Vignette: Climate Change Effects on Flooding During Hurricane Sandy (2012)

Joel C. Dietrich

NC State University, Raleigh, NC, United States

Hurricane Sandy devastated the Northeast US coastline in 2012. In New York City, it caused power outages that affected nearly 2 million people, forced evacuations of 6500 patients from hospitals and nursing homes, prevented 1.1 million children from attending school for a week, and disrupted the daily travel of about 11 million commuters (Special Initiative for Rebuilding and Resiliency, 2013). Many of these impacts were related to flooding of critical infrastructure (Fig. 1), including nearly 90,000 buildings, and more than $5 billion in damages in the mass transit system (Bernstein, 2013). The maximum observed water level at the tidal gauge located at the southern tip of Manhattan was 5.3 m above the station datum and 2.8 m above the expected tide. This additional water, known as storm surge, was pushed from the open sea by strong winds during the storm. Sandy was one of several recent storms to cause flooding along the US Gulf and Atlantic coasts, including Katrina and Rita (2005), Gustav and Ike (2008), Irene (2011), Isaac (2012), and Hermine and Matthew (2016). Climatic changes are

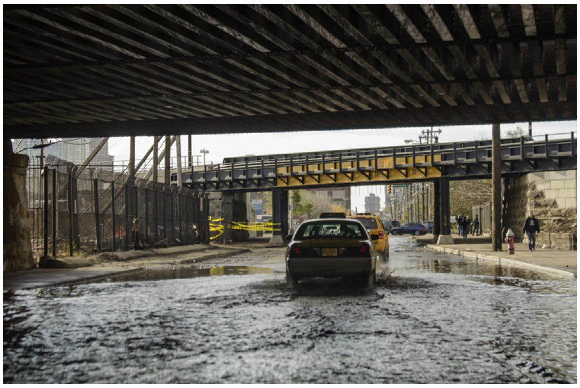

FIGURE 1 Flooding in Hoboken, New Jersey following Hurricane Sandy. *Credit: Liz Roll/FEMA, 2012.*

Disaster Epidemiology
http://dx.doi.org/10.1016/B978-0-12-809318-4.00020-4

causing these storms to be larger and more intense, last longer, and move farther northward. Their impacts will be more severe to communities in coastal regions in the future.

Climate change has its greatest effect on hurricanes through global warming. Hurricanes act as heat engines (Willoughby, 1999). A hurricane, also known generally as a tropical cyclone, exchanges heat between two reservoirs: the ocean, which is typically warmer in the tropical regions where the cyclone is formed, and the atmosphere, which is much colder at the altitudes near the top of the cyclone. Air is pulled toward the center of the cyclone as it moves over the ocean, picking up water vapor and heat through turbulence at the air–sea interface. This warm air rises near the eyewall, cools as it is pushed outward at high altitudes, and then falls downward to repeat the cycle. Thus hurricanes are sensitive to the sea surface temperature, and they can strengthen quickly when they move over a patch of warmer water. There are several ocean currents that contribute warm water to this process, most notably the Loop Current and Gulf Stream, which connect the warm water from the Caribbean Sea through the Gulf of Mexico and up the eastern coast of the United States. And these waters are becoming warmer. More than 90% of the overall increase in energy due to climate change is stored in the oceans (IPCC, 2013). In regions where tropical cyclones are likely to form, the sea surface temperatures have increased by several tenths of a degree Celsius during the past several decades, due primarily to human-caused changes in greenhouse gases (Santer et al., 2006).

Water expands as it warms, and thus global warming is also a contributor to sea level rise. The global mean sea level has increased by about 1.8 mm/year since 1900, with a larger recent increase by about 3 mm/year since 1993 (Church & White, 2011). This sea level rise is highly variable in location, depending on the local land movement, and it can be larger in regions where the land is shifting downward. In southeastern Virginia, where groundwater withdrawals have caused compaction of aquifers, land subsidence has caused more than half of the relative sea level rise of about 4 mm/year since 1950 (Eggleston & Pope, 2013). These global and local factors contribute to the difficulty in predicting sea level rise through this century. A simple continuation of recent trends would cause an increase in global mean sea level of 17 cm by 2100, and the inclusion of additional warming would further increase this prediction to a range from 28 to 98 cm, depending on the emission scenario (Church et al., 2013). These rising water levels will exacerbate the effects of storm-induced flooding because they provide a higher base level for the storm surge.

This increase in base water level is made worse by an increase in extreme storm frequency. Tropical cyclones are not occurring more often, at least according to the historical record and weather satellite data since the 1970s, but they are becoming more powerful (Frank & Young, 2007). Theory and observations suggest an upper limit on the intensity of tropical cyclones (Bister & Emanuel, 1998), and climate models show an increase in intensity toward this upper limit due to anthropogenic global warming (Knutson & Tuleya, 2004). To analyze these trends, researchers have suggested metrics to combine storm characteristics such as frequency, intensity, and duration. Power dissipation, which is a measure of the potential destructiveness of hurricanes, has more than doubled during the past 30 years (Emanuel, 2005). And storms are moving poleward by 50–60 km per decade (Kossin, Emanuel, & Vecchi, 2014). Thus, when a storm makes landfall in the coastal United States, it is more powerful and more likely to cause flooding than in the past.

These trends converged during Hurricane Sandy. In New York City, the sea level rise during the anthropogenic era has caused the mean flood heights to increase by 1.24 m (Reed et al., 2015), including by 56 cm during the last 250 years (Kemp & Horton, 2013). This increase in base flood level has combined with increases in storm potential to push water toward shore. Flood heights that used to be rare, such as floods that occurred with a probability of once per 100 years, could increase in frequency to occur once every 4 years in the Northeast United States (Frumhoff, McCarthy, Melillo, Moser, & Wuebbles, 2007) and once every 3–20 years in New York City (Lin, Emanuel, Oppenheimer, & Vanmarcke, 2012). During Sandy, the storm surge and flooding were severe due to the extreme size of the storm, which became the largest on record (Blake, Kimberlain, Berg, Cangialosi, & Beven, 2013). Before its landfall on the New Jersey coast, Sandy had tropical-storm- and hurricane-strength winds that extended 778 km and 333 km from its center, respectively (Demuth, Demaria, & Knaff, 2006). These tropical-storm-strength winds had a diameter that was equivalent to the distance from North Carolina to Maine, and they contained more than twice the energy as Hurricane Ike (2008). These winds pushed storm surge against the Northeast US coastline, causing flooding of coastal communities and devastation of critical infrastructure. Hurricane Sandy was an example of recent trends in natural disasters due to climate change, and it emphasizes the need for research and investment in resilient communities.

References

Bernstein, A. (2013). *U.S. Transportation Secretary LaHood announces $3.7 billion in additional Hurricane Sandy disaster relief aid for transit agencies*. U.S. Department of Transportation Document DOT 46–13.

Bister, M., & Emanuel, K. A. (1998). Dissipative heating and hurricane intensity. *Meteorology and Atmospheric Physics, 50*, 233–240.

Blake, E. S., Kimberlain, T. B., Berg, R. J., Cangialosi, J. P., & Beven, J. L., II (2013). *Tropical cyclone report: Hurricane Sandy, (AL182012), 22–29 October 2012*. National Hurricane Center Rep., 157 pp.

Church, J. A., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, S., Levermann, A., et al. (2013). Sea level change. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, et al. (Eds.), *Climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Church, J. A., & White, N. J. (2011). Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics, 32*(4), 585–602.

Demuth, J., Demaria, M., & Knaff, J. A. (2006). Improvement of advanced microwave sounder unit tropical cyclone intensity and size estimation algorithms. *Journal of Applied Meteorology, 45*, 1573–1581.

Eggleston, J., & Pope, J. (2013). Land subsidence and relative sea-level rise in the southern Chesapeake Bay region. *U.S. Geological Survey Circular, 1392*, 30.

Emanuel, K. A. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. *Nature, 436*, 686–688.

Frank, W. M., & Young, G. S. (2007). The interannual variability of tropical cyclones. *Monthly Weather Review, 135*, 3587–3598.

Frumhoff, P. C., McCarthy, J. J., Melillo, J. M., Moser, S. C., & Wuebbles, D. J. (2007). *Confronting climate change in the U.S. Northeast: Science, impacts, and solutions. Synthesis report of the Northeast Climate Impacts Assessment (NECIA)*. Cambridge, MA: Union of Concerned Scientists (UCS).

IPCC. (2013). Summary for policymakers. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, et al. (Eds.), *Climate Change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Kemp, A. C., & Horton, B. P. (2013). Contribution of relative sea-level rise to historical hurricane flooding in New York City. *Journal of Quaternary Science, 28*(6), 537−541.

Knutson, T. R., & Tuleya, R. E. (2004). Impact of CO2-induced warming on simulated hurricane intensity and precipitation: Sensitivity to the choice of climate model and convective parameterization. *Journal of Climate, 17*, 3477−3495.

Kossin, J. P., Emanuel, K. A., & Vecchi, G. A. (2014). The poleward migration of the location of tropical cyclone maximum intensity. *Nature, 509*, 349−352.

Lin, N., Emanuel, K. A., Oppenheimer, M., & Vanmarcke, E. (2012). Physically based assessment of hurricane surge threat under climate change. *Nature Climate Change, 2*, 462−467.

Reed, A. J., Mann, M. E., Emanuel, K. A., Lin, N., Hortone, B. P., Kemp, A. C., et al. (2015). Increased threat of tropical cyclones and coastal flooding to New York City during the anthropogenic era. *Proceedings of the National Academy of Sciences of the United States of America, 112*(41), 12610−12615.

Santer, B. D., Wigley, T. M. L., Gleckler, P. J., Bonfils, C., Wehner, M. F., AchutaRao, K., et al. (2006). Forced and unforced ocean temperature changes in Atlantic and Pacific tropical cyclogenesis regions. *Proceedings of the National Academy of Sciences of the United States of America, 103*, 13905−13910.

Special Initiative for Rebuilding and Resiliency (SIRR). (2013). *A stronger, more resilient New York*. Available at http://www.nyc.gov/html/sirr/html/report/report.shtml.

Willoughby, H. E. (1999). Hurricane heat engines. *Nature, 401*(6754), 649−650.