The MODIS aerosol products: Evaluation, Aggregation, Trends and …

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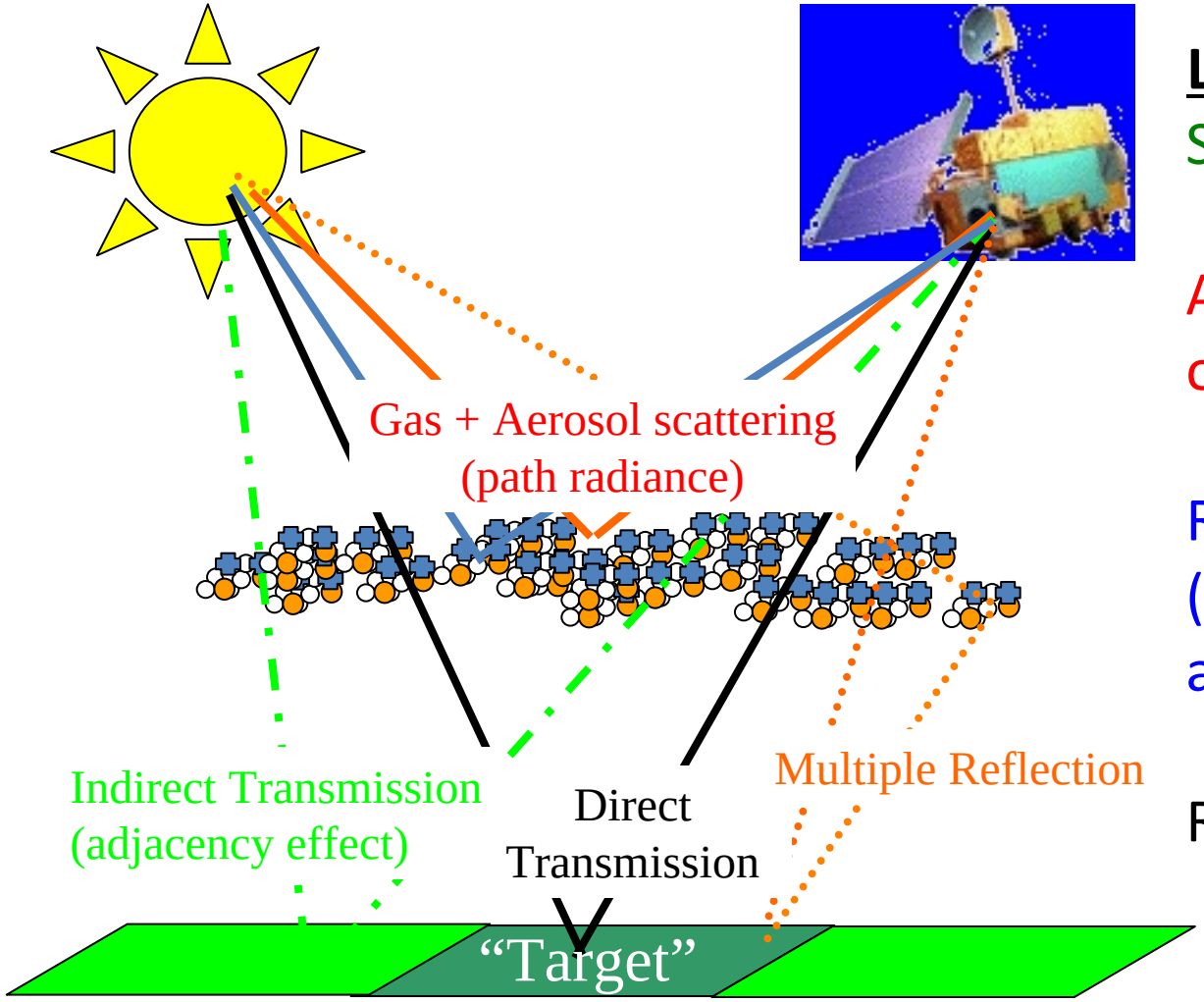
Lorraine Remer, Ralph Kahn, Greg Leptoukh, Rich Kleidman, Shana Mattoo, Arnon Karneili, Clare Salustro

Haze over Maryland: Marafu, Taubman, Dickerson

Organization

- Motivation: Characterization of MODIS products
- MODIS aerosol algorithms
- Validation of AOD, with some caveats
- Aggregation to Level 3 grid: daily, monthly
- What now?

The Satellite Signal is complicated



Lots of Assumptions!!

Surface Properties

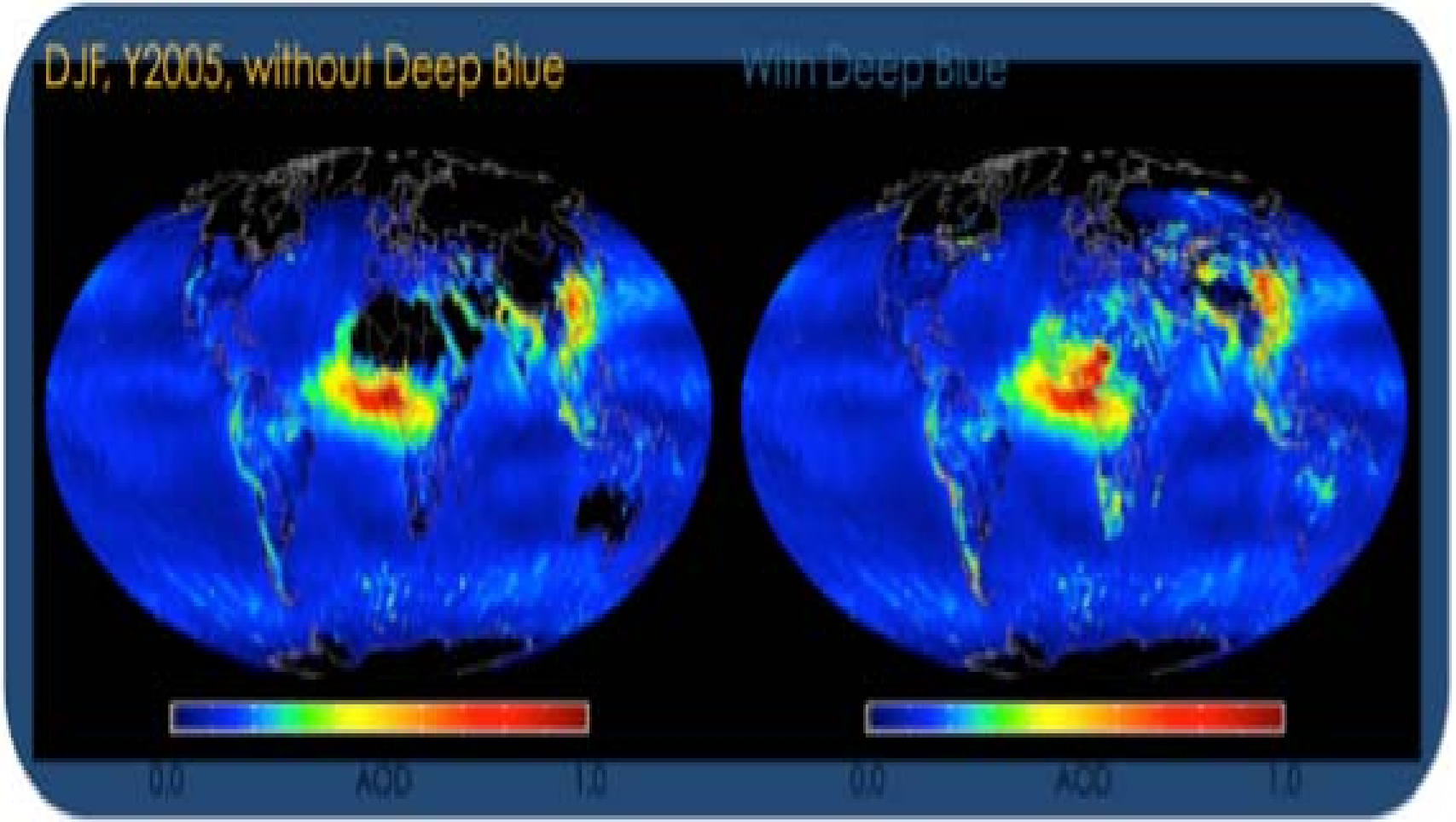
Aerosol physics: size, optical properties

Radiative Transfer (including Rayleigh and wavelength)

Retrieval Math

(also cloud masking, pixel selection, to improve statistics!)

New capabilities! Deep Blue! "Collection 5.1"



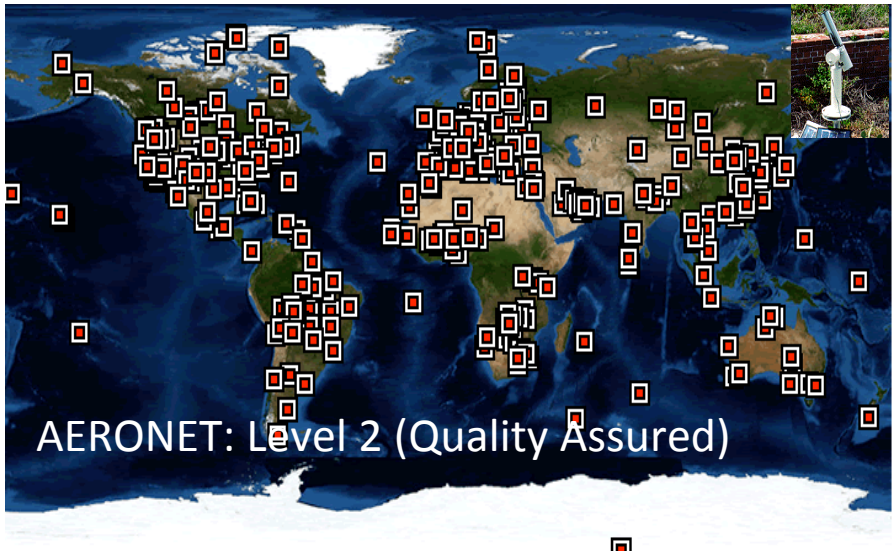
N.C. Hsu, C. Salustro, et al.

Level 2 Products

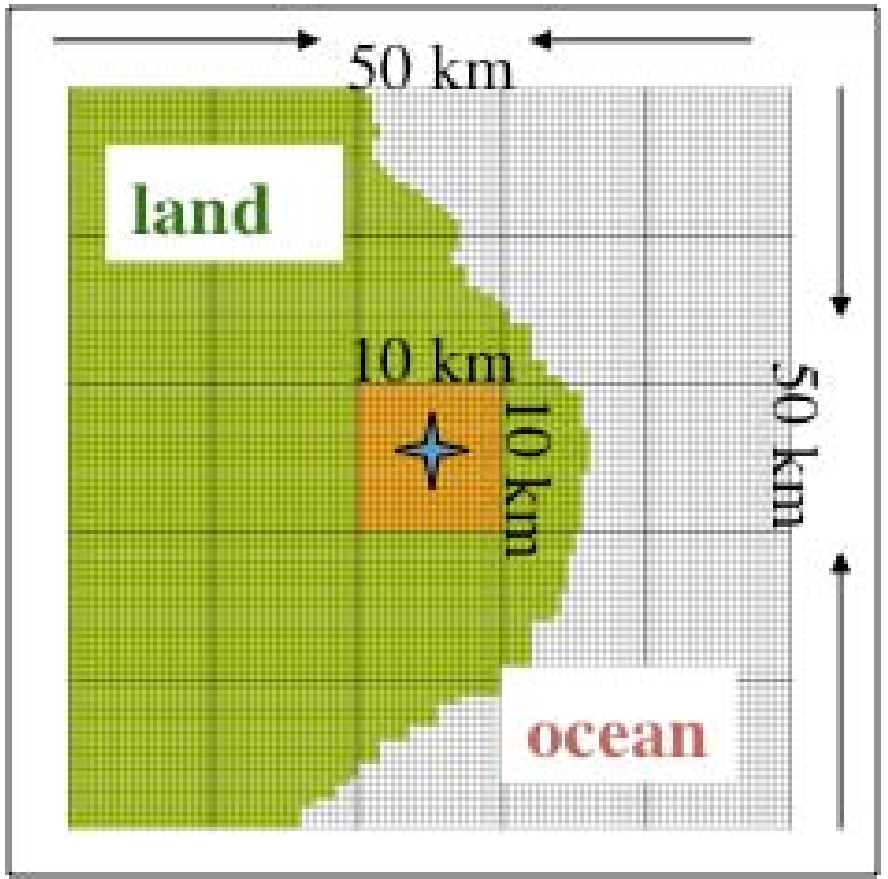
- Over ocean (Dark target): Uses obs. in 6λ (VIS-NIR-SWIR)
  - Assumed: LUT for 9 aerosol "modes", ocean surface for V=6m/s
  - Retrieved: τ, η (0.55 μm); chosen "fine" and "coarse" modes
  - Derived/Diagnostic: τ_f (0.55 μm); spectral τ, α, QA
- Over land (Dark target): Uses obs. in 3λ (VIS-SWIR)
  - Assumed: LUT for 4 aerosol "models" (fixed location/season), land surface parameterization
  - Retrieved: τ, η (0.55 μm)
  - Derived/Diagnostic:, τ_f (0.55 μm); spectral τ, α, QA
- Over land (Bright target / Deep Blue): Uses obs in 3λ (NUV-VIS)
  - Assumed: surface reflectance; aerosol type
  - Retrieved: τ (0.41 μm)
  - Derived/Diagnostic: τ (0.55 μm); spectral τ, SSA, QA

Note huge variety of assumptions and information contents

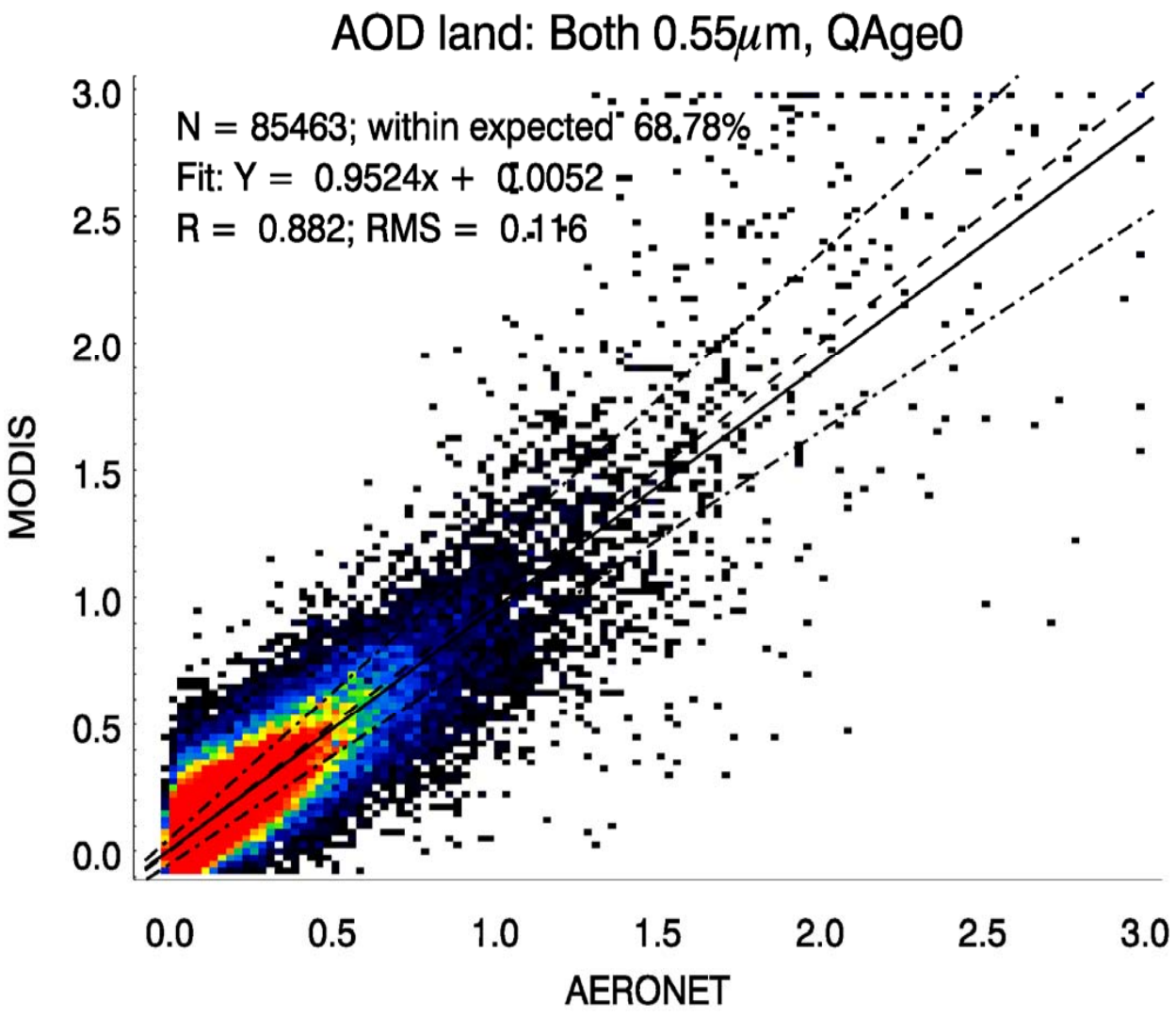
Evaluation of MODIS L2 products: Collocation with AERONET



- Some sites used for both land and ocean
- Goal: 66% within Expected Uncertainty (EU) =
  - Dark Land: $\pm(0.15\tau + 0.05)$
  - Ocean: $\pm(0.05\tau + 0.04)$
  - Bright Land: ???



Evaluation over Dark-Land: Scatterplot

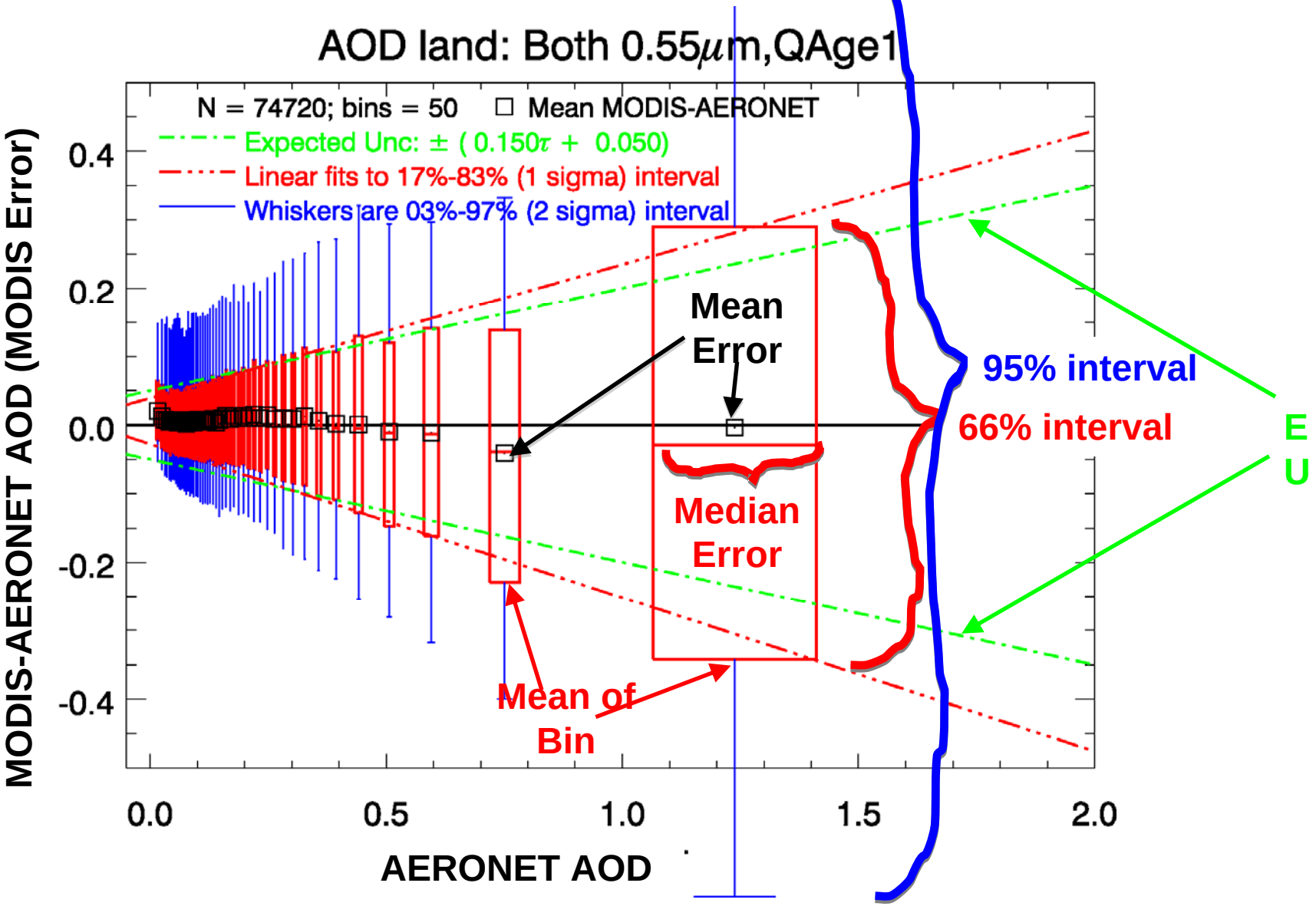


- EU = ±(0.15τ + 0.05)
- Regression = Solid Line
- Colors = "#" of collocations
- 1-1 line = dashed line
- EU = dot-dash
- > 68%:
- SUCCESS = "Validation"

Validation?

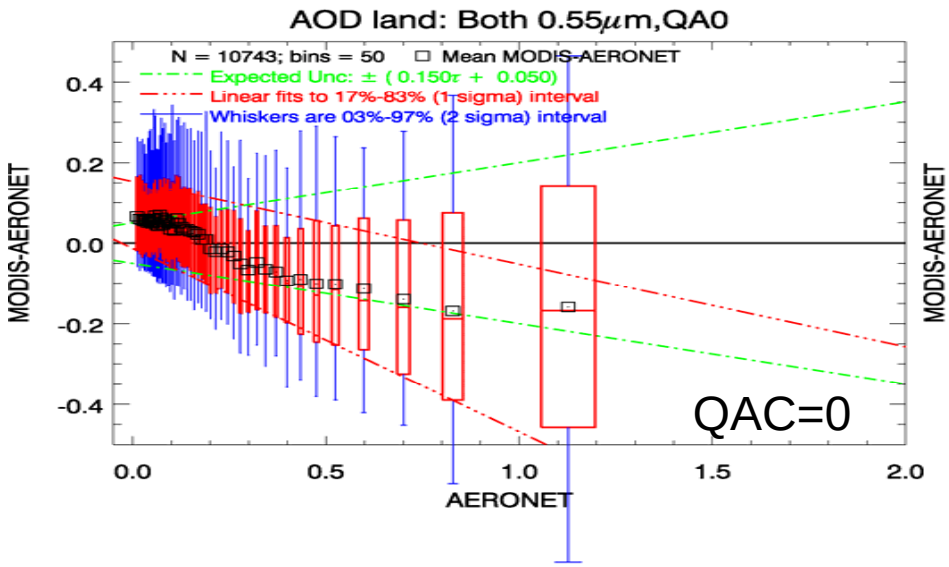
But we are not done…

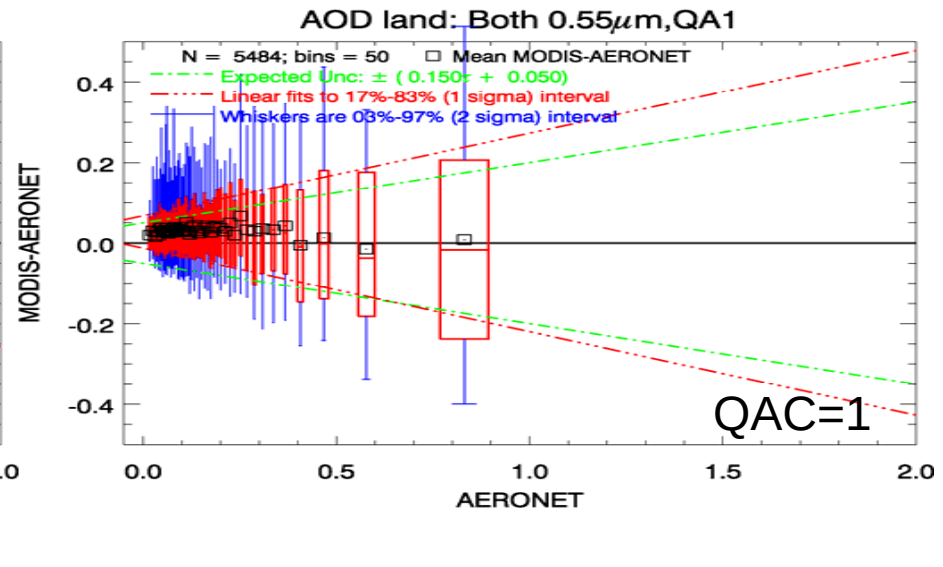
… Plotted a different way

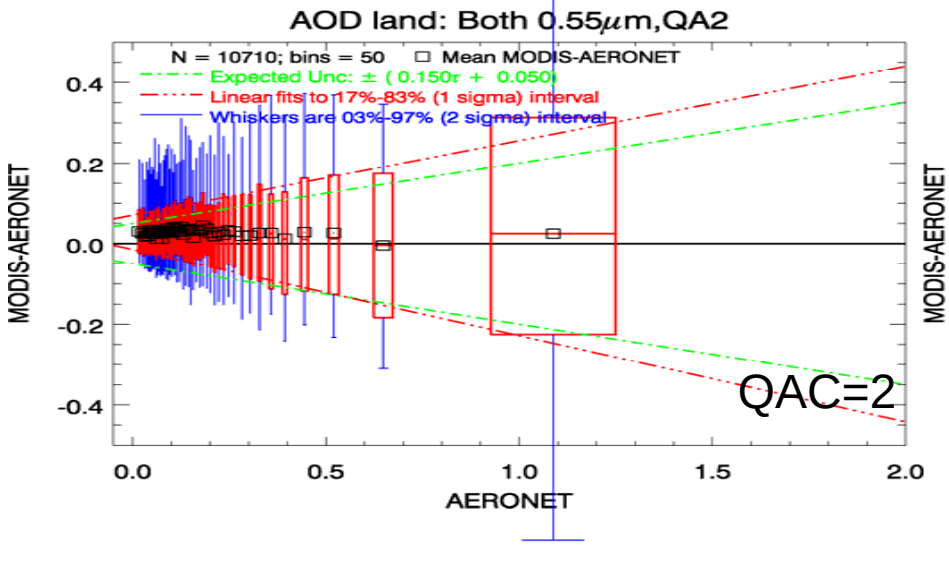


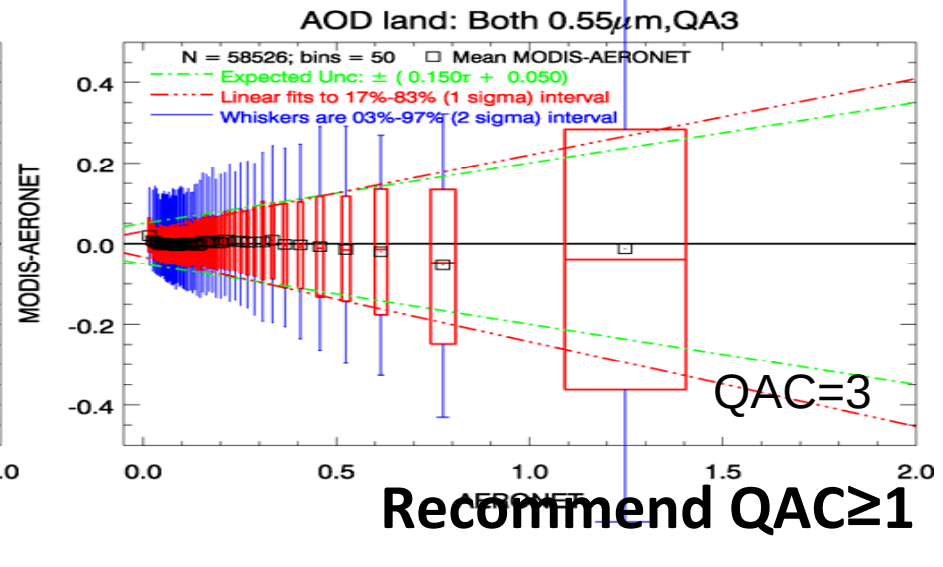
50 “Bins” of sorted “true” AOD measured by AERONET

Function of QAC (Confidence)



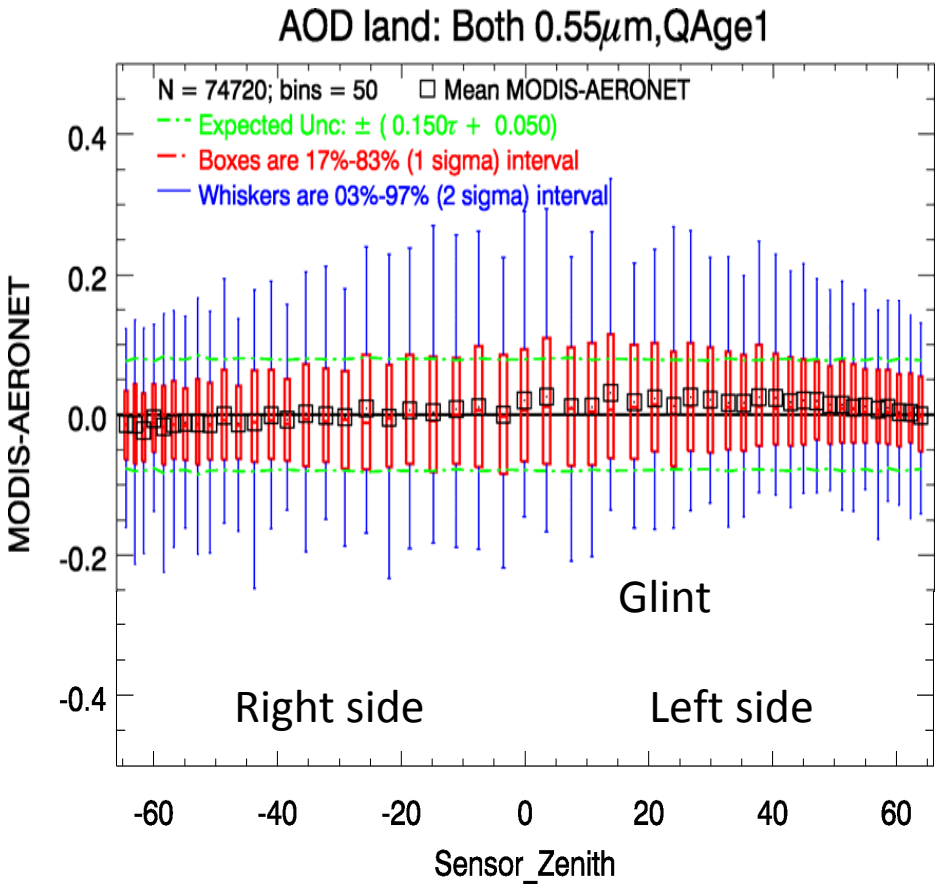


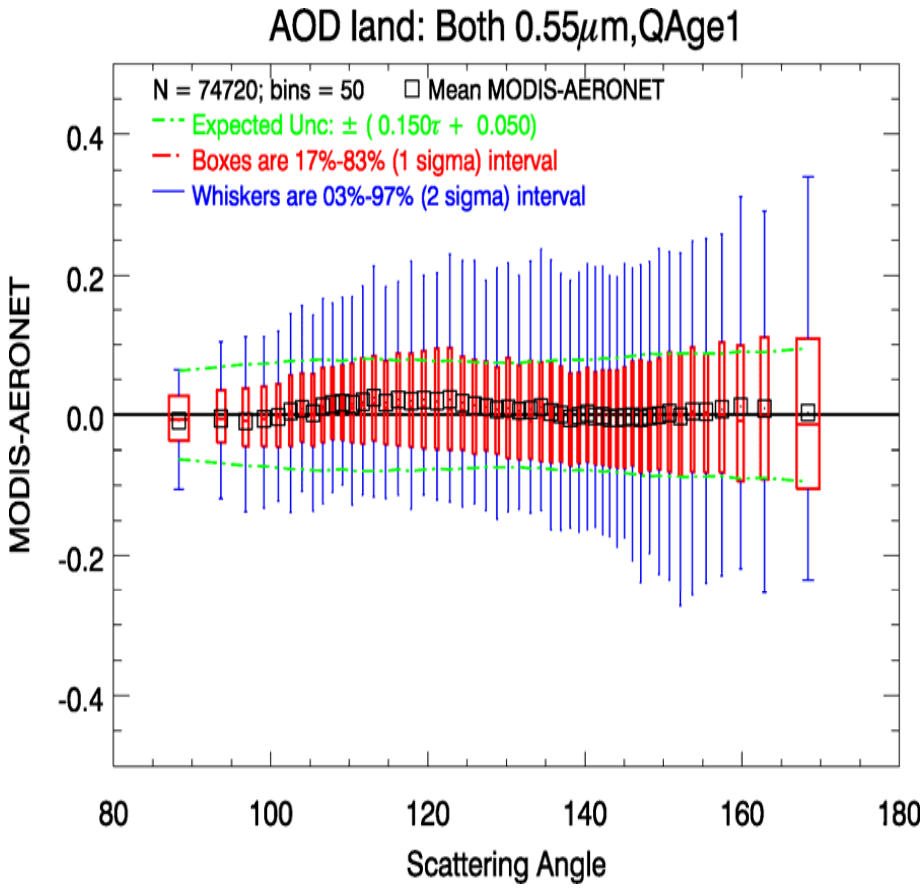




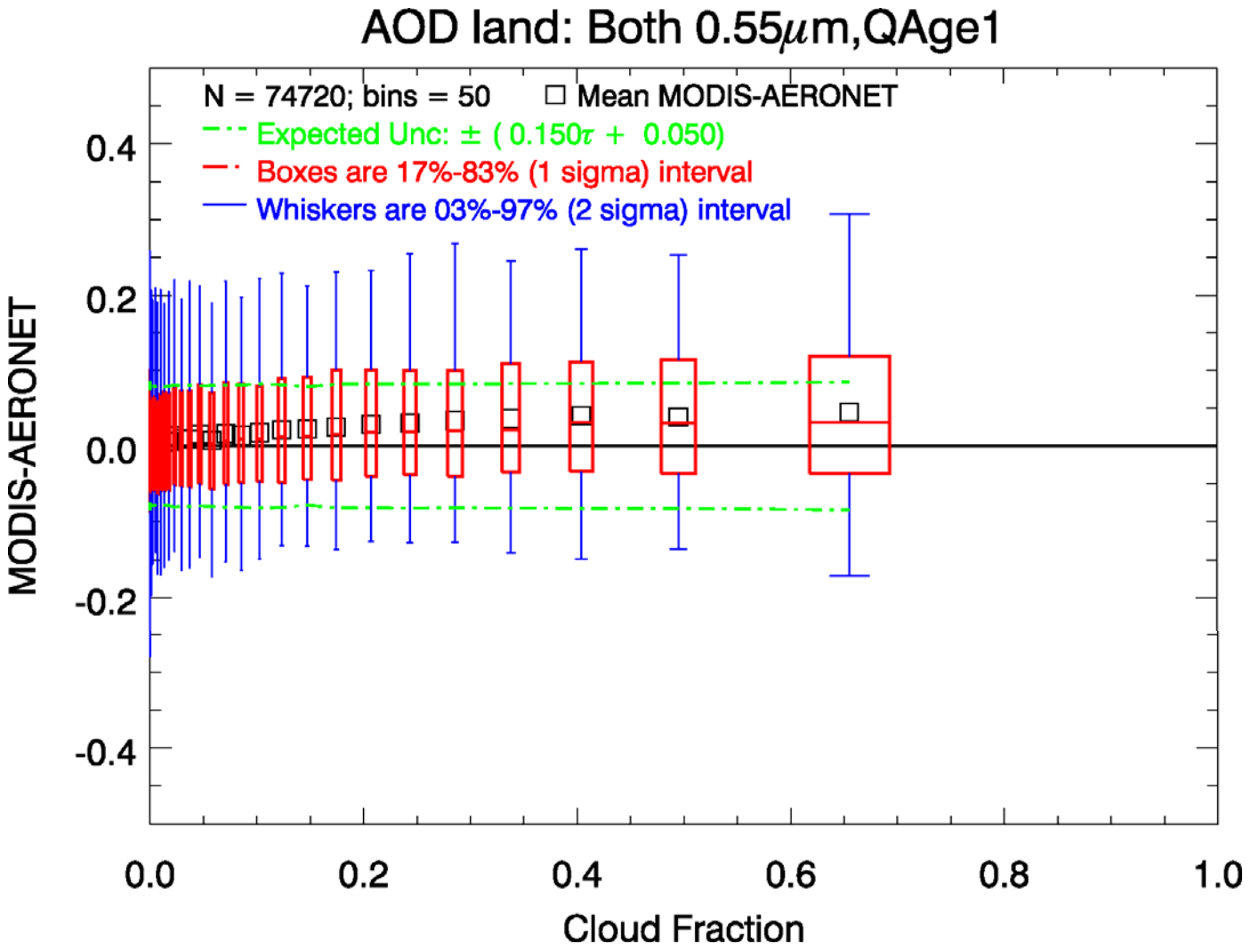
Recommend QAC≥1

Sensor View and Scattering Angles



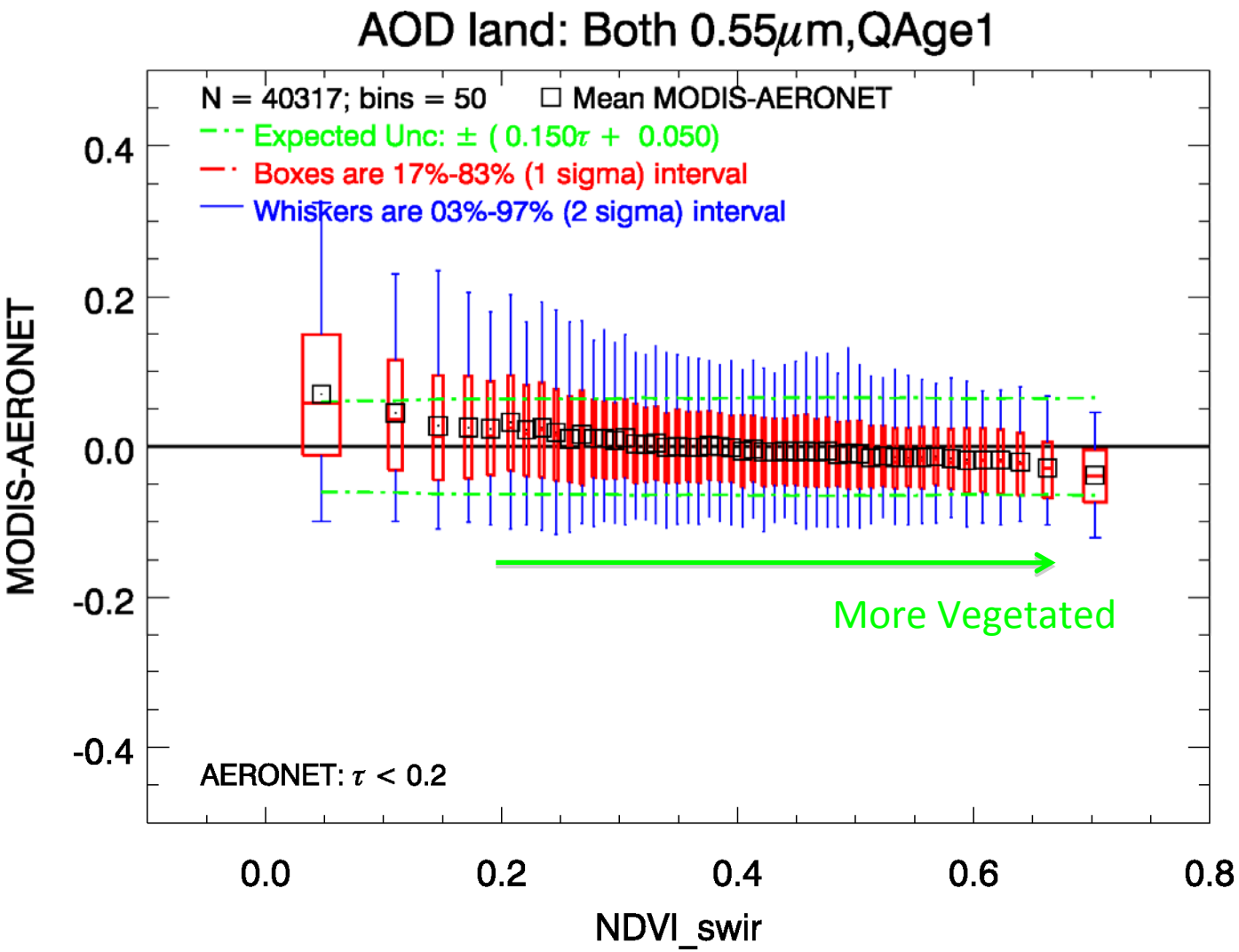


Cloud Fraction



Increasing Cloud fraction → increasing Cloud contamination

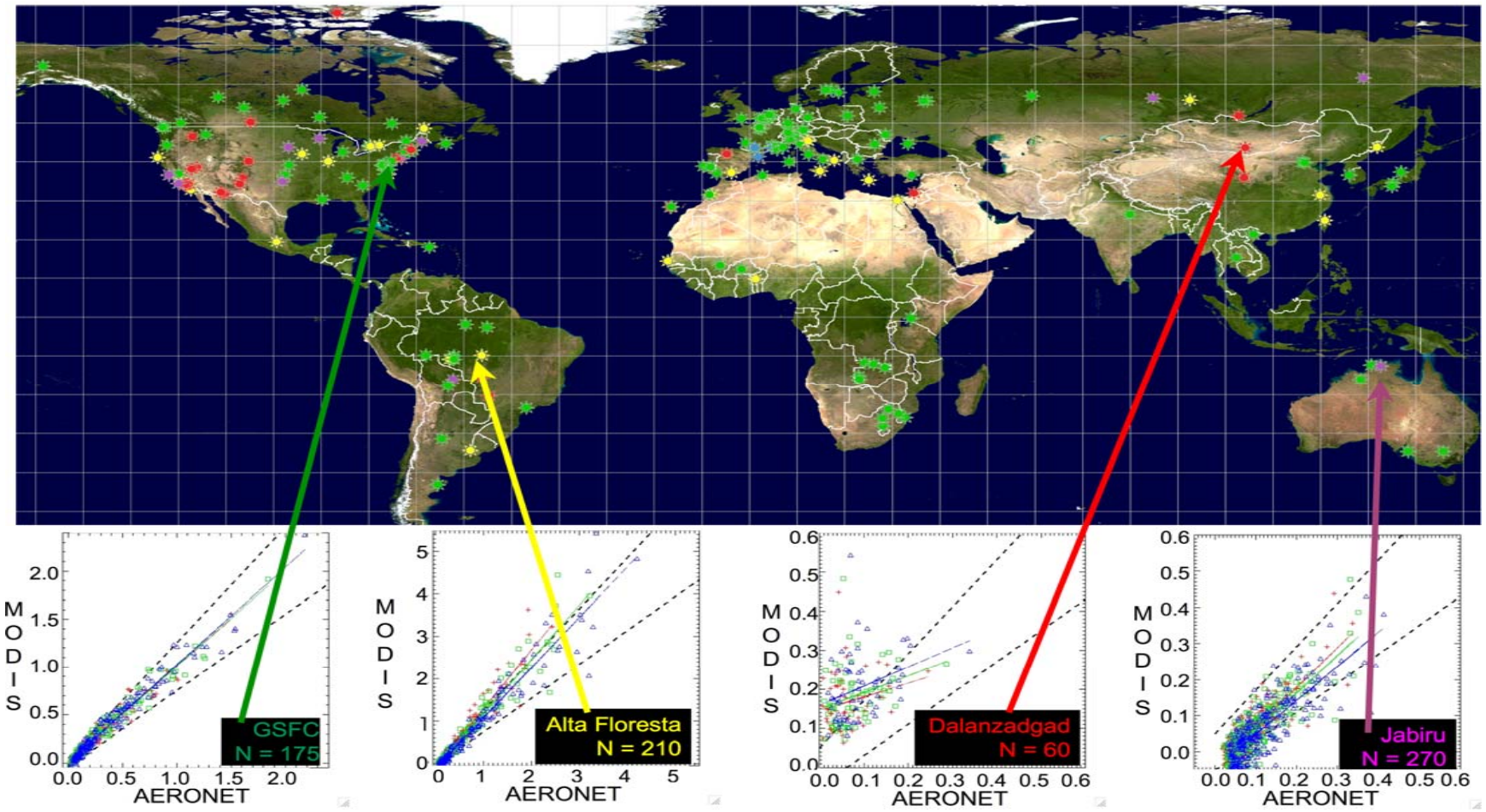
Dependence on surface assumptions



NDVI dependence for clean conditions, where surface dominates.

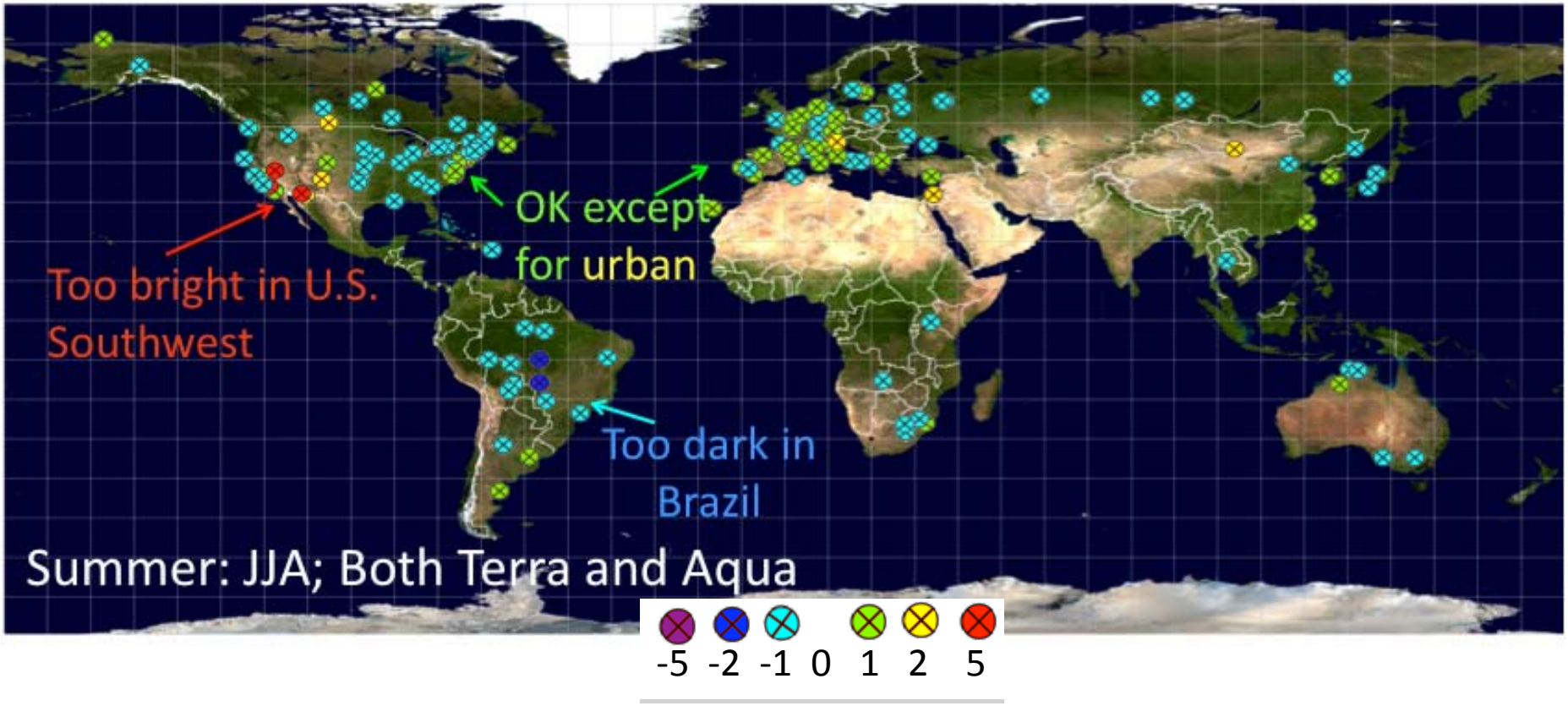
Site by Site by season comparison

Terra; Summer: JJA



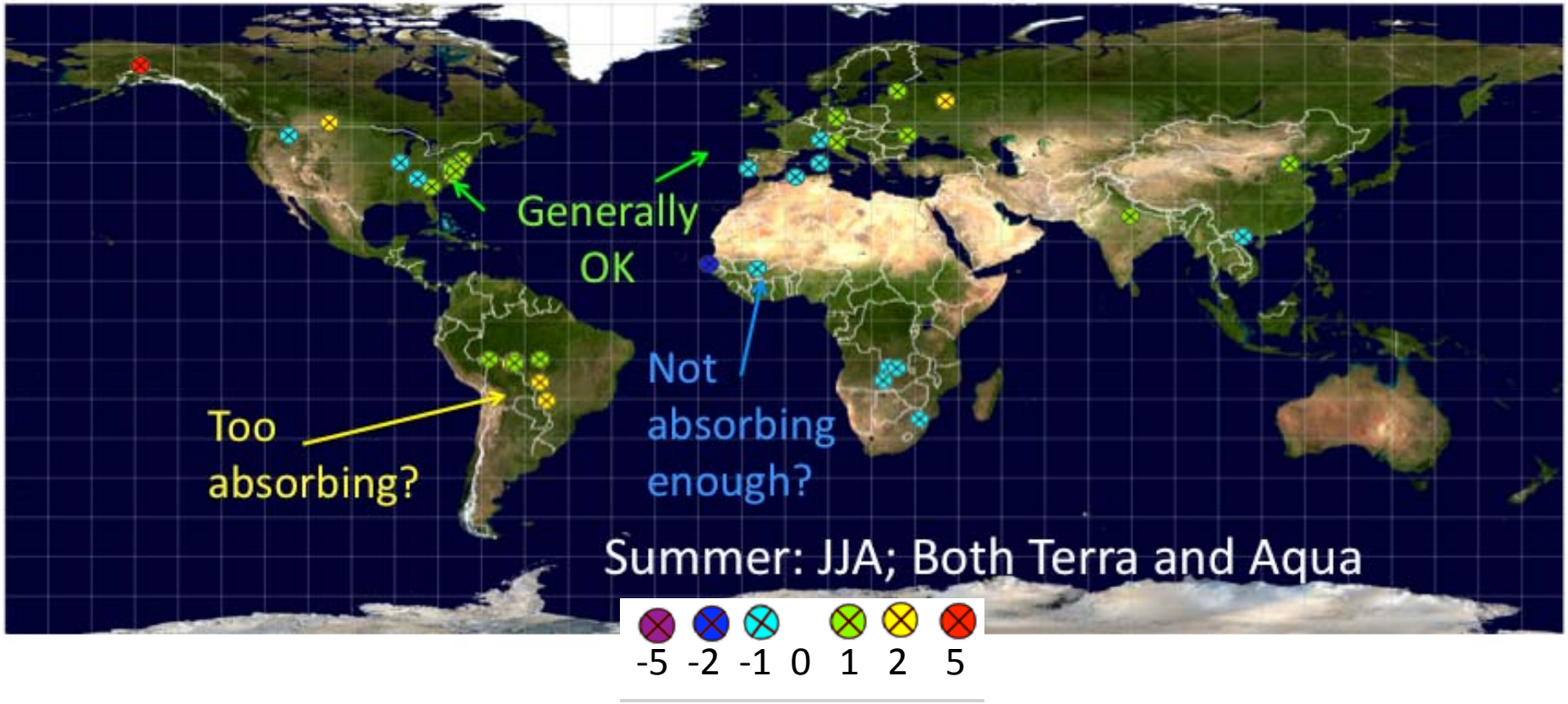
- Colors represent the comparison of MODIS vs AERONET for multiple wavelengths:
- Greener colors represent >66% within Expected Uncertainty
- Warmer colors (Orange/Red) are worse comparison at 0.55 μm
- Cooler colors (Blue/Purple) are worse comparison at 0.47 or 0.66 μm
- Better over “greener” surfaces; worse over “brighter” surfaces

surface assumption dominates $\tau < 0.2$ (according to AERONET)



- Colors are "fraction of EU", defined as $(\tau_{mean,MODIS} - \tau_{mean,AERONET}) / EU\ (\tau_{mean,AERONET})$
- Greenish colors are "within EU"
- cooler colors are MODIS underestimate; warmer are MODIS overestimate

Aerosol assumptions dominate $\tau > 0.5$ (according to AERONET)



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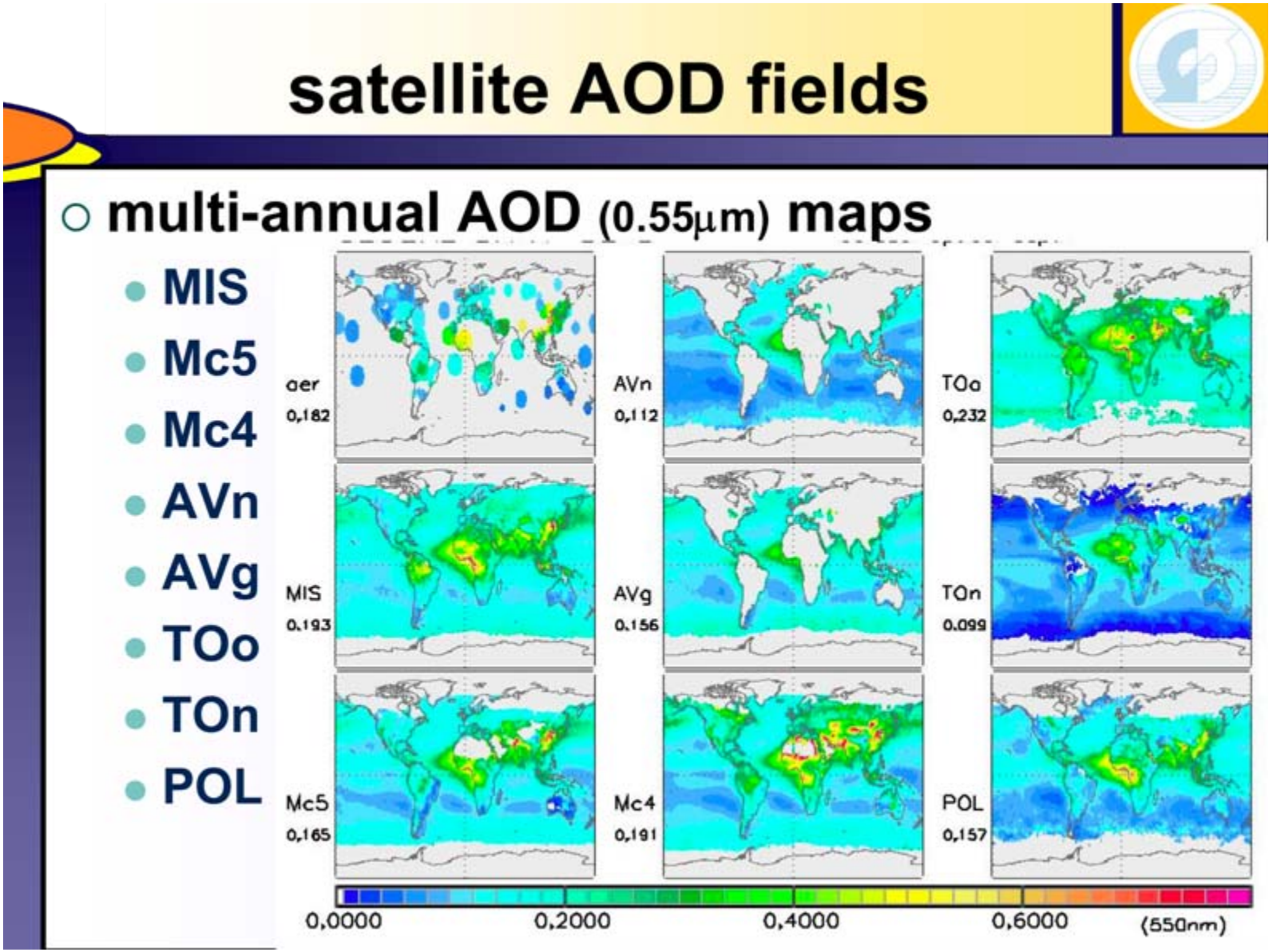
Evaluation Summary

- MODIS dark-target AOD (Land and Ocean) is "validated"
  - 66% within defined Expected Uncertainty
  - Biases at certain locations
  - Dependence on QA; Recommend QAC≥1
  - Residual biases in AOD are being quantified
  - Ocean: Spectral AOD, Ångstrom, fine AOD are reasonable but have systematic biases (location/season/scene)
  - Land: Spectral AOD, Angstrom, size are **diagnostic** of assumptions and are **not quantitative**
- MODIS deep blue AOD is being evaluated
  - (see Clare Salustro's poster)
  - Working on comparing dark/deep retrievals for desert fringes

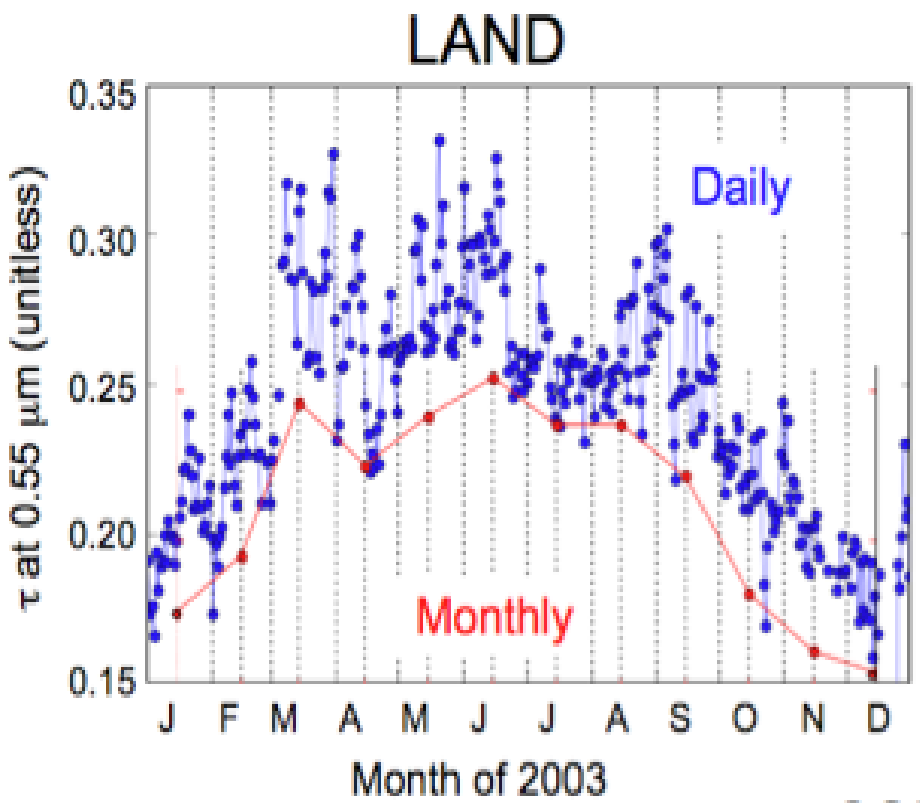
An AEROCOM predicament

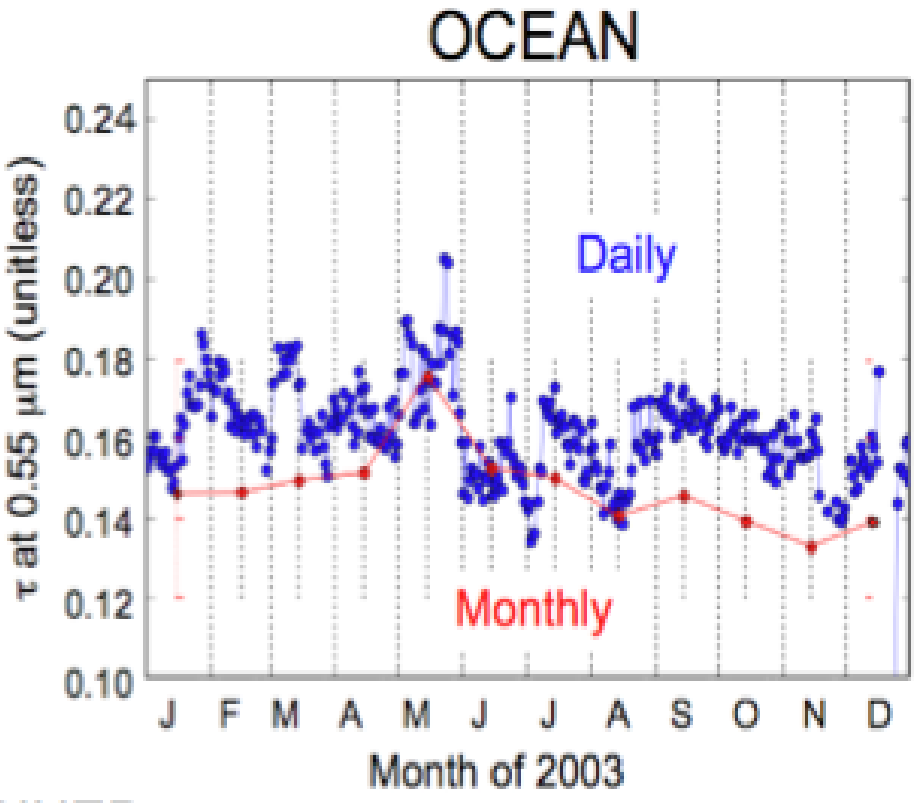


Stolen from S. Kinne; AEROCOM web site

Which would you trust?

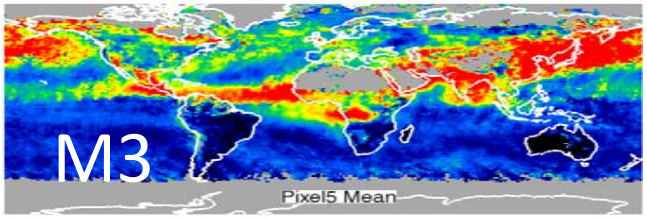
Let's "trust" MODIS!

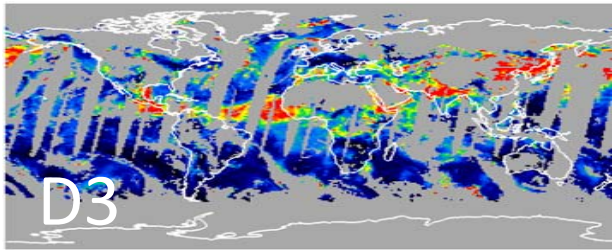


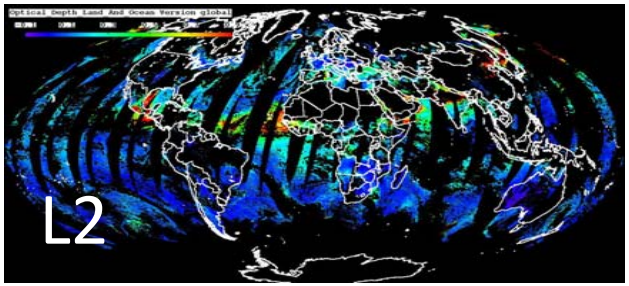


- Global averages from "Giovanni"
- D3 : 'Mean' products; M3 : 'Mean_Mean' products
- >10% uncertainty in monthly mean???
- Due to pixel weighting for computing M3; clear sky bias

How to compute global mean $\overline{\overline{\tau}}$?







$\overline{\overline{\tau}}$ M3-> and all decisions for aggregation and weighting within

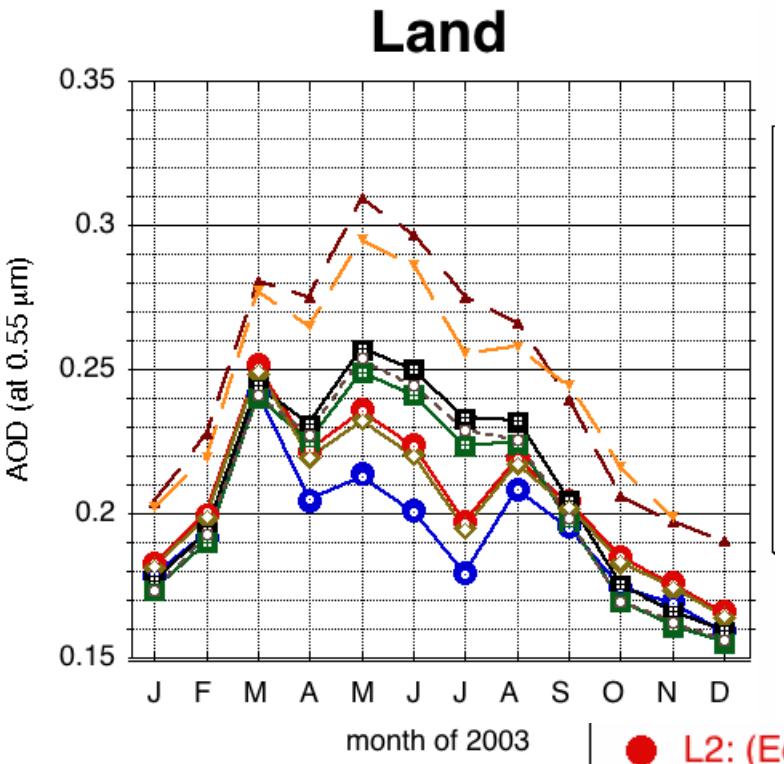
$\overline{\overline{\tau}}$ D3-> and decisions for aggregation and weighting (simple, pixel counts, confidence?)

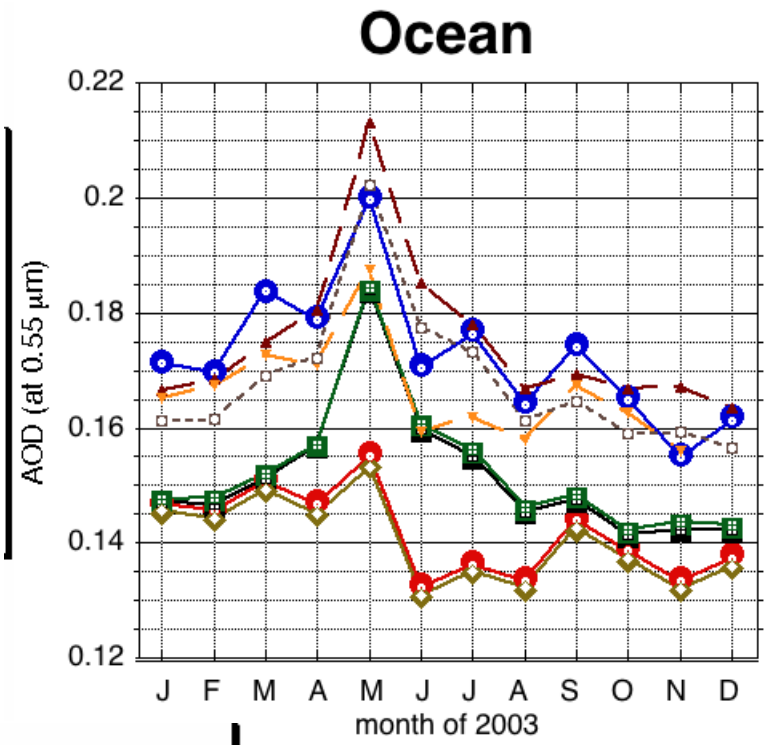
$\overline{\overline{\tau}}$ L2-> Sampling VS global aerosol representation

- Many choices for aggregation and weighting
- Accentuate different aerosol/cloud features
- Accentuate different limitations of MODIS sampling

Levy et al., TGARS 2009

Many choices: Much diversity





L2: (Equal)
L2: (Confidence)
M3 Mean_Mean: (EqArea)
M3 QA_Mean_Mean: (EqArea)
M3 Mean_Mean: (Pixel)

D3 Mean: Straight (Pixel)
D3 QA_Mean: Straight (Conf)
D3 Mean: 1T(PixelP5), 2S(EqArea)
D3 QA_Mean: 1T(PixelP5), 2S(EqArea)
D3 Mean: Straight (PixelP5)
D3 Mean: 1T(EqDay), 2S(EqArea)
D3 Mean: 1S(EqArea), 2T(EqDay)
D3 QA_Mean: 1T(Conf), 2S(EqArea)

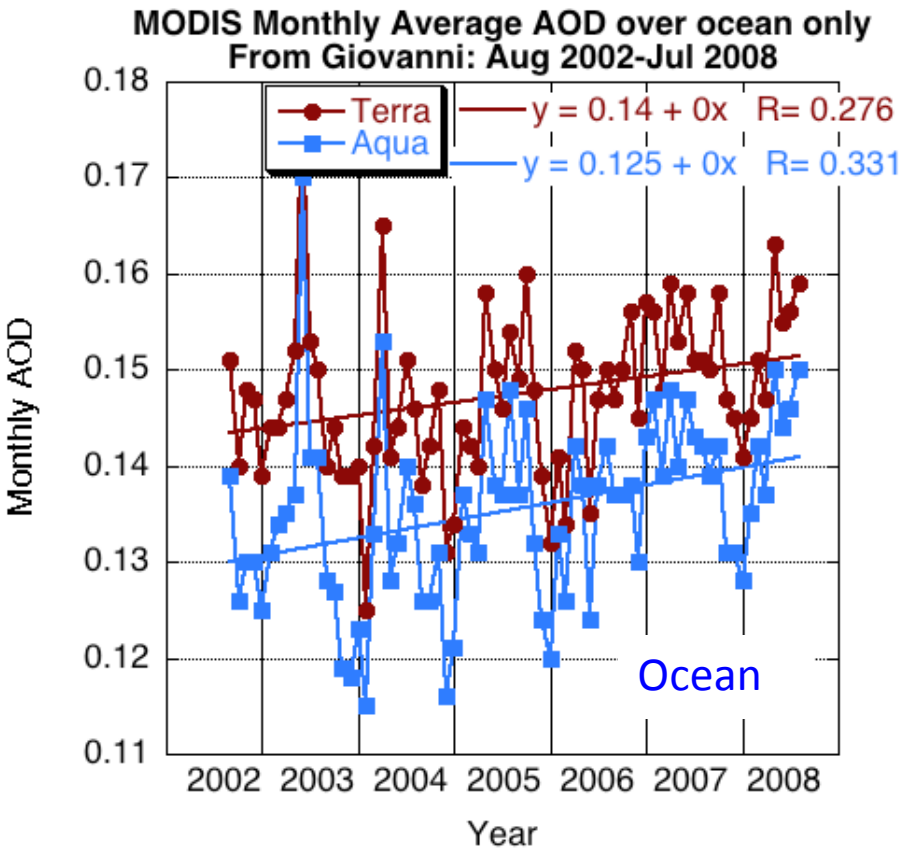
- Global means vary by **40%**!

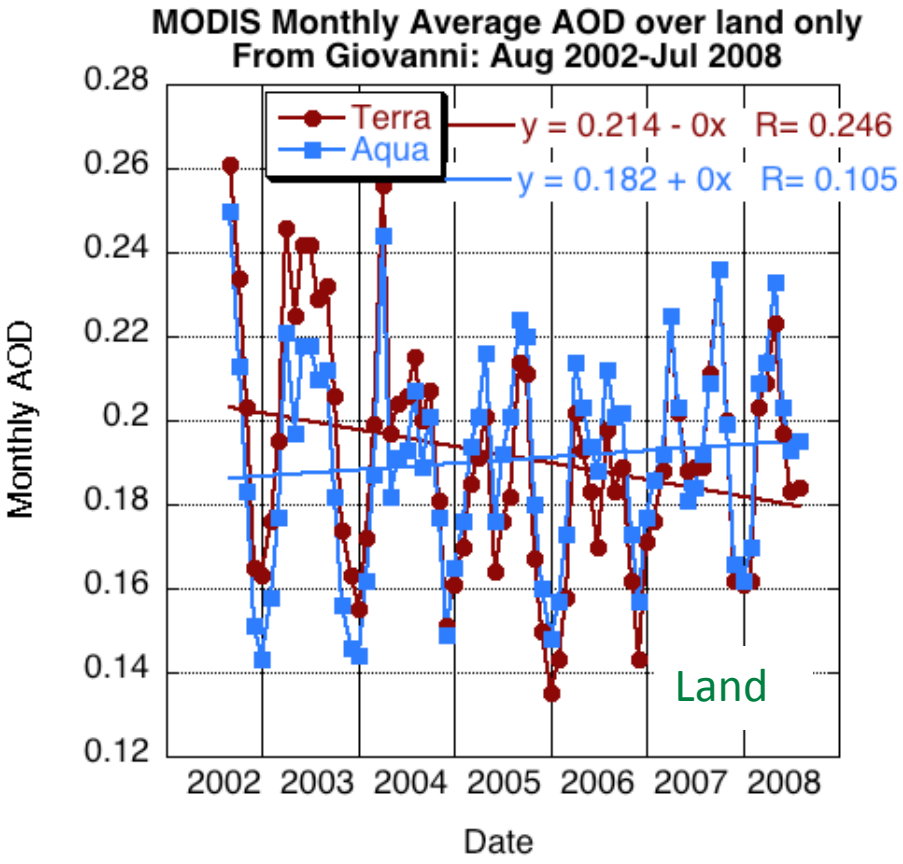
Aggregation Summary

- MODIS has complicated sampling
- Aggregation requires many assumptions
- MODIS Giovanni is one (or more) answers
- There are many other answers
- Dangerous to rely on only one of them

Trends?

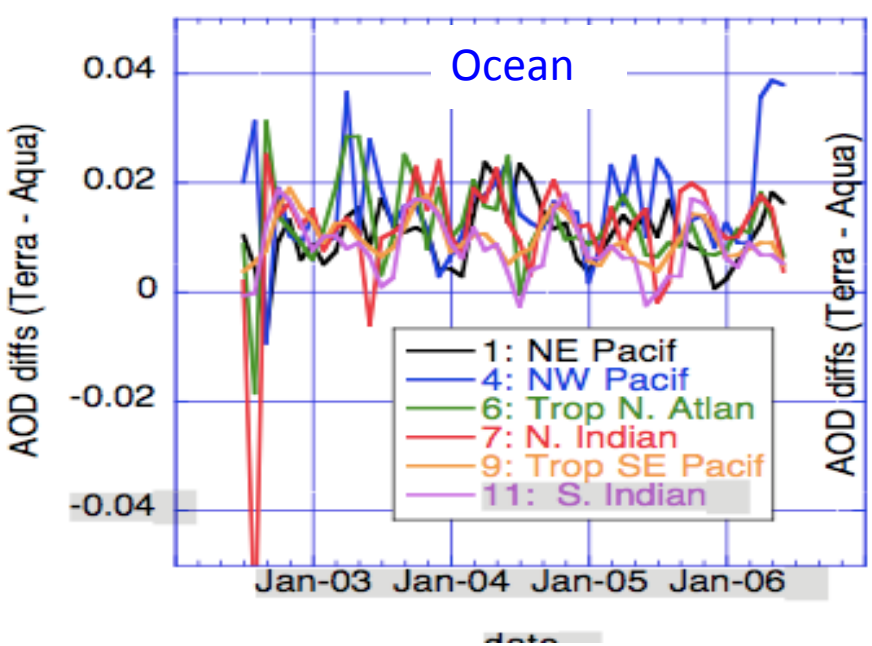
Terra ≠ Aqua

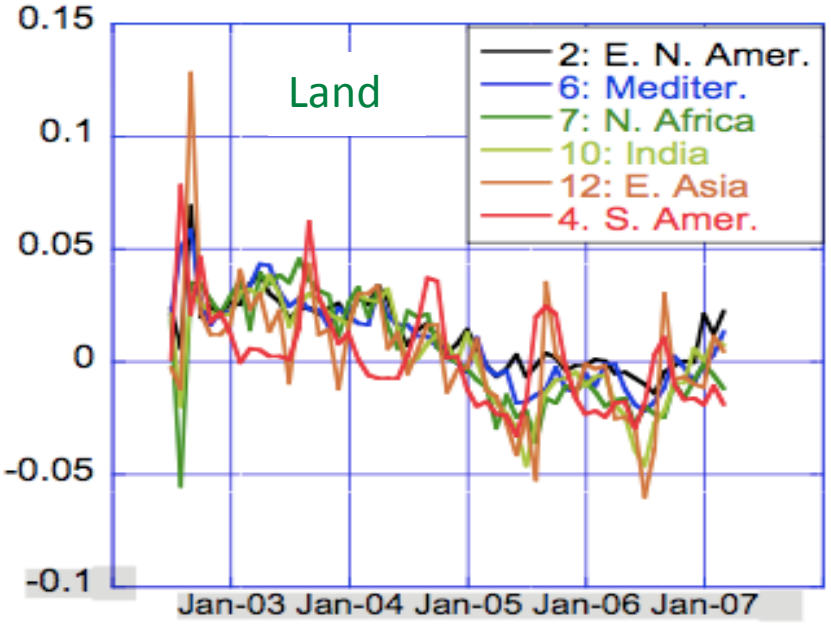




- Over ocean, Terra consistent with Aqua, but +0.015 (10%)
- Over land, Terra down, Aqua up???

And the differences are everywhere

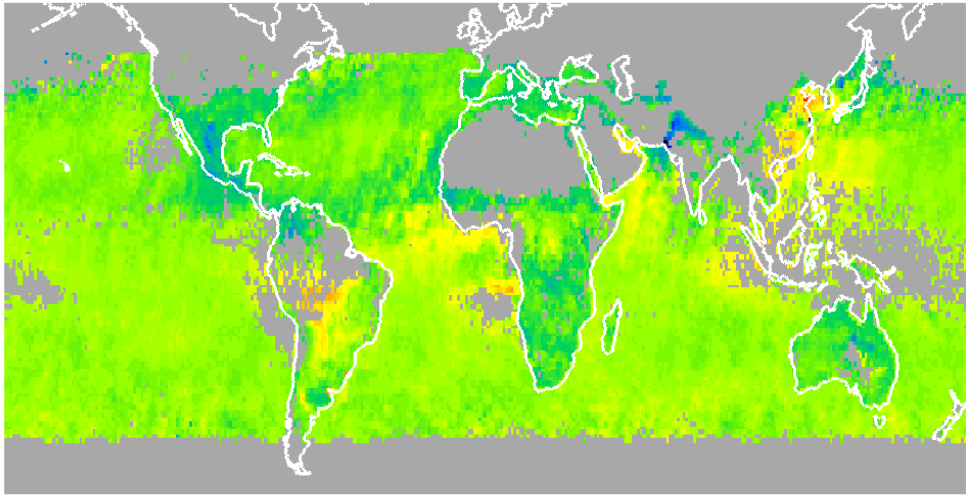




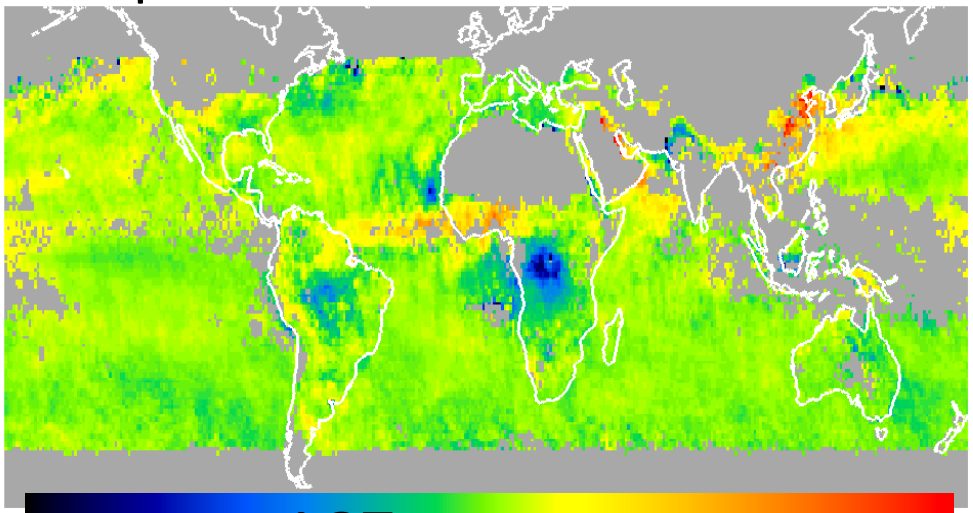
- Differences as well when comparing to AERONET
  - Land Terra: overestimate before 2004; Terra underestimate after 2004
  - Land Aqua: No trend!
  - Ocean Aqua and Terra: No trend!
- **<<2% differences in calibration!**
- **We cannot rely on absolute values or trends, yet.**

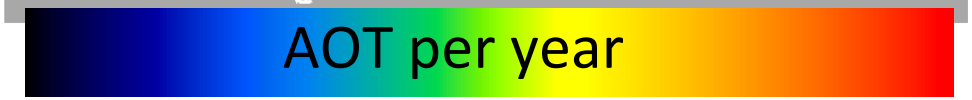
1° x 1° AOD trends

Terra

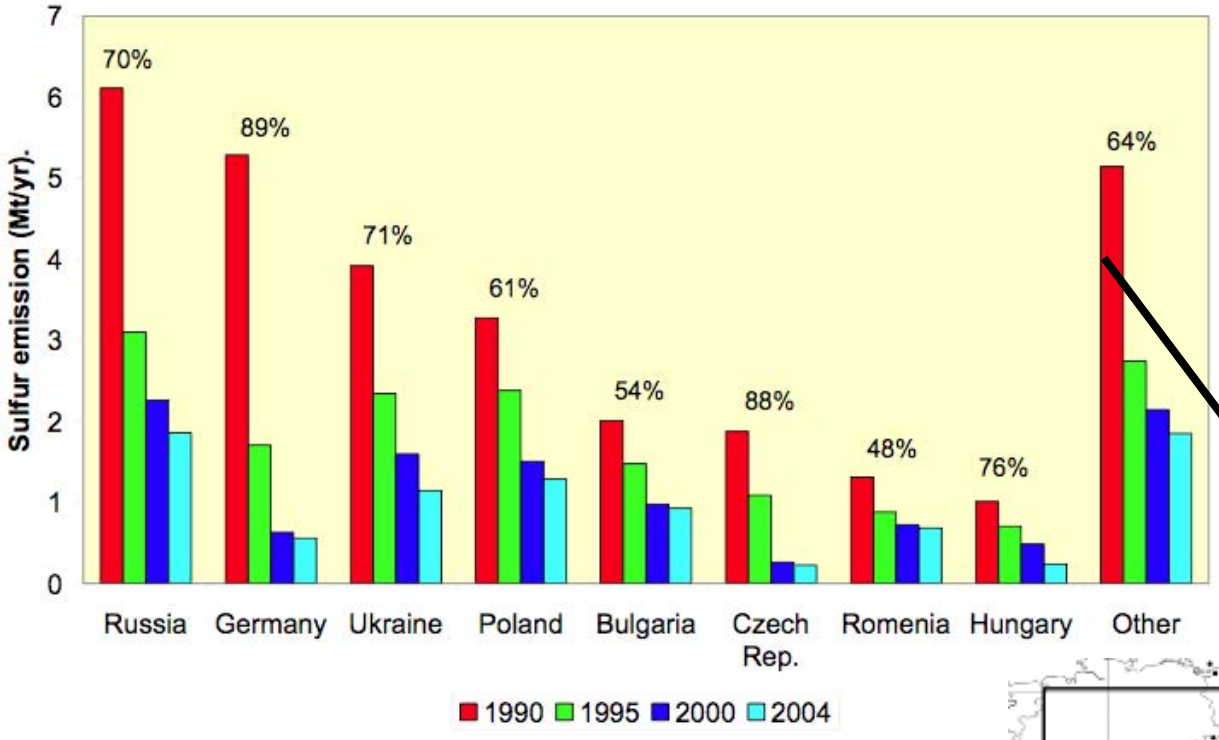


Aqua

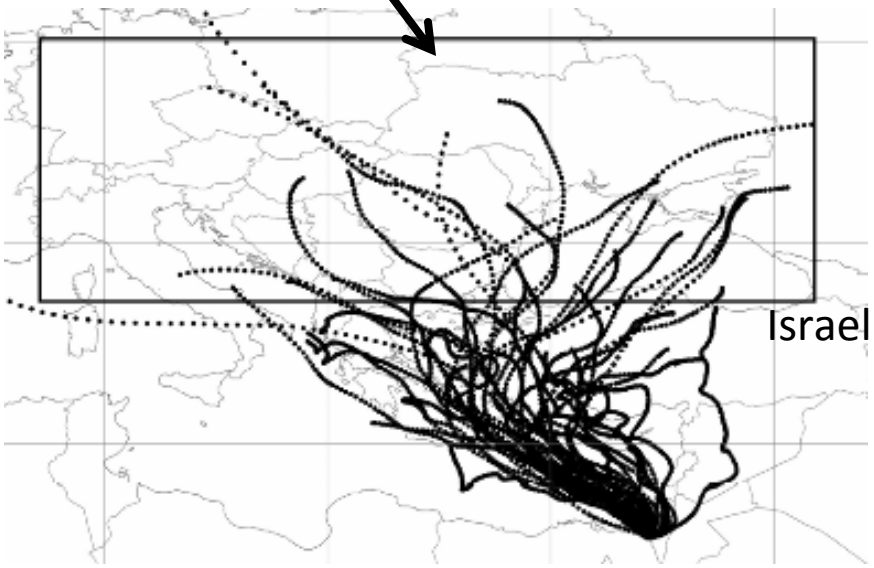




Sulfur decrease in Eastern Europe;



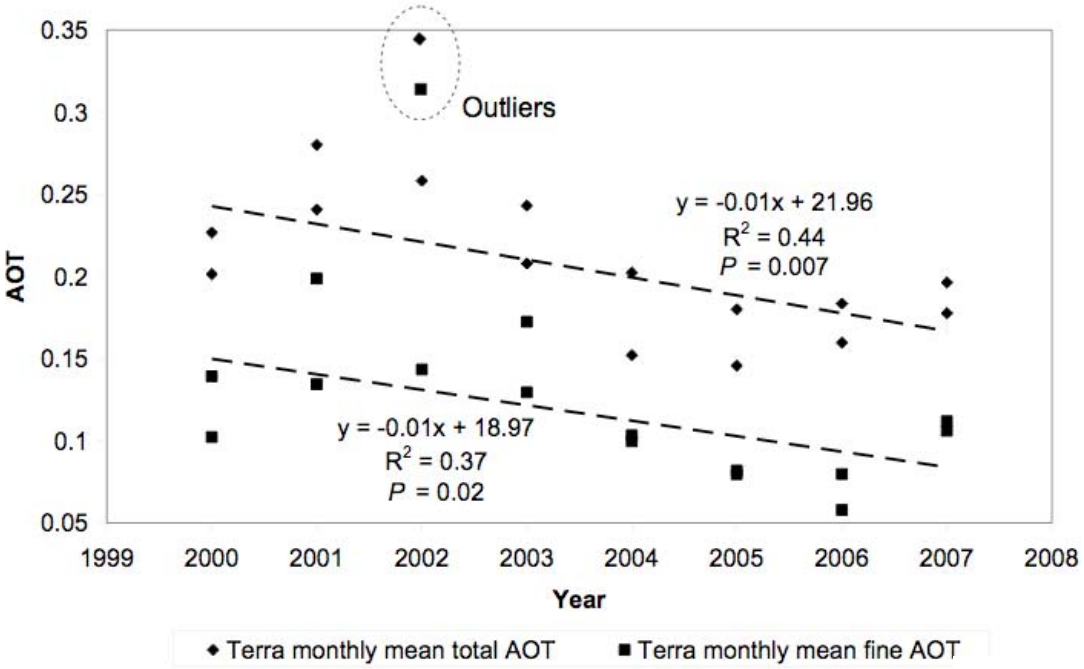
A case study



Is there reduction in downwind AOT during the summer?

Karneili et al., 2009

Terra over region

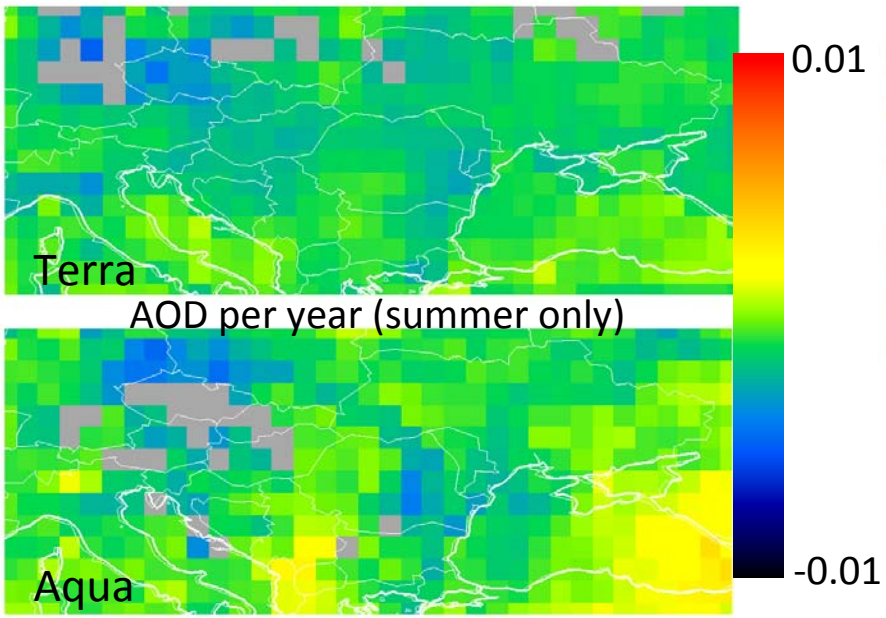


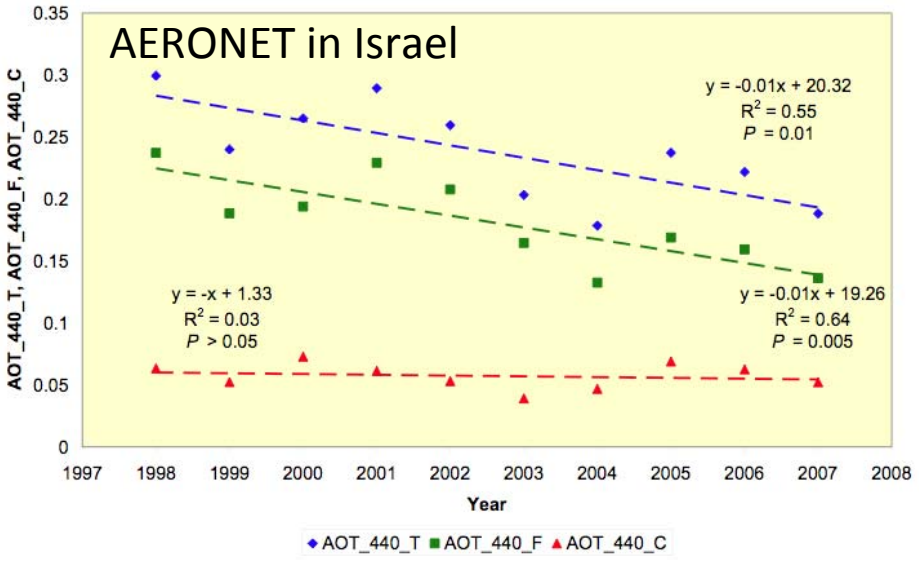
Remote sensing shows trends

Downward trend of total AOD
Which is a result of fine AOD only

Consistent with reduction in sulfur

Summertime





Karneili et al., 2009

Conclusions

- Level 2, Dark-target AOD is validated
  - >66% match with collocated AERONET sites, within Expected Uncertainty (EU)
  - Residual biases are being characterized
- Level 2, Deep blue AOD is being evaluated
  - We are developing a “best of” joint aerosol product for increased coverage
  - Evaluating dark VS deep algorithms in desert fringes
- Data are not absolute truth!
  - A ‘well-calibrated’ measurement (radiance) has uncertainties
  - The ‘retrieved’ parameter (Level 2) has compounded uncertainties
  - Aggregations (Level 3) again compound uncertainties.
- Trend studies are inconclusive
  - Sampling differences between the two sensors
  - Some tiny calibration issues
- Next steps!
  - Analyses of pixel counts, data confidence and regional dependencies
  - Correlations with clouds (And new MODIS “aerosol” cloud products)
  - Collaborative/Interpretative evidence (surface, aircraft, etc)
  - Integration with MISR and other instruments (Aqua, A-train, etc)
  - Of course, MODELS and AEROCOM! We must work together!