Synthesis and Assessment Product 4.6

Chapter 4

Effects of Global Change on Human Settlements

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4.1 Introduction

Human settlements are where people live; so effects of climate change on settlements are directly relevant to human well-being. This chapter briefly summarizes current knowledge about climate change vulnerabilities and impacts in human settlements in the United States, potentials for adaptation to climate change in U.S. settlements, conclusions and recommendations based on what is currently known, and research needs to improve the available knowledge.

As such recent events as Hurricane Katrina in 2005 and electric power outages during the hot summer of 2006 have demonstrated dramatically, climate can affect U.S. cities and smaller settlements. Settlements, and in particular larger urban areas, have often been the focus of human efforts to control exposures to climate and other manifestations of nature, reducing their importance in our everyday lives as we live and work inside climate-controlled structures, surrounded by natural features that are engineered to fit our convenience.

But it has been sobering to find that even the world's most advanced societies cannot ignore climate, even in built areas. Climate affects the costs of assuring comfort at home and work for the affluent and, for the poor, levels of comfort in terms of temperature and humidity. Climate provides inputs for a good life: water, products and services from agriculture and forestry, pleasures and tourist potentials from nature, biodiversity, and outdoor recreation. Climate affects the presence and spread of diseases and other health problems, and it is associated with threats from natural disasters: floods, fires, droughts, wind, hail, ice, heat, and cold waves. If the climate is changing, therefore, then that is important news for U.S. settlements.

Certain kinds of circumstances are likely to cause particular concerns for cities and towns in the United States as they consider possible implications of climate change. For instance, some settlements are located in especially vulnerable areas, such as on or near coasts subject to storms and sea-level rise. Some have economies linked to economic sectors especially sensitive to climate variation, such as agriculture or tourism. Some settlements are already stressed by other forces that might interact with climate change effects, such as rapid population growth, aging physical infrastructures, poverty, and social friction. Some are considerably dependent on linkage systems, such as bridges or electric power lines, which could be vulnerable to impacts of climate change.

On the other hand, some U.S. settlements may find opportunities in climate change. Warmer winters are not necessarily undesirable. Periods of change tend to reward progressive, well-governed communities. Considering climate change effects may help to focus attention on other important issues for the long-term sustainable development of settlements and communities. In many regards, U.S. cities and counties – along with some U.S. states – have been more active in considering climate change as a policy issue than has been the case at the national level, not because they are required to do so by

national policy but because they choose to do so in order to respond to local driving forces. In particular, larger settlements are sometimes more aware of their roles as emitters of greenhouse gases, and therefore a part of the causes of climate change, than of their possible vulnerabilities to impacts (see Potentials for Adaptation to Climate Change, below). Furthermore, planning for the future is an essential part of public policy decision-making in urban areas. Since infrastructure investments in urban areas are often both large and difficult to reverse, climate considerations are increasingly perceived as one of a number of relevant issues to consider when planning for the future (Ruth, 2006a). If U.S. settlements, especially larger cities, respond effectively to climate change concerns, their actions could have far-reaching implications for human well-being, because these areas are where most of the U.S. population lives, large financial decisions are made, political influence is often centered, and many technological and social innovations take place.

Meanwhile, our pattern of human settlement in the U.S. is changing. Besides shifts of population from frost-belt to sun-belt settlements, patterns are changing in other ways as well. For instance, what once appeared to be an inexorable spread of households from urban centers to peripheries is showing renewal in many city centers as metropolitan areas continue to expand across multiple jurisdictions (Solecki and Leichenko, 2006). And modern information technologies are enabling people to perform what were historically urban functions from relatively remote locations. Assessing effects of climate change on human settlements in the U.S. is complicated by the fact that we are changing in our settlement patterns and preferences.

These are important questions for both our settlements and the nation as a whole, but the ability to illuminate the issues is severely limited by the fact that little research has been done to date specifically on effects of climate change on U.S. cities and towns. Reasons appear to include (a) a general lack of support for climate change impact research, compared with climate system and mitigation research, (b) limitations in capacities to project climate change impacts at the geographic scale of a metropolitan area (or smaller), and (c) the fact that none of the federal agencies currently active in climate science research has a clear responsibility for settlement impact issues. To some degree, gaps can be filled by referring to several comprehensive analyses that do exist, to literature on effects of climate *variation* on settlements and their responses, to research on climate change impacts on cities in other parts of the world, and to analogs from the U.S. historical experience with responses of urban areas to significant environmental changes (see Box: U.S. Urban Responses to Environmental Change: A Historical Perspective). But this is little more than a place to start.

Whatever the reasons, the current knowledge base provides only a shaky basis for developing conclusions and recommendations at this time. In many cases, the best that can be done right now is to sketch out the landscape of issues that should be considered by both urban decision-makers and the research community as a basis for further discussion, offering illustrations from the relatively small research literature that is now available.

4.2 Climate Change Vulnerabilities and Impacts in Human Settlements

Consider first the possible impacts of climate change on settlements in the U.S., what determines the vulnerability of a particular settlement to such impacts, and how the impacts could affect our settlement patterns and various systems related to those patterns.

Determinants of vulnerabilities/impacts

In many cases, it has been difficult to project impacts of climate change on human settlements in the U..S., in part because climate change forecasts are not specific enough for the scale of settlement decision-making (as for other relatively local-scale impact questions) but more profoundly because climate change is not the only change being confronted by settlements. More often, attention is paid to vulnerabilities to climate change, if those changes should occur.

(1) Vulnerabilities to or opportunities from climate change are related to three factors, both in absolute terms and in comparison to other areas (Clark et al., 2000): Exposure to climate change. To what climate changes is a place likely to be exposed: temperature or precipitation changes, changes in storm exposures and/or intensities, changes in the sea level?

(2) Sensitivity to climate change. If primary climate changes were to occur, how sensitive are the activities and populations of a settlement to those changes. For instance, a city dependent substantially on a regional agricultural or forestry economy, or to the availability of abundant water resources, might be considered more sensitive than a city whose economy is based mainly on an industrial sector less sensitive to climate variations.

(3) Coping capacity. Finally, if effects are experienced due to a combination of exposure and sensitivity, how able is a settlement to handle those impacts without disabling damages, perhaps even with new opportunities?

At the current state of knowledge, vulnerabilities to possible impacts (including possible opportunities as well as possible costs, despite the negative implications of the term "vulnerability") are easier to project than actual impacts because they *estimate risks or opportunities* associated with possible consequences rather than *estimating the consequences* themselves. And vulnerabilities are shaped not only by existing exposures, sensitivities, and coping capacities but also by the ability of settlements to develop adaptive responses to risks (see Adaptation below).

U.S. URBAN RESPONSES TO ENVIRONMENTAL CHANGE: A HISTORICAL PERSPECTIVE

Over time, American cities have been affected in many ways by environmental change and environmental events. Anthropogenic actions or beliefs, however, in many cases shaped the severity of the environmental impacts. Founders of cities often evidenced a lack of care in regard to their sitting, focusing on the positive aspects of a location such as commercial or recreational possibilities or the availability of a precious mineral but ignored risks such as flooding potential, limited water, food or fuel supplies, or the presence of health threats. Oftentimes urbanites severely exploited their environments, polluting ground water and adjacent water bodies, building in unsafe and fragile locations, changing landforms, and filling in wetlands. Construction of the urban built environment involved vast alterations in the landscape, as forests and vegetation and wildlife species were eliminated and replaced by highways, suburbs, and shopping malls. The building of wastewater and water supply systems had the effect of altering regional hydrology, creating large vulnerabilities. Still other cases of the disregarding of environmental risk to cities involved sets of beliefs such as the weather was changing permanently for the good, technology could solve problems, or new resources could be discovered.

The response of many cities to environmental change and increases in environmental risk was to seek ways to modify or control environmental events using technology. Cities exposed to flooding built levees and seawalls and channelized rivers. When urbanites depleted and polluted local water supplies cities went outside their boundaries to seek new supplies. building reservoirs, aqueducts, and creating protected watersheds. When urban consumption exhausted local fuel sources, cities adapted to new fuels, embraced new technologies, or searched far beyond city boundaries for new supplies. Many of these actions resulted in the extension of the urban ecological footprint, so that urban growth and development impacted not only the urban site but also increasingly the urban hinterland and beyond.

There are few examples of environmental disasters or climate change actually resulting in the abandonment of an urban site. One case appears to be that of the Hohokam Indians of the Southwest, who built extensive irrigation systems, farmed land, and built large and dense settlements over a period of approximately 1,500 years. Yet, they abandoned their settlements and disappeared into history. The most prominent explanation for their disappearance is an ecological one - that the Hohokam irrigation systems suffered from salinization and water logging, eventually making them unusable. Other factors besides the ecological ones may have also entered into the demise of their civilization and abandonment of their cities, but the ecological explanation appears to have the most supporters.

In the case of America in the 19th and 20th centuries, however, no city has been abandoned because of environmental or climatic factors. Galveston, Texas suffered from a catastrophic tidal wave but still exists as a human settlement, now protected by a extensive sea wall. Johnstown, Pennsylvania has undergone major and destructive flooding since the late 19th century, but continues to survive as a small city. Los Angeles and San Francisco, are extremely vulnerable to earthquakes, but still continue to increase in population. And, in coming years New Orleans almost certainly will experience a hurricane as or more severe than Katrina, and yet rebuilding goes on, encouraged by the belief that technology will protect it in the future. Whether or not ecological disaster or extreme risk will eventually convince Americans to abandon their cities, as the Hohokam did, has yet to be determined.

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Projected impacts of climate change on settlements in the U.S

Possible impacts of climate change on settlements in the U.S. are usually assessed by projecting climate changes at a regional scale: temperature, precipitation, severe weather events, and sea level rise. Ideally, these regional projections are at a relatively detailed scale, and ideally they consider seasonal as well as annual changes and changes in extremes as well as in averages; but these conditions cannot always be met.

The most comprehensive assessments of possible climate change impacts on settlements in the U.S. have been two studies of major metropolitan areas:

(1) New York: The first U.S. *National Assessment of Potential Consequences of Climate Variability and Change*, often referred to as "The National Assessment" (NACC, 2000) included twenty "regional assessments," one of which was specifically designed to examine possible consequences for a large metropolitan area: the "Metropolitan East Coast," essentially the New York city area (Rosenzweig and Solecki, 2001a; also see Rosenzweig and Solecki, 2001b, and Solecki and Rosenzweig, 2006). This assessment concluded that impacts of climate change on this metropolitan area are likely to primarily negative over the long term, with potentially significant costs increasing as the magnitude of climate change increases, although there are substantial uncertainties.

(2) Boston: A later study considered Climate's Long-term Impacts on Metro Boston (CLIMB), focused on possible interactions between climate change and infrastructure systems and services in the Boston area, along with integrated impact and response strategies (Kirshen *et al.*, 2004; also see Kirshen *et al.*, 2006 and forthcoming). This study concluded that long-term impacts of climate change are likely to depend at least as much on behavioral and policy changes over this period as on temperature and other climate changes.

Other U.S. studies include Seattle (Hoo and Sumitani, 2005) and Los Angeles (Koteen *et al.*, 2001) (Table 1). Internationally, studies have included several major metropolitan areas, such as London (London Climate Change Partnership, 2004) and Mexico City (Molina *et al.*, 2005) as well as possible impacts on smaller settlements (e.g., AIACC: see www.aiaccproject.org). A relevant historical study of effects of an urban heat wave in the U.S. is Klinenberg, 2003.

Vulnerabilities of settlements to impacts of climate change vary regionally (see Box and Vignettes below), but they generally include some or many of the following impact concerns:

1 Effects on health. It is well-established that higher temperatures in urban areas are related to higher concentrations of ozone, which in turn cause respiratory problems. There is also some evidence that combined effects of heat stress and air pollution may be greater than simple additive effects (Patz and Balbus, 2001). Moreover, historical data show relationships between mortalities and temperature extremes (Rozenzweig and Solecki, 2001a). Other health concerns include

changes in exposure to water and food-borne diseases, vector-borne diseases, concentrations of plant species associated with allergies, and exposures to extreme weather events such as storms, floods, and fires (see health chapter of SAP 4.6).

2 *Effects on water and other urban infrastructures.* Changes in precipitation patterns may lead to reductions in meltwater, river flows, groundwater levels, and in coastal areas lead to saline intrusion in rivers and groundwater, affecting water supply; and warming may increase water demands (Kirshen, 2002; Ruth *et al.*, forthcoming). Moreover, storms, floods, and other severe weather events may affect other infrastructures such as sanitation, transportation, supply lines for food and energy, and communication. Exposed structures such as bridges and electricity transmission networks are especially vulnerable. In many cases, infrastructures are interconnected; an impact on one can also affect others (Kirshen, *et al.*, forthcoming). An example is an interruption in energy supply, which increases heat stress for vulnerable populations (Ruth *et al.*, 2006a).

3 *Effects of severe weather events*. Clearly, settlements in risk-prone regions have reason to be concerned about severe weather events, ranging from severe storms combined with sea-level rise in coastal areas to increased risks of fire in drier arid areas. Vulnerabilities may be especially great for rapidly-growing and/or larger metropolitan areas, where the potential magnitude of both impacts and coping requirements could be very large (IPCC, 2001b).

4 *Effects on energy requirements*. Warming is virtually certain to increase energy demand in U.S. cities for cooling in buildings while it reduces demands for heating in buildings (see SAP 4.5). Demands for cooling during warm periods could jeopardize the reliability of service in some regions by exceeding the supply capacity, especially during periods of unusually high temperatures (see Vignette below). Higher temperatures also affect costs of living and business operation by increasing costs of climate control in buildings (Amato *et al.*, 2005; Ruth and Lin, 2006c; Kirshen *et al.*, forthcoming).

5 *Effects on the urban metabolism*. An urban area is a living complex mega-organism, associated with a host of inputs, transformations, and outputs: heat, energy, materials, and others (Decker *et al.*, 2000). An example is the Urban Heat Index (UHI), which measures the degree to which built/paved areas are associated with higher temperatures than surrounding rural areas (see box: Climate Change Impacts on he Urban Heat Island Effect (UHI)). Imbalances in the urban metabolism can aggravate climate change impacts, such as roles of UHI in the formation of smog in cities.

Table 1. Overview of Integrated Assessments of Climate Impacts and Adaptation in U.S. Cities

	Bloomfield *et al.*, 1999	**Kooten *et al.*, 2001**	**Rosenzweig *et al.*, 2000**	**Kirshen *et al.*, 2004**	**Hoo and Sumitani, 2005**
Location:	Greater Los Los Angeles	New York	Metropolitan New York	Metropolitan Boston	Metropolitan Seattle
Coverage:					
Water supply	X	X	X	X	
Water Quality				X	
Water Demand				X	
Sea-level Rise	X		X	X	X
Transportation				X	X
Communication					
Energy			X	X	
Public Health					
Vector-borne Diseases					
Food-borne Diseases		X			
Temperature-related Mortality				X	
Temperature-related Morbidity	X	X			
Air-quality Related Mortality					
Air-quality Related Morbidity			X		
Oher	X	X	X		
Ecosystems					
Wetlands					
Other (Wldfires)	X		X		
Urban Forests (Trees and Vegetation)		X			
Air Quality		X			X
Extent of:					
Quantitative Analysis	Low	Medium	Medium	High	Low
Computer-based Modeling	None	Low	Low	High	None
Scenario Analysis	None	None	Medium	High	Medium
Explicit Risk Analysis	None	None	None	Medium	None
Involvement of:					
Local Planning Agencies	None	None	High	High	High
Local Government Agencies	None	None	High	High	High
Private Industry	None	None	None	Low	None
Non-profits	None	None	Low	High	None
Citizens	None	None	None	Medium	None
Identification of:					
Adaptation Options	X	X	X	X	X
Adaptation Cost			X	X	
Extent of Integration Across Systems	None	None	Low	Medium	Low
Attention to Differential Impacts (e.g., on individual types of businesses, specific sub-populations)	None	None	Low	Low	Low

Table 2. Regional vulnerabilities of settlements to impacts of climate change in the United States.

REGIONAL VULNERABILITIES OF SETTLEMENTS TO IMPACTS OF CLIMATE CHANGE

Region	Vulnerabilities	Major Uncertainties
Metro NE	Flooding, infrastructures, health, water supply, sea-level rise	Storm behavior, precipitation
Larger NE	Changes in local landscapes, tourism, water, energy needs	Ecosystem impacts
Mid-Atlantic	Multiple stresses	Ecosystem impacts
Coastal SE	More intense storms, sea-level rise, flooding, heat stress	Storm behavior, coastal land use, sea-level rise
Inland SE	Water shortages, heat stress, UH1, economic impacts	Precipitation change, development paths
Upper Midwest	Lake and river levels, extreme weather events, health	Precipitation change, storm behavior
Inner Midwest	Extreme weather events, health	Storm behavior
Appalachians	Ecological change, reduced demand for coal	Ecosystem impacts, energy policy impacts
Great Plains	Water supply, extreme events, stresses on communities	Precipitation changes, weather extremes
Mountain West	Reduced snow, water shortages, fire, tourism	Precipitation changes, effects on winter snowpack
Arid Southwest	Water shortages, fire	Development paths, precipitation changes
California	Water shortages, heat stress	Temperature and precipitation changes, infrastructure impacts
Northwest	Water shortages, ecosystem stresses, coastal effects	Precipitation changes, sea-level rise
Alaska	Effects of warming, vulnerable populations	Warming, sea-level rise
Hawaii	Storms and other weather extremes, freshwater supplies, health	Storm behavior, precipitation change

6 Effects on economic competitiveness, opportunities, and risks. Climate change has the potential not only to affect settlements directly but also to affect them through impacts on other areas linked to their economies at regional, national, and international scales (Rosenzweig and Solecki, 2006). In addition, it can affect a settlement's economic base if it is sensitive to climate, as in areas where settlements are based on agriculture, forestry, water resources, or tourism (IPCC, 2001b).

7 Effects on social and political structures. Climate change can add to stress on social and political structures by increasing management and budget requirements for public services such as public health care, disaster risk reduction, and even public security. As sources of stress grow and combine, the resilience of social and political structures that are already somewhat shaky is likely to suffer, especially in areas with relatively limited resources (Sherbinin *et al.*, 2006). *Especially vulnerable populations (also see Quality of Life* chapter of SAP 4.6*).* Where climate change adds to stress levels in settlements, it is likely to be especially problematic for vulnerable parts of the population: the poor, the elderly, those already in poor health, the disabled, those living alone, those with limited rights and power (e.g., recent in-migrants with limited English skills), and/or indigenous populations dependent on one or a few resources. As one example, warmer temperatures in urban summers have a more direct impact on populations who live and work without air-conditioning. Implications for environmental justice are clear; see, for instance, Congressional Black Caucus Foundation, 2004.

8 Effects of sea level rise. Approximately half of the U.S. population, 160 million people, will live in one of 673 coastal counties by 2008 (NOAA, 2005). Obviously, settlements in coastal areas – particularly on gently-sloping coasts – should be concerned about sea level rise in the longer term, especially if they are subject to severe storms and storm surges and/or if their regions are showing gradual land subsidence (Neumann *et al.*, 2000; Kirshen *et al.*, 2004).

In general, however, climate change effects on human settlements in the U.S. are imbedded in a variety of complexities that make projections of quantitative impacts over long periods of time very difficult. For instance, looking out over a period of many decades, it seems likely that other kinds of change – such as technological, economic, and institutional – will have more impact on the sustainability of most settlements than climate change per se (IPCC, forthcoming). Climate change will interact with other processes, driving forces, and stresses; and its significance, positive or negative, will largely be determined by these interactions. It is therefore difficult to assess effects of climate change without a reasonably clear picture of future scenarios for these other processes, which are usually not available.

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VIGNETTES OF VULNERABILITY - I

Alaskan settlements

Human settlements in Alaska are already being exposed to impacts from global warming (ACIA, 2004), and these impacts are expected to increase. Many coastal communities see increasing exposure to storms, with significant coastal erosion, and in some cases facilities are being forced either to relocate or to face increasing risks and costs. Thawing ground is beginning to destabilize transportation, buildings, and other facilities, posing needs for rebuilding, with ongoing warming adding to construction and maintenance costs. And indigenous communities are facing major economic and cultural impacts. One recent estimate of the value of Alaska's public infrastructure at risk from climate change set the value at tens of billions of today's dollars by 2080, with the replacement of buildings, bridges, and other structures with long lifetimes having the largest public costs (Larsen *et al.*, 2007).

Coastal SE settlements

Recent hurricanes striking the coast of the U.S. Southeast cannot be attributed clearly to climate change, but if climate change increases the intensity of storms as projected (IPCC, 2001b; Emanuel, 2005) that experience suggests a range of possible impacts. Consider, for example, the case of Hurricane Katrina (IPCC, forthcoming). In 2005, the city of New Orleans had a population of about half a million, located on the delta of the Mississippi River along the U.S. Gulf Coast. Urban development throughout the 20th Century has significantly increased land use and settlement in areas vulnerable to flooding, and a number of studies had indicated growing vulnerabilities to storms and flooding. In late August 2005, Hurricane Katrina moved onto the Louisiana and Mississippi coast with a storm surge, supplemented by waves, reaching up to 8.5 m above sea level. In New Orleans, the surge reached around 5m, overtopping and breaching sections of the city's 4.5m defenses, flooding 70 to 80 % of New Orleans, with 55 % of the city's properties inundated by more than 1.2 m and maximum flood depths up to 6 m. 1101 people died in Louisiana, nearly all related to flooding, concentrated among the poor and elderly. Across the whole region, there were 1.75 million private insurance claims, costing in excess of $40 billion (Hartwig, 2006), while total economic costs are projected to be significantly in excess of $100 billion. Katrina also exhausted the federally backed National Flood Insurance Program (Hunter, 2006), which had to borrow $20.8 billion from the Government to fund the Katrina residential flood claims. In New Orleans alone, while flooding of residential structures caused $8-$10 billion in losses, $3-6 billion was uninsured. 34,000-35,000 of the flooded homes carried no flood insurance, including many that were not in a designated flood risk zone (Hartwig, 2006). Six months after Katrina, it was estimated that the population of New Orleans was 155,000, with the number projected to rise to 272,000 by September 2008 – 56% of its pre-Katrina level (McCarthy *et al.*, 2006).

VIGNETTES OF VULNERABILITY – II

Arid Western settlements

Human settlements in the arid West are affected by climate in a variety of ways, but perhaps most of all by water scarcity and risks of fire. Clearly, access to water for urban populations is sensitive to climate, although the region has developed a vast system of engineered water storage and transport facilities, associated with a very complex set of water rights laws (NACC, 2001). It is very likely that climate change will reduce winter snowfall in the West, reducing total runoff – increasing spring runoff while decreasing summer water flows. Meanwhile, water demands for urban populations, agriculture, and power supply are expected to increase. If total precipitation decreases or becomes more variable, extending the kinds of drought that have affected much of the interior West in recent years, water scarcity will be exacerbated, and increased water withdrawals from wells could affect aquifer levels and pumping costs. Moreover, drying increases risks of fire, which have threatened urban areas in California and other Western areas in recent years. The five-year average of acres burned in the West is more than 5 million, and urban expansion is increasing the length of the urban-wildlands interface (Morehouse *et al.*, 2006).

Summer 2006 Heat Wave

In July and August 2006, a severe heat wave spread across the United States, with most parts of the country recording temperatures well above the average for that time of the year. For example, temperatures in California were extraordinarily high, setting records as high as 130 degrees. As many as 225 deaths were reported by press sources, many of them in major cities such as New York and Chicago. Electric power transformers failed in several areas, such as St. Louis and Queens New York, causing interruptions of electric power supply, and some cities reported heat-related damages to water lines and roads. In many cities, citizens without home air-conditioning sought shelter in public and office buildings, and city/county health departments expressed particular concern for the elderly, the young, pregnant women, and individuals in poor health. Although this heat wave cannot be attributed directly to climate change, it suggests a number of issues for human settlements in the U.S. as they contemplate a prospect of temperature extremes in the future that are higher and/or longer-lasting than historical experience.

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CLIMATE CHANGE IMPACTS ON THE URBAN HEAT ISLAND EFFECT (UHI)

Climate change impacts on the Urban Heat Island (UHI) effect will primarily depend upon the geographic location of a specific city, its urban morphology (i.e. landscape and built-up characteristics), and areal extent (i.e., overall spatial "footprint"). These factors will mitigate or exacerbate how the UHI phenomenon (Figure 2) is affected by climate change, but overall, climate change will most likely impact the UHI effect in the following ways:

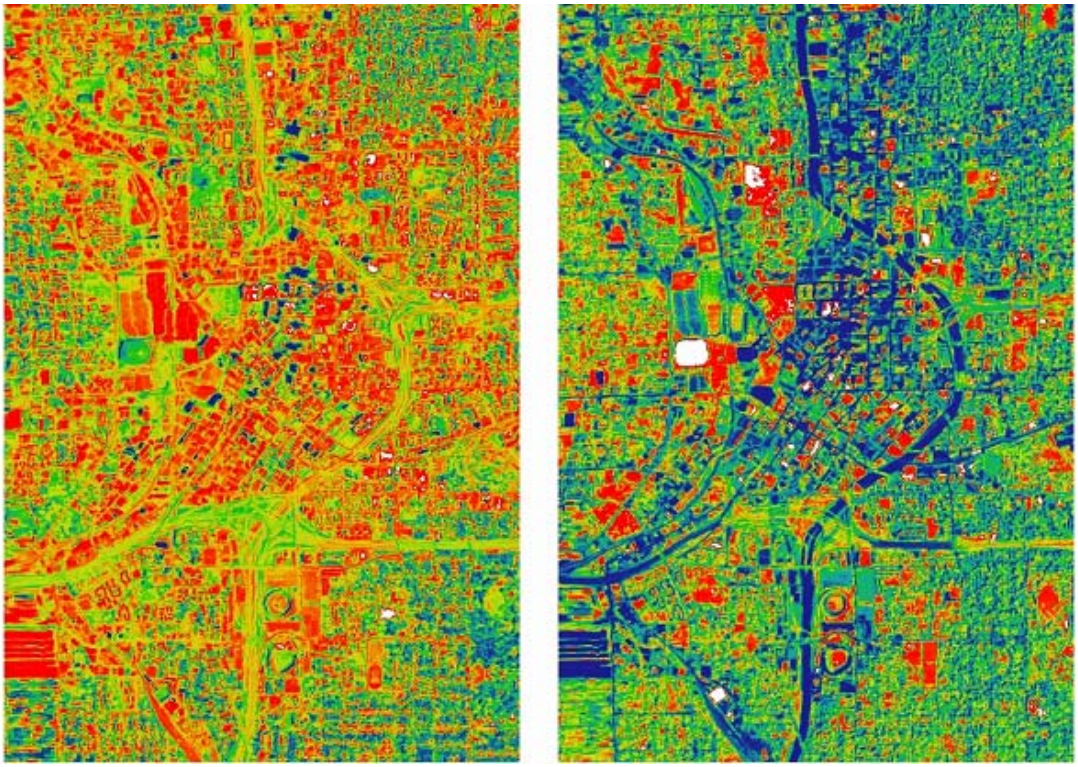

Figure 2. Example of urban surface temperatures and albedo for the Atlanta, Georgia Central Business District (CBD) area derived from high spatial resolution (10m) aircraft thermal remote sensing data. The image on the left illustrates daytime surface heating for urban surfaces across the CBD. White and red colors indicate very warm surfaces (~40-50°C). Green relates to surfaces of moderately warm temperatures (~25-30°C). Blue indicates cool surfaces (e.g., vegetation, shadows) (~15-20°C). Surface temperatures are reflected in the albedo image on the right where warm surfaces are dark (i.e., low reflectivity) and cooler surfaces are in red and green (i.e., higher reflectivity). The images exemplify how urban surface characteristics influence temperature and albedo as drivers of the urban heat island effect (Quattrochi et al., 2000).

- Exacerbation of the intensity and areal extent of the UHI as a result of warmer surface and air temperatures along with the overall growth of urban areas around the world. Additionally, as urban areas grow and expand, there is a propensity for lower albedos which forces more a more intense UHI effect. (There is also some indication that sustained or prolonged higher nighttime air temperatures over cities that may result from warmer global temperatures will have a more significant impact on humans than higher daytime temperatures.)

- As the UHI intensifies and increases, there will potentially be a subsequent impact on deterioration of air quality, particularly on ground level ozone caused by higher overall air temperatures and an increased background effect produced by the UHI as an additive air temperature factor that helps to elevate ground level ozone production. Additionally, particulate matter ($PM_{2.5}$) will potentially increase due to a number of human induced and natural factors (e.g., more energy production to support higher usage of air conditioning).

CLIMATE CHANGE IMPACTS ON THE URBAN HEAT ISLAND EFFECT (UHI) -- continued

- The UHI has an impact on local meteorological conditions by forcing rainfall production either over, or downwind, of cities. As the UHI effect intensifies, there will be a higher probability for urban-induced rainfall production (dependent upon geographic location) with a subsequent increase in urban runoff and flash flooding.

- Exacerbation and intensification of the UHI will have impacts on human health:

    - increased incidence of heat stress
    - impact on respiratory illnesses such as asthma due to increases in particulate matter caused by deterioration in air quality as well as increased pollination production because of earlier pollen production from vegetation in response to warmer overall temperatures

(Lo and Quattrochi, 2003; Brazel and Quattrochi, 2006; Ridd, 2006; Stone, 2006)

In many cases, these interactions involve not only direct impacts such as warming or more or less precipitation but, sometimes more important, second, third, etc. order impacts, as direct impacts cascade through urban systems and processes (e.g., warming which affects urban air pollution which affects health which affects public service requirements which affects social harmony: Kirshen *et al*., forthcoming). Some of these higher-order impacts, in turn, may feed back to create ripple effects of their own. For example, a heat wave may trigger increased energy demands for cooling, which may cause more air conditioners and power generators to be operated, which could lead to higher urban heat island effects, inducing even higher cooling needs.

Besides such a "multi-stress" perspective, it is highly likely that effects of climate change on settlements is shaped by certain "thresholds," below which effects are not major but where effects rather quickly become major because some kind of limiting point is reached. An example might be a city's capacity to cope with sustained heat stress of with a natural disaster. In general, these climate-related thresholds for human settlements in the U.S. are not well-understood.

But for either multi-stress assessments of threshold analyses, changes in climate extremes are very often of more concern than changes in climate averages. Besides extreme weather events, such as hurricanes or tornadoes, ice storms, winds, heat waves, drought, or fire, settlements may be affected by changes in daily or seasonal high or low levels of temperature or precipitation, which are seldom projected by climate change models (see Figure 1).

Finally, human settlements may be affected by climate change mitigation initiatives as well as by climate change itself. Examples could include effects on policies related to energy sources and uses, environmental emissions, and land use (see Adaptation below). The most direct and short-term effects would likely be on settlements in regions whose economies are closely related to the production and consumption of large quantities of fossil fuels. Indirect and longer

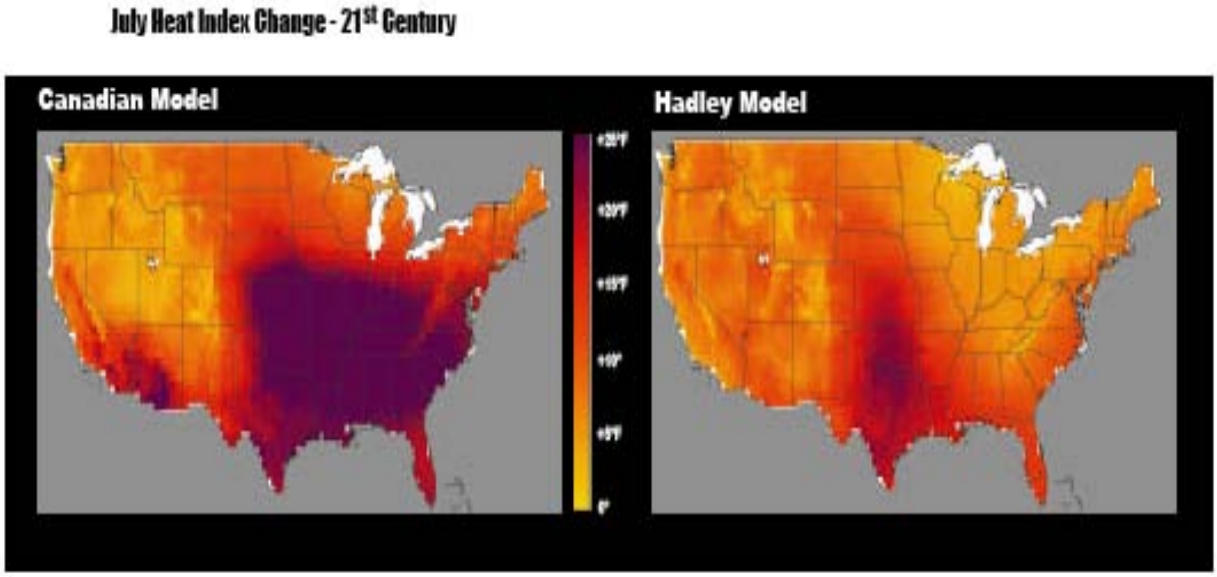

Figure 1. The U.S. National Assessment (NACC, 2001) projected changes in the July heat index for regions of the U.S. For the already hot and humid Southeast, for instance, the UK Hadley model suggested increases of 8 to 15 degrees F. for the southern-most states, while the Canadian model projected increases above 20 degrees for much of the region.

term effects are less predictable . At the same time, climate change can have positive as well as negative implications for settlements. Examples of possible positive effects include:

(1) Reduced winter weather costs and stresses. Warmer temperatures in periods of the year that are normally cold are not necessarily undesirable. They reduce cold-related stresses and costs (e.g., costs of warming buildings and costs of clearing ice and snow from roads and streets), particularly for cold-vulnerable populations. They expand opportunities for warmer-weather recreational opportunities over larger parts of the year, and they expand growing seasons for crops, parks, and gardens.

(2) Increased attention to long-term sustainability. One of the most positive aspects of a concern with climate change can be that it stimulates a broader discussion of what sustainability means for a city or smaller settlement (Wilbanks, 2003; Ruth, 2006). Even if climate change itself may not be the most serious threat to

sustainability, considering climate change impacts in a multi-change, multi-stage context can encourage and facilitate processes that lead to progress in dealing with other sources of stress as well.

(3) Improved competitiveness compared with settlements subject to more serious adverse impacts. While some settlements may turn out to be "losers" due to climate change impacts, for instance related to perceptions of increased storm risks or effects on tourism, others may be "winners," as changes in temperature or precipitation result in added economic opportunities (see the following section). In addition for many settlements climate change can be an opportunity not only to compare their net impacts with others, seeking advantages as a result, but to present a progressive image by taking climate change (and related sustainability issues) seriously. Examples might include cities in the border south who try to persuade prospective sun-belt retirees that locations farther south, especially in coastal locations, could be too hot or too storm-prone to be good places to move, or settlements in some sections of the northern part of the country who make a case that reduced costs for winter heating are greater than increased costs for summer cooling.

Possible effects on U.S. settlement patterns and characteristics

As climate change affects individual settlements in the U.S., large and small, those changes are likely to have effects on population patterns involving hosts of settlements at regional and national scales, in combination with other driving forces (even if other forces are often more important, such as demographic changes). Most of the possible effects are linked with changes in regional comparative advantage, with consequent migration of population and economic activities (Ruth and Coelho, forthcoming).

Examples of such possible issues include:

(1) Particular regional risks. It is likely that regions exposed to risks from climate change will see a movement of population growth and economic activity to other locations. One reason is public perceptions of risk, but a more powerful driving force may be the availability of insurance. The insurance sector is one of the most adaptable of all economic sectors, and its exposure to costs from severe storms and other extreme weather events is likely to lead it to withdraw (or to make much more expensive) private insurance coverage from areas vulnerable to climate change impacts (IPCC, forthcoming), which would encourage both businesses and individual citizens to consider other locations over a period of several decades.

(2) Areas whose economies are linked with climate-sensitive resources or assets. Settlements whose economic bases are related to such sectors as agriculture, forestry, tourism, water availability, or other climate-related activities could be affected either positively or negatively by climate change, depending partly on the

adaptability of those sectors (i.e., their ability to adapt to changes without shifting to different locations).

(3) Shifts in the comparative cost structure of climate control. Related to a range of possible climate change effects – higher costs for space cooling in warmer areas, higher costs of water availability in drier areas, more or less exposure to storm impacts in some areas, and sea level rise – regions of the U.S. and their associated settlements are likely to see gradual changes over the long term in their relative attractiveness for a variety of human activities. One example, although its likelihood is highly uncertain, would be a gradual migration of the "Sun Belt" northward, as retirees and businesses attracted by environmental amenities find that regions less exposed to very high temperatures and seasonal major storms are more attractive as places to locate.

(4) Changes in regional comparative advantage related to shifts in energy resource use. If climate mitigation policies result in shifts from coal and other fossil resources toward non-fossil energy sources, or if climate changes affect the prospects of renewable energy sources (especially hydropower), regional economies related to the production and/or use of energy from these sources could be affected, along with regional economies more closely linked with alternatives.

(5) Urban "footprints" on other areas. Resource requirements for urban areas involve larger areas than their own bounded territories alone, and ecologists have sought to estimate the land area required to supply the consumption of resources and compensate for emissions and other wastes from urban areas (e.g., Folke *et al.*, 1997). By possibly affecting the sizes and patterns of settlements, along with the resource capacities of source areas for their inputs and destinations of their outputs, climate change could affect the nature, size, and geographic distribution of these footprints.

As one example, no other region in the U.S. is likely to be as profoundly changed by climate change as Alaska, our nation's part of the polar region of Earth. Because warming is more pronounced closer to the poles, and because settlement and economic activities in Alaska have been shaped and often constrained by Arctic conditions, in this region warming is especially likely to reshape patterns of human settlement.

Besides impacts on built infrastructures designed for permafrost foundations and effects on indigenous societies (see Vignette above), many observers expect warming in Alaska to stimulate more active oil and gas development (and perhaps other natural resource exploitation), and if thawing of Arctic ice permits the opening of a year-round Northwest sea passage it is virtually certain that Alaska's coast will see a boom in settlements and port facilities (ACIA, 2004).

Possible effects on other systems linked with settlements

Human settlements are foci for many economic, social, and governmental processes, and we know from historical experience that catastrophes in cities can have significant economic, financial, and political effects much more broadly.
The case which has received the most attention to date is insurance and finance (IPCC, forthcoming). Other cases of possible ripple effects are on media and other information/communications sources, often city-focused, whose messages are affected by the personal experiences of those who are their purveyors.
Most importantly, perhaps, in a one-person/one-vote democratic process in an urbanizing country, the politics of responses to climate change concerns will depend considerably on the experiences and viewpoints of urban dwellers.

4.3 Potentials for Adaptation to Climate Change in Human Settlements

Settlements are important in considering prospects for adaptation to climate change, both because they represent concentrations of people and because buildings and other engineered infrastructures are ways to manage risk and monitor/control threats associated with climate extremes and other effects, such as disease vectors.

Where climate change might present risks of adverse impacts for U.S. settlements and their populations, there are two basic alternatives to respond to such concerns (a third is combining the two). One response is to contribute to climate change mitigation strategies, i.e., by taking actions to reduce their greenhouse gas emissions and by showing leadership in encouraging others to support such actions (see Box: Roles of Settlements in Climate Change Mitigation). The second response is to consider strategies for adaptation to the changes, i.e., finding ways either to reduce sensitivity to projected changes or to increase the settlement's coping capacities. Adaptation can rely mainly on anticipatory actions to avoid damages and costs, such as "hardening" coastal structures to sea-level rise; and/or adaptation can rely mainly on response potentials, such as emergency preparedness; or it can include a mix of the two approaches. Research to date suggests that anticipatory adaptation may be more cost-effective than reactive adaptation (Kirshen *et al.*, 2004).

Adaptation could be important to the well-being of U.S. settlements as climate change emerges over the next century. As just one example, the New York climate impact assessment (Rosenzweig and Solecki, 2001a) projects significant increases in heat-related deaths based on historical relationships between heat stress and mortality, while the Boston CLIMB assessment (Kirshen *et al.*, 2004) projects that, despite similar projections of warming, heat-related deaths will decline over the coming century because of adaptation (See section 3.5). Whether or not adaptation to climate change occurs in U.S. cities is therefore a potentially very serious issue. The CLIMB assessment includes analyses showing that in many cases adaptation actions taken now are better than adaptation actions delayed until a later time (Kirshen *et al.*, 2006).

Perspectives on adaptation by settlements

In most cases, for decision-makers in U.S. settlements considering climate change as yet one more source of possible risks and stress while they wrestle with a host of challenges every day. For them, climate change is different as an issue because it is relatively long-term in its implications, future impacts are surrounded by uncertainties, and public awareness is growing from a relatively low level to a higher level of concern. Because climate change is different in these ways, it is seldom attractive to consider allocating massive amounts of funding or management attention to current climate change actions for that reason alone. What generally makes more sense is to consider ways that actions which reduce vulnerabilities to climate change impacts (or increase prospects for realizing benefits from climate change impacts) are also desirable for other reasons as well: often referred to as "co-benefits." Examples include actions that reduce vulnerabilities to current climate variability regardless of long-term climate change, actions that add resilience to water supply and other urban infrastructures that are already stressed, and actions that make metropolitan areas more attractive for their citizens in terms of their overall quality of life.

Human settlements have used both "hard" approaches such as infrastructure and "soft" approaches such as regulations to capture services or protection from their climate and their environment. Examples include water supply and waste water systems, drainage networks, buildings, transportation systems, land use and zoning controls, water quality standards and emission caps, and tax incentives. All of these are designed in part with climate and environmental conditions in mind. The setting of regulations has always been a context of benefit-cost analysis and political realities; and infrastructure is also designed in a benefit-cost framework, subject to local design codes. The fact that both regulations and infrastructures vary considerably across the U.S. reflects cultural, economic, and environmental factors; and this suggests that mechanisms exist to respond to concerns about climate change. Urban designers and managers deal routinely with uncertainties, because they must consider uncertain demographic and other changes; thus, if climate change is properly institutionalized into the urban planning process, it can just be handled as yet another uncertainty.

Major categories of adaptation options

Adaptation strategies for human settlements, large and small, include a wide range of possibilities such as:

- Changing the location of people or activities (within or between settlements) – especially addressing the costs of sustaining built environments in vulnerable areas: e.g., siting and land use policies practices to shift from more vulnerable areas to less, adding resilience to new construction in vulnerable areas, increased awareness of changing hazards and associated risks, assistance for the less-advantaged (including actions by the private insurance sector as a likely driving force).

- Changing the spatial form of a settlement – managing growth and change over decades without excluding critical functions (e.g., architectural innovations improving the sustainability of structures, reducing transportation emissions by reducing the length of journeys to work, seeking efficiencies in resource use through integration of functions, and moving from brown spaces to green spaces). Among the alternatives receiving the most attention are encouraging "green buildings" (e.g., green roofs: Parris, 2007; see Rosenzweig *et al.*, 2006a; Rosenzweig *et al.*, 2006b) and increasing "green spaces" within urban areas (e.g., Bonsignore, 2003).

- Technological change to reduce sensitivity of physical and linkage infrastructures – e.g., more efficient and affordable interior climate control, surface materials that reduce heat island effects (Quattrochi *et al.*, 2000), waster reduction and advanced waste treatment, better warning systems and controls.

- Institutional change to improve coping capacity, including assuring effective governance, providing financial mechanisms for increasing resiliency, improving structures for coordinating among multiple jurisdictions, targeting assistance programs for especially impacted segments of the population, and adopting sustainable community development practices (Wilbanks *et al.*, 2007). Policy instruments include zoning, building and design codes, terms for financing, and early warning systems (Kirshen, Ruth, and Anderson, 2005).

- "No regrets" or low net cost policy initiatives that add resilience to the settlement and its physical capital – e.g., in coastal areas changing building codes for new construction to require coping with projected amounts of sea-level rise over the expected lifetimes of the structures.

The choice of strategies from among the options is likely to depend on "co-benefits" in terms of other social, economic, and ecological driving forces; the availability of fiscal and human resources; and political aspects of "who wins" and "who loses."

Current considerations of adaptation strategies

In most cases to date in the U.S., settlements have been more active in climate change mitigation than climate change adaptation (see box), but there are some indications that adaptation is growing as a subject of interest (Solecki and Rosenzweig, 2005; Ruth, 2006). For example, Boston has built a new wastewater treatment plant at least one-half meter higher than currently necessary to cope with sea level rise, and in a coastal flood protection plan for a site north of Boston the U.S. Corps of Engineers incorporated sea-level rise into their analysis (Easterling, Hurd, and Smith, 2004). California is considering climate change adaptation strategies as a part of its more comprehensive attention to climate change policies (Franco, 2005). And, of course, Alaska is already pursuing ways to adapt to permafrost melting and other climate change effects.

Meanwhile, in some cases settlements are taking actions for other reasons that add resilience to climate change effects. An example is the promotion of water conservation, which is reducing per capita water consumption in cities that could be subject to increased water scarcity (City of New York, 2005).

It seems very likely that local government will play an important role in climate change responses in the U.S. Many adaptation options must be evaluated at a relatively local scale in terms of their relative costs and benefits and their relationships with other urban sustainability issues, and local governments are important as guardians of public services, able to mobilize a wide range of stakeholders to contribute to broad community-based initiatives (as in the case of the London Climate Change Partnership, 2004). Because climate change impact concerns and adaptation potentials tend to cross jurisdictional boundaries in highly fragmented metropolitan areas, local actions might encourage cross-boundary interactions that would have value for other reasons as well.

While no U.S. communities have developed comprehensive programs to mitigate the effects of heat islands, some localities are recognizing the need to address these effects. In Chicago, for example, several municipal buildings have been designed to accommodate vegetated rooftops. Atlanta has had a Cool Communities "grass roots" effort to educate local and state officials and developers on strategies that can be used to mitigate the UHI. This Cool Communities effort was instrumental in getting the State of Georgia to adopt the first commercial building code in the country emphasizing the benefits of cool roofing technology (Young, 2002; Estes, Jr. *et al.*, 2003). Also see the "Excessive Heat Events Guidebook" developed by the Environmental Protection Agency in collaboration with NOAA, CDC, and DHS to provide information for municipal officials in the event of an excessive heat event: http://www.epa.gov/hiri/about/heatguidebook.html.

Alternatives for enhancing adaptation capacities

In most cases, the likelihood of effective adaptation is related to the capacity to adapt, which in turn is related to such variables as knowledge and awareness, access to fiscal and human resources, and good governance (IPCC, 2001b). Strategies for enhancing such capacities in U.S. settlements are likely to include the development and use of local expertise on climate change issues (AAG, 2003), attention to the emerging experience with climate change effects and response strategies globally and in other U.S. settlements, information sharing about adaptation potentials and constraints among settlements and their components (likely aided by modern information technology), and an emphasis on participatory decision-making, where local industries, institutions, and community groups are drawn into discussions of possible responses.

Conclusions and Recommendations

Even from a current knowledge base that is very limited, it is possible to conclude several things about effects of climate change on human settlements in the United States:

(1) Climate change will seldom be a primary factor in an area's development compared with other driving forces for development. It is likely to be a secondary factor, with its importance determined mainly by its interactions with other factors, except in the case of major abrupt climate change (very likely).

(2) Effects of climate change will vary considerably according to location-specific vulnerabilities, and the most vulnerable areas are likely to be Alaska, coastal and river basin locations susceptible to flooding, arid areas where water scarcity is a pressing issue, and areas whose economic bases are climate-sensitive (very likely).

(3) Except for Alaska, the main impact concerns have to do with changes in the intensity, frequency, and/or location of extreme weather events and, in some cases, water availability rather than changes in temperature (very likely).

(4) Over the time period covered by climate change projections, potentials for adaptation through technological and institutional development as well as behavioral changes are considerable, especially where such developments meet other sustainable development needs as well, especially considering the initiatives already being shown at the local level across the U.S. (extremely likely).

(5) While uncertainties are very large about specific impacts in specific time periods, it is possible to talk with a higher level of confidence about vulnerabilities to impacts for most settlements in most parts of the U.S. (virtually certain).

(6) Clarifying these vulnerabilities and reducing uncertainties about impacts would benefit from a higher level of effort in impact research (virtually certain).

(7) Promoting climate change mitigation and adaptation discussions at an urban/settlement scale will benefit from involvement of stakeholders (virtually certain).

Based on this first preliminary assessment, it is recommended that:

(1) Research on climate change effects on human settlements in the U.S., especially major metropolitan areas, be given a much higher priority in order to inform metropolitan-area scale decision-making.

(2) In particular, in-depth case studies of selected urban area impacts and responses be added without extended delay. Priorities include coastal areas of the Southeast, interior areas of the Southeast, arid areas of the Southwest, coastal areas of the Northwest, and the Great Lakes region of the Midwest.

(3) Organizations who represent urban area decision-making in the U.S. be encouraged to engage more actively in discussions of climate change impact and response issues.

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ROLES OF SETTLEMENTS IN CLIMATE CHANGE MITIGATION

Although the US government has not committed itself to climate change mitigation policies at the national level, an astonishing number of state and local authorities are actively involved in considerations of how to mitigate greenhouse gas emissions (Selin and Vandeveer, 2005; Rabe, 2006; Selin, 2006). US states and cities are joining such initiatives as ICLEI (217 U.S. local government members: ICLEI, 2006), the US Mayor Climate Protection Agreement (10 mayors), the Climate Change Action Plan, the Regional Greenhouse Gas Initiative (RGGI) (Selin, 2006), and the Large Cities Climate Leadership Group (3 large cities).([1]) Those initiatives focus on emissions inventories; on such actions aimed at reducing GHG emissions as switching to more energy efficient vehicles, using more efficient furnaces and conditioning systems, and introducing renewable portfolio standards (RPS), which mandate a formal increase in the amount of electricity generated from renewable resources; on measures to adapt to negative social, economic and environmental impacts; and on actions to promote public awareness (see references in footnote 1).

Different drivers lie behind these mitigation actions. Authorities and the population at large have begun to "perceive" such possible impacts of climate change as rising sea level, extreme shifts in weather, and losses of key resources. They have realized that a reduction of GHG emissions opens opportunities for longer economic development (e.g. investment in renewable energy: Rabe, 2006). In addition, climate change can become a political priority if it is reframed in terms of local issues (i.e. air quality, energy conservation) already in the policy agenda (Betsill, 2001; Bulkeley and Betsill, 2003; Romero Lankao, 2007)

The promoters of these initiatives face challenges related partly to inertia (e.g. the time it takes to replace energy facilities and equipment with a relatively long life of 5 to 50 years: Haites *et al.*, 2007). They can also face opposition from organizations who do not favor actions to reduce GHG emissions, some of whom are prepared to bring legal challenges against state and local initiatives (Rabe, 2006:17). But the number of bottom-up grassroots activities currently under way in the US is impressive, and that number appears to be growing.

[1] ICLEI is the International Council for Local Environmental Initiatives. Local governments participating in ICLEI's Cities for Climate Protection (CCP) Campaign commit to a) conduct an energy- and emissions-inventory and forecast, b) establish an emissions target, c) develop and obtain approval for the Local Action Plan, d) Implement policies and measures, and e) monitor and verify results (ICLEI, 2006: April 20 2006 www.iclei.org). The Large Cities Climate Leadership Group is a group of cities committed to the reduction of urban carbon emissions and adapting to climate change. It was founded following the World Cities Leadership Climate Change Summit organized by the Mayor of London in October 2005. For more information on the US Mayor Climate Protection Agreement see http://www.seattle.gov/mayor/climate/

(4) Responsibility be assigned to one U.S. government agency to lead the national effort to improve information about climate change vulnerabilities, impacts, and responses for the nation's cities and smaller settlement.

(5) In all of these connections, a structure and a process be established for informing U.S. urban decision-makers about what climate change effects might mean for their cities, how to integrate climate change considerations into what they do with building codes, zoning, lending practices, etc. as mainstreamed urban decision processes.

(6) Structures be developed and supported over the long term to document experiences with urban/settlement climate change responses and provide information about these experiences to decision-making, research, and stakeholder communities.

Research Needs

According to a number of sources, including NACC, 1998; Parson *et al.*, 2003; Ruth, 2006; and Ruth, Donaghy, and Kirshen, 2004, research needs for improving the understanding of effects of climate change on human settlements in the United States include:

(1) Increasing the number of case studies of settlement vulnerabilities, impacts, and adaptive responses in a variety of different local contexts around the country.

(2) Developing better projections of climate change at the scale of U.S. metropolitan areas or smaller, including scenarios projecting extremes and scenarios involving abrupt changes.

(3) Developing realistic, socially acceptable strategies for shifting human populations and activities away from vulnerable locations.

(4) Improving the understanding of vulnerable populations within and among urban areas: populations with limited capacities for response, limited ability to affect major decisions.

(5) Improving the understanding of how urban decision-making is changing as populations become more heterogeneous and decisions become more decentralized and "democratic," especially as this affects adaptive responses.

(6) Improving abilities to associate projections of climate change in U.S. settlements with changes in other driving forces related to impacts, such as changes in metropolitan/urban patterns and technological change.

(7) Improving the understanding of relationships between settlement patterns (both regional and intra-urban) and resilience/adaptation.

(8) Considering possible impact thresholds and what they depend upon.

(9) Improving the understanding of vulnerabilities of urban inflows and outflows to climate change impacts.

(10) Improving the understanding of second and third-order impacts of climate change in urban environments, including interaction effects among different aspects of the urban system.

(11) Reviewing current regulations, guidelines, and practices related to climate change responses to help inform community decision-makers and other stakeholders about potentials for relatively small changes to make a large difference.

Meeting these needs is likely to require a rich partnership between the federal government, state and local governments, industry, non-governmental organizations, foundations, and academia, both because the federal government will have only limited resources to invest in such research and because the research effort will benefit from full participation by all.

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