Multi-Sensor Aerosol Data Assimilation Using MODIS MISR and CALIPSO Aerosol Products

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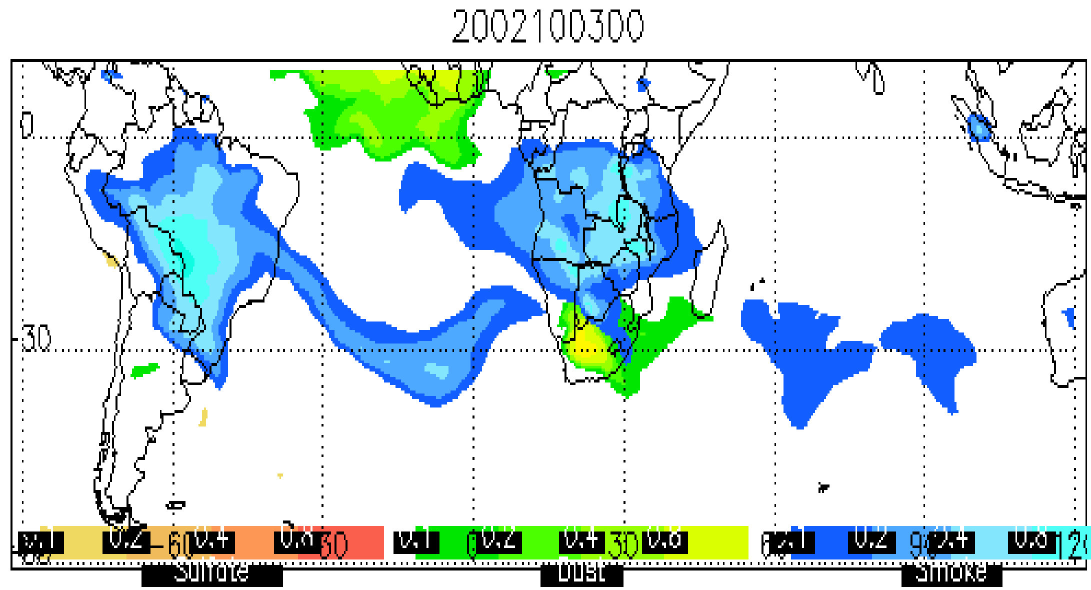
JCSDA 9th Workshop on Satellite Data Assimilation

Goals and Challenges

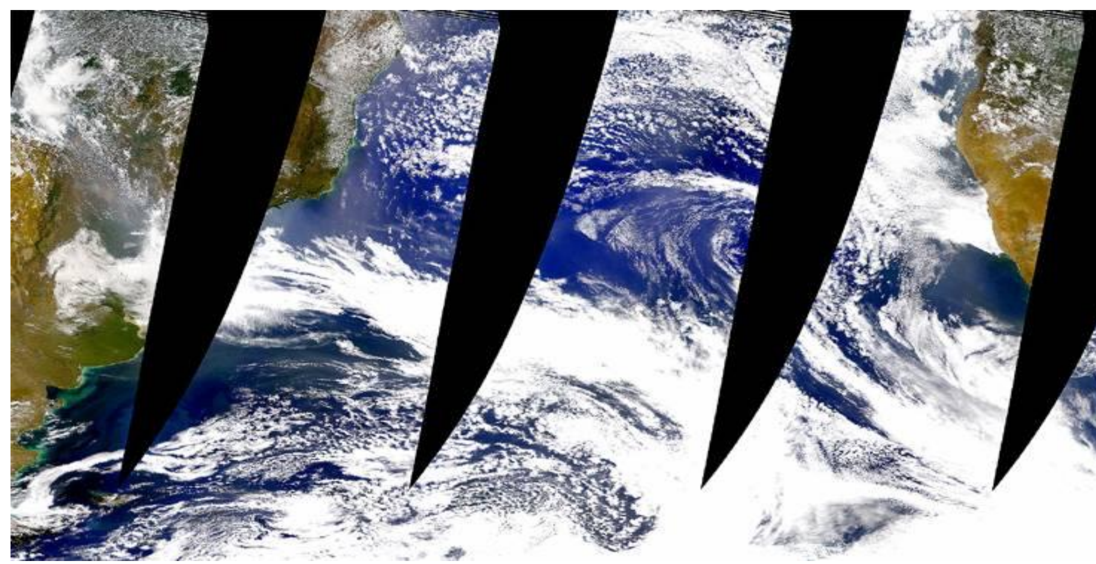


<u>*Goals:*</u>

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

<u>*Challenges and questions:*</u>

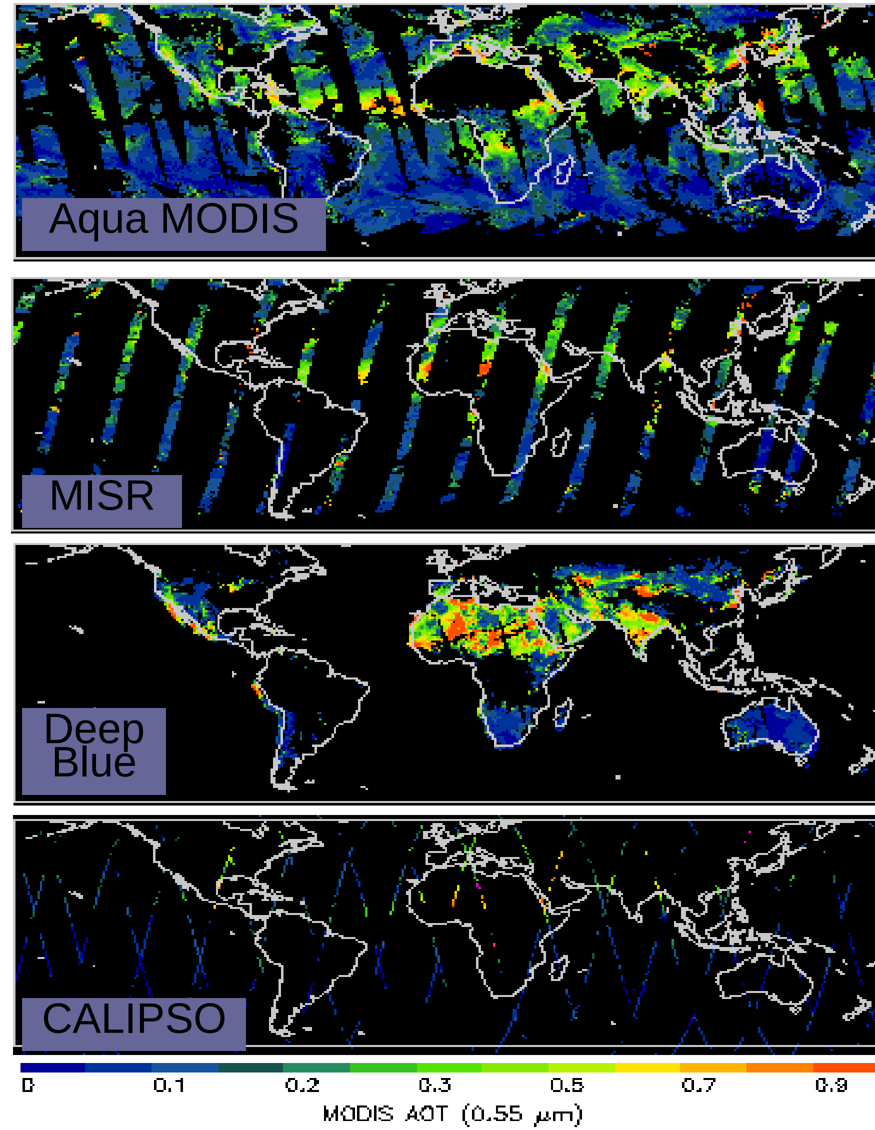
- We need to work in <u>*operational*</u> mode. Need something <u>*robust*</u>.
- We need to fully utilize the available data streams. What ways can multi-sensor data streams help?
- Do the satellite products and model results make physical sense?



Question: 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 true global coverage?
- The vertical profile from CALIPSO is critical, but the spatial limitations of the orbital track raise a new set of concerns.

Daily coverage

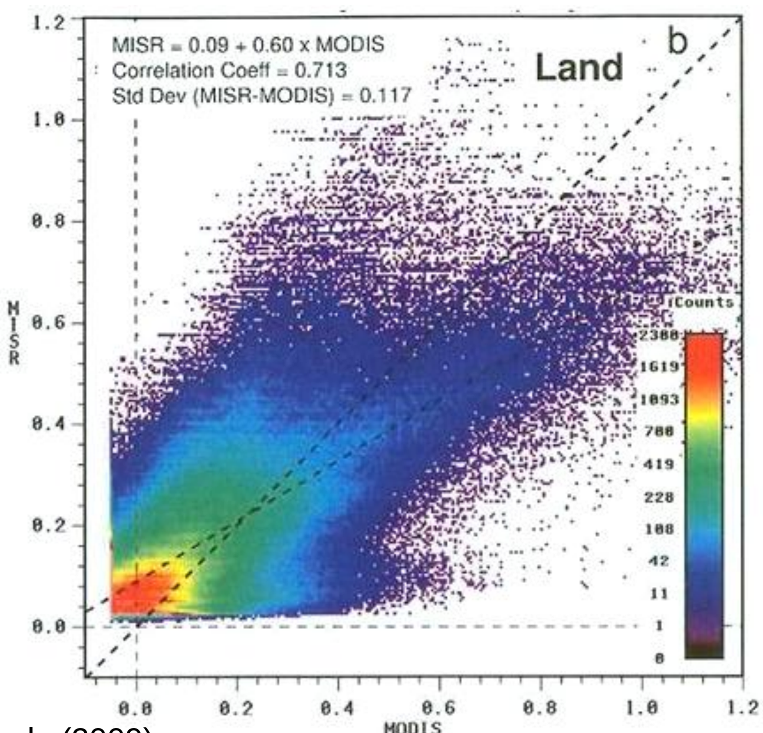


Questions: Data Quality and Bias Constraint MODIS versus MISR

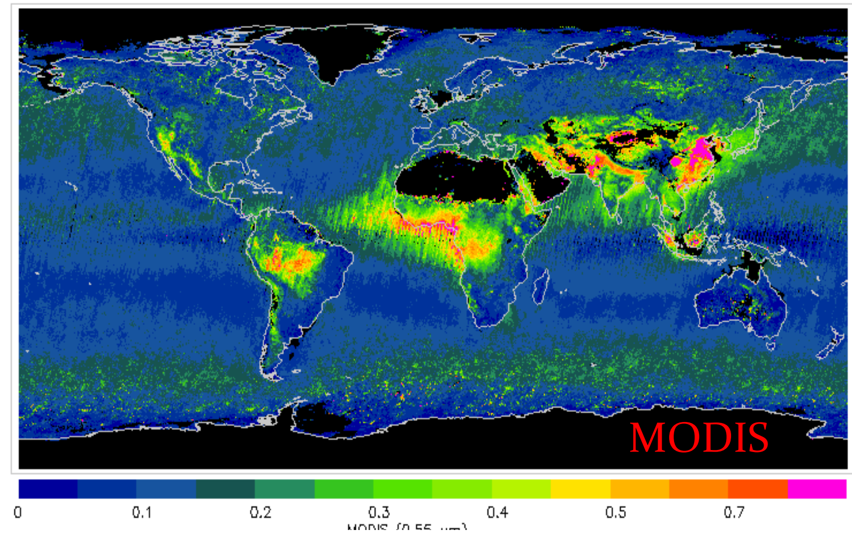
Over ocean, agreement is good and MISR compliments MODIS glint regions.

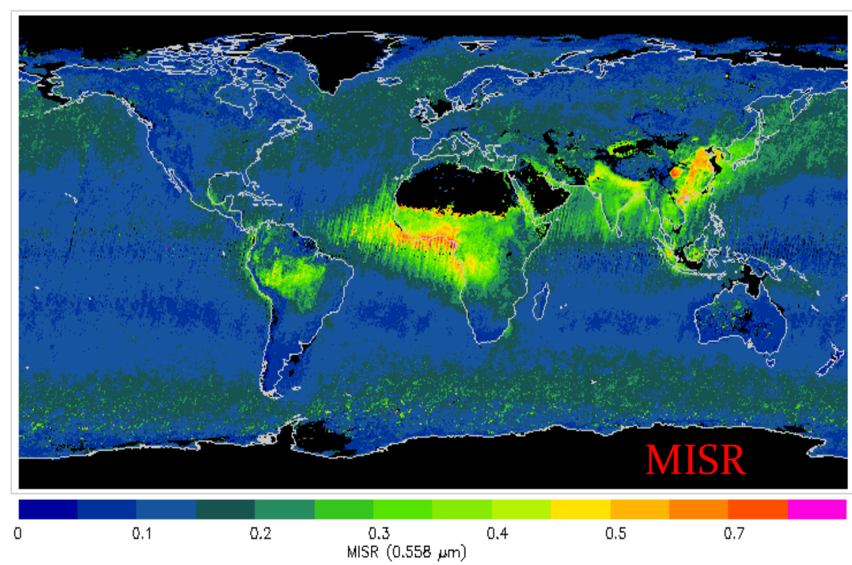
Over land, qualitatively similar, but large uncertainties exist and extreme differences will degrade model performance.

But, cloud errors are found over water for both products.



Kahn et al., (2009)



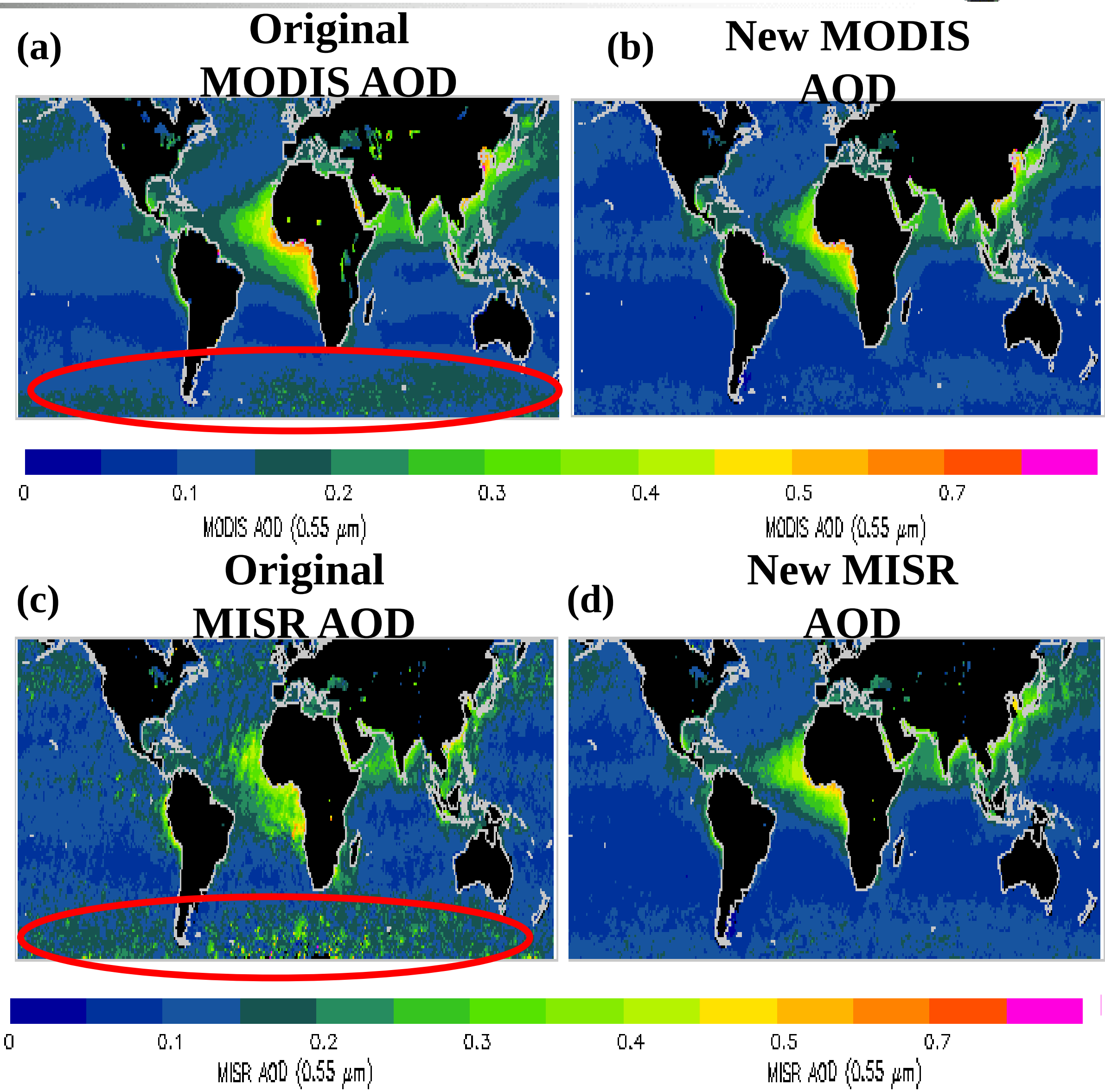


Shi et al., (2011)

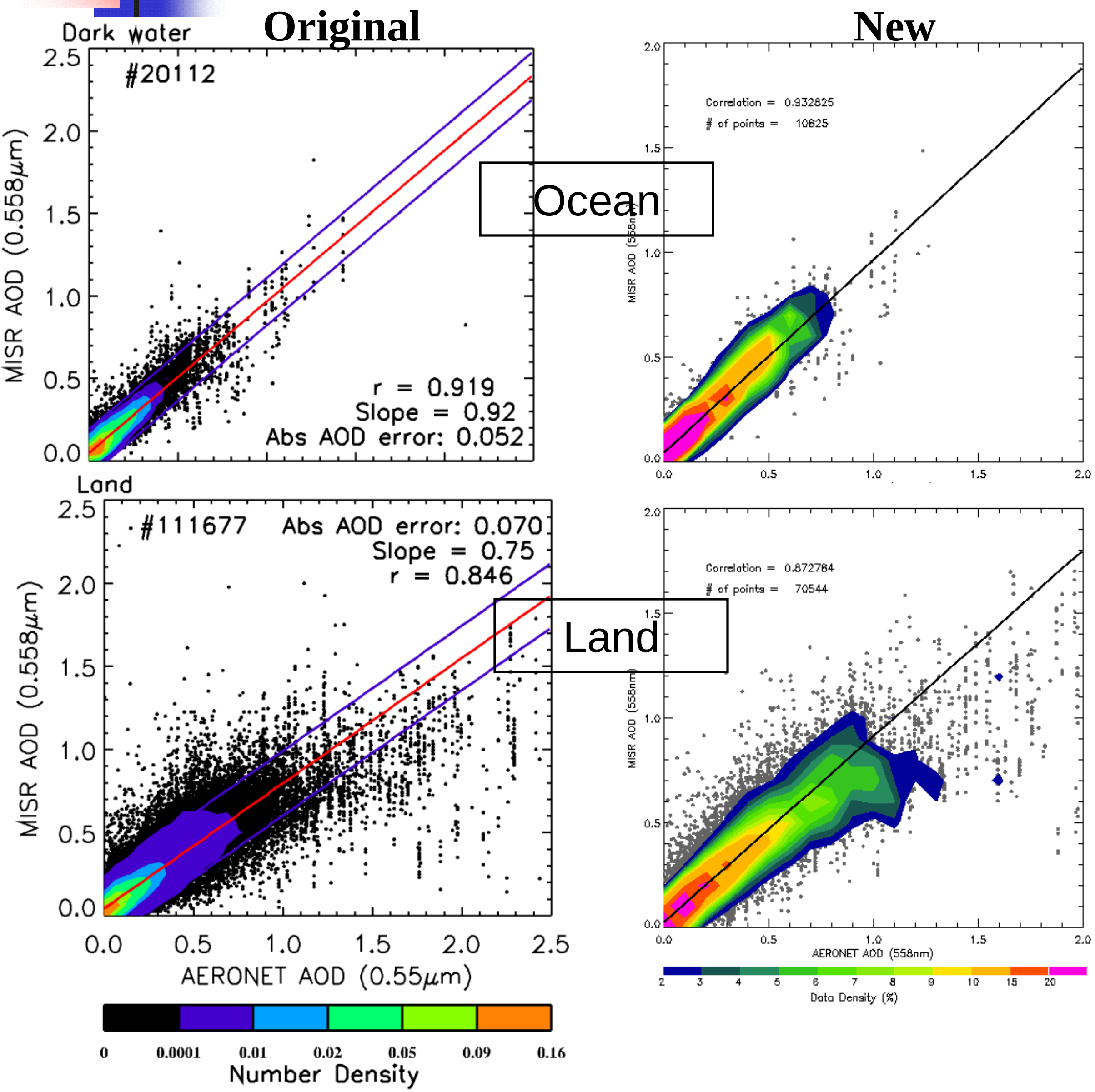
Screening Bias From Products

Example: Over-ocean satellite AOD data

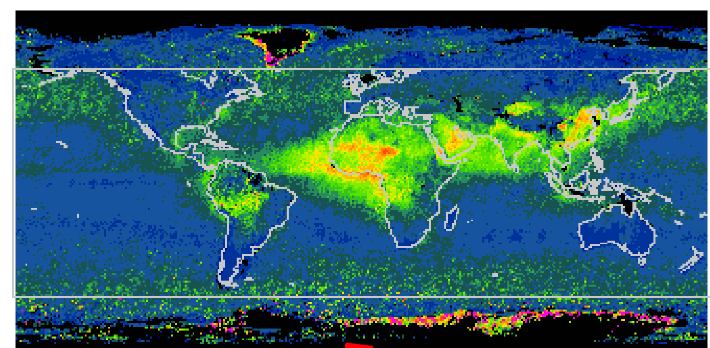
- We begin with NRTPE Collection 5 MOD04 AOD data. Shown is 2005 annual average.
- QA: Data are screened using spatial tests and thresholds. Empirical corrections are made based on satellite and NOGAPS environmental data.
- End result: more than 50% correction in data over southern oceans and Asian outflow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



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

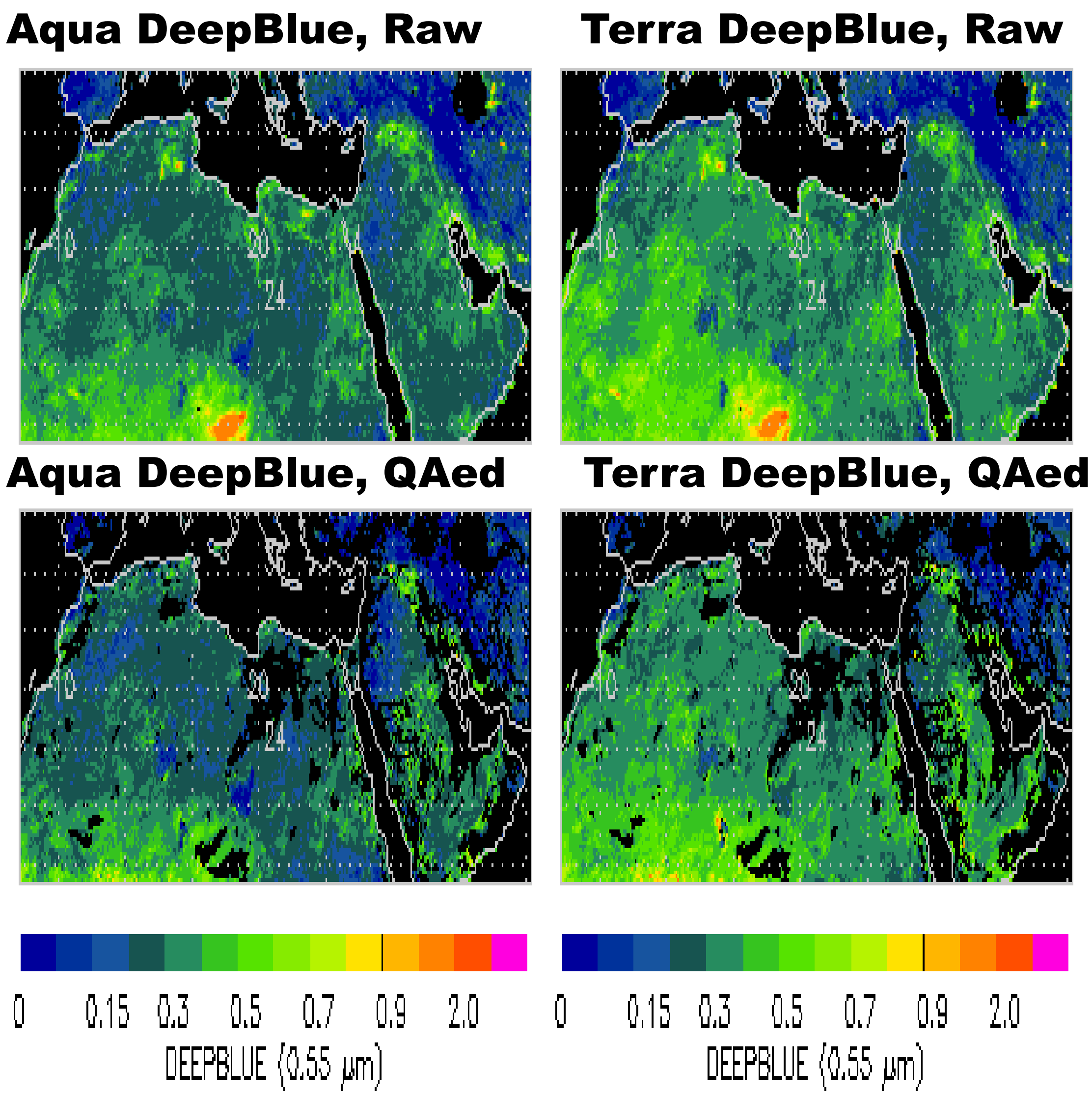


MODIS DeepBlue Product

- The DeepBlue AOD values (with QA = very good) are in good agreement with the AERONET data, especially in North African regions.

- Uncertainties are found to be associated with:
    - Aerosol Microphysics (aerosol type or aerosol size)
    - Surface Albedo
    - Scattering Angle

- Preliminary results show that QA procedures and the empirical correction reduced the uncertainties of the DeepBlue AOD by 14-20% for total AOD and 20-30% for AOD > 1.0 . Noises are removed from the Arabian Peninsula.

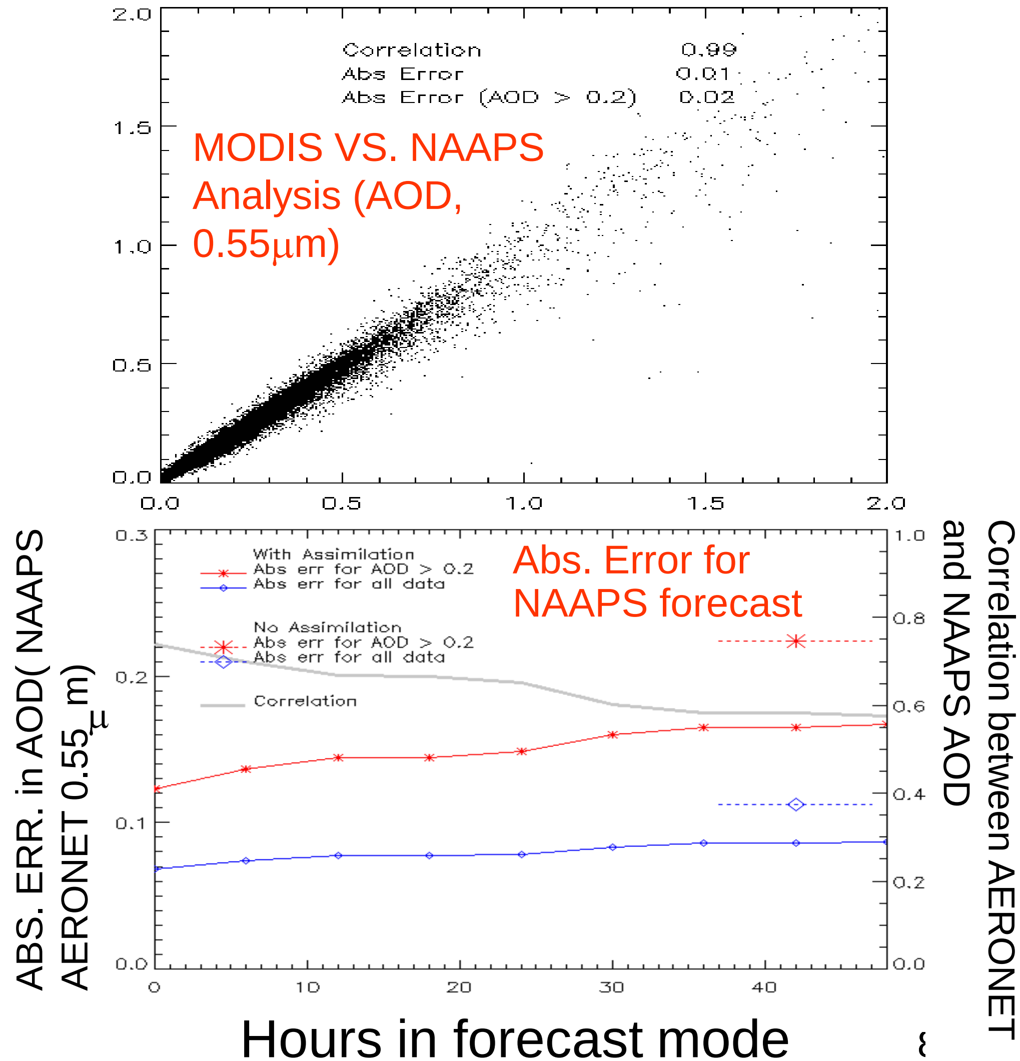


Shi, Y, Zhang, J, J. Reid, and C. Hsu (2010), Evaluation of the MODIS Deep Blue aerosol product over the North Africa Regions for aerosol forecasts related applications, Abstract A31A-0025 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

Evaluation

(Single-sensor over-water aerosol data assimilation)

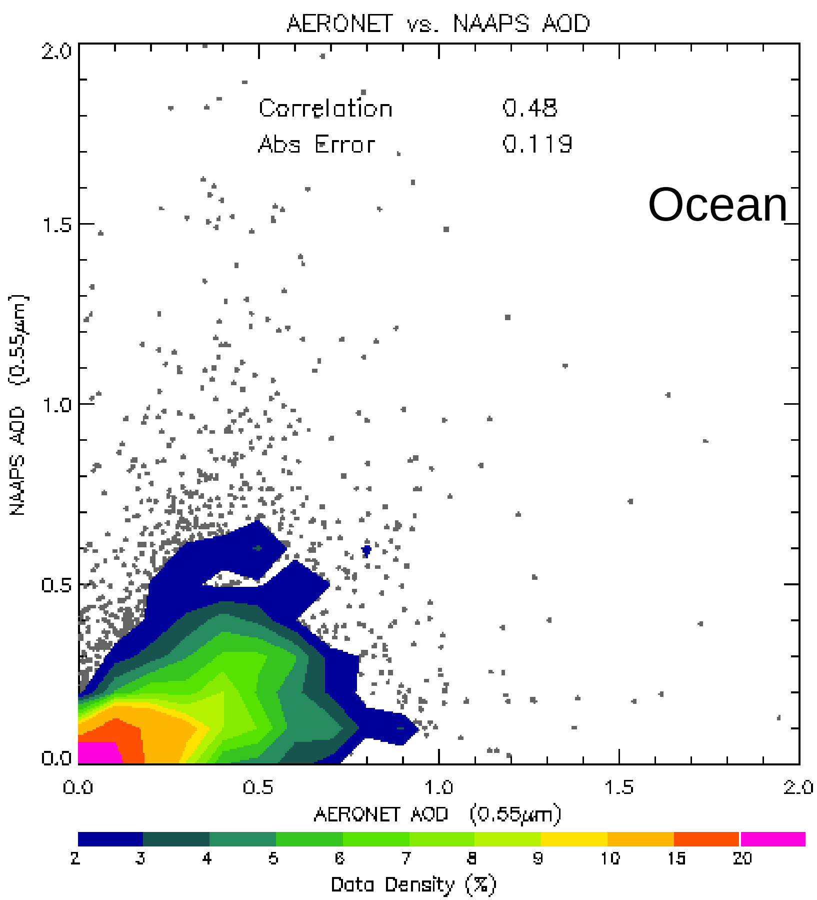
- Five month comparison vs. AERONET of NAVDAS-AOD using MODIS Level 2 data (Terra+Aqua) with additional screening and corrections.
- Can reproduce observations at the analysis fields.
- NAAPS mean bias reduced by nearly 1/3 for 48-hour forecast.
- Currently operational at FNMOC



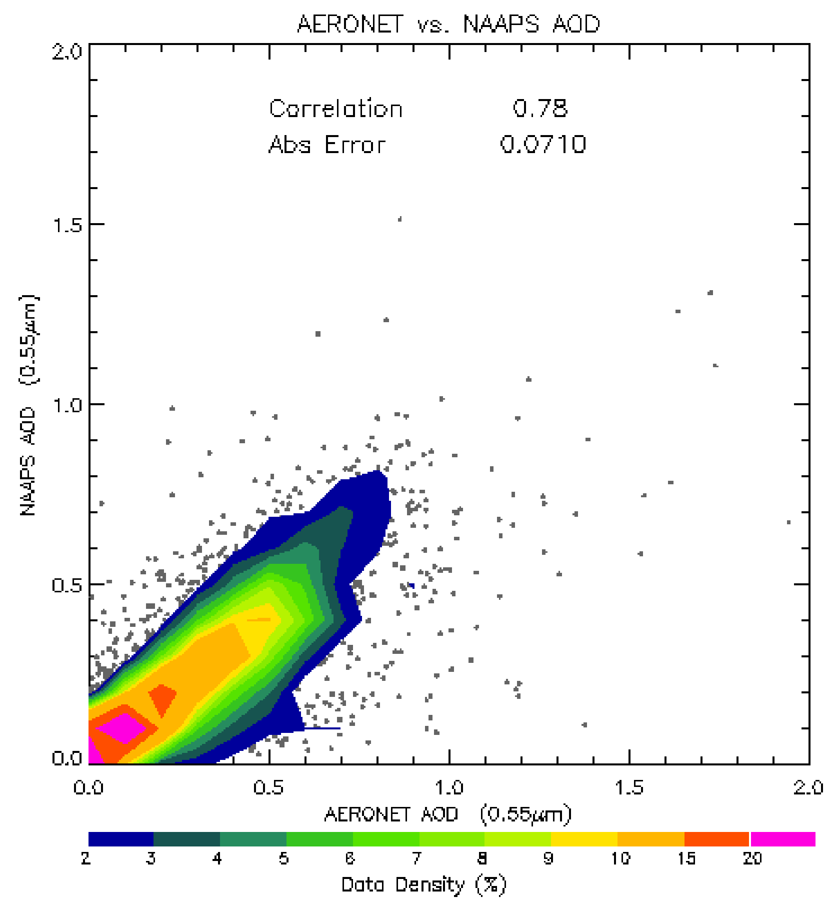
Zhang, J. and J. S. Reid, D. Westphal, N. Baker, and E. Hyer, A System for Operational Aerosol Optical Depth Data Assimilation over Global Oceans, accepted for *J. Geophysical Research-Atmospheres,, 2007.*

Multi-Sensor Assimilation
(Over-ocean case)

Natural run



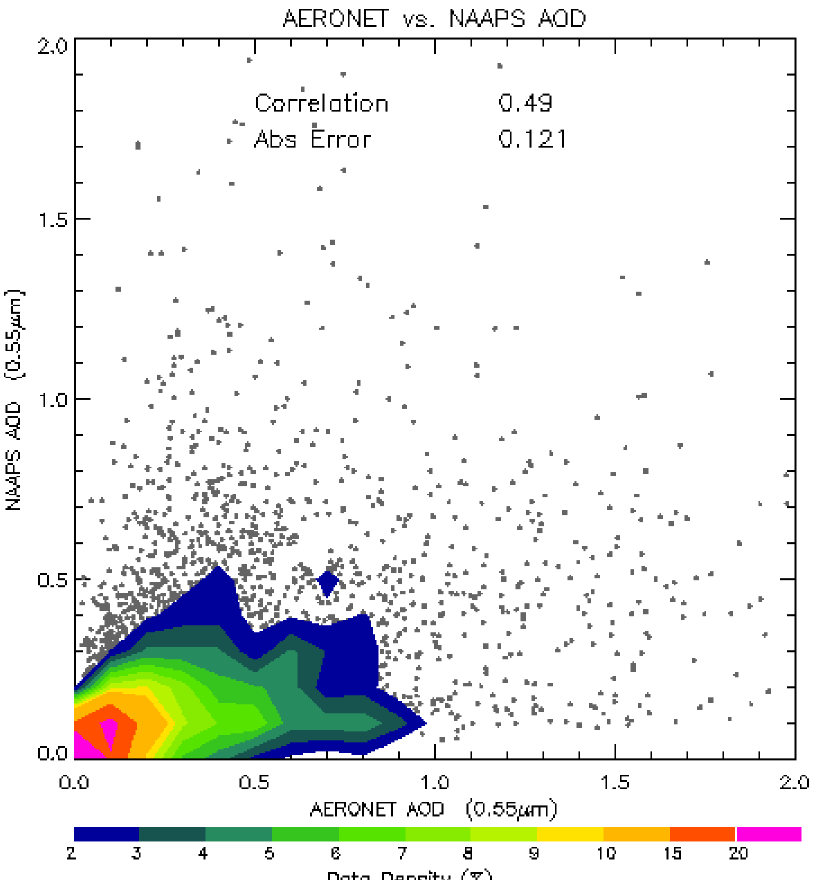
+ Land/Ocean MODIS
+ Land/Ocean MISR



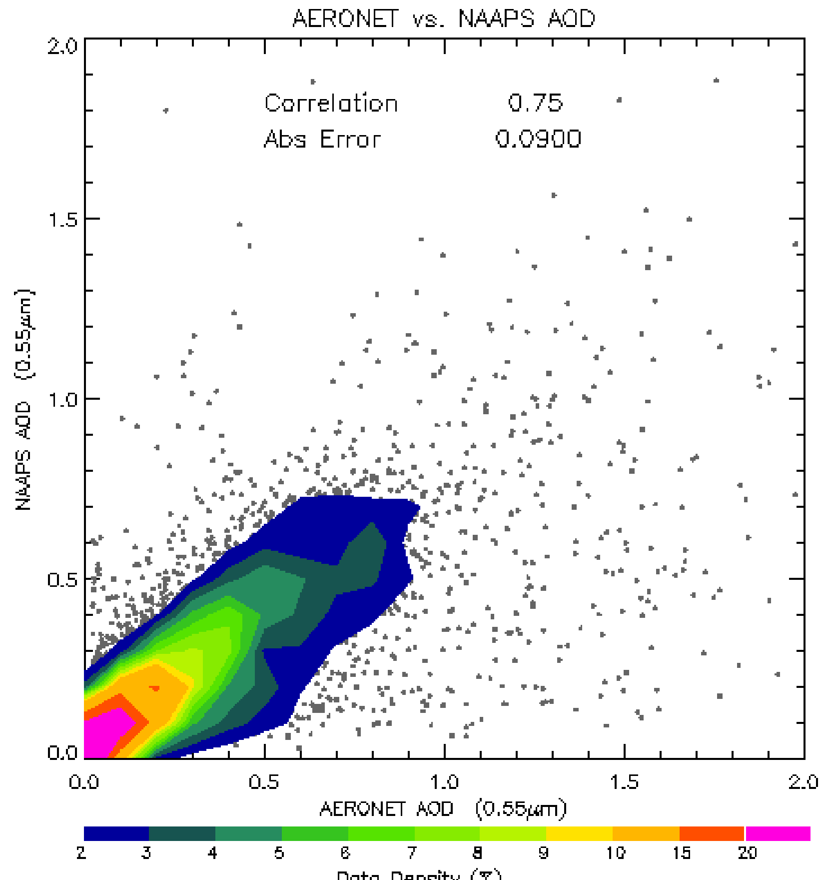
Over-ocean aerosol analyses benefit from the MODIS aerosol product
Adding more sensors/data yields incremental improvements.

Multi-sensor assimilation Over land case:

Natural run



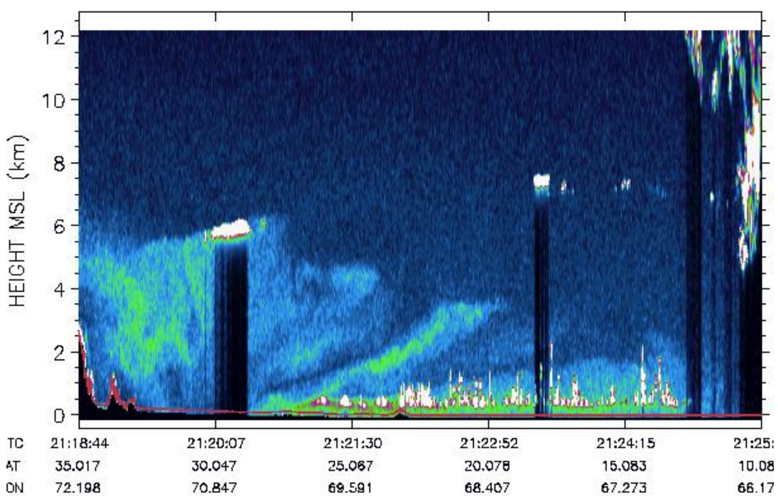
+ Land/Ocean MODIS
+ Land/Ocean MISR

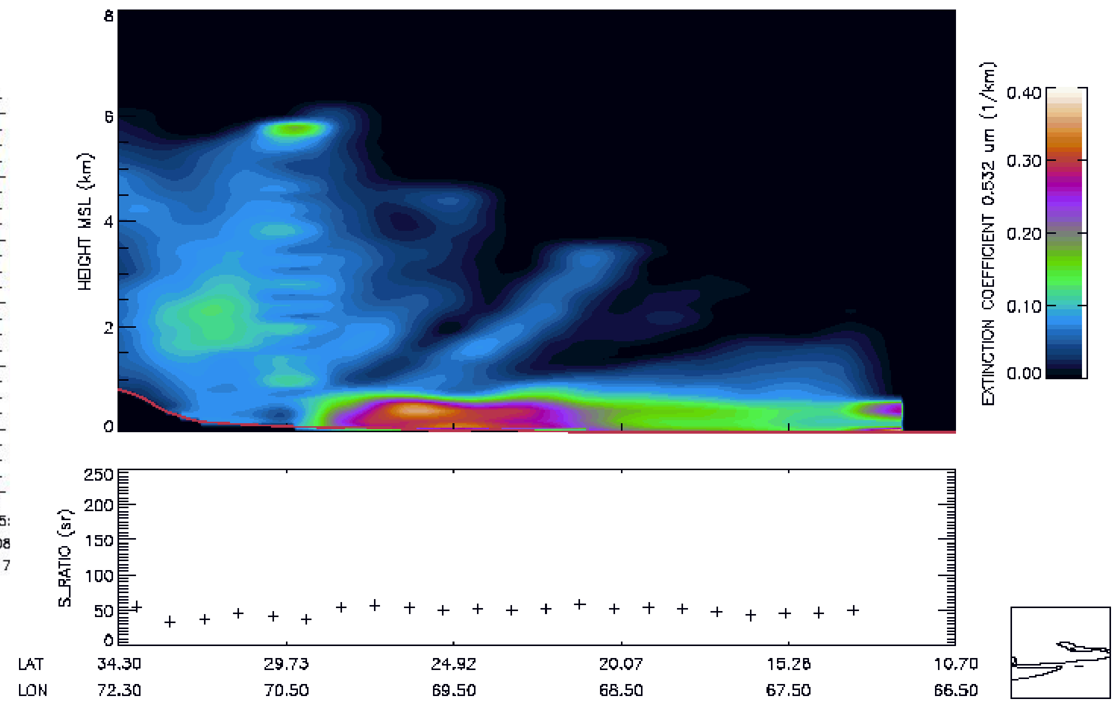


Multi-sensor assimilation is critical to over-land aerosol assimilation. Improvements are observable with each new sensor added.

The Next Step: 3DVAR Assimilation

- NASA-generated Level 2 0.333 km CALIOP cloud detection product (cloud detection)
- 1° along-track averages (to fit with NAAPS resolution)
- Convert from attenuated backscatter to extinction coefficient





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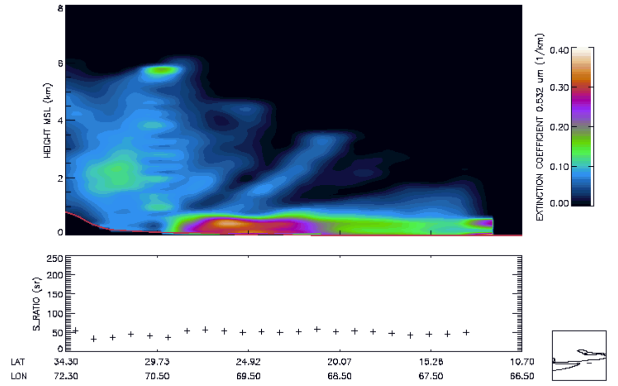
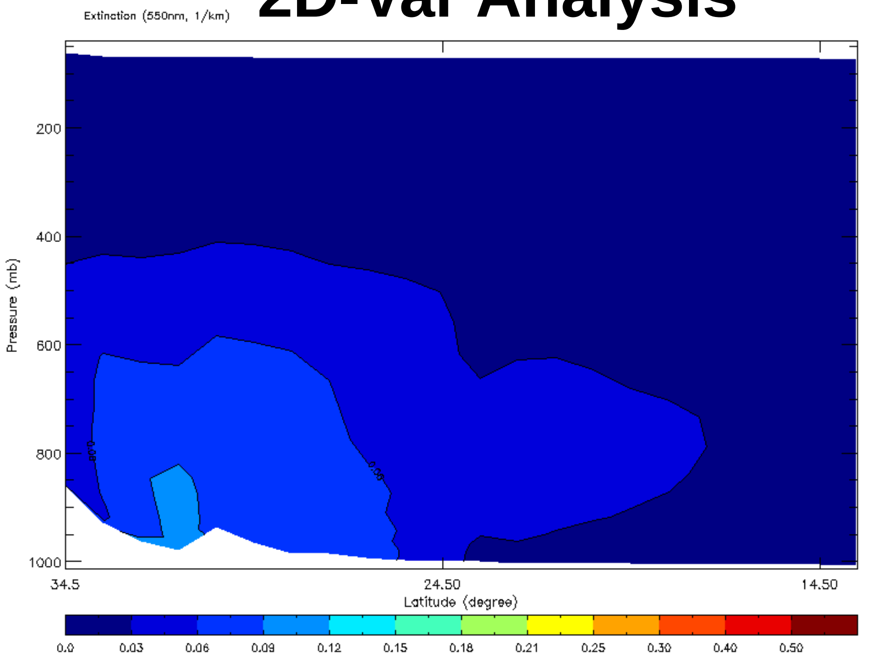
Campbell, J. R., J. S. Reid, D. L. Westphal, J. Zhang, E. J. Hyer and E. J. Welton, CALIOP aerosol subset processing for global aerosol transport model data assimilation, *J. Sel. Top. Appl. Earth Obs. and Rem. Sens.*, doi:10.1109/JSTARS.2010.2044868, *3*, 203-214, 2010.

The Next Step: 3DVAR Assimilation

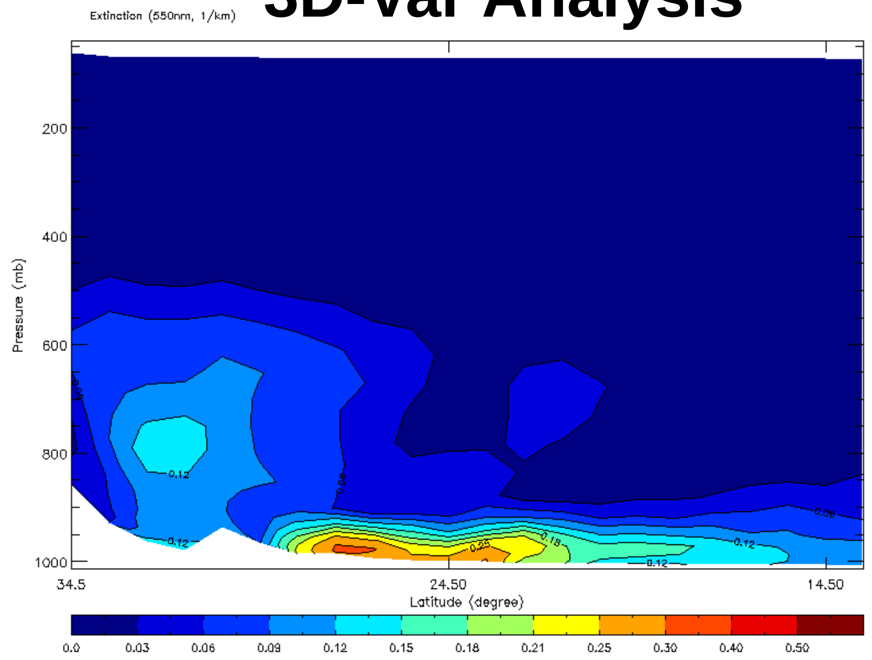
- Assimilate
- Vertical distribution of AOD is significantly altered



2D-Var Analysis



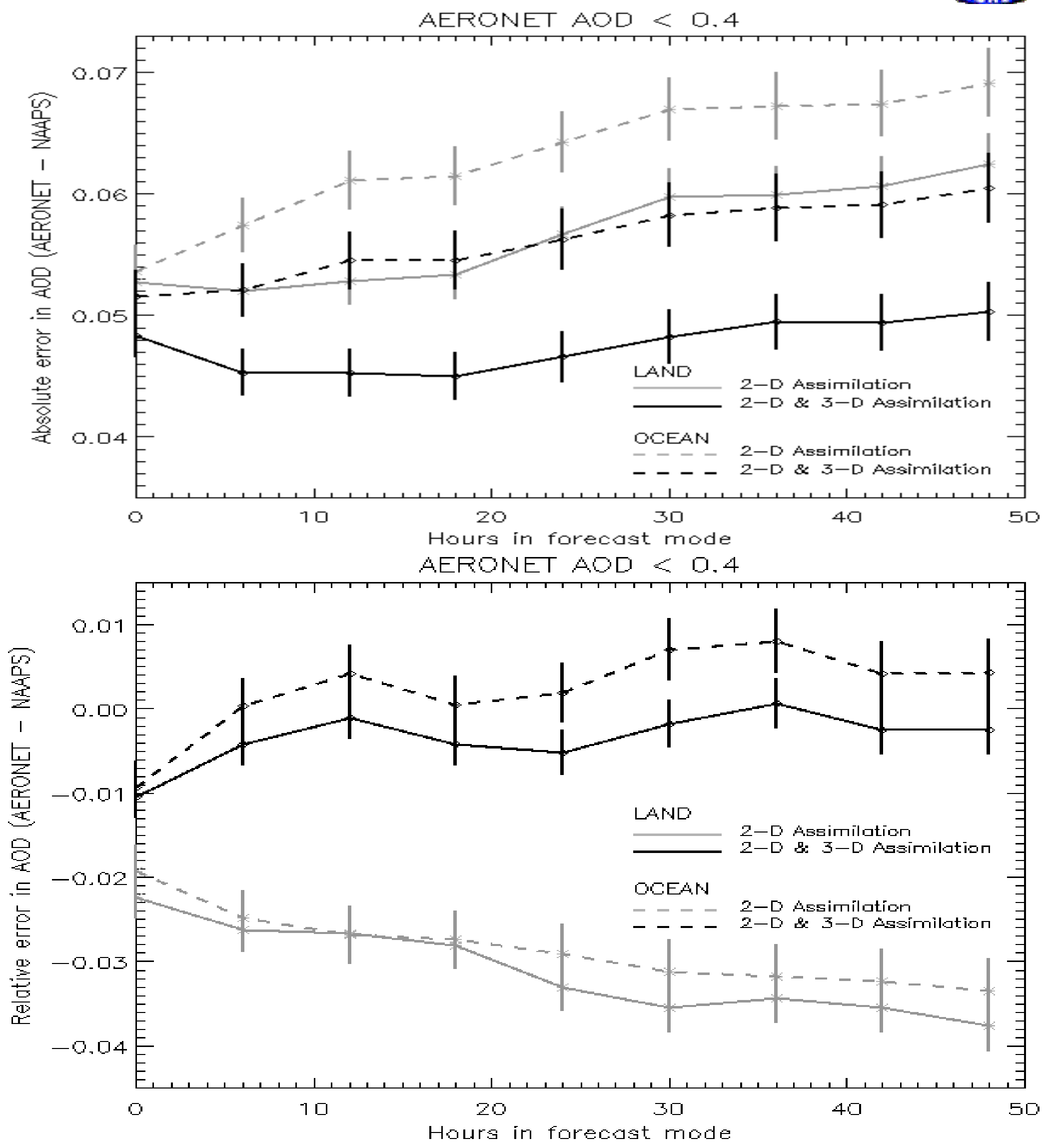
3D-Var Analysis



Zhang et al. (2011, submitted)

Assimilating CALIOP Data

- Effect of CALIOP assimilation on NAAPS
  - AERONET Comparison
- CALIOP helped improve NAAPS performance



Zhang et al. (2011, submitted)

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Future plan

- 4Dvar assimilation of either 2D satellite aerosol optical depth retrievals [e.g. *Benedetti et al.*, 2009] or vertical lidar-derived extinction coefficient profiles [e.g. *Yumimoto et al.*, 2008; *Uno et al.*, 2008].
- 4D ensemble Kalman filter assimilation of ground-based measurements [e.g. *Schutgens et al.*, 2010] and lidar data [e.g. *Sekiyama et al.*, 2010].
- Radiance assimilation [e.g. Weaver et al., 2006]. The CRTM is a dual Navy/Community priority for which we see great potential to applying radiance assimilation.

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.