Detecting HAB's in the Gulf of Mexico: Problems with atmospheric correction and shallow waters

Kendall L. Carder, Jennifer P. Cannizzaro, F. Robert Chen, and Chuanmin Hu
College of Marine Science, University of South Florida, St. Petersburg, FL 33701

INTRODUCTION

Harmful algal blooms (HAB) of the toxic dinoflagellate *Karenia brevis* occur regularly in the Gulf of Mexico causing fish and marine mammal mortalities and human respiration irritation. Bloom concentrations above background levels (1-10^3 cells l^{-1}) usually occur in late summer and fall most heavily along the central West Florida Shelf (WFS).

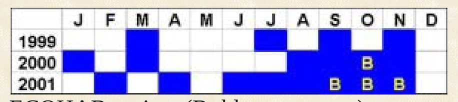
Using shipboard radiometry, a method has been developed for classifying *K. brevis* populations with greater than 10^4 cells l^{-1} based on low backscattering-to-chlorophyll ratios (Cannizzaro et al., accepted). Chlorophyll concentrations for positively identified blooms are then quantified using fluorescent line height (FLH) data to avoid signal-to-noise problems common to blue wavebands required by most chlorophyll algorithms.

Preliminary application of the classification technique to SeaWiFS data did not always provide consistent results (Hu et al., accepted). Why might this be??? We will explore two important reasons: 1) calibration/atmospheric correction problems for satellite radiometric data and 2) chlorophyll concentration and backscattering coefficient overestimations in optically shallow waters due to bottom reflectance.

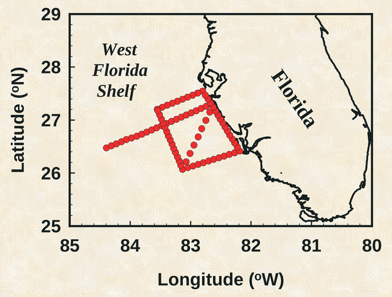
A new technique for classifying optically shallow waters and quantifying chlorophyll concentrations and backscattering coefficients more accurately is introduced and recent red-tide blooms are identified and tracked.

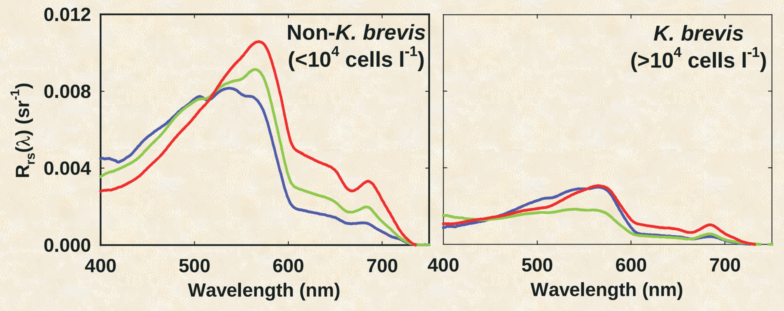
ALGORITHM DESCRIPTION

Multi-year, multi-season data were collected on the WFS as part of the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) program.



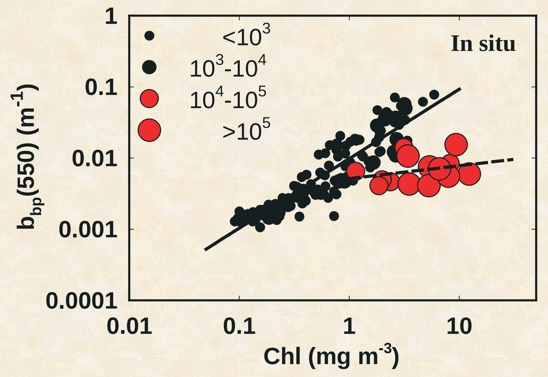
ECOHAB cruises (B=bloom present)

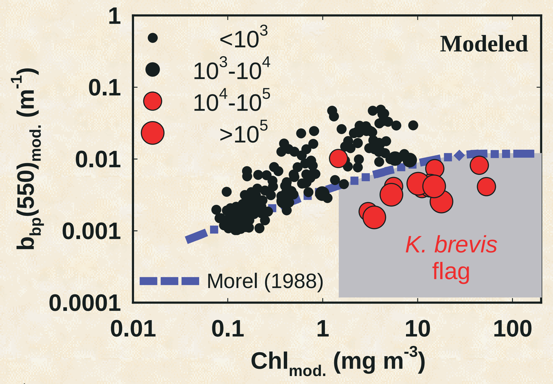




Median $R_{rs}(\lambda)$ for Chl's:
1-2 mg m^{-3}
2-5 mg m^{-3}
5-10 mg m^{-3}

← *K. brevis* blooms are ~4x's <u>less</u> reflective than non-*K.brevis* blooms.

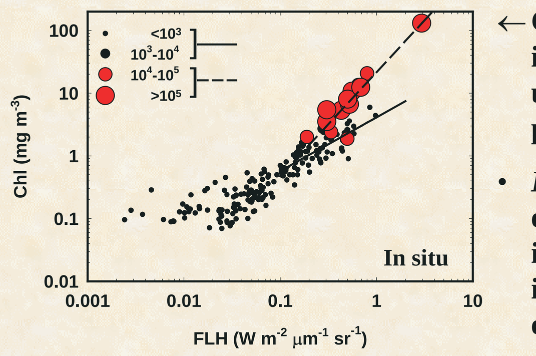




↑ *K. brevis* blooms exhibit <u>low</u> chlorophyll-specific particulate backscattering coefficients relative to high-chlorophyll, diatom-dominated estuarine blooms.

- Model results (not shown) indicate that backscattering (NOT absorption) is responsible for the four-fold decreased reflectivity observed in *K. brevis* blooms.

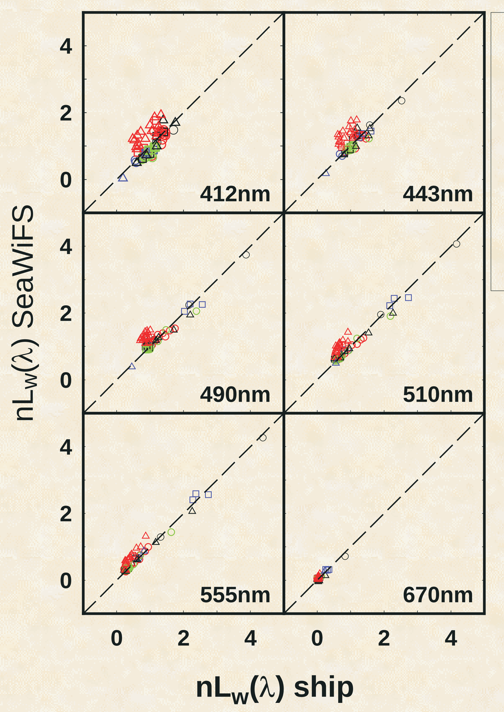
↑ Similar patterns are observed when $b_{bp}(550)$ and Chl were estimated semi-analytically from shipboard $R_{rs}(\lambda)$ data (Carder et al., 1999) indicating that satellite radiometric data (SeaWiFS and MODIS) can be used to identify *K. brevis* blooms from space.



← Chlorophyll concentrations in positively identified blooms can then be quantified using fluorescence line height (FLH) data provided by MODIS.

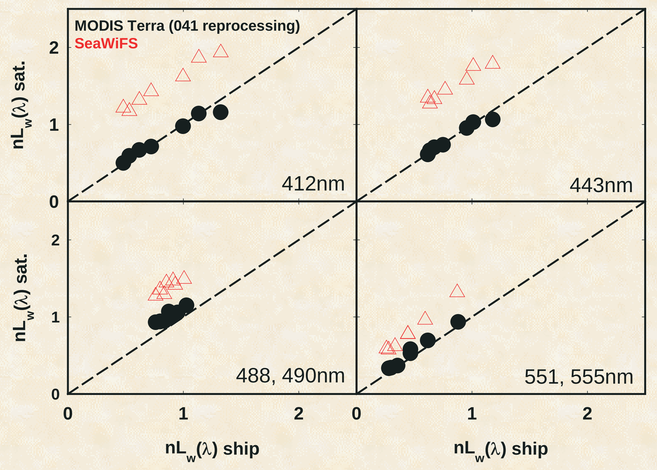
- *K. brevis* bloom and non-bloom waters exhibit differing fluorescence efficiencies indicating the importance of bloom identification prior to chlorophyll estimations.

ATMOSPHERIC PROBLEMS



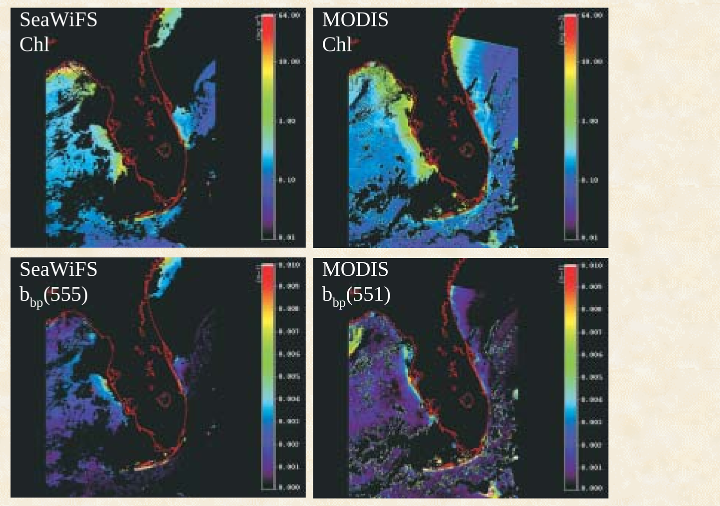
← SeaWiFS and shipboard water-leaving radiance match-up data (provided by S. Bailey and J. Werdell, NASA-SIMBIOS team) agree well for all ECOHAB cruises except eh0901 (28-30 August 2001).

← The SeaWiFS true color browse image for 28 August 2001 indicates that the entire ECOHAB region was blanketed by a large aerosol feature spread along the U.S. east coast and into the Gulf of Mexico.



↑ MODIS Terra (reprocessing 041) $nL_w(\lambda)$ data (28 August 2001), however, agree with the shipboard data.

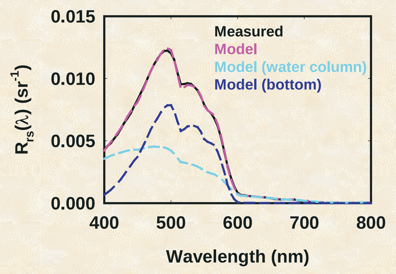
- MODIS and shipboard radiances measured in low-chlorophyll (~0.125 mg m^{-3}) offshore waters approach clear water radiance values ($L_w(550)$~0.28; Gordon and Clark, 1981), supporting their accuracy.



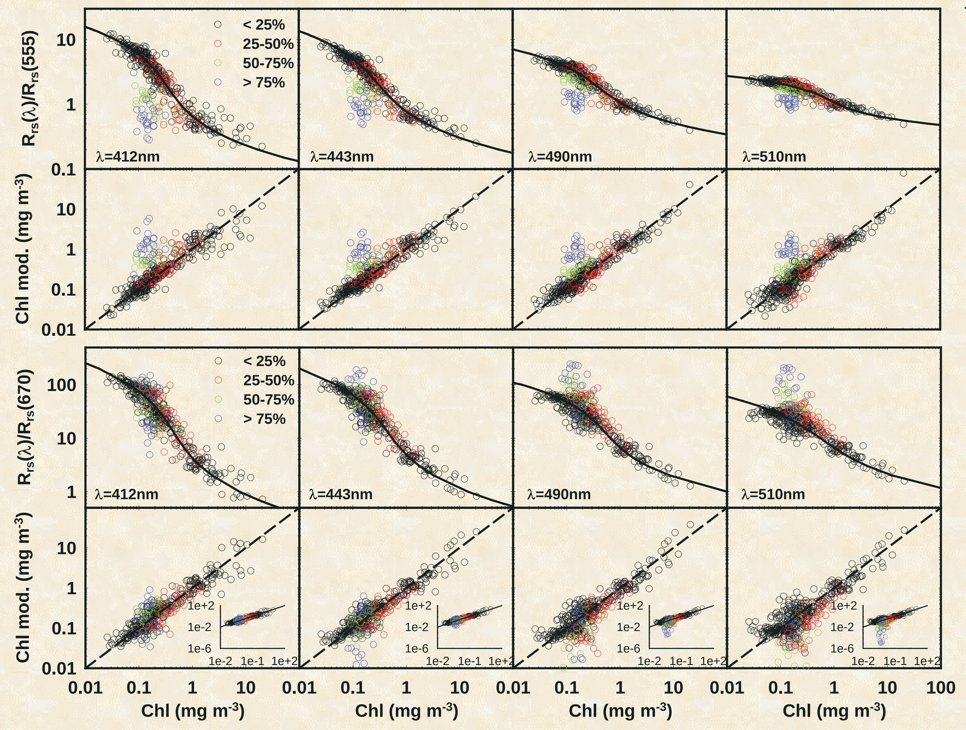
↑ Poorly corrected SeaWiFS $nL_w(\lambda)$ data moderately affect estimations of chlorophyll concentration that are based on radiance ratios, but profoundly affect retrievals of backscattering coefficients estimated directly from water-leaving radiance values.

- Aerosol types selected for the SeaWiFS and MODIS data differed significantly.
- MODIS epsilon values were higher than SeaWiFS values indicating that a bluer-rich, more appropriate aerosol model was selected for the MODIS data.
- Whether this represents a case of aerosol epsilon ambiguity as between SeaWiFS single-scattering epsilon and multi-scattering epsilon models (Wang, 2004) or some other problem is not known.
- How frequently this problem occurs is also unknown, and is a main concern if HAB's are to be detected and quantified accurately in the Gulf of Mexico.
- Clear-water radiance flags will be used for clear regions (e.g. Loop & Florida Currents) to identify similar aerosol-correction problems along with intercomparison of SeaWiFS, Aqua and Terra scenes to ensure that algorithm performance is not degraded by calibration and atmospheric issues.

SHALLOW WATER PROBLEMS



← Shipboard $R_{rs}(\lambda)$ data (n=450) collected during four multi-year (1998-2001) field programs (ECOHAB, FSLE, TOTO and CoBOP) were partitioned into water column and bottom reflectance spectra by optimization (Lee et al., 1999) to estimate 555nm bottom reflectance contributions Cannizzaro and Carder, in prep.).



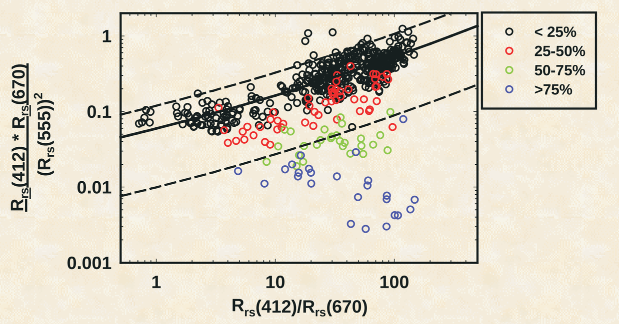
← Traditional empirical chlorophyll algorithms based on $R_{rs}(\lambda_i)/R_{rs}(555)$ where λ_i is 412, 443, 490 and 510nm were examined.

-Simple cubic polynomial functions were fit to log-transformed data with 555nm bottom reflectance contributions less than 25% and then applied to the entire data set.

-Chlorophyll concentrations for data with bottom contributions greater than 50% were significantly overestimated for all band ratios ($R_{rs}(\lambda_i)/R_{rs}(555)$) examined (see Table below).

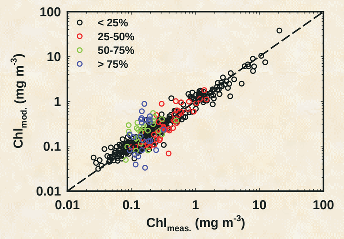
-Switching the reference waveband from 555nm to 670nm and setting λ_i to 412nm improves chlorophyll retrievals in optically shallow waters.

Band ratio	RMS_{lin}	bias
$R_{rs}(412)/R_{rs}(555)$	0.752	0.082
$R_{rs}(443)/R_{rs}(555)$	0.611	0.070
$R_{rs}(490)/R_{rs}(555)$	0.561	0.051
$R_{rs}(510)/R_{rs}(555)$	0.683	0.037
$R_{rs}(412)/R_{rs}(670)$	0.480	-0.009
$R_{rs}(443)/R_{rs}(670)$	0.517	-0.036
$R_{rs}(490)/R_{rs}(670)$	1.173	-0.127
$R_{rs}(510)/R_{rs}(670)$	1.998	-0.213



← The following classification criteria were developed to identify optically shallow waters from space in order to improve chlorophyll concentration and backscattering retrievals in shallow coastal regions such as the WFS.

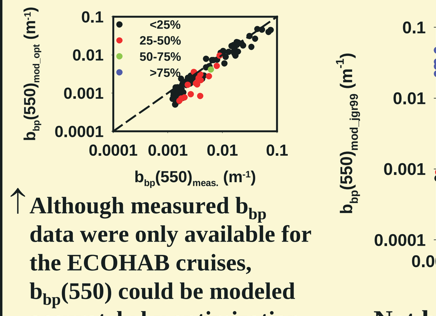
- Using $R_{rs}(412)/R_{rs}(670)$ as a surrogate for Chl and the spectral curvature about 555nm $((R_{rs}(412)*R_{rs}(670))/(R_{rs}(555)^2))$, shipboard $R_{rs}(\lambda)$ data were separated into "optically deep" (above upper dashed line) and "optically shallow" (below lower dashed line) waters. The solid line was generated by fitting a quadratic polynomial regression function through log-transformed data with bottom reflectance contributions less than 25% at 555nm. The upper and lower dashed lines, parallel to this solid function, provided the lowest RMS error (0.406) for the blended chlorophyll concentrations (see below).



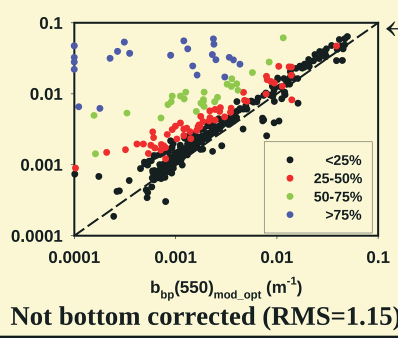
← Chlorophyll concentrations for optically deep and optically shallow waters were estimated using $R_{rs}(490)/R_{rs}(555)$ and $R_{rs}(412)/R_{rs}(670)$, respectively. Concentrations for "transitional waters" were blended to prevent algorithm-switching artifacts.

- This technique offers advantages over alternative methods for estimating chlorophyll concentrations in optically shallow waters. While removal of bottom reflectance via optimization (Lee et al., 1999; Carder et al., 2000) has been proven successful, this technique is computationally expensive when applied to entire scenes. Calculating chlorophyll concentrations from FLH data is another promising method, but is hampered by variability observed in fluorescence efficiencies (Cannizzaro et al., accepted).

Since backscattering coefficients are typically derived directly from $R_{rs}(\lambda)$ values instead of from reflectance ratios, bottom reflectance causes greater overestimations in backscattering compared to chlorophyll concentrations:

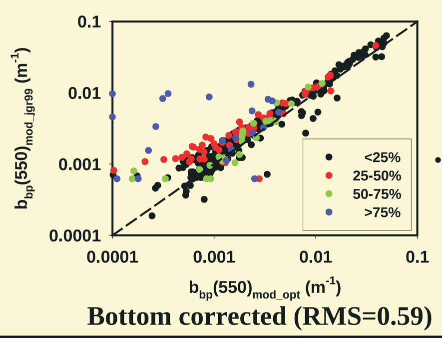


↑ Although measured b_{bp} data were only available for the ECOHAB cruises, $b_{bp}(550)$ could be modeled accurately by optimization.



Not bottom corrected (RMS=1.15)

← $b_{bp}(550)$ values derived from $R_{rs}(555)$ (Carder et al., 1999; JGR99) are overestimated significantly (~2 orders of magnitude) due to bottom reflectance compared to optimization-derived values where bottom reflectance has been removed.

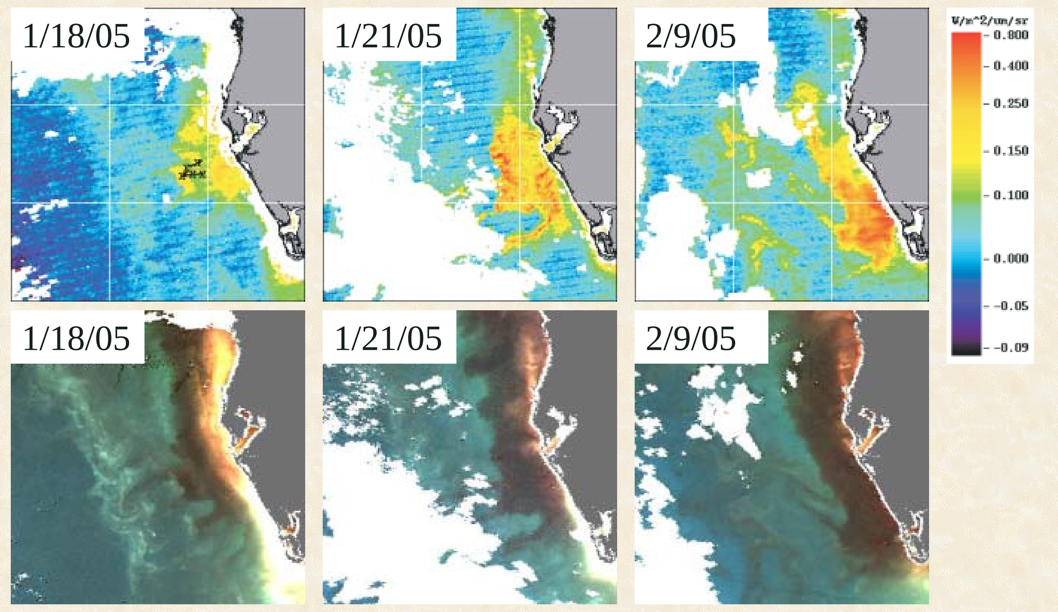


Bottom corrected (RMS=0.59)

↙ Classifying the data according to the criteria developed above, optically shallow $R_{rs}(555)$ values were estimated from "bottom-free" $R_{rs}(670)$ values using a power function ($R_{rs}(555)=1.42*R_{rs}(670)^{0.77}$; $r^2=0.94$, n=275) developed from optically deep waters and were corrected for bottom reflectance.

- Estimating $b_{bp}(550)$ values from measured $R_{rs}(555)$ values for optically deep waters, modeled $R_{rs}(555)$ values for optically shallow waters, and blended $R_{rs}(555)$ values for transitional waters reduced the RMS error by half.

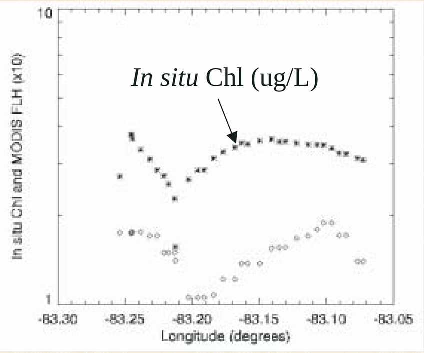
OPERATIONAL APPLICATIONS



Top: MODIS fluorescence line height (FLH) imagery, produced and broadcast at USF in near real-time (http://modis.marine.usf.edu). Overlaid on the 1/18/05 image are the coordinated ship tracks and station locations.
Bottom: SeaWiFS enhanced RGB composite imagery showing dark water patches in the Tampa Bay coastal area. Clearly, not all dark water is due to phytoplankton bloom (i.e., high FLH values).

	K. brevis	[Chl a]
Station #	(counts/L)	(ug/l)
1	60000	3.38
2	77000	1.87
3	173000	4.21
4	248000	2.56
5	340000	6.84

Water samples from the 1/19/2005 survey contain medium to high concentrations of *Karenia brevis.*



In situ Chl (ug/l) and MODIS FLH (x10) along the 1/19/2005 ship transect (top leg). For WFS non-red tides, FLH (x10) values overlie in situ Chl values (Hu et al., submitted) consistent with higher fluorescence efficiencies observed for the ECOHAB non-red tide data (Cannizzaro et al., accepted; see far left).

FUTURE WORK

- ➢ Validation and refinement of shallow water and HAB classification techniques using SeaWiFS and MODIS (Terra and Aqua) data.
- ➢ Collection of additional field data in shallow waters and *K. brevis* blooms. Recent field and MODIS data were collected with Dr. Chuanmin Hu and Dr. Frank Müller-Karger (USF) and Dr. Cynthia Heil (Florida Fish and Wildlife Research Institute) on the WFS (19 January 2005) during a red tide event.
- ➢ Continued collaboration with Dr. Chuanmin Hu and Dr. Cynthia Heil
- ➢ Application of HAB classification technique to
  - Examine the inter-annual spatial and temporal <u>variability</u> of chlorophyll concentrations for past blooms and background phytoplankton populations in order to better understand the contribution of *K. brevis* to annual primary productivity and carbon sequestration in the Gulf of Mexico,
  - Determine the <u>response</u> of *K. brevis* blooms (i.e. size, frequency, and duration) to short-term climatic events such as El Niño, and
  - <u>Predict</u> future blooms and through coordination with existing state monitoring programs to target discrete sampling locations more accurately.

Acknowledgements

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