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Office of Naval Research ONR Science & Technology

NRL Aerosol Data Assimilation Update

ICAP 8th Working Group Meeting

College Park, MD

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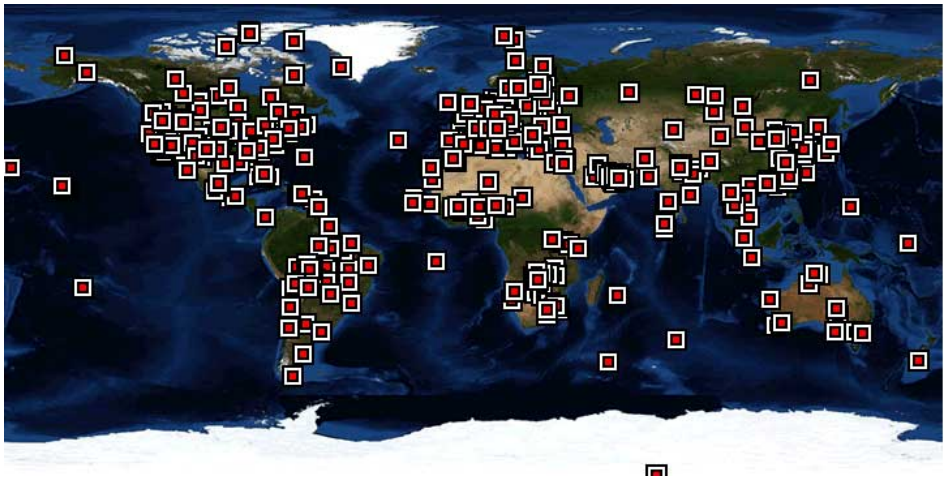
NRL Aerosol Data Assimilation Overview

http://www.image.ucar.edu/DAReS/DART/

- A new ensemble system for Navy aerosol forecasting was developed (ENAAPS-DART) and recently published [Rubin et al. 2016].
- ENAAPS-DART is being implemented semi-operationally with an 80 member ensemble for MODIS AOT assimilation.
- AERONET tested as a base observing network for aerosol data assimilation.


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

- Testing of a new skewed distribution algorithm for ensemble data assimilation [Hodyss 2011, 2012].
- Evaluation of the ensemble for lidar data assimilation.

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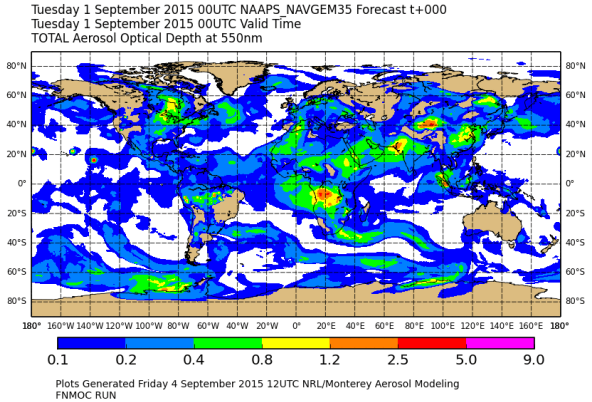
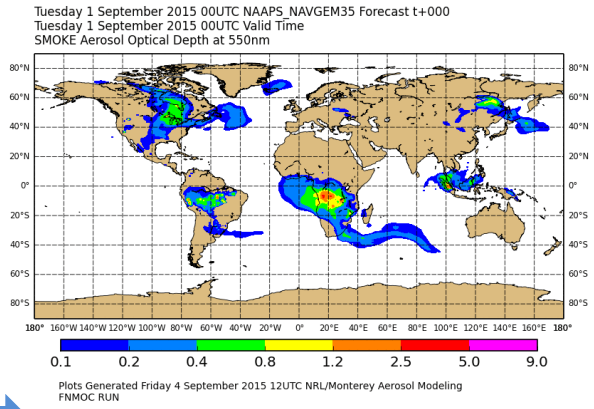
Operational Navy Aerosol Forecasting

- **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

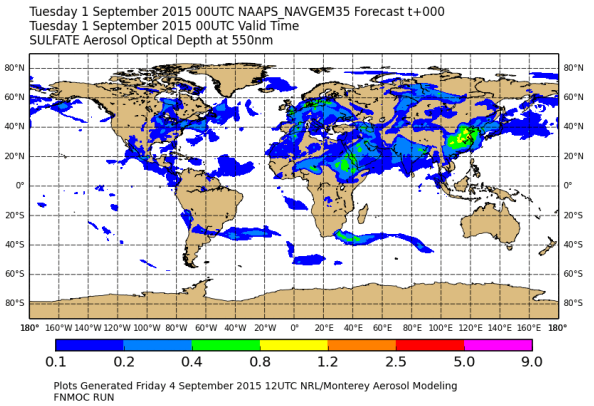
Total



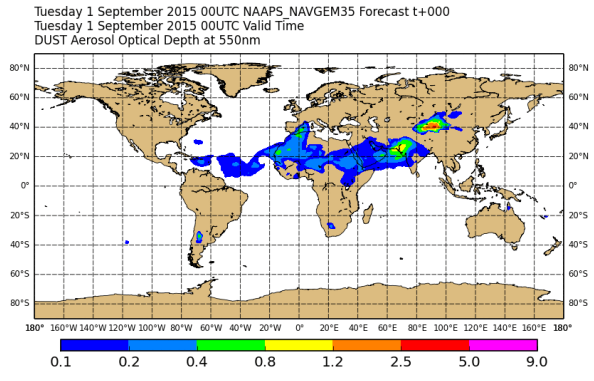
Smoke



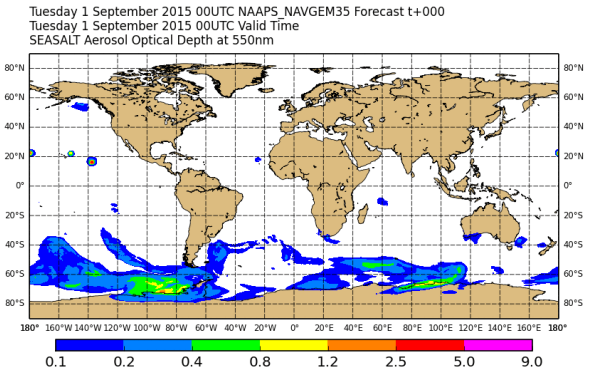
Anthro/Biogenic Fine



Dust

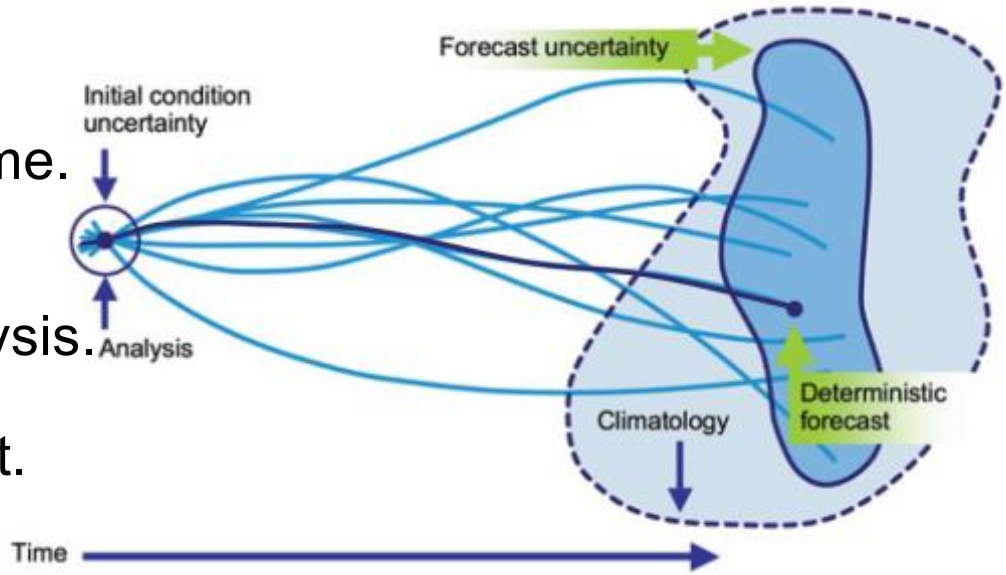


Sea Salt



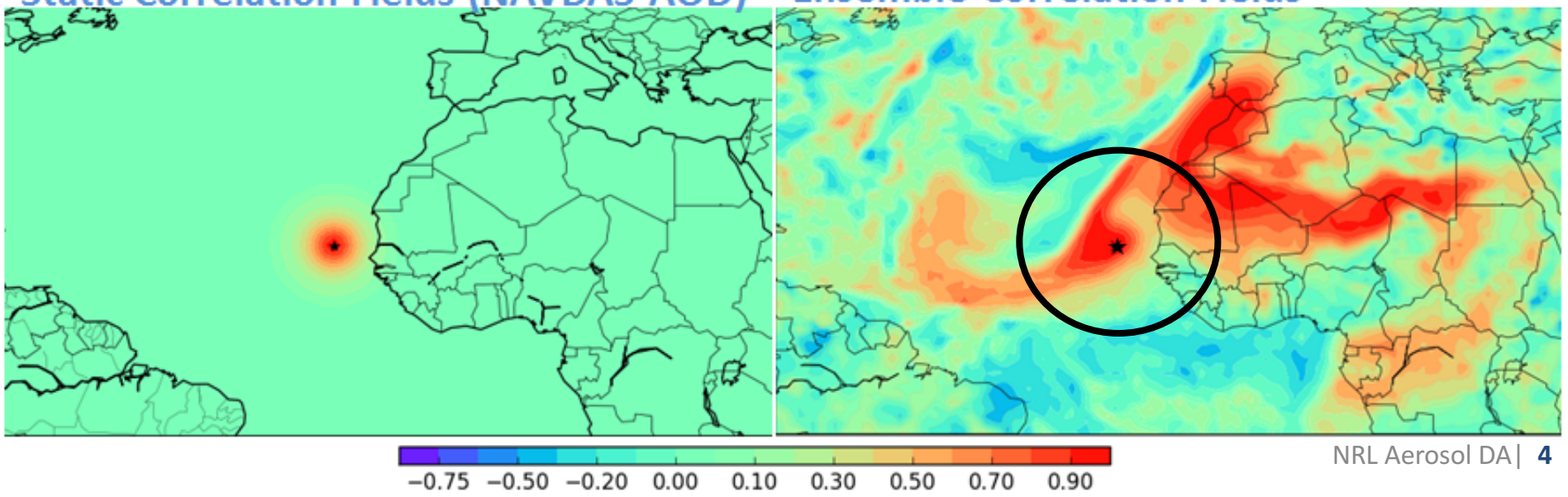
Flow-Dependence: Making better use of observational information

- 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.



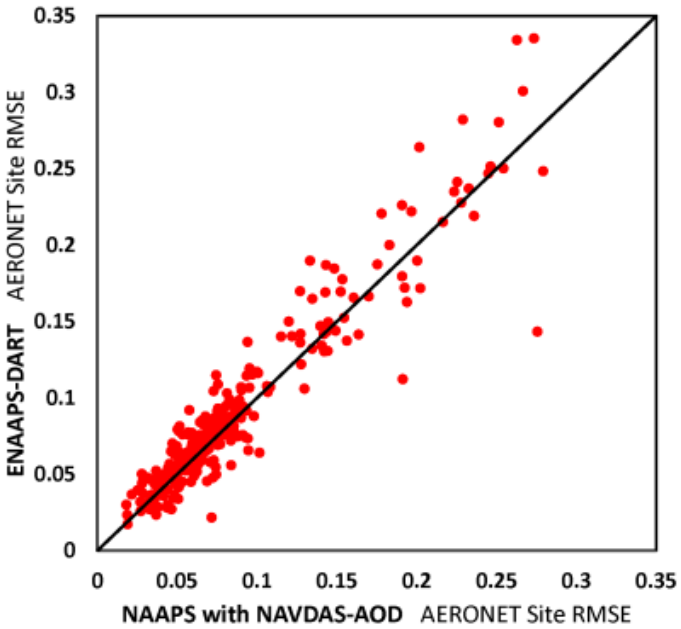
Static Correlation Fields (NAVDAS-AOD)

Ensemble Correlation Fields



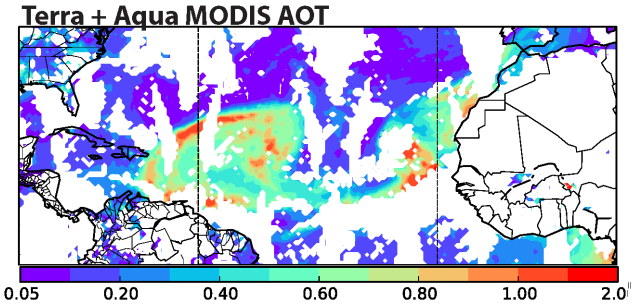
ENAAPS coupled to an Ensemble Adjustment Kalman Filter [Rubin et al. 2016]

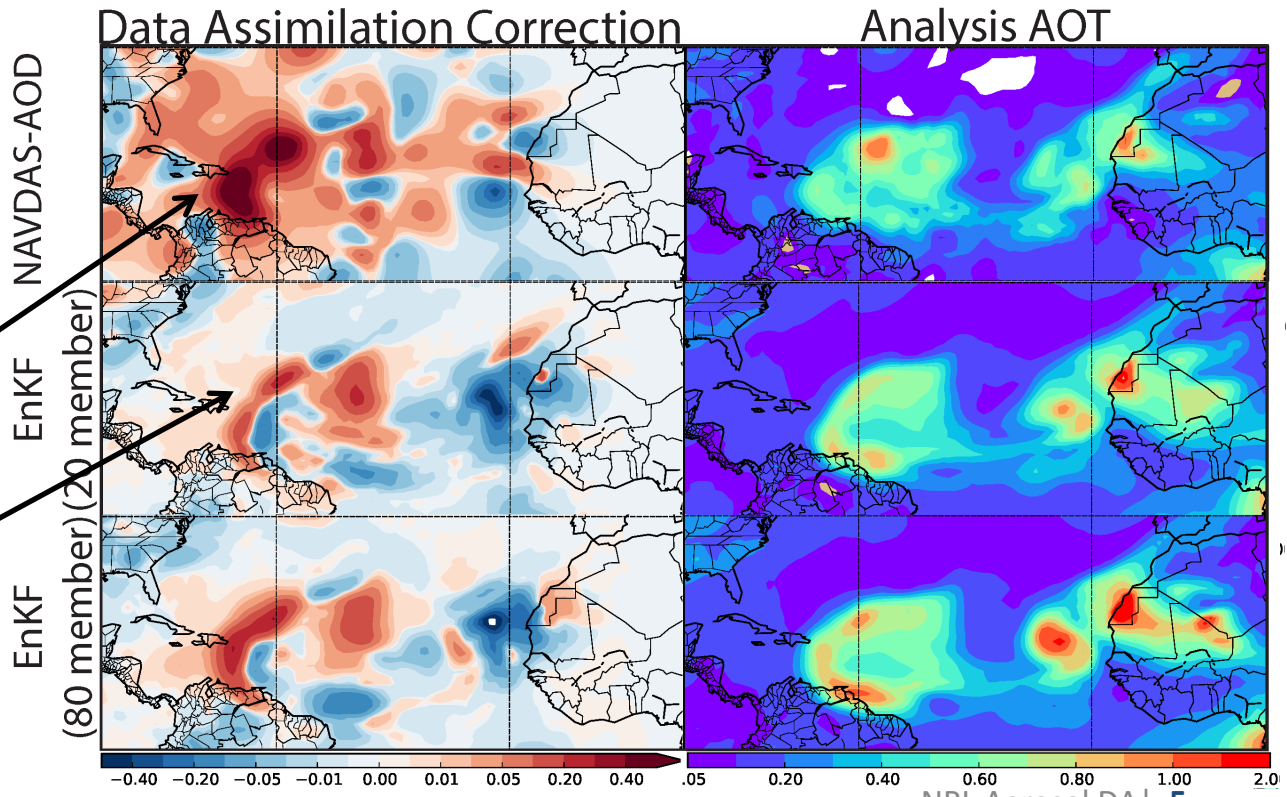
1. Using an RMSE metric, ENAAPS-DART performs about the same as NAAPS with NAVDAS-AOD at AERONET sites (6 month experiment, 20 member)



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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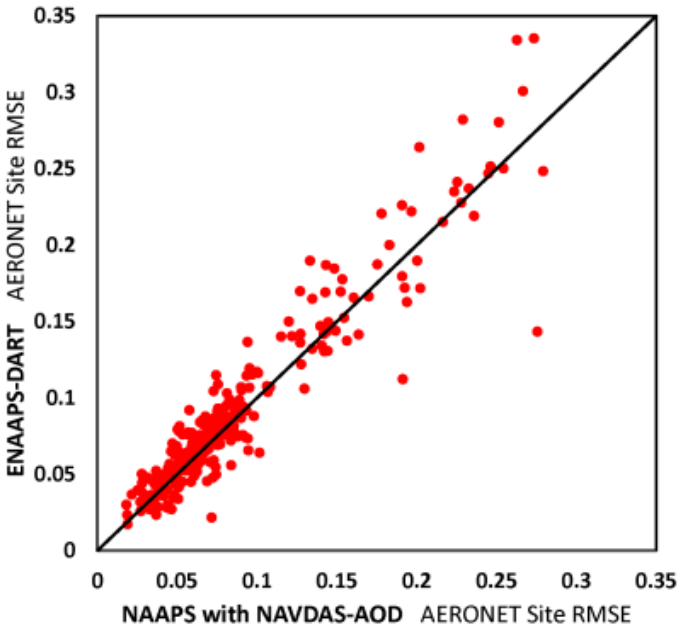

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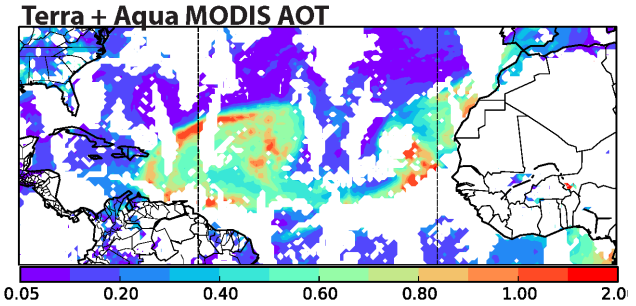
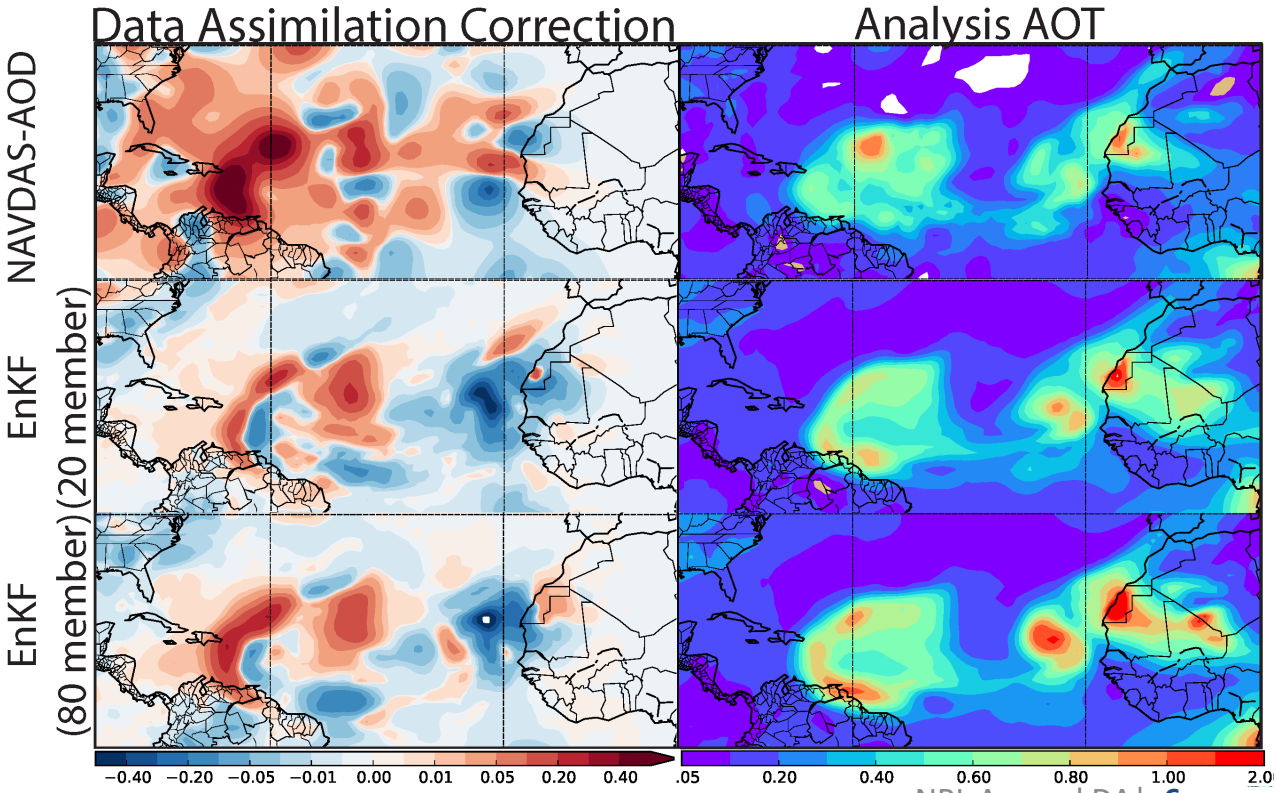
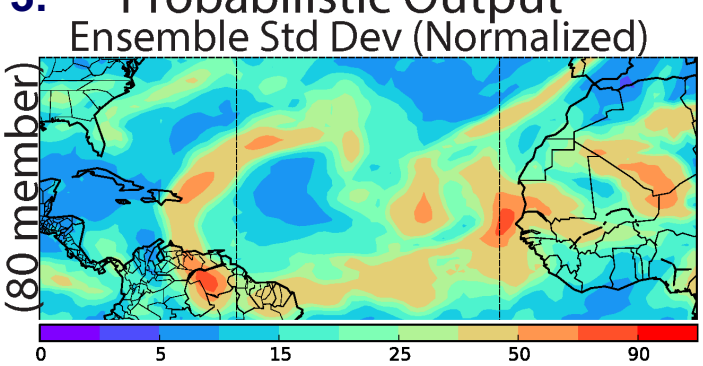
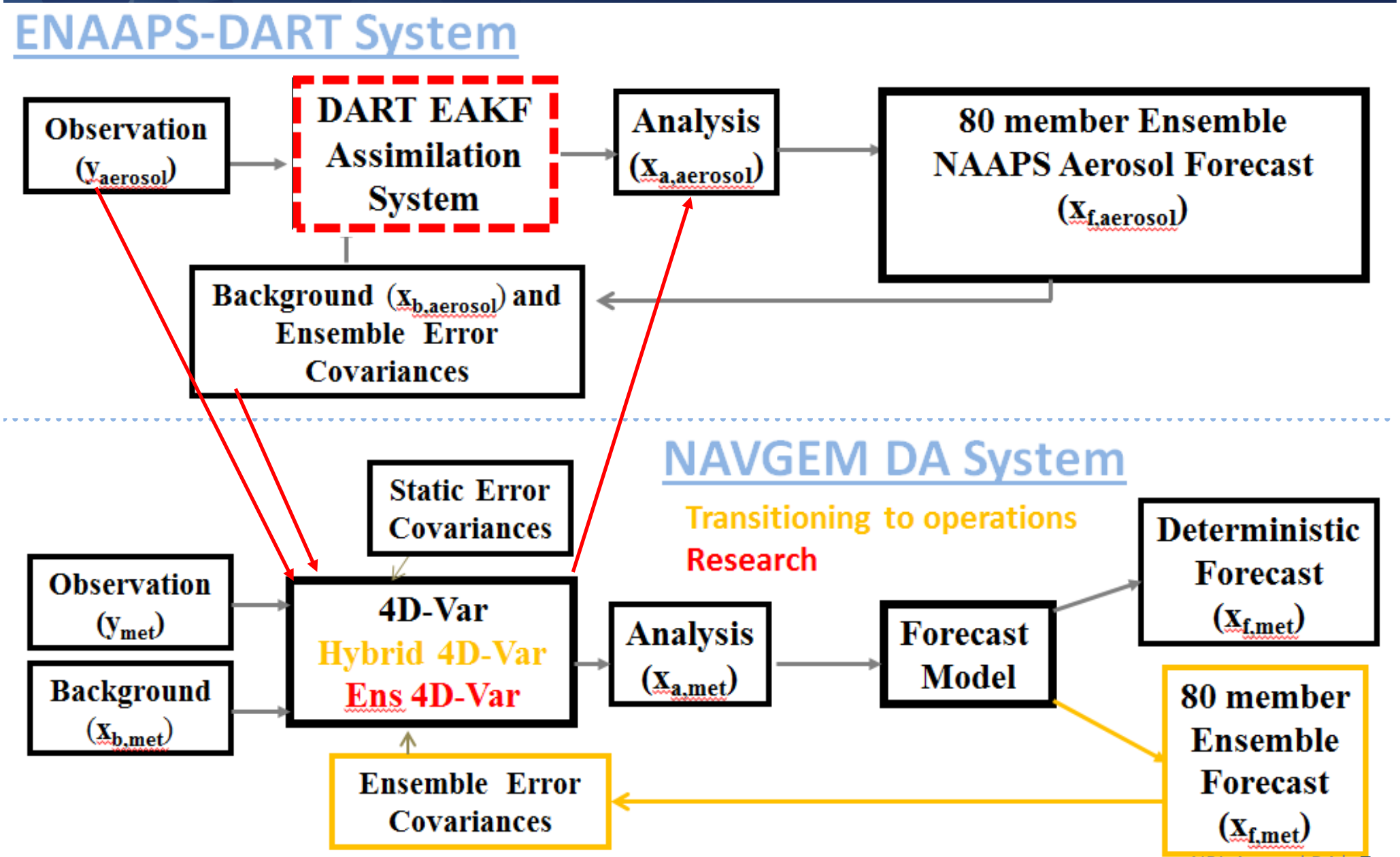




3. Probabilistic Output



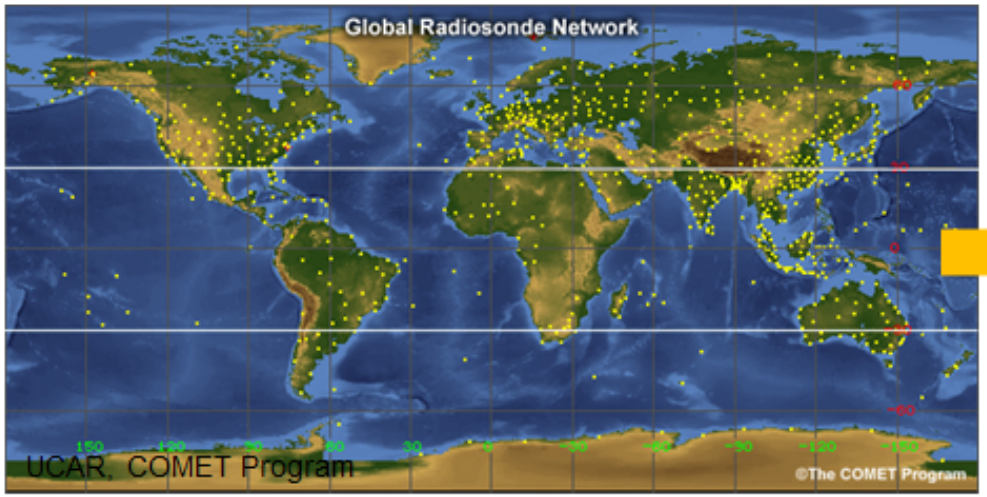
ENAAPS and Numerical Weather Prediction



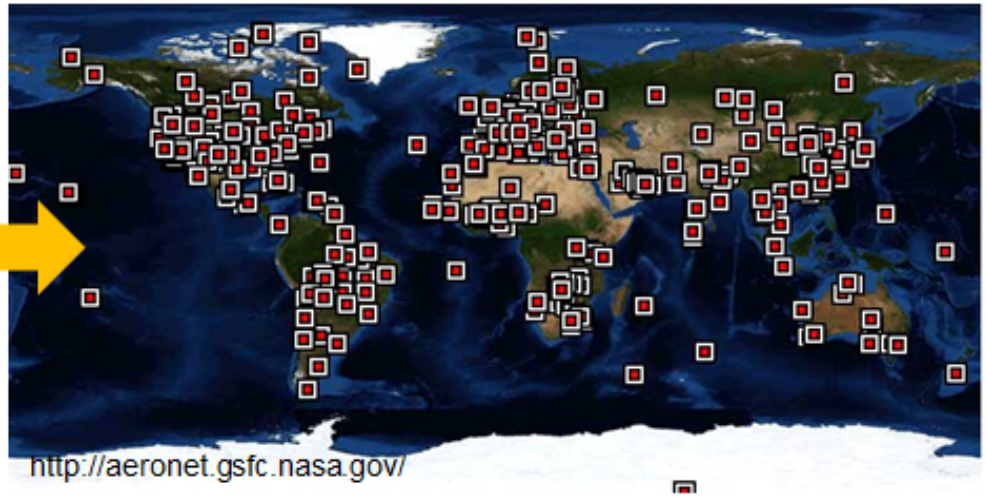
AERONET Assimilation: Radiosondes of the aerosol world?

- ENAAPS-DART 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?



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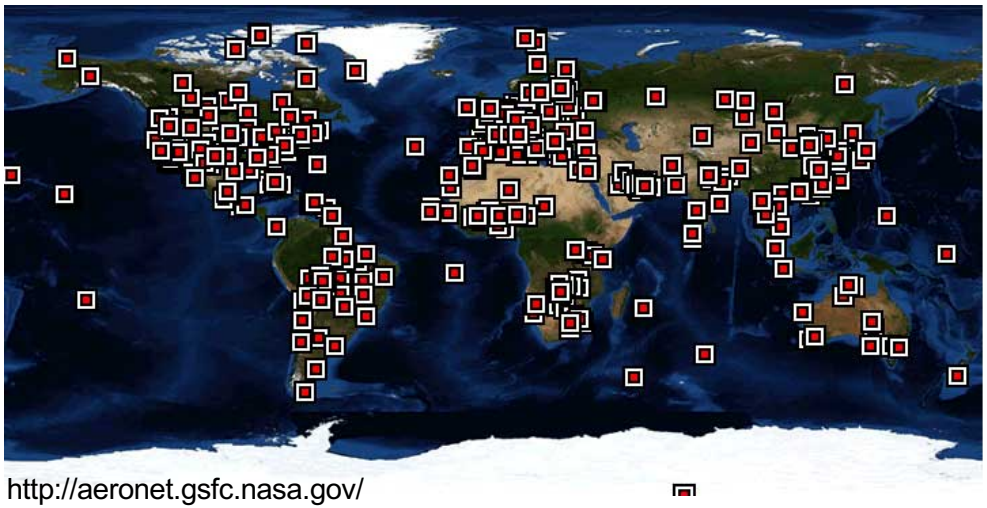
Assimilation of AERONET observations for aerosol forecasting

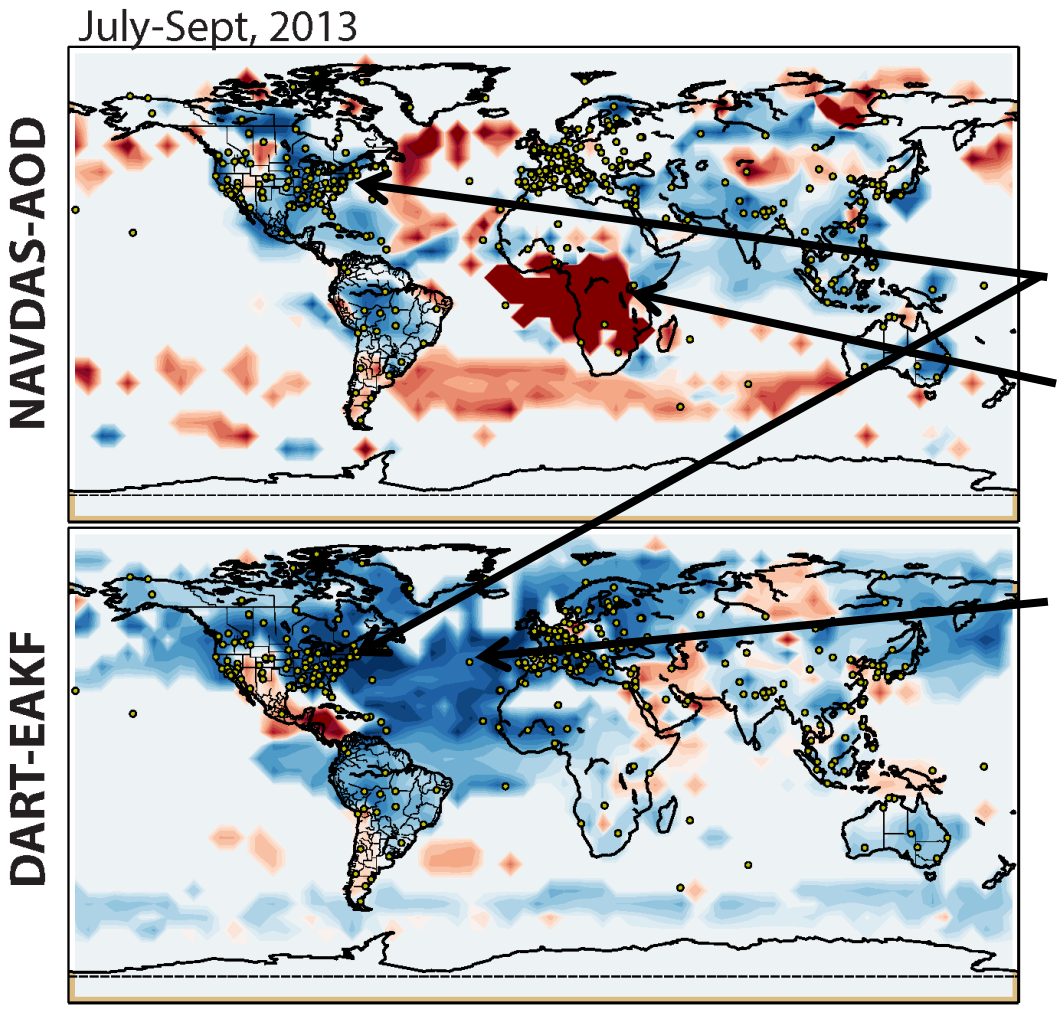
1. Is the successful use of this network of observations dependent on the data assimilation methodology?
2. What is the impact of data assimilation of AERONET on its own and combined with other observations?
3. Can this network serve as a backup if satellite observations are not available?
4. Can we identify locations where new sites would be most beneficial?



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

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

Impact of Assimilating AERONET on AOT Analysis RMSE



Error Decrease

−100 −70 −40 −10 0 10 40 70 100

Error Increase

Percent Change in Error Due to AERONET Assimilation

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

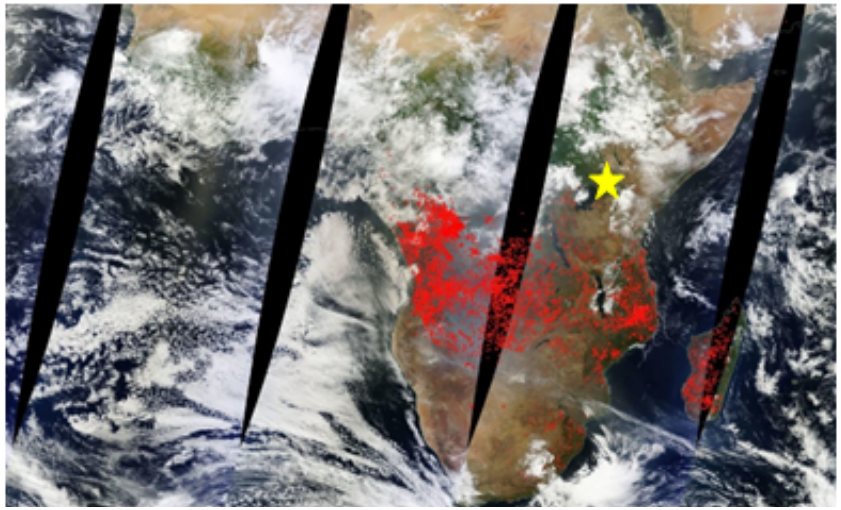
1. **Analysis verified with MODIS AOT**
2. **Largest error reduction in high observation density regions**
3. **Large increases in error can occur with NAVDAS-AOD (2D-Var data assimilation)**
4. **The spatial extent of the error reduction is much greater with EAKF**

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

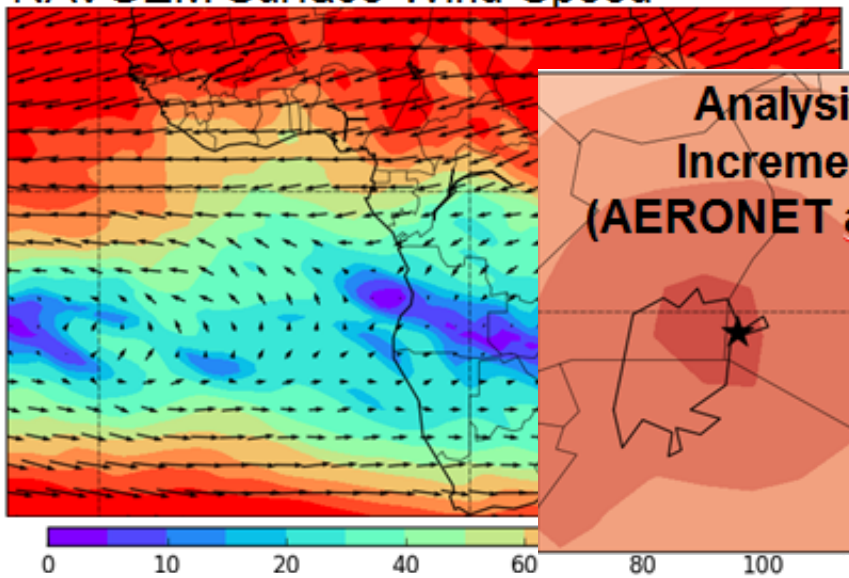
Why do sparse obs like AERONET negatively impact the NAAPS with 2D-Var system?

Case Study: August 12, 2013 (12Z)

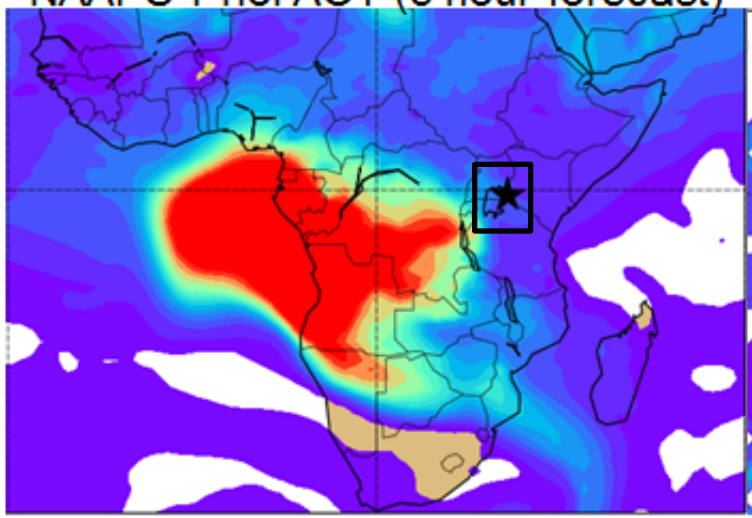
MODIS Fire Detections, NASA Worldview



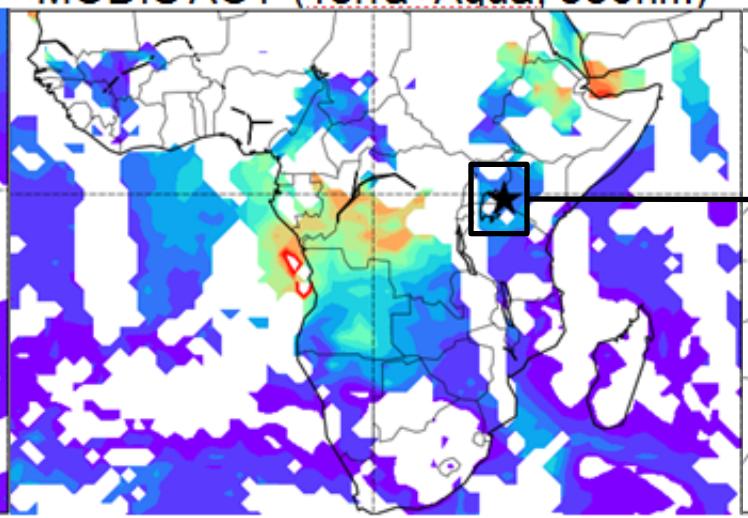
NAVGEM Surface Wind Speed



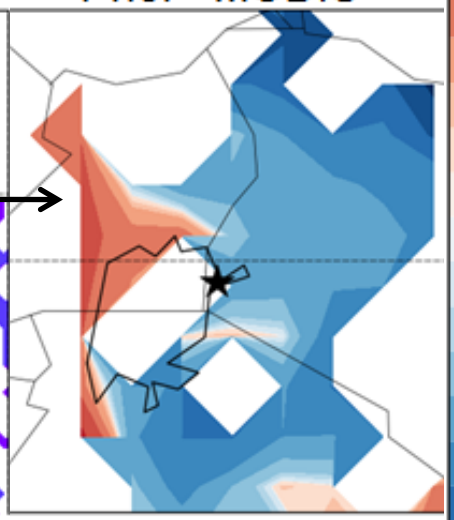
NAAPS Prior AOT (6 hour forecast)

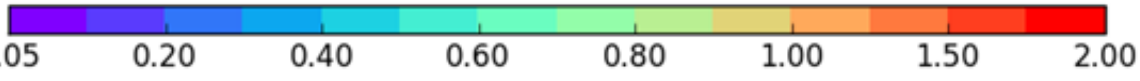


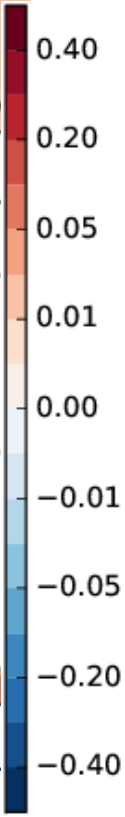
MODIS AOT (Terra+Aqua, 550nm)



Prior - MODIS



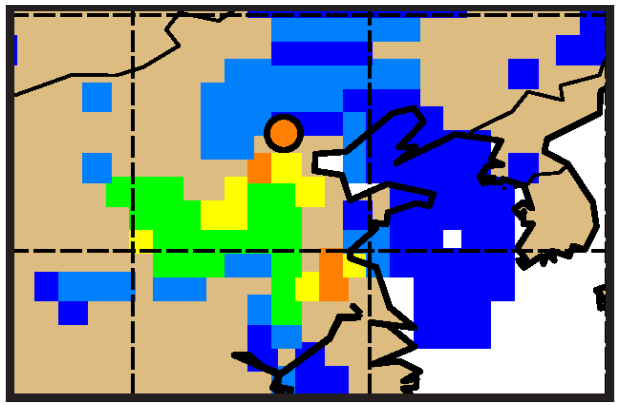




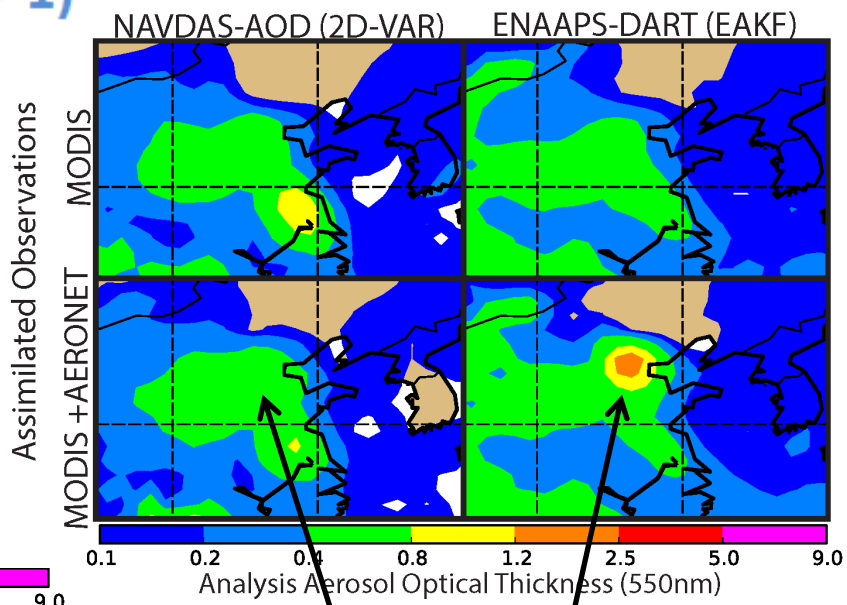
Assimilation of AERONET observations with MODIS AOT: What is the main impact?

Large Aerosol Events (AOT > 1)

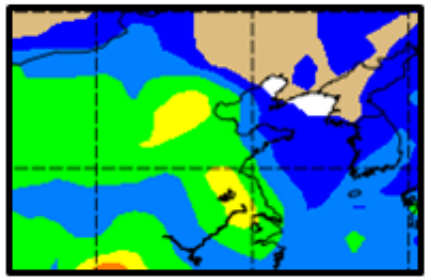
Beijing, China 20130903



Assimilated MODIS+AERONET

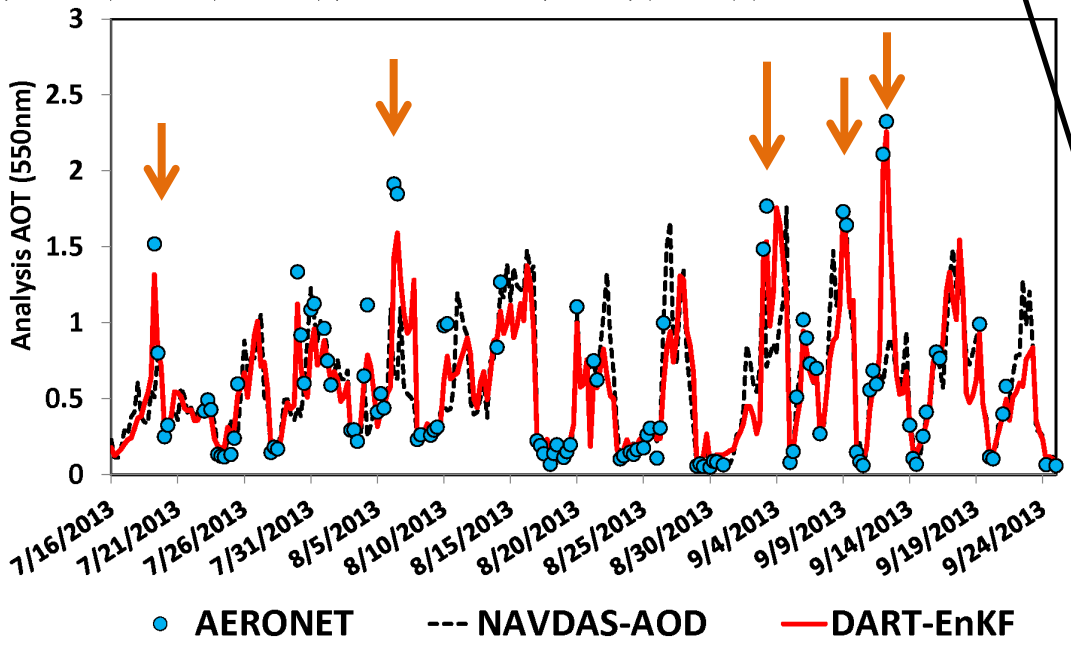


ICAP-MME



http://www.nrlmry.navy.mil/aerosol/

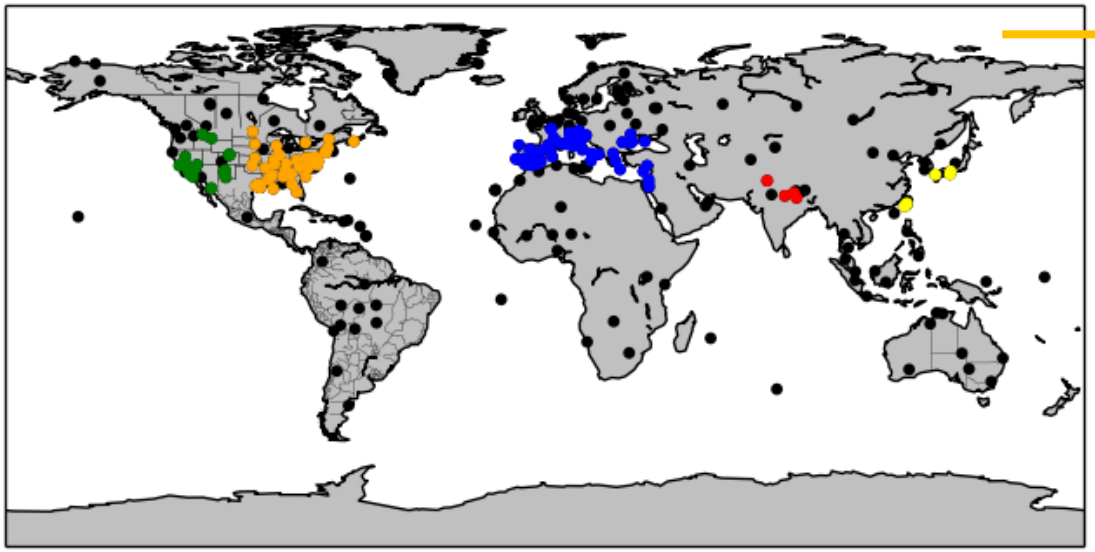
[Sessions et al. 2015]



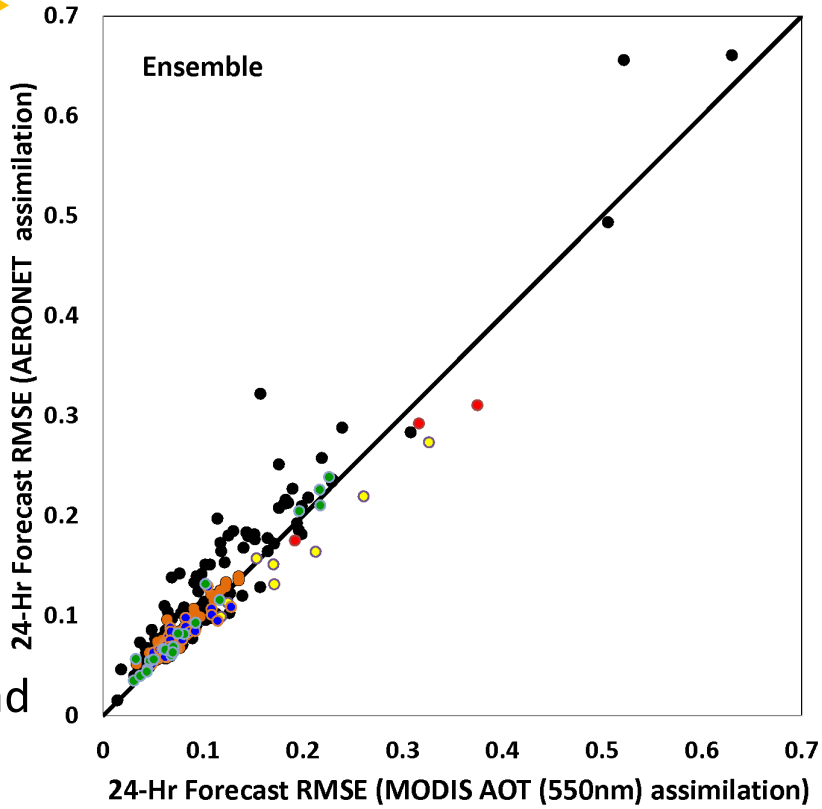
- Big peaks in MODIS AOT often get screened out before DA
- This results in AOT fields getting dragged dowr by DA.
- AERONET beneficial in filling in these gaps
- Ensemble DA does better in capturing very large AOT peaks when assimilating both MODIS and AERONET
- 2D-Var gets dragged down by surrounding MODIS obs, similar to MODIS only assim
- 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

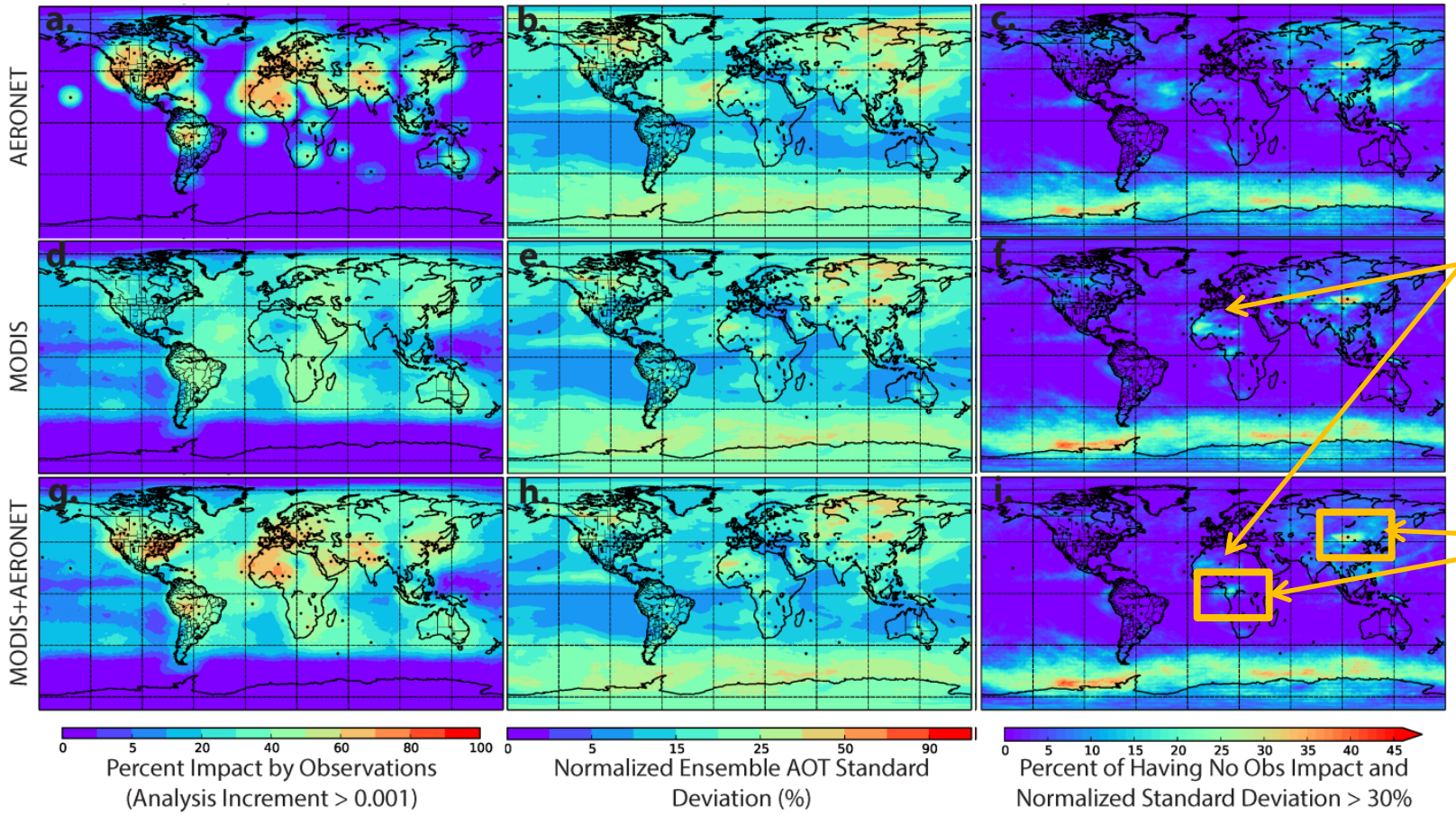
AERONET could serve as a back-up over land for synoptic scale events if satellite observations are not available

Where would new observations be most beneficial?

New observations are idea in locations where:

1. Observational constraint is limited
2. Forecast uncertainty in relatively large

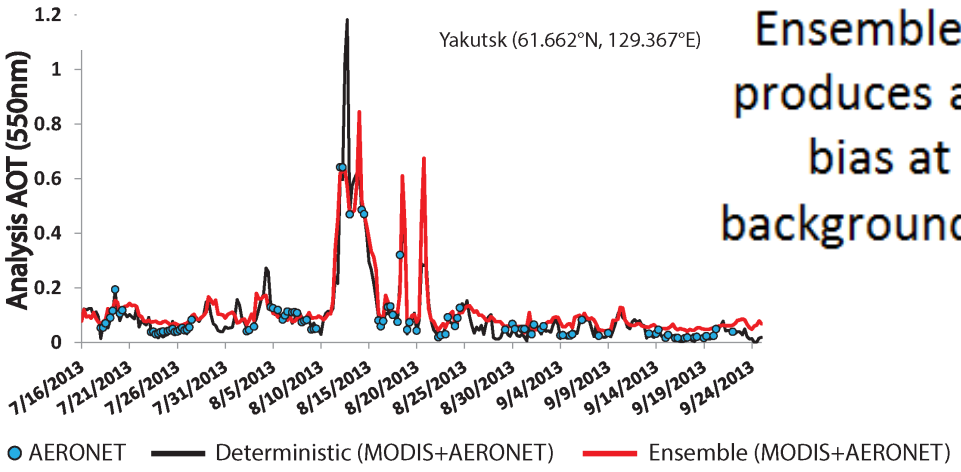
Ensemble system provides a quantitative measure of forecast uncertainty…



AERONET helpful in North Africa

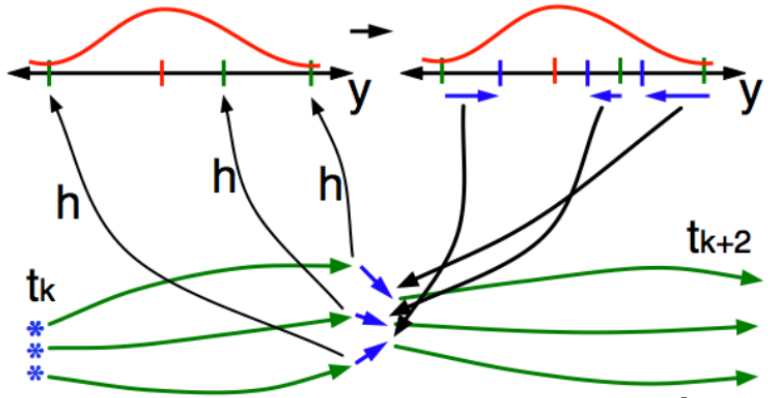
Also can see where new sites might be beneficial

Accounting for skewness in ensemble data assimilation



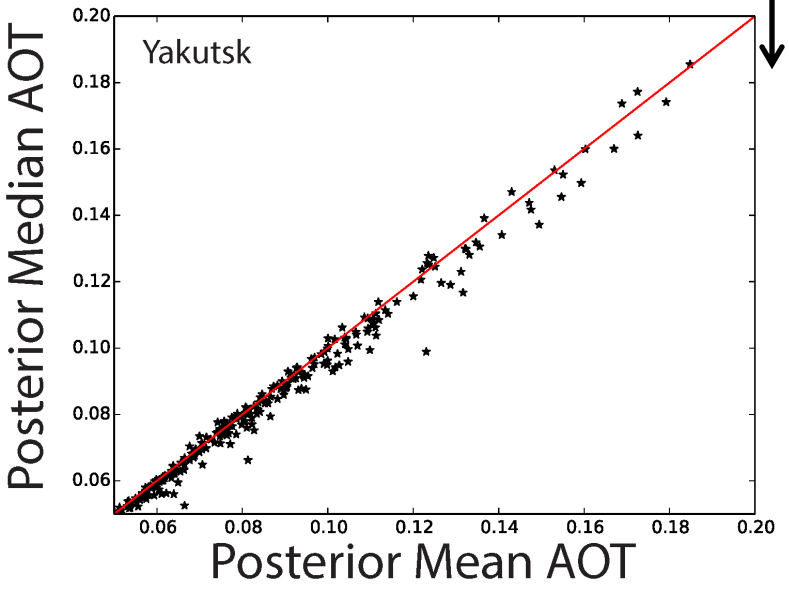
Ensemble system produces a positive bias at near-background aerosol.

Ensemble data assimilation methods assume a Gaussian distribution:

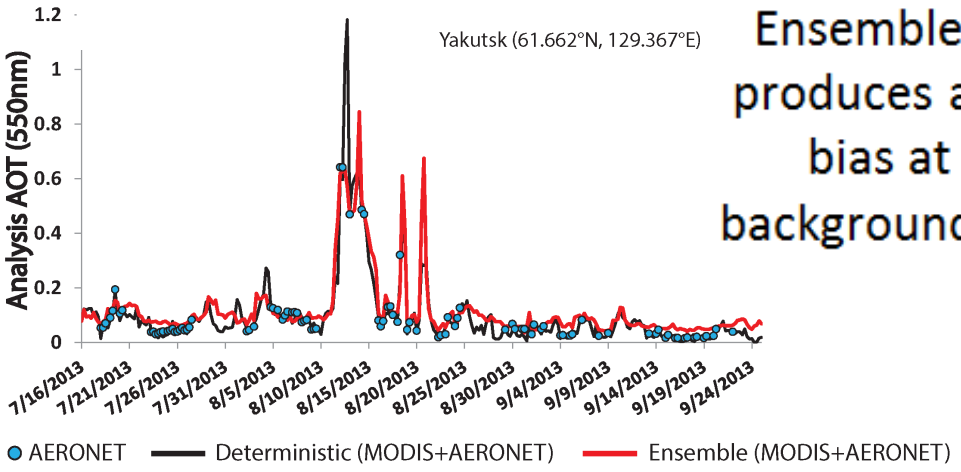


http://www.image.ucar.edu/DAReS/DART/

The mean being greater than the median is common when the distribution is positively skewed.



Accounting for skewness in ensemble data assimilation



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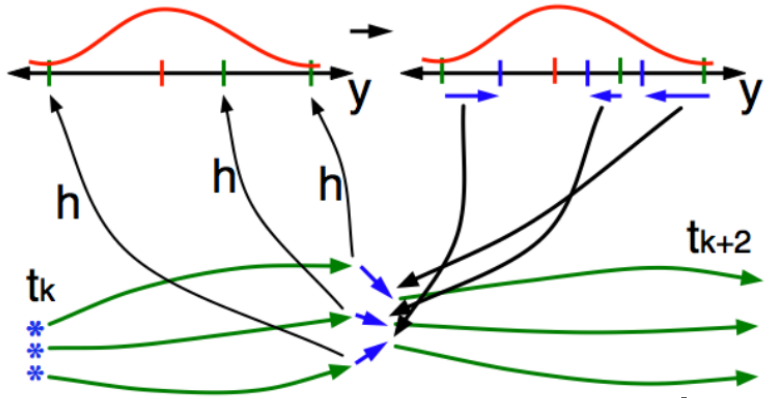
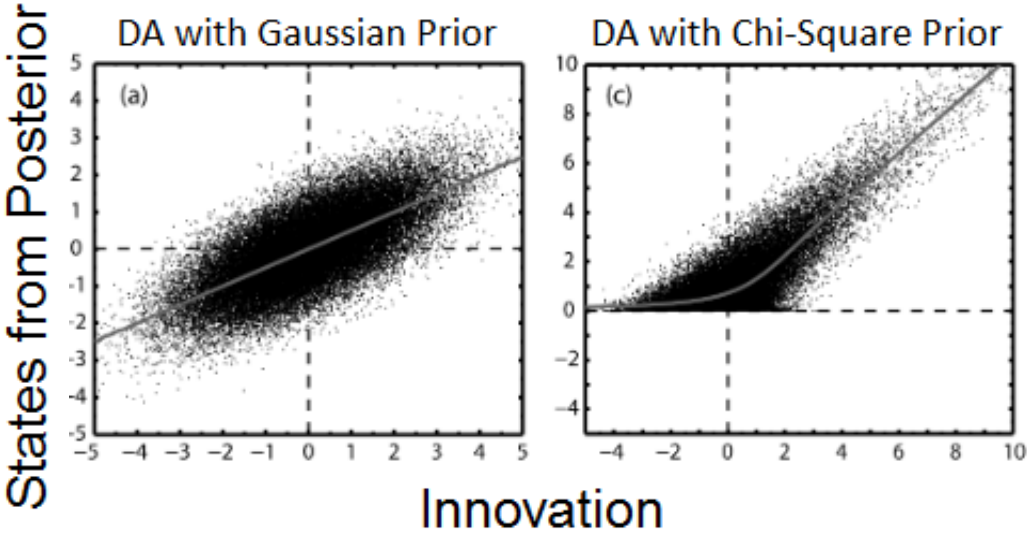
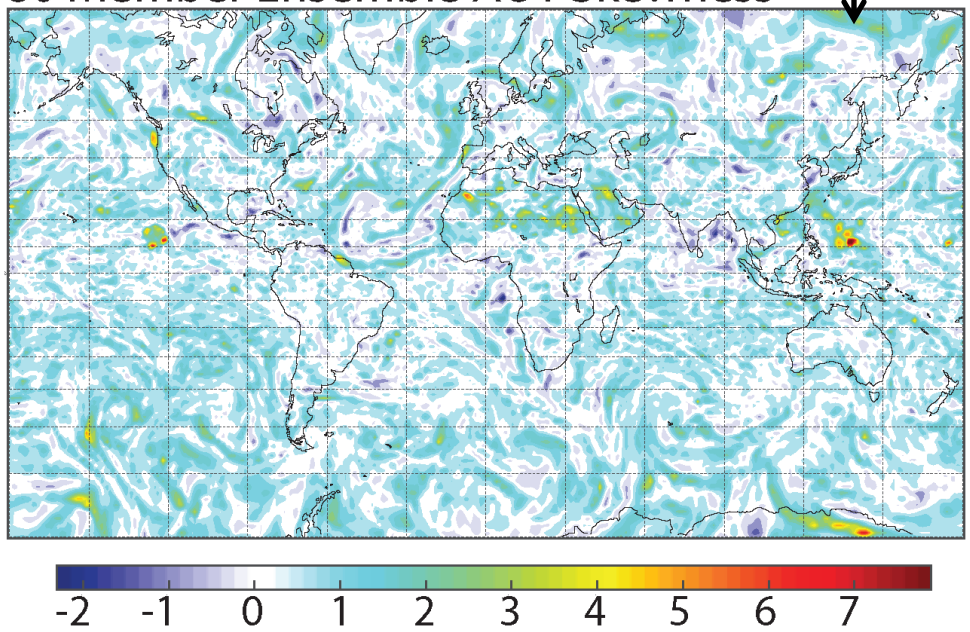


http://www.image.ucar.edu/DAReS/DART/

Testing algorithm of Hodyss 2012 for applying nonlinear regressions to produce the posterior.



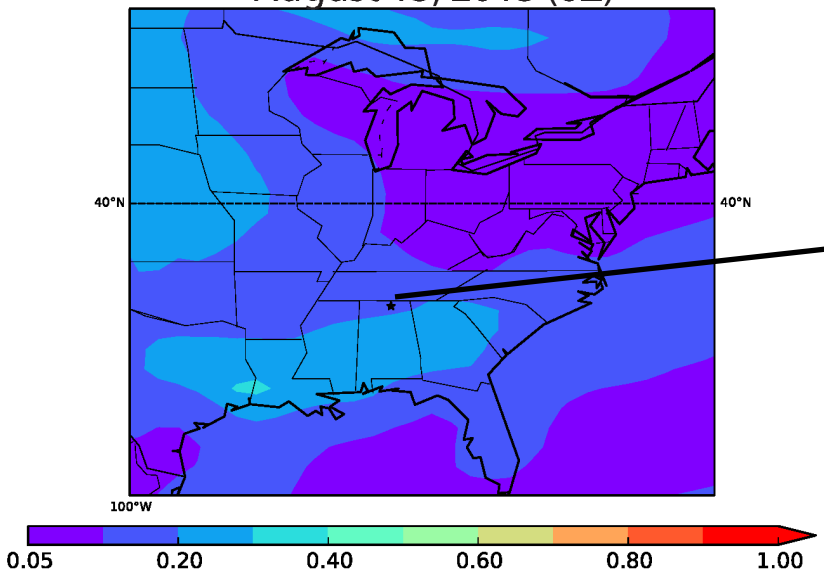
80 Member Ensemble AOT Skewness



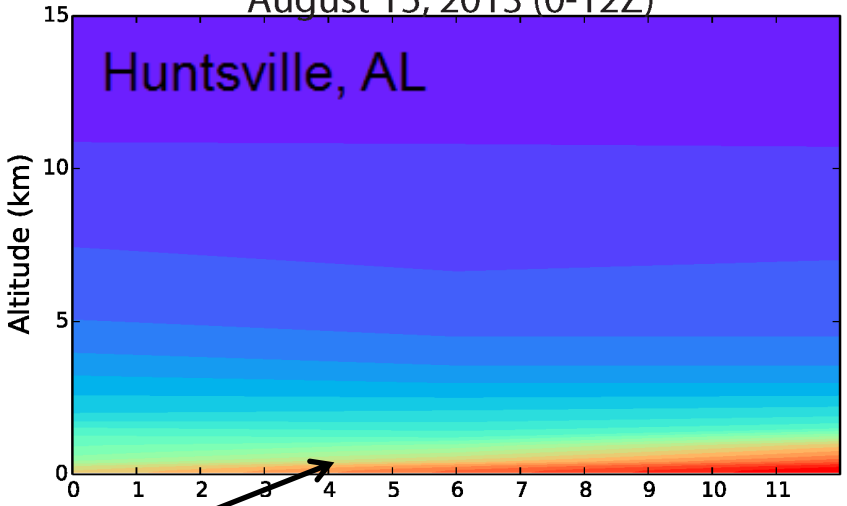
Ensemble Data Assimilation: Moving to the Vertical

First, we need to understand what the ensemble is capable of in the vertical…

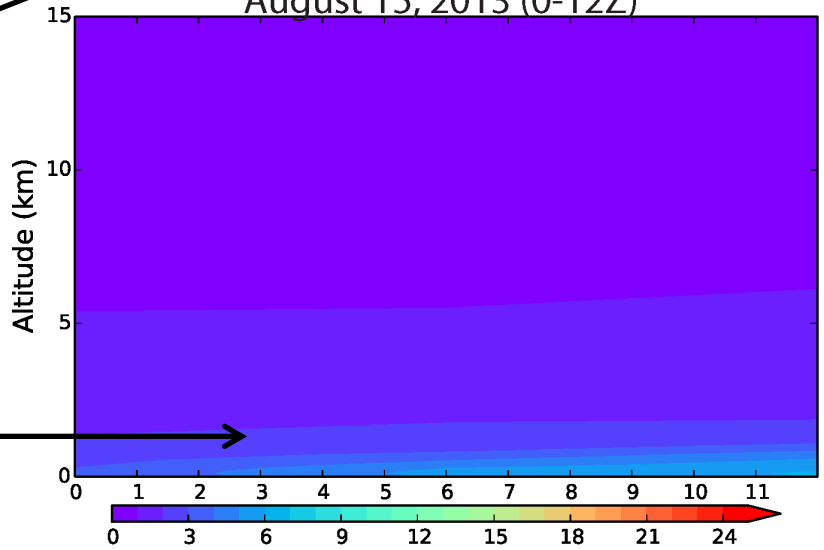
6-hr Forecast Mean AOT - 80 Member ENAAPS
August 15, 2013 (6Z)



6-hr Forecast Mean Aerosol Mass (µg/m3)
August 15, 2013 (0-12Z)



Ensemble StDev Aerosol Mass (µg/m3)
August 15, 2013 (0-12Z)



In general with NAAPS/ENAAPS, we find that the aerosol mass is concentrated at the surface with some diffusion in the vertical.

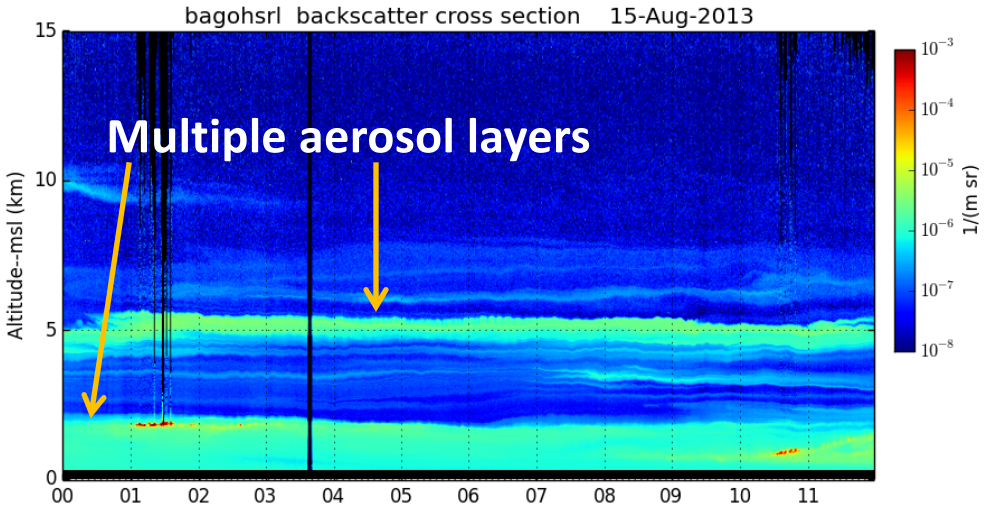
At the same time, the ensemble spread is limited away from the surface.

Ensemble Data Assimilation: Moving to the Vertical

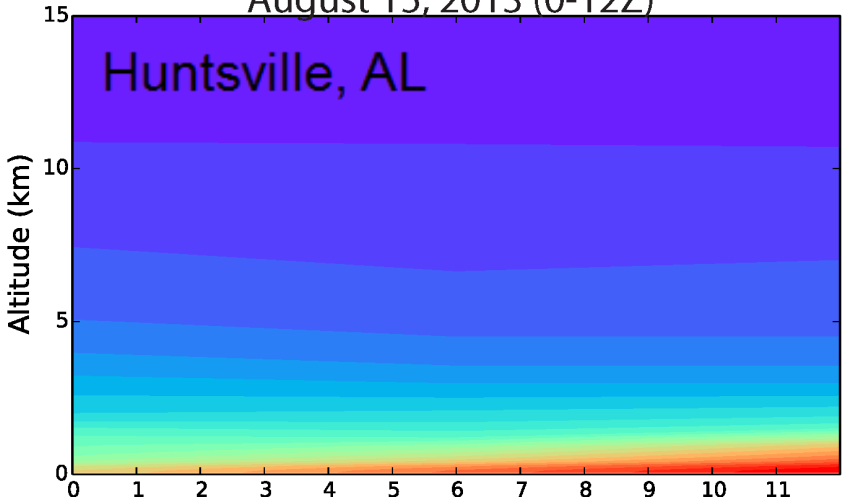
First, we need to understand what the ensemble is capable of in the vertical…

Assimilating this vertical observational information can be a challenge for a pure ensemble system, especially elevated aerosol layers like seen in the HSRL.

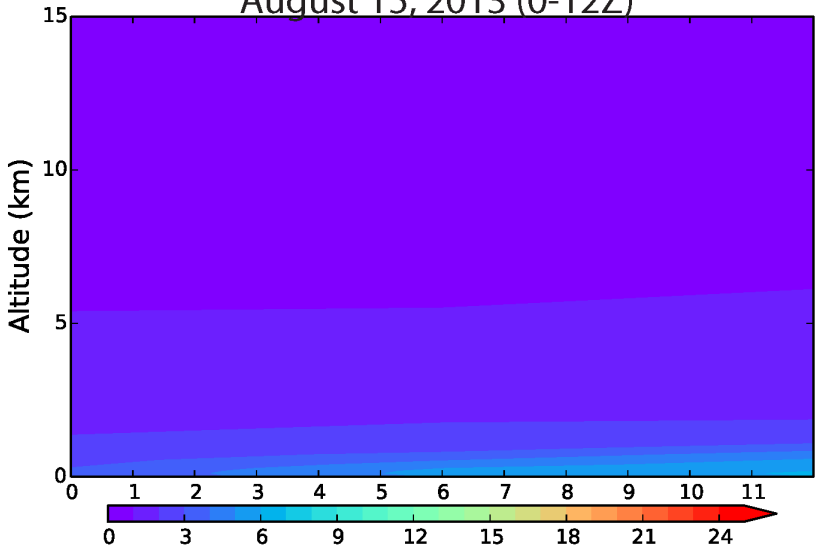
University of Wisconsin HSRL
Huntsville, AL



6-hr Forecast Mean Aerosol Mass (µg/m3)
August 15, 2013 (0-12Z)



Ensemble StDev Aerosol Mass (µg/m3)
August 15, 2013 (0-12Z)



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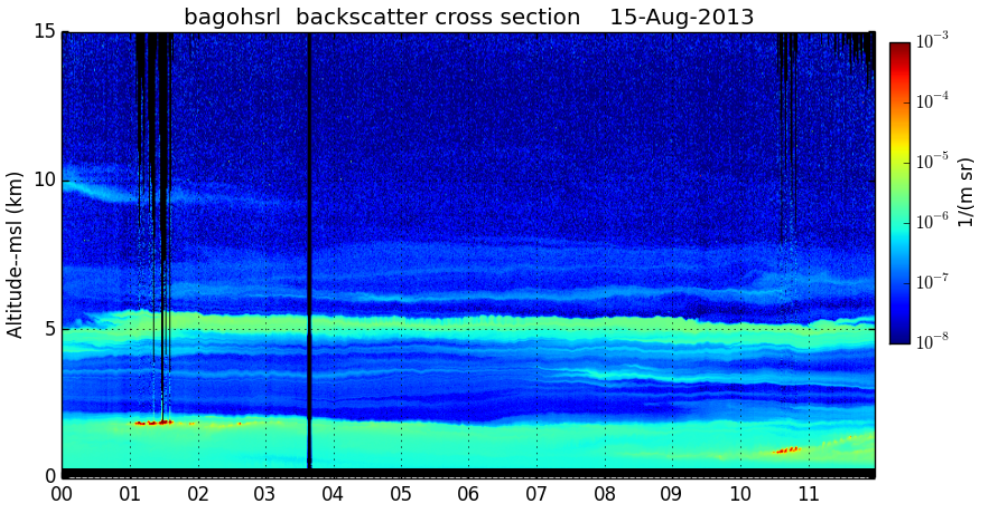
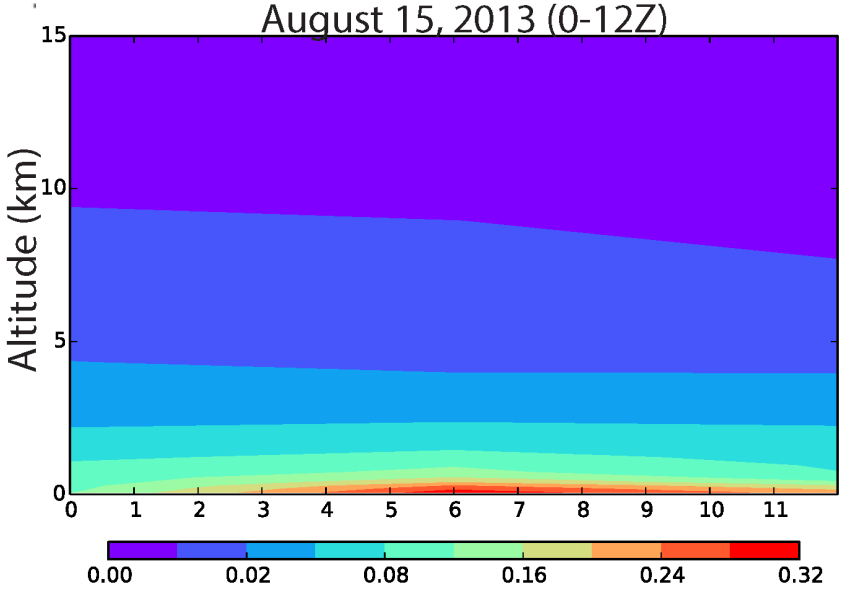
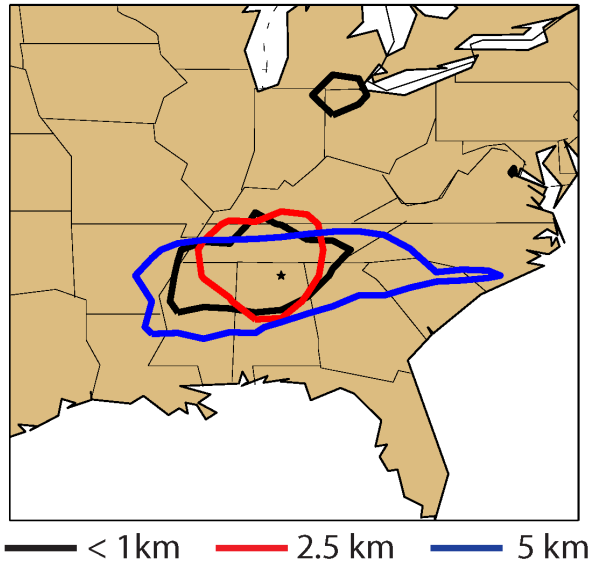
Ensemble Data Assimilation: Moving to the Vertical

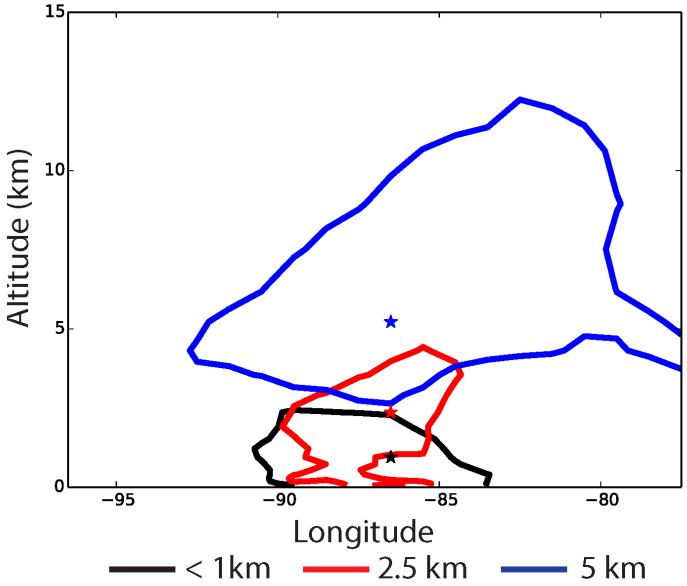
In ENAAPS, how would the obs information spread?

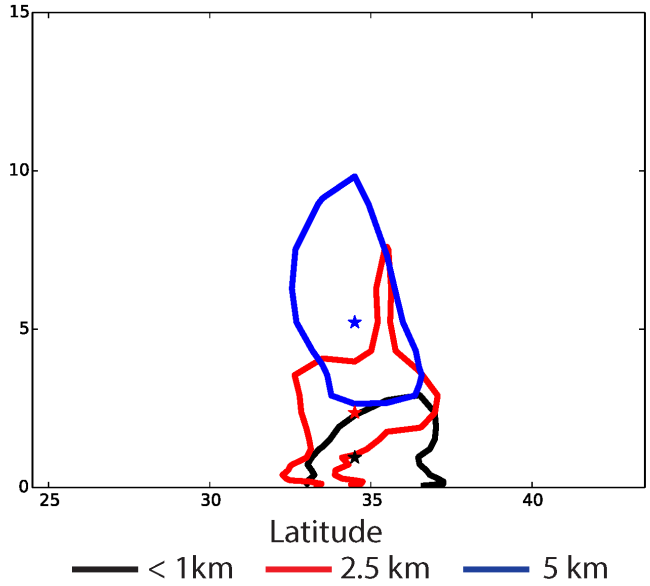




e-folding extinction correlations at 3 levels







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Ensemble Data Assimilation: Moving to the Vertical

Some of the questions that we need to address:

1. What are the observational errors for lidar? Average obs? Backscatter to extinction?
2. Can we rely on a pure ensemble system for assimilating observational information in the vertical? Or do we need a hybrid strategy?
3. Should we look to add new sources of variability in the ensemble to capture the uncertainty in the vertical? Emission injection heights, deposition velocities?
4. What is the behavior of adaptive inflation in the vertical?
5. Vertical localization?

Assimilation of vertical information for aerosol is complicated. Therefore, we need to rely on case studies (ie. Huntsville) to understand the behavior before we can apply the dataset globally.

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NRL Aerosol Data Assimilation Recap…

- The ENAAPS-DART system has been developed and is being implemented in a semi-operational configuration with 80 member ensemble. This will be used to feed into the NWP system as well.
- 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 forecast results indicate that AERONET could serve as a backbone observing system for aerosol forecasting, not just for verification.
- A new methodology (Hodyss 2012) for dealing with skewness in the ensemble prior is being tested within the ENAAPS-DART framework. This may help with near-background biases found in ENAAPS-DART.
- The ensemble is being analyzed in order to understand the possibilities for lidar assimilation. Results currently indicate that a hybrid method would be beneficial with vertical constraint, while still allowing for the ensembles to spread observational information in the horizontal.