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Modeling biomass burnings by coupling a sub-grid scale plume model with Adaptive Grid CMAQ

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1. INTRODUCTION

Biomass burning plumes are not well resolved in current modeling systems due to insufficient grid resolution and/or inadequate sub-grid treatments. The assumption of complete mixing and absence of fine-scale phenomena may lead to artificial dilution and inaccurate results. Features of air pollution transport at sub-grid scales are not well resolved in Eularian grid models. To address these issues in CMAQ, we developed a comprehensive modeling system that enhances the ability to predict air quality impacts from biomass burnings. The adaptive grid method that increases grid resolution has been demonstrated to accurately track the biomass burning plumes at the regional grid scales (*Garcia–Menendez et al. 2010).* In the original version of AG-CMAQ all prescribed burning emissions have been input into a column where the center of the fire is located. More precise emissions inputs to the air quality model such as the spatial spread and vertical profile at the sub-grid scale are also required for more accurate solutions.

Daysmoke is a Lagrangian plume model, used to predict short range dispersion of prescribed burning plumes. It is designed to simulate smoke rise and distribution in a veering/shearing wind field with variable stability *(Liu et al 2010)*. The model can avoid artificial dilution and will model $PM_{2.5}$ transport at sub-grid scales for CMAQ but requires large number of data points to be computed for a very small area in CMAQ model domain.

Our new modeling system consists of the Adaptive Grids CMAQ (AG-CMAQ) coupled with Daysmoke as the sub-grid scale plume model. The coupled system is called Adaptive Grid Daysmoke CMAQ (AGD-CMAQ), and the purpose of this model is to be able to obtain more accurate characterization of plume concentrations in a grid model. The resultant model is tested by simulating a real air pollution episode and its performance is compared to that of fixed grid CMAQ and original AG-CMAQ.

2. MODELING SYSTEM DESCRIPTION

Daysmoke is responsible for tracking the trajectories of emitted smoke parcels during each CMAQ time step. At the end of the time step, there is a process called "handover" which will check for certain conditions and determine the interface where Daysmoke shares its information with CMAQ. Handover consists of 5 major parts. First, it will convert smoke emissions that Daysmoke keeps track in units of mass to concentration by dividing the smoke plume boundaries into a 100 by 100 grid for each adaptive grid layer. Secondly, the smoke emissions are also converted into concentrations using the adaptive grid from AG-CMAQ which has already been adapted according to a fire tracer. The concentrations calculated in these two different grids are then compared by adding up the differences of the concentrations for every one hundredth of the total downwind distance of the plume, about 10 to 15 meters. The interface where Daysmoke emissions are transferred into AG-CMAQ is named "the wall", and the wall must satisfy two boundary conditions. First, the wall must be set after the plume is fully developed, and it can not be farther than 16 km from the fire. Second, the wall must be set at a certain distance from the fire where the concentration difference is minimum. This way the outputs from the sub grid model are carried over to the air quality model with least possible compromise in vertical and spatial resolution.

Any emission parcel beyond the wall is inserted into the appropriate grid cell of AG-CMAQ at appropriate times. All other particles remain in Daysmoke and their trajectories are recalculated until those parcels travel beyond the wall. This process will continue until all of the parcels emitted from the fire have been inserted into grid cells and converted into grid concentrations in AG-CMAQ.

3. CASE STUDY

In the southeastern U.S., prescribed burns are used as a wildfire prevention and habitat restoration strategy. In the morning of Feb. 28 2007, there were two planned forest fires 80 km upwind from Atlanta. It was not till late afternoon the same day that the air quality in the Atlanta metropolitan area was impacted by the heavy smoke from the two prescribed burns. Fine particulate matter levels at monitoring sites throughout the area increased to nearly 150 $\mu g/m^3$ (*Hu, et al., 2008).*

The two prescribed fires that affected air quality in Atlanta were at Oconee National Forrest and Piedmont National Wildlife Refuge. With both sites combined, about 3,000 acres were burned for as long as 5 hours. The smoke from the burns was completely gone when it started raining at noon the next day. The emissions from the two burns are estimated using FEPS. The same meteorology used in CMAQ is also applied to Daysmoke. Feb. 28 Atlanta smoke episode has already been simulated with a 4 km fixed grid photochemical model and is discussed in *Hu, et al., 2008*. The first approach of combining Daysmoke with AG-CMAQ, where the output emissions from Daysmoke were injected into a AG-CMAQ column, is discussed in *Garcia–Menendez et al. 2010.* In this study, the event was simulated with AGD-CMAQ, which consists of CMAQ version 4.5 combined with Daysmoke using the "handover" described above.

3.1 *AGD-CMAQ* Simulation and Results

The Feb. 28, 2007 Atlanta smoke incident is simulated using three different CMAQ versions mentioned before and the results are compared. Model inputs and setup are kept the same as those used for the fixed-grid simulation covering Northeastern Georgia as described in *Hu el al., 2008*. Grid refinement in AG-CMAQ and AGD-CMAQ is driven by fire related $PM_{2.5}$ concentrations. The simulation starts at 21Z on Feb. 27 and finishes at 05Z on Mar. 1 using an output time step of 30min. The first burn started at 15Z on Feb. 28, which is also when grids start to adapt, consistent with the initial emissions release from the fires. The concentration peaks from the fires were observed at 6 monitoring sites in/around Atlanta and the sites are numbered from the station closest to the fire in the graphs below.

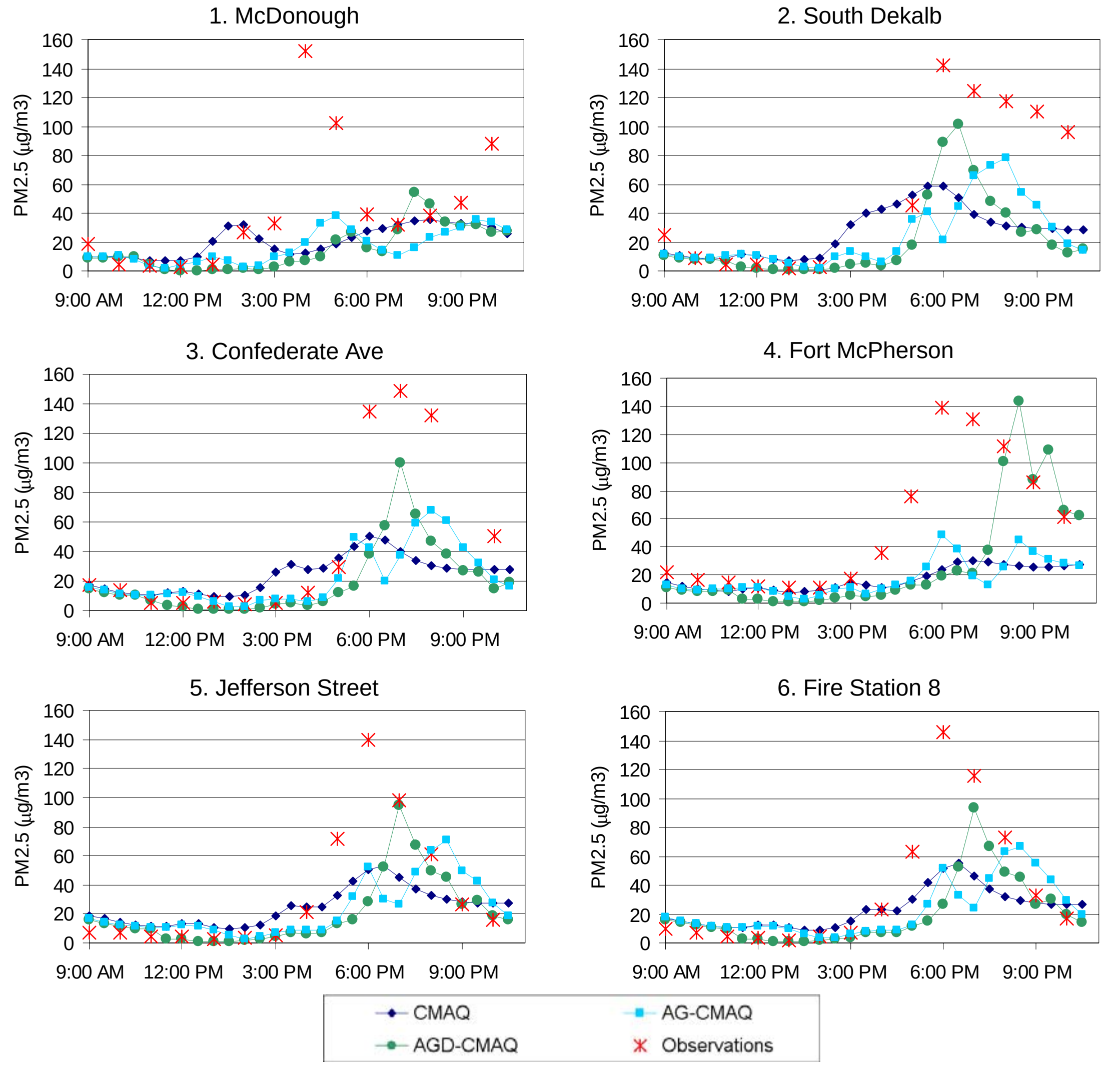

Figure 1. Measured (red) and modeled $PM_{2.5}$ concentrations using standard CMAQ (dark blue), AG-CMAQ (light blue), and AGD-CMAQ (green) at the Mc Donough, South DeKalb, Confederate Avenue, Fort McPherson, Jefferson Street and Fire Station 8 air quality monitoring sites in the Atlanta metropolitan area.

Figure 1 compares the performances of standard CMAQ, AG-CMAQ and AGD-CMAQ to the hourly measured concentrations at sites near Atlanta that experienced a significant increase in $PM_{2.5}$ concentration from 9am to 10:30pm EST. Significant differences can be observed in all three simulations. The artificial dilution effect in uniform grid is thought to be the reason why the standard CMAQ concentrations consistently under-predict peak $PM_{2.5}$ concentrations and concentrations generally start to increase sooner than the other two models with adaptive grids. AG-CMAQ reduces the initial over prediction of $PM_{2.5}$ concentrations and predicts higher concentration peaks compared to standard CMAQ results. The double concentration peak behavior is observed with a fixed grid as well but more significantly in AG-CMAQ. The two peaks appear in AG-CMAQ because the two smoke plumes from the two burn sites remain separated and reach out to Atlanta consecutively. On the other hand, the double concentration peaks are no longer apparent in AGD-CMAQ. AGD-CMAQ tends to predict higher concentration peaks, and seems to predict the closest to the observations for most of the monitoring sites. To compare the performances quantitatively, the mean normalized errors were calculated and they are shown in Figure 2.

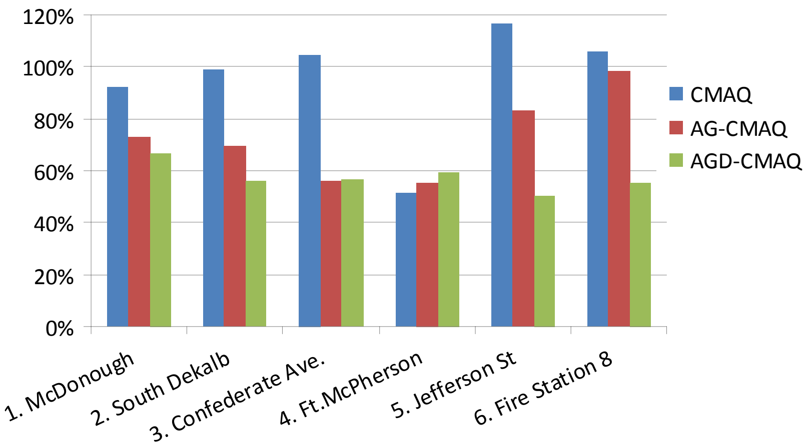

Figure 2. Mean normalized error for modeled $PM_{2.5}$ concentrations using standard CMAQ (blue), AG-CMAQ (red), AGD-CMAQ (green) at the Mc Donough, South DeKalb, Confederate Avenue, Fort McPherson, Jefferson Street and Fire Station 8 sites in Atlanta metropolitan area.

The mean normalized error is calculated for the duration of the fires using the following equation, where for every hour *i* up to N, $C_{observed}$ is the measured $PM_{2.5}$ concentration and C_{model} is the predicted $PM_{2.5}$ concentration.

$$\text{mean normalized error} = \frac{1}{N}\sum_{i}^{N}\left(\frac{|C_{observed} - C_{model}|}{C_{observed}}\right)_i$$

On average, AGD-CMAQ performs the best followed by AG-CMAQ then standard CMAQ. 5 out of 6 times AGD-CMAQ has much lower error than standard CMAQ has, except for Fort McPherson. Going back to the concentration plot for Fort McPherson in Figure 1, AGD-CMAQ was the only model that captured the $PM_{2.5}$ concentration peak well, but it over predicted the concentrations at times. AG-CMAQ performs better than AGD-CMAQ does for Confederate Ave. site as well but only by 0.83%. Decrease in artificial dilution is achieved through adaptive grid refinement. On top of that, deciding when and where to carry the information from the sub grid model to the air quality model improves the plume impact predictions. We believe that the simulation with AGD-CMAQ better describes local dispersion of fire emissions and their regional air quality impacts.

4. CONCLUSION AND FUTURE WORK

Plumes from particular sources such as power plants, wild land fires, and urban and industrial centers can be simulated more accurately using both finer grid resolution and sub-grid scale models. The combination of the two can provide more detailed simulations of the plume evolution without too much artificial dilution. Here, an adaptive grid version of CMAQ has been coupled with a sub-grid model for biomass burn plumes, Daysmoke, to create AGD-CMAQ. In AGD-CMAQ, smoke emissions are first tracked by Daysmoke as parcels then inserted into the grid cells of AG-CMAQ at appropriate times and places using a procedure called ”handover”. AGD-CMAQ’s benefits have been verified in an application to the Feb. 28, 2007 Atlanta smoke incident.

In the future, the model evaluation will continue for other burn cases, especially for a series of prescribed burns at Fort Benning, GA. We are also in the process of having the grid system adapt to minimize the error during the handover process. A Fourier analysis technique will be used to determine the right moment to hand over the plume from the sub-grid scale plume model to the air quality model.

5. REFERENCES

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