Floridian Coastline Recession

February 18, 2008

Abstract

Rising sea levels are of significant concern as global temperatures continue to mount. Predicted increases in sea level place coastal regions and cities in danger. This danger is far from uniform; many factors contribute to the relative infiltration of water and its consequent effect on land. Naive considerations of elevation alone would result in a poor model of what happens in real life. This is especially true for the state of Florida, whose low elevation, extensive coastal regions, and variety of shoreline development make it particularly susceptible to inhomogeneous effects due to climate change. To evaluate these effects in their full extent and diversity, we present a model that considers a broad range of factors, taking into account such parameters as coastal convexity, drainage characteristics, and vegetal population densities. Furthermore, our model accounts for the dynamic nature of evolving coastlines by constructing a field of vectors normal to the coast at any given time, and utilizing this field to direct the evolution of the coast over the next time step. Coastal recession, as directed by these vectors, is then scaled by local hazard factors, to obtain a refined model of coastline change. The results and implications of this model are evaluated in this paper.

Contents

1 Introduction

Global climate change and the ensuing rise in sea level due to the melting of the north polar ice cap will have a profound effect on water infiltration along continental coastlines. Depending on the geographical features of a given region, land surface can recede substantially as a result of even a small rise in sea level. Because coastal geographies change over time and predictions regarding sea level rise tend to vary among different studies, the effects and extent of water infiltration are difficult to predict. Floridas susceptibility attributed to its geographic location and uniformly low elevation - makes it an important case study and model for this global phenomenon. Moreover, the fact that Floridas metropolitan areas are concentrated on the coasts is representative of population distributions for the rest of the world. To best model the effects of sea level rise on Floridian coasts over time, we apply previously made global predictions to the time-dependent geographic attributes of the state. Specifically, implementing documented flood hazard data [1] for Floridian coastlines and a range of predictions for sea-level rise, we construct a model of coastal recession using a time-dependent vector field.

2 Variations in Global Sea Level Rise Predictions

Even amongst the most well-documented studies of climate change, there are considerable disparaties in the predicted extent of sea level increase over the next 100 years. Within a given study, predictions vary by region, as well. In particular, for the next 100 years, global average sea level rise predictions vary from 8 cm to 88 cm, while predictions for Florida range from 0 cm to 50 cm. Narrowing our focus to Florida over the next 50 years, predictions suggest sea level increase anywhere between 0 cm and 20 cm [3]. Thus, in order to accurately gauge the effects of climate change, it is important that our model be able to adapt to different predictions, while taking into account Florida's unique geographic disposition. Below, we will assume an extreme situation. In particular, we will take the sea level increase as a function of time to be given by

$$f(t) = 9.675 \cdot t \text{ mm/yr} + \frac{1}{2}t^2 \cdot 0.013 \text{ mm/yr}^2,$$

where t is measured in years.

3 Elevation Considerations

Perhaps the most primitive approach to gauging water infiltration along continental coastlines is considering the implications of elevation alone. As a benchmark, we take note of the results of this model. We assume that the rate of sea level increase around Florida has roughly the global average value. (function).

Beginning with 45,342 points of elevation data from the National Geophysical Data Center [4], we linearly extrapolated elevation values for midpoint regions in order to get a better idea of the extent of coastline inundation. As exhibited in Figures 1 and 2 below, even after a time step of 50 years, the extent of water infiltration is difficult to gauge when considering Florida in its entirety. Thus, we opt to consider coastal effects on a finer scale. Below are the results of this model for (some place) over 50 years. We will compare these results with the results of our model, as a check on our model's feasibility.

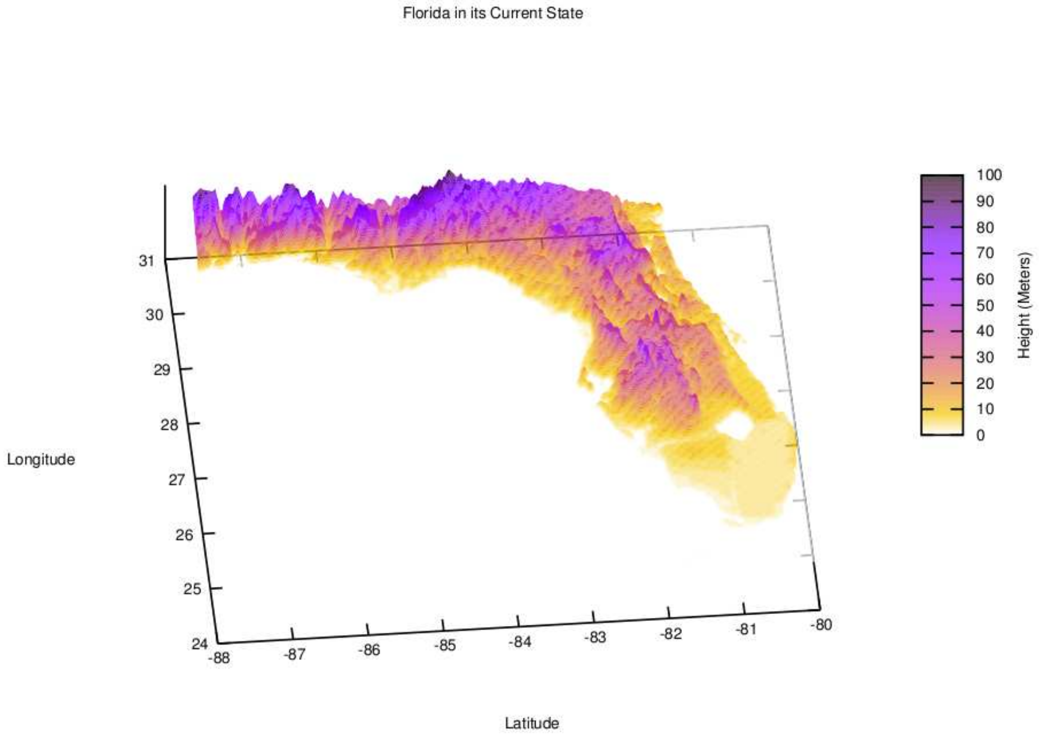

Figure 1: Florida before 0.5m sea level increase.

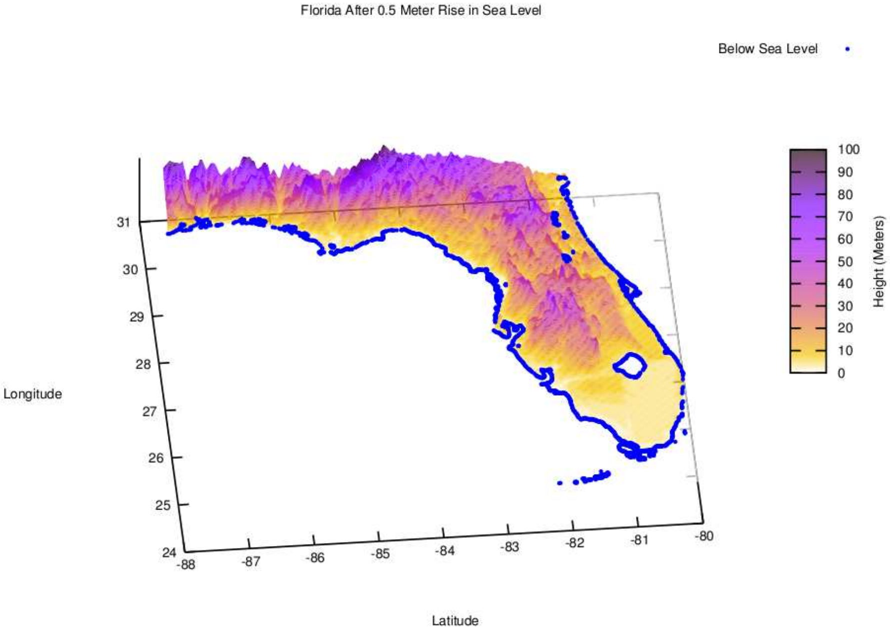

Figure 2: Florida after 0.5m sea level increase, based solely on elevation data.

3.1 Factors Contributing to Flood Susceptibility

The elevation model has obvious deficiencies. It neglects the effects of coastal shape, manmade structures, relative position to inland bodies of water, weather patterns, and many other factors. For example, basins with as little as 5% lake and wetland area may have 40% to 60% lower flood peaks than comparable basins without such hydrologic features[2]. We wish to acknowledge the contribution of these parameters in our model. In particular, we identify the level of coastal flood risk due to sea level rise using the results of a Florida coastline study done at Duke University [1]. A table of factors that are taken into consideration appears on the following page.

To implement our model, we used the National Geophysical Data Center's Coastline Extractor feature to obtain 85,000 points of longitude-latitude data to generate a detailed map of Florida's existing coastline[5]. To consider the above factors in our model, we obtained risk data for Florida's eastern coast from a sequence of maps detailing the vulnerability of each section of shoreline, in accordance with the Duke study[1]. We then plotted risk values as a function of latitude and longitude (which were found using Google Map features) for the eastern coast of Florida, and then imposed this risk data on our generated map of Florida's coastline. We then proceeded to use this criteria for our water infiltration model.

Parameter	**High**	**Moderate**	**Low**
Site elevation	< 10 feet	10-20 feet	> 20 feet
Beach width, slope, and thickness	Narrow and flat, thin with mud, peat, or stumps exposed	Wide and flat, or narrow and steep; not eroding	Wide with well-developed berm; accreting
Overwash	Overwash aprson or terrace (frequent overwash)	Overwash fans (occasional overwash)	No overwash
Site position relative to inlet of river mouth	Very near	Within sight	Distant
Dune configuration	No dunes (see Overwash)	Low, narrow, or discontinuous dunes	High (30 feet), continuous, wide, unbreached ridge, dune field
Coastal shape	Concave or embayed	Straight	Convex
Vegetation on Site	Little, toppled, or immature vegetation	Well-established shrubs and grasses, none toppled	Mature vegetation, forested, no evidence of erosion
Drainage	Poor	Moderate	Good
Area landward of site	Lagoon, marsh, or river	Floodplain or low-elevation terrace	Upland
Natural offshore protection	None, open water	Frequent bars offshore	Submerged reef, limited fetch
Offshore shelf	Wide and shallow	Moderate	Steep and narrow
Engineering structures	Shore-hardening structures and/or beach fill	Few structures and infrequent need for beach fill	Natural beach free of engineering structures

Figure 3: Factors taken into account when determining flood risk.

3.2 Modeling Water Infiltration

Because coastlines are always evolving we wish to construct a model that takes this fact into account. Fractals are one way of representing coastlines[7]. It is known that coasts naturally evolve in the same manner as fractal patterns[6]. However, the Floridian coastline is far from natural due to the impact of human development. Likewise we want to be able to consider water permeability based on hazard levels for points along the coast. Moreover we note that shores experience erosion due to everyday wave patterns along the coast. Thus our model focuses on the effects of erosion perpendicular to the current shoreline at any given time, taking into account the level of risk for each point along the coast.

We model the coastline using vectors. That is, for every point on the coast, we generate a vector that points inland perpendicular to the coastline. The vector at each point is determined by taking the points on either side of the given point and constructing a vector that is normal to the vector connecting these points (see Figure 4) and pointing inland.

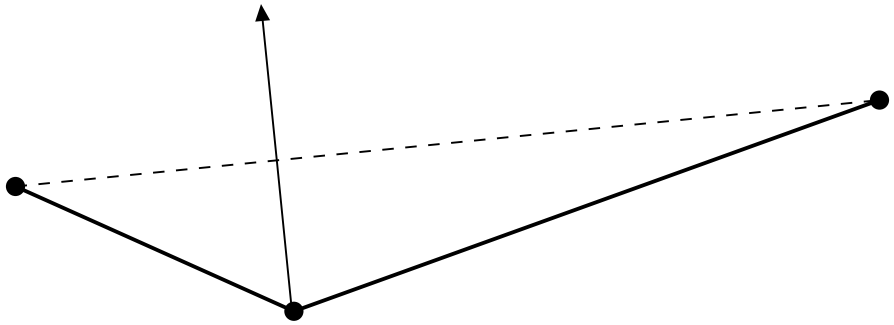

Figure 4: Respresentation of normal vector constructed by taking the normal to the line between adjacent points along Florida's coastline.

Each vector is initially given a magnitude which corresponds to the rate of sea level rise. Instead of assuming an even rate of sea level rise everywhere along the coast, we implement our hazard factor data (see Figure) to make a correction factor for each vector. We do this as follows:

- Select a point on the current coastline.
- Find the nearest point for which hazard data exists (typically not more than 100 meters away).
- Assume the point on the coast has the same hazard value as the selected hazard point.
- Determine correction factor based on this hazard value by multiplying the normal vector by the scalar corresponding to the hazard value.

- We then translate the initial point to the end of the scaled normal vector, and repeat this process.

Each iteration of the above process represents 10 years of elapsed time. Thus, the result after n iterations is the predicted coast of Florida in $n \times 10$ years. Results, where they are noticeable, are shown below.

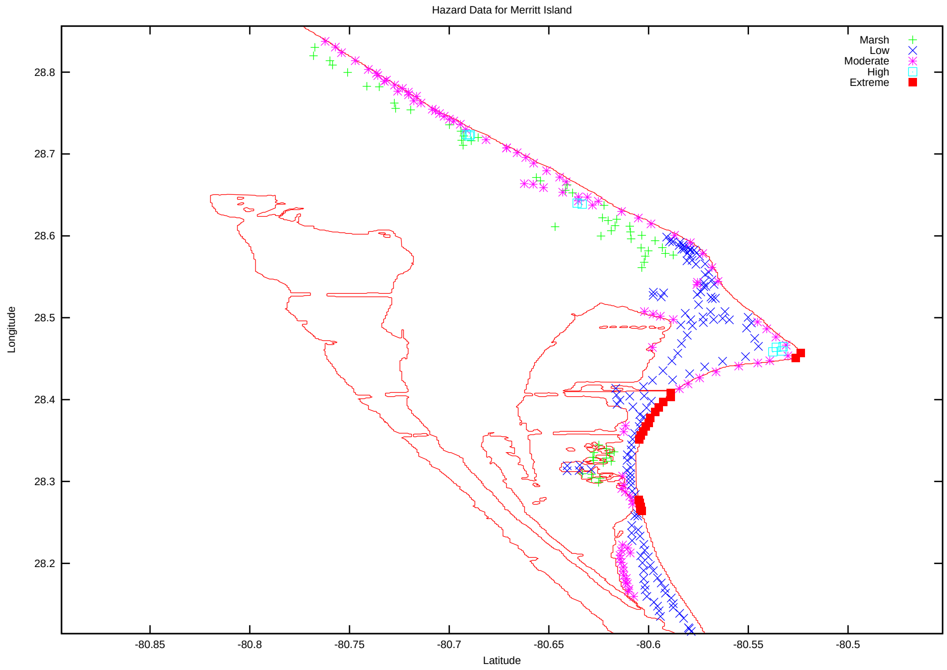

Figure 5: Hazard values imposed on a coastline map.

4 Considering Effect on Cities

Considering the extreme case of global sea level rise, which overestimates expected sea level increases around Florida by several times, we found that there is little threat posed to cities along the coast. In particular, the application of our model to the Tampa region shows that the city will experience almost no threat of flooding due to sea level increase - see Figures below. Consequently there is no impending crisis as concerns cities on the coast. However, we recommend that coastline cities consider the hazard evaluations included in this paper so that they are better prepared for more extreme events beyond the window of 50 years.

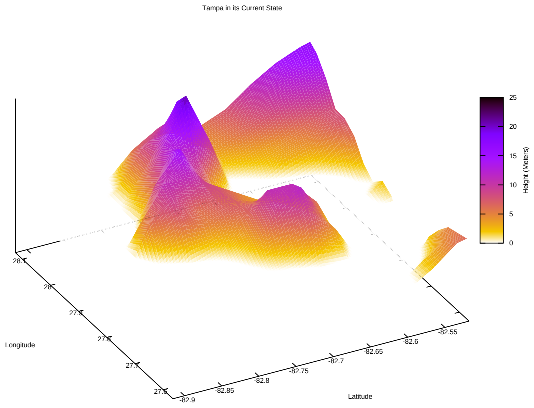

Figure 6: A high-risk region of Tampa before any sea level increase.

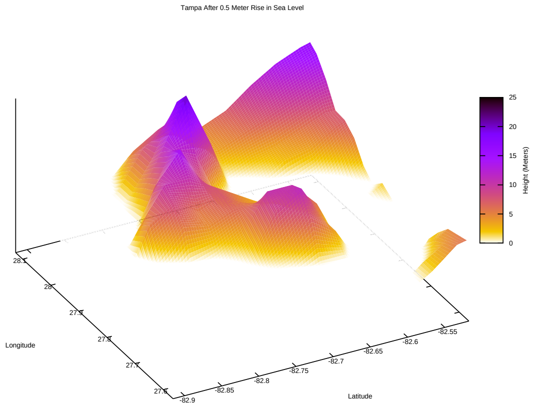

Figure 7: The same high-risk region of Tampa after 0.5m of sea level increase.

5 Conclusion

In considering the time-dependent coastline shrinkage of Florida's shores, we found that water infiltration will be minimal as pertains to cities. While we consider the most extreme case of sea level rise, other rates of sea level increase can be modeled by appropriately normalizing the normal vectors used in our model. Furthermore, a more detailed set of elevation data and flood risk levels would have enabled us to more accurately model these effects.

6 References

References

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