Bottom Albedo Images to Improve Classification of Benthic Habitat Maps

William J Hernandez, *Ph.D*
Post-Doctoral Researcher NOAA CREST
University of Puerto Rico, Mayaguez, Puerto Rico, Global Science and Technology, Inc.
william.hernandez@upr.edu

Roy A. Armstrong, , *Ph.D*
Professor
University of Puerto Rico, Mayaguez, Puerto Rico

Outline

- Introduction
  - Study Area
  - Challenges
  - Sensors (Active/Passive)
- Bottom Albedo Images
- Benthic Habitat Map of La Parguera Reserve
- Conclusions

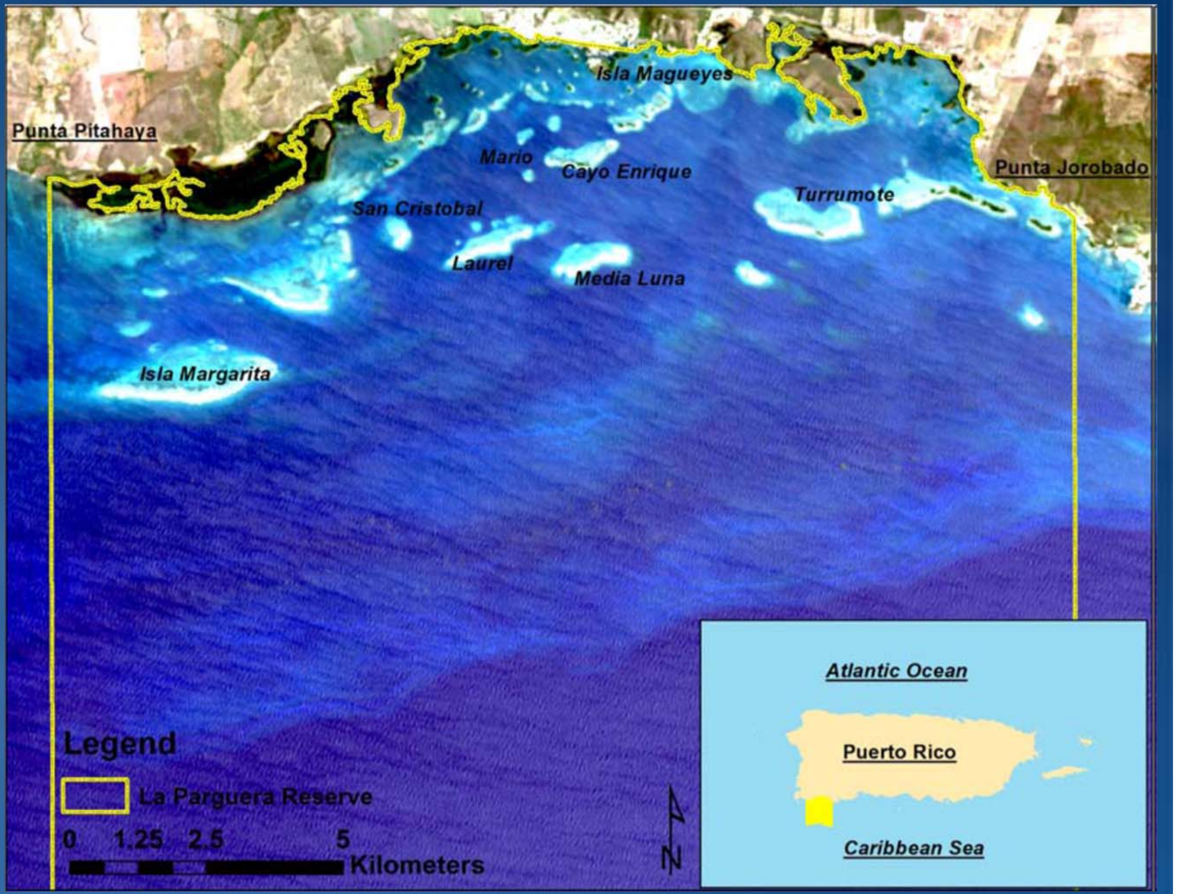
Introduction

Coastal areas

- Important resources
- Ecosystems affected by human-based and natural factors.

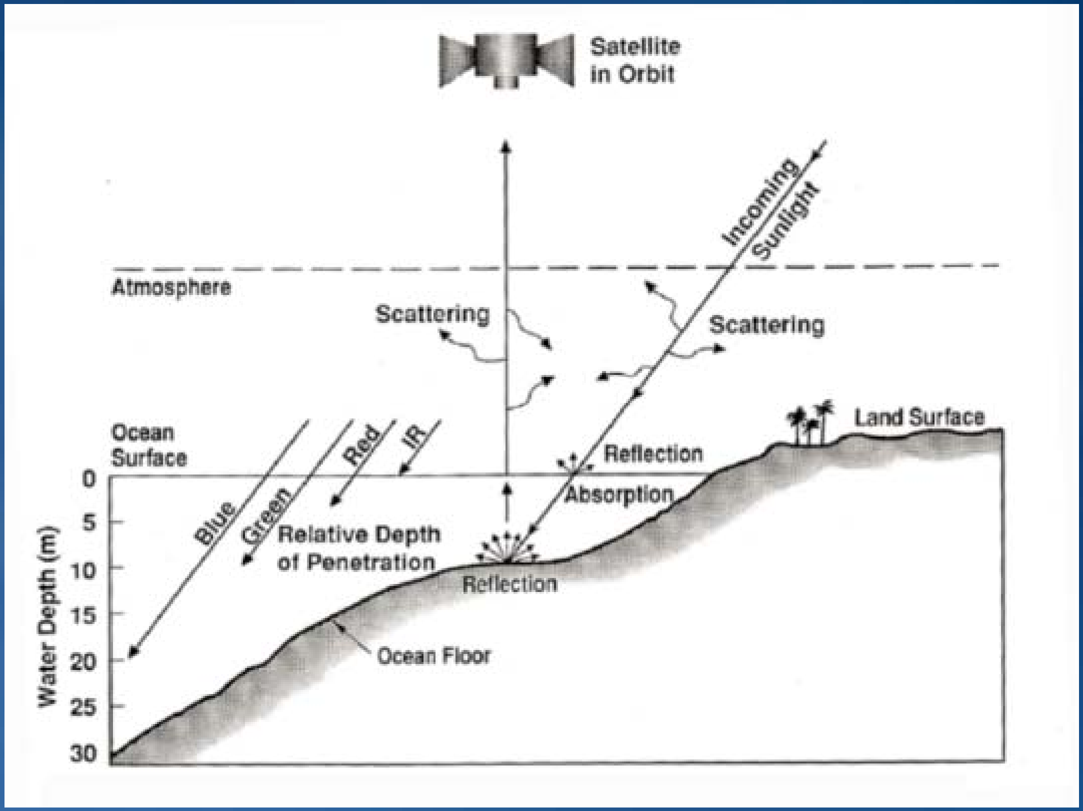
Study Area

- **La Parguera**
  - **DNR Natural Reserve**
  - **Aprox. 12,500 acres**
  - **Depth = ~18 m**
  - **Unique habitats**



Challenges

- **Use of Remote Sensing Techniques**
- **Depth**
  - **Variable**
  - **Detection limits**
- **Variable substrate**
  - **Consolidated**
  - **Unconsolidated**
- **Turbidity**
  - **attenuation**



(Purkis 2005)

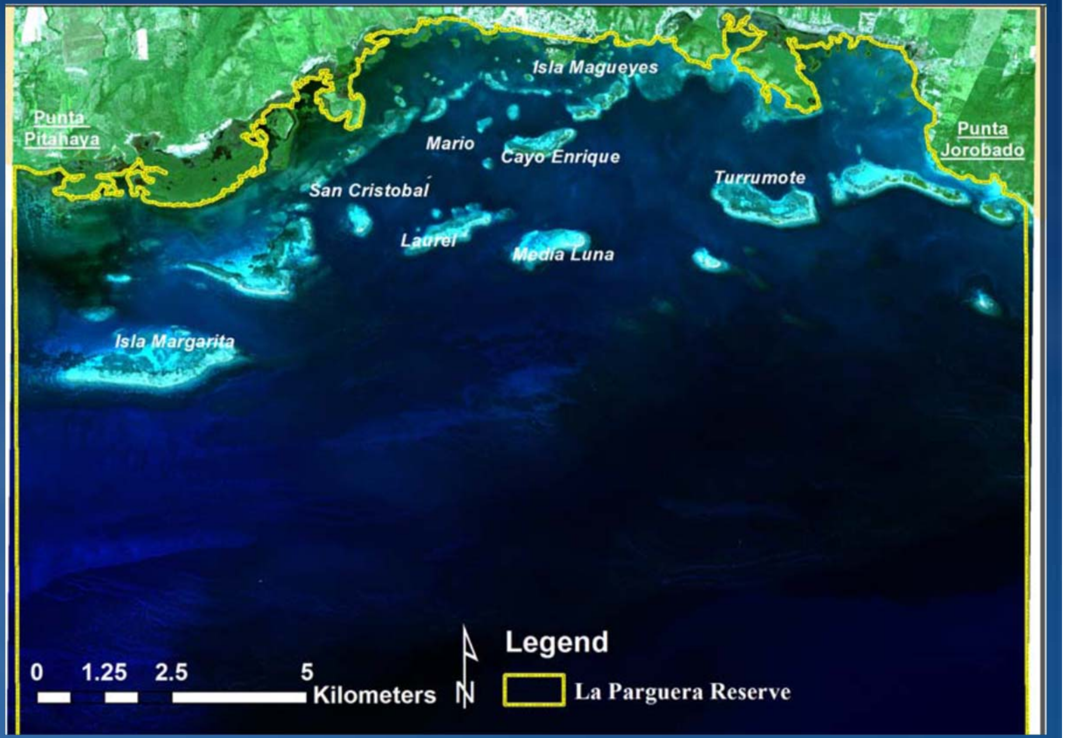
Sensors

- AVIRIS (Airborne Visible Infrared Imaging Spectrometer)
- December 2005
- 224 Bands (370-2500 nm)
- Hyperspectral
- Visible range: 400-700 nm (32 bands)
- 10 nm bandwidth
- High signal to noise ratio (~1,000:1)
- Spatial resolution: ~3m

AVIRIS mosaic

Sensors

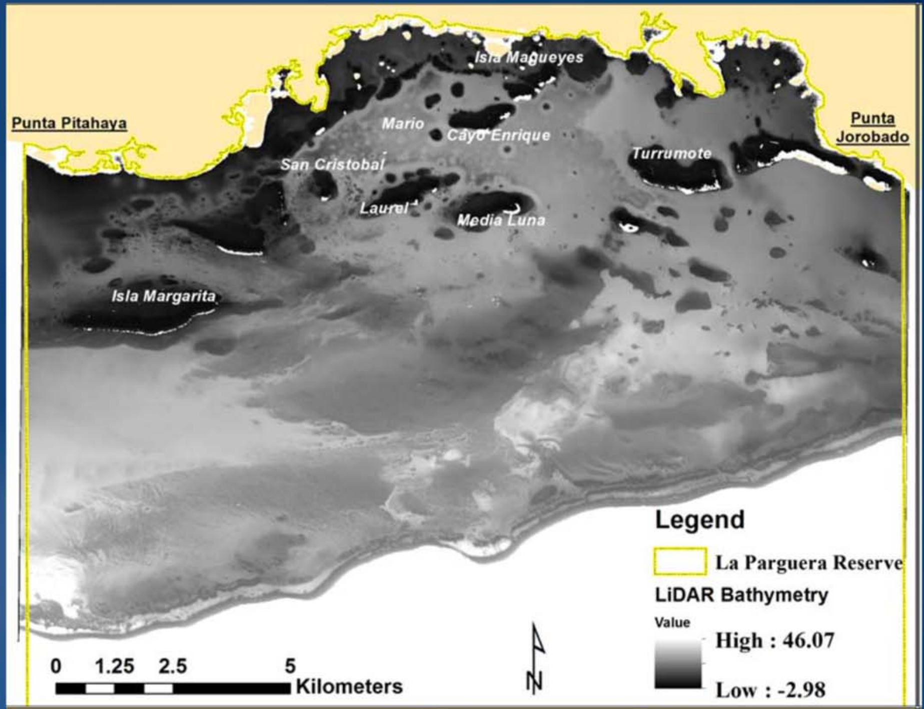
- **Worldview 2 (WV2)**
- **December 2011**
- **8 bands, 5 visible**
- **Multispectral**
- **~2 m spatial resolution**
- **"Coastal band" (425nm)**

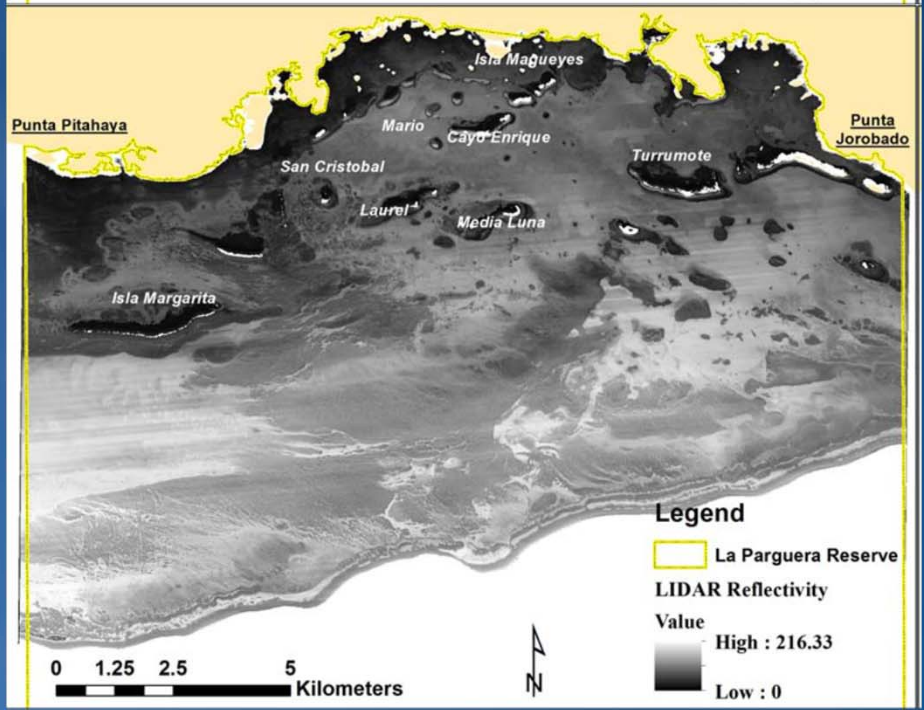


WV2 Imagery

Sensors

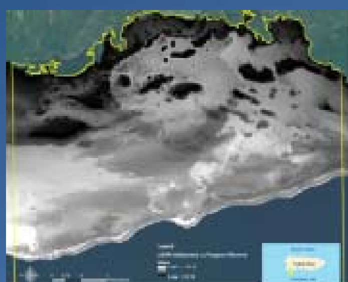
- **LiDAR SHOALS**
  - **2006**
  - **(LADS) Mk II Airborne System.**
  - **Infrared beam (1064 nm)**
  - **Green beam(532nm)**
  - **4 x4 meters bathymetry surface**
  - **5x5 meters intensity surface**





AVIRIS image

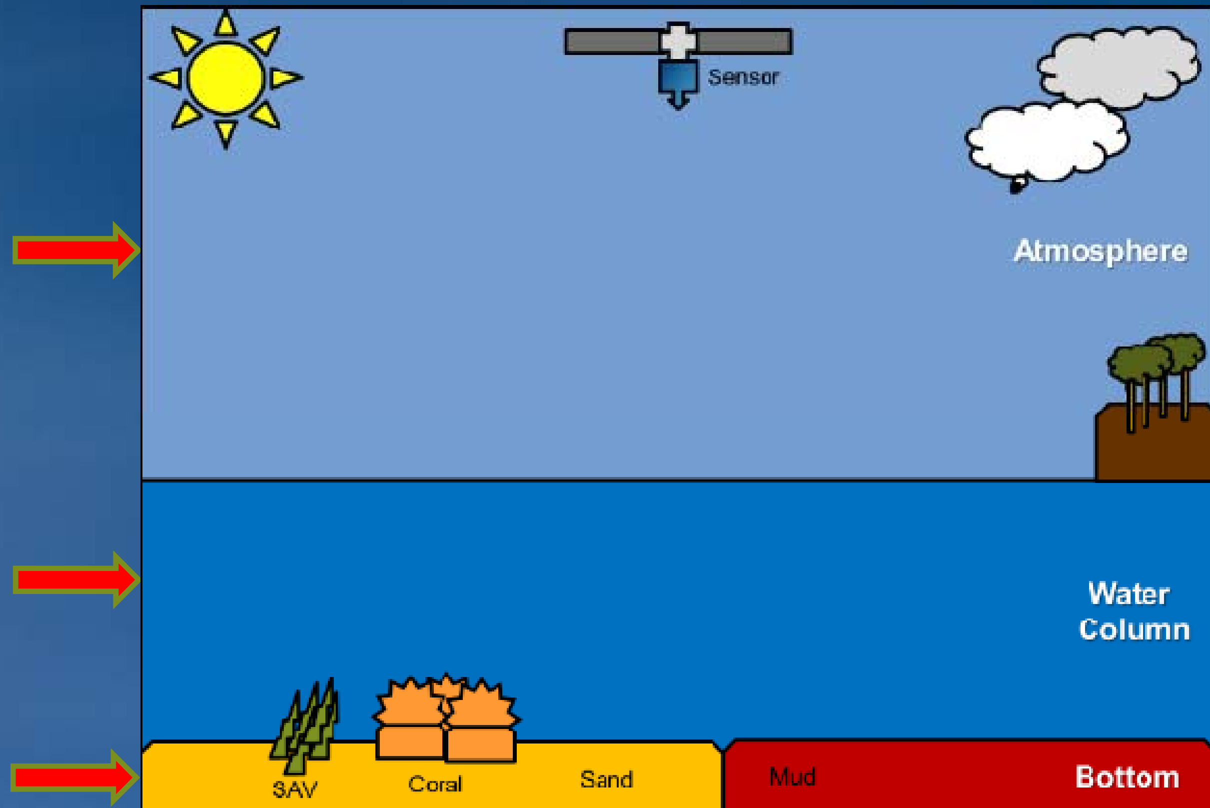
WV2 image



LiDAR SHOALS

Bio-optical sampling

METHODS



Pre-processing Steps (ArcGIS 10.3 and ENVI 5.2)

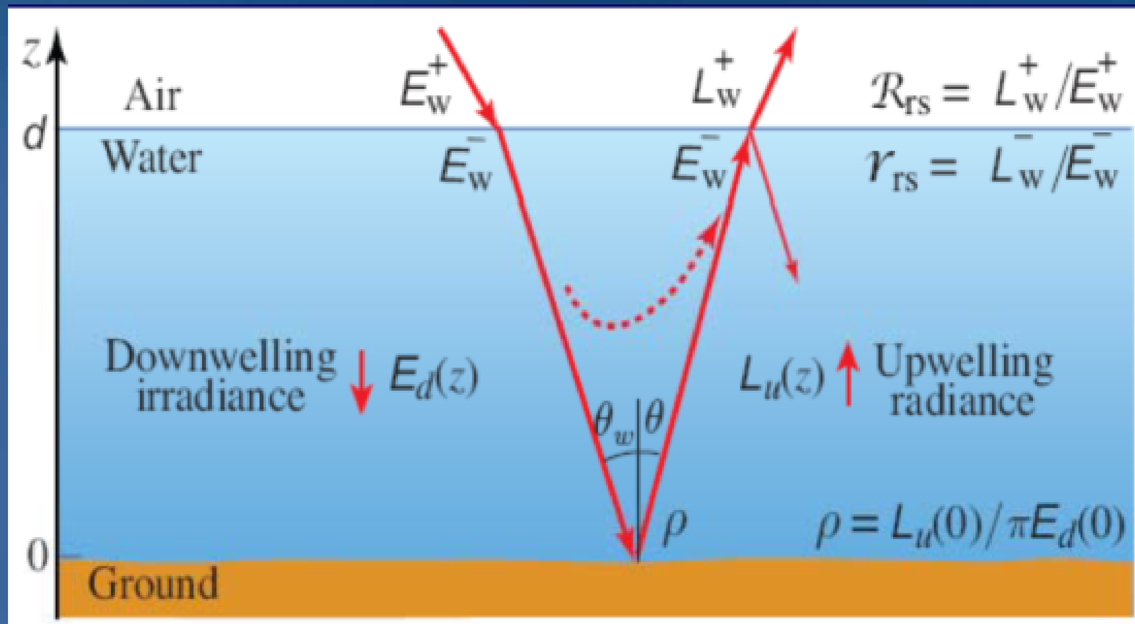
- co-registration,
- landmask,
- atmospheric correction

Bottom Albedo Map from water column correction (ArcGIS 10.3)

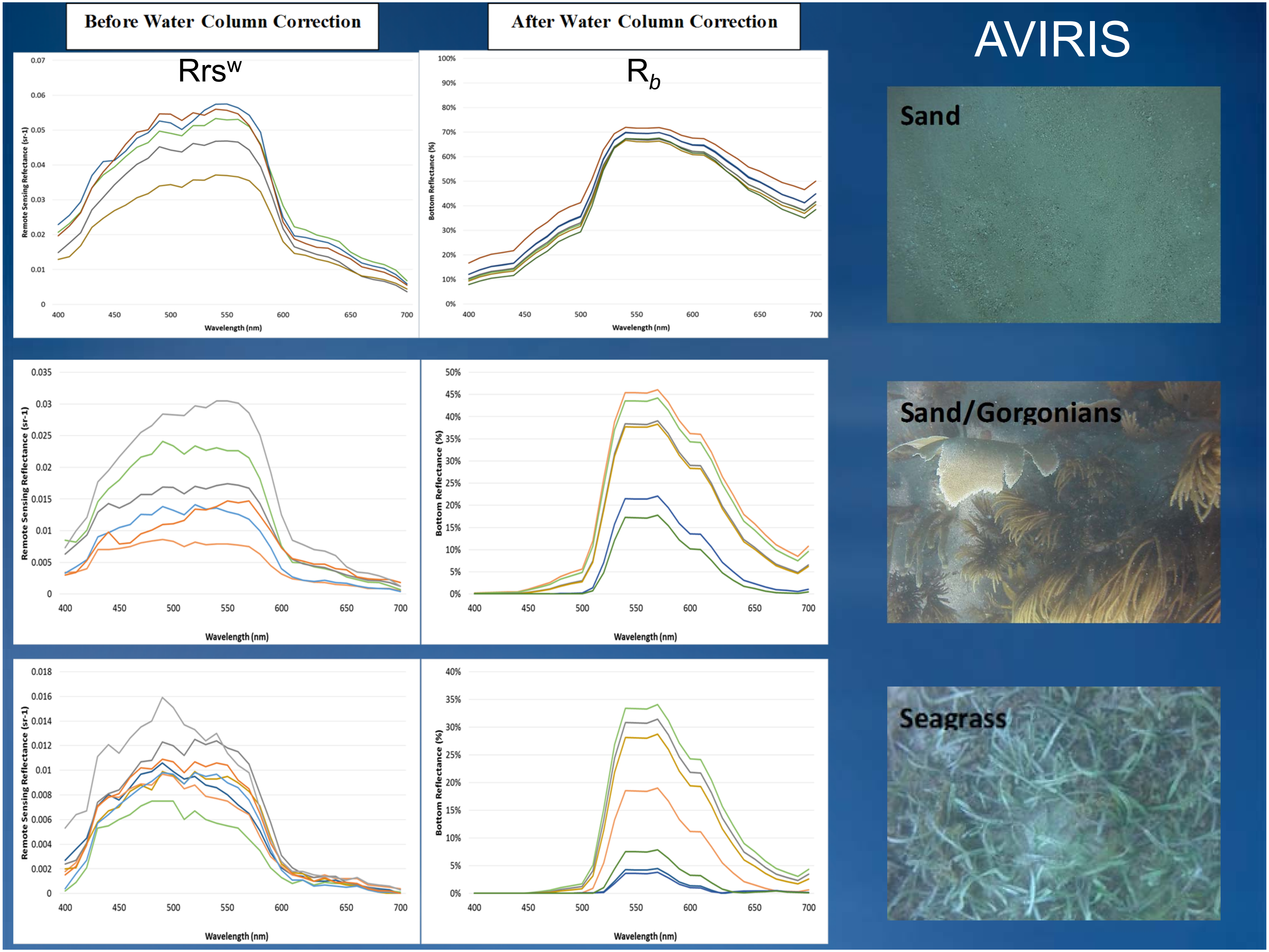
Benthic Habitat Map of La Parguera Reserve (ArcGIS 10.3)

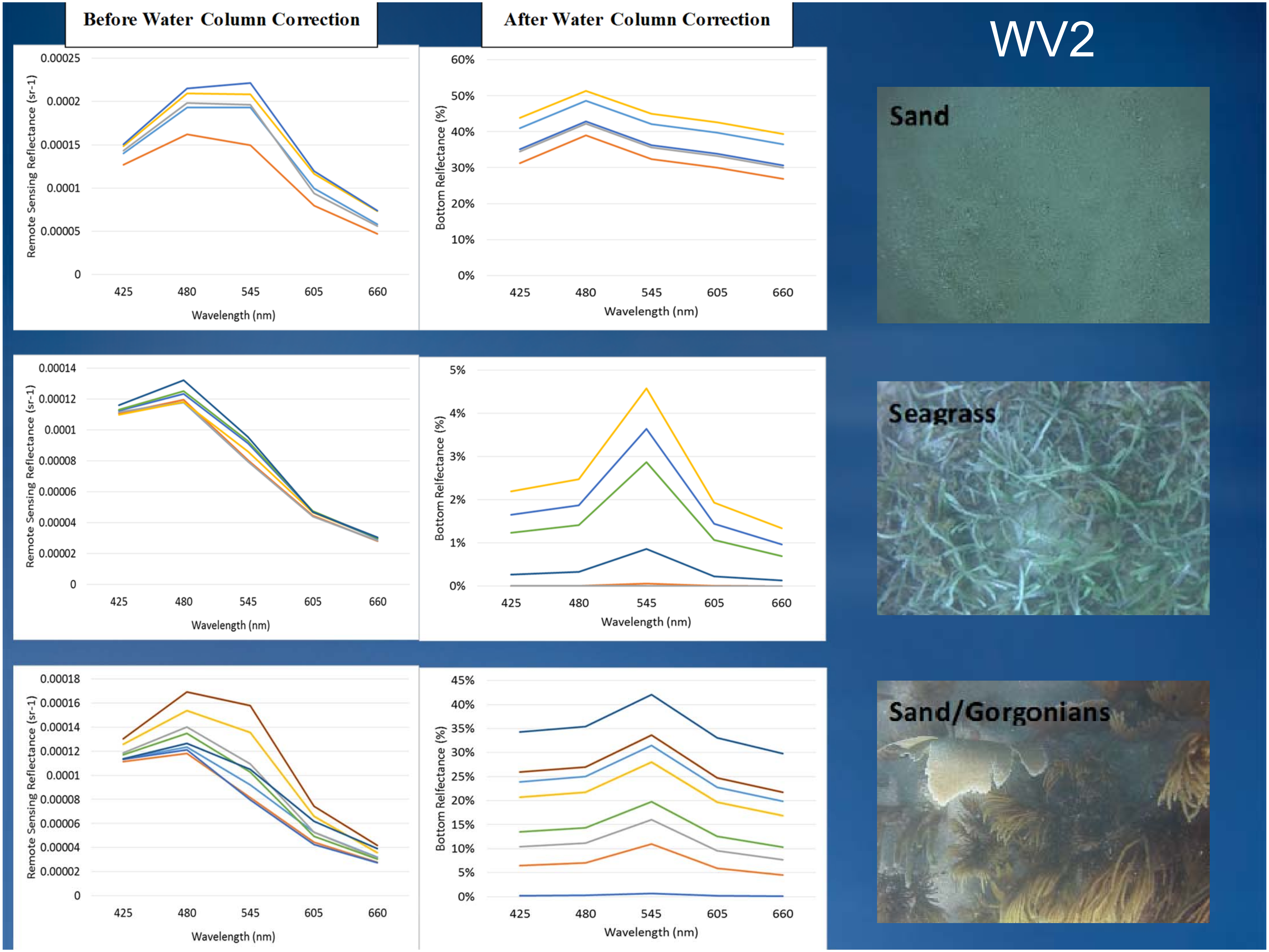
Water Column Correction
Bottom Albedo Images

- $R_{rs}(\lambda) = R_{rs}^{w}(\lambda) + R_{rs}^{b}(\lambda)$ (Lee et al. 1994, 1999)

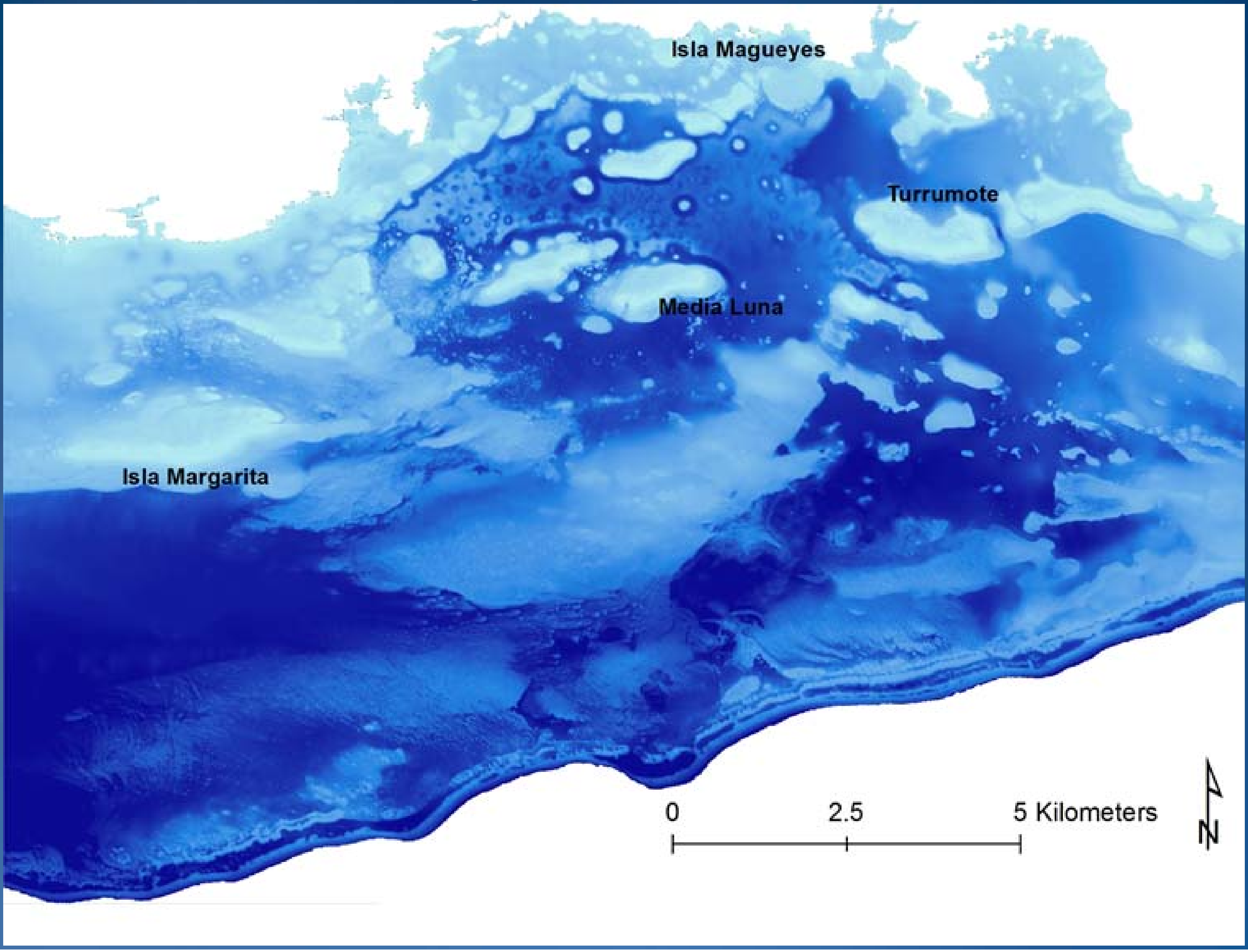


- $R_{rs}^{w}(\lambda) \approx 0.05[b_b(\lambda) / a(\lambda) + b_b(\lambda)]\ [1 - e^{-3.2[a(\lambda) + b_b(\lambda)]Z}]$
-
- $R_{rs}^{b}(\lambda) \approx 0.173\ \rho(\lambda)\ e^{[-2.7a(\lambda) + b_b(\lambda)]Z}$

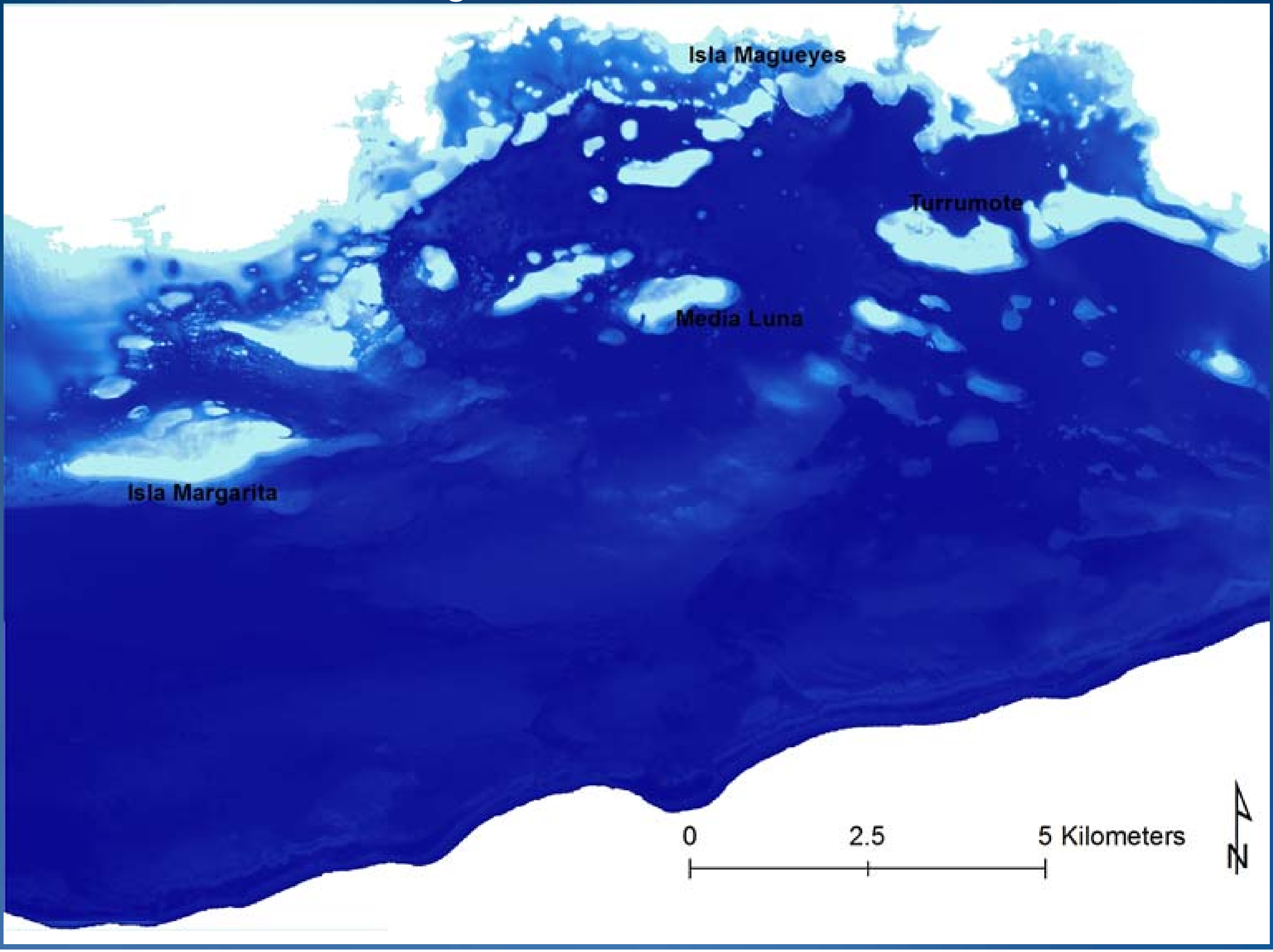

Before Water Column Correction
After Water Column Correction
AVIRIS
Rrsw
Rb
Remote Sensing Reflectance (sr-1)
Bottom Reflectance (%)
Wavelength (nm)
Sand
Sand/Gorgonians
Seagrass


Before Water Column Correction
After Water Column Correction
WV2
Remote Sensing Reflectance (sr-1)
Bottom Relfectance (%)
Wavelength (nm)
425
480
545
605
660
0.00025
0.0002
0.00015
0.0001
0.00005
0
60%
50%
40%
30%
20%
10%
0%
Sand
0.00014
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
5%
4%
3%
2%
1%
Seagrass
0.00018
0.00016
45%
35%
25%
15%
5%
Sand/Gorgonians

AVIRIS Bottom Albedo Image

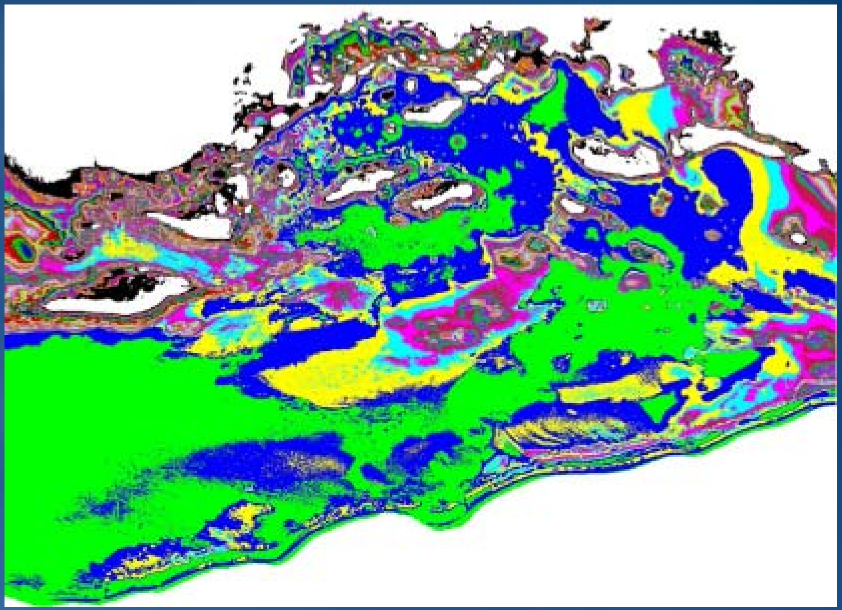


WV2 Bottom Albedo Image

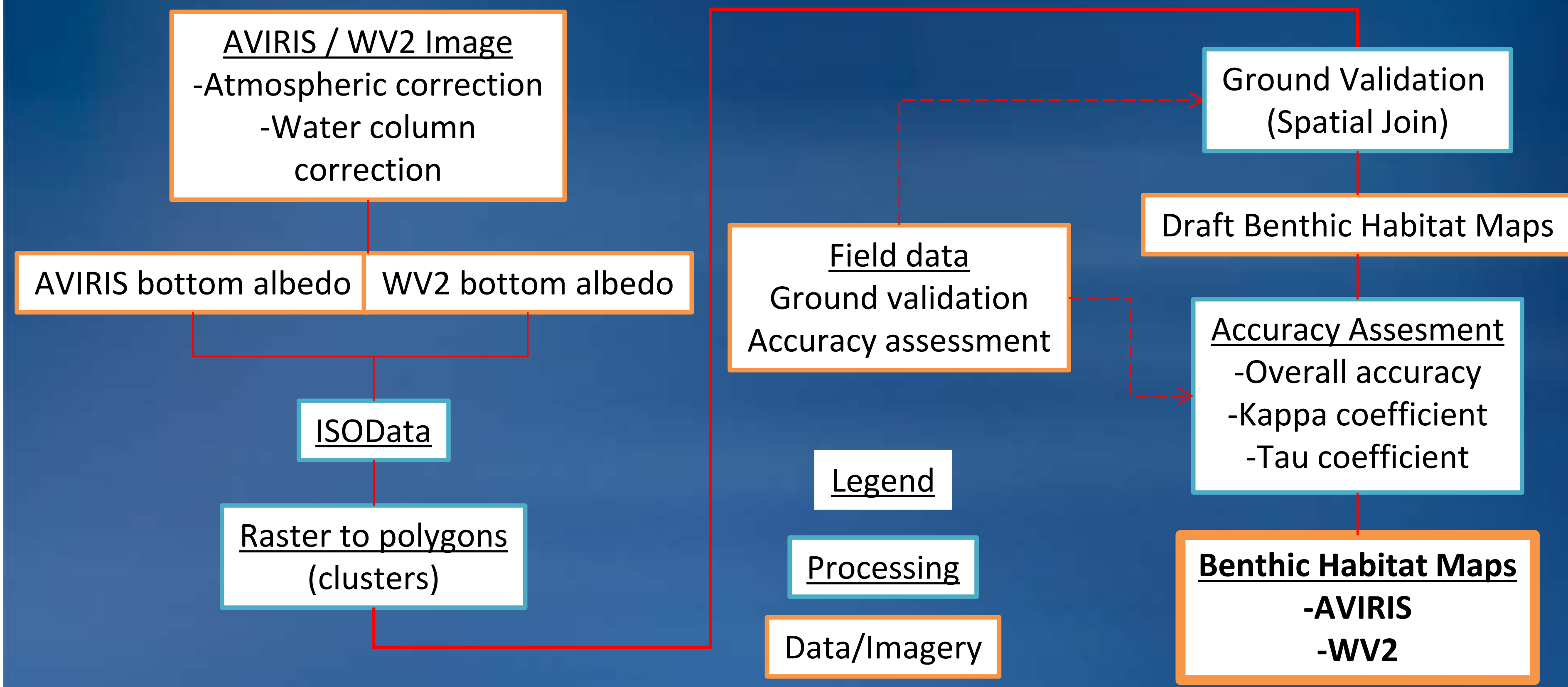


Benthic Habitat Mapping

- **Goals**
  - **Develop a high-resolution benthic habitat map**
    - **AVIRIS and WV2 modeled bottom albedo**
- **Importance**
  - **Identify ecologically important habitats in La Parguera**
  - **Coral reef habitat maps as a management tool.**



Methods



AVIRIS / WV2 Image
-Atmospheric correction
-Water column
correction
AVIRIS bottom albedo
WV2 bottom albedo
ISOData
Raster to polygons
(clusters)
Field data
Ground validation
Accuracy assessment
Ground Validation
(Spatial Join)
Draft Benthic Habitat Maps
Accuracy Assesment
-Overall accuracy
-Kappa coefficient
-Tau coefficient
Benthic Habitat Maps
-AVIRIS
-WV2
Legend
Processing
Data/Imagery

Segmentation

- The Iterative Self Organizing Data (ISODATA) algorithm
  - unsupervised classification
  - statistical clustering algorithm
  - Various iterations and combinations of maximum clusters were evaluated.
    - 150 clusters with 5 iterations were selected as the maximum for the ISODATA classification
  - spectral clusters that appeared to belong to multiple class / benthic habitat (confused pixels) were also identified.

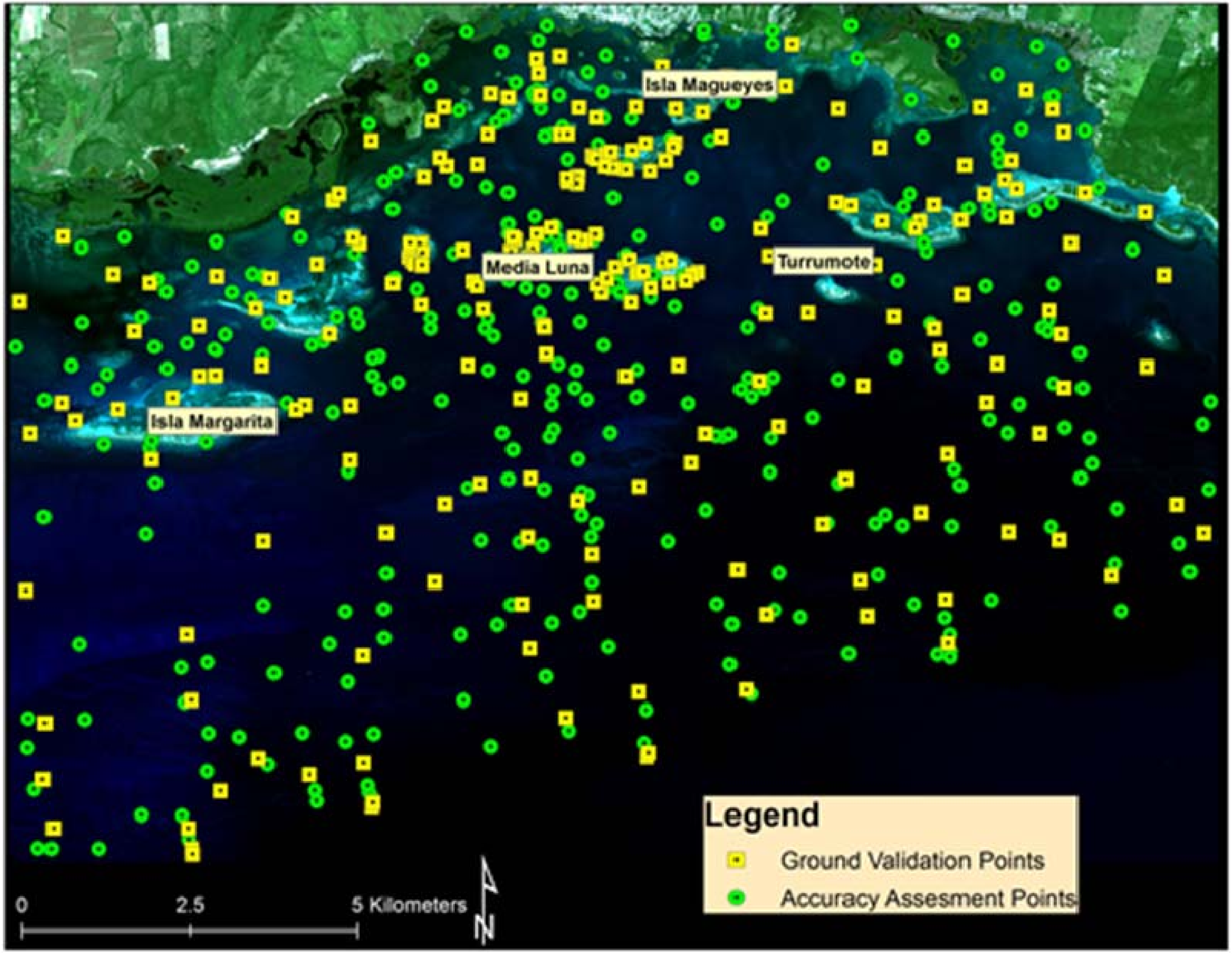
Sampling Sites

- Delta Vision Pro
  - Drop Camera HD Video (1080p)
  - 10-second video collected
  - DVR

- Trimble Juno GPS
  - 10-second averaging
  - dGPS
  - 2 meters

- Synchronized GPS and video

Ground Validation and Accuracy Assessment Points



Benthic habitat classification scheme

(1) Coral Reefs **(2) Seagrass** **(3) Hardbottom**

(4) Mix: Sand/ Hardbottom/Coral

(5) Mud

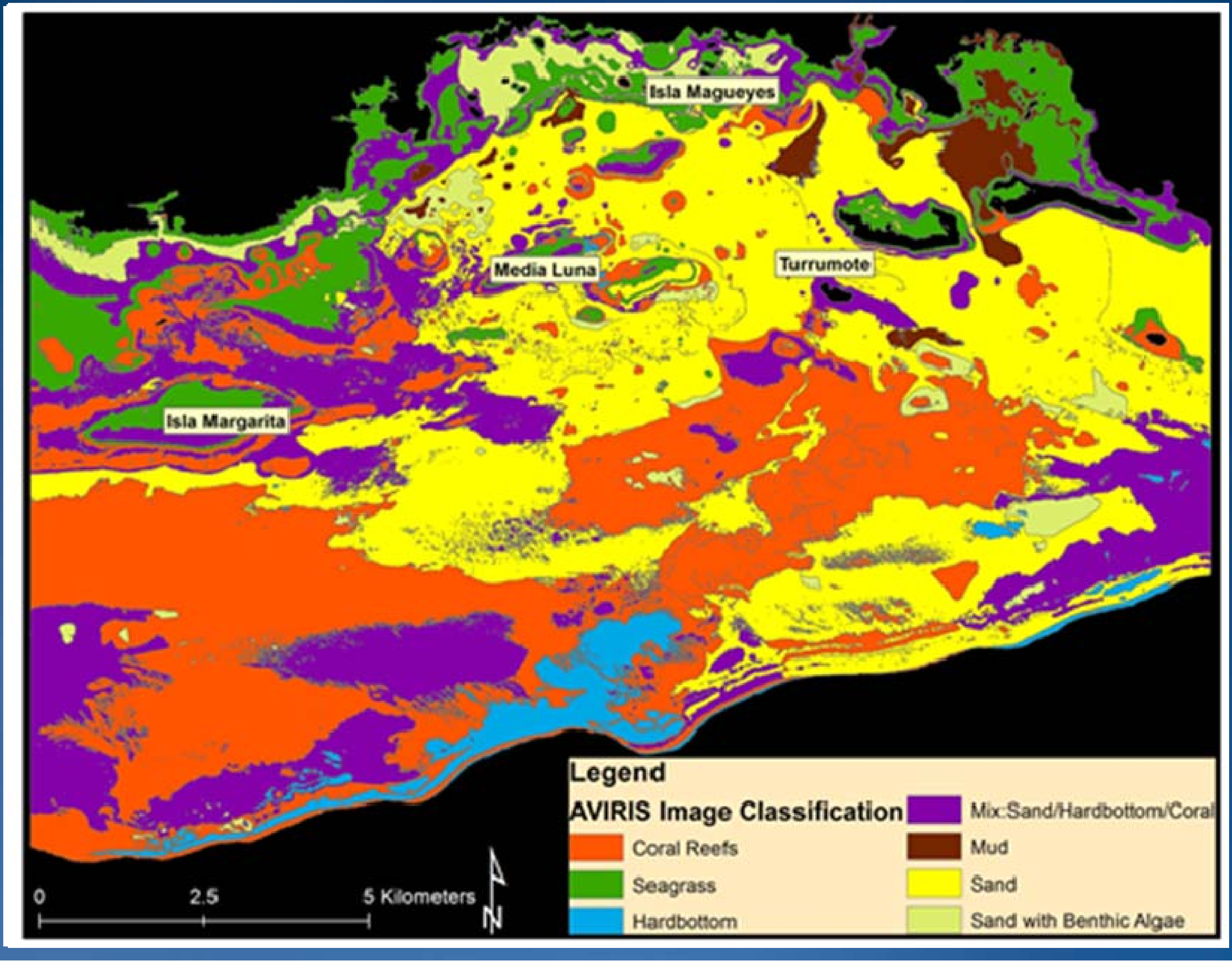
(6) Sand

(7) Sand with Benthic Algae

Classification

- Clusters obtained from ISODATA classification
- Converted to polygons in ESRI ArcMap 10.3.
- Spatial Join Tool
  - Polygons assigned to a class based on ground validation.
  - Joining based on spatial location.
  - Attribute of the nearest point is collected and a distance value is recorded.
  - All polygons were aggregated and assigned to a specific benthic habitat category.
  - The final polygon layer were aggregated based on the benthic class using the Dissolve Tool from ESRI ArcMap 10.3.

AVIRIS (after water column correction)



Accuracy Assessment

- Confusion matrix (Jensen 1996)
- Individual classes
  - Overall accuracy
  - Producer accuracy (classifier)
    - percent of the time, that benthic type was classified as such.
  - User accuracy (management)
    - each time an area labelled as a sand on the map is visited, there is a 89.29% probability that it is actually sand.
  - Kappa coefficient (“true” versus “chance” agreement)
    - reduction in error generated by a classification process, compared with a completely random classification.
  - Tau coefficient
    - Indicates correct classification of pixels than expected by chance.

AVIRIS Image Classification

Truth Data

Classified Data	Coral Reefs	Seagrass	Hardbottom	Mix: Sand/Hardbottom /Coral	Mud	Sand	Sand with Benthic Algae	**TOTAL**	**PRODUCER ACCURACY**
Coral Reefs	62	5	6	13	0	0	6	**92**	**67.39%**
Seagrass	4	33	1	4	0	0	2	**44**	**75.00%**
Hard Bottom	2	0	12	1	0	0	1	**16**	**75.00%**
Mix: Sand/Hardbottom/ Coral	13	13	2	40	0	0	7	**75**	**53.33%**
Mud	0	4	0	0	13	0	1	**18**	**72.22%**
Sand	11	4	0	4	7	25	1	**52**	**48.08%**
Sand with Benthic Algae	0	2	0	0	0	3	19	**24**	**79.17%**
TOTAL	**92**	**61**	**21**	**62**	**20**	**28**	**37**	**321**	
USER ACCURACY	**67.39%**	**54.10%**	**57.14%**	**64.52%**	**65.00%**	**89.29%**	**51.35%**		

Overall Accuracy	**Kappa Coefficient**	**Tau Coefficient**
63.55%	**0.55**	**0.59**

WV2 Image Classification

Truth Data

Classified Data	Coral Reefs	Seagrass	Hardbottom	Mix: Sand/Hardbottom/ Coral	Mud	Sand	Sand with Benthic Algae	**TOTAL**	**PRODUCER ACCURACY**
Coral Reefs	65	5	2	13	0	2	2	**89**	**73.03%**
Seagrass	6	36	0	2	0	1	5	**50**	**72.00%**
Hard Bottom	1	0	12	1	0	2	0	**16**	**75.00%**
Mix: Sand/Hardbottom/ Coral	9	7	2	40	0	0	5	**63**	**63.49%**
Mud	0	5	0	0	15	0	2	**22**	**68.18%**
Sand	9	5	5	6	5	23	4	**57**	**40.35%**
Sand with Benthic Algae	1	7	0	0	0	0	19	**27**	**70.37%**
TOTAL	**91**	**65**	**21**	**62**	**20**	**28**	**37**	**324**	
USER ACCURACY	**71.43%**	**55.38%**	**57.14%**	**64.52%**	**75.00%**	**82.14%**	**51.35%**		

Overall Accuracy	**Kappa Coefficient**	**Tau Coefficient**
64.81%	**0.57**	**0.60**

Findings

AVIRIS classification = 63.55%

WV2 classification = 64.81%.

- Total classified area
  - AVIRIS = 168.24 km^2, WV2 = 168.39 km^2
- Classes
  - Very similar total area per class for AVIRIS and WV2.
  - Coral reefs class total
    - AVIRIS = 30% (50.32 km^2) (10,822 polygons)
    - WV2 = 14% (22.89 km^2) (11,652 polygons)
  - Sand class total
    - AVIRIS = 32% (53.50 km^2) (1,539 polygons)
    - WV2 = 40% (67.27 km^2) (1,452 polygons)

Findings

- **Classification Remarks**
  - **Sensors performs equally well in deep and shallow environments.**
    - **Even with WV2 bottom albedo limitations.**
- **Image acquisition dates.**
  - **Massive bleaching event occurred during the AVIRIS image acquisition followed by a coral reef mass-mortality (Eakin et al. 2010).**
  - **Detrimental to *Montastraea (Orbicella) annularis* complex resulting in mortalities in the order of 50% (Garcia-Sais et al. 2008).**
  - **These factors may explain the difference in the total area covered of the coral reef class between the AVIRIS image (50.32 km^2) and the WV2 (22.89 Km^2).**

Photo Interpretation vs Object-based Classification

- Bauer et al. (2012) used photo interpretation for the classification for the southwest Puerto Rico area, including La Parguera.
  - Total coral reefs class was 44.1 km^2 (662 polygons including aggregated reefs, aggregated patch reefs, patch reefs and spur and groove).
- Total area for AVIRIS (50.3 km^2) and WV2 (22.9 km^2)
  - (~10,000 polygons)
- Total overlapped areas between the studies
  - AVIRIS was 19.1 km^2 (38%), WV2 was 12.4 km^2 (54%).
- 1 kilometer vs 4 meters
- Subjective vs Objective

Conclusions and Remarks

- Benthic habitat maps developed from bottom albedo images of both AVIRIS and WV2 sensors.
- Atmospheric and water column corrections (with LiDAR) improve the benthic habitat mapping.
- Reduction in the coral reefs class total could be attributed to temporal differences of the images depicting the changes in habitat types within the reserve.
- A major contribution of this study was that no previous benthic habitat map was available for La Parguera Reserve that provided:
  - Spatial scale (4 square meters).
  - Covered the extent of the reserve (deep areas).
  - Utilized the full spectral range of the imagery.
  - Methods extrapolated to other areas.
  - Change detection.

Web Mapping Application

References:

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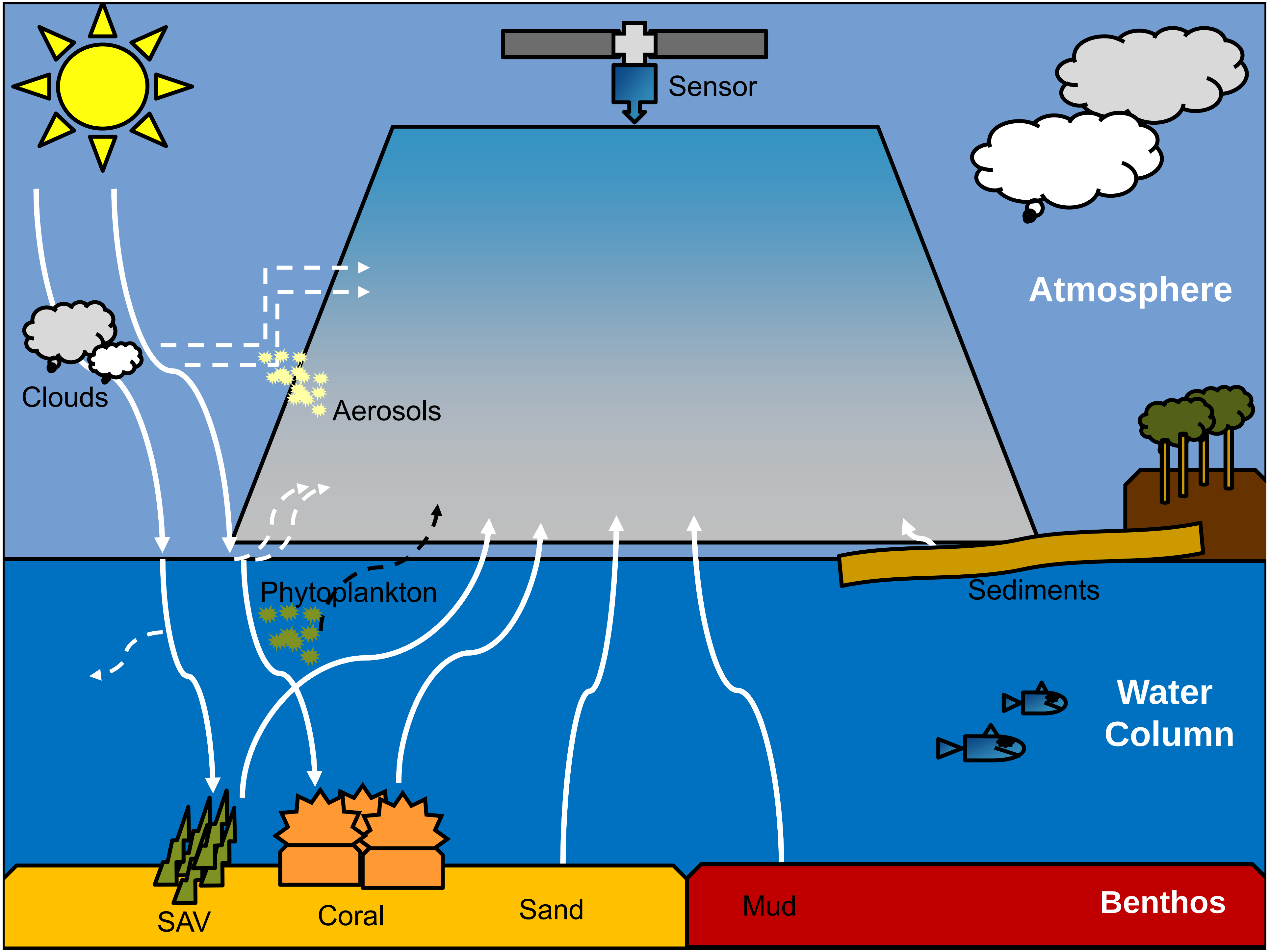
Mishra, Deepak R. Narumalani, Sunil Rundquist, Donald Lawson, Merlin and R. Perk. 2005. Enhancing the detection and classification of coral reef and associated benthic habitats: A hyperspectral remote sensing approach. Journal of Geophysical Research, Vol. 112, C08014.

Purkis, S. J. 2005. A “Reef-Up” Approach to Classifying Coral Habitats From IKONOS Imagery. IEEE Transactions On Geoscience And Remote Sensing, Vol. 43, No. 6, June 2005.


Sensor
Atmosphere
Clouds
Aerosols
Phytoplankton
Sediments
Water
Column
SAV
Coral
Sand
Mud
Benthos

Findings

- Overall Accuracy
  - AVIRIS classification = 63.55%
  - WV2 classification = 64.81%.
  - Mumby et al. (1998) CASI sensor (81%) and Landsat TM (31%)
  - Mishra et al. (2007) AISA of 83.6% and 80.6% from IKONOS
  - Purkis (2005) IKONOS of 69% for seven classes
  - Our study area
    - ~168 Km^2
    - depth range from 0-41 meters (average depth = ~18 meters).

Findings

- Producer's Accuracy (classifier)
  - AVIRIS
    - Sand with benthic algae (79.2%), Seagrass and Hardbottom (75%)
  - WV2
    - Hardbottom (75.%), Coral reefs (73%), Seagrass (72.%)
- User's Accuracy (manager)
  - AVIRIS
    - Sand (89.3%), Coral Reefs (67.4%), Mud (65%) class,
  - WV2
    - Sand (82.3%), Coral reefs (71.4%), Mud (75%)

Findings

- Kappa coefficient
  - AVIRIS (55%) and WV2 (57%). “Moderate” classification (Landis and Koch 1977)
  - Mishra et al. (2005 and 2007) IKONOS 77.4% and AISA 80.8% for seven classes.
  - Arce Arce (2005) and Zayas-Santiago (2011) very similar kappa coefficient compared to our study.
- Tau coefficient
  - AVIRIS (59%) and WV2 (60%).
  - Purkis (2005) IKONOS 65% for seven classes.
  - Mumby and Edwards (2002) reduced in IKONOS (67% to 47%) and Landsat TM (61% to 24%), and CASI hyperspectral image (85%-78%) when classes were increased from 4 to 13 classes.

Coastal and Marine Remote Sensing Instruments