Remote sensing of shallow-water bathymetry: Leveraging multispectral satellite ocean color observations

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Question and Objective

Ocean color satellites allow for derivation of important biogeochemical properties for global oceans. Limited to multispectral resolution, however, it remains difficult to generate geophysical properties, e.g., water depth, over global shallow waters with the satellite remote sensing reflectance ($R_{\lambda}(\lambda)$). This study evaluates a new algorithm for practical application of multispectral ocean color observations to the retrieval of water depth for optically shallow waters.

Method and Algorithm

- Semi-analytical approach designed for hyperspectral $R_{\lambda}(\lambda)$

Ocean color community has invested great efforts in shallow water remote sensing with semi-analytical algorithms. An extensively tested algorithm is the so-called hyperspectral optimization processing exemplar (HOPE) (Lee et al., 1998, 1999). A shallow-water reflectance model is established as:

$$
R_{\lambda}(\lambda) = \exp \left[ -\frac{1}{\cos \theta_r} \left( \frac{D_0 (1 + D_1 \omega_i (\lambda))^\nu}{\cos \theta_r} \right) \right]$$

Five unknowns of $P, G, X, B,$ and $H$ can be determined by quantifying the difference between the observed spectrum, $R_{\lambda,obs}(\lambda)$, and modeled spectrum, $R_{\lambda,mod}(\lambda)$.

$$
\text{cost} = \sum \left( R_{\lambda,mod}(\lambda) - R_{\lambda,obs}(\lambda) \right)^2
$$

Cost function

- Two-spectrum optimization approach (2-DOA) for multispectral $R_{\lambda}(\lambda)$

Our new algorithm incorporates two independent $R_{\lambda}(\lambda)$ spectra measured at the same location in the spectral optimization, thus allowing to generate much improved estimation for water depth with multispectral satellite ocean color observations. The workflow is schematically shown below:

$$
P, G, X, B, R, H \Rightarrow R_{\lambda,mod}(\lambda)$$

Performance Evaluation

- Hyperspectral $R_{\lambda}(\lambda)$ data are synthesized to cover a wide range of depths, three benthic types (coral, seagrass, and sand), and turbidity. These $R_{\lambda}(\lambda)$ data are then interpolated to represent the measurements for Landsat-8/OLI, SNPP/VIIRS, and Sentinel-3A/OLCI.

- The bottom albedo spectra for coral, seagrass, and sand were derived from Hochberg et al. (2003).
- 2-DOA uses a fixed bottom albedo spectrum (bright band) (Lee et al., 1999).
- 2-DOA used fixed lower and upper constraints and dynamic initial values.

- Error statistics for model-estimated water depth (0.5-30 m)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Range (interval)</th>
<th>Levels</th>
<th>LandSat-8/OLI</th>
<th>SNPP/VIIRS</th>
<th>Sentinel-3A/OLCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P$</td>
<td>0.049 - 0.19 (0.003)</td>
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<td></td>
</tr>
<tr>
<td>$G$</td>
<td>0.001 - 0.01 (0.0001)</td>
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<td>$X$</td>
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<td>$B$</td>
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<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R$</td>
<td>0.95</td>
<td>1</td>
<td></td>
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</tr>
<tr>
<td>$H$</td>
<td>0.007 - 0.01 (0.001)</td>
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<td>0.0126</td>
<td>0.0126</td>
<td>0.0113</td>
</tr>
<tr>
<td>$X_r$</td>
<td>0.001 - 0.01</td>
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<td>0.0126</td>
<td>0.0126</td>
<td>0.0113</td>
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<tr>
<td>$B_r$</td>
<td>0.001 - 0.01</td>
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<td>0.0126</td>
<td>0.0126</td>
<td>0.0113</td>
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<tr>
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<td>2</td>
<td>0.0126</td>
<td>0.0126</td>
<td>0.0113</td>
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<tr>
<td>$H_r$</td>
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<td>2</td>
<td>0.0126</td>
<td>0.0126</td>
<td>0.0113</td>
</tr>
</tbody>
</table>

- Depth-specific error statistics for model-estimated water depth

- Cost function

$$
\text{cost} = \sum \left( R_{\lambda,mod}(\lambda) - R_{\lambda,obs}(\lambda) \right)^2
$$

Depth-specific error statistics for model-estimated water depth

- Conclusions

- A new algorithm is developed for shallow-water bathymetric estimation for multispectral satellite ocean color sensors.

- Evaluation shows substantial improvement in the estimated depth product over 0-30 m.

Acknowledgment: http://www.soest.hawaii.edu/coasts

Bathymetry from Satellite Images

- Olowalu Reef (Maui, Hawaii)
- Florida Keys
- The Bahamas