Hyperspectral Remote Sensing Of The Coastal Ocean: Adaptive Sampling And Forecasting Of Nearshore In Situ Optical Properties

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LONG-TERM GOAL

In collaboration with Institute of Marine and Coastal Sciences faculty at Rutgers University, we propose to develop and validate an integrated adaptive sampling and modeling system for nowcasting and forecasting the 3-dimensional evolution of inherent optical properties (IOPs) in coastal waters. This will be accomplished by developing an integrated observation network providing real-time data allowing for adaptive sampling in nearshore coastal waters. The data will also be used to develop hyperspectral remote sensing techniques for optically complex coastal waters while also providing biological/optical data for coupled data assimilative hydrodynamic ecosystem models currently under development.

OBJECTIVES

The primary objectives are to 1) develop and deploy moored, shipboard, and autonomous bio-optical systems in the coastal ocean to ground-truth remote sensing imagery, 2) quantify the physical, chemical and biological processes that define the spatial and temporal variability in the spectral IOPs and spectral leaving radiance for the nearshore coastal ocean during summer-time upwelling, 3) refine and calibrate existing hyperspectral optical models to derive IOPs from remotely sensed data using the above datasets and, 4) in collaboration with other principal investigators couple a radiative transfer ecosystem module to the data-assimilative hydrodynamic model.

APPROACH

We are conducting a series of Coastal Predictive Skill Experiments (CPSE) each summer at the Long-term Ecosystem Observatory (LEO-15) offshore Tuckerton, NJ. In support of the modeling effort by Rutgers, data collected from the observation network during the summer are compared with model outputs. Results from these studies are then used to make improvements in an operational setting for the following summer. Our phenomenological focus is on the recurrent upwelling centers that form along the southern New Jersey coast and their impact on phytoplankton distributions, colored dissolve material, sediment resuspension, in-water optical properties and dissolved oxygen. The recurrent nature of the upwelling provides a natural testbed for large fluctuations in physical/biological/optical parameters within a definable area. Coordinated shipboard (physical and bio-optical) and multiple AUV adaptive sampling surveys of the upwelling centers were conducted based on the real-time observations and the model forecasts. The 1999 CPSE represented a multi-institution effort funded by ONR through the Hyperspectral Coupled Ocean Dynamic Experiment (HyCODE), the Coastal Ocean Modeling and Observation Program (COMOP), and the two awards from the National Ocean Partnership Program. There were 14 major partners during the 1999 experiment.

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WORK COMPLETED

One focus in 1999 was expanding the optical instrumentation in the existing Long-term Ecosystem Observatory (LEO-15) in order to collect optical data on scales commensurate with the physical observation systems. The existing infrastructure at LEO-15 used during the 1999 CPSE included, real-time remote sensing (satellites and surface current radar), two autonomous robotic profilers (measuring conductivity-temperature, fluorometery, optical backscatter, and currents), several different classes of AUV vehicles (measuring conductivity-temperature, currents, optical backscatter, turbulence, and bioluminescence), shipboard systems (undulating systems for measuring conductivity-temperature-fluorometry, towed system to measure currents, and a bio-optics package for measuring spectral fluorescence absorption/attenuation, and radiometry). A third bio-optical profiling node was constructed and deployed during the 1999 CPSE. The node was outfitted with an absorption/attenuation meter (ac-9), a spectral backscatter sensor/fluorometer (HS-2), a fast repetition rate fluorometer (FRR), and a laser particle sizer (LISST). Shipboard systems were expanded by adding a spectral backscatter sensor/fluorometer (HS-6, Figure 1), a tethered hyperspectral radiometer buoy (TRSB), a laser particle sizer (LISST), and CTD. Communication between ship to shore and between ships were made in real-time by the addition of H/F radio modems to LEO allowing for adaptive sampling of nearshore hydrographic/features. In collaboration with WHOI and UCSB, bioluminescence sensors were integrated in a Remote Environmental Monitoring Underwater Survey system (REMUS) and their utility was demonstrated from ships and AUVs (Figure 2). The recent addition of 2 hyperspectral radiometers for mooring and shipboard deployments will further enhance the observational network for the CPSE 2000 summer experiments.

The 1999 CPSE experiment was a success with all components of the observation system working well. The 28 day experiment consisted of physical/optical ship surveys (up to four ships on a single day), multiple flights of AUVs, and repetitive profiling of the autonomous nodes. The optical survey vessel logged 23 missions and in addition to the *in situ* optical data, collected over 700 discrete samples for laboratory analyses. The samples are being analyzed for filter pad absorption spectra, fluorescence excitation-emission spectra, phytoplankton pigmentation (via HPLC), and nutrients. Pigment standards were provided by collaboration with Hofmann-LaRoche Pharmasuticals. A smaller proportion of these samples are being analyzed for particulate organic carbon, suspended particulate matter, and microscopic phytoplankton taxonomy. Backscatter data was collected in concert with an ac-9 and radiometry data and will facilitate optical closure exercises using Hydrolight 4.0. During a 60 hour experiment the optical profiler was used to define the importance of tides on the variability of *in situ* inherent optical properties. The optical profiler was mounted next to diver visibility targets, which was videotaped by an underwater camera during the experiment. This data set will be used to assess the veracity of Naval swimmer visibility algorithms using IOP data as inputs. Data processing is rapidly approaching completion and will soon be uploaded into Rutgers Open Data Access Network (RODAN) and ONR's global optical database (in collaboration with Dr. Smart, NRL).

RESULTS

Summertime southerly wind events results in the coastal upwelling that as the winds subside evolve into recurrent upwelling centers with enhanced optical loads. The optical signals can be dominated by inorganic particles during the earliest phases of the upwelling cycle, but particulate organic carbon (POC) rapidly becomes the dominant optical constituent. The POC is correlated with the diatom marker pigment of fucoxanthin. During the 1999 CPSE experiments, cross-shelf transects revealed subsurface southward flowing jets that contained high concentrations of phytoplankton. The IOPs were coherent with local currents emphasizing the importance of advective processes. The upwelling did not mature until late in the 1999 summer CPSE that allowed efforts to focus on the source water of the upwelling. The source water appears to originate from the around 20 km north of LEO-15 study area and had spectral signatures that were distinct from offshore waters. The cold water near the coast then flows southward until it encounters a topographic high in the bottom bathmetry just to the south of LEO. Transported material in the coastal jets accumulates leading to the enhanced remote sensing reflectance (Figure 1). *In situ* measurements of the inherent optical properties agree well with satellite-derived estimates of the inherent optical properties using the newest generation of ocean color algorithms from NRL (Figure 1).

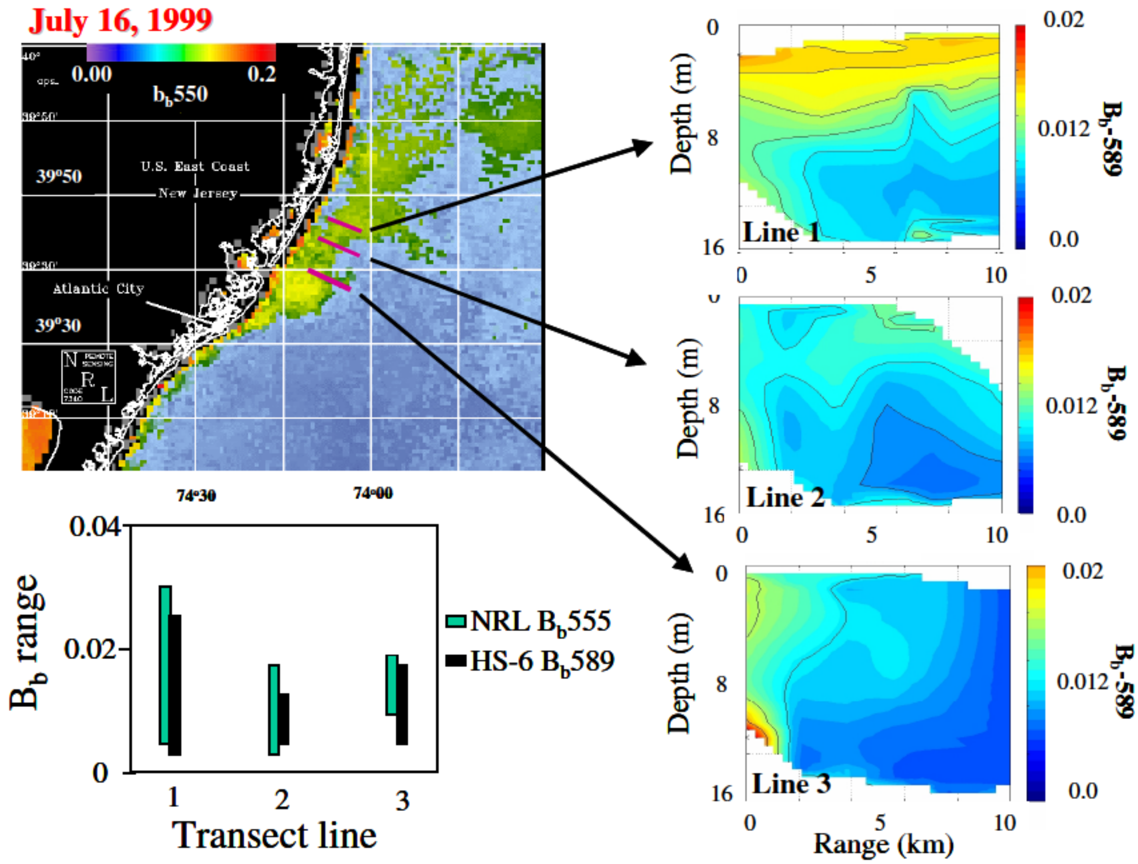

Figure 1. Coherence between measured in situ light backscatter (at 589 nm) and backscatter estimated using ocean color imagery and NRL's remote sensing algorithms.

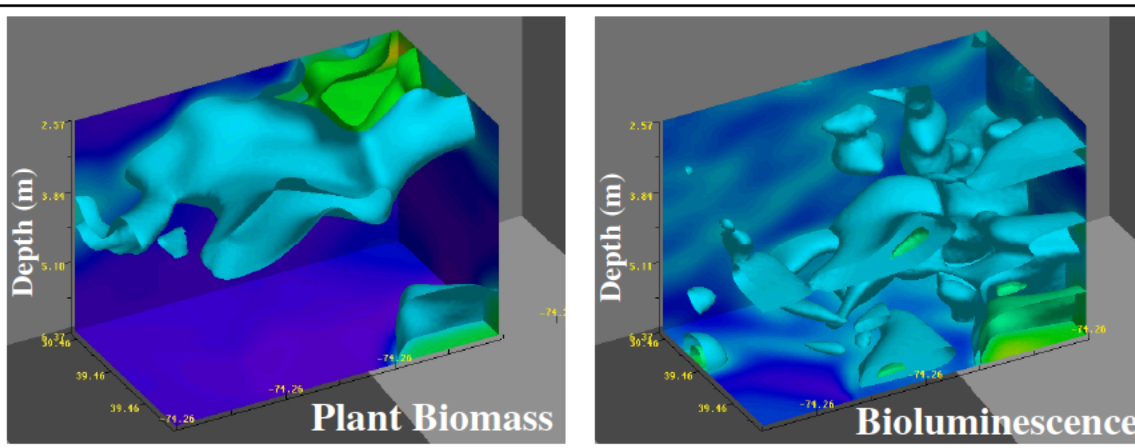

Figure 2. Volume rendering of fluorescence (left) and bioluminescence potential (right) obtained from a REMUS deployment at LEO-15 in July 1999. The fluorescence isosurfaces are 380 (light blue) and 961 (green) voltage units. Bioluminescence isosurfaces are rendered at $5x10^{10}$ (light blue) and $1.1x10^{11}$ (green) photons/sec/L. The LxWxH axis are Longitude (~300m), Latitude (~150m) and Depth (2-7 meters). For orientation, east is to the right and north is into the page. Data cubes are rendered using kriging interpolation techniques.

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IMPACT/APPLICATION

1) There were a total of 13 Abstracts related to the summer LEO efforts presented at the ASLO conference in Santa Fe. Additionally, a total of 20 Abstracts related to the summer 1999 experiment have been submitted to the February ASLO/AGU conference in San Antonio. 2) Methods for real-time communication of shipboard towed data allowed for adaptive sampling of small-scale features critical to validating newly developed ocean algorithms by NRL. 4) An autonomonous bio-optical robotic node was developed, deployed, and tested during the 1999 CPSE. 2) Results and HyCODE lead to the success of two grants recently awarded to Dr. Moline (see below). The first project is a collaborative research project with Dr. Case (UCSB) to fabricate a real-time profiling bioluminescence instrument to examine bioluminescence dynamics in the coastal waters off New Jersey. The addition of this instrument will allow for continuous vertical profiling of bioluminscence over a long-term deployment. Bioluminescence data will also be retrieved in conjunction with fluorometric measurements, making it possible to determine the trophic nature of the particulate material impacting the optical signatures (see Figure 2). 3) The second recently funded project is a NASA NIP award. The objectives of this study directly relate to the HyCODE program goals. NIP program objectives are focused on adaptive sampling of phytoplankton community structure, productivity and growth rates within convergence zones present in recurrent upwelling eddies within the Mid-Atlantic Bight. A UV/VIS spectrophotometer with integrating sphere has been purchased on this grant which will be used to measure filter pad absorption spectra and DOM spectra. 4) A new collaboration between Dr. Moline and Roche Vitamins Inc. (a subsidiary of Hofmann-LaRoche Pharmasuticals Inc.) has been developed, whereby Roche is providing pigment standards to Dr. Moline's laboratory for resolving phytoplankton pigments and phytoplankton community composition. This directly benefits the HyCODE program

TRANSITIONS

Optical approaches and HyCODE hydroscatt instrumentation are being used in the NSF-NOAA EEGLE program, which, in part, is focused on sediment-dominated turbidity plumes in nearshore coastal environments.

RELATED PROJECTS

ONR – "Hyperspectral remote sensing of the coastal ocean: adaptive sampling and forecasting of nearshore in situ optical properties". Leo-15 HyCODE efforts during the 1999 CPSE experiment were N000149910196 (Drs. Schofield, Glenn and Haidvogel), N000149910199 (Dr. von Alt), N000149910198 (Dr. Bissett) (see Table 1)

NASA – "Adaptive sampling of phytoplankton responses to episodic physical forcing in the nearshore coastal ocean: Characterizing the significance of convergences in upwelling eddies." This award will extend from 1999 to the summer of 2002.

ONR – "High resolution temporal sampling of the nearshore vertical structure of bioluminescence." This award will extend from 1999 to the summer of 2001.

PUBLICATIONS

Schofield, O., Gryzmski, J., Bissett, P., Kirkpatrick, G., Millie, D. F., Moline, M. A. Roesler, C. 1999. Optical monitoring and forecasting systems for harmful algal blooms: Possibility or pipedream? Journal of Phycology. 35: (In press)

Kirkpatrick, G., Millie, D. F., Moline, M. A., Schofield, O. 2000. Absorption-based discrimination of phytoplankton species in naturally mixed populations. Limnology and Oceanography (In press)

Moline, O., Schofield, O., Gryzmski, J. 2000. Impact of dynamic light and nutrient environments on phytoplankton communities in the coastal ocean. In Dynamic Modeling. Springer Verlag (In press)

Schofield, O., Frazer, T., Kirkpatrick, G., Millie, D. F., Moline, M. A. 2000. Using in situ fluorescence to assess chlorophyll a, colored dissolved organic matter and phycobilin-containing microalgae. Continental Shelf Research (submitted)