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

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LONG-TERM GOAL

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 physical/optical data for coupled data assimilative hydrodynamic ecosystem models currently under development.

OBJECTIVES

Our 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 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. Model and observation network

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improvements tested each winter with existing data are used in an operational setting 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, in-water optical properties and dissolved oxygen. 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 over 14 major partners during the 1999 experiment.

Key individuals, affiliations and roles		
Oscar Schofield	Rutgers	Bio-optical Observations
Scott Glenn	Rutgers	Physical Observations
Dale Haidvogel	Rutgers	Ocean Modeling
Roni Avissar	Rutgers	Atmospheric Modeling
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Mark Moline	Cal-Poly	Phytoplankton Biology
Doug Webb	Webb Research	Coastal Electric Glider
Don Barrick	CODAR Ocean Sensors	CODAR
Bob Rhodes	NRL	MODAS
Allan Wiedemann	NRL	*In situ* Optics
Bob Arnone	NRL	Ocean Color Algorithms
Ed Levine	NUWC	Turbulence REMUS AUV
Paul Bissett	FERI	Radiative Transfer Modeling
Jim Case	UCSB	Bioluminscence

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 (see http://marine.rutgers.edu/cool) was fully utilized during the 1999 CPSE. 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 fast repetition rate fluorometer (FRR), and a laser particle sizer (LISST). Shipboard systems (existing systems were ac-9/Satlantic radiometer/Safire) were expanded to provide satellite validation (Figure 1) by adding a spectral backscatter sensor (HS-6), a tethered hyperspectral radiometer buoy (TRSB), a laser particle sizer (LISST), and CTD. Communication between ship to shore and between ships was made in real-time by the addition of H/F radio modems to LEO allowing for adaptive sampling of nearshore hydrographic/features. Currently a Remote Environmental Monitoring Underwater Survey system (REMUS) with a 7 wavelength spectral radiometer and fluorometer is under development. In collaboration with WHOI and UCSB, bioluminescence sensors were integrated and their utility was demonstrated from ships and AUVs (Figure 2).

The 1999 CPS 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 physical survey vessel logged 17 missions and provided real-time high quality data via Freewave modem to the bio-optical survey vessel for adaptive sampling strategies. 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. A smaller proportion of these samples are being analyzed for particulate organic carbon, suspended particulate matter, and phytoplankton taxonomy. Shipboard efforts were supported by numerous AUV operations supported by ONR's COMOP program (see below). 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). Apparent and inherent optical properties are spectrally correlated and optical closure between the IOP and AOPs appears to be achieved reasonably well (within a few percent) at depths greater the 1.5 meters using Hydrolight 4.0. Agreement is currently less robust in surface waters (10-40% mismatch).

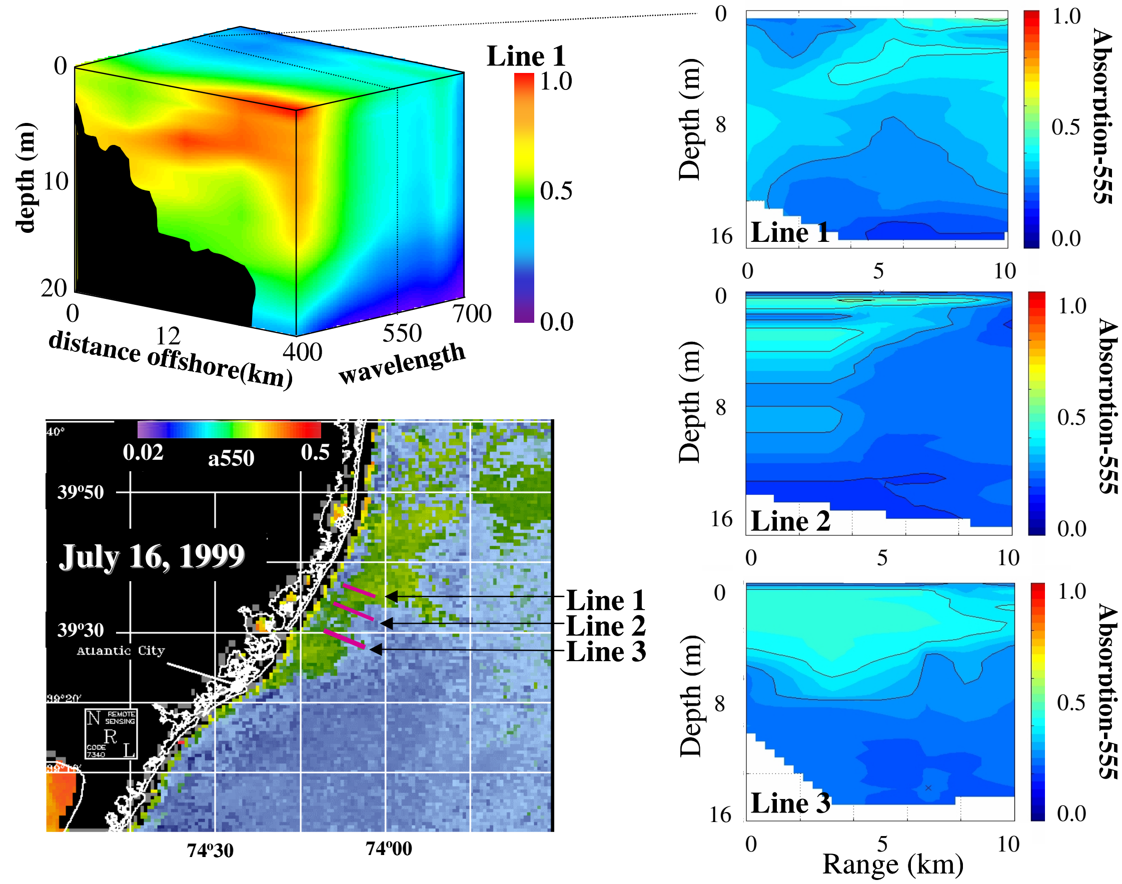

Figure 1. Comparison of in situ ac-9 measurements with estimates for ocean color remote sensing for absorption on July 16, 1999 at LEO-15.

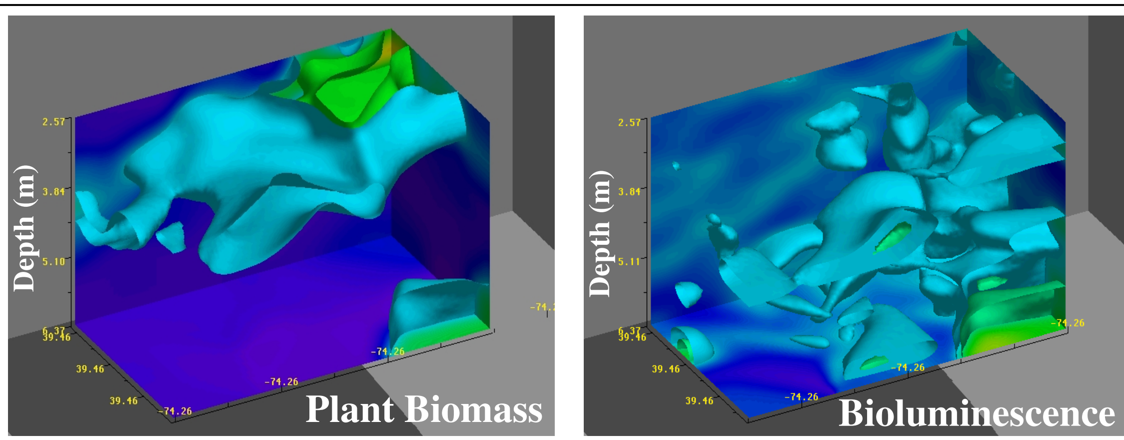

Figure 2. Volume rendering of fluorescence (left) and bioluminescence potential (right) obtained from a REMUS deployment at LEO-15 in July 1999. The fluorescence isosurfaces are 380 (light blue) and 961 (green) voltage units. Bioluminescence isosurfaces are rendered at $5x10^{10}$ (light blue) and $1.1x10^{11}$ (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.

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. By invitation from the National Academy of Sciences to the Japanese-American Frontiers of Science Symposium, CPSE results were presented in Tsukuba, Japan. 2) The rapid environmental assessment capability of LEO provided spatially extensive updates of the physics, chemistry and biology on time scales of an hour or better. In this well-sampled ocean ensemble model forecasts with differing model parameterizations can be used to identify regions in which additional data can be used to keep a model on track. 3) 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.

TRANSITIONS

1) Optical approaches being developed are now being used in the NSF-NOAA EEGLE program, which, in part, is focused on sediment-dominated turbidity plumes in nearshore coastal environments. 2) The datasets collected by the CPSE are displayed on our World Wide Web pages in near-real time. During the summer our Web access peaked at 33,000 hits per day, with a hit defined here as a mouse click on any of our pages. Over 90% of these hits were through commercial Internet access providers not associated with Rutgers. 3) The RODAN system is being used as a data management template for other HyCODE validation sites. 4) Our optical techniques and infrastructure are central to a Phase I and Phase II NOAA SBIR awarded to Poulos Technologies Inc. to develop microspectrograph-based radiometer/fluorometers

RELATED PROJECTS

The other LEO-15 HyCode efforts during the 1999 CPSE experiment were N000149910197 (Dr. Moline), N000149910199 (Dr. von Alt), N000149910198 (Dr. Bissett), N0001499C0021 (Dr. Agrawal) (see Table 1). Furthermore significant support to develop the optical infrastructure was provided by National Undersea Research Program (NURP). Data assimilative modeling and adaptive sampling aspects of this program directly collaborated with the ONR-sponsored "Coastal Ocean Modeling and Observation Program: Real-Time Adaptive Sampling" (N00014-97-0767). Ocean-atmosphere coupled modeling benefited from the National Ocean Partnership Program (NOPP) "Demonstration of a Relocatable Regional Ocean Atmosphere Modeling System with Coastal Autonomous Sampling Networks". In collaboration with Dr. Moline (through NASA and ONR) efforts were funded to 1) quantify impacts of small scale episodic convergences and divergences of phytoplankton and 2) developing a high resolution temporal sampling capability for bioluminescence. In collaboration with Dr. Paul Bissett (N00014980844) we are developing optical inversion algorithms for particulate and phytoplankton spectra.

PUBLICATIONS

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