparison with AERONET and MAN



- Aqua for 8 months (Jan + July, 2003, 2008 and 2010; Apr + Oct 2008).
- Overall, not much change over ocean (slope, intercept, correlation)
- But 30% more valid points to compare with (1141 versus 830).
- AERONET are gray and colored, MAN are black dots

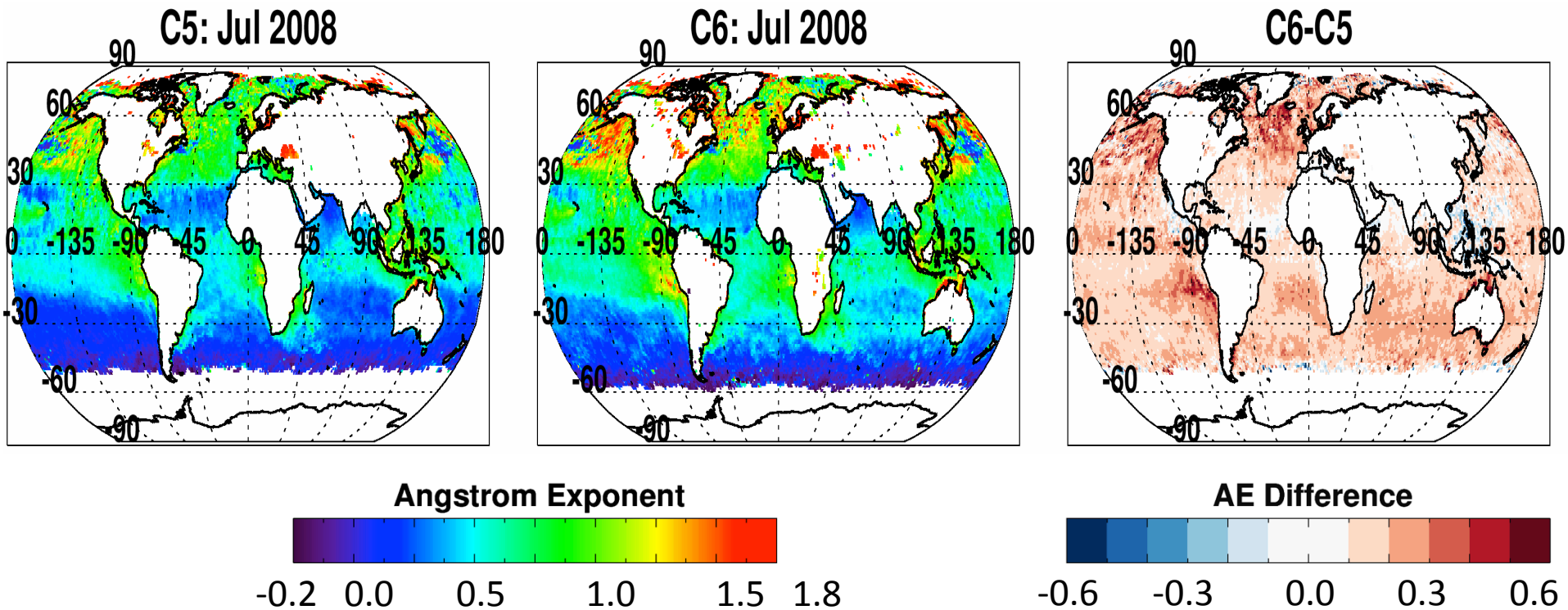
Better way to see MODIS improvement



- MODIS error (MODIS–AERONET) versus AERONET; zero "error" is dashed line
- Boxes represent middle 67% of each dataset, whiskers are middle 95% of MODIS-AERONET
- Solid lines are "expected error" (EE) envelope; note asymmetry (new definition for C6).
- Note that in C6, that the MODIS error is within EE for nearly all bins of AOD
- C5 EE = ±(0.03 + 5%). C6 EE = (-0.02 – 10%), (+0.04 + 10%))
- Less overall "bias" in C6.

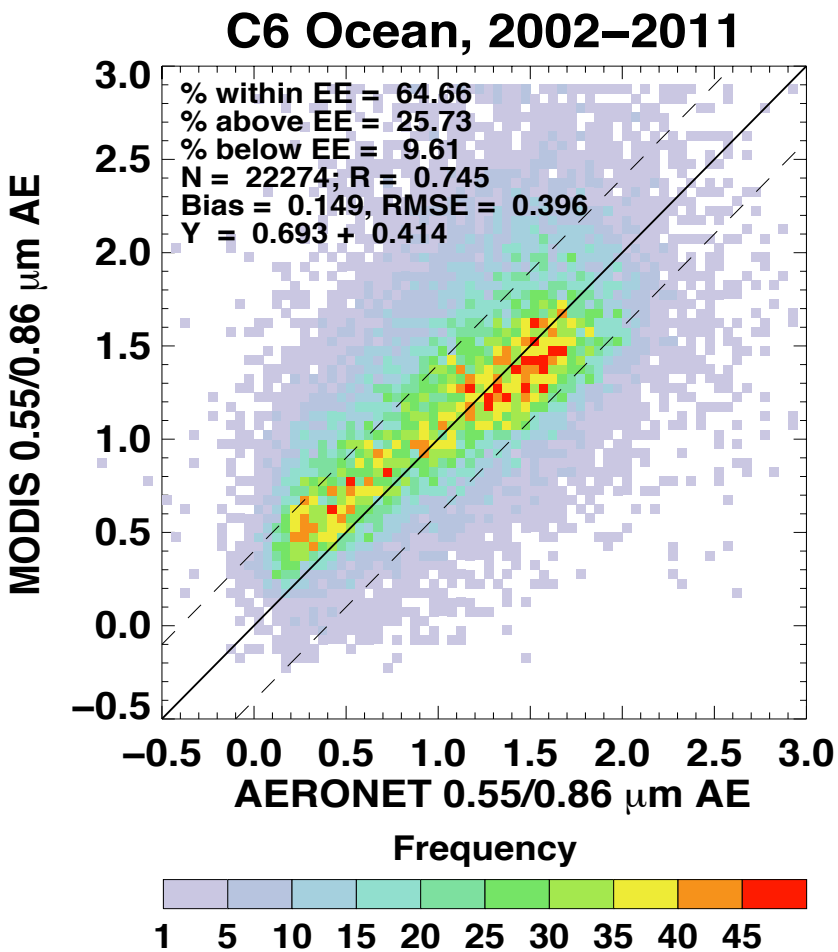
See updates (10 years of Aqua) on L. Munchak's poster!

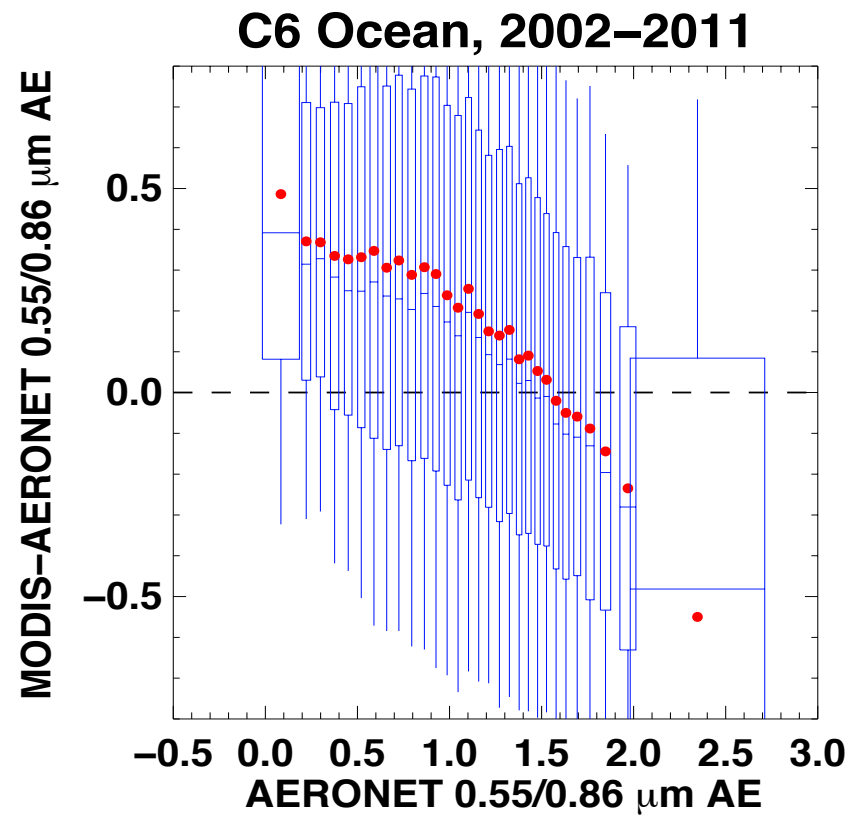
Impact on Ångström Exponent



- AE calculated from 0.55 vs 0.86 μm
- Comparison is for Aqua
- Overall increase of global AE (+0.18).

Reasonable validation of AE within ±0.4



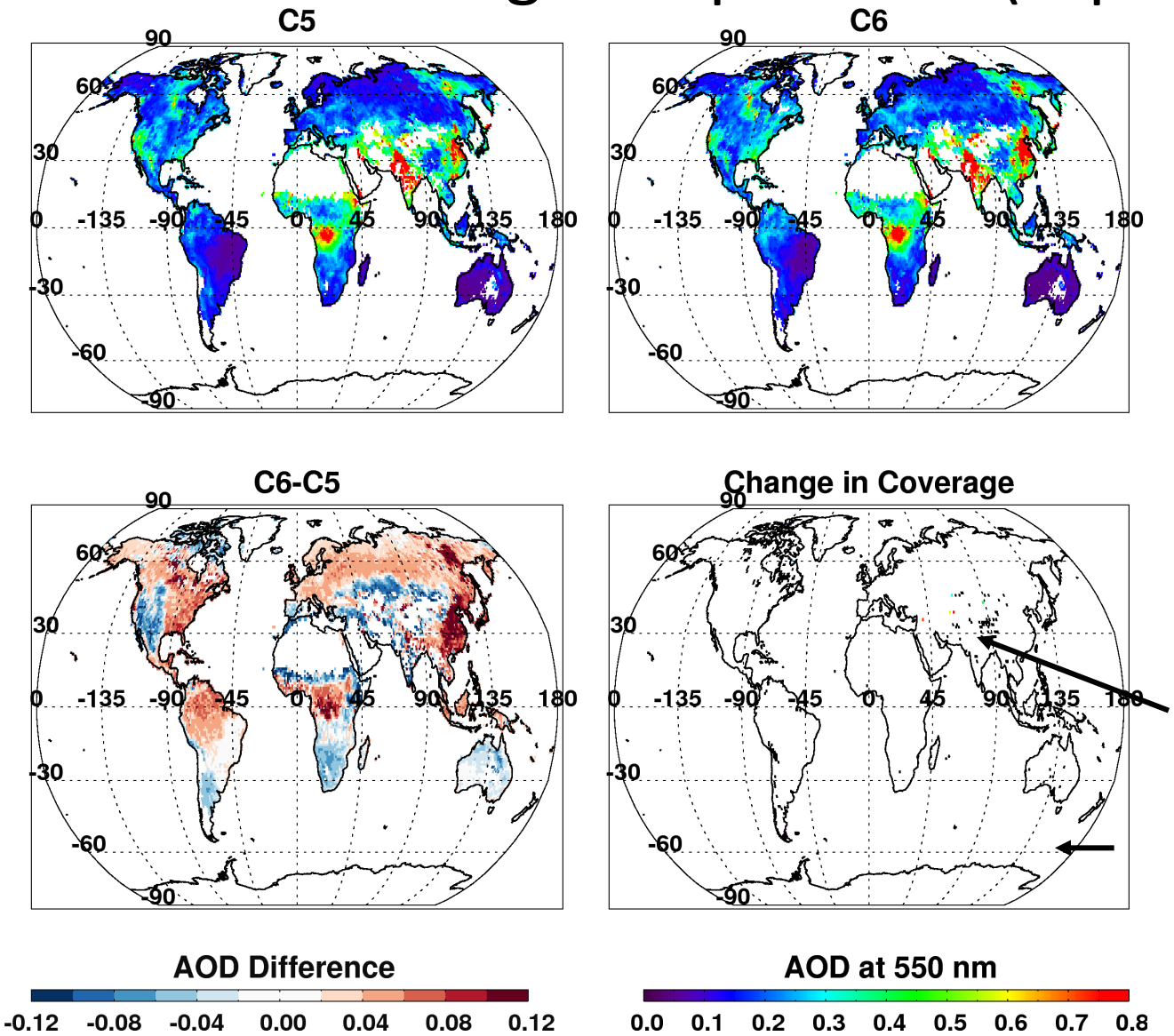


MODIS "range" is less than AERONET

See L. Munchak's poster!

Aerosol over land

Dark target over land
Overall changes to products (Aqua, Jul 2008)



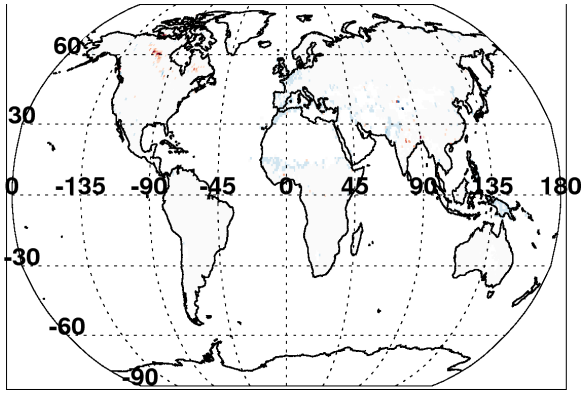
- Overall decrease of AOD in semi-arid
- Overall increase over vegetation
- Strong increase over Eastern Asia

- Slight change in coverage here and there

Why the changes?

C6-C5 land: Due to many incremental changes (Aqua, July 2008)

New reflectance and geo-location inputs



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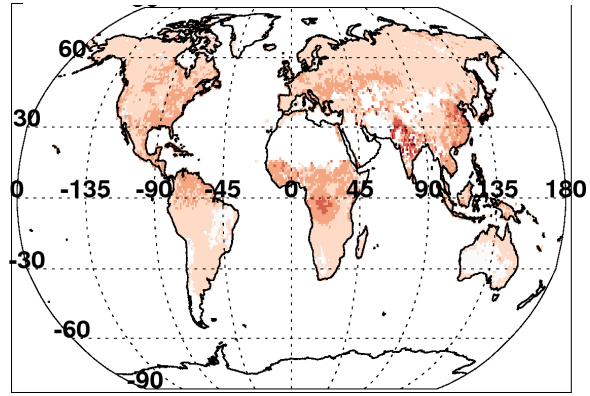
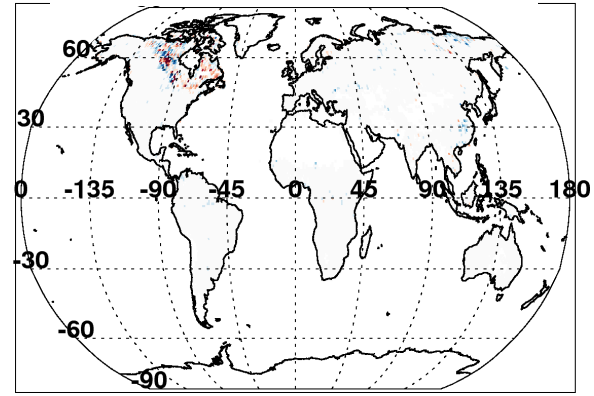
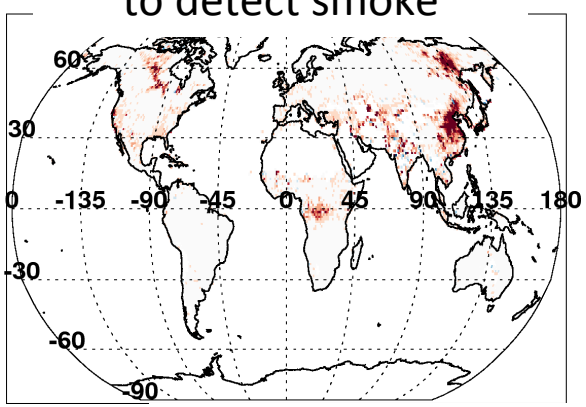


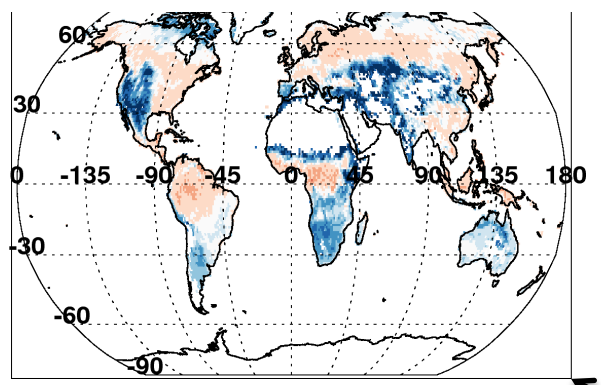
Re-define land and sea

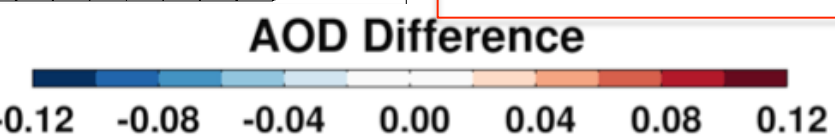


Improved cloud mask to detect smoke



Fixed surface reflectance dependence on TOA NDVI

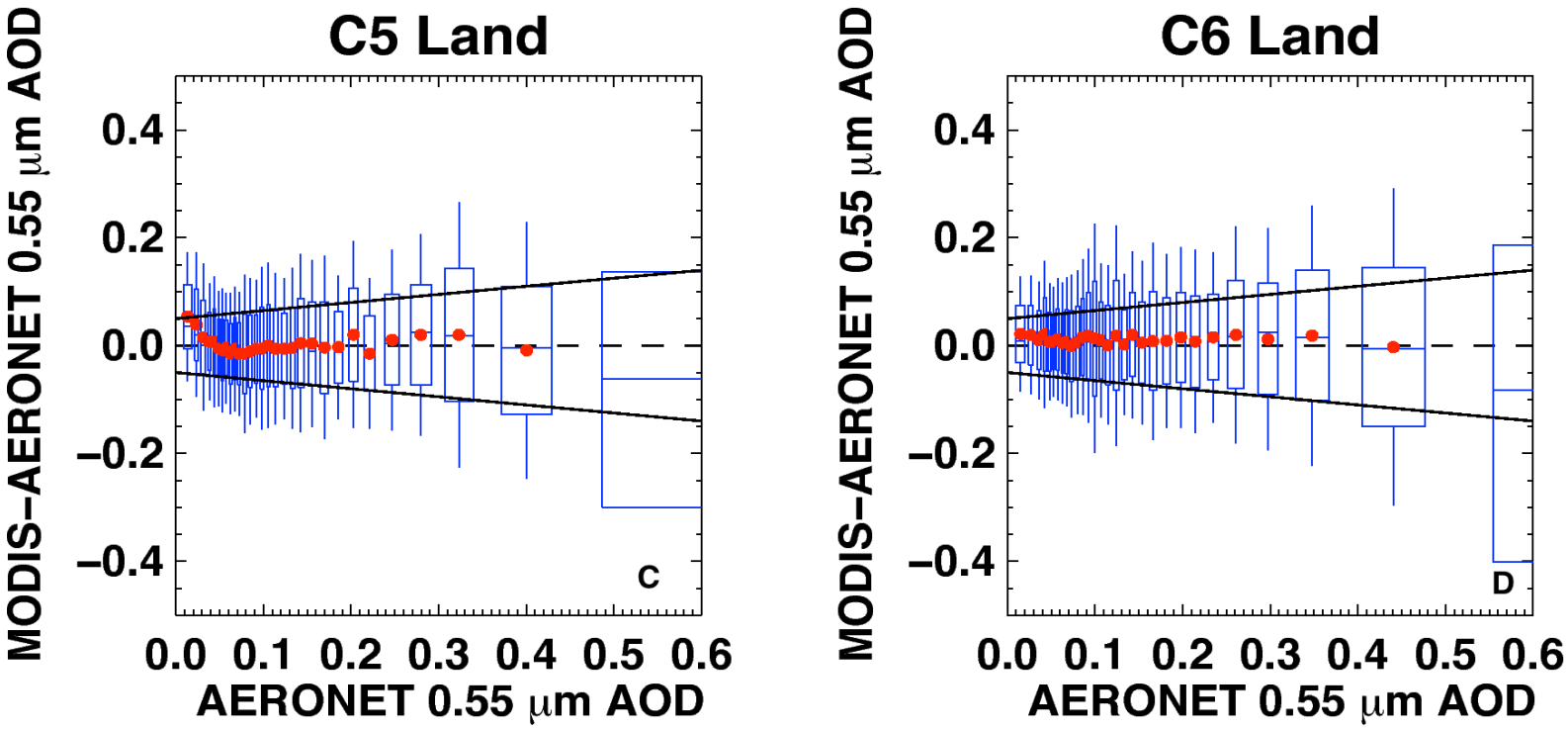




- Also changed "Quality Assurance" Filtering
- Changed aerosol definitions of land and sea
- Etc

This was a major bug!

Preliminary comparison with AERONET (8 months of Aqua data)

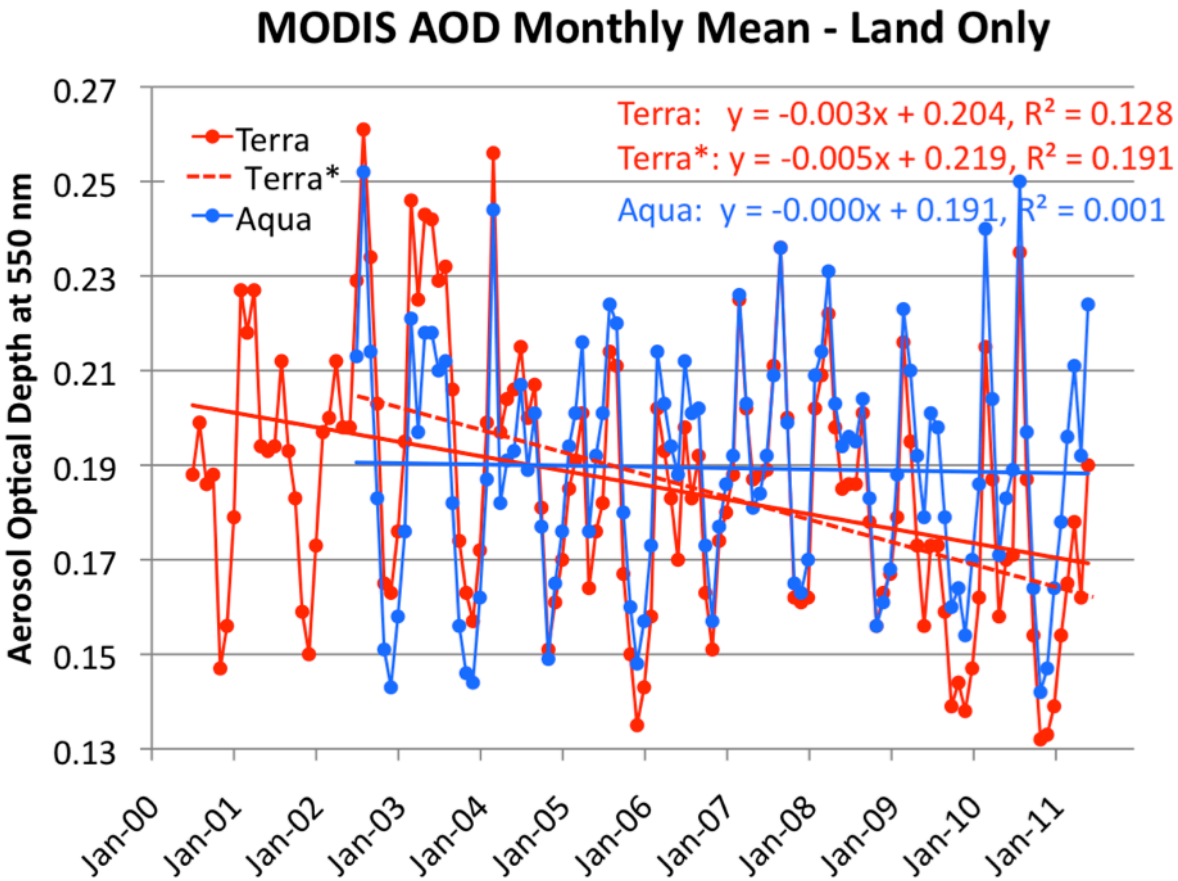


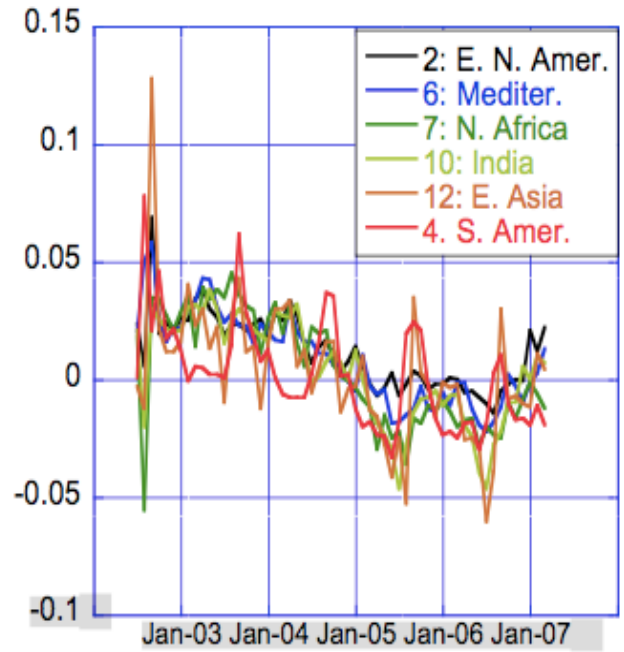
- MODIS error (MODIS–AERONET) versus AERONET; zero "error" is dashed line
- Boxes are middle 67% of dataset, whiskers are middle 95% of MODIS-AERONET
- Solid lines are "expected error" (EE) envelope; no asymmetry
- C6 MODIS error is within EE for nearly all bins of AOD (even at low values)
- C5 EE = ±(0.05 + 15%)). Keep definition for C6.

See updates (10 years of Aqua) on L. Munchak's poster!

Terra versus Aqua

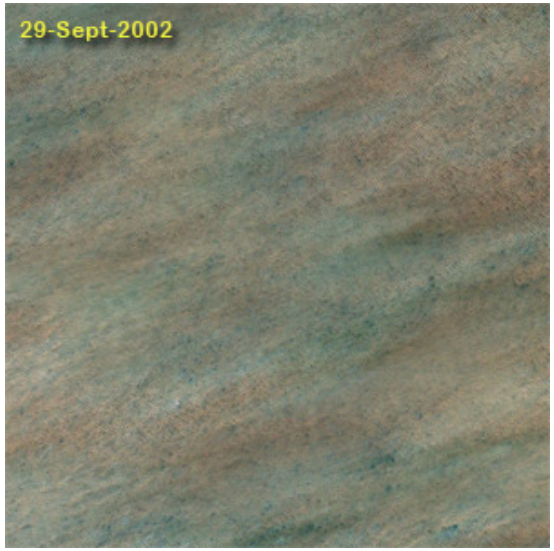
If we had used Collection 5





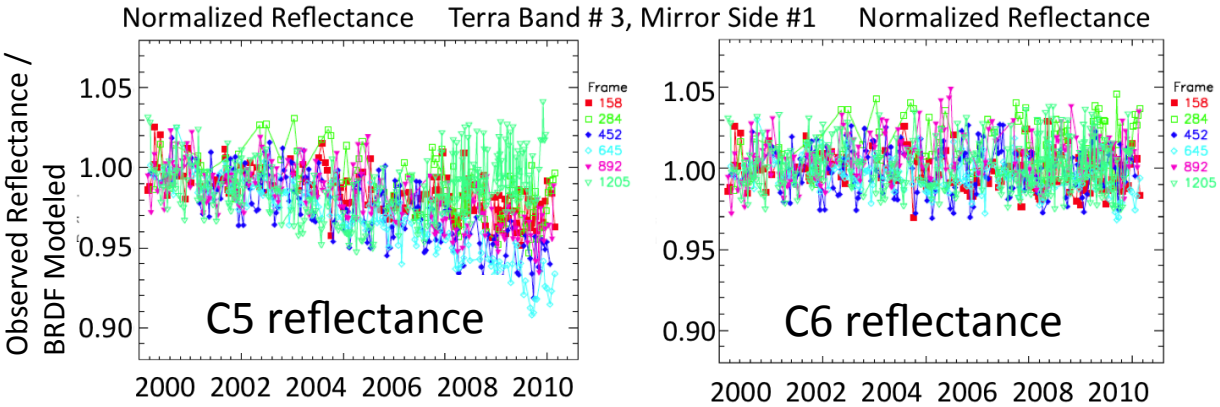
- Over land, Terra *decreases* (-0.04/decade), Aqua *constant*
- Terra / Aqua divergence is the same everywhere on the globe!
- In NH, observations are 1.5 hours apart, while SH are 4.5 hours
- So, probably not due to diurnal cycle of aerosol

Why? MODIS reflectance over desert sites: C5



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

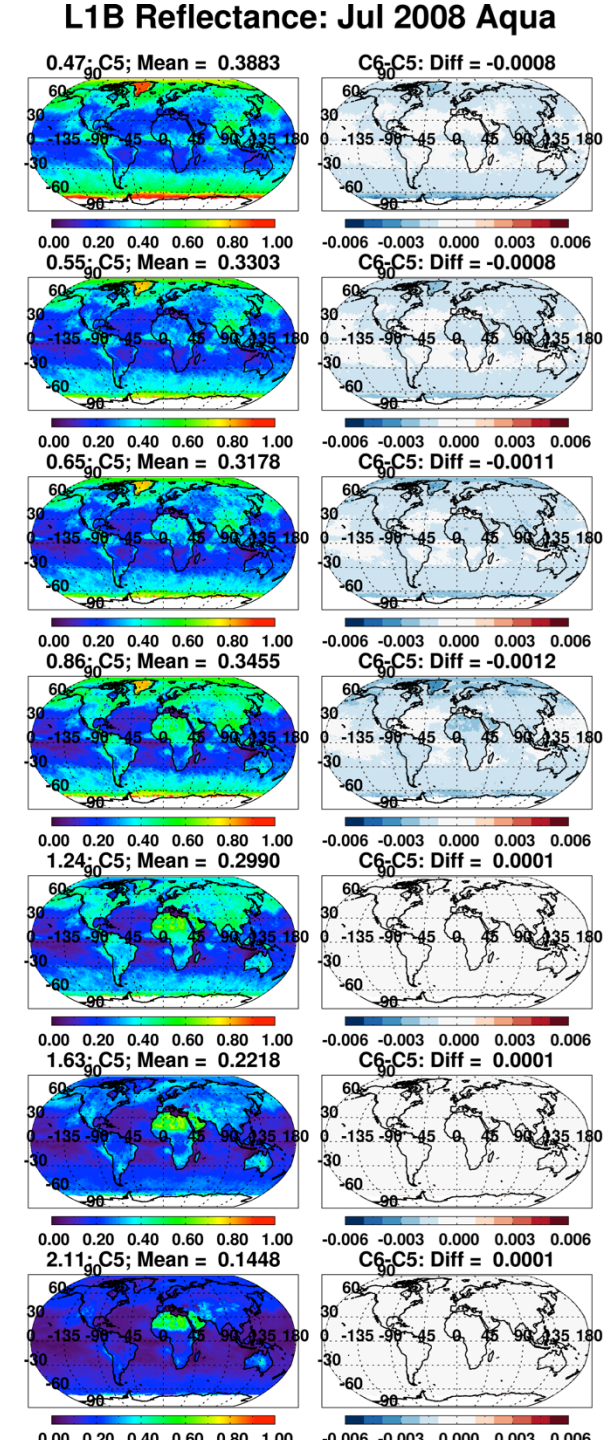


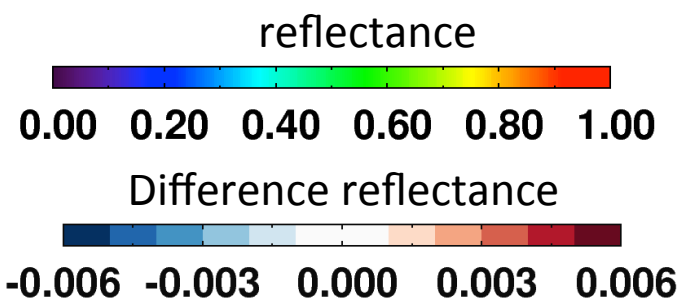
(4) Characterize and de-trend MODIS observations
(5) Create a new L1B dataset for C6.

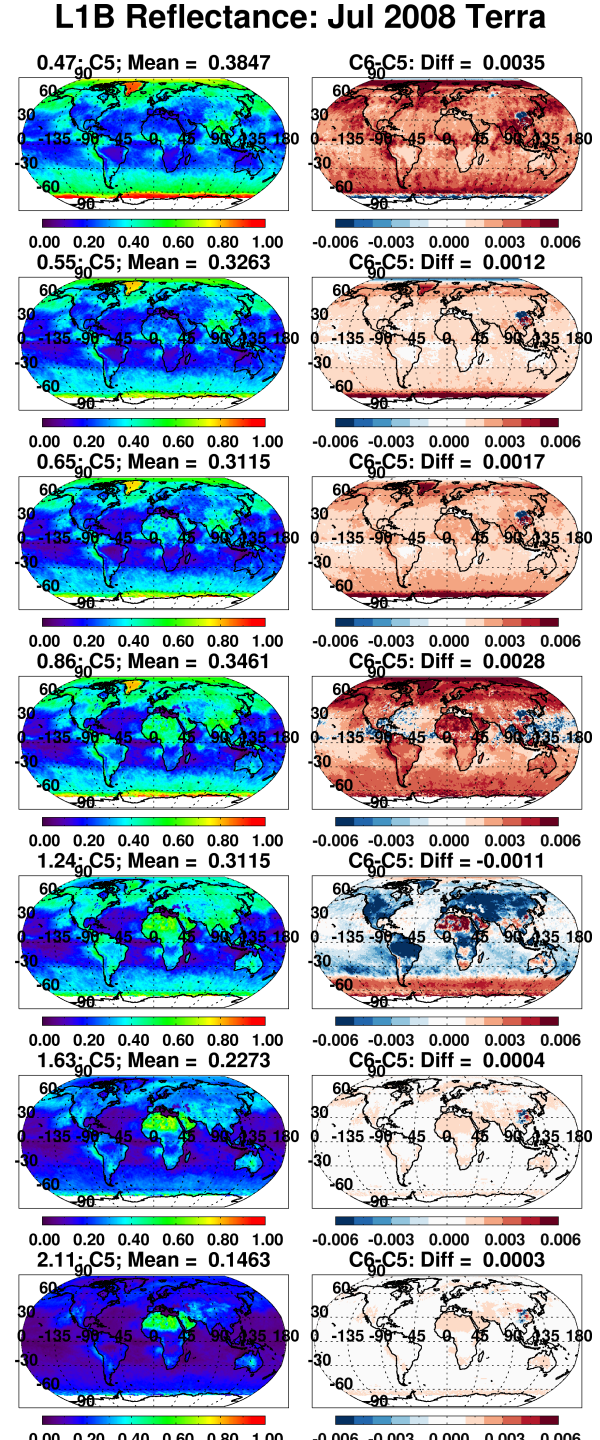
Impact to "observed" reflectance

- "Global" Aqua changes in visible bands by -0.001 or less
- "Global" Terra changes in visible bands by +0.002 or more

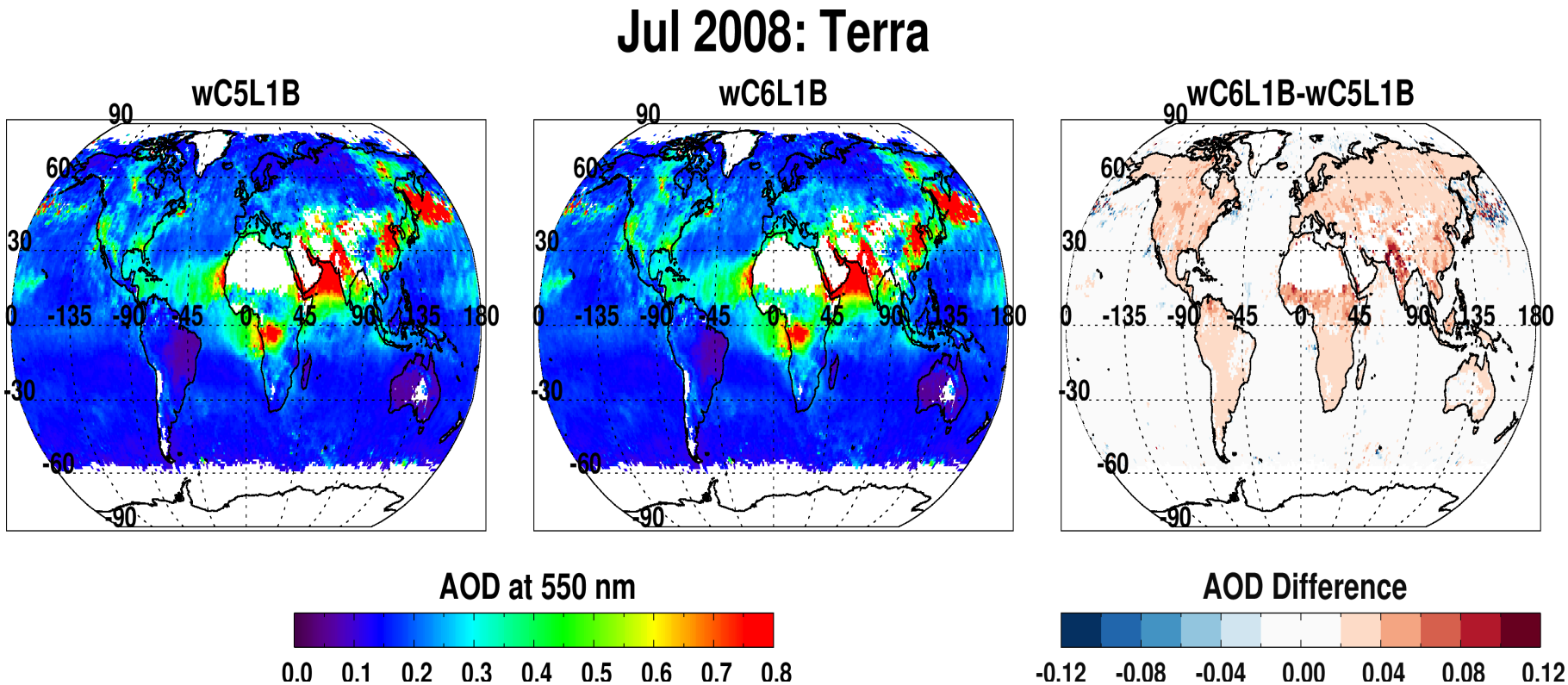
- Overall Aqua changes are relatively stable, but Terra's changes vary over time.





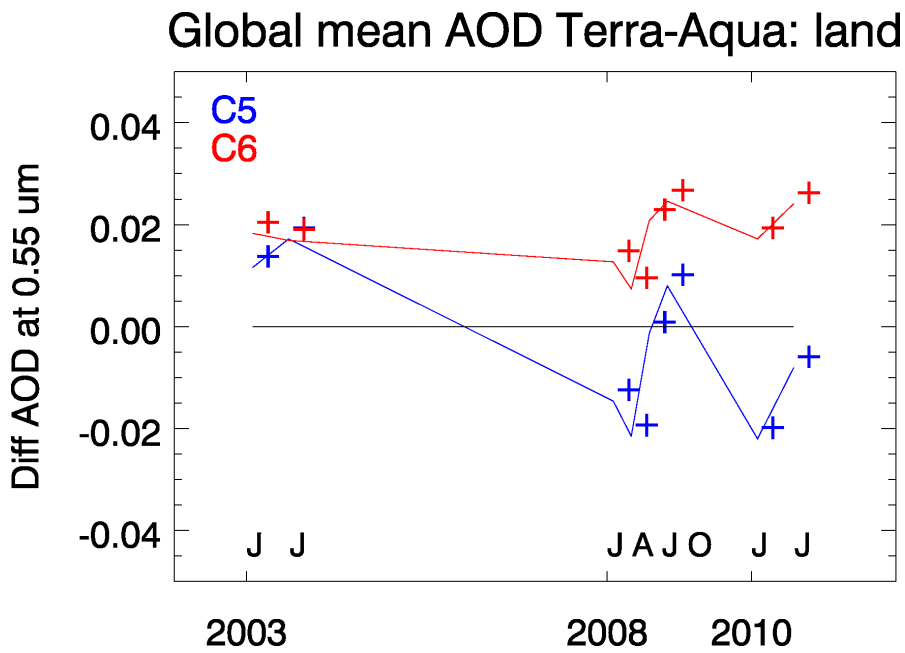


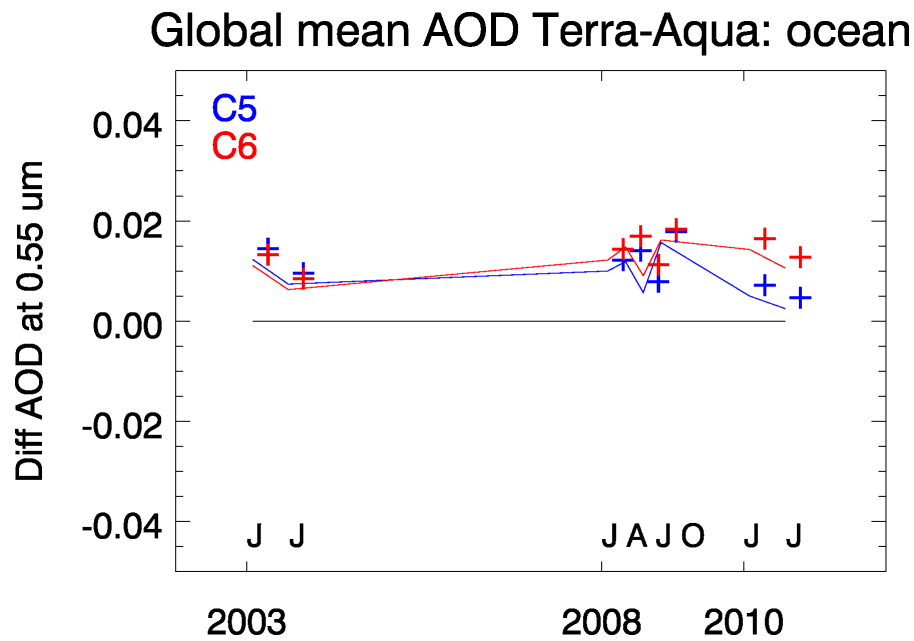
Impact of New Terra calibration



- Big changes to blue and red bands
- Biggest impacts over land
  - Global increase by 0.02 (for this particular month). 10% of global mean!
- Smaller impacts over ocean
  - Global increase by 0.004 (for this particular month)

Impact of new calibration on trend of Terra-Aqua AOD





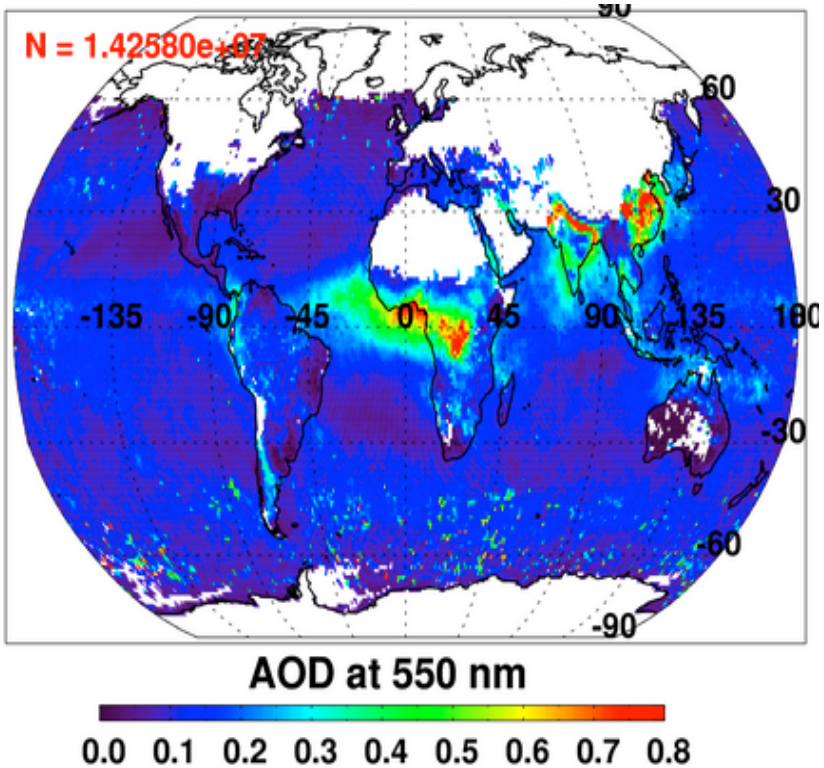
- 8 months processed with same dark-target aerosol algorithms
- Terra now more "in sync" with Aqua time series
- **New calibration → Terra/Aqua divergence removed for C6!**
- (Terra-Aqua) offset remains 0.02 (land) and 0.015 (ocean)

What else for C6 Level 2?

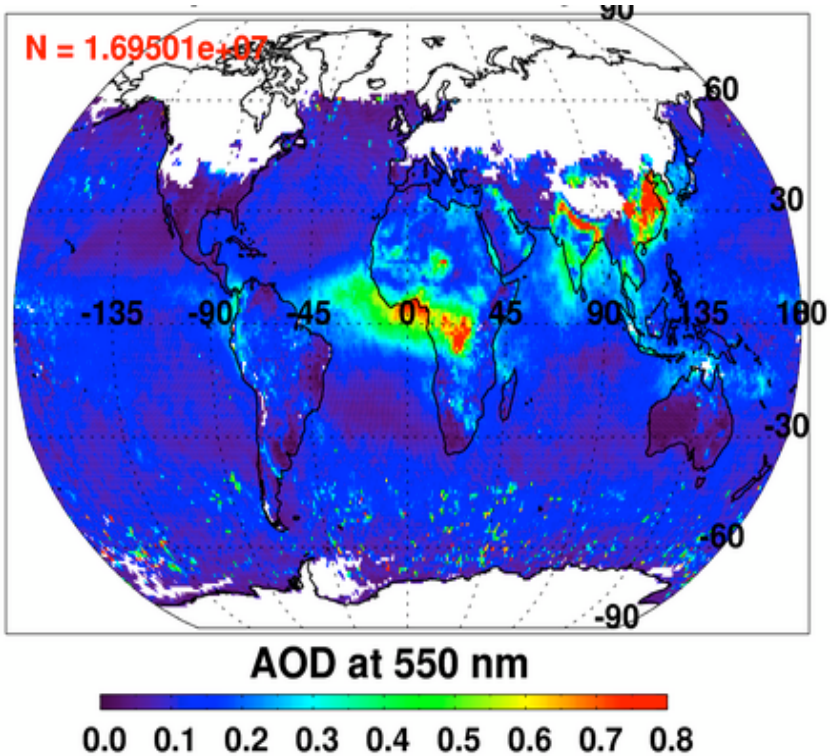
- Diagnostic SDSs (wind speed, integer QAC, topographic elevation, etc)
- “Cloud mask”, “distance to nearest cloud”
- Changes to SDS names

Deep Blue/Dark Target Merge:

Dark Target AOD



DeepDark AOD



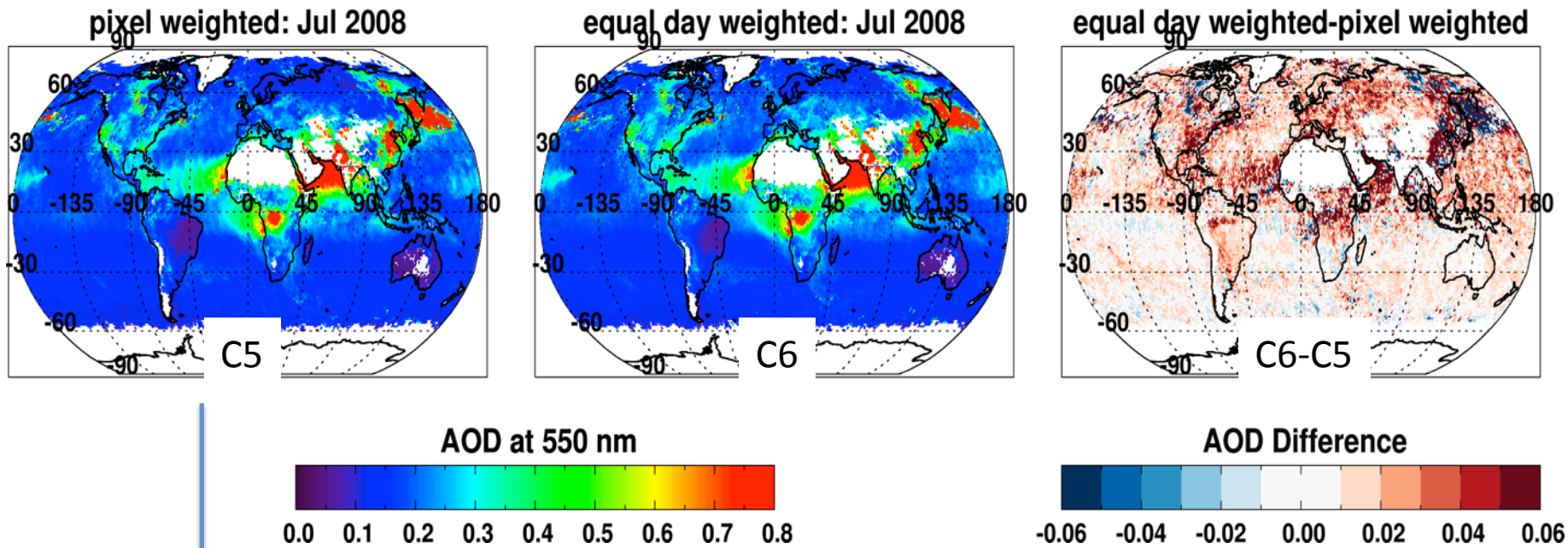
Merging deep blue & dark target produces best global coverage

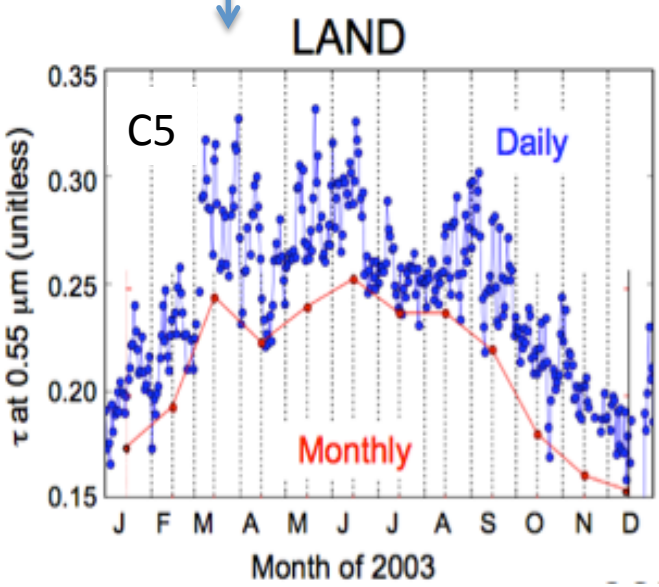
- **Deep blue is land-only; need dark target for oceans**
- **Deep blue introduces coverage over Australian outback, Sahara desert and Arabian peninsula**
- **Still no coverage over snow (see: most of Northern Hemisphere).**

LOOKS REASONABLE, BUT NOT VALIDATED YET!!!!

Beyond MxD04_L2

Changes to Level 3 (MxD08_M3)

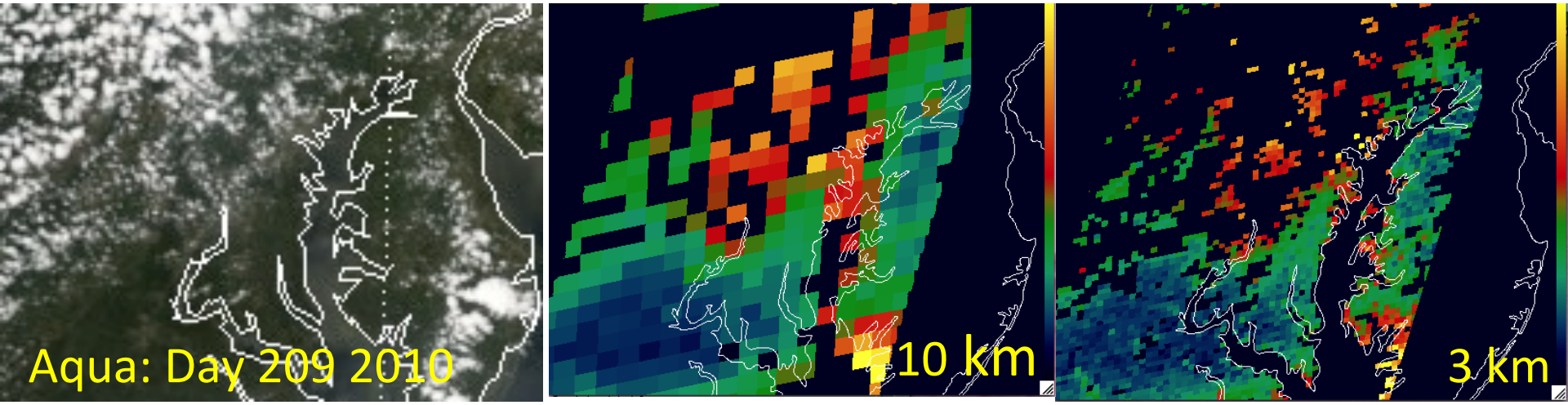




- In C5, averaging daily data did not look like monthly data (left, from Giovanni web application)
- C5 monthly was "pixel weighted". A day with 100 retrieved pixels was worth 10 times more than one with 10. It was clear-sky biased.
- C6 monthly is "equal day" weighted. If at least five pixels in a day, than that day counts.
- → Increases monthly mean AOD over land, and ocean. Less clear sky biased?

MxD04_3K (a new 3 km aerosol product)

- Driven by air quality community,
- Maybe also some applications to aerosol/clouds.
- Currently Dark target only



Munchak, L., R.C. Levy, S. Mattoo, L.A. Remer, B.N. Holben, J.S. Schafer, C.A. Hostetler, and R.A. Ferrare (2013). MODIS 3km Aerosol Product: applications over land in an urban/suburban region *Atmos. Meas. Tech*, *6*, 1747-1759, doi:10.5194/amt-6-1747-2013

Remer, L., S. Mattoo, R.C. Levy, and L. Munchak (2013). MODIS 3km Aerosol Product: Algorithm and Global Perspective *Atmos. Meas. Tech*, *6*, 1829-184, doi:10.5194/amt-6-1829-2013

J. M. Livingston, J. Redemann, et al, (2013). Comparison of MODIS 3-km and 10-km resolution aerosol optical depth retrievals over land with airborne Sunphotometer measurements during ARCTAS summer 2008, Atmos. Chem. Phys. Disc,

MxDATML2 product

- Combines the "best of" MxD04_L2 (10 km) aerosol, MxD06_L2 (5 km) cloud products, and other atmosphere prods
- For joint analyses of aerosols and clouds (at granule level

From MxD06 (clouds) 5 km:

- Latitude
- Longitude
- Cloud_Optical_Thickness
- Cloud_Optical_Thickness_Uncertainty
- Cloud_Optical_Thickness_PCL
- Cloud_Optical_Thickness_16
- Cloud_Optical_Thickness_16_PCL
- Cloud_Optical_Thickness_37
- Cloud_Optical_Thickness_37_PCL
- Cloud_Optical_Thickness_Uncertainty_16
- Cloud_Optical_Thickness_Uncertainty_37
- Cloud_Effective_Radius
- Cloud_Effective_Radius_Uncertainty
- Cloud_Effective_Radius_PCL
- Cloud_Effective_Radius_16
- Cloud_Effective_Radius_16_PCL
- Cloud_Effective_Radius_37
- Cloud_Effective_Radius_37_PCL
- Cloud_Effective_Radius_Uncertainty_16
- Cloud_Effective_Radius_Uncertainty_37
- Cloud_Water_Path
- Cloud_Water_Path_Uncertainty
- Cloud_Water_Path_PCL
- Cloud_Water_Path_16
- Cloud_Water_Path_16_PCL
- Cloud_Water_Path_37
- Cloud_Water_Path_37_PCL
- Cloud_Water_Path_Uncertainty_16
- Cloud_Water_Path_Uncertainty_37
- Cloud_Optical_Thickness_1621
- Cloud_Optical_Thickness_Uncertainty_1621
- Cloud_Effective_Radius_1621
- Cloud_Effective_Radius_Uncertainty_1621
- Cloud_Water_Path_1621
- Cloud_Water_Path_Uncertainty_1621
- Cloud_Phase_Optical_Properties
- Cloud_Quality_Assurance
- Cirrus_Reflectance
- Cloud_Top_Pressure
- Cloud_Top_Temperature
- Cloud_Top_Height
- Cloud_Height_Method
- Cloud_Top_Pressure_1km
- Cloud_Top_Temperature_1km
- Cloud_Top_Height_1km
- Surface_Temperature_1km
- OS_Top_Flag_1km
- Infrared_obs_minus_calc
- Cloud_Mask_SPI
- Cloud_Multi_Layer_Flag
- Cloud_Fraction
- Cloud_Phase_Infrared
- Cloud_Phase_Infrared_1km

From MxD04 (aerosol) 10 km:

- Latitude_10km
- Longitude_10km
- Solar_Zenith_10km
- Viewing_Zenith_10km
- Relative_Azimuth_10km
- Aerosol_Optical_Depth
- Aerosol_Angstrom_Exponent_Ocean
- Aerosol_Land_Sea_Flag
- Aerosol_Cloud_Pixel_Distance_Land_Ocean
- Aerosol_Cloud_Fraction_Ocean
- Aerosol_Cloud_Fraction_Land
- Aerosol_Land_Ocean_Quality_Flag
- AOD_550_Dark_Target_Deep_Blue_Combined
- AOD_550_Dark_Target_Deep_Blue_Combined_QA_Flag
- AOD_550_Dark_Target_Deep_Blue_Combined_Algorithm_Flag
- Deep_Blue_Aerosol_Optical_Depth_550_Land
- Deep_Blue_Angstrom_Exponent_Land
- Deep_Blue_Single_Scattering_Albedo_412_Land
- Deep_Blue_Aerosol_Optical_Depth_550_Land_Best_Estimate
- Deep_Blue_Aerosol_Optical_Depth_550_Land_QA_Flag
- Deep_Blue_Aerosol_Optical_Depth_550_Land_Uncertainty
- Aerosol_Quality_Assurance_Land
- Aerosol_Quality_Assurance_Ocean

From MxD05 (precip water) 10 km:

- Precipitable_Water_Infrared_ClearSky
- Precipitable_Water_Near_Infrared_ClearSky

From MxD35 (Cloud Mask) 5 km:

- Cloud_Mask

From MxD07 (Profiles) 5 km:

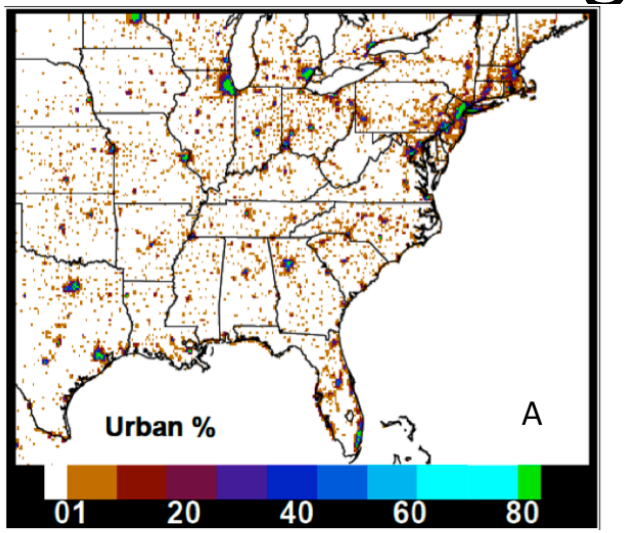
- Total_Ozone
- Lifted_Index
- K_Index
- Total_Totals_Index

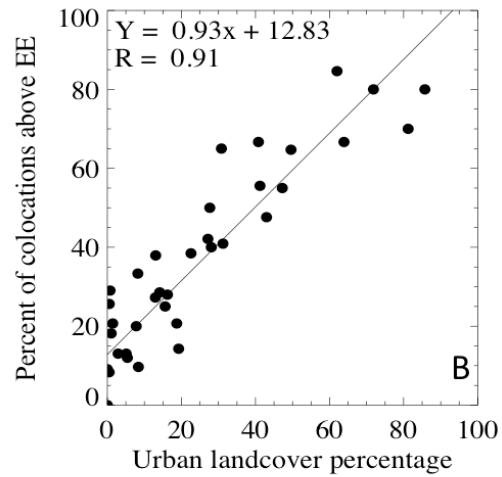
Platnick, King, Hubanks,..

Towards collection 7

- Accounting for bias over urban areas
- Determining per-retrieval uncertainty
- Residual calibration/polarization errors

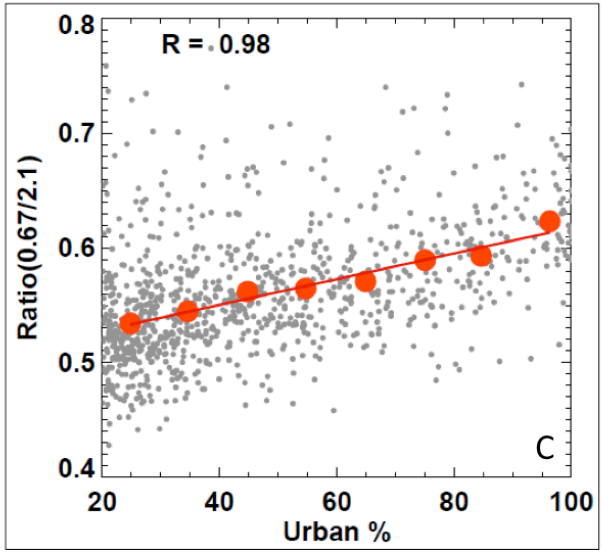
Accounting for Urban bias

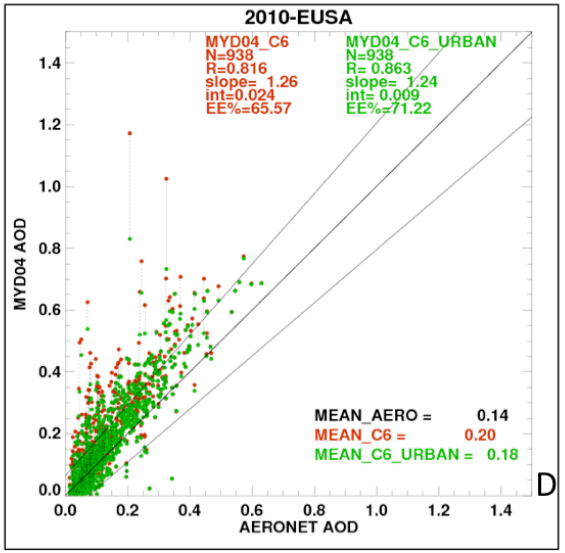




More urban --> higher bias

Over MD/DC during DISCOVER-AQ





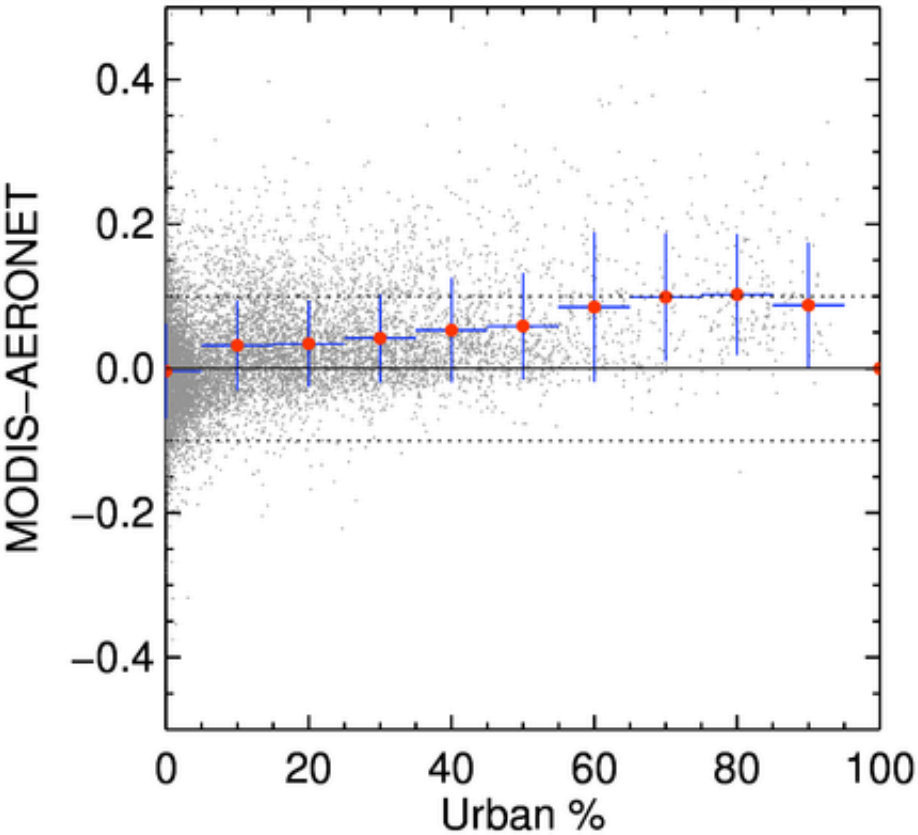
Looking at possible corrections

Applied to E-USA over 2010

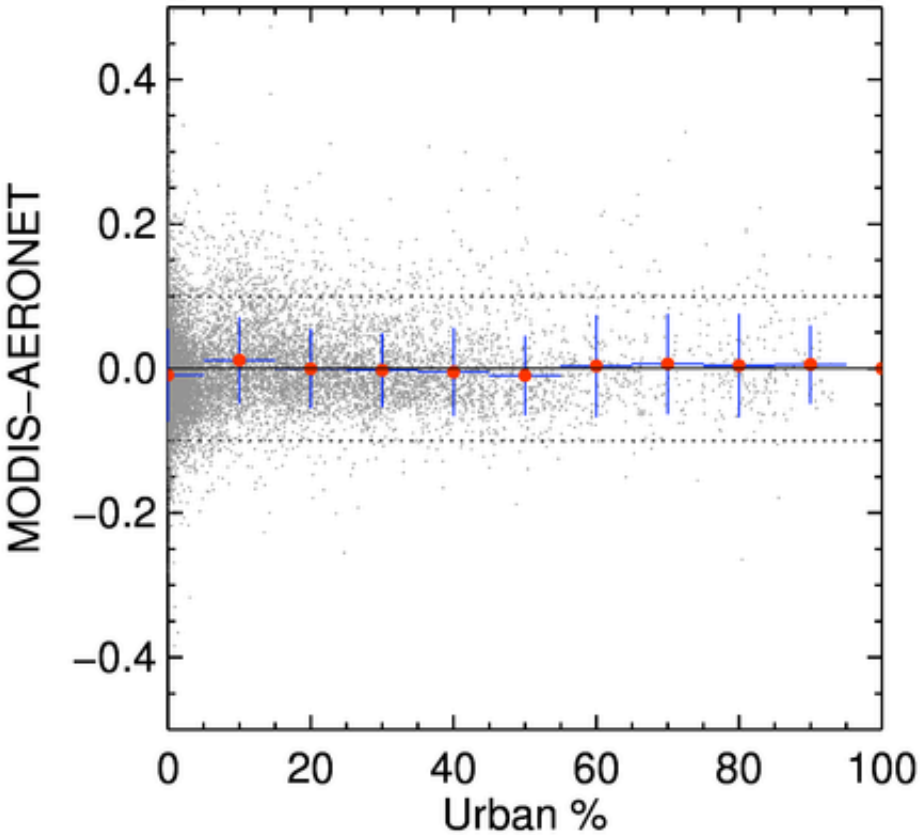
- Can we reduce artificial urban hotspots without impacting surrounding rural areas?

United States: 2002-2010 Aqua

C6 Retrieval



Retrieval using Urban fix



At least over the U.S, we can correct the positive urban bias.

See Pawan Gupta's poster!

Characterizing uncertainty in Aerosol Optical Depth Retrieval

There are two broad error sources :

1. Measurement / Input Uncertainties

- **Calibration Uncertainty [1 – 2%]**
- **Standard Deviation of reflectance in 10 x 10 km retrieval box [1 – 2%]**
- **Uncertainty in the Ancillary data used for atmospheric correction [~3.5%]**
- **Cloud contamination [τ Bias of +0.04 (Terra) and +0.01 (Aqua),** *Hyer et al.,2011*]
- **Snow contamination**

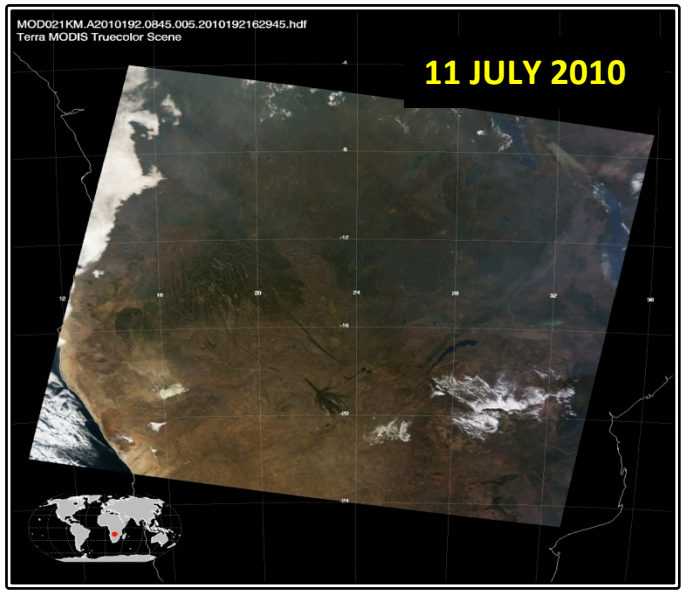
2. Retrieval Assumptions

- **Surface reflectance**
- **Aerosol models**

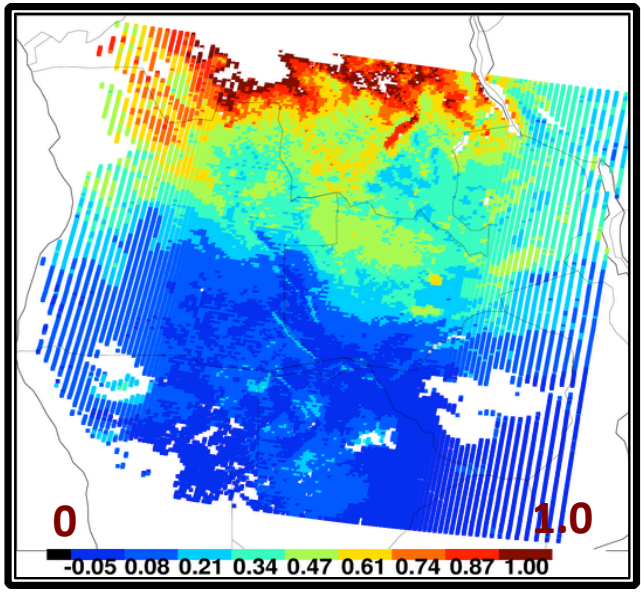
See Falguni Patadia's poster!

Example : Uncertainty in AOD retrieval from Reflectance Standard Deviation

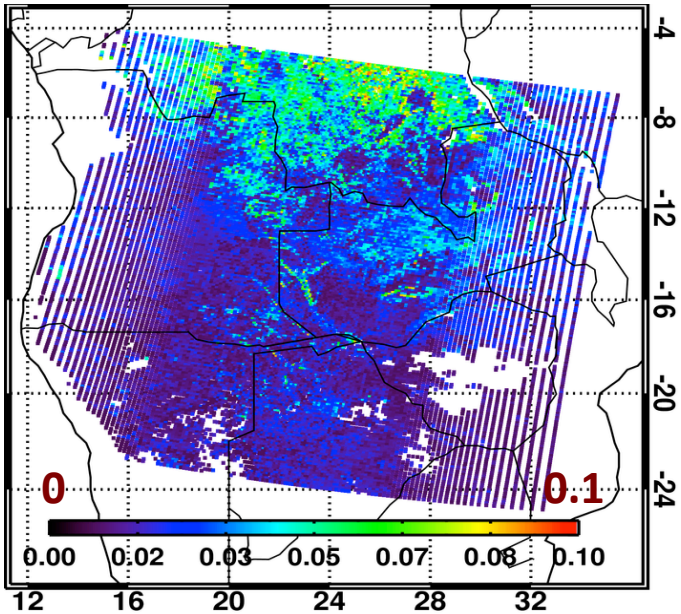
MODIS L1B RGB Image over Central Africa



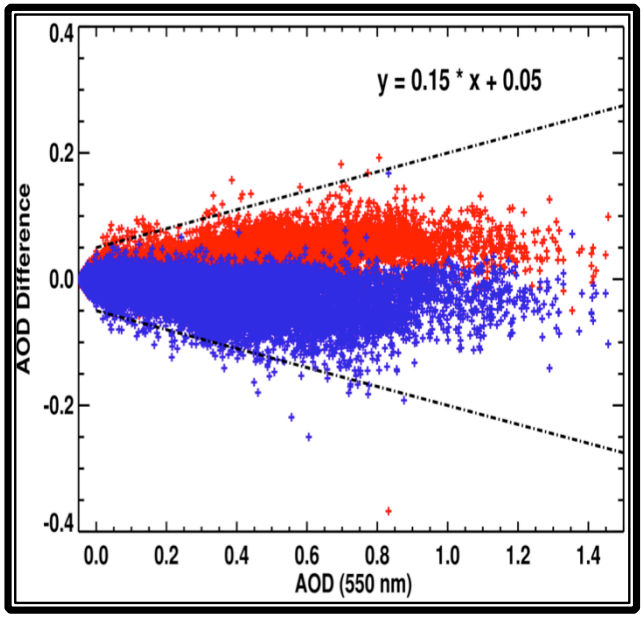
MODIS AOD (554 nm)



Absolute Error in AOD



Absolute AOD Error Relative to AOD

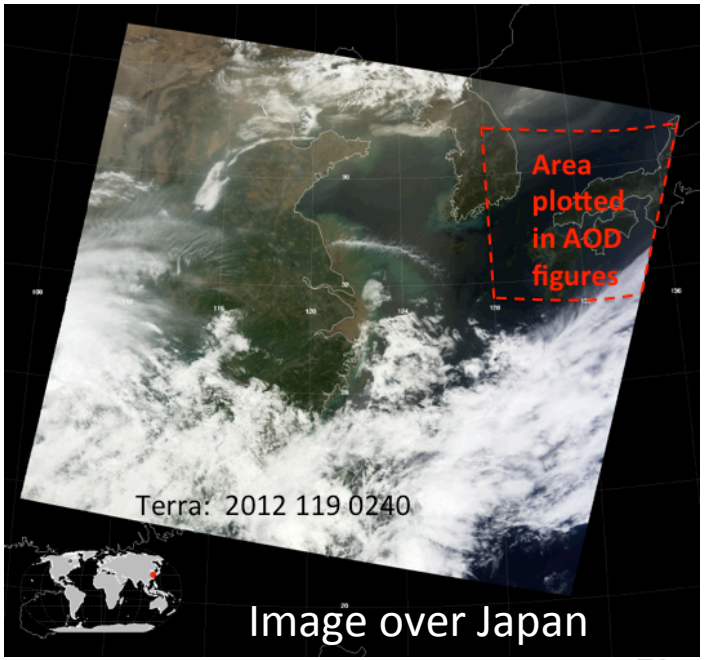


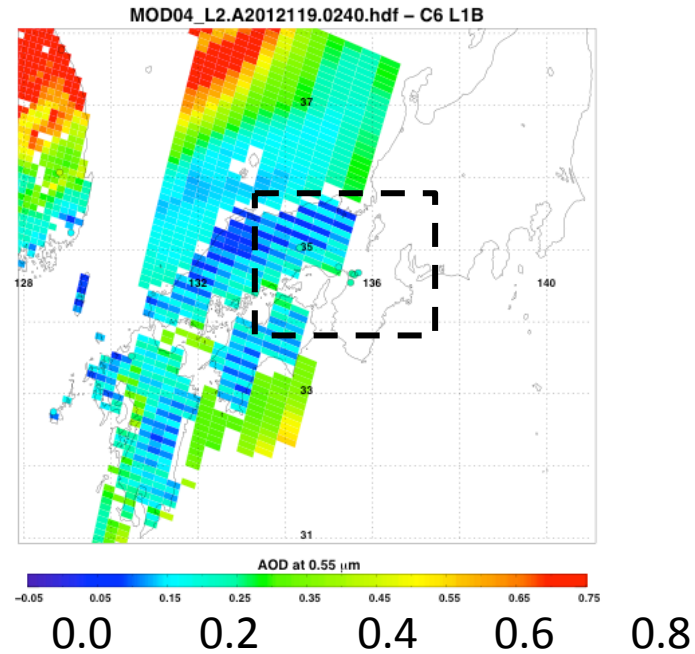
AOD differences due to standard deviation of reflectance within 10 X 10 km box

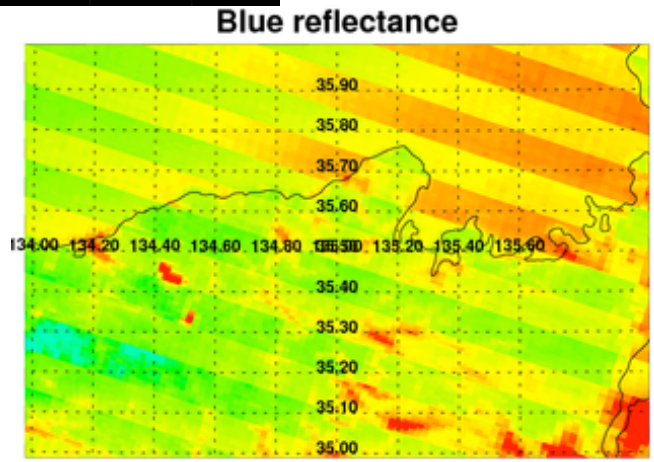
Compared to EE envelope

See Falguni's poster!

Residual calibration/polarization errors







Hear Alexei Lyapustin's talk!

- Dealing with "striping" of 0.1 AOD in recent (post 2012) Terra data
- Seems to be a mirror polarization sensitivity issue.

Dark-target aerosol retrieval: Beyond MODIS

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 (versus on Aqua since 2002)

Swath: 3050 km (vs 2030 km)

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

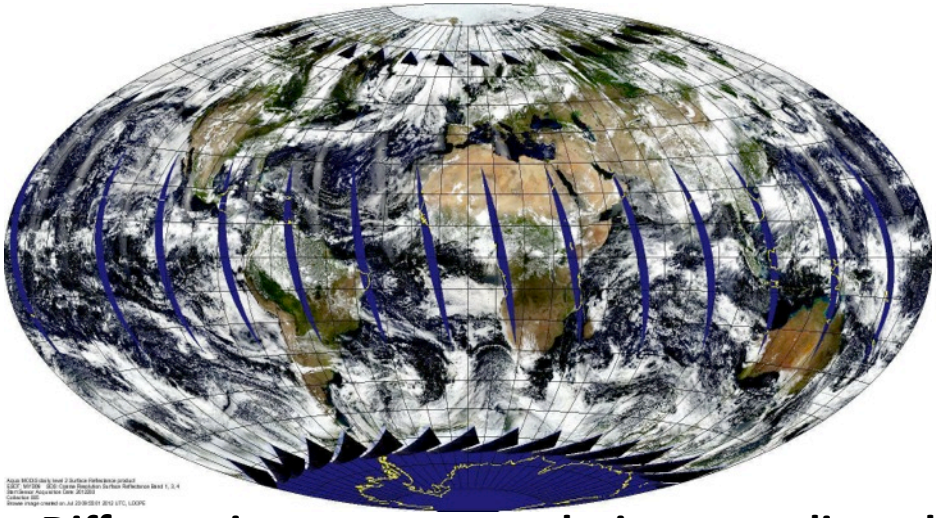
Spatial Resolution: 375m (5 bands) 750m (17 bands): versus 250m/500m/1km

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

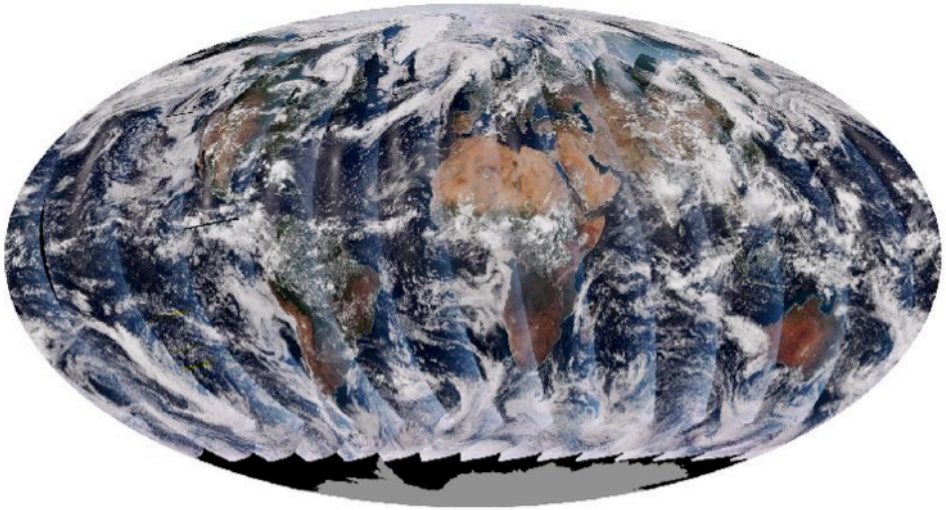
Aerosol Retrieval: Created and maintained by scientists partnered with NOAA (NASA), with a strategy of maximizing environmental data record - EDR (climate data record – CDR)

ALSO: Different cloud masks, different aggregation techniques, different pixel selections.

Aqua (13:30 Local Time, Ascending)



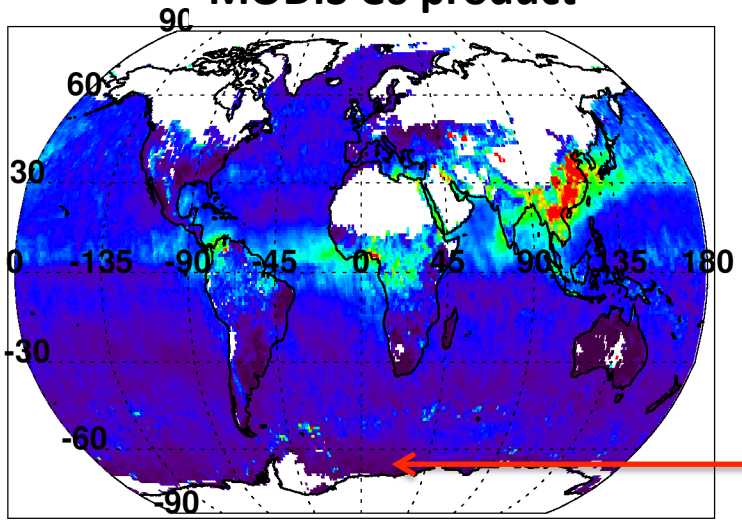
Suomi-NPP (13:30 Local Time, Ascending);



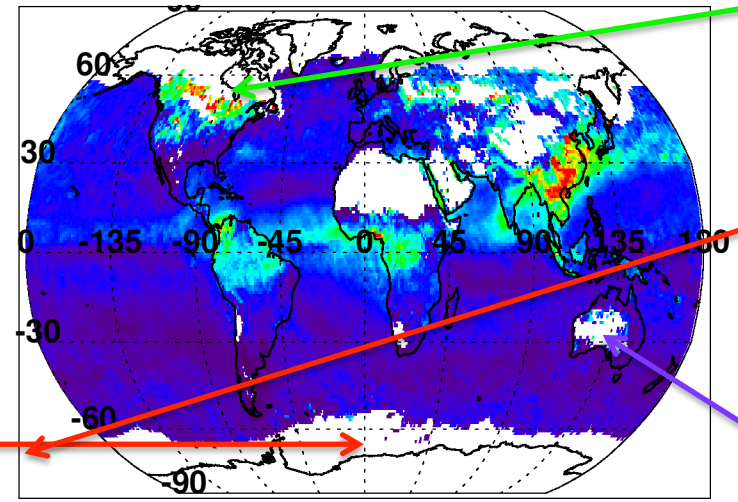
Different instrument, resolution, sampling, cloud masking, algorithms, etc.
Will VIIRS "continue" the MODIS aerosol data record?

ONE RETRIEVAL ALGORITHM: Consistent Across Platforms

MODIS C6 product



NOAA-VIIRS product

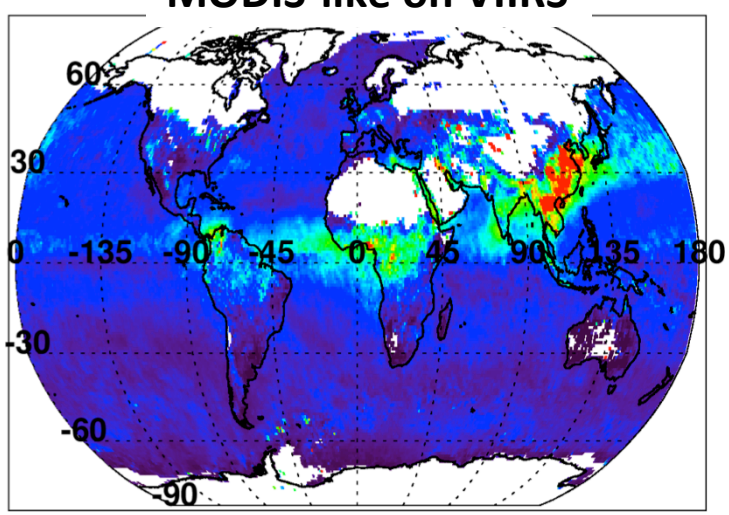


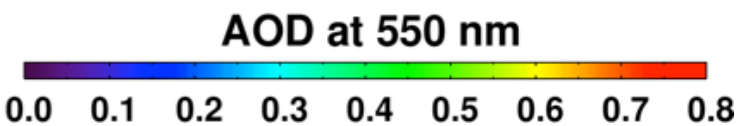
Different snow thresholds?

Different SZA thresholds

?

MODIS-like on VIIRS





Still different, but much more similar over both land and ocean

We make VIIRS consistent with MODIS. (we learned from Terra vs Aqua)

MODIS-like algorithm on ANY sensor! For climate continuity

- MODIS
- VIIRS
- MAS/E-MAS/AMS (Airborne spectrometers and historical experiment data)
- International sensors
- Future sensors (e.g. PACE / ACE) as a baseline for testing new ideas

Many details, but can be done!

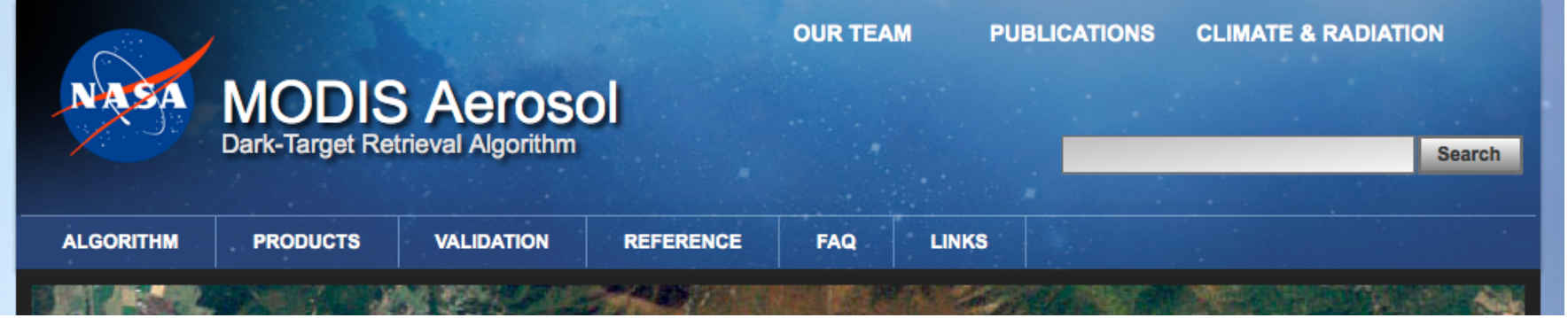
Okay: summary time

Summary (C6)

- There are many ways to retrieve aerosol properties from MODIS, and there is more than one set of algorithms/ products
- Dark-target algorithm/products updated for C6
- Changes are "modest" but lead to significant changes in retrieved global aerosol
- New products: DB/DT merge, MxD04_3K, etc
- Documentation:
  - Algorithm papers have been published
  - ATBD in progress
  - Website under development
- C6 processing (Level 2) for Aqua almost finished. Terra begin soon? Level 3 soon?
- Validation (vs AERONET, MAN, etc) in progress
- Calibration/polarization/trending issues still being studied

Summary (Towards C7)

- Corrections for urban surface bias
- Development of “pixel level” uncertainty products
- Calibration/polarization/trending issues still being studied
  - Why is Terra offset from Aqua?
- Development of generic dark-target algorithm to be used on VIIRS, airborne and other spectral remote sensing datasets. (a Super C7).



- Web site in development
- 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