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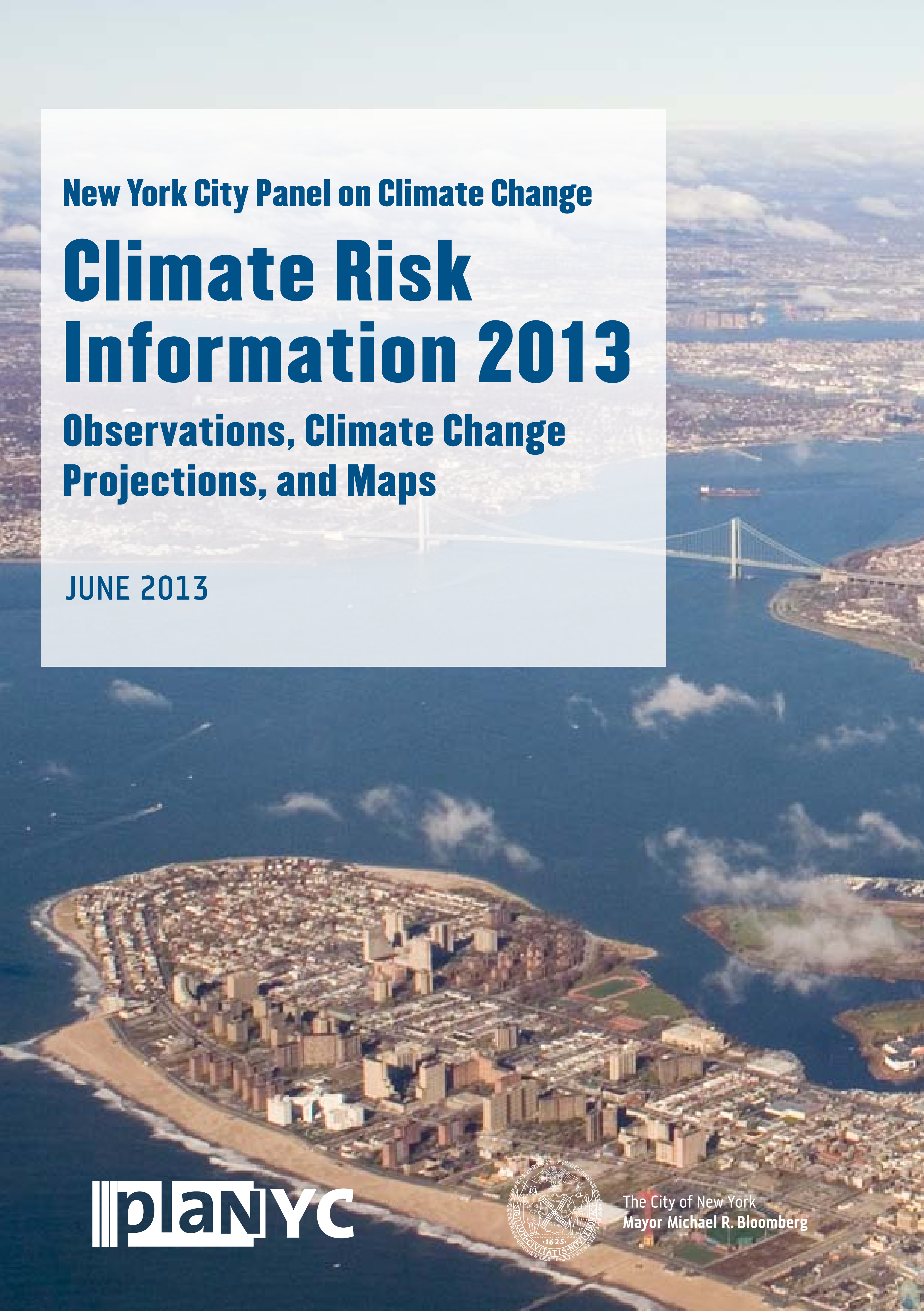
New York City Panel on Climate Change

Climate Risk Information 2013

Observations, Climate Change Projections, and Maps

JUNE 2013



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The City of New York
Mayor Michael R. Bloomberg

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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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New York City Panel on Climate Change

Climate Risk Information 2013

Observations, Climate Change Projections, and Maps

Supplementary Information*

*Supplementary Information sections of the CRI 2013 are available online at www.nyc.gov/planyc, www.nyc.gov/resiliency, www.ccrun.org, and www.cunysustainablecities.org

planyc

June 11, 2013 version

Executive Summary

Climate change poses significant risks to New York City's communities and infrastructure. Hurricane Sandy has focused attention on the effects that extreme climate events have on New York City, reminding New Yorkers that the city is vulnerable to a range of climate hazards today and in the future.

To help respond to climate change in New York City and accomplish the goals outlined in PlaNYC, the City's long-term sustainability plan, Mayor Bloomberg convened the First New York City Panel on Climate Change (NPCC1) in 2008. The NPCC – a body of leading climate and social scientists and risk management experts – was charged with advising the Mayor and the New York City Climate Change Adaptation Task Force on issues related to climate change and adaptation. It produced a set of climate projections specific to New York City.

Following Hurricane Sandy, Mayor Bloomberg convened the second New York City Panel on Climate Change (NPCC2) in January 2013 to provide up-to-date scientific information and analyses on climate risks for use in the Special Initiative for Rebuilding and Resiliency (SIRR). In response to the Mayor's charge to the Panel, this Report provides new climate change projections and future coastal flood risk maps for New York City. This climate risk information is designed to inform community rebuilding plans, and help to increase current and future resiliency of communities, and citywide systems and infrastructure to a range of climate risks.

New York City Temperature, Precipitation, and Sea Level – Observed Trends

Trends in temperature, precipitation, and sea levels have increased overall throughout the century, but with interannual and decadal variations. Mean annual temperature in New York City has increased 4.4°F from 1900 to 2011. Mean annual precipitation has increased 7.7 inches from 1900 to 2011 (a change of 1.4 percent per decade). Year-to-year precipitation variability was greater from 1956 to 2011 than from 1900 to 1955. Sea level in New York City (at the Battery) has risen 1.1 feet since 1900. It is not possible to attribute any single extreme event such as Hurricane Sandy to climate change. However, sea level rise occurring over time in the New York City area increased the extent and the magnitude of coastal flooding during the storm.

Future Climate Projections for New York City[1,2]

By mid-century, temperatures are extremely likely[3] to be higher in New York City. Global climate models (GCMs) project that mean annual temperatures will increase. Specifically:

- By the 2020s, the middle range of projections is 2.0°F to 3.0°F and the high estimate is 3.0°F
- By the 2050s, the middle range of projections is 4.0°F to 5.5°F and the high estimate is 6.5°F

Total annual precipitation in New York City will likely increase by mid-century. Mean annual precipitation increases as projected by GCMs are:

- By the 2020s, the middle range of projections is 0 percent to 10 percent, and the high estimate is 10 percent
- By the 2050s, the middle range of projections is 5 percent to 10 percent, and the high estimate is 15 percent

Higher sea levels are extremely likely by mid-century. Projections for sea level rise in New York City are:

- By the 2020s, the middle range of projections is 4 to 8 inches, and the high estimate is 11 inches
- By the 2050s, the middle range of projections is 11 to 24 inches, and the high estimate is 31 inches

By the 2050s, the NPCC projects the following changes in extreme events:

- Heat waves are very likely to become more frequent, more intense, and longer in duration
- Heavy downpours are very likely to increase in frequency, intensity, and duration
- Coastal flooding is very likely to increase in frequency, extent, and height as a result of increased sea levels

1 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), and changes are expressed relative to the baseline period 1971 – 2000. For sea level rise, the timeslice represents a 10-year average centered around the given decade (i.e., the time period for the 2020s is from 2020-2029), and changes are expressed relative to the 2000 – 2004 baseline. Projections rounded to the nearest half degree, five percent and inch.

2 Shown are the middle range (25th to 75th percentile) and high estimate (90th percentile) of the projections. 25th percentile = value at which 75 percent of the projections are higher; 75th percentile = value at which 25 percent of the projections are higher; 90th percentile = value at which 10 percent of the projections are higher. In the first New York City Panel on Climate Change (NPCC1) Climate Risk Information (Horton and Rosenzweig, 2010), the central range was defined as 17th to 83th percentile.

3 Probability of occurrence and likelihood defined as (IPCC, 2007):

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

Baseline Climate and Mean Annual Changes

Air temperature Baseline (1971 - 2000) 54°F	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020s	+ 1.5°F	+ 2.0°F to + 3.0°F	+ 3.0°F
2050s	+ 3.0°F	+ 4.0°F to + 5.5°F	+ 6.5°F
Precipitation Baseline (1971 - 2000) 50.1 inches	**Low-estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High-estimate (90th percentile)**
2020s	-1 percent	0 to + 10 percent	+ 10 percent
2050s	1 percent	+ 5 to + 10 percent	+ 15 percent
Sea level rise Baseline (2000-2004) 0 inches	**Low-estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High-estimate (90th percentile)**
2020s	2 inches	4 to 8 inches	11 inches
2050s	7 inches	11 to 24 inches	31 inches

Based on 35 GCMs (24 for sea level rise) and two Representative Concentration Pathways. Baseline data are from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) United States Historical Climatology Network (USHCN), Version 2 (Menne et al., 2009). Shown are the 10th percentile, 25th percentile, 75th percentile, and 90th percentile 30-year mean values from model-based outcomes.Temperature values are rounded to the nearest 0.5°F, percipitation values are rounded to the nearest 5 percent, and sea level rise values rounded to the nearest inch.

Quantitative Changes in Extreme Events

			2020s			2050s		
		Baseline (1971 - 2000)	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	18	24	26 to 31	33	32	39 to 52	57
	Number of heat waves/year	2	3	3 to 4	4	4	5 to 7	7
	Average heat wave duration (in days)	4	5	5 to 5	5	5	5 to 6	6
	Number of days/year with minimum temperature at or below 32°F	72	50	52 to 58	60	37	42 to 48	52
Intense Precipitation	Number of days/year with rainfall at or above 2 inches	3	3	3 to 4	5	3	4 to 4	5
Coastal Floods at the Battery*	Annual chance of today's 100-year-flood	1.0 percent	1.1 percent	1.2 to 1.5 percent	1.7 percent	1.4 percent	1.7 to 3.2 percent	5.0 percent
	Flood heights associated with 100-year-flood (stillwater + wave heights)	15.0 feet	15.2 feet	15.3 to 15.7 feet	15.8 feet	15.6 feet	15.9 to 17 feet	17.6 feet

*Baseline period for sea level rise is 2000-2004. Based on 35 GCMs and two Representative Concentration Pathways. Data are from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) United States Historical Climatology Network (USHCN), Version 2 (Menne et al., 2009). The 10th percentile, 25th percentile, 75th percentile, and 90th percentile values from model-based outcomes across the GCMs and Representative Concentration Pathways are shown. Decimal places are shown for values less than 1, although this does not indicate higher precision/certainty. Heat waves are defined as three more consecutive days with maximum temperatures at or above 90 °F. The flood heights include the effects of waves.

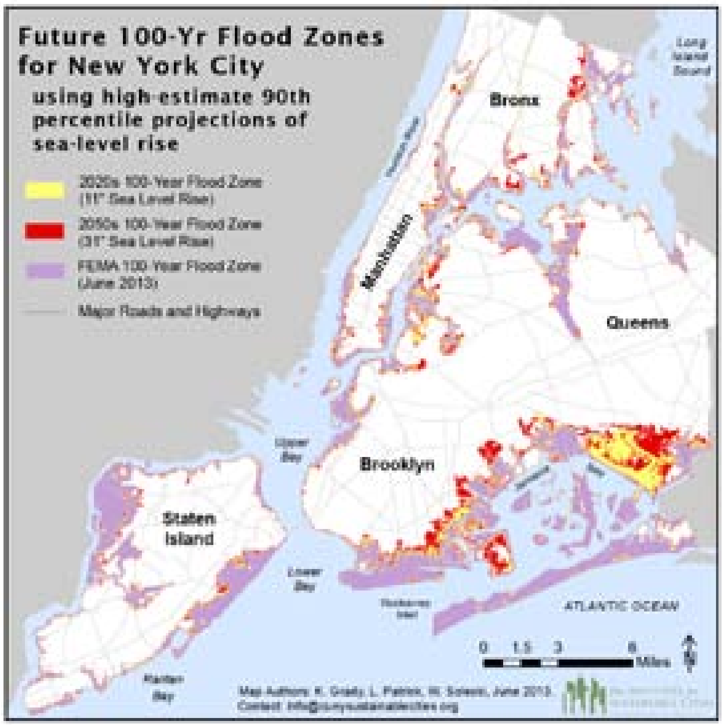
Disclaimer: Like all projections, the NPCC climate projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system, and limited understanding of some physical processes. The NPCC characterizes levels of uncertainty using state-of-the-art climate models, multiple scenarios of future greenhouse gas concentrations, and recent peer-reviewed literature. Even so, the projections are not true probabilities, and the potential for error should be acknowledged.

Future Coastal Flood Risk Maps

Maps that show future coastal flood risk (including areas affected by coastal storm surges combined with sea level rise), related vulnerability, and potential impacts are important ways of communicating information to a wide variety of stakeholders and decision-makers. To estimate potential impacts of sea level rise on the spatial extent of the current 100- and 500-year flood zones, the NPCC2 developed a series of maps incorporating NPCC2 projections for sea level rise with FEMA's 2013 Preliminary Work Maps. Because of limitations in the accuracy of flood projections, these maps should not be used to judge site-specific risks, insurance rates, or property values; however, they do illustrate the trends of future flooding for these events.

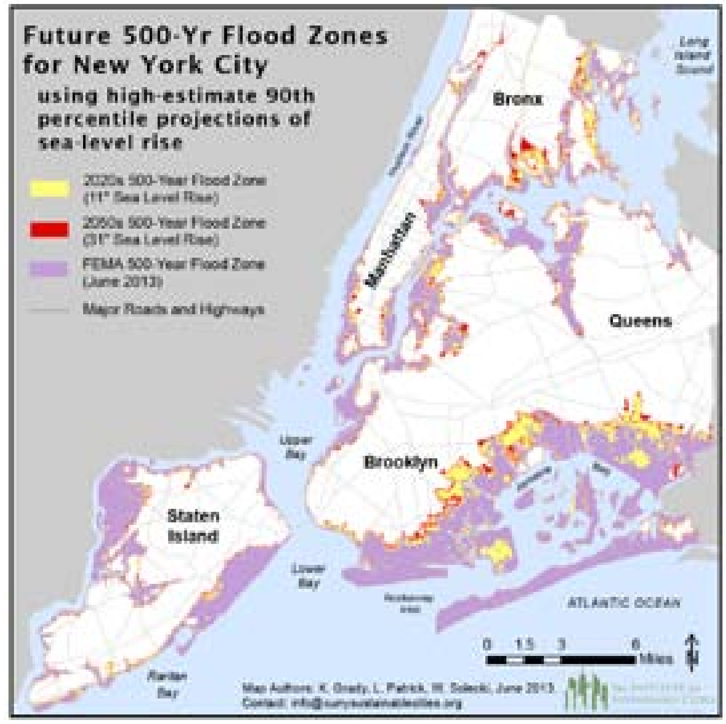
The maps presented below illustrate the potential impact of sea level rise on the areas of New York City that could be subject to the 100- and/or 500-year flood in the 2020s and 2050s due to high estimate projections for sea level rise. The areas shaded in yellow represent the potential flood extent of the 100- and 500-year flood in the 2020s with 11 inches of sea level rise, and the areas shaded in red represent the potential flood extent of the 100- and 500-year flood in the 2050s with 31 inches of sea level rise. While these new maps superimpose sea level rise onto FEMA's flood maps, they do not account for other changes in climate, such as possible changes in storm intensity and frequency that could affect storm surge occurrences and heights.

Future 100-Year Flood Zones for New York City



The potential areas that could be impacted by the 100-Year flood in the 2020s and 2050s based on projections of the high-estimate 90th percentile sea level rise scenario (see Table 3).

Future 500-Year Flood Zones for New York City



The potential areas that could be impacted by the 500-Year flood in the 2020s and 2050s based on projections of the high-estimate 90th percentile sea level rise scenario (see Table 3).

Disclaimer: Like all environment-related projections and associated map products, the NPCC Future Flood Maps have uncertainty embedded within them. In this case, uncertainty is derived from a set of data and modeling constraints. Application of state-of-the-art climate modeling, best mapping practices and techniques, and scientific peer review was used to minimize the level of uncertainty. Even so, the map product should be not recognized as the actual spatial extent of future flooding and the potential for error acknowledged.

Recommendations

The NPCC2 makes the following recommendations for further research and outreach regarding climate change in the New York City area.

- Develop improved methods for estimating probabilities of changes in an expanded range of climate hazards – including humidity, drought, ice storms, snowfall, lightning, and winds – and combined climate hazards such as back-to-back heat waves and coastal floods.
- Improve computational and statistical modeling of the climate system to better understand changes in future coastal flooding (including height and frequency) based on:

  (i) Multiple factors contributing to sea level rise

  (ii) Changes in tropical cyclone and nor'easter storm characteristics (e.g., frequency, severity, duration, and track)

  (iii) Combined effects of sea level rise and changes in storm characteristics
- Improve representation of future coastal flooding through enhanced dynamic flood inundation (storm surge) modeling and flood hazard mapping techniques.
- Improve understanding and mapping of neighborhood vulnerability to the range of current and future climate stresses, such as river flooding, heat waves, and the urban heat island effect.
- Develop a system of indicators and monitoring co-generated by stakeholders and scientists to track data related to climate risks, hazards, and impacts to better inform climate change-related decision-making in New York City.
- Improve ways to communicate data and information on how changes in climate will affect the frequency of climate hazards and their impacts in the future, and the uncertainties surrounding these estimates, to provide greater transparency to potential users at city, state, and national levels.

Climate Change and New York City

The climate is changing in many ways, and there is a growing body of literature documenting these changes. Recent observations reported in the National Climate Assessment Public Review Version (NCA; USGCRP, 2013) show that the Northeast of the U.S. is warming and that heavy downpours are increasing in the region. The Special Report on Extreme Events (SREX) of the Intergovernmental Panel on Climate Change (IPCC) found that these and other changes are also occurring in many parts of the world (IPCC, 2012).

For example, it is very likely that there has been an overall decrease in the number of cold days and nights, and an overall increase in the number of warm days and nights globally for most land areas with sufficient data. The SREX also found that there have been statistically significant trends in the number of heavy precipitation events in some regions around the world. Several recent publications have confirmed that sea levels continue to rise globally (e.g., Parris et al., 2012) with higher local rates of rise in the Northeast U.S. (Sallenger et al., 2012).

In New York City, mean annual temperature has increased 4.4°F and mean annual precipitation has increased 7.7 inches (a change of 1.4 percent per decade) from 1900 to 2011. Year-to-year precipitation variability was greater from 1956 to 2011 than from 1900 to 1955. Sea level in New York City (at the Battery) has risen 1.1 feet since 1900.

Hurricane Sandy has focused attention on the significant effects that extreme climate events have on New York City. Other recent events in the U.S., such as the widespread drought of 2012, have also raised awareness of the impacts of weather and climate extremes. While it is not possible to attribute any single extreme event such as Hurricane Sandy to climate change, sea level rise already occurring in the New York City area, in part related to climate change, increased the extent, and magnitude of coastal flooding during the storm.

New York City Mayor Michael R. Bloomberg convened the First New York City Panel on Climate Change (NPCC1) in 2008 to help respond to climate change in New York City and accomplish the goals outlined in PlaNYC, the City's long-term sustainability plan (PlaNYC 2008; 2011). The NPCC – a body of leading climate and social scientists and risk management experts – was charged with advising the Mayor and the New York City Climate Change Adaptation Task Force on issues related to climate change and adaptation. It produced a set of climate projections specific to New York City which was released in 2009 (NPCC, 2010).

In September 2012, the City passed Local Law 42 that established the New York City Panel on Climate Change as an ongoing body. The NPCC is required to meet at least twice a year to review recent scientific data on climate change and its potential impacts, make recommendations for projections for the 2020s, 2050s, and 2080s within one year of the publication of the IPCC Assessment Reports, or at least every three years, and advise the City's Office of Long-Term Planning and Sustainability (OLTPS) on a communications strategy related to climate science.

Following Hurricane Sandy, Mayor Bloomberg convened the Second New York City Panel on Climate Change (NPCC2) in January 2013 to provide up-to-date scientific information and analyses on climate risks for use in the Special Initiative for Rebuilding and Resiliency (SIRR). In response to the Mayor's charge to the panel, this report provides climate change projections and future coastal flood risk maps. The report presents quantitative and qualitative information about future climate hazards, focusing on temperature, precipitation, and sea level.

NPCC2 follows the risk management approach developed in NPCC1. In this approach, climate hazards are extreme climatic or weather events that cause harm and damage. Climate risk is the product of the likelihood of a climate hazard occurring and the magnitude of consequences should that event occur (Box 1). While mitigation of greenhouse gas emissions is essential to reducing the magnitude of long-term changes in climate, the NPCC2 Climate Risk Information 2013 will inform community rebuilding plans, and help to increase current and future resiliency of communities, citywide systems, and infrastructure to a range of climate risks.

Box 1: Key Definitions and Terms

Climate Change

Climate change refers to a significant change in the state of the climate that can be identified from changes in the average state or the variability of weather, that persist for an extended time period, typically decades to centuries or longer. Climate change can refer to the effects of 1) persistent anthropogenic or human-caused changes in the composition of the atmosphere and/or land use, or 2) natural processes, such as volcanic eruptions, and Earth's orbital variations (based on IPCC, 2007a).

Climate Hazard

A climate hazard is an extreme climatic or weather event, such as heat waves, floods, wind, rain, ice, snow, and drought that can cause harm and damage to people, property, infrastructure, land, and ecosystems. Hazards are expressed in quantified measures, such as flood height in feet, wind speed in miles per hour, and inches of rain, ice, or snowfall, that are reached or exceeded in a given period of time.

Risk

The NPCC2 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.

Uncertainty

Uncertainty denotes a state of incomplete knowledge that results from lack of information, natural variability in the measured phenomenon, instrumental and modeling errors and/or from disagreement about what is known or knowable.

See Glossary for additional definitions.

Hurricane Sandy and Links to Climate Change

Hurricane Sandy struck New York City on October 29, 2012. The storm track and intensity were forecast in advance, with some weather prediction models suggesting the possibility of a strike in the Mid-Atlantic region of the U.S. more than one week before the storm hit. At 945 mb, Sandy had the lowest recorded central pressure – a measure of storm strength – at landfall of any storm north of North Carolina.[4] Sandy's wind field was exceptionally large, with tropical storm force winds extending approximately 1,000 miles. The arrival of the peak storm surge of 9.4 feet coincided closely with high tide through much of the region. The storm tide at the Battery[5] at southern Manhattan was 14.1 feet above mean lower low water (MLLW), or 11.3 feet above the North American Vertical Datum (NAVD88) (Blake et al., 2013).

Sea level rise occurring in the New York City area increased the extent and the magnitude of coastal flooding during the storm. Since 1900, relative sea level[6] has risen approximately 1.1 feet in New York City (Horton and Rosenzweig, 2010). This sea level rise is primarily due to global factors (thermal expansion of the oceans as they warm, loss of land-based ice and land water storage), but also partially due to local factors (land subsidence and changes in the height of the coastal North Atlantic ocean relative to the global average). As sea levels continue to rise, coastal flooding will occur more frequently, and future coastal storms will cause more flood damage than they otherwise would have (NPCC, 2010).

Hurricane Sandy gained additional strength from unusually warm upper ocean temperatures in the North Atlantic. As the climate continues to warm, temperatures in the upper layers of the ocean are expected to increase, which could allow storms to reach greater strength. Although hurricanes[7] depend on a range of climate variables and it is not clear how all these variables will change, a number of recent studies suggest that the number of the most intense hurricanes may increase globally (Elsner et al., 2008; Bender et al., 2010; Knutson et al., 2010). It is more likely than not that these hurricanes will also increase in the North Atlantic Basin.

Loss of sea ice related to warming in the Arctic Ocean may also have influenced Sandy's path and intensity (Greene et al., 2013). The volume of sea ice in early fall has decreased by almost 80 percent since the late 1970s, and research has linked sea ice decline to changes in the atmospheric steering currents known as the jet stream, and consequently to changes in the frequency and intensity of extreme weather (Liu et al., 2012; Francis and Vavrus, 2012). While the jet stream configuration that allowed Sandy to turn westward and strike New Jersey was unusual, possible links to loss of sea ice remain uncertain.

4 Although the 1938 Great New England Hurricane is analyzed to have made landfall with a central pressure of 941 mb, no pressure below 946 mb was recorded (Blake et al. 2013).

5 The storm tide is the total water elevation, including the storm-generated surge and "normal" astronomical tide (NOAA Tides and Currents tidesandcurrents.noaa.gov).

6 The relative (or local) sea level rise is the sea level at a given locality with respect to the land. Sea level rise varies spatially due to changes in vertical crustal motion, including ongoing glacial isostatic adjustments, tectonic movements, groundwater extraction, and also due to gravitational, rotational and isostatic effects of ice mass loss, and changes in ocean circulation.

7 Hurricanes are an intense form of tropical cyclone. Tropical cyclones are categorized based on their wind speeds. In addition to hurricanes, tropical storms and tropical depressions (also classified by wind speed) also impact the New York City area.

Uncertainty and Risk Management

The scientific understanding of climate change and its impacts has increased dramatically in recent years. Nevertheless, there remain substantial uncertainties (Box 2) (IPCC, 2007; 2012). Due to this incomplete state of knowledge, choosing among policies for reducing future losses from extreme events such as Hurricane Sandy is an exercise in risk management (Yohe and Leichenko, 2010; Kunreuther et al., 2013). Given differing risk tolerances among stakeholders, a risk management approach allows for a range of possible outcomes to be examined with associated uncertainties surrounding their likelihoods (see Table 1).

Climate change uncertainties are amplified at smaller geographical and temporal scales. For example, at regional and local scales[8] and at short time periods, uncertainties are large due to factors such as random variations in the jet stream. Another source of uncertainty at fine spatial scales is the presence of local processes, such as land/sea breezes, that are not represented in coarse-resolution global climate models used to make projections.

The NPCC2 seeks to present climate uncertainties clearly in order to facilitate risk-based decision-making on the use of policy tools such as incentives, regulations, and insurance. The goal is to make New York City more resilient to mean changes in climate and to future extreme events.

Table 1. Probability of Occurrence

Likelihood	Probability of Occurrence
Virtually certain	>99% probability of occurrence
Extremely likely	>95% probability of occurrence
Very likely	>90% probability of occurrence
Likely	>66% probability of occurrence
More likely than not	>50% probability of occurrence
About as likely as not	33-66% probability of occurrence

The treatment of likelihood is similar to that developed and used by the IPCC. The six likelihood categories used here are as defined in the IPCC 4th Assessment Report, Working Group I (IPCC 2007a).

Projections and Likelihoods

Ranges of model-based outcomes and likelihoods based on analysis of scientific literature are tools that the NPCC2 uses to illustrate uncertainties in climate hazards. For temperature and precipitation projections, the NPCC2 presents two types of future climate information: 1) climate model-based outcomes with associated percentiles and 2) qualitative projections with associated likelihoods. Sea level rise projections follow a hybrid approach based on both global climate model outputs and recent peer-reviewed scientific literature.

The NPCC2 presents a range of outcomes based on climate model results and differing future greenhouse gas emissions. These results are presented as the 10th, 25th, 75th, and 90th percentiles of the distribution of model-based outcomes (Figure 1) (see Section 6). Feedback from stakeholders in New York City helped to guide the selection of the percentiles. It is important to note that these model-based outcomes do not encompass the full range of possible futures; for example, feedbacks in the climate system that may not be captured in current GCMs could produce changes outside of the projected ranges (Harris et al., 2013; Rougier, 2007).

8 Regional scale refers to a grouping of several states that are generally within relatively close proximity to one another, whereas local refers to a particular geographic location (e.g., a city) and its immediate surrounding area. In the context of this report, regional refers to the Northeast United States, while local refers to the New York City metropolitan area.

Box 2: Sources of Climate Related Uncertainty

1. Random Uncertainties in the Climate System

Some physical processes in the climate system are random, which limits predictability. There is also inherent variability in the climate system, e.g., day-to-day, or year-to-year fluctuations in temperature, precipitation, etc.

Example: A small perturbation in the atmosphere can lead to unpredictable changes over time.

2. Uncertainties Related to Climate Measurements

Since it is difficult to measure climate variables with complete accuracy, observations of climate variables are often presented with their associated uncertainties. Some measurement of uncertainty is related to the random nature of certain climate system processes as described above.

Example: Sources of measurement uncertainties in the current climate include errors arising from weather station instruments and changes in their locations, and those arising from poorly documented storm-surge elevations.

3. Climate Model Uncertainties

Model uncertainties for projecting future climate arise from the lack of or incomplete understanding of some processes in the climate system as simulated in GCMs and inaccuracies in the way climate processes are represented at the coarse spatial resolution of GCMs (GCMs calculate climate variables over geographic areas of approximately 125 x 115 miles). The sensitivity of the overall climate system to changes in climate drivers[9] is another uncertainty in climate modeling.

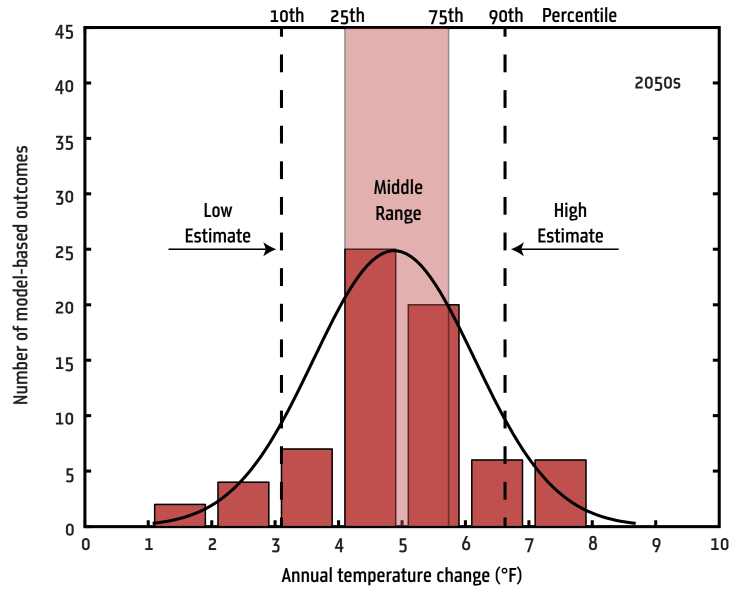
Example: Future storms may change in location and strength, and storm surge effects may vary along the complex coastline of the New York region, in ways that climate models cannot yet predict.

4. Uncertainties in Future Climate Drivers

It is difficult to project how greenhouse gas emissions, pollutant aerosols, black carbon, and land use may change in the future. These are anthropogenic climate drivers (or climate forcing factors) that alter the global energy balance, which in turn lead to changes in the climate system.

Example: Uncertainties associated with projecting climate drivers arise from the inability to specify future changes in factors such as population, economic growth, and technological developments, and resultant effects on emissions, aerosols, and land use change.

Figure 1. Model-Based Range of Outcomes for 2050s Annual Temperature Change



Model-based range of outcomes (distribution) for 2050s temperature change relative to the 1971 - 2000 base period. Based on 35 global climate models and 2 representative concentrations pathways. The 10th, 25th, 75th, and 90th percentiles of the distribution are presented.

Where climate models are not robust enough to present quantitative ranges of outcomes, the NPCC provides qualitative projections with associated likelihoods. In presenting information about extreme events not well simulated by global climate models, the assignment of likelihood of future occurrences is based on a process that is similar to that developed and used in the NPCC1 Climate Risk Information (Horton and Rosenzweig, 2010). The six likelihood categories used are defined in the IPCC AR4 WG I Technical Summary (2007a). The assignment of climate hazards to these categories is based on analyses of global climate simulations and recent peer-reviewed scientific literature.

9 Changes in the atmospheric concentrations of GHGs and aerosols, land cover, and solar radiation alter the energy balance of the climate system and are thus drivers of climate change. They affect the absorption, scattering, and emission of radiation within the atmosphere and at the Earth's surface. The resulting positive or negative changes in energy balance due to these factors are expressed as radiative forcing, which is used to compare warming or cooling influences on global climate (IPCC, 2007a).

Observed Climate

Critical climate variables affecting New York City include temperature, precipitation, and sea level. This section of the report presents observations of mean climate and extreme events. Observations for New York City are placed in a broader regional and global context, since observed trends over large spatial scales are an important source of predictability with respect to New York City's future climate.

Mean Climate

Mean annual trends are provided for temperature, precipitation, and sea level for 1900 to 2011. All three trends are significant at the 99 percent level.

Temperature

Annual mean air temperature in New York City (Central Park) was approximately 54°F from 1971-2000. Annual mean temperature has increased at a rate of 0.4°F per decade over the 1900 to 2011 period in Central Park, although the trend has varied substantially over shorter periods (Figure 2). For example, the first and last 30-year periods were characterized by faster warming than the middle segment of the record.

The temperature trend for the New York City region is broadly similar to the trend for the Northeast United States.[10] Specifically, most of the Northeast has experienced a trend towards higher temperatures, especially in recent decades.[11] This trend is present in both rural and urban weather stations.

Precipitation

Annual average precipitation ranges between approximately 43 and 50 inches, depending on the location within New York City. Precipitation has increased at a rate of approximately 0.7 inches per decade over 1900 to 2011 in Central Park (Figure 3). New York City experiences significant precipitation throughout the year, and relative to most of the world, it experiences little variation in precipitation from month to month in the typical year.

While mean annual precipitation levels increased over the past century, year-to-year (and multi-year) variability of precipitation has also become more pronounced. The standard deviation, a measure of variability, increased from 6.1 inches from 1900 to 1955 to 10.1 inches from 1956 to 2011.

Precipitation in the larger Northeast region also increased modestly in the 1900s. For precipitation, the long-term trend in the Northeast generally cannot be distinguished from natural variability.

Sea Level Rise

Sea level rise in New York City has averaged 1.2 inches per decade since 1900 (Figure 4). This is nearly twice the observed global rate of sea level rise of 0.7 inches per decade over a similar time period (Church and White, 2011). As with temperature, the long-term upward trend in sea level has included multi-decadal periods characterized by lower rates of increase, such as the early part of the 20th century, and much of the 1960s and 1970s.

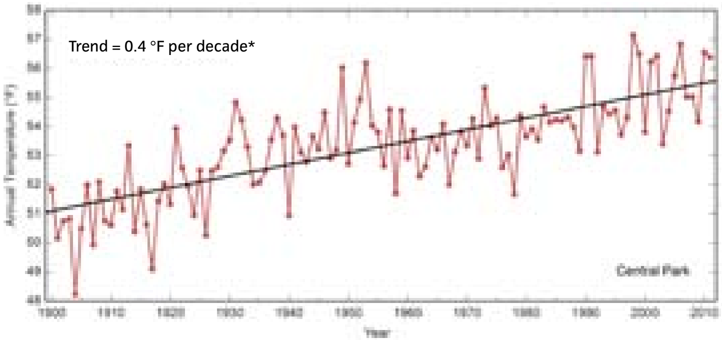
There are multiple processes that contribute to sea level rise, including: changes in ocean height; expansion of ocean water as it warms (i.e., thermal expansion); vertical land movements; loss of ice from glaciers, ice caps, and land-based ice sheets; gravitational, isostatic, and rotational effects resulting from ice mass loss and land water storage (see Section 4 and Supplementary Information for further discussion). Most of the observed climate-related rise in global mean sea level over the past century can be attributed to thermal expansion. However, loss of land-based ice has surpassed thermal expansion in recent decades and is expected to be the largest component of global sea level rise during the 21st century (Church et. al., 2011).

In New York City, approximately 45 percent of the observed sea level rise of 1.2 inches per decade since 1900 is due to land subsidence, with the remaining sea level rise driven by climate-related factors.

10 The Northeast (as defined in the National Climate Assessment (NCA, 2013)) includes the following 12 states; Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia.

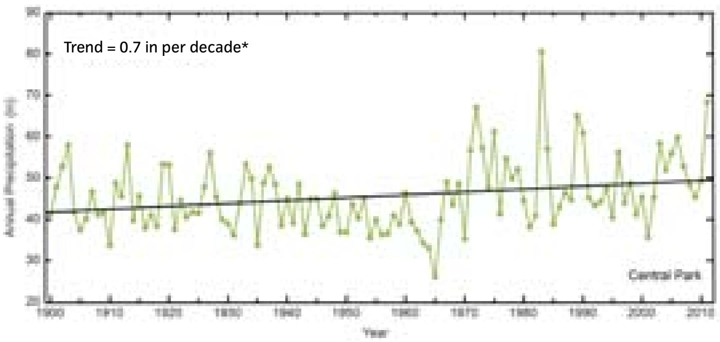
11 Some local historical records may have been affected by urban influences, such as the urban heat island effect, and other local and station-specific factors, such as time of observation and station location. The future projections described in this report primarily reflect the influences of global processes. While New York City's warming trend cannot be attributed to the urban heat island, its baseline climate is higher than surrounding areas in part due to the urban heat island effect.

Figure 2. Observed Annual Temperature in New York City



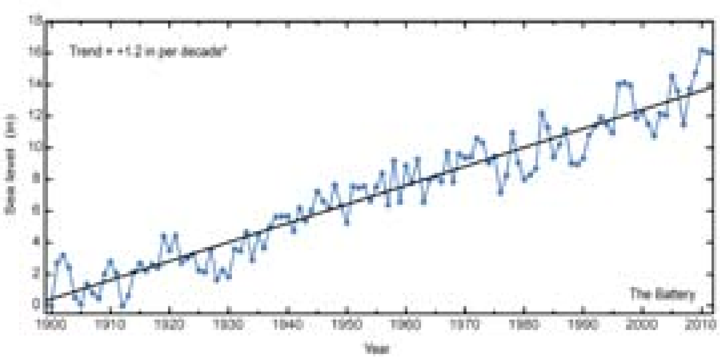
Observed annual temperature in Central Park (1900 - 2011). Data are from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) United States Historical Climatology Network (USHCNv2) (Menne et al., 2009). Trend is significant at the 99 percent level.

Figure 3. Observed Annual Precipitation in New York City



Observed annual precipitation in Central Park (1900 - 2011). Data are from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) United States Historical Climatology Network (USHCNv2) (Menne et al., 2009). Trend is significant at the 99 percent level.

Figure 4. Observed Annual Sea Level in New York City



Observed annual mean sea level (in) at the Battery, New York City, relative to the year 1900. Data are from the Permanent Service for Mean Sea Level (PSMSL). Trend is significant at the 99 percent level.

Extreme Events

Extreme events are intense climate occurrences, such as heat waves, heavy rainfall, and coastal floods, that can have significant impacts on New York City. For temperature, extreme events include both heat waves and cold weather outbreaks (see Figure 5). 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 surges represent short-term, high-water levels superimposed onto mean sea level. In the New York City area, hurricanes and nor'easters produce the largest storm surges.

Observed extreme event trends at local scales are often not statistically significant due to high natural variability and limited record length (Horton et al., 2011). At regional and global scales some extreme event trends are statistically significant; researchers have attributed some changes in extreme events at large spatial scales to human influences on global climate (IPCC, 2012).

Extreme Temperature and Heat Waves

Extreme temperature events can be defined in several ways using daily data from Central Park since 1900.[12] The NPCC uses the following metrics:

- Individual days with maximum temperatures at or above 90°F
- Individual days with maximum temperatures at or above 100°F
- Heat waves, defined as three consecutive days with maximum temperatures at or above 90°F
- Individual days with minimum temperatures at or below 32°F

During the 1971 to 2000 period, New York City averaged 18 days per year at or above 90°F, 0.4[13] days per year at or above 100°F and two heat waves per year. The number of extreme events in a given year is highly variable. For example, in 2010 New York City experienced temperatures of 90°F or higher on 37 different days; in 2009 temperatures of 90°F or higher only occurred 7 times. None of these post-1900 trends for extreme heat events can be distinguished statistically from random variability.

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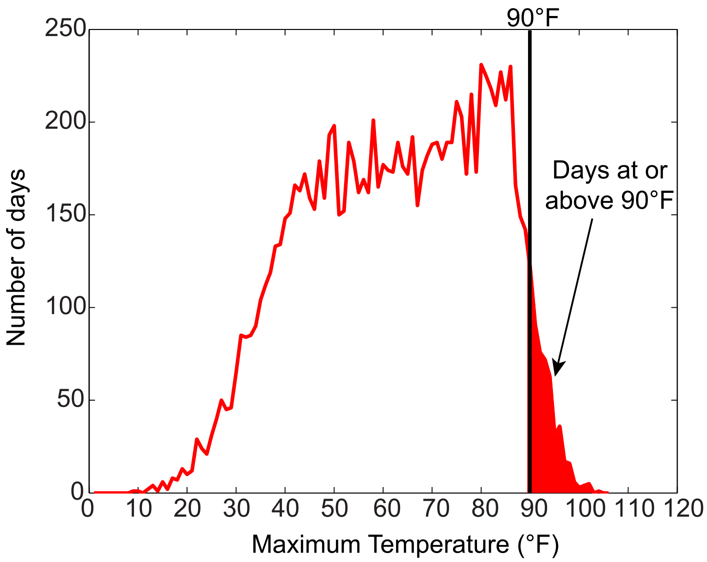
12 Temperatures from the meteorological station in Central Park tend to be lower than some other parts of New York City.

13 For extreme events decimal places are shown for values less than 1, although this does not indicate higher precision/certainty.

Figure 5. Distribution of Maximum Daily Temperature in New York City



When a single climate variable or combinations of variables approach the tails of their distribution, this is referred to as an extreme event. Distribution of observed cumulative daily maximum temperatures in Central Park from 1971 to 2000, with an extreme event threshold of days with maximum temperature at or above 90°F.

Extreme Precipitation

Extreme precipitation events as defined in this report include the number of occurrences per year of precipitation at or 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 4 or more inches of rain. As with extreme temperatures, year-to-year variations in extreme precipitation events are large.

There has been a small but not statistically significant trend towards more extreme precipitation events in the New York City area since 1900. For example, the four years with the most occurrences of 2 or more inches of rain (1983, 1989, 2007, and 2011) have all occurred since 1980. Since extreme precipitation events tend to occur relatively infrequently, long time series of measurements over large areas are needed to identify trends; there is a relatively large 'burden of proof' required to distinguish a significant trend from random variability. Over the larger Northeast U.S. region, intense precipitation events (defined as the heaviest 1 percent of all daily events) have increased by approximately 70 percent over the period from 1958 to 2011 (USGCRP, 2013).

Coastal Storms

The two types of storms with the largest influence on the coastal 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 (Lin et al., 2010). Nor'easters, which tend to occur during the cold season (November to April), from fall to spring, are generally associated with smaller surges and weaker winds than hurricanes. Nevertheless, nor'easters affect New York more frequently (several times a year) than hurricanes (Karvetski et al., 2009) and their negative impacts can be large, in part because their lengthy duration leads to longer periods of high winds and high water. These often coincide with high tides and high waves that can lead to significant flooding and beach erosion (Hondula and Dolan, 2010).

The greatest coastal inundation occurs when the surge caused by a storm's wind and wave effects coincides with high astronomical tides. At the Battery, the mean range of tide[14] is 4.53 feet, but can be as large as 7.70 feet[15] during the most extreme spring tides (NOAA Tides and Currents, 2013). The annual maximum in daily tidal range at the Battery is approximately 7.5 feet (Orton et al., 2012). Because of the complexity of the New York City coastline, there can be a large spatial variation in the extent and timing of flooding associated with any particular storm.

There has been an increase in the overall strength of hurricanes and in the number of strong (Category 4 and 5) hurricanes in the North Atlantic since the early 1980s (USGCRP, 2013). There is some evidence of an overall increase in storm activity near the Northeast U.S. coastline during the second half of the 1950-2010 period (USGCRP, 2013). However, it is not possible to make definitive statements about storms trends at finer spatial scales such as the New York City area.

14 The mean range of tide is defined as the difference in height between mean high water and mean low water (NOAA Tides and Currents, 2013).

15 The maximum range of tide is defined as the difference in height between NOAA's highest astronomical tide (HAT) and lowest astronomical tide (LAT).

Methods of Climate Projections

The NPCC2 generates a range of model-based outcomes for temperature, precipitation, and some sea level rise components from GCM simulations based on two Representative Concentration Pathways (RCPs) (Boxes 3 and 4). The RCPs represent a range of possible future global concentrations of greenhouse gases over the 21st century. Simulation results from 35 GCMs were available to produce temperature and precipitation projections; simulation results from 24 GCMs were available to contribute to sea level rise projections.

Global Climate Models

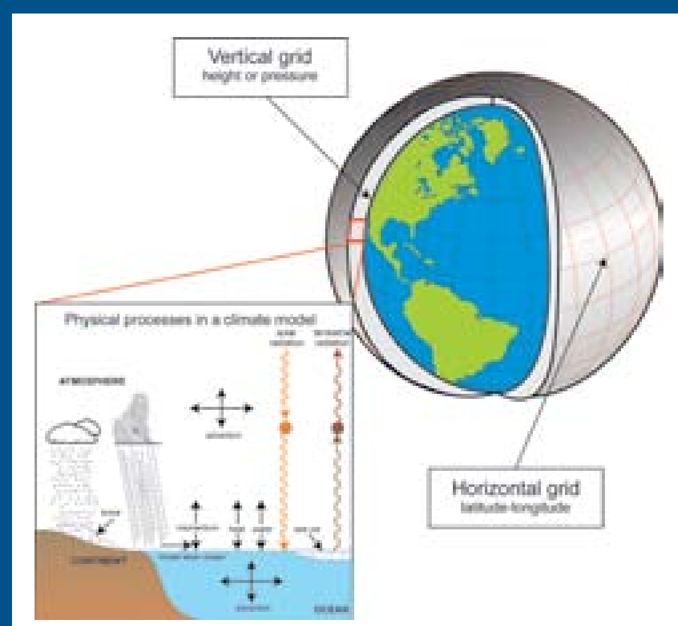
The GCM simulations used by the NPCC2 are from the Coupled Model Intercomparison Project Phase 5 (CMIP5) and were developed for the upcoming IPCC Fifth Assessment Report (AR5) (see Supplementary Information). Relative to the previous climate model simulations from CMIP3 used in NPCC1, the CMIP5 models generally have higher spatial resolution and include more diverse model types (Knutti and Sedlacek, 2012). The CMIP5 models for the first time include some Earth System Models, which include interaction between chemistry, aerosols, vegetation, ice sheets, and biogeochemical cycles (Taylor et al., 2012). For example, warming temperatures in an Earth System Model lead to changes in vegetation type and the carbon cycle, which can then feedback on temperature. There have also been a number of improvements in model-represented physics and numerical algorithms. For example, some CMIP5 models include better treatments of physical features like rainfall and cloud formation that can occur at small 'sub-grid' spatial scales. These improvements have led to better simulation of many climate features (e.g., WCRP 2012; Stroeve et al., 2012).

The large number of available GCMs enables model-based assessment of future climate projections across a range of climate sensitivities.[16] The NPCC2 projections were calculated from the GCM results archived at the WCRP/PCMDI.[17]

Box 3: Global Climate Models (GCMs)

GCMs are mathematical representations of the behavior of the Earth's climate system over time, that can be used to estimate how sensitive the climate system is to changes in atmospheric concentrations of greenhouse gases and aerosols (Figure 6). Each model simulates physical exchanges among the ocean, atmosphere, land, and ice. Over the past several decades, climate models have increased in both complexity and computational power.

Figure 6. Global Climate Model Processes and Gridboxes



16 The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is defined as the equilibrium global average surface warming following a doubling of CO_2 concentration (IPCC, 2007a).

17 We acknowledge the World Climate Research Programme's Working Group on coupled Modeling, which is responsible for CMIP, and we thank the climate modeling groups (listed in the Supplementary Information) for producing and making available their model output. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

Although GCMs are the primary tools used for long-range climate prediction, they do have limitations. For example, they simplify some complex physical processes, in part because the spatial and temporal scales of some climate variables such as thunderstorms are finer than the resolutions of GCMs. GCMs also do not fully include all relevant local climate processes such as urban heat island effects and land/sea breezes. There is also growing evidence that climate models may be underestimating the rate of change in critical systems, including the cryosphere (the frozen parts of the earth). For example, Arctic sea ice retreat (Stroeve et. al., 2012), mass loss from the Greenland and West Antarctic ice sheets (IPCC, 2007), and declining northern high-latitude snow cover are all happening more quickly than projected by GCMs (Brutel-Vuilmet et. al., 2013). For these and other reasons, the climate in New York City may change in ways not captured by the global climate models, which could lead to temperature, precipitation, and sea level rise changes outside the range presented here.

Representative Concentration Pathways

RCPs are a set of trajectories of greenhouse gas emissions, aerosols, and land use changes developed for the climate modeling community as a basis for long-term and near-term climate modeling experiments (Moss et al., 2010) (Figure 7). These data are used by global climate models to project the effects of these climate drivers on future climate (Box 4). The NPCC2 used a set of global climate model simulations driven by two RCPs, known as 4.5 and 8.5, which had the maximum number of GCM simulations available from WCRP/PCMDI. RCP 4.5 and RCP 8.5 were selected to bound the range of anticipated greenhouse gas forcing at the global scale (Box 4).

Climate Model-Based Outcomes

The combination of 35 GCMs and two RCPs produces a 70 (35 x 2)-member matrix of outputs for temperature and precipitation. For each time period, the results constitute a model-based range of outcomes (i.e., a distribution that shows for any given change, the number of models that agree), which can be used in risk-based decision-making and from which percentiles are calculated. This approach gives equal weight to each GCM and to each of the two RCPs selected.[18]

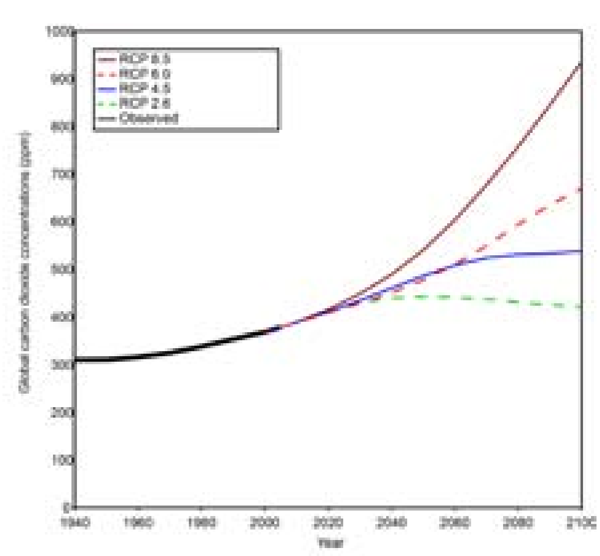
The results for future time periods are compared to the model results for the baseline period (1971 to 2000). Mean temperature change projections are calculated via the delta method. The delta method is a type of bias-correction[19] whereby the difference between each model's future simulation and that model's baseline simulation is used, rather than 'raw' outputs from the models. The delta method is a long-established technique for developing local climate change projections (Gleick 1986; Arnell 1996; Wilby et al., 2004; Horton et al., 2011). Mean precipitation change is similarly based on the ratio of a given model's future precipitation to that model's baseline precipitation (expressed as a percentage change[20]). Sea level rise projections, which use different techniques for individual components, are described below and in the Supplementary Information.

Box 4: RCPs Used for NPCC2 Climate Projections

RCP 4.5 is a scenario in which total radiative forcing, and in turn greenhouse gas concentrations, are stabilized after 2100 due to substantial reductions in emissions before 2100. In terms of land use, the use of cropland and grasslands decreases as a result of reforestation programs, yield increases and changes in diet (van Vuuren et. al., 2011).

RCP 8.5 is characterized by greenhouse gas emissions that continue to increase over time. While emissions growth begins to slow down and eventually level off, greenhouse gases continue to accumulate, resulting in very high concentrations in the atmosphere by 2100. This scenario is highly energy intensive as a result of high population growth and slow technological development. In terms of land use, the use of cropland and grasslands increases, spurred by an increase in global population (van Vuuren et. al., 2011).

Figure 7. Representative Concentration Pathways



Observed carbon dioxide concentrations through 2005, and future carbon dioxide concentrations for four representative concentration pathways. The two representative concentration pathways used for NPCC2 projections are the solid lines.

18 Alternate approaches (e.g., based on evaluation of how models have performed historically) might weight models (and RCPs) differently. The pros and cons of model weighting are discussed in detail in Horton et al., 2011 and Brekke et al., 2008.

19 Bias-correction is standard practice when using climate model outputs, since long term model changes through time are considered more reliable than actual values, especially when assessing an area—like New York City—that is much smaller than the size of a climate model gridbox.

20 The ratio approach is used for precipitation because it minimizes the impact of model biases in average baseline precipitation, which can be large for some models/months.

Local Projections

Local 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 from GCM to GCM because each GCM has a different spatial resolution (i.e., the unit area over which calculations are made). These spatial resolutions of the GCMs range from as fine as ~50 miles by ~40 miles to as coarse as ~195 x ~195 miles, with an average resolution of approximately 125 x 115 miles. Changes in temperature and precipitation through time (for example, three degrees of warming by a given timeframe) are New York City area-specific. Comparison to results from nearby land-based gridboxes reveals similar changes for the neighboring region (see Supplementary Information). 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 because extreme events are more localized phenomena.[21]

Timeslices

Although it is not possible to predict the temperature, precipitation, or sea level for a particular day, month or year, GCMs are valuable tools for projecting the likely range of changes over decadal to multi-decadal time periods. These projections, known as timeslices, are expressed relative to the baseline period, 1971 to 2000 for temperature and precipitation and 2000 to 2004 for sea level rise. The timeslices are centered around a given decade. For example, the 2050s timeslice refers to the period from 2040 to 2069 for temperature and precipitation, and 2050 to 2059 for sea level rise.

Thirty-year timeslices (10-year timeslices for sea level rise) are used to indicate the climate 'normals' for those decades; by averaging over this period, much of the unpredictable year-to-year variability, or 'noise,' is cancelled out, while the long-term influence of increasing greenhouse gases, or 'signal,' remains. The selection of the 10-year rather than 30-year timeslice for sea level is due to the higher signal of sea level rise to year-to-year variability. Thirty-year averaging is the standard used by the meteorologists and climate scientists (WMO, 1989). While thirty-year timeslices are insufficient to remove all natural variability (Deser et al., 2012; Harding et al., 2012), use of longer timeslices is undesirable since the relatively rapid rate of climate change makes assumptions of stationarity[22] within a period increasingly tenuous as it gets longer.

The projections here focus on the predictable signals in mean and extreme temperature and precipitation associated with changes in greenhouse gases, pollutant aerosols and other climate forcing factors; they do not capture local-scale changes in land use or the urban heat island. For the analysis of extreme events, thirty-year timeslices are used since high and unpredictable natural variability is expected to dominate locally at shorter timescales.

Changes in Extreme Events

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 (Grotch and MacCracken, 1991), a hybrid projection technique is used. 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 GCM-RCP combinations are then applied (added in the case of degrees of temperature change and multiplied in the case of percentage change in precipitation) to the observed daily 1971 to 2000 temperature and precipitation data from Central Park to generate 70 time series of daily data. This is a simplified approach to projections of extreme events, since it does not allow for possible changes in variability through time.[23]

21 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).

22 Stationarity is defined here as having common statistical properties over time (e.g., mean, variance, and other statistics are all constant).

23 In general the delta method is more reliable for temperature than precipitation, since precipitation could experience a large change in variability in the future. Furthermore, in regions with distinct wet and dry seasons, the delta method can introduce large errors in models that do not capture correctly the precipitation seasonality. This is expected to be less of an issue in New York City, given the absence of strong precipitation seasonality.

Sea Level Rise Methods

The NPCC2 sea level rise projections for New York City have been developed using a component-by-component analysis (Table 2) (see Supplementary Information). Components include changes in local ocean height; thermal expansion; vertical land movements; loss of ice from glaciers, ice caps, and land-based ice sheets; gravitational, isostatic, and rotational effects resulting from ice mass loss; and land water storage. Others (e.g., Perrette et al., 2013; Slangen et al., 2012) have taken a similar regionalized approach to sea level rise projections, with less specificity to the New York City region.

For each of the components of sea level change, the NPCC2 estimated the 10th, 25th, 75th, and 90th percentiles of the distribution.[24] The sum of all components at each percentile is assumed to give the aggregate sea level rise projection. This method does not take into account potential correlation between components. For example, Greenland ice sheet mass loss may affect the sea surface height via associated freshening (infusion of non-saltwater) of the North Atlantic and associated changes in the Gulf Stream. Additionally, mass losses from different ice sheets may be linked via global climate. At present, these factors are currently too uncertain to incorporate into a quantitative analysis.

Table 2. Sea Level Rise Projection Components

Sea Level Rise Component	Global or Local	Description	Method	Sources
Global thermal expansion	Global	Ocean water expands as it warms	Single globally-averaged term from CMIP5 data	http://cmip-pcmdi.llnl.gov/cmip5/
Local changes in ocean height	Local	Local to regional changes in ocean water density and circulation	Local values from CMIP5 data	http://cmip-pcmdi.llnl.gov/cmip5/
Loss of ice from Greenland and Antarctic ice sheets	Global	Loss of land based ice sheets adds mass to the ocean	Expert elicitation, with additional probabilistic analysis and comparison with other studies	Bamber and Aspinall, 2013
Loss of ice from glaciers and ice caps	Global	Loss of ice from glaciers and ice caps adds mass to the ocean	Range from two recent analyses and comparison with other studies	Radic, 2013; Marzeion, 2012; Shepherd et. al., 2012
Gravitational, rotational, and isostatic 'fingerprints'[+] of ice loss	Local	With loss of land-based ice (see the above two terms), regional sea level impacts differ due to gravitational, rotational and 'fast' (elastic) isostatic responses	Coefficients from literature linking each ice sheet and the glaciers/ice caps to a NYC fingerprint are applied after ice loss from each source has been determined	Mitrovica et al., 2009; Perrette et al., 2013; Gomez et al., 2010
Vertical land movements/ glacioisostatic adjustments (GIA)	Local	Local land height is decreasing in response to the last deglaciation (slow isostatic response)	Latest version of Peltier's Glacial Isostatic Adjustment (GIA) model	Peltier, 2012
Land water storage	Global	Water stored in reservoirs and dams and extracted from groundwater changes the ocean's mass and sea level	Global estimates derived from recent literature	Konikow, 2011; Wada et al., 2012; Church et al., 2011

+ Land-based ice compresses the lithosphere, exerts a gravitational pull on the surrounding ocean and alters the Earth's rotation. The combination of these terms produces a spatial varying sea level change when land-based ice mass changes. This spatial pattern is often referred to as a 'fingerprint.'

24 No uncertainty range was estimated for subsidence, since it is well-known for the Battery (Peltier, 2012), or for the individual fingerprints. The first two terms here were combined in each model (for internal consistency) before estimating the percentiles of the distribution.

Climate Projections

This section presents climate projections for the 2020s and 2050s for temperature, precipitation, sea level rise, and extreme events. Quantitative projections are given for most variables, although for some extreme events, only qualitative statements are possible. This report focuses on projections for temperature, precipitation, and sea level rise through the 2050s. In future work, the NPCC2 will extend the projections to the end of the century and will include a larger set of climate variables.

Mean Annual Changes[25]

Higher temperatures and sea level rise are extremely likely (Table 1) for the region. For temperature and sea level rise, all simulations project continued increases through the 2050s. Although most GCM simulations indicate small increases in precipitation, some do not, and natural precipitation variability is large; thus, precipitation projections are less certain than temperature projections.

Temperature

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 2.0°F to 3.0°F by the 2020s for the middle range, and 3.0°F for the high-estimate. By the 2050s, the middle range of projections is 4.0°F to 5.5°F and the high-estimate is 6.5°F (Table 3).

Table 3 indicates that by the 2050s, New York City's mean temperatures throughout a 'typical' year may bear similarities to a city like Norfolk, Virginia. Temperature increases are projected to be comparable for all months of the year.

The two RCPs project similar temperature changes up to the 2020s; after the 2020s, temperature changes produced by RCP 8.5 are higher than those produced by RCP 4.5. It takes several decades for the different RCPs to produce large differences in climate due to the inertia of the climate system.

Precipitation

Total annual precipitation in New York City and the surrounding region will more likely than not increase. Mean annual precipitation increases projected by the GCMS are 0 to 10 percent by the 2020s for the middle range, and 10 percent for the high-estimate. By the 2050s, the middle range of projections is 5 to 10 percent and the high-estimate is 15 percent (Table 3).

Table 3 indicates that the majority of global climate models (45 of the 70 outcomes) project small increases of 0 to 10 percent in annual precipitation, although a few project increases of as much as 20 percent by the 2050s, and several others project small decreases of percent. In general, the projected changes in precipitation in the global climate models associated with increasing greenhouse gases are small relative to year-to-year variability. Precipitation increases are expected to be largest during the winter months; projections of precipitation changes in summer are inconclusive, with approximately half the models projecting precipitation increases, and half projecting decreases.

Sea Level Rise

By the 2020s, sea level at the Battery is projected to rise by between 4 and 8 inches for the middle range and by 11 inches for the high estimate (Table 3). By the 2050s, the middle range expands to 11 to 24 inches, and 31 inches for the high estimate. As decades progress, the expansion of the range is driven by uncertainty in land-based ice mass change, ocean thermal expansion, and regional ocean dynamics.

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25 Projections for temperature and precipitation are the middle range (25th to 75th) percentile of global climate model (GCM) projections; for sea level rise they are the middle range (25th to 75th) percentile of the sum of multiple sea level components, projected individually using GCMs and literature sources. For the GCM outputs, 25th percentile = value at which 75 percent of the global climate model results are higher; 75th percentile = value at which 25 percent of the global climate model results are higher; 90h percentile = value at which 10 percent of the global climate model results are higher. In NPCC1, central range was defined as 17 to 83 percentile.

Table 3. Baseline Climate and Mean Annual Changes

Air temperature Baseline (1971 - 2000) 54°F	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020s	+ 1.5°F	+ 2.0°F to + 3.0°F	+ 3.0°F
2050s	+ 3.0°F	+ 4.0°F to + 5.5°F	+ 6.5°F
Precipitation Baseline (1971 - 2000) 50.1 inches	**Low-estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High-estimate (90th percentile)**
2020s	0 percent	0 to + 10 percent	+ 10 percent
2050s	0 percent	+ 5 to + 10 percent	+ 15 percent
Sea level rise Baseline (2000-2004) 0 inches	**Low-estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High-estimate (90th percentile)**
2020s	2 inches	4 to 8 inches	11 inches
2050s	7 inches	11 to 24 inches	31 inches

Based on 35 GCMs (24 for sea level rise) and two Representative Concentration Pathways. Baseline data are from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) United States Historical Climatology Network (USHCN), Version 2 (Menne et al., 2009). Shown are the 10th percentile, 25th percentile, 75th percentile, and 90th percentile 30-year mean values from model-based outcomes.Temperature values are rounded to the nearest 0.5°F, percipitation values are rounded to the nearest 5 percent, and sea level rise values rounded to the nearest inch.

Table 4. Quantitative Changes in Extreme Events for the 2020s

Extreme Event	Baseline (1971 - 2000)	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Number of days/year with maximum temperature at or above 90°F	18	24	26 to 31	33
Number of days/year with maximum temperature at or above 100°F	0.4	0.7	1 to 2	2
Number of heat waves/year	2	3	3 to 4	4
Average heat wave duration (in days)	4	5	5 to 5	5
Number of days/year with minimum temperature at or below 32°F	72	50	52 to 58	60
Number of days/year with rainfall at or above 1 inch	13	13	14 to 15	16
Number of days/year with rainfall at or above 2 inches	3	3	3 to 4	5
Number of days/year with rainfall at or above 4 inches	0.3	0.2	0.3 to 0.4	0.5

Based on 35 GCMs and two Representative Concentration Pathways. Data are from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) United States Historical Climatology Network (USHCN), Version 2 (Menne et al., 2009). The 10th percentile, 25th percentile, 75th percentile, and 90th percentile values from model-based outcomes across the GCMs and Representative Concentration Pathways are shown. Decimal places are shown for values less than 1, although this does not indicate higher precision/certainty. Heat waves are defined as three more consecutive days with maximum temperatures at or above 90 °F.

Table 5. Quantitative Changes in Extreme Events for the 2050s

Extreme Event	Baseline (1971 - 2000)	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Number of days/year with maximum temperature at or above 90°F	18	32	39 to 52	57
Number of days/year with maximum temperature at or above 100°F	0.4	2	3 to 5	7
Number of heat waves/year	2	4	5 to 7	7
Average duration (in days)	4	5	5 to 6	6
Number of days/year with minimum temperature at or below 32°F	72	37	42 to 48	52
Number of days/year with rainfall at or above 1 inch	13	13	14 to 16	17
Number of days/year with rainfall at or above 2 inches	3	3	4 to 4	5
Number of days/year with rainfall at or above 4 inches	0.3	0.3	0.3 to 0.4	0.5

Based on 35 GCMs and two Representative Concentration Pathways. Data are from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) United States Historical Climatology Network (USHCN), Version 2 (Menne et al., 2009). The 10th percentile, 25th percentile, 75th percentile, and 90th percentile values from model-based outcomes across the GCMs and Representative Concentration Pathways are shown. Decimal places are shown for values less than 1, although this does not indicate higher precision/certainty. Heat waves are defined as three or more consecutive days with maximum temperatures at or above 90°F .

Disclaimer: Like all projections, the NPCC climate projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system, and limited understanding of some physical processes. The NPCC characterizes levels of uncertainty using state-of-the-art climate models, multiple scenarios of future greenhouse gas concentrations, and recent peer-reviewed literature. Even so, the projections are not true probabilities, and the potential for error should be acknowledged.

Extreme Events

Tables 4 and 5 indicate how the frequency of heat waves, cold events, and intense precipitation in the area is projected to change in the 2020s and 2050s based on the GCM x RCP combinations. The average number of extreme events per year for the baseline period is shown, along with the low estimate (10th percentile), middle 50 percent range (from the 25th to the 75th percentiles), and high estimate (90th percentile) of model-based projections.

Hot and Cold Weather Events

The total number of hot days, defined as days with a maximum temperature at or above 90 and 100°F, is expected to increase as the 21st century progresses. By the 2020s, the frequency of days at or above 90°F may increase by more than 50 percent relative to the 1971 to 2000 base period; by the 2050s, the frequency may more than double. While 100 degree days are expected to remain relatively rare, the percentage increase in their frequency of occurrence may exceed the percent change in days at or above 90°F.

The frequency and duration of heat waves, defined as three or more consecutive days with maximum temperatures at or above 90°F, are very likely to increase. In contrast, extreme cold events, defined as the number of days per year with minimum temperature at or below 32°F, are expected to become more infrequent, with a 25 percent decrease projected by the 2020s and more than a 33 percent decrease by the 2050s. The extreme event temperature projections shown in Table 5 are based on observed data for Central Park. Some parts of New York City currently experience more extreme temperature days than Central Park, while others experience fewer. This pattern is expected to continue in the future as well.

Extreme Precipitation

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 in this report as at or more than 1, 2, and 4 inches) at daily timescales. 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.

Box 5: Uncertainties of Quantitative Projections

There are several reasons why future climate changes may not fall within the quantitative range projected by the NPCC. Actual greenhouse gas emissions may not fall within the envelope encompassed by the two Representative Concentration Pathways (RCPs) used here. 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 of the range of the GCMs used here. Other possible types of climate changes outside model-based estimates, that could have large impacts on the region, cannot be ruled out. These could include changes in extreme events in the region caused by reductions in Arctic sea ice that exceed climate model projections (Liu et al., 2012).

Coastal Floods and Storms

Sea level rise increases the frequency, extent, and height of coastal flooding.[26] The changes in coastal flood heights shown in Table 6 for the Battery are solely due to the projected sea level rise. 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 2050s, the middle range sea level rise projections alone suggests that coastal flood levels which currently occur on average once per decade may occur once every three to six years. The NPCC estimates that due to sea level rise alone, the today's 1-in-100 year flood may occur approximately 5 times more often by the 2050s with the high-estimate for sea level rise.

These projected flood heights apply only to the Battery in lower Manhattan. Some parts of New York City, such as the northernmost points where the Bronx and the Hudson River meet, currently experience lower flood heights than the Battery and many other exposed coastal locations. This relationship is expected to continue in the future.

26 This analysis of coastal flooding is based solely on present-day storms and sea level rise. It does not consider changes in other factors that could influence coastal flooding, including future changes in 1) storm characteristics, 2) geomorphology, erosion, and sediment transport, 3) subsurface water flows and subterranean infrastructure, 4) aboveground infrastructure (e.g., sea walls), or 5) coastal wetlands.

Table 6. Coastal Flood Heights and Recurrence for the Battery

a. 2020s Coastal Flood Heights

	Baseline	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Stillwater Flood heights associated with 10-year flood	7.0 feet	7.2 feet	7.3 to 7.7 feet	7.9 feet
Flood heights associated with 100-year flood (stillwater + wave heights)	15.0 feet	15.2 feet	15.3 to 15.7 feet	15.8 feet
Stillwater Flood heights associated with 100-year flood	10.8 feet	11.0 feet	11.1 to 11.5 feet	11.7 feet
Stillwater Flood heights associated with 500-year flood	14.4 feet	14.6 feet	14.7 to 15.1 feet	15.3 feet

The percentiles in the top row refer to the values for projected sea level rise. Flood heights for the 2020s are derived by adding the sea level rise projections for the corresponding percentiles to the baseline values. Baseline flood heights associated with the 10-year, 100-year, and 500-year floods are based on the stillwater elevation levels (SWELs). For 100-year flood, height is also given for stillwater plus wave heights. Flood heights are referenced to the NAVD88 datum.

b. 2020s Flood Recurrence

	Baseline	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Annual chance of today's 10-year flood	10 percent	10.9 percent	11.8 to 15.2 percent	16.9 percent
Annual chance of today's 100-year flood	1 percent	1.1 percent	1.2 to 1.5 percent	1.7 percent
Annual chance of today's 500-year flood	0.2 percent	0.2 percent	0.2 to 0.3 percent	0.3 percent

The percentiles in the top row refer to the values for projected sea level rise.

c. 2050s Coastal Flood Heights

	Baseline	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Stillwater Flood heights associated with 10-year flood	7.0 feet	7.6 feet	7.9 to 9.0 feet	9.6 feet
Flood heights associated with 100-year flood (stillwater + wave heights)	15.0 feet	15.6 feet	15.9 to 17 feet	17.6 feet
Stillwater Flood heights associated with 100-year flood	10.8 feet	11.4 feet	11.7 to 12.8 feet	13.4 feet
Stillwater Flood heights associated with 500-year flood	14.4 feet	15.0 feet	15.3 to 16.4 feet	17.0 feet

The percentiles in the top row refer to the values for projected sea level rise. Flood heights for the 2050s are derived by adding the sea level rise projections for the corresponding percentiles to the baseline values. Baseline flood heights associated with the 10-year, 100-year, and 500-year floods are based on the stillwater elevation levels (SWELs). For 100-year flood, height is also given for stillwater plus wave heights. Flood heights are referenced to the NAVD88 datum.

d. 2050s Flood Recurrence

	Baseline	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Annual chance of today's 10-year flood	10 percent	14.3 percent	17.2 to 31.3 percent	46.5 percent
Annual chance of today's 100-year flood	1.0 percent	1.4 percent	1.7 to 3.2 percent	5.0 percent
Annual chance of today's 500-year flood	0.2 percent	0.3 percent	0.3 to 0.4 percent	0.7 percent

The percentiles in the top row refer to the values for projected sea level rise.

Qualitative Projections of Extreme Events

For some of the extreme event climate factors, future changes are too uncertain at local scales to allow quantitative projections. For example, the relationships between short duration extreme precipitation events and different types of storms, and between droughts and temperature/precipitation, are complex. Qualitative information for some of these factors is provided in Table 7.

By mid-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 and thereby induce heat stress.

By the 2050s, it is more likely than not that late-summer short-duration droughts will increase in New York City (Rosenzweig et. al., 2011). It is unknown how multi-year drought risk in the New York City area may change in the future.

As the century progresses snowfall is likely to become less frequent, with the snow season decreasing in length (IPCC, 2007). Possible changes in the intensity of snowfall per storm are highly uncertain. It is unknown how the frequency and intensity of ice storms and freezing rain may change.

Table 7. Qualitative Changes in Extreme Events

Projected direction of change by the 2050s, as well as likelihood associated with the qualitative projection. For these variables, quantitative projections are not possible because of insufficient information.

	Spatial Scale of Projection	Direction of Change by the 2050s	Likelihood	Sources
Heat Index	New York City area	Increase	Very likely	NPCC, 2010; IPCC, 2012; Fischer and Knutti, 2012.
Short duration drought	New York City area	Increase	More likely than not	Rosenzweig et. al., 2011
Multi-year drought	New York City area	Unknown	--	Dai, 2012
Ice storms/freezing rain	New York City area	Unknown	--	NPCC 2010; ClimAID 2011
Seasonal snowfall	New York City area	Decrease	Likely	IPCC, 2007, 2012; Liu et al., 2012
Downpours	New York City area	Increase	Very likely	IPCC 2012; USGCRP, 2013
Lightning	New York City area	Unknown	--	USGCRP, 2013; Price and Rind, 1994
Tropical cyclones				
Total number	North Atlantic Basin	Unknown	--	--
# of Intense hurricanes	North Atlantic Basin	Increase	More likely than not	USGCRP, 2013; IPCC, 2012
Extreme hurricane winds	North Atlantic Basin	Increase	More likely than not	USGCRP, 2013; IPCC, 2012
Intense hurricane precipitation	North Atlantic Basin	Increase	More likely than not	USGCRP, 2013; IPCC, 2012
Nor'easters	New York City area	Unknown	--	IPCC 2012; Colle et al. 2013

Probability of occurrence and likelihood defined as (IPCC, 2007): Virtually certain; >99% probability of occurrence, Extremely likely; >95% probability of occurrence, Very likely; >90% probability of occurrence, Likely; >66% probability of occurrence, More likely than not; >50% probability of occurrence, About as likely as not; 33 to 66% probability of occurrence.

Box 6: Extreme Event Definitions

Heat Index

The Heat Index is a measure of how hot it really feels when relative humidity is factored in with the actual air temperature (National Weather Service).

Short Duration Drought

Short-duration drought is defined as droughts lasting anywhere from a few weeks to a few months. Common to all types of drought is the fact that they originate from a deficiency of precipitation resulting from an unusual weather pattern (NCDC).

Multi-Year Drought

Multi-year drought is defined as droughts lasting anywhere from several months to several years. Common to all types of drought is the fact that they originate from a deficiency of precipitation resulting from an unusual weather pattern (NCDC).

Ice Storms/Freezing Rain

Precipitation events with freezing rain.

Seasonal Snowfall

Seasonal total of frozen precipitation that typically comes from winter season nor'easters and other cold season mid-latitude weather systems.

Downpours

Intense rainfall over a short duration. Includes convective precipitation events (thunderstorms), weather frontal systems, and storms (nor'easters and tropical cyclones).

Lightning

A visible electrical discharge produced by a thunderstorm (National Weather Service).

Tropical Cyclones and Hurricanes

Hurricanes are an intense form of tropical cyclone, with wind speeds in excess of 74 mph. Hurricanes are categorized based on their wind speeds, ranging from Category 1 (74 - 95 mph); 2 (96 -110 mph); 3 (111-130 mph); 4 (131-155 mph); to 5 (greater than 155 mph) on the Saffir-Simpson scale (National Hurricane Center). Hurricanes of Category 3 or higher are 'Intense Hurricanes.' While hurricane landfalls are rare in the New York City area, weaker tropical storms (39-73 mph winds) and tropical depressions (winds less than 39 mph) impact the New York City region more frequently.

Nor'easters

Cool season extra tropical cyclones, most common between October and April.

Downpours, defined as intense precipitation at sub-daily, but often sub-hourly, timescales are very likely to increase in frequency and intensity, for the reasons outlined in the section above on extreme precipitation. Changes in lightning are currently too uncertain to support even qualitative statements.[27]

It is unknown how the total number of tropical cyclones will change in the North Atlantic Basin. However, it is more likely than not that the number of the most intense hurricanes will increase in the North Atlantic, along with the extreme winds associated with these strong storms (IPCC, 2012). As the ocean and atmosphere continue to warm, intense precipitation from hurricanes is more likely than not to increase as well (IPCC, 2012). It is unknown how nor'easters in the New York City area may change in the future.

27 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).

Future Coastal Flood Risk Maps

Maps that show future coastal flood risk (including areas affected by coastal storm surges combined with sea level rise), related vulnerability, and potential impacts are important ways of communicating information to a wide variety of stakeholders and decision-makers. The NPCC1 developed maps in response to stakeholder needs that illustrate the alteration of the spatial extent of the current 100-year flood with future sea level rise. The NPCC2 has revised these maps to reflect updated sea level rise data and to include projections for the 500-year flood extent.

Maps, Inputs and Procedures

To estimate potential impacts of sea level rise on the spatial extent of the current 100- and 500-year flood zones, the NPCC2 developed a series of maps incorporating NPCC2 projections for sea level rise with FEMA's 2013 Preliminary Work Maps. Because of limitations in the accuracy of flood projections, these maps should not be used to judge site-specific risks, insurance rates, or property values; however, they do illustrate the trends of future flooding for these events.

Figures 8 and 9 illustrate the potential impact of sea level rise on the areas of New York City that could be subject to the 100- and/or 500-year flood in the 2020s and 2050s due to high estimate projections for sea level rise. The areas shaded in yellow represent the potential flood extent of the 100- and 500-year flood in the 2020s with 11 inches of sea level rise, and the areas shaded in red represent the potential flood extent of the 100- and 500-year flood in the 2050s with 31 inches of sea level rise. Flood extents were determined by adding the NPCC2 high estimate (90th percentile) projections for sea level rise to FEMA's base flood elevations and extending the sum value landward until it reached an equivalent topographic elevation (for a detailed discussion of the mapping methodology, including uncertainty and error see the Supplementary Information section titled Mapping Methodology and Data Uncertainty).

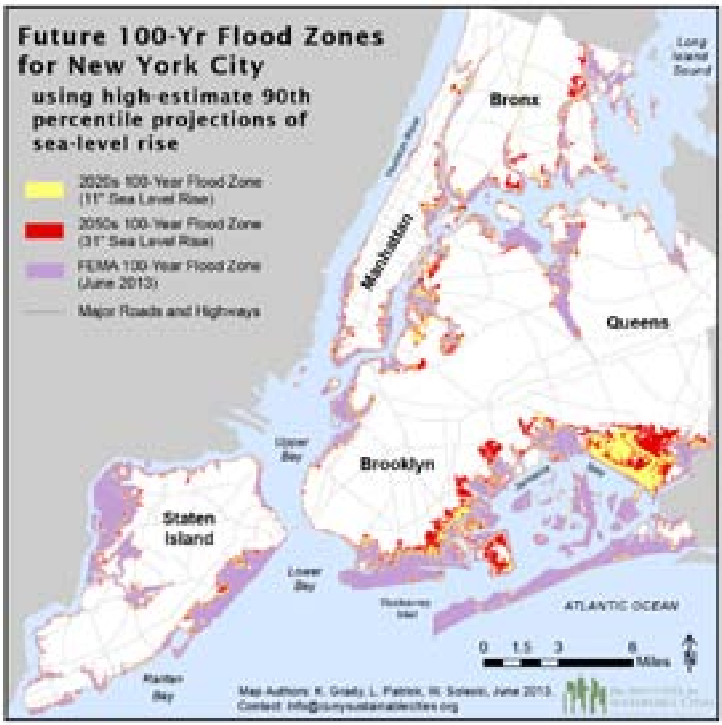
These maps are purely illustrative and contain numerous sources of uncertainty, however, specifically they define three distinct areas of interest: 1) areas currently within the 100- and 500-year flood zones, 2) areas that are not currently within the 100- and 500-year flood zones, but will potentially be in the future, and 3) areas that are not currently in the 100- and 500-year flood zones and are unlikely to be in a flood zone during the timeslices used in this report.

Box 7: Data Sets Used for Mapping

1. FEMA Advisory Base Flood Elevation Maps for New York City
   - Flood extent and advisory base flood elevation information for the 500-year flood.
   - Release Date: February 2013
2. FEMA Preliminary Work Maps for New York City
   - Flood extent and base flood elevation information for the 100-year flood.
   - Release date: June 2013
3. Digital Elevation Model (DEM), 2010 for New York City
   - Surface developed from LiDAR data collected in the spring 2010 over New York City
   - LiDAR points were interpolated to create a 1 foot resolution surface with cell values corresponding to ground elevation values in feet above mean sea level.
   - Horizontal Positional Accuracy: Root mean square error (RMSE) 33.08 cm
   - Horizontal Datum: North American 1983
   - Vertical Positional Accuracy: Root mean square error (RMSE) 9.5cm
   - Vertical Datum: NAVD88
4. NYC Borough Boundaries (NYC Department of City Planning). September 2008

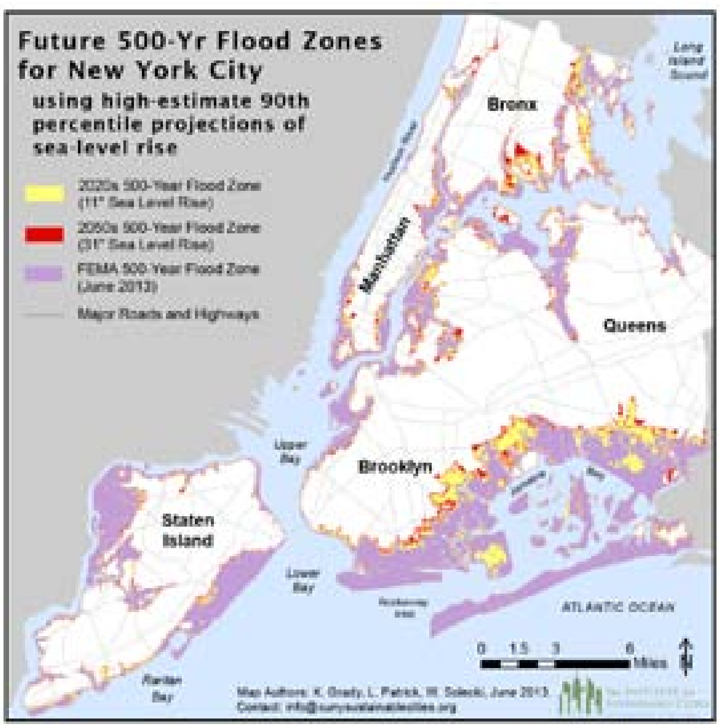
Coastal flooding and storm surge are connected hazards that occur during extreme weather events such as tropical storms, hurricanes, and nor'easters. The high winds and low barometric pressure of these intense storm systems act to push ocean water inland, resulting in coastal flooding. The water that is pushed ashore, referred to as the storm surge, can often be several meters above mean water level. New York City is especially vulnerable to the storm surge of hurricanes and nor'easters because of its dense population and unique position at the apex of the New York Bight - a right angle configuration of the New York and New Jersey coastlines that can act to funnel and amplify storm surge in the Lower New York Harbor.

Figure 8. Future 100-Year Flood Zones for New York City



The potential areas that could be impacted by the 100-year flood in the 2020s and 2050s based on projections of the high-estimate 90th percentile sea level rise scenario (see Table 3).

Figure 9. Future 500-Year Flood Zones for New York City



The potential areas that could be impacted by the 500-year flood in the 2020s and 2050s based on projections of the high-estimate 90th percentile sea level rise scenario (see Table 3).

Disclaimer: Like all environment-related projections and associated map products, the NPCC Future Flood Maps have uncertainty embedded within them. In this case, uncertainty is derived from a set of data and modeling constraints. Application of state-of-the-art climate modeling, best mapping practices and techniques, and scientific peer review was used to minimize the level of uncertainty. Even so, the map product should be not recognized as the actual spatial extent of future flooding and the potential for error acknowledged.

Primary Design Standard for New York City: The One Percent Annual Chance Flood

The primary design standard for coastal flooding and storm surge in the United States is the Federal Emergency Management Agency (FEMA) defined 100-year flood, also known as the 1 percent annual chance flood. The 100-year flood is defined as a flood that has a 1 percent chance of being equaled or exceeded in any given year. For nearly 40 years, the 100-year flood zone has been considered a high risk flooding area and subject to special building codes, and insurance and environmental regulations. The 500-year flood is the flood that has a 0.2 percent chance of being equaled or exceeded in any given year. Flood insurance is available though not required for structures in the 500-year floodplain. The 0.2 percent annual-chance flood maps and associated flood elevations are of special interest as a guide for essential and critical facilities such as utilities, transportation, and other infrastructure that supply services to the public, and on which business continuity depends.

FEMA's Flood Insurance Rate Maps (FIRMs) are developed from various sources of information including historical flood, meteorological, and hydrological data. The 100-year flood zone, also known as the Special Flood Hazard Area (SFHA), is identified on these maps, as well as site-specific base flood elevations (BFEs), also known as the 100-year flood elevation. These maps are used by federal agencies to determine if flood insurance is required when banks provide federally insured loans or grants for new construction and/or substantially improved buildings.

In New York State, compliance with the National Flood Insurance Program is mandatory for all jurisdictions. Development activity within the FEMA 100-year flood zone is subject to building code standards due to the high flood risk. New York City building codes also require adding "freeboard" (additional vertical safety margins) to the BFE. The NPCC2 added sea level rise projections to FEMA's 100- and 500-year base flood elevations to estimate the scope and direction of the impact of sea level rise on the most recent available FEMA map and data products (Preliminary Work Maps issued in June 2013). Base flood elevations refer to the elevations, relative to a given datum (FEMA's 2013 maps use the NAVD88), to which floodwaters are anticipated to rise during the 100-year flood event including waves along the coasts. They are the sum of the stillwater elevation (SWEL) and wave elevation above the SWEL. The NPCC2 maps illustrate increasing areas of flooding due to sea level rise; however the maps include several types of potential errors in the specification of flood boundary due to data and information limitations, including scope and error inherent in storm and storm surge modeling, GIS methodology, and accuracy of land elevation data. While these new maps superimpose sea level rise onto FEMA's flood maps, they do not account for other changes in climate, such as possible changes in storm intensity and frequency that could affect storm surge occurrences and heights.

The resulting maps offer a perspective on city-wide risk, how that risk changes through time, and how it varies under different scenarios of sea level rise. They serve to identify areas of future risk that should be subject to more intensive study and to highlight areas presently exposed to the 100-year flood that are particularly vulnerable to rising sea-levels.

NPCC2 2013 Future Flood Map Products

Two specific map products were produced as part of this analysis.

1. GIS shapefiles of the future 100-year flood extent for the 2020s and 2050s based on FEMA's Preliminary Work Maps (PWMs) for New York City and the NPCC2 high-estimate sea level rise projections of 11 inches for the 2020s and 31 inches for the 2050s.

2. GIS shapefiles of the future 500-year flood extent for the 2020s and 2050s based on FEMA's Advisory Base Flood Elevation Maps (ABFEs), and the NPCC2 high-estimate sea level rise projections of 11 inches for the 2020s, and 31 inches for the 2050s.

Future Presentation

The New York City Panel on Climate Change has taken a leadership role in developing maps which illustrate how the spatial extent of the current 1 percent annual chance flood potential can be altered with future sea level rise. In doing so, the NPCC has sought to increase the transparency of the mapping process in order to accurately communicate the strengths and limitations of the information presented on the maps. The NPCC seeks to accomplish increased transparency through clear representation of a) the character and structure of the data presented by the maps, b) the mapping process itself, and c) the potential interpretation of the map products.

In regard to the scientific data presented by maps, the NPCC has attempted to include all relevant statements regarding data uncertainty because these uncertainties will be transmitted onto the maps. Such sources of uncertainty include, for example, uncertainty associated with sea level rise projections, tropical cyclone, and storm surge modeling, the resolution of digital elevation models and those introduced by GIS tools and methods. These data and procedural uncertainties limit the precision of the map product, which in turn limits the user's ability to determine whether any specific parcel or element of infrastructure will be flooded during future storm surge-related flood events and at what height.

Transparency

The NPCC's approach for increasing transparency of the mapping process is designed to improve users' understanding of what the maps do and do not convey with respect to future coastal flood risks. This transparency also will assist users in determining what additional precautionary measures they may want to consider in addressing their specific needs for safety, business continuity, and resilience.

Additional statements regarding the methodology and data uncertainty are presented in the Supplementary Information.

Conclusions and Recommendations

While mitigation of greenhouse gas emissions is essential to reducing the magnitude of long-term changes in climate, the NPCC2 Climate Risk Information 2013 will inform community rebuilding plans, and help to increase current and future resiliency of communities, city-wide systems, and infrastructure to a range of climate risks.

Conclusions

The mean annual temperature in New York City increased 4.4°F from 1900 to 2011, while mean annual precipitation has increased 7.7 inches (a change of 1.4 percent per decade). Year-to-year precipitation variability was greater from 1956 to 2011 than from 1900 to 1955. The rise in temperature and precipitation has not been steady but includes decadal fluctuations.

Sea level in New York City (at the Battery) has risen 1.1 feet since 1900. It is not possible to attribute any one extreme event such as Hurricane Sandy to climate change. However, sea level rise occurring in the New York City area increased the extent and the magnitude of coastal flooding during the storm.

The NPCC2 projects a rise in mean annual temperatures of 2.0°F to 3.0°F (middle range) and 3.0°F (high-estimate) by the 2020s relative to the 1971 to 2000 base period. By the 2050s the mean annual temperature is projected to increase by 4.0°F to 5.5°F (middle range) and 6.5°F (high-estimate) relative to the 1971 to 2000 base period. Mean annual precipitation is projected to increase by 0 percent to 10 percent (middle range) and 10 percent (high-estimate) by the 2020s relative to the 1971 to 2000 base period. By the 2050s, mean annual precipitation is projected to increase by 5 to 10 percent (middle range) and 15 percent (high-estimate) relative to the 1971 to 2000 base period.

By the 2020s, sea level is projected to rise 4 to 8 inches (middle range) and 11 inches (high-estimate) relative to the 2000 to 2004 base period. By the 2050s, sea level is projected to rise 11 to 24 inches (middle range) and 31 inches (high-estimate) relative to the 2000 to 2004 base period. The future flood maps illustrate how this sea level rise will expose additional areas of New York City to flooding during extreme storm events.

The number of days at or above 90°F per year (18 days per year for 1971 to 2000) is expected to increase to approximately 26 to 31 days per year (middle range) by the 2020s and to increase to approximately 39 to 52 days per year (middle range) by the 2050s. The number of heat waves (three consecutive days at or above 90°F) per year, is very likely to shift from 2 heat waves per year in the current base climate (1971 to 2000) to 3 to 4 heat waves per year (middle range) by the 2020s, and to 5 to 7 heat waves per year (middle range) per year by the 2050s.

Heavy downpours are very likely to increase in intensity, extent, and height. Coastal flooding is very likely to increase in frequency, extent, and height as a result of increased sea levels.

Recommendations

The NPCC2 makes the following recommendations for further research and outreach regarding climate change in the New York City area.

- Develop improved methods for estimating probabilities of changes in an expanded range of climate hazards – including humidity, drought, ice storms, snowfall, lightning, and winds – and combined climate hazards such as back-to-back heat waves and coastal floods.
- Improve computational and statistical modeling of the climate system to better understand changes in future coastal flooding (including height and frequency) based on:

  (i) Multiple factors contributing to sea level rise

  (ii) Changes in tropical cyclone and nor'easter storm characteristics (e.g., frequency, severity, duration, and track)

  (iii) Combined effects of sea level rise and changes in storm characteristics
- Improve representation of future coastal flooding through enhanced dynamic flood inundation (storm surge) modeling and flood hazard mapping techniques.
- Improve our understanding and mapping of community and neighborhood vulnerability to the range of current and future climate stresses, such as river flooding, heat waves and the urban heat island effect.
- Develop a system of indicators and monitoring co-generated by stakeholders and scientists to track data related to climate risks, hazards, and impacts, and to evaluate adaptations to better inform climate change-related decision-making in New York City.
- Improve ways to communicate data and information on how changes in climate will affect the frequency of climate hazards and their impacts in the future, and the uncertainties surrounding these estimates, to provide greater transparency to potential users at city, state, and national levels.

References

Arnell, N. W. (1996) Global Warming, River Flows and Water Resources. Wiley, Chichester, West Sussex, UK.

Bamber, J. L., and W. P. Aspinall, 2013: An expert judgement assessment of future sea level rise from the ice sheets. Nature Clim. Change, 3, 424-427.

Bender, M. A., T. R. Knutson, R. E. Tuleya, J. J. Sirutis, G. A. Vecchi, S. T. Garner, and I. M. Held, 2010: Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes. Science, 327, 454-458.

Blake, E.S., T.B. Kimberlain, R.J. Berg, J.P. Cangialosi, and J.L. Beven II, 2013: Tropical Cyclone Report: Hurricane Sandy (AL182012). National Hurricane Center.

Brekke, L. D., M. D. Dettinger, E. P. Maurer, and M. Anderson, 2008: Significance of model credibility in estimating climate projection distributions for regional hydroclimatological risk assessments. Climatic Change, 89, 371-394.

Brutel-Vuilmet, C., M. Ménégoz, and G. Krinner, 2013: An analysis of present and future seasonal Northern Hemisphere land snow cover simulated by CMIP5 coupled climate models. The Cryosphere, Volume 7, Issue 1, 2013, pp. 67-80, 7, 67-80.

Church, J. A., and N. J. White, 2011: Sea level rise from the late 19th to the early 21st century. Surveys in Geophysics, 32, 585-602.

Church, J. A., and Coauthors, 2011: Revisiting the Earth's sea level and energy budgets from 1961 to 2008. Geophysical Research Letters, 38, L18601.

Colle, B.A., Zhang, Z., Lombardo, K.A., Chang, E. Liu, P., and Zhang, M., 2013: Historical evaluation and future prediction of eastern North America and western Atlantic extratropical cyclones in the CMIP5 models during the cool season. Journal of Climate. doi: 10.1175/jcli-d-12-00498.1.

d'Angremond K. and E.T.J.M. Pluim-Van der Velden, 2001: Introduction to coastal engineering. Delft University of Technology. Delft, Netherlands.

Dai, A., 2012: Increasing drought under global warming in observations and models. Nature Climate Change, 3(1), 52-58.

Deser, C., A. Phillips, V. Bourdette, and H. Teng, 2012: Uncertainty in climate change projections: the role of internal variability. Climate dynamics, 38, 527-546.

Elsner, J. B., J. P. Kossin, and T. H. Jagger, 2008: The increasing intensity of the strongest tropical cyclones. Nature, 455, 92-95.

Fischer, E. M., and Knutti, R., 2012: Robust projections of combined humidity and temperature extremes. Nature Climate Change.

Francis, J. A., and S. J. Vavrus, 2012: Evidence linking Arctic amplification to extreme weather in mid latitudes. Geophysical Research Letters, 39.

Gesch, D. B., 2009: Analysis of Lidar Elevation Data for Improved Identification and Delineation of Lands Vulnerable to Sea level Rise. Journal of Coastal Research, 49-58.

Gleick, P. H., 1986: Methods for evaluating the regional hydrologic impacts of global climatic changes. Journal of hydrology, 88, 97-116.

Greene, C., J. Francis, and B. Monger, 2013: Superstorm Sandy: A series of unfortunate events. Oceanography, 26, 8-9.

Grotch, S. L., and M. C. MacCracken, 1991: The use of general circulation models to predict regional climatic change. Journal of Climate, 4, 286-303.

Harding, B., A. Wood, and J. Prairie, 2012: The implications of climate change scenario selection for future streamflow projection in the Upper Colorado River Basin. Hydrology and Earth System Sciences, 9, 847-894.

Harris, G. R., D. M. Sexton, B. B. Booth, M. Collins, and J. M. Murphy, 2013: Probabilistic projections of transient climate change. Climate Dynamics, 1-36.

Hondula, D. M., and R. Dolan, 2010: Predicting severe winter coastal storm damage. Environmental Research Letters, 5, 034004.

Horton, R.M., V. Gornitz, D.A. Bader, A.C. Ruane, R. Goldberg, and C. Rosenzweig, 2011: Climate hazard assessment for stakeholder adaptation planning in New York City. J. Appl. Meteorol. Climatol., 50, 2247-2266.

Horton, R., and C. Rosenzweig, 2010: Climate Risk Information. *Climate Change Adaptation in New York City: Building a Risk Management Response*, C. Rosenzweig and W. Solecki, Eds., Annals of the New York Academy of Sciences, 1196, 147 - 228.

Intergovernmental Panel on Climate Change, 2007a: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt,M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Intergovernmental Panel on Climate Change, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

Karvetski, C., R. B. Lund, and F. Parisi, 2009: A statistical study of extreme nor'easter snowstorms. Involve, 2, 341-350.

Knutson, T. R., and Coauthors, 2010: Tropical cyclones and climate change. Nature Geoscience, 3, 157-163.

Knutti, R., and J. Sedlacek, 2012: Robustness and uncertainties in the new CMIP5 climate model projections. Nature Clim. Change, 3, 369-373.

Konikow, L. F., 2011: Contribution of global groundwater depletion since 1900 to sea level rise. Geophysical Research Letters, 38.

Kunkel, K. E., et al., 2013: Monitoring and understanding trends in extreme storms. Bull. Amer. Meteorol. Soc., 94(4), 499-514.

Kunreuther H., G. Heal, M. Allen, O. Edenhofer, C.B. Field, and G. Yohe 2013: Risk Management and Climate Change. Nature Climate Change. 3, 447-450.

Lin, N., K. Emanuel, J. Smith, and E. Vanmarcke, 2010: Risk assessment of hurricane storm surge for New York City. Journal of Geophysical Research: Atmospheres (1984–2012), 115.

Liu, J., J. A. Curry, H. Wang, M. Song, and R. M. Horton, 2012: Impact of declining Arctic sea ice on winter snowfall. Proceedings of the National Academy of Sciences, 109, 4074-4079.

Marzeion, B., A.H. Jarosch, and M. Hofer, 2012. Past and future sea level change from the surface mass balance of glaciers. The Cryosphere Discussions, 60(4), 3177-3241.

Menne, M. J., C.N. Williams, and R.S. Vose, 2009: The US Historical Climatology Network monthly temperature data, version 2. Bull. Am. Meteorol. Soc, 90(7), 993-1007.

Mitrovica, J. X., N. Gomez, and P. U. Clark, 2009: The sea level fingerprint of West Antarctic collapse. Science, 323, 753-753.

Moss, R. H., and Coauthors, 2010: The next generation of scenarios for climate change research and assessment. Nature, 463, 747-756.

National Digital Elevation Program (NDEP), 2004: Guidelines for Digital Elevation Data Version 1.0. Accessed at http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf.

New York City Panel on Climate Change. (2010). Climate Change Adaptation in New York City: Building a Risk Management Response. C. Rosenzweig & W. Solecki, Eds. Prepared for use by the New York City Climate Change Adaptation Task Force. Annals of the New York Academy of Sciences. 2010. New York, NY. 354pp. http://www.nyas.org.

NOAA Tides and Currents, 2013. Center for Operational Oceanographic Products and Services. Accessed from http://tidesandcurrents.noaa.gov/.

Orton, P., N. Georgas, A. Blumberg, and J. Pullen, 2012: Detailed modeling of recent severe storm tides in estuaries of the New York City region. Journal of Geophysical Research: Oceans (1978–2012), 117(C9).

Parris, A., and Coauthors, 2012: Global Sea level rise Scenarios for the US National Climate Assessment. US Department of Commerce, National Oceanic and Atmospheric Administration, Oceanic and Atmospheric Research, Climate Program Office.

Peltier, 2012: GIA data sets. Available at: http://www.psmsl.org/train_and_info/geo_signals/gia/peltier/drs250.PSMSL.ICE5GV1.3_VM2_L90_2012b.txt.

Peltier, R., 2012: The Younger-Dryas Cold reversal: Ice-Earth-Ocean Interactions During a Period of Rapid Climate Change. Quaternary International, 279, 373.

Perrette, M., F. Landerer, R. Riva, K. Frieler, and M. Meinshausen, 2013: A scaling approach to project regional sea level rise and its uncertainties. Earth System Dynamics, 4, 11-29.

Price, C., & D. Rind, 1994. Modeling global lightning distributions in a general circulation model. Monthly Weather Review, 122(8).

PlaNYC, 2007: A Greener, Greater New York. City of New York.

PlaNYC, 2011: A Greener, Greater New York. City of New York.

Radic, V., A. Bliss, A. C. Beedlow, R. Hock, E. Miles, and J. G. Cogley, 2013: Regional and global projections of twenty-first century glacier mass changes in response to climate scenarios from global climate models. Climate Dynamics, 1-22.

Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, and P. Grabhorn, 2011: Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Annals of the New York Academy of Sciences, 1244, 2-649.

Rougier, J., 2007: Probabilistic inference for future climate using an ensemble of climate model evaluations. Climatic Change, 81, 247-264.

Sallenger Jr, A. H., K. S. Doran, and P. A. Howd, 2012: Hotspot of accelerated sea level rise on the Atlantic coast of North America. Nature Climate Change, 2, 884-888.

Shepherd, A., and Co-Authors, 2012: A reconciled estimate of ice-sheet mass balance. Science 338:1183-1189.

Slangen, A., C. Katsman, R. van de Wal, L. Vermeersen, and R. Riva, 2012: Towards regional projections of twenty-first century sea level change based on IPCC SRES scenarios. Climate dynamics, 38, 1191-1209.

Stroeve, J. C., M. C. Serreze, M. M. Holland, J. E. Kay, J. Malanik, and A. P. Barrett, 2012: The Arctic's rapidly shrinking sea ice cover: a research synthesis. Climatic Change, 110, 1005-1027.

Taylor, K. E., R. J. Stouffer, and G. A. Meehl, 2012: An overview of CMIP5 and the experiment design. Bulletin of the American Meteorological Society, 93, 485-498.

Titus, J. G., and C. Richman, 2001: Maps of lands vulnerable to sea level rise: modeled elevations along the US Atlantic and Gulf coasts. Climate Research, 18, 205-228.

USGCRP, 2013: National Climate Assessment, Public Review Version, available online at: http://ncadac.globalchange.gov/.

Van Vuuren, D. and Co-Authors, 2011: The representative concentration pathways: an overview. Climatic Change, 109(1-2), 5-31.

Wada, Y., L. P. Beek, F. C. Sperna Weiland, B. F. Chao, Y. H. Wu, and M. F. Bierkens, 2012: Past and future contribution of global groundwater depletion to sea level rise. Geophysical Research Letters, 39.

Wilby, R., S. Charles, E. Zorita, B. Timbal, P. Whetton, and L. Mearns, 2004: Guidelines for use of climate scenarios developed from statistical downscaling methods. IPCC task group on data and scenario support for impacts and climate analysis.

World Climate Research Programme (WCRP), 2011: WCRP Coupled Model Intercomparison Project-Phase 5-CMIP5. Clivar Exchanges Newsletter No. 56.

World Meteorological Organization, 1989: Calculation of monthly and annual 30-year standard normals. WCDP 10 and WMOTD 341, World Meteorological Organization.

Wu, S.-Y., B. Yarnal, and A. Fisher, 2002: Vulnerability of coastal communities to sealevel rise: a case study of Cape May county, New Jersey, USA. Climate Research, 22, 255-270.

Yohe, G. and R. Leichenko, 2010: Adopting a risk-based approach. Climate Change Adaptation in New York City: Building a Risk Management Response, C. Rosenzweig and W. Solecki, Eds., Annals of the New York Academy of Sciences, 1196, 29-40.

Additional Sources of Information

Federal Geographic Data Committee, 1998: "Geospatial positioning accuracy standards part 3: National standard for spatial data accuracy." FGDC-STD-007.3-1998, Accessed at: http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3.

Gesch, D. B., 2009: Analysis of Lidar Elevation Data for Improved Identification and Delineation of Lands Vulnerable to Sea level Rise. Journal of Coastal Research, 49-58.

Li, X., R. J. Rowley, J. C. Kostelnick, D. Braaten, J. Meisel, and K. Hulbutta, 2009: GIS analysis of global impacts from sea level rise. Photogrammetric Engineering and Remote Sensing, 75, 807-818.

Pokhrel, Y. N., N. Hanasaki, P. J. F. Yeh, T. J. Yamada, S. Kanae, and T. Oki, 2012: Model estimates of sea level change due to anthropogenic impacts on terrestrial water storage. Nature Geosci, In Press.

Poulter, B., and P. Halpin, 2008: Raster modelling of coastal flooding from sea- level rise. International Journal of Geographical Information Science, 22, 167-182.

Glossary and Abbreviations

Adaptation

The term "adaptation" is used to describe 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 vs. reactive, private vs. public, and autonomous vs. planned. Examples are raising river or coastal dikes and the substitution of sensitive plants with more temperature shock resistant ones.

AMOC

The Atlantic Meridional Overturning Circulation (AMOC) is the name used to describe the northward flow of warm, shallow water, and the southward flow of cold, deeper water within the Atlantic Ocean Basin. When the northward flowing warm water reaches the North Atlantic, it loses buoyancy, sinks and then flows back southward as North Atlantic deep water. This circulation pattern has a large influence on climate, particularly in Europe, which is much milder than it would otherwise be in the absence of the AMOC (Lynch-Stieglitz et al., 2007).

AR4

The IPCC is tasked with providing Assessment reports at regular time intervals on the physical basis of climate change, its impacts, and adaptation and mitigation strategies to avoid, prepare for, and respond to current and projected impacts. The Fourth Assessment Report (AR4) was published in 2007 and is the most recently completed assessment report from the IPCC (IPCC, 2009).

AR5

The IPCC is tasked with providing Assessment reports at regular time intervals on the physical basis of climate change, its impacts, and adaptation and mitigation strategies to avoid, prepare for, and respond to current and projected impacts (IPCC, 2009). The Fifth Assessment Report (AR5) is scheduled to be published in three sections between 2013 and 2014. Compared with previous reports, AR5 will place greater stress on the socioeconomic aspects of climate change and implications for sustainable development, risk management, and framing a response which involves both mitigation and adaptation (IPCC, 2013).

Carbon Dioxide (CO_2)

CO_2 is a naturally occurring gas, and a by-product of burning fossil fuels or biomass, land use changes, and 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 forcing, or to persistent anthropogenic changes in the composition of the atmosphere or land use.

Climate Forcing

This term is used to describe 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

In this context, these are climate variables which could have specific consequences 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.

Emissions Scenarios (see RCPs)

The IPCC periodically develops several sets of scenarios to reflect advances in research and new data. In earlier assessment reports, the IPCC produced socio-economic scenarios that would result in different future greenhouse gas and aerosol emissions, assessed the effects of those emissions on the climate system, and combined them with other environmental changes to evaluate the effect on human systems. For the AR5 report, a new scenario process has been employed which considers alternative futures in global greenhouse gas and aerosol concentrations as its starting point. These new scenarios are known as Representative Concentration Pathways (RCPs), which are measured in terms of the additional radiative forcing applied by varying future concentrations of greenhouse gases in the atmosphere. Unlike previous scenarios which were each associated with one socio-economic scenario, each RCP can be reached through many socio-economic pathways (CIESIN, 2011).

Global Climate Models (GCMs)

GCMs are numerical representations of the climate system based on the physical, chemical, and biological properties of its components (accounting for all or some of its known properties), their interactions, and feedback processes. 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 these 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 (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), and ozone (O3) 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.

Hazard

Hazard is the quantification of a given peril. A peril can be flooding, wind, rain, ice, snow. The hazard provides a quantitative measure of that peril, for instance flood height in feet, wind speed in miles per hour, and inches of rain, icing, or snowfall. For probabilistic hazard assessment the hazard is defined as the amplitude of the hazard that is reached or exceeded during a given unit time. It typically is associated with some uncertainties. A deterministic hazard is a single value, e.g., 5 inches of rain (without any specific reference to how often it would occur during a given time).

IPCC

The Intergovernmental Panel on Climate Change (IPCC) 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

The term "mitigation" is used to describe technological change and substitution that reduces 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.

NPCC

The New York City Panel on Climate Change (NPCC) is a panel of experts first convened in 2008 to advise the Mayor and New York City on climate change and adaptation. The specific tasks of the NPCC are to create climate change projections for the New York City region, develop planning tools to help guide stakeholders in their adaptation planning and strategy-creation process, examine how the regulatory environment influences infrastructure-related decision making, and produce a summary report on climate change adaptation for New York City outlining major themes and best practices to include in a comprehensive adaptation program (Rosenzweig and Solecki, 2010).

Paleoclimate

The study of past Earth climates prior to the instrumental record. Paleoclimate research uses the Earth's historical climate record based on geophysical, geochemical and sedimentological, and fossil data analyses to reconstruct various past environments and events in Earth's climate history.

RCPs

For the AR5 report, a new scenario process has been employed which considers alternative futures in global greenhouse aerosol concentrations as its starting point. These new scenarios are known as Representative Concentration Pathways (RCPs), which are measured in terms of the additional radiative forcing applied by varying future concentrations of greenhouse gases in the atmosphere. Unlike previous scenarios which were each associated with one socio-economic scenario, each RCP can be reached by many socio-economic pathways (CIESIN, 2011).

Relative Sea Level

Sea level is changing at varying rates at different locations. As opposed to the global mean sea level trend, the relative sea level trend describes the rate of change at a given coastal location. The relative sea level trend is measured as a combination of the global sea level rate and vertical land motion at that location (NOAA, 2013).

Risk

Risk is the product of the likelihood of an event occurring (the hazard), and the magnitude of the consequence should that event occur. For the purposes of this document, likelihood is defined as the probability of occurrence of a climate hazard. Risk implies the expectation of future impacts, which are by nature also uncertain. (This NPCC2 Report contributes quantitative and qualitative information about the likelihood of future climate hazards through the climate change projections and the production of maps. The climate hazards projections provide key information needed to understand climate risks, since they are a critical factor in determining subsequent impacts.)

Scenario

A scenario is 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 and 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.

Timeslice

Projections in this document are given in two timeslices: the 2020s and 2050s. 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

Uncertainty is an expression of the degree to which a value is unknown (e.g., the future state of the climate system or of a single climate variable). Uncertainty can result from lack of information, natural variability in the climate system, 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 and technology. 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).

Glossary References

CIESIN IPCC Data Distribution Centre. Scenario Process For AR5. Accessed from http://sedac.ciesin.columbia.edu/ddc/ar5_scenario_process/.

Intergovernmental Panel on Climate Change, 2009: Summary Description of the IPCC Process. Accessed from https://www.ipcc-wg1.unibe.ch/statement/WGIsummary22122009.html.

Intergovernmental Panel on Climate Change, 2013: Activities. Accessed from http://www.ipcc.ch/activities/activities.shtml#.UYvcjtLD_Z4.

Lynch-Stieglitz, J., and Coauthors, 2007: Atlantic Meridional Overturning Circulation During the Last Glacial Maximum. Science, 316, 66-69.

NOAA Tides and Currents. Sea Levels Online. Accessed from http://www.tidesandcurrents.noaa.gov/sltrends/.

Rosenzweig, C., and W. Solecki, 2010: Introduction to Climate Change Adaptation in New York City: Building a Risk Management Response. Annals of the New York Academy of Sciences, 1196, 13-18.

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