Optical Detection and Assessment of the Harmful Alga, *Karenia brevis*

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LONG-TERM GOALS

Our overall hypothesis is that populations of the red tide species *Karenia brevis* give rise to distinct and identifiable optical signatures in inherent optical properties and remote sensing reflectance. Accordingly, the primary objective of this project is to refine and evaluate optical approaches to detect and assess bloom events of *K. brevis*, and to define limits of detection. An additional objective is to examine hyperspectral optical observations to characterize optically distinct patterns and features in complex coastal waters.

OBJECTIVES

Specific objectives of this research include the following:

1) Measurements of inherent and apparent optical properties will be conducted in areas frequented by *Karenia brevis* bloom events off the west Florida coast, and attempt to identify key optical indices for discriminating blooms of K. brevis from other phytoplankton and other sources of optical variability.

2) We will examine the utility of inversion methods to retrieve phytoplankton absorption from reflectance, and subsequently evaluate this with regard to optical criteria for detection of *K. brevis* and other phytoplankton taxa.

APPROACH

The funded research was focused on addressing the following tasks:

*Task 1: Conduct measurements of multi-spectral and hyperspectral inherent and apparent optical properties in Florida shelf waters in and around regions impacted by bloom events of Karenia brevis.*
Discrete profiles of the inherent optical properties were assessed with various in situ instruments including a WETLabs Inc absorption/attenuation meter (ac-9), HOBI Labs Hydrosat-6 backscattering sensor, and a suite of Satlantic radiometers (including a hyperspectral tethered radiometric buoy). We have also successfully deployed an 84 spectral channel WETLabs, Inc. ac-s absorption/attenuation meter for determination of particulate and dissolved absorption. Measurements of particulate backscatter have been made using four different instruments, the HOBI Labs, Inc. a-beta, a HOBI Labs, Inc. Hydroscat-6, and a WET Labs, Inc. ECO-VSF3, and most recently, a WET Labs, Inc. BB9. High spectral resolution surface remote sensing reflectance was acquired using a Satlantic Hyperspectral Tethered Remote Sensing Buoy (HTSRB), an Analytical Spectral Devices FieldSpec handheld radiometer, and a Satlantic HyperSAS radiometer (Surface Acquisition System above-water radiometer). The latter was acquired through a DURIP grant associated with this project. In addition, a Satlantic MicroPro profiling radiometer was used to provide profiles of upwelling radiance and downwelling irradiance, and could also be used to provide an independent measure of remote sensing reflectance.

Field operations were conducted in fall of 2003, summer of 2004, and most recently, observations were conducted in September 2006.

Task 2: Examine the utility of inversion methods to retrieve phytoplankton absorption from hyperspectral reflectance, and evaluate with regard to optical criteria for detection of K. brevis and other phytoplankton taxa.

We are conducting a comparative investigation of inversion methods for retrieval of pigment absorption from reflectance. These include an algorithm currently under development by Schofield’s lab and the decomposition algorithm of Lee et al. (2002). This latter approach utilizes a quasi-analytical algorithm to calculate the particle backscattering coefficient and the total absorption coefficient from measured remote-sensing reflectance. The algorithm has been shown to work well in coastal waters, and retrieve pigment absorption spectra that differ in correspondence with the type of phytoplankton present.

WORK COMPLETED

This project was in its final year under a no-cost extension and has been involved in three field deployments now building up a large optical database. Cruises off west Florida were conducted 3-7 November 2003 and July 11-16 2004 on the R/V Suncoaster. These cruise efforts were conducted in conjunction with Schofield’s AUV projects. Participation in cruises during fall of 2004 and 2005 was limited due to hurricane activity in the Gulf. Data were also available to the project from 1999 and 2001 cruises. More recently we participated in a MERHAB cruise 18-22 September 2006 (Fig. 1). Laboratory experiments to determine inherent optical properties of K. brevis were conducted in early 2002 at Mote Marine Laboratory by a University of Southern Mississippi Ph.D. student, Kevin L. Mahoney (graduated in August 2003). His dissertation research contributed to this project. Additional laboratory experiments were conducted at Mote Marine Laboratory in March 2004 by USM postdoctoral researcher Dr. Susanne Craig (now at Dalhousie University) and USM Master’s student Megan Butterworth. Follow-up studies were also performed at USM in September 2006 and these results have been published in an M.S. thesis. A Rutgers Ph.D. student, Rachael Sipler, used data from this effort which is central to her thesis. Results from this project have been described in three recent publications (Kerfoot et al., 2005; Craig et al., 2006; Schofield et al., 2006). Additional manuscripts are in preparation.
RESULTS

In prior reports for this project, results were presented for the 2003 cruise, which illustrated optical discrimination techniques optimized for phytoplankton taxa and other optically-active constituents (Schofield et al., 2006). Additionally, the utility of hyperspectral reflectance for monitoring and detection of *K. brevis* blooms was illustrated for measurements of remote sensing reflectance, $R_{rs}$, made during a series of cruises off the west Florida shelf including 9-14 September 1999 (R/V *Pelican*), 20-25 October 2001 (R/V *Suncoaster*) and 3-7 November 2003 (R/V *Suncoaster*).

Phytoplankton absorption coefficient, $a_{ph}$, retrievals were performed using the Lee et al. (2002) quasi-analytical algorithm (QAA). The retrieved $a_{ph}$ spectra were then compared to a reference absorption spectrum obtained from filter pad measurements of a *K. brevis* culture using a similarity index (SI) analysis (Millie et al., 1997). The magnitude of the SI was found to be significantly correlated with surface cell number as determined by microscopic enumeration. These findings have been described in Craig et al. (2006). Here, we present preliminary two new sets of results: one from the September 2006 cruise off the west Florida shelf, when a substantial bloom of *K. brevis* was encountered (Fig. 1) and the second set illustrating the use of hyperspectral remote sensing reflectance for tracking water mass properties in the Mississippi River plume.

During the September 2006 cruise off the west Florida shelf, measured parameters included attenuation and absorption using an ac-9 and an ac-s (WET Labs), backscattering coefficient using an ECO bb9 (WETLabs, Inc.), and fluorescence of chlorophyll a, phycocyanin, and chromophoric dissolved organic matter (CDOM) using an ECO Triplet (WETLabs, Inc.). Remote sensing reflectance, including sky and water surface radiance were measured using a handheld FieldSpec (Analytical Spectral Devices, Inc.).

Here we compare observations at four stations with contrasting levels of *K. brevis* cell concentrations. At Stations 58 and 59, high surface concentrations were observed ($1.9 \times 10^6$ and $0.46 \times 10^6$ cells per...
liter respectively) while cells were low in number or absent at Stations 16 and 17 further to the south (Fig. 2). Observations of remote sensing reflectance ($R_{rs}$) for the northern bloom stations were characterized by very different spectral shapes than observed for the southern stations (Fig. 3). Spectra for Stations 16 and 17 were characteristic of clear ocean water, with highest reflectances at shorter wavelengths. In contrast, stations to the north showed a distinct peak around 550 nm.

Figure 2. Station map showing selected stations showing relatively high surface concentrations of Karenia brevis at Stations 58 and 59 off Tampa Bay and low concentrations at Stations 16 and 17 to the south during the 18-22 September 2006 aboard the R/V Suncoaster. Units on the color bar were cell counts of K. brevis in cells per liter.

We applied the Lee et al. (2002) quasi-analytical algorithm (QAA) to retrieve total absorption and absorption by phytoplankton ($a_{ph}$) from the reflectance spectra. The results were compared to in situ measurements of total absorption made with a WETLabs, Inc. ac-s (Fig. 4). The high temperatures and relatively clear water conditions made near surface measurements with the ac-s difficult due to degassing and frequent bubble formation in the flow path. Data were selected from depths as close to the surface as possible, but deep enough to minimize bubble contamination. In general, the trends in absorption were consistent for the two methods, with much lower values at Stations 16 and 17 and higher values especially at shorter wavelengths at Stations 58 and 59 (Fig. 4). Spectral shapes for both the ac-s and QAA-derived total absorption at Stations 16 and 17 were atypical, lacking the expected increasing absorption in the blue wavelengths. The values of total absorption at these stations were quite low and, in the case of the ac-s, sensitive to noise in the data at shorter wavelengths (larger standard deviations in Fig. 4). Additionally, the QAA does not perform as well at longer wavelengths. The absolute magnitudes of absorption differed with the QAA method yielding generally higher values at the clear water stations (Stations 16 and 17) and slightly lower values at Station 59. In addition, the QAA-derived total absorption for Station 58 showed distinct spectral features in contrast to ac-s, which showed a general increase in absorption with decreasing wavelength at Station 58. These observed differences can be at least partially attributed to the fact that the sensors are viewing different portions of the water column.
The Similarity Index (SI) as described in Millie et al. (1997) was applied to in situ total absorption data and to the phytoplankton absorption \( a_{ph} \) retrieved from reflectance by the QAA method (Table 1; \( a_{ph} \) data not shown). Higher values of SI were observed for both in situ and reflectance-derived absorption data. SI values for the reflectance data were actually more closely related to cell concentrations \( r^2=0.948 \) than for the in situ data. This could be attributed to the fact that the ac-s data included non-algal absorption and the fact that ac-s measurements were confined to discrete depths slightly below the surface which may not have coincided to the highest cell concentrations.

**Table 1. Similarity Indices (SI) for in situ total absorption determined with the acs and phytoplankton absorption \( a_{ph} \) retrieved from remote sensing reflectance using the QAA method.**

<table>
<thead>
<tr>
<th>Station</th>
<th>SI (In situ total a)</th>
<th>SI ( a_{ph} ) from QAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>0.25</td>
<td>0.12</td>
</tr>
<tr>
<td>17</td>
<td>0.071</td>
<td>-0.039</td>
</tr>
<tr>
<td>58</td>
<td>0.40</td>
<td>0.48</td>
</tr>
<tr>
<td>59</td>
<td>0.44</td>
<td>0.52</td>
</tr>
</tbody>
</table>

**Figure 3.** Remote sensing reflectance as determined using a FieldSpec (Analytical Spectral Devices, Inc.) handheld radiometer. At Stations 16 and 17, reflectances were highest at shorter wavelengths while at Stations 58 and 59, a distinct peak in reflectance was observed around 550 nm.
Figure 4. Comparison of total absorption derived from remote sensing reflectance using the Lee et al. (2002) quasi-analytical algorithm (red circles) with in situ measurements using a WETLabs, Inc. ac-s (black line; blue dotted lines indicate plus or minus one standard deviation). Trends in absorption were generally consistent for the two methods, with much lower values at Stations 16 and 17 (top left and right, respectively) and higher values especially at shorter wavelengths at Stations 58 and 59 (bottom left and right, respectively).

In the remainder of this report, preliminary results are provide to illustrate the utility of remote sensing reflectance as means of tracking water mass properties in an optically complex coastal regime, the Mississippi River plume. Reflectance measurements were conducted using a Satlantic HyperSAS radiometer system which was acquired through a DURIP project associated with this project. Logistical constraints prevented its use during bloom events off west Florida. However, it was used successfully to provide underway reflectance observations during a 3-7 October 2005 cruise aboard the R/V Pelican in the vicinity of the Mississippi River delta.

In addition to reflectance measurements, information about inherent optical properties of the water masses was provided by measurements of total absorption with a WETLabs, Inc. ac-s and chromophoric dissolved organic matter (CDOM) with an ac-9 equipped with a 0.2 μm cartridge filter (Fig. 5). Optical properties at three stations were compared to illustrate the pronounced gradients in inherent optical properties from highly turbid river water (Station 7) to river plume (Station 8) to coastal water (Station 9).
Figure 5. Spectral beam attenuation (top left), total absorption and absorption due to chromophoric dissolved organic matter (CDOM) (bottom left) show a decreasing trend for three stations progressing from the Mississippi River delta Head of Passes (Station 7) through the plume (Station 8) to coastal water (Station 9). Stations locations were shown on a composite satellite image of diffuse attenuation at 490 nm \( K(490) \). For all measurements, values increased with decreasing wavelength. At Stations 7 and 8, absorption was dominated by CDOM, while particulate absorption was greater for the coastal station (Station 9).

HyperSAS reflectance measurements were obtained while in transit between Stations 7 and 8 and between Stations 8 and 9 (Fig. 6). River water reflectance was relatively high (>0.01 sr\(^{-1}\)) with a maximum around 560 nm. For reflectances determined while underway from Station 8 to 9, a shift was seen in reflectance from a “river” type signal to lower values with maximum reflectance shifted to between 500 and 550 nm (Fig. 6).
Figure 6. Remote sensing reflectance ($R_{rs}$, sr$^{-1}$) determined using the Satlantic HyperSAS above water radiometer while in transit between Stations 7 and 8 and Stations 8 and 9 (measurement locations shown as magenta crosses on composite satellite image of $K(490)$). The river and plume reflectances showed maximum values greater than 0.01 sr$^{-1}$ with a spectral maximum around 560 nm. For the transit from Station 8 to 9, maximum reflectance decreased and shifted toward shorter wavelengths.

To illustrate the transition in water mass properties between Stations 8 and 9, spectra were normalized to the value of reflectance at 555 nm (Fig. 7). Normalized reflectance increased in the blue and ultraviolet wavelengths due to decreasing absorption and decreased in the red and near infrared due to decreasing particulate backscattering. These results illustrate the utility of highly-resolved, hyperspectral remote sensing reflectance measurements to discern optically distinct patterns and features in complex coastal regimes.
IMpACT/APPLICATIONS

An anticipated product of this effort will be the development of improved optical approaches for detection of *K. brevis* and other algal taxa that may be applied to observations made using moored or ship-deployed instrumentation, autonomous vehicles, or satellite or aircraft remote sensing. The ability to use reflectance data to characterize water mass properties provides an illustration of its utility for objective water mass tracking in the coastal ocean.

TRANSITIONS

We have been in consultation with Dr. Rick Stumpf of NOAA for using the reflectance method as a possible augmentation to the existing Harmful Algal Bloom Forecasting System.

RELATED PROJECTS

This ONR-funded project is closely coordinated with another project funded by the NASA Oceanography Program in the Office of Earth Science (S. E. Lohrenz and G. L. Kirkpatrick, co-PIs). As part of the ONR Mine Countermeasures program, Schofield and other Rutgers investigators will deploy optical gliders equipped with sensors for hyperspectral absorption (Brevebuster capillary waveguide absorption meter), backscatter at two wavelengths and attenuation at one wavelength (WETLabs, Inc. SAM). Deployment of Remote Environmental Measuring UnitS (REMUS) autonomous vehicle equipped with a similar suite of optical sensors is planned by M. Moline (Cal
Polytech) as part of his ONR Young Investigator project. Additionally two DURIPs are related to this effort. In one DURIP, a hyperspectral above water reflectance meter was awarded to Steven Lohrenz. In a second DURIP, two optical gliders were awarded to Oscar Schofield.

REFERENCES


PUBLICATIONS RESULTING FROM THIS PROGRAM SUPPORT

(**graduate students or post-doctoral researchers)


