ENVIRONMENTAL PROPERTIES OBSERVED FROM AVIRIS DATA

Zhongping Lee,[1] Kendall L. Carder and Robert F. Chen

Abstract

In this study, we are showing that the under-water information of broad area can be adequately obtained with an imaging spectrometer, such as the Airborne Visible-InfraRed Imaging Spectrometer (AVIRIS). Using a newly developed algorithm, environmental properties of Tampa Bay were derived from AVIRIS data. The derived properties include bottom depth, bottom albedo, and absorption coefficients. The derived bottom depths were compared with bathymetry charts and found to agree very well. Also, the derived image of bottom albedo shows clear bottom patterns, while the image of absorption shows the waters of study were quite mixed. These results suggest that the algorithm used works very well for the retrieval of under-water properties of shallow water environments.

1. Introduction

Remote sensing by aircraft or satellite has been proven very useful to quickly provide important environmental information over large areas. However, due to reasons from research priorities to problem complexity, shallow nearshore waters are less studied using satellite imagery. When it was studied, such as depth retrievals from Landsat images (Clark et al., 1987), many assumptions were made or some kind of ground truth data were required. Those assumptions may be adequate for some studied areas, but they are difficult to apply to more complicated regions. A reliable and practical technique, with the ability to be applied broadly, is desired for retrieving properties of shallow/nearshore coastal waters from spectral imagery.

Based on a semi-analytical model for shallow-water remote sensing (Lee et al., 1998), and using an optimization approach (Lee et al., 1999), under-water information such as bottom depth and water-column properties have been ***analytically and simultaneously*** derived from above-water, shipborne data. In the processing, no other data were used than the measured remote-sensing reflectance. The retrieved depths agreed with the true depths within 8% for a range of 2 to 25 meters for waters of the west Florida shelf, the Florida Keys and the Bahamas (Lee et al., 1999), where water's beam attenuation coefficient at 440nm ranging from 2.0 to 0.05m^{-1}. These kinds of results provide confidence that properties of submerged coastal environments such as bathymetry, water quality parameters (e.g., absorption, back scattering coefficients) and bottom albedo can be derived just from the passive hyperspectral data, as long as the data are calibrated, atmospherically corrected and have an adequate signal-to-noise ratio.

In this study, using AVIRIS data over the Tampa Bay area, we show that the model-driven optimization technique (Lee et al., 1999) can be applied to spectral images of fairly turbid shallow coastal waters to adequately retrieve under-water information, with no need for a prior knowledge about water optical properties or bottom reflection. Actually all the information was derived from AVIRIS data.

[1]Department of Marine Science, University of South Florida (zplee@monty.marine.usf.edu)

2. Aviris data

AVIRIS (Low Altitude) data over Tampa Bay were collected from a Twin-Otter aircraft flying at 12,500 feet altitude on October 18, 1998 at noon. The area contained complex bathymetric and bottom features of sand and grass types. Figure 1 shows the study area. The AVIRIS LA radiance calibration and atmospheric correction were performed vicariously using the method of Carder et al (1993), which was consisted of comparing modeled-upwelling radiance at the aircraft altitude to AVIRIS data for a deep-water site (not on this image) where the water-leaving radiance was known and relatively uniform. After the correction, the ratio of the calculated water-leaving radiance to MODTRAN4-calculated downwelling total irradiance at the surface provided remote-sensing reflectance $R_{rs}(\lambda)$ curves.

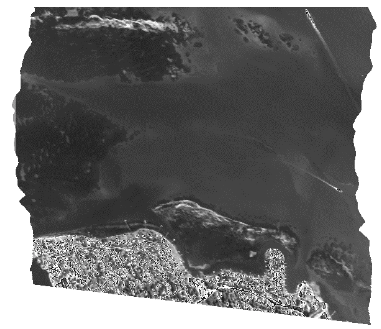

Figure 1. The study area.

From Figure 1, it is easy to imagine that the study area is very complicated, with bottom types ranging from sand to seagrass, and very turbid waters. Traditional approaches often have to avoid regions like this, due to lack of knowledge about the water column contributions, the attenuation coefficients, and bottom albedos.

3. Inverting remote-sensing reflectance (R_{rs}) spectra

In order to retrieve the bottom depth, the water-column contributions and optical properties of the water column have to be known or derived. Traditionally values for water-column contributions were replaced by values of adjacent deep waters (e.g., Polcyn et al., 1970; Lyzenga, 1978), and water-attenuation values were assumed known *a prior* (Paredes and Spero, 1983) or empirically derived by regression using a few true depths provided by LIDAR or on-site ship measurements (Lyzenga, 1981, 1985). All of these methods require some true depths or known attenuation values. This suggests that if neither of those conditions is met, bottom depth could not be derived. This is the most common situation remote-sensors encounter.

To be able to derive properties of shallow-water environments anytime and anyplace, it is desired to ***simultaneously*** derive bottom depth and albedo and the optical properties of the water column. The model-driven optimization technique developed by Lee et al. (1999) demonstrated that most of the under-water information could be derived from the measured spectrum of remote-sensing reflectance and some generic optical properties of constituent end-members of the system (e.g., Lee et al., 1998, 1999).

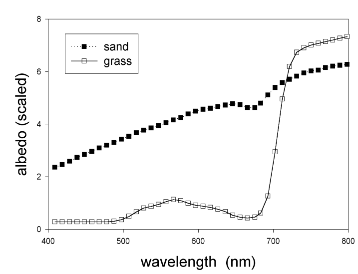

Figure 2. Spectral curvatures of sand and seagrass albedo.

Since a bottom pixel in the image could be of sand or seagrass or some kind of mixture, and the spectral curvatures of sand and seagrass albedos differ greatly (see Figure 2), we used the following empirical conditions to select the albedo curvature to be used in the inversion for each pixel:

if $R_{rs}(\lambda)$ of a pixel satisfy

$$R_{rs}(550) < 0.01 \text{ and } R_{rs}(710)/R_{rs}(670) > 1.1,$$

the albedo curvature of seagrass is used, otherwise, the albedo curvature of sand is used.

A computer program has been built for processing large data points. Note that no field data are required except the measured $R_{rs}(\lambda)$ curves.

4. Results and discussion

Figures 3 - 6 show the retrieved results from AVIRIS data. Since the optimization program runs longer time for inversion than for empirical algorithms, we sub-sampled the AVIRIS image by every 2 pixels to reduce the overall processing time. This sub-sampled image loses spatial resolutions from 5m to 10m, but still shows the general features retrieved from the spectral imagery.

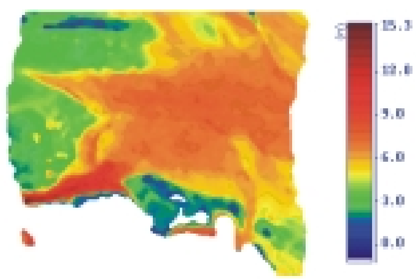

Figure 3. Image of derived depths.

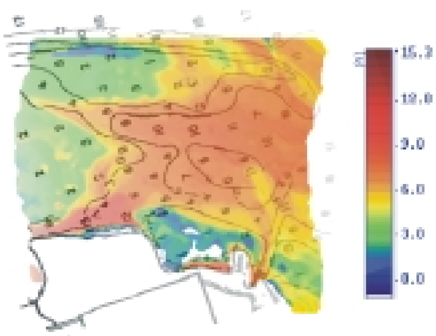

Figure 4. Comparison of depths from AVIRIS and NOAA chart.

Figure 3 shows the image of retrieved bottom depth. The derived depths are in a range of 1 to 15 feet after tidal correction. From this AVIRIS image, we see that the bottom was deeper in the middle (7 - 9 feet), surrounded by shallower sand/grass plateaus (2 - 5 feet), with the deepest place being the channel in the left-lower corner.

To see how good the derived depths were, we superimposed the depth chart from NOAA chart No.11414 on the AVIRIS image (Figure 4). The depths in the chart were surveyed before June 1990. Clearly we see that they both were quite consistent with each other, except the places where seems substantial environmental changes.

Figure 5 shows the image of bottom albedo at 550nm. The bottom albedo values ranged from 0.04 to 0.2 in general, with a few pixels around 0.3 (top-mid-left). These values are consistent with the values of typical grass (low values) and sandy bottoms (high values). If we set criteria such that albedo values less than 5% for pure seagrass, greater than 10% for pure sand, then this image suggests that it is seagrass on the left side, sand on the right. On the top-mid-left, there is a strip of shallow sandy bar. Increased organic fraction in the sediments lowers the albedo values as does patchy grass found in a pixel.

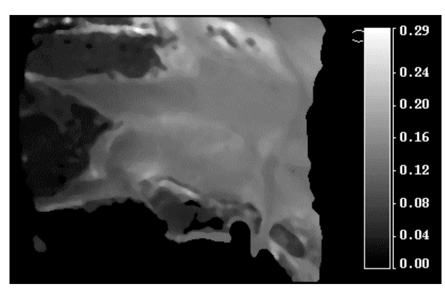

Figure 5. Image of derived albedo at 550nm.

Figure 6 shows the image of the total absorption coefficient at 440nm. Most of the absorption values fall in a range of 0.6 - 1.1m^{-1}, with a few higher values of 2.0m^{-1} at the shallow, land boundaries (the city of St. Petersburg, Florida; also see Figure 1). In the middle of the image, the absorption coefficient is generally uniform, with a value of 0.7m^{-1}. Comparing Figure 6 and Figure 5, we see little covariance between images, except for the grass canopies in extremely shallow waters. This suggests that the water of the image is rather uniform, and the small patchiness were revealed through hyperspectral inversion.

Figure 6. Image of derived *a*(440).

As we can see from the above images, there were no significant co-variances between the retrieved water-column and bottom variables. These results suggest that the process used in this study works very well for the retrieval of under-water properties of shallow water environments. And, with the retrieved information regarding bottom depth and optical properties of the waters, it would be straightforward to estimate the light availability to bottom features. This will certainly help analyze the health of benthic habitats of coastal shallow waters.

5. References

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