**Comparing Historical Sea Level Rise Between Charleston, SC and San Diego, CA**

**Introduction**

Sea level rise (SLR) is a dynamic and ongoing process influenced by a combination of global, regional, and local factors. While fluctuations in sea level have occurred throughout Earth's history, recent observations show a marked acceleration linked to anthropogenic climate change. However, the impacts of SLR are not uniform across coastal regions. Tectonic activity, land subsidence or uplift, and oceanographic patterns cause significant variation in how sea levels change over space. The current project compares historical SLR trends in two U.S. coastal cities: Charleston, South Carolina, and San Diego, California. Despite both being situated along the coast, these cities have experienced different rates and patterns of sea level change, reflecting the complex interplay of natural and human-driven forces at regional scales. By examining these differences, we can gain a clearer understanding of localized sea level dynamics and their implications for coastal planning and adaptation strategies.

**Background**

Historical SLR:

Sea level has undergone significant changes throughout Earth’s history, largely driven by variations in climate and ice sheet dynamics. During the Last Interglacial period, around 125,000 years ago, global temperatures were significantly higher than pre-industrial levels, resulting in a global mean sea level (GMSL) that was approximately 6 to 9 meters higher than today.1 Over the last 20,000 years, sea levels rose dramatically as Earth transitioned out of the last ice age, fueled by the melting of large continental ice sheets.1,2

Following the disappearance of the Laurentide Ice Sheet roughly 7,000 years ago, GMSL stabilized, remaining relatively consistent for much of the last two millennia.1 However, this long period of stability ended with the onset of the Industrial Revolution in the late 19th century. Since the 1880s, global sea levels have been gradually rising, initially driven by the thermal expansion of seawater due to ocean warming. More recently, the accelerated melting of glaciers and polar ice sheets has contributed to an increased rate of rise. Between 1880 and 2009, the global average sea level rose by approximately 210 mm.3

Spatial Variability:

Several processes contribute to regional differences in sea level trends, including vertical land motion, ocean circulation patterns, and tectonic activity. One key factor is whether the land itself is rising or sinking over time. Charleston is one of the fastest-sinking cities in the United States, with one study estimating a subsidence rate of about 5 mm per year.4 In contrast, San Diego shows little to no evidence of subsidence, in fact, some areas have even shown signs of uplift.4,5

Beyond vertical land motion, regional ocean dynamics also play a significant role. The Atlantic coast is influenced by changes in the Gulf Stream and regional ocean dynamics. A weakening Gulf Stream can cause higher local sea levels along the Southeast coast, including Charleston.4,6 On the other hand, The Pacific coast is influenced by the California Current, upwelling, and large-scale climate oscillations (e.g., El Niño-Southern Oscillation).5,7 These processes can suppress or enhance sea level rise, but long-term trends are generally less affected by rapid ocean current changes compared to the Atlantic.5

The underlying geology of each region also plays a critical role in how sea level rise is experienced locally. Charleston is located on a passive continental margin with little tectonic uplift, making it more susceptible to subsidence and higher relative sea level rise.4 While Southern California is tectonically active, the immediate coastal area around San Diego is relatively stable, with some areas experiencing minor uplift, which can offset sea level rise.5

**Methods and Data:**

To analyze historical sea level rise, I obtained monthly tide gauge data for both Charleston and San Diego from NOAA and imported the CSV files into R. I began by plotting the monthly sea level data to visualize trends over time and examined the data distributions for each city. To assess statistical differences between the two datasets, I applied the Wilcoxon signed-rank test and the Kolmogorov–Smirnov (K-S) test.

Next, I created a linear model for each city to quantify long-term sea level trends. These models were then used to project future sea level changes, specifically estimating sea level rise by the year 2100. To visualize spatial impacts, I downloaded NOAA raster data for sea level rise scenarios and created maps of each city, overlaying the projected inundation areas with local census data to highlight potential population exposure.

**Results:**

To begin the analysis, I used ggplot2 in R to create line plots of the monthly sea level data for both Charleston and San Diego, allowing for a visual assessment of trends over time (see figure 1). I then generated histograms for each dataset to examine the underlying distributions. Figure 2 shows the distribution of the Charleston data, representing a close to normal distribution. Figure 3 shows the distribution of the San Diego data, which is not normally distributed, leading me to select non-parametric statistical tests for further analysis. This ensured that the comparisons between the two cities’ sea level trends were appropriate given the nature of the data.

The linear models for each city reveal clear differences in the rate of sea level rise. In Charleston, the model shows an average increase of approximately 3.51 mm per month, or about 42.12 mm per year. If this trend continues, sea levels in Charleston are projected to rise by roughly 0.39 meters (around 1 foot) by the year 2100. In comparison, San Diego's model indicates a slower rate of increase—about 2.23 mm per month, or 26.76 mm per year. Based on this trend, San Diego is projected to experience a sea level rise of approximately 0.24 meters, or slightly less than 1 foot, by 2100. These differences highlight how local factors influence long-term sea level trends, even within the same country.

To compare the sea level data between Charleston and San Diego, I used two non-parametric statistical tests: the Wilcoxon signed-rank test and the Kolmogorov–Smirnov (K-S) test. The Wilcoxon test assessed differences in central tendency between the two datasets. It returned a test statistic of W = 880,300 with a p-value of 0.2933, indicating that there is no statistically significant difference in the medians of sea level measurements between the two cities. This suggests that, on average, their sea levels are not drastically different over the observed period.

However, the K-S test, which compares the overall distribution shapes, told a different story. With a D value of 0.12215 and a p-value of 4.099e-09, the test strongly rejected the null hypothesis that the two datasets come from the same distribution. This result points to significant differences in the patterns and variability of sea level rise between Charleston and San Diego. In other words, even if their average sea levels aren't significantly different, the way sea levels change over time in each city follows a different trajectory, likely influenced by regional factors such as ocean dynamics and land motion.

To visualize the projected impacts of sea level rise, I created maps for both Charleston and San Diego using the sea level projections generated from the linear models (Figures 4 and 5, respectively). These maps display the estimated extent of sea level rise by 2100 and are overlaid with U.S. Census tract boundaries to highlight the human dimension of potential flooding.

**Discussion and Conclusion:**

This analysis demonstrated how, due to oceanographic, geophysical, and climatic factors, SLR varies significantly between regions. While Charleston and San Diego both are experiencing rising sea levels, the rate and nature of that rise differ. Charleston's higher rate, projected to reach approximately 0.39 meters by 2100, is influenced by factors such as land subsidence and changes in the Gulf Stream. In contrast, San Diego, with more geological stability and even localized uplift, is projected to see a lower rise of around 0.24 meters by the end of the century.

Statistical testing supported these distinctions. The Wilcoxon signed-rank test found no significant difference in the medians of sea level measurements between the two cities, but the Kolmogorov–Smirnov test revealed significant differences in their overall distributions. This suggests that while the central trends may appear similar, the underlying patterns and variability of SLR are distinct. This is likely driven by regional ocean currents, tectonics, and vertical land motion.

Mapping the projected sea level rise with census tract data added a critical spatial and social dimension to the analysis. These maps help identify communities at greater risk and emphasize the need for locally tailored adaptation strategies. Charleston, with its combination of rapid subsidence and vulnerable coastal development, faces especially heightened exposure.

This project did not come without its limitations, however. One of those being the use of a linear model to analyze the historical sea levels. This is because a linear model assumes a constant rate of increase and does not capture more complex temporal patterns in the data such as autocorrelation. Additionally, since it is established that SLR will most likely be increasing at an exponential rate8, a linear model will be unable to capture that relationship, meaning that my results are most likely underestimating SLR.

Another notable limitation involves the sea level rise raster used for San Diego. While the linear model projected approximately 0.75 feet of sea level rise by 2100, the NOAA raster datasets available only included sea level rise scenarios in 0.5-foot increments. As a result, I rounded up and used the 1-foot raster for visualization. This means the map slightly overrepresents the extent of projected inundation in San Diego and does not precisely reflect the results of the linear model. Although this approach ensures consistency in the visual presentation, it introduces a small degree of inaccuracy in portraying localized flood risk.

Completing this project taught me a lot about working independently in R, especially when it came to performing tasks that we didn’t cover in class. I learned how to search for relevant examples online and adapt code to fit the specific needs of my project, which gave me more confidence in troubleshooting and problem-solving on my own. If I were to do this project again, I would dive deeper into time series analysis in R to more accurately model and project future sea level rise. I would also spend more time searching for raster datasets that better match the projected SLR for San Diego, to improve the accuracy of my spatial visualizations.

Overall, this study reinforces that sea level rise is not a uniform process, but one that varies regionally due to differences in vertical land motion, ocean currents, and coastal geomorphology. By comparing Charleston and San Diego, it becomes clear how local conditions, such as subsidence in Charleston or relative stability in San Diego, can significantly influence both the rate and impact of sea level rise. The integration of statistical tests, linear modeling, and spatial mapping provided a comprehensive approach to understanding these differences and identifying areas of heightened risk. While limitations exist, such as simplified projections and raster resolution mismatches, the results highlight the importance of localized data and analysis in informing adaptation strategies. A region-specific approach is critical for developing effective, evidence-based responses to future coastal hazards.

**Figures:**

**A graph showing a sea level

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Figure : Historical SLR

A graph of a number of sea level

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Figure : Histogram of Charleston's Monthly MSL

A green and white graph

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Figure : Histogram of San Diego's Monthly MSL

A map of a city

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Figure : Map of Charleson, SC with 1-foot of SLR

A map of the state of california

Description automatically generated

Figure : Map of San Diego, CA with 1-foot of SLR

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