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Oceanography/Remote Sensing Team

Mentor:
Dr. Sonia Gallegos
Principal Investigator, Naval Research Laboratory
Stennis Space Center, Mississippi
(228) 688-4867
Gallegos@nrlssc.navy.mil

Danielle Graves, Student Researcher
http://nia.ecsu.edu/ureoms2004/personal/graves/index.html

Erica Pinkney, Student Researcher
http://nia.ecsu.edu/ureoms2004/personal/pinkney/index.html

Team Page:
http://nia.ecsu.edu/ureoms2004/teams/ors/index.html

The Spatial Variability of the Northwestern Gulf of Mexico During 2002

Mentors: Dr. Sonia Gallegos and Naval Research Laboratory Stennis Space Center Mississippi, 39529

Dr. Malcolm LeCompte Elizabeth City State University ECSU Campus Box 672 Elizabeth City, NC 27909

Authors: Danielle C. Graves and Erica K. Pinkney
Elizabeth City State University
ECSU Campus Box 672
1704 Weeksville Rd.
Elizabeth City, NC 27909

Abstract- A pilot study was undertaken to determine the spatial and temporal variability of chlorophyll concentrations in the northwestern Gulf of Mexico during 2002. The chlorophyll parameter was obtained from daily Level-3 estimations of Sea-Viewing Wide-Field-of–view Sensor (SeaWiFS) data computed by the Naval Research Laboratory. An empirical eigenfunction (EOF) analysis was performed on the data using the Karhunen-Loeve (KL) algorithm. Ten empirical eigenfunctions were computed. This analysis revealed that 15% of the variance around the mean is accounted by the first empirical eigenfunction, which is identified with chlorophyll fluctuations around the Mississippi Delta, Lakes Pontchartrain and Borgne, the Mississippi Sound, and the Mobile, Pensacola, and Choctawhatchee Bays. The eigenfunction shows that the chlorophyll in near-shore water is changing more rapidly than the rest of the shelf waters. The second EOF which contained 3% of the variance is found to be related to changes in chlorophyll in bays and estuaries to the east of the delta, exclusively. The third EOF (%) was identified with the waters flowing east from the mouth of the Mississippi into bays and estuaries. The fourth EOF (%) is identified with changes in chlorophyll concentrations at the mouth of the Mississippi River proper, propitiated by the river flow. Because this EOF is also identified with waters of Lakes Pontchartrain and Borgne as well as with the Mississippi Sound, it is possible that the changes observed may not be related to chlorophyll but to increases in dissolved and particulate components brought about by an increase in rain fall.

I. Introduction

SeaWiFS, is an eight-channel radiometer flying onboard of the Orbimage-NASA satellite SeaStar. It was designed for global and regional measurements of the upwelling radiance from the ocean in the visible channels (ocean color). These measurements enable the construction of algorithms to compute chlorophyll concentrations in surface waters of the ocean, which in turn, are indices of biological activity in the marine environment. SeaWiFS revisits the approximate same spot on the earth once daily at noon (Local Solar Time). It provides coverage of over ninety percent of the ocean's surface every two days. Global ocean color is mapped at a resolution of 4.5 kilometers and regional data at 1 km at nadir (the point directly beneath the satellite).

SeaWiFS was launched by NASA through an agreement with the Orbimage Corporation to quantitatively determine global ocean productivity. It was designed to measure radiances associated with "chlorophyll, and associated pigments, organic matter, and suspended particulate matter in the oceans, [4]." During the development of SeaWiFS, NASA set up a primary set of goals and expectations for SeaWiFS data in particular which include but is not limited to determining the spatial and temporal distributions of phytoplankton blooms along with the magnitude and variability of primary production by marine phytoplankton on a global scale. Also, identifying large-scale spatial and temporal distribution of spring blooms in the global oceans.

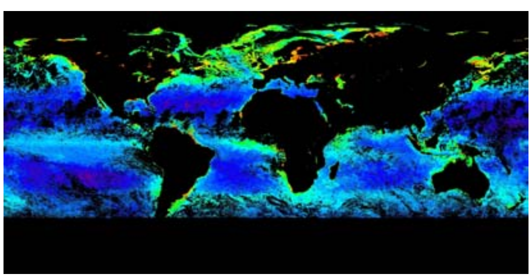

Figure 1.1 Chlorophyll SeaWiFS Global Image

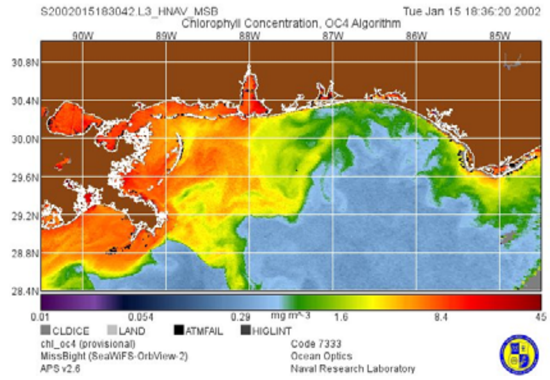

Figure 1.2 Level 3 SeaWiFS Imagery of the Mississippi Bight from Jan. 15, 2002 used in this study

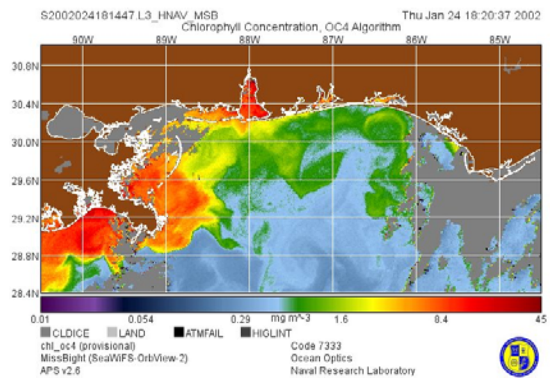

Figure 1.3 Level 3 SeaWiFS Imagery of Mississippi Bight from Jan. 24, 2002 used in this study

SeaWiFS data is available at different processing levels, ranging from 0 to 3. Throughout this research, Level 3 imagery (Figures 1.2 and 1.3) provided by the Naval Research Laboratory was utilized. By the time an image reaches level 3, it has been digitized, appended with calibration and navigation data, along with instrument and selected spacecraft telemetry. It has also been atmospherically corrected.

II. Discussion of Methods

The goal of this study was to quantify the spatial and temporal variability of chlorophyll concentrations throughout the northwestern Gulf of Mexico. The data used in this investigation were Level 3 Local Area Coverage (LAC), which were processed with the NRL chlorophyll algorithm for purposes of this study. There images that were used covered a period from January 1 to December 31, 2002. Figures 1.2 and 1.3 are examples of the data utilized.

An archive of the level 3 SeaWiFS imagery corresponding to the Mississippi Bight was created. Hard copies of the imagery were compiled and every image was inspected for flaws. Usable images, as shown in figures 1.2 and 1.3, consist of images that contain an ample amount of data that can be analyzed without a great deal of noise marks and missing data. Upon viewing the entire year's data, 345 images were found to be fit for analysis. The images that were not used either had multiple noise marks, missing data, or sometimes both as shown in figures 2.1 and 2.2. Missing data images occur as a result of the area of interest not lying completely in the swath of the observing satellite.

All of the Naval Research Laboratory images are stored in a database. In order to manipulate the images to project specifications, a copy of the directory containing the usable chlorophyll SeaWiFS images was created. After creating this directory, the images were converted from the default HDF format to binary image format (flat file). This was necessary because the data analysis programs do not currently support HDF formatted files. The conversion was accomplished using ImgSDStoImg, which is a NRL program used to convert images to different formats.

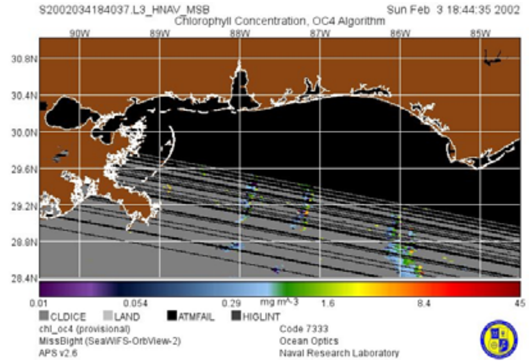

Figure 2.1 Example of Unusable Level 3 SeaWIFS Imagery. It contains no data and several noise marks.

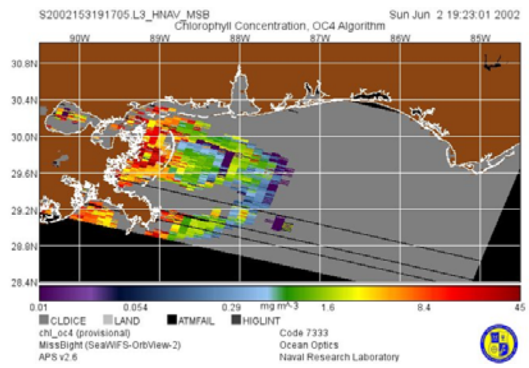

Figure 2.2 Example of Unusable Level 3 SeaWIFS Imagery. It contains missing scan lines and elongated pixels (edge of the orbit).

After reformatting the files, a composite list was constructed of all of the binary files using "vi," the standard UNIX editor.

An Empirical Orthogonal Function (EOF) method known as the Karhunen-Lo`eve algorithm (KLmask) was applied to the imagery. The EOF analysis is widely used in the Oceanographic and Meteorological sciences. It separates data that represents physically relevant patterns from those that contain noise variations. KLmask has been previously used for the characterization and statistical reconstruction of human faces (Sirovich and Kirby, 1987) [3], and for the analysis of turbulent flows in airplane exhausts. In oceanography, it has been used in studies of the Gulf Stream (Everson et al., 1997) [1]. This is the first time that this technique has been used with ocean color imagery to quantify the variability of concentrations in SeaWiFS imagery.

III. Results

Ten empirical eigenfunctions were computed. However, only the first four EOFs were examined due to the small variability that they contained. The first EOF, depicted in figure 3.1, explained 15% of the variance around the mean. This eigenfunction shows that the chlorophyll in near-shore water is changing more rapidly than the rest of the shelf waters.

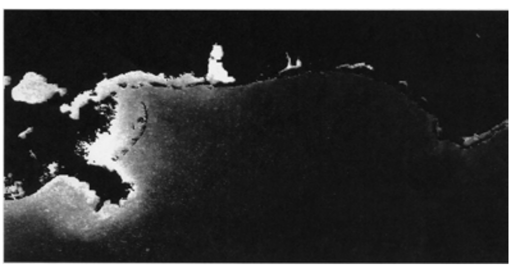

Figure 3.1 EOF #1

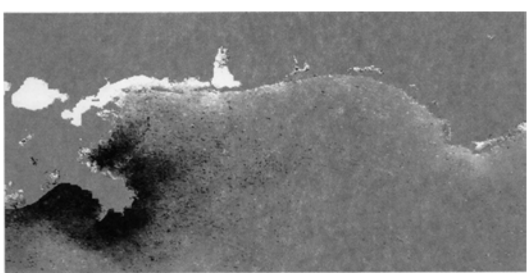

Figure 3.2 EOF #2

The second EOF, figure 3.2, contained 3% of the variance, which is related to changes in chlorophyll levels in bays and estuaries to the east of the delta. The variance of the third EOF was approximately 2%. There was no image output for the third EOF but the percentage was still accurate.

The fourth EOF, figure 3.3, was identified with changes in chlorophyll concentrations at the mouth of the Mississippi and had a variance of approximately 1%. Table 1 presents the percentage variability contained in each of the ten EOF's.

Due to technical difficulties, the only variable that was able to be examined was the spatial aspect.

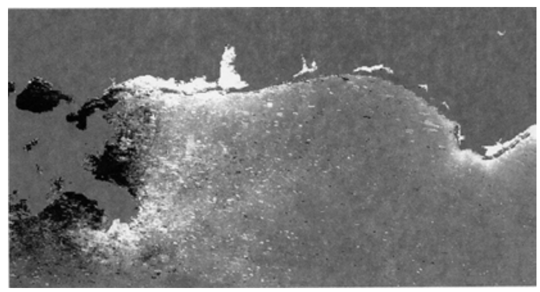

Figure 3.3 EOF #4

1	0.152111
2	0.0383729
3	0.0215807
4	0.0171282
5	0.0148892
6	0.0134543
7	0.0128389
8	0.0121684
9	0.0112851
10	0.0111638

Table 1. Percentage of the variability around the mean contained in each of the 10 EOF's computed in this study.

IV. Results and Recommendations

This is a preliminary study that lasted 10 days. It was an exercise to introduce the intricacies of the SeaWiFS data, processing and algorithms. It was also an introduction to the complexity of analyzing large amounts of satellite imagery and interpretation of the results. This study was part of much larger effort by NRL to quantifying the variability of the northwestern Gulf of Mexico and the factors that contribute to this variability. In this study, we aimed at computing the spatio-temporal variability of the chlorophyll, exclusively. However, due to unforeseen technical problems that could not be corrected during the brief co-op at NRL, only the spatial analysis could be completed.

The results of the spatial analysis indicate that the spatial variability of the northern Gulf of Mexico cannot be explained with 10 EOF's. It would require many more EOF's to fully explain the variability of these waters. Therefore a more in-detail analysis is recommended in which the open and coastal waters are analyzed separately in order to avoid the high variability of the coastal waters from masking those of the open waters.

Future recommendations include obtaining the temporal variability of the same area of interest in order to associate each EOF with a given month or period in the year 2002.

Additionally, new data such as winds and currents can be introduced to the analysis. This would allow the comparisons of variability in ocean color imagery to that of the wind or current patterns.

V. References

[1]. R. Everson, P. Cornillon, L. Sirovich, A. Webber, "An empirical eigenfunction analysis of sea surface temperatures in the western north atlantic," *Journal of Physical Oceanography*, vol. 27, pp. 468-479, March 1997.

[2]. R. Everson and L. Sirovich, "The Karhunen-Lo`eve procedure for gappy data," *Journal of the Optical Society of America A*, vol. 12, no. 8, pp.1657-1664, August 1995.

[3]. L. Sirovich, M. Kirby, "Low-dimensional procedure for the characterization of human faces," *Journal of the Optical Society of America A*, vol. 4, pp.519-524, March 1987.

[4]. "Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Level 3 Data," www.iitk.ac.in/phy/phy101/seawifs.html