Application and evaluation of high-resolution WRF-CMAQ with simple urban parameterization

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Abstract   The 2-way coupled WRF-CMAQ meteorology and air quality modeling system is evaluated for high-resolution applications by comparing to a regional air quality field study (Discover-AQ). The model was modified to better account for the effects of urban environments. High-resolution spatial data for fractions of impervious surfaces and tree canopy from the National Land-Cover Database (NLCD) were processed for each grid and used to scale ground heat capacity and to constrain vegetation coverage and characteristics. These simple algorithms along with modified albedo and roughness length in urban areas result in improved simulation of urban heat island and urban boundary layers. The reduced nocturnal stability and enhanced vertical mixing lead to reduced temperature and humidity biases and reduced under-predictions of ozone concentrations in urban areas.

1. Introduction

A new modeling system for coupled meteorology and air quality composed of the Weather Research and Forecast (WRF) model (Skamarock et al. 2008) and the Community Multiscale Air Quality (CMAQ) model (Byun and Schere, 2006) has been recently developed and evaluated for regional and mesoscale applications (Wong et al. 2012). The 2-way coupled WRF-CMAQ model has several advantages over traditional sequential meteorology and air quality modeling systems including more frequent data transfer of meteorological information (e.g. winds, temperature, and humidity) to the chemical transport model. As model grid resolution increases, the frequency of data transfer should also increase such that me-

teorological input is updated more frequently than the typical hourly interval. Another advantage of 2-way coupled systems is the possibility of feedback of chemical information to the meteorological processes that can be affected by gaseous or aerosol species. Currently, direct feedback effects of aerosols on shortwave and long wave radiation is implemented in the WRF-CMAQ system while an experimental implementation of effects of aerosols on CCN activation and cloud microphysics is being evaluated.

2. Urban parametrization

Meteorological and air quality modeling at high-resolutions in urban areas requires consideration of the specific characteristics of urban environments that affect surface energy and moisture budgets, dynamic wind drag, and mechanical turbulence generation. In recent years urban surface models with three levels of complexity have been added to WRF (Chen et al. 2011): a bulk surface scheme, a single-layer model, and a multi-layer model all of which are coupled to the Noah land surface model (LSM). However, since the coupled WRF-CMAQ system relies on the Pleim-Xiu LSM (PX LSM) (Pleim and Xiu, 1995) for meteorological surface fluxes as well as chemical air-surface exchange (i.e. dry deposition and bi-directional flux) simple urban parameterizations have been added to the PX LSM that leverage the very high resolution (30 m) impervious surface fraction data that are available as part of the National Land Cover Database (NLCD, http://www.mrlc.gov/nlcd06_data.php) to scale surface heat capacity. In addition, albedo and roughness length for the four NLCD urban related land use categories have been revised to better represent developed areas. The NLCD tree canopy coverage data is also used to better account for the effects of urban trees on evapotranspiration and latent heat flux.

3. Comparison to Field Studies

A persistent problem in air quality modeling of urban areas is the over-prediction of surface emitted pollutants, such as CO, NO_X and primary PM, and under-prediction of O_3 during the morning and evening hours. The precise cause of these persistent errors is not known but a prime suspect is an under-prediction of turbulent mixing in the PBL during these transitional times. The neglect of urban surface effects may contribute to these problems since the urban heat island tends to destabilize the lower boundary layer at night and delay the evening transition to downward sensible heat flux. In addition, urban structures induce mechanical turbulence on wind flow through the building canopy.
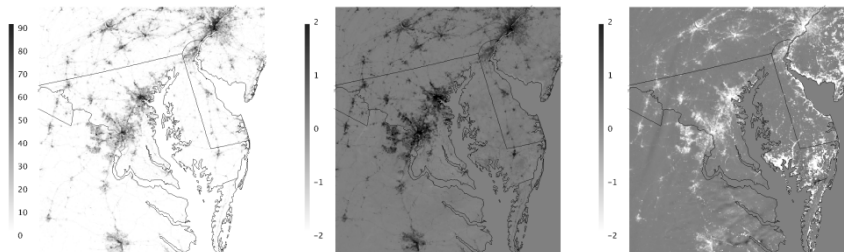
Fig. 1. Impervious surface fraction (left), skin temperature difference (Urban – Base) at July 2, 0600 LT (center), and July 2, 1100 LT (right).

The simple urban parameterization for the PX LSM, outlined above, is tested for the Discover-AQ field study in July 2011 by running Base and Urban versions of WRF-CMAQ on 4 km and 1 km resolution grids over the Mid-Atlantic region. Figure 1 shows the percentage of impervious surface for every grid cell in the 1 km grid resolution model domain as well as the effects of the urban scheme compared to the base case on skin temperature at two times on July 2, 2011. In urban areas with high fractions of impervious surfaces, the skin temperature is warmer at 6 am LT in the Urban run because of slower nighttime cooling due to greater heat capacity while the Urban run is cooler at 11 am LT because of slower late morning heating.

The urban modifications reduce average 2-m temperature and mixing ratio biases in and around the urban areas (not shown). Consequently, average hourly ozone concentrations are higher in the Urban run, mainly in the evening and overnight, because of the deeper and less stable nocturnal boundary layers in the Urban run that better simulates the UHI effects (Figure 2, top). Figure 2 (bottom) also demonstrates that the higher ozone concentrations are in better agreement with observations since average bias is reduced for the Urban run in the urban areas.

4. Conclusions

A new simple bulk urban parameterization that leverages the highly accurate, high resolution impervious fraction and tree canopy fraction data that are available in the NLCD has been implemented in the PX LSM in the 2-way coupled WRF-CMAQ model system. Model comparisons and evaluation for the Discover-AQ field study show that the Urban scheme improves representation of the UHI effects that lead to reduced biases of 2 m temperature and mixing ratio as well as ozone concentrations in urban areas. The effects of the Urban scheme on air quality are most pronounced in the evening when the transition to a stable regime is delayed relative to the Base run resulting in reduced over-predictions of NO_x and reduced under-predictions of O_3.

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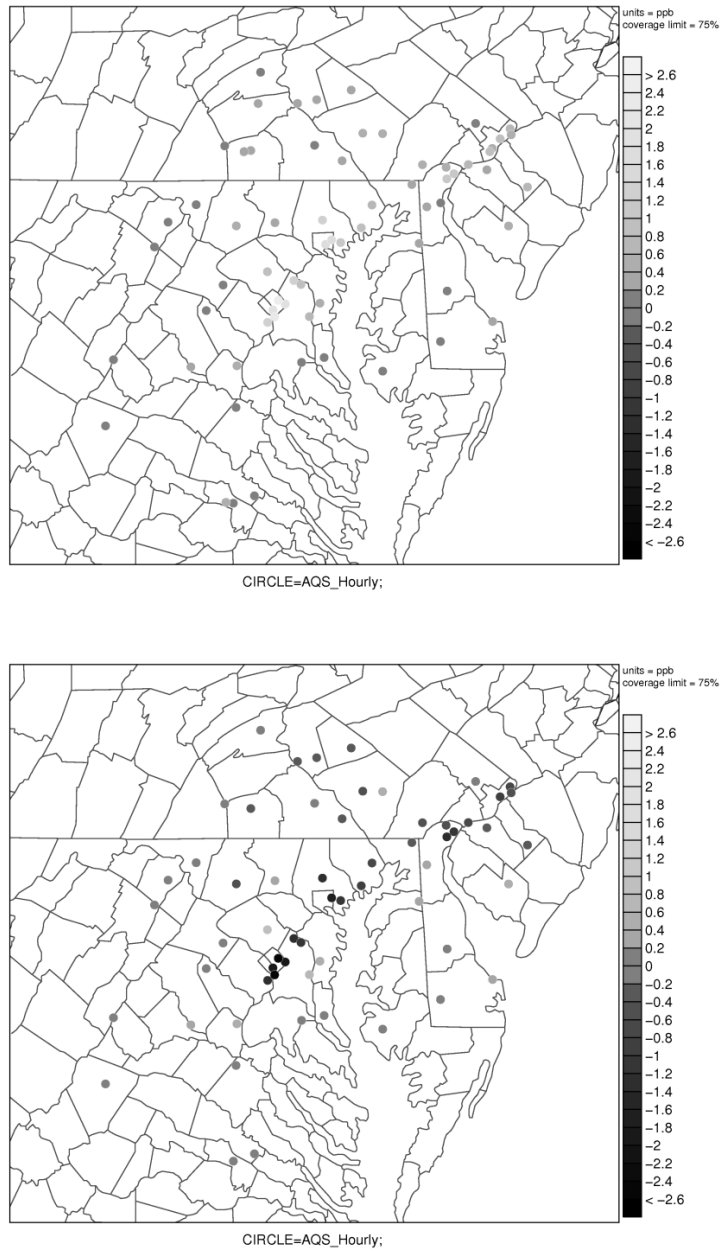
Fig. 2. **Hourly ozone difference (Urban – Base) (top) and difference in hourly bias (Urban – Base) (bottom) averaged over July 1 – 16, 2011.**

References

Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M., Duda, M.G., X-Y Huang, Wang, W., Powers, J.G., 2008. A Description of the Advanced Research WRF Version 3, NCAR Tech Note NCAR/TN 475 STR, 125 pp. [Available from: UCAR Communications, P.O. Box 3000, Boulder, CO 80307.].

Byun, D., Schere, K.L., 2006. Review of the governing equations, computational algorithms, and other components of the models-3 community multiscale air quality (CMAQ) modeling system. *Appl. Mechanics Rev*. 59, 51-77.

Wong, D. C., Pleim, J., Mathur, R., Binkowski, F., Otte, T., Gilliam, R., Pouliot, G., Xiu, A., Young, J. O., and Kang, D.: WRF-CMAQ two-way coupled system with aerosol feedback: software development and preliminary results, Geosci. Model Dev., 5, 299–312, doi:10.5194/gmd-5-299-2012, 2012.

Chen, F., S. Miao, M. Tewari, J.-W. Bao, and H. Kusaka (2011), A numerical study of interactions between surface forcing and sea breeze circulations and their effects on stagnation in the greater Houston area, J. Geophys. Res., 116, D12105, doi:10.1029/2010JD015533.

Pleim, J. E. and Xiu, A.: Development and testing of a surface flux and planetary boundary layer model for application in mesoscale models, J. Appl. Meteor., 34, 16–32, 1995.

5. Questions and Answers

Steve Hanna: Why did you not want to use the WRF-Urban model developed by Fei Chen and colleagues at NCAR?

Answer: The main reason is that the current WRF-Urban options are tied to the Noah land surface model (LSM) and the TKE PBL schemes. We have been developing and using the Pleim-Xiu LSM and the ACM2 non-local closure PBL scheme, neither of which can be used with the Urban options. We not only use these schemes in WRF but also in the air quality part of the system (CMAQ) for PBL mixing, dry deposition, and bi-directional surface fluxes. We are not certain that the simple urban modifications described here are sufficient and plan to continue development and evaluation including intercomparison with the WRF-Urban models.

Douw Steyn: Why iterate only once?

Answer: This question refers to the new iterative technique for data assimilation in the soil temperature and moisture for high-resolution (1 – 4 km) modeling which was discussed in the presentation but could not be included in this extended abstract due to page limitations. We have tried 2 iterations but saw only minor reductions in error. Thus, in the trade-off between accuracy and run time we don't feel that multiple iterations are worthwhile. However, we will do more testing.

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