Synergy of Atmospheric Aerosol Information: The importance of "getting it right".
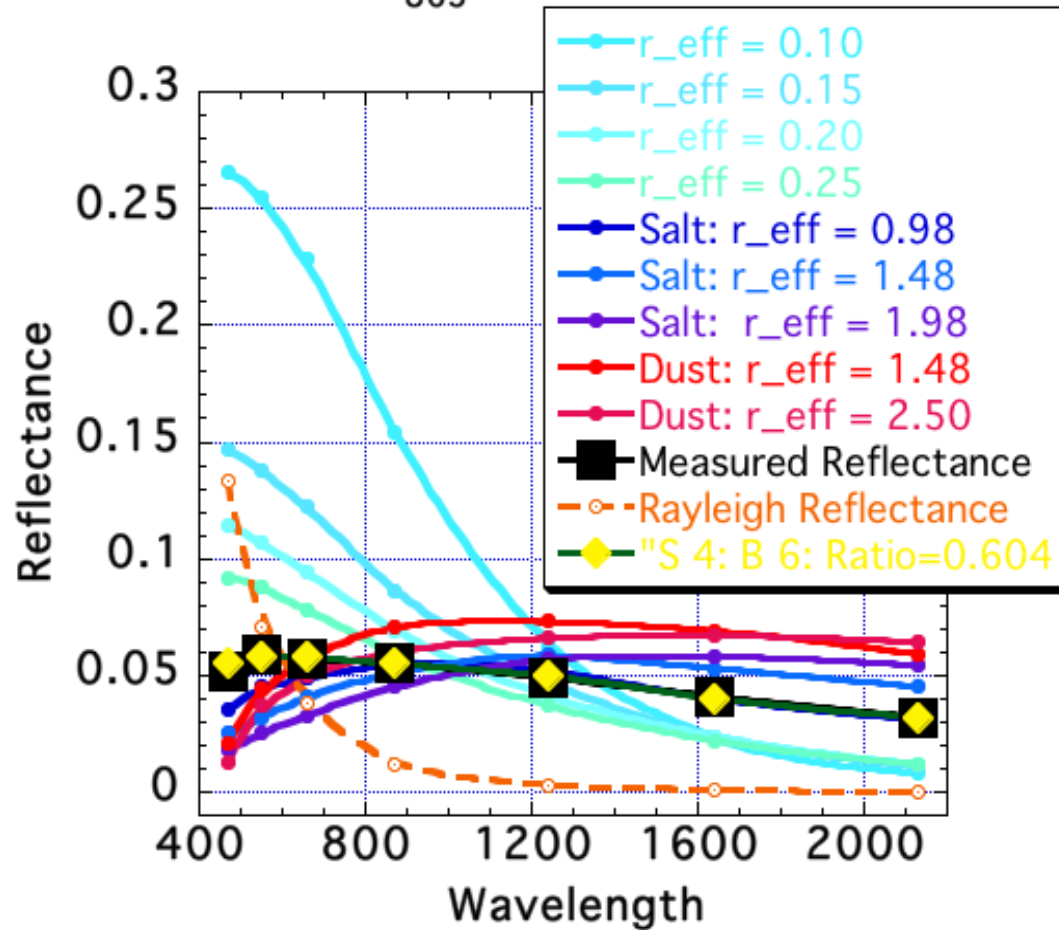
Robert C. Levy (SSAI @ 613.2)

Contributors: S. Mattoo, L. Remer, R. Kleidman, R. Kahn, S. Gassó, G. Leptoukh…

Climate and Radiation Research Code 613.2

MODIS Aerosol Algorithm

Modeled and Observed Reflectance from MODIS
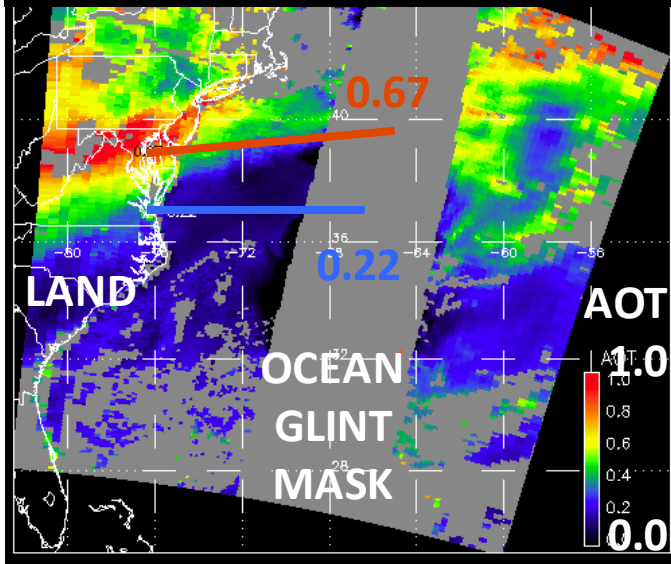July 21, 14:50: $\tau_{865} = 0.48$

Legend:
- r_eff = 0.10
- r_eff = 0.15
- r_eff = 0.20
- r_eff = 0.25
- Salt: r_eff = 0.98
- Salt: r_eff = 1.48
- Salt: r_eff = 1.98
- Dust: r_eff = 1.48
- Dust: r_eff = 2.50
- Measured Reflectance
- Rayleigh Reflectance
- "S 4: B 6: Ratio=0.604

Aerosol Retrieval Bands

Band	Bandwidth	Resolution
1	620-670 nm	250 m
2	841-876 nm	250 m
3	459-479 nm	500 m
4	545-565 nm	500 m
5	1230-1250 nm	500 m
6	1628-1652 nm	500 m
7	2105-2155 nm	500 m

- Ocean: Inversion of 6λ excludes Band 3. balanced on Band 2
- Land: Inversion of 3λ includes Band 3
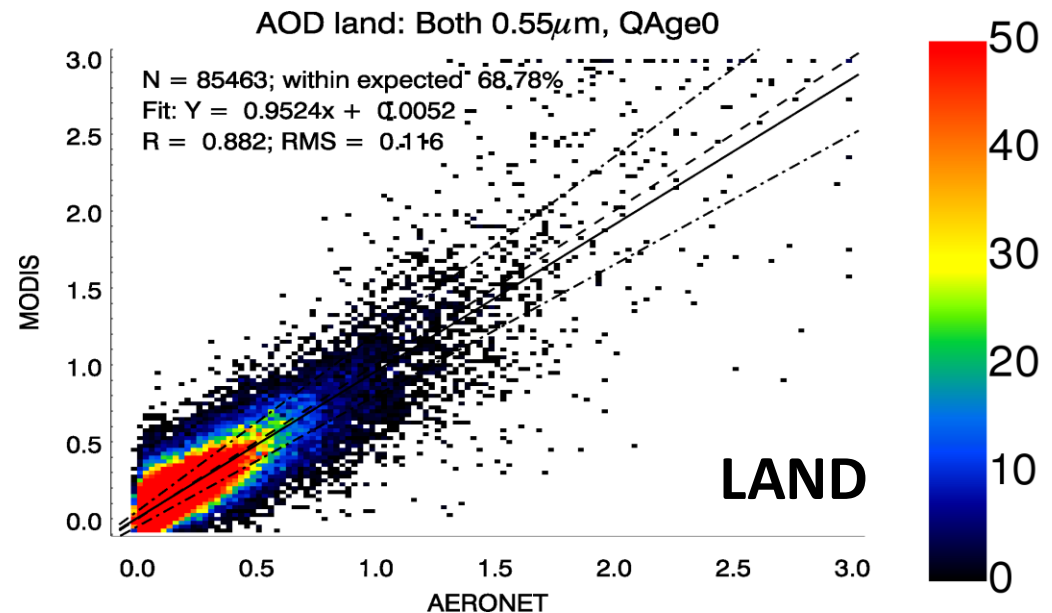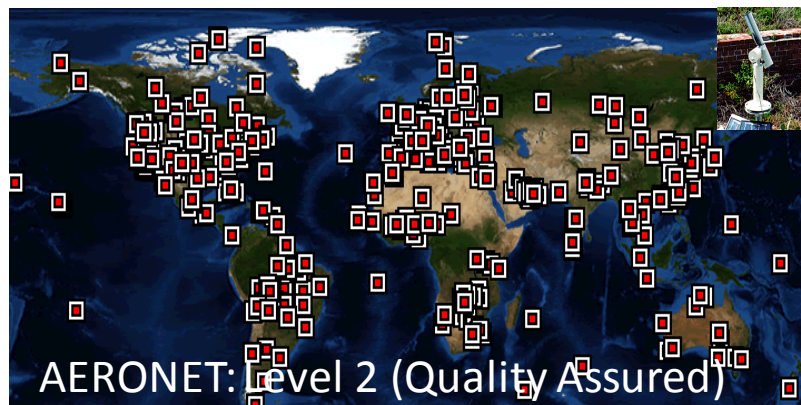
Evaluation of the C005 Aerosol Product

Validation: quantifying the expected error

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

0.67

0.22

LAND

OCEAN

GLINT

MASK

AOT
1.0

0.0

AERONET: Level 2 (Quality Assured)

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: $\pm(0.05\tau + 0.04)$

AOD land: Both 0.55μm, QAge0

N = 85463; within expected 68.78%
Fit: Y = 0.9524x + 0.0052
R = 0.882; RMS = 0.116

MODIS

AERONET

LAND
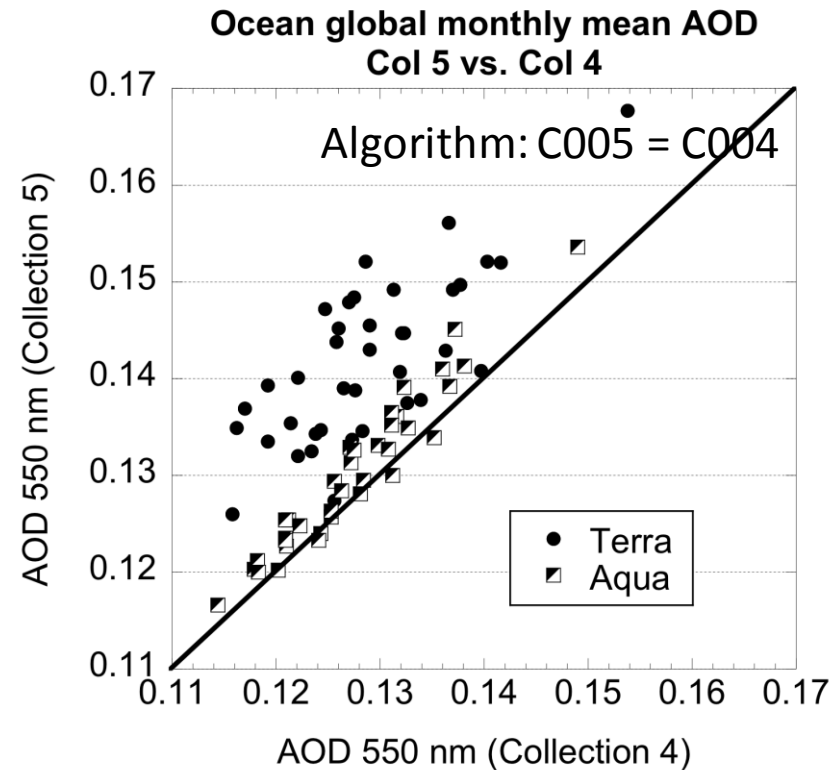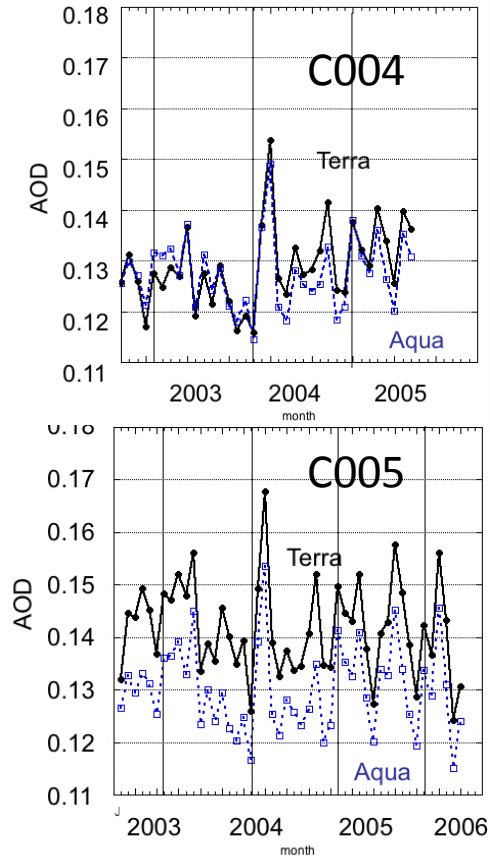
Levy et al., ACP 2010

C005 Validation Summary

- MODIS C005 dark-target AOD (Land and Ocean) is "validated",
    - 66% within defined error envelope, globally
    - Generally, more tightly constrained than C004

- In other words, no major surprises!

- Therefore, we analyzed C005 data to answer some basic questions about global aerosol…

Q1: What is global mean AOD?
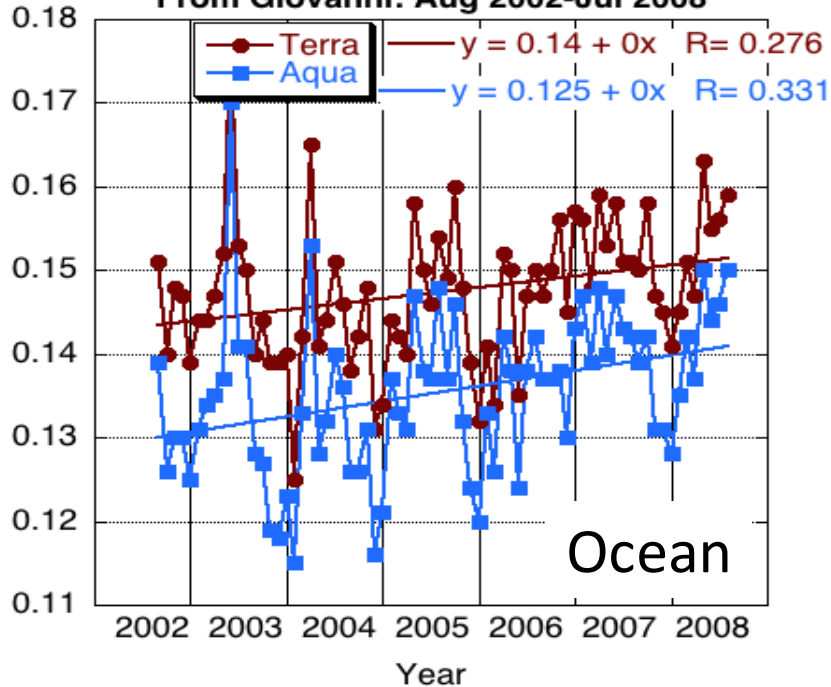
A1: It depends on the instrument and the Collection

- We expected C005 mean = C004 mean
- C005 Terra > C004 Terra and C005 Terra > C005 Aqua
- **_This is result of changing L1B observational input!_** *Remer et al., JGR 2009*
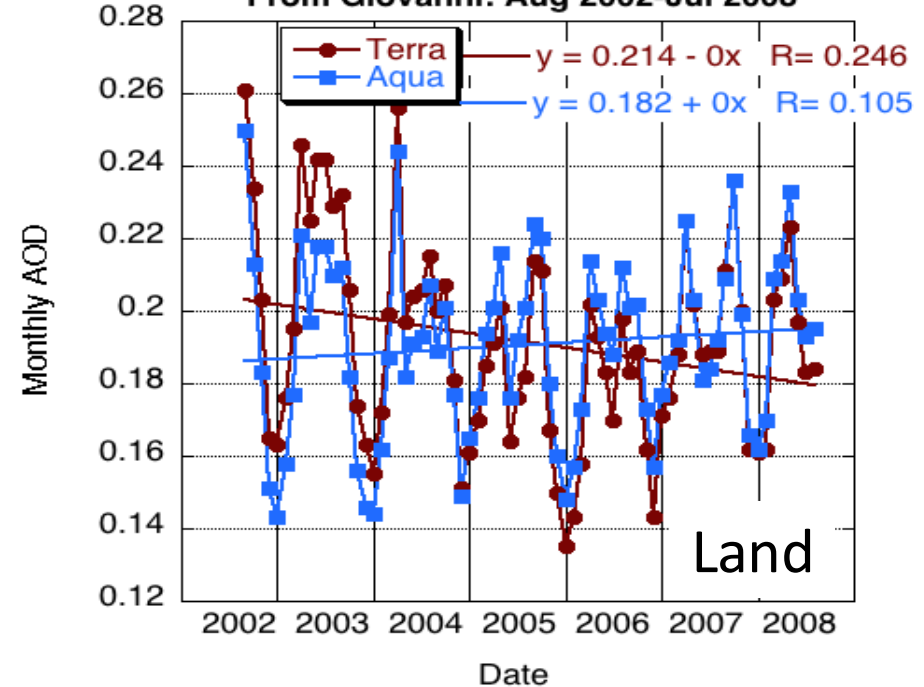
Q2: Is global aerosol increasing or decreasing?
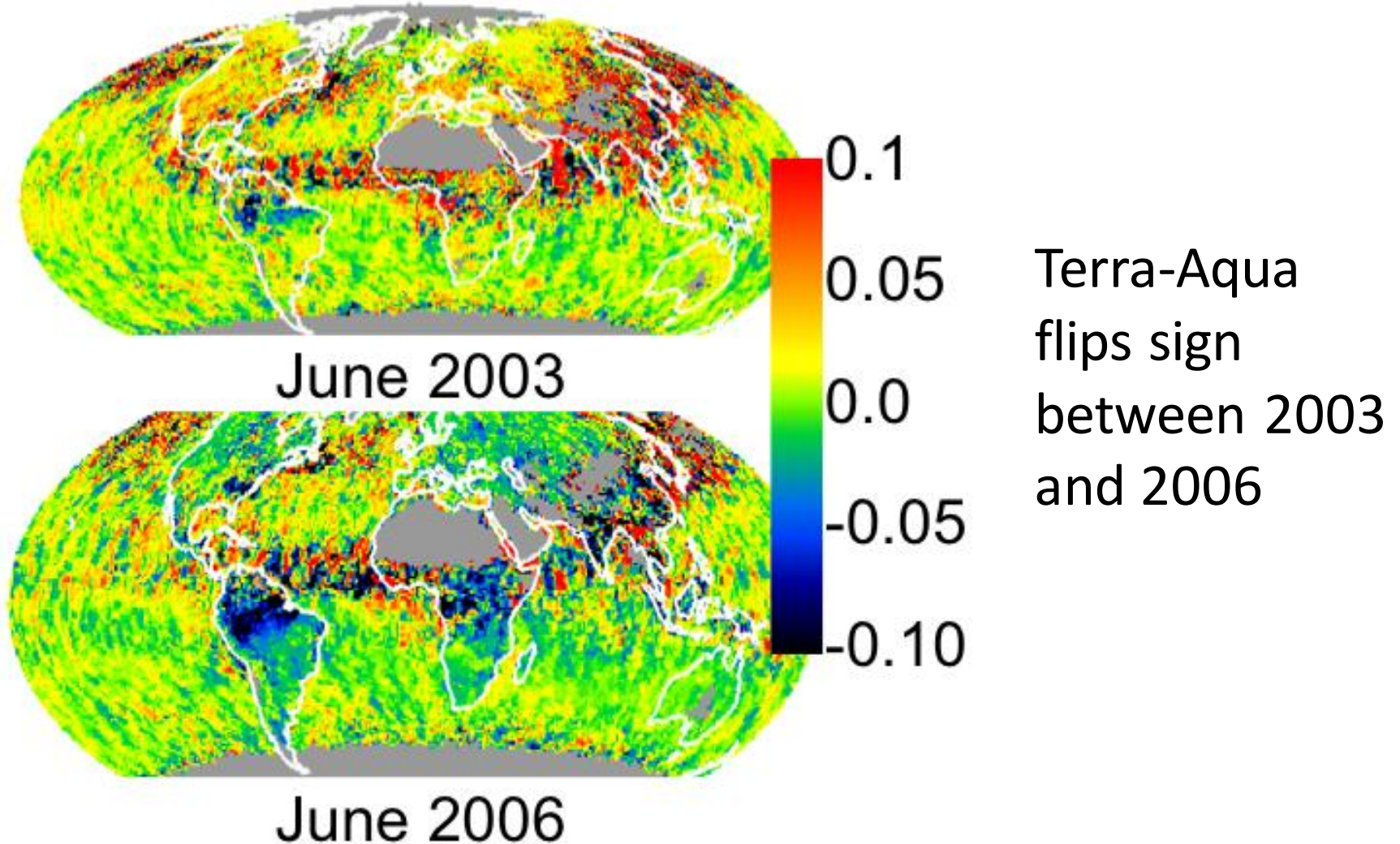
A2: A Definite Maybe

- 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
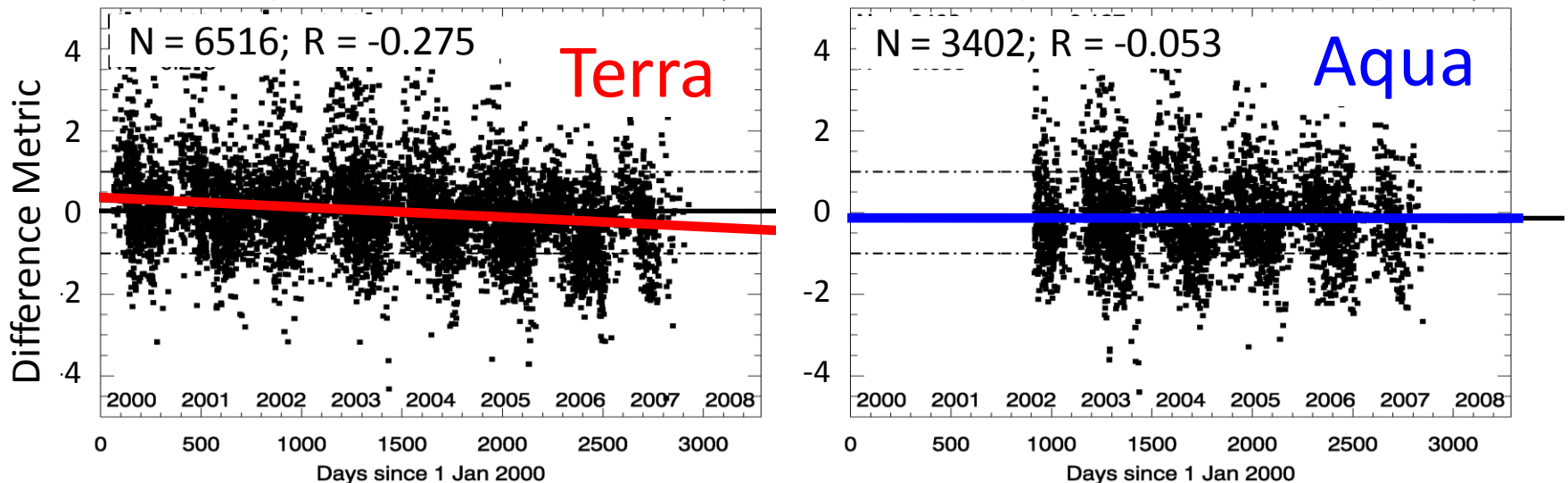
Terra ≠ Aqua (1)

- 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

Terra ≠ Aqua (2)

June 2003

June 2006

0.1
0.05
0.0
-0.05
-0.10

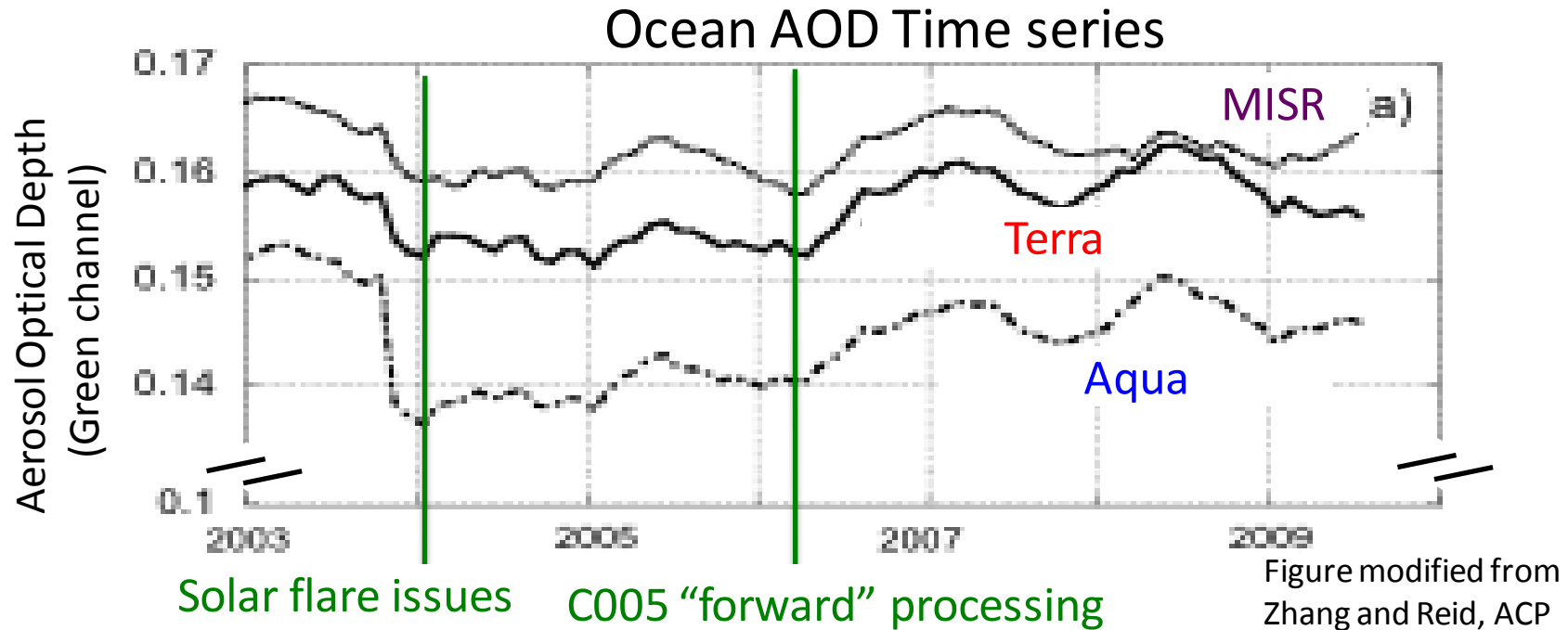Terra-Aqua flips sign between 2003 and 2006

Performance of MODIS instruments may be changing...

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 "bias".***
- Same games played over ocean, show negligible increase of both instruments versus AERONET, with Terra biased high and Aqua biased low.

Ocean: No trend after removing bias

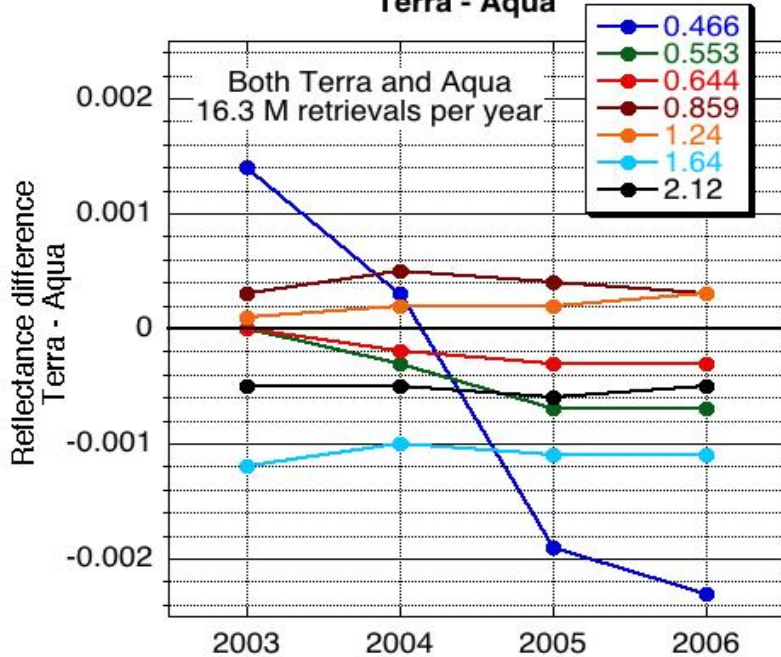### Ocean AOD Time series

Figure modified from Zhang and Reid, ACP

- Zhang and Reid found up trends for both Terra and Aqua –MODIS over ocean.
- There was no apparent trend for MISR, also flying on Terra.
- They corrected MODIS for biases, including cloud fraction and changes in MODIS vs AERONET "agreement":
- They concluded that there is *negligible trend in AOD of 0.0003 / per year"*.
- Apparent MODIS "trends" may be "jumps", related to artifacts of calibration.

AOD trends and trends of instrument calibration

Yearly mean L2 spectral reflectance ($\rho = \pi/\mu_0 * \rho_{L1B}$) **used for calculating 10 km aerosol over ocean Terra - Aqua**

Legend:
- 0.466
- 0.553
- 0.644
- 0.859
- 1.24
- 1.64
- 2.12

Both Terra and Aqua 16.3 M retrievals per year

Y-axis: Reflectance difference Terra - Aqua (0.002, 0.001, 0, -0.001, -0.002)

X-axis: year (2003, 2004, 2005, 2006)

Linking $\Delta\tau$ to $\Delta\rho$ (Terra-Aqua)
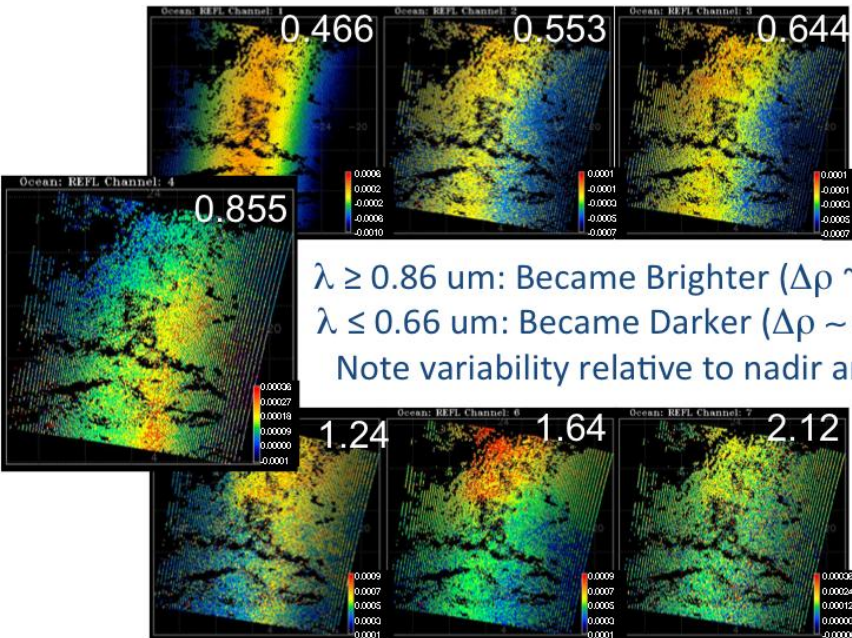
$\Delta\rho=0.001 \rightarrow \Delta\tau=0.01$

- Band #3 (466 nm) is *reported* but *not used* for ocean retrieval. Band #3 is *used* over land.
  - Land trend of $\Delta\tau$ consistent with $\Delta\rho$
- Band #2 (859 nm) is *central* for ocean retrieval
  - No trend, but consistent offset

- **Band #3 drives Terra-Aqua trend over land**
- **Band #2 drives Terra-Aqua offset over ocean**
- **Effects are non-linear, so other bands must also be studied**
- **Maybe not "calibration" per se, but other *artifacts* of sensor degradation (meeting with MCST and alg. developers tomorrow!)**
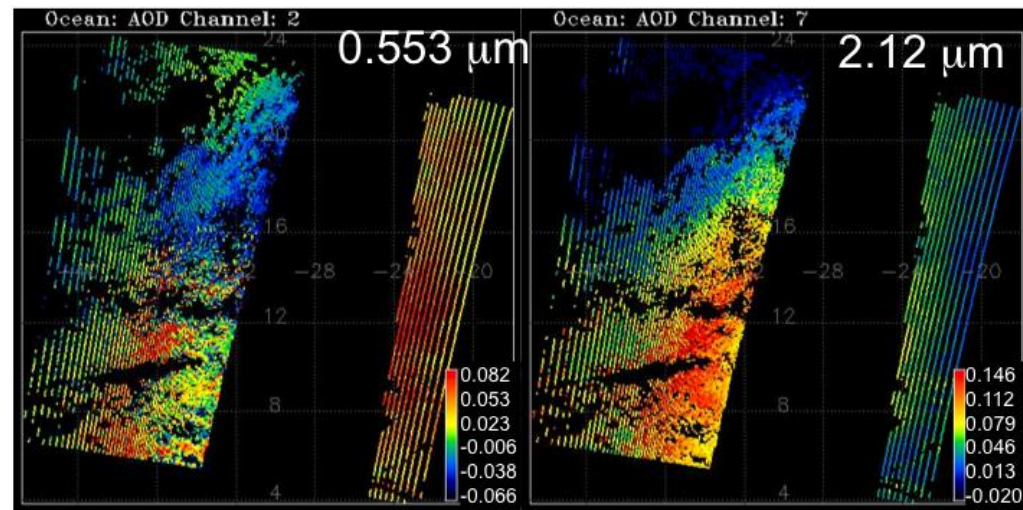
Example of C5-C4 L1B change

Changes in L1B reflectance: Terra, C5-C4

$\lambda \geq 0.86$ um: Became Brighter ($\Delta\rho \sim 0.0002$)
$\lambda \leq 0.66$ um: Became Darker ($\Delta\rho \sim$ -0.0001)
Note variability relative to nadir and glint

Impact on retrieved AOD: Terra, C5-C4

Impact varies spectrally, and depends on specific geometry and aerosol/surface conditions
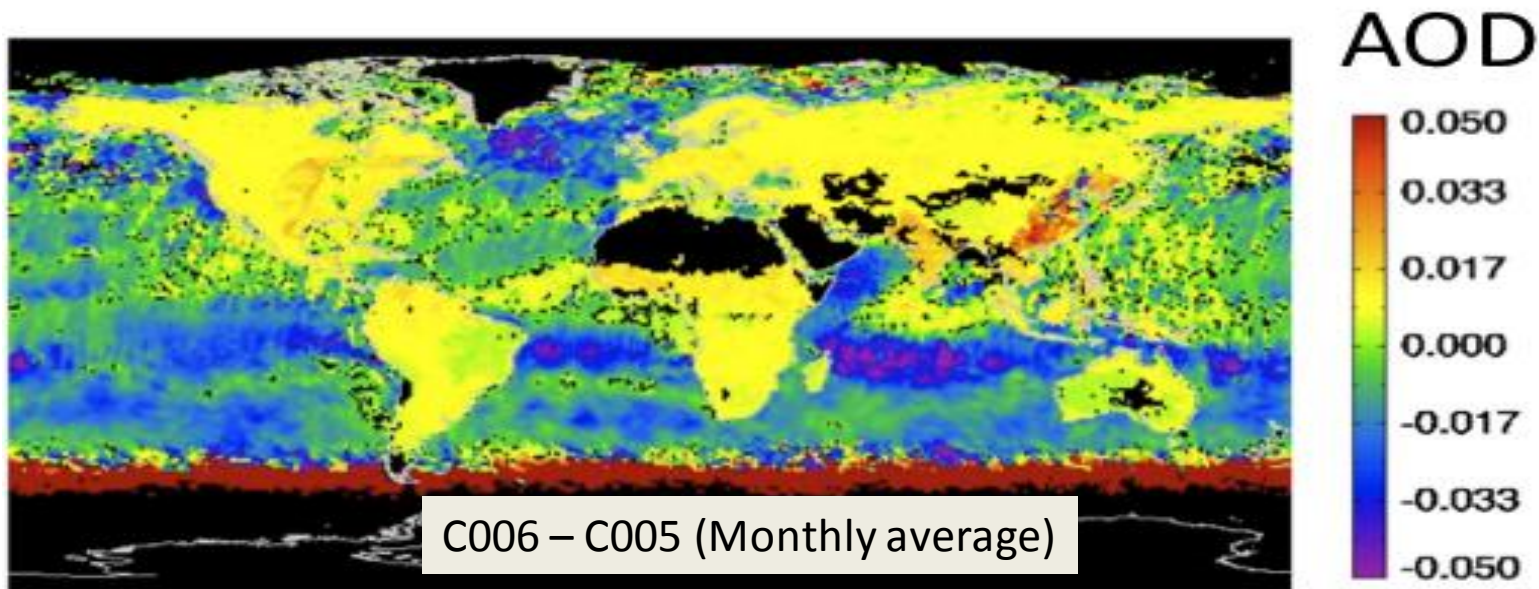
Means and Trends

Surprises in C005

- Calibration differences and drifts are sufficient to explain a portion of the apparent MODIS trends and Terra/Aqua discrepancies.

- In cooperation with MODIS calibration team, we are searching the instrumental record, and identifying issues that we must correct for and deal with.

- *Data producers (us) and data users (you) must be aware of potential artifacts in the data.*

- Case studies and other inter-comparisons are necessary for interpreting the satellite data correctly.

Looking ahead to Collection 6

Other changes for C006

- The C005 product was good, but it can be better
    - Plenty of changes for aerosol algorithm (both land and ocean)
    - LUT consistency (wavelengths, Rayleigh optical depth).
    - QA consistency: Make sure QA is assigned correctly

C006 – C005 (Monthly average)

- Many new products as well (for another talk)
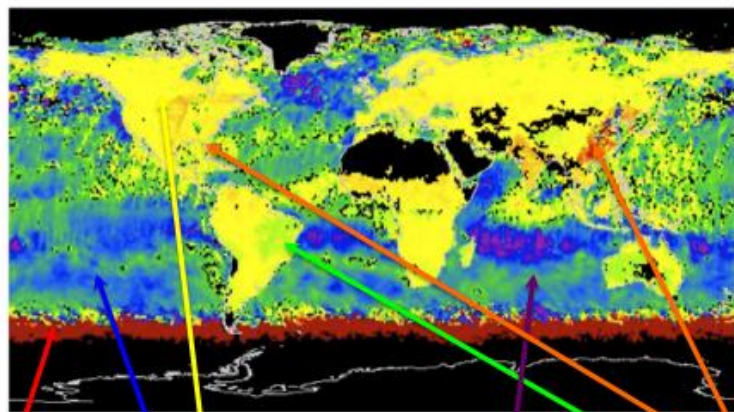
TEST, TEST, and TEST some more!

C006 development paradigm is:

- We know that C006 Radiance product will be different than C005.

- Have MCST produce test versions of C006 radiances over many days, months, and seasons throughout both Terra and Aqua lifetimes.

- Use the production team (LAADS) to make many tests, on different combinations of C005 and C006 algorithms/radiances

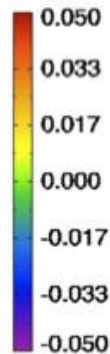- **Characterize C006 aerosol product *before* becoming operational**

"Getting it right" (or at least well characterized)

C6-C5: Algorithm only

C6-C5: Algthm + Calibration

AOD
- 0.050
- 0.033
- 0.017
- 0.000
- -0.017
- -0.033
- -0.050

Global Correction of Rayleigh optical depth:
- 0.01 increase over land
- 0.01 decrease over ocean

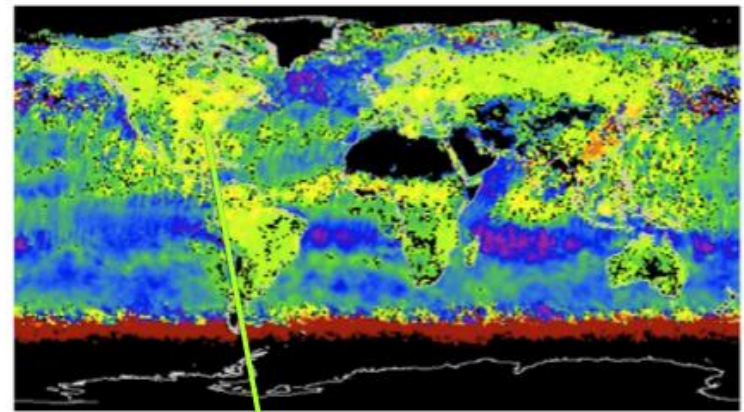**Allowing SZA up to 84°:**
- high latitude coverage

New aerosol model map boundaries over land:
- increase over SE Asia and N. American plains
- decrease over Brazil savanna and Australia

Multiple wind speed LUT Over ocean
- >0.02 decrease near glint and where large wind speed (e.g. roaring 40s in SH
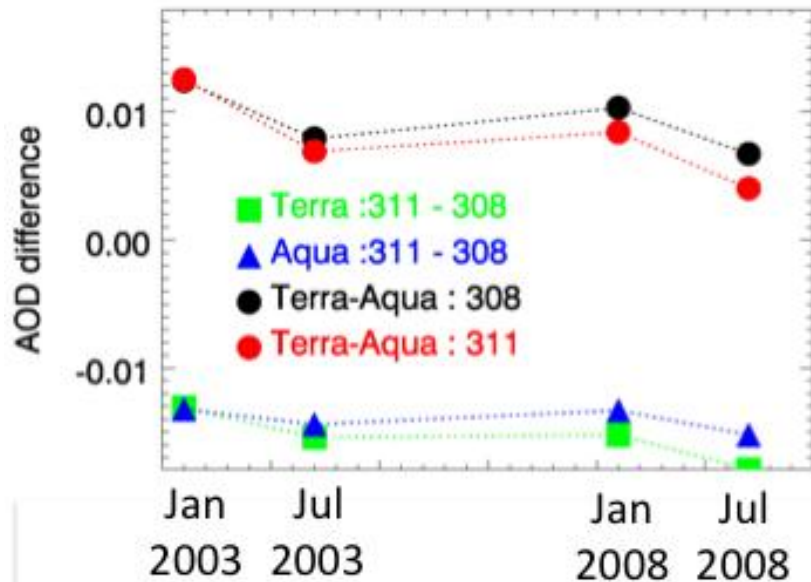
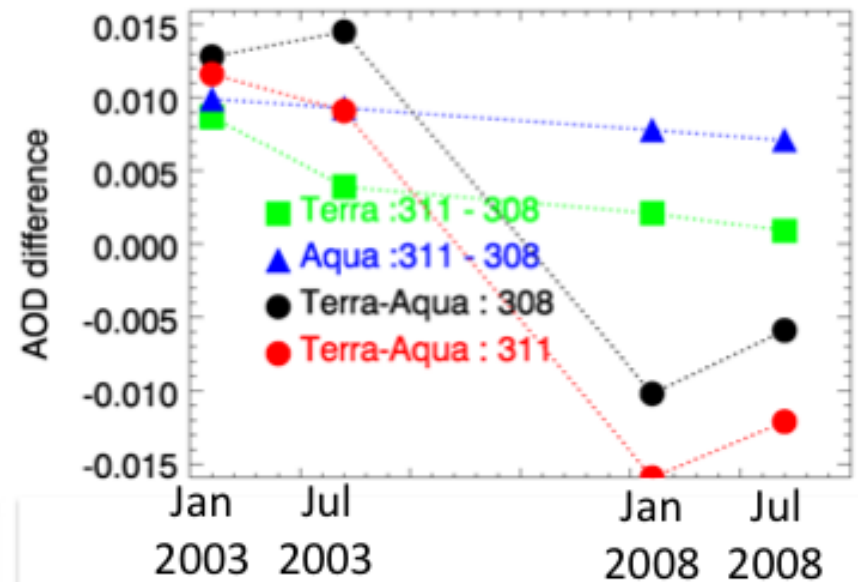**Calibration:**
- Cuts over land-increase in half

In collaboration with LAADS, via B. Ridgway

Predicted impacts from LAADS tests

Differences in mean AOD at 553 nm: ocean

Differences in mean AOD at 553 nm: land

"308" (C5 calibration, C5 algorithm) versus "311" (C6, C6)
Four whole months, Jan and July, 2003 and 2008.

Land: Terra-Aqua "trend" would remain in C006
Ocean: Terra-Aqua "offset" would remain in C006

Getting it right

- C006 production will begin sometime this year.

- Our product is part of a "food chain"

- Our goal is to characterize the aerosol product *before* it becomes operational

- Part of our job is to ensure that *Science* and *Nature* papers are not published because of artifacts of the instruments and/or algorithms!

Summary

- Our own evaluation of C005 is ongoing
- We have found "surprises" in the aerosol statistics
- People are writing *Science/Nature* papers about aerosol statistics
- C005 surprises seem to be related to calibration and instrument degradation artifacts.

Summary

- We don't want surprise artifacts in C006 data
- This time, we are doing testing, testing, and more testing *before* C006 is operational
- At least we want to know what the issues are
- Is the problem one of "polarization correction" for Band #3?
- What about offsets in Band #2?
- Do other groups care?
- How do we fix? Purpose of this meeting

Thank you