Aerosol Data Assimilation Over Oceans

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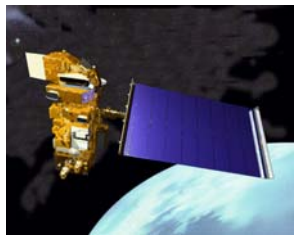
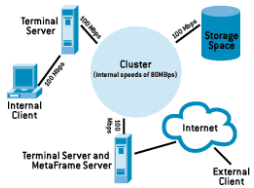
Acknowledgment

We are grateful to Yoram Kaufman of GSFC, father of modern day aerosol remote sensing, for his thoughtful review and excellent suggestions.

Aspects of aerosol science





Data assimilation

In situ

Satellite

Model

aerosol

Clouds

Bio-sphere interaction…

Atmospheric correction

Air pollution

Visibility

precipitation

Climate forcing and Change

Background

- NRL Aerosol Analysis and Prediction System (NAAPS)

- MODIS level II aerosol optical depth (AOT) is best suitable for near real-time aerosol data assimilation.

- NRL Atmospheric Variational Data Assimilation System (NAVDAS)

Why MODIS?

•Satellite observations have been used in retrieving aerosol optical properties such as optical depth and size parameters.

•Examples of satellite aerosol retrievals: AVHRR, GOES, TOMS, SeaWiFs, MISR, POLDER, SAGE, VIRS, MODIS….

•Most of retrievals are limited to either limited number of channels (e.g. AVHRR, GOES), coarse resolution (e.g. VIRS) or suffering calibration difficulties (e.g. GOES).

•*MODIS has 36 channels and detects aerosols and retrieves properties with high accuracy (over oceans, $\pm 0.03 \pm 0.05\tau$) [Remer et al., 2002].*

•*Key: Near real time (through NRTPE* - the Near Real Time Processing Effort)

Aerosol Forecasting Approach
NRL Aerosol Analysis and Prediction System (NAAPS)

- Apply physically based regional and global aerosol models:
  Emphasis on source functions and transport phenomenology

- Emphasis on aerosol particles that impact visibility:

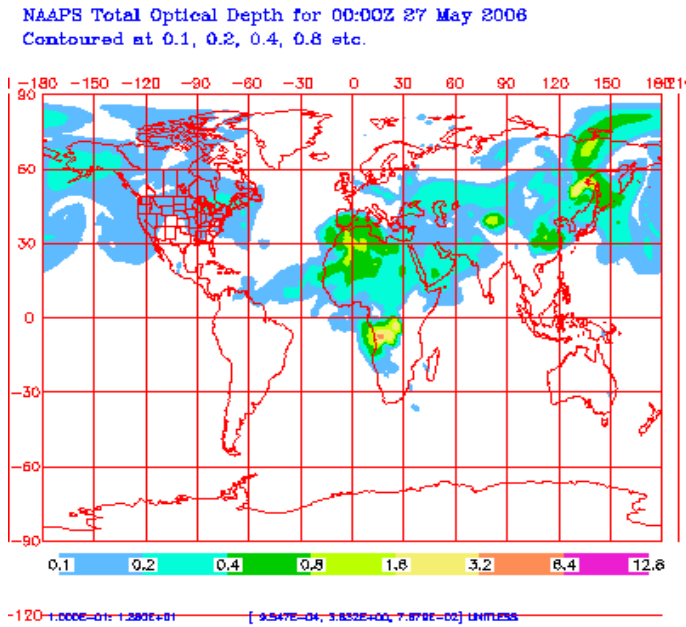
  Dust
  Smoke
  Sulfate
  Sea salt

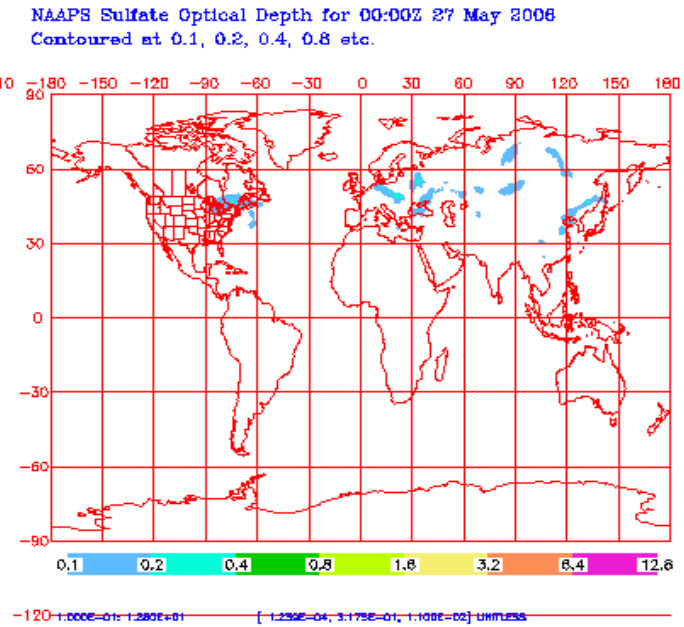
- Focus on operational capability and real-time data streams

- Worlds only truly operational global aerosol model, 5-day forecast at FNMOC

NRL Aerosol Analysis and Prediction System (NAAPS)

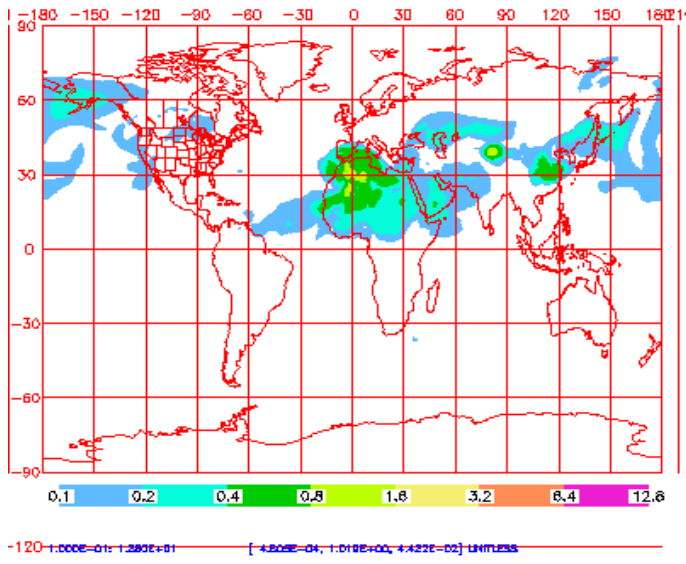
Total AOT

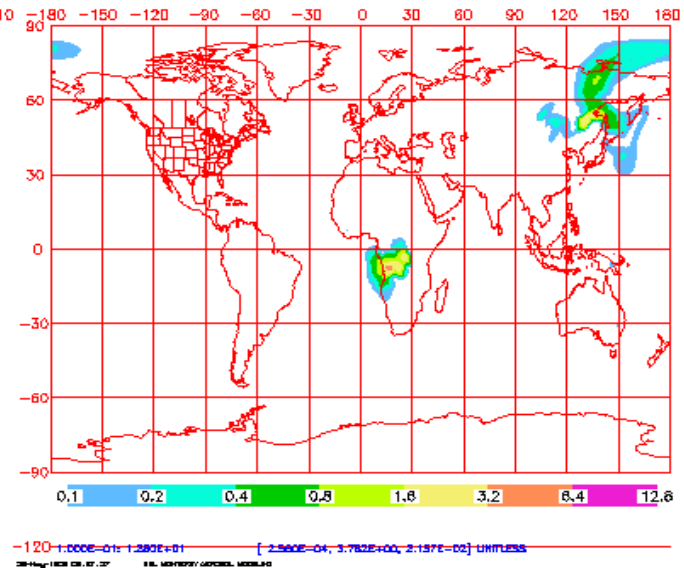




Sulfate AOT

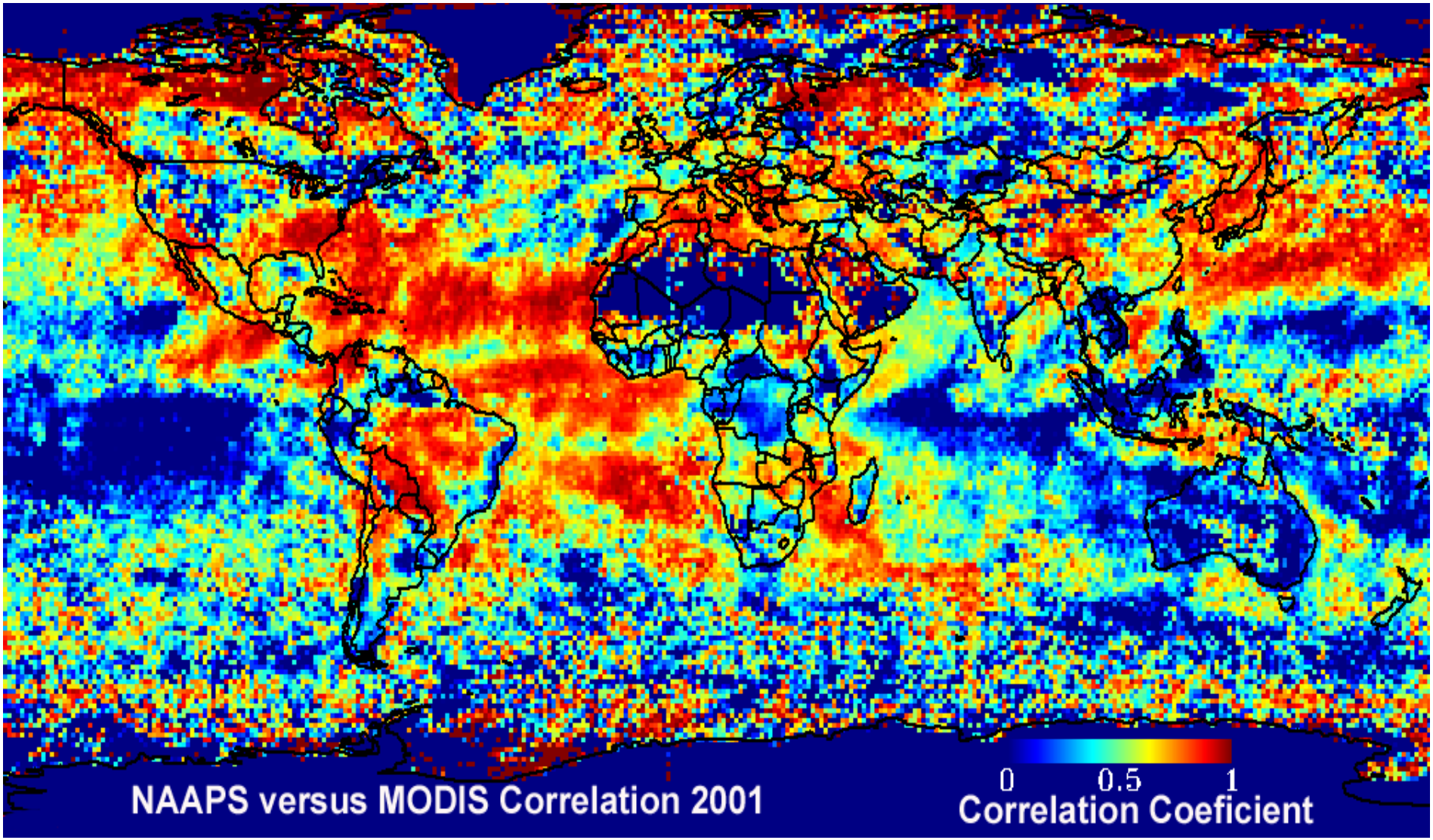
Dust AOT



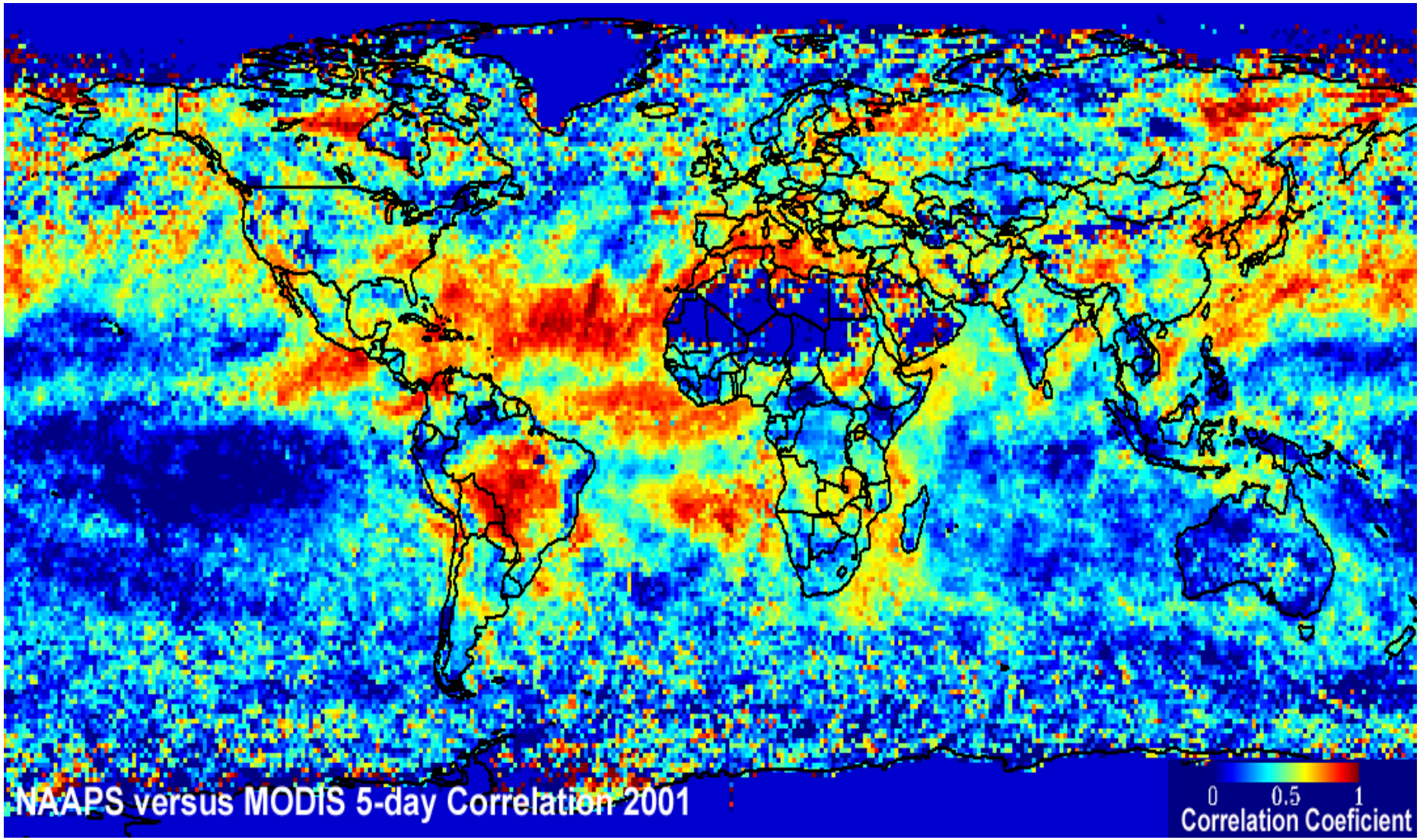


Smoke AOT

NAAPS Performance
Monthly Correlations: Climate Model View



NAAPS Performance
5-day Correlations: Forecast Model View



Step 1: Understanding your data source

- MODIS level II aerosol optical depth (AOT) is best suitable for near real-time aerosol data assimilation.

- However, MODIS (MODerate-resolution Imaging Spectroradiometers) satellite data have uncertainties, especially in the regions with cirrus clouds, coastal waters and complicated land features.

- An objective analysis of MODIS data is necessary to estimate the true benefits and uncertainties of MODIS data before implementing them into aerosol analysis-forecast applications.

Aerosol retrieving procedures

- Assume surface characteristics (Lower boundary condition)
- Assume aerosol properties (phase function, absorption, etc)
- Know meteorological conditions (wind, clouds, etc)
- Apply radiative transfer calculation and inverse retrieving algorithm

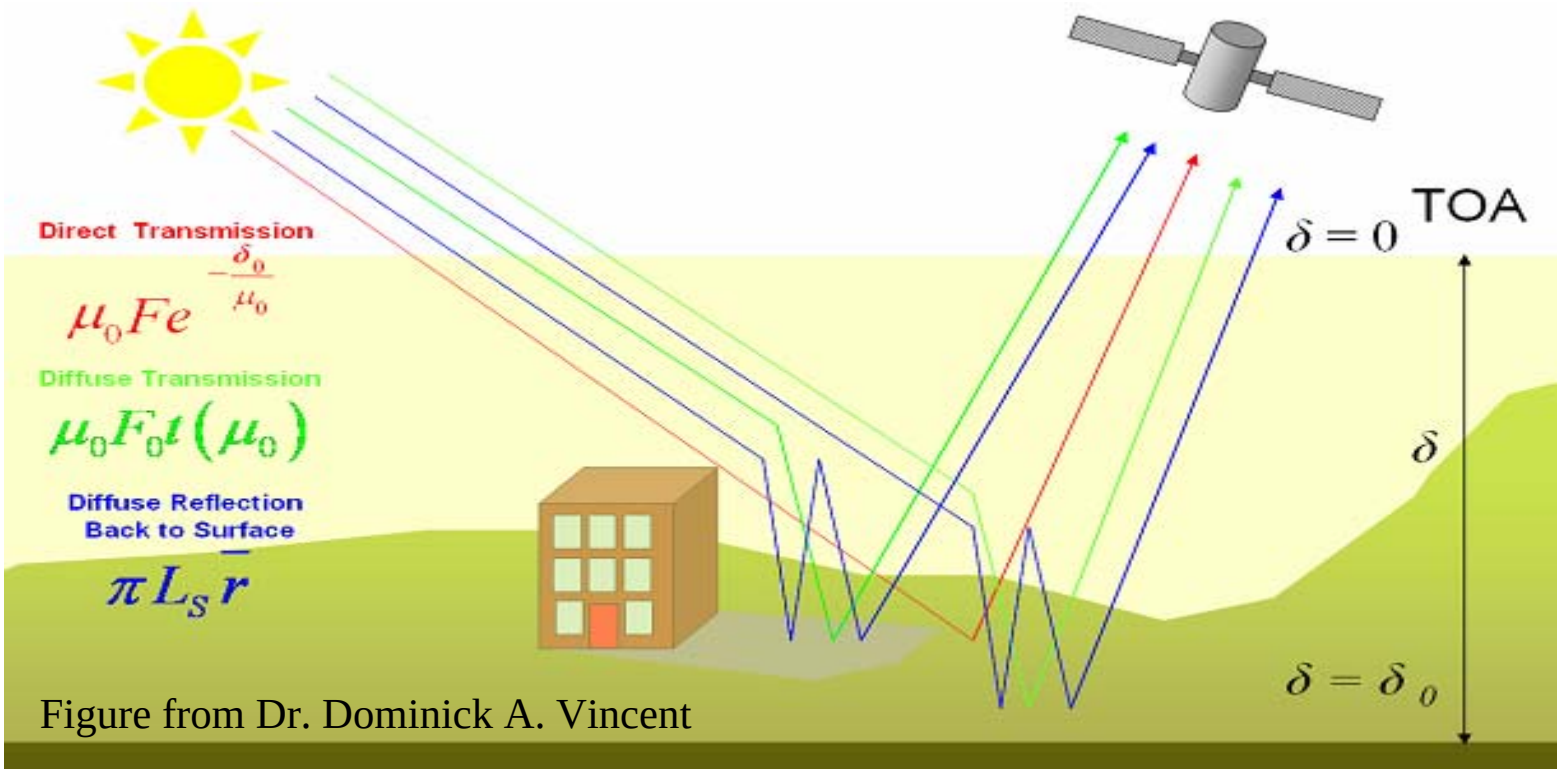
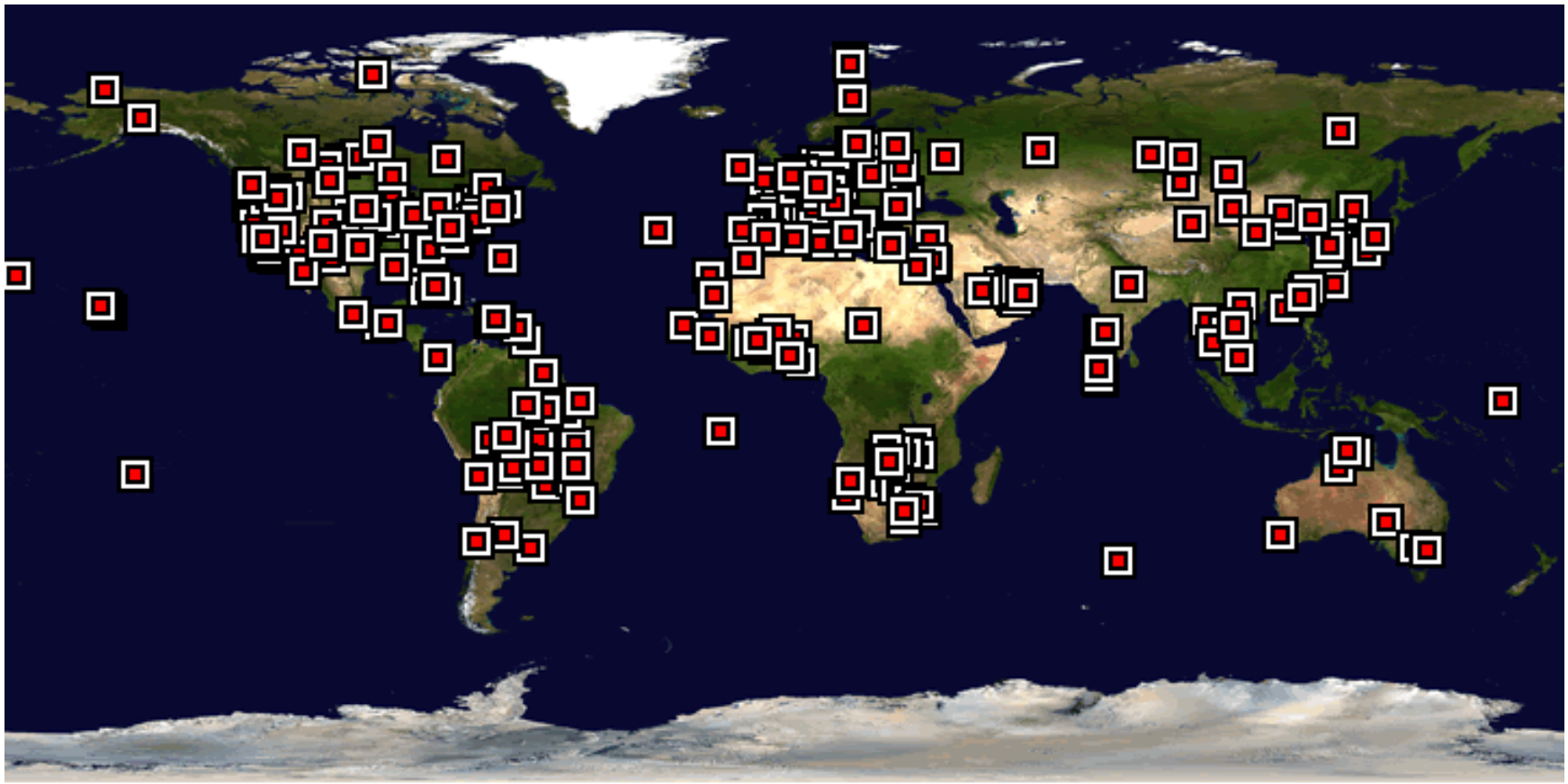


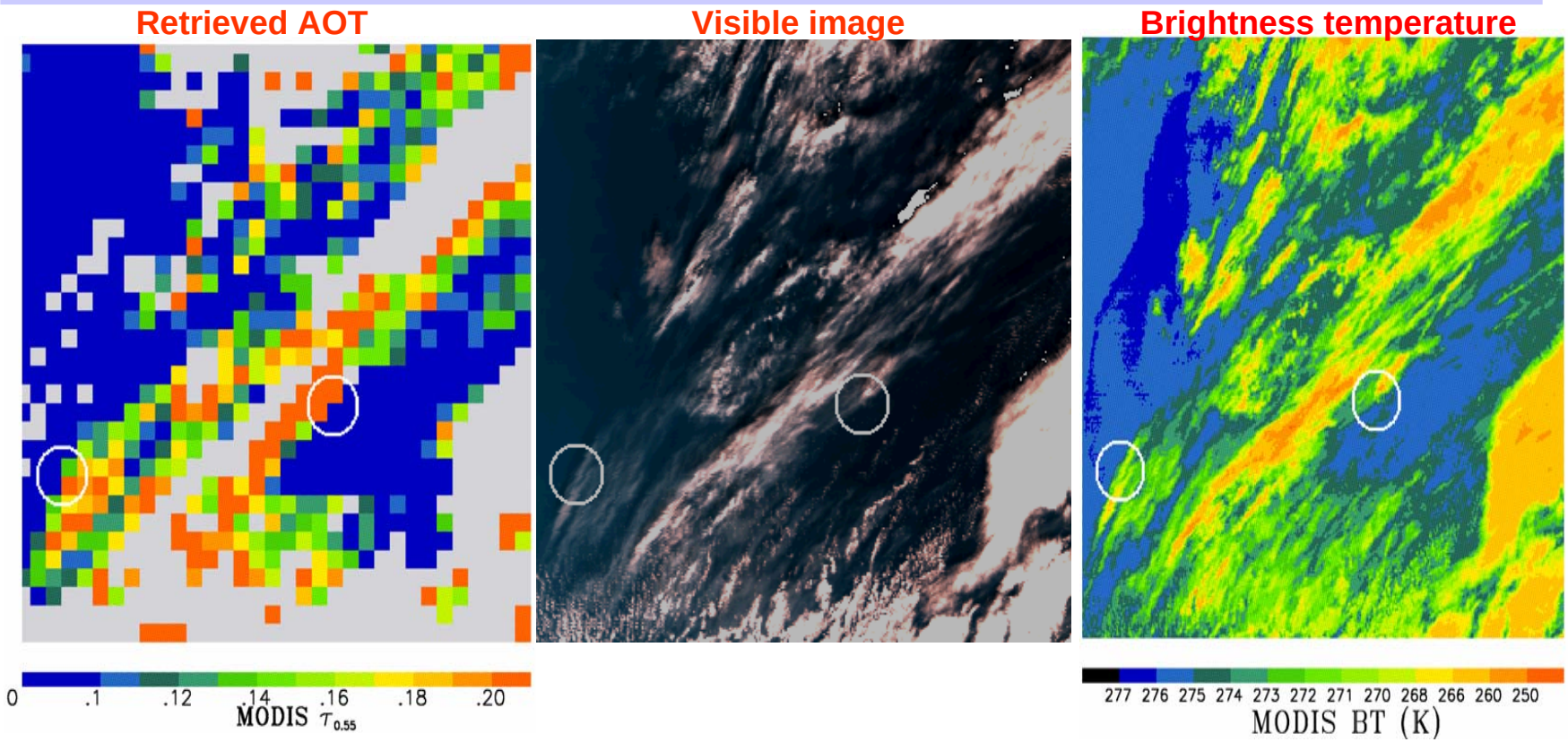
Figure from Dr. Dominick A. Vincent


Aerosol Robotic Network (AERONET)



Uncertainties in MODIS aerosol products due to cloud artifacts

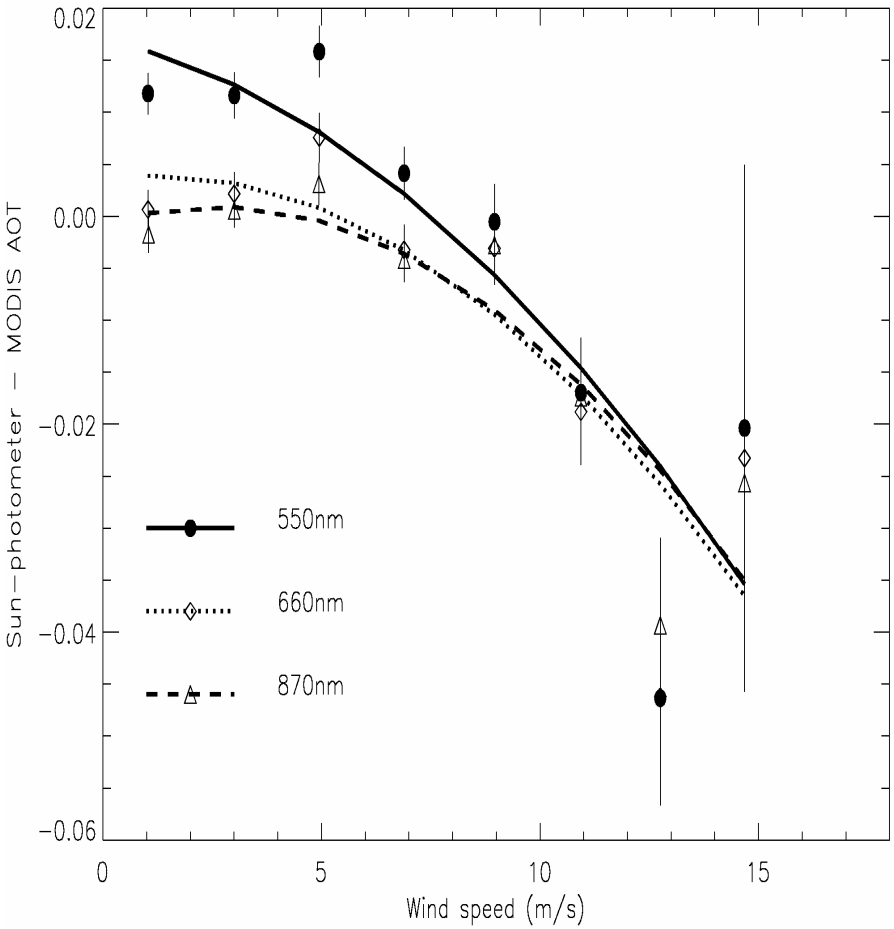
- Cloud fraction effect could result in a 10-20% overestimation in monthly mean aerosol optical depth of MODIS retrieval over cloud free oceans. Local errors can be as high as a factor of two.
- This cloud-contaminated AOT is still widely used in the aerosol modeling community.



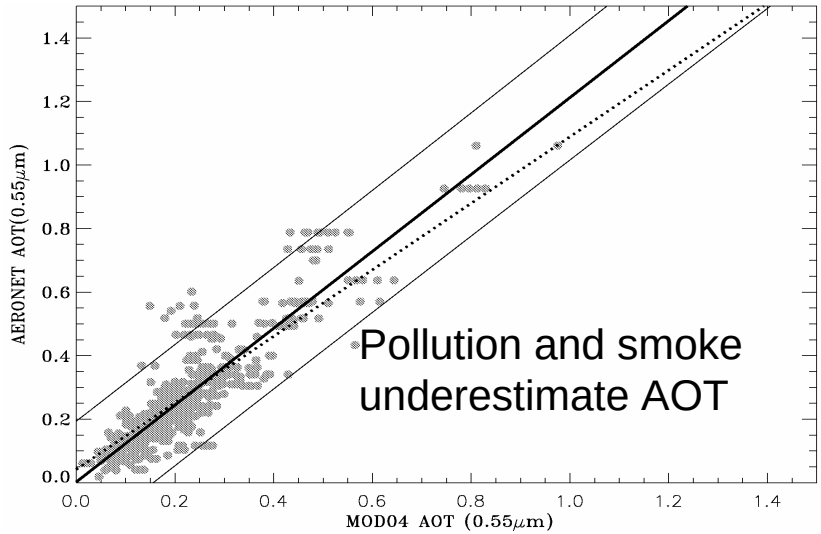
Zhang, J., J. S. Reid, and B. N. Holben, An analysis of potential cloud artifacts in MODIS over ocean aerosol optical thickness products, *Geophysical Research Letters*, VOL. 32, L15803, doi:10.1029/2005GL023254, 2005.

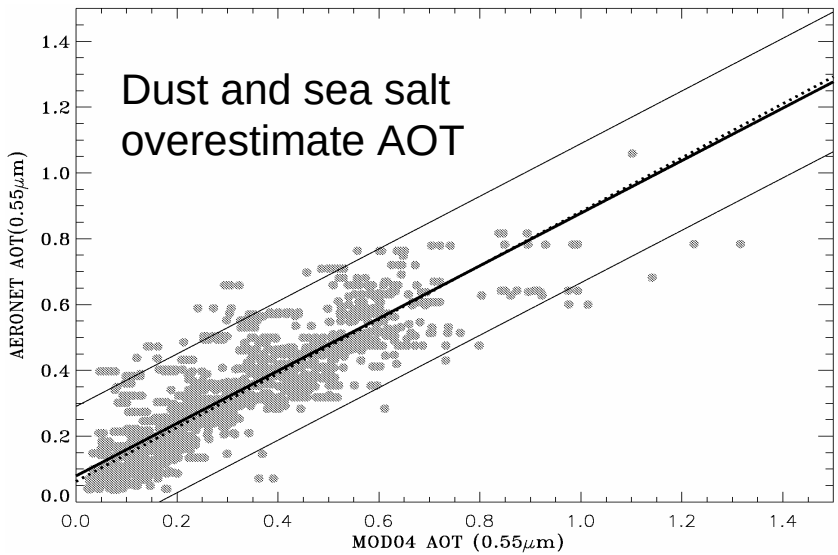
Uncertainties in MODIS aerosol products due to other artifacts

Identify & quantify uncertainties
(1) Near surface wind speed



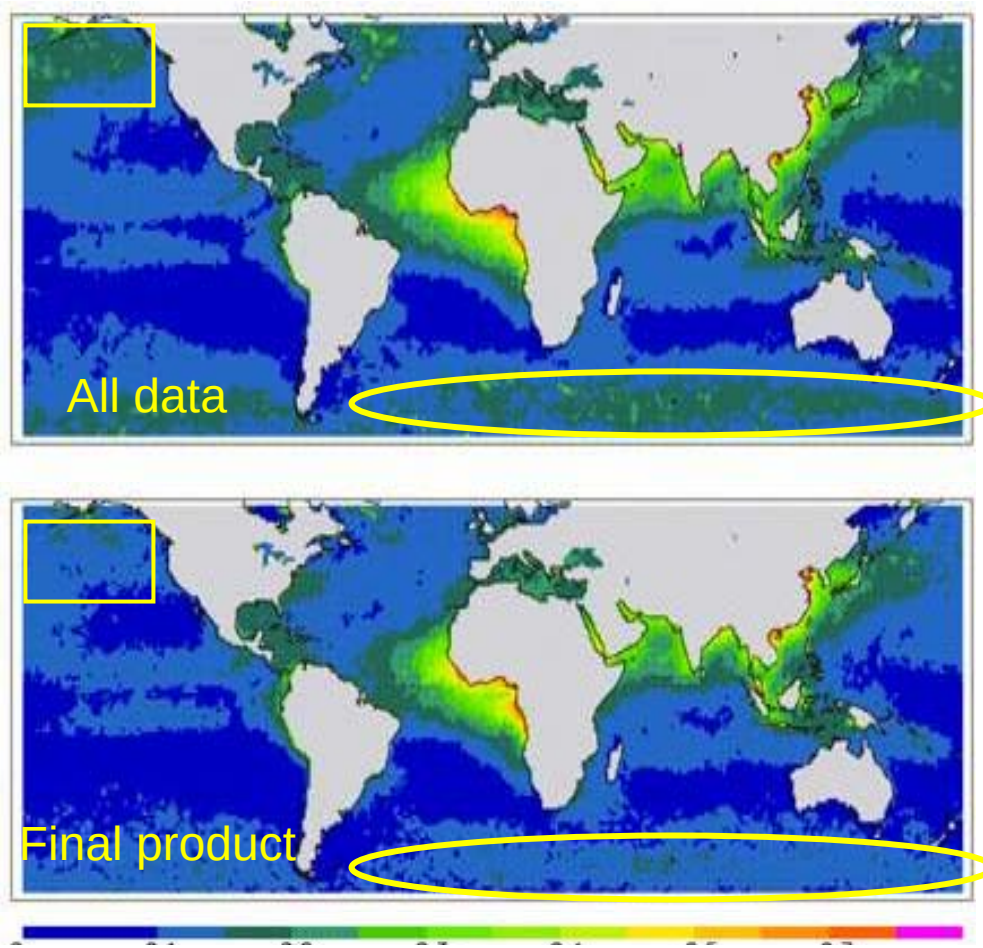
Identify & quantify uncertainties
(2) Aerosol microphysics





Impact of QA and Aggregation on Assimilated Data

- We begin with NRTPE MYD04 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 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, accepted by *J. Geophys. Res.*, 2006.

NRL Atmospheric Variational Data Assimilation System

- System has been designed to optimally utilize present and future satellite sensors.

- Determine the best estimate (**analysis**) of the current state of the atmosphere given a current forecast (**background**) and some **observations**.

- Improve forecasts by improving initial conditions

NAVDAS

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

- **Observation errors (R) are determined from sun-photometer observations**

- **Back ground errors (P) are determined from both sun-photometer observations (error variance) and MODIS aerosol product (error correlation length)**

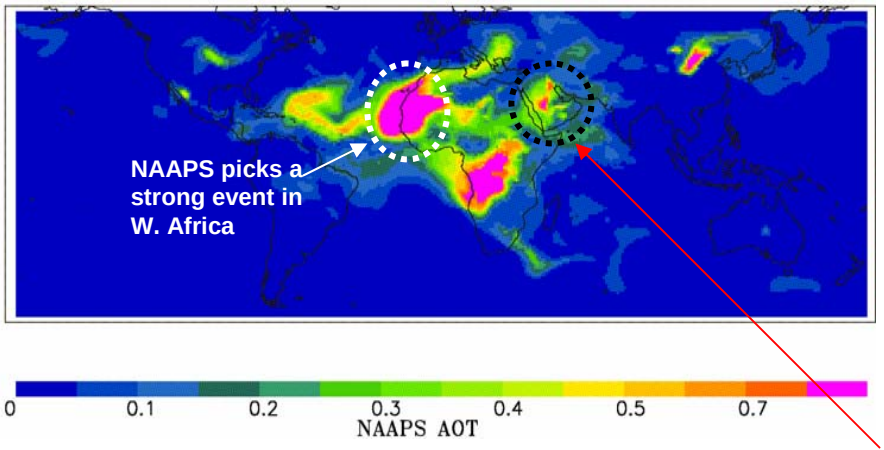
- **H (forward operator) is partitioned based on FAROP (Forecast of Aerosol Radiative Optical Properties)**

Step 2: Preliminary results on aerosol data assimilation

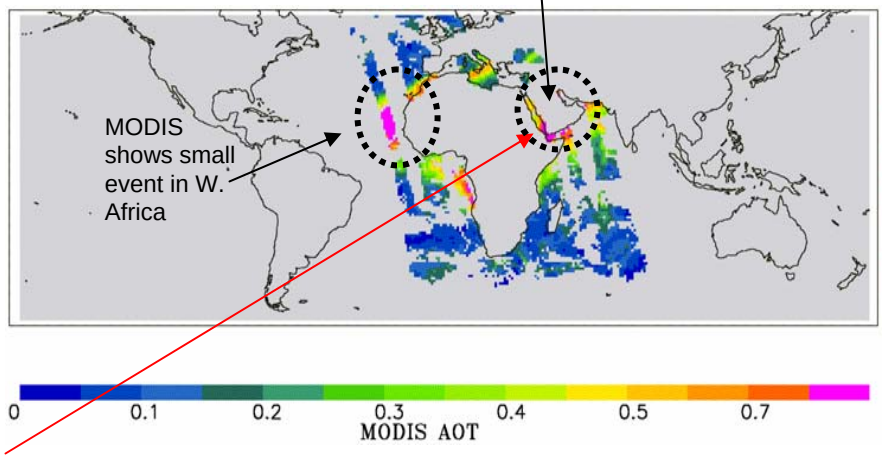
Application of modified MODIS AOT

NAAPS predicts low AOT in SW Asia but MODIS observes high AOT (big event) in the Red Sea and the Gulf of Aden

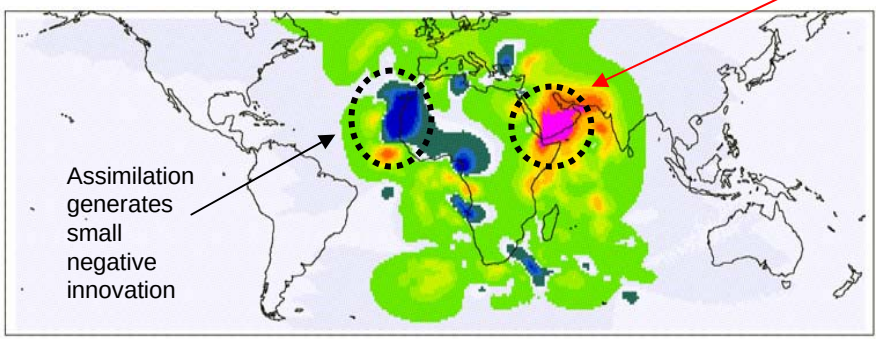
NAAPS first guess of AOT (12-h fcst) for 12Z, July 19, 2005



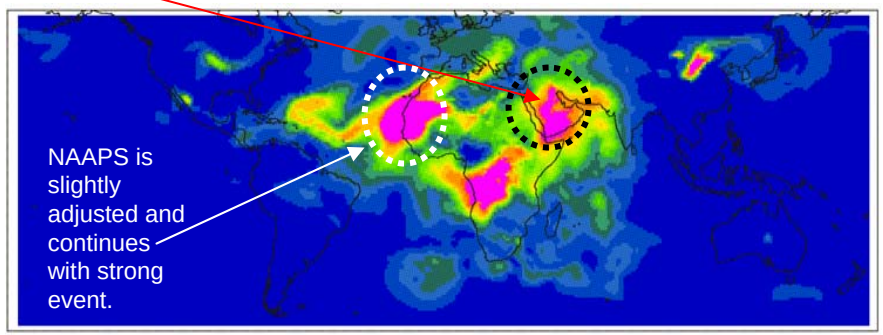
MODIS retrieved AOT for 9-15Z, July 19, 2005



NAVDAS output (NAAPS first guess + MODIS assimilation)



NAAPS updated AOT analysis (NAVDAS output + first guess)



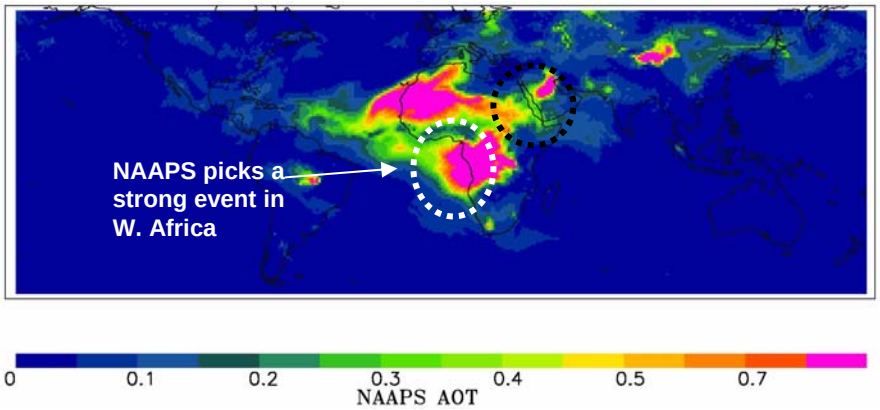
AOT assimilation results in spreading the event in SW Asia, then updated NAAPS also picks up this big event and carries to the next run

Conclusion: the preliminary result looks very promising and more work is going on.

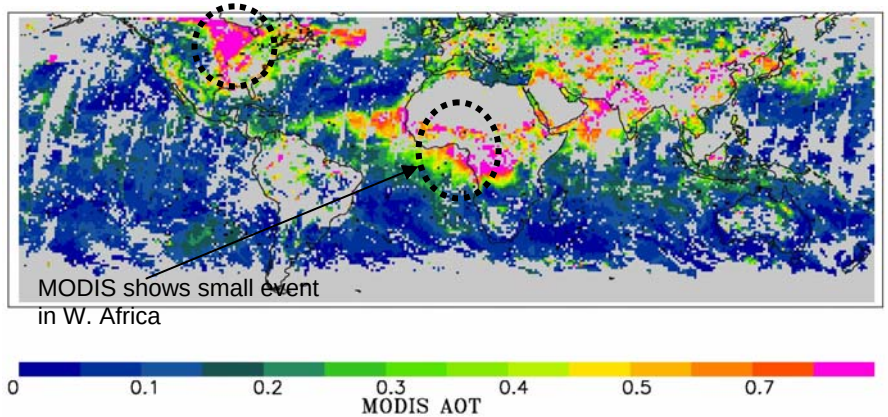
Step 2: Preliminary results on aerosol data assimilation

Five day forecast

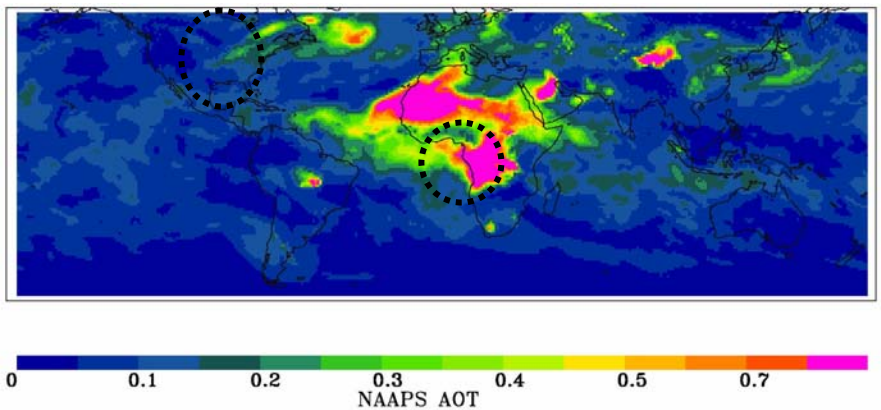
NAAPS AOT (120-h fcst) for 18Z, July 19, 2004



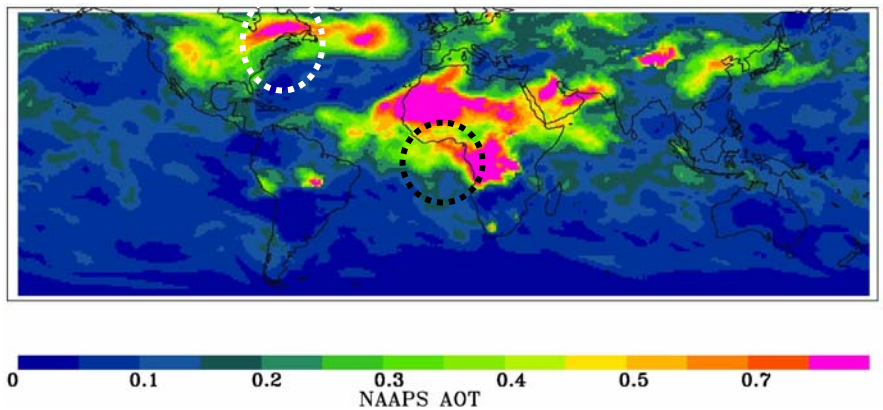
MODIS retrieved AOT for July 17-19, 2004



ECL=100 km; BEV=0.1τ+0.1



ECL=385 km; BEV=0.3τ+0.1



Conclusion: the preliminary result looks very promising and more work is going on.

Future plans

1. Aerosol climatology (Vertical partitioning, adjoint of observation operator H)
2. Background error analysis
3. Extend to over land data assimilation
4. Examine aerosol forecast skill with and without aerosol assimilation
5. Link source functions to assimilation corrections

Summary of Year One Progress

Empirical correction and quality control procedures were applied and the absolute difference between SP and MODIS τ reduced 10-20%. Empirical corrections include corrections for artifacts due to cloud contaminations and biases that related near surface wind speed and the ratio of small mode to total aerosol optical depth. QCQA procedures include cloud screen, stand-alone check, buddy check and other QCQA checks.

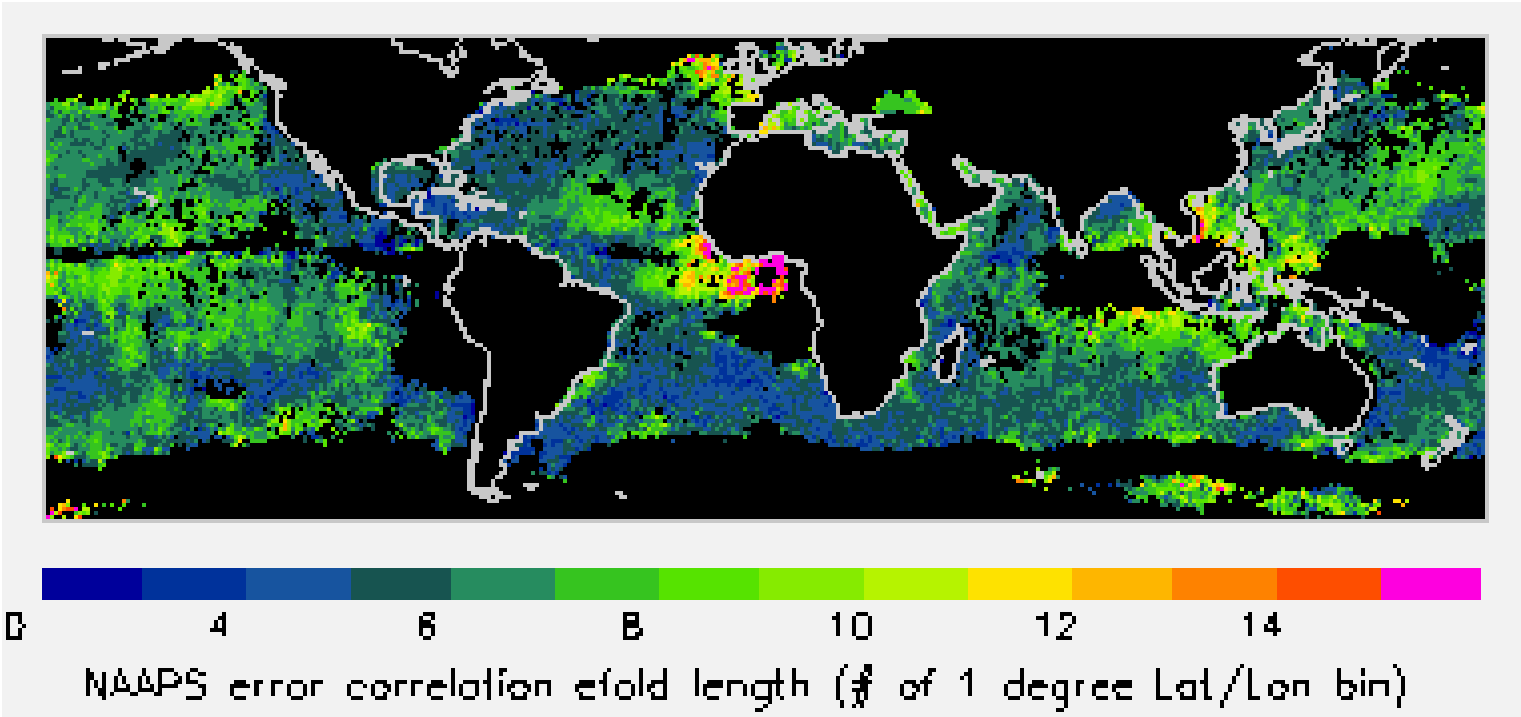
After applying empirical corrections and QA procedures, the aerosol plumes at the roaring 40's and some high northern latitudes are significantly reduced indicating cloud contamination and biases due to near surface wind speed patterns could be responsible for a large portion of the high aerosol optical depth plumes observed over that regions.

This study sets the stage for the future data assimilation study that uses MOD04/MYD04 aerosol products.

Error statistics

Need: (1) MODIS/NAAPS error variance

(2) NAAPS error correlation e-fold length



(Sep. – Dec. 2004)