Squares, Circles and GIANT Spreadsheets: AERONET and the Dark Target aerosol algorithm

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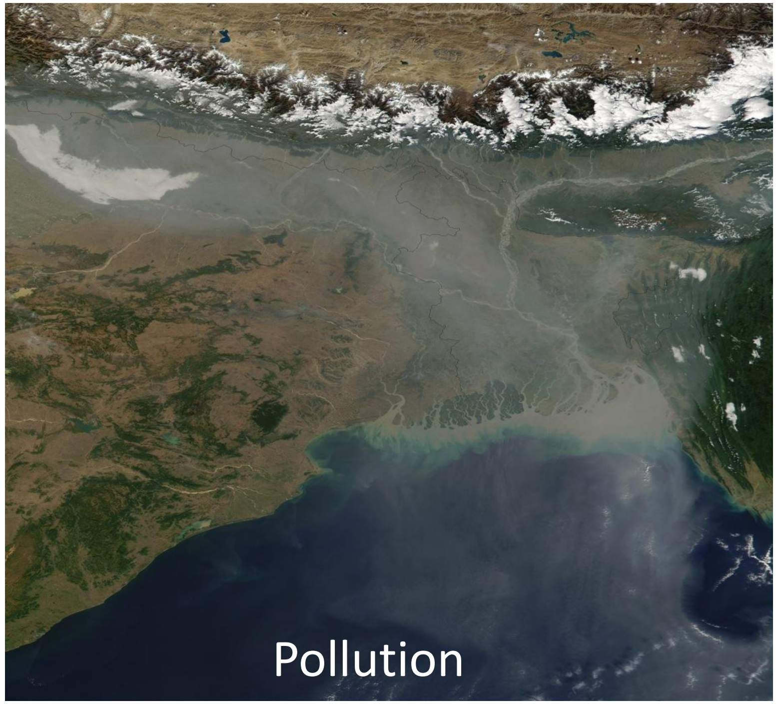
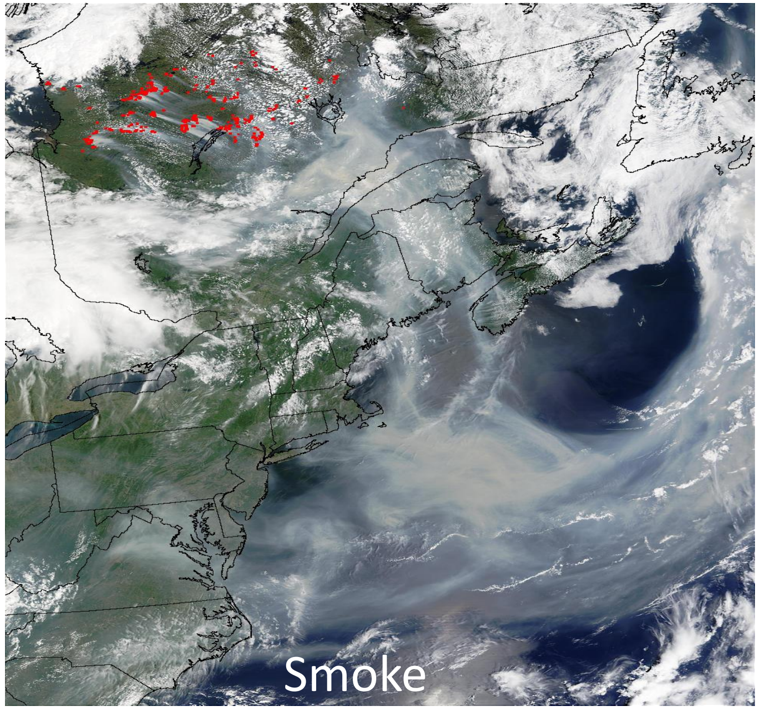
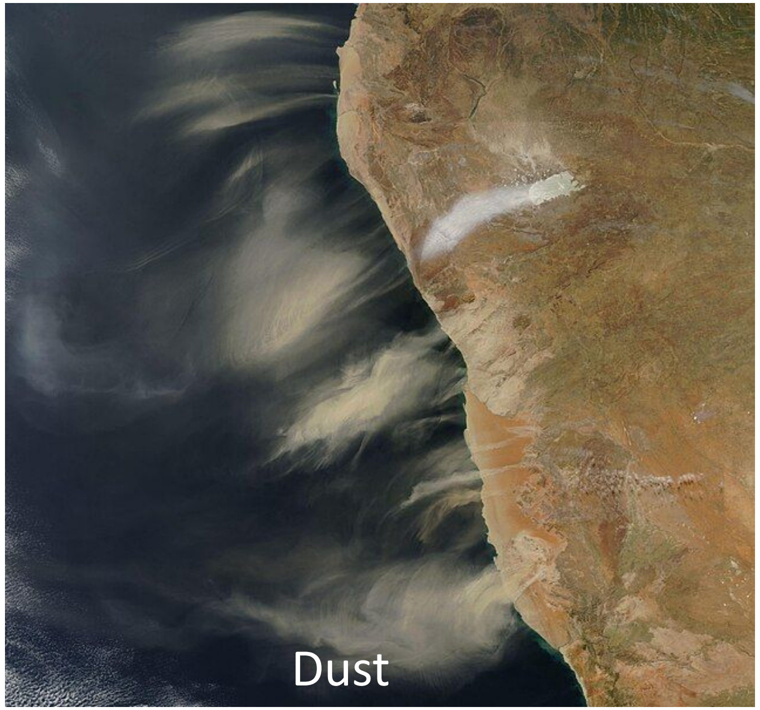
Contributions from Maksym Petrenko, Yingxi Shi, Mijin Kim







I joined the MODIS aerosol team in August 1998

- Charles (Validation & Fires)
- Vanderlei (Clouds & Absorption)
- Rong-Rong (image Processing)
- Rich (Case studies)
- Shana (programmer)
- Yoram (vision)
- Marcia (visiting faculty)
- Lorraine (Ocean alg: Aerosol models)
- Allen (Land algorithm)
- Rob (filling in cracks)

My first day in 1998

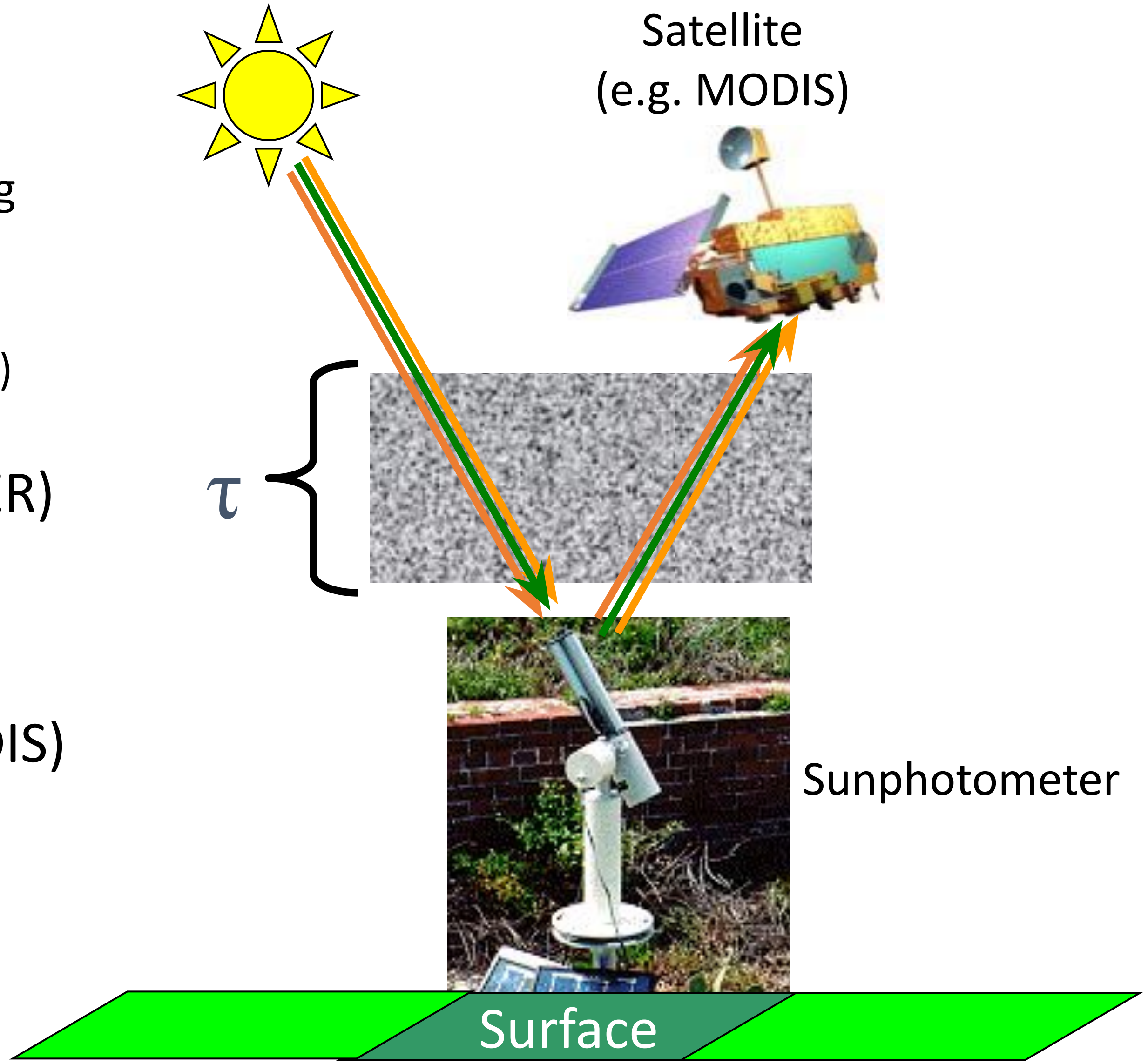
"A global team for a global algorithm"

Passive VIS/NIR Remote sensing 101

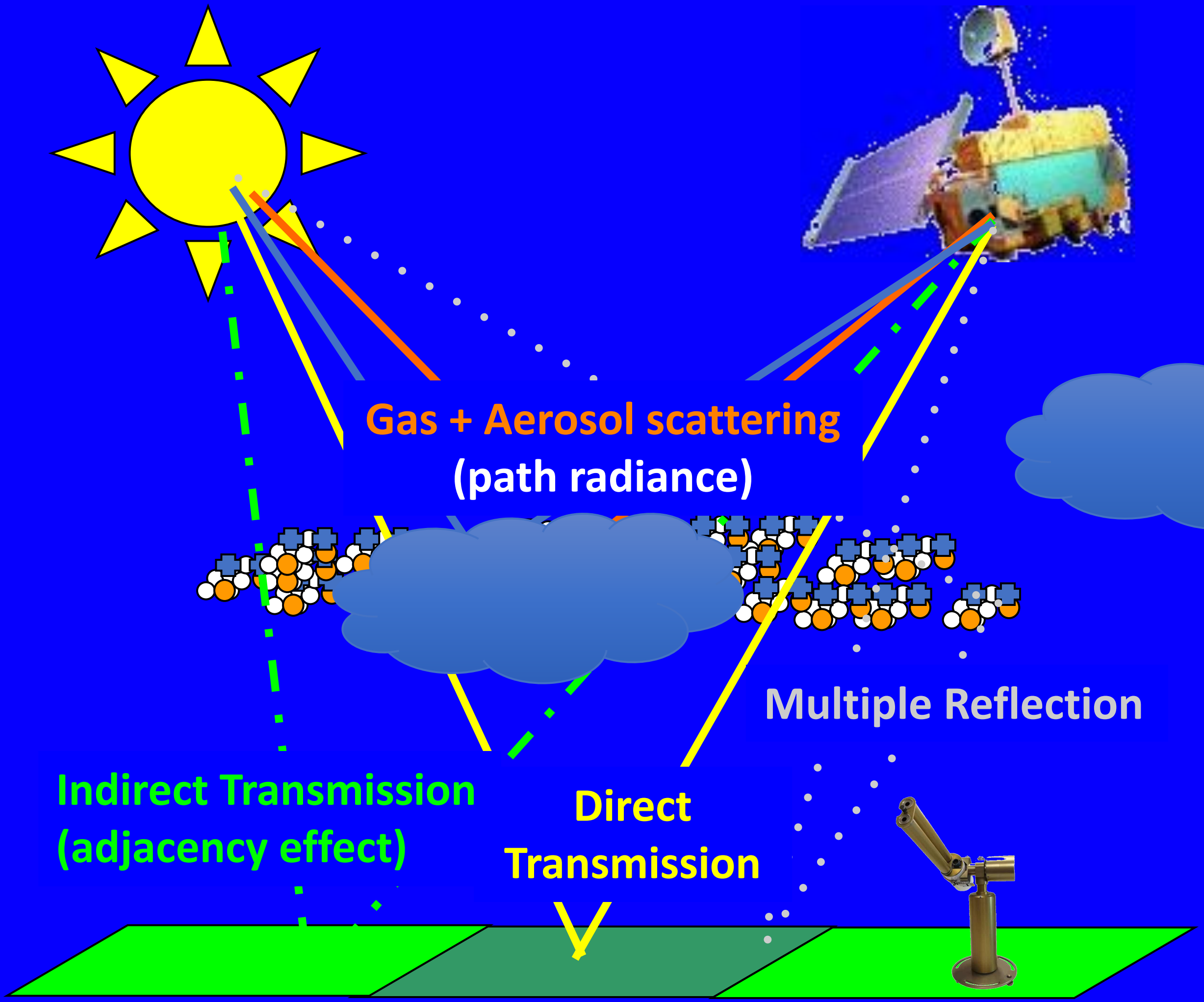
- Steps to observing aerosol properties
  - Measure spectral light extinction/scattering
  - Separate the aerosol signal from the total,
  - Retrieve aerosol optical properties
  - Infer aerosol physical properties (size, type)

- FROM THE GROUND (SUNPHOTOMETER)
  - Ground reflectance mostly negligible
  - Extinction: directly relates to AOD

- FROM SPACE (Satellite/sensor like MODIS)
  - Ground reflectance NOT negligible
  - Scattering: more assumptions necessary



The satellite reflectance signal is complicated…
DT has many assumptions, AERONET heavily used to constrain!

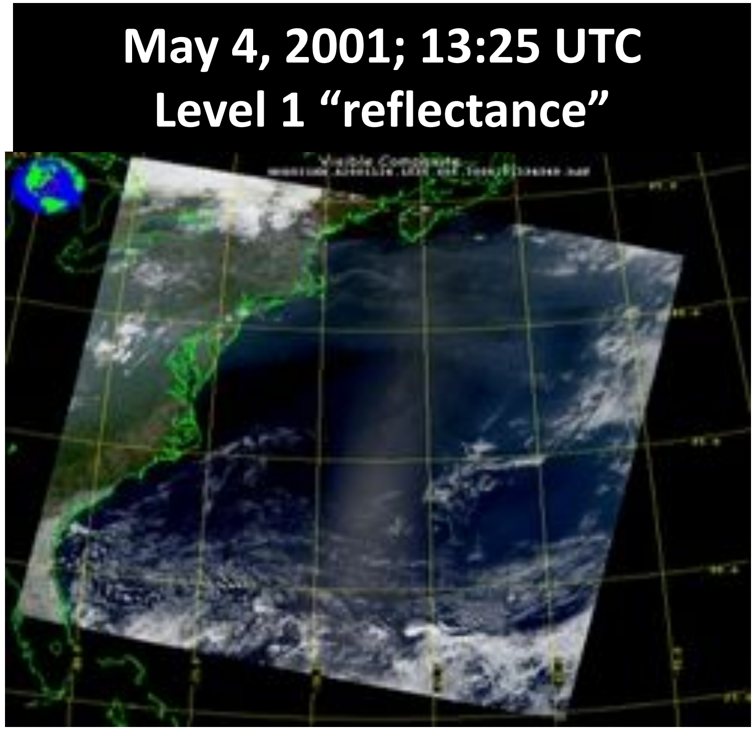


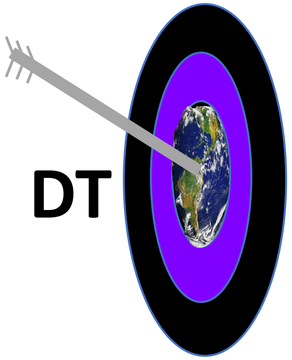
We must deal with:

1) The surface
2) 3-D reflective processes
3) Rayleigh scattering
4) Gas absorption
5) Clouds
6) **The AEROSOL!**

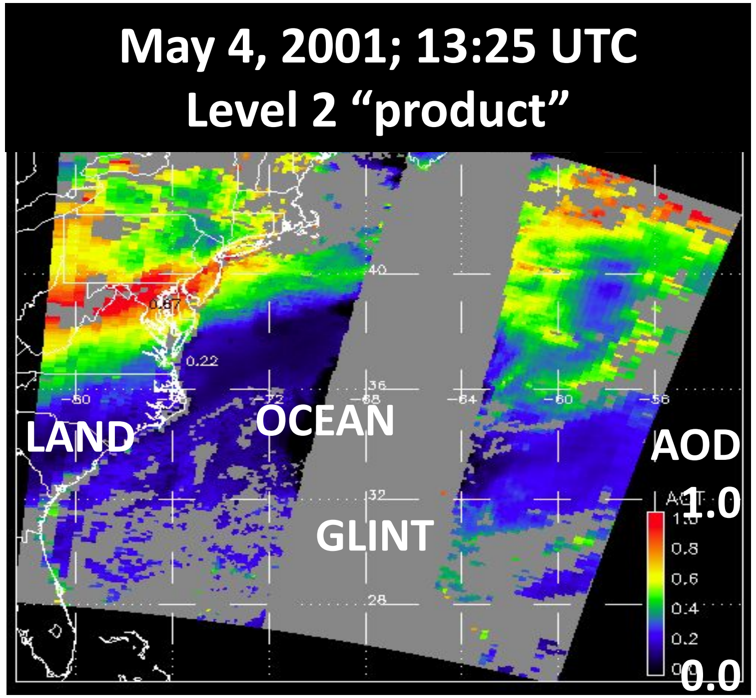
Dark Target Aerosol retrieval Algorithm ("dark surfaces")

What a sensor observes





Attributed to aerosol (AOD)



- Established by Kaufman, Tanré, Remer, et al (1997)
- Modified by Remer, Levy, Gupta, Sawyer, Shi et al (2005, 2010, 2013, 2015, 2020, etc.)

- **Requires**: Observations of spectral reflectance in selected bands between "blue" and "SWIR" wavelengths (other bands help with cloud/surface masking and filtering)
- **Retrieves**: AOD at 0.55 μm, spectral AOD (AE), Fine Model Weighting (FMW), cloud-cleared reflectances, diagnostics, quality assurance

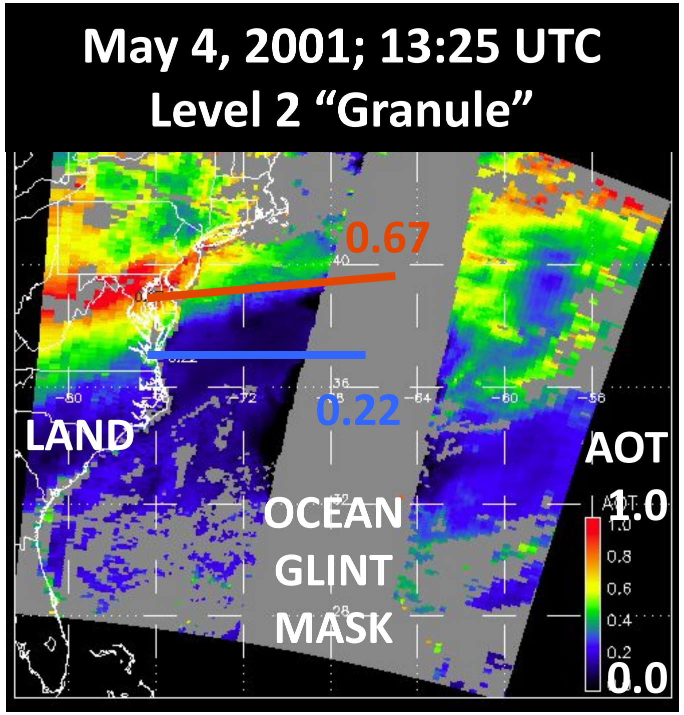
AERONET was and continues to be fundamental to DT in many ways

- Development of satellite algorithm (Lorraine discussed during her earlier talk)
  - Inversions: Create aerosol “models” (size distribution, shape, refractive index)
  - Sun Observations: Atmospheric correction □ surface reflectance parameterization (SRP)

- Evaluation of satellite products (nearly the remainder)
  - Sun Observations: validate retrieved AOD products
  - Inversions: validate the model choices

- Rinse and repeat: 1) Update assumptions. 2) apply to new satellite sensors. 3)Validate. 4) Updates should represent new sites with different conditions. See Mijin Kim poster

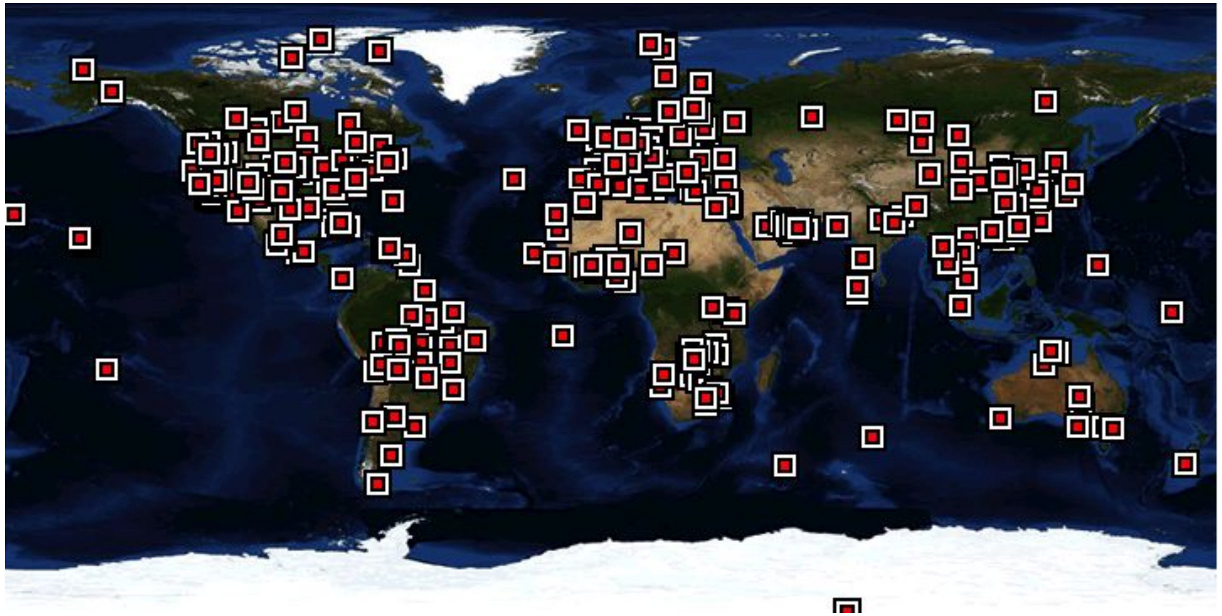
Validation: Use AERONET (and MAN) to evaluate satellite results



Compare land and ocean products to AERONET, separately

•Validation: 66% within "Expected Error" (EE) defined as

•Note that EE may vary for different sensors

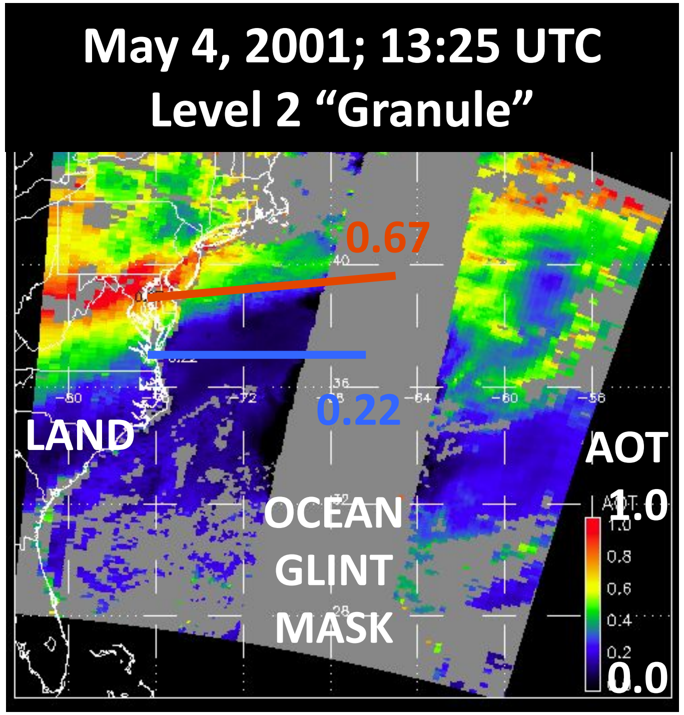


AERONET:
representing different types of aerosols, clouds, and meteorological regimes

We want to "collocate" the satellite and the ground-based observations.

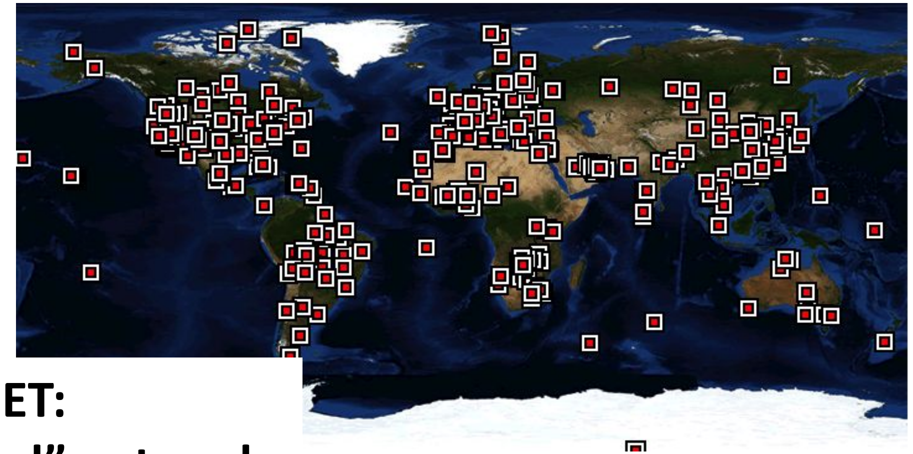
What we learn about our MODIS product from AERONET

Derivation of Expected Error envelopes (compare with theoretical)

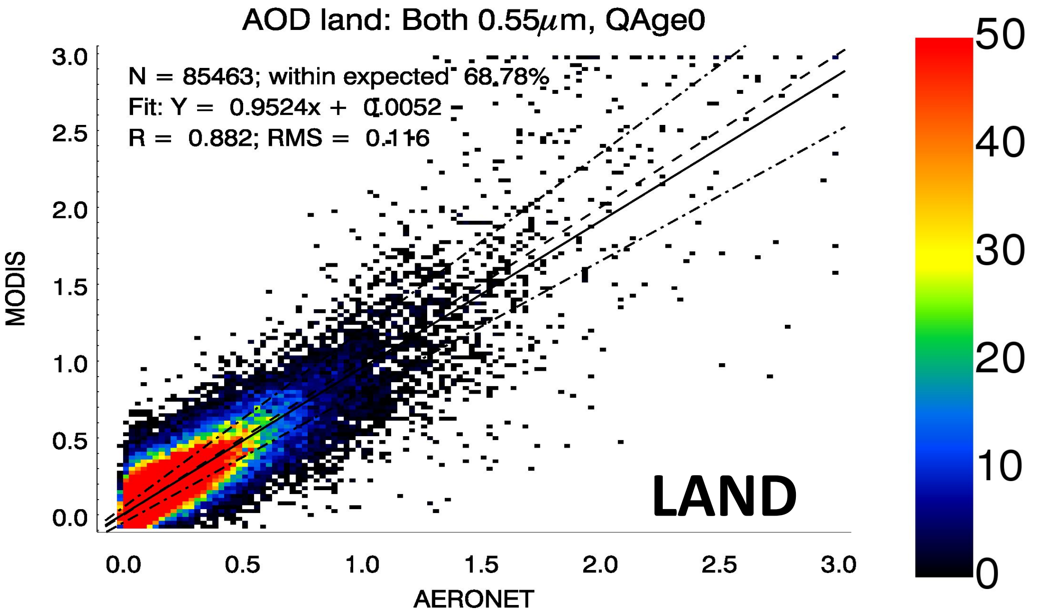


Compare land and ocean products to AERONET, separately

- Validation: 66% within "Expected Error" (EE) defined as
    - Land: ±(0.15τ + 0.05)
    - Ocean: ±(0.05τ + 0.04)
- Note that EE may vary for different sensors



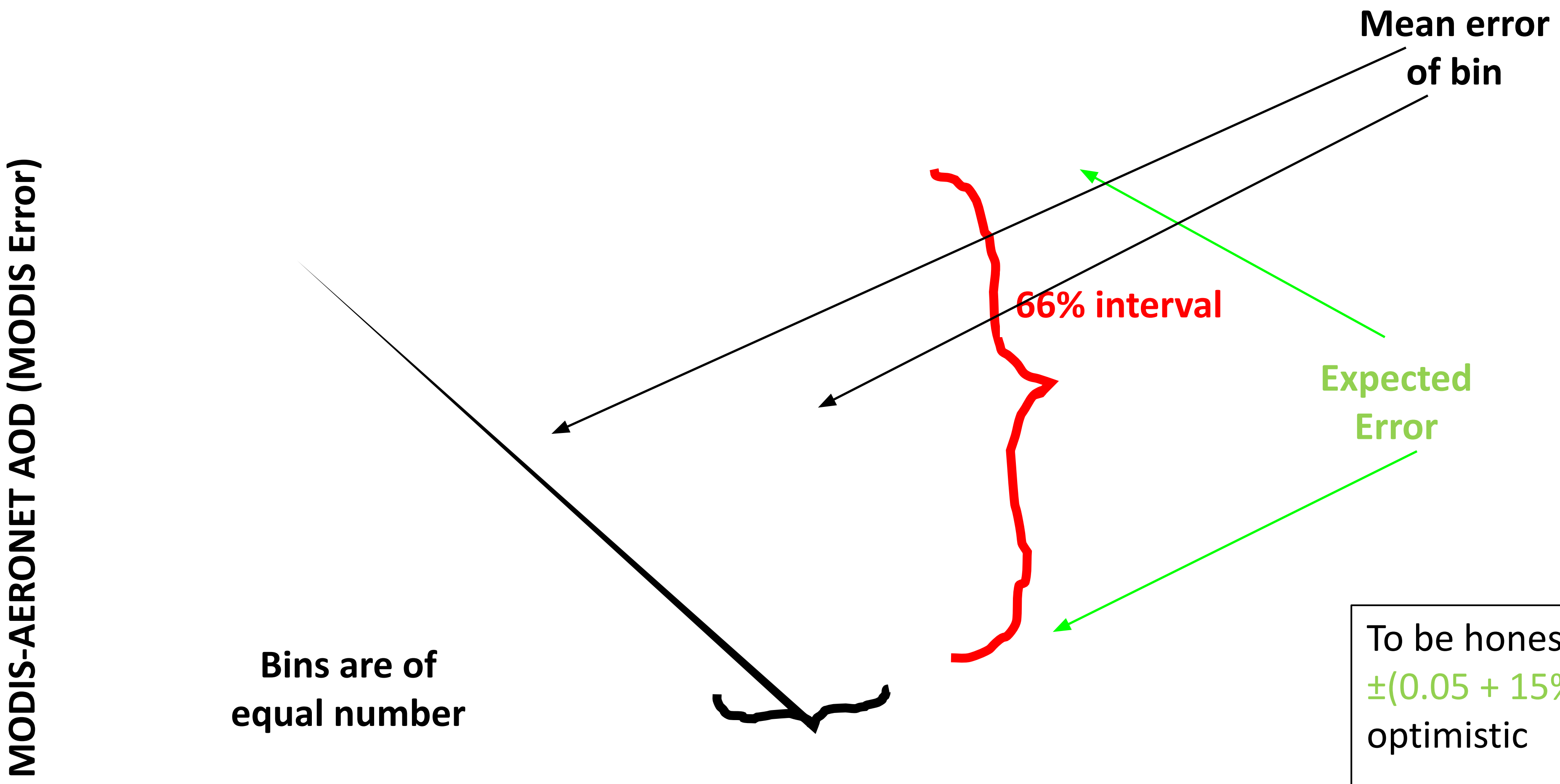
AERONET:
A "global" network



Levy et al., ACP 2010

… Plotted a different way

AOD @ 553 nm; Land; Highest confidence

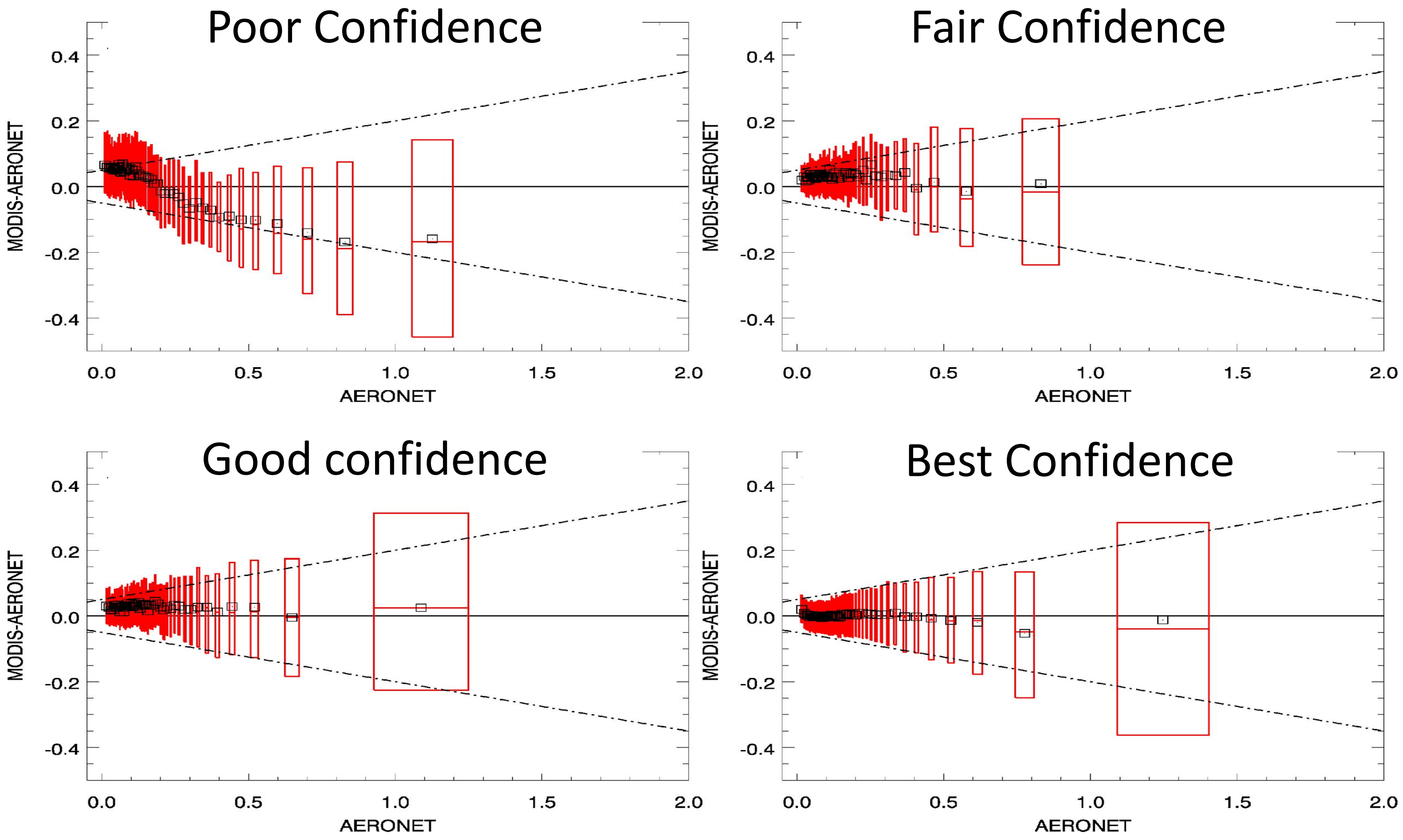


To be honest, maybe ±(0.05 + 15%) is too optimistic

Maybe better is ±(0.05 + 20%) for land.

By "binning", we can visualize systematic biases

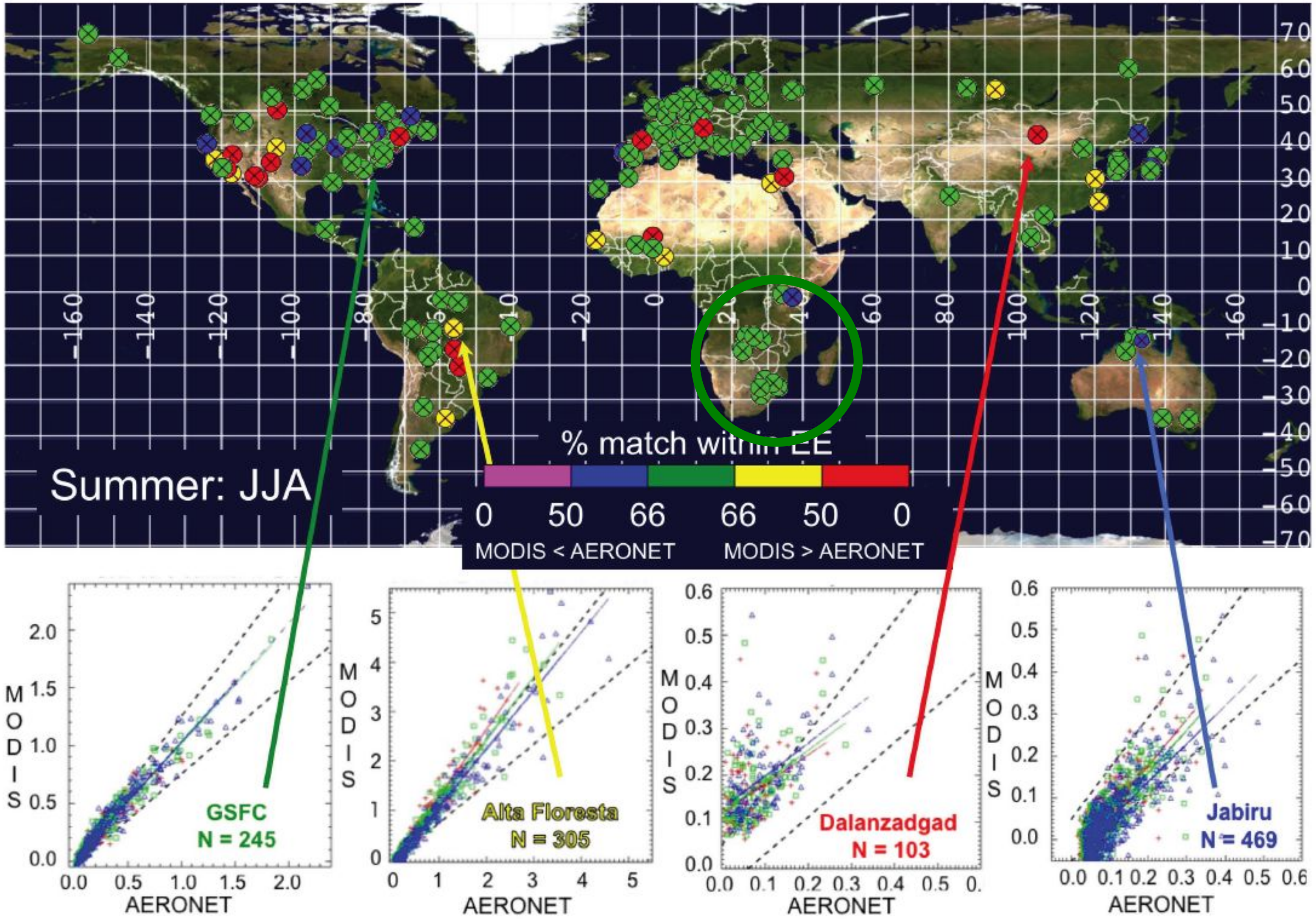
Satellite Retrieval "Quality Flags" are VERY important



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

Levy et al., ACP 2010

Location is also VERY important!

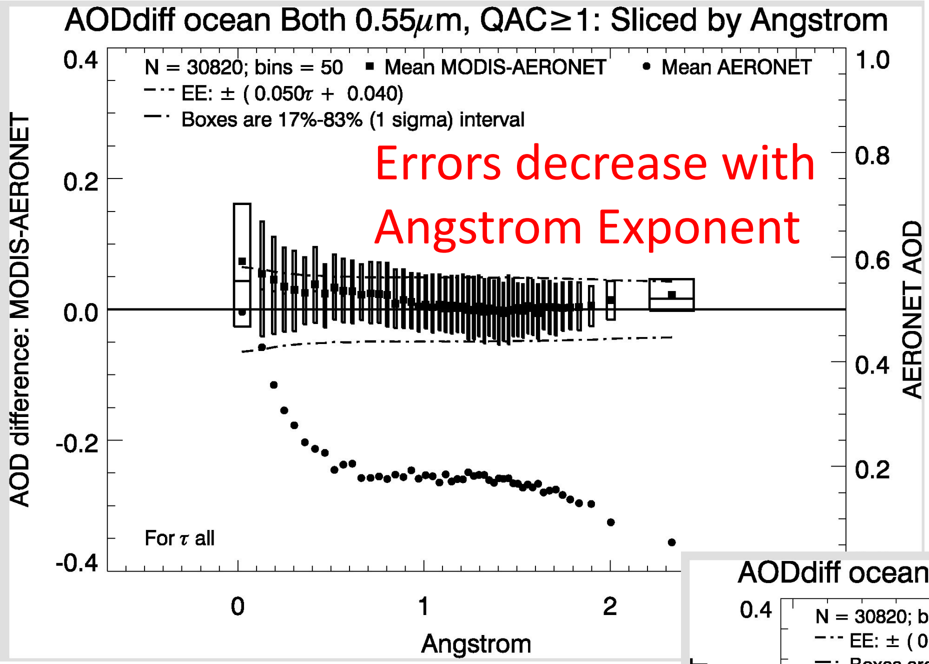


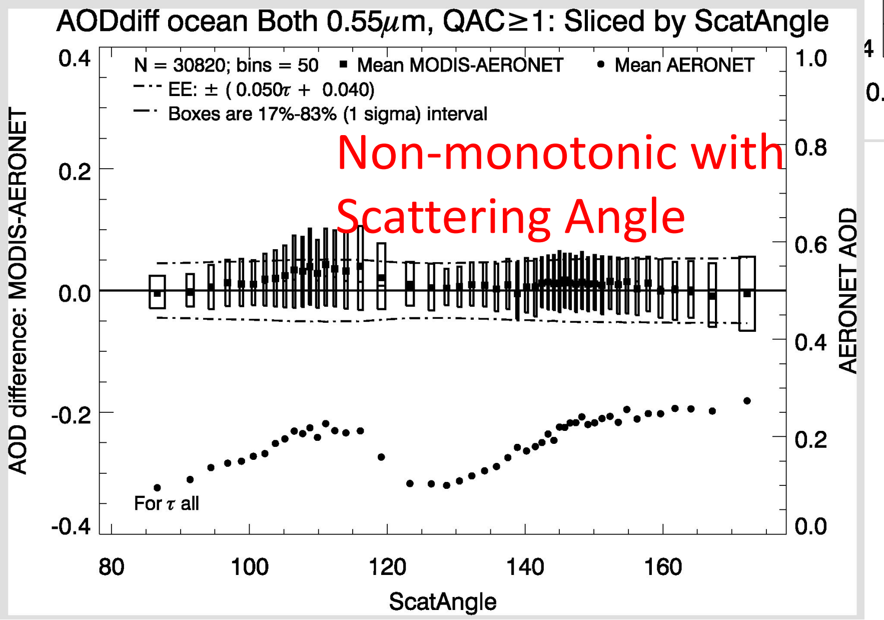
Geographical Mapping identifies regions of agreement as well as issues

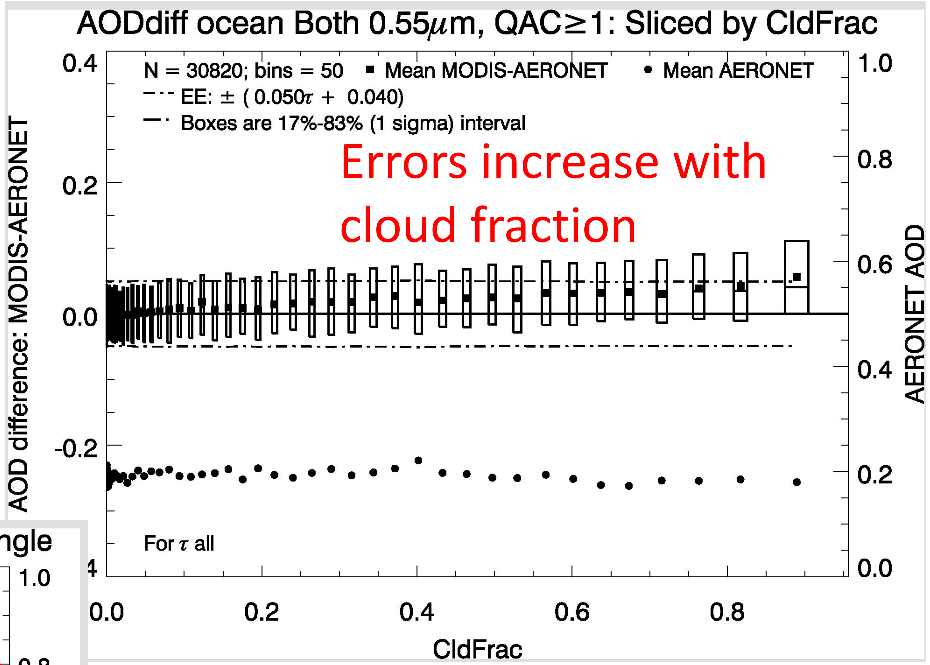
Use colors to denote “goodness” of agreement.

Levy et al., ACP 2010

"Slicing and Dicing": Error as function of different conditions.







For each plot:

- Left axis is satellite – AERONET (for boxes)
- Right axis is AERONET (dots)
- Bottom axis is variable in question

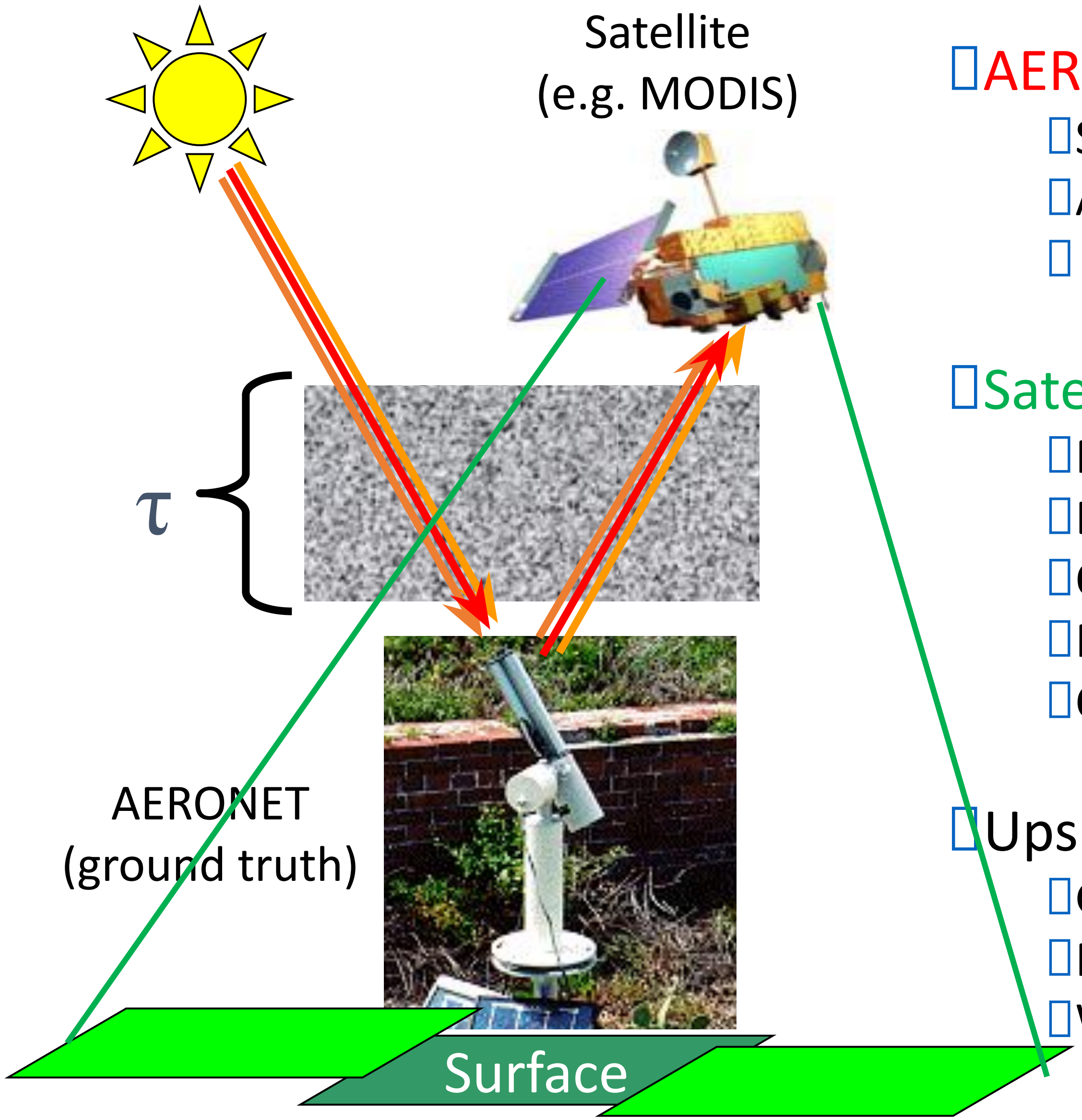
Note many other dependencies can be explored

Expected Error ratio (fraction of expected error) to find calibration drift!

- EE for global AOD is defined using absolute & relative terms, for example:
  - EE = ±(constant + %AOD)), where AOD is measured at ground by AERONET
- EER = $(satellite - ground)$ / $(EE(ground))$
- -1 < EER < 1 means that retrieval is "within EE"

- Using EER, we were able to show that MODIS-Terra's was drifting creating a trend in our agreement with AERONET
- It has since been much improved (no such trending)

Let’s talk about co-location



- AERONET is a point measurement
  - Sun observations approximately every 15 mins (mid-day)
  - AOD uncertainty ≤0.02
  - Observes sun via an angle
- Satellite observes an area
  - MODIS Native “pixels” on order of ~1 km
  - Dark Target retrieval “boxes” on order of ~10 km
  - Observes surface from angle - different than AERONET
  - May be surface topography and/or heterogeneity
  - Clouds may obscure part of retrieval “box”
- Upshot
  - Ground and satellite are not measuring the same thing
  - Need spatial/temporal statistics.
  - What is an appropriate strategy for co-location?

What is the best strategy for co-location?

- It depends on what you are trying to do
  - Maximize number of co-locations?
  - Evaluate local/regional/global retrievals?

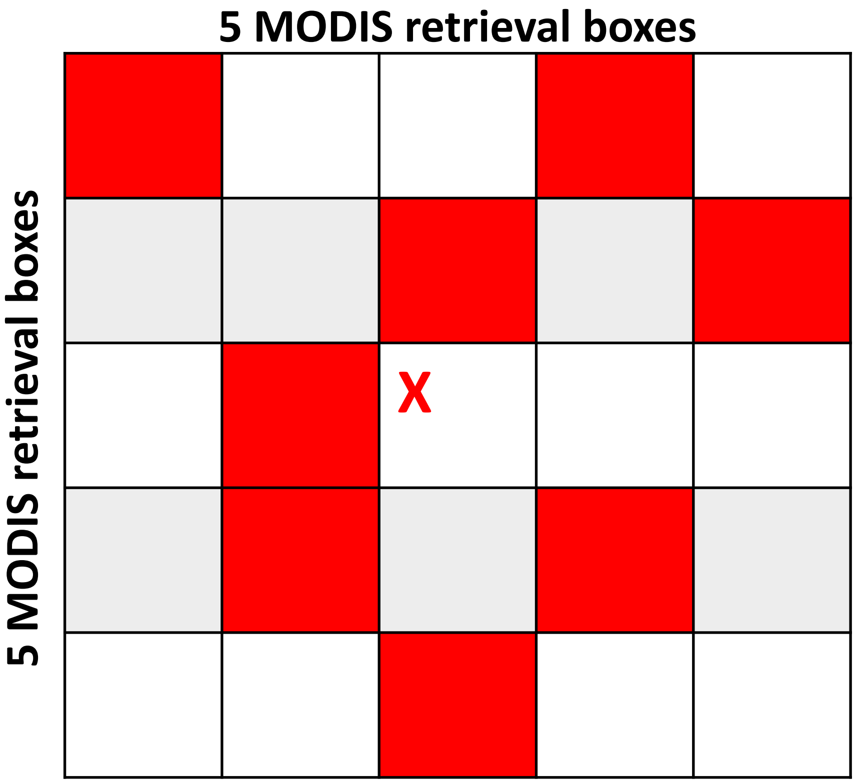
Land or ocean	Δx (km)	Δt (min)	AERONET Mean	MODIS Mean	R	Slope	Offset	N	% EE	% above EE	% below EE
land	7.5	15	0.131	0.168	0.83	0.997	0.04	794	62	29	9
land	7.5	30	0.144	0.189	0.84	1.069	0.03	2674	62	31	7
land	7.5	60	0.152	0.201	0.84	1.046	0.04	3280	62	31	7
land	25	15	0.129	0.149	0.88	0.944	0.03	1081	71	21	8
land	25	30	0.139	0.164	0.86	0.971	0.03	3611	71	22	7
land	25	60	0.149	0.175	0.86	0.961	0.03	4513	70	23	7
ocean	7.5	15	0.135	0.145	0.91	0.91	0.02	145	66	24	10
ocean	7.5	30	0.134	0.147	0.93	0.936	0.02	495	70	23	7
ocean	7.5	60	0.136	0.149	0.93	0.959	0.02	626	70	23	7
ocean	25	15	0.129	0.145	0.90	1.048	0.01	449	67	24	9
ocean	25	30	0.147	0.170	0.93	1.127	0.0	1507	66	26	8
ocean	25	60	0.152	0.171	0.93	1.086	0.0	1915	67	25	8

* Expected error for land is $\pm 0.05 \pm 0.15$ AOD, and for ocean it is $\pm 0.03 \pm 0.05$ AOD.

Remer, Mattoo, Levy and Munchak, 2013. *https://amt.copernicus.org/articles/6/1829/2013/amt-6-1829-2013.pdf*

MAPSS (2002) = MODIS Aerosol and associated Parameters Spatio-temporal Statistics (“Squares”)

- “data structure developed for comprehensive and rapid global validation of MODIS aerosol products at near real time. ”
- “to achieve a meaningful and balanced validation, we compare spatial statistics from MODIS with corresponding temporal statistics from sunphotometers. ”
- □ Window = 5 x 5 for satellite and ±30 minutes for sunphotometer (“average travel speed of an aerosol front is of the order ~50 Km/h.”)
- computes number, mean, standard deviation, median, min, max for both satellite and sunphotometer at all wavelengths. Also “plane fitting” of spatial (satellite) and temporal (sunphotometer) windows.
- The output ”.csv” file known as the ***GIANT Spreadsheet*** because it had hundreds of columns, and eventually thousands of rows!
- MAPSS ran automatically for many years, providing statistics for MODIS (Terra and Aqua).



- A 5x5 “Square” of MODIS 10 km retrieval boxes, centered on the AERONET site (**X**)
- Statistics would be based on valid retrievals (shaded)

Ichoku et al., 2002; https://doi.org/10.1029/2001GL013206

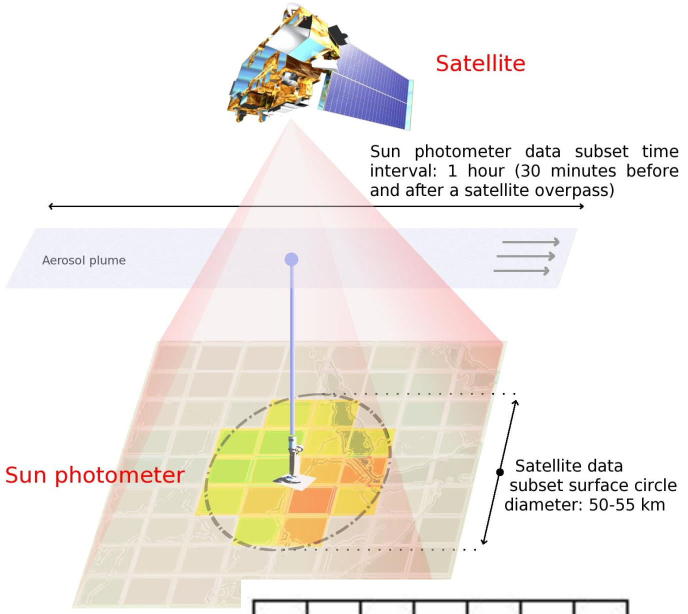
MAPSS (2012) = Multi-sensor Aerosol Products Sampling System ("Circles")

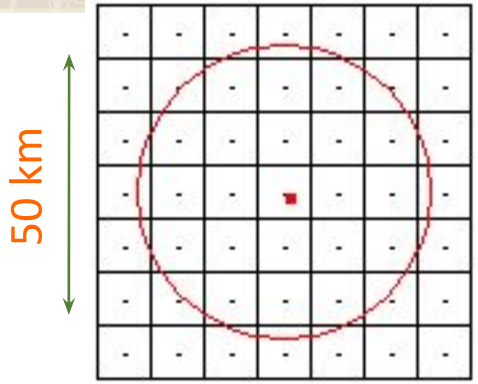
- "consistently samples and generates the spatial statistics (mean, standard deviation, direction and rate of spatial variation, and spatial correlation coefficient) of aerosol products from *multiple spaceborne sensors, including MODIS (on Terra and Aqua), MISR, OMI, POLDER, CALIOP, and SeaWiFS.*

- Samples of satellite aerosol products are extracted over Aerosol Robotic Network (AERONET) locations as well as over other locations of interest such as those with available ground-based aerosol observations.. "

- "the multi-sensor data sampling space is now defined by a circle of approximately 50-km diameter. " But a Window diameter = 55km "would enable overall balanced sampling within the circular sample space for the different data products, at least near nadir"

- New MAPSS adopted to Giovanni system and ran automatically for many years. Could it be resurrected?



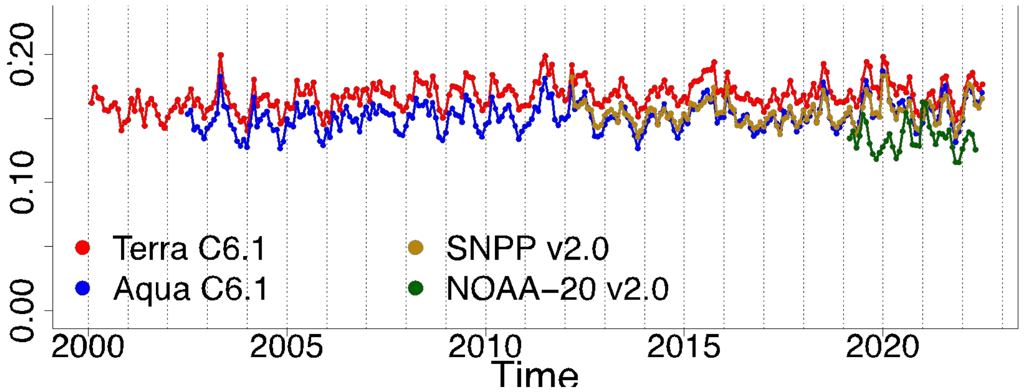


- A 27.5 km "circle" of MODIS 10 km retrieval boxes, centered on the AERONET site (**X**)

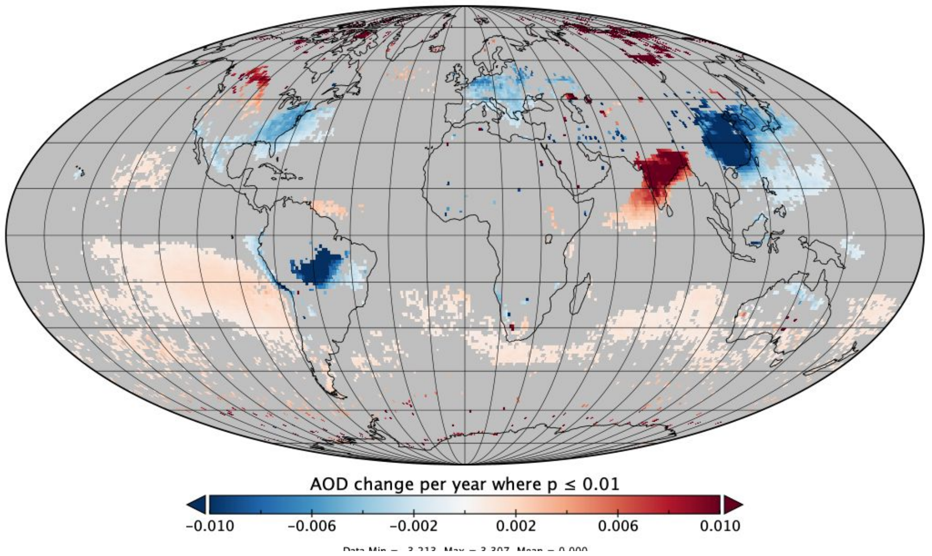
Petrenko, M., et al., https://doi.org/10.5194/amt-5-913-2012

MODIS: Now in collection 6.1 and also VIIRS Version 2.0 for continuity
We still have biases, but we understand more
And have 20+ years of data!

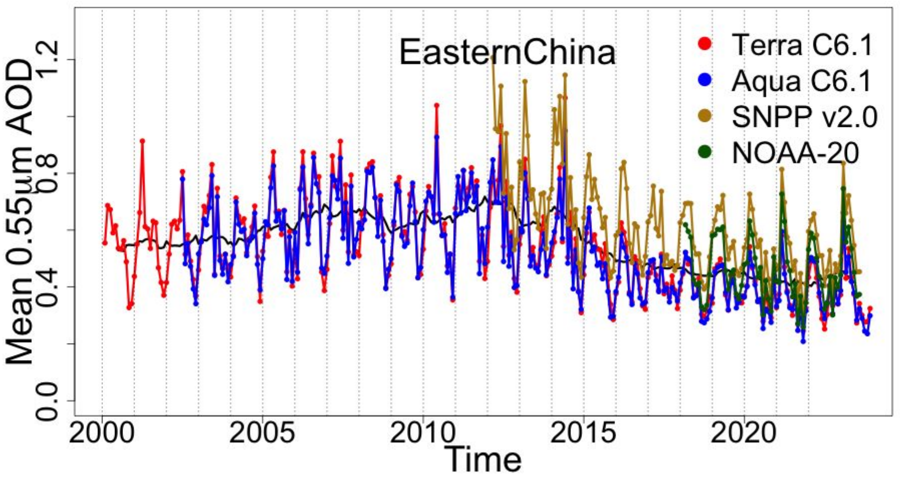
Time Series: Add VIIRSs on S-NPP and JPSS series



20-year Trend in AOD: 2002-2022



Explore Regional trends with continuity of LEO:



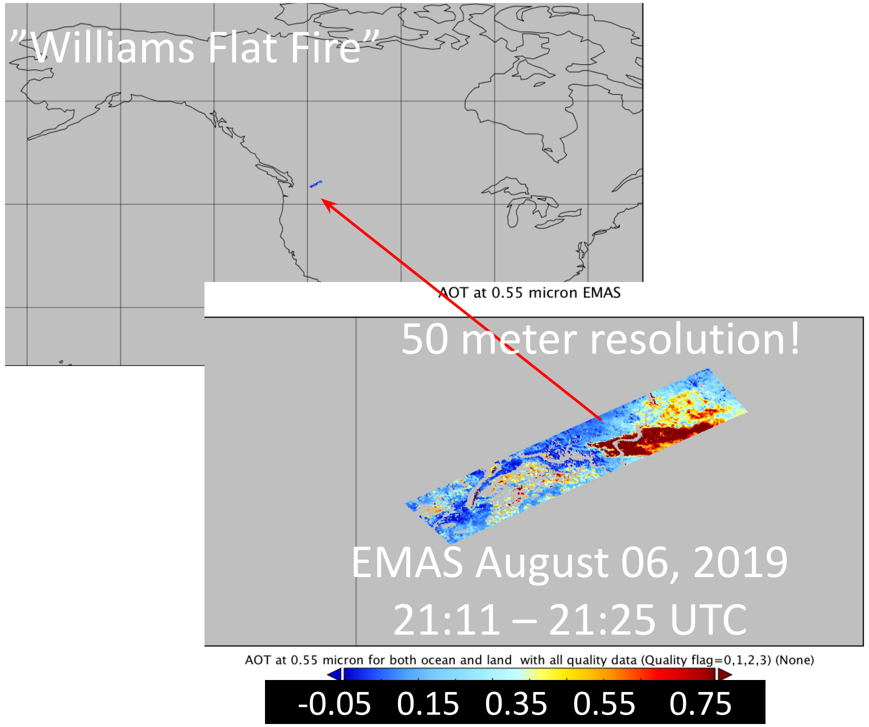
But what about for higher resolution data?

- Higher resolution imagers (Landsat – like? Commercial sensors?)
- Airborne remote sensing (50 meter ”pixels”)
- Geostationary imagers (≤10 minute cadence)

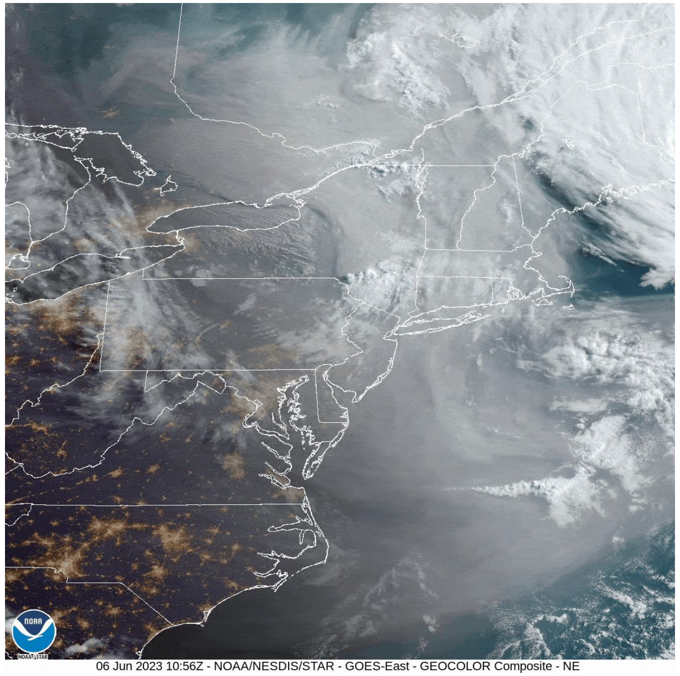
Does ±30 minutes and ~25 km make sense?

How do you “validate” the higher temporal / spatial?

Smoke observed by airborne



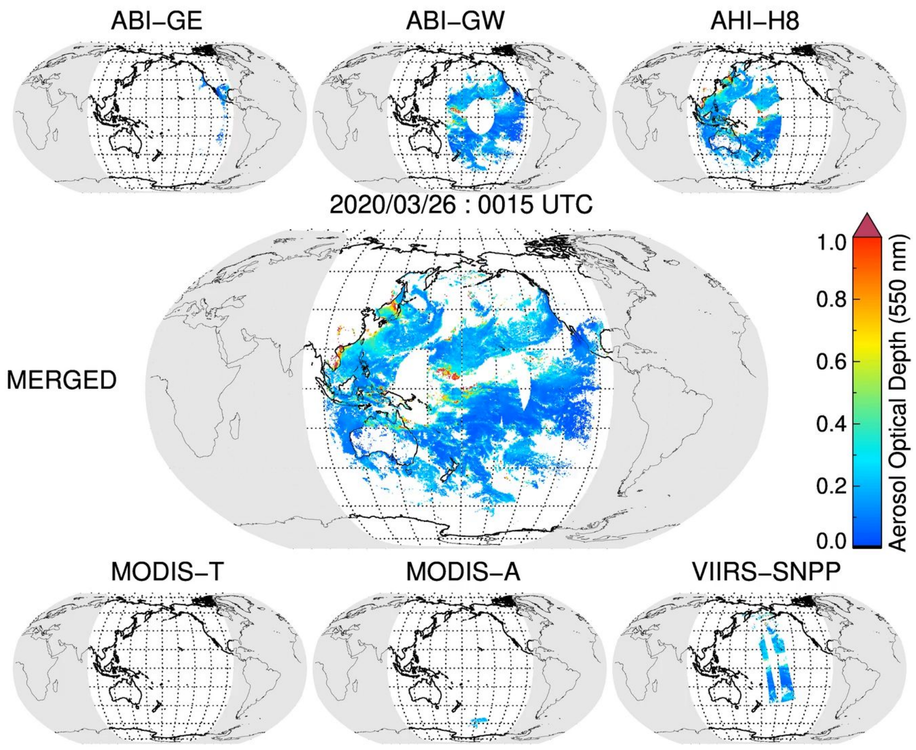
Smoke observed by GOES-East



Using AERONET to evaluate each product!

- One challenge on how to describe statistics “in bulk”
- ±30 minute AERONET window maybe does not make sense with GEO is every 10 minutes. How do we “prove” the usefulness of the high cadence GEO?
- ±27.5 km radius remote sensing window maybe doesn’t make sense when entirety of swath (e.g. eMAS airborne) is only 37 km. How do you ”prove” the usefulness of the high spatial resolution?

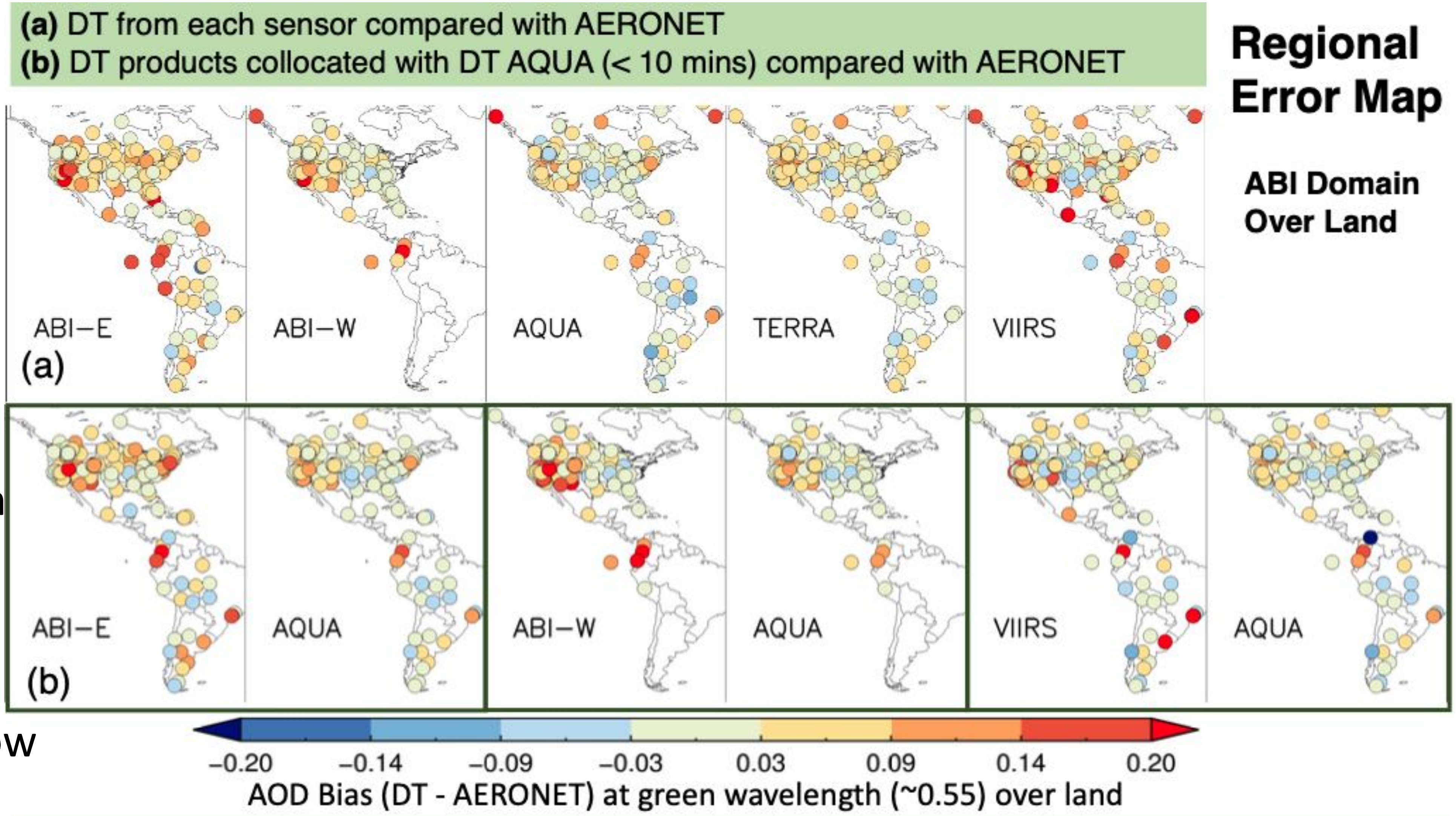
XAERDT: GEO-LEO product on 6 sensors



XAERDT: GEO-LEO "In bulk" Comparison with AERONET

Independent compared with AERONET

3-WAY collocation with Aqua and AERONET

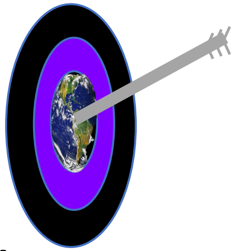


Regional Error Map

ABI Domain Over Land

GEO-LEO window is ±15 mins and ±20 km

Summary (1)



- The Dark Target (DT) aerosol algorithm compares remote-sensed observations with pre-computed Lookup Tables (LUTs) that represent expected aerosol/molecular/surface conditions.
- AERONET and the DT algorithm share a long history:
  - AERONET sun and sky used for development of DT
  - AERONET sun and sky used for validation
  - AERONET sun and sky inform the needs for improvement
- Methods for validation have evolved throughout our 30+ years together
- Early concepts were about a spatial/temporal window of ±30 minutes and ~25 km square or circle.
- With high-resolution and GEO sensors, we have to re-define these windows.

Summary (2)

- The DT retrieval algorithm has derived a >24-year time series, that coupled with 22 years from Aqua, provides robust characterization of global aerosol and regional aerosol trends.
- With both Terra and Aqua leaving nominal orbits, DT is ported to VIIRS (on Suomi-NPP and JPSS series) enabling Low-Earth-Orbit (LEO) continuity through the 2030s.
- For tracking regional aerosol and characterizing aerosol diurnal cycles, we have ported DT to GEOstationary platforms (Himawari and GOES-R series) and are working on a GEO-LEO synergy.
- AERONET will remain integral as we validate and improve.

MODIS and VIIRS products 2000-present

GEO-LEO experiment: 2019-2022 only

https://darktarget.gsfc.nasa.gov/