Introduction

Take a bath…but be careful because, as the north polar ice cap melts due to predicted increasing global temperatures, the next time you go out on your back patio, you may find yourself in your own private beach resort. Our goal in this problem is to consider the effects that the melting of the north polar ice cap would have on land. Also, we specifically model how it would impact Florida's coast, specifically large metropolitan areas, over the next fifty years in decade intervals.

Definitions

- **Retreat:** Using an equation called Bruun's Rule, one can model rate of retreat, R, of a shoreline, based on the sea level rise, S, and the slope angle of the beach, θ. The equation is:

$$R = S(\cot\theta)$$

- **Rise in sea level:** The rise in sea level, S (in meters/year).
- **Beach Angle:** The slope angle of the beach, θ, measured in degrees.

Assumptions

- We have accurate data about varying sea levels over time and that the distribution is large enough to be considered normal
- The average global temperature is changing at a fixed constant rate over time
- Sea level change is uniform and immediate
- Sea level rise is linear
- All of a state or country's coastline is beach or sedimentary (erodible) and non-marshland
- The shore being eroded is a single long beach with no factors such as large storms or beach replenishment over time
- The primary (first set of) dunes are moving relative to and at an equal rate to the erosion
- The mean change in the American Eastern Seaboard's sea level is the mean sea level change for the world. This is due to the fact that there is a main current from the thermohaline circulation (current flow around the world due to water density) that runs roughly parallel to the American Eastern Seaboard.
- For our erosion model, the beach angle, θ, is constant at 10 degrees. Most beaches have slopes that are gentle (very low grade) so an approximation of 10 degrees is appropriate.
- Florida's coast is a closed system with little to no outside effect. This is important because Bruun's Rule is extremely accurate for closed systems.

Problem Formulation

We want to find the average (mean) sea level rise for the oceans of the world. The data used to model this is quite accurate and of obvious use. The data was collected by the National Oceanic and Atmospheric Administration (NOAA) from 1988 to 2008 using approximately 60 research stations across the American Eastern Seaboard. Using this raw data from NOAA, we were able to roughly compute an average mean sea level rise in the Atlantic Ocean and, by our assumptions, the oceans of the world. We looked at the data and from this we modeled the overall ocean sea level rise as a linear function of the form $SLR = \mu_T t + SLR_0$ where:

- SLR = Sea Level Rise (meters) since 1988
- μ_T = Mean Sea Level Rise (meters). This was calculated by taking the average sea level of all the data collected from 1988 to 2008
- t = time (years); where t = 0 corresponds to the year 1988
- SLR_0 = Initial Seal Level (meters); calculated by taking the average sea level of all stations on the American Eastern Seaboard on January 1, 1988

Results – Basic Model

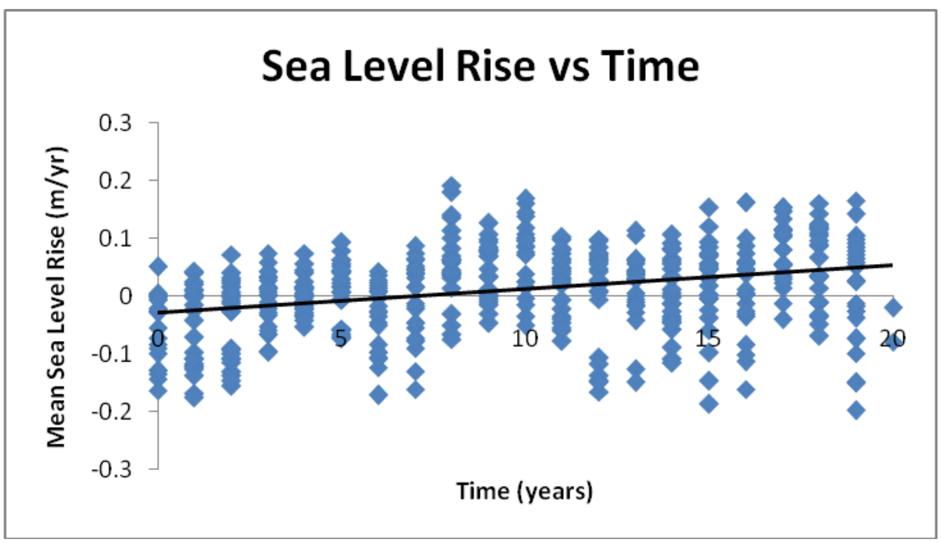
Since the data collected was given in monthly increments we must convert our answers from meters per month into meters per year by dividing by 12. We implemented our simple model for the sea level rise of Florida using the following equation:

$$SLR = 0.00098483t - 0.0113292$$

Applying this basic model to Florida's coastline, we can predict the rise in sea level for every decade. Using our model, we will model the change in sea level per decade compared to the current level (2008).

Decades	Rise in Sea Level since 2008 (in meters)
2008-2017	0.0098896
2018-2027	0.0196966
2028-2037	0.0295449
2038-2047	0.0393932
2048-2057	0.0492415

We can also how our model looks when compared to actual data from NOAA for one of the data collection stations.



From this we can see that, per decade, the average rise in sea level is about ten millimeters. This will have an effect on Florida's coast and large urban areas. Specifically, we will discuss the effects on major cities with populations of over 150,000 residents. These cities include Cape Coral, Pembroke Pines, Fort Lauderdale, Orlando, Hialeah, St. Petersburg, Tampa, Miami, and Jacksonville.

Results – Enhanced Model

Now we shall try applying these data to an enhanced model which will also take into account the erosion of the beaches. Using Bruun's Rule, $R = S(\cot\theta)$, and the model for the average sea level rise above, we can make an enhanced model that will predict the erosion per year given by

$$R = \cot(10^{o})(0.00098483t - 0.0113292)$$

Where R is the rate of erosion in meters per year and t is the time in years (t = 0 corresponds to 1988). A basic table shows the erosion rate of Florida over the fifty year period as follows

Decades	Erosion of Shoreline since 2008 (in meters)
2008-2017	0.056087
2018-2027	0.111705
2028-2037	0.167557
2038-2047	0.223410
2048-2057	0.279262

This equates to a rough loss of 55 millimeters of beach every decade.

Analysis

There are two primary ways to respond to the rising sea level: Defend the current coastline or allow it to naturally migrate inland (Oppenheimer). Each of these options has a large impact on the surrounding cities. Poor planning in zoning of beach areas and sheltering dunes make a large impact on the overall effect of erosion and sea level rise on a city. However, this affects the surrounding city by reducing the expansion and growth of the city in the coastal direction. Florida could implement a system of purchasing key beach or land zones that impact flood prone or vulnerable areas of land. Naturally allowing the beach to migrate inland is also quite difficult. Using external barriers to deflect and blunt the effects of waves on the beaches works only to a certain extent before they actually begin to hurt the system more than to help (Oppenheimer). The only true way to allow the coast to adapt is to stop the development of coastal zones. This reduction, and ideal cessation, allows the coast to adapt and evolve at a similar pace as the rising sea level.

Such limitations will curve the growth of large cities such as Tampa or Jacksonville by not only curtailing development but also because the encroaching water levels will begin to claim current buildings, both private and industrial. On top of this, many cities will begin to "water proof" their buildings, essentially trying to limit the amount of damage caused by both rising water levels and erosion.

Almost all of the cities listed contain at least 4% water inside the total area of the city. Only Hialeah has less at 2.53% water ("Florida"). The Intergovernmental Panel on Climate Change (IPCC) suggests that nearly 33% of wetlands could be converted to open water by 2080 (Coastal Zones…). This will increase the probability and frequency of flooding due to severe weather (i.e. hurricanes, tropical storms, and strong thunderstorms). On top of this, according to the City of Tampa's hazards section, it is predicted that the probability of at least one major hurricane (category 3,4, or 5) hitting the U.S. East Coast, including the peninsula of Florida, is 50%, which is far above the average for the last century of 31% (Tampa Emergency...).

Strengths

- the accuracy of our sea level model when compared to current predictions for sea level rise
- the accuracy of the data with which we have used to perform our regression
- Bruun's Rule for the enhanced model
- Normalcy
- Realistic and probable responses to rising sea level threat

Weaknesses

- The coasts are not a true closed system. There are many factors that influence erosion besides beach slope (i.e. lateral drift of sediment, particle size)
- The model is based off of data from 1988 and could be more accurate if data prior to 1988 was used. This data was not used because much of it was incomplete or undocumented for large spans of time (i.e. more than one year)

Future Considerations

It would be interesting and fun to model coast and beach system in a system of partial differential equations or at least a dependent system of equations that would factor in more variables such as wind, sediment composition, particle size, and major storms. Also, it would be good to model how a manmade structure such as a jetty would impact coastal erosion.

Conclusion

We set out to create a model to determine the effects of the melting of the north polar ice cap due to the rising global temperature on land. Specifically looking at the effect on Florida's coast and Florida's large metropolitan areas over the next fifty years using decade intervals.

We began by modeling the expected sea level rise off of accurate data from NOAA and creating a line to predict future values of sea level rise. We took data points from data collection stations on the entire American Eastern Seaboard and calculated the mean total sea level rise and an average initial value (beginning in 1988 running to 2008). We were then able to model erosion in certain areas of Florida based off of our model for the overall sea level rise. This allowed us to discuss how coastal flooding (sea level rise) and erosion will affect large metropolitan cities in Florida. Florida's large metropolitan cities would slowly begin to flood and loose buildings to erosion and rising sea level. The majority of Florida's large metropolises have at least 4% of the total city area being water, not land. The rise in sea level would begin to encroach upon industrial and residential buildings considering that much of Florida is built upon a system of canals and inlets. This reclamation would curb growth of the cities and cause a large economic impact on the towns as they move to prepare against encroaching water.

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