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North Carolina Water Resources

Utilizing NASA Earth Observations to Monitor Harmful Algal Blooms in the Albemarle Sound of North Carolina



**Technical Report**

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# I. Abstract

Harmful algal blooms (HABs) cause significant ecological damage to aquatic systems by disrupting water chemistry, producing toxins, and blocking sunlight to submerged vegetation and other organisms. In the Albemarle and Pamlico Sounds, the USGS North Carolina Water Science Center biologists monitor HABs by taking point samples throughout the region, but they lack a method to monitor the spatial extent of HABs throughout the entire sound during the year. For this project, Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) Level 2 OC3M-derived chlorophyll data was downloaded from NASA Goddard Space Flight Center’s Ocean Color SeaDAS Website via a Linux operating system. The OC3M algorithm used multispectral reflectance bands available from Aqua MODIS to calculate the concentration of chlorophyll-a, which is used as a proxy for the presence of algae. Chlorophyll concentration values from these layers were then extracted from days with spatially and temporally corresponding *in situ* water samples for comparison. Then, images of monthly chlorophyll means were processed into a time-series video representation of algae extent throughout the sounds. End-users were able to use the ten year time series to supplement their *in situ* data to assess HAB behavior throughout the region.

**Keywords**

North Carolina, Remote Sensing, Harmful Algal Blooms (HAB), Albemarle Sound, Pamlico Sound, bio-toxins, submerged aquatic vegetation (SAV), Earth Observations

# II. Introduction

The objective of this project was to monitor the extent of harmful algal blooms (HAB) in the Albemarle and Pamlico Sounds in North Carolina using NASA Earth observation imagery and ancillary data gathered between 2004 and 2014, and to address the Water Resources application area by giving end-users a tool to assess water quality as it related to HAB extent on a large scale.

The Albemarle and Pamlico Sounds are part of the Albemarle-Pamlico Estuarine Complex, the largest lagoonal estuarine system in the United States. This system receives drainage from approximately 30,000 square miles of watershed including discharge from the Chowan, Roanoke, Pasquotank, Neuse, and Tar-Pamlico Rivers (EPA, 2007). As the nation’s second largest estuary, the Albemarle-Pamlico system supports a diverse seagrass and submerged aquatic vegetation (SAV) population as well as rich fishery characterized by a mix of estuarine and pelagic species (Mallin et al., 2008). SAV plays a vital role in the sound by providing habitats for fish and aquatic invertebrates (Paerl, H.W. and T.G. Otten, 2013). The biodiversity and overall health of the estuary has become compromised over recent decades due to increased urbanization and industrialization in response to rapid population growth along the North Carolina coast. In addition, shifting agricultural interest during the 1980s led to a decline in tobacco farming which was promptly succeeded by an expansion of commercial swine production (Mallin et al., 2008). Together, these activities have increased the introduction of chemical and physical stressors from urban and agricultural runoff into the delicate estuarine ecosystem (EPA, 2007). Excessive eutrophication from anthropogenic sources have altered natural relationships between primary producers and have created an optimal environment for Harmful Algal Bloom (HAB) activity (Paerl, H.W. and T.G. Otten, 2013; Fu et al., 2012).

Harmful phytoplankton are capable of producing neurotoxins and hepatotoxins in concentrations lethal to wildlife and domestic animals (Lopez et al., 2008; Mallin et al., 2008). They can also manufacture endotoxins and dermatotoxins, causing serious irritation and various sublethal effects (Clercin, 2012). Humans who inhale toxins that HABs release into the air, drink water contaminated by HABs, or eat affected fish or shellfish may manifest gastrointestinal, neurological, dermal, or respiratory symptoms varying in severity from mild to fatal depending on the amount and type of HABs present (Seltenrich, 2014; Trevino-Garrison, 2015). While only certain species of phytoplankton produce deadly chemicals, all HABs deplete dissolved oxygen, alter water chemistry, and prevent sunlight from reaching the bottom of the sound (Paerl, H.W. and T.G. Otten, 2013).

Between 2004-2014, the state of North Carolina performed limited monitoring of HABs in the Chowan and Pasquotank rivers, and routinely monitored Chlorophyll-a on a monthly basis at 15 stations in the Albemarle Sound. Nearly a quarter of water samples conducted by North Carolina’s Water Science Center during the summer of 2012 contained dangerous, toxin-producing phytoplankton. Several species of *Anabaena, Anabaenopsis, Aphanizomenon, Aphanocapsa, Microcystis, Pseudanabaena,* and the particularly aggressive *Cylindrospermopsis raciborskii* were detected. The synergistic effect of nutrient pollution and reduced light availability in the water column has caused damage to previously healthy areas of SAV throughout the Albemarle and Pamlico Sounds (Mallin et al., 2008).

The USGS North Carolina Water Science Center and the Albemarle-Pamlico National Estuary Program are interested in a 10-year history of algal bloom activity throughout the estuary system for the identification of patterns in HAB extent as it related to seasonal and climatic fluctuations. They will use the results of this project to expand their current knowledge of HABs and later predict HAB extent with further statistics, passing the information to the State of North Carolina.

# III. Methodology

Data Acquisition:

This project used Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) ocean color products to represent algae extent throughout the Albemarle-Pamlico Estuary. Aqua MODIS Level 2 daily swath Data was downloaded from NASA Goddard Space Flight Center’s Ocean Color SeaDAS Website using a Linux operating system.

 *In situ* water quality data was provided by Michelle Moorman from the USGS North Carolina Water Science Center. Additional water quality data was downloaded from the National Water Quality Monitoring Council website along with water sampling station coordinates.

Data Processing:

Originally, level 2 swath daily ocean color data were downloaded from NASA Goddard Space Flight Center’s Ocean Color SeaDAS Website from January 2004 to December 2014. These data layers were reduced to a study area bounding box with the geographic extent: -36.4 N, -34.9 S, -77.1 E, and -75.4 W*.* Any image that did not at least capture the entire bounding box was rejected to prevent inclusion of partial images. Then, all layers were reprojected using SeaDAS from their original sinusoidal form to the projected coordinate system, NAD 1983 State Plane North Carolina FIPS 3200. In SeaDAS, the standard OC3M algorithm was applied to produce a chlorophyll result layer for each of the remaining days in the data set. The results were saved as GeoTIFF files and exported for use in ESRI ArcGIS software.



*Figure 1: The standard OC3M algorithm*

Using ESRI ArcMap, the OC3M calculated chlorophyll layer was separated from each daily multispectral composite files and copied to a new single layer raster file. These rasters were further clipped, resampled, and rectified to ensure uniform extent and pixel size by using a Python script.

Many of the *in situ* water sample data were missing spatial locations. To correct this, the entries were matched to geographic coordinates in the station location table by station number using a table join in ArcMap. A single composite table was created using Excel to list all *in situ* sample dates, latitude coordinates, longitude coordinates, and chlorophyll-a concentrations for use in SeaDAS to extract MODIS chlorophyll pixel values for comparison. MODIS Chlorophyll values were extracted at station locations from images acquired within one day of *in situ* sample date. Water sample point shapefiles were created from XY event layers in ArcMap for use in additional cartographic products displaying point sample values.

To create a time-series representation of algae extent throughout the Albemarle-Pamlico Estuary, monthly means of chlorophyll concentration over the ten year period were calculated using a Python script. These images were exported using ArcMap and processed into a final informational time-series video product.

Data Analysis:

Analysis

In general, it is determined that Aqua MODIS satellite imagery does not provide an accurate way of determining chlorophyll levels in the case 2 waters of the Albemarle and Pamlico sounds. The sample set Root Mean Square (RMS) between satellite and *in situ* data was calculated using [2] where *n* is the total number of samples, *i* is the sample index, MODIS is the satellite sensor value, and *in situ* is the *in situ* value.

$\sqrt{\frac{1}{n}\sum\_{i=1}^{n}\left(MODIS\_{i} - in situ\_{i}\right)^{2}}$ [2]

Additionally, a linear regression model was developed using the standard MATLAB *fitlm* function using satellite and *in situ* data sets as inputs. In order to visualize correlation divergence, the total sample set was sorted in ascending order of MODIS values and indexed while retaining the associated *in situ* reference.

# IV. Results & Discussion

* Analysis of Results:

Of 3135 total *in situ* chlorophyll sample points, only 628 were able to be compared with available MODIS chlorophyll concentrations. Plotting *in situ* data versus MODIS data showed very weak correlation. After sorting and indexing the sample sets, a plot of sample index versus chlorophyll concentration showed major divergence above sample index 500. In this case, the sample index is purely arbitrary and only serves visualization.

The RMS calculated with [2] of the original dataset was 79.78mg\*m^-3 and MATLAB’s *fitlm* returned an RMS confidence of 72.7mg\*m^-3. Restricting RMS calculation to the first 400 sample indices reduced RMS to 15.5059mg\*m^-3 and *fitlm* RMS reduced to 10.8mg\*m^-3. By raising the MODIS sensor values to the two-thirds power [3] and applying the *fitlm* function the RMS error further reduced to 2.92.

$Chlorophyll A≈MODIS[chlor a]^{\frac{2}{3}},chlor a<22.4\frac{mg}{m^{3}}$ [3]

This suggests that the MODIS sensor has the greatest accuracy in determining case 2 water chlorophyll a when its values lie below 22.3811 mg\*m^-3.

* Errors & Uncertainty:

The OC3M algorithm was developed from global *in situ* data from various coastal regions and oceans, it may not be the optimal algorithm for calculating chlorophyll concentrations in the Albemarle-Pamlico Estuary. Recent research has revealed that the accuracy of chlorophyll analysis in optically complex waters is greatly dependent upon the availability of specific algorithms developed in the region or water body of interest. This research suggest confirmation that the MODIS sensor may not be able to accurately detect algae or cyanobacteria. MODIS does not have spectral bands covering 620-650 nm or around 700 nm, which are the best for detecting phycocyanin and chlorophyll in eutrophic waters, respectively. Detecting ocean color in these wavelengths may only happen when chlorophyll concentrations are very high (Reinart, A. and T. Kutser, 2006).

Water samples conducted by USGS and other entities occurred at varying depths beneath the water surface. The OC3M algorithm is used for calculating near-surface chlorophyll, only. This sampling difference may contribute to the poor correlation between the two sets chlorophyll concentrations.

* Future Work:

Although corollary confidence is low, further analysis can be done using the data collected from this project to produce a more refined analysis of algae extent throughout the study area. Most importantly, application of an alternative algorithm or creation of an estuary-specific algorithm for the Albemarle-Pamlico Sounds and verification of its accuracy is needed.

# V. Conclusions

It remains undetermined whether using MODIS sensor data can accurately measure chlorophyll a and, subsequently predict or detect harmful algal blooms. What is known, however, is that current research has been unable to generate an adequate model for detecting harmful algal blooms. [3] supports a limit accuracy verified with historical data, yet further research is necessary in order to both refine this model and verify its results.

# VI. Acknowledgments

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# VIII. Appendices

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