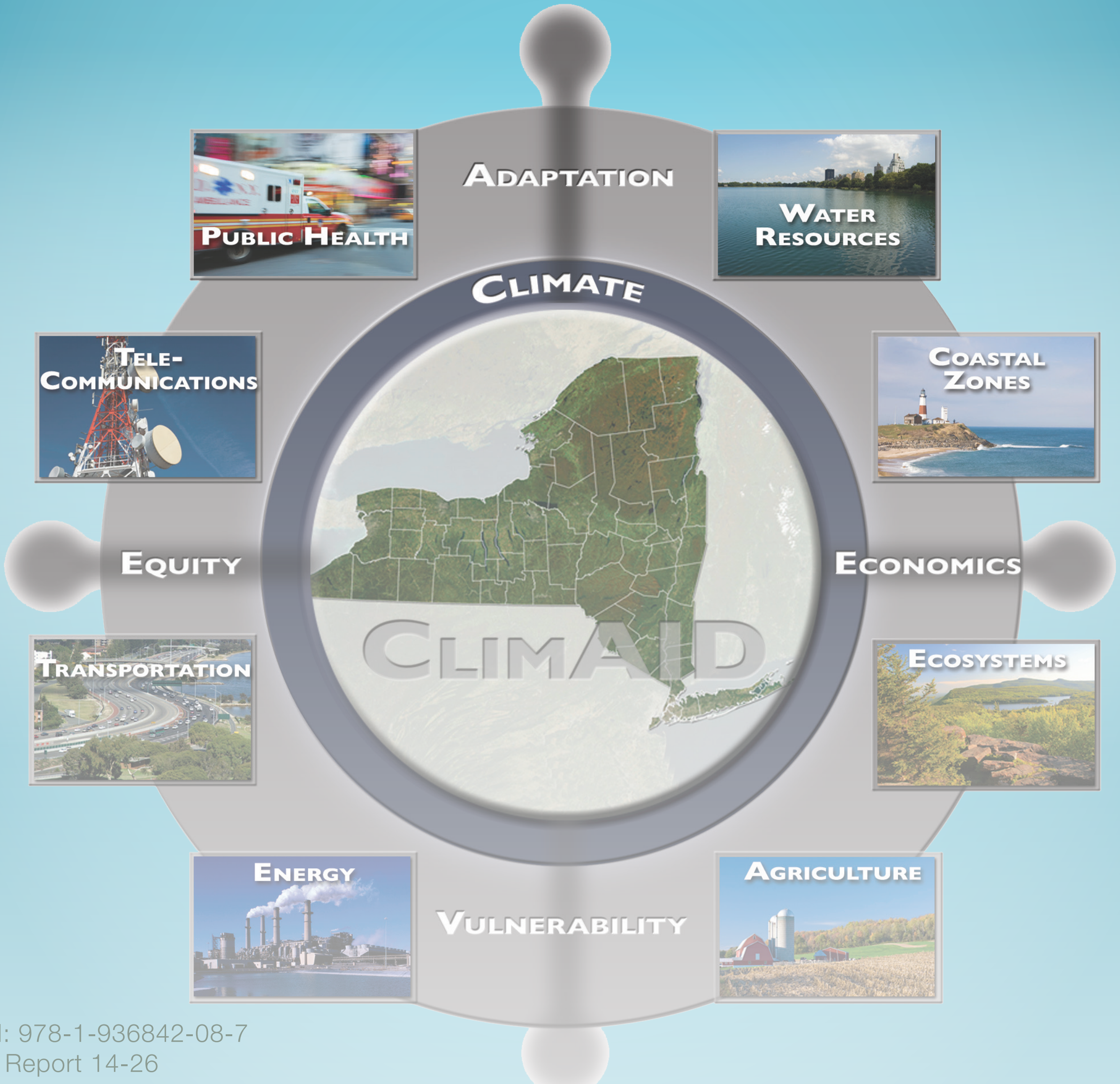
New York State Energy Research and Development Authority

Climate Change in New York State

Updating the 2011 ClimAID Climate Risk Information
Supplement to NYSERDA Report 11-18
(Responding to Climate Change in New York State)



ISBN: 978-1-936842-08-7
Final Report 14-26
September 2014

The New NY WORKS for Energy

nyserda
Energy. Innovation. Solutions.

NYSERDA's Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Mission Statement:

Advance innovative energy solutions in ways that improve New York's economy and environment.

Vision Statement:

Serve as a catalyst – advancing energy innovation, technology, and investment; transforming New York's economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

Core Values:

Objectivity, integrity, public service, partnership, and innovation.

Portfolios

NYSERDA programs are organized into five portfolios, each representing a complementary group of offerings with common areas of energy-related focus and objectives.

Energy Efficiency and Renewable Energy Deployment

Helping New York State to achieve its aggressive energy efficiency and renewable energy goals – including programs to motivate increased efficiency in energy consumption by consumers (residential, commercial, municipal, institutional, industrial, and transportation), to increase production by renewable power suppliers, to support market transformation, and to provide financing.

Energy Technology Innovation and Business Development

Helping to stimulate a vibrant innovation ecosystem and a clean energy economy in New York State – including programs to support product research, development, and demonstrations; clean energy business development; and the knowledge-based community at the Saratoga Technology + Energy Park® (STEP®).

Energy Education and Workforce Development

Helping to build a generation of New Yorkers ready to lead and work in a clean energy economy – including consumer behavior, youth education, workforce development, and training programs for existing and emerging technologies.

Energy and the Environment

Helping to assess and mitigate the environmental impacts of energy production and use in New York State – including environmental research and development, regional initiatives to improve environmental sustainability, and West Valley Site Management.

Energy Data, Planning, and Policy

Helping to ensure that New York State policymakers and consumers have objective and reliable information to make informed energy decisions – including State Energy Planning, policy analysis to support the Regional Greenhouse Gas Initiative and other energy initiatives, emergency preparedness, and a range of energy data reporting.

Climate Change in New York State

Updating the 2011 ClimAID Climate Risk Information Supplement to NYSERDA Report 11-18 (Responding to Climate Change in New York State)

Final Report

Prepared for:

New York State Energy Research and Development Authority
Albany, NY

Amanda Stevens

Prepared by:

Columbia University
Radley M. Horton
Daniel A. Bader
Cynthia Rosenzweig

Cornell University
Arthur T. DeGaetano

City University of New York
William Solecki

ISBN: 978-1-936842-08-7

NYSERDA Report 14-26
NYSERDA Contract 35741
September 2014

Notice

This report was prepared by Columbia University, Cornell University, and the City University of New York in the course of performing work contracted for and sponsored by the New York State Energy Research and Development Authority (hereafter "NYSERDA"). The opinions expressed in this report do not necessarily reflect those of NYSERDA or the State of New York, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it. Further, NYSERDA, the State of New York, and the contractor make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report. NYSERDA, the State of New York, and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

NYSERDA makes every effort to provide accurate information about copyright owners and related matters in the reports we publish. Contractors are responsible for determining and satisfying copyright or other use restrictions regarding the content of reports that they write, in compliance with NYSERDA's policies and federal law. If you are the copyright owner and believe a NYSERDA report has not properly attributed your work to you or has used it without permission, please email print@nyserda.ny.gov.

Acknowledgments

NASA Goddard Institute for Space Studies and NOAA Consortium for Climate Risk in the Urban Northeast scientists also contributed to the work.

Suggested Citation

Horton, R., D. Bader, C. Rosenzweig, A. DeGaetano, and W.Solecki. 2014. Climate Change in New York State: Updating the 2011 ClimAID Climate Risk Information. New York State Energy Research and Development Authority (NYSERDA), Albany, New York.

Table of Contents

List of Figures

List of Tables

1 Introduction

In its 2013-2014 Fifth Assessment Report (AR5), the Intergovernmental Panel on Climate Change (IPCC) states that there is a greater than 95 percent chance that rising global average temperatures, observed since the mid-20th century, are primarily due to human activities. As had been predicted in the 1800s (Ramanathan and Vogelman 1997, Charlson 1998), the principal driver of climate change over the past century has been increasing levels of atmospheric greenhouse gases associated with fossil-fuel combustion, changing land-use practices, and other human activities. Atmospheric concentrations of the greenhouse gas carbon dioxide are now approximately 40 percent higher than in preindustrial times. Concentrations of other important greenhouse gases, including methane and nitrous oxide, have increased rapidly as well (Hartmann et al. 2013).

The AR5 report notes that society has already emitted more than half the extra greenhouse gas emissions that can be released while retaining a reasonable chance of staying under the 3.6 °F (2 °C) warming threshold defined as "dangerous" climate change. Given that greenhouse gas emissions have continued to accelerate, this suggests that efforts to mitigate the severity of climate change by reducing greenhouse gas emissions would need to be ramped up globally if the target is to be met.

The AR5 report also notes that climate change impacts are already occurring, and that some additional future impacts from climate change are inevitable. Many greenhouse gases persist in the atmosphere for centuries to millennia, and higher concentrations of heat-trapping gases are already influencing many climate processes, including accelerated melting of ice sheets, which respond over a long period of time. Adaptation measures are needed to minimize the current impacts of climate change and to prepare for unavoidable future impacts. To inform adaptation efforts in New York State, this update provides updated climate projections to Horton et al. 2011a, based on the new climate models developed for the AR5 report, additional observed data, and improved physical understanding.

Based on advances in physical understanding and a new set of more complex climate models and more powerful computing, the climate risks chapter (Horton et al. 2011a) of the ClimAID Report (Rosenzweig et al. 2011) is updated here. Specific advances include:

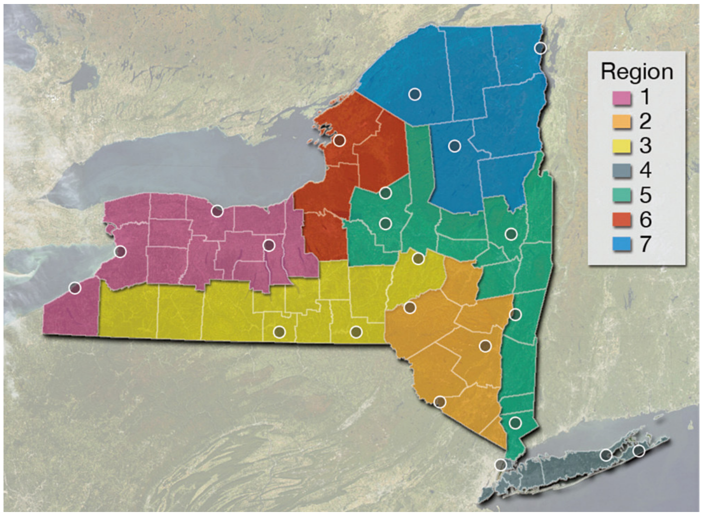
- A probabilistic approach to sea level rise that includes additional components (e.g., gravitational and other effects on regional sea level caused by ice sheet changes, and storage/extraction of water on land).
- Use of higher spatial resolution climate models that include new features such as how vegetation may respond to temperature and precipitation change.
- Additional observed data reflecting the post Irene and Sandy era.
- Updated information about our physical understanding of extreme events.

The new climate models generally have a higher spatial resolution and include more diverse model types (Knutti and Sedlacek 2012). While these advances yield some changes in the results relative to the original ClimAID work, these changes are generally small relative to the uncertainties involved in long-term projections. As a result, this update amplifies many of the messages of the original ClimAID report.

As with the original ClimAID assessment, New York State was divided into seven regions for this update (**Figure 1**). The geographic regions are grouped together based on a variety of factors, including type of climate and ecosystems, watersheds, and dominant types of agricultural and economic activities. The broad geographical regions are: Western New York and the Great Lakes Plain (Region 1), Catskill Mountains and the West Hudson River Valley (Region 2), the Southern Tier (Region 3), the coastal plain composed of the New York City metropolitan area and Long Island (Region 4), the East Hudson and Mohawk River Valleys (Region 5), the Tug Hill Plateau (Region 6), and the Adirondack Mountains (Region 7).

Climate analysis for this update was conducted on data from seven official meteorological observing stations. These stations were selected based on a combination of factors, including length of record, relative absence of missing data, and consistency of station observing procedure.

Figure 1. ClimAID Climate Regions



Global climate model-based quantitative projections are provided within each region for:

- Temperature.
- Precipitation.
- Sea level rise (coastal and Hudson Valley regions only).
- Extreme events.

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

- Heat indices.
- Frozen precipitation.
- Lightning.
- Intense precipitation of short duration.
- Storm (hurricanes, nor'easters, and associated wind events).

The new climate projections for New York State use methods developed by the New York City Panel on Climate Change (NPCC) to provide updated climate information for the City following Hurricane Sandy (NPCC, 2014). The observed trends and future climate projections in this update report for Region 4 (New York City metropolitan area and Long Island) were created as part of the NPCC process.

Global climate models and representative concentration pathways selected for use by the NPCC are again used in this NYSERDA report. The advanced methodology for sea level rise projections developed by the NPCC is extended here for other coastal areas in New York State. Quantitative and qualitative projections for temperature, precipitation, sea level, and extreme events are provided in this report, as was done for New York City (NPCC, 2014).

The NPCC was reconvened following Hurricane Sandy in January 2013 to provide updated climate risk information for the City to be used in rebuilding and resiliency efforts. The engagement of scientists and stakeholders, a fundamental part of the NPCC's work, was critical to developing the updated projections for New York State. The interactions between the City and State are illustrative of the cross-scale linkages that are essential to building climate resilience.

2 Observed Climate

2.1 Average Temperature and Precipitation

New York State's climate can be described as humid continental. The average annual temperature varies from about 40 °F in the Adirondack Mountains to about 55 °F in the New York City metropolitan area. The wettest parts of the State — including parts of the Adirondacks and Catskills, the Tug Hill Plateau, and portions of the New York City metropolitan area — average approximately 50 inches of precipitation per year. Parts of Western New York are relatively dry, averaging about 30 inches of precipitation per year. In all regions, precipitation is relatively consistent in all seasons, although droughts and floods do occur.

2.2 Sea Level Rise

Currently, rates of sea level rise on New York State's coastlines have ranged across the region from 0.86 to 1.5 inches per decade, averaging 1.2 inches per decade since 1900. Sea level rise rates over this time period, which are measured by tide gauges, include both the effects of global warming since the onset of the Industrial Revolution and the residual crustal adjustments to the removal of the ice sheets. Most of the observed current climate-related rise in sea level over the past century can be attributed to expansion of the oceans as they warm, although melting of glaciers and ice sheets is gradually becoming the dominant contributor to sea level rise (Church et al. 2011).

2.3 Snowfall

New York State averages more than 40 inches per year of snow. Snowfall varies regionally, based on topography and the proximity to large lakes and the Atlantic Ocean. Maximum seasonal snowfall is more than 175 inches in parts of the Adirondacks and Tug Hill Plateau, as well as in the westernmost parts of the State. The warming influence of the Atlantic Ocean keeps snow in the New York City metropolitan area and Long Island below 36 inches per year.

Lake-enhanced heavy snow events frequently occur near the Great Lakes, generating as much as 48 inches of snow in a single storm. These events, which can last anywhere from an hour to a few days, affect places downwind of the Great Lakes (and, to a lesser extent, the Finger Lakes) in Western New York. Parts of Western New York (including Buffalo) receive snowfall from Lake Erie, while the Tug Hill region and the lakeshore cities of Watertown and Oswego experience snowfall from Lake Ontario. Lake-enhanced snowfall is localized; areas within miles of each other can experience large differences in snowfall totals.

In southern parts of the State, snowfall amounts occasionally exceed 20 inches during nor'easters. New York City, for example, experiences snowstorms that exceed 20 inches about once every 25 years (New York State Climate Office 2003).

2.4 Extreme Events

New York State is affected by extremes of heat and cold, intense rainfall and snow, and coastal flooding caused by tropical storms and nor'easters. Due to the large regional variations in the State's climate, no single extreme event metric is appropriate for the entire State. For example, in the northern parts of the State, 0 °F may be an appropriate threshold for some stakeholder applications impacted by extreme cold, whereas 32 °F is more appropriate in the southern coastal plain, where maritime air from the Atlantic Ocean moderates temperatures.

2.4.1 Extreme Temperature and Heat Waves

Extreme hot days and heat waves are thus defined in several ways to reflect the diversity of conditions experienced across New York State:

- Individual days with maximum temperatures at or above 90 °F.
- Individual days with maximum temperatures at or above 95 °F.
- Heat waves, defined as three consecutive days with maximum temperatures above 90 °F.

Extreme cold days are also defined to reflect the state's regional climate variations:

- Individual days with minimum temperatures at or below 32 °F.
- Individual days with minimum temperatures at or below 0 °F.

In all locations, the number of extreme events from year to year is highly variable.

2.4.2 Extreme Precipitation and Flooding

Throughout New York State, heavy rainfall can lead to flooding in all seasons. Urban areas (due to impermeable surfaces, including roads and buildings) and low-lying areas are particularly vulnerable. In much of central and northern New York State, flooding is most frequent in spring, when rains and rapid snowmelt lead to runoff. Ice jams sometimes contribute to serious flooding in very localized areas during spring and winter as well. Farther south, inland floods are more frequent during the summer in urban areas. During late summer and fall, larger river systems are vulnerable to flooding associated with tropical systems.

Across the State, mechanisms responsible for producing heavy rainfall vary and are generally more common near the coasts. Intense precipitation can be associated with small-scale thunderstorms, most common in the warmer months. Large-scale coastal storms (see the next section about Coastal Storms), including cold/cool-season nor'easters (which can produce snow and ice in addition to rain) and warm-season tropical cyclones, can also produce intense precipitation. Hurricane Sandy, which struck in late October 2012, was an example of a hybrid storm that reflected a blend of a warm season tropical cyclone and a mid-latitude cool-season system.

2.4.3 Coastal Storms

The two types of storms with the largest impact on the coastal areas of the State are tropical cyclones and nor'easters. Tropical cyclones, which strike New York State infrequently (generally between July and October), can produce large storm surges along the coast, and can cause wind damage and intense precipitation throughout the entire State. During 2011 and 2012, New York State experienced all three of these climate hazards, due to tropical cyclones Lee, Irene, and Sandy. Nor'easters are far more frequent and of longer duration; they generally do not occur during the warmest months. Nor'easters are generally associated with smaller surges and weaker winds along the coast than tropical cyclones. Nevertheless, nor'easter flood effects can be large, since their long duration can extend the period of high winds, high water, and wave action over multiple tidal cycles.

As was tragically revealed by Hurricane Sandy, a large fraction of New York City and coastal Long Island, especially the south shore (facing the Atlantic Ocean), is less than 10 feet above average sea level and is vulnerable to coastal flooding during major storm events, both from excessive rainfall and from coastal storm surges. Hurricane Irene and Tropical Storm Lee revealed that inland flood risks associated with storm rainfall can be greatest in high-elevation regions away from the coast. Heavy rains from Hurricane Irene and Tropical Storm Lee were part of a broader wet-weather pattern (rainfall totals for August and September exceeded 25 inches across much of the Northeast) that left the region predisposed to extreme flooding. For example, the Schoharie Creek in New York experienced a 500-year flood after Hurricane Irene.

2.5 Historical Analysis

An analysis of historical trends in annual average temperature and precipitation was conducted at one station with a long data record in each of the seven regions (**Table 1**). The observed monthly data source is Version 2.5 of the United States Historical Climatology Network (USHCN) product (Menne et al. 2013)[1].

---

[1] This data set, which is fully homogenized (non-climatic changes removed) and includes an urbanization adjustment, is a slight update of the one used in the 2011 ClimAID report. This change and the calculation of trends over a longer time period (1901 through 2012 vs. through 2000 previously) account for differences in the trends in this report versus the 2011 report.

Average annual temperature and precipitation trends were calculated for the 1900-2012 time period. By analyzing more than a full century, the role of unpredictable decade-to-decade variability can be reduced relative to the climate change signal associated with increasing greenhouse gas concentrations.

Table 1. Observed Climate Trends in New York State

a. Annual Temperature (1901 – 2012)

Observed Weather Station	Temperature Trend (°F/decade)
Region 1 – Rochester	0.32**
Region 2 – Port Jervis	0.35**
Region 3 – Elmira	0.09*
Region 4 – New York City	0.33**
Region 5 – Albany	0.22**
Region 6 – Watertown	0.22**
Region 7 – Indian Lake	0.21**

b. Annual Precipitation (1901 – 2012)

Observed Weather Station	Precipitation Trend (in/decade)
Region 1 – Rochester	0.34**
Region 2 – Port Jervis	0.35
Region 3 – Elmira	0.58**
Region 4 – New York City	0.76**
Region 5 – Albany	0.90**
Region 6 – Watertown	0.54**
Region 7 – Indian Lake	0.19

* Trend is significant at the 95% significance level
** Trend is significant at the 99% significance level
All data are from NOAA NCDC USHCN V2.5 dataset.

2.5.1 Temperature

Temperatures are warming across New York State, with an average rate of warming over the past century of 0.25 °F per decade. The annual temperature trends for six of the seven stations are significant at the 99 percent level over the 1900 - 2012 time period. The warming observed in these stations across New York State is broadly consistent to the trend for the Northeast United States, which was 0.16 °F per decade for the 1895 to 2011 period (Horton et al. 2014).

2.5.2 Precipitation

All seven stations in New York State used for the trend analysis in this update experienced increasing precipitation over the past century. The linear trends at five of seven of the stations are significant at the 99 percent level over the 1900 - 2012 time period. In addition to increased mean annual precipitation, year-to-year (and multiyear) variability of precipitation has also become more pronounced. For all stations in the update, the standard deviation of annual precipitation (a measure of variability) was greater over the 1956 to 2012 period compared to 1900 to 1955. Precipitation in the larger Northeast region also increased modestly since the 1900s at a rate of 0.4 inches per decade for the 1895 to 2011 period (Horton et al., 2014).

3 Climate Projections

For this update, global climate models were used to develop a set of climate projections for New York State. Projections were made for changes in mean annual climate and extreme events. Model-based distributions for temperature, precipitation, sea level rise, and extreme events are created based on global climate model simulations (GCMs) and representative concentration pathways (RCPs; Moss et al. 2010) used in the AR5 report (IPCC 2013). This approach is similar to that used in the 2011 ClimAID report and has been applied to many regions, including locally for New York City (City of New York, 2013; NPCC, 2013).

Like all projections, these 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. Levels of uncertainty are characterized 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, so the specific numbers should not be emphasized, and the potential for error should be acknowledged.

3.1 Projection Methods

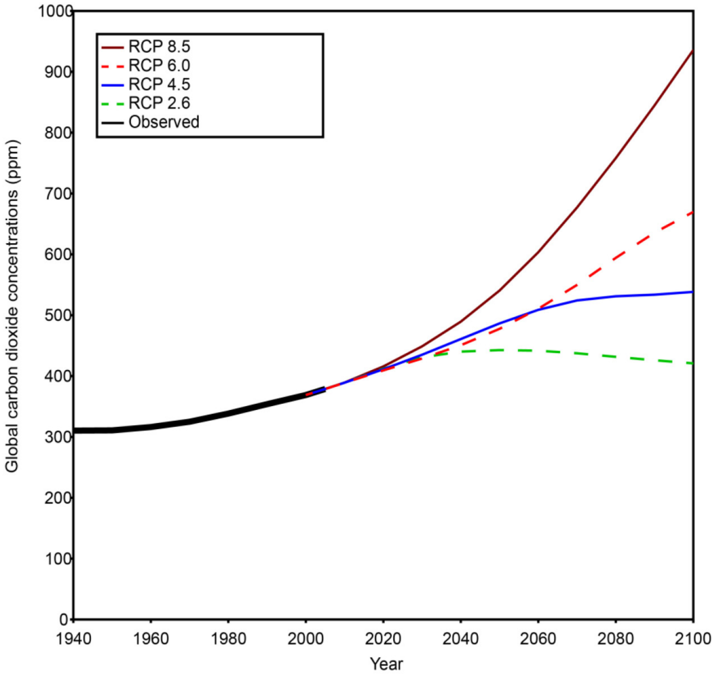
GCMs are mathematical representations of the behavior of the Earth's climate system over time, which can be used to estimate how sensitive the climate system is to changes in atmospheric concentrations of greenhouse gases and aerosols. Each model simulates physical exchanges among the ocean, atmosphere,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

The GCM simulations used for this update are from the Coupled Model Intercomparison Project Phase 5 (CMIP5) and were developed for the IPCC Fifth Assessment Report (AR5). Relative to the previous climate model simulations from CMIP3 used in the 2011 ClimAID report, 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 can 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., Stroeve et al. 2012).

3.1.1 Representative Concentration Pathways

As with the climate models themselves, the input emissions scenarios should be periodically updated to incorporate advances in the science. RCPs are the new emissions scenarios used in the AR5 report and in this update (**Figure 2**). The 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). These data are used by global climate models to project the effects of these climate drivers on future climate.

Figure 2. Carbon Dioxide Concentrations



Observed CO_2 concentrations through 2005, and future carbon dioxide concentrations for four representative concentration pathways. The two representative concentration pathways used for this report's projections are the solid lines (RCP 4.5 and RCP 8.5).

Previous IPCC analyses (and the ClimAID report) used the "Special Report on Emissions Scenarios" (SRES; IPCC 2000), which based emissions trajectories on particular socioeconomic assumptions about potential futures (e.g., high economic growth and rapid deployment of low-carbon fuels). In contrast, the RCPs are not associated with any particular socioeconomic pathway. They are purely pathways of greenhouse gas (and other climate driver) concentrations, drawn from the literature and representing a wide range of potential future concentrations. Given that they are not tied to a particular set of socioeconomic assumptions, the RCPs could occur due to various combinations of social, technical, policy, and economic situations.

This update 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 (35) available from World Climate Research Programme's/Program for Climate Model Diagnosis and Intercomparison (WCRP/PCMDI) (Taylor et al., 2012). RCP 4.5 and RCP 8.5 were selected to bound the range of anticipated greenhouse gas forcing at the global scale.

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 4.5 is comparable to a lower-emissions SRES scenario from previous IPCC reports, such as the B1 scenario used in the 2011ClimAID report.

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). RCP 8.5 is comparable to a high-emissions SRES scenario from previous IPCC reports, such as the A2 scenario used in the 2011 ClimAID report.

3.1.2 Model-Based Distributions

The combination of 35 GCMs and two RCPs produces a 70 (35 × 2)-member matrix of outputs for temperature and precipitation. Results are presented across this range of outcomes at selected points in the distribution. In this update, we show the 10th, 25th, 75th, and 90th percentiles.[2] For each time period, the results constitute a model-based range of outcomes, which can be used in risk-based decision making. This approach gives equal weight to each GCM and to each of the two RCPs selected.[3]

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[4] 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. 2011b). 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[5]).

3.1.3 Sea Level Rise

For this update, sea level rise projections for coastal New York State and the tidal Hudson River have been developed using an innovative component-by-component analysis (**Table 2**) that blends climate model outputs and expert judgment for variables like ice sheet dynamics that climate models are unable to simulate. 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 based on fewer components.

For each of the components of sea level change, this update estimated the 10th, 25th, 75th, and 90th percentiles of the distribution. Each component at a given percentile (e.g., the 90th percentile) is summed, with the result defined as the same percentile (e.g., the 90th percentile). This risk-averse approach accounts for the fact that each component's percentile may not reflect the true probability distribution. This approach also implicitly includes the possibility of potential positive correlation between components. For example, Greenland ice sheet mass loss could increase the relative height of the sea surface on the Northeast U.S. coastline 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 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 et al., 2013; Marzeion et al. 2012
Gravitational, rotational, and isostatic 'fingerprints' of ice loss	Local	With loss of ice, 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 deglaciation (slow isostatic response)	Latest version of Peltier's Glacial Isostatic Adjustment (GIA model)	Peltier, 2004
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	Church et al., 2011; Milly et al., 2010

---

[2] For example, the 90th percentile means that 90 percent of the values in the (35 × 2) matrix are lower (and 10 percent are higher).

[3] Both in recent years and over the longer history of the emissions scenario process, greenhouse gas emissions and concentrations have tracked much closer to RCP 8.5/A2 than to RCP4.5/B1 (Le Quere 2009).

[4] Bias-correction is standard practice when using climate model outputs, since long-term changes through time are considered more reliable than actual values, especially when assessing an area—like one of the seven regions of New York State—that is comparable in size to a climate model gridbox.

[5] 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.

3.1.4 Extreme Event Methods

Extremes of temperature and precipitation (with the exception of drought) tend to have their largest impacts at daily rather than monthly time scales. Because monthly output from climate models is considered more reliable than daily output (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 each regional station to generate 70 time series of daily data. This simplified approach to projections of extreme events does not allow for possible changes in variability through time. More tailored approaches to downscaling that consider possible changes in variability, such as those being led by DeGaetano et al., are an important advancement to the more traditional approach described here.

3.1.5 Regional Projections

The projections for the seven regions of New York State are based on global climate model output from each model's single land-based model gridbox covering the center of each region. The precise coordinates of each model's gridboxes differ since each global climate model has a different spatial resolution. These spatial resolutions of the GCMs range from as fine as approximately 50 miles by approximately 40 miles to as coarse as approximately 195 by approximately 195 miles, with an average resolution of approximately 125 miles by 115 miles. Changes in temperature and precipitation through time (for example, three degrees of warming by a given time period) are region-specific. Neighboring regions, however, exhibit similar average changes in climate. This spatial similarity indicates that the average change results shown here are not very sensitive to how the region was defined geographically.

By applying the projected changes from the relevant gridbox to observed data, the projections become specific to the region. For example, although Albany's projected change in temperature through time is similar to New York City's, the number of current and projected days per year with temperatures below 32 °F differs between the two locations, with Albany experiencing more cold days than New York, even in a warmer climate, owing to Albany's more northerly (and colder) location. Thus, the spatial variation in baseline climate is much larger than the spatial variation of projected climate changes.

3.1.6 Timeslices

Although it is not possible to predict the temperature, precipitation, or sea level, for a particular day, month, or year in the future, GCMs are valuable risk-assessment tools for projecting the likely range of changes over multidecadal time periods. These projections, known as timeslices, are expressed relative to the baseline period, 1971 to 2000 for temperature and precipitation (2000 – 2004 for sea level rise). The timeslices are centered around a given decade. For example, the 2080s timeslice refers to the period from 2070 to 2099. For sea level rise, the multidecadal approach is not necessary due to lower interannual variability; the 2020s timeslice for sea level (for example) therefore refers to the period from 2020–2029. Thirty-year timeslices (10-year timeslices for sea level rise) are used to provide an indication of the climate normals for those decades. By averaging over this period, much of the random year-to-year variability — or noise — is cancelled out, while the long-term influence of increasing greenhouse gases — or signal — remains.

This update also provides climate projections for 2100. Projections for 2100 require a different approach from the 30-year timeslices centered on the 2020s, 2050s, and 2080s. The primary difference is that because the vast majority of climate model simulations end in 2100, it is not possible to make a projection for the 30-year timeslice centered on the year 2100. Projections for 2100 are an average of two methods that avert this climate model output availability constraint by adding a linear trend to the final timeslice (2080s), and extrapolating that trend to 2100.[6]

3.2 Mean Annual Changes

Higher temperatures and sea level rise are extremely likely for New York State. For temperature and sea level rise, all simulations project continued increases over the century, with the entire central range of the projections indicating more rapid temperature and sea level rise

---

[6] The two techniques are:

a. Add each representative concentration pathway (RCPs) ensemble mean final period linear trend (FPLT) to the final timeslice projections for the corresponding RCP, and calculate the four distribution points (i.e., 10th, 25th, 75th, and 90th percentiles).

b. Add the FPLT from each individual model and RCP to the final timeslice for the corresponding model and RCP, and then calculate the four distribution points (i.e., 10th, 25th, 75th, and 90th percentiles).

* Approaches a and b were averaged to generate projections for 2100.

than occurred during the last century. Although most projections indicate small increases in precipitation, some do not. Natural precipitation variability is large; thus, precipitation projections are less certain than temperature projections. For all variables, the numerical projections for later in this century are less certain than those for earlier in the century (i.e., the ranges of outcomes become larger through time), due to uncertainties in the climate system and the differing possible pathways of the greenhouse gas emission scenarios

3.2.1 Temperature

Average annual temperatures are projected to increase across New York State by 2.0–3.4 °F by the 2020s, 4.1–6.8 °F by the 2050s, and 5.3–10.1 °F by the 2080s[7] (**Table 3**). By the end of the century, the greatest warming is projected to be in the northern parts of the State. The State's growing season could lengthen by about a month, with summers becoming more intense and winters milder. The climate models suggest that each season will experience a similar amount of warming relative to the baseline period.

Beginning in the 2040s, the representative concentration pathways diverge, producing temperature patterns that are distinguishable from each other. This "delayed" divergence is because it takes several decades for the climate system to respond to changes in greenhouse gas concentrations. It also takes decades for different representative concentration pathways to produce large differences in greenhouse gas concentrations.

3.2.2 Precipitation

Regional precipitation across New York State is projected to increase by approximately 1-8 percent by the 2020s, 3-12 percent by the 2050s, and 4-15 percent by the 2080s[7] (**Table 3**). By the end of the century, the greatest increases in precipitation are projected to be in the northern parts of the State. Although seasonal projections are less certain than annual results, much of this additional precipitation is projected to occur during the winter months. During the late summer and early fall, in contrast, total precipitation is slightly reduced in many climate models. In general, the projected changes in annual precipitation in the global climate models associated with increasing greenhouse gases are small relative to year-to-year variability.

Table 3. Mean Annual Changes

Region 1 (Rochester) – Temperature

Baseline (1971-2000) 47.7 °F	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	+ 1.8 °F	+ 2.3 to 3.2 °F	+ 4.0 °F
2050s	+ 3.7 °F	+ 4.3 to 6.3 °F	+ 7.3 °F
2080s	+ 4.2 °F	+ 5.7 to 9.6 °F	+ 12.0 °F
2100	+ 4.6 °F	+ 6.3 to 11.7 °F	+ 13.8 °F

Region 1 (Rochester) – Precipitation

Baseline (1971-2000) 34.0 inches	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	0 percent	+ 2 to + 7 percent	+ 8 percent
2050s	+ 2 percent	+ 4 to + 10 percent	+ 12 percent
2080s	+ 1 percent	+ 4 to + 13 percent	+ 17 percent
2100	- 3 percent	+ 4 to + 19 percent	+ 24 percent

Region 2 (Port Jervis) – Temperature

Baseline (1971-2000) 50.0 °F	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	+ 1.6 °F	+ 2.2 to 3.1 ° F	+ 3.5 °F
2050s	+ 3.1 °F	+ 4.2 to 6.1 °F	+ 6.9 °F
2080s	+ 4.0 °F	+ 5.4 to 9.6 °F	+ 10.7 °F
2100	+ 4.3 °F	+ 6.2 to 11.2 °F	+ 12.6 °F

Region 2 (Port Jervis) – Precipitation

Baseline (1971-2000) 46.0 inches	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	- 1 percent	+ 1 to + 8 percent	+ 10 percent
2050s	+ 1 percent	+ 3 to + 11 percent	+14 percent
2080s	+ 2 percent	+ 6 to + 14 percent	+ 18 percent
2100	- 6 percent	+ 1 to + 18 percent	+ 24 percent

Region 3 (Elmira) – Temperature

Baseline (1971-2000) 47.5 °F	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	+ 1.8 °F	+ 2.3 to 3.3 °F	+ 3.8 °F
2050s	+ 3.6 °F	+ 4.4 to 6.3 °F	+ 7.1 °F
2080s	+ 4.2 °F	+ 5.7 to 9.9 °F	+ 11.6 °F
2100	+ 4.5 °F	+ 6.3 to 11.7 °F	+ 13.8 °F

Region 3 (Elmira) – Precipitation

Baseline (1971-2000) 35.0 inches	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	- 4 percent	+ 1 to + 7 percent	+ 9 percent
2050s	+ 2 percent	+ 4 to + 10 percent	+ 15 percent
2080s	+ 3 percent	+ 6 to + 14 percent	+ 16 percent
2100	- 2 percent	+ 5 to + 20 percent	+ 26 percent

Table 4 continued on next page

---

[7] Presented in the text is the middle range (25th to 75th percentile) of the projections. The 10th and 90th percentile values can be found in Table 3.

Table 3. Mean Annual Changes (continued)

Region 4 (New York City) – Temperature

Baseline (1971-2000) 54.6 °F	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	+ 1.5 °F	+ 2.0 to 2.9 °F	+ 3.2 °F
2050s	+ 3.1 °F	+ 4.1 to 5.7 °F	+ 6.6 °F
2080s	+ 3.8 °F	+ 5.3 to 8.8 °F	+ 10.3 °F
2100	+ 4.2 °F	+ 5.8 to 10.4 °F	+ 12.1 °F

Region 4 (New York City) – Precipitation

Baseline (1971-2000) 49.7 inches	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	- 1 percent	+ 1 to + 8 percent	+ 10 percent
2050s	+ 1 percent	+ 4 to + 11 percent	+ 13 percent
2080s	+ 2 percent	+ 5 to + 13 percent	+ 19 percent
2100	- 6 percent	- 1 to + 19 percent	+ 25 percent

Region 5 (Saratoga) – Temperature

Baseline (1971-2000) 47.6 °F	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	+ 1.7 °F	+ 2.3 to 3.2 °F	+ 3.7 °F
2050s	+ 3.5 °F	+ 4.5 to 6.2 °F	+ 7.1 °F
2080s	+ 4.1 °F	+ 5.6 to 9.7 °F	+ 11.4 °F
2100	+ 4.4 °F	+ 6.1 to 11.4 °F	+ 13.6 °F

Region 5 (Saratoga) – Precipitation

Baseline (1971-2000) 38.6 inches	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	-1 percent	+ 2 to + 7 percent	+ 10 percent
2050s	+ 2 percent	+ 4 to + 12 percent	+ 15 percent
2080s	+ 3 percent	+ 5 to + 15 percent	+ 17 percent
2100	- 1 percent	+ 5 to + 21 percent	+ 26 percent

Region 6 (Watertown) – Temperature

Baseline (1971-2000) 45.4 °F	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	+ 1.9 °F	+ 2.3 to 3.4 °F	+ 3.9 °F
2050s	+ 3.7 °F	+ 4.4 to 6.4 °F	+ 7.2 °F
2080s	+ 4.3 °F	+ 5.9 to 10.0 °F	+ 11.8 °F
2100	+ 4.5 °F	+ 6.3 to 11.9 °F	+ 13.9 °F

Region 6 (Watertown) – Precipitation

Baseline (1971-2000) 42.6 inches	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	0 percent	+ 2 to + 6 percent	+ 8 percent
2050s	+ 2 percent	+ 4 to + 10 percent	+ 13 percent
2080s	+ 3 percent	+ 6 to + 12 percent	+ 15 percent
2100	+ 1 percent	+ 7 to + 20 percent	+ 26 percent

Region 7 (Indian Lake) – Temperature

Baseline (1971-2000) 39.9 °F	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	+ 1.8 °F	+ 2.3 to 3.4 °F	+ 3.8 °F
2050s	+ 3.7 °F	+ 4.5 to 6.4 °F	+ 7.4 °F
2080s	+ 4.2 °F	+ 5.8 to 10.1 °F	+ 11.8 °F
2100	+ 4.4 °F	+ 6.2 to 11.9 °F	+ 13.9 °F

Region 7 (Indian Lake) – Precipitation

Baseline (1971-2000) 40.8 inches	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	0 percent	+ 3 to + 6 percent	+ 9 percent
2050s	+ 2 percent	+ 4 to + 12 percent	+ 15 percent
2080s	+ 3 percent	+ 6 to + 13 percent	+ 17 percent
2100	- 2 percent	+ 8 to + 20 percent	+ 26 percent

Based on 35 GCMs and two Representative Concentration Pathways. Baseline data are for the 1971 to 2000 base period and are from the NOAA National Climatic Data Center (NCDC) Shown are the low-estimate (10th percentile), middle range (25th percentile to 75th percentile), and high-estimate (90th percentile).

Like all projections, these 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. Levels of uncertainty are characterized 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, so the specific numbers should not be emphasized, and the potential for error should be acknowledged.

3.2.3 Sea Level Rise

Sea level is projected to rise along the New York State coastline and in the tidal Hudson by 3-8 inches by the 2020s, 9-21 inches by the 2050s, and 14-39 inches by the 2080s (**Table 4**). The high-end estimate for sea level rise by the 2080s is 58 inches. 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.

3.3 Changes in Extreme Events

The frequencies of heat waves, cold events, intense precipitation, drought, and coastal flooding in the seven regions are projected to change in the coming decades, based on average global climate model shifts (**Table 5**). The average number of extreme events per year for the baseline period is shown, along with the middle range of the model-based projections, defined as the 25th to 75th percentile of the distribution. Because factors other than a shift in the mean could affect extremes, the relative magnitude of projected changes, rather than the actual projected number of events, should be emphasized.

3.3.1 Heat Waves and Cold Events

The total number of hot days in New York State is expected

Table 4. Sea Level Rise Projections

a. Region 4 – Montauk Point

Baseline (2000-2004) 0 inches	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	2 in	4 to 8 in	10 in
2050s	8 in	11 to 21 in	30 in
2080s	13 in	18 to 39 in	58 in
2100	15 in	21 to 47 in	72 in

b. Region 4 – New York City

Baseline (2000-2004) 0 inches	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	2 in	4 to 8 in	10 in
2050s	8 in	11 to 21 in	30 in
2080s	13 in	18 to 39 in	58 in
2100	15 in	22 to 50 in	75 in

c. Region 5 – Troy Dam

Baseline (2000-2004) 0 inches	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
2020s	1 in	3 to 7 in	9 in
2050s	5 in	9 to 19 in	27 in
2080s	10 in	14 to 36 in	54 in
2100	11 in	18 to 46 in	71 in

Projections are based on a 6-component approach that incorporates both local and global factors. The model-based components are from 24 GCMs and two Representative Concentration Pathways. Shown are the low-estimate (10th percentile), middle range (25th percentile to 75th percentile), and high-estimate (90th percentile). Projections are relative to the 2000-2004 base period.

Like all projections, these 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. Levels of uncertainty are characterized 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, so the specific numbers should not be emphasized, and the potential for error should be acknowledged.

to increase as this century progresses. The frequency and duration of heat waves, defined as three or more consecutive days with maximum temperatures at or above 90 °F, are also expected to increase (**Table 5**). In contrast, extreme cold events, defined both as the number of days per year with minimum temperature at or below 32 °F and those at or below 0 °F, are expected to decrease as average temperatures rise. While some research suggests that loss of Arctic sea ice could paradoxically lead to more cold air outbreaks (e.g., Liu et al. 2012), the balance of evidence suggests that as the century progresses, cold air outbreaks will become increasingly rare. Some parts of each region, such as cold high-altitude zones, are likely to experience fewer heat events and more cold events in the future than regional averaging would suggest because these areas have colder baseline climates.

Table 5. Extreme Event Projections

a. Region 1 – Rochester

2020s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (8 days)	12	14 to 17	19
# of Heat Waves (0.7 heat waves)	2	2 to 2	2
Duration of Heat Waves (4 days)	4	4 to 4	4
Days below 32 °F (133 days)	99	103 to 111	116
Days over 1” Rainfall (5 days)	4	5 to 5	6
Days over 2” Rainfall (0.6 days)	0.6	0.6 to 0.7	0.8

2050s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (8 days)	18	22 to 34	42
# of Heat Waves (0.7 heat waves)	2	3 to 4	5
Duration of Heat Waves (4 days)	4	4 to 5	5
Days below 32 °F (133 days)	78	84 to 96	102
Days over 1” Rainfall (5 days)	4	5 to 5	6
Days over 2” Rainfall (0.6 days)	0.5	0.6 to 0.8	0.9

2080s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (8 days)	22	27 to 57	73
# of Heat Waves (0.7 heat waves)	3	3 to 8	8
Duration of Heat Waves (4 days)	4	5 to 6	6
Days below 32 °F (133 days)	59	68 to 88	97
Days over 1” Rainfall (5 days)	4	5 to 6	7
Days over 2” Rainfall (0.6 days)	0.5	0.6 to 0.9	1

Table 5 continued on next page

Table 5. Extreme Event Projections (continued)

b. Region 2 – Port Jervis

2020s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (12 days)	16	19 to 25	27
# of Heat Waves (1 heat wave)	2	3 to 3	4
Duration of Heat Waves (4 days)	4	5 to 5	5
Days below 32 °F (138 days)	106	108 to 116	120
Days over 1” Rainfall (12 days)	11	12 to 13	14
Days over 2” Rainfall (2 days)	2	2 to 2	3

2050s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (12 days)	24	31 to 47	56
# of Heat Waves (1 heat wave)	3	4 to 6	8
Duration of Heat Waves (4 days)	5	5 to 6	6
Days below 32 °F (138 days)	79	86 to 100	108
Days over 1” Rainfall (12 days)	12	13 to 14	15
Days over 2” Rainfall (2 days)	2	2 to 3	3

2080s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (12 days)	31	38 to 77	85
# of Heat Waves (1 heat wave)	4	5 to 9	9
Duration of Heat Waves (4 days)	5	5 to 7	8
Days below 32 °F (138 days)	59	65 to 89	101
Days over 1” Rainfall (12 days)	12	13 to 15	16
Days over 2” Rainfall (2 days)	2	2 to 3	3

c. Region 3 – Elmira

2020s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (10 days)	15	17 to 21	23
# of Heat Waves (1 heat wave)	2	2 to 3	3
Duration of Heat Waves (4 days)	4	4 to 5	5
Days below 32 °F (152 days)	119	122 to 130	134
Days over 1” Rainfall (6 days)	6	6 to 7	7
Days over 2” Rainfall (0.6 days)	0.6	0.7 to 0.9	1

2050s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (10 days)	22	26 to 41	47
# of Heat Waves (1 heat wave)	3	3 to 6	6
Duration of Heat Waves (4 days)	5	5 to 5	5
Days below 32 °F (152 days)	94	100 to 114	120
Days over 1” Rainfall (6 days)	6	6 to 7	8
Days over 2” Rainfall (0.6 days)	0.7	0.8 to 1	1

2080s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (10 days)	28	33 to 67	79
# of Heat Waves (1 heat wave)	3	4 to 9	9
Duration of Heat Waves (4 days)	5	5 to 6	7
Days below 32 °F (152 days)	72	79 to 103	116
Days over 1” Rainfall (6 days)	6	7 to 8	8
Days over 2” Rainfall (0.6 days)	0.7	0.8 to 1	1

Table 5. Extreme Event Projections (continued)

d. Region 4 – New York City

2020s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (18 days)	24	26 to 31	33
# of Heat Waves (2 heat waves)	3	3 to 4	4
Duration of Heat Waves (4 days)	5	5 to 5	5
Days below 32 °F (71 days)	50	52 to 58	60
Days over 1” Rainfall (13 days)	13	14 to 15	16
Days over 2” Rainfall (3 days)	3	3 to 4	5

2050s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (18 days)	32	39 to 52	57
# of Heat Waves (2 heat waves)	4	5 to 7	7
Duration of Heat Waves (4 days)	5	5 to 6	6
Days below 32 °F (71 days)	37	42 to 48	52
Days over 1” Rainfall (13 days)	13	14 to 16	17
Days over 2” Rainfall (3 days)	3	4 to 4	5

2080s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (18 days)	38	44 to 76	87
# of Heat Waves (2 heat waves)	5	6 to 9	9
Duration of Heat Waves (4 days)	5	5 to 7	8
Days below 32 °F (71 days)	25	30 to 42	49
Days over 1” Rainfall (13 days)	14	15 to 17	18
Days over 2” Rainfall (3 days)	3	4 to 5	5

e. Region 5 – Saratoga

2020s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (10 days)	14	17 to 22	23
# of Heat Waves (1 heat waves)	2	2 to 3	4
Duration of Heat Waves (4 days)	4	5 to 5	5
Days below 32 °F (155 days)	123	127 to 136	139
Days over 1” Rainfall (10 days)	10	10 to 11	12
Days over 2” Rainfall (1 day)	1	1 to 2	2

2050s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (10 days)	22	27 to 41	50
# of Heat Waves (1 heat waves)	3	4 to 6	7
Duration of Heat Waves (4 days)	5	5 to 6	6
Days below 32 °F (155 days)	98	104 to 119	125
Days over 1” Rainfall (10 days)	10	11 to 12	13
Days over 2” Rainfall (1 day)	1	1 to 2	2

2080s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (10 days)	27	35 to 70	82
# of Heat Waves (1 heat waves)	4	5 to 8	9
Duration of Heat Waves (4 days)	5	5 to 7	9
Days below 32 °F (155 days)	77	84 to 109	120
Days over 1” Rainfall (10 days)	10	11 to 13	14
Days over 2” Rainfall (1 day)	1	1 to 2	2

Table 5 continued on next page

Table 5. Extreme Event Projections (continued)

f. Region 6 – Watertown

2020s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (3 days)	5	6 to 8	10
# of Heat Waves (0.2 heat waves)	0.6	0.8 to 0.9	1
Duration of Heat Waves (4 days)	3	4 to 4	4
Days below 32 °F (147 days)	116	119 to 126	130
Days over 1” Rainfall (6 days)	6	7 to 8	8
Days over 2” Rainfall (0.8 days)	0.6	0.7 to 1	1

2050s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (3 days)	9	12 to 21	26
# of Heat Waves (0.2 heat waves)	1	1 to 3	3
Duration of Heat Waves (4 days)	4	4 to 4	5
Days below 32 °F (147 days)	96	102 to 113	119
Days over 1” Rainfall (6 days)	7	7 to 8	9
Days over 2” Rainfall (0.8 days)	0.7	0.7 to 1	1

2080s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (3 days)	12	17 to 44	57
# of Heat Waves (0.2 heat waves)	1	2 to 6	7
Duration of Heat Waves (4 days)	4	4 to 6	6
Days below 32 °F (147 days)	78	85 to 104	114
Days over 1” Rainfall (6 days)	7	7 to 9	10
Days over 2” Rainfall (0.8 days)	0.7	0.8 to 1	1

g. Region 7 – Indian Lake

2020s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (0.3 days)	0.5	0.8 to 2	2
# of Heat Waves (0 heat waves)	0	0.1 to 0.2	0.2
Duration of Heat Waves (3 days)	3	3 to 4	4
Days below 32 °F (193 days)	159	162 to 172	177
Days over 1” Rainfall (7 days)	7	7 to 8	9
Days over 2” Rainfall (0.8 days)	0.7	0.8 to 1	1

2050s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (0.3 days)	2	3 to 6	10
# of Heat Waves (0 heat waves)	0.2	0.3 to 0.7	1
Duration of Heat Waves (3 days)	3	3 to 4	4
Days below 32 °F (193 days)	131	138 to 154	161
Days over 1” Rainfall (7 days)	7	8 to 9	10
Days over 2” Rainfall (0.8 days)	0.8	0.9 to 1	1

2080s	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Days over 90 °F (0.3 days)	3	5 to 19	27
# of Heat Waves (0 heat waves)	0.2	0.5 to 2	3
Duration of Heat Waves (3 days)	4	4 to 5	5
Days below 32 °F (193 days)	107	118 to 143	156
Days over 1” Rainfall (7 days)	8	8 to 10	11
Days over 2” Rainfall (0.8 days)	0.8	0.9 to 1	1

Projections for temperature and precipitation are based on 33GCMs and 2 RCPs. Baseline data (shown in parenthesis) are for the 1971 to 2000 base period and are from the NOAA National Climatic Data Center (NCDC). Shown are the low-estimate (10th percentile), middle range (25th to 75th percentile), and high-estimate (90th percentile) 30-year mean values from model-based outcomes. 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.

Like all projections, these 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. Levels of uncertainty are characterized 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, so the specific numbers should not be emphasized, and the potential for error should be acknowledged.

3.3.2 Intense Precipitation

Although the increase in total annual precipitation is projected to be relatively small, larger increases are projected in the frequency, intensity, and duration of extreme precipitation events (defined as events with more than 1, 2, or 4 inches of rainfall) at daily timescales. The projections for New York State are consistent with global projections (Meehl et al. 2007) and with trends observed nationally (Karl and Knight 1998, Kunkel et al., 2008).

3.3.3 Coastal Floods and Storms

As sea levels rise, coastal flooding associated with storms will very likely increase in intensity, frequency, and duration. The changes in coastal flood intensity and height shown in **Table 6** are solely due to gradual changes in sea level through time. Any increase in the frequency or intensity of storms themselves would result in even more frequent large flood events. By the end of this century, sea level rise alone will contribute to a significant increase in large coastal floods; coastal flood levels that currently occur once per decade on average may occur once every one to three years. Due to sea level rise alone, flooding at the level currently associated with the 100-year flood may occur about 19 times as often by the end of the century. It should be noted that the more severe current 100-year flood event is less well characterized than the less severe current 10-year flood, due to the limited length of the historical record.

The relative flood vulnerability between locations is likely to remain similar in the future. Thus, the future flood heights projected for the Battery (the southern tip of Manhattan) are likely to exceed flood heights for portions of the State that currently experience lower flood heights[8] than the Battery.

3.3.4 Other Extreme Events

Some of the extreme events that have a large impact throughout the state cannot be quantitatively projected into the future at local scales due to high degree of uncertainty (e.g., Vose et al. 2014, Kunkel et al. 2013). Qualitative information for some of these factors is discussed in this section, including:

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

Table 6. Coastal Flood Heights and Return Periods for the Battery, NY (Region 4)

a. 2020s

	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Annual chance of today's 100-year flood (1 percent)	1.1 percent	1.2 to 1.5 percent	1.6 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

b. 2050s

	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Annual chance of today's 100-year flood (1 percent)	1.5 percent	1.7 to 2.9 percent	4.5 percent
Flood heights associated with 100-year flood (stillwater+wave heights) (15.0 feet)	15.7 feet	15.9 to 16.8 feet	17.5 feet

c. 2080s

	Low Estimate (10th Percentile)	Middle Range (25th to 75th Percentile)	High Estimate (90th Percentile)
Annual chance of today's 100-year flood (1 percent)	2.0 percent	2.4 to 7.1 percent	18.5 percent
Flood heights associated with 100-year flood (stillwater+wave heights) (15.0 feet)	16.1 feet	16.5 to 18.3 feet	19.9 feet

Shown are the low-estimate (10th percentile), middle range (25th to 75th percentile), and high-estimate (90th percentile) 10-year mean values from model-based outcomes. Flood heights are derived by adding the sea level rise projections for the corresponding percentiles to the baseline values. Baseline flood heights associated with the 100-year flood are based on the stillwater plus wave heights. Flood heights are referenced to the NAVD88 datum. Source: NPCC, 2013

By the end of the century, extreme heat indices (which combine temperature and the amount of moisture in the air) 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 more moisture in the air can produce severe health effects by restricting the human body's ability to cool itself.

---

[8] Flood heights differ for reasons including coastal bathymetry and orientation of the coastline relative to storm trajectories.

Annual ice cover has decreased 71 percent on the Great Lakes since 1973; models suggest this decrease will lead to increased lake-effect snow in the next couple of decades through greater moisture availability (Burnett et al. 2003). By mid-century, lake-effect snow will generally decrease as temperatures below freezing become less frequent (Kunkel et al. 2002). The high ice extent of the 2013-2014 winter highlights the fact that natural variability is expected to continue, even as long-term trends gradually shift the statistics in favor of low-ice winters.

By the end of the century, it is more likely than not that late-summer short-duration droughts will increase in New York State (Horton et al. 2011a). It is unknown how multi-year drought risk may change in the future.

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 previous section on extreme precipitation. Changes in lightning are currently too uncertain to support even qualitative statements (Vose et al. 2014).

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, although it is plausible that higher temperatures in cold parts of the State (where temperatures are often far below freezing in the current climate) could support higher snowfall totals during individual snow events (because of the increase in moisture-holding capacity of a warmer atmosphere). It is unknown how the frequency and intensity of ice storms and freezing rain may change.

It is unknown how the total number of tropical cyclones will change in the North Atlantic Basin (Horton and Liu 2014). However, it is more likely than not that the number of the most intense hurricanes will increase in the North Atlantic Basin, along with the extreme winds associated with these strong storms (IPCC 2012). Even if the strongest hurricanes become more frequent in the North Atlantic Basin, the implications for New York State are unclear because individual storm tracks are highly variable and potential changes in tropical cyclone tracks are poorly understood (Kozar et al. 2013, Christensen et al. 2013). As the ocean and atmosphere continue to warm, intense precipitation from hurricanes will more likely than not increase as well (Knutson et al. 2010, IPCC 2012). It is unknown how nor'easters in the Northeast may change in the future, although one recent study (Colle et al. 2013) using CMIP5 models projects nor'easter tracks could shift to the west, potentially increasing impacts for parts of New York State.

4 Conclusions and Recommendations

As the 21st century progresses, increasing greenhouse gas concentrations are projected to lead to large increases in the frequency, intensity, and duration of both extreme heat events and coastal flooding. Intense precipitation events are also projected to become increasingly frequent, mirroring observed trends for the Northeast region. Cold air outbreaks, in contrast, are projected to gradually become less and less frequent. Steady increases in average temperature, precipitation, and sea level are also projected to pose unique challenges to New York State.

The results described here are generally consistent with the original ClimAID findings (Rosenzweig et al. 2011; Horton et al. 2011). By the 2080s, the range and upper bound are slightly higher, due to the inclusion of more climate models (35 models now, as opposed to 16 originally) and the fact that RCP8.5 is a slightly higher-end scenario than A2 by the 2080s. Given uncertainties, specific differences in the quantitative projections between the original and updated reports should not be emphasized.

Although the climate information presented here is essential for impact and adaptation assessment, several caveats are necessary. First, more research is needed on how variability may change in the future. Second, research is also needed on how conditions in unique microclimates may differ from the regional projections provided here. Examples include the subalpine environments of the Adirondack High Peaks region, portions of western New York that sit in lake-effect snow zones, and the Atlantic coast, where changes in land-sea contrasts could modify the rate of warming under certain weather regimes. Third, the climate models and representative concentration pathways described here do not capture the full range of possible changes in mean conditions.

Although climate models are the best tools for projecting future changes, it is possible that climate sensitivity to changes in greenhouse gas concentrations could exceed or fall below the range in the global climate models used here. For example, the rapid loss of Arctic sea ice at rates in excess of climate model projections (Liu et al. 2013) could, through positive feedbacks, lead to more rapid warming than climate models project. Similarly, greenhouse gas concentrations could end up outside the range of the two RCPs used here. Given the extreme climate changes projected under the RCP 8.5 scenario, risk management in New York State could hinge on a suite of aggressive greenhouse gas mitigation strategies to complement ambitious adaptation initiatives.

5 References

Arnell, N.W. 1996. *Global Warming, River Flows, and Water Resources.* Chichester, United Kingdom: Wiley.

Bamber, J. L., and Aspinall, W. P. 2013. An expert judgement assessment of future sea level rise from the ice sheets. *Nature Clim. Change, 3*(4), 424-427.

Burnett, A.W., Kirby, M.E., Mullins, H.T., and Patterson, W.P. 2003. Increasing Great Lake–Effect Snowfall during the Twentieth Century: A Regional Response to Global Warming? *Journal of Climate, 16*(21), 3535-3542. doi: 10.1175/1520-0442(2003)016<3535:IGLSDT>2.0.CO:2

Charlson, R. J. 1998. Direct Climate Forcing by Anthropogenic Sulfate Aerosols: The Arrhenius Paradigm a Century Later. In *The Legacy of Svante Arrhenius. Understanding the Greenhouse Effect,* edited by Henning Rodhe and Robert Charlson, 59-71. Stockholm: Royal Swedish Academy of Sciences.

Christensen, J.H., Krishna Kumar, K., Aldrian, E., An, S.-I., Cavalcanti, I.F.A., de Castro, M., ... Zhou, T. 2013. Climate Phenomena and their Relevance for Future Regional Climate Change. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 1218-1308). Cambridge, United Kingdom: Cambridge University Press

Church, J. A. et al. 2011. Revisiting the Earth's sea-level and energy budgets from 1961 to 2008. *Geophysical Research Letters, 38*(18), L18601. doi: 10.1029/2011GL048794

City of New York. 2013. New York City Special Initiative on Rebuilding and Resiliency. "A Stronger More Resilient New York" (pp. 438).

Colle, B. A., Zhang, Z., Lombardo, K. A., Chang, E., Liu, P. and Zhang, M. (2013). Historical Evaluation and Future Prediction of Eastern North American and Western Atlantic Extratropical Cyclones in the CMIP5 Models during the Cool Season. *Journal of Climate,* 26(18), 6882-6903. doi: 10.1175/JCLI-D-12-00498.1

Gleick, P.H. 1986. Methods for evaluating the regional hydrologic effects of global cliamte changes. *Journal of Hydrology*, 88, 97-116.

Gomez, N., Mitrovica, J.X., Huybers, P. and Clark, P.U. (2010). Sea level as a stabilizing factor for marine-ice-sheet grounding lines. *Nature Geosci,* 3(12), 850-853.

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

Hartmann, D.L., A.M.G. Klein Tank, M. Rusticucci, L.V. Alexander, S. Brönnimann, Y. Charabi, F.J. Dentener, E.J. Dlugokencky, D.R. Easterling, A. Kaplan, B.J. Soden, P.W. Thorne, M. Wild and P.M. Zhai. (2013). Observations: Atmosphere and Surface. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Ed.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 159-254). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Horton, R. et al. (2014). Chapter 16: Northeast. In J. M. Melillo, T. C. Richmond & G. W. Yohe (Eds.), *Climate Change Impacts in the United Steas: The Third National Climate Assessment* (pp. 371-395): U.S. Global Change Research Program.

Horton, R. M., and J. Liu, 2014: Beyond Hurricane Sandy: What Might the Future Hold for Tropical Cyclones in the North Atlantic? *Journal of Extreme Events*, 01, 1450007 DOI: 10.1142/S2345737614500079

Horton, R., D. A. Bader, L. Tryhorn, A. DeGaetano, and C. Rosenzweig, 2011a: Climate Risks. *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation: Technical Report.,* C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, and P. Grabhorn, Eds., New York State Energy Research and Development Authority, 15-48.

Horton, R.M., Gornitz, V., Bader, D.A., Ruane, A.C., Goldberg, R., & Rosenzweig, C. 2011b. Climate Hazard Assessment for Stakeholder Adaptation Planning in New York City. *Journal of Applied Meteorology and Climatology, 50*(11), 2247-2266. doi: 10.1175/2011JAMC2521.1

IPCC. 2000. *Special Report: Emissions Scenarios.* Nebojsa Nakicenovic, N., and Swart, R. (Eds.). Cambridge, UK: Cambridge University Press.

IPCC. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

IPCC. 2012: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Cambridge, UK: Cambridge University Press.

IPCC. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

Karl, T.R. and Knight, R.W. 1998. Secular Trends of Precipitation Amount, Frequency, and Intensity in the United States. *Bulletin of the American Meteorological Society, 79*(2), 231-241. doi: 10.1175/1520-0477(1998)079<0231:STOPAF>2.0.CO;2

Knutson, T. R. et al. 2010. Tropical cyclones and climate change. *Nature Geosci. 3*(3), 157-163.

Knutti, R. and Sedlacek, J. 2013. Robustness and uncertainties in the new CMIP5 climate model projections. *Nature Clim. Change, 3*(4), 369-373.

Kozar, M.E., Mann, M.E., Emanuel, K. A. and Evans, J. L. 2013. Long-term variations of North Atlantic tropical cyclone activity downscaled from a coupled model simulation of the last millennium. *Journal of Geophysical Research: Atmospheres, 118*(24), 13,383-313,392. doi: 10.1002/2013JD020380

Kunkel, K. E. 2002. Assessment of Potential Effects of Climate Change on Heavy Lake-Effect Snowstorms Near Lake Erie. *Journal of Great Lakes research, 28*(4), 521-536. doi: 10.1016/S0380-1330(02)70603-5

Kunkel, K.E., Bromirski, P.D., Brooks, H.E., Cabazos, T., Douglas, A.V., Emanuel, K.A., ... Smith, R.L. 2008. Observed changes in weather and climate extremes *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands* (pp. 222). Washington, DC: A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.

Kunkel, K. E. et al. 2013. Monitoring and Understanding Trends in Extreme Storms: State of Knowledge. *Bulletin of the American Meteorological Society,* 94, 499-514.

Le Quere, C. 2009. Trends in the sources and sinks of carbon dioxide. *Nature Geoscience, 2,* 831-836.

Liu, J., Curry, J.A., Wang, H., Song, M. and Horton, R. M. 2012. Impact of declining Arctic sea ice on winter snowfall. *Proceedings of the National Academy of Sciences, 109*(11), 4074-4079. doi: 10.1073/pnas.1114910109

Liu, J., Song, M., Horton, R.M., & Hu, Y. 2013. Reducing spread in climate model projections of a September ice-free Arctic. Proceedings of the National Academy of Sciences, 110(31), 12571-12576. doi: 10.1073/pnas.1219716110

Marzeion, B., Jarosch, A. H. and Hofer, M. 2012. Past and future sea-level change from the surface mass balance of glaciers. *The Cryosphere,* 6(6), 1295-1322. doi: 10.5194/tc-6-1295-2012

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., ... Zhao, Z.-C. (2007). Global Climate Projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averty, M. Tignor and H. L. Miller (Eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 94 pp). Cambridge, United KingdomCambridge University Press.

Menne. M. J., Williams, Jr., C.N., and Vose, R.S. 2013. United States Historical Climatology Network (USHCN) Version 2.5 Serial Monthly Dataset. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Milly, P. C. D. et al. 2010. Terrestrial Water-Storage Contributions to Sea-Level Rise and Variability *Understanding Sea-Level Rise and Variability* (pp. 226-255): Wiley-Blackwell.

Mitrovica, J.X., Gomez, N., & Clark, P.U. (2009). The Sea-Level Fingerprint of West Antarctic Collapse. *Science, 323*(5915), 753. doi: 10.1126/science.1166510

Moss, R. H. et al. 2010. The next generation of scenarios for climate change research and assessment. *Nature, 463*(7282), 747-756.

New York City Panel on Climate Change (NPCC). 2013. *Climate Risk Information 2013: Observations, Climate Change Projections, and Maps.* New York, NY: Prepared for use by the City of New York Special Initiative on Rebuilding and Resiliency.

New York City Panel on Climate Change (NPCC). 2014. *A Knowledge Base for Cliamte Resilience in New York City: Post-Hurricane Sandy Science and Assessment.* C. Rosenzweig and W. Solecki (Eds.) Forthcoming.

New York State Climate Office. 2003. "The Climate of New York: Snowfall." Updated 1 July 2003. Accessed 29 June 2010 http://nysc.eas.cornell.edu/climate_of_ny.html

Peltier, W. R. 2004. Global Glacial Isostasy and the Surface of the Ice-AgreEarth:The ICE-5G (VM2) Model and GRACE. *Annual Review of Earth and Planetary Sciences,* 32, 111-149.

Perrette, M., Landerer, F., Riva, R., Frieler, K., and Meinshausen, M. 2013. A scaling approach to project regional sea level rise and its uncertainties. *Earth Syst. Dynam., 4*(1), 11-29. doi: 10.5194/esd-4-11-2013

Radić, V., Bliss, A., Beedlow, A. C., Hock, R., Miles, E. and Cogley, J. G. 2014. Regional and global projections of twenty-first century glacier mass changes in response to climate scenarios from global climate models. *Climate Dynamics, 42*(1-2), 37-58. doi: 10.1007/s00382-013-1719-7

Ramanathan, V. and Vogelmann, A. M. 1997. Greenhouse Effect, Atmospheric Solar Absorption and the Earth's Radiation Budget: From the Arrhenius-Langley Era to the 1990s. *Ambio, 26*(1), 38-46. doi: 10.2307/4314548

Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn (Eds.). 2011. *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation.* Technical Report 11-18. New York State Energy Research and Development Authority (NYSERDA), Albany, NY. nyserda.ny.gov

Slangen, A. B. A., Katsman, C. A., Wal, R. S. W., Vermeersen, L. L. A., and Riva, R. E. M. 2012. Towards regional projections of twenty-first century sea-level change based on IPCC SRES scenarios. *Climate Dynamics, 38*(5-6), 1191-1209. doi: 10.1007/s00382-011-1057-6

Stroeve, J.C., Serreze, M.C., Holland, M.M., Kay, J.E., Malanik, J., & Barrett, A.P. 2012. The Arctic's rapidly shrinking sea ice cover: a research synthesis. *Climatic Change, 110*(3-4), 1005-1027. doi: 10.1007/s10584-011-0101-1

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2011). An Overview of CMIP5 and the Experiment Design. *Bulletin of the American Meteorological Society, 93*(4), 485-498. doi: 10.1175/BAMS-D-11-00094.1

van Vuuren, D.P., Edmonds, J. A., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K. A., ... Rose, S. K. (2011). The representative concentration pathways: an overview. *Climatic Change, 109*(1-2), 5-31. doi: 10.1007/s10584-011-0148-z

Vose, R. S., Applequist, S., Bourassa, M. A., Pryor, S.C., Barthelmie, R. J., Blanton, B., ... Young, R. S. (2014). Monitoring and Understanding Changes in Extremes: Extratropical Storms, Winds, and Waves. *Bulletin of the American Meteorological Society, 95*(3), 377-386. doi: 10.1175/BAMS-D-12-00162.1

Wilby, R. L., Charles, S., Zorita, E., Timbal, B., Whetton, P., and Mearns, L. (2004). Guidelines for use of climate scenarios developed from statistical downscaling methods. IPCC Supporting Material, available from the DDC of IPPC TGCIA (pp. 27).

New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, New York 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

Climate Change in New York State

Updating the 2011 ClimAID Climate Risk Information Supplement to NYSERDA Report 11-18 (Responding to Climate Change in New York State)

Final Report
September 2014

ISBN: 978-1-936842-08-7

State of New York
Andrew M. Cuomo, Governor

New York State Energy Research and Development Authority
Richard L. Kauffman, Chair | John B. Rhodes, President and CEO