New image analysis method improves assessment of coral reefs

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Using hyperspectral remote sensing data, a new processing technique extracts multiple layers of environmental information about a coral reef ecosystem.

Coral reefs, like many of our planet’s ecosystems, are threatened by increasing pressures from anthropogenic stressors and the impacts of global change. The current consensus is that without efforts directed towards their conservation and protection, coral reefs face a decline. These remarkable underwater communities play important roles in marine health and biodiversity, and provide numerous additional ecological, economic, and aesthetic benefits. Effective management involves merging knowledge from a diverse set of scientific and social disciplines, and also requires effective tools for assessing reef status and health. Remote sensing, which provides the advantage of synoptic spatial coverage, offers a valuable tool for mapping and monitoring coral reefs.

Remote sensing imagery enables repeatable, quantitative assessments of environmental characteristics such as habitat composition. However, the effective use of remote sensing of coral reefs is challenged by the confounding effects of the overlying water column. Specifically, the strong absorption of light (at all wavelengths except in the visible portion of the spectrum), spatially and temporally variable water properties, and influences from surface waves all make it difficult to resolve information on the benthic habitat. As a result, image analysis typically requires significant simplifying assumptions and/or a priori information regarding these variables, or, as presented here, a methodology for simultaneously deriving both the water column parameters and benthic characteristics.

Remote sensing analysis capabilities continue to improve, particularly with respect to sensor performance and algorithm sophistication. These advances can improve the classification accuracy in coral reef applications, particularly in the field of hyperspectral remote sensing. Rather than being restricted to a limited subset of spectral bands, hyperspectral imagery measures numerous, narrow, contiguous portions of the spectrum. This spectral detail provides valuable added information to improve image analysis capabilities, and also enables the differentiation and classification of multiple environmental parameters.

The hyperspectral imagery used in this research was acquired by the National Aeronautics and Space Administration (NASA) Airborne Visible Infrared Imaging Spectrometer (AVIRIS) over Kaneohe Bay, Hawaii in 2000. AVIRIS measures 224 spectral bands from 370–2500nm at a spectral resolution of 10nm. Images were collected using an ER-2 aircraft at an altitude of 20km, producing a nominal pixel size of 17m and a swath width of 10km.

Figure 1. Model-derived benthic composition for Kaneohe Bay, Hawaii, with an inset showing patch reefs and a portion of the reef flat.

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Figure 2. The hyperspectral project study area in southwestern Puerto Rico is centered on Enrique Reef.

Kaneohe Bay is a partially enclosed embayment on the windward shore of Oahu containing fringing reefs, an extensive barrier reef, numerous patch reefs, and a large lagoon area. Among its benthic habitats, the bay includes a range from coral- to algae-dominated systems.

The image analysis approach used in this study integrates a series of processing steps to resolve the complex interactions between atmospheric conditions, bathymetry, sea surface state, water optical properties, and bottom composition. The method starts with radiometrically corrected AVIRIS imagery, which is preprocessed using the Tafta algorithm for atmospheric correction and a straightforward 750nm normalizing scheme to remove the effects of sunglint. The next step is to implement the semi-analytical inversion model developed by Lee et al., which uses a nonlinear optimization scheme to independently derive bathymetry and water properties for every pixel in the image.

Our innovation is to take the output from these processing steps and use it as the basis for a spectral unmixing scheme to derive benthic composition. Specifically, we measured reflectance spectra representing the dominant benthic components (e.g., spectral endmembers for sand, coral, and algae) and independently transformed them for each pixel using output from the inversion model as input to a forward version of the same model. Next, we used a constrained non-linear unmixing model to classify benthic composition as a function of the fractional contribution from each endmember (see Figure 1). Analysis using field data as ground truth indicated an overall accuracy of 80% for this method in water depths from 0–3m for mapping the distribution of coral, algae, and sand in Kaneohe Bay.

Current research aims to improve this processing scheme and develop other new subsurface coastal remote sensing analysis methods. This research is being conducted as part of a broad-reaching collaborative effort within the National Science Foundation-sponsored Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (Gordon-CenSSIS). The coral reef component of this research is centered on projects in southwestern Puerto Rico (see Figure 2), where an extensive set of field and image data is being compiled. The objective here is to collect multiple levels of image, field, and laboratory data with which to validate physical models, inversion algorithms, feature extraction tools, and classification methods for subsurface aquatic sensing. The data currently includes airborne, satellite, and field-level hyperspectral and multispectral images, in situ spectral signatures, water bio-optical properties, and information on habitat composition and benthic cover. Ultimately, by improving and extending the overall capabilities for benthic habitat monitoring, the resulting spatial analysis tools will contribute an essential component of resource management decisions and risk management evaluations.

A portion of this work was supported by NASA Headquarters under Earth System Science Fellowship Grant NGT5-ESS/01-0000-0208. Work was also supported by Gordon-CenSSIS under the Engineering Research Centers Program of the National Science Foundation (Award Number EEC-9986821).

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References