# A Look-up-Table Approach to Inverting Remotely Sensed Ocean Color Data


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## LONG-TERM GOAL

The overall goal of this work is to develop and evaluate a new spectrum-matching technique for inverting remotely sensed hyperspectral signals to recover environmental information.

## OBJECTIVES

We are developing and evaluating a new technique for the extraction of environmental information such as water-column inherent optical properties and shallow-water bottom depth and classification from remotely-sensed hyperspectral ocean-color spectra. Our technique is based on a "look-up-table (LUT)" approach in which the measured spectrum is compared with a large database of spectra corresponding to known water, bottom, and external environmental conditions. The water and bottom conditions of the water body where the spectrum was measured are then taken to be the same as the conditions corresponding to the database spectrum that most closely matches the measured spectrum. The research issues center on development and evaluation of spectrum-matching algorithms, including quantification of how various types of errors in the measured spectrum influence the retrieved environmental data.

## APPROACH

The technique has been developed using Hydrolight-generated pseudodata. We are now in the process of applying the LUT technique to Ocean PHILLS (Ocean Portable Hyperspectral Imager for Low-Light spectroscopy; Davis, et al., 2002) imagery taken during the CoBOP (Coastal Benthic Optical Properties) field experiments.

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**The overall goal of this work is to develop and evaluate a new spectrum-matching technique for inverting remotely sensed hyperspectral signals to recover environmental information.**

15. SUBJECT TERMS

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The Hydrolight radiative transfer numerical model (www.hydrolight.info; Mobley, 1994; Mobley and Sundman, 2001a,b) gives an exact solution of the in-water radiative transfer equation given the water inherent optical properties (IOPs, namely the absorption and scattering properties of the water body), the incident sky radiance, and the bottom depth and reflectance (bottom BRDF). The water IOPs can be built up from any number of components, such as various microbes, dissolved substances, organic detritus, mineral particles, or microbubbles. For remote-sensing purposes, the relevant Hydrolight output is the spectral water-leaving radiance or the remote-sensing reflectance.

The first step in the recovery of environmental information from a hyperspectral image is to construct a database containing spectra from a large number of Hydrolight runs corresponding to different combinations of water composition (different microbial, dissolved, or mineral substances at different concentrations), bottom conditions (sand, seagrass, coral, etc. at various depths), sky conditions (different solar angles and atmospheric conditions), sensor viewing directions, wavelengths, and so on. The resulting water-leaving radiances in the database, $L_{wd}(\lambda)$, are in principle all unique (but in practice may often be similar; $\lambda$ is the wavelength). Given a measured water-leaving radiance $L_{wm}(\lambda)$ (obtained after atmospheric correction of an at-sensor radiance), one can then "look up" the $L_{wd}(\lambda)$ spectrum that most closely matches $L_{wm}(\lambda)$. The water IOPs and bottom conditions in the actual water body are then taken to be the values that were used in Hydrolight to generate the selected $L_{wd}(\lambda)$. We thus effect an inversion of the measured spectral signature by the conceptually simple process of spectrum matching and then looking up the answer in the database.

## WORK COMPLETED

This year's work consisted primarily of algorithm development and evaluation using Hydrolight-generated synthetic data. Representative IOPs and bottom reflectances measured during the CoBOP field experiments at Lee Stocking Island (LSI), Bahamas were assembled. Figure 1 shows some of the bottom reflectance spectra obtained in the vicinity of LSI. These data, along with measured and modeled IOPs for Case 1 and 2 water and bottom reflectances from other locations, were used in a special version of Hydrolight to generate a database of 2,200 $R_{rs}$ spectra. An independent test set of $R_{rs}$ spectra was similarly generated. These initial spectra were used for in debugging code, examining ideas and spectrum-matching algorithms, and discussion of database formats, before proceeding with the generation of a larger database for operational use.

Six different spectrum matching algorithms were developed and compared using the pseudodata (for which the "correct answer" is known). The initial results were very encouraging. We therefor then generated an expanded database of 5,750 $R_{rs}$ spectra for use in processing a PHILLS image acquired on May 20, 2000 during the closure experiment of the final CoBOP field year. These spectra were generated by 5,750 independent Hydrolight runs using all combinations of 10 sets of water inherent optical properties, the 23 bottom reflectance spectra of Fig. 1, and 25 water depths. These $R_{rs}$ spectra are shown in Fig. 2. These spectra are now being used for pixel-by-pixel processing of the PHILLS image.

This work does not involve the acquisition of field data. Therefore, no data have been submitted to any national data archive.

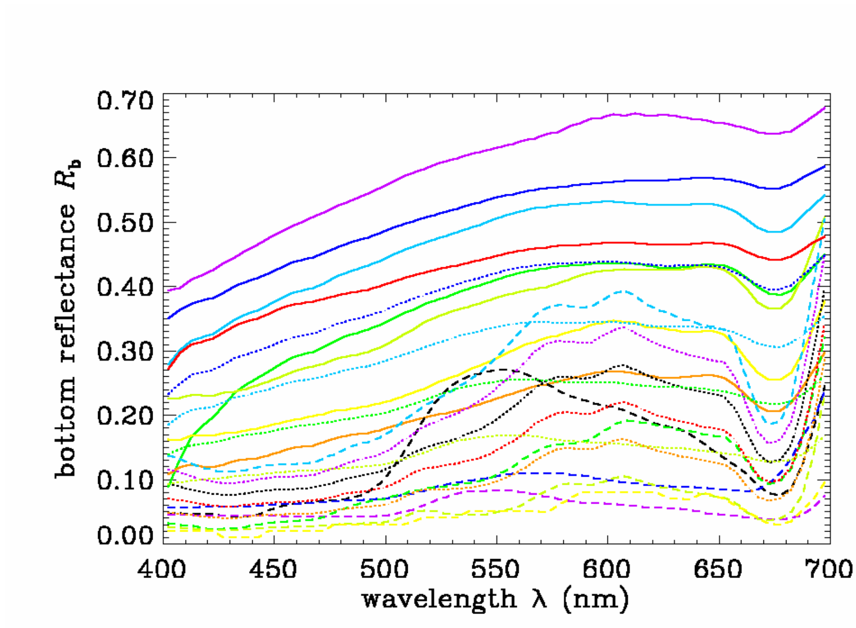


***Figure 1. The 23 bottom reflectance spectra used to generate the remote-sensing reflectance database of Figure 2. Solid lines are measured reflectances for sediments (ooid sand, grapestone, etc). The dashed lines are measured spectra for biota (seagrass, corals, red and green algae). The dotted lines are spectra for combinations (e.g., 40% sea grass and 60% sand).***

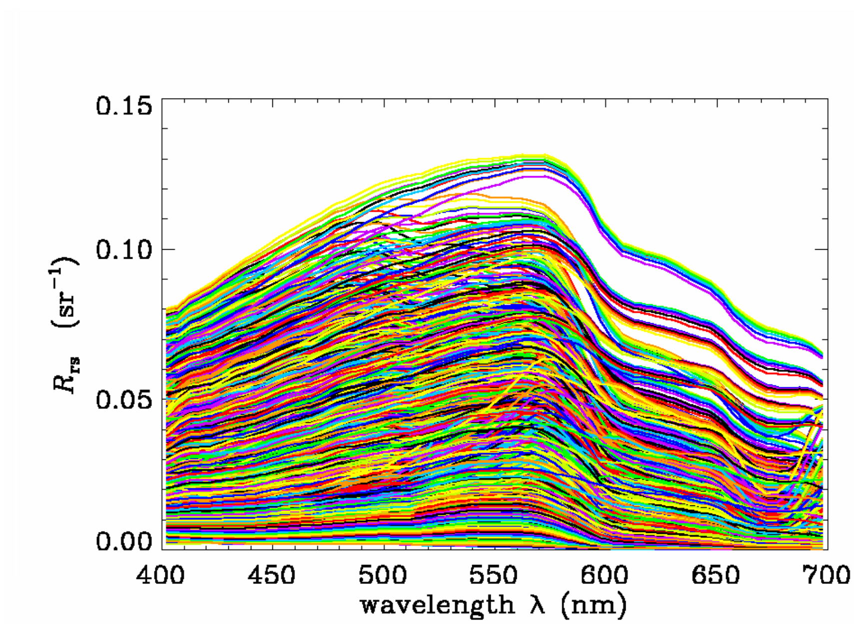


***Figure 2. The 5,750 remote-sensing reflectance spectra (10 sets of IOPs x 23 bottom reflectances x 25 bottom depths) being used to match PHILLS spectra pixel by pixel.***

## RESULTS

The algorithm evaluation based on the pseudodata led to the following conclusions. Details can be found in Mobley (2002).

- The database search problem is numerically simpler and faster than originally thought. For example, doing a brute-force search of 100,000 randomly generated 60-wavelength $R_{rs}$ spectra to see which one is closest to a given spectrum requires only 0.1 seconds on a 600 MHZ PC. In practice, spectral databases will likely contain far fewer spectra, and search times will not be a problem. This means that near-real-time processing of PHILLS images may be feasible.

- The choice of spectrum-matching algorithm may not be critical, and wavelength-uncorrelated random noise is not likely to be a problem. The six different spectrum-matching algorithms evaluated so far performed comparably in finding the closest database spectrum. There are some minor differences, but all did rather well at extracting environmental information when applied to the test spectra. Wavelength-uncorrelated random noise does not greatly impede the spectrum matching. (However, it remains to be seen if there are significant differences in algorithm performance when applied to real data, which may have noise characteristics that favor particular search algorithms.)

- Finally, the LUT approach to retrieving IOP, bottom reflectance, and bottom depth information from remote-sensing reflectances performed well with the test data.

The details of this work will be reported at the Ocean Optics XVI conference.

## IMPACT/APPLICATION

The problem of extracting environmental information from remotely sensed ocean color spectra is fundamental to a wide range of basic and applied science problems. No single inversion technique can be expected to be superior in all situations; therefore all techniques must be evaluated. In addition to investigating a new type of inversion, part of our work is to evaluate when the LUT technique is superior to other techniques, and when it is not. This work thus adds to the existing suite of remote sensing analysis techniques.

## TRANSITIONS

The various databases of water IOPs, bottom reflectances, and resulting $R_{rs}$ spectra, along with all specialized Hydrolight code and spectrum-matching algorithms have been transitioned to Dr. Curtiss Davis (NRL Code 7212) to support his exploitation of the Ocean PHILLS hyperspectral ocean color remote sensing system to retrieve bottom bathymetry and bottom classification information in optically shallow waters.

## RELATED PROJECTS

This work is being conducted in conjunction with Dr. Curtiss Davis and colleagues at the Naval Research Laboratory, Washington D.C., who are separately funded under Hyperspectral Characterization of the Coastal Ocean (HCCO). The PHILLS image now being analyzed was provided by NRL. The water IOPs and bottom reflectance spectra used to generated the $R_{rs}$ database spectra characteristic of Lee Stocking Island, Bahamas were obtained from CoBOP investigators Charles Mazel, Pamela Reid, Emmanuel Boss, and Ronald Zaneveld.

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