Jet Propulsion Laboratory
California Institute of Technology

Estimation of Benthic Reflectance with Bayesian Linear Mixture Models

David R. Thompson[1], Eric Hochberg[2], Gregory P. Asner[6], Heidi Dierssen[3], Bo-Cai Gao[4], Rodrigo Garcia[5], Michelle Gierach[1], Robert O. Green[1], David Knapp[6], Zhongping Lee[5], Stéphane Maritorena[7], Pantazis Mouroulis[1], Ian McCubbin[1], Ronald Fick[8]

[1] Jet Propulsion Laboratory, California Institute of Technology
[2] Bermuda Institute of Ocean Sciences
[3] University of Connecticut
[4] Naval Research Laboratory
[5] University of Massachusetts
[6] Carnegie Institute for Science
[7] University of California Santa Barbara
[8] University of Florida

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Adapted from…

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Airborne mapping of benthic reflectance spectra with Bayesian linear mixtures

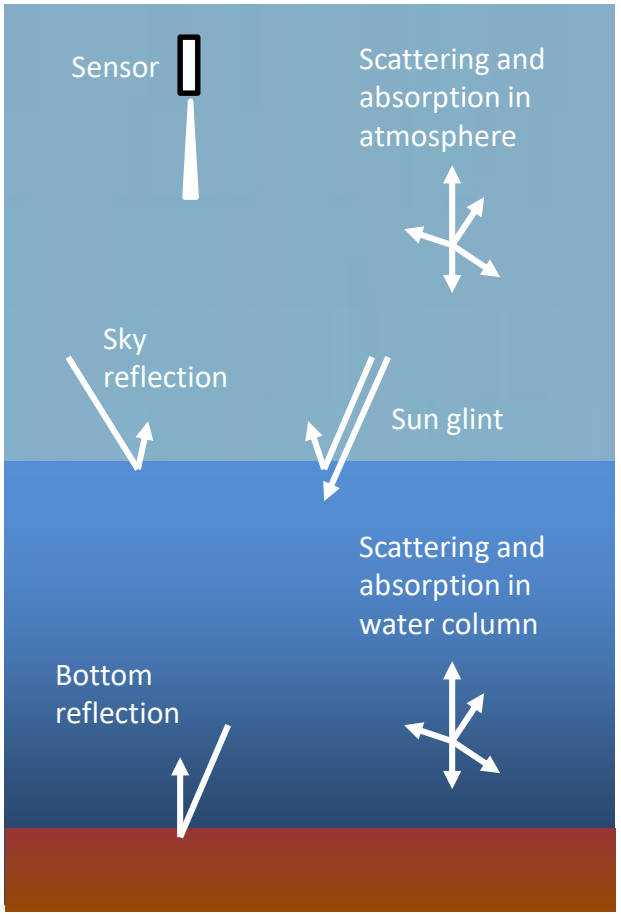
David R. Thompson[a,*], Eric J. Hochberg[b], Gregory P. Asner[c], Robert O. Green[a], David E. Knapp[c], Bo-Cai Gao[d], Rodrigo Garcia[e], Michelle Gierach[a], Zhongping Lee[e], Stephane Maritorena[f], Ronald Fick[g]

[a] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA*
[b] *Bermuda Institute of Ocean Sciences, St. George's GE 01, Bermuda*
[c] *Carnegie Institution for Science, Stanford, CA 94305, USA*
[d] *Naval Research Laboratory, USA*
[e] *University of Massachusetts, Boston, MA, USA*
[f] *University of California Santa Barbara, Santa Barbara, CA, USA*
[g] *University of Florida, Gainesville, FL, USA*

Agenda

- Water column estimation algorithm
- Validation with CAO Hawaii data
- Initial maps from CORAL Hawaii data

Major steps



Retrieved quantities

<u>Step 1</u>
Aerosol optical depth τ
Aerosol type ζ
Water leaving reflectance R_{rs}

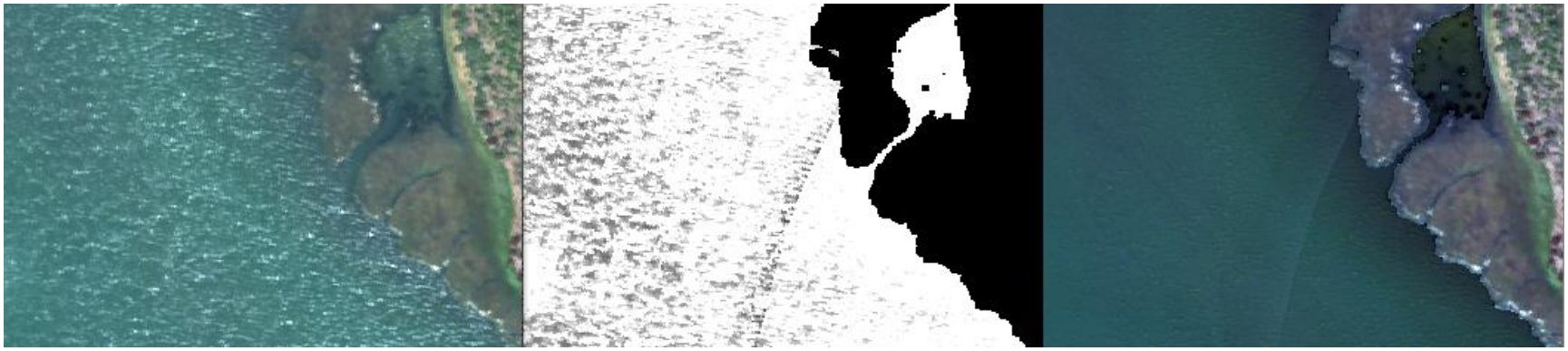
<u>Step 2</u>
Glint-corrected R_{rs0}

<u>Step 3</u>
Backscatter b_b
Attenuation K_d
Depth H
Benthic reflectance R_b

Graphic inspired by [Kirk, 2011].

Glint correction

Glint is (approximately) spectrally uniform, so we can estimate it using "dark" NIR bands and subtract this contribution from the other channels [Gao et al., 2010].



Original **Estimated glint** **Corrected L2**

Incorporating air/water interface correction, for water leaving reflectance below the surface:

Glint contribution

$$Rrs_0 = \frac{R_{rs} - q}{1.562(R_{rs} - q) + 0.518}$$

Adapted from [Lee et al., Applied Optics 37(27) 1998.]

R_b Inversion Procedure

Posit the relation [Maritorena et al., 1994]:

$$R_{rs0} = R_{inf} + (R_b - R_{inf})\, e^{-2K_d H}$$

bb / ($2K_d$)

Benthic reflectance

Attenuation

Depth

R_b Inversion Procedure

Posit the relation [Maritorena et al., 1994]:

$$R_{rs0} = R_{inf} + (R_b - R_{inf})\, e^{-2K_d H}$$

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Benthic reflectance

Attenuation

Depth

Problem: underdetermined

K_d, bb, and R_b yield (3N + 1) parameters for just N measurements

R_b Inversion Procedure

Posit the relation [Maritorena et al., 1994]:

$$R_{rs0} = R_{inf} + (R_b - R_{inf})\, e^{-2K_d H}$$

bb / ($2K_d$) — Benthic reflectance — Attenuation — Depth

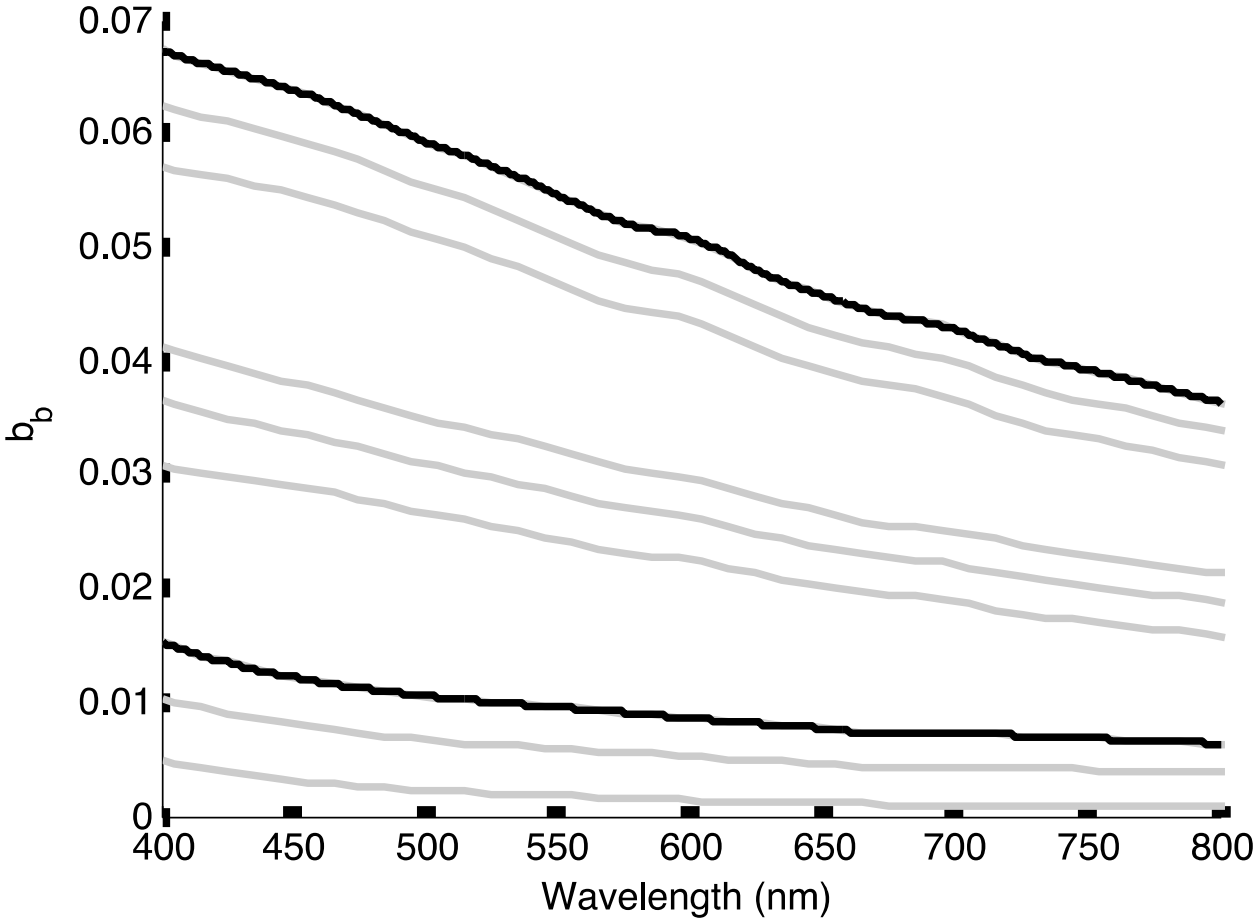
Problem: underdetermined

K_d, bb, and R_b yield (3N + 1) parameters for just N measurements

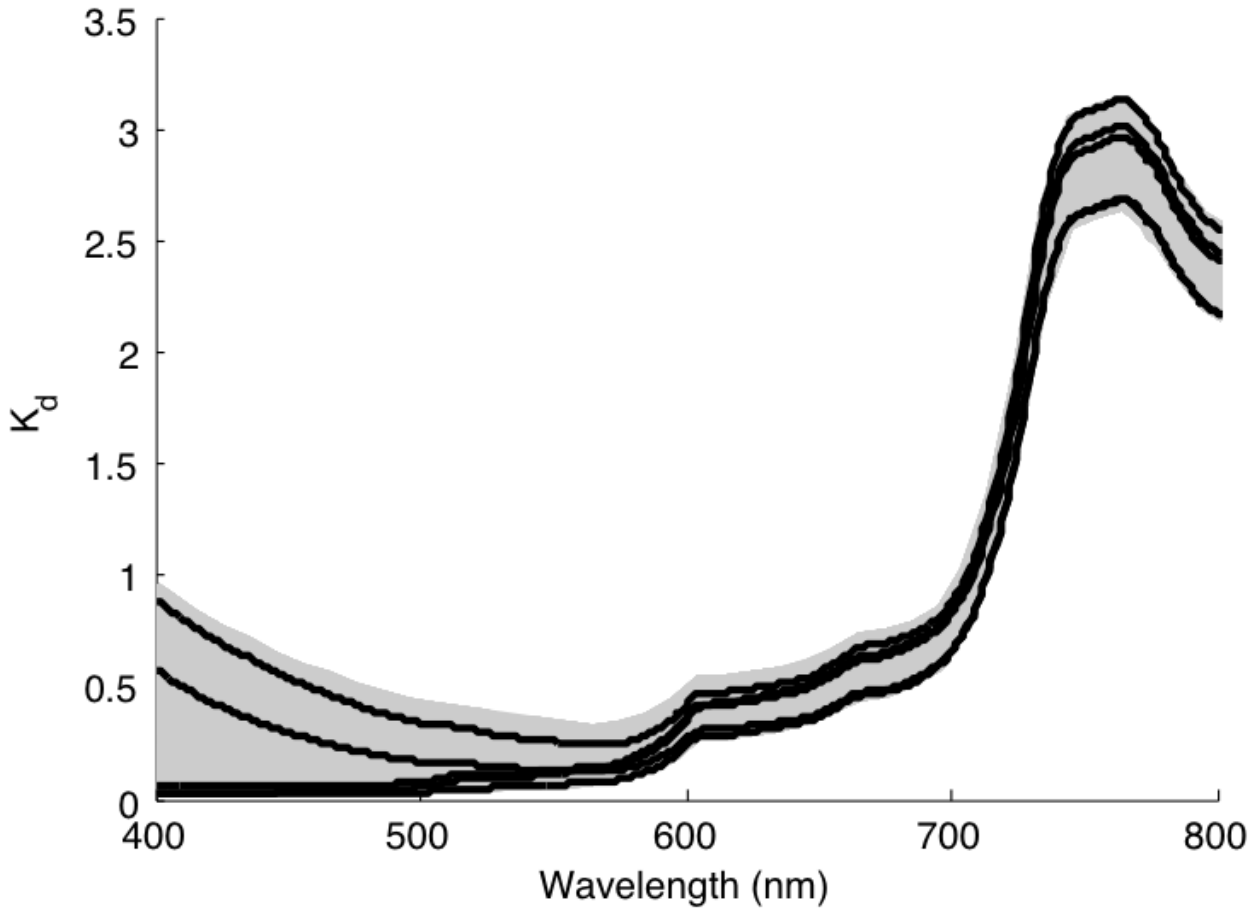
Solution: represent as linear mixtures

Parameterize K_d, bb, and R_b as nonnegative linear combinations of endmember spectra, and retrieve mixing coefficients (~20 DOF)

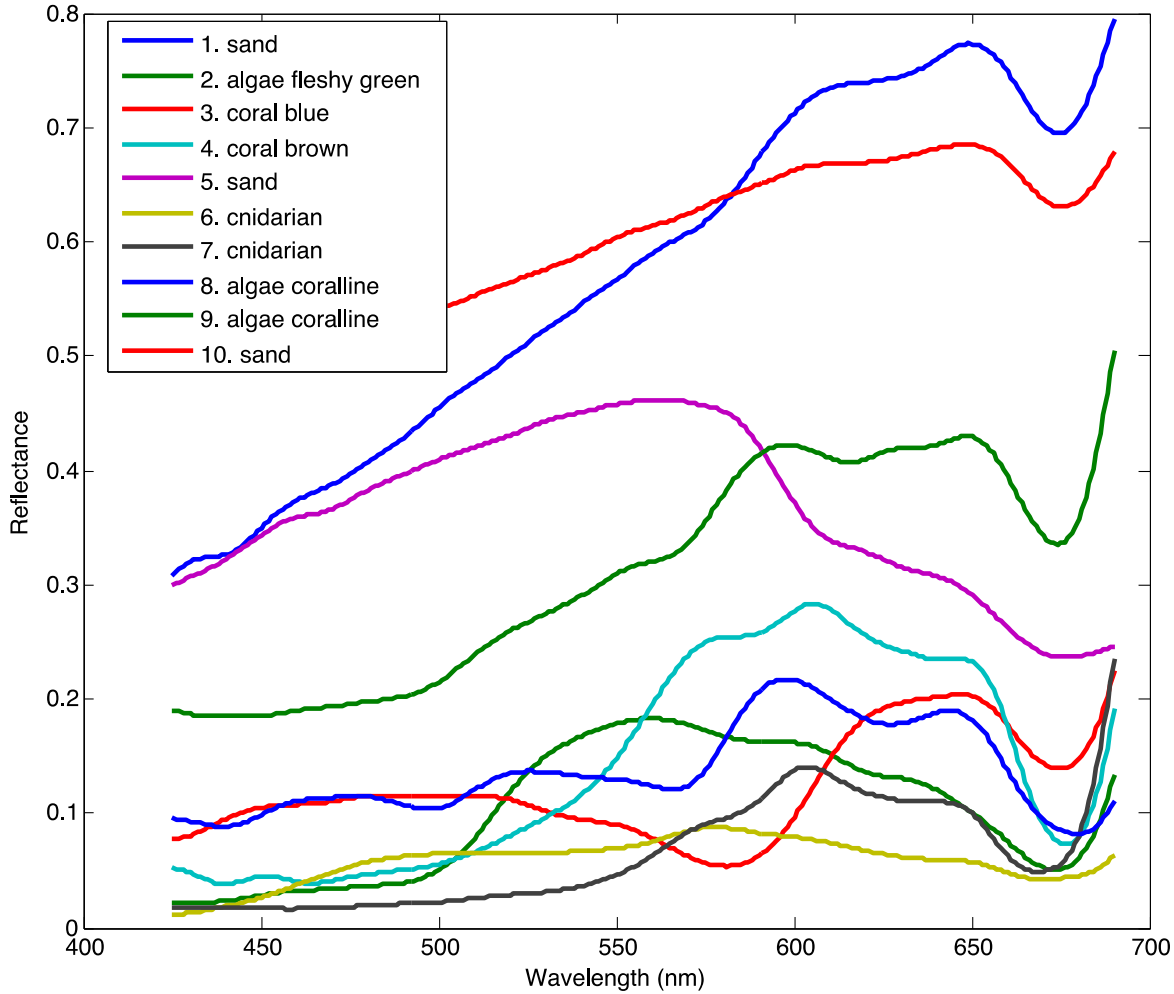
Example of b_b endmember library



Example of K_d endmember library



Example of R_b endmember library



david.r.thompson@jpl.nasa.gov

Procedure

Posit the relation [Maritorena et al., 1994]:

$$R_{rs0} = R_{inf} + (A - R_{inf})\, e^{-2K_d H}$$

bb / ($2K_d$)

Albedo

Attenuation

Depth

Procedure

Posit the relation [Maritorena et al., 1994]:

$$R_{rs0} = R_{inf} + (A - R_{inf})\, e^{-2K_d H}$$

R_{inf}: $bb / (2K_d)$

A: Albedo

K_d: Attenuation

H: Depth

Optimize via Levenberg Maquardt, minimizing:

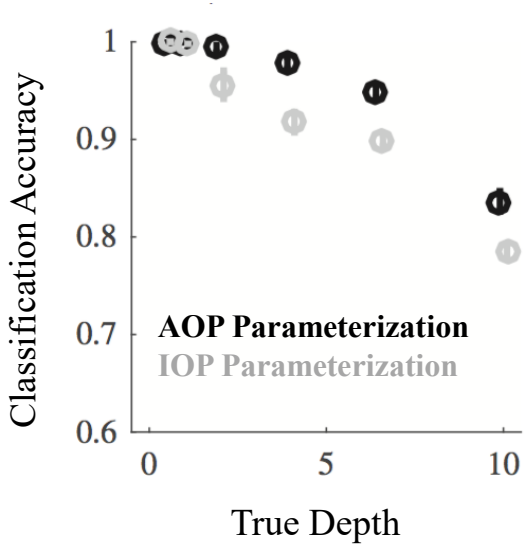
$$\begin{aligned} \text{Error}(x) = \; & (R_{rs0} - R_{rs0}^*) \\ & + \alpha_{bb590} (\mu_{bb50} - bb_{590}^*) \\ & + \alpha_{kd450} (\mu_{kd450} - K_{d450}^*) \\ & + \alpha_{kd590} (\mu_{kd590} - K_{d590}^*) \\ & + \alpha_{H} (\mu_{H} - H^*) \end{aligned}$$

Model fit vs. measurement

Statistical priors to constrain the other free parameters

Retrieval performance simulation

- Apparent Optical Property and Intrinsic Optical Property parameterizations
- In AOP Depth and R_b are decoupled through an extra degree of freedom
- IOP gives best absolute depth, AOP gives slightly better R_b fidelity



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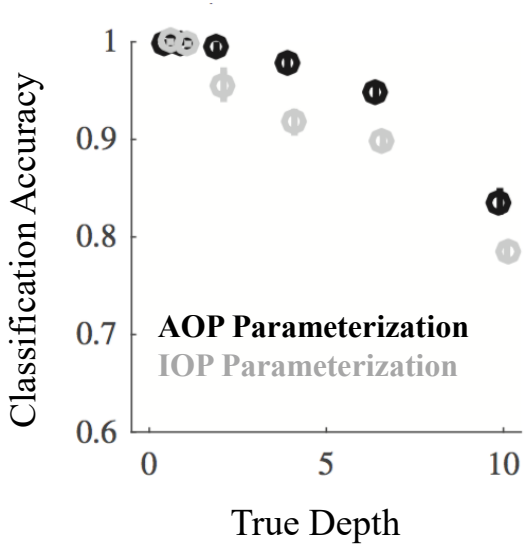

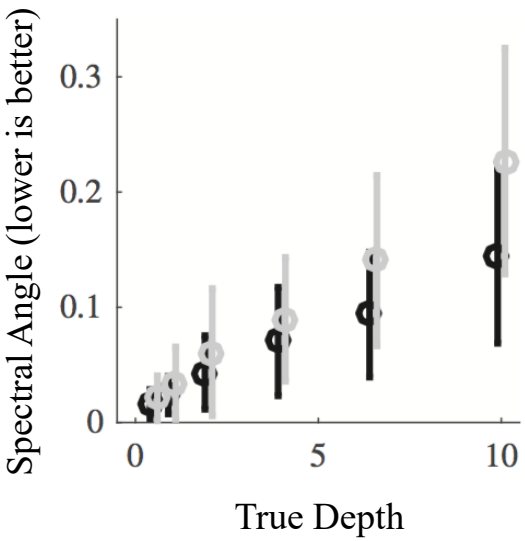

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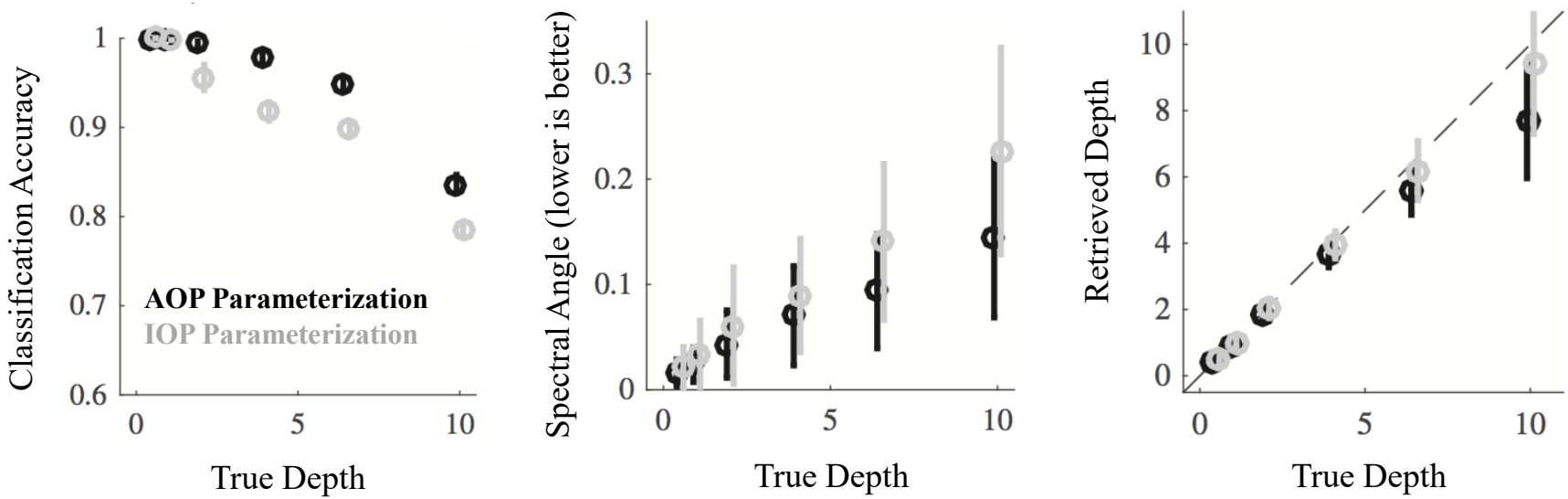

Agenda

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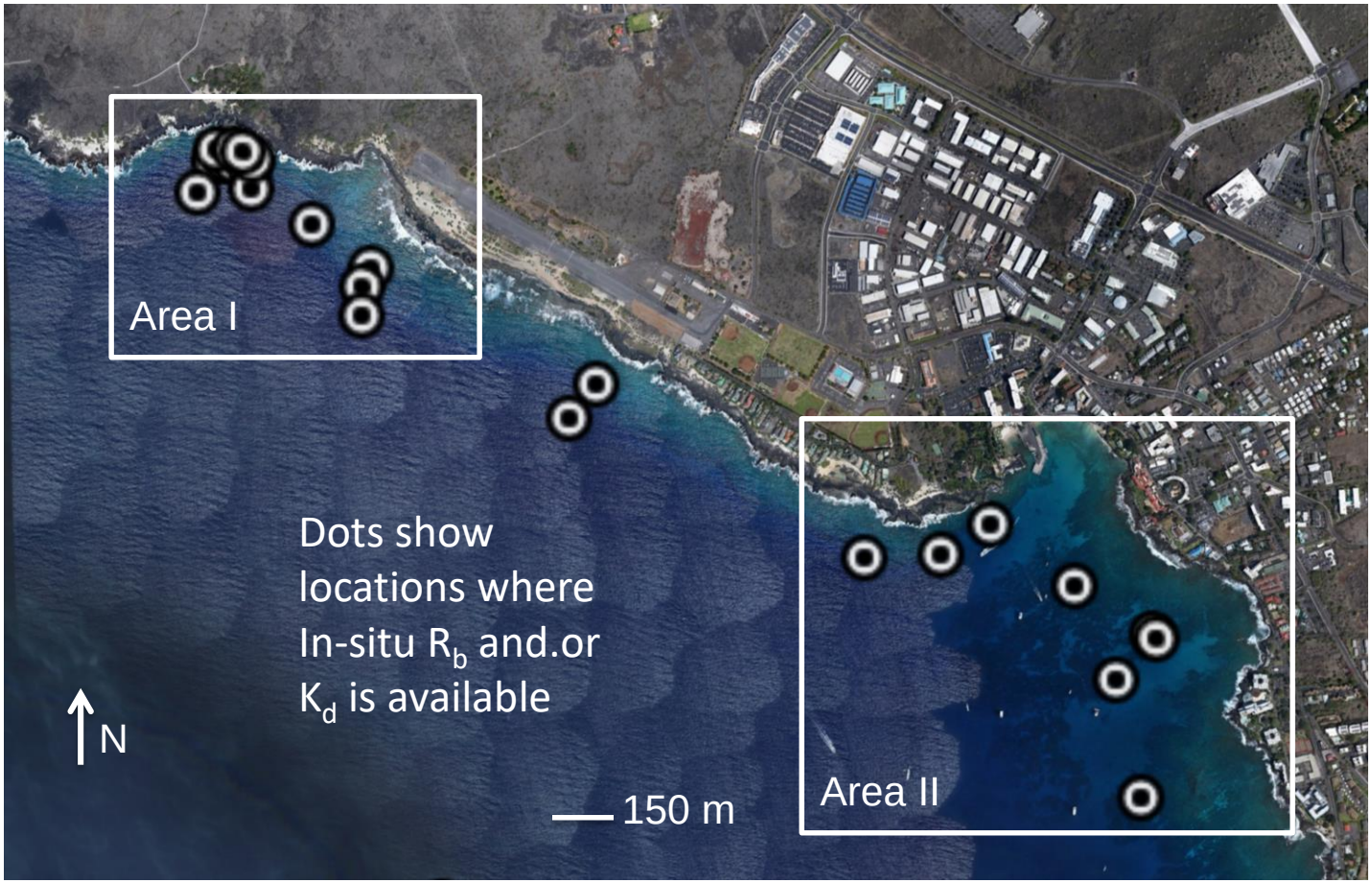
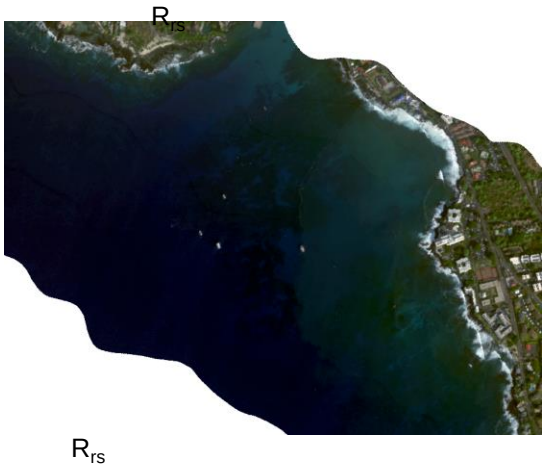
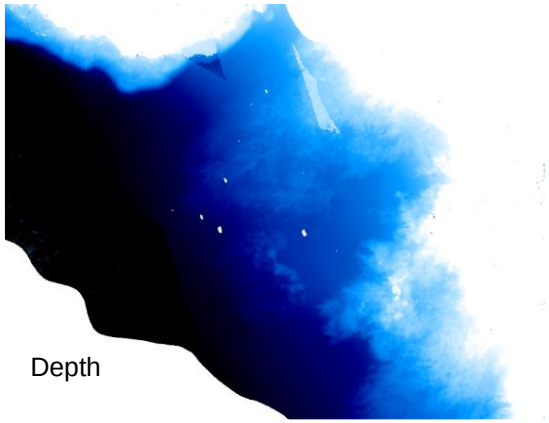
Validation sites

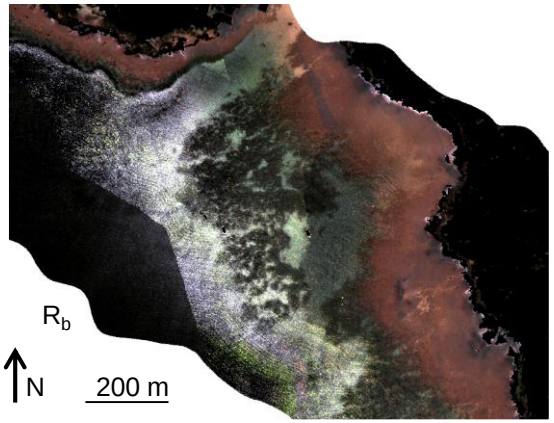


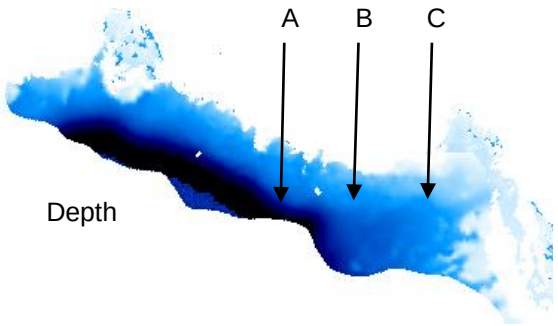
Airborne VSWIR data collected by the Carnegie Airborne Observatory

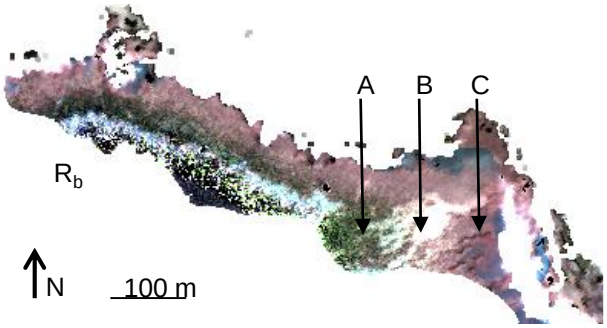
Benthic reflectance maps



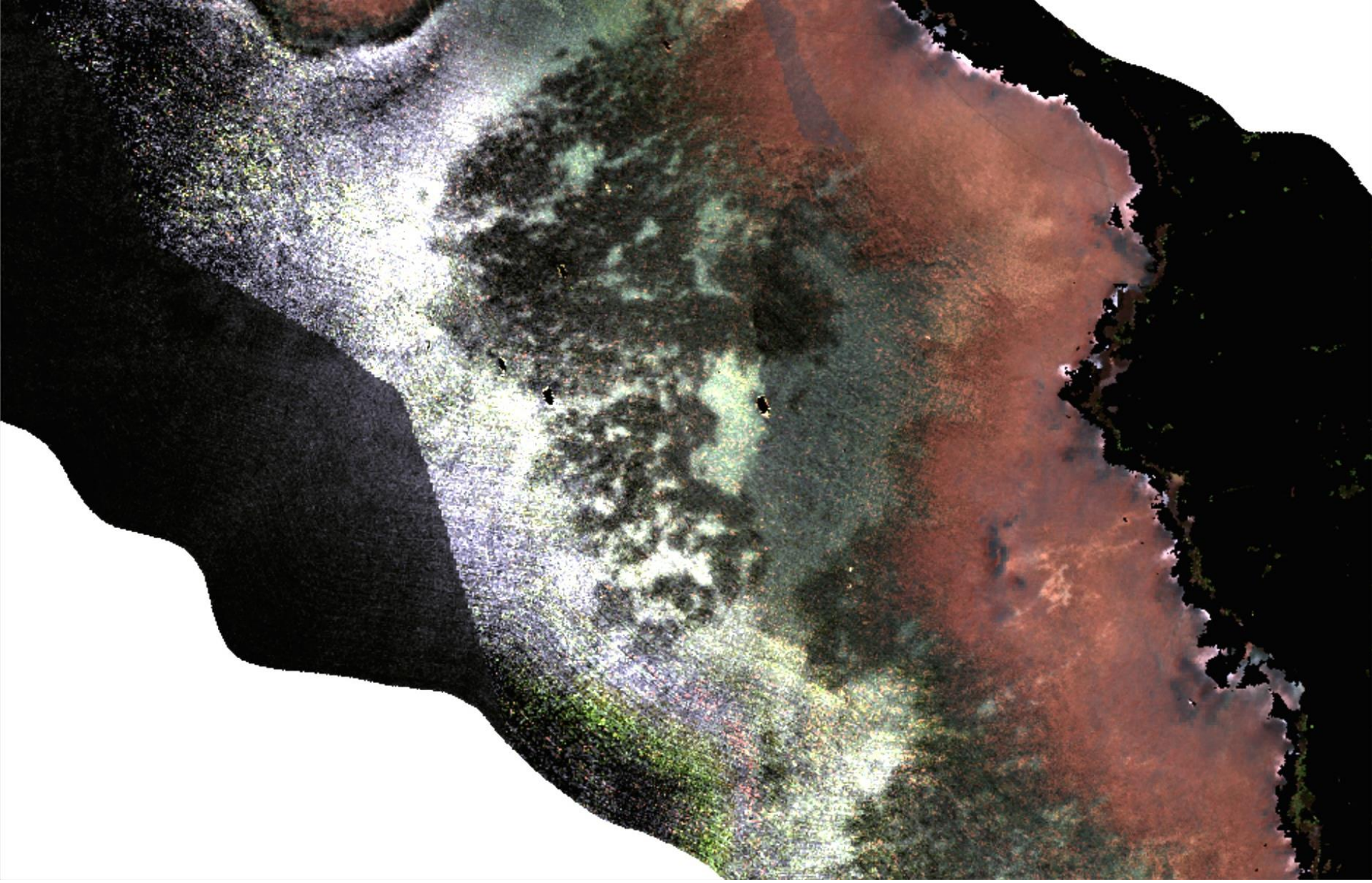








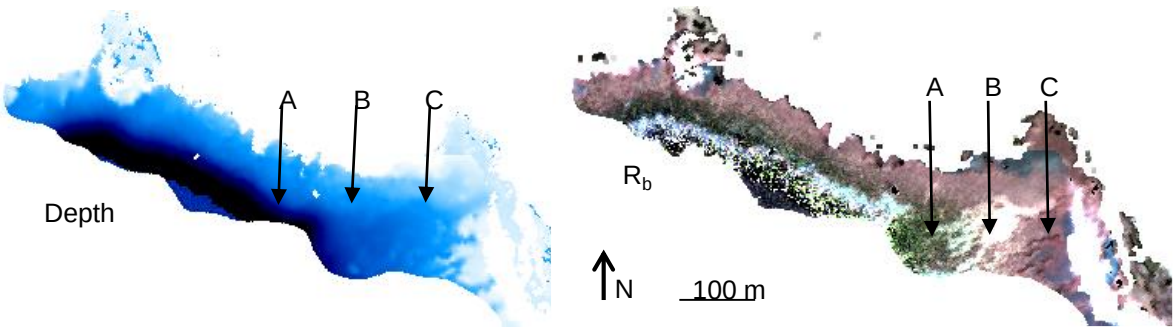
Airborne VSWIR data collected by the Carnegie Airborne Observatory

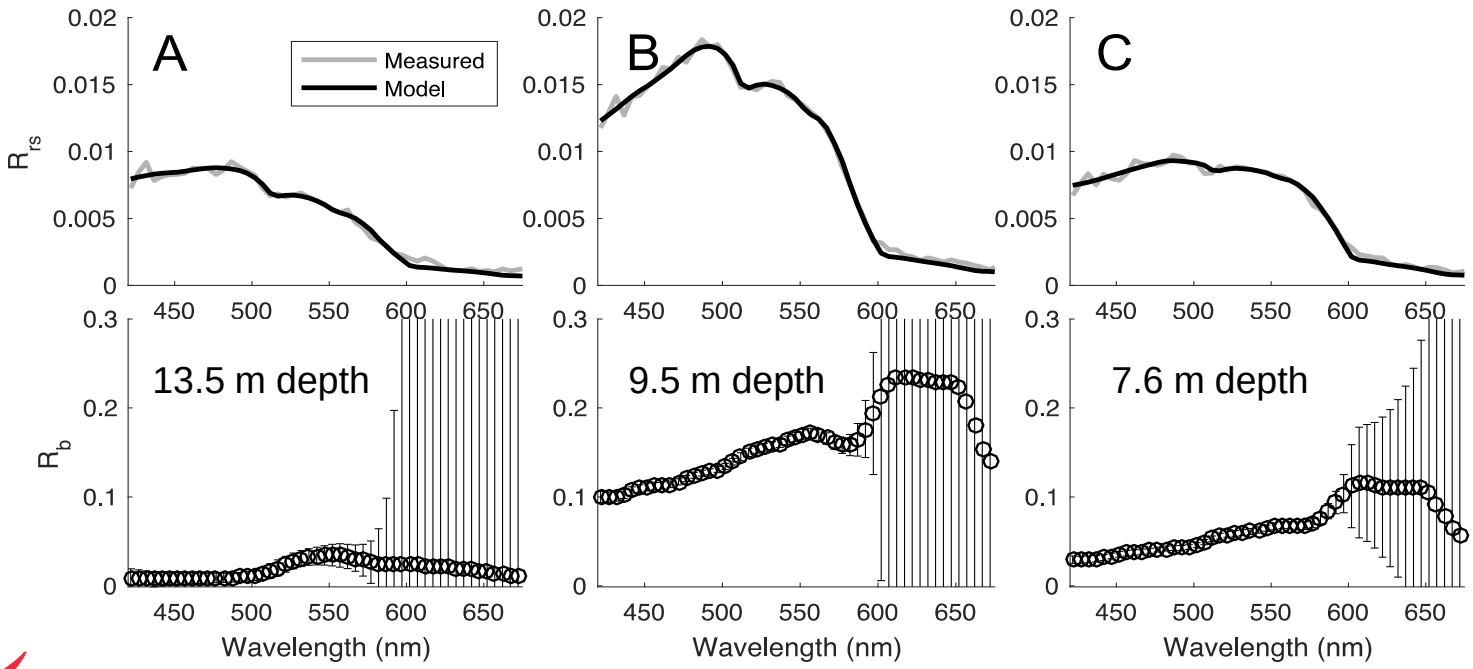


Airborne VSWIR data collected by the Carnegie Airborne Observatory

R_{rs} and Bottom Reflectance

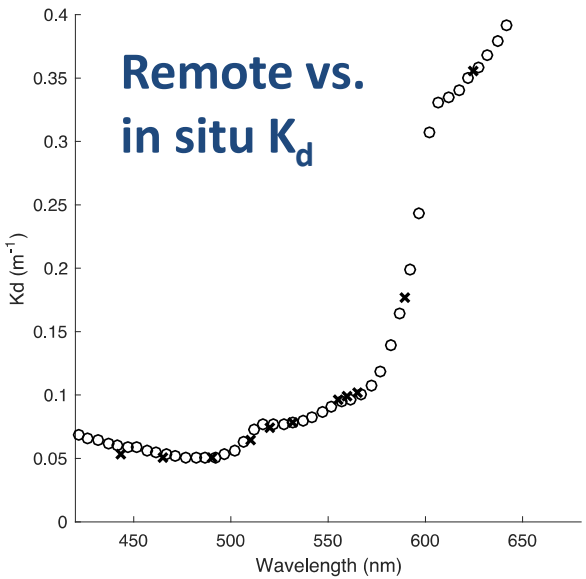
Airborne VSWIR data collected by the Carnegie Airborne Observatory (CAO)

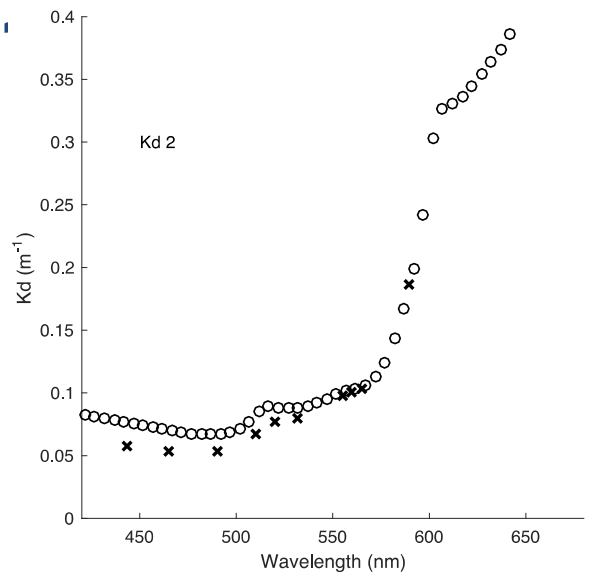


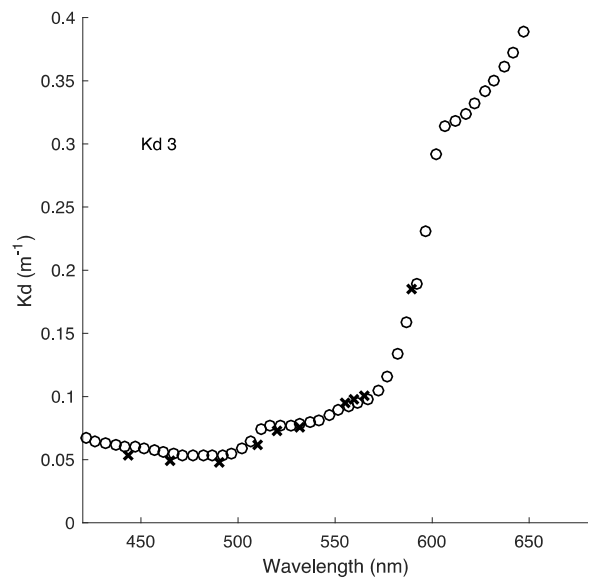


david.r.thompson@jpl.nasa.gov

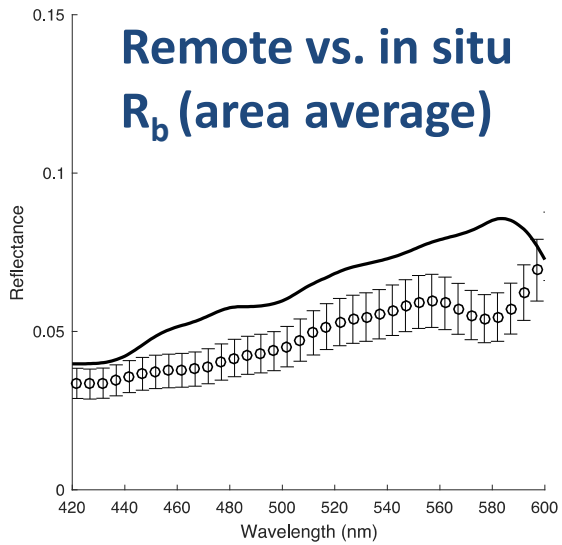
Remote vs. in situ K_d

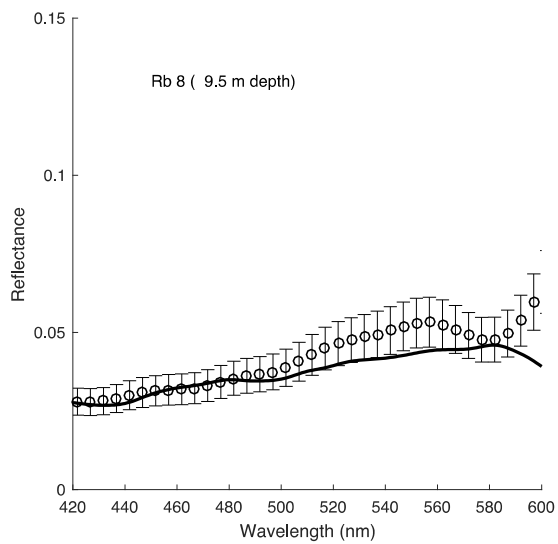


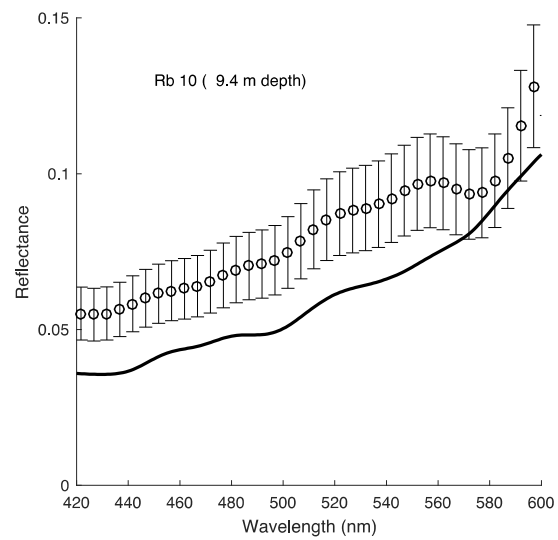




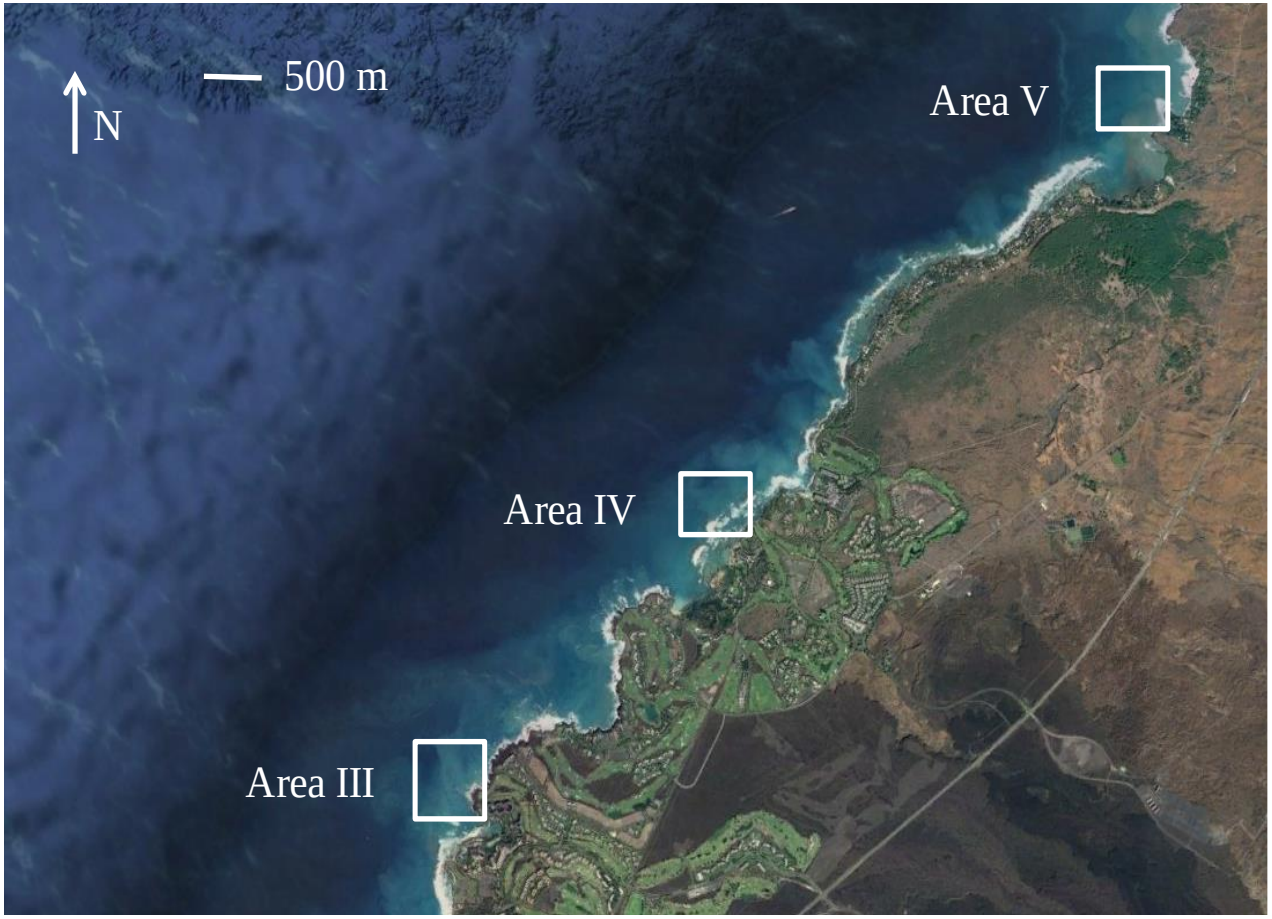
Remote vs. in situ R_b (area average)





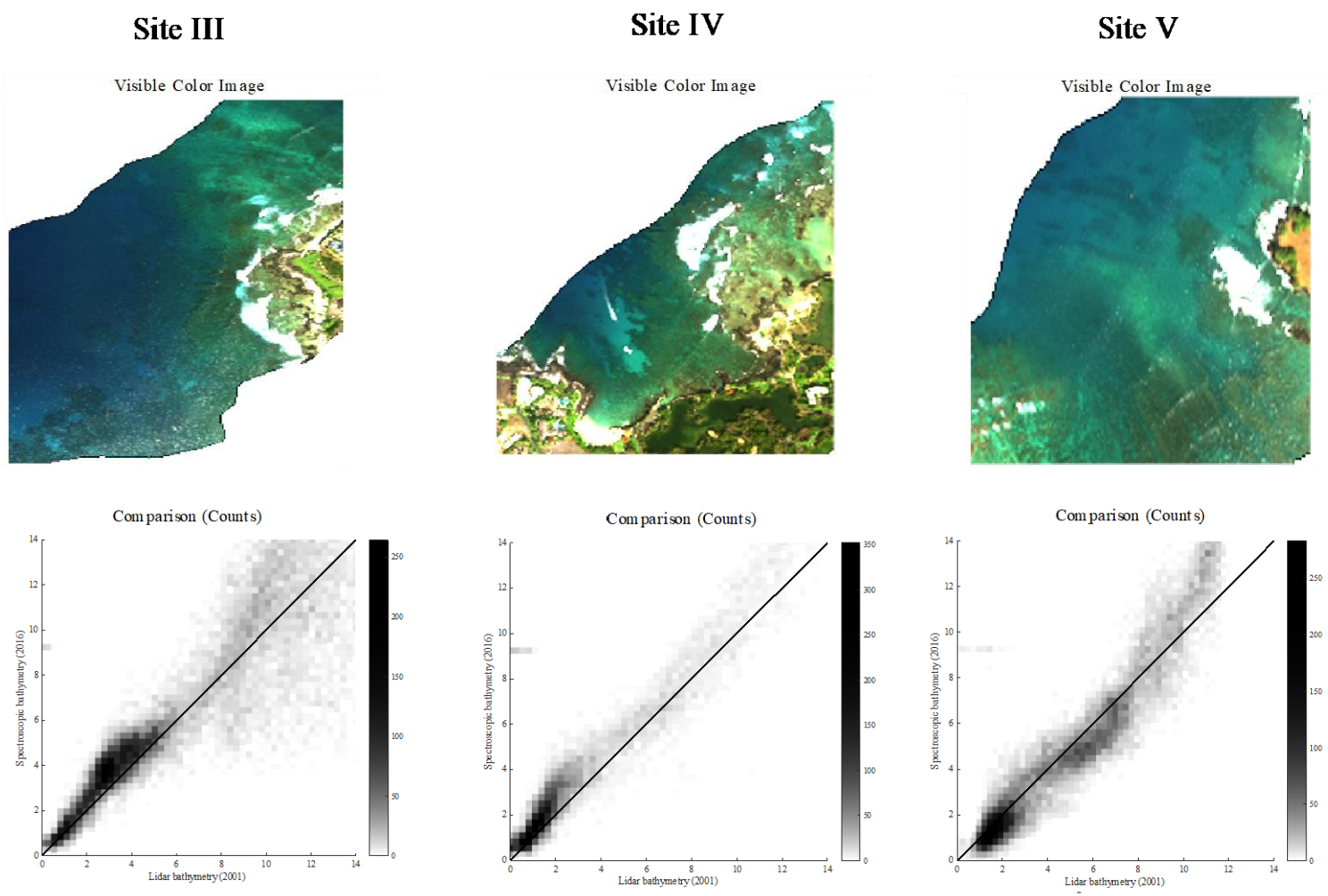


Depth Validation sites



Airborne VSWIR data collected by the Carnegie Airborne Observatory

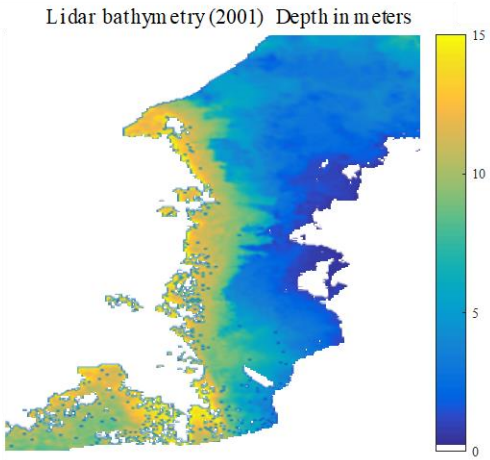
Depth vs. SHOALS (2001) Lidar

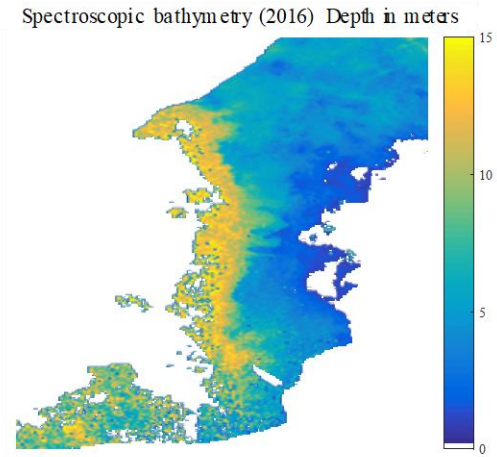


Airborne VSWIR data collected by the Carnegie Airborne Observatory

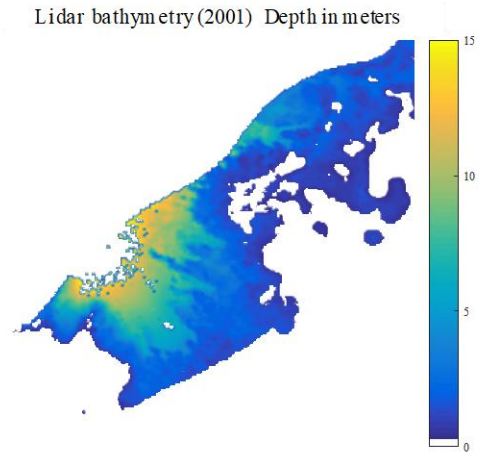
Depth vs. SHOALS (2001) Lidar

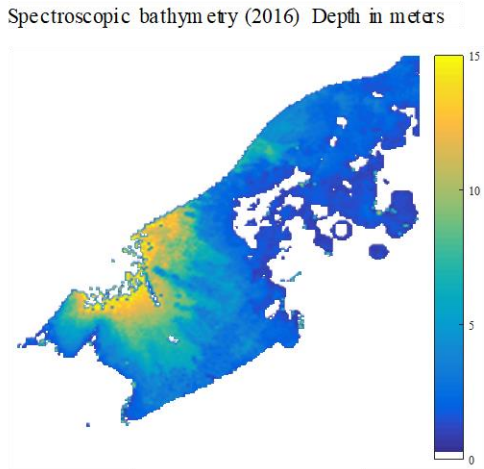
Site III



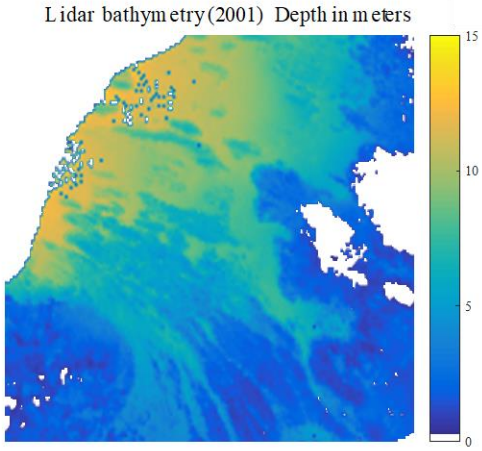


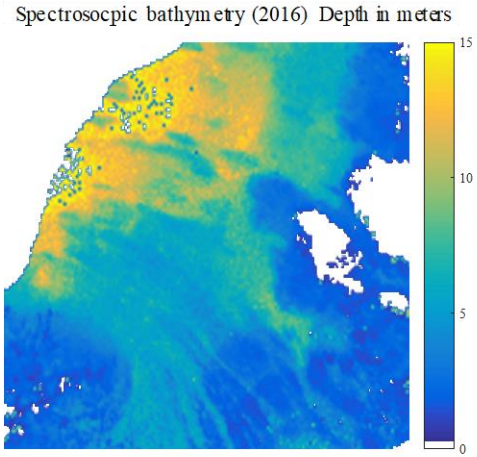
Site IV





Site V





Airborne VSWIR data collected by the Carnegie Airborne Observatory

Agenda

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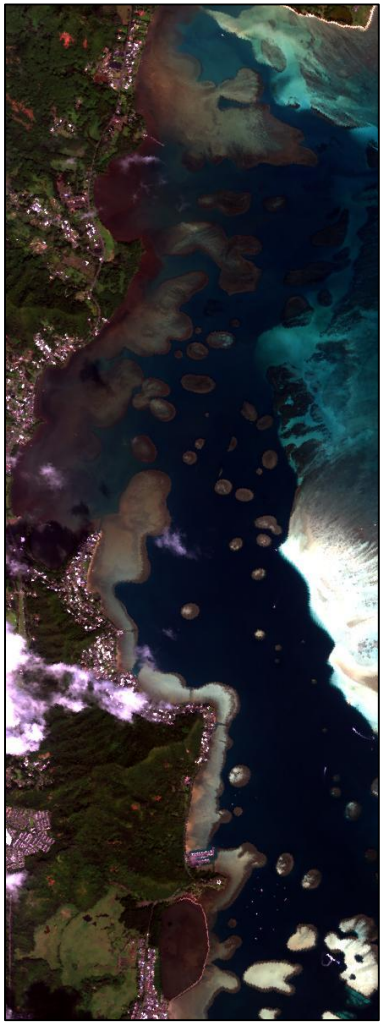
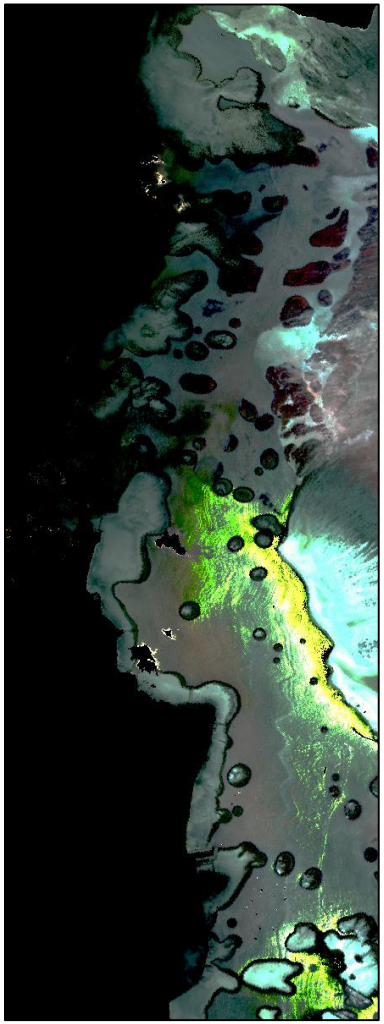
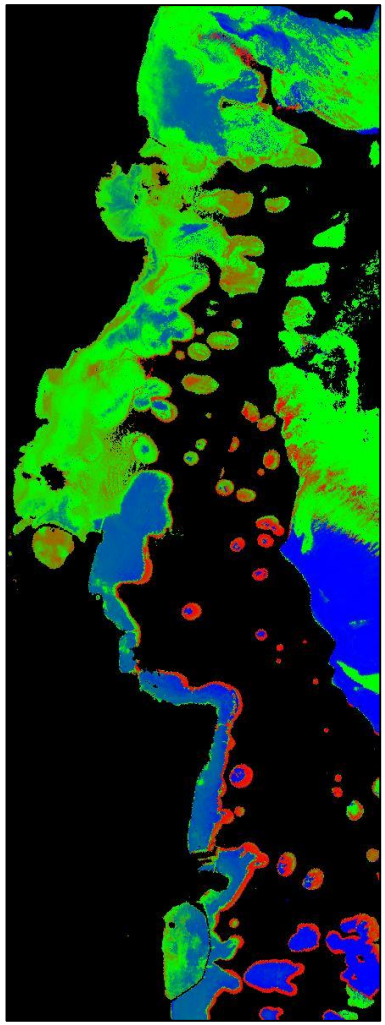
Water-leaving Reflectance



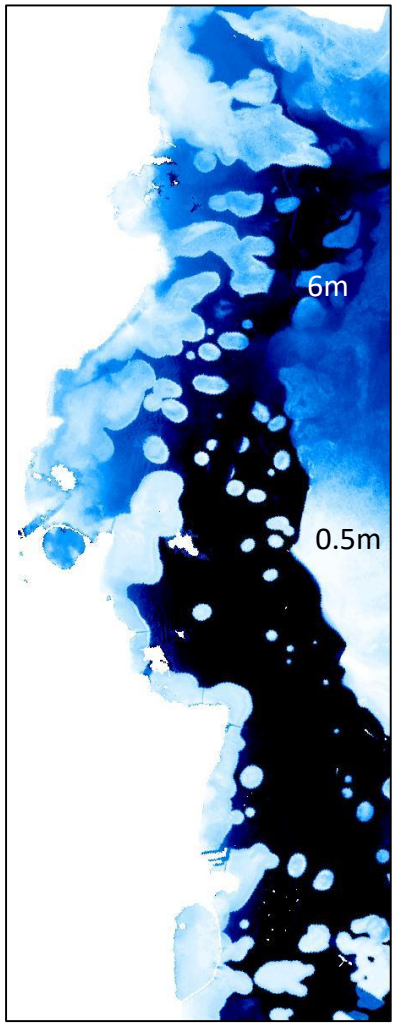
Benthic reflectance



Coral Algae Sand



Depth



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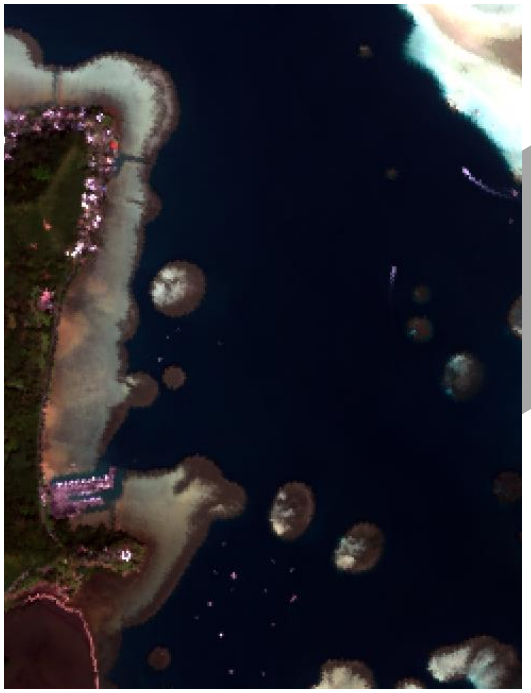
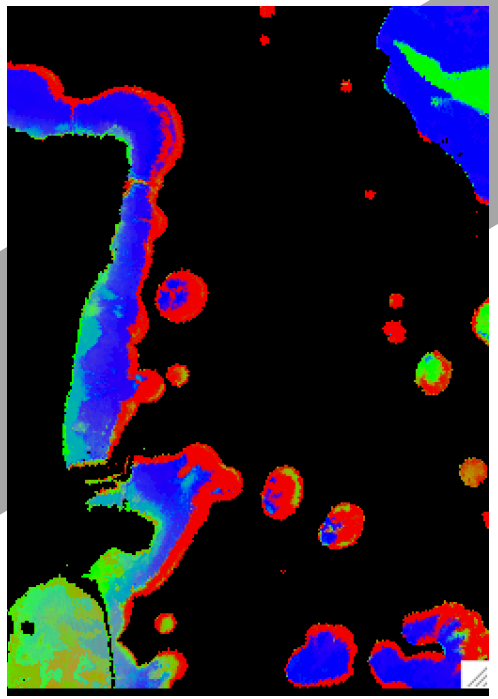
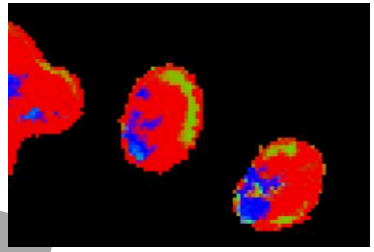
Consistency check

Overflights in 2016 and 2017





Coral Algae Sand



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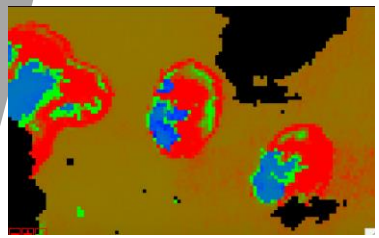

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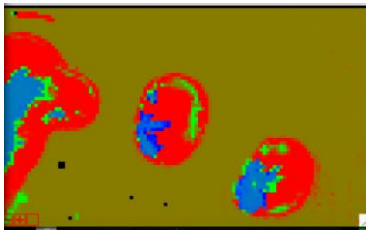

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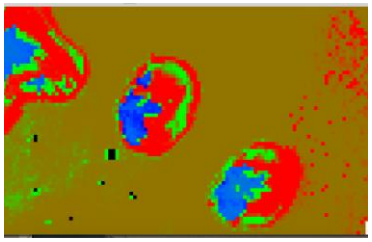

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Thanks!

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- **The Carnegie Institute for Science**, for use of Carnegie Airborne Observatory data in this pilot project
- **The PRISM and CORAL teams**