The Looming Threat of Rising Sea Levels to the Florida Keys

Caleb Melancon

1. Introduction

Sea levels are rising, and possibly faster than we thought before. In a recent report in 2017 by the National Oceanic and Atmospheric Administration (NOAA), estimates for sea level rise over the next 100 years have appeared to double since the last estimates in 2012. The report claims that the average sea level will rise somewhere between 1 foot at the lower end of their anticipated range and 3 feet near the higher end. While not all coastal communities will be adversely affected by this rise, the Florida Keys (a low-lying chain of islands off the southern coast of Florida) could be totally submerged in the next few centuries. In this study, we are observing how the main islands will be affected by both the low and high-end estimates that NOAA has produced.

2. Methodology

In order to evaluate the extent flooding within the Florida Keys, I will have to do an analysis on the effects of sea level based the topography and elevation of the islands. In order to do this, I am mainly using tools from the Spatial Analyst ArcGIS toolbox.

2.1 Data Collection

The data used in this project was collected from several different sources. The National Centers for Environmental Information (NOAA) provided the digital elevation models from which all of my calculations (section 2.3) were made, and the US Census Bureau provided the polygons of the islands that I was working on.

NOAA Sea Level Rise Viewer DEM

Cell size: 16.4 ft, Vertical Accuracy: 10 cm. Used for raster calculations
https://coast.noaa.gov/dataviewer/#/lidar/search/-9158990.47724296,2808907.9154236573,-8903385.054657328,2952609.5285997884

US Census Places

Used for polygons of islands provided land measurements
https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2017&layergroup=Places

US Census Florida Roads/Highways

Used purely for visual aid
https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2017&layergroup=Roads

US Water Polygons

Used for labeling bodies of water
https://www.arcgis.com/home/item.html?id=1630b19fafbe4c9589306d967e418088

2.2 Data Preprocessing

The NOAA Sea Level DEM's were downloaded as seven separate rasters. The website allows the user to select the projection, datum, and file format prior to downloading as seen in Figure 1. In order to more easily manage the DEM data, I first used the "Mosaic To New Raster" tool in the Data Management toolbox. This tool allowed me to combine the seven separate rasters into one. The resulting raster was very large, so I generated pyramids in order to render the images more quickly.

Figure 1: NOAA Data Viewer provides an easy to use downloading wizard.

The US Census Places and Roads/Highways downloads provided me with shapefiles of the major islands in the Florida Keys and the highway passing through them. The shapefile was referenced to the NAD83 datum, and after placing it into arcMaps I was able to do a projection to the Florida State Plane as used for the DEM data. No further pre-processing was needed.

The US Water Polygon was easily downloaded from ESRI as a shapefile referenced to WGS 1984. After being projected to NAD 83 Florida State Plane, no further pre-processing was required.

2.3 Data Processing & Analysis

Hillshade My first step in order to make the maps more visually appealing was to create a hillshade from the DEM data. Using the "Hillshade" tool in the Spatial Analyst toolbox (Figure 2), I was able to generate a shaded relief raster of the DEM data. The source of illumination was kept on the default setting. I repeated this for each of the 3 elevations that are described later in the Raster Calculations section.

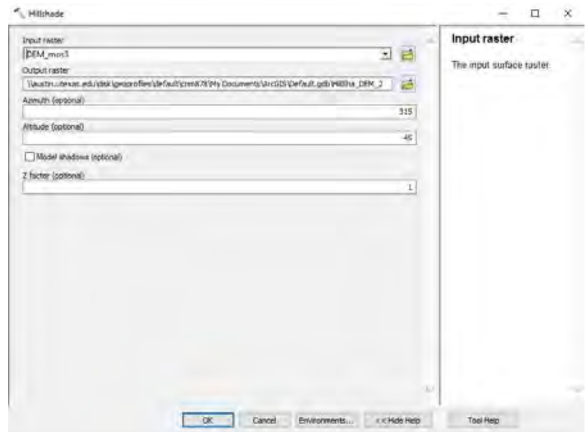


Figure 2: The Hillshade tool provides a shaded relief from the DEM surface raster.

Clipping My first step, which isn't necessarily "clipping", was to reduce the Places shapefile to only the islands I was interested in. The Place shapefile included all places in florida recorded by the US census, and since I was only interested in the islands, I manually selected the 13 islands available and extracted them from the Place shapefile then saved them as their own shapefile. This allowed me to easily navigate the attribute table in order to gather the data used for the excel calculations.

In order to speed up the raster calculation described in the following section, I clipped the DEM raster to the Places shapefile so that the calculation would only be performed within the areas of interest. In order to do this, I used the "Extract By Mask" tool (Figure 3) in the Spatial Analyst toolbox. After the raster calculations (as described in the following section) I then had to clip all three sea level rasters (msl, 1ft rise, and 3 ft rise) to each Place in order to calculate the area of the land covered by water.

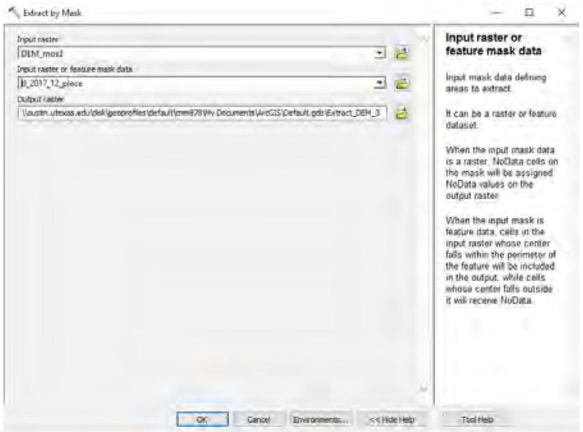


Figure 3: The Extract By Mask tool allows you to clip a raster to a polygon.

This process was also conducted using the Extract by Mask tool, but before using the tool I had to select which Place I was clipping to. Once selected, the Extract by Mask tool only clipped to the selected Place rather than the entire Place shapefile. I repeated this step for each island and for each of the 3 sea level rasters, resulting in 39 new rasters.

Contour For each of the three DEM's I would be using, I created a single contour at sealevel (0 ft) in order to more clearly display the outline of the land that was still above sea level. This was done using the "Contour" tool in the Spatial Analyst toolbox.

Raster Calculations The rasters used for the calculations were produced using the "Raster Calculator" tool in the Spatial Analyst toolbox. The first step I took was to create two more elevation rasters, one 1 ft below the original, and one 3 ft below. To do this, I used the Raster Calculator and subtracted 1 (and 3) from the original DEM (Figure 4). This produced two rasters that were 1 and 3 feet below the original.

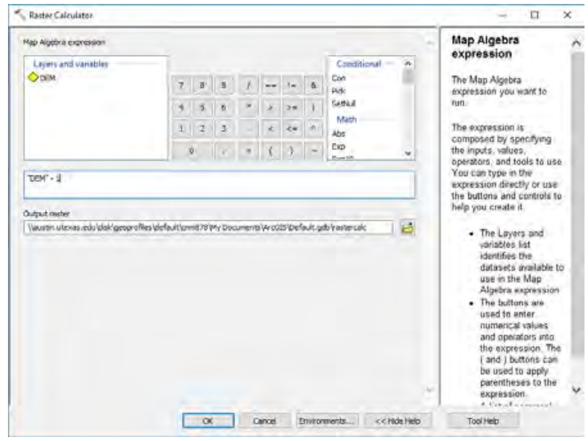


Figure 4: By subtracting 1 from the original DEM, the Raster Calculator tool produced a raster with 1 foot subtracted from all of the cells of the original.

The next step was to create binary rasters that would represent the sea level at today's mean sea level (msl) and then 1 and 3 ft above the msl (Figure 5). In order to do this, I created three binary rasters. Each raster was produced using the Raster Calculator tool. The input "Con("DEM_X" <= 0,1)" produces a raster that has the value of 1 in all cells that are less than or equal to 0 ft on the DEM (below sea level).

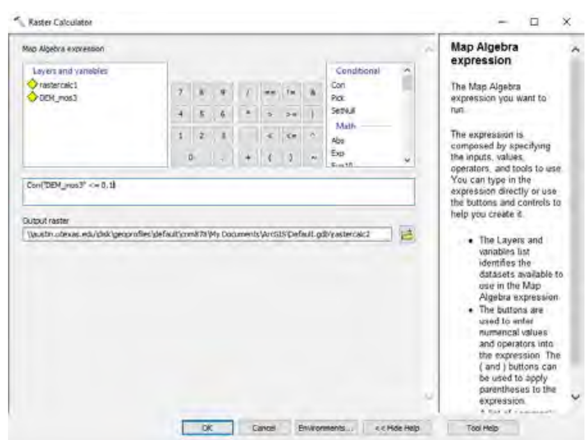


Figure 5: The Raster Calculator was used to create binary rasters for each sealevel, producing a raster that only had values where the land was beneath 0 ft.

Symbology The vertical data in the DEM ranged from -0.305 ft to 45 ft (the 45 ft cell seemed to be an outlier and could not be located on the map). Most of the data was below 5 ft. Because of the outlier, I chose to use a classified symbology (Figure 6). I classified it manually, using values in ½ foot increments from <0 to 5+. This resulted in the most visually appealing color scheme for the elevation models. I then increased the transparency to 40% so you can see the hillshade beneath for a 3D effect. After creating the first symbology, I saved it as a template to easily be used on the other DEM's.

The Hillshade rasters were already symbolized using a standard deviation stretch, but I reduced the standard deviation to 2 (down from 2.5) in order to increase the contrast.

The binary rasters for the different sea levels that I created were symbolized a dark blue and the transparency was turned up to 50% so you can see the submerged DEM and hillshade. I made the symbology for the water shapefile (from the US Water Polygons) have no color, because I was only using it for its labels. The labels were colored Apatite Blue to stand out from the dark blue used for the binary raster.

I chose for the Places symbology to be a white line with a hollow area to show the outline of the island that is selected.

The roads were symbolized using a default road symbol in the ESRI database.

Analysis After all of the binary rasters for sea level were clipped to the island boundaries, I was then able to begin my calculation in Excel. Land and sea areas were provided in the attribute table of Places. This gave me a total area for each Place. I then calculated the area of each island covered in water by multiplying the number of cells that had a value of 1 (below sea level) and multiplying that number by the dimensions of the raster cells (16.4 ft x 16.4 ft). This gave me an area in sq. ft of each island, which I then converted to sq. miles. After this, I subtracted my calculated are of water from the total area in each Place (land + water) to get the new area of land. I then calculated the percent land lost by subtracting the current amount of land from the original, then divided by the original amount of land. The results of this are shown in Table 1.

3. Conclusion

By the looks of it, the Florida Keys have a very grim future. Even if water levels only rise by the low estimate of 1 ft, total land lost will reach nearly 75%, with some islands losing over 90%, and others losing as little as 35%. But if the sea rises by the high estimate of 3 ft, the Florida Keys will essentially vanish. Total land loss will be nearly 98%. All islands will be at least 90% submerged, and many of the islands will be almost 99% underwater.

The following maps on pages 6-18 show the extent of the flooding. Each map has 3 panels focusing on one island, showing the present conditions and what the island would look like after 1 ft and 3ft of sea level rise.

Island	Land Area (sq. mi)			Percent Land Loss	
	Present	1 ft Water	3 ft Water	1 ft Water	3 ft Water
Key West	5.60	2.83	0.17	49.53	96.88
Stock Island	0.84	0.16	0.00	80.29	99.56
Big Coppitt Key	1.15	0.21	0.00	81.68	99.90
Cudjoe Key	5.17	0.34	0.01	93.41	99.75
Big Pine Key	10.20	1.00	0.01	90.22	99.93
Marathon	8.44	2.16	0.01	74.46	99.84
Key Colony Beach	0.44	0.28	0.00	36.10	99.97
Duck Key	0.60	0.23	0.01	61.73	98.19
Layton	0.17	0.01	0.00	91.16	99.98
Islamorada, Village of Island	6.44	2.52	0.16	60.86	97.49
Tavernier	2.51	0.75	0.05	69.98	98.15
Key Largo	12.06	3.96	0.82	67.14	93.22
North Key Largo	18.59	4.20	0.30	77.42	98.39
Total	72.22	18.66	1.55	74.16	97.85

Table 1: Effect of rising sea waters on the islands of the Florida Keys recognized in the US Census.

Sea Level Rise in the Florida Keys, Florida by year 2100

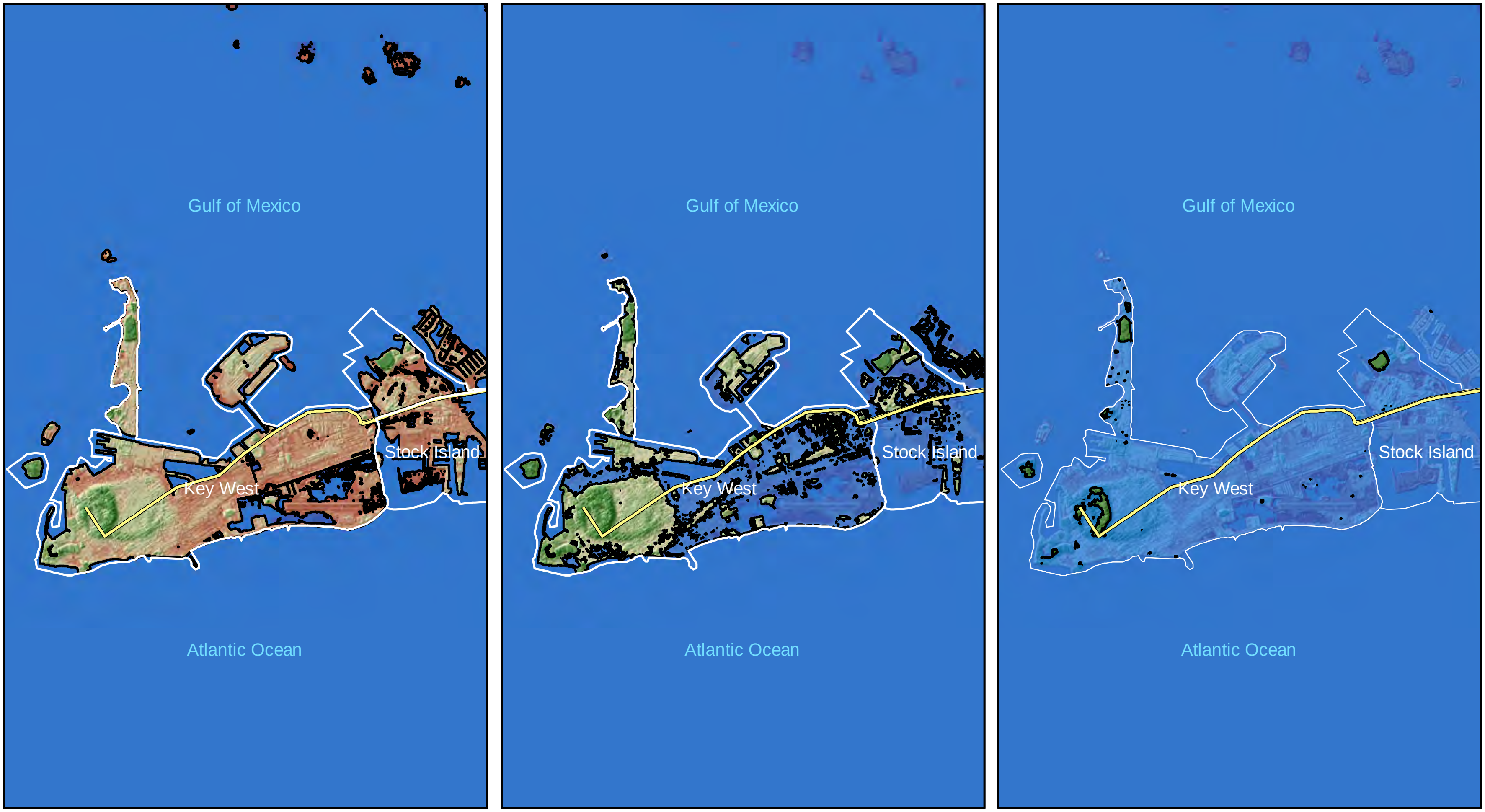
Caleb Melancon
May 5, 2018

Key West

N

0 0.5 1 2 3 4 Miles

1:120,000



Present Sea Level | 1 ft Sea Level Rise | 3 ft Sea Level Rise

Explanation

Elevation (ft)

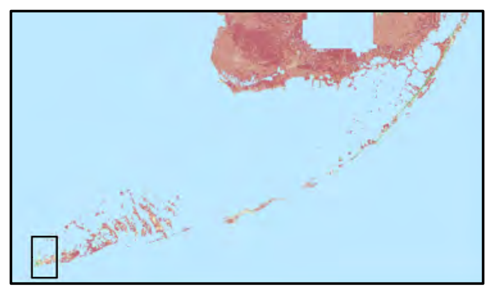
<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

Florida State Road A1A

Contour_DEM_mos1

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**5.60**
Percent Submerged (1 ft):	**49.53%**
Percent Submerged (3 ft):	**96.88%**



Sea Level Rise in the Florida Keys, Florida by year 2100

Stock Island

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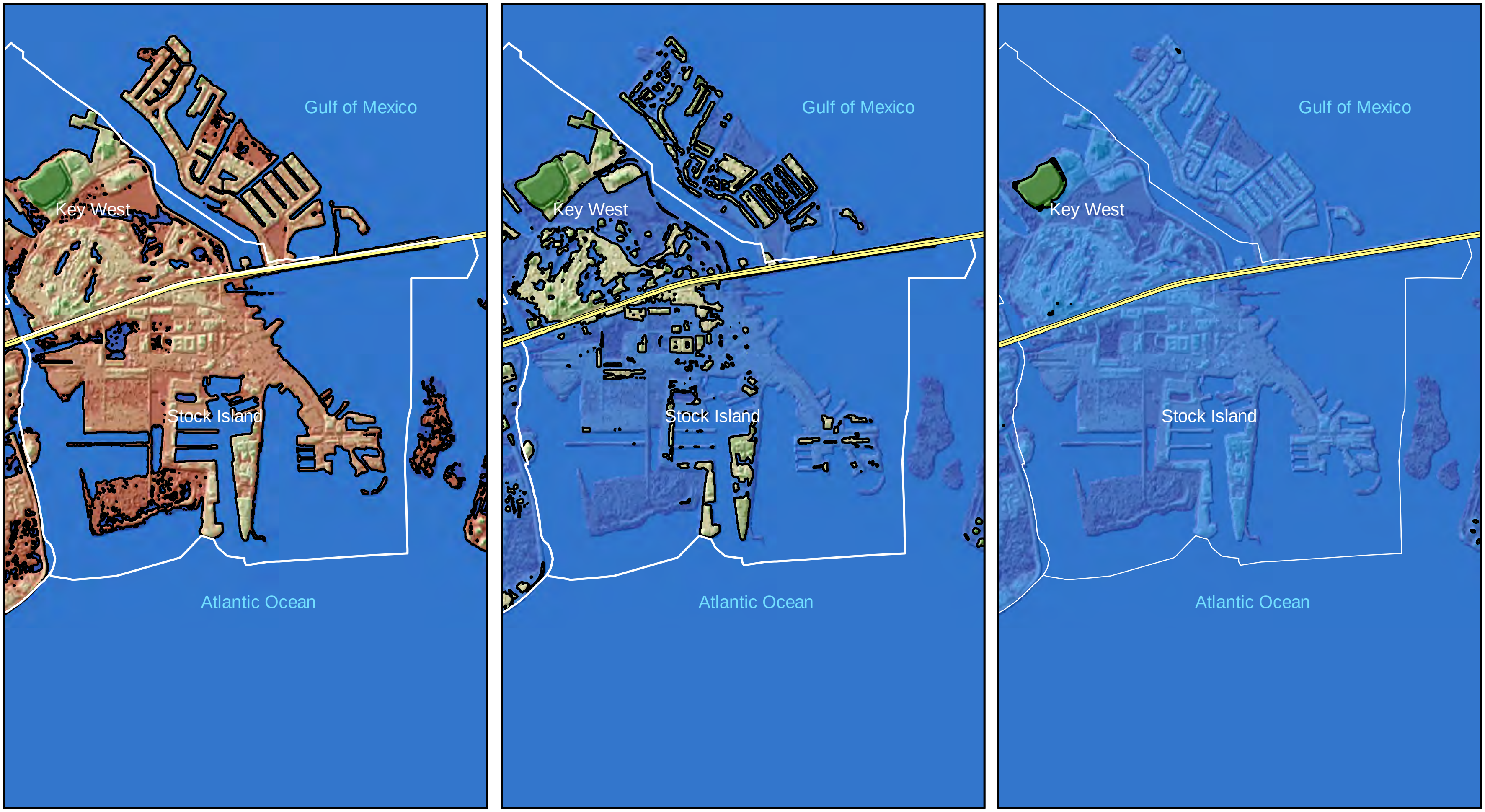
May 5, 2018

N

0 0.2 0.4 0.8 1.2 1.6 Miles

1:45,000



Present Sea Level

1 ft Sea Level Rise

3 ft Sea Level Rise

Explanation

Elevation (ft)

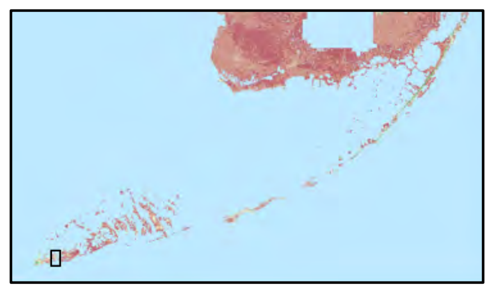
<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

Florida State Road A1A

Contour_DEM_mos1

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**0.84**
Percent Submerged (1 ft):	**80.29%**
Percent Submerged (3 ft):	**99.56%**



Caleb Melancon
May 5, 2018

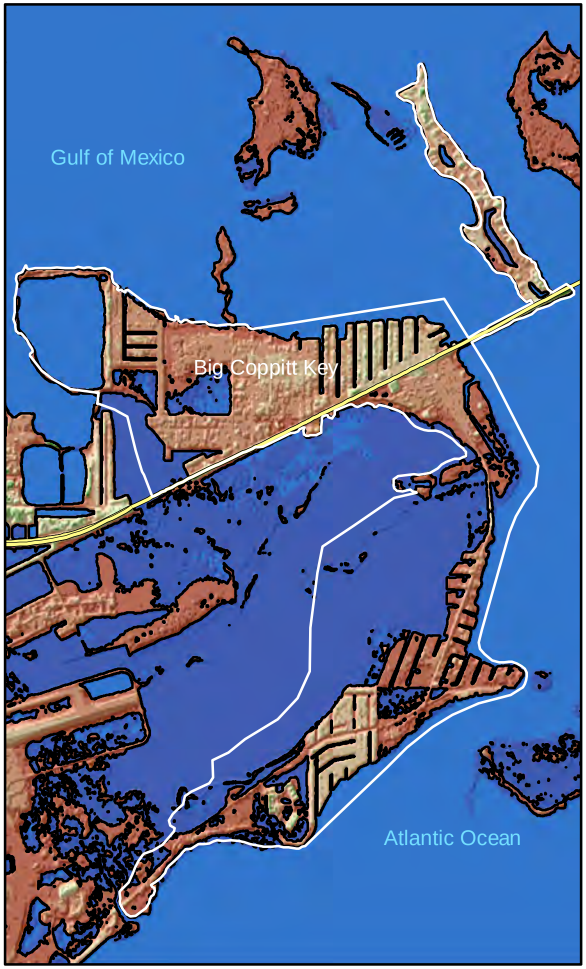
Sea Level Rise in the Florida Keys, Florida by year 2100

Big Coppitt Key

N

0 0.2 0.4 0.8 1.2 1.6 Miles

1:45,000



Present Sea Level

1 ft Sea Level Rise

3 ft Sea Level Rise

Explanation

Elevation (ft)

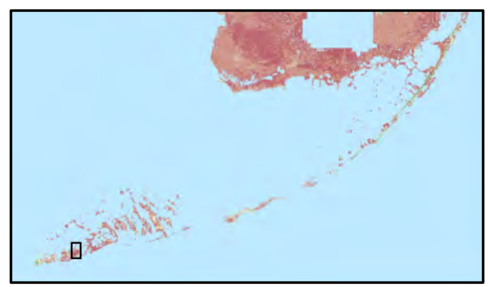
<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

Florida State Road A1A

Contour_DEM_mos1

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**1.15**
Percent Submerged (1 ft):	**81.68%**
Percent Submerged (3 ft):	**99.90%**



Caleb Melancon
May 5, 2018

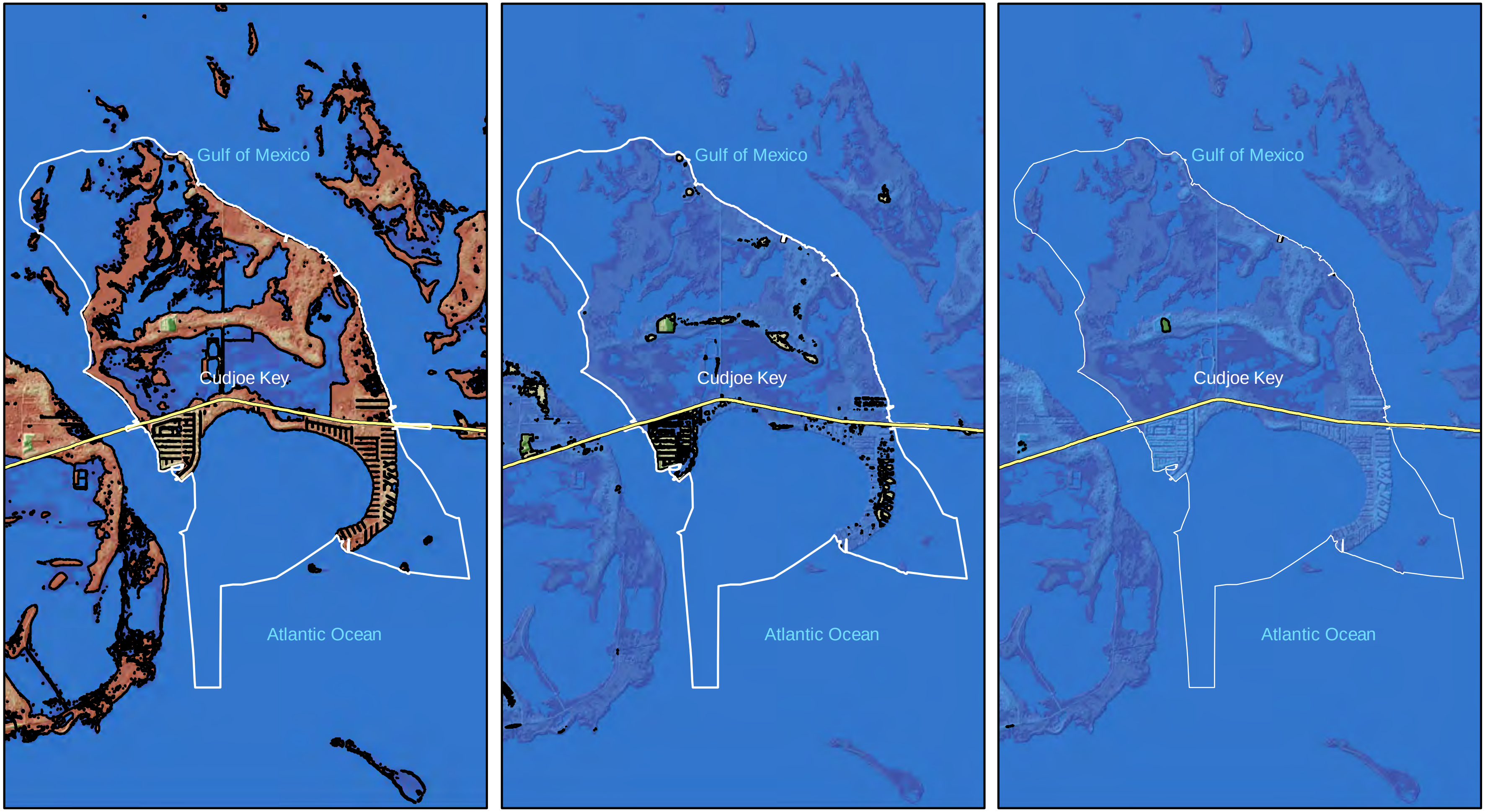
N

Sea Level Rise in the Florida Keys, Florida by year 2100

Cudjoe Key

0 0.5 1 2 3 4 Miles

1:100,000



Present Sea Level | 1 ft Sea Level Rise | 3 ft Sea Level Rise

Explanation

Elevation (ft)

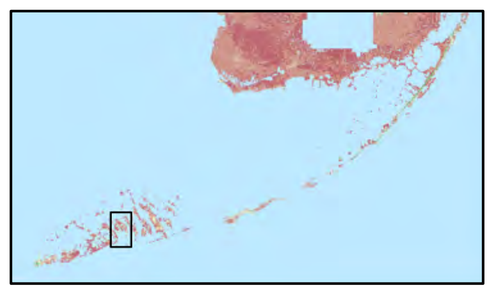
<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

Florida State Road A1A

Contour_DEM_mos1

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**5.17**
Percent Submerged (1 ft):	**93.41%**
Percent Submerged (3 ft):	**99.75%**



Sea Level Rise in the Florida Keys, Florida by year 2100

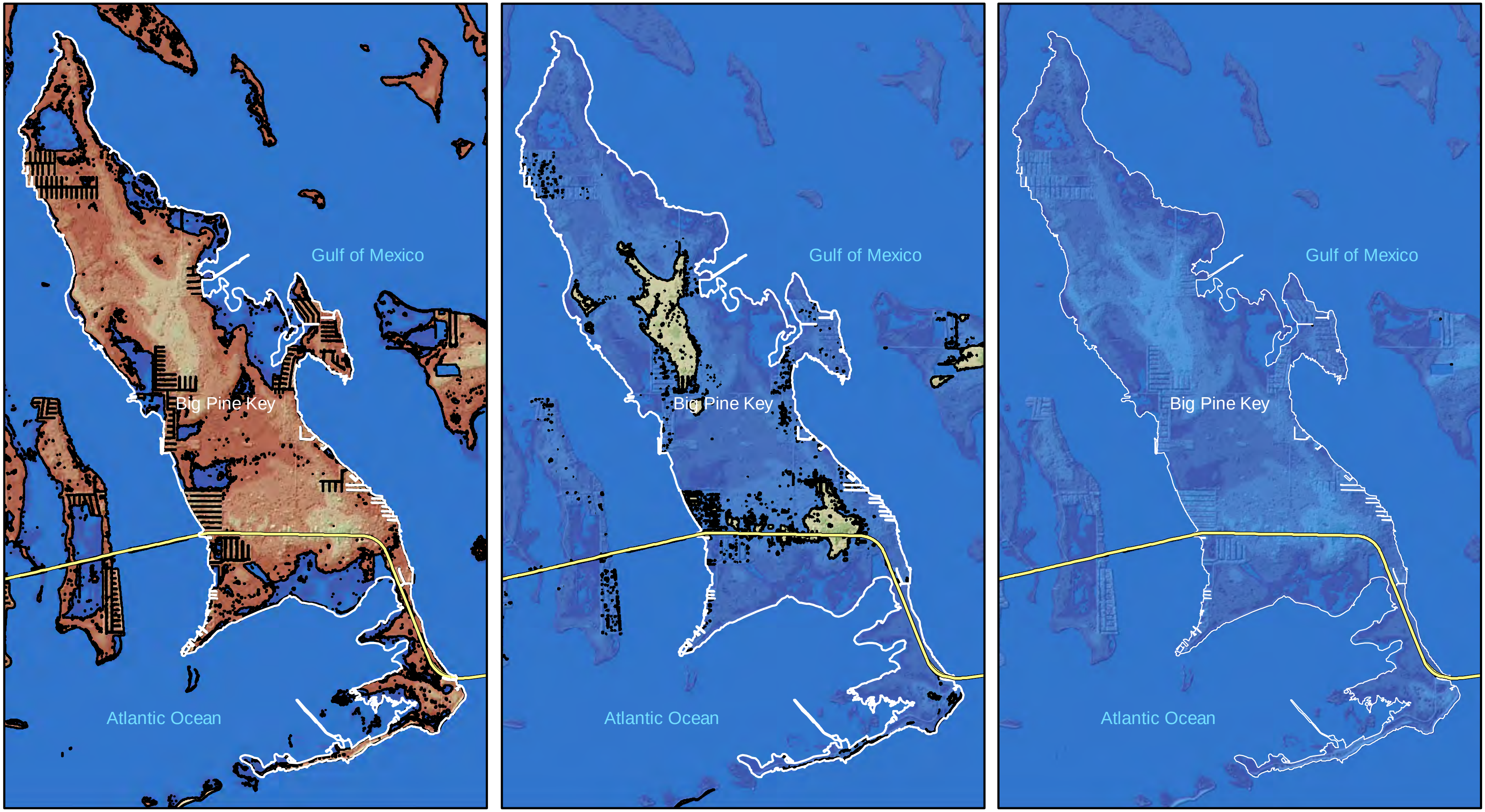
Caleb Melancon
May 5, 2018

Big Pine Key

N

0 0.5 1 2 3 4 Miles

1:106,000



Present Sea Level | 1 ft Sea Level Rise | 3 ft Sea Level Rise

Explanation

Elevation (ft)

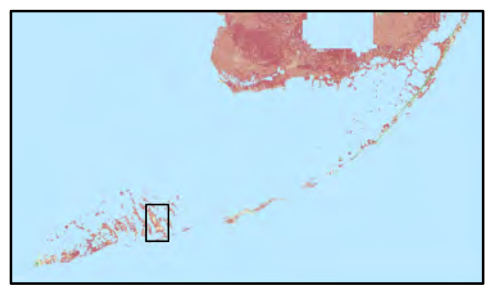
<0 | 0 - 0.5 | 0.5 - 1 | 1 - 1.5 | 1.5 - 2 | 2 - 2.5 | 2.5 - 3 | >3

Florida State Road A1A

Contour_DEM_mos1

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**10.20**
Percent Submerged (1 ft):	**90.22%**
Percent Submerged (3 ft):	**99.93%**



Sea Level Rise in the Florida Keys, Florida by year 2100

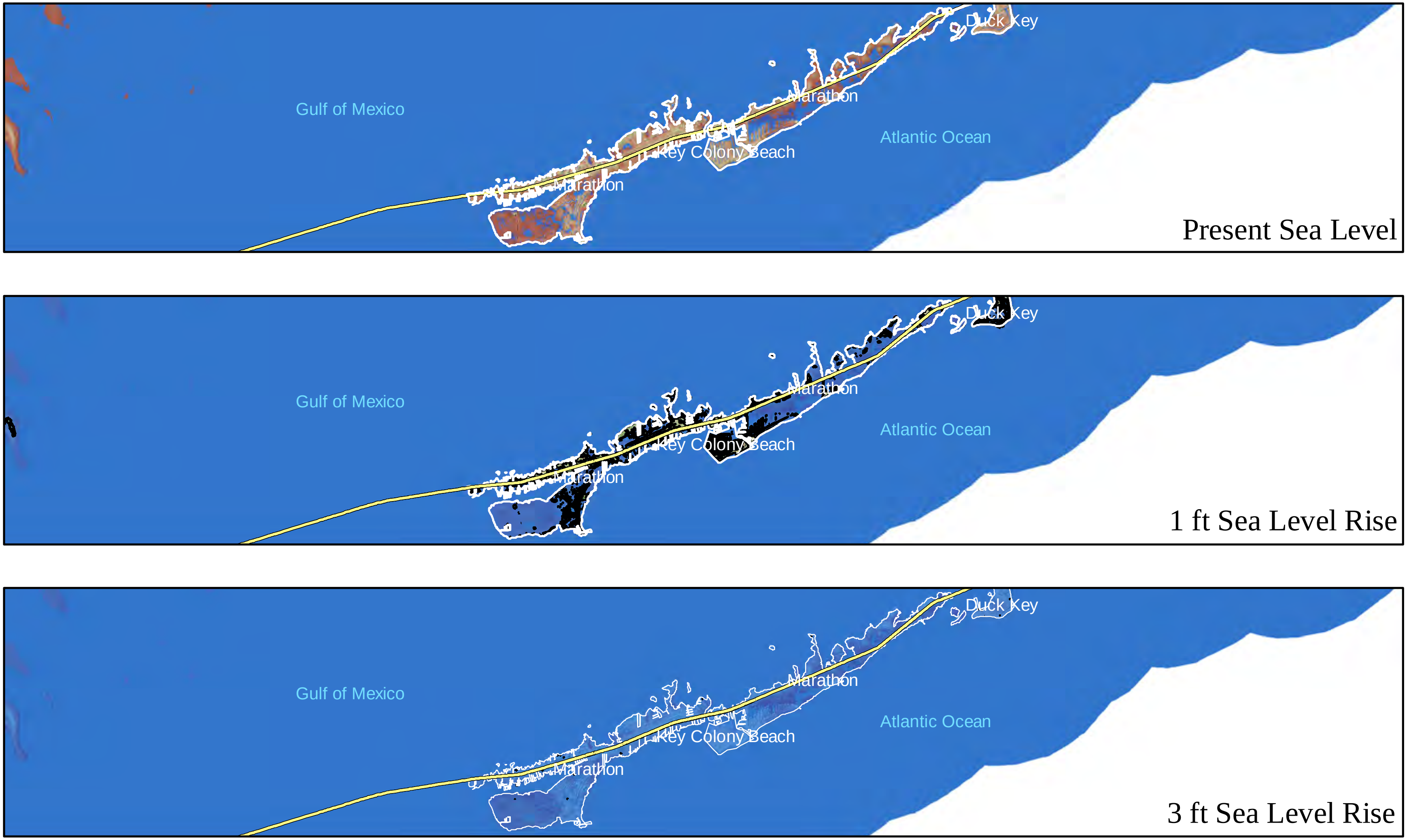
Marathon

Caleb Melancon
May 5, 2018

N

0 1 2 4 6 8 Miles

1:247,000



Explanation

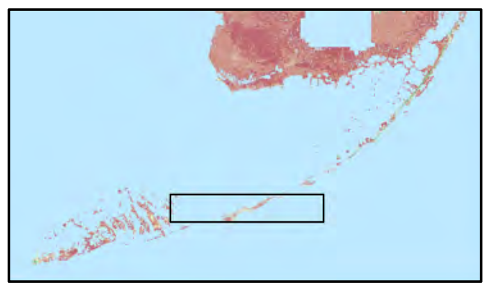
Elevation (ft)

<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

Florida State Road A1A

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**8.44**
Percent Submerged (1 ft):	**74.46%**
Percent Submerged (3 ft):	**99.84%**



Sea Level Rise in the Florida Keys, Florida by year 2100

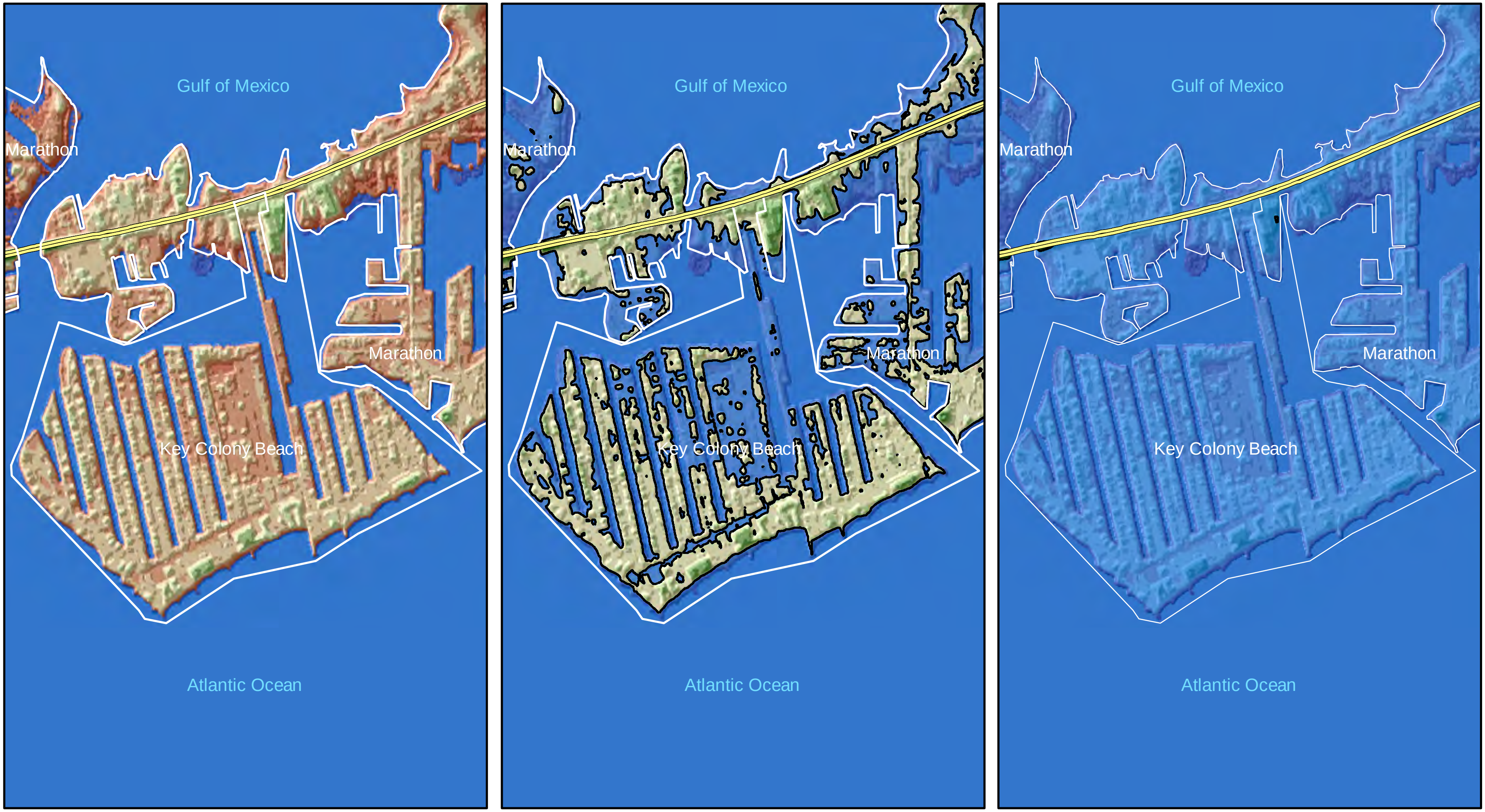
Caleb Melancon
May 5, 2018

N

0 0.1 0.2 0.4 0.6 0.8 Miles

Key Colony Beach

1:27,000



Present Sea Level | 1 ft Sea Level Rise | 3 ft Sea Level Rise

Explanation

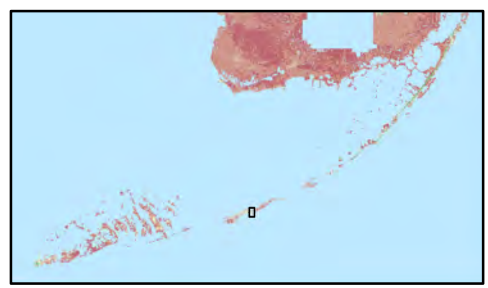
Elevation (ft)

<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

Florida State Road A1A

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**0.44**
Percent Submerged (1 ft):	**36.10%**
Percent Submerged (3 ft):	**99.97%**



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May 5, 2018

Sea Level Rise in the Florida Keys, Florida by year 2100

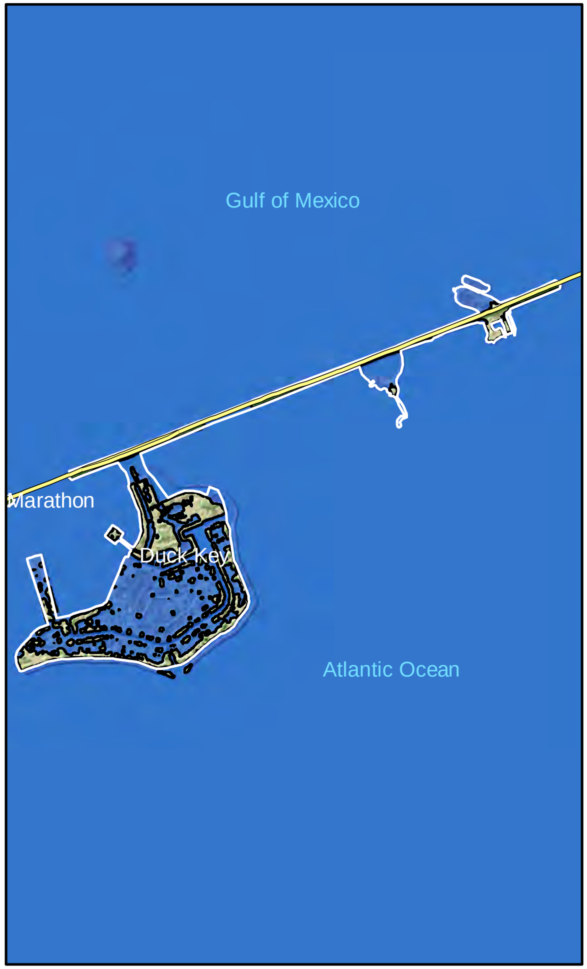
Duck Key

N

0 0.2 0.4 0.8 1.2 1.6 Miles

1:55,000

Present Sea Level



1 ft Sea Level Rise

3 ft Sea Level Rise

Explanation

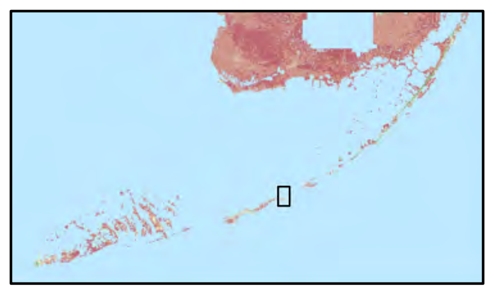
Elevation (ft)

<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

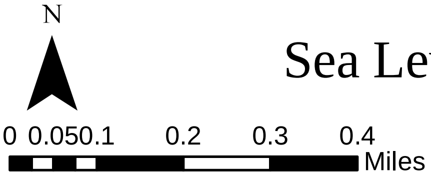
Florida State Road A1A

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**0.60**
Percent Submerged (1 ft):	**61.73%**
Percent Submerged (3 ft):	**98.19%**



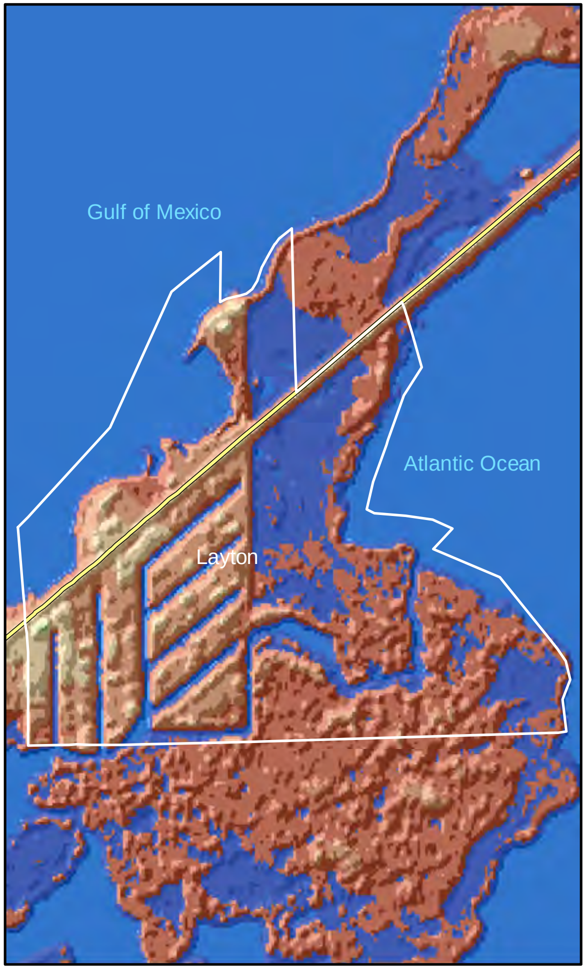
Caleb Melancon
May 5, 2018



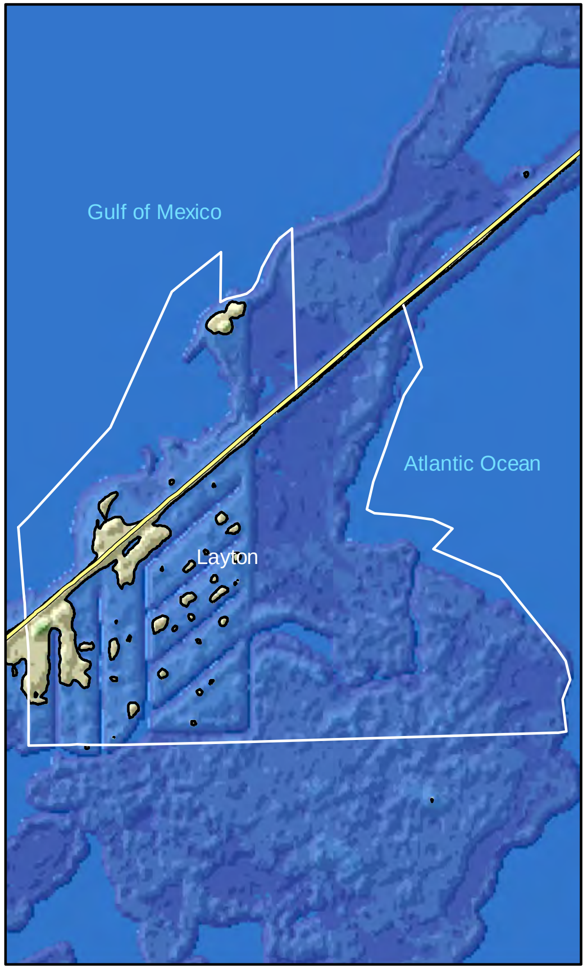
Sea Level Rise in the Florida Keys, Florida by year 2100

Layton

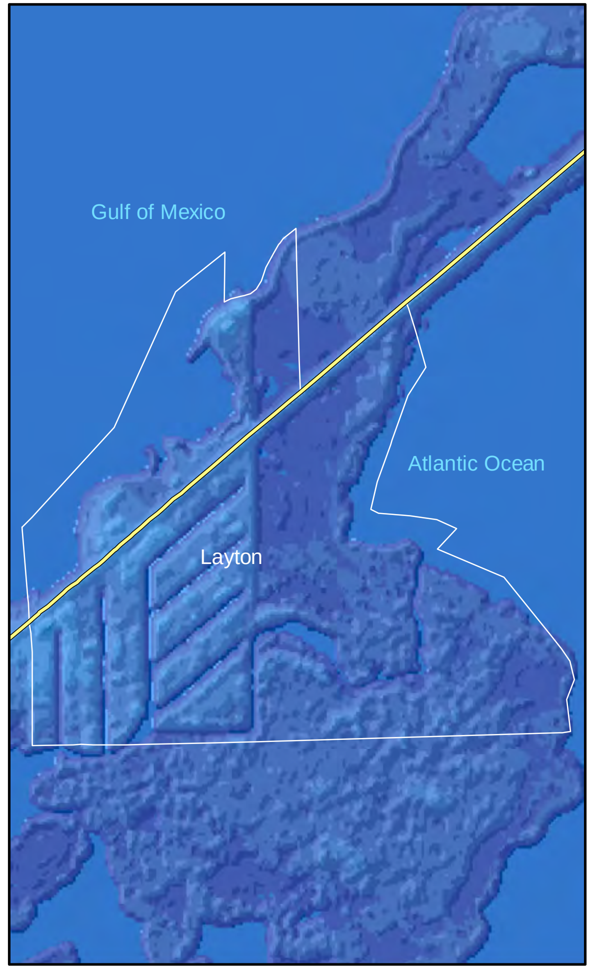
1:14,000



Present Sea Level



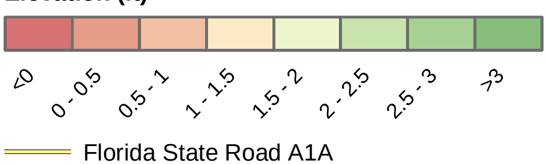
1 ft Sea Level Rise



3 ft Sea Level Rise

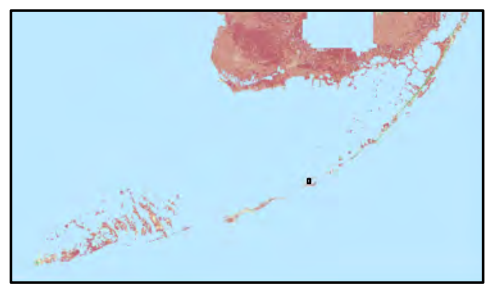
Explanation

Elevation (ft)



NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**0.17**
Percent Submerged (1 ft):	**91.16%**
Percent Submerged (3 ft):	**99.98%**



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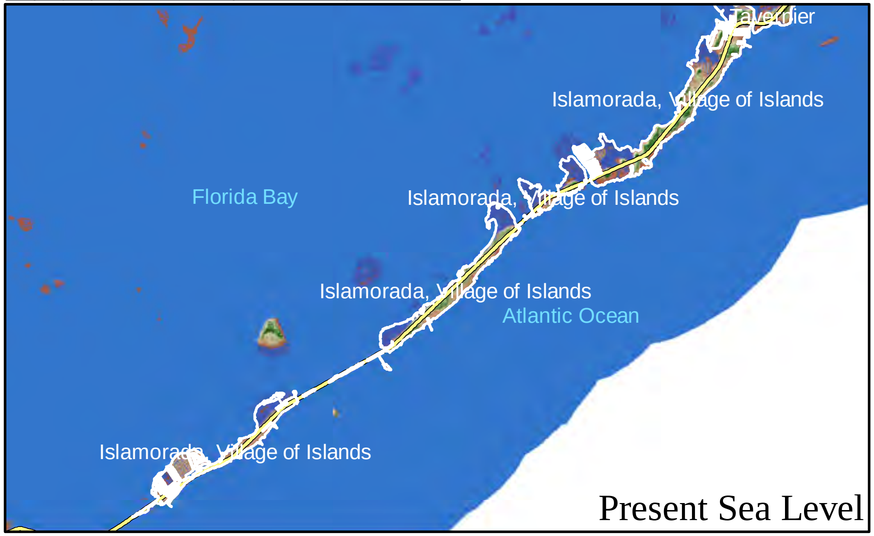
May 5, 2018

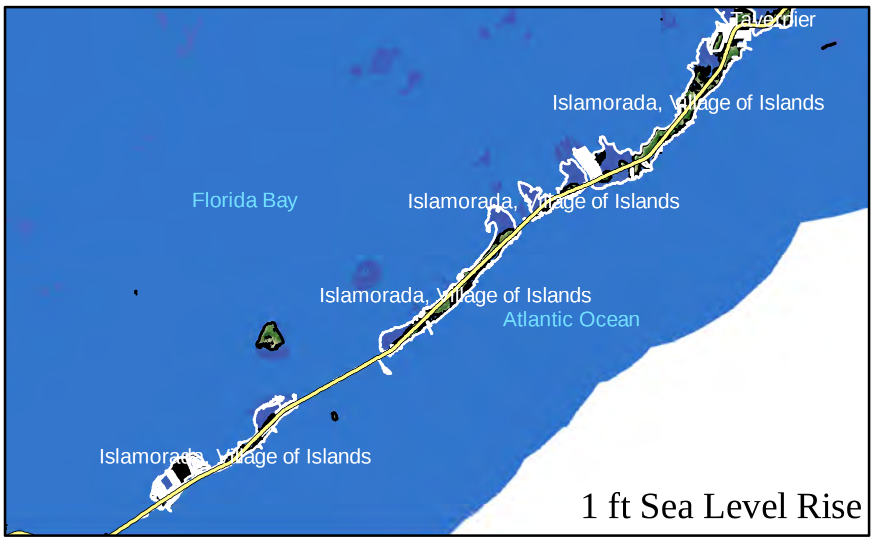
Sea Level Rise in the Florida Keys, Florida by year 2100

Islamorda, Village of Islands

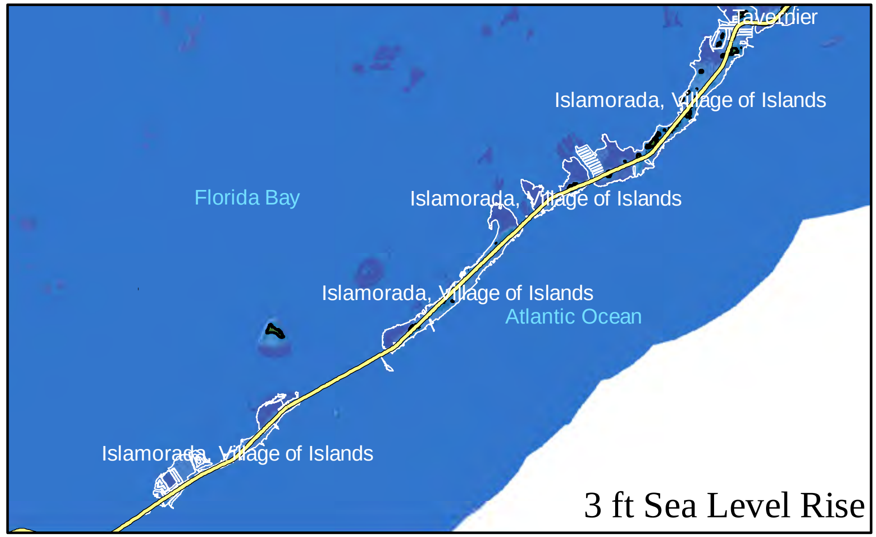
N

0 1.25 2.5 5 7.5 10 Miles





1:268,000



Explanation

Elevation (ft)

<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

Florida State Road A1A

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**6.44**
Percent Submerged (1 ft):	**60.86%**
Percent Submerged (3 ft):	**97.49%**

N

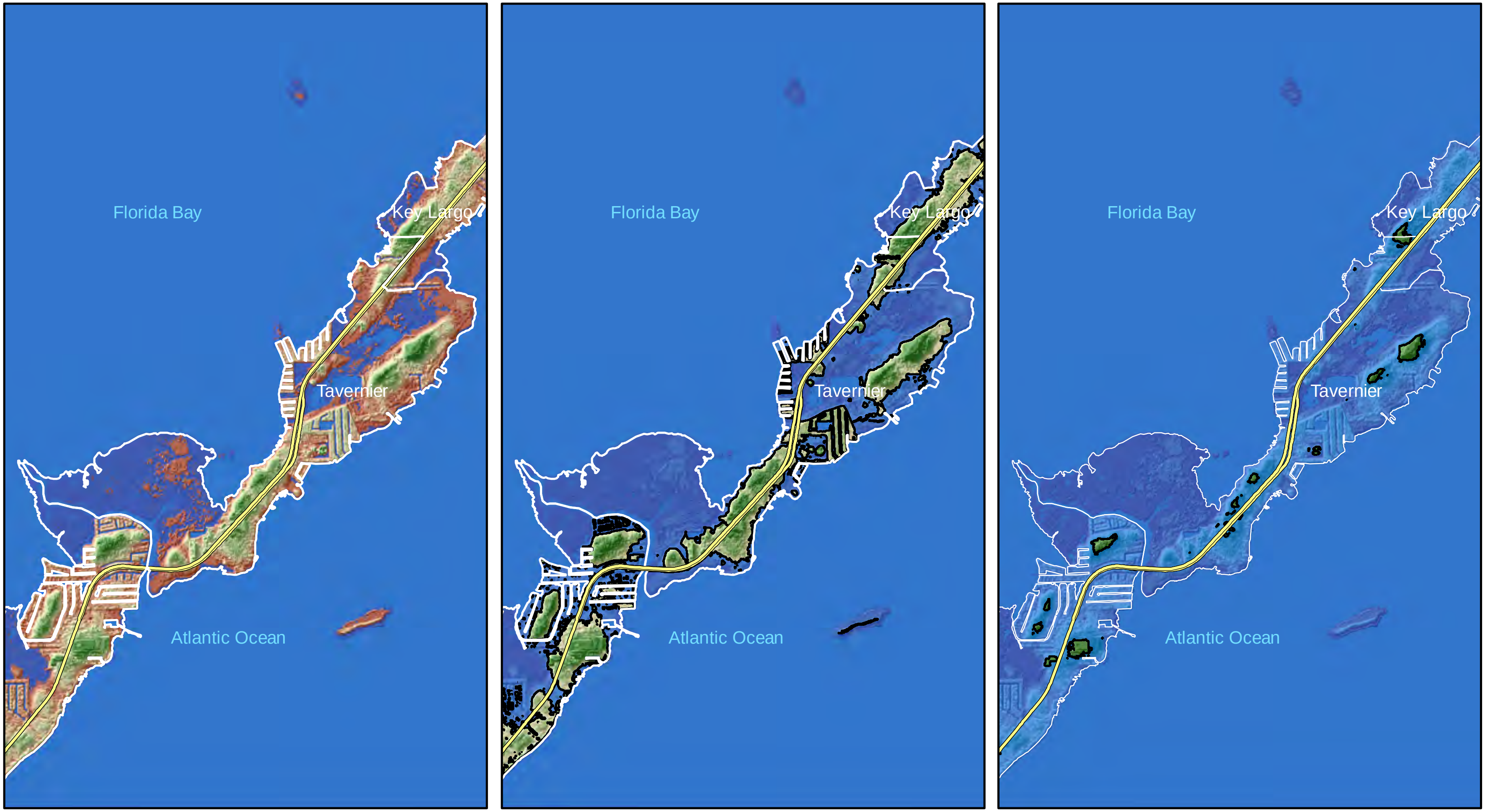
0 0.3750.75 1.5 2.25 3 Miles

Sea Level Rise in the Florida Keys, Florida by year 2100

Tavernier

Caleb Melancon
May 5, 2018

1:79,000



Present Sea Level | 1 ft Sea Level Rise | 3 ft Sea Level Rise

Explanation

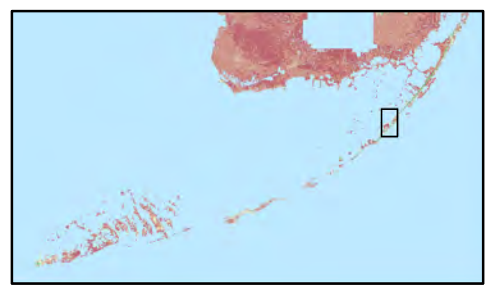
Elevation (ft)

<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

Florida State Road A1A

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**2.51**
Percent Submerged (1 ft):	**69.98%**
Percent Submerged (3 ft):	**98.15%**



Sea Level Rise in the Florida Keys, Florida by year 2100

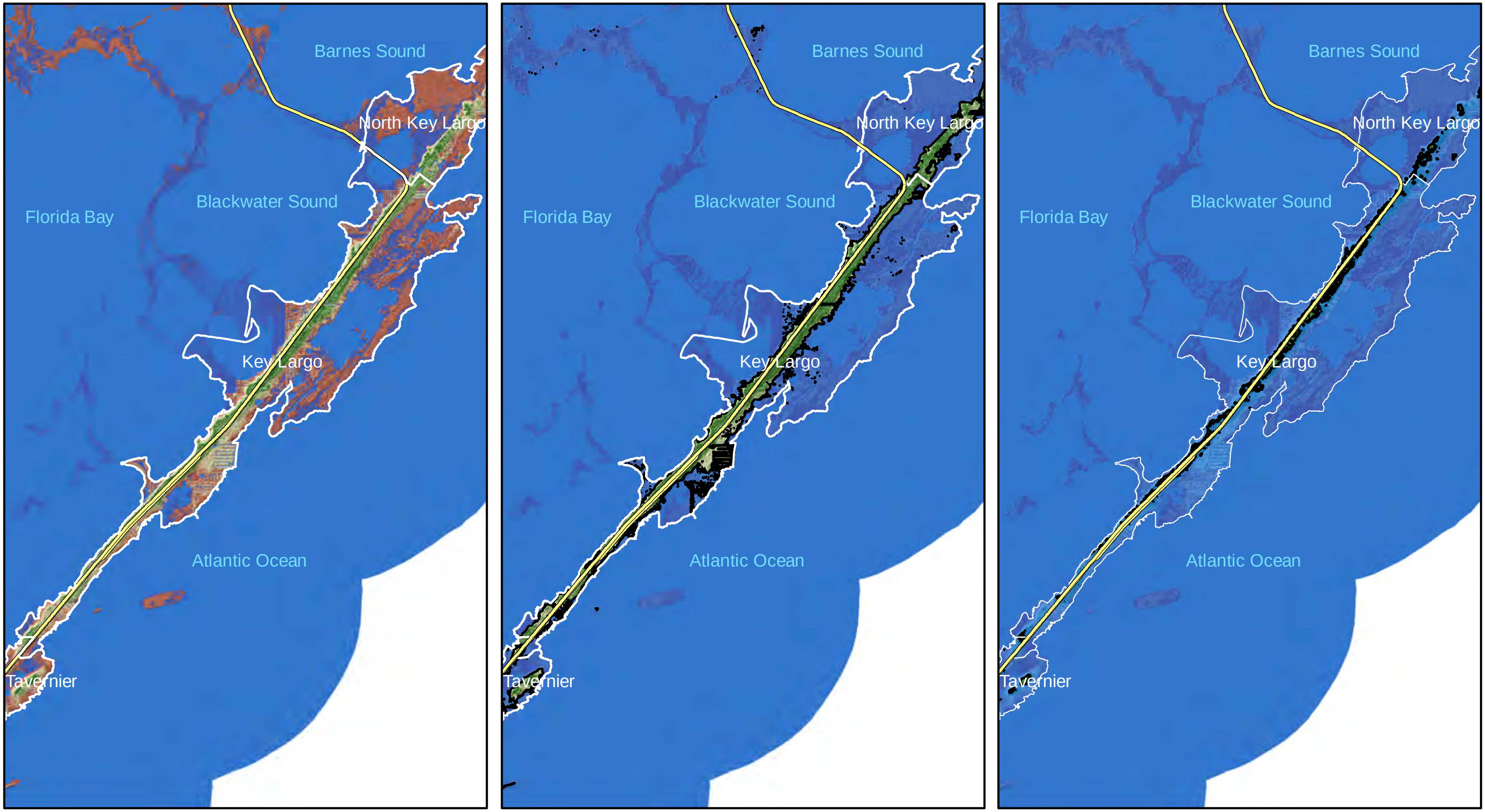
Caleb Melancon
May 5, 2018

Key Largo

N

0 0.75 1.5 3 4.5 6 Miles

1:207,000



Present Sea Level | 1 ft Sea Level Rise | 3 ft Sea Level Rise

Explanation

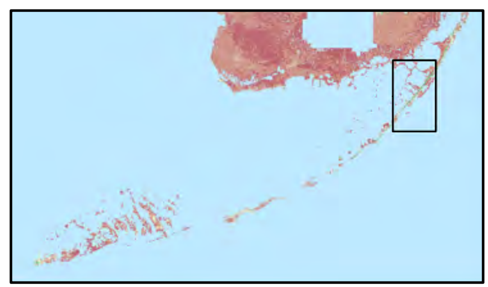
Elevation (ft)

<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

Florida State Road A1A

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**12.06**
Percent Submerged (1 ft):	**67.14%**
Percent Submerged (3 ft):	**93.22%**



N

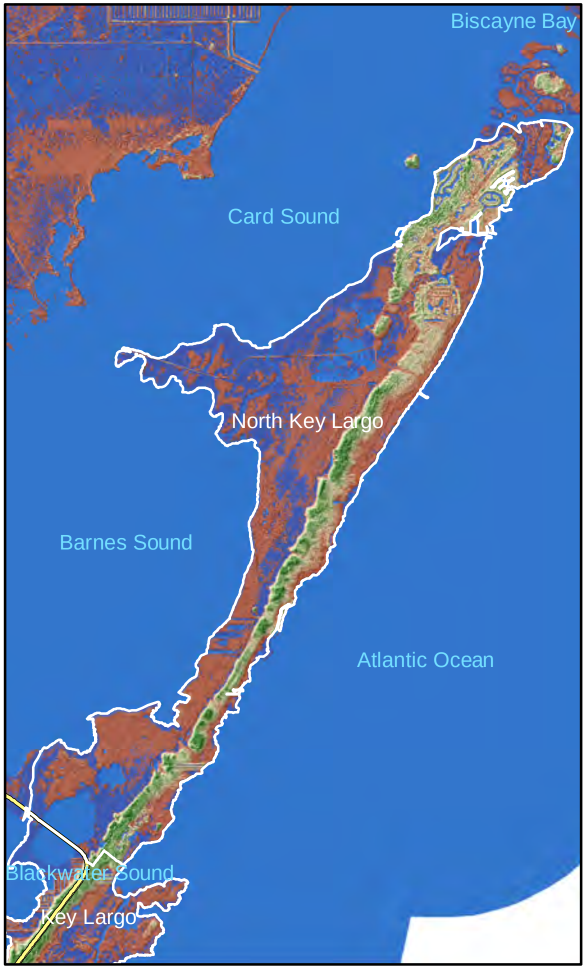
0 0.75 1.5 3 4.5 6 Miles

Sea Level Rise in the Florida Keys, Florida by year 2100

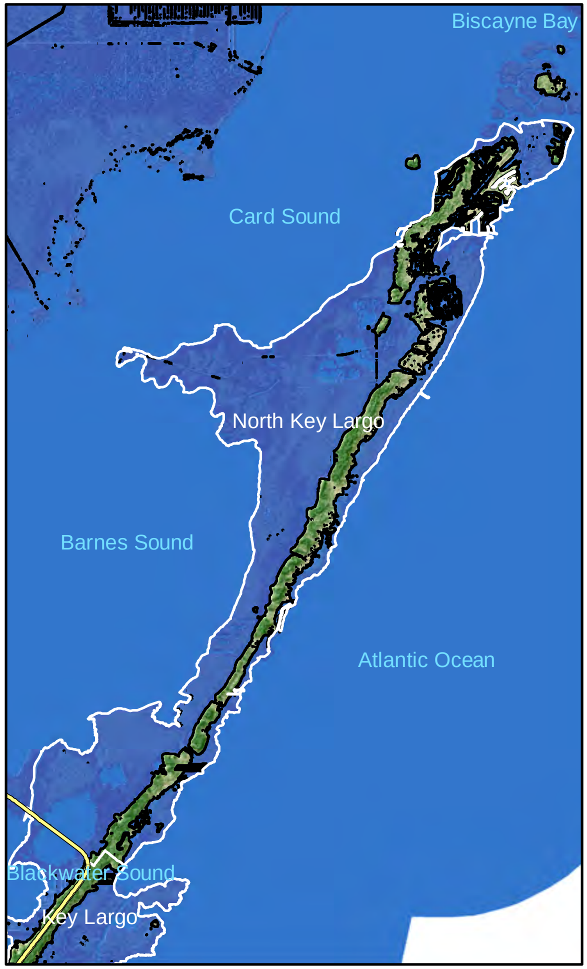
North Key Largo

Caleb Melancon
May 5, 2018

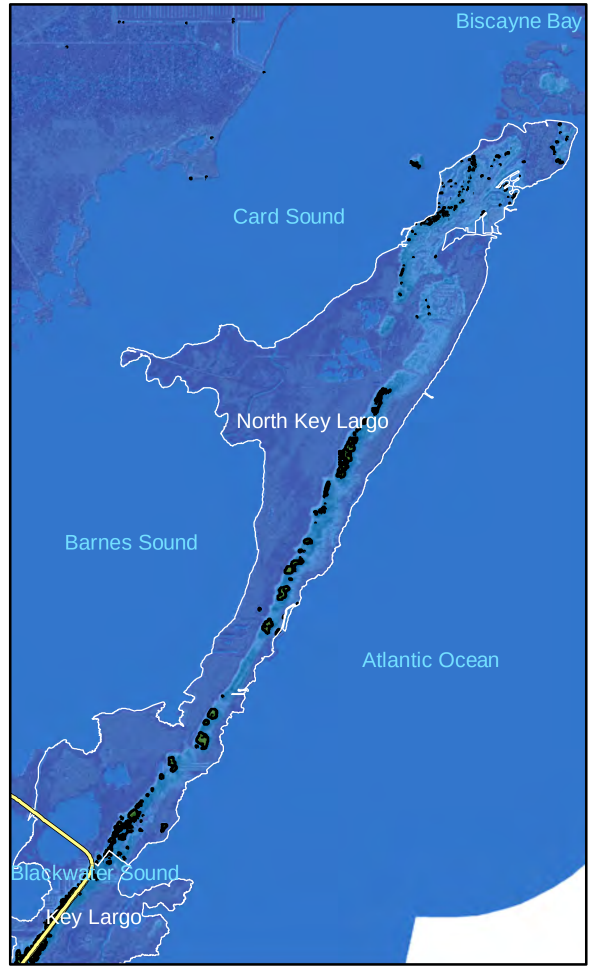
1:183,000



Present Sea Level



1 ft Sea Level Rise



3 ft Sea Level Rise

Explanation

Elevation (ft)

<0, 0 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, >3

Florida State Road A1A

NAD_1983_NSRS2007_Transverse_Mercator

Total Land Area msl (sq. mi):	**18.59**
Percent Submerged (1 ft):	**77.42%**
Percent Submerged (3 ft):	**98.39%**