WATER COLUMN CORRECTIONS OF AVIRIS DATA FOR HYPERSPECTRAL CHARACTERIZATION OF BENTHIC MARINE COMMUNITIES IN PUERTO RICO

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ABSTRACT

In December 2005 NASA's Airborne Visible Infrared Imaging Spectrometer (AVIRIS) was flown at low altitude over selected coastal areas in Puerto Rico. In support of the AVIRIS mission, simultaneous field data were collected on underwater calibration target reflectance and spectral signatures of benthic components. The *in situ* flat-field calibration target reflectance was evaluated as a new way of correcting for the effects of water column attenuation. This approach transforms at-sensor radiances, in the absence of atmospheric corrections, to underwater reflectance factors. In testing this technique, an atmospheric correction was first performed using Tafkaa followed by the water column correction. We used black and white tarps as underwater calibration targets in the back-reef lagoon of a coral reef in La Parguera, Puerto Rico. A sand area was used as a validation target for the corrected AVIRIS image. Field and AVIRIS reflectance values agreed by <10% from 400-600 nm to up to 18% from 600-700 nm. Representative field spectra from corals and other benthic types showed good agreement with AVIRIS estimates considering the heterogeneity of these benthic habitats even at the relatively high (~3 m) spatial resolution of the AVIRIS data.

INTRODUCTION

The information provided by satellite remote sensing on coral reefs and other heterogeneous benthic communities has been limited by the spectral and spatial resolution and the low signal to noise ratio of existing satellite sensors. The exponential attenuation of the water column is another limiting factor for the remote sensing detection and quantification of benthic biotopes. The variable absorption and scattering properties of the water column will modify the magnitude and spectral shape of the benthic reflectance. Even in highly transparent tropical waters, the confounding effects of variable bathymetry could be significant. In reviewing relevant papers, only 4 studies out of 45 (9 per cent) attempted water column corrections (i). The implementation of water column correction algorithms could be difficult in areas that lack detailed bathymetry or where the water attenuation coefficients are highly variable.

The best known water column correction technique creates a single "depth-invariant" band from each pair of visible spectral bands (ii, iii). In this algorithm, the exponential attenuation of the water column is first linearized for each band followed by the calculation of the ratio of the attenuation coefficients of each pair of bands.

In December 2005 the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) was flown on NASA's Twin Otter aircraft at low altitude over selected coastal areas in southwestern Puerto Rico producing a pixel size of approximately 3 m. The AVIRIS has 224 contiguous spectral bands from 380 to 2500 nm and a spectral resolution of about 10 nm. Of these, 32 bands are in the visible region (400-700 nm) with a high (~1000) signal to noise ratio. This AVIRIS mission provided the ideal dataset for studies of shallow coral reef environments and the opportunity to evaluate a water column correction technique that uses underwater homogeneous calibration targets or "flat fields".

Field spectra from corals, algae, gorgonians, seagrass, and sand were compared to the corresponding AVIRIS-derived spectra in areas where these targets were dominant within the AVIRIS spatial resolution. This work is part of a larger study that includes the classification of benthic types using spectral signatures, temporal and spatial trends in coral reef biodiversity, and the impact of the 2005 bleaching event in Puerto Rico and the US Virgin Islands (iv).

METHODS

During December 12-13, 2005, AVIRIS was flown in a grid of overlapping solar azimuth lines over La Parguera, Puerto Rico (Figure 1). During both days field spectra of the calibration targets at Enrique Reef and profiles of water spectral attenuation coefficients were obtained throughout the study area. A GER 1500 (Spectra Vista Corporation) spectroradiometer in an underwater housing was used to obtain spectral measurements of the white and black calibration targets within 30 minutes of the aircraft overflight. Each tarp measured 10 x 10 m and was placed in the back-reef

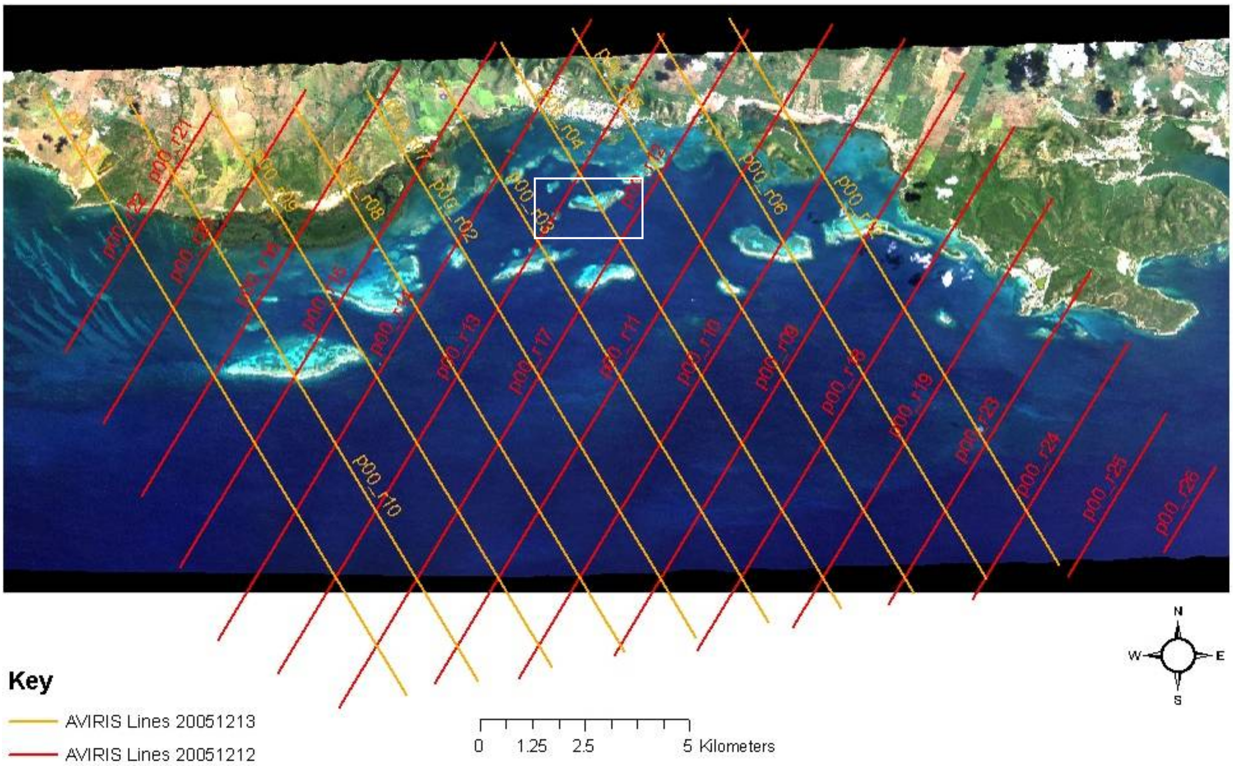


Figure 1: December 12-13, 2005 AVIRIS flightlines over La Parguera, Puerto Rico. The white box shows the location of Enrique Reef.

lagoon of Enrique Reef at a depth of 2 meters (Figure 2). A Spectralon standard calibration panel was used to convert the *in situ* radiance measurements to reflectance factors. Spectral measurements from a nearby sand area were used for validation purposes. The spectroradiometer and Spectralon panel were also used to generate a spectral library of the dominant benthic types.

Figure 2: The dark (left) and bright (right) underwater calibration tarps at Enrique Reef.

The AVIRIS data was first preprocessed for the suppression of a halo present in the near-infrared bands around the central stripe of the imagery. This halo was caused by stray-light leakage following an upgrade to the instrument in 2004. It was suppressed by matching the digital numbers at the boundary with a fade function away from the image centerline (Figure 3). This anomaly affects the estimate of water vapour column concentration and optical depth determinations. The atmospheric correction was performed using Tafkaa, an algorithm for atmospheric correction of imaging spectrometry data (v, vi). Two runs of Tafkaa were used: the first to determine an appropriate water vapour and optical depth over the water within each flight line followed by a second run to apply those values across the scene, including the land pixels. The JPL supplied geocorrection ancillary data was used for georeferencing the images.

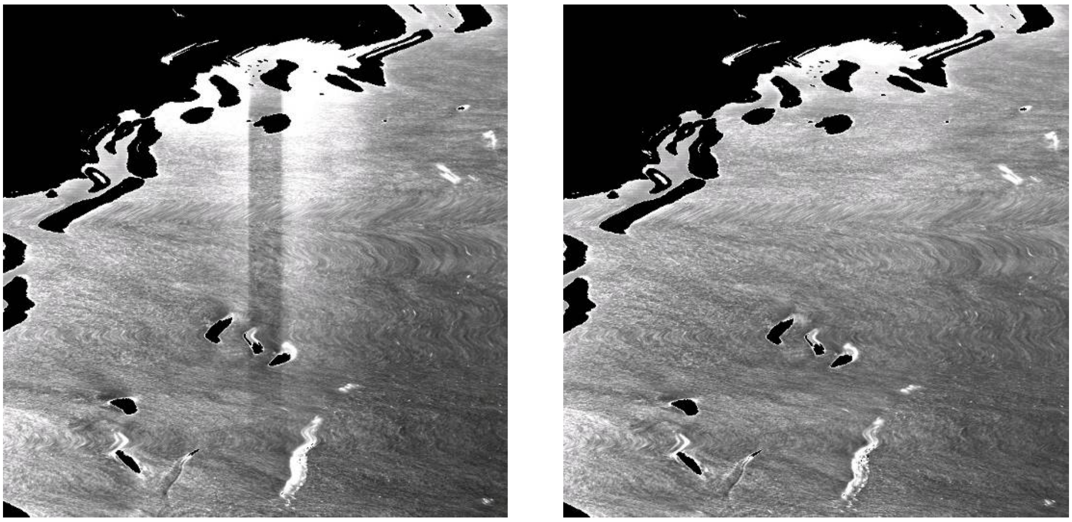


Figure 3: Original subset image with central stripe (left) and after halo suppression (right).

RESULTS

The AVIRIS subset of Enrique Reef, after preprocessing and water column correction, is shown in Figure 4. The large green areas in the back-reef lagoon are seagrass beds. At the validation site, the AVIRIS sand spectrum agrees with field values within 10% from 400-600 nm and up to 18% from 600-700 nm (Figure 5). Spectral absorption features are preserved, mostly corresponding to pigment absorption by microbial layers. The effect of water column correction on the spectral signature of corals is shown in Figure 6. In this case, the absorption features that characterize corals and other benthic organisms with endosymbiotic algae or zooxanthellae are completely masked by the water column (Figure 6a). The AVIRIS water column corrected data provides spectral curves (Figure 6b) that more closely resemble the *in situ* spectra of corals (Figure 6c). The observed

Figure 4: AVIRIS subset of Enrique Reef and adjacent reefs after water column correction. The white and dark pixels within the central oval are the underwater calibration tarps.

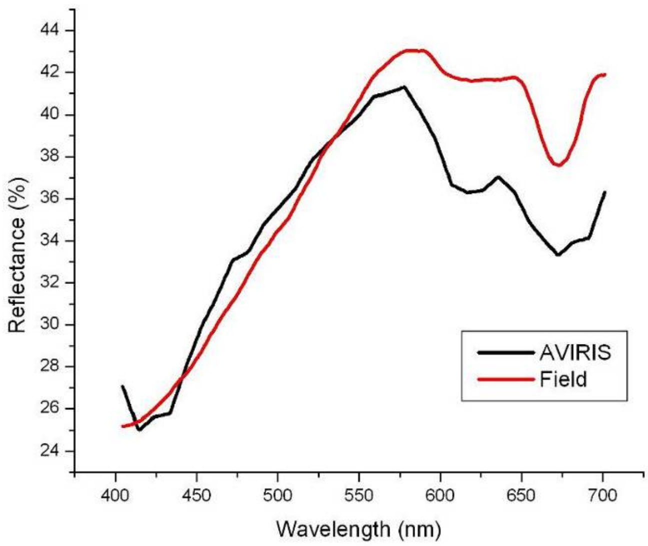
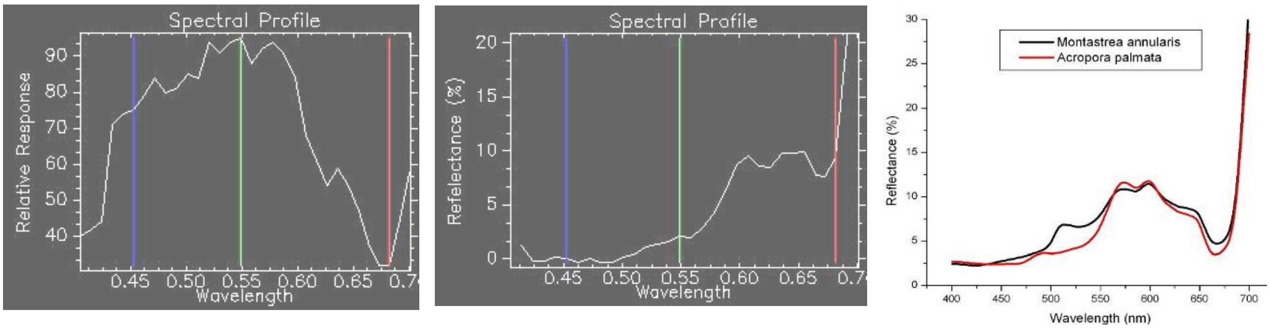


Figure 5: Water column correction validation using a sand target.



A B C

Figure 6: AVIRIS coral spectrum without water column correction (A) and after the correction (B). Representative field spectra from two species of corals is shown for comparison (C).

differences are probably due to variations in species assemblages, degree of pigmentation and mortality, structural complexity, shade, and the presence of other organisms or exposed substrates within the AVIRIS pixel size. Further processing of the data using unmixing algorithms will address some of these issues.

CONCLUSIONS

Unlike Lyzenga's (ii, iii) approach to water column corrections, the field calibration methodology presented here preserves the full dimensionality of the remote sensing data in its original spectral space. In addition, no field data or image-base estimates of the spectral attenuation coefficients are required. The main limitations of this approach are the logistics of placing calibration targets of adequate size (3 times the pixel size) underwater and the measurements of their reflectance properties during the overflight. This technique is also applicable to data that is not atmospherically corrected since at-sensor radiance is converted to underwater *in situ* reflectance. Since the corrections are made for the depth of the calibration targets, areas with variable bathymetry will require a different approach or further processing if the water attenuation coefficients are known. In the case of Enrique Reef, since the back-reef lagoon has a nearly constant depth of 2 m, this was not a factor to be considered. This water correction technique was useful for extracting spectral data from coral reef benthic types producing data that compared favourably to field measurements. Both the shape and magnitude of the reflectance curves are consistent with *in situ* spectral measurements of corals and other benthic organisms.

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