

Hyperspectral Modeling of Harmful Algal Blooms on the West Florida Shelf

W. Paul Bissett
Florida Environmental Research Institute
4807 Bayshore Blvd.
Suite 101
Tampa, FL 33611
phone: (813) 837-3374 x102 fax: (813) 902-9758 email: pbissett@flenvironmental.org

Award Number: N00014-98-1-0844
<http://www.flenvironmental.org>

LONG-TERM GOALS

Harmful Algal Blooms [HABs] are an ecological response to the physical, chemical, biological, and optical forcing in the marine environment. Successful forecasting of HABs requires simulating the competitive interactions of the total phytoplankton assemblage and the resultant feedback mechanisms into the spectral light and nutrient fields. Our goal is to develop the phytoplankton interaction equations to predict the assemblage shifts and resulting phytoplankton blooms on the West Florida Shelf [WFS].

(NOTE: Expansion Award – Deriving Nowcast/Forecast Techniques for Bioluminescence Potential in Monterey Bay – is described in an addendum to this report.)

OBJECTIVES

- 1) The development of a predictive phytoplankton ecological simulation for 7 functional groups of phytoplankton, including the toxic dinoflagellate, *Karenia brevis*.
- 2) Incorporation of the phytoplankton model into a larger ecological simulation of the marine ecosystem that contains multiple nutrients and spectral light propagation, EcoSim 2.0.
- 3) Couple EcoSim 2.0 to a 2-dimensional physical simulation of the WFS to demonstrate the veracity of the ecological equations.

APPROACH

We hypothesized that the competitive interactions between the various functional groups of phytoplankton for light and nutrients on the WFS at times yielded biomass concentrations of *K. brevis* sufficient to produce a toxic effect to the marine ecosystem. This hypothesis was generated as part of a larger NOAA/EPA/ONR program to study the regional impacts and processes of the Ecology and Oceanography of Harmful Algal Blooms [EcoHAB]. The EcoHAB:Florida program extends between the 10-m and 50-m isobaths, along the Florida coast from Tampa Bay to Charlotte Harbor, and is sampled at monthly intervals with continuous underway measurements of u, v, temperature, salinity, in vivo chlorophyll fluorescence, CDOM, and transmissometry. At discrete stations, additional data are now collected on distributions of NO₃, NO₂, PO₄, SiO₄, Fe (III), Dissolved Organic Phosphorous

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 2001		2. REPORT TYPE		3. DATES COVERED 00-00-2001 to 00-00-2001	
4. TITLE AND SUBTITLE Hyperspectral Modeling of Harmful Algal Blooms on the West Florida Shelf				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Florida Environmental Research Institute,,4807 Bayshore Blvd.,Suite 101,,Tampa,,FL, 33611				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Harmful Algal Blooms [HABs] are an ecological response to the physical, chemical, biological, and optical forcing in the marine environment. Successful forecasting of HABs requires simulating the competitive interactions of the total phytoplankton assemblage and the resultant feedback mechanisms into the spectral light and nutrient fields. Our goal is to develop the phytoplankton interaction equations to predict the assemblage shifts and resulting phytoplankton blooms on the West Florida Shelf [WFS].					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 12	19a. NAME OF RESPONSIBLE PERSON
a REPORT unclassified	b ABSTRACT unclassified	c THIS PAGE unclassified			

[DOP], Dissolved Organic Nitrogen [DON], Dissolved Inorganic Carbon [DIC], Dissolved Organic Carbon [DOC], chlorophyll, phaeopigments, PN, PC, PP, $\delta^{15}\text{N}$ of PN and NO_3 , cell counts of all dominant phytoplankton species, and abundances of mesozooplankton species.

In the above hypothesis, a functional group represents a suite of phytoplankton species with similar spectral light and nutrient response functions, i.e. diatoms of a particular size. In order to test this hypothesis, it is necessary to build a suite of ecological equations that effect competition for resources in such a way as to allow for niche separation, and thus, competitive dominance for each functional group under their optimal set of growth conditions. An earlier numerical model, Ecological Simulation 1.0 [EcoSim 1.0], was developed for the oligotrophic Sargasso Sea, which incorporated the competitive interactions for nitrogen and spectral light for 4 functional groups of phytoplankton (Bissett et al., 1999a; Bissett et al., 1999b). This simulation effort suggested that it may be possible to expand more rudimentary phytoplankton-zooplankton-nutrient [PZN] models into a more predictive ecological description of the phytoplankton food web.

It was proposed that we apply the phytoplankton methodology used in the creation of EcoSim 1.0 to attempt a predictive set of equations for an expanded number of functional groups (7) representing the phytoplankton populations on the WFS. These functional groups include: 1) colonial nitrogen-fixing cyanobacteria, e.g. *Trichodesmium* sp., 2) large diatoms, 3) small diatoms, 4) coccoid cyanobacteria, e.g. *Synechococcus* sp., 5) coccoid picoplankton, e.g. *Prochlorococcus* sp., 6) non-toxic dinoflagellates, 7) toxic dinoflagellates, *K. brevis*. Since the physical regime of the coastal ocean is far more active than could be represented by a one-dimensional mixing model, it was also proposed that we expand the spatial domain of the simulation to incorporate advective impacts on the sources of nutrients and phytoplankton populations, as well as the sources and sinks for other optically active constituents, e.g. Colored Dissolved Organic Matter [CDOM] and sediments.

The ecological (physical, chemical, biological, and optical) modeling of the WFS is a collaborative effort between W. P. Bissett at the Florida Environmental Research Institute [FERI], J. J. Walsh and R. H. Weisberg at the University of South Florida [USF], and R. W. Garwood at the Naval Postgraduate School [NPS]. Details of their participation can be found in the Progress Report of J. J. Walsh, Award Number N00014-99-1-0212. In addition, the development of EcoSim 2.0 formulations for CDOM dynamics and Inherent and Apparent Optical Property [IOP and AOP] predictions are supported under N00014-00-1-0411 and N00014-99-1-0198, respectively.

WORK COMPLETED

Our focus was to complete the numerical analysis of the 1998 red tide on the West Florida Shelf with - 1) the inclusion of estuarine shoreward boundary conditions, 2) sensitivity analyses of grazing rates and non-redfield dynamics of carbon-based growth, and 3) comparisons between EcoSim 2.0 AOP output with Hydrolight 4.1 AOP output using EcoSim 2.0 simulated IOPs.

The inclusions of estuarine fluxes were necessary for this simulation analysis because of two hurricanes that impacted this region during the late summer and fall of 1998. These events cause the release of a tremendous amount of fresh water from the Charlotte Harbor Estuary onto the WFS. The subsequent small bloom of *K. brevis* (order 10^5 cells liter⁻¹) found during the ECOHAB Process studies appeared to be associated with strong salinity fronts, suggesting a physical accumulation mechanism and/or an estuarine supply of nutrient. Simulations completed without a shoreward flux of nutrients did

not produce the such? blooms of *K. brevis* (see below), so it was considered necessary to include these conditions prior to the completion and publication of this work.

As part of our continuing development of EcoSim into a truly predictive model of IOPs and upwelling irradiance, we needed to address ecological and optical issues through sensitivity analyses and module development for individual components of the code. Within the ecological modules there are a series of competitive interactive schemes that facilitate the shift in the phytoplankton assemblage as resources are added and subtracted to the simulation. Two of the major phytoplankton interactions are non-redfield growth dynamics and differential grazing and lytic losses. The non-redfield growth dynamics are incorporated in two ways. The first is via the inclusion of luxury uptake dynamics (nutrient uptake beyond immediate assimilatory need), and the second is via the ability to invoke cellular division (carbon growth) at less than optimal cellular nutrient stocks. The differential grazing stress is simulated via Michaelis-Menten functions with varying half-saturation constants. The description of these dynamics can alter the resultant species assemblage and part of our work was to discern the veracity of the numerical description, and the sensitivity of the parameter selection.

In addition, hyperspectral light is a resource for the phytoplankton assemblage, and the accurate description of the downwelling light field is an important resource input to the resultant phytoplankton community. During this period we began comparing our simulated AOPs with those estimated by a more rigorous radiative transfer code, Hydrolight 4.1 to determine if our simplified estimate of the downwelling irradiance was a reasonable input to the phytoplankton growth equations.

RESULTS

Figures 1 and 2 demonstrate the importance of adding the shoreward boundary conditions. In the simulation run for Figure 2, we altered the no flux shoreward boundary condition seen in Figure 1 to one that allowed nutrients, DOM, and CDOM to flow across the boundary on day-of-year 267 and 309. These days were chosen because they were the days of maximum offshore wind stress following Hurricanes Georges and Mitch, respectively. The accumulation of *K. brevis* and other non-toxic phytoplankton resulted from the input and accumulation of nutrients near shore. Were the nutrients input at redfield proportional the ensuing bloom would have been most composed of diatoms. However, the fresh water inputs to the WFS from central Florida are very rich in phosphorous and nitrogen relative to silica in both inorganic and organic forms. This allows for the greater relative growth performance of the other slower growing phytoplankton species.

In the testing of the phytoplankton growth equations we found that the luxury uptake equation set had a much greater relative effect on phytoplankton competition than did the ability to grow at less than optimal nutrient stocks. However, we also found from the modified Droop equations that we are not responding in a heuristically pleasing manner to changes in intra-cellular nutrient stocks. The luxury uptake equations and the modified Droop equations are hypothesized quantitative equations relating nutrient uptake and intra-cellular stocks to total cellular (carbon) growth. These equations were developed to explain a plethora of laboratory and field phytoplankton data, but have not been explicitly tested in the laboratory. That the model responds as well as it does to the environmental forcing in 1-D and 2-D simulations suggests we may have the right approach. However, we would like to team with a phytoplankton experimentalist to explicitly test our equations.

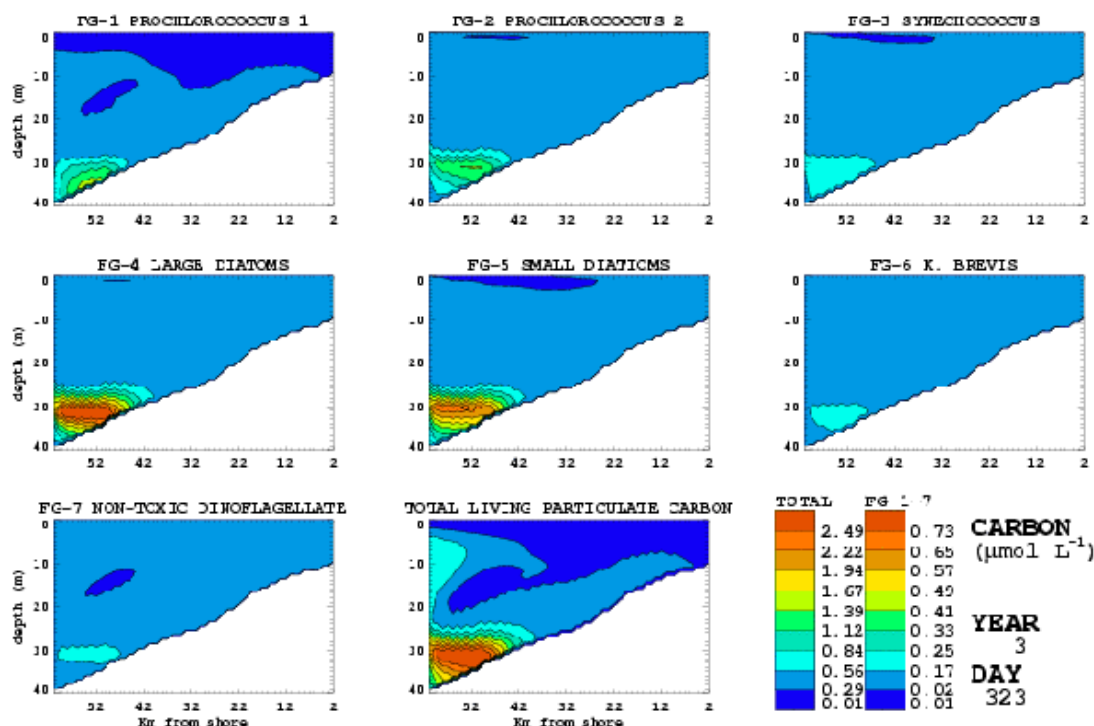


Figure 1. EcoSim 2.0 Functional Group results on day-of-year 323 of 1998.
Note lack of shoreward phytoplankton populations.

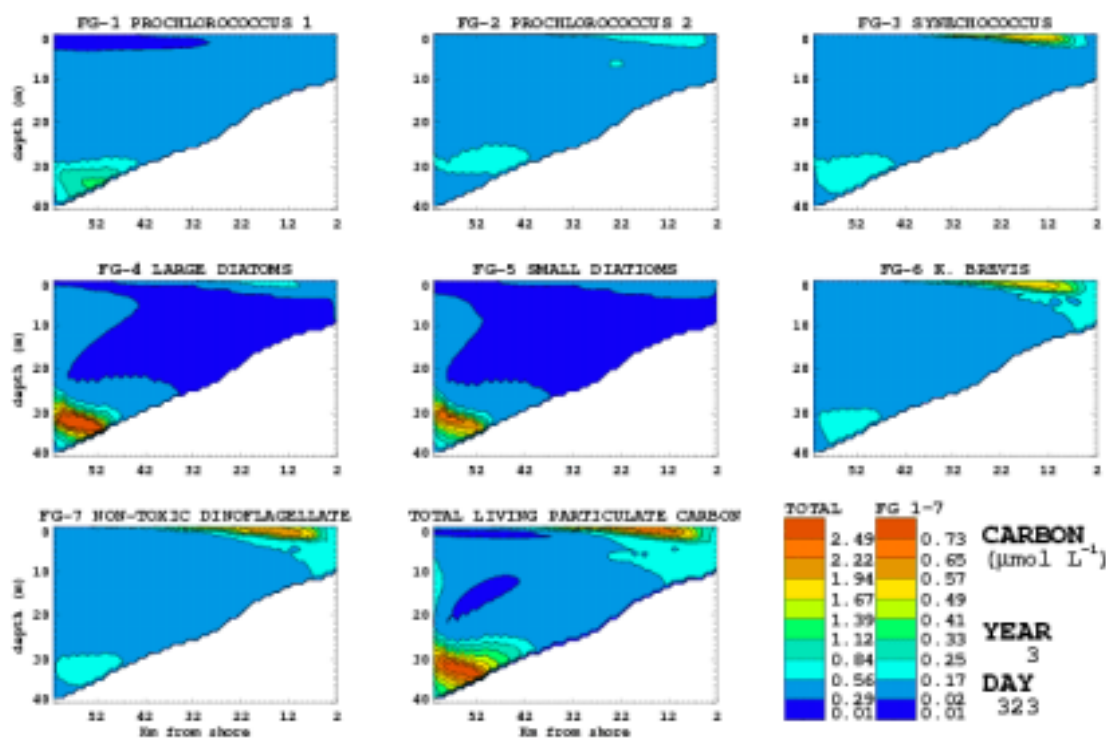


Figure2. EcoSim 2.0 Functional Group results on day-of-year 323 of 1998 with open shoreward boundary conditions on day-of-year 267 and 309. *Note the increase in phytoplankton populations near the coast, dominated by dinoflagellates. Actual numbers of K. brevis from cell counts made during ECOHAB Process cruises match those simulated.*

Figure 3 shows a comparison between the EcoSim downwelling irradiance and Hydrolight 4.1 for day-of-year 270 and 306 at local noon on each day. The Hydrolight runs were created using the IOPs for absorption and scattering hindcast by EcoSim and a Petzold phase function for the particulate scattering. We have seen that in the first comparison, the contours of percent irradiance are nearly the same for the simplified downwelling irradiance calculations from EcoSim and the more robust calculations from Hydrolight. However, the Hydrolight calculations did include a bottom reflectance calculation (EcoSim does not currently include this as an option). When bottom reflectance is included in the calculation of downwelling irradiance, we can see a ~10 to 15% difference in the irradiance calculations. It is not clear how much this will impact the ecological, or future Rrs, predictions for these waters. Clearly, in optically shallow waters bottom reflectance must be included to predict Rrs. However, ecologically it may not be as necessary because phytoplankton communities in optically clear waters are typically nutrient limited not light limited. Hence their competitive interactions are driven by nutrient dynamics rather than available photons.

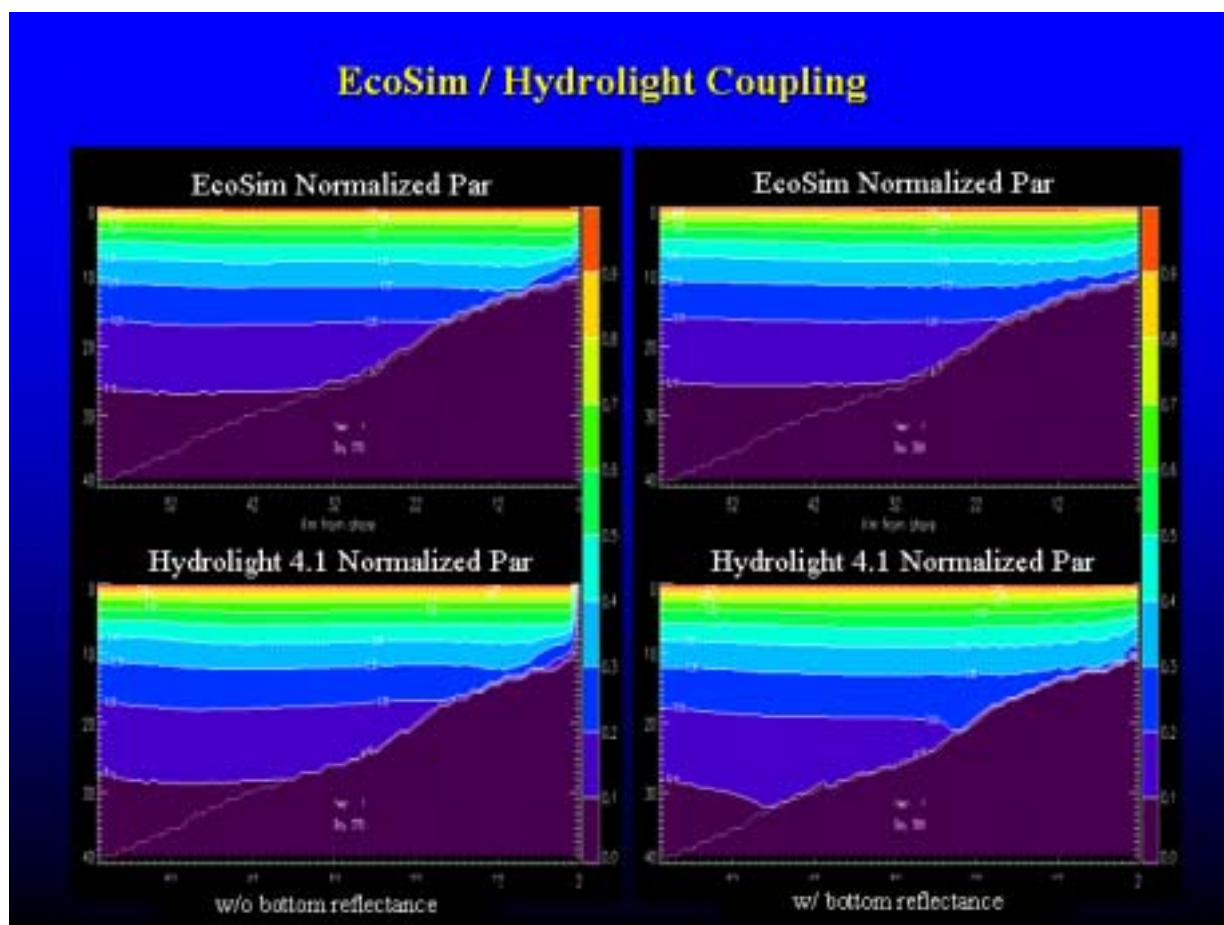


Figure 3. EcoSim 2.0 AOP predictions versus Hydrolight 4.1 predictions using the same EcoSim-predicted IOPs. Left panel demonstrates the small differences between EcoSim and Hydrolight when bottom reflectance is ignored. Right panel shows the impact of bottom reflectance in these optically clear waters. Differences appear to be as high as 10-15% for waters greater than 10 m in depth.

IMPACT/APPLICATIONS

Prediction of the HABs will enable resource managers and governmental offices to better warn the general public of the impending dangers from toxin releases into the near-shore environment. In addition, the successful forecast of phytoplankton interactions and subsequent biomass accumulations will help provide the necessary depth-dependent IOPs and AOPs for prediction of the in-water light field, water clarity, and laser performance prediction models.

RELATED PROJECTS

1) John Walsh (USF, N00014-99-1-0212) is a collaborator in the development of the ecological interactions and analysis of EcoHAB data, as well as responsible for the adaptation of the physical circulation models for use with EcoSim 2.0.

2) Bob Weisberg (USF, N00014-98-1-0158) is developing a primitive equation model at ~10-km resolution to analyze the observed current fields on the West Florida shelf. The physical circulation model is an adaptation of the Princeton Ocean Model [POM] that employs a topography-following sigma coordinate system in the vertical and an orthogonal curvilinear coordinate system in the horizontal.

REFERENCES

- Bissett, W.P., Carder, K.L., Walsh, J.J. and Dieterle, D.A., 1999a. Carbon cycling in the upper waters of the Sargasso Sea: II. Numerical simulation of apparent and inherent optical properties. *Deep-Sea Research I*, 46(2): 271-317.
- Bissett, W.P., Walsh, J.J., Dieterle, D.A. and Carder, K.L., 1999b. Carbon cycling in the upper waters of the Sargasso Sea: I. Numerical simulation of differential carbon and nitrogen fluxes. *Deep-Sea Research I*, 46(2): 205-269.

PUBLICATIONS

- Schofield, O., Arnone, R., Bissett, W. P., Crowley, M., Moline, M. A., Glenn, S. (2001) Cyclops is dead: Tapping the international constellation of ocean color satellites. *Backscatter* (submitted)
- Schofield, O., Bergmann, T., Kohut, J., Glenn, S. M., Pegau, W. S., Boss, E., Davis, C., Synder, W., Bowles, J., Kappus, M., Arnone, B., Weidemann, A. Bissett, W. P., Moline, M. A., Heine, E. L., Case, J., Herren, C. (2001) Adaptive sampling of a “Red River” in the coastal waters using a coastal ocean observatory. *EOS* (submitted)
- Bissett, W. P., Schofield, O., Glenn, S., Cullen, J. J., Miller, W. L., Plueddemann, A. J., Mobley, C. D., (2001) Resolving the impacts and feedbacks of ocean optics on upper ocean ecology. *Oceanography*, 14:(in press).
- Schofield, O., Bergmann, T., Bissett, W.P., Grassle, F., Haidvogel, D., Kohut, J, Moline, M., Glenn, S. (2001). The Long Term Ecosystem Observatory: An integrated coastal observatory. *Journal of Oceanic Engineering*, (in press).

- Walsh, J.J., B. Penta, D.A. Dieterle, and W. P. Bissett. (2001) Predictive ecological modeling of harmful algal blooms. Human Ecological Risk Assessment, (in press).
- Walsh J.J., Haddad K.D., Dieterle, D.A., Weisberg, R.H., Li, Z., Yang, H., Muller-Karger, F.E., Heil, C.A., and Bissett, W.P., (2001). A numerical analysis of landfall of the 1979 red tide of *Karenia brevis* along the west coast of Florida. Continental Shelf Research, (in press).
- Bissett, W.P., Schofield, O., Mobley, C., Crowley, M.F., and Moline, M.A. (2000). In "Methods in Microbiology, Volume 30: Marine Microbiology" (J.H. Paul, ed), Optical Remote Sensing Techniques in Biological Oceanography. Academic Press, London. 519-540.
- Schofield, O., Grzyski, J., Bissett, W.P., Kirkpatrick, G., Millie, D.F., Moline, M., and Roesler, C.S. (1999). Optical monitoring and forecasting systems for harmful algal blooms: possibility or pipe dream? Journal of Phycology, 35, 1477-1496.
- Walsh, J.J., Dieterle, D.A., Muller-Karger, F.E., Bohrer, R., Bissett, W.P., Varela, R.J., Aparicio, R., Diaz, R., Thunell, R., Taylor, G.T., Scranton, M.I., Fanning, K.A., and Peltzer, E.T. (1999). Simulation of carbon-nitrogen cycling during spring upwelling in the Cariaco Basin. Journal of Geophysical Research 104, 7807-7825.
- Bissett, W. P., J. J. Walsh, D. A. Dieterle and K. L. Carder (1999) Carbon cycling in the upper waters of the Sargasso Sea: I. Numerical simulation of differential carbon and nitrogen fluxes. Deep-Sea Research, 46(2):205-269.
- Bissett, W. P., K. L. Carder, J. J. Walsh and D. A. Dieterle (1999) Carbon cycling in the upper waters of the Sargasso Sea: II. Numerical simulation of apparent and inherent optical properties. Deep-Sea Research, 46(2):271-317.
- Bissett, W. P., J. S. Patch, K. L. Carder and Z. Lee (1997) Pigment packaging and chlorophyll a-specific absorption in high-light oceanic waters. Limnology and Oceanography, 42(5): 961-968.

ADDENDUM – PROGRESS REPORT FOR EXPANSION AWARD

Deriving Nowcast/Forecast Techniques For Bioluminescence Potential In Monterey Bay

LONG-TERM GOALS

Bioluminescence is the biological response of a wide range of single and multi-cellular organisms to physical or biological stimulus. The Maximum Bioluminescence Potential (MBP) is a measure of the type and number of bioluminescent organisms in a given volume of water. Direct measurement or prediction of the ecological state (ecotone) of the marine environment may yield quantitative information on the MBP, as well as the 24-96 hour transport of a water mass's MBP.

OBJECTIVES

- 1) Develop methodology to “tag” a water mass’s MBP to hydrography and IOPs.
- 2) Predict bioluminescence upwelling radiance signal from a set of IOPs and the depth-dependent MBP.

APPROACH

This project is a small expansion award (1 year duration beginning in July 2000) to facilitate the analysis of bioluminescence and IOPs data collected during the MUSE experiment in August 2000 in Monterey Bay. Our participation in this project is based on our hypothesis that - 1) the background MBP of a water mass is a function of the ecological state, 2) convergent mechanisms may lead to biological and physical accumulations of bioluminescence material that cause the maximum potential to increase by orders of magnitude, 3) the ecotone, optical properties, and convergent mechanisms can be discerned from a combination of remote sensing and modeling, 4) short-term nowcast/forecast of the maximum bioluminescence potential and water-leaving radiance can be achieved with coupled model/data systems. Our goals during this project are mainly to test the feasibility of these hypotheses through data analysis and limited model development.

WORK COMPLETED

Our focus this year was to develop water-tagging techniques for the MUSE 2000 AUV data set. This data set included temperature, salinity, Optical BackScatter [OBS], fluorometry, and MBP. The calibrated data was provided to us at the end of July 2001. We chose to focus on August 29th and September 1st, day-of-year 242 (Figure 1) and 245, respectively. Our goal was to try and find a method by which we could relate the MPB of the field experiment to the hydrography being forecast by the NPS/NRL ICON physical modeling effort. Relating MPB to the temperature and salinity variables of ICON would allow us to forecast MBP as a conservative tracer of the water mass.

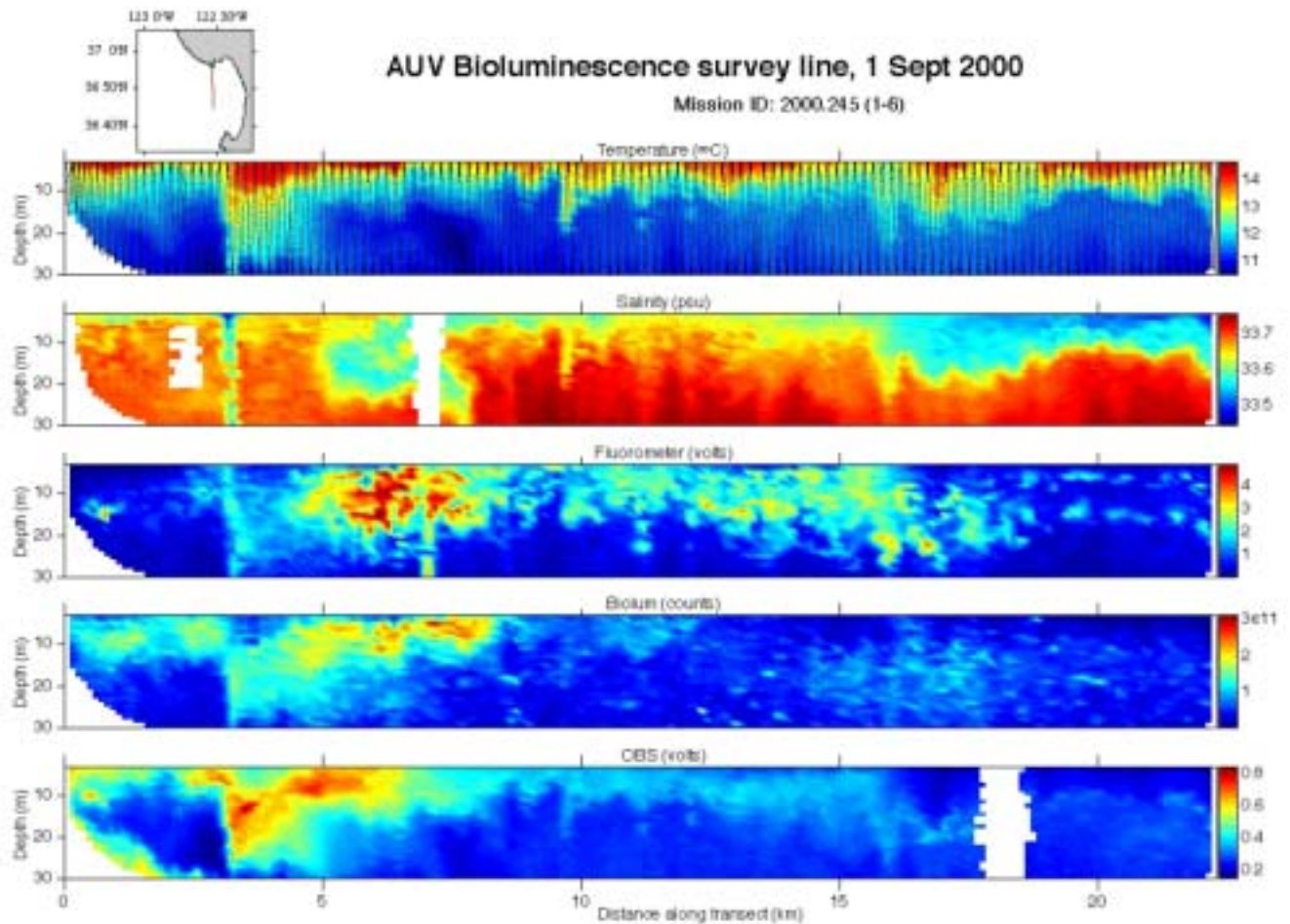


Figure 1. MUSE AUV data from the night of August 29, 2000.

RESULTS

It quickly became evident that temperature and salinity did not provide enough information to differentiate all of the water mass types shown in Figure 1. As a result there was not a way to effectively simulation the MBP as a function of temperature and salinity. We therefore decided to attempt a different methodology to discriminate between unique water masses. Figure 2 shows a schematic for cluster analysis, where information from additional data sets is added to those of temperature and salinity to further discriminate the water mass types. In this case, there are three dimensions with which to separate the water mass types, and the data are grouped according to their “nearness” to each other as measured by the Euclidian distance between each of the data points.

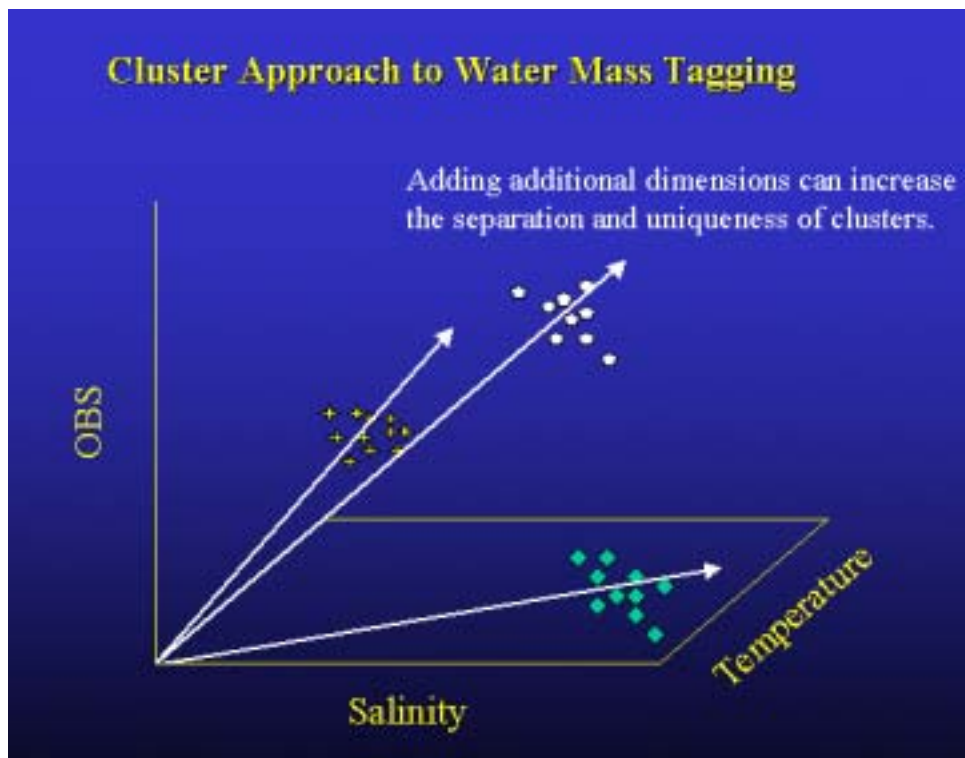


Figure 2. Schematic of Cluster Analysis of Oceanographic Field Data.

Once the groups are clustered, a centroid vector is calculated through the center of the cluster. This vector is then used to describe the entire cluster in further analysis. The AUV data actually contains five dimensions with which to discriminate the water masses. Figure 3 shows an example of such a cluster analysis. In this case, bioluminescence potential is used to help discriminate the water mass, and as such it is expected that some clusters should correspond quite well with the MBP from figure 1. Subsequent clustering without MBP still showed good agreement with the actual profiles (not shown). However, predicted MBP results from centroid vector analysis showed decreasing veracity with the elimination of each dimension. By the time the dimensionality was reduced to 2 (temperature and salinity), there was very little correspondence between actual and predicted MBP. Further work is necessary to transfer these techniques into a numerical simulation that will give a short-term forecast of MBP.

IMPACT/APPLICATION

A quantitative relationship between maximum bioluminescence potential and the ecological state of the marine environment would allow for the development of a MBP model as a function of measured or simulated hydrographic and remote sensing data. In addition, coupling the MBP with the IOPs of the water column would allow for the determination of detection risk potential as a function of water depth, as well as performance prediction modeling of BL detection sensors.

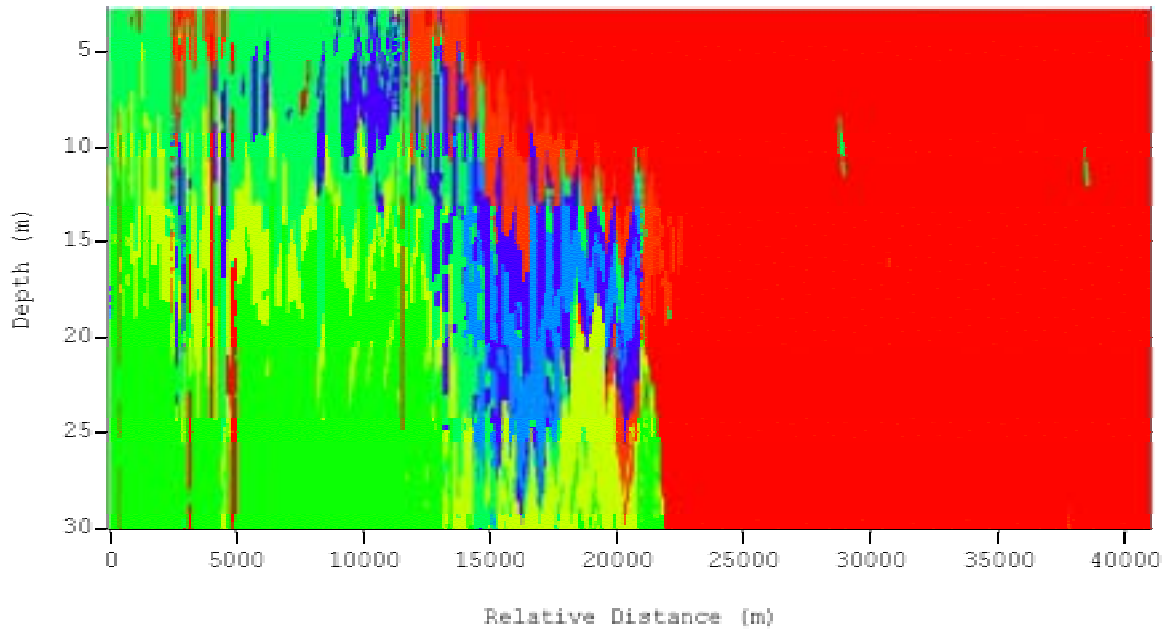


Figure 3. Results of Cluster Analysis of MUSE Data from day 242 and 245. The blue clusters assignments correspond to water masses with high bioluminescence potential. This shows reasonable agreement with panel 4 from Figure 1.