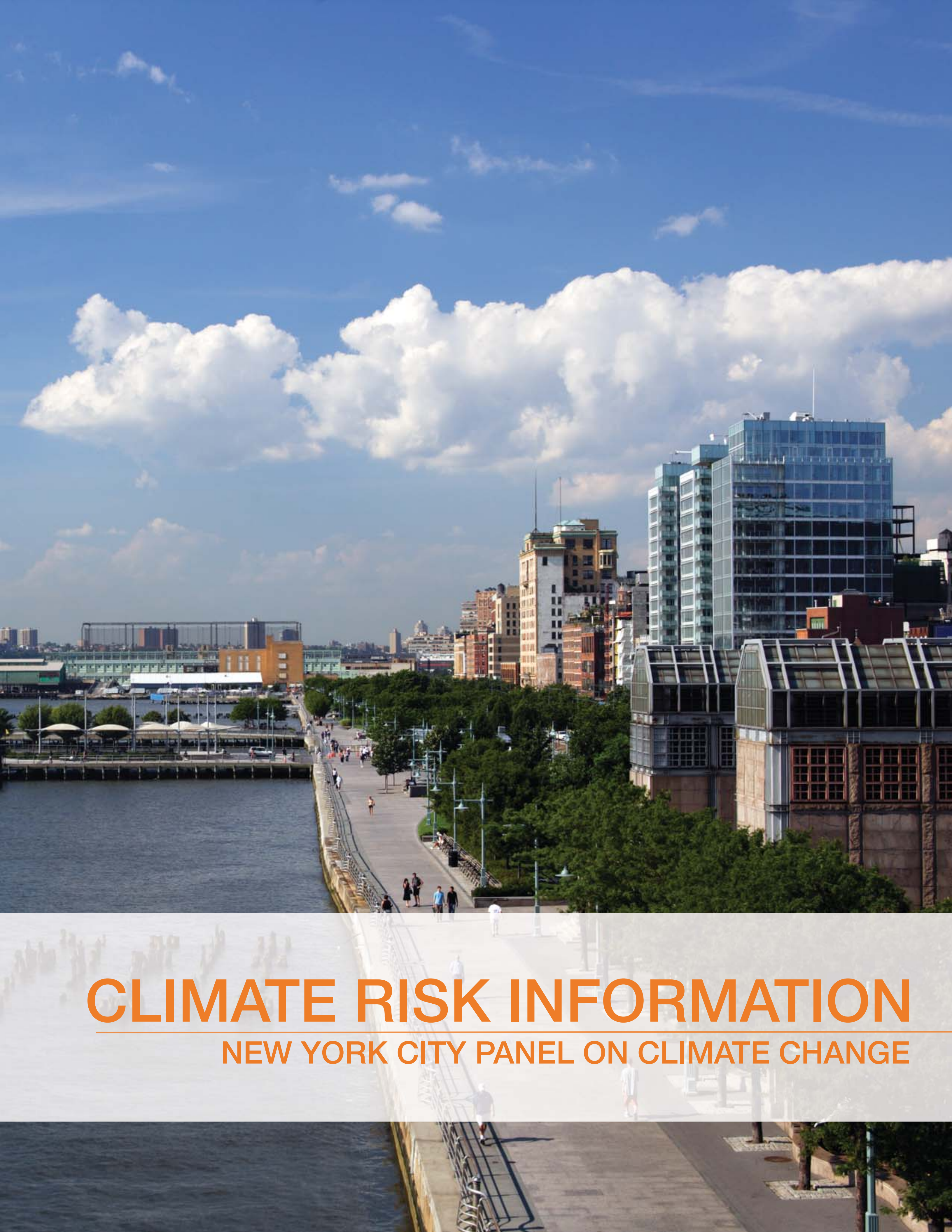

CLIMATE RISK INFORMATION

NEW YORK CITY PANEL ON CLIMATE CHANGE

NEW YORK CITY PANEL ON CLIMATE CHANGE

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CLIMATE RISK INFORMATION

NEW YORK CITY PANEL ON CLIMATE CHANGE

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The information in this document reflects the views and opinions of the New York City Panel on Climate Change and not the City of New York.

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

Climate change poses a range of hazards to New York City and its infrastructure. These changes suggest a need for the City to rethink the way it operates and adapts to its evolving environment. To respond to these changes and accomplish the goals outlined in PlaNYC, the City's comprehensive sustainability plan, Mayor Michael Bloomberg, with funding from the Rockefeller Foundation, convened the New York City Panel on Climate Change (NPCC) in August 2008. The NPCC, which consists of leading climate change and impact scientists, academics, and private sector practitioners, was charged with advising the Mayor and the New York City Climate Change Adaptation Task Force (the "Task Force") on issues related to climate change and adaptation as it relates to infrastructure. This document, one of three in a series of workbooks to be produced for the Task Force, provides climate change projections for New York City and identifies some of the potential risks to the City's critical infrastructure posed by climate change.

KEY FINDINGS

Warmer **temperatures** are extremely likely in New York City and the surrounding region. Mean annual temperatures are projected by global climate models (GCMs) to increase by[1]:

- 1.5 – 3 °F by the 2020s[2]
- 3 – 5 °F by the 2050s
- 4 – 7.5 °F by the 2080s

1 Projections shown are the 67% central range of GCM projections. Full GCM ranges are included in Appendix B.

2 The temperature and precipitation timeslices reflect a 30-year average centered around the given decade, i.e., the time period for the 2020s is from 2010-2039. For sea level rise, the timeslice represents a 10-year average.

There is universal agreement among the GCMs that temperatures will increase over the next century.

Total annual **precipitation** in New York City and the surrounding region will more likely than not increase. Mean annual precipitation increases projected by GCMs are:

- 0 – 5% by the 2020s
- 0 – 10% by the 2050s
- 5 – 10% by the 2080s

The GCMs are in less agreement about the direction of precipitation change, and precipitation is characterized by large inter-annual variability, making these projections more uncertain than those for temperature.

Rising **sea levels** are extremely likely. GCM-based projections for mean annual sea level rise in New York City are:

- 2 – 5 inches by the 2020s
- 7 – 12 inches by the 2050s
- 12 – 23 inches by the 2080s

Because GCMs do not capture all of the processes which may contribute to sea level rise, an alternative method that incorporates observed and longer-term historical ice-melt rates is also included. This "rapid ice-melt" approach suggests sea level could rise by approximately 41 to 55 inches by the 2080s.

Short-duration climate hazards can pose particular threats to infrastructure. Among these **extreme events**:

- Heat waves are very likely to become more frequent, intense, and longer in duration

- Brief, intense precipitation events that can cause inland flooding are also likely to increase
- Storm-related coastal flooding due to sea level rise is very likely to increase
- It is more likely than not that droughts will become more severe

Infrastructure Impacts

These climate changes will have consequences for New York City's critical infrastructure.

Temperature-related impacts may include:

- Increased summertime strain on materials
- Increased peak electricity loads in summer & reduced heating requirements in winter

Precipitation-related impacts may include:

- Increased street, basement & sewer flooding
- Reduction of water quality

Sea level rise-related impacts may include:

- Inundation of low-lying areas & wetlands
- Increased structural damage & impaired operations

Indicators & Monitoring

Climate change, impacts and adaptation strategies should be regularly monitored and reassessed as part of any climate change adaptation strategy.

Climate indicators to monitor include:

- Earth's carbon cycle
- Sea level
- Changes in polar ice
- Advances in climate science

Infrastructure impacts to be monitored include:

- Combined-sewer overflow events (CSO)
- Flooding & associated damages
- Climate-related power outages
- Indirect impacts, including ecosystem changes & effects of changes in other regions

In addition to tracking climate and impacts science, advances in technology, materials science, and adaptation strategies should also be monitored. Adaptation plans should be assessed both to determine whether they are meeting their intended objectives and to discern any unforeseen consequences. For example, by monitoring trends in population, the economy, policy, operations, management and material costs, future adaptation strategies can be iteratively tailored to ensure they remain consistent with broader citywide objectives.

About the New York City Panel on Climate Change

Convened by Mayor Michael Bloomberg, the NPCC advises the Mayor on issues related to climate change and adaptation. Made up of climate change and impacts scientists, legal, and insurance and risk management experts, the NPCC is modeled on the Intergovernmental Panel on Climate Change (IPCC). Among its ongoing activities, the NPCC is working to develop climate change projections for New York City; create a set of workbooks to assist the City's Climate Change Adaptation Task Force; and draft a technical report on the localized effects of climate change on New York City—similar to the IPCC reports on global climate change. The NPCC is chaired by Dr. Cynthia Rosenzweig of NASA Goddard Institute for Space Studies and Columbia University Earth Institute's Center for Climate Systems Research, and Dr. William Solecki of CUNY Institute for Sustainable Cities at Hunter College. The NPCC is funded through a grant from the Rockefeller Foundation.

About the Rockefeller Foundation

The Rockefeller Foundation was established in 1913 by John D. Rockefeller, Sr., to "promote the well-being" of humanity by addressing the root causes of serious problems. The Foundation supports work around the world to expand opportunities for poor or vulnerable people and to help ensure that globalization's benefits are more widely shared. With assets of nearly $4 billion, it is one of the few institutions to conduct such work both within the United States and internationally.

CLIMATE CHANGE SCENARIOS & NEW YORK CITY

1

Global mean temperatures and sea levels have been increasing for the last century, accompanied by other changes in the earth's climate. As these trends continue, climate change is increasingly being recognized as a major global concern. An international panel of leading climate scientists, the Intergovernmental Panel on Climate Change (IPCC), was formed in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to provide objective and up-to-date information regarding the changing climate. In its 2007 Fourth Assessment Report (AR4), the IPCC stated that there is a greater than 90% chance that warming temperatures since 1750 are primarily due to human activities. As described by the IPCC and as had been predicted in the 19th century, the principal driver of climate change over the past century has been increasing levels of atmospheric greenhouse gases associated with fossil-fuel combustion, changing land-use practices, and other human activities. Atmospheric concentrations of the major greenhouse gas carbon dioxide (CO_2) are now more than one-third higher than in pre-industrial times. Concentrations of other important greenhouse gases, including methane (CH_4), ozone (O_3) and nitrous oxide (N_2O) have increased as well. Largely as a result of work done by the IPCC and the United Nations Framework Convention on Climate Change (UNFCCC), efforts to mitigate the severity of climate change by limiting levels of greenhouse gas emissions are underway globally.

Because of greenhouse gas forcing mechanisms already in the climate and the long timeframe of some climate system processes, awareness is growing that some impacts from climate change are inevitable. Responses to climate change have grown beyond a focus on mitigation to include adaptation measures in an effort to minimize the impacts of climate change already underway and to prepare for unavoidable future impacts.

Climate Change & New York City

Climate change is extremely likely to bring warmer temperatures to New York City and the surrounding region. Heat waves are very likely to become more frequent, intense, and longer in duration. Total annual precipitation will more likely than not increase and brief, intense rainstorms are also likely to increase. Towards the end of the 21st century, it is more likely than not that droughts will become more severe. Additionally, rising sea levels are extremely likely, and are very likely to lead to more frequent and damaging flooding related to coastal storm events in the future.

To respond to climate changes in New York City and accomplish the goals outlined in PlaNYC, the City's comprehensive sustainability plan, Mayor Michael Bloomberg, with funding from the Rockefeller Foundation, convened the New York City Panel on Climate Change (NPCC) in August 2008. The NPCC, which consists of climate change and impacts scientists, and legal, insurance and risk management experts, was charged with serving as the technical advisory body for the Mayor and the New York City Climate Change Adaptation Task Force (the "Task Force") on issues related to climate change, impacts and adaptation.

DEFINITIONS & TERMS

The following terms form the basis of the Climate Risk Information (CRI) and are defined here for clarification.

Risk

Generally the NPCC defines *risk* as a product of the likelihood of an event occurring (typically expressed as a probability) and the magnitude of consequences should that event occur. The CRI provides quantitative and qualitative estimates of the likelihood of occurence of the projected climate changes, along with a general description of the types of potential consequences for New York City's infrastructure. Thus, the CRI lays the foundation for climate risk estimates developed with further consideration of consequences addressed in the Adaptation Assessment Checklist (AAC). These risk estimates can be adapted and improved as additional information becomes available.

Scenarios

Climate change scenarios provide a coherent and plausible description of possible future conditions (Parson et al., 2007). For example, the IPCC Special Report on Emissions Scenarios (SRES) (IPCC, 2000) provides multiple future 'storylines,' each with different assumptions about population and economic growth, and technological and land-use changes, that lead to greenhouse gas emissions and atmospheric concentration trajectories. While no one single emissions scenario or global climate model projection will occur exactly as specified in the future, a combination of a suite of global climate model simulations and greenhouse gas emissions profiles provides a range of possible climate outcomes that can be expressed as a set of projections that reflects the current level of expert knowledge. This approach to climate change scenarios has been developed by the IPCC and provides the basis for the IPCC Assessment Reports, including the 2007 AR4.

Local Climate Change Information

Based on the scenarios of greenhouse gas emissions and global climate model simulations, *local climate change information* is given for the key climate variables through *quantitative and qualitative projections* reflecting a model-based range of values for New York City and the surrounding region. Although the model-based frequency distribution should not be mistaken for the true probability distribution, the model-based quantitative approach provides valuable information for many climate variables. The IPCC (2007) uses this approach to make regional temperature and precipitation projections.

As noted by the IPCC, climate models either do not provide results, or the results are too uncertain for some variables to be incorporated into a quantitative model-based projection. For these variables, the most likely direction of change is provided in this document. The lack of precision for these qualitative projections makes possible statements of likelihood, where the actual, rather than the model-based likelihood of the directional change is qualitatively estimated. Both the quantitative and qualitative approaches closely follow the methods used in the IPCC AR4 report.

Climate Risk Factors

Climate risk factors are a distillation of a wide range of climate change information to the subset of climate hazards that are of most consequence for New York City's infrastructure. They are used by the NPCC to determine the impacts of climate change on the City. Climate risk factors are generated based on expert judgment using the quantitative and qualitative climate-hazard information framed by climate change impact information from stakeholders. The 'risk factors' identified in this workbook are not complete statements of 'risk' as traditionally defined, since they do not explicitly include the magnitude of consequences or impacts. Rather, the risk factors are generalized climate variables prioritized by considerations of the potential consequences for the region's infrastructure. Qualitative statements of the likelihood of occurrence of these tailored climate risk factors are provided as well. Finally, as a bridge to the AAC and Climate Protection Levels (CPL), potential impacts and consequences of the climate risk factors are listed. These potential impacts are further described in the AAC and CPL.

Uncertainty and Likelihoods

Climate projections are characterized by large uncertainties. At the global scale these uncertainties can be divided into two main categories:

- *Uncertainties in future greenhouse gas concentrations* and other climate drivers which alter the global energy balance, such as aerosols and land-use changes;
- *Uncertainties in how sensitive the climate system will be* to greenhouse gas concentrations and other climate drivers.

When planning adaptations for local and regional scales, uncertainties are further increased for two additional reasons:

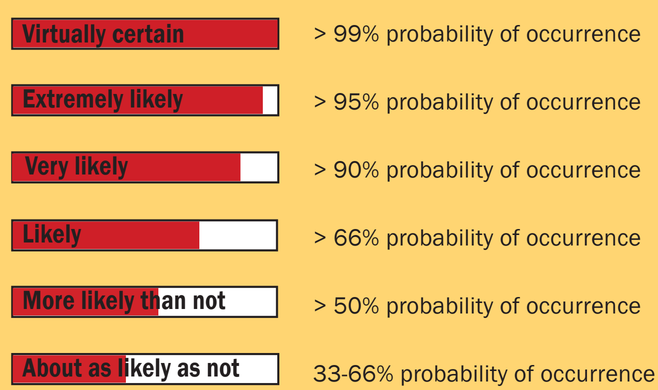
- *Climate variability* (which is mostly unpredictable) can be especially large over small regions, partially masking more uniform effects of climate change;
- *Changes in local physical processes* that operate at fine scales, such as land/sea breezes, may not be fully captured by the global climate models used to make projections.

By providing projections that span a range of global climate models and greenhouse gas emissions scenarios, the global uncertainties may be reduced, but they cannot be fully eliminated. Averaging projections over thirty-year timeslices and showing changes in climate through time, rather than absolute climate values, reduces the local and regional scale uncertainties, although it does not address the possibility that local processes may change with time.

The treatment of likelihood in the CRI is similar to that developed and used by the IPCC (Figure 1). The six likelihood categories used here are as defined in the IPCC Working Group (WG) I Technical Summary (2007). The assignment of climate hazards to these categories is based on global climate simulations, published literature, and expert judgment.

FIGURE 1.

Probability of Occurrence



The Task Force was also launched in August 2008 to identify climate change risks and opportunities for the City's critical infrastructure[3] and to develop coordinated adaptation strategies. The Task Force consists of 38 city, state and federal agencies; regional public authorities; and private companies that operate, maintain or regulate critical infrastructure in the region.

The NPCC has been charged with creating three workbooks to guide Task Force members through the process of identifying climate risks to their critical infrastructure, creating adaptation plans, and considering the regulatory environment as it pertains to climate change adaptation. This Climate Risk Information (CRI) workbook provides a summary of climate data and projections for New York City and identifies potential risks to the City's critical infrastructure posed by climate change. The Adaptation Assessment Checklist (AAC) guides stakeholder consideration of the climate information presented in the CRI in their risk-management and planning processes. The Climate Protection Levels (CPL) workbook evaluates some of the policies, rules and regulations which govern infrastructure to determine how they could be affected by climate change.

Climate Risk Information

The CRI is designed to help New York City decision-makers better understand climate science and the potential consequences for city infrastructure. The CRI contains information on key climate hazards for New York City and the surrounding region, likelihoods of the occurrence of the hazards, and a list of initial implications for the city's critical infrastructure.

GCM-based quantitative projections are provided for:

- temperature,
- precipitation,
- sea level rise, and
- extreme events

3 For the efforts of the City's Task Force, critical infrastructure is defined as systems and assets (excluding residential and commercial buildings, which are being addressed through other City efforts) that support activities that are vital to the city and for which the diminished functioning or destruction of such systems and assets would have a debilitating impact on public safety and/or economic security.

Potential for changes in other variables are also described, although in a more qualitative manner because quantitative information for them is either unavailable or considered less reliable. These variables include:

- heat indices,
- frozen precipitation,
- intense precipitation of short duration,
- lightning, and
- storms (hurricanes, nor'easters and associated wind events)

The climate hazards described should be monitored and assessed on a regular basis. Indirect climate change impacts on infrastructure beyond the scope of this document, such as ecosystem changes and climate change in other regions, should also be taken into consideration.

Section 2 of this document presents observed climate information for temperature, precipitation, sea level rise, and extreme events in New York City. Section 3 presents scenario results for the region from GCM simulations of three greenhouse gas emissions pathways in a quantitative form where possible and qualitatively for climate variables characterized by higher uncertainty. In Section 4, these data are combined with likelihoods and potential impacts on infrastructure. Section 5 outlines key indicators for monitoring and reassessment.

For planning purposes the NPCC focuses on the coming decades of the 21st century. Although projections for the 22nd century are characterized by even larger uncertainties and are beyond most current infrastructure planning horizons, they are briefly discussed because climate change is a multi-century concern.

Much of the information in this packet is generally applicable to other developed coastal urban centers, although the projected likelihood, magnitude and nature of the climate hazards, as well as certain infrastructure consequences, will vary. Nevertheless, the analytical framework applied here may guide other cities as they embark on climate change adaptation efforts.

OBSERVED CLIMATE 2

This section of the document presents observed climate information for temperature, precipitation, sea level rise and extreme events in New York City.

TEMPERATURE

New York City has a temperate, continental climate, with hot and humid summers and cold winters. Records show an annual average air temperature from 1971-2000 of approximately 55 degrees Fahrenheit.

The annual mean temperature in New York City has risen 2.5 degrees Fahrenheit since 1900 (Figure 2), although the trend has varied substantially. For example, the first and last 30-year periods were characterized by warming, while the middle segment, from 1930 to the late 1970s, was not.

The temperature trends for the New York City region are broadly similar to trends for the Northeast United States. Specifically, most of the Northeast has experienced a trend towards higher temperatures, especially in recent decades.

PRECIPITATION

The City's climate is characterized by substantial precipitation in all months of the year. Annual average precipitation amounts range between approximately 43 and 50 inches depending on the location within New York City. While mean annual precipitation levels have increased only slightly over the course of the past century, inter-annual variability of precipitation has become more pronounced (Figure 2).

Precipitation in the Northeast also increased modestly in the 1900s, although the trend reversed slightly in the last decades of the 20th century.

SEA LEVEL RISE

Prior to the industrial revolution, sea level had been rising along the East Cost of the United States at rates of 0.34 to 0.43 inches per decade, primarily because of regional subsidence as the Earth's crust still slowly re-adjusts to the melting of the ice sheets since the end of the last ice age. Within the past 100 to 150 years however, as global temperatures have increased, regional sea level has been rising more rapidly than over the last thousand years (Gehrels, et al., 2005; Donnelly et al., 2004; Holgate and Woodworth, 2004).

Currently, rates of sea level rise in New York City range between 0.86 and 1.5 inches per decade, with a long-term rate since 1900 averaging 1.2 inches/decade, as seen in Figure 2. The sea level rise rates shown in Figure 2, measured by tide gauges, include both the effects of recent global warming and the residual crustal adjustments to the removal of the ice sheets.

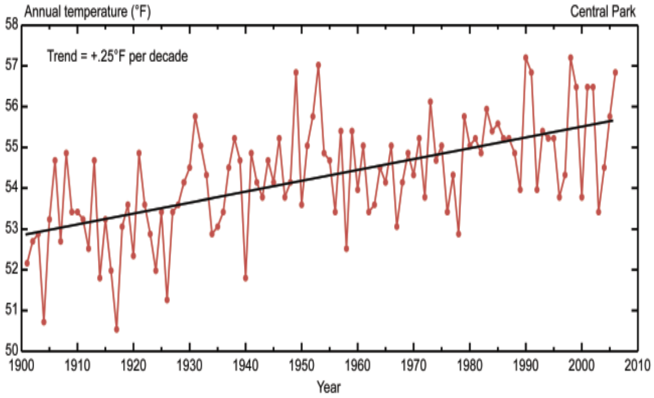
Most of the observed current climate-related rise in sea level over the past century can be attributed to expansion of the oceans as they warm, although melting of land-based ice may become the dominant contributor to sea level rise during the 21st century.

FIGURE 2.

Observed Climate in New Yok City

Observed annual temperature and precipitation in Central Park, 1901-2006 (Columbia Center for Climate Systems Research) and sea level rise at the Battery tide gauge station (1901-2006), NYC. All three trends are significant at the 95% levels.

Source: http://tidesandcurrents.noaa.gov



EXTREME EVENTS

The critical climate factors affecting New York City can be divided into three general categories: temperature, precipitation, and sea level rise. Each of these climate variables operates at a variety of timescales. When experienced in limited duration, they are referred to as an extreme event. Heat waves and cold air events are examples of temperature-related extreme events. For precipitation, the extreme event timescales are asymmetric; heavy precipitation events generally range from less than one hour to a few days, whereas droughts can range from months to years. While sea level rise is a gradual process, storm surge represents short-term high-water levels superimposed onto mean sea level. The key types of storms in the region are hurricanes and nor' Easters.

Extreme Temperature and Heat Waves

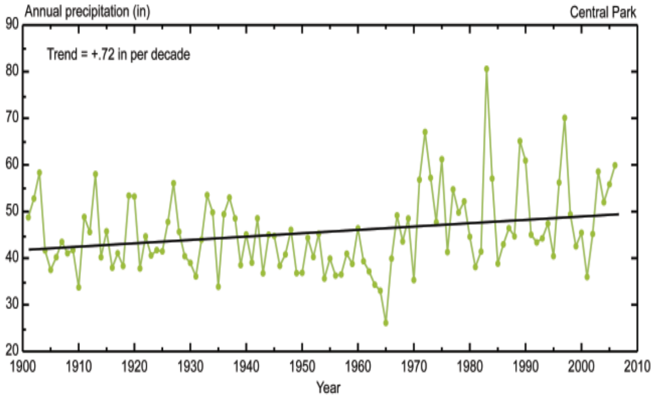
Hot days and heat waves may be defined in several ways using daily data available for Central Park since 1900. These data are presented in Appendix A in terms of:

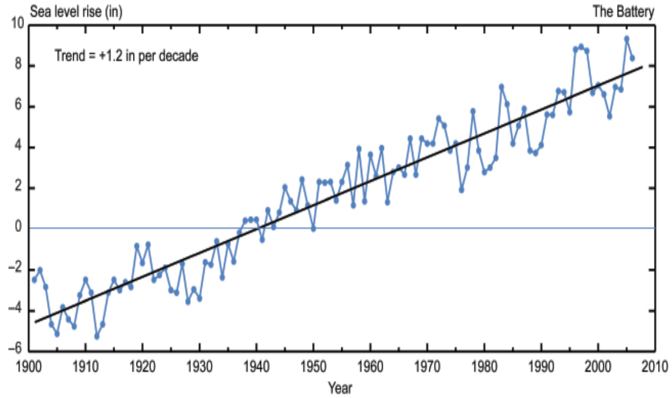
- Individual days with maximum temperatures above 90°F
- Individual days with maximum temperatures above 100°F
- Heat waves, defined as three consecutive days with maximum temperatures above 90°F

During the 1971-2000 period, New York City averaged 14 days per year over 90 degrees, 0.4 days over 100 degrees, and two heat waves per year. The number of events in a given year is highly variable. For example, in 2002 New York City experienced temperatures of 90 degrees or higher on 33 different days; in 2004 temperatures of 90 or higher only occurred twice. None of the post-1900 trends for these heat events can be distinguished statistically from random variability. However, seven of the ten years with the most days over 90 degrees in the 107-year record have occured since 1980.

Extreme Precipitation

Appendix A includes information on the number of occurrences per year of precipitation above 1, 2, and 4 inches for New York City since 1900. Between 1971 and 2000, New York City averaged 13 days per year with 1 inch or more of rain, 3 days per year with 2 or more inches of rain, and 0.3 days per year with more than 4 inches of rain. As with extreme temperatures, year to year variations in extreme precipitation events were large. The aforementioned pattern of increasing inter-annual variability late in the 20^{th} century occurred roughly concurrently with a small but not statistically significant trend towards more extreme precipitation events in the region. For example the three years with the most





occurrences of more than 2 inches of rain have all occurred during the last three decades. Since extreme precipitation events tend to occur relatively infrequently, long time series are needed to identify trends; there is a relatively large 'burden of proof' required to distinguish a meaningful trend from random variability.

Coastal Storms

The two types of storms with the largest influence on the region are hurricanes and nor'easters. Hurricanes strike New York very infrequently, generally between July and October, and can produce large storm surges and wind damage. Nor'easters are generally associated with smaller surges and weaker winds than hurricanes. Nevertheless, nor'easter effects can be large, in part because their long duration means an extended period of high winds and high water, often coinciding with high tides.

A large fraction of New York City and the surrounding region lies less than 10 feet above mean sea level, and infrastructure in these areas is vulnerable to coastal flooding during major storm events, both from inland flooding and from coastal storm surges. The current 1-in-100 year flood can produce approximately an 8.6-foot surge for much of New York City. Hurricanes, because they can be more intense, are more likely than nor'easters to cause a 1-in-100 year and 1-in-500 year flood. Nor'easters are the main source of the 1-in-10 year coastal floods, since they are more frequent and longer in duration than hurricanes.

Because the most extreme storms are even rarer than temperature and precipitation extreme events, documenting their occurrence over New York's longer-term history is challenging given reporting inconsistencies over time. Although no trend in observed storms is evident, characterizing historical storms is a critical first step in understanding future storms and their impacts, especially because rising sea levels will result in more severe coastal flooding when storm surges occur.

Appendix A presents a list of key hurricane events from the past two centuries. For most of the hurricanes, a basic description of key statistics and impacts is included.

FUTURE PROJECTIONS 3

Building on New York City and the surrounding region's historical climate information, Section 3 gives climate projections for the 21st century for temperature, precipitation, sea level rise and extreme events. Model-based quantitative projections are given for each of these variables. For some extreme events, only qualitative statements are possible due to large uncertainties.

METHODS

The NPCC used IPCC-based methods to generate model-based probabilities for temperature, precipitation, and sea level rise from GCM simulations based on three GHG emission scenarios (Figure 3). Simulation results from 16 GCMs are used for both temperature and precipitation, and results based on seven GCMs are used for sea level rise.

Model-based Probability

The combination of 16 GCMs and three emissions scenarios produces a 48 (16 x 3)-member matrix of outputs for temperature and precipitation; for each scenario time period and variable, the results constitute a "model-based" probability function. The results for the future time periods are compared to the model results for the 1971-2000 baseline period. Mean temperature change projections are calculated as the difference between each model's future simulation and the same model's baseline simulation, whereas mean precipitation is based on the ratio of a given model's future precipitation to the same model's baseline precipitation (expressed as a percentage change). Sea level rise methods are more complex, since sea level rise is not a direct output of most Global Climate Models (GCMs).

Sea Level Rise Methods

The IPCC-based methods used to project sea level rise for the New York City region include both global (global thermal expansion and meltwater from glaciers, ice caps, and ice sheets) and local (local land subsidence and local water surface elevation) components.

Within the scientific community, there has been extensive discussion of the possibility that the IPCC approach to sea level rise may substantially underestimate the range of possible increases. For this reason, an alternative 'rapid ice-melt' approach has been developed based on paleoclimate studies. Starting around 20,000 years ago, global sea level rose 394 feet and reached nearly present-day levels around 8,000-7,000 years ago. The average rate of sea level rise during this ~10,000-12,000-year period was 0.39-0.47 in/yr. This information is incorporated into the rapid ice-melt scenario projections. More information on this method, including how it is integrated with the GCM-based methods, can be found in Appendix C.

Extreme Events Methods

Extremes of temperature and precipitation (with the exception of drought) tend to have their largest impacts at daily rather than monthly time scales. Because monthly output from climate models is considered more reliable than daily output, a hybrid projection technique was employed. Modeled changes in monthly temperature and precipitation are based on the same methods described for the annual data; monthly changes through time in each of the 16 GCMs and three emissions scenarios were then applied to the observed daily Central Park from 1971-2000 to generate 48 time series of daily data.[4] This is a simplified approach to projections of extreme events, since it does not allow for possible changes in variability through time. However, because changes in variability for most climate hazards are considered highly uncertain, the approach described can assist long-term planners as they prepare for extreme events.

Global Climate Models

Global climate models (GCMs) are mathematical representations of the behavior of the Earth's climate system through time. Each model couples the ocean, the atmosphere, and the land and ice surfaces, and climate models have increased in complexity as computational power has increased.

4 Because they are rare, the drought and coastal storm projections were based on longer time periods. See Appendix B for more information.

Recent integrated climate model simulations, done for the IPCC 2007 report, were run at higher spatial resolution than earlier models and, due to improved physical understanding, incorporated more accurately complex physical processes such as cloud physics. Current generation climate models are able to generally reproduce the warming that occurred over the 20th century when run in a 'hindcast' mode with accurate historical greenhouse gas concentrations. These models are also able to reproduce some of the key climate characteristics of paleoclimates that were far different than today's climate, which lends additional confidence that GCMs future simulations will be generally realistic as well. Out of the IPCC simulations, the 16 state-of-the-art global climate models that had available output for each of the 3 emissions scenarios (only 7 GCMs are available for sea level rise) were selected to develop the CRI for New York City. See Appendix B for a description of the global climate models used.

FIGURE 3.

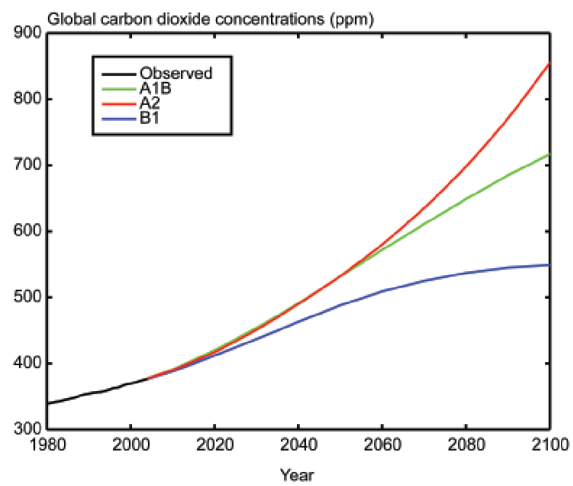
Emission Scenarios Used by the NPCC

A2: *Relatively rapid population growth and limited sharing of technological change combine to produce high greenhouse gas levels by the end of the 21st century, with emissions growing throughout the entire century.*

A1B: *Effects of economic growth are partially offset by introduction of new technologies and decreases in global population after 2050. This trajectory is associated with relatively rapid increases in greenhouse gas emissions and the highest overall CO_2 levels for the first half of the 21st century, followed by a gradual decrease in emissions after 2050.*

B1: *This scenario combines the A1 population trajectory with societal changes tending to reduce greenhouse gas emissions growth. The net result is the lowest greenhouse gas emissions of the three scenarios, with emissions beginning to decrease by 2040.*

Source: IPCC Special Report on Emissions Scenarios (SRES) (IPCC, 2000)



Observed CO_2 concentrations through 2003, and future CO_2 concentrations in the A1B, A2, and B1 scenarios (2004 – 2100).

The large number of available GCMs makes possible model-based probabilistic assessment of future climate projections across a range of climate sensitivities (defined as the mean equilibrium temperature response of a global climate model to doubling carbon dioxide (CO_2), relative to preindustrial levels). The outputs of recent simulations of these models are collected by the World Climate Research Program (WCRP) and the Program for Climate Model Diagnosis and Intercomparison (PCMDI) (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php), at the Lawrence-Livermore Laboratory in Berkeley, California. The GCM results developed by the NPCC were calculated from the source model output from WCRP/PCMDI.

Although GCMs are the primary tool used for long-range climate prediction, they do have limitations. For example, they simplify some complex physical processes, such as convective rainfall. In addition, the spatial and temporal scales of some climate variables such as thunderstorms are finer than the resolutions of GCMs. Finally, they do not fully include all relevant local climate forcings, including some aerosols, black carbon, land-cover changes and urban heat island effects, and solar variability.[5] For these and other reasons, climate may change in ways not captured by the models, leading to temperature, precipitation, and sea level rise changes outside the range presented in the NPCC CRI scenarios.

Emissions Scenarios

To produce future climate scenarios, GCM simulations are driven with projected greenhouse gas emissions scenarios. The three GHG emissions scenarios that were drivers for many GCMs and available from WCRP/PCMDI were selected for use by the NPCC (Figure 3). The A2, A1B, and B1 emissions scenarios force the GCMs with greenhouse gas concentrations determined by particular developmental storylines. Each represents a unique blend of demographic, social, economic, technological, and environmental assumptions (IPCC, 2000).

Additional SRES scenarios, such as the 'high-end' A1FI scenario, yield very different greenhouse gas concentrations than the three scenarios shown above by the end of the 21st century. The A1FI scenario was not included in the model based approach described here because very few GCM simulations are available. However, high-end climate change scenarios along the lines of A1FI are discussed qualitatively throughout the document, especially in the rapid ice-melt section as such trajectories should continue to be monitored and reassessed over time.

5 Changes in these additional factors are expected to have a smaller influence on climate change than increases in greenhouse gases during the 21st century.

Regional Projections

The regional projections are based on GCM output from the single land-based model gridbox covering New York City and its surrounding region. The precise coordinates of the gridbox differ since each GCM has a different spatial resolution. These resolutions range from as fine as ~75 x ~100 miles to as coarse as ~250 x ~275 miles, with an average resolution of approximately 160 x 190 miles. Changes in temperature and precipitation through time (for example, three degrees of warming by a given timeframe) are New York City region-specific; however, comparison to results from nearby land-based gridboxes reveals similar changes for the neighboring region, as shown in the maps in Appendix B (Figures 8 and 9). This spatial similarity increases confidence in the NPCC projections. In general, the applicability of the projections decreases with distance from New York City; the decrease is more pronounced for extreme events than for mean annual changes.[6]

By applying the projected changes from the relevant gridbox to observed data, the projections become specific to New York City. For example, although Poughkeepsie's projected change in temperature through time is similar to New York City's, the number of current and projected days per year with temperatures below 32 degrees differs between the two locations; the spatial variation in baseline climate is much larger than the spatial variation of projected climate changes.

6 Projections of extreme events are conditioned on historical data (which has large spatial variation), whereas projections of mean annual changes are conditioned only on model changes through time (which have less spatial variation).

Timeslices

Although it is not possible to predict the temperature, precipitation, or sea level for a particular day, month, or even specific year due to fundamental uncertainties in the changing climate system, GCMs are a valuable tool for projecting the likely range of changes over decadal to multi-decadal time periods. These projections, known as timeslices, are expressed relative to the given baseline period, 1971-2000 (2000-2004 for sea level rise). The timeslices are centered around a given decade, for example, the 2050s timeslice refers to the period from 2040-2069.[7] Thirty-year timeslices (10-year for sea level rise) are used to provide an indication of the climate 'normals' for those decades; by averaging over this period, much of the random year-to-year variability, or 'noise', is cancelled out, while the long-term influence of increasing greenhouse gases, or 'signal', remains. Thirty-year averaging is the standard used by the meteorological and climate communities.

MEAN ANNUAL CHANGES

Higher temperatures and sea level rise are extremely likely for the region. For temperature and sea level rise, all simulations project continued increases over the century, with the entire central range projecting more rapid temperature and sea level rise than occurred over the 20th century. Although most projections indicate small increases in precipitation, some do not and natural precipitation variability is large; thus, precipitation projections are less certain than temperature projections. The specific projections for all variables later in the century relative to earlier in the century are characterized by larger uncertainty (i.e., the ranges of outcomes become larger through time) due to uncertainties in the climate system and the possible pathways of the greenhouse gas emission scenarios.

Figure 4 blends observed data and projected changes for temperature, precipitation and sea level rise, respectively, to provide context on how projected changes in the region compare to historical trends and long-term variability. The black line on the left-hand side of the figures shows the historic values, and the right-hand side of the graphs shows the range of projections across the GCMs over the course of the 21st century. To emphasize the climate signal and deemphasize the unpredictable year-to-year variability, a ten-year filter has been applied to the observed data and model output.

Table 1 shows the baseline climate, and projected changes in temperature, precipitation, and sea level rise relative to the given baseline for the timeslices. In order to highlight where the various GCM and emissions scenario projections agree, the values in rows two through four indicate the central 67% range of the projected model-based changes; the highest and lowest 16.7% of values are excluded from the table. The maximum and minimum values of the projections, as well as the entire distribution, are shown in Appendix B.

Temperature

The temperature changes shown in Table 1 indicate that by the 2080s, New York City's mean temperatures throughout a 'typical' year may bear similarities to a city like Raleigh, North Carolina or Norfolk, Virginia today; increasing by 1.5 to 3°F by the 2020s, 3 to 5°F by the 2050s, and 4 to 7.5°F by the 2080s. The growing season could lengthen by approximately a month, with summers becoming more intense and winters more mild. The climate model simulations suggest that the amount of warming may be relatively consistent for each of the four seasons.

For temperature, only beginning around the 2030s do the three emissions scenarios produce temperature patterns that are distinguishable from each other; this is due to both the large inertia of the climate system and the fact that it takes time for the different emissions scenarios to produce large differences in greenhouse gas concentration.

7 For sea level rise, the multidecadal approach is not necessary due to lower inter-annual variability; the 2050s timeslice for sea level (for example) therefore refers to the period from 2050-2059.

Precipitation

Table 1 indicates that regional precipitation may increase by approximately 0 to 5 percent by the 2020s, 0 to 10 percent by the 2050s and 5 to 10 percent by the 2080s. While seasonal projections are less certain than annual results, the climate models tend to distribute much of this additional precipitation during the winter months. During September and October, in contrast, total precipitation is slightly reduced in many climate models. Monthly and seasonal breakdowns of both temperature and precipitation projections are included in Appendix B.

Figure 4 shows that precipitation is characterized by large historical variability, even with 10-year smoothing. For precipitation, only from the 2040s on does the lower-concentration B1 scenario produce smaller increases in precipitation than the A1B and A2 scenarios, although even after the 2040s there are occasional periods where B1 precipitation exceeds A2. At no point in the century are the A2 and A1B scenario-based precipitation projections consistently distinguishable.

Sea Level Rise

The GCM-based sea level rise projections in the third row of Table 1 indicate that sea level may rise by 2 to 5 inches in the 2020s, 7 to 12 inches in the 2050s, and 12 to 23 inches in the 2080s. Figure 4 shows

TABLE 1.

Baseline Climate and Mean Annual Changes[1]

Source: Columbia Center for Climate Systems Research

	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central range[2]	55°F	+ 1.5 to 3°F	+ 3 to 5°F	+ 4 to 7.5°F
Precipitation Central range[2]	46.5 in	+ 0 to 5 %	+ 0 to 10 %	+ 5 to 10 %
Sea level rise[3] Central range[2]	NA	+ 2 to 5 in	+ 7 to 12 in	+ 12 to 23 in
Rapid Ice-Melt Sea Level Rise[4]	NA	~ 5 to 10 in	~ 19 to 29 in	~ 41 to 55 in

1 Based on 16 GCMs (7 GCMs for Sea Level Rise) and 3 emissions scenarios. Baseline is 1971-2000 for temperature and precipitation and 2000-2004 for sea level rise. Data from National Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA). Temperature data are from Central Park; precipitation data are the mean of the Central Park and La Guardia Airport values; and sea level data is from the Battery at the southern tip of Manhattan (the only location in NYC for which comprehensive historic sea level rise data are available).

2 Central range = middle 67% of values from model-based probabilities; temperatures ranges are rounded to the nearest half-degree, precipitation to the nearest 5%, and sea level rise to the nearest inch.

3 The model-based sea level rise projections may represent the range of possible outcomes less completely than the temperature and precipitation projections. See page 18 for more information.

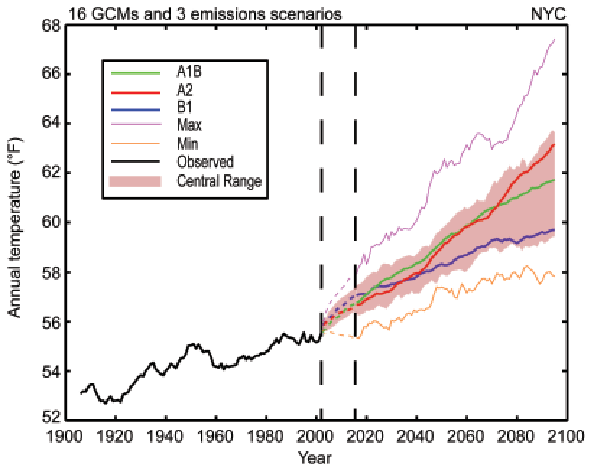
4 "Rapid ice-melt scenario" is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic Ice sheets and paleoclimate studies. See Appendix C for further description.

FIGURE 4.

Observed Climate & Future Projections for New York City

Combined observed (black line) and projected temperature, precipitation and sea level rise. Projected model changes through time are applied to the observed historical data. The three thick lines (green, red, and blue) show the average for each emissions scenario across the 16 GCMs (7 in the case of sea level). Shading shows the central range. The bottom and top lines, respectively, show each year's minimum and maximum projections across the suite of simulations. A ten-year filter has been applied to the observed data and model output. The dotted area between 2003 and 2015 (2002-2015 for Sea Level Rise) represents the period that is not covered due to the smoothing procedure.

Source: Columbia Center for Climate Systems Research



that the B1 scenario produces smaller increases in sea level than the A1B and A2 scenarios beginning in the 2050s, and only around 2080 does the A2 scenario produce larger values than A1B. The separation of A2 from A1B occurs approximately 10 years earlier for temperature than for sea level rise, in part reflecting the large inertia of the ocean and ice sheets relative to the atmosphere.

The model-based sea level rise projections shown in Figure 4 and the third row of Table 1 are characterized by greater uncertainty than the temperature projections, due largely to the possibility that future dynamical changes in polar ice sheets not captured by the GCMs may accelerate melting beyond currently projected levels. This uncertainty is weighted towards the upper bound; that is, the probability of sea level rise lower than described in the GCM projections in the third row of Table 1 is very low, but the probability of sea level rise exceeding the GCM projections is higher.

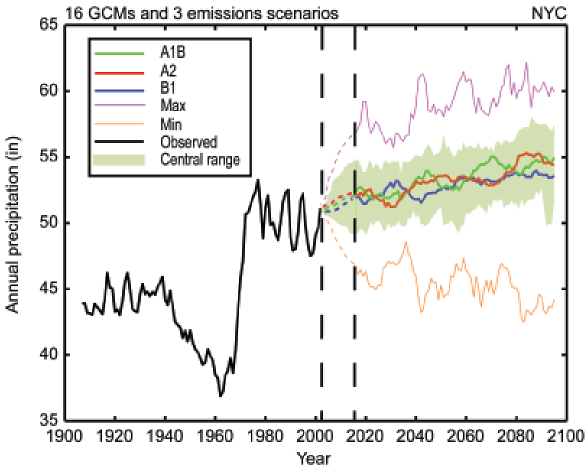
The 'Rapid Ice-Melt Sea Level Rise' scenario shown in the fourth row of Table 1 addresses this possibility. It is based on extrapolation of recent accelerating rates of ice melt from the Greenland and West Antarctic Ice sheets and on paleoclimate studies that suggest sea level rise on the order of ~.39 to .47 inches per decade may be possible. The potential for rapid ice-melt should be considered in part because of the large magnitude of consequence should it occur. More information on this topic, including additional references, can be found in Appendix C. To assess the risk of accelerated sea level rise over the coming years, scientific understanding, as well as many key indicators, should be monitored and reassessed (see Section 5).

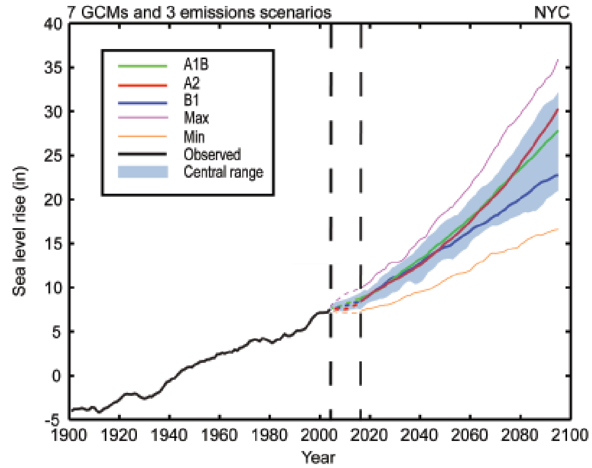
EXTREME EVENTS

Despite their brief duration, extreme events can have large impacts on infrastructure, so they are a critical component of climate change impact assessment. Table 2 indicates how the frequency of heat waves, cold events, intense precipitation, drought, and coastal flooding in the New York City region are projected by the GCMs to change in the coming decades. The average number of extreme events per year for the baseline period is shown, along with the central 67% of the range of the model-based projections. The full range of results can be found in Appendix B.

Heatwaves & Cold Events

The total number of hot days, defined in the CRI as days with a maximum temperature over 90 or 100 degrees Fahrenheit, is expected to increase





as the 21st century progresses. The frequency and duration of heat waves, defined as three or more consecutive days with maximum temperatures above 90 degrees Fahrenheit, are also expected to increase. In contrast, extreme cold events, defined as the number of days per year with minimum temperature below 32 degrees Fahrenheit, are expected to become rarer. The extreme event temperature projections shown in Table 2 are based on observed data for Central Park. Because some parts of New York City, including the south shore of Brooklyn and Queens currently experience significantly fewer extreme heat days, they will probably experience fewer heat events than those shown in the table for Central Park in the future as well.

Intense Precipitation & Droughts

Although the percentage increase in annual precipitation is expected to be relatively small, larger percentage increases are expected in the frequency, intensity, and duration of extreme precipitation (defined as more than 1, 2, and 4 inches) at daily timescales. This projection is consistent both with theory and observed trends nationally over the 20th century. Because some parts of New York City, including parts of coastal Brooklyn and Queens currently experience significantly fewer extreme precipitation days than Central Park, they may experience fewer extreme precipitation days than those shown in the table for Central Park in the future as well.

Twenty-first century drought projections reflect the competing influences of more total precipitation and more evaporation due to higher temperatures. By the end of the 21st century the effect of higher temperatures, especially during the warm months, on evaporation is expected to outweigh the increase in precipitation, leading to more drought, although drought projections are marked by relatively large uncertainty. Changes in the distribution of precipitation throughout the year, and timing of snowmelt, could potentially make drought more frequent as well. According to the IPCC, snow season length is very likely to decrease over North America.

The results indicate that severe drought frequency, as defined by the 12-month average Palmer Drought Severity Index (PDSI), is essentially unchanged for the 2020s, but increases thereafter. For the 2050s, the frequency is approximately doubled, and by the 2080s the frequency is approximately five times greater. The rapid increase in drought risk through time is reflective of a non-linear response in the PDSI; as temperature increases in summer become large, potential evaporation increases dramatically. See Appendix B for more information on the PDSI and its applicability.

TABLE 2.

Quantitative Changes in Extreme Events

Note: Extreme events are characterized by higher uncertainty than mean annual changes. The central range (middle 67% of values from model-based probabilities) across the GCMs and greenhouse gas emissions scenarios is shown. See Appendix B for the full range of values.

Category	Extreme Event	Baseline (1971-2000)	2020s	2050s	2080s
Heatwaves & Cold Events	# of days/year with maximum temperature exceeding:				
	90° F	14	23 to 29	29 to 45	37 to 64
	100° F	0.4[1]	0.6 to 1	1 to 4	2 to 9
	# of heat waves/year[2]	2	3 to 4	4 to 6	5 to 8
	Average duration (in days)	4	4 to 5	5 to 5	5 to 7
	# of days/year with minimum temperature below 32° F:	72	53 to 61	45 to 54	36 to 49
Intense Precipitation & Droughts	# of days per year with rainfall exceeding:				
	1 inch	13	13 to 14	13 to 15	14 to 16
	2 inches	3	3 to 4	3 to 4	4 to 4
	4 inches	0.3	0.2 to 0.4	0.3 to 0.4	0.3 to 0.5
	Drought occurs, on average[3]	~once every 100 yrs	~once every 100 to 100 yrs	~once every 50 to 100 yrs	~once every 8 to 100 yrs
Coastal Floods & Storms[4]	1-in-10 yr flood to reoccur, on average	~once every 10 yrs	~once every 8 to 10 yrs	~once every 3 to 6 yrs	~once every 1 to 3 yrs
	Flood heights associated with 1-in-10 yr flood (in feet)	6.3	6.5 to 6.8	7.0 to 7.3	7.4 to 8.2
	1-in-100 yr flood to reoccur, on average	~once every 100 yrs	~once every 65 to 80 yrs	~once every 35 to 55 yrs	~once every 15 to 35 yrs
	Flood heights associated with 1-in-100 yr flood (in feet)	8.6	8.8 to 9.0	9.2 to 9.6	9.6 to 10.5
	1 in 500-yr flood to reoccur, on average	~once every 500 yrs	~once every 380 to 450 yrs	~once every 250 to 330 yrs	~once every 120 to 250 yrs
	Flood heights associated with 1-in-500 yr flood (in feet)	10.7	10.9 to 11.2	11.4 to 11.7	11.8 to 12.6

1 Decimal places shown for values less than 1 (and for all flood heights), although this does not indicate higher precision/certainty. More generally, the high precision and narrow range shown here are due to the fact that these results are model-based. Due to multiple uncertainties, actual values and range are not known to the level of precision shown in this table.

2 Defined as three or more consecutive days with maximum temperature exceeding 90°F.

3 Based on minima of the Palmer Drought Severity Index (PDSI) over any 12 consecutive months. More information on the PDSI and the drought methods in general can be found in Appendix B.

4 Does not include the rapid ice-melt scenario.

Coastal Floods & Storms

As sea levels rise, coastal flooding associated with storms will very likely increase in intensity, frequency, and duration. The changes in coastal flood intensity shown here are solely due to gradual changes in sea level through time. Any increase in the frequency or intensity of storms themselves would result in even more frequent future flood occurrences relative to the current 1-in-10 and 1-in-100 year coastal flood events. By the end of the 21st century, sea level rise alone suggests that coastal flood levels which currently occur on average once per decade may occur once every one to three years (see Table 2).

The more severe current 1-in-100 year is less well characterized that than 1-in-10 year event because there is the possibility that flood height may vary by century. The NPCC estimates that due to sea level rise alone the 1-in-100 year flood may occur approximately four times as often by the end of the century. The current 1-in-500 year flood height is more uncertain since the historical record is shorter than 500 years. By the end of the century, the 1-in-500 year flood event may occur approximately once every 200 years.

The flood heights shown in Table 2 correspond to the Battery in lower Manhattan. Some parts of New York City, such as the northernmost points where the Bronx and the Hudson meet, currently experience lower flood heights than the Battery and many other exposed coastal locations. This relationship is expected to continue in the future.

TABLE 3.

Qualitative Changes in Extreme Events

This table shows the probable direction of change over the 21st century, as well as the likelihood associated with the qualatative projection. For these variables, which can have large impacts on infrastructure, quantitative projections are not possible due to insufficient information.

Extreme Event	Probable Direction Throughout 21st Century	Likelihood[1]
Heat Index[2]	⋀	Very likely
Ice storms/ Freezing rain	⋀	About as likely as not
Snowfall frequency & amount	⋁	Likely
Intense Hurricanes	⋀	More likely than not
Nor'easters	Unknown	
Lightning	Unknown	
Downpours (precipitation rate/hour)	⋀	Likely
Extreme winds	⋀	More likely than not

1 Likelihood definitions given on page 7.

2 The National Weather Service uses a heat index related to temperature and humidity to define the likelihood of harm after "prolonged exposure or strenuous activity" (http://www.weather.gov/om/heat/index.shtml).

HIGH-END SCENARIOS & LONGER-TERM PROJECTIONS

This section describes: 1) the possibility that climate changes in the 21st century may deviate beyond the ranges projected by global climate models, 2) the rapid ice-melt sea level rise scenario, and 3) potential climate change beyond the 21st century.

There are several reasons why future climate changes may not fall within the model-based range projected by the NPCC. Actual greenhouse gas emissions may not fall within the envelope encompassed by the three emissions scenarios used here (A2, A1B, B1). This could be due either to changes in greenhouse gas concentrations directly related to changes in human activities, or indirectly due to changes in the earth's carbon and methane cycles brought on by a changing climate.

Additionally, the 21st century climate's sensitivity to increasing greenhouse gases may fall outside the range of the sixteen climate models used in this workbook. Other possible types of climate changes exceeding model-based estimates, that could have large impacts on the region, cannot be ruled out. These could include shifts in the average latitudes/ tracks of moisture-laden storms traversing Eastern North America, and/or changes in ocean circulation in the North Atlantic.

Rapid Ice-Melt Sea Level Rise Scenario

The rapid ice-melt scenario in this document addresses the possibility of more rapid sea level rise than the IPCC-based approach yields. The motivation to consider sea level rise exceeding IPCC-based estimates is due to several factors, including:

- Recent accelerated ice melt in Greenland and West Antarctic, which may indicate the potential for high levels of sea level rise over multiple centuries if ice melt rates continue to accelerate;[8]
- paleoclimatic evidence of rapid sea level rise;
- Not all sea level rise components are properly simulated by global climate models, increasing uncertainty about GCM-based sea level rise projections, and;
- The potentially large implications for a coastal city of more rapid sea level rise.

Additionally, recent well-documented decreases in summer and fall Arctic sea ice area and volume, although not a significant direct cause of sea level rise, are also raising concern since the decreases:

- Point to polar climate sensitivity higher than predicted by models, and
- Could potentially modify atmospheric and oceanic conditions over a broader region, with implications for Greenland's Ice Sheet. For example, if warmer air were transported out of the Arctic to Greenland, Greenland's coastal and low-elevation glaciers might receive more moisture in the form of rain, and less as snow.

Starting around 20,000-21,000 years ago, global sea level began to rise from a low of 120 meters (394 feet) below present-day sea level to close to present levels by 7,000-8,000 years ago (Peltier and Fairbanks, 2006; Fairbanks, 1989). Most of the rise was accomplished in a 10,000-12,000 year period; thus the average rate of sea level rise over this period ranged between 0.39 and 0.47 in/yr.

During shorter periods of more rapid rise, known as meltwater pulses, lasting several centuries, maximum rates of sea level rise ranged between 1.6 and 2.4 in/yr or 40 and 60 mm/yr. These meltwater pulse sea level rise rates are considered too high to be matched during the 21st century, since they occurred 1) after the ice sheets had already been undermined by millenia of forcing, and 2) as abrupt intervals associated with singular events (i.e., ice dams breaking) at a time when total ice extent was much greater than today.

In the rapid ice-melt scenario, we assume that glaciers and ice sheets melt at an average rate comparable to that of the last deglaciation, (i.e., total ice melt rises linearly at 0.39-0.47 in/yr until 2100). Inasmuch as the rise is more likely to be

8 Neither the Greenland nor West Antarctic ice sheet has yet to significantly contribute to global and regional SLR, but because potential SLR is large, should current melt patterns continue to accelerate, their statuses should be monitored.

exponential, we use the average present-day ice rate of 0.04 in/yr (1.12 mm/yr) (sum of observed mountain glacier melt [IPCC,2007] and ice sheets [Shepherd and Wingham, 2007]) between 2000-2004 (our base period), going to 39-47 inches (all of this rise is attributed to ice melt). We then fit an exponential curve to three points: 2000, 2002 (mid-pt. 2000-2004), and 2100. We then add the other components -- thermal expansion, local ocean dynamics, and subsidence -- from the GCM-based simulations and local information to this exponential meltwater estimate for three timeslices. The rapid ice-melt values combine the central range of the GCM components and the range of estimates of rapid ice-melt from the paleoclimate literature for multi-millennia timescales. Additional technical information about the possibility of rapid sea level rise, as well as an expanded methodology discussion, is provided in Appendix C.

Longer-term Projections

Projections for the 22nd century are beyond most current infrastructure planning horizons. However, planning for some long-lived infrastructure, which hypothetically could include for example new aqueducts and subway lines, would justify consideration of climate in the 22nd century. Furthermore, many pieces of infrastructure intended only to have a useful lifespan within the 21st century may remain operational beyond their planned lifetime. It is also possible that future projects aimed specifically at climate change adaptation might benefit during their planning stages from long-term climate guidance.

Because 22nd century climate is characterized by very high uncertainty, only qualitative projections are possible, especially at a local scale. Despite uncertainties, the large inertia of the climate system suggests that the current directional trends in two key climate variables, sea level rise and temperature, will probably continue into the 22nd century (Solomon et. al, 2009). Given the large inertia of the ice sheets on Greenland and West Antarctica, continued evidence during the next decade of acceleration of dynamically-induced melting would greatly increase the probability that these ice sheets would contribute significantly to sea level rise in the 22nd century, even if greenhouse gas concentrations, and perhaps even global temperatures, were to stabilize at some point during the 21st century.

Other Extreme Events

For some of the extreme event climate factors that have a large impact on infrastructure, future changes are too uncertain at local scales to allow quantitative projections. Qualitative information for some of these factors is provided in Table 3, including:

- Heat indices, which combine temperature and humidity
- Frozen precipitation (snow, sleet, and freezing rain)
- Intense precipitation of short duration (less than one day)
- Lightning
- Large-scale storms (tropical storms/hurricanes and nor'easters) & associated extreme wind.

By the end of the century, heat indices are very likely to increase, both directly due to higher temperatures and because warmer air can hold more moisture. The combination of high temperatures and high humidity can produce severe additive effects by restricting the human body's ability to cool itself. The National Weather Service heat index definition is based on the combination of these two climate factors.

Ice storms and freezing rain have disproportionate effects on infrastructure. There is some indication that the frequency and intensity of ice storms and freezing rain may increase. Snowfall is likely to become less frequent with the snow season decreasing in length. Possible changes in the intensity of snowfall per storm are highly uncertain.

Intense hurricanes and associated extreme wind events will more likely than not become more frequent due to expected warming of the upper ocean in the tropical cyclone genesis regions (IPCC AR4). However, because changes in other critical factors for tropical cyclones, including wind shear, the vertical temperature gradient in the atmosphere, and patterns of variability including the El Niño Southern Oscillation (ENSO) and the Meridional Overturning Circulation are not well known, there is the possibility that intense hurricanes and their extreme winds will not become more frequent or intense. It is also unknown whether the most probable tracks or trajectories of hurricanes and intense hurricanes may change in the future.

Downpours, defined as intense precipitation at sub-daily, but often sub-hourly, timescales are likely to increase in frequency and intensity, for the reasons outlined in the section above on extreme precipitation. Changes in nor'easters and lightning are currently too uncertain to support even qualitative statements.[9]

Uncertainties Related to Extreme Events

Because extreme events are by definition rare, they are characterized by higher uncertainty than the annual averages described in the previous section. Table 2 is based on the assumption that the distribution of extreme events will remain unchanged while mean temperature, precipitation, and sea level rise shift. A change in the distribution of extreme events could have a large effect on the results shown here. Rather than focusing on the precise numbers, the magnitude of changes should be emphasized.

While Table 2 provides an estimate of how the occurrence of extreme events may change for the average future year, extreme events in individual years will continue to be characterized by high variability; in some cases only when many years, or even decades, are averaged will the pattern of changes in extreme events become evident. For example, New York City's drought of record was a multi-year event that occurred four decades ago in the 1960s; no drought since that time in New York has approached it in severity. Generally speaking, changes in variability are considered very uncertain, although there are exceptions (for example, precipitation at daily timescales is likely to increase in variability).

9 Although some research does suggest that lightning may become more frequent with warmer temperatures and more moisture in the atmosphere (Price and Rind, 1994, for example).

INFRASTRUCTURE IMPACTS 4

The following table is meant to be used as the basis for discussions with stakeholders. The changes in mean climate and climate extremes previously described may critically affect many aspects of New York City's infrastructure. Potential first-order impacts obtained from a literature review and using expert judgment are described in Table 4, which is organized by climate variable (temperature, precipitation, and sea level rise) and specific climate risk factor.

The likelihood of the directional change of each climate factor is given, based on expert judgement. Climate changes may also lead to indirect or second-order impacts which should also be considered in planning. Such impacts may include local ecosystem changes and consequences of climate change in other regions. In general, impacts are expected to grow more severe as the 21st century progresses, although year-to-year variability will remain high throughout the century. More information on impacts can be found in Appendix D.

TABLE 4.

Air Temperature, Precipitation and Sea Level Rise Impacts in NYC and the Surrounding Region

	Climate Risk Factor	Likelihood[1]
Air Temperature Impacts in NYC	• More hot days	Very likely
	• Hotter summers	Very likely
	• More frequent & intense heat waves	Very likely
	• Warmer winters	Very likely
	• Fewer & less extreme cold air outbreaks	Very likely
	• Warmer water temperatures	Very likely
Precipitation Impacts in NYC	• Reduced snowfall	Likely
	• More frequent intense rainfall	Likely
	• Increased average annual precipitation	More likely than not
	• More frequent and intense droughts[4]	More likely than not
Sea Level Rise Impacts In NYC	• Higher average sea levels	Extremely likely
	• More frequent and intense coastal flooding	Very likely
	• Shortened 100-year flood recurrence period	Very likely

1 Based on IPCC definitions. See "Uncertainty" on page 7 for definitions.

2 Based on information from sources including Rosenzweig and Solecki, 2001; New York City Department of Environmental Protection, 2008; Greater London Authority, 2005; Metropolitan Transportation Authority, 2007.

3 Magnitude of threats increase throughout time.

4 For organizational purposes, droughts are included in the precipitation section, although droughts are also associated with temperature changes.

	Potential Implications for NYC Infrastructure[2,3]
	• Increase in peak electricity load, resulting in more frequent power outages • Fluctuation in voltage, damaging equipment and interrupting service • Degradation of and increased strain on materials • Increase of demand on HVAC systems • Reduction of electricity and transportation service disruptions • Increase in construction season • Reduction of energy/heating requirements in winter • Reduction of road damage associated with freezing and refreezing of surfaces • Decrease of water quality due to biological and chemical impacts • Increase in costs associated with cooling water for power plant operations
	• Increase of street, basement and sewer flooding • Increase in risk of low-elevation transportation, energy and communications infrastructure flooding and water damage • Increase in delays on public transportation and low-lying highways • Increase in nutrient loads, eutrophication, taste and odor problems and loadings of pathogenic bacteria and parasites in reservoirs • Increase in Combined Sewer Overflow (CSO) events, polluting coastal waterways • Reduction of the need for winter weather road and airport operations
	• Decrease in average reservoir storage and changes in operating rules and usage • Degradation of and increased strain on materials • Increase in strain on upstate reservoirs
	• Encroachment of saltwater on freshwater sources and ecosystems, increasing damage to infrastructure not manufactured to withstand saltwater exposure • Increase in pollution released from brownfields and other unprotected waste sites • Inundation of low-lying areas and wetlands, and higher rates of beach and salt marsh erosion • Increase of inflow of seawater to sewers and Wastewater Pollution Control Plants (WPCP) and reduced ability of discharging Combined Sewer Overflows (CSO) and WPCP effluent by gravity • Increase of salt front up the Hudson and Delaware Rivers, leading to reduced supply of drinking water
	• Increase in street, basement and sewer flooding • Increase in flood risk of low-elevation infrastructure and wastewater treatment plants • Increase in delays on public transportation and low-lying highways • Increase in structural damage to infrastructure due to flooding and wave action • Increase in need for use of emergency management procedures

INDICATORS & MONITORING

5

Monitoring and reassessment are critical components of any climate change adaptation plan. These should be done taking into account changes in climate science, impacts, technological advancements, and adaptation strategies.

In order to successfully monitor future climate and climate impacts, specific indicators to be tracked must be identified in advance. These indicators are of two types. First, **climate indicators** such as extreme precipitation, can provide an early indication of whether climate changes are occurring outside the projected range.[10] Given the large uncertainties in climate projections, monitoring of climate indicators can play a critical role in refining future projections and reducing uncertainties. Second, **climate-related impact indicators** provide a way to identify consequences of climate change as they emerge. For example, lower water quality is a climate-related impact of extreme precipitation.

Regional climate indicators to monitor include, but are not limited to:[11]

Temperature-related

- Mean annual temperatures
- Degree-days in the hot and cold seasons
- Temperature extremes
- Coastal and inland water temperatures

Precipitation-related

- Mean annual precipitation
- Extreme precipitation events
- Droughts

Sea level rise and coastal flood-related

- Mean sea level
- High water levels
- Extreme wind events

Additional **larger-scale climate indicators** should include:

- Tropical storms over the entire North Atlantic basin, as well as climatic conditions (including upper ocean temperatures) that support tropical cyclones
- Variability patterns that influence the region, such as the North Atlantic Oscillation (NAO) and the El Niño Southern Oscillation (ENSO)
- Evidence of changes in the Earth's carbon cycle

The possibility of rapid climate change in general, and sea level rise in particular, are two areas where the importance of monitoring and reassessment has been well documented. **Indicators of rapid ice melt** to monitor could include, but should not be limited to:

- Status of ice sheets
- Changes in sea ice area and volume
- Global and regional sea level
- Polar upper-ocean temperatures

Climate variables cause certain **climate-related impacts**, which will also need to be monitored. These impacts include, but are not limited to:

- Shoreline erosion
- Localized inland flooding

10 Although one potential pitfall of monitoring over short timescales, especially for small regions, is that it is easy to mistake natural variability for a long-term trend.

11 Many of these indicators are already tracked to some degree by Task Force members

- Biological and chemical composition of waters
- Changes in vegetation

Infrastructure can be impacted either directly by a climate risk factor (such as sea level rise) or by a climate-related impact (such as shoreline erosion). **Infrastructure-specific impacts** which may result from these climate indicators or climate-related impacts are likely to include but are not limited to:

- Infrastructure damage from climate-related factors
- Impacts on operations, including transportation delays
- Combined sewer overflow events (CSOs)
- Climate-related power outages

In addition to monitoring climate and impacts, advances in scientific understanding, technology and adaptation strategies should also be monitored. Technological advances, such as those in materials science and engineering, could influence design and planning, and potentially result in cost savings. Monitoring adaptation plans in the region should be done both to determine if they are meeting their intended objectives and to discern any unforeseen consequences of the adaptation strategies. Some adaptation strategies will also have to be reassessed in the context of non-climatic factors that are themselves based on uncertain projections. For example, by monitoring trends in population, economic growth, and material costs, infrastructure managers can tailor future climate change adaptation strategies to ensure they remain consistent with broader citywide objectives. Monitoring and reassessment of climate science, technology and adaptation strategies will no doubt reveal additional indicators to track in the future.

APPENDICES 6

A. OBSERVED EXTREME EVENTS

Temperature

Precipitation

Hurricanes

B. GCM METHODS & RESULTS

Global Climate Models

United States & Regional Maps

Temperature

Precipitation

Extreme Events

Full Range of Model-based Results

C. SEA LEVEL RISE METHODS & PROJECTIONS

Sea Level Rise Components

Process

Comparison of Sea Level Rise Methods

Rapid Ice-Melt Sea Level Rise Scenarios in Context

D. SECTOR-SPECIFIC IMPACTS

APPENDIX
OBSERVED EXTREME EVENTS

A

FIGURE 5.

Observed High Temperature Extremes

Hot days and heat waves in Central Park (1901-2007), based on maximum temperatures exceeding 90°F, 100°F, and 90°F for three consecutive days.

Source: Columbia Center for Climate Systems Research

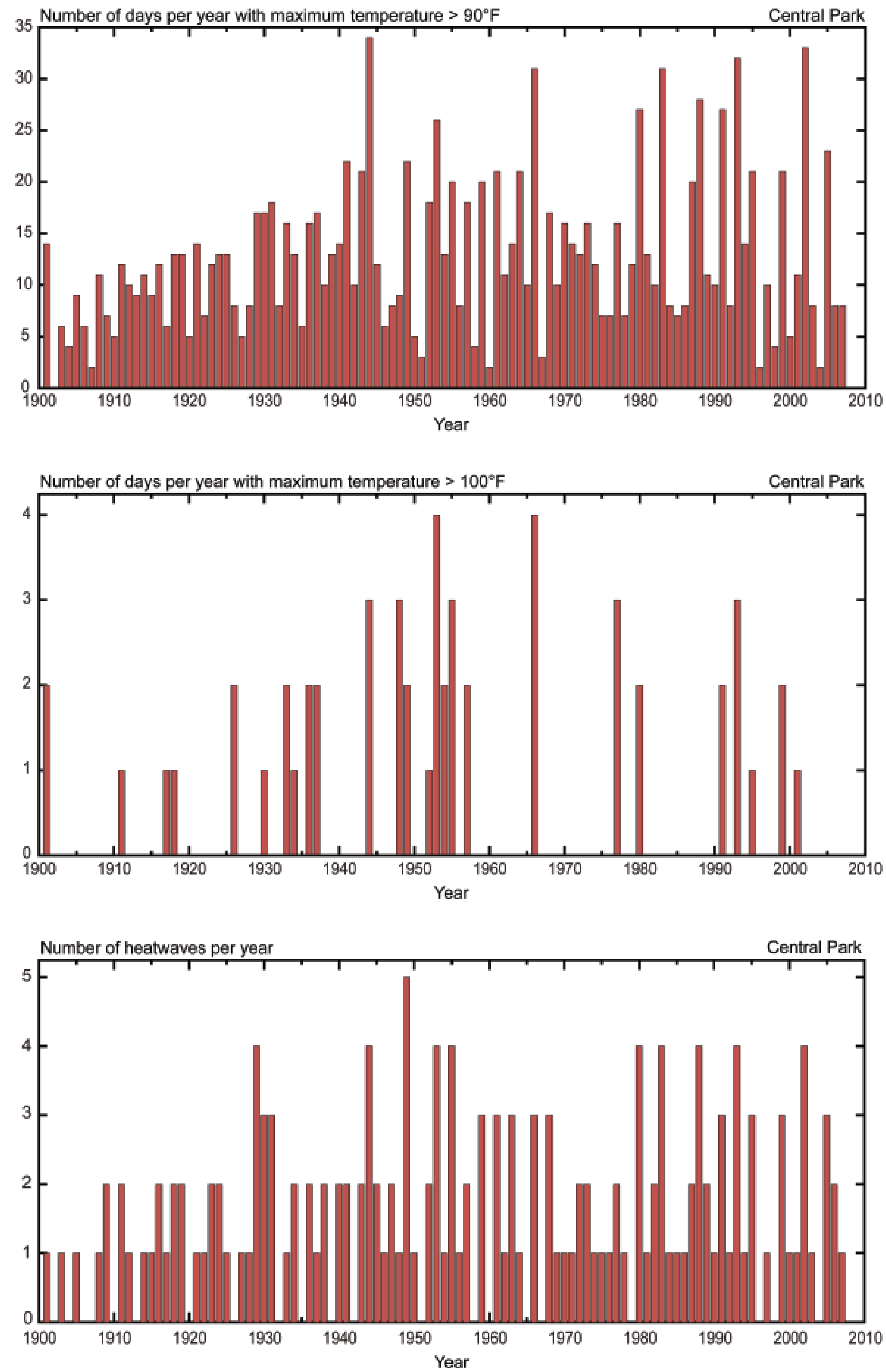


FIGURE 6.

Observed Intense Precipitation Events

Heavy precipitation events in Central Park (1901-2007), based on daily precipitation exceeding 1, 2, and 4 inches.

Source: Columbia Center for Climate Systems Research

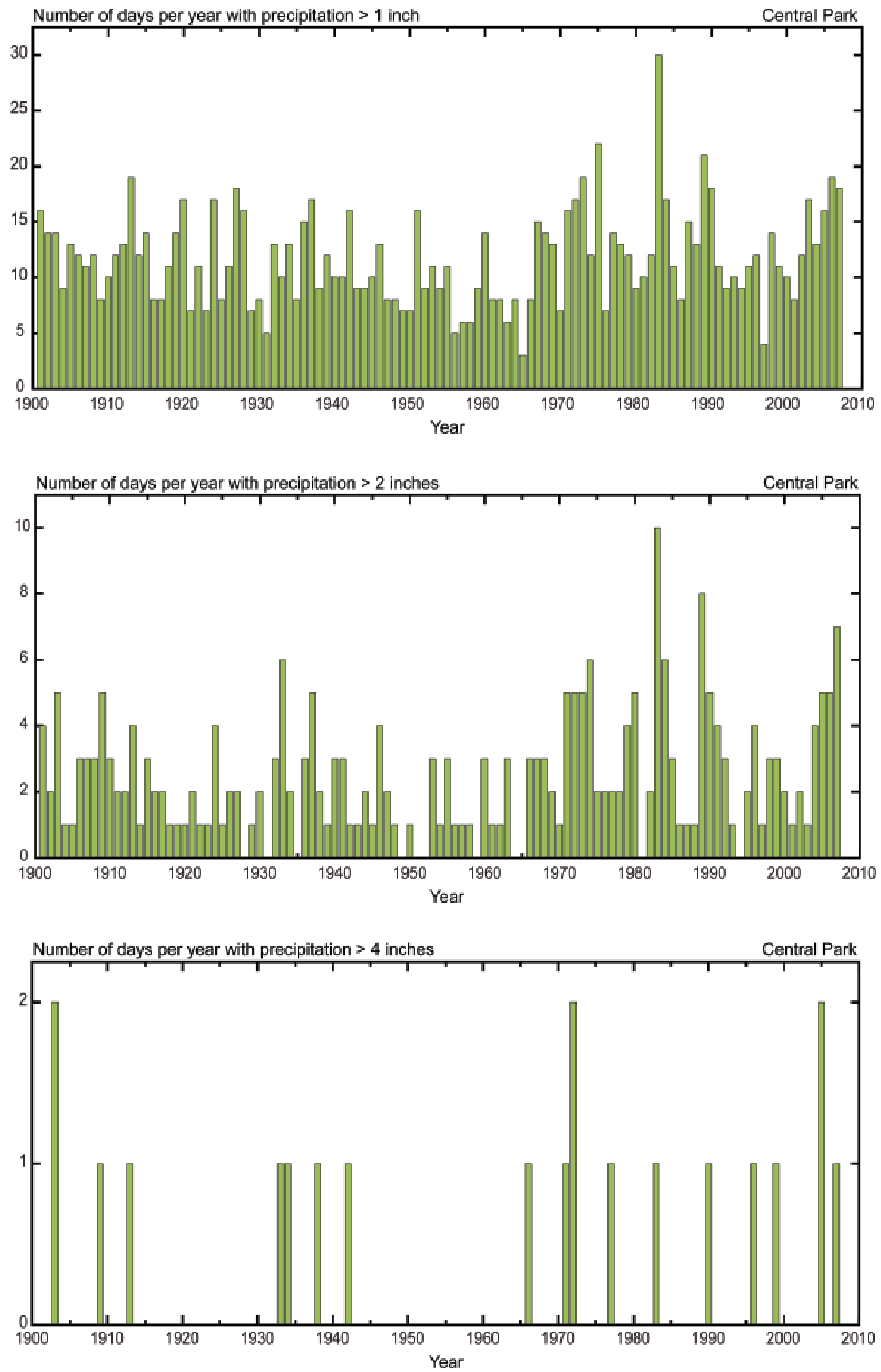


TABLE 5.

Hurricanes. Dates & Major Impacts

Date	Name	Category*	Description (mb = millibars)
Sept 3-5, 1815	Great September Gale of 1815	3	Eastern Long Island and New England
Sept 3, 1821		1-2	Central Pressure (CP) 979-985 mb, max. winds 55-78 mph; only direct strike on NYC; surge 13 ft in 1 hr; flooded lower Manhattan as far north as Canal Street
Sept 1858	New England Storm	1	CP 976 mb, max. winds 90 mph
Sept 1869	Eastern New England Storm	1	CP 963 mb, max. winds 115 mph
Aug 23, 1893	Midnight Storm	1-2	CP 986 mb, max. 30 mph. Flooded south Brooklyn and Queens. Hog Island (near Rockaway Beach) disappeared
Sept 21, 1938	Long Island Express/ New England Storm	3	CP 946 mb. Long Island and southern New England, ~ 700 people killed. Gusts to 100 mph in NYC, surge up to 17 ft in southern New England, 10-12 ft in Long Island
Sept 15, 1944		1	CP 947 mb. Hit central Long Island
Aug 1954	Carol	3	CP 960 mb; sustained winds >100 mph, gusts 115-125 mph, affected eastern Long Island
Sept 12, 1960	Donna	3	CP 930 mb; sustained winds 100 mph; gusts to 125 mph; 11 ft surge. 8.36 ft highest recorded water level at the Battery. Lower Manhattan to West & Cortland Streets flooded nearly waist deep
Sept 21, 1961	Esther	1-2	CP 927 mb; max. winds 145 mph; affected eastern Long Island
June 1972	Agnes	1	CP 980 mb. Significant flooding
Aug 10, 1976	Belle	1	CP 980 mb, peak gusts 95 mph
Sept 27, 1985	Gloria	2-3	CP 942 mb, max. winds 105 mph. 6.14 ft water level. Struck at low tide
Aug 1991	Bob	2	CP 962 mb, max.winds 105 mph. Eastern Long Island to Cape Cod.
Sept 1999	Floyd	2	Sustained winds 60 mph, 10-15 in rain upstate New Jersey and New York State in 24 hrs. Major inland flooding

*Estimated storm maximum; not necessarily experienced in NYC region

APPENDIX B

GCM METHODS & PROJECTIONS

FIGURE 7.

IPCC AR4 Global Climate Models

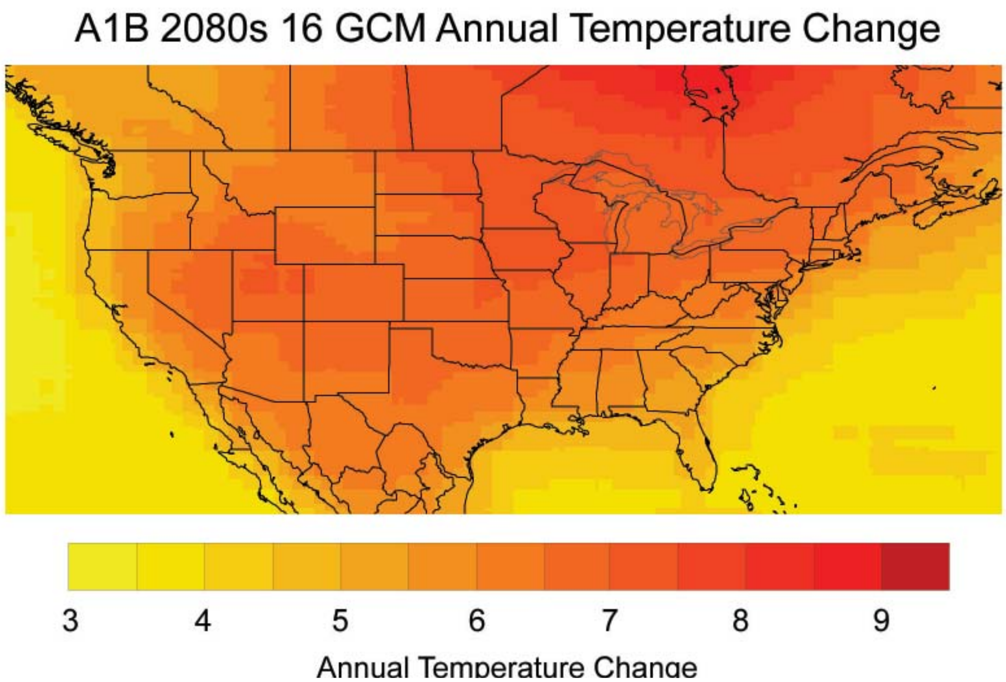
GCMs used for NPCC climate risk information, host center, grid box resolution, and equilibrium climate sensitivity of atmospheric component to a doubling of carbon dioxide.

Institution	GCM name	Resolution	Equilibrium climate sensitivity °F (°C) for doubling of CO_2
Bjerknes Centre for Climate Research, Norway	bccr_bcm2_0	2.8x2.8	Not Available
Canadian Centre for Climate Modeling and Analysis, Canada	cccma_ cgcm3_1_t63	3.75x3.75	3.4
CERFACS, National Weather Research Center, METEO-FRANCE, France	cnrm_cm3	2.8x2.8	Not Available
CSIRO Atmospheric Research, Australia	csiro_mk3_0	1.88x1.88	3.1
Geophysical Fluid Dynamics Laboratory, USA	gfdl_cm2_0	2x2.5	2.9
Geophysical Fluid Dynamics Laboratory, USA	gfdl_cm2_1	2x2.5	3.4
NASA Goddard Institute for Space Studies, USA	giss_model_e_r	4x5	2.7
Institute for Numerical Mathematics, Russia	inmcm3_0	4x5	2.1
Pierre Simon Laplace Institute, France	ipsl_cm4	2.5x3.75	4.4
Center for Climate Systems Research; National Institute for Environmental Studies; Frontier Research Center for Global Change, Japan	miroc3_2_ medres	2.8x2.8	4.0
Meteorological Institute of the University of Bonn, Germany	miub_echo_g	3.75x3.75	3.2
Meteorological Research Institute, Japan	mri_ cgcm2_3_2a	2.8x2.8	3.4
Max Planck Institute for Meteorology, Germany	mpi_echam5	1.878x1.88	
National Center for Atmospheric Research, USA	ncar_pcm1	2.8x2.8	2.1
National Center for Atmospheric Research, USA	ncar_ccsm3_0	1.4x1.4	2.7
Hadley Centre for Climate Prediction, Met Office, UK	ukmo_hadcm3	2.5x3.75	3.3

FIGURE 8.

Annual Temperature Changes in the 2080s

Temperature increase (°F) for the 2080s relative to the 1971-2000 baseline, for the A1B scenario averaged across the 16 GCMs to form an ensemble mean. Top map is United States. Bottom is Northeast United States.



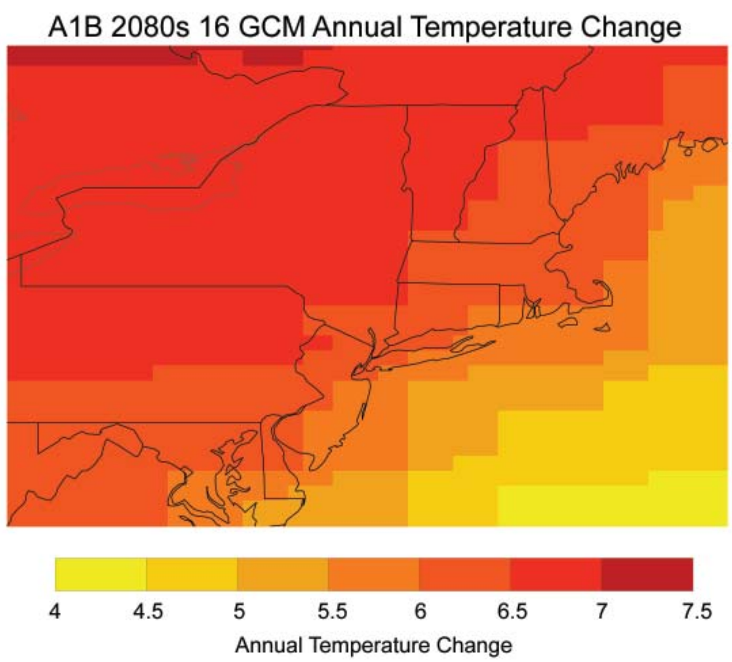
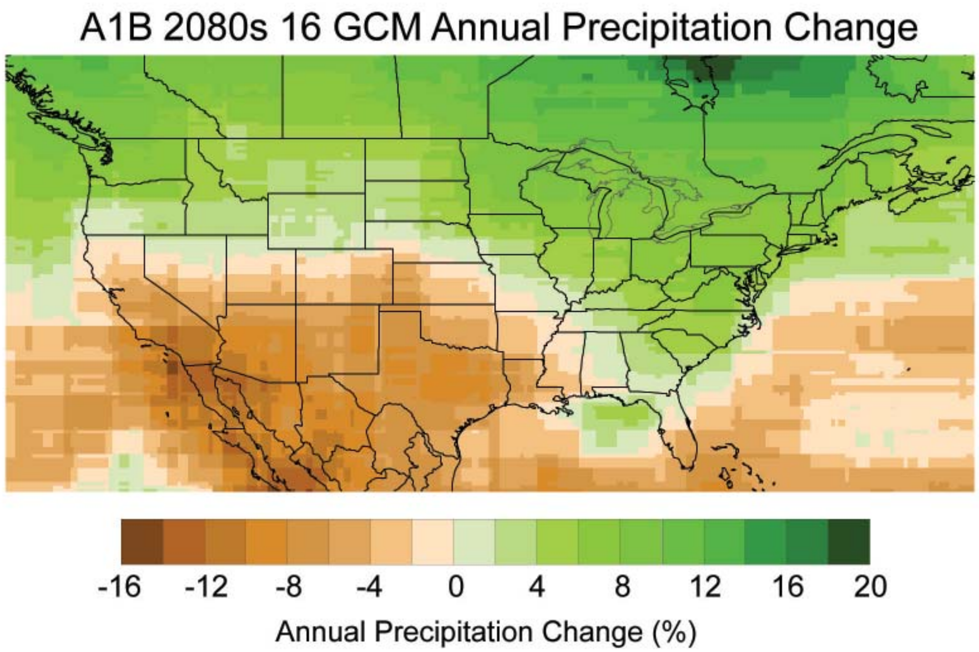
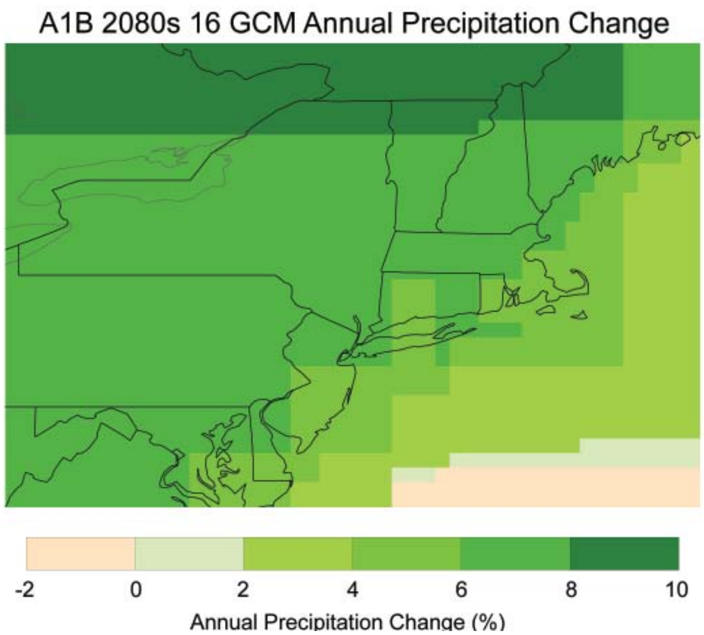


FIGURE 9.

Annual Precipitation Changes in the 2080s

Percentage change in precipitation for the 2080s relative to the 1971-2000 baseline, for the A1B scenario with each of the 16 GCMs percentage changes averaged to form an ensemble mean. Top map is United States. Bottom is Northeast United States, including New York City.





UNITED STATES AND REGIONAL MAPS

Figures 8 and 9 place the mean temperature and precipitation projections for the New York City region in a broader geographical perspective. Shown are the changes in temperature and precipitation for the 2080s relative to 1971-2000. These changes are averaged across the 16 GCMs; the A1B scenario is shown in these figures, but the spatial pattern is similar for the two other emissions scenarios. The maps reveal that the mean changes described for New York City are consistent over the entire Northeastern U.S. Consistency at the larger scale gives more support to the New York City results than would be the case if the results did not extend beyond the metropolitan-scale.

Temperature

While the overall patterns are consistent across the Northeastern U.S., there are differences. Ocean regions are expected to warm less than interior regions. Since New York is a coastal city, it may experience slightly less warming (~0.5°F) than more inland regions by the 2080s. Generally speaking, more southerly latitudes than New York City's are expected to experience less warming, while more northerly latitudes are expected to experience more warming.

Precipitation

Precipitation projections are very consistent across the Northeastern U.S. Near the Canadian border, precipitation is projected to increase somewhat more than in the Northeast as a whole. More noteworthy is the region of projected slight decrease in precipitation in the ocean region approximately 200 miles to the southeast. The proximity of this region to New York City indicates that the possibility of slightly decreased mean precipitation for New York City, although less likely than not, cannot be ruled out.

FULL RANGE OF MODEL-BASED PROBABILITY RESULTS

The full range and distribution of the GCM projections are shown in the following tables. Unless otherwise indicated, results are based on 16 GCMs (7 GCMs for sea level rise) and three emissions scenarios (A2, A1B, B1), as previously discussed. This section, like earlier sections, is divided into mean changes and changes in extreme events.

Tables 6 and 9 are expanded versions of Tables 1 and 2. Whereas the earlier tables only show the central 67% of model-based projections (which are repeated here in parentheses), this table also shows minimum and maximum GCM-projected values, since these extreme values may also be of use for some planning applications. These extreme values, like all model-based values, should not be mistaken as the true outer bound of possible outcomes; rather they reflect the outer bound of the model-based projections.

TABLE 6.

Baseline Climate and Mean Annual Changes (Relative to Baseline Years)

	Baseline 1971-2000[1]	2020s	2050s	2080s
Air temperature Central range[2]	55° F	+ 0.5 (1.5 to 3) 3.5°F	+ 2.5 (3 to 5) 7.5°F	+ 3 (4 to 7.5) 10°F
Precipitation Central range	46.5 in[3]	- 5 (0 to 5) 10%	- 10 (0 to 10) 10%	- 10 (5 to 10) 15%
Sea level rise[3] Central range	NA	+ 1 (2 to 5) 6 in	+ 5 (7 to 12) 14 in	+ 9 (12 to 23) 26 in

1 Based on 16 GCMs (7 GCMs for sea level rise) and 3 emissions scenarios. Baseline is 1971-2000 for temperature and precipitation, and 2000-2004 for sea level rise. Data from Natinal Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA). Temperature data are from Central Park; precipitation data are the mean of the Central Park and La Guardia Airport values; and sea level data are from the Battery at the southern tip of Manhattan (the only location in NYC for which comprehensive historic sea level rise data are available).

2 Minimum, central 67% range, and maximum values from model-based probabilities; temperatures ranges are rounded to the nearest half-degree, precipitation to the nearest 5%, and sea level rise to the nearest inch.

3 The model-based sea level rise projections may represent the range of possible outcomes less completely than the temperature and precipitation projections. See rapid ice-melt scenario Table 10 for rapid ice-melt projections.

FIGURE 10.

Model-Based Frequency Distribution of Temperature Changes

Frequency distribution of model-based temperature changes (°F) in NYC, relative to the 1971-2000 base period, for 16 models and three emissions scenarios

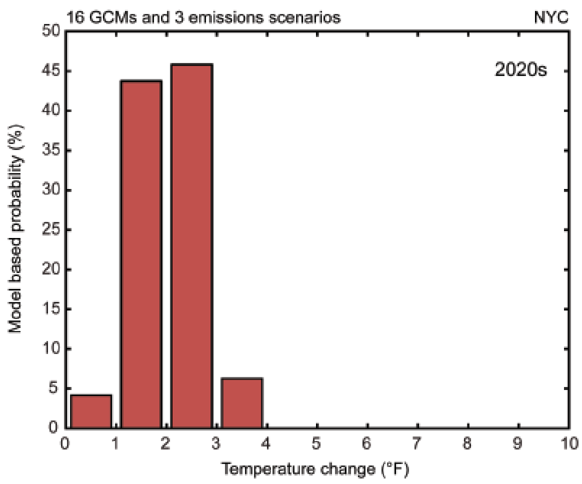


FIGURE 11.

Projected Temperature Changes by 30-Year Timeslice.

The maximum and minimum values across the 16 GCMs and 3 emissions scenarios are shown as black horizontal lines; the central 67% of values are shown in the shaded areas; the median is the red line

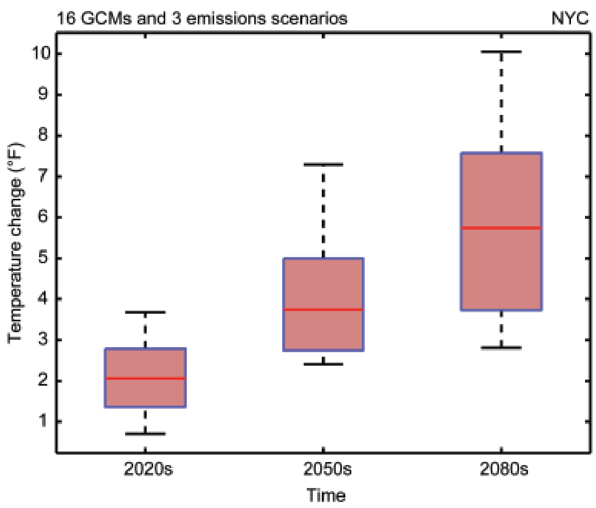
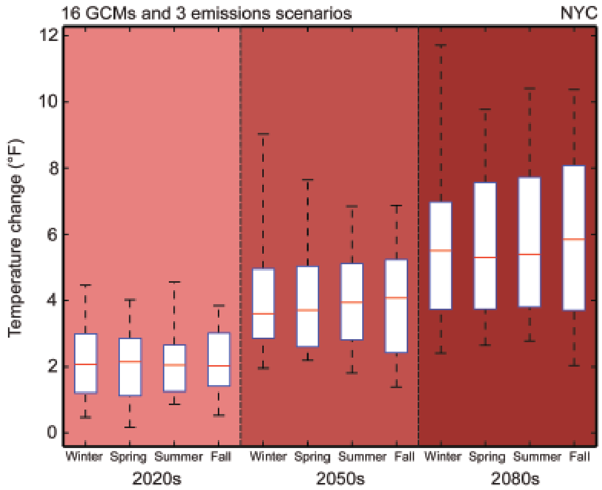


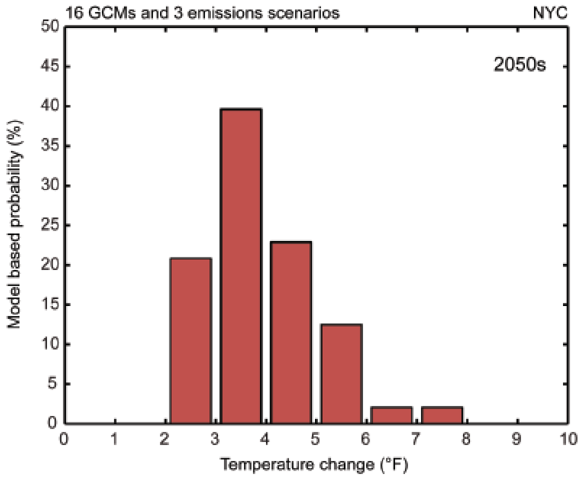
FIGURE 12.

Projected Seasonal Temperature Changes

Temperature change by season per timeslice. Central 67% of values shown.

Winter: December-February
Spring: March-May
Summer: June-August
Fall: September-November





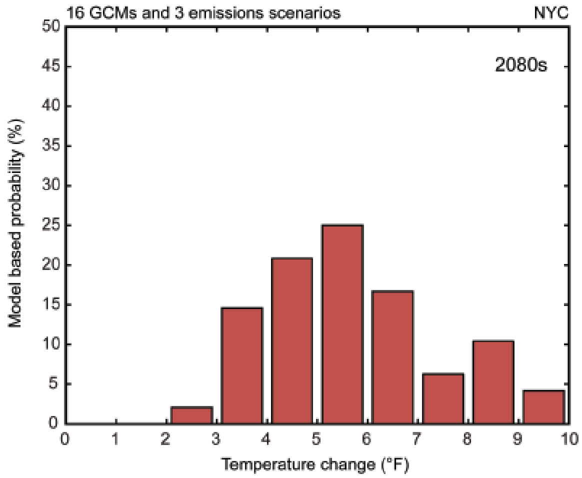


TABLE 7.

Monthly Temperature Projections

While the model-average temperature (°F) changes are similar in all months and seasons, the variation among the climate model projections is the largest in the winter months

	Temperature 2020s	Temperature 2050s	Temperature 2080s
January	-0.4 (1 to 3) 5.9	1.7 (2.7 to 5.1) 7.4	0.6 (3.7 to 7.1) 12.4
February	-1.3 (0.2 to 3) 6.5	0.03 (2.1 to 4.9) 9.5	0.7 (3.4 to 7.7) 10.7
March	-0.3 (1 to 3.2) 4.3	1.4 (2.6 to 5.3) 7.5	2.7 (4 to 7.5) 9.5
April	-0.1 (1.2 to 3.3) 4.3	1.4 (2.5 to 5.4) 8.3	1.9 (3.9 to 7.8) 10.8
May	0.5 (1.3 to 2.8) 4.1	2 (2.4 to 4.7) 7.2	2.0 (4 to 6.9) 9.8
June	0.4 (1.1 to 2.4) 4.0	1.9 (2.6 to 4.5) 5.4	2.5 (3.4 to 6.9) 9.6
July	0.8 (1.3 to 2.9) 5.1	1.7 (2.7 to 5.7) 7.2	2.8 (3.9 to 7.7) 11.2
August	0.8 (1.4 to 2.9) 4.5	1.8 (2.8 to 5.9) 8.2	2.5 (4.2 to 8.5) 12.5
September	-0.2 (1 to 2.9) 3.8	1.2 (2.4 to 5.5) 7.4	1.9 (3.9 to 8) 10.5
October	0.2 (1.3 to 3.1) 4.7	1.7 (2.7 to 5.1) 7.6	2.3 (4 to 8) 10.3
November	0.3 (1.3 to 3) 4	0.8 (2.3 to 5.3) 7.1	1.5 (3.3 to 8.0) 10.3
December	0.7 (1.4 to 3.3) 4.5	2 (3.1 to 5.3) 10.2	2.5 (3.9 to 7.4) 12

FIGURE 13.

Model-Based Frequency Distribution of Precipitation Changes

Frequency distribution of model-based precipitation changes (%) in NYC, relative to the 1971-2000 base period, for 16 models and three emissions scenarios.

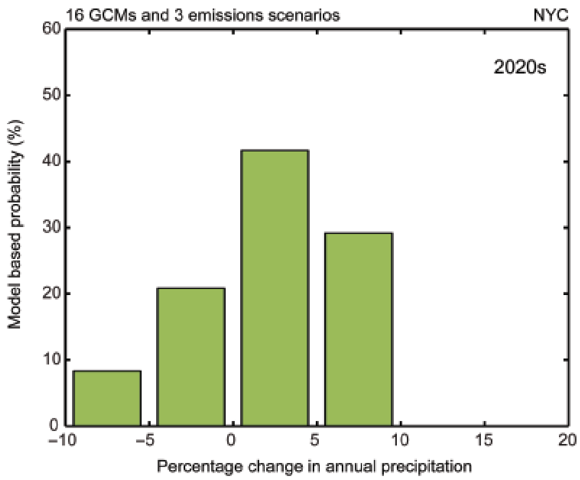


FIGURE 14.

Projected Precipitation Changes by 30-Year Timeslice

Projected precipitation changes (%) by 30-year time slice. The maximum and minimum values across the 16 GCMs and 3 emissions scenarios are shown as black horizontal lines; the central 67% of values are shown in the shaded areas; the median is the red line.

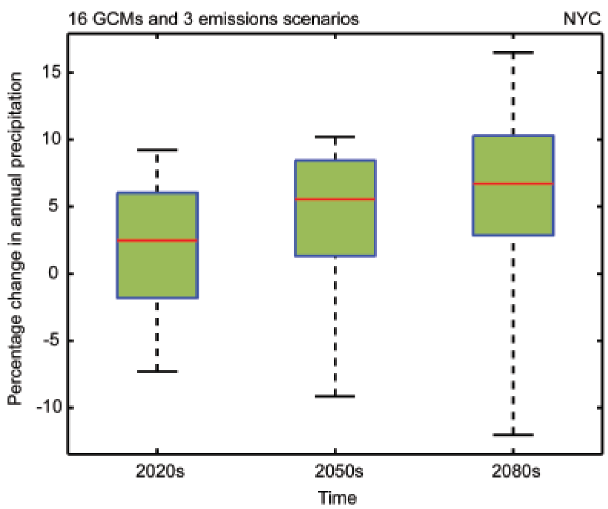
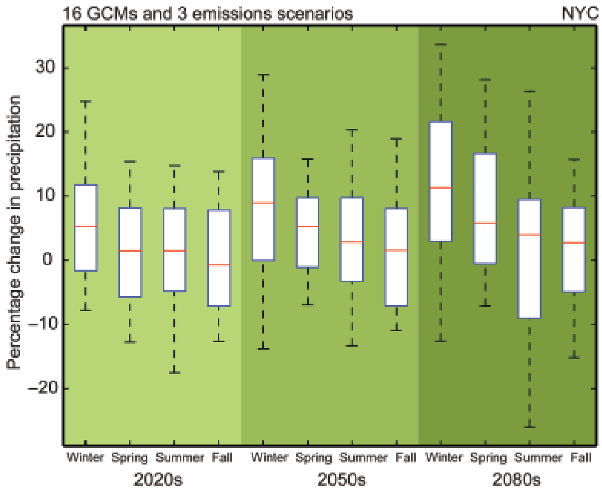


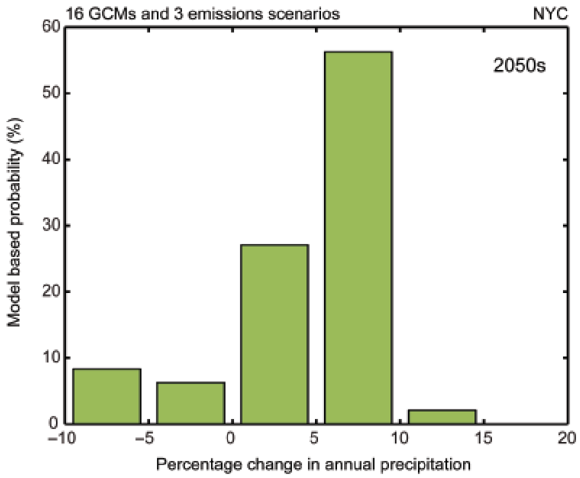
FIGURE 15.

Projected Seasonal Precipitation Changes

Precipitation change (%) by season per timeslice. Central 67% of values shown.

Winter: December-February
Spring: March-May
Summer: June-August
Fall: September-November





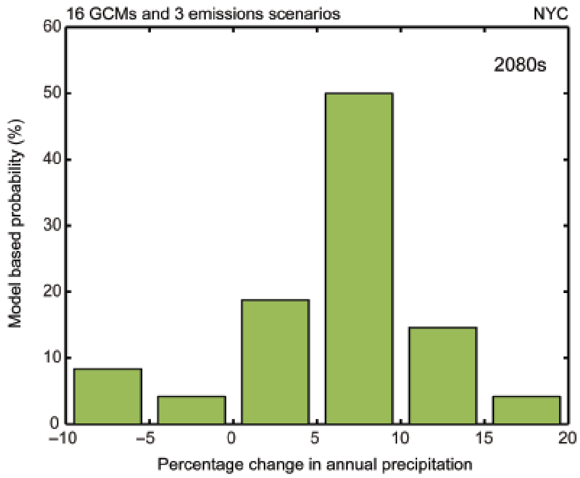


TABLE 8.

Monthly Precipitation Projections

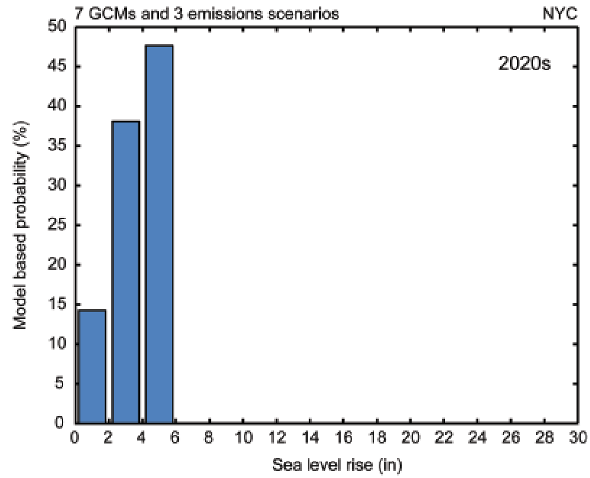
The model-average precipitation changes (%) and the variation among the models are generally larger during the winter months.

	Precipitation 2020s	Precipitation 2050s	Precipitation 2080s
January	-14 (-2 to 17) 71	-19 (-5 to 26) 47	-22 (0 to 27) 55
February	-15 (-8 to 14) 27	-21 (-9 to 11) 31	-22 (-3 to 17) 43
March	-25 (-11 to 10) 26	-14 (-5 to 13) 26	-12 (-2 to 24) 29
April	-17 (-5 to 12) 19	-9 (-4 to 17) 43-20	-20 (-1 to 18) 51
May	-24 (-6 to 11) 27	-27 (-8 to 11) 45	-21 (-3 to 15) 29
June	-26 (-10 to 12) 19	-23 (-11 to 12) 32	-21 (-12 to 11) 39
July	-27 (-9 to 9) 25	-26 (-5 to 14) 34	-39 (-14 to 14) 44
August	-27(-8 to 13) 28	-22 (-6 to 14) 34	-27 (-10 to 18) 42
September	20 (-9 to 9) 29	-27 (-13 to 14) 44	-25 (-13 to 10) 46
October	-26 (-16 to 11) 26	-22 (-14 to 11) 25	-24 (-14 to 8) 16
November	-14 (-8 to 15) 24	-21 (-10 to 17) 28	-19 (-7 to 25) 41
December	-7 (-2 to 15) 38	-14 (0 to 27) 44	-8 (2 to 28) 54

FIGURE 16.

Model-Based Frequency Distribution of Sea Level Rise

Frequency distribution for projected sea level rise (in) in NYC, relative to the 2000-2004 base period, for 7 GCMs and 3 emissions scenarios.



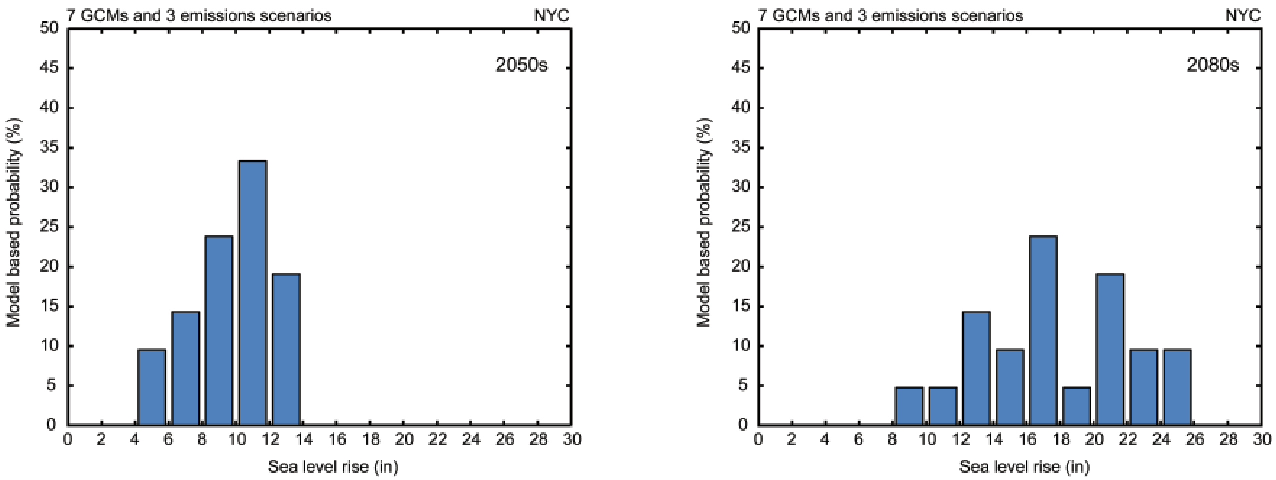
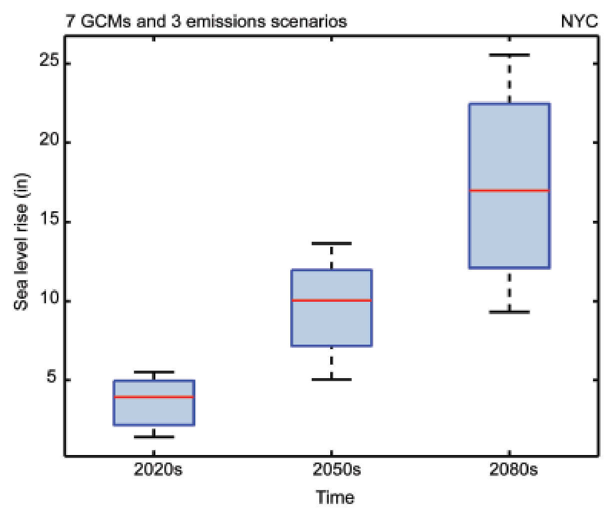


FIGURE 17.

Projected Sea Level Rise Changes by 10-Year Timeslice

Box and whisker plot of projected sea level rise by 10 year time slice. The maximum and minimum values across the 7 GCMs and 3 emissions scenarios are shown as black horizontal lines; the central 67% of values are shown in the shaded areas; the median is the red line



EXTREME EVENTS

Temperature-Related Extreme Events

For high extremes of temperature, two critical thresholds were analyzed: the number of days with maximum temperatures of 90°F or higher and of 100°F or higher. Because the negative impacts of extreme heat accelerate with the length of time that the heat is experienced, the number of heat waves, defined here as 3 or more consecutive days with temperatures exceeding 90°F, was also analyzed. For low extremes of temperature, the critical threshold analyzed was the number of days with minimum temperatures below 32°F.

Precipitation-Related Extreme Events

The critical precipitation thresholds were the number of days per year with precipitation exceeding 1 inch, 2 inches or 4 inches. Intense precipitation on hourly timescales can have disproportionate impacts on city infrastructure, but due to limited local historical data at hourly timescales and the challenge of extrapolating monthly precipitation changes from GCMs to hourly timescales, hourly precipitation projections are not included in this set of scenarios.

Droughts reflect a complex blend of climate and non-climate factors that operate at a number of time scales and are fundamentally different from other extreme events in that they are of longer duration. The drought timescale can last from a few months to multiple years so, for this analysis, an intermediate timescale of twelve consecutive months was selected. In addition to precipitation, the other critical drought component is potential evaporation, which has a more complex relationship to drought. High temperatures, strong winds, clear skies, and low relative humidity all increase evaporative potential. Actual evaporation will generally be less than potential evaporation however, since water is not always present for evaporation. For example, there will be little evaporation from dry soils, and as plants become water stressed under drought conditions, they become more effective at restricting their water loss to the atmosphere. Drought is also driven by water demand, so water management decisions and policies can influence the frequency, intensity, and duration of droughts.

The Palmer Drought Severity Index (PDSI) uses temperature and precipitation to generate region-specific measures of drought and flood intensity. Because the calculation is strongly influenced by conditions in prior months, the PDSI is a good indicator of long-term phenomena like droughts. Potential limitations of the PDSI as used in this capacity include but are not limited to exclusion of the water demand component, the challenge of accurately capturing how potential evaporation changes with time, and not directly including water supplies stored on the ground as snow and ice.

The drought analysis conducted here included two phases. First, the monthly PDSI was calculated for monthly Central Park data from 1901-2000. Based on this calculation, the lowest consecutive 12 month-averaged PDSI value was defined as the 1-in-100 year drought. It should be noted that: 1) the drought record over the last 100 years can only provide a very rough estimate of the true 1-in-100 year drought, and 2) drought over a 12-month interval is only one possible definition.

In the second phase, the monthly changes in temperature and percentage changes in precipitation through time for each GCM and emissions scenario were applied to the observed Central Park record. The number of times that the 1-in-100 year, 12-month drought threshold (as defined in the paragraph above) was exceeded was then recalculated. Only events that did not overlap in time were counted.

Coastal Flood & Storm-Related Extreme Events

The quantitative analyses of changes in coastal flooding presented in this document are based on changes in sea level only, not in storm behavior. Projections were made by superimposing future changes in mean sea level onto the historical data set. The sea level rise projections are for the decadal means of the 2020s, 2050s, and 2080s relative to the mean sea level of the base period from 2000 to 2004. For coastal flooding, the critical thresholds were the 1-in-10 year, 1-in-100 year and 1-in-500 year flood events.

The 1-in-10 year event was defined using historical hourly tide data from the Battery. Forty years worth of hourly sea level data were available from a period spanning 1960-2006 (nearest-neighbor temporal interpolation was used to fill in missing data points for those years with little missing data). The Battery tide gauge was used to assess the frequency and duration of extreme coastal flood events. The raw tidal data are accessible from the NOAA website: http://tidesandcurrents.noaa.gov.

Mean sea level was used as the reference datum. For the purposes of the storm analysis, additional calculations were made. First, data were detrended (to remove the linear sea level trend), and normalized by dividing the data by the long-term mean. This procedure gives water levels that include the influence of astronomical tides. To calculate surge levels, which more directly reflect the strength of the storm itself than do water levels, the difference between the actual flood level and the predicted level (the astronomical tide) was calculated. This approach allows assessment of the frequency and duration of extreme flood events. The NPCC defines the 1-in-10 year event as the storm surge thresholds corresponding to the 4th largest surge over the 40-year period of tide data. Once the 1-in-10 year threshold was identified, the final procedure involved adding 21st century sea level rise projections to the historical storm data as modified above to assess how frequently these flood levels would occur during the 21st century.

Inasmuch as hourly data are unavailable from tide gauges prior to 1960, different methods were applied for estimating the 1-in-100 year flood and 1-in-500 year floods. The 1-in-100 and 1-in-500 year storms were analyzed using flood return interval curves ("stage-frequency relationships") that provide a correlation between the water elevation by coastal storms vs. the likelihood of occurrence. These curves include both surge and tidal components. An increase in sea level results in a higher flood height for a storm of a given return interval (e.g., if the 100-year flood level is currently 8.6 feet, the new 100-year flood after 2 feet of sea level rise will be 10.6 feet). An alternative approach also taken here is to calculate the decrease in the return period for a given flood height with sea level rise (e.g., what will be the change in return period for the current 100-year flood if sea level rises 2 ft by 2080?). The 1-in-500 year estimate especially must be considered highly uncertain.

The surge data for the 100-year and 500-year storm calculations are based on data provided by the U.S. Army Corps of Engineers for the Metro East Coast Regional Assessment (Rosenzweig and Solecki, 2001). In that study, the Army Corps used the USACE Waterways Experiment Station (WES) Implicit Flood Model (WIFM) developed in the 1980s as the hydrodynamic storm surge model. This is a dynamical model that includes subgrid barriers, and allows grid cells to become flooded during a simulation. The surge data were calculated relative to the National Geodetic Vertical Datum of 1929 (NGVD29) at high tide (thus actually a storm flood level), excluding the effects of waves, for "combined" nor'easters and hurricanes. The flood height data were converted to the North American Vertical Datum of 1988 (NAVD88) by subtracting 0.338 m (1.11 ft) from the flood heights given by the Army Corps. The conversion factors can be obtained from the National Geodetic Survey.

As research continues to advance, it may become possible to better estimate the surge associated with the 1-in-100 year and especially the 1-in-500 year historical storm, which is currently not well known.

TABLE 9.

Baseline Climate and Mean Annual Changes (Relative to Baseline Years)

	Extreme Event	Baseline (1971-2000)	2020s	2050s	2080s
Heat Waves & Cold Events	# of days/year with maximum temperature exceeding:				
	90°F	14	19 (23 to 29) 38	23 (29 to 45) 58	29 (37 to 64) 79
	100°F	0.4[1]	0.5 (0.6 to 1) 3	0.6 (1 to 4) 8	1 (2 to 9) 19
	# of heat waves/year[2]	2	2 (3 to 4) 5	3 (4 to 6) 7	4 (5 to 8) 9
	Average duration (in days)	4	4 (4 to 5) 5	4 (5 to 5) 6	5 (5 to 7) 8
	# of days/year with minimum temperature below 32° F:	72	48 (53 to 61) 66	31 (45 to 54) 56	22 (36 to 49) 56
Intense Precipitation & Droughts	# of days per year with rainfall exceeding:				
	1 inch	13	11 (13 to 14) 15	11 (13 to 15) 16	11 (14 to 16) 17
	2 inches	3	2 (3 to 4) 4	2 (3 to 4) 5	2 (4 to 4) 5
	4 inches	0.3	0.1 (0.2 to 0.4) 0.5	0.2 (0.3 to 0.4) 0.6	0.1 (0.3 to 0.5) 0.7
	Drought occurs, on average[3]	~once every 100 yrs	~once every 33 (100 to 100) NA[4] yrs	~once every 8 (50 to 100) NA yrs	~once every 2 (8 to 100) 100 yrs
Coastal Floods & Storms	1-in-10 yr flood to reoccur, on average	~once every 10 yrs	~once every 8 (8 to 10) 10 yrs	~once every 3 (3 to 6) 8 yrs	~once every 1 (1 to 3) 3 yrs
	Flood heights associated with 1-in-10 yr flood (in feet)	6.3	6.5 (6.5 to 6.8) 6.8	6.8 (7.0 to 7.3) 7.5	7.1 (7.4 to 8.2) 8.5
	1-in-100 yr flood to reoccur, on average	~once every 100 yrs	~once every 60 (65 to 80) 85 yrs	~once every 30 (35 to 55) 75 yrs	~once every 15 (15 to 35) 45 yrs
	Flood heights associated with 1-in-100 yr flood (in feet)	8.6	8.8 (8.8 to 9.0) 9.0	9.0 (9.2 to 9.6) 9.7	9.4 (9.6 to 10.5) 10.7
	1 in 500-yr flood to reoccur, on average	~once every 500 yrs	~once every 370 (380 to 450) 470 yrs	~once every 240 (250 to 330) 380 yrs	~once every 100 (120 to 250) 300 yrs
	Flood heights associated with 1-in-500 yr flood (in feet)	10.7	10.9 (10.9 to 11.2) 11.2	11.2 (11.4 to 11.7) 11.9	11.5 (11.8 to 12.6) 12.9

The minimum, central range (middle 67%), and maximum of values from model-based probabilities across the GCMs and greenhouse gas emissions scenarios is shown. More information on the methods used to define extreme events can be found in Appendix B.

1 Decimal places shown for values less than 1, although this does not indicate higher precision/certainty. More generally, the high precision and narrow range shown here are due to the fact that these results are model-based. Due to multiple uncertainties, actual values and range are not known to the level of precision shown in this table.

2 Defined as three or more consecutive days with maximum temperature exceeding 90°F.

3 Based on minima of the Palmer Drought Severity Index (PDSI) over any 12 consecutive months.

4 'NA' indicates no occurrences per 100 years.

APPENDIX C
SEA LEVEL RISE METHODS & PROJECTIONS

Sea Level Rise Components

The IPCC-based approach uses four components to develop regional sea level rise scenarios:

- Global thermal expansion
- Local land subsidence
- Meltwater from glaciers, ice caps, and ice sheets
- Local water surface elevation

The thermal expansion and local water surface elevation terms are derived directly from the AR4 coupled Atmosphere-Ocean GCMs that have outputs enabling sea level rise to be projected. Local land subsidence (in the New York City region due chiefly to glacial isostatic adjustments) is derived from relevant studies (Peltier, 2001; Peltier's ICE-5Gv1.2 ice model (2007) http://www.pol.ac.uk/psmsl/peltier/index.html), and melt water estimates are derived from studies assessed in the IPCC Fourth Assessment Report (IPCC, 2007).

An example of the application of the four-component method is described by the University of Washington Climate Impacts Group (2008), in which the four global and local components are discussed in detail. Other assessments and studies that have included the local/regional water elevation term are UKCIP (2002), and Walsh et al. (1998). Previous use of similar methods for the New York City region includes the generation of scenarios for the New York City Department of Environmental Protection (NYCDEP 2008; Rosenzweig et al., 2007). The method is currently in use in other projects including the New York State Sea Level Rise Task Force, and The Nature Conservancy sea level rise adaptation project for parts of Long Island.

Processes

Each of the sea level rise components reflects complex underlying processes and is associated with differing levels of uncertainties.

Thermal expansion is driven directly by rising global temperatures, as heat in the lower atmosphere is transferred to the oceans.

Local land subsidence in the New York City area is primarily the result of glacial isostatic collapse of the peripheral bulge, in response to the removal of the ice sheets in Canada (where the land has been and still is rising). The net effect of this process results in a lowering of the land surface in this region.

The *meltwater* component is more complex. Higher temperatures directly cause loss of ice mass through surface melting. Increases in precipitation have the potential to offset surface melting, if the precipitation is in a frozen state. The estimates used in the IPCC method for meltwater are based in large part on temperature and precipitation. As discussed in the IPCC Fourth Assessment Report (IPCC, 2007), these estimates may be low because they do not include the most recent scientific assessments of ice dynamics. The two critical dynamical factors are: 1) basal melting of land based ice sheets, often associated with the formation of meltwater ponds (this water travels down moulins, i.e., crevasses at the surface extending to depth, and lubricates the base of the glacier, allowing it to slide toward lower elevations and the sea); and 2) weakening of coastal ice serving as a dam for land ice, due to thinning from below caused by a warming ocean.

Finally, the *local surface elevation* term is determined by local and regional ocean circulation, atmospheric pressure, and ocean density (mainly related to temperature, but with a salinity component). Among these local terms, ocean circulation has the largest impact on local sea level elevation at climate time scales. This dominant ocean circulation term is driven both by the 3-dimensional density structure of the ocean (due to temperature and salinity variations) and surface wind stress. The local surface elevation term is positive in all but one of the global climate models used to calculate these projections. The IPCC (2007) reports that the near-coastal northwest Atlantic is likely to experience local sea level rise if the Meridional Overturning Circulation and Gulf Stream weaken this century, as predicted by many GCMs (see Lowe and Gregory, 2006 for more discussion of the relationship between the circulation and regional sea level rise; Gregory, 2001 provides discussion for additional regions). Inclusion of this term generally increases sea level rise projections for the New York City region.

At present, the local land subsidence and global thermal expansion components can be characterized as having relatively more certainty; the meltwater term is probably the least certain, with local surface elevation in between.

Comparison to Other Sea Level Rise Methods

The use of the adapted IPCC methods permits analysis of the four main components of sea level rise and provides consistency with projection efforts in some other regions. Some other methods for global sea level rise projections are available, such as the Rahmstorf method (Rahmstorf, 2007), which is based on an empirical relationship between observed sea level rise and global surface temperature. This method has been applied to the current generation of climate models (Horton et al., 2008). Estimates from this method are generally somewhat higher than the IPCC projections, which further suggests the IPCC methods may be based on a low estimate of sea level rise sensitivity.

Even the Rahmstorf/Horton method does not cover the full range of possible future sea level rise outcomes. Because it is based on empirical recent historical relationships between temperature and sea level rise, it does not address the possibility of a greater sensitivity of sea level rise to temperature as temperatures increase further away from equilibrium values. This increased sensitivity, should it occur, would probably be largely due to changes in the meltwater component brought on by dynamical changes in the ice sheets. The 'rapid ice-melt' scenario developed by the NPCC for the New York City region takes into account the potential for a substantial increase in the rate of melting based on recent observations of accelerated icemelt, new scientific understanding of icemelt dynamics, and paleoclimate studies. The projections call for ~5-10 inches of sea level rise by the 2020s, ~19-29 inches by the 2050s, and ~41-55 inches by the 2080s. Due to large uncertainties, no quantitative probability or qualitiative likelihood can be assigned to the rapid ice-melt scenario. However, these estimates are comparable to other recent esitmates, including Pfeffer et al. (2008) and Grinsted et al. (2009).

Comparisons of the current generation of New York City regional sea level rise scenarios with IPCC global scenarios (plus local subsidence added here to facilitate comparison), the empirical method (Rahmstorf/Horton), and with the rapid ice-melt scenarios are provided in Table 10. The model-based New York City region scenarios are generally higher than the IPCC plus local subsidence estimates due to the inclusion of local water surface elevation factors. The empirically-based Rahmstorf/Horton projections tend to be higher than the global IPCC-based approach, but lower than the rapid ice-melt scenario.

Figure 18 shows the range of sea level rise results based on the four methodologies for the 2080s timeslice.

Rapid Ice-Melt Sea Level Rise Scenario in Context

Satellites detect a thinning of parts of the Greenland Ice Sheet at lower elevations, and glaciers are disgorging ice into the ocean more rapidly, adding

TABLE 10.

Total Sea Level Rise Projections in Inches for the New York City Region for Four Methods

Sources: CCSR, 2008; IPCC, 2007; Horton et al., 2008.

Average (minimum to maximum)	**2020s**	**2050s**	**2080s**	**2090s**[1]
IPCC Global Estimate + Local Subsidence	NA[2]	NA[2]	NA[2]	(10.4 to 23.4)[5]
IPCC-adapted Methods for the NYC Region	3.7 (1.4 to 5.5)[3]	9.7 (5.0 to 13.6)[3]	17.8 (9.3 to 25.6)[3]	22.2 (14.9 to 30.0)[6]
Rahmstorf/Horton Method + Local Subsidence	4.9 (3.7 to 6.2)[4]	13.1 (10.0 to 16.6)[4]	24.6 (18.2 to 31.6)[4]	28.1 (22.6 to 33.7)[7]
Rapid Ice-Melt Sea Level Rise	~4 to 10[8]	~17 to 30[8]	~37 to 59[8]	~48-70[9]

1 Shown below if a comparison for the 2090s of the four methods, with the baseline years and selection of extreme values calibrated to the IPCC AR4.

2 IPCC projections not available for this time period.

3 The first number shown is the mean based on seven available GCMs and three available emissions scenarios (B1, A1B, and A2). Base period is 2000-2004. The numbers in parentheses represent the minimum and maximum values, respectively, based on the seven available GCMs and three available emissions scenarios.

4 The first number shown is the mean based on eleven available GCMs and three available emissions scenarios. Base period is 2000-2004. The numbers in parentheses represent the minimum and maximum values, as described in Horton et al. 2008.

5 IPCC (2007) projection is from a different set of GCMs. Mean is not available; numbers represent the 5-95% range. Local subsidence is from Peltier (2007), as it is for the other two methods. Meltwater is included in a similar way in both rows 2 and 3. For easy comparison with rows 3 and 4, IPCC AR4 results are only shown for three emissions scenarios (B1, A1B, and A2).

6 Base period is calibrated to 1980-1999 (rather than 2000-2004); the numbers in parentheses represent the second smallest and second largest values, respectively, based on seven available GCMs and three available emissions scenarios; these two values facilitate comparison with the IPCC AR4 methods shown in row 3, since (as in the IPCC AR4) 5 percent of values are higher and 5 percent are lower.

7 Base period is calibrated to 1980-1999 (rather than 2000-2004); the numbers in parentheses represent the third smallest and third largest values, respectively, based on the eleven available GCMs and three available emissions scenarios; these values facilitate comparison with the IPCC AR4 methods shown in row 3, since 6 percent of values are higher and 6 percent are lower.

8 Numbers shown represent GCM minimim and maximum values across two rapid ice-melt component ranges shown in Table 11.

9 Base period is calibrated to 1980-1999 (rather than 2000-2004); the numbers represent the second smallest and second largest values, respectively, based on the seven available GCMs and three emissions scenarios calculated using the two rapid ice-melt component ranges.

0.01 to 0.02 in/yr to the sea within the last decade (Rignot and Kanagaratnam, 2006). The West Antarctic Ice Sheet may also be thinning (~0.015 in/yr from 2002-2005; Velicogna and Wahr, 2006b). The combined ice sheet melting of Greenland and Antarctica from the 1990s to the present is adding some 0.01 in/yr to sea level rise (Shepherd and Wingham, 2007).

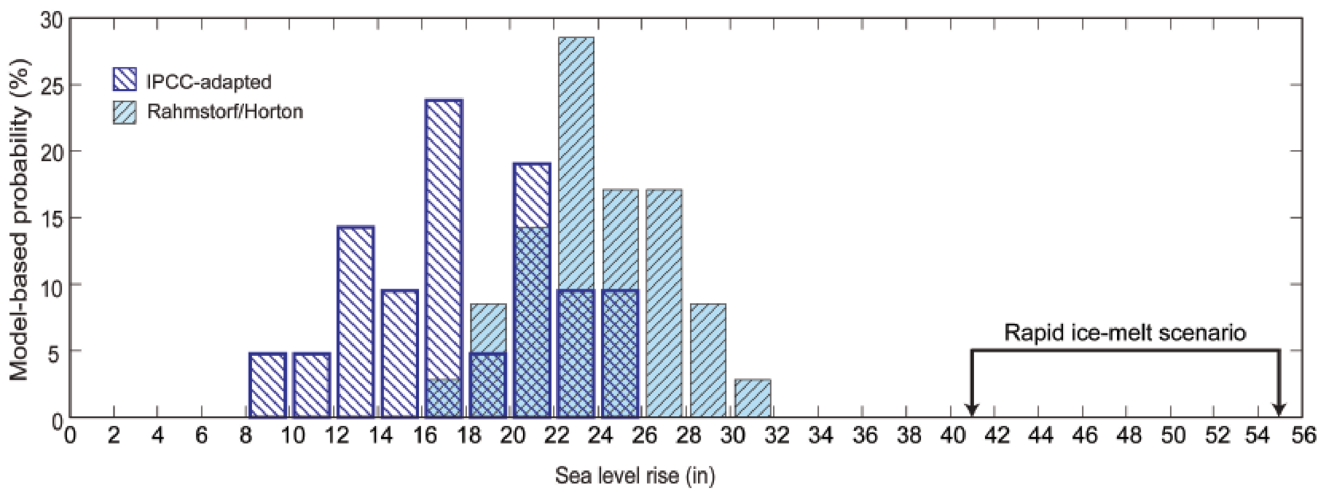
Global warming could cause further thinning of these ice sheets. Either ice sheet, if melted completely, contains enough ice to raise sea level by approximately 23 feet (7 m). A regional temperature rise of only 3°C (Gregory et al., 2004) or 3.2 to 6.2°C (IPCC, 2007), may be enough to destabilize Greenland irreversibly. While such temperature increases fall within the range of several future climate projections by 2100, major breakdown of the ice sheet would probably lag warming by several centuries. If basal melting rates for buttressing Antarctic ice shelves exceed 16.4 to 33.8 ft/yr, the West Antarctic Ice Sheet (WAIS) could break up within several centuries (Alley et al., 2005).

Given the limitations of current GCMs to represent ice sheet dynamics accurately, thus adding to the uncertainty in future sea level rise projections, an alternative approach is to examine paleo-sea level analogs.These analogs include an episode of rapid sea level rise linked to the deglaciation and dis-

FIGURE 18.

Comprehensive set of sea level rise projections for the New York City and the surrounding region.

This schematic shows sea level rise projections for the 2080s, relative to the 2000-2004 period, based on three distinct methodologies. The dark blue hatched bars show projections based on the IPCC-adapted method. The light blue hatched bars show projections based on the Rahmstorf/Horton method, adjusted for local conditions. Each of the two is shown as a histogram, with the y-axis containing the model-based probability for that model alone, associated with the sea level rise interval shown on the x-axis. The Rapid Ice-Melt sea level rise is indicated by the bracket on the x-axis; no probability is associated with this range.



integration of the Laurentide ice sheet (that once covered most of Canada and the northern United States). Since major continental ice sheets are no longer present, the overall supply of ice is smaller, so that the analogy to the past may not be exactly equivalent (Rohling et al., 2008). However, past rapid rises are described to investigate potential upper bounds rates of sea level rise. Table 11 shows how the meltwater component of the rapid ice-melt scenario at the century timescale is developed based on paleoclimate literature.

TABLE 11.

Paleoclimate Basis for Rapid Ice-Melt Scenario

Source: Fairbanks, 1989; Bard et al., 1990; Peltier and Fairbanks, 2006.

Paleoclimate Literature	NPCC Ice-Melt Component per Century
Global Average	
~394 ft in 11,000 years -- 0.43 in/yr	43 inches per century
Lower & Upper Bound (assuming main period of SLR lasted between 12,000 and 10,000 years)	
~394 ft in 12,000 years -- 0.39 in/yr ~394 ft in 10,000 years -- 0.47 in/ys	39-47 inches per century

APPENDIX

SECTOR-SPECIFIC IMPACTS

D

Table 12 reflects implications of climate change identified by members of the City's Task Force after initial discussions of climate change scenarios and potential impacts that were shared with the NPCC. Because some of the impacts of climate change will vary by sector (communications, energy, transportation, and water & waste), implications are divided into sector-specific columns to highlight the respective impacts. Each row represents the impact of specific climate factors. In general, impacts are expected to become more severe over the course of the 21st century.

TABLE 12.

Air Temperature, Precipitation and Sea Level Rise Impacts in NYC and the Surrounding Region, by Sector

	Communication Infrastructure Implications	Energy Infrastructure Implications	
Temperature, Heat Waves & Cold Events	**Hotter summers could:** • result in expansion of copper wiring, causing more static, and in some cases serious blockages • lead to sagging of above ground cables • result in longer growing seasons, increasing the need for more frequent vegetation clearing from above ground cables • place strain on equipment and machinery, increasing interruptions and the need for more frequent maintenance and reduced lifetimes • increase the need for cooling machinery	• place strain on equipment and machinery, increasing the need for maintenance and reducing lifetimes • lead to disruption of conduits • result in expansion of heat sensitive equipment • increase the need for cooling of machinery	
	More frequent and intense heat waves, and hot days could: • increase energy demand, resulting in more frequent power outages • result in fluctuations in voltage, damaging equipment and interrupting service	• increase energy demand, resulting in more frequent power outages • result in fluctuations in voltage, damaging equipment and interrupting service • increase fuel costs	
	Fewer and less extreme cold air outbreaks could:	• reduce heating demand in winter • reduce strain on equipment and machinery, reducing the need for maintenance and extending lifetimes	
	Warmer water temperatures could:		
Precipitation, Intense Precipitation & Droughts	**Increased average annual precipitation could:** • place strain on equipment and machinery, increasing the need for maintenance and reducing lifetimes	• improve potential for hydropower • lead to more Combined Sewer Overflow (CSO) events, polluting coastal waterways and reducing ability of power plants to discharge water into sewers • increase turbidity in reservoirs affecting costs associated with cleaning water for cooling • place strain on equipment and machinery, increasing the need for maintenance and reduce lifetimes	
	More frequent and intense drought could: • place strain on equipment and machinery, increasing need for maintenance and reducing lifetimes		
	More frequent intense rainfall could: • lead to more flooding of underground cables, equipment and fuel tanks • result in a possible collapse of conduits • decrease accessibility to underground infrastructure for repairs	• lead to more street, basement and sewer flooding which will overload drainage systems, resulting in increased wear and tear on equipment and infrastructure	
Sea Level Rise, Coastal Floods & Storms	**Higher average sea level could:** • increase salt water encroachment on freshwater sources, resulting in increased damage to infrastructure not manufactured to withstand saltwater exposure • increase rates of coastal erosion and/or permanent inundation of low-lying areas, resulting in increased maintenance costs and replacement cycles • increase pollution runoff from brownfields and waste storage facilities	• increase salt water encroachment on freshwater sources, resulting in increased damage to infrastructure not manufactured to withstand saltwater exposure • increase rates of coastal erosion and/or permanent inundation of low-lying areas, resulting in increased maintenance costs and replacement cycles • increase pollution runoff from brownfields and waste storage facilities	
	More frequent & intense coastal flooding could: • increase frequency of use of emergency management actions • exacerbate street, basement and sewer flooding	• increase frequency of use of emergency management actions • exacerbate street, basement and sewer flooding, and increase the use of energy to control floodwaters	

	Transportation infrastructure Implications	Waste & Water Infrastructure Implications	
	• place strain on equipment and machinery, increasing the need for maintenance and reducing lifetimes • result in expansion of heat-sensitive equipment • increase the need for cooling of machinery • deteriorate road and rail infrastructure from buckling and expansion	• result in longer growing seasons and greater plant water uptake, leading to less water in reservoirs and increased likelihood of droughts • place strain on equipment & machinery, increasing need for maintenance and reduce lifetimes • increase the need for cooling of machinery	
	• increase energy demand, resulting in more frequent power outages and requiring energy restrictions on use of HVAC and other systems • result in fluctuations in voltage, damaging equipment and interrupting service • increase the number of passengers overheating while waiting for trains • increase heat levels of equipment	• increase water demand, including for recreational uses • create water pressure and delivery problems, straining water supply systems • increase in heat levels of playgrounds	
		• result in increased odor from waste transfer facilities • influence water quality, including insect and pest populations • result in warmer water temperatures, creating pressure for more dam releases to maintain fish life, which reduces water supply	
	• place strain on equipment and machinery, increasing the need for maintenance and reduce lifetimes • require heavier use of pumps • lead to more Combined Sewer Overflow (CSO) events, polluting coastal waterways and potentially impacting water transportation and associated infrastructure	• lead to more Combined Sewer Overflow (CSO) events, polluting coastal waterways • increase turbidity in reservoirs affecting water quality • increased sediment requiring more frequent dredging • place strain on equipment & machinery, increasing need for maintenance and reduce lifetimes	
	• place strain on some water equipment and machinery, increasing need for maintenance and reducing lifetimes	• affect average reservoir storage and therefore would also affect operating rules • result in drought strain on vegetation	
	• lead to more street, basement and sewer flooding which will overload drainage systems, resulting in increased accidents and delays, and more wear and tear on equipment and infrastructure	• lead to more street, basement and sewer flooding which will overload drains • cause an increase in nutrient loads, eutrophication, taste and odor problems • lead to loadings of pathogenic bacteria and parasites	
	• increase salt water encroachment on freshwater sources, resulting in increased damage to infrastructure not manufactured to withstand saltwater exposure • increase rates of coastal erosion and/or permanent inundation of low-lying areas, resulting in increased maintenance costs and replacement cycles • increase runoff from brownfields and waste storage facilities • decrease clearance levels under bridges	• increase salt water encroachment on freshwater sources and ecosystems, resulting in increased damage to freshwater water and waste infrastructure • increase pollution runoff from brownfields and waste storage facilities lead to permanent inundation of low-lying areas, wetlands and piers and marine transfer stations • increase rates of beach and salt marsh erosion	
	• increase frequency of use of emergency management actions • exacerbate street, basement and sewer flooding, and will also lead to structural damage to infrastructure due to wave action	• increase frequency of use of emergency management actions • exacerbate street, basement and sewer flooding, and will also lead to structural damage to infrastructure due to wave action	

GLOSSARY & ABBREVIATIONS

7

Adaptation*
Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes and the substitution of more temperature shock resistant plants for sensitive ones.

AR4
The Fourth Assessment Report of the IPCC, released in 2007. At the time of publication of this document, AR4 was the most recent IPCC report.

Baseline*
The reference for measurable quantities from which an alternative outcome or projections can be measured.

Carbon Dioxide (CO_2)*
CO_2 is a naturally occurring gas, and a by-product of burning fossil fuels or biomass, of land-use changes and of industrial processes. It is the principal anthropogenic greenhouse gas that affects Earth's radiative balance.

Climate Change*
Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/ or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

NYC Climate Change Adaptation Task Force (Task Force)
An initiative of PlaNYC, the Task Force is working to identify the risks and opportunities posed by climate change to the City's critical infrastructure and to develop coordinated adaptation strategies to address these risks. The Task Force consists of approximately 38 city, state, and federal agencies, regional public authorities, and private companies that operate, maintain or regulate critical infrastructure in New York City.

Climate Forcing*
Any mechanism that alters the global energy balance, causing the climate to change. Examples of climate forcings include variations in greenhouse gas concentrations and solar radiation.

Climate Hazards*
Climate variables which could have particular consequence for New York City and the surrounding region. The main climate hazards discussed in this document are related to temperature, precipitation, sea level rise, and extreme events.

Critical Infrastructure
For the efforts of the Task Force, critical infrastructure is defined as systems and assets (excluding residential and commercial buildings, handled by other City efforts) that support other activities which are so vital to the city that the diminished functioning or destruction of such systems and assets would have a debilitation impact on public safety and/or economic security.

Emissions Scenarios (see SRES)*

Global Climate Models (GCMs)*

A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity, i.e. for any one component or combination of components a hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented, or the level at which the parameters are assessed empirically. Coupled atmosphere/ocean/sea-ice Global Climate Models provide a comprehensive representation of the climate system. There is an evolution towards more complex models with active chemistry and biology.

Greenhouse Gases (GHGs)*

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine-containing substances, sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons.

HVAC

Heating Ventilation Air Condition Systems of key importance to many industrial and office buildings. These systems are especially important to maintaining proper temperature of vital system equipment.

Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change was formed in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), and is the international advisory body on climate change.

Likelihood of Occurrence Ranges*

>99%: Virtually certain
>95% Extremely likely
>90% Very likely
>66% Likely
>50% More likely than not
33 to 66% About as likely as not

Mitigation*

Technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce GHG emissions and enhance sinks.

NYC Panel on Climate Change (NPCC)

Convened by Mayor Michael Bloomberg, the New York City Panel on Climate Change is composed of climate change and impacts scientists, and legal, insurance, and risk management experts. The NPCC advises the Mayor and the City on issues related to climate change and adaptation and is developing a series of workbooks to help the City's Climate Change Adaptation Task Force identify at-risk infrastructure and develop adaptation strategies.

Paleoclimate

Paleoclimate research uses the earth's historical climate record from geophysical, geochemical and sedimentological data analyses to reconstruct various time periods and events in Earth's climate history.

Risk

Risk is the product of the likelihood of an event occurring and the magnitude of consequence should that event occur. For the purposes of this document, likelihood is defined as the probability of occurrence of a climate hazard.

Scenario*

A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts, but are useful to provide a view of the implications of developments and actions.

SRES*

The IPCC's Special Report on Emissions Scenarios, released in 2000. Each emissions scenario presented in the SRES makes different assumptions about population growth, economic growth, technological change, and land-use change, that lead to greenhouse gas emissions and atmospheric concentration trajectories. While no one single emissions scenario or global climate model projection will occur exactly as specified in the future, a combination of a suite of global climate model simulations and greenhouse gas emissions profiles provides a range of possible outcomes that can be expressed as a set of projections that reflects the current level of expert knowledge.

Timeslice

Projections in this document are given in three timeslices, 2020s, 2050s and the 2080s. The projections are a 30-year average (10 years for sea level rise), centered around each of the given timeslices. Climate models cannot predict what the specific climate will be in any given year, due in part to the inter-annual variability of the climate variables, so the given projections are averages of future climate.

Uncertainty*

An expression of the degree to which a value is unknown (e.g. the future state of the climate system). Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgment of a team of experts).

***** - As defined by, or derived from definitions used by the IPCC. See IPCC AR4 Glossary.

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