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MITIGATING NEW YORK CITY'S HEAT ISLAND WITH URBAN FORESTRY, LIVING ROOFS, AND LIGHT SURFACES

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ABSTRACT

New York City, like other large cities, is warmer than surrounding areas due to the urban heat island effect, which is defined as an increase in urban air temperature as compared to surrounding suburban and rural temperature. The development of a heat island has regional-scale impacts on energy demand, air quality, and public health. Heat island mitigation strategies, such as urban forestry, living/green roofs, and light surfaces, could be implemented at the community level within New York City, but their effects need to be tested with comparable methodologies. This study uses a regional climate model (MM5) in combination with observed meteorological, satellite, and GIS data to determine the impact of each of the mitigation strategies on surface and near-surface air temperature in the New York Metropolitan Region over space and time. The effects of localized changes in land-surface cover in six case study areas are evaluated in the context of regional atmospheric mixing.

1. INTRODUCTION

An urban heat island is created when naturally vegetated surfaces – e.g., grass and trees – are replaced with non-reflective, water-resistant impervious surfaces that absorb a high percentage of incoming solar radiation (Taha, 1997). The development of an urban heat island is a time-varying process involving the physical geography and built environment of a metropolitan region (Grimmond and Oke, 1999).

In the presence of high moisture levels, vegetation plays a dominant role in surface cooling through evaporation and latent heat removed from soils and evaporation from plants (known as transpiration) (Taha et al, 1991). In urban areas, where the fraction of the surface covered by vegetation is particularly low and surfaces tend to be water-resistant, potential surface cooling due to the loss of latent heat from vegetation and soil is reduced.

The rate at which solar energy is absorbed and re-radiated depends not only on the physical properties of different surface types, but also on their configuration within the urban landscape, regional meteorology, and localized microclimate (Oke, 1987; Sailor, 1995). This can lead to the formation of local 'hot spots', which may shift in space with diurnal and seasonal cycles, under particular meteorological conditions, and with land-use changes (Unwin, 1980). Thus, it could better be described as an 'urban heat island archipelago'.

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Interactions between patterns of surface heating and regional meteorology determine the overall intensity of the heat island over space and time at each moment. In general, the intensity is greatest on calm, clear days in the summer and fall.

On clear days, incoming short-wave radiation has a direct path to the surface. In this case, internal surface properties, such as heat capacity, play the dominant role in spatial surface-heating differences. On cloudy days, a much larger percentage of incoming radiation is reflected, reducing surface heating. In this case, meteorological conditions tend to outweigh surface properties and the potential for urban heat island development will likely not be realized (Rosenzweig et al., 2005).

The addition of anthropogenic heat and pollutants from power plants, industrial processes, and vehicles into the urban atmosphere can further contribute to the intensity of the urban heat island effect (Taha, 1997). Anthropogenic heat can directly raise near-surface air temperatures while air pollution increases absorption of radiation in the lower troposphere, often contributing to the creation of an inversion layer. The inversion layer not only prevents rising air from cooling at the normal rate, but also affects dispersion of pollutants that are produced in the urban area.

Although the heat island effect occurs throughout the year, its occurrence during the summer months is of particular public policy concern because of the association of higher temperatures with increases in air conditioning demand (Rosenfeld et al., 1995), enhanced air pollution (Hogrefe et al., 2004) and heat-stress related mortality and illness (Sailor et al., 2002; Kunkel et al., 1996; Knowlton et al., 2004).

1.1 The Urban Heat Island in New York City

Urban heat island conditions have been observed in New York City for more than a century (Gedzelman et al, 2003). Currently, New York City's summertime nocturnal heat island averages ~7.2ºF (~4ºC). This means that during the summer months the daily minimum temperature in the city is on average ~7.2ºF (~4ºC) warmer than surrounding suburban and rural areas (Gedzelman et al., 2003, Kirkpatrick and Shulman, 1987).

Satellite imagery shown in this report suggests that during the day, the hotter neighborhoods tend to be in northwestern Brooklyn, eastern Queens (Long Island City), and the South Bronx. Newark, Hoboken, and Jersey City are also part of the New York Metropolitan Region's heat island archipelago. At night, Midtown Manhattan tends to be hottest, and this pattern is observed during other seasons as well (Childs and Raman, 2005).

New York City's heat island can be particularly pronounced during heat waves, which are often characterized by low wind speeds and a reduced sea-breeze, in addition to high temperatures. During heat waves, heat island impacts also tend to be further amplified (Rosenzweig et al., 2005).

2. PROJECT OBJECTIVES

The project sought to provide recommendations to policy-makers based on study results. The specific goals of this project are to:

1. Analyze and model the heat island effect in New York City;
2. Test urban forestry, living roofs, and light surfaces as potential heat island mitigation strategies;
3. Improve scientific understanding of how mitigation strategies might affect New York City's surface and near-surface air temperatures;
4. Summarize results from the mitigation scenario analysis city-wide and across six case studies; and
5. Evaluate potential interactive conseq-uences associated with heat islands with particular attention to land use, electric loads, and potential air quality and/or health impacts.

2.1 Case Study Areas

In addition to the city-wide case study, six smaller case study areas were selected according to several criteria: location within an electrical load pocket, as defined by Con Edison; measurement of warmer than average near-surface air temperatures (i.e., a hot spot); and presence of available area for testing a range of urban heat island mitigation strategies. In addition, an effort was made to include some low-income, high-minority neighborhoods to potentially allow the results to be used to address environmental equity concerns.

- Mid-Manhattan West
- Lower Manhattan East
- Fordham Bronx
- Maspeth Queens
- Crown Heights Brooklyn
- Ocean Parkway Brooklyn

The case study areas are shown in Figure 1. One of the key differences between the case study areas is their available area in which to implement mitigation strategies (Table 1).

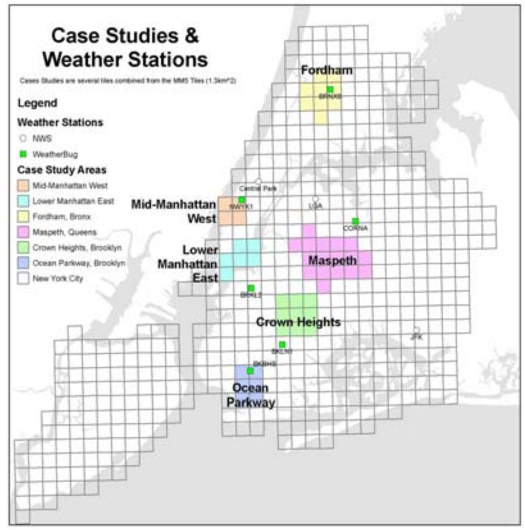

Figure 1. Case study areas and weather stations. Grid boxes correspond to the MM5 model 1.3 km grid.

3. STUDY METHODS, DATA, AND MODELS

The summer of 2002 was chosen as the time period for this study. A remote sensing and geographic information system (GIS) data library was developed to characterize the numerous dimensions of New York City's heat island. Satellite-derived surface temperatures (Figure 2) were regressed on other satellite-derived and/or GIS-based environmental variables to determine the extent to which surface temperature depends on vegetation and albedo and other land-surface characteristics within each case study area.

3.1 Heat Waves Selected

Heat waves were selected using observed meteorological data. National weather service (NWS) data from Central Park were used to identify three heat waves during the summer of 2002. The three heat waves are July 2nd – 4th (HW1), July 28th – August 7th (HW2), and August 11th – August 18th (HW3). A heat wave is defined as at least three consecutive days with maximum temperatures above 90ºF (32.2ºC) in Central Park.

Table 1. Base percentages for each land surface type and potential for mitigation

Case Study Area	Grass (%)	Trees (%)	Impervious (%)	At-Grade Impervious (%)	Impervious Roofs (%)	Est. Avail. for Street Trees (%)
New York City	14.1	21.9	64.1	45.9	18.1	17.0
Mid-Manhattan West	2.6	3.1	94.3	49.3	45.0	26.1
Lower Manhattan East	8.3	8.1	83.6	48.2	35.4	29.4
Fordham Bronx	9.2	22.1	68.7	47.1	21.5	21.1
Maspeth Queens	17.5	22.3	60.2	38.2	22.0	17.9
Crown Heights	8.1	17.2	74.7	45.6	29.1	24.9
Ocean Parkway	5.5	14.8	79.6	50.8	28.9	23.2

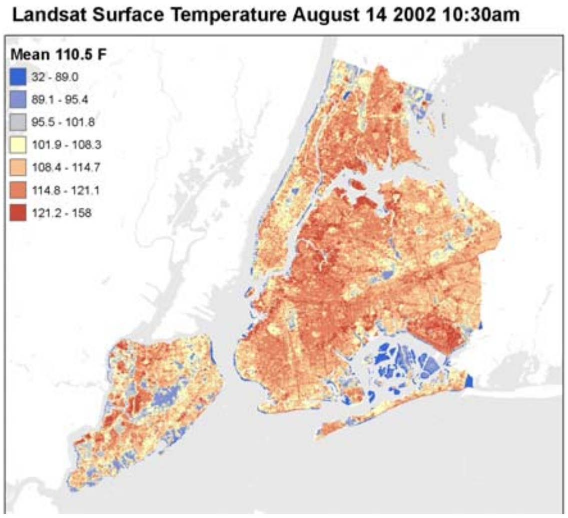

Figure 2. Remotely sensed thermal satellite data. Landsat ETM, August 14, 2002 at 10:30 AM, Band 6, resolution is 60 meters.

HW1 was the hottest and driest of the three heat waves, but only lasted for a few days. HW2 and HW3 were about equally hot, but during HW3 JFK was considerably cooler than Central Park, in part due to winds blowing from the south across the water. Conditions during HW3 were also more humid than during HW2. During HW2 and HW3, scattered showers punctuated the overall dryness.

3.2 Characterization of New York City's Heat Island on Heat-Wave Days

Observed meteorological data and remotely-sensed satellite data for the New York metropolitan region were used to characterize the spatial and temporal dimensions of the city's heat island on August 14, 2002, one of the hottest heat-wave days during the summer of 2002. The NWS data were spatially interpolated across the region to determine spatial patterns in near-surface air temperatures over the course of the day. Landsat data from the same day were used to characterize the spatial dimensions of New York City's surface heat island. The Landsat thermal data have a spatial resolution of 60 meters, and thus reveal surface heating differences at a finer scale than the NWS data. These surface heating differences contribute to the development of the heat island effect by creating local hot spots where energy is retained.

3.3 MM5 Regional Climate Model

The Penn State/NCAR MM5 regional climate model was used to test the mitigation scenarios. The MM5 regional climate model is a state-of-the-art three-dimensional, non-hydrostatic model that dynamically simulates the interactions among a range of land-surface cover and climate variables (Grell et al., 1994 and www.ucar.edu/mm5overview. html).

MM5 version 3.7 was run with high-resolution land-surface data and simultaneous energy balance models for impervious, grass, tree, and water surfaces (MM5 v3.7+SEBM) for each of the three heat waves. Version 3.7 is the latest model release; in this project, version 3.6 was replaced with version 3.7 to improve the sensitivity of near-surface air temperature to different surface types. A key difference between the two versions is the incorporation of a new horizontal diffusion scheme that improves MM5 results in regions with complex topography (e.g. urban areas), especially when MM5 is run at fine grid resolutions (Zaengl, 2002). Version 3.7 also includes an improved upper radiative boundary condition.

Within New York City, MM5 was run at 1.3 km grid resolution (initialized and forced with input from a 4-km domain). The Myeong et al. (2003) database of land-cover in New York City was used to specify a percent area *impervious*, a percent area *grass*, a percent area *trees*, and a percent area *water* within each grid box to achieve sub-grid scale resolution of the different land-surface types. MM5 results for the 3 PM afternoon temperature peak and the 6 PM evening energy peak were used in the mitigation scenario analysis. In MM5, peak surface temperatures tend to occur in the mid-afternoon around 3 PM. Energy use is of particular concern during the evening peak demand time represented by 6 PM.

Model performance was evaluated by comparing hourly near-surface air temperatures simulated by the MM5 model to National Weather Service and Weatherbug weather station data using the average error, root mean square error (RMSE), and correlation coefficients. Wind speed, wind direction, and sea-level pressures simulated by the MM5 were also compared to observations. The comparisons showed that the model simulation represent regional climate adequately. MM5 was then used to determine potential reductions in surface temperature and near-surface air temperature with each mitigation scenario during the three heat waves. The mitigation scenarios are listed in Table 2.

4. RESULTS

Results for the maximum conversion scenarios ("100 % available areas are converted to either vegetation or high albedo") 2-meter air temperature reductions are shown In Table 3. The top half of the table gives 24-hour average reductions and the bottom half gives 3:00 pm reductions, for both New York City as a whole, and the six case study areas In general, substantial reductions in New York City surface and near-surface air temperature can be achieved by implementing heat island mitigation strategies. Vegetation cools surfaces more effectively than increases in albedo, and the most effective mitigation strategy per unit area redeveloped is curbside planting. However, the greatest absolute temperature reductions are possible with light surfaces because 64% of New York City's surface area could be redeveloped from dark, impervious surfaces to lighter high-albedo surfaces. New street trees could be planted in 17% of the city's surface area.

Living roofs offer greater cooling per unit area than light surfaces, but less cooling per unit area than curbside planting. They may be the best option in neighborhoods with limited street-level redevelopment opportunities; however, given their rooftop location, they may have less of an impact on energy demand than tree planting, due to lack of shading on sides of buildings.

5. CONCLUSIONS

Results of this study show that the mitigation strategies tested can reduce surface and near-surface air temperatures, but there is substantial variability in the magnitude of their effect across scenarios, case study areas, and heat wave days. Potential reductions in near-surface air temperature may be underestimated because the effect of shading is not represented by the regional climate model and because atmospheric mixing tends to dampen land-surface cover changes.

Although street trees provide the greatest cooling potential per unit area, light surfaces provide the greatest overall cooling potential when available area is taken into account because there is more available area in which to implement this strategy compared to the other strategies.

5.1 Other Benefits of Mitigation Strategies

In addition to reduced energy demand, mitigation of New York City's heat island could improve air quality and public health, as well as reduce the city's contribution to greenhouse gas emissions. Reduced energy demand could also reduce the cost of air conditioning for both residential and commercial customers.

5.2 Recommendations

Recommendations arising from the results of this study include:

1) Implement urban heat island mitigation strategies appropriate to conditions in individual neighborhoods and communities.
2) Plant street trees as an effective strategy for urban heat island mitigation in New York City.
3) Implement urban heat island strategies at large enough spatial extents to be effective.
4) Monitor temperature of tree-planting programs and green roofs to observe actual mitigation levels over time. Use results to improve calibration and validation of energy balance and regional climate models.

Continue improving satellite data analyses, meteorological datasets, and regional climate models to better represent.

Table 2. Mitigation scenarios

Strategy	Mitigation Scenario
Urban Forestry	1) Urban Forestry/Grass-to-Trees (open space planting) 2) Urban Forestry/Street-to-Trees (curbside planting) 3) Urban Forestry/Grass + Street-to-Trees (open space + curbside planting)
Light Surfaces	4) Light Surfaces/Roof-to-High Albedo (light roofs) 5) Light Surfaces/Impervious-to-High Albedo (light surfaces)
Living Roofs	6) Living Roofs/Roof-to-Grass
Ecological Infrastructure	7) Urban Forestry/Grass + Street-to-Trees and Living Roofs
Urban Forestry + Light Roofs	8) Urban Forestry/Grass + Street-to-Trees and Light Roofs
Combination of All	9) 50% Open Space + 50% Curbside + 25% Living Roofs + 25% Light Roofs

Table 3. MM5 weighted average near-surface air temperature reductions for selected mitigation scenarios averaged over all times of day, at 3 PM.

Average reduction over all times of day	Open Space Planting (ºF)	Curbside Planting (ºF)	Living Roofs (ºF)	Light Roofs (ºF)	Light Surfaces (ºF)	Ecological Infrastructure (ºF)	Urban Forestry + Light Roofs (ºF)
New York City	-0.1	-0.6	-0.4	-0.4	-1.3	-1.3	-1.2
Mid-Manhattan West	0.0	-0.9	-1.1	-0.8	-1.7	-1.9	-1.7
Lower Manhattan East	-0.1	-1.0	-0.9	-0.7	-1.6	-1.7	-1.6
Fordham Bronx	-0.1	-0.7	-0.5	-0.4	-1.3	-1.6	-1.5
Maspeth Queens	-0.2	-0.6	-0.5	-0.4	-1.1	-1.3	-1.2
Crown Heights Brooklyn	-0.1	-0.9	-0.7	-0.6	-1.4	-1.8	-1.6
Ocean Parkway Brooklyn	-0.1	-0.8	-0.7	-0.6	-1.5	-1.4	-1.3
Average 3 PM Reduction							
New York City	-0.3	-1.0	-0.8	-0.6	-2.2	-1.8	-1.6
Mid-Manhattan West	0.0	-1.5	-1.8	-1.4	-2.9	-2.6	-2.3
Lower Manhattan East	-0.2	-1.8	-1.5	-1.2	-2.8	-2.5	-2.4
Fordham Bronx	-0.2	-1.2	-0.8	-0.7	-2.1	-1.9	-1.8
Maspeth Queens	-0.3	-1.1	-0.9	-0.7	-2.0	-1.8	-1.7
Crown Heights Brooklyn	-0.2	-1.5	-1.2	-1.0	-2.5	-2.4	-2.2
Ocean Parkway Brooklyn	-0.1	-1.5	-1.3	-1.0	-2.8	-2.1	-2.0

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