Mid-Atlantic Sea Level Rise and Coastal Development

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DISCUSSION PAPER

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1. Introduction

Between now and 2030, sea level rise will not yet be an economic game changer for most Mid-Atlantic coastal areas. However, the most low-lying areas, typically landfilled former wetlands, are already seeing major challenges due to a rapid increase in the frequency of flooding, and this will only get worse. Relative sea level rise over the last 200 years has been about 2 feet across the mid-Atlantic coast, though higher for some areas with high subsidence rates. The rate of relative sea level rise has so far approximately tripled, comparing pre-industrial rates to recent decades. In spite of this, the region has generally had accelerating growth in the coastal economy. Therefore, it is clear that some sea level rise can be tolerated. The economy recovers and regains momentum after major storms because the federal government contributes beach replenishment, infrastructure is rebuilt higher and stronger, and homes are built back larger and more expensive.

However, in the long-term, accelerating sea level rise is an existential threat to all coastal properties of the Mid-Atlantic and the entire blue economy. Repetitive flooding can create uninhabitable conditions once nuisance flooding passes a threshold that has been estimated to be 30 days per year (Sweet & Park, 2014) or in the event of repetitive structural flooding or erosion. Another danger is that there could be a point where the federal government coastal protection investment declines or is too spread out nationwide to be sufficient at any one location.

Whether and when a coastal development collapse will occur is highly uncertain and depends on politics as well as melting polar glaciers, but it is very likely more than 10 or 20 years away for most areas. This conclusion, however, has an asterisk due to climate change – past storm patterns are no longer guaranteed to tell us about the present. If we learn that record-setting Mid-Atlantic coastal storms like Hurricane Sandy are now much more likely to occur (so far most evidence does not support this) then this optimism will be mistaken.

Below, I expand upon these perspectives in greater detail, summarizing the historical trends in Mid-Atlantic sea level, presenting likely future changes at 2030 and 2100, including uncertainty estimates, and translating these numbers into physical impacts and implications for the coastal economy of the region. I discuss the science and research gaps that lead to even greater uncertainty in the response of the coastal natural systems and society to this sea level rise, and end by presenting a list of conclusions and recommendations.

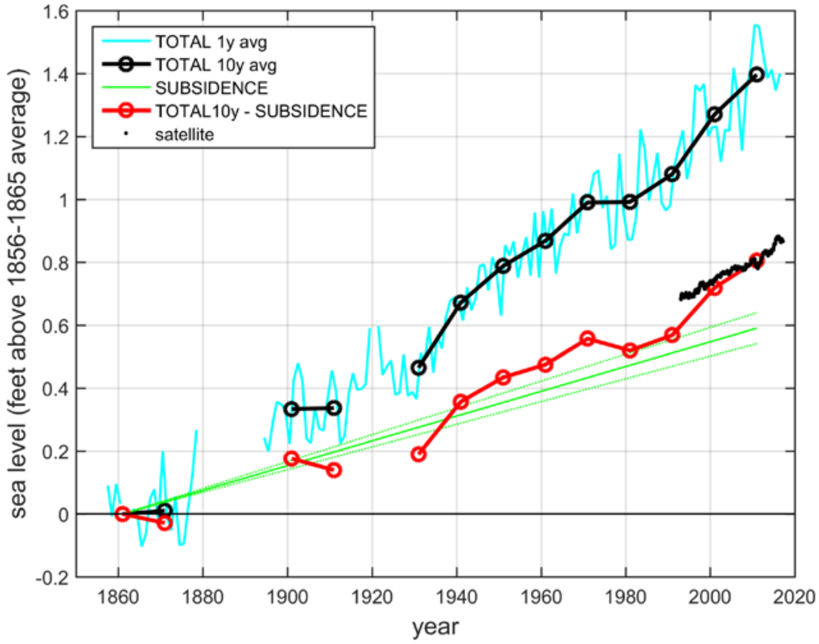

Figure 1. New York City relative sea level (RSL) from 1850 to present (light blue; NOAA 2017), with 10-year running averages in black. The RSL signal is separated into estimated land subsidence (green; 0.5 inches per decade, from Kemp et al., 2017) and their difference, an estimate of the actual rising sea level (red). The recent satellite-based estimates of global sea level rise have been superimposed (black), offset to the 1896-2005 Mean Sea Level (based on data described in Church & White, 2011).

2. Historically Continual, yet Accelerating Sea Level Rise

Sea level rise has affected the Mid-Atlantic for thousands of years, due to the influence of the last ice age as well as compaction of sediments for many locations (see spatial map in Miller et al., 2013). The influence of the last ice age regionally is to cause land subsidence by vertical movement of continental plates, termed glacio-isostatic adjustment (GIA). This adjustment has persisted for over 10,000 years due to the removal of the massive weight of ice over areas to the north and the relatively constant, slow geological response. Compaction is caused by long-term natural compaction of coastal plain sediments, but also in the modern era by human groundwater withdrawals (Miller et al., 2013).

At New York City's bedrock locations, land subsidence induced sea level rise rates are about 0.5 inches per decade, due purely to GIA (Kemp et al., 2017). On the New Jersey coast on the other hand, rates are about 0.8-0.9 inches per decade, reflecting an important role for compaction. Compaction of coastal plain sediments is a continual, natural process, though it was substantially worsened in the 20th century by spatially-varying groundwater pumping (Miller et al., 2013).

Sea level rise has accelerated globally (Dieng et al., 2017), and locally this can be seen in the historical data, particularly if one removes the land subsidence signal (**Figure 1**). Recent (1993-2015) relative sea level rise rates are about 3 times faster than those that existed before the industrial revolution, assuming that rate simply reflects the natural land subsidence induced rates (this is the case prior to the mid-1800s; Kemp et al., 2017). For example, recent sea level rise has occurred at about 1.6 inches per decade for New York City, about three times the preindustrial rate of 0.5 inches per decade.

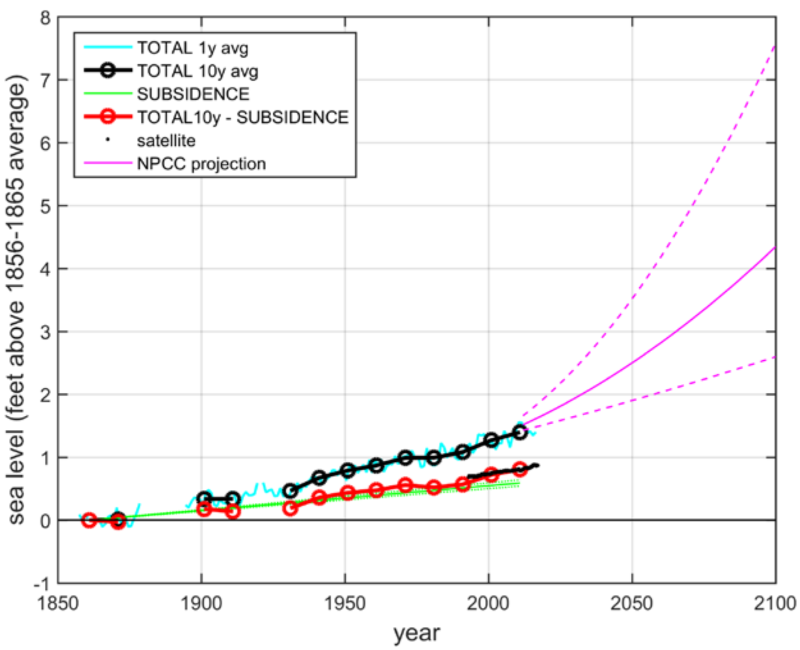

Figure 2. Same as Fig. 1, but adding the New York City Panel on Climate Change sea level rise projections (magenta - 10th, 50th, 90th percentiles) out to 2100 (Horton et al., 2015b). The midpoint between the 25th and 75th percentiles for the 50th percentile.

3. Future Sea Level Rise and Uncertainties

The view at 2030

A typical Mid-Atlantic sea level rise projection for 2030 is 0.8 ft, relative to the year 2000 sea level (with a 0.6-1.0 ft 67% uncertainty range). A high-end, 95th-percentile prediction is 1.1 ft (values for New Jersey; Kopp et al., 2016). Considering the projection period is over halfway complete, the central projection of 0.8 ft between 2000 and 2030 is equivalent to an additional ~5 inches from 2017 to 2030. Similar projections of sea level rise come from the New York City Panel on Climate Change (**Figure 2**).

The view at 2100

Sea level rise at 2100 depends strongly on the human response to the climate change problem, with large differences in projections corresponding to “high emissions” versus “low emissions” scenarios. Projected sea level rise for 2100 at low emissions is 2.3 ft (with a 1.7-3.1 ft 67% uncertainty range). A high-end, 95th-percentile prediction is 3.8 ft. Projected sea level rise for 2100 at high emissions is 3.4 ft (with a 2.4-4.5 ft 67% uncertainty range). A high-end, 95th-percentile prediction is 5.3 ft (Kopp et al., 2016). Similar central estimates from the New York City Panel on Climate Change, with a 50^{th} percentile of 3 ft. High-end estimates differ due to differing methods, and the 90^{th} percentile estimate from NPCC is 6.25 ft (Horton et al., 2015b). Spatial variations across the Mid-Atlantic should be much smaller in this region than the large uncertainty in sea level rise. Even more extreme sea level rise could occur by 2100 if Antarctic ice sheet collapse occurs, yet reductions in emissions can ameliorate the rise at 2100 and with dramatic differences at 2300 (Garner et al., 2017).

Additional Uncertainties

The hurricane season of 2017 saw the end of a decade-long "major hurricane landfall drought" in the Unites States (Hall & Hereid, 2015) and major hurricanes Harvey, Irma and Maria all affected the U.S. mainland or island territories. This brought the concern back to the forefront about the potential for climate change to cause an increase in hurricane intensity. This still remains an active area of research, but the present consensus is that climate change may reduce the total number of hurricanes, but is likely to increase the number of major hurricanes (e.g., Horton et al., 2015a).

One of the most difficult problems that climate change creates is that one can no longer reliably look to the past storm climate with certainty that it will tell us about present and future risk. We know that sea level rise is worsening floods, raising their probability of a given flood level, but we do not have a clear scientific consensus on whether a storm like Sandy was made more likely to occur and to take its devastating left-hand turn. The end result is even greater uncertainty in the 2030 and 2100 projections in this paper than the sea level rise values themselves. Due to Sandy's being a record-setting event, a 260-year return period at New York City and the highest flood there in the City's history (Orton et al., 2016), any increase in the likelihood of this type of storm would have very negative impacts on the Mid-Atlantic region.

Coastal property values already are very strongly reliant on federal support for beach replenishment. Beaches provide an important recreational attractor for the blue economy, and beaches and their dunes are an important absorber of wave energy that protects the front row of homes. Therefore, a crucial uncertainty as sea level rise accelerates and the costs of coastal protection accelerate, is that there could be a point where the federal government coastal protection investment declines or is too spread out nationwide to be sufficient at any one location.

4. Physical Effects and Implications for Coastal Development

Many low-lying areas, typically developments on landfill, already have had a rapid acceleration in the number of floods per year (**Figure 3**). These are often located on the backsides of barrier islands or in back-bay communities. Nuisance flooding is defined for each tide gauge location by the National Weather Service, and is an event where low-lying roads become flooded and storm drains are overwhelmed. These regions already face danger for property values and development, particularly if they are approaching the estimated "tipping point" of 30 flood days per year (Sweet & Park, 2014) or will approach it by 2030. Elevating structures or constructing sea walls can be helpful for this problem, and pumping systems can be helpful for draining rainfall that won't drain from streets. However, these come at a high expense, and costs may fall on property owners or cause a large rise in property taxes.

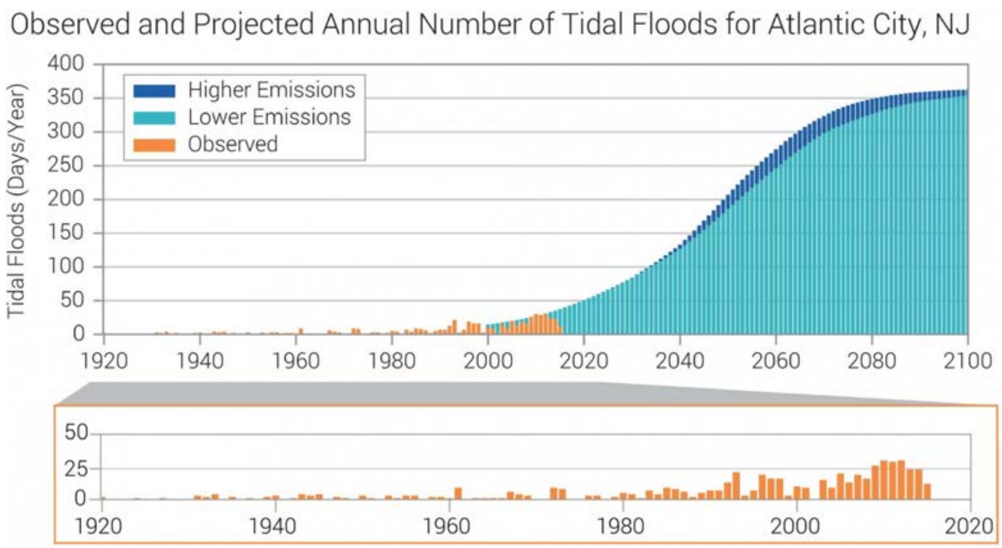

Figure 3. Number of nuisance flood days per year (water levels of 3.5 ft above NAVD88 for the Atlantic City tide gauge station) as observed for 1920-2020 (bottom) and projected out to 2100 (top) with two different emissions pathways. Only the lowest-lying areas are wetted by this water level, typically landfilled former wetlands. These areas are already approaching 25 nuisance floods per year, and this number will grow to 50-100 by 2030, representing a major challenge for these areas. This plot is from the NOAA website http://stateclimatesummaries.globalchange.gov.

Looking further off to the future, sea level rise is an existential threat to coastal development and the blue economy, because it can render large areas of coastal property uninhabitable. Even mid-range projections of about 3 ft of sea level rise for 2100 are a severe threat to coastal property, due to causing regular tidal flooding at most locations and due also to causing much deeper flooding during severe but annually-occurring winter coastal storms (e.g. nor'easters). An example of flooding for a severe "5-year flood" event with 32 inches of sea level rise is shown in **Figure 4**, portraying 2-3 ft deep water over much of the highly-populated Rockaway Peninsula region.

While reducing emissions will have little effect on the growing number of nuisance floods for very low-lying areas, it can have a large effect for development on higher land areas and looking further into the future. It will have little effect in terms of reducing the number of nuisance flood events reducing the increasing numbers of floods for low-lying areas already experiencing nuisance floods (**Figure 3**), because sea level rise responds very slowly to warming and the benefit comes too late. However, considering higher land areas and looking further out to the year 2100 or 2300 there are substantial reductions in sea level rise and flooding (Garner et al., 2017; Kopp et al., 2016). Flood mappers are increasingly available to view the difference between projected sea level rise for low-emissions and high-emissions pathways, and the differences grow much larger with time into the future (Climate Central, 2017; Garner et al., 2017).

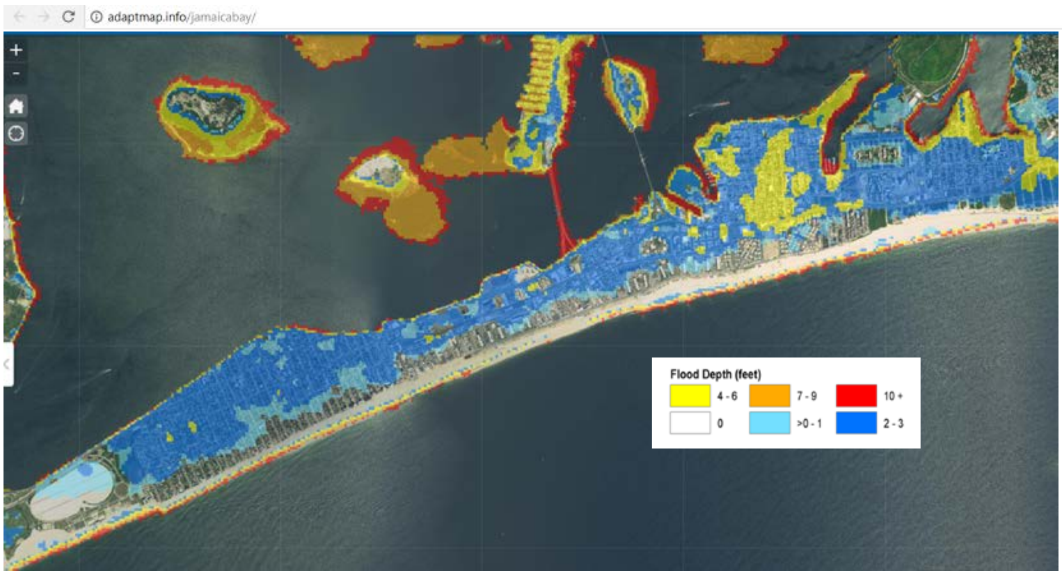

Figure 4. Even central estimates of sea level rise of about 3 ft at 2100 lead to frequent nuisance tidal flooding and widespread, deep flooding during storm surge events. This map shows flood depths on Rockaway Peninsula, New York, for a 5-year storm on top of 32 inches of sea level rise. Areas of the Mid-Atlantic that do not have seawalls or storm surge barriers will likely see a collapse of coastal property values if this amount of sea level rise occurs (map is from http://AdaptMap.info/jamaicabay).

3. Conclusions and Recommendations

Primary conclusions which may be drawn on Mid-Atlantic sea level rise and its coming consequences are:

- A short-term perspective on the impact of sea level rise in 2030 on coastal development in the Mid-Atlantic region is that it will not yet be an economic game changer for most Mid-Atlantic coastal areas.
- The most low-lying areas of the region, typically landfilled former wetlands, are already experiencing a rapid increase in the frequency of flooding, and this will only get worse.
- The multi-decadal picture for sea level rise in the Mid-Atlantic is much grimmer, particularly if looking out to 2100 or further. Sea level rise could make some areas uninhabitable, and is a high risk to coastal property value and the blue economy.
- There is a clear risk that human-caused sea level rise will accelerate and devastate coastal areas of the Mid-Atlantic, leaving it completely different from the present. Differences may

eventually include permanently eroded beaches, seawalls that may block views and worsen access, and frequent flooding that blocks roads and impacts properties.

A few recommendations that can help reduce these impacts are:

- New developments should be built with substantial freeboard, above FEMA's base flood elevation plus allowing for 3 ft of sea level rise to ensure their longevity.
- Society should dramatically reduce greenhouse gas emissions. In the near-term this will not have a noticeable impact on sea level rise rates, but in the long-term, and with respect to the "existential threat" of sea level rise to our coastal communities many decades into the future, mitigation of emissions can have a large impact.
- Coastal municipalities or states should prepare adaptation plans with multiple sea level rise scenarios (e.g. 1 and 3 ft), and detailed guidance is increasingly available on sea level rise for different planning horizons (e.g., Kopp et al., 2016). Plans can include barriers for protection, but also can aim to use softer approaches such as wetlands, dunes, and zoning changes.

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