Ensemble-based Assimilation of Aerosol Observations in GEOS-5

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Introduction

MERRA-2 is the latest Aerosol Reanalysis produced at NASA's Global Modeling Assimilation Office (GMAO) from 1979 to present. This reanalysis is based on a version of the GEOS-5 model radiatively coupled to GOCART aerosols and includes assimilation of bias corrected Aerosol Optical Depth (AOD) from AVHRR over ocean, MODIS sensors on both Terra and Aqua satellites, MISR over bright surfaces and AERONET data. In order to assimilate lidar profiles of aerosols, we are updating the aerosol component of our assimilation system to an Ensemble Kalman Filter (EnKF) type of scheme using ensembles generated routinely by the meteorological assimilation. Following the work performed with the first NASA's aerosol reanalysis (MERRAero), we first validate the vertical structure of MERRA-2 aerosol assimilated fields using CALIOP data over regions of particular interest during 2008.

Summary of GEOS-5 Reanalysis Activities

Name	Nominal Resolution	Period	Aerosol Data	Available
MERRA-1	50 km	1979-present	NONE	Now
MERRAero	50 km	2002-present	MODIS C5	Now
FP for Instrument Teams	50 km	1997-	MODIS C5	In progress
MERRA-2	50 km	1979-present	AVHRR, MODIS C5, MISR, AERONET	Now!!!
MERRA-2 Dynamical Downscaling	12.5 km	2000-2015	AVHRR, MODIS C5/C6, MISR, AERONET	Q1 2016

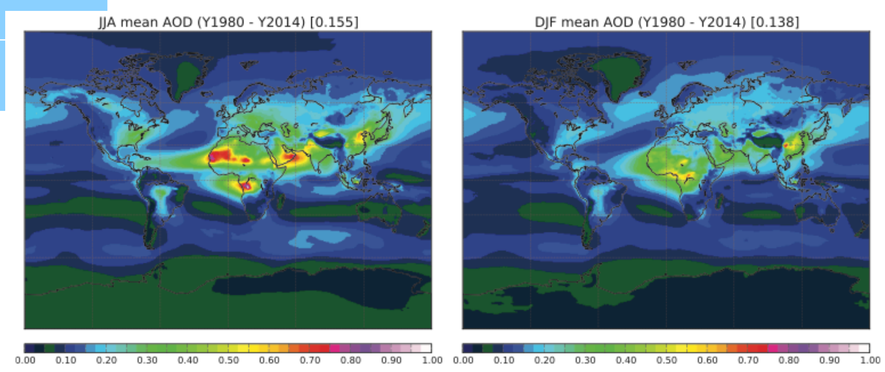
Aerosols in MERRA-2

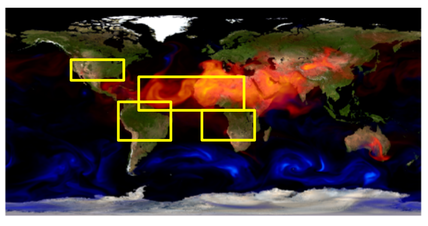
Feature	Description
Model	GEOS-5 Earth Modeling System (w/ GOCART) Interactive aerosols with AOD data assimilation Land sees obs. precipitation (like MERRA*Land*)
Aerosol Data Assimilation	Local Displacement Ensembles (LDE) Neural Net MODIS Aerosol Optical Depth Retrievals MISR AOD data over bright surfaces AERONET AVHRR Neural Net Retrieval
Period	1980-present
Resolution	Horizontal: nominally 50 km Vertical: 72 layers, top ~85 km
Aerosol Species	Dust, sea-salt, sulfates, organic & black carbon

In MERRA-2 ensembles are created using the Local Displacement Ensembles method (LDE)

- Construct perturbation ensembles by means of isotropic displacements around central grid box.
- Weigh each ensemble member by its fit to 2D AOD analysis.

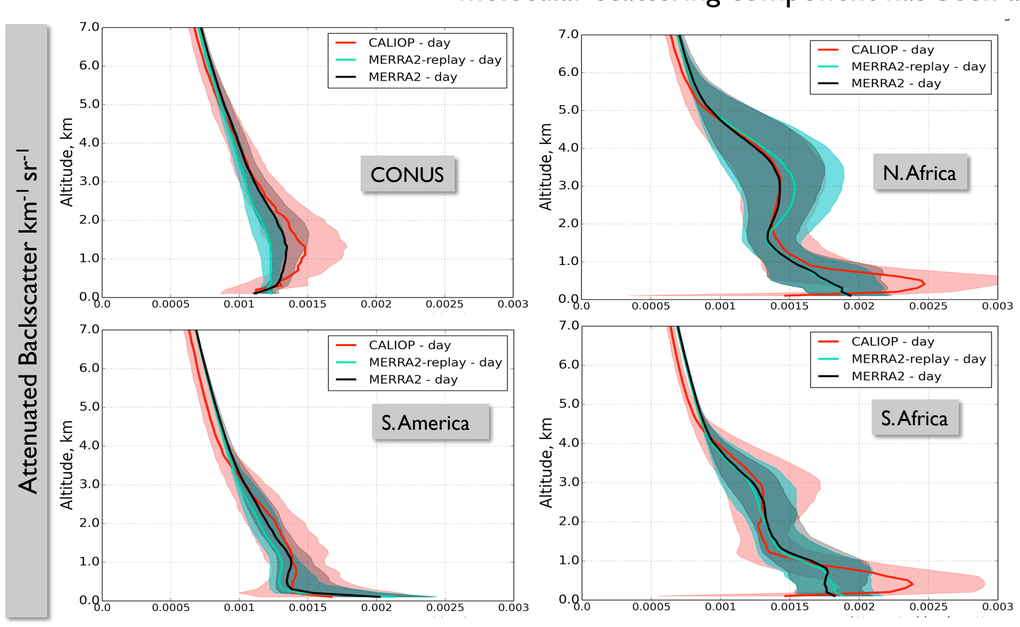
MERRA-2 550 nm AOD



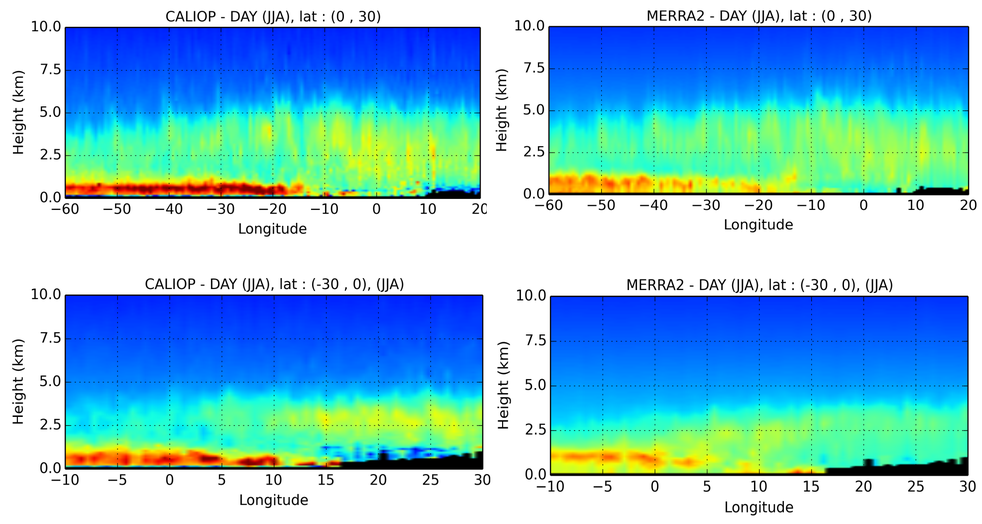


MERRA-2 vertical structure : comparisons with CALIOP

Below: JJA 2008 regional averages of CALIOP 532 nm total attenuated backscatter coefficients (aerosols + molecular) and the corresponding attenuated backscatter coefficients sampled from the model during day. For the sake of comparison, the molecular scattering component has been added to the MERRA-2 profiles.



Above: The solid red and black lines are the median for CALIOP and MERRA-2 during the day. Shaded areas represent between the 25% and 75% percentiles of all modeled and observed profiles. **Below** we show meridional cross sections in JJA comparing CALIOP and MERRA-2 attenuated backscatter over northern Africa (top) and southern Africa (bottom).



Aerosols Data assimilation in MERRA-2:

3D Aerosol Concentration Analysis:

$$x^a = x^f + P^f H^T (H P^f H^T + R)^{-1} (y^o - H x^f) \equiv x^f + \delta x^a$$

where y is AOD and x is aerosol concentration.

2D AOD analysis:

Since the AOD observable is 2D, it is common to solve the AOD analysis equation:

$$y^a \equiv H x^a = y^f + H P^f H^T (H P^f H^T + R)^{-1} (y^o - H x^f) \equiv y^f + \delta y^a$$

Projecting AOD into Concentration Increments:

The 3D concentration increments is related to the 2D AOD increments by:

$$\delta x^a = P^f H^T (H P^f H^T)^{-1} \delta y^a$$

If the background error covariance P^f is parameterized in terms of ensemble perturbations:

$$X = (x_1 x_2 ... x_E)$$

$$Y = HX = (H x_1 H x_2 .... H x_E) = (y_1 y_2 ... y_E)$$

so that

$$P^f \sim X X^T$$

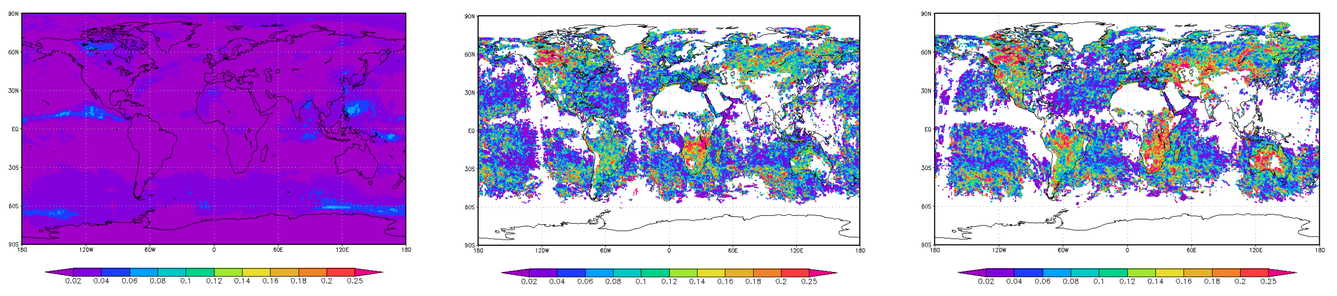
it follows that

$$\delta x^a = X Y^T (Y Y^T)^{-1} \delta y^a$$

Resolving the analysis equation using an EnKF scheme and meteorological ensembles generated by the GEOS-5 hybrid system: How much spread do we get?

The implementation of the EnKF in the GEOS-5 model is currently in progress. Initial tests are performed by first assimilating AOD from MODIS, MISR and AERONET, using GEOS-5 produced meteorological ensembles and by comparing the results with the current reanalysis from MERRA-2.

AOD at 550 nm: spread of the ensembles | AOD 550 nm (MODIS AQUA): Var(O-F) | AOD 550 nm (MODIS TERRA): Var(O-F)



→ **Above:** The ensembles do not have enough spread compared to the variance of O-F during a 2 week period of this study. The effectiveness of the ensemble data assimilation system is highly dependent on having sufficient spread in the ensemble members in order for the observations to impact the model forecast. We need to improve the spread in the ensembles in order to assimilate the attenuated backscatter coefficient or AOD. This can be accomplished by either perturbing the emissions or by combining with the LDE method described above.

Conclusion and future work

- The ensemble-based data assimilation system for aerosols is under development for use in GEOS-5. Currently tests are being performed by assimilationg AOD from MODIS, MISR and AERONET using the meteorological ensembles generated by the hybrid system which are compared with the current results from MERRA-2.
- Next we will be assimilating CALIOP attenuated backscatter observations in the data assimilation system.

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