The Collection 6 "dark-target" MODIS Aerosol products

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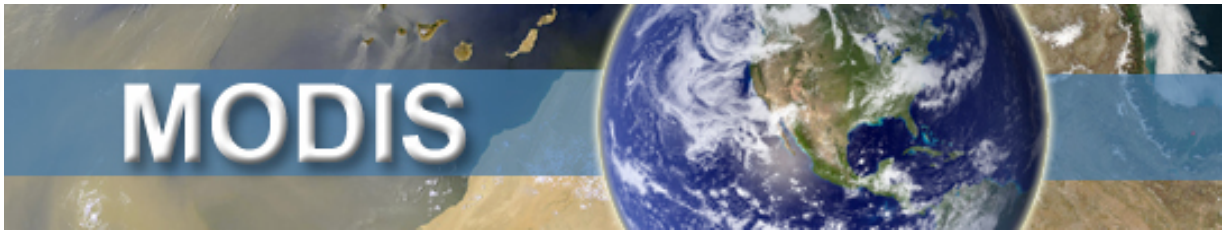


Didn't we introduce C6 at last year's AEROCOM?

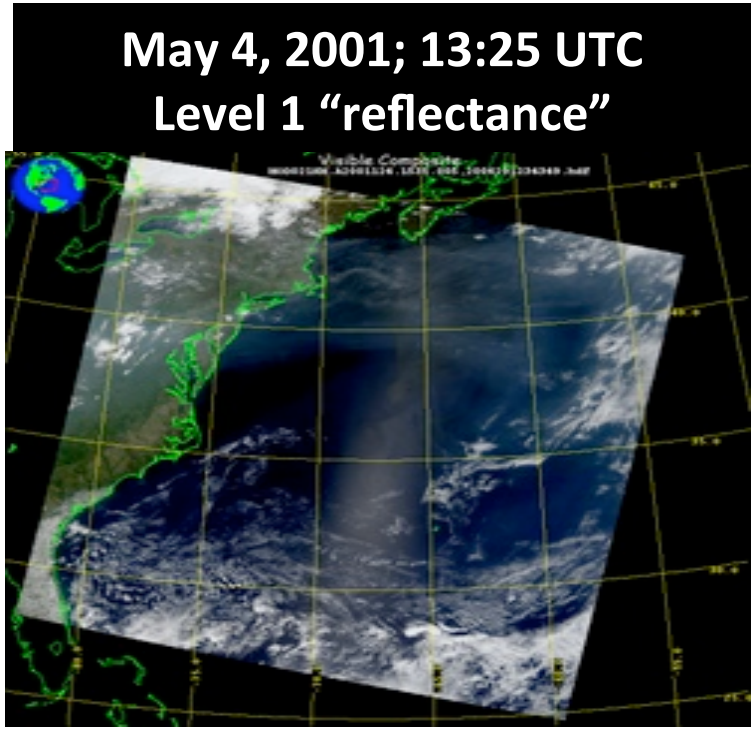
- Yes, we did! We thought that C6 was imminent
- We told you that we had made changes to our algorithm, and also had accounted for changes in MODIS calibration.
- We even described the new 3 km product.
- ----------
- But, we had not accounted for every "upstream" change
- We found bugs in our code.
- And all other science groups (cloud mask, cloud products, land products, etc.) were wading through the same issues
- ----------
- Dark-target aerosol has been "ready" since June 2013.
- However, the "big button" won't be pushed until **everyone** is ready.
- Aqua will be first (Level 2), then Terra (L2), then Level 3.
- Start date for Aqua C6 is expected "by mid-October 2013".

Trying to get C6 product finished is like…:

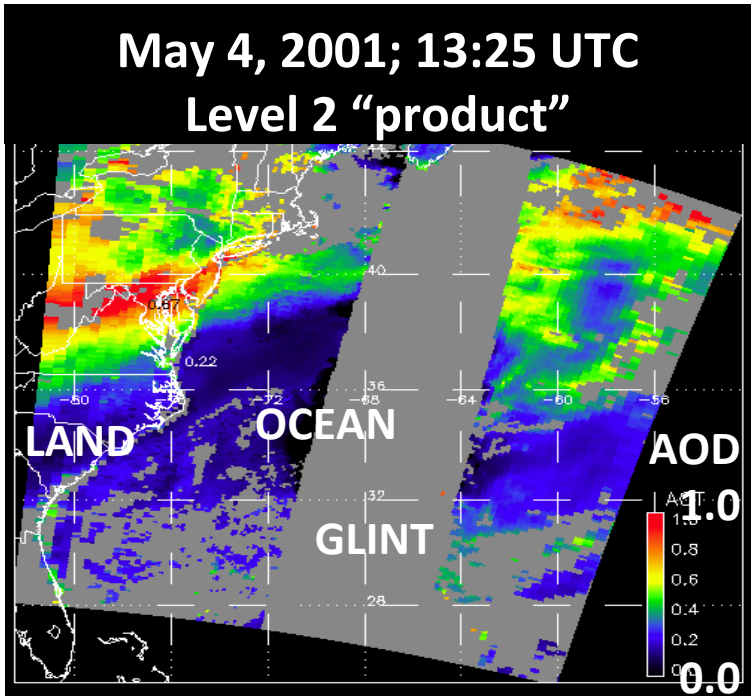
Video found on You-Tube
Note: no harm to cat

Aerosol retrieval from MODIS

What MODIS observes



Attributed to aerosol (AOD)

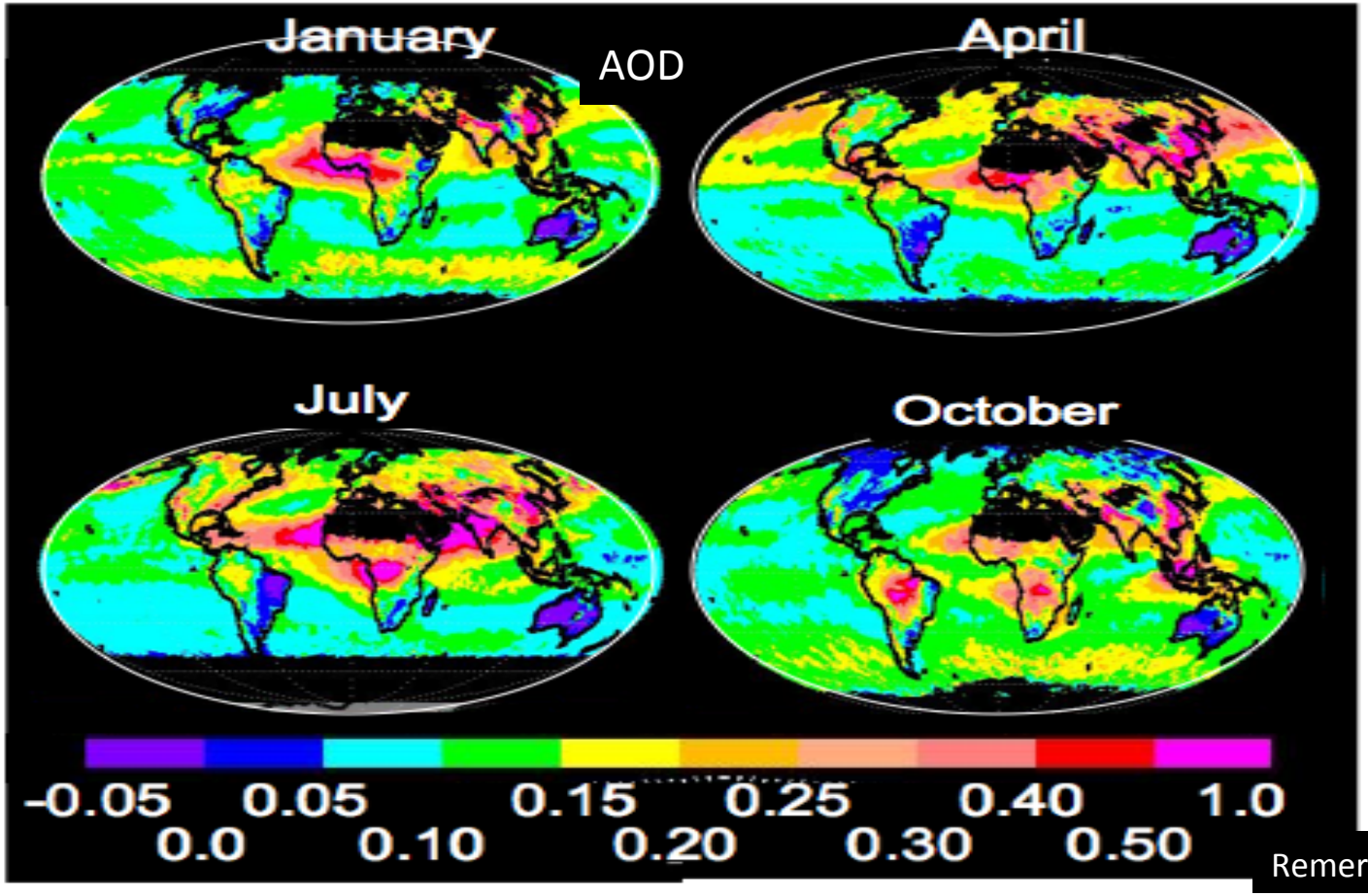


There are many different "algorithms" to retrieve aerosol from MODIS

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)

A MODIS view of global aerosol system (over dark targets) Collection 5

As envisioned by Y. Kaufman and D. Tanré
And produced by the MODIS-aerosol team at NASA GSFC



Remer et al, 2008

We have two sophisticated sensors (aboard Terra and Aqua), with stable orbits, excellent calibration teams and validated aerosol retrievals.

But we always want to do better.

Overall Dark target algorithm updates

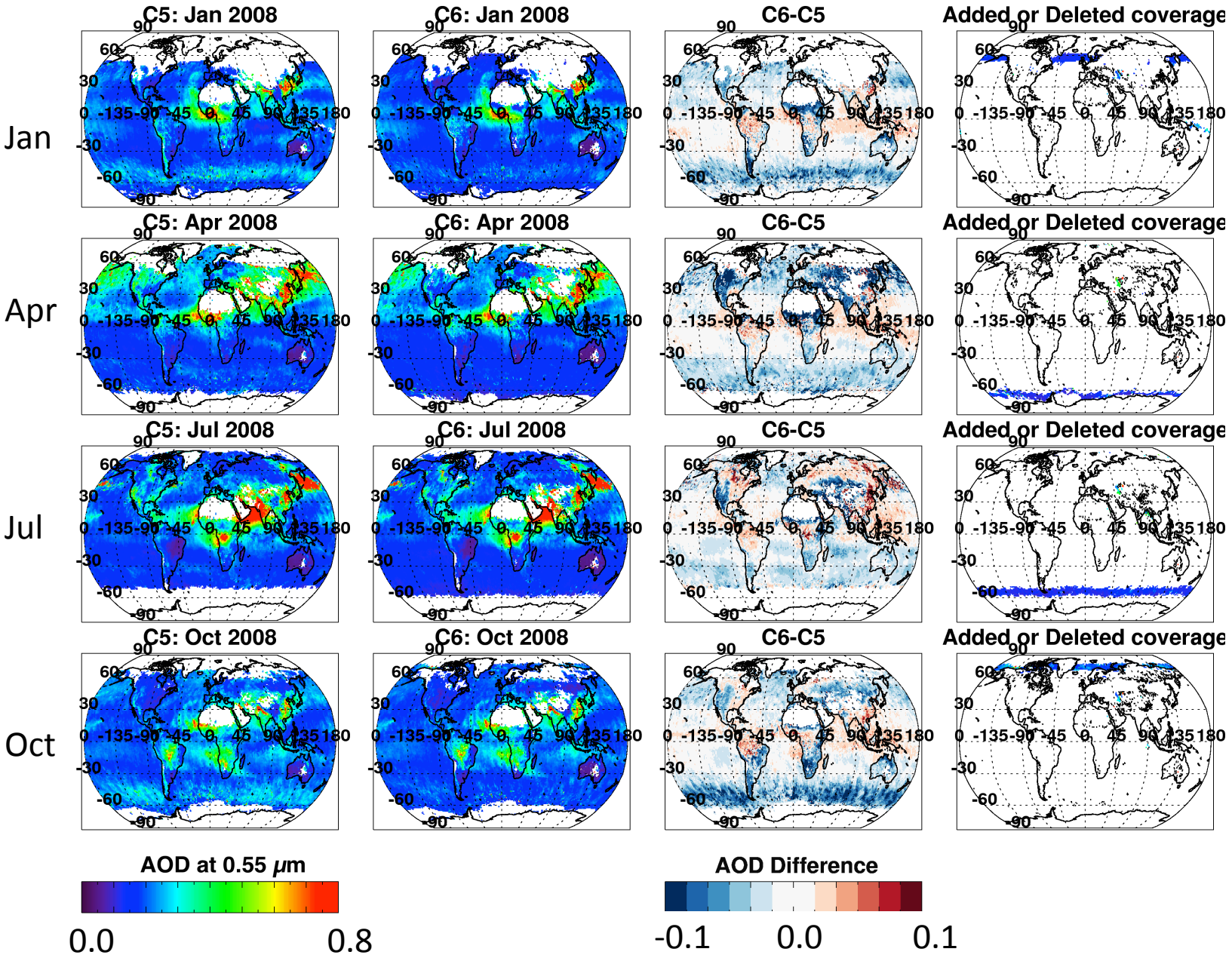
Yesterday was accepted to AMT!

- Levy, R., S. Mattoo, L.A. Munchak, L.A. Remer, A.M. Sayer, and N. Hsu (2013). The Collection 6 MODIS Aerosol Products over Land and Ocean *Atmos. Meas. Tech. Disc.* (6), 159-259

Outline

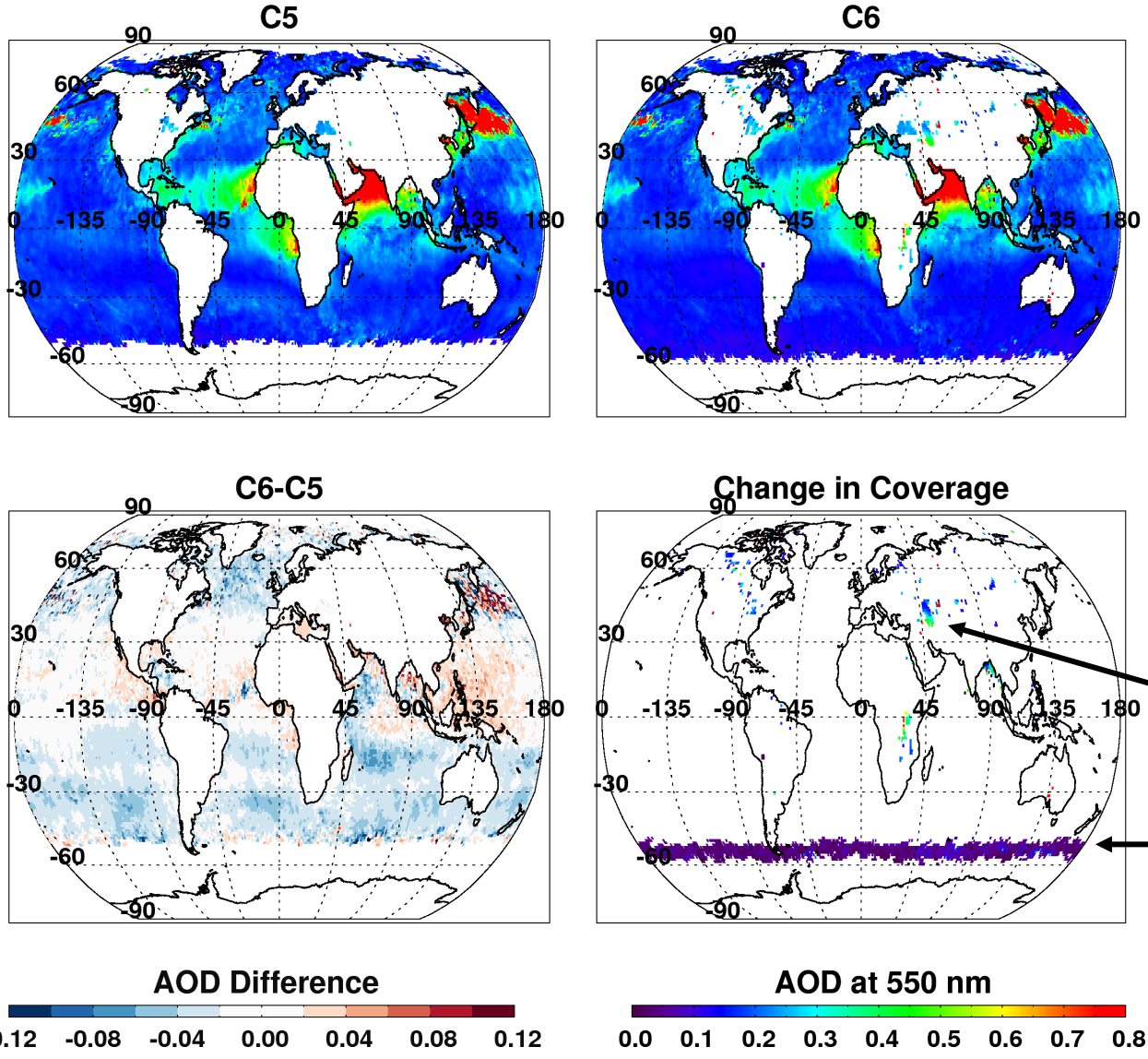
- “Overall” changes (C6 versus C5)
- “incremental” updates (and rationale behind)
- Ocean versus Land
- Some preliminary validation (for Aqua)
- Terra versus Aqua
- Level 3 protocol
- Loose ends

Overall changes (C6 vs C5): Aqua, 2008



Aerosol over ocean

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



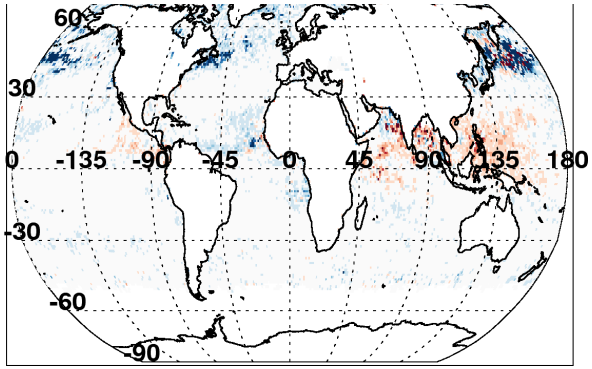
- Overall decrease of AOD in mid-latitudes
- Strong decrease in "roaring 40s" (even stronger in other months)
- Overall increase in tropics

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

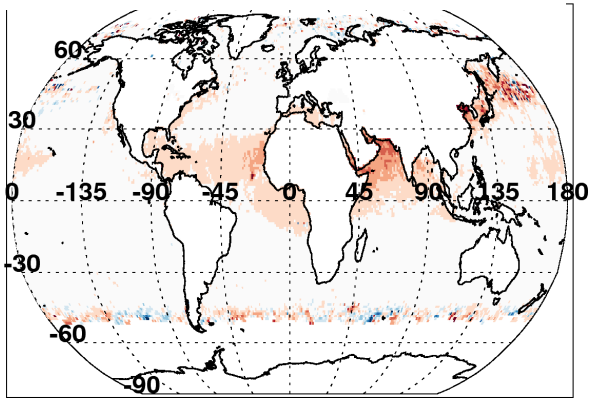
Why the changes?

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

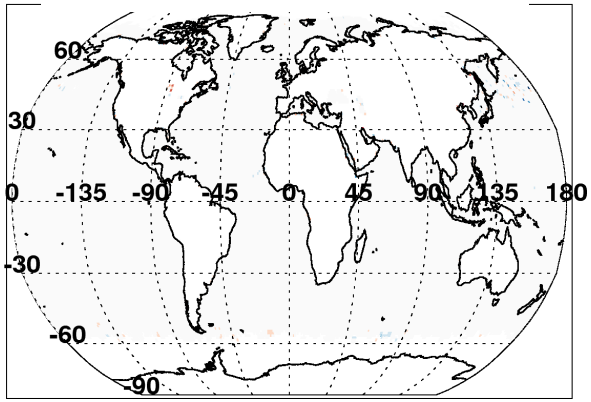
New reflectance, geo-location inputs, Wisconsin cloud mask



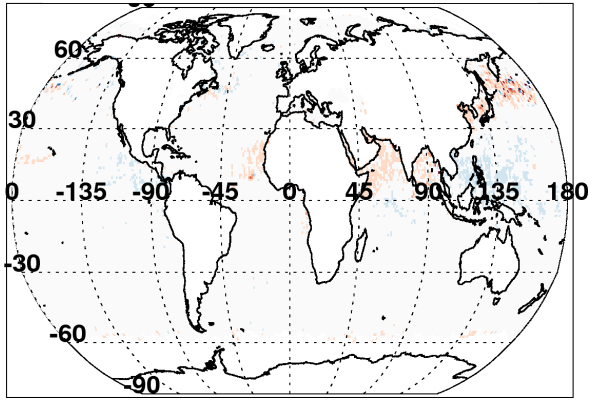
Updated radiative transfer



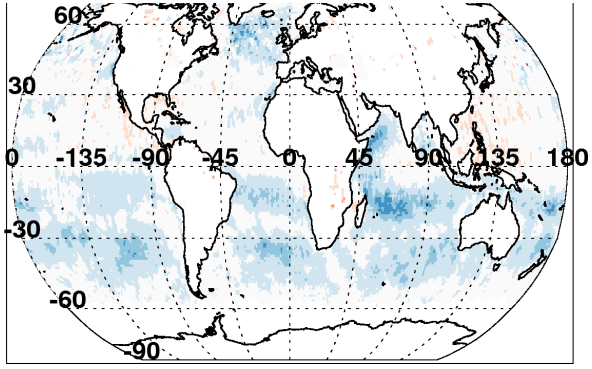
Re-define land and sea

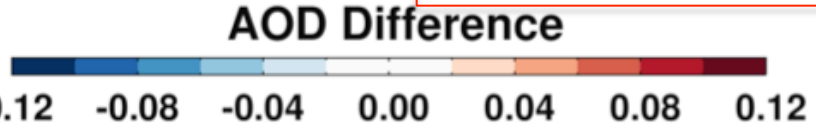


Improved cloud mask



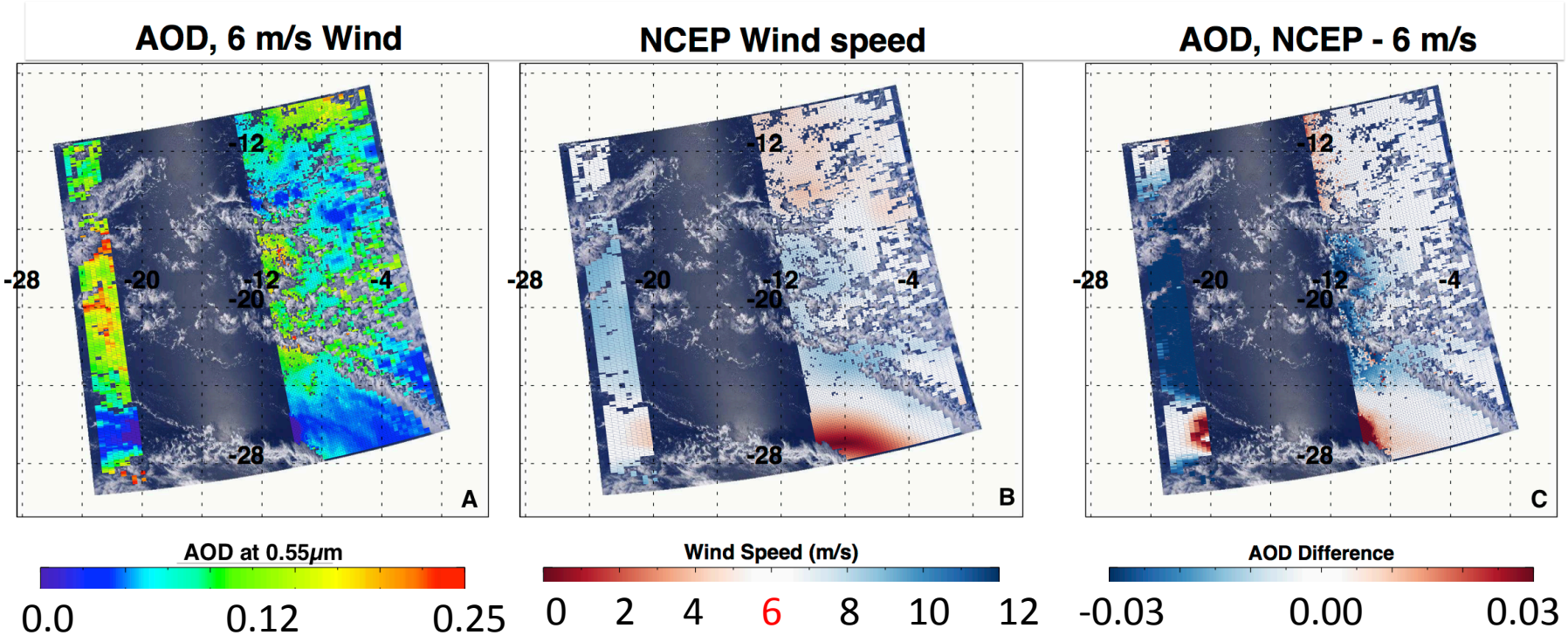
Account for wind speed impact on surface





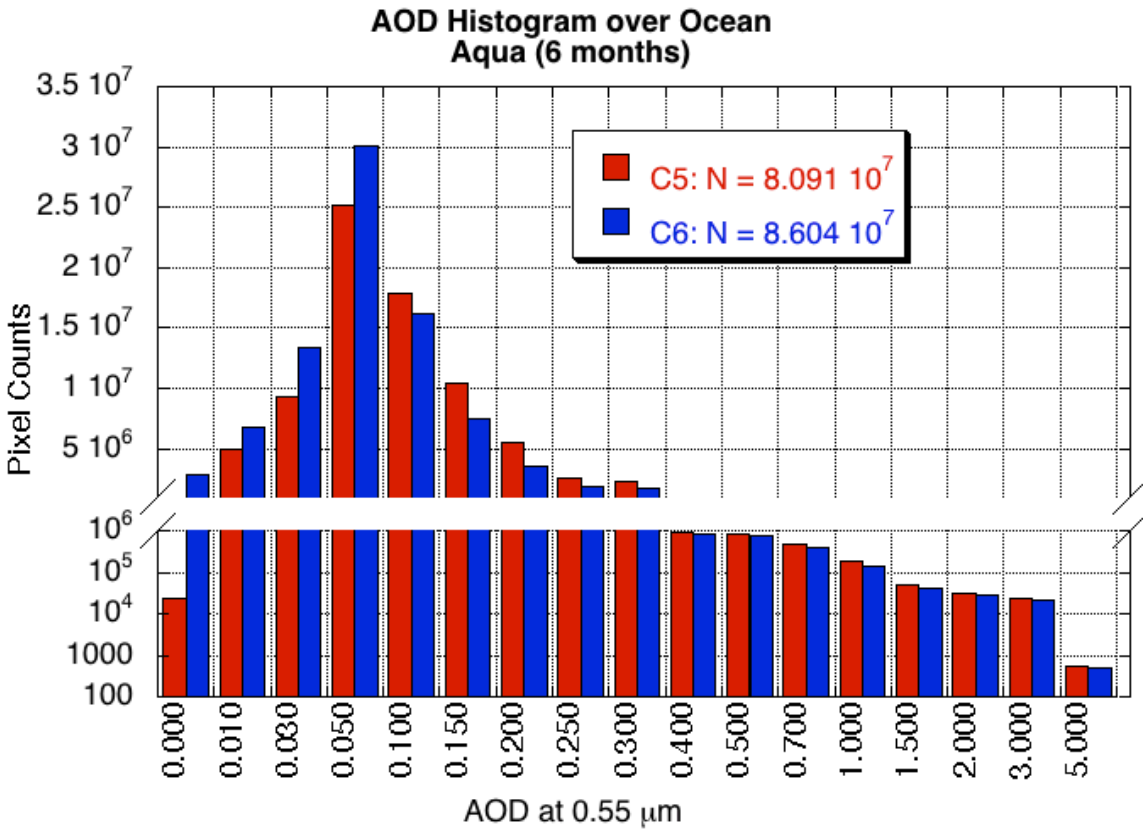
- Also changed "Quality Assurance" Filtering
- Changed aerosol definitions of land and sea
- Etc

Biggest "science" change for C6: Introduce wind speed dependence (ocean)



- Higher wind speeds → more ocean foam and diffused glitter pattern
- C5: Aerosol LUT calculated for 1 wind speed (6 m/s).
- C6: LUT calculated for 4 wind speeds (v=2, 6, 10, 14 m/s)
- Retrieved AOD is reduced when v>6 (increased when v<6)
- Reduces AOD near 40° glint mask edges and in "Roaring 40s" of south Oceans.
- MODIS now in line with other satellite algorithms (VIIRS, SOAR on SeaWIFS)

Example of “minor” update with major impact
Quality assurance over ocean

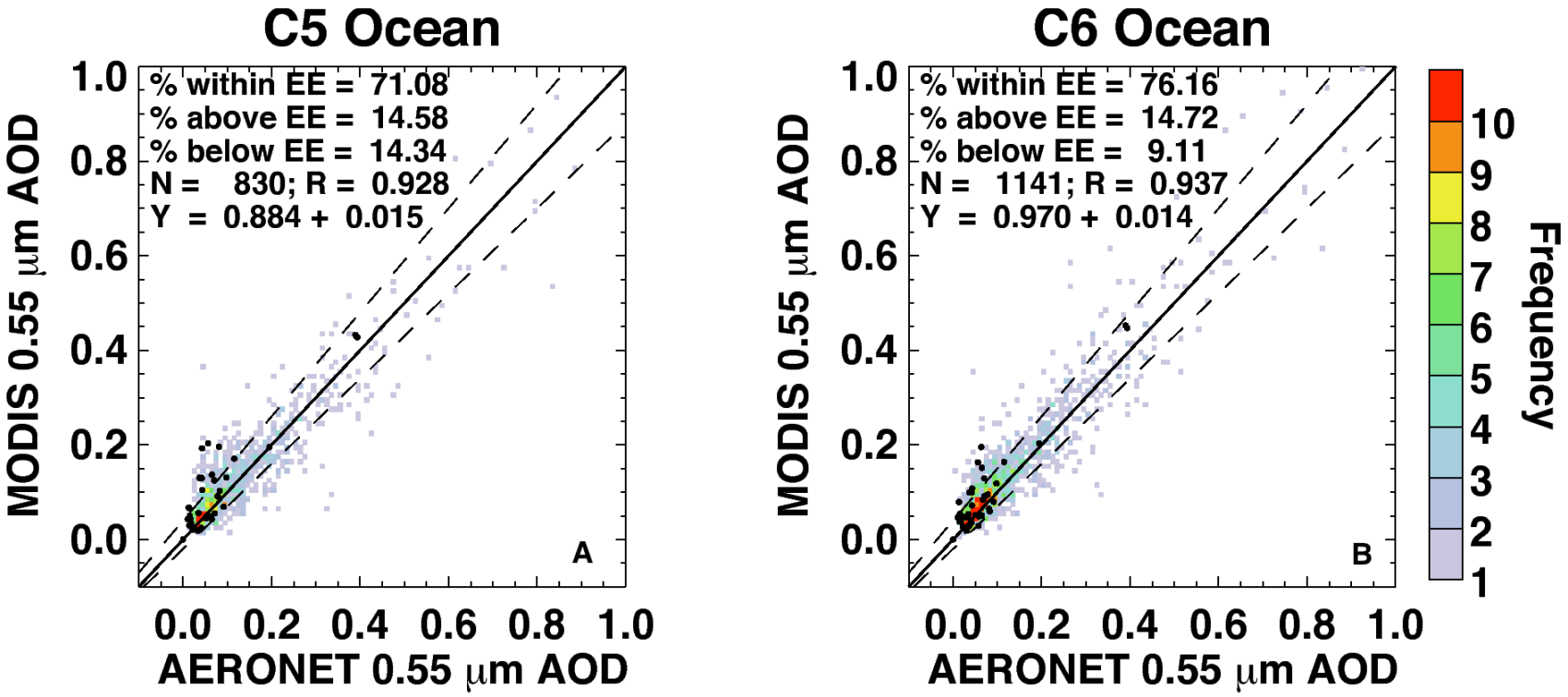


- Old (C5): Quality assurance depends on success of a retrieval solution. If aerosol signal is too small, then do not include in daily/monthly statistics.

New (C6) : Sometimes signal is small, but we are confident that it is small. Include in daily/monthly statistics.

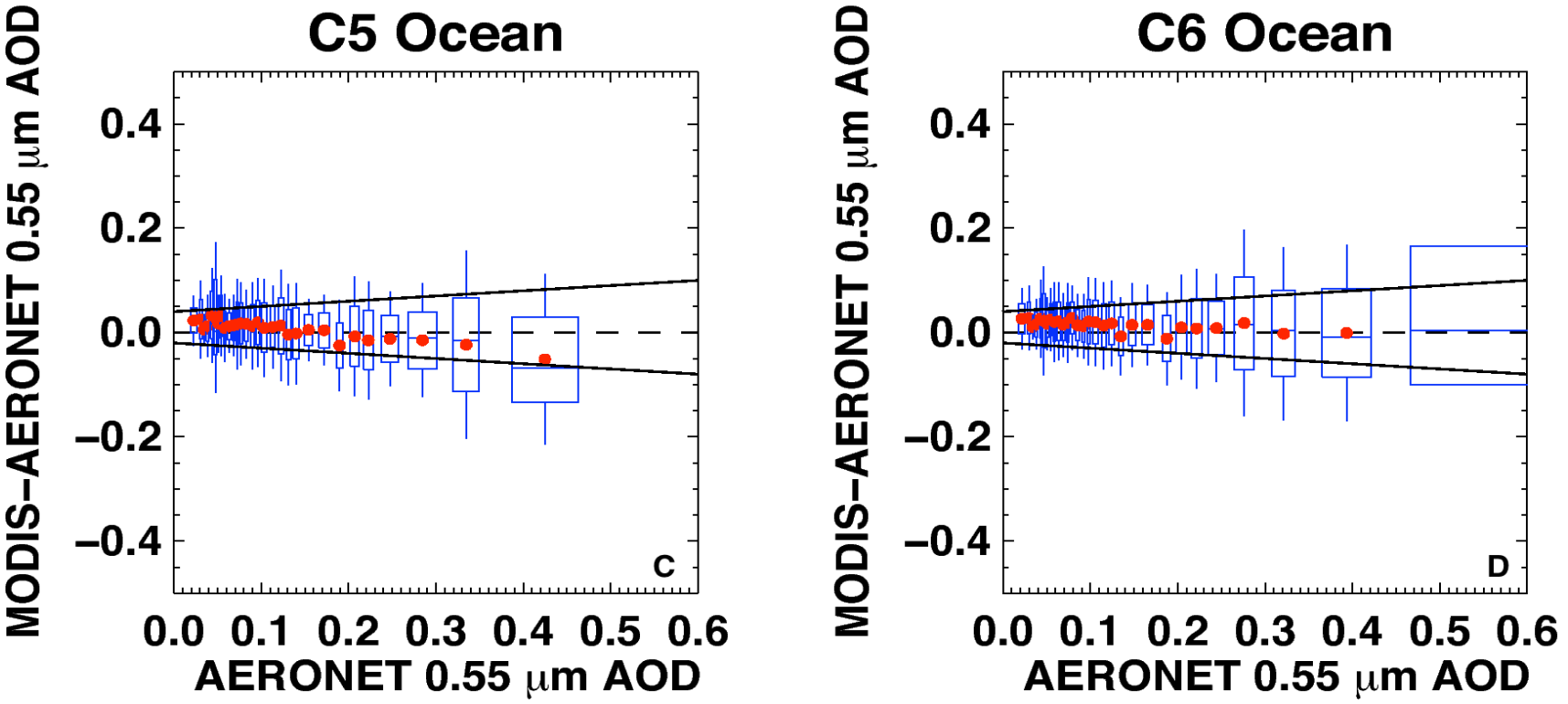
- But “major” influence on estimating regional and global mean AOD

Comparison with AERONET and MAN



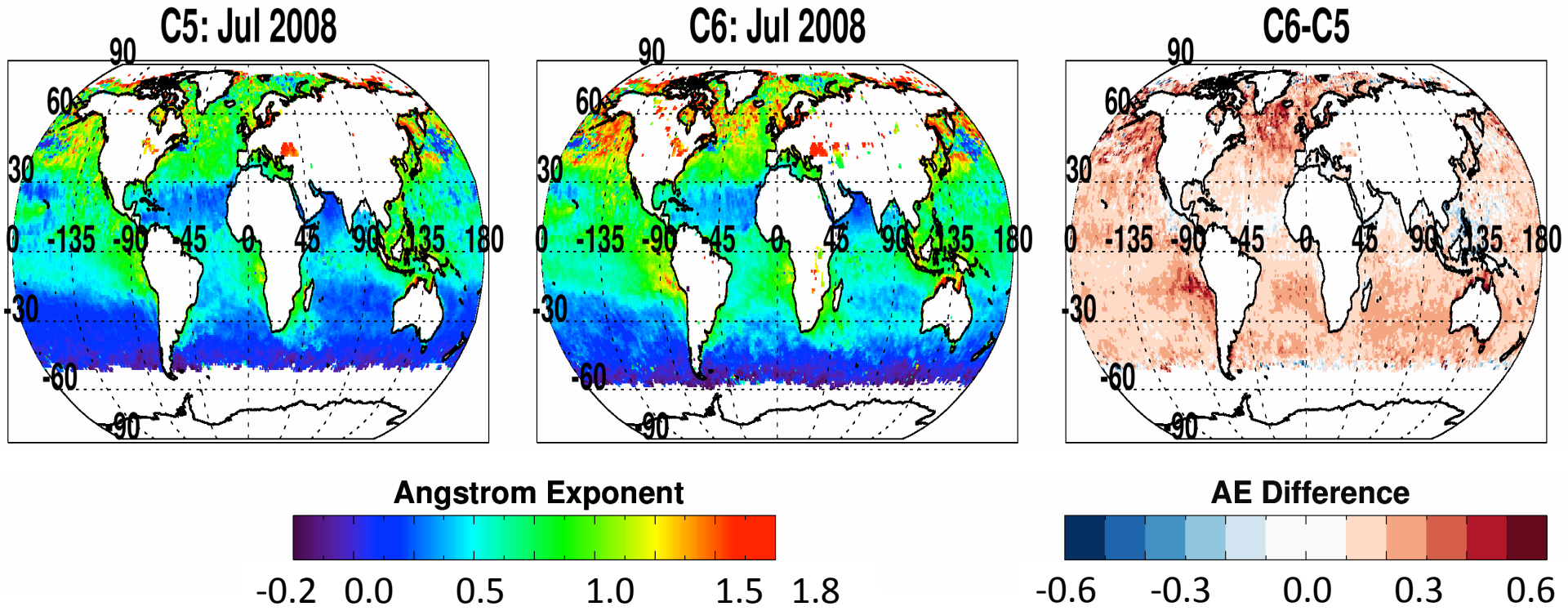
- Aqua for 8 months (Jan + July, 2003, 2008 and 2010; Apr + Oct 2008).
- Overall, not much change over ocean (slope, intercept, correlation)
- But 30% more valid points to compare with (1141 versus 830).
- AERONET are gray and colored, MAN are black dots

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%))

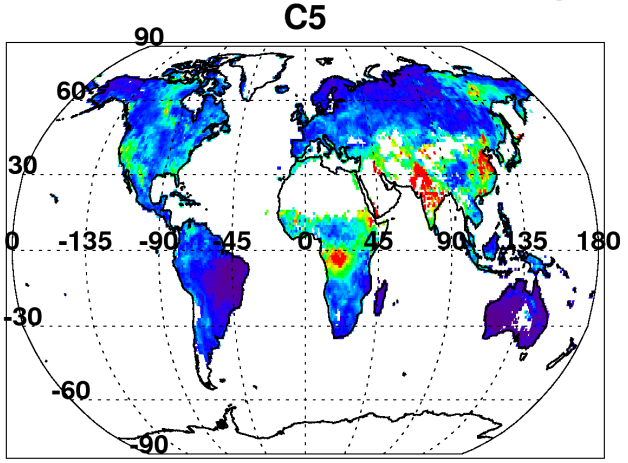
Impact on Ångström Exponent

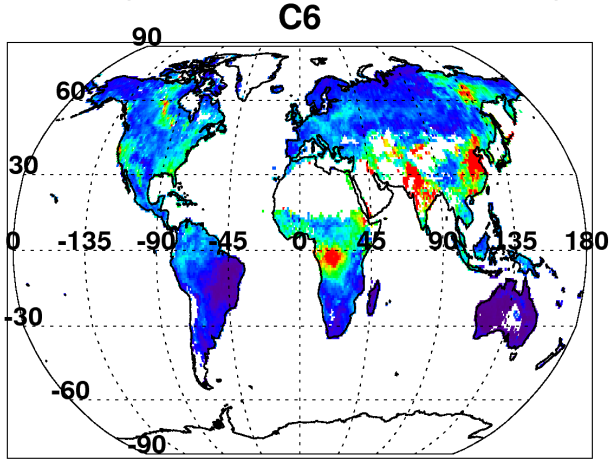


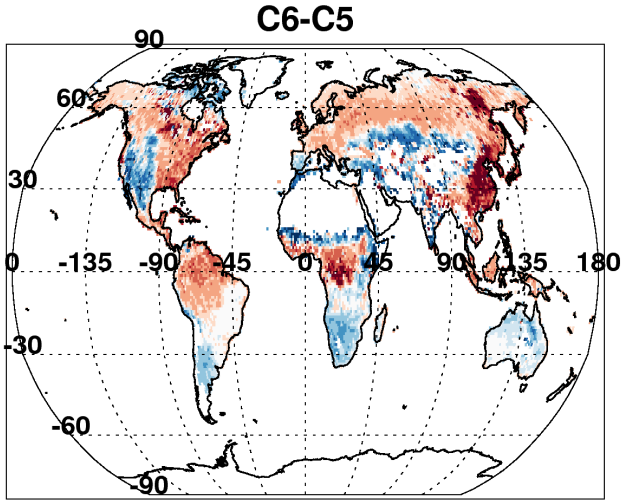
- Comparison is for Aqua
- Overall increase of global AE (+0.18).

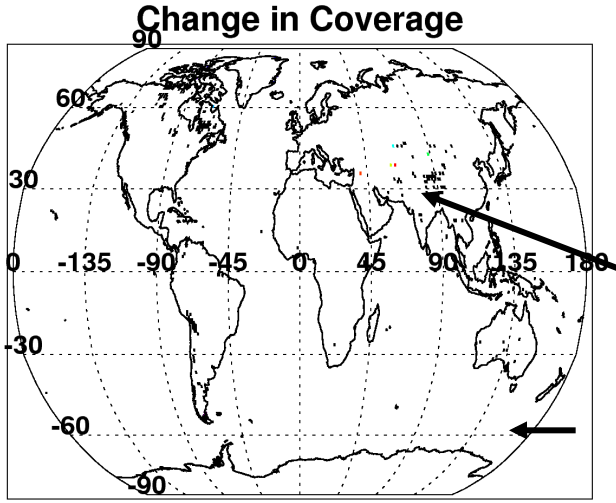
Aerosol over land

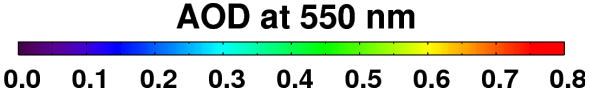
Dark target over land
Overall changes to products (Aqua, Jul 2008)











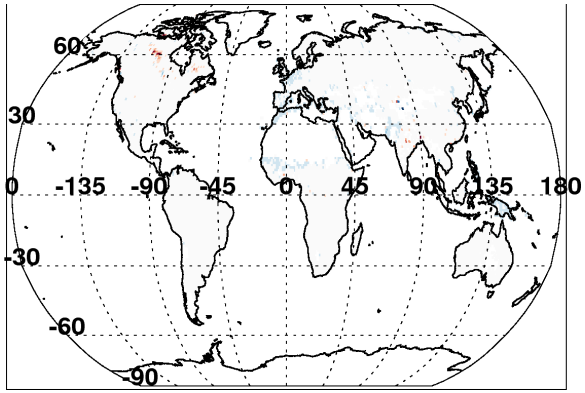
- Overall decrease of AOD in semi-arid
- Overall increase over vegetation
- Strong increase over Eastern Asia

- 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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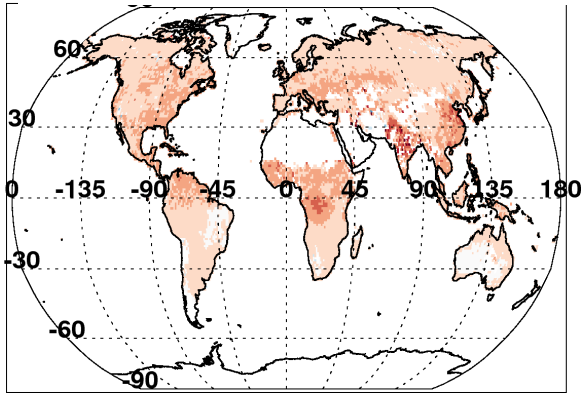
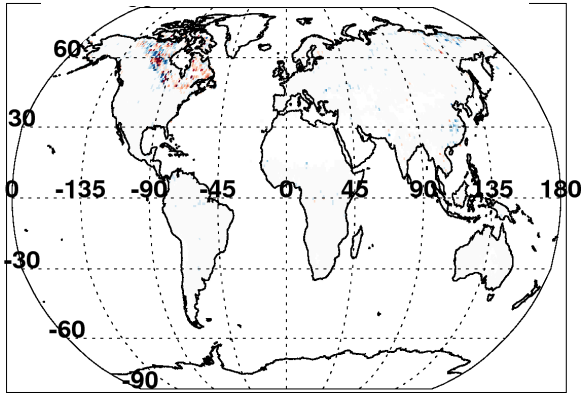
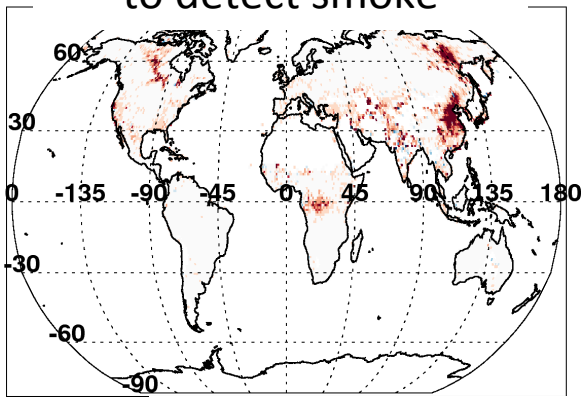


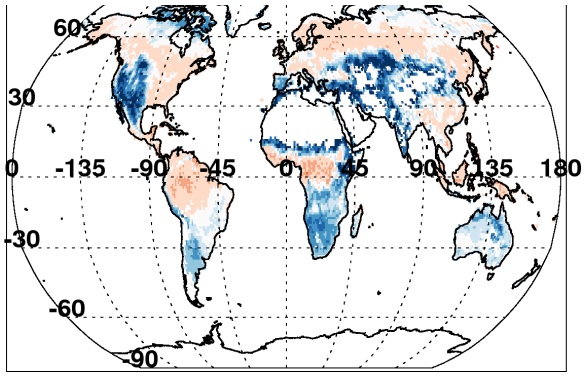
Re-define land and sea

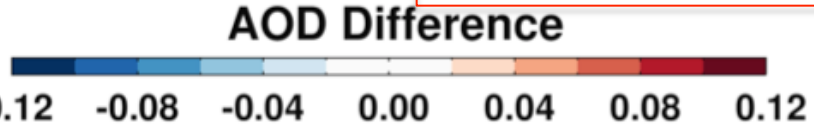


Improved cloud mask to detect smoke



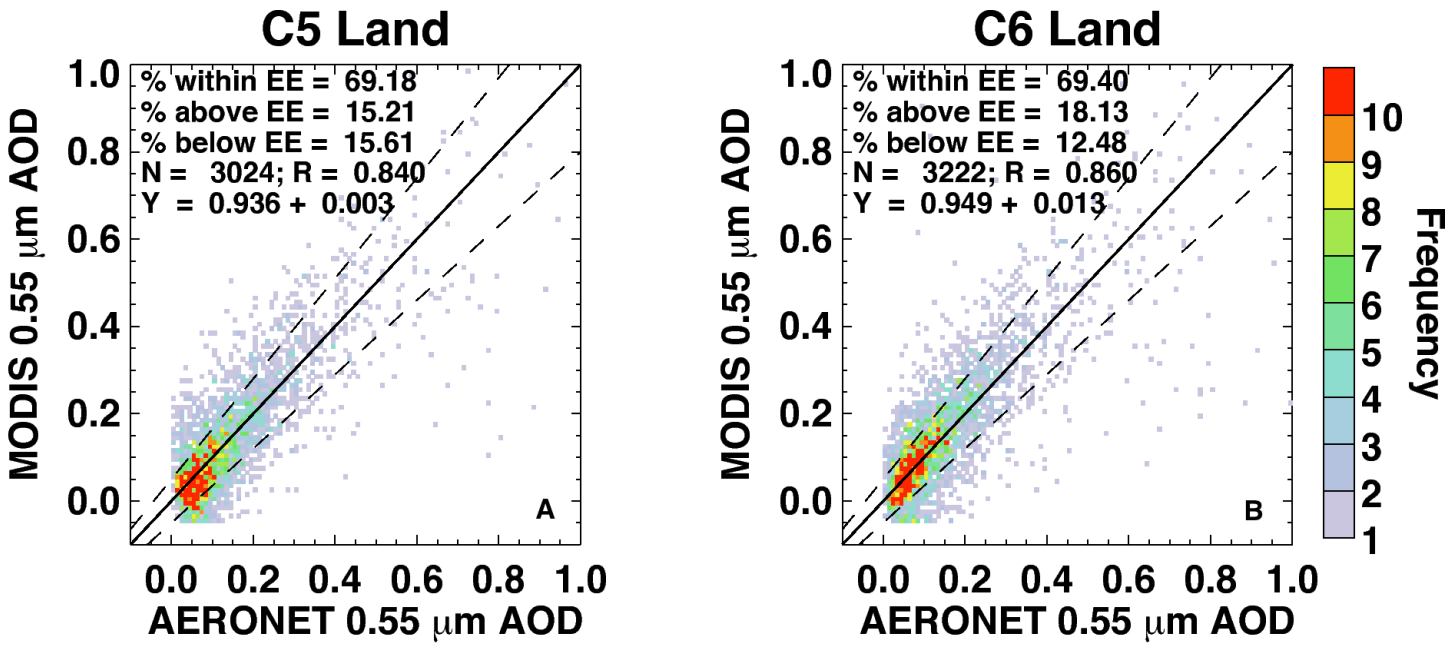
Fixed surface reflectance dependence on TOA NDVI





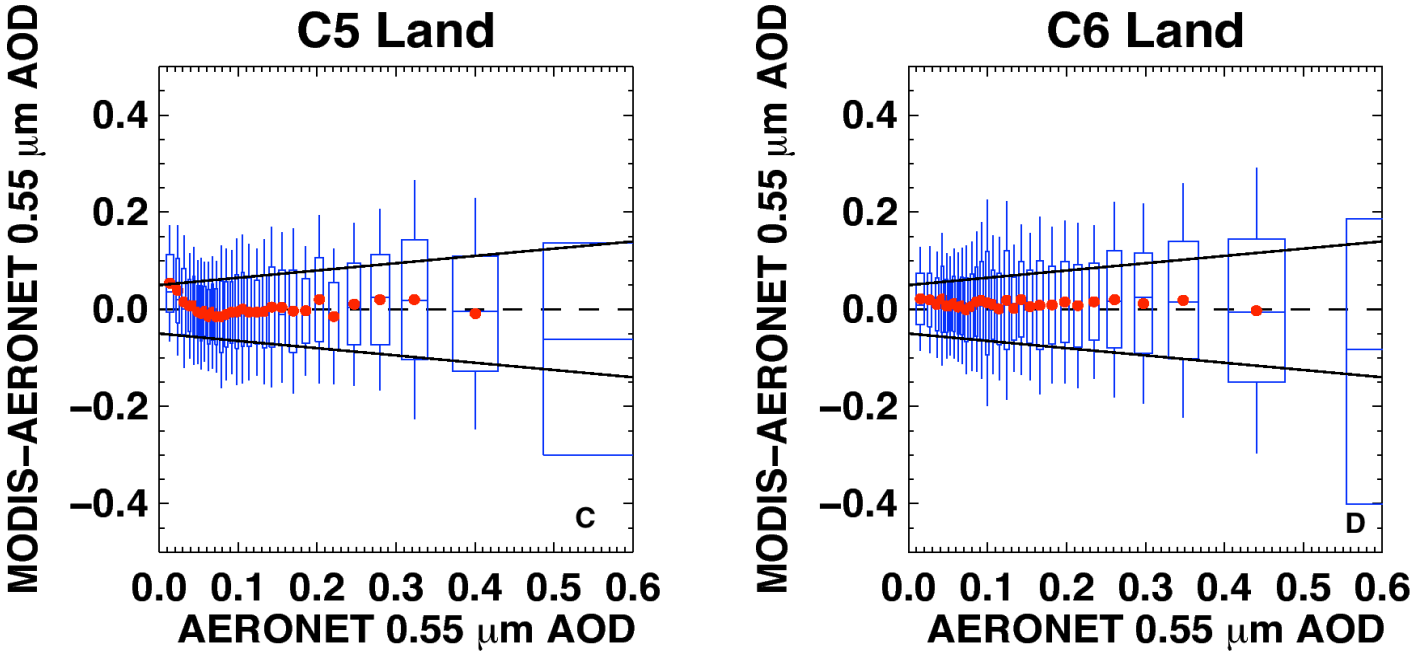
- Also changed "Quality Assurance" Filtering
- Changed aerosol definitions of land and sea
- Etc

Comparison with AERONET



- Aqua for 8 months (Jan + July, 2003, 2008 and 2010; Apr + Oct 2008).
- Overall, not much change over land (slope, intercept, correlation)
- 8% more valid points to compare with (3222 versus 3024).
- More “spread out” along 1-1 line near zero.

Better way to see MODIS improvement



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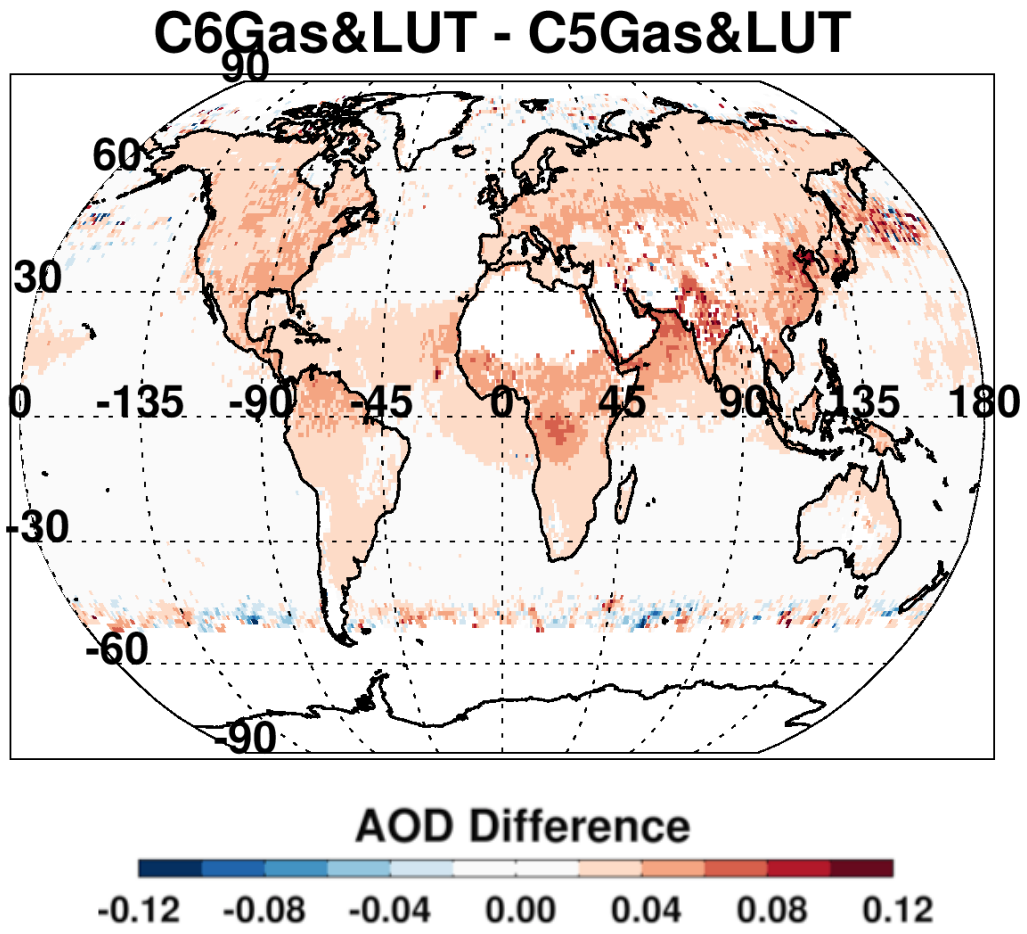
- Solid lines are "expected error" (EE) envelope; no asymmetry
- C6 MODIS error is within EE for nearly all bins of AOD (even at low values)
- C5 EE = ±(0.05 + 15%)). Keep definition for C6.

Other details

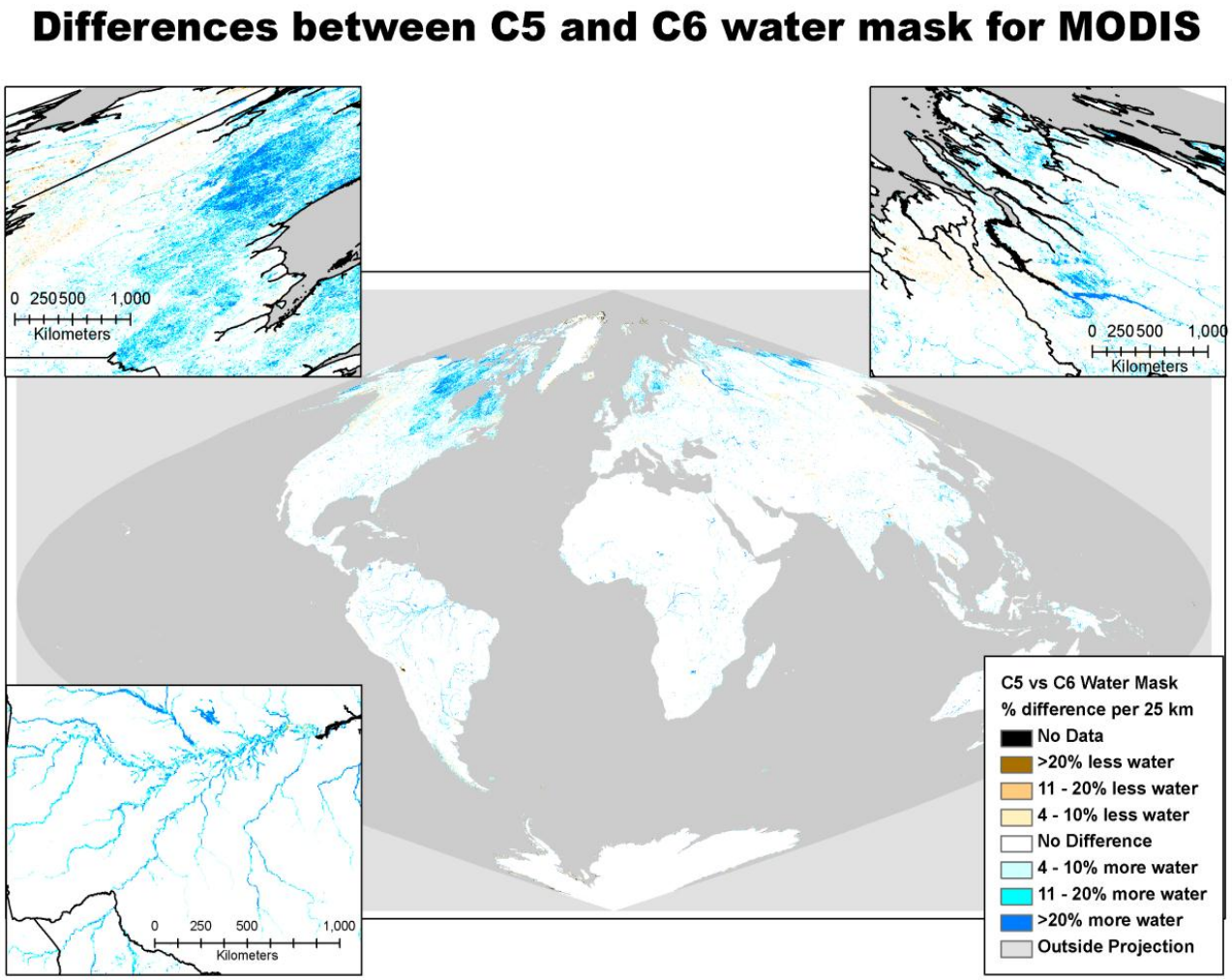
What do we mean by RT updates?



- Recalculate "center wavelengths" from MODIS filter functions
- Ensure consistency between land and ocean retrievals
- Recalculate gas absorption coefficients and optical depths for H_2O, O_3, CO_2, NH_3, O_2, etc.
- (now use LBL-AER code)
- Extend valid solar zenith angle from 72° to 84°.

C5: Center wavelengths: pre-launch assumptions (1999)
C5: Gas correction: circa 1997 (no documentation)

What do we mean by re-define Land/Sea ?



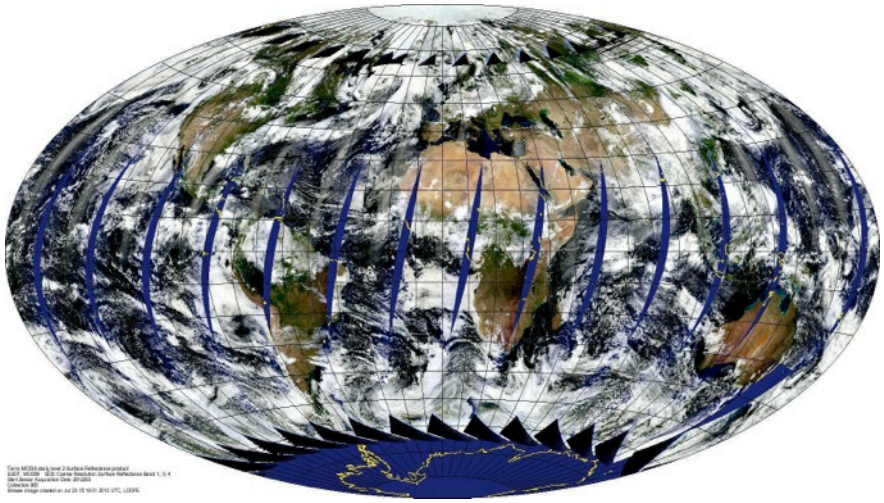
- Aerosol retrieval reads flags from "upstream" files, to guess whether land or ocean
- In C5, "coastal" was rare. It was treated as land, and NDVI test was used to deselect water pixels
- C6 uses much higher resolution database
- For C6, "coastal" is ubiquitous, especially near high-latitude lakes.

Carroll, Wolfe, et al.

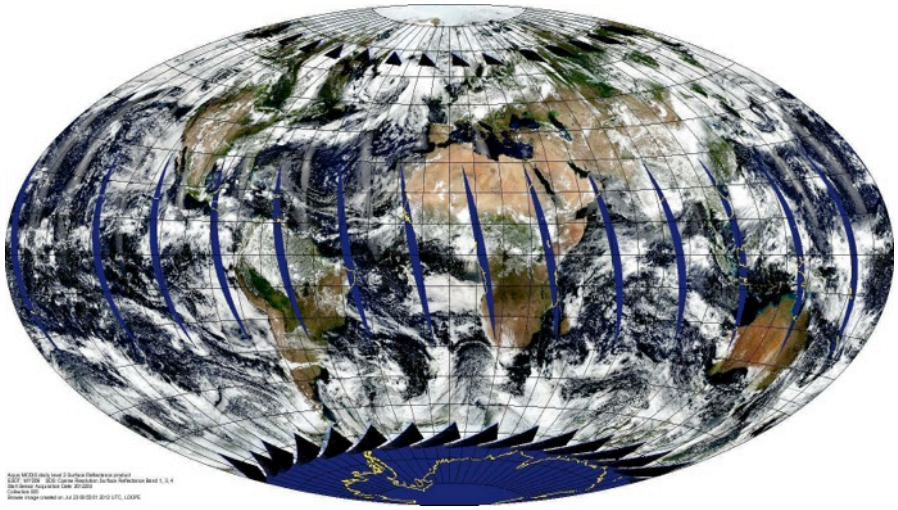
Finally, calibration issues

MODIS instruments = “identical twins”

Terra (10:30 Local Time, Descending)



Aqua (13:30 Local Time, Ascending)

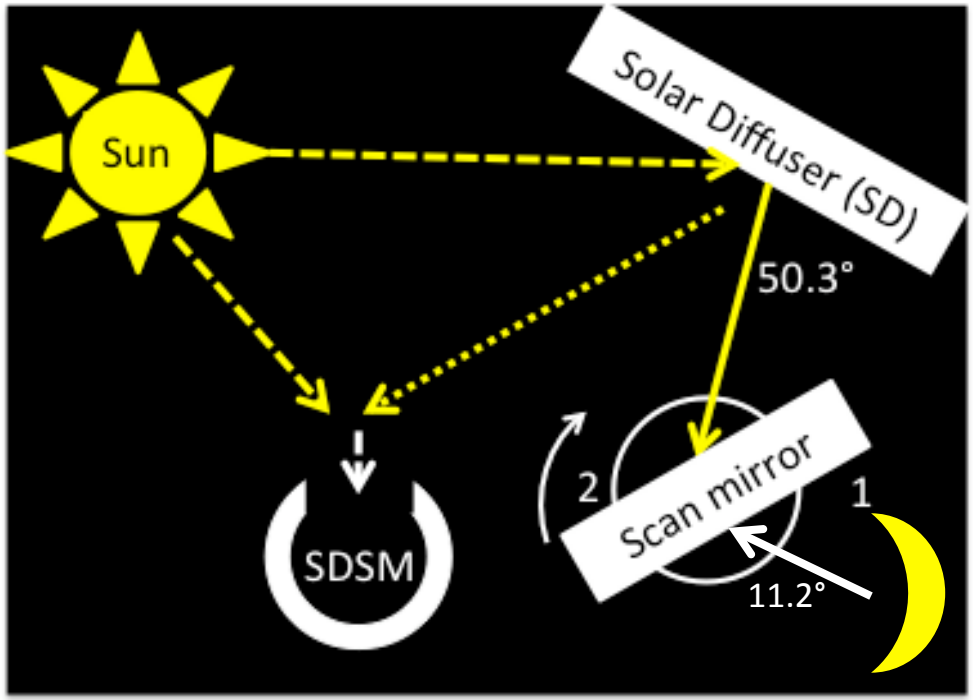


Like human twins:

- Each instrument has had a different life experience
  (pre-launch, during-launch, during orbit)
- They see the same world, but from different perspective
- Different *aging* patterns
  (for optics, sensor characteristics, electronics)

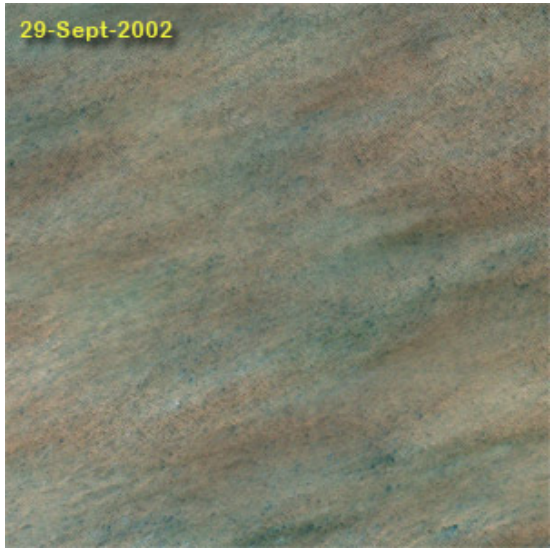
MODIS Calibration & Support Team (MCST) works very hard!

Instrument calibration tied to pre-launch assumptions



- The BRFs of the Solar Diffuser (SD) and mirrors were characterized pre-launch.
- The Solar Diffuser Stability Monitor (SDSM) views the SD at a fixed angle.
- What if the BRF of Terra's SD/mirrors has changed? (Accumulation of "junk").
- Viewing only one angle would not be sufficient to monitor changing BRF.

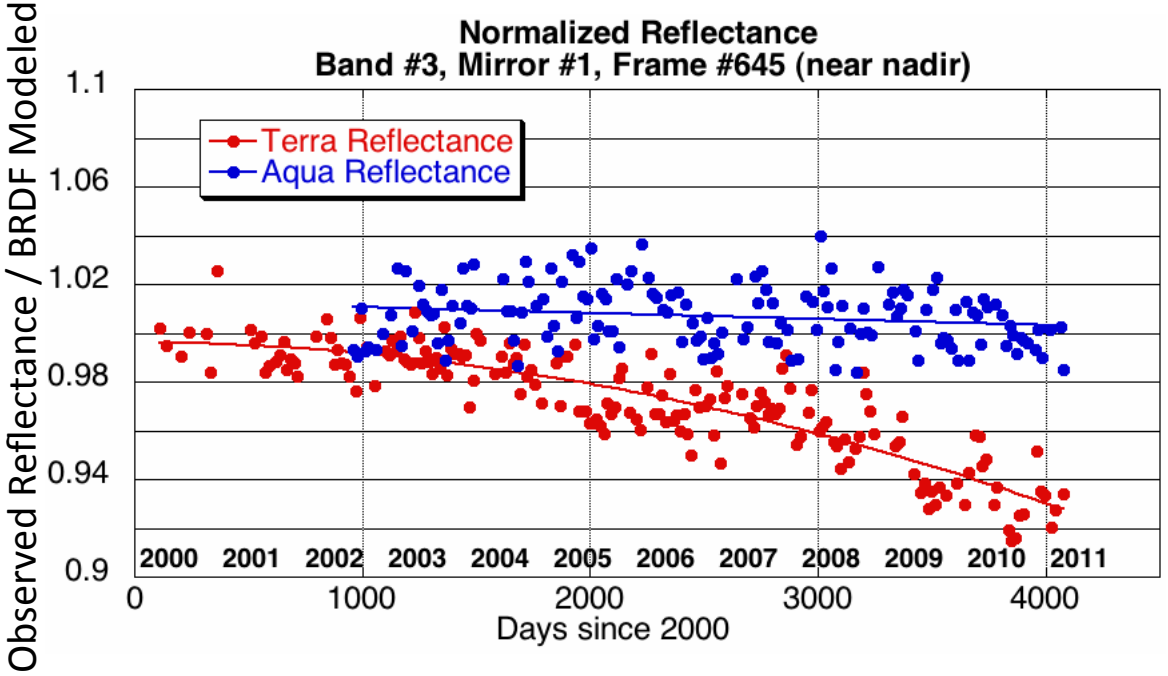
MODIS reflectance trends over desert sites



desert test sites

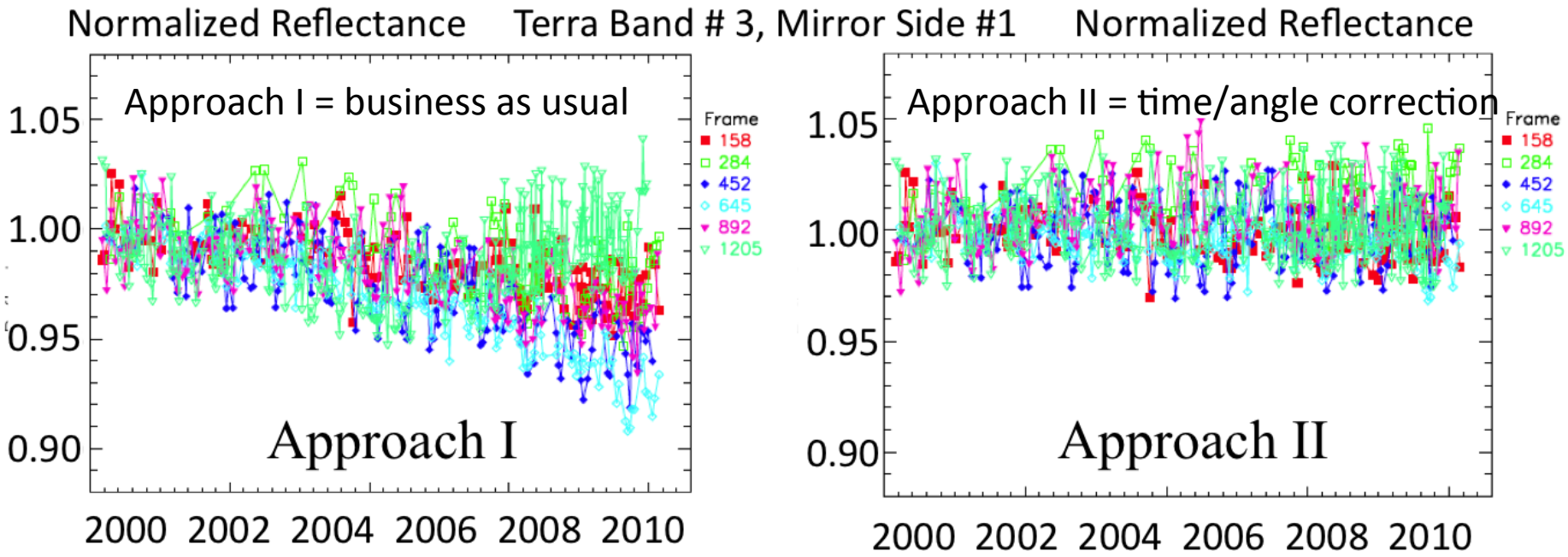
(1) Collect clear-sky MODIS data over desert sites
(2) Develop site-specific BRDF from first 3 years of mission
(3) Over time, compare "observed" reflectance with BRDF modeled reflectance, for different view angles

- Trends in Terra Band #3 (0.47 μm). No trend for Aqua
- Trend varies with Scan Angle (or Frame #)



(4) Apply de-trending algorithm to MODIS observations

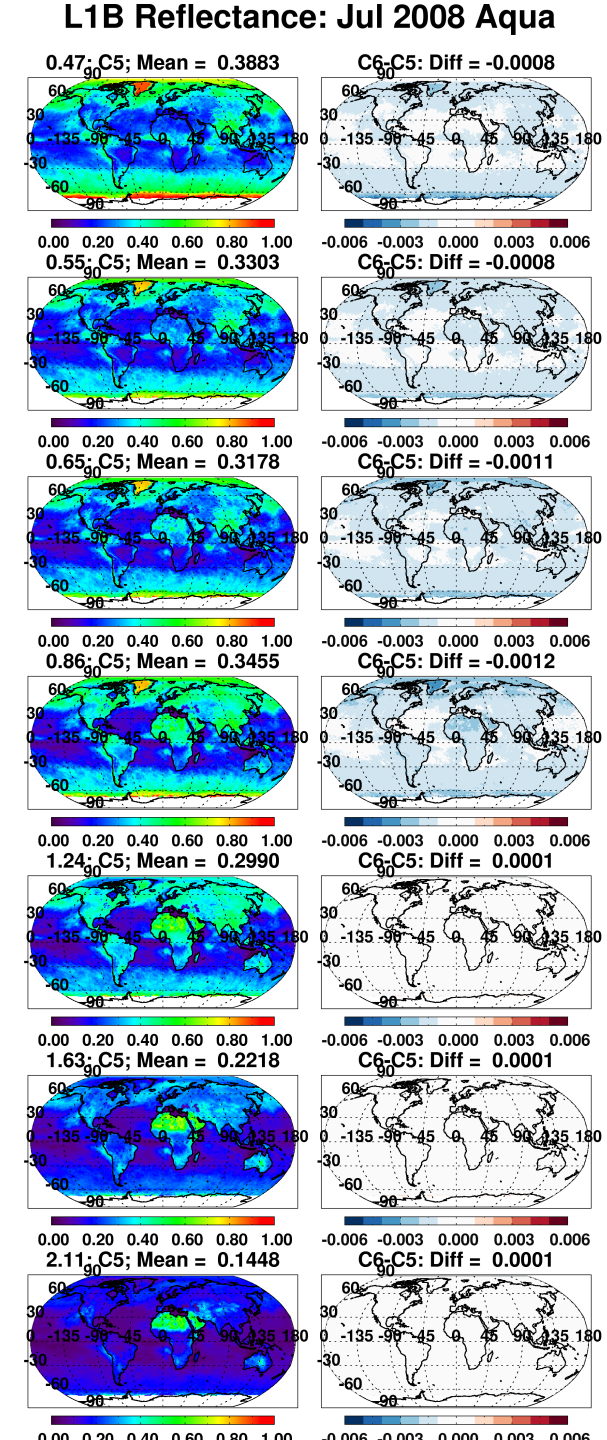
De-trend applied to C6:
Removes the temporal/angular reflectance trends



- B3 (466 nm)
  - 7% *decrease* near nadir
  - 0% change on right (near Moon)
  - 3% *increase* on left

MCST: Junqiang Sun

(5) Apply de-trended observations to aerosol retrieval algorithm



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

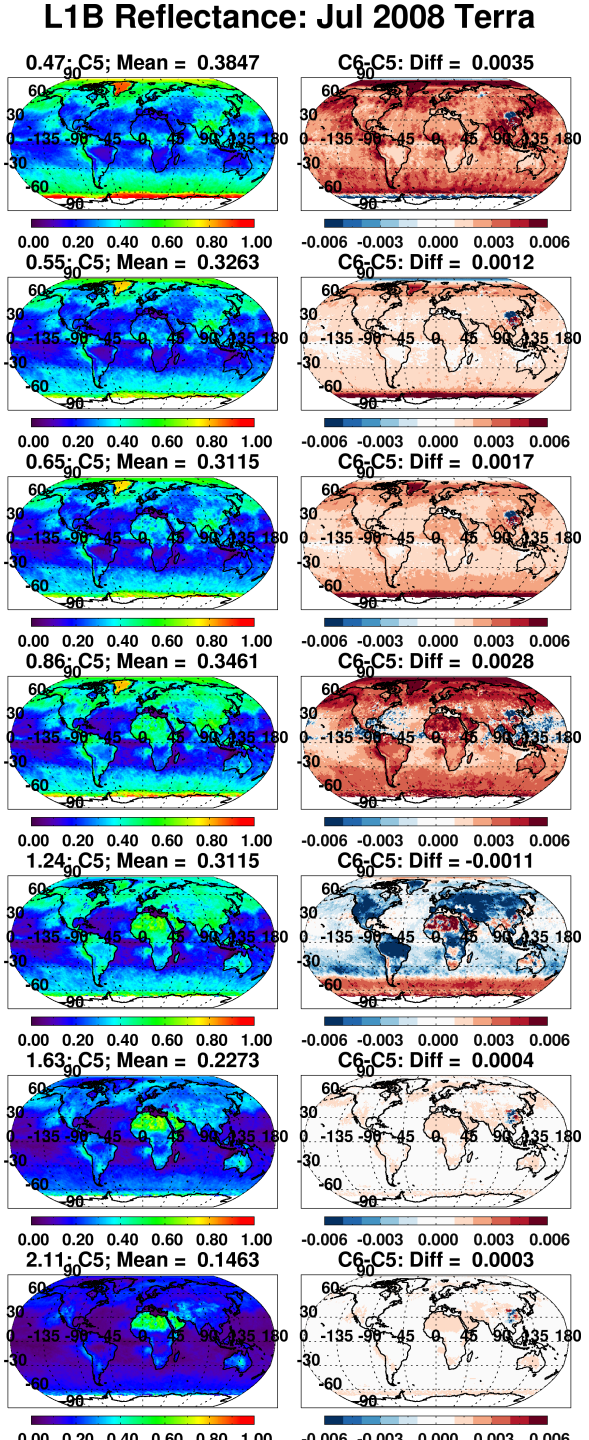
- Overall Aqua changes are relatively stable, but Terra's changes vary over time.

reflectance

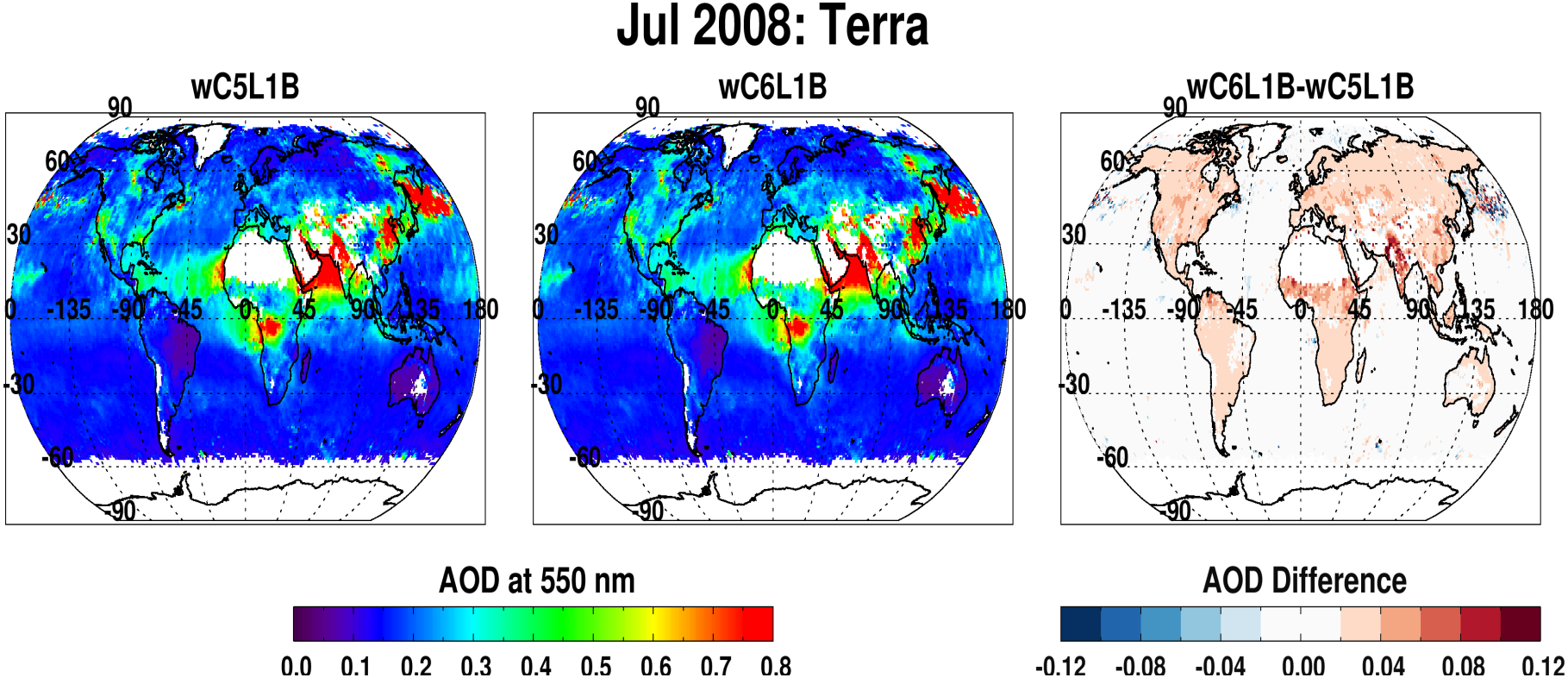
0.00 0.20 0.40 0.60 0.80 1.00

Difference reflectance

-0.006 -0.003 0.000 0.003 0.006



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)

MODIS: Climate Data Records (CDRs)?

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

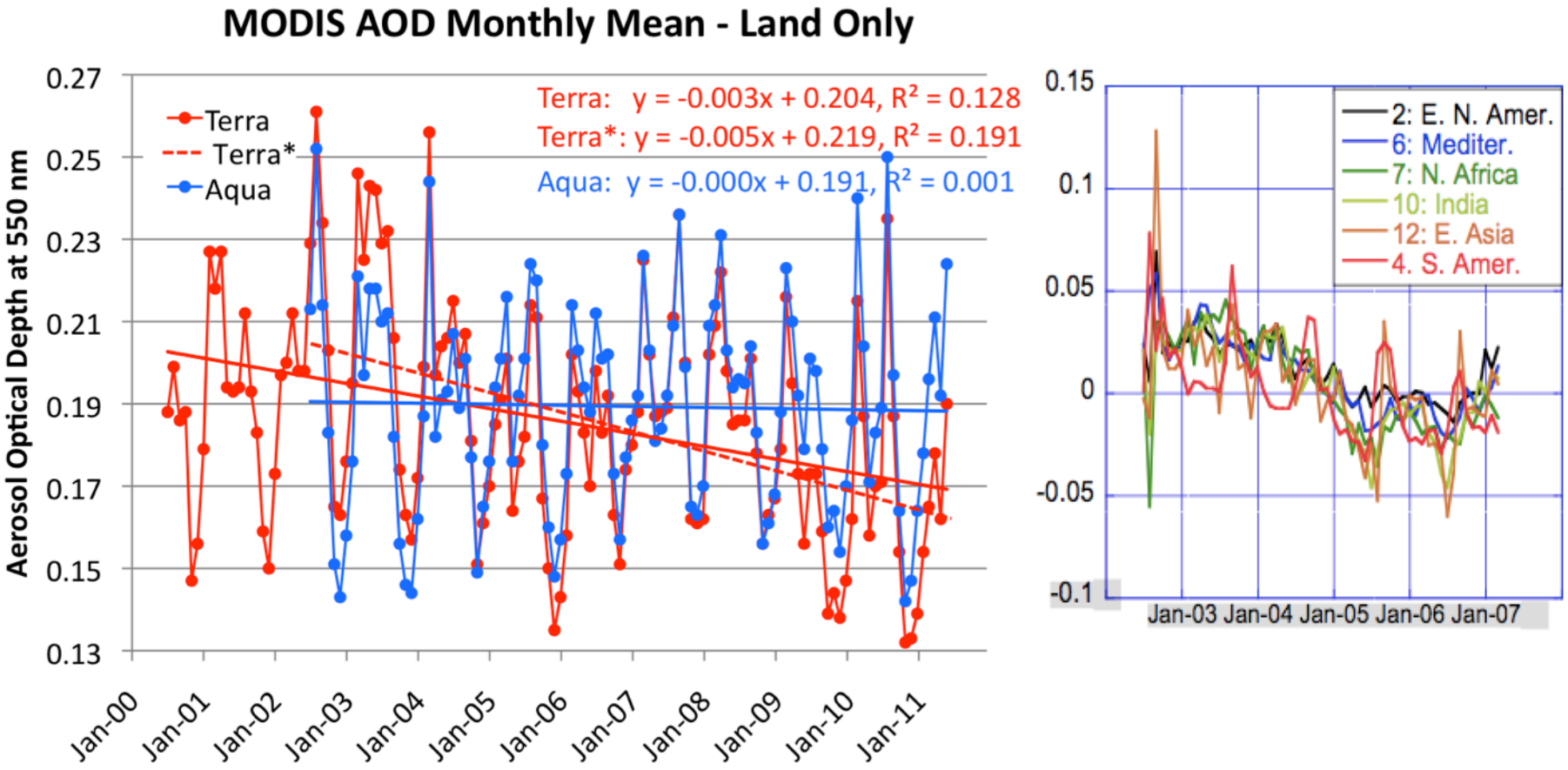
From: Climate Data Records from Environmental Satellites: Interim Report (2004)

Some requirements

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

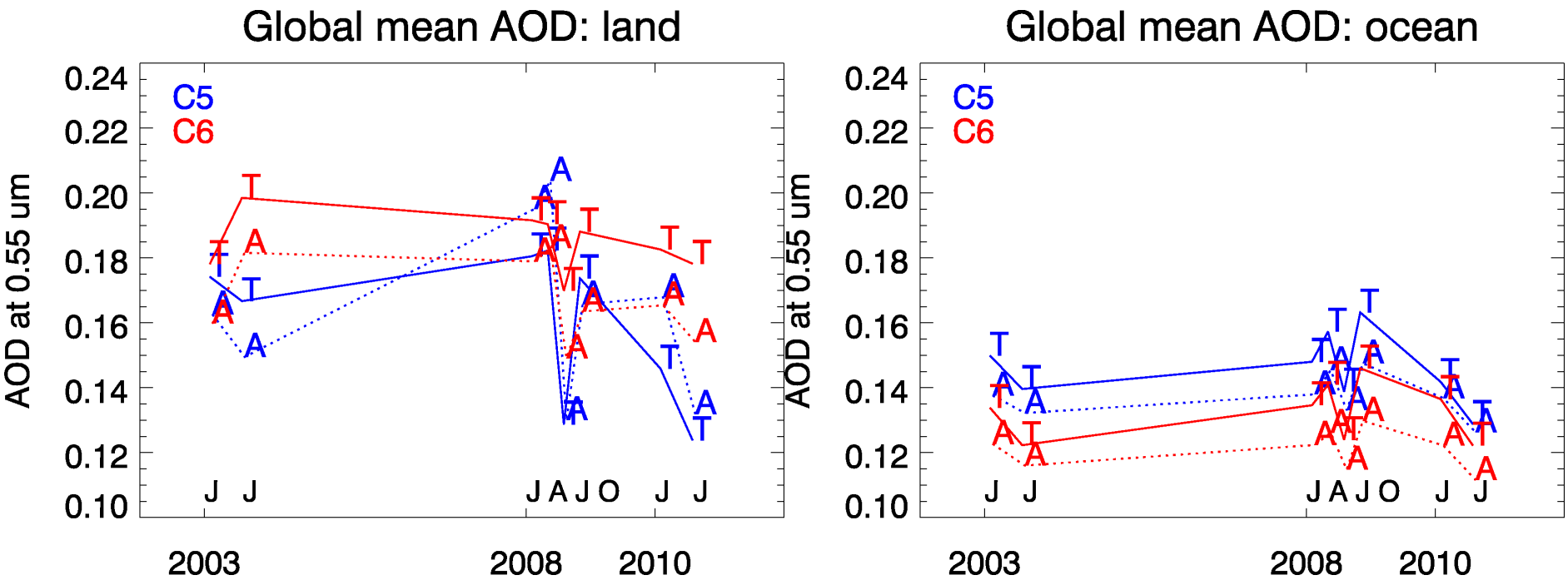
Have we sufficiently characterized the MODIS aerosol product?

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

Impact of new calibration on trend

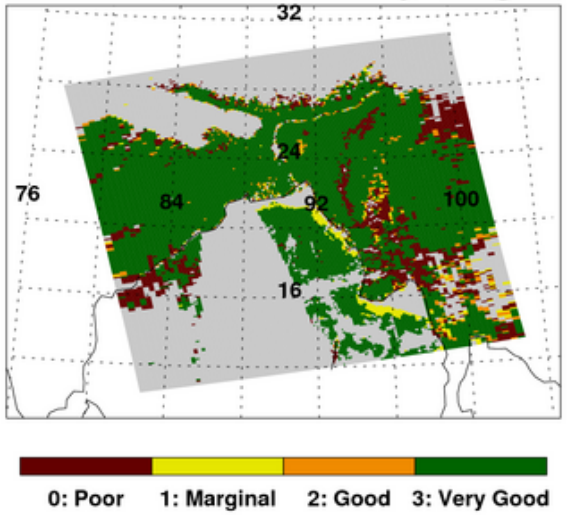


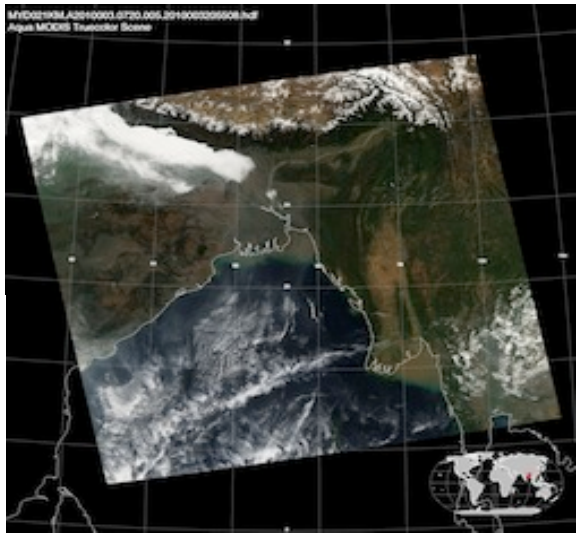
- 8 months processed with same dark-target aerosol algorithms
- Terra (T) Approach II now "in sync" with Aqua (A) time series
- (Terra-Aqua) offset remains 0.01 (ocean) and 0.015 (land)
- Aqua AOD reduced from 0.14 to 0.12 over ocean
- **New calibration → Terra/Aqua divergence removed for C006!**

What else for C6 Level 2?

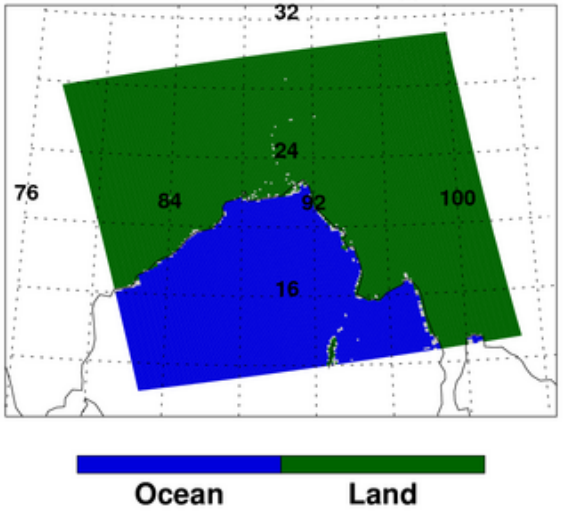
Diagnostic SDSs

Land_Ocean_Quality_Flag

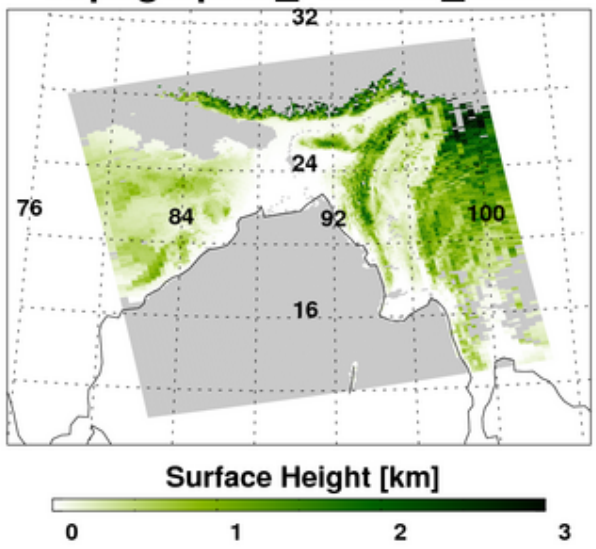




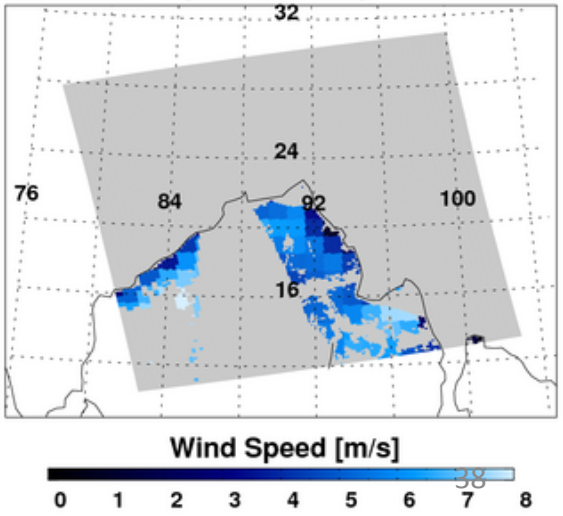
Land_Sea_Flag



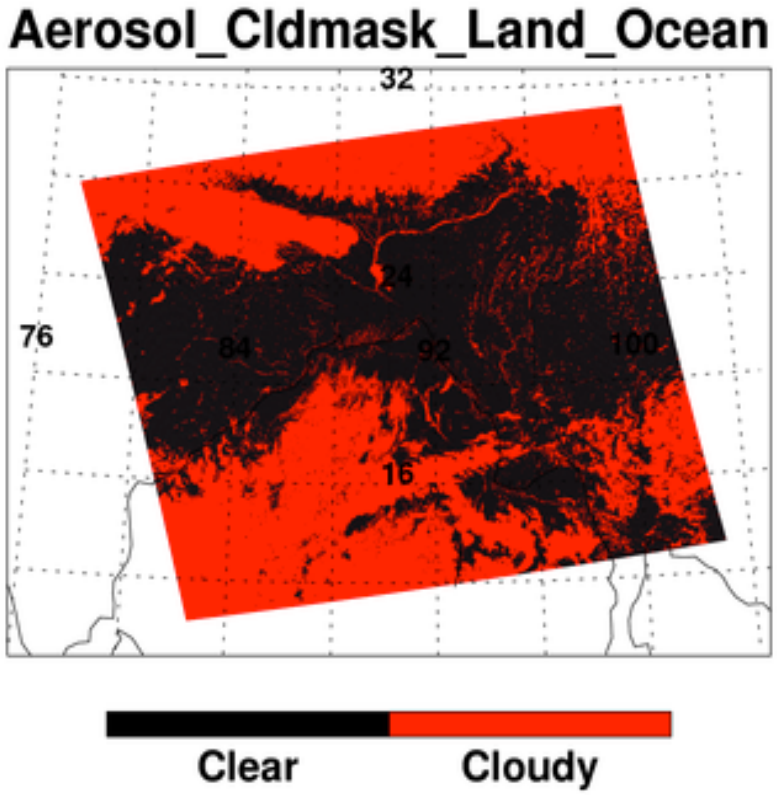
Topographic_Altitude_Land



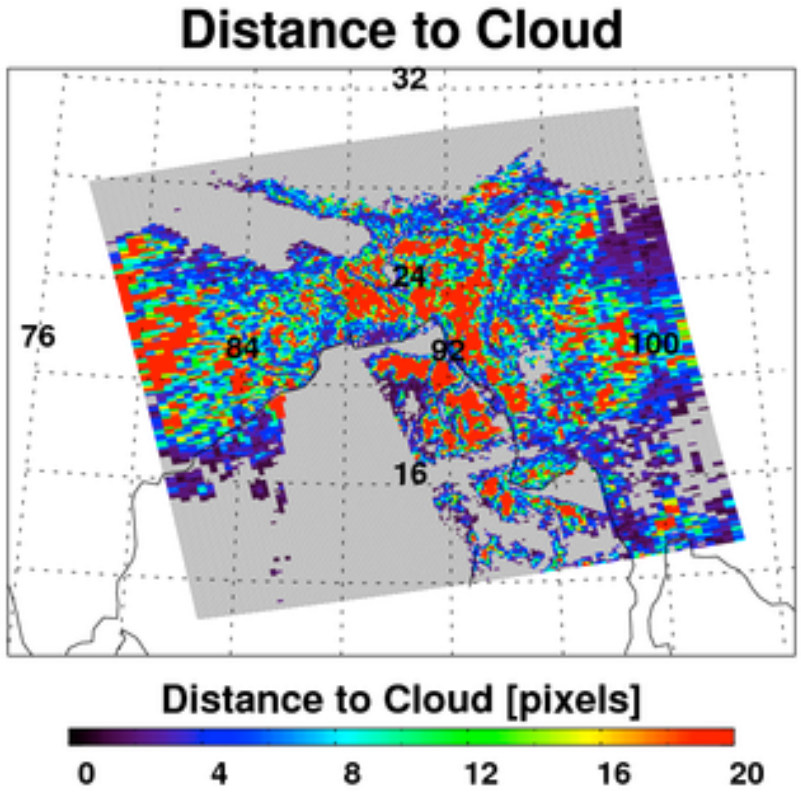
Wind_Speed_Ncep_Ocean



Cloud and Aerosol SDSs



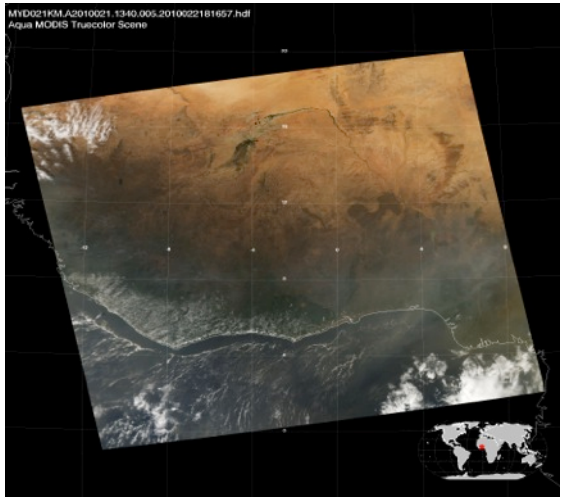
500 meter resolution cloud mask used in aerosol retrieval. Can be (at times, significantly) different than MOD35



Number of pixels between an aerosol retrieval and the closest cloud. Not validated yet.

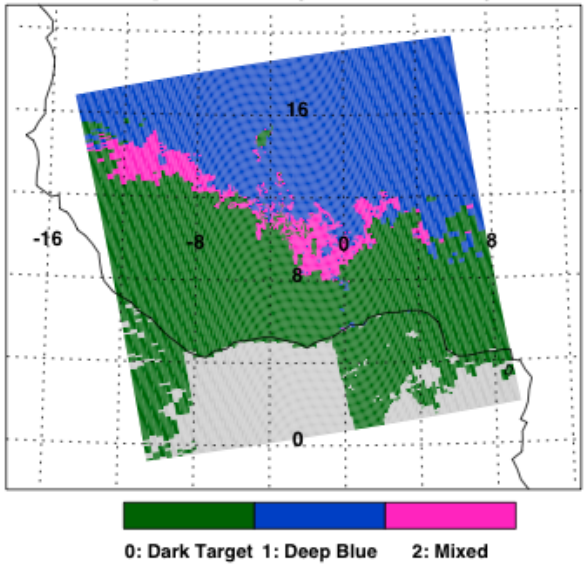
The Dark/Deep merge

Jan 21 2010 at 13:40 UTC



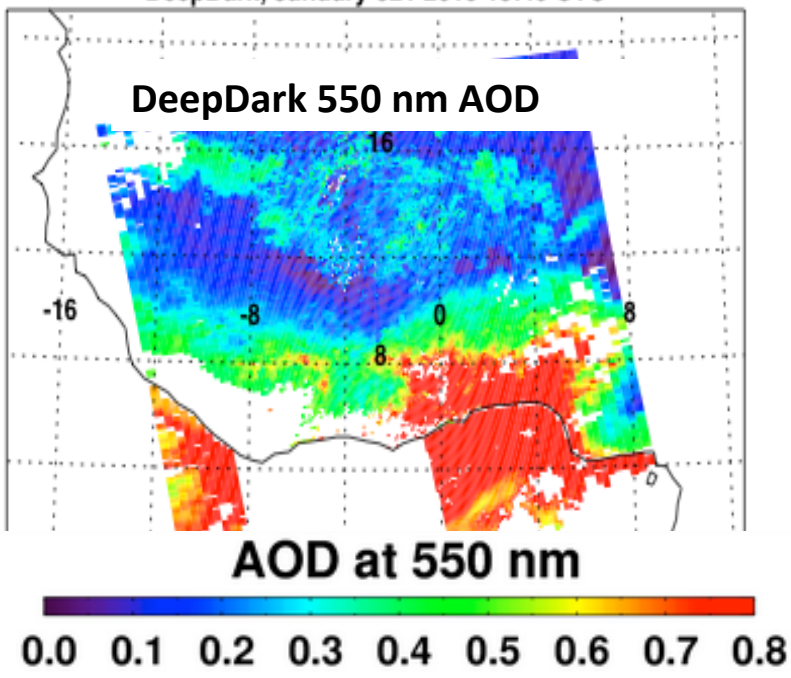
- **Dark, bright, and transitional regions are identified by monthly mean NDVI**
- **In Dark regions, value from dark-target retrieval is used**
- **In bright regions, value from deep-blue is used**
- **In transition regions, AOD is merged, dependent on QA of retrievals**

DeepDark Algorithm Flag



DeepDark, January 021 2010 13:40 UTC

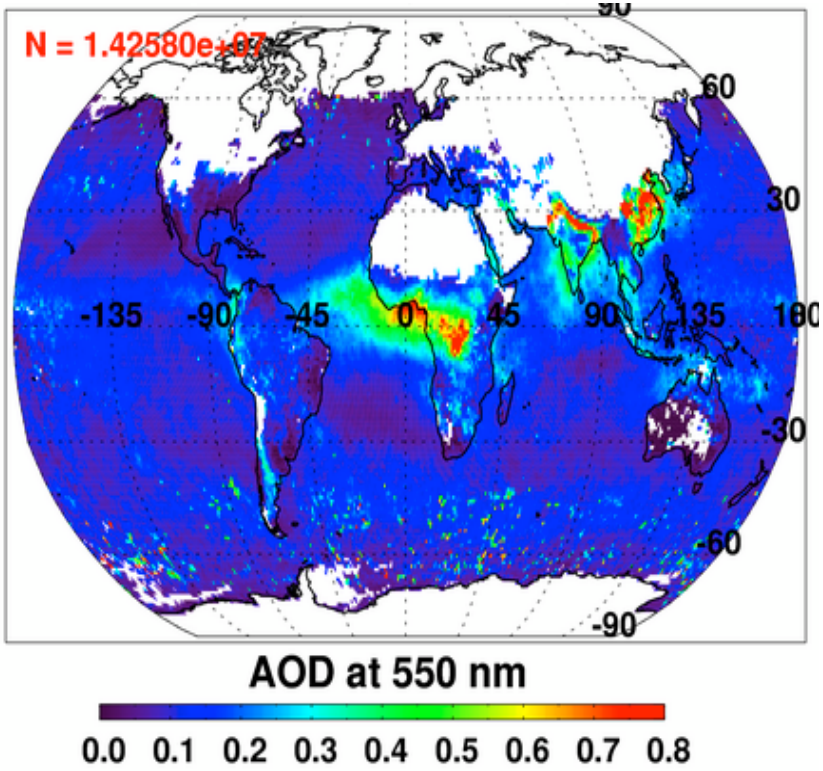
DeepDark 550 nm AOD



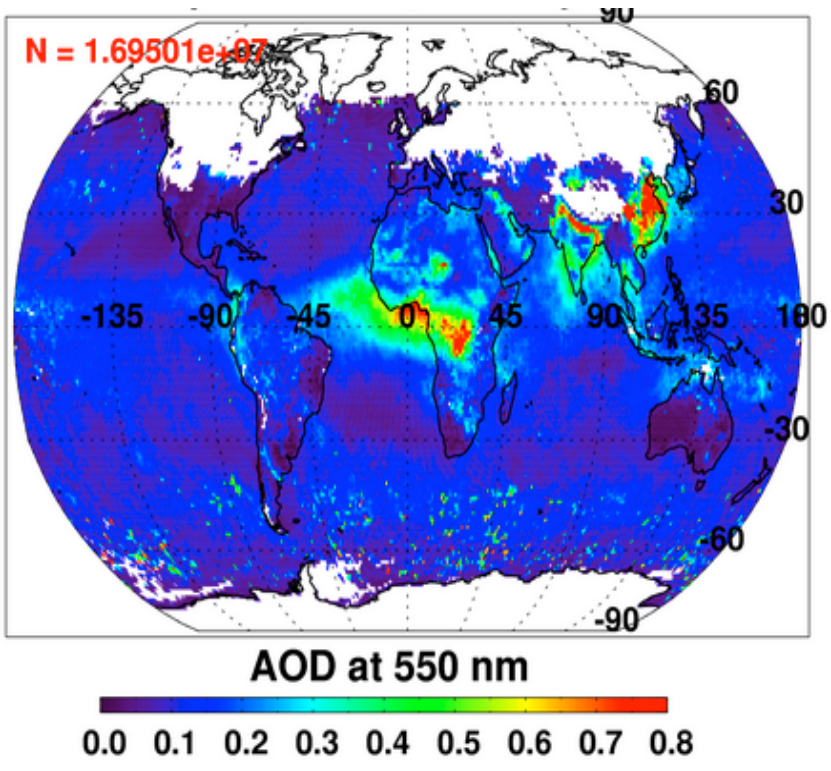
C. Hsu, A. Sayer, C. Bettenhousen, S. Mattoo, L. Munchak, R. Kleidman, et al.,

Monthly mean AOD for Aqua, January 2010

Dark Target AOD



DeepDark AOD



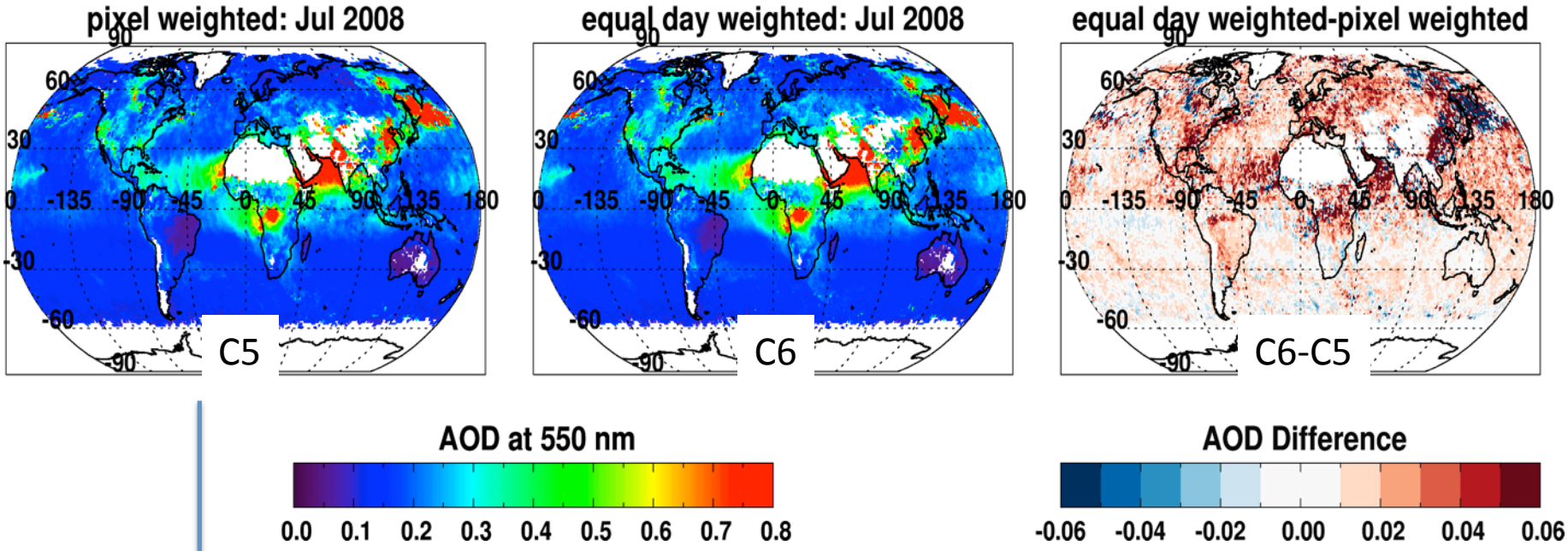
Merging deep blue & dark target produces best global coverage

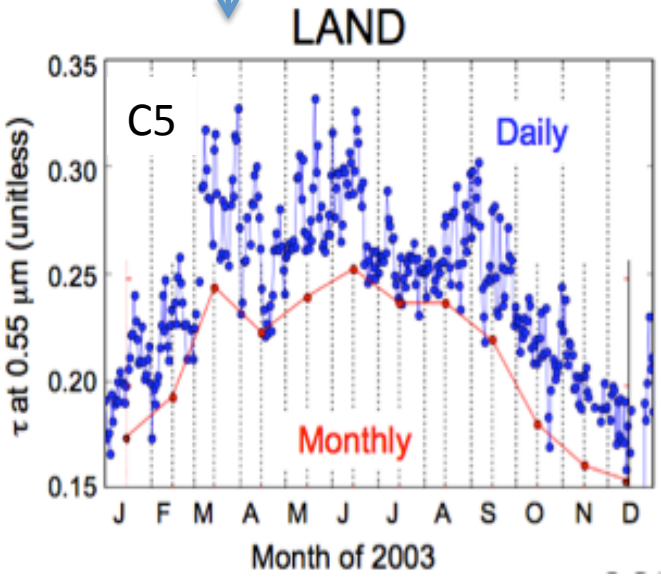
- **Deep blue is land-only; need dark target for oceans**
- **Deep blue introduces coverage over Australian outback, Sahara desert and Arabian peninsula**
- **Still no coverage over snow (see: most of Northern Hemisphere).**

LOOKS REASONABLE, BUT NOT VALIDATED YET!!!!

Beyond MxD04_L2

Changes to Level 3 (MxD08_M3)

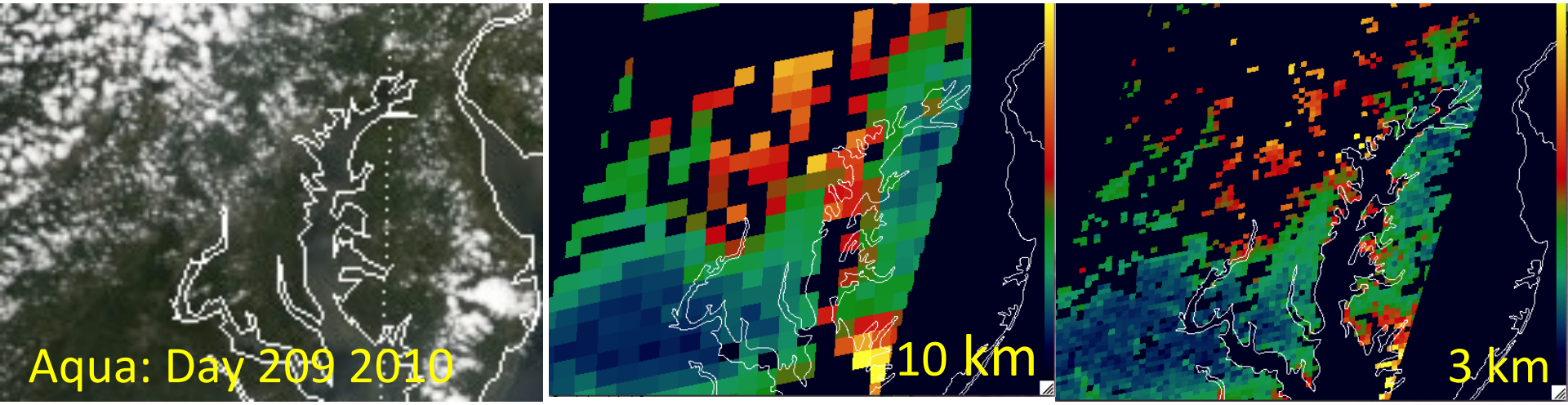




- In C5, averaging daily data did not look like monthly data (left, from Giovanni web application)
- C5 monthly was "pixel weighted". A day with 100 retrieved pixels was worth 10 times more than one with 10. It was clear-sky biased.
- C6 monthly is "equal day" weighted. If at least five pixels in a day, 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:

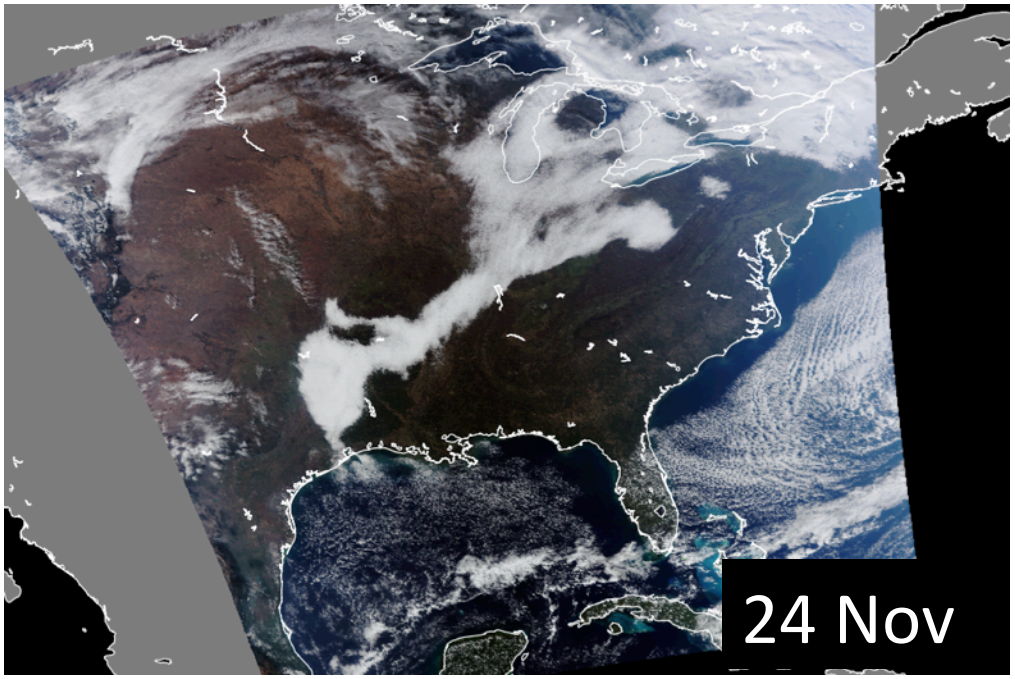
- Total_Ozone
- Lifted_Index
- K_Index
- Total_Totals_Index

Platnick, King, Hubanks,..

Dark-target aerosol retrieval: Beyond MODIS

Suomi-NPP VIIRS

Visible Infrared Imager Radiometer Suite



Multiple VIIRS granules stitched. Image by Geoff Cureton, CIMSS

- Launched 28 Oct 2011; "first light" Nov 22
- Different instrument, resolution, sampling, cloud masking, algorithms, etc.
- Lorraine described operational products

- Can VIIRS "continue" the MODIS aerosol data record?
- Working on adapting MODIS dark-target algorithm to VIIRS data (as well as other satellite and air borne remote sensing data).

Okay: summary time

Summary (1)

- There are many ways to retrieve aerosol properties from MODIS, and there is more than one set of algorithms/ products
- Dark-target algorithm/products are updated for C6
- Changes are “modest” but lead to significant changes in retrieved global aerosol
- Dark-target and Deep-blue products are merged, leading to more global coverage
- Documentation is still under development. Some papers have been published; my “overall” paper accepted to AMT.
- According to my latest sources, Collection 6 processing is expected to begin sometime during October. It will start with Aqua Level 2, then Terra, then Level 3. **WE WILL BLAST AEROCOM EMAIL WHEN IT HAPPENS!**

Summary (2)

- The MODIS aerosol products have matured over the last 13 years.
  - They are well characterized (striving for better)
  - We understand the strengths and limitations
  - Our products are “useful” and in a useful format.
  - The global community (both research and operational) depends on the MODIS aerosol products

Summary (3)

- MODIS aerosol retrieval was intended for global *climate* applications
  - MODIS aerosol products → climate data records?
  - Not yet
  - but artificial trends can be removed by reformulating instrument calibration and quality assurance
  - More evaluation is needed.

Summary (4)

- MODIS aerosol retrieval was intended for *global* climate applications
  - Air quality events are sometimes on urban and local scales
  - Aerosol properties change near clouds
  - → The MODIS dark-target team is offering 3 km operational aerosol data.
  - There are two published papers, and one in revision.

Summary (5)

- MODIS is not the only thing
  - NPP-VIIRS is online
  - VIIRS is “similar”, yet different then MODIS
  - TBD: How different?
  - More evaluation is needed.
  - Now that MODIS Collection 6 is delivered, we can focus on NPP-VIIRS.

- Onward towards Collection 7 !!!
  - Includes reporting per-pixel uncertainty
  - Correction for bias over urban areas