Modeling impacts of New York metropolitan land cover on regional precipitation

Wei Wu[1], Luis E. Ortiz[2], Jorge Gonzalez[2], Robert Bornstein[3], Martin Schoonen[1], Jeffrey Tongue[4]

[1] Brookhaven National Laboratory, Upton, NY 11973, United States

[2] The City College of New York, 160 Convent Ave., New York, NY 10031, United States

[3] San Jose State University, 1 Washington Square, San Jose, CA 95192, United States

[4] National Weather Service, Upton, NY, 11973, United States

Abstract

Metropolitan land cover has been found to significantly impact regional weather and climate. In this study, we use the community mesoscale Weather Research and Forecasting (WRF) model and an urbanized version of the WRF (uWRF) model to investigate impacts of New York metropolitan land cover on regional precipitation. A storm case, with heavy precipitation, moving from west to east of New York City, in September 2010 was chosen for a testbed. We found that the total accumulated precipitation from both the WRF and uWRF models shows much enhanced precipitation on the periphery of New York City and Long Island suburbs due to the presence of the cities, in comparison with a simulation by replacing New York metropolitan area with deciduous broadleaf forest. The modeled results concur with early findings from radar observations in terms of urban-induced precipitation bifurcation. Impacts of the replacement of the metropolitan land cover on thermodynamic properties are investigated, including land surface latent and sensible heat fluxes, convective available potential energy, and moist enthalpy. Findings from this study suggest that the urban building barrier effect is probably the major cause for the precipitation bifurcation found in this study.

1. Introduction

Many studies have shown that metropolitan land cover significantly impacts regional precipitation[1-3]. Such impacts include: 1) modification of airflow pathway of moving convective thunderstorms due to the urban barrier effect; 2) enhancement of moist convergence and convective processes due to the urban heat island effect and elevated roughness or friction of urban area, to trigger the initiation of convective storms; and 3) higher urban aerosol concentration essential for the enhancement of cloud formation. However, our understanding of impacts of metropolitan land cover on regional precipitation remains incomplete. The recent literature review[3] pointed out that larger urban surface roughness is not likely to play a major role in urban induced precipitation, and urban-modified precipitating systems can either increase or decrease precipitation over and downwind of cities. Such findings suggest a need of advancing in-depth understanding of urban impacts on regional precipitation. In this study, we aim to use the state-of-art WRF and uWRF regional models to test sensitivities of regional precipitation to New York metropolitan land cover.

2. Methodology

The Advanced Research WRF's version 3.5.1[4], and an urbanized version of the WRF (uWRF)[5-6] were used for this study. Three nested model domains were devised for the WRF experiments with two-way communication. Outer domain (d01: 1071 km x 1071 km) was run at a horizontal grid increment of 9 km. The first nested domain (d02: 360 km x 360 km) was run at 3 km horizontal grid increment. The second nested inner domain (d03: 90 km x 90 km) was run at a 1 km horizontal grid increment. Modeled results from the inner domain (d03) were used for New York City (NYC) analyses, while those from the first nested domain (d02) were used for analyses over Long Island (LI) suburbs including Nassau (western) and Suffolk (eastern) Counties. All the three model domains are centered at the Manhattan – the center of NYC. We use the North American Regional Reanalysis (NARR)[7] data as initial and boundary conditions to drive the models. A storm case, with heavy precipitation, moving from the west to the east of NYC from September 16 to 17, 2010, was chosen for a testbed.

Model configuration was made using physics parameterizations favor to mesoscale convective precipitation study. The schemes used include the WRF Single-Moment 6-class microphysics scheme[8], the Kain-Fritsch cumulus scheme[9], the BouLac planetary-boundary-layer parameterization scheme[10], the Rapid Radiative Transfer scheme[11] for longwave radiation calculation, the Dudhia scheme[12] for shortwave radiation calculation, and the Noah land surface model[13]. The cumulus parameterization was turned off for the finest resolution domain (d03), since at 1 km resolution the WRF model is able to resolve convective processes explicitly. Model spinup time is 24 hours. No observational nudging was used in any of the simulations.

Three model runs were conducted to test sensitivities of precipitation distributions over NYC and its downwind LI suburbs to New York metropolitan land cover. The first run is a WRF control run, using the Moderate Resolution Imaging Spectroradiometer derived 20-class land use classification. The second run is a WRF forest run, by replacing New York metropolitan land cover with the deciduous broadleaf class - the most common class in New York metropolitan neighboring areas. To accommodate the land cover change, we employed the NARR derived soil moisture at the four soil levels (i.e. 0-10 cm, 10-40 cm, 40-100 cm, 100-200 cm) that equals the value of the closest deciduous broadleaf forest grid points. The third run is a high-resolution uWRF run, using the uWRF model with more specified treatments of urban land cover, such as the Building Environment Parameterization with the Building Energy Model[14-15] and the National Urban Database and Access Portal Tool data[16].

3. Results and Discussions

The spatial distributions of modeled precipitation over NYC and over its downwind LI suburbs were first examined. We found that the total accumulated precipitation from the models exhibits a bifurcation phenomenon due to the presence of the cities, that is, much enhanced precipitation on the periphery of NYC and LI suburbs, in comparison with a simulation by replacing New York metropolitan land cover with deciduous broadleaf forest. Figure 1 shows an example about the total precipitation difference (i.e., the Control run minus the Forest run). The precipitation bifurcation phenomenon could be formed from a combined effect of: 1) the enhancement of land surface moisture availability due to the replacement of New York metropolitan land cover with deciduous broadleaf forest, which has a potential to influence precipitation formation; 2) the urban building barrier effect[17], which blocks the moist airflow from the ocean induced by a mesoscale circulation to impact precipitation formation.

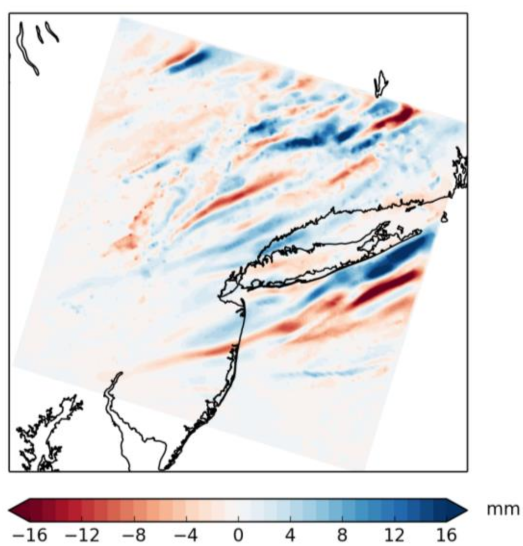

Figure 3: Differences in total accumulated precipitation (the Control run minus the Forest run).

By comparing modeled precipitation with the NARR data and surface-based observations (i.e., the Cooperative Observer Network stations), we found that the models had a significant (6-hour) delay in simulating the arrival timings of the storm to NYC, and tended to underpredict the observed total accumulated precipitation over NYC (not shown).

For seeking thermodynamic understanding of the modeled precipitation, we analyzed changes in land surface latent and sensible heat fluxes, convective available potential energy, and moist enthalpy. Results show that the replacement of the New York metropolitan land cover with deciduous broadleaf forest significantly increases land surface latent heat flux and decreases land surface sensible heat flux (not shown). However, the combined effect shows almost no change in the resulting convective available potential energy and moist enthalpy before and after the replacement of the New York metropolitan land cover (not shown).

Further analyses show that the eastward moving storm system was mainly driven by a mesoscale circulation with a strong westerly wind component from the west of NYC, and the heavy precipitation was formed at the confluence zone of a strong southwesterly wind from the west of NYC and a strong southerly wind from the south of NYC and LI (not shown). Thus, the urban building barrier effect, which blocked the moist airflow from the ocean (i.e., the south of NYC and LI), probably played a key role in shaping the precipitation distributions.

4. Summary

We use the state-of-art WRF and uWRF regional models to investigate sensitivities of NYC's and LI suburbs' precipitation distributions to New York metropolitan land cover. We found that New York metropolitan land cover induced precipitation bifurcation phenomenon, due probably to the urban building barrier effect for this specific case tested. Findings from this study confirm urban induced precipitation bifurcation phenomenon over NYC as found in a previous study based on radar observations[17]. Our analyses show the importance of the urban building barrier effect in influencing regional precipitation. This study illustrates the complexity of the nature of urban-precipitation interactions, and reveals current state-of-art regional models' capability in simulating precipitation over this urban coastal region.

Acknowledgment This study has been supported by the Brookhaven National Laboratory's (BNL) Graduate Research Internship Program, Laboratory Directed Research and Development Program, the US Department of Energy's Atmospheric Systems Research (ASR) Program under Contract No. DE-SC0012704 and Earth System Modeling (ESM) Program, the National Oceanic and Atmospheric Administration – Cooperative Remote Sensing Science and Technology Center (NOAA-CREST), NOAA CREST - Cooperative Agreement No: NA11SEC4810004, and the National Science Foundation Grants CNS-0958379, CNS-0855217, ACI-1126113 through the City University of New York High Performance Computing Center at the College of Staten Island. We thank Gary Stevens (BNL) for assistance on setting up and maintaining BNL computer system for the experiments.

5. References

[1] Shepherd, J. M., 2005, A review of current investigations of urban-induced rainfall and recommendations for the future, *Earth Interact.*, 9, 1– 27.

[2] C. G. Collier, 2006, The impact of urban areas on weather, *Quart. J.R. Meteorol. Soc*, 132, 1–25, doi: 10.1256/qj.05.199

[3] Han, J. Y., Jong-Jin Baik, Hyunho Lee, 2014, Urban impacts on precipitation, *Asia-Pacific J. of Atmos. Sci.*, 50, 17-30.

[4] Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, M. G. Duda, X.-Y. Huang, W. Wang, and J. G. Powers 2008, A Description of the Advanced Research WRF Version 3. NCAR Technical Note, NCAR/TN-475+STR, 113 pp.

[5] Chen, F., H. Kusaka, R. Bornstein, J. Ching, C. S. B. Grimmond, S. Grossman-Clarke, T. Loridan, K. W. Manning, A. Martilli, S. Miao, D. Sailor, F. P. Salamanca, H. Taha, M. Tewari, X. Wang, A. A. Wyszogrodzki, and C. Zhang, 2010, The integrated WRF/urban modelling system: development, evaluation, and applications to urban environmental problems, *Int. J. Climatol*., 31, 273–288.

[6] Gutierrez, E., J.E. González, M. Arend, A. Martilli, and R. Bornstein, 2013, A new modeling approach to forecast building energy demands during extreme heat events in complex cities. *J. of Solar Energy Engineering*, 135, doi: 10.1115/1.4025510. http://www.wrf-model.org

[7] Mesinger, F., et al., 2006, The North American Regional Reanalysis, *Bull. Am. Meteorol. Soc*., 87, 343-360, doi: 10.10175/BAMS-87-3-343.

[8] Hong, S.-Y. and J,-O. J, Lim, 2006, The WRF single-moment 6-class microphysics scheme (WSM6), *J. Korean Meteor*., 42, 129-151.

[9] Kain, John S., 2004, The Kain–Fritsch convective parameterization: An update, *J. Appl. Meteor*., 43, 170–181.

[10] Bougeault, P. and P. Lacarrere, 1989, Parameterization of Orography–Induced Turbulence in a Mesobeta—Scale Model, *Mon. Wea. Rev*., 117, 1872–1890.

[11] Mlawer, Eli. J., Steven. J. Taubman, Patrick. D. Brown, M. J. Iacono, and S. A. Clough, 1997, Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated–k model.

[12] Dudhia, J., 1989, Numerical study of convection observed during the Winter Monsoon Experiment using a mesoscale two–dimensional model, *J. Atmos. Sci*., 46, 3077–3107.

[13] Tewari, M., F. Chen, W. Wang, J. Dudhia, M. A. LeMone, K. Mitchell, M. Ek, G. Gayno, J. Wegiel, and R. H. Cuenca, 2004, Implementation and verification of the unified NOAH land surface model in the WRF model, 20th conference on weather analysis and forecasting/16th conference on numerical weather prediction, 11–15.

[14] Martilli, A., A. Clappier, and M. W. Rotach, 2002: An urban surface exchange parameterisation for mesoscale models. *Bound.-Layer Meteorol*., 104, 261–304.
[15] Salamanca, F., A. Krpo, A. Martilli, and A. Clappier, 2010: A new building energy model coupled with an urban canopy parameterization for urban climate simulations—part I. formulation, verification, and sensitivity analysis of the model. *Theor. Appl. Climatol.*, 99, 331–344, doi:10.1007/s00704-009-0142-9.
[16] Ching, J., Brown, M., Burian, S., Chen, F., Cionco, R., Hanna, A., Hultgren, T., McPherson, T., Sailor, D., Taha, H., Williams, D., 2009, National Urban Database and Access Portal Tool. *Bull. Amer. Meteor. Soc.*, 90, 1157–1168.
[17] Bornstein, R., LeRoy, M., 1990. Urban barrier e!ects on convective and frontal thunderstorms. Preprint volume, Fourth AMS Conference on Mesoscale Processes, Boulder, CO, 25-29 June.