Analysis of EO-1 Hyperion over Agatti and Boat Islands, India

Sumisha Velloth[1], Raghavendra S. Mupparthy[1], Shailesh Nayak[2]

[1]National Centre for Medium Range Weather Forecasting, Noida, 201307, UP, India
[2]Earth System Science Organization, Ministry of Earth Sciences, New Delhi, India
Corresponding author: sumishavelloth@gmail.com

Abstract. Amongst the available satellite remote sensing options to distinguish between various shallow water habitat classes, such as healthy corals, algal cover, sea-grass cover, degraded corals, algal ridges, reef flat, knolls, lagoon, debris and sandy areas, hyperspectral remote sensing is one of the best options by virtue of its spectral capabilities, while high spatial resolution still being a necessary and sufficient condition to spatially resolve fine morphological features. Even with high spatial resolutions (5-30 m), the accuracy through unsupervised classification of different eco-morphological classes is an issue without appropriate *in situ* verification to resolve artifacts. In addition, the discrimination capability of habitat classes using multi/hyperspectral satellite data is dependent on the efficacy of the correction scheme for the atmospheric effects and the intervening water-column. In the present study, a seamless ocean-atmospheric correction called Coupled Ocean Atmospheric Radiative Transfer (COART) was applied to Earth Observation (EO-1) Hyperion data acquired over the coral reefs of Agatti Island in the Lakshadweep Islands and Boat Island in the Andaman Islands, India. The results from the study indicate that correction for the intervening water column helps in identifying submerged features in the reef slope and reef flat. The study concludes that the Hyperion data have sufficient discrimination capabilities for classification of broad habitat classes and can further be improved by using coupled radiative transfer models.

Key words: EO-1 Hyperion, COART, Coral Reef, *k*-Means Classification.

Introduction

Monitoring coral ecosystems requires systematic mapping of the habitat: species, morphology, benthic classes, water quality and observations of environmental stressors. Mapping these parameters provides the baseline for us to conduct change detection studies, improve alert systems and adopt proper conservation strategies. In view of the biodiversity, *in situ* techniques are the most accurate way to map the ecosystem, however, they are time consuming, expensive, intrusive and could also be destructive in fragile areas. Optical remote sensing techniques offer synoptic, cost effective means of mapping and monitoring coral reefs over large areas. However, the accuracy of classification is an issue, without *in situ* verification. In addition, satellite data for coral reef studies need to be corrected for the contributions due to the intervening atmospheric, water column and the air-water interface.

Past studies using multispectral data have demonstrated that classification accuracy improves with increasing spatial resolution (Smith et al. 1975; Green et al. 1996; Mumby et al. 1997). Multispectral data at resolutions of 5-50 m have been primarily used for mapping eco-geomorphic classes and conservation zones, providing important baseline data for coastal zone managers. Under the aegis of United Nations Educational, Scientific and Cultural Organization (UNESCO), many agencies worldwide have developed eco-morphological atlases of coral reefs at different levels and capacities, with imagery from the LANDSAT satellite program being the workhorse. Researchers have also applied SPOT and higher spatial resolution data, such as imagery from IKONOS and QuickBird, for coral reef studies. In India, data from sensors, including Linear Imaging Self-Scanning (LISS)-III and LISS-IV, both onboard the Indian Remote Sensing (IRS) Resourcesat-1 satellite (IRS-P6), have been used in preparation of the Coral Reef Atlas (Nayak et al. 2003). The spatial resolutions of LISS-III and LISS-IV are 23.5 and 5.8-m, respectively.

Hyperspectral sensors have shown the potential for species discrimination, benthic classification and geomorphological mapping, as well as water quality assessment (Brando and Dekker 2003; Guild et al. 2008). Specifically, researchers have applied data from CHRIS/PROBA (Sterckx et al. 2005), AVIRIS (Guild et al. 2008), EO-1 Hyperion (Brando and Dekker 2003) and HYMAP (Heege et al. 2007) for coral reef studies. Hyperspectral sensors have the ability to spectrally discriminate between multiple classes and thus can help in improving the accuracies of classification maps.

At the data level, one of the major problems associated with remote sensing data is the intervening effects of the atmosphere. In the case of remote sensing of shallow water benthos, the intervening water column further adds to the problem. Recent studies on coral reefs, such as by Brando and Dekker 2003; Sterckx et al. 2005; Goodman and Ustin 2007; Guild et al. 2008, addressed the atmosphere and water column separately. All of the mentioned studies have used algorithms based on MODerate spectral resolution atmospheric TRANsmittance (MODTRAN) for atmospheric correction, while few have used HydroLight (Mobley 1994), a proprietary software package, for solving radiative transfer in water and the remaining studies did not account for water column. HydroLight solves the forward optical model by parameterizing the concentrations of optical active in-water-substances (OAS) like chlorophyll, colored dissolved organic matter (CDOM) and suspended sediments to get the radiance distribution at the water surface. Without the correction for water column, the submerged features in the scene could be misclassified or missed all together.

In terms of processing software, the three most commonly used commercial packages for both multispectral and hyperspectral imagery are: ERDAS-Imagine, ENvironment for Visualization of Images (ENVI) and PCI-Geomatica. All three lack water column correction capability, and for a robust atmospheric correction scheme such as Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) in ENVI, the atmospheric correction module typically has to be purchased separately in addition to the main software. However, as the present study highlights there are free alternatives to the commercial processing packages.

Two coral reef sites in India were selected for the study: Agatti Island in Lakshadweep Islands and Boat Island in Andaman Islands (Fig. 1). Broadly, the reefs of Agatti Island can be morphologically classified as an atoll, dominated by reef flats and lagoon shoals. The Agatti Island is characterized by the presence of coral reefs on the west coast of the Island, with a lagoon in between (Pillai and Jasmine 1989). Geomorphologically, the Boat Island has fringing reefs submerged in the continental shelf. The reefs of Boat Island are rich in soft corals (Pillai 1996).

Material and Methods

Hyperion was launched on November 21, 2000 as part of the New Millennium Program onboard the EO-1 spacecraft by National Aeronautical and Space Administration (NASA) as a one-year technology validation/demonstrator mission. Presently it is in extended mission mode and data can be acquired on request. Hyperion is a hyperspectral sensor operating in a "push-broom" fashion, with a spatial resolution of 30 m and a standard scene width of approximately 7.6 km. It has a total of 242 bands covering a spectral range from 355 to 2577 nm with an average spectral resolution of the sensor at full width half maximum (FWHM) of 10.99 nm (Pearlman et al. 2003).

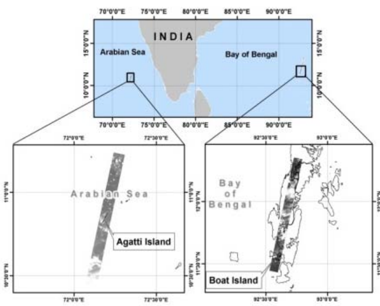

Figure 1: Hyperion image of the selected study areas: Agatti Island and Boat Island of India. Shown here is band 29 centered at 640.5 nm.

Hyperion data for this study were acquired from the United States Geological Survey (USGS) website using its online interface, the *NewEarthExplorer* (http://edcsns17.cr.usgs.gov/NewEarthExplorer/). The data were acquired as Georeferenced Tagged Image File Format (GeoTIFF) representing systematically terrain corrected data (L1T). The acquisition details are tabulated in Table 1.

	Agatti Island	Boat Island
Date and time of acquisition [Julian Day]	Aug 21, 2003; 0519 UTC [233]	Sep 27, 2003; 0358 UTC [270]
Path	147	134
Row	52	52
Sensor look angle, senz (degree)	0.61	1.91
Sun elevation, solz (degree)	61.75	61.35
Sun azimuth angle, sola (degree)	84.16	115.95

Table 1: Hyperion data acquisition details over the selected study sites.

Additionally, 5-year monthly climatologies of chlorophyll concentration, total suspended sediment concentration, and aerosol optical thickness were obtained as ocean color products from Aqua-MODIS (http://oceancolor.gsfc.nasa.gov). Similarly, the atmospheric water vapor was inferred from the

Special Sensor Microwave/Imager (SSM/I) on board F14 and F15 satellites (http://www.remss.com) and the integrated ozone concentrations was set as the model default of 0.35 atm-cm. The wind speeds were obtained as model outputs from the National Centre for Medium Range Weather Forecasting (NCMRWF) and as observations from QuikSCAT.

In view of the prohibitive costs of commercial processing software and their licenses, separate GUI-based processing software called *HyperCorals* was built in MATLAB®. To avoid atmospheric and water column correction costs, the present study made use of a free coupled correction scheme for atmospheric and water column called COART (Jin et al. 2006). It is available online and can be run using a web-based interface at http://snowdog.larc.nasa.gov/jin/rtset.html. In this study, COART was integrated into *HyperCorals* along with the processing and classification of Hyperion data.

Atmospheric and Water Column Correction

The model was run at spectral resolution of 5 nm, to obtain radiance at two height levels: Top of the Atmosphere (TOA) and the water surface (depth, $z=0^+$) along with the water leaving radiance (L_w). The modeled radiances were convolved with the sensor spectral response function (SRF) to derive the modeled radiance (L_{mod}) at Hyperion band-centers. The land and cloud areas were masked out in the image data using short wave infra-red (SWIR) bands and the rest of pixels were assumed to be cloud free. Table 2 summarizes the set-up for the radiance output. Table 3 shows the correction scheme for the atmospheric component. For both study sites, the chosen atmospheric model was "*Tropical*", with the mixed layer aerosol represented by the *MODTRAN Maritime* model.

	Agatti Island	Boat Island
Wavelength range [nm]	350-2600	350-2600
zenith angle [degrees]	0.61	1.91
azimuth angle [degrees]	0	0
Latitude (representative)	10.99 N	11.49 N
Longitude (representative)	72.24 E	92.56 E

Table 2: Basic COART model set-up.

It was assumed that there was no stratospheric aerosol and the optical properties of atmospheric layer were defined by aerosol, water and trace gasses as shown in Table 3, after accounting for the Rayleigh scattering.

	Agatti Island	Boat Island
Aerosol loading (by visibility in km)	23	20
Total integrated precipitable water (g/cm^2)	4.2	4.3
Trace gas (CO_2 and CH_4) factor	[1, 1]	[1, 1]
Clouds	None	None

Table 3: Inputs for the atmospheric component.

The water depth varies at Agatti Island from zero to 2 m over shallow lagoons and about two to six meters over deep lagoons, while it ranges from 1 to 5 m over reef flats and increases to a maximum of 50 m over reef slopes (about 300 m from the southern shore). At Boat Island, the bathymetry varies from zero to a maximum of 3 m below the mean sea-level with most reefs at shallow depths.

	Agatti Island	Boat Island
Wind speeds (m/s)	2	2
Water column depths [land, ocean] (m)	[0,3]	[0,2]
Bottom albedo	0.1	0.05
Chlorophyll concentration (mg/m^3)	0.2	0.2
Particle scattering coefficient [b_o, n, k]	[0.45, 0.6, 0.62]	[0.45, 0.6, 0.62]
Particle scattering phase function	Petzold Average ($b_b/b=0.0183$)	Petzold Average ($b_b/b=0.0183$)

Table 4: Ocean component: inputs for the bio-optical model.

However in this study, for simplicity, the depth at all pixels was assumed to be constant at 3 m and 2 m at Agatti and Boat Islands, respectively. The water column depth over the land areas was set to zero. The COART model on the other hand can be solved for varying depths based on bathymetry data. Table 4 tabulates the inputs used for the water column correction. In this study, the waters were assumed to be optically deep clear waters (Case-1 Waters) and dictated only by the concentration of chlorophyll;

hence the Petzold's phase function was assumed to be small. Suspended sediments were assumed to be negligible, and hence the scattering was dominated by chlorophyllous particles. The particle scattering coefficient, b_p, was calculated as shown in Equation 1, where the parameters b_0, n, and k are input as shown in Table 4.

$$b_p(\lambda) = b_0\left(550/\lambda\right)^n [Chl]^k \qquad \ldots 1$$

The bottom albedo was assumed as shown in Table 4, based on a separate sensitivity study using derivative analysis (results not presented here). For detailed information on bio-optical models see the International Ocean Color Coordination Group (IOCCG) Report Series (http://www.ioccg.org) and references therein. The retrieved radiances were converted into reflectances.

k-Means Classification

Following the correction of the satellite data, *k*-means clustering was applied on a 3D image cube subset from the original image. The first two dimensions of the 3D matrix correspond to the spatial dimensions of the image, while the third corresponds to 42 bands of wavelength (Hyperion bands 8 through 49) in the spectral range 426.8 – 844 nm. In order to apply the classification algorithm efficiently, the 3-D image cube was reshaped to a 2-D matrix where the rows are sorted column-wise and represent spatial information, while the number of spectral bands becomes the new column. The pair-wise distance between the row vectors x_p and x_q, was computed using the *city block* distance metric as shown in Equation 2.

$$d_{pq} = \sqrt[k]{\sum_{j=1}^{n} \left|x_{pj} - x_{qj}\right|} \qquad \ldots 2$$

Note that the Equation 2 is a general expression for Minkowski's metric, where *n* is the length of the spectra. For the case where *k* equals to unity, the equation represents *city block* distance and for *k*=2, the equation represents Euclidean distance.

Results and Discussion

The COART corrected images for Agatti and Boat Island are shown in Fig. 2 and Fig. 3, respectively. As can be seen from the figures, the haze in the imagery has been removed, with improved contrast. The rectangular boxes overlaid on the image indicate the regions where the contrast is visually perceptible. Note that masking out the land and clouds does improve the contrast of the image by stretching, but not as clearly as observed in the Fig. 2 and Fig. 3. *HyperCorals* uses bands in SWIR region for cloud type and detection and for land masking. The issue of cloud shadow still remains, even though the clouds themselves have been masked.

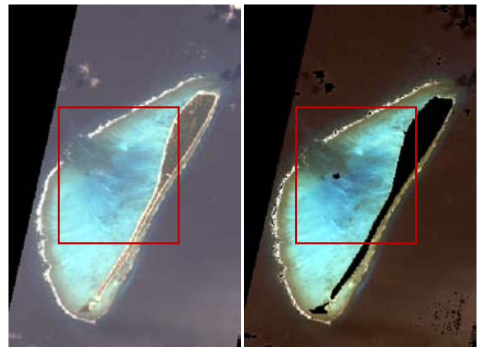

Figure 2: Impact of COART correction on Agatti Island. The left panel in the Figure shows the images before correction, while the right panel shows after the application of COART. The boxes highlight the enhancement in the intermediate and deep lagoon regions. The land and clouds are masked in black color.

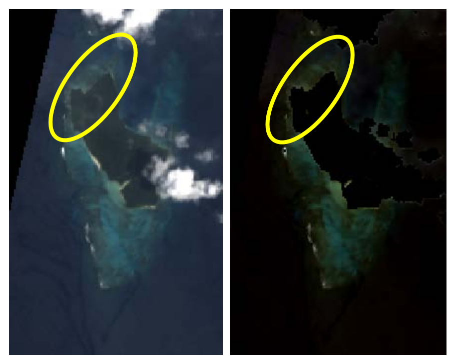

Figure 3: Effect of COART correction on Boat Island. The left panel in the Figure shows the images before correction, while the right panel shows after the application of COART. The ellipse highlights submerged area within the reef crest and reef flat. The land and clouds are masked in black color.

k-Means Classification Maps

The Hyperion data were mapped with a total of 25 clusters using *k*-Means algorithm and *city block* distance metric and the results are shown in Fig. 5. The classification process was performed in *HyperCorals*. From the 25 clusters, unwanted classes like land, cloud and ocean pixels were masked out, thus resulting in 12 and 10 clusters for Agatti and Boat Islands, respectively. It is interesting to note that the *city block* metric is able to capture morphologically consistent patterns, not random noise.

The resulting maps with COART correction were compared with the available eco-morphological atlas maps (Fig. 4) prepared by Space Application Centre (SAC), Indian National Centre for Ocean Information Services (INCOIS) and Centre for Earth Science

Studies (CESS) using LISS-III imagery. The RS and RF classes in the atlas map of Agatti Island (Fig. 5) have been further classified into SR, deeper reef flat, RS and RF using Hyperion and COART.

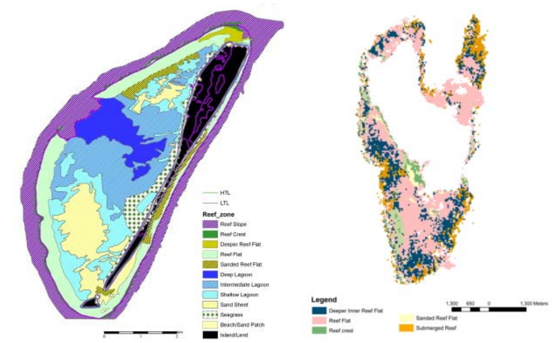

Figure 4: Eco-morphological zonation maps prepared using LISS III data for Agatti Island (left panel; source: CESS) and Boat Island (right panel, source: INCOIS).

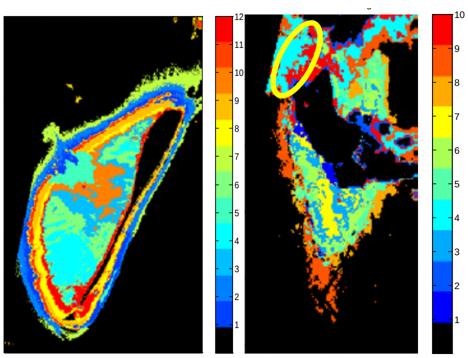

Figure 5: *k*-Means classification after COART correction for Agatti Island (left), where the classes are represented as 1 and 2: Reef Slope (RS); 3: Intermediate Lagoon (IL); 4: Sand Sheet (SS); 5 and 10: Deep Lagoon (DL); 6 and 12: Shallow Lagoon (SL); 7: Submerged Reef (SR); 8, 9 and 11: Reef Flat (RF); Boat Island (right), where 1 and 2: RS; 3: Reef Crest (RC); 4, 5, 8, 9, and 10: SR; 6 and 7: RF.

It was observed that the correction for the water column enables identification of submerged features (see the ellipse in Fig. 5). In the atlas map of Boat Island (Fig. 4) based on LISS-III data, the area under ellipse (see Fig. 5) was classified as ocean pixel and discarded, but COART is able bring out the submerged features of the reef crest.

Conclusion

This study indicates that geomorphological classes like RS, RF and RC (defined in Fig. 5) can be further classified if the water column contribution is removed from the image. The removal of water column contribution has enhanced the classification of submerged reefs and COART can be used cost-effectively vis-à-vis commercial packages for coral reefs and benthic studies. The correction process can be further improved by using realistic water column depths on a pixel-by-pixel basis. The *k*-means clustering technique is a good alternative to ISODATA, which when implemented in *HyperCorals* was found to be computationally more expensive.

Acknowledgement

The authors thank Drs. Thomas Charlock and Zhonghai Jin of NASA Langley Research Center for making available the COART online. The authors express their gratitude to U. S. Geological Survey for making available the EO-1 Hyperion data and NASA's Ocean Color Web for making available MODIS data. SSM/I data are produced by Remote Sensing Systems and sponsored by the NASA Earth Science MEaSUREs DISCOVER Project. Data are available at www.remss.com. The authors wish to acknowledge INCOIS and CMLRE for the network facilities. The authors also thank the reviewers for their helpful comments in the preparation of this manuscript.

References

Brando VE, Dekker A (2003) Satellite hyperspectral remote sensing for estimating estuarine and coastal water quality. IEEE T Geosci Remote 41:1378-87

Goodman JA, Ustin SL (2007) Classification of benthic composition in a coral reef environment using spectral unmixing. J Appl Remote Sens. 1:011501

Green EP, Mumby PJ, Clark CD (1996) A review of remote sensing for the assessment and management of tropical coastal resources. Coast Manage 24:1-40

Guild L, Lobitz B, Armstrong R, Gilbes F, Goodman J, Detres Y, Berthold R, Kerr J (2008) NASA Airborne AVIRIS and DCS remote sensing of coral reefs. Proc 11th Int Coral Reef Sym 1:623:627

Heege T, Hausknecht P, Kobryn H (2007) Hyperspectral seafloor mapping and direct bathymetry calculation using HyMap data from the Ningaloo reef and Rottnest Island areas in Western Australia. 5th EARSeL SIG IS Workshop Belgium

Jin Z, Charlock TP, Rutledge K, Stamnes K, Wang Y (2006) Analytical solution of radiative transfer in the coupled atmosphere-ocean system with a rough surface. Appl Optics 45:7443-7455

Mobley CD (1994) Light and Water: radiative transfer in natural waters Academic Press, New York, p 565

Mumby PJ, Green EP, Clark CD, Edwards AJ (1997) Coral Reef Habitat mapping: How much detail remotesensing can provide. Mar Biol 130:193-202

Nayak S, and et al. (2003) Eco-morphological zonation of selected coral reefs of India using remotely sensed data. SAC/RESIPA/MWRG/MSCED/SN/16/2003

Pearlman, JS, Barry PS, Segal CC, Shepanski J, Beiso D, Carman SL (2003) Hyperion, a Space-Based Imaging Spectrometer. IEEE Trans. Geosci. Remote 41 (6):1160-1173

Pillai CSG, Jasmine S (1989) The coral fauna Lakshadweep, CMFRI Bulletin Marine living resources of the union territory of Lakshadweep An Indicative Survey With Suggestions For Development, 43, pp. 179-195

Pillai CSG (1996) Coral reefs of India, their conservation and management, **In**: *Marine Biodiversity: Conservation and management*. Menon NG and Pillai CSG, **(eds.)** CMFRI, Cochin, pp. 16-31

Smith VE, Rogers RH, Reed LE (1975) Thematic mapping of coral reefs using LANDSAT data, Proc10th Int Sym Rem Sens Env 1:585

Sterckx, S, Debruyn W, Vanderstraete T, Goossens R, van der Heijden P (2005) Hyperspectral data for coral reef monitoring. A case study: Fordate, Tanimbar, Indonesia. EARSeL EProc 4 (1)