



Assimilation of AEROSol Robotic NETwork (AERONET) data for aerosol forecasting: Radiosondes of the aerosol world?

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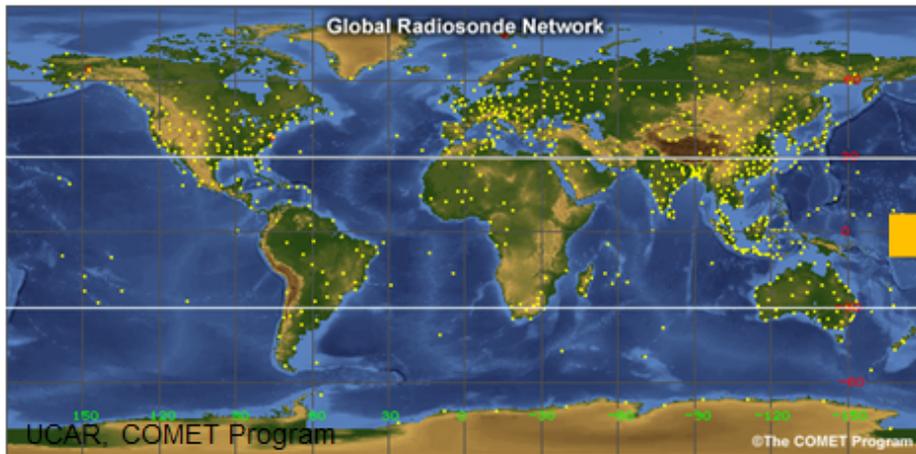
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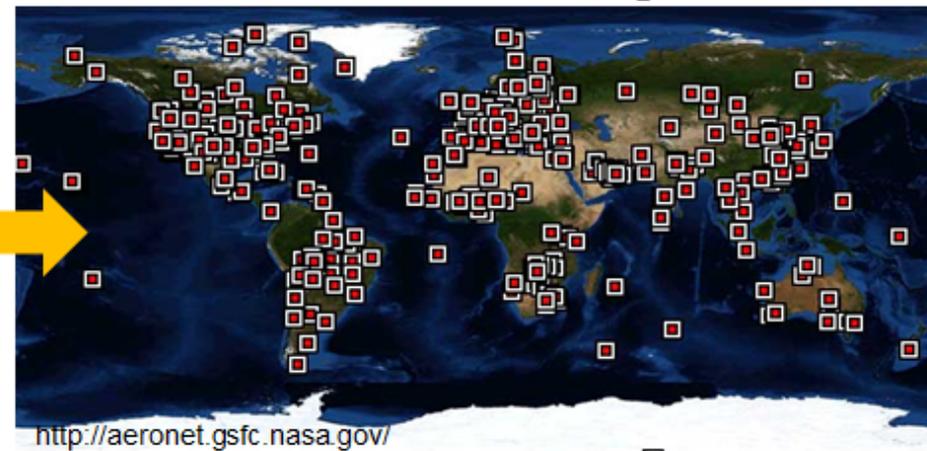
AERONET Assimilation: Overview

- A new ensemble system for Navy aerosol forecasting was developed:
 - The ensemble Navy Aerosol Analysis Prediction System coupled to an Ensemble Adjustment Kalman Filter (EAKF) from NCAR's Data Assimilation Research Testbed [Anderson 2001, Anderson et al. 2009].
 - ENAAPS-DART [Rubin et al. 2016]
 - Base system assimilates data assimilation quality MODIS Aerosol Optical Thickness (AOT) [Zhang et al. 2006, Shi et al. 2011, Hyer et al. 2011]
- The ability of the EAKF data assimilation system to spread observational information in the system using flow-dependent error covariances makes it ideal for expanding the aerosol observing network, particularly for sparse observations.

Numerical Weather Prediction



Aerosol Forecasting?

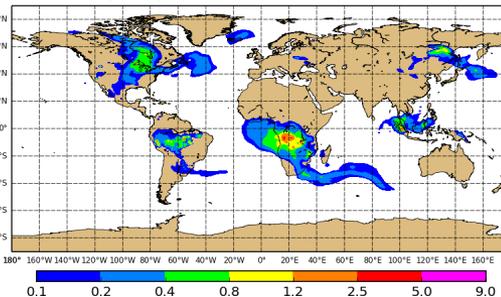


Operational Navy Aerosol Forecasting

- Navy Aerosol Analysis Prediction System (NAAPS) [Christensen et al. 1997]
 - Offline, NAVGEM Met (winds, temp, humidity etc.)
 - 4 aerosol species, out to 6 days, 1/3 degree resolution
- Navy Variational Data Assimilation System for Aerosol Optical Depth (NAVDAS-AOD) [Zhang et al. 2008]
 - 2D-Var
 - Data assimilation quality MODIS AOT
 - Forecast initial condition

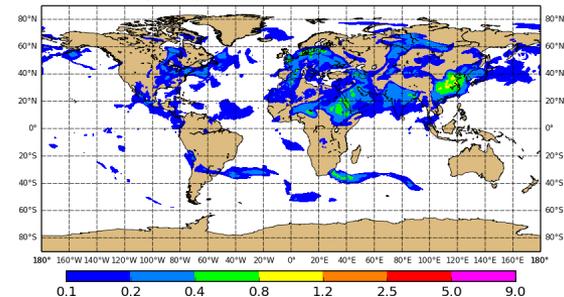
Smoke

Tuesday 1 September 2015 00UTC NAAPS_NAVGEM35 Forecast t+000
Tuesday 1 September 2015 00UTC Valid Time
SMOKE Aerosol Optical Depth at 550nm



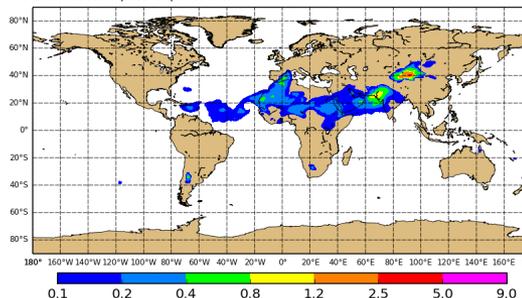
Anthro/Biogenic Fine

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SULFATE Aerosol Optical Depth at 550nm



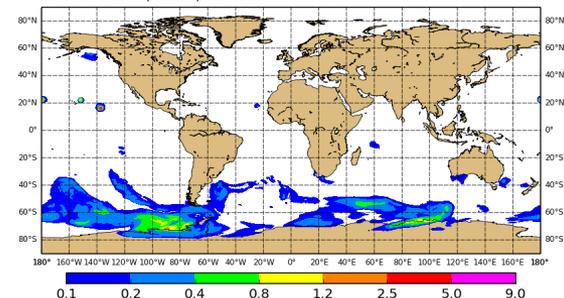
Dust

Tuesday 1 September 2015 00UTC NAAPS_NAVGEM35 Forecast t+000
Tuesday 1 September 2015 00UTC Valid Time
DUST Aerosol Optical Depth at 550nm



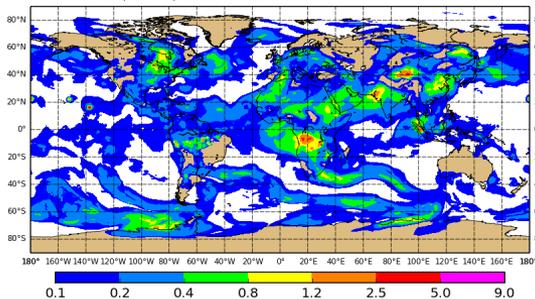
Sea Salt

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Tuesday 1 September 2015 00UTC Valid Time
SEASALT Aerosol Optical Depth at 550nm



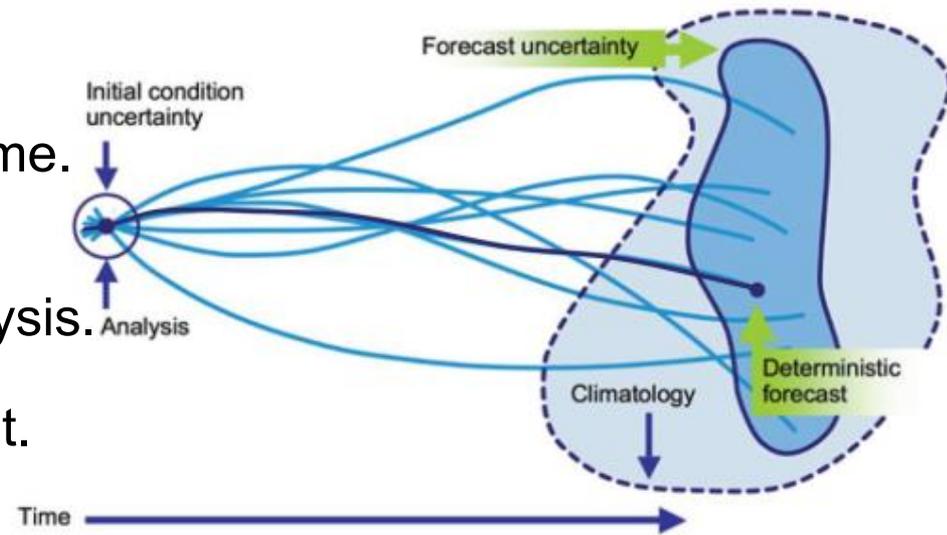
Total

Tuesday 1 September 2015 00UTC NAAPS_NAVGEM35 Forecast t+000
Tuesday 1 September 2015 00UTC Valid Time
TOTAL Aerosol Optical Depth at 550nm

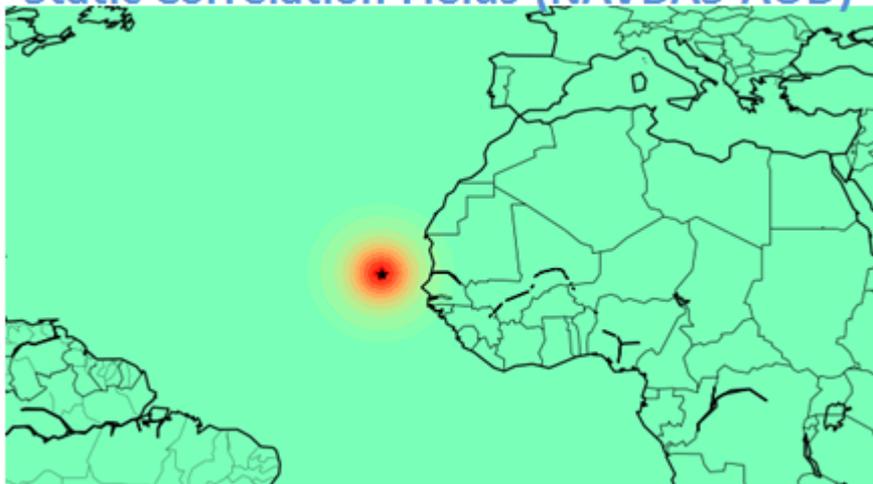


Flow-Dependence: Making better use of observational information

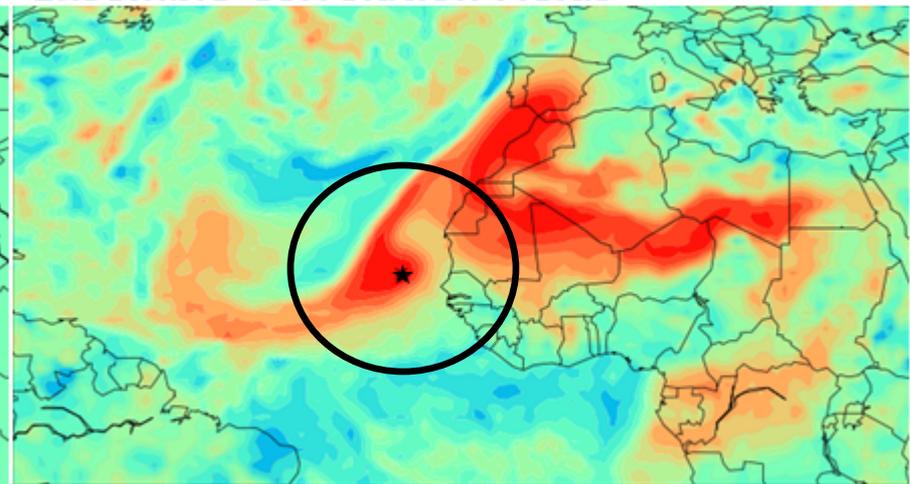
- Ensembles provide a means for representing flow-dependent forecast uncertainty that varies in space and time.
- Flow-dependent representation of uncertainty results in a better DA analysis.
- Ensembles provide probabilistic output.



Static Correlation Fields (NAVDAS-AOD)

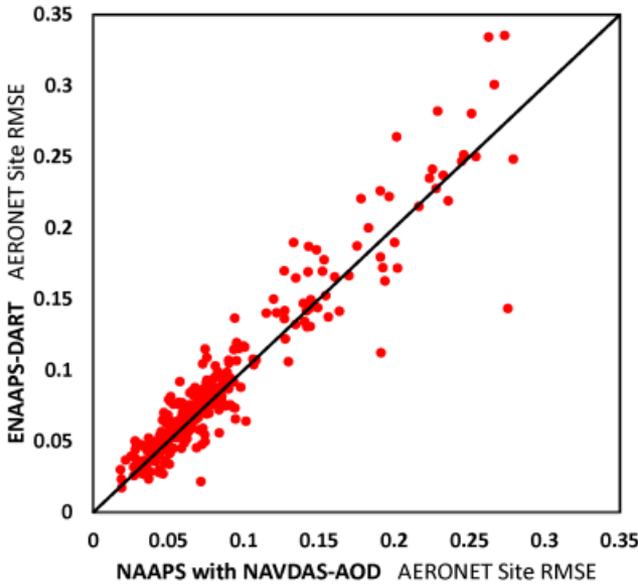


Ensemble Correlation Fields

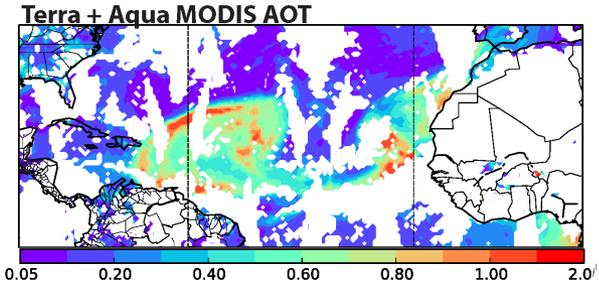


ENAAPS coupled to an Ensemble Adjustment Kalman Filter [Rubin et al. 2016]

1. Using an RMSE metric, ENAAPS-DART performs about the same as NAAPS with NAVDAS-AOD at AERONET sites (6 month experiment, 20 member)



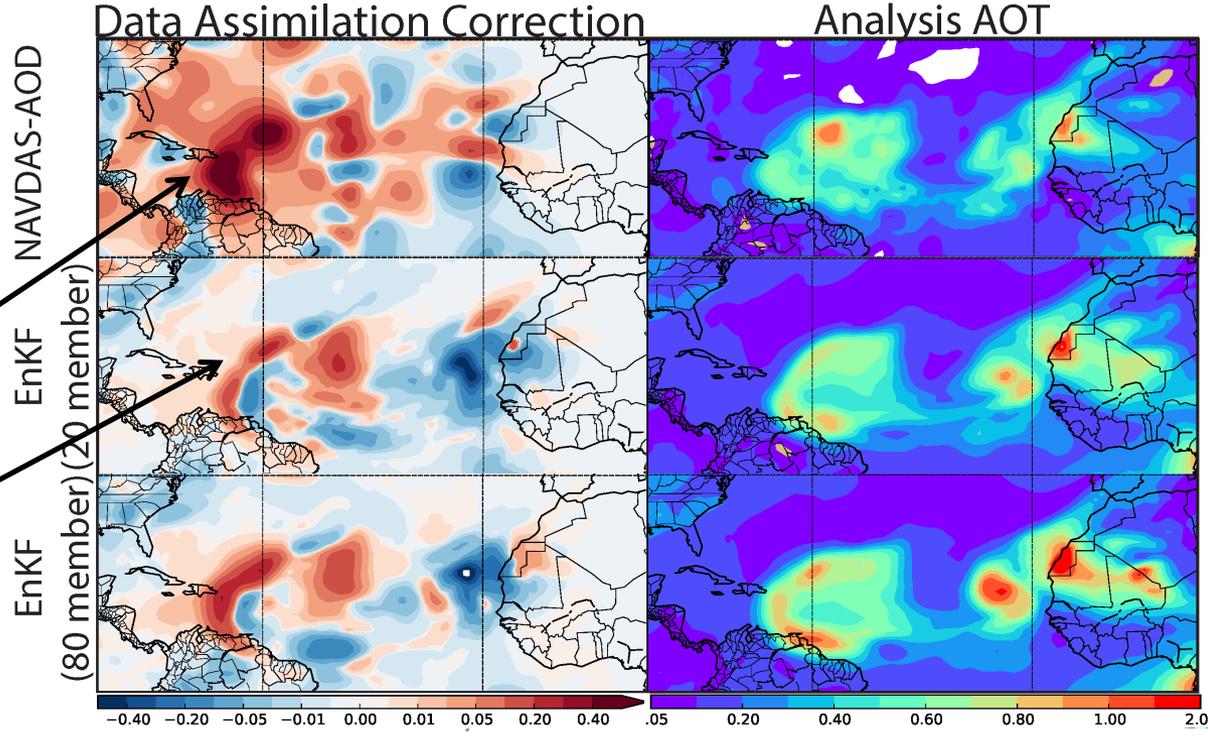
2. Case studies reveal differences
Dust Event (Aug 2, 2013)



NAVDAS-AOD: observationally driven, produces large DA corrections

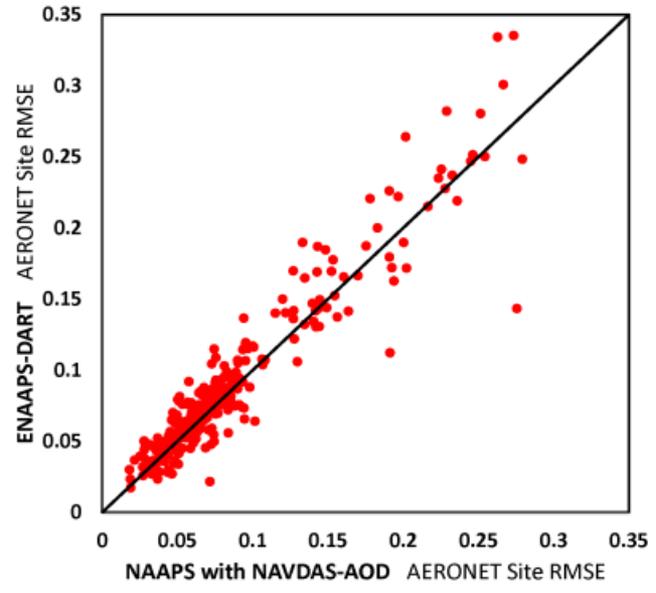
EAKF: captures dust front shape (not magnitude).

* Significant improvement with 80 members in magnitude and position

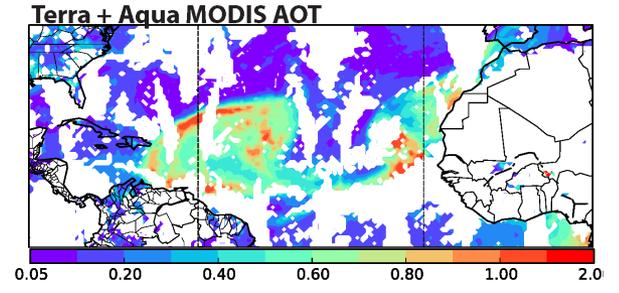


ENAAPS coupled to an Ensemble Adjustment Kalman Filter [Rubin et al. 2016]

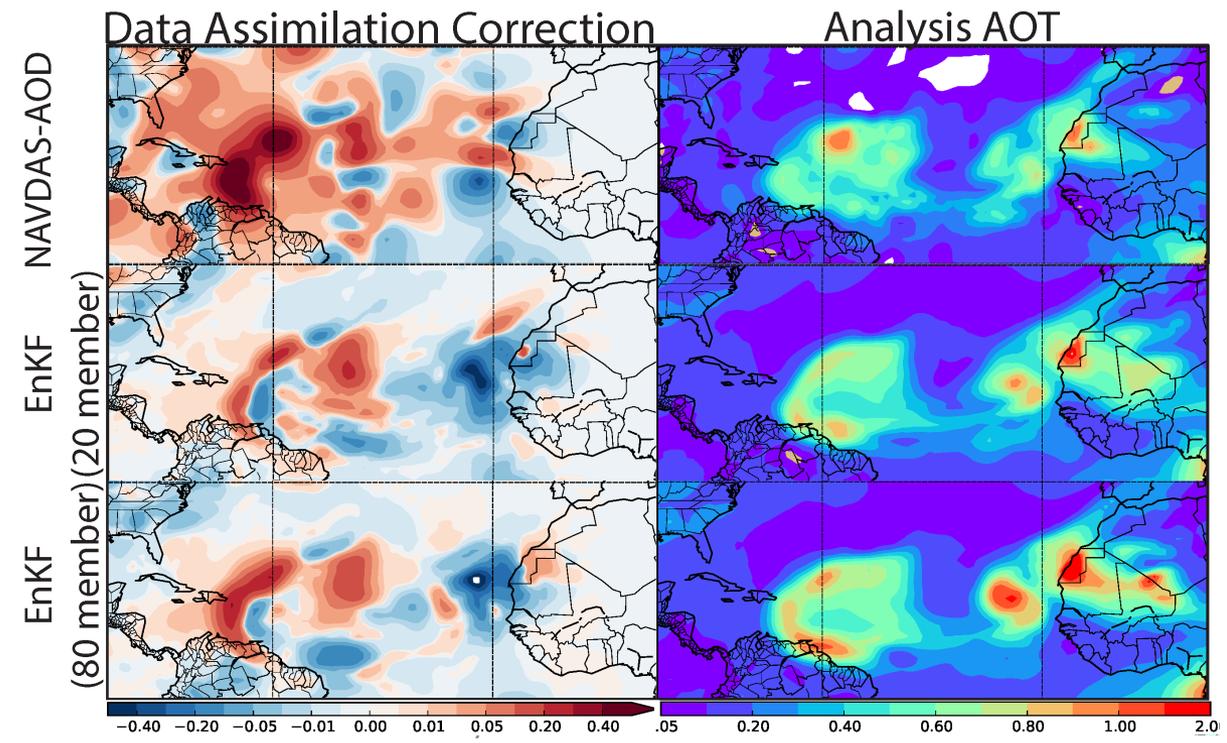
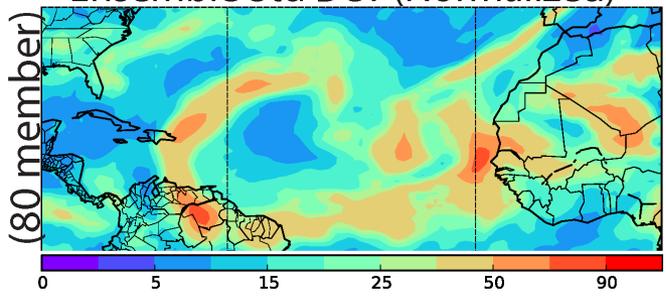
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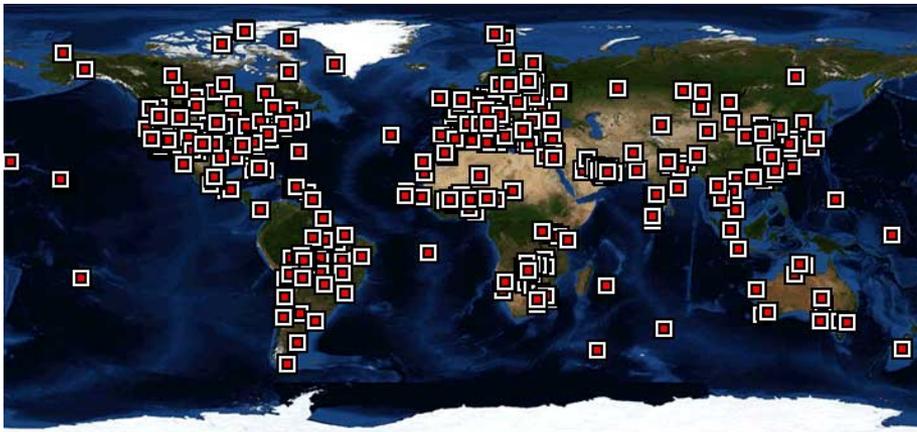


3. Probabilistic Output
Ensemble Std Dev (Normalized)



Assimilation of AERONET observations for aerosol forecasting

1. Is the successful use of this network of observations dependent on the data assimilation methodology?
2. What is the impact of data assimilation of AERONET on its own and combined with other observations?
3. Can this network serve as a backup if satellite observations are not available?



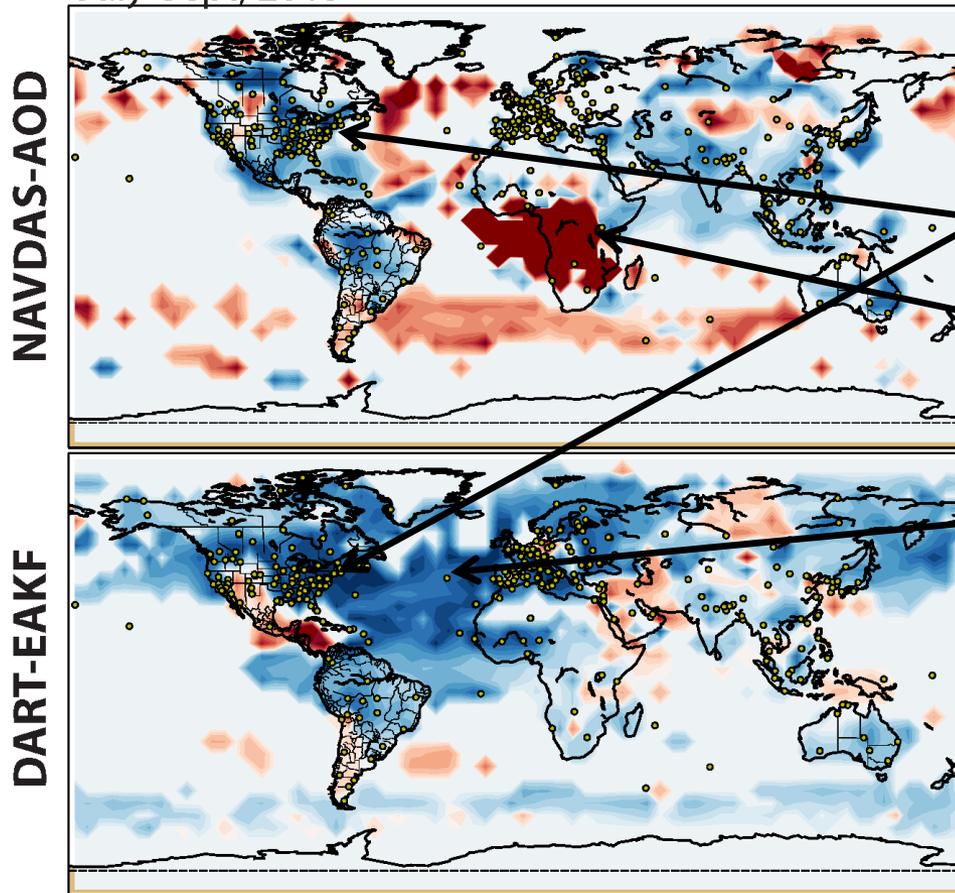
<http://aeronet.gsfc.nasa.gov/>



<http://www.nasa.gov/topics/earth/features/aeronet.html>

Impact of Assimilating AERONET on AOT Analysis RMSE

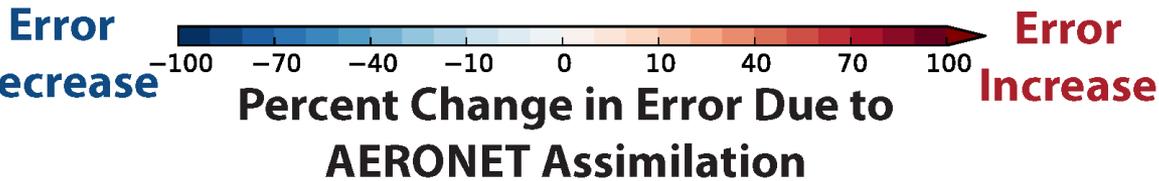
July-Sept, 2013



Only ground-based AERONET AOT observations are assimilated (● = obs site)

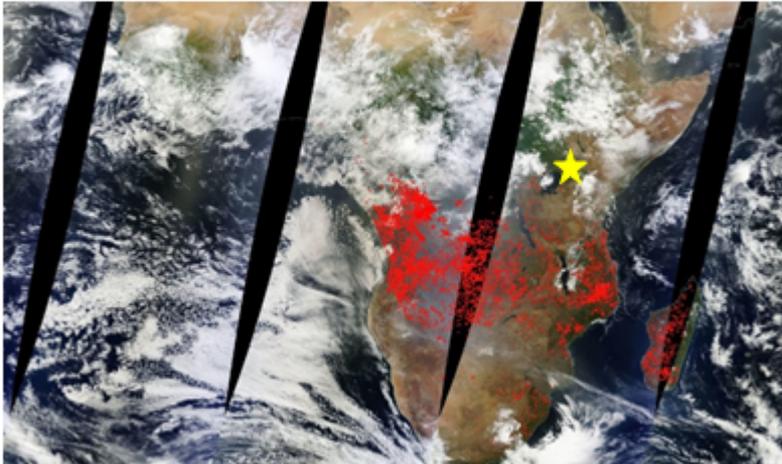
1. Analysis verified with MODIS AOT
2. Largest error reduction in high observation density regions
3. Large **increases in error** can occur with NAVDAS-AOD (2D-Var data assimilation)
4. The spatial extent of the **error reduction** is much greater with EAKF

These results demonstrate the importance of flow-dependent covariances for assimilating sparse aerosol-related observations on a global scale (ship, aircraft obs, lidar...)

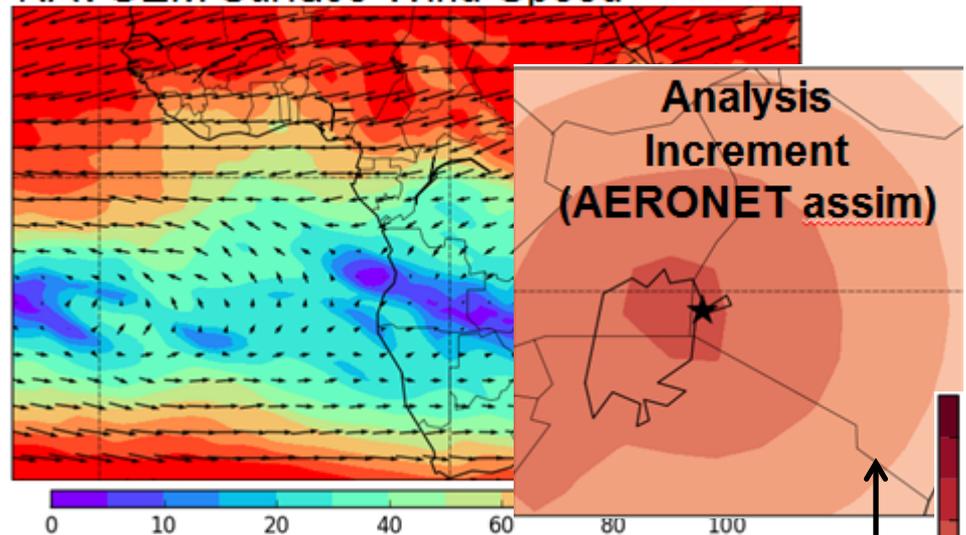


Why do sparse obs like AERONET negatively impact the NAAPS with 2D-Var system?

Case Study: August 12, 2013 (12Z)
MODIS Fire Detections, NASA Worldview



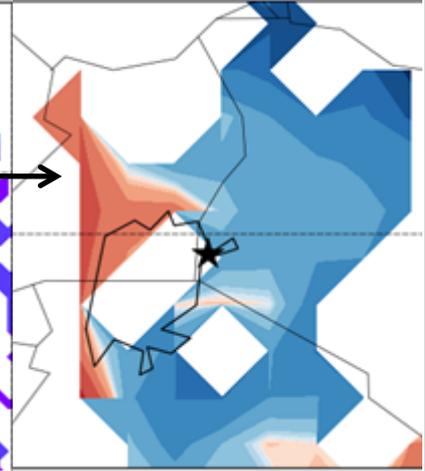
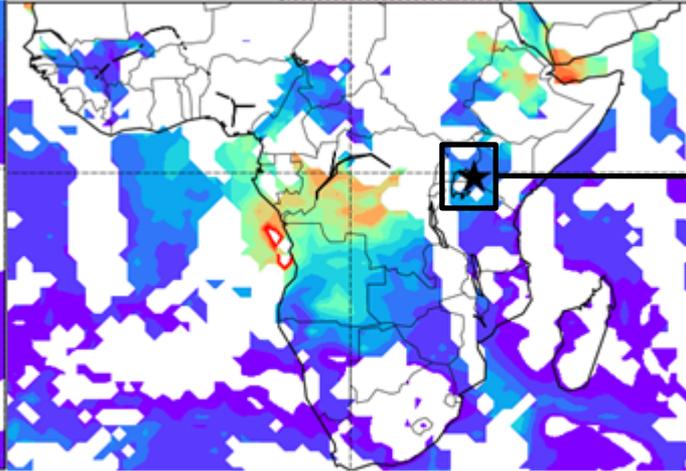
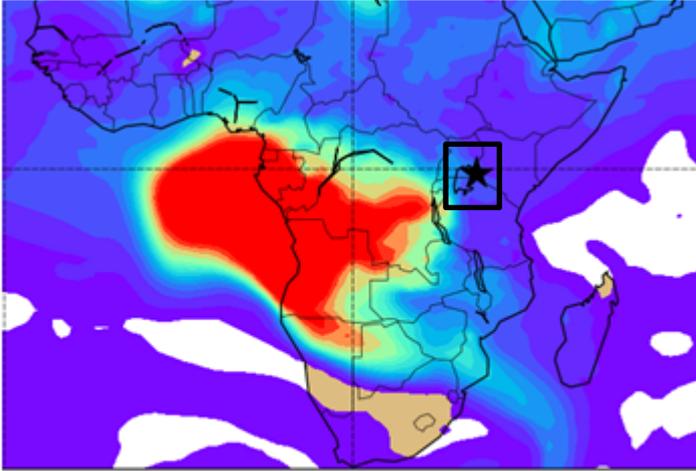
NAVGEM Surface Wind Speed



NAAPS Prior AOT (6 hour forecast)

MODIS AOT (Terra+Aqua, 550nm)

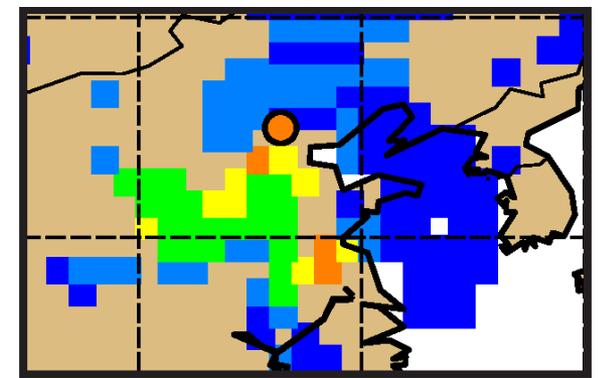
Prior - MODIS



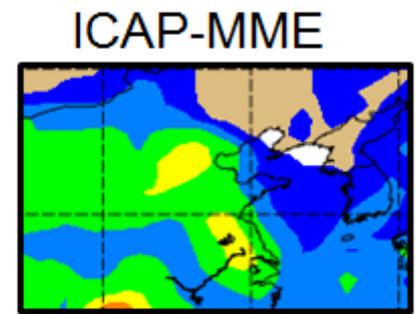
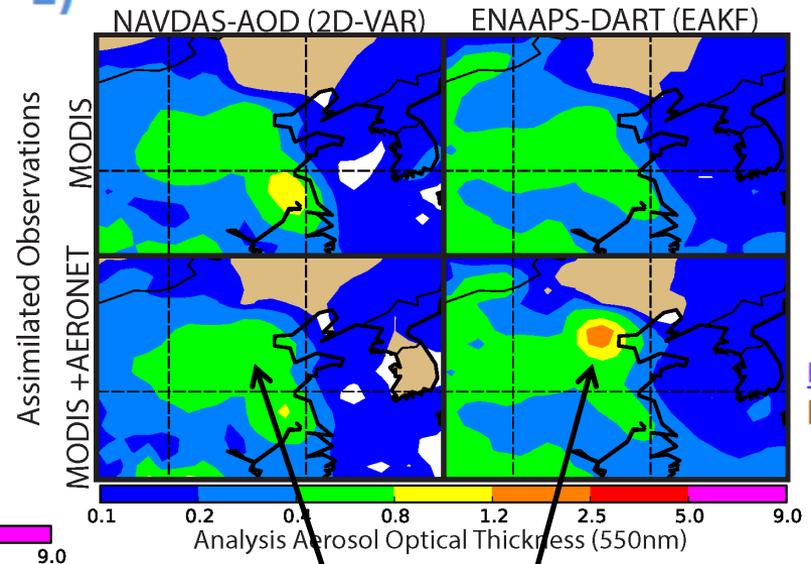
Assimilation of AERONET observations with MODIS AOT: What is the main impact?

Large Aerosol Events (AOT > 1)

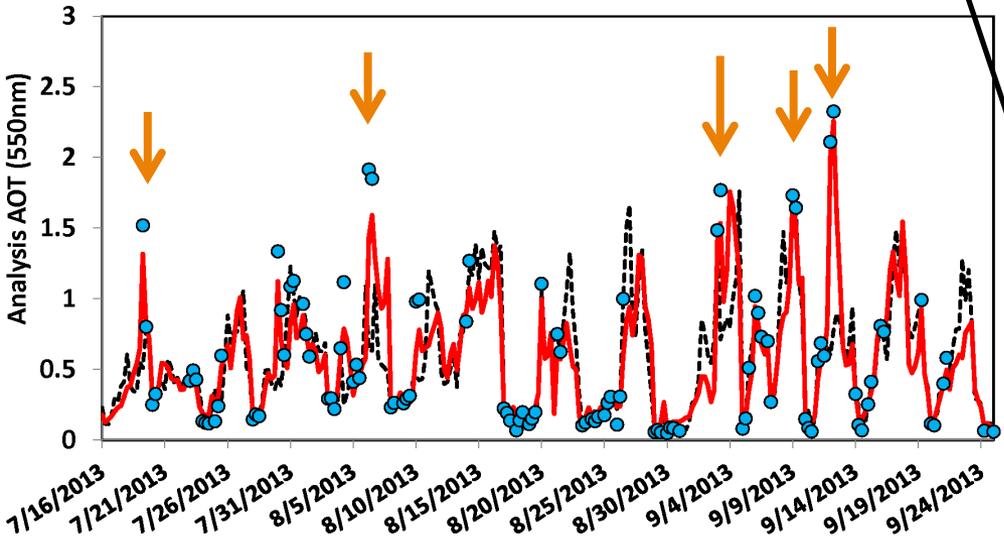
Beijing, China 20130903



Assimilated MODIS+AERONET



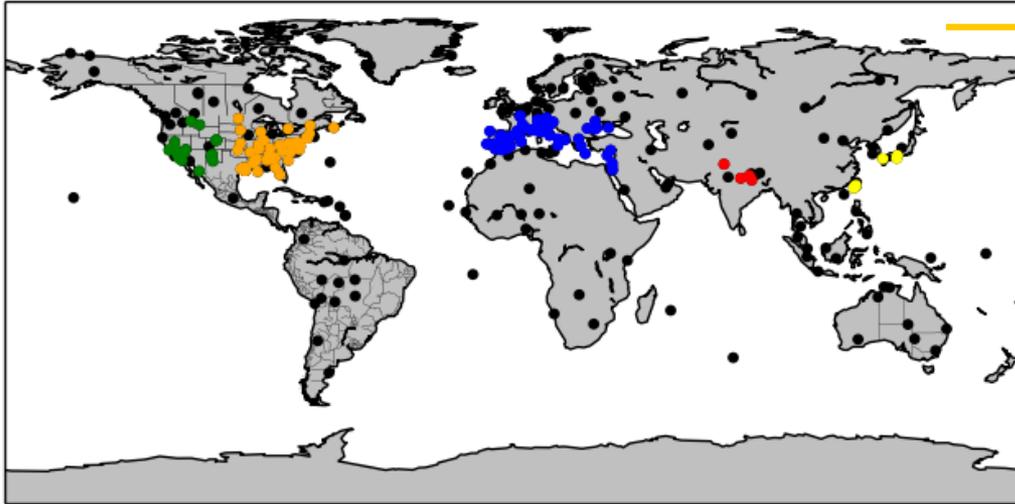
<http://www.nrlmry.navy.mil/aerosol/>
[Sessions et al. 2015]



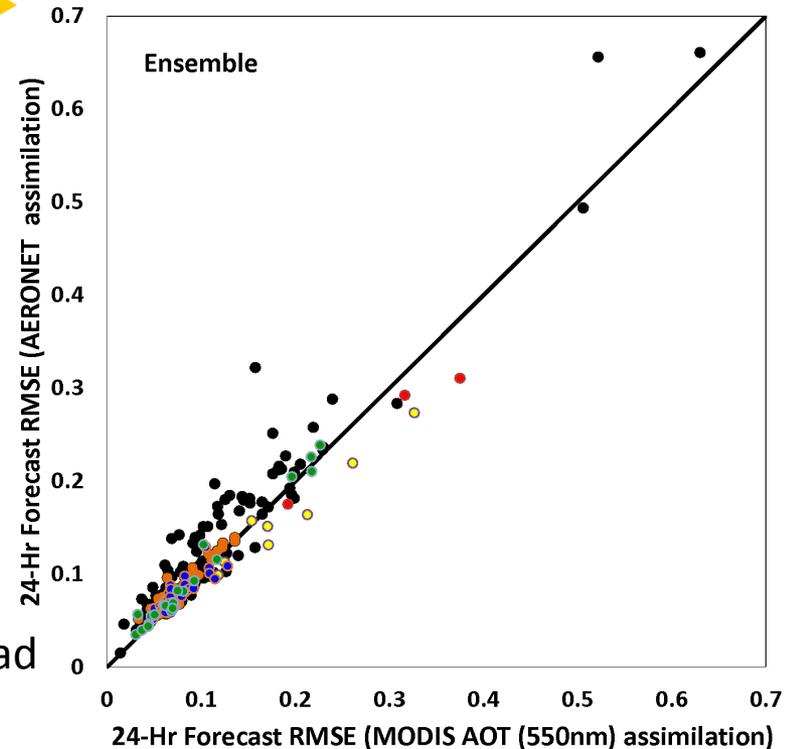
- Big peaks in MODIS AOT often get screened out before DA
- AERONET beneficial in filling in these gaps
- Ensemble DA does better in capturing very large AOT peaks when assimilating both MODIS and AERONET
- 2D-Var gets dragged down by surrounding MODIS obs
- Consistently found in timeseries

What is the impact of AERONET assimilation on the 24-hr forecast?

AERONET Sites with Observations During Experiment



24-hr Forecast Verification



- Verification of the 24-hr forecast at AERONET sites (forecast and obs are now independent)
- Forecasts initialized with AERONET only assimilation had reduced RMSE at several sites in India and East Asia
- RMSE was approximately the same for regions where AERONET observations are dense

AERONET could serve as a back-up over land for synoptic scale events if satellite observations are not available

AERONET Assimilation: What did we learn?

- Having **flow-dependent** forecast uncertainties is important for **assimilating sparse observations** such as AERONET
- It is expected that this same finding will apply to other types of observations such as surface measurements, lidar, aircraft measurements...
- The biggest impact of incorporating AERONET observations into the data assimilation component of the aerosol forecasting system is the ability to capture **peak aerosol events (AOT > 1)** as well as **temporal variability**.
- 24-hour aerosol forecasts initialized with analysis fields from AERONET AOT only assimilation produced similar verification metrics to forecasts initialized with MODIS AOT only, particularly for **high observation density regions**, and reduced RMSE at downwind sites in **India and Asia**.
- These results indicate that AERONET could serve as the backbone observing system for aerosol forecasting, not just for verification.
- The ENAAPS-DART system is going to 80 members on a semi-operational basis, which is expected to significantly improve how observations spatially impact the system and overall performance.