INVESTIGATING THE USE OF A HIGH RESOLUTION WRF-URBAN CANOPY MODEL SIMULATION WITH CMAQ

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1. INTRODUCTION

Results from a nested Weather Research and Forecasting model coupled with an urban canopy model (WRF-UCM) and a CMAQ simulation covering an air pollution event on 9 July 2007 are presented. WRF-UCM and CMAQ were run with four nested domains at 13.5, 4.5, 1.5, and 0.5km horizontal resolution from 12UTC 7 to 12UTC 10 July 2007. This period is notable because of a July 9 air quality episode during which 8-hour maximum ozone concentrations reached 125 ppbv in northeastern Maryland. Output from CMAQ is compared with ozone observations from the AIRNOW network. An objective of this study is to investigate the influence of grid resolution on the model simulations and the interaction of the air quality with the urban heat island, the Chesapeake Bay breeze, and cloud processes.

2. METHOD

The NCEP Final Reanalysis was used for initial and boundary conditions to run WRF Version 2.2.1 coupled with an urban canopy model within the Noah Land Surface model (WRF-UCM). Emissions were created with the Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System from 2009 projected emission from US Regional Planning Offices and 2007 Continuous Emissions Monitoring data from the EPA. CMAQ Version 4.6 was run with chemical initial and boundary conditions from a 36km horizontal resolution WRF-chem simulation that was initialized on 6 July 2007. Chemical initial and boundary conditions for the WRF-chem simulation

came from MOZART. WRF-UCM and CMAQ configuration options are shown in Table 1.

Table 1. WRF-UCM and CMAQ configuration options.

Atmospheric Processes	WRF-UCM
Radiation	LW: RRTM SW: Goddard
Surface Layer	Monin-Obukhov
Land Surface Model	Noah
Boundary Layer	MYJ
Cumulus	Grell-Devinyi ensemble (13.5km and 4.5km only)
Microphysics	WSM-3
	CMAQ
Mechanism	cb05_ae4_aq
General coordinate driver	Air density based for mass-conserving advection
Advection	Piecewise Parabolic Method
Vertical diffusion	Eddy diffusivity theory
CMAQ cloud module	RADM

3. ANALYSIS

3.1 Meteorology

The 13.5km WRF-UCM smoothes small scale features that are captured in the 0.5km domain, such as the PBL height shown in Figure 1. A definitive land-water boundary is shown in the 0.5km domain while the 13.5km domain's land-water boundary is smoothed. Coarser resolution model simulations are unable to capture large abrupt changes in surface characteristics, such as land-water or frontal boundaries. The impact of

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this smoothing is most noticeable in the 13.5km domain; its bay breeze starts later and is weaker than in the 0.5km domain. Figure 2 shows that the bay breeze is reasonably well captured in the 4.5, 1.5, and 0.5km domains at 17UTC 9 July 2007, but is not seen yet in the 13.5km domain.
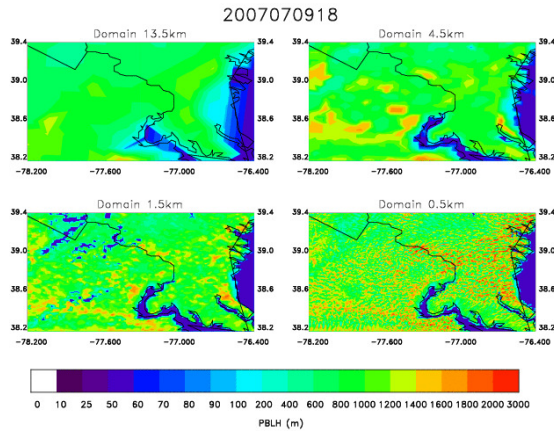

Fig. 1. WRF-UCM PBL height at 18UTC 9 July 2007. The letters D and B in the 13.5km figure mark the location of Washington, DC and Baltimore, MD respectively.
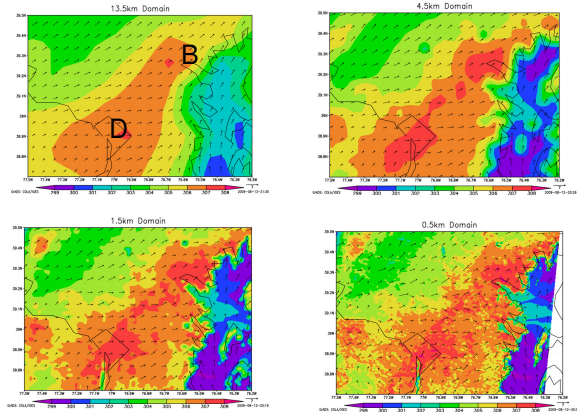

Fig. 2. WRF-UCM 2-m temperature and 10-m wind speed at 17UTC 9 July 2007. The letters D and B in the 13.5km figure mark the location of Washington, DC and Baltimore, MD respectively.

3.1 Emissions

High resolution emissions that were created with SMOKE makes it possible to pick out major highways by viewing model output NO_x concentrations. Figure 3 shows NO_x concentrations for 18UTC 9 July 2007.
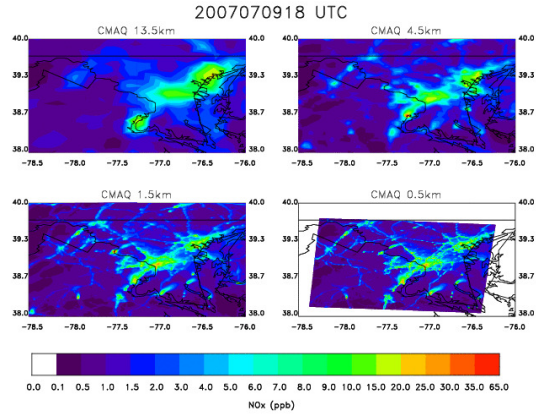

Fig. 3. CMAQ NO_x concentrations near the surface at 18UTC 9 July 2007.

3.1 Ozone

Figure 4 shows 8-h maximum ozone concentrations from AIRNOW observations, a 12km WRF-chem simulation, and the 13.5, 4.5, 1.5, and 0.5km CMAQ simulations. The 12km WRF-chem simulation and the 13.5km CMAQ simulations have higher ozone concentrations near the surface over the Chesapeake Bay. Since the 13.5km simulated bay breeze is weaker and starts later than in the fine resolution domains, this allows more pollutants to flow near the surface over the bay Since the 13.5km simulated bay breeze is weaker and starts later than in the fine resolution domains, this allows more pollutants to flow near the surface over the bay where there is a low PBL height. Higher resolution model runs simulated a stronger bay breeze causing pollutants to be transported upward and more ozone to be produced aloft. Figure 5 shows ozone, nitrogen dioxide, and nitrogen monoxide profiles averaged over the entire domain 4 at 18UTC 9 July 2007.
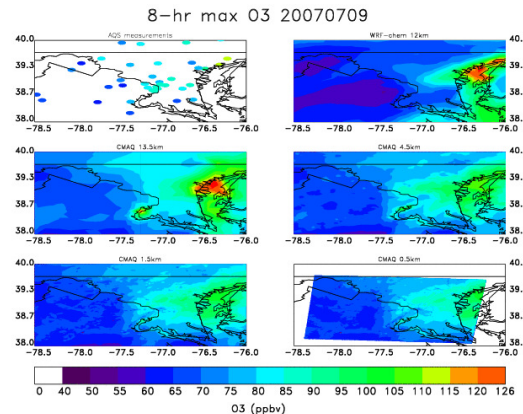
Fig. 4. 8-h maximum ozone concentrations on 9 July 2007 from AIRNOW observations, a 12km WRF-chem simulation, and a 13.5, 4.5, 1.5, and 0.5km CMAQ simulation.
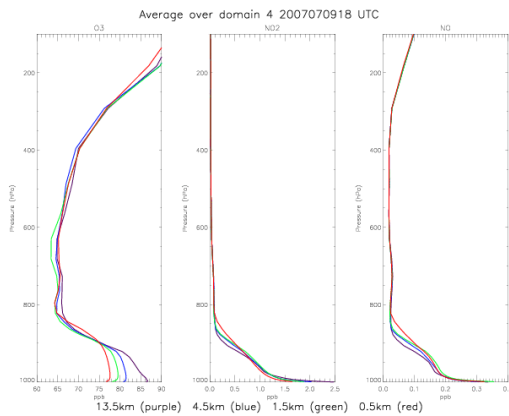

Fig. 5. Ozone, NO_2, and NO profiles averaged over domain 4 at 18UTC 9 July 2007.

3.1 SO$_2$

Convection is calculated explicitly in high resolution model simulations. A realistic representation of convective and cloud processes is necessary to accurately calculate aqueous phase chemistry, such as the oxidization of sulfur dioxide, within air quality models as shown here:
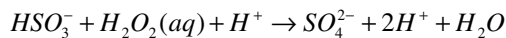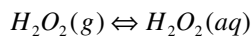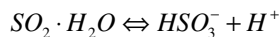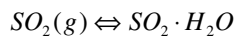
$$SO_2(g) \Leftrightarrow SO_2 \cdot H_2O$$
$$SO_2 \cdot H_2O \Leftrightarrow HSO_3^- + H^+$$
$$H_2O_2(g) \Leftrightarrow H_2O_2(aq)$$
$$HSO_3^- + H_2O_2(aq) + H^+ \rightarrow SO_4^{2-} + 2H^+ + H_2O$$

Figure 6 shows CMAQ calculated SO_2 columns from the surface to 215mb averaged over domain 4 for the four domains. Figure 7 shows 4.5, 1.5, and 0.5km domains SO_2 columns minus the 13.5km SO_2 column averaged over domain 4. During the afternoon and evening hours the finer domains cause more vertical motion and more SO_2 to be transported through clouds where it is oxidized to form sulfate aerosols. On the other hand, 13.5km parameterized convection causes more SO_2 to be transported through clouds in the early morning hours just before sunrise. Figure 8 shows sulfur dioxide and sulfate aerosol profiles averaged over domain 4 for all four domains at 4UTC and 12UTC 9 July 2007, just before and after the 13.5km domain oxidizes SO_2 more rapidly than the other domains.
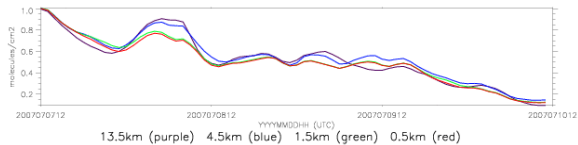

Fig. 6. 13.5, 4.5, 1.5, and 0.5km column integrated sulfur dioxide below 215mb averaged over domain 4.
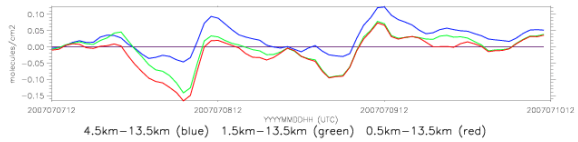

Fig. 7. 4.5, 1.5, and 0.5km column integrated sulfur dioxide below 215mb minus 13.5km column integrated sulfur dioxide averaged over domain 4.
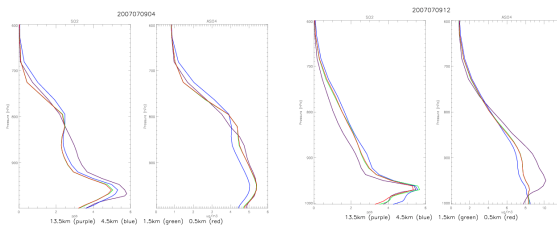

Fig. 8. Sulfur dioxide and sulfate aerosol profiles averaged over domain 4 at 4UTC 9 July 2007 and 12UTC 9 July 2007.

4. CONCLUSIONS

High resolution model simulations are capable of capturing small scale features that are not simulated in coarse model runs. This allows high resolution runs to more accurately simulate a bay breeze and vertical transport. High resolution runs with convection calculated explicitly allows more SO_2 to be transported vertically through clouds where it is oxidized in the afternoon and evening hours. The 13.5km simulation with the Grell-Devinyi cumulus scheme caused more SO_2 to be oxidized in the early morning hours. Ongoing work is looking into why more SO_2 is being oxidized in the 13.5km domain in the early morning.

5. REFERENCES

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