Chapter 14

Stakeholder-Driven Research for Climate Adaptation in New York City

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New York City (NYC) is the economic, cultural, and financial center of the United States. Favored by its geographic location at a harbor and river mouth, NYC has maintained its status as the country's most populous city since the first census was held in 1790. Over this time, NYC's population increased more than 100-fold to over 8 million, with 19 million people in its metropolitan area (Solecki 2012). Much of the city's key infrastructure, including roads, subways and commuter trains, airports, water supply and treatment facilities, and electricity distribution network, was built during the first half of the twentieth century, and since then most of the available funding has been used to maintain and repair the existing network (Griffis 1996). The devastation of parts of that infrastructure under (post-)Hurricane Sandy at the end of October 2012 has again drawn attention to the city's lack of readiness for weather extremes, the risk for many of which appears to be increasing under anthropogenic global warming (Barnett et al. 2006; Min et al. 2011; Sillmann et al. 2013).

Here, after a brief overview of New York City's geography and climate, I will discuss how climate and extremes have been changing over recent decades. I will summarize past and ongoing research programs that seek to better understand the city's vulnerability to climate change or to develop adaptation strategies, with an emphasis on research undertaken in partnership with stakeholders such as city agencies, utilities, and insurers. I will conclude with suggestions for future research directions and lessons from New York City's experience which may be applicable to other places.

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14.1 New York City's Geography and Climate

New York City is primarily an island city, with most of the population living on Manhattan, Staten, and Long islands. Out of the five boroughs, only the Bronx is mostly on the mainland. The city is low-lying, with around 5 % of its area within 1 m of sea level and maximum elevations below 100 m. Many neighborhoods and tunnel entrances are within 3 m of sea level, as are the city's airports and sewage treatment facilities.

New York City has a humid subtropical climate, with a mean annual temperature of 13 °C and pronounced seasons moderated by the adjacent ocean. There are around ten wet days per month throughout the year, with 1.3 m/year precipitation and 0.7 m/year snow.

New York City has an unusually safe, reliable, and inexpensive water delivery system for a city its size. Built between the mid-nineteenth and mid-twentieth centuries, this consists of dammed reservoirs in protected hill watersheds in upstate New York with water flowing down into the city via aqueducts and water tunnels. The area of the contributing watersheds, which are either owned by the city directly or managed by it to maintain water quality, is several times that of the city itself. There is also a water intake from the Hudson river for emergency use.

14.2 Climate Change in New York City

The longest climate record in the city is the weather station in Central Park, maintained since 1876. This shows very pronounced warming of winter low temperatures by more than 5 K (Fig. 14.1a). Summer hot extremes have also warmed in recent decades, but have not yet regained their 1930s peak (Fig. 14.1b). The pattern seen of winter temperatures warming faster than summer and nighttime (daily minimum) temperatures warming faster than daytime (daily maximum) values is one that is widespread in the region (Betts 2011; Krakauer 2012). In addition to global warming due to increasing concentrations of greenhouse gases, the temperature records may also show the influence of regional climate forcing due to anthropogenic aerosols, which may account for the cooling seen between about 1940 and 1970 (Baines and Folland 2007). As well, there may be local climate forcing due to the urban heat island effect (Bornstein 1968), although for weather stations sited in parks, the urban heat island seems to have negligible impact on annual mean temperature (Peterson 2003; Hausfather et al. 2013).

Precipitation in New York City increased abruptly soon after the area's drought of record (1963–1965), and is now at remarkably high levels some 25 % above those typical before 1970 (Fig. 14.2a). Similar trends are seen on a regional basis (Krakauer and Fung 2008). The heaviest daily precipitation, which causes flash floods and combined sewer overflows (Willems et al. 2012), has increased proportionally faster (some 35 %, Fig. 14.2b), broadly consistent with national and

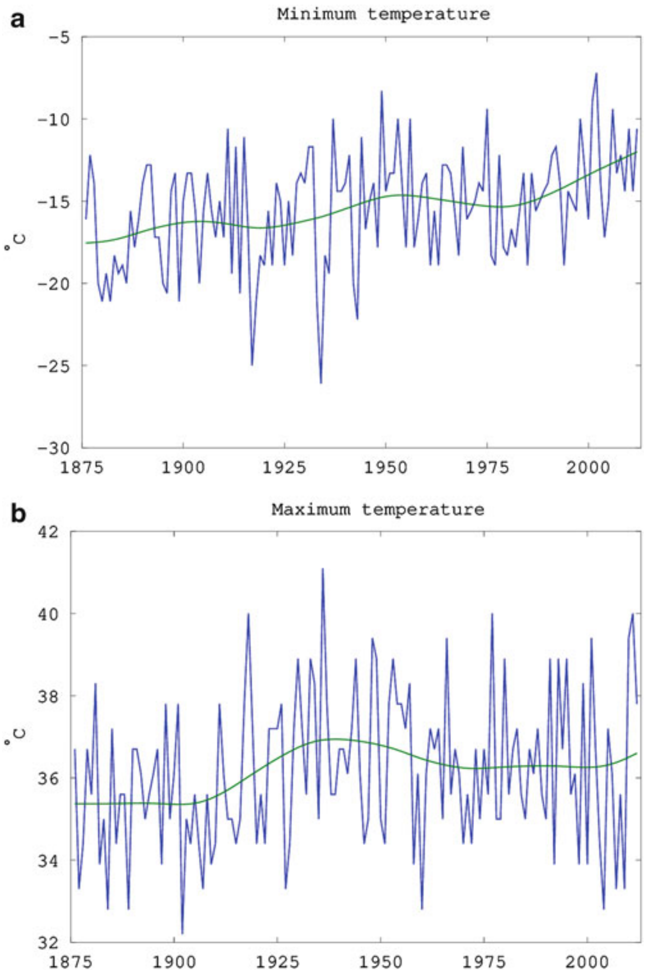


Fig. 14.1 (**a**) Annual minimum temperatures in New York City. (**b**) Annual maximum temperatures. The smooth curves use cubic splines, as in Krakauer and Krakauer (2012)

global trends (Donat et al. 2013) and expectations for trends under global warming (Min et al. 2011; Trenberth 2011).

Mean sea level measured at the Battery, on Manhattan's southern tip, has increased some 50 cm since the mid-1800s, of which 25 cm has been since 1950 (Fig. 14.3a). The recent rate of increase has been 3 mm/year, comparable to the global mean. As a result of changes in ocean circulation driven by global warming, the region is projected to face sea level rise that is faster than the global mean in the coming decades (Yin et al. 2010), with a further small contribution from postglacial subsidence. The more relevant quantity for determining flood damage is the maximum sea level in a time period, which occurs during storms and is also affected by the tidal range

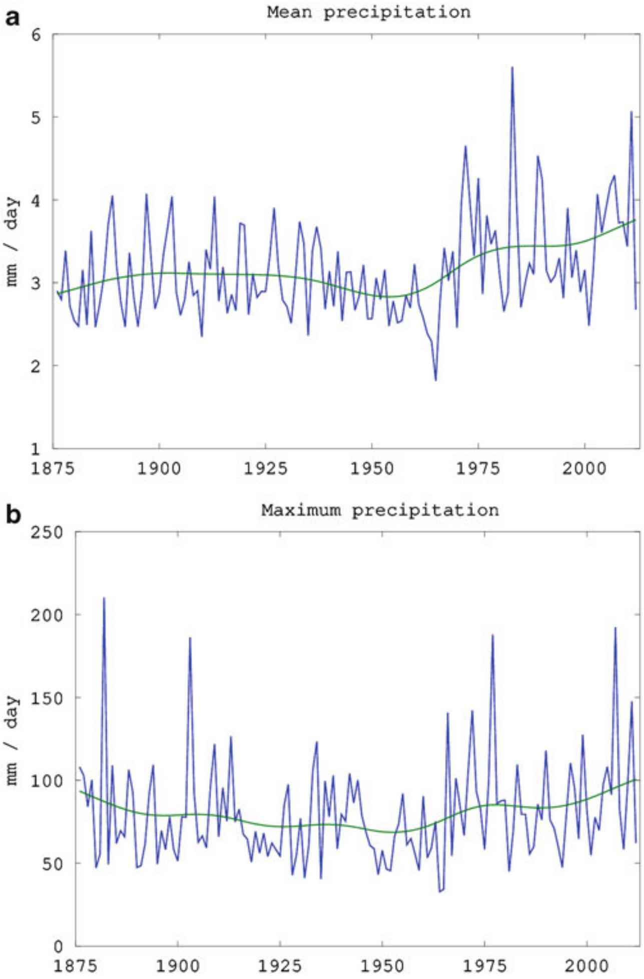
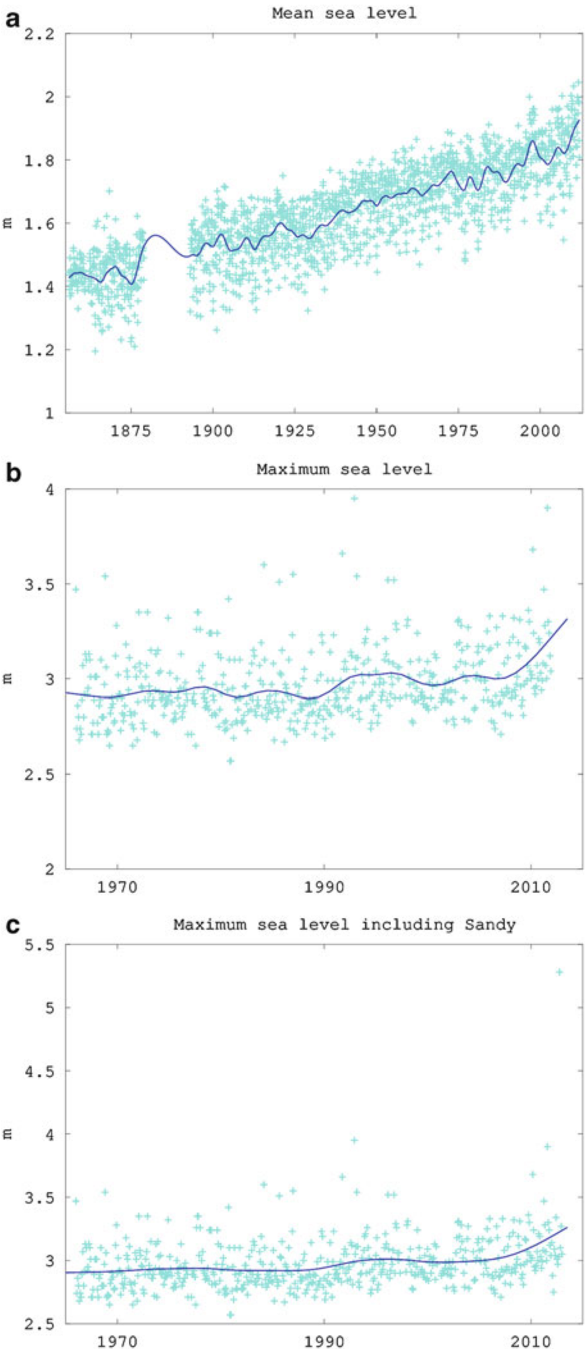


Fig. 14.2 (**a**) Annual precipitation in New York City. (**b**) Maximum daily precipitation

(which is about 1.5 m). The monthly maximum sea level has shown little trend from the 1960s until the mid-2000s. Over the last few years, even before Hurricane Sandy in October 2012, several particularly high surges were recorded, suggesting that the area that may be expected to be flooded on a yearly basis is expanding (Fig. 14.3b). Hurricane Sandy's storm surge was far above the range of the period of record (at least since the mid-nineteenth century) (Fig. 14.3c), and its storm surge magnitude had previously been estimated to have a return interval of some 500 years (Lin et al. 2012). However, placing it within this recent increasing trend makes it more plausible that we will see additional flood events of similar magnitude in the upcoming years. This trend toward higher storm surges in recent years may be linked to shifting storm tracks and characteristics due to Arctic sea ice loss, which sharply worsened over the same period (Francis and Vavrus 2012; Greene et al. 2013).

Fig. 14.3 (**a**) Mean sea level. (**b**) Monthly maximum sea level through 2011. (**c**) Monthly maximum sea level through 2012 (showing the storm surge due to Hurricane Sandy; note the change in vertical axis scale)



14.3 Climate Change Vulnerability and Adaptation Assessments

As part of the First National Climate Assessment, published in 2000, extensive investigations were made on climate change impacts and hazards for the Metropolitan East Coast (MEC), the New York City metropolitan area (Rosenzweig and Solecki 2001). Gornitz et al. (2002) projected sea level increases of 11–30 cm beyond late twentieth century levels by the 2020s, 18–60 cm by the 2050s, and 24–108 cm by the 2080s, resulting in loss of coastal wetlands and increased flood hazards for near-coast buildings. Assessment of regional sea level rise impact continued under the U.S. Climate Change Science Program (CCSP 2009) based on detailed coastal elevation mapping (Weiss et al. 2011; Shepard et al. 2012). Blake et al. (2000) and Frei et al. (2002) investigated the impact of global warming on New York City's water supply, finding that substantially decreased runoff by the 2080s is possible due to increasing evapotranspiration due to warmer conditions year-round.

New York City and its municipal agencies began to together address the impacts of climate change as part of PlaNYC, launched by Mayor Michael R. Bloomberg in 2007 to prepare the city to handle the increased population expected by 2030 while improving quality of life and reducing negative environmental impacts. Climate Change is one of the 10 "areas of interest" in PlaNYC. In 2008, Bloomberg convened a Climate Change Adaptation Task Force, consisting of representatives from city and state agencies as well as private companies that operate infrastructure, "to develop adaptation strategies to secure the City's infrastructure from the effects of climate change". A New York City Panel on Climate Change (NPCC), modeled after the United Nations' Intergovernmental Panel on Climate Change and consisting of 15 experts in climate science, economics, law, and other fields, was formed to provide the Adaptation Task Force with "climate-change projections; help … identify at-risk infrastructure; develop adaptation strategies and draft guidelines for design of new structures".

NPCC's report "Climate Change Adaptation in New York City: Building a Risk Management Response" was published by the New York Academy of Sciences in 2010 (NPCC 2010). This built on and updated the earlier MEC investigations by the same lead scientists, focusing specifically on the city. Expected changes in climate quantities such as temperature and precipitation were given based on the full range and the middle two-thirds of climate models that submitted results to the IPCC's Fourth Assessment Report (2007). The exception to this was the range for sea level, which was extended upward, to 30–140 cm by the 2080s, to include possible more rapid melting of ice sheets, with the upper bound taken to be the average ice sheet-melting rate during the last deglaciation. However, the risk for extreme storm surges of given height above sea level was assumed to remain the same in the absence of convincing historical observations or model simulations of a trend; as seen above, this may be proving overoptimistic. Several categories of extreme events were considered: for example, both severe drought and heavy precipitation were likely to become more common. Likely impacts of these climate changes on infrastructure were listed in some detail, grouped by category of climate change (temperature, precipitation, sea level) and by infrastructure sector (communication, energy, transportation, water and waste). The report advocated the concept of Flexible Adaptation Pathways that would improve the resilience of infrastructure incrementally, tied to current maintenance cycles, while monitoring local and global climate changes and impacts to determine whether more drastic (and costly) adjustments are required (Rosenzweig et al. 2011).

The city's Green Codes Task Force (2010, http://www.nyc.gov/html/gbee/html/codes/proposals.shtml) suggested changes to city law to encourage and facilitate adaptation based on the findings of the NPCC report (Sussman et al. 2010). Examples included creating a new map of flood zones to use in city planning that takes expected sea level rise into account; requiring safe storage of toxic materials in low-lying areas so that they do not spill during floods; and requiring environmental impact statements for proposed city projects to discuss the expected impact of climate change on the project. Many of these proposals were enacted in 2010–2011 (http://www.c40cities.org/c40cities/new-york/city_case_studies/green-codes-task-force).

More ambitious programs for adaptation were presented at a 2-day conference held in 2009 by the American Society of Civil Engineers (ASCE) titled "Against the Deluge: Storm Surge Barriers to Protect New York City", which took heed of the flooding of parts of New Orleans by Hurricane Katrina in 2005 (Hill et al. 2013). This reported on hydrodynamic modeling of the feasibility and impacts of barriers that could be raised to keep an impending storm surge out of New York harbor carried out at Stony Brook University with funding from New York state's Sea Grant Program and the New York City Department of Environmental Protection (Bowman et al. 2005; Colle et al. 2008). The inability of the city's infrastructure to withstand hurricane storm surges even before considering sea level rise has been long appreciated (Kussman 1957; Mather et al. 1967). Several designs for different configurations of barriers were also presented. It was noted that regulatory and financial obstacles to such barriers were historically only overcome in other cities after a damaging flood made it possible to get wide public and institutional support. Accordingly, ASCE held a follow-up conference on the topic on April 2013 to explore "potential solutions to reduce the impact of storm surge and flooding caused by Sandy".

14.4 Climate Change Adaptation Research Case Studies

14.4.1 A Bridge Rating System for Scour Hazard Under Sea Level Rise

Scour as a result of flooding, resulting in failure of the foundation, is the leading mode of bridge failure nationally. For bridges over waterways, the 100- and 500-year storm recurrence periods serve as the key design criteria to design and protect bridges against scour according to Federal Highway Administration specifications;

the design storms are based on Federal Emergency Management Administration flood maps that do not currently include any provision for sea level rise. A recent civil engineering doctoral dissertation at the City College of New York (CCNY) (Shields 2012) modeled scour during 100- and 500-year flood events for a sample coastal bridges in the NYC metropolitan area, using both present and high-end projected 2080s sea level (+140 cm, based on the NPCC). A revision to the existing New York State Department of Transportation (NYSDOT) prioritization system for bridge rehabilitation was proposed to take into account vulnerability under sea level rise, along with other factors such as bridge age and the availability of alternative routes. This research program was undertaken with the cooperation of NYSDOT and the Port Authority of New York and New Jersey, which provided bridge plans used in the modeling study. However, no concrete changes in bridge maintenance standards by state and city regulators have yet been made. Follow-up research at CCNY is aimed at estimating regional changes in heavy precipitation extremes, which affect river runoff extremes and hence scour potential for interior bridges that span rivers.

14.4.2 Improving Models of Evapotranspiration from the New York City Water Supply Area

The New York City Department of Environmental Protection (DEP) has been hosting postdoctoral fellows from the City University of New York (CUNY), which includes CCNY, for several years. These scientists have been helping DEP to research climate change impacts on water quantity and quality by developing hydrological models and measurements (Rosenzweig et al. 2007; Matonse et al. 2011; Zion et al. 2011). Extending this collaboration, CCNY and DEP scientists, funded by NASA Earth Science Division's Applied Sciences Program, are working to use thermal, microwave, and other remote sensing data to infer soil moisture and evapotranspiration spatiotemporal patterns from the watersheds under drought conditions and compare these with those in the watershed hydrology models DEP uses for scenario planning and operational management. The increase in evapotranspiration with warming potentially threatens New York City's water supply in future decades, particularly in the summer and early fall months, but there have not been any measurements of evapotranspiration in the city watersheds for calibrating and validating the models being used by DEP to project risks to the water supply. Preliminary results comparing modeled evapotranspiration with that derived from MODIS satellite imagery (Mu et al. 2011; Ryu et al. 2011) show some discrepancies between remotely sensed and modeled evapotranspiration (Fig. 14.4). These can be understood as reflecting systematic bias in the model formulation, such as too little water storage in the soil (Krakauer et al. 2012). Correcting such biases should enable more realistic predictions of the impact of climate change on water. These predictions could, in turn, affect the reservoir operation rules and watershed management strategies that NYCDEP adopts in order to supply sufficient water

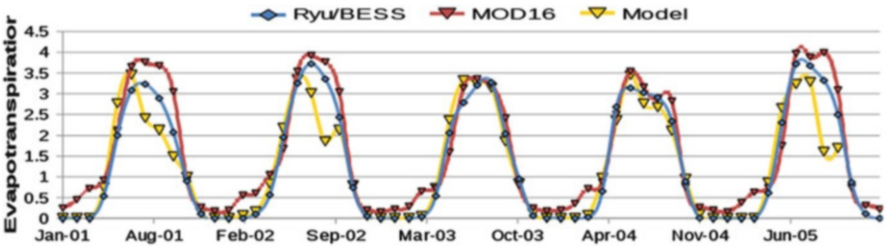


Fig. 14.4 Evapotranspiration (mm/day) for one of the New York City water supply watersheds as simulated with NYCDEP's current operational model and as estimated from remote sensing using two algorithms (MOD16, Mu et al. 2011 and BESS, Ryu et al. 2011). The modeled evapotranspiration frequently appears too low in late summer

while maintaining turbidity standards by controlling eutrophication and sediment loading in its watersheds, which is necessary in order to avoid a costly requirement for filtration (Bryant et al. 2008).

14.5 Conclusions

Solecki (2012) notes that New York City's climate change adaptation trajectory is unusual among global cities in that it has the technical resources to commission science, engineering, and policy research specific to its needs. Through projects such as those discussed here, New York City is leveraging its human capital to make better use of current facilities and regulatory frameworks, providing a potential model for other jurisdictions. National and global city forums provide one way to share the lessons learned with smaller cities that do not have such resources (Rosenzweig et al. 2010).

The widespread devastation resulting from Hurricane Sandy may cause stakeholders' perception of needed research to shift to problems having more immediate applications—for example, more could be done for local armoring (Bolonkin 2007) or relocation of vital infrastructure links such as electric transformers. Increasing population and development, institutional inertia, and tight budgets have all slowed work toward improving preparedness in New York City (as in many other cities). A truly long-term perspective that takes into account the possibility of tens of meters of sea level rise if greenhouse gas concentrations do not drop from their current levels (Hansen et al. 2008; Foster and Rohling 2013) currently seems beyond the ambit of the municipal administration. To use the terminology of Kates et al. (2012), New York City will eventually move from incremental to transformational adaptation.

The challenge of adaptation to climate change may be viewed in terms of overcoming barriers in understanding, planning, and management (Moser and Ekstrom 2010). From this perspective, New York City has achieved at least provisional understanding of many climate challenges, as synthesized in the NPCC (2010) report. As for planning and management, some options have been presented, but the broad range of stakeholders that need to be engaged in the process of selecting, monitoring, and evaluating options for the more far-ranging of the needed adaptation strategies have not yet weighed in. These stakeholders include, first and foremost, New York City voters, taxpayers, and ratepayers. Outreach to a broad cross-section of New York City residents could occur through public comment opportunities, through local organs such as the community boards (Hum 2010), and through nonprofit and community groups such as those who manage and advocate for community gardens (Smith and Kurtz 2003; Eizenberg 2012). With a successor to Mayor Bloomberg to be elected in November 2013, the type of future political leadership for climate adaptation and the degree to which it can engage not only the research community and city agencies but a broad array of stakeholders remains to be seen.

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