Hyperspectral Modeling of Harmful Algal Blooms on the West Florida Shelf

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SUMMARY

We hypothesized that the ecological interactions on the West Florida Shelf that yield the conditions favorable for a HAB formation were a set of deterministic functions of the supply of multiple limiting nutrients and spectral light to the autotrophic community. Further, these functions could be codified into a quantitative numerical model of phytoplankton competitive interactions, and with the right physical forcing, yield a simulation of *K. brevis* populations that approximated those measured during an ECOHAB field campaign. To be generally applicable over a wide range of environmental forcing conditions and therefore transportable to areas and times of limited validation data, the quantitative model would have to rely on limited parameter tuning.

This research effort has taken a one-dimensional open ocean ecological model of phytoplankton carbon and nitrogen dynamics and developed a two-dimensional coastal ecological model that resolves non-stoichiometric supply and use of multiple limiting nutrients of nitrogen, phosphorous, silica, and iron, as well as the use of spectral light by phytoplankton. By explicitly resolving these functions, this ecological model (EcoSim 2.0) is more generally applicable to a wider range of coastal and open ocean environmental conditions than models using less robust quantifications of light and nutrient dynamics. In addition, the simulation yields predicted IOPs and AOPs, which include water-leaving radiance, that allows for direct comparison of in situ and remote sensing optical measurements to direct closure between environmental forcing and resulting optical properties. Using this ecological model we have simulated the conditions that gave rise to a small red tide on the WFS in 1998 off the coast of Charlotte Harbor and have reproduced the measured concentrations of *K. brevis*, as well as the absorption from colored particulates and CDOM during this event.

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].

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Hyperspectral Modeling of Harmful Algal Blooms on the West Florida Shelf

SUMMARY

We hypothesized that the ecological interactions on the West Florida Shelf that yield the conditions favorable for a HAB formation were a set of deterministic functions of the supply of multiple limiting nutrients and spectral light to the autotrophic community. Further, these functions could be codified into a quantitative numerical model of phytoplankton competitive interactions, and with the right physical forcing, yield a simulation of *K. brevis* populations that approximated those measured during an ECOHAB field campaign. To be generally applicable over a wide range of environmental forcing conditions and therefore transportable to areas and times of limited validation data, the quantitative model would have to rely on limited parameter tuning.

This research effort has taken a one-dimensional open ocean ecological model of phytoplankton carbon and nitrogen dynamics and developed a two-dimensional coastal ecological model that resolves non-stoichiometric supply and use of multiple limiting nutrients of nitrogen, phosphorous, silica, and iron, as well as the use of spectral light by phytoplankton. By explicitly resolving these functions, this ecological model (EcoSim 2.0) is more generally applicable to a wider range of coastal and open ocean environmental conditions than models using less robust quantifications of light and nutrient dynamics. In addition, the simulation yields predicted IOPs and AOPs, which include water-leaving radiance, that allows for direct comparison of in situ and remote sensing optical measurements to direct closure between environmental forcing and resulting optical properties. Using this ecological model we have simulated the conditions that gave rise to a small red tide on the WFS in 1998 off the coast of Charlotte Harbor and have reproduced the measured concentrations of *K. brevis*, as well as the absorption from colored particulates and CDOM during this event.

(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 [DOP], Dissolved Organic Nitrogen [DON], Dissolved Inorganic Carbon [DIC], Dissolved Organic Carbon [DOC], chlorophyll, phaeopigments, PN, PC, PP, δ15N of PN and NO3, 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-1999

This past year has been focused in three areas. First, the establishment of the functional groups to be modeled; their ecological interactions and parameters; developing the methodology to simulating time-dependent changes in particle-specific absorption, scattering, and scattering phase function. Our second task was the collection of hyperspectral data and its analysis. Lastly, was the analysis of the optical properties of EcoSim 1.0 and the creation of simulated water leaving radiance values based on simulated IOPs.

Table 1. Competition parameters of functional groups of phytoplankton in relation to grazing stress effected by their predators, macrozooplankton (MZ) and protozoans (PN), during an annual cycle of thermal-modulated (15°C to 30°C) growth on the West Florida Shelf.

	Small diatom	Large diatom	*K. brevis*	Other dino-flagellate	Cocco-litho-phore	Flag-ellate	*Tricho-desmium*	*Synech-ococcus*
Diameter (μm)	8	50	25	25	6	2	10	0.8
w_s (m day^{-1})	[biomass]^2		Disperse and/or migrate		1.5	0.0	buoyant	0.0
μ_{max} (day^{-1} @ 10°C)	0.6	0.5	0.1	0.3	0.9	0.5	0.2	0.5
μ_{max} (day^{-1} @ 20°C)	1.2	1.0	0.2	0.6	1.9	0.9	0.4	1.0
M_{max} (day^{-1} @ 30°C)	2.4	2.0	0.4	1.2	0.6	1.8	0.8	2.0
I_{sat} (μE m^{-2} sec^{-1})	190	190	65	150	425	275	300	125
$K_{nitrate}$ (mmol m^{-3})	0.4	1.5	0.5	1.0	0.2	0.2	NA	0.2
$K_{ammonium}$ (mmol m^{-3})	0.8	1.0	0.5	0.9	0.1	0.2	NA	0.1
K_{DON} (mmol m^{-3})	NA	NA	0.1	0.2	NA	NA	NA	NA
$K_{phosphate}$ (mmol m^{-3})	0.4	0.4	0.2	0.2	0.4	0.6	2.0	2.0
K_{DOP} (μmol m^{-3})	NA	NA	10	10	NA	NA	10	NA
K_{iron} (μmol m^{-3})	0.1	0.3	0.2	0.2	0.05	0.04	1.0	0.03
$K_{silicate}$ (mmol m^{-3})	0.8	1.5	NA	NA	NA	NA	NA	NA
r_I (% μ_{max})	10	10	25	25	10	15	50	10
P_i (% MZ or PN)	60MZ	10MZ	1MZ	19MZ	60PN	90PN	10MZ	100PN
K_p (10^{-2} mg^{-1} Chl m^2)	4.8	2.3	3.5	4.8	4.8	5.7	4.8	6.5
C cell^{-1} (pg)	32	1750	300	450	18	6	200	0.06
C/chl (pg pg^{-1})	55	45	30	45	75	100	200	30

RESULTS-1999

The ecological parameters for the 7 groups of phytoplankton can be briefly seen in Table 1. These parameters are for the initial development of EcoSim–WFS, and represent the "Redfield" case, where the intracellular pools of organic constituents do not change as a function of light and nutrient conditions. These will be combined with the static cellular IOP description for each functional group. There are two reasons for static descriptions of the organic pools and particle specific-optical properties. First, it is a more numerically efficient coding scheme, and error propagation is more easily discerned in a large 3-D scheme. Second, the data for variations in intracellular stocks of C, N, P, Fe, and Si, as well as the complete IOP description as a function of growth rates and nutrient conditions do not presently exist. We are currently working with a number of research groups to obtain this data, and will incorporate it as it becomes available.

A sample of the results from the ECOHAB/NRL Spectral Signatures over-flights in October 1998 can be found in Figure 1. The over-flights occurred over a two-week period and coincided with a multi-ship field operation that collected ecological, hydrographical, and optical validation data. Figure 1 is a pseudo-RGB image of data taken at 10,000 feet over the Sunshine Skyway Bridge and was used as part of a vicarious calibration exercise. There were instrument calibration and data quality issues that are still being resolved, and it is unclear whether this data can be made useful. The Ocean PHILLS has undergone a refit since this experiment (see ONR COBOP program), and we may have to wait until the 2001/2002 over-flights to obtain usable data.

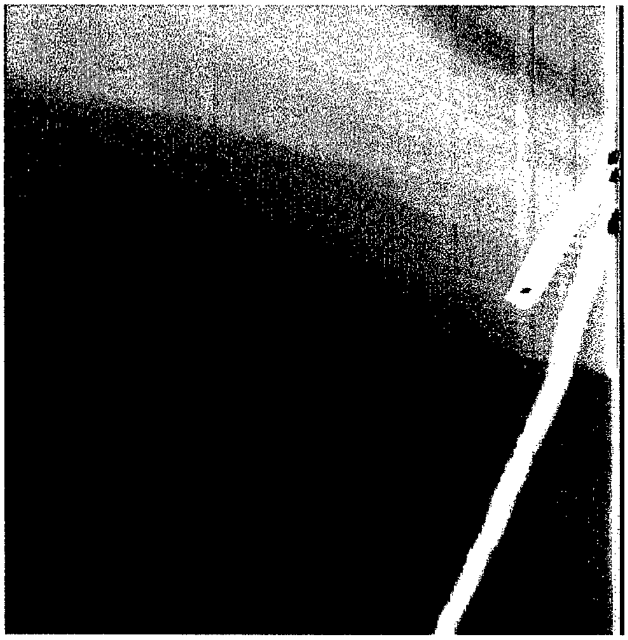

Figure 1. Ocean PHILLS Pseudo-RGB – Sunshine Skyway Bridge

Figure 2 shows a comparison of EcoSim 1.0 predicted chlorophyll a in the Sargasso Sea versus a compilation of the 6 years of CZCS data at the site folded into a single year time-series CZCS. The first 2 lines were published in 1999 [Bissett et al., 1999, Deep-Sea Research, V42:271-317]. The third line is the output from a SeaWiFS algorithm [Carder et al., 1998, Journal of Geophysical Research, MODIS Special Issue] that uses $R_{rs}(\lambda)$ at 412, 443, 490, 510, 555, 670 to estimate the chlorophyll a concentration. EcoSim $R_{rs}(\lambda)$ was calculated with a modified version of Hydrolight 3.0 that ingested the predicted IOPs from the daily output of EcoSim 1.0 to yield daily above-water reflectance values (as well as, depth-dependent AOPs). The major discrepancy is in the summer when the SeaWiFS chlorophyll a is much higher than EcoSim and CZCS. This result is expected since the IOPs in EcoSim 1.0 utilized 'Smith and Baker, 1981' absorption values for "pure" seawater. These pure water absorption values have been shown to be too high in the blue [Pope, 1993, Ph.D. Dissertation, Texas A&M University, College Station]. The SeaWiFS uses more accurate values for pure water absorption. The differences between the 'Smith and Baker' and the Pope absorption values is most noticeable during the summer when CDOM absorption is nearly non-existent in these waters. The SeaWiFS algorithm-estimated chlorophyll a is probably impacted by the erroneously high absorption values from EcoSim in the blue. The pure water absorption issue will be rectified in EcoSim 2.0.

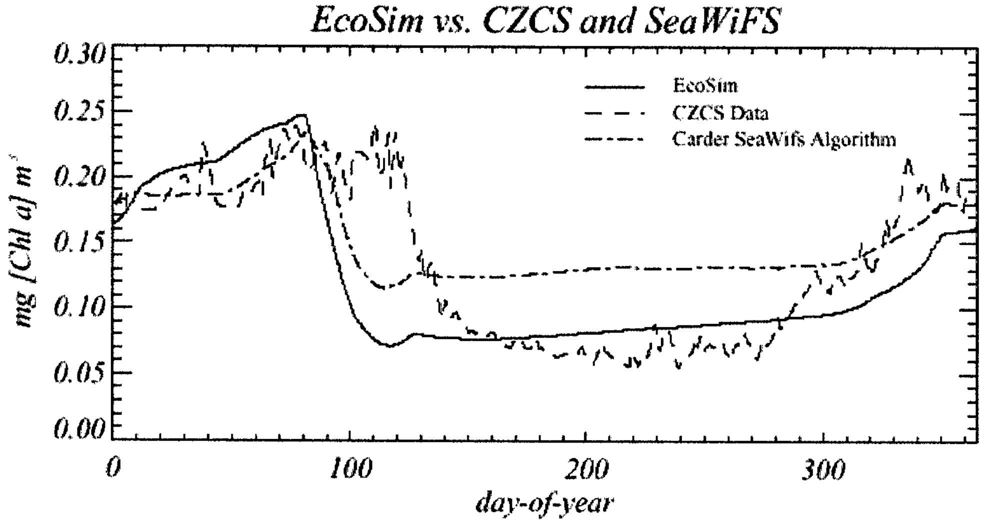

Figure 2. Comparisons of EcoSim with CZCS data and Rrs-derived chlorophyll. The EcoSim line is predicted surface water chlorophyll a concentration using a seasonally-forced 1-D physical model in the Sargasso Sea. The CZCS line represents a six year time-series of pigment estimates folded into a single year time-series. The Carder SeaWiFS algorithm line represents calculated chlorophyll a from $R_{rs}(\lambda)$. This wavelength dependent reflectance was calculated from EcoSim predicted IOPs and Hydrolight 3.0 for every day of the year (365 independent runs to 150 m).

WORK COMPLETED-2000

It became rapidly clear that phytoplankton competition for nutrient resources on the WFS extended beyond the earlier EcoSim 1.0 assumption of nitrogen limitation in the forms of nitrate and ammonium. In fact, it appears that phytoplankton on the WFS compete for inorganic and organic nutrient supplies in the form of nitrate, ammonium, phosphate, silicate, iron, dissolved organic nitrogen, and dissolved organic phosphate in ways that suggest varying stoichiometries in the source supply and phytoplankton uptake of these nutrients. These interactions are shown graphically in Figure 4. Based on the competing needs of solving the computational ecological problems of multiple limiting resources and three-dimensional circulation modeling, Dr. J. J. Walsh and I have decided to split the tasks in order to best utilize experience and resources. Dr. J. J. Walsh, USF, will focus on three-dimensional aspects of the phytoplankton ecological dynamics using a fixed stoichiometric model based on Table 1, and Dr. W. P. Bissett, FERI, will develop the non-stoichiometric and hyperspectral optical code in a two-dimensional framework. The three-dimensional circulation model will be coupled to EcoSim 2.0 code once their individual development is complete.

One of the reasons for the relative success of EcoSim 1.0 was in the complexity of the nutrient uptake equations that allow for the non-stoichiometric assimilation of nitrogen and carbon. The expansions of these equations to 7 functional groups competing on 8 forms of nutrient sources required a significant amount of model coding, testing, and evaluation. In addition, the collection and analysis of the initialization and validation data also required a tremendous amount of time and effort. However, we were successful this year in completing the 2-dimensional description of the EcoHAB study site. The phytoplankton uptake and growth equations now allow for differential uptake and non-Redfield storage of nitrogen, phosphorous, silica, and iron. In addition, each functional group has a unique set of light

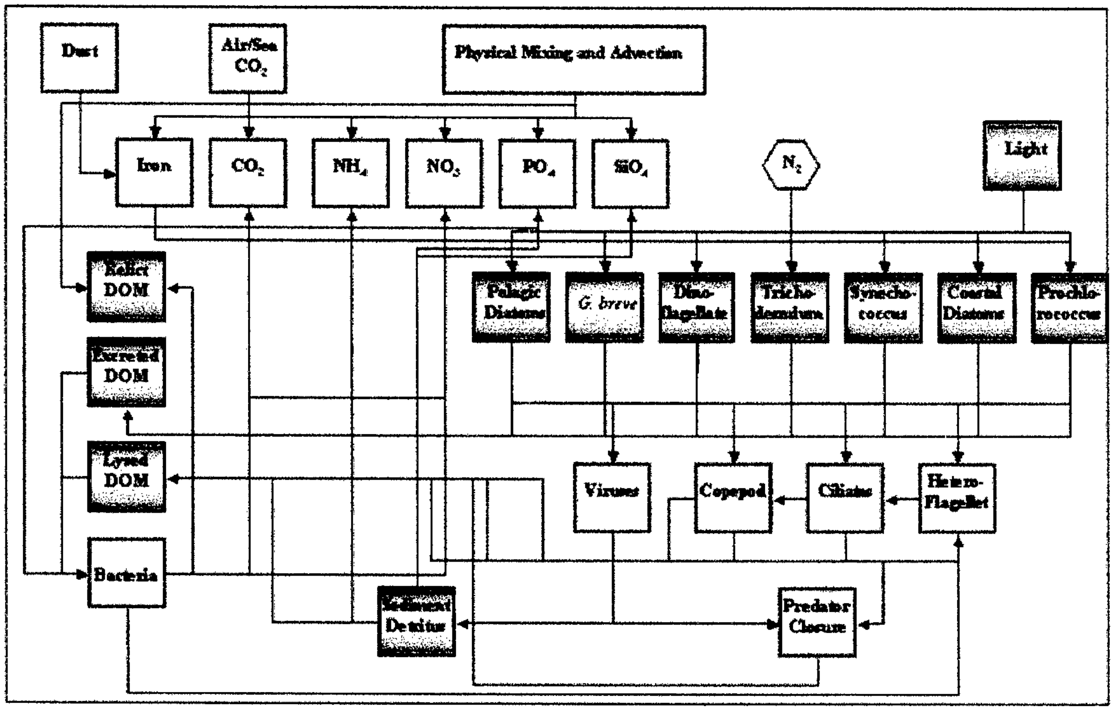

Figure 4. Schematic of light and nutrient interactions in EcoSim 2.0.

harvesting pigments, which vary as a function of nutrient and light history, as well as growth rate. A circulation model developed by D. Dieterle at USF physically drives the 2-d representation. The physics were formulated as a diagnostic model, and the velocity field was forced to adjust to a prescribed density field. Hydrostatic and Boussinesq approximations were invoked, and linear dynamics were assumed outside the non-linear bottom stress formulation. A complete description of the ecological and physical model will be found in a forthcoming manuscript (Readers of this report should check the above web site for a preprint of the completed manuscript). This 2-dimensional representation focuses on the year 1998, as there was an extensive NRL optical field program in addition to the regular EcoHAB surveys (see - http://www7240.nrlssc.navy.mil/ocolor/ and select TB98 for details).

RESULTS-2000

An example of the phytoplankton results can be seen in the functional group chlorophyll a profiles (Figure 5) in November. These profiles represent the phytoplankton response to a nutrient injection from a Loop Current intrusion at the shelf break. In this case, the supply of nutrients is near Redfield proportions and the chlorophyll accumulation is dominated by the diatom species. This is as expected, as these functional groups are the fastest growing when supplied with adequate light (Figure 6) and nutrients. These results appear to accurately simulate the normal oligotrophic conditions, with episodic inorganic nutrient from the shelf break.

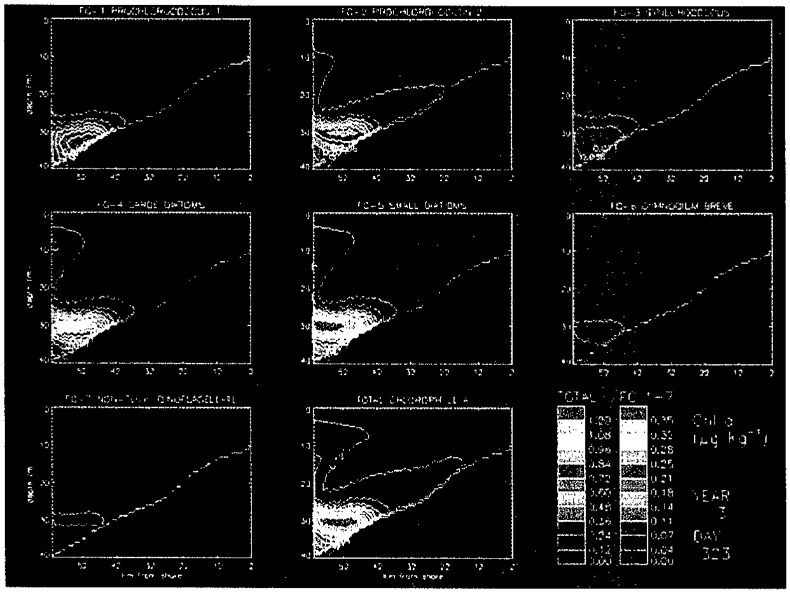

Figure 5. Simulated functional group chlorophyll a for November 1998.

November 1998 was also the year of a small bloom *K. brevis* near the mouth of Charlotte Harbor (~10^5 cells per liter). This bloom was in waters > 10 meters in depth, and appears to be driven by DON fluxes from the estuary. The outflows of high DON waters were the result of fresh water runoff from the passage of two hurricanes during the previous 6 weeks. We will add shoreward boundary conditions during 2001 to address the influx of nutrients, organics, and optical constituents onto the WFS.

WORK COMPLETED-2001

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.

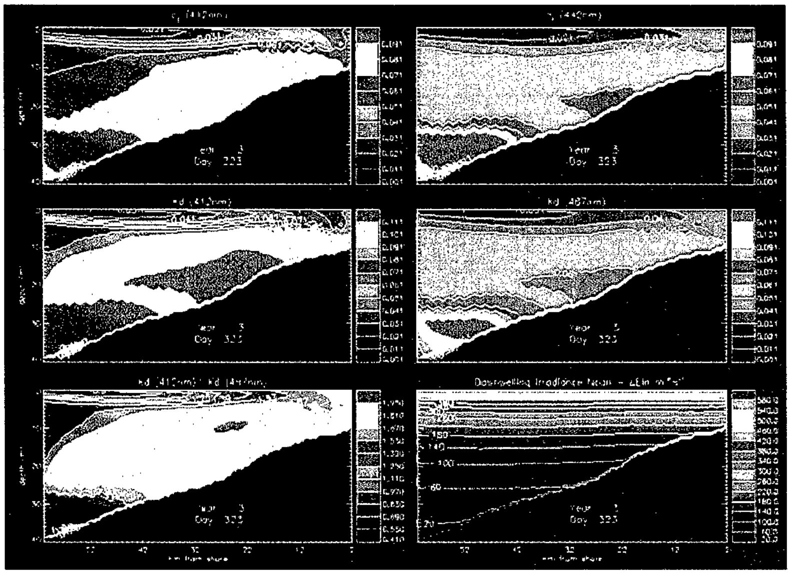

Figure 6. Representative IOPs and AOPs for simulated November 1998 on the WFS; top panels) total absorption at 412 and 442 nm, middle panels) diffuse attenuation coefficient [Kd] at 412 and 487 nm, and bottom panels) Kd(412):Kd(487) ratio and total downwelling irradiance.

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 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 though 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 Michalis-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.

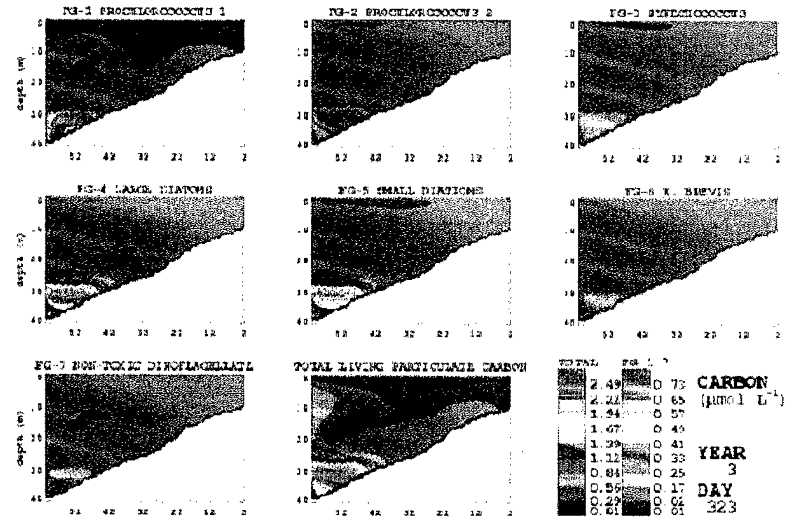

Figure 7. EcoSim 2.0 Functional Group results on day-of-year 323 of 1998. Note lack of shoreward phytoplankton populations.

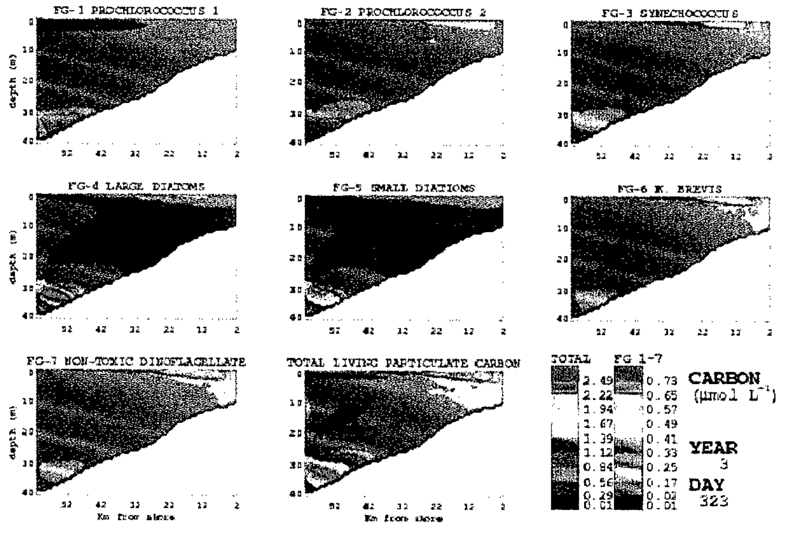

Figure 8. EcoSim 2.0 Functional Group results on day-of-year 323 of 1998 with open shoreward boundary conditions on day-of-year 267 and 309. Note the increase in phytoplankton populations near the coast, dominated by dinoflagellates. Actual numbers of K. brevis from cell counts made during ECOHAB Process cruises match those simulated.

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-2001

Figures 7 and 8 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 modify 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 9 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

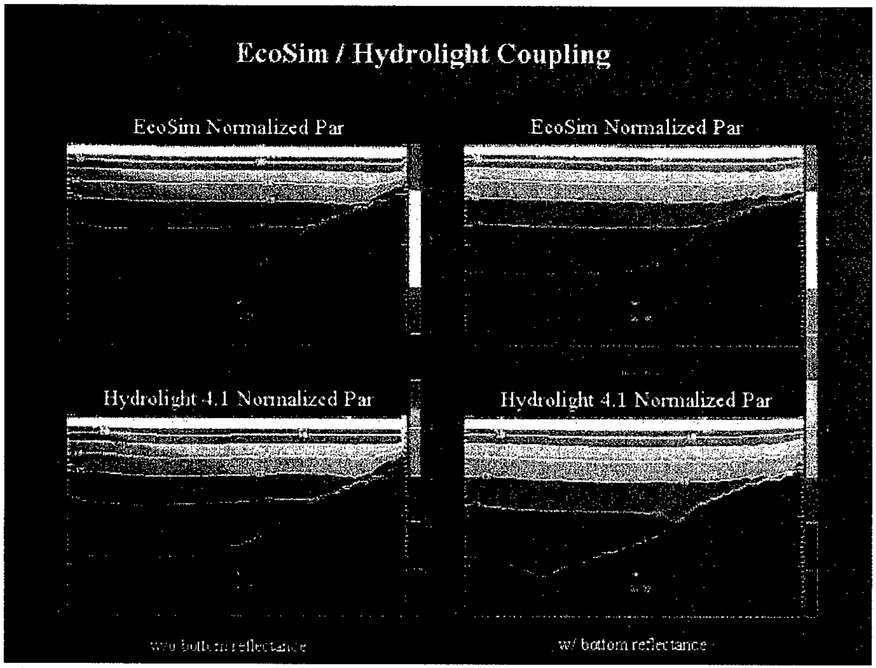

Figure 9. EcoSim 2.0 AOP predictions versus Hydrolight 4.1 predictions using the same EcoSim-predicted IOPs. Left panel demonstrates the small differences between EcoSim and Hydrolight when bottom reflectance is ignored. Right panel shows the impact of bottom reflectance in these optically clear waters. Differences appear to be as high as 10-15% for waters greater than 10 m in depth.

clear waters are typically nutrient limited not light limited. Hence their competitive interactions are driven by nutrient dynamics rather than available photons.

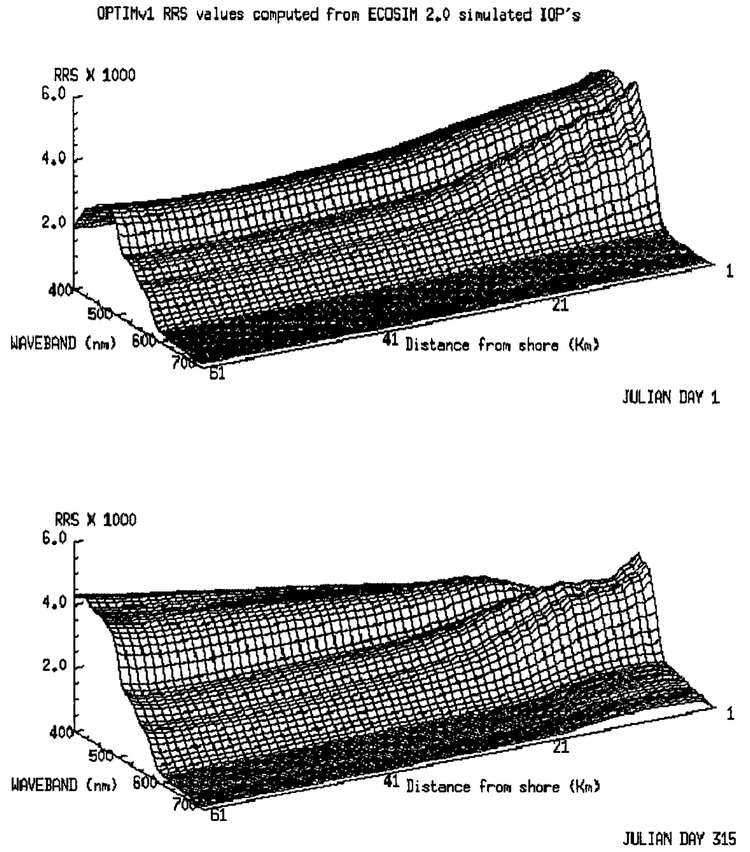

Figure 10. Predicted Remote Sensing Reflectance (Rrs) as a function of wavelength and distance offshore from EcoSim 2.0 simulation of the WFS in 1998. Upper panel is from the day-of-year 1. Lower panel is from day- of- year 315. There is a large surface bloom of phytoplankton on day 315 near the shore resulting from estuarine outflows following Hurricane Mitch in 1998.

The simulated IOPs from the WFS were output every 3 days and yield over 7000 one-dimensional depth-dependent profiles of absorption and scattering. A variant of Hydrolight 4.1 (OPTIMv1) was used to generate a water leaving radiance solution for each of these profiles. The water leaving radiance values were solved for at local 10:30 am each simulated day, using RATRAN to derive the input solar irradiance field. These runs are at a spectral resolution of 60 wavebands between 400 and 700 nm (d_lambda=5 nm), yielding over 420,000 simulated R_{rs} values. Figure 10 shows the spectral R_{rs} plots as a function of wavelength and transect position across the shelf for day-of-year 1 and 315. On day 1 there is very little absorption and scattering from optical constituents in the water, and the rise in spectral Rrs results mainly from bottom reflectance. However on day 315 there is a large population of phytoplankton in the surface waters resulting from an estuarine outflow following Hurricane Mitch. This population was dominated by dinoflagellates, some of which were the toxic *Karenia brevis*.

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. The ability to predict water-leaving radiance directly (as opposed to derived product fields of chlorophyll and CDOM) will better constrain our ecological simulations. Explicit simulation of the optical properties allows for the direct initialization and validation of this model by a large number of in situ and remote sensing optical instruments that should minimize the need for direct field measurements to constrain the simulated results. For Naval applications, this optical simulation will also provide the IOPs necessary for active sensor performance prediction modeling and diver visibility modeling.

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.

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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) Develop methodology to 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 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.

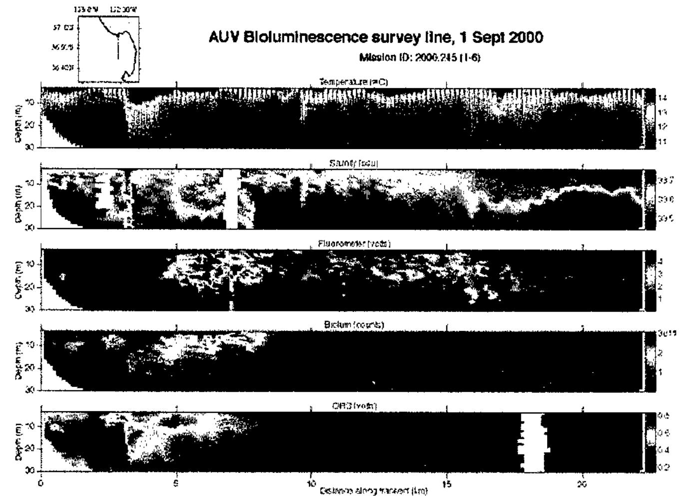

Figure A.1. MUSE AUV data from the night of August 29, 2000.

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 A.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 A.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.

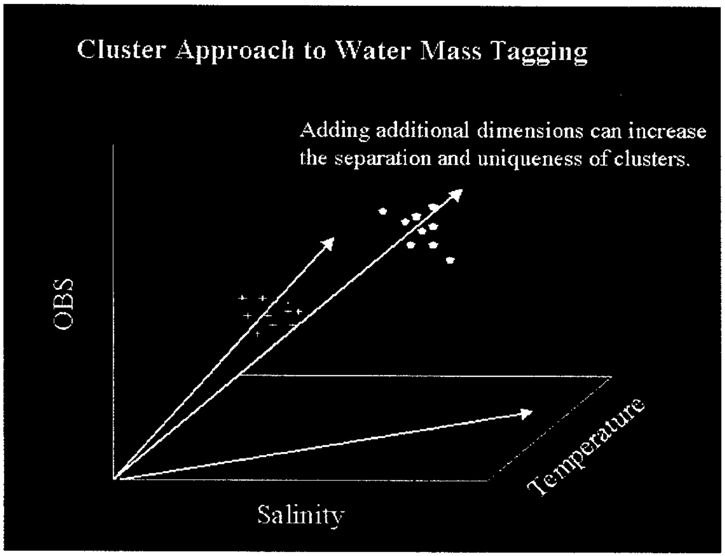

Figure 2. Schematic of Cluster Analysis of Oceanographic Field Data.

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 A.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 A.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.

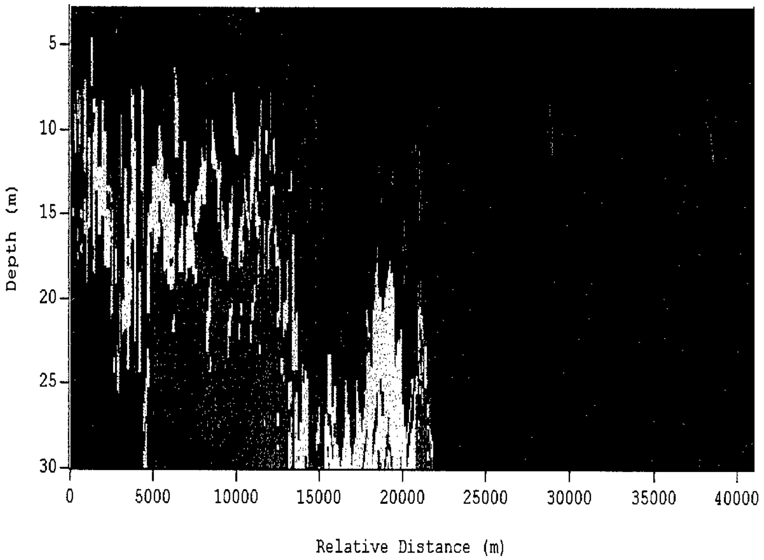

Figure A.3. Results of Cluster Analysis of MUSE Data from day 242 and 245. The blue clusters assignments correspond to water masses with high bioluminescence potential. This shows reasonable agreement with panel 4 from Figure A.1.

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.