Data Mining the CoBOP Data Base to Separate Bottom Albedo from Bottom Roughness and Illumination Effects

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LONG-TERM GOALS

The deconvolution, quantification, and interpretation of various components of water-leaving radiance in shallow coastal waters are the long-term goals of the project. Data-sharing with other CoBOP investigators.

OBJECTIVES

In this project, objectives have included the development of instrumentation and models to measure and predict the contribution of bottom reflectance to upwelling radiance in coastal waters. An underlying objective, then, is the development of the methodologies required to remotely classify bottom types in varying water depths. Intrinsic in this effort are the quantification of the optical properties of the water column and the need to perform rigorous data calibration/validation while working toward optical closure, and to address the inherent problems of scale between *in situ* and remotely sensed data. In this funding year, emphasis was placed on information extraction and quantification of optical effects of a corrugated ocean bottom (e. g. sand waves) on bathymetry and bottom albedo calculations from water-leaving radiance. Additional papers were to be completed.

APPROACH

In the first funding year of the CoBOP project (FY96), transects over coral bottoms in the Dry Tortugas were laid out and mapped by divers and by the Fluorescence Imaging Laser Line Scanner (FILLS). Instrumentation aboard our Remotely Operated Vehicle (ROV) and Autonomous Underwater Vehicle (AUV) platforms were used to determine the color and intensity of bottom elements from different altitudes (Costello et al., 1997). The goal was to correct imagery for path radiance and attenuation, providing bottom albedo estimates for the dominant bottom types/features, to image bottom fluorescence, and to measure the vertical spectral structure of the upwelling and downwelling light fields. The analyses required rigorous validation, calibration, and modeling efforts. Simultaneously, effort was expended toward developing, relatively low-cost methods that could exploit gross bottom reflectance signatures to yield useful data.

In FY1998-2000, CoBOP field campaigns were conducted from the Caribbean Marine Research Center (CMRC) located on Lee Stocking Island, Exuma Islands, Bahamas. Our responsibilities were similar to those at the Dry Tortugas with the addition of extensive optical measurements of atmospheric parameters as well as characteristics of sediments, grass beds, and mixed bottom types in addition to coral environments.

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Recent work has been directed toward mining, archiving, and sharing of data. Fruitful collaborations with other investigators are culminating in several publications (see below).

WORK COMPLETED

Data sharing:

Date: 9/26/01

Type: Inter-University/WOOD database

Data: 1998-2000 CoBOP ap,ad,ag,rrs, and chl in WOOD format (SEABASS), all stations

To: Jeffrey Smart, Johns Hopkins University – Applied Physics Lab

General efforts:

- A method to quantify the spectral effects of bottom texture (i.e. sand waves) on retrieval products of remote sensing (bottom albedo and depth) has been developed (Carder et al. in press).

- A method which utilized color video taken from the OV-II AUV to calculate the percent live sea-bottom cover (Renadette et. al., 1997, 1998; Hou et. al., 1999) has been extended to multi-spectral imagery (Hou et al., 2001; Farmer et al., 2001; English et al. 2002).

- A method developed to model and utilize downwelling irradiance spectra affected by wave focusing and trans-spectral phenomenon (Costello et. al. 1998a; Costello et al., 2002) has been extended to include the upwelling radiance light field and provide for the calculation of reflectance as a function of depth (Costello et. al. 1998b). Current work extends the methodology to include bottom albedos and water-leaving radiance.

- An analytical model was developed to predict the effect of internally reflected light over shallow,"patchy" bottoms (Costello and Carder, 1999).

- Application of the bi-static, laser-line imager ROBOT providing 3-D measures of sand waves, stromatolites, grass beds, and mine simulants have been reported (Carder et al. 2001; Hou et al. 2002).

Summary of CoBOP field efforts

- over 2,000 Hyperspectral (512-channel) downwelling irradiance and upwelling radiance spectra were acquired during 100+ vertical profiles performed using the ROSEBUD ROV over sand, sea grass, and corals.

- 6-channel, intensified bottom-albedo-video, NTSC-color-video bottom imagery, and a suite of IOP measurements were also obtained during each ROV deployment during each year.

- nearly 200 JSD drop-package casts were performed from the R/V Suncoaster and the R/V Subchaser. The JSD recorded CTD, ac-9, 0.2 micron-filtered ac-9, 488-nm attenuation, 830 nm backscatter, 6-channel HS-6 backscatter, Flashpak CDOM fluorescence, and chlorophyll fluorescence.

- Sea surface Rrs, filter pad (pigment, detrital, and CDOM) absorption and fluorometric chlorophyll were obtained at 118 stations.

- Color video bottom imagery was obtained during mapping transects in all field campaigns using the R/V Subchaser stern-mounted bottom camera. The imagery is overlaid with GPS position and time. The Subchaser ship computer simultaneously logs water depth and surface temperature, boat speed and heading, and data from the boat meteorological instrumentation. The data are being input into a GIS data base (ArcView V3.1) for integration with data from other investigators.

- land-based atmospheric data were obtained (Reagan solar transmissometer, Licor, Micro-tops) daily as well as frequent ship-based R_{rs} measurements in support of the FILLS sensor flying aboard the AN-2 aircraft (C. Davis, NRL Washington).

RESULTS

- Bottom texture (i.e. sandwaves) can spectrally alter upwelling radiance as a function of sun angle due to the spectral difference between diffuse and collimated solar illumination (Carder et al. in press). Aircraft images were collected near Lee Stocking Island (LSI), Bahamas with wave-like features for bright sand bottoms during times when solar zenith angles were large. The image contrast between leading and trailing sand-wave facets approached a 10-15% difference due to algae accumulations in wave troughs or topographic variations of the bottom. Reflectance contrast for blue light was greater than for red and green wavelengths when algae or detritus is present in the troughs. However, the contrast at green and red wavelengths was greater than at blue wavelengths when caused by the interplay between bottom topography and oblique illumination.

- Water-Raman scattering and chlorophyll a fluorescence are extremely significant components of the upwelling light field at depths > 2 m and wavelengths > 520 nm over coraline environments and cannot be ignored in evaluating bottom-reflected (active or passive) radiance.

- Solar-stimulated fluorescence at 685 nm from sediments due to benthic diatoms is ubiquitous on the Florida shelf, off the Florida Keys, and around Lee Stocking Island, Bahamas in sufficient intensity to allow the acquisition of narrow-band fluorescence bottom imagery (intensified video) from depths of 7 m to > 20 m.

- Animals (e.g. sponges) and man-made objects are readily apparent by their dark contrast with the bright, red, bottom fluorescence from benthic diatoms, coral symbionts, and macrophytes.

- Range to various components in an image greatly affects the 685-fluorescence signal since the e-folding depth through water is 2.5 m. Correction for range is critical for image interpretation.

- Wave focusing has a very significant spectral impact on the instantaneous downwelling light field on clear days providing red-rich irradiance in focal zones and blue-rich irradiance in divergence zones. Field measurements of IOPs and AOPs have allowed spectral model closure calculations to simulate the instantaneous spectral light field measurements. Increases in aerosols decrease these fluctuations due to wave focusing, stabilizing the light field (Costello et. al., 1998a). In clear, shallow coastal waters, upwelling radiance can be significantly affected by bottom reflection of focused downwelling irradiance (Costello et. al., 1998b).

- High-contrast, "patchy" bottoms in shallow waters can produce an increase in downwelling irradiance of up to 20% due to internal reflection of light beyond the critical angle (~48°) from bright sandy regions. Furthermore, the increased irradiance changes as a function of sensor depth convolved with the water column depth and the horizontal distance to contrasting "patches" (Costello and Carder, 1999). This large an effect indicates models assuming homogeneity in horizontal light fields must be applied judiciously.

- Adjacency effects can cause a significant overestimate of bottom albedo for grass or coral as determined by in-water or air- or space-borne sensors (Hou et al. 2001, Farmer et al. 2001).

IMPACT/APPLICATIONS

Analysis of our hyperspectral light-profile data sets indicated that wave focusing and Raman scattering added significant complexity to models of the submarine light field. Moreover, modeling efforts toward addressing the complexities using Smith and Baker's (1981) water absorption numbers were generally fruitless. Use of Pope and Fry (1997) numbers, modeled skylight and sunlight fields (Gregg and Carder, 1990) and focus/defocus of the sunlight contribution provided modeled light fields consistent with measurements. Fluorescence and primary production models need to consider the nonlinear aspects of this light field versus traditional time-averaged methods.

Variations in the 685 nm fluorescence yields, suggested by our observations, ranged from high for hard-bodied coral, medium for branching coral, to low for benthic diatoms. These differences suggest possible automatic classification schemes if adequate range information is available. Certainly, non-vegetative bottom features such as animals and man-made objects are sharply discernible when viewed at 685 nm, and path radiance due to backscattering does not reduce image contrast for fluorescence-dominated scenes.

Calibration changes with vibration, temperature, and time for aircraft and spacecraft sensors. Recalibration is critical since a small change in calibration can introduce large errors. For example, the atmosphere contributes 90% (or more) of the radiance received at a space-borne sensor. Just a 2% shift in calibration would, then, result in a 20% error in the calculated water-leaving radiance. Reinersman et al. (1998) provide a vicarious method to re-calibrate a sensor that simply depends on finding small, compact clouds in a scene.

TRANSITIONS

The hyperspectral data acquired during this project has aided other projects (see RELATED PROJECTS section) in efforts toward the development and validation of algorithms for remote sensing of water constituents and bathymetry in coastal waters. In addition to the transitions reported through the publications referenced, the CoBOP-generated data base has been sent to the WOODS Data Center.

RELATED PROJECTS

As part of the CoBOP Directed Research Initiative, this project is synergistic with numerous other CoBOP investigations and several multi-discipline investigations are underway. This project also provides significant data to and benefits from important instrumentation developed under "Optical Variability and Bottom Classification in Turbid Water" (ONR CODE 3220M).

Other collaborative projects:

ONR - *An AUV-based investigation of the role of nutrient variability in the predictive modeling of physical process in the littoral ocean*. PIs - K.A. Fanning and J.J. Walsh (USF).

ONR - *A simulation analysis of the time-dependent roles of phytoplankton and CDOM in effecting the 3-dimensional structure of inherent optical properties on the West Florida shelf*. PI - J.J.Walsh (USF)

ONR - *A Multi-Disciplinary Investigation of the Nature and Predictability of Sediment Resuspension in Shallow Water: Its Effect on Water Column and bottom Optical Properties*. PIs - A.C. Hine, D.P. Howd, D. Mallinson, D. Naar (USF), D. Wilson (USGS)

NRL - *Hyperspectral Modeling of Harmful Algal Blooms on the West Florida Shelf*. PI - W. P. Bissett (Florida Environmental Research Institute)

NASA Project - *Hyperspectral characterization of gelbstoff for application to remote sensing of carbon cycling in coastal regions*. PIs - P.Coble and C.Castillo (USF)

NASA (EOS) - *High spectral resolution MODIS algorithms for ocean chlorophyll in case II waters*. PI - K. Carder

NOAA - *Ocean Color Algorithm Evaluation for Remote Sensing of Coastal and Estuarine Waters*. PIs - R. Stumpf, P.Testor, J.Pennock, C.Tomas, R. Arnone, and K.Carder

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