Multi-Sensor Aerosol Data Assimilation

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Aerosol Observability Workshop, April 29, 2010

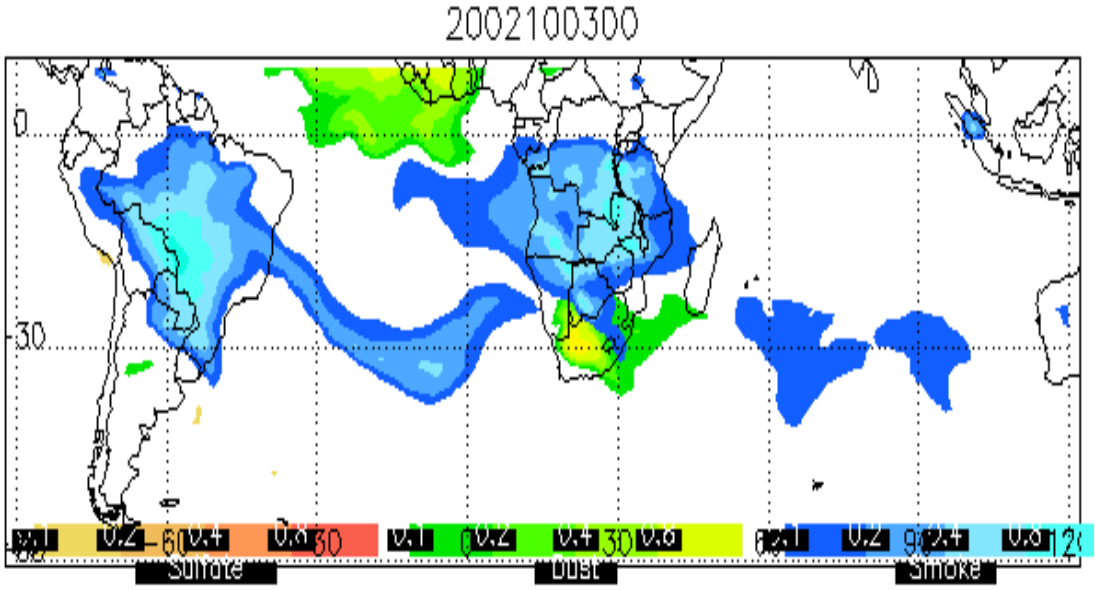
Goals and Challenges

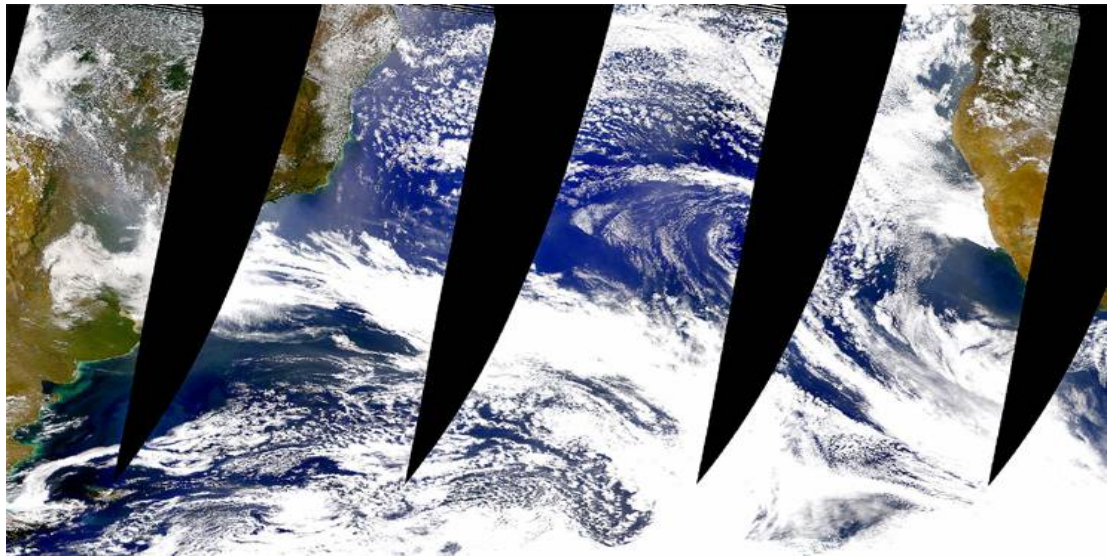
Goals:

- Improve aerosol and visibility forecasts
- Assess aerosol/climate impact
- Characterize regional air quality

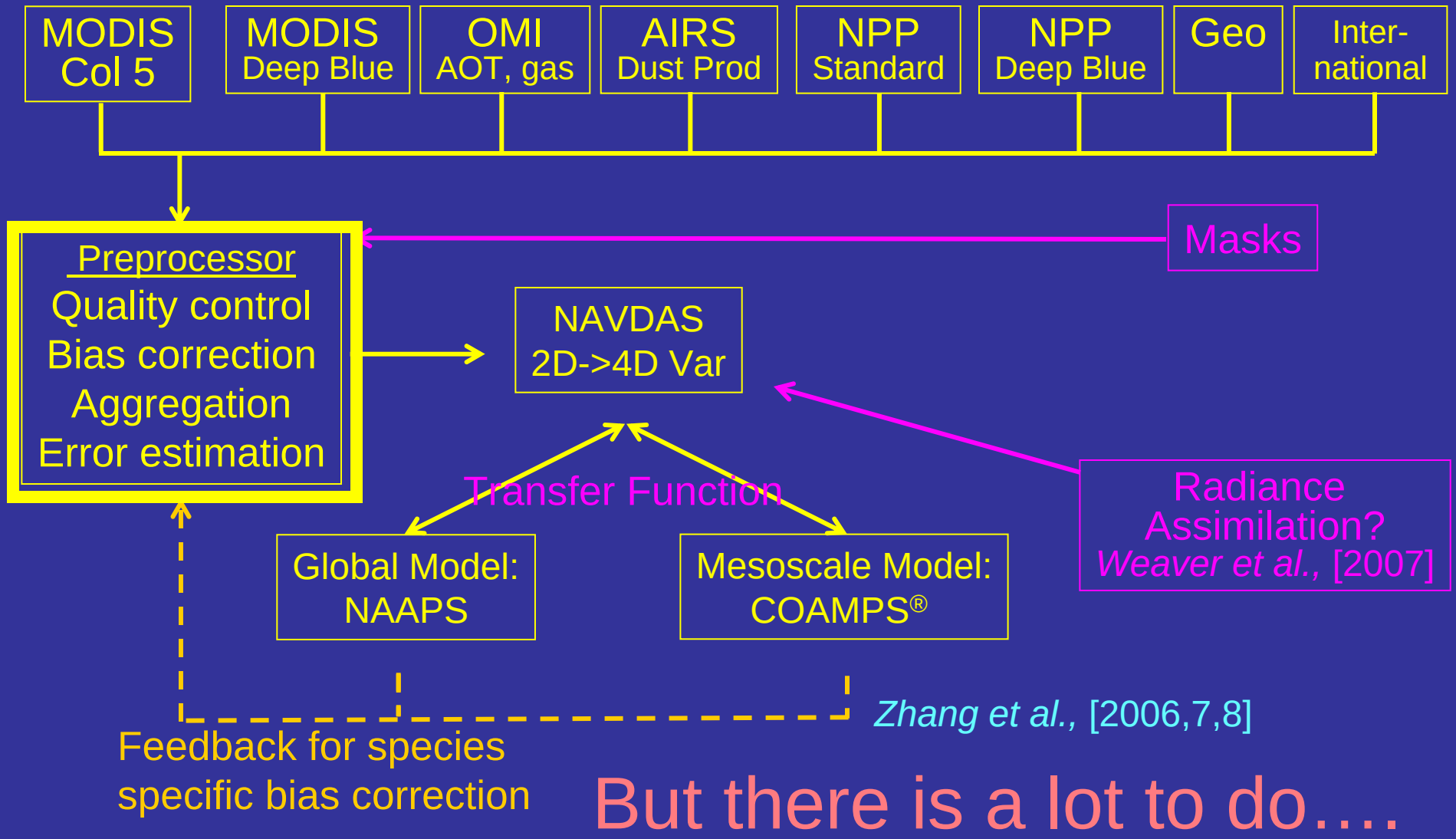
Challenges and questions:

- We need to work in *operational* mode. Need something *robust*.
- We need to fully utilize the available data streams. What ways can multi-sensor data streams help?
- Do the satellite products and model results make physical sense?





Navy Desired AOT Operational Data Assimilation: 2007



But there is a lot to do….

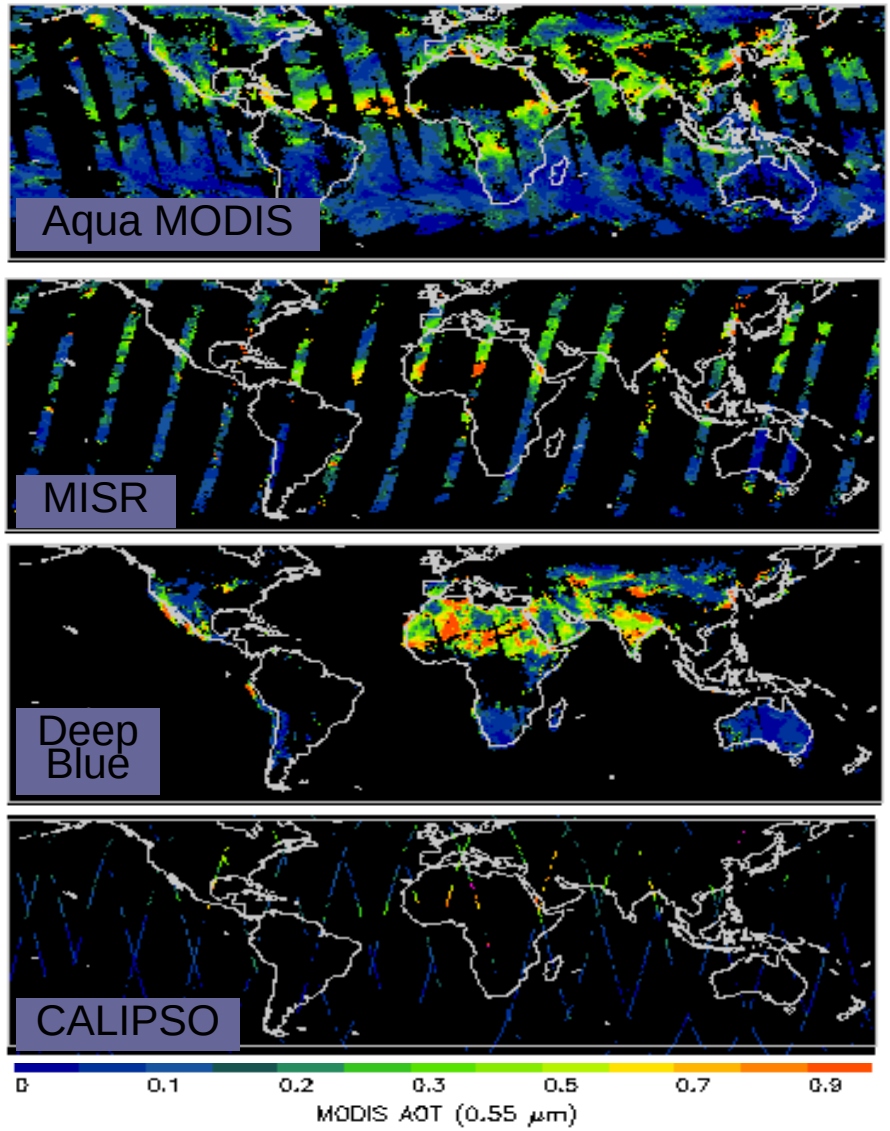
Five questions you should ask before multi-sensor assimilation

1. Coverage: Is the coverage sufficient for your application? If not, how will you spread your information?
2. Data Quality: Do your products have similar uncertainties? If not, are you really adding information?
3. Correlated Error: Are the data sets really independent or do they share similar biases?
4. Longevity: Is there a sufficient product time-series for your application?
5. *Bottom line*: Does the product add enough information to the process to justify the effort?

Example: Spatial coverage

- Need daily data, not long-term averages.
- MODIS provides the most global coverage. But, data is lacking over bright surfaces and where sun glint biases the scene.
- MISR data increases observability over bright land surfaces. But the spatial coverage of MISR is much narrower than MODIS.
- DeepBlue represents an important step forward for MODIS. Could the DeepBlue product lead to closing the question?
- The vertical profile from CALIPSO is critical, but the spatial limitations of the orbital track raise a new set of concerns.

Daily coverage

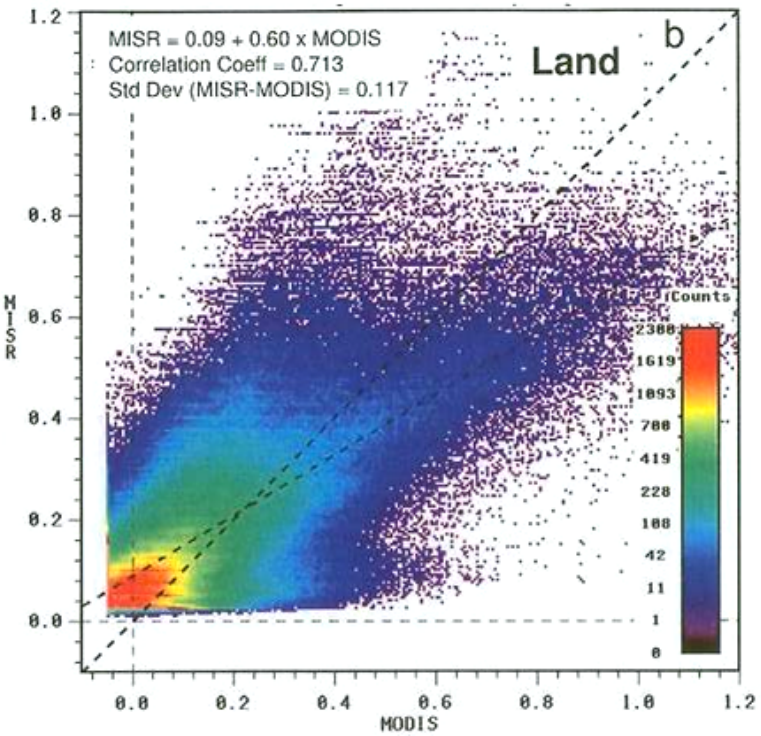


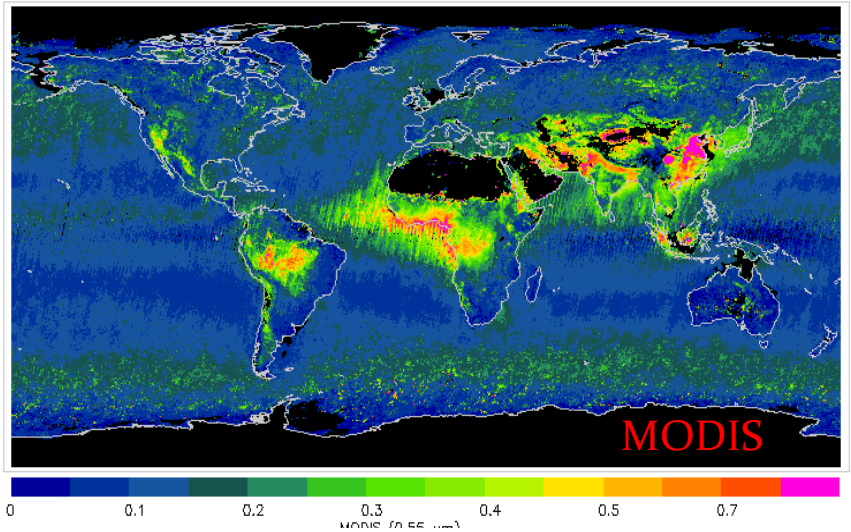
Challenge: Data Quality and Bias Constraint MODIS versus MISR

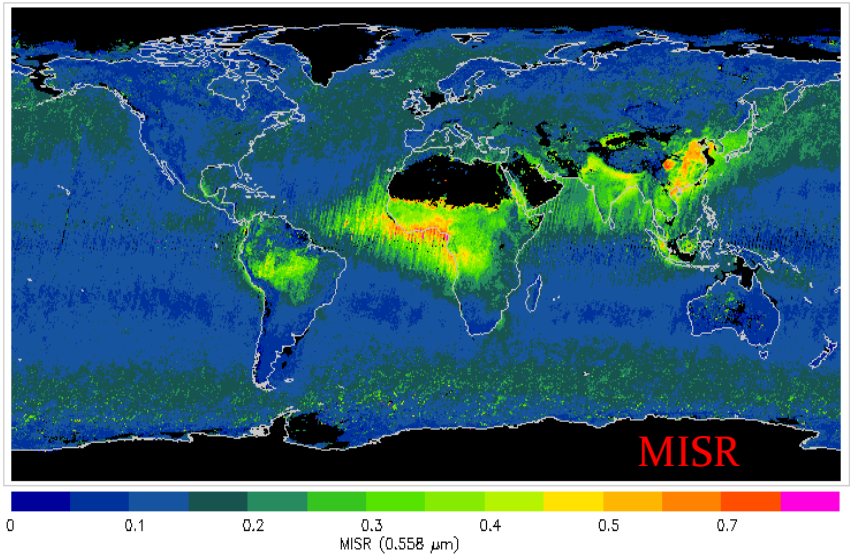
Over ocean, agreement is good and MISR compliments MODIS glint regions.

Over land, qualitatively similar, but large uncertainties exist and extreme differences will degrade model performance.

But, correlated errors are found over water

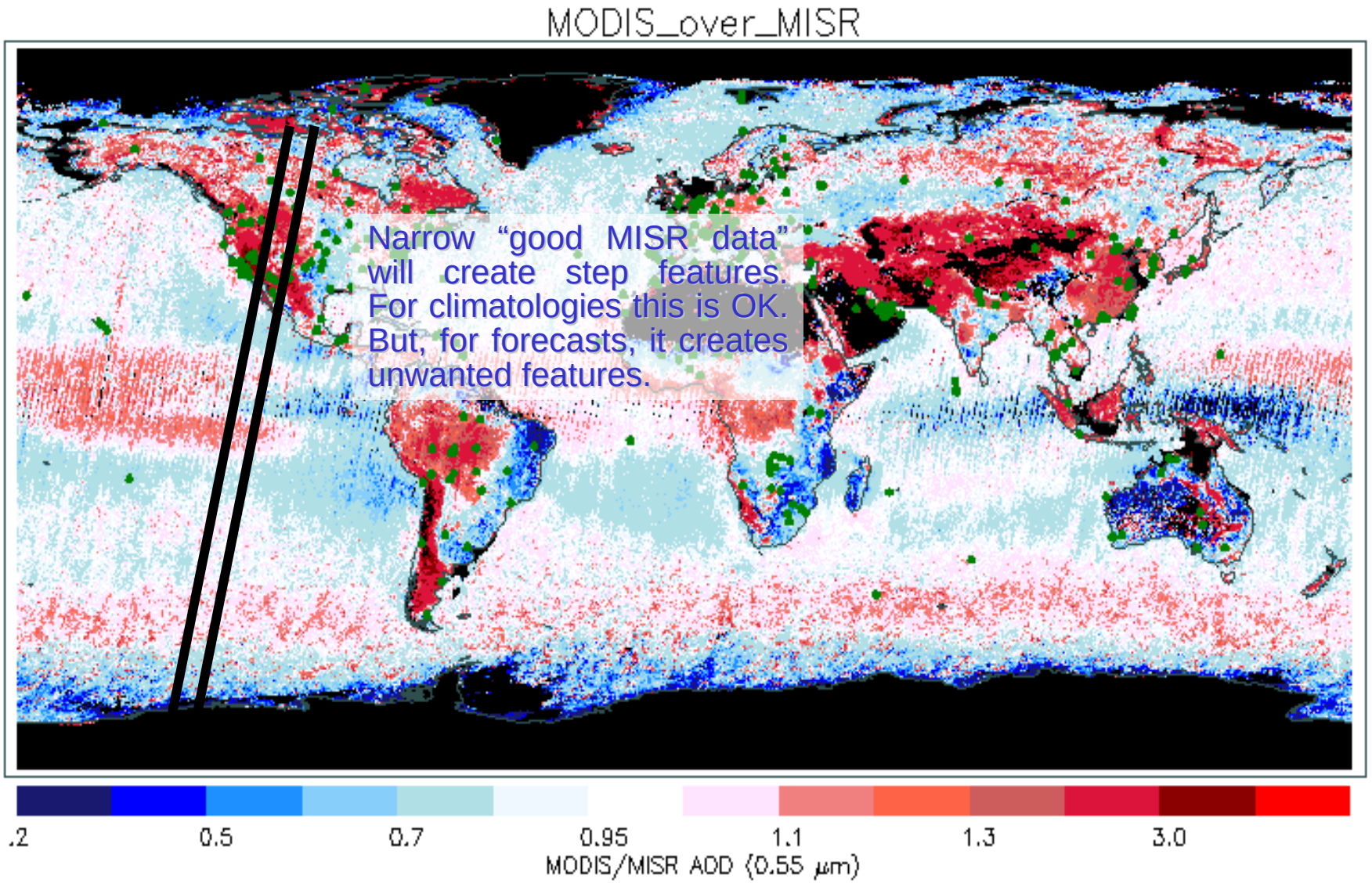






Kahn et al., (2009)

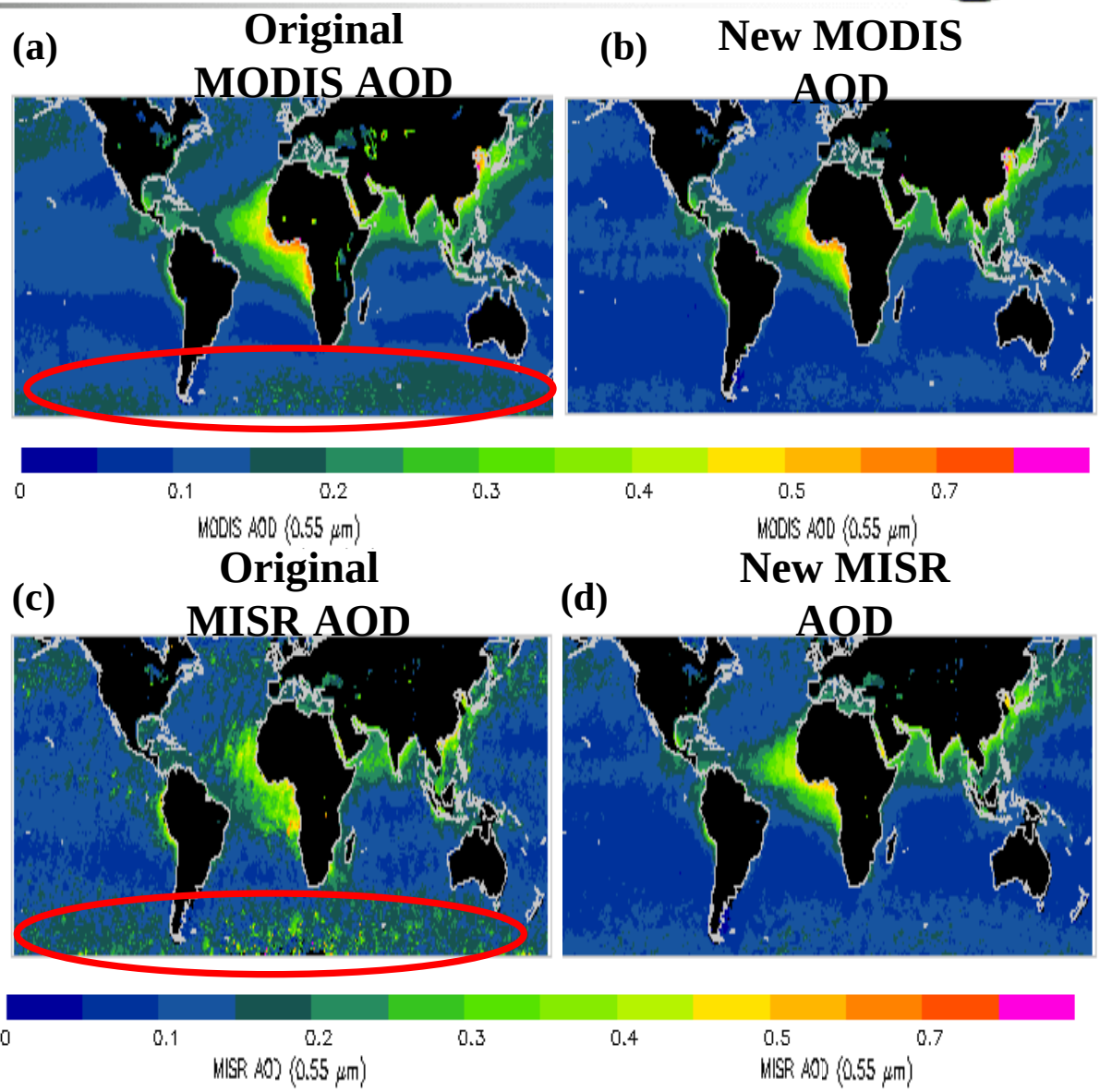
Regional and Correlated Error: larger feature differences and coastal bias



Screening Bias From Products

Example: Over-ocean satellite AOD data

- We begin with NRTPE Collection 5 MOD04 AOD data. Shown is 2005 annual average.
- QA: Data are screened using spatial tests and thresholds. Empirical corrections are made based on satellite and NOGAPS environmental data.
- End result: more than 50% correction in data over southern oceans and Asian outflow to the north Pacific. 15-20% reduction in error globally.



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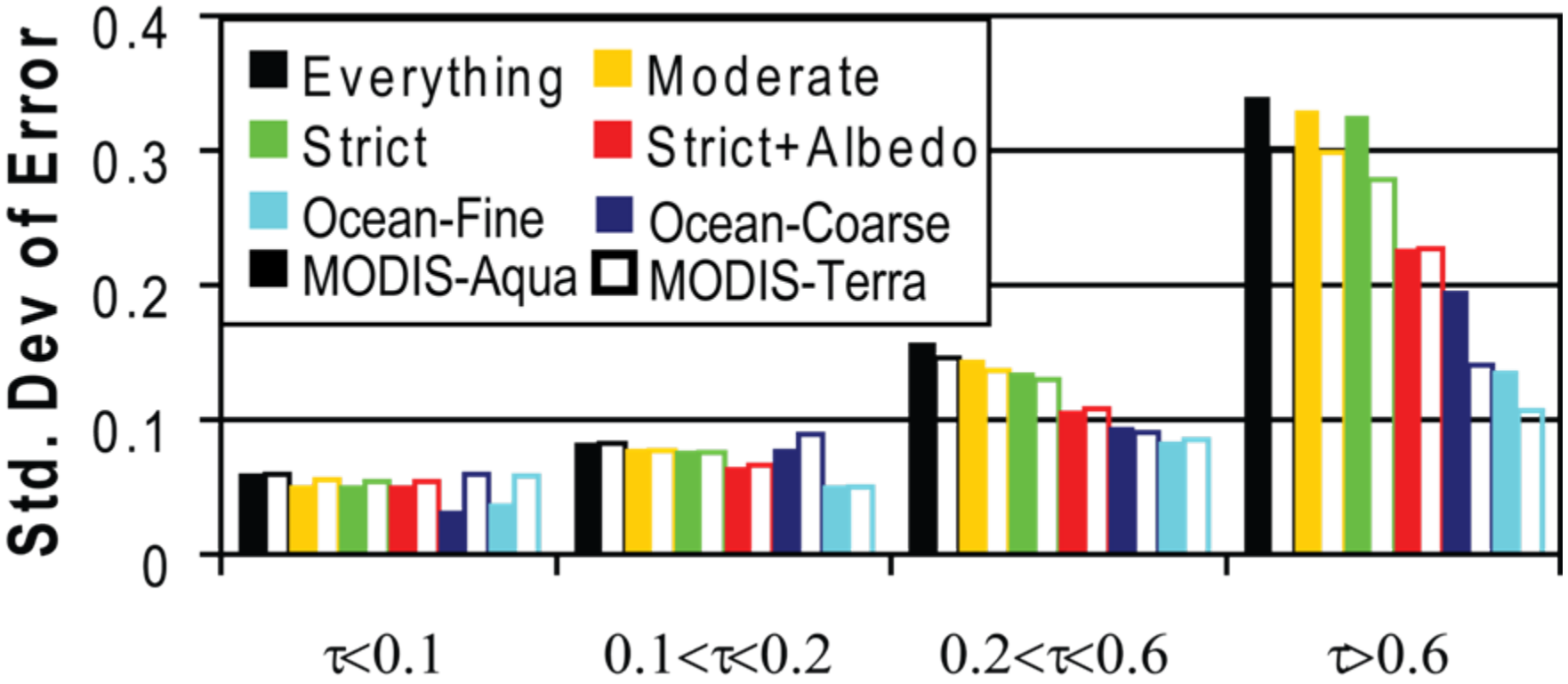
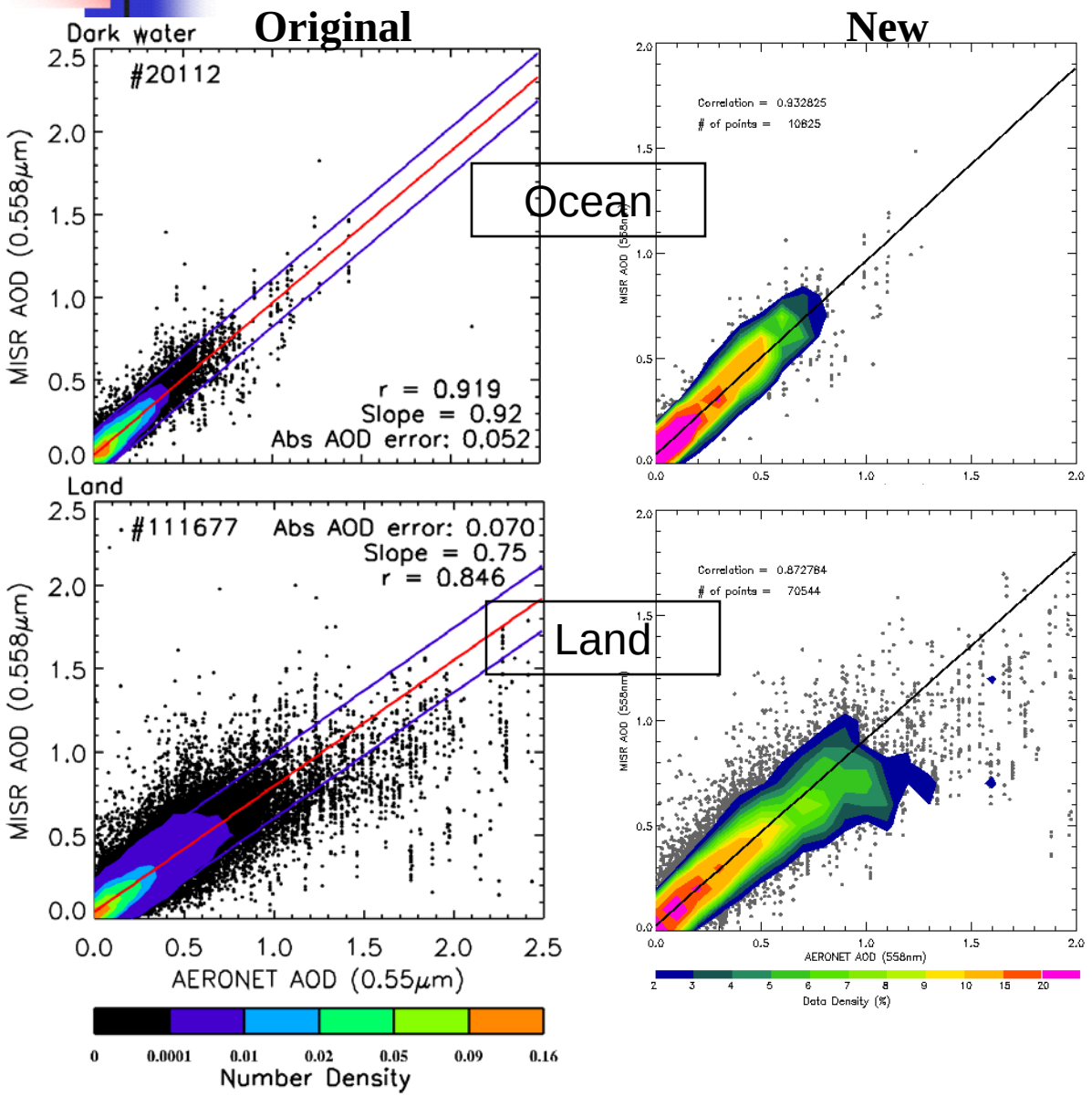
QC and QA Processing for Collection 5 Over-Land MODIS AOD

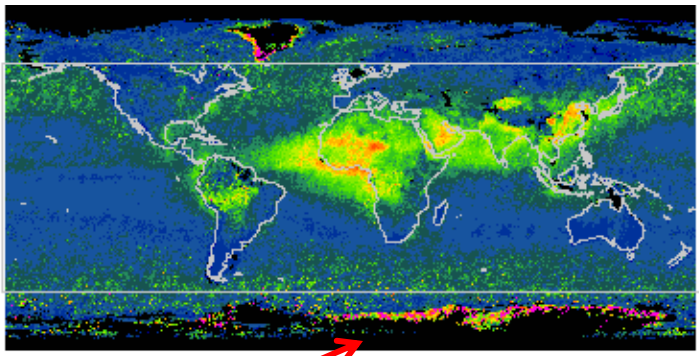


- **With albedo filter, numbers approach ocean values**
- **Ocean numbers from Zhang & Reid, *JGR* 2006**

MISR (Over land and ocean)

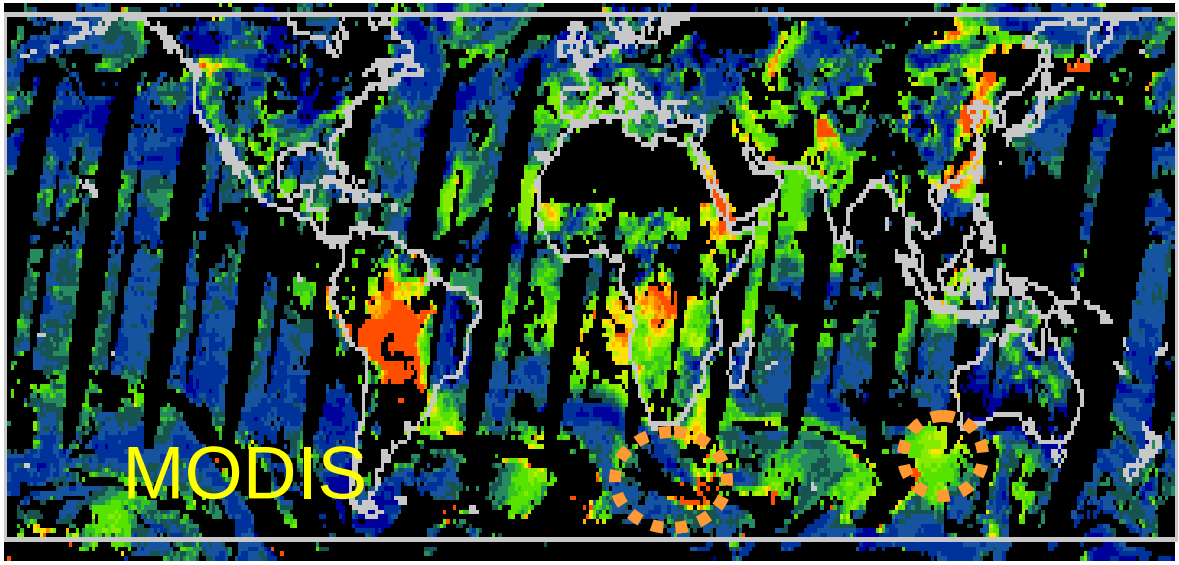


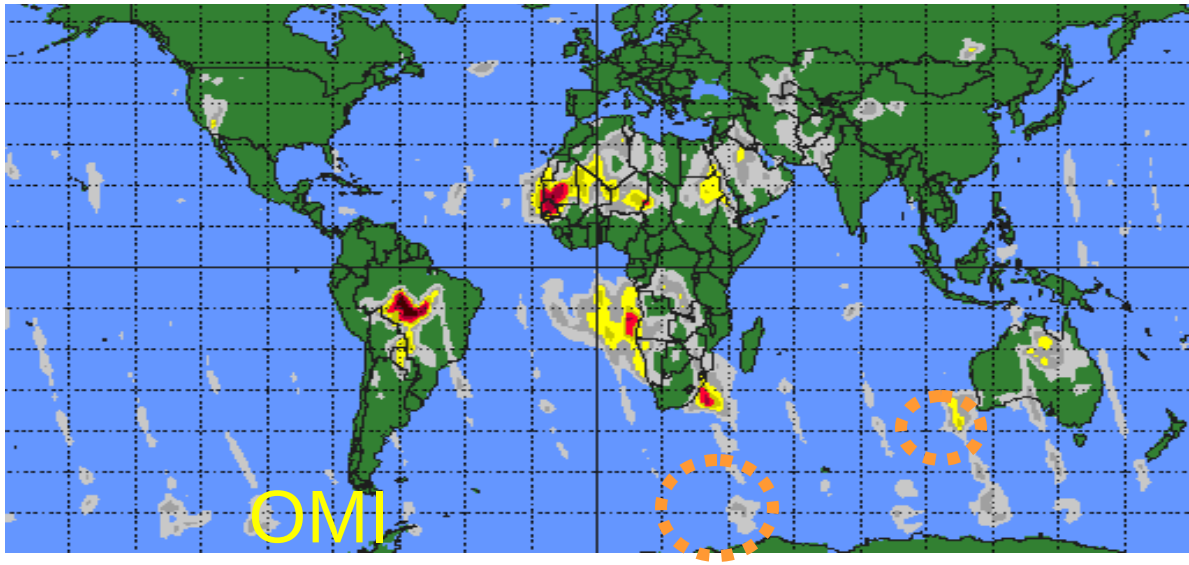
- Much better performance over land compared with MODIS
- Still need QA and QC procedures
- Underestimates fine mode AOD case
- ~10-15% reduction in absolute error



Adding additional sensors and methods: Comparisons and logic trees

- What do we do if the products have massively varying efficacy?
- Example: OMI Aerosol index and AODs. Similar coverage as MODIS, but low performance
- Don't need to necessarily assimilate AODs.
- But, we can use products to double check for specific features.
- Products can be used to help differentiate species.
- Can be used in areas of high cloud cover.

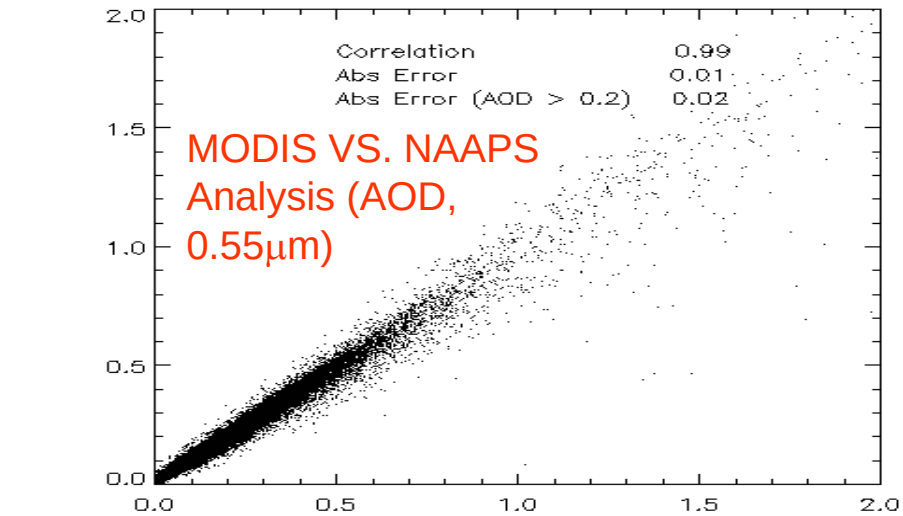


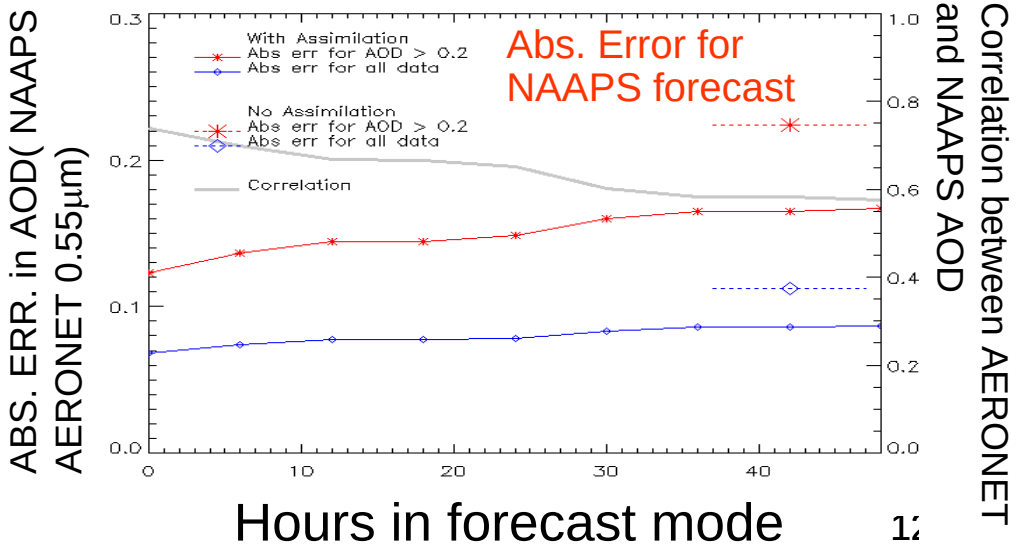


Evaluation

(Single-sensor over-water aerosol data assimilation)

- Five month comparison vs. AERONET of NAVDAS-AOD using MODIS Level 2 data (Terra+Aqua) with additional screening and corrections.
- Can reproduce observations at the analysis fields.
- NAAPS mean bias reduced by nearly 1/3 for 48-hour forecast.
- Currently operational at FNMOC





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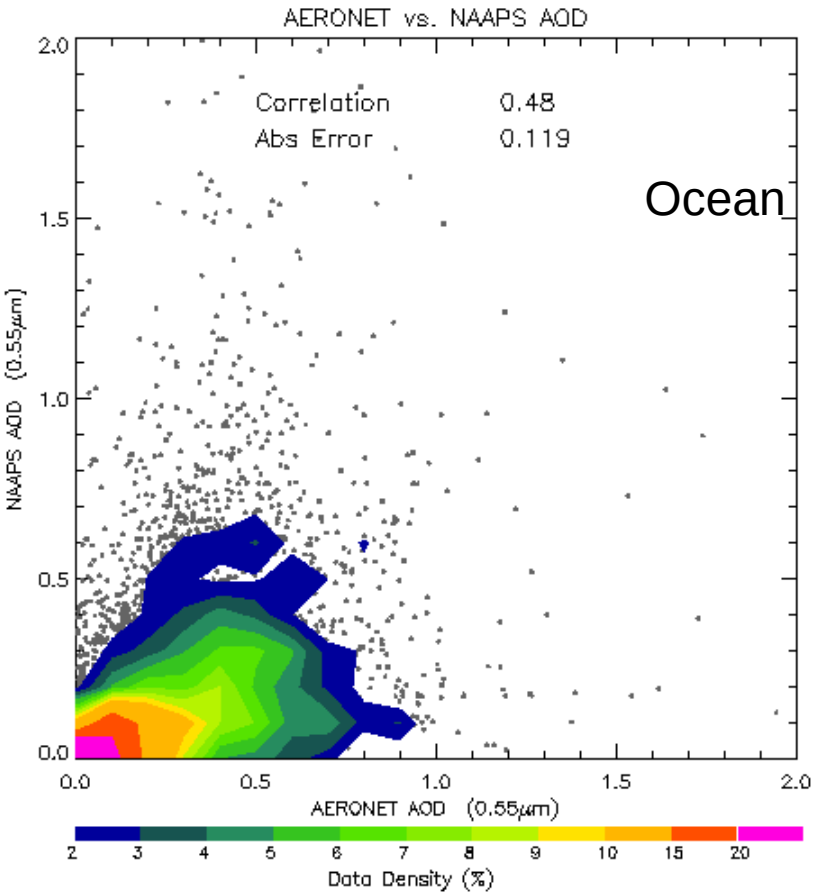
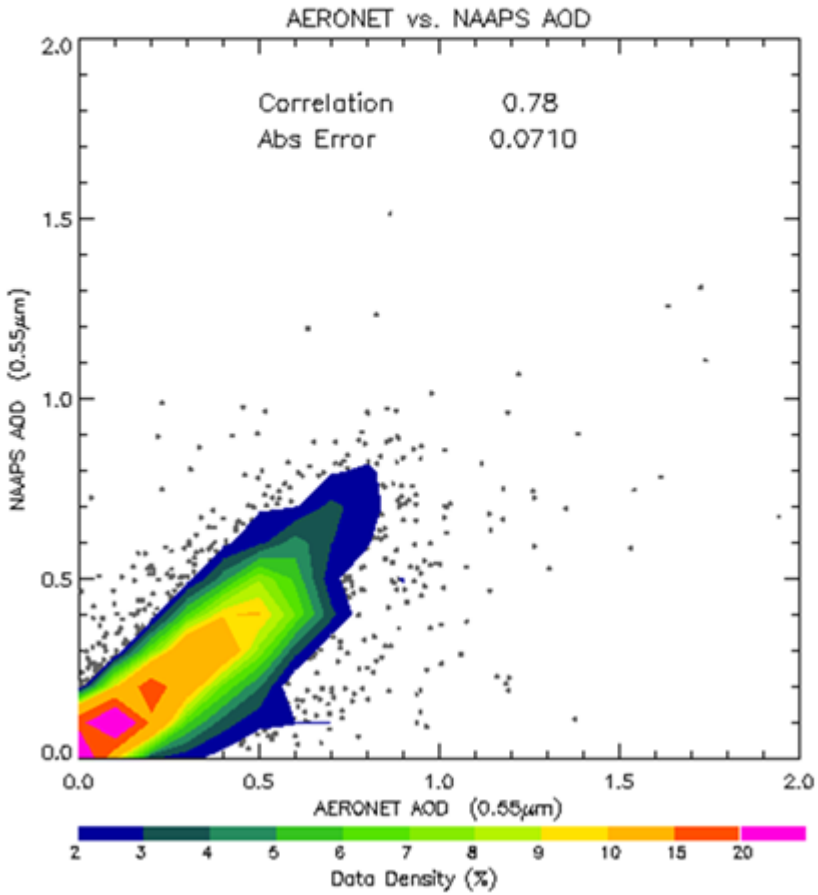
Zhang, J. and J. S. Reid, D. Westphal, N. Baker, and E. Hyer, A System for Operational Aerosol Optical Depth Data Assimilation over Global Oceans, accepted for *J. Geophysical Research-Atmospheres,, 2007.*

Multi-Sensor Assimilation
(Over-ocean case)

Natural run

+ Land/Ocean MODIS
+ Land/Ocean MISR



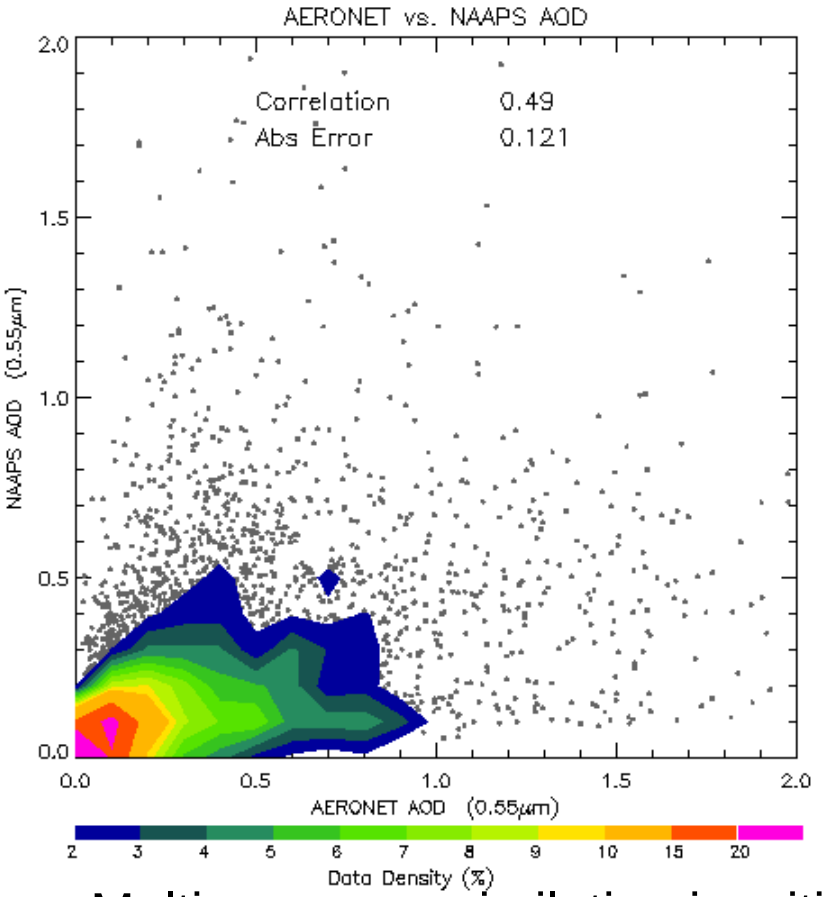


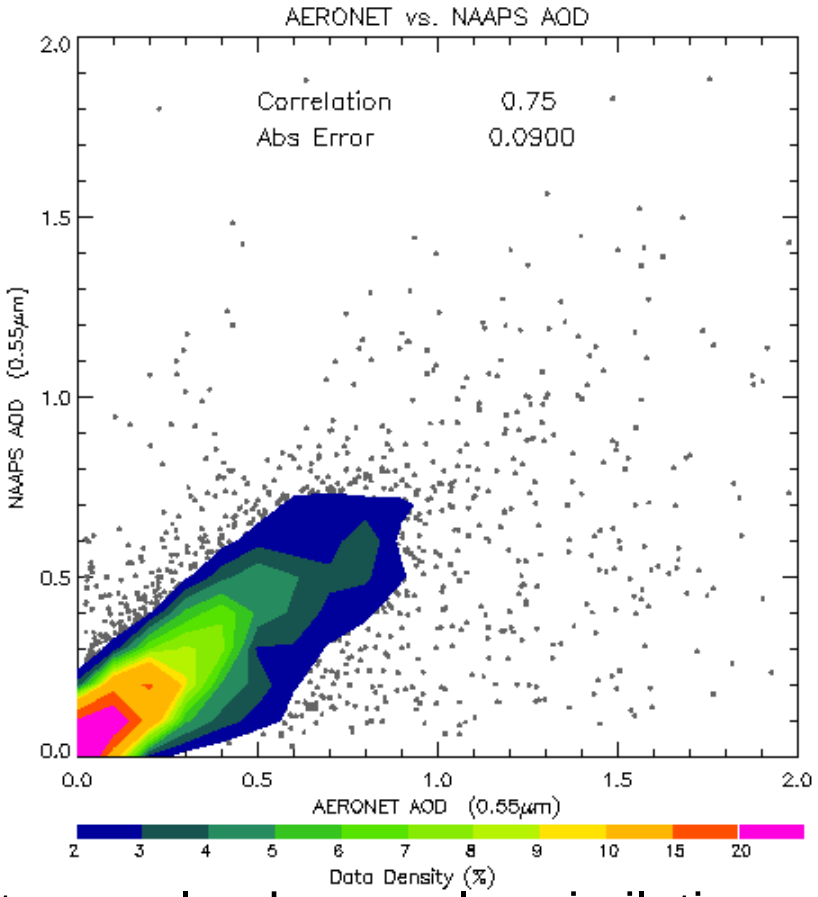
Over-ocean aerosol analyses benefit from the MODIS aerosol product
Adding more sensors/data yields incremental improvements.

Multi-sensor assimilation Over land case:

Natural run

+ Land/Ocean MODIS
+ Land/Ocean MISR

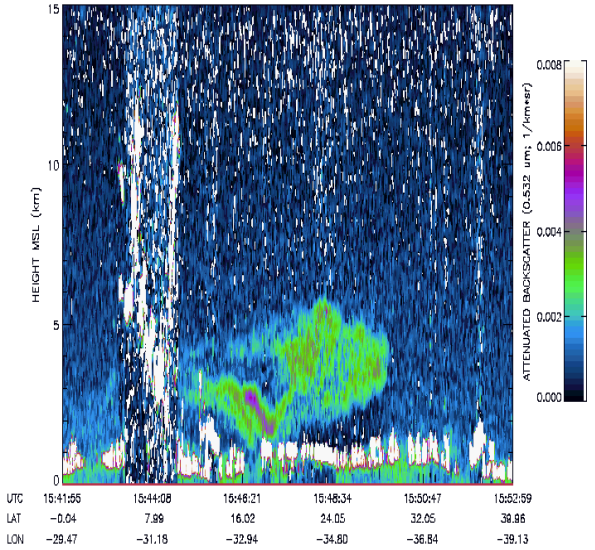


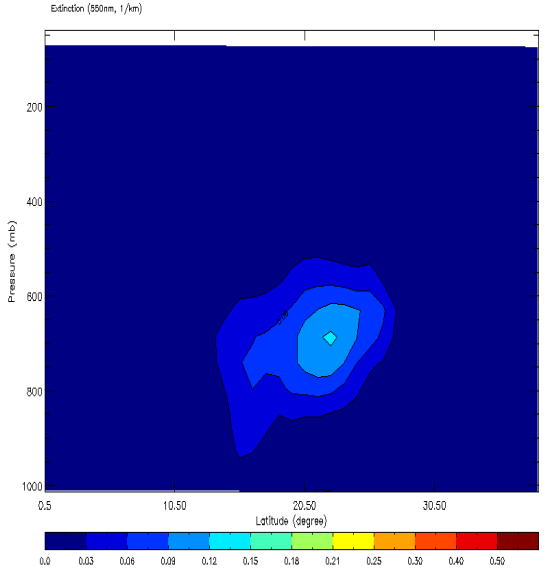


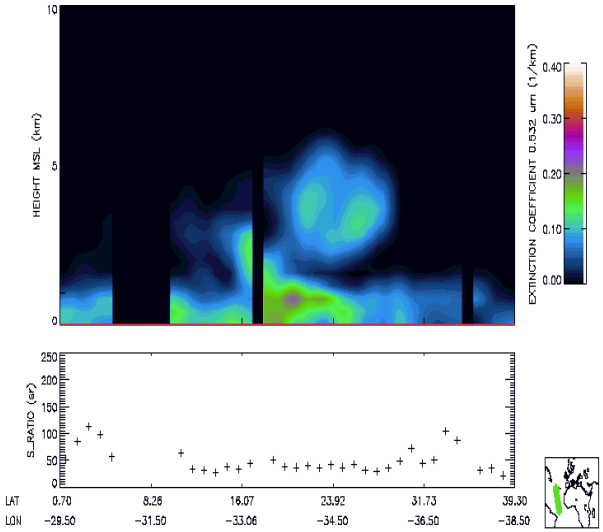
Multi-sensor assimilation is critical to over-land aerosol assimilation. Improvements are observable with each new sensor added.

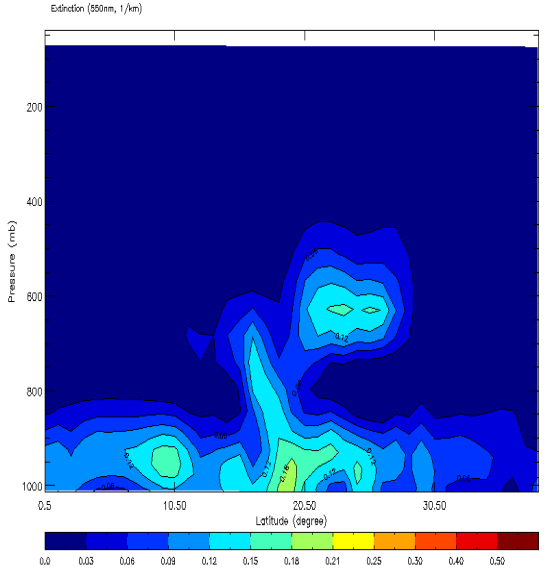
The Next Step: 3DVAR Assimilation

- Constrain the vertical distribution of aerosols in NAAPS using CALIPSO.
- The expense of errors in the vertical analysis field is corresponding downwind errors, since trajectory paths typically diverge with time and height.
- Following the same path travelled in building 2DVAR AOD assimilation, we are developing QA/QC metrics and evaluating multiple years of data to assess improvements to the model.
- To be continued…



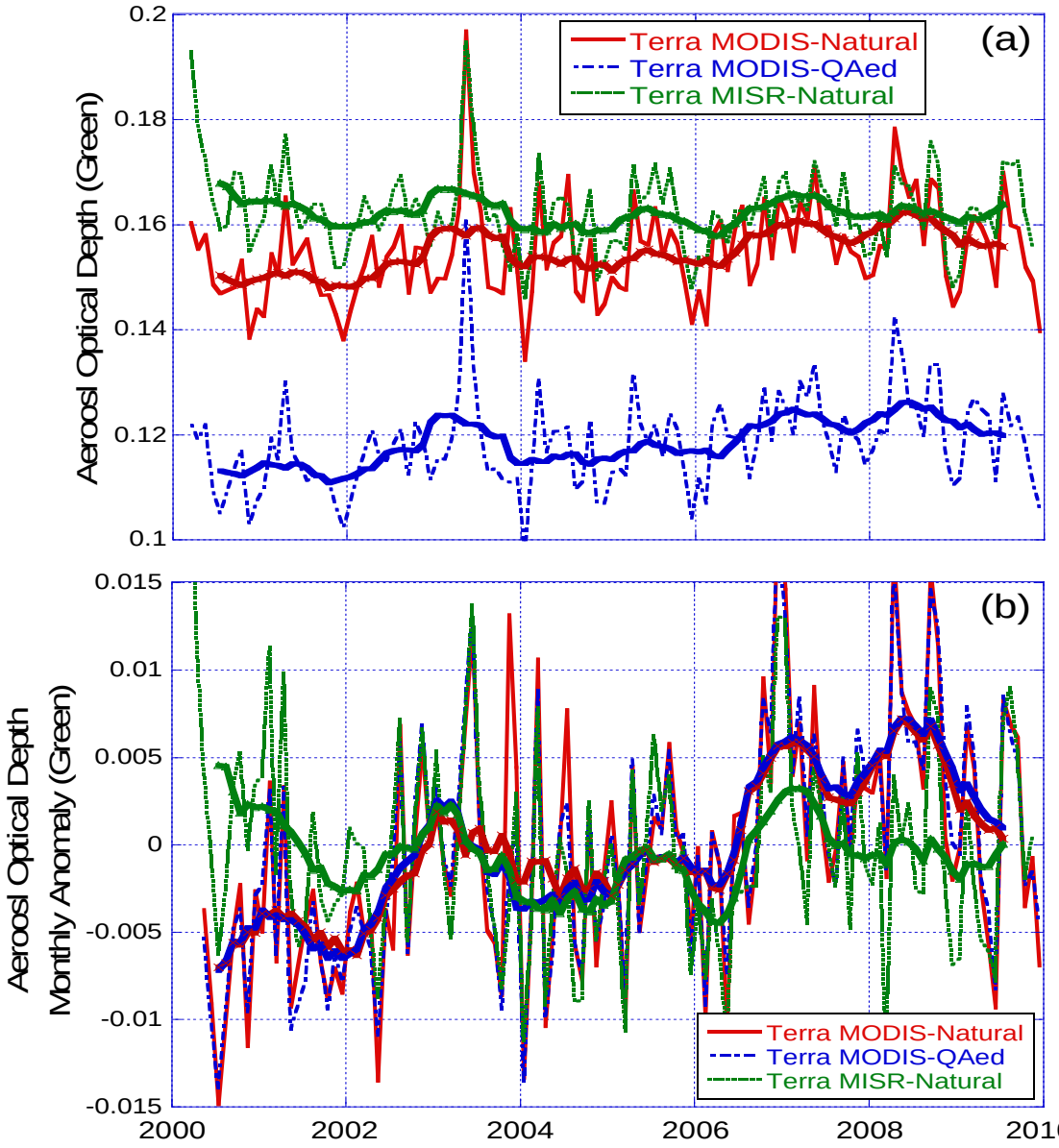






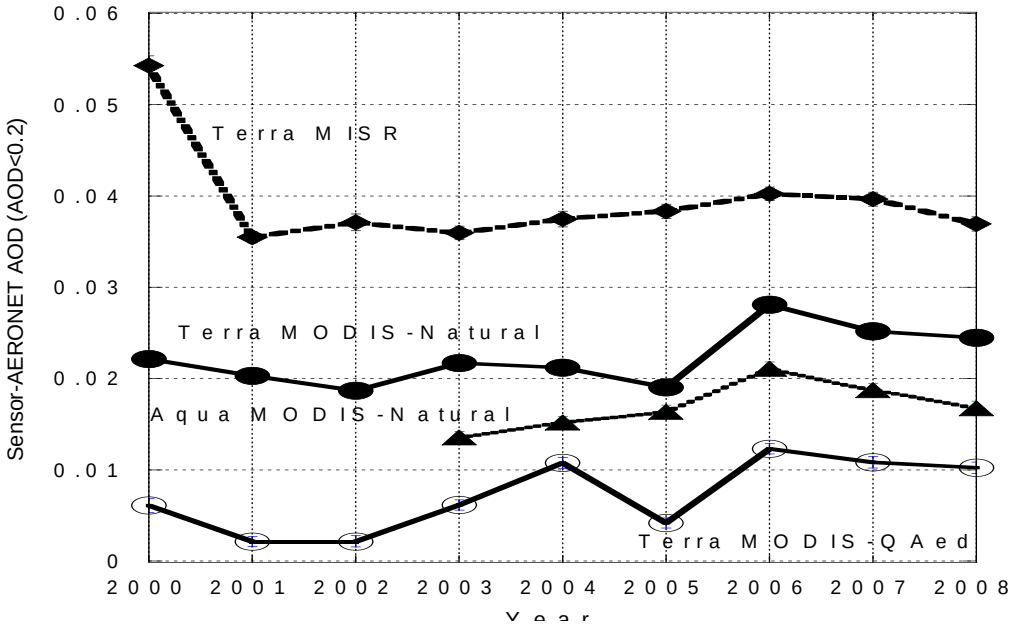
Example Climate Application: Aerosol Trend Analysis

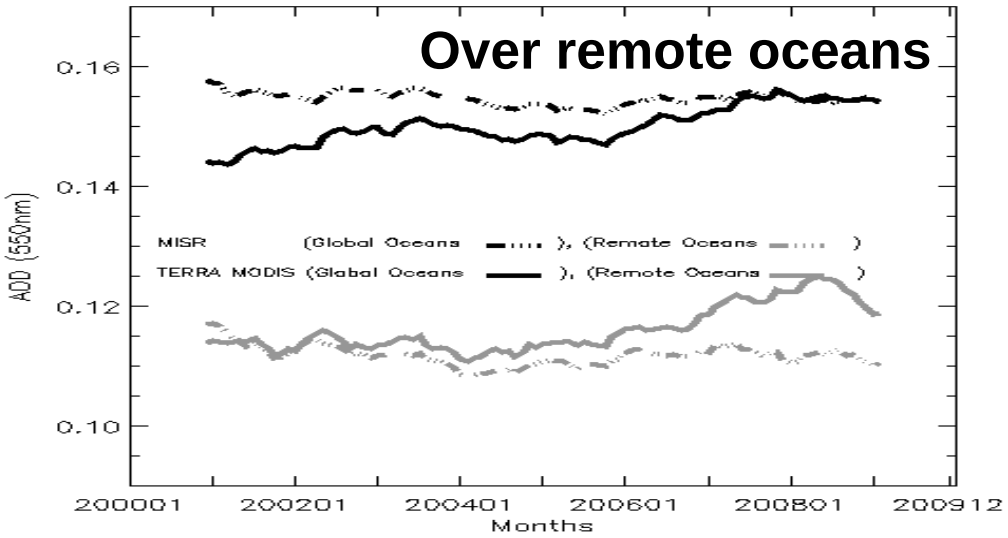
- QAed over-water MODIS aerosol product is evaluated to study long-term trends
- The monthly mean AOD distribution from the QAed and raw Collection 5 MODIS datasets are nearly identical except that those of the QAed products are systematically low, which is possibly due to the removal of cloud-contaminated data.
- No trend is found from MISR data, yet an increasing trend is found from both Aqua and Terra MODIS.
- Could discrepancies be linked to calibrations?



Aerosol Trend Analysis

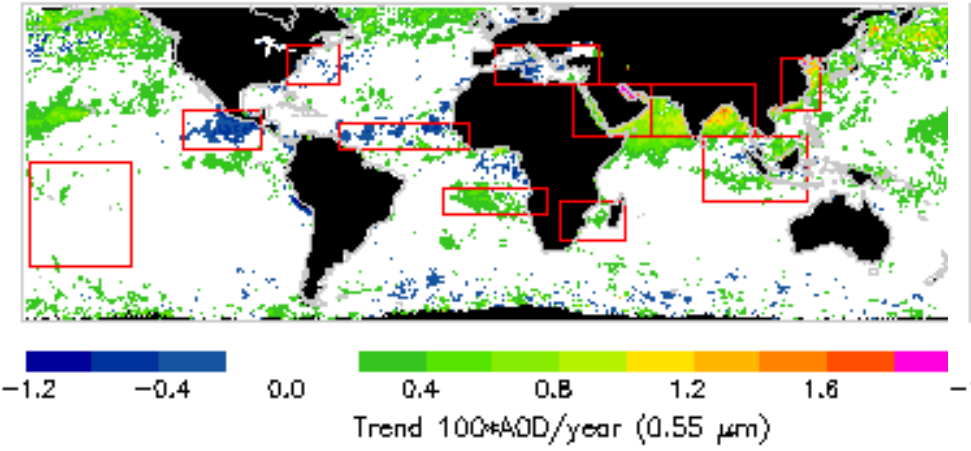
- Spatially and temporally collocated MODIS and MISR data
- Increasing AOD trends were found for MODIS over both remote oceans and global oceans.
- No significant trend is found from the MISR AOD data.
- Comparing with AERONET data shows a similar story



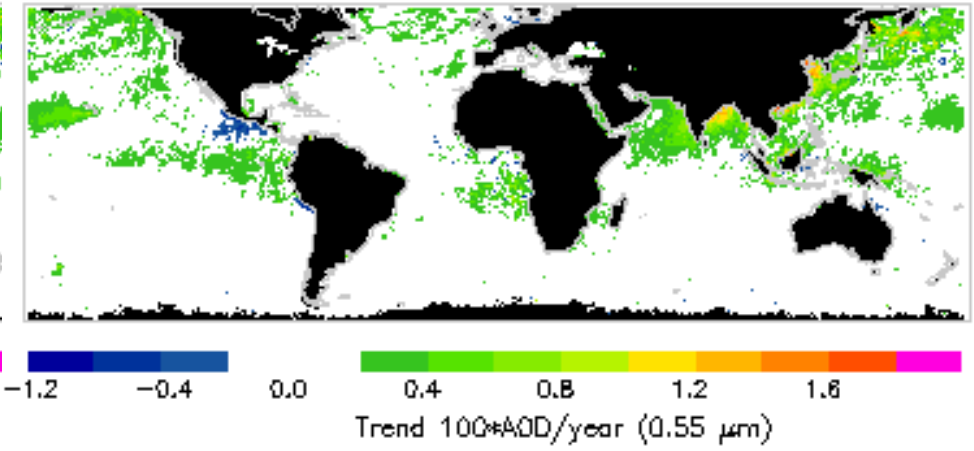


Aerosol Trend Analysis

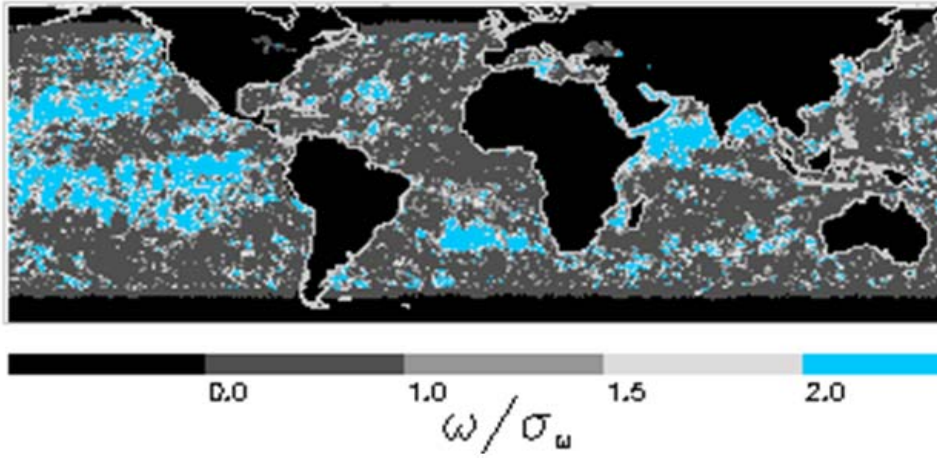
10-year AOD trends

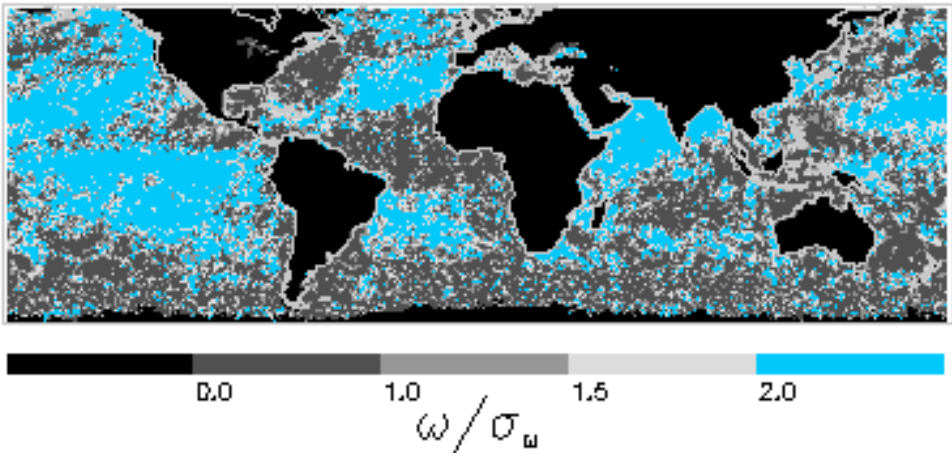


10-year trend of the anthropogenic AOD



Spatial distribution of the $|\omega/\sigma_\omega|$





Aerosol Trend Analysis

	Latitude (°)	Longitude (°)	Slope AOD/per 10 year	$\|\omega/\sigma_\omega\|$	Corrected slope AOD/per 10 year	MISR Slope AOD/per 10 year
Global Oceans			0.010	3.60	0.003	-0.003
(NW Coast) Africa	5°S – 15°N	60°W – 10°E	-0.008	0.64	-0.015	-0.034
(SE Coast) Africa	30°S – 15°S	25°E – 50°E	0.011	1.52	0.004	-0.007
(SW Coast) Africa	20°S – 10°S	20°W – 20°E	0.020	1.45	0.013	-0.001
Arabian Sea	10°N – 30°N	30°E – 60°E	0.090	6.07	0.083	0.047
Central America	5°N – 20°N	120°W-90°W	-0.016	1.73	-0.023	-0.030
Coastal China	20°N – 40°N	110°E – 125°E	0.069	4.06	0.062	0.038
Indian Bay of Bengal	10°N – 30°N	60°E – 100°E	0.078	5.45	0.071	0.036
Mediterranean Sea	30°N – 45°N	0° – 40°E	-0.009	0.94	-0.016	0.011
(E Coast) US	30°N – 45°N	80°W – 60°W	-0.008	1.07	-0.015	-0.019
Southeast Asia	15°S – 10°N	80°E – 120°E	0.014	0.80	0.007	-0.001

Summary

- Aerosol modeling and forecast efforts should fully utilize multi-sensor data streams, such as multi-channel, multi-angle, and polarized passive sensors combined with ground and space lidars.
- Yet, QA and QC procedures are critical to accurate and efficient aerosol data assimilation techniques.
- CALIPSO (and, soon, ESA/EarthCare) data represent the culminating piece of the full 3D system.
- Climatological studies provide insights into the quality of multi-sensor data streams.