AOD Assimilation Using JEDI at NOAA/ESRL/GSD and EMC: Early Results and Prospects

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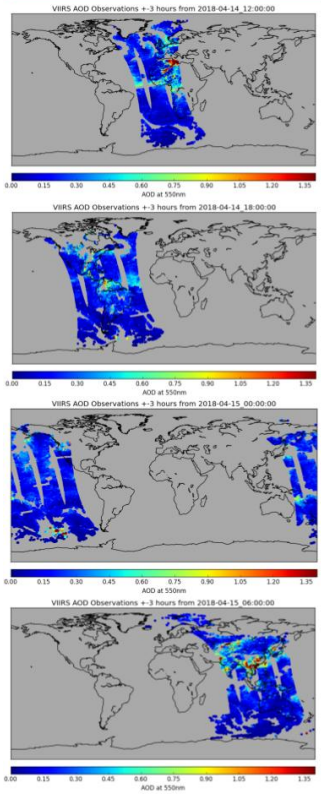
Introduction

Aerosols are tiny particles (measured in microns) suspended in the atmosphere that have a direct and indirect impact on Earth's radiation budget. Depending on their size, shape, and color, they can scatter incoming sunlight back to space, or absorb some of the energy, leading to warming. Additionally, many act as cloud condensation nuclei, and their influence on the size and type of cloud droplets can lead to changes in how clouds absorb and reflect radiation.

In addition to these radiative forcings, numerous aerosols also can influence air quality as well as affect atmospheric chemistry, including the destruction of stratospheric ozone. While many operational Numerical Weather Prediction centers including the US Navy and the European Centre for Medium-Range Weather Forecasts (ECMWF) produce a global aerosol analysis product operationally, no such product exists currently from NOAA. The NEMS GFS Aerosol Component (NGAC) model, operational since 2012, currently provides global deterministic forecasts of aerosol concentrations and derived products including aerosol optical depth (AOD), but the forecasts are not constrained by observations.

Thus there is a need to develop the capability for operational global aerosol analyses at ESRL and NCEP.

Observations Assimilated



Left: Spatial plots of the thinned AOD at 550 nm observations from VIIRS on Suomi-NPP used for the analysis centered on (from top to bottom):

- 2018-04-14 12z
- 2018-04-14 18z
- 2018-04-15 00z
- 2018-04-15 06z

Note that because AOD retrievals can only occur during daytime hours, each six-hour analysis window can only have a maximum spatial coverage of around 25% of the globe

Observations from the NOAA NESDIS JPSS Visible Infrared Imaging Radiometer Suite (VIIRS) Level 2 AOD at 550 nm product from the Suomi-NPP satellite are used for assimilation. The data are quality controlled to only use high quality retrievals, and any negative AOD values are also thrown out. Additionally, the data are thinned spatially from their native 750m resolution to approximately 0.5° resolution, to save on disk space and processing computation time as even at this resolution the observations are much denser than the model resolution. Observations occurring within 3 hours of the analysis time are then aggregated into one input file for assimilation.

Observation Operator

An observation operator has been added to the JEDI Unified Forward Operator (UFO) to support the assimilation of AOD observations using simulated AOD at 550 nm computed using the Community Radiative Transfer Model (CRTM). Aerosol mass concentrations as well as meteorological variables (temperature, specific humidity) are passed from the model state to CRTM to produce AOD at each model layer and integrated to compare to the VIIRS AOD observation to compute innovations.

Model Description

- **FV3GFS-GSDChem**
  - FV3GFS model coupled with the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model
  - Essentially the FV3GFS model but with the inclusion of 20 additional tracers to to provide online transport of:
    - 5 dust tracers binned by size
    - 5 sea salt tracers binned by size
    - Hydrophobic and hydrophilic organic and black carbon
    - 4 sulfur tracers including sulfate aerosols
    - PM2.5 and PM10
- Emissions
  - Wildfire burning emissions from Fire Radiative Power (FRP) data combined with a plume rise model
  - Anthropogenic emissions are from the Community Emissions Data System (CEDS) and the Hemispheric Transport of Air Pollution (HTAP) v2.
  - Dust and sea salt emissions are based off of model simulated near-surface winds

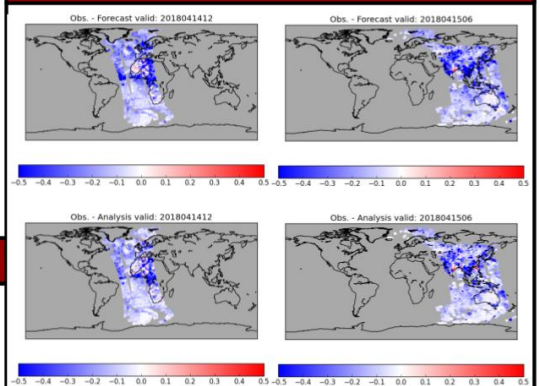
Meteorological variables are not assimilated in this experiment but increments from regridded GDAS analysis are added for each cycle.

Experiment Setup

Proof-of-Concept Initial Test using JEDI-3DEnsVar

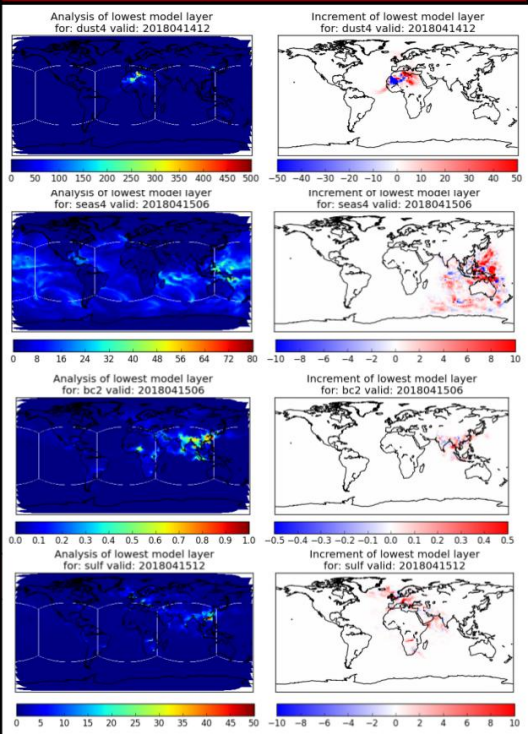
- 3DEnsVar - background error is derived from an ensemble forecast rather than a precomputed background error
  - Includes information about the current state of the atmosphere and not just a climatology
  - 10 Ensemble members used
  - Actual analysis is performed on the ensemble mean
- Both FV3GFS-GSDChem and JEDI analysis performed at C48 resolution (approximately 2 degree x 2 degree) with 64 vertical levels
- First, the ten ensemble members are spun up with 24-hour forecasts cycling from 2018-04-06 00z until 2018-04-14 00z. Then a 9-hour forecast with a restart file produced at hour 6 is ran starting at 2018-04-14 00z.
- To test capabilities of JEDI for use in AOD assimilation, 9-hour forecasts, cycled every 6 hours, are then generated initialized starting at 2018-04-14 06z through 2018-04-15 18z
- The aerosol analysis is performed every 6 hours on the ensemble mean (using the 6 hour ensemble forecast to compute background error) but the increments are not yet passed back to the model ensemble members (as the EnKF capability is not currently working).
  - Thus, while we can show increments and plot O-F and O-A, since the analysis is unable to update the model prognostic fields, there is no change to the subsequent aerosol forecasts at this time

AOD O-F and O-A



Above: Spatial plots of the VIIRS AOD observations minus CRTM simulated AOD from the forecasted aerosol mass concentrations (top panels) and the VIIRS AOD observations minus CRTM simulated AOD from the aerosol mass concentrations in the analysis (bottom panels) for 2018-04-14 12z (left) and 2018-04-15 06z (right)

Aerosol Species Increments



Examples of analyses (left) and increments (right) for the lowest model layer for different aerosol species (top: dust in size bin 4; sea salt in size bin 4; hydrophilic black carbon; and sulfate) for different analysis cycles. (units:μg/kg)

Ongoing and Future Work

- "True" cycling cannot be realized for ensemble as EnKF in JEDI not currently available; work is on-going to implement operational EnKF code for the native FV3 grid.
- Current 3D-EnsVar assimilation entirely based on ensemble covariance as static component is not available yet. Once it is accomplished this work can be easily extended to 4D-EnsVar.
- CRTM lacks flexibility to account for five sea-salt bins (currently four bins present); work is on-going to improve parameterization of hygroscopic growth of particles and parameterization of their radiative properties and to allow greater flexibility of the code.
- Development of a robust workflow using rocoto to facilitate ensemble forecasts as well as JEDI analyses
- A strategy to prescribe perturbations to emission sources for individual members is being devised for effective ensemble-based assimilation.
- A methodology is being developed to address non-Gaussian distributions of errors.
- A methodology is sought to sample/thin high density observations for efficient assimilation.
  - The solution presented in this poster was a simple preprocessing step to thin to a fixed grid
- Capability of dual-resolution 3D-EnsVar in JEDI would be of great benefit for ensemble-based DA.
- Because of non-linearities in chemical parameterizations it is uncertain when adjoint of GOCART will be available to allow for 4D-Var; collaboration is sought to investigate this opportunity.
- Assimilation of satellite radiances in place of L2 products is being considered and explored.

- Some concurrent work is occurring at EMC to extend existing regional AOD assimilation capabilities in GSI to work for global domains for potential use in production before JEDI is ready for operational use
- Options are being explored to use fewer control variables (instead of 14+ tracers) in the analysis for an aerosol data assimilation system to fit into operational constraints at NCEP.
  - Other possibilities include running a separate aerosol analysis from the meteorological analysis and combining the increments before each forecast