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URBAN CLIMATE MODELING, HEAT ISLAND MITIGATION AND LOCAL KNOWLEDGE: CO-PRODUCING SCIENCE FOR URBAN POLICY

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ABSTRACT

Over the past few decades, climate shifted from a local to a global issue with rising concern over global climate change. Now, studies on urban climate and heat island mitigation are re-localizing climate science, often adapting global models to the city scale. This paper explores how environmental planners engaged with climate scientists to model heat island mitigation strategies, including urban forestry, green roofs, and light surfaces. Drawing on original data documenting the New York Regional Heat Island Initiative (NYRHII), we present three case studies highlighting how global science was localized as researchers struggled to present scientifically valid and politically acceptable results. Through the cases, we demonstrate how science-policy expertise was co-produced. The frame of co-production suggests that legitimate science policy must draw from both technical and social insights. In the first case, we highlight the process of co-production by exploring how the local knowledge of planners was incorporated into regional-scale climate models, altering simulated reductions in urban air temperature. We characterize local knowledge as contextually valid information that is not derived solely through disciplinary techniques but relies on the experiences and 'expertise' of local actors. The second case explores how municipal agency involvement shaped the mitigation scenarios by providing context on available space for tree planting and high-albedo paving materials, altering the study's policy implications. A third case explores how the collaborative research altered the implementation of urban forestry programs in New York City, and particularly the South Bronx. Since heat island mitigation requires intervention in the face of high technical and political uncertainty, the process of co-production – where planners and researchers collaboratively review policy-relevant science – is necessary for both professional and local knowledge to use the best available science to design locally appropriate policies. We conclude that local knowledge, too often overlooked or dismissed by climate scientists, is crucial for making locally relevant urban heat island science policy.

1. INTRODUCTION

Urban environmental planners increasingly are faced with two seemingly divergent policy trends: the globalization of environmental policy issues and the devolution of policy responsibilities to local, often municipal, governments. Local governments are commissioning expert scientific advice, formulating policy goals, setting standards, and developing new institutions for environmental governance and sustainability. These trends have placed new demands on scientists to effectively communicate their findings in new settings and scales, and on local policy makers who are faced with combining global science with contextual knowledge of their city or region. Climate change is one policy arena where planners are increasingly localizing global environmental science.

We first explore in brief how climate shifted from a local to a global issue. Next, we present three case studies of urban heat island (UHI) mitigation highlighting how global science was re-localized as researchers struggled to present scientifically valid and politically acceptable results.

1.1 Climate change and the urban heat island

Global climate change caused by increasing concentrations of carbon dioxide (CO_2) and other greenhouse gases is altering regional and local climates around the world. In response, some municipal governments are setting local greenhouse gas emissions reduction targets and/or developing climate change adaptation strategies.

Many cities face the additional challenge of local climate change associated with urbanization. Paving over vegetation with heat-trapping, impervious surfaces directly alters local climate in urban areas leading to elevated near-surface air temperature, a condition referred to as the urban heat island (UHI).[1] Global climate change may intensify local heat islands (Rosenzweig et al. 2005).

The urban heat island effect can be detected throughout the year, but is of particular public policy concern during summer because higher near-surface air temperature is associated with increases in electricity demand for air conditioning, air pollution, and heat-stress related mortality and illness (Rosenfeld et al. 1995; Nowak et al. 2000; Sailor et al. 2002; Hogrefe et al. 2004). Exposure to excessive heat kills more people each year in the United States than deaths from all other weather-related events combined (MMWR 2006). In addition to mortality, hospital admissions due to serious illnesses, such as heat stroke, heat exhaustion, cardiovascular, and respiratory problems, are a serious public health concern related to heat events (Semenza et al. 1999).

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[1] For further reading on urban climate and urban heat islands, see Landsberg (1981), Oke (1987), and Taha (1997). Arnfield (2003) and Grimmond (2007) review the heat island literature.

Heat island impacts interact with aging energy and water infrastructure and the anticipated regional effects of global climate change. This has led local decision makers to ask whether heat island mitigation can help to address some of these related urban challenges, for example by reducing electricity demand for cooling, absorbing stormwater runoff, and reducing the health impacts of heat waves. Heat island mitigation strategies include planting trees, incorporating vegetation into rooftops (green roofs), and increasing the reflectivity (albedo) of impervious surfaces.

1.2 Re-scaling global science for urban policy

This paper explores how scientists studying heat island mitigation strategies for the city of New York grappled with localizing global climate models, and how policy and social objectives of municipal planners shaped this process. We argue that urban heat island mitigation is a key site for studying how global science is "re-scaled" for urban policy making (EPA 2006). UHI mitigation also requires planners to grapple with how global science can be attentive to local inequities in vulnerability, since access to material resources, social networks and other protective services can influence which groups and places are more or less susceptible to adverse impacts from a heat event (Klinenberg 2003).

Through the case studies, we demonstrate how science-policy expertise was co-produced (Jasanoff 2004) by exploring how the local knowledge of planners was incorporated into climate models. We characterize local knowledge as contextually valid information that is not derived solely through disciplinary techniques but relies on the experiences and 'expertise' of local actors.

We also illustrate how healthy city planning must draw on what Funtowitz and Ravitz (1993) have called post-normal science. In post-normal science, social and public policy makers ask questions of science that conventional scientific methods alone cannot answer. Instead, policy decisions must rely on science that: (a) crosses disciplinary lines; (b) enters into previously unknown investigative territories; (c) requires the deployment of new methods, instruments, protocols, and experimental systems, and; (d) involves politically sensitive processes and results (Jasanoff 1990).

Healthy city planning requires a new orientation to science that embraces these characteristics and aims to incorporate them into the analytic and intervention process. The co-production framework offers one such orientation to science that aims to embrace the social, uncertain and emergent characteristics of healthy city planning by suggesting that legitimate science policy must draw from both technical and social insights. Co-production also extends Habermas' (1975) critical discussion of 'decisionism,' or a model where policy processes are conceptualized as a series of completely unrelated decisions over issue meaning, authority and legitimacy, each one of which has no interaction with any other. Instead, co-production aims to problematize the origins and substance of the meanings of policy issues, who was included or left out of generating these meanings, and, builds on constructivist work in the social sciences highlighting that scientific legitimacy is simultaneously a social, political and material phenomenon, none of which can be neatly disentangled from the other (Hacking 1999).

As we will investigate throughout this paper, UHI mitigation raises challenging questions for municipal planners that are "trans-science," or those involving science but unanswerable by technical expertise alone (Weinberg 1972). Ultimately, this paper argues that the processes of localizing in environmental politics shifts the fundamental criteria for credible and accountable regulatory science, from factors assessed only by detached scientific peers to a more 'socially robust science,' where science is valid not only inside but outside the laboratory, validity is achieved through involving an extended group of experts, including lay 'experts,' and accountability reflects norms of democratic politics.

2. FROM LOCAL TO GLOBAL IN CLIMATE DISCOURSE

Over the past few decades, climate shifted from a local to a global issue with rising concern over global climate change. While few people would object that climate change is a global phenomenon, the organization of international political action and global institutions to address this problem is relatively new. Further, the recognition that urban policy and design have central roles to play in minimizing the severity of micro-temperature increases, and resulting morbidity and mortality, is an even more recent policy frame. For most of the twentieth century, the development of climatology as a field of scientific inquiry took place as part of the broader field of meteorology. The 1941 Yearbook of Agriculture, Climate and Man, published by the US Department of Agriculture, stated that: "The distinction between climate and weather is more or less artificial, since the climate of a place is merely a build-up of all the weather from day to day and the weather is merely a day-by-day break down of the climate (Hambidge 1941). By 1978, Robert White, then chief of he US National Weather Service and World Climate Conference, defined climate as pertaining to: "the statistics of weather parameters over time periods of two weeks and greater" (White 1978). For much of the twentieth century, climate was another way of describing the weather and there was little impetus to intergovernmental institutions to make climate policy.

By 1988, climate began to take on an international focus when the Intergovernmental Panel on Climate Change (IPCC) was created as a joint endeavor of the United Nations Environment Program and the World Meteorology Organization. The UN General Assembly charged the IPCC with conducting a review of the knowledge on climate change and making recommendations for a possible future international convention on climate. By the late 1980s, a shift toward a global representation of climate had occurred in scientific and policy discourses. This shift was facilitated by computer models of atmospheric circulation that represented the Earth's climate as an integrated, global system (Edwards 2001). The US National Climate Program embraced computer modeling to replace statistical aggregation as the central focus of climatology (NRC 1982). As modeling grew, climate was no longer studied as a separate entity, but instead as a component of the earth system linked to the world's oceans, vegetation, and ice caps. By the early 1990s, the term climate had gone from signifying an aggregation of local weather patterns to signifying an ontologically unitary whole capable of being understood and managed on a scale no smaller than the globe itself (Miller 2001).

The work of the IPCC derived its understanding of climate from the work of climate modelers. Influential IPCC reports in 1990 and 1995 organized findings around a systemic view of climate and climate change, and made clear the necessity for, and possibility of, a global politics of climate (IPCC 1995). In less than a decade, the IPCC helped shift the climate discourse from one of changes in local and regional weather patterns to one of degradation of the global environment, effectively globalizing the climate. At the same time, the IPCC brought together delegates from around the world under the auspices of the World Climate Conference, setting the scale for appropriate policy responses. However, the involvement of political delegates again shifted the discourse of climate change, from an issue controlled by an 'epistemic community' of IPCC scientists (Haas 1992), to an issue that raised fundamental questions about poverty, development, equity, and access to technological and financial resources, particularly for developing countries. The framework to address climate change was eventually split into separate working groups, where "political" questions would be addressed by an International Negotiating Committee and "scientific" issues by the IPCC.

The global discourse of climate change has failed to generate significant international action to reduce the CO_2 concentration in the atmosphere. However, many local governments have committed themselves to potentially costly programs of action on climate change mitigation and adaptation. For example, by December 2006, over 230 American cities – including New York, Los Angeles and Chicago - had signed the US Mayors Climate Protection Agreement, committing over 50 million people living in these cities to meet or beat the emissions reduction targets defined by the Kyoto Protocol (ICLEI 2006). A number of cities including London, New York, Boston, Halifax, Vancouver, and Seattle have assessed likely climate change impacts and developed adaptation plans (Clean Air Partnership 2007). In some cases, co-benefits of climate change adaptation and heat island mitigation have been identified – for example, heat island mitigation can reduce stress on the electricity distribution system in the summertime. Some cities, including Austin, Seattle, Washington D.C., and Tokyo have passed legislation specifically aimed at mitigating the urban heat island. These efforts reflect, in part, the notion that local accountability can act as an independent criterion for evaluating global scientific research.

3. CASE STUDIES ON THE RE-LOCALIZATION OF GLOBAL SCIENCE

Through three case studies, we highlight the challenges global science encounters when trying to make predictions and policy prescriptions at the micro-scale, and the important, but non-objective inputs that come from local knowledge. In the first case, we demonstrate how the local knowledge of planners was incorporated into climate models, altering simulated reductions in urban air temperature. The second case explores how municipal agency involvement shaped the mitigation scenarios by providing context on available space for tree planting and high-albedo paving materials, altering the study's policy implications. A third case explores how the collaborative research altered the implementation of urban forestry programs in New York City, and particularly the South Bronx.

We draw on original data documenting the New York City Regional Heat Island Initiative (NYCRHII) including meeting minutes and presentations, email correspondence between researchers and an advisory committee, report drafts, reviewer comments, and internal research notes. The NYCRHII is a research consortium consisting of the Columbia University Center for Climate Systems Research, the Hunter College – City University of New York (CUNY) Geography Department, and SAIC, a scientific consulting firm based in Albany. In 2004, the New York State Energy Research and Development Authority (NYSERDA), a public benefit corporation that funds research into energy supply and efficiency, as well as energy-related environmental issues in New York State, sponsored a NYCRHII effort that aimed to combine modeling of urban climate in NYC with an evaluation of the temperature reduction benefits and cost-effectiveness of UHI mitigation strategies (Rosenzweig et al. 2006).

The broad range of links between heat island mitigation and other local environmental policy goals provided an opportunity for NYSERDA to convene a broad-based Advisory Committee of stakeholders interested in understanding how their specific mandates and priorities might overlap with objectives that could be achieved through heat island mitigation.[2] The goals of greatest interest to the Advisory Committee included reducing peak electricity demand in the summertime, improving quality of life through neighborhood greening, and addressing environmental equity concerns (Rosenzweig et al. 2006).

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[2] The advisory committee consisted of the following agencies and organizations: United States Department of Agriculture Forest Service; New York Energy Consumers Council, Inc.; New York City Mayor's Office of Environmental Coordination; Sustainable Energy Partnerships; New York City Department of Design and Construction; United States Environmental Protection Agency – Region II; New York City Department of Parks and Recreation; Consolidated Edison Company of New York; Environmental Energy Alliance of New York; New York City Department of City Planning; New York State Department of Environmental Conservation.

3.1 Localizing global climate models

Urban heat island conditions have been observed in New York City for more than a century (Rosenthal et al., 2003). Currently, the heat island signal – measured as the difference between urban core and surrounding rural near-surface air temperature readings taken at National Weather Service stations – averages ~7.2ºF, meaning that during the summer months the daily minimum temperature in the city is on average ~7.2ºF warmer than surrounding suburban and rural areas (Gedzelman et al. 2003; Kirkpatrick and Shulman 1987; Gaffin et al. 2008).[3] Satellite imagery (Figure 1) suggests that radiative surface (skin) temperatures also vary across city neighborhoods, with northwestern Brooklyn, eastern Queens (Long Island City) and the South Bronx the warmest areas during the day while Midtown Manhattan tends to be the warmest at night.[4] New York City's heat island can be particularly pronounced during heat waves, which are often characterized by low wind speed, in addition to high temperature (Rosenzweig et al. 2005).

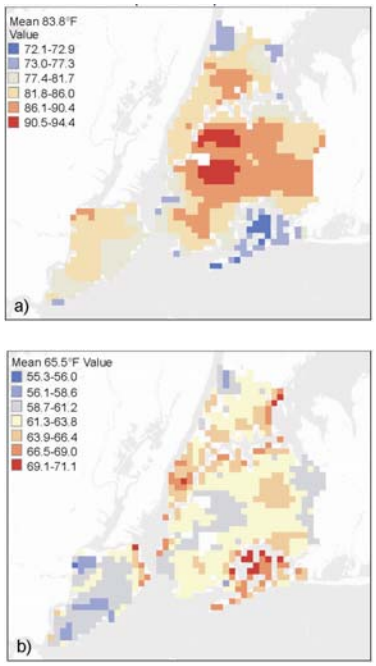

Figure 1. New York City surface (skin) temperature. a) September 8 002, 10:30 AM EST. b) September 8 2002, 10:30 PM EST. Notes: Data were extracted from remotely-sensed MODIS land-surface temperature and emissivity data. Spatial resolution is 1 km. *Source: Rosenzweig et al. (2006).*

Scientists with the NYCRHII combined climate modeling with analysis of remotely-sensed and spatial data including radiative surface (skin) temperature, reflectivity of surfaces, vegetation density, street and intersection network densities, building heights, and neighborhood energy use. The ability of the NYCRHII to bring these disparate data sets together through an interdisciplinary research approach gave the team authority in both global science and localization.

The climate modeling team used the Pennsylvania State University/National Corporation for Atmospheric Research Mesoscale Model (MM5) to compare the possible effectiveness of each of the mitigation strategies at reducing near-surface air temperature in several case study neighborhoods.[5] The strategies and neighborhoods were selected collaboratively by researchers and advisors. The principal strategies consisted of: (a) planting trees in open spaces (grassy areas) or along streets; (b) blanketing rooftops with vegetation (living roofs/green roofs); and, (c) increasing the reflectivity of built surfaces (high-albedo roofs and surfaces). The case study neighborhoods were: Mid-Manhattan West, Lower Manhattan East, Fordham in the Bronx, Maspeth in Queens, and Crown Heights and Ocean Parkway, both in Brooklyn (Rosenzweig et al. 2006).

Urban climate modeling required the team to understand and predict the behavior of the Earth's climate system in a heterogeneous, urban setting. Constructing realistic mitigation scenarios that could be evaluated using the model also required an intimate knowledge of New York City.

One of the first challenges for the NYCRHII was downscaling the MM5 regional climate model to obtain variation at the scale of an urban neighborhood. This required specifying variables at a modeling resolution of 1.3 km, rather than the 4 km or greater resolution at which MM5 is normally run. The team also incorporated high-resolution land-surface cover data to better represent the mix of trees, grass, and built surfaces in each neighborhood (Myeong et al. 2001; OASIS 2001).

The climate modelers saw this 'localization challenge' not as a constraint, but as an opportunity to innovate with new modeling techniques and data inputs (3 May 2005 conference call notes). Yet, a key challenge arose after initial model predictions suggested that the selected UHI mitigation scenarios - would not significantly reduce local temperatures. MM5 model runs suggested that potential temperature reductions on the order of 0.2ºF were possible for most of the individual mitigation strategies (i.e., open-space planting, street trees, green roofs, and light roofs) if implemented in 50% of the available area for these interventions, and twice that if implemented in 100% of the available area (6 July 2005 draft report).

When these results were presented to the Advisory Committee, they noted that the NYCRHII results contrasted a 2002 report by the North East State

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[3] Temperatures are reported in Fahrenheit throughout this paper for consistency with the NYCRHII report.

[4] The heat island signal is traditionally measured as the urban-rural difference in near-surface air temperature. Variation in radiative surface (skin) temperature – often studied using remotely-sensed satellite imagery – has helped to characterize more fully surface heating characteristics of a city and how they contribute to local variation in near-surface air temperature. For additional reading, see Oke (2006) and Rosenzweig et al. (2008).

[5] See Lynn et al. (2007) and Rosenzweig et al. (2008) for more information on the modeling strategy.

Forester's Association that found near-surface air temperature reductions of up to 1.8ºF on a summer afternoon in Manhattan when trees were added to all available open space in NYC (Luley and Bond 2002). The NYCRHII research team agreed with the local policy makers that the MM5 model results were low and, at least anecdotally, that the limited temperature reductions from the different mitigation scenarios might need to be re-evaluated (18 August 2005 email). Given the low results, comments from advisors began to center on the need to "communicate that this is a climate modeling effort on a regional basis complicated by enormously complex urban land use, building and street geometry, as well as dynamic drivers like wind, rivers, ocean effects," and "as a modeling effort includes considerable uncertainties," as well as "explicitly lay out how this study is different from prior efforts" (22 August 2005 email). Using recommendations from the Advisory Committee, the research team went back to work focusing on whether they had properly represented the urban environment in their model. In addition, the modelers reviewed the model outputs for surface and near-surface temperatures, eventually proposing "re-interpolation of near-surface air temperature for selected heatwave(s) and recalculation of key mitigation scenario results" (26 August 2005 email).

In modeling studies of heat island mitigation, the temperature at 2-meters above the ground, often referred to as near-surface air temperature, generally is the variable of interest. In a city, this would be defined at human height – 2-meters above the sidewalk. In a model, features such as buildings, grass, and trees that vary in height are flattened onto the surface layer and described with numeric parameters. Difficulty arises in interpreting the results – is the 2-meter temperature still 2-meters above the ground, or is it 2-meters above the average building height, or 2-meters above the tops of trees? Does the 2-meter temperature – which the model derives from its simulation of temperatures at higher levels in the atmosphere – adequately account for the strong influence of heat-trapping built surfaces in the urban environment?

The research team debated internally over how to re-work the modeled "near-surface air temperature" to better reflect expected conditions in New York City. While some members of the research team expressed confidence that the original temperature outputs reflected the best of global climate science, others were concerned that the results showed almost no temperature variations in NYC despite the radically different mitigation scenarios. In response to one team member's suggestion that a weighted average of simulated 2-meter air temperature and radiative surface temperature be used, another team member commented:

> It doesn't make sense to interpolate between two meters and the surface…the mitigated ground surface will be cool, but the overlying air will be warm (although less than without mitigation)…Instead, I would recommend to tell the story as it is, and take the opportunity to teach our clients some science at the same time (10 September 2005 email).

One of the projects external advisors had been involved in the modeling for the North East State Forester's Association Study. When asked for advice, he wrote:

> We did use the average of the ground and lowest layer temperatures to generate vegetative emissions. However, all subsequent analysis involved either the ground or layer 1 temperatures by themselves (no averaging)…Perhaps there are better ways to estimate near-surface temps" (30 August 2005 email).

Nonetheless, the eventual consensus was that given low confidence in the mitigation results, a weighted average was the best approach. By October 2005, only three months after the July 6 report first suggested limited temperature variations, the NYCRHII team decided to generate a composite near-surface air temperature that would then be used to estimate the possible effectiveness of the mitigation scenarios. The composite temperature weighted the local surface temperature (e.g. the temperature of the asphalt road, grass, tree-canopy, or rooftop) 30% and the original 2-meter air temperature 70%.[6] An October 2005, draft report noted that:

> Because the 2-meter air temperatures calculated with MM5 do not capture the full effect of New York City's highly heterogeneous surfaces on the city's heat island, a weighted average of MM5 calculated surface and 2-meter air temperatures was calculated to better represent New York City's near-surface air temperature.

In a subsequent peer-reviewed article based on the NYCRHII research, the term 'weighted average' was replaced with 'urban air temperature', with the following explanation:

> The designation of urban air temperature encompasses the effect of a heterogeneous mix of land-surface cover, including variation in the height of built surfaces and vegetation, on surface air temperature within the urban canopy layer (Rosenzweig et al. 2008).

This localization of global science occurred largely because state and city advisors did not view the original NYCRHII outputs as consistent with their understanding of likely temperature change and the impact of mitigation scenarios. While the climate scientists grappled with whether to respond to these concerns, their ultimate decision to alter the model based on this 'local knowledge' would radically change the project's results. After generating a new set of estimated changes in (urbanized) near-surface air temperature (Table 1, October 2005 results), the NYCRHII was now able to weigh-in on the efficacy of the different mitigation scenarios.

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[6] Weights were arrived at by optimizing the fit of the linear weighting function to the observed data by minimizing root mean square error over all case study areas.

Table 1. Selected mitigation scenario results presented in the July 2005 draft, October 2005 draft, and June 2006 final report. Numbers correspond to the average near-surface air temperature reduction simulated with the MM5 regional climate model. Differences in temperature reductions across the case study areas reflect differences in the existing configuration of the neighborhood and available area for implementing mitigation strategies. Differences in near-surface air temperature reduction across mitigation strategies reflect differences in the cooling potential of each strategy per unit area and the available area for implementation. Differences across the drafts primarily reflect a change in how near-surface air temperature was defined and calculated between the July and October 2005 drafts (see the first case study, discussed in section 3.1), and a change in how the available area for implementation of some strategies was changed between the October 2005 and June 2006 drafts (see the second case study, discussed in section 3.2).

	Urban heat island mitigation strategy								
	Street trees (ºF)			**Green (living) roofs (ºF)**			**High-albedo (light) surfaces (ºF)**		
Case Study Area	Jul 2005	Oct 2005	Jun 2006	Jul 2005	Oct 2005	Jun 2006	Jul 2005	Oct 2005	Jun 2006
New York City	-0.2	-0.6	-0.2	-0.2	-0.4	-0.3	-0.5	-1.3	-0.4
Mid-Manhattan West	-0.4	-0.9	-0.3	-0.3	-1.1	-0.9	-0.5	-1.7	-0.7
Lower Manhattan East	-0.4	-1.0	-0.3	-0.3	-0.9	-0.7	-0.6	-1.6	-0.6
Fordham Bronx	-0.2	-.0.7	-0.4	-0.2	-0.5	-0.4	-0.5	-1.3	-0.4
Maspeth Queens	-0.2	-0.6	-0.2	-0.2	-0.5	-0.4	-0.5	-1.1	-0.4
Crown Heights Brooklyn	-0.2	-0.9	-0.5	-0.3	-0.7	-0.5	-0.5	-1.4	-0.5
Ocean Parkway Brooklyn	-0.2	-0.8	-0.5	-0.2	-0.7	-0.6	-0.5	-1.5	-0.5
	Jul 2005	Oct 2005	Jun 2006	Jul 2005	Oct 2005	Jun 2006	Jul 2005	Oct 2005	Jun 2006
Primary reason for change	Original results	Shift from 2-meter temp to average near-surface temp	Parks Dept. steet-tree planting data	Original results	Shift from 2-meter temp to average near-surface temp	Reduced available area based on green roofs research	Original results	Shift from 2-meter temp to average near-surface temp	Change in assumed materials and thus per-unit area cooling
Primary responsible party	Original results	Climate modeling team	NYC Parks Dept. advisors	Original results	Climate modeling team	Climate modeling team	Original results	Climate modeling team	NYC Dept. of Design and Construct. advisor

3.2 Localizing mitigation scenarios and the science-policy boundary

After the temperature assumptions were changed, new modeling results showed that increasing vegetation is expected to reduce near-surface air temperature more effectively than increasing the reflectivity of built surfaces. When the new results were reviewed by the Advisory Committee, these local representatives again questioned the scientists' model assumptions. In this case study, we explore the role of municipal agency representatives in localizing the mitigation scenarios, a process that occurred at the science-policy boundary.

At a meeting of the Advisory Committee in November 2005, a representative from the NYC Department of Design and Construction (DDC), a city agency that permits and oversees most large construction projects, did not believe that roadway and sidewalk surfaces could be lightened to raise their albedo to 0.5. An albedo of 0.5 suggests that 50% of incident solar radiation is reflected and surfaces with a higher albedo tend to be cooler than those with a lower albedo. Most surfaces in the city have an albedo of approximately 0.15, meaning that only 15% of incident solar radiation is reflected. According to the DDC, it is feasible to raise this albedo to 0.2 (20% solar radiation reflected) with commercially produced light-colored paving materials.

The NYC Department of Parks and Recreation (Parks Department) also expressed concern with the scientists' new results, questioning their estimates of available area for planting street trees. The local agency representatives suggested that the modelers' assumptions were twice as high as their own estimates. Both the Parks Department and DDC's comments presented the modelers with new sets of challenges for localizing global climate science.

In the October 2005 draft report, the NYRCHII team presented mitigation scenarios that showed significant temperature reductions from widespread lightening of surfaces (see Table 1), but that these interventions were likely not cost-effective. These findings differed substantially from the DDC's own research on heat island mitigation, which found that "using light colored aggregate in roadways is very cost-effective in reducing the Urban Heat Island Effect, since it pays for itself in less than a year" and that "street trees and light colored roof surfaces are also quite cost-effective, with payback periods in the six year range" (Kerr and Yao 2004). The DDC representative to the Advisory Committee challenged the local accuracy of the scientists' albedo assumptions, stating to the modeling team:

> We may be differing in our methods in ways that are leading to vastly different conclusions. I looked at an inexpensive change that would be easy to make, and tried to calculate its impact. Perhaps your study targeted a high reflectivity and then calculated [the] cost to achieve that, which seems to be over a hundred times as expensive, including, as it does, a change to the binder. Is it possible for you to look at the smaller, but much less costly, change in reflectivity, due to a simple change in aggregate color, and to study the cost effectiveness of doing just that? (10 November 2005 email message).

The NYC Department of Transportation (DOT) also weighed in and questioned whether the modeling team had an accurate sense of local roadway paving practices and costs. According to a representative of the DOT:

> [S]upplies of the proven and accepted choice (quartz) for light colored aggregate (LCA) are locally available from LI [Long Island] sources and there are also some NJ sources eager to supply new or scaled up demands as needed…as far as white binders, they found costs, durability, logistics and maintenance issues make the product unsatisfactory at this point – they have tried it in particular locations to identify turning lanes etc…costs were in the hundred [dollar] per ton as opposed to the ten [dollar] per ton for standard practice; premature wear and potholes, logistics of spot maintenance w[ith] different material using the same equipment (30 November 2005 email message).

Advisory Committee members challenged the climate modelers for missing local policy choices for purchasing and using construction materials. Since these internal-agency decisions are often tacit and invisible to the outsider, climate modelers would not be expected to know these details. However, the input suggests not only how the global gets localized, but how acceptance of model-based mitigation scenarios is generated. Trust and accountability when relocating global science for healthy city planning can come from a sensitivity to and incorporation of local knowledge and expertise, more so than in the climate forecasting itself.

As a result of the DDC and DOT comments and data, the scientists again revised their mitigation scenarios. For the mitigation scenario addressing surface lightening, the albedo assumption for light paving materials was changed from 0.5 to 0.2 and the incremental cost from $3.25 per square foot to $0.03 per square foot, both figures recommended by the Advisory Committee (Rosenzweig et al. 2006).[7] These changes had two significant and countervailing effects on the cost-benefit ratio of the light surfaces UHI mitigation scenarios: (1) a substantial drop in the estimated temperature impact of light surfaces (i.e. a reduced benefit) (see Table 1, June 2006 results) and (2) a reduction in the cost of this intervention.

From the standpoint of temperature reduction benefits, the changes in the light surfaces scenario also improved the standing of the scenarios involving vegetation. The Parks Department was an advocate for tree planting as an UHI mitigation scenario, but their representatives were increasingly skeptical of the methods used to estimate the area available for planting streets trees. In a response to a project meeting at the end of 2005, a Parks Department representative to the Advisory Committee wrote to the group:

> Folks, I am not yet comfortable with the analytical method used to calculate the maximum growing area for street trees…I would hate for the street tree numbers to not reflect the actual maximum area they are physically able to occupy (which is far less than described above); this would throw the whole model off, as well as the recommendations derived from it. Can we try to resolve ASAP? I certainly hope I am wrong but I feel very nervous about this part of the study (28 November 2005 email message).

The Parks Department was reacting to the NYCRHII methodology for estimating the available area for street trees. The Parks Department had used a geographic information system (GIS) to develop a Street Tree Inventory database identifying plantable street segments. The database also contained the number of existing trees, as well as the number of new trees that could be planted, along each individual street segment. If combined with an estimate of the typical canopy size of mature trees in New York City, this information could be used to estimate the total available area for street trees. Instead of incorporating the specific information on the number of trees that could be planted, the NYCRHII team used the more general information on plantable segments to estimate available area by using GIS to create a 30-meter buffer around each plantable street (17 November 2005 email message).

The Parks Department advisors suggested that the modelers, using their own methods, had greatly overestimated the available area for tree planting, possibly by as much as 100%. They insisted that the area available for street tree planting was similar to that available for open space planting (i.e. planting trees in parks), reported on a city-wide basis as 14.1% for street trees versus 17.0% for open space. The Parks Department was particularly skeptical of NYCRHII assumptions suggesting that in Mid-Manhattan the available area for open space planting was 2.6% compared to 26.1% for street trees, and a

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[7] Although the albedo assumption for light paving materials was changed from 0.5 to 0.2, the albedo assumption for light roofs remained 0.5 because bright white coatings with 0.5 albedo are available. The light surfaces scenario includes a combination of lightened roofs and pavement, with an overall average albedo of 0.3.

similar scenario existed in Brooklyn, where open space planting was estimated at just 5.5% compared to 23.2% for street trees (October 2005 draft report).

After a series of one-on-one phone conferences, the GIS team members of the NYCRHII agreed to recalculate the available area for street trees using the Parks Department methodology. Prior to the recalculation, street trees had emerged as the UHI mitigation strategy with the greatest potential to reduce near-surface air temperature when compared with open space planting, living roofs, and light roofs (October 2005 draft report).[8] After the recalculation, green (living) roofs emerged as the most effective UHI mitigation strategy.[9]

However, few on the NYCRHII research team or the Advisory Committee felt comfortable promoting green roofs, a relatively new and expensive technology, as a more effective way to reduce NYC's heat island compared with planting trees, an option already being promoted by NYSERDA, the New York State Department of Environmental Conservation (DEC) and the Parks Department. By the time the final report was issued, the wording of conclusions comparing the mitigation scenarios was vague. The final version of the NYCRHII report noted:

> Taking available areas in the city for each strategy into account, curbside planting, living roofs, and light roofs and surfaces have comparable cooling effects. (Note that light surfaces require an area many times greater than the area for street trees needed to achieve comparable cooling)…Light surfaces, light roofs, and curbside planting tend to have lower costs per 0.1ºF temperature reduction as well as per on-peak MW reduction (Rosenzweig et al. 2006).

3.3 From global science to local policy

From the outset, NYSERDA, the DEC, and the Parks Department had institutional commitments to urban reforestation that influenced their non-objective challenges to the NYCRHII scientists. Some of these commitments had timelines that could not be altered to accommodate the reduced pace of NYCRHII research as scientists struggled to localize models.

In April 2005, while the NYCRHII climate modeling was still underway, NYSERDA released a Request for Proposals (RFP) for the NYC Urban Reforestation Pilot (NYSERDA 2005). The release of the RFP was timed to coincide with the original expected completion of the NYCRHII research report (May 2005), although the final version of the report would not be submitted to NYSERDA until June 2006. Although the RFP implicitly legitimates the new program by mentioning the ongoing NYCRHII research and stating that proposals must be focused on one of the neighborhoods being studied by the NYCRHII, it does not include any NYCRHII findings (NYSERDA 2005).

However, in a Program Opportunity Notice (PON) released in October 2007, NYSERDA explicitly legitimates a large-scale tree-planting program in the South Bronx by citing NYCRHII findings. The $8.0 million PON states:

> Through the New York Regional Heat Island study, NYSERDA showed that hardscape tree planting in the Bronx may help reduce summertime temperatures resulting in lower building cooling loads. Additional attributes include improved air quality, habitat creation, increased property values, and improved quality of life. This solicitation is intended to have a lasting effect on the microclimates in the Bronx by planting approximately 6,000 trees in the next 3-4 years (NYSERDA 2007).

In effect, the report was used to legitimate policy through seemingly objective and detached analyses (Mukerji 1989). These examples also highlight how UHI mitigation is 'post-normal' regulatory science – or science that demands answers to pressing but uncertain policy questions. Research science, on the other hand, generally operates under no comparable time pressures; in principle, it can wait indefinitely to produce results. Accordingly, the meanings of reliability and legitimacy are different for regulatory and research science. The reliability of regulatory science cannot and should not necessarily be measured according to the same criteria as the reliability of research science.

The report was commissioned by NYSERDA specifically to legitimate tree-planting programs, but the DDC advisor was sensitive to parallel political processes that the report was poised to influence:

> The City Council is considering a cool roofing bill, which, if passed, will need to be approved by the Mayor. There is also a Mayor's Task Force on Sustainability that is looking at Heat Island reduction strategies such as more trees and lighter pavements. The decision-makers in these processes are very interested in demonstrable cost-effectiveness of all sustainable strategies, and they are likely to come across this report. So we need to be careful that we don't present something that is tailored to a ConEd decision-making process that can be misconstrued in the context of the City's decision-making process (10 November 2005 email).

In meetings and written communications, the DDC tended to emphasize the cost-benefit trade-offs of the mitigation strategies, whereas NYSERDA and the DEC tended to emphasize the benefits of planting trees. This emphasis was partly in response to the

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[8] Although the light surfaces scenario was estimated to have a greater temperature impact than the street trees scenario, 3 times more area would need to be redeveloped to achieve comparable cooling (October 2005 report draft).

[9] The NYCRHII team noted several caveats associated with how green roofs were modeled, including the assumptions that green roof vegetation is similar to grass and that grass planted on rooftops has the same effect on near-surface air temperature as grass planted at street level (Rosenzweig et al. 2006).

New York State Governor's direction that NYSERDA and the DEC "identify ways that tree plantings can contribute to energy reduction goals" (DEC 2005). This directive was a bit different from the research question answered by the NYCRHII scientists, which boiled down to "which heat island mitigation strategies are more effective at reducing near-surface air temperature and electricity demand."

However, throughout the research process, NYSERDA posed detailed questions to the NYCRHII scientists concerning the possible effectiveness of different tree-planting designs. When it ultimately became clear that design questions could not be answered solely with modeling techniques, NYSERDA and the DEC engaged NYCRHII scientists in follow-up research involving data collection at local field sites under consideration for planting programs. Before funding the follow-up research, the DEC challenged the NYCRHII:

> Will the follow-up work lead to being able to predict specific areas of the Bronx (1 km blocks for example) where tree planting would have the greatest effect on the [heat island effect]….[w]ill the follow-up work lead to recommendations on scale of planting trees, that is will we be able to predict the value of cluster tree planting? Or will density in a specific area have little measurable effect…..will you be better able to predict the [heat island effect] value for park/open space planting beyond the immediate grass to tree conversion of surface. In other words, would blocks of forest within the Bronx have overall Bronx [heat island effect] value? And is there any spatial relationship to it? While your follow up work is important to project planning, it also will be important for us in proposal evaluation and overall project credibility (24 May 2006 email)

To address design questions, the NYCRHII decided to take to the streets, combining scientific protocols for collecting temperature data in the field with urban reconnaissance on the physical characteristics and traffic flows of each street. Working with a forester from the DEC, the NYCRHII team identified individual streets to visit. The team looked for streets in similar residential neighborhoods with and without trees.

The intensive nature of data collection in the field limited the number of sites that the NYCRHII was able to visit, but by combining science with local knowledge gained on the street, the team was still able to offer a much more detailed assessment of the role of trees in cooling the urban environment:

> Field measurements suggest that maximizing tree-canopy density may increase the amount of cooling per tree. This suggests that an optimal tree-planting strategy may include planting in places where a continuous tree canopy can be created, such as planting along both sides of narrow streets, planting multiple lines of trees along wide boulevards, and planting along streets that border existing tree-canopy from parks and other open spaces…..A clear difference between shaded and unshaded areas within a single street emerged with sufficiently intensive sampling. A strategy of sampling different types of areas within a single street is the best way to control for other factors, including differences in building stock, orientation, winds, and traffic. However, because air temperature variations within tree shade in urban areas can be quite small and variable, one will sometimes observe an increase in air temperature when moving from sun to shade as a result of breezes and other factors (Rosenzweig and Solecki 2006).

Tree-planting remains a prominent heat island mitigation strategy in New York City, and NYSERDA notes in its 2008 Strategic Outlook:

> To reduce the urban heat island effects in the South Bronx, NYSERDA used $10 million from the New York City Department of Environmental Protection to successfully plant several thousand street trees and ensure their long-term survival…..The trees planted by NYSERDA's Greening the Bronx will be part of the tree count for the Million Trees NYC program, which was kicked off in September 2007 by the New York City Department of Parks and Recreation and the private, not-for-profit, New York Restoration Project (NYSERDA 2008).

4. CONCLUSIONS

The case studies suggest that both local planners and global scientists have important expertise to offer the process of localizing global climate science for urban policy, and that neither the local nor the global ought to be an a priori privileged form of knowledge. When climate modeling encounters the complex and contentious built and political environments of cities, disagreements over the legitimacy of technical analyses, the appropriate kinds of 'expertise' for making regulatory science, and the extent and breadth of political accountability are all likely to be the norm, rather than the exception. The co-production framework can offer city planners and climate scientists a way to move forward in such contentious policy situations.

The NYCRHII process also revealed details about the substance and methods of 'extended peer review.' Differently situated participants on the Advisory Committee not only highlighted local data relevant to modeling the urban context that 'outside' researchers missed, they also suggested that co-producing legitimate regulatory science required attention to the social and political landscape for making recommendations. Through a continuous, and open, peer review process, scientists reconsidered initial findings and incorporated local data into their models.

Since the science of localization is 'post-normal', the identification of independent, objective peers is often both difficult and controversial. In contentious policy environments early and on-going extended peer review – using multiple modes of interaction from face-to-face deliberations to email exchanges to comments on draft documents – rather than a single, end-of-pipe review process that is more typical of scientific review process, can help adjudicate conflicts. Adversarial science and policy disputes might be avoided, or at least minimized, if more agreement between scientists and urban planners could be negotiated before and during the research process rather than waiting until conclusive reports are issued.

This call for 'democratizing' the science-policy review process is not new. The US National Research Council determined in a landmark 1996 report that the quality of risk information disseminated by federal regulators will be improved if the risk analytic process develops through coupled procedures of analysis and deliberation, and recommended wide stakeholder participation in the development and critique of regulatory science. Thus, urban planners grappling with the new challenge of localizing global science ought to draw from over a decade of lessons and policy experiments in the democratization of science policy making.

As an analytic and policy domain, urban climate policy represents a series of challenges for both scientists and city planners. Since heat island mitigation requires intervention in the face of high technical and political uncertainty, the process of co-production – where planners and researchers collaboratively review policy-relevant science – is necessary for both professional and local knowledge to use the best available science to design locally appropriate policies. Uncertain science coupled with heterogeneous policy contexts demands a new conceptual approach and normative process that can account for the challenges of localizing the global while retaining technical legitimacy and building political accountability. As urban policy makers are increasingly asked to generate policy responses to mitigate and adapt to climate change, decision-makers must learn to simultaneously ascertain emerging facts about the natural world while confronting issues of social authority and credibility, so that 'doing science' merges with 'doing politics.'

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