IOCCG LECTURE 2
OPTICALLY SHALLOW REMOTE SENSING

Dr. Heidi Dierssen
University of Connecticut

Photo: H. Dierssen
Pulsed export of $>7 \times 10^{10}$ g of carbon directly to seafloor (negatively buoyant). This is equivalent to the daily carbon flux of phytoplankton biomass in the pelagic tropical North Atlantic and 0.2–0.8% of daily carbon flux from the global ocean.

Potential export of unattached benthic macroalgae to the deep sea through wind-driven Langmuir circulation

H. M. Dierssen,¹ R. C. Zimmerman,² L. A. Drake,²⁻³ and D. J. Burdge²

H. Dierssen, IOCCG 2016
2) Florida Bay

McPherson et al. 2011
Buonassissi and Dierssen 2010
Dierssen et al. 2015
Hedley et al. 2016
Remote Sensing of **Optically Shallow** Water

1) Benthic Reflectance ($R_b$)  
   Canopy and Sediment

2) Water Column Optical Properties

3) Water Depth (H) and  
   Canopy Height

4) Air-water Interface  
   Waves, Glint and Whitecaps

5) Atmosphere -- aerosols

6) Tools to survey  
   -Sensors  
   -Radiative Transfer Models
   Hydrolight (Mobley)  
   3D canopy model (Hedley)

---

H. Dierssen, IOCCG 2016
Coral Reef in Clear Water

Coral Reef in Turbid Water

H. Dierssen, IOCCG 2016
Requirements for Optically Shallow Remote Sensing

Spectral Resolution
- Hyperspectral is generally required to differentiate bottom types (e.g., coral vs. macroalgae (Hochberg and Atkinson 2000))
- Otherwise, you need a priori knowledge of site and limited in what you can differentiate (e.g., reef extent)

Spatial Resolution
- Depends on science question
- 1 – 10 m Aircraft or In-water AUVs
- 30-100 m Hyperspectral Satellites
- 200-1000 m Ocean color satellites

Image Processing
- Removal of sun glint
- Atmospheric correction
- Water column correction

Ancillary Data
- Field data
- Rrs
- IOPs
- Benthic cover
- Aerosols (sun photometer)
- Bathymetry

H. Dierssen, IOCG 2016
Case Study with the Airborne Hyperspectral PRISM Sensor

Built in 2012 by NASA JPL funded by NASA Ocean Biology and Biogeochemistry to address challenges of coastal remote sensing. Hyperspectral (350-1050 nm), integrated on Twin Otter Platform for <1 m pixels and also on ER2 or GV5 for 10 m pixels.

Photo: E. Heupel
Portable Remote Imaging SpectroMeter (PRISM): NASA Coastal Applications

Mouroulis et al. 2013

<table>
<thead>
<tr>
<th>Spectral</th>
<th>Range</th>
<th>350-1050 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling</td>
<td>2.85 nm</td>
<td></td>
</tr>
<tr>
<td>Resolution (FWHM)</td>
<td>3.5 nm</td>
<td></td>
</tr>
<tr>
<td>Calibration uncertainty</td>
<td>&lt; 0.1 nm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spatial</th>
<th>Field of view</th>
<th>30.7°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous FOV sampling</td>
<td>0.882 mrad</td>
<td></td>
</tr>
<tr>
<td>IFOV resolution (FWHM)</td>
<td>0.97 mrad</td>
<td></td>
</tr>
<tr>
<td>Cross-track spatial pixels</td>
<td>608</td>
<td></td>
</tr>
<tr>
<td>Ground resolution</td>
<td>0.35 – 20 m</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radiometric</th>
<th>Range</th>
<th>0 to max. beach R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling</td>
<td>14 bit</td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td>&gt;99%</td>
<td></td>
</tr>
<tr>
<td>Calibration uncertainty</td>
<td>&lt;2%</td>
<td></td>
</tr>
<tr>
<td>SNR</td>
<td>2000 @450 nm*</td>
<td></td>
</tr>
<tr>
<td>Polarization variation</td>
<td>&lt; 1%</td>
<td></td>
</tr>
</tbody>
</table>

| Uniformity             | Spectral cross-track uniformity | >95%             |
|                       | Spectral IFOV mixing uniformity | >95%             |
Tackling Sun Glint

• Can align overflights into or out of sun
  – Avoid Across-track glint

• Remove glint
  – Empirical linear relationships
  – Wave features removed baseline at 980 nm

Photos: Hyspiri sunglint subgroup report.
Can be helpful to develop hourly flight lines or morning/afternoon lines to avoid sun glint
PRISM Atmospheric Correction Procedure

1. Calculate molecular & aerosol scattering with 6s
2. Retrieve pressure altitude, H₂O vapor, liquid by fitting absorption features
3. Apply LUTs
4. Residual suppression based on a reference target

Aerosol particle type distribution, AOD at 550nm
Transmission $T_d T_u$, Sky albedo $s$, Path reflectance $r_a$

Top of atmosphere apparent reflectance $\rho$

$$\rho = \frac{\pi L}{F \cos(\theta)}$$

Reflectance spectrum

$$r_s = \frac{\rho / T_g - r_a}{T_d T_u + s(\rho / T_g - r_a)}$$

Corrected reflectance spectrum

Gao, Thompson and Gierach 2016
Methods for Remote Sensing

• Empirical -- pick known endmembers, thresholds, waveband ratios, etc...

• Look Up Table (LUT)
  – Propagate benthic reflectance in Hydrolight
    • different depths and water IOPs
  – Spectral matching of Rrs to a LUT library of Rrs

• Semi-analytical Inversion Modeling
  Majority based on HOPE model
    (Lee et al. 1998, 1999)
    • P, G, X, B, H
    • B=Benthic Reflectance
    • H=Water depth

P=a_phy (440)
G=a_g(440)
X=b_{bp}(550)

Slope parameters
  • Scdom= 0.015
  • Y=0.5

H. Dierssen, IOCCG 2016
Interpretation of hyperspectral remote-sensing imagery by spectrum matching and look-up tables


Fig. 8. Randomly chosen selection of 2% of the 41,591 EcoLUT-generated $R_{rs}$ spectra in the LUT database (832 spectra plotted).

6. Bottom classification based on diver observation (squares) and video recorded from a small boat (circles).
Assumptions and Variations for Inversion Model HOPE

• Initial assumptions can be tuned
• Models vary in terms of:
  – Retrieve mixture of benthos
  – Retrieve more water column properties
• Can propagate uncertainty estimates
A physics-based method for the remote sensing of seagrasses

John Hedley a,*, Brandon Russell b, Kaylan Randolph b, Heidi Dierssen b

a Environmental Computer Science Ltd, Raymond Penny House, Tiverton, Devon EX16 6JR, United Kingdom
b Department of Marine Sciences, University of Connecticut, Groton, CT 06340, USA
Image analysis compared to in-situ LAI data

- Basic pattern matches in-situ data
- Spatial variation in in-situ LAI is higher
- Need for more appropriate sampling regimes for meter-scale imagery
- Can convert to CARBON storage


H. Dierssen, IOCCG 2016

H. Dierssen, UCONN

IOCCG Summer Lecture 2016
How well does the model work in Turbid Water? Example provided

Elkhorn Slough, CA
For deeper habitats, imagers can be mounted on Remotely Operated Vehicles.

Requires a light source

Johnsen et al. 2013

H. Dierssen, UCONN

H. Dierssen, IOCCG 2016

IOCCG Summer Lecture 2016
About CORAL

It is estimated that 33-50% of coral reefs worldwide have been largely or completely degraded (International Society for Reef Studies Consensus Statement, October 2015). Yet the data supporting these predictions are surprisingly sparse, and thereby their relation to the environment is unclear. The COral Reef Airborne Laboratory (CORAL) will pave the way to better predict the future of this global ecosystem and steward them through global change by addressing the question: **What is the relationship between coral reef condition and biogeophysical forcing parameters?** Over a three-year campaign, CORAL will:

**Objective 1.** Measure the condition of representative coral reefs across the global range of reef biogeophysical values. The primary indicators for coral reef condition are benthic cover (ratio of coral, algae, and sand), primary productivity, and calcification.
PRISM Data Dissemination

http://prism.jpl.nasa.gov/alt_locator/

Below are sample data sets as acquired on 18 and 19 of January 2014 in Florida and 24 July 2012 in the Monterey Bay County area.

### L1B Data Products
- Grass Line, FL - View quicklook | Download data (4.5 GB)
- Island Line, FL - View quicklook | Download data (4.5 GB)
- Elkhorn, CA - View quicklook | Download data (9 GB)
- Elkhorn, CA - View quicklook | Download data (10 GB)

### L2 Data Products
- Grass Line, FL - View quicklook | Download data (4.8 GB)
- Island Line, FL - View quicklook | Download data (4.1 GB)
- Elkhorn, CA - View quicklook | Download data (7.4 GB)
- Elkhorn, CA - View quicklook | Download data (8.2 GB)
- Elkorn, CA - View quicklook | Download data (8.1 GB)

View data product readme file.
Concluding thoughts

• Great strides in optically shallow remote sensing
  – Better Sensors
  – Better Algorithms
  – Hopefully will become cheaper for different applications

• Lots of exciting research yet to be done

• Go out and bring ocean spectroscopy to the community:
  – physiologists, benthic ecologists and coastal decision makers
Select References


H. Dierssen, IOCCG 2016
Select References


