REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
17-07-2007	Conference Proceeding	

4. TITLE AND SUBTITLE
Effects of Nutrients and Physical Forcing on Satellite-Derived Optical Properties Near the Mississippi River Delta

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
0601153N

6. AUTHOR(S)
Rebecca Green, Richard Gould, Paul Martinolich

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
73-8782-05-5

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Oceanography Division
Stennis Space Center, MS 39529-5004

8. PERFORMING ORGANIZATION REPORT NUMBER
NRL/PP/7330-06-6318

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
800 N. Quincy St.
Arlington, VA 22217-5660

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS
nutrients; optical properties; Mississippi River; satellite imagery

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Richard Gould
Unclassified	Unclassified	Unclassified	UL	7	19b. TELEPHONE NUMBER (Include area code) 228-688-5587

Effects of Nutrients and Physical Forcing on Satellite-Derived Optical Properties Near the Mississippi River Delta

Rebecca Green, Richard Gould, and Paul Martinolich
Ocean Sciences Division, Naval Research Laboratory, Stennis Space Center, MS 39529-5004, USA

ABSTRACT

We investigated the effects of various chemical and physical forcing mechanisms on optical properties near the Mississippi River delta using a multi-year timeseries of satellite imagery. Recent cruise data has provided in situ measurements to ground-truth satellite estimates of partitioned absorption (phytoplankton, detritus, sediment, and colored dissolved organic matter components). In our time-series analyses, we addressed long-term timescales of variability (2002-2004) using monthly composite SeaWiFS imagery and fifteen different physical forcing variables. Correlation and stepwise regression analyses, performed on each image pixel, revealed which forcing mechanisms were most responsible for optical variability. For example, Mississippi River nitrate concentration explained only a portion of the seasonal variability observed in phytoplankton absorption on the Louisiana shelf, and physical factors, such as river discharge and wind speed were as important in determining variability. Such observations have management implications for hypoxia in terms of mandates to decrease nutrient loading to the Mississippi River watershed. Our goal is to develop a robust statistical model for optical prediction. To this end, we applied our stepwise regression model to physical properties for 2005, a year not included in model development. Our model fairly well predicted $a_{ph}(443)$ on the Louisiana-Texas shelf, with an average error of ~30%. In the future, we hope to improve our predictions using seasonally specific models and to analyze shorter timescales (days to weeks) of variability.

INTRODUCTION

The Louisiana/Texas continental shelf is a highly dynamic river-dominated margin and the site of the 2nd largest zone of coastal hypoxia in the world (Rabalais et al. 2002) . Temporal and spatial variability in nutrient concentrations, freshwater input, and winds are examples of the physical forcing mechanisms which cause variability in phytoplankton growth and optical properties in shelf surface waters (e.g., Lohrenz et al. 1999). Assessing the mechanisms responsible for interannual variability in phytoplankton growth is a necessary step towards understanding controls on the size of the hypoxic zone. With accurate ground-truth measurements for these coastal waters, time-series of satellite-derived surface water properties can be used to better understand variability in particulate and dissolved constituents on the shelf. An interannual time-series analysis of SeaWiFS imagery (1997-2000) showed that wind-driven variability in suspended sediment concentrations was important in shallow areas and that this region was spatially separated from areas of high discharge-related variability (Salisbury et al. 2004). Our goal in the present study was to apply time-series analysis methods to understanding and ultimately predicting variability in phytoplankton, detrital, and colored dissolved organic matter (CDOM) absorption using a suite of potential physical forcing mechanisms.

METHODS

Cruise Measurements - Measurements of partitioned absorption and remote sensing reflectance (R_{rs}) were obtained during several cruises in coastal waters of the northern Gulf of Mexico. Absorption coefficients for phytoplankton (a_{ph}), detritus (a_d), and CDOM (a_{CDOM}) were determined for surface water samples on a spectrophotometer (Analytical Spectral Devices, ASD) using GF/F filters (0.7 μm nominal pore size) and hot methanol extraction. Remote sensing reflectance was measured using a hand-held, above-water spectral radiometer (ASD or Spectrix). Three new surveys in the northern Gulf of Mexico were combined with three datasets previously collected in this region (Lee et al. 1998) to develop a regionally-specific algorithm for a_{ph}. Previously determined algorithms were used to separate a_d and a_{CDOM} based on separation of the scattering coefficient into organic and inorganic components (Gould et al. 2003).

Remote Sensing Imagery – Local Area Coverage (LAC) Sea-Viewing Wide-Field-of-View Sensor (SeaWiFS) data of ~1 km resolution were collected, processed, and archived for the Gulf of Mexico region (80°W - 98°W; 17°N - 31°N) using a SeaSpace TeraScan satellite receiving system and NRL's Automated Processing System (APS) (Martinolich 2005). APS Version 3.4 utilized atmospheric correction algorithms proscribed by NASA's fifth SeaWiFS reprocessing (Stumpf et al. 2003; Arnone et al. 1998). The present atmospheric correction method used by APS improves estimates of bio-optical parameters in coastal regions by applying an iterative technique in which water-leaving radiance at 765 and 865 nm is estimated from water leaving radiance at 670 nm. In our time series analyses, we used monthly composite imagery for 2002-2005 which were temporal averages of all valid pixels in each month.

Time Series Analyses - Correlation and regression analyses were used to analyze the impacts of different chemical and physical factors on driving mean monthly optical variability. Sources of physical data included USGS for Mississippi River nutrient concentrations (NO_3, PO_4, and Si; St. Francisville site), USACE for Mississippi River discharge (Tarbert Landing), NDBC for wind magnitude and direction (station BURL1) and wave height (buoy 42040), the IASNFS circulation model for current speed and direction and SST (Ko et al. 2003), and the LUMCON weather station for solar radiation, precipitation, and water height. In the case of point measurements, such as river discharge, the same physical time series was assumed at all image pixels. In contrast, results from the IASNFS model provided a unique physical time series at each image pixel. A stepwise regression analysis between all physical variables and mean monthly satellite-derived $a_{ph}(443)$ was performed for the time period 2002-2004. The results of this analysis were then applied to 2005 for the same suite of mean monthly physical variables to determine how well temporal and spatial variability in $a_{ph}(443)$ could be predicted.

RESULTS

Algorithm Development - We developed a regionally-specific $a_{ph}(443)$ algorithm for the northern Gulf of Mexico using optical measurements from six cruises. Optimization resulted in the following best fit algorithm:

$$a_{ph}(443) = 10\^[-1.2226 - 1.8330*\rho + 3.1440*\rho^2 - 3.3354*\rho^3 - 1.1188*\rho^4], \qquad (1)$$

where $\rho = \log_{10}[R_{rs}(490)/R_{rs}(555)]$. Our relationship (Fig. 1A) better described variability in $a_{ph}(443)$ (Fig. 1B) than more global relationships (Lee et al. 1998), which generally underestimated the higher concentrations observed in coastal waters. Satellite-derived ratios of $R_{rs}(490)/R_{rs}(555)$ were similar to in situ measured values (Fig. 1C), resulting in satellite-derived $a_{ph}(443)$ which were generally similar to measured values (Fig. 1D). Values of $a_d(443)$ and $a_{CDOM}(443)$ were calculated using previously determined algorithms, as stated in the Methods; there accuracy in our region of interest will be better validated in future work.

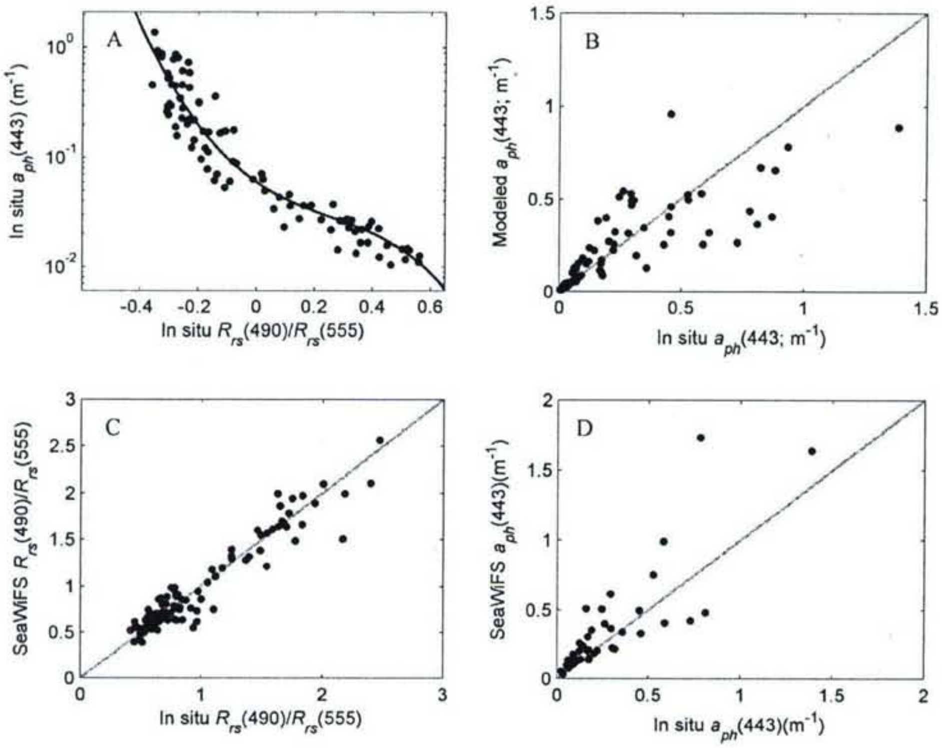

Figure 1. Algorithm development for $a_{ph}(443)$ in northern Gulf of Mexico coastal waters showing (A) our model based on $R_{rs}(490)/R_{rs}(555)$, (B) modeled versus measured a_{ph}, (C) comparison of satellite-derived and measured R_{rs} ratios, and (D) satellite-derived versus measured a_{ph} using our model.

Correlation Analyses - We first performed simple correlation analyses between the various physical driving variables and partitioned absorption coefficients for 2002-2004. Here we present example correlations for some of the most important physical variables. As expected, Mississippi River nitrate concentration was found to be well correlated with a_{ph} (Fig. 2A), but not with a_d or a_{CDOM} (Fig. 2B-C), lending support to our methodology for separating a_{ph} from a_d and a_{CDOM}. Mississippi River discharge was well correlated with all partitioned absorption coefficients (Fig. 3). High correlations of discharge with a_{ph} and a_{CDOM} were observed at distance down shelf from the Mississippi River mouth (Fig. 3A-B), whereas high correlations with a_d were confined relatively near the river mouth (Fig. 3C), presumably due to fast settling of river-borne particles. High correlations were also observed between wind magnitude and partitioned absorption coefficients, with differences in the spatial distributions of correlation patterns for the different constituents. An inverse relationship was generally observed between wind magnitude and a_{ph} in coastal regions (Fig. 4A), presumably because increased mixing resulted in light limited growth. In contrast, positive correlations were observed for a_{CDOM} and a_d (Fig. 4B-C), suggesting contributions from resuspension in shallow areas.

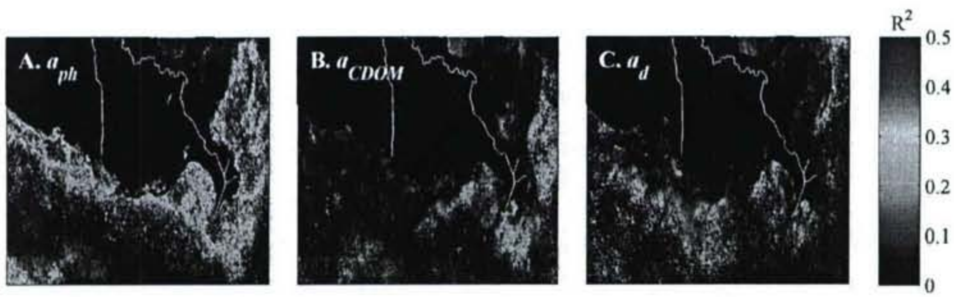

Figure 2. For mean monthly data (2002-2004), correlations of Mississippi River nitrate concentration with (A) $a_{ph}(443)$, (B) $a_{CDOM}(443)$, and (C) $a_d(443)$.

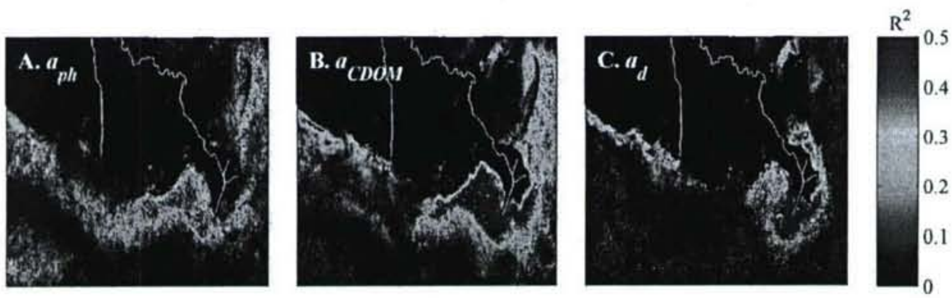

Figure 3. For mean monthly data (2002-2004), correlations of Mississippi River discharge with (A) $a_{ph}(443)$, (B) $a_{CDOM}(443)$, and (C) $a_d(443)$.

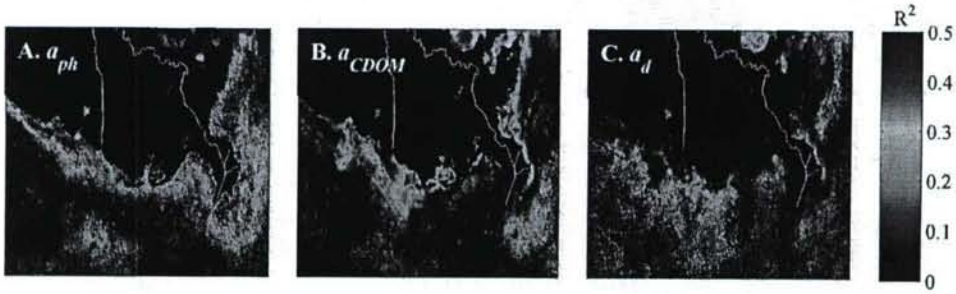

Figure 4. For mean monthly data (2002-2004), correlations of wind magnitude (station BURL1) with (A) $a_{ph}(443)$, (B) $a_{CDOM}(443)$, and (C) $a_d(443)$.

Stepwise Regression Analysis - A model was developed for partitioned absorption coefficients using a suite of physical variables and multliple regression analysis. Fifteen physical variables were included in the analysis, as listed in the Methods. We used a backward stepwise regression model, which starts with all the terms in the model and removes the least significant terms until all remaining variables are statistically significant. We are still in the process of analyzing the a_d and a_{CDOM} data, and here only present results for a_{ph}. The resulting model for a_{ph} resulted in a relatively good fit between predicted and satellite-derived values, with R^2 in the range of 0.5 to 0.8 in nearshore waters (Fig. 5). As expected, Mississippi river discharge, riverine [NO_3], and wind magnitude were the three variables most often included in the final model (Fig. 6A-C). Though not as important overall, certain variables were important in specific regions of the shelf, such as water height which was often included in the model off Terrebonne Bay (Fig. 6D).

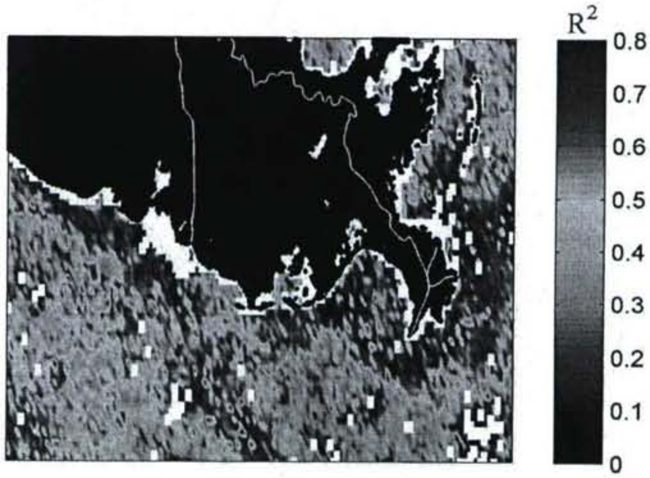

Figure 5. For mean monthly data (2002-2004), correlation between a_{ph} predicted by the stepwise regression model and actual values at each image pixel.

Our ultimate goal is to develop a model for predicting optical properties in a year not included in model development. To this end, we applied our model results to mean monthly physical properties in 2005, to see how well we could predict a_{ph}. Some months were predicted particularly well, such as

April 2005 (Fig. 7), for which the mean error between predicted and actual a_{ph} was 28%. We hope to improve our predictions in the future by developing a seasonally specific model.

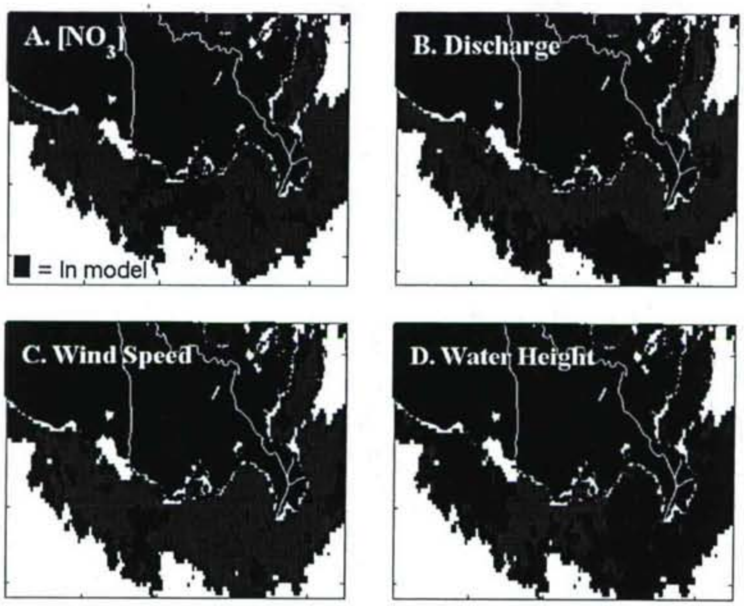

Figure 6. Inclusion regions based on stepwise regression a_{ph} model for example forcing variables, including (A) Mississippi River [NO$_3$], (B) river discharge, (C) wind speed, and (D) water height. Inclusion in the model is indicated in red, whereas exclusion is indicated in blue.

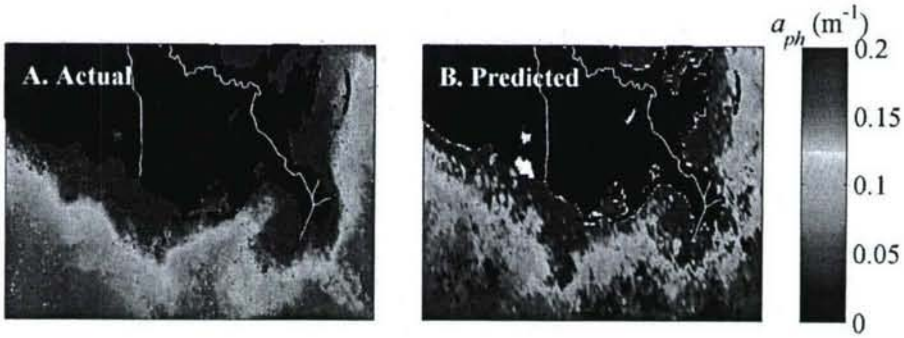

Figure 7. Prediction of mean April 2005 a_{ph}(443) using the results of the stepwise regression analysis and mean monthly physical variables. We compare the actual SeaWiFS image (panel A) to the predicted image (panel B).

ACKNOWLEDGEMENTS

This work was supported by an NRC Research Associateship award to R. Green, and NRL Program PE0601153N and NASA grant NNH04AB02I to R. Gould. We thank S. Lohrenz for the opportunity to participate on a recent cruise, W. Goode for assistance in cruise preparation, and S. Ladner for help in post-processing of cruise data.

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