How do changes to the urban environment affect precipitation and air quality?

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- **What?**
  - This project investigates how landuse changes in an urban environment affect meteorology and air quality. To begin this investigation a modeling study was performed to investigate the cause of the urban heat island in Baltimore, MD and Washington, DC and how the heat island affects meteorology. This preliminary study is shown here.
- **How?**
  - Regional meteorology modeling was performed with the PSU NCAR mesoscale model (MM5) (Grell et al., 1994) with a domain covering the Washington, DC and Baltimore, MD metropolitan areas at 4km horizontal resolution. MM5 simulations were performed from 00 UTC August 3, 2006 to 00 UTC August 6, 2006 for 7 cases: (1) base, (2) natural, (3) albedo, (4) soil moisture, (5) emissivity, (6) roughness length, and (7) thermal inertia and heat capacity. The base case used appropriate land-use parameters (i.e., albedo, moisture availability, emissivity, roughness length, thermal inertia and heat capacity) for each grid box. In the natural case, urban grid boxes were reclassified as "broadleaf deciduous forest" and land-use parameters were changed accordingly (see Table 1) (Anderson et al., 1976). For the other five cases, only the identified parameter was changed to its natural value at urban locations. These sensitivity runs were designed to identify which particular land-use parameter had the largest impact on meteorology.

Table 1: *USGS land-use / land-cover classification for urban and broadleaf deciduous forest surface parameters (Anderson et al., 1976).*

	Urban	Broadleaf Deciduous Forest
albedo (%)	15	16
Moisture availability (%)	10	30
emissivity (% at 9μm)	88	93
roughness length (cm)	80	50
thermal inertia (cal cm^{-2} K^{-1} $s^{-1/2}$)	0.03	0.04
heat capacity (Jm^{-3} K^{-1})	1.67	2.63

Urban Heat Island Analysis

Figure 1 compares near surface temperatures for the base- and natural-cases. Temperatures over urban areas (Baltimore, MD and Washington, DC) are higher by 1-2 K in the base case confirming the presence of the urban heat island. Base case minus each specific case temperature is shown in Figure 2. Figure 2 shows that on this particular day lack of soil moisture in urban areas was the predominant cause of the urban heat island. The urban heat island caused a circulation to take place similar to the circulation over a warm lake during the nighttime hours by increasing convergence over the warm air in an urban area as shown in Figure 3. More surface convergence and updrafts were present in an urban heat island and more surface divergence and downdrafts were present in areas adjacent to urban areas.

Figure 1: *Base case and natural case near surface temperature at 3pm EDT August 6, 2006. Urban areas are outlined in black and coastline is outlined in gray.*

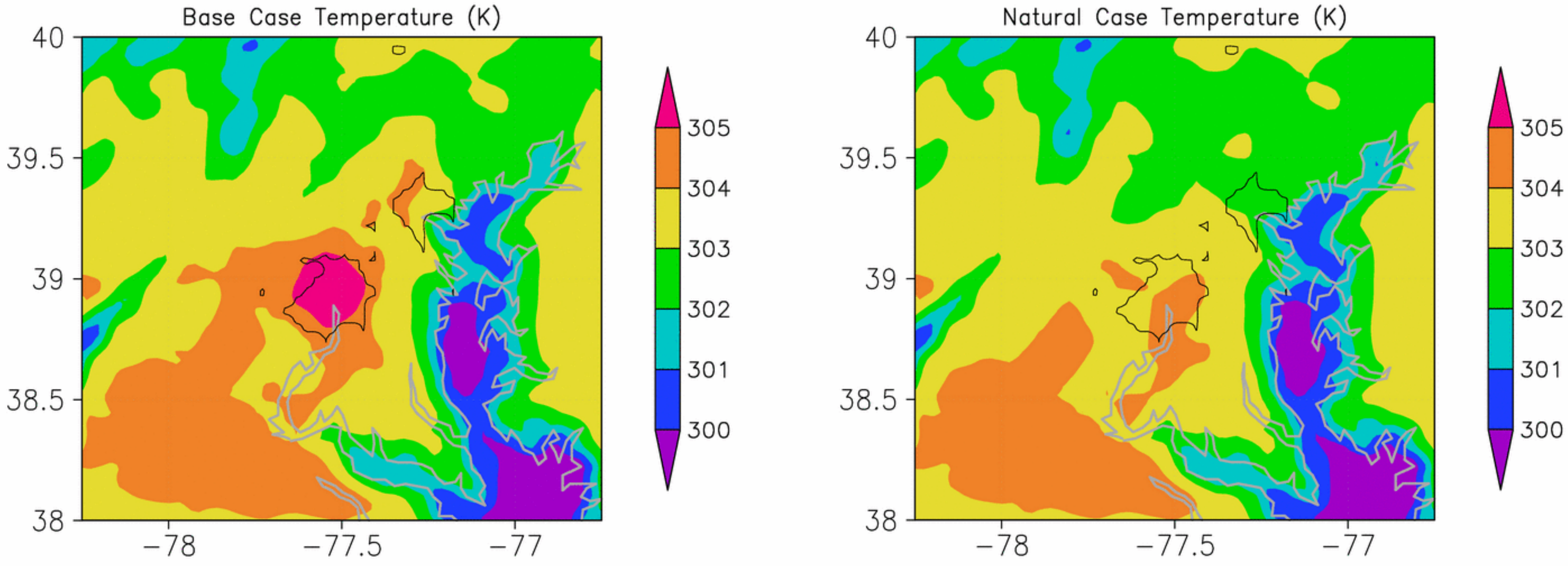


Figure 2: *Base case minus emissivity, roughness length, heat capacity, natural, soil moisture, and albedo cases near surface temperature at 3pm EDT August 6, 2006. Urban areas are outlined in black and coastline is outlined in gray.*

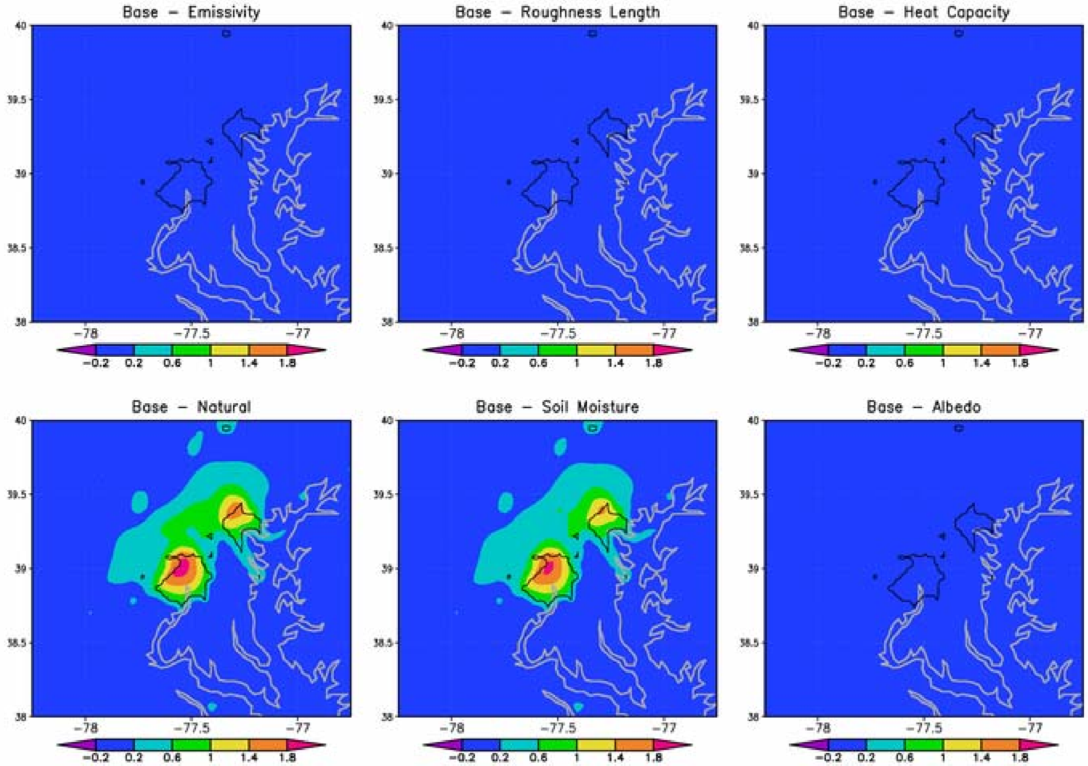
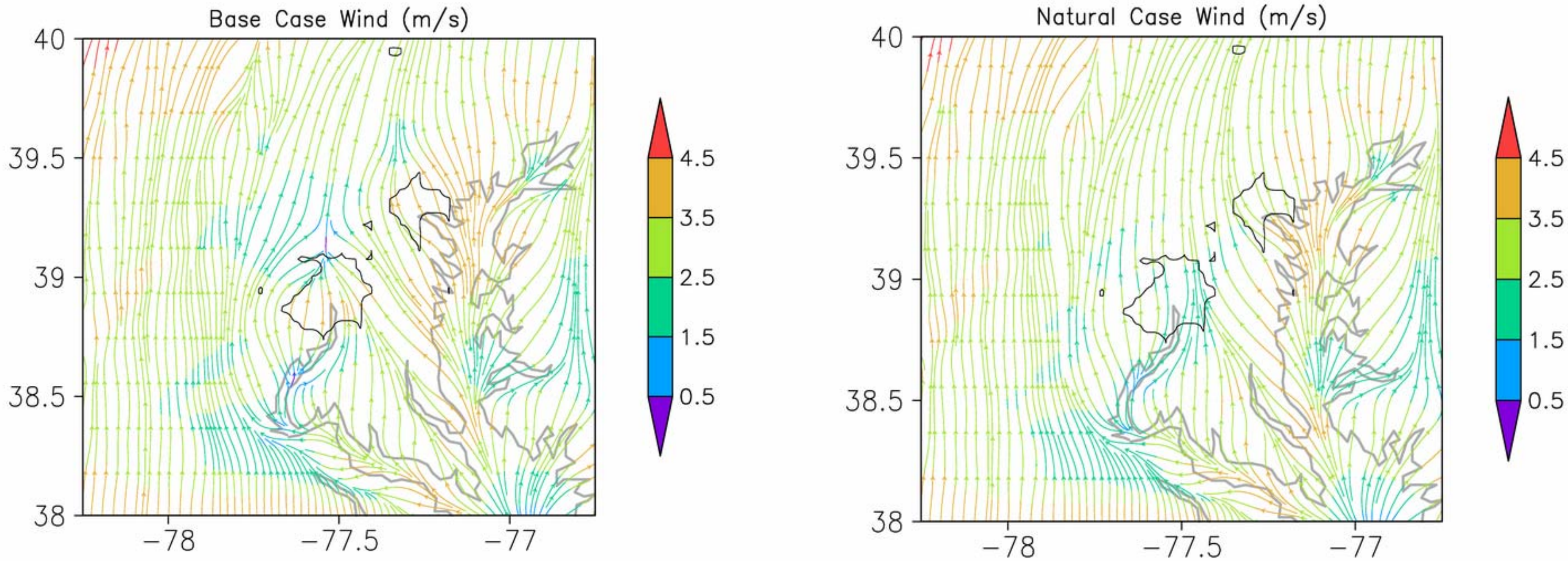


Figure 3: *Wind fields for base and natural cases at 3pm EDT August 6, 2006. Urban areas are outlined in black and coastline is outlined in gray.*



Chesapeake Bay breeze and the Urban Heat Island

In addition, the Washington, DC urban heat island influenced the Chesapeake Bay breeze. Figure 4 shows the base case minus natural case near surface temperature when westerlies were advecting warm air due to the urban heat island toward the Chesapeake Bay. The magnified temperature gradient acted to strengthen the bay breeze so there was more surface convergence (see Figure 5 which shows the near surface wind for the base and natural cases). The increased convergence due to the urban heat island resulted in more rising air over the land and more surface divergence and downdrafts over the cool water during the daytime hours. Differences in vertical velocity between the base and natural case are shown in Figure 6.

Figure 4: *Base minus natural case near surface temperature at 3pm EDT August 7, 2006. Urban areas are outlined in black and coastline is outlined in gray.*

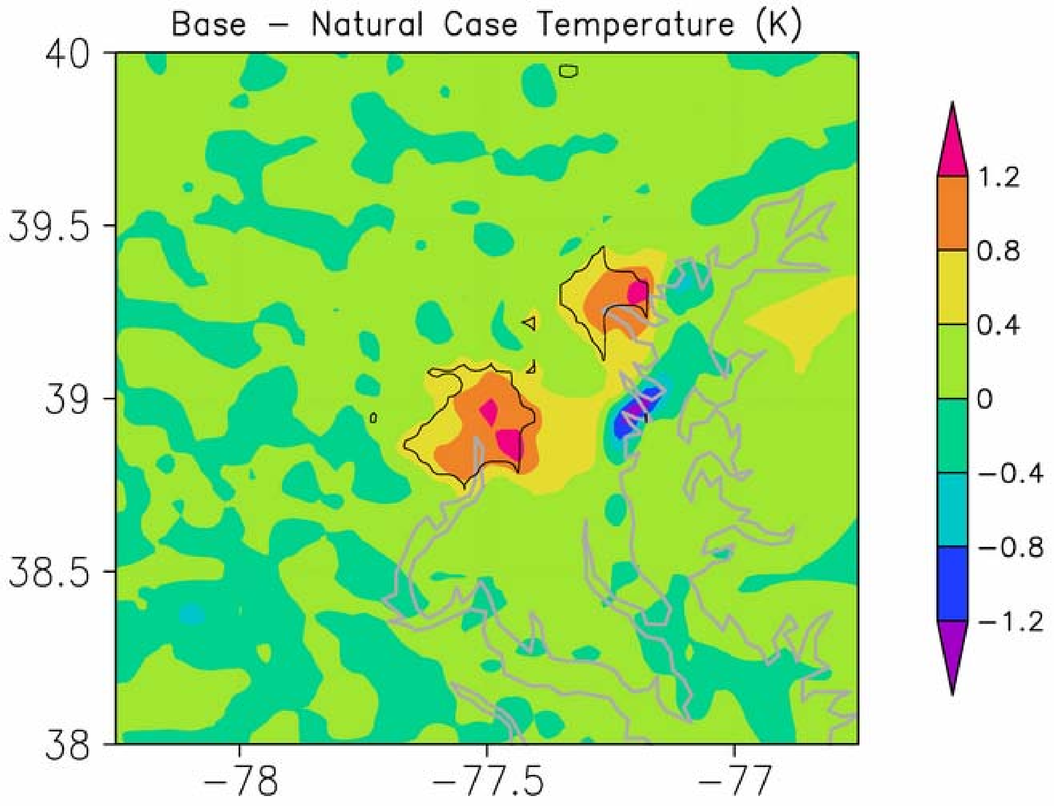


Figure 5: *Base and natural case wind at 3pm EDT August 7, 2006. Urban areas are outlined in black and coastline is outlined in gray.*

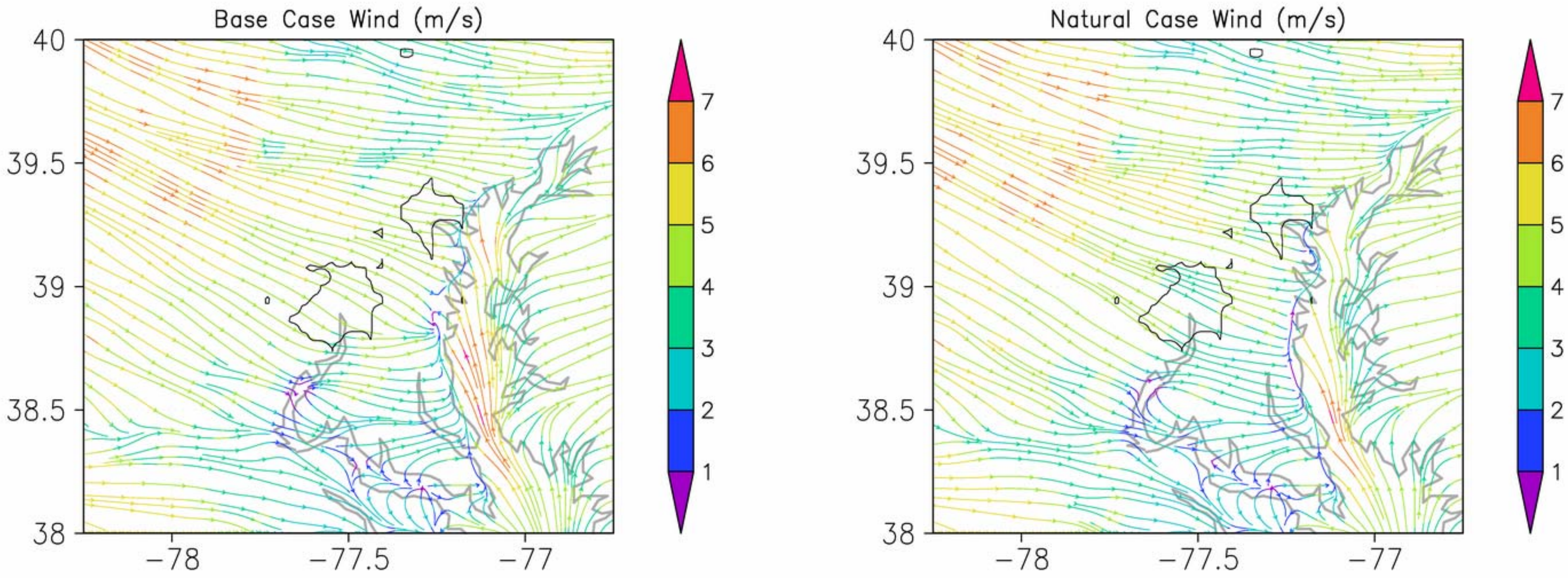
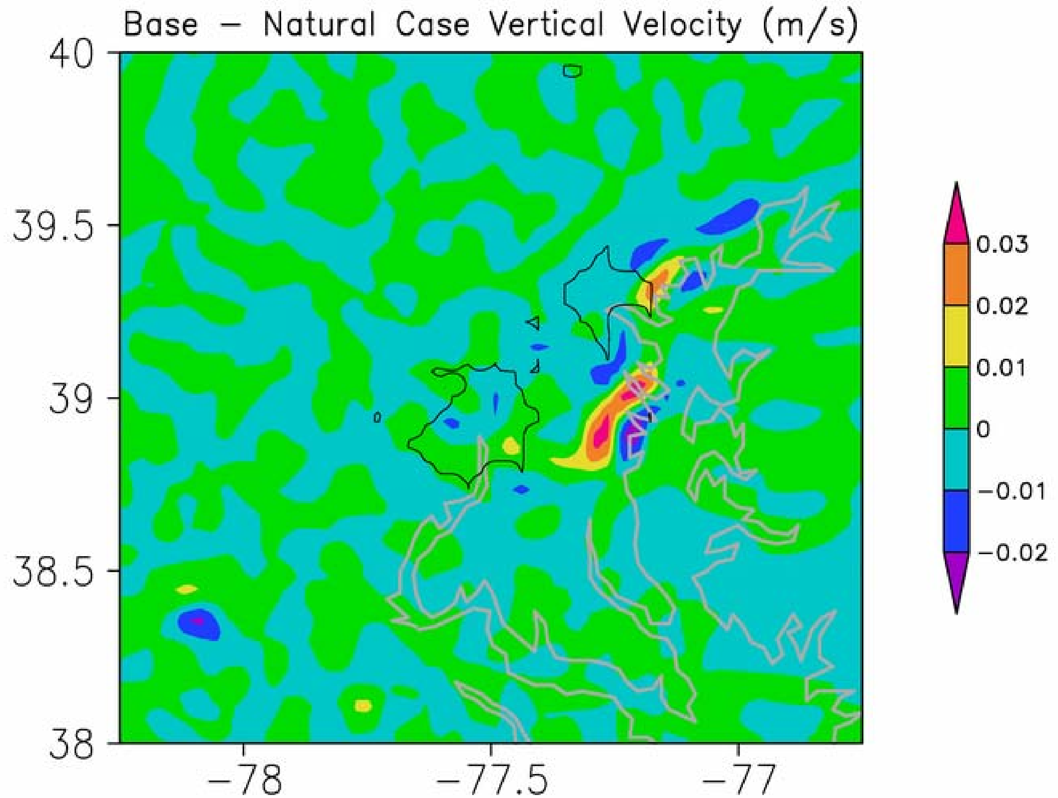


Figure 6: *Base minus natural case vertical velocity at 3pm EDT August 7, 2006. Urban areas are outlined in black and coastline is outlined in gray.*



Significance

Temperature and wind changes due to urbanization may affect precipitation and air quality. Higher surface temperatures increase instability while more surface convergence enhances upward motion. Together these processes can affect cloud formation and precipitation. A change in temperature also affects the rate at which ozone and secondary aerosols are created and destroyed. In addition, changing wind fields modify the ventilation and dispersion of pollutants.

What next?

Future work also includes simulations with the EPA's Community Multi-scale Air Quality (CMAQ) model for a base case and a case with more trees planted in urban areas. The base case will be evaluated with ground, aircraft, and satellite observations. Planting more trees in a city will decrease the urban heat island effect, therefore altering the local meteorology. In addition, more trees in a city will result in more biogenic emissions. Comparing the two simulations will show how changing the urban land-use by planting more trees could alter air quality. Also, Weather Research and Forecasting model with integrated chemistry (WRF-chem) simulations will be performed to investigate how land-use and anthropogenic emissions changes affect precipitation and air quality. The model will be run for a base case, altered land-use case, altered emissions case, and a combination of altered land-use and emissions case to address the question "How do changes to the urban environment affect precipitation and air quality?" The base case will be evaluated with ground, aircraft, and satellite observations.