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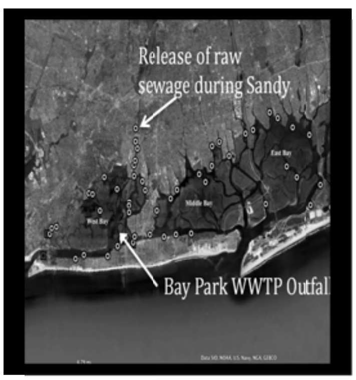

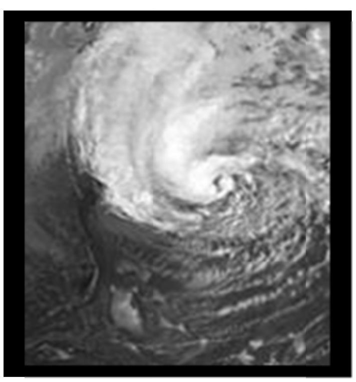

Stony Brook University

NYS RISE

Resiliency Institute for Storms & Emergencies

Climate Risk Report for Suffolk and Nassau
TR-0-14-01

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Executive Summary

Past Change

The mean annual temperature in Nassau and Suffolk has increased 5°F from 1900 to 2010. This value is larger than the transient variations between multi-year averages (Figure E1), making this trend statistically significant. Additionally, the mean annual precipitation has increased 5 inches during this period. However, year-to-year precipitation variability is large making this trend statistically insignificant (Figure E1). Finally, the sea-level has risen about 1 foot during this period, which is a statistically significant change (Figure E2).

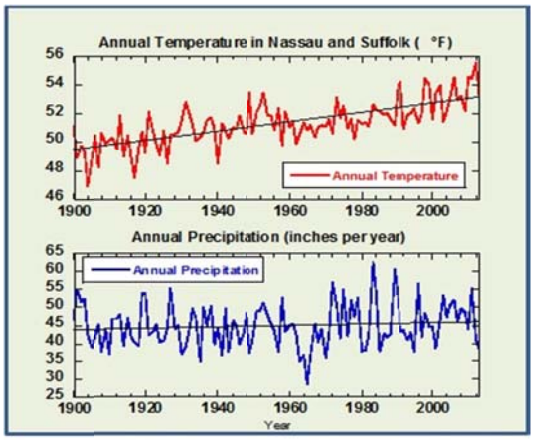


Figure E1: Time series of annual temperature (°F)and precipitation (inches) in Nassau and Suffolk since 1900. The black lines are the linear fit. Data are from the Earth System Research Laboratory of the National Oceanic and Atmospheric Administration).

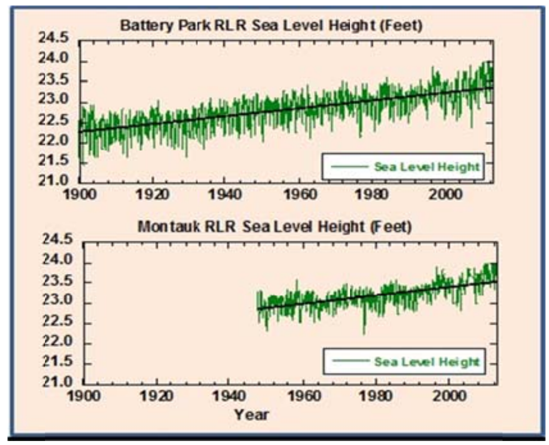


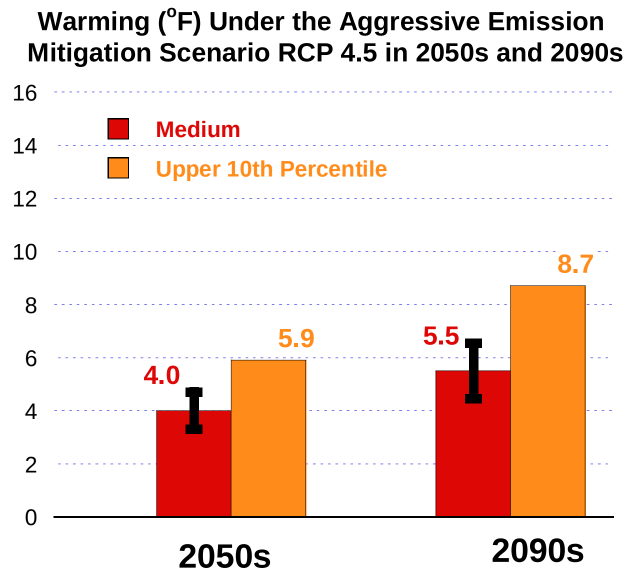
Figure E2: Time series of monthly sea level height relative to the Revised Local Reference (RLR) (in feet) at Battery Park, New York City since 1900 and at Montauk in Suffolk since 1947. The black lines are the linear fit. Data are from the Permanent Service for Mean Sea Level (PSMSL))

Future Change in Temperature

Under an aggressive mitigation scenario of greenhouse emissions for the 21st Century, hereafter referred to Radiative Concentration Pathway 4.5 (RCP 4.5), by 2050s, the medium value of projected warming in Nassau and Suffolk is 4.0°F relative to the 1985-2004 reference period. The likely warming will be between 3.3°F and 4.7°F (middle range), with a high estimate of 5.9°F (upper 10th percentile). By the 2090s, the warming is projected to be 5.5°F, with a likely range of 4.4°F to 6.5°F (middle range), and a high estimate of 8.7°F (upper 10th percentile) (Figure E3).

Under the "business as usual" emission scenario, hereafter referred to as RCP8.5, by the 2050s, the medium value of projected warming in Nassau and Suffolk is 5.4°F relative to the 1985-2004 reference period. The likely warming will be between 4.3°F to 6.5°F (middle range), with a high-estimate of 7.5°F. By the 2090s, mean annual temperature is projected to increase by 10.1°F, with a likely range of 8.4°F to 12.0°F (middle range), and a high estimate of 14.4°F (Figure E4).

Figure E3 (right): Climate warming (°F) relative to 1985-2004 in Nassau and Suffolk from an ensemble of 29 models under the aggressive mitigation scenario of greenhouse emissions RCP4.5. The red bars are the medium warming projected by the ensemble of models; the black intervals denote the middle range (25th and 75th percentile values) of the models; the orange bars denote the upper 10th percentile. Projected warming is given for 2050s and 2090s. Model simulations are from the Coupled Model Intercomparison Project (CMIP5) archived at the Lawrence Livermore National Laboratory.



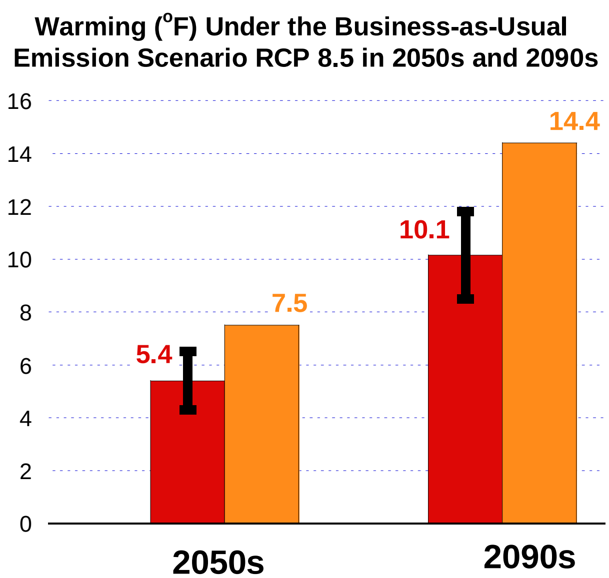


Figure E4 (left): Climate warming (°F) relative to 1985-2004 in Nassau and Suffolk from an ensemble of 29 models under the business-as-usual scenario of greenhouse emissions RCP8.5. The red bars are the medium warming projected by the ensemble of models; the black intervals denote the middle range (25th and 75th percentile values) of the models; the orange bars denote the upper 10th percentile. Projected warming is given for 2050s and 2090s. Model simulations are from the Coupled Model Intercomparison Project (CMIP5) archived at the Lawrence Livermore National Laboratory.

Future Change in Precipitation

Precipitation is projected to increase in Nassau and Suffolk. The signal is significant only after the middle of the 21st Century. Precipitation is about 10 (medium-estimate) to 20 (high-estimate) percent more at the end of the 21st Century in the RCP4.5 scenario, and 15 (medium-estimate) to 25 (high-estimate) percent more in the RCP 8.5 scenario.

Sea Level Rise[1]

The sea level is projected to rise along the Nassau and Suffolk coasts. Under the conservative RCP 4.5

[1] The calculation of sea-level rise is described in Appendix A1.

emission scenario, by the end of the 21st century, the sea-level is projected to rise in the two counties by 24.3 inches, with the 95% uncertainty range[2] of 12.0 to 36.3 inches relative to the 1985-2004 reference period (Figure E5). Under the pessimistic RCP 8.5 emission scenario, the sea-level is projected to rise 34.0 inches with the 95% uncertainty range of 23.0 to 45.1 inches. Projected values for the two counties are similar.

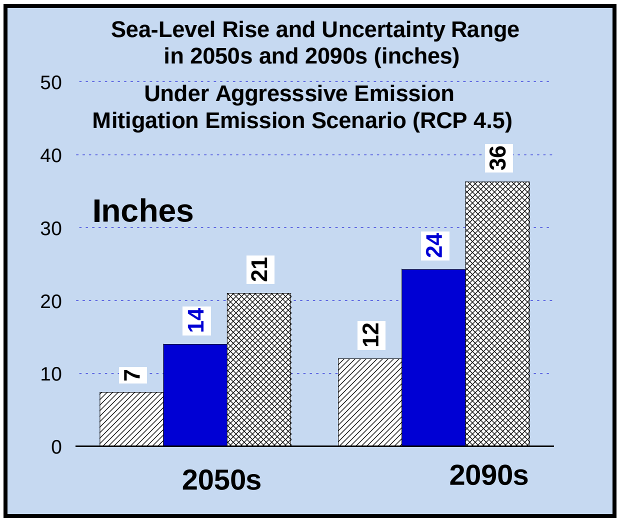


Figure E5: Projected sea-level rise relative to the reference period of 1985-2004 in Nassau and Suffolk under the aggressive mitigation scenario of greenhouse emissions RCP4.5 in 2050s and 2090s. The blue bars are the mean values of sea level rise (feet); the hatched bars represent the 95% uncertainty range. Calculations are based on the Coupled Model Intercomparison Project (CMIP5) archived at the Lawrence Livermore National Laboratory and methods used in the Fifth Assessment Report (AR5) by the Inter-governmental Panel for Climate Change (IPCC).

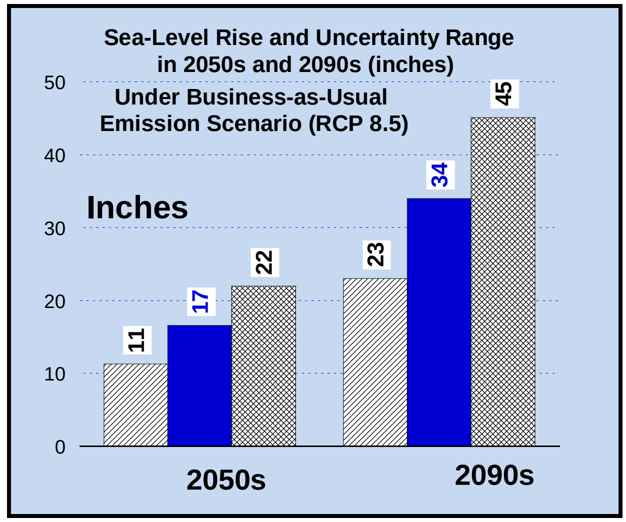


Figure E6: Projected sea-level rise relative to the reference period of 1985-2004 in Nassau and Suffolk under the "business as usual" scenario of greenhouse emissions RCP8.5 in 2050s and 2090s. The blue bars are the mean values of sea level rise (feet); the hatched bars represent the 95% uncertainty range. Calculations are based on the Coupled Model Intercomparison Project (CMIP5) archived at the Lawrence Livermore National Laboratory and methods used in the Fifth Assessment Report (AR5) by the Inter-governmental Panel for Climate Change (IPCC).

Projected Extreme Events

The number of days at or above 90°F per year in the two counties will increase threefold in the 2050s and fourfold in the 2090s from the current mean of 7.4 days in Nassau under the RCP 4.5 scenario. The number of days at or above 90°F per year in the two counties will increase fourfold in the 2050s and fivefold in the 2090s from the current mean of 4.7 days in Suffolk. In the pessimistic RCP 8.5 scenario, by the 2090s, Nassau is projected to have 57 to 77 days per year with a maximum temperature over 90°F (middle range), with a high estimate of 90 days per year. Suffolk will have 45 to 69 days per year with a maximum temperature over 90°F (middle range), with a high-estimate of 83 days per year.

By the end of 21st Century, under the RCP 4.5 mitigation scenario, the average number of days per year exceeding 100°F in Nassau will be 1.5 to 2.9 days (middle range), with a high estimate of 3.7 days. The average number of days per year exceeding 100°F in Suffolk will be 0.7 to 1.5 days (middle range), with a

[2] The projected value has 5% possibility of being smaller than the lower end of the range, and 95% possibility of being smaller than the upper end of the range. This terminology follows the convention used in Church et al. (2013).

high estimate of 2.2 days (Table E1).

By the end of 21st Century, under the RCP 8.5 "business as usual" scenario, the average number of days per year exceeding 100°F in Nassau will be 6.9 to 14.4 days (middle range), with a high-estimate of 17.6 days. The average number of days per year exceeding 100°F in Suffolk will be 3.5 to 10.8 days (middle range), with a high estimate of 15.0 days (Table E2).

Table E1 (below): Average number of days in 2090 with maximum temperature at or above 100°F in 2090s in each year under the aggressive mitigation scenario of greenhouse emissions RCP 4.5. Model simulations are from the Coupled Model Intercomparison Project (CMIP5) archived at the Lawrence Livermore National Laboratory performed by 29 models. The calculation assumed that the day-to-day temperature variability in the future is the same as in the base period.

Extreme Hot Days Per Year T(max) > 100°F		Baseline 1985-2004	Low-estimate (10^{th} percentile)	Middle range (25^{th} to 75^{th} percentile)	High-estimate (90^{th} percentile)
RCP 4.5	**Nassau**	0.3	1.0	1.5 to 2.9	**3.7 days per year**
RCP 4.5	**Suffolk**	0.1	0.3	0.7 to 1.5	**2.2 days per year**

Table E2 (below): Average number of days in 2090s with maximum temperature at or above 100°F in each year under the "business as usual" scenario of greenhouse emissions RCP 8.5.

Extreme Hot Days Per Year T(max) > 100°F		Baseline 1985-2004	Low-estimate (10^{th} percentile)	Middle range (25^{th} to 75^{th} percentile)	High-estimate (90^{th} percentile)
RCP 8.5	**Nassau**	0.3	4.0	6.9 to 14.4	**17.6 days per year**
RCP 8.5	**Suffolk**	0.1	2.4	3.5 to 10.8	**15.0 days per year**

Projected changes in the occurrence of extreme precipitation, defined as the number of days per year in which precipitation exceeds 1 inch per day, were not detected in both counties. This is true for both the RCP 4.5 and RCP 8.5 scenarios even though mean precipitation is projected to increase.

Changes in the frequency of hurricanes and winter storms cannot be projected with confidence at the present time, although some evidence suggests that their intensities will increase under global warming.

Future Coastal Flood Risk Maps

Flooding zones are projected to be larger along the coasts of Nassau and Suffolk. Figure E5 shows the projected change of the coastal flood maps under the RCP 8.5 emission scenario in the 2050s (yellow) and 2090s (red) in Nassau adjacent to the Bay Park Sewage Treatment Plant (STP). The projected value used the upper bound of the 95% uncertainty range.

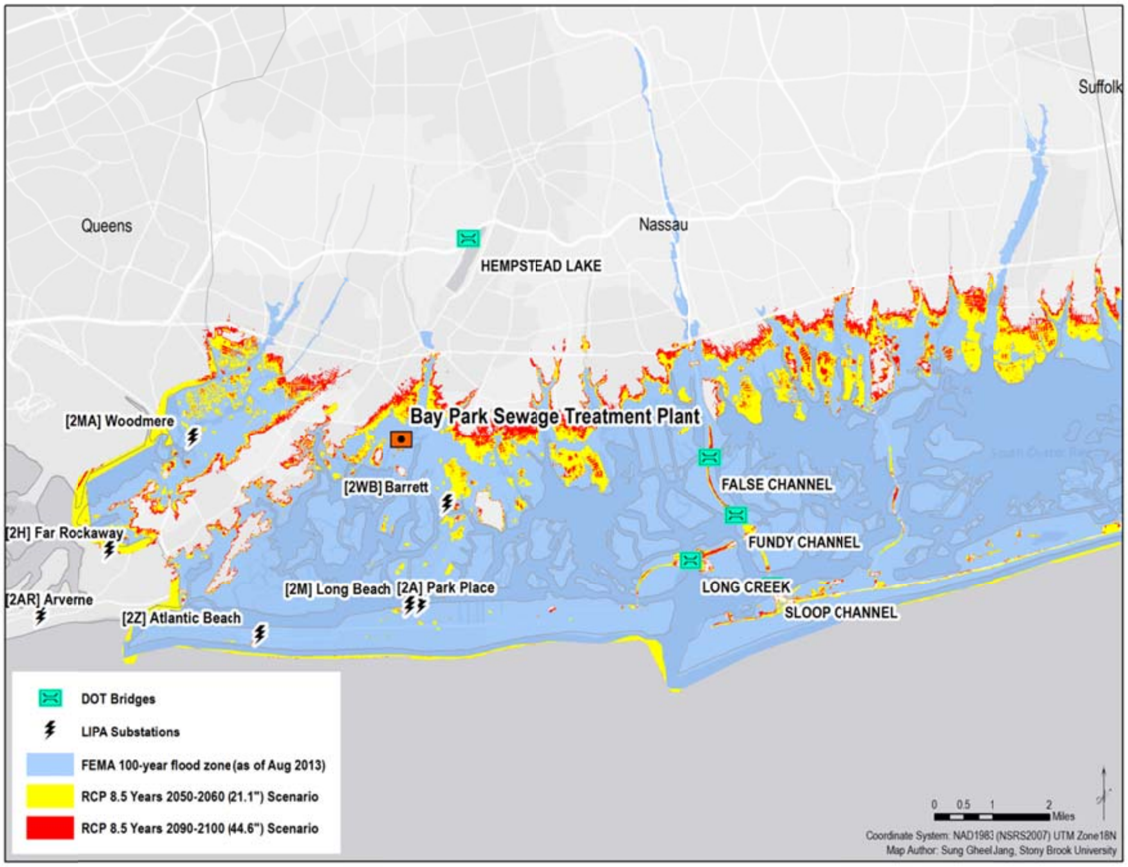


Figure E5 (above): FEMA 100-year flood zone (blue), and projected changes of 100-year flood zones for 2050s (yellow) and for 2090s (red) under the RCP 8.5 scenario of greenhouse emissions. Projected sea level rise is based on the Coupled Model Intercomparison Project (CMIP5) archived at the Lawrence Livermore National Laboratory using the same methods as in the Fifth Assessment Report (AR5) by the Inter-governmental Panel for Climate Change (IPCC). The magnitude of sea level rise is the upper 10th percentile of all model simulations. Labeled in the figure are locations of the Bay Park STP in Nassau, the bridges and LIPA substations.

Recommendations

1. Reconstruction and future planning of infrastructure and communities in Nassau and Suffolk should incorporate projected risks of climate change from coastal flooding due to sea level rise, and heat waves due to hotter summers. This is consistent with the first goal of the Mitigation Strategy of the New York SHMP to promote a comprehensive state hazard mitigation policy framework. Specific recommended mitigation actions include zoning, building codes, capital improvement programs, open space preservation, and storm water management systems.

2. For facilities within the current 100-year flood zones, protective walls or structures should be enhanced or planned to withstand the projected level of sea-level rise. For facilities adjacent to the periphery of current 100-year flood zones, the new flood maps with climate change information should be referenced for new siting or for fortification. Specific recommended actions include protecting public, historic, and private structures, as well as critical facilities and

infrastructure in these areas. These actions will be consistent with the second goal of the SHMP Mitigation Strategy by protecting, upgrading and strengthening existing structures from coastal flooding through acquisition, elevation, relocation, and retrofit. For Nassau and Suffolk counties, protective measures should be made for wastewater treatment plants and residential septic systems in the vulnerable areas.

3. A warmer climate is expected in the 21st Century regardless of what emission scenario is used. In the "business as usual" scenario, the extreme hot days in Nassau and Suffolk with maximum temperature exceeding 100^{o}F will become more common. Facilities should be designed to anticipate heat waves that can stress energy supply and distribution systems, health and drinking water systems, public facilities, and transportation systems. Recommended mitigation actions include sustainable and resilient construction and design measures to reduce or eliminate the impacts of heat waves, promotion of green and natural infrastructure such as public beaches and parks, and better building and rebuilding practices that reduce heat-related stress and energy consumptions.

4. Awareness of future climate risks such as sea-level rise and more intense heat waves should be communicated to residents and communities so that reconstruction plans and investment strategies are designed and implemented appropriately by all stakeholders. This is consistent with the SHMP goal to increase awareness and promote relationships with stakeholders, citizens, elected officials, and property owners to develop opportunities for mitigation of natural hazards.

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Introduction

This report projects future changes of temperature, precipitation, sea-level, and extreme weather events in Nassau and Suffolk counties of New York State for three periods of the 2020s, 2050s, and 2090s. It describes climate change risks that were identified in the New York State Hazard Mitigation Plan (SHMP) for Nassau and Suffolk. The climate risk information in this report complements those in the ClimateAID project (Rosenzweig et al. 2011; Horton et al. 2014; sponsored by the New York State Energy Research and Development Authority) by providing county-level details and by using updated model results. The report was prepared for the New York State Office of Storm Recovery (OSR) to assist the state with recovery and reconstruction efforts from Superstorm Sandy, Hurricane Irene and Tropical Storm Lee.

Past Climate and Trends

Mean Climate and Recent Trends

Climate change poses many risks to communities and infrastructure in different regions. For Nassau and Suffolk, the most significant risks are from sea-level rise, precipitation flooding, and temperature changes. Additional risk factors include wind gusts, snow and freezing rains, and humidity for fire hazards.

This section of the report presents observations of mean climate, climate trends, and extreme weather events in the recent past in Nassau and Suffolk. The observations are described in the context of larger regional and global changes. The mean climate and climate trends in the recent past give the necessary background on projected future climate changes.

Temperature

For the reference period of 1985 to 2004, annual mean air temperatures for Nassau and Suffolk were 48.8°F and 53.5°F respectively when averaged over the National Weather Service's Cooperative Observer Program (COOP) stations (Figure 1). Seasonal temperatures in the two counties are plotted in Figure 2.

Temperature may vary from one location to another, and even within the counties depending on factors such as distance to the coasts, impact of sea-land breeze, and land surface features including trees and urban structures. Such variations are at most a few degrees, much smaller than the diurnal, seasonal, and interannual variations and variability caused by atmospheric circulation systems. This report focuses on long-term climate changes relative to the 20-year reference period of 1985 to 2004. Variations from diurnal, seasonal, interannual, and synoptic variations are therefore largely averaged out. Spatial variations of long-term climate trends within the counties are not expected to vary much within the counties except at locations where anthropogenic land use and land cover occur.

Annual mean temperature has increased at a rate of 0.45°F per decade over the 110-year record averaged over all stations in Nassau and Suffolk. Even though annual temperatures in the two counties vary substantially from year to year, the trend during this period is statistically significant (Figure 3a).

These warming trends are consistent with the temperature trend of 0.4°F per decade in New York City reported by the New York City Panel on Climate Change (NPCC, 2013).

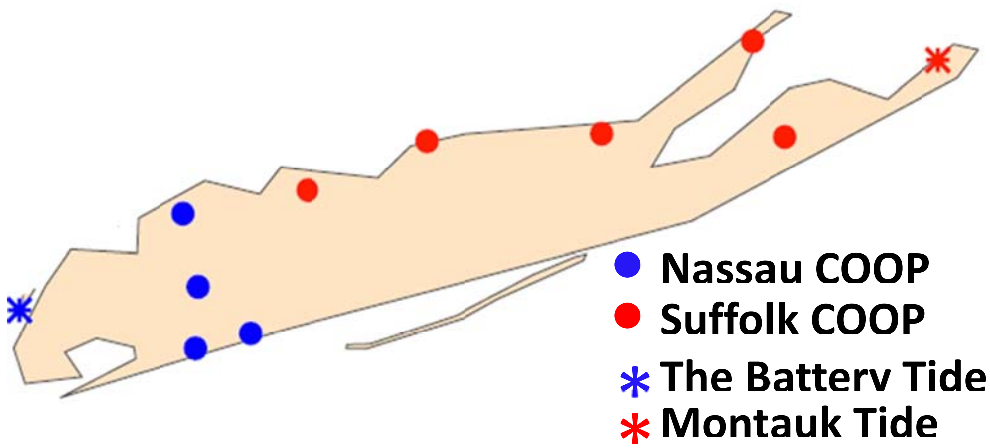

Figure 1 (above): Locations of the National Weather Service's COOP stations in Nassau and Suffolk

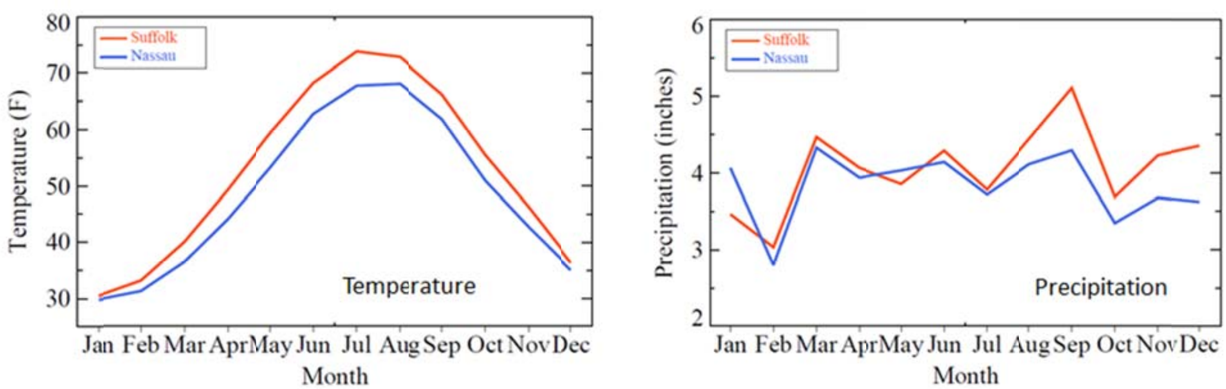

Figure 2 (above): 1985-2004 mean seasonal variation of near surface air temperature (left) and monthly accumulated precipitation (right) in Suffolk and Nassau (data from the Earth System Research Laboratory of the National Oceanic and Atmospheric Administration)

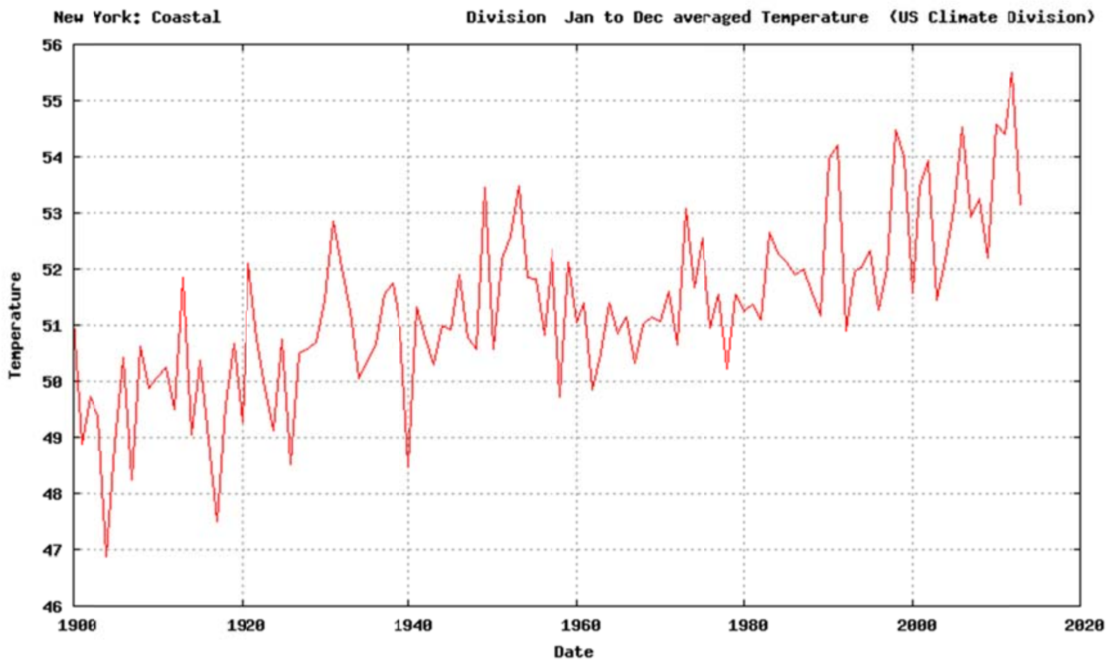

Figure 3a (above): Time series of annual temperature since 1900 in Nassau and Suffolk (data from *the* Earth System Research Laboratory of the National Oceanic and Atmospheric Administration)

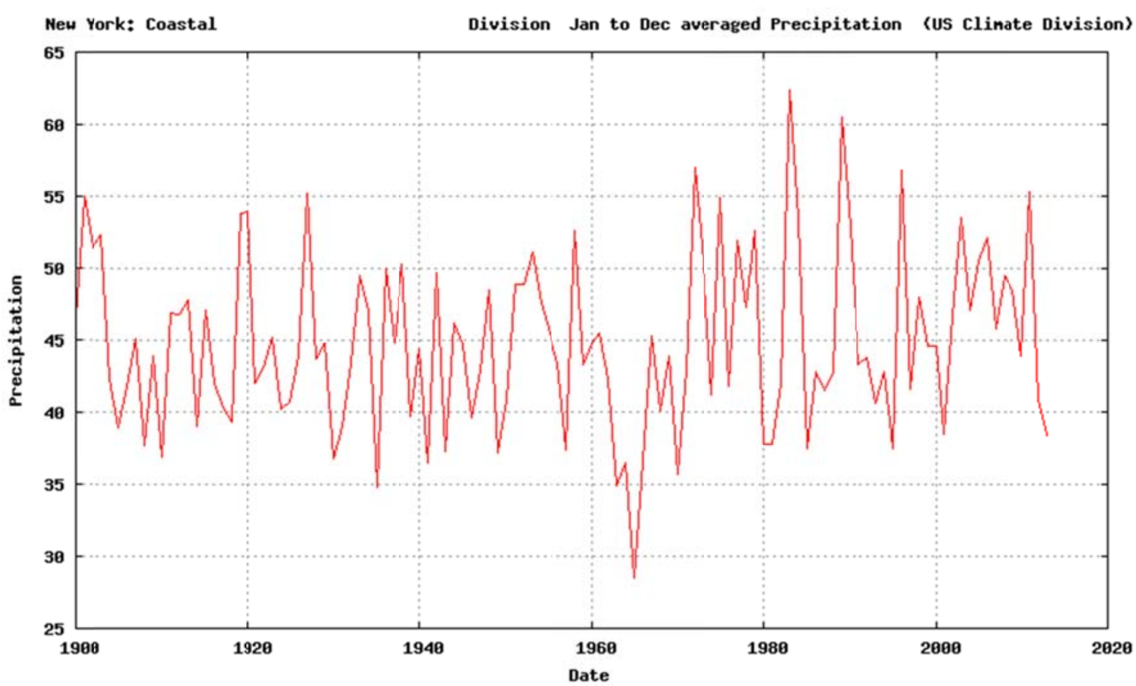

Figure 3b (above): Time series of annual precipitation since 1900 in Nassau and Suffolk (data from the Earth System Research Laboratory of NOAA)

Precipitation

For the baseline period of 1985 to 2004, annual mean air precipitation for Nassau and Suffolk are 45.2 and 47.1 inches of water equivalent, respectively, when averaged over the COOP stations (Figure 1). Seasonal variations are not as large as temperature in terms of percentage change (Figure 2). The small seasonal variations in the two counties differ from those in many other regions where seasonality from monsoon rainfall are dominant, such as in the US Southwest.

Precipitation varies greatly in different locations on a daily and yearly basis. These variations are primarily caused by atmospheric weather systems. Due to these variations, long-term precipitation trends within the counties may not represent signals of climate change even after averaging. Therefore, trends in precipitation need to be interpreted in the larger regional and global context, in which sampling noises are reduced.

Annual mean precipitation has increased at a rate of 0.45 inches per decade over the 110-year period in Nassau and Suffolk (Figure 3b). Because of the large interannual variations, the trends have low confidence levels. However, these trends are consistent with the precipitation trend in the US Northeast (Kunkle et al. 2013).

Sea-Level Rise

Sea-level rise in Nassau and Suffolk in the past century has been calculated using tidal gauge stations located in Battery Park in New York City (NYC), and Montauk in Suffolk County (Figure 1). Sea-level rise has averaged about 1.1 inches per decade since 1900 in NYC and Montauk (Figure 4). These trends are larger than the observed global rate of sea-level rise, which is 0.7 inches per decade over a similar time period (Church and White, 2011). The relatively larger values are consistent with the current understanding of how changes in ocean circulation contribute to sea-level rise along the US Northeast, and with the thermal effects of global warming and vertical change of land elevation (Schlesinger et al. 2010).

Factors contributing to sea-level rise include thermal expansion of global ocean water when it warms, changes in ocean height caused by ocean currents, melting of ice from land ice (glaciers, Greenland and Antarctic ice caps, and other land ice sheets), vertical movement of land, and mass loss and land water storage (Church et. 2013). Most of the observed climate-related rise in global mean sea level over the past century is due to thermal expansion. In the last two decades, land ice melting has contributed equally to sea-level rise.

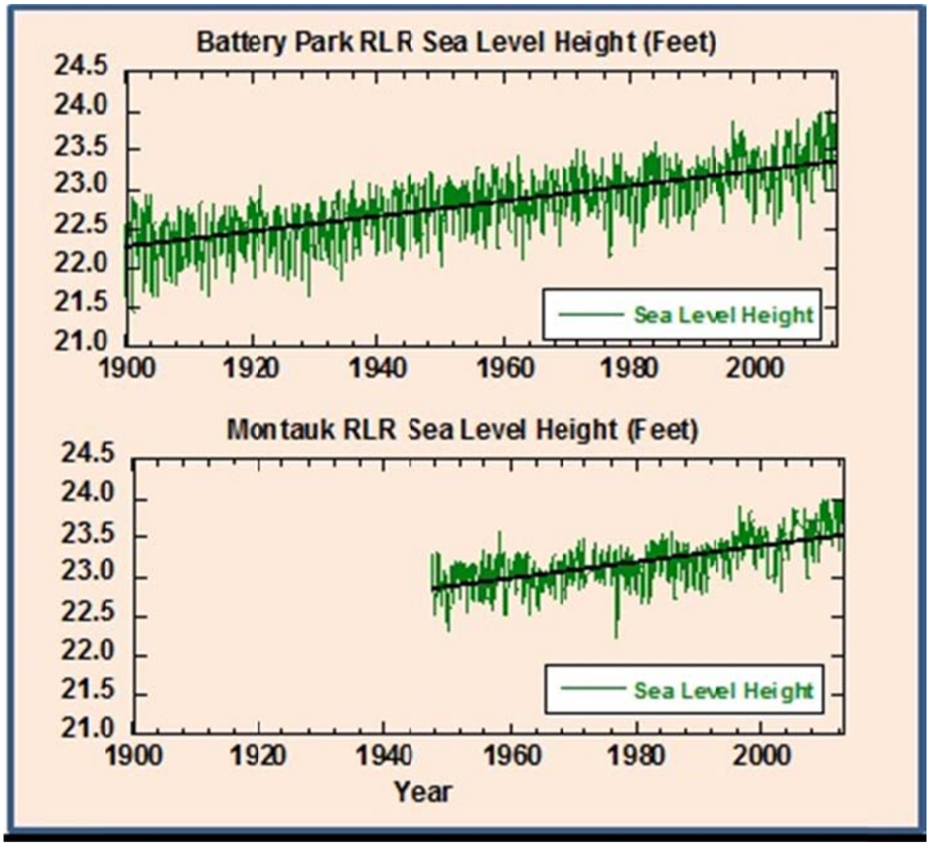

Figure 4 (above): Monthly mean sea-level height from The Permanent Service for Mean Sea Level (data from Permanent Service for Mean Sea Level (PSMSL): http://www.psmsl.org/).

Extreme Events

Extreme events from heat waves, cold outbreaks, heavy rainfall, droughts, and coastal floods can have significant impacts on the communities in Nassau and Suffolk. Coastal flooding is caused by storm surges associated with hurricanes and Nor'easters, as well as heavy precipitations. Because these are rare events, extreme event trends at local scales are often not statistically significant (Horton et al., 2011). Future trends need to be interpreted in the regional and global context as a result of long-term climate change.

Extreme Temperature and Heat Waves

According to the NPCC, extreme temperature events include:

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

Using this definition, we characterized extreme temperature events faced by Nassau and Suffolk by evaluating daily temperature data from all stations in Figure 1. We also determined the average duration of all heat waves in days.

During the 1985-2004 reference period, Nassau County averaged 7.4 days per year at or above 90°F, 0.3 day per year at or above 100°F, 0.7 heat waves per year with an average duration of 3.8 day, and 80.6 number of days below 32°F. These metrics vary from location to location and from year to year, and are best used as benchmarks to measure future changes.

During the same reference period, Suffolk County averaged 4.7 days per year at or above 90°F, 0.1 day per year at or above 100°F, and 0.6 heat waves per year with an average duration of 4.1 days.

Extreme Precipitation

Extreme precipitation events are defined as the number of days per year when daily precipitation is at or above 1, 2, and 4 inches for Nassau and Suffolk, averaged over the 1985-2004 reference period. Nassau County averaged 11.1 days per year with 1 inch or more of precipitation, 2.5 days per year with 2 or more inches of precipitation, and 0.2 day per year with 4 or more inches of precipitation. In the winter season, 1 inch of precipitation is equivalent to 8 to 20 inches of snow depending on air temperature.

Suffolk County averages 12.6 days per year with 1 inch per day or more of rain, 2.8 days per year with 2 or more inches per day of rain, and 0.2 days per year with 4 or more inches per day of rain.

Extreme precipitation largely varies from location to location, and from year to year. These variations are caused by both synoptic weather systems and mesoscale weather systems. The trends in extreme precipitation events at county scales in the past record are not statistically significant.

Storm surges

Hurricanes and nor'easters can cause significant storm surges along the Long Island coast. The hurricane season in the North Atlantics is between July and October, but can extend from June to November (Fig 5). Nor'easters impact the region from November to April, and occur more frequently than hurricanes.

Storm surges that coincide with high tides cause the most severe flooding. The relatively long duration of Nor'easters can cause storm surge to overlap with high tides, which can result in severe damages (Hondula and Dolan, 2010). At Battery Park, the mean tide range is 5.48 feet, but can be as large as 7.70 feet during the most extreme spring tides (NOAA Tides and Currents, 2013). The annual maximum daily tidal range at Battery Park is approximately 7.5 feet (Orton et al., 2012). At Montauk, the mean tide range is 4.97 feet.

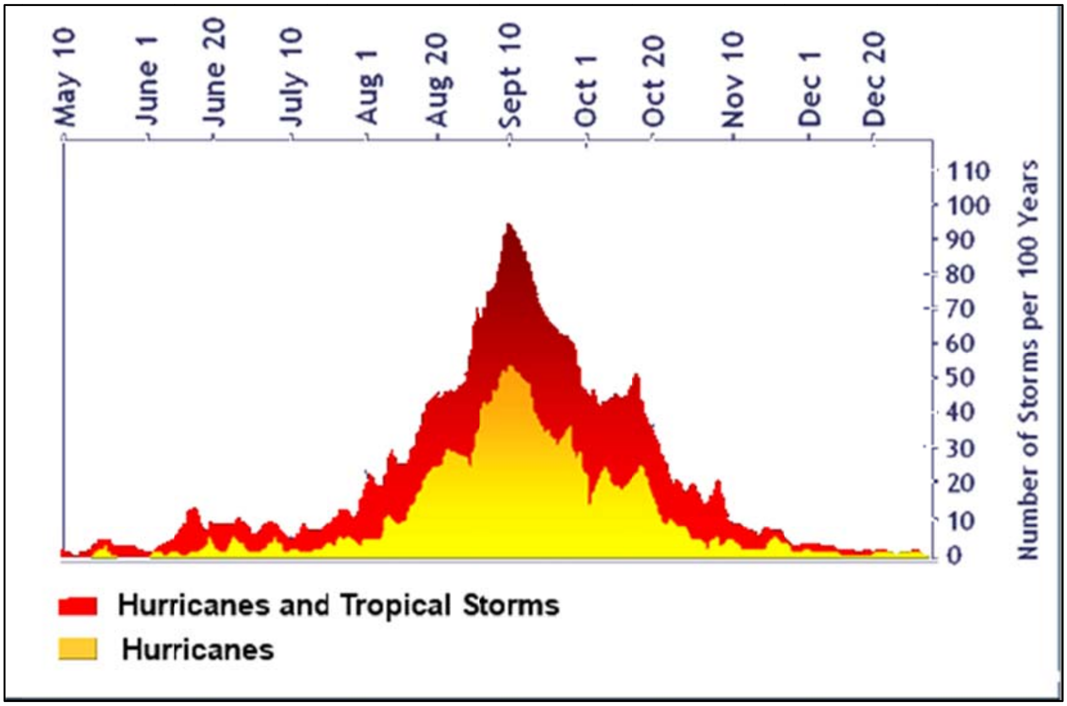

Figure 5 (above): Seasonal distribution of Atlantic hurricanes and tropical storms (source: NOAA Hurricane Center).

The overall strength of hurricanes, and the number of strong (Category 4 and 5) hurricanes in the North Atlantic have increased since the early 1980s (USGCRP, 2013). Evidence suggests that storm activity near the Northeast US coastline has increased during the second half of the 1950-2010 period (USGCRP, 2013). This evidence is consistent with the latest scientific literature (Colle et al., 2013). However, we cannot make definitive statements about storm trends at finer spatial scales such as Long Island. Recent high impact storms to the region, including Superstorm Sandy and Hurricane Irene, were associated with the extratropical transition of hurricanes to cyclones that were amplified by the phasing of low pressure centers propagating eastward from the North American continent. While the frequency of significant hurricane impacts on Long Island has been high in the last five years relative to the earlier three decades, there is lack of sufficient data or theory to make conclusions on trends and the role of climate change.

Future Climate Risks

Methods of Climate Projections

NYS RISE projected future changes of temperature, precipitation, and some sea-level rise in Nassau and Suffolk by using numerical model simulations from global general circulation models (GCMs). These simulations were obtained from the Coupled Model Intercomparison Project Version 5 (CMIP5), which were also used in the Fifth Assessment (AR5) by the Inter-governmental Panel for Climate Change (IPCC) and in the NPCC Climate Change Report for NYC (NPCC, 2013). These models calculate atmospheric winds, temperature, air pressure, precipitation, atmospheric radiation, clouds, ocean currents and temperature, salinity, land surface temperature, soil moisture, and a suite of other meteorological variables over the globe at approximately 150-kilometer resolutions. These models use the seasonal variation of solar radiation, surface topography and vegetation, emissions of greenhouse gases, and aerosols as inputs to calculate the evolution of global climate. They solve the geophysical fluid dynamics equations and associated atmospheric, oceanic, hydrological, and other processes in time steps of about 20 minutes extending to the end of the 21st Century. The data are archived at the Program for Climate Model Diagnosis and Intercomparison (PCMDI) Earth System Grid (ESG).[3]

GCMs have many uncertainties mainly resulting from the coarse spatial grids of about 150 kilometers. These grids cannot resolve mesoscale phenomena and processes such as convection, clouds, and deterministic rainfall, which are alternatively parameterized. The coarse resolution is due to the limitation of current supercomputers. Even on massively parallel computing platforms with millions of processors, GCMs still cannot conduct century-long simulations that can resolve mesoscale phenomena at 30 kilometer resolutions. Few countries have such computing capabilities at the present time. Other sources of GCM uncertainties are from cloud-climate feedbacks, aerosol-induced cloud changes, diffusion by mesoscale eddies in the ocean, and the dynamical motions of ice sheets (Gent et al. 2012; Zhang et al. 2013). Most of the GCMs that participated in CMIP5 have been calibrated to current climate system conditions and sea-level rise changes outside the range presented here. Climate changes simulated by the GCMs are derived from referenced simulations without anthropogenic surface emissions of greenhouse gases and aerosols.

Due to model uncertainties, ensemble results from multiple models participating in CMIP5 are used in this report. These models are listed in Table A2 in the Appendix. The spread among the multiple models is used to estimate the ensemble mean and the 90th percentile. Model results from the land grids nearest to Nassau or Suffolk are extracted. The single grid values may contain large sampling biases. They are most useful when interpreted in conjunction with values in the larger surrounding regions and with theoretical understanding of the underlying physical mechanisms.

Representative Concentration Pathways

The emissions of greenhouse gases and aerosols for the 21st Century are based on different scenarios of population growth, gross domestic product (GDP) per capita, advances in energy use and energy technology, carbon policy, and cooperation among different nations (Moss et al. 2010). Two scenarios are used in this report including the Representative Concentration Pathway (RCP) 4.5 (Thomson et al. 2011) and RCP 8.5 (Van Vuuren et al. 2011). RCP 4.5 represents an aggressive mitigation scenario in which alternative energy becomes dominant, and countries work together to combat climate change so that emissions from greenhouse gases decrease after they peak in 2050. In this scenario, the climate radiative forcing to the atmosphere from anthropogenic emissions is 4.5 watts per square meter over the globe. RCP 8.5 represents a scenario in which little coordinated actions among the nations are made to curb emissions so that the greenhouse emission continues to increase in the 21st Century. In this scenario, the climate radiative forcing to the atmosphere from anthropogenic emissions is 8.5 watts per

[3] CMIP5: http://cmip-pcmdi.llnl.gov/cmip5/data_getting_started.html.

square meter over the globe.

This report considers RCP 4.5 to represent the most optimistic mitigation scenario and RCP 8.5 to mimic the “business as usual” scenario. Although there are many uncertainties in future emission scenarios, these two should span the most likely range.

Climate Model Bias Corrections

As in NPCC (2013), the results for future time periods are compared to the model results for the reference period of 1985 to 2004. Mean temperature change projections are calculated via the delta method. The delta method does self-correction of bias whereby each model’s reference simulation is subtracted from the model’s future simulation (Gleick 1986; Arnell 1996; Wilby et al., 2004; Horton et al., 2011). Mean precipitation and sea-level changes are similarly based on the relative change between the future periods and the reference period.

Time Horizons

To condense the data, three 11-year time slices of projected future climate are reported. These represent the climate change in the next twenty years from the present, the middle of the 21st century and the end of the 21st century, all relative to the reference period of 1985-2004. The three periods are from 2020 to 2029, from 2050 to 2059, and from 2090 to 2099. For each individual model, interdecadal variation of natural climate variability may affect the climate change signal. These natural variabilities are averaged out and reduced when ensemble model results are used.

Projected Variables

Projections of temperature and precipitation are directly provided by the GCMs. Annual mean temperature and precipitation data are used to derive their mean changes. Daily temperature and daily precipitation data are used to determine the extreme events.

Sea-level rise projections are derived from a component-by-component analysis (IPCC, 2013). Current GCMs only use one component, changes in ocean circulations, to determine sea-level rise. Other components are derived indirectly from changes in ocean temperature, salinity, ice mass, and soil moisture. Components also include vertical land movements and gravitational, isostatic, and rotational effects resulting from ice mass loss that are determined separately. Table 1 from the NPCC (2013) summarizes the sea-level rise components. Other studies include similar components (Perrette et al., 2013; Slangen et al., 2012). Detailed descriptions to derive the sea-level rise for Nassau and Suffolk are in the Appendix A1.

Table 1 (below): Sea-Level Rise Projection Components (NPCC).

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, thermal and dynamic	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; Church et al. 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	Church et al. 2013
Gravitational, rotational, and isostatic	Local	With loss of land-based ice (see the above two terms), regional sea level impacts differ due to gravitational, rotational and 'fast' (elastic) isostatic responses	Multiple calculations from sea-level equation.	Mitrovica et al., 2009; Perrette et al., 2013; Gomez et al., 2010; Peltier, 2012
Vertical land movements/ glacioisostatic adjustments (GIA)	Local	Local land height is decreasing in response to the last deglaciation (slow isostatic response)	Latest version of Peltier's Glacial Isostatic Adjustment (GIA) model	Peltier, 2012
Land water storage	Global	Water stored in reservoirs and dams and extracted from groundwater changes the ocean's mass and sea level	Global estimates derived from recent literature	Konikow, 2011; Wada et al., 2012; Church et al., 2011

Projected Future Changes in Temperature, Precipitation, and Sea-Level Rise

This section presents climate projections for temperature, precipitation, sea-level rise, and extreme events in Nassau and Suffolk for three periods including 2020-2029, 2050-2059, and 2090-2099. Both scenarios of RCP 4.5 and RCP 8.5 are provided, and represent the likely bounds of future greenhouse gas emissions.

Temperature

RCP 4.5

Under the optimistic climate mitigation scenario, RCP 4.5, Table 2 shows the temperature change in Nassau and Suffolk for the three future periods relative to the reference period of 1985-2004. The reference period annual temperature for Nassau and Suffolk are 48.8°F and 53.5°F, respectively.

For the period of 2020-2029, the temperature will most likely increase by 1.6°F to 2.5°F in both counties. The higher end estimate from the ensemble of models (90th percentile) is about 3.0°F. Values for the two counties are very similar. The lower end estimate (10th percentile) is 1.1 °F.

For the period of 2050-2059, the temperature will most likely increase by 3.3°F to 4.7°F in both counties. The higher end estimate from the ensemble of models (90th percentile) is 5.9°F. The lower end estimate (10th percentile) is 2.6°F.

For the period of 2090-2099, the temperature will most likely increase by 4.5°F to 6.4°F in both counties. The higher end estimate from the ensemble of models (90th percentile) is 8.7°F. The lower end estimate (10th percentile) is 3.2°F.

Table 2 (below): Temperature change relative to the reference period of 1985-2004 from the RCP 4.5 climate change scenario.

RCP4.5	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020-2029			
Nassau	1.1°F	1.6°F to 2.5°F	3.1°F
Suffolk	1.1°F	1.6°F to 2.4°F	3.0°F
2050-2059			
Nassau	2.6°F	3.3°F to 4.7°F	5.9°F
Suffolk	2.6°F	3.3°F to 4.7°F	5.9°F
2090-2099			
Nassau	3.2°F	4.5°F to 6.5°F	8.7°F
Suffolk	3.2°F	4.4°F to 6.4°F	8.7°F

The temperature change values for the two counties are at the low end of the values projected for NYC by the NPCC for the 2050s (NPCC 2013). This is primarily because NPCC combined both the RCP 4.5 and RCP 8.5 projections into one single value. Overall, these RCP 4.5 changes are consistent with temperature change projections in the US Northeast (IPCC 2013).

RCP 8.5

Under the "business as usual" emission scenario, RCP 8.5, Table 3 shows the temperature change in Nassau and Suffolk for the three future periods relative to the reference period of 1985-2004.

For the period of 2020-2029, the projected warming is similar to the RCP 4.5 scenario. The temperature will most likely increase by 1.6°F to 2.6°F in both counties. The higher end estimate from the ensemble of models (90th percentile) is about 3.6°F. The lower end estimate (10th percentile) is 0.9°F.

For the period of 2050-2059, the projected warming in RCP 8.5 is about 1.2°F to 1.7°F more than the projected warming in the RCP 4.5 scenario. The temperature will most likely increase by 4.3°F to 6.5°F in both counties. The higher end estimate from the ensemble of models (90th percentile) is 7.5°F. The lower end estimate (10th percentile) is 3.8°F. These values are approximately the same magnitudes as the climate warming at the end of the 21st Century for RCP 4.5.

For the period of 2090-2099, warming in RCP 8.5 is 4°F or more than the warming in the RCP4.5 scenario. The temperature will most likely increase by 8.7°F to 12.0°F in both counties. The higher end estimate from the ensemble of models (90th percentile) is 14.4°F. The lower end estimate (10th percentile) is 7.4°F.

Table 3 (below): Temperature change relative to the reference period of 1985-2004 from the RCP 8.5 climate change scenario.

RCP 8.5	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020-2029			
Nassau	1.2°F	1.6°F to 2.4°F	3.6°F
Suffolk	0.9°F	1.6°F to 2.8°F	3.6°F
2050-2059			
Nassau	3.8°F	4.4°F to 6.5°F	7.5°F
Suffolk	3.8°F	4.3°F to 6.4°F	7.5°F
2090-2099			
Nassau	7.4°F	8.7°F to 12.0°F	14.4°F
Suffolk	7.4°F	8.4°F to 11.6°F	14.4°F

The values presented above for the two counties are larger than values projected by the NPCC for the 2050s in NYC (NPCC 2013). This is primarily because NPCC combined both the RCP 4.5 and RCP 8.5 projections into one single value. Overall, these RCP 4.5 changes are consistent with temperature change projections in the US Northeast (IPCC 2013).

Precipitation

RCP 4.5

Under the optimistic climate mitigation scenario, RCP 4.5, Table 4 shows the precipitation change in Nassau and Suffolk for the three future periods relative to the reference period of 1985-2004. The reference period annual precipitation for Nassau and Suffolk are 45.2 and 47.1 inches of water equivalent per year, respectively.

For the period of 2020-2029, precipitation will most likely increase. The higher end estimate from the ensemble of models (90th percentile) is an increase of 4.2 inches, but the lower end estimate (10th percentile) is a decrease of about 1.4 inches. The models do not give consistent signs of the precipitation changes. Values for the two counties are very similar.

For the period of 2050-2059, the precipitation will most likely increase by 0.6 to 4.4 inches per year. The higher end estimate from the ensemble of models (90th percentile) is 6.6 inches. The lower end estimate (10th percentile) is -0.7 inches.

For the period of 2090-2099, precipitation will most likely increase by 2.3 to 5.9 inches in both counties. The higher end estimate from the ensemble of models (90th percentile) is 8.1 inches. The lower end estimate (10th percentile) is 0.9 inches. All models projected an increase in precipitation. The projected high end precipitation is about 17 percent more than the reference period precipitation.

Table 4 (below): Precipitation change relative to the reference period of 1985-2004 from the RCP 4.5 climate change scenario (unit: inches per year).

RCP 4.5	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020-2029			
Nassau	-1.4	-0.3 to 3.3	4.2
Suffolk	-1.3	-0.2 to 3.3	4.1
2050-2059			
Nassau	-0.5	0.6 to 4.4	6.6
Suffolk	-0.7	0.4 to 4.5	6.5
2090-2099			
Nassau	0.9	2.1 to 6.1	7.6
Suffolk	1.0	2.3 to 5.9	8.1

Overall, these values are consistent with precipitation change projections in the US Northeast (IPCC 2013) and for NYC for the 2050s (NPCC 2013).

RCP 8.5

Under the "business as usual" emission scenario RCP 8.5, Table 5 shows the precipitation change in Nassau and Suffolk for the three future periods relative to the reference period of 1985-2004.

For the period of 2020-2029, precipitation will most likely increase by 0.6 to 4.1 inches per year. The higher end estimate from the ensemble of models (90th percentile) is an increase of 4.8 inches, but the lower end (10th percentile) estimate is a decrease of about 1.7 inches. The models do not give consistent signs of the precipitation changes.

For the period of 2050-2059, precipitation will most likely increase by 1.6 to 5.0 inches per year. The higher end estimate from the ensemble of models (90th percentile) is an increase of 6.7 inches. The lower end (10th percentile) estimate is a decrease of 0.4 inches.

For the period of 2090-2099, precipitation will most likely increase by 4.3 to 8.7 inches. This represents a 10 to 20 percent increase of precipitation compared to the reference period. The higher end estimate from the ensemble of models (90th percentile) is 11.3 inches. The lower end (10th percentile) estimate is 1.5 inches. All models projected an increase of precipitation. The projected high end precipitation is about 17 percent more than the reference period precipitation.

Table 5 (below): Precipitation change relative to the reference period of 1985-2004 from the RCP 8.5 climate change scenario (unit: inches per year).

RCP 8.5	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020-2029			
Nassau	-1.7	0.8 to 3.9	4.8
Suffolk	-1.5	0.6 to 4.1	4.6
2050-2059			
Nassau	-0.2	1.6 to 5.0	6.7
Suffolk	-0.4	1.1 to 5.0	6.7
2090-2099			
Nassau	1.5	4.0 to 8.8	11.8
Suffolk	1.7	4.3 to 8.7	11.8

Overall, these values are consistent with precipitation change projections in the US Northeast (IPCC 2013) and for NYC for the 2050s (NPCC 2013).

Sea Level Rise[4]

RCP 4.5

Under the optimistic climate mitigation scenario, RCP 4.5, Table 6 shows sea-level rise in Nassau and Suffolk for the three future periods relative to the reference period of 1985-2004.

For the period of 2020-2029, the mean value of projected sea-level rise is 6.6 inches. The 25th to 75th percentile range of sea-level rise is 5.2 to 8.0 inches. The high end estimate (95% uncertainty) is 10.6 inches for the average of the two counties. Values for the two counties are very similar.

For the period of 2050-2059, the mean value of projected sea-level rise is 14 inches. The 25th to 75th percentile range of sea-level rise is 11.2 to 16.8 inches. The high end estimate (95% ucertainty) is 21

[4] Calculation method is described in Appendix A1.

inches for the average of the two counties.

For the period of 2090-2099, the mean value of projected sea-level rise is 24.3 inches. The 25th to 75th percentile range of sea-level rise is 29.3 to 33.8 inches. The high end estimate (95% uncertainty) is 36.3 inches for the average of the two counties.

Table 6 (below): Sea-level rise relative to the reference period of 1985-2004 from the RCP 4.5 climate change scenario (unit: inch).

RCP 4.5	Mean Value	95% low bound	10th percentile	25th to 75th percentiles	90th percentile)	95% upper bound
2020-2029						
Nassau	**6.2**	3.7	3.7	4.8 to 7.6	8.9	**10.6**
Suffolk	**7.0**	4.3	4.6	5.7 to 8.3	9.4	**10.5**
Bi-County	**6.6**	4.0	4.1	5.2 to 8.0	9.2	**10.6**
2050-2059						
Nassau	**14.2**	7.3	8.8	11.4 to 17.0	19.6	**21.0**
Suffolk	**13.8**	7.4	8.5	11.0 to 16.6	19.1	**21.0**
Bi-County	**14.0**	7.4	8.7	11.2 to 16.8	19.3	**21.0**
2090-2099						
Nassau	**24.2**	11.8	14.6	19.2 to 29.2	33.7	**36.4**
Suffolk	**24.3**	12.2	14.9	19.4 to 29.2	33.8	**36.3**
Bi-County	**24.3**	12.0	14.8	19.3 to 29.2	33.8	**36.3**

RCP 8.5

Under the "business as usual" emission scenario RCP 8.5, Table 7 shows sea-level rise in Nassau and Suffolk for the three future periods relative to the reference period of 1985-2004.

For the period of 2020-2029, the mean value of projected sea-level rise is 7.5 inches. The 25th to 75th percentile range of sea-level rise is 9 to 10.3 inches. The high end estimate (95% uncertainty) is 11 inches for the average of the two counties. Values for the two counties are very similar.

For the period of 2050-2059, the mean value of projected sea-level rise is 16.6 inches. The 25th to 75th percentile range of sea-level rise is 18.8 to 20.8 inches. The high end estimate (95% uncertainty) is 22 inches for the average of the two counties.

For the period of 2090-2099, the mean value of projected sea-level rise is 34 inches. The 25th to 75th percentile range of sea-level rise is 29.5 to 38.5 inches. The high end estimate (95% uncertainty) is 45.1 inches for the average of the two counties.

Table 7 (below): Sea-level rise relative to the reference period of 1985-2004 from the RCP 8.5 climate change scenario (unit: inch).

RCP 8.5	Mean Value	95% low bound	10th percentile	25th to 75th percentiles	90th percentile)	95% upper bound
2020-2029						
Nassau	**7.5**	3.7	4.5	5.9 to 9.1	10.5	**11.3**
Suffolk	**7.4**	4.1	4.9	6.1 to 9.0	9.9	**10.6**
Bi-County	**7.5**	3.9	4.7	6.0 to 9.0	10.2	**11.0**
2050-2059						
Nassau	**16.6**	11.2	12.4	14.4 to 18.8	20.8	**22.0**
Suffolk	**16.6**	11.4	12.5	14.4 to 18.8	20.7	**22.0**
Bi-County	**16.6**	11.3	12.4	14.4 to 18.8	20.8	**22.0**
2090-2099						
Nassau	**34.1**	23.2	25.5	29.5 to 38.4	42.7	**45.2**
Suffolk	**33.8**	22.7	25.1	29.2 to 38.4	42.5	**45.0**
Bi-County	**34.0**	23.0	25.3	29.4 to 38.4	42.6	**45.1**

Projection of Extreme Events

In this report, extreme temperature events are described as the number of days with maximum temperatures at or above 90°F, the number of days with maximum temperatures at or above 100°F, heat waves with three or more consecutive days with maximum temperatures at or above 90°F, and the number of days with minimum temperatures at or below 32°F. Extreme precipitation is described as the number of days when precipitation exceeds the thresholds of 1, 2, and 4 inches per day.

This section describes the metrics of extreme events for the 2050-2059 and 2090-2099 periods in Nassau and Suffolk counties. These metric will be compared with occurrences in the baseline period of 1985-2004. This report does not describe extreme events of heavy snowfall and wind gusts. These are left for future studies.

RCP 4.5 - Nassau County

Under the optimistic RCP 4.5 emission scenario, by 2050-2059, the number of days in Nassau County with temperatures exceeding 90°F will likely increase to 19 to 27 days per year from the 7.4 days in the reference period (Table 8). This range will change to 25 to 37 days per by 2090-2099 (Table 9).

The number of heat waves will increase from 0.7 per year in the reference period to 2.0 to 3.2 events by 2050-2059, with about the same average duration of three days (Table 8). This range will change to 2.8 to 4.7 events by 2090-2099, with the average duration not statistically different from the present climate (Table 9).

By 2050-2059, the number of days in Nassau County with temperatures below 32°F will decrease from 80 days per year to 43 to 55 days per year (Table 8). By 2090-2099, the number of days with temperatures below 32°F will decrease to 34 to 50 days per year.

The projected number of extreme precipitation days with a rate larger than 1 inch per day is not statistically different from the present day value for both the 2050-2059 (Table 8) and the 2090-2099 (Table 9) periods under RCP 4.5.

Table 8 (below): Projection of extreme events in Nassau County in 2050-2059 under RCP 4.5.

Extreme Events		**Baseline 1985-2004**	**Low-estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High-estimate (90th percentile)**
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	7.4	15.8	19.0 to 27.0	30.9
	Number of days/year with maximum temperature at or above 100°F	0.3	1.2	1.6 to 3.1	4.0
	Number of heat waves	0.7	1.7	2.0 to 3.2	3.8
	Average heat waves duration (in days)	3.8	3.2	3.6 to 4.3	4.4
	Number of days/year with minimum temperature at or below 32F	80.6	35.2	43.3 to 54.6	59.9
Intense Precipitation	Number of days/year with rainfall at or above 1 inch	11.1	10.9	11.0 to 11.3	11.4
	Number of days/year with rainfall at or above 2 inches	2.5	2.4	2.4 to 2.5	2.5
	Number of days/year with rainfall at or above 4 inches	0.2	0.2	0.2 to 0.2	0.2

Table 9 (below): Projection of extreme events in Nassau County in 2090-2099 under RCP 4.5.

Extreme Events		Baseline 1985-2004	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	7.4	19.8	25.3 to 36.8	41.4
	Number of days/year with maximum temperature at or above 100°F	0.3	1.0	1.5 to 2.9	3.7
	Number of heat waves	0.7	2.1	2.8 to 4.7	5.7
	Average heat waves duration (in days)	3.8	3.6	4.1 to 4.5	4.8
	Number of days/year with minimum temperature at or below 32F	80.6	20.3	34.0 to 49.7	54.9
Intense Precipitation	Number of days/year with rainfall at or above 1 inch	11.1	11.0	11.2 to 11.4	11.5
	Number of days/year with rainfall at or above 2 inches	2.5	2.4	2.4 to 2.5	2.5
	Number of days/year with rainfall at or above 4 inches	0.2	0.2	0.2 to 0.2	0.2

RCP 4.5 - Suffolk County

Under the optimistic RCP 4.5 emission scenario, by 2050-2059 the number of days in Suffolk County with temperatures exceeding 90°F will likely increase to 15 to 20 days per year from the 4.7 days in the reference period (Table 10). This range will change to 19 to 28 days per year by 2090-2099 (Table 11).

The number of heat waves will increase from 0.6 per year in the reference period to 2.0 to 2.6 by 2050-2059, with about the same average duration of three days (Table 10). This range will change to 2.4 to 3.6 by 2090-2099, with the average duration not statistically different from the present climate (Table 11).

The number of days with temperatures below 32°F will decrease from 98 days per year to 59 to 72 days per year by 2050-2059 (Table 10), and 46 to 64 days per year by 2090-2099 (Table 11).

The projected number of extreme precipitation days with a rate larger than 1 inch per day is not statistically different from the present day value for both the 2050-2059 (Table 10) and the 2090-2099 (Table 11) periods under RCP 4.5. This is similar to Nassau County.

Table 10 (below): Projection of extreme events in Suffolk County in 2050-2059 under RCP 4.5.

Extreme Events		**Baseline 1985-2004**	**Low-estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High-estimate (90th percentile)**
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	4.7	12.3	15.1 to 20.5	25.3
	Number of days/year with maximum temperature at or above 100°F	0.1	0.2	0.3 to 0.8	1.4
	Number of heat waves	0.6	1.6	2.0 to 2.6	3.2
	Average heat waves duration (in days)	4.1	2.6	2.9 to 3.9	4.3
	Number of days/year with minimum temperature at or below 32F	97.6	44.4	58.9 to 71.5	76.0
Intense Precipitation	Number of days/year with rainfall at or above 1 inch	12.6	12.3	12.4 to 12.6	12.8
	Number of days/year with rainfall at or above 2 inches	2.8	2.7	2.7 to 2.8	2.9
	Number of days/year with rainfall at or above 4 inches	0.2	0.2	0.2 to 0.2	0.2

Table 11 (below): Projection of extreme events in Suffolk County in 2090-2099 under RCP 4.5.

Extreme Events		Baseline 1985-2004	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	4.7	15.4	19.7 to 27.6	33.5
	Number of days/year with maximum temperature at or above 100°F	0.1	0.5	0.7 to 1.8	2.6
	Number of heat waves	0.6	2.0	2.4 to 3.6	4.3
	Average heat waves duration (in days)	4.1	2.8	3.5 to 4.4	4.6
	Number of days/year with minimum temperature at or below 32F	97.6	28.6	46.1 to 64.2	71.8
Intense Precipitation	Number of days/year with rainfall at or above 1 inch	12.6	12.5	12.5 to 12.8	12.8
	Number of days/year with rainfall at or above 2 inches	2.8	2.7	2.8 to 2.9	2.9
	Number of days/year with rainfall at or above 4 inches	0.2	0.2	0.2 to 0.2	0.2

RCP 8.5 - Nassau County

For Nassau County, under the “business as usual” RCP 8.5 emission scenario, by 2050-2059, the number of days with temperatures exceeding 90°F will increase to 26 to 38 days per year from the 7.4 days in the reference period (Table 12). This range will change to 57 to 77 days per by 2090-2099 (Table 13).

The number of heat waves will increase from 0.7 per year in the reference period to 3.0 to 5.3 events by 2050-2059, with the average duration about half a day longer (Table 12). This range will change to 7 to 8 events by 2090-2099, with the average duration 2 to 4 days longer than the present climate (Table 13).

The number of days with temperature below 32°F will decrease from 80 days per year to 33 to 49 days per year by 2050-2059 (Table 12), and 14 to 28 days per year by 2090-2099 (Table 13).

The projected number of extreme precipitation days with a rate larger than 1 inch per day is not statistically different from the present day value for both the 2050-2059 (Table 12) and the 2090-2099 (Table 13) periods under RCP 8.5.

Table 12 (below): Projection of extreme events in Nassau County in 2050-2059 under RCP 8.5.

Extreme Events		**Baseline 1985-2004**	**Low-estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High-estimate (90th percentile)**
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	7.4	22.0	26.0 to 38.2	42.3
	Number of days/year with maximum temperature at or above 100°F	0.3	1.2	1.6 to 3.1	4.0
	Number of heat waves	0.7	2.4	3.0 to 5.3	6.0
	Average heat waves duration (in days)	3.8	3.8	4.0 to 4.6	5.0
	Number of days/year with minimum temperature at or below 32F	80.6	28.1	33.8 to 49.0	54.9
Intense Precipitation	Number of days/year with rainfall at or above 1 inch	11.1	11.0	11.1 to 11.4	11.5
	Number of days/year with rainfall at or above 2 inches	2.5	2.4	2.4 to 2.5	2.5
	Number of days/year with rainfall at or above 4 inches	0.2	0.1	0.2 to 0.2	0.2

Table 13 (below): Projection of extreme events in Nassau County in 2090-2099 under RCP 8.5.

Extreme Events		Baseline 1985-2004	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	7.4	43.8	56.7 to 77.2	89.7
	Number of days/year with maximum temperature at or above 100°F	0.3	4.0	6.9 to 14.4	17.6
	Number of heat waves	0.7	6.2	7.1 to 8.1	8.3
	Average heat waves duration (in days)	3.8	5.0	6.1 to 8.5	9.0
	Number of days/year with minimum temperature at or below 32F	80.6	9.7	14.5 to 28.6	36.0
Intense Precipitation	Number of days/year with rainfall at or above 1 inch	11.1	11.2	11.3 to 11.7	11.9
	Number of days/year with rainfall at or above 2 inches	2.5	2.5	2.5 to 2.6	2.6
	Number of days/year with rainfall at or above 4 inches	0.2	0.2	0.2 to 0.2	0.2

RCP 8.5 - Suffolk County

under the "business as usual" RCP 8.5 emission scenario, by 2050-2059, the number of days in Suffolk County with temperature exceeding 90°F will likely increase to 19 to 29 days per year from the 4.7 days in the reference period (Table 14). This range will change to 45 to 69 days per by 2090-2099 (Table 15).

The number of heat waves will increase from 0.6 per year in the reference period to 2.3 to 3 by 2050-2059, with about the same average duration (Table 14). This range will change to 5.7 to 7.5 by 2090-2099 (Table 15), with the average duration 2 to 3 days longer than the present climate.

The number of days with temperature below 32°F will decrease from 98 days per year to 46 to 62 days per year by 2050-2059 (Table 14), and 22 to 39 days per year by 2090-2099 (Table 15).

The projected number of extreme precipitation days with a rate larger than 1 inch per day is not statistically different from the present day value for both the 2050-2059 (Table 14) and the 2090-2099 (Table 15) periods under RCP 8.5. This is similar to Nassau County.

Table 14 (below): Projection of extreme events in Suffolk County in 2050-2059 under RCP 8.5.

Extreme Events		**Baseline 1985-2004**	**Low-estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High-estimate (90th percentile)**
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	4.7	16.0	19.3 to 29.4	37.0
	Number of days/year with maximum temperature at or above 100°F	0.1	0.5	0.7 to 1.8	2.6
	Number of heat waves	0.6	2.0	2.3 to 3.8	4.8
	Average heat waves duration (in days)	4.1	3.0	3.5 to 4.6	5.1
	Number of days/year with minimum temperature at or below 32F	97.6	37.6	45.8 to 61.7	69.7
Intense Precipitation	Number of days/year with rainfall at or above 1 inch	12.6	12.4	12.5 to 12.7	12.8
	Number of days/year with rainfall at or above 2 inches	2.8	2.8	2.8 to 2.8	2.8
	Number of days/year with rainfall at or above 4 inches	0.2	0.2	0.2 to 0.2	0.2

Table 15 (below): Projection of extreme events in Suffolk County in 2090-2099 under RCP 8.5.

Extreme Events		Baseline 1985-2004	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Heat waves and cold weather events	Number of days/year with maximum temperature at or above 90°F	4.7	36.5	45.3 to 68.6	83.1
	Number of days/year with maximum temperature at or above 100°F	0.1	2.4	3.5 to 10.8	15.0
	Number of heat waves	0.6	4.7	5.7 to 7.5	7.8
	Average heat waves duration (in days)	4.1	4.9	5.7 to 8.1	8.2
	Number of days/year with minimum temperature at or below 32F	97.6	16.3	21.5 to 38.9	46.8
Intense Precipitation	Number of days/year with rainfall at or above 1 inch	12.6	12.4	12.6 to 12.9	13.1
	Number of days/year with rainfall at or above 2 inches	2.8	2.8	2.8 to 2.9	2.9
	Number of days/year with rainfall at or above 4 inches	0.2	0.2	0.2 to 0.2	0.2

Future Coastal Flood Risk Maps

Surges from 100-year storms were used to map flooding regions in Nassau and Suffolk. The 100-year still water height from these storms is from the U.S. Geological Survey. As in the Flood Insurance Rate Map (FIRM) used by FEMA, the breaking wave height of 0.55 times the 100-year still water height is added to the baseline storm surge level to create the FIRM zone. Projected sea-level rise is added to the baseline surge level to obtain the flooding zone under climate change for Nassau and Suffolk.

The areas shaded in blue in Figures 6 and 7 show the potential impact areas in Nassau and Suffolk subject to the 100-year flood without climate change. The areas shaded in yellow and red show the impact of 95% upper bound of projected sea-level rise in the 2050s and 2090s under RCP 4.5. Also labeled in the figures are the locations of vulnerable LIPA substations and bridge scouring sites from the NYS Department of Transportation.

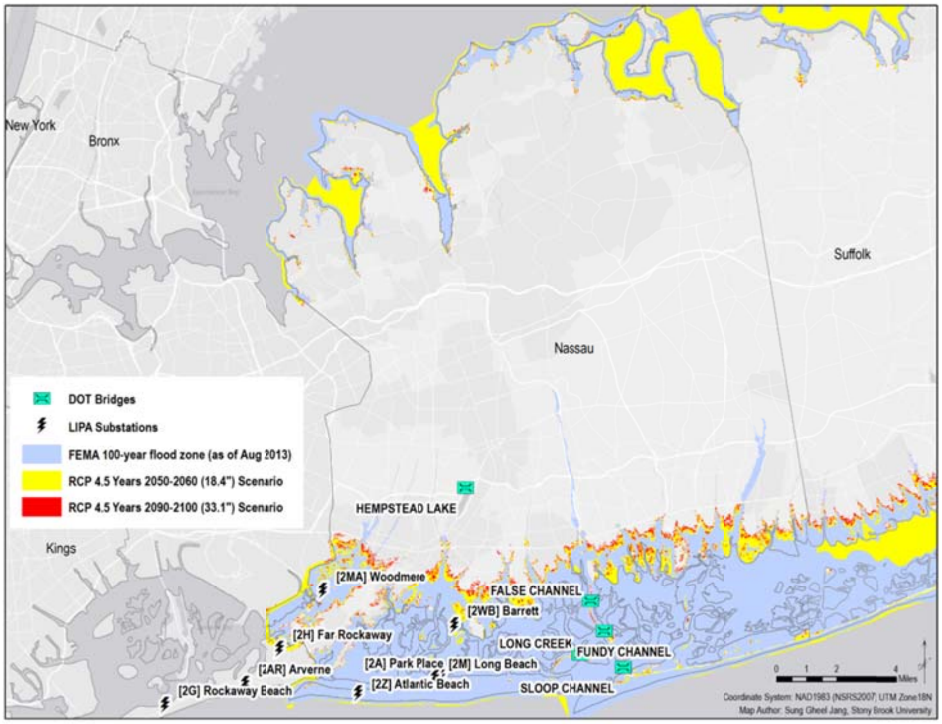

Figure 6 (above): Area in Nassau of 100-year flooding and impact of climate change under RCP 4.5 scenario for 2050s (yellow) and 2090s (red).

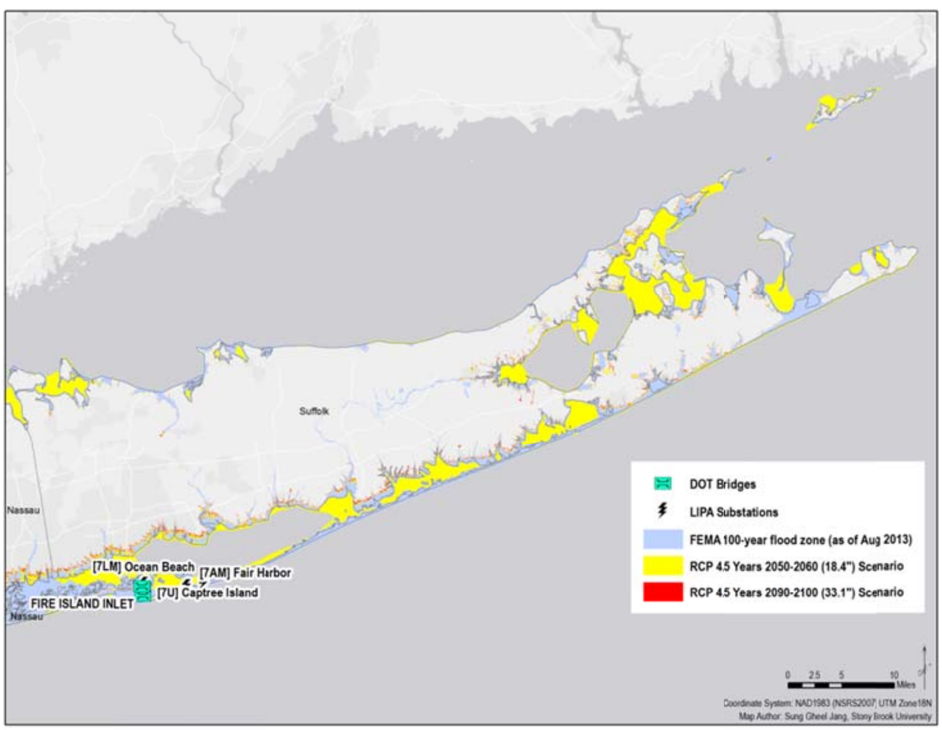

Figure 7 (above): Area in Suffolk of 100-year flooding and impact of climate change under RCP 4.5 scenario for for

2050s (yellow) and 2090s (red).

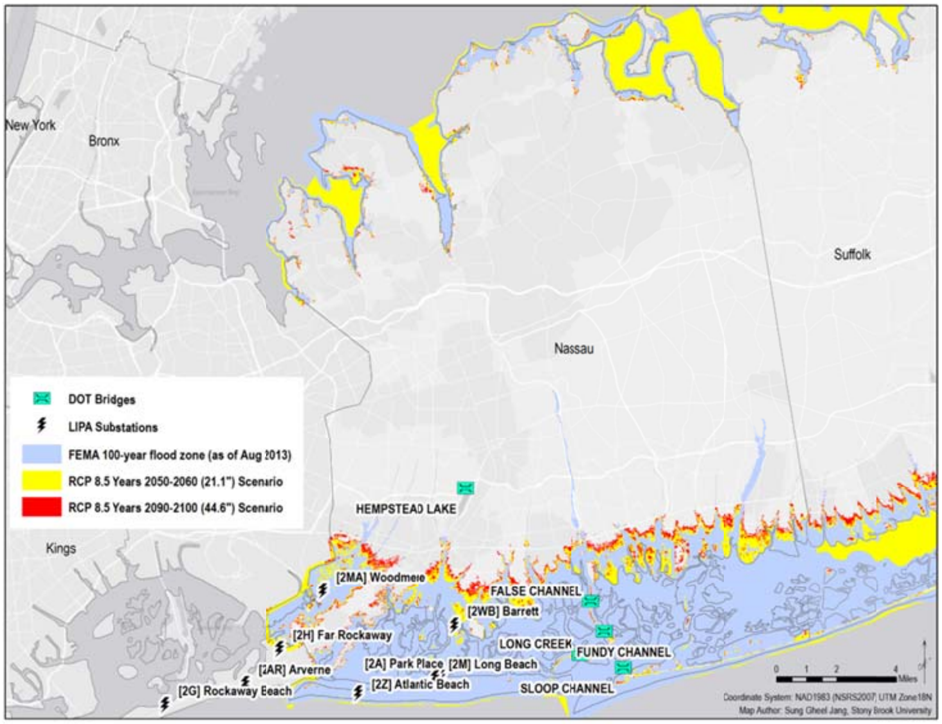

Figure 8 (above): Area in Nassau of 100-year flooding and impact of climate change under RCP 8.5 scenario for 2050s and 2090s.

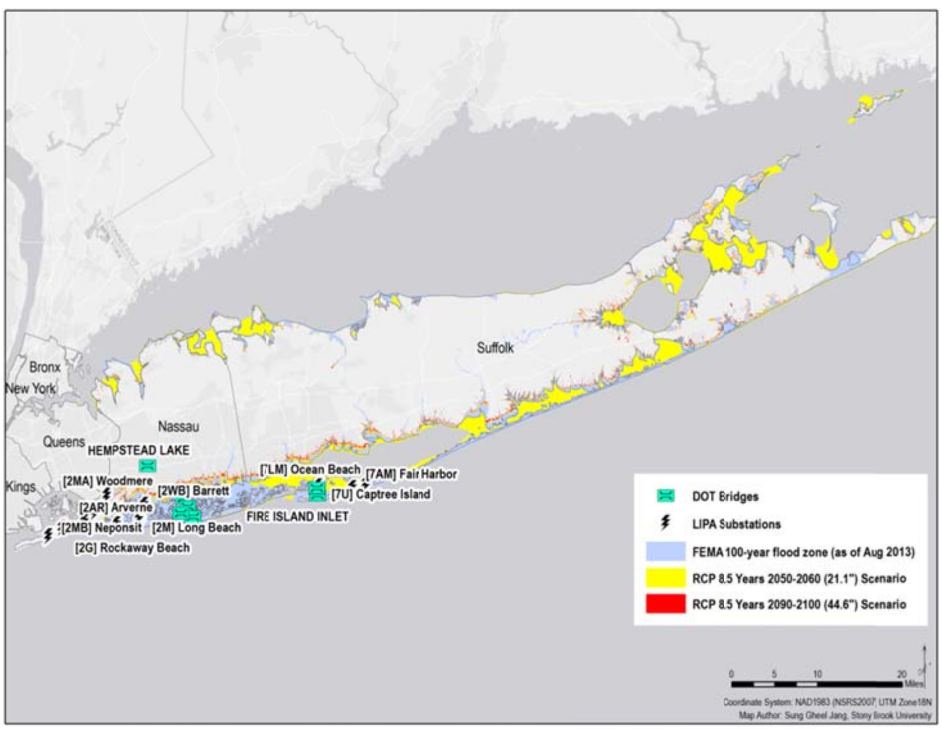

Figure 9 (above): Area in Suffolk of 100-year flooding and impact of climate change under RCP 8.5 scenario for 2050s and 2090s.

The areas shaded in blue in Figures 8 and 9 show the potential impact areas in Nassau and Suffolk subject to the 100-year flood without climate change. The areas shaded in yellow and red show the impact of 95% upper bound of projected sea-level rise in the 2050s and 2090s under RCP 8.5. Also labeled in the figures are the locations of vulnerable LIPA substations and bridge scouring sites from the NYS Department of Transportation.

As noted in NPCC (2013), these maps are illustrative and contain numerous sources of uncertainties. They are presented as reference to grossly locate areas currently within the 100-year flood zones, areas that are not currently within the 100-year flood zones but will potentially be in the future, and areas that are not currently in the 100-year flood zones and are unlikely to be in a flood zone in the 21st Century. High resolution mapping is needed for specific locations and projects, and will be done as needed and in the future.

Conclusions

- The mean annual temperature in Nassau and Suffolk has increased 5°F from 1900 to 2010. This value is larger than the transient variations between multi-year averages, making this trend statistically significant. Mean annual precipitation has increased 5 inches during this period. However, year-to-year precipitation variability is large making this trend statistically insignificant.
- Under the optimistic mitigation scenario of greenhouse emissions (RCP 4.5) for the 21st Century, by the 2050s, the medium value of projected warming will be 4.0°F relative to the 1985-2004 reference period in Nassau and Suffolk. The likely warming will be between 3.3°F and 4.7°F (middle range), with a high estimate of 5.9°F (upper 10th percentile). By the 2090s, the warming is projected to be 5.5°F, with a likely range of 4.4°F to 6.5°F (middle range), and a high estimate of 8.7°F (upper 10th percentile).
- Precipitation is projected to increase in Nassau and Suffolk. The signal is significant only after the middle of the 21st Century. Precipitation is about 10 (medium-estimate) to 20 (high-estimate) percent more at the end of the 21st Century in the RCP4.5 scenario, and 15 (medium-estimate) to 25 (high-estimate) percent more in the RCP 8.5 scenario.
- The sea level is projected to rise along the Nassau and Suffolk coasts. Under the conservative RCP 4.5 emission scenario, by the end of the 21st century, the sea-level is projected to rise in the two counties by 24 inches (mean estimate), with an upper bound of 36 inches relative to the 1985-2004 reference period. Under the pessimistic RCP 8.5 emission scenario, the sea-level is projected to rise 34 inches (mean estimate), with an upper bound of 45 inches. Projected values for the two counties are similar.
- The number of days at or above 90°F per year in the two counties will increase threefold in the 2050s and fourfold in the 2090s from the current mean of 7.4 days in Nassau under the RCP 4.5 scenario. The number of days at or above 90°F per year in the two counties will increase fourfold in the 2050s and fivefold in the 2090s from the current mean of 4.7 days in Suffolk. In the pessimistic

RCP 8.5 scenario, by the 2090s, Nassau is projected to have 57 to 77 days per year with a maximum temperature over 90°F (middle range), with a high estimate of 90 days per year. Suffolk will have 45 to 69 days per year with a maximum temperature over 90°F (middle range), with a high-estimate of 83 days per year.

- By the end of 21st Century, under the RCP 4.5 mitigation scenario, the average number of days per year exceeding 100°F in Nassau will be 1.5 to 2.9 days (middle range), with a high estimate of 3.7 days. The average number of days per year exceeding 100°F in Suffolk will be 0.7 to 1.5 days (middle range), with a high estimate of 2.2 days.
- By the end of 21st Century, under the RCP 8.5 "business as usual" scenario, the average number of days per year exceeding 100°F in Nassau will be 6.9 to 14.4 days (middle range), with a high-estimate of 17.6 days. The average number of days per year exceeding 100°F in Suffolk will be 3.5 to 10.8 days (middle range), with a high estimate of 15.0 days.
- Projected changes in the occurrence of extreme precipitation, defined as the number of days per year in which precipitation exceeds 1 inch per day, were not detected in both counties. This is true for both the RCP 4.5 and RCP 8.5 scenarios even though mean precipitation is projected to increase.
- Changes in the frequency of hurricanes and winter storms cannot be projected with confidence at the present time, although some evidence suggests that their intensities will increase under global warming.

Recommendations

1. Reconstruction and future planning of infrastructure and communities in Nassau and Suffolk should incorporate projected risks of climate change from coastal flooding due to sea level rise, and heat waves due to hotter summers. This is consistent with the first goal of the Mitigation Strategy of the New York State Hazard Mitigation Plan (SHMP) to promote a comprehensive state hazard mitigation policy framework. Specific recommended mitigation actions include zoning, building codes, capital improvement programs, open space preservation, and storm water management systems.

2. For facilities within the current 100-year flood zones, protective walls or structures should be enhanced or planned to withstand the projected level of sea-level rise. For facilities adjacent to the periphery of current 100-year flood zones, the new flood maps with climate change information should be referenced for new siting or for fortification. Specific recommended actions include protecting public, historic, and private structures, as well as critical facilities and infrastructure in these areas. These actions will be consistent with the second goal of the SHMP Mitigation Strategy by protecting, upgrading and strengthening existing structures from coastal flooding through acquisition, elevation, relocation, and retrofit. For Nassau and Suffolk counties, protective measures should be taken for wastewater treatment plants and residential septic systems in the vulnerable areas.

3. A warmer climate is expected in the 21st Century regardless of what emission scenario is used. In the "business as usual" scenario, the extreme hot days in Nassau and Suffolk with maximum temperature exceeding 100°F will become more common. Facilities should be designed to anticipate heat waves that can stress energy supply and distribution systems, health and drinking water systems, public facilities, and transportation systems. Recommended mitigation actions include sustainable and resilient construction and design measures to reduce or eliminate the impacts of heat waves, promotion of green and natural infrastructure such as public beaches and parks, and better building and rebuilding practices that reduce heat-related stress and energy consumptions.

4. Awareness of future climate risks such as sea-level rise and more intense heat waves should be communicated to residents and communities so that reconstruction plans and investment strategies are designed and implemented appropriately by all stakeholders. This is consistent with the SHMP goal to increase awareness and promote relationships with stakeholders, citizens, elected officials, and property owners to develop opportunities for mitigation of natural hazards.

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Appendix A1: Method of Sea-level Rise Calculations

Sea-level rise is calculated by the sum of the following 10 geophysical components: 5 ice components (Greenland dynamic ice and surface mass balance, Antarctic dynamic ice and surface mass balance, and glaciers), 3 ocean components (dynamic sea-surface height due to ocean circulation and spatial distribution of ocean temperature and salinity, global thermosteric expansion, and the inverse barometer effect from the atmosphere), terrestrial water storage, and the glacial isostatic adjustment. The three ocean components are calculated from 21 Coupled General Circulation Models. All components were calculated as in Church et al. (2013), which was also used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR5).

Since the global models are with coarse spatial resolutions of about 200 kilometers by 200 kilometers, the spatial distribution of sea-level rise for each model is interpolated to 0.1 degree by 0.1 degree along the coast. To account for the seasonal differences, we added the seasonal amplitude to the annual mean values in deriving the data in Tables 6 and 7. The seasonal adjustments range from 0.2 to 1.7 inches.

Table A2: Climate Models

Simulations of future climate scenarios are from twenty-six climate models in the Coupled Model Intercomparison Project (CMIP5). The twenty six models are described below. Projections of precipitation and surface temperature in Nassau and Suffolk counties are derived from these simulations.

Model Abbreviation	Model Institution and Country	Component Resolutions
ACCESS1-0	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	Atmosphere: AGCM v1.0 (N96 grid-point, 1.875 degrees EW x approx 1.25 degree NS, 38 levels) ; ocean: NOAA/GFDL MOM4p 1 (nominal 1.0 degree EW x 1.0 degrees NS, tripolar north of 65N, equatorial refinement to 1/3 degree from 10S to 10 N, cosine dependent NS south of 25S, 50 l evels); sea ice: CICE4.1 (nominal 1.0 degree EW x 1.0 degrees NS, tripolar north of 65N, equatorial refinement to 1/3 degree from 10S to 10 N, cosine dependen t NS south of 25S); land: MOSES2 (1.875 degree EW x 1.25 degree NS, 4 levels"
ACCESS1-3	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology,	Atmosphere: AGCM v1.0 (N96 grid-point, 1.875 degrees EW x approx 1.25 degree NS, 38 levels); ocean: NOAA/GFDL MOM4p 1 (nominal 1.0 degree EW x 1.0 degrees NS,

	Australia)	tripolar north of 65N, equatorial refinement to 1/3 degree from 10S to 10 N, cosine dependent NS south of 25S, 50 l evels); sea ice: CICE4.1 (nominal 1.0 degree EW x 1.0 degrees NS, tripolar north of 65N, equatorial refinement to 1/3 degree from 10S to 10 N, cosine dependen t NS south of 25S); land: CABLE1.0 (1.875 degree EW x 1.25 degree NS, 6 levels
bcc-csm1-1	Beijing Climate Center(BCC),China Meteorological Administration,China	atmosphere: BCC_AGCM2.1 (T42L26); land: BCC_AVIM1.0;ocean: MOM4_L40 (tripolar, 1 lon x (1-1/3) lat, L40);sea ice: SIS (tripolar,1 lon x (1-1/3) lat)
BNU-ESM	GCESS,BNU,Beijing,China	N/A
CanESM2	CCCma (Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada)	atmosphere: CanAM4 (AGCM15i, T63L35) ocean: CanOM4 (OGCM4.0, 256x192L40) and CMOC1.2 sea ice: CanSIM1 (Cavitating Flui d, T63 Gaussian Grid) land: CLASS2.7 and CTEM1
CMCC-CM	CMCC - Centro Euro-Mediterraneo per i Cambiamenti	N/A
CMCC-CMS	CMCC - Centro Euro-Mediterraneo per i Cambiamenti Climatici, Bologna, Italy	N/A
CNRM-CM5	CNRM (Centre National de Recherches Meteorologiques, Meteo-France, Toulouse, France) and CERFACS (Centre Europeen de Recherche s et de Formation Avancee en Calcul Scientifique, Toulouse, France)	Atmosphere: ARPEGE-Climat (V5.2.3i, TL127L31); Ocean: NEMO (nemo3.2.v11.3, ORCA1degL42); Sea Ice: GELATO (V5.47f); River Routing: TRIP (v1); Land: SURFEX (v5.1.c); Coupler : OASIS 3
CSIRO-Mk3-6-0	Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) Marine and Atmospheric Research (Melbourne, Au stralia) in collaboration with the Queensland Climate Change Centre of Excellence (QCCCE) (Brisbane, Australia)	atmosphere: AGCM v7.3.8 (T63 spectral, 1.875 degrees EW x approx. 1.875 degrees NS, 18 levels); ocean: GFDL MOM2 .2 (1.875 degrees EW x approx. 0.9375 degrees NS, 31 levels)
FGOALS-g2	IAP (Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China) and THU (Tsinghua University)	atmosphere: GAMIL (gamil2, 128x60L26); ocean: LICOM (licom2, 360x196L30); ice: CICE (cice4_lasg, 360x196L4); land: C LM (clm3, 128x60)
GISS-E2-H-CC	NASA/GISS (Goddard Institute	Atmosphere: GISS-E2; Ocean: H

	for Space Studies) New York, NY	
GISS-E2-R	NASA/GISS (Goddard Institute for Space Studies) New York, NY	Atmosphere: GISS-E2; Ocean: R
HadGEM2-CC	Met Office Hadley Centre, Fitzroy Road, Exeter, Devon, EX1 3PB, UK, (http://www.metoffice.gov.uk)	atmosphere: HadGAM2(N96L60); ocean: HadGOM2 (lat: 1.0-0.3 lon: 1.0 L40); land-surface/vegetation: MOSES2 and TRIF FID; ocean biogeochemistry: diat-HadOCC
HadGEM2-ES	Met Office Hadley Centre, Fitzroy Road, Exeter, Devon, EX1 3PB, UK, (http://www.metoffice.gov.uk)	atmosphere: HadGAM2 (N96L38); ocean: HadGOM2 (lat: 1.0-0.3 lon: 1.0 L40); land-surface/vegetation: MOSES2 and TRI FFID; tropospheric chemistry: UKCA; ocean biogeochemistry: diat-HadOCC
inmcm4	INM (Institute for Numerical Mathematics, Moscow, Russia)	inmcm4 (2009)
IPSL-CM5A-LR	IPSL (Institut Pierre Simon Laplace, Paris, France)	atmos : LMDZ4 (LMDZ4_v5, 96x95x39); ocean : ORCA2 (NEMOV2_3, 2x2L31); seaIce : LIM2 (NEMOV2_3); ocnBgchem : P ISCES (NEMOV2_3); land : ORCHIDEE (orchidee_1_9_4_AR5)
IPSL-CM5A-MR	IPSL (Institut Pierre Simon Laplace, Paris, France)	atmos : LMDZ4 (LMDZ4_v5, 144x143x39); ocean : ORCA2 (NEMOV2_3, 2x2L31); seaIce : LIM2 (NEMOV2_3); ocnBgchem : PISCES (NEMOV2_3); land : ORCHIDEE (orchidee_1_9_4_AR5)
IPSL-CM5B-LR	IPSL (Institut Pierre Simon Laplace, Paris, France)	LMDZ5 (LMDZ5_NPv3.1, 96x95x39); ocean : ORCA2 (NEMOV2_3, 2x2L31); seaIce : LIM2 (NEMOV2_3); ocnBgchem : PISCES (NEMOV2_3); land : ORCHIDEE (orchidee_1_9_4_AR5)
MIROC5	AORI (Atmosphere and Ocean Research Institute, The University of Tokyo, Chiba, Japan), NIES (National Institute for Environmen tal Studies, Ibaraki, Japan), JAMSTEC (Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan)	MIROC-AGCM6 (T85L40); ocean: COCO (COCO4.5, 256x224 L50); sea ice: COCO (COCO4.5); land: MATSIRO (MATSIRO, L6); aerosols: SPRINTARS (SPRINTARS 5.00, T85L40)
MIROC-ESM-CHEM	JAMSTEC (Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan), AORI (Atmosphere and Ocean Research Institute , The University of Tokyo, Chiba, Japan), and NIES (National Institute for Environmental Studies, Ibaraki, Japan)	MIROC-AGCM (MIROC-AGCM 2010, T42L80); ocean: COCO (COCO3.4, 256x192 L44); sea ice: COCO (COCO3.4); land: MATSIRO (MATSIRO, L6); aerosols: SPRINTARS (SPRINTARS 5.00, T42L80):atmospheric-chemistry: CHASER (CHASER 4.1, T42L80): ocean-biogeochemistry: NPZD ; la nd-biogeochemistry: SEIB-DGVM (SEIB-

		DGVM, T42)
MIROC-ESM	JAMSTEC (Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan), AORI (Atmosphere and Ocean Research Institute , The University of Tokyo, Chiba, Japan), and NIES (National Institute for Environmental Studies, Ibaraki, Japan)	atmosphere: MIROC-AGCM (MIROC-AGCM 2010, T42L80); ocean: COCO (COCO3.4, 256x192 L44); sea ice: COCO (COCO3.4); land: MATSIRO (MATSIRO, L6); aerosols: SPRINTARS (SPRINTARS 5.00, T42L80):atmospheric-chemistry: CHASER (CHASER 4.1, T42L80): ocean-biogeochemistry: NPZD ; la nd-biogeochemistry: SEIB-DGVM (SEIB-DGVM, T42)
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany	ECHAM6 (REV: 4619), T63L47 ; land: JSBACH (REV: 4619); ocean: MPIOM (REV: 4619), GR15L40; sea ice: 4619; marine bgc: HAMOCC (REV: 4619)
MPI-ESM-MR	Max Planck Institute for Meteorology, Germany	atmosphere: ECHAM6 (REV: 4936), T63L47 ; land: JSBACH (REV: 4936); ocean: MPIOM (REV: 4936), GR15L40; sea ice: 4936; marine bgc: HAMOCC (REV: 4936)
MRI-CGCM3	MRI (Meteorological Research Institute, Tsukuba, Japan)	atmosphere: GSMUV (gsmuv-110112, TL159L48); ocean: MRI.COM3 (MRICOM-3_0-20101116, 1x0.5L51); sea ice: MRI.COM3; land : HAL (HAL_cmip5_v0.31_04); aerosol: MASINGAR-mk2 (masingar_mk2-20110111_0203, TL95L48)
NorESM1-ME	Norwegian Climate Centre	atmosphere: CAM-Oslo (CAM4-Oslo-noresm-ver1_cmip5-r139, f19L26); ocean: MICOM (MICOM-noresm-ver1_cmip5-r139, gx1v 6L53); ocean biogeochemistry: HAMOCC (HAMOCC-noresm-ver1_cmip5-r139, gx1v6L53); sea ice: CICE (CICE4-noresm-ver1_cmip5-r139); land: CLM (CLM4-noresm-ver1_c mip5-r139)
NorESM1-M	Norwegian Climate Centre	atmosphere: CAM-Oslo (CAM4-Oslo-noresm-ver1_cmip5-r139, f19L26); ocean: MICOM (MICOM-noresm-ver1_cmip5-r139, gx1v 6L53); ocean biogeochemistry: HAMOCC (HAMOCC-noresm-ver1_cmip5-r139, gx1v6L53); sea ice: CICE (CICE4-noresm-ver1_cmip5-r139); land: CLM (CLM4-noresm-ver1_c mip5-r139)

Table 2 Twenty-one CMIP5 models used for the projections of sea level rise in Nassau and Suffolk counties

Model Abbreviation	Model Institution and Country	Component Resolutions
ACCESS1-0	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	Atmosphere: AGCM v1.0 (N96 grid-point, 1.875 degrees EW x approx 1.25 degree NS, 38 levels) ; ocean: NOAA/GFDL MOM4p 1 (nominal 1.0 degree EW x 1.0 degrees NS, tripolar north of 65N, equatorial refinement to 1/3 degree from 10S to 10 N, cosine dependent NS south of 25S, 50 l evels); sea ice: CICE4.1 (nominal 1.0 degree EW x 1.0 degrees NS, tripolar north of 65N, equatorial refinement to 1/3 degree from 10S to 10 N, cosine dependen t NS south of 25S); land: MOSES2 (1.875 degree EW x 1.25 degree NS, 4 levels"
ACCESS1-3	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	Atmosphere: AGCM v1.0 (N96 grid-point, 1.875 degrees EW x approx 1.25 degree NS, 38 levels); ocean: NOAA/GFDL MOM4p 1 (nominal 1.0 degree EW x 1.0 degrees NS, tripolar north of 65N, equatorial refinement to 1/3 degree from 10S to 10 N, cosine dependent NS south of 25S, 50 l evels); sea ice: CICE4.1 (nominal 1.0 degree EW x 1.0 degrees NS, tripolar north of 65N, equatorial refinement to 1/3 degree from 10S to 10 N, cosine dependen t NS south of 25S); land: CABLE1.0 (1.875 degree

		EW x 1.25 degree NS, 6 levels
bcc-csm1-1	Beijing Climate Center(BCC),China Meteorological Administration,China	atmosphere: BCC_AGCM2.1 (T42L26); land: BCC_AVIM1.0;ocean: MOM4_L40 (tripolar, 1 lon x (1-1/3) lat, L40);sea ice: SIS (tripolar,1 lon x (1-1/3) lat)
CanESM2	CCCma (Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada)	atmosphere: CanAM4 (AGCM15i, T63L35) ocean: CanOM4 (OGCM4.0, 256x192L40) and CMOC1.2 sea ice: CanSIM1 (Cavitating Flui d, T63 Gaussian Grid) land: CLASS2.7 and CTEM1
CCSM4	NCAR (National Center for Atmospheric Research) Boulder, CO, USA	f09_g16 (0.9x1.25_gx1v6)
CMCC-CM	CMCC - Centro Euro-Mediterraneo per i Cambiamenti	N/A
CNRM-CM5	CNRM (Centre National de Recherches Meteorologiques, Meteo-France, Toulouse, France) and CERFACS (Centre Europeen de Recherche s et de Formation Avancee en Calcul Scientifique, Toulouse, France)	Atmosphere: ARPEGE-Climat (V5.2.3i, TL127L31); Ocean: NEMO (nemo3.2.v11.3, ORCA1degL42); Sea Ice: GELATO (V5.47f); River Routing: TRIP (v1); Land: SURFEX (v5.1.c); Coupler : OASIS 3
CSIRO-Mk3-6-0	Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) Marine and Atmospheric Research (Melbourne, Au stralia) in collaboration with the Queensland Climate Change Centre of Excellence (QCCCE) (Brisbane, Australia)	atmosphere: AGCM v7.3.8 (T63 spectral, 1.875 degrees EW x approx. 1.875 degrees NS, 18 levels); ocean: GFDL MOM2 .2 (1.875 degrees EW x approx. 0.9375 degrees NS, 31 levels)
GISS-E2-R	NASA/GISS (Goddard Institute for Space Studies) New York, NY	Atmosphere: GISS-E2; Ocean: R
HadGEM2-ES	Met Office Hadley Centre, Fitzroy Road, Exeter, Devon, EX1 3PB, UK, (http://www.metoffice.gov.uk)	atmosphere: HadGAM2 (N96L38); ocean: HadGOM2 (lat: 1.0-0.3 lon: 1.0 L40); land-surface/vegetation:

		MOSES2 and TRI FFID; tropospheric chemistry: UKCA; ocean biogeochemistry: diat-HadOCC
inmcm4	INM (Institute for Numerical Mathematics, Moscow, Russia)	inmcm4 (2009)
IPSL-CM5A-LR	IPSL (Institut Pierre Simon Laplace, Paris, France)	atmos : LMDZ4 (LMDZ4_v5, 96x95x39); ocean : ORCA2 (NEMOV2_3, 2x2L31); seaIce : LIM2 (NEMOV2_3); ocnBgchem : P ISCES (NEMOV2_3); land : ORCHIDEE (orchidee_1_9_4_AR5)
IPSL-CM5A-MR	IPSL (Institut Pierre Simon Laplace, Paris, France)	atmos : LMDZ4 (LMDZ4_v5, 144x143x39); ocean : ORCA2 (NEMOV2_3, 2x2L31); seaIce : LIM2 (NEMOV2_3); ocnBgchem : PISCES (NEMOV2_3); land : ORCHIDEE (orchidee_1_9_4_AR5)
MIROC5	AORI (Atmosphere and Ocean Research Institute, The University of Tokyo, Chiba, Japan), NIES (National Institute for Environmen tal Studies, Ibaraki, Japan), JAMSTEC (Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan)	MIROC-AGCM6 (T85L40); ocean: COCO (COCO4.5, 256x224 L50); sea ice: COCO (COCO4.5); land: MATSIRO (MATSIRO, L6); aerosols: SPRINTARS (SPRINTARS 5.00, T85L40)
MIROC-ESM-CHEM	JAMSTEC (Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan), AORI (Atmosphere and Ocean Research Institute , The University of Tokyo, Chiba, Japan), and NIES (National Institute for Environmental Studies, Ibaraki, Japan)	MIROC-AGCM (MIROC-AGCM 2010, T42L80); ocean: COCO (COCO3.4, 256x192 L44); sea ice: COCO (COCO3.4); land: MATSIRO (MATSIRO, L6); aerosols: SPRINTARS (SPRINTARS 5.00, T42L80):atmospheric-chemistry: CHASER (CHASER 4.1, T42L80): ocean-biogeochemistry: NPZD ; la

		nd-biogeochemistry: SEIB-DGVM (SEIB-DGVM, T42)
MIROC-ESM	JAMSTEC (Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan), AORI (Atmosphere and Ocean Research Institute , The University of Tokyo, Chiba, Japan), and NIES (National Institute for Environmental Studies, Ibaraki, Japan)	atmosphere: MIROC-AGCM (MIROC-AGCM 2010, T42L80); ocean: COCO (COCO3.4, 256x192 L44); sea ice: COCO (COCO3.4); land: MATSIRO (MATSIRO, L6); aerosols: SPRINTARS (SPRINTARS 5.00, T42L80):atmospheric-chemistry: CHASER (CHASER 4.1, T42L80): ocean-biogeochemistry: NPZD ; la nd-biogeochemistry: SEIB-DGVM (SEIB-DGVM, T42)
MPI-ESM-MR	Max Planck Institute for Meteorology, Germany	atmosphere: ECHAM6 (REV: 4936), T63L47 ; land: JSBACH (REV: 4936); ocean: MPIOM (REV: 4936), GR15L40; sea ice: 4936; marine bgc: HAMOCC (REV: 4936)
MRI-CGCM3	MRI (Meteorological Research Institute, Tsukuba, Japan)	atmosphere: GSMUV (gsmuv-110112, TL159L48); ocean: MRI.COM3 (MRICOM-3_0-20101116, 1x0.5L51); sea ice: MRI.COM3; land : HAL (HAL_cmip5_v0.31_04); aerosol: MASINGAR-mk2 (masingar_mk2-20110111_0203, TL95L48)
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		CLM (CLM4-noresm-ver1_c mip5-r139)
NorESM1-M	Norwegian Climate Centre	atmosphere: CAM-Oslo (CAM4-Oslo-noresm-ver1_cmip5-r139, f19L26); ocean: MICOM (MICOM-noresm-ver1_cmip5-r139, gx1v 6L53); ocean biogeochemistry: HAMOCC (HAMOCC-noresm-ver1_cmip5-r139, gx1v6L53); sea ice: CICE (CICE4-noresm-ver1_cmip5-r139); land: CLM (CLM4-noresm-ver1_c mip5-r139)

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