Modeling New York City Impacts on Long Island weather during the July 2010 heat wave

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Abstract

With extreme heat events projected to increase in frequency, duration and magnitude, understanding their impacts on large urban centers and their neighboring areas has become increasingly important. Studying these events in cities requires a level of spatial detail that is not traditionally found in reanalysis and station data sets, and thus the use of techniques such as dynamical downscaling becomes essential. This study uses the Weather Research and Forecast model version 3.5 as a regional climate model to perform dynamical downscaling of 32 km resolution North American Regional Reanalysis in order to study the sensitivity of key climate variables such as surface temperatures and surface fluxes to the presence of New York City during the heat wave event of July 2010. The sensitivity experiment consists of three simulations: a control run using unaltered land use index, a forest run with a modified land use index and soil moisture profile, and a run using the Building Energy Parameterization (BEP) and Building Energy Model (BEM) options in WRF. The impacts of the urban center's heat island during the heat wave event on neighboring Long Island, NY are scrutinized. Results show that the control and urbanized simulations were able to successfully capture the maximum daily temperatures associated with the heat wave event, as well as the strong nighttime urban heat island signal. The model showed the greatest sensitivity in nighttime minimum temperatures, with values in the forest case reaching up to 2°C cooler than the control and urbanized simulations over New York City, while Long Island minimum temperatures were up to 1°C cooler. Peak sensible heat fluxes were 20% higher over the city in the urbanized simulation due to the increased anthropogenic heat contribution. Over Long Island, the largest change in sensible heat fluxes was observed in the forest case, with peak sensible heat flux 7% lower than in the other two cases.

1. Introduction

The New York Metropolitan Area (NYMA), comprised of New York City and neighboring urban centers, is the most highly populated region in the United States, with roughly 20 million inhabitants. The densely populated urban land cover has attracted researchers' attention to studying heat island effect (Bornstein 1968; Gaffin et al. 2008; Gedzelman et al. 2003). This heat island effect has been shown to have detrimental impacts on mortality (Curriero et al. 2002; Anderson and Bell 2012; Petkova et al. 2013). However, what is less studied are the impacts of large urban centers on their neighboring regions. These impacts have been studied for the case of the bifurcation of moving storm fronts in Atlanta (Bornstein and Lin 2000) and Indianapolis (Niyogi et al. 2011), in the United States. Other possible effects lie in the advection of thermal effects, as the thermal heat plume of a city can affect the temperature and wind vertical structures downwind of a city. Additionally, with projected increasing temperatures, the frequency, duration, and magnitude of heat waves are also projected to increase (Meehl 2004). This is exacerbated in large urban centers, where temperature differences can already be much higher than in neighboring regions, leading to an increase in hot days and heat waves, as seen in Shanghai by Tan et al. 2010.

Traditionally, climate studies were performed using coarse resolution General Circulation Models (GCMs). However, as the spatial resolution of these models generally lies in the range of 100-200 km, they are not well suited to the study of urban centers where highly heterogeneous features such as changes in land cover, coastlines, and the presence of buildings contribute substantially to the energy and water balances (Oke 1988). High resolution dynamical downscaling has become a popular tool for such studies, as it allows experimentation with configurations of land cover as well as initial and boundary conditions.

Here, the heat wave event that affected the Eastern United States in July 4-9, 2010 is used as a case study.

This event saw reported temperatures in New York City reach up to 39.4 °C, matching the fifth warmest day on record, with eight mortalities as a direct consequence (National Climatic Data Center).

2. Data and Methods

The Weather Research and Forecast Model (WRF) version 3.5 was used as a regional climate model (RCM). To study the effects of the New York metropolitan area on neighboring Long Island (LI), an experiment consisting of four simulations was constructed using the North American Regional Reanalysis (NARR) as initial and boundary conditions. The simulations consisted of a control case (CONTROL) using the standard version of the WRF model and MODIS 20 category land classification, a case where the land cover over New York Metropolitan Area is modified to deciduous broadleaf forest (FOREST), a case using the Building Environment Parameterization (BEP) with the Building Energy Model (BEM) (Martilli et al. 2002; Salamanca et al. 2010) (URBAN), and finally, a simulation using a latent heat parameterization for the urban component of the model (LATENT). The BEP and BEM physics, which use a multi-layer approach to the parameterization of the urban canopy, have been used by Gutiérrez et al (Gutiérrez et al. 2015), showing improvement in resolving temperature and wind speed patters over New York City. The Latent heat parameterization alters the energy and water partitions to include the presence of cooling towers in buildings, as well as the effects of accumulated water. Results from the simulation cases, including 2 m temperature, 2 m water vapor mixing ratio, and surface fluxes are compared to the CONTROL case, the driving model data, and to available observations. As part of the more involved urban canopy and building energy modeling, a detailed data set derived from the Primary Land Use Tax-Lot Output (PLUTO), which includes building heights and ground area has been integrated into the URBAN and LATENT simulations in order to benefit fully from the advanced physical parameterizations. Furthermore, in order to reconstruct a broadleaf forest environment in the FOREST case, the soil moisture profile has been modified to match that of the neighboring grid points containing this non-urban land cover category. The simulation domain used is detailed in Figure 1. The outer domain, called d01, uses a 9 km spatial resolution. To increase the level of detail in around the NYMA, a 3 km resolution domain is used for the first nested domain d02. Both nests use two-way feedback. Finally, in order to resolve the detail of the urban canopy, a second nested domain d03 is included with a spatial resolution of 1 km. The physics used in all simulation cases are detailed in Table 2. The land cover categories, corresponding to the CONTROL case, the FOREST case, and the disaggregated urban used in URBAN and LATENT, are shown in Figure 2.

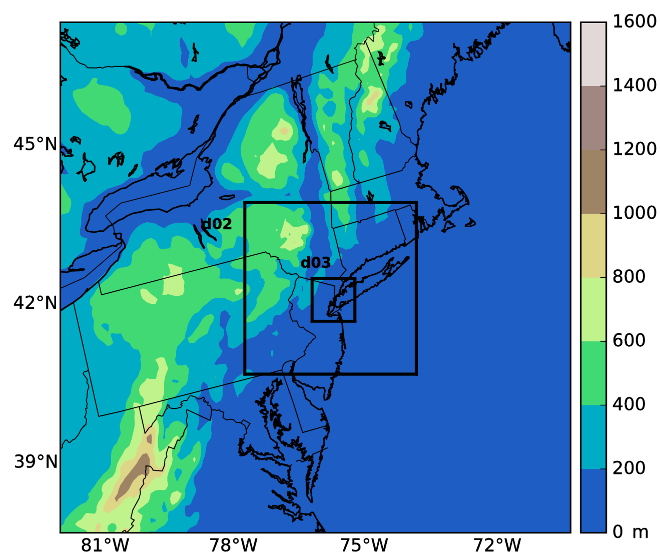

Figure 1: Simulation domains used in all study cases. Filled contours denote terrain height in meters.

Table 1: List of simulations performed with the land cover and urban parameterization used.

Case	Land Cover Source	Urban Parameterization
CONTROL	MODIS 20-Cat	None
FOREST	Modified MODIS 20-class	None
URBAN	MODIS 20-Cat, PLUTO	BEP + BEM
LATENT	MODIS 20-Cat, PLUTO	BEP + BEM + Latent

Table 2: Physics options used in all the simulation cases for each of the domain grids (d01, d02, d03).

Option	d01	d02	d03
Horizontal Resolution (km)	9	3	1
Microphysics	–	–	WSM6
Cumulus	Kain-Fritsch	Kain-Fritsch	--
PBL	BouLac	BouLac	BouLac
LW Radiation	RRTM	RRTM	RRTM
SW Radiation	Dudhia	Dudhia	Dudhia
Land Surface Model	NOAH	NOAH	NOAH

3. Simulation Results

The spatial distribution of the daily maximum and minimum temperatures are shown in Figure 3 and Figure 4. The maximum temperature distribution for the CONTROL simulation (Figure 3) exhibits a high temperature core that extends throughout the entire NYMA. This homogeneity is due to the lack of distinction between different types of urban land cover. Meanwhile, in the URBAN and LATENT cases, since the anthropogenic heat is now partitioned into latent and sensible heat, the high temperature core in the New York City boroughs of Manhattan, Brooklyn, and Queens show somewhat lower temperatures. Meanwhile, in Bronx (north of Manhattan), where cooling towers are less common due to the prevalence of mostly high intensity residential land use, temperatures are higher. This dependence of the temperature distribution is apparent in the URBAN and LATENT cases, which show similar spatial patterns in this area. The nighttime urban heat island effect can be seen in the minimum temperature distributions (Figure 4). In this case, the URBAN and Control simulations show a similar extent of the heat island. However, the LATENT simulation, with its partitioning of the anthropogenic heat, shows a smaller extension. As expected, the effect completely disappears in the FOREST simulations.

Figure 6 (top) shows the temporal progression of 2 m air temperature for New York City and Suffolk county in Long Island. During the daytime, maximum temperatures are dominated by the heat wave conditions, showing small to no difference among the different cases in the Long Island domain. Meanwhile, in the NYC domain, the CONTROL simulation exhibits slightly higher temperatures during the day, with faster cooling at night leading to lower minimum temperatures than in the URBAN and LATENT cases. Nighttime minimums in the Long Island domain are lower in the FOREST simulation than in the other cases by up to 2 °C, even though the land cover is mostly non-urban with parts having Low-Intensity Residential land use. These differences are largest during the heat wave event. Finally, the water vapor mixing ratio grows to maximum levels at the peak of the heat wave event. As expected, the FOREST simulation shows the highest values, as the deciduous broadleaf land cover, coupled with the increased soil moisture allow for higher evaporation at night, leading to the evaporative cooling that makes the heat island effect disappear. The diurnal cycle of the surface fluxes (Figure 5) show a peak close to 14:00:00 local time. The URBAN and LATENT cases show the highest sensible heat, due to the added anthropogenic heat contribution from building air conditioning use and urban canopy dynamics. The latter shows increased heating north of Manhattan, as evidenced by the higher daily maximums in those areas. The FOREST case shows by far th largest latent heat fluxes, reaching at some time periods more than double the magnitude of the other three cases, a pattern that occurs for both NY and LI. Bowen ratio values peak at over 5, characteristic of dry conditions such as those inherent to a heat wave event.

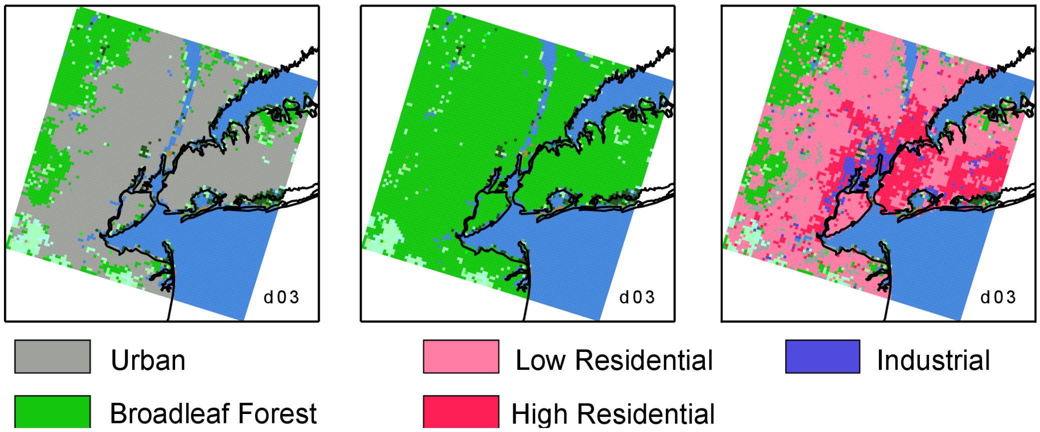

Figure 2: Land cover categories used in the CONTROL case (left), the FOREST case (center), and the disaggregated urban used in URBAN and LATENT (right).

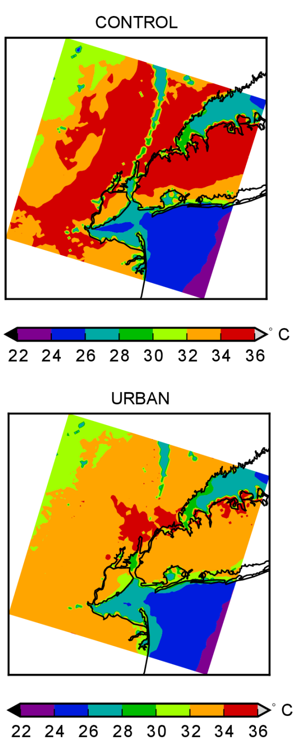

Figure 3: Average of the daily maximum temperature distribution for the heat wave event (July 4-9).

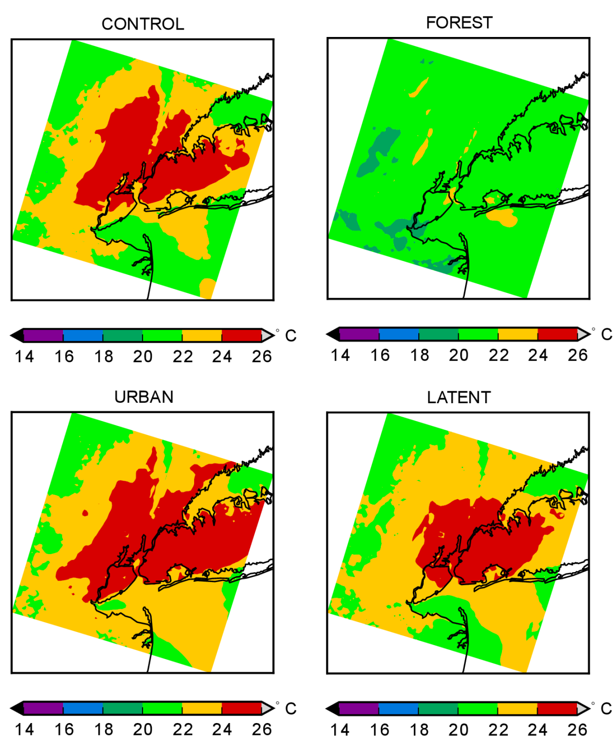

Figure 4: Average of the daily minimum temperature distribution for the heat wave event (July 4-9).

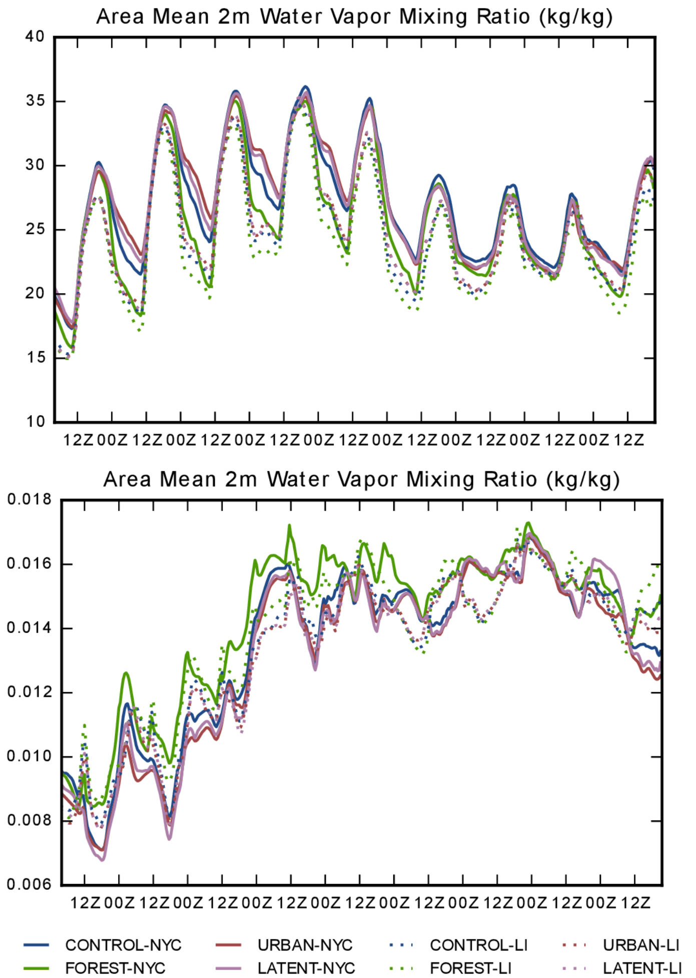

Figure 6: Simulation results for 2 m air temperature and 2 m water vapor mixing ratio for the counties that comprise New York City (solid lines) and the Suffolk county in Long Island (dashed lines).

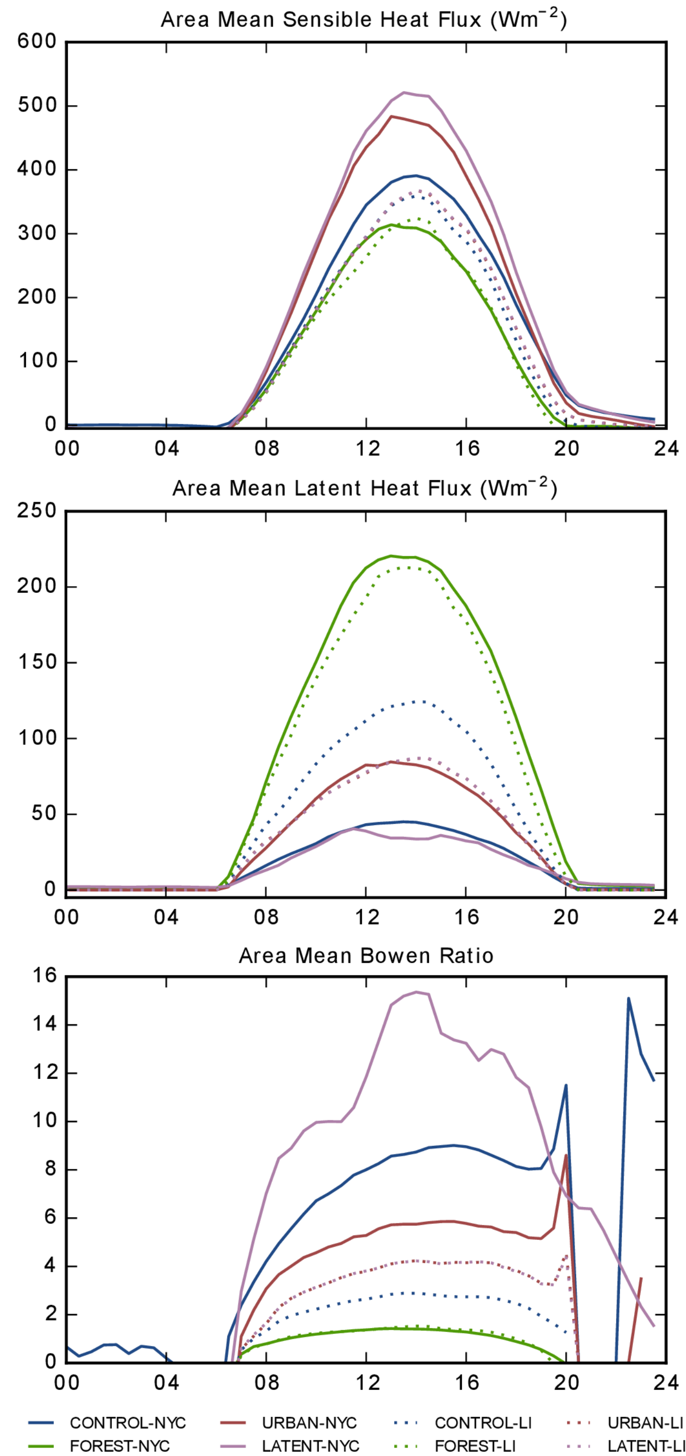

Figure 5: Diurnal cycle of sensible heat flux (top), latent heat flux (middle), and the Bowen Ratio (bottom) for the NYC (solid lines) and LI domains (dashed lines).

4. Conclusion

This study consists of an experiment designed to assess the sensitivity of the weather conditions in Long Island to the urban land cover in the NYMA, during a heat wave event. Results from the regional model used show a detailed spatial distribution of the nighttime urban heat island effect, which appears to be heavily sensitive to the urban physics scheme used. However, as expected, the model shows that eliminating the urban land cover makes the urban heat island disappear. The FOREST case daily minimum temperature in the Long Island region (Suffolk County) is consistently lower than in the other simulations for the same region during the heat wave event, where the urban heat island effect is strongest, reaching a difference of up to 2 °C. The CONTROL simulation also shows faster nighttime cooling compared to the URBAN and LATENT cases. This could be due to added evaporative cooling, which is supported by the high 2 m water vapor mixing ratio relative to the URBAN and LATENT cases.

5. Acknowledgments

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