National Aeronautics and Space Administration

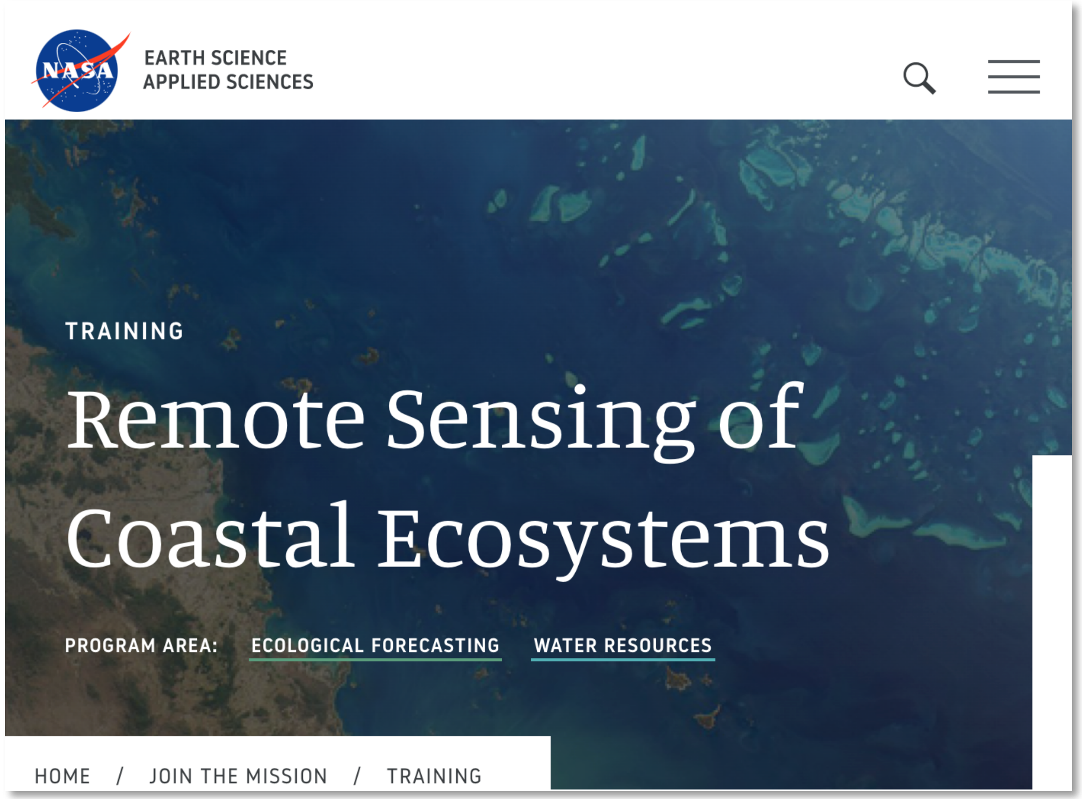
Remote Sensing of Coastal Ecosystems

Juan L. Torres-Pérez and Amber McCullum

August 25th – September 8th, 2020

Course Structure and Materials

- Three, 1-hour sessions on August 25, September 1, and September 8
- The same content will be presented at two different times each day:
  - Session A: 11:00-12:00 EST (UTC-4) (English)
  - Session B: 14:00-15:00 EST (UTC-4) (Spanish)
  - **Please only sign up for and attend one session per day.**
- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
  - https://appliedsciences.nasa.gov/join-mission/training/english/remote-sensing-coastal-ecosystems
- Q&A following each lecture and/or by email at:
  - juan.l.torresperez@nasa.gov or
  - amberjean.mccullum@nasa.gov



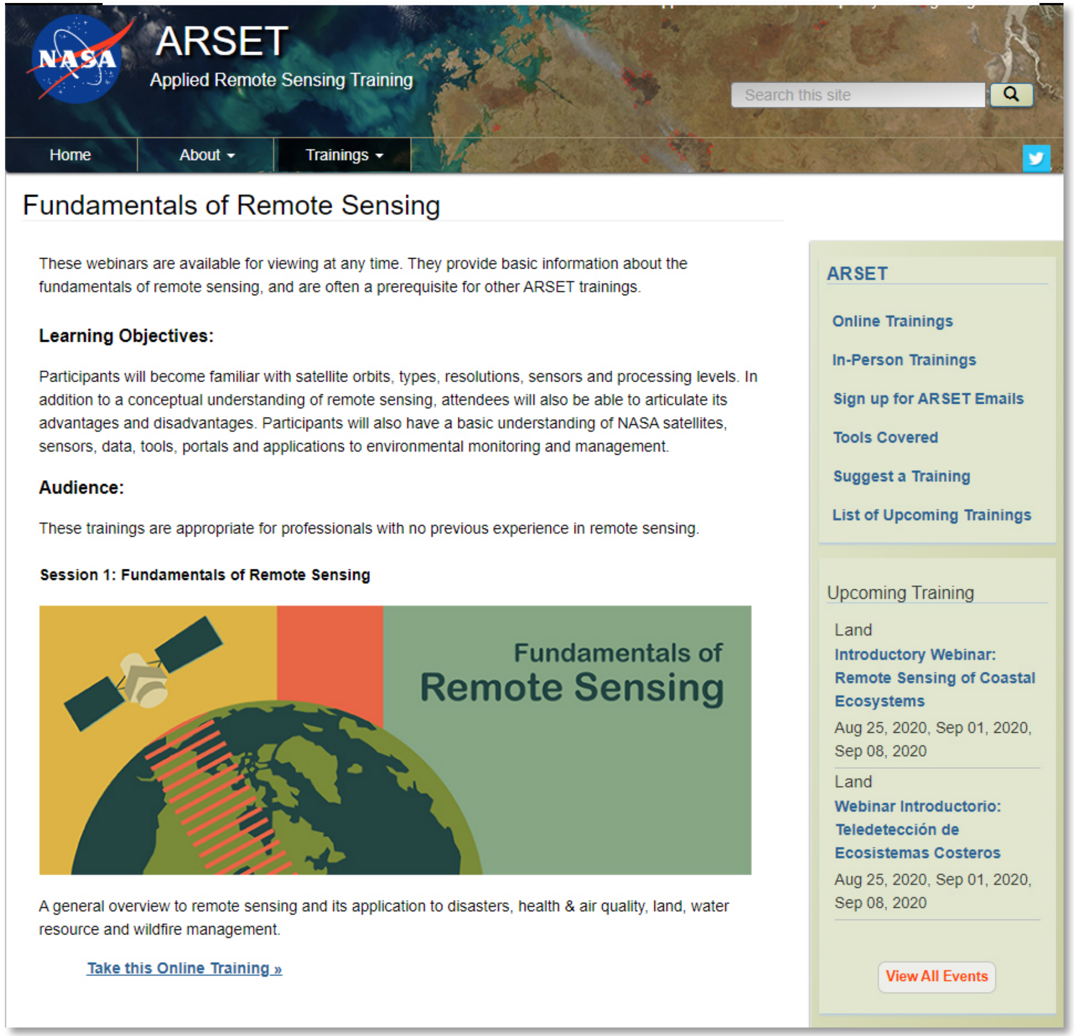
Homework and Certificates

- **Homework:**
  - One homework assignment
  - Answers must be submitted via Google Forms
  - **HW Deadline: Tuesday Sept 22**

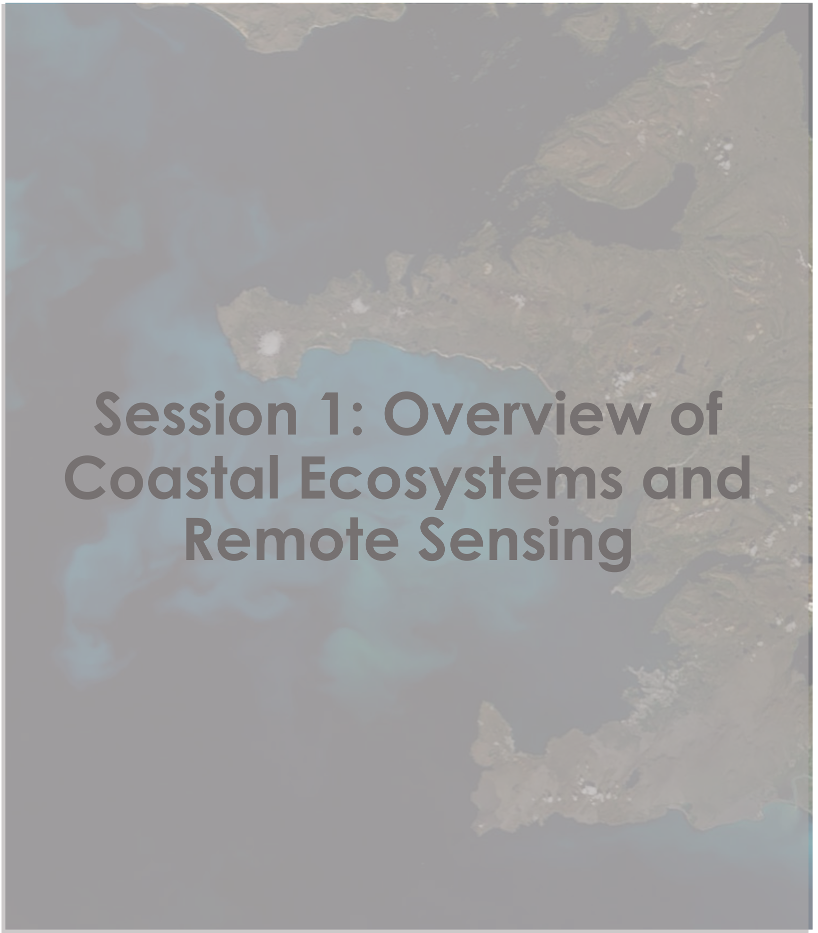
- **Certificate of Completion:**
  - Attend both live webinars
  - Complete the homework assignment by the deadline (access from ARSET website)
  - You will receive certificates approximately two months after the completion of the course from: marines.martins@ssaihq.com

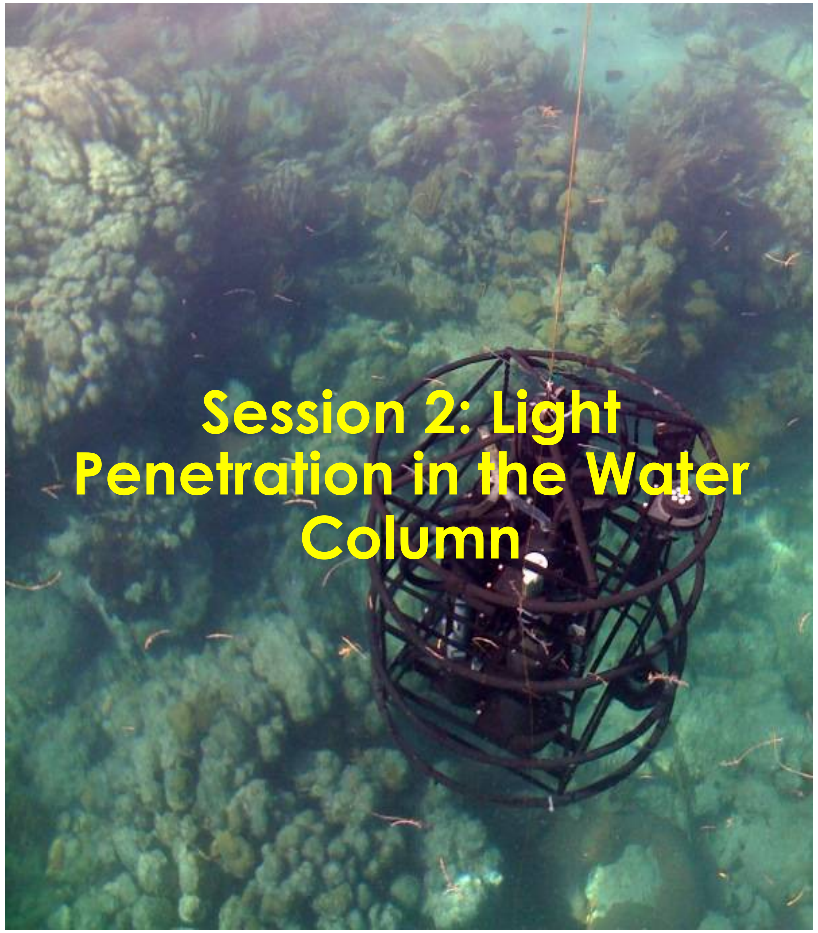
Prerequisites

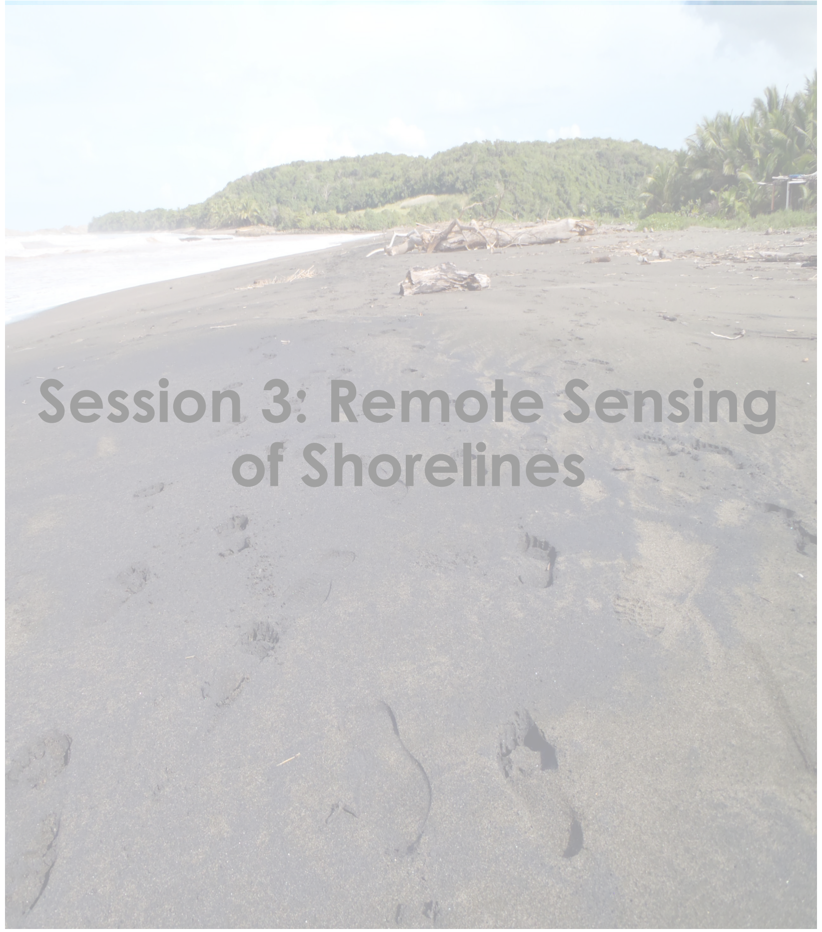
- Prerequisites:
  - Please complete Sessions 1 & 2A of Fundamentals of Remote Sensing or have equivalent experience.
- Course Materials:
  - https://appliedsciences.nasa.gov/join-mission/training/english/remote-sensing-coastal-ecosystems



Course Outline







Learning Objectives

By the end of this session, you will be able to:

- Identify the main optical properties of the water column and how these affect the remote sensing signal from benthic components
- Distinguish some of the field measurements necessary for validation and calibration of ocean color data

Sampling for water quality parameters in Case II waters. Credit: Univ. PR Bio-optical Oceanography Lab

Requirements for Coastal Water Quality Remote Sensing

Spatial Resolution

< 10 m to 100s of meters

However, most satellite ocean color data have a spatial resolution of about 1 km.

Temporal Resolution

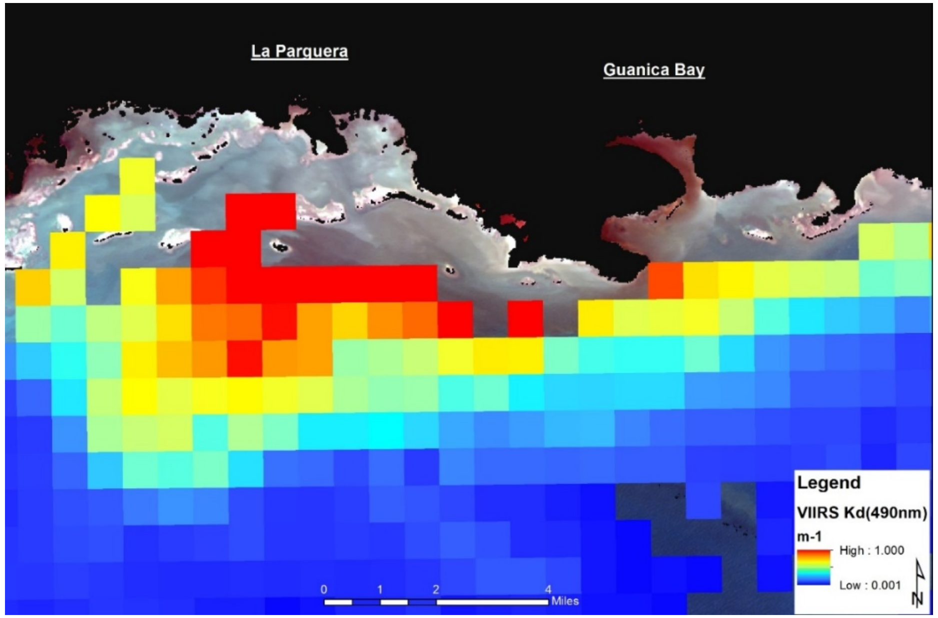
Coastal ocean phenomena are measured at short temporal scales (e.g. hours to days).

Spectral Resolution

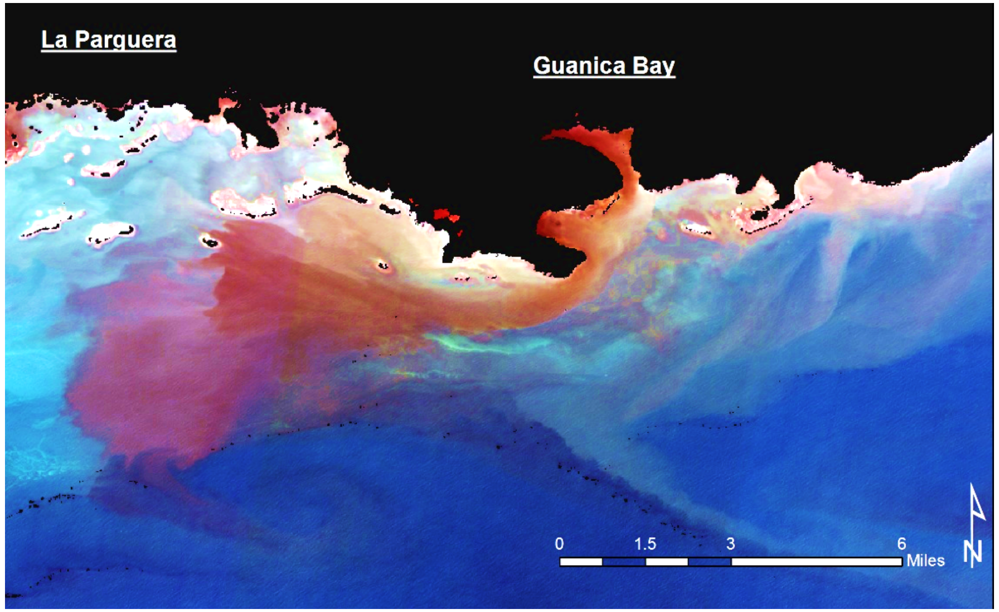
Optically-complex coastal waters require hyperspectral data for spectrally separating the signals from optically-competing water column parameters.

Credit: Univ. PR Bio-optical Oceanography Lab

Influence of Spatial Resolution



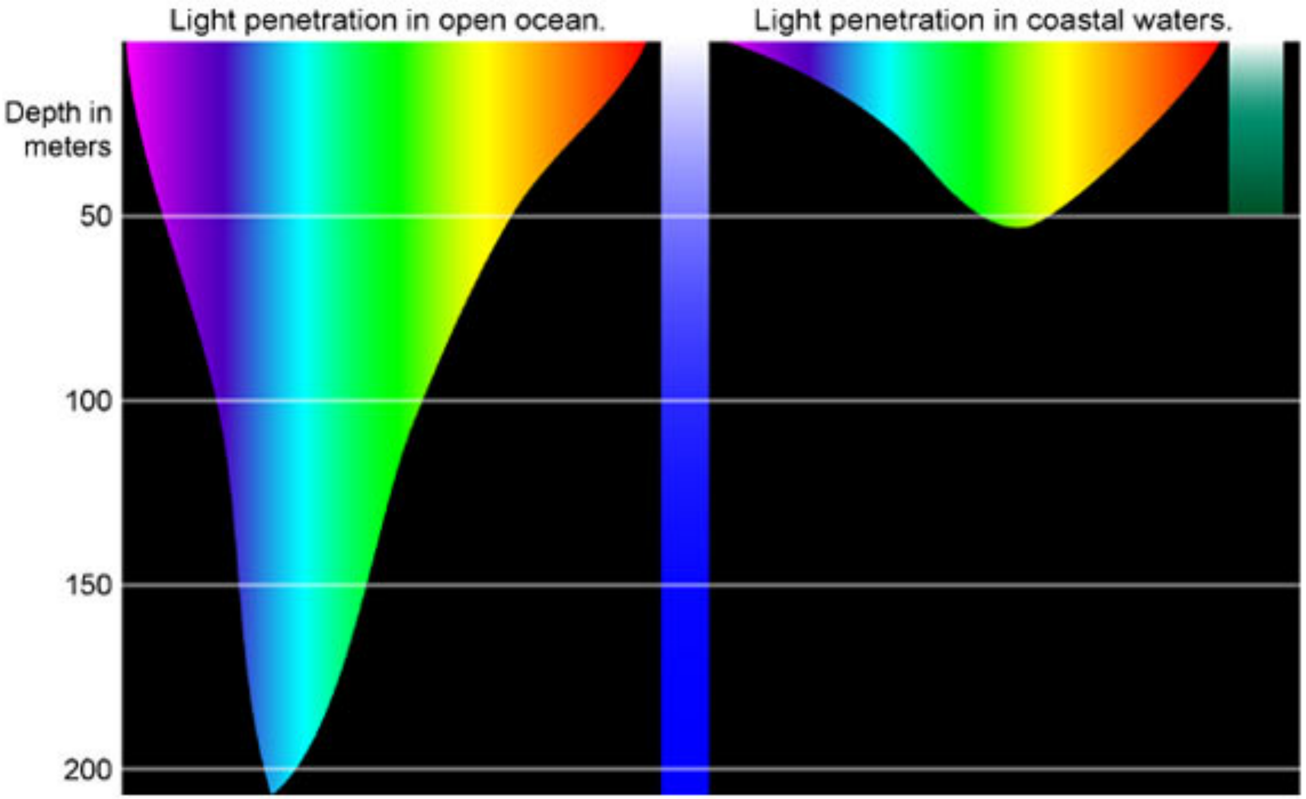
VIIRS image of turbidity, Kd (490 nm) wavelength (Level 2 Science Quality) averaged for November 11-13 at 750m

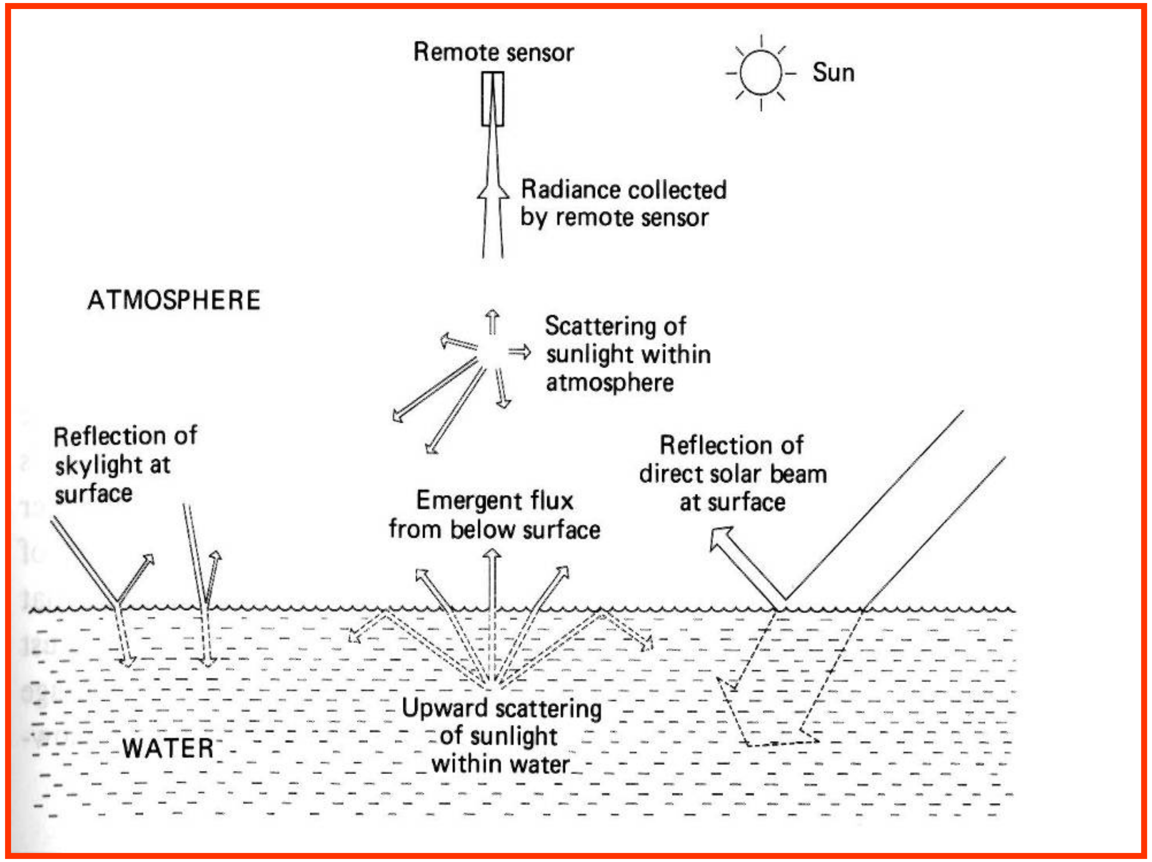


Landsat 8 OLI image (with landmask) for November 12, 2014

Credit: Univ. PR Bio-optical Oceanography Lab

Penetration of Light in the Ocean



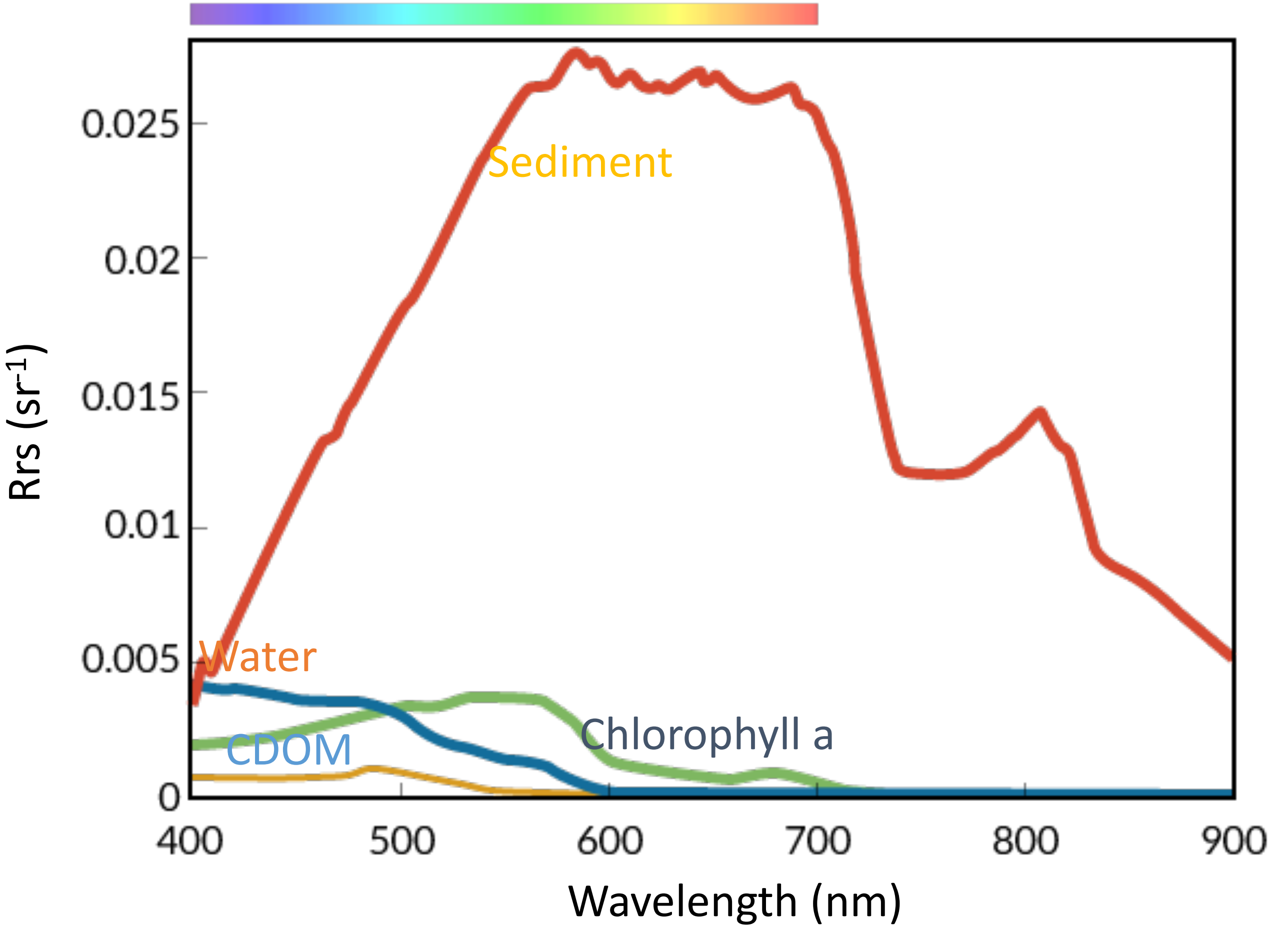


What does the color of the water tell us?

Credit: Univ. PR Bio-optical Oceanography Lab

In Situ Data Collection for Characterizing Water Bodies in Coastal Areas

- Water Samples
  - Chl a
  - TSS/TSM
  - Colored Dissolved Organic Matter (CDOM)
- Spectral
- Optical Properties
  - Inherent Optical Properties (IOP)
  - Apparent Optical Properties(AOP)



Water Optical Properties

Inherent Optical Properties (IOP's)

- Depend only upon the medium and are independent of the ambient light field
- Are easily defined but can be exceptionally difficult to measure, particularly in the field
- Common IOP's are:
  - Absorption
  - Scattering

Apparent Optical Properties (AOP's)

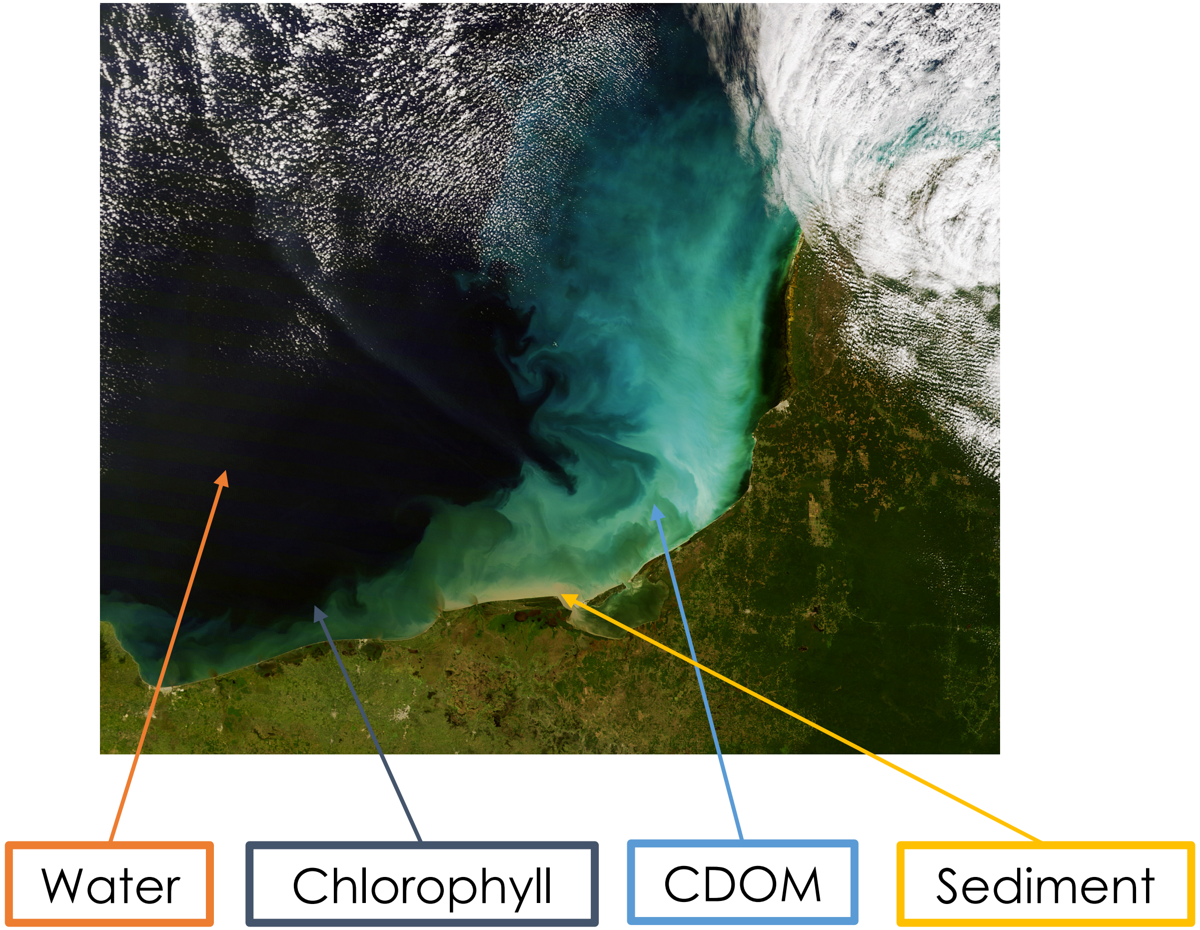
- Depend both on the medium and on the geometric structure of the ambient light field
- Display enough regular features and stability to be used as descriptors of the water body
- Generally much easier to measure, but are difficult to interpret because of how the environment affects them
- Common AOP's are:
  - Vertical Attenuation Coefficient (Kd)
  - Reflectance

Inherent Optical Properties (IOPs) and the 'Color' of Water

Light absorption (a) by photoplankton (ph), sediment (s), water (w), and CDOM

$$a = a_{ph} + a_s + a_{CDOM} + a_w$$

Light scattering (b) by particles in forward (b_f) and backward (b_b) direction $b = b_f + b_b$



Vertical Attenuation Coefficient: A Widely Used AOP

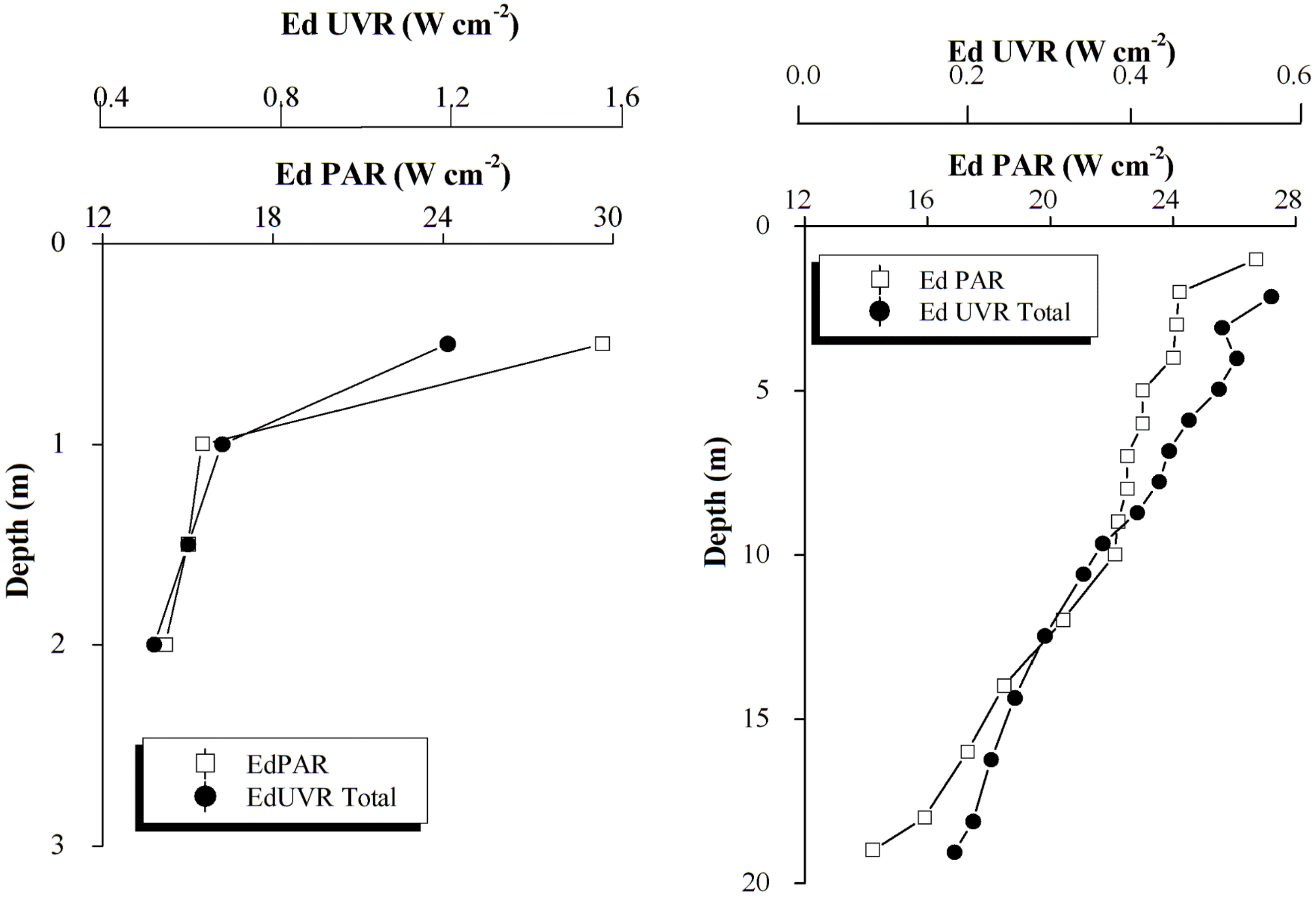
- $K_{d\ (PAR)}$ is the best optical parameter to characterize different water bodies in relation to the availability of PAR.

  Units: m-1

$$E_z = E_0\, e^{-kz}$$

- K_d is calculated as the slope of ln $E_d(z)$ or by measuring the downwelling irradiance at two depths using:

$$Kd = \frac{1}{Z_2 - Z_1} \ln \frac{Ed(z_1)}{Ed(z_2)}$$



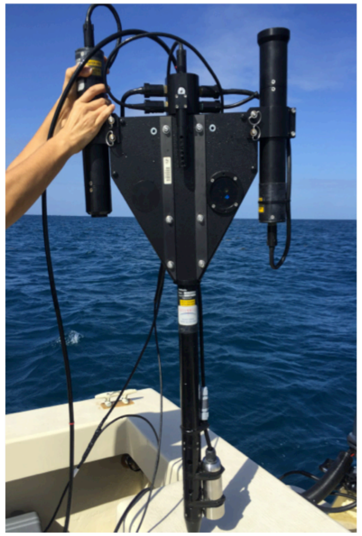
Credit: Torres-Pérez et al (2007) Photochem. Photobiol.

Typical Field Instrumentation for Water Quality Characterization

Surface water samples are used for measuring CDOM, Total Suspended Matter, and Chlorophyll.

Profiling sensor package that includes a CTD, a fluorometer, an ac-9 for absorption and attenuation, and a HydroScat-6 sensor for backscattering

GER-1500 spectroradiometer measures radiance and irradiance. This is used to calculate remote sensing reflectance (Rrs).

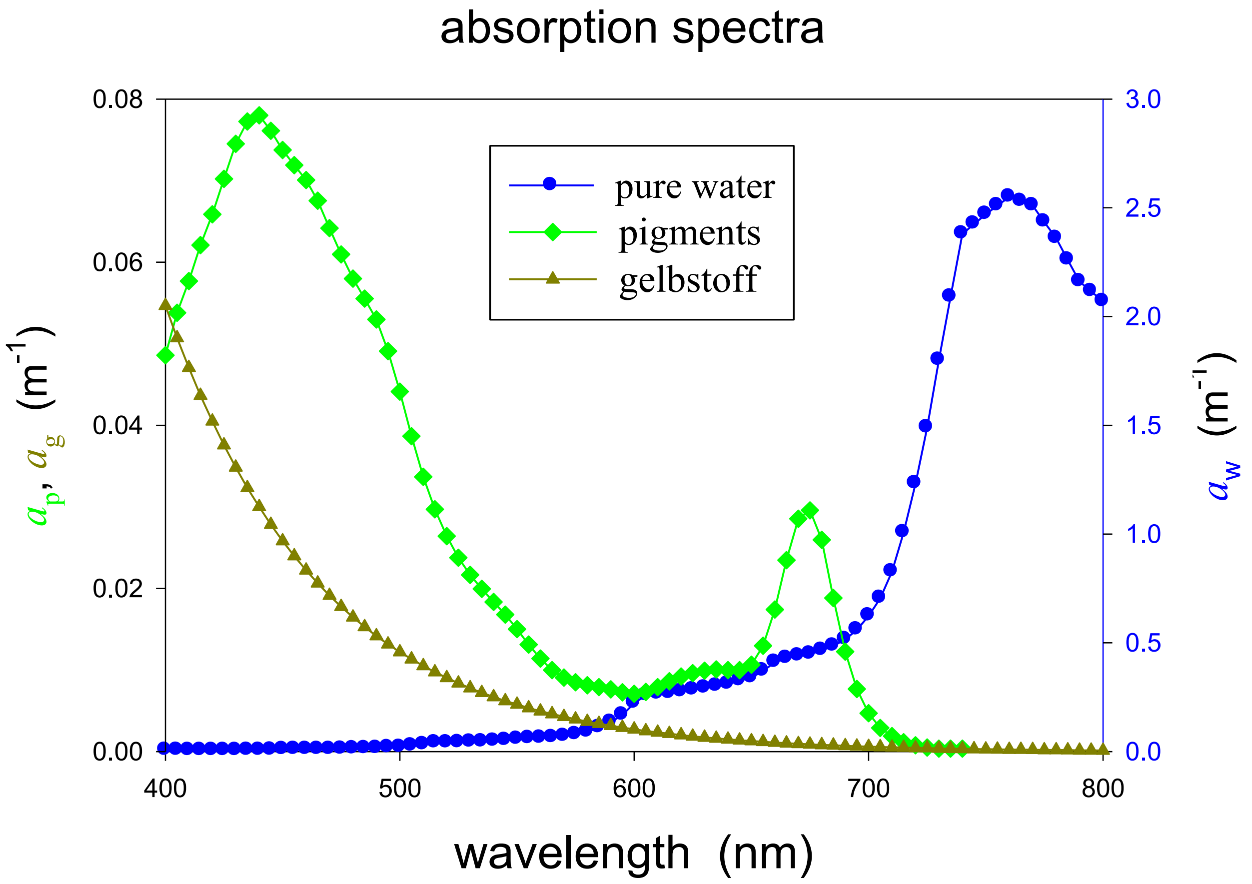


Satlantic HyperPro Profiling Spectroradiometer is used to derive spectral vertical attenuation coefficient (Kd)

Credit: Univ. PR Bio-optical Oceanography Lab

Absorption of Water, CDOM, and Phytoplankton

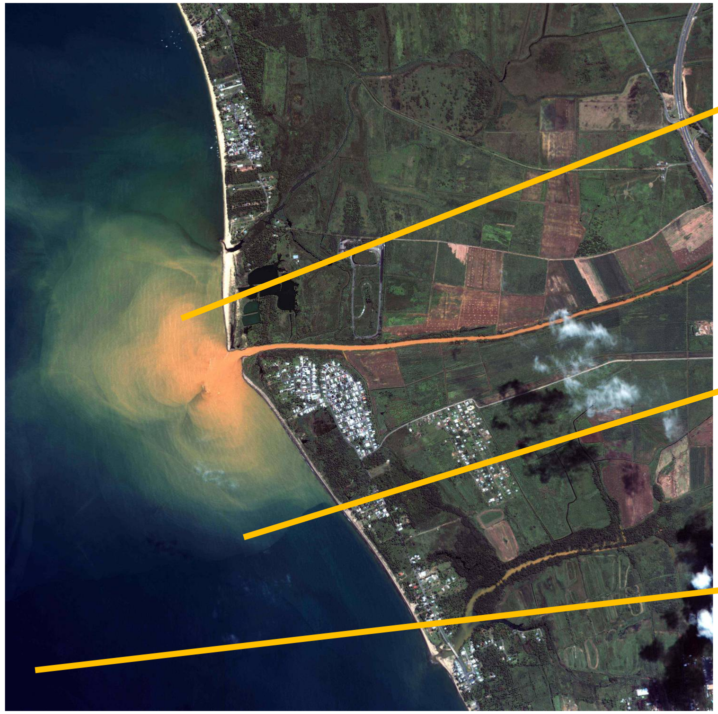
- Water absorbs strongly in the red and NIR.
- CDOM absorbs strongly in the blue region.
- Phytoplankton (Chl a) absorbs strongly in the blue and red regions of the spectrum.



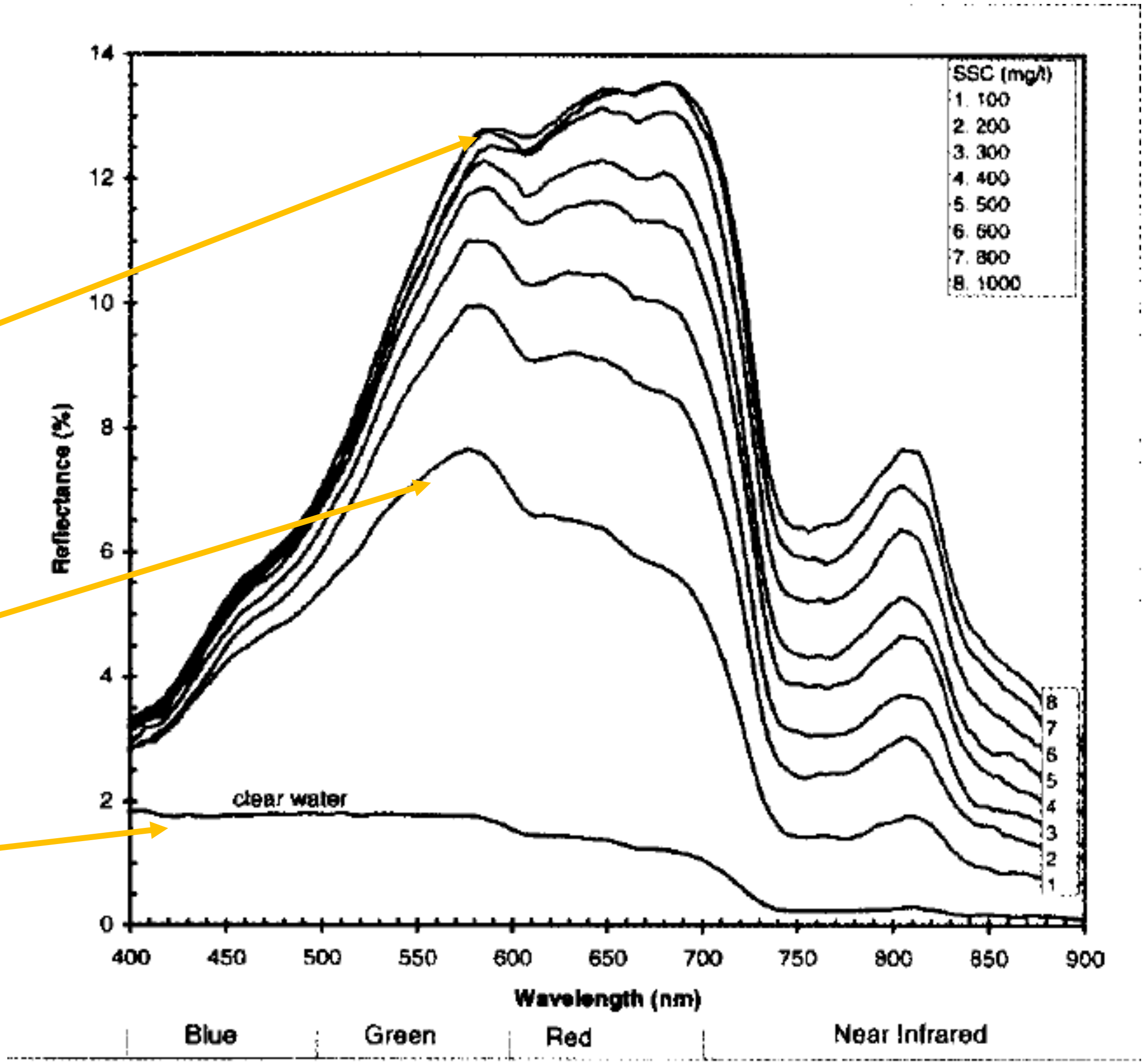
Credit: Univ. PR Bio-optical Oceanography Lab

Total Suspended Solids

- Usually have a strong reflectance in the yellow-red and the NIR
- Affected by sediment type/composition

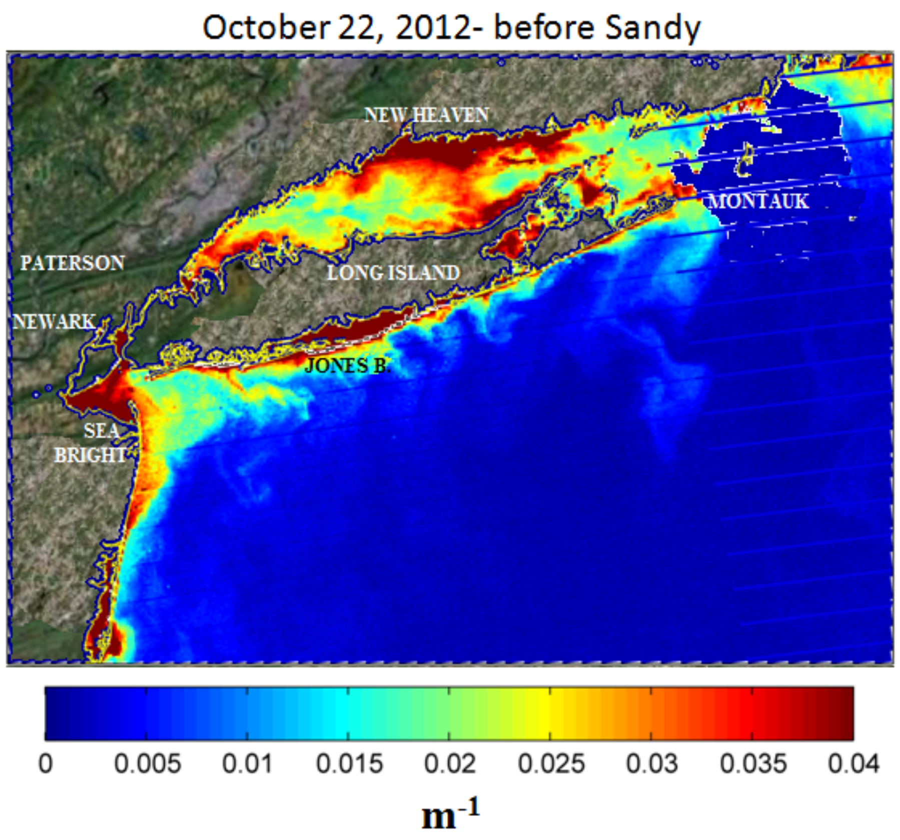


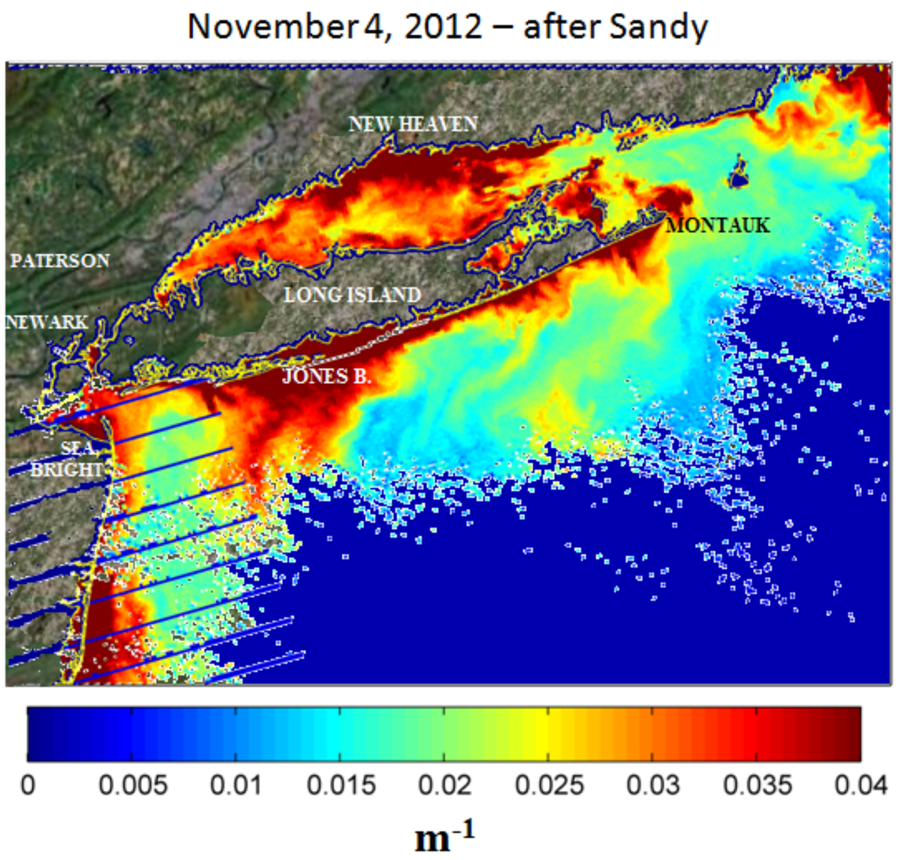
IKONOS image Añasco River plume (West Coast PR). Credit: Univ. PR Bio-optical Oceanography Lab



From Lodhi et al. 1998

Increased Suspended Particulate Backscattering after Hurricane Sandy Obtained from VIIRS Satellite Data

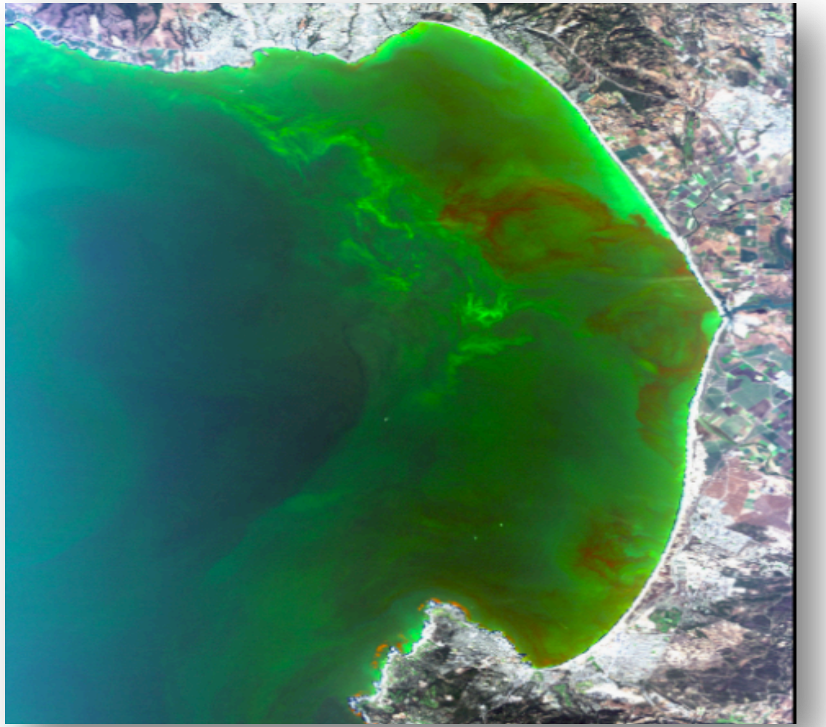


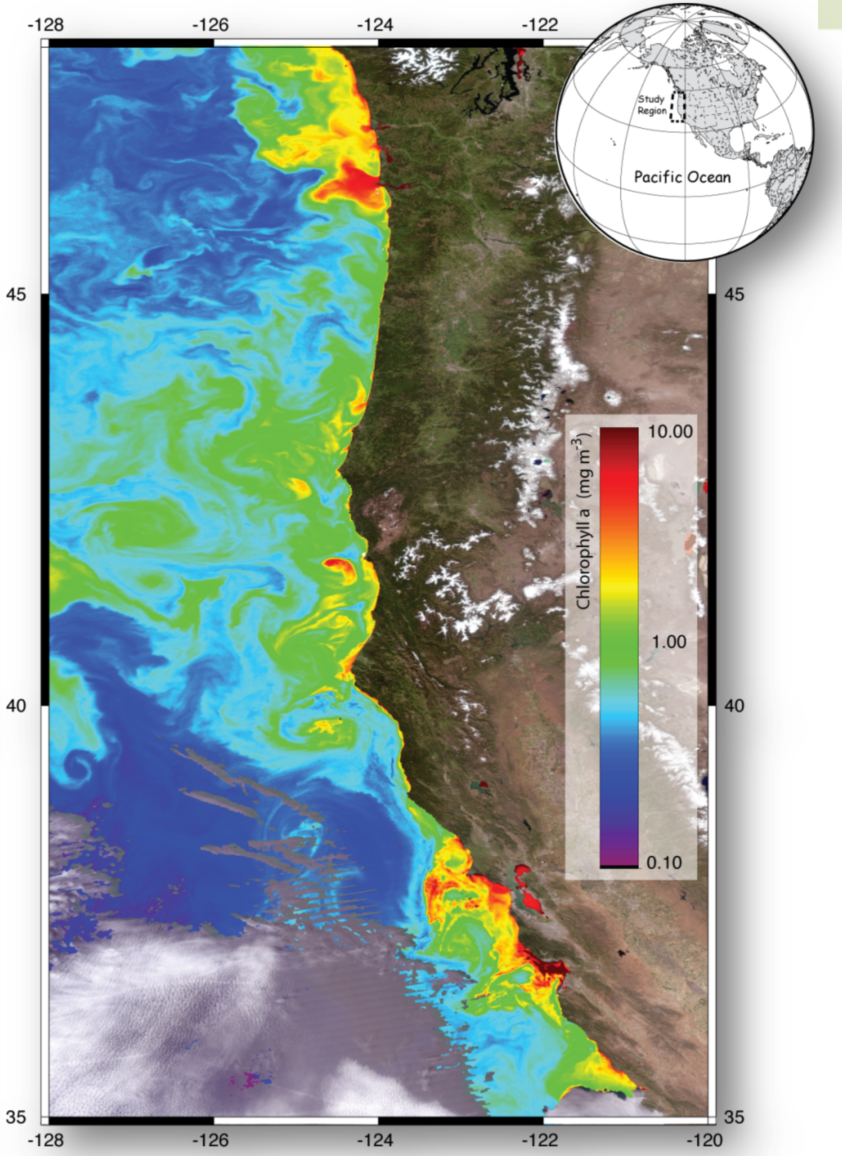


Credit: Univ. PR Bio-optical Oceanography Lab

Chlorophyll a

- Indicator of phytoplankton biomass and blooms
- Indirect indicator of nutrients





Credit: Liane Guild (NASA), Raphe Kudela (UC Santa Cruz)

CDOM Detection

- Colored Dissolved Organic Matter (CDOM) is the optically-active part of dissolved organic matter (DOM).
  - CDOM – Also known as yellow substance, chromophoric dissolved organic matter, and gelbstoff
  - Occurs naturally, but can increase due to runoff or as a result of extreme weather events (hurricanes)
  - Reduces light availability, particularly in the blue region
  - Band combinations in the ~440 nm and >600 nm are used to quantify CDOM
  - The new "Coastal" band in L8 (Band 1) has proven to be very useful for CDOM detection.

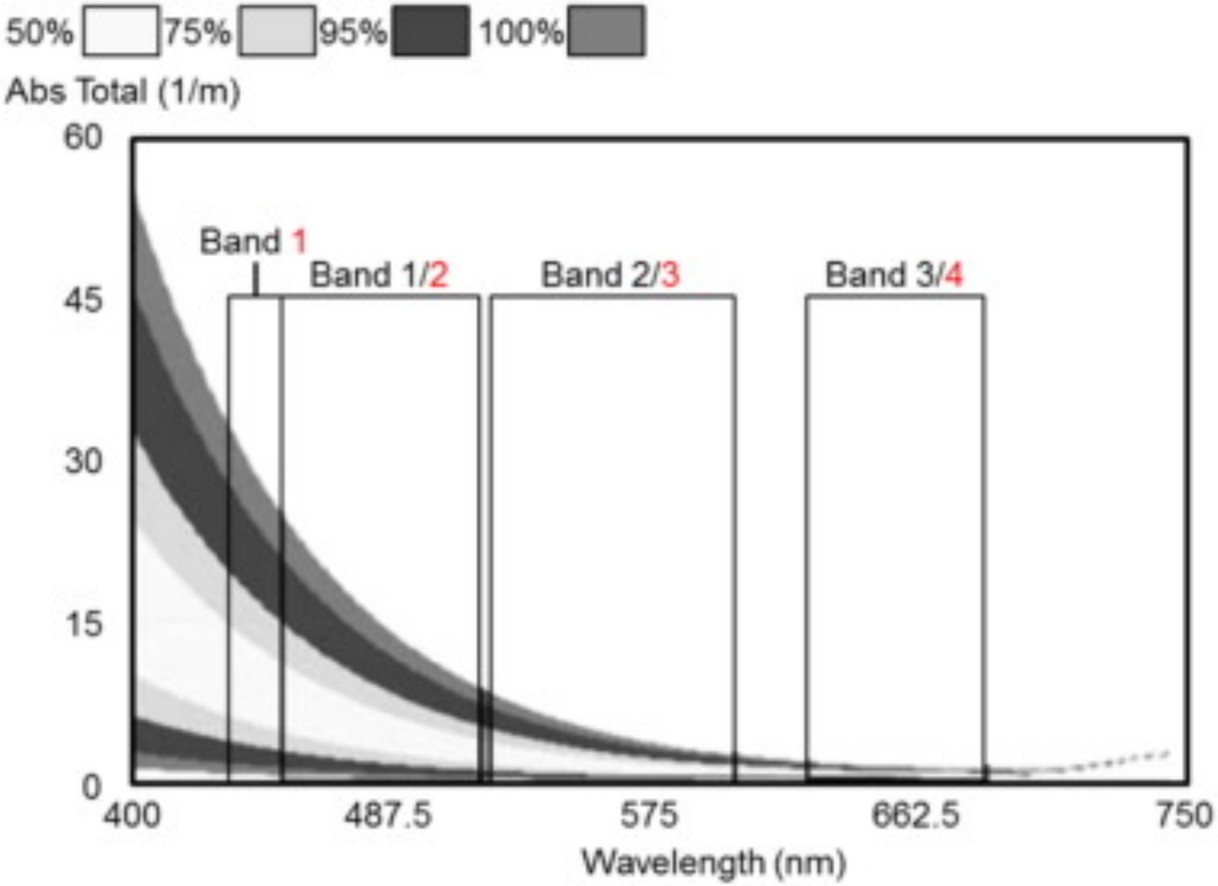
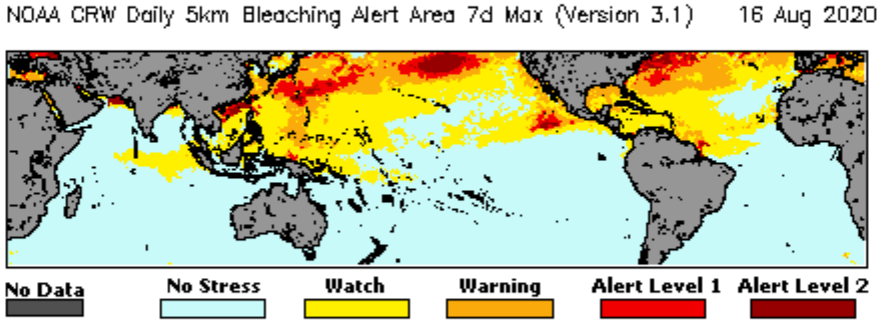


Image Credit: Slonecker et al 2016

Direct and Indirect Monitoring of Shallow Coastal Ecosystems

- **Direct** – The reef itself is the target of remote sensing.
  - Addresses benthic properties, geomorphological features, habitat complexity, etc.
- **Indirect** – Focuses on the oceanic and atmospheric environment around the reef.
  - SST and bleaching events
  - Low salinities and high turbidity from episodic rainfall events
  - Water optical properties (AOP and IOP)
  - CDOM, Chl-a, turbidity, etc.
  - Atmospheric – Solar insolation, UV radiation incidence and penetration in the water column, aerosols, etc.

Credit: Univ. PR Bio-optical Oceanography Lab



Credit: NOAA Coral Reef Watch Program

Assessment of Coral Reef Biodiversity Using Remote Sensing

- Biodiversity refers to the abundance, variety, and genetic constitution of natural living communities.
- Also defined as the sum of all biotic variation from the level of genes to an ecosystem.
- Addresses the spatial and temporal patterns in biological diversity and richness.
- Bleaching may result locally in a loss of biodiversity.
- In terms of remote sensing, we need to define the relevant environmental proxies that will indirectly reflect species richness patterns and will help explain the processes that shape these patterns.
- Example: The use of Kd (PAR) to estimate percent cover of living corals, species diversity, and richness.

Image: Los Roques, Venezuela. Credit: Univ. PR Bio-optical Oceanography Lab

Direct Monitoring of Benthic Ecosystems

- Traditionally, pixel-based classifications use differences in the spectral signatures to discriminate between benthic features.
  - Requires the availability of a robust spectral library of benthic components
  - Limited by the spectral and spatial resolutions of the sensors
- Other methods such as Object-Based Image Analysis (OBIA) incorporate characteristics not usually considered by traditional remote sensing techniques (texture, shape).
  - Allow for the definition of specific geomorphological classes

Credit: Khaled Bin Sultan Living Oceans Foundation and NASA ARC Laboratory for Advanced Sensing

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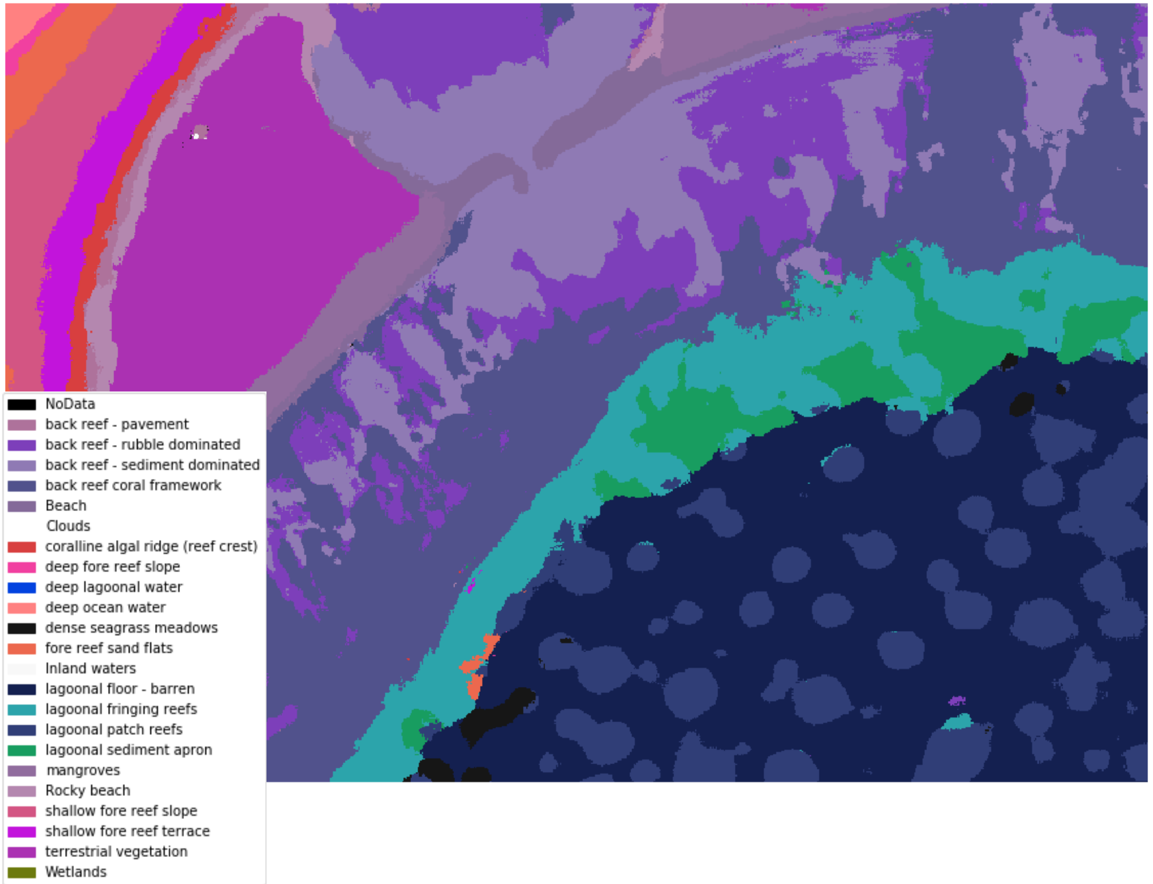
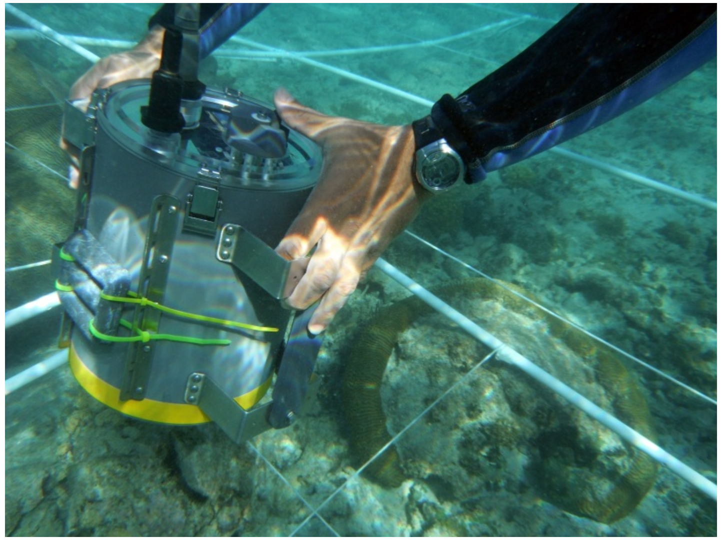
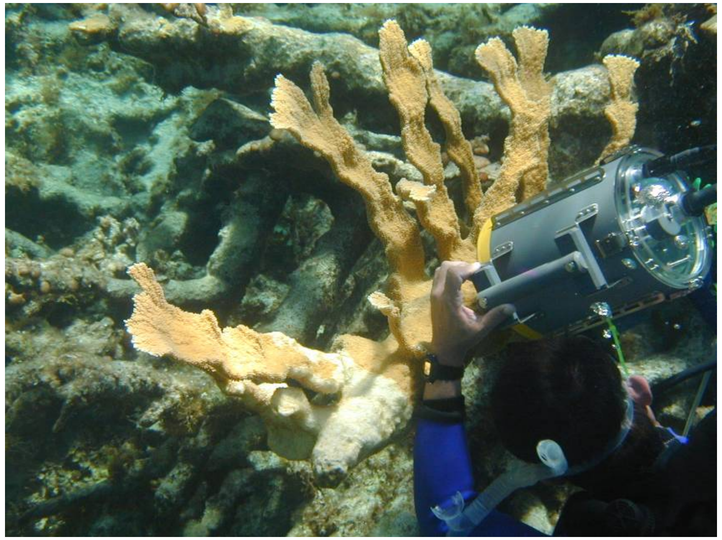


Credit: Khaled Bin Sultan Living Oceans Foundation and NASA ARC Laboratory for Advanced Sensing

In situ Spectral Characterization of Benthic Components

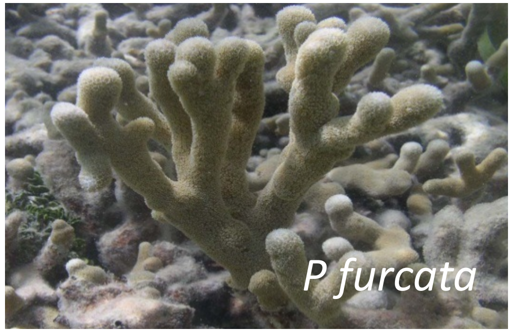
- There is a need for better spectral discrimination of reefs' benthic components.
- Aid in the cal/val of satellite or airborne images
- Provides for a non-invasive tool to assess the health of benthic organisms (corals, kelps)
- Can be used in physiological studies to follow the development of a potentially devastating event such as bleaching or disease outbreaks

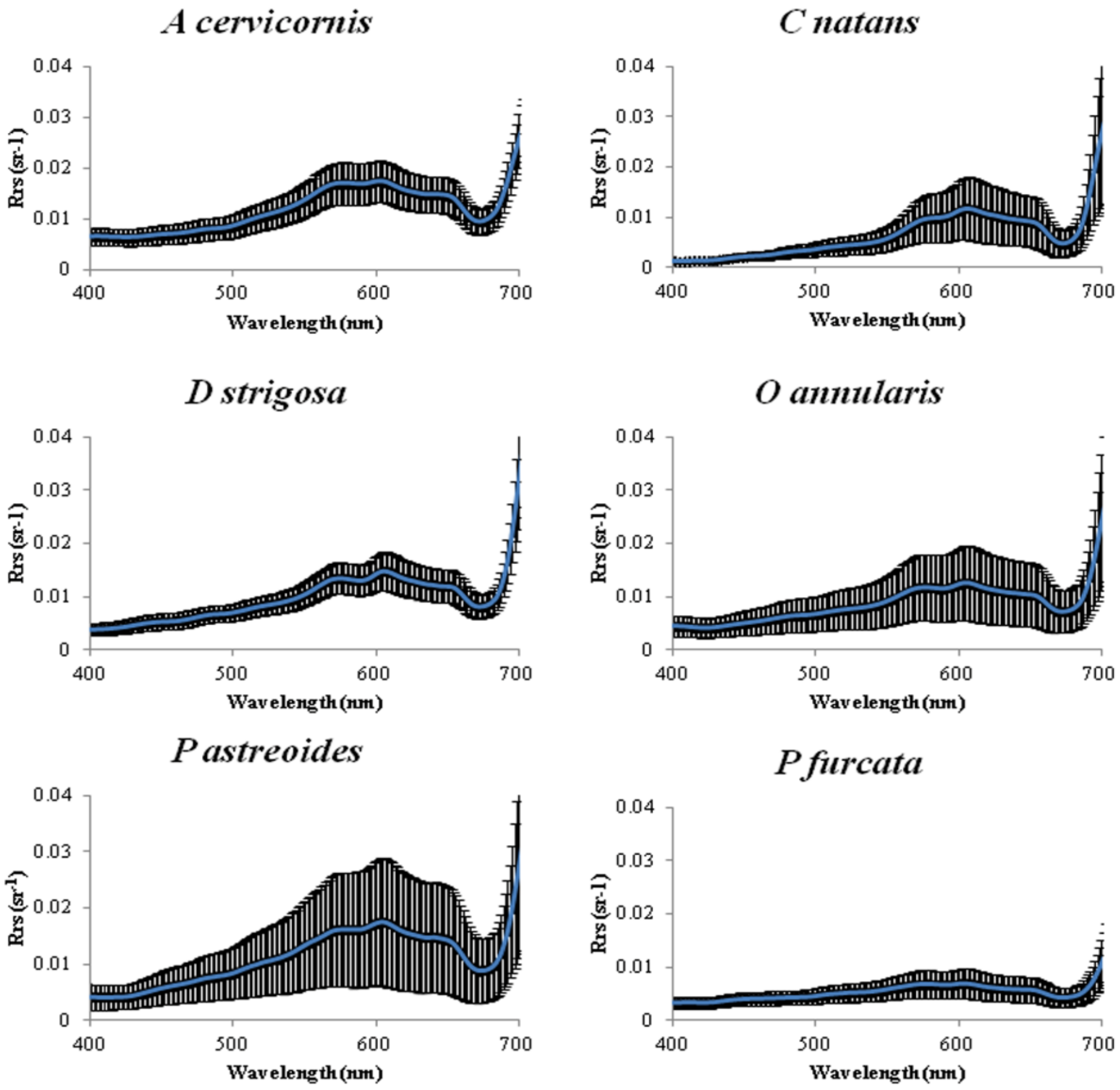




Torres-Pérez et al. 2015. PLoSONE

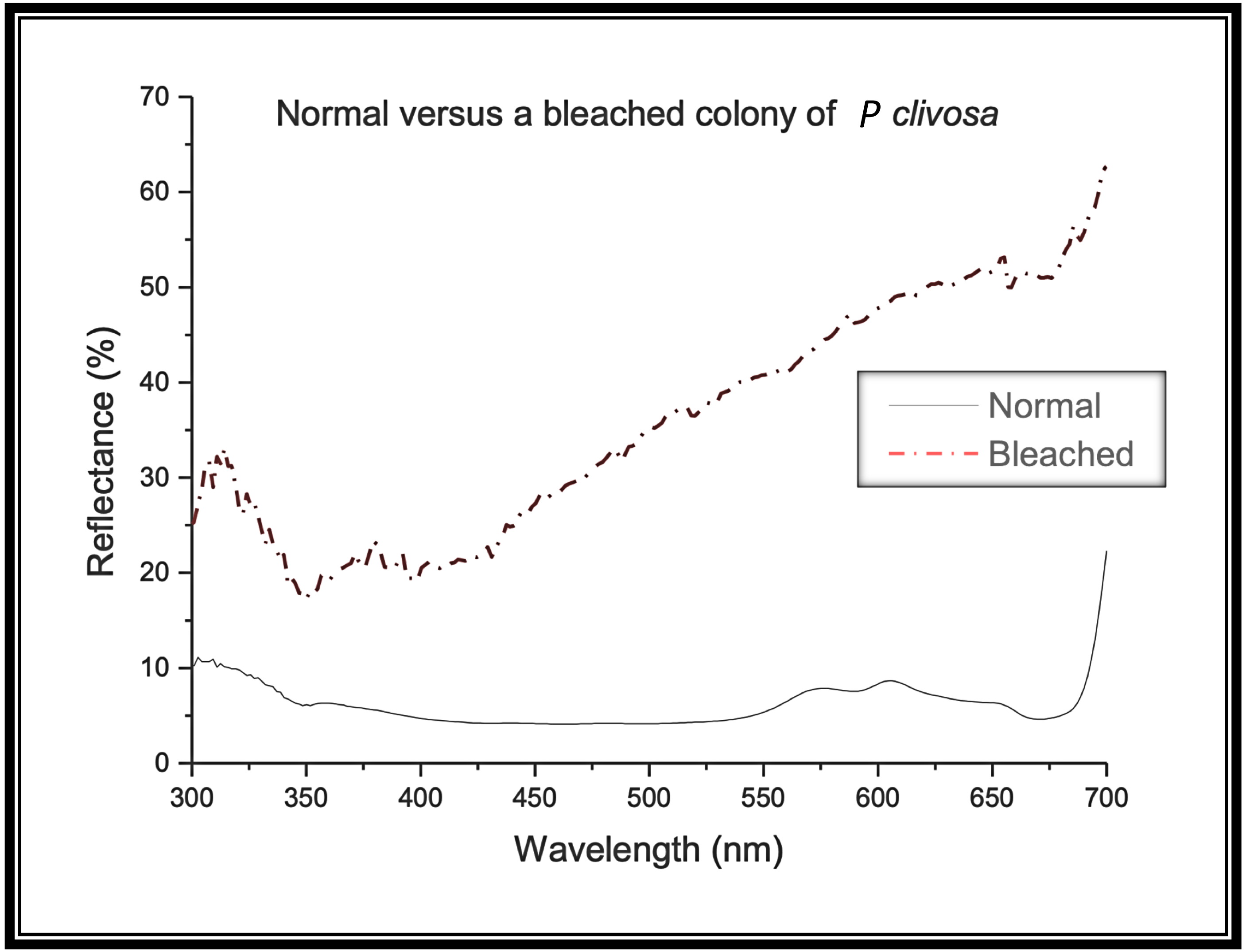
In situ Spectral Characterization of Benthic Components

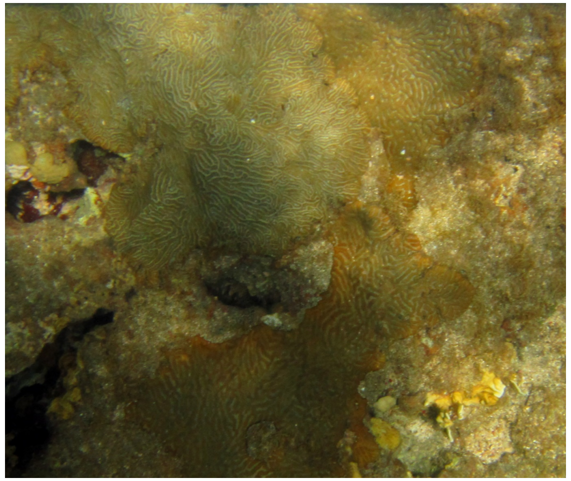




Torres-Pérez et al. 2015. PLoSONE

Spectral Characterization of Stress

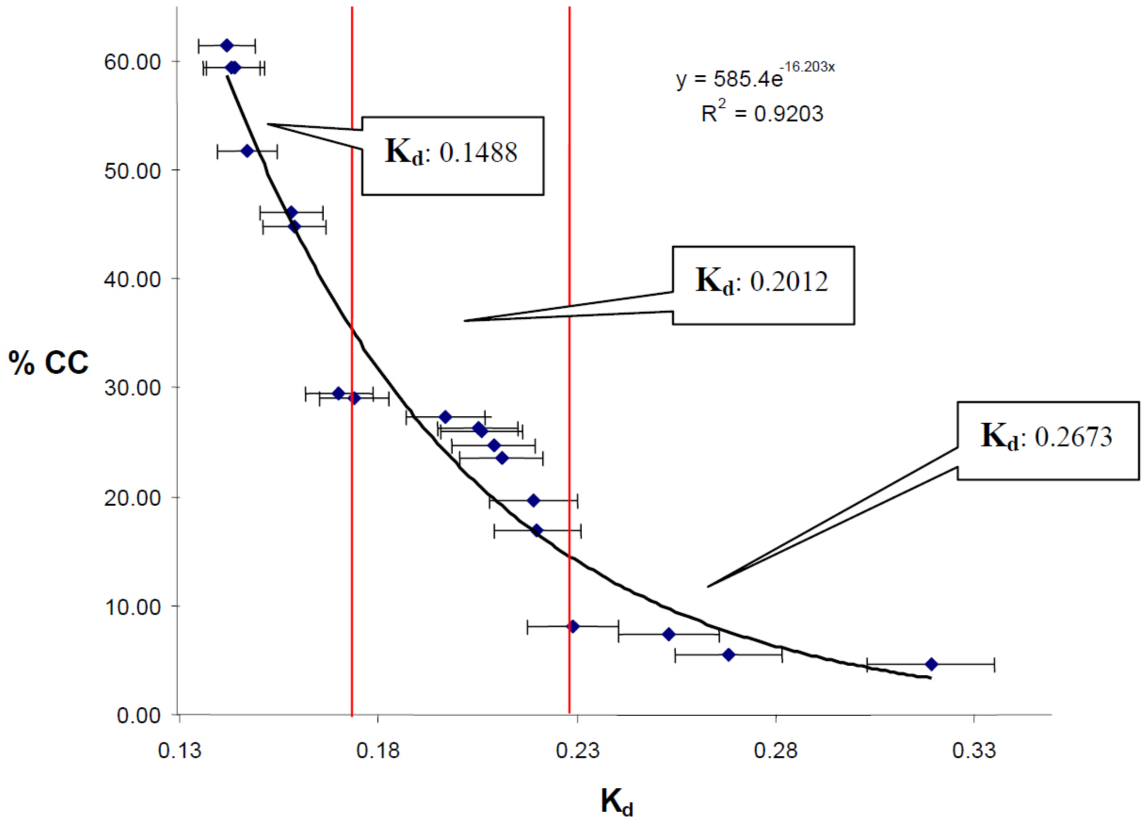




Top: Healthy brain coral colony. Bottom: Bleached brain coral colony. Credit: Torres-Pérez

Indirect Monitoring of Benthic Ecosystems

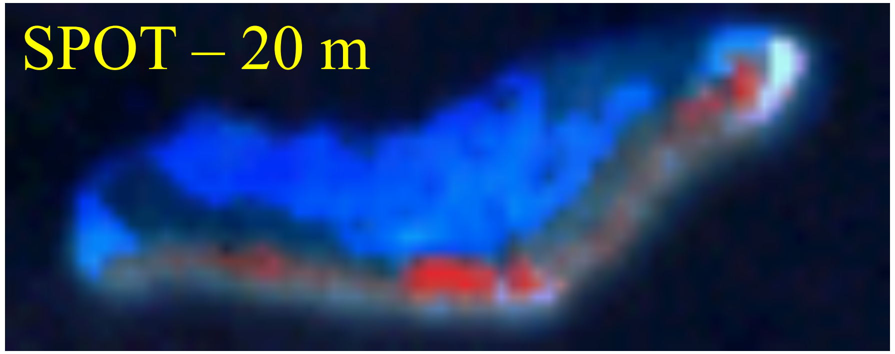
- Kd can be used to estimate ecological indicators (percent cover of dominant groups/species, species diversity and richness).
  - For coral reefs, light attenuation (due to high sediment concentrations) is inversely proportional to hard coral cover and directly proportional with percent macroalgal cover.
- Similarly, increases in SST are correlated with occurrence of extreme coral bleaching events.
- UV radiation is directly correlated with a reduction in coral growth and reproduction.

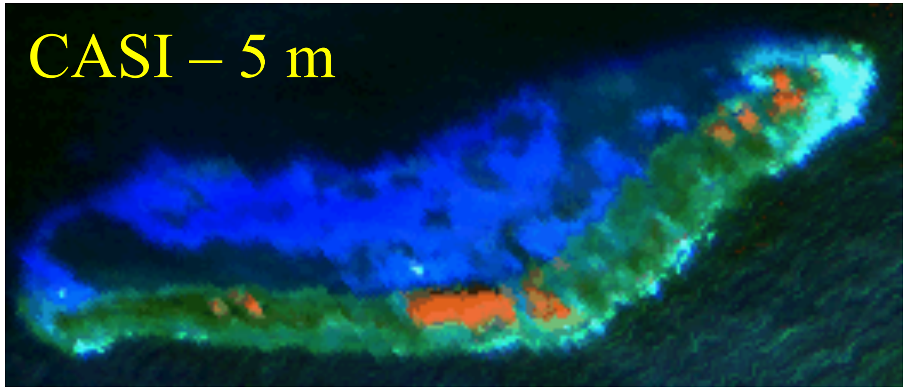


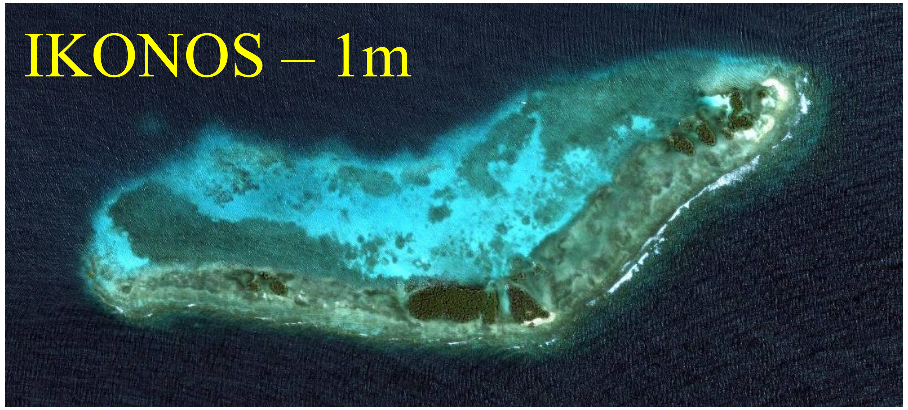
Credit: Univ. PR Bio-optical Oceanography Lab

Limitations of Satellite Imagery for Complex Coastal Ecosystems

- Coarse resolution for highly heterogeneous ecosystems can be as little as tens of meters!
- Usually, meter or sub-meter scale is needed for accurate representation, even with only a few classes (e.g. coral, seagrass, sand, mangroves).





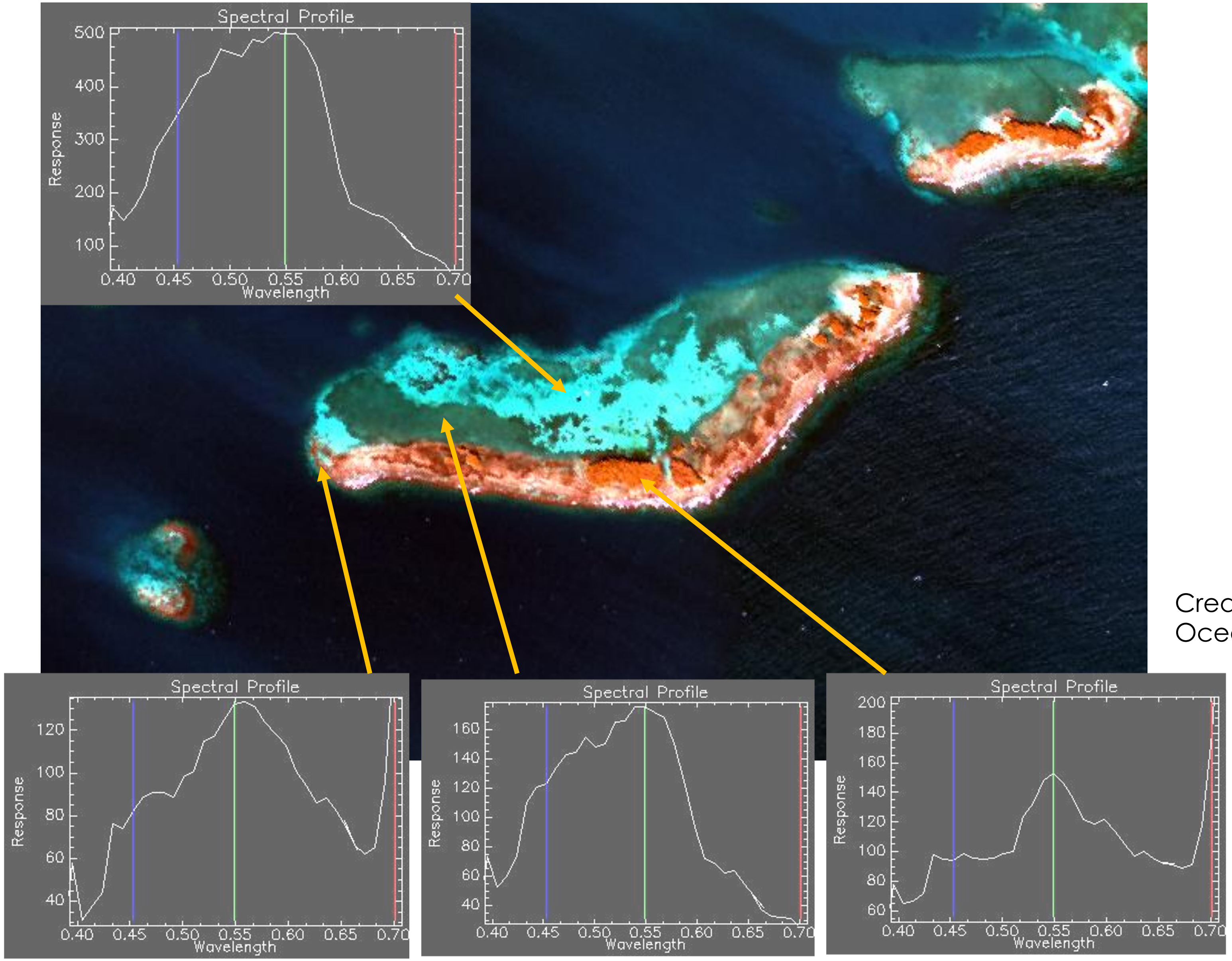


Limitations of Satellite Imagery for Complex Coastal Ecosystems

- Limited to the first tens of meters of depth
- Even in very clear waters, light attenuation affects the retrieval of benthic information.
- Deeper communities can be extensive and out of reach for remotely-sensed satellite imagery.
- Characterization of these deep communities is important as they can be refugia and reservoir of biodiversity.
  - Usually accessible with other means:
    - Side-scan and multibeam sonars
    - Underwater autonomous vehicles

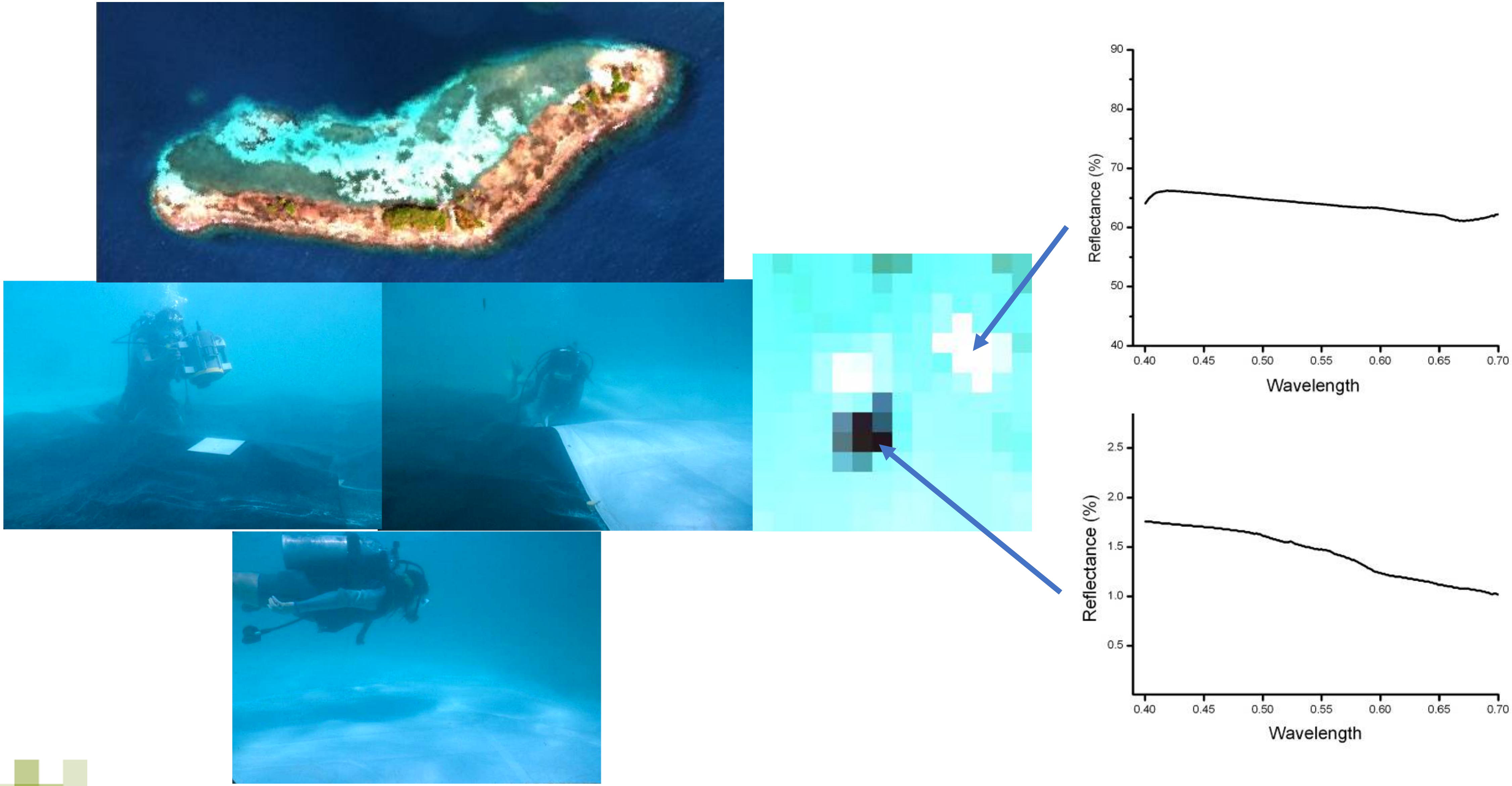
IKONOS imagery of Southwest PR. Credit: Univ. PR Bio-optical Oceanography Lab

Atmospherically Corrected AVIRIS (Hyperspectral) Image



Credit: Univ. PR Bio-optical Oceanography Lab

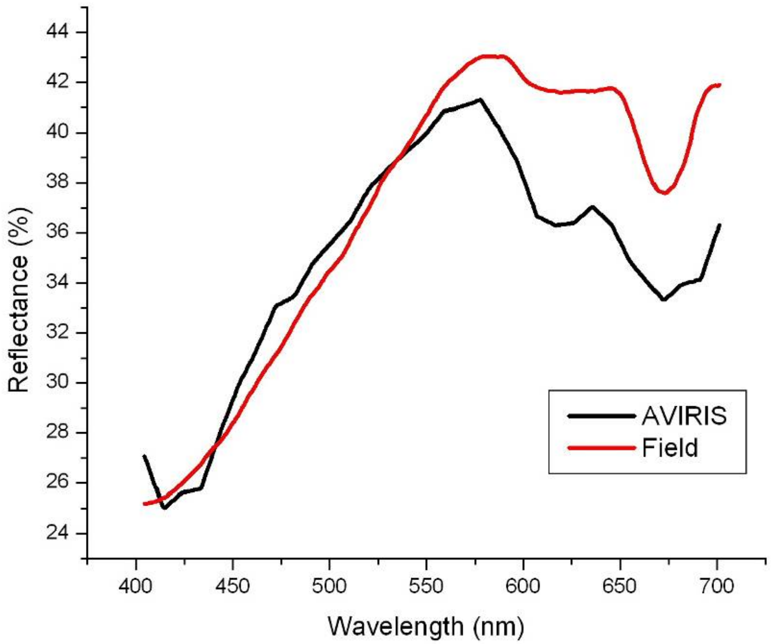
Underwater Flat-Field Calibration Targets for Water Column Correction



Credit: Univ. PR Bio-optical Oceanography Lab

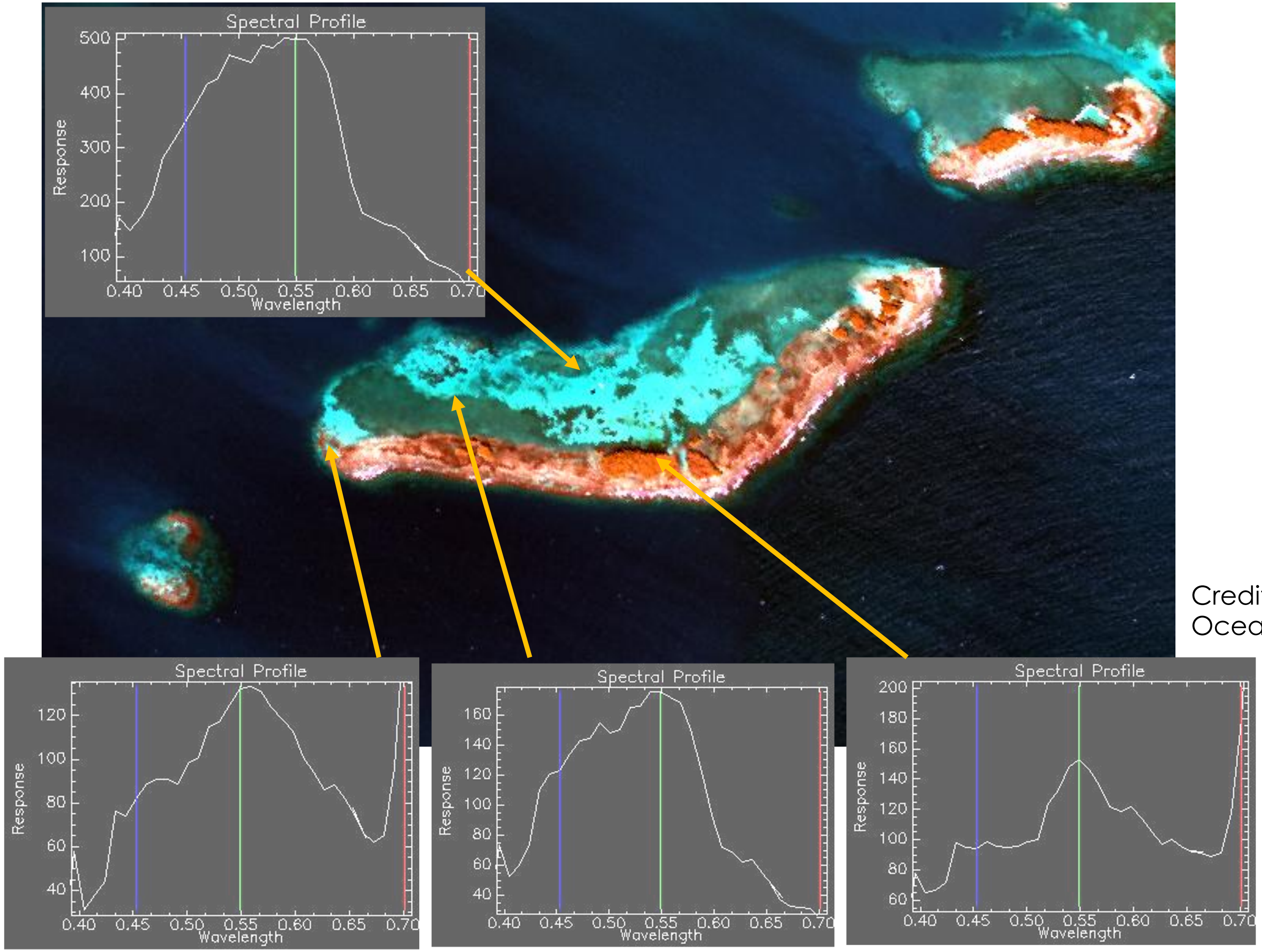
Water Column Correction Validation

- AVIRIS (Hyperspectral)agrees with field values within 10% from 400-600 nm and up to 18% between 600-700 nm.
- Spectral features are preserved, mostly corresponding to pigment absorption by microbial layers.



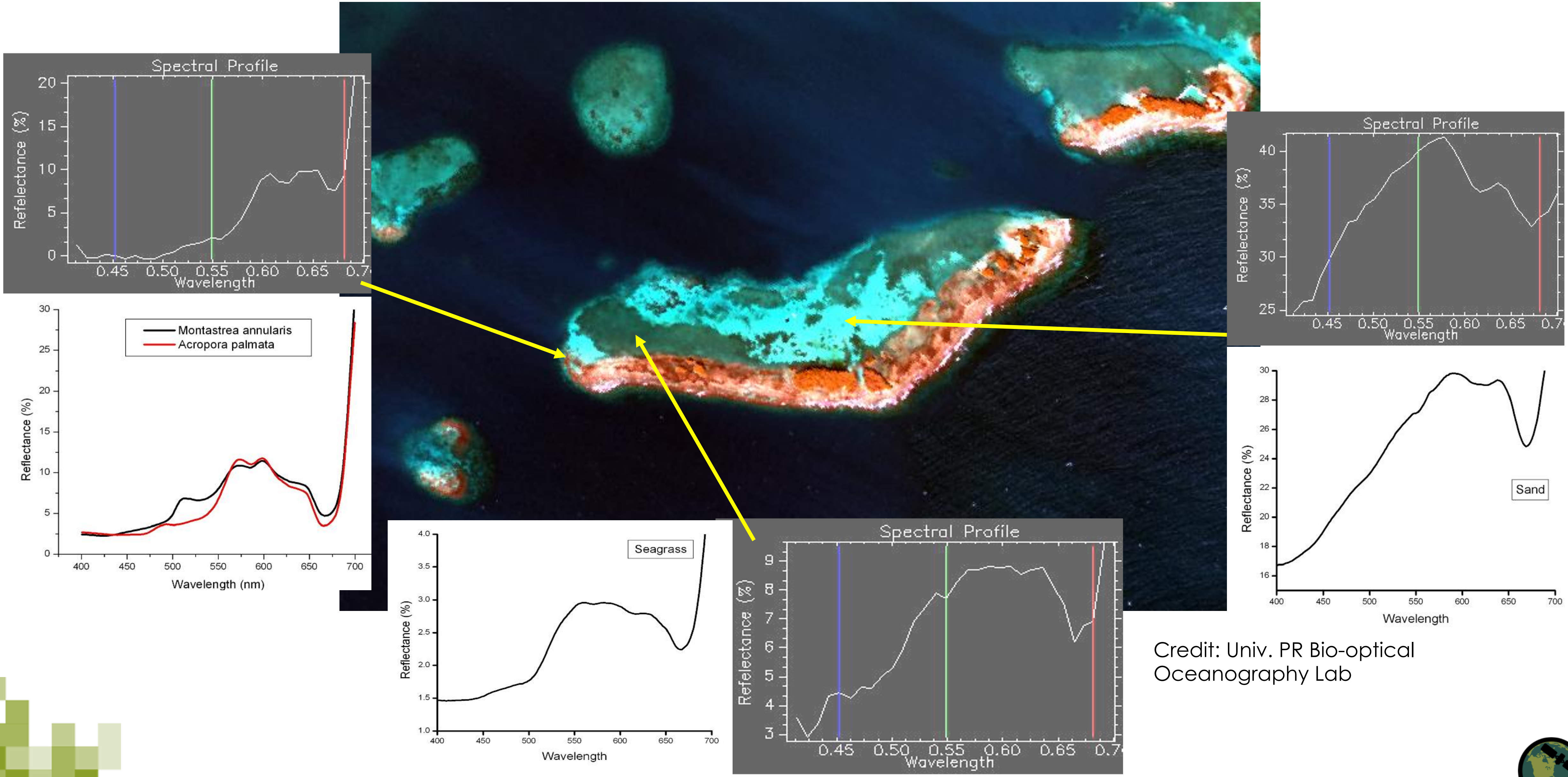
Credit: Univ. PR Bio-optical Oceanography Lab

Atmospherically Corrected AVIRIS (Hyperspectral) Image (Before Water Column Correction)



Credit: Univ. PR Bio-optical Oceanography Lab

Atmospherically Corrected AVIRIS (Hyperspectral) Image (After Water Column Correction)



Credit: Univ. PR Bio-optical Oceanography Lab

In Summary

- The presence of land-derived, suspended or dissolved constituents in coastal waters makes it difficult to use remote sensing data to study shallow to moderate depth ecosystems.
- The color of the water provides a lot of information on the composition of dissolved and suspended materials in the water column.
- Most of the time, field data is necessary to validate the spectral information from the sensor.
- Even in “clear” coastal waters such as in those usually found in the tropics, light attenuation occurs fast in the water column and obtaining information for benthic classification is challenging.

Next Session (Sept 8th): Remote Sensing of Shorelines

Contacts

- ARSET Contacts
  – Amber McCullum: AmberJean.Mccullum@nasa.gov
  – Juan Torres-Perez: juan.l.torresperez@nasa.gov

- General ARSET Inquiries
  – Ana Prados: aprados@umbc.edu

- ARSET Website:
  – http://appliedsciences.nasa.gov/arset

Questions

- Please enter your questions into the Q&A box.
- We will post the questions and answers to the training website following the conclusion of the course.

Thank You!