Characterizing the Threats of Sea Level Rise to the Northern Gulf Coast

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Introduction

The global mean sea level is currently reported to be rising at a rate of 3.3 mm/yr and continuing to accelerate. Global mean sea level rise (MSLR) is driven by several factors. The two main categories of sea level rise are steric and eustatic effects. Steric effects involve the expansion of the volume of water and are due to fluctuations in ocean water density from temperature and salinity change. With the global mean temperature of the planet on the rise, ocean temperatures are also rising and showing up as expansion in measurements of sea level. Eustatic effects involve the change in sea level due to changes in the mass of water in the oceans. This includes precipitation, evaporation, and freshwater drainage into the oceans but also includes glacial and ice cap melt, as well as polar ice sheet melt. In particular, the recent melting of the Antarctic and Greenland ice sheets and the uncertainties with predicting future melting will dominate the predictions of total sea level rise in the next century. It is predicted that the global mean sea level could rise between 30 and 100cm, or over 3ft, in the 21st century depending on the dynamics of ice sheet melt.

The regions most vulnerable to the rising sea level are the low elevation coastal zones that are present in many nations across the globe. These regions are home to over 10% of the world's population, often in densely settled, highly urbanized areas. It is of importance not only to monitor the global MSLR, but also the local relative sea level rise (RSLR) with respect to the coastal land. A decrease in land elevation along a coast will contribute to an increase in relative sea level. When measuring and modeling RSLR, additional factors come into play that cause differences in MSLR and RSLR: the changes in elevation of coastal zones and river delta beds relative to which sea level is measured and directly observed/felt by the locals. Land compaction and subsidence is the decrease in elevation of land largely affected by ground water and oil withdrawal by humans. Additionally, the alteration of water flow particularly in rivers changes the sediment aggradation dynamics, which are the ways in which rivers naturally deposit and wash away sediment. Sediment aggradation contributes to the maintenance of wetland and river delta land masses against erosion. Altering of river flows through dams and urbanization limit sediment aggradation and contribute to a decrease in land mass over time, a decrease in elevation, and a higher relative sea level.

Problem Formulation

In this project, the present rate of relative sea level rise along the Northern Gulf Coast is mapped. Then regions falling within the zones threatened by predicted total 21st Century sea level rise are also shown. The total area of land predicted to be below sea level is calculated.

Data Collection

Data was sourced from NOAA SLR Data, and the U.S. Department of the Interior - Coastal Vulnerability to Sea-Level Rise: U.S. Gulf Coast.

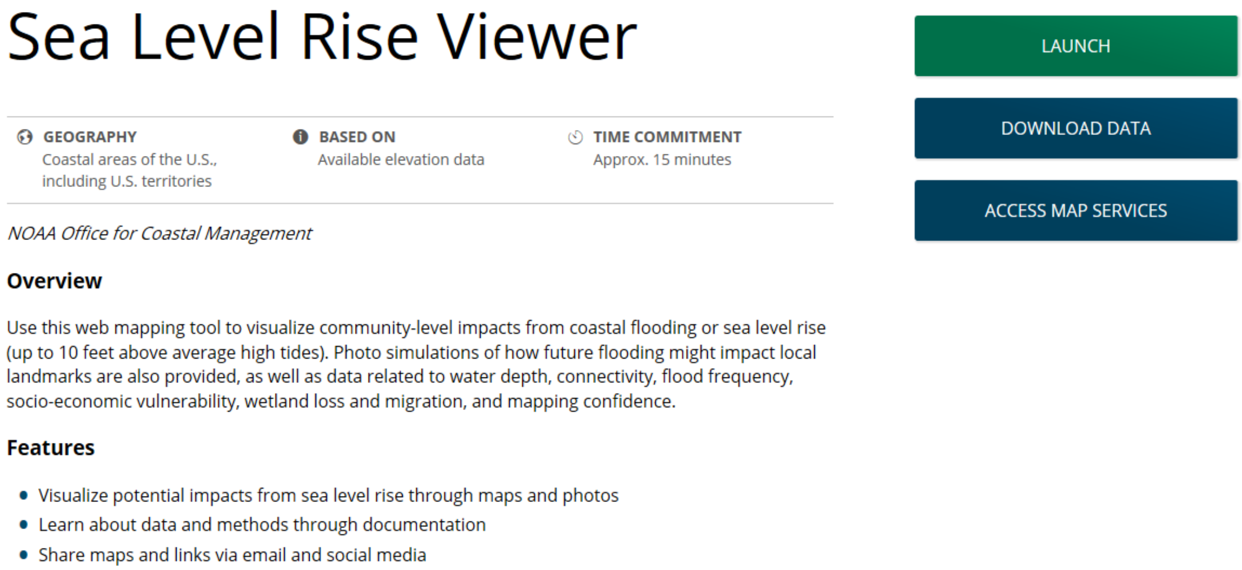


Figure 1: NOAA Sea Level Rise Viewer [1]

NOAA has an extensive network of tide gauge stations monitoring the ocean tides and sea level all over the US coasts. The NOAA SLR datasets contain information on regions vulnerable to different degrees of SLR from 0ft to up to 10ft rise. The data and maps in this tool illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction [1]. Water levels are relative to Mean Higher High Water (MHHW) (excludes wind driven tides) and elevations are derived from DEMS [1]. The intended use of this data is purely as a screening-tool for management decisions and future planning. The regions were broken into individual state coastlines which were further broken into several local segments. The regions at risk of varying SLR were stored as polygon features in individual geodatabase files. These files were stored in the NAD 83 coordinate system. The 3ft benchmark was used in this project to represent the upper limit on projected 21st Century Sea Level Rise.

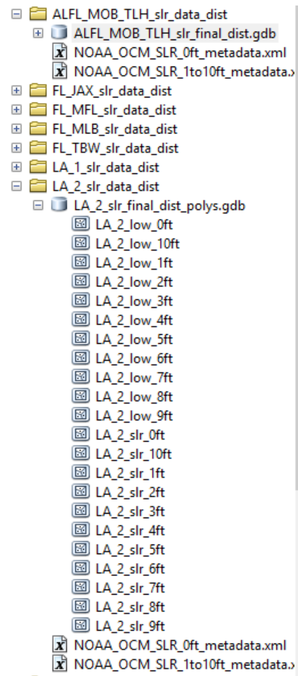


Figure 2: Screenshot of NOAA Deliverables in ArcCatalog [1]

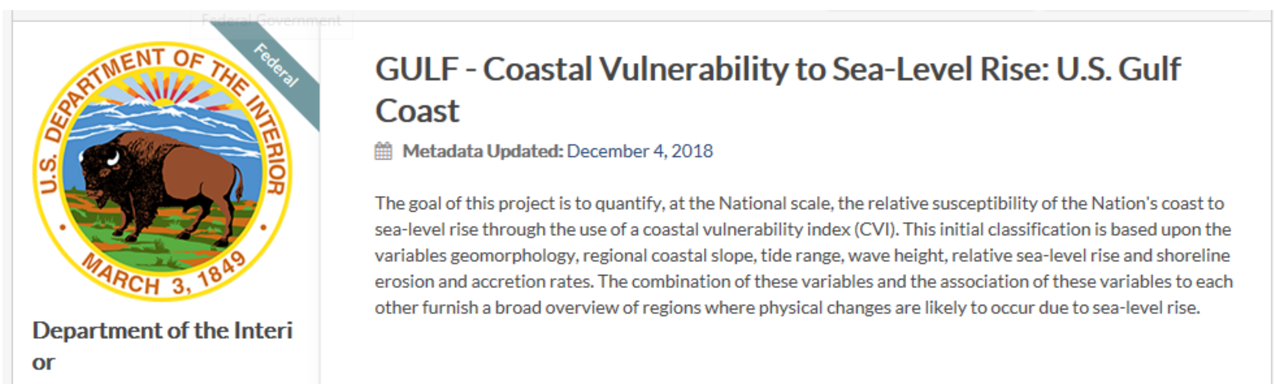


Figure 3: Department of the Interior GULF Coastal Vulnerability [2]

The U.S. Dept. of the Interior collected data that was used to generate the risk ratings in the Coastal Vulnerability Index (CVI) for problematic sea level rise based on the following factors: geomorphology, regional coastal slope, tide range, wave height, relative sea-level rise and shoreline erosion, and accretion rates. Their datasets include each of their factors and their weighting in order to generate the CVI risk ratings along the U.S. Gulf Coast. Also provided were shapefiles denoting North American Coastal boundaries. These files were stored in the NAD 83 coordinate system.

Also used were shapefiles of water bodies along the Gulf from the U.S. Environmental Protection Agency (USEPA) and the U.S. Geological Survey (USGS). These were used to correlate with relative sea level rise and erosion rates.

Figure 4: USGS and USEPA Coastal Waterbodies Data [3]

Quantifiable data on surface elevation changes and subsidence rates was not found readily available for incorporation into ArcGIS. NOAA had 10-m DEMs for the entire globe present in their database, however, there were difficulties clipping the massive global DEM to a usable area of interest.

Data Pre-processing

No pre-processing was necessary in order to incorporate the NOAA geodatabases or CVI shapefiles into ArcGIS. They were already present in acceptable formats with appropriate coordinate systems defined.

ArcGIS Processing

In order to calculate the amount of area along the Gulf Coast that would be subject to 3ft sea level rise, the polygons provided in the NOAA geodatabases needed to be clipped by the US coastal boundary provided in the CVI shapefile.

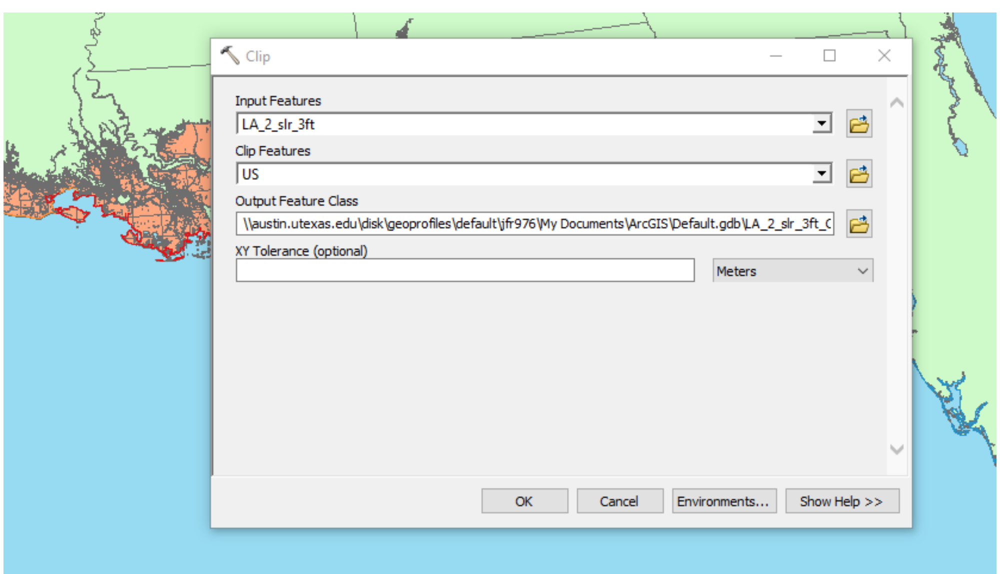


Figure 5: Area Clipping of Regions Vulnerable to Potential 3ft Sea Level Rise

At this point, the map was projected to the North American Lambert Conformal Conic in order to calculate shape areas by choosing the coordinate system of the data frame in Properties.

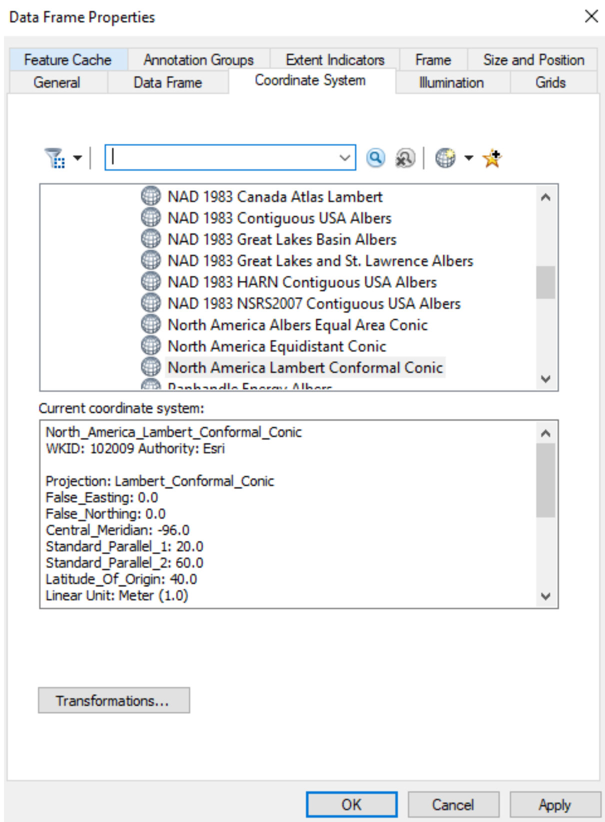
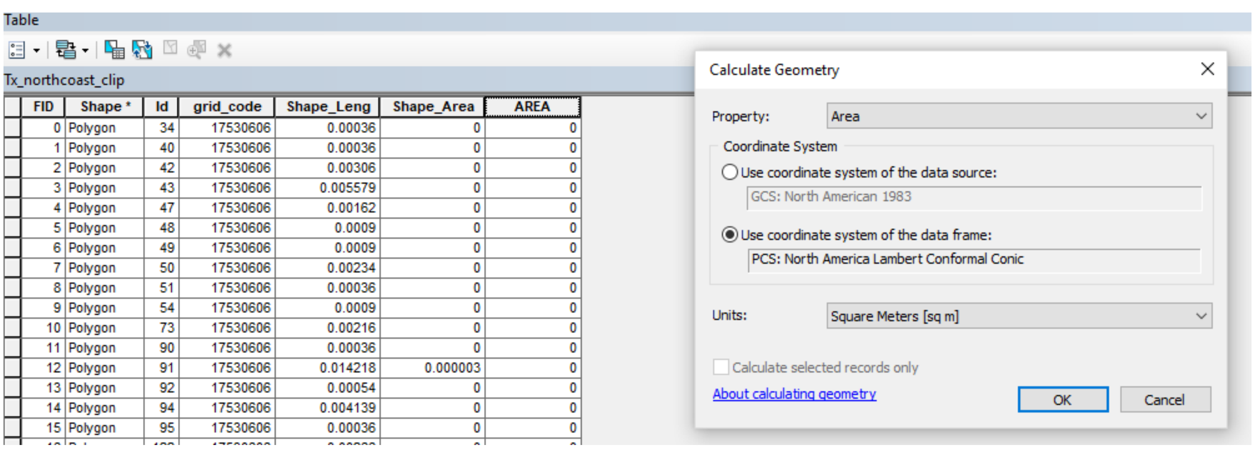


Figure 6: Projection into North American Lambert Conformal Conic

Then a new field was added to the attribute tables of the NOAA polygons called AREA and the calculate geometry tool was used to generate areas square kilometers.



FID	Shape *	Id	grid_code	Shape_Leng	Shape_Area	AREA
0	Polygon	34	17530606	0.00036	0	0
1	Polygon	40	17530606	0.00036	0	0
2	Polygon	42	17530606	0.00306	0	0
3	Polygon	43	17530606	0.005579	0	0
4	Polygon	47	17530606	0.00162	0	0
5	Polygon	48	17530606	0.0009	0	0
6	Polygon	49	17530606	0.0009	0	0
7	Polygon	50	17530606	0.00234	0	0
8	Polygon	51	17530606	0.00036	0	0
9	Polygon	54	17530606	0.0009	0	0
10	Polygon	73	17530606	0.00216	0	0
11	Polygon	90	17530606	0.00036	0	0
12	Polygon	91	17530606	0.014218	0.000003	0
13	Polygon	92	17530606	0.00054	0	0
14	Polygon	94	17530606	0.004139	0	0
15	Polygon	95	17530606	0.00036	0	0

Figure 7: Calculation of Area of Vulnerable Regions to 3ft Sea Level Rise

Using the CVI shapefile and mapping each of the values contained within the attribute table, it is possible to recalculate an assessment of coastal vulnerability. Specifically of interest in this project is the correlation between erosion rates and relative sea level rise. Erosion, coupled with decreased sediment aggradation, lead to higher rates of relative sea level rise than the observed global mean sea level rise.

TIDE_M_	TIDERISK	SLOPE___	SLOPERISK	ERR_M_YR_	ERRRISK	SL_MM_YR_	SLRISK	GEOM	WAVES_M_	WAVERISK	CVIVALUE	CVIRISK	TIDE	WAVES	SLOPE	EROSION	SEALEVEL	GEOMORPHOL	CVI
0.64	5	0.0129	5	0	3	2.5	3	4	0.4	1	12.25	2	Very High	Very Low	Very High	Moderate	Moderate	High	Moderate
0.64	5	0.0149	5	0	3	2.5	3	4	0.4	1	12.25	2	Very High	Very Low	Very High	Moderate	Moderate	High	Moderate
0.64	5	0.0142	5	0	3	2.5	3	4	0.4	1	12.25	2	Very High	Very Low	Very High	Moderate	Moderate	High	Moderate
0.64	5	0.0139	5	0	3	2.5	3	4	0.4	1	12.25	2	Very High	Very Low	Very High	Moderate	Moderate	High	Moderate
0.64	5	0.0158	5	0	3	2.5	3	4	0.4	1	12.25	2	Very High	Very Low	Very High	Moderate	Moderate	High	Moderate
0.64	5	0.0186	5	0	3	2.5	3	4	0.4	1	12.25	2	Very High	Very Low	Very High	Moderate	Moderate	High	Moderate
0.64	5	0.0174	5	0	3	2.5	3	4	0.4	1	12.25	2	Very High	Very Low	Very High	Moderate	Moderate	High	Moderate
0.62	5	0.0229	4	-0.066	3	2.5	3	4	0.4	1	10.95	2	Very High	Very Low	High	Moderate	Moderate	High	Moderate
0.62	5	0.0226	4	-0.072	3	2.5	3	4	0.4	1	10.95	2	Very High	Very Low	High	Moderate	Moderate	High	Moderate
0.633	5	0.0189	5	0	3	2.5	3	4	0.4	1	12.25	2	Very High	Very Low	Very High	Moderate	Moderate	High	Moderate
0.62	5	0.0229	4	-0.153	3	2.5	3	5	0.4	1	12.25	2	Very High	Very Low	High	Moderate	Moderate	Very High	Moderate
0.62	5	0.0238	4	-1.5	4	2.5	3	5	0.4	1	14.14	2	Very High	Very Low	High	High	Moderate	Very High	Moderate
0.636	5	0.0246	4	2	2	2.5	3	5	0.4	1	10	2	Very High	Very Low	High	Low	Moderate	Very High	Moderate
0.651	5	0.0206	5	-0.64	3	2.5	3	5	0.4	1	13.69	2	Very High	Very Low	Very High	Moderate	Moderate	Very High	Moderate
0.64	5	0.0241	4	2	2	2.5	3	5	0.4	1	10	2	Very High	Very Low	High	Low	Moderate	Very High	Moderate
0.677	5	0.0215	5	2	2	2.5	3	5	0.4	1	11.18	2	Very High	Very Low	Very High	Low	Moderate	Very High	Moderate
0.78	5	0.0221	4	-1.5	4	2.5	3	5	0.4	1	14.14	2	Very High	Very Low	High	High	Moderate	Very High	Moderate
0.78	5	0.025	4	-1.5	4	2.5	3	5	0.4	1	14.14	2	Very High	Very Low	High	High	Moderate	Very High	Moderate
0.78	5	0.0242	4	-1.5	4	2.5	3	5	0.4	1	14.14	2	Very High	Very Low	High	High	Moderate	Very High	Moderate
0.78	5	0.025	4	-1.5	4	2.5	3	5	0.4	1	14.14	2	Very High	Very Low	High	High	Moderate	Very High	Moderate
0.78	5	0.0259	4	-1.5	4	2.5	3	5	0.4	1	14.14	2	Very High	Very Low	High	High	Moderate	Very High	Moderate
0.78	5	0.0222	4	2	2	2.5	3	5	0.4	1	10	2	Very High	Very Low	High	Low	Moderate	Very High	Moderate

Figure 8: CVI Data Attribute Table for Recalculation of Sea Level Rise Risk [2]

Results and Conclusions

Given predictions of 21st Century global mean sea level rise reaching a maximum of over 3ft by 2100, the regions vulnerable to 3ft of sea level rise were isolated. Calculating the areas of the regions, approximately 32,232 square kilometers of coastal land along the Gulf will be greatly affected or lost to the rising oceans. Particularly at risk is the Mississippi Delta, whose already low elevation means that any change in sea level would consume large portions of land. Of the square kilometers lost, 24,576 square kilometers of land are within Louisiana alone, 76% of the total loss. Furthermore, the Mississippi Delta is already showing relative sea level rise rates higher than the global mean. With no acceleration, the sea would rise over 1m in 100 years. Accounting for global acceleration of sea level rise due to the melting polar ice sheets, the rise witnessed in this region could be well over 1m. In the future, relative sea level rise projected over the next century could be used to produce more accurate maps of affected areas. Not included in the NOAA data are rates of erosion, subsidence, and future urbanization which would alter the projected vulnerabilities. Additionally, DEMs and topographical maps overlain underneath would better illustrate other geological factors that might contribute to the coastline receding such as slope of the coastal land and terrain type (marshes, wetlands, rocky or sandy beaches).

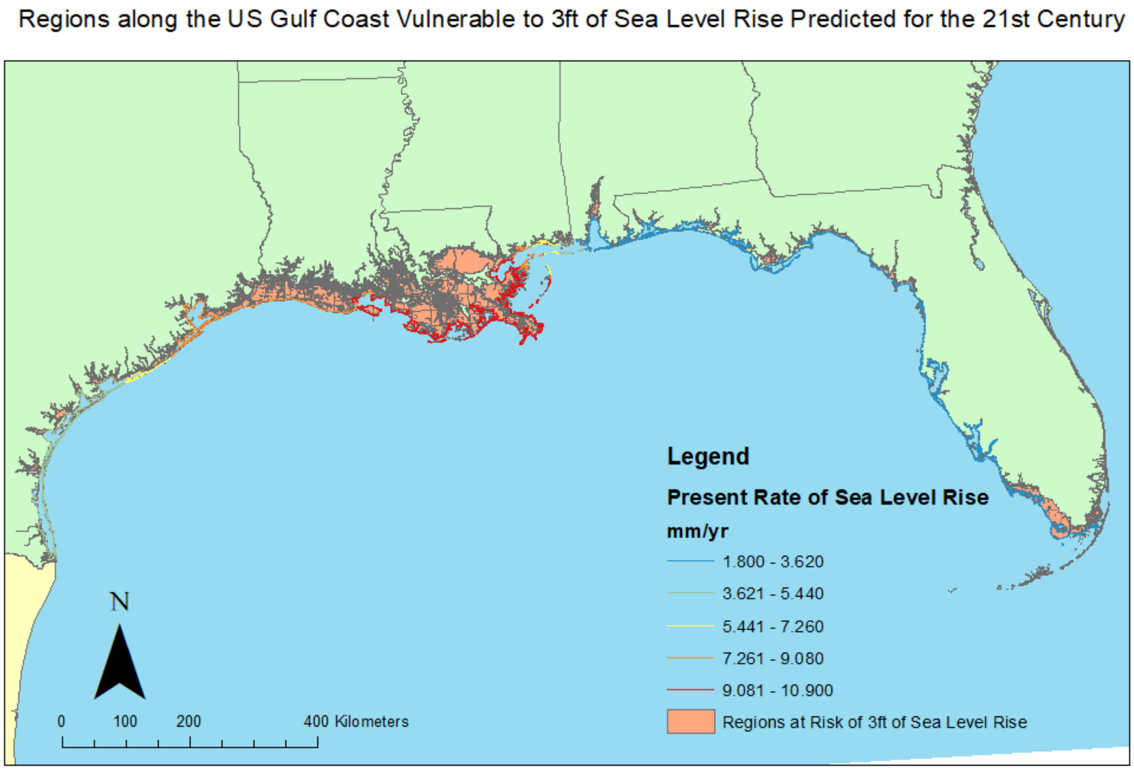


Figure 9: Regions along the US Gulf Coast vulnerable to 3ft of Sea Level Rise predicted for the 21st Century

In the second map, we show the present rate of sea level rise correlated with the rate of erosion seen at the coast. As mentioned earlier, altered sediment aggradation of the Mississippi along with continued erosion are contributing greatly to the higher than average relative mean sea level rise. It is also interesting to note the overlap between regions of high relative sea level rise, erosion, and the presence of bodies of water, particularly swamps and marshes.

Not seen in the map are rates of land compaction or subsidence, although it is uncertain if those effects were isolated from the observed rate of erosion. There is sparse data on measured subsidence. One source to see overall elevation change would be to look at GPS position time series for stations and tide gauges along the coast. A limiting factor however is the accuracy of GPS and the Terrestrial Reference Systems. In order to track changes in elevation on the order of mm/yr, knowledge of locations within a terrestrial reference frame and their rate of movement would need accuracies of 0.1mm/yr. A source to visualize mean sea level rise would be from satellite radar altimetry. It would be interesting to correlate a continuous global sea level rise measurement to local point measurements of sea level rise and changes in coastal elevation.

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12/6/18

Relative Sea Level Rise (SLR) and Level of Coastal Erosion
Along the US Gulf Coast

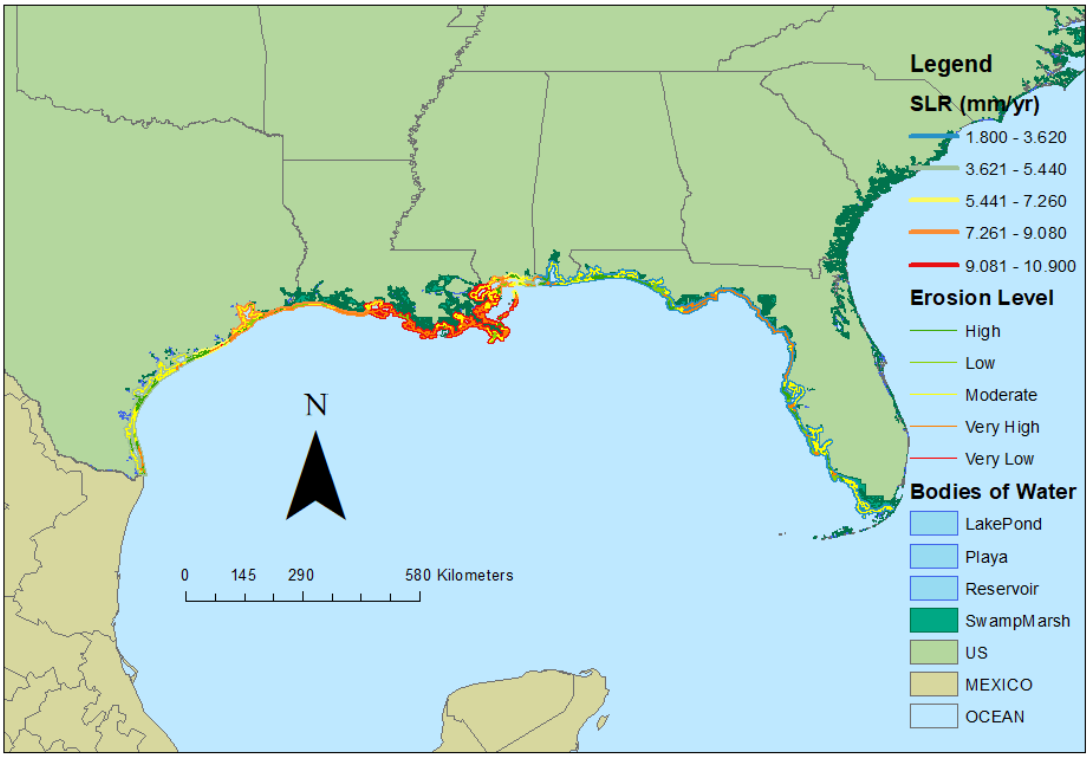

Figure 10: Relative Sea Level Rise and Level of Coastal Erosion Along the US Gulf Coast

Resources:

[1] https://coast.noaa.gov/slrdata/ (Metadata updated September 2018)

[2] https://catalog.data.gov/dataset/gulf-coastal-vulnerability-to-sea-level-rise-u-s-gulf-coast (Metadata updated as of Dec 4 2018)

[3] https://www.arcgis.com/home/item.html?id=fb550b02a38f4d5e8499da658f49643d

Title: Gulf of Mexico coastal waterbodies
Credits: U.S. Environmental Protection Agency (USEPA) and the U.S. Geological Survey (USGS).
Publication Date: 6/16/2010
Publisher: Conservation Biology Institute

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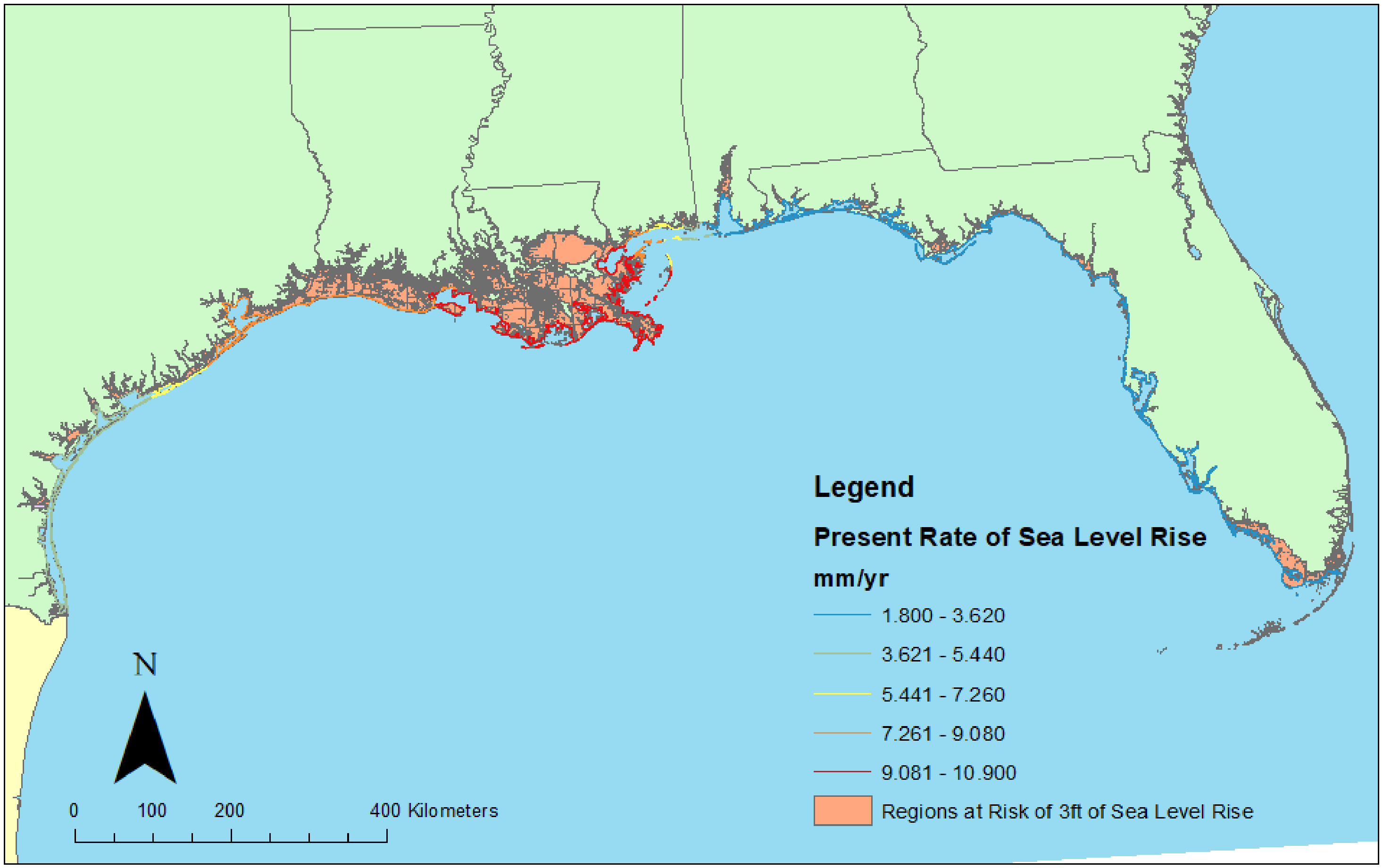
Regions along the US Gulf Coast Vulnerable to 3ft of Sea Level Rise Predicted for the 21st Century



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Relative Sea Level Rise (SLR) and Level of Coastal Erosion Along the US Gulf Coast