Fusion of Hyperspectral Imagery and Bathymetry Information for Inversion of Bioptical Models

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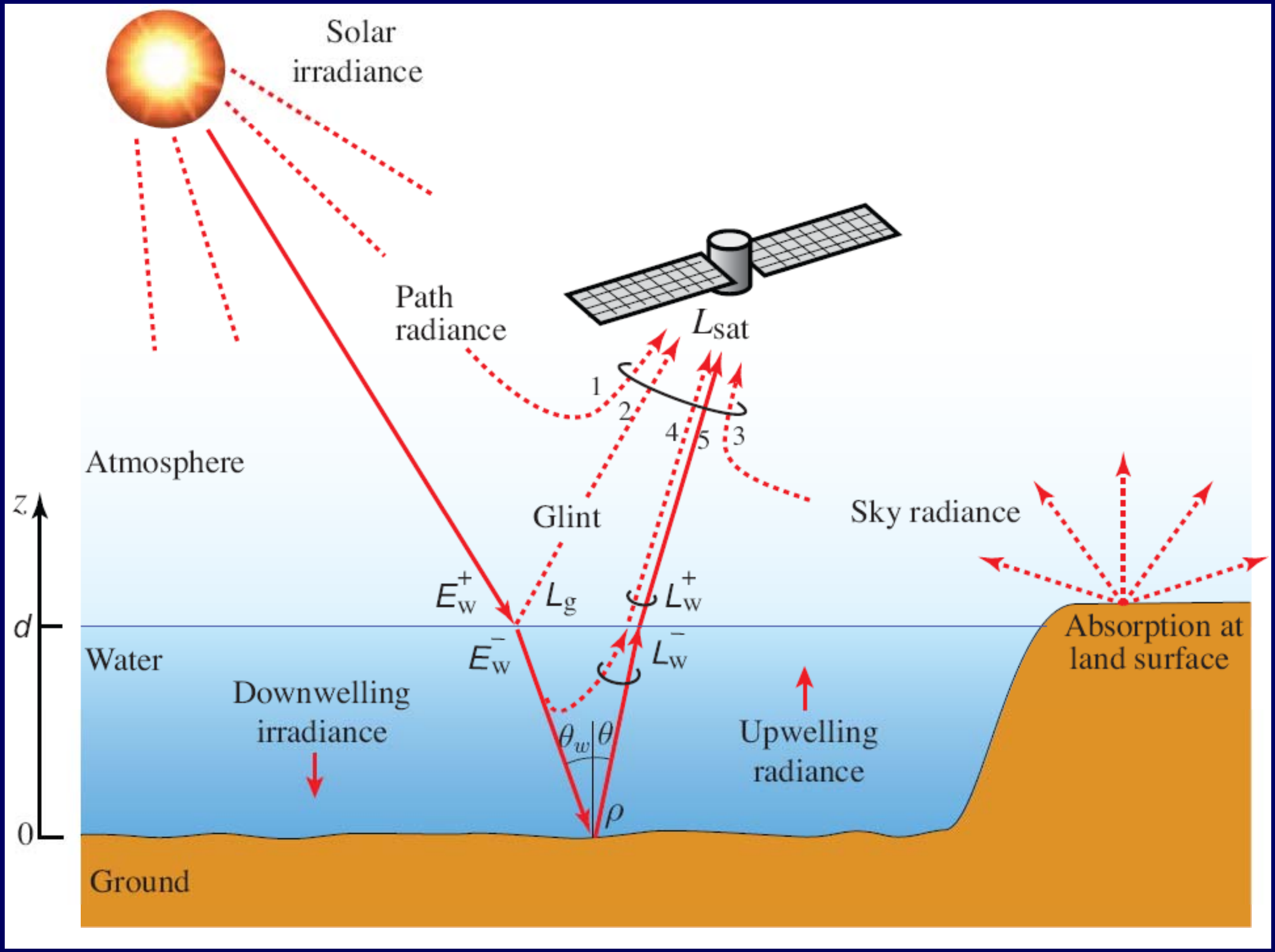
Overview

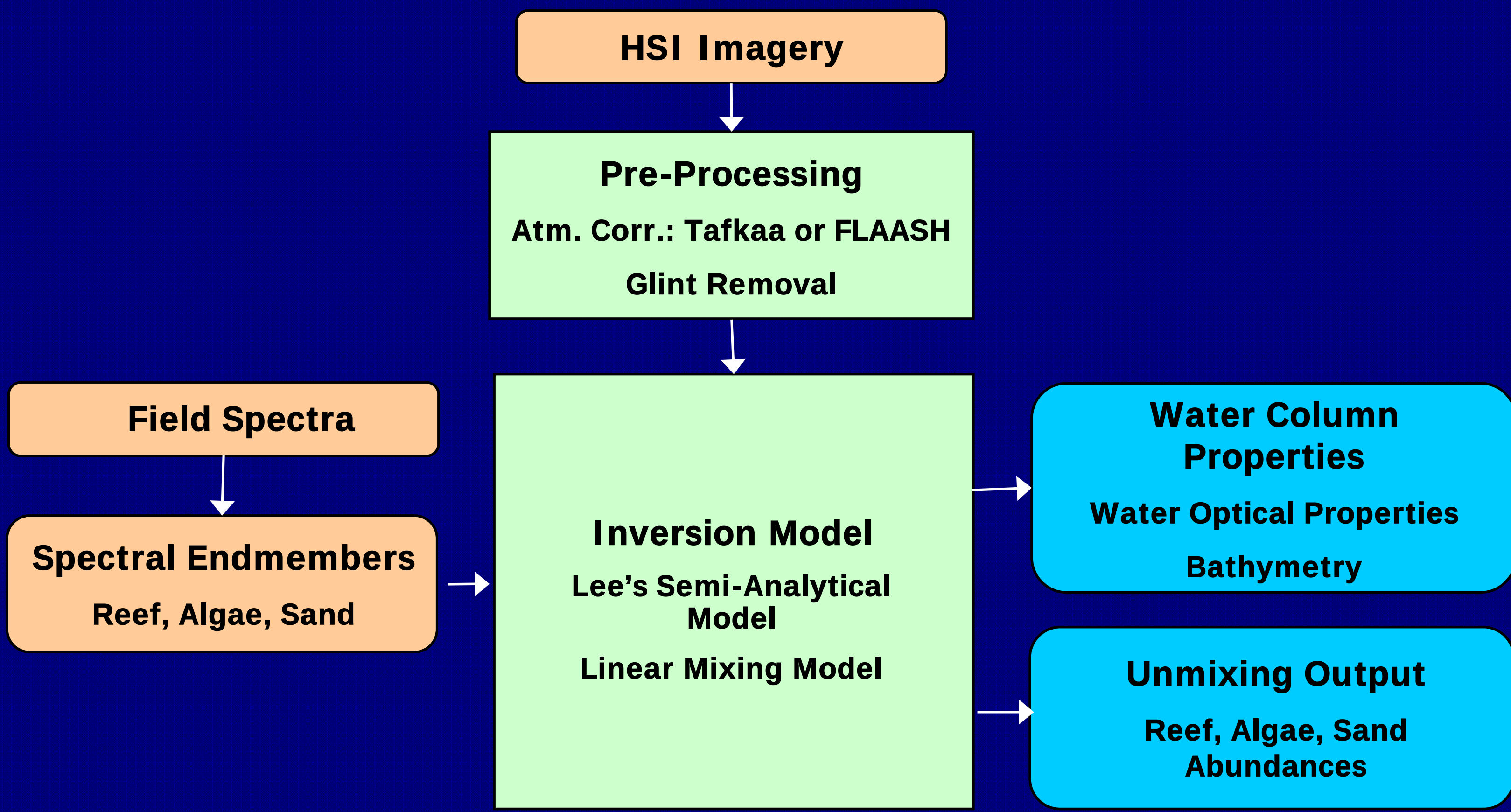
- Remote sensing of shallow waters:
  - Lee’s Model
  - Inversion algorithms
    - Only HSI
    - HSI + Bathymetry
- Example using Synthetic Data
- Experiments with real data from Enrique Reef in SW PR.
- Conclusions

Remote sensing of shallow waters

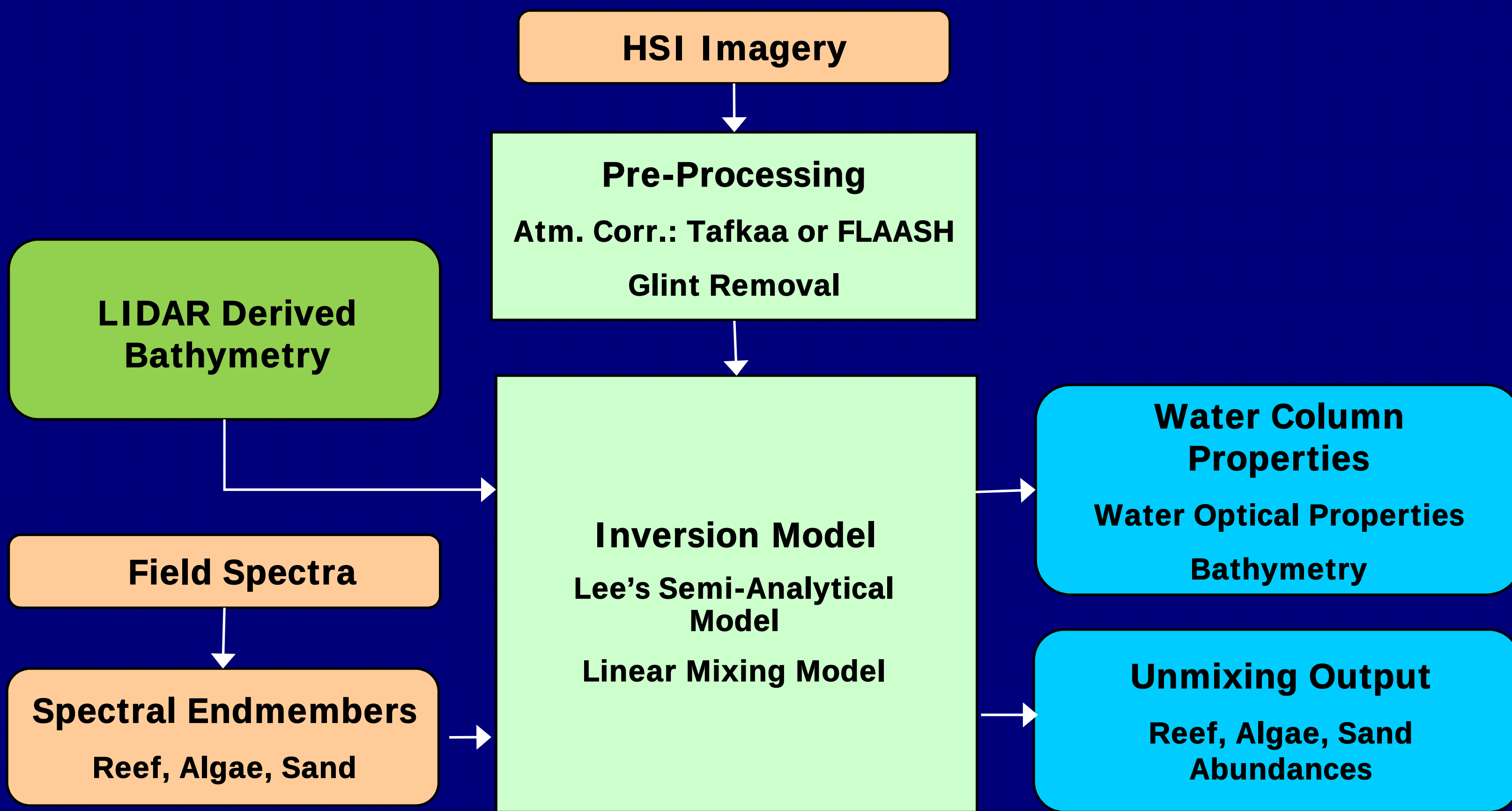


From B.E. Saleeh, ed., Introduction to Subsurface Sensing and Imaging, preprint

HSI Coastal Image Analysis Methodology



HSI Coastal Image Analysis Methodology



Lee's Bio-optical Model

Remote Sensing Reflectance : $$R_{rs} = \frac{0.5 r_{rs}}{1 - 1.5 r_{rs}}$$

Subsurface Remote Sensing Reflectance:

$$r_{rs} = \underbrace{r_{rs}^{dp}\left(1 - exp\left\{-\left[1 + \frac{D_u^C}{cos(\theta_w)}\right] kH\right\}\right)}_{\text{Water Column Component}} + \underbrace{\frac{1}{\pi} B\rho exp\left\{-\left[1 + \frac{D_u^B}{cos(\theta_w)}\right] kH\right\}}_{\text{Bottom Component}}$$

Water Column Component **Bottom Component**

Lee's Model is parameterized by: $$R_{rs} = f(P, B, G, BP, H)$$

Lee's inversion approach is given by: $$\hat{\gamma}_{Lee} = \arg\min \frac{\left\|R_{rs} - \hat{R}_{rs}(\gamma, \rho_{sand})\right\|_2^2}{\|R_{rs}\|_2^2}$$

Lee's Method to Determine IOP and Bathymetry

- Nonlinear least squares optimization

$$\hat{\boldsymbol{\gamma}}_{\text{Lee}} = \arg\min_{\gamma} \frac{\left\| \mathbf{R}_{\text{rs}} - \hat{\mathbf{R}}_{\text{rs}}\left(\boldsymbol{\gamma}, \overline{\boldsymbol{\rho}}_{\text{sand}}\right) \right\|_2^2}{\left\| \mathbf{R}_{\text{rs}} \right\|_2^2}$$

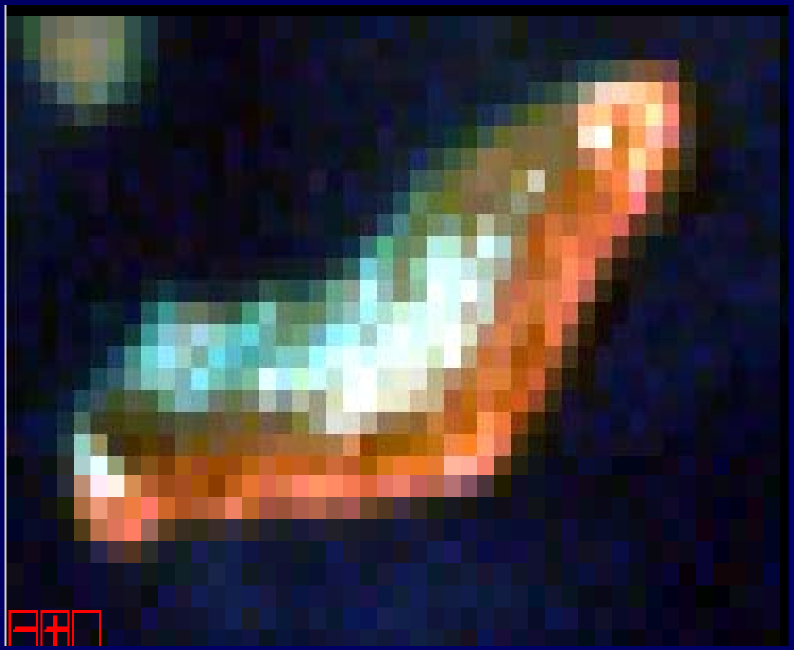
where $\gamma = [P, B, G, BP, H]^T$

and ρ_{sand} is a 550-nm normalized sand spectra.

Model originally intended for the estimation of optical properties not for bottom mapping.

Challenge:
Low spatial resolution of hyperspectral sensors

IKONOS PAN Sharpened Image
Multispectral Sensor
1m PAN, 4m/4 bands MSI



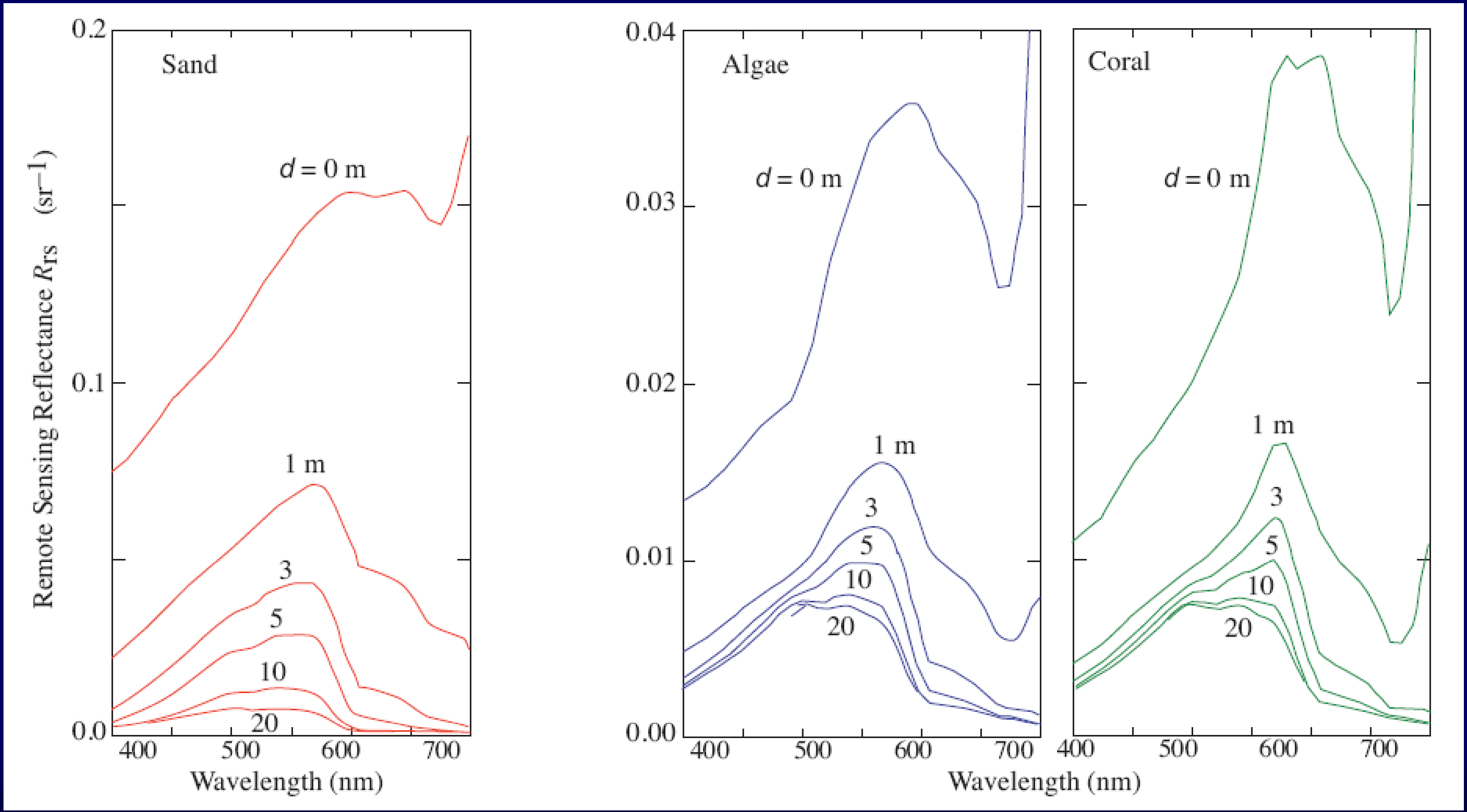
Hyperion Image
Hyperspectral Sensor
30 m, 220 bands, 10nm

Linear Mixing Model

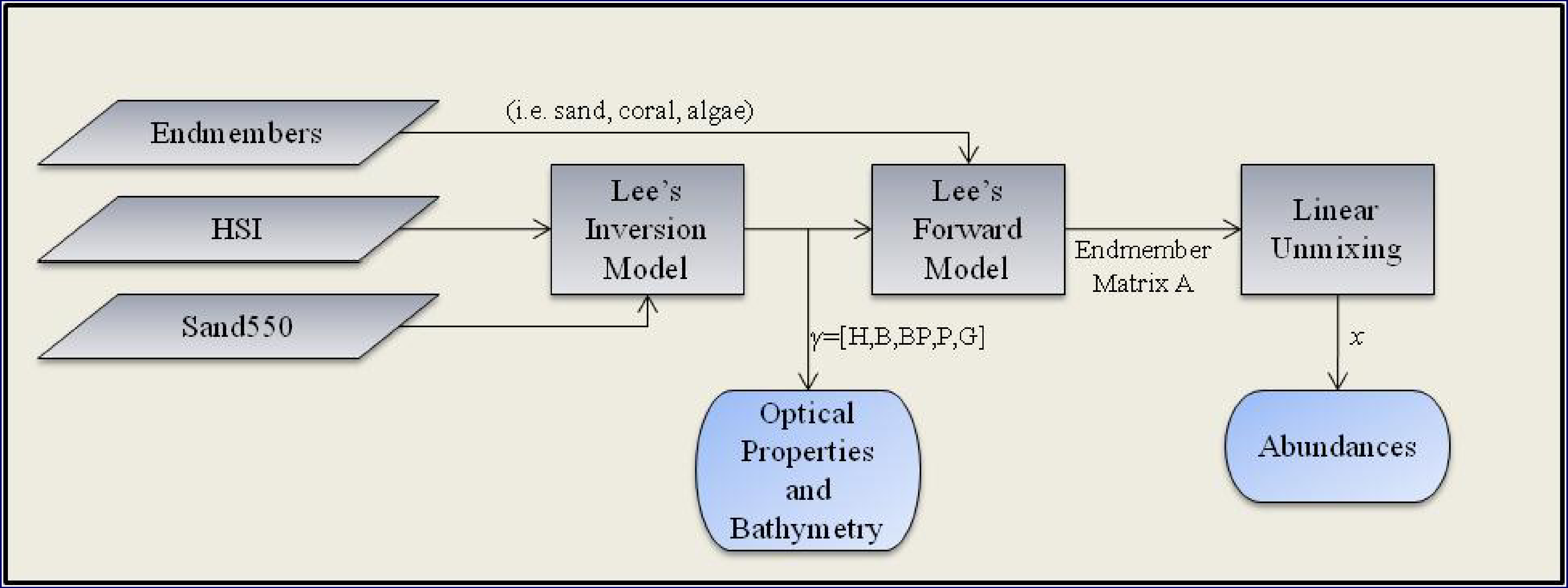
$$\mathbf{R}_{rs}(x, y) = \sum_{i=1}^{P} f_i \overline{R}_i(x, y)$$

where P is the number of endmembers and $\overline{R}_i$ is the i-th endmember.

Effect of the water column



Lee's Inversion with Linear Unmixing at the Surface (LIGU)



Goodman, J., and Ustin, S. L., "Classification of benthic composition in a coral reef environment using spectral unmixing". Journal of Applied Remote Sensing. 011501(1), (2007).

Lee's Bio-optical Model + LMM at the Bottom

Subsurface Remote Sensing Reflectance:

$$r_{rs} = \underbrace{r_{rs}^{dp}\left(1 - exp\left\{-\left[1 + \frac{D_u^C}{cos(\theta_w)}\right]kH\right\}\right)}_{\text{Water Column Component}} + \underbrace{\frac{1}{\pi}\rho exp\left\{-\left[1 + \frac{D_u^B}{cos(\theta_w)}\right]kH\right\}}_{\text{Bottom Component}}$$

Water Column Component **Bottom Component**

$$\bar{\boldsymbol{\rho}}_{\text{bottom}} = \mathbf{Sf}$$

$$\mathbf{S} = \left[\bar{\boldsymbol{\rho}}_{\text{sand}} \quad \bar{\boldsymbol{\rho}}_{\text{algae}} \quad \bar{\boldsymbol{\rho}}_{\text{reef}}\right]$$

CIUB Approach (cont.)

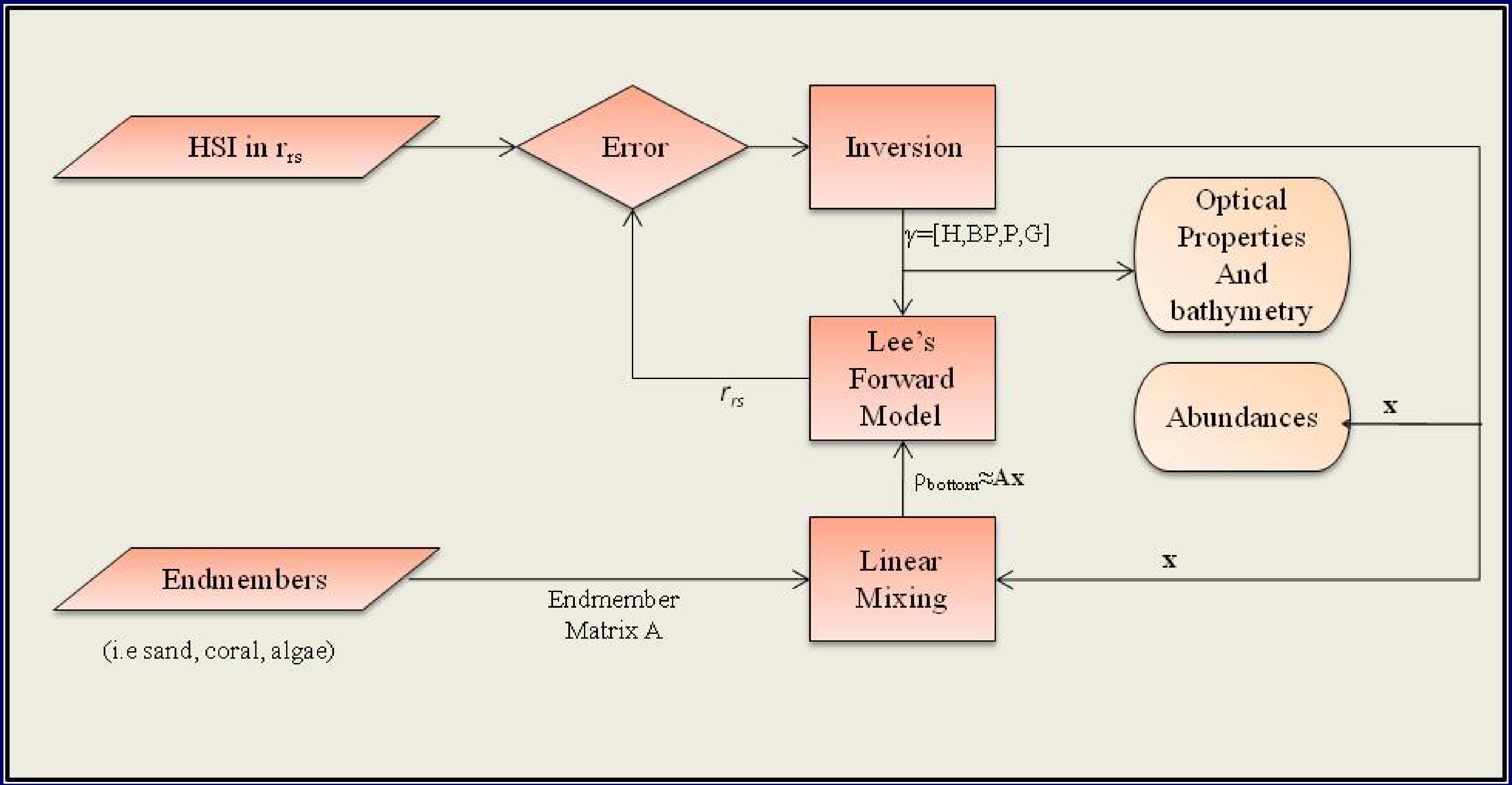
- Inverse problem

$$\left(\hat{\bar{\gamma}}, \hat{\mathbf{f}}\right) = \arg\min_{\bar{\gamma},\mathbf{f}} \frac{\left\| \mathbf{r}_{rs} - \hat{\mathbf{r}}_{rs}\left(\bar{\gamma}, \mathbf{S}\mathbf{f}\right) \right\|_2^2}{\left\| \mathbf{r}_{rs} \right\|_2^2}$$

$$= \arg\min_{\bar{\gamma},\mathbf{f}} \frac{\left\| \mathbf{b}\left(\bar{\gamma}\right) - \mathbf{A}\left(\bar{\gamma}\right)\mathbf{f} \right\|_2^2}{\left\| \mathbf{r}_{rs} \right\|_2^2}$$

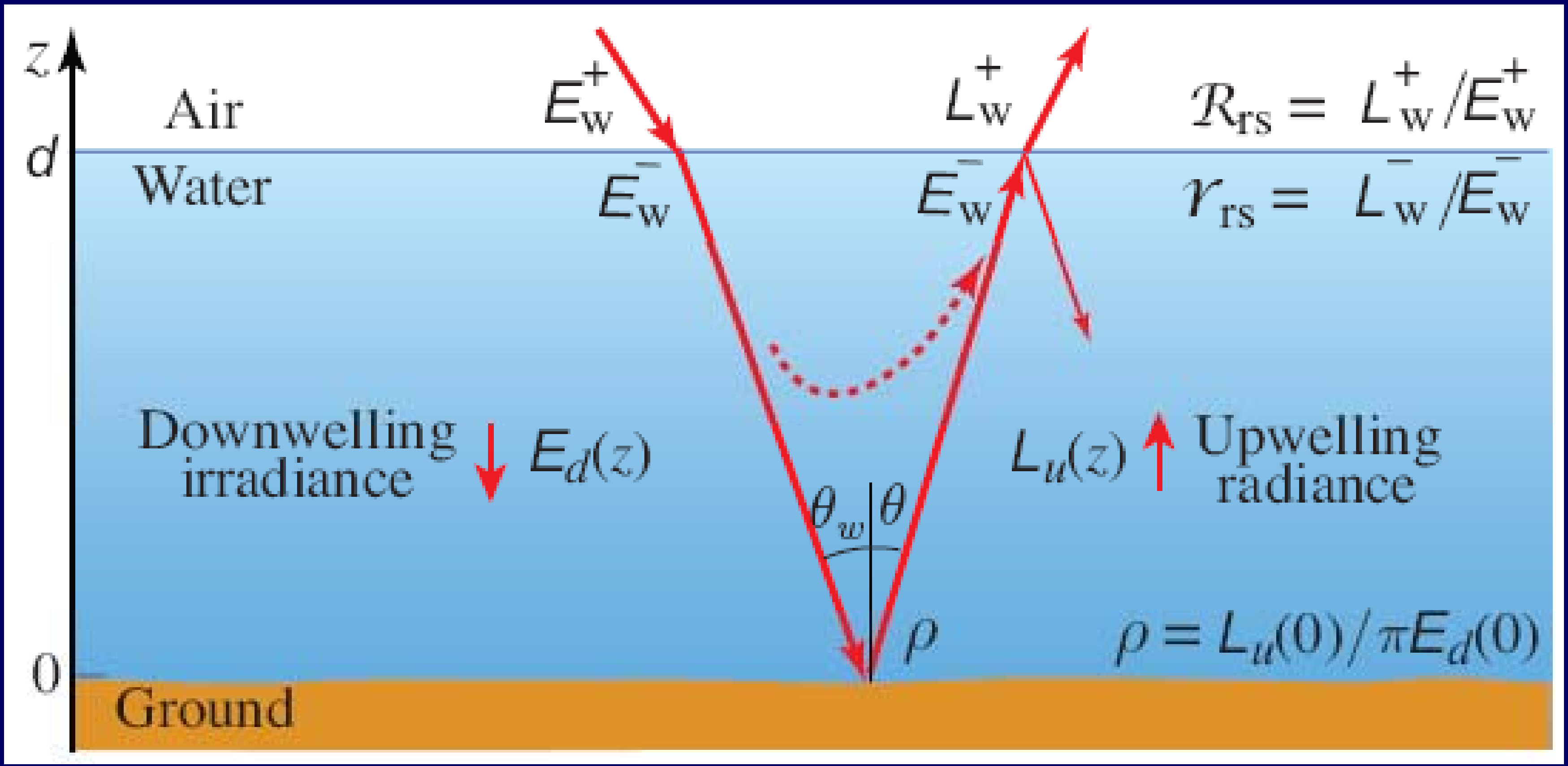
Partially Linear Nonlinear Least Squares Problem

Combined Inversion with Unmixing at the Bottom (CIUB)



Velez-Reyes, M., Goodman, J., Rosario, S., and Castrodad, A., "Subsurface unmixing with application to underwater classification." Proc. SPIE , Vol. 6743, (2007).

Limitations



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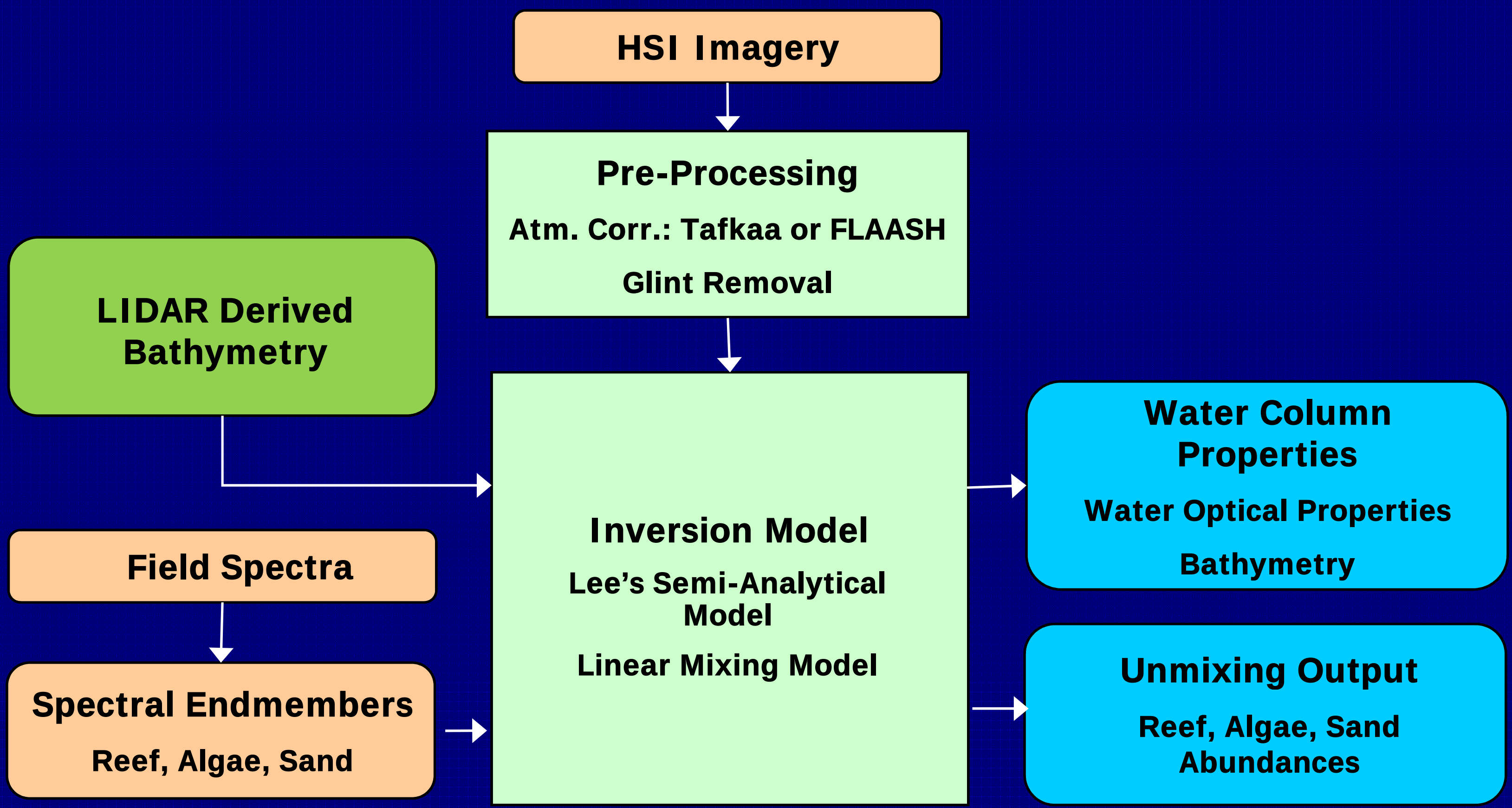
HSI Coastal Image Analysis Methodology



Fusion of LIDAR and HSI

- LIDAR data can be used to further constrain the inversion procedure

- Examples of research work

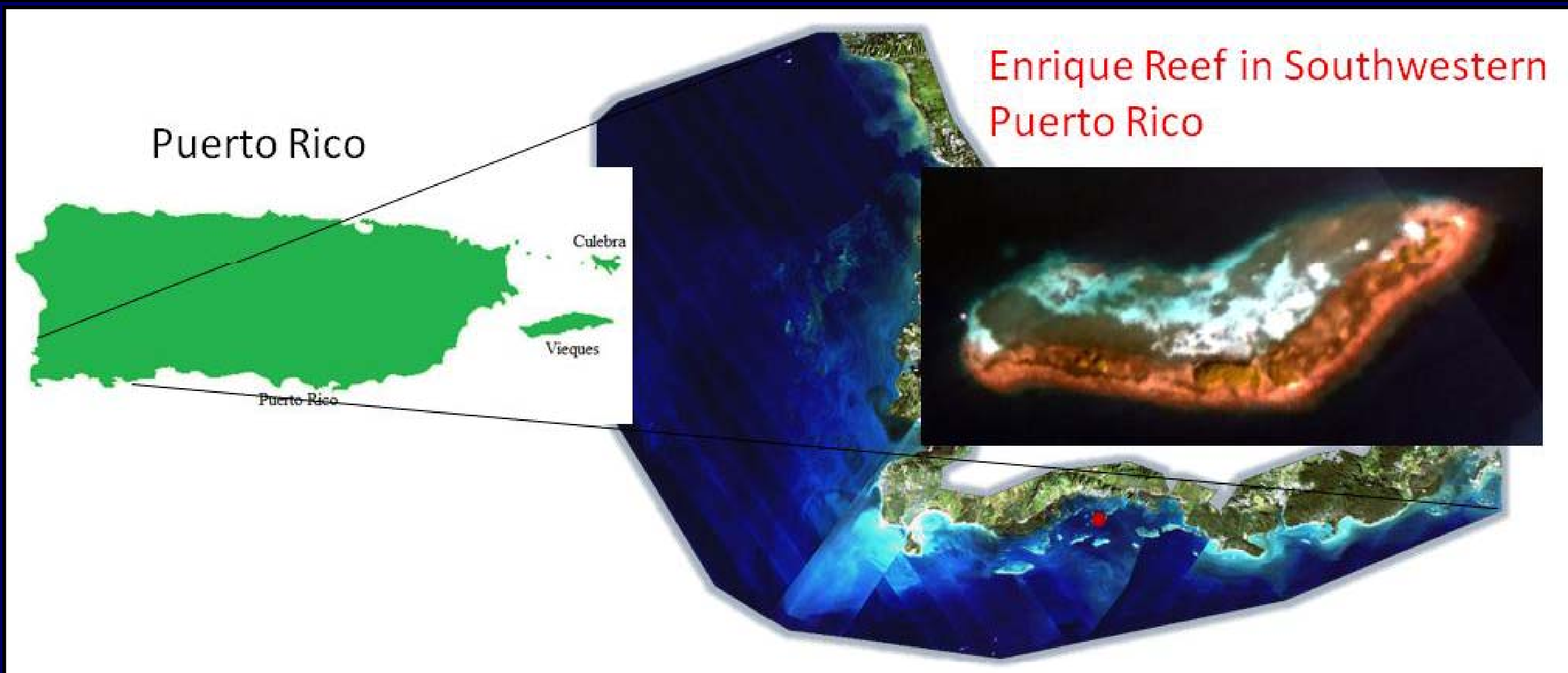
  - Sault, et. al. [7] used data fusion of SHOALS bathymetry and CASI hyperspectral imagery to classify shorelines

  - Lee [8] used the pseudoreflectance derived from SHOALS data to classify sea bottom, which was then fused with an AVIRIS image classification through decision methods such as Dempter-Shafer algorithms and bayesian classifier.

  - Tuell and Park [9] describe a process to invert radiative transfer model from hyperspectral image using the depth, reflectance and attenuation parameter derived from SHOALS data as initialization parameters for the inversion.

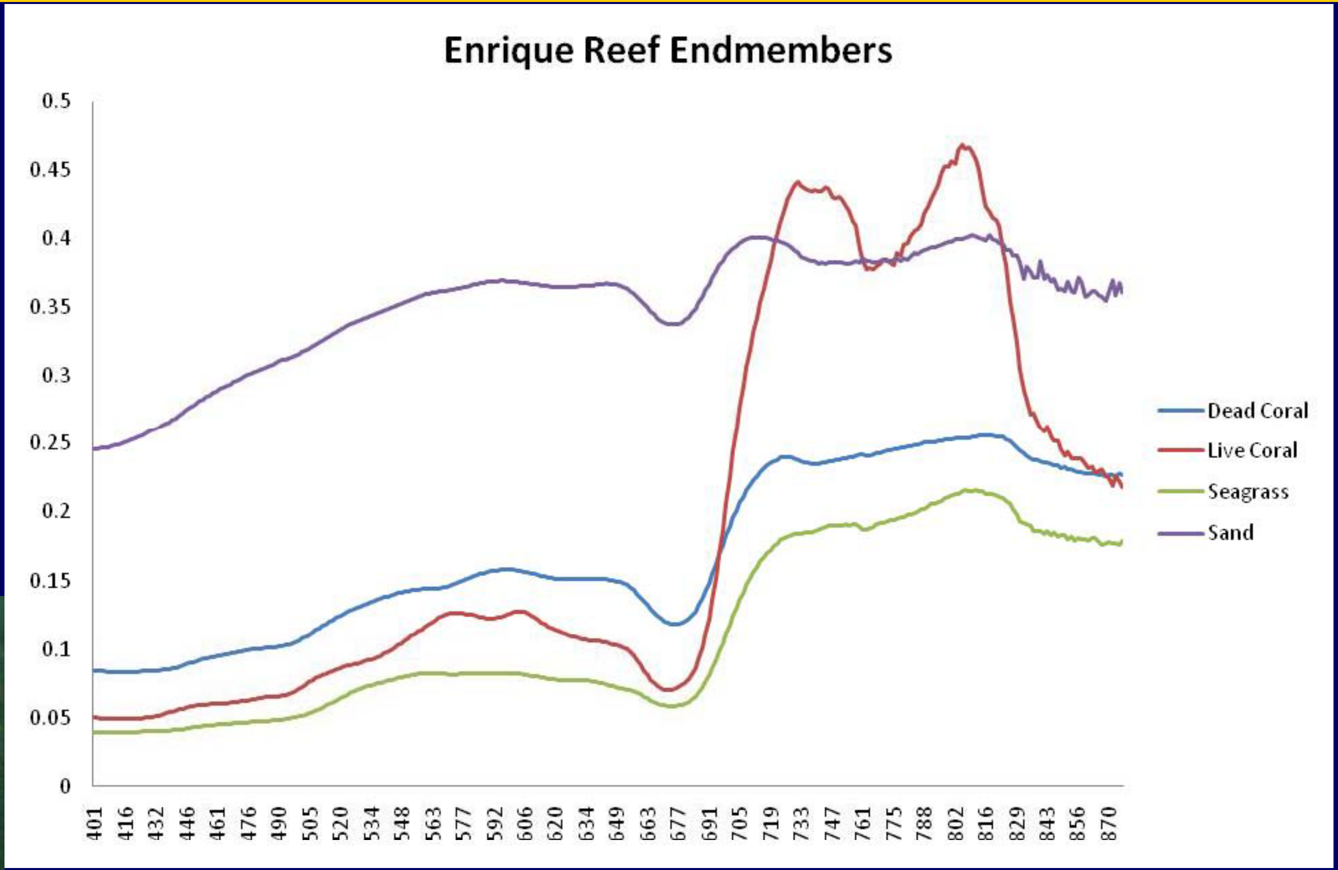
Experimental Results with Enrique Reef Imagery

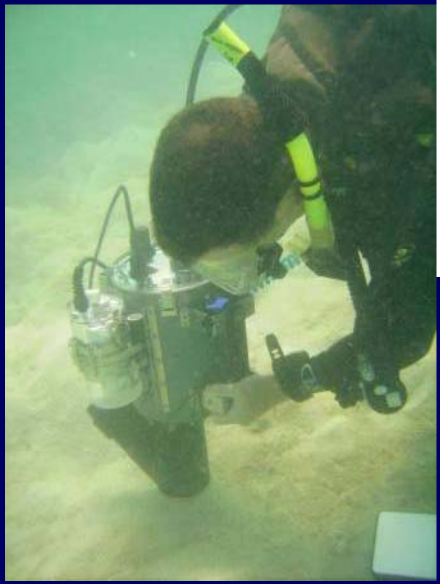
Hyperspectral imagery was acquired in December of 2007 using the AISA sensor. Atmospheric correction algorithm was done using Flaash using a procedure provided by Dr. Steven Adler-Golden from Spectral Sciences, Inc.



A Nice Picture of Enrique

Field Spectra: Bottom Endmembers

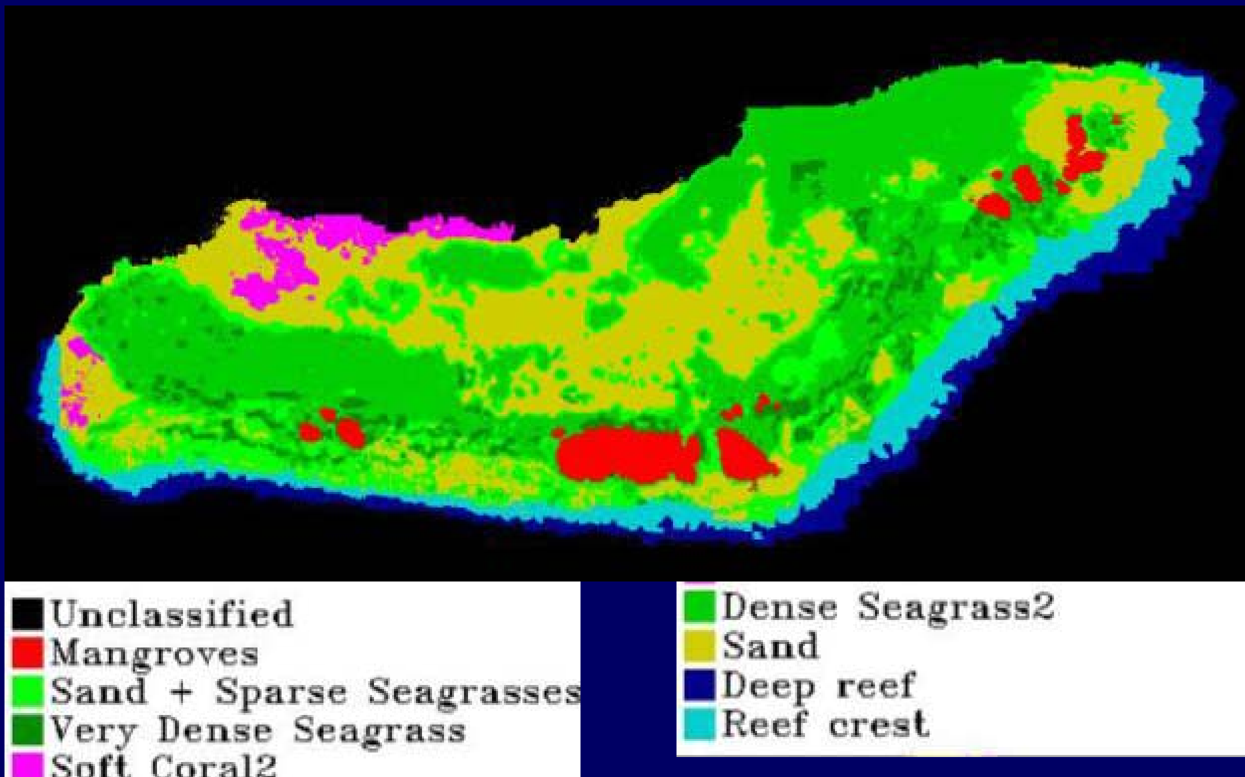


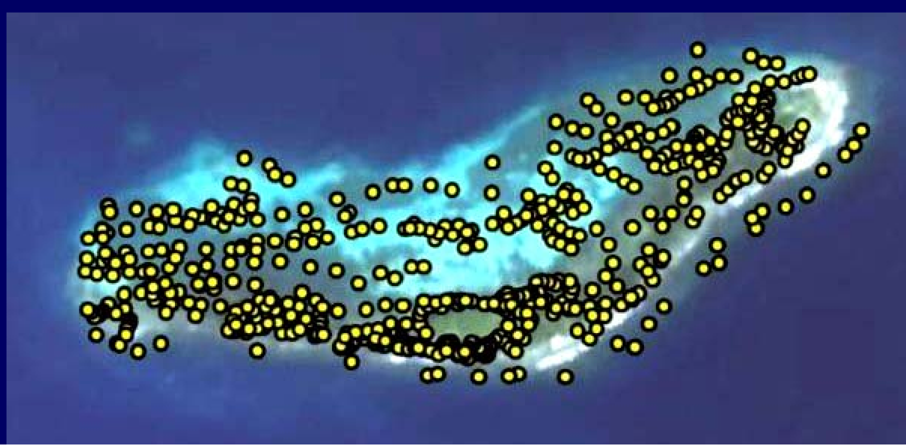


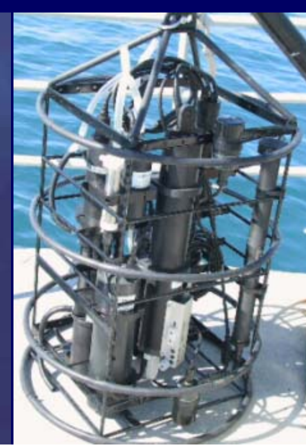
Modified GER 1500 with artificial illumination

J. Goodman (UPRM) and T. Corl (SVC)

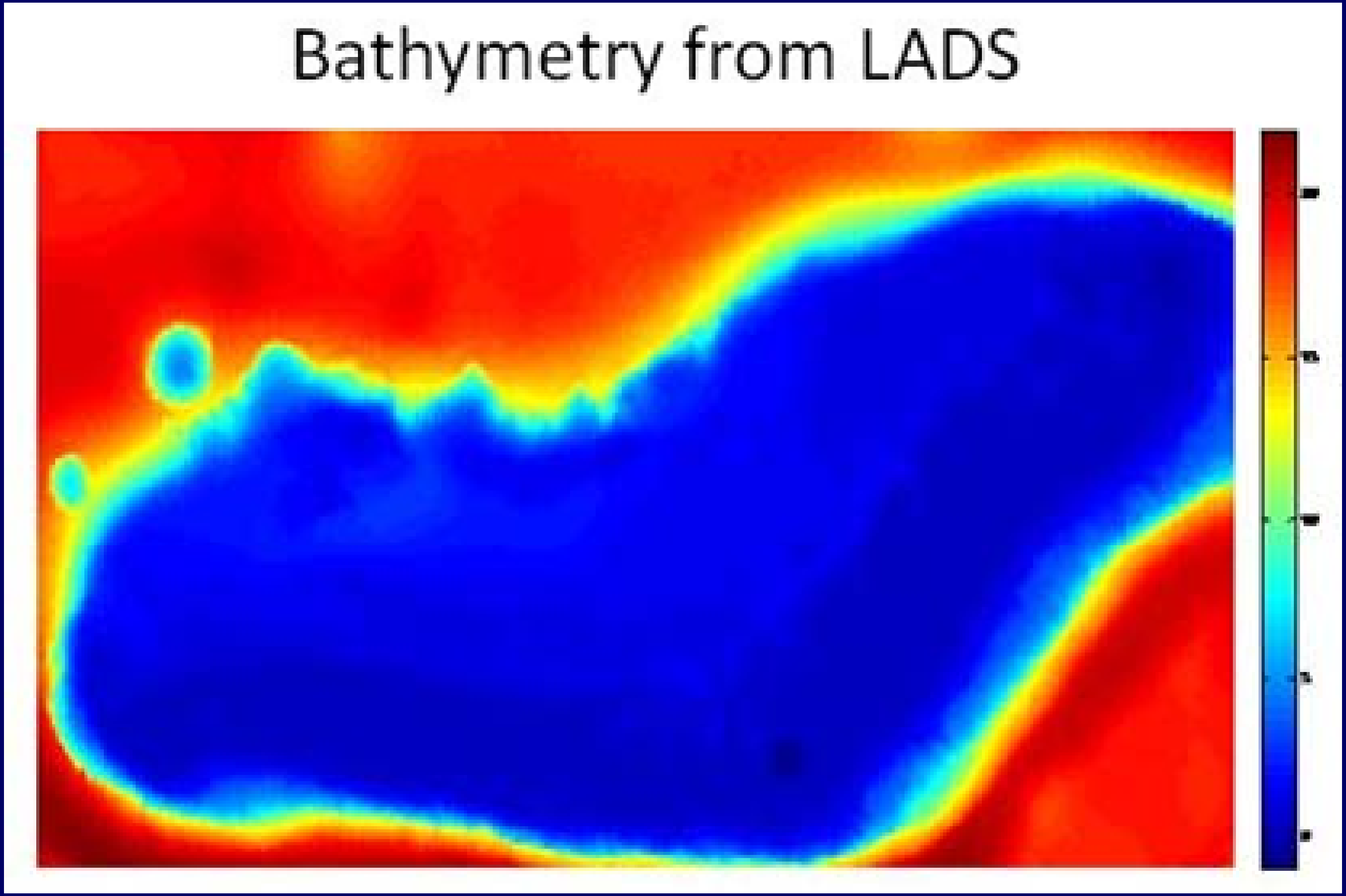
Ground Truth Classification Map





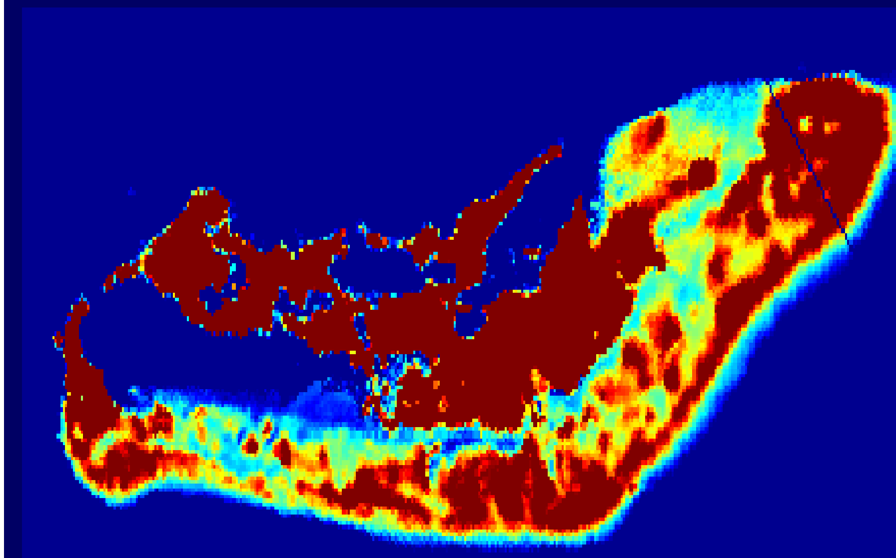


Tenix LADS Bathymetry provided by NOAA

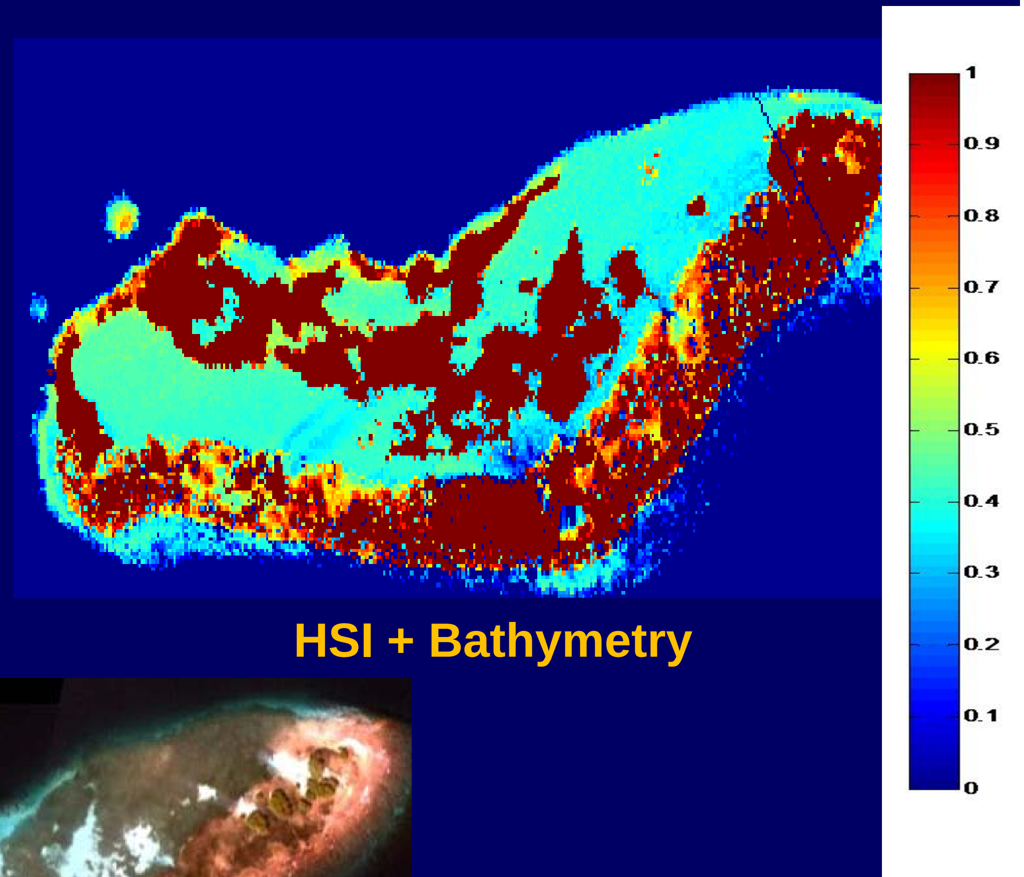


Laser Altimeter Depth Sounder (LADS) from Tenix LADS

Enrique Reef: Sand Abundance

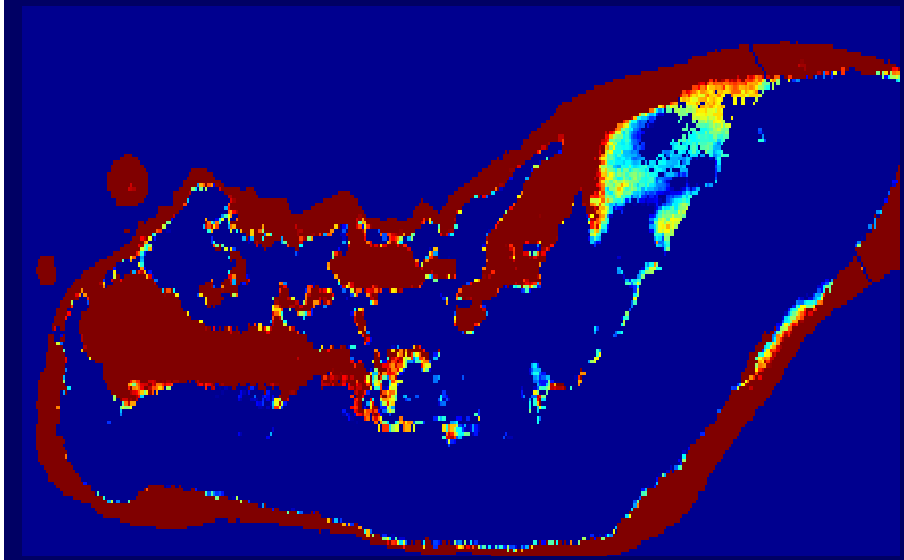


HSI

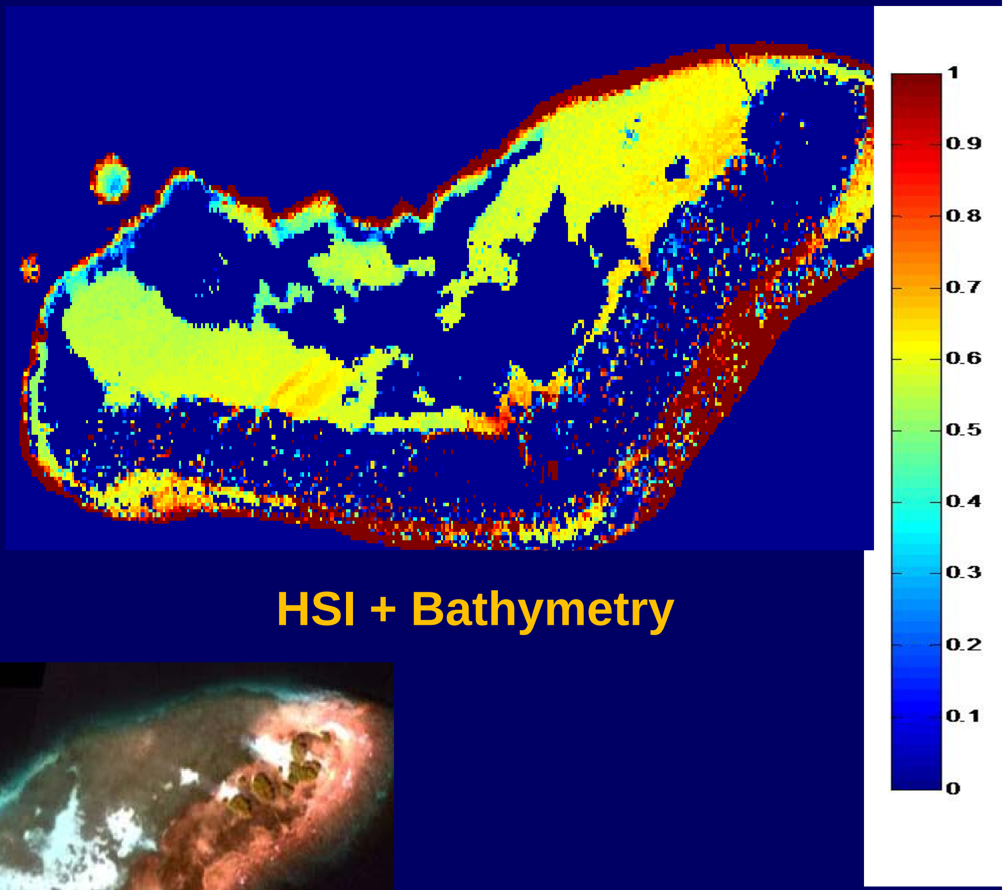


HSI + Bathymetry

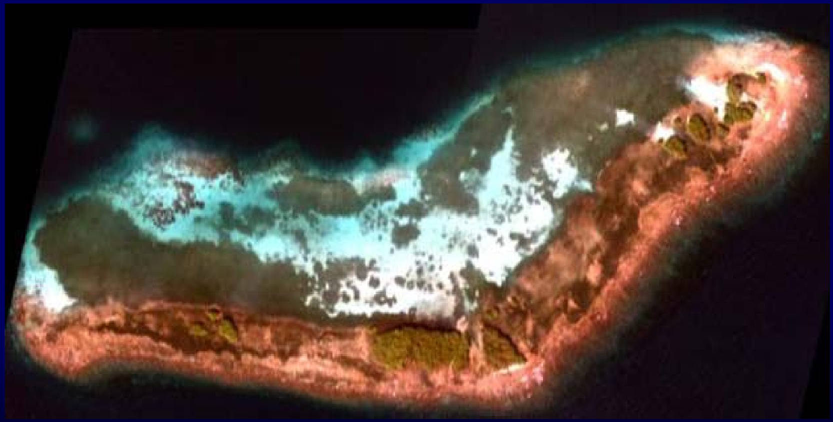
Enrique Reef: Seagrass Abundance



HSI



HSI + Bathymetry



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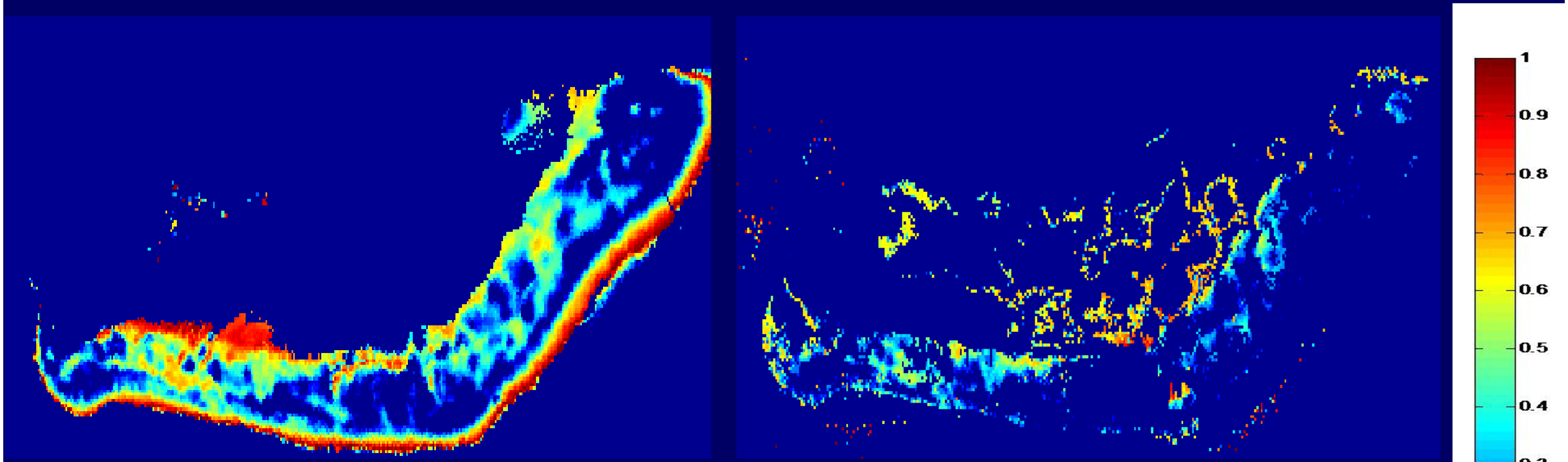
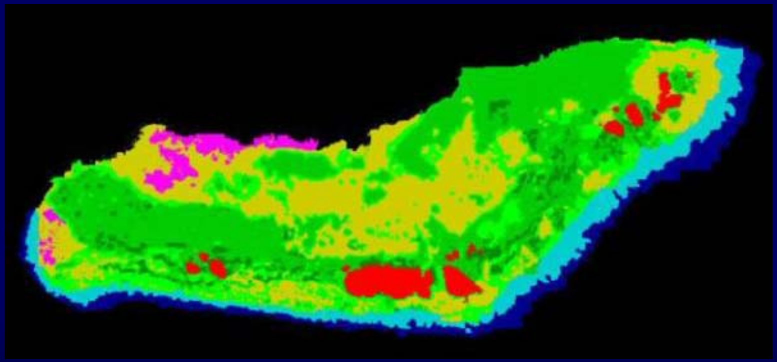
Enrique Reef: Live Coral Abundance



HSI

HSI + Bathymetry



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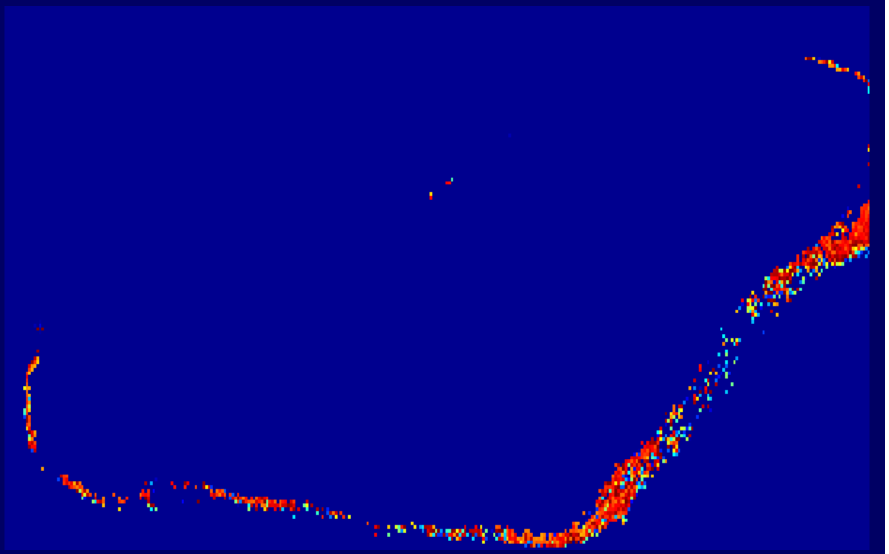
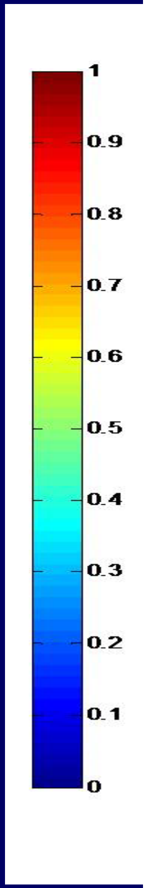
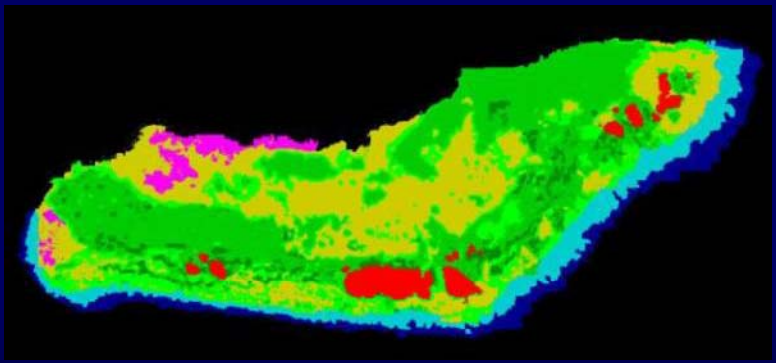
Enrique Reef: Dead Coral Abundance

HSI

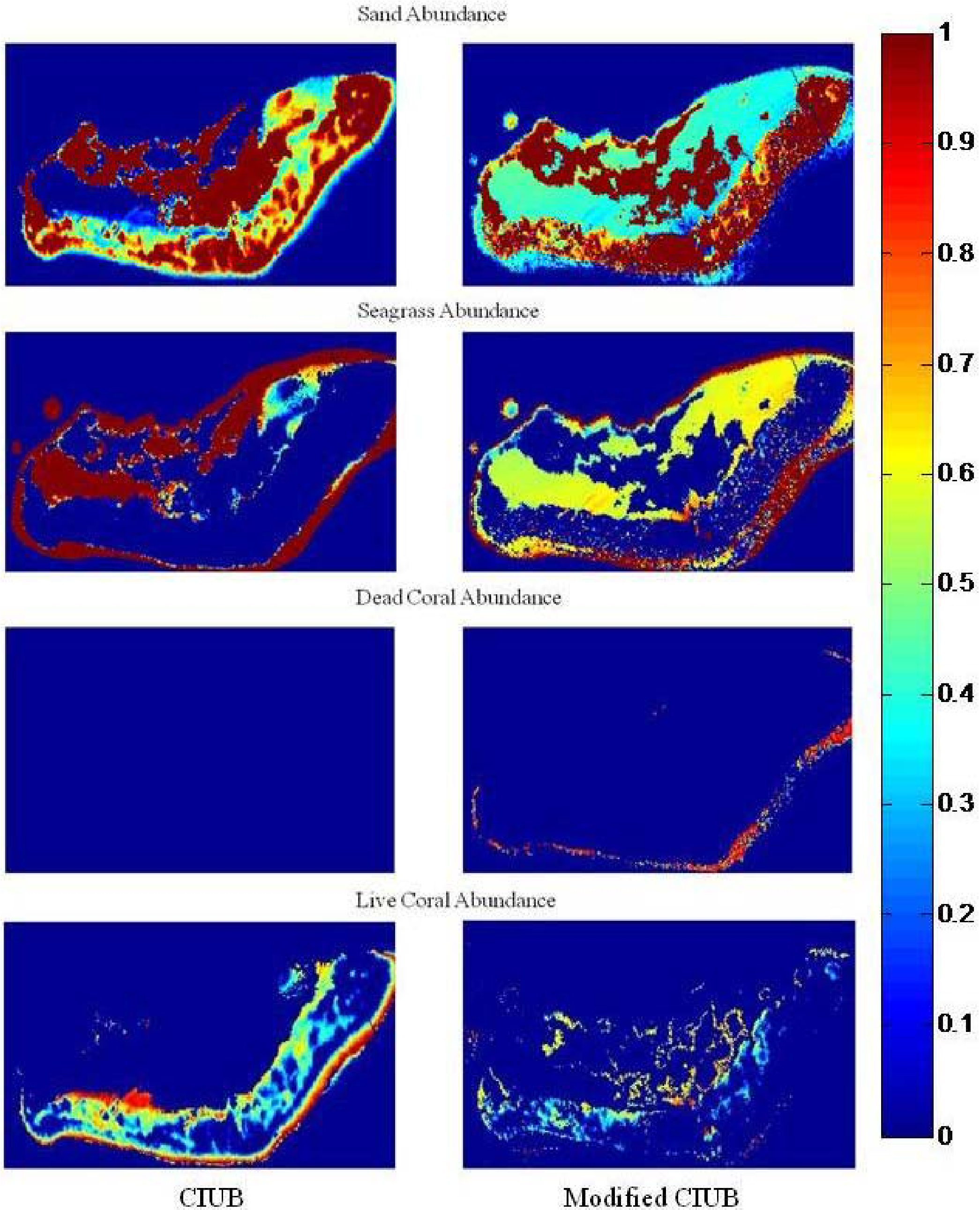


HSI + Bathymetry

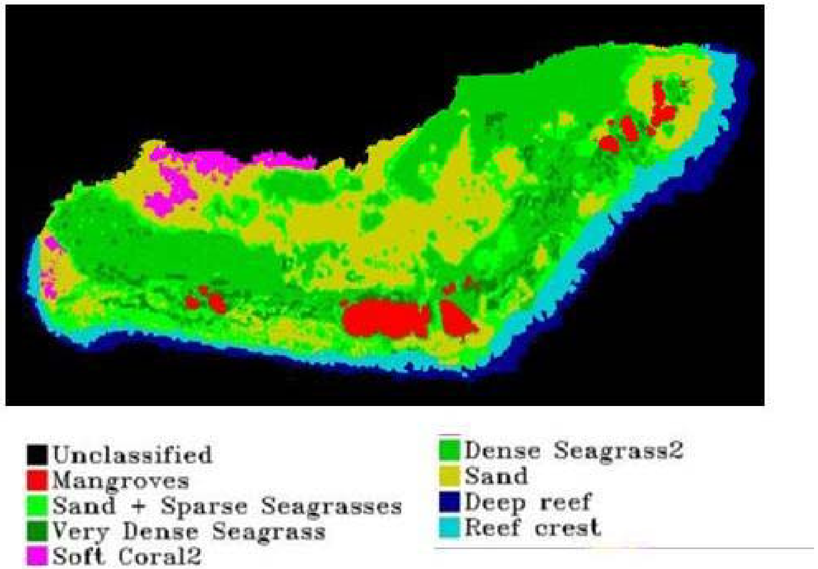




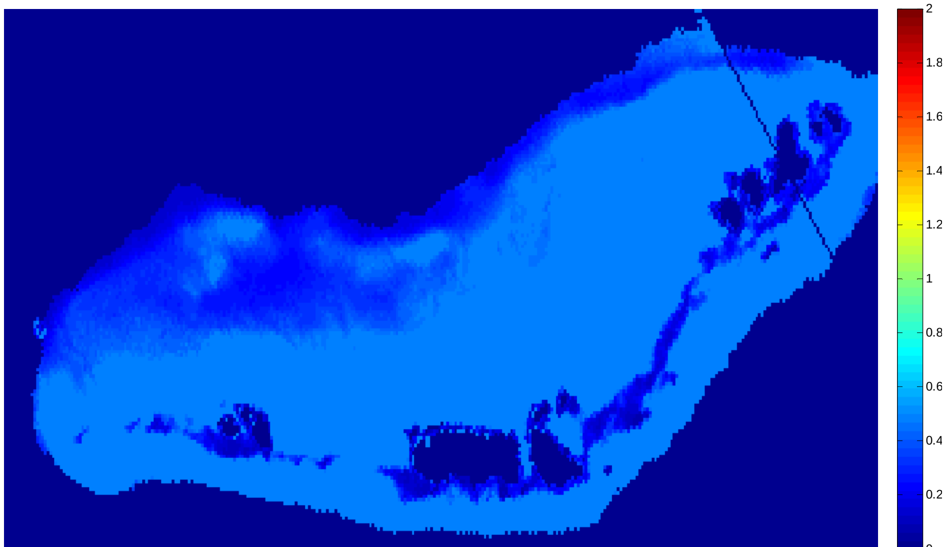
Fractional Abundance Estimates for Enrique Reef



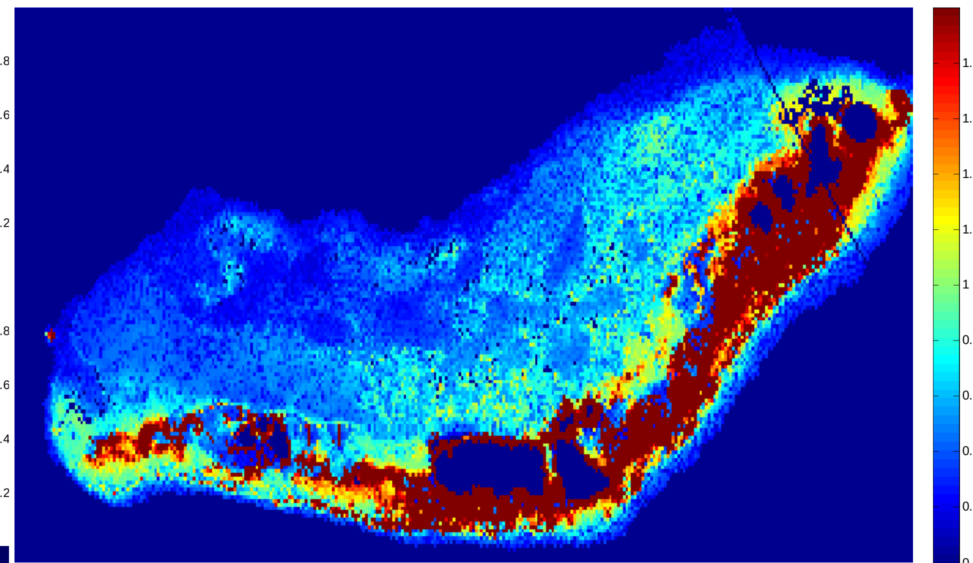
Classification Map



Combined Backscattering Coefficient at 550nm

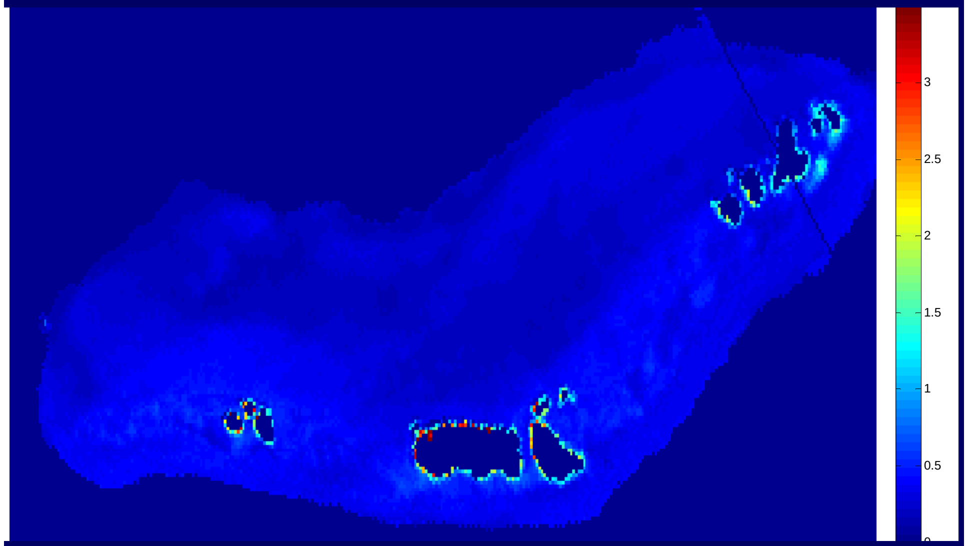


HSI

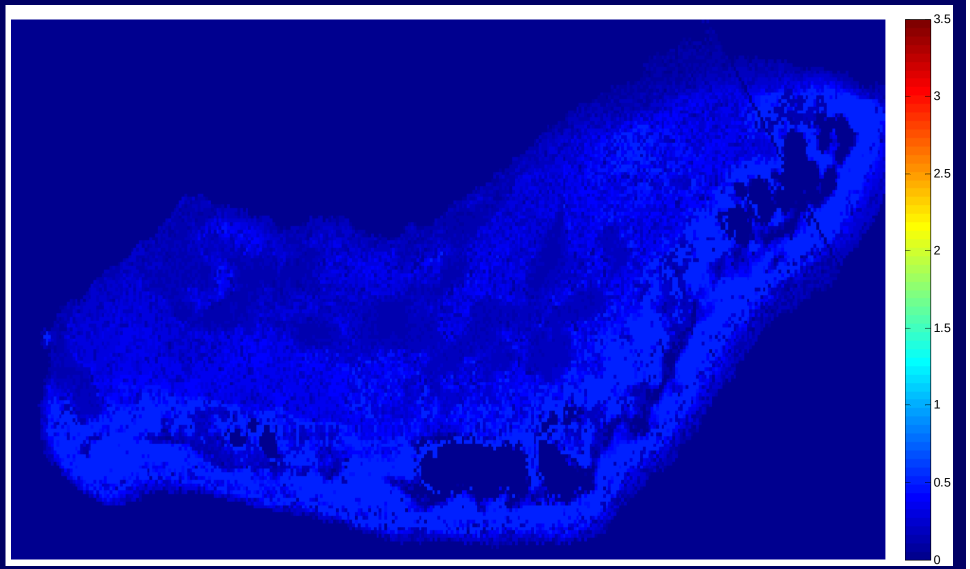


HSI + Bathymetry

Absorption coefficient for gelbstoff and detritus at 440 nm

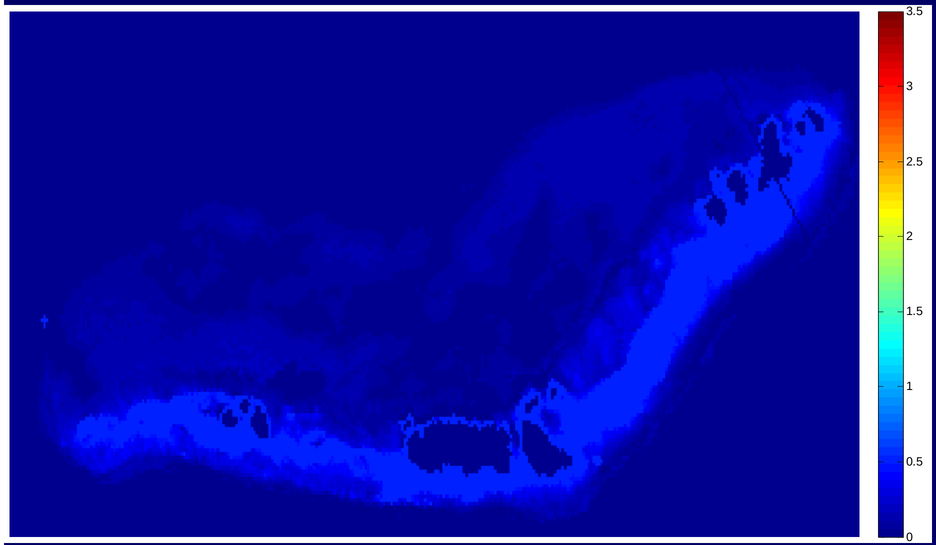


HSI

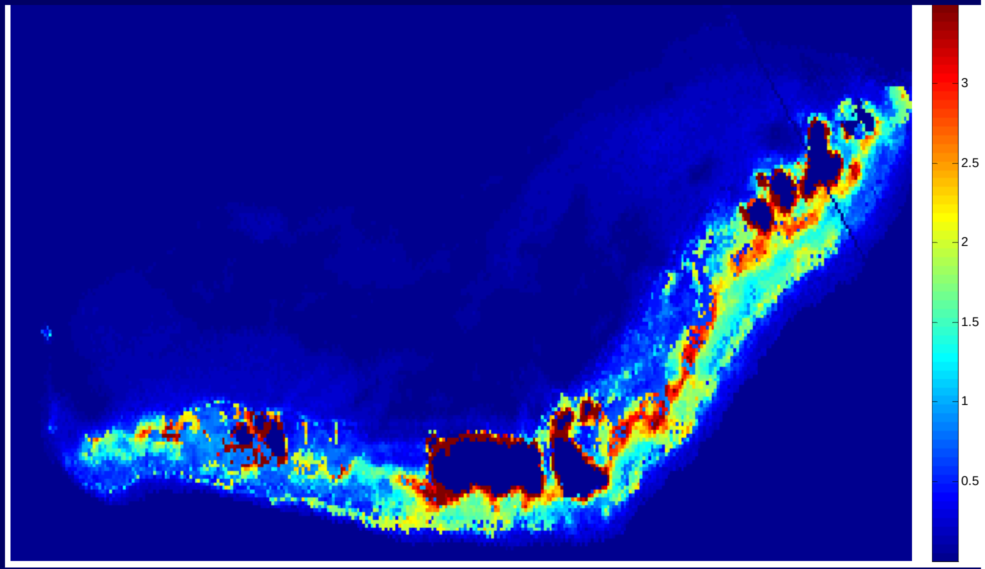


HSI + Bathymetry

Absorption coefficient for phytoplankton at 440 nm



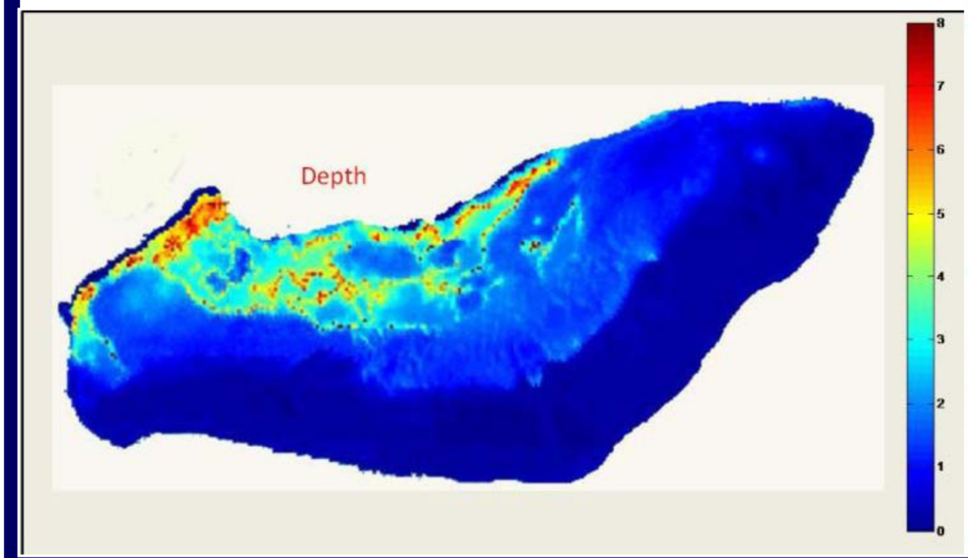
HSI



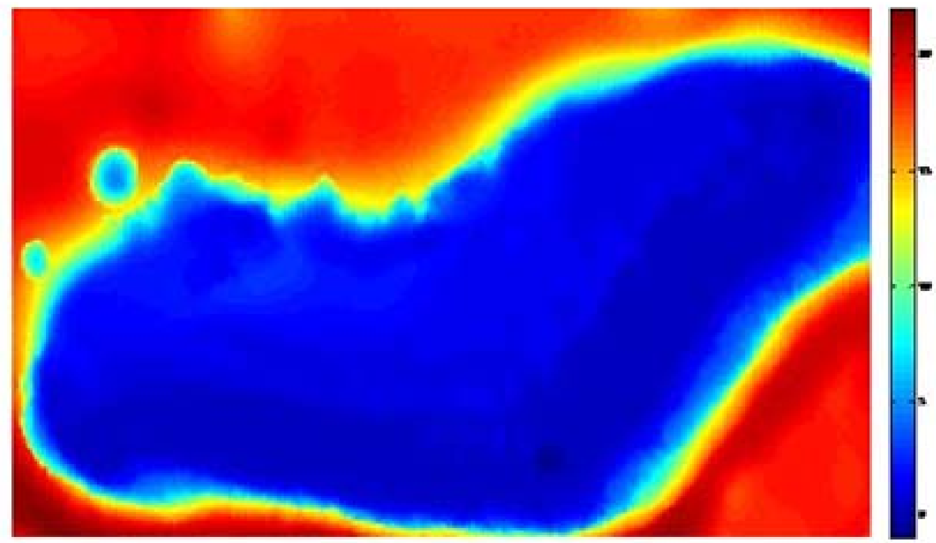
HSI + Bathymetry

Example using AISA image from Enrique Reef

Bathymetry estimated using CIUB



Bathymetry from LADS



Conclusions

The experimental results demonstrate the potential improvements in accuracy of estimates of bottom composition and optical properties of water when jointly using hyperspectral and bathymetry data.

The bathymetry data allows to further constrain the inversion problem enabling resolving better the spatial structures of optical parameters and bottom composition.

Questions??

Acknowledgements

- Research was sponsored by the Engineering Research Centers Program of the NSF under grant EEC-9986821.
- Dr. Steven Adler-Golden from Spectral Sciences, Inc., provided the algorithm for atmospheric correction of AISA imagery with FLAASH.
- Carmen Zayas and Samuel Rosario compiled the classification map of Enrique Reef.