Using HyspIRI to Identify Benthic Composition in Shallow Coral Reef Ecosystems

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Overarching Project Goals

Will the spectral characteristics of HyspIRI-like data allow for the accurate retrieval of reef benthic composition?

1. **Simulation analysis** to characterize the practical limits of discrimination of coral reef benthic composition.

2. **Validation** of benthic fractions from AVIRIS imagery using field observations.
Questions – Simulation Analysis

• Under what conditions can we expect good benthic discrimination – what are the no-go conditions?

• Which benthic types are difficult to discriminate?

• What is the minimum fraction of live coral detectable under various water column conditions?

Answer these questions by examining errors related to unmixing, water conditions, inversion modeling, and atmospheric effects.
Multiple Endmember Spectral Mixing Analysis (MESMA)

1/10 endmembers

Coral

Turf

Algae

Sand

Each Mixture Modelled w/ $9^3$ (729) Endmember Combinations

Mixtures including:
Live Coral
Sand
5 Algal Types
(Turf, Brown, Green, Red, CCA)
48 Fractional Mixtures

Spectral Derivatives

- Coral
- Algae
- Sand

1st Derivative

2nd Derivative

Wavelength (nm)
Error Due to MESMA Unmixing

Spectral Mixtures → MESMA → Error
Changes in Reflectance Due to Water Properties

7000 Water Columns

Low Chl, Low CDOM, Low Sed., 15m Depth

Med Chl, Med CDOM, Low Sed., 8m Depth

High Chl, Med CDOM, High Sed., 1m Depth
## Realistic Range of Environmental Factors

<table>
<thead>
<tr>
<th>Variable</th>
<th>Values for Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (m)</td>
<td>1, 2, 3, 5, 8, 10, 15</td>
</tr>
<tr>
<td>Wind Speed (m s(^{-1}))</td>
<td>0, 1, 2, 5, 10</td>
</tr>
<tr>
<td>CDOM (m(^{-1}))</td>
<td>0.01, 0.02, 0.05, 0.1, 0.5</td>
</tr>
<tr>
<td>Chlorophyll concentration (mg m(^{-3}))</td>
<td>0, 0.1, 0.25, 0.5, 1</td>
</tr>
<tr>
<td>Suspended carbonate sediment (g m(^{-3}))</td>
<td>0, 0.1, 0.2, 0.5, 1, 2, 5, 10</td>
</tr>
</tbody>
</table>
Error Due to Water Column

Spectral Mixtures → MESMA → Error

Spectral Mixtures + Water Column → MESMA Known H₂O → Error
Error Due to Inversion Model

Spectral Mixtures → MESMA → Error

Spectral Mixtures + Water Column → MESMA Known H₂O → Error

Spectral Mixtures + Water Column → Inversion Model → MESMA Derived H₂O → Error
Error Due to Atmospheric Effects and Correction

- Spectral Mixtures → MESMA → Error
- Spectral Mixtures + Water Column → MESMA Known H₂O → Error
- Spectral Mixtures + Water Column → Inversion Model → MESMA Derived H₂O → Error
- Spectral Mixtures + Water Column + Atmosphere → Atm. Correction

Atmosphere Correction
Error Due to Atmospheric Effects and Correction

Spectral Mixtures → MESMA → Error

+ Spectral Mixtures + Water Column → MESMA Known H₂O → Error

+ Spectral Mixtures + Water Column → Inversion Model → MESMA Derived H₂O → Error

+ Spectral Mixtures + Water Column + Atmosphere → Atm. Correction → Error

Inversion Model → MESMA Derived H₂O → Error
Results of MESMA/Derivatives

• Coral and algae are difficult to separate with MESMA, but not all algal types produce similar errors.

• Derivatives (1\textsuperscript{st} & 2\textsuperscript{nd}) of mixed spectra and endmembers produce better results.

\begin{align*}
\text{Coral Mixed w/ Turf Algae} \\
&: r^2 = 0.90 \\
&: y = 0.85x + 0.12
\end{align*}

\begin{align*}
\text{Coral Mixed w/ Red Algae} \\
&: r^2 = 0.65 \\
&: y = 0.64x + 0.10
\end{align*}
Error Due to Water Column

Spectral Mixtures → MESMA → Error

Spectral Mixtures + Water Column → MESMA
Known $H_2O$ → Error
Effect of Water Constituents on Error

Mean Absolute Error

- Coral
- Algae
- Sand

Chl (mg m\(^{-3}\))

Depth (m)

Sediment (g m\(^{-3}\))

Turf
Red
Green
Brown
CCA
Effect of Sediment and Depth on Error

Coral Error

Algae Error

Mean Absolute Error
Effect of Chlorophyll and Sediment on Error

Coral Error

Algae Error
Effect of Chlorophyll and Depth on Error

Coral Error

Algae Error
Confusion between Coral and Algal Types

![Graphs showing difference in mean error for different algal and coral types across depth, chlorophyll (Chl), and sediment content.](image)
Minimum Benthic Fraction Thresholds

Coral

Turf Algae

Sand

Depth = 3 m, clear water

~10 - 25%

~25%

~15%
Conclusions so far...

• Deep water areas consistently have the most error, but this is modulated by suspended sediment and chlorophyll concentration. No go conditions will be dependent on the level of acceptable error.

• Coral cover is consistently confused as algal cover, and this effect increases with depth. Brown algae leads to the most confusion.

• At a relative absolute error level of 0.5, there will need to be around 25% of coral or algae fraction, and 15% sand fraction for acceptable discrimination.
Ongoing work...

- Water column inversion & atmospheric effects will help refine no go conditions

- Use MESMA to detect the correct **algal type** in a mixed pixel

- Validation of optimized unmixing algorithm with in water photomosaics
250 Phototransects Across 5 Hawaiian Islands

- Molokai: 40 Transects
- Oahu: 108 Transects
- Lanai: 32 Transects
- Maui: 40 Transects
- Hawaii: 30 Transects
Phototransect Collection (250)

Photo: Juan Torres-Perez
Spectral Transects (56/250)
Phototransects w/ Spectra
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• Deep water areas consistently have the most error, but this is modulated by suspended sediment and chlorophyll concentration. No go conditions will be dependent on the level of acceptable error.

• Coral cover is consistently confused as algal cover, and this effect increases with depth. Brown algae leads to the most confusion.

• At a relative error level of 0.5, there will need to be around 25% of coral or algae fraction, and 15% sand fraction for acceptable discrimination.
Effect of Chlorophyll and Depth on Error

Coral Error

Algae Error

Effect of Chlorophyll (Chl) and Depth on Error.
Effect of Different Algal Types on Error

- **Turf**
  - Depth + Chl -

- **Red**
  - Depth + Chl 0

- **Green**
  - Depth + Chl -

- **Brown**
  - Depth + Chl 0

- **CCA**
  - Depth + Chl +
Examine effect of noise on unmixing

Required SNR

Wavelength (nm)

SNR

0.5 Refl
0.25 Refl
0.05 Refl
0.01 Refl

SNR Look-Up Table

Reflectance (%)

SNR

Wavelength (nm)

JPL 2015
Required SNR has negligible effect on unmixing

\[ \text{Refl}_{\text{Noisy}} = \text{Refl}(1 + 0.5 \frac{N(0,1)}{\text{SNR}}) \]
How is this analysis unique and useful?

• Unmixing benthic fractions: MESMA and spectral derivative techniques

• Focus on AVIRIS/HyspIRI-like bands

• Full quantification of error related to:
  • spectral unmixing techniques
  • effects of a range of water constituents on error
  • error related to water inversion and atmospheric effects

• Examine different classes of algae