Benthic Habitat Mapping and Bio-optical characterization of La Parguera Marine Reserve using passive and active remote sensing data

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Outline

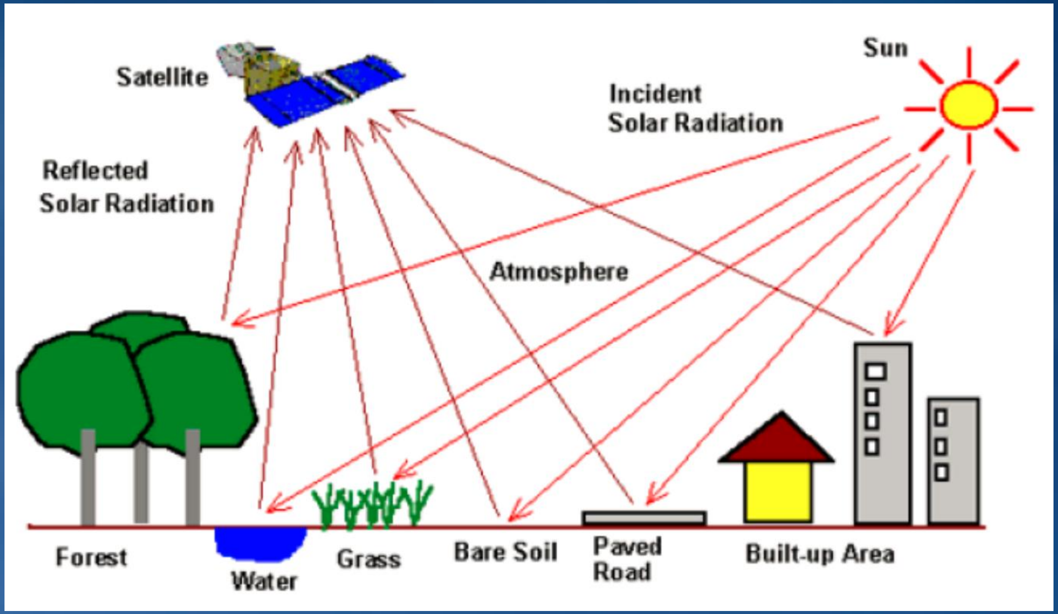
- Study area
- Why use Remote Sensing?
- Challenges
- Sensors (Active/Passive)
  - AVIRIS
  - WV2
  - LiDAR SHOALS
- Methods
  - Bathymetry
  - Water quality optical parameters
  - Benthic habitat
- Conclusion/Benefits

Study Area

- La Parguera
  - DNR Natural Reserve
  - Est. 1979
  - Aprox. 12,500 acres
  - Unique habitats include coral reefs, seagrass beds, and mangroves forest and cays
  - Biobays
  - Marine life

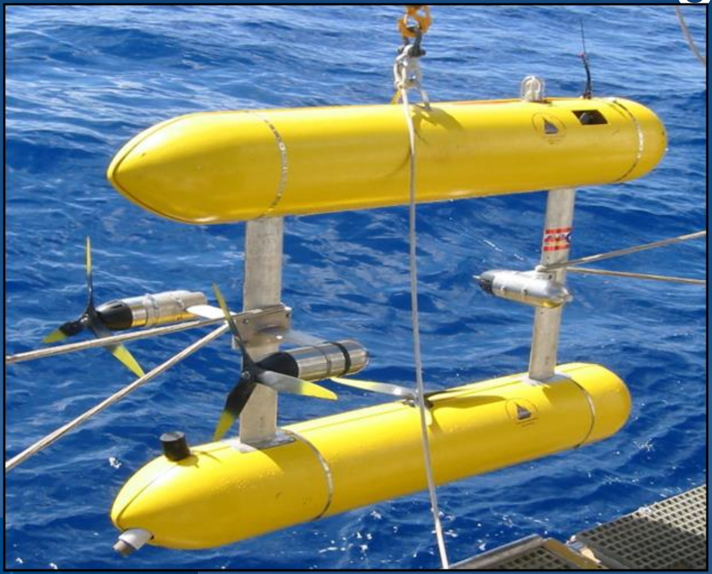
Why use Remote Sensing?

- "Snapshot"
- Survey large areas
- Detect trend
- Cost/effectivity
- Regional effects
- Objective classification



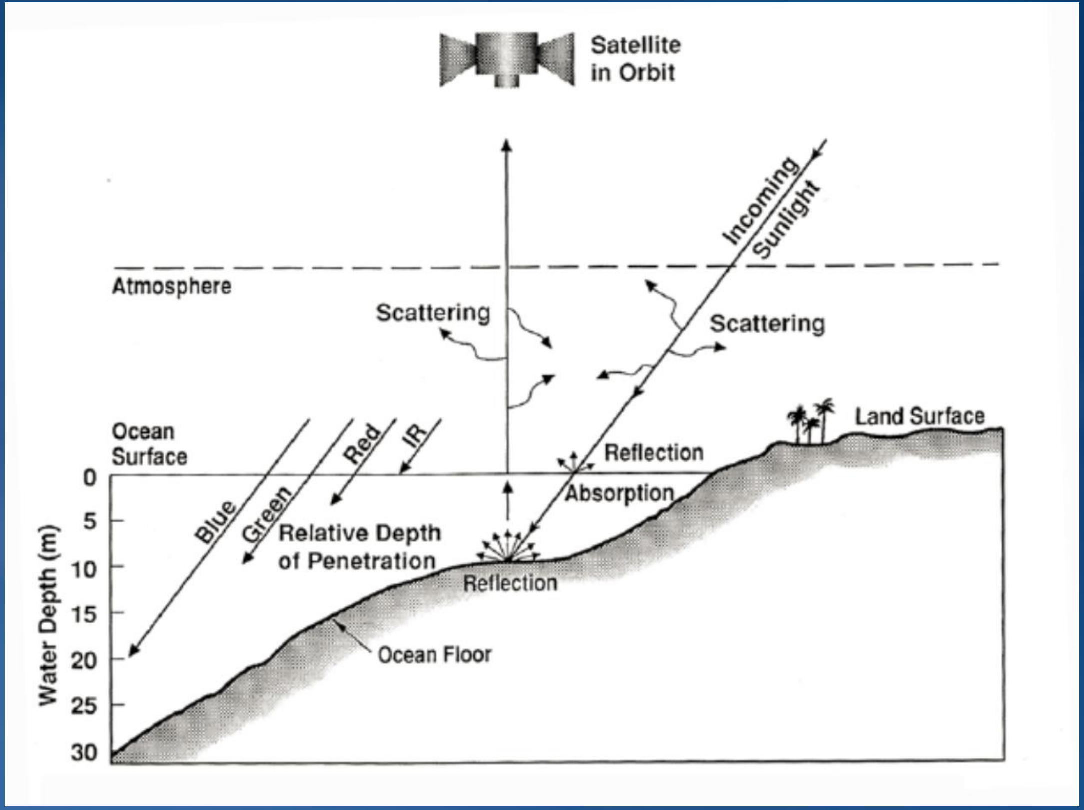
http://www.crisp.nus.edu.sg/~research/tutorial/optical.gif

Coastal and Marine Remote Sensing Instruments



Challenges

- **Depth**
  - **–Variable**
  - **–Detection limits**
- **Variable substrate**
  - **–Consolidated**
  - **–Unconsolidated**
- **Turbidity**
  - **–attenuation**

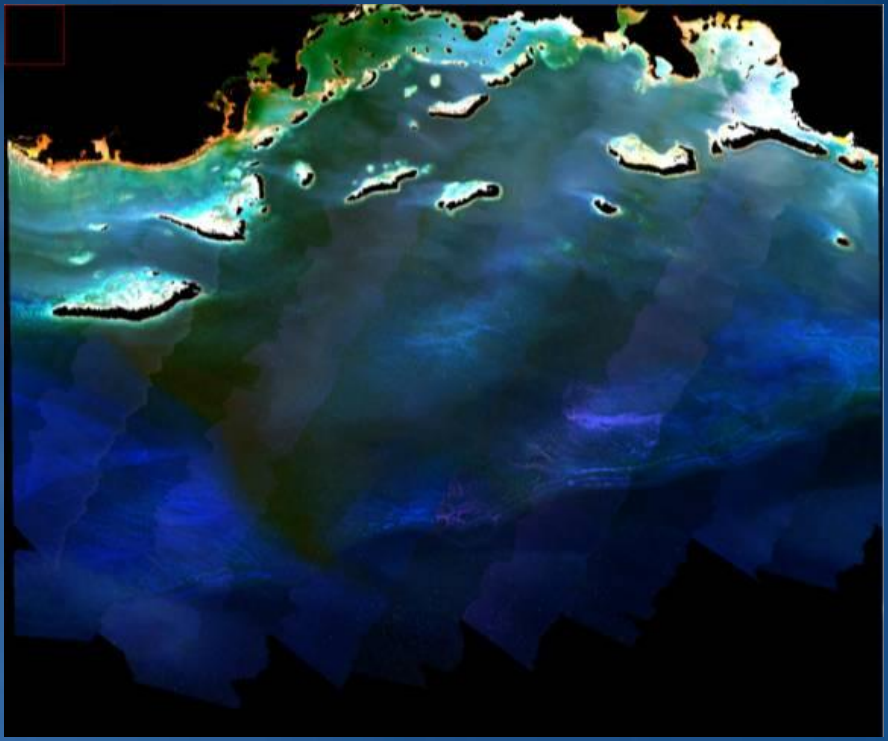


Active and Passive Remote Sensing of Shallow Coastal Environments

- **Goals**
  - **High resolution bathymetry estimation.**
  - **Evaluate of optimum atmospheric correction.**
  - **Water column correction of the multispectral data.**
  - **Bio-optical properties of the water column using *insitu* data and image derived Apparent Optical Properties/Inherent Optical Properties (AOP/IOP).**
  - **Empirical relationship from bottom albedo from passive sensors and *in situ* bio-optical data with LiDAR intensity (reflectivity) to establish an**
  - **Develop a detailed benthic habitat map for La Parguera Natural Reserve**

Sensors

- AVIRIS (Airborne Visible Infrared Imaging Spectrometer)
- December 2005
- 224 Bands (370-2500 nm)
- Visible range: 400-700 nm (32 bands)
- 10 nm bandwidth
- High signal to noise ratio (~1,000)
- Altitude: ~3.5 km
- Spatial resolution: ~3m
- (Guild et al., 2007)

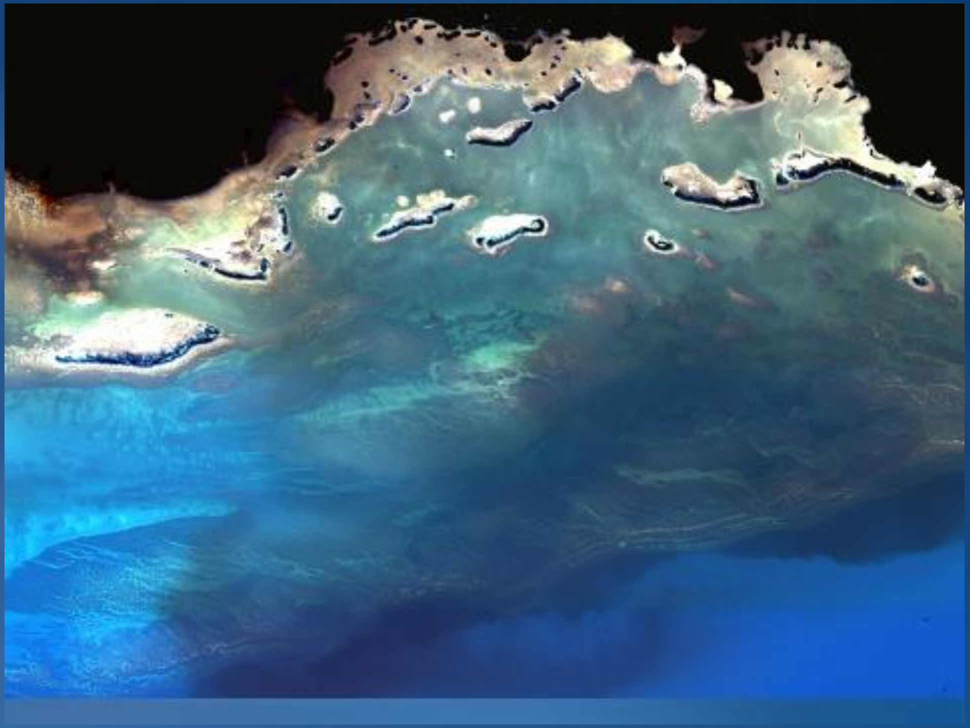


AVIRIS mosaic

Sensors

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

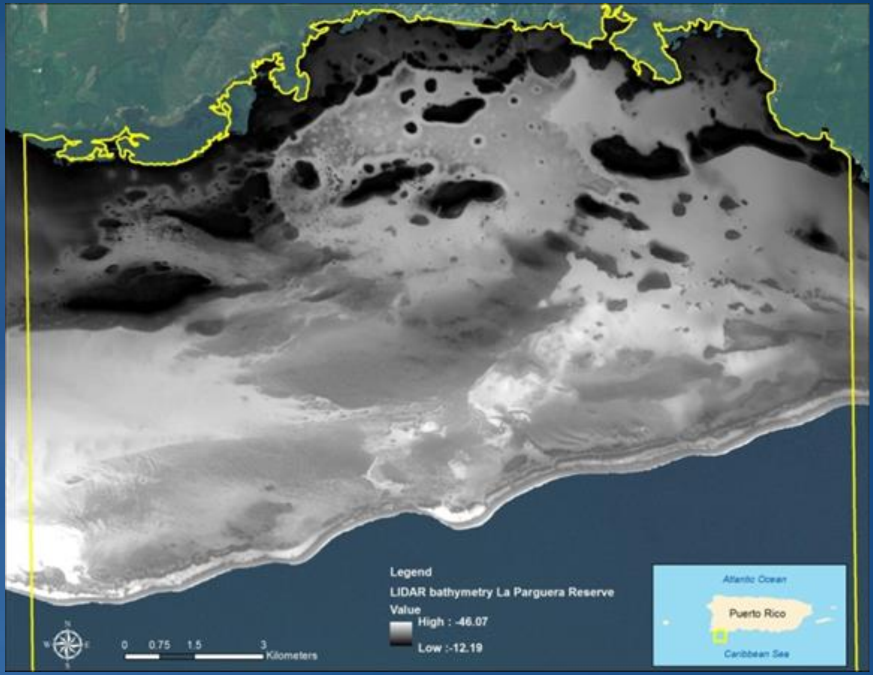
- (Collin,et al., 2012)



WV2 Imagery

Sensors

- **LiDAR SHOALS**
- **Bathymetry**
  - **2006**
  - **(LADS) Mk II Airborne System.**
  - **Infrared beam (1064 nm) and green beam(532nm)**
  - **4 x4 meters bathymetry surface**
  - **5x5 meters intensity surface**
- **(Costa et al., 2009)**

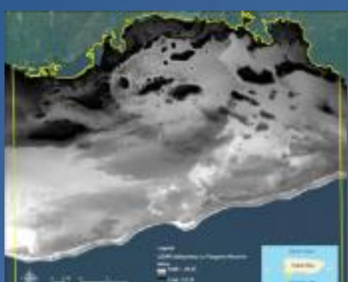


LIDAR bathymetry

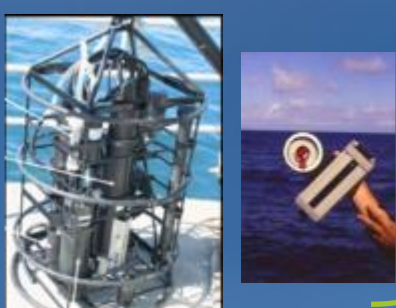
METHODS

AVIRIS image

WV2 image

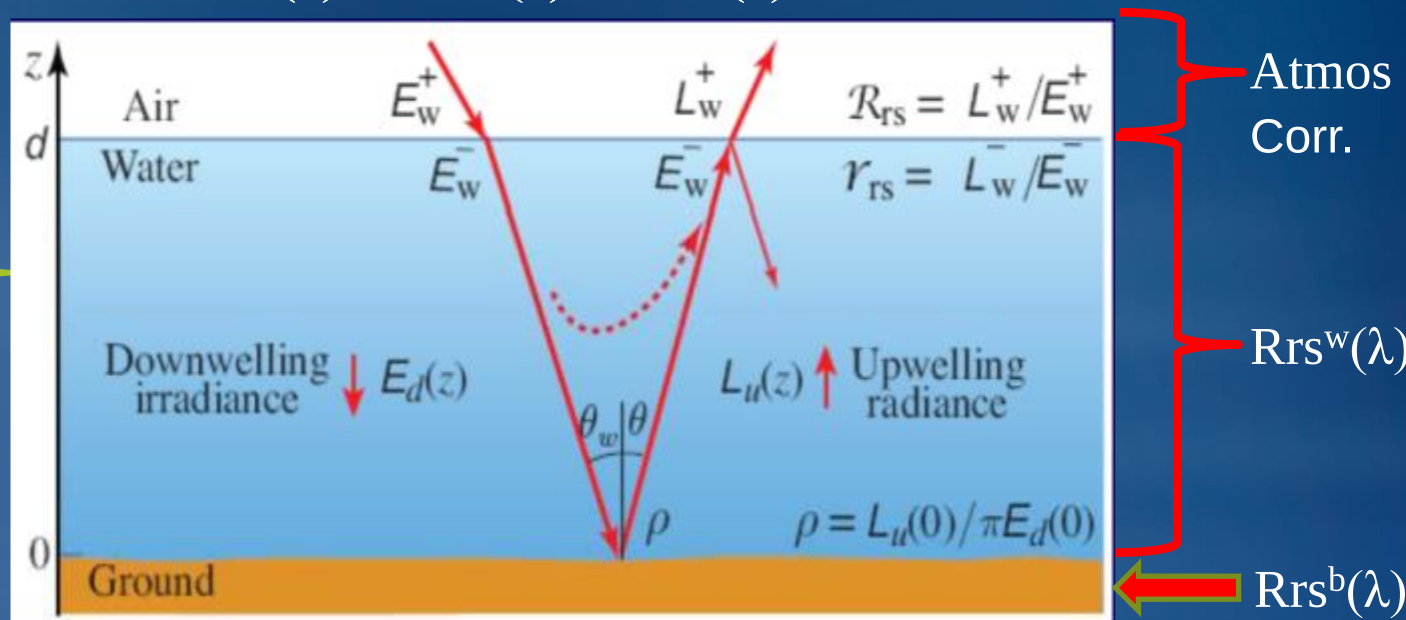


LiDAR SHOALS



Bio-optical sampling

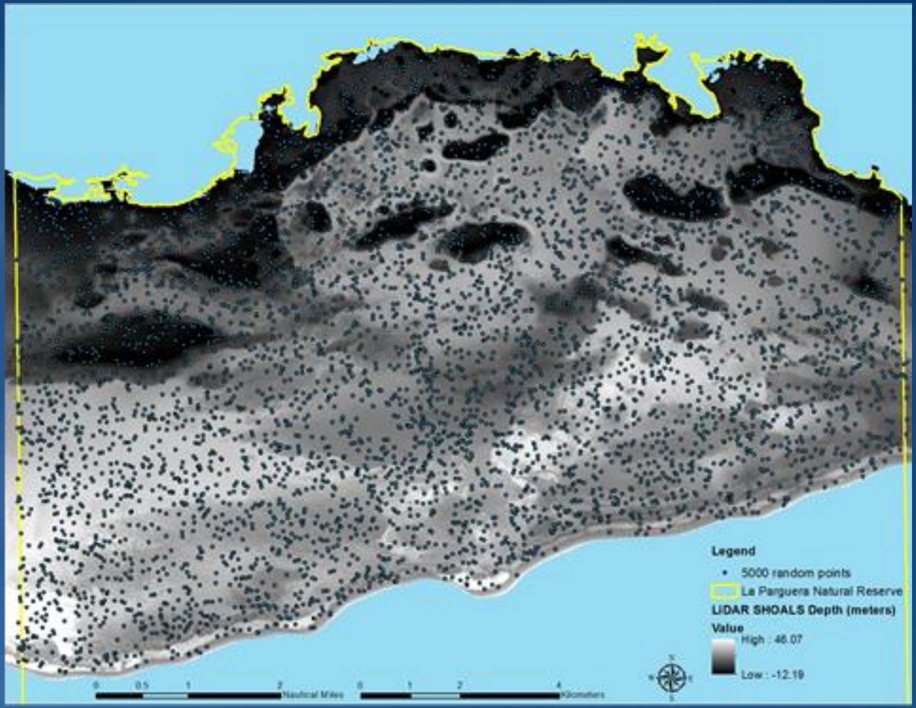
$Rrs(\lambda) = Rrs^{w}(\lambda) + Rrs^{b}(\lambda)$ *Lee, et al. 1994*

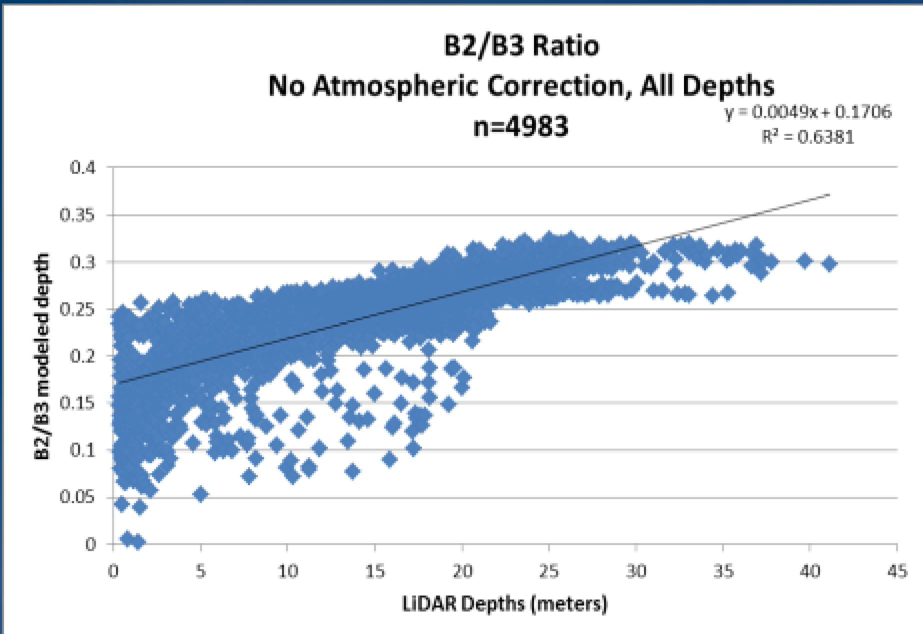


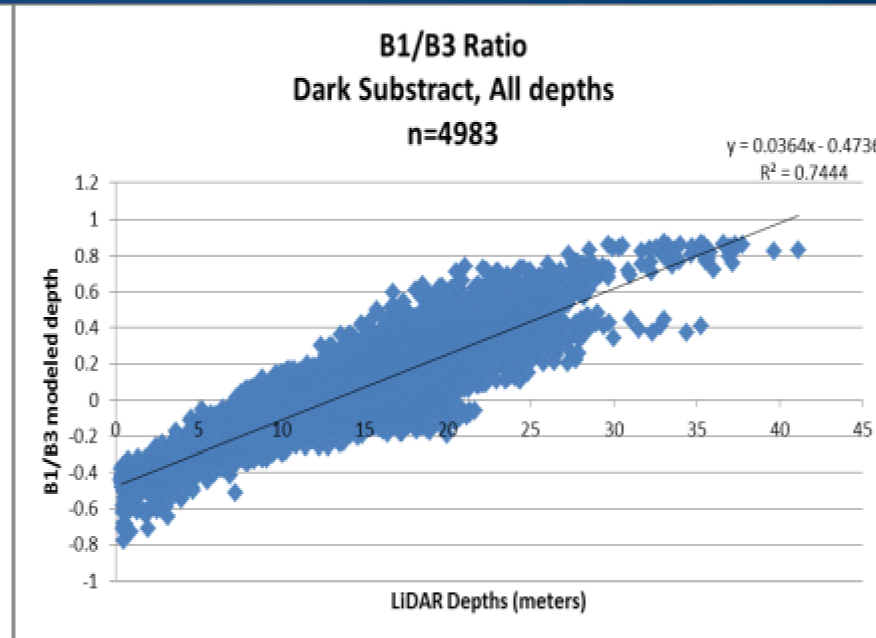
- *Image Preprocessing (co-registration, normalized radiances)*
- *Atmospheric correction (No Atmos, Dark Sub, FLAASH, TAFKAA, CSA)*
- *Water column correction (Inversion Algorithm, PCA, ICA)*
- Optical properties (AOPs / IOPs *insitu, image derived).*
- *Bathymetry (passive and active sensor).*
- *Empirical relationship bottom albedo / LiDAR reflectivity.*
- *High resolution benthic habitat map La Parguera Reserve.*

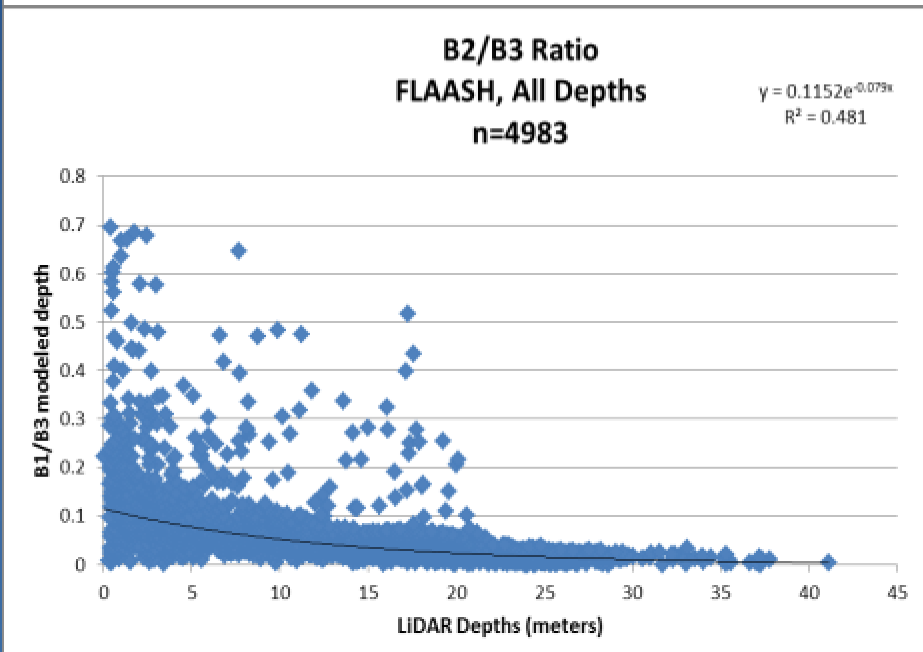
Bathymetry

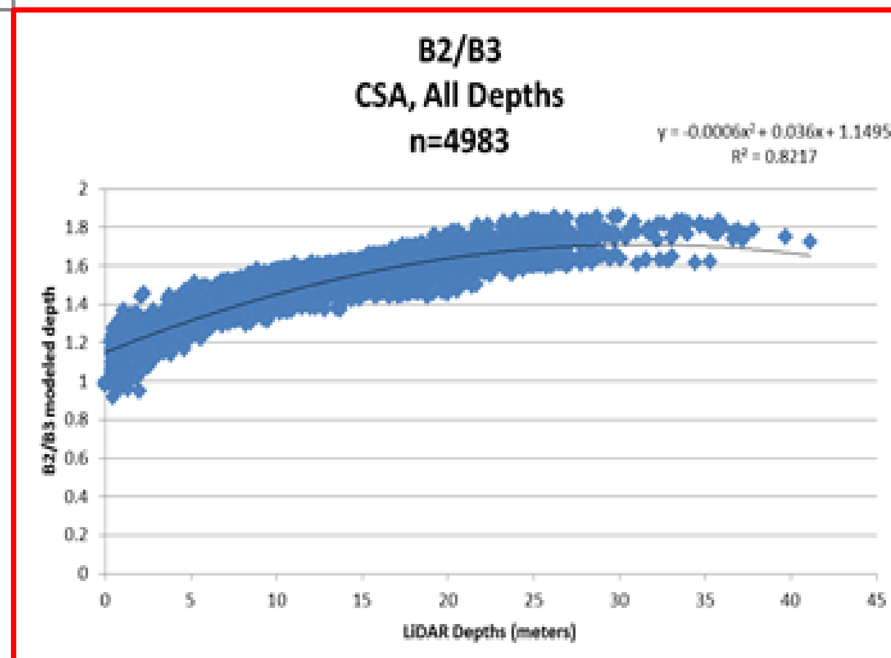
- Accurate determination of water depth.
- Atmospheric corrections
  - NO atmospheric correction
  - Dark substract
  - FLAASH
  - Cloud Shadow Approach (CSA)
- Depth estimation
  - Band ratios (Lyzenga, 1978, Philpot, 1989)
    - World View 2 (multispectral)
    - LiDAR Bathymetry




B2/B3 Ratio
No Atmospheric Correction, All Depths
n=4983
y = 0.0049x + 0.1706
$R^2 = 0.6381$
B2/B3 modeled depth
LiDAR Depths (meters)


B1/B3 Ratio
Dark Substract, All depths
n=4983
y = 0.0364x - 0.4736
$R^2 = 0.7444$
B1/B3 modeled depth
LiDAR Depths (meters)


B2/B3 Ratio
FLAASH, All Depths
n=4983
$y = 0.1152e^{-0.079x}$
$R^2 = 0.481$
B1/B3 modeled depth
LiDAR Depths (meters)

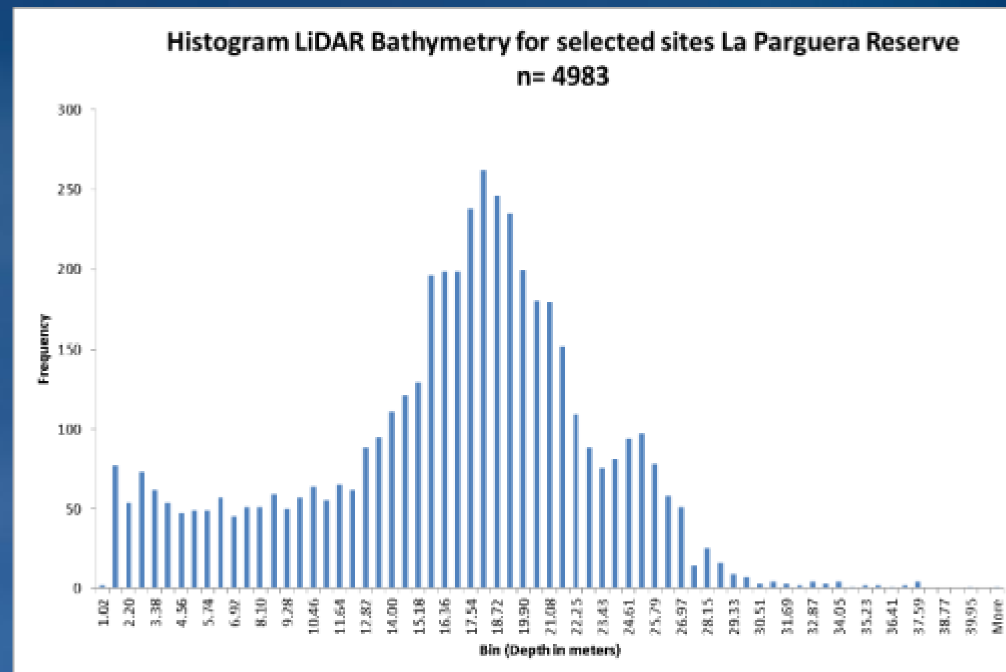

B2/B3
CSA, All Depths
n=4983
$y = -0.0006x^2 + 0.036x + 1.1495$
$R^2 = 0.8217$
B2/B3 modeled depth
LiDAR Depths (meters)

Results

Band Ratios

WV2

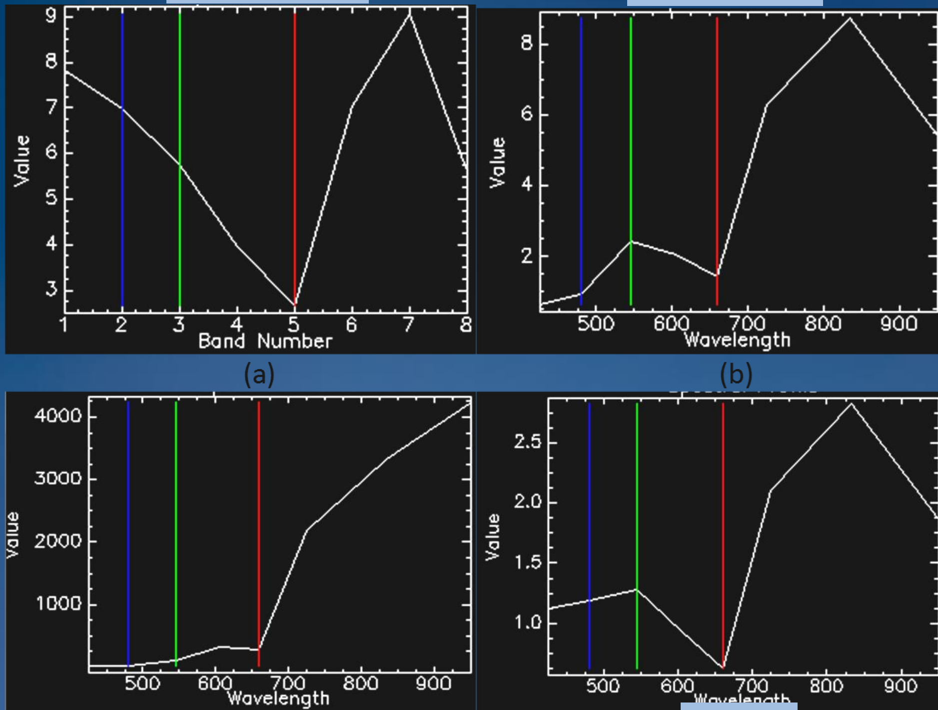
- CSA
  - best results for all band ratios (B1/B2, B1/B3, B2/B3)
  - all depth values/ranges
- "best fit" second order polynomial equation
- (r^2 =0.822).



- Depth range: 1.00 – 41.13 meters
- Average depth: 16.26 meters

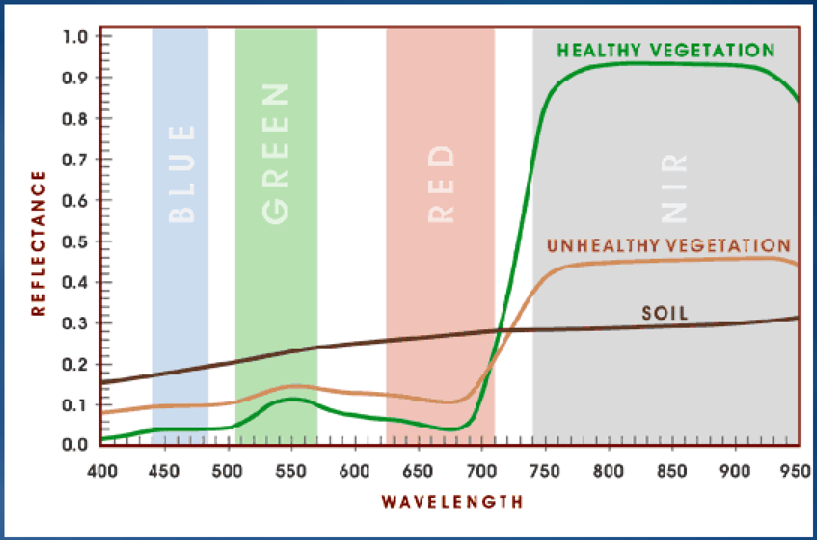
No Atmos

Dark Sub



FLAASH

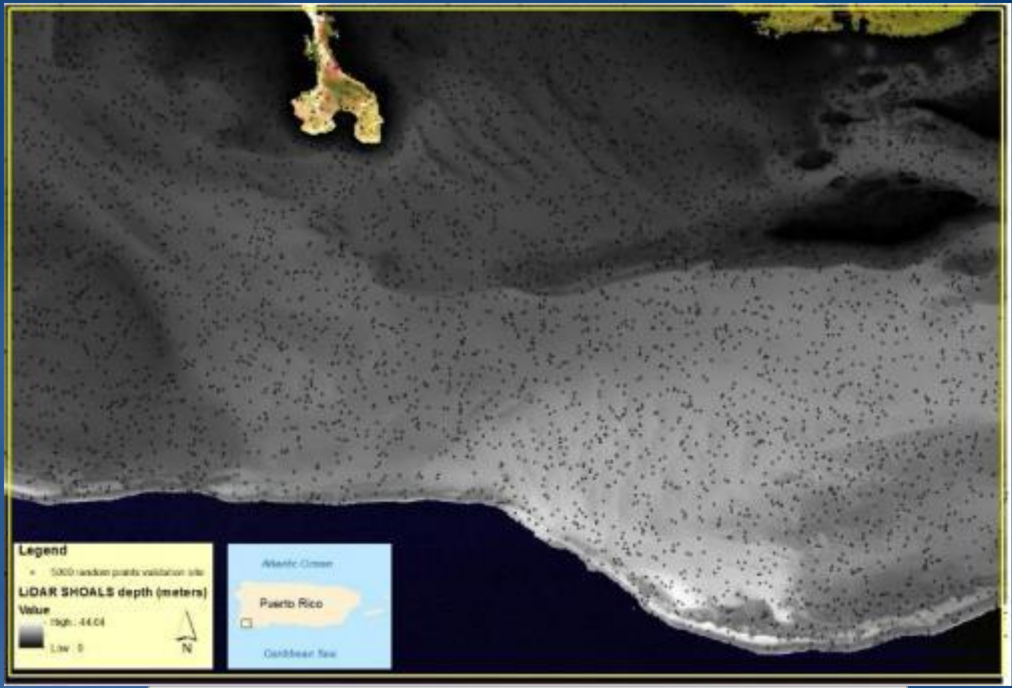
CSA

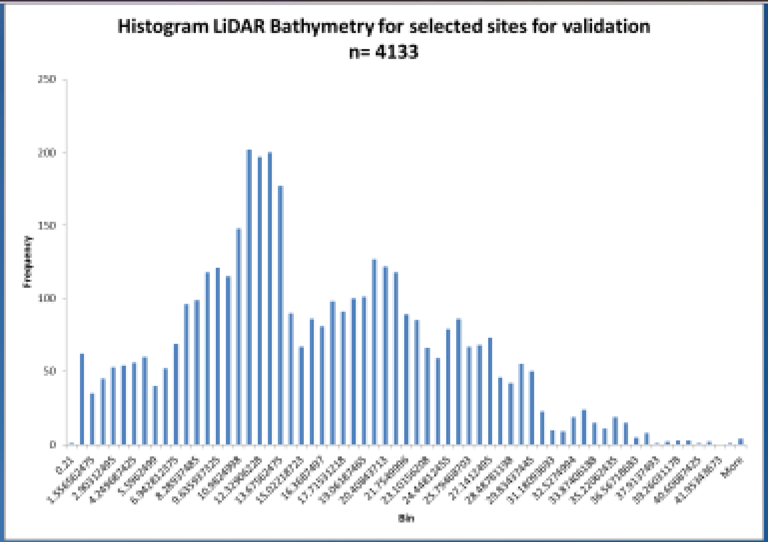


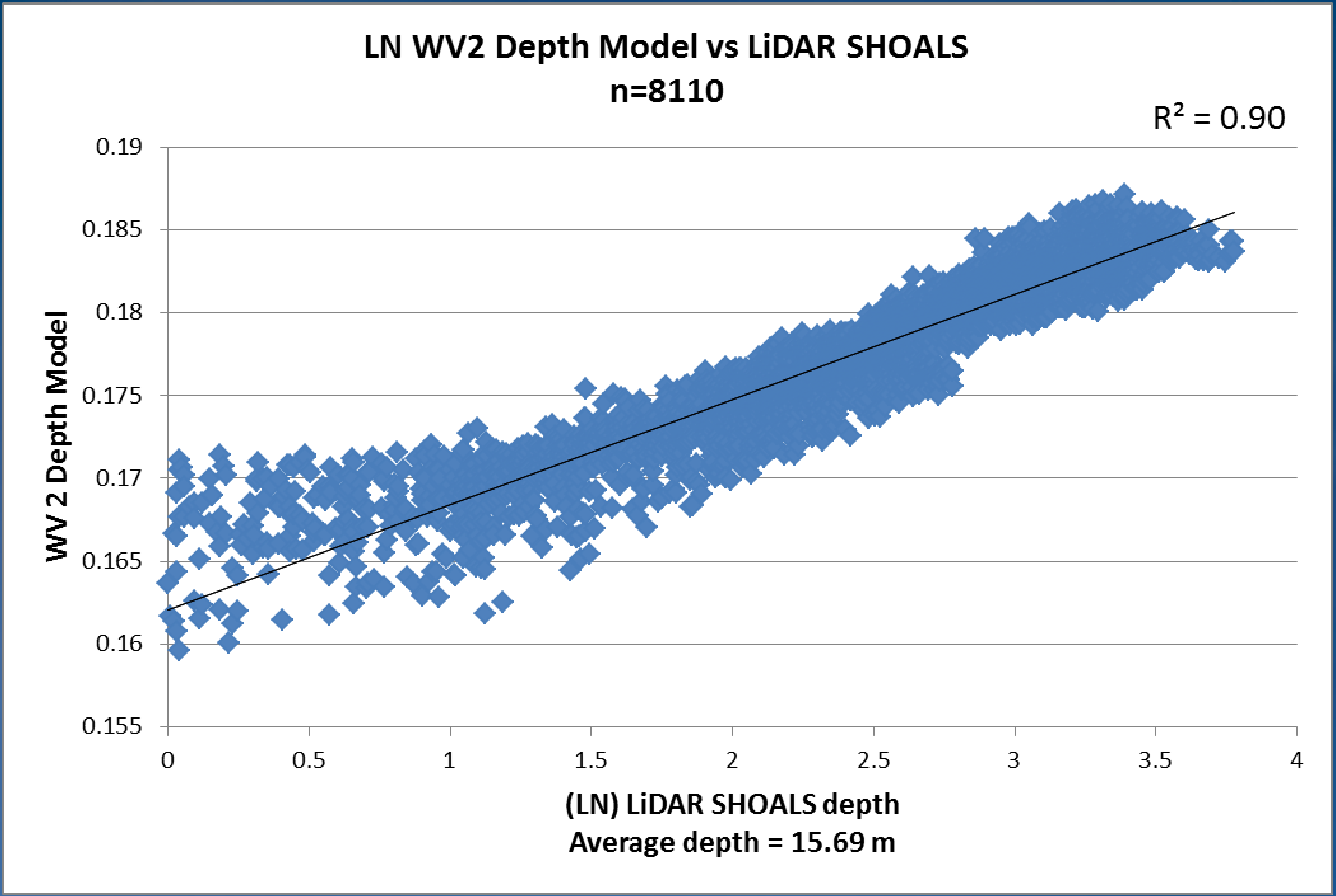
Results cont…

Band Ratio

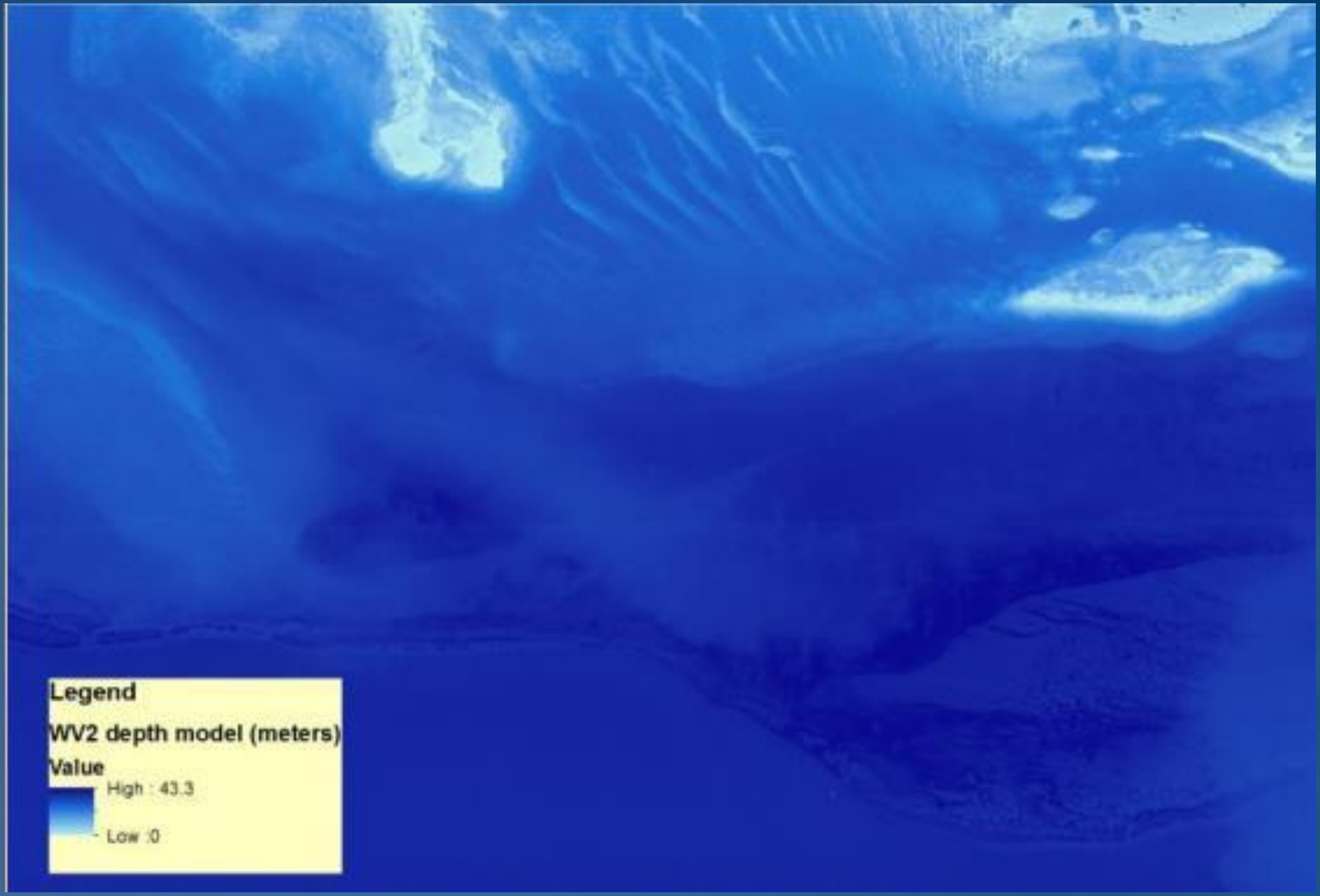
- WV2
  - B2/B3 ratio CSA
  - (y = -0.0006x² + 0.0359x + 1.1498).
  - Evaluate model performance
  - WV2 image subset of the image
  - accuracy in depth estimation when compared with LiDAR depths.







LN WV2 Depth Model vs LiDAR SHOALS
n=8110
R² = 0.90
0.19
0.185
0.18
0.175
0.17
0.165
0.16
0.155
WV 2 Depth Model
0
0.5
1
1.5
2
2.5
3
3.5
4
(LN) LiDAR SHOALS depth
Average depth = 15.69 m



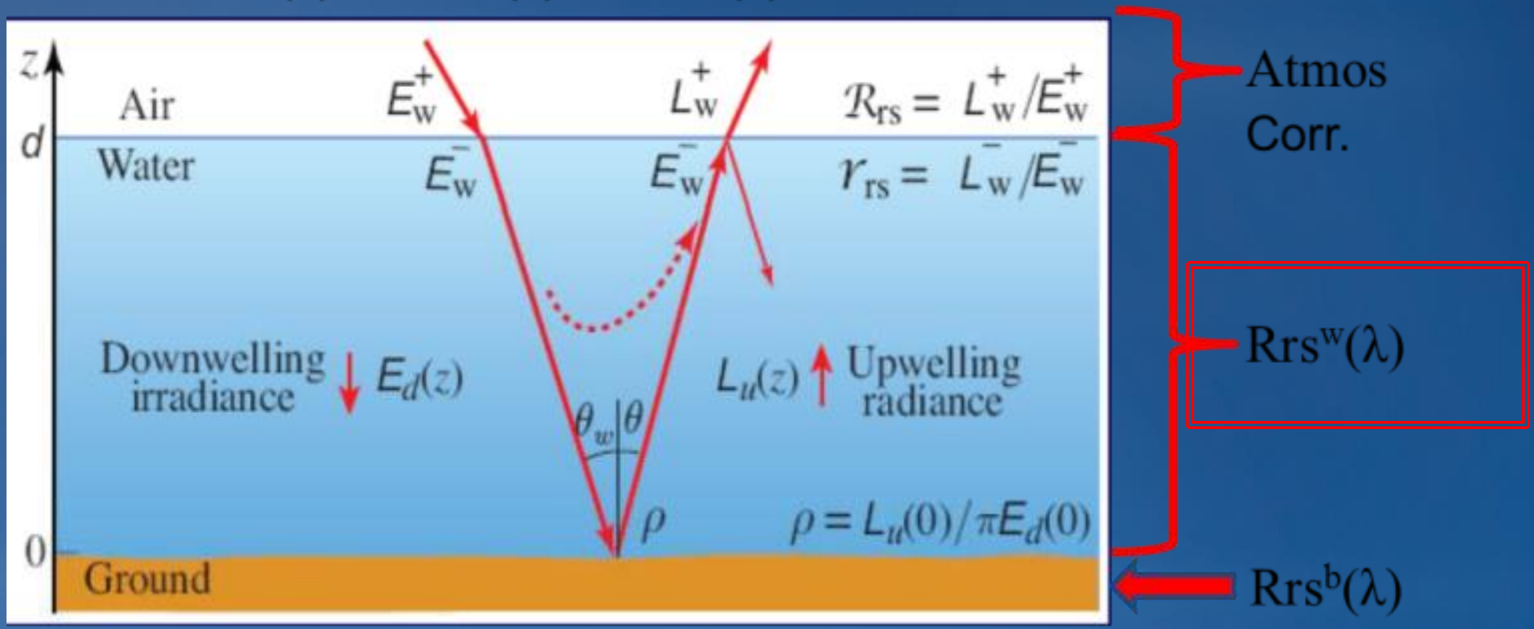
Band Ratio

- WV2 Depth Model
  - R2 = .902
  - RMSE: 1.56m
  - Depth range: 1-43.3 m
  - Average depth: 15.66 m

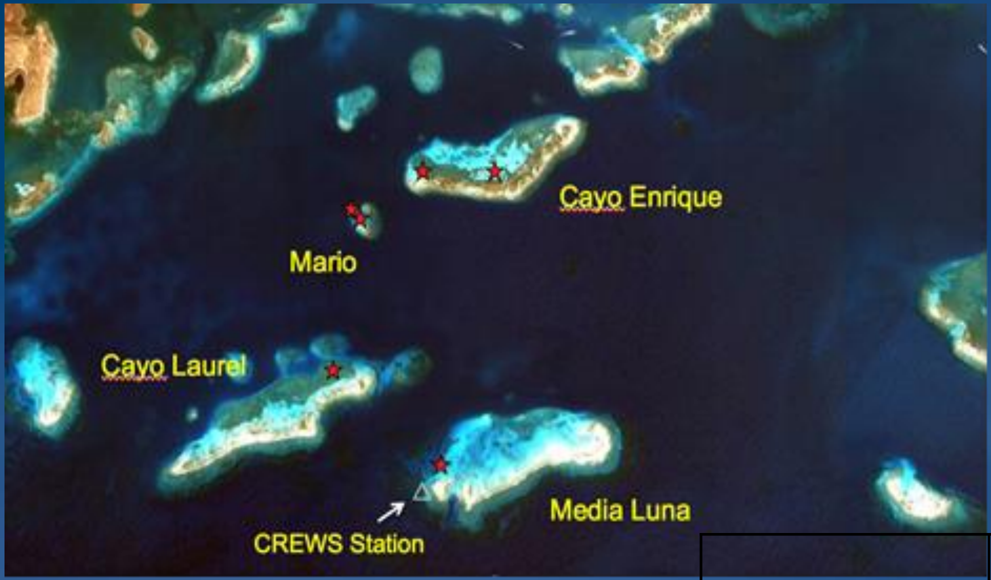
Bottom albedo and water column correction

- Research
  - The AVIRIS hyperspectral sensor was used to obtain bottom albedo, as well as other properties based on model drive image optimization techniques (Lee, et al., 1999, 2001).

$$Rrs(\lambda) = Rrs^{w}(\lambda) + Rrs^{b}(\lambda)$$ *Lee, et al. 1994*



Bio-Optical Sampling Monthly Campaign (May-2007--September-2009)



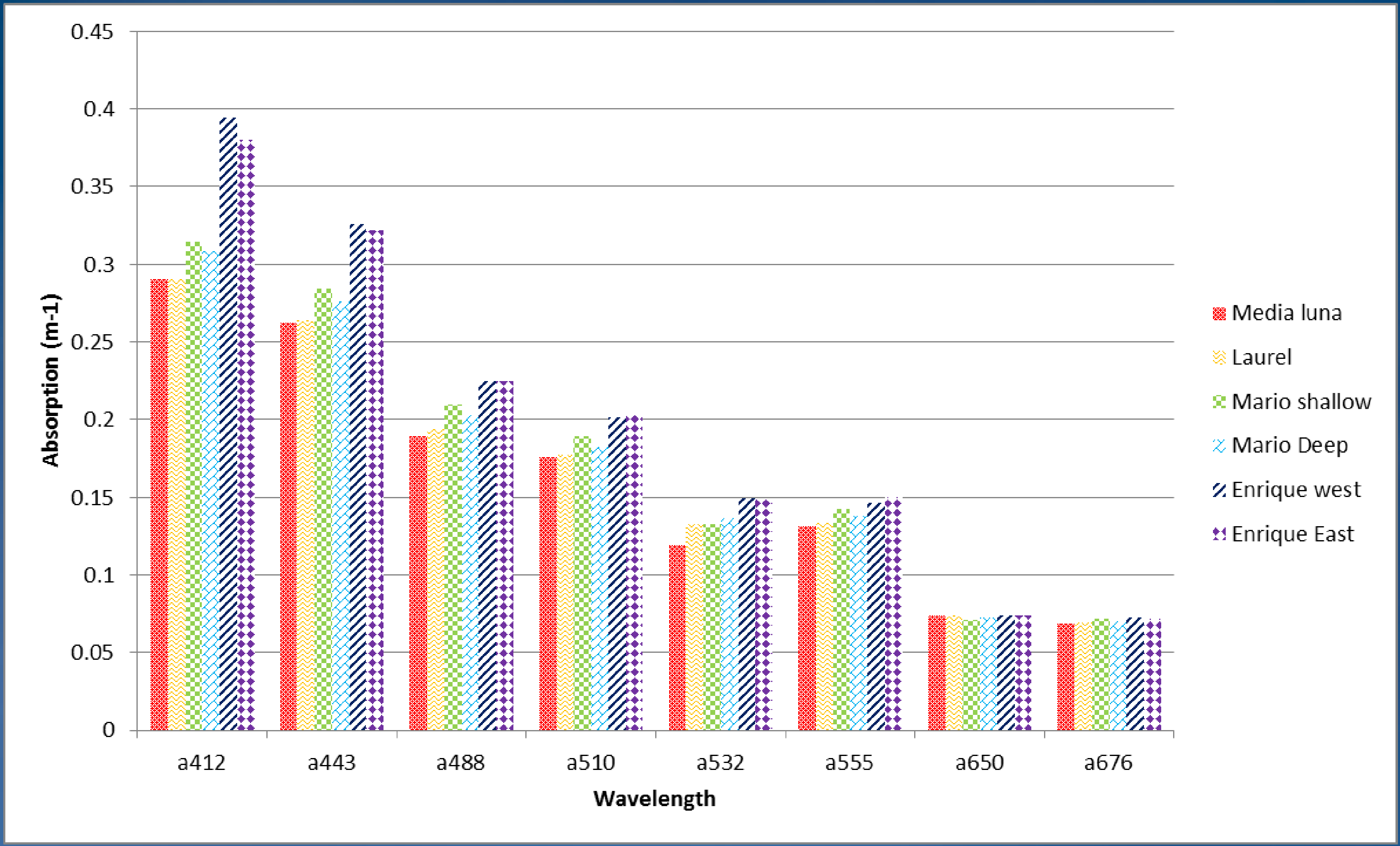
Armstrong, et al., 2012

Bio-optical sampling

Measurements

- Absorption
- Scattering
- Attenuation
- Backscattering
- CTD

Station	Reef	Bottom Type	Depth (m)
1	Media Luna	Sand/Coral	3
2	Laurel	Seagrass	2
3	Mario Shallow	Sand/Coral	4.5
4	Mario Deep	Mud	18
5	Enrique West	Seagrass	2.0
6	Enrique East	Sand	1.5


0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Absorption (m-1)
a412
a443
a488
a510
a532
a555
a650
a676
Wavelength
Media luna
Laurel
Mario shallow
Mario Deep
Enrique west
Enrique East

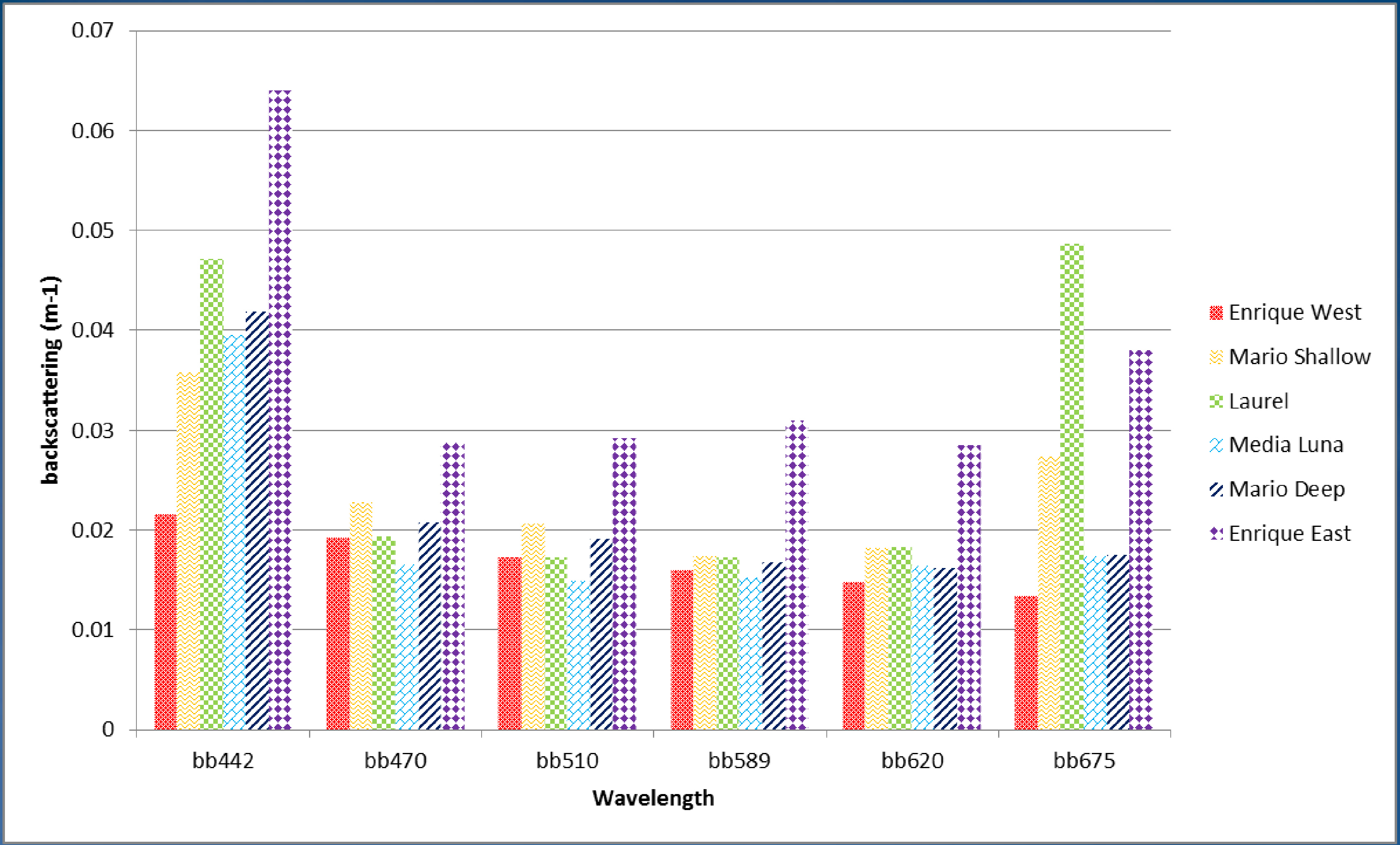

0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
backscattering (m-1)
bb442
bb470
bb510
bb589
bb620
bb675
Wavelength
Enrique West
Mario Shallow
Laurel
Media Luna
Mario Deep
Enrique East

Image derived Inherent Optical properties (Lee, et al., 1998, Mishra, et al., 2007)

Band	λ, m^{-1}	a (λ), m^{-1}	a_w (λ), m^{-1}	b_b (λ), m^{-1}	b_{bw} (λ), m^{-1}	M (λ)
1	405	0.3506	0.00530	0.0049	0.0033	1.7463
2	414	0.3628	0.00444	0.0045	0.0029	1.7312
3	424	0.3474	0.00478	0.0043	0.0027	1.6550
4	434	0.3292	0.00530	0.0040	0.0024	1.5648
5	443	0.3107	0.00696	0.0038	0.0022	1.4673
6	453	0.2918	0.00969	0.0036	0.0020	1.3627
7	462	0.2808	0.01005	0.0036	0.0020	1.3077
8	472	0.2589	0.0109	0.0034	0.0018	1.1982
9	482	0.2399	0.0131	0.0032	0.0016	1.0955
10	491	0.2220	0.0150	0.0031	0.0015	1.00
11	501	0.2092	0.0204	0.0030	0.0014	0.9118
12	511	0.2045	0.0325	0.0028	0.0012	0.8310
13	520	0.1978	0.0409	0.0028	0.0012	0.7578
14	530	0.1867	0.0434	0.0027	0.0011	0.6924
15	539	0.1789	0.0474	0.0026	0.0010	0.6350
16	549	0.1778	0.0565	0.0025	0.0009	0.5860
17	559	0.1749	0.0619	0.0024	0.0008	0.5457
18	568	0.1737	0.0672	0.0023	0.0007	0.5146
19	578	0.1858	0.0836	0.0023	0.0007	0.4935
20	588	0.2222	0.1220	0.0023	0.0007	0.4840
21	597	0.2940	0.1925	0.0023	0.0007	0.4903
22	607	0.3660	0.2629	0.0022	0.0006	0.4983
23	617	0.3788	0.2707	0.0021	0.0005	0.5223
24	626	0.4005	0.2834	0.0021	0.0005	0.5659
25	636	0.4395	0.3012	0.0021	0.0005	0.6683
26	646	0.4740	0.325	0.0021	0.0005	0.7201
27	655	0.5226	0.371	0.0020	0.0004	0.7323
28	665	0.5781	0.429	0.0004	0.0004	0.7205
29	672	0.5931	0.448	0.0004	0.0004	0.7008
30	682	0.6073	0.478	0.0004	0.0004	0.6245
31	692	0.6395	0.538	0.0004	0.0004	0.4901
32	701	0.6838	0.624	0.0004	0.0004	0.2891

Absorption and backscattering coefficients derived from the AVIRIS image (100x100 pixel window). Absorption of pure water [aw (λ)] derived from Pope and Fry, (1997); the backscattering coefficient of pure seawater [bbw (λ)] is half the scattering coefficient. The scattering coefficients for optically pure seawater were the values proposed by Buiteveld et al. (1993) increased by a factor of 1.30 to account for the presence of salt (Morel, et al., 2007; Twardowski, et al., 2007). M is a statistically derived coefficient taken from Austin and Petzold (1986).

AVIRIS Image derived IOP
(Lee, et al., 1998,1999, 2001; Mishra, et al., 2007)

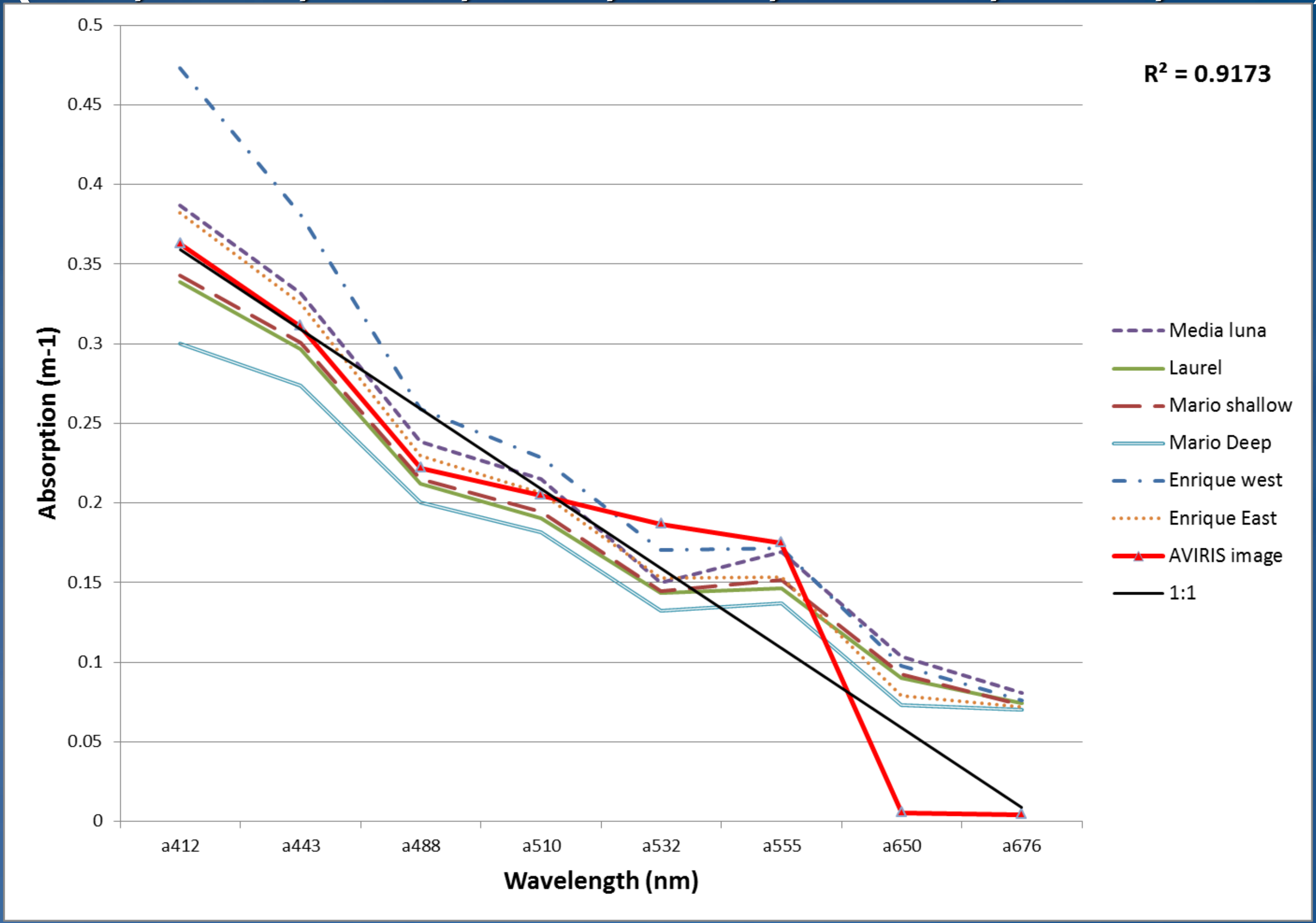


Image-derived absorption (a) compared with in situ monthly values from May 2007 to August 2009 for La Parguera

AVIRIS Image derived IOP
(Lee, et al., 1998, Mishra, et al., 2007)

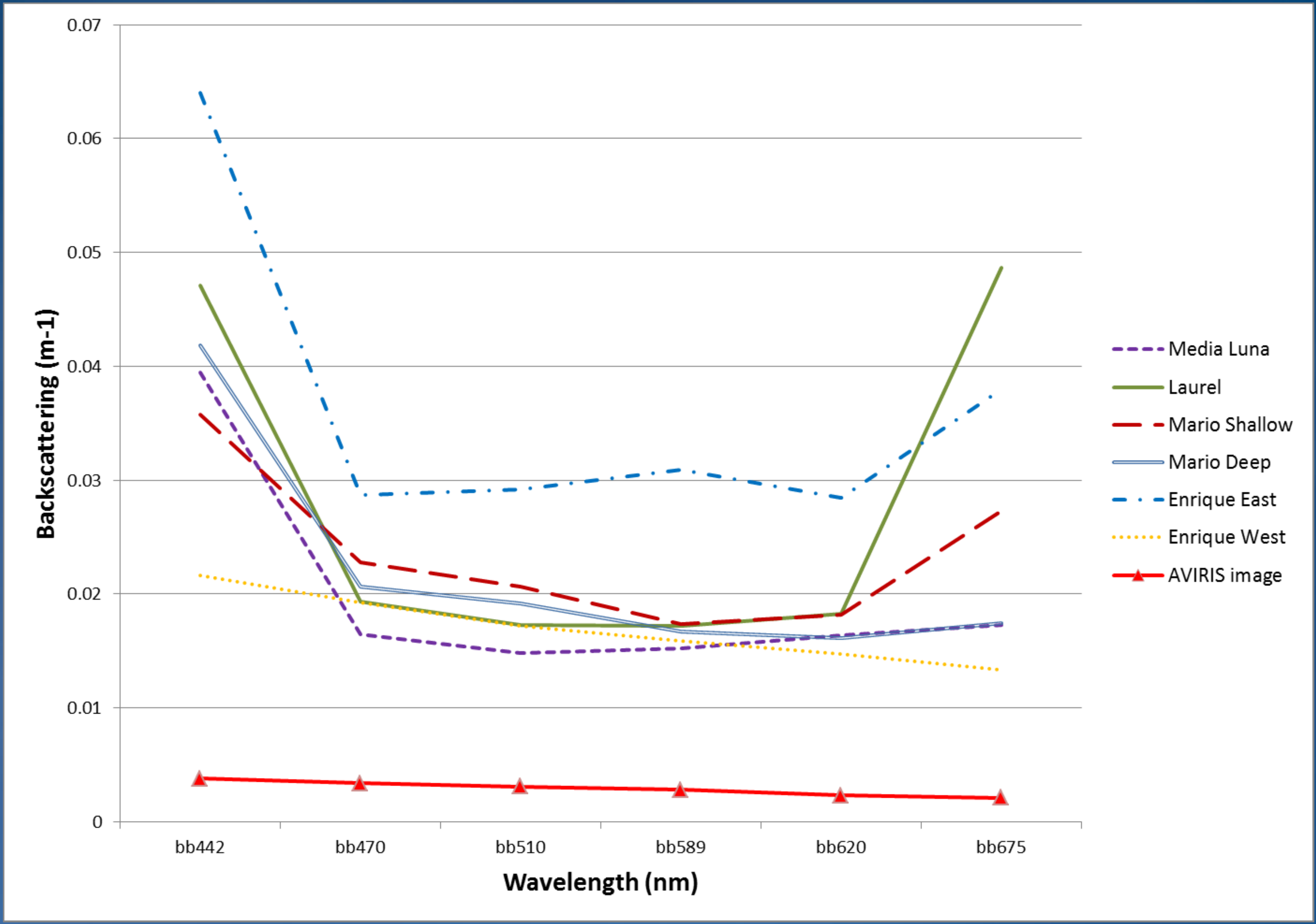


Image-derived backscattering (Bb) compared with insitu monthly values from May 2007 to August 2009 for La Parguera.

AVIRIS Image derived AOP (Lee, et al., 2005)

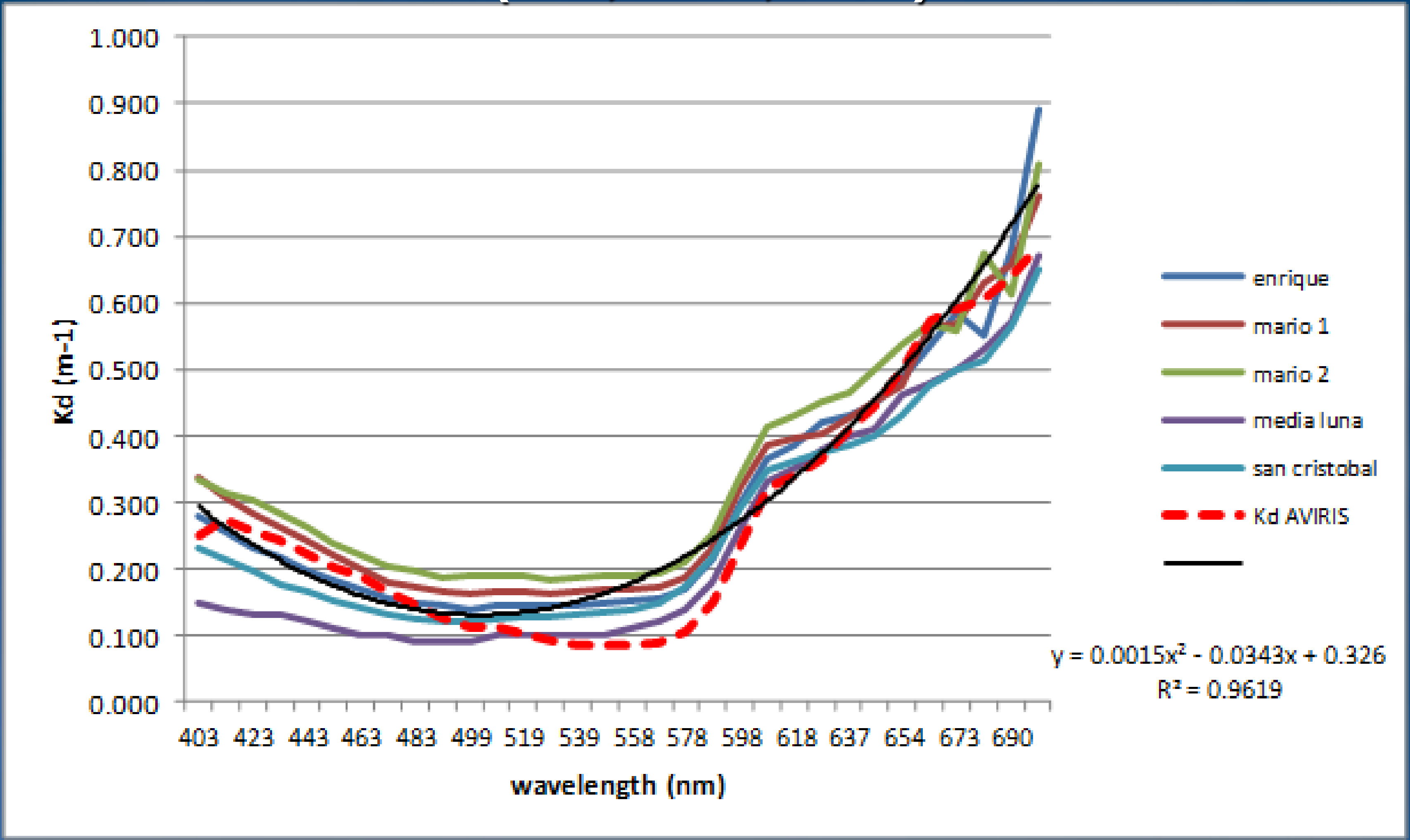
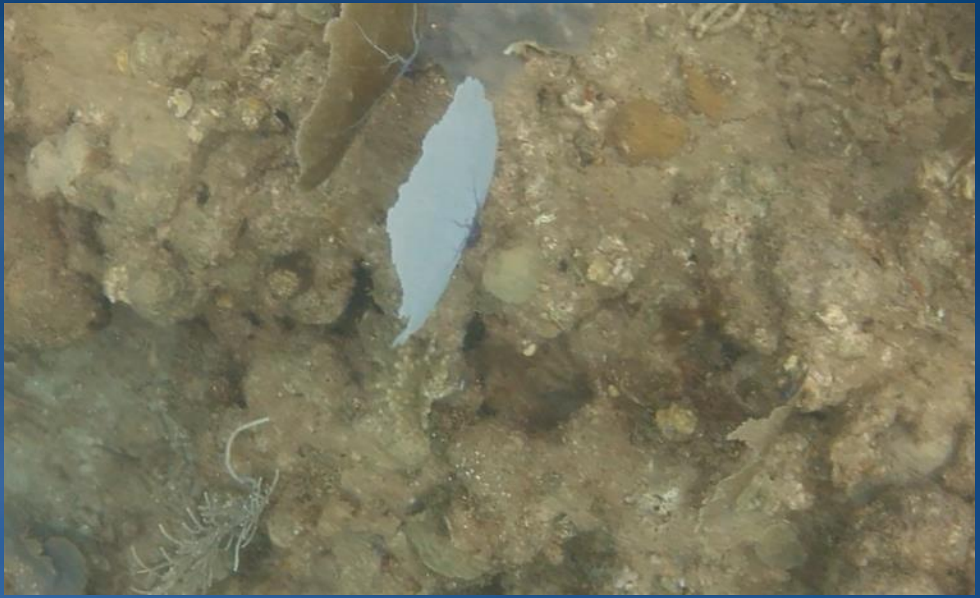
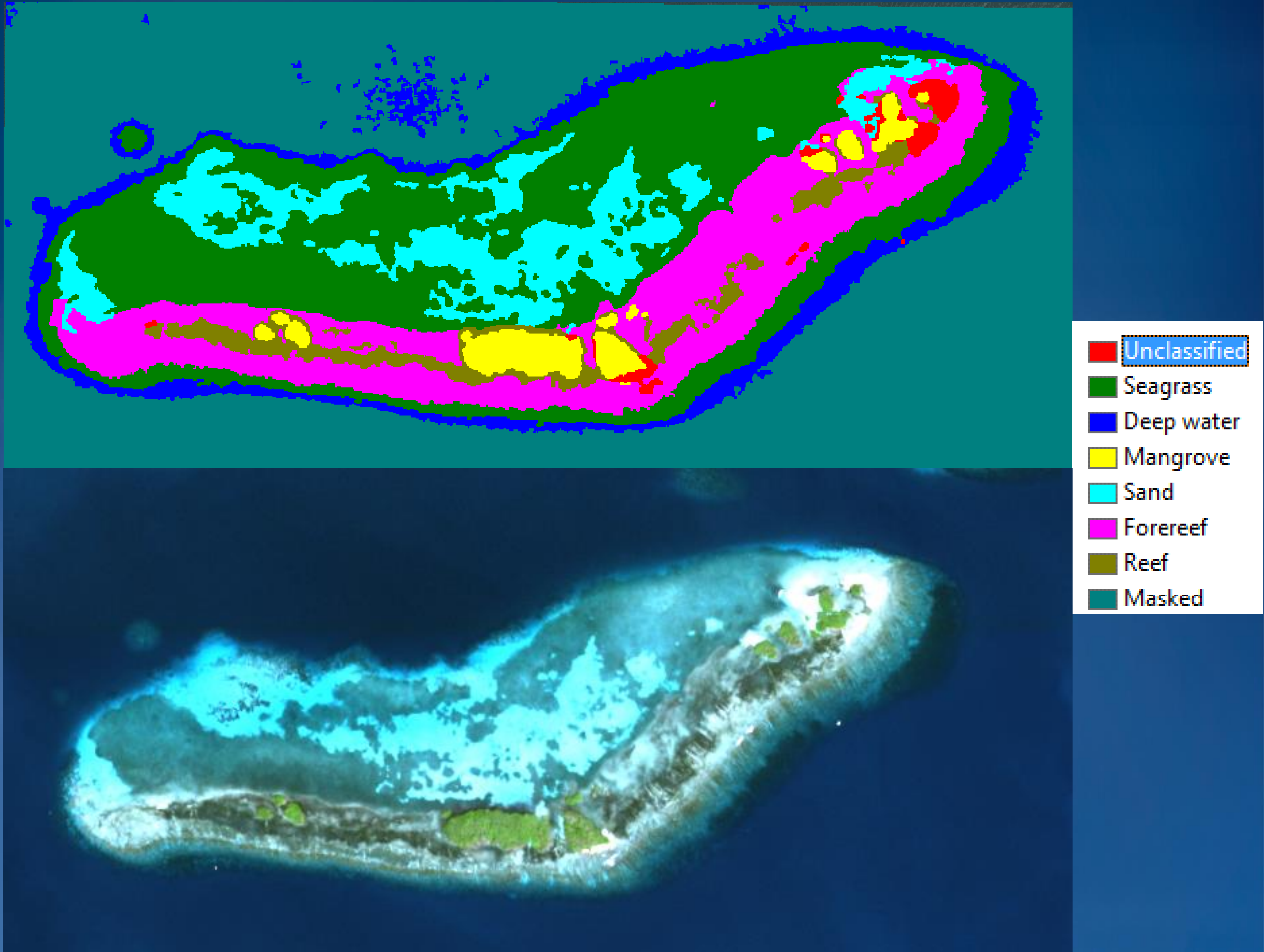


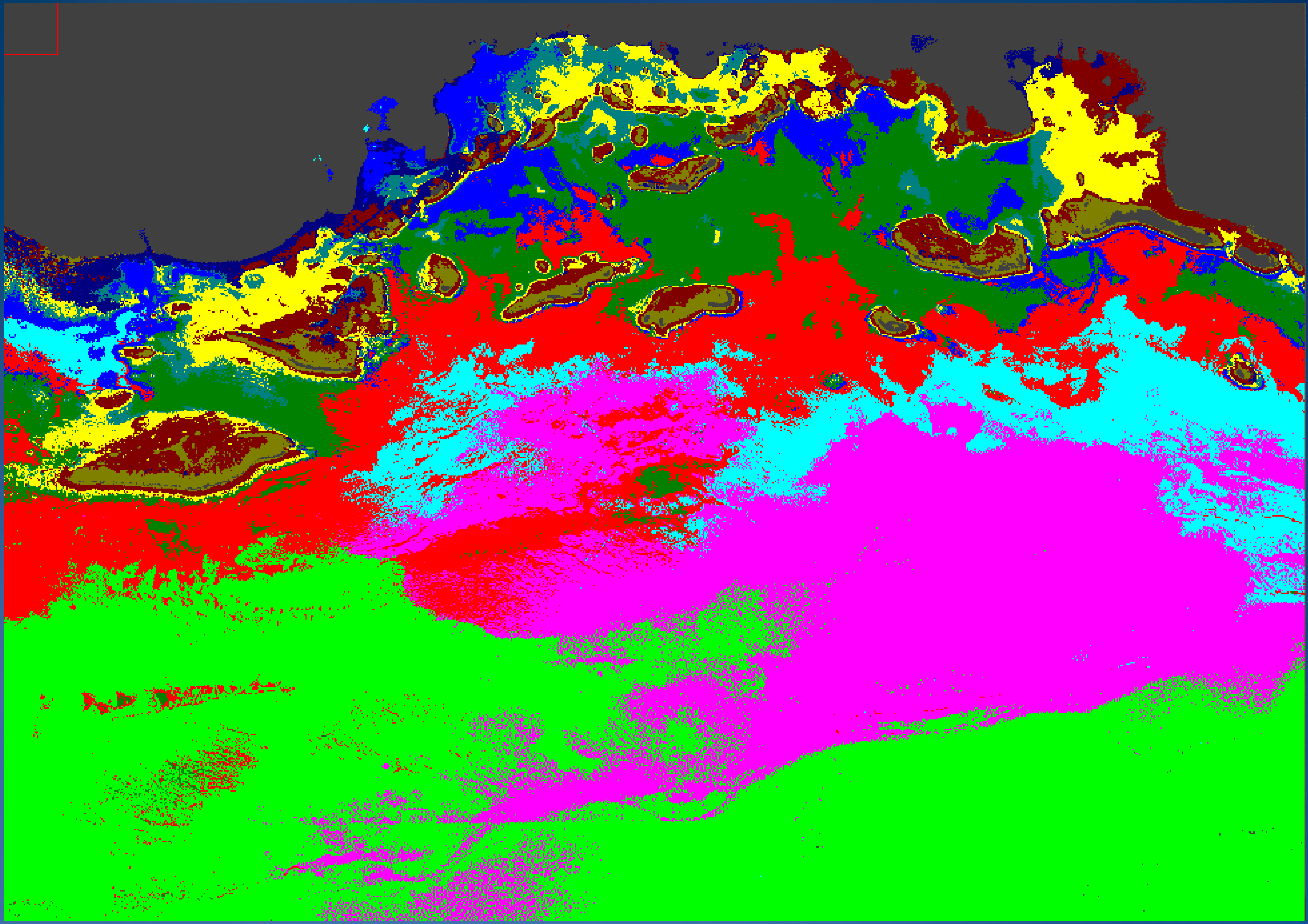
*Image derived vertical attenuation coefficient (Kd) compared with in situ values from selected sites at La Parguera Reserve. Kd values were collected coincident with image collection. Image derived Kd (red dashed line) was calculated for optically deep waters using an equation proposed by Lee, et al. (2005) (Kd =m0*a+v*bb θ=45º).*

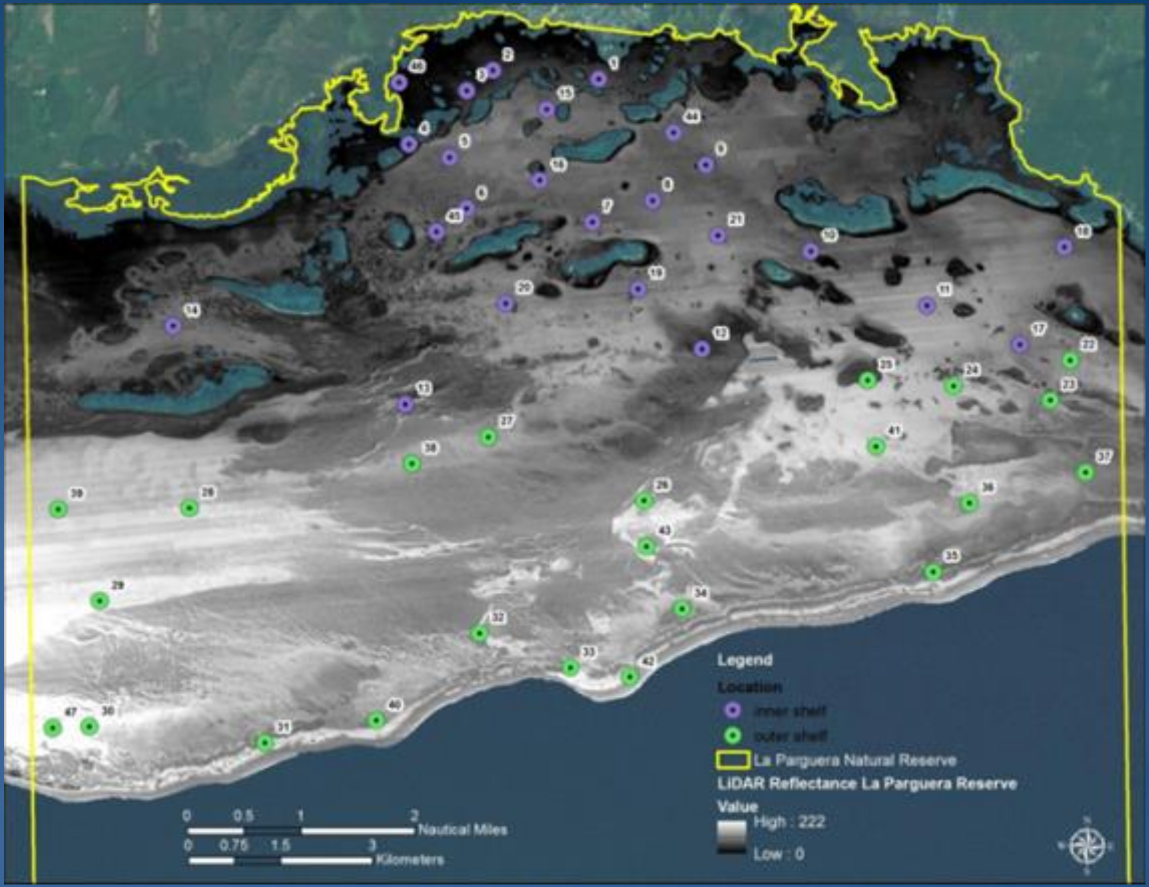
Benthic Habitat Mapping

- **Before/after water column correction**
- **For AVIRIS and WV2**
- **Using various methods**
  - **Supervised classification**
- ***Insitu* Validation**




Unclassified
Seagrass
Deep water
Mangrove
Sand
Forereef
Reef
Masked





NEXT STEPS

- Continue field sampling
  - IOPs, AOPs, benthic habitat
- Finalize water column corrections
- Image classification and bottom albedo map

Conclusions:

- Importance of the atmospheric correction selection in the image processing.
- Fast approach to obtain bathymetry from imagery.
- Evaluate the limits of detection of a high resolution passive sensor in estimating bathymetry.
- Characterization and temporal evaluation of bio-optical properties (IOP/AOP) of the waters in La Parguera Reserve.
- Baseline optical data for validation of other sensors.
- Develop a high resolution benthic habitat as a baseline mapping tool for managers of the reserve.

QUESTIONS?

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