ADAPTIVE SAMPLING IN THE COASTAL OCEAN AT THE LONG ECOSYSTEM OBSERVATORY

M. A. Moline[1], *W. P. Bissett*[2], *S. Glenn*[3], *D. Haidvogel*[3] *and O. Schofield*[3]
[1]*Biological Sciences Department, California Polytechnic State University, San Luis Obispo, CA 93407*
[2]*Florida Environmental Research Institute, 4807 Bayshore Blvd. Suite 101, Tampa, FL 33611*
[3]*Coastal Ocean Observation Laboratory, Institute of Marine and Coastal Sciences, Rutgers University, 71 Dudley Road, New Brunswick, NJ 08901-8521*

ABSTRACT

A multi-platform inter-disciplinary observation network has been operating at the Rutgers University Long-term Ecosystem Observatory (LEO) since 1996, with real-time capabilities beginning in July 1999. The network integrates numerous remote (satellites and shore- based), stationary (surface and subsurface), moveable (ships and AUVs) observation systems. The observation network provides spatially extensive updates of the physics, optics, chemistry and biology on time scales of an hour or less which are communicated in real-time to shipboard scientists and AUV operators. This rapid environmental assessment capability is already changing current paradigms for ocean adaptive sampling strategies. For example, in the well-sampled ocean, where forecast errors are dominated by uncertainties in the model physics or future boundary conditions rather than initial conditions, ensemble forecasts with differing model parameterizations can be used to identify regions in which additional data can be used to keep a model on track. Furthermore these approaches are key for sampling episodic events that play a disproportionately large role in driving the biogeochemistry of the coastal ocean. Results from the 1999 and 2000 seasons demonstrate the usefulness of the LEO network to identify, track and sample small-scale (10 m) features that would otherwise go unnoticed with traditional sampling approaches. For example, during HyCODE 2000, real-time data from physical survey vessels identified offshore convergence features. These observations combined with the surface current CODAR measurements were used to adjust and successfully maneuver other ships that were outfitted with bio-optical instrumentation. Bioluminescent *Ceratium fusus,* a red-tide dinoflagellate, were observed in the convergence zone. The covergence zone resulted from material collecting against a southward flowing alongshore jet of low saline water and tidally driven onshore flow of offshore waters. The feature was dramatically impacted by tidal forcing with convergence at high tide and dispersion at low tide.

INTRODUCTION

The present study was part of the ONR-sponsored Coastal Ocean Modeling and Observation Program (COMOP) and the Hyperspectral Coupled Ocean Dynamics Experiment (HyCODE). Both programs support extensive research efforts at the Rutgers

University Long-term Ecosystem Observatory (LEO-15) to further develop and evaluate an integrated adaptive sampling and modeling system for nowcasting and forecasting the often rapid 3-dimensional evolution of the physical and optical properties in the nearshore coastal ocean. HyCODE is designed to utilize hyperspectral imagery to improve understanding of the diverse processes controlling inherent optical properties (IOPs) in the coastal ocean. The program will also develop operational ocean color algorithms in both the optically-shallow ocean and the optically-deep ocean (LEO-15). The goal for this program is to demonstrate the scientific and technical capability to characterize the littoral environment with remote sensors.

The LEO-15 is a functioning real time observational network of satellites, radar, autonomous nodes, research vessels, aircraft and autonomous vehicles located and/or deployed off the New Jersey coast. This interactive multiplatform network covers relevant time and space scales to examine coastal physical processes and their effects on the nearshore optical properties and the major radiatively active constituents during summer upwelling events. The present paper focuses on the description of this observational network and provides an example from summer 2000, illustrating the utility of this network in identification, quantification, and interpretation of spatial and temporal variability of physical processes and associated bio-optical responses on the Middle Atlantic Bight (MAB). This paper will also discuss future directions in expanding the utility of this observatory.

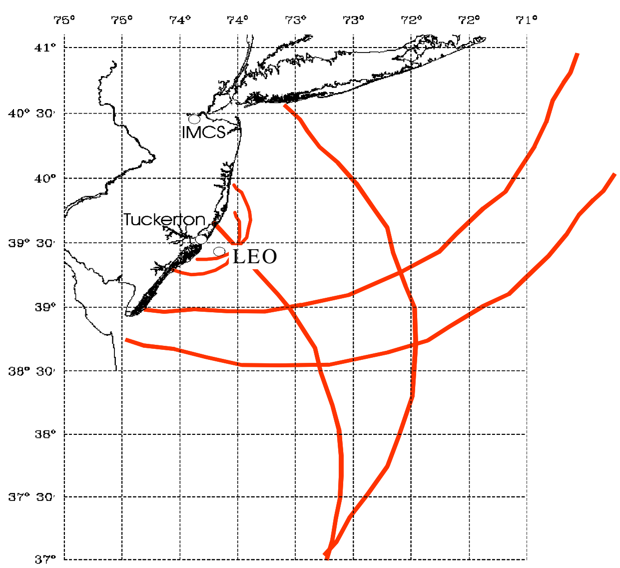

Figure 1: Location of the Long-Term Ecosystem Observatory (LEO-15) relative to the coast of New Jersey in the Middle Atlantic Bight. The red lines indicate the coverage of surface currents provided by CODAR arrays. The two CODAR arrays provided a nested grid of surface current information.

METHODS

Current capabilities

The LEO-15 study area is located off the New Jersey coast in the Middle Atlantic Bight (MAB; Figure 1). The Coastal Ocean Observation Laboratory recently hosted the third in a continuing annual series of Coastal Predictive Skill Experiments (CPSE) at the Long-term Ecosystem Observatory (LEO-15) located offshore Tuckerton, New Jersey. The first CPSE focused on improving nowcast skill via data assimilation, the second CPSE on improving forecast skill via improved boundary forcing (top and bottom), scales of variability in inherent optical properties and turbulent closure, and the third CPSE on the demonstration of rapid environmental assessment techniques in a 30 km x 30 km research space for coupled physical/bio-optical adaptive sampling. Over 200 scientists, students and engineers from over 30 academic, naval and industrial institutions participated in the July 2000 CPSE, operating a coordinated research fleet consisting of 13 surface ships, 2 aircraft, and both propeller-driven and glider-type Autonomous Underwater Vehicles (AUVs). The assets available for the 2000 summer experiment covered many of the requisite scales for phytoplankton variability. Components include:

Remote Sensing

Near-real time thermal infrared (Advanced Very High Resolution Radiometer) and ocean color (SeaWiFS) sensors provide sea-surface temperature and chlorophyll concentration estimates, respectively, for data assimilation and model validation. Delay-mode RADARSAT data were provided through NOAA. The satellite imagery is complemented by a shore-based CODAR SeaSonde High-Frequency Radar System that generates real-time surface current fields every hour. Two different classes of CODAR are part of the network. One intermediate scale CODAR array which provides high resolution surface current vectors. A single Long Range CODAR system was installed providing radial coverage over a ten-times greater area however at a degraded spatial resolution. Aircraft overflights were with the PHILLS hyperspectral sensor, a Microwave Salinity Mapper (through the NRL CO-JET program), and the GPS Altimeter (APL). The combined remote sensing systems provide surface data with spatial resolution varying between 3 m to 1.5 km.

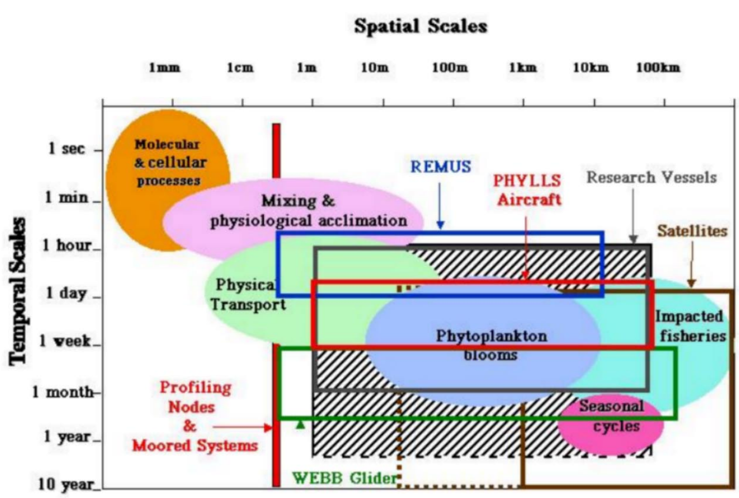

Figure 2: Temporal and spatial scales of sampling platforms in theLEO-15 observational network as related to coastal processes. Highlighted are the sampling capabilities of the Autonomous Underwater Vehicles (AUV's; WEBB Glider and REMUS systems), research vessels, the PHYLLS aircraft, satellites and the profiling and moored systems. The hatched background is the time/space boundaries of the ROMS model. Reworked from Dickey et al. (1993)

Autonomous Nodes

The LEO-15 system consists of two robotic nodes 10 km off the southern coast of

New Jersey connected to shore via an electro fiber-optic cable. Each node has a vertical profiler outfitted with CTD/OBS/PAR/Fluorometer instrument package, and is augmented with an upward looking ADCP. A third optical node was installed and tested during the 1999 summer experiment. The optical node is equipped with an ac-9, a Sequoia LISST, a bioluminescence bathyphotometer, a Wetlabs Volume scattering meter, and a HOBI labs Hydroscat-2.

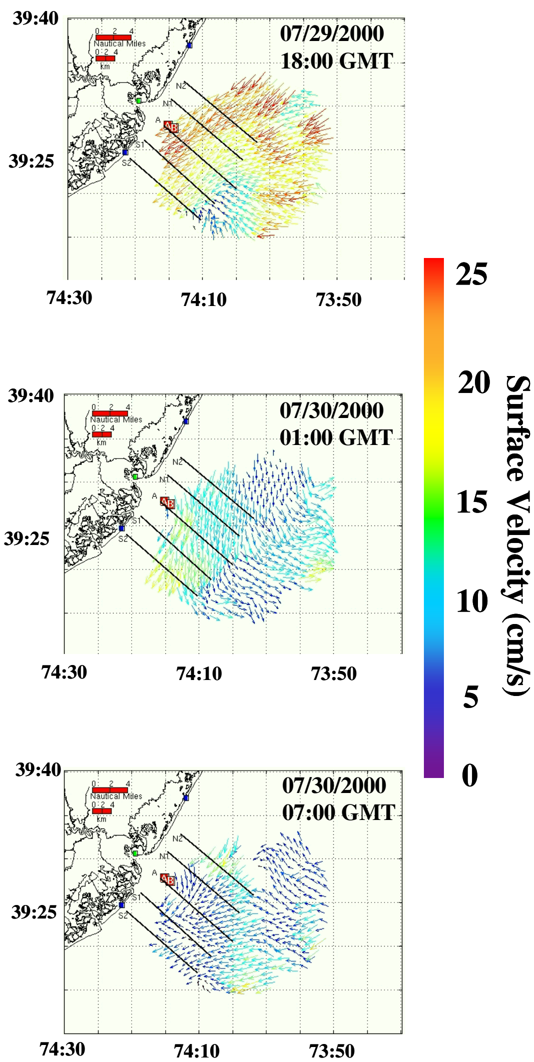

Figure 3. Raw CODAR-derived surface currents. Transects were largely conducted along the S1-line. On the offshore region outside the southward flowing jet, a convergence zone is visible on the rising tide. This resulted in slicks and increases in turbidity which then were dispersed on the slack tide (01:00 GMT).

Shipboard Adaptive Sampling

Research vessels are outfitted for rapid response surveys of observed or predicted ocean features. One such survey vessel is equipped with a surface-towed ADCP and an undulating towed CTD/Fluorometer/OBS system. Data from this vessel is beamed back to shore real-time to help guide other field assets to adjust sampling transects “on the fly”. The bio-optical survey vessel currently includes a suite of instruments (CTD, spectral radiometers, ac-9, SaFire, a hyperspectral TRSB radiometer buoy, above water reflectance meter, and backscatter sensor).

Autonomous Underwater Vehicles.

Two types of Remote Environmental Monitoring UnitS (REMUS) AUVs were successfully operated at LEO-15 in 1998. REMUS Survey AUVs equipped with CTDs and upward/downward looking

ADCPs , and spectroradiometers flew cross-shelf transects. A Webb Slocum Electric Glider was deployed for ten days offshore Tuckerton, New Jersey for its first untethered open ocean flight. The Glider's nominal mission profile consisted of a series of 2.5minute undulations with a surfacing interval every 45 minutes. During the surface interval, a new GPS position is collected, data was transferred to shore, and new mission profiles were downloaded with a Freewave modem. The Glider was recovered on Saturday, July 22. Over the 10-day period, the Glider collected 5,190 CTD casts without ever returning to the dock.

Models

Three- to four-day duration ocean forecasts were generated twice a week for a total of 8 forecast cycles during each of the July CPSE experiments using the Regional Ocean Modeling System (ROMS). The ocean forecasts were forced with standard products from the Navy Operational Regional (NORAPS), Global (NOGAPS) Atmospheric Prediction Systems, and Regional Atmospheric Modeling Systems (RAMS). Assimilation data included satellite SST, CODAR surface currents, and subsurface CTD data via Optimal Interpolation (OI) and CODAR surface currents via nudging. The ROMS circulation model continues to be advanced. It is being complemented by a parallel effort to construct an optically-based ecosystem food web model. The Ecological Simulation (EcoSim) 1.0 model is being modified for use in coastal waters. The model has simulated the seasonal succession of phytoplankton communities and changes in the optical properties in the Sargasso Sea (Bissett et al. 1999a,b). This model describes the temporal changes in the in situ optical constituents and the impact on water clarity and resulting feedbacks on the ecosystem. EcoSim utilizes the spectral distribution of light energy, along with temperature and nutrients, to drive the growth of phytoplankton functional groups (FG) representing broad classes of the phytoplankton species.

RESULTS

One focus of the summer 2000 field efforts was to find, characterize, and describe the dynamics of small optically-significant features. This is particularly difficult in coastal waters that are dominated often by strong coastal jets and numerous turbulent boundary layers. Short-term statistical current forecasts were constructed by decomposing the CODAR currents into tidal and non-tidal components, moving the tidal component forward in time, and persisting either the latest non-tidal currents or the trend in the latest non-tidal currents. Short-term (several hours) statistical forecasts of this type were used during the July 2000 CPSE to adjust the position of the optical boats looking for bio-optical features in the convergence zones. Initially CODAR fields were suggested convergence zones would be located on the offshore side of the southern portion of our study space (see end of S1 line at 18:00 GMT in Figure 3). By the time ships were adjusted and on location the once onshore flow tidal flow had reversed leading to the dispersion of biological material that was visible by ships earlier in the day. However these turbid features re-appeared on the subsequent tide reversal once again

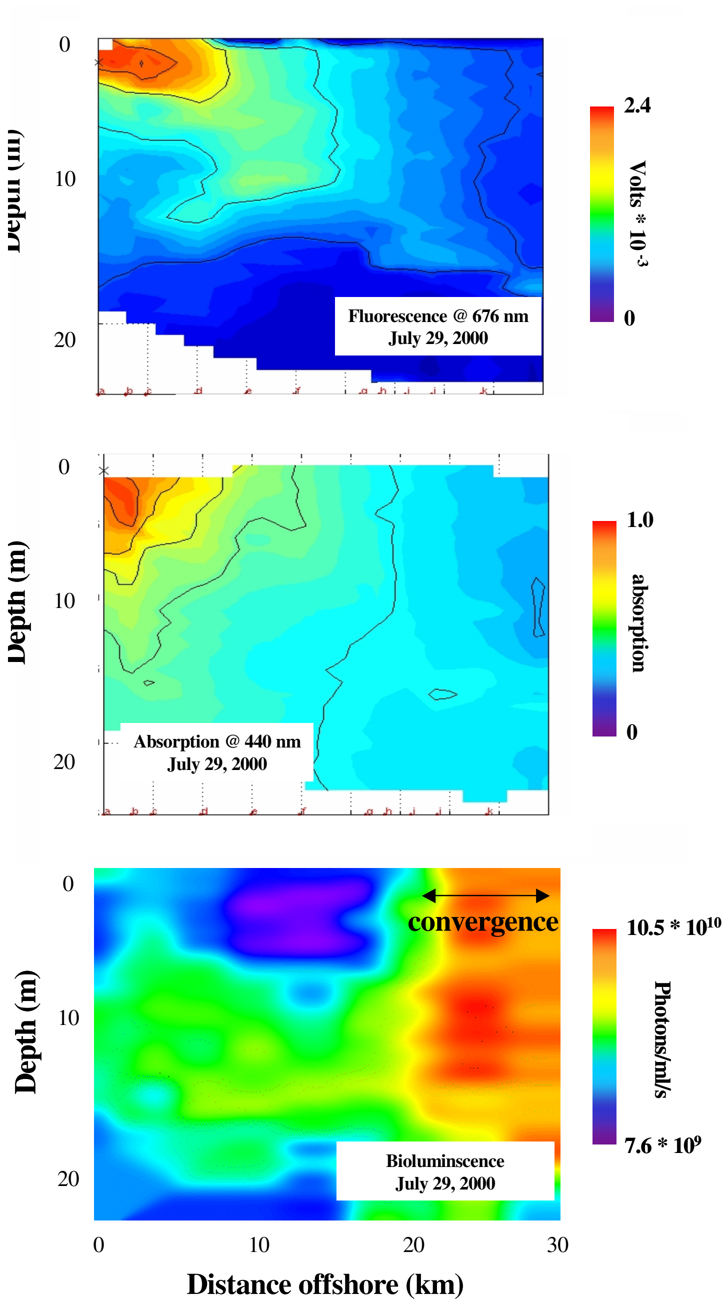

Figure 4. Bio-optical variability during Operation Black Moon focused on real-time characterization of bioluminescence.

leading to an accumulation of material in a convergence zone. The material in the convergence zone could be optically characterized given the guidance of real-time data from the ships and the CODAR fields. The highly turbid waters on the inshore side (Figure 4) of the convergence front was associated with the southward flowing jet of low saline water. The low saline water largely resulted from terresterial washout in response to the heavy rainfall in the New Jersey region. These waters were highly turbid with high phytoplankton stocks (Figure 4). Despite the high turbidity, bioluminescent loads were very low in these low saline waters. The bioluminescence potential was significantly higher in the clear offshore waters and was associated with the red-tide dinoflagellate *Ceratium fusus*. Characterization of this bioluminescence front was critically dependent on the short-term forecasts which provided the existence of a convergence zones caused by an incoming tide hitting the persistent alongshore freshwater jet. While statistical forecasts are useful in the short term, longer-term planning (several days) relied on dynamical forecasts generated through data assimilation, which were improved by the continuous data stream.

These techniques will be critical for developing effective coastal management tools that requires both short and long term forecasts to prepare and proactively respond to episodic events.

Expansion of the Observatory

The fourth CPSE scheduled for July 2001 will expand the research space to the regional scale (300 km x 300 km) of the New Jersey Shelf (NJS). Backbone components of the LEO-NJS observation network will include: (a) long-range CODAR surface currents, (b) high-resolution (both spatially and spectrally) ocean color imagery from international and aircraft, (c) time series from both the nearshore cabled observatory and the offshore mooring. We believe Glider AUVs capable of week deployments is a key addition to coastal observatory efforts.

The regional LEO-NJS network will serve as one prototype for the numerous regional coastal observatories either planned or under construction. We believe this framework of spatially extensive remote sensing and surface current radar systems complemented with long duration gliders is key to future coastal observatories.