An Operational Aerosol Data Assimilation System (NAVDAS-AOD)

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Three Year Project summary

(1) Proposed: An operational aerosol assimilation package.

Accomplishment: Developed an operational aerosol assimilation package NAVDAS-AOD [*Zhang et al., 2008, JGR*].
Run daily in semi-operational (research) mode.
In transitioning to FNMOC.

(2) Proposed: Understand the uncertainties in the operational MODIS aerosol product.

Accomplishment: Developed QA and QC processes for both over ocean and over land MODIS aerosol product. Develop a new level 3 MODIS aerosol product that is suitable for aerosol data assimilation [e.g. *Zhang and Reid. 2006 JGR*].
Run daily in semi-operational (research) mode.
In transitioning to FNMOC.

Background

NRL aerosol data assimilation system (NAVDAS-AOD) includes:

NAVDAS-AOD

Model:

Navy/NRL Aerosol Analysis and Prediction System (**NAAPS**), the world's only truly operational global aerosol model.

Observations:

Newly derived Level 3 AOD product based on NRPTE MODIS level II data stream. Later, MISR, MODIS Deep Blue.

The assimilation system:

NRL Atmospheric Variational Data Assimilation System (**NAVDAS**)

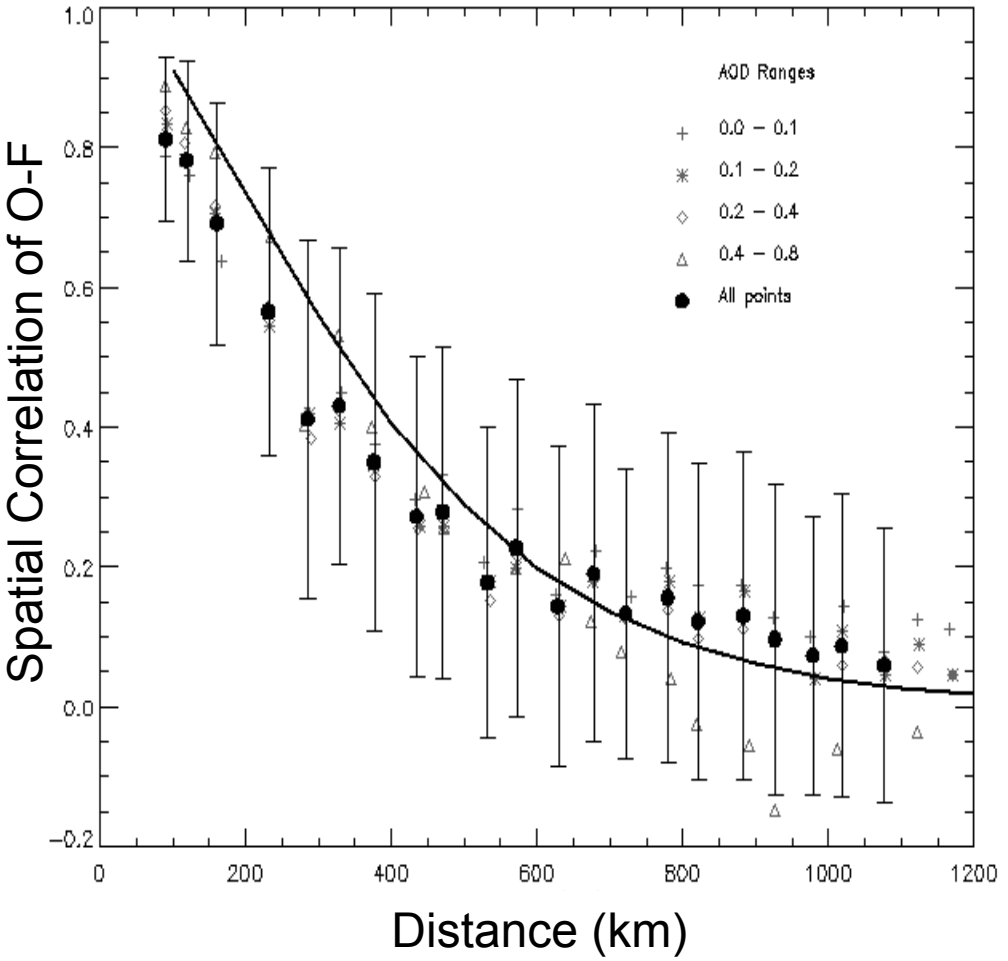
Background (NAAPS)

- Operational at FNMOC, twice-daily, 6-day forecasts of SO_2, sulfate, dust, sea salt, and smoke concentration
- Grid: 1X1 degree; 30 levels to 100 mb
- Operational global weather model (NOGAPS) provides forecasts of P, T, q, u, v, w, K_z, cloud parameters, precip., stress, and ground wetness at 6-hour intervals
- SO_2 emission inventory; oceanic DMS emission
- Dust deflation depends on threshold velocity, forecasted stress, rain, and ground wetness
- Smoke emission based on satellite detection of fires
- Linear gas-phase chemistry
- Dry deposition: function of specie, stress, stability, surface type
- Wet removal: function of precipitation rate, specie, cloud type

Background (NAVDAS)

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{P}_b\mathbf{H}^T[\mathbf{H}\mathbf{P}_b\mathbf{H}^T + \mathbf{R}]^{-1}[\mathbf{y} - H\{\mathbf{x}_b\}]$$

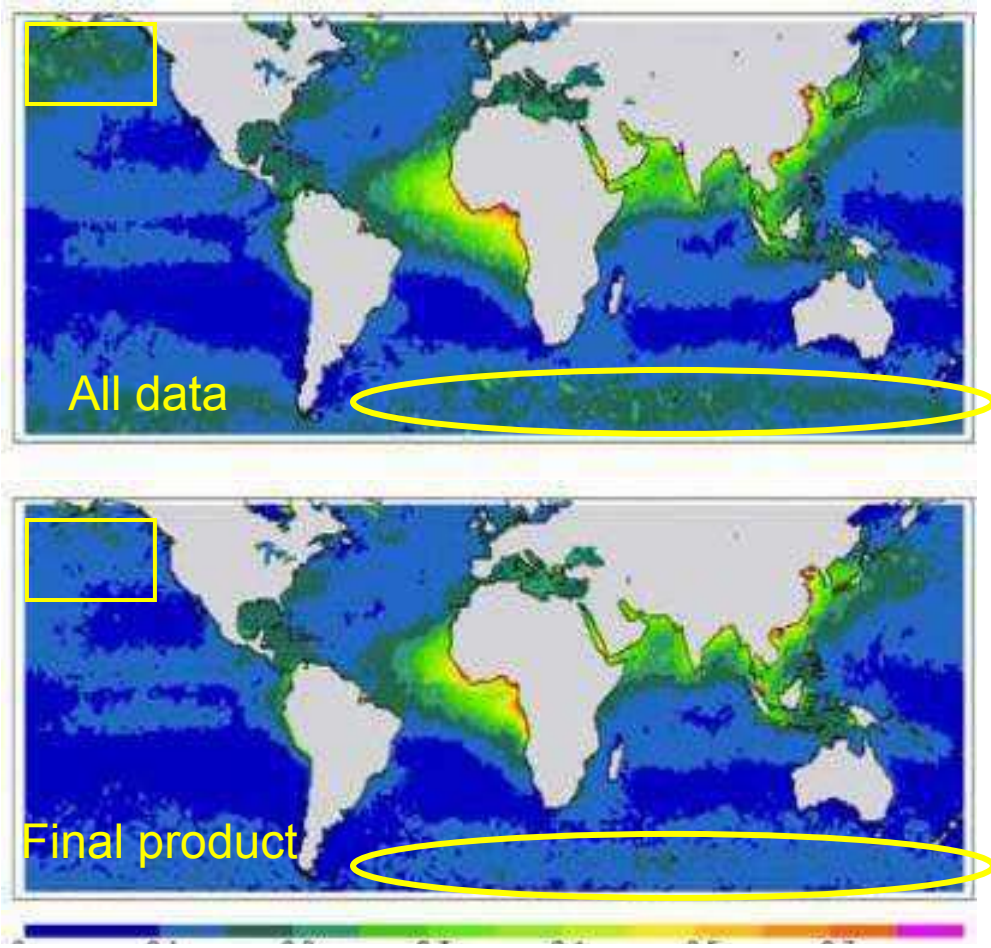
- Using 2-D var version of NAVDAS
- Error variance terms were estimated using AERONET data
- No error correlation for satellite observations
- Horizontal background error correlation model (SOAR)
- Background error correlation length was found to be ~200 km



Background (Satellite): Near real time QA and Aggregation on Level 3 Assimilated Data

Zhang and Reid [2006]

- We begin with NRTPE Collection 4 MOD04 AOT data. Shown is 2004 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 southern oceans and Asian outflow to the north Pacific. 15-20% reduction in error globally.



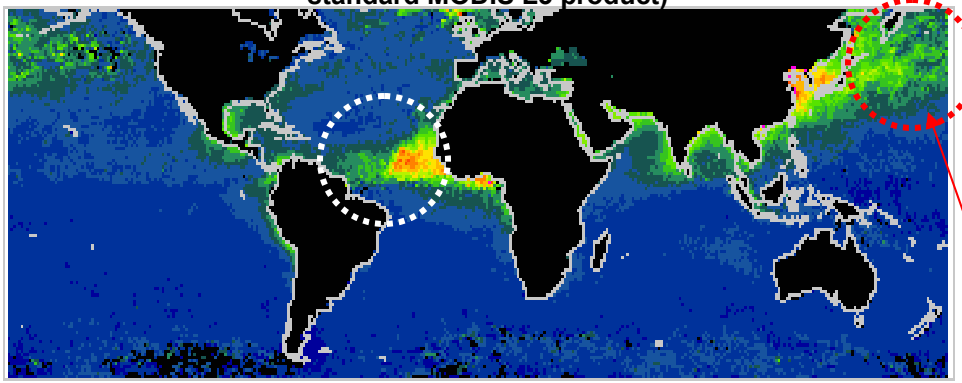
Zhang, J. and Reid., J.S., MODIS Aerosol Product Analysis for Data Assimilation: Assessment of Level 2 Aerosol Optical Thickness Retrievals, *J. Geophys. Res.*, 2006.

Single sensor over water aerosol data assimilation & validation

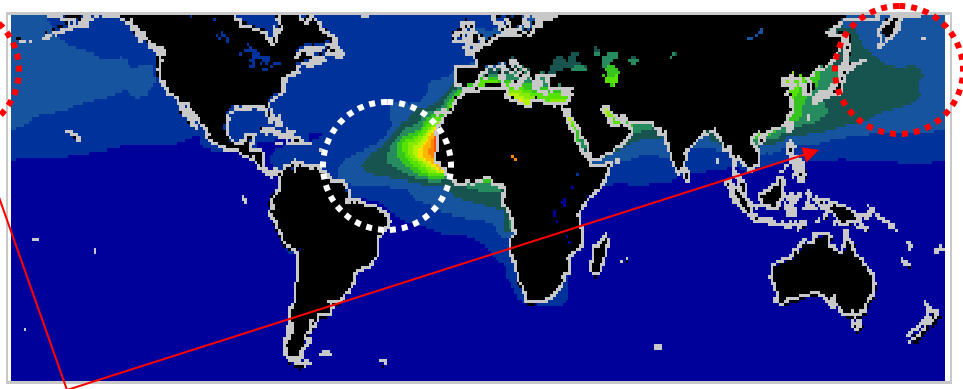
Single sensor over water aerosol data assimilation

Application of modified collection 4 MODIS AOD

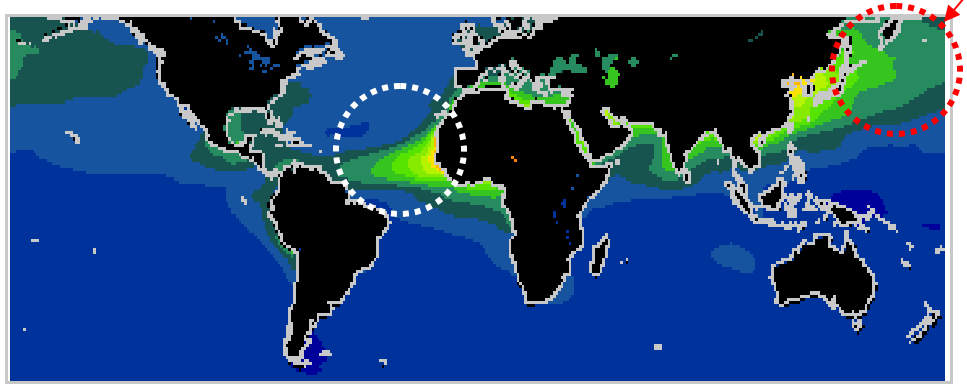
MODIS AOD (March-May, 2006, notice the difference to the standard MODIS L3 product)



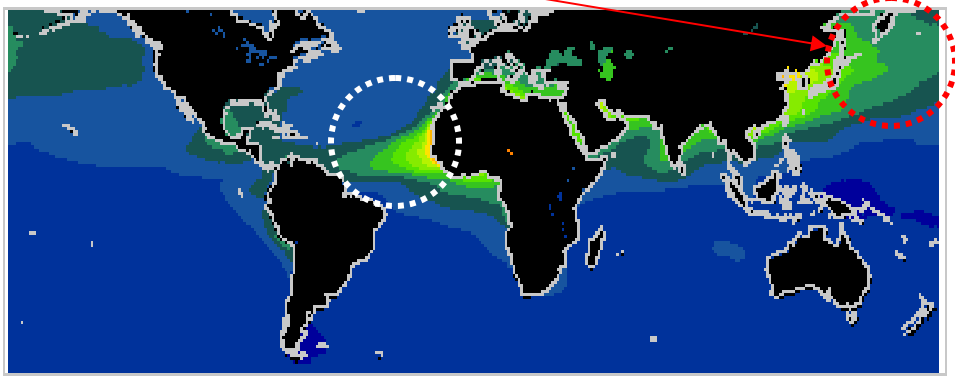
NAAPS AOD, no assimilation (March-May, 2006)



NAAPSAOD analysis (March-May, 2006)



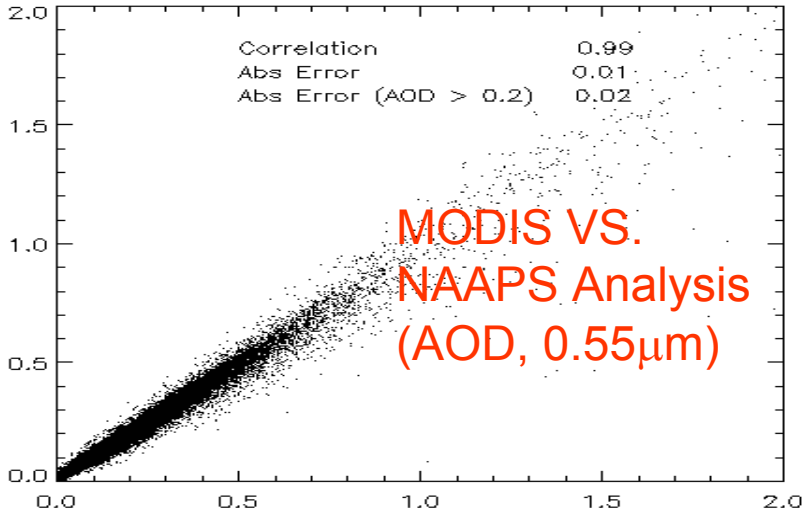
NAAPS AOD 6 hour forecast (March-May, 2006, with assimialtion)

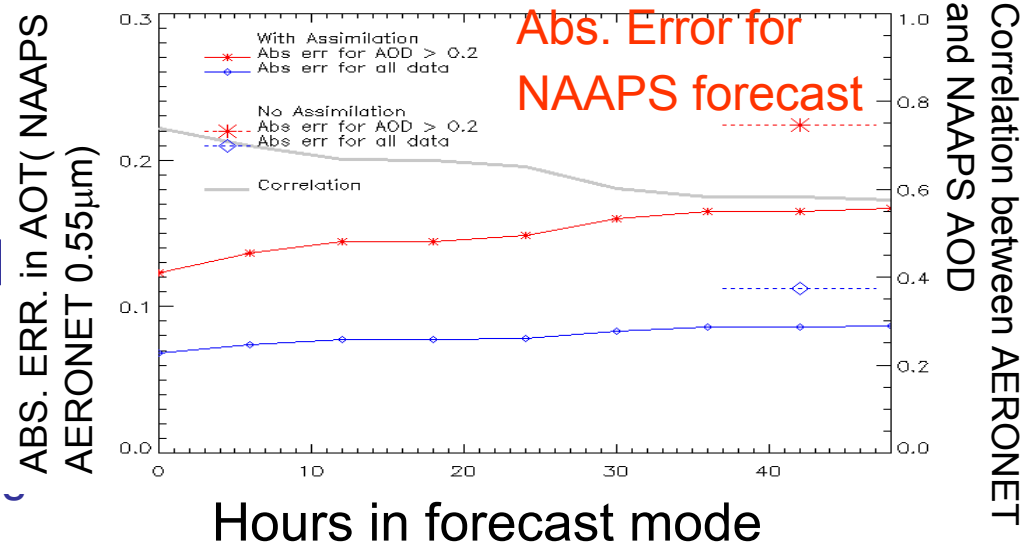


Summary for single sensor over water aerosol data assimilation

Five month evaluation vs. AERONET of NAVDAS-AOD using MODIS level 2 (Terra+Aqua) with additional screening and corrections.

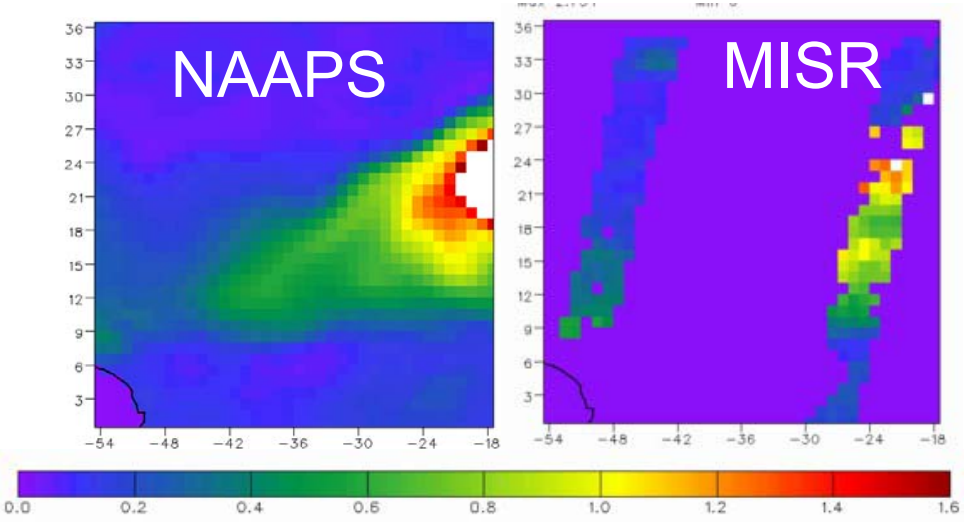
- Can reproduce observation at the analysis fields.
- NAAPS mean bias reduced by nearly 1/3 for 48-hour forecast
- Currently in transition to 6.2 daily run

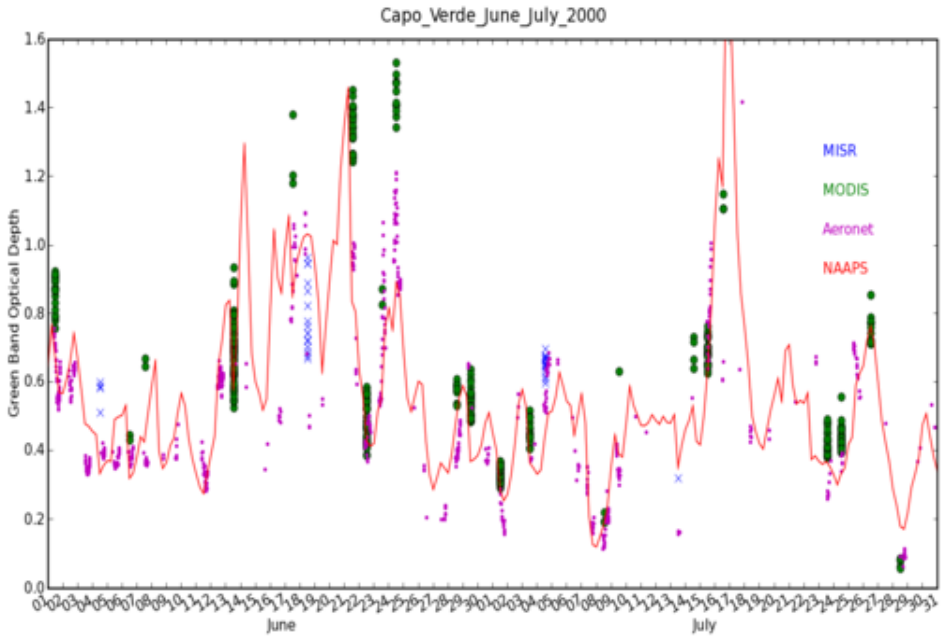


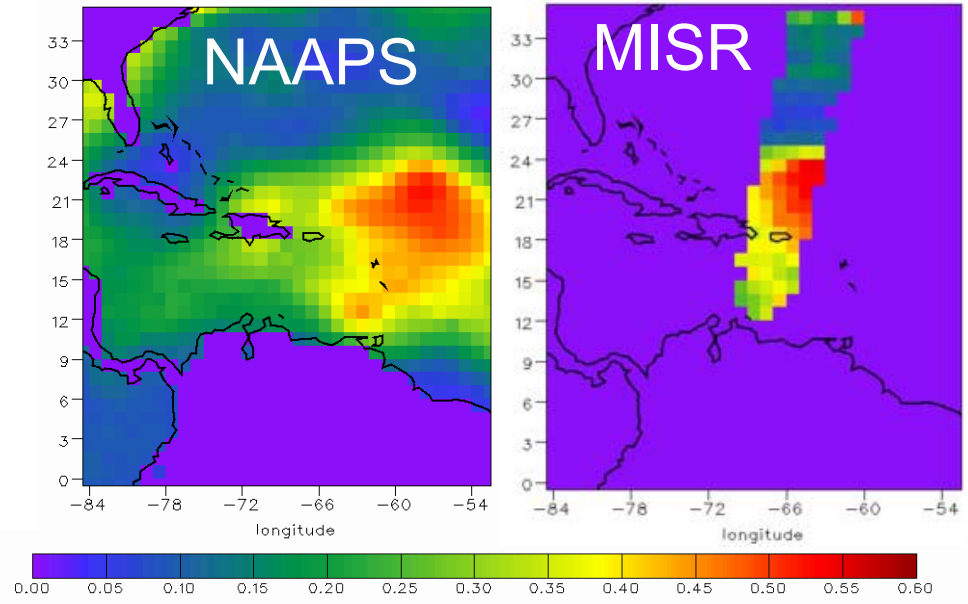


Zhang, J. and J. S. Reid, D. Westphal, N. Baker, and E. Hyer, A System for Operational Aerosol Optical Depth Data Assimilation over Global Oceans, accepted for *J. Geophysical Research-Atmospheres,, 2007.*

Independent evaluation of NAVDAS-AOD (Kalashnikova et al., 2008)







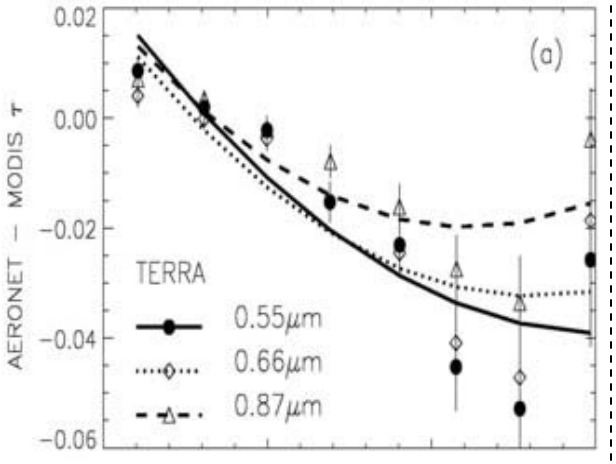
- All plots from Kalashnikova et al., 2008.
- NAAPS AOD agrees well with MISR and AERONET for June and July of 2000.

Kalashnikova O. V., et al.,, Mineral dust transport characterization over the Atlantic from combined satellite aerosol retrievals, Geophysical Research Abstracts, Vol. 10, EGU2008-A-11193, 2008, SRef-ID: 1607-7962/gra/EGU2008-A-11193, EGU General Assembly 2008.

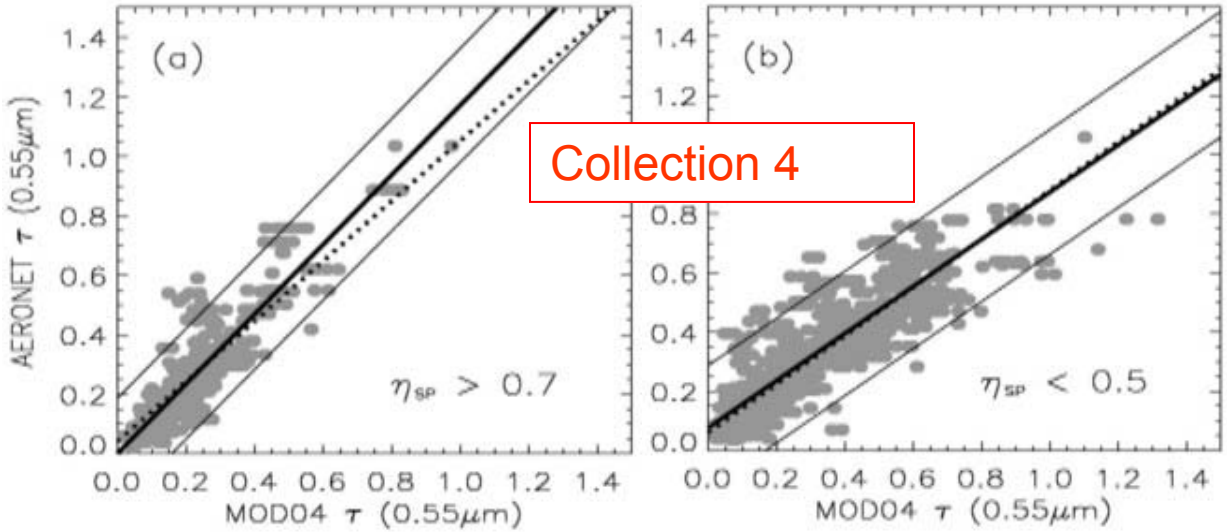
Identify & quantify uncertainties in collection 5 over ocean MODIS AOD

Identify & quantify uncertainties in collection 5 over ocean MODIS AOD

Ocean Wind speed

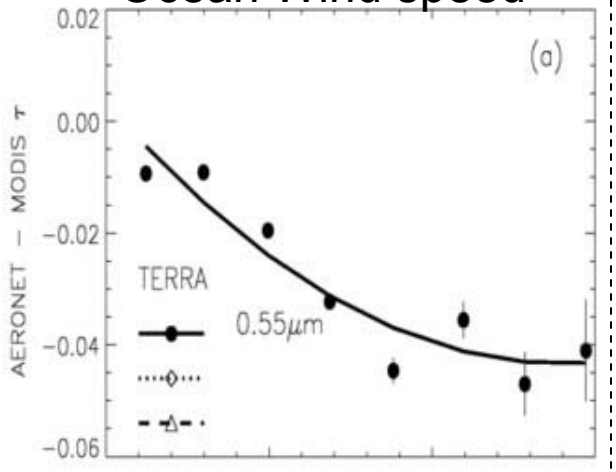


Fine mode to total AOD

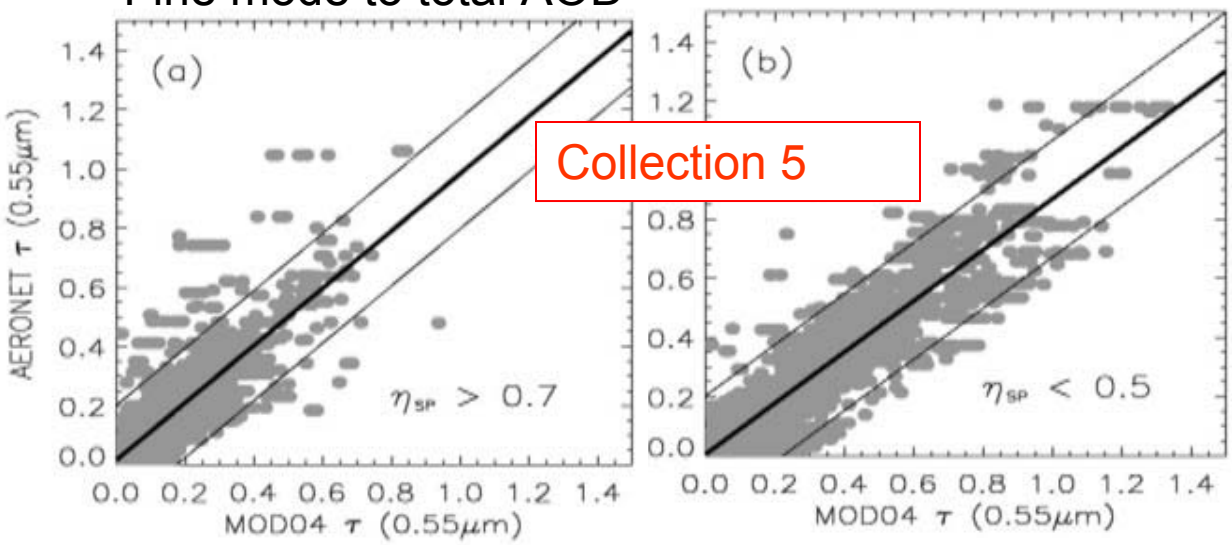


Collection 4

Ocean Wind speed



Fine mode to total AOD

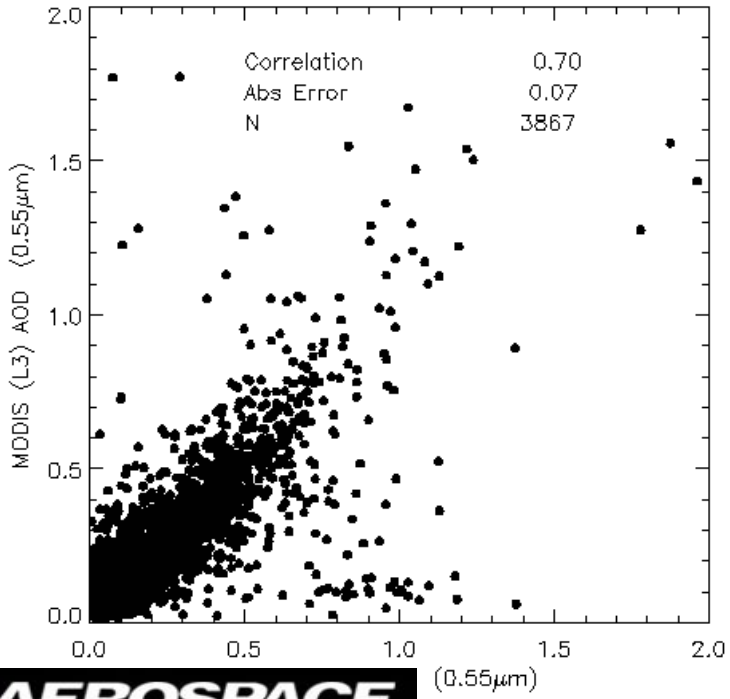


Collection 5

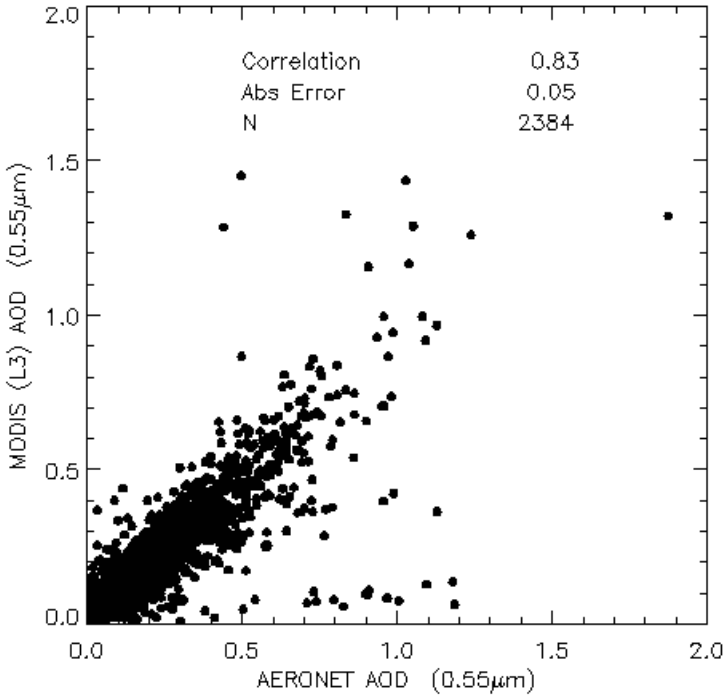
In progress: for QC and QA of *collection 5* over ocean MODIS AOD

- **Biases due to lower boundary condition still exist**
- **Biases due to cloud contamination and cloud artifacts still exist**
- **20% reduction in absolute errors**

a) Terra+Aqua MODIS AOD (Level 3 daily average), before QA and QC, Jan. – Dec. 2006



b) Terra+Aqua MODIS AOD (Level 3 daily average), after QA and QC, Jan. – Dec. 2006



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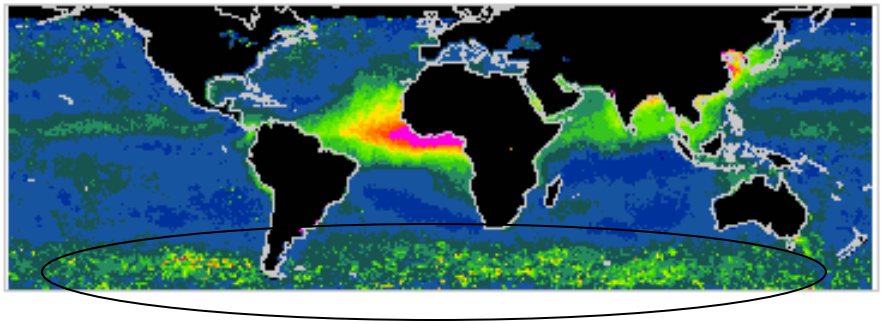
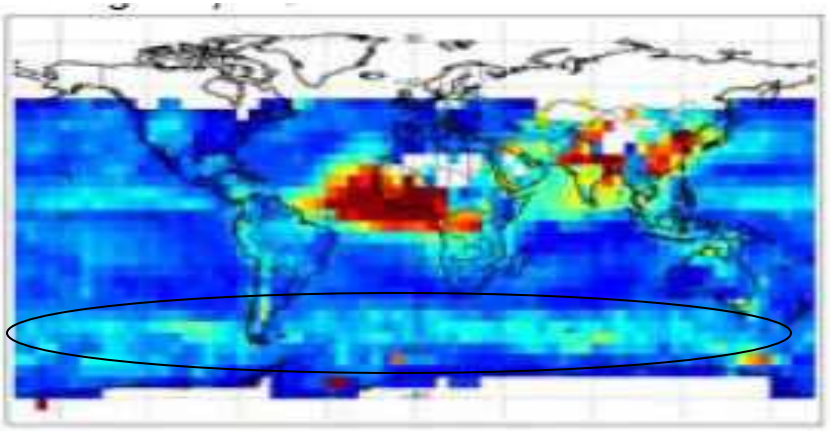
In progress: for QC and QA of collection 5 over ocean MODIS AOD

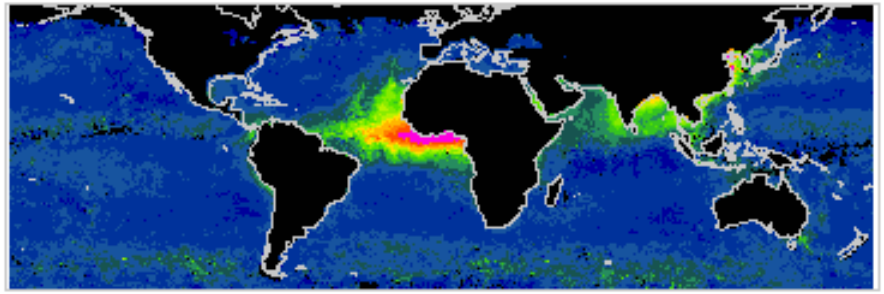
a) Terra+Aqua MODIS AOD, before QA and QC, Jan 2007



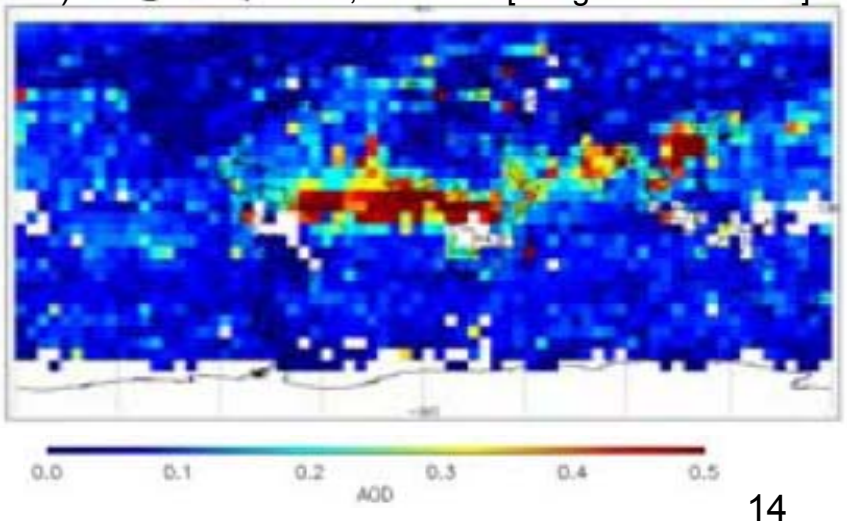
b) Aqua MODIS AOD, Jan 2007 [Vaughan et al. 2007]



c) Terra+Aqua MODIS AOD, After QA and QC, Jan 2007



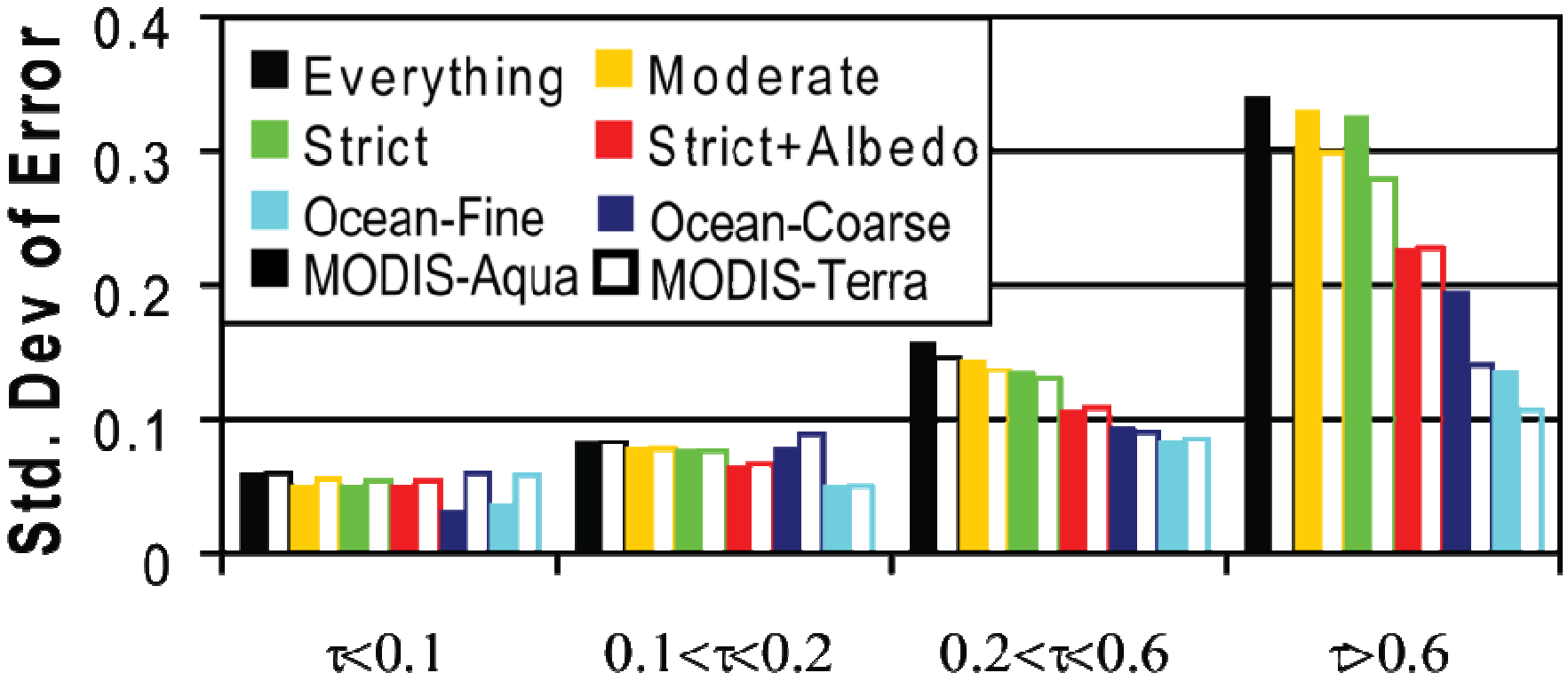
d) **CALIPSO** AOD, Jan 2007 [Vaughan et al. 2007]



Figures b and d are from Mark Vaughan and co-authors, CALIPSO Aerosol Backscatter and Extinction Characterization Using the MODIS and OMI Products, *Eos Trans. AGU, 88*(52), Fall Meet. Suppl., Abstract A23A-0882 .

Identify & quantify uncertainties in collection 5 over land MODIS AOD

QC and QA processes for the collection 5 over land MODIS AOD



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

QC and QA processes for the collection 5 over land MODIS AOD

- c5 is a Huge Improvement over c4 over-land AOD
- Modest Gains from filters using MOD04 metadata
  - Reduce data volume by 50%, reduce RMSE by 16%
- Better gains eliminating high-albedo areas
  - Data volume = 30%, RMSE reduction = 36%
  - At this time, no albedo product for real-time use
- AOD CV + Coverage not as good as ocean product, but getting there

Applications

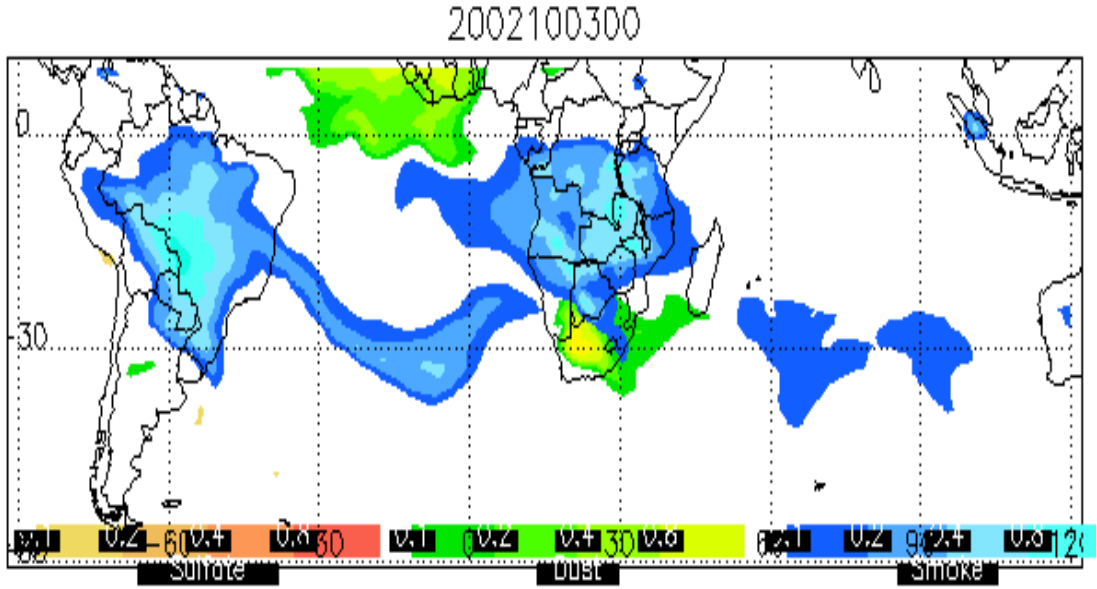
(1) Multi-sensor fusion

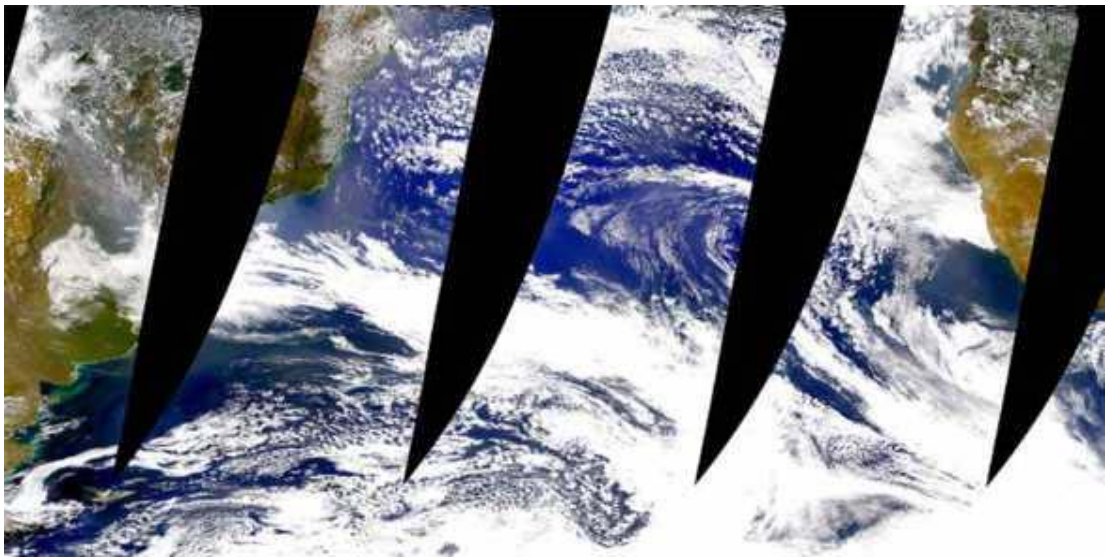
(2) Aerosol forcing

(3) Nighttime aerosol detection

(1) Using aerosol assimilation for data fusion

- Combined the strength of Satellite aerosol studies and aerosol modeling studies.
- High temporal resolution, weight averaging based on data error statistics.
- Aerosol optical property estimates over cloudy regions, useful for studies like aerosol indirect forcing studies.
- Directly applicable to operational aerosol forecast.

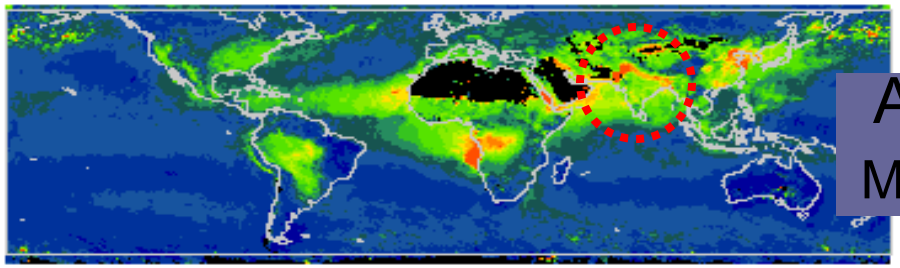




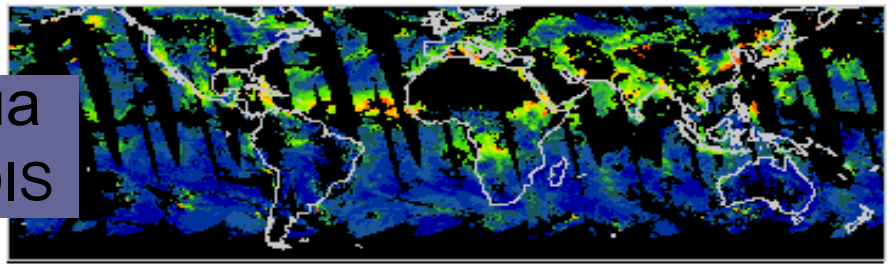
(1) Data fusion, simple multi-sensor case (06-08, 2005)

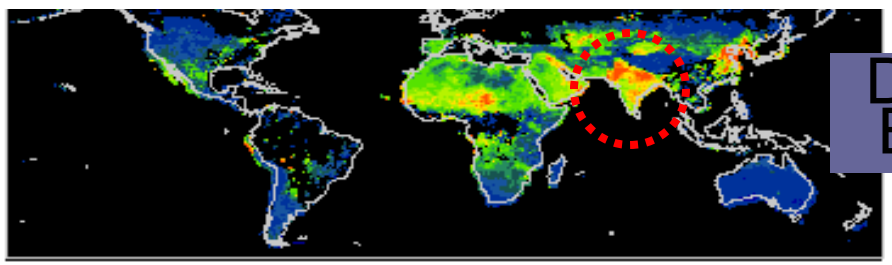
Monthly (June- Aug, 2005)

Daily

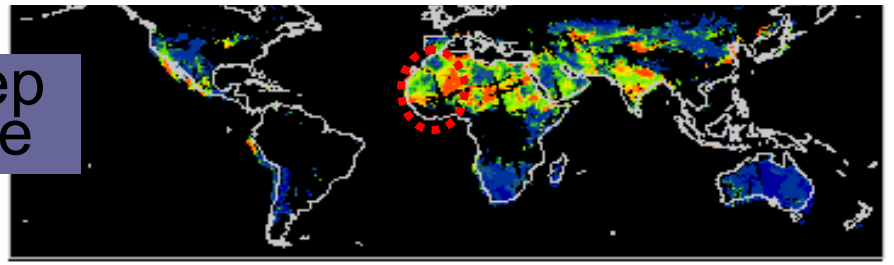


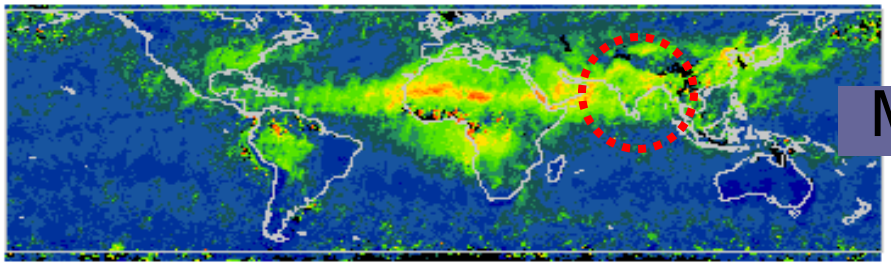
Aqua MODIS



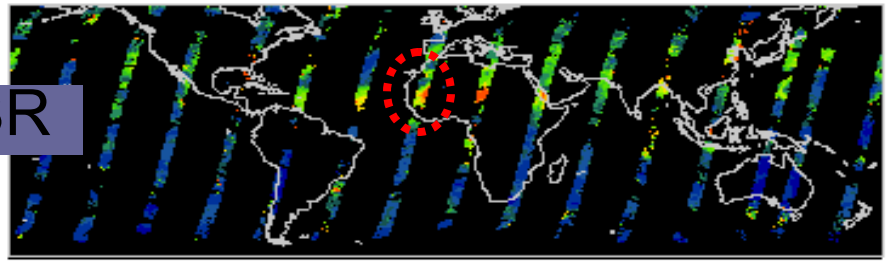


Deep Blue

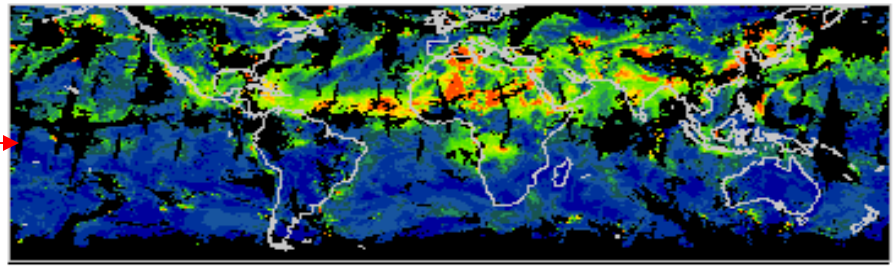




MISR

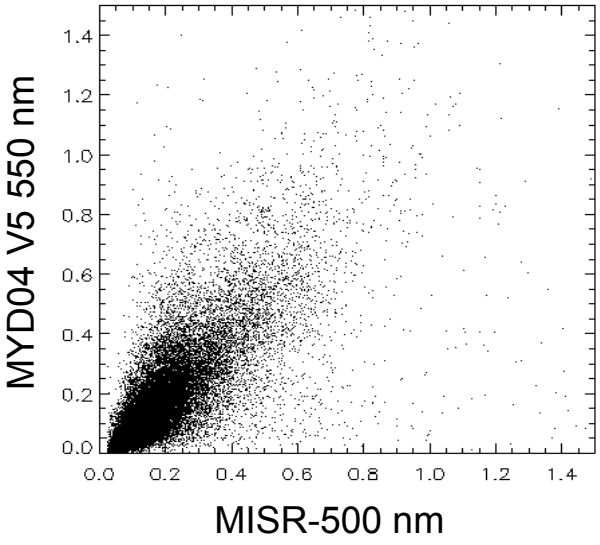


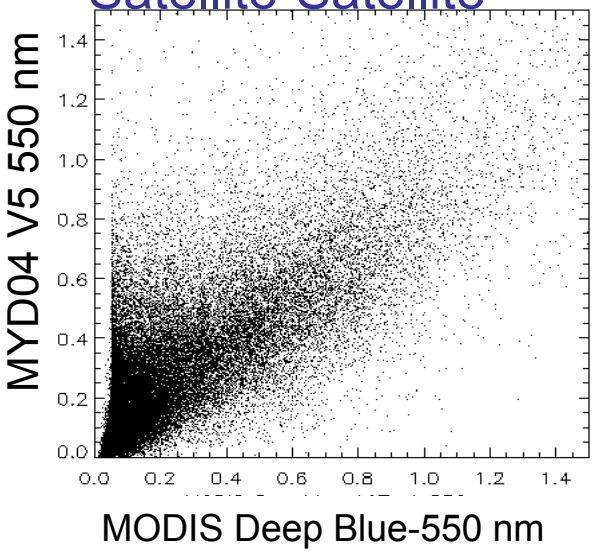
Combined daily product-near total global coverage

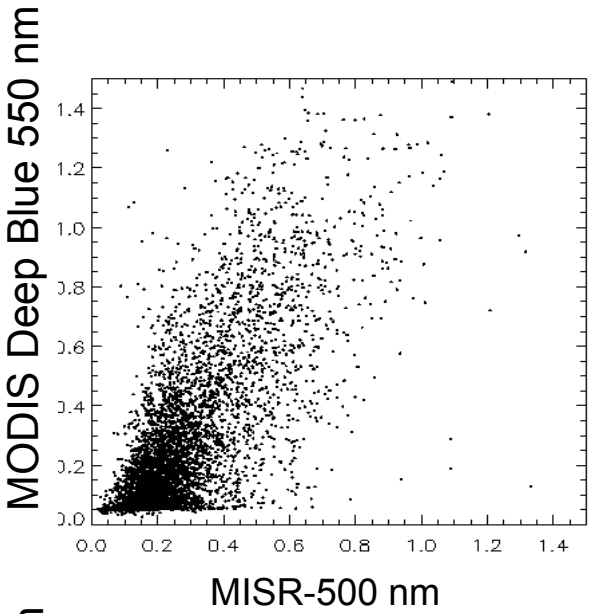


(1) Inter-comparisons among satellite aerosol products

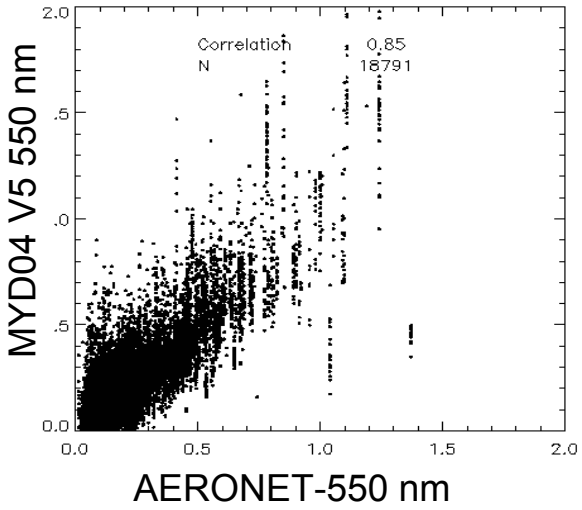
Satellite-Satellite

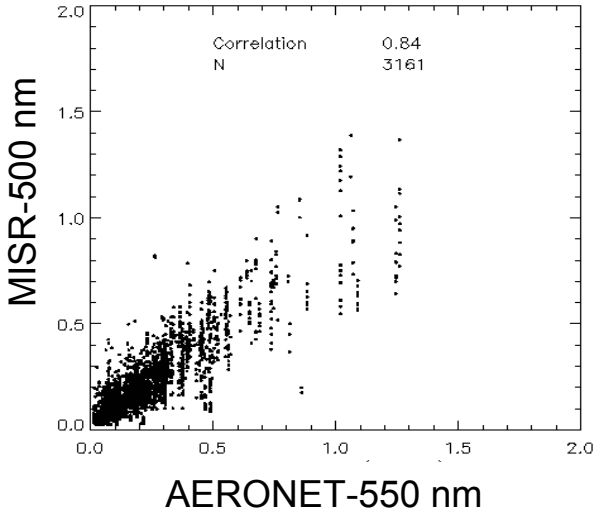


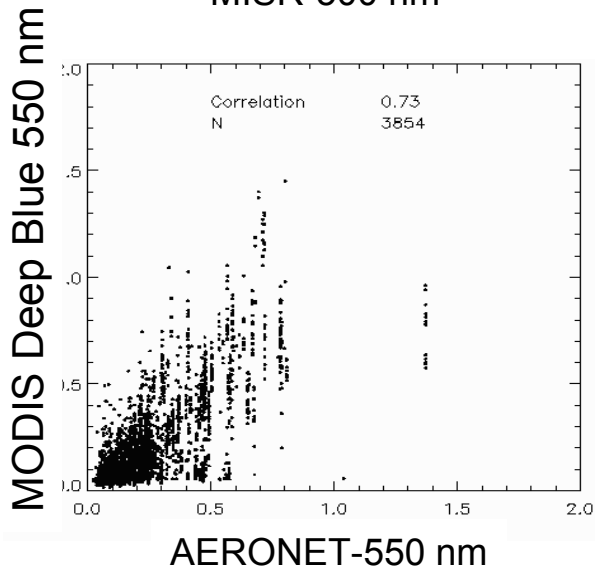




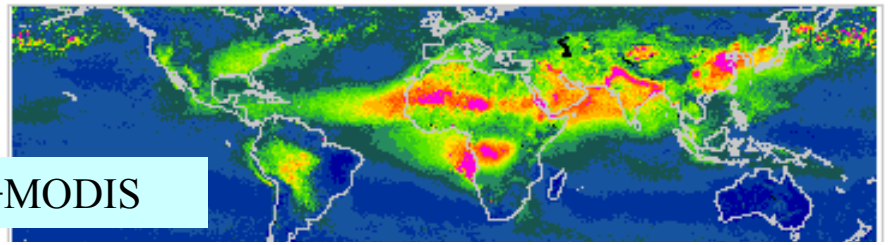
Satellite-AERONET



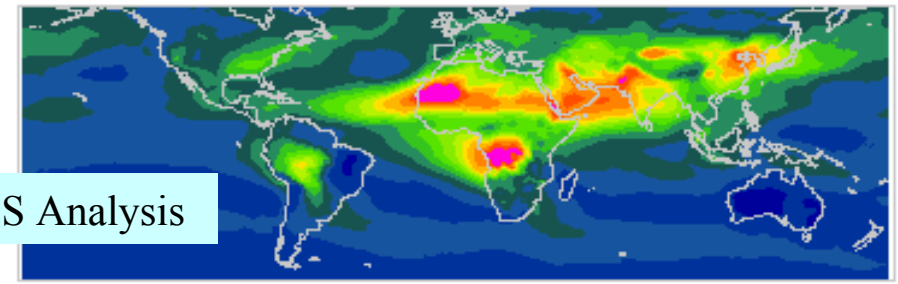




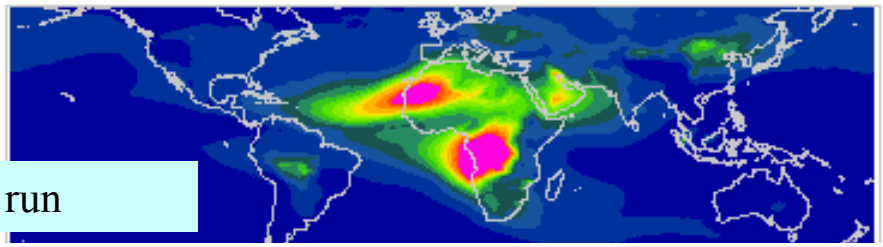
(1) Analysis versus forecast (AOD) (June-Aug, 2005)



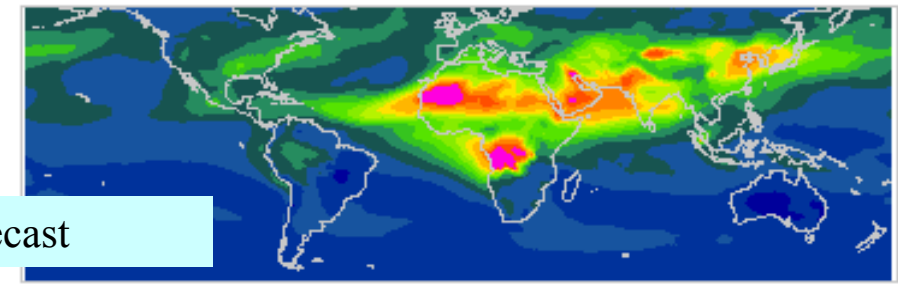
MISR+MODIS



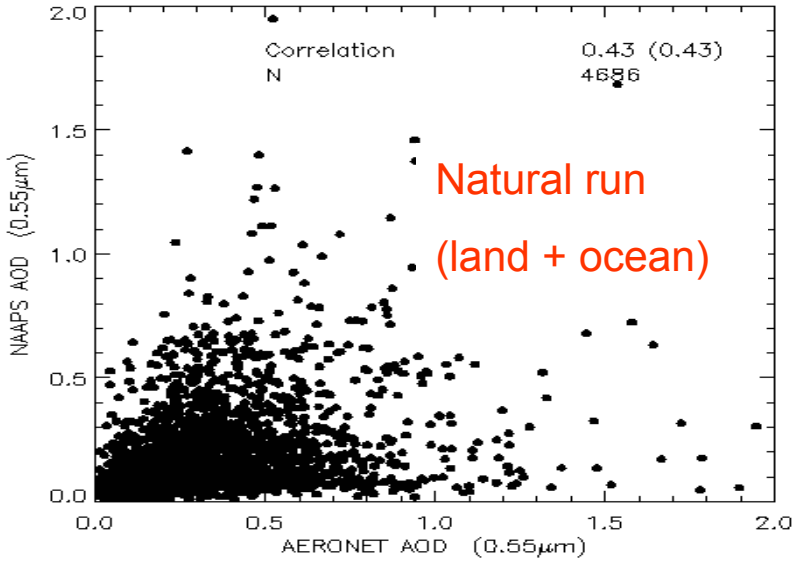
NAAPS Analysis

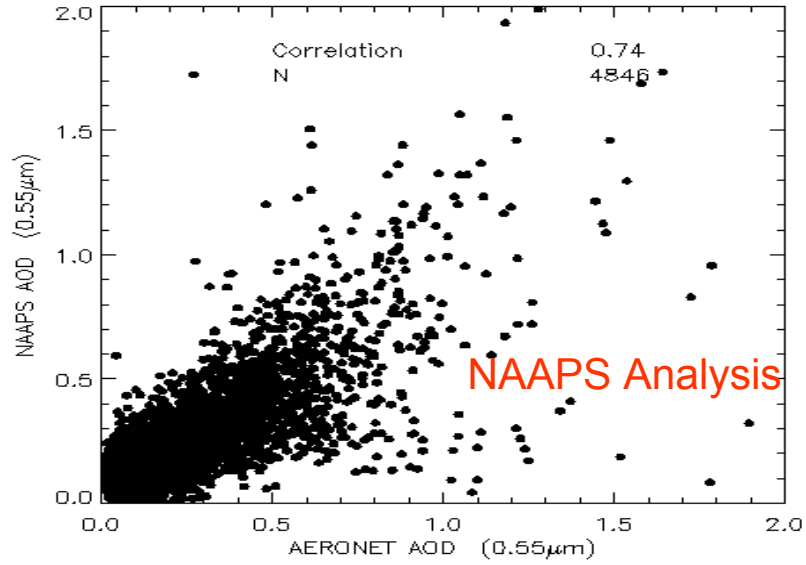


Natural run



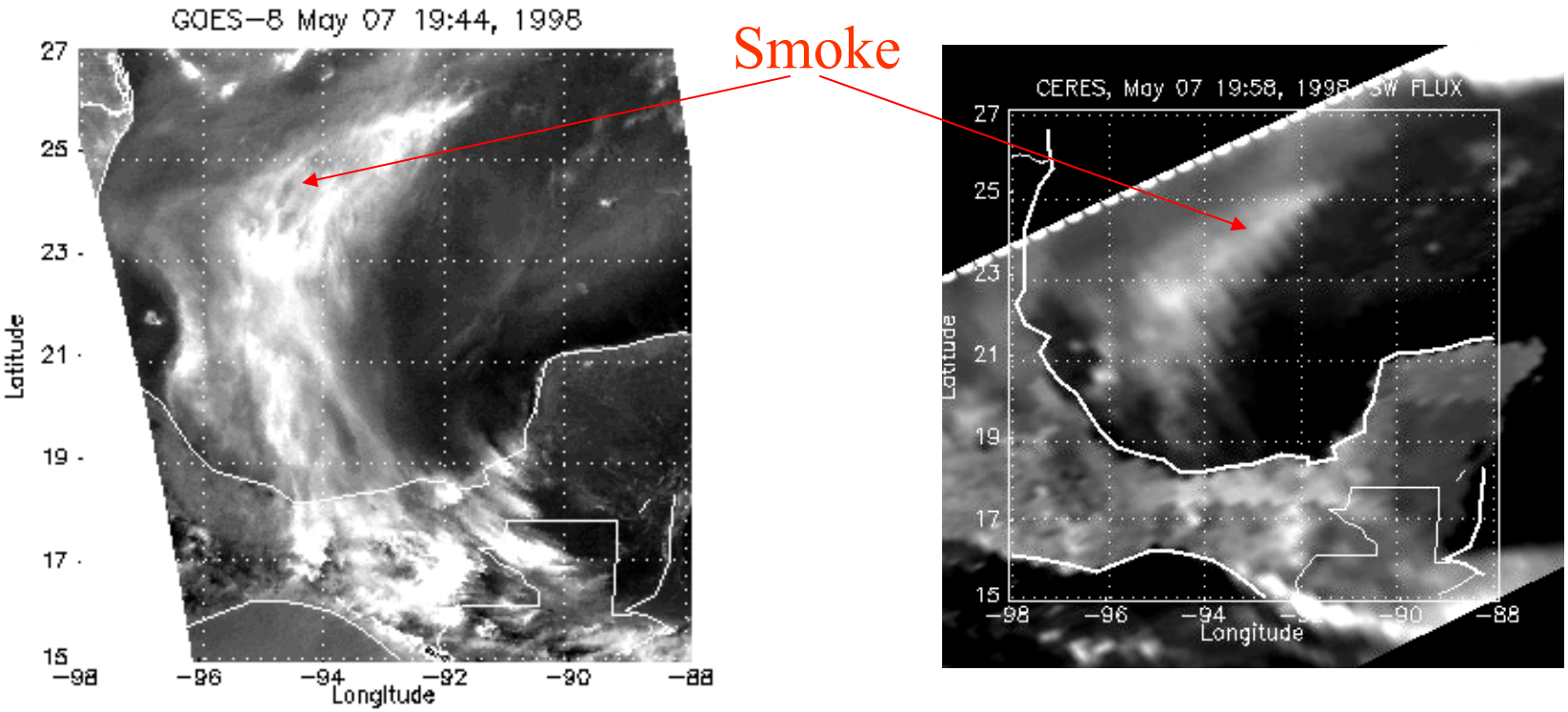
6h forecast



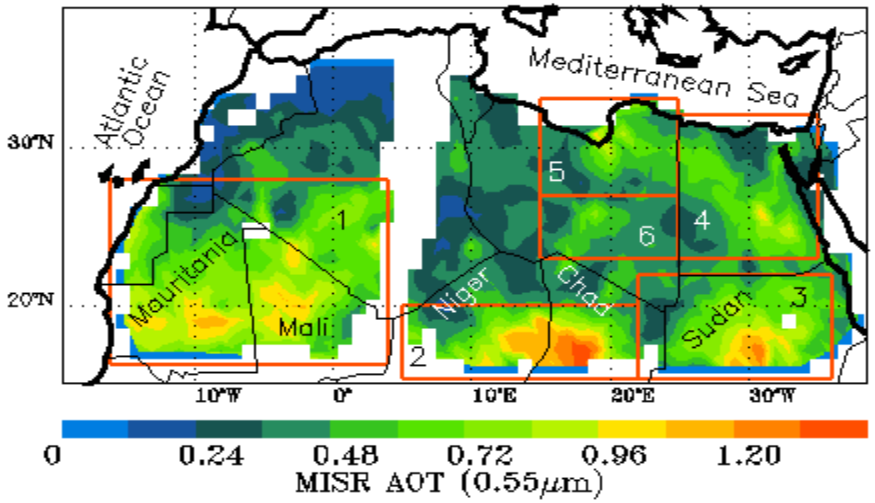


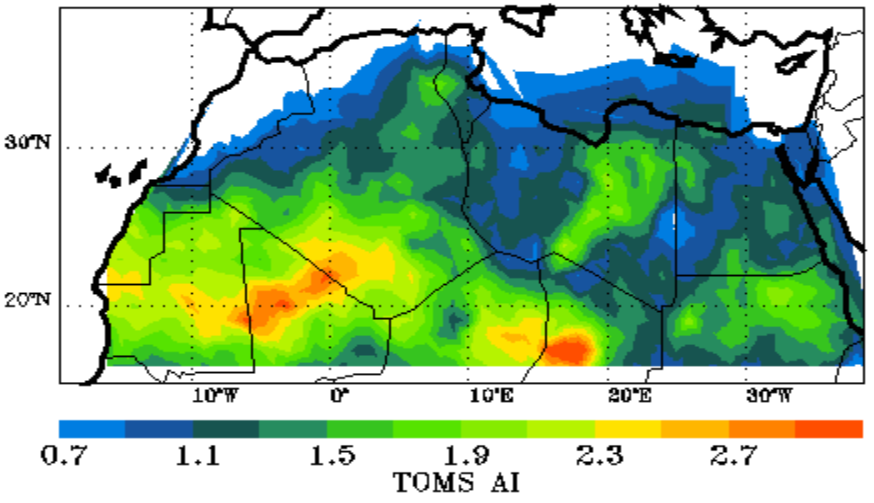
(2) Hope: Aerosol forcing studies, approaches from combining satellite and MODEL

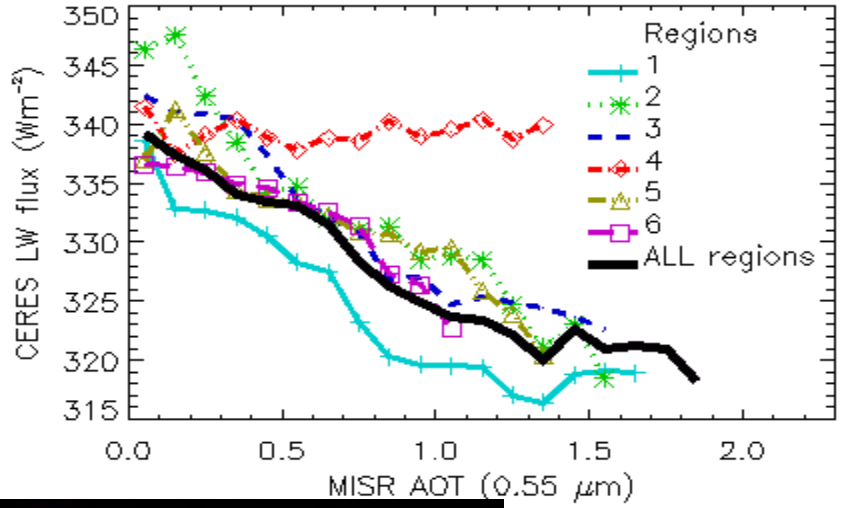
- MODIS/MISR data have finer spatial resolutions that can be used in detecting aerosol and cloud properties within a CERES footprint.

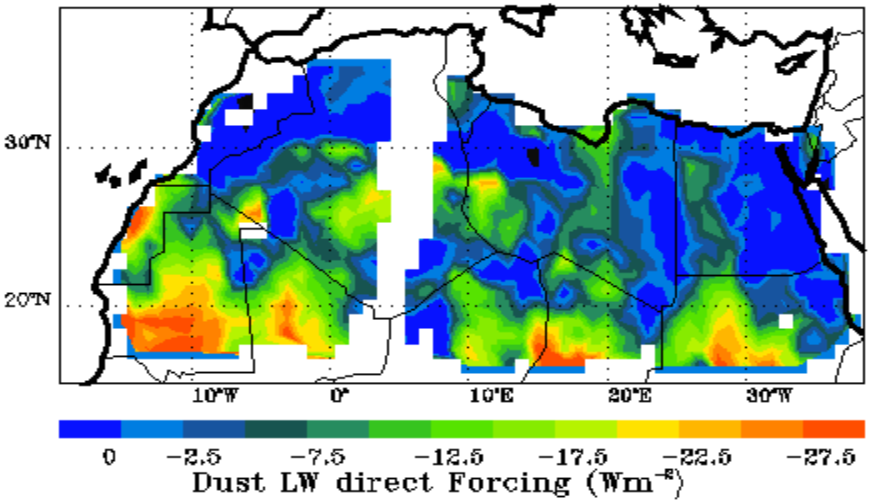


(2) Potential application: LW forcing over Saharan region









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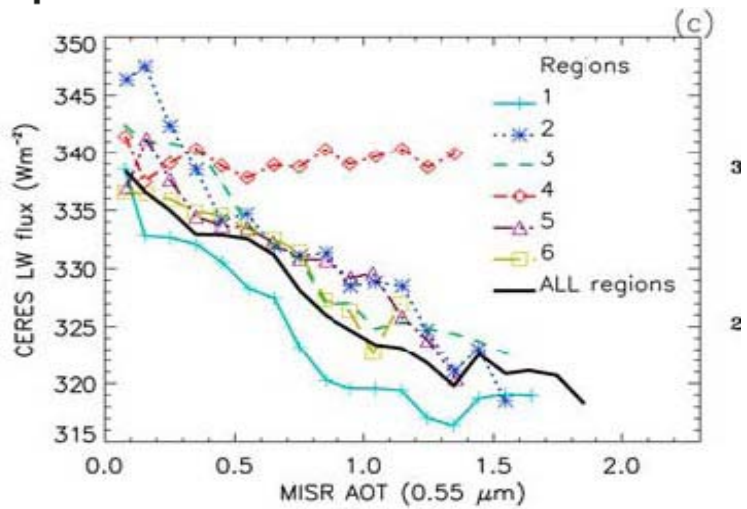
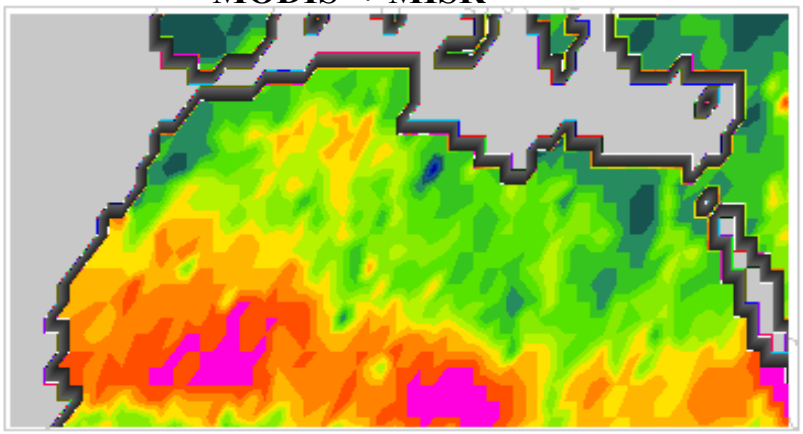
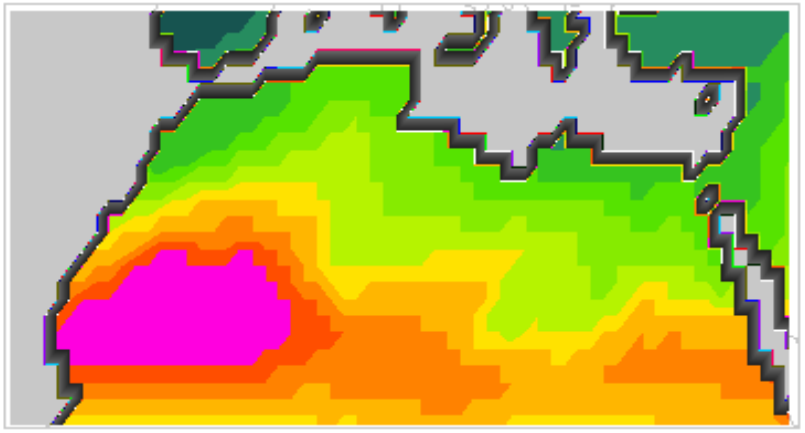
(2) Potential application: LW forcing over Saharan region



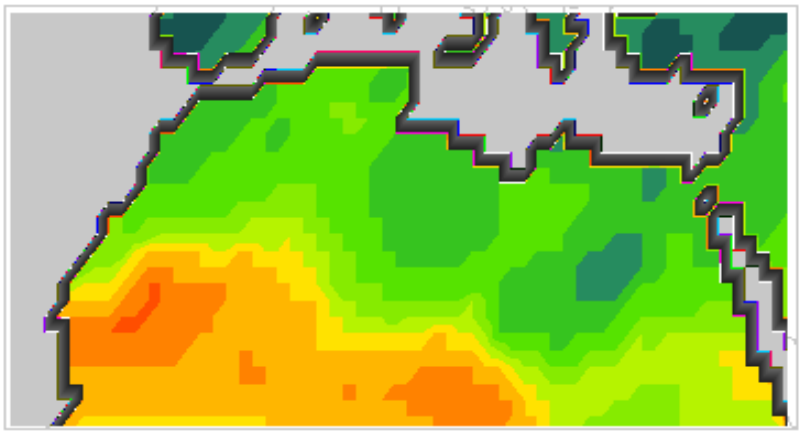
MODIS + MISR



NAAPS + MODIS + MISR



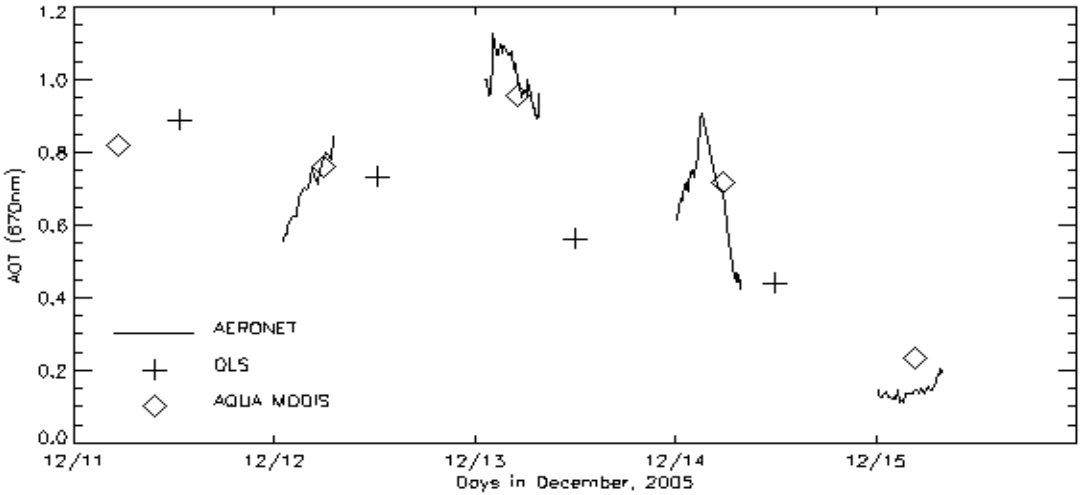
NAAPS + MODIS + MISR + DEEPBLUE

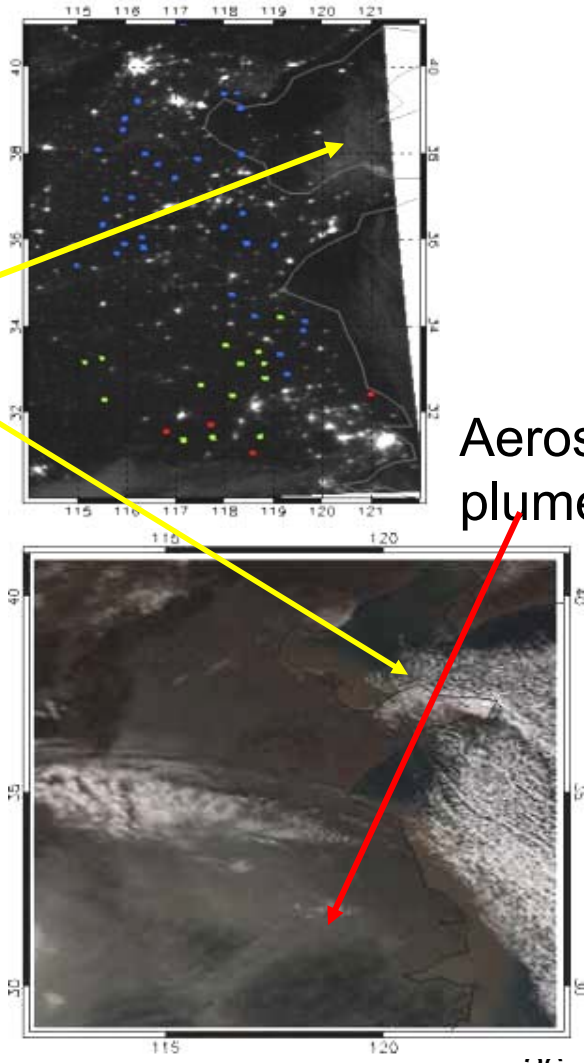


LW forcing (Wm^{-2})

(3) Night-time aerosol observations

- Aerosol retrieval using city lights
- Use the Operational Linescan System (OLS) data
- Problems
- Hopes





Zhang, J. and J. S. Reid, J. Turk, and S. Miller, Strategy for studying nocturnal aerosol optical depth using artificial lights, IJRS, 2008.

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FY 08 Milestones

1. **Continue test and validate over-water aerosol assimilation.**
   - **Accomplishment #1** Full-scale validation.

2. **Over ocean aerosol data assimilation.**
   - **Accomplishment #1** QA and QC collection 4 (C4) over-water MODIS aerosol product.
   - **In Progress** Update and re-validate QA/QC for the over water MODIS collection 5 (C5) AOD data.

3. **Over land aerosol data assimilation.**
   - **Working on #1** QA and QC MODIS C5 over-land aerosol product.
   - **In Progress** Construct over-land MODIS level 3 aerosol product.

4. **Scientific applications.**
   - **Accomplishment #1** Test the possibility of multi-sensor data fusion.
   - **Accomplishment #2** Nighttime aerosol study.

FY 07-08 Publications

1. Peer reviewed journal, published or accepted

Zhang, J., J. S. Reid, D. L. Westphal, N. L Baker, and E. J. Hyer, 2008: A system for operational aerosol optical depth data assimilation over global oceans, J. Geophys. Res., 113, D10208, doi:10.1029/2007JD009065.

Zhang, J. and J. S. Reid, J. Turk, and S. Miller, 2008: Strategy for studying nocturnal aerosol optical depth using artificial lights, (In Press) International Journal of Remote Sensing.

2. Conference Proceedings & Other

Kalashnikova O. V., R. A. Kahn, M. Garay, J. Zhang, and J. S. Reid, Mineral dust transport characterization over the Atlantic from combined satellite aerosol retrievals, Geophysical Research Abstracts, Vol. 10, EGU2008-A-11193, 2008, SRef-ID: 1607-7962/gra/EGU2008-A-11193, EGU General Assembly 2008.

Zhang, J, J. S. Reid, D. L. Westphal, C. Hsu, S. A. Christopher, R. A. Kahn, Combined use of MODIS, MISR, CERES, and a data assimilation method for estimating aerosol climate forcing over Saharan regions, *Eos Trans. AGU, 88*(52), Fall Meet. Suppl., Abstract A12A-05, 2007.

Reid, J. S., J. Zhang, C. Hsu, S. A. Christopher, E. J. Hyer, A. P. Kuciaskas, D. L. Westphal, R. A. Kahn, J. A. Hansen, Application of Multi-Sensor Fusion to the Aerosol Forecasting Problem *Eos Trans. AGU, 88*(52), Fall Meet. Suppl., Abstract A11E-03, 2007.

Hyer, E. J., J. Zhang, J. S. Reid, C. A. Curtis, D. L. Westphal, Biomass burning source characterization requirements in air quality models with and without data assimilation: challenges and opportunities, *Eos Trans. AGU, 88*(52), Fall Meet. Suppl., Abstract A52D-04, 2007.