Assimilation of Satellite Derived Aerosol Products to Improve PM2.5 Predictions

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1. Introduction

PM2.5 (particulate matter less than 2.5 μm in median aerodynamic diameter) concentration is one of the key indicators of air quality. High concentration of PM2.5 can cause serious human health problems (e.g., premature death, respiratory and cardiovascular diseases) and reduce visibility. NASA's Multi-Access Satellite Aerosol (MIDA) project focuses on developing systems and data products that provide hourly PM2.5 predictions with uncertainties due to uncertainties in meteorological conditions and emissions. Validation studies show that satellite derived column aerosol optical depth (AOD) and aerosol concentration (PM2.5) are well correlated. Thus, we propose an analysis-forecast cycling scheme to assimilate satellite derived aerosol products into the industrial haze episode and the wild fire episode that occurred in the summer of 2006. We used MODIS (Moderate Resolution Imaging Spectroradiometer) and AERONET (Aerosol Robotic Network) instruments onboard Terra/Aqua satellites to assimilate surface AOD and MODIS from MODIS instruments on Terra/Aqua satellites to assimilate column AOD. Each run of experiments consisted of four or five AOD analyses and daily simulations starting at 12Z. The initial conditions for the "BASE" experiments valid at 12Z August 1 for industrial haze episode and at 12Z September 3 for the wild fire episode were constructed from the output concentrations of the previous model simulations, which were "cold" started with static initial conditions two days earlier. The initial conditions for the data assimilation experiments were generated with the Analysis-Pre-DA Cycling scheme.

2. The CMAQ Model System

The CMAQ model system was originally developed at EPA and adopted by NMS2000 as the regional or puzzled forecasting system (AGPS). The major inputs include emissions from the EPA National Emissions Inventory (NEI) and meteorological and surface characteristics from the WRF/ARPS Nonhydrostatic Mesoscale Model (WRF/ARPS). The aerosol version of the AGPS covers CONUS with 442x265 mesh grid at 12 km resolution. There are 22 precipitation layers vertically. The CMAQ AODs with AERONET AODs and CMAQ surface PM2.5 with AIRNow observations overlaid as small circles. The left panel was from the base run and the right panel was from the hourly GOES AOD assimilation experiment. The intensity over the east coast region got greatly reduced through the GOES AOD assimilation. Improvement in other regions can also be observed.

3. Analysis-Forecast Cycling Scheme

Instead of taking model output concentration for the initial condition, we propose to use the model output AOD as the first guess and satellite NO2 as input observations to generate AOD analysis, with which the difference between model output AOD and the analysis AOD is the initial condition. For each day, a DA run was started at 12Z for 48 hours, and the data assimilation window covers up to the first 12 hours, depending on the assimilation frequency. The data assimilation window covers up to the first 12 hours, depending on the assimilation frequency. The proposed option is called "Analysis-Forecast Cycling" scheme and displayed as thick solid arrow, the initial condition is taken as static initial conditions two days earlier. The initial condition for the "BASE" experiment show little responses to the wild fire event. This is mostly because the corresponding bio-mass burning event is not included in the model. With GOES assimilation runs, better correlations for both AOD and PM2.5 are obtained. Under-predicted AOD and over-predicted PM2.5 indicate that the current DA scheme does not assimilate aerosol near the surface and too little above in this case.

4. Simulation experiments and Results

An industrial haze episode along the east coast during the early August 2006 and a wild fire episode in the northwestern region during the early August 2006 were selected to test the proposed Analysis-Forecast Cycling scheme. The AOD retrievals derived from GOES-12 satellite and from MODIS instruments on board Terra/Aqua satellites were assimilated. Each run of experiments consisted of four or five AOD analyses and daily simulations starting at 12Z. The initial conditions for the "BASE" experiments valid at 12Z August 1 for industrial haze episode and at 12Z September 3 for the wild fire episode were constructed from the output concentrations of the previous model simulations, which were "cold" started with static initial conditions two days earlier. The initial conditions for the data assimilation experiments were generated with the Analysis-Pre-DA Cycling scheme.

5. Conclusions

GOES AOD retrievals

4 km X 4 km horizontal resolution over CONUS
Every 30 minute during daytime
MODIS AOD retrievals

More accurate AOD retrievals from advanced instruments
Limited spatial coverage (orbit) and temporal resolution (once a day)

We matched-up model output AOD with AERONET AOD. With GOES AOD assimilated (left), the correlation is slightly decreased from 0.66 to 0.51. The slope is improved from 0.34 to 0.57. With MODIS AOD assimilated (right), the correlation increases to 0.59 and the slope is improved to 0.40, as much as by the GOES DA assimilation experiments. Under-predicted AOD and over-predicted PM2.5 indicate that the current DA scheme does not assimilate aerosol near the surface and too little above in this case.

For the wild fire episode, the BASE run did not simulate the aerosol vertical structure well due to the lack of biomass burning emissions. As a result, the DA-GOES run failed to vertically redistribute aerosol loading very well, holding most of aerosol loading near the surface and too little above.

Above are the scatter plots of the match-ups of model output vs. AERONET AOD (left) and AIRNow PM2.5 concentrations (right). The results from the BASE experiment show little responses to the wild fire event. This is mostly because the corresponding bio-mass burning event is not included in the model. With GOES assimilation runs, better correlations for both AOD and PM2.5 are obtained. Under-predicted AOD and over-predicted PM2.5 indicate that the current DA scheme does not assimilate aerosol near the surface and too little above in this case.

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