S4: Benthic Habitat Monitoring

Miguel Vélez-Reyes
Roy Armstrong
Hanumant Singh
James A. Goodman
Luis O. Jimenez
To demonstrate how CenSSIS technology can impact our capability to monitor and assess the state of benthic habitat systems

- Multi-spectral discrimination
- Local probing and mosaicing
- SeaBED: Field Site Enrique Reef
- SeaBED: AUV
Coral Reef Health Assessment Is An Important Societal Issue

Airborne or Satellite Hyperspectral Remote Sensing

Satellite and Airbone Remote Sensing is Limited to 20 meters

Benthic Habitat quantitative imaging needs multimodal/multiplatform capability

SeaBED AUV
S4: Integrating Research Across Thrusts

L3
PLUS

L2
Validating TestBEDs

SeaBED

L1
Fundamental Science

Bio-Med

Fundamental Science

Enviro - Civil
Benthic Habitat Mapping

R1: Radiative Transfer Modeling

R2: MSD & LPM

R3: Algorithm Implementation
The **S4** TEAM

**Faculty**
- M. Velez-Reyes, S.D. Hunt, L.O. Jimenez, R. Torres, W. Rivera, UPRM/ECE
- F. Gilbes, UPRM/Geology
- R. Armstrong, UPRM/Marine Sciences
- H. Singh, WHOI/AOPE
- B. Roysam, RPI/ECSE

**Post Doctoral Investigator**
- James Goodman, UPRM/LARSIP

**Staff**
- Samuel Rosario, UPRM/LARSIP

**Collaborators**
- L. Guild, NASA-Ames
- C. Bachmann, M. Montes, NRL-Washington
- Z. Lee, NRL-Stennis
- Graciela Garcia-Moliner, NOAA CFMC
- Tom Corl, Spectra Vista, Corp.
- Grady Tuell, Optech International, Inc.
- Art Gleason, RSMAS, U. of Miami
- Sam Purkis, NOVA Southeastern Univ., FL

**Students**
- **8 Ph.D.**
  - Alejandra Umaña, UPRM/CISE
  - Julio M. Duarte, UPRM/CISE
  - Yahya Masalmah, UPRM/CISE
  - Oscar Pizarro MIT/WHOI
  - Ryan Eustice MIT/WHOI
  - Chris Roman MIT/WHOI
  - Hari Iyer, RPI/ECSE
  - Vanessa Ortiz, RPI/ECSE

- **6 MS**
  - Alexey Castrodad, UPRM/ECE
  - Jeannette Arce, UPRM/Geology
  - Jose Diaz-Santos, UPRM/ECE
  - Carlos Rivera, UPRM/ECE
  - Carolina Gerardino, UPRM/ECE
  - Carmen Zayas, UPRM/MS

- **6 UG**
  - Vanessa Vazquez, UPRM/ECE
  - Jose Casillas, UPRM/ECE
  - Samir Darbaly, UPRM/ECE
  - Neyka Ramos, UPRM/ECE
  - Maria Vasquez, UPRM/ECE
  - Pedro Falto, UPRM/ECE
“Quality is generally quite good and in many aspects is excellent.”

“All investigators demonstrated excellent understanding of the topic and approaches related to mapping shallow water benthic water habitats.”

“Relevance is extremely high to marine scientists and marine-environmental managers.”

“Relevance is particularly demonstrated by the recent .... airborne flights of the AVIRIS airborne hyperspectral imager over Florida and Puerto Rico ... in response to wide spread coral bleaching ... in the Bahamas and Caribbean Sea. This phenomena needs to be assessed and the S4 CenSSIS research team is in an excellent position to help conduct this effort.”
SUSTAINABILITY: Proposals

- James Goodman, PI, Taking Coastal Mapping to a New Level: Assessing Habitat Composition and Water Properties of Shallow Coastal Ecosystems along the Coast of Puerto Rico Using Hyperspectral Remote Sensing, NOAA, Caribbean Coral Reef Institute, $133,296 (awarded), 2 years (09/06 – 08/08) **Awarded**

- James Goodman, PI, Subsurface Sensing of Aquatic Environments, NASA, New Investigator Program, Amount: $359,680 (pending), 3 years


- R. Armstrong (PI, UPRM), J. García, Y. Detres, H. Singh (WHOI), R. Camilli, Grant Title: Characterization of deep hermatypic coral reef biodiversity in Puerto Rico and the US Virgin Islands using Autonomous Underwater Vehicles (AUV) and advanced diving technology. NOAA. Amount: $1,500,000.00
Presentations Outline

- Roy Armstrong, UPRM: Why Coral Reefs?
- Hanu Singh, WHOI: SeaBED Autonomous Underwater Vehicle
- James Goodman, UPRM: SeaBED
- Luis Jimenez, UPRM: Benthic Habitat Mapping using Hyperspectral Imaging
S4: Coral Reef Monitoring

Why Coral Reefs?

Roy A. Armstrong
UPRM

CenSSIS Site Visit
April 5, 2006
The Importance of Coral Reefs

- Coral reefs are highly productive coastal ecosystems that are often described as the marine equivalent of rainforests in terms of biodiversity.
- For many tropical countries coral reefs are a major or principal source of income from fisheries, tourism, and recreation.
- It has been estimated that coral reefs provide nearly US$30 billion annually in net benefits in goods and services globally.
The Status of Coral Reefs

- Coral reefs are among the most threatened coastal ecosystems worldwide.
- Coral reef ecosystems have been subject to unprecedented degradation over the past few decades.
- Recent accelerated coral reef decline is mostly related to anthropogenic impacts such as increased sedimentation, nutrient overloading and overfishing.
The Status of Coral Reefs

- Severe impacts to coral reefs can also result from hurricane disturbances, flooding (low salinities), high and low temperature extremes, and diseases.
- Coral reef bleaching is a common stress response of corals and other reef organisms to many of the various disturbances mentioned above.
Challenges: Exponential Attenuation of Light in the Aquatic Medium and Heterogeneity of the Habitat

**Problems of the medium:**

- High variability of IOPs (scattering, absorption) and AOPs (Lu, Ed, Kd)
- Surface reflection, refraction and wave action
- Variable bathymetry
- Variable water column bio-optical properties (chlorophyll, CDOM, suspended sediments)

**Problems of the reef habitat:**

- Spatially and structurally variable
- Coral reefs are a heterogeneous mixture of corals, sponges, gorgonians, algae, sand, etc.
What is the Extent and Condition of Coral Reefs in the US Caribbean?

Bathymetry of Puerto Rico - Virgin Islands Geological Platform
Potential Reef Habitat
Remote Sensing Platforms and Sensor Requirements for Coral Reef Assessments

- **Insular Shelf (0-20 m) Shallow-water Reefs**
  - Satellite Sensors – HYPERION, IKONOS, Landsat TM, SPOT
  - Airborne Sensors – AVIRIS

- **Upper Insular Slope (30 – 100 m) Deep Reefs**
  - Seabed Autonomous Underwater Vehicle (AUV)
    - Optical and Acoustic Imaging
Spatial Resolution Requirements for Coral Reef Studies

Landsat TM – 30 m
HYPERION

SPOT – 20 m

IKONOS – 1 m

HYPERION

CASCI – 5 m
Caribbean coral suffers record die-off

World's coral reef loss 'an underwater holocaust'

WASHINGTON (AP) -- A one-two punch of bleaching from record hot water followed by disease has killed ancient and delicate coral in the biggest loss of reefs scientists have ever seen in Caribbean waters.

Researchers from around the globe are scrambling to figure out the extent of the loss. Early conservative estimates from Puerto Rico and the U.S. Virgin Islands find that about one-third of the coral in official monitoring sites has recently died.

This old chunk of brain coral is at least 90 percent dead from the disease called "white plague."
Coral Reef Bleaching

Photos courtesy of Hector Ruiz and Juan Torres
Coral Bleaching Spectral Response

Normal versus a bleached colony of *D. clivosa*

- Reflectance (%)
- Wavelength (nm)

- Normal
- Bleached
AVIRIS 2004 and 2005 Hyperspectral Missions

Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) 224 spectral bands

2004 – Puerto Rico
• August 19, 2004
• 8 Flightlines
• Altitude 65,000’
• Pixel Size ~17 m

2005 – Puerto Rico & USVI
• December 12-20, 2005
• Altitude 12,000’
• Pixel Size ~3.5 m
Field Sampling in Support of the AVIRIS Missions

- **Mayaguez Bay (2004)**
  - Apparent and Inherent water optical properties
- **La Parguera Reefs – NASA and UPRM researchers**
  - Remote sensing reflectance (Rrs) of corals and other benthic communities
  - Spectral water attenuation coefficients
  - Chlorophyll, turbidity, Rrs at 13 stations
- **Calibration Targets (La Parguera)**
  - Flat fields – Rrs
  - Sunphotometer measurements (AOT)
Why Study Deep Coral Reefs?

• In shallow waters (< 20 m) of the Caribbean Region, a coral decline of 80% over the last 30 years has been documented (Gardner et al. 2003).
• Deeper reefs (> 30 m) are largely unknown.
• They appear to be healthier than shallow water reefs.
• Habitats of commercially important fish species.
• Source of coral larvae for recruitment and potential recovery of the shallower reef areas.
• There could be several times as much reef habitat deep as there is shallow.
Why Study Deep Coral Reefs With AUVs?

• Effective airborne or satellite remote sensing of coral reefs is limited to shallow, optically clear water.
• The deep hermatypic corals (30 to 100 m) lie beyond the range of safe diving operations.
• The Seabed AUV is an ideal platform for large scale benthic imaging.
• AUVs can be configured to carry a wide variety of imaging sensors and other instruments such as CTDs, side scan sonars, multi-beam and pencil beam sonar sonars, chemical sensors, video plankton recorders, and others.
• We developed the use of pencil beam sonar data from the AUV to derive the rugosity index of coral reefs.
Coral Reef Habitat at 40 m

Hind Bank Marine Conservation District, St. Thomas, USVI
Major Science Accomplishments

• Pioneer work on AUV characterization of deep coral reef habitats.

• The AUV data provided, for the first time, a quantitative assessment of a unique coral reef habitat present in deeper insular shelf areas.
• Developed a methodology to derive the rugosity index of coral reefs from the Seabed AUV.

• CenSSIS investigators participated in a multi-agency effort to assess the impact of the 2005 massive bleaching events in the US Caribbean using hyperspectral AVIRIS data.

• Unprecedented database of coral reef spectral signatures, water optical properties, and state-of-the-art hyperspectral data to map and assess the condition of shallow-water coral reefs.
## Pending Proposals

<table>
<thead>
<tr>
<th>Grant Title</th>
<th>Characterization of deep hermatypic coral reef biodiversity in Puerto Rico and the US Virgin Islands using Autonomous Underwater Vehicles (AUV) and advanced diving technology</th>
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<tr>
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<td>J. García, Y. Detres, H. Singh (WHOI), R. Camilli (WHOI)</td>
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<td>Date:</td>
<td>May 2006-April 2009</td>
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<td>Agency:</td>
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</tr>
<tr>
<td>Date:</td>
<td>April 2006 – March 2009</td>
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<td>Agency:</td>
<td>NASA</td>
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<tr>
<td>Amount:</td>
<td>$405,963</td>
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S4 - The Seabed AUV
Hanumant Singh

- Arctic AUVs
- Gas Blowout
- Benthic Habitat PMFS
- Aussie Seabed
- Chile - Microbial Mats
- Deep Coral - Bermuda, Puerto Rico
- Multiple AUVs SMAR
- Archaeology - Med
Sample Applications

- Gas Blowout - Tsunamis
- Coral Reef Mapping and Monitoring
- Shipwrecks and Archaeology
Platforms

Figures of Merit

Launching is optional, recoveries are not
Go new places, do new things
Cost per bit of information
Reliability
Simplicity (can you give it away)
The Seabed AUV

Depth Capability 2000 m
Size 2.0m(L), 1.5m(H),
Mass 280 kg in air
Speed Range (Typical) 0-1.5m/s (1.0m/s)
Batteries - 2kWh rechargeable Li-ion Pack (10 hour endurance)
Propulsion Four DC thrusters - Fore 100N; Lateral 50N; Vertical 50N
Navigation and Attitude - Depth Paroscientific pressure sensor, 0.01%
Position LBL+ 300 kHz RDI navigator, 0.1-1m
Micromodem for low bandwidth comms
MST 300kHz Sidescan
Pixelfly 1280x1024 12bit camera
Imagenex 675 kHz pencil beam sonar
Puerto Rico, Coral Reef Mapping Efforts
South drop St. John

Gromanic Bank

MCD Hind Bank
Sample Imagery
Photomosaicing has enabled Quantitative Mapping and Spatial Analysis for Commercially Important Species.
Multiple AUVs in the Arctic

Autonomous Manipulation and Sample Return

Acoustic Communications based Command and Control
NSF ERC Funding (~130k/yr) + Cost Share ($50k /yr) = $175k/yr

Title: Technology Development for an Autonomous Sample and Return Mission
Funding Agency: NASA
Amount: $3,100,000
Period of Performance: 01/2004 01/2007

Title: SST Smarter Sensing: Integrating payloads, navigation, and vehicles for Underwater Exploration
PIs: H. Singh, J. Whelan, Brian Bingham, Rich Camilli
Funding Agency: NSF
Funding Amount: $748,000

Funding Agency: NSF
Funding Amount: $3,000,000

Title: Collaborative Research: Hydrothermal Processes on the Gakkel Ridge.
PIs: R. Reves-Sohn, H. Singh, S. Humphries, T. Shank
Funding Agency: NSF
Period of Performance: 01/2005 - 12/2007
Funding Amount: $518,004
Legacy

Underwater Imaging Toolbox

Seabed AUV (four built – more coming)

Benthic Habitat, Archaeology, Geology, Arctic Studies, Chemical Sensing

Our Students
Center for Subsurface Sensing & Imaging Systems

SeaBED
James Goodman
UPRM

Looking Into Hidden Worlds
**Mission:** To develop multi/hyperspectral signal and image processing algorithms that will enable the solution of problems in benthic habitat monitoring.

**Objectives:** Provide researchers with a set of testing facilities and data for assessing the analysis capabilities of subsurface aquatic remote sensing.

- Develop controlled test environments with both natural and artificial illumination sources.
- Collect an array of spectral, optical and image data from a fully characterized natural reef system.
- Incorporate temporal measurements to encompass natural environmental variations and facilitate change detection analysis.
SeaBED CONCEPT

- SeaBED is a 3-Tiered Experiment Platform for Hyperspectral Remote Sensing of Coastal Environments

1) Indoor tank

2) Outdoor tank

3) Field site
SeaBED STUDENT PROJECTS

Indoor Experiments

Outdoor Spectral Data Collection
Demonstrated need for working with “real world” data
- Inherent system variability and heterogeneity
- Natural environmental conditions

Unique multi-level characterization of field study area
- Multiple airborne and satellite based sensor systems
  - Different spatial and spectral resolution
  - Multi-temporal data
- Comprehensive in situ field measurements

Data legacy available for collaboration and distribution
- Web-based community access via CenSSIS
- Database for sensor/algorithm testing and validation
SeaBED FIELD DATA

Field Measurements:
- Aquatic optical properties
- Georeferenced benthic reflectance
- Spectral library (species)
- Benthic Composition
- Detailed habitat map

Coral Rubble
A. cervicornis
M. annularis
Gorgonians
S. siderea
T. testudinum

Pump
CTD
AC-9
Battery Pack
Fluorometer
OCR-200
OCR-200

Data Logger
HS-6

Coral: Porites compressa
SeaBED IMAGERY

**Completed Collection**
- AVIRIS Images:
  - August 19, 2004
  - December 12, 2005
  - December 13, 2005

**Planned/Ongoing Collection**
- HYPERION Images:
  - August 15, 2002
  - January 15, 2003
  - March 13, 2004
  - March 29, 2004
  - September 5, 2004
  - February 17, 2006
- IKONOS Images:
  - 2002 Composite

**Multi/Hyperspectral Data:**
- IKONOS
- HYPERION
- AVIRIS
- Spectra Vista
- Optech
2004 AVIRIS MISSION

**Puerto Rico:**
- August 19, 2004
- 8 Flightlines
- Altitude ~20.1 km
- Pixel Size ~17 m
- Total Length 750 km
- Total Area 8500 km²

**Florida:**
- August 17, 2004
- 6 Flightlines
- Altitude ~14.3 km
- Pixel Size ~13 m
- Total Length 350 km
- Total Area 3000 km²

**AVIRIS Deployment:**
- Robins AFB, Georgia
- ER-2 Platform
NEW INDUSTRIAL COLLABORATIONS

Spectra Vista Corporation

CenSSIS Involvement:
Underwater Field Instrument Development
Airborne Data Validation Using SeaBED

Optech International, Inc.

CenSSIS Involvement:
Field Data Collection
Airborne Data Validation Using SeaBED

GER-1500 Field Spectrometer

Airborne Imaging Spectrometer

SHOALS Imaging Bathymeter
Reflectance Characteristics of the Benthic Substrate
in the Coastal Region of Broward County, Florida

Technical Report for:
Optech International Inc.

Prepared by:
J. Goodman (UPRM-CenSSIS)
S. Purkis and A. Carter (NCRI)

Purpose:
Underwater spectral measurements
Image mosaic and classification
Ground support for new SHOALS/CASI sensor
Data Source/Collaborator:
Optech International Inc.

Instrument (Fused System):
Active Lidar Sensor: SHOALS
Passive Hyperspectral Sensor: CASI-1500

Location:
Broward County, Florida

Purpose:
Development of Enhanced Subsurface Coastal Mapping Applications
Underwater Multispectral Imaging

Application of CenSSIS Image Registration

- 6-Band Underwater Multispectral Camera
- Subsurface Imaging of Benthic Habitats
- Multi-temporal and Multi-spectral Image Registration
- CenSSIS Software Application
- New Collaboration with U. Miami (A. Gleason)
APPLICATION COLLABORATIONS

- Field Data Collection
- Ground Support
- Spectral Experiments
- Image Analysis/Processing
- Validation Site
- Coastal Habitat Mapping
Taking Coastal Mapping to a New Level

AVIRIS
- 224 Spectral Bands
- 16m Resolution

Image Processing
- Benthic Classification
- Water Optical Properties
- Bathymetry
SUSTAINABILITY: Proposals

Utilizing High-Performance Computing to Investigate Performance and Sensitivity of an Inversion Model for Hyperspectral Remote Sensing of Shallow Coastal Ecosystems
  PI: James Goodman (UPRM)
  Co-I: Wilson Rivera (UPRM)
  Source: NASA, Puerto Rico Space Grant Consortium
  Amount: $29,940 (awarded), 1 year (03/05 – 02/06)

Taking Coastal Mapping to a New Level: Assessing Habitat Composition and Water Properties of Shallow Coastal Ecosystems along the Coast of Puerto Rico Using Hyperspectral Remote Sensing
  PI: James Goodman (UPRM)
  Source: NOAA, Caribbean Coral Reef Institute
  Amount: $133,296 (awarded), 2 years (09/06 – 08/08)

Subsurface Sensing of Aquatic Environments
  PI: James Goodman (UPRM)
  Source: NASA, New Investigator Program
  Amount: $359,680 (pending), 3 years

Evaluation of Spatial and Spectral Scale for Remote Sensing of Biodiversity in Coral Reefs and Associated Biotopes
  PI: Liane Guild (NASA-ARC)
  Science PI: Roy Armstrong (UPRM)
  Co-I: James Goodman (UPRM), Brad Lobitz (NASA-ARC), Stephen Dunagan (NASA-ARC)
  Source: NASA, Terrestrial Ecology and Biodiversity
  Amount: $405,962 (pending), 3 years
Benthic Habitat Mapping using Hyperspectral Imaging

Luis Jiménez
UPRM
Goals

- Objective: Subsurface Classification & Object Recognition
- Challenge 1: Uncertainty in the Medium and Changes: Shallow Waters
  - Subsurface Classification by means of Inversion and Regularization
  - Change Analysis
- Challenge 2: Low level of Desired Signal
  - Resolution Enhancement Filtering
  - Inversion Analysis and Unmixing
Challenge 1: knowledge of medium’s physical parameters
Use of Lee’s Semi-analytic Model

\[ S_{Bottom}(\lambda_i) = \frac{\rho(\lambda_i)}{\pi} e^{-2[\alpha(\lambda_i) + \beta(\lambda_i)]H} \]

\[ a_i = \frac{1}{\pi} e^{-2[\alpha(\lambda_i) + \beta(\lambda_i)]H} \]

\[ r_{rs}(\lambda_i) = S_{Col}(\lambda_i) + \rho(\lambda_i) a_i(\lambda_i) \]

Our variable of interest
Subsurface Classification

Regularization & Sensor Fusion

\[
\rho_{reg}(\lambda_i) = \frac{a_i^2(\lambda)}{a_i^2(\lambda) + \eta^2} \cdot \frac{r_{rs}(\lambda_i) - S_{col}(\lambda_i)}{a_i(\lambda)}
\]

\[+
\frac{\eta^2}{a_i^2(\lambda) + \eta^2} \cdot \rho_0(\lambda_i)
\]

Classification or Object Recognition

Independent set of Stored Spectral Library

Spectral Library of Stored Spectral Signatures (\(\rho_0\)'s)
Subsurface Classification of HYPERION Data

NOAA Benthic Habitat Map

HYPERION data
Subsurface Classification of HYPERION Data

NOAA Benthic Habitat Map

Classification with raw data
Subsurface Clasification of HYPERION Data

NOAA Benthic Habitat Map

Subsurface Classification: Inversion and Regularization
Change Analysis from Hyperspectral Images

- Data obtained from Hyperion sensor
  - 220 bands
  - La Parguera, Lajas, Puerto Rico
- Piecewise affine transformation
- Image Correction – ACORN
- Band Selection – Singular Value Decomposition Band Subset Selection

Type of Change

<table>
<thead>
<tr>
<th>Coral Reef - Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Grass – Sand</td>
</tr>
<tr>
<td>Sand – Sea Grass</td>
</tr>
</tbody>
</table>
Challenge 2: Small Signal from the Water

What we Measure

- Optical Properties of the Water
- Bottom Reflectance
- Bathymetry

What we want

Need to have good signal to noise ratio to be able to classify benthic habitats

From C.O. Davis, HSI of the Littoral Battle Space, NRL Code 7203

From NEMO Overview
Nemo.nrl.navy.gov
Improving Signal to Noise Ratio by Taking Advantage of Spectral Oversampling

- Due to oversampling, the signal spectrum occupies a small portion of the discrete spectra
- Information from the power spectral density of the signatures of interest is used to design a low pass filter that will result in higher SNR and classification accuracy.

\[
X(\Omega) = \sum_{n=-\infty}^{\infty} x[n] e^{-j\Omega n}
\]

\[
X[n] = \int_{-\pi}^{\pi} x(\Omega) e^{j\Omega n} d\Omega
\]

Original Spectrum

FFT

Low pass filter

IFFT

Filtered Spectrum
Resolution Enhancement Filtering

- Resolution enhancement filtering (REF) developed at CenSSIS leads to improved SNR of Hyperion data for coastal remote sensing.

Before Filtering

Channel 8: 426.82nm

Channel 216: 2314.81nm

After Filtering

Resolution Enhancement Filter
Resolution Enhancement Improves Classification Accuracy in Hyperion Imagery

2004 Hyperion Image over Enrique Reef

<table>
<thead>
<tr>
<th>Image Preprocessing Scheme</th>
<th>Overall Classification Accuracy (%)</th>
<th>Increase in accuracy from None</th>
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</thead>
<tbody>
<tr>
<td>None</td>
<td>99.5495</td>
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<td>0.4505</td>
</tr>
<tr>
<td>RE</td>
<td>100</td>
<td>0.4505</td>
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Training Samples

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<th>Image Preprocessing Scheme</th>
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<tr>
<td>None</td>
<td>95.5157</td>
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<td>TSVD</td>
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<tr>
<td>RE</td>
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<td>4.4843</td>
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Testing Samples

Algorithm Benchmarked Against Reduced Rank Filtering

Algorithm is part of the Hyperspectral Toolbox
Challenge: Low Spatial Resolution in Hyperspectral Environmental RS

IKONOS Image
Multispectral Sensor
1 meter, 4 bands

Hyperion Image
Hyperspectral Sensor
30 meters, 192 bands
INVERSION ANALYSIS and UNMIXING

AVIRIS

Atmospheric Correction
- Tafkaa
- Glint Removal

Inversion Model
- Semi-Analytical

Inversion Output
- Water Constituent Properties
  - Bottom Albedo (550 nm)
  - Bathymetry
- RMSE

Forward Model
- Semi-Analytical

Linear Unmixing Model

Unmixing Output
- Reef, Algae, Sand Distribution
- RMSE

Input Parameters
- Absorption Properties
- Bottom Reflectance

Field Spectra

Spectral Endmembers
- Reef, Algae, Sand

2006 CenSSIS Site Visit
S4 Final Remarks

Miguel Vélez-Reyes
Roy Armstrong
Hanumant Singh
James A. Goodman
Luis O. Jimenez

Center for Subsurface Sensing & Imaging Systems

Looking Into CenSSIS
Hidden Worlds
Taking Coastal Mapping to a New Level

**NOAA State-of-the-Art**
- Aerial Photo-Mosaic
- Manual Classification

**CenSSIS**
- AVIRIS: Hyperspectral
  - 2004 Puerto Rico

**Habitat Map**
- Sand
- Coral
- Algae

**Water Depth**
- 0 m
- 10 m
- 20 m

224 Bands
10 nm Spectral
17 m Spatial

NOAA 2001
New Quantitative Techniques Developed for Analysis of Deep Reef Systems

Bathymetry of Puerto Rico

Reef Health Established by Classification of Bottom Composition Imagery Collected using AUV

Structural Complexity Derived from Rugosity Estimates using Pencil Sonar Data

equal letters denote no statistical difference between sites (p < 0.05)
Future Work

- SeaBED AUV transfer to UPRM: Joint UPRM/WHOI MRI proposal to NSF
- Analysis of AVIRIS 2005 data to study bleaching impact in the Caribbean
- Detailed field map of Enrique Reef
- Comprehensive Campaign
- Iterative methods for inversion and unmixing
- Radiative transfer modeling
- Fluorescence Imaging of Reefs
- LIDAR/hyperspectral fusion: Optech Dataset