Correlations between the Concentrations of Chlorophyll a in Surface Waters and Dissolved Oxygen in Bottom Waters of the Northern Gulf of Mexico

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Abstract - **Hypoxia is an environmental condition of low concentrations of dissolved oxygen that is detrimental to marine animals. It is a result of excessive input of fluvial nutrients to the coastal environment that leads to rapid growth of phytoplankton. When phytoplankton die and sink, they consume dissolved oxygen during decomposition. Water column stratification, especially a strong stratification in summer, is essential for the development of hypoxia. Seasonal occurrence of hypoxia has been observed in many coastal waters. The most prominent hypoxia in the United States was observed in the Northern Gulf of Mexico. For more than two decades, scientists have been monitoring the hypoxia in the Northern Gulf of Mexico by conducting annual ~ 2-week-long cruise in summer and developing strategies for reducing the flux of nutrients and the size of hypoxia. There are many shortcomings in the current monitoring method. The major shortcoming is poor temporal and spatial resolutions of these field studies.**

We propose to conduct the following research project to overcome some of these shortcomings and to lay a foundation for high resolution monitoring of hypoxia with satellite remote sensing. The project is based on the hypothesis that there is a linear correlation between the concentrations of chlorophyll a in surface waters and dissolved oxygen in bottom waters. To test this hypothesis we will: (1)* obtain SeaWiFS data and process it for sea surface chlorophyll a; (2) obtain dissolved oxygen data from NOAA's National Coastal Data Development Center (NCDDC); (3) select chlorophyll a data that coincide with dissolved oxygen data; (4) correlate the concentrations of dissolved oxygen in bottom waters to that of chlorophyll a in surface waters; (5) correlate the water column apparent oxygen utilization (AOU) to concentrations of chlorophyll a in surface waters. If our hypothesis is proven true, the correlations to be derived will enable monitoring of the future evolution of hypoxia in the Northern Gulf of Mexico with satellite remote sensing. This will significantly increase both temporal and spatial resolutions of hypoxia mapping. The correlations could also be used to evaluate the past evolution of the hypoxia in the Northern Gulf of Mexico (i.e. from 1997 when SeaWiFS was launched).

I. Introduction

Hypoxia is a low concentration of oxygen in estuaries that has been reported in many costal regions including the coast of North Carolina and the Northern Gulf of Mexico. For hypoxia to occur it requires two conditions: nutrients and stratification. Hypoxia is caused by excess nutrients in the water. Nutrients can come from many sources, such as fertilizers applied to agricultural fields, golf courses, and suburban lawns; deposition of nitrogen from the atmosphere; erosion of soil containing nutrients; and sewage treatment plant discharges. With a strong stratification of water columns , surface water is lighter this prevents bottom from dissolving oxygen.

Most prominent hypoxia of the United States is found in the Louisiana, Texas, Mississippi Shelf, in Gulf of Mexico.

Hypoxia in the Northern Gulf of Mexico is increasing rapidly in the last three decades. In the late eighties the area of hypoxia was reported at about 10,000 km^2. Recent studies have shown that the area of hypoxia reached more than 20,000 km^2 in 2003.

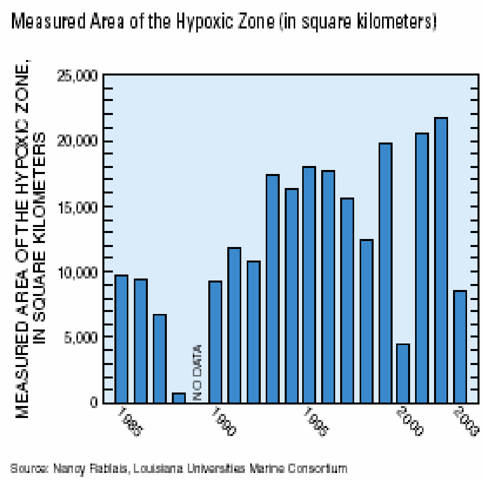

Figure 1. The temporal variation of hypoxia in the Northern Gulf of Mexico. (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2004)

A. Review of Literature

A global problem that is really beginning to arise is Coastal eutrophication. It is really increasing in coastal regions because of an increase agricultural production. The farmers and people associated with them have altered the nitrogen and phosphorus cycles. They have also increased the nutrients load. Because of the increased nutrients it can result in filthy water quality since more phytoplankton cause more toxic algal species. This can also cause more turbidity, oxygen-depleted waters and loss of habitat it also lowers marine biodiversity and alters the ecosystems normal way of life. It didn't become noticeable that the symptoms of eutrophication were not minor and just in the area and that they were large scale until the last half of the 20th century.

The Mississippi and the Atchafalaya Rivers are attached to the Northern Gulf of Mexico, this is an example of a system of a world wide trend of increasing river borne nutrients and resulting diminution of coastal water quality. Out of all of the rivers in the world The Mississippi River ranks in the top 10 in length, freshwater discharge, and sediment delivery, and it drains 41% of the contiguous United States.

A third of the flow from the Mississippi River mainstream is sent into the Atchafalaya River, where it comes together with the Red River for eventual delivery through a delta 210 kilometers west of the main Mississippi River birdfoot delta. Prevailing currents from east to west move most of the freshwater, suspended sediments, and dissolved and particulate nutrients onto the Louisiana and Texas continental shelf. At the terminus of this massive river system is the largest zone of oxygen-depleted coastal waters in the western Atlantic Ocean.

II. Data and Methods

The field data was obtained by National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service between June 14 through June 16, 2006. National Coastal Data Development Center provided data sets of raw data. The hypoxia survey data was obtained from United States Geological Survey (USGS).
Monthly means chlorophyll a from July 1998 to July 2006 was obtained from NASA Distributed Active Archive Centers (DAACs).

The data was processed by using a software package called MATLAB, which assisted us to extract oxygen and *chlorophyll a* from raw files, and permitted us to calculate correlation coefficient. The correlation coefficient reflects a degree of association or strength of relationship between two variables that is represented by a number. If a relationship is perfect, the value of r is either +1 or -1. If there is no association between variables, r =0. MATLAB also enabled the creation of cruise track map.

MATLAB codes was produced to study the correlation between *chlorophyll a* and dissolved oxygen in three various ways. An initial code was created in MATLAB to generate a map of dissolved oxygen in bottom waters. An additional code was devised to analyze the correlation coefficient of oxygen in bottom waters between chlorophyll *a* fluorescence of surface waters. This enabled the depth verses correlation coefficient to be plotted. Below are examples of perfect positive relationship(r = +1), perfect negative relationship(r = -1), and no association between variables (r = 0).

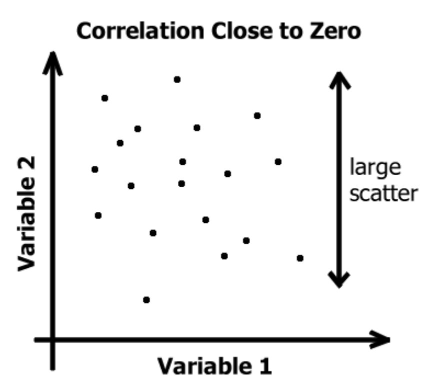

Figure 2. The closer to zero the correlation coefficient is, the less the points fall on a straight line

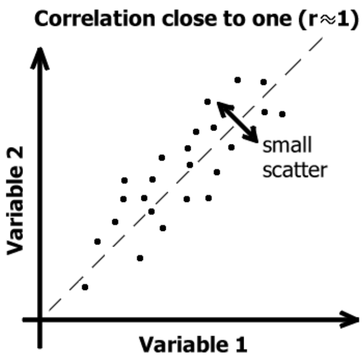

Figure 3. The closer the correlation coefficient is to one, the more the points will fall along the line.

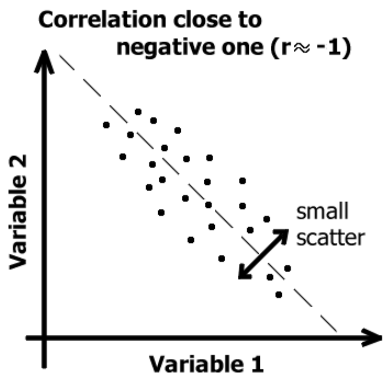

Figure 4. The closer the correlation coefficient is to negative one, the more the points will fall along the line.

```
figure(6)
longitude(longitude<-100) = nan;
latitude(longitude<-100) = nan;
oxygen=hypox(1,:);
oxygen(longitude<-100) = nan;
longitude1 = longitude(~ isnan
(longitude));
latitude1 = latitude (~isnan
(longitude));
oxygen1 = oxygen(~isnan(longitude));
xiv = linspace(min(longitude1),
max(longitude1), 50);
yiv = linspace(min(latitude1), max
(latitude1), 50);
[x y z] =griddata(longitude1,
latitude1,oxygen1, xiv, yiv')
ax = worldmap('hi', [26 30.5], [-98
-88], 'none');
```

```
pcolorm(((z))),colormap(jet);
caxis([0 7]);
plotm(latitude, longitude, '-x');
AddGulf
h = colorbar
set(get(h,'YLabel'),'String',
'Bottom water dissolved oxygen (ml
L^{-1})')
```

Figure 5. MATLAB code created for graphing the correlation coefficient.

III. Results

Our results showed that the dissolved oxygen in sub-surface waters and the sea surface chlorophyll a are correlated. The first correlation that is shown is the size of hypoxia and the mean of the chlorophyll a. The second correlation is between sea surface chlorophyll a at a particular location and dissolved oxygen in sub-surface waters . Figure 6 shows that the size of hypoxia expands with the increase of mean chlorophyll a. The size of hypoxia of Northern Gulf Mexico was determined annually for more than two decades by Dr. Rabalais and her group. Her data for the last nine years were selected for this correlation. The chlorophyll a was determined by SeaWiFS since August 1997 until today. Monthly means chlorophyll a for July was used for this correlation.

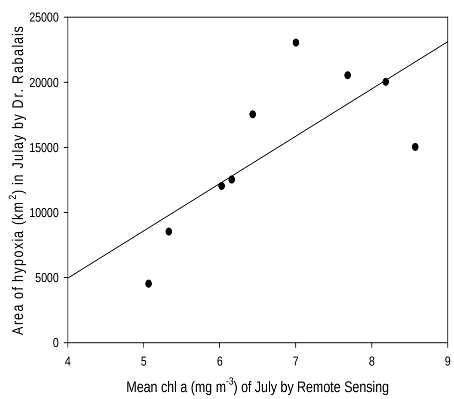

Figure 6. The correlation of the area of hypoxia verses the mean sea surface chlorophyll a measured by satellite. The area of hypoxia was determined by Dr. Rabalais during annual survey.

There was a positive correlation between the size of hypoxia and sea surface chlorophyll a. The correlation was moderate with a r = 0.74. It appears

that the correlation was excellent for mean chlorophyll a of less than 7(mg m $^{-3}$).
Although the dissolved oxygen in bottom waters appeared to decrease with the increase of chlorophyll in surface waters, the correlation was not very good (Figure 7). Part of the problem is that data from deeper regions are mixed together with coastal regions.

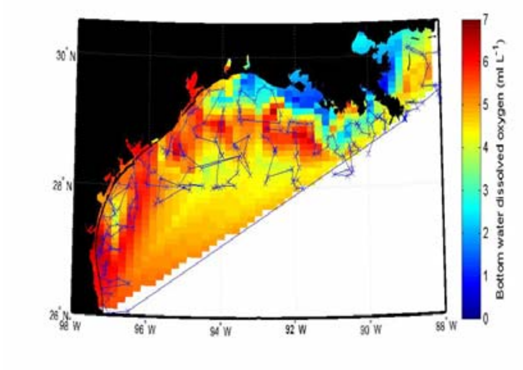

Figure 7. The distribution of dissolved oxygen in bottom waters based on survey of July 2006. The x marks represents the location of field measurements conducted.

In Figure7. Hypoxia was detected in near shore regions only in 2006. These regions include areas near the mouth of Atchafalaya River and Mississippi River. The size of hypoxia is abnormal in 2006.

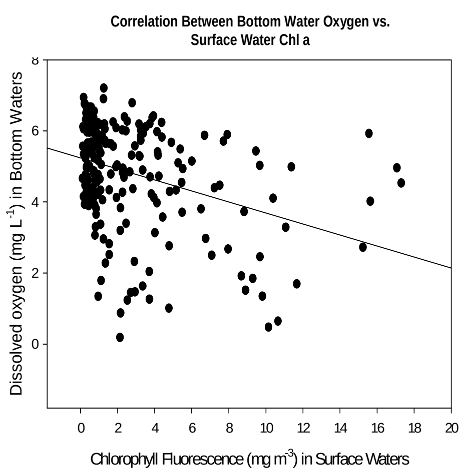

Figure **8.** The correlation between dissolved oxygen bottom waters and chlorophyll fluorescence in surface waters.

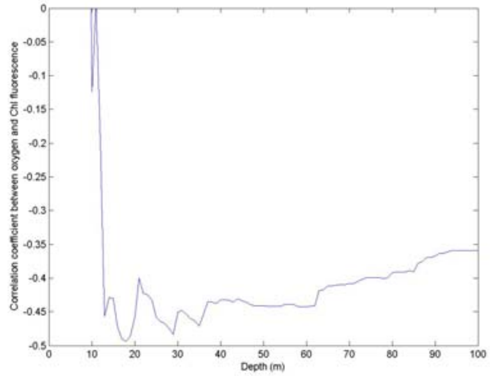

Figure 9. Variation of correlation coefficient depths. Correlation coefficient is between dissolved oxygen in bottom waters and chlorophyll a in surface waters.

With the successive elimination of deeper samples, the correlation coefficient increased from 0.35 to approximately 0.5 (Figure 8.). This trend supports the notion that hypoxia develops in costal regions.

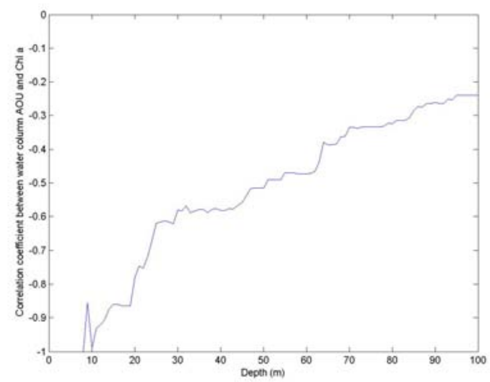

Figure 10. Variation of correlation coefficient depths. Correlation coefficient is between apparent oxygen utilization of the water column and chlorophyll a in surface waters.

When dissolved oxygen of bottom water is replaced with the Apparent Oxygen Utilization (AOU) of water column in the correlation. This yields a stronger correlation and amplified correlation coefficient. By extracting shallower samples, the correlation coefficient improved from - 0.3 to -0.9 (Figure 9).

IV. Conclusion

In conclusion, our hypothesis was proven correct when the entire region is looked at and at specific locations. A positive correlation between remotely sensed chlorophyll a and the size of hypoxia was established. This correlation enables prediction of the size of hypoxia from satellite remote sensing. The negative correlations between chlorophyll a fluorescence and both bottom water oxygen and water column AOU were established for costal waters of The Northern Gulf of Mexico. These correlations show the potential for predicting the distribution of hypoxia .

V. Future Research

The recommendation for future research is to further investigate the correlations and predict hypoxia in the Northern Gulf of Mexico. In our correlation between the area of hypoxia and sea surface chlorophyll a (Figure 6), it appears that samples with chlorophyll a less than 7 yields a higher correlation coefficient. The research is needed to find the explanation of a lower correlation coefficient in Figure 6 when samples with chlorophyll a greater than 7 are included. Furthermore, with the explanation of lower correlation coefficient in Figure 6, research can be conducted predicting the area of hypoxia using remote sensing for the Northern Gulf of Mexico.

Additionally, the year 2006 was immediately after Hurricanes Katrina and Rita which altered the normal patterns of the water stratification in the Northern Gulf of Mexico. Although both Figures 9 and 10 showed potential of predicting the distribution of lower oxygen sub surface waters, however a much greater correlations are expected for the years without hurricane effect. The recommendation for further research is to obtain similar correlations using data of year 2005 or 2004. Such correlations can be use to predict the distribution of hypoxia using satellite data.

VI. Acknowledgements

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VII. References

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