Temporal and Spatial Variations of Sea Surface Temperature and *Chlorophyll a* in Coastal Waters of North Carolina

Mentor: Dr. Jinchun Yuan (*ECSU*)
Elizabeth City State University
Elizabeth City, NC 27909

Authors:
Brittany Maybin (*SC*), Yao Messan (*NCA&T*), Phillip Moore (*SAC*), Chelsea Goins (*ECSU*)

Abstract- **Temperature and *chlorophyll a* (*chl a*) are two fundamental properties of seawater. Traditionally, both temperature and *chl a* are determined by shipboard sensors that can only provide limited temporal and spatial coverage. Consequently, the distribution of temperature and *chl a* in coastal water of North Carolina is poorly known. In this study, satellite remote sensing was used to study the temporal and spatial variations of the coastal waters of North Carolina. The region (34°N, 40°N, 78°W, 74°W) of our study included the Chesapeake Bay, Albemarle and Pamlico Sound, and a part of Northeast North Atlantic Ocean. Two sets of data, *chl a* and sea surface temperature (SST) were used for this study. Monthly *chl a* concentration based on 10 years of Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data and SST data based on 5 years of Aqua-Moderate Resolution Imaging Spectroradiometer (MODIS) data was obtained from the NASA website (GIOVANNI). (1) The monthly climatology of sea surface *chl a* was calculated from monthly remote sensing data; (2) Temporal variation of area averaged *chl a* and SST for selected regions (i.e. Albemarle Sound, Chesapeake Bay) was calculated; (3) Temporal variations of both *chl a* and SST distribution animation was also created.**

I. INTRODUCTION

The Chesapeake Bay is the largest estuary in the United States. The Bay's width ranges from 3.4 miles near Aberdeen, Maryland, to 35 miles near the mouth of the Potomac River [1]. It is a complex ecosystem that provides homes, food, and protection to a large array of plants and animals. Fish and plants migrate and live in the Bay and surrounding coastal areas like the Albemarle and Pamlico Sound. The Albemarle and Pamlico Sound are also estuaries home to a large array of aquatic wildlife.

Chlorophyll is the green pigment that allows plants to convert sunlight into organic compounds during photosynthesis. More specifically, this study focused primarily on *chl a*, the predominant type found in algae. Algae, or phytoplankton, are the primary producers of food and oxygen in the aquatic food web [1]. It is important to calculate *chl a* concentrations in the Chesapeake Bay and North Carolina coastal regions because *chl a* is an indicator of phytoplankton and plant growth.

The concentration of microscopic marine plants, called phytoplankton, can be derived from satellite observation and the quantification of ocean color. Ocean color data is critical to the study of ocean primary production. "Primary production" refers to the organic material in the sea that is produced by "primary producers" who exist at the lowest levels of the food chain and use sunlight or chemical energy, rather than other organic material, as sources of energy [2]. Algae supplies food for animals living in the water.

High concentrations of *chl a* in the Bay and North Carolina coastal waters indicate nutrient pollution because excess nutrients fuel the growth of algae [3]. An excess amount of algae can be detrimental to plant and animal life. Excess algae blocks sunlight that passes to the lower depths of the bay and coastal waters. However, *chl a* is necessary to keep a balanced food web for the animal life. A calculation of *chl a* is a good indicator of the amount of algae in this region.

Studies for the seasonal variations of *chl a* concentrations and sea surface temperature have been conducted in different areas around the world [2]. Ocean data from Sea-viewing Wide Field-of-view Sensor (SeaWiFS) has been acquired daily in the North Carolina coastal regions and Chesapeake Bay area since September 1997. SeaWiFS monthly global products have been added to a web-based online visualization and analysis tool called Giovanni developed by the GES DISC that provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth science remote sensing data [3]. In this present study, SeaWiFS monthly data were examined to identify the seasonal variations of *chl a* and sea surface temperature in this area.

II. DATA AND ANALYSIS TOOL

This study analyses *chl a* and SST from satellite sensors in the Chesapeake Bay and North Carolina coastal regions (34°N, 40°N, 78°W, 74°W). Both *chl a* and SST were obtained using NASA Ocean Biology Processing Group (OBPG). The chlorophyll a calculated using the SeaWiFS data during the time period of January 1997 to December 2007 [3]. The purpose of the (SeaWiFS) Project is to provide quantitative data on global ocean bio-optical properties. Subtle changes in ocean color signify various types and quantities of marine phytoplankton (microscopic marine plants), the knowledge of which has both scientific and practical applications. The SeaWiFS Project develops and operates a research data system that enables us to process, calibrate, validate, archive, and distribute data received from an Earth-orbiting ocean color sensor [4].

The SST was processed by the OBPG using the same data processing system that generates SeaWiFS ocean color data. SST is acquired using Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua satellite [3]. MODIS is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites mapping the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths [5].

Initial data explorations of *chl a* and SST were conducted by using the Giovanni system. The system is an easy accessible and easy-to-use online tool that allows the user to access Earth remote sensing data. The system provides longitude-latitude maps, animations, statistical analyses, scatter plots, and correlation coefficient maps. Giovanni handles data with different temporal and spatial resolutions, which allows global and regional oceanographic research. Currently, the Giovanni-Ocean instance includes monthly ocean data that is routinely updated and provided through SeaWiFS and MODIS-Aqua [3].

Microsoft Excel was an instrumental tool in calculating the monthly *chl a* concentrations. GIOVANNI was used to calibrate the monthly *chl a* concentrations for each month from 1998-2007. The data was saved as a text file and opened up in an Excel spreadsheet. The monthly averages for each month were calculated spanning from 1998 to 2007 using Excel. This data was then entered into Matlab to create the images seen in Fig. 1 below.

III. RESULTS PART I

The graph below shows the distribution of *chl a* in the Chesapeake Bay area and coastal water of North Carolina (Fig. 1). The data is an average of *chl a* for each month during a time span from 1998 to 2007. *Chl a* is measured in mgm^3 and presented in the log scale. The red regions signify regions marked by high levels of *chl a*, and the blue identifies the area with a low *chl a* concentration. The *chl a* indicates how much nutrient the area contains to provide a good environment for the development of plants.

As seen in Fig. 1, starting from the month of January, the *chl a* concentration is largest on the coastal ocean and as we go deep in the open ocean, the *chl a* concentration decreases. According to the graph, the highest concentration of *chl a* is located on the coast toward the Chesapeake Bay and the Albemarle Sound. In the months starting from July to

December, concentrations show significant decreases in and around the Chesapeake Bay. There are isolated areas in the Albemarle Sound region where high levels of *chl a* exist.

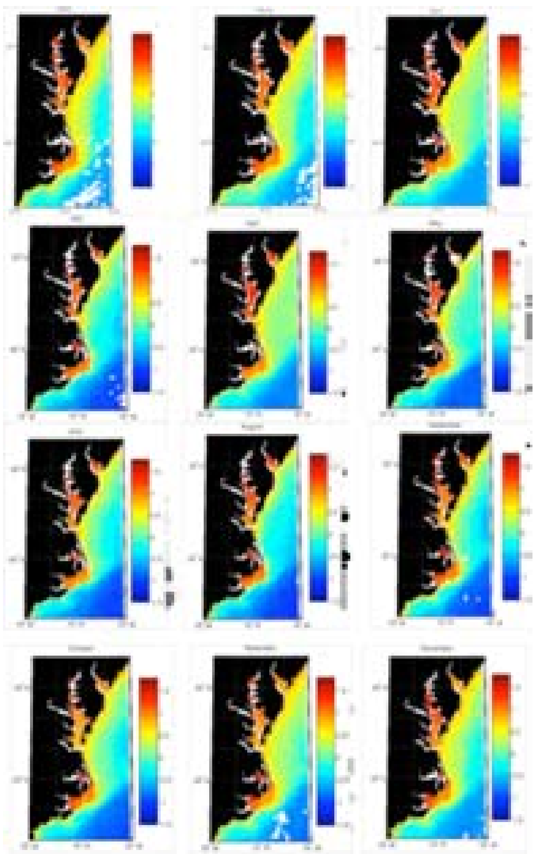

Fig. 1 Monthly distribution of *chlorophyll a* in the Chesapeake Bay and North Carolina coastal regions, composite of nine years of SeaWiFS data from January 1998 to December 2007.

From the months of January to April, the concentration of *chl a* increases. Concentrations decrease from the month of May until December. April has a peak of *chl a* in the Chesapeake Bay. The month of August has the greatest peak in *chl a* in this region during the nine year time span. In the coastal ocean, there is a noticeable decrease from the month of January to August followed by gradual increases the rest of the year of *chl a*. In the coastal open ocean, from January to May, there is an increase June to October. During May and October, the greatest coastal open peaks occur. Further in the open ocean, the concentration of *chl a* decreases from January until August and it increases for the rest of the year. August is the peak of the chlorophyll a concentration in the open ocean.

In September through November, the concentrations diminish in comparison to the months of December through June along the coast. From December through November the concentration of the *chl a* concentration decreases in the ocean. According to Fig. 1, *chl a* concentration are greater in the coastal ocean than in the open seas because the coastal land has more nutrition than the sea.

IV. RESULTS PART II

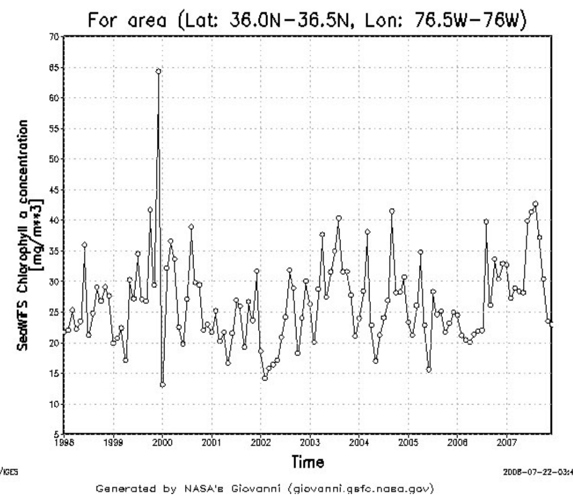

Fig 2a. *Chl a* Concentrations of the Albemarle Sound from January 1998 December 2007

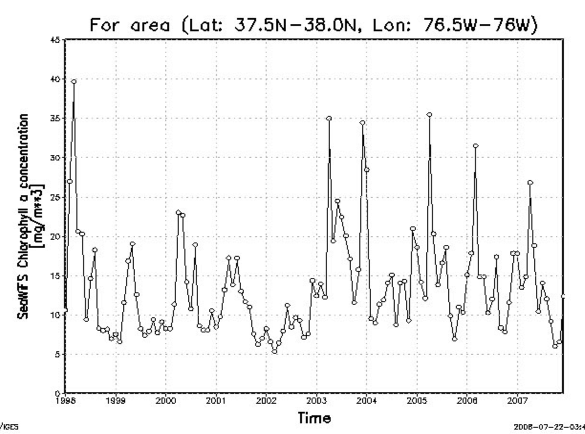

Fig2b. *Chl a* Concentrations of the Chesapeake Bay from January 1998 December 2007

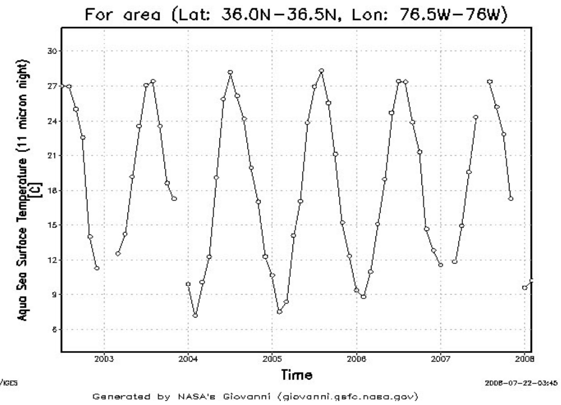

Fig2c. SST of the Albemarle Sound from July 2002 to February 2008

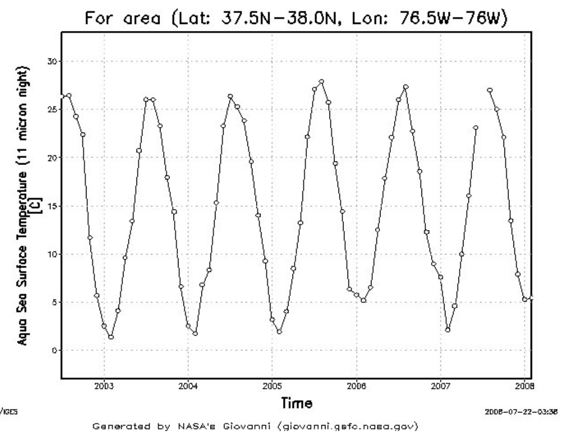

Fig2d. SST of the Chesapeake Bay from July 2002 to February 2008

Figures 2a and 2b represent the *chl a* for the Albemarle Sound and Chesapeake Bay. *Chl a* was gathered from SeaWiFS from the time span of January 1998 to December of 2007. After the data was gathered, Giovanni was used to create graphs that show the *chl a* levels over the time span. In the area of Chesapeake Bay, there was a large jump in 2003 that remained constant to 2007. The increase doubles the *chl a* levels of the years prior to 2003. At the time the research was conducted, it was unknown as to why such a dramatic increase would have occurred. One thing to take into account for future work is the wind during that time period. Wind could explain the increase, but why would such an increase remain constant? If wind is the cause, then why did the amount of wind in the area increase and remain constant? Future research is needed to further explain what is happening.

Figures 2c and 2d represent the SST for the Albemarle Sound and Chesapeake Bay. SST was gathered from MODIS from July 2002 until February 2008. The results for SST for each area were very predictable and consistent for each area. Both the Albemarle Sound and Chesapeake Bay had high periods in the summer and low periods in the winter. The data for SST was found in Giovanni. There were three different calculations for SST. The calculations are SST (11 micron day), SST (11 micron night), and SST (4 micron night). The SST (11 micron night) was chosen because it is least likely affected by weather changes.

V. RESULTS PART III

The following coordinates (34°N, 40°N, 78°W, 74°W) were entered into the Giovanni database using OBPG SeaWiFS Monthly Global 9-km Products in order to create an animation of *chl a* from September of 1998 through December 2007. During the summer and fall months the concentration of *chl a* was high along the coast.

Similarly, an animation of the SST was created using OBPG MODIS-Aqua Monthly Global 9-km Products found on the GIOVANNI website for the same region from July 2007 to February 2008. Changes in the temperature could be seen viewed along latitudinal and longitudinal lines. Increases in the SST occurred closer to the coast and moving closer to the equator.

When looking at the animations it is important to know what the different colors stand for. On the *chl a* animation, colors closer to red signify high concentrations of *chl a* and those close to blue signify low concentrations. On the SST animation, hot pink means high temperature and purple means low temperature.

VI. SUMMARY

Nine years of data collected using SeaWiFS and Aqua-MODIS yields a significant amount of data mapping the *chl a* concentrations and SST in the Chesapeake Bay and North Carolina coastal regions. Seasonal cycles of *chl a* in the Chesapeake Bay and North Carolina coastal regions were found to be prominent. Maximum and minimum *chl a* occurs each year. Due to the need of a sufficient supply of nutrients, the majority of *chl a* is concentrated along the coast where phytoplankton and algae can receive nutrients from the land. Concentrations are greater along the coast than in the open ocean. In the summer, the concentration of *chl a* is high on the coast but as the year progresses concentrations in the open ocean increase. *Chl a* concentrations are higher in the summer because more sunlight reaches the water than during the other months.

Particularly interesting was a jump in the *chl a* between the years of 2002 to 2003. Before 2003, *chl a* concentrations in the Chesapeake Bay were significantly lower than after 2003. Unfortunately, because of the limited scope of this research, no conclusions were drawn as to the reasons behind this significant increase in *chl a* during 2003.

The SST cooling index has a maximum in the summer and a minimum in the winter. The maximum is a result of warmer temperatures during the summer months and cooler temperatures during the winter. Warmer temperatures near the equator increase the SST of the water.

VII. FUTURE RESEARCH

After observing the *chl a* averages for each area, it was noticed that there was a large increase in *chl a* in the Chesapeake Bay area in-between the years of 2002 to 2003. Conducting future research to determine the cause of this dramatic increase would be beneficial to this study. It has been stated in previous research studies that sea surface winds (SSW) may contribute to variations in *chl a*. Using the microwave scatterometer (QuikSCAT) data to calculate and correlate SSW to *chl a* may help determine the influx of *chl a* in 2003. Given more time, the scope of this research would include a study of SSW in the Chesapeake Bay and North Carolina coastal regions. Correlations between *chl a*, SST, and SSW could be made to determine the causes of any seasonal variations, upwelling, and winter blooms in this area.

Considering the effects of surrounding human and wildlife on *chl a* concentrations and SST in the Chesapeake Bay and North Carolina coastal regions would greatly improve this research. Any available data and statistics on the populations for the area can aid in showing any kind of disturbance in the area that may have caused a shift in the drastic rise in *chl a* during 2003. Such a disturbance may be a result of severe weather and/or pollution caused by land development or other factors in the area.

Finding any improvements made to Aqua-MODIS and SeaWiFs instruments would improve this study. Improvements in the instruments could potentially and drastically change the data we collected. It is possible that if the satellites were updated around 2003 that, that could have been the cause in the major increase of *chl a*.

Past research has proven that coastal upwelling contributes greatly to the *chl a* concentrations and SST in any given area. Upwelling occurs when coast-parallel winds drive surface waters offshore causing cold, nutrient rich water to displace warm surface water [6]. These occurrences push cold, nutrient rich water to the surface increasing the concentration of *chl a* and decreasing the SST. Most upwelling occurs during winter months when the temperatures are cooler. Although sunlight is limited during the winter, increases in *chl a* are made due to the large amounts of nutrients located at the water's surface caused by upwelling. The decrease in SST and increase in *chl a* during the winter months may be a direct result of upwelling. Factoring in coastal upwelling would have greatly improved this research. Given more time, this study would include correlations between SST, *chl a*, and SSW.

VIII. ACKNOWLEDGEMENTS

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