Chesapeake Bay Analysis on Climate

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Abstract

This analysis was done to explore the changes in marine climate data in the Chesapeake Bay Region from 2013 to 2023. The Chesapeake Bay is vulnerable to the effects of climate change as it threatens the marine life and coastal communities that rely on it. Using data collected from the National Oceanic and Atmospheric Administration, marine data such as air temperature, sea surface temperature, wind speed, and wind direction were analyzed in the context of the bay. The analysis used tools such as AWS, SQL, R, and Python to explore summary statistics and create visualizations to understand the changes and possible impacts of the analyzed variables over the past 10 years. The work revealed an increase and positive trend in air and sea surface temperature as well as a decrease in yearly average wind speed. A heat map created in the analysis also revealed the total percent change in air and sea surface temperature in specific geographic locations of the Chesapeake Bay. The details of the analysis showcase the continuing effects of climate change on the region and connect these changes to the dangerous effects it has on the marine life that occupy the bay. This analysis seeks to continue the conversation of climate change and the effects it has on surrounding communities and populations to encourage impactful change.

Introduction

Climate change is a big topic today as we continue to see its effects on nature and weather patterns across the globe. This research project aims to identify the effects of climate change in the Chesapeake Bay Region from 2013-2023. According to the Chesapeake Bay Program [1], the Chesapeake Bay Region is one of the most vulnerable in the nation to the effects of climate change. Rising water levels, caused by thermal expansion, are expected to continue rising faster than the global average due to the land around the region sinking [1]. The rising water levels contribute to coastal flooding, erosion, and loss of wetlands and marshes [1]. Flooding and erosion can also be affected by wind and waves. In addition to the rising sea level, the rise in air and water temperature threatens marine life in the region [1]. A study done in the region saw that ~92% of the bay water experienced warming temperatures from 1960-2010 [1]. This warming in temperature decreases the amount of oxygen water can hold causing marine life to suffocate [1]. Wind is also an important factor in oxygenating the waters of the Chesapeake Bay. Less wind on the water hinders layers of the bay from mixing and moving oxygen to the bottom of the bay where critical marine life, like oysters, live [2]. The wind on the Chesapeake also helps to mix the fresh water from streams and rivers connected to the bay mix with the salt water from the ocean helping to disperse nutrients through the area [2]. Using data collected from the National Oceanic and Atmospheric Administration this paper will explore marine data collected from the Chesapeake Bay Region addressing the following research questions:

1. *Is there a relationship between air and sea surface temperature in the Chesapeake Bay region between 2013 and 2023?*
2. *Is there a relationship between wind direction, wind speed, and wave characteristics in the Chesapeake Bay region between 2013 and 2023?*
3. *Are there seasonal or yearly differences or trends in temperature and wind data in the Chesapeake Bay region between 2013 and 2023?*

Literature Review

There is a lot of research about climate change and its effects on our oceans. The National Oceanic and Atmospheric Administration (NOAA) Global Marine Observations gathered from the International Comprehensive Ocean-Atmosphere data set (ICOADS) offers extensive information on surface and air temperatures, weather, waves, wind, and more from 1662 to present day from all over the world. In many cases, this data is analyzed to compare past and present ocean data in the context of climate change.

Highlighting climate change measures over time, The United States Environmental Protection Agency (EPA) reports on ocean climate change indicators, as well as others. These ocean indicators include ocean heat, sea surface temperature, sea level, land erosion, coastal flooding, and ocean acidity [3]. The EPA gathers data from various contributors, including ICOADS, to analyze trends in these climate indicators [3]. Analyzing sea surface temperature (SST) from ICOADS, the EPA reported an increase in SST during the 20th century which continues to rise [4]. These changes in SST vary regionally and can have an impact on ocean circulation patterns as SST increases. This indicator is important as it can affect weather and other environmental factors such as shifting storm tracks, increasing the risk of heavy rain, threatening marine life, and more [4].

Researching circulation changes and wind, Godshall and Walker [5] used ICOADS data to understand circulation differences, which are associated with air temperatures, over time. They found that within periods of climate cooling and warming lay systematic shifts in wind which suggested circulation changes [5]. Godshall and Walker [5] noted clockwise shifts in the 1950's and 60's winter wind direction. In comparison, the 1970s recorded a counterclockwise shift associated with the warming climate of the time. Further, Godshall and Walker [5] analyzed salinity level changes showcasing the wind shifts' significant effects on water circulation which is also affected by SST as noted in the EPA [4] reports.

With respect to the Chesapeake Bay, circulation is an important factor in protecting marine life. As discussed in Breck Sullivan's article [2], wind aids in the Chesapeake Bay water circulation mixing fresh waters from the bay's water sheds with the salt water of the ocean. This circulation affects the salinity of the water, and paired with temperature, affects the physical characteristics of the bay. Low salinity in the bay can cause invasive freshwater species to spread into parts of the bay and affect the oyster population, important in bay water filtration, which prefer salt water [6]. Higher water temperatures and low wind speeds can also impact the size of "dead zones" in the bay [7]. Dead Zones occur where there is not enough oxygen circulating through the water which creates a hypoxic environment for marine life [7]. Hotter temperatures and weak winds can increase the size of dead zones and make them last longer causing fish to move away to find oxygen and killing immobile species like oysters [6,7]. The warming waters and dead zones create a "habitat squeeze" limiting the waters certain species can occupy [6].

The EPA states, and past research shows, that ocean factors influence weather on both local and global scales while climate changes alter many of these ocean factors [2]. It is evident from this past research that ocean and climate indicators are related and that further research on these indicator trends gives deeper insights into the severity of climate change effects. Throughout this project, analyzing SST, air temperature, wind, and wave patterns in the Chesapeake Bay from 2013-2023, we can predict to see similar results in terms of changing wind speeds and sea surface temperatures as was documented in previous research. While many similar ocean analytics have been done, taking a closer look at the Chesapeake Bay region within a small 10-year window may yield different insights or show less significant changes in indicator trends than analyses that cover centuries of recorded data.

Strategy & Methods & Tools

The data used for this analysis was gathered from the NOAA Global Marine Database [8]. Specific areas of interest and attributes can be ordered through the NOAA website. The original data order contained data for the entire Mid-Atlantic region from 2013-2023 but was then filtered to the Chesapeake Bay Region using Python due to data capacity. The filtered and cleaned data set contains 19,457,524 rows of marine data including latitude, longitude, date, air temperature, sea surface temperature, wave height, wind direction, wind speed, past weather, present weather, swell direction, and swell height. An initial data exploration was conducted on a random sample of the data using AWS Glue Data Brew. This sample uncovered various columns that had missing data shown in the figure below.

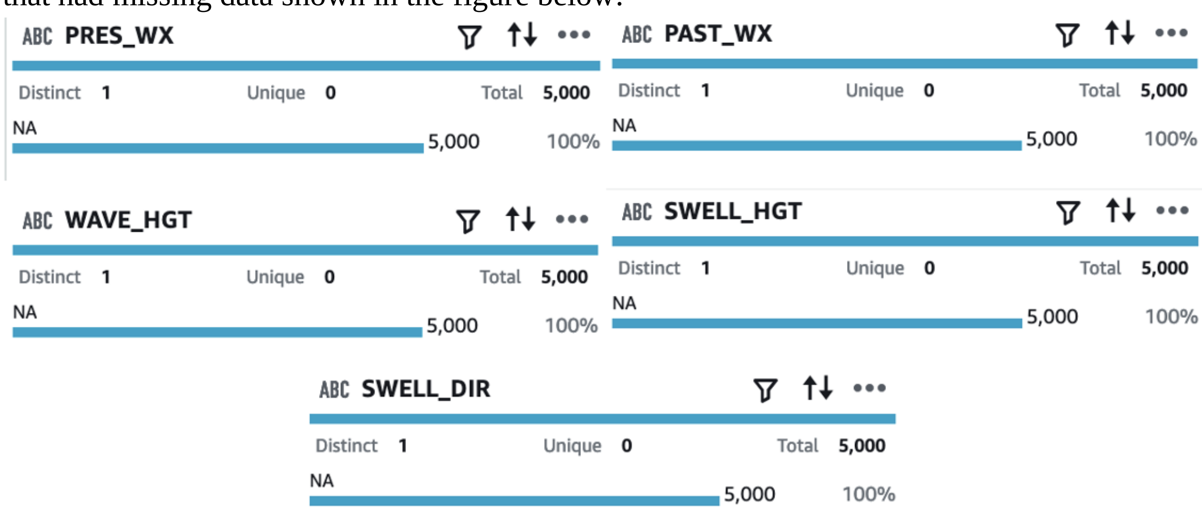

Figure 1: Samples with NA Values from AWS Glue Data Brew

After data exploration in AWS, further analysis of null values in the data set was conducted in R. Past and present weather, wave height, swell direction, and swell height data contained ~99% missing values and was therefore excluded from the analysis. Additional missing values were present in air temperature (22%), sea surface temperature (45%), wind direction (11%), and wind speed (11%). Due to the missing data, the analyses explore the average by month and year in an attempt to gather trends and conclusions aimed at the proposed research questions.

The data was cleaned further, eliminating columns with 99% null values, formatting the date column, adding a wind direction column as “N”, "NE", "E", "SE", "S", "SW", "W", and "NW", and adding season columns for fall, spring, summer, and winter. Several tools were used in the analysis including MySQL for summary statistics, Python for cleaning and data visualizations, and R for visualizations. The table below displays the data schema for the cleaned data set.

Field	Type
rownum	int
datecol	date
station	tinytext
longitude	decimal(10,0)
latitude	decimal(10,0)
airtemp	decimal(10,0)
seatemp	decimal(10,0)
waveh	int
windd	int
winds	int
windd2	tinytext
month	int
season	tinytext
year	int

Table 1: SQL Schema

Analysis

A. *Air temperature and Sea Surface Temperature*

year	avg_sst
2013	60.6637
2014	61.4994
2015	61.1095
2016	62.1503
2017	62.3484
2018	60.8824
2019	61.8953
2020	62.2221
2021	63.0293
2022	61.8452
2023	62.8020

Table 3: Average Air Temperature per Year

year	avg_at
2013	58.9337
2014	60.0915
2015	60.1503
2016	59.7178
2017	60.8290
2018	59.8771
2019	60.3899
2020	60.1198
2021	61.1306
2022	59.4189
2023	60.7112

Table 2: Average Sea Surface Temperature per Year

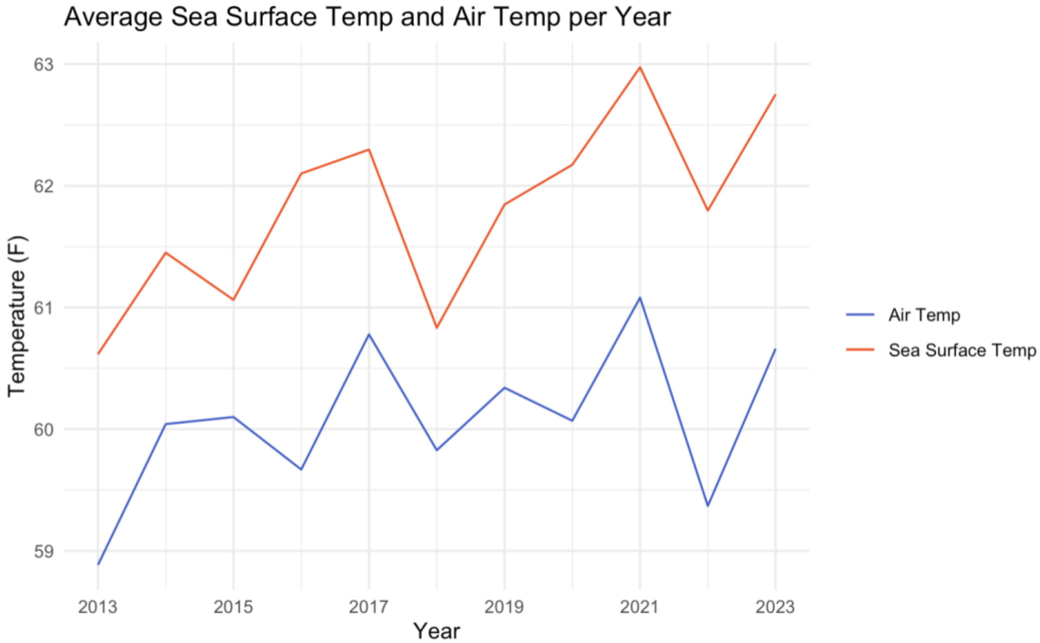

Figure 2:Average Sea Surface and Air Temperature per Year

Yearly air temperature and sea surface temperatures within the region were examined first in this analysis. Table 2 displays the yearly averages with air temperature ranges from a low of 58 degrees Fahrenheit to a high of 61 degrees Fahrenheit. Table 3 displays the sea surface temperatures in 2013-2023 ranging between 61 degrees Fahrenheit and 63 degrees Fahrenheit. In Figure 1, we can see the trend of air and sea surface temperatures between 2013 and 2023 appears to be increasing. When adding a trend line to the air and sea surface temperature trends, shown in figures 3 and 4 below, we can see the increasing trend line in blue.

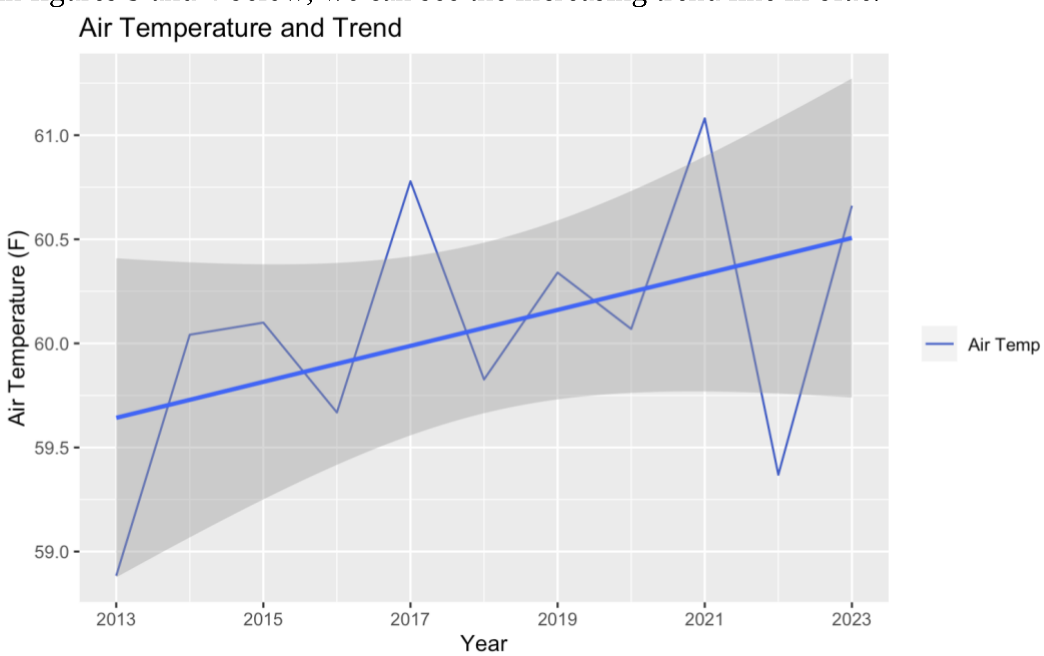

Figure 3: Yearly Air Temperature Trend

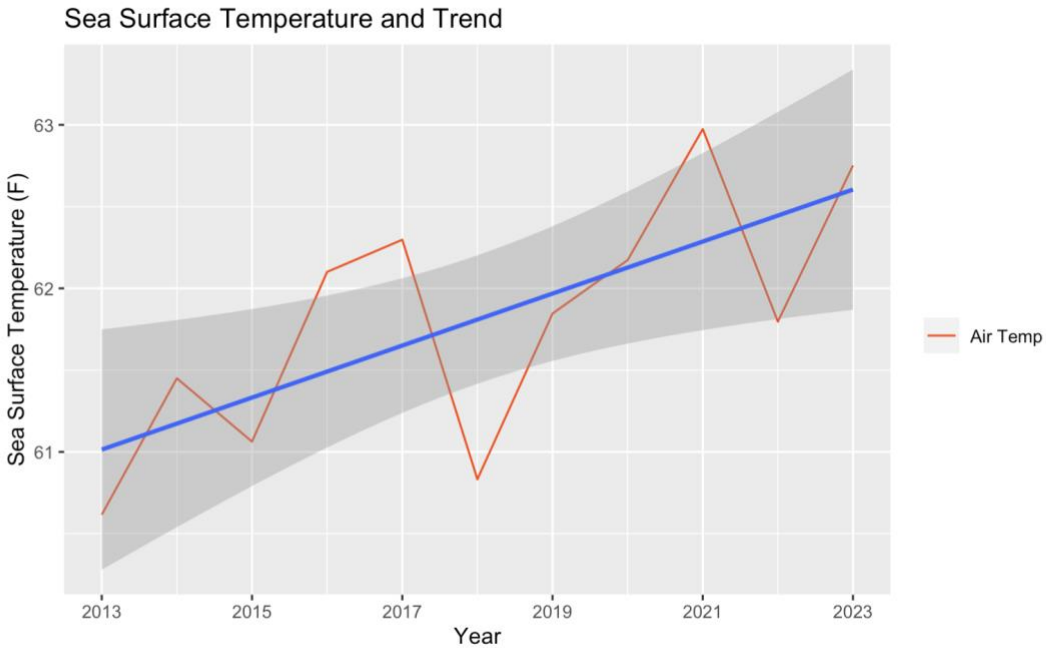

Figure 4: Yearly Sea Surface Temperature Trend

The increasing trend in air and sea surface temperature trends suggests the region could be facing the effects of climate change. Next, we explored the yearly seasonal averages of air and sea surface temperature trends, shown in Figure 5 below.

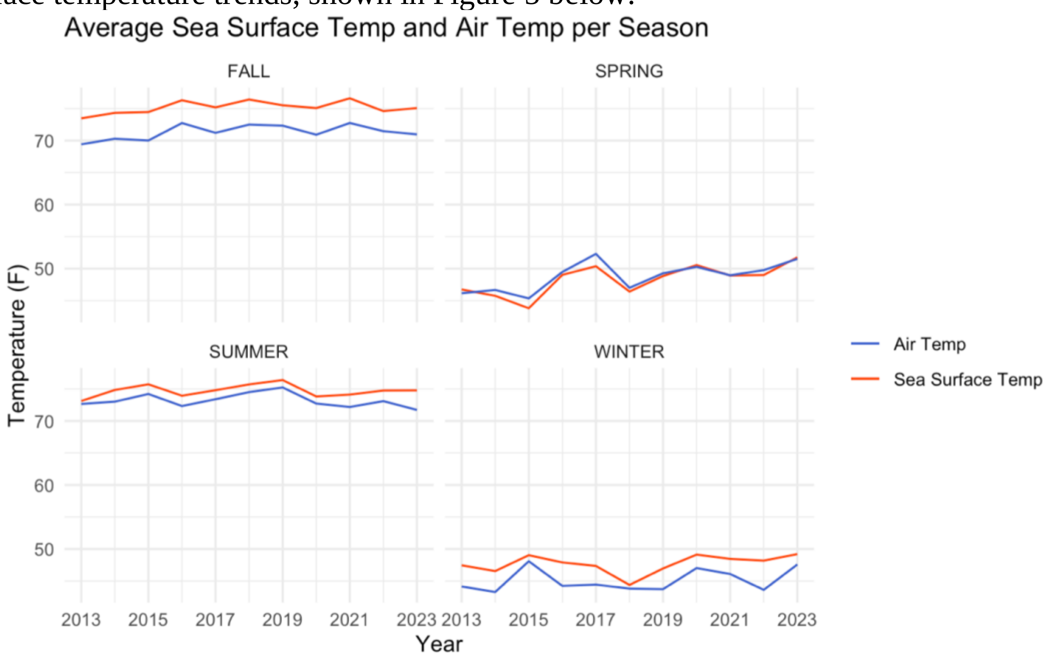

Figure 5: Yearly Seasonal Air and Sea Surface Temperature Trends

The increasing yearly trend is not as apparent on the seasonal level, particularly in the summer and fall times. A slight increase in temperature is seen in the spring and winter seasons. From Figure 5, we can see the air and sea surface temperatures follow similar trends with little difference in temperature in the summer and spring seasons. Similarly, the fall air and sea surface temperatures follow a similar trend but with a slight temperature difference. While the winter temperatures look to follow a similar trend there are years where the air and sea surface temperatures differ (ex. 2022) and years where they are similar (ex. 2015).

B. Wind Speed and Wind Direction

Next, the region's wind speed and wind direction were analyzed to explore changes in wind direction suggesting wind circulation changes.

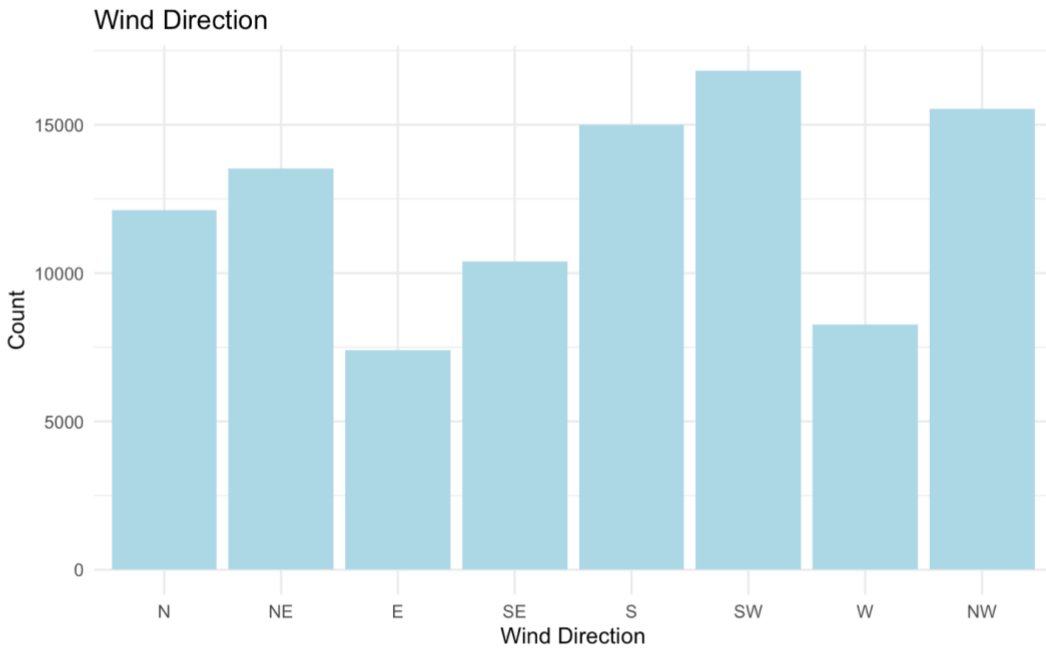

Figure 6: Wind Direction 2013-2023

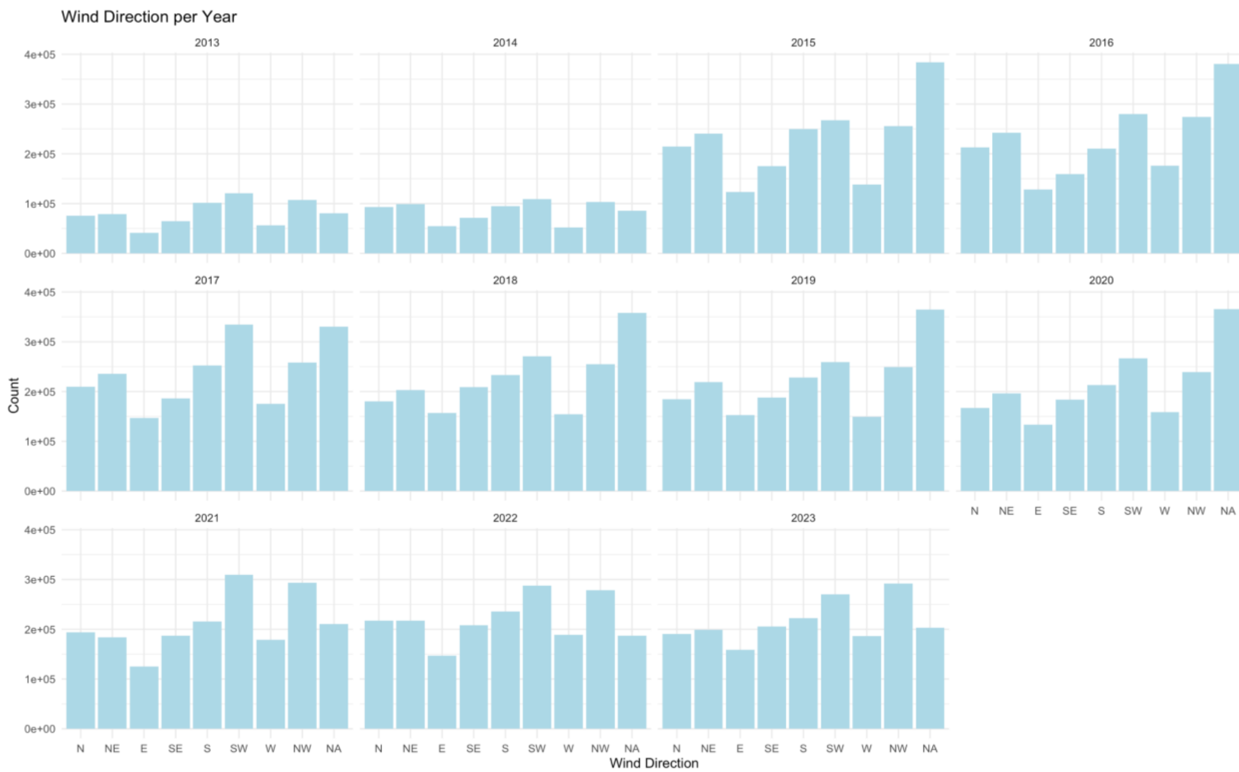

Figure 7: Yearly Wind Direction

Figure 6 displays the count of wind directions between 2013 and 2023. From the bar plot, we can see the primary wind directions north, northeast, northwest, south, and southwest. To investigate the yearly trends, the bar plot was faceted by year, as shown in Figure 7. Looking at the figure, particularly from 2015-2023 we can see the wind direction distribution becoming more uniform which could indicate a circulation change occurring. The relationship between wind speed to wind direction was also analyzed, see Figure 8.

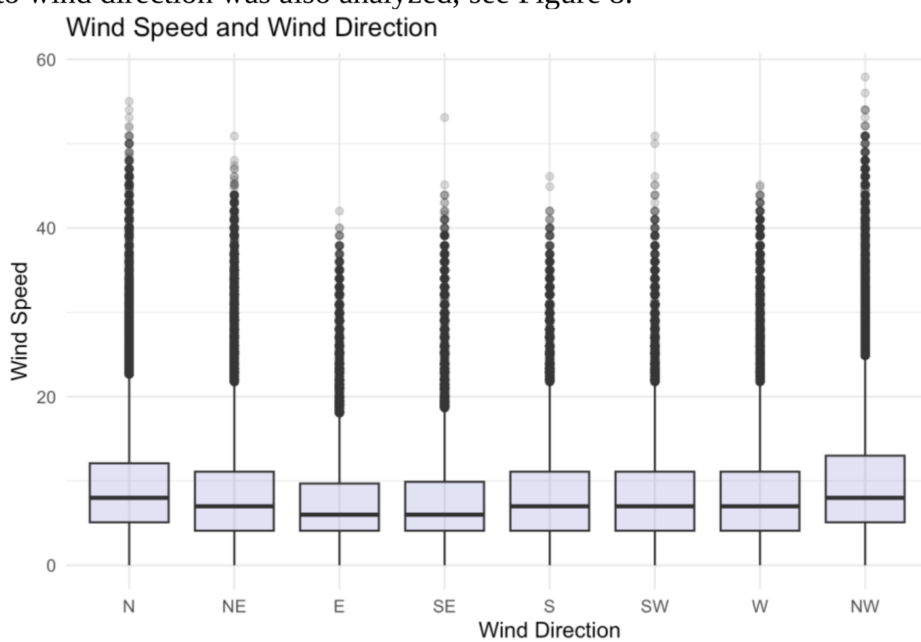

Figure 8: Box Plot of Wind Speed and Wind Direction

From the box plot in Figure 8, the wind speed appears to be normally distributed between wind directions with an average wind speed of about 5-8 knots. There are several outliers of wind speed in each direction reaching almost 60 knots. Finally, concerning wind speed and wind direction, wind speed was analyzed on a yearly and seasonal lens.

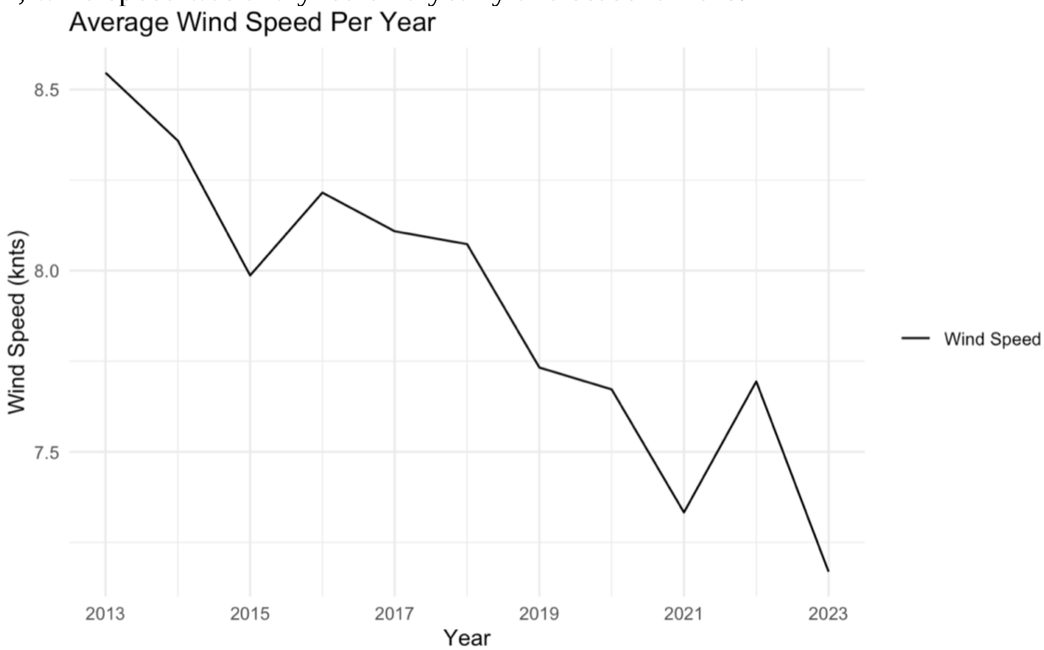

Figure 9: Yearly Average Wind Speed

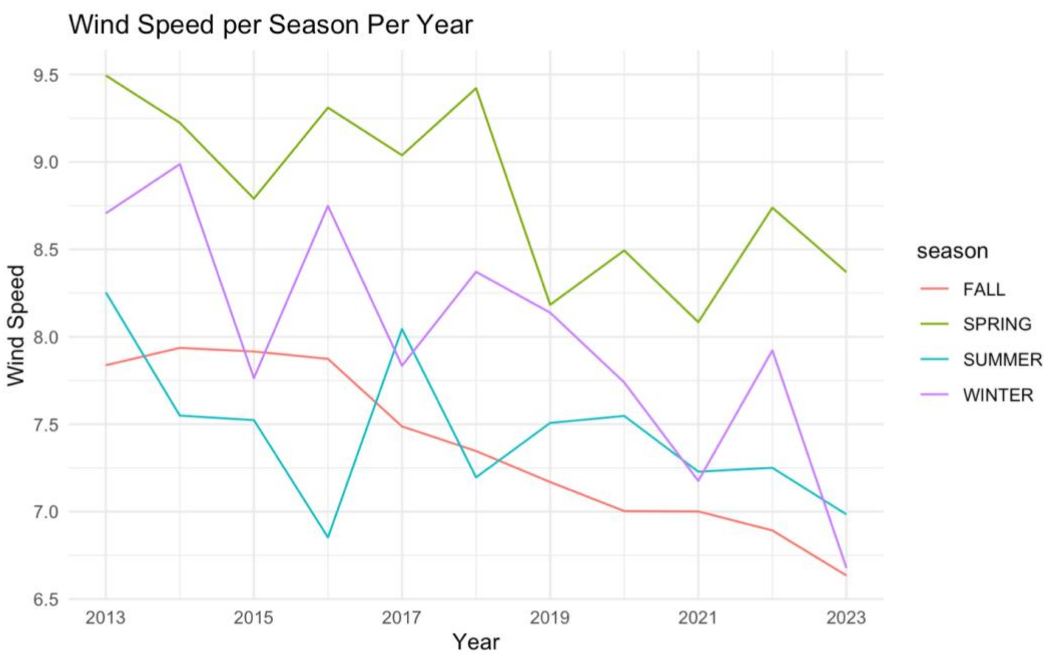

Figure 10: Seasonal Yearly Average Wind Speed

Figure 10 shows the yearly seasonal average wind speeds with the spring and winter being the windiest seasons on average. Both figures 9 and 10 depict a decreasing trend in wind speeds from 2013-2023 on both a yearly and seasonal scale. This is an interesting finding connected to climate change and the Chesapeake Bay region as wind is important in oxygenating the water.

C. Correlation

Despite the low number of records for wave height in the data set, a correlation matrix was created to see the correlation between wind speed and wave height records as well as the correlation between air and sea surface temperature.

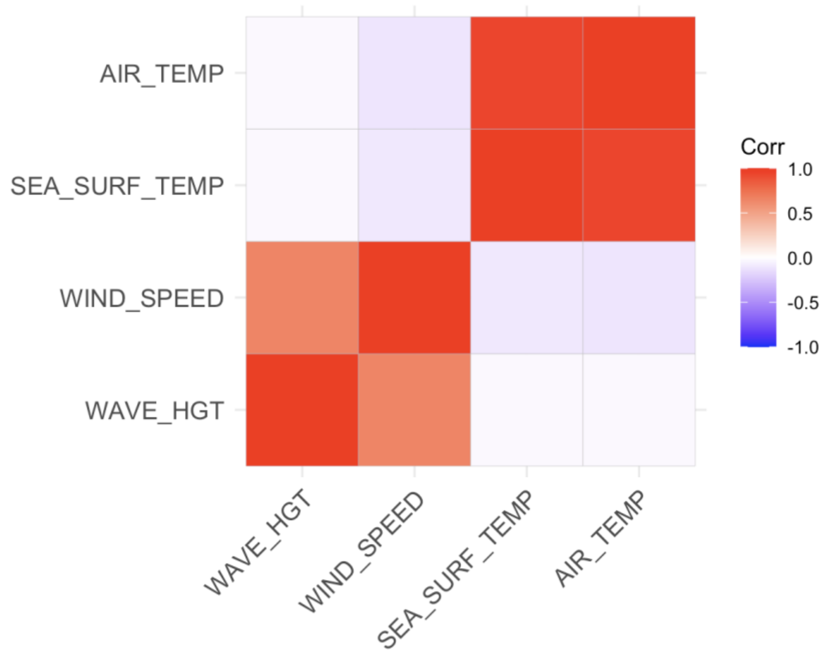

Figure 11: Correlation Matrix

Figure 11 depicts the correlation between wave height, wind speed, air temperature, and sea surface temperature. The darker the red color in the correlation matrix the more positively correlated the attributes are. From the figure, we can see that sea surface temperature and air temperature are highly correlated as well as wind speed and wave height for the available records. It also appears that air and sea surface temperatures have a slightly negative correlation to wind speed.

D. Geographical changes

In the final portion of this analysis, the geographical changes in air temperature were visualized using a heat map created in Python. figures 12 and 13 below depict the total percent change in air and sea surface temperature from 2013-2023.

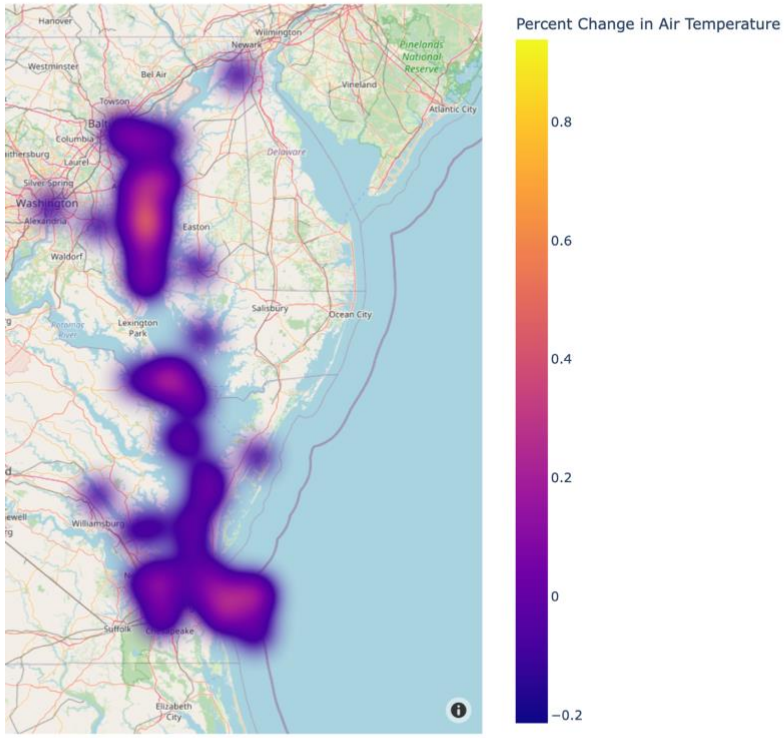

Figure 12: Heat Map of Percent Change in Air Temperature

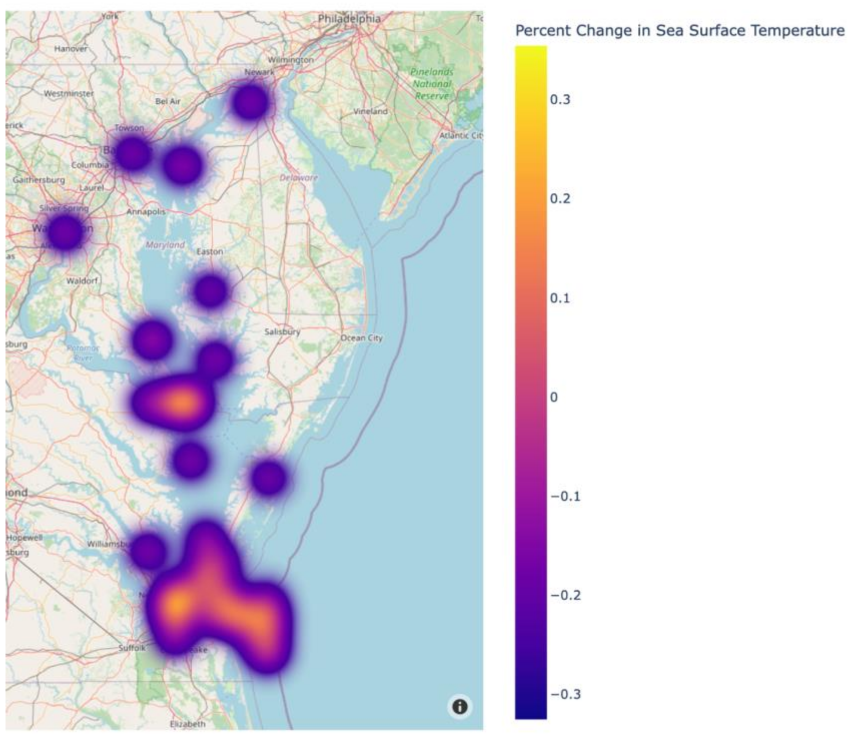

Figure 13: Heat Map of Percent Change in Sea Surface Temperature

The total percent change was calculated from the latitude and longitude points of buoy stations and mapped to the Chesapeake Bay Region. Lighter colors on the map indicate higher changes in air and sea surface temperature. From Figure 12, we can see a higher rise in air temperature near the mouth of the Chesapeake and the section that flows between Baltimore and Washington D.C. Figure 13 shows less warming in the north of the Chesapeake, but significant increases at the start of the Chesapeake Bay near Norfolk Virginia.

Results

1. *Is there a relationship between air and sea surface temperature in the Chesapeake Bay region between 2013 and 2023?*

The correlation matrix shown in Figure 11 depicts a strong positive correlation between air and sea surface temperature. This correlation can also be seen in figures 2 and 6 which plot the yearly and seasonal averages in temperatures. Following the yearly averages per year in air and sea surface temperatures in Figure 2, an increase in air temperature is often paired with an increase in sea surface temperature, similarly with decreases, except from 2014-2015 and 2019-2020. The seasonal yearly averages in air and sea surface temperature are nearly identical in the spring and summer months and follow the same trend in the fall spring and summer.

2. *Is there a relationship between wind direction, wind speed, and wave characteristics in the Chesapeake Bay region between 2013 and 2023?*

The box plot in Figure 8 suggests that there is no relationship between wind direction and wind speed as the wind speed is uniformly distributed among wind directions with an average between 5 and 8 knots. Of the minimal records of wave height from the collected data, there was a correlation to wind speed as shown in the correlation matrix, Figure 11. It is suggested in future research to collect more wave height data to confirm this correlation.

3. *Are there seasonal or yearly differences or trends in temperature and wind data in the Chesapeake Bay region between 2013 and 2023?*

Yes, as shown in Figure 5, air and sea surface temperatures are higher in the summer and fall months and lower in the spring and winter. Figures 3 and 4 show an increasing trend in yearly air and sea surface temperatures in the Chesapeake Bay region. The heat maps in figures 12 and 13 depict the total percent change in air and sea surface temperatures in specific areas of the Chesapeake Bay. From these heatmaps, we can see areas with the greatest percent change and increasing trend in temperatures from 2013-2023. With respect to wind direction and wind speed, the common wind direction in the Chesapeake Bay area is between northwest and northeast and south/southwest (shown in Figure 6). These are the primary wind directions for all years between 2013 and 2023 as shown in Figure 7, but the distribution appears to be more uniform between the wind directions as time passes especially in 2022 and 2023. Figure 10 shows the differences in yearly average wind speed per season. This chart depicts a seasonal difference in wind speed with spring and winter often being the windiest seasons. Both figures 9 and 10 indicate a decreasing trend in average wind speed within the region.

Discussion and Conclusions

Throughout this analysis, NOAA ICOADS marine data was collected and analyzed to discover the effects of climate change in the Chesapeake Bay Region. Due to the size of the data collected, only 10 years of data was analyzed. While the results of the analysis suggest that, even for a short time, the region is experiencing climate change effects, analyzing a larger time period of data in the region could reveal more about the speed and severity of its effects. Studying a larger period of this data could also reveal if the increase in the past 10 years is statistically significant to past recorded data. Severe storms and rainfall were also common factors brought up in research evaluating the effects of climate change in the Chesapeake Bay region, but the limited records concerning past and present weather from the pulled data, could not be analyzed in this project. Future research on this topic could include more information about severe storms and heavy rainfall and if the frequency of these events is increasing as they may have a connection to climate change effects.

As the consequences of climate change continue to be revealed through research in the Chesapeake Bay area, it is important to understand the changes in the environment. This analysis revealed changes in air temperature, sea surface temperature, and wind in the Chesapeake Bay region in the last 10 years. Changes in these attributes harm the ecosystem in the bay as discussed in the literature review. Wind, air, and sea surface temperature are important factors in circulating the water in the bay ensuring safe oxygen levels, salinity, and temperature for the marine life that occupy the region. This analysis sheds light on the changing climate in the region and its connection to the marine populations it affects. It is important to continue research efforts in this area and communicate findings to promote conversation and inspire positive solutions to climate change.

Citations

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