Florida Coastal Flooding Today, Tomorrow, and the Coming Decades

A Flooding Report funded by the Miami Herald

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1 Executive Summary

MAIN TAKEAWAYS

- This report highlights the importance of user-friendly and high-impact flooding thresholds for various scenarios and the corresponding impacts. The top concern for most people living in coastal cities is flooding on their street or in their community. Common impact flooding thresholds allow the public access to information that is digestible and pertinent to their local communities.

- Localized approaches to coastal flooding are critical for improved assessment of risk for decision makers. Coastal flooding is affected by a number of factors that vary based on location, such as ocean circulation, tidal flow, elevation, and sea level rise. Regionalized flooding thresholds and sea level rise projection scenarios at more locations can provide more accurate and high-resolution flooding projections.

- This report sheds light on the urgent necessity of extensive climate change mitigation and lowered emissions. The risk of flooding for both 1 hour and 6 hours is reduced drastically under the Extensive Mitigation scenarios. While sea level rise will still continue to play a role in increased flooding days, a major reduction in greenhouse gas emissions and efficient and immediate mitigation and adaptation efforts will lead to less frequent and persistent flooding, saving infrastructure and lives.

EXECUTIVE SUMMARY

When will a particular coastal city have a 70% chance of at least one hour of flooding once a week? At least six hours of flooding once a week? These questions underline the following project to assess the future of flooding in coastal Florida cities with user-friendly impact thresholds.

Nuisance flooding occurs 300-900% more frequently than it did 50 years ago (NOAA Climate.gov 2021). Nuisance flooding is usually associated with high tide and is non-destructive, but can damage infrastructure, create road hazards, and disrupt people's day-to-day lives.

Because of the accelerated rate of sea level rise along Florida's coast, high tides are frequently becoming nuisance floods, even on days without rainfall. The IPCC reported that "anthropogenic drivers will continue to increase the exposure and vulnerability of coastal communities to future SLR in the absence of major adaptation efforts compared to today (high confidence)" (IPCC SROCC Ch4). This translates to more frequent and intense coastal flooding.

While the observed global sea level has been rising steadily over the past century, the amount of sea level rise Florida can expect in the next few decades is still uncertain. As high tides are frequently becoming floods, the need for localized assessments of future coastal flooding is pressing. Here, a number of climate scenarios provided by NOAA are used to assess the future of coastal flooding on a local scale. The scenarios, developed by Sweet et al. (2017) to understand flooding projections around the globe, were previously regionalized to specific areas along the U.S. coast.

The report includes the projected number of flooding days at nine Florida tide gauge stations. The projections include flooding that occurs at least 1 hour per day, referred to as *frequent* flooding, and at least 6 hours per day, referred to as *persistent* flooding. Flooding that lasts for 1 hour or less per day is a nuisance and can cause hazards for drivers and pedestrians, but often is not life-threatening. However, flooding that persists for 6 or more hours per day can pose serious threats, particularly to infrastructure and human life.

An additional flooding threshold of at least 52 days of flooding per year is used. A reference to "crossing the threshold" refers to the year in which a region has a 70% chance of experiencing at least 52 days per year of flooding, or weekly flooding on average. Three NOAA projection scenarios are used, referenced here as "Minimal Mitigation", "Limited Mitigation", and "Extensive Mitigation" to emphasize the potential outcomes based on future emissions and mitigation. Seventeen (17) Florida cities are analyzed using regionalized projection data to assess when the area has a 70% chance (calculated using NOAA projections (Sweet et al. 2017) and land elevation) of crossing the 52-day threshold of flooding for both

1 hour and 6 hours of flooding. All graphics included in this report as well as 3 scenarios for the 1-hour and 6-hour flooding categories for the cities analyzed are available in the associated Google Drive.

Virginia Key, Key West and Vaca Key (tide gauges) are all projected to have at least 1 hour of flooding almost every day of the year by 2060 under the Minimal Mitigation scenario. Key West and Vaca Key are both at very high flood risk, with the majority of both the islands expected to experience 6 hours of flooding weekly by 2060. Even under the Extensive Mitigation scenario, all three locations have a 70% chance or higher of crossing the 1-hour flooding threshold by 2060. Due to the low elevation of Key West, Vaca Key, and the coastal regions of Miami, much of the coastline and inlet regions are at risk for both increased frequency and persistence of flooding.

Ft. Myers, Naples, Melbourne, Satellite Beach, St. Augustine, and Daytona Beach are most at risk along the Intracoastal and river inlet regions, primarily under the Minimal Mitigation scenario for 1 hour of flooding. These regions are expected to experience more frequent flooding in the future, but not necessarily more persistent flooding. The Gulf regions of St. Petersburg, Tampa, Clearwater, Bradenton, and Panama City are not expected to cross the 52-day flooding threshold under most scenarios by 2060 due to higher elevation and a higher water level threshold for flooding.

2 Methodology

The goal of this project is to assess how localized flooding will increase in the future as a result of sea level rise by determining when a location will cross certain flooding thresholds. For the public to be able to utilize these results to make preparations and decisions, understandable and impactful flooding thresholds are chosen. The Mean Higher High Water (MHHW) level is the daily high tide highest water level averaged over multiple decades (primarily the National Tidal Datum Epoch: 1983-2001). A graphic showing Mean Higher High Water in relation to other sea levels is shown in Figure 1.

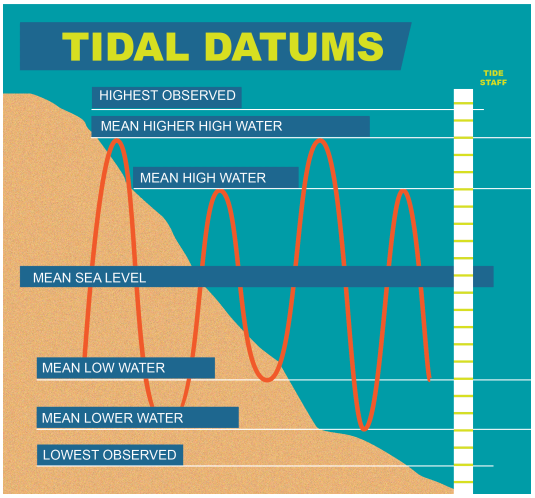

Figure 1: Tidal Datums showing daily water levels relative to Mean Sea Level. Graphic taken from https://tidesandcurrents.noaa.gov/datum-updates/ntde/.

1

Data used for this project are hourly values of feet above Mean Higher High Water (MHHW) from https://tidesandcurrents.noaa.gov/. A timeseries of hourly water levels shown in "feet above MHHW" can be seen in Figure 2 for the Virginia Key (Miami) Florida tide gauge station. A flood hour has been defined as a water level exceedance above the Mean Higher High Water line at each tide gauge station dependent on the location according to Sweet et al. (2018) (see Fig. 3). These flooding thresholds have a persuasive impact since people living in coastal regions are familiar with common tidal terms, such as *mean higher high water*, and the accompanying flooding.

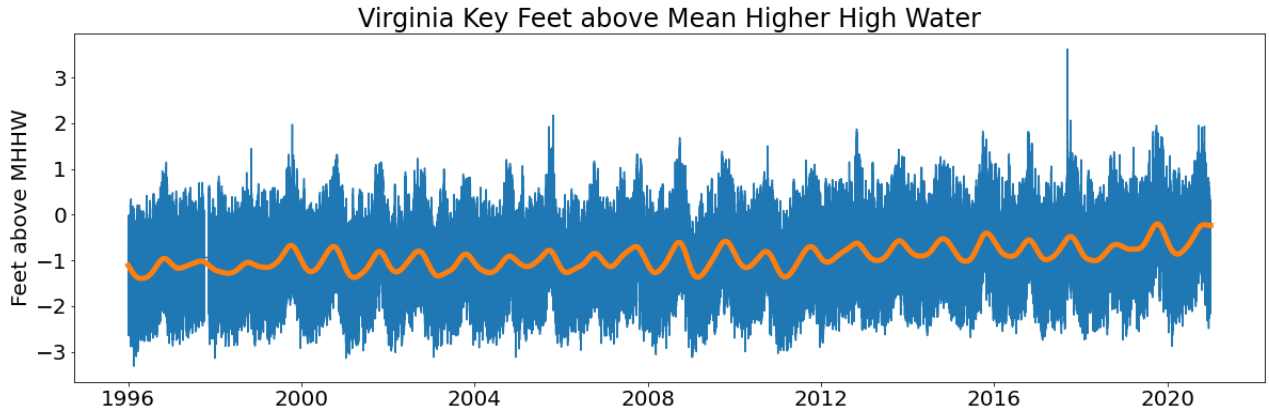

Figure 2: Hourly water level in feet above Mean Higher High water (MHHW) at the Virginia Key (Miami) FL tide gauge station. Orange line is the low-pass filtered timeseries to show the annual cycle.

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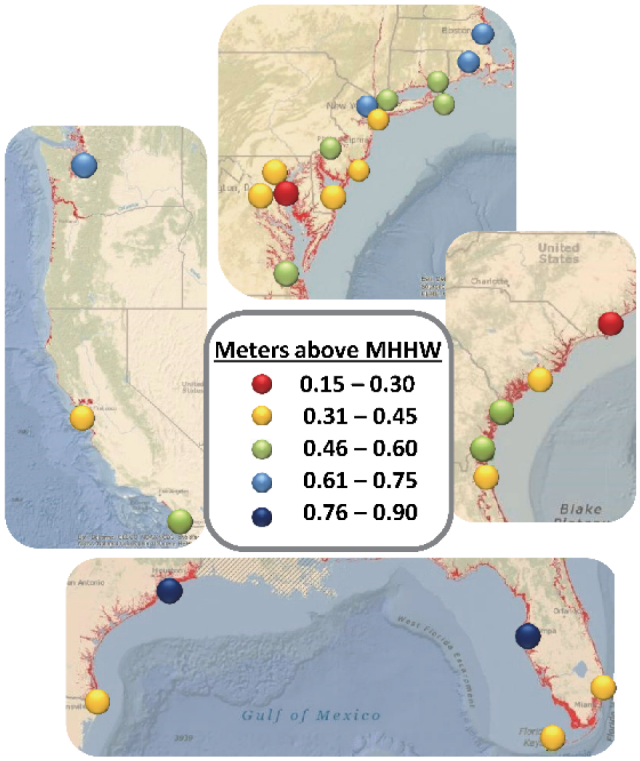

Figure 3: Long-term tide gauges with official NOAA flood thresholds for minor (high tide) flooding with exposed topography (red) mapped by the NOAA SLR Viewer. Taken from Sweet et al. (2018).

3

Two categories for a flood day are defined: 1) flooding that occurred for at least one hour, and 2) flooding that occurred for at least six hours. The six hours of flooding do not necessarily have to be consecutive to count as a "6-hour flood day", because multiple hours

of flooding at both high tides has roughly equivalent significant damage as standing flooding for six or more consecutive hours. Both categories are analyzed as they have different impact levels. One hour of flooding is often nuisance flooding and can disrupt walkways and roadways, damage certain infrastructure, and be an annoyance to drivers and pedestrians. Six hours of flooding can cause significant infrastructure damage, block roadways and walkways, create breeding grounds for mosquitoes in standing water, and pose life-threatening risks. Therefore, it is important for public use to analyze both categories for diverging impacts. Figure 4 shows the observed flooding days for the Virginia Key (Miami), FL tide gauge station for one-hour and six-hours of flooding from 1996 to 2020.

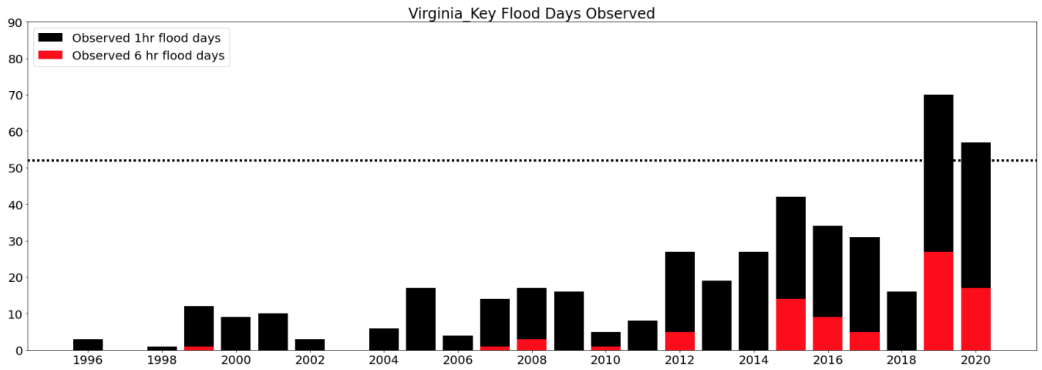

Figure 4: The number of flood days at the Virginia Key (Miami) FL tide gauge station from 1996-2020. The black bars indicate number of days when flooding occurred for at least one hour per day. Red bars indicate number of days when flooding occurred for at least six hours per day. The black dotted line indicates the 52-day per year weekly flooding threshold.

4

Projections of sea level rise have been produced by NOAA under multiple scenarios of greenhouse gas emissions and are documented in Sweet et al. (2017). We utilize the "Intermediate-High", "Intermediate", and "Intermediate-Low" projection scenarios, which correspond to 1.5 meters, 1.0 meters, and 0.5 meters of global mean sea level rise by 2100, respectively. The scenarios correspond to possible future sea levels based on different greenhouse gas emissions pathways. The graphics and following text refer to the "Intermediate-High", "Intermediate", and "Intermediate-Low" scenarios as the "Extensive Mitigation", "Limited Mitigation", and "Minimal Mitigation" scenarios, respectively, as the emissions scenarios represent the outcome of different mitigation strategies. Extensive, large-scale mit-

igation would need to take place urgently for the "Intermediate-Low" scenario to be followed. Lowered carbon dioxide and other greenhouse gas emissions would lead to following closer to the Intermediate-Low/Extensive Mitigation scenario, while moderate reduction in emissions and modest mitigation would follow the Intermediate/Limited Mitigation scenario, and continued or similar emissions to today with minimal to no mitigation would follow near to the Intermediate-High/Minimal Mitigation scenario. The regionalized sea level projections from Sweet et al. (2017) are used, which incorporate global and local factors into projections for many locations along the U.S. coast. Thus, each tide gauge location has a flooding threshold (in feet above MHHW) and sea level rise projections for each decade out to 2060 specific to its location (Fig. 5).

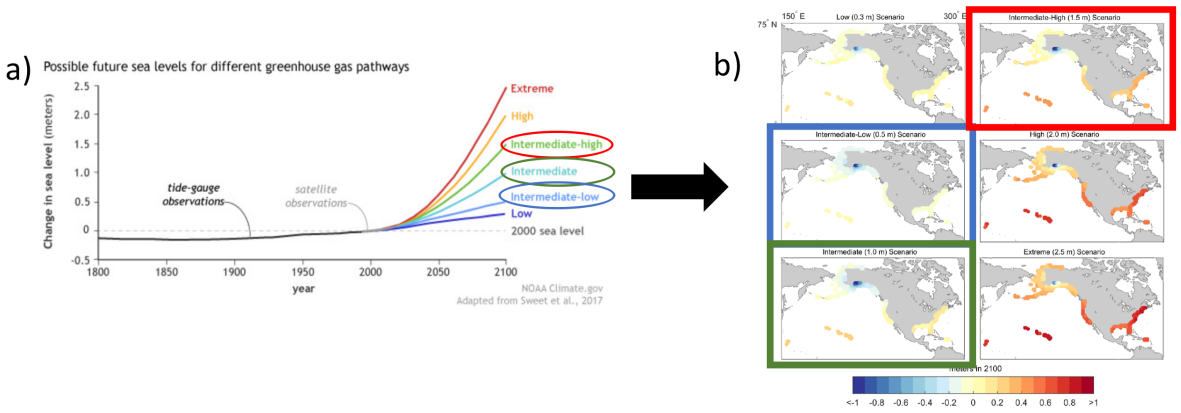

Figure 5: a) Observed sea level from tide gauges (dark gray) and satellites (light gray) from 1800-2015, with future sea level through 2100 under six possible future scenarios (colored lines). The scenarios differ based on potential future rates of greenhouse gas emissions and differences in the plausible rates of glacier and ice sheet loss. NOAA Climate.gov graph, adapted from Figure 8 in Sweet et al. (2017). b) Climate-related relative sea level change (in meters) for 2100 relative to the corresponding global mean seal level rise for that scenario. Adapted from Sweet et al. (2017).

At every tide gauge station, the regionalized NOAA projected sea level is calculated for each decade out to 2060 beginning in 2000 for each scenario. These decadal sea level projections for the three scenarios analyzed are used to calculate a regression line (line-of-best-fit). See Figure 6 for the projected sea level values for Virginia Key (Miami), FL under the Minimal Mitigation scenario for an example. The regression line process is repeated for the Minimal, Limited, and Extensive Mitigation scenarios (see Fig. 7).

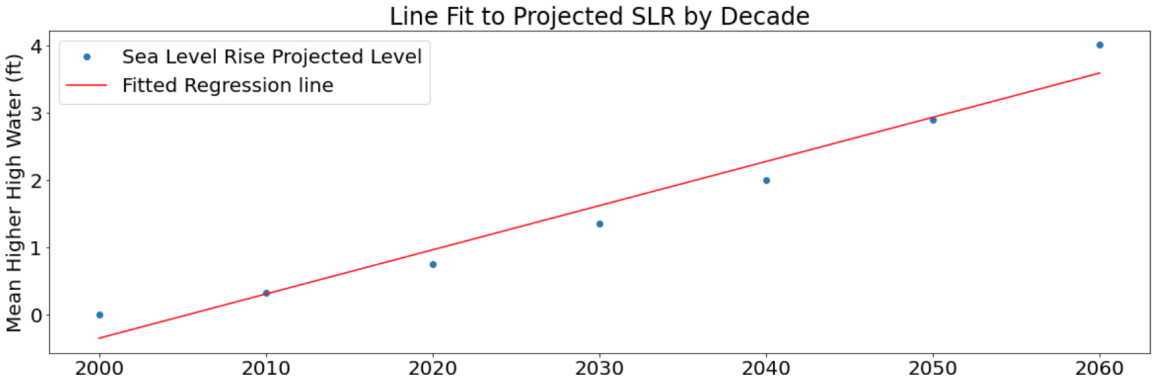

Figure 6: The red line is the regression line (line-of-best-fit) for the projected sea levels. The blue dots indicate the NOAA projected sea level for each decade from 2000 through 2060 at Virginia Key (Miami) FL in feet above Mean Higher High Water used to fit the regression line. All regression lines used have an R-squared value of .95 or higher.

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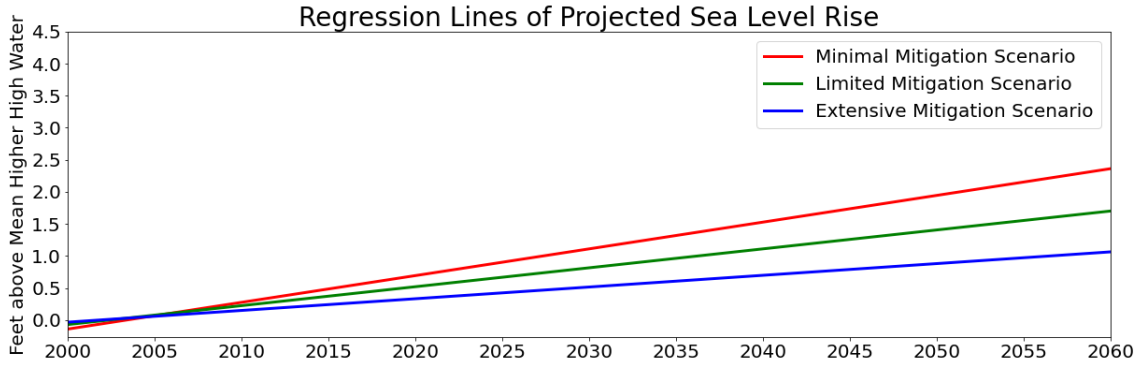

Figure 7: The regression lines (lines-of-best-fit) for the regionalized NOAA projected sea levels to 2060 (Sweet et al. 2017) for the Minimal (red), Limited (green), and Extensive (blue) Mitigation scenarios (corresponding to NOAA's Intermediate High, Intermediate, and Intermediate Low scenarios).

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For each projection scenario, there is also a low, medium and high sub-scenario, corresponding to the 17th, 50th, and 83rd percentile of the climate-related sea level projections consistent with the global mean sea level scenario. Thus, the sea level has a 17% chance of exceeding the high sub-scenario, a 50% chance of exceeding the medium sub-scenario, and a 83% chance of exceeding the low sub-scenario. The scenario values are a summation of the climate-related sea level with a linear non-climatic background relative sea level (RSL) trend applied (Sweet et al. 2017) (Fig. 8).

For the future projections, the hourly MHHW timeseries is detrended then sliced from 2010 - 2020. The decadal chunk is added to the regression line for each future decade,

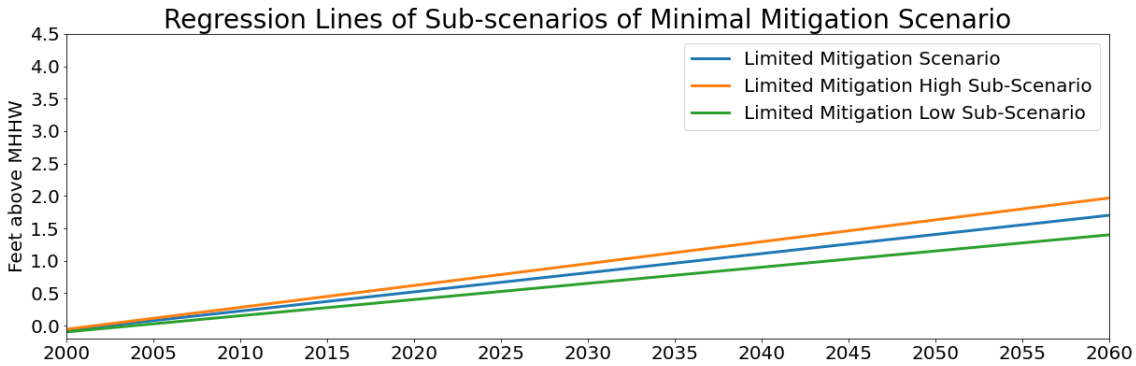

Figure 8: The regression lines (lines-of-best-fit) for the regionalized NOAA projected sea levels to 2060 (Sweet et al. 2017) for the high, medium, and low sub-scenarios for the Limited Mitigation projection scenario. The sub-scenarios correspond to the 17th, 50th, and 83rd percentile of the climate-related sea level projections consistent with the global mean sea level scenario. The scenario values are a summation of the climate-related sea level with a linear non-climatic background relative sea level (RSL) trend applied (Sweet et al. 2017),

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resulting in an hourly timeseries of feet above MHHW projected out to 2060. The same process is repeated for each scenario and sub-scenario at each tide gauge location analyzed and can be seen in Figure 9.

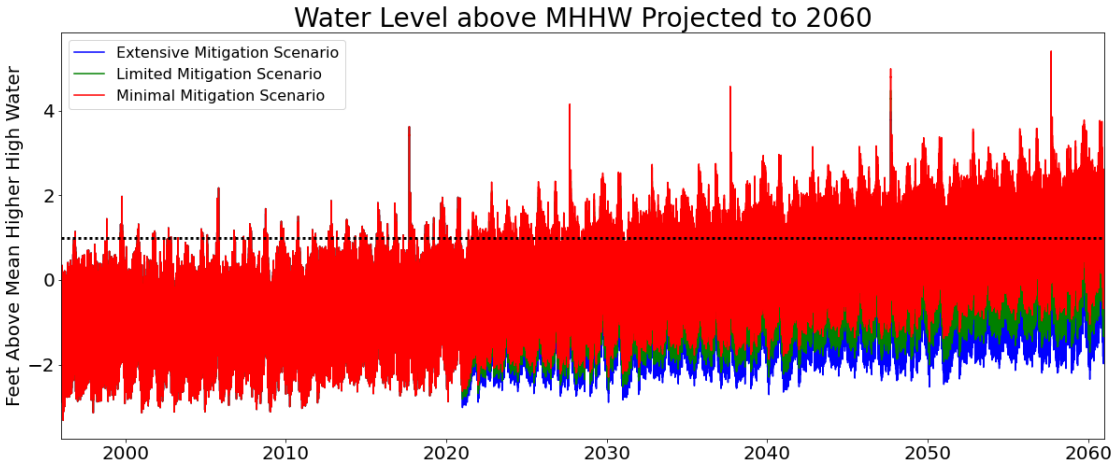

Figure 9: A projection of hourly MHHW exceedance out to 2060 at Virginia Key (Miami) FL for the Minimal (blue), Limited (green), and Extensive Mitigation (red) Scenarios. The projected MHHW is calculated by adding the detrended observed MHHW from 2010-2020 to the regression line (see Fig. 7) for each scenario. The black dotted line indicates one ft above MHHW, which is the flooding threshold at the Virginia Key tide gauge station. Any hour at or above 1ft above MHHW is considered a flood hour at this tide gauge station.

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The number of flood days per year is counted for the 1- hour and 6- hours flooding

categories. See Figures 10 and 11 for the annual flood days in Virginia Key (Miami), FL. The black dotted line indicates the 52 days per year threshold after which a location will experience more than 52 days per year of flooding. In other words, 52 days of flooding per year averages to at least once a week of flooding, but most flooding likely occurs within a few months during seasons with higher tides. The black bars are the observed flood days in the past, while the red, green, and blue envelopes correspond to the Minimal, Limited, and Extensive projection scenarios respectively, with the boundaries of the envelopes defined by the 17th (upper) and 83rd (lower) percentile sub-scenarios. Thus, the averaging of the 50th and 83rd percentile lines results shows when there is a roughly 70% chance that the location will cross the weekly flooding threshold under each scenario for both flooding categories.

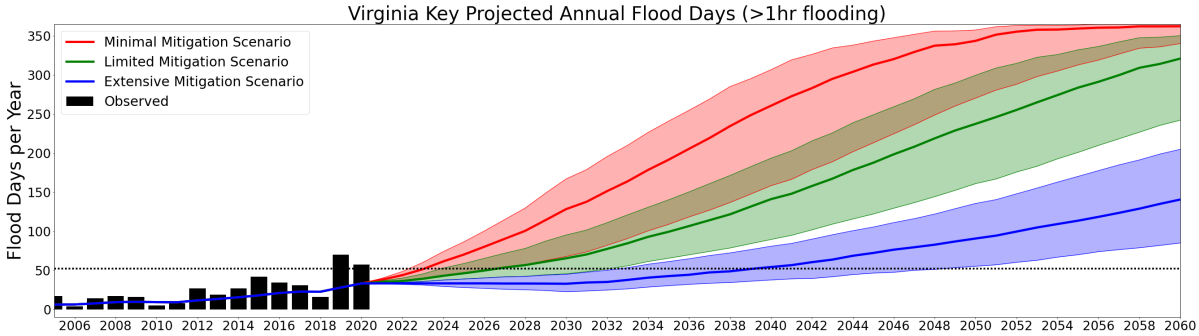

Figure 10: The number of flood days per year for the 1 hour flooding category at Virginia Key (Miami), FL. A flood day is defined as 1ft or more above MHHW for at least one hour per day. The black dotted line indicates the 52 days per year threshold after which a location will experience more than 52 days per year of flooding. The black bars are the observed flood days in the past, while the red, green, and blue envelopes correspond to the Minimal, Limited, and Extensive projection scenarios respectively, with the boundaries of the envelopes defined by the 17th (upper) and 83rd (lower) percentile sub-scenarios.

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These flood projections are made for each tide gauge station assessed, but most people are concerned about flooding their individual neighborhood, not at the tide gauge station. To localize the impacts of the projected flooding, the projections are used to assess when communities will cross the thresholds.

Digital Elevation Model (DEM) data derived from LiDAR elevation data are used for the topographic maps taken from

https://coast.noaa.gov/dataviewer. The data are referenced vertically to the North

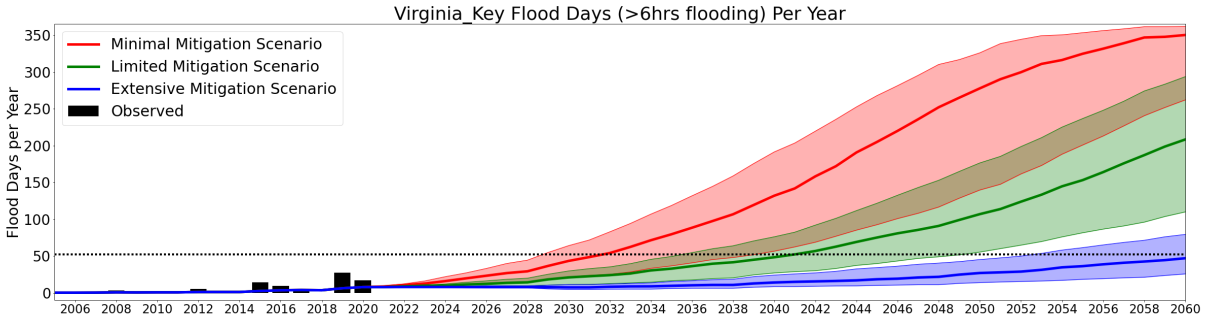


Figure 11: Same as the Fig. 10 but for at least six hours of flooding per day.

11

American Vertical Datum of 1988 (NAVD88) with vertical units of meters and horizontally to the North American Datum of 1983 (NAD83). The resolution of the data are approximately 5 meters. The flooding projections are calculated at scaled increasing elevations above sea level. All tide gauges are assumed to be at sea level with 0ft elevation. At Virginia Key (Miami), FL, for example, a flood at the tide gauge is defined at 1ft above MHHW (Sweet et al. 2018), meaning an area at 1ft elevation would flood at 2ft above MHHW (1ft for elevation and 1ft for the flooding threshold). The number of flood days are counted at all elevations within each city. The mean of the 50th and 83rd percentile sub-scenarios is used to calculate the year when there will be 70% chance of crossing the weekly flooding threshold. Figure 12 shows when regions of Miami-Dade County have a 70% chance of weekly flooding or more for the Minimal Mitigation projection scenario for 1 hour of flooding per day. The same process is repeated for each city analyzed, using the specified flooding threshold, tide gauge and elevation maps for each community.

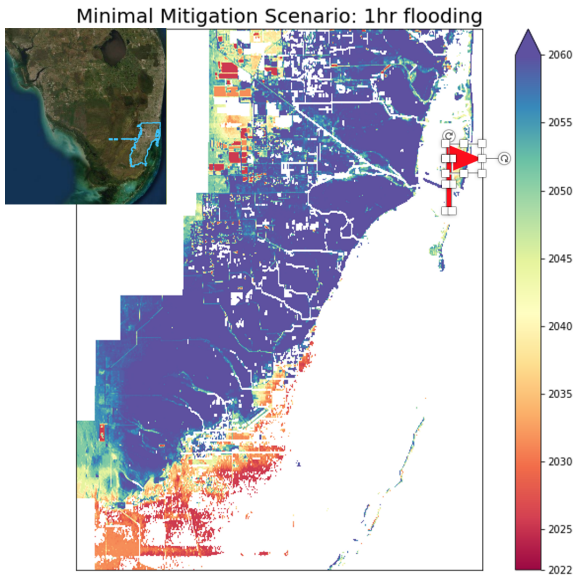


Figure 12: A map of Miami-Dade County showing when a place has a 70% chance of flooding for at least 52 days per year. These projections are made under the Minimal Mitigation (Intermediate-High) Scenario with a daily flooding threshold of 1 hour flooding per day. Purple areas indicate regions which are not expected to cross the threshold by 2060. Maps are made using projection data at the Virginia Key, FL tide gauge station and Miami-Dade County LiDAR elevation data. The blue highlighted region in the inset map in the upper left corner shows Miami-Dade County. The bottom of the red flag shows the corresponding tide gauge location.

3 Cities

When will a community have a 70% chance of flooding 52 days per year?

Each of the following cities has been assessed to answer the above question under three sea level projection scenarios (Extensive, Limited, and Minimal Mitigation) for both 1 hour and 6 hours of flooding, as 6 hours of flooding presents much higher risk and damage. Since there are limited tide gauge stations on the Florida coast with regionalized sea level rise projections from NOAA, multiple cities sometimes use the same tide gauge data. Each of the following cities will have the following specified and/or included:

-Tide gauge location used for assessment

-Flooding threshold (feet above MHHW) for the tide gauge according to Sweet et al. (2018)

-Projected Flood Days per Year for each tide gauge station

-A map showing when the region has a 70% of flooding for 1 hour or 6 hours of flooding for the Extensive, Limited, and Minimal Mitigation scenarios (when applicable*).

*Note that many regions do not cross the threshold under some or all scenarios before 2060 due primarily to elevation, tidal flow, and consequences from carbon emissions. Therefore, only those scenarios in which a region has large areas at risk of crossing the flooding threshold before 2060 are shown. However, a region that is not expected to cross the threshold by 2060 can still be at risk of less frequent flooding. All graphics included in this report as well as 3 scenarios for the 1-hour and 6-hour flooding categories for the cities analyzed are available in the associated Google Drive.

The tide gauge locations have been indicated by a red flag either on the inset maps or the maps of the cities. The maps showing estimates for the year in which the flooding thresholds will be crossed are calculated using the water levels at the tide gauge station, and the estimates are based solely on the elevation of an area. Uncertainty increases moving away from the tide gauge location, as other factors such as local circulation, terrain, and land use can play a role in the flooding in an area.

3.1 Miami

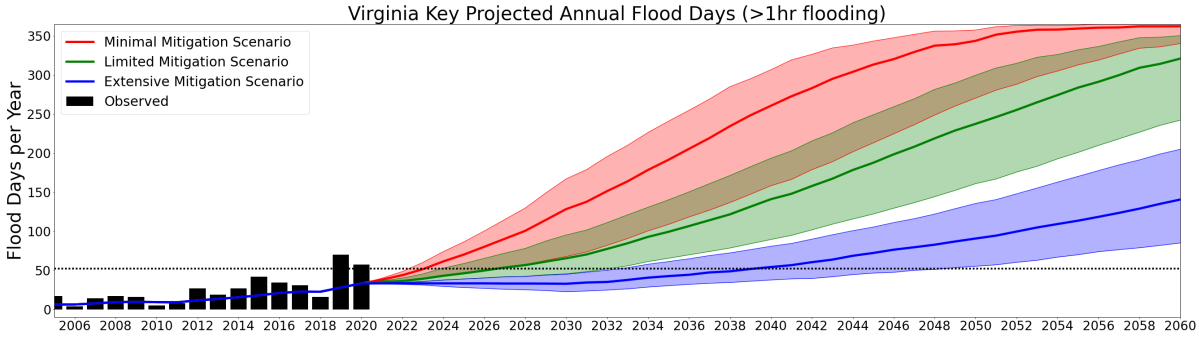
Miami uses data for the entirety of Miami-Dade County. Under all three mitigation scenarios, Miami crosses the weekly flooding threshold by 2060 for 1 hour of flooding. Under the Minimal and Limited Mitigation scenarios, Miami crosses the weekly flooding threshold for 6 hours of flooding per day by 2060. Under the Minimal Mitigation scenario for both 1 hour and 6 hours of flooding, Miami reaches close to daily flooding, which would pose significant hazards and risks for pedestrians, drivers, and infrastructure.

Many areas of Miami-Dade are low-lying even though they are far from the coast. For example, much of Northwest Miami-Dade lies within a few feet of sea level, and thus is projected to cross multiple flooding threshold in this decade. These projections are supported by Miami-Dade County's Flood Zone assessments, which indicate much of Northwest Miami-

Dade as flood zones (https://mdc.maps.arcgis.com/home/index.html). The southeastern portion of Miami-Dade located along Biscayne Bay is also at high risk of crossing multiple flooding thresholds by the end of this decade.

Tide gauge location: Virginia Key, FL. See red flag in Fig. 12

Flooding threshold: 1 foot above MHHW



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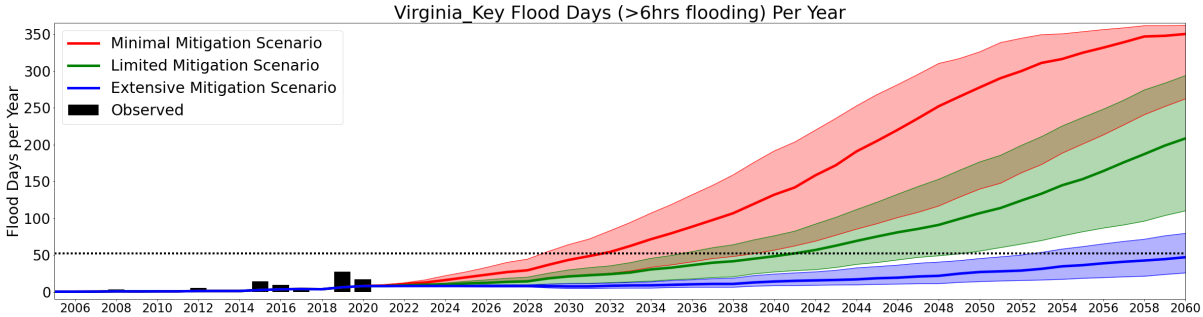

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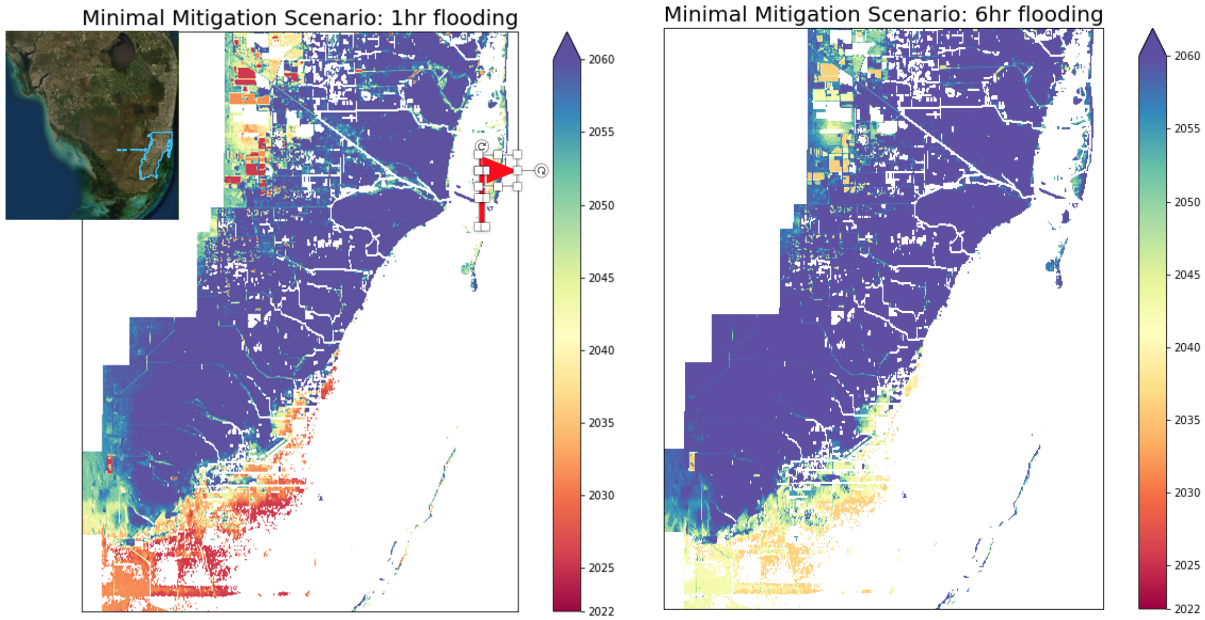
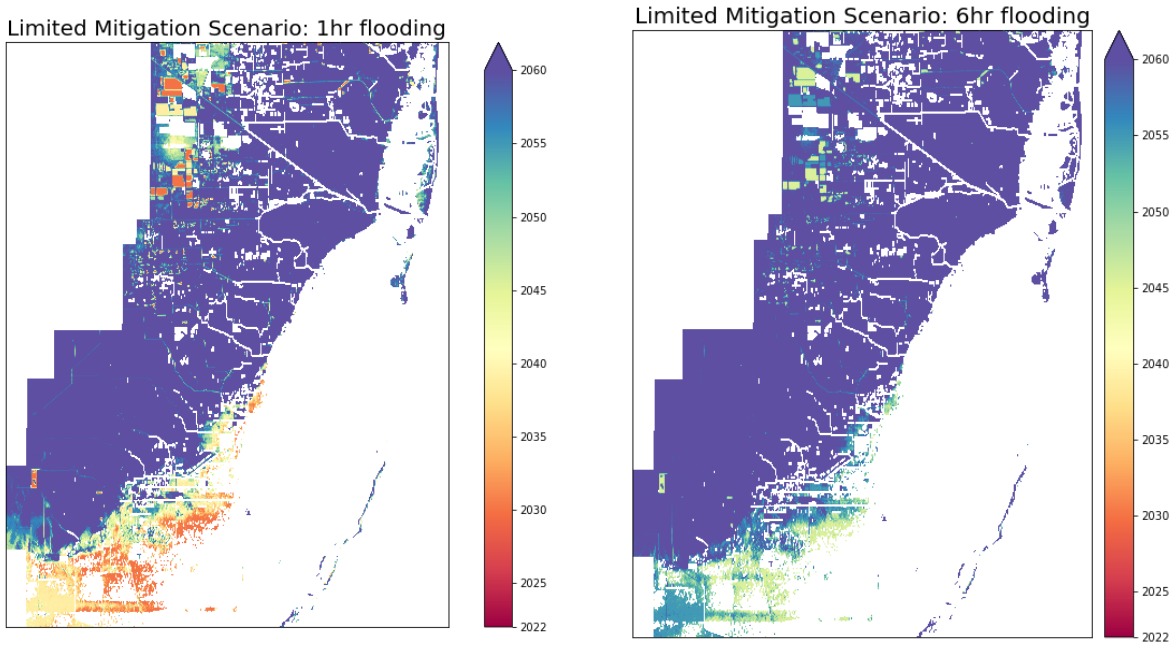
When will Miami-Dade have a 70% chance of flooding 52 days per year?





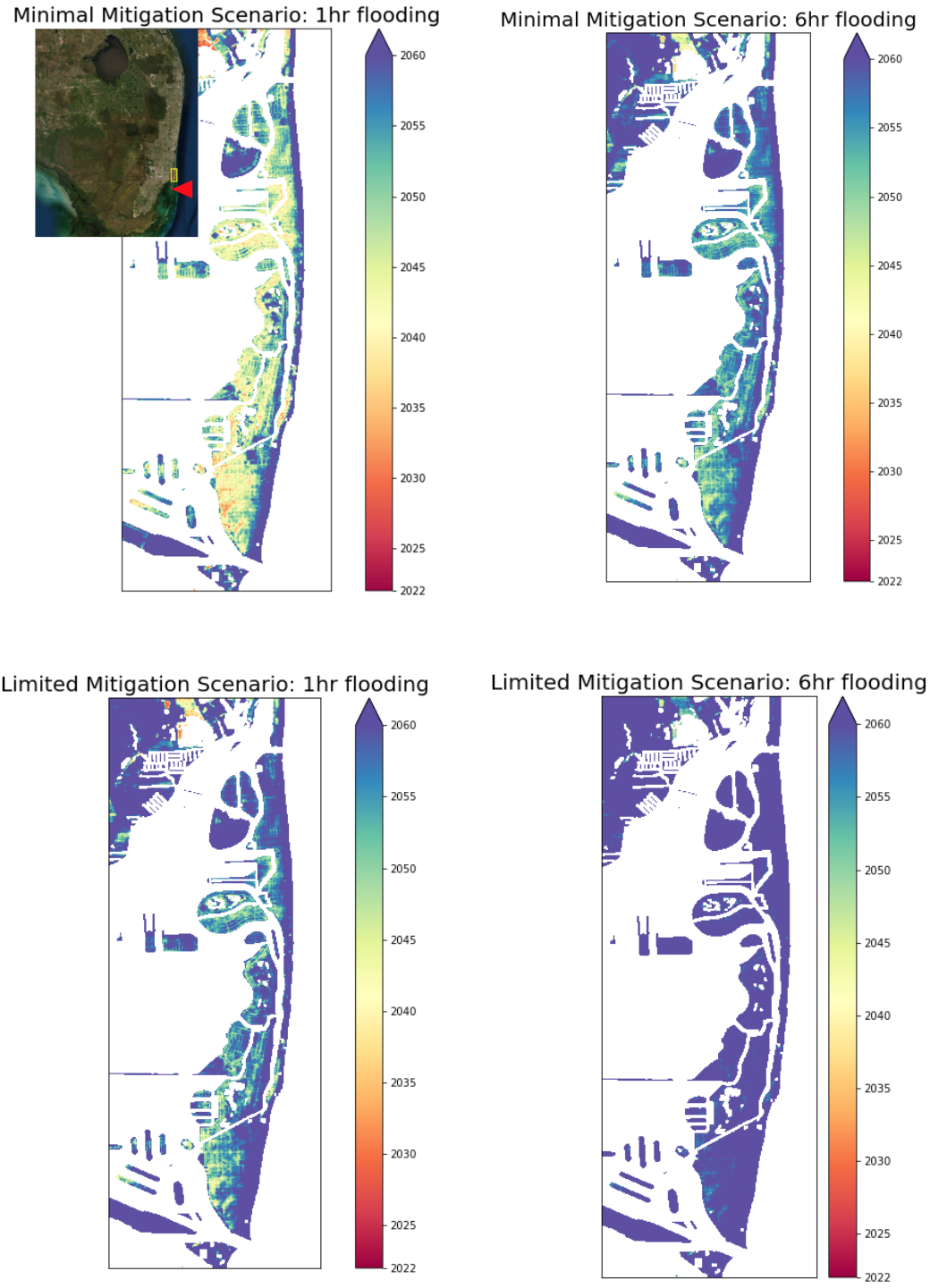
3.2 Miami Beach

Miami Beach uses the same data as for Miami-Dade County. Miami Beach is primarily low-lying with lower elevations on the bay-side (western) than on the ocean-side. Therefore, more flooding is projected to occur on the bay-side regions of Miami Beach while the sandy beaches help to protect the ocean-side of the city from crossing the flooding thresholds.

Tide gauge location: Virginia Key, FL. See red flag in Fig. 12

Flooding threshold: 1 foot above MHHW

When will Miami Beach have a 70% chance of flooding 52 days per year?



3.3 Ft. Lauderdale/ Hollywood

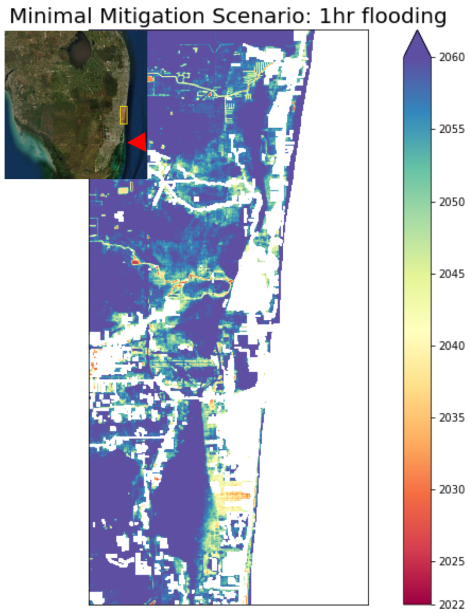
The Ft. Lauderdale and Hollywood region is located along the coast of Southeast Florida with multiple inlets and rivers surrounded by very low-lying areas. Much of the inlet/river areas at or near sea level are expected to cross the 52-day threshold for 1 hour and 6 hours of flooding under the Minimal and Limited Mitigation scenarios by 2060. The Intracoastal area is also at risk of crossing the threshold for 1 hour and 6 hours under the Minimal Mitigation scenarios.

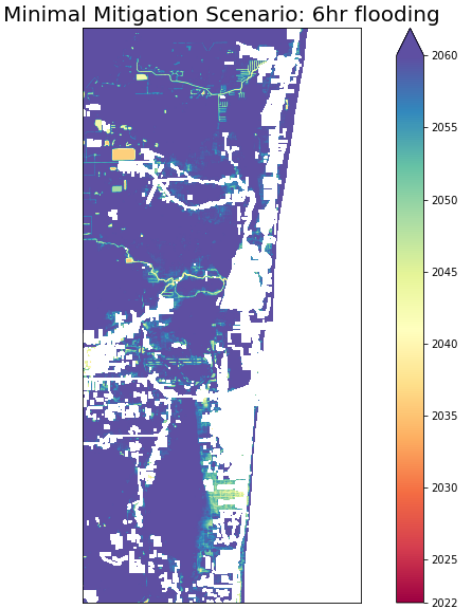
Note that the tide gauge data and projections used for these estimates are at Virginia Key (Miami) indicated by the red pointer in the top left corner of the figure below, since this is the closest tide gauge with regionalized sea level rise projections. Uncertainty in the projections increases the farther a location is from the tide gauge station.

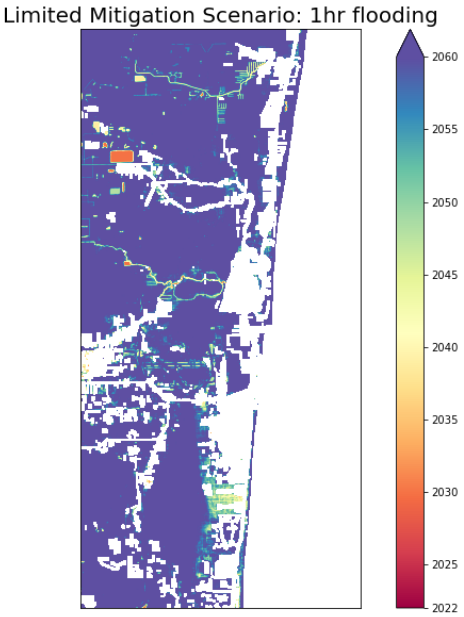
Tide gauge location: Virginia Key, FL. See red flag in Fig. 12 or indicator flag in top left figure below.

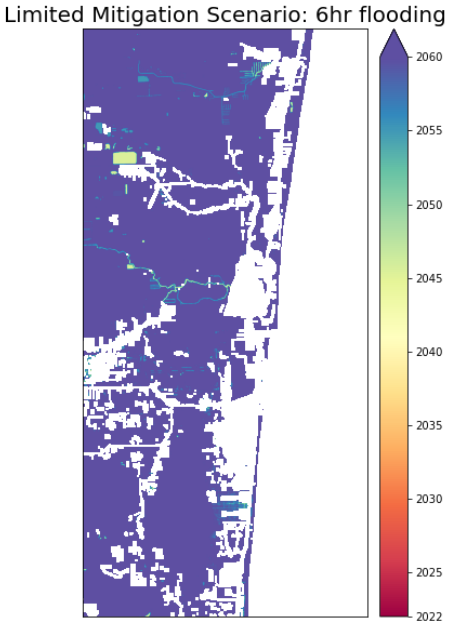
Flooding threshold: 1 foot above MHHW

When will Ft. Lauderdale/ Hollywood have a 70% chance of flooding 52 days per year?









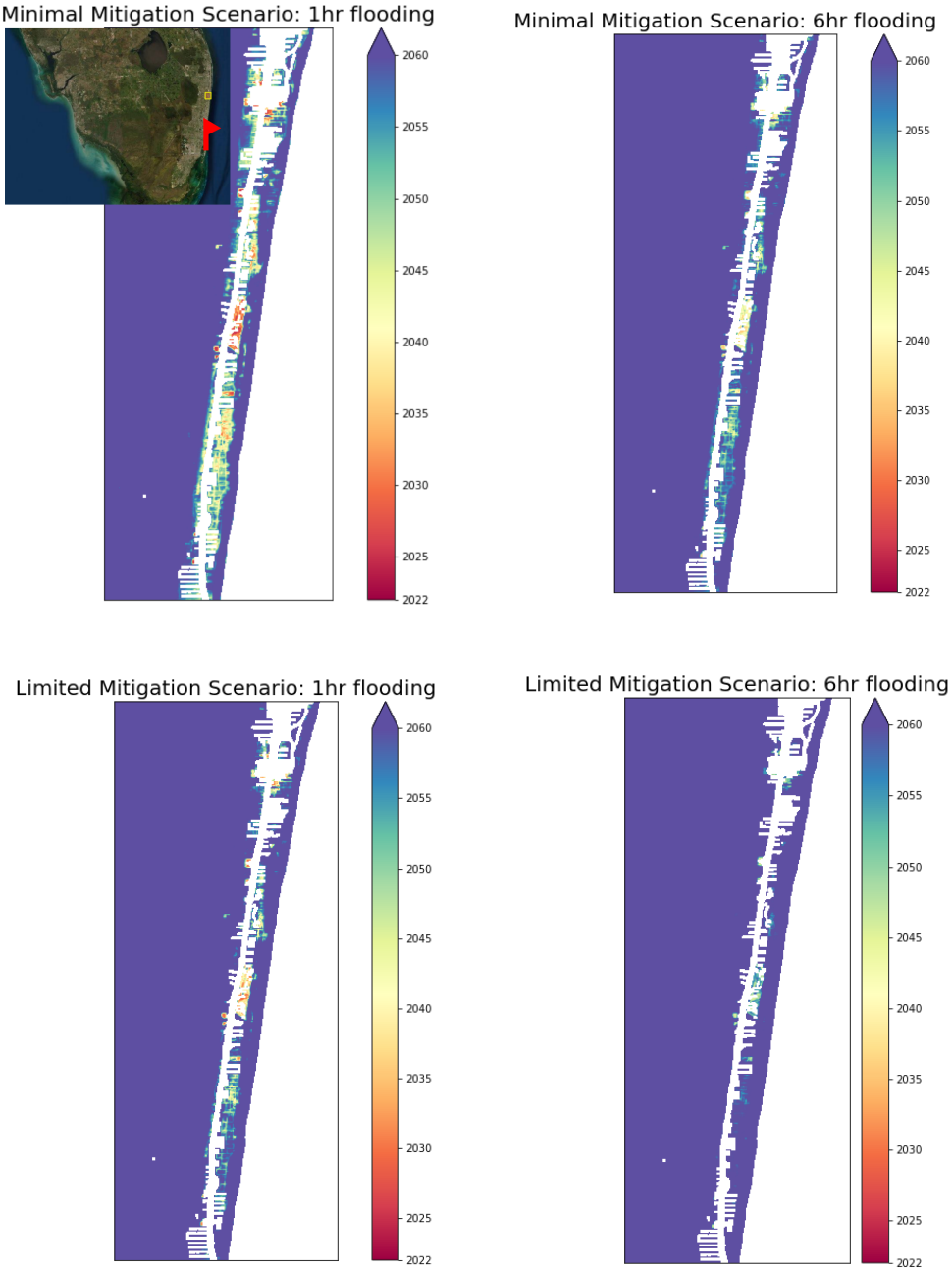
3.4 Delray Beach

Delray Beach is located on the coast of Southeast Florida. The inland regions of Delray have high elevations that likely won't experience much flooding in the coming decades. However, the low-lying coastal beach areas, especially along the Intracoastal are expected to cross the 52-day threshold for 1 hour and 6 hours of flooding under both the Minimal and Limited Mitigation scenarios.

Tide gauge location: Virginia Key, FL. See red flag in Fig. 12 or indicator flag in top left figure below.

Flooding threshold: 1 foot above MHHW

When will Delray Beach have a 70% chance of flooding 52 days per year?



3.5 Key West

Under all three projection scenarios, Key West is expected to cross the 52-day threshold by 2050 for 1 hour flooding, and Key West is expected to cross the 52-day threshold by

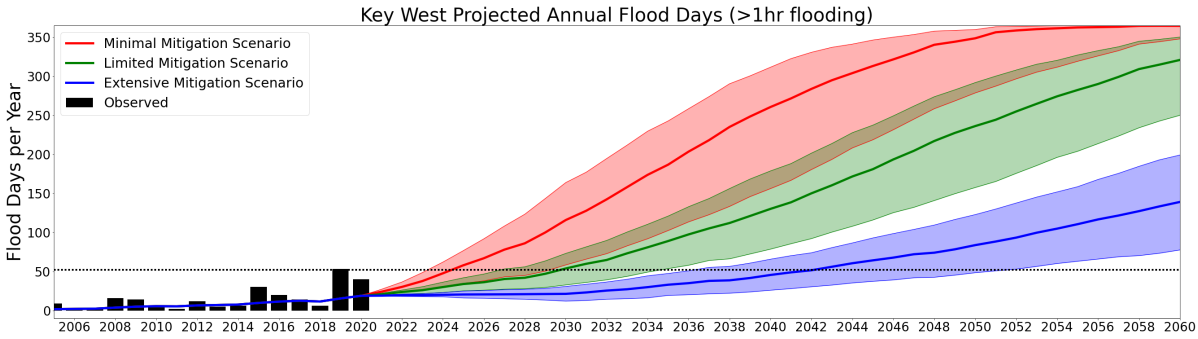
2060 for 6 hours of flooding, with the exception of the Extensive Mitigation scenario. Under the Minimal and Limited Mitigation scenarios, Key West is expected to have at least 1 hour flooding per day almost daily; under the Extensive Mitigation scenario, Key West is expected to have 1 hour flooding about half the days of the year.

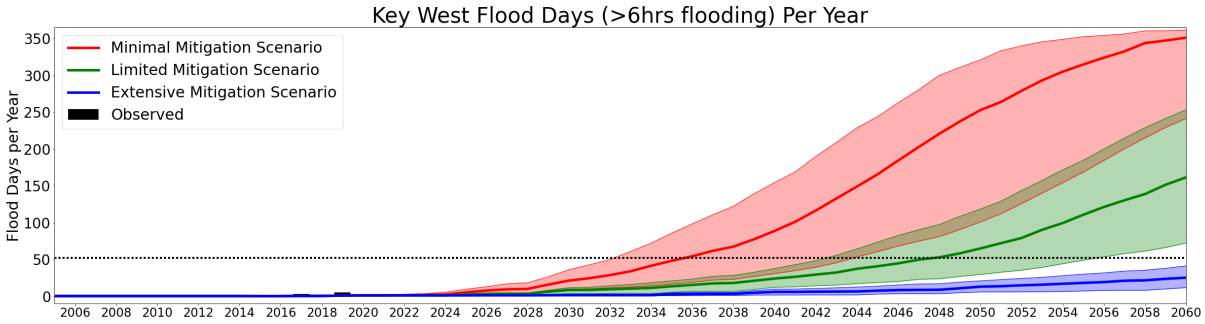
Key West is predominantly low-lying with much of the elevation below 5ft. Therefore, most of Key West is expected to experience frequent and persistent flooding under all projection scenarios, except for the slightly higher elevation regions in the Downtown region. Even under the Extensive Mitigation scenario, portions of Key West are expected to have at least 6 hours of flooding each week by 2060. This will pose significant hazards to people and infrastructure.

Key West is a good example of the necessity of extensive mitigation and adaptation in the near future. Under the Minimal Mitigation scenario, almost all of Key West except Downtown has a 70% chance of weekly 1 hour flooding in the next few decades. However, under the Extensive Mitigation scenarios, much less of Key West is at risk.

Tide gauge location: Key West, FL. See red flag in the top left figure below.

Flooding threshold: 1 foot above MHHW




Key West Flood Days (>6hrs flooding) Per Year
Minimal Mitigation Scenario
Limited Mitigation Scenario
Extensive Mitigation Scenario
Observed
Flood Days per Year
0
50
100
150
200
250
300
350
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
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2032
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2036
2038
2040
2042
2044
2046
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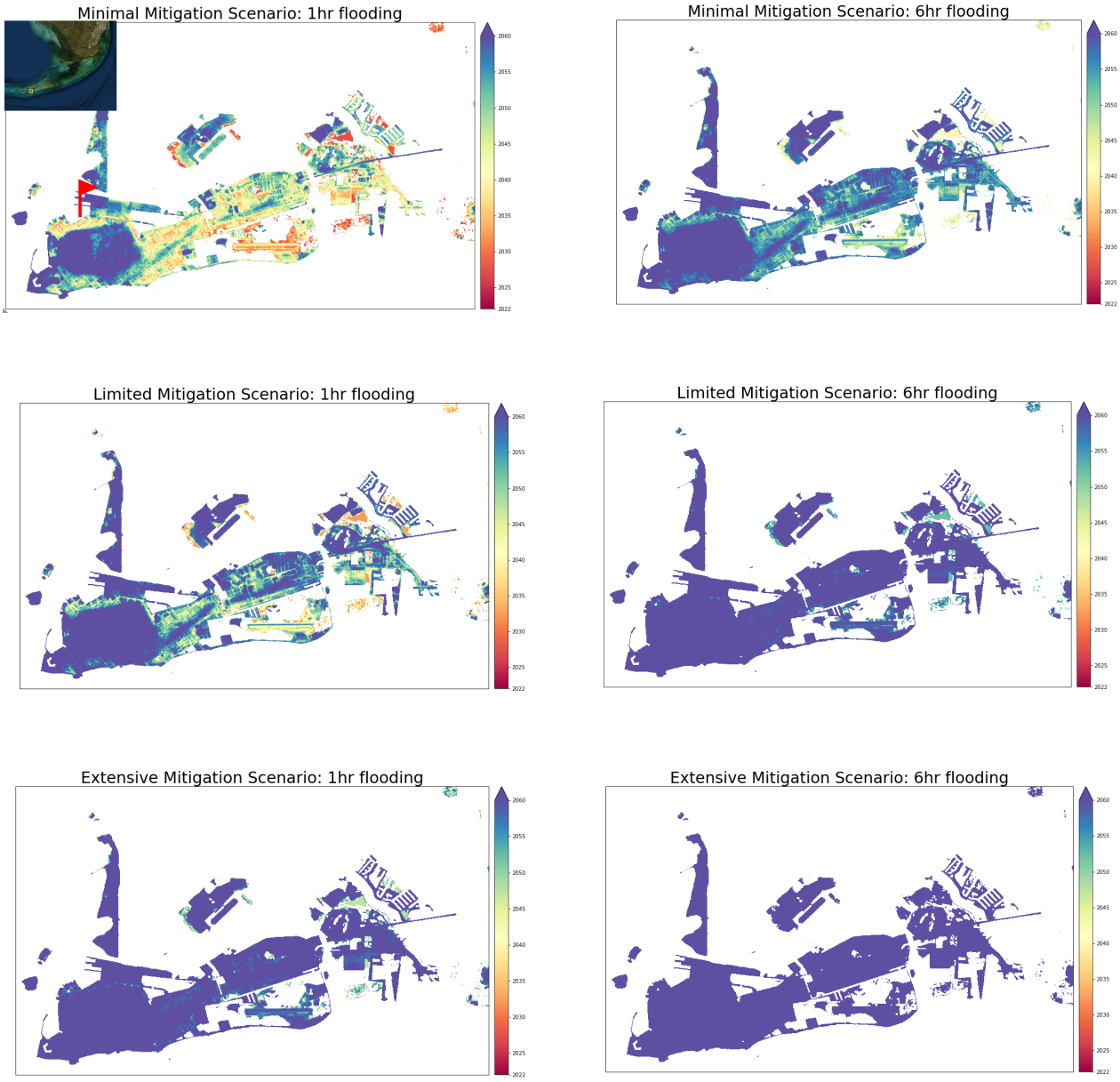
2050
2052
2054
2056
2058
2060

When will Key West have a 70% chance of flooding 52 days per year?



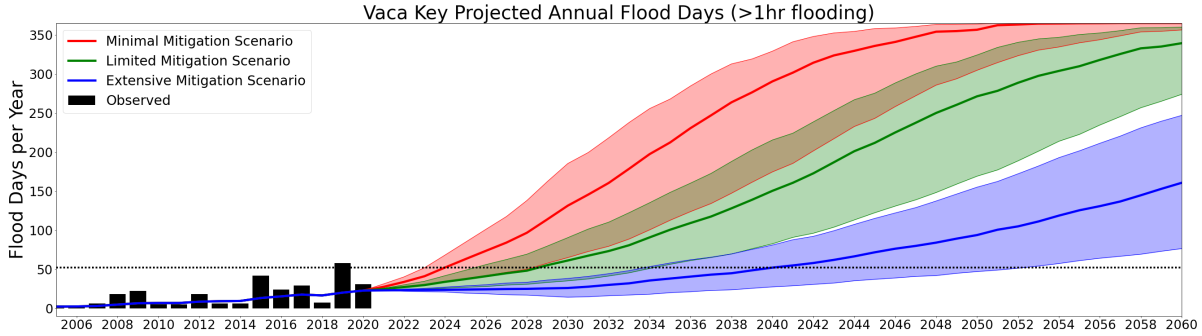
3.6 Vaca Key

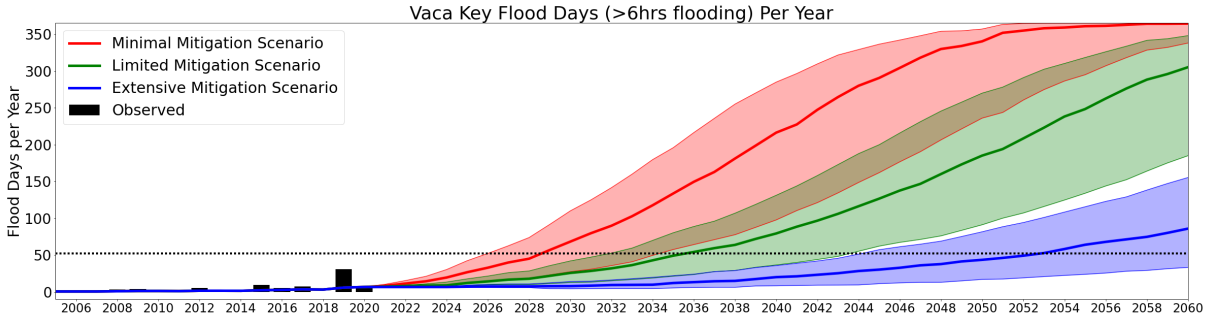
Vaca Key has similar topography and flooding projections as Key West since it is also predominantly low-lying with most elevation at 3ft or below. Therefore, much of Vaca Key and the neighboring, more populous key, Marathon, are expected to see frequent and

persistent flooding. The tide gauge is also located on the Florida Bay/ Gulf of Mexico side of the Key, contrasting the Miami and nearby East Coast cities which have Atlantic facing tide gauges. Despite the body of water in which the tide gauge sits, sea level rise is expected to dramatically affect Vaca Key and Marathon, particularly the inlet regions. This results in the 52-day threshold being crossed by 2060 or earlier under all three projection scenarios for 1 hour and 6 hours of flooding. Following the Minimal Mitigation scenario for 6 hours of flooding, Vaca Key has a high likelihood of experiencing at least 6 hours of flooding every day, which would pose significant hazards to people and infrastructure. Vaca Key, like Key West, shows the importance of mitigating and adapting to rising seas quickly.

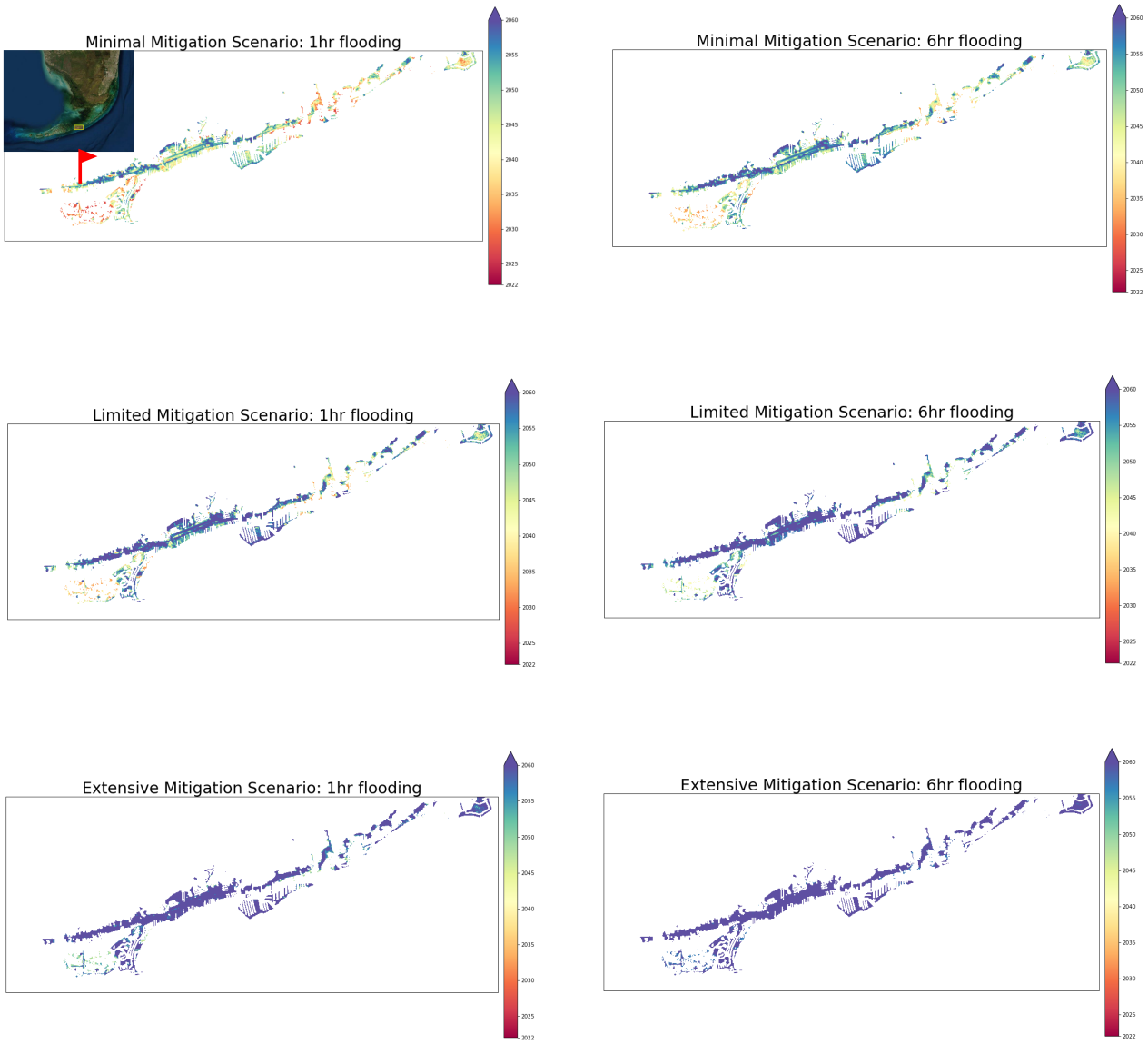
Tide gauge location: Vaca Key, FL. See red flag in the top left figure below.

Flooding threshold: 1 foot above MHHW





When will Vaca Key have a 70% chance of flooding 52 days per year?



3.7 Naples

Under the Minimal and Limited Mitigation scenarios, Naples will has at least a 70% chance of crossing the flooding threshold for 1 hour flooding per day, with almost daily 1 hour flooding under the Minimal Mitigation scenario. However, only under the Minimal Mitigation scenario does Naples cross the threshold for 6 hours of flooding. Naples has not

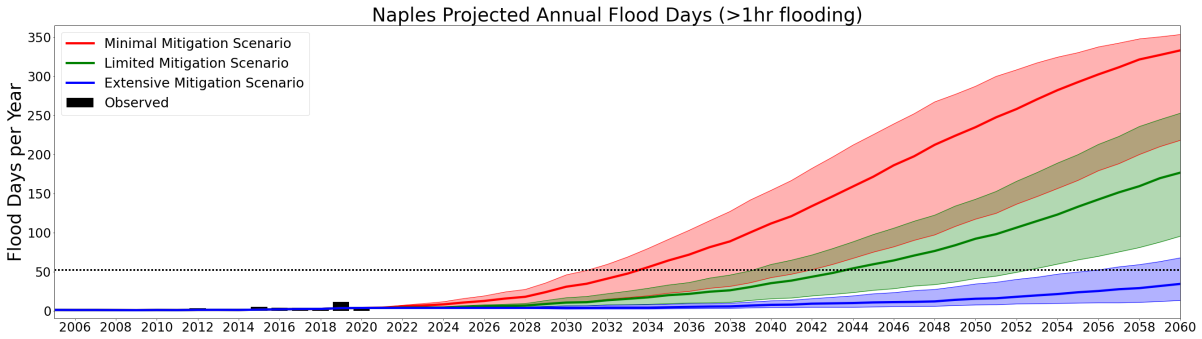
historically had many days of flooding, with almost no days have at least 6 hours of flooding. However, due to sea level rise, Naples may see frequent, but not necessarily persistent flooding in the coming decades.

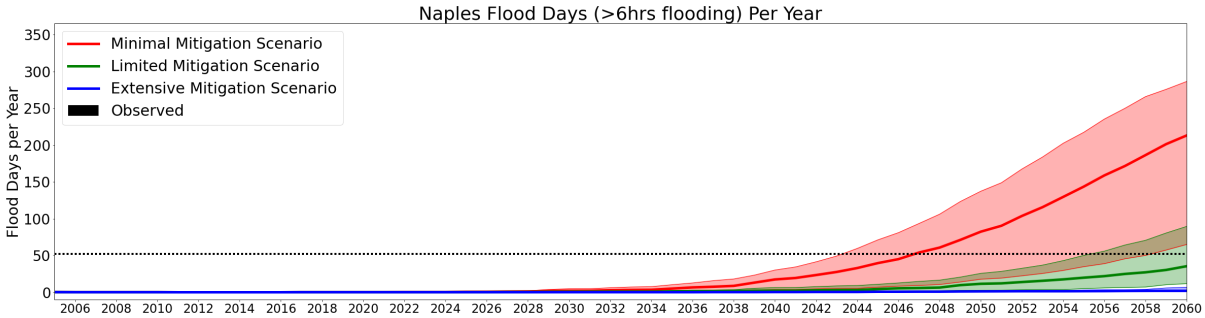
Naples has its most low-lying areas in the southern region, and thus the southern coastal areas are the most at risk for flooding. However, under the Limited Mitigation Scenario, little to no area in Naples is expected to cross the 52-day flooding threshold by 2060.

The flooding threshold of 1.5ft above MHHW for Naples was chosen as a weighted mean between two regionalized locations analyzed, St. Petersburg and Key West.

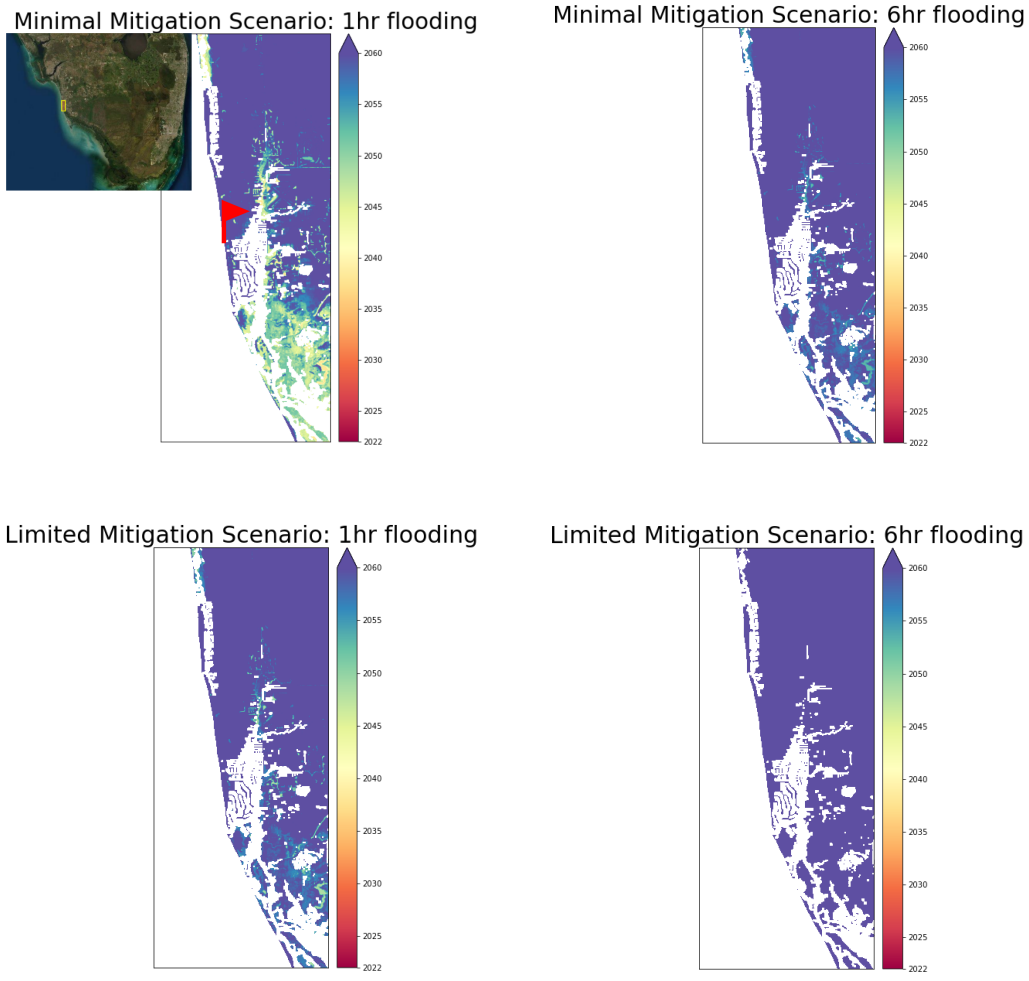
Tide gauge location: Naples, FL. See red flag in the top left figure below.

Flooding threshold: 1.5 feet above MHHW





When will Naples have a 70% chance of flooding 52 days per year?



3.8 Fort Myers

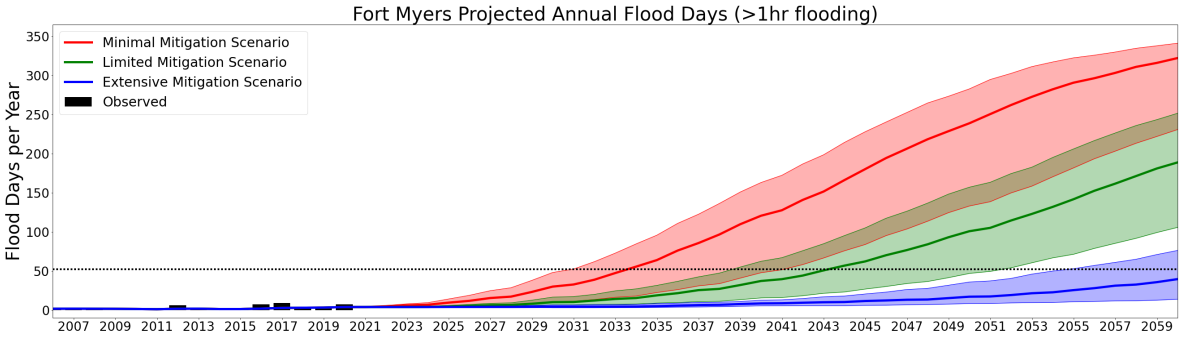
Fort Myers is expected to cross the 52-day flooding threshold for 1 hour of flooding under both the Minimal and Limited Mitigation scenarios by 2060, and cross the 6-hour flooding threshold under the Minimal Mitigation scenario. Similar to Naples, Fort Myers has not historically seen many 1-hour or 6-hour flooding days, but due to sea level rise, the area will see an increase in both categories unless thee is extensive mitigation.

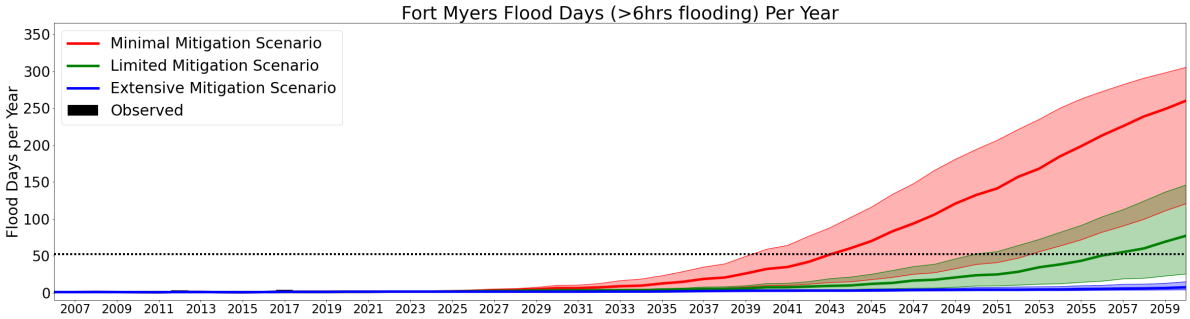
The maps of Fort Myers also include the surrounding low-lying areas of Sanibel Island, Pine Island, and Cape Coral. Fort Myers is located on the southern side of the river, south of

the red flag tide gauge indicator. The city of Fort Myers is not expected to cross the flooding threshold for 1 hour or 6 hours under any Mitigation scenario by 2060, but the islands and nearby coastal regions are at higher risk.

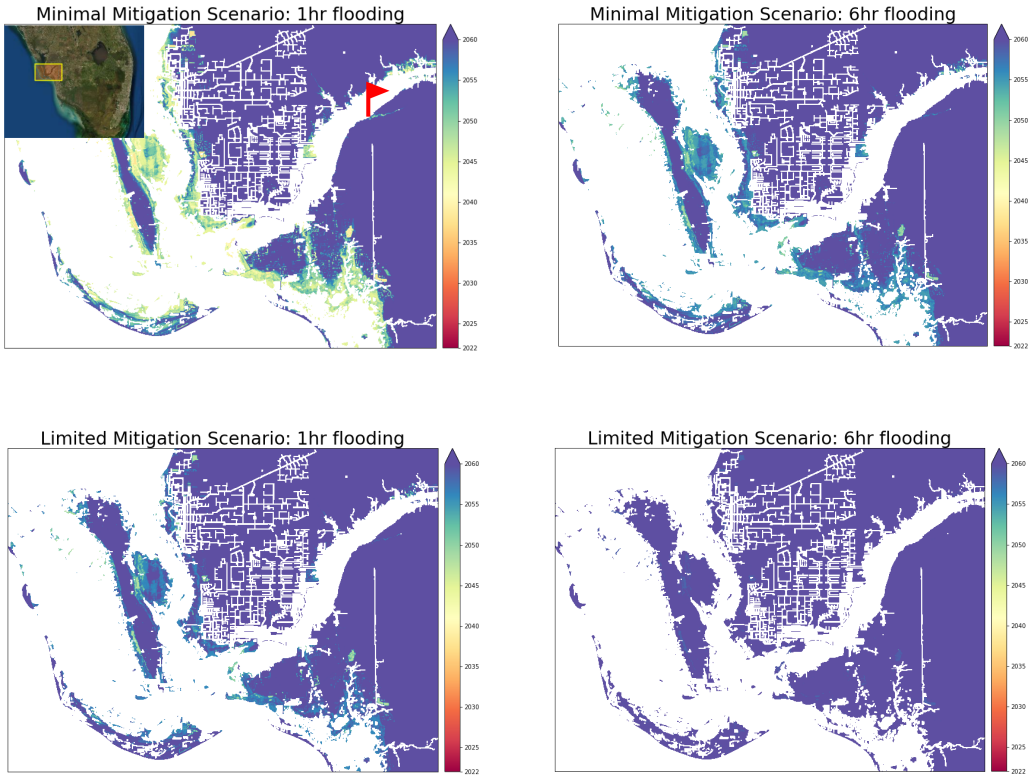
Tide gauge location: Fort Myers, FL. See red flag in the top left figure below.

Flooding threshold: 1.5 feet above MHHW





When will Fort Myers have a 70% chance of flooding 52 days per year?



3.9 St. Augustine

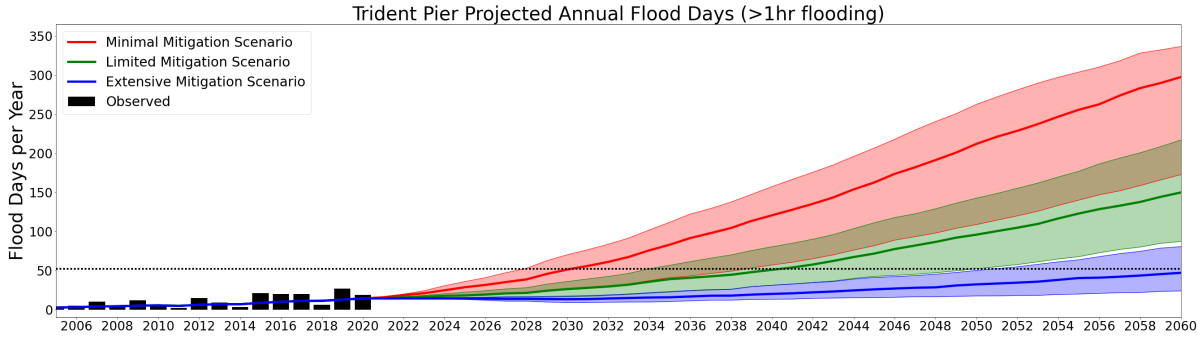
The Trident Pier tide gauge station in Port Canaveral is the nearest available tide gauge station to St. Augustine, Melbourne, Satellite Beach, and Daytona Beach with regionalized sea level rise projection scenarios. Flooding at this location is expected to cross the 1 hour weekly threshold by 2060 under the Minimal and Limited Mitigation scenarios, while the 6-hour flooding days may not cross the threshold under any scenario by 2060. This implies that Trident Pier and the surrounding areas could see frequent flooding, but not persistent flooding. This is also reflected in the higher number of historical 1-hour flooding days than 6-hour flooding days, which means flooding is likely a nuisance but not a serious hazard.

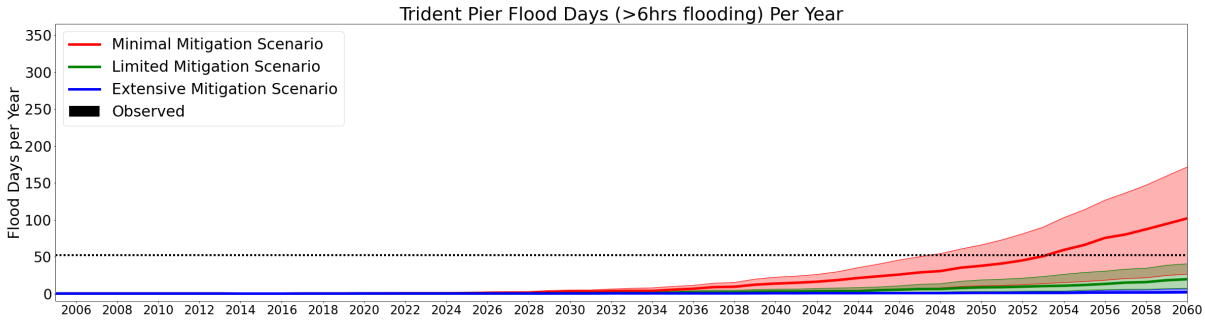
The most at-risk areas of St. Augustine are located along the Intracoastal. The inlet of St. Augustine allows water flow into the mainland region, resulting in some of the Intracoastal

area to be projected to cross the weekly flooding threshold of 1 hour flooding under the Minimal Mitigation scenario in the next few decades. However, most of the Intracoastal region is not expected to cross the threshold for 6 hours of flooding.

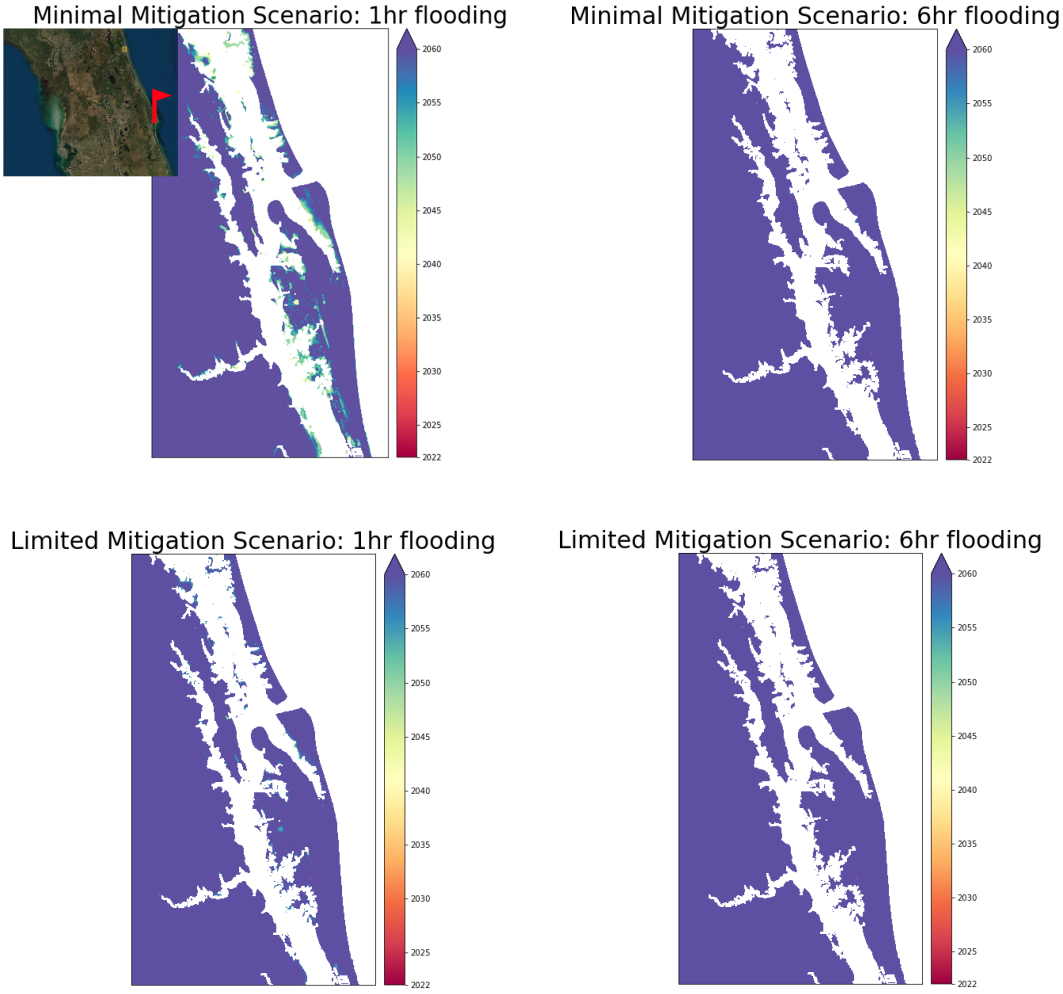
Tide gauge location: Trident Pier, FL. See red flag in the top left figure below.

Flooding threshold: 1.5 feet above MHHW





When will St. Augustine have a 70% chance of flooding 52 days per year?



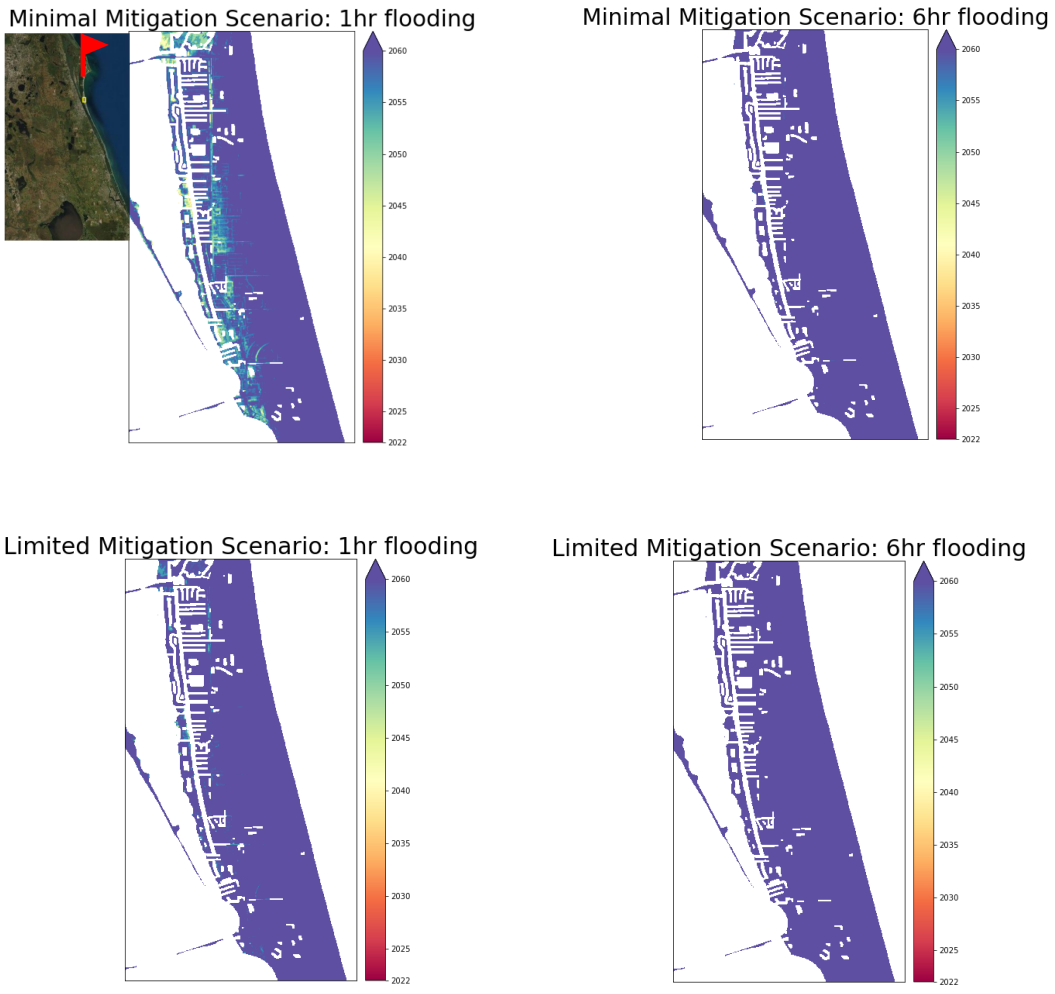
3.10 Satellite Beach

Satellite Beach is a coastal barrier beach area located south of Port Canaveral. While the sandy beaches protect the oceanside region similar to Miami Beach, the Intracoastal region is at most risk of crossing the 1 hour flooding threshold by 2060. Following the projections at Trident Pier, Satellite Beach is more at risk for frequent flooding at least once per week, but likely not persistent flooding last for 6 hours or more, particularly under the Minimal Mitigation scenario. There is little to no likelihood that Satellite Beach will cross the flooding threshold by 2060 for 6 hours of flooding under the scenarios analyzed.

Tide gauge location: Trident Pier, FL. See red flag in the top left figure below.

Flooding threshold: 1.5 feet above MHHW

When will Satellite Beach have a 70% chance of flooding 52 days per year?



3.11 Melbourne

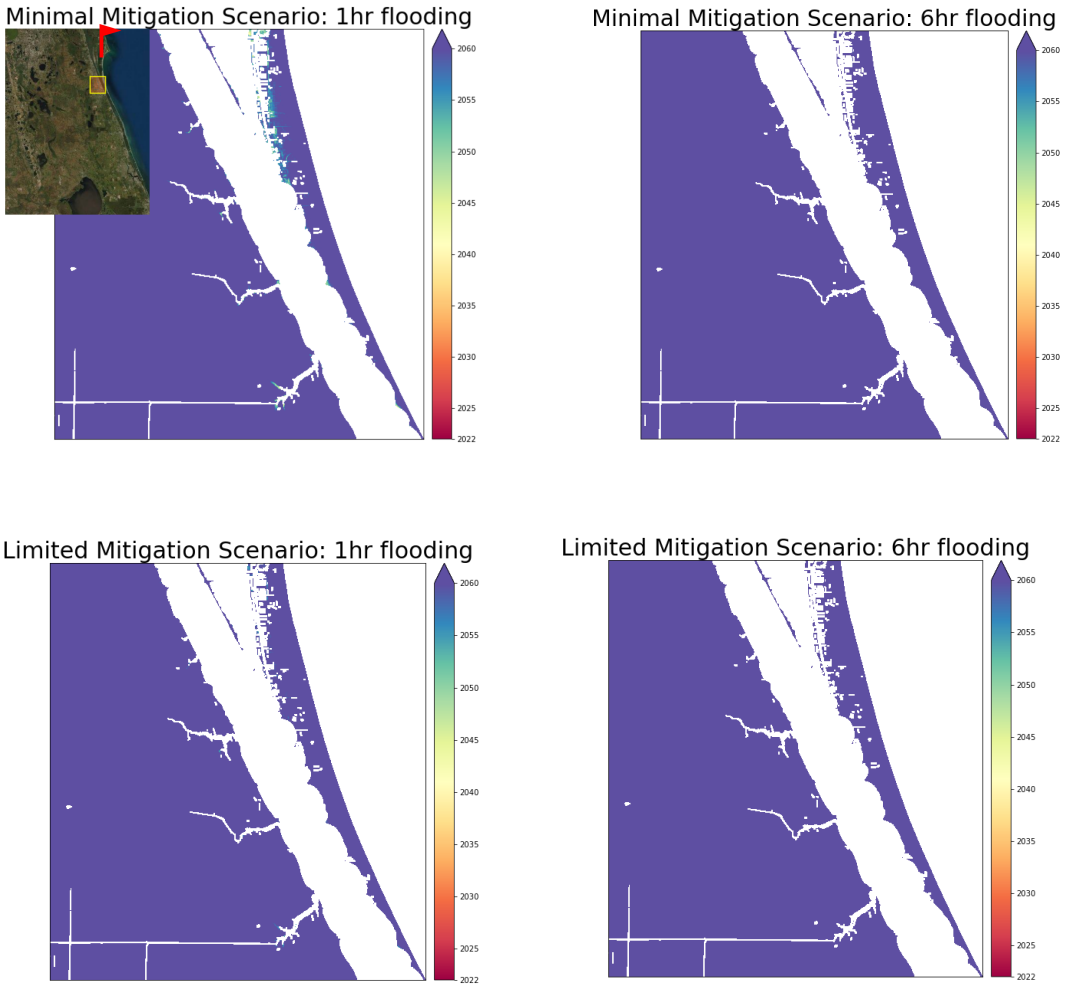
Melbourne is located on the mainland south of Satellite Beach. The high elevation of the area, even located along the coast and river inlets, result in much of the region not expected to cross the flooding threshold by 2060 for any scenario. The Melbourne flooding map projections differ from the Vaca Key and Ft. Lauderdale/Hollywood projections, which

cross the flooding thresholds around the river inlet regions due to lower elevation. Satellite Beach can be seen to the northeast of Melbourne with 1 hour flooding days projected on the Intracoastal side. The majority of Melbourne (mainland region) is not projected to cross the 1-hour or 6-hour flooding thresholds by 2060 under all scenarios analyzed due primarily to the relatively high elevation of the region, even along the inlets.

Tide gauge location: Trident Pier, FL. See red flag in the top left figure below.

Flooding threshold: 1.5 feet above MHHW

When will Melbourne have a 70% chance of flooding 52 days per year?



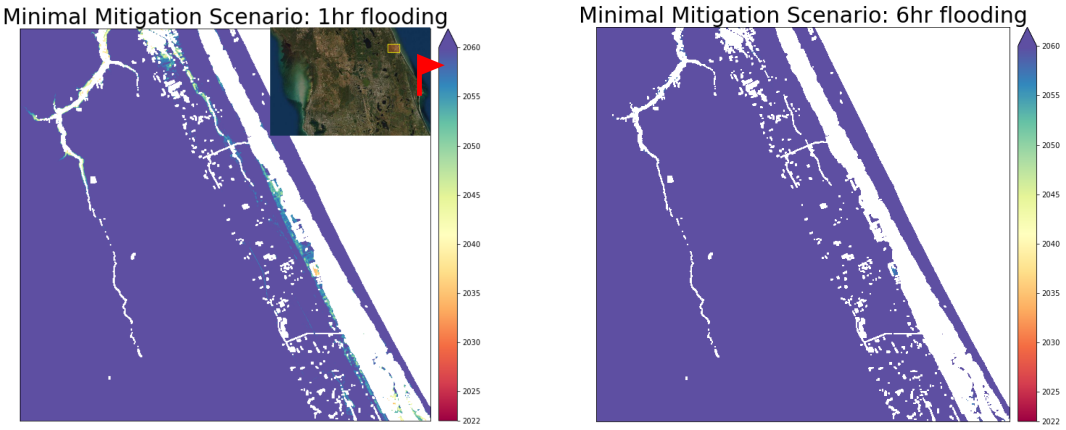
3.12 Daytona Beach

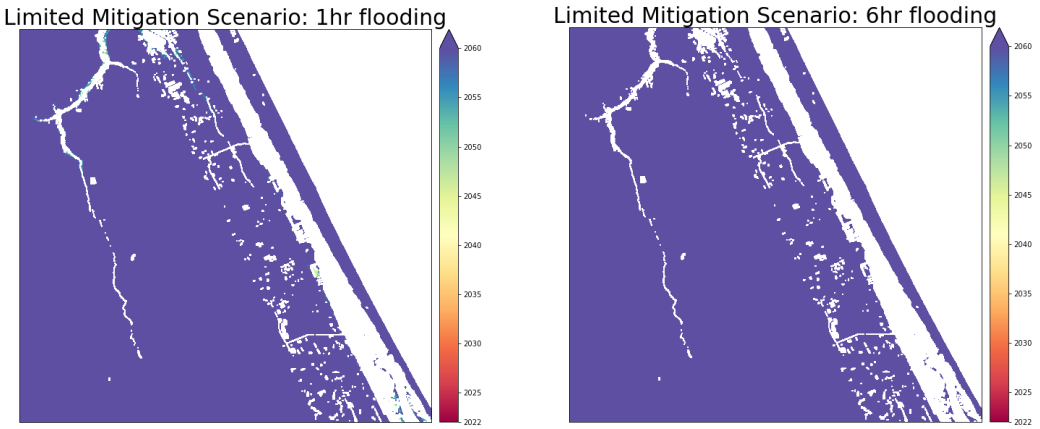
Daytona Beach is located north of St. Augustine and includes the mainland and the barrier island region. Like the other stations using the Trident Pier projections (St. Augustine, Satellite Beach and Melbourne), Daytona Beach is not expected to experience weekly persistent flooding, i.e. crossing the 6-hour flooding threshold by 2060 under the scenarios analyzed. However, regions of mainland coastal area along the Intracoastal have a 70% chance of crossing the 1 hour flooding threshold under the Minimal Mitigation scenario in the next few decades. The northern areas of Daytona Beach mainland in the low-lying areas near water are also at risk of crossing this threshold.

Tide gauge location: Trident Pier, FL. See red flag in the top left figure below.

Flooding threshold: 1.5 feet above MHHW

When will Daytona Beach have a 70% chance of flooding 52 days per year?



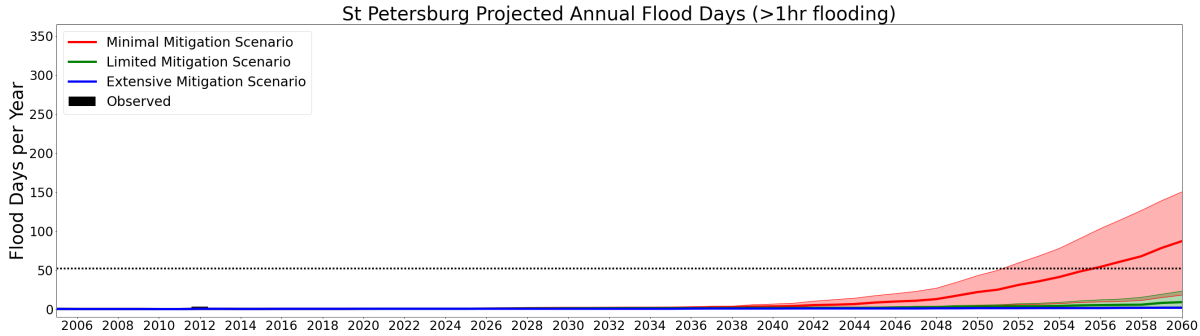


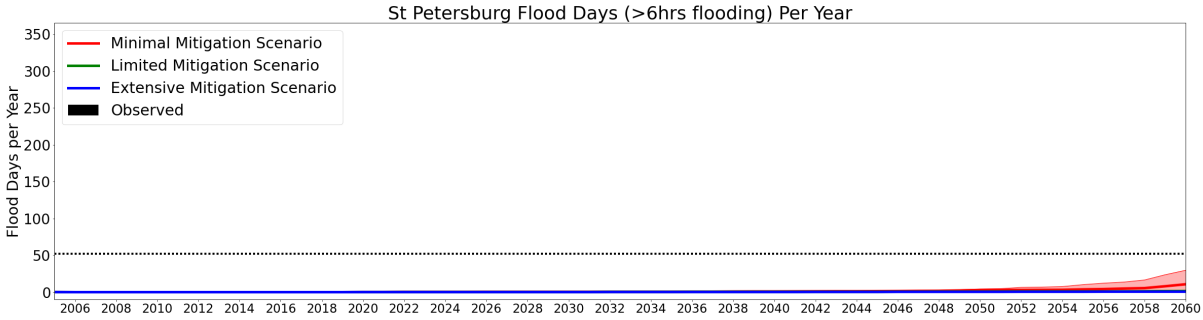
3.13 St. Petersburg

Due to the high flooding threshold in the St. Petersburg region, exceedance of 2.5ft above MHHW (see Fig. 3) and the projected rate of sea level rise in the region, it is unlikely that St. Petersburg will have a 70% chance of crossing the 52-day flooding threshold by 2060 under any of the mitigation scenarios analyzed. While the high sub-scenario and medium sub-scenario lines of the Minimal Mitigation Scenario cross the 52-day threshold before 2060, the "70%" chance of crossing the threshold is calculated by averaging the medium and low sub-scenarios, and this projection does not cross the 52-day flooding threshold by 2060. These regionalized flooding thresholds are calculated by Sweet et al. (2016) at 28 NOAA tide gauge stations in the U.S., using a number of factors including local tidal fluctuations and ocean currents. St. Petersburg and the surrounding areas highlight the importance of a regionalized approach to projecting sea level rise and the future of coastal flooding. It is important to note that under the Minimal Mitigation Scenario, the number of 1 hour flooding days is increasing and likely will cross the 52-day flooding threshold by the end of the century.

Tide gauge location: St. Petersburg, FL. See red flag in the map below.

Flooding threshold: 2.5 feet above MHHW (see Fig. 3 for regionalized flooding threshold).





When will St. Petersburg have a 70% chance of flooding 52 days per year?

It is unlikely that St. Petersburg will have a 70% chance of crossing the 52-day flooding threshold by 2060 under any of the mitigation scenarios analyzed.

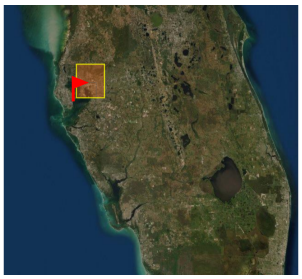
3.14 Tampa

Tampa is located close to the St. Petersburg tide gauge station on Tampa Bay inland from the Gulf of Mexico. It also uses a 2.5ft above MHHW threshold for flooding- as opposed to 1ft above MHHW is Miami and the Keys- which results in few flooding days

under all mitigation scenarios. Tampa and the surrounding areas highlight the importance of a regionalized approach to projecting sea level rise and the future of coastal flooding.

Tide gauge location: St. Petersburg, FL. See red flag in the map below.

Flooding threshold: 2.5 feet above MHHW (see Fig. 3 for regionalized flooding threshold).



When will Tampa have a 70% chance of flooding 52 days per year?

It is unlikely that Tampa will have a 70% chance of crossing the 52-day flooding threshold by 2060 under any of the mitigation scenarios analyzed.

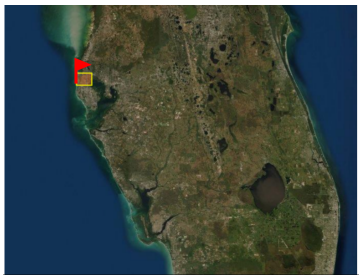
3.15 Clearwater

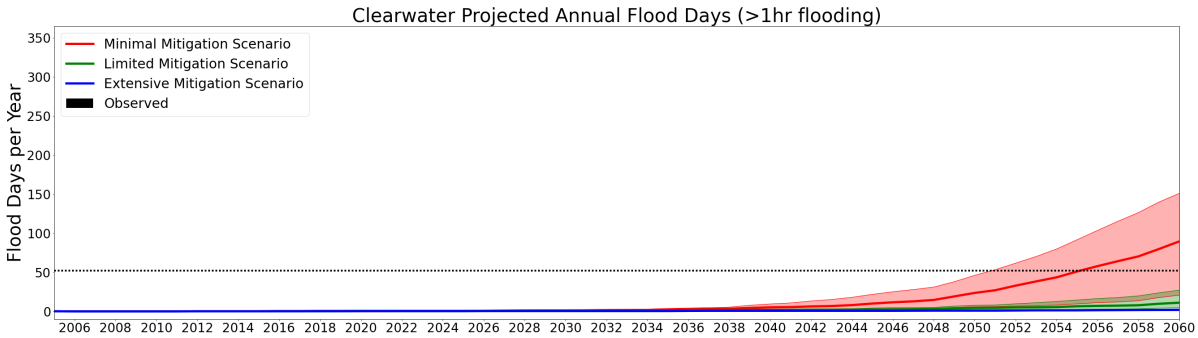
Due to the high flooding threshold in the Clearwater region, exceedance of 2.5ft above MHHW (see Fig. 3) and the projected rate of sea level rise in the region, it is unlikely that Clearwater will have a 70% chance of crossing the 52-day flooding threshold by 2060 under any of the mitigation scenarios analyzed. Clearwater and the surrounding areas further highlight the importance of a regionalized approach to projecting sea level rise and the future of coastal flooding. The regionalization calculation was done by Sweet et al. (2016) was only conducted at 28 tide gauge stations, the closest to Clearwater being St. Petersburg. Thus, regionalized flooding thresholds and sea level rise projection scenarios at more locations could provide more accurate and high-resolution flooding projections. It is important to note that

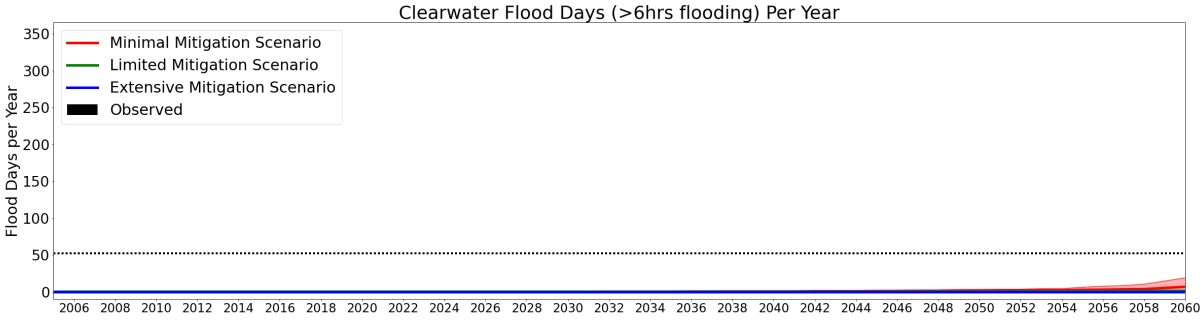
under the Minimal Mitigation Scenario, the number of 1 hour flooding days is increasing and likely will cross the 52-day flooding threshold by 2100.

Tide gauge location: Clearwater, FL. See red flag in the map below.

Flooding threshold: 2.5 feet above MHHW







When will Clearwater have a 70% chance of flooding 52 days per year?

It is unlikely that Clearwater will have a 70% chance of crossing the 52-day flooding threshold by 2060 under any of the mitigation scenarios analyzed.

3.16 Bradenton

Bradenton is located closest to the Clearwater tide gauge station, and uses the St. Petersburg exceedance threshold of 2.5ft above MHHW for flooding, resulting in few flood days per year. The Bradenton region includes both the Intracoastal region and the river inlet, and follows the projections for the Clearwater tide gauge station as the majority lies nearer to the coast than Tampa Bay/ St. Petersburg tide gauge station. Bradenton and the surrounding areas highlight the importance of a regionalized approach to projecting sea level rise and the future of coastal flooding.

Tide gauge location: Clearwater, FL. See red flag in the map below.

Flooding threshold: 2.5 feet above MHHW (see Fig. 3 for regionalized flooding threshold).

When will Bradenton have a 70% chance of flooding 52 days per year?

It is unlikely that Bradenton will have a 70% chance of crossing the 52-day flooding threshold by 2060 under any of the mitigation scenarios analyzed.

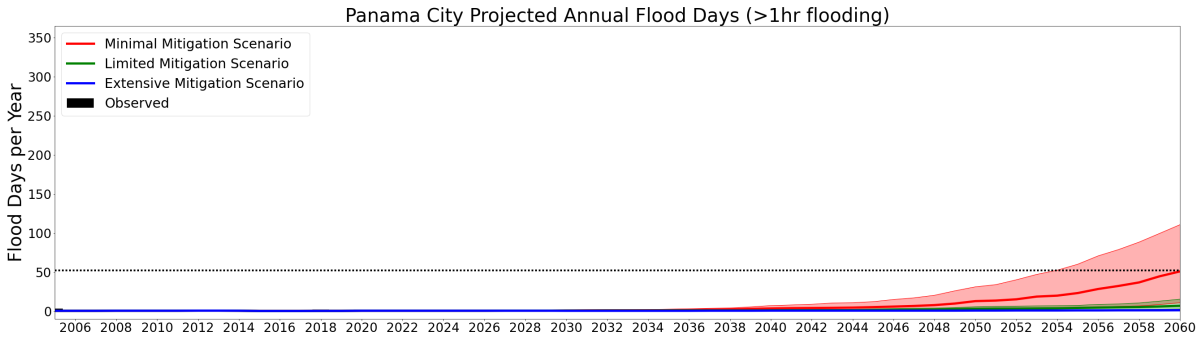
3.17 Panama City

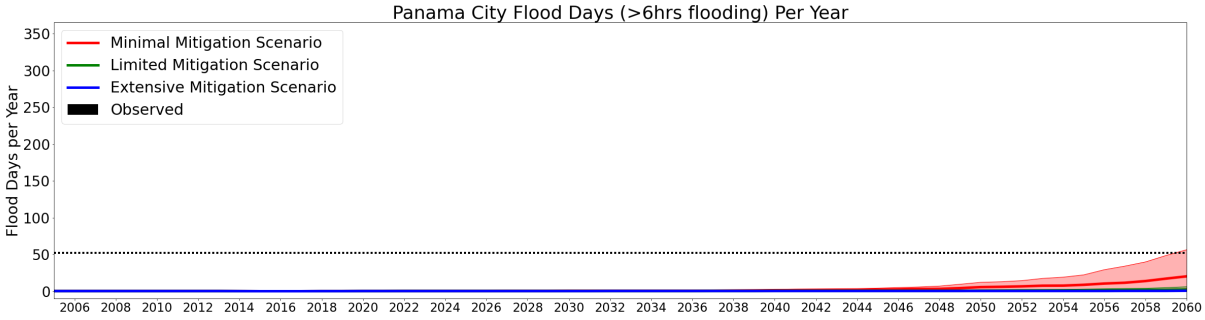
Due to the high flooding threshold in the Panama City region (exceedance of 2.5ft above MHHW (see Fig. 3)) and the projected rate of sea level rise in the region, it is unlikely that Panama City will have a 70% chance of crossing the 52-day flooding threshold by 2060 under any of the mitigation scenarios analyzed.

The Gulf cities analyzed- Panama City, St. Petersburg, Tampa, Clearwater, and Bradenton- all use a flooding threshold of 2.5ft above MHHW, which results in projections of less flooding than the East Coast cities and Keys, which use 1- 1.5 ft above MHHW thresholds. Local circulation and tidal flow as well as elevation all play a role in sea level rise projections and the future of flooding in various cities.

Tide gauge location: Panama City, FL. See red flag in the map below.

Flooding threshold: 2.5 feet above MHHW





When will Panama City have a 70% chance of flooding 52 days per year?

It is unlikely that Panama City will have a 70% chance of crossing the 52-day flooding threshold by 2060 under any of the mitigation scenarios analyzed.

List of Figures

4 References

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