Chapter 2
Climate Projections and Vulnerabilities

Introduction to Climate Change[1,2]

Climate change is occurring in New York and around the globe. Global mean temperatures and sea levels have been increasing for the last century, accompanied by other changes in the Earth's climate. While Earth's climate is subject to natural variation, the changes we currently see in our climate result largely from human activities, which have increased atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs), as well as aerosols (black carbon and sulfate). The natural greenhouse effect keeps the Earth warm enough to support life, but higher amounts of GHGs from human activities have increased average global temperatures and led to other climate changes and effects. Relatively small increases in average global temperature can cause large changes in the Earth's climate system. Warming of the Earth is unequivocal, documented by observations of higher global average air, land surface, and ocean temperatures; widespread melting of mountain glaciers and ice sheets; and rising global average sea level.[3] Figure 2-1 depicts the trends of these key climate indicators.[4]

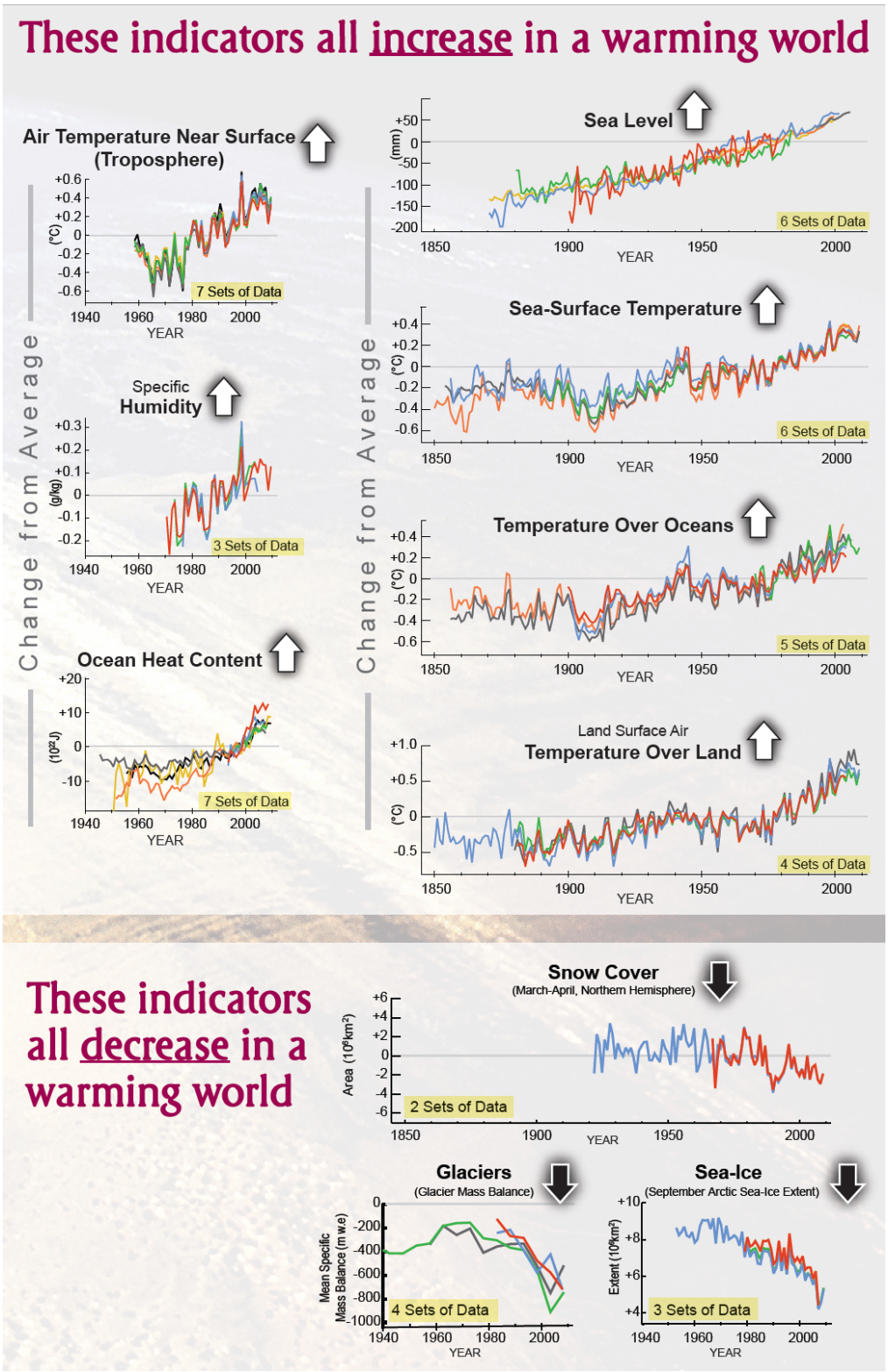
[1] Climate science is complex and evolving. Much of the text in this chapter on New York's climate and vulnerability to climate change is from the ClimAID project (see Appendix H for the draft summary report). For a more thorough description of climate change in New York State, including references, please see the draft of the full ClimAID report available at www.nyserda.org/programs/environment/emep/home.asp . For additional information on climate science and national and global impacts of climate change we recommend the reader consult summary documents from the US National Academy of Sciences, the Intergovernmental Panel on Climate Change (IPCC), United States federal agencies including the National Oceanic and Atmospheric Administration (NOAA) and Environmental Protection Agency (EPA), and peer reviewed scientific literature.

[2] Definitions of many climate science terms can be found in an appendix at the end of this chapter.

[3] Intergovernmental Panel for Climate Change. *Climate Change 2007: Synthesis Report; Summary for Policymakers*. 2007. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm

[4] National Oceanic and Atmospheric Administration. *The State of the Climate Highlights*. 2009. http://www.ncdc.noaa.gov/bams-state-of-the-climate/

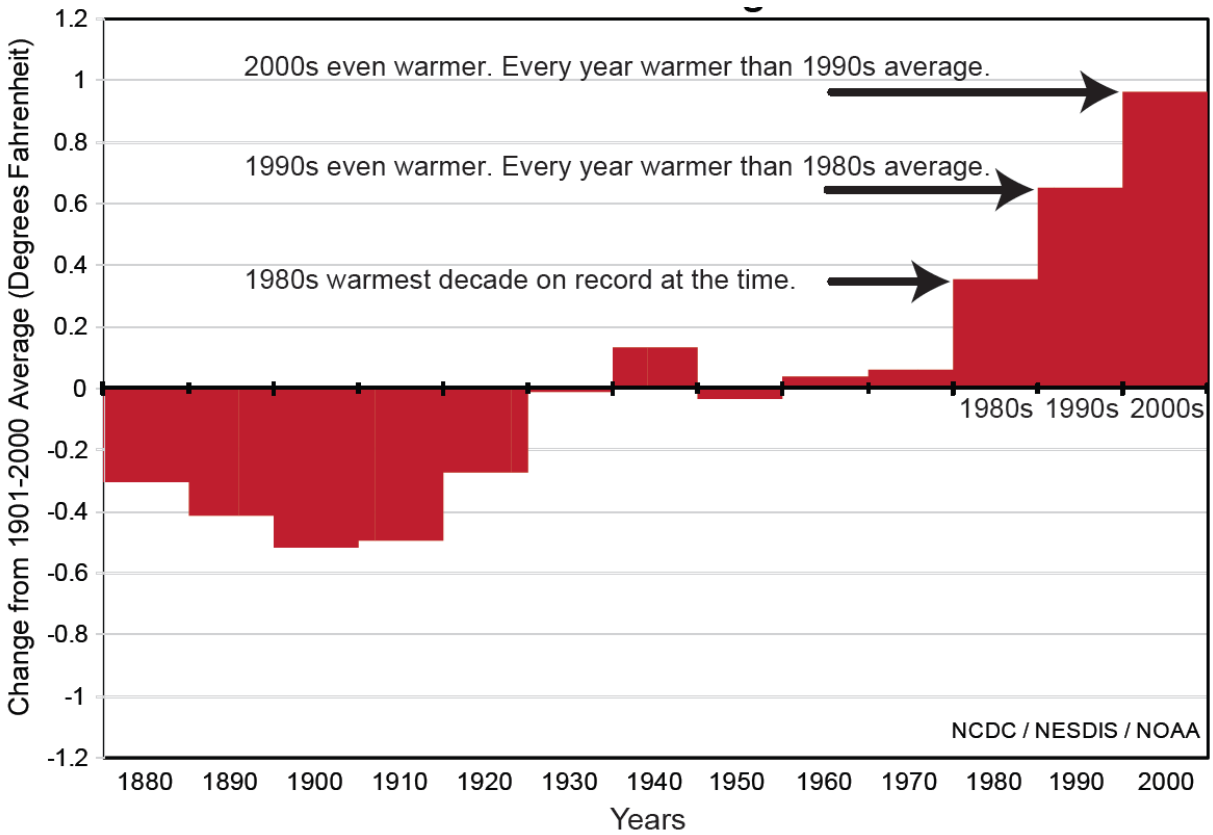
Figure 2-1. Indicators of a Warming World



The panels show changes in climate indicators over several decades. Each of the different colored lines in each panel represents an independently analyzed dataset. *Source: The State of the Climate Highlights: National Oceanic and Atmospheric Administration (NOAA), 2009.*

In the approximately 150 years since industrialization began, concentrations of GHGs in the Earth's atmosphere have risen to higher levels than at any time in the past 800,000 years; atmospheric concentrations of CO_2 are now more than one-third higher than in pre-industrial times. The most rapid rates of warming have occurred during the past 35 years. Each of the last three decades has been much warmer than the decade before it, with each one setting a new and significant record for the highest global temperature. Figure 2-2 depicts this decade-to-decade warming.

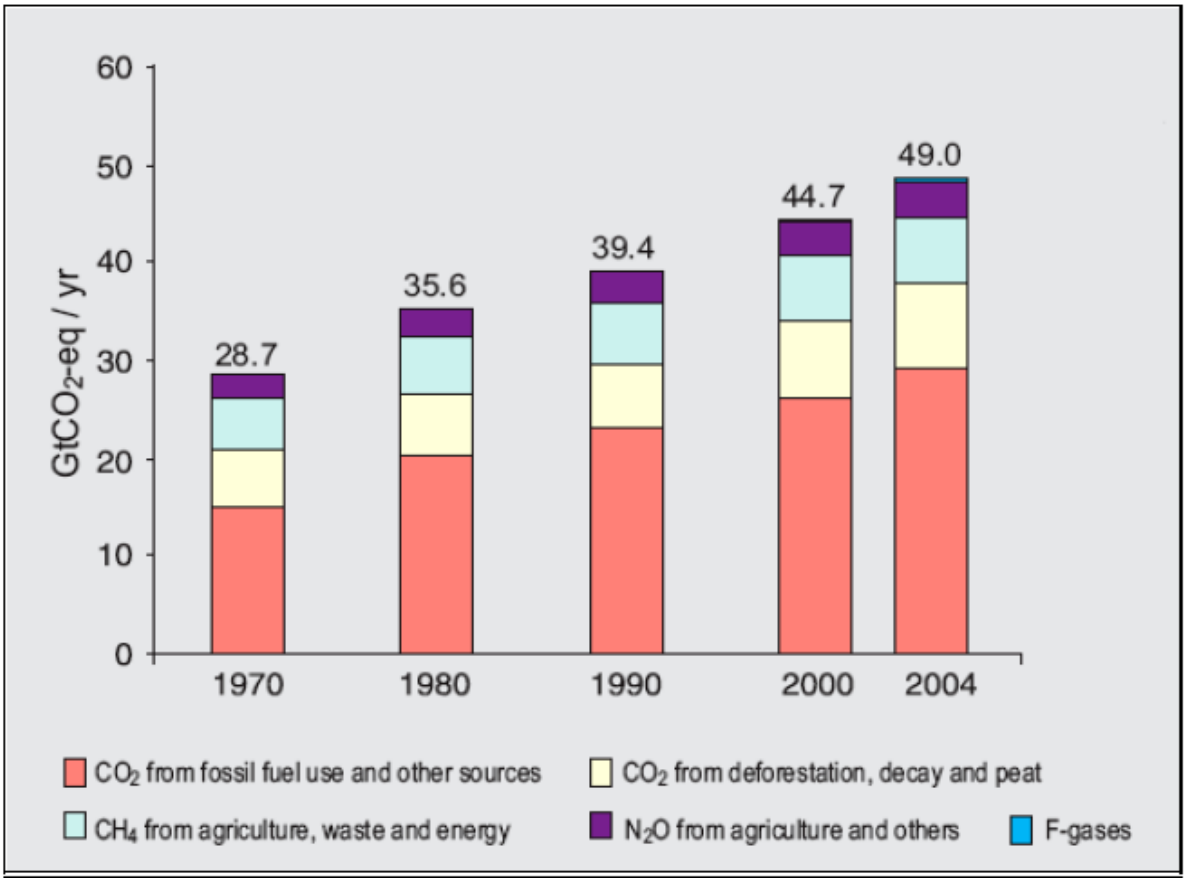
Figure 2-2. Global Temperature Change, Decade Averages



Source: *The State of the Climate Highlights: National Oceanic and Atmospheric Administration*, 2009.

Many human activities contribute GHGs to the atmosphere, but the primary contributor is combustion of fossil fuels (coal, oil, and natural gas), which releases large amounts of CO_2 to the air. Particulate emissions (such as black carbon) from the combustion of fossil fuels and biomass, while short-lived in the atmosphere, also contribute to climate change. Other GHGs, especially methane, nitrous oxide, and halocarbons such as fluorocarbons (F-gases in Figure 2-3), are also released to the atmosphere by human activities, primarily due to fuel combustion and agricultural and industrial processes. As shown in Figure 2-3, global annual emissions of anthropogenic GHGs have increased significantly since 1970.

Figure 2-3. Global Emissions of Anthropogenic Greenhouse Gases, 1970 to 2004



Global annual emissions of anthropogenic GHGs increased significantly from 1970 to 2004. Source: IPCC. *Climate Change 2007: Synthesis Report, Summary for Policymakers*, Figure SPM3 [modified], p.5.

Efforts to lessen the severity of climate change by limiting levels of anthropogenic GHG emissions are already underway in some areas around the globe. However, because the added GHGs will remain in the atmosphere for centuries and some parts of the climate system respond gradually, awareness is growing that some additional climate changes are inevitable. Responses to climate change have grown beyond a focus solely on *mitigating* the amount of GHGs released into the atmosphere to include *adaptation* measures that minimize and prepare for the *effects* of anticipated climate change.

Projections of Future Global Climate Change

Climate scientists use analyses of historical climate conditions combined with complex, computer-based, global climate models to project how the climate will respond in the future to natural and anthropogenic forcings, such as increased GHG concentrations. The models run many different scenarios of future GHG emissions based on estimates of economic and social growth. Model output provides ranges of future temperature increases, rather than point estimates, primarily due to uncertainty regarding which future scenario will occur and limitations in knowledge of how the climate system will respond. Despite the uncertainties, all global climate models project that the Earth will warm in the next century, with a consistent geographical pattern.

Climate model experiments show that even if no additional GHGs were added to the atmosphere, further warming still would occur due mainly to a lag in ocean temperature response. Many of the GHGs currently being added to the Earth's atmosphere have long residence times. For example, 33 percent of the anthropogenic CO_2 added to the atmosphere today will remain in the air for at least 100 years, and 19 percent will remain at 1,000 years.[5] This means that GHGs added now to the atmosphere will continue to warm the planet for hundreds and, possibly, even thousands of years.

Stabilizing Atmospheric Greenhouse Gas Concentrations

To stabilize the atmospheric concentrations of GHGs, GHG emissions must approach equilibrium—a state of balance between GHG sources and sinks. The likelihood and extent of many climate change impacts in New York and elsewhere depend, in part, upon the global concentration of atmospheric GHGs. Generally, the higher the concentrations at which GHGs are stabilized, the greater the average global temperature increase.

Climate Science is the Basis for GHG Stabilization Goals

Since GHGs exert their climate-altering properties on a global scale, emission reductions must occur not only in New York, but globally. In 1992, 154 nations, including the United States, agreed to a series of overarching goals to minimize the risks from climate change, embodied in the United Nations Framework Convention on Climate Change (UNFCCC). Article 2 of the UNFCCC establishes the treaty's long-term objective of "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the Earth's climate system."

Scientific evidence suggests that limiting the global average temperature increase to approximately 3.6°F (2°C) above pre-industrial temperatures may minimize the likelihood of the most severe climate impacts and is consistent with the UNFCCC goal of avoiding dangerous climate change.[6] Figure 2-4[7] illustrates the range of potential physical impacts at varying levels of global temperature change. For each impact category, a colored arrow indicates the possible temperature range for a specific physical change to occur: an unbroken arrow with redder color indicates greater likelihood and severity of the physical event. It is important to note that the most severe effects, or "Abrupt and Major Irreversible Changes," may be prevented if the rise in global average temperature is limited to approximately 3.6°F (2°C). Climate change impacts also depend upon the vulnerability and adaptive capacity of natural systems and human populations. Effective management of climate change risks requires policy and decision makers to take flexible, yet significant and sustained actions to reduce GHG emissions and build the state's resiliency to climate change impacts; to learn from new research, monitoring data and scientific assessments; and to adjust future actions accordingly.

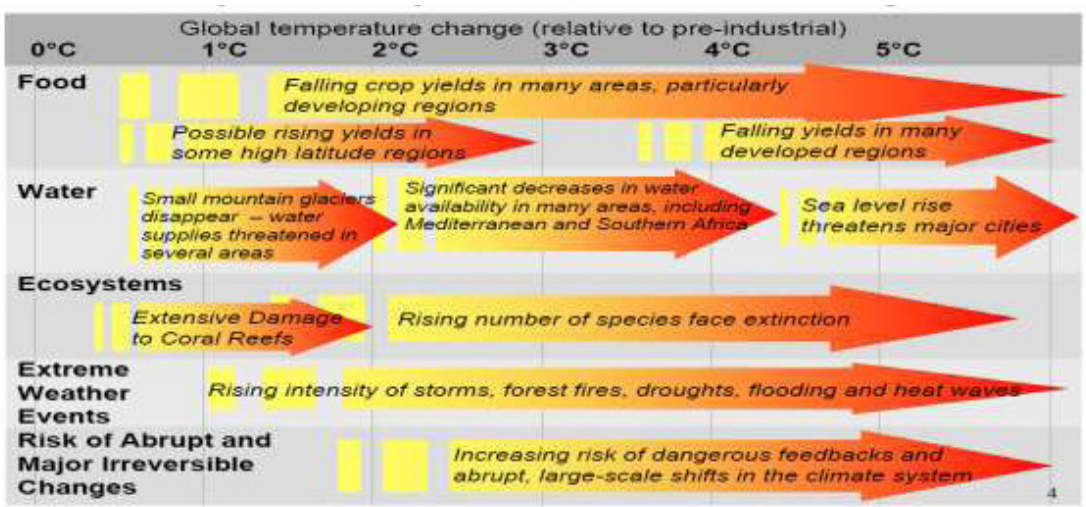
---

[5] Hansen, J. et. al., (46 co-authors). Dangerous Human-Made Interference with Climate: A GISS Model Study: Figure 9(a) Carbon Cycle Constraints (a) Decay of Pulse CO2 Emissions. *Atmospheric Chemistry and Physics*, 7: 1-262007b. . http://www.atmoschem-phys.org

[6] Parry, M.L., O.F. Canziani, J.P. Palutikof, and Co-authors Technical Summary. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. 2007.http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-ts.pdf

[7] Stern, N. *The Economics of Climate Change: The Stern Review: Executive Summary*. Figure 2, pp v. 2007. http://www.hmtreasury.gov.uk/sternreview_index.htm

Figure 2-4. Projected Impacts of Climate Change



Source: The Economics of Climate Change: The Stern Review, Cambridge University Press, 2007.

The atmospheric GHG concentration that will result in a 3.6°F (2°C) increase in global temperatures cannot be known with great accuracy. The best scientific estimates available, including estimates from the 2007 IPCC Report, indicate that if atmospheric GHG concentrations are stabilized in the atmosphere at approximately 450 ppm of carbon dioxide equivalent (CO_2e), or total GHGs, there is a medium likelihood that warming will not exceed 3.6°F (2°C).[8] To achieve stabilization of atmospheric concentrations at this level, the IPCC estimates that net global GHG emissions must approach zero by the end of this century.[9,10] The interim targets along the pathway to a 450 ppm CO_2e stabilization level require global emissions to peak no later than 2015 and to decrease to 85 percent below year 2000 levels by 2050.[11] The IPCC did not evaluate intermediate reductions for timeframes other than year 2050.

Apportioning GHG Reductions

Determining how much individual states or nations should reduce emissions through mid-century requires consideration of allocation equity and reduction effectiveness.[12] The UNFCCC approach to apportioning GHG emission reduction requirements between developed and

[8] The concentration of greenhouse gases in the atmosphere is already at approximately 375 ppm CO_2e and currently rising at roughly 2.5 ppm every year. IPCC. 2007.

[9] Using paleoclimate evidence and observations of current rates of global change, some recent studies suggest that today's atmospheric GHG concentrations already are too high to maintain the climate to which humanity, wildlife, and the rest of the biosphere are adapted. See: Hansen et al. *Target Atmospheric CO_2: Where Should Humanity Aim?* 2008. http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter3.pdf

[10] Fisher, B.S., N. Nakicenovic, K. Alfsen, J. Corfee Morlot, F. de la Chesnaye, J.-Ch. Hourcade, K. Jiang, M. Kainuma, E. LaRovere, A. Matysek, A. Rana, K. Riahi, R. Richels, S. Rose, D. van Vuuren, R. Warren. Issues Related to Mitigation in the Long Term Context. In *Climate Change 2007: Mitigation*. 2007. p. 199

[11] Meinshausen, M. (edited by Schellnhuber et. al.) What Does a 2°C Target Mean for Greenhouse Gas Concentration? In *Avoiding Dangerous Climate Change*, 2006.

[12] As previously discussed, global emissions of GHGs must eventually be in quasi-equilibrium with GHG removal mechanisms to allow for stabilization of atmospheric GHG concentrations.

developing nations considers a broad spectrum of parameters, including population, gross domestic product (GDP), GDP growth, and global emission pathways that lead to climate stabilization.[13] Applying these parameters, the UNFCCC concludes that, to reach the 450 ppm CO_2e stabilization target, developed countries must reduce GHG emissions by 80 to 95 percent from 1990 levels by 2050. This is the basis for the Executive Order 24 greenhouse gas reduction goal of 80 by 50.

Summary of the ClimAID Report - Climate Change and New York State

Initiated in 2008, the Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State (ClimAID) was funded by the New York State Energy Research and Development Authority (NYSERDA) as part of its Environmental Monitoring, Evaluation, and Protection (EMEP) Program. The ClimAID team was made up of university and research scientists who are specialists in climate change science, effects, and adaptation. Researchers came primarily, but not exclusively, from Columbia University, Cornell University, and Hunter College of the City University of New York. The goals of the ClimAID project are to provide New York State decision makers with cutting-edge information on the state's vulnerability to, and its ability to derive benefits from, climate change and to facilitate the development of adaptation strategies informed by both local experience and scientific knowledge. Further aims of ClimAID are to identify data gaps and monitoring needs to help guide future efforts. As part of the project, the ClimAID team evaluated a set of climate change scenarios for New York State to facilitate the assessment of potential impacts under future conditions.

New York State is vulnerable to a changing climate but, at the same time, has a great potential to adapt to its effects. From the Great Lakes to Long Island Sound, from the Adirondacks to the Susquehanna Valley, climate change will increasingly affect the people and resources of New York State. *Climate hazards* include higher temperatures and more frequent and intense heat waves leading to greater incidence of heat morbidity and mortality, decreased air quality and increased health risks for those with medical conditions such as cardiovascular disease, renal disease, emphysema, and others; increased short-duration warm season droughts and extreme rainfall events affecting food production, natural ecosystems, and water resources; and sea level rise, resulting in both gradual inundation of natural and human habitats and greater risk of damage from coastal storms.

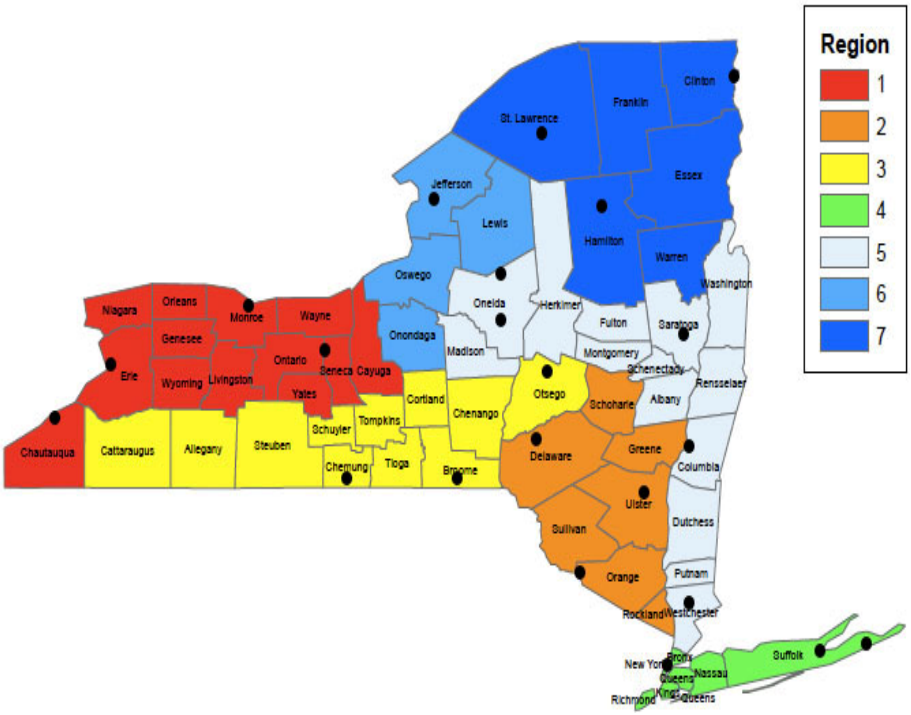
The uncertainties inherent in climate projections and the complex linkages among climate change, physical and biological systems, and socioeconomic factors pose special challenges for New York State decision makers. However, there is a large amount of local and scientific knowledge on climate change that is critical to understanding not only the necessary urgency and magnitude of GHG mitigation, but to reducing vulnerability and building adaptive capacity to respond to the changing climate as well.

The ClimAID researchers divided New York State into seven regions, shown below in Figure 2-5. Historical climate trends and future projections were analyzed for each region and the state as

[13] UNFCCC. *Synthesis of Information Relevant to the Determination of the Mitigation Potential and to the Identification of Possible Ranges of Emission Reduction Objectives of Annex 1 Parties: An Update.* 2008. http://unfcccbali.org/unfccc/images/document/technical_papper.pdf

a whole. Understanding how New York's climate has changed in the past and is projected to change in the future allows for the exploration and identification of potential effects.

Figure 2-5. Regions of New York State used in the climate assessment



Dots represent meteorological stations used in climate analysis. Source: ClimAID.

The current climate in New York State can be described as humid and continental. Key features of New York State's climate include the following:

- Temperature varies widely across the state. Average annual temperature varies from 40°F in the Adirondacks to near 55°F in the New York City metropolitan region.
- Precipitation amounts also vary. Average annual precipitation ranges from approximately 30 inches in Western New York to nearly 50 inches in the New York City region, Tug Hill Plateau, and Adirondacks.
- A variety of extreme events occurs throughout the state:
    - Heat waves, defined as three consecutive days with maximum temperatures above 90°F, are common in urban areas, especially in the southern parts of the state.
    - Short-duration flooding, which can result from heavy rainfall and runoff from snowmelt, affects the entire state.
    - Lake effect snow is a major climate hazard in western and central New York State.
    - Areas along the Atlantic coast and Hudson River Valley are especially prone to coastal storms and their associated effects, including heavy precipitation, high winds, and coastal flooding.

Observed Climate Trends

Temperature and Precipitation

Temperatures in New York State have risen over the course of the 20th century, with the greatest warming coming in recent decades. There has also been an increase in the number of extreme hot days (days at or above 90ºF) and a decrease in the number of cold days (days at or below 32ºF). Statewide, there has been no discernable trend in annual precipitation, which is characterized by large variability, both from year to year and over decades. Table 2-1 shows observed 20th century trends in temperature and precipitation for select meteorological stations in New York.

Table 2-1. 1900-1999 Temperature and Precipitation Trends in New York State

Temperature (°F / decade)

	Annual	Spring	Summer	Fall	Winter
Albany	0.18**	0.25**	0.13*	0.06	0.29**
Elmira	0.01	- 0.02	- 0.09	0.00	0.17
Indian Lake	0.15**	0.13	0.05	0.14*	0.29*
NYC	0.39**	0.45**	0.33**	0.28**	0.53**
Port Jervis	0.06	0.09	0.02	- 0.08	0.20*
Rochester	0.20**	0.26**	0.19**	0.10	0.25*
Watertown	0.17**	0.17*	0.15**	0.08	0.31**

Precipitation (inches / decade)

	Annual	Spring	Summer	Fall	Winter
Albany	1.13**	0.33	0.34	0.36**	0.10
Elmira	0.30	0.01	- 0.08	0.26	0.11
Indian Lake	- 0.06	- 0.01	- 0.04	0.08	- 0.10
NYC	0.47	0.24	- 0.05	0.25	0.04
Port Jervis	0.11	0.15	- 0.21	0.12	0.04
Rochester	0.29	0.01	0.15	0.20*	- 0.07
Watertown	0.35	- 0.01	0.05	0.23*	0.09

* Significant at the 95% level; ** Significant at the 99% level

Sea Level Rise

Sea level in the coastal waters of New York State and up the Hudson River has been steadily rising over the 20th century. As global temperatures have increased, rates of sea level rise have increased as well. During the 20th century, global sea level rise was primarily the result of thermal expansion of ocean waters. Sea level rise in New York coastal regions is a factor of both global sea level rise and local changes in height of the land relative to the height of the continental land mass. Over the 20th century, the rate of sea level rise for the New York coastal region was 1.2 inches per decade. The difference between this rate and the rate of global sea level rise (0.7 inches per decade) was due primarily to local subsidence.

ClimAID Projections of Future New York State Climate Conditions

For the assessment, investigators developed *projections* of temperature, precipitation, and extreme events for each of the seven climate regions and New York State as a whole. For sea level rise, projections were developed for the marine coastal region and the Hudson River estuary. These projections were based on climate data from 16 (seven for sea level rise) *global climate models* (GCMs) and three GHG *emission scenarios*. In addition to these climate projections, for eight sectors across the state (corresponding to the sectors discussed in the Adaptation chapter of the Interim Report), sector-specific climate risks were defined with stakeholder input, and "tailored products" were developed for use in the sector assessments (e.g., the number of heating-degree days in future years was projected for use in the energy sector assessment).

The combination of multiple GCMs and emissions scenarios produced a range of possible outcomes for each future time period and *climate variable*. The results constitute "model-based" probability functions and are presented as a probabilistic range across the potential outcomes.

What is an emission scenario?

An emissions scenario is plausible representation of future global greenhouse gas emissions. Each emissions scenario represents a unique blend of demographic, social, economic, technological, and environmental assumptions. The ClimAID analysis used three scenarios:

A2: Relatively rapid population growth and limited sharing of technological change combine to produce emissions growth throughout the century and high greenhouse gas levels by the end of this century.

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

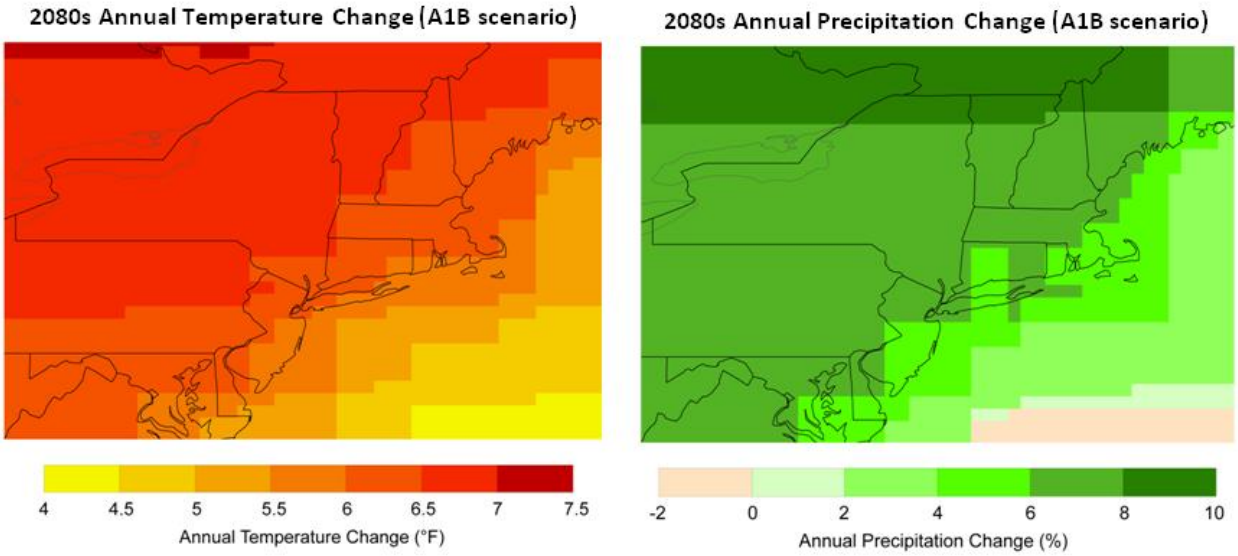
B1: This scenario combines the A1 population trajectory with societal changes tending to reduce greenhouse gas emissions growth. The net result is the lowest greenhouse gas emissions of the three scenarios, with emissions beginning to decrease by 2040.

Higher average annual temperatures and sea level rise are extremely likely for New York State. For temperature and sea level rise, all climate models analyzed project continued increases over the coming century, with a high likelihood of more rapid temperature increases and sea level rise than occurred over the 20th century. Although most projections indicate small increases in precipitation, some do not, and decade-by-decade precipitation variability is large; therefore, precipitation projections are less certain than temperature projections.

New York State Temperature and Precipitation Projections

Figure 2-6 shows the projected changes in average annual temperature and precipitation for the state, averaged across the 16 GCMs for one of the three scenarios for possible future GHG emissions. Although only a single emission scenario is shown (the A1B "middle" emissions scenario), the spatial pattern is similar for the other two scenarios. Table 2-2 shows specific mean annual change projections for seven regions of the state.

Figure 2-6. Projected changes in annual temperature and precipitation for the 2080s in the Northeast, under the A1B ("middle") emissions scenario, relative to the 1970-1999 baseline



°F)

Table 2-2. Temperature and Precipitation Projections for the Seven ClimAID Regions

Region 1	Baseline[1] 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	48° F	+1.5 to 3.0° F	+3.0 to 5.5° F	+4.5 to 8.5° F
Precipitation Central Range	37 in	0 to +5 %	0 to +10 %	0 to 15 %

Stations used for Region 1 are Buffalo, Rochester, Geneva, and Fredonia.

Region 2	Baseline[1] 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	48° F	+1.5 to 3.0° F	+3.0 to 5.0° F	+4.0 to 8.0° F
Precipitation Central Range	48 in	0 to +5 %	0 to +10 %	+5 to 10 %

Stations used for Region 2 are Mohonk Lake, Port Jervis, and Walton.

Region 3	Baseline[1] 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	46° F	2.0 to 3.0° F	+3.5 to 5.5° F	+4.5 to 8.5° F
Precipitation Central Range	38 in	0 to +5 %	0 to +10 %	+5 to 10 %

Stations used for Region 3 are Elmira, Cooperstown, and Binghamton.

Region 4	Baseline[1] 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	53° F	+1.5 to 3.0° F	+3.0 to 5.0° F	+4.0 to 7.5° F
Precipitation Central Range	47 in	0 to +5 %	0 to +10 %	+5 to 10 %

Stations used for Region 4 are New York City (Central Park and LaGuardia Airport), Riverhead, and Bridgehampton.

Region 5	Baseline[1] 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	50° F	+1.5 to 3.0° F	+3.0 to 5.5° F	+4.0 to 8.0° F
Precipitation Central Range	51 in	0 to +5 %	0 to +10 %	+5 to 10 %

Stations used for Region 5 are Utica, Yorktown Heights, Saratoga Springs, and the Hudson Correctional Facility.

Region 6	Baseline[1] 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	44° F	+1.5 to 3.0° F	+ 3.5 to 5.5° F	+4.5 to 9.0° F
Precipitation Central Range	51 in	0 to +5 %	0 to +10 %	+5 to 15 %

Stations used for Region 6 are Boonville and Watertown.

Region 7	Baseline[1] 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	42° F	+1.5 to 3.0° F	+3.0 to 5.5° F	+4.0 to 9.0° F
Precipitation Central Range	39 in	0 to +5 %	0 to +10 %	+5 to 15 %

Stations used for Region 7 are Wanakena, Indian Lake, and Peru.

[1] The baselines for each region are the average of the values across all the stations in the region.

[2] Shown are the central ranges (middle 67%) of values from model-based probabilities; temperature ranges are rounded to the nearest half-degree and precipitation to the nearest 5%.

Sea Level Rise

In 2007, the IPCC concluded that global sea level will likely rise between 7 and 23 inches by the end of the century (2090-2099), relative to the base period (1980-1999), not counting unexpected rapid changes in ice flow from the Greenland and Antarctic ice sheets. These projections do not consider all ice sheet melting processes or cover the full likely range of global temperature increase given in the IPCC Fourth Assessment Report (up to 11.5 ºF). The "rapid ice-melt" scenario is an alternative method to estimate future sea level rise that incorporates observed and longer-term historical melt rates, and documented rates of melting in past climate eras, and includes the possibility of accelerated melting of land-based ice sheets and glaciers. Projections based on this scenario are higher than the IPCC projections.

For the ClimAID assessment, a set of projections for the ocean coastal area of New York State (including the tidal extent of the Hudson River north to Troy) was developed based on IPCC global climate models and methods.[14] A set of higher projections for a "rapid ice melt scenario" was also developed. These projections are provided in Table 2-3.

Table 2-3. Sea Level Rise Projections (relative to 2000-2004 baseline)

Region 4: Lower Hudson Valley, New York City, & Long Island	2020s	2050s	2080s
Sea Level Rise[1] Central Range	+ 2 to 5 in	+ 7 to 12 in	+ 12 to 23 in
Sea Level Rise[1,2] Rapid Ice Melt	+ 5 to 10 in	+ 19 to 29 in	+ 41 to 55 in
Region 5: Mid-Hudson Valley & Capital Region	**2020s**	**2050s**	**2080s**
Sea Level Rise[1] Central Range	+ 1 to 4 in	+ 5 to 9 in	+ 8 to 18 in
Seal Level Rise[1,2] Rapid Ice Melt	+ 4 to 9 in	+ 17 to 26 in	+ 37 to 50 in

[1] Shown are the central ranges (middle 67%) of values from model-based probabilities rounded to the nearest inch.
[2] The rapid ice melt scenario is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimate studies.

Changes in Extreme Events

Extreme climate events, such as heat waves and heavy rainstorms, significantly impact New York's communities and natural resources and often have disproportionate effects on urban and rural systems. Probabilities of the future occurrence of extreme events in New York State were developed, based on climate models. The following are likely to occur during the 21st century:

- Heat waves are expected to become more frequent and intense.
- Intense precipitation events are expected to become more frequent.
- Storm-related coastal flooding is expected to increase due to rising sea levels.

[14] The 2009 New York City Panel on Climate Change sea level rise projections for the New York City area are identical to the ClimAID projections for Region 4.

As an example, projections for such events in Central New York (Region 3) are shown in Table 2-4.

Table 2-4. Projections of changes in extreme events: minimum/maximum; central range* for Central New York (Region 3)

	Extreme Event	Baseline	2020s	2050s	2080s
Heat waves & Cold Events	# of days per year with max temperature at or above:				
	90°F	10	11/25; 14 to 19	15/45; 21 to 33	19/70; 26 to 56
	95°F	1	2/7; 2 to 4	2/18; 4 to 10	4/38; 7 to 24
	# of heat waves per year[2]	1	1/3; 2 to 3	2/6; 3 to 4	2/9; 3 to 8
	average duration (in days)	4	4/5; 4 to 5	4/5; 4 to 5	4/7; 5 to 5
	# of days per year with min temperature at or below 32°F	152	116/145; 122 to 124	86/168; 106 to 122	68/124; 87 to 114
Intense Precipitation	Number of days per year with rainfall exceeding:				
	1 inch	6	5/8; 6 to 7	5/8; 6 to 7	5/10; 6 to 8
	2 inches	0.6[1]	0.5/1; 0.6 to 0.9	0.5/1; 0.6 to 1	0.4/2; 0.7 to 1

* The minimum, central range (middle 67%), and maximum of values from model-based probabilities across the GCMs and GHG emissions scenarios are shown.

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

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

There is potential for changes in other climate variables as well. However, because quantitative information is either unavailable or considered less reliable, the changes in these variables are described qualitatively at this time. ClimAID researchers developed confidence levels for these projections using a system similar to that used by in the IPCC's Fourth Assessment Report (Table 2-5). These ratings are based on the correspondence between climate model projections and observed climate, agreement among climate models, and expert judgment.

Table 2-5. Explanation of ClimAID Confidence Level Terminology

Term	Probability of Occurrence
Extremely likely	**> 95%**
Very likely	**> 90%**
Likely	**> 66%**
More likely than not	**> 50%**

Table 2-6 shows the probable direction of change over the 21st century for New York City and Long Island, as well as the likelihood associated with the qualitative projection. For these variables, which can have large effects on infrastructure, quantitative projections are not possible due to insufficient information.

Table 2-6. Qualitative changes in extreme events for New York City and Long Island (Region 4)

Extreme Event	Probable Direction Throughout 21st Century	Likelihood[1]
Heat index[2]	↑	Very likely
Ice storms/ freezing rain	*Unknown*	
Snowfall frequency & amount	↓	Likely
Downpours (precipitation rate/hour)	↑	Likely
Lightning	*Unknown*	
Intense hurricanes	↑	More likely than not
Nor'easters	*Unknown*	
Extreme winds	↑	More likely than not

[1] Likelihood definitions found in Table 2-5

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

Longer-term Projections

Consideration of climate projections past the year 2100 is beyond the current planning horizons of most infrastructure managers. However, planning for some long-lived infrastructure, which, for example, could include new aqueducts and subway lines, may need to consider the climate during the next century. Furthermore, many pieces of infrastructure intended only to have a useful lifespan within this century may remain operational beyond their planned lifetimes. It is

also possible that future projects aimed specifically at climate change mitigation or adaptation might benefit during their planning stages from long-term climate guidance.

Because the climate of the 2100s is highly uncertain, only qualitative projections are possible, especially at a local scale. Despite uncertainties, at least two key climate variables, sea level rise and temperature, will in all probability continue to increase into the next century. Additionally, if evidence over the next decade continues to show accelerated melting of the ice sheets on Greenland and West Antarctica, it would greatly increase the probability that these ice sheets would contribute significantly to sea level rise in the next century, even if GHG concentrations, and perhaps even global temperatures, were to stabilize at some point during this century.

Uncertainty and Likelihoods

Projections of future climate conditions are characterized by large uncertainties. At the global scale these uncertainties can be divided into two main categories:

- Uncertainties in future land-use changes and emissions of GHG gases and other climate drivers, such as aerosols and black carbon
- Uncertainties regarding the sensitivity of the climate system to GHG concentrations and other climate drivers.

When considering future changes at local and regional, geographic scales, uncertainties increase, for two additional reasons:

- Climate variability, such as precipitation extremes, can be especially large over small regions, partially masking more uniform effects of climate change.
- Changes in local atmospheric processes that operate at small scales, such as land or sea breezes, may not be captured by the global climate models used to make projections.

Uncertainties may be reduced by using projections generated from a range of global climate models and GHG emissions scenarios as was done with ClimAID, but they cannot be fully eliminated. Additionally, averaging the projections over 30-year time periods and showing changes in climate through time, rather than absolute climate values, reduces the local- and regional-scale uncertainties. However, these techniques do not address the possibility that local processes may change with time.

New York State's Vulnerability to Climate Change

Climate change is already impacting New York State's society, economy, and natural ecosystems. With changes in temperature, precipitation patterns, and sea level projected to continue, the impacts to New York State are likely to increase. Presented here are the eight sectors of the state considered in the ClimAID assessment, including some of the sector-specific impacts expected as the climate continues to change.

Agriculture

Agriculture is a significant component of the New York economy and includes large wholesale grower-shippers selling products nationally and internationally, a substantial dairy industry, and thousands of small farm operations selling direct retail and providing communities throughout

the state with local, fresh produce. Farmers will be on the front lines of coping with climate change, but the direct impacts on crops, livestock, and pests, and the costs of farmer adaptation will have cascading effects beyond the farm gate and throughout the New York economy.

Climate change presents both economic challenges and opportunities for agriculture in New York State. Warmer temperatures, a longer growing season, and increased atmospheric carbon dioxide could create opportunities for farmers with enough capital to take risks on expanding production of warmer temperature-adapted crops (e.g., European red wine grapes, peaches, tomato, watermelon) assuming a market for new crops can be developed. However, the dairy industry as well as many of the high-value crops that currently dominate the state's agriculture economy (e.g., apples, cabbage, potatoes), benefit from the state's historically relatively cool climate. As New York's climate changes, some crops may have yield or quality losses associated with increased frequency of drought; increased summer high temperatures; increased risk of freeze injury as a result of more variable winters; and increased pressure from weeds, insects, disease, or other factors. Dairy milk production per cow will decline in the region as temperatures and the frequency of summer heat stress increase.

The impacts from climate change will occur on top of non-climate stressors already affecting the sector. For example, as with many other businesses in New York and elsewhere, agriculture is sensitive to the volatile and rising costs of energy. Also, New York farmers are affected by rapidly changing consumer preferences and demands of supermarket buyers; increasingly, farmers must consider global market forces and international competition as well as competition from neighboring states. As a final example, too much as well as too little rainfall is currently a recurrent problem for farmers in New York. Currently, summer precipitation is insufficient to fully meet the water needs of non-irrigated crops most years, while brief, intense rainfall events can have detrimental effects on crops. Climate change is likely to exacerbate these challenges.

Coastal Zones

For the ClimAID assessment, the coastal zone is defined as the shoreline of New York State, including coastal wetland areas and inland areas adjacent to the shoreline that are likely to be affected by sea level rise and coastal storms. Also considered are the potential effects of climate change up the Hudson River estuary to the Troy Dam.

Global sea level rise due to climate warming will have a significant impact on New York's coastal areas, in addition to other impacts like ocean circulation changes and higher water temperatures. The effects of global sea level rise will be amplified in New York State due to coastal subsidence caused by ongoing adjustments of the Earth's crust to the melting of the ice sheets that began 20,000 years ago.

New York's coastal zones, including the New York City metropolitan region, are becoming more developed, further increasing their vulnerability to flooding, coastal erosion, and sea level rise. Sea level rise will greatly amplify risks to coastal populations and will lead to permanent inundation of low-lying areas, more frequent flooding by storm surges, and increased beach erosion. Saltwater could reach farther up the Hudson River and into estuaries, contaminating urban water supplies. Tides and storm surges may propagate farther up the Hudson River increasing flood risk far from the coast.

High water levels, strong winds, and heavy precipitation resulting from strong coastal storms already cause billions of dollars in damages and disrupt transportation and power distribution systems. Barrier islands are being dramatically altered by strong coastal storms as ocean waters over wash dunes, create new inlets, and erode beaches. Warming ocean waters have the potential to produce stronger storms by increasing the source of energy for these storms.

Non-climate-related stresses will compound the effects of climate change. In the coastal region, most of these are associated with human consumption of natural resources and land-use practices. For example, coastal development, construction of organized drainage, and impervious surfaces have led to a reduction in groundwater recharge and degraded coastal water quality. The interconnection among precipitation, land use, and local fish populations has also been documented, suggesting that increased urbanization may lead to a reduction in stream biodiversity. In addition to water-quality-related stresses, fish stocks and other marine ecosystems may be affected by harvesting practices, disease, normal population dynamics (increased predation), and recruitment processes. Over-development along the coast increases the demand for groundwater, which could lead to drawdown of the aquifer and increased saltwater intrusion. Coastal infrastructure also inhibits natural migration of marine systems, including wetlands and barrier islands.

The most economically significant risks and vulnerabilities in the coastal areas are the multifaceted risks from higher sea levels and consequent higher storm surges. Substantial economic losses can be expected in buildings, infrastructure (including underground infrastructure for utilities, such as gas lines and telecommunications cables), natural areas, and recreation sites. Other impacts from precipitation changes, higher temperatures, higher ocean temperatures and ocean acidification will also have significant impacts.

Ecosystems

Ecosystems, as defined here, encompass the plants, fish, wildlife, and other biotic resources of all natural and managed landscapes (e.g., forests, grasslands, aquatic systems) in New York State except those land areas designated as agricultural or urban. This sector includes timber and maple syrup industries, as well as tourism and recreation businesses conducted within natural and managed ecosystems. It also encompasses wetlands, waterways, and lakes as well as their associated fisheries. Ecosystems services provided by New York's landscapes include preservation of freshwater quality, flood control, soil conservation, carbon sequestration, biodiversity support, recreation, and preservation of wild places and heritage sites.

The initial impacts of climate change on natural systems are already apparent, with documented accounts of changes in the seasonal timing of events like bud-break or flowering and species range shifts across the Northern Hemisphere. Within the northeastern United States, researchers have documented earlier bloom dates of woody perennials, earlier spring arrival of migratory birds, and other biological and ecological responses. Species and ecosystems are responding directly to climate drivers and indirectly to secondary effects, such as changes in timing and abundance of food supply, changes in habitat, and increased pest, disease, and invasive species pressure. Ultimately, biodiversity, net primary productivity, and biogeochemical cycles could be affected by climate change. To date, however, there is not yet clear evidence of climate change impacts on important ecosystem services such as carbon sequestration, or water storage and quality in New York State; our understanding of climate change impacts diminishes as

projections are scaled up from individual species and ecosystem structure to ecosystem function and services.

Within the next several decades, New York State is likely to see widespread shifts in species composition in the state's forests and other natural landscapes, with the loss of spruce-fir forests, alpine tundra, and boreal plant communities. Warmer temperatures will favor the expansion of some invasive species into New York, such as the aggressive weed kudzu and the insect pest hemlock woolly adelgid. Some habitat and food generalists (such as white-tailed deer) may also benefit. Additionally, higher levels of carbon dioxide tend to preferentially increase the growth rate of fast-growing species, which are often weeds and other invasive species. Both of these climate factors could also increase the productivity of some hardwood tree species, provided growth is not limited by other factors such as drought or nutrient deficiency.

Lakes, streams, inland wetlands, and associated aquatic species will be highly vulnerable to changes in the timing, supply, and intensity of rainfall and snowmelt; groundwater recharge; and duration of ice cover. Increasing water temperatures will negatively affect brook trout and other native coldwater fish.

In coastal areas, sea level rise may become the dominant stressor acting on vulnerable salt marshes. Loss of coastal wetlands reduces fish and shellfish populations. Higher water temperatures also affect these populations. Some marine species, such as lobsters, are shifting their ranges north out of New York State, while other species, such as the blue claw crab, are increasing in the warmer waters.

The impacts of climate change cannot be viewed in isolation, as other stressors are also affecting ecosystems and will affect vulnerability to climate change. While society and policy makers are likely to focus on ecosystem services, adaptation interventions by natural resource managers often will be implemented at the level of species, communities, and habitats. As climate changes and the habitable zones of wild species continue to shift northward and/or up in elevation throughout the century, natural resource managers will face new challenges in maintaining ecosystem services and difficult decisions regarding changes in species composition of natural communities.

For revenue-generating aspects of the ecosystem sector, including winter tourism and recreational fishing, climate change may impose obvious economic costs. For other facets, such as forest-related ecosystem services, heritage value of alpine forests, and habitat for endangered species, the economic costs associated with climate change are real but more difficult to quantify.

Energy

New York State’s electricity and gas supply and distribution systems are highly reliable. As they are designed to operate under a wide range of temperature and weather conditions, the system is deliberately robust and resilient. However, threshold conditions (as opposed to the mean or standard conditions) or shifts in thresholds caused by climate change can create vulnerability within the energy sector and substantially increase the cost of maintaining reliability.

Climate change is anticipated to impact the energy sector in several ways: First, energy demand will change due to a changing combination of heating and cooling needs, stressing power supplies and increasing peak demand loads. With higher mean temperatures and increased numbers of extremely hot days, the cost of maintaining a reliable supply of electricity is likely to increase in all parts of the state. In particular, climate change will place additional pressures on New York City, where the system is already taxed during very hot summer days. Extreme weather events may also increase costs of meeting electricity demand.

Second, the physical structures (power plants, electrical lines, etc.) will be affected by changing climate conditions. Increased air and water temperatures may affect the operation of some power plants. Transformers and distribution lines for both electricity and gas supply are vulnerable to extreme weather events, temperature, and flooding. Coastal infrastructure is vulnerable to flooding as a result of sea level rise and severe storms.

Renewable generation may also be affected. Hydropower is vulnerable to drought and changes in precipitation patterns. The availability and reliability of solar power systems are vulnerable to changes in cloud cover (although this may be offset by advances in technology), and wind power systems are similarly vulnerable to changes in wind speed and direction. The extent to which cloud cover and wind will be affected by climate change is currently unclear. The effect of climate change on low-carbon biomass as an energy feedstock is also unclear, though it is important to note that biomass availability depends to some degree on the suitability of weather conditions during the growing season.

Additional indirect impacts on the energy sector, such as the financial impacts on investors or insurance companies linked to vulnerable energy system assets or on customers forced to grapple with more volatile energy prices resulting from changing climate conditions, may be even more important than the direct impacts. New York's energy and electricity sector is a key focus for a variety of the mitigation policy options presented in the Interim Report. Reliance on this sector to help power the clean-energy economy must consider the expected impacts from an already changing climate.

Public Health

Climate change vulnerabilities in the public health sector are, to a large extent, ones in which public health and environmental agencies are already engaged. However, climate change places an additional resource and cost burden on public health agencies. Climate-related risk factors include heat events, extreme storms, disruptions of water supply and quality, decreased air quality, changes in timing and intensity of pollen and mold seasons, and alterations in patterns of infectious disease vectors and organisms. Demand for health services and the need for public health surveillance and monitoring will increase as climate continues to change.

As a result of these climate risks, some climate-related health vulnerabilities have emerged. Heat-related illness and death are projected to increase, while cold-related death is projected to decrease. Increases in heat-related death are projected to outweigh reductions in cold-related death. Cardiovascular and respiratory-related illness and death will be affected by worsening air quality, including possibly more smog, wildfires, pollens, and molds.

Vector-borne diseases, such as those spread by mosquitoes and ticks (such as West Nile virus), may expand or their distribution patterns change. Water- and food-borne diseases are likely to increase without adaptation intervention. Water supply, recreational water quality, and some food production will be at increased risk due to increased temperatures and changing precipitation patterns.

More intense storms and flooding could lead to increased stress and mental health impacts, impaired ability to deliver public health and medical services, increased respiratory diseases such as asthma, and increased outbreaks of gastrointestinal diseases.

These vulnerabilities span a range from the relatively direct, data-rich and well understood to more complex, multi-factorial systems for which both data and models are currently underdeveloped. Uncertainties pervade any effort to predict either direct or indirect health impacts of climate change. These uncertainties increase the importance of building resilience into the public health system to cope with inevitable surprises to come.

Telecommunications and Information Infrastructure

Telecommunications infrastructure is vital to New York State's economy and welfare; its capacity and reliability are essential to the effective functioning of global commerce and the state's economy and is especially vital during emergencies. The sector has important public functions, but it is largely privately operated. The sector poses special challenges to climate change analysis. Businesses in the sector are reluctant to disclose some classes of information that would be relevant to climate change assessments because of competitive pressures.

The rapid technological changes inherent in technology and information systems mean that the planning horizons and life spans for much of its infrastructure are at best on the order of a decade. The sector is tightly coupled to the energy sector, with power outages affecting the reliability of communication services; many of its communication lines also are located on the same poles as power lines. Modern digital technologies, including communication services based on fiber optics, broadband, and the Internet, can be more vulnerable to power outages than traditional landline technology.

A central concern of the communication infrastructure sector is how to ensure that the perpetual introduction of new technologies enhances the reliability and uninterrupted access to services. Such a focus is essential both now and in the future, when the risks from climate change may increase.

Communication service delivery is vulnerable to hurricanes, lightning, ice, snow, wind storms, and other extreme weather events, some of which are projected to change in frequency and intensity. Communication lines and other infrastructure are vulnerable to the observed and projected increase in heavy precipitation events and resulting flooding and freezing rain. In coastal and near-coastal areas, sea level rise in combination with coastal storm surge flooding will be a considerable threat especially later this century. The delivery of communication services is sensitive to power outages, such as those resulting from the increased demand associated with heat waves, which are expected to increase with climate change.

Under current climate conditions and severe weather events, there are already serious vulnerabilities that often prevent the telecommunications sector from delivering services to the public.

Transportation

There is a very large range of potential climate change impacts on the state's transportation system, but the primary impacts and costs will be on infrastructure investment and management of rising sea levels and the accompanying increase in storm surges for coastal areas.

The highest concentration of transportation infrastructure is located in regions that are population centers and vital drivers of the New York economy. Climate change threatens many of these dense metropolitan transportation systems. Ground transportation systems (roads and rails) in coastal population centers, for example, are often placed underground in tunnels very close to or below sea level and are vulnerable to sea level rise. Since transportation is a networked system, delays, failures, and catastrophic failures in one system often have cascading effects on other parts of the system.

Over the next few decades, heat waves, heavy precipitation events, and windstorms are likely to dominate the causes for moderate, more frequent transportation problems such as flooded streets and delays in mass transit. By 2050 at the latest, sea level rise and storm surge will become more significant threats. By later this century, these threats will be so severe that major adaptations will have to be in place, not only in the coastal zone, but up the Hudson River estuary to cities including Troy and Albany. Low-lying transportation systems such as subways and tunnels, especially in coastal and near-coastal areas, are at particular risk of flooding as a result of sea level rise and heavy-precipitation events.

Materials used in transportation infrastructure, such as asphalt and train rails, are vulnerable to increased temperatures and frequency of extreme heat events. Air-conditioning requirements in buses, trucks, and trains, and ventilation requirements for tunnels will increase. Runways may require lengthening in some locations since hotter air provides less lift, necessitating higher speeds for takeoff.

The Great Lakes may see a shorter season of winter ice cover, leading to a longer shipping season. However, reduced ice cover is also likely to mean an increase in "lake effect" snow events, which cause various transportation-related problems.

Air- and land-based transportation systems are vulnerable to ice and snowstorms, although requirements for salting and snow removal may decrease as snow tends to turn more often into rain. Freeze/thaw cycles that disturb roadbeds may increase as winter temperatures rise. Currently, New York State has the most days per year of freezing rain in the nation, affecting air and ground transportation directly and also indirectly through electric and communication outages.

Water Resources

New York State's water resources are managed by an array of large and small agencies, governments, and institutions, with little statewide coordination. In 2000, New York State's 19 million residents consumed approximately 2,200 million gallons per day of fresh surface water

and 890 million gallons per day of fresh groundwater for public water supply, irrigation, and industrial uses. This water comes from a diverse range of sources, each with different levels of vulnerability to climate change.

Although there are several water quality concerns directly linked to average air temperatures, in general, hydrologic processes are dependent on multiple interacting climate factors. In addition to temperature, possible future changes in timing and quantity of snow, rainfall, and evaporation may have the following impacts on the state's water resources:

- Rising air temperatures intensify the water cycle by driving increased evaporation and precipitation. The resulting altered patterns of precipitation include more rain falling in heavy events, often with longer dry periods between rain events. Such changes can have a variety of effects on water resources.
- Increasing water temperatures in rivers and streams will affect aquatic heath and reduce the capacity of streams to assimilate effluent from wastewater treatment plants.
- Heavy downpours have increased over the past 50 years and this trend is projected to continue, causing an increase in localized flash flooding in urban areas and hilly regions. Flooding has the potential to increase pollutants in the water supply and inundate wastewater treatment plants and other vulnerable development within floodplains.
- At the same time as downpours occur more often, more moderate rain events are expected to become less frequent during the summer, resulting in additional and possibly longer summer dry periods and affecting water supply systems with limited storage. Reduced summer flows on large rivers and lowered groundwater tables could lead to conflicts among competing water users.

Although New York is a water-rich state, it is already experiencing water resource challenges. The most economically significant risks may be to coastal infrastructure, including wastewater treatment plants and water supply systems (ground and surface) from rising sea levels and associated storm surges. The state's water and wastewater treatment infrastructure is in dire need of repair and upgrade; the anticipated challenges associated with a changing climate will only exacerbate the situation.

Inland flooding is also an important risk. Other economically important risks and vulnerabilities include the costs of droughts of potentially increased intensity and frequency, losses in hydropower production, and increased costs of water quality treatment. If there are more-frequent climate-related power losses, this could be costly in both economic and regulatory terms to water supply and wastewater treatment plants.

Demand for water continues to grow, including for human consumption, agricultural use, and energy production. As other parts of the country experience large changes in drought frequency and intensity, New York's water resources may become a defining economic asset resulting in the migration of people and businesses into the state. This may bring some economic benefits, but will present new challenges as pressure on water resources increases.

Conclusion

The impacts of climate change in New York State will vary across sectors. However, it is likely that significant societal and natural resource disruption will result, and associated costs incurred in all sectors if the climate change threat is not addressed. Adaptation planning and GHG mitigation efforts can reduce the potential economic impacts.