

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

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LONG-TERM GOALS

We are developing and validating an integrated rapid environmental assessment capability that will be used to feed a developing nowcast/forecast system. The focus of the rapid environmental assessment is characterizing the 3-dimensional evolution of inherent optical properties (IOPs) in nearshore coastal waters. This is being 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

I propose to make biological/chemical/optical measurements that supplement the the data collected by the existing observation network in the coastal waters off the coast of New Jersey. Obtaining a suite of fine-scale physical, chemical and biological measurements will significantly advance our understanding of the processes governing the temporal and spatial variability of in water IOPs in the coastal ocean. This, combined with the forecasting objectives of the observational network, will also provide a mechanism and framework for predicting these dynamics in the coastal ocean. In working with other principal investigators, the specific objectives of this projects are:

To develop and deploy moored, shipboard, and autonomous bio-optical systems in the coastal ocean to ground-truth remote sensing imagery.

To use rapid environmental assessment techniques to 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

To refine and calibrate existing hyperspectral optical models to derive IOPs from remotely sensed data using the above datasets.

To collaborate with other principal investigators to couple a radiative transfer ecosystem module to the data-assimilative hydrodynamic model.

APPROACH

We have been 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 improvements tested each winter with existing data are used in an operational setting the following summer. The above scenario closely resembles the current paradigm for Rapid Environmental Assessment in preparation for an approaching crisis. Well before the crisis, the climatology is the most useful (and may be the only) environmental product for mission planning. As the crisis approaches, the usefulness of climatology rapidly degrades, and accurate forecasts take over as the most desired environmental product. When the crisis is imminent, forecasts also begin to lose their value as operators depend more on real-time data products and nowcast analyses. 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 resulting environmental assessment capability is used then to adaptively characterize the spatial and temporal variability in the in-water inherent optical properties.

The 2000 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). There were over 27 major institutional partners during the 2000 experiment. This resulted in an experiment fleet of 13 ships, 2 aircraft, and 2 classes of AUVs. Efforts for the experiments centered around a 4 week Coastal Predictive Skill Experiment (CPSE) focused understanding the forcing of the nearshore variability in the inherent optical properties.

WORK COMPLETED

Weekly planning relied on dynamical forecasts generated through the Regional Ocean Model (ROMs) forecasts, which at the time of the 2000 experiment suggested there would be a persistent southward flowing nearshore jet with mild downwelling through the majority of the experiment. These forecasts and the most recent CODAR fields routinely assisted the physical survey vessel in deciding what survey lines should be occupied. The existing infrastructure used by the LEO-15 research team during the 2000 CPSE included, real-time remote sensing (satellites and surface current radar), two autonomous robotic profilers (measuring conductivity-temperature, fluorometry, optical backscatter, and currents), several different classes of AUV vehicles (propellor-driven and glider), shipboard systems (undulating systems for measuring conductivity-temperature-fluorometry, towed system to measure currents, and a profiling bio-optics package for measuring absorption, attenuation, spectral fluorescence, and radiometry). The LEO nodes, connected to shore via an electrofiber optic cable allowing real-time communication, was outfitted with an absorption/attenuation meter (ac-9), a HOBI-Labs HS-2 backscatter sensor, a laser particle sizer (LISST), a bioluminescence sensor, and a

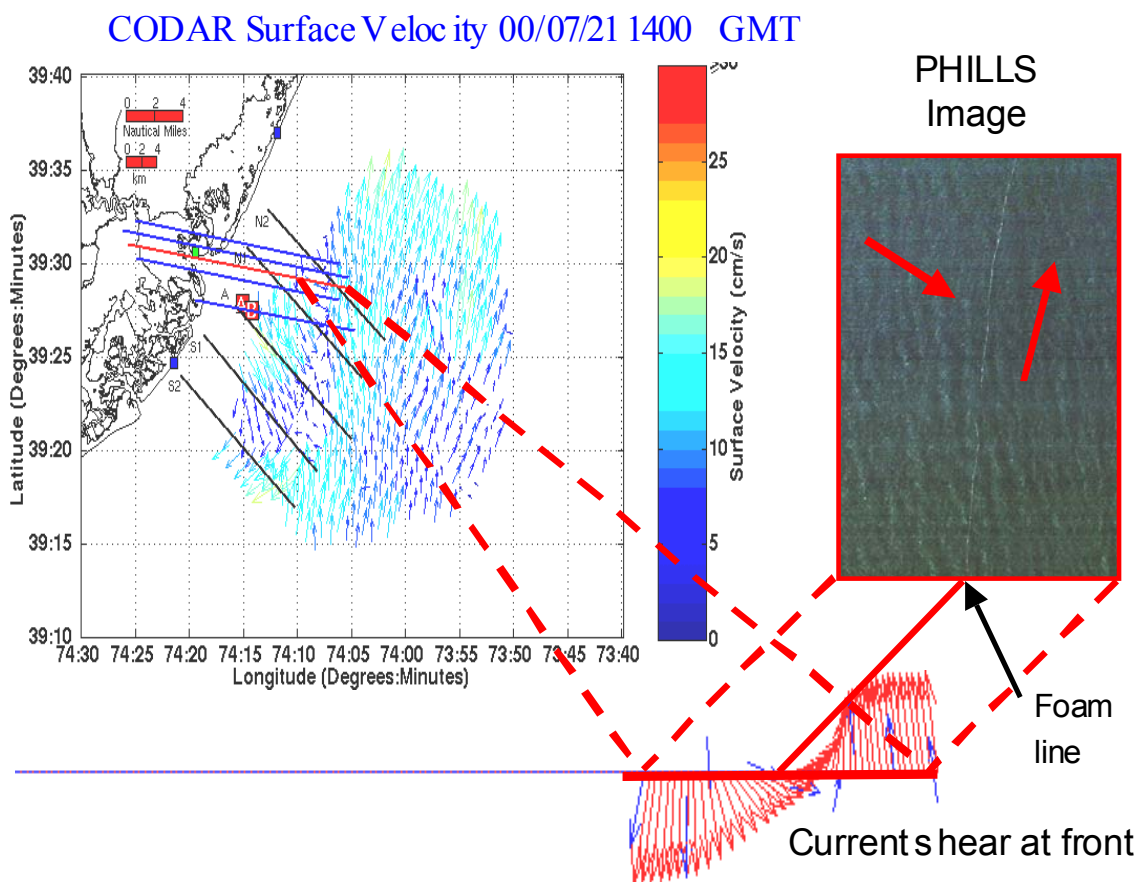
Wetlabs VSF meter. Shipboard optical systems included a spectral backscatter sensor (HS-6), a hyperspectral radiometer for remote sensing reflectance (HR-3), a tethered hyperspectral radiometer buoy (TRSB), a laser particle sizer (LISST), an ac-9, Safire and CTD. Communication between ship to shore and between ships were made real-time by H/F modems allowing for adaptive sampling of nearshore hydrographic/features. A Remote Environmental Monitoring Underwater Survey system (REMUS) was outfitted with an ADCP, CTD, 7 wavelength spectral radiometer and fluorometer for the CPS 2000 summer experiments. The REMUS AUVs logged 444 km of flights and the Webb Glider on its first ocean mission, over a 10-day period, collected 5,190 CTD casts without ever returning to the dock.

The 2000 CPSE experiment was a success with all components of the observation system working well. The 28 day experiment consisted of physical/optical ship surveys of up to six ships on a single day, multiple flights of untended AUVs, and repetitive profiling of the autonomous nodes. In excess 4000 discrete samples for laboratory analyses. Seven hundred samples will be used for each of the following analyses; filter pad absorption spectra, fluorescence excitation-emission spectra, phytoplankton pigmentation (via HPLC), and nutrients. A smaller proportion of these samples will be analyzed for suspended particulate matter and phytoplankton taxonomy. These efforts also complemented larger naval efforts used to calibrate hyperspectral PhiLs ocean color imagery, a NAVAIR Lidar system, and a suite of NRL-derived satellite and diver visibility algorithms.

RESULTS

One focus of the summer 2000 field efforts was to find and characterize the dynamics of small-scale (1-100 m) optically-significant features that would be visible in high resolution ocean color imagery. Several features were characterized during the 2000 CPSE were characterized including a 1) topographic steering of material flux along a nearshore ripple bed, 2) the presence of diatom and dinoflagellate rivers in our research site, and 3) tidal forcing of the coastal slicks visible in hyperspectral imagery.

During the CPSE PHILLS hyperspectral data clearly delineated the presence of offshore slicks that were visible in aircraft imagery (Fig. 1). Real-time analysis of the CODAR data showed that the foam line was associated with a strong current shear. Research ships were dispatched to study this feature in detail. Continual monitoring of the CODAR data showed that the current shear disappeared some hours later due to changes in tides and wind. The ship measurements confirmed this change and the coincident narrow continuous foam line. Over the month, the CODAR fields suggested convergence zones should be consistently located on the offshore side of the southern portion of our study space; however in the time that ships were placed into position, it was observed that the currents had reversed. The net result was that the convergence zone was no longer present due to a tidal reversal. By the time ships were on location the once onshore flow tidal flow had reversed leading to the dispersion of biological material.



1. A strong offshore foam line was observed during the PHILLS data collection. Analysis of the concurrent CODAR data showed a strong convergence at the location of the foam line.

To predict the behavior of these slicks, 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) forecasts of this type were used then used to adjust the position and timing of the optical boats searching for the convergence zones. These slicks consistently reappeared on inward tides. The highly turbid water on the inshore side (Fig. 2) of the convergence was associated with the southward flowing jet of low saline water. The low saline water largely resulted from terrestrial washout in response to the heavy rainfall in the Mid-Atlantic region. The turbidity was associated with high phytoplankton stocks and high scattering reflecting the significant presence nonbiogenic particles (Fig. 2). Despite the high turbidity, bioluminescent loads were very low in these low saline waters. The bioluminescence potential was significantly higher in the offshore waters beyond the low saline water. The bioluminescence was associated with the red-tide dinoflagellate *Ceratium fusus*. This allowed over two nights ships and Navy dive teams to be located in optimal locations for field detection experiments.

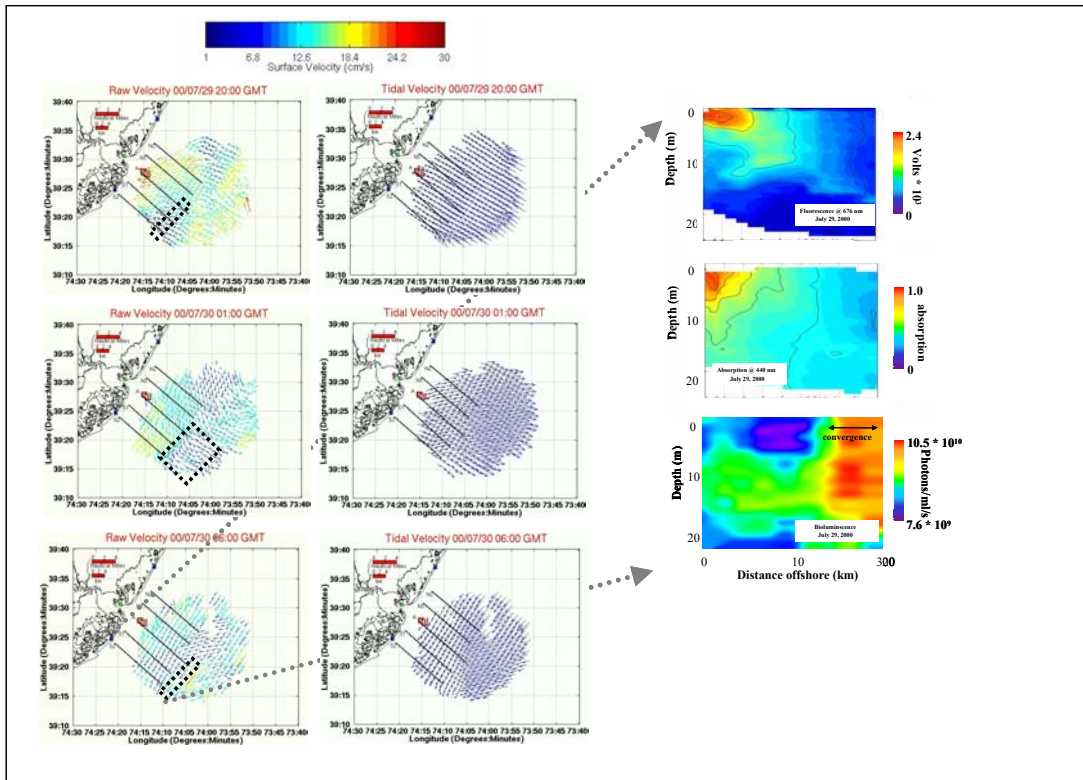


Fig. 2. CODAR field illustrating the tidal forcing of slicks in offshore slicks. The convergence feature was dominated by silt and diatoms on the inshore side of the front. The offshore was dominated by bioluminescent dinoflagellates and invertebrates.

IMPACT/APPLICATION

ONR/NRL/NAVO involvement at LEO is growing at an accelerating rate. Validation of satellite, diver visibility and bioluminescence algorithms began this summer with Navy divers working on site at LEO. Validation of Navy atmospheric, ocean current and wave models (COAMPS, MODAS, SWAN) is ongoing or is being planned with NRL, FNOC and NLMOC. With a NAVO liaison, we have drafted a collaborative plan to establish a cooperative effort that takes advantage of the wealth of data collected, and rapid environmental assessment methods employed at LEO-15.

TRANSITIONS

The data and new optical algorithms will be freely shared. Data will be disseminated from both the ONR WOOD database and Rutgers Ocean Data Access Network (RODAN). The goal is to provide simple access to the LEO datasets. Three main access points are being constructed. Most users are expected to access the datasets via the World Wide Web, browse through them, and download the quality-controlled but raw data they desire for further processing on their own.

RELATED PROJECTS

Three additional projects aid in my group's collection and analysis of the data for the HyCODE effort. These include NASA's New Investigator Program award "Adaptive

sampling of phytoplankton responses to episodic physical forcing in the nearshore coastal ocean: Characterizing the significance of convergences in upwelling eddies", ONR "High resolution temporal sampling of the nearshore vertical structure of bioluminescence" (N00014-00-1-0008) , and ONR's Young Investigator Award " High-Resolution Structure Of Bioluminescence Potential In The Nearshore Coastal Waters: Processes And Prediction" (N000-14-00-1-0570).

PUBLICATIONS

Kirkpatrick, G., Millie, D. F., Moline, M. A., Schofield, O. (2000). Absorption-based discrimination of phytoplankton species in naturally mixed populations. *Limnology and Oceanography* 42: 467-471.

Moline, M., Schofield, O., Gryzmski, J. (2000). Impact of dynamic light and nutrient environments on phytoplankton communities in the coastal ocean. In: Modeling Dynamic Systems: Dynamic Modeling for Marine Conservation Ecological Understanding. Lindholm, J. and Ruth, M. (eds) Springer Verlag (In press).

Bissett, P., Schofield, O., Mobley, C. and Moline, M. (2000). Ocean color remote sensing of microbial communities in the aquatic ecosystems. In: Methods in Marine Microbiology. Paul, J. (ed). Academic Press (In Press).

Schofield, O., Bergmann, T., Bissett, W. P., and Moline, M. A. (2000). Deconvolving phytoplankton community composition absorption from bulk measurements in turbid coastal waters. SPIE (accepted).

Moline, M. A., Bissett, W. P., Glenn, S., Haidvogel, D., Schofield, O. (2000). An operational multi-scale real-time long-term ecosystem observatory (LEO-15) for the coastal ocean. SPIE (accepted).

Tozzi, S., Schofield, O., Moline, M. A., Bergmann, T., Crowley, M., Arnone, R. (2000). Variability in measured and modeled remote sensing reflectance and comparison of SeaWiFS and *in situ* chl *a* distribution for coastal waters at LEO-15. SPIE. (accepted).

Bergmann, T., Schofield, O., Cullen, J., Glenn, S. Moline, M. A. Concurrence of inherent optical properties and particulate organic carbon concentrations in the Middle Atlantic Bight: Applications of ocean color imagery in coastal waters SPIE. (accepted).

Schofield, O., Bissett, W. P., Haidvogel, D., Moline, M. A., Glenn, S. Integrated coastal ocean observatories. *Transactions of the Institute of Electrical and Electronics Engineers*. (2001, submitted).

Schofield, O., Bissett, W. P., Haidvogel, D., Moline, M. A., Glenn, S. Blueprint for a national network of coastal ocean observatories. *Backscatter* (2001 submitted)