

Hyperspectral Remote Sensing of the Coastal Ocean: Adaptive Sampling and Forecasting of *In situ* Optical Properties

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LONG-TERM GOAL

We are developing an integrated rapid environmental assessment capability that will be used to feed an ocean nowcast/forecast system. The goal is to develop a capacity for predicting the dynamics in inherent optical properties in coastal waters. This is being accomplished by developing an integrated observation system that is coupled to a data assimilative hydrodynamic bio-optical ecosystem model. The system will be used to develop hyperspectral remote sensing techniques for optically complex nearshore coastal waters in support of the development and validation of the Navy Earth Map Observer (NEMO) satellite system.

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) 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

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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 have been conducting a series of Coastal Predictive Skill Experiments (CPSE) at the Long-term Ecosystem Observatory (LEO-15) in order to understand the physical forcing of the nearshore optical properties. The goal is to improve current operational oceanography approaches, which are currently based on climatologies. For mission planning, climatologies are a useful (and may be the only) environmental product; however as the mission approaches, the usefulness of climatology rapidly degrades, and accurate forecasts take over as the most useful environmental product. Our goal is to develop the capacity for nowcasting/forecasting for mission planning. To this end, coordinated shipboard (physical and bio-optical) and AUV adaptive sampling surveys of upwelling eddies were conducted based on real-time remote observations and the model forecasts. The observational capability is used then to improve model forecasts in the physics and the associated in-water optical properties. This system is used to ground-truth hyperspectral imagery in support of the Navy Earth Map Observer (NEMO).

WORK COMPLETED

Weekly planning relied on 8 dynamical forecasts generated through the Regional Ocean Model (ROMs) forecasts, which during the 2001 experiment successfully predicted alternating upwelling/downwelling events. The model forecasts were improved due to the coupling of ROMs to the high-resolution COAMPs weather forecasts. These forecasts, real-time CODAR fields, and *in situ* data from the autonomous nodes assisted in choosing flight missions for the aircraft (PHILLs-1, PHILLs-2, AVIRIS, Proteus, SPECTIR) and position three ships under the aircraft for *in situ* validation. The *in situ* nodes were outfitted to measure the inherent optical properties (absorption, scatter, attenuation, angular scattering, backscatter) and biology (fluorescence, bioluminescence, particle number and size). Ships were outfitted to measure the inherent optical properties (absorption, scattering, attenuation, backscatter), apparent optical properties (irradiance, radiance, reflectance, remote sensing reflectance), and biology (fluorescence, particle size and number, bioluminescence). The 29-day experiment consisted of four ships, five aircraft, data from the international constellation of ocean color satellites, a nested surface current radar network, flights of untended AUVs, and profiling of *in situ* nodes. In excess of 200 discrete samples for laboratory analyses were collected. The samples are being analyzed for filter pad absorption spectra, particle size, phytoplankton pigmentation, and nutrients. A smaller proportion of these samples will be analyzed for suspended particulate matter, particulate carbon/nitrogen, dissolved oxygen, primary productivity and dissolved organic carbon. Field sampling was coordinated through the modeling/observation system and allowed for 1) 16 clean overflights providing hyperspectral ocean color data with complete remote sensing ground truth data from the research fleet, 2) 5 days with more than two aircraft flying at one time allowing for one of the first times vicarious calibration between aircraft systems, and 3) calibration of atmospheric parameters using NASA-funded aircraft.

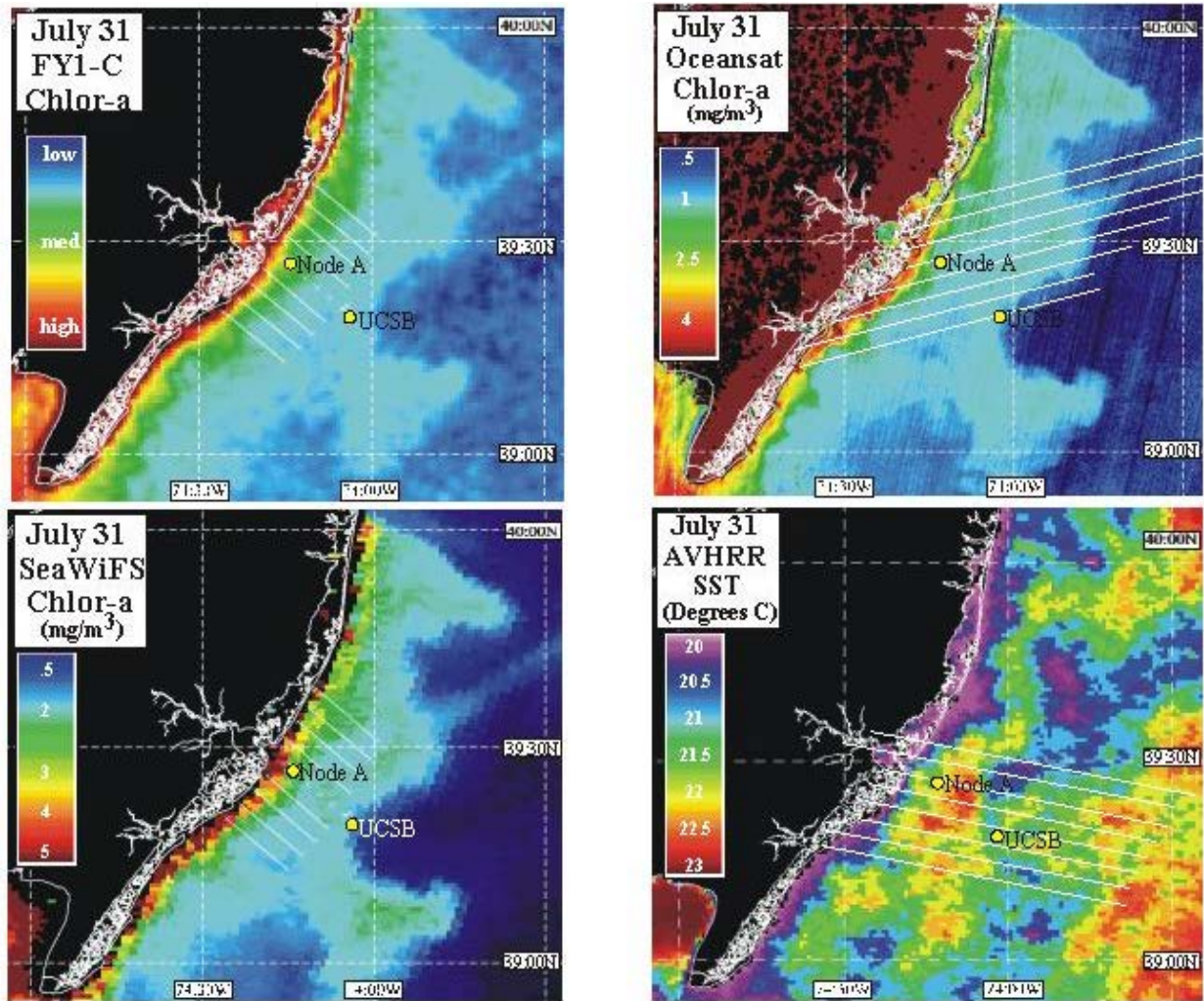


Figure 1. Cross-calibration between the ocean color satellites. The satellites represent systems from the United States (SeaWiFS, AVHRR), China (FY-1C), and India (Oceansat). The ocean color measurements show strong coherence and AM overpasses by FY-1C allowed ships to be repositioned to ground truth features in the SeaWiFS and Oceansat satellite passes in the PM. Both PHILLS aircraft flew on this day, and the AM (Oceansat panel) and PM (AVHRR panel) flight patterns (white lines) as well as ship tracks (SeaWiFS & FY1-C panels) are presented.

RESULTS

We experienced upwelling and downwelling events in the summer of 2001. Topographic variations associated with ancient river deltas caused upwelled water to evolve into a recurrent upwelling center. Frequent wind reversals resulted in downwelling followed by subsequent upwelling. The net result was a sustained phytoplankton bloom extending over 40 km offshore. The bloom was characterized by two distinct zones of high chlorophyll in the nearshore (chlorophyll $a > 5 \text{ mg m}^{-3}$) and offshore waters ($> 1.5 \text{ mg m}^{-3}$) (Figure 1). Associated with the high chlorophyll were optically turbid waters above the

thermocline ($a_{440} \text{ nm} > 2.0 \text{ m}^{-1}$). Below the thermocline, the water was optically-clear ($a_{440} \text{ nm} < 1.0 \text{ m}^{-1}$). The bottom water temperatures were as low as 10 degrees Celsius, indicating cold pool water from the continental shelf. Indications were that sinking organic carbon from above the thermocline was leading to significant oxygen declines in the bottom waters. The surface flow field consisted of a cyclonic eddy within the cold upwelling center and a northward flowing surface jet on the warm side of the upwelling front that made a sharp anticyclonic turn around the cold center. Subsurface current observations indicated that the northward-flowing upwelling jet on the offshore side was confined to the upper water column above the thermocline, and as in past years a southward-flowing, subsurface jet was observed on the nearshore side below the thermocline. The optical features of the upwelled waters were dominated by particulate organic carbon (POC). The bulk *in situ* absorption measurements could be inverted into the particulate and dissolved components as well as the dominant phytoplankton spectral class (Figure 2). Phycobilin-containing algae were problematic. In these waters a significant number of cryptophytes are present and the current IOP inversion models utilize spectral shapes more representative of low light adapted cyanobacterial picoplankton. This ability to define phytoplankton community composition using bulk optical parameters provides a means for initializing the EcoSim model which is now coupled to the ROMs ocean forecast model. Hindcast modeling efforts will assess our skill at providing 3-4 day forecasts for optical properties during the next 2 years.

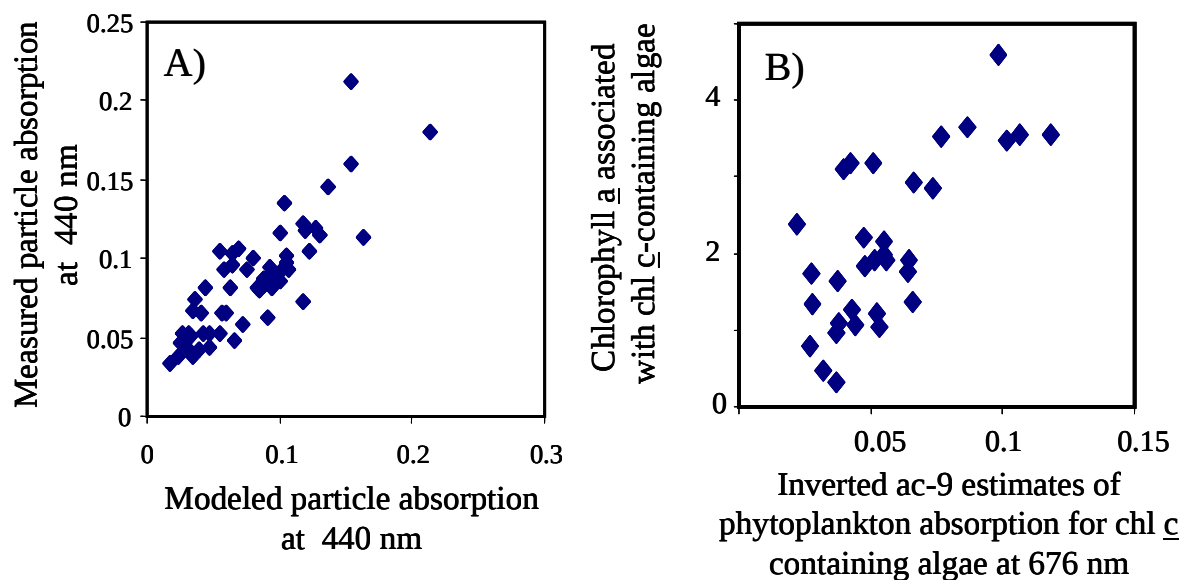


Figure 2. Inversion of ac-9 data into particle and class-specific phytoplankton absorption. A) The AC-9 estimated particle absorption at 440 nm versus that measured from absorption measurements made on discrete samples. B) Estimated absorption for chlorophyll *c* containing algae from the bulk *in situ* IOPS against pigment derived estimates of chromophytic phytoplankton.

IMPACT/APPLICATIONS

An integrated system for predicting the 3-dimensional structure of coastal currents, water density and in-water optical properties on the time scales of days is essential to numerous naval operations such as

mine counter measures, special forces operations, amphibious landings, and shallow water anti-submarine warfare. The NEMO satellite is being designed to hyperspectral ocean color data for mapping in-water constituents in areas of high naval interest and the derived algorithms from HyCODE will be key to the satellites development. Finally hydrodynamic/optical forecasting system provides the key to integrate and forecast the observed optical properties over time. Finally HyCODE was played a central role to developing optical REMUS AUV and Webb Glider capability. All these observation and modeling systems are relocatable and will be key for future naval operations. Finally development of such a forecasting systems for predictive optics will also be a key civilian deliverable for coastal water quality management.

TRANSITIONS

The data is being freely shared. Data will be disseminated to the ONR WOOD database. Data that is just being finished processed will be burned to data CD's (summer 2000 and 2001) and then shipped to the WOOD system in October. Additionally, data will be available via Rutgers Ocean Data Access Network (RODAN). The optical data is currently being utilized by NRL and NASA remote sensing projects. Finally the ongoing real-time data, for which the HyCODE program was central to for development, continues to be accessed via the web (over 50,000 hits/day) by the general public, Naval METOC groups, and the U.S. Coast Guard.

RELATED PROJECTS

There were over 27 major institutional partners during the 2000-2001 experiments a large number supported by the HyCODE program. These efforts also complemented other independent efforts such as 1) validation of NAVAIR's KSS Lidar system, 2) ONR-YIP funded AUV bioluminescence prediction efforts, 3) ONR-STTR sponsored efforts to develop a "smart" fleet of automated Webb Gliders, 4) SeaSpace Inc. efforts to intercalibrate the international constellation of ocean color satellites, 5) calibration and refinement of a suite of NRL-derived satellite algorithms, 6) calibration of atmospheric parameters with NASA's atmospheric Chesapeake Lighthouse and Aircraft Measurements for Satellites experiment, 7) field infrastructure for NASA's YIP and PECASE remote sensing projects, and 8) model development for ONR's CBLAST Program.

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