Optical Variability and Bottom Classification in Turbid Waters: Phase III

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LONG-TERM GOALS

Real-time determination of the optical and bathymetric climate available for operation of various Navy and Coast Guard assets in the coastal zone using a mixture of AUV, ROV, surface-vessel, fixed moorings/towers, and air/space-borne observational assets. This includes advanced heat-budget modeling applicable to coastal regions, methods for early detection of *K. brevis* (red-tide) and other algal blooms, remote determination of optical properties (absorption and scattering) of the water, harmful algal blooms, depth and bottom albedo. These provide model inputs and validation data for predicting visibility and the performance of optical systems as well as heat budget and primary production models, useful in asset selection for Homeland Security operations.

OBJECTIVES

The development of optical methodologies valid for Case II coastal waters for the remote determination of water and bottom optical properties including visibility, water and bottom optical absorption, algal concentrations, bathymetry, bottom albedo, vegetation cover, and bottom structure are being pursued. These include interpretation of hyperspectral, high-resolution imagery from aircraft and satellites, development and deployment of suites of small instruments on remotely operated and autonomous underwater vehicles (ROVs, AUVs) and a multi-disciplinary network of moored sensors. Data are used in development/application of radiative transfer models and algorithms for predicting optical properties and extracting information from the remote data. Effects of vertical structure in the optical properties (e.g. river plumes, suspended sediments) and turbidity must be recognized for the data retrievals to be accurate, and the instruments and methodologies necessary to quantify such structure are being developed and utilized on underwater vehicles and moorings.

A focus for our work this year is in direct response to the September 11 attacks on the United States and the call for increased attention to Homeland Security with an emphasis on Port Security. We have accelerated our efforts toward the quantification of performance parameters for underwater imaging systems and for now-casting the optical properties of the water column at scales appropriate to application in Homeland Security strategies.

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14. ABSTRACT
Real-time determination of the optical and bathymetric climate available for operation of various Navy and Coast Guard assets in the coastal zone using a mixture of AUV, ROV, surface-vessel, fixed moorings/towers, and air/space-borne observational assets. This includes advanced heat-budget modeling applicable to coastal regions, methods for early detection of K. brevis (red-tide) and other algal blooms, remote determination of optical properties (absorption and scattering) of the water, harmful algal blooms, depth and bottom albedo. These provide model inputs and validation data for predicting visibility and the performance of optical systems as well as heat budget and primary production models, useful in asset selection for Homeland Security operations.

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APPROACH

We have developed models for inverting hyperspectral data from air- and space-borne sensors in vertically homogeneous waters to estimate absorption, back-scattering, and beam-attenuation coefficients, as well as bathymetry and bottom albedo (see PUBLICATIONS). We have also presented methodologies for advanced coastal-water heat budget modeling (Warrior et al. 2002) and early detection of red-tide and other algal blooms (Cannizaro et al. 2003). These can be used as initial or boundary conditions for heat-budget, primary production and visibility models and to predict where certain mine-counter-measure assets can productively be deployed or not.

Water clarity, bathymetry, and bottom albedo are critical variables affecting optical searches for objects in the water column or on the bottom. Object contrast with the background optical field or its 3-dimensional shape can be used in object-classification schemes. We are using elastic and inelastic scattering and active and passive imaging systems and are evaluating how system performance degrades with increased turbidity, range, and optical structure (e.g. layers) over a variety of bottom types and beneath underwater structures, e.g. ship hulls (Hou et al, 2002: Reinersman and Carder, 2002; 2003).

We have developed several optical packages for deployment on ROVs and AUVs to measure the optical properties of the water column and bottom to provide an assessment of the accuracy of the model assumptions and retrieval values from air-borne sensors, and we have deployed these as part of the CoBOP and HYCODE field activities. Several of these [e.g. Bottom Classification and Albedo Package, BCAP, Real-Time Ocean Bottom Optical Topographer, (ROBOT), and the Mobile Inspection Platform (MIP)] have been developed and tested on ROVs or AUVs including our ROSEBUD remotely operated vehicle (ROV), the Ocean Explorer class autonomous underwater vehicles, and USF's Center for Ocean Technology (COT) ROVEX vehicle (Carder et al., 2001; Costello and Carder, 1997; Costello et al., 1998a, 1998b; Renadette et al., 1997, 1998).

WORK COMPLETED

Oceanography is inherently a multi-disciplinary science and our group is a team of oceanographers dedicated to developing optical methodologies that address real-world applications. These efforts require acquisition of extensive field data (above and below the surface) and extensive modeling. Analysis and comprehensive interpretation of field data and model results requires us to address physical, biological, chemical, and geological processes which affect water optics. The range and success of our work, then, is most directly presented via a list of 23 publications (14 refereed) produced by our group in 2002 and 2003. Please refer to the **PUBLICATIONS** section below.

RESULTS

Elastic and inelastic 3-D images for inspection of ship hulls were acquired by inverting the ROBOT system (a prototype for the Mobile Inspection Platform) on our ROSEBUD ROV in the relatively turbid water ($c532 \approx 3.0$/m) of Tampa Bay. 2-Way maximum ranges of 18 e-folding lengths were determined in the elastic mode and 12 e-folding lengths in the fluorescence mode using the Xybion intensified camera as a receiver. Fluorescence-mode imagery would be most useful in highly scattering waters because of the elimination of on-line path radiance. The Fluorescence mode would also be useful, for example, in detecting a recently-attached object (e.g. a limpet mine) on a ship hull since the recent object would not have sufficient algal growth to fluoresce. Figure 1 shows a 3-dimensional fluorescence image acquired during the Submerged Target Aging Experiment (Stage). The (inverted) image is of the hull of a small boat to which a pair of targets were added each week. Note that the targets were painted flat black and would not necessarily reflect highly enough to be visualized in a reflective mode.

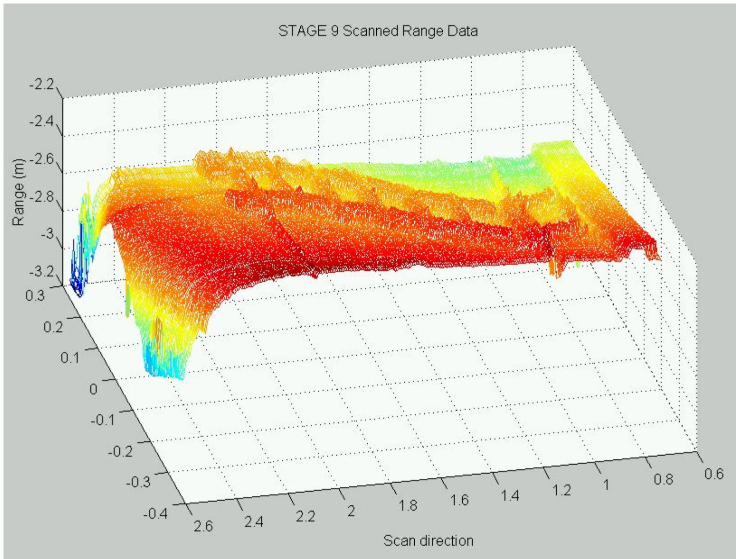

Figure 1. A 3-dimensional laser-line image acquired in the fluorescence mode. Note that the image is possible because of fluorescence of algal scum on the boat hull and aged targets. The targets consisted of sections of PVC pipe that were painted flat black and not likely to be visualized in a reflective mode.

Bathymetry and bottom-albedo maps (Fig. 2) were derived from PHILLS hyperspectral radiometer images of turbid Charlotte Harbor. Both are needed for 2 and 3-D models of the light field for ports and waterways and beneath ships (see Reinersman and Carder, 2003) and are useful indicators of hazards to navigation.

Red-tide blooms with chlorophyll_a concentrations greater than 2-3 mg/m^3 or 10,000-20,000 cells/liter can be discriminated and quantified from space-craft or aircraft ocean-color data by both chlorophyll-specific backscattering and fluorescence (Cannizzaro et al. 2003). Concentrations as high as 140 mg/m^3 were quantified by fluorometric remote sensing.

Ship-shadow measurements were acquired in the field along with IOP and AOP measurements as well as bottom albedo to validate the results from a structured light model (HyMOM, Reinersman and Carder, 2003). Initial analysis shows good agreement between field measurements and model results.

IMPACT/APPLICATIONS

In last year's report, we discussed solar-stimulated fluorescence imagery of the bottom. This type of passive, off-band imagery can be acquired in any area where the depth is sufficient to effectively quench 685 nm reflected solar radiation and where blue-green radiation penetrates sufficiently to stimulate 685 nm fluorescence to a level which allows image formation by the sensor. The significance is two-fold: first, since the bottom is the source, the imagery acquired is free from the backscattered path radiance generally associated with contrast degradation in underwater imagery second, animals and man-made objects do not, generally, fluoresce at 685 nm. Given the appropriate environmental parameters, this makes possible the visualization of bottom objects that may not be apparent using either active or passive reflection (elastic) imaging techniques. Applicability ranges from assessment of the standing stock of sponges to underwater mine detection.

This year we found that laser-line imagery of ship hulls at 532nm will excite fluorescence of algal scum on the hulls for easy observation with intensified cameras at 685nm. Recent ship-bottom modifications will display a differing fluorescence signature from the undisturbed hull. The technique is also applicable to vertical underwater structures (e.g. pilings, sea walls) that are of interest in Port Security.

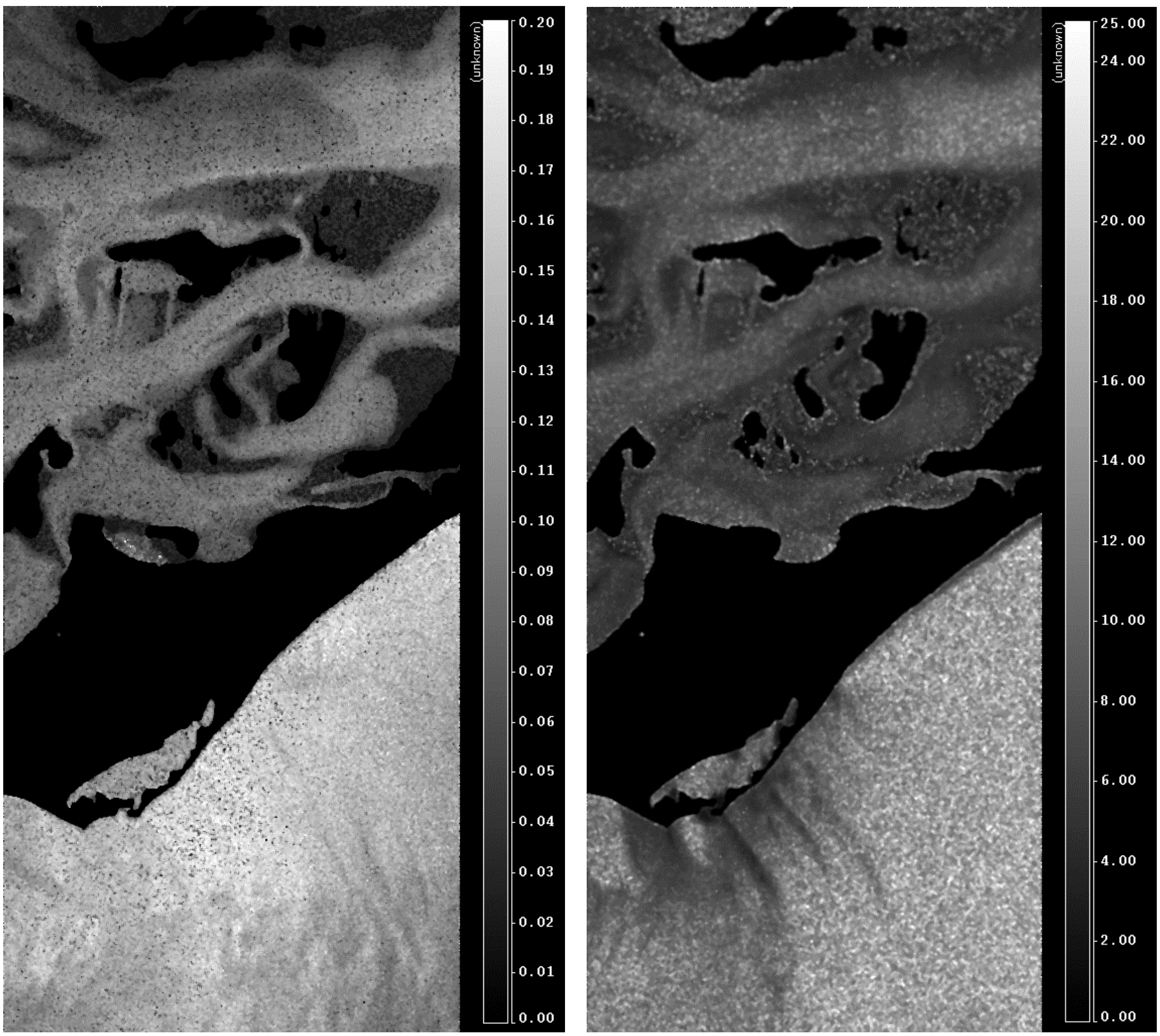

Figure 2. Bottom-albedo (left) and bathymetry (right) maps around Cayo Costa Island, Florida. Bottom albedo varied between 3% (grass) in the shallow (< 4 ft.) inshore areas and 20% (sand) for the deeper (> 10ft.) offshore (bottom). Inshore channels were sandy with intermediate albedos.

Large scale maps of water properties and bottom depth and albedo are critical in the assessment of visibility, navigability, and underwater sensor performance. In the same vein, the ability to detect algal blooms from space or aircraft-borne sensors is important to both economic and security concerns.

TRANSITIONS

Our red tide detection algorithm has been transitioned to NOAA Coastwatch.

RELATED PROJECTS

This project has a close association with the ROBOT project (Kaltenbacher et al.). ROBOT is an AUV/ROV deployed, laser-line imaging system designed to produce 3-dimensional maps of underwater surfaces (bottoms, seawalls, hulls, etc.) We are utilizing our methodologies and hardware to quantify and predict performance parameters for both the on-line and fluorescence (see RESULTS) modes of operation of the ROBOT systems well as to develop algorithms for automatic (computerized) target recognition.

We are also collecting field data regarding the structure of the underwater light field around objects (e.g. ship and seawall shadows) under various environmental conditions for the validation of the "Hybrid Modular Optical Model To Predict 2-D and 3-D Environments in Ports…" (HyMOM, ONR, Reinersman and Carder).

We are actively supporting three ONR projects headed by John Kloske, USF Center for Ocean Technology, and Scot Tripp, US Coast Guard Research and Development Center, toward utilizing our methodologies in Homeland Security. These projects include Advanced Underwater Port Security Systems and the Development and Evaluation of the Mobile Inspection Platform, first deployed on our ROSEBUD ROV. The ROV has also been used for evaluation deployments of the ISS ranging camera and Echoscope and Tritech Mini-king imaging sonars (Steve Lawrance, Subsea Technologies, Inc.) as well as the Coda Echoscope 1600 3-D Real Time acoustic sonar (Angus Ludsdin, Codaoctopus, Ltd.)

We are investigating the efficacy of different stimulation wavelength and sources in active fluorescence imagery and identification of bottom objects. This work is in conjunction with Charles Mazel, Physical Sciences, Inc.

Efforts within our group toward model inversion (funded through ONR/CoBOP and NASA) utilizing remote sensing reflectance provides bathymetry and water optical properties. Most recently, efforts have been focused on providing sea-truth and image interpretation for the PHILLS hyperspectral imaging sensor owned by NRL Washington (Curtiss Davis) and operated by Paul Bissett, Florida Evironmental Research Institute.

Finally, this project benefits from the database acquired during the ONR project Coastal Benthic Optical Properties (CoBOP, Carder and Costello) field campaigns.

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