

AEROSOL DATA ASSIMILATION USING GLOBAL CHEMISTRY AND AEROSOL FORECAST SYSTEM (GCAFS)/JEDI

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An Introduction to Aerosol Forecasting

A world map with a heatmap overlay showing aerosol concentrations. The map uses a color scale from light purple to dark blue to represent different levels of aerosol density. High concentrations are visible in the Indian Ocean region, particularly around India and Southeast Asia, and in the North Atlantic. The map also shows the outlines of continents and major ocean basins.

Aerosols - fine, solid or liquid particles in the atmosphere (e.g., dust, smoke, pollution, sea salt).

Impacts on forecasts:

- **Weather:** Modifying radiation balance, cloud formation, and precipitation patterns.
- **Air quality:** Affect PM_{2.5}/PM₁₀ concentration, health, and visibility.

Forecasting challenges:

- Accurate aerosol forecasts require realistic initial conditions (ICs).
- IC's can often be biased due to sparse in-situ observations and model limitations.

Goal and Objective

Goal:

Demonstrate the current aerosol data assimilation (DA) capabilities of **NOAA's GCAFS/JEDI** and establish a foundation for the next phase, i.e., develop a framework to extend the system toward **vertical profile-level assimilation** for improved aerosol representation in initial conditions and forecasts.

Objectives:

Phase I – Assimilation of VIIRS AOD:

- Assimilate **NOAA VIIRS aerosol optical depth (AOD)** observations to constrain aerosol fields in the model's initial conditions (ICs).
- Evaluate model performance post-assimilation using independent observations and **MODIS** to quantify improvements in forecast accuracy.

Phase II – Vertical Profile Comparison:

- Compare **model vertical profiles** with **CALIOP extinction coefficient profiles**.
- Analyze concentration differences and identify representative discrepancies between modeled and observed vertical structures.



Model Setup and DA

Method

Option	Model
CCPP	FV3-GFS-v17-coupled-p8
Land Surface	Unified Noah Land Surface Model
PBL	Saturated Eddy-diffusivity Mass-Flux scheme
Chemistry	GOCART
Fire emission	QFED
Microphysics	Thompson microphysics
Radiation	Rapid Radiative Transfer Model

Model - GCAFS - weakly coupled model

Assimilation framework - JEDI

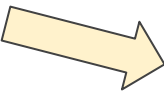
Domain/resolution - Global, C96 = 1 degree~100km

Forecast length - 6h/cycle for 16 days

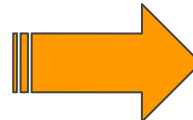
Control - UFS forecast with regridded MERRA-2 data into IC's

Assimilation method - **3DFGAT**

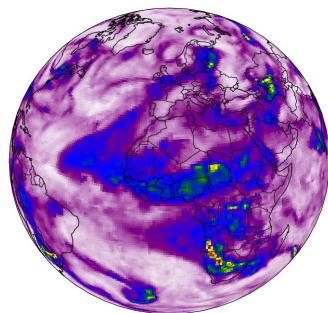
NOAA VIIRS obs



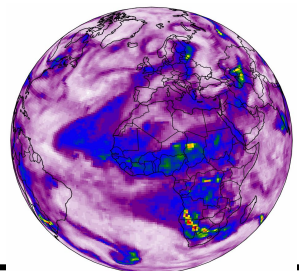
DA
3DFGAT



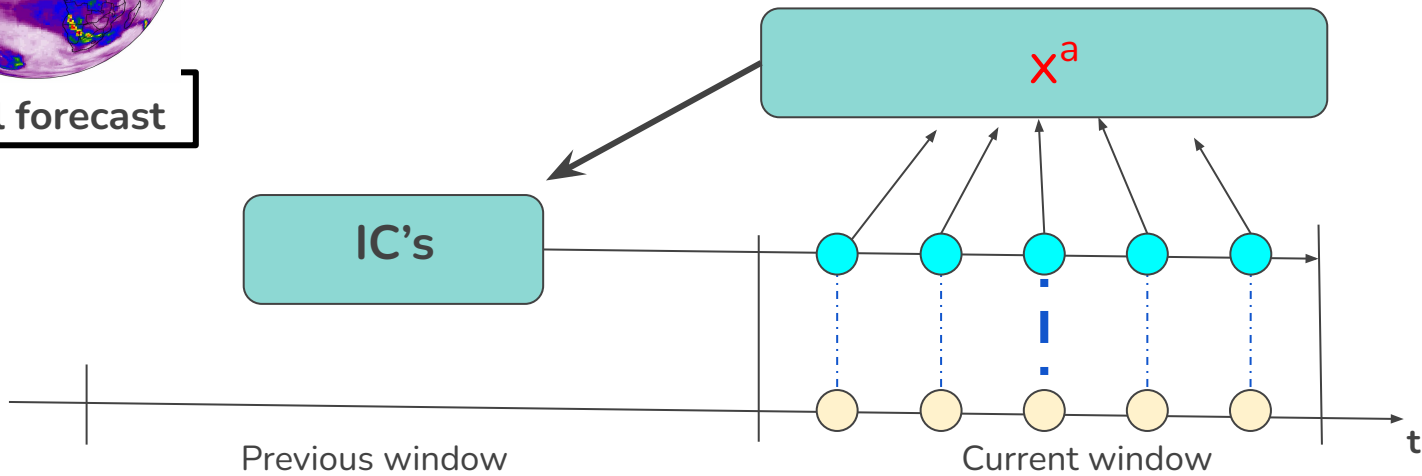
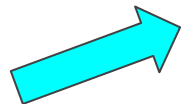
DA Method: 3DFGAT



Analysis (x^a)



model forecast



Phase I

ASSIMILATING NOAA VIIRS AEROSOL OPTICAL DEPTH (AOD) OBSERVATIONS

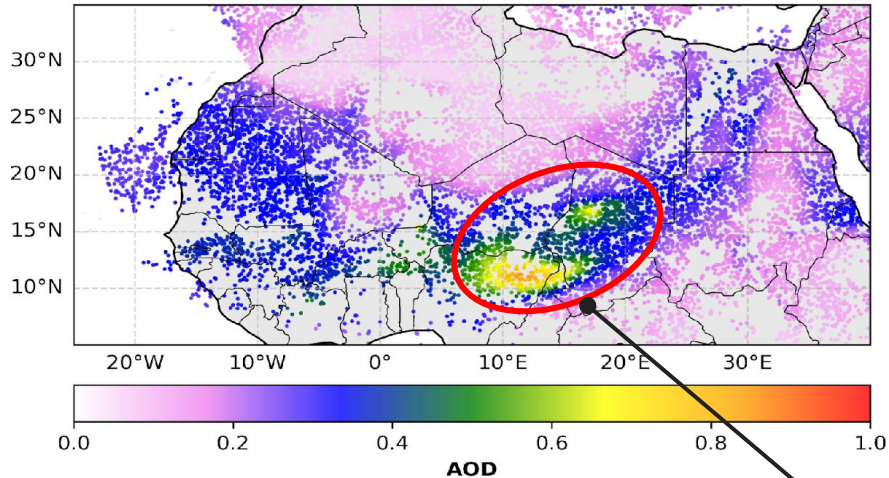
Experiment period - 2023.09.30.00z - 2023.10.16.00z

Results: Innovation (observations - background (H(x)))

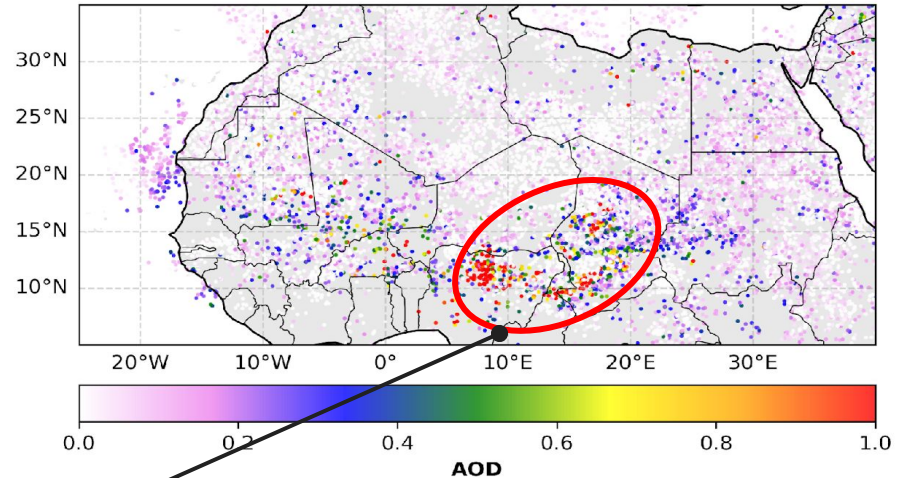
*Forecast time:
2023.10.08 12z

How far is our the background (in observation space) from our observations?

Background



Innovation (y - H(x))



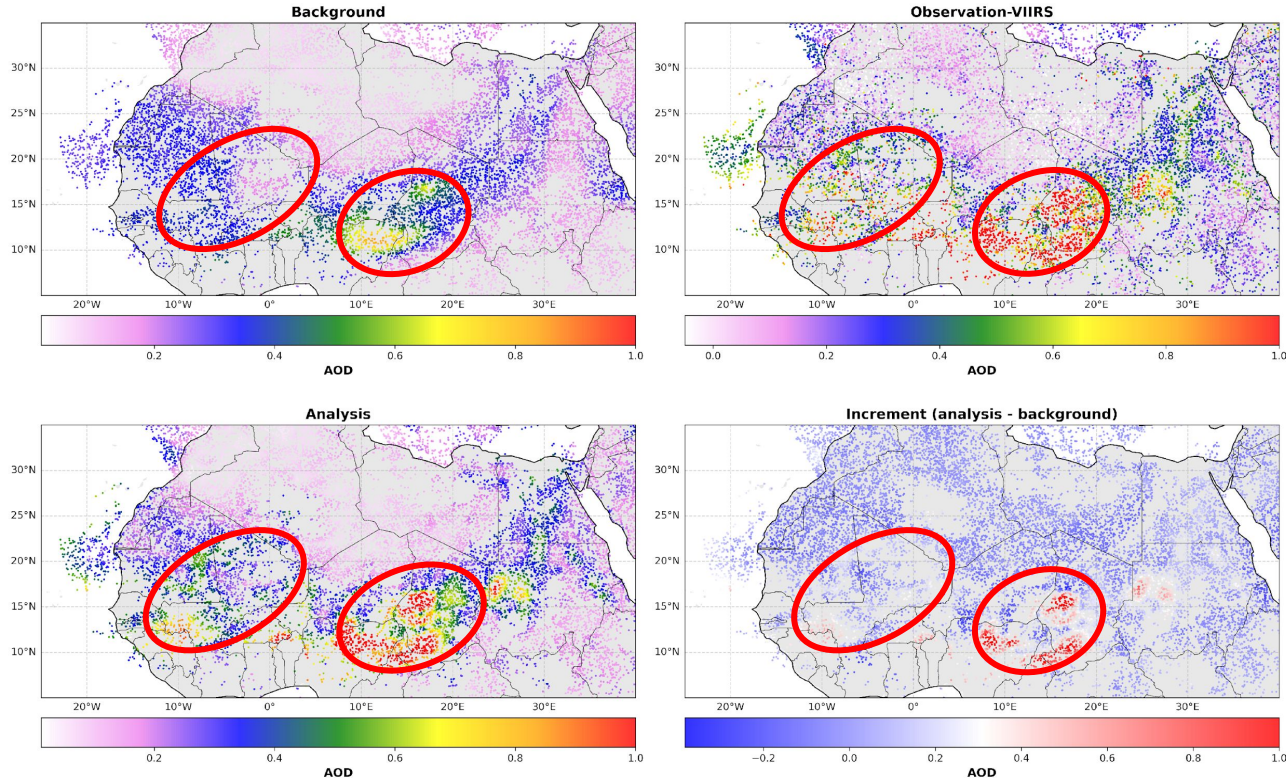
The highlighted region points to a noticeable difference in aerosol loading in the Sahel and sub-Saharan region. The model moderately underestimates aerosol on average over the North African region.

Results: Increment (analysis - background)

How much correction is done to our model state.

*Forecast time:
2023.10.08 12z

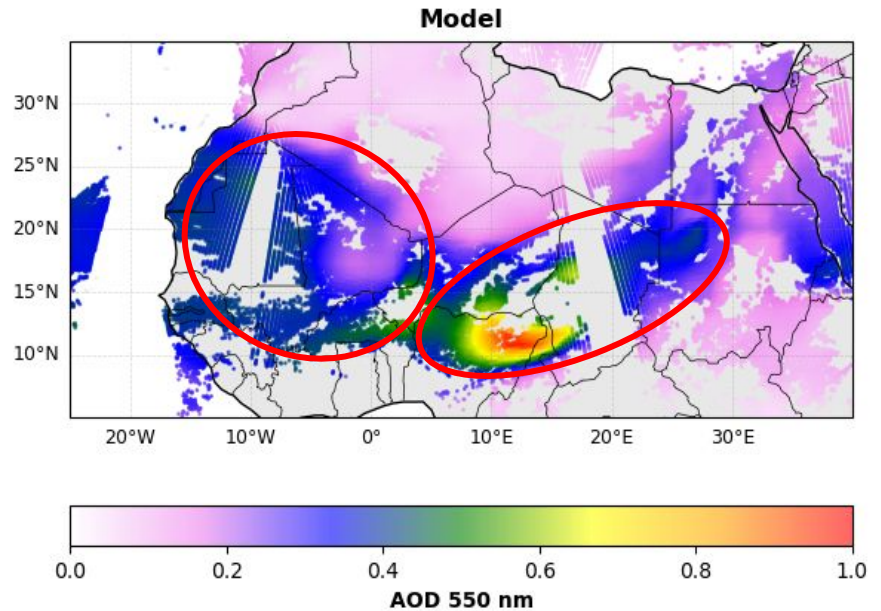
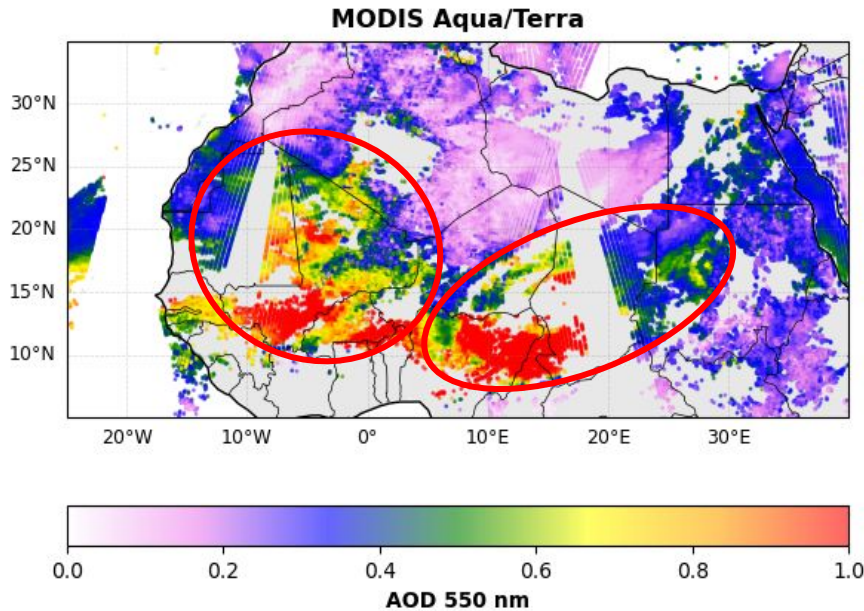
Comparison of AOD: Background, Observation, Analysis and Increment



- The DA method adjusts the background by constraining the analysis toward the observations, reducing overestimations and compensating for underestimations.
- In effect, biases are reduced in the background field, pulling the analysis closer to the observations in regions where values are over- or underestimated.

Results: Verification with MODIS (Terra/Aqua)

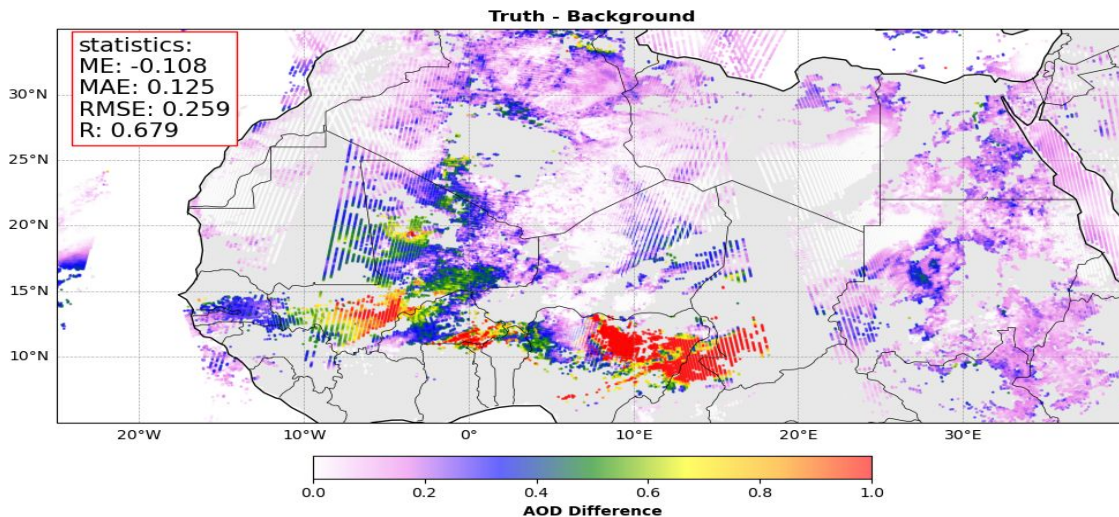
*Forecast time:
2023.10.08 12z -f12



- Verification shows model underestimate AOD in Area within the Sahara and Sahel/sub-Sahel region.
- On the average model predicts spatial patterns moderately.

Results: Verification with MODIS (Terra/Aqua)

*Forecast time:
2023.10.08 12z - f12



Remarks

- The analysis fields exhibit appropriate adjustments relative to the background (forecast), indicating that the assimilation system effectively applied increments derived by optimally combining information from the background and observations.
- The analysis shows that the DA system successfully reduced large misfits in AOD.

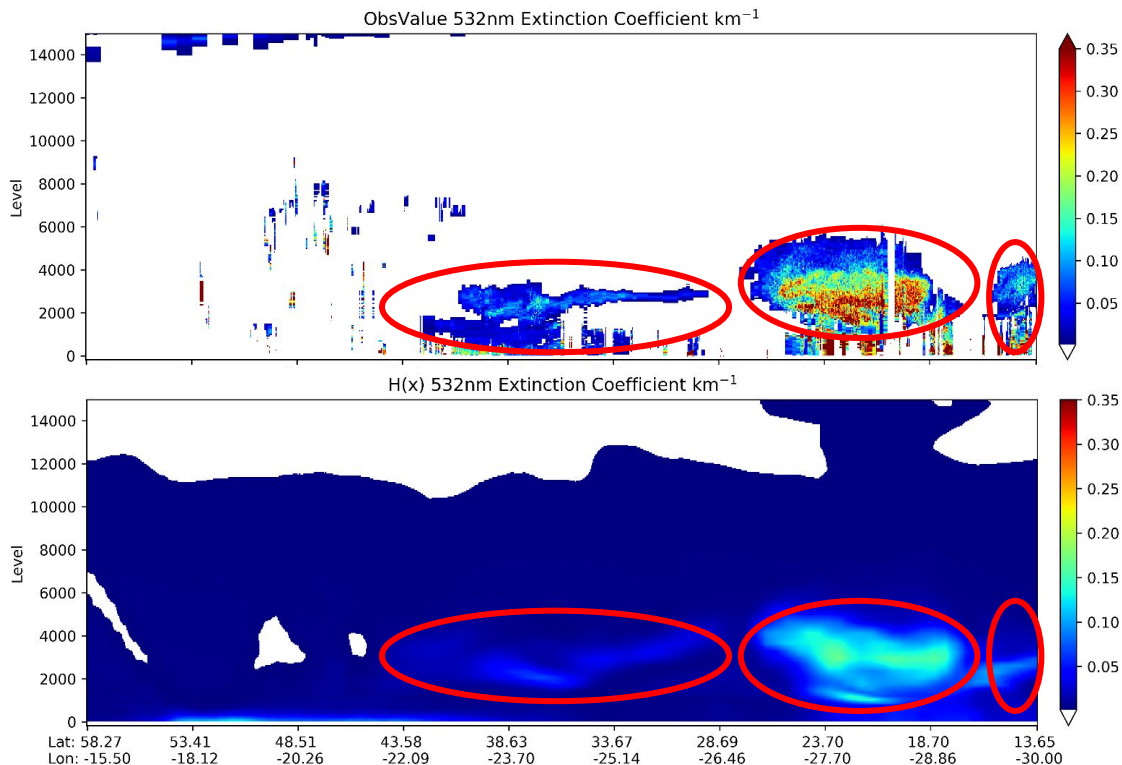
Metric	Interpretation
Bias	The model underestimates AOD on average.
Mean Absolute Error	Deviation of the model from the truth.
RMSE	Indicates the effect of large errors resulting in the deviation
Correlation (R)	Moderate-to-strong spatial agreement between model and truth.

Phase II

in preparation for next step ,

**COMPARE MERRA-2 WITH
CALIOP EXTINCTION VERTICAL PROFILES.**

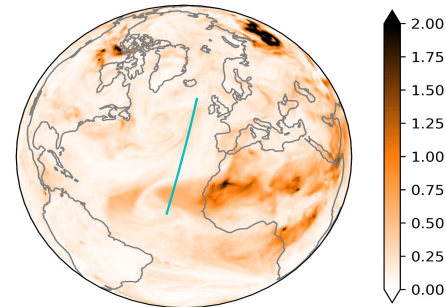
DEMO lidar operator: LiDAR H(x) of Extinction Coefficient from JEDI/UFO/CRTM with GOCART GEOS-5 LUT



*White area: ext < 0.001

MERRA-2 AODANA

time = 2019-07-22T06:00:00



- MERRA-2 shows reasonable distribution.
- Assimilation of extinction/backscatter profile may improve it.
- The operator for attenuated backscatter is under development.

LiDAR operator is still under development.



Summary:

- AOD is a measure of extinction of light over a whole atmospheric column, it carries a **limited** amount of information on the chemical composition and sizes of particles and also cannot provide information on the **vertical distribution** in the atmosphere.
- Consequently, the resulting analysis is largely determined by the **prior information** contained in the model state at a given time. This provides very **limited** ability for AOD DA to **correct aerosol speciation, size, and vertical distributions** in the atmosphere.

Next Steps:

- Conduct high resolution experiment restricted to the temporal window of valid CALIOP dataset June (2006-2023).
- Compare model state with CALIOP extinction profiles.
- Develop the CALIOP Lidar Forward Operator.
- Working on the capability to assimilate CALIOP profiles in JEDI.

Acknowledgments

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