

From Sea to Shining Sea: Looking Ahead with the National Park Service Moody's Mega Math Challenge 2017: Team #9491 Executive Summary

There is a natural inclination for humanity to view the Earth as our steadfast, never-changing home. After all, it seems as permanent as the ground beneath our feet. However, nothing could be further from the truth, especially in today's rapidly changing climates. Global temperatures are on the rise, and with them comes an increase in sea levels, wildfires, and hurricanes, three serious, expensive issues. Unfortunately for the National Park Service (NPS), who guard ninety-seven coastal units, coastlines are especially vulnerable to such problems. Thus, the NPS must take extra precautions and expenditures to maintain and protect them. With limited budget, however, a critical problem presents itself: where exactly should these efforts be focused?

To answer this question, our group developed a model addressing the issue of rising sea levels in the future for all five coastal parks in question: Acadia National Park, Cape Hatteras National Seashore, Kenai Fjords National Park, Olympic National Park, and Padre Island National Seashore. Our model determines "high", "medium", and "low" thresholds for sea levels by drawing lines one-half standard deviation above and one-half below the mean, dividing the data roughly into thirds. It then uses an exponential moving average five years around every data point, which weighs sea level fluctuations as they occur. We linearly extrapolated the data 10, 20, 50, and 100 years into the future, and found that our results correlated extensively with existing research of ocean current behavior, confirming to us that results had sound basis in reality.

We were also tasked with the creation of a climate-related vulnerability model to relay to the NPS through a scoring system the risk of climate-influenced damage to any given coastal unit over the next 50 years. The formula of our scoring system was inspired by an existing Climate Vulnerability Index (CVI). Although its name indicates similarity to our model, its purpose is in fact predicting people's vulnerability to the climate. First of all, we changed the variables to four specific climate-related events found to be highly influential monetarily and in some instances, through lives lost, to National Parks and the nation as a whole: tropical storms, wildfires, lowering of air quality, and sea level. We then converted each of these events into scorable quantities, and through analysis of the past frequency and severity of these events, extrapolated the variable scores into the future using our own adapted model. These final scores would be beneficial to the NPS in determining the vulnerability of any given coastal unit to climate-related damage and expenditure many years into the future.

Finally, we were tasked with recommending the NPS of where funding should be allotted to repair climate-related damage in the future, incorporating our vulnerability model. Aware of the Service's sometimes limited financial resources, we incorporated visitor statistics into our recommendation model, to help them serve the greatest possible amount of people. Through a machine-learning algorithm, we incorporated all four variables present in our climate-related vulnerability model and correlated them with visitor count data over the past twenty years. The artificial intelligence program then built a predictive algorithm from the data to predict visitor count, which was a Gaussian process featuring a numerical vector, which was refined through repeated testing to 77% accuracy. Based on this algorithm, for the first ten years, the NPS should prioritize funding to Cape Hatteras, at twenty years should prioritize Acadia, and finally, at 50, should invest most heavily in Padre Island. The Service should certainly take these predictions into consideration to best honor the beautiful areas that they are charged to protect.

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1 Introduction

1.1 Background

In 2014, a novel analysis of global exposure to rising sea levels and coastal flooding showed that 147 to 216 million people who currently live on land will be below sea level or regular flood level by the end of the 21st century (Strauss). Rising sea level is a serious threat to people who live near the ocean, with low-lying areas to suffer more frequent flooding and very-low-lying areas to face complete submerging. Rising sea level is also a serious issue because saltwater contaminates aquifers and inland crop fields, thus reducing both our water and food supply. Furthermore, rising sea levels damages our economies due to the washing-away of prime beachfront properties and recreational areas (Harvey). Due to the negative effect that flooding has around the globe, it is important to understand and predict where severe flooding will take place in the future. By building an effective model that can predict where sea level rises will occur, we can better prepare for those situations, and make plans that minimize loss of property and life.

Additionally, nature is a delicate place that ensures the homeostasis of Earth's biosphere, and thus it is critical to protect. Recent climatic changes are threatening nature by increasing the severity and frequency of events such as air pollution, wildfires, hurricanes, and rises in sea level, so organizations that intend to protect natural areas are more important than ever. By using our model to assess which natural areas are optimal to conserve and generate income from, we are able to better divert the efforts and resources of conservation organizations such as the National Park Service. This increases the ability and effectiveness of organizations' attempts to defend Earth's precious ecosystems.

1.2 Restatement of the Problem

With global factors such as climate affecting park resources and visitor experience, we have been asked to:

- Create a model of changes of sea level for five parks - Acadia National Park, Cape Hatteras National Seashore, Kenai Fjords National Park, Olympic National Park, and Padre Island National Seashore - and to predict sea levels at those parks 10, 20, and 50 years into the future, ideally with 100-year viability of the model's predictive ability.
- Develop a climate vulnerability scoring system to quantify the risk of and from climate-related events affecting any given National Park Service coastal unit in the next 50 years, considering both likelihood and severity of such events.

- Advise the National Park Service on where to make future expenditures in recovery from climate-related damage by incorporating visitor statistics into the vulnerability scoring system.

2 Tides of Change

2.1 Assumptions

1. Sea level is significantly influenced by temperature and heat index, as temperature fluctuations cause higher or lower sea levels similar to heat index fluctuations.
2. Increases in global temperature cause glaciers and the polar ice caps to melt and release freshwater into the oceans.
3. Within 100 years, the direction and target areas of major world currents will not be altered by changing the salinity and temperature of the water they carry, as modern ocean currents have taken thousands of years to form their paths.
4. Global emissions of “greenhouse gases” will remain on their current trend as it is unlikely (or at least unforeseeable) that humanity will significantly increase or decrease its emissions within the next century.

2.2 Background

2.2.1 Ocean Currents

The oceans' currents are created as a result of varying temperatures across our planet's varying latitudes. As the atmosphere is warmed nearest to the equator, the hot air at the planet's surface is heated, causing it to rise and draw in cooler air to take its place, creating circulation cells. Wind patterns associated with these cells drive surface currents (Trujillo and Thurman) which push the surface water to higher latitudes where the air is colder. This cools the water to a point where it is capable of dissolving more gasses and minerals, making it dense in comparison to lower latitude waters, which in turn causes it to sink to the ocean's bottom, forming what is known as North Atlantic Deep Water (NADW) in the north and Antarctic Bottom Water (AABW) in the south. (Talley) Driven by the sinking and upwelling that occurs in lower latitudes, as well as the force of the winds on surface water, currents circulate water throughout the world's oceans.

Global warming changes these processes, especially in the regions where deep water is formed. With the warming of the oceans and subsequent melting of glaciers and the polar ice cap, an abundance of freshwater is released into the high latitude regions where deep water is formed. This extra water that is added dilutes the contents of the water arriving from lower latitudes, reducing the density of the surface water. This makes the water sink more slowly than it normally would (Roach). Furthermore, the volume that the water occupies increases due to the resultant decrease in density. Additionally, the volume that water occupies increases when temperature increases due to its chemical properties. As water gets warmer, it takes up more space. Each drop of water only expands by a little bit, but when you multiply this expansion over the entire depth of the ocean, it all adds up and causes sea level to rise.

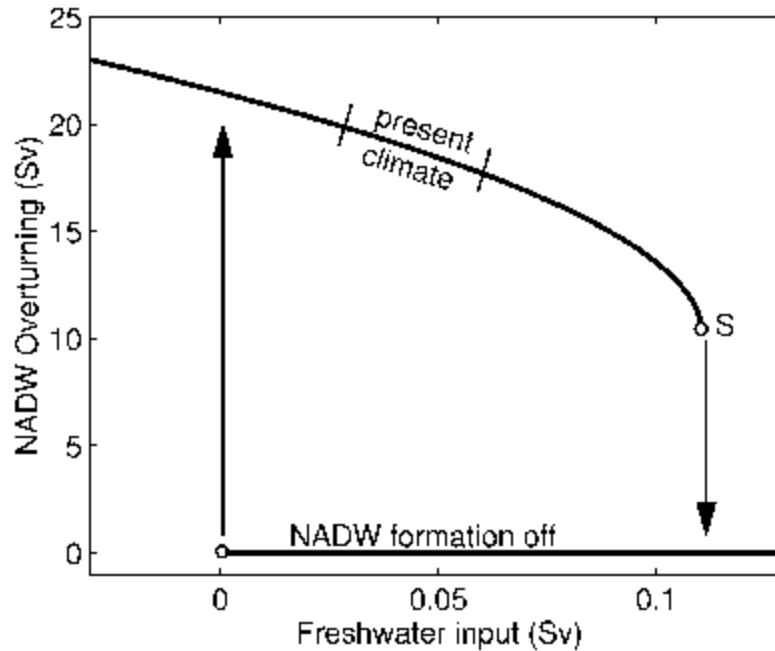


Figure 1: The addition of freshwater to North Atlantic Deep Water (NADW) decreases the ability of the water to overturn and circulate, thus disrupting the ocean currents that ensure the steady transfer of warm and cold water throughout Earth's oceans.

Ocean currents play a vital role in maintaining the climate of our planet by moving streams of warm and cool water around in a consistent cycle. Changes to the water in these currents may result in a severe change in the oceans, most notably in the sea level. By understanding the intricate relationships between the numerous ocean currents that circulate through Earth's oceans, the following predictions were made about the effect that an increase in global temperature would have on the currents that run near Acadia National Park, Cape Hatteras national Seashore, Kenai Fjords National Park, Olympic National Park, and Padre Island National Seashore.

Acadia National Park, Maine

Acadia National Park is primarily affected by the North Atlantic Current, which contains the North Atlantic Deep Water (NADW). The NADW becomes flooded with freshwater gained from the polar ice caps, which are melting due to global climate change and heating at Earth's poles. This added Arctic freshwater makes the NADW less dense, and thus increases the sea levels there.

Cape Hatteras National Seashore, North Carolina

Cape Hatteras National Seashore is primarily affected by the North Atlantic Current, which contains the NADW. The NADW becomes flooded with freshwater gained from the polar ice caps, which are melting due to global climate change and heating at Earth's poles. This added Arctic freshwater makes the NADW less dense, and thus increases the sea levels there.

Kenai Fjords National Park, Alaska

Kenai Fjords National Park is primarily by Alaskan Current, which draws its water from the North Pacific Current (NPC). The NPC, in turn, is joined by the Oyashio Current, which introduces cold freshwater from the Arctic. With the melting polar ice caps, the Oyashio Current will bring a unusually large amount of cold water from the Arctic to the NPC. This, in turn, will cool the relatively warm Alaskan Current. This increase in cold water will create a somewhat deep water region, thus reducing sea levels.

Olympic National Park, Washington

Olympic National Park is primarily affected by the cool California Current, which draws its water from the North Pacific Current (NPC). The NPC, in turn, is joined by the Oyashio Current, which introduces cold freshwater from the Arctic. With the melting polar ice caps, the Oyashio Current will bring a unusually large amount of cold water from the Arctic to the NPC. This, in turn, will further cool the relatively cold California Current. This increase in cold water will create a somewhat deep water region, thus reducing sea levels.

Padre Island National Seashore, Texas

Padre Island National Seashore is primarily affected by the Loop Current, which runs through the Gulf of Mexico and provides warm air and water to the coastline of Texas. The Loop Current draw its warm water from the Gulf Stream, which directly brings water from the equator. Due to an increase in Earth's heating from the Sun at the equator and an increase in Earth's temperature due to the Greenhouse Effect, this Gulf Stream's water becomes warmer, and thus the water in the Gulf of Mexico becomes warmer. This decreases water density, which increases sea levels in the region.

2.3. Our Model

2.3.1 Overview of the Model

Our team's model to determine the risk of sea level change in the five selected parks (Acadia National Park, Cape Hatteras National Seashore, Kenai Fjords National Park, Olympic National Park, and Padre Island National Seashore) incorporated a mixture of computer simulations in MATLAB and artificial intelligence in Wolfram Mathematica.

Before we could do any computer simulations, however, we had to determine thresholds for "high", "medium" and "low" sea levels. To do this, we took in all the raw sea level data, regardless of year or national park. We then took the standard deviation and mean of this data. Since one standard deviation up and down from the mean is the middle 68% of the data, half a standard deviation up and down from the mean will give us the middle 34% of the data. We calculated the standard deviation of all the sea level data to be 0.0874747. The mean of all the data is 0.0141094. Thus, the thresholds calculated to divide the data roughly into thirds are one half of a standard deviation up and down from the mean. This gives us the numbers -0.029628 and 0.0578467. So, all data points lower than -0.029628 are in the lower third of the data set, labeled "Low", every data point between -0.029628 and 0.0578467 are in the middle 34%, labeled "Medium", and every data point above 0.0578467, in the top third, is labeled "High."

In order to predict sea level risk in the future, an in-house MATLAB code was generated to calculate the exponential moving average (EMA) of the known monthly mean sea levels. That data was then linearly extrapolated the data to acquire fixed values for mean sea levels in 10, 20, 50, and 100 years. The EMA was calculated using the equation:

$$(1) \bar{Y} = \alpha \left(\frac{Y_t}{S_j} \right) + (1 - \alpha)\bar{Y}_{t-n}$$

where \bar{Y} is the calculated average, S is the seasonal factor, Y is the actual value, α is the smoothing factor, and t is the time. The seasonal factor was calculated by the following equation:

$$(2) \bar{S}_j = K_s + (1 + K_s)S_j$$

where K_s represents the dampening factor, calculated by:

$$(3) K_s = \frac{1}{\sqrt{d}}$$

where d is the number of years of data (Armstrong). The seasonal factor accounts for the varying uncertainty in estimating the factors influencing sea level change, such as mean temperature and ocean currents (Mimura), while the smoothing factor in equation (1) determines how much weight is to be placed on the most recent data. An arbitrary value of 0.2 was used as the smoothing factor to account for global changes in temperature and pressure. The benefits of using exponential smoothing are that it puts a larger emphasis on more recent events. Therefore, it responds to changes more quickly than a simple moving average and shows a more accurate interpolation for the future. In addition, applying an EMA to the data made it easier to see a correlation of the mean sea level with respect to time, and erased a lot of the noise without sacrificing the integrity of the initial data.

To obtain more accurate interpolations, a 5 year EMA was used.

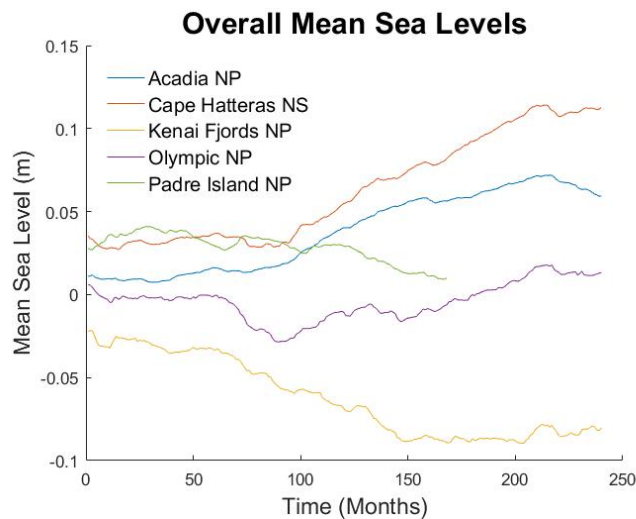


Figure 2. The exponential moving average (EMA) for the mean monthly sea levels in all 5 regions. Data was collected from January 1997 to December 2016. Months where no data was collected was not factored.

A linear regression was applied to moving average to extract the values at 10, 20, 50, and 100 years into the future.

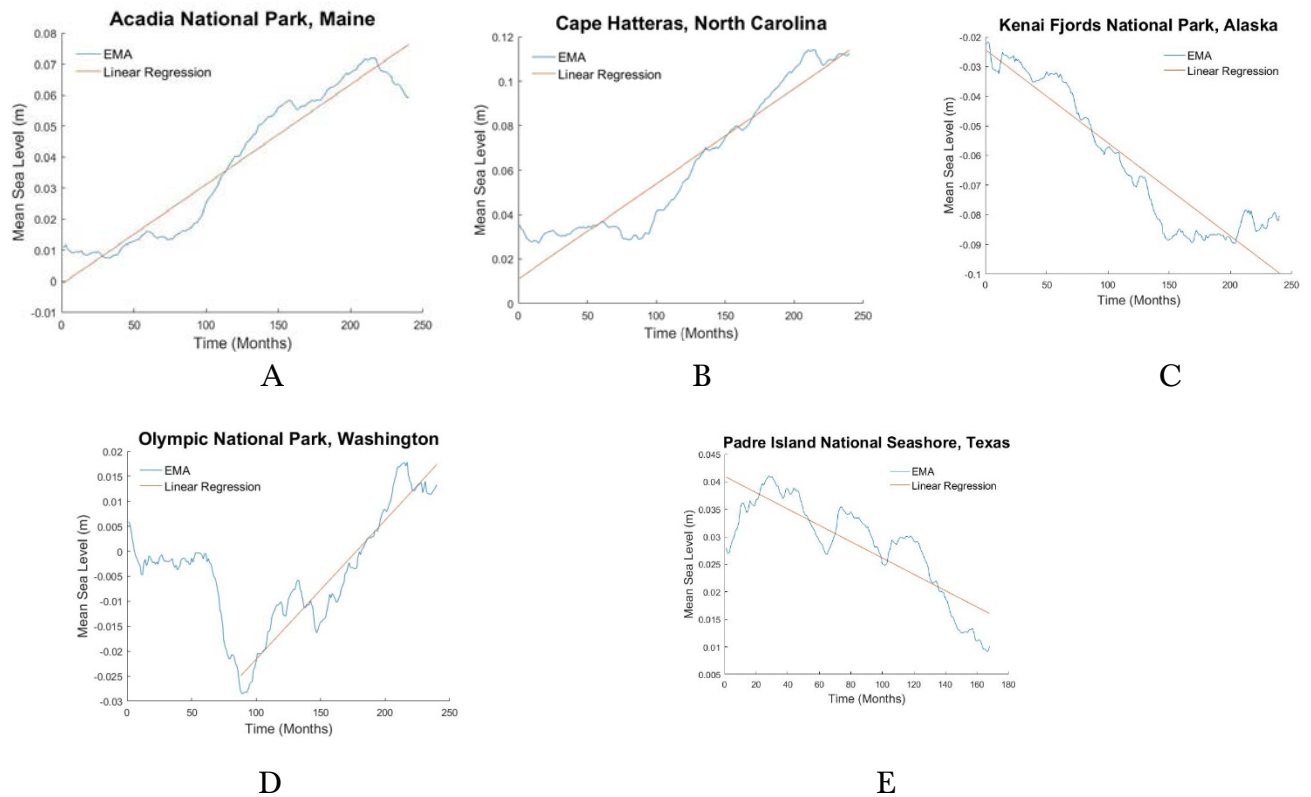


Figure 3. The exponential moving average (EMA) for the mean monthly sea levels in each individual region from January 1997 to December 2016. Linear regression lines show an overall correlation over time, in (A) Acadia National Park, Maine. (B) Cape Hatteras National Seashore, North Carolina. (C) Kenai Fjords National Park, Alaska. (D) Olympic National Park, Washington. (E) Padre Island National Seashore, Texas.

Name of Park	10 Years	20 Years	50 Years	100 Years
Acadia National Park	0.116887 HIGH	0.155527 HIGH	0.271447 HIGH	0.464647 HIGH
Cape Hatteras National Seashore	0.1549 HIGH	0.2029 HIGH	0.3469 HIGH	0.5869 HIGH
Kenai Fjords National Park	-0.1323 LOW	-0.1683 LOW	-0.2763 LOW	-0.463 LOW
Olympic National Park	0.0585 HIGH	0.0945 HIGH	0.2025 HIGH	0.3825 HIGH
Padre Island National Seashore	0.005	-0.007	-0.043	-0.103

	MEDIUM	MEDIUM	LOW	LOW
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Table 1 Predicted values for mean sea levels in all 5 locations measured in meters (m). Interpretations of high, medium, and low risk are also included at each cell.

We then used artificial intelligence algorithm to predict the sea level given data about temperature and heat index at that time. Mathematica uses artificial intelligence algorithms to construct a logistic regression model that fits the raw data inputted into the program. It correlates the variables of both temperature (t) and heat index (h) with that of sea level (s) to create a data set filled with associations between t and h with s. We took in raw data of temperature and heat index and at any time and matched them up to the sea level at that time, and inputted this association into Mathematica’s artificial intelligence algorithms. We use a training set and a testing set, with the training set being 80% of our data and the test set the rest 20%. Mathematica generated a Logistic Regression for classification and prediction of sea levels. The final accuracy percentage for our model, as calculated by running the Logistic Regression model on the test set, was 77%. The Confusion Matrix Plot can be seen below.

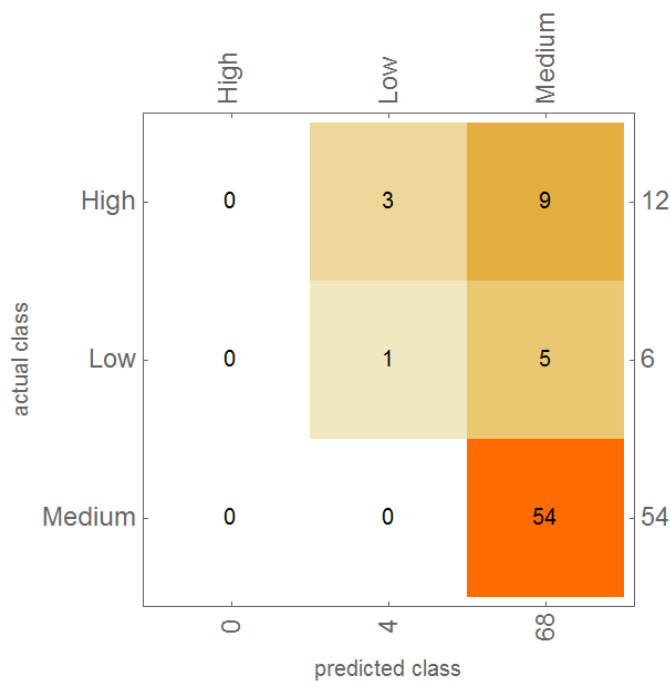


Figure 4 The Confusion Matrix Plot shows the predicted class on the bottom, with the actual class on the right axis. The darker the shade of red, the more accurate the prediction.

2.3.2 Conclusion

We see from the MATLAB-generated table that some national parks have a trend of rising sea levels, while some have a decreasing trend.

Acadia National Park, in Maine, and Cape Hatteras National Seashore, in North Carolina, both have increasing trends. In 10 years, both will be at a “High” level of sea

levels. In 100 years, Acadia will be at 0.464647 mm and Cape Hatteras will be at 0.5869 mm. This is consistent with our predictions in the “Ocean Currents” section.

Olympic National Park, in Washington state, also shows an increasing trend, and will be at a “High” level in 10 years and will be at 0.3825mm in 100 years. This increasing trend is inconsistent with our research on ocean currents, but Olympic National Park’s 100-year estimate is considerably lower than Acadia and Cape Hatteras, which is expected.

Kenai Fjords National Park and Padre Island National Seashore both show a decreasing trend, and will be labeled “Low” in half a century. This is consistent with our predictions in the “Ocean Currents” section. The artificial intelligence model means that, given temperature and heat index data about a month (available from sources such as the Farmer’s Almanac), we can predict whether sea levels will be “High,” “Medium,” or “Low, ” with an 77% accuracy, which is much better than the estimated 33% accuracy we get from simply guessing. This is a useful tool, as we can now determine the sea level for any location on earth, with 77% accuracy, given just the temperature and heat index of that location. This can help the National Park Service estimate the amount of land they will lose to the ocean, and thus they can take precautions to secure the national parks if the model outputs that the sea level is too high.

3 The Coast is Clear?

3.1 Assumptions

1. The severity of a climate-related event in a region can be based on its associated monetary loss, number of casualties, and the likelihood of the event affecting a specific area. This is a reasonable measure because such events can be measured, and thus compared, based on their results.
2. Monetary loss of a natural disaster takes into account infrastructure damage, in addition to loss of economic output (e.g. business interruptions, jobs stopped for weeks).
3. Monetary loss attributed to air pollution includes the medical treatment necessary to treat illnesses caused by the pollution (e.g, respiratory illnesses including asthma)

3.2 Our Model

While investigating different types of climate-related phenomena and their effects on coastal National Park units, our group found a select group of the most significant phenomena. We found that, in terms of monetary cost to the National Park Service, tropical storms, wildfires, air pollution, and rising sea levels were the most costly to deal with. These four events also cause great loss of life throughout the United States each year (and also in the parks), and so we incorporated this loss of life as a factor in our climate vulnerability rating calculation as well.

The model takes multiple factors into account for each climate-related event in the calculation of an accurate climate vulnerability score for the National Park Service’s coastal units. These are:

- Monetary cost of the event to the NPS (m)
- Loss of life due to the event (L)
- Probability of occurrence (p): changes depending on park location and climate.

We take these variables for each event so that there is a distinct m , L , and p for each event type, based on the time and location. This means that tropical storms have a distinct m value, wildfires have a distinct m value, and so on. The same applies for variables L and p in the CVI calculation for any given coastal unit.

Taking wildfires as an example, $mWildfire$ was calculated by looking at the monetary loss of several wildfires over the time period from 1997 to 2017. $LWildfire$ was calculated by looking at the lives lost in several wildfires over the time period from 1997 to 2017. $pWildfire$ was calculated by taking the prevalence of wildfires in each of the national parks from 1997 to 2017.

We then plug in these values into the formula:

$$\frac{\sum(M_x + L_x + P_x)}{M_{avg} + L_{avg} + P_{avg}}$$

This formula outputs our Climate Vulnerability Index (CVI). The larger the CVI, the more vulnerable the climate of the national park is. This formula takes into account 4 natural events that we selected as the most devastating: wildfires, tropical storms, air pollution, and rising sea levels.

We then went on to estimate the CVI for each of the national parks in 10, 20, and 50 years.

	10 Years	20 Years	50 Years
Acadia National Park	3724.66	6331.26	14150.9
Cape Hatteras National Seashore	-8456.89	-13345.7	-28012.2
Olympic National Park	-1473.92	-3568.89	-9854.19
Padre Island National Seashore	-3121.59	-2938.93	-2391.89

These CVI values for four national parks in the future shows that Acadia National Park has a large, increasing CVI value, a warning that the climate of Acadia is in danger. Padre Island National Seashore also has a slightly increasing CVI value, but has a good CVI value to begin with, so is in less danger. Both Olympic National Park and Cape Hatteras National Seashore have decreasing, good CVI values, meaning their environments are not in serious risk.

4 Let Nature Take Its Course?

4.1 Assumptions

1. The number of visitors who attend parks is affected by climatic changes, such as unusually high and low temperatures, and natural disasters, such as hurricanes. This is because visitors will be physically unable to attend parks during such times, and the disorder in the aftermath of disasters discourages visitor attendance.
2. The value of climate-related budgeting provided to the park is solely based on whether or not visitors attend, and will be used solely to recover from climate-related events and restore the park to visitor-friendly conditions. For example, being the habitat to an endangered species of animal would not increase the priority for a park's recovery funding, but being a popular visitor destination would.

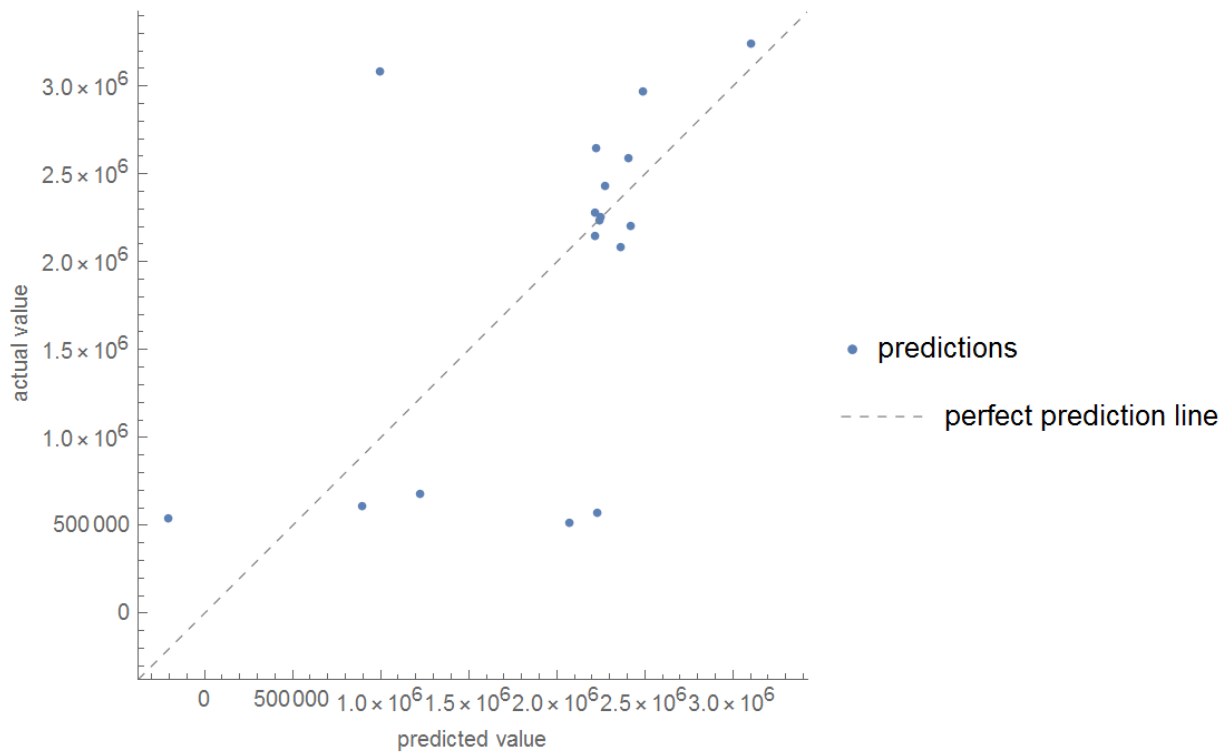
4.2 Our Model

The National Park Service (NPS) works to achieve its mission of protecting United States' precious ecosystems with limited financial resources. In the event that costs (such as those caused by climate-related events) exceed revenues and funding, NPS must decide where it is most optimal to spend the organization's resources and efforts.

To determine where it is best to spend resources and effort, we incorporated data about various natural disasters (wildfires, tropical storm, air pollution, and rising sea levels), visitor statistics, and the vulnerability scores obtained in "Part 2," to create a new AI-based model in Wolfram Mathematica. This model predicts changes in the number of visitors for each park 10, 20, and 50 years from now. By using the aforementioned data, our model was able to determine where the most visitors will go, and thus spend their money at. Using these results, the NPS can better decide where they should allocate their future financial resources.

To estimate the number of visitors to each National Park in the future, we used the same variables as in Part 2. These are wildfires, tropical storms, air pollution, and rising sea levels.

For example, we take the calculated wildfire damage, tropical storm damage, air pollution damage, and rising sea levels damage and input it into a Mathematica artificial intelligence model. This artificial intelligence model takes a four-item numerical vector with these elements: wildfire damage, tropical storm damage, air pollution damage, and rising sea levels damage. We did this for every year from 1997 to 2016, and created an association linking the four-item numerical vector with the visitors for that year. This association was then split 80% into a training set, and 20% into a testing set. Wolfram Mathematica was then used to apply artificial intelligence algorithms to the data. Mathematica created a Gaussian Process to take in a numerical vector input and output the number of visitors to that National Park in that year. The comparison plot to this Gaussian Process artificial intelligence model is shown below.



The comparison plot shows the perfect prediction line, the line on which perfect prediction is reached. Data points in the test set that were predicted with the Gaussian Process artificial intelligence model are shown in blue, and the distance from the perfect prediction line shows the accuracy of the predictions.

We used this Gaussian Process artificial intelligence model to output the predicted visitor data to the National Parks for the next 10, 20 and 50 years, shown below.

	10 Years (Visitors)	20 Years (Visitors)	50 Years (Visitors)
Acadia National Park	2576760	2392730	2225660
Cape Hatteras National Seashore	3122320	2236510	2227710
Olympic National Park	2013920	2221230	2227260
Padre Island National Seashore	1462300	2196770	2227710

This result gives us our recommendation as to where the National Park Service should invest their money. Cape Hatteras National Park, in the next 10 years, will have a drastically high amount of visitors than any of the other national parks, so the National Park Service should focus their finances there. In 20 years, all of the National Parks are near each other in visitor count. However, Acadia National Park has a slim increase in visitors over the other parks. So, finances should go here. Alternatively, if we look at the 50 year estimate, we see that Padre Island National Seashore has the largest growth rate in visitors, so it is also acceptable to invest money there.

5.1 Conclusions

Due to limited amount of available data, this model does not take into consideration other factors that may have a significant impact on sea level rises and the number of visitors that attend parks. Rather, we only considered the factors (temperature and heat index, and data about various natural disasters (wildfires, tropical storm, air pollution, and rising sea levels), visitor statistics, and the vulnerability scores obtained in “Part 2,” respectively) that we believed to most significantly affect the aforementioned topics. These factors are key to their respective issues, and thus provide us with a reasonably accurate, albeit generalized, idea as to how various situations will play out in the future.

Based on the predictions made by our model, we found that the National Park Service should invest its climate-damage repair budget first in Cape Herrera National Seashore for the next 10 years, then in Acadia National Park at year 20, and then finally, at the 50 year mark, to place the most resources in Padre Island National Park, based on the wedding of visitor statistics and climate vulnerability through our combined visitor-vulnerability model. In the future, as the climate changes even more drastically and the parks face even more challenges, the National Park Service will need the power of analytics and data on their side. That is where models such as ours come in; we hope that we can help to pave the way toward more sophisticated and intricate looks into the future of our National Parks, and into our stewardry of them.

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