June 19, 2000

Climate Change and a Global City:
An Assessment of the Metropolitan East Coast Region

Assessment Synthesis

The Metropolitan East Coast (MEC) Assessment of Impacts of Potential Climate Variability and Change is one of eighteen regional components of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change for the Nation, organized by the U.S. Global Change Research Program. The goal of each regional assessment is to understand the impacts of climate variability and change on the physical systems and human activities of a specific area of the United States. Key to the process is the identification of sectors that are vulnerable to the additional stresses that increased climate variability and change will introduce and the potential for adaptation strategies to cope with them.

The MEC Regional Assessment focuses on the issues of climate change in a major urban center. Understanding climate impacts in urban areas is becoming increasingly important, since human populations are more concentrated in cities, and the number and size of cities are growing. It is estimated that over half of the world's population lives in cities or on coasts.

The study area for the Metro East Coast Assessment covers the thirty-one counties of the New York City metropolitan region (Fig. 1). The area consists of 13,000 square miles (33670 square kilometers), with jurisdictions involving 1,600 cities, towns, and villages in the three states of New York, New Jersey, and Connecticut. The total regional population is 19.6 million, of which 7.3 live in New York City.

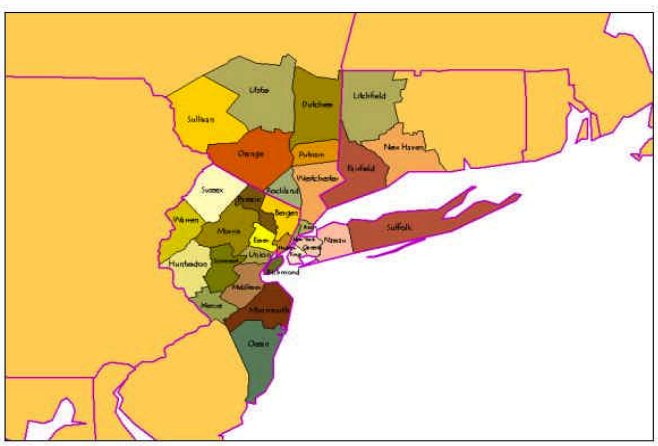


Figure 1. Metropolitan East Coast Region.

This region is defined as a global city, a mega-city that also constitutes a key site for international business and enterprise, and along with its cultural and political dominance is positioned atop the global urban hierarchy. Other global cities include London and Tokyo among a few others.

The MEC Regional Assessment examines how three interacting elements of global cities react and respond to climate variability and change. The three elements are: *people* (i.e., socio-demographic conditions), *place* (i.e., physical and ecological systems), and *pulse* (i.e., decision-making and economic activities).

The MEC project focuses on seven sector studies: Coasts, Infrastructure, Wetlands, Water Supply, Public Health, Energy Demand, and Institutional Decision-Making. Each sector study assess historical and potential climate impacts through analysis of the current conditions, lessons and evidence derived from past climate variability, scenario predictions, coping strategies, policy recommendations, and knowledge gaps.

Background

The Global Change Research Act of 1990 created the United State Global Change Research Program (USGCRP) in order that the United States analyze and evaluate the potential impacts of global climate change. The USGCRP initiated *The U.S. National Assessment: The Potential Consequences of Climate Change and Variability* in 1997. The National Assessment process involves examination of potential impacts of climate at a regional level as well as a sectoral level across the United States, synthesizing the results into a final Assessment Report.

For the regional assessments, the USGCRP initially divided the United States into twenty regions, each of which was charged with engaging researchers from a variety of disciplines in the exploration of the current and future impacts of climate on the region. The MEC Regional Assessment: *Climate Change in a Global City: An Assessment of the Metropolitan East Coast Region* is the primary Assessment activity that focuses specifically on the impacts of climate change and variability in an urban area.

The MEC team developed its project based on the template given by the USGCRP in its charge to the regions that were to compose the National Assessment. Each of the regions developed its projects independently, focusing on different sectors of activity, involving stakeholders in unique ways, and producing a variety of products for scientific, technical and general review. All products also are to be reviewed during a public comment period.

The first step for the Metro East Coast Assessment was a two-day workshop hosted by and held at Columbia University. The *Metro East Coast Climate Impacts Assessment Workshop* on March 23 and 24, 1998 brought regional stakeholders, government representatives, scholars, NGOs, and members of the general public together to explore the creation of an integrated regional assessment of climate impacts. The charge to the workshop was to develop a network of stakeholders, to prepare assessments of the vulnerabilities and opportunities resulting from regional climate variability and change, and to recommend future steps to develop a partnership between stakeholders, researchers, and the federal government.

Four questions from the National Assessment provided the foundation for the workshop:

1. Independent of climate, what are the dominant stresses and issues currently of concern to stakeholders in the region?
2. How might greater climatic variability or climate changes increase or decrease those stresses?
3. What kinds of information do we need to help us think about climate change and climate variability in the region?
4. Given our current knowledge, what coping mechanisms might be taken to minimize stresses and at the same time address the climate change issue?

The goal of the initiating workshop was to promote discussion between researchers and stakeholders in order to open the door to a method of research that focuses on relevance and utility. Through the workshop proceedings, specific areas of research were identified as the most important foci of a regional assessment in the New York Metropolitan area: Coastal Resources, Infrastructure, Water Resources, Public Health, and Institutional Decision-Making.

Since the initial workshop, we have amended the list of research foci to include: Coasts, Infrastructure, Wetlands, Water Supply, Public Health, Energy Demand, and Institutional Decision-Making. Researchers examine the vulnerabilities and adaptation strategies of each of these sectors. Through the involvement of stakeholders throughout the research process, the researchers have been able to identify physical impacts, decision-making challenges, and opportunities for possible preventative measures.

Building on interactions at the initiating workshop, the research objectives and study framework were developed. The objective of *Climate Change and a Global City: An Assessment of the Metropolitan East Coast* is to assess the potential climate change impacts on the New York City metropolitan area. This study is an application of state-of-the-art climate change science to a set of linked sectoral assessment analyses for the Metro East Coast (MEC) region.

We illustrate how three interacting elements of global cities react and respond to climate variability and change with a broad study framework (Fig.2). These elements include: *people* (e.g., socio-demographic conditions), *place* (e.g., physical systems), and *pulse* (e.g., decision-making and economic activities).

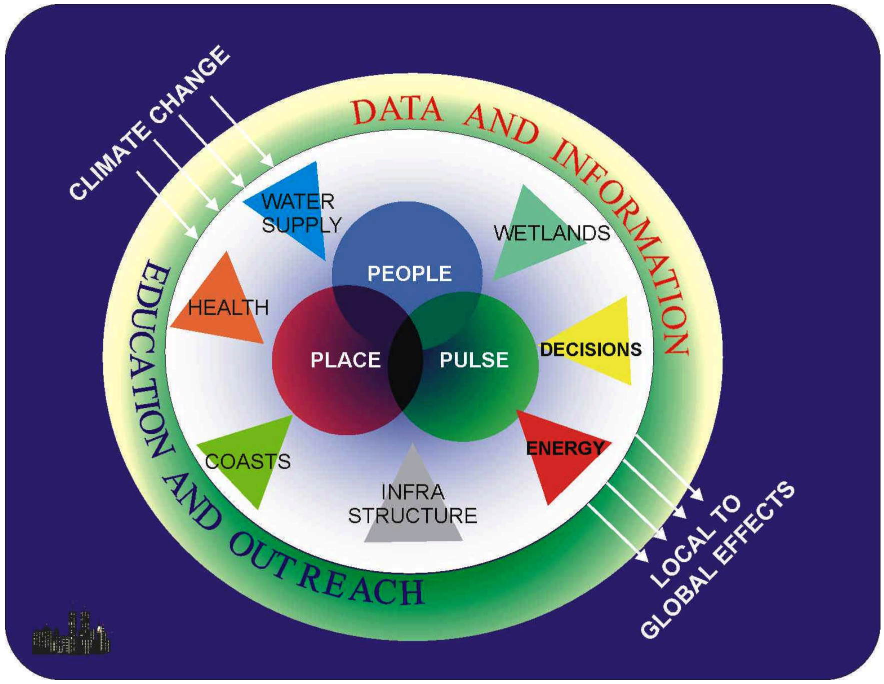


Figure 2. Study framework and study sectors

The framework assumes that a comprehensive assessment of potential climate change can be derived from examining the impacts within each of these elements and at their intersections. Thus, the assessment attempts to determine the *within-element* and the *inter-element* effects. The seven interacting sector studies represent the three intersecting elements.

Each study assesses potential climate change impacts on the sector and on the intersecting elements, through the analysis of the following parts:

1) Current conditions of sector in the region;

2) Lessons and evidence derived from past climate variability;

3) Scenario predictions affecting sector; potential impacts of scenario predictions;

4) Knowledge and information gaps;

5) Critical issues, including identification of additional research questions, effectiveness of modeling efforts, equity of impacts, potential non-local interactions, and policy recommendations; and

6) Identification of adaptation strategies – i.e., resilience building, mitigation strategies, new technologies, education that affects decision-making, and better preparedness for contingencies.

Stakeholder Involvement

The assessment mandate from the USGCRP included the involvement of key stakeholders at the regional level. The MEC project has defined stakeholders as: institutions whose activities are and will be impacted by present and future climate variability and change and thus, have a stake in being involved in research of potential impacts. Through a research partnership that involves collaboration, on-going feedback, and product review, the MEC Assessment hopes to make its research relevant and useful in decision-making across sectors of activity in the New York metropolitan region.

Each of the MEC Assessment's seven sectors: Coasts, Infrastructure, Wetlands, Water Resources, Public Health, Energy Demand, and Institutional Decision-making, collaborates with representatives from one or more stakeholder institutions. Table 1 illustrates the stakeholder institutions that are involved in the Assessment process.

Table 1. Stakeholder Partners

Sector	Partner
Coasts	New York District of U.S. Army Corps of Engineers
Wetlands	New York State Department of Environmental Conservation National Park Service, Gateway National Recreation Area
Infrastructure	Federal Emergency Management Agency, Region II The Port Authority of New York and New Jersey
Water Supply	Southeastern New York Intergovernmental Water Supply Council
Public Health	New York City Department of Health
Energy Supply	New York State Energy Research and Development Authority
Decision-Making	*All*
Meta-Stakeholder	U.S. Environmental Protection Agency, Region II
General Stakeholders	Regional Plan Association New Jersey Department of Environmental Protection New Jersey Business and Industry Association

The stakeholder representatives have been involved in the Metropolitan East Coast Assessment since its inception. The representatives from the stakeholder institutions have attended the monthly meetings of the project team. Key to the success of the relationships between the researchers and the stakeholders is the regularly scheduled outreach. Every other month, the MEC team meets at the offices of a stakeholder to present the project, its findings and to discuss the areas in which the stakeholder's activities and the Assessment's foci interface. During the outreach meetings, several questions help to frame the discussions:

1) Which activities of the stakeholder agency are most relevant to the issue of climate change?

2) What are the time frames of stakeholder's decision-making horizons?

3) Is the potential for climate change taken into account *explicitly* in any decision-making processes?

4) What information (relevant to any aspect of the project) can MEC provide to the stakeholder? Are there data that MEC can collect that would be of use to stakeholder?

5) Does the stakeholder have data that would be useful to MEC team?

6) How can we make the information that we create useful, relevant and specific to the stakeholder?

The integration of stakeholders into the research process has promoted an awareness and understanding of climate impacts research in the stakeholder community. By working closely with the researchers, the representatives from the stakeholder agencies have been able to incorporate their specific data and concerns into the climate scenarios of the project, with the result that climate variability and change can be considered in the decision-making process of the involved stakeholders.

The on-going involvement of stakeholders in the MEC Assessment has been beneficial in strengthening the research process and results and in building a regional network of interests around the discussion of climate impacts. The representatives from stakeholder agencies have been able to forge working relationships with each other around the concerns of climate impacts. Interagency interactions, along with interdisciplinary interactions, have emerged as one of the prime by-products of the process. Just as climate impacts cannot be successfully addressed by a single academic discipline, institutional responses to potential can not occur independently. Climate impacts cross sectors and necessitate integrated institutional attention.

The MEC study, along with the other regional assessments, is a necessary first step in building a decision-making community that is informed about potential impacts of climate change and variability and that has the tools to act in preparation and response to these potential impacts. In order to further build upon the initial successes of the stakeholder involvement there must be a renewed commitment to focus on the issue of climate impacts on an urban environment.

Metropolitan East Coast Region

The New York metropolitan region is one of the most important urban areas in the world. As of the 1990, U.S. Census, the region has a total population of roughly 20 million, of which 7.3 million live in New York City. While the region is only an area of 13,000 square miles (33670 square kilometers), it maintains great physical and demographic diversity. The study area for the Metro East Coast Assessment covers the 31 counties of the New York City metropolitan region. The jurisdictions include 1,600 cities, towns, and villages in the three states of New York, New Jersey, and Connecticut. The largest financial trading market of the world controls the economic heartbeat of the region. The MEC general economy is mostly based on service industries, which depend on modern, sophisticated means of communication and transportation. Approximately, 45% of the national earnings in securities and commodities trading are generated in Manhattan alone (Yaro and Hiss 1996). The gross regional product (GRP) is estimated at ~$1 trillion.

The activities of this urban conglomeration place tremendous pressure on the regional land and water resources. Approximately 30% of the land area have been fully converted to urban uses. The regional water demand is 1500 million gallons per day (mgd), which presents decision-makers with increasing concerns about the quality and quantity of the regional water supply.

A complex web of formal and informal processes that involve the public, nonprofit, and private sectors governs the MEC region's institutional framework for land use and development. The overarching considerations of environmental protection, health, and safety entwine often. Institutional adaptation and flexibility must arise in order for links to form that will allow integrated decision-making regarding climate change.

With close to 1500 miles (2413.5 kilometers) of coastline, the region's development has been intimately connected to the ocean. Infrastructure has emerged that fits this situation. For example, four of the five New York City boroughs are located on islands. More than 2200 bridges and a system of tunnels that carries rails and roads connect them with each other and the mainland. The MEC maintains a versatile, high-volume transportation system by air, roads and rails (above and below ground), as well as on the water. These and other essential infrastructure elements are often used to capacity.

People

The region has a rich demographic history and is ever evolving. The region's population grew dramatically throughout the latter part of the 19th, largely through massive immigration from Europe. While the region remained mostly rural through the mid-part of the 20th century, several large urban concentrations developed. Predominant among the urban centers on the eastern seaboard was New York City, which held by far the largest percentage of the region's population. In 1950, the City made up 56.6% of the region' 13.9 million people. Other significant urban concentrations included Newark, NJ, Jersey City, NJ, Yonkers, NY, and Bridgeport, CT, among other sites.

Since 1950, the population growth of the region has lagged behind that of other metropolitan areas in the United States. Even so, the population continued to increase and reached 19.7 million by 1990. By that time, New York City lost some of its dominance in the region. The City, in 1990, made up only 37.1% of the region's population. Population decentralization was an important demographic trend during this period. Rapid suburbanization and associated white flight fostered a dramatically changed physical and social landscape. The rate of per capita land demand increased steadily during this period. Land conversion increasingly took place on more vulnerable land including flood-prone areas and coastal locations. Coastal development was particularly intense along the Atlantic Ocean coasts of New Jersey and Long Island.

These shifts also have been associated with changes in regional employment patterns. Employment growth in the older urban counties has been very slow, and in many cases has shown absolute declines; while employment growth in the outer suburban counties has been very strong. For example, urban counties loss 307,000 jobs from 1970 to 1995;

while the suburban counties gained 2,018,400 (U.S. Bureau of Economic Analysis, U.S. Census of Population).

Both of these shifts have meant a significant change in the overall level of wealth in the region. While some neighborhoods in New York City, particularly in Manhattan, remain extremely wealthy. The migration of the middle and upper middle class from older, urban areas along with a relocation of jobs has meant increasing spatial inequity within the region with respect to income levels. As of 1995 census estimates, almost 24% of the population lived below the poverty level in the New York City; while the population living below poverty level in Connecticut was about 8%, in New Jersey it was nearly 9%. Nearly 16% of New York State's total population (including the City) lived under the poverty level according to 1995 census data. For a large percentage of the region's population, the high poverty levels correspond with lower access to adequate health care and other social services.

Another important component in the region is the diversity of the population. While the New York metropolitan region has always been defined as a region of immigrants, the recent period of increased international migration has meant a further diversification of the population in the region. Many areas, both in urban and suburban, have significant ethnic, black, and Hispanic populations. The region also has large populations of elderly and immuno-compromised people, particularly people living with HIV/AIDS.

Place

The New York metropolitan region has a very diverse landscape. It is a water-dominated region. Several large waterways and water bodies, such as the Newark Bay/Hackensack Meadowlands, the Hudson River, East River and Long Island Sound, Peconic Bay, Jamaica Bay, the Arthur Kill, and the Raritan River estuary, cut deeply into the land area. Three physiographic regions are present within the region including the coastal plain, the piedmont, and the Appalachian highlands.

The most prevalent natural hazards are flooding events either occurring from heavy precipitation or, in coastal areas, from storm surges. Tropical Storm Floyd in September 1999 was one of the largest storms on record with respect to damages. It cost an estimated $1 billion dollars worth on damage in the region. Other significant floods occurred in September 1882, October 1903, September 1966, and November 1977,. The region also is subject to moderate droughts. The drought of record was in 1965 during which the region received 55 percent of the average rainfall (47.25 inches/per year). Other significant drought events occurred in 1910, 1935, and 1964. In typical years, rainfall is relatively evenly distributed throughout the year with a slightly higher level occurring in March and November.

The pre-historic ecology of the region has been tremendously modified. The region is now a heavily human-dominated landscape. In some exurban areas such as extreme eastern Long Island, northwestern New Jersey, and parts of Connecticut and upstate New York more distant from New York City still maintain extensive wildlife habitat and ecological function. The ecological function of the more settled part of the region is low;

however, the few remaining larger-scale (i.e., greater than 500 hectares) habitat sites for example the Hackensack Meadowlands, the Great Swamp both in New Jersey and Jamaica Bay provide critical stopping points for the migratory bird species.

The built environment comprises the most prominent feature of the region. For example, the region maintained as of 1990, 7.7 million housing units, and current estimates include approximately 2000 miles (3218 kilometers) of major highway, and 1250 miles (2011.25 kilometers) of railway. Much of the built environment in New York City itself, and adjacent older urban and suburban areas, pre-dates 1950. Maintenance of the infrastructure and buildings is a massive and continuing process. In the outlying counties, the vast majority of the construction is more recent. Currently, the greatest amount of new construction in taking place in these outlying areas. Revitalization and redevelopment is taking place in selected areas in the older urban core, such as the Hudson River waterfront area in New Jersey.

Pulse

The region is highly dynamic. Highly complex socio-economic systems form the basis of the region's pulse. The region is organized around massive inflows and outflows and intraregional flows. As a largely urban site almost all of the food supply has to be imported into the region, and increasingly much of the solid and hazardous waste is exported out. In the case of NYC water supply, fresh water also is brought into the region. Energy via the vast energy grid throughout the Northeast and Mid-Atlantic also is imported into the region.

Population migration also has been significant component of the region's pulse. In the past three decades more than 3 million people have migrated into the region. As a major port, the region is tied to the world through shipping. Another important component of the region's pulse is the financial services industry. The MEC region is one of the most important financial and business centers in the world. As such, local decisions and transactions that take place in the region everyday have important implications for locations throughout the world. Furthermore, any significant disruption to the communication and transportation systems can have dire economic consequences, not only locally, but also nationally and globally. An assessment of potential climate change impacts must take into account the possibility that future extreme weather events in the MEC region could disrupt these activities.

Current Stresses and Likely Future without Climate Change

The region faces several stresses, besides climate change, that limit its current and future viability. These include maintaining continued economic growth, inequity among the region's residents, and the region's environmental quality. Throughout the latter part of the 20th century, the region experienced a dramatic shift in economic activity. The metro area's manufacturing sector declined significantly. Hundreds of thousands of manufacturing jobs were lost. This transformation was accompanied by a significant rise in often lower paying, service sector employment, and higher paying financial industry and high tech (e.g., biotechnology, and computers) jobs.

This economic bifurcation has created a situation of growing inequity in the MEC region. Like other urbanized populations in the U.S., the region is becoming more divided as the gap emerges between high wage and high skill residents and low wage and low skill residents. Class divisions are further exasperated by increasing residential segregation along economic, social, and racial lines. Large disadvantaged underclass populations are still present in degraded communities throughout older urban centers in the region, even during this current era of unprecedented prosperity.

The region also continues to face many environmental challenges that threaten regional ecosystem function, environmental conditions, and daily quality-of-life. The most critical environmental issues for the region include air and water pollution, and suburban sprawl. The region air quality still exceeds federal mandates for several pollutants. Surface and ground water supplies, and coastal waters face constant threat. Recent years has meant seen much of the remaining open space and farmland present at the distant edges of the region became sites for significant land speculation and conversion. These sites include northwestern New Jersey, the farthest eastern edges of the North and South Forks of Long Island, in the lower Hudson River Valley, and throughout southwestern Connecticut.

These current stresses create multiple tensions throughout the region. Local and state governments and other interests compete for scarce resources often times to the detriment of the long-term viability of the region. Often haphazard patterns of investment and disinvestments have created disadvantaged populations and degraded environments. Regional cooperation on these issues of common concern is relatively rare.

Regional Climate and Potential Change

The climate of the New York metropolitan region varies significantly within its boundaries. Higher topography over northwestern New Jersey amplifies snowfall and summer precipitation. Cooling sea breezes occur along the coast under certain conditions, an effect that also helps to dampen thunderstorms as they approach New York City. The urban heat island causes the city to be warmer than the surrounding regions due to the absorption of sunlight by buildings during the day and reradiation at night. It is primarily a phenomenon that occurs at night. Heating of buildings on winter nights, and air conditioning during the summer also creates excess heat in cities. Given these processes, the effects of climate variability and climate change will likely differ spatially and temporally both within the region and from surrounding regions. Under a warming climate, the urban heat island effect will increasingly become an issue of regional concern in regard to energy demand and air quality.

In the Metro East Coast Regional Assessment, researchers and stakeholders studied the impacts of and adaptation to regional climate variability and change in the seven sectors (Coasts, Infrastructure, Wetlands, Water Supply, Public Health, Energy Demand, and

Institutional Decision-Making). Impacts of climate were analyzed utilizing several approaches:

1. Historical trends
2. Current extreme events
3. Climate change scenarios

Historical Trends

Historical trends of monthly temperature and precipitation in the Metro East Coast region over the last century are shown in Figures 3 to 6. The data are from the NOAA/NCDC USHCN, US Historical Climatology Network. The have been corrected for the effect of the urban heat island and are averaged over 23 meteorological stations in the region (Table 1). While there are fluctuations on inter-annual and decadal time-scales in the average temperatures of the past century, there is also a long-term warming trend. The average annual temperature in the over the last century has increased by almost 2°F, or ~0.2° Fahrenheit per decade (Fig. 3). Warming has been greatest in winter, particularly in recent decades (Fig. 4). It is very difficult, however, to determine the causes of the observed climate trends.

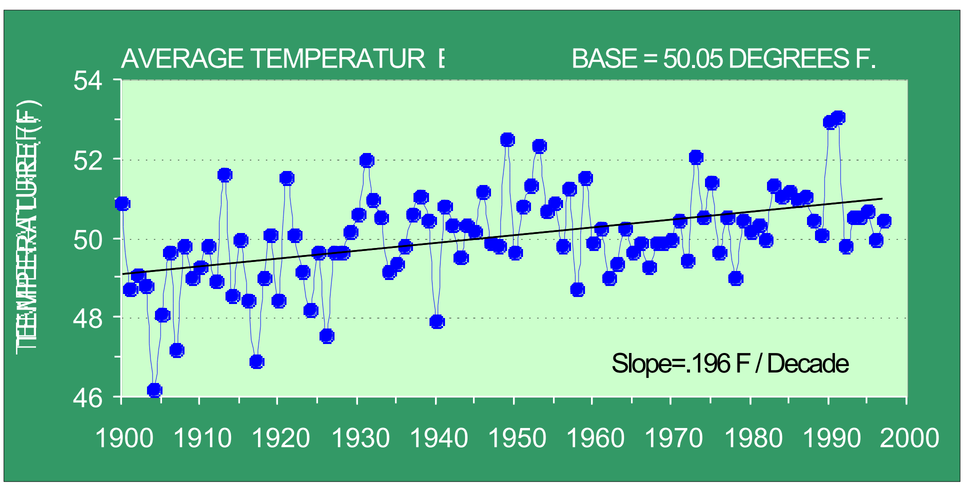
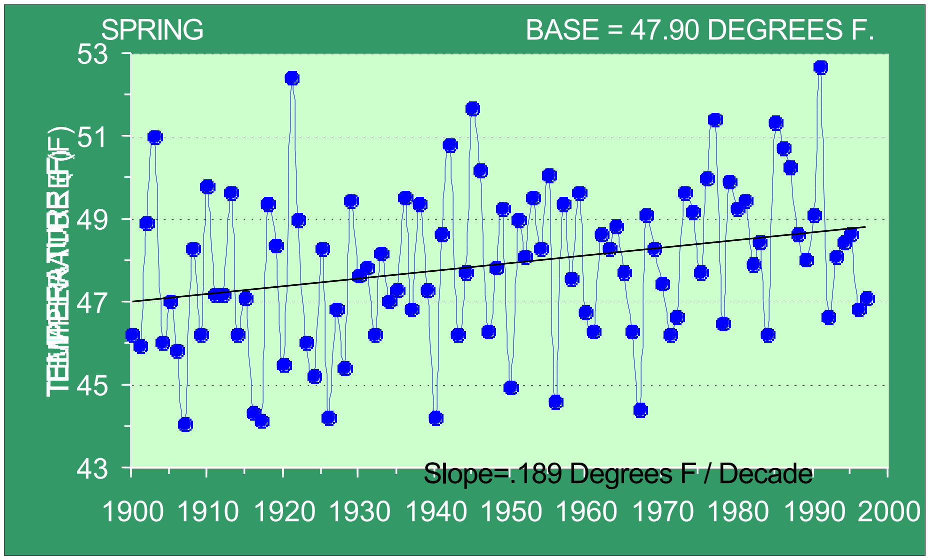
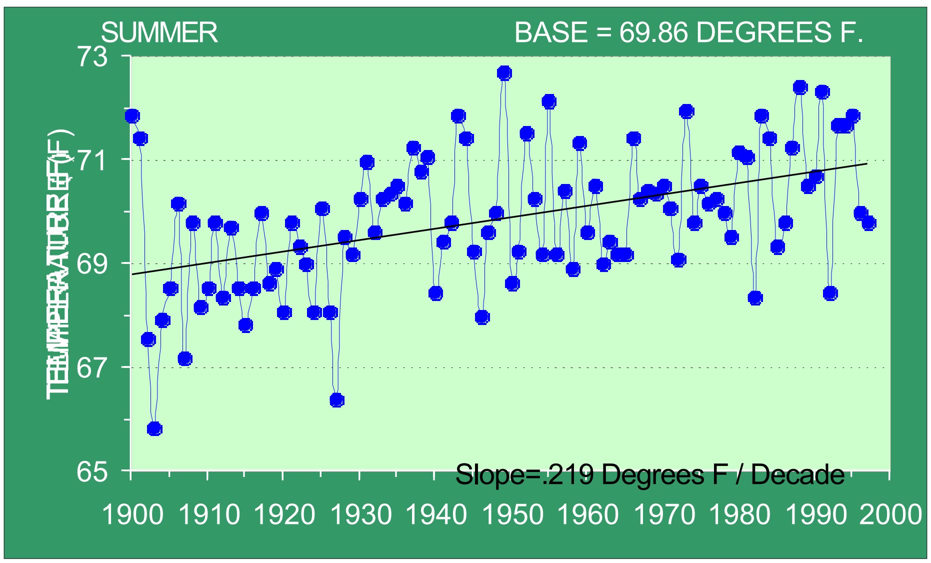
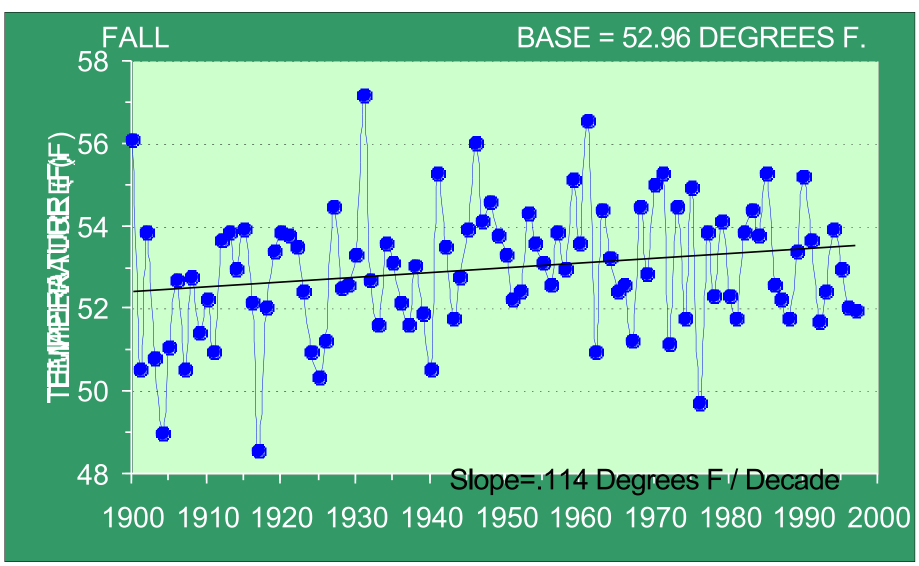


Fig. 3. Observed average annual temperatures for the 1900s (°F) averaged over 23 stations in the MEC region.


SPRING
BASE = 47.90 DEGREES F.
53
51
49
47
45
43
Slope=.189 Degrees F / Decade
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000


SUMMER
BASE = 69.86 DEGREES F.
73
71
69
67
65
Slope=.219 Degrees F / Decade
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000


FALL
BASE = 52.96 DEGREES F.
58
56
54
52
50
48
Slope=.114 Degrees F / Decade
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000

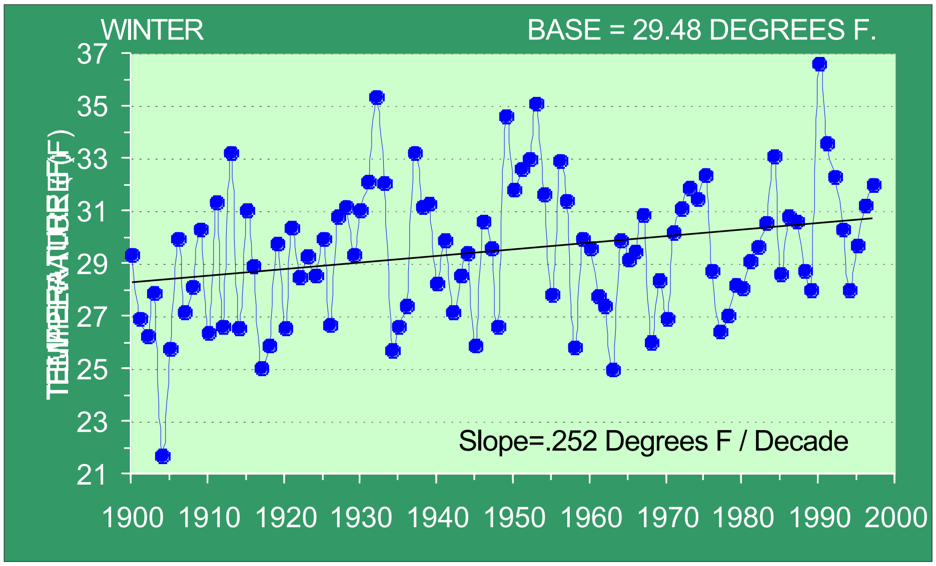


Fig. 4. Observed average seasonal temperatures for the 1900s (°F) averaged over 23 stations in the MEC region.

Precipitation in the region averages 45.9 inches per year. Over the last 100 years, precipitation has increased by an average of about 0.1 inch per decade, causing a small overall increase of about 1 inch (Fig. 5). Seasonally, precipitation in the spring and fall has been increasing, while summer and winter precipitation have declined. In recent decades, winter precipitation, especially snow, has decreased significantly (Fig. 6).

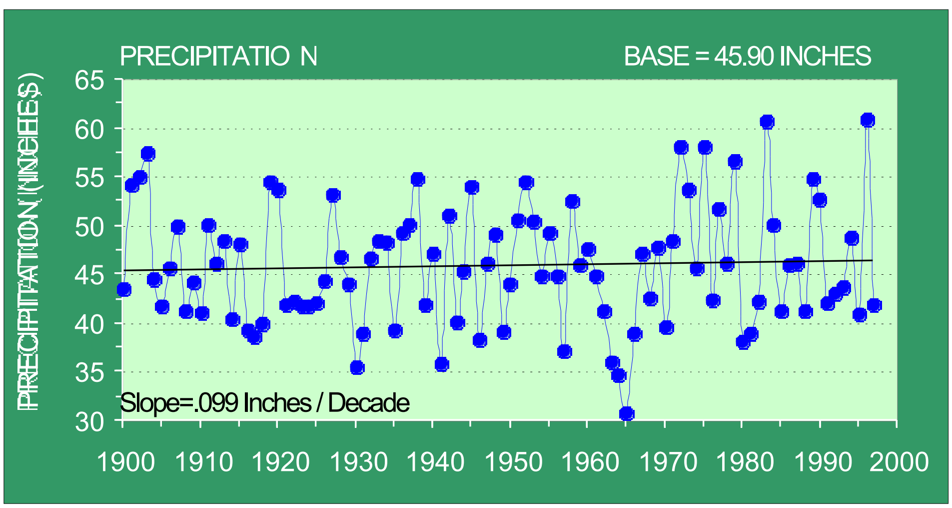
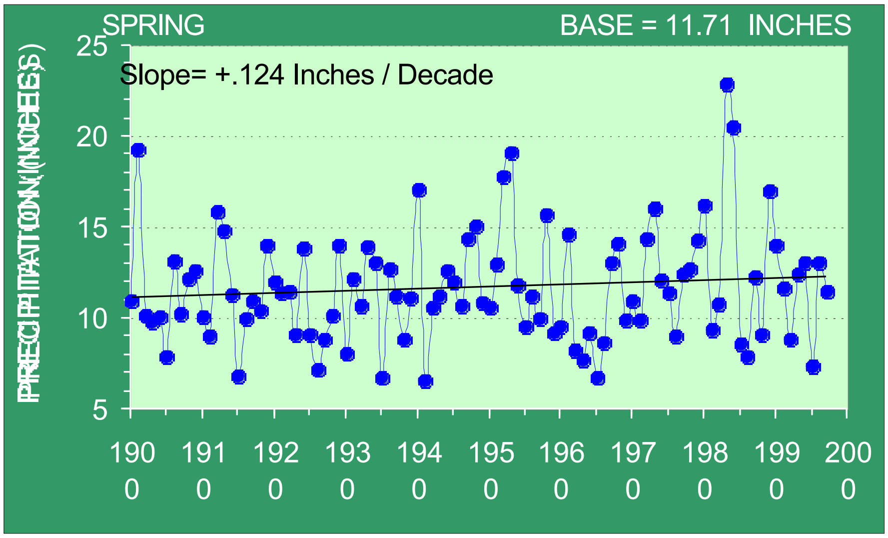


Fig. 5. Observed average annual precipitation for the 1900s (inches), averaged over 23 stations in the MEC region.


SPRING
BASE = 11.71 INCHES
Slope= +.124 Inches / Decade
PRECIPITATION (INCHES)
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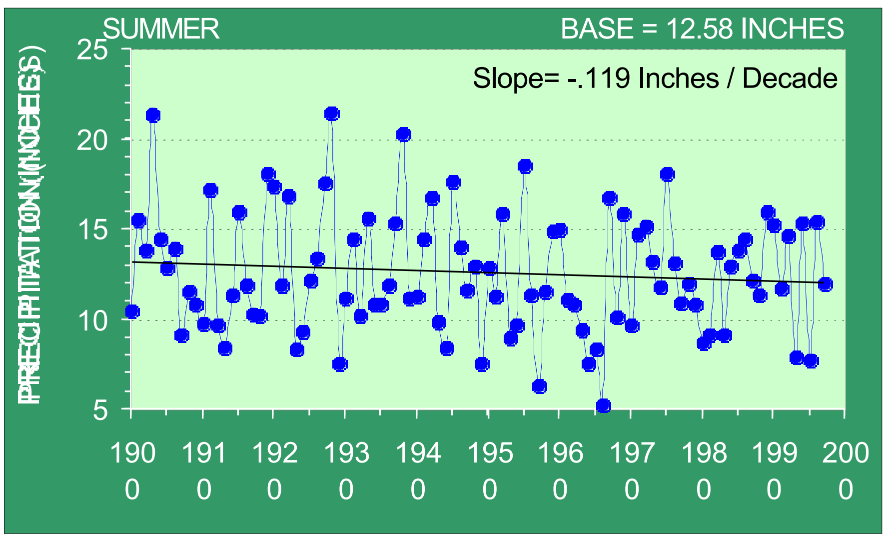
SUMMER
BASE = 12.58 INCHES
Slope= -.119 Inches / Decade
PRECIPITATION (INCHES)
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20
15
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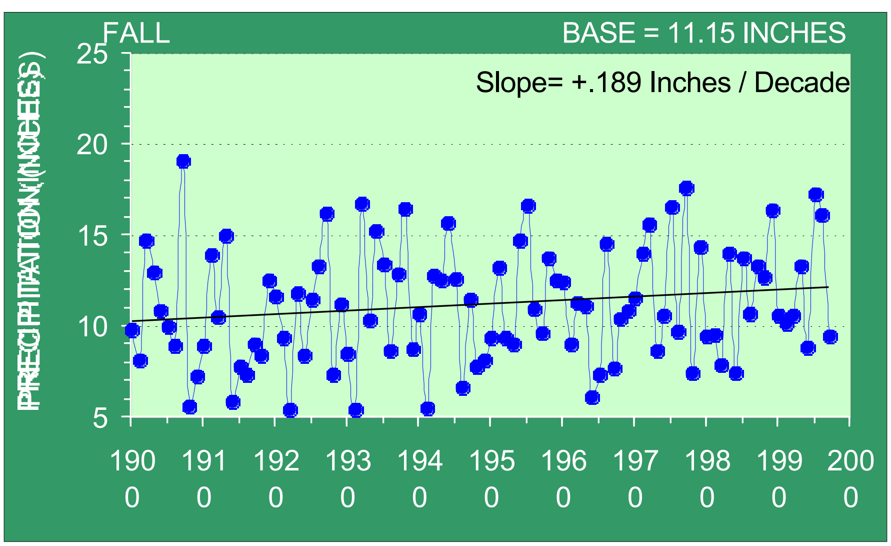
FALL
BASE = 11.15 INCHES
Slope= +.189 Inches / Decade
PRECIPITATION (INCHES)
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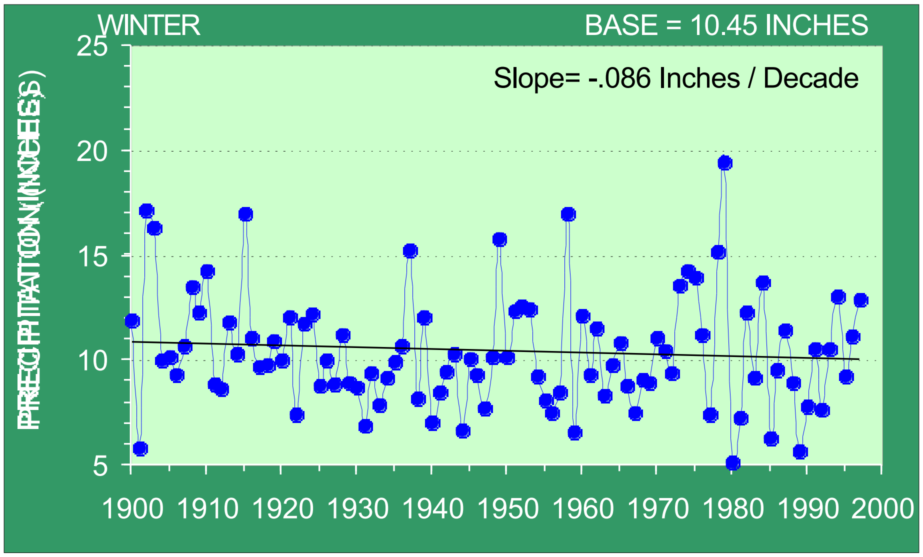

Fig. 6. Observed average seasonal precipitation for the 1900s (inches), averaged over 23 stations in the MEC region.

Table 1. Metro East Coast Assessment meteorological stations. (Source: US Historical Climatology Network, NOAA/NCDC http://www.ncdc.noaa.gov/ol/climate/research/ushcn/ushcn.html#KDK88)

City	State	Lat.	Long.	Years
Falls Village	CT	41.95	-73.37	1916-1997
Groton	CT	41.35	-72.05	1900-1997
Stamford 5N	CT	41.13	-73.55	1919-1997
Atlantic City State Marina	NJ	39.38	-74.43	1900-1997
Belvidere Bridge	NJ	40.83	-75.08	1900-1997
Boonton 1SE	NJ	40.90	-74.40	1900-1997
Charlotteburg Reservoir	NJ	41.03	-74.43	1900-1997
Flemington 5NNW	NJ	40.57	-74.88	1900-1997
Hightstown 2W	NJ	40.27	-74.57	1900-1997
Longbranch Oakhurst	NJ	40.27	-74.00	1913-1997
New Brunswick 3SE	NJ	40.47	-74.43	1900-1997
Plainfield	NJ	40.60	-74.40	1900-1997
Tuckerton	NJ	39.60	-74.35	1900-1997
Bridgehampton	NY	40.95	-72.30	1930-1997
Glenham	NY	41.52	-73.93	1932-1997
Mohonk Lake	NY	41.77	-74.15	1900-1997
Port Jervis	NY	41.38	-74.68	1900-1997
Poughkeepsie	NY	41.63	-73.92	1900-1997
Scarsdale	NY	40.98	-73.80	1904-1997
Setauket Strong	NY	40.97	-73.10	1900-1997
Walden 1ESE	NY	41.55	-74.17	1925-1997
West Point	NY	41.38	-73.97	1900-1997
Yorktown Heights 1W	NY	41.27	-73.80	1900-1997

Current Extreme Events

Over the course of the Metro East Coast Assessment (1998-2000), there were major climate extreme events. The impacts of and responses to these events formed part of the Assessment study. During the summer of 1999, there were heat waves, an intense precipitation event that flooded the FDR Drive and subways, and associated blackouts in a lower socioeconomic neighborhood of northern Manhattan. An intense summer drought may have contributed to the fatal outbreak of the West Nile-like virus in August and September 1999. In September 1999, Hurricane Floyd brought large-scale flooding in Northern New Jersey.

Climate Change Scenarios

Climate change scenarios are the essential first step in assessment of the impacts of and adaptations to climate change. Future climate change scenarios are defined as plausible combinations of climatic conditions that may be used to test possible impacts and to evaluate responses to them. Scenarios may be used to identify vulnerabilities and to identify thresholds at which impacts become negative or severe. They are also used to compare the relative vulnerability among sectors in the same region, among similar sectors in different regions, or among different regions as a whole.

There is still considerable uncertainty regarding how fast and by how much climate may change in the future, on how different regions may experience the change, or on how the variability (as well as the mean values) of climatic parameters may change. To cope with these uncertainties, climate scenarios of different types have been developed for climate change impact analyses. These include scenarios based on arbitrary changes in climate variables, previous warm episodes in historically observed climate, and on global climate model (GCM) and regional climate model simulations.

Uncertainties. The design of impact studies often includes a set of scenarios consistent with the current state of knowledge regarding global climate change. Since current knowledge is incomplete and still uncertain, the scenarios are meant to span a range of possible future climate conditions. By analyzing multiple scenarios, the direction and relative magnitudes of potential responses may be assessed. It is still difficult, if not impossible, to ascribe probabilities to any of the various climate change scenarios, owing to uncertainties regarding future emissions of radiatively active trace gases and tropospheric aerosols and the potential response of the climate system to those emissions. Scenarios are also uncertain because global climate models lack realism in their simulation of current climate processes, especially regional hydrology. Thus, there is still considerable uncertainty in projecting climate change due to anthropogenic greenhouse gas forcing, at both global and regional scales.

For all these reasons, impact studies based on climate scenarios are not viewed as predictions, but rather descriptions of possible futures. Nonetheless, they can be useful in defining, for critical biophysical and socioeconomic systems, directions and relative magnitudes of change, as well as potentially critical threshold of climate-sensitive processes. By these means, researchers and decision-makers are able to conduct “practice” exercises, which may help them anticipate future conditions and prepare possible adaptations to those conditions in a flexible manner. Through the use of a range of plausible scenarios, assessment researchers can project possible impacts created by climate variability and change as well as to evaluate the region’s responses.

Scenarios used in the Metro East Coast Assessment. Several types of climate scenarios are utilized in the Metro East Coast Assessment: (1) Sensitivity tests to arbitrary changes in climate variables; (2) Trends in historical climate data; and (3) Projections generated through global climate models. All scenarios used in the Assessment were developed specifically for the New York metropolitan area.

Sensitivity Tests

Several of the sector studies carried out impact analyses using sensitivity tests to arbitrary changes in climate variables. Tests with such simple changes can help identify the sensitivities of systems to changes in the defined variables. However, such tests do not offer a comprehensive and consistent set of climate variables, since in reality precipitation, evaporation, wind and other variables are all likely to change concurrently and interactively with change in temperature. Sensitivity tests do provide an opportunity, however, to define possible thresholds beyond which impacts may become severe, and a set of responses to which other types of scenarios may be compared.

In the Metro East Coasts Regional Assessment, the Water Supply Sector tested the sensitivity of the Palmer Drought Severity Index calibrated for the region to changes in temperature and precipitation. The Energy Demand Sector tested the sensitivity of total and peak energy demands to arbitrary combinations of temperature and relative humidity.

Current Trends Scenarios

The Current Trends scenario reflects a possible future climate if the temperature and precipitation trends were to continue as they have been over the last century, without major changes in the climate system. The Current Trends Scenario does not assume any additional forcing from greenhouse gas or aerosol sulfate increases beyond what is implicitly present in the Current Trends Scenario.

If the average warming trend of the past century were to continue over the next century (the basis of the Current Trends Scenario), the average annual temperature for the MEC region would increase by almost 1.0^{o}F by the 2020s, 1.5^{o}F by the 2050s, and over 2.5^{o}F in the 2080s. If the average precipitation trend from the past century were to continue over the next century (Current Trends Scenario), there would be a small increases in precipitation through the century: 1% increase in the 2020s, 1.6% increase in the 2050s and a 2.3% increase in the 2080s.

GCM Scenarios

Global climate models are mathematical models of the global climate system. They are used to simulate how climate responds to specific forcings such as projected increases in CO_2 and other greenhouse gases, and changes in sulfate aerosols. The models simulate climate, from which regional scenarios are developed. The global climate models (GCMs) used in the Metro East Coast study are those utilized in the U.S. National

Assessment of the Potential Consequences of Climate Variability and Change: the United Kingdom Hadley Centre[1](HC) and the Canadian Centre for Climate Modeling and Analysis[2] (CC) (Table 2).

Table 2. Description of global climate models used in the Metro East Coast Assessment.

SCENARIO	Resolution (lat. x long.)	Sensitivity*
Hadley Centre	2.5° x 3.75°	2.6°C
Canadian Climate Centre	3.75° x 3.75°	3.5°C

*Sensitivity to $2xCO_2$ equilibrium experiments.

Both GCMs are coupled atmosphere-ocean models, and have been used to run simulations of 1% equivalent CO_2 increase per year before present and 1% per year compounded increase of CO_2 in the future (Fig. 7 and 8).

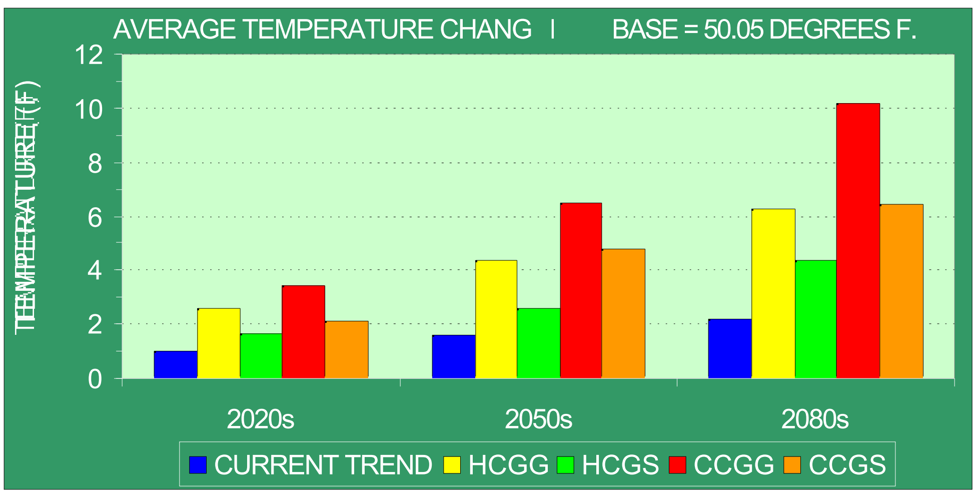

Fig. 7. Projected change in temperature for the Current Trends, HCGG, HCGS, CCGG, and CCGS scenarios. HCGG=Hadley Centre Greenhouse Gases; HCGS=Hadley Centre Greenhouse gases and Sulfate aerosols; CCGG=Canadian Centre Greenhouse Gases; CCGS= Canadian Centre Greenhouse gases and Sulfate aerosols.

[1] Flato, GM, Boer GJ, Lee WG, McFarlane NA, Ramsen D, Reader MC, Weaver AJ (1997). The Canadian Centre for Climate Modeling and analysis global coupled models and its climate.

[2] Johns TE, Carnell RE, Crossley JF, Gregory JM, Mitchell JFB, Senior CA, Tett SFB and Wood RA (1997). The second Hadley Centre coupled ocean-atmosphere GCM: Model description, spinup and validation. Climate Dynamics 13: 103-134.

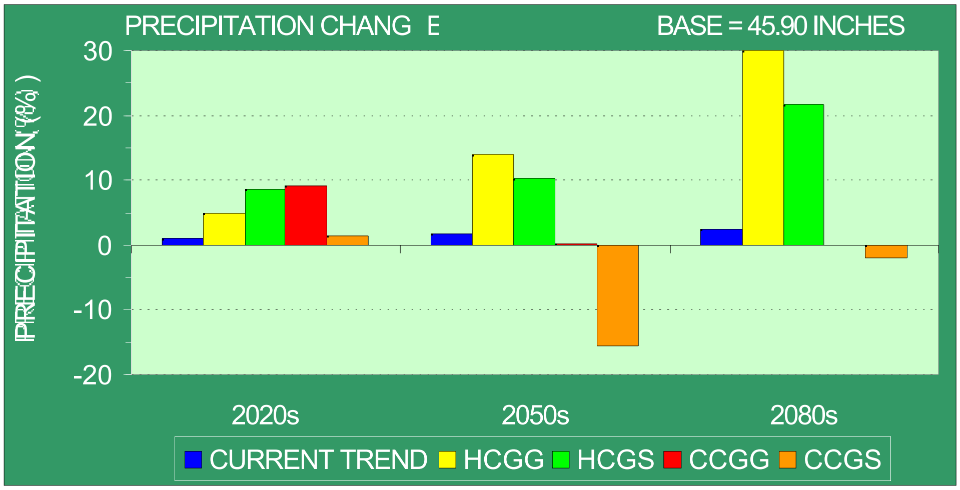

Fig. 8. Projected change in precipitation for the Current Trends, HCGG, HCGS, CCGG, and CCGS scenarios. HCGG=Hadley Centre Greenhouse Gases; HCGS=Hadley Centre Greenhouse gases and Sulfate aerosols; CCGG=Canadian Centre Greenhouse Gases; CCGS= Canadian Centre Greenhouse gases and Sulfate aerosols.

There are two types of scenarios for each GCM: the first accounts for the effects of greenhouse gases on the climate (GG) and the second accounts for the effect of greenhouse gases and sulfate aerosols (GS). Greenhouse gases from burning of fossil fuels, land-use change, and other anthropogenic activities absorb longwave radiation and tend to warm the climate. Sulfate aerosols are emitted as by-products of industrial activities and create a cooling effect as they reflect and scatter solar radiation. Thus, the scenarios that incorporate both greenhouse gases and sulfate aerosols tend to be slightly cooler than those with greenhouse gas forcing alone (Table 3).

Table 3. The climate scenarios used in the Metro East Coast Regional Assessment.

SCENARIO	Description
Current Trends	Projection of historical temperature and precipitation trends (1900-1999)
HCGG	Hadley Centre, with forcing from greenhouse gases
HCGS	Hadley Centre, with forcing from greenhouse gases and sulfate aerosols
CCGG	Canadian Centre for Climate Modeling and Analysis, with forcing from greenhouse gases
CCGS	Canadian Centre for Climate Modeling and Analysis, with forcing from greenhouse gases and sulfate aerosols

To create the climate change scenarios, GCM simulated temperature and precipitation were linearly interpolated across the gridboxes in the Metro East Coast region. Differences (differences for temperature changes; ratios for precipitation changes) between the GCM climate variables simulated for the study periods and for 1961-1990 were calculated at the midpoint of the 23 stations used in the study. The GCM differences or ratios) were then applied to the observed mean regional climate variables. Study periods were the decades of the 2020s, 2050s, and 2080s.

The GCMs project warming for the New York Metropolitan Region, ranging from 1.7-3.5°F annual temperature rises in the 2020s, 2.6-6.5°F in the 2050s, and 6.3-10.2°F by the 2080s. Climate change is projected by global climate models to cause regional warming in both winter and summer. In the 2050s, the range of winter temperature rise is 3.3 to 5.6°F. The summer temperature rise for summer in the 2050s is projected to range between 2.7 and 7.6°F.

Global climate models project that the number of days with the National Weather Service Heat Index (a combined index of temperature and relative humidity used as a proxy for the discomfort caused by heatwaves) above 90°F will increase from 14 days (1997-1998 base) to a range of 24 to 40 days in the 2020s, 30 to 62 days in the 2050s, and 40 to 89 days in the 2080s.

Precipitation projections of the global climate model scenarios do not agree in magnitude or direction (+1.4% to +9% in the 2020s; -15.6% to +14% in the 2050s, and -2% to +30% by the 2080s), indicating possible hydrological uncertainty in the future. The Hadley Centre scenarios show increasing levels of precipitation, while the Canadian Centre scenarios project varying precipitation changes over time.

The HCGG scenario forecasts future temperature increases of 2.6°F in the 2020s, 4.4°F in the 2050s and 6.3°F in the 2080s. According to the HCGG scenario, the MEC region can expect 5% more precipitation in the 2020s, almost 14% more in the 2050s and 30% more precipitation in the 2080s, as compared to the average precipitation over the past 30 years.

The HCGS scenario projects future temperature increases of 1.7°F in the 2020s, 2.6°F in the 2050s and 6.3°F by the 2080s. The average annual precipitation forecasts from the HCGS scenario are: a 9% increase in the 2020s, a 10% increase in the 2050s and a 22% increase in the 2080s.

The CCGG scenario forecasts average annual temperature increases of 3.5°F in the 2020s, 6.5°F in the 2050s and 10.2°F in the 2080s. The CCGG projects very little change in precipitation over the next century: in the 2020s, precipitation would increase by 9% compared to the average precipitation over the past 30 years. The precipitation levels for the 2050s would be a slight .1% higher than the average for the past 30 years, followed by a forecast of .1% increase in annual precipitation in the 2080s.

The CCGS scenario projects an average annual temperature increase of 2.1°F for the 2020s, an increase of 4.8 °F in the 2050s and an increase of 6.5°F in the 2080s. These temperature increases accompany projections of precipitation decrease over the century with a 1.4% increase in precipitation in the 2020s, a -15.6% precipitation decrease in the 2050s and a –2.1 decrease in precipitation levels, as compared to the GCM simulated 1961-1990 period.

These five scenarios (Current Trends, HCGG, HCGS, CCGG, CCGS) provide a range of future possible climates. The five scenarios used in the MEC Assessment vary in the magnitude of the projected temperature changes, but they all follow a warming trend, with the GCM models projecting overall higher temperature changes than the current trend (1900-1990). The Current Trends Scenario's projected temperature changes are lower than temperature changes projected by the GCM scenarios because the GCM scenarios account for increasing feedback from greenhouse gases that act as forcing mechanisms to warm the Earth's atmosphere.

While each of the five future scenarios provide a distinct projection of regional precipitation change, it is important to note that the precipitation projections of the GCM scenarios do not agree either in magnitude or direction (as opposed to the projected temperature changes, which agree in direction, but not magnitude). The Hadley Centre's scenarios show increasing levels of precipitation, while the Canadian Centre projects varying precipitation changes over time.

Conclusion: Climate Variability and Change and its Impacts in the Metro East Coast Region

Climate is changing in the New York Metropolitan Region. Over the past 100 years, temperature in the region has warmed nearly 2^{o}F; however, it is very difficult to determine the causes of the observed climate trends. The rate and amount of temperature rise is projected to increase over the 21st century due to anthropogenic greenhouse warming. Gradual changes may be punctuated by surprises, such as intense precipitation events. Substantial uncertainties about climate change remain, including the rate and magnitude of projected regional changes.

The use of a range of plausible scenarios enabled the Metro East Coast Assessment researchers to project possible impacts created by climate variability and change as well as to evaluate the MEC region's responses. An assessment exercise such as the Metro East Coast is useful in developing preparedness for extreme climate events in the present as well as readiness for a changing climate.

Climate change will affect people in cities multidimensionally. Heightened frequencies of storm-surges will damage major infrastructure juxtaposed to already threatened coastal wetlands; health impacts cannot be separated from the impacts of augmented heatwaves on energy demand. Finally, since global cities are major sites of international capital and labor flows, climate change impacts may not be limited by a city's boundaries. For example, a major climate-related disruption of the New York Stock Exchange would have reverberating impacts on global financial markets.

The complex nature of potential climate change impacts in urban regions poses tremendous challenges to urban environment managers to respond cooperatively, flexibly, and with far longer decision-making timeframes than currently practiced. Given the already fragmented nature of urban environments and jurisdictions, the political and social responses to the global climate issue in cities should begin at once. Transforming the urban management paradigm to better prepare for climate change will safeguard against negative feedbacks around the world.

Possible Institutional Adaptations to Climate Change

How can environmental managers in urban areas respond to the potential challenges and opportunities of climate change, and how can they bring the issue into their everyday decision-making processes? Several types of potential adaptations can be achieved at both the conceptual and operational levels. At the conceptual level, decision-makers must be pro-active with respect to potential climate change and variability, responsive to potential environmental changes on longer time horizons, and flexible in the face of increased uncertainty.

At the operational level, climate variability and change could be associated with several initiatives. These include enhanced methods for defining and entraining potential climate change impacts into planning decisions, increased inter-agency communication and cooperation, and education and outreach programs. Current major capital reinvestment activities and structural shifts in management regimes in the Metro East Coast region provide excellent pathways for integration of climate change adaptation into stakeholders' decision-making practices.

Climate Impact Indicators

Through our communication with stakeholders in the course of the Metropolitan East Coast Regional Assessment, we recognize that the impact of potential climate change has to be put into the discourse of the everyday decision-making process. Rates of possible sea level rise, temperature and precipitation shifts are relatively remote to the average decision-maker and region resident. Impacts must be put into contexts that are meaningful. For example, sea level rise will mean an "x" amount of increased costs of beach renourishment and temperature increases will mean a "y" increase in acute asthma attacks. The development of a set of cost-based, urban-focused climate change impact indicators would make a significant contribution.

Inter-Agency Climate Task Force

Increased intra-sectoral and inter-sectoral communication amongst agencies and institutions also would greatly increase the response capacity of local decision-makers to potential climate change impacts. This kind of enhanced communication would allow decision-makers to identify potential problems and define common solutions. Examples of the general utility of within-sector interactions already are present in the MEC region. SENYIWSAC (Southeastern New York Intergovernmental Water Supply Advisory Council) is a volunteer, non-regulatory group of water supply managers that communicate on common problems and planning initiatives. Regional air traffic control protocols for the region's three major airports and numerous smaller airports are another example.

Inter-sectoral working groups are fewer. Such groups are critical for addressing the multidimensional impacts that cut across sector lines. In metropolitan regions, this type of interaction is especially important given the highly integrative nature of the urban environment problems such as the links between public health and energy demand, and the links between the ecological and infrastructural components of the coastal environment. Interagency task forces developed as part of regional multidimensional environmental management activities, such as the Florida Everglades and Chesapeake Bay, can serve as valuable examples of how to develop climate change-related groups.

Climate Awareness Program

As an education and outreach component, a regional Climate Awareness Program would be effective to inform both the decision-makers and the general public about the nature of current climate processes, lessons learned in responding to climate extremes, and future climate change. Enhanced training of weather forecasters in the region about the climate change issue along with climate awareness websites or other easily accessibility sources of updated information would facilitate this process. In the case of the Metro East Coast Regional Assessment, CIESIN (Center for International Earth Science Information Network) is developing a Climate Awareness website for the region with the Columbia Earth Institute of Columbia University.