Coastal Applications of WorldView-2 High Resolution Multi-Spectral Imagery

G. Marchisio, G. Miecznik, F. Pacifici, C. Padwick
Overview

• Information content of WV-2 bands, as applicable to bathymetric retrievals
  • Spectral characterization of WV-2 MS bands
  • Qualitative assessment of WV-2 MS bands
• More that one approach to optical bathymetry
  – Machine learning approach (mono imagery)
  – Rigorous radiative-transfer modeling combined with Bayesian error estimation (mono imagery)
  – Photogrammetric techniques (stereo imagery)
• Will answer the following questions:
  – How accurate?
  – How deep?
  – Which bands?
  – What about sea floor reflectivity?
• Conclusions
Spectral Response Comparison with Quickbird

- Narrower Panchromatic Band
- Broader Multi Spectral Coverage
- Fills Gaps in Spectrum
- Sharper Multi Spectral Channels
Information content in shallow water imagery

- The following sequences of slides illustrate qualitatively how the combination of:
  - Broader spectral coverage
  - Continuous spectral coverage
  - Sharper spectral channels

available in WorldView-2 provide a finer level of spectral penetration than is otherwise achievable with traditional VNIR sensors

- We show this progressive transition at different locations
WorldView-2
First Images
4 band 2m Image
November 23, 2009
Aitutaki Lagoon
Aitutaki Lagoon

wave patterns and submerged aquatic vegetation

linear reefs
WorldView-2
First Images
R, RE, NIR1
2m Image
November 23, 2009

Aitutaki
Lagoon

submerged aquatic vegetation
Aitutaki Lagoon

submerged aquatic vegetation
WorldView-2
First Images
G, Y, R
2m Image
November 23, 2009

Aitutaki
Lagoon
WorldView-2
First Images
B, G, Y
2m Image
November 23, 2009

Aitutaki Lagoon
WorldView-2
First Images
C, B, G
2m Image
November 23, 2009

Aitutaki
Lagoon
Florida Keys
WorldView-2
First Images
2m Image
November 28, 2009
Bathymetry Using Worldview2 Spectral Bands

Governing Equation:
\[ L_d = L_b e^{-gz} + L_w \]

- **Ld** - radiance at detector
- **Lb** - radiance sensitive to bottom
- **g** - two way attenuation coefficient
- **z** - depth
- **Lw** - radiance over deep water


- Water absorptivity varies spectrally from band to band
- As the depth increases, the reflected irradiance decreases faster in the high-absorptivity spectral band (e.g. green band) than in the low-absorptivity band (e.g. blue band)
Bathymetry Using Worldview2 Spectral Bands

**Governing Equation:**

\[ L_d = L_b e^{-gz} + L_w \]

- \( L_d \): radiance at detector
- \( L_b \): radiance sensitive to bottom
- \( g \): two way attenuation coefficient
- \( z \): depth
- \( L_w \): radiance over deep water


Observed spectrum is a function of:

1. water depth
2. bottom reflectance spectra
3. water column inherent optical properties (IOPs)
4. viewing geometry
Sensitivity of WV02 bands to seafloor type

Ooid sand – large reflectivity
Coral – small reflectivity

Sensor right above the water surface
Clear water
1m/s wind speed

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Machine Learning Assessment of Worldview2 Potential for Bathymetry Studies

• Input a stack of WV-2 spectral features:
  – Converted radiance values from the 8 WV-2 bands
  – 28 unique pairs of NDVI-style band ratios computed from the above

• Apply supervised machine learning methods:
  – Logistic Regression
  – Classification Trees with k-fold Cross-Validation
  – Tree Ensembles
  – Neural Networks

• Train and validate on independent ground truth
• Generate confusion matrices
• Perform predictor ranking
### Classification Agreement

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More than 99% of the 4,910 validation samples are in the \{+/-1 m\} accuracy.
## Classification Agreement for Bathymetry
(Against LIDAR GT – Florida)

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Acc (%) | Acc[1 m] | Acc[2 m] |
---------|----------|----------|
86.09 | 97.96 | 99.35 |
99.36 | 98.08 | 97.31 |
99.65 | 98.73 | 99.28 |
WorldView-2
First Images
4 band
2m Image
November 28, 2009

Florida Keys
Bathymetry and Sea Bed Modeling

WorldView-2
First Images
4 band
2m Image
November 28, 2009

Florida Keys
### Classification Agreement for Bathymetry + Sea Bed

#### Input Node - Predict: Tree Ensemble (363)

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Bathymetry and Sea Bed Modeling

WorldView-2
First Images
4 band
2m Image
November 28, 2009

Florida Keys

(rectilinear edge guides discharges from channels 1 and 2)

(sewage water collects here)
Bathymetry and Sea Bed Modeling

rectilinear edge guides discharges from channels 1 and 2

sewage water collects here
How Deep Can We See?

WorldView-2
true color image
San Diego, CA
February 14, 2010
Cumulative Error for Bathymetry

Graph showing the cumulative error in depth (m) as a function of depth (m). The error is represented by vertical bars with a mean line at zero. The graph indicates a trend of increasing error with depth, with some fluctuations.
Cumulative Error for Bathymetry (20 m depth)
Where is Most of the Predictive Power?

- NIR bands play little role except in the near surface
- C, B, G most useful for pure bathymetry
- Y, R, RE track submerged aquatic vegetation and coral, which in turns correlate with depth levels
Physical Modeling vs. Machine Learning

• Machine learning models need to be retrained with GT for each individual scene making it currently impractical for automated and unsupervised application.

• Radiative-transfer approach combined with optimal estimation retrieval methodology offers more flexibility.
  – Top of the atmosphere (TOA) radiances are modeled using rigorous radiative transfer equations in water (HYDROLIGHT) and atmosphere (MODTRAN).
  – Bayesian approach, with real (TOP radiances) and pseudo (a-priori) measurements is used to derive unknown water depth.
Lee- Stocking Island test site
Sounding data acquired in June 2001
Image collected in December 2010
Spectral libraries from Lee-Stock Islands used to simulate the environment

Accuracy (RMS error < 30 cm)
Conclusions

- There is sufficient information content in WV02 spectral bands to retrieve water depths with 1-2m errors for waters as deep as 18 m.
- Coastal, Green, and Blue bands help with near-shore bathymetry
- Coastal, Green, Yellow and RE bands help with Benthic Habitat and Substrate/Sea Floor Mapping
  - Habitat maps can have accuracy ~90%
- Accuracy may not be high as Lidar or Sonar but wider geographic coverage and high refresh rate at a fraction of the cost
- Physical retrievals require very small training set (bottom reflectance and water IOP) compared with supervised classification methods.
  - Rich spectral libraries are available
  - Spectral libraries are typically representative of millions of square kilometers.