This problem focuses on global climate change and its specific effect on coastal parks.

Objectives

- Create a model of sea level change, define if it is high risk, do this for 10, 20, and 50 years (by 2:00 pm)
- Create a model that shows vulnerability to climate change in the parks listed, create a ranking system through a list of climate change effects, determine how this correlates to the future 50 years (by 6:00 pm)
- Create model which relates the previous effects of climate change to the amount of visitors. Explain how this could affect future visitation and how this should guide financial investments (by 9 pm)

Summary

P1: Using copious amounts of sea level data we were able to create a model to find the risk of sea level rise in terms of low, medium, and high risk of sea level change in five national parks across the united states. These parks were Acadia NP, Cape Hatteras NS, Kenai Fjords NP, Olympic NP, and Padre Island NS. By using the equations generated by the model we were able to plug in and find values for 10, 20, and 50 years in the future. By using a T test with these future values we were able to get a p value which was used to determine the risk of sea level rise. Our model suggests that all of the national parks used have a high risk of sea level rise in the next 10, 20, and 50 years with the exception of Kenai Fjords NP which has a medium chance of sea level rise in the next 10 years.

P2: In this question, we used real-world statistics of the effects of climate change, such as gas emissions, temperature change, change in precipitation, wildfires, and hurricanes to determine the vulnerability of the regions of the U.S. in which the named national parks are located over the next fifty years. We also accounted for the possible preparation of each state in their final score.

P3: In this question, we found and plotted the amount of gas emission and visitors for each park in the past years to find if there was a correlation. We then found the equation of each graph. This equation will tell us the amount of visitors per year, taking into account the effect of gas emissions. We would then distribute financial resources accordingly with the national parks that have the highest amount of visitors receiving the highest number of resources.

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Restatement of Problem

The problem asks us to do the following

- Build a mathematical model for sea level rise in Acadia National Park, Cape Hatteras National Seashore, Kenai Fjords National Park, Olympic National Park, and Padre Island National Seashore to determine a risk rating of high, medium, or low for the next 10, 20, and 50 years.
- Develop a model that is able to assign a climate vulnerability score to any NPS coastal Unit.
- Create a model for visitor changes in national parks and use its output to determine where future financial resources should go.

Part I: Tides Of Change

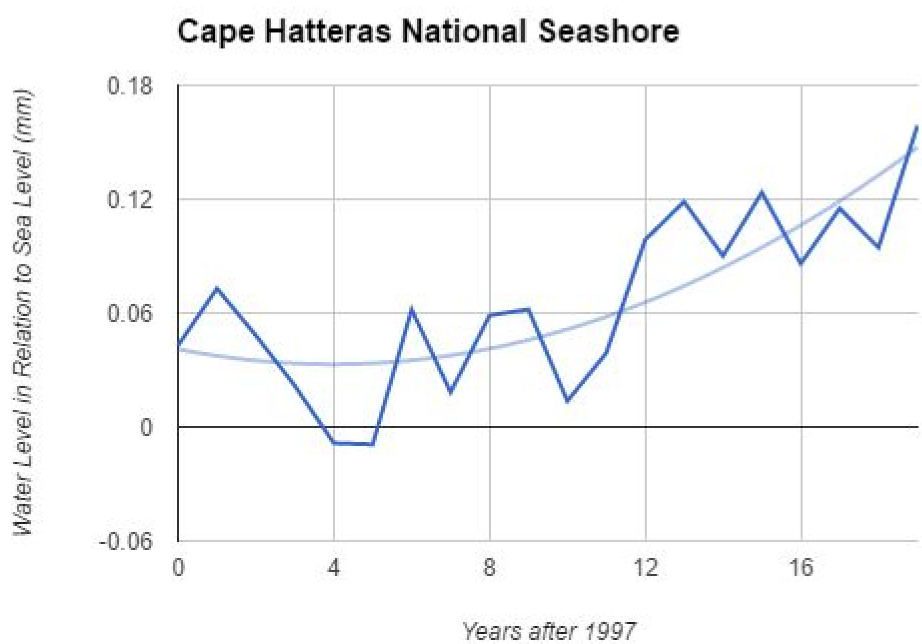
To create our model for the sea level change risk for the next 10, 20, and 50 years we made an assumption that past recorded data can be used to accurately predict future changes.

A. **Restatement of Problem**
   The change in sea level is not a world-wide constant. Many different areas will face many different sea level changes, both in direction and intensity. The goal of part one is to create a model for the next 10, 20 and fifty years that will be accurate enough to sort the risk of sea level change into three categories: high, medium, and low.
B. **Assumptions**
   - Sea level change refers to a positive or negative change from a locations sea level.
   - The world average for sea level change accurately conveys the average sea level change for the United States.
   - The average of a twelve month period can be accurately represented as a year of data.
   - The data listed in the source is an accurate representation of the actual sea levels.

- We assume that a low risk in terms of sea level rise is any p-value above .05, a medium risk is a p-value between .05 and .01, while a high risk is any p-value below .01.
- Assuming that the null hypothesis is true, that the difference between the yearly mean sea level and the previously calculated local average is zero, the p value shows the probability of observing results this large or larger due to sampling error alone

C. Creating the Model

- We began by using the monthly mean sea level provided in the Sea Level Trends spreadsheet provided to create the yearly mean Sea level (Citation 10). The mean sea level was averaged in cycles of twelve to correspond with the years. Years where there existed no data for any of the twelve months were omitted, and years with only partial data were based on what was available. The yearly mean sea levels were placed into graphs by park data collection center. Each graph started at year zero and continued until data was no longer available. Lines of best fit were created based on graphs made in Google sheets. Polynomial equations to the order of two were used to create the lines of best fit.

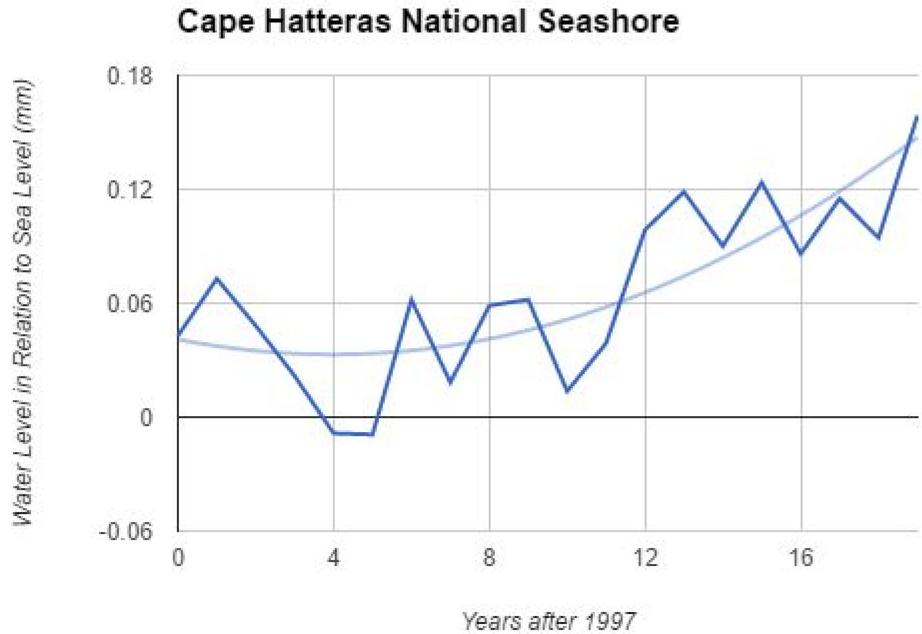


X-values matching with to 10, 20, and 50 years into the future were plugged into the line of best fit equations. For example, the x -values used were 29 for ten years into the future, 39 for twenty years into the future, and 69 for fifty years into the future.

After our predictions were created, we used them in a t-test to establish the risk of sea level change. The formula $s_N = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}$ was used to create the standard deviation for each set of data from each park collection center. The yearly mean sea level was assumed to be (x_i - $\bar{x}$). The p-value cas created using a standard one-mean two-tailed t-test, with the formula of $\boxed{t = \frac{\bar{x} - \mu}{s/\sqrt{n}}}$. All t-tests were performed in Ti-84 calculator. The p value was used to determine the risk of sea level in terms of low, high, and medium. Low risk was considered to be p-values above .05, medium risk was considered to be p-values between .05 and .01, and high risk was considered to be p-values below .01.

D. Justification:

To create an accurate model we chose to use a line graph to plot the average yearly distance from sea level. Using the r^2 value we determined that a polynomial equation of the order of two creates the best line of fit. We then used a T-test to determine p values that were used to create an estimate for an accurate representation of low, medium, and high vulnerability. P-values of .05 and .01 were used due to their prevalence in statistical tests, as .05 is the commonly accepted standard and .01 is the standard for more vital issues.



The model above shows how we got a line of best fit for Cape Hatteras National Seashore. The x-axis represents the number of years after 1997. The y-axis represents the average yearly displacement from the average sea level. Each yearly point was plotted on the graph and a line graph was created. The dark blue line on the graph shows the total distance from average sea level. We then used a polynomial equation of the order two to create a line of best fit. The equation for the line of best fit for Cape Hatteras National Seashore is **y = 5.061*10*-4x^2 - 4.016*10*-3x + 0.04**.
The N-value, or the number of entries used, was 20. The standard deviation formula yielded a SD of 0.07912247457. Both of these values were essential for the use of the t-test. The result was the p-values of 3.777*10^-14 for the ten year prediction, 3.549*10^-19 for the twenty year prediction, and 4.410*10^-24 for the fifty year prediction.

E. Results

	10 Years	20 Years	50 Years
Acadia NP	3.381*10^-9	-6.156*10^-12	3.66*10^-18
Cape Hatteras NS	3.777*10^-14	3.549*10^-19	4,910*10^-29

Kenai Fjords NP	.0195	3.157*10^-12	1.325*10^-26
Olympic NP	2.596*10^-6	2.345*10^-12	3.581*10^-21
Padre Island NS	8.186*10^-4	5.111*10^-9	6.64*10^-18

	10 Years	20 Years	50 Years
Acadia NP	High	High	High
Cape Hatteras NS	High	High	High
Kenai Fjords NP	Medium	High	High
Olympic NP	High	High	High
Padre Island NS	High	High	High

Based on the model we created, the rising of the sea level in several national parks across the United States is a high risk. Only one park was at only a medium risk, and that was both within the next ten years, and closer to a high probability than a low one.

F. Discussion

The model we used had a reasonable R^2 value, indicating the relative accuracy of it. The line of best fit matched up fairly well with the available data. Each function for the prediction of the sea level was tailored for each individual data set. This was done in hopes of providing more accurate predictions.

While the R^2 was reasonable, it wasn't anything particularly special. It could have possibly been improved by a polynomial line of best fit of a higher order or by basing sea level rise predictions on other information in addition to past information.

Part II: The Coast is Clear?

A. Restatement

Determine what events are caused by climate change. Judge the severity of these events in Acadia National Park, Cape Hatteras National Seashore, Keia Fjords National Park, Olympic National Park, and Padre Island National Seashore. Create a common score to judge the severity of the events in each location. Determine the vulnerability of each location to the effect of climate change by using the severity and likelihood of climate change's events. Create a mathematical model to represent the common score. Use this common score to judge vulnerability over the next fifty years.

B. Assumptions

- Effects of climate change include natural disasters (wildfires and hurricanes/storms), changes in precipitation (rain and snow), and air quality (gas emissions).
- All numerical values per total state area are proportional to the areas of national parks.
- All changes in numerical values (temperature, precipitation in inches, etc) over the last decade multiplied by five are equal to the change in numerical values over the next fifty years.
- Effects (temperature, precipitation, etc) that happened within the region of the park, also happened within the park.
- All changes in numerical values over time are caused by climate change.
- We are assuming all data and references provided are valid.

C. Design the Model

$$\frac{[(Wildfires\ score) + (Hurricane/tornado\ score) + (Precipitation\ score) + (Gas\ emission\ score) + (Temperature\ score)] - 5(Preparedness\ score)}{5}$$

=Vulnerability score of a single national park

We determined that events caused by climate change and their severity in the locations of each park should be measured by their average change over the past ten years to account for how they will change over the next fifty years. We set these values to chosen scales from 1-10. We add these scales together and divide them by five to find our raw vulnerability score. We then take into account the fact that states might have preparations in place to stilt the effects of climate change over the next fifty years. We subtract this preparedness score from our raw score to get the park's official score.

D. Justify the Model

Hurricanes

i. Data found from a credible source expresses each state's probability of hurricanes on a score from 1-10. (citation 5)

State	Likeliehood of Hurricane
Maine	6.8
Washingt(	5.9
North Car(	6.4
Texas	9.4
Alaska	8.1

Wildfires

i. Calculate the average of the acres per fire for each state over the last ten years. (citations 7, 4, and 6)

Maine		
Year	# Fires	# Acres
2016	796	946
2015	375	574
2014	282	158
2013	426	743
2012	551	489
2011	308	116
2010	558	353
2009	482	481
2008	442	535
2007	491	423
2006	614	1794
AVERAGES	484.091	601.091
Acres/Fire:	1.24169	

e

North Carolina		
2016	4007	88109
2015	3828	15220
2014	4625	15601
2013	3514	24547
2012	3463	35590
2011	5279	119482
2010	4213	21463
2009	3344	25142
2008	4414	95938
2007	7000	54658
2006	5540	24995
AVERAGES	4475.18	47340.5
Acres/Fire:	10.5784	

Alaska		
2016	572	496467
2015	768	5111404
2014	384	233561
2013	603	1316879
2012	416	286887
2011	515	293018
2010	689	1125419
2009	527	2951597
2008	340	62648
2007	448	525017
2006	308	266266
AVERAGES	506.364	1151742
Acres/Fire:	2274.54	

Washington		
2016	1272	293717
2015	2013	1137664
2014	1480	386972
2013	1527	152603
2012	1342	259526
2011	993	17480
2010	870	56820
2009	1976	77250
2008	1303	147264
2007	1268	214925
2006	1579	410060
AVERAGES	1420.27	286753
Acres/Fire:	201.9	

Texas		
2016	9300	356,680
2015	9272	184418
2014	9677	131138
2013	70	10743
2012	10620	179602
2011	3470	2722623
2010	6748	210320
2009	16614	753261
2008	16713	1570586
2007	700	36304
2006	3062	1564170
AVERAGES	7840.55	701804
Acres/Fire:	89.5096	

ii. Use this proportion to solve for an approximate number of fires per the national park.

$\frac{number\ of\ fires}{state\ acreage} = \frac{\#\ of\ fires}{acreage\ of\ park}$

<u>Sample Calculation:</u>

Maine:

$\frac{487.0909}{72696900} = \frac{x}{49052}$

x= 1.04853 fires/acreage of park

iii. $\frac{number\ of\ fires}{acreage\ of\ park}\ x\ \frac{acreage\ destroyed}{fire}$

<u>Sample Calculations:</u>

Maine:

$\frac{1.0485}{49052}$ x $\frac{1.24169}{1} = 2.654 \text{ x } 10^{-5}$ acreage of park destroyed by fire

iv. Multiply acreage of park destroyed by fire by 100 to convert to a percentage

Sample Calculations:

Maine:

$(2.654 \times 10^{-5})(100) = 2.654 \times 10^{-3}$ percent of park destroyed by fire

v. Determine a score of severity on a scale of 1-10 by the amount of acreage destroyed by fire

Acreage Destroyed Per Fire	Score
0	0
0>200	1
200>400	2
400>600	3
600>800	4
800>1000	5
1000>1200	6
1200>1400	7
1400>1600	8
1600>1800	9
1800>	10

Temperature

i. Find the average temperature change in each region over the last ten years from an online source (citation 1).

Sample Calculation:

Maine:

0.272 degrees Fahrenheit

ii. Create a scale from 1-10 to score severity of temperature change, setting the maximum temperature change as 10, and dividing all values by this maximum. Then multiply the quotient by 10. (citation 1)

Sample Calculation:

Maine:

Max= Alaska= .5 degrees Fahrenheit

(.272)/(.5)=.544

(.544)(10)=5.44

Temperature	
Maine	0.272
North Carolina	0.054
Alaska	0.5
Washington	0.129
Texas	0.114
change in F°/10 years	

Precipitation

	Average from 1980-2010	2015Average	Difference	Average change in inches per year
Maine	41.93	35.57	-6.36	-1.272
Washington	50	57.56	7.56	1.512
North Carolina	58.04	69.59	11.55	2.31
Texas	31.76	45.01	13.25	2.65
Alaska	18.54	19.37	0.83	0.166

(citation 3)

i. Subtract the 1980-2010 average inches of precipitation from the 2015 average using the equation (2015 average) - (1980-2000 average) = x to get the average inches per five years for each state.

Sample Calculation

Maine:

35.57 - 41.93 = -6.36 average inches/5 years

ii. Divide x by five to find y, the precipitation change in inches per year.

Sample Calculation

Maine:

-6.36 / 5 = -1.272

iii. Take the absolute value of y to get the magnitude of precipitation change in inches per year.

Sample Calculation

Maine:

$|y| = 1.272$

iv. To determine a score of severity between 1 and 10, make the maximum change in inches per year 10. To calculate the score of all other park areas, divide their change in inches per year by the maximum, and multiply the quotient by 10.

Sample Calculation

Maine:

1.272/2.65=.48

0.48x10= 4.8

Gas Emissions

Maine	0.097899
North Carolina	1.11563
Washington	0.59647
Texas	4.76798
Alaska	0.715075
change/year in millions of metric tons	

i. Plot the total gas emissions for each state from the year 1980-2014, use the slope as the total change of carbon dioxide emitted per year (citation 8)

ii. Divide all values by the largest value, which is Texas, to rate them all in perspective to one another.
iii. Multiply by ten to put on a scale from one to ten
<u>Sample Calculation:</u>
i.

494.4	481.2	458.8	464.9	490.1
496.2	493.8	499.6	532.3	552.1
562.5	557.4	556.8	575.1	573.4
578.0	621.4	646.5	652.1	628.4
652.5	646.9	655.9	649.3	642.6
618.5	629.4	626.3	590.7	556.8
589.5	608.7	603.2	631.1	641.7

After plotting, we find the mean change in millions of metric tons per year of carbon emissions is 4.76798.
ii. After dividing by the largest number, 4.76798, we get a value of 1.
iii. By multiplying by 10, we get that Texas has a gas emission score of 10.
<u>Preparedness</u>
i. Data found from a credible source (citation 5) expresses each state's expected preparedness for the effects of climate change on a scale of 1-10

State	Preparedness
Maine	1.7
Washingt	1.2
North Car	2
Texas	0.3
Alaska	7.8

E. Results of the Model

North Carolina	
Hurricanes Score	6.4
Wildfires Score	2
Precipitation Score	8.7
Gas Emissions Score	2.34
Temperature Score	1.08
Preparedness Score	2

Maine	
Hurricanes Score	6.8
Wildfires Score	1
Precipitation Score	4.8
Gas Emissions Score	0.21
Temperature Score	5.44
Preparedness Score	1.7

Washington	
Hurricanes Score	5.9
Wildfires Score	2
Precipitation Score	5.7
Gas Emissions Score	1.25
Temperature Score	2.58
Preparedness Score	1.2

Alaska	
Hurricanes Score	8.1
Wildfires Score	10
Precipitation Score	0.63
Gas Emissions Score	1.5
Temperature Score	10
Preparedness Score	7.8

Texas	
Hurricanes Score	9.4
Wildfires Score	1
Precipitation Score	10
Gas Emissions Score	10
Temperature Score	2.28
Preparedness Score	0.3

Total Scores	
North Carolina	2.104
Maine	1.95
Washington	2.286
Alaska	-1.754
Texas	6.236

Sample Calculations for total scores:

Maine: Use the equation

$$\frac{[(Wildfires\ score) + (Hurricane/tornado\ score) + (Precipitation\ score) + (Gas\ emission\ score) + (Temperature\ score)] - 5(Preparedness\ score)}{5}$$

with the previously found scores for Maine.

$$\frac{(1+6.8+4.8+0.21+5.44)-5(1.7)}{5} = 1.95$$

These results show Texas as the most vulnerable (closest to positive 10) park to the effects of climate change. Alaska has a score closest to negative 10, making it the most prepared for the events considered (change in temperature and precipitation, an increase in gas emissions, and the possibility of natural disasters).

F. Discussion

- The limitations of this model include its inability to represent all effects of climate change, its reliance on average value estimates, and the fact that it does not account for the amount of impact each effect has compared to each other.
- Strengths of this model include that multiple effects of climate change were accounted for, and that preparedness to combat climate change decreases the vulnerability of the parks.

- To strengthen the model, we could have included the percentages of our effects caused by climate change. Our effects were not solely caused by climate change, so other causes should have been considered.

Part III: Let Nature Take its Course?

A. **Restatement**

Using trends and statistics in visitation at the listed parks, as well as the scores calculated in part II, predict how visitation trends will change long term due to the effects of climate change. Create a mathematical model to represent these long term changes in visitation, and express how the NPS should invest to stifle negative changes.

B. **Assumptions**

- Gas emissions are the most important factor of the vulnerability because as gas emissions increase, temperature increases which increases evaporation and precipitation and natural disasters.
- Visitors in the national parks will continue to increase at the rate that they have increased since 1980.
- Gas emission rates found in part II will stay constant as the amount of gas emitted in the states will not greatly increase or decrease.
- National parks with the most visitors need to be allocated the highest amount of financial resources.

C. **Design the Model**

a. Once it was decided that gas emissions were the most important, an equation was found that showed the correlation between gas emissions and the number of visitors to each park.
b. Begin by finding an equation for the millions of metric tons of carbon emission change per year starting at the year 2000. In this case, 2000 was year 0, so any x-value plugged in was years after 2000. (citation 8)
c. Use the equation from part b to calculate the expected amount of carbon emission for a particular year. (citation 9)
d. Plot carbon emission versus the number of visitors for each state park each year. This will give an equation that will predict the number of visitors given a specific amount of carbon emission.
e. Use the expected amount of carbon emission from part c and plug into the equation to d to find the expected number of visitors for x amount of years after 2000.

D. **Justification of the Model**

a. For all states:

$g(x)$ = gas emissions for x years after 2000 given in millions of metric tons
$v(g)$ = visitors for x millions of metric tons

b. For Texas

$g(x) = -3.2775x + 645.816$

$v(g) = 48.5072g + 591113.4$

c. For Maine

$g(x) = .7386x + 44.043$

$v(g) = -6912.325g + 3821392$

d. For Alaska

$g(x) = -.6082x + 24.5308$

$v(g) = -5997.166g + 2451721.27$

e. For Washington

$g(x) = -.4889x + 79.7758$

$v(g) = 11823.845g + 2228403.51$

f. North Carolina

$g(x) = -1.8892857x + 154.4717$

$v(g) = 5719.008g + 1527884.55$

E. Results of the Model

a. Differences between actual visitors in 2016 and 2015 compared to predicted visitors

b. Texas
   i. 2015: -37,216
   ii. 2016: 14,116

c. Maine
   i. 2015: -629,187
   ii. 2016: -131,872

d. Alaska
   i. 2015: -2,062,621
   ii. 2016: -2,016,432

e. Washington
   i. 2015: 178,811
   ii. 2016: 311,052

f. North Carolina
   i. 2015: 25,398
   ii. 2016: 173,279

Most of the data we collected showed that when gas emissions were taken into consideration, the number of visitors was less than it should be, which shows that an increase in gas emissions is having a negative impact on the number of visitors to the national parks. It would also have a larger detrimental effect in the future, as we would expect the number to keep decreasing with more gas emission, which is what our models form part 2 predict.

We would advise the National Parks Service to spend more money on parks that have less gas emissions, for they will need more staff and resources to support more visitors. We would also advise to invest in processes that will lead to less gas emissions because it will bring in more visitors and profits.

F. Discussion

We assumed that gas emissions impacted the other climate change effects, which altogether led to the greatest change in visitation. This generalization meant that we neglected other possible sources of visitation changes. To save time, we only drew statistics from the 2000's. If we had used statistics from before intense industrialization, we could have observed a more distinct comparison between time period, gas emissions, and visitor population. We could have improved our model had we used a greater range of values and focused on other climate change effects. However, we were able to assume and utilize statistics from what seems to be the most important impact of climate change. By plotting the year, number of visitors, and the amount of emissions, we were able to view a strong correlation.

Citations

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