

# Sea Level Rise: Risk and Resilience in Coastal Cities

*Erin A. Thead*

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1400 16th St. NW, Suite 430, Washington, DC 20036

## *Introduction*

One of the most dire impacts of anthropogenic climate change is a rise in the global sea level caused by the melting of glaciers and land-based ice caps, as well as a smaller increase from expansion due to the higher temperature of the water itself. Unlike some other predicted effects of climate change, this impact has already been observed for some time. Indeed, not only is there evidence that sea levels are rising; there is also evidence both that the *rate* of sea level rise has been increasing in recent years and that it will continue to increase.<sup>1</sup> Figure 1 shows the average sea level increase from its 1993-2013 midpoint.

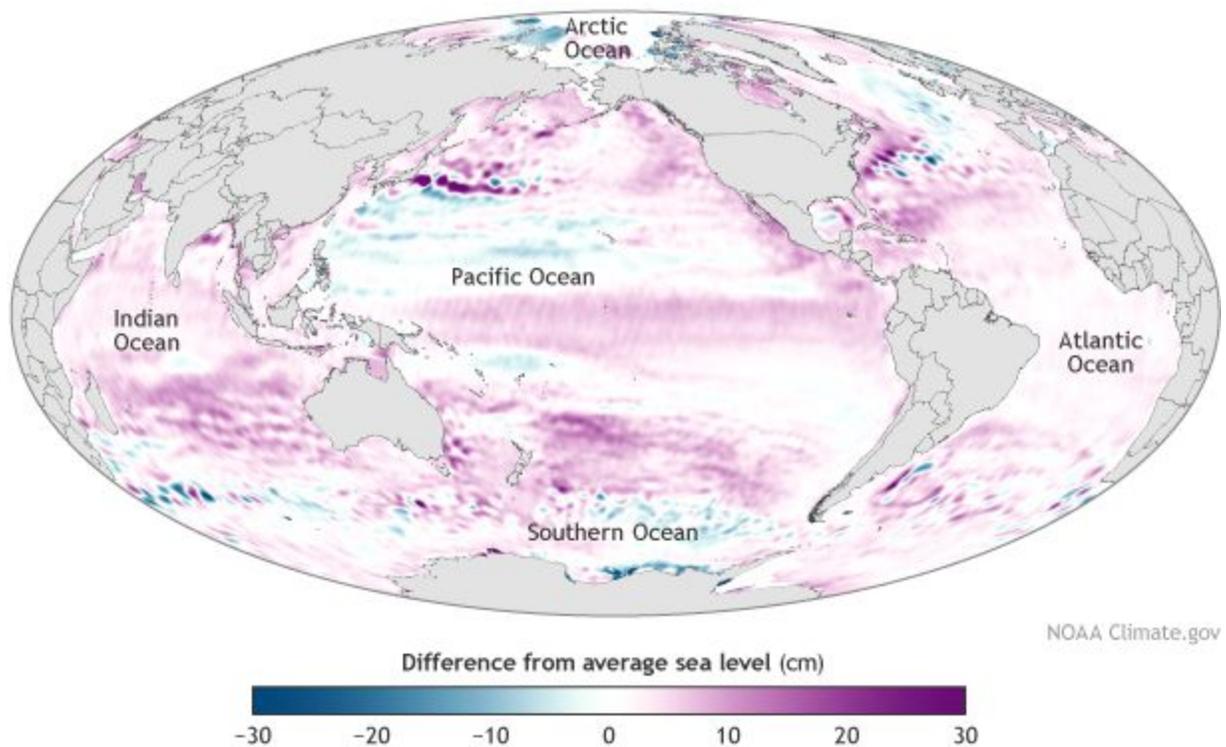


Figure 1. 2014 sea level compared to the mean sea level from 1993-2013. *Credit: National Oceanic and Atmospheric Administration, Climate.gov*

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As Figure 1 makes clear, the impact of sea level rise is not felt equally around the globe. Some locations experience greater rise than others because of local terrain, local hydrological factors, and oceanic currents, among other regional factors. Unfortunately, many large cities are located on coastlines that are particularly vulnerable to sea level rises. Improvements in high-resolution modeling have made it possible for the expected sea level rises in specific locations to be mapped, both in worst-case and expected-case scenarios. This very detailed awareness of the hazard has, in many locations, led to positive planning and actions to mitigate the impact. This article will describe the latest scientific thinking about the magnitude of global sea level rise, detail some solutions that coastal cities around the globe are implementing to mitigate risk, and offer general suggestions for good resilience planning for locations that will be impacted by this threat.

## *A Growing Concern*

Recently, a team of scientists published a study that found that the rate of sea level rise in the 20<sup>th</sup> century was greater than it had been in 2,800 years.<sup>2</sup> Sea levels have risen almost 3 inches globally in the most recent 20 years and rise on an average of 1/8 inch each year. Melting land ice is responsible for a larger—and ever-increasing—amount of the global sea level rise in recent decades, as opposed to thermal expansion of seawater. A compounding problem with ice melt is that it can accelerate through positive feedback. Snow-covered ice has a high reflectivity or albedo, which means that radiation is reflected back from it and not as much is absorbed as heat. Water, however, has a very low albedo and does absorb high amounts of solar radiation and heat held in the earth's lower atmosphere. Once ice has started melting, the process accelerates without an external influence to cause refreezing. Short-term climatic patterns that temporarily raise global temperature averages, such as a strong El Niño event, can therefore exacerbate the long-term trend unless a strong cooling event occurs quickly thereafter.

The current best estimates predict that sea level will rise up to 6.6 feet, or 2 meters, by the year 2100. Until recent years, this figure was viewed as pessimistic, with a rise of 3 feet considered more likely. Recent studies raise the concern that the 6.6-foot estimate is actually the more probable one with “business as usual” carbon emissions. Earlier work accounted for glacial and Arctic melt, but had

greater uncertainty about the West Antarctic Ice Sheet. The new research, developed in the last three years, modeled that the West Antarctic sheet would be undermined by warmed seawater, accelerating its decline.<sup>3</sup> The study also found that adhering to the agreements in the Paris climate summit of 2015, and thereby keeping the mean global temperature increase under 2°C, would lessen the melting of the West Antarctic Ice Sheet. Nonetheless, even in this optimistic case, some sea level rise will continue to occur due to current greenhouse gas levels in the atmosphere and the attendant warming.

## *Coastal Resilience in the United States*

Several American coastal cities have begun plans to minimize the effects of sea level rise. In New York City, the areas of the city that are in the “100-year flood zone” and “500-year flood zone”—in other words, that have a 1 percent chance and 0.2 percent chance of flooding each year—are expected to expand<sup>4</sup>. Figure 2 shows a map of New York City with expected flood zones that are based on the projection of 2.5-foot global sea level rise by the year 2050.



Figure 2. Current and projected future flood risks for New York City assuming 2.5 foot sea level rise by 2050. *Credit: Federal Emergency Management Agency/National Oceanic and Atmospheric Administration*

In response to the flood analysis and the destruction wrought by Sandy, the city developed a comprehensive resilience plan.<sup>5</sup> In this plan, the city specifically analyzed the effects of Sandy as a near-worst-case impact and the projected future flood zones. It determined several actions to take to minimize the risks. To protect coasts against tidal flooding, the city plans to reinforce beaches, build bulkheads, and protect sand dunes that act as natural barriers. The city may also enact rock breakwaters offshore to attenuate waves associated with storms, and erect storm walls and levees in areas that are particularly vulnerable to storm surge. The city's plan contains a rigorous geological analysis of the landscape and makes recommendations specific to boroughs and neighborhoods based on what types of mitigation strategies the rock and soil in each locale can support.

Boston is another American city that has developed a comprehensive climate resiliency plan.<sup>6</sup> Since it is on a coastline, Boston's greatest risks from climate change are flooding and storm surge. Boston's plan emphasizes community awareness and education as critical tools for climate preparedness. As Brian Swett, a lead developer of Boston's climate plan and formerly the chief of Boston's Department of Environment, stated with regard to storm surge,

If I told somebody, even in July, that we're expecting 20 inches of snow in two days, everybody has that mental checklist up here in Boston: Make sure I know where the shovel is; I know the streets not to park on because there'll probably be a parking ban; I got my bread and my milk; I've got salt for the walkway. We don't have that mental checklist up here for hurricanes and we certainly don't drill for it [...].<sup>7</sup>

The Boston climate plan also puts emphasis on outreach to low-income households, small business owners, and other vulnerable residents, by working closely with other city departments that focus on these residents' concerns. Low-income residents in particular utilize public services such as buses more than other residents, and as the tragedy of Hurricane Katrina in New Orleans showed, these residents are most vulnerable in the event of a needed evacuation.

Cities that have smaller populations than the East Coast metropolises and rely heavily on tourism for economic development are also making preparations. Tybee Island, a barrier island near Savannah, Georgia, is a popular tourist destination during the summer months. The sea level on this island's coastline has risen 10-11 inches since 1935, and as in most areas of the world, it is expected to continue rising.<sup>8</sup> The city, also named Tybee Island, developed a resilience plan to cope with rising sea levels. The city has a single road that allows access on and off the island, so shoring up this road—U.S. Highway 80—and improving it to minimize traffic bottlenecks was a key part of the city's resilience plan. As in other cities, reinforcing natural barriers to inland flooding was also important, so protecting Tybee Island's beaches from erosion was another crucial part of the plan.

## *Coastal Resilience around the Globe*

Cities elsewhere around the world have begun to grapple with the risks of sea level rise as well. In Australia, coastal cities face the threats of tidal flooding, non-tropical storm flooding, and tropical cyclone storm surge just as cities in the U.S. do. Australian states and municipalities also have significant authority over their own policies, comparably to the U.S. The national government of Australia has issued a strategic plan for climate resilience and adaption, which recommends procedures to states and municipalities.<sup>9</sup>

The Australian resilience plan acknowledged that coastal cities were built with the assumption that weather and tidal conditions would fall within a known historical range that includes a stable sea level, and therefore that expected rises from climate change pose a threat. The government of Australia is in the process of developing an online tool, known as CoastAdapt, that will help local officials understand specific risks their areas face and provide specialized information about resilience options.

A specific example of this type of local resilience planning is the analysis of seawalls in Sydney. The city has several older seawalls, and authorities were unsure of their reliability in the face of climate change and extreme events. The government of Australia oversaw a project to assess the seawalls

for their current condition that included analysis of the materials used in the seawalls, maintenance, stability, and strength. The project officials then proposed improvement suggestions for each seawall examined.

Many cities in Europe are also vulnerable to sea level rise. European cities are not at risk of hurricane storm surge due to their northerly latitudes and location on coastlines that do not experience tropical cyclones, but they are vulnerable to tidal flooding and non-tropical storm flooding. Some are also built below sea level and rely on levees for protection.

An example of the latter is the city of Rotterdam in the Netherlands, which is 90 percent below sea level and surrounded by several rivers. Dikes protect the city from inundation. In 1953, Rotterdam suffered an extremely deadly flood that breached the dikes, killing 1,800 people, a tragedy that foreshadowed Hurricane Katrina in New Orleans fifty-two years later. In response, the Dutch government directed funding to a massive project to build dikes around areas of the city. Unfortunately, over the years the structures have damaged the environment and aquatic ecosystems. In a more sustainable, ecologically sound, and physically robust plan, the government is now shoring up the natural coastline of the city by rebuilding sand dunes and expanding shores with sediment.<sup>10</sup>

## *Lessons and Strategies for Resilience*

As we have seen, governments at all levels are assessing the dangers for specific locations and analyzing the current infrastructure the world over. It is possible to model expected flood risk at an extremely high resolution and perform engineering analyses on existing infrastructure—natural and manmade—with a great degree of precision. The results are a set of plans tailored for the specific needs and capabilities of each location. Climate change does not affect all parts of the earth in the same way, and even sea level rise will not be globally uniform, so highly individualized resilience planning is a must. Their diversity notwithstanding, however, the plans do have some things in common. The ideas that appear repeatedly, in resilience plans around the globe, do so because they are broadly applicable, and in many cases, planners have arrived at them through past experience.

Cities that wish to develop their own coastal resilience plans should look to these repeat ideas as guidance.

First, coastal cities at particular risk of flooding should protect any natural barrier islands that are present. These islands are the first line of defense against storm surge, whether from tropical cyclones or other storms at sea. Cities that can afford it, and can do so in an environmentally friendly way, might follow the example of New York City and erect artificial breakwaters offshore if they do not have any natural barrier islands. These structures could also serve as artificial reefs for marine life if oceanic conditions permit.

Many coastal cities have artificial seawalls and levee structures. These structures tend not to be as robust against extreme events as natural barriers, but cities that have them should follow the example of Sydney and examine them in close detail to determine their robustness. Of course, to be fully effective, civil authorities should conduct this type of analysis with an eye to the specific level and type of risk that a given city is expected to face from sea level rise. Resilience planners in very low-lying locations should also keep in mind the lessons of New Orleans and Rotterdam, emphasizing shoreline and wetland restoration as the first and best defense instead of relying wholly on a system of levees to fight the natural course of rivers. For locations that are below sea level, natural restoration approaches are more robust against flooding and have proved far better for surrounding ecosystems. Cities should not neglect existing seawalls and levee structures, but they should be part of a broader strategy.

Finally, resilience analysts should always consider the human factor, particularly in the context of extreme flood events that would pose a high threat to life and require partial or full evacuation of the city during the emergency. This type of risk is especially acute for cities that are low-lying, prone to storms, or located at the mouths of significant river systems. Officials should take guidance from Boston's plan, which emphasizes promoting community education about the flood threat and devoting special attention to vulnerable populations that rely on public services. The plan for Tybee Island, a much smaller municipality, takes into account its reliance on tourism and the dependence

of its evacuation route on a single highway. Planners should always consider the specific local needs of a city, whatever its size.



Climate change is already causing sea levels worldwide to rise, and we can only expect this trend to continue. Our best, most current science predicts that ice cap melting and thermal expansion of seawater will produce a combined average rise of up to 6.6 feet by the beginning of the next century. This level of rise would inundate some beaches and overflow many barrier islands that serve as natural protection against storm surge from tropical and non-tropical cyclones. It would also raise the risk of tidal flooding, and in areas that are expected to see an increase in rainfall, flash flooding and river flooding would compound the flood risk associated with coastal waters. The risks of sea level rise to coastal cities must be taken seriously, and the kinds of concrete, specific, individually tailored flood resilience plans illustrated here are a very positive step. While emissions reductions can lessen the magnitude of this impact, some rise is going to occur. It is imperative for areas at risk to adapt to this new hazard, and fortunately, they are beginning to do just that. These pioneering coastal cities have created plans that offer excellent guidance. Hopefully, resilience planners in other locations around the world will follow their lead.

*Erin A. Thead is a Graduate Research Fellow at the Climate Institute and a doctoral candidate in Earth and Atmospheric Sciences at Mississippi State University.*

## Notes

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