Remote sensing methods to map and monitor coastal habitats and bathymetry

Janet Anstee and Hannelie Botha
Development of Earth observation methods for water quality and coastal habitat assessment

- Characterisation of aquatic bio-optics & substrates
- Calibration and validation facilities
- Algorithms
- Accuracy and uncertainty metrics
- Multi-sensor model-data integration
1. Atmospheric correction and air-water interface effects removal (RT physics-based and increasingly relying on ANN for fast processing)

2. For optically deep waters: adaptive linear matrix inversion method (aLMI) using variable sets of SIOPS (Specific Inherent Optical Properties) to allow for varying water types within one image

3. For optically shallow waters: enhancement of enhanced implementation of the inversion/optimization approach by Lee et al. (1999, 2001) by including multiple substratum types (SAMBUCA)
SAMBUCA is an enhancement (by Brando et al. 2009) of the inversion/optimization method by Lee et al. (1998; 1999; 2001) to enable:

- Retrieval of chlorophyll-a, CDOM and NAP concentrations in varying water types
- Pure and mixed substratum-type compositions
- Retrieval of vertical attenuation (for optically deep water)
- Retrieval of bathymetry
- Estimating the contribution of the substratum-type to the remote sensing signal (SDI)
The challenge for water quality and coastal habitat assessment

Coastal and coral reef water bodies are a mixture of:

• optically shallow,
• quasi optically deep
• and optically deep waters (gradients of clear to turbid waters & varying bottom visibility)

• substrate visibility and optical complexity affects water quality parameters model retrievals

• Previous approaches using empirical regression-based techniques cannot account for the complexity of these waters
SAMBUCA: Semi Analytical Model for Bathymetry, Unmixing and Concentration Assessment

- Step 1: Noise estimation
  - NE\Delta r_{rsE}

- QA variables
  - SDI
  - \Delta

- Step 2: Inversion optimisation SAMBUCA
  - SIOPs
  - Concentration ranges
  - Substrate spectral library
  - NE\Delta r_{rsE}
  - Raw output:
    - Substratum
    - Concentrations (C_{CHL}, C_{CDOM}, C_{NAP})

- Step 3: Quality control SAMBUCA
  - QC’ed output
    - Substratum
    - Concentrations (C_{CHL}, C_{CDOM}, C_{NAP})

It is sensor agnostic: it works across multispectral to hyperspectral EO
Optically Shallow Waters Inversion Methods
SAMBUCA

- Implementing the Open Source code on the National Computational Infrastructure (NCI) facility at the Australian National University.
- This enables processing at higher resolution, within shorter periods of time and provide access to new tools and techniques (such as time-series analysis) when applied on the Digital Earth Australia DataCube.
- This research is currently being supported through a joint CSIRO-GA project.
Western Port Bay

- Inversion retrievals of
- WQ information
- bathymetry
- substrate type
- Light Attenuation $K_d(490)$
Example: Georgina Cay, Coral Sea

- Land/clouds/sunglint

![Graph showing measured vs. retrieved depth](image)

- Measured depth (m)
- Retrieved depth (m)
Example: Georgina Cay, Coral Sea

![Map of Georgina Cay, Coral Sea]

**Quality control**

- Land/clouds/sunlight

- Measured depth (m) vs. retrieved depth (m)

- Equation: \( y = 0.8187x + 0.6458 \)
- Coefficient of determination: \( R^2 = 0.8066 \)
Example: Funafuti, Tuvalu
Example: Funafuti, Tuvalu
SAMBUCA approach
(applied on Quickbird imagery, Botha et al., 2010)

Pre-processing:
1. De-glinting
2. Atmospheric correction

Aquatic Physics-based inversion model (SAMBUCA Model)

Water optical properties

Information Products

Substratum reflectance spectra

Quickbird image

Terrestrial Supervised classification (spectral angle mapping)

Remote sensing for habitat mapping and change detection in tropical Commonwealth marine protected areas – phase 2
E.J. Botha, A.G. Dekker, Y.J. Park, J.M. Anstee, N. Cherukuru, L. Clementson
June 2010
Parameterizing SAMBUCA: Substrates

Spectral sensitivity of satellite data:

<table>
<thead>
<tr>
<th></th>
<th>Sand and mud</th>
<th>Zosteraeae</th>
<th>Posidonia australis</th>
<th>Ruppia megacarpa</th>
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<tbody>
<tr>
<td>Laminated TM bands</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>Cymodocea serrulata</td>
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<td></td>
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<table>
<thead>
<tr>
<th>Acropora sp</th>
<th>0.913</th>
<th>0.492</th>
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<tbody>
<tr>
<td>Sand</td>
<td>1.010</td>
<td></td>
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</table>

Data prepared from:
Archival spectral library derived from historical in situ measurements.

normalized Spectral Separability Metric, nSSM ([Botha, et al. 2013](#)) accounts for spectral shape and magnitude features in multispectral datasets by combining the Spectral Angle Mapper (SAM), metric with an Euclidian Minimum Distance metric.
Parameterizing SAMBUCA: Water Column

Optical complexity and seasonal differences:

Oct 07 - Dry Season

Feb 08 – Wet Season

Data prepared from:

• Archival spectral library derived from historical in situ measurements
• Field campaign measurements over a range of seasons would improve the accuracy of the SAMBUCA retrievals
Parameterising a semi-analytical model

• Operational continental scale water quality
• OWT classification reduce optical complexity of water bodies
Measured SIOPs:
- CHL (μg L⁻¹)
- NAP (mg L⁻¹)
- aCDOM₄₄₀nm
- γₐCDOM
- a*PHY
- a*NAP₄₄₀nm
- γₐNAP
- bb*NAP₅₅₅nm
- γbbNAP

Solar zenith = 30°
Depth = 20m (optically deep)
Wind speed = 0 m s⁻¹
Salinity = 35
Temperature = 20°C

Ecolight model

Transfer spectral clusters to input SIOP matrix for analysis

Input SIOPs grouped by spectral clusters

ANOVA
- Each input factor by spectral groups

Tukey HSD test
- All possible grouping pairs
- Each input factor

Factors significantly different between groupings

Clusters significantly different for all significant factors

Median SIOPs for each cluster

Hierarchical clustering:
- Metric: Euclidian distance
- Linkage criteria: Centroid

Normalization:
- $\frac{(R_{rs} - \mu)}{\sigma}$

Spectral clusters

Merge similar clusters

yes

no
Coastal SIOPs
(2001 – 2017, 286 observations)
## Coastal Clusters

<table>
<thead>
<tr>
<th>Cluster</th>
<th>n</th>
<th>Description</th>
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<tbody>
<tr>
<td>C17</td>
<td>6</td>
<td>Turbid tropical wet season</td>
</tr>
<tr>
<td>C3</td>
<td>135</td>
<td>Clear coastal dominated by CDOM absorption</td>
</tr>
<tr>
<td>C5</td>
<td>39</td>
<td>Coastal waters with a strong estuarine influence</td>
</tr>
<tr>
<td>C6</td>
<td>6</td>
<td>Turbid tropical dry season</td>
</tr>
<tr>
<td>C7</td>
<td>55</td>
<td>Open coastal waters with higher amounts of suspended organic material than C3</td>
</tr>
</tbody>
</table>

**Cluster Description:***

- **C17**: Turbid tropical wet season
- **C3**: Clear coastal dominated by CDOM absorption
- **C5**: Coastal waters with a strong estuarine influence
- **C6**: Turbid tropical dry season
- **C7**: Open coastal waters with higher amounts of suspended organic material than C3.
## Final clusters

### Coastal (5)

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### Inland (6)

<table>
<thead>
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<tbody>
<tr>
<td>i5</td>
<td>42</td>
<td>Clear NAP dominated</td>
</tr>
<tr>
<td>i7</td>
<td>21</td>
<td>Clear CDOM dominated</td>
</tr>
<tr>
<td>i8</td>
<td>27</td>
<td>Turbid</td>
</tr>
<tr>
<td>i13</td>
<td>6</td>
<td>Highly turbid NAP dominated</td>
</tr>
<tr>
<td>im1</td>
<td>5</td>
<td>Green – phytoplankton dominated</td>
</tr>
<tr>
<td>im2</td>
<td>4</td>
<td>Turbid – highly reflective</td>
</tr>
</tbody>
</table>

#### Figures

- Figure (a) shows Chl-a concentration (g L⁻¹).
- Figure (b) shows NAP concentration (mg L⁻¹).
- Figure (c) shows NAP concentration at 440 nm (m² g⁻¹).
- Figure (d) shows NAP concentration at 555 nm (m² g⁻¹).
- Figure (e) shows CDOM absorption (nm⁻¹).
- Figure (f) shows CDOM absorption (nm⁻¹).
- Figure (g) shows CDOM absorption (nm⁻¹).
- Figure (h) shows CDOM absorption (nm⁻¹).
Final clusters

Absorption budget
Final clusters

Absorption budget
Final clusters
Potential applications
gap analysis using an EO Data Cube
Conclusions

• First steps towards a spatial and spectral gap analysis method for SIOP data.
• Despite obvious gaps in the datasets, there are distinct similarities of coastal and estuarine water properties in eastern, southern and western Australia.
• There is a lack of temporal data to understand the variability associated with seasons.
• The cluster analysis returned several small clusters that were both spectrally and bio-optically unique but did not have enough observations to be statistically sound.
• Further surveys (especially in nice places) are required to capture unique end-members before a full continental-scale model can be implemented for all waters in Australia.
Thank you

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