

The dark-target aerosol remote sensing from MODIS, circa 2011

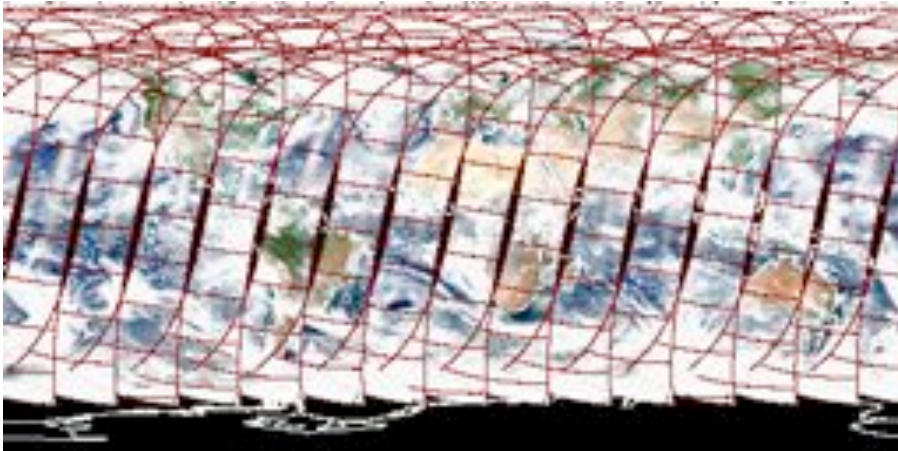
Robert Levy (SSAI and NASA/GSFC)
Shana Mattoo (SSAI and NASA/GSFC)
Lorraine Remer (GSFC)
Bill Ridgway (SSAI and NASA/GSFC)
Junqiang Sun (Sigma and NASA/GSFC)
Steve Platnick (GSFC)
Richard Kleidman (SSAI/GSFC)



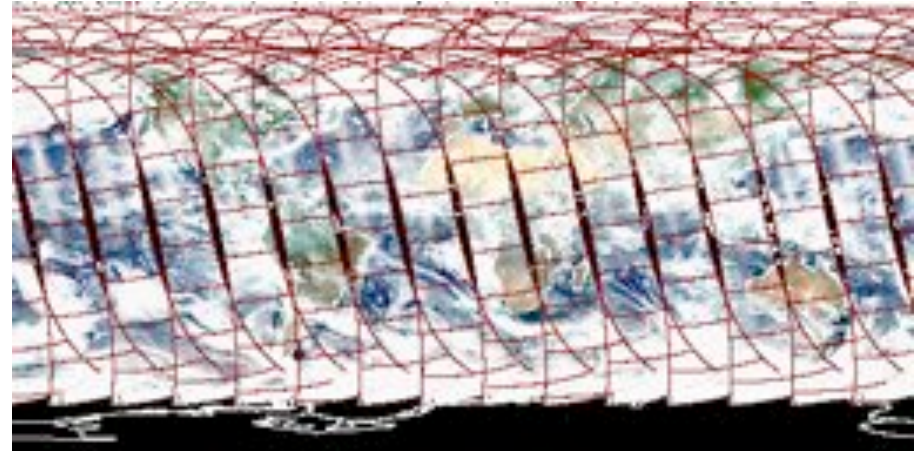
MODIS

Moderate resolution Imaging Spectroradiometer

Terra (10:30, Descending)



Aqua (13:30, Ascending)

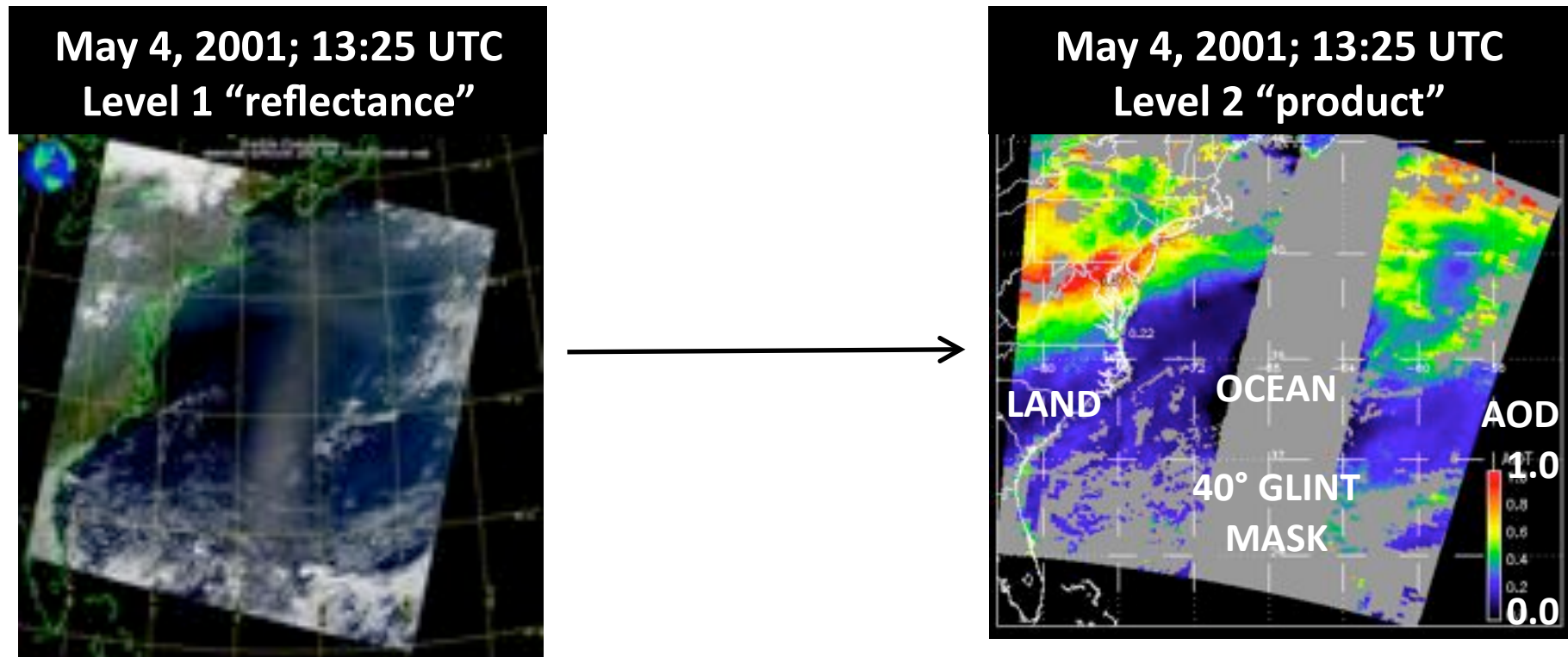


“Identical Twins” – Have different personalities!!!

Outline

- MODIS Dark target algorithms
- Evaluation of Collection 5 (C005)
- Trends and MODIS calibration
- Transitioning to C006
- Different approaches to C006 L1B calibration
- Combined Deep Blue/Dark Target product
- 3-km product (New applications)
- What is left to do before C006 operational.

Evaluation of C005/C051 Dark Target Products



History: Separate algorithms over

LAND (dark targets, vegetation and dark soil, Kaufman et al., 1997)

OCEAN (dark, far from glint, Tanré et al., 1997).

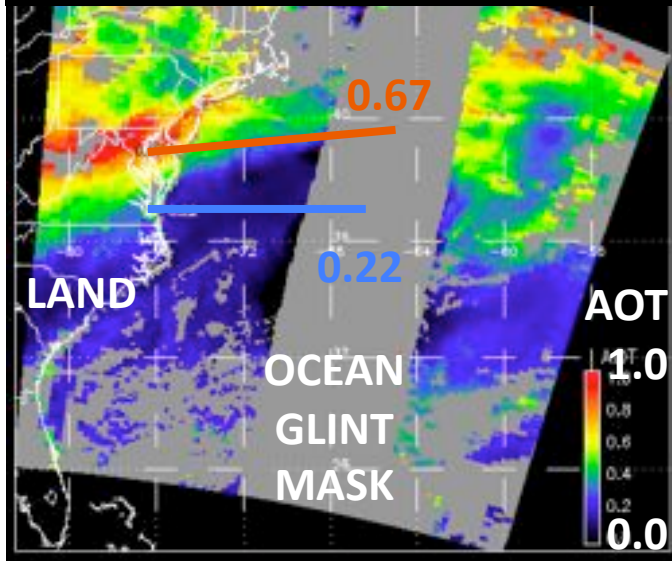
Now: algorithms are identical for Collection 5 (C005) and Collection 51 (C051).

LAND (Levy et al., 2007)

OCEAN (Remer et al., 2005, 2008).

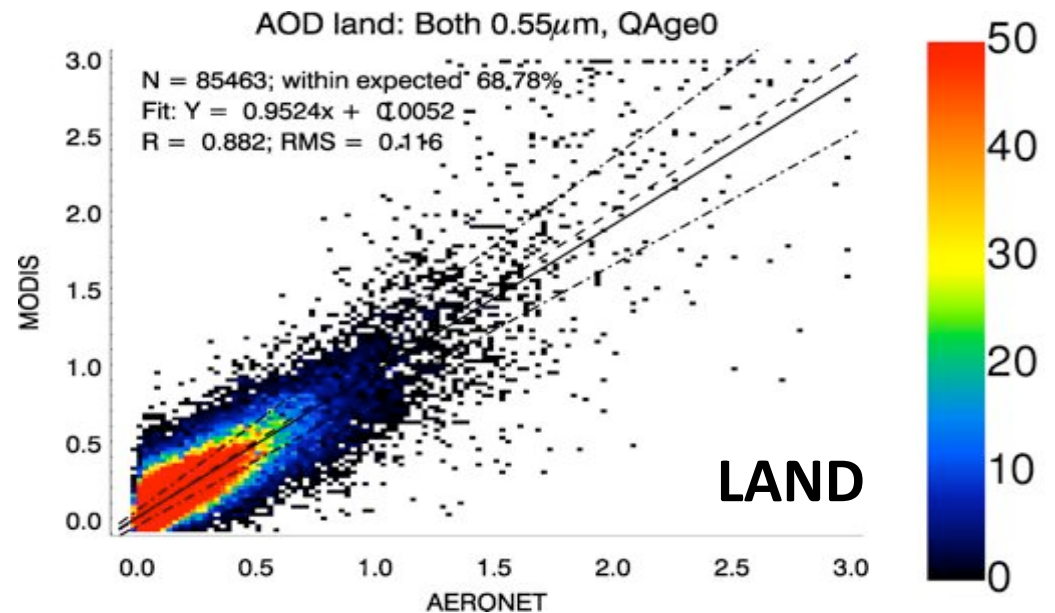
Validation: quantifying the expected error

May 4, 2001; 13:25 UTC
Level 2 "Granule"



First steps:

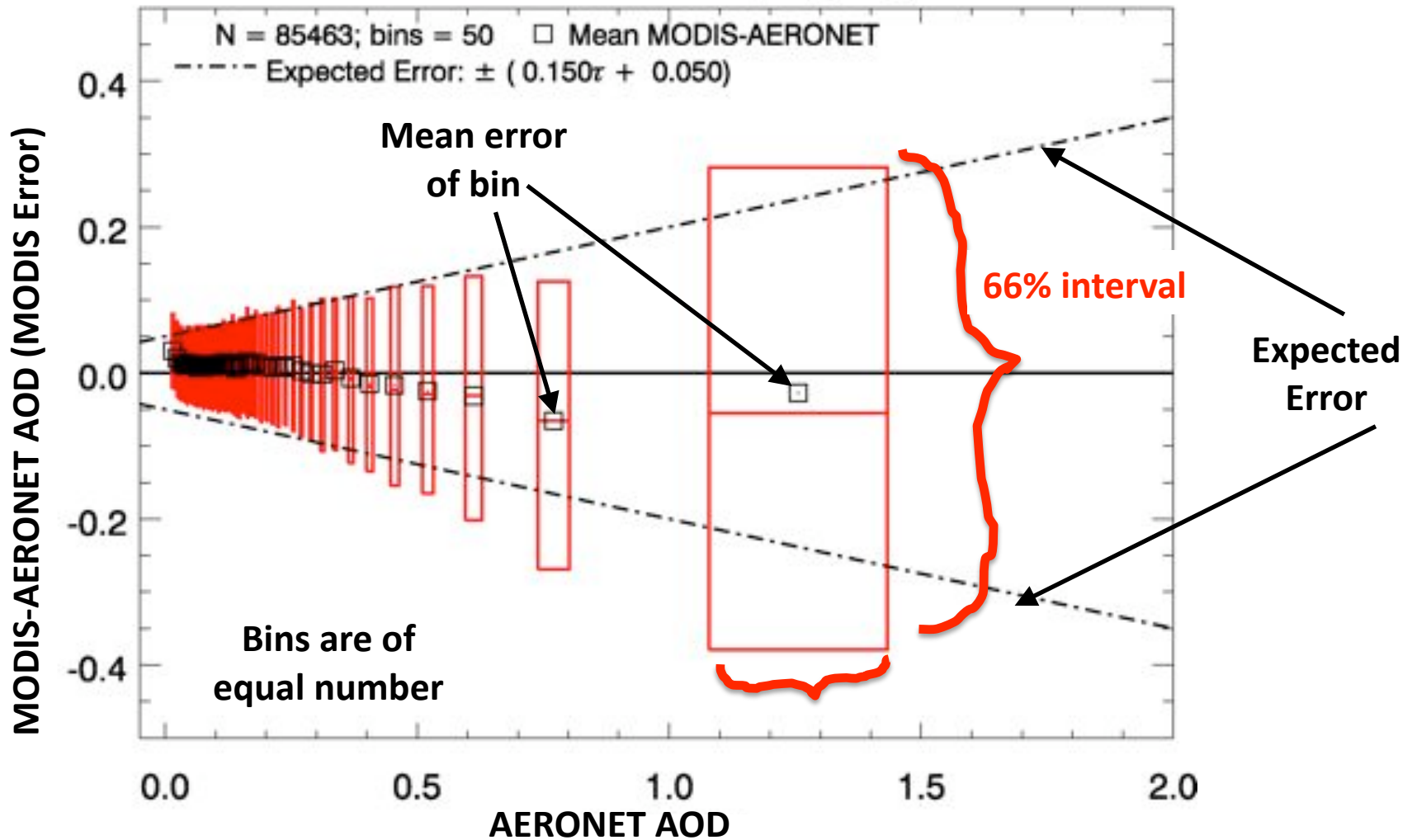
- Pictures look good
- Compare both land and ocean products to AERONET, separately
- Validation: 66% are within "Expected Error" (EE) defined as
 - Land: $\pm(0.15\tau + 0.05)$
 - Ocean: $\pm(0.05\tau + 0.04)$



Levy et al., ACP 2010

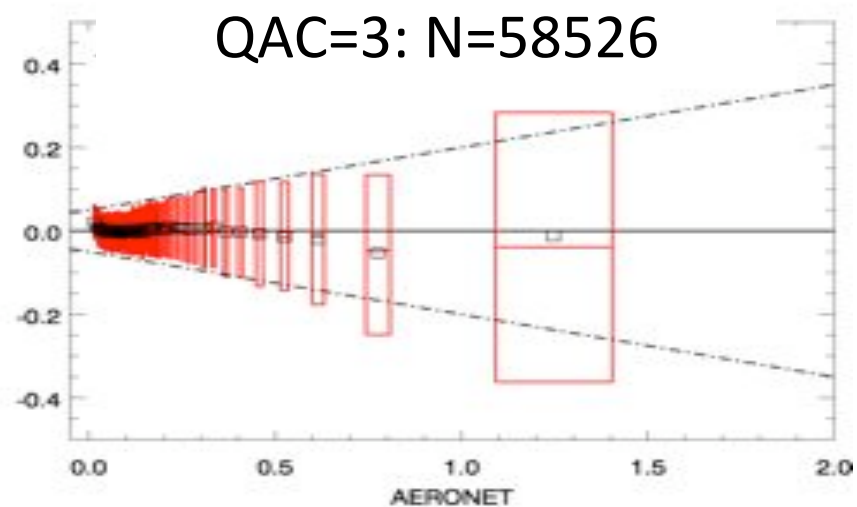
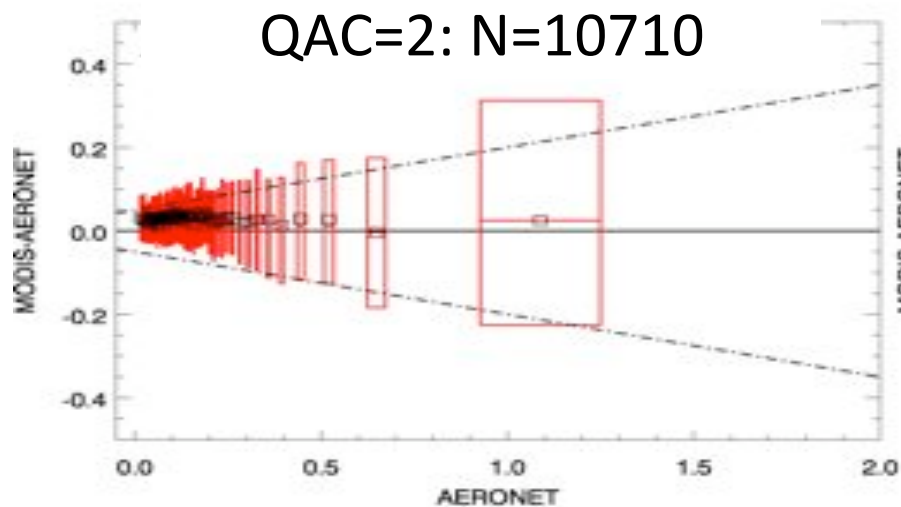
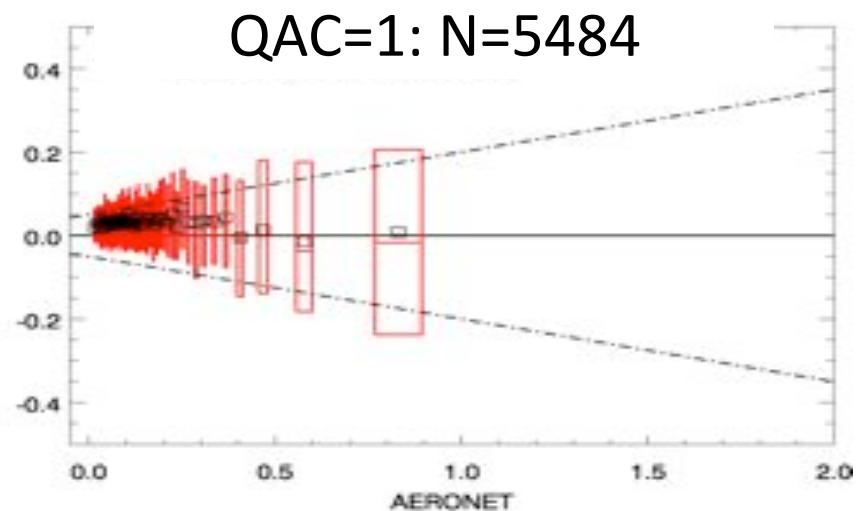
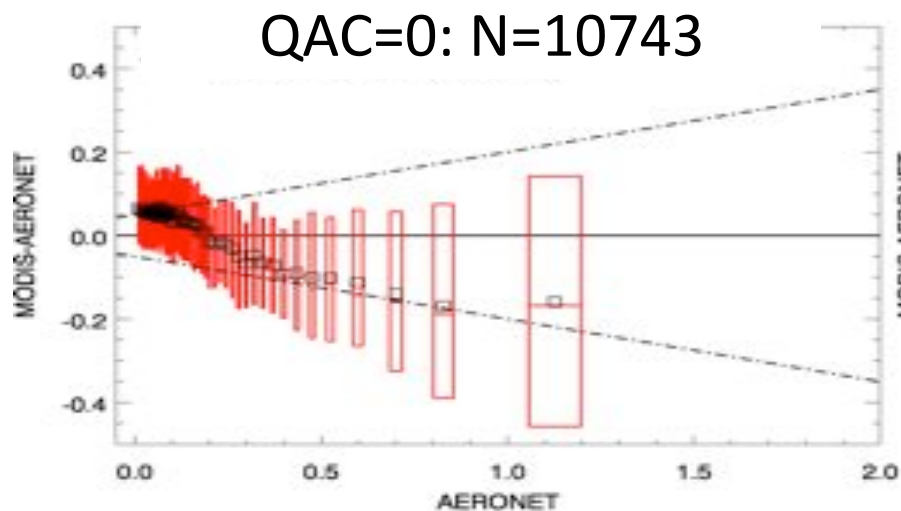
... Plotted a different way

AOD @ 553 nm; Land; N = 85468



By “binning”, we can visualize systematic biases

“Quality Flags” are VERY important



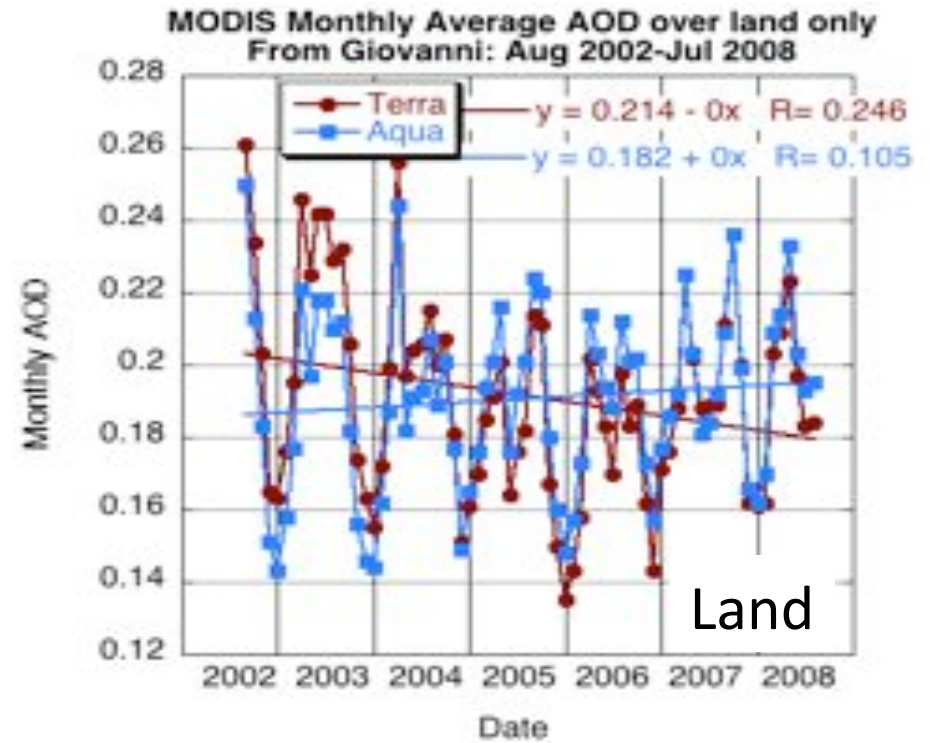
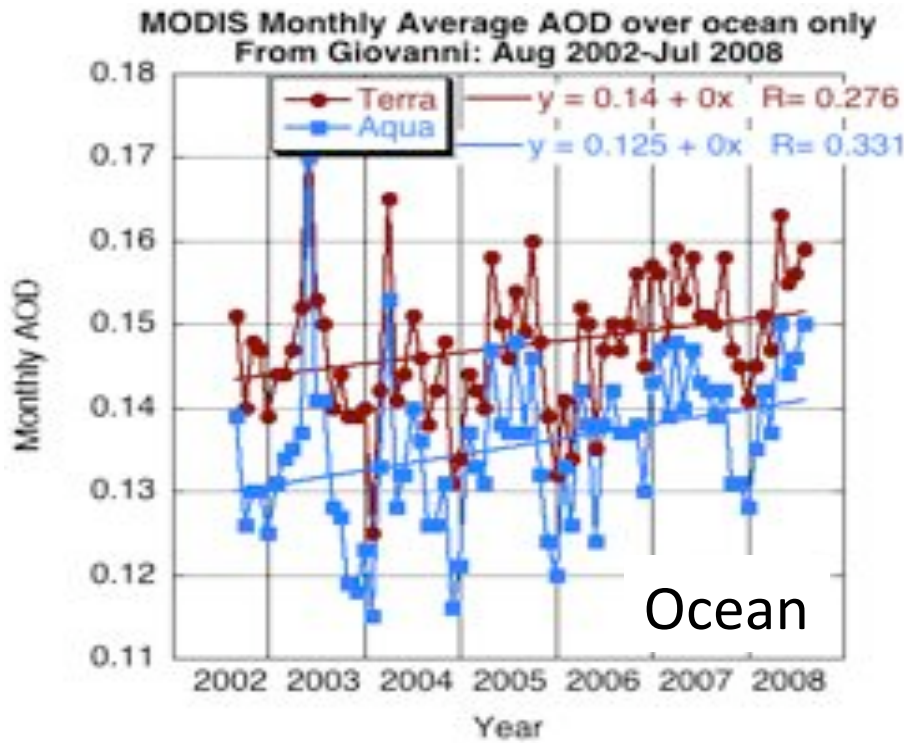
Systematic biases decrease with QAC: Recommend QAC=3 over land

C005 Validation Summary

- MODIS C005 dark-target AOD (Land and Ocean) is “validated”, generally as we expected it to be.
 - 66% within defined error envelope, globally
 - Generally, more tightly constrained than C004
 - Quality Flags are important!
 - Biases are location/scene/condition dependent!
 - No major difference between Terra and Aqua
 - Residual biases in AOD are continually being quantified
- In other words, no major surprises!
- Therefore, we analyzed C005 data to answer some basic questions about global aerosol...

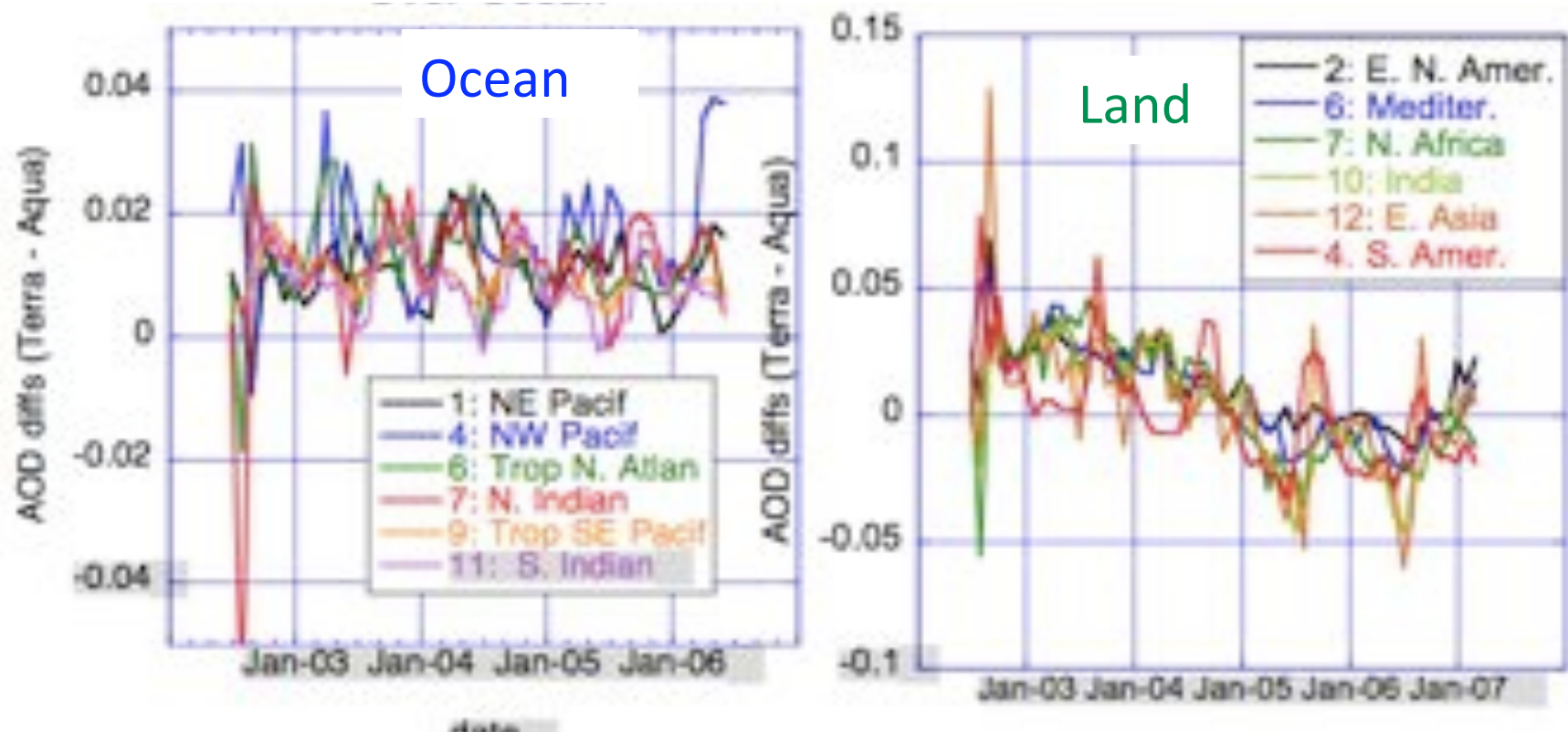
Q: Is global aerosol increasing or decreasing?

A: A Definite Maybe



- Over ocean,
 - Terra and Aqua are increasing (+0.001/yr), and are both significant at 95%
 - Terra > Aqua by +0.01 (10%).
- Over land,
 - Terra decreases (-0.004/yr), and is significant at 95% level
 - Aqua increases (+0.0007/yr), and is not significant at 95% level

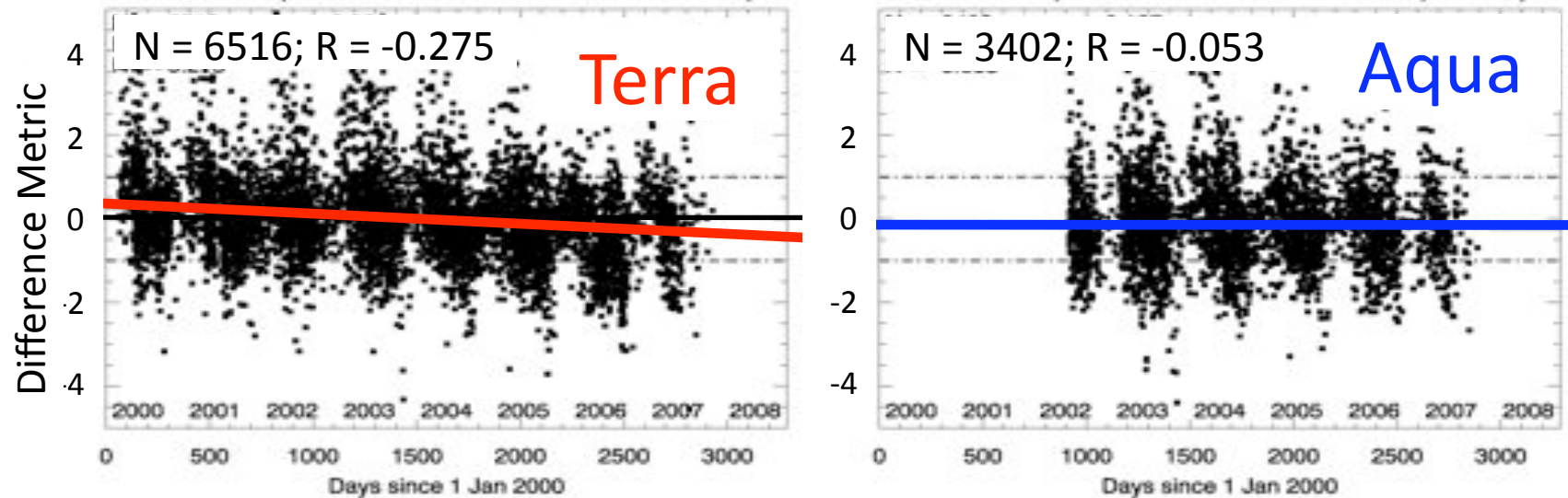
Terra \neq Aqua



- Terra – Aqua is the same everywhere on the globe!
 - Ocean: Terra-Aqua = 0.01;
 - Land: Terra-Aqua changes from +0.02 to -0.01.
- Details of aggregation and sampling are NOT primary driver
- All-regional behavior suggests not local diurnal cycle

A: Trends may be related to instrument changes

Trends of MODIS-AERONET “agreement” over time (land)



- Over land: 14 AERONET sites with >7 years of data (plotted)
- Metric decreases for **Terra** ($R = -0.275$, **significant**), which means that in <2004, MODIS overestimates AOD, but >2004 MODIS underestimates! No trend for Aqua.
- ***AOD Trends over land may be actually changes of instrument’s “personality”.***
- Same games played over ocean, show negligible increase of both instruments versus AERONET, with Terra biased high and Aqua biased low.



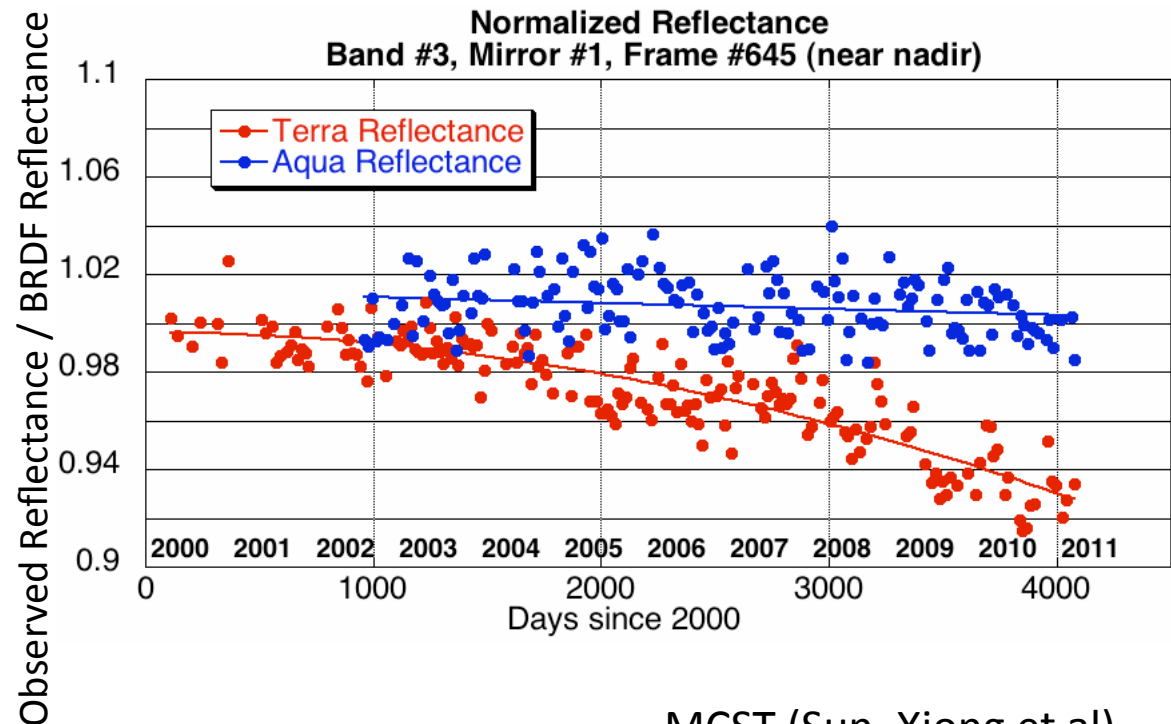
Tracking MODIS RSB radiometric stability from reflectance trends over CEOS desert sites



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!



MCST (Sun, Xiong et al)

Means and Trends

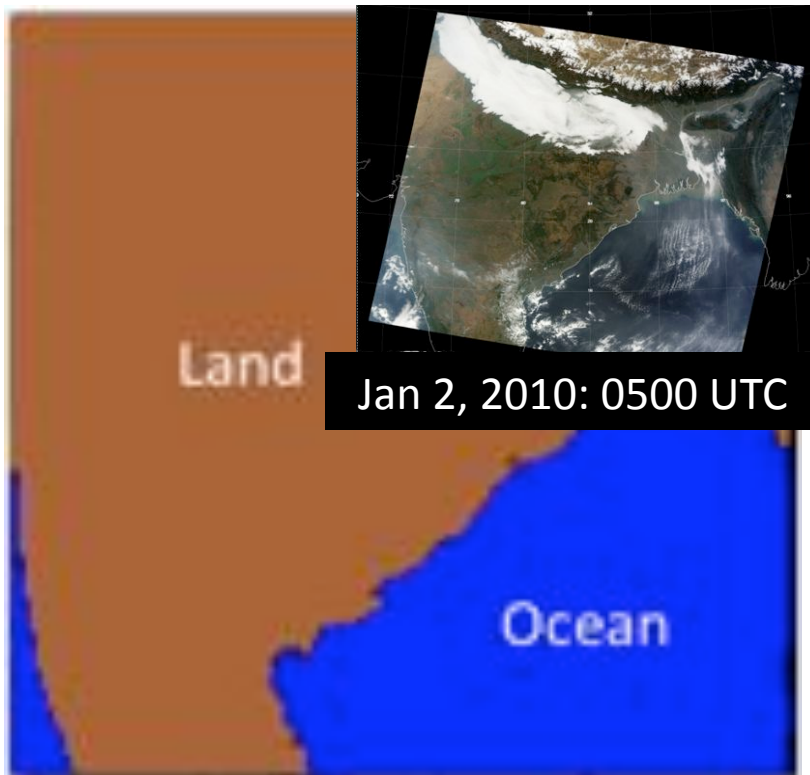
Surprises in C005

- Means greatly depend on the methodology for aggregation, weighting and averaging
- The C005 data record shows trends for Terra over land that do not agree with Aqua.
- Calibration differences and drifts are sufficient to explain a portion of the apparent MODIS trends and Terra/Aqua discrepancies.

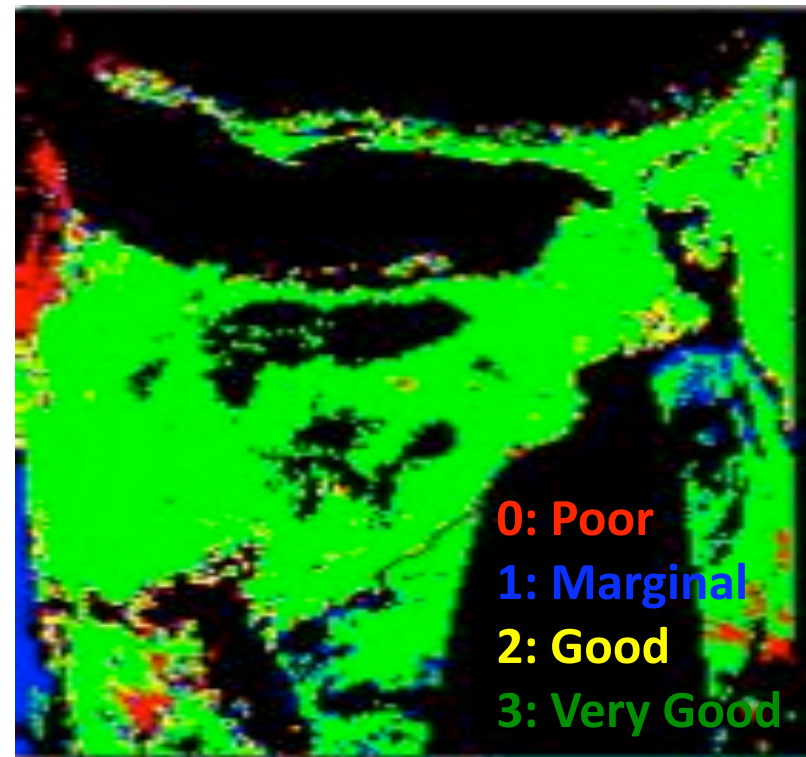
Looking ahead to Collection 6

Users complained. We have listened.

“Land_Sea_Flag”



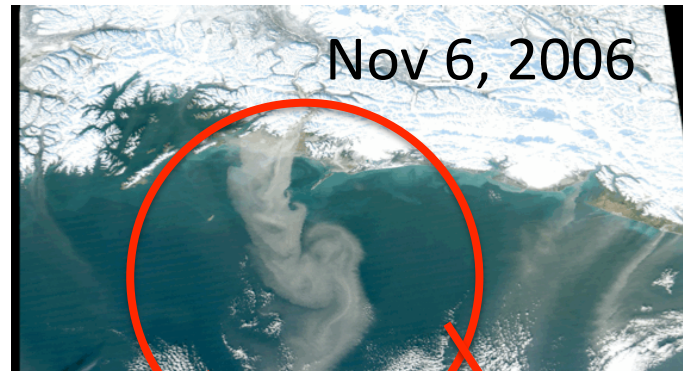
“Land_Sea_Quality_Flag”



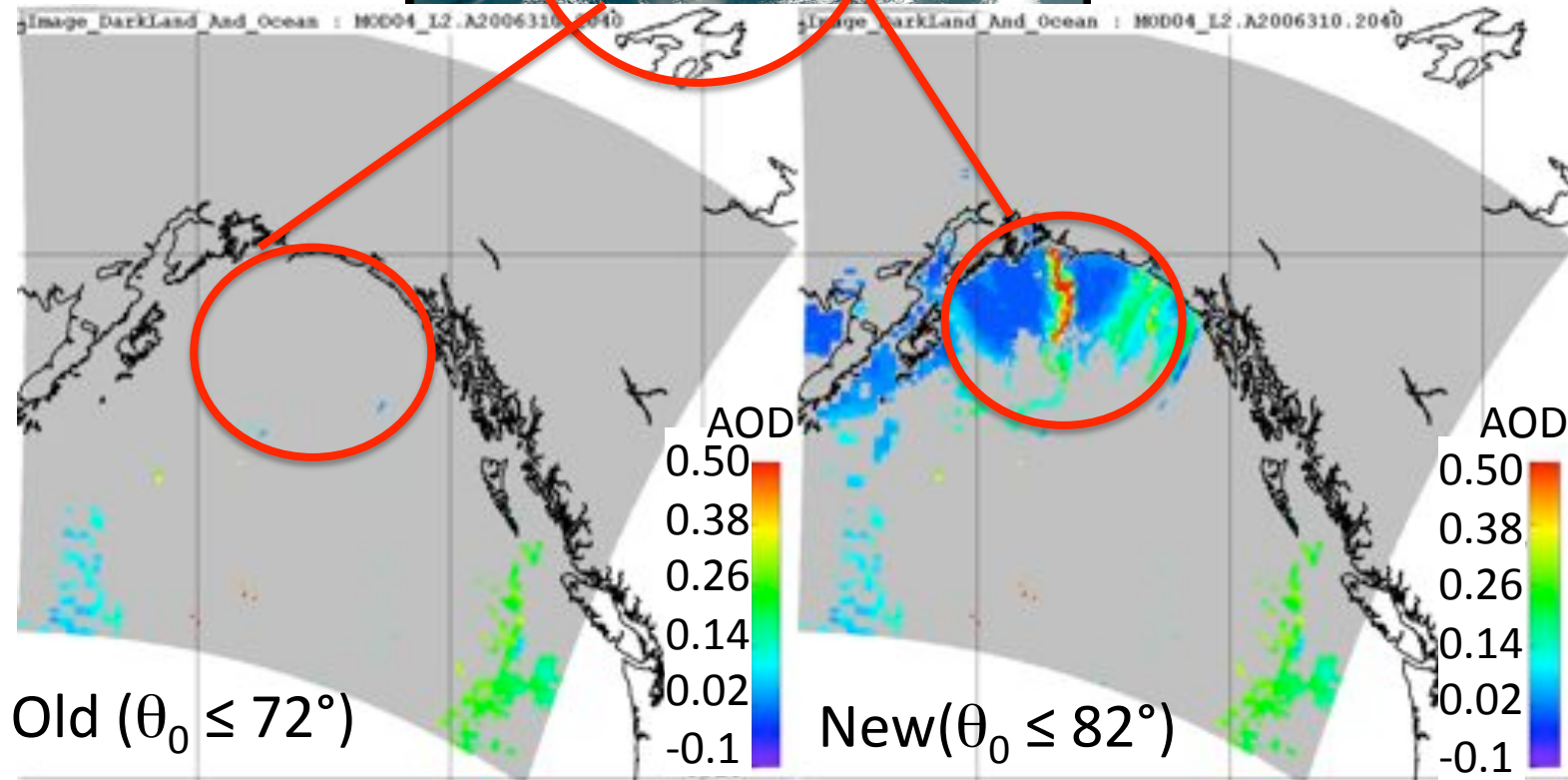
C006: “integer” SDS instead of bit-byte decoding

C006 will increase coverage in high latitudes

Dust event
Copper River
Gulf of Alaska

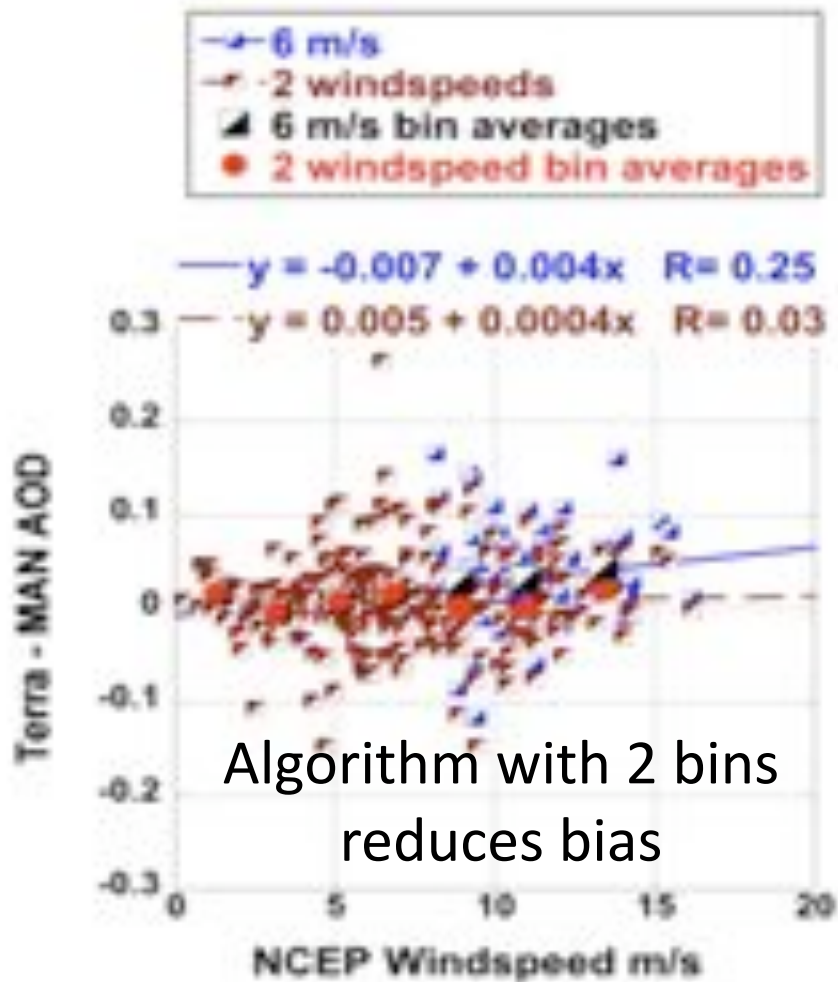


Relaxing threshold for
valid solar zenith angle
increases coverage and
“discovers” NEW DUST
SOURCE!



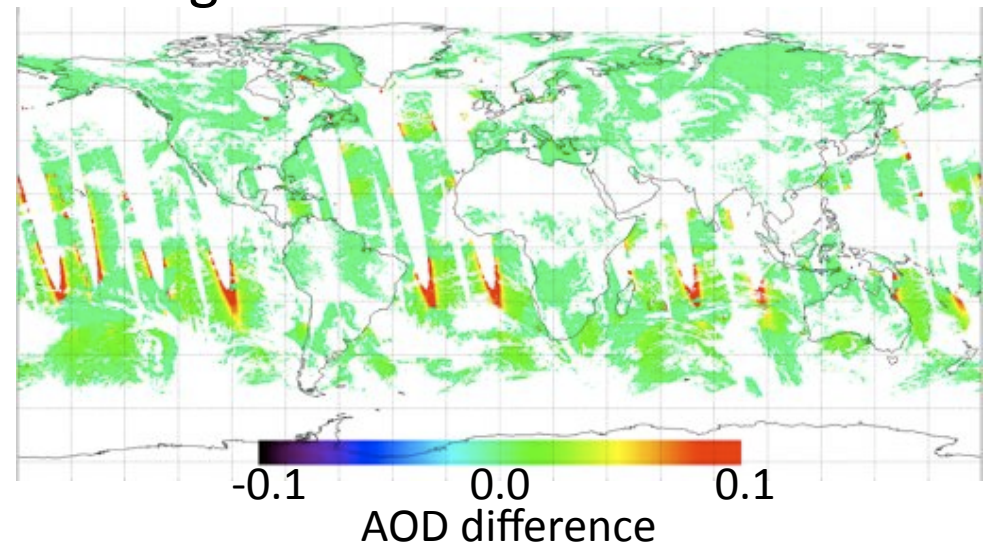
Crusius et al., GRL, 2011

C006 will be more accurate near ocean glint



- C005 bias related to windspeed
- C006 calculates ocean surface as function of windspeed.
- Biggest change near glint edges

Algorithm test: C006 – C005



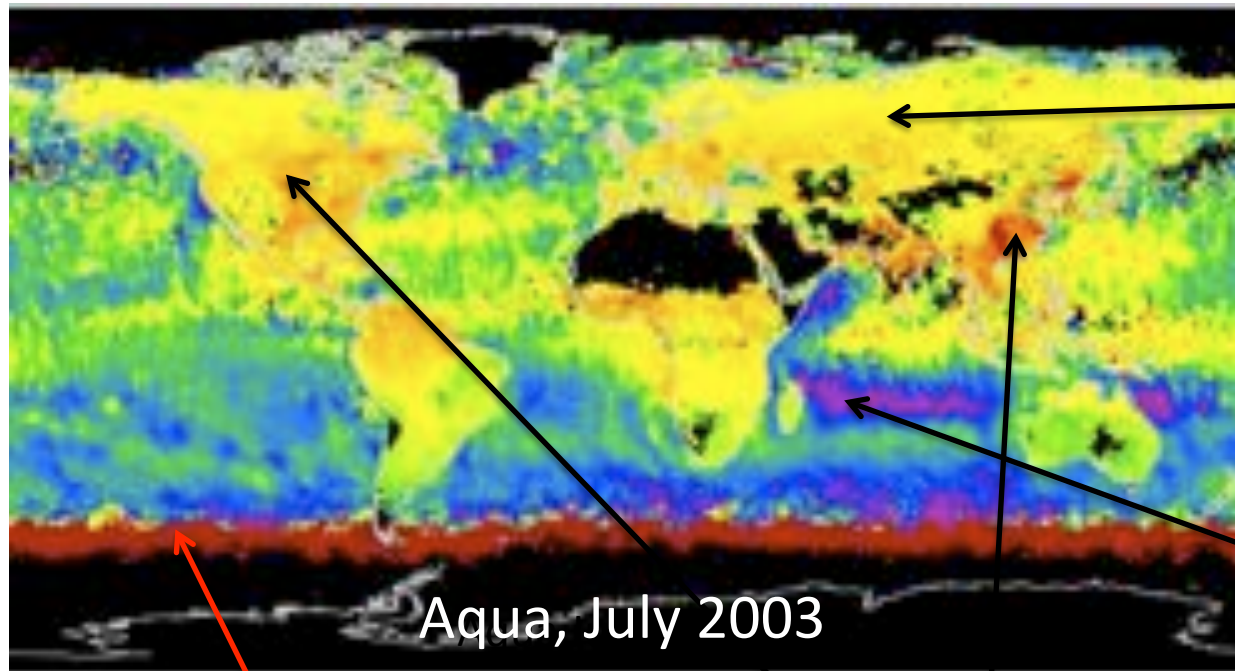
"MAN vs MODIS": Kleidman et al., TGRS, 2011

Changes for C006 product

- Major changes to Level 2 algorithm
 - Over land, aerosol model map is updated (new boundaries).
 - Over ocean, sediment mask logic is updated.
 - LUT consistency (adjustments in wavelengths, Rayleigh optical depth).
 - QA consistency: Make sure QA is assigned correctly
- Other changes to Level 2 algorithm and products
 - Useful “integer” values and diagnostics for QA, land/sea flag
 - Diagnostic SDS parameters: elevation, glint angle, wind speed
- “New” products (contained within standard 10 km file)
 - Combined Deep Blue/Dark Target retrieval
 - 500 m resolution “aerosol” cloud mask and “distance” to nearest cloud.
 - “dark target” reflectance computed in additional wavelengths, such as 0.412 μm (band #8), 0.443 μm (band #9), 3.75 μm (band #15)

C6 – C5: AOD differences

Expected changes due to Algorithm changes



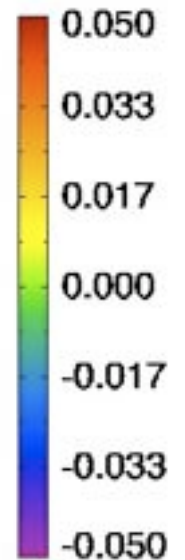
0.01 increase over land due to Rayleigh adjustments

0.02 to 0.05 decrease over ocean due to:

- Rayleigh adjustments
- Wind speed Adjustments
- QA definition changes

Extend coverage towards the polar regions

0.03 to 0.05 increase over land due to changes in aerosol model map borders
Central US and East Asia



TEST, TEST, and TEST some more!

C005 development paradigm was:

- The proposed C005 algorithm was tested on a small “test-bed” of C004 radiance inputs
- We did not consider that the C005 radiance inputs might also be different
- The C005 aerosol product was characterized *after* becoming operational, and we found:
 - Artificial differences between Terra and Aqua
 - Artificial trends in global AOD

TEST, TEST, and TEST some more!

C006 development paradigm is:

- We know that C006 Radiance product will be different than C005.
- Produce test versions of C006 radiances over many days, months, and seasons throughout both Terra and Aqua lifetimes.
- Test different combinations of C005 and C006 algorithms/radiances
- **Characterize C006 aerosol product *before* becoming operational**

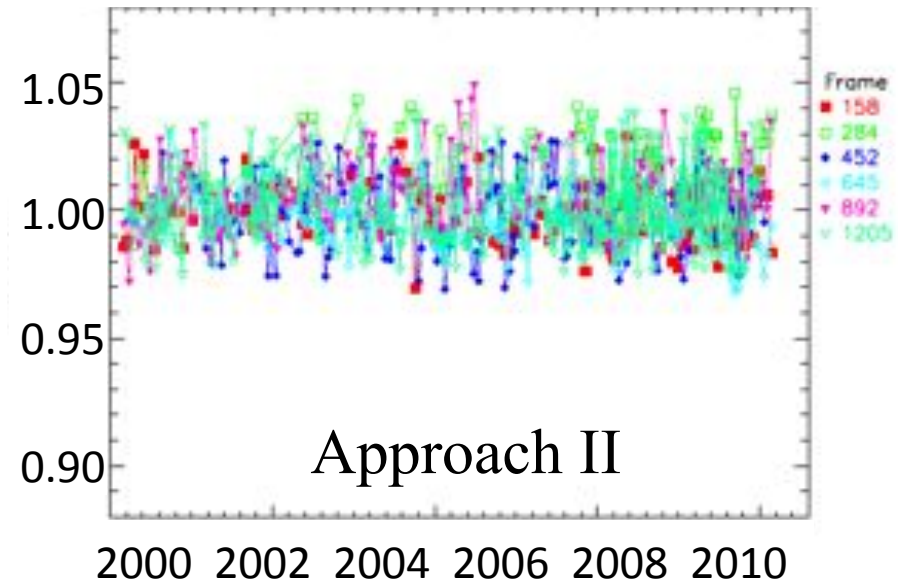
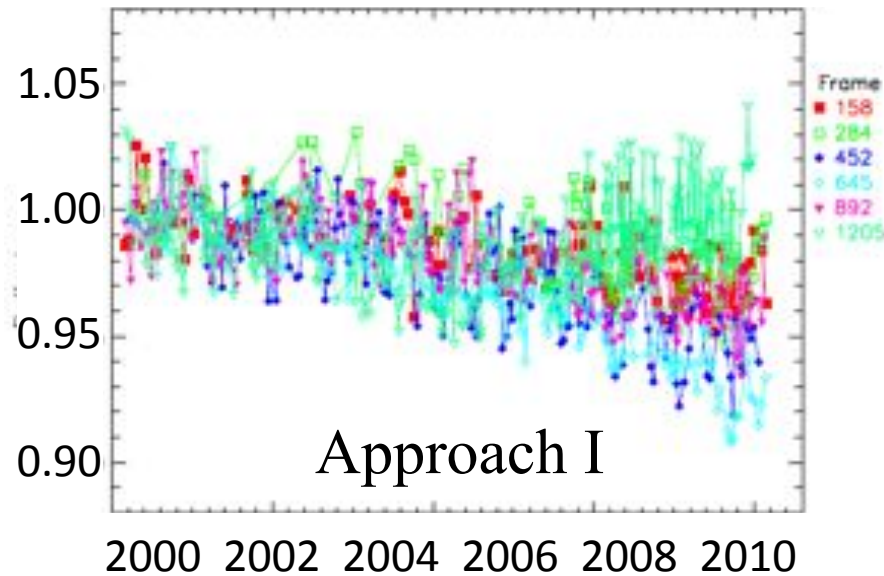


C6 Calibration: Testing Two approaches

Approach 1: Calibration coefficients are based on traditional methods of using moon and solar diffuser information only. Cannot account for unexpected changes in solar diffuser and mirrors.

Approach 2: Calibration coefficients modified by accounting for desert-based Earth View data trends. Terra only

Normalized Reflectance Terra Band # 3, Mirror Side #1 Normalized Reflectance

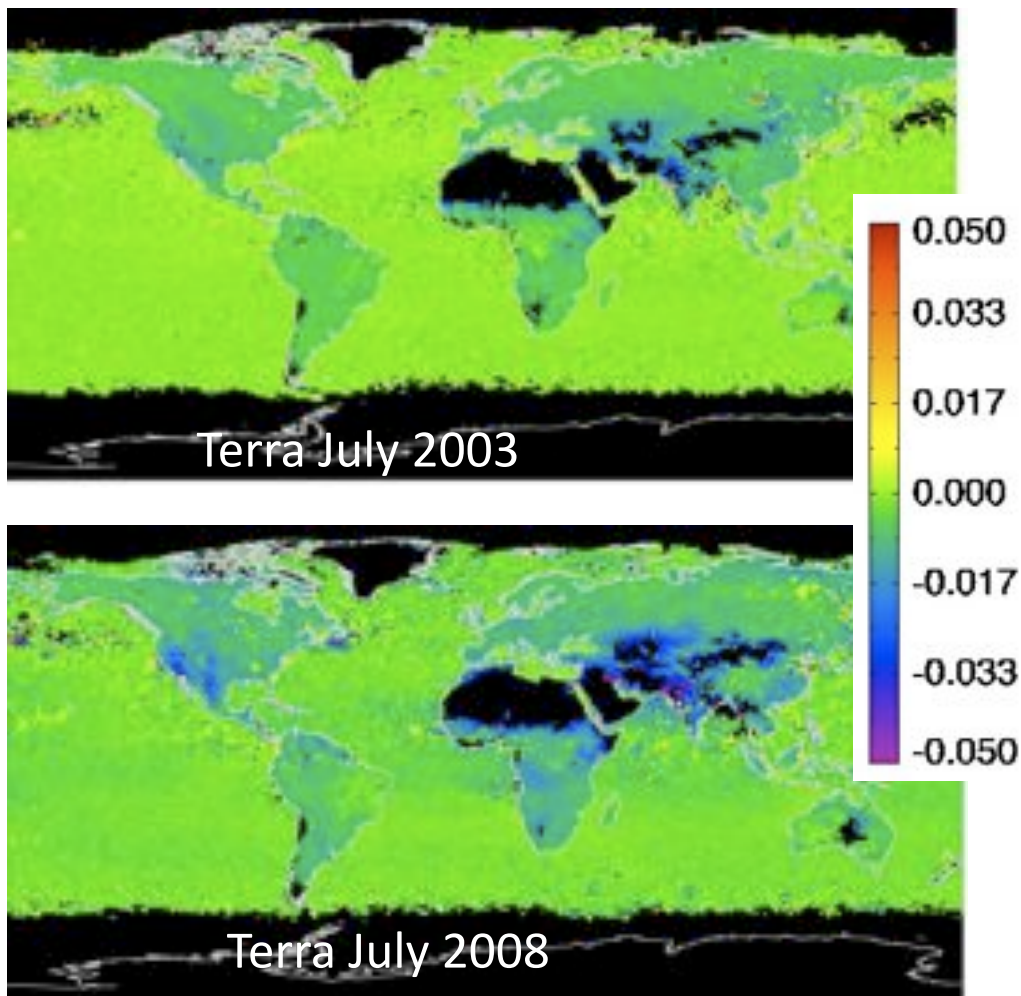


VERY PRELIMINARY ANALYSIS FOLLOWS!

J. Sun

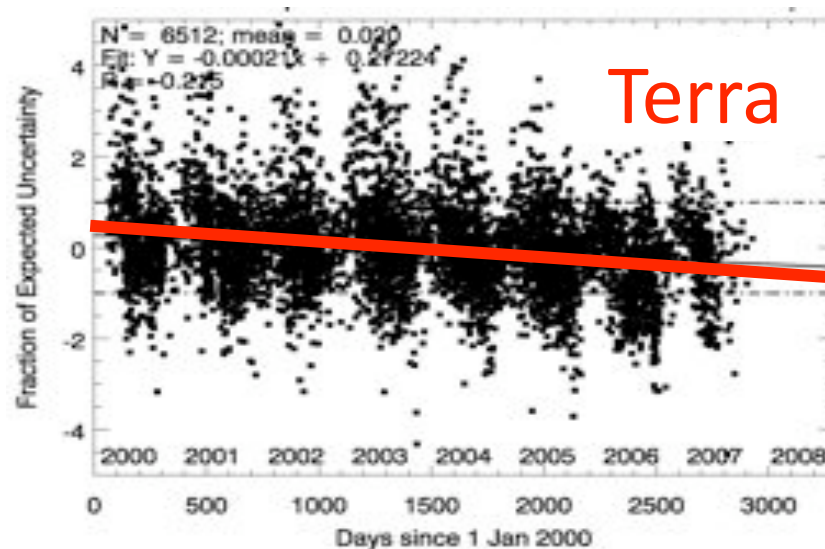
Differences in L1B only: C6#1 – C5

Aerosol Retrieval Algorithms are identical

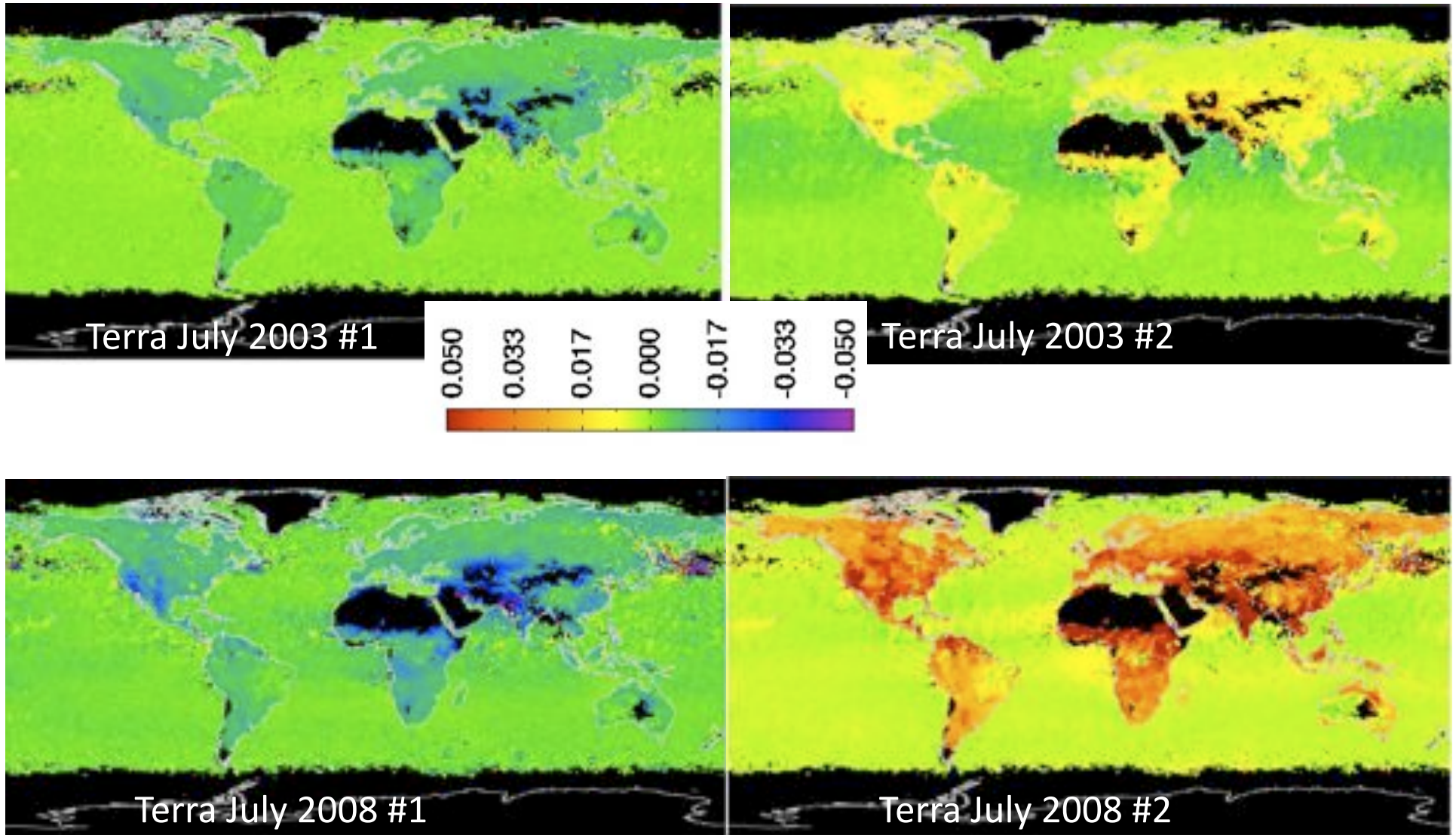


Changes to C6 L1B cause:

- up to 0.03 decrease in Terra AOD
- Intensifies over time
- Will intensify trend of differences with AERONET



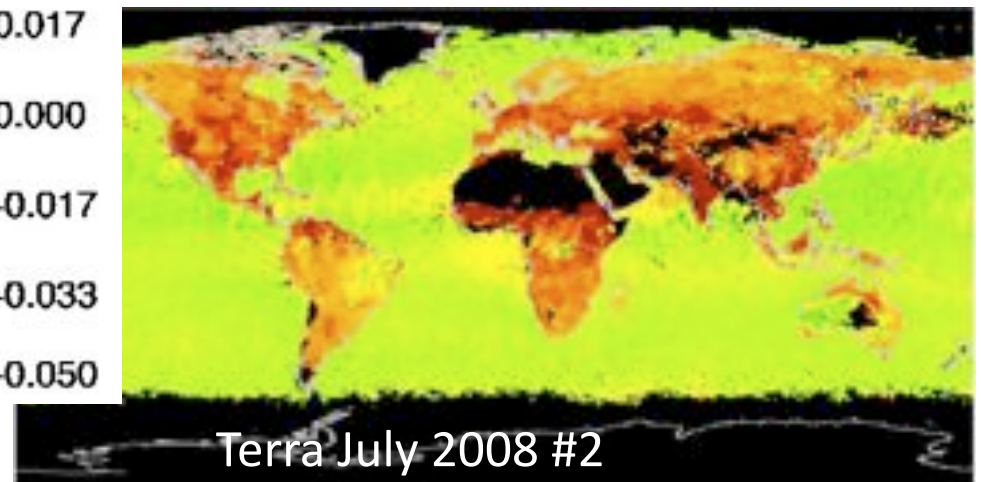
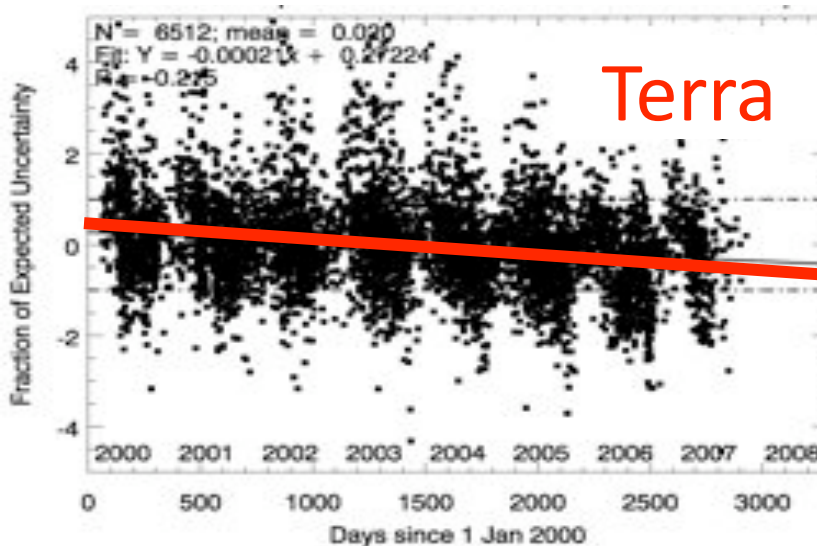
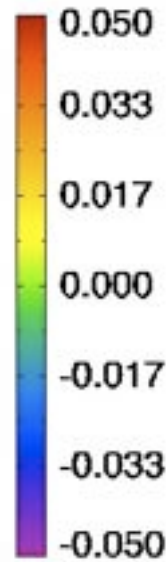
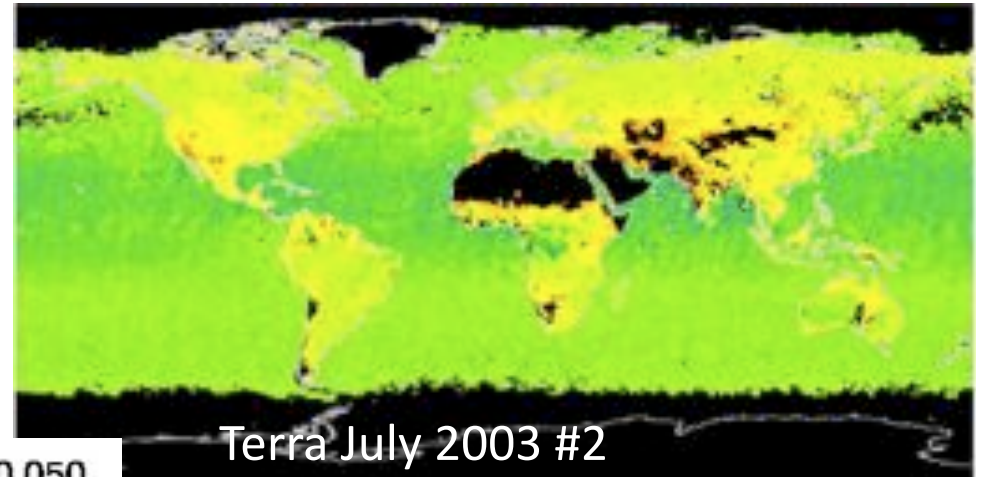
Now introduce Alternative calibration (Approach #2)



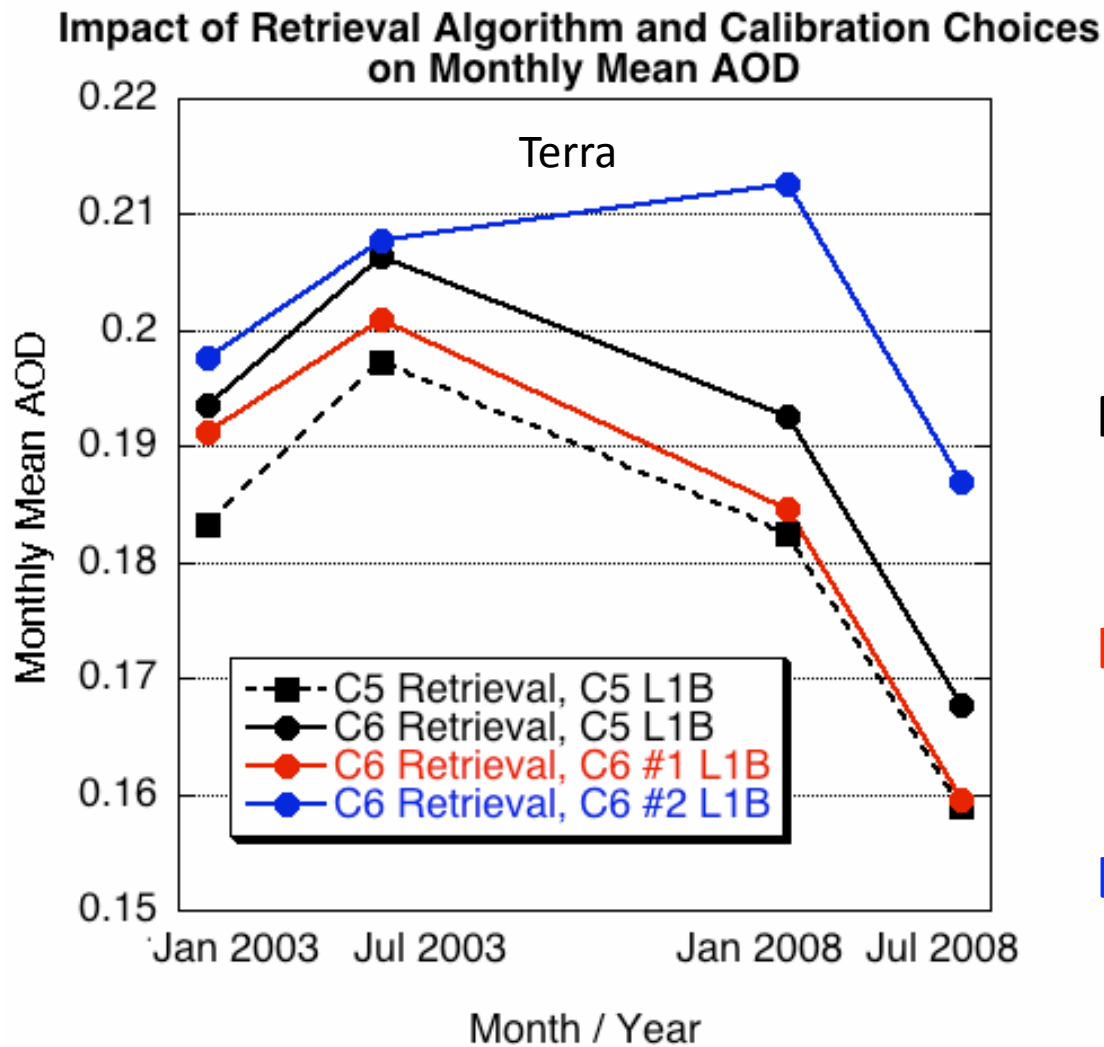
Differences in L1B only: C6#2 – C5

Alt calib changes to C6 L1B cause:

- up to 0.05 **increase** in Terra AOD
- **Intensifies over time**
- Will **mitigate** trend of differences with AERONET
- Will need to investigate whether this overshoots ideal?



C6 Calibration: Approach #1 vs #2 (Land)



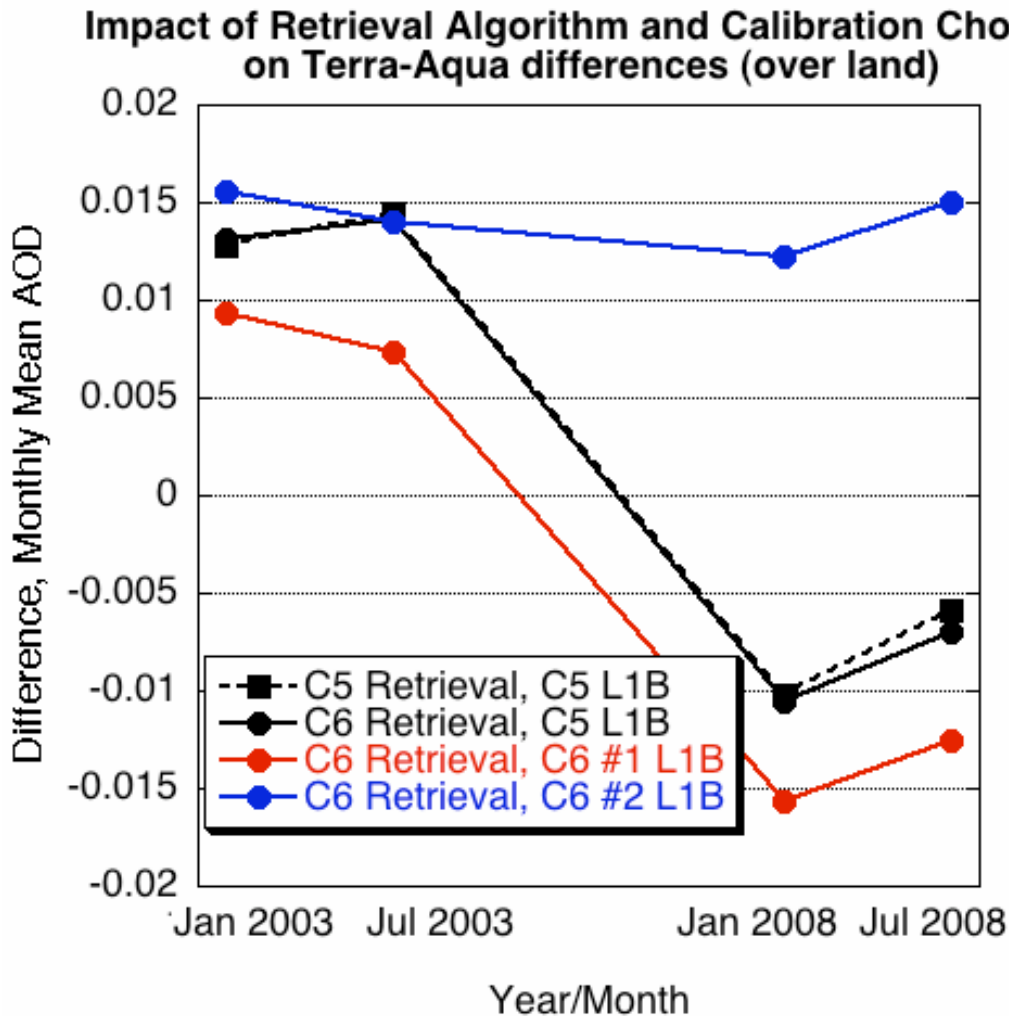
Impacts to monthly mean Terra

Retrieval: C5->C6
Increase of 0.01

L1B: C5 -> C6 #1
Decrease of 0.005

L1B: C6 #1 -> C6 #2
Increase of 0.01 in 2003
Increase of 0.03 in 2008

C6 Calibration: Approach #1 vs #2 (Land)



Impacts to Terra-Aqua difference

Retrieval: C5->C6

Same trend, same offset

L1B: C5 -> C6 #1

Same trend, reduced offset

L1B: C6 #1 -> C6 #2

Trend removed

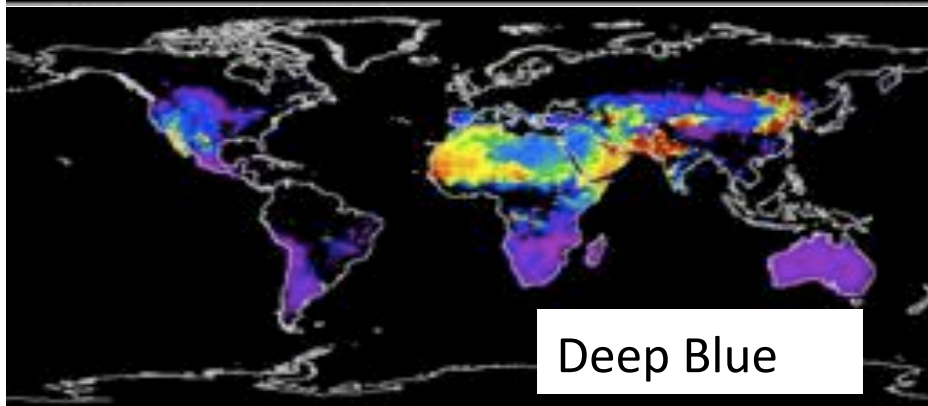
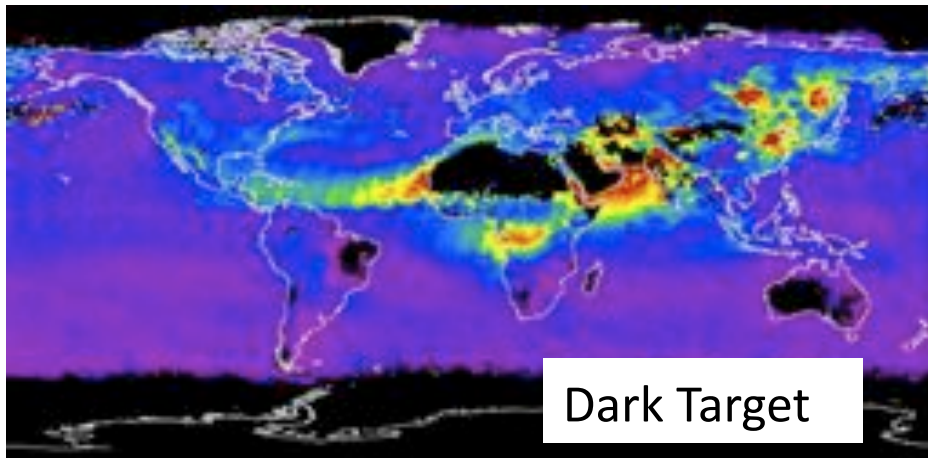
Constant offset of 0.015

Summary of calibration studies

- C5 Terra AOD trend over land consistent with recently found trends in Band #3
- If standard calibration (e.g. Approach #1) is used for C6 calibration, then trend will remain for C6.
- If alternative calibration (e.g. Approach #2) is used for C6 calibration, then Terra trend might be removed.
- Even with Approach #2, Terra seems to be biased high compared to Aqua
- Size parameters are sensitive to multi-band calibration changes, and may sometimes be a compensating response.
- More testing is necessary.

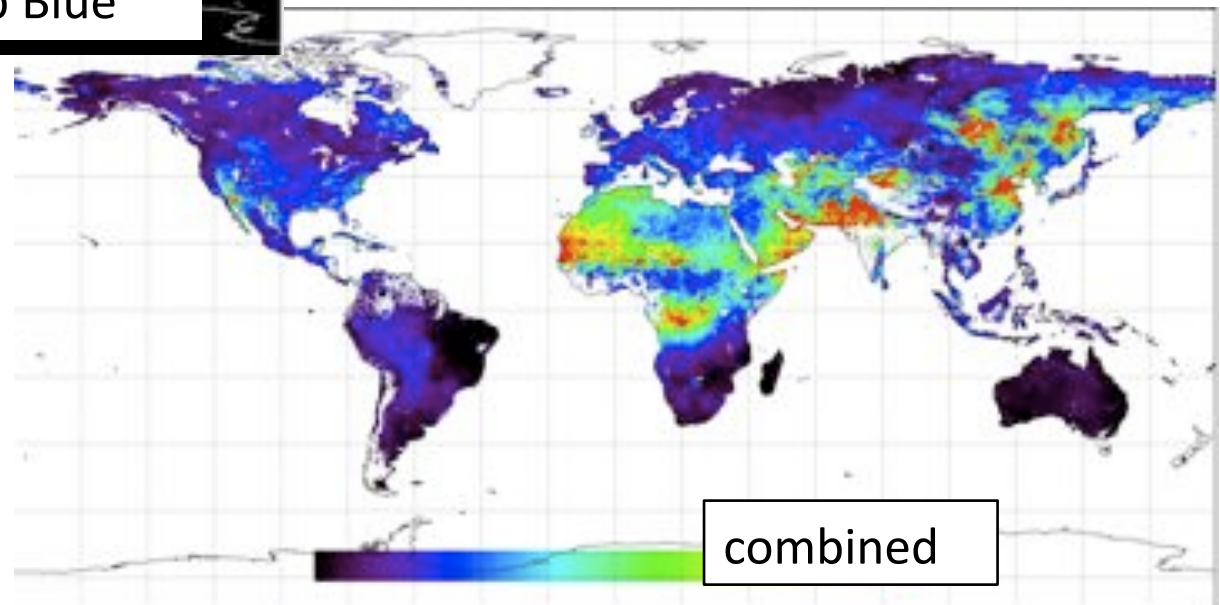
Dark Target/Deep Blue combined product

Terra July 2003 New combined DB/DT AOD

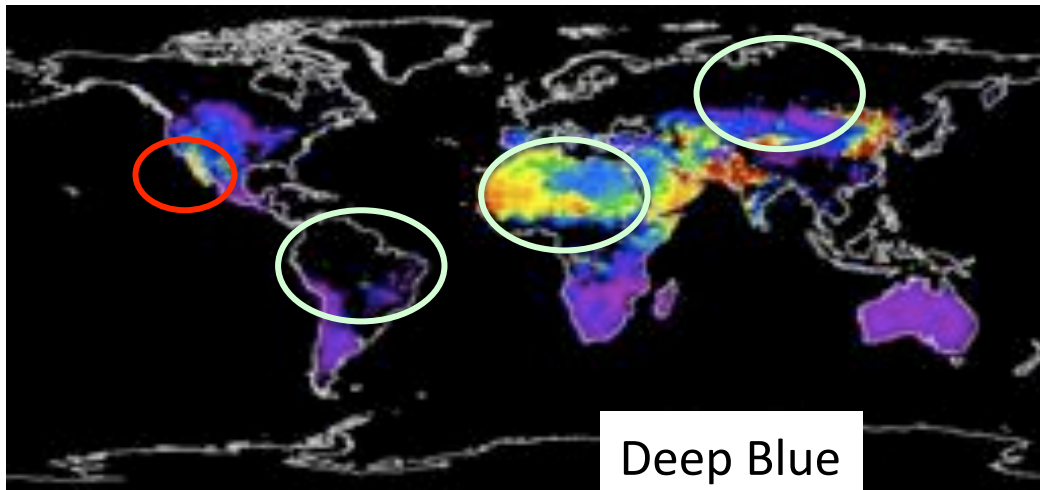
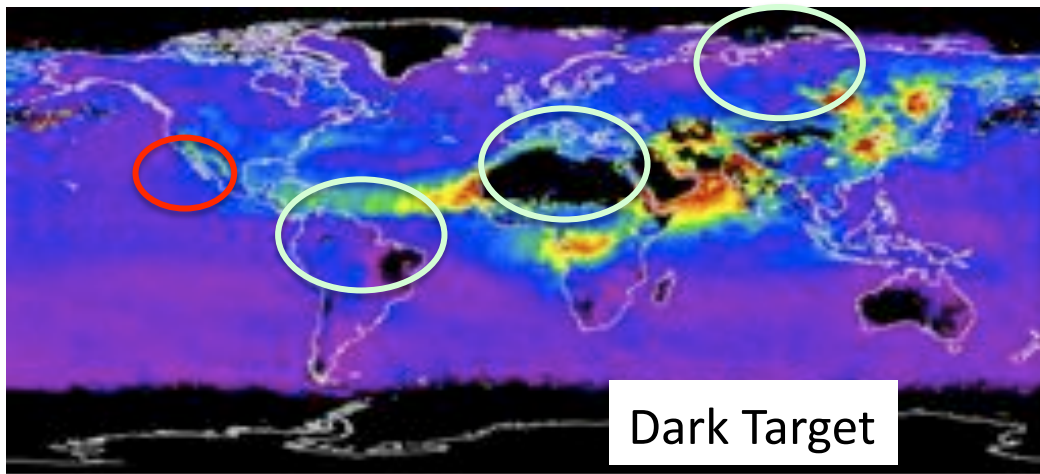


Combining “Algorithm”

- If DB is good quality AND DT is not, THEN DB
- If DT is good quality AND DB is not, THEN DT
- If both good quality, THEN $0.5*DB + 0.5*DT$

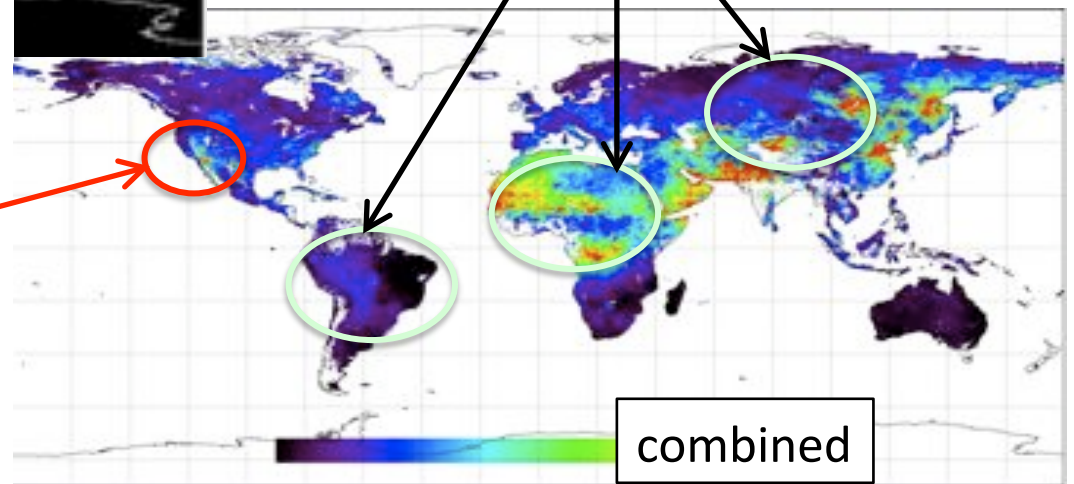


Terra July 2003
New combined DB/DT AOD



Some "suspicious"
extremes are mitigated

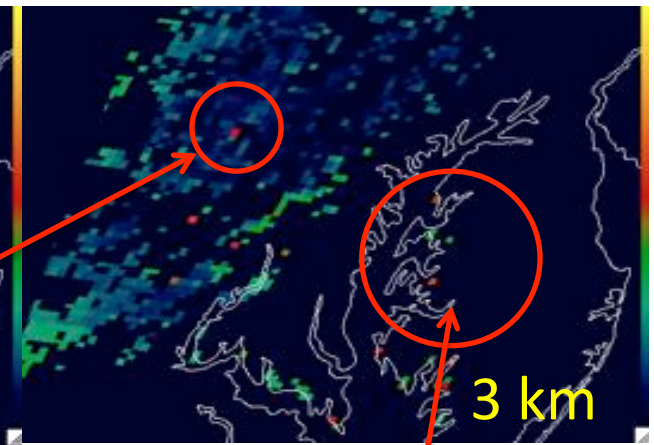
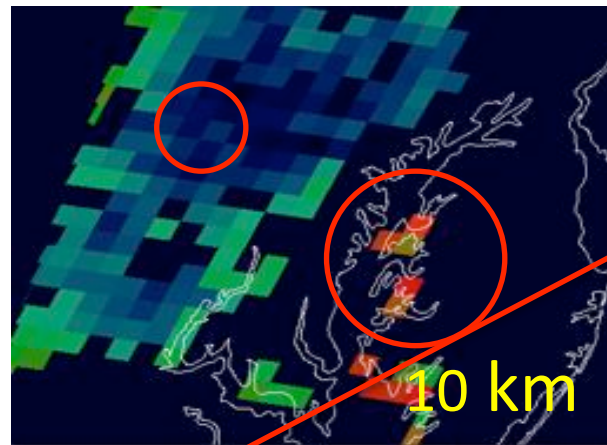
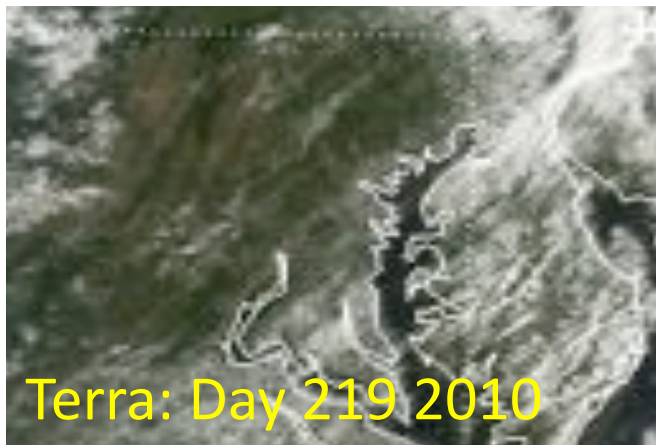
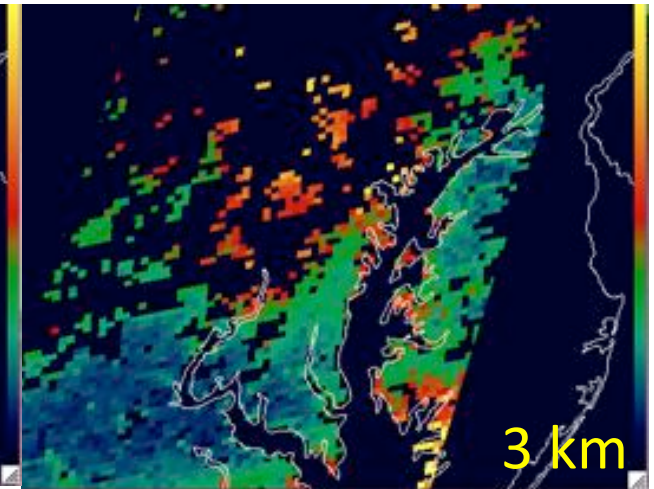
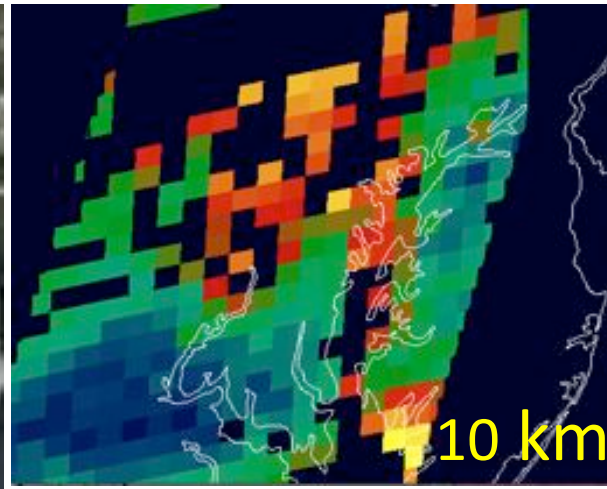
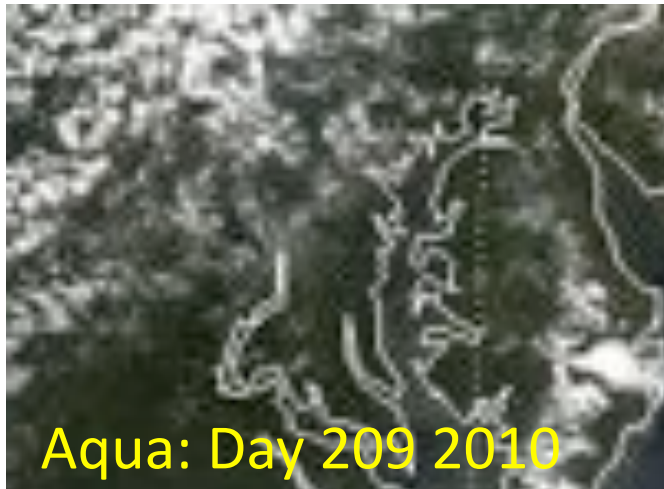
Coverage over Deserts,
Rain forests and
northern forests!



New applications:
MODIS 3 km product (operational for C006)

S. Mattoo, M. Martins, L. Remer, B. Holben, et al

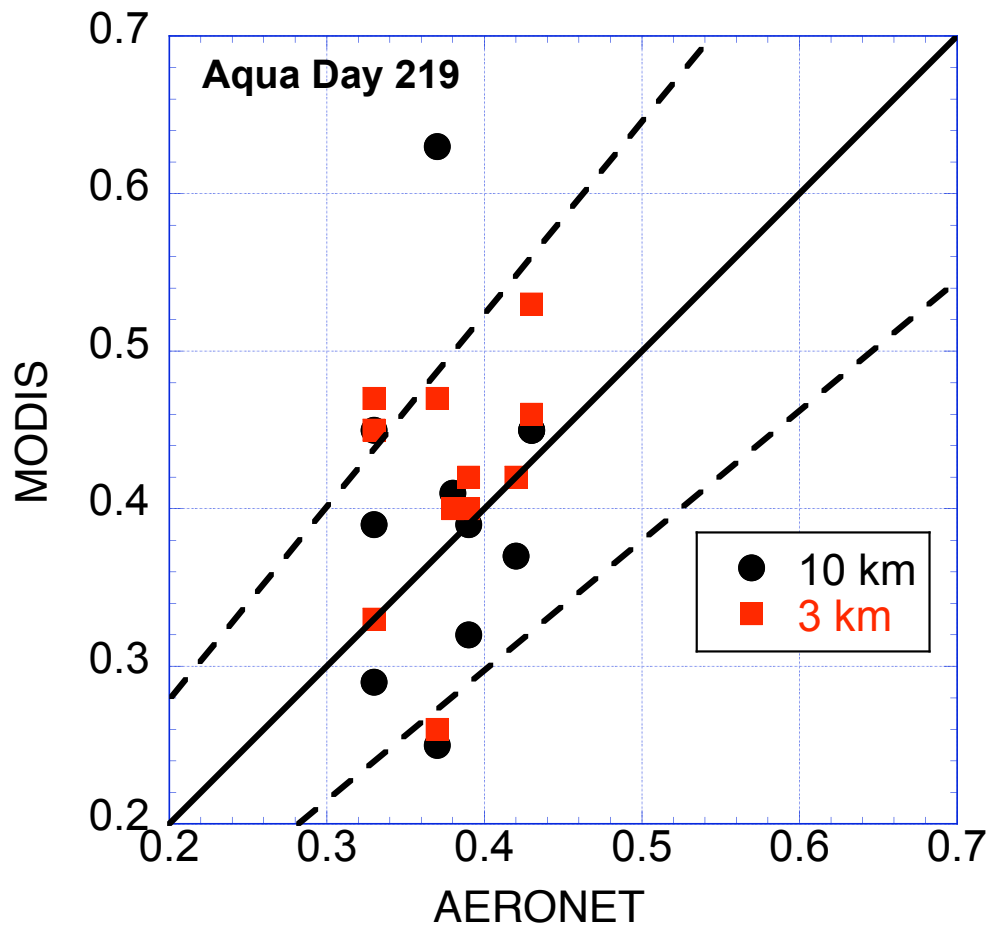
MODIS 3 km product over suburban (MD) landscape (DRAGON, summer 2010)



- 3 km mirrors 10 km product (pattern and magnitude)
- 3 km introduces **noise**, but also can reduce spatial impact of **outliers**

MODIS 3 km product over Maryland, Summer 2010

Compare with AERONET (DRAGON)



11 AERONET stations from Baltimore to College Park; Olney to Bowie.

station	AERO NET	MODIS 3 km	MODIS 10km
BLTIM	0.29	0.28	0.17
LAUMD	0.26	0.24	0.20
OLNES	0.23	0.22	0.09
RCKMD	0.25	0.33	0.19

- Overall, 3 km mirrors 10 km “validation”.
- 3 km validation sometimes improves with higher resolution matching

Before we “sign” off on Collection 6

1. Evaluate changes made to “Level 3” aerosol protocol and products
2. Consult with Christina about the DB/DT Combination product
3. Evaluate 3 km product output in MODAPS tests
4. See if most recent L1B/algorithm combo draws us nearer to or further from AERONET, both standard and alternative calibration
5. Once L1B calibration is FROZEN, make one more iteration.

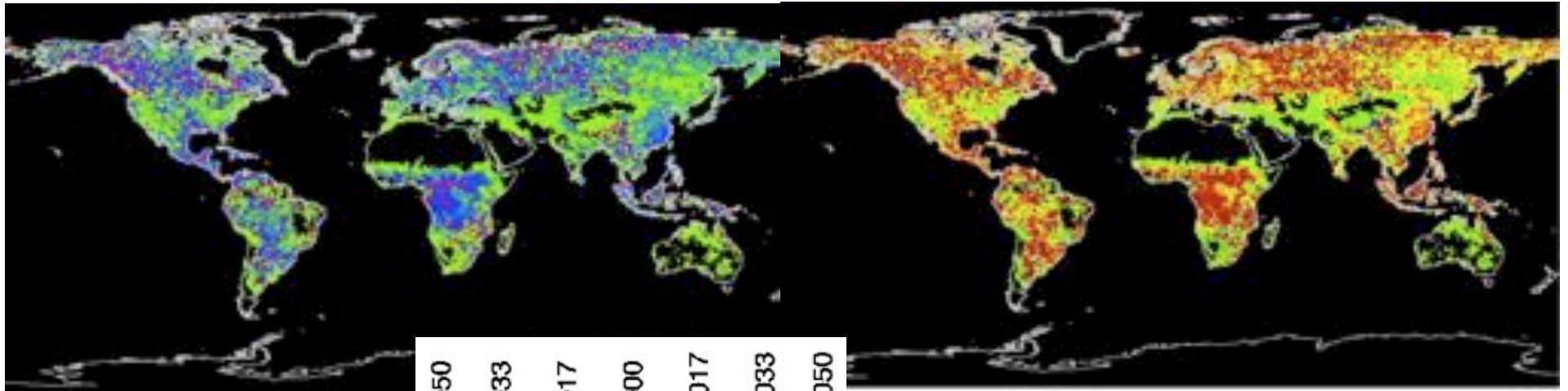
- Collection 5 dark target AOD has been validated over land and ocean. QA flags are very important!
- Over land, Terra and Aqua have contradictory AOD trends.
- C005 Trend inconsistencies are “consistent” with recently found trends in band #3 reflectance.
- We are making improvements to aerosol retrieval algorithm and adding products for C006.
- To combat the Terra “trending” we are testing different approaches for creating C006 L1B data.
 - Approach #1 (no Earth View inputs): Terra’s AOD Trend remains
 - Approach #2 (includes Earth View): Terra’s AOD Trend is removed, Terra-Aqua offset remains.
- C006 will include a Combined Deep Blue/Dark Target product
- C006 will have a separately produced 3km product (in addition to 10km)
- We have much testing before C006 becomes “operational”
- Impacts to aerosol size parameters are being evaluated (backup slides)

Thank you

Fine fractions C6-C5: L1B differences only

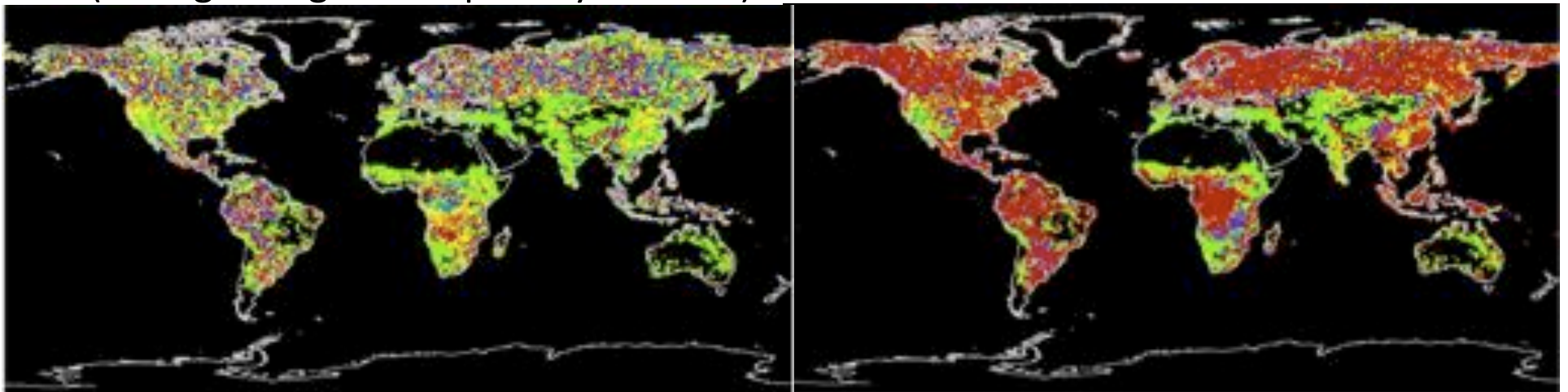
Terra July 2003
(movement towards more dust)

Terra July 2003 **Alternative calib**
(movement towards less dust)



Terra July 2008
(strong changes but spatially random)

Terra July 2008 **Alternative calib**
(intensifies)

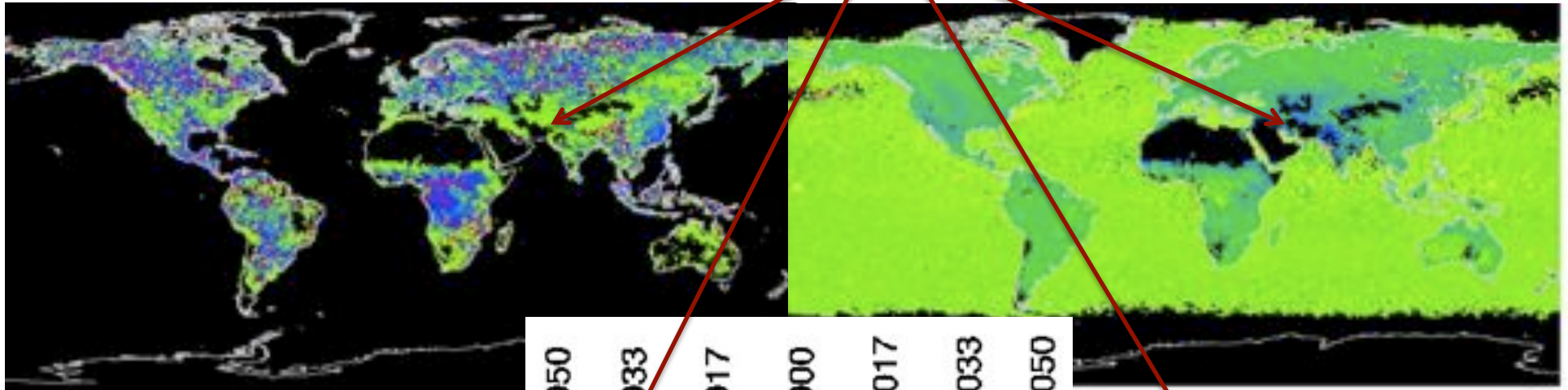


C6-C5: L1B differences only

Areas with most AOD change,
have least fine fraction change
Algorithm is compensating

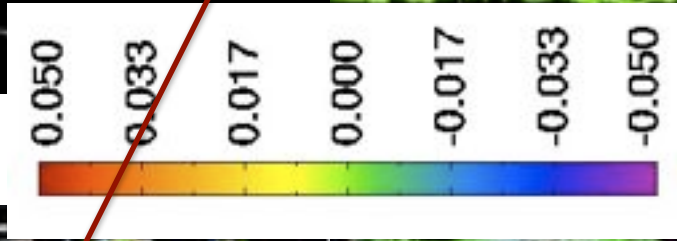
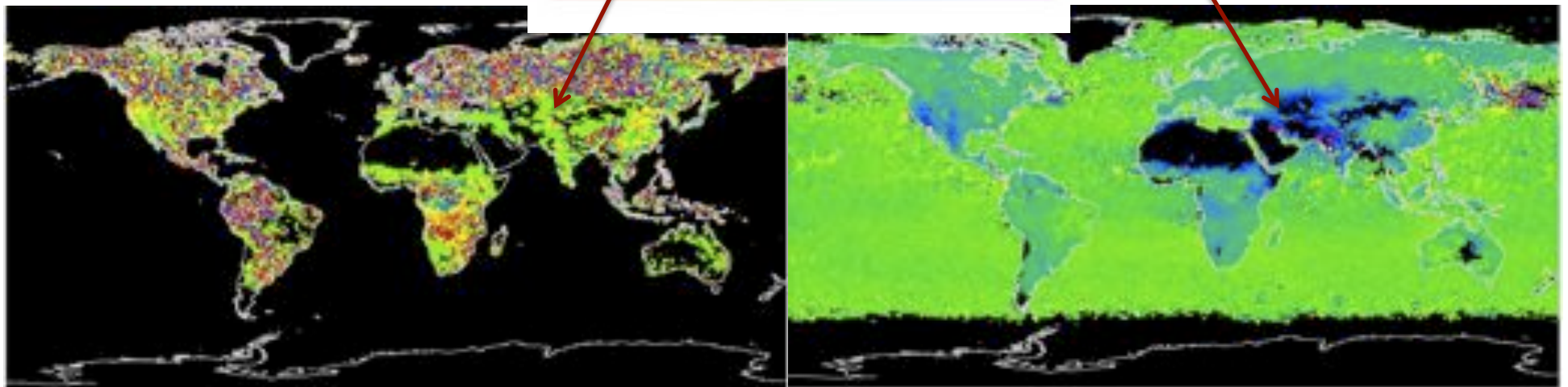
Terra July 2003 fine fraction

Terra July 2003 AOD



Terra July 2008 fine fraction

Terra July 2008 AOD

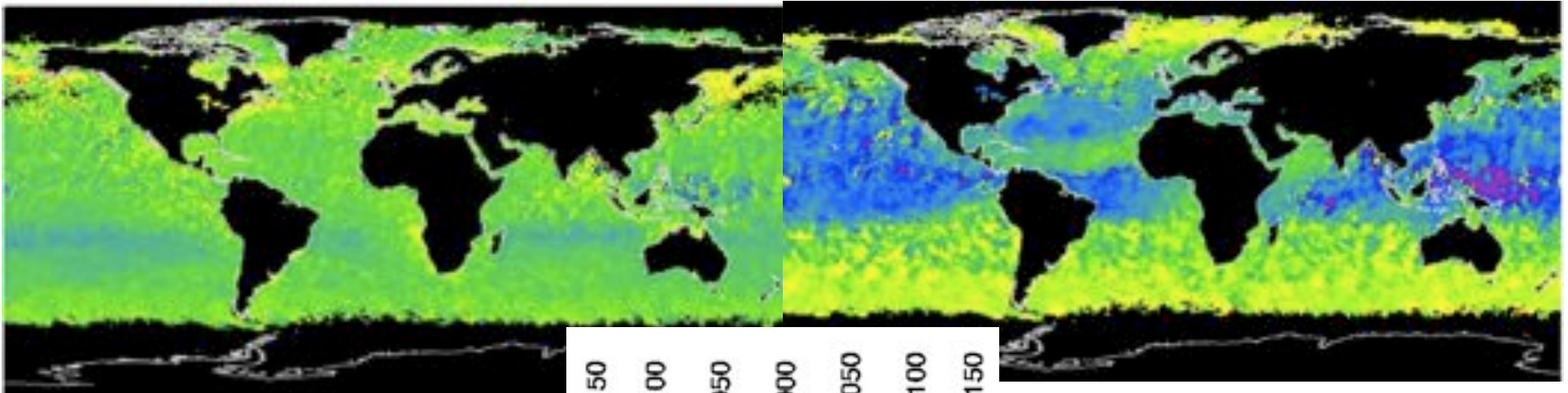


C6 – C5 Angstrom exponent: **L1B changes only**

Calibration changes show up over ocean
only in size parameters, and these
are very sensitive to calibration

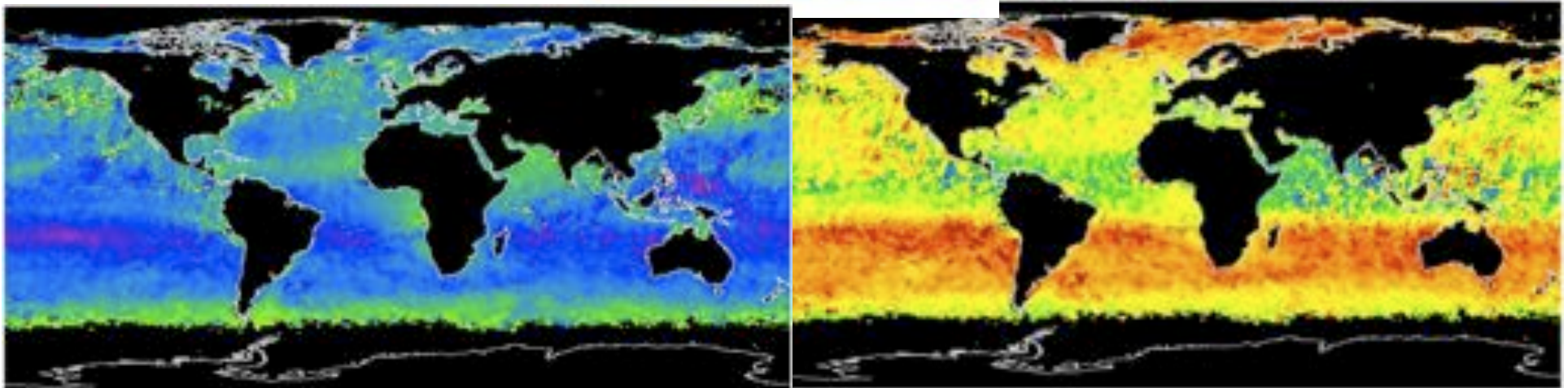
Terra July 2003

Terra July 2003 **Alternative calib**



Terra July 2008

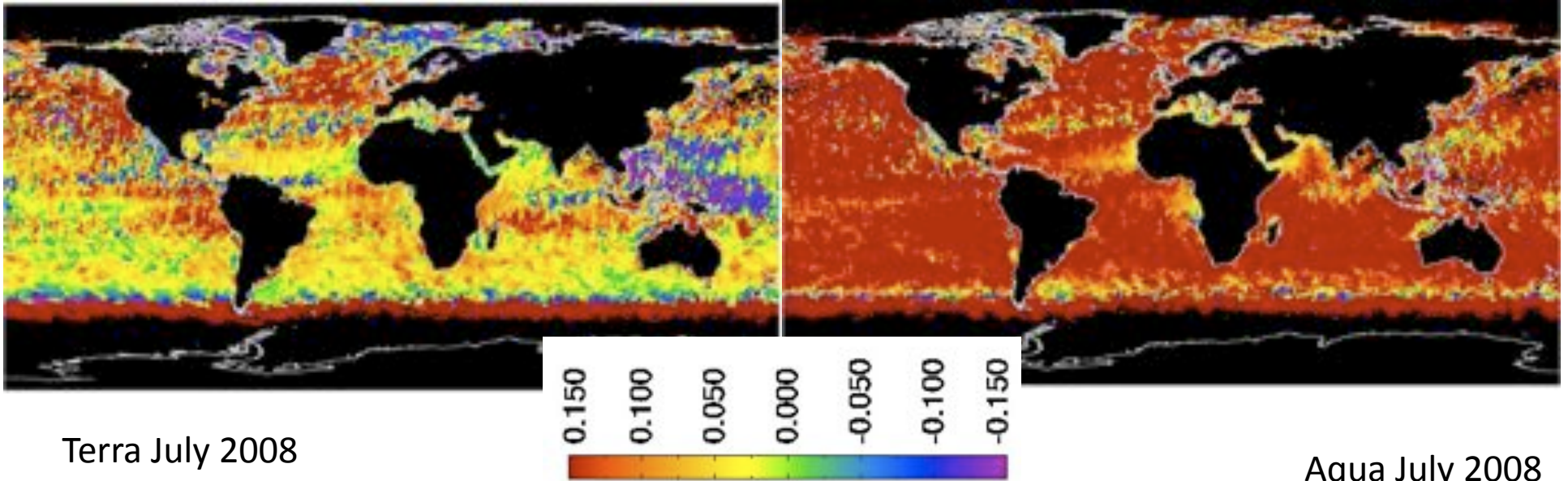
Terra July 2008 **Alternative calib**



Angstrom Exponent 1 Difference
Aqua size parameters affected more than Terra

Terra July 2003

Aqua July 2003



Terra July 2008

Aqua July 2008

