Sea Level Rise Final Paper

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1.0 Problem Description

Sea levels have been rising, causing huge problems such as flooding, eroding, loss of habitat, and contamination ("Sea Level Rise: Causes and Consequences"). The rising levels are caused by factors such as climate change, ice melt, land sinkage, and thermal expansion. We focused on two case studies, New Orleans and San Francisco, that are geographically different in order to show how sea level rise affects areas differently. We looked into each of their current infrastructure, and collected data to model future sea level rise for the two areas. We also delved into ways coastal cities can prepare for the rising sea levels, and how city vulnerabilities can add to the complications.

1.1 Causes of Sea Level Rise

There are four main causes of sea level rises. The two we focused on, ice melt and thermal expansion, cause global effects. The other two factors only affect specific areas. Ice melt causes two-thirds of global sea rise with Antarctica and Greenland being the two main sources ("Sea Level Rise Causes"). Antarctica is proven to be the biggest threat because it contains 90% of the earth's ice, and scientists have estimated it contributes a maximum of six feet to sea level rise ("Sea Level Rise Causes"). Estimated to be the other one-third of global sea rise is thermal expansion, meaning as sea temperature rises, water expands. It is difficult to measure the exact effects of thermal expansion because it varies depending on the ocean depth and location. Deeper water expands more than shallow water due to the greater pressure, therefore it has a higher expansion rate ("Sea Level Rise Causes"). We will use data analytics to measure and model ice melt and thermal expansion and their effects on sea level rise.

1.2 Effects of Sea Level Rise

Sea level rise has both global and local effects from the flooding of major coastal cities to the loss of habitat for people, fish, birds, and plants. We are analyzing the effects of sea level rise on two major cities located on both U.S. coasts: New Orleans, Louisiana and San Francisco, California. We are analyzing local sea levels and elevation, global sea surface temperature, and global ice melt rate over time to measure the severity of sea level rise. The combination of these factors will aid us in creating a prediction model of sea level rise for both of our case studies.

2.0 Hypothesis and Research Questions

If sea levels continue to rise, more damage will occur in coastal areas. Some of our research questions include: What is causing sea levels to rise? How are sea levels affecting coastal areas? What is the current infrastructure of New Orleans and San Francisco? How much are sea levels predicted to rise around New Orleans and San Francisco? What can coastal cities do to protect themselves from sea levels rising?

3.0 Data Sources

Our group used sources including *Sustainability for All* and *NOAA* to research the causes and effects of sea level rise. It was helpful to gain motivation and narrow down our project topic. Following informational sources, we found the Coastline Retreat Simulation from *NASA* which helped us decide that our case studies should be an East and West Coast city, allowing us to compare global effects, like ice melt and thermal expansion, and local effects, such as elevation ("Coastline Retreat From Sea-Level Rise Simulation").

3.1 Ocean Temperature

The Sea Level Rise Organization provided us with a dataset for average global sea surface temperature increase from 2000 to 2014 ("Sea Level Rise Causes"). From this we were able to create a linear regression of ocean surface temperature increase from 2000 to 2014, which will be helpful in looking at the thermal expansion side of sea level rise. We also used this sea surface temperature data as a variable in our random forest model.

3.2 Ice Melt

We used the NASA GRACE (Gravity Recovery and Climate Experiment) satellite data to measure and observe monthly changes in Antarctica and Greenland ice mass from 2002 to 2020 (Wiese et al.). We found ice melt to be a factor of sea level rise and important when drawing conclusions on sea level rise predictions.

3.3 Sea Level

The GSFC dataset, "Global Mean Sea Level Trend from Integrated Multi-Mission Ocean Altimeters" was used to create a linear regression model of global mean sea levels from 1993 to 2020 ("GSFC," 2017). It contained measurements with and without global isostatic adjustment as well as final data with global isostatic adjustment and annual and semiannual signals removed. This is helpful to compare the rates of sea level rise at our two case studies to global levels. The *NOAA* "Sea Level Trends" datasets contained numerical sea level rise information for both San Francisco, CA and New Orleans, LA from 1940 to 2020 ("Sea Level Trends," 2019). These datasets were used to create linear regression models overtime for both of our case studies. Then we compared rates of sea level rise at our case studies to global rates of sea level rise. The data was also used as features in our random forest prediction of sea level rise.

3.4 Satellite Imagery

We explored three different satellites to visually model sea level rise overtime: Landsat, Modis, Sentinel. Landsat 8 Top of Atmosphere Tier 1 from 2013 to 2020 proved to be the most useful, as we used it to code our timelapses in python. To develop our digital elevation models, we used satellite imagery from the NASA SRTM, Shuttle Radar Topography Mission. These SRTM TIFF images were captured from EarthExplorer courtesy of the U.S. Geological Survey ("EarthExplorer," 2020). This allowed us to explore the relationship between coastal land elevation and rising sea levels.

4.0 Model Descriptions

Our models contain our analysis of the local and global contributing factors of sea level rise: Ocean temperature, ice melt, sea level, local coastline, and elevation. We model each factor individually, and after we bring them together with the random forest model. Then with thorough analysis we conclude how thermal expansion and ice melt aid in the increased sea levels of New Orleans, Louisiana and San Francisco, California.

4.1 Ocean Temperature

Thermal expansion is a primary cause of sea level rise so it is important to take this into account when analyzing sea level rise in our case studies. We were able to find global averages for ocean surface temperature and create a linear regression model from it. The positive trend of sea surface temperature is concurrent with increasing ice melt and sea levels.

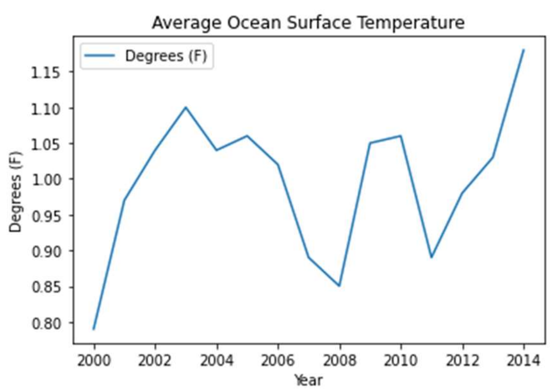


Figure 1

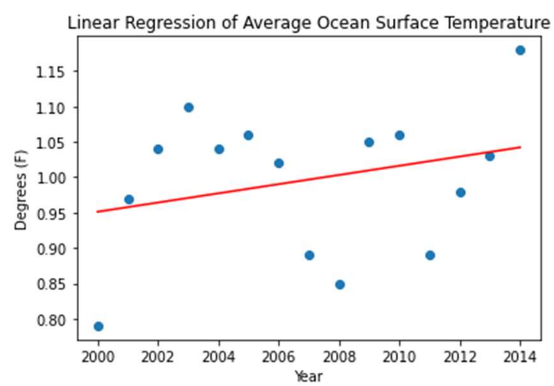


Figure 2

4.2 Ice Melt

With ice melt being a main cause of sea level rise, we analyzed the rate of ice melt in two primary cases, Antarctica and Greenland. The NASA GRACE satellite data allowed us to show these changes from 2002 to 2020 (Wiese et al.). Our two case studies are likely to be impacted by ice melt differently, as New Orleans is on the East coast and San Francisco on the West Coast.

Antarctica Ice Melt	Greenland Ice Melt

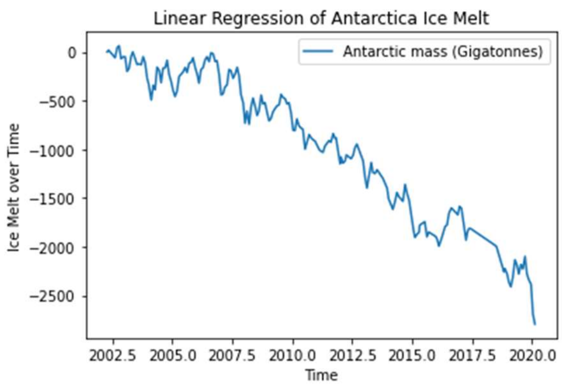


Figure 3

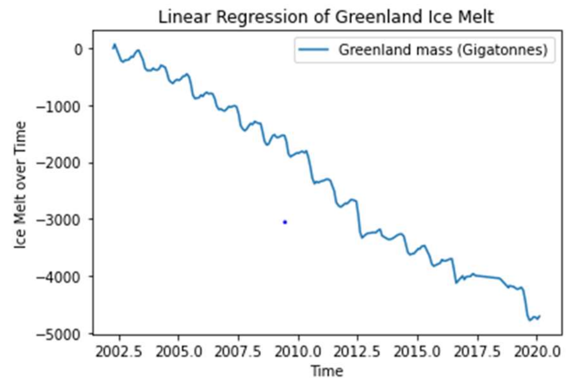


Figure 4

Comparison of Antarctica and Greenland

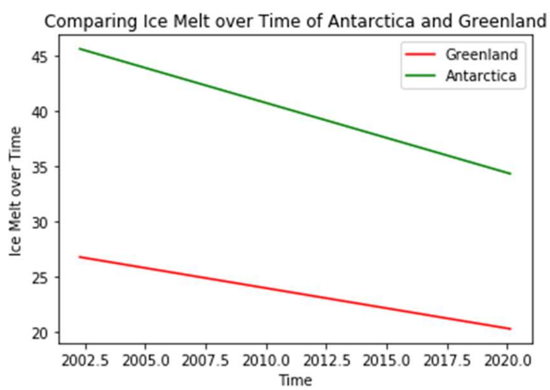


Figure 5

The comparison of the two ice masses in Figure 5 show that as mentioned previously, the Antarctic ice mass is melting at a slightly faster rate than the Greenland ice mass. The Antarctic ice mass is also larger, potentially causing more damage to coastal cities than the Greenland mass.

4.3 Sea Level

Before analyzing sea level rise locally in our two case studies, it is important to analyze sea levels globally. The dataset used for global mean sea levels was by NASA GSFC from 1993 to 2020 (“GSFC,” 2017). This dataset was used to create a linear regression model of global mean sea levels. It contained measurements with and without global isostatic adjustment as well as final data with global isostatic adjustment and annual and semiannual signals removed. This is helpful to compare the rates of sea level rise at our two case studies to global levels. The data was also used as a variable in the random forest model.

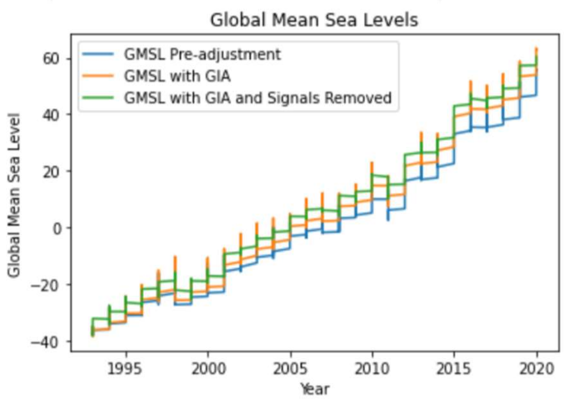


Figure 6

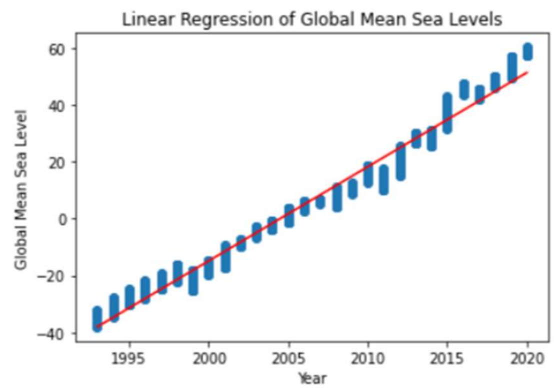


Figure 7

After analyzing global sea level rise, we focused on our case studies, New Orleans, LA and San Francisco, CA. The NOAA provided datasets for monthly sea levels in our case studies from around 1940 to 2020 ("Sea Level Trends - NOAA Tides & Currents"). New Orleans has a higher slope for sea level rise when compared to San Francisco, as you can see in Figure 8 versus 9 and 10 versus 11. This makes sense as New Orleans is already facing serious problems with sea level rise. New Orleans also follows the global trend for sea level rise more closely than San Francisco does.

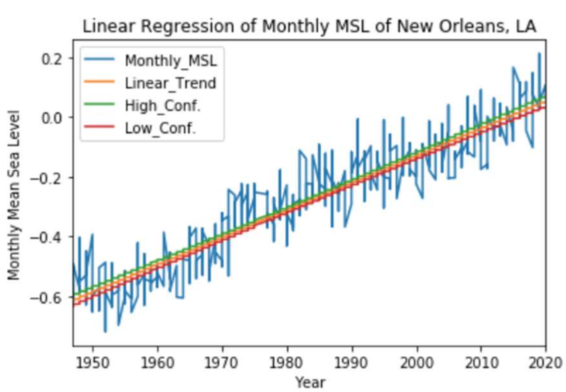


Figure 8

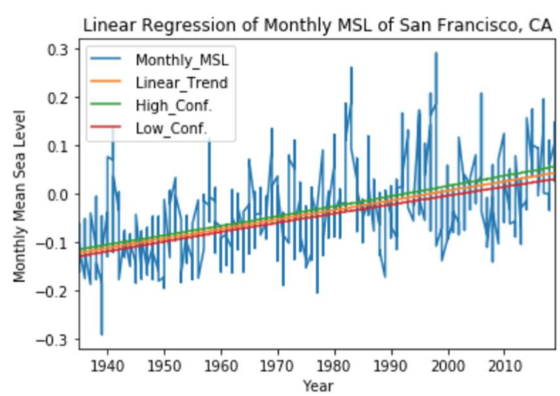


Figure 9

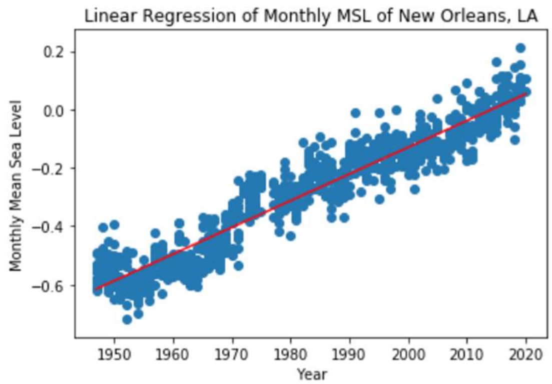


Figure 10

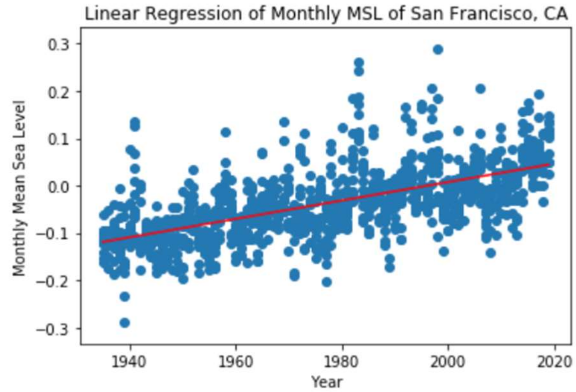
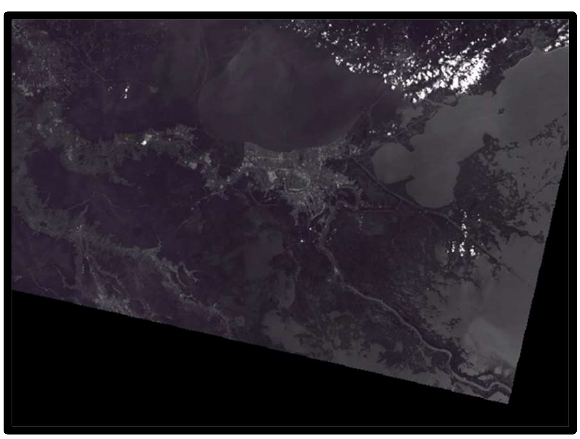
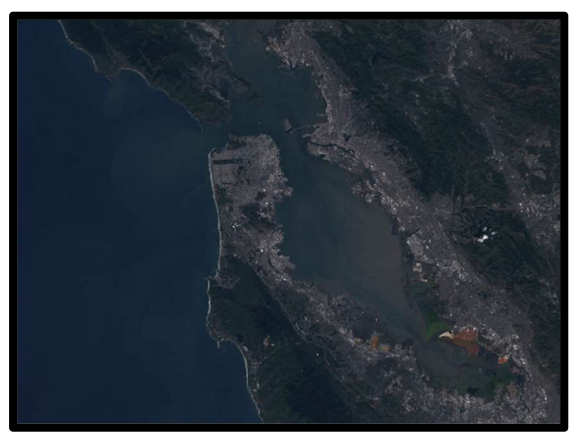


Figure 11

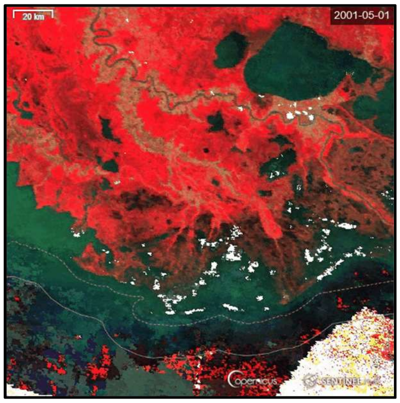
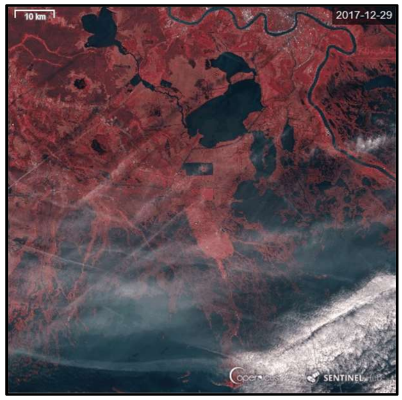
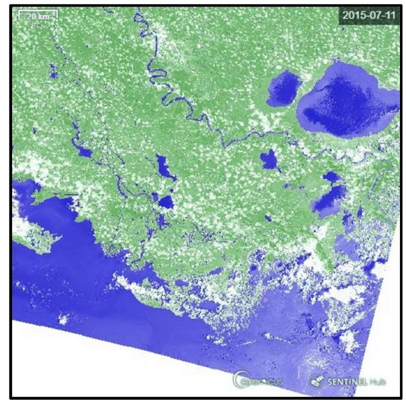
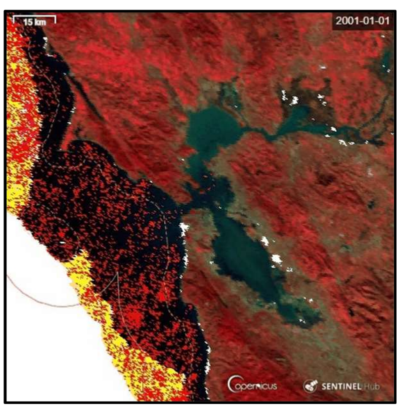
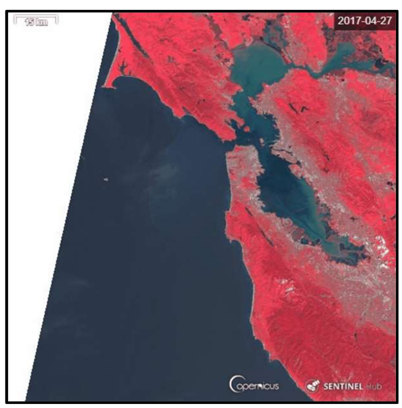
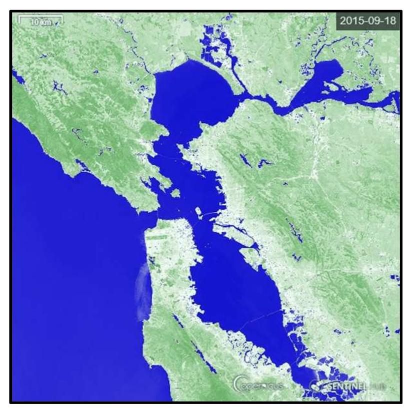
4.4 Timelapse of Coastline

To visualize sea level rise in our two case studies, we used timelapse imagery with Google Earth Engine from 2013 to 2020. Timelapses of New Orleans, LA and San Francisco were initially created using the Landsat 8 Top of Atmosphere Tier 1 collection and Google Earth Engine. Cloudy scenes were filtered out and the bands were changed to achieve the best visual of the city over time. The videos were then processed and exported to Google Cloud, then converted to gifs. A tutorial by Andrew Cutts, *Building Time-Lapse Imagery with Google Earth Engine* was adapted to do this for the two case studies (Cutts, 2017).

New Orleans, Louisiana	San Francisco, California
 Figure 12	 Figure 13

In the process of creating time lapses of our two case studies, we discovered a resource to create Modis, Landsat 8, and Sentinel-2 timelapses. This application allowed cloudy scenes to be filtered and the bands changed to provide brighter images than our previous timelapses. The EO-

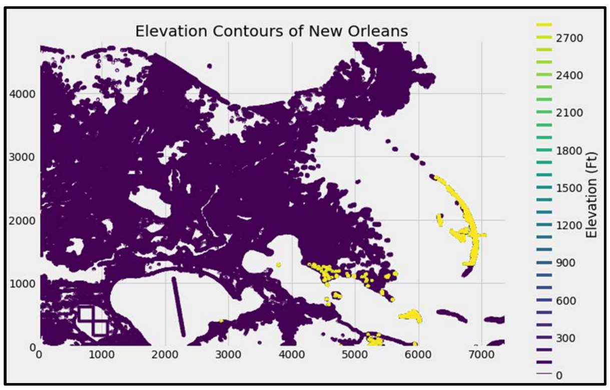
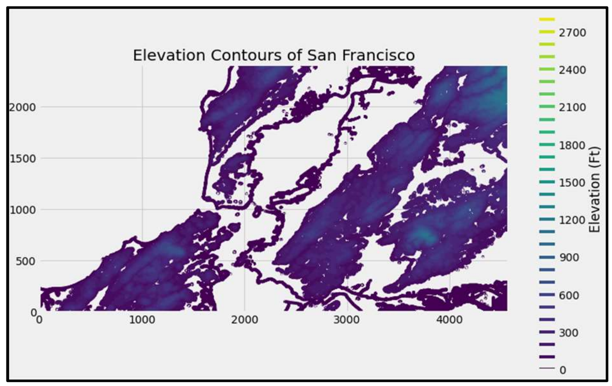
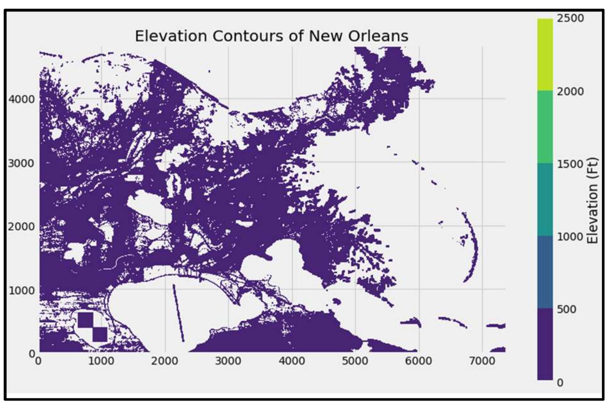
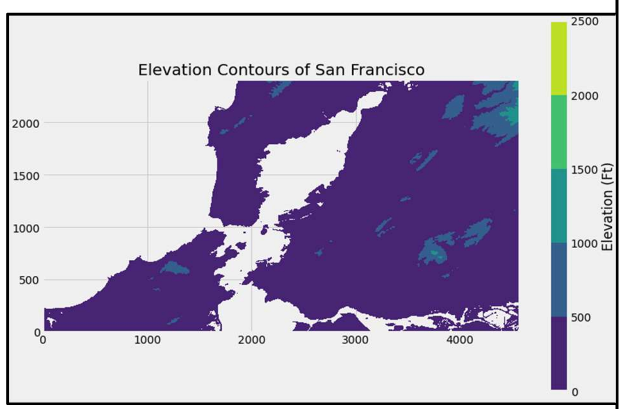
Browser by *Sentinel Hub* allowed us to better visualize sea level rise in New Orleans, LA and San Francisco, CA (“EO-Browser,” 2018).

Modis	Landsat	Sentinel 2
New Orleans, Louisiana		
 05-2001 to 05-2009 Figure 14	 12-2017 to 01-2020 Figure 15	 07-2015 to 10-2018 Figure 16
San Francisco, California		
 01-2001 to 01-2009 Figure 17	 04-2017 to 02-2020 Figure 18	 09-2015 to 02-2020 Figure 19

Although this tool allowed for brighter contrasted images, the time periods were not long enough in many of the images. Figures 12 and 13 provide better visualizations due to the longer time scales of how our case studies land has changed over time.

4.5 Elevation Models

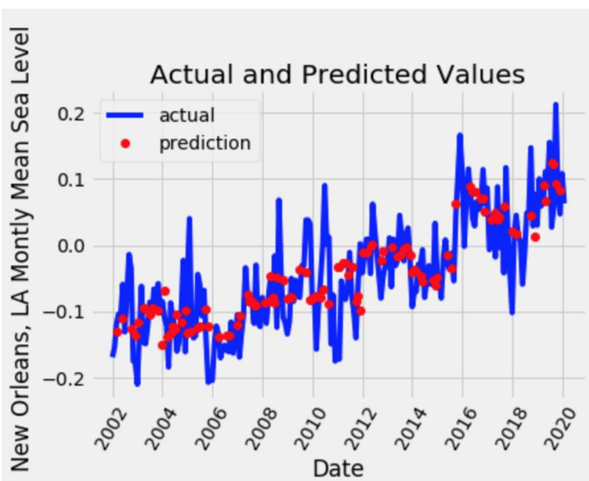
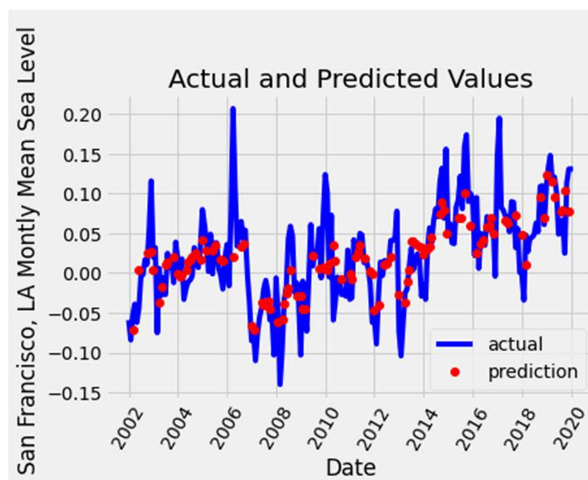
When analyzing sea level rise at our two case studies, it is crucial to look at elevation. This indicates where our case studies will be dealing with problems related to sea level rise. To create elevation models of our case studies, we first collected Shuttle Radar Topography Mission images of the locations (“Earth Explorer, 2020). To create elevation models from these images, we were able to adapt a tutorial by Matt Oakley and Max Joseph, *Visualizing Elevation Contours from Raster Digital Elevation Models in Python* (Oakley and Joseph, 2019). Python dependencies used were GDAl Geospatial Data Abstraction Library, Numpy, Matplotlib, and Elevation. The SRTM images were transferred to 2D Numpy arrays, cleaned, and applied with Matplotlib’s ‘contour’ and ‘contourf’. Both areas being of low elevation led to a scale of up to 3000 feet above sea level being used.

New Orleans, Louisiana	San Francisco, California
 Figure 20	 Figure 21
 Figure 22	 Figure 23

It is evident that New Orleans is close to sea level everywhere, as Figure 22 does not show many areas of higher elevation. In the contoured image of New Orleans, Figure 20, there are a few high areas we concluded to be barrier islands. San Francisco, Figure 23, shows several places of higher elevation that may not be affected by sea level rise as soon as lower areas. This is synchronous with New Orleans having a higher rate of rising sea levels, as it is closer to sea level as a whole.

4.6 Random Forest Prediction

Our group decided to tie our different approaches to analyzing sea level rise together with a random forest model. We were able to adapt a tutorial by Will Koehrsen, *Random Forest in Python* to create our models for San Francisco, CA and New Orleans, LA (Koehrsen, 2017). The initial models each featured the local sea level rise data and took in variables for the year, month, linear trends of the data, global sea surface temperature data, Greenland and Antarctic ice melt data, and global mean sea level rise data. The final New Orleans model had an accuracy of 82.6% with a mean absolute error of .004. The San Francisco model produced a low accuracy including Antarctic ice melt data, so we removed this as a variable and increased the accuracy by 40% to get 79.85% accuracy. This goes along with our conclusion that cities on the East and West coast are affected differently by ice melt in different places. Our models show that San Francisco is more affected by Greenland ice melt, while New Orleans is more affected by Antarctic ice melt. The random forest model allowed us to focus and predict sea level rise while taking into account the different causal data analyzed previously.

New Orleans, Louisiana	San Francisco, California
 Figure 24	 Figure 25

5.0 Results and Discussion

We concluded that when predicting the future of sea level rise, it is important to take in data like increasing sea surface temperature and ice melt, as thermal expansion and ice melt were two of our main causes of sea level rise. The pieces of the random forest model are interesting alone, but together build a more realistic model of sea level rise in our case studies. The accuracy for the New Orleans random forest prediction was 82.6% with a mean absolute error of .004. The accuracy for the San Francisco model was 79.85% with a mean absolute error of .003. The initial linear regression models we created could not take variables like this into account, therefore the random forest model does a more accurate job at predicting sea levels. We have made our project goals replicable through our notebooks in hopes that more can be done to predict future sea levels. With our comprehensive look at sea level rise, we are able to analyze our two case studies' plans of action for sea level rise.

5.1 Plans of Action

Due to the rising sea levels, coastal cities have to take necessary steps to be prepared. These steps include locating flood risks, creating better infrastructure, and observing how the sea levels will affect low-income families living along the coastline. Cities are taking different approaches depending on their current infrastructures, such as raising roads or building walls. For example, New Orleans previously initiated a 14.6 billion upgrade of levees and floodwalls (Frank, 2019). In addition, New Orleans created a 25 billion dollar plan for levees, sediment pumping, and creating natural infrastructure, all to minimize the effects of sea level rise ("Sea Level Rise"). In San Francisco, the Bay Area is considering creating green infrastructure to absorb the additional water and are working to repair the 3-mile long seawall across the waterfront (Littman, 2018). Other efforts cities have made to adapt to the rise of sea levels involve restoring shorelines and the relocation of communities.

Coastal cities also have to take into account their vulnerabilities, such as increasing population, poor infrastructure, and high rates of homelessness. Both New Orleans and San Francisco rank in the top ten cities in the United States for high homelessness ("Homeless", 2019). New Orleans was able to reduce their homelessness since 2011 by 85% since enacting a ten year plan to end homelessness. Although they are still among the top ten cities for homelessness, this shows they are able to enact and follow through with a plan. Cities dealing with sea level rise effects can work together to create effective plans of action. Homeless people are one of the most vulnerable groups of people, where it is difficult to find shelter and an adequate food supply in extreme events due to sea levels rising. Also, low-income families may find moving because of erosion and flooding from sea level rise extremely difficult. It is important to include homeless and low-income families in these plans of actions. As sea levels continue to rise, coastal cities will have to constantly adapt and make changes to protect those living in the affected areas.

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