Hyperspectral Data for Land and Coastal Systems

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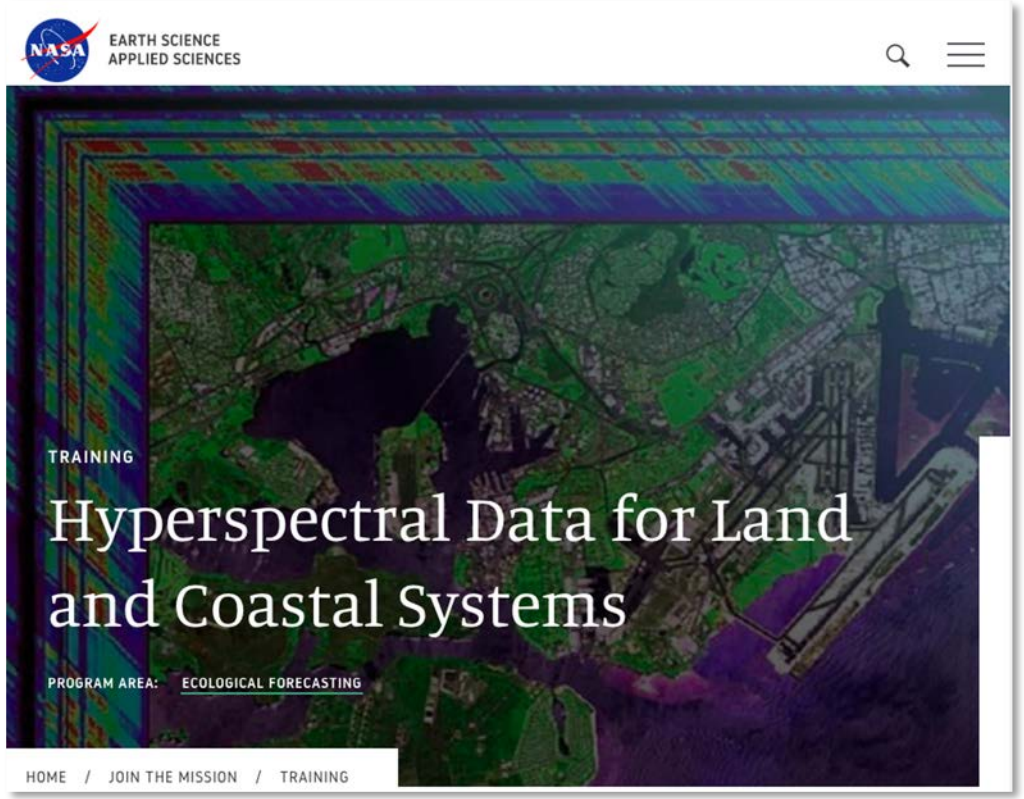
February 2, 2021

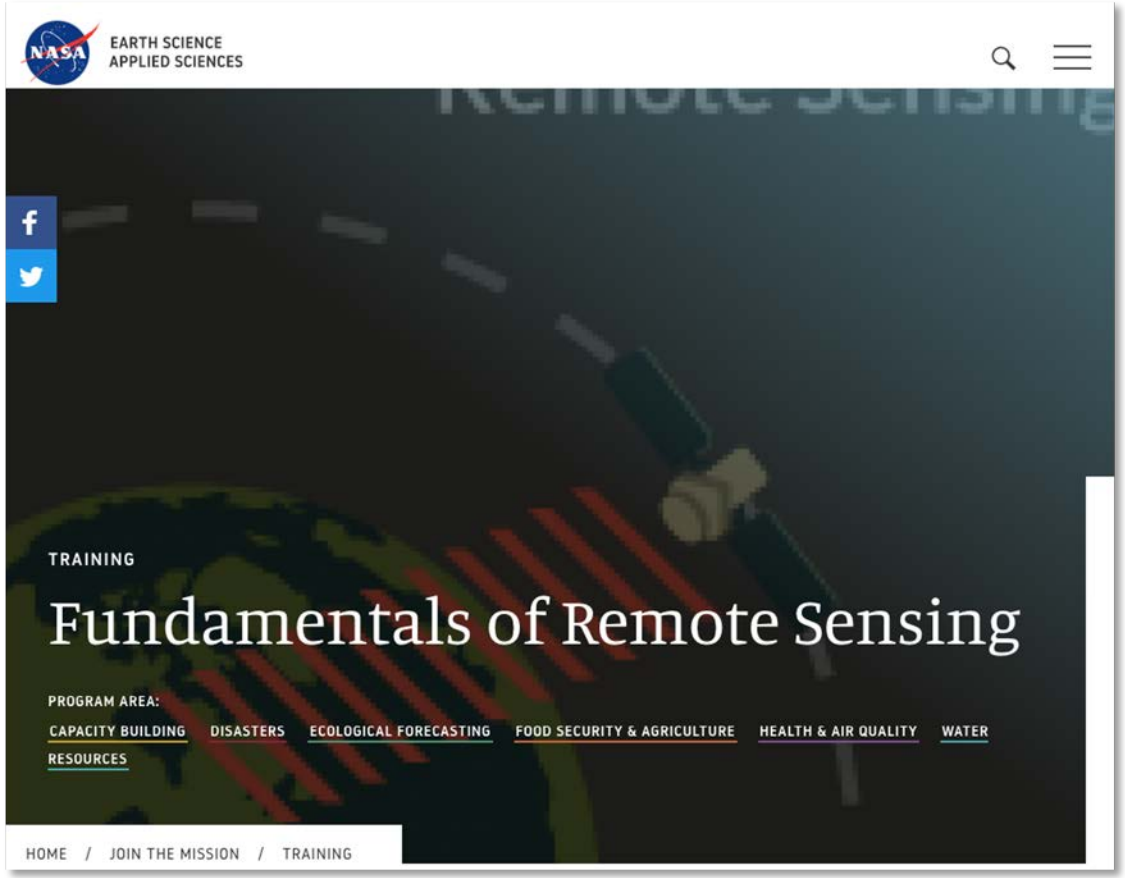
Course Structure and Materials

- Three, 1.5-hour sessions on January 19, January 26, and February 2
- The same content will be presented at two different times each day:
  - Session A: 11:00-12:30 EST (UTC-5)
  - Session B: 16:00-17:30 EST (UTC-5)
  - **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/hyperspectral-data-land-and-coastal-systems
- Q&A following each lecture and/or by email at:
  - juan.l.torresperez@nasa.gov
  - amberjean.mccullum@nasa.gov or
  - bengtsson@baeri.org



Prerequisites

- Prerequisites:
  - Please complete Fundamentals of Remote Sensing or have equivalent experience.
- Course Materials:
  - https://appliedsciences.nasa.gov/join-mission/training/english/fundamentals-remote-sensing



Homework and Certificates

- **Homework:**
  - One homework assignment
  - Answers must be submitted via Google Forms
  - **HW Deadline: Tuesday February 16**

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

Course Outline

Session 1: Overview of Hyperspectral Data

Session 2: Hyperspectral Data for Land Management

Session 3: Hyperspectral Data for Coastal and Ocean Systems

Learning Objectives

- By the end of this session, you will be able to…
  - Identify regions within the electromagnetic spectrum where particular pigments are absorbed and how this translates to airborne or space-based hyperspectral data
  - Recall the main differences between hyperspectral data and multispectral data
  - Contrast the use of hyperspectral data across diverse coastal ecosystems
  - Apply techniques to access, download, and display hyperspectral data for coastal and ocean systems

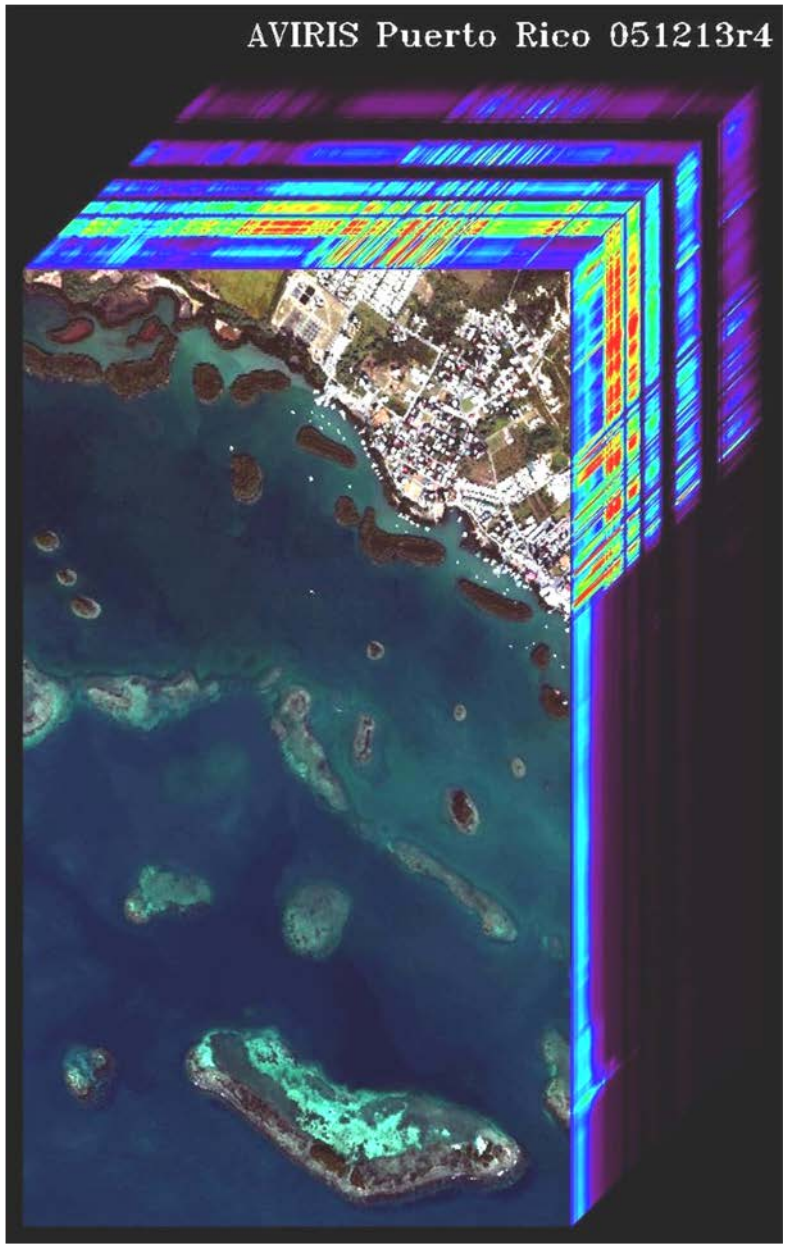
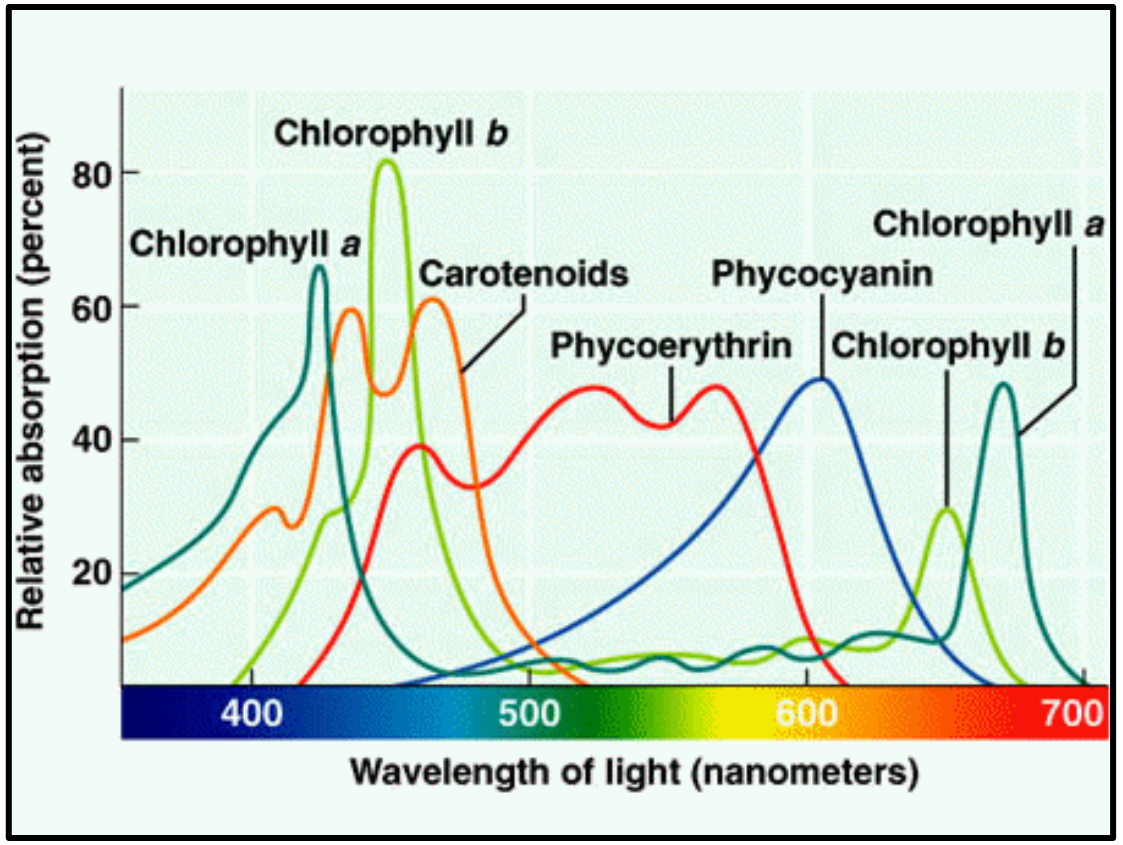


Image Credit: NASA JPL

Many pigments/compounds absorb in the visible range.

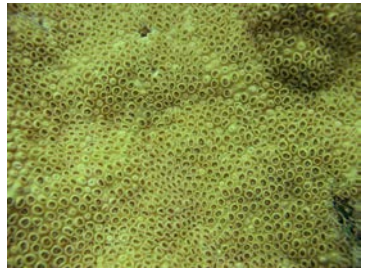
- **Chlorophylls** – Chl *a*, *b*, c_1, c_2, etc.
  - Main components of the photosynthetic apparatus
- **Phycobilisomes** – Phycoerythrin, phycocyanin
  - Work as light-harvesting antennas
  - Capture photons between 500-650nm
- **Carotenes** – Photoprotection; help dissipate excess energy within the cells
  - Carotenoids (i.e. Peridinin, β-carotene)
  - Xanthophylls (i.e. Diadinoxanthin, Zeaxanthin, etc.)



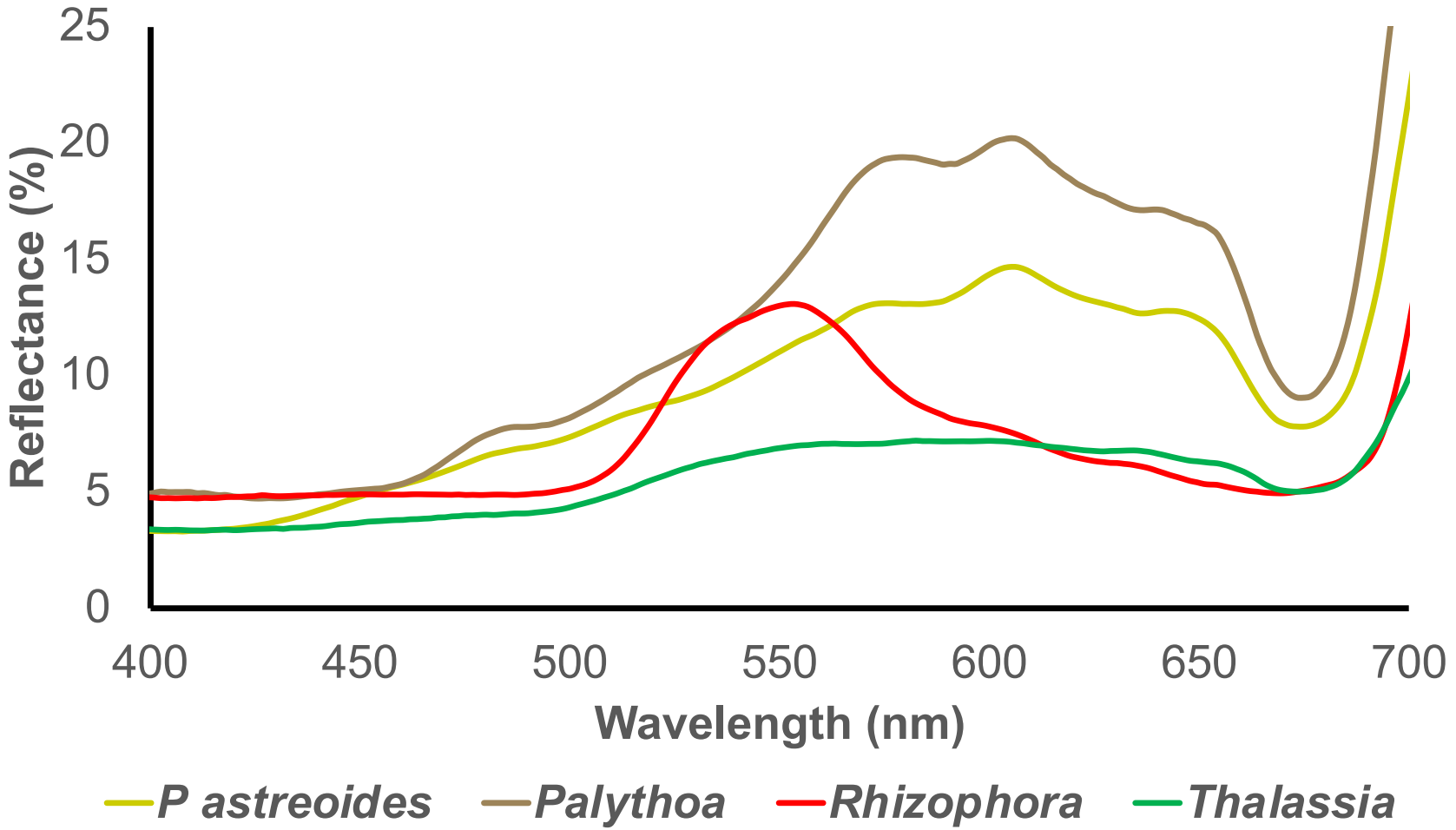
Credit: https://www.simply.science/images/content/biology/cell_biology/photosynthesis/conceptmap/Photosynthetic_pigments.html

Spectral Comparison of Different Coral Reef Components

Porites astreoides
(mustard hill coral)



Palythoa caribaeorum
(zoanthid)



Rhizophora mangle
(red mangrove)

Thalassia testudinum
(turtle grass)

Torres-Pérez (Unpublished)

Multispectral vs. Hyperspectral

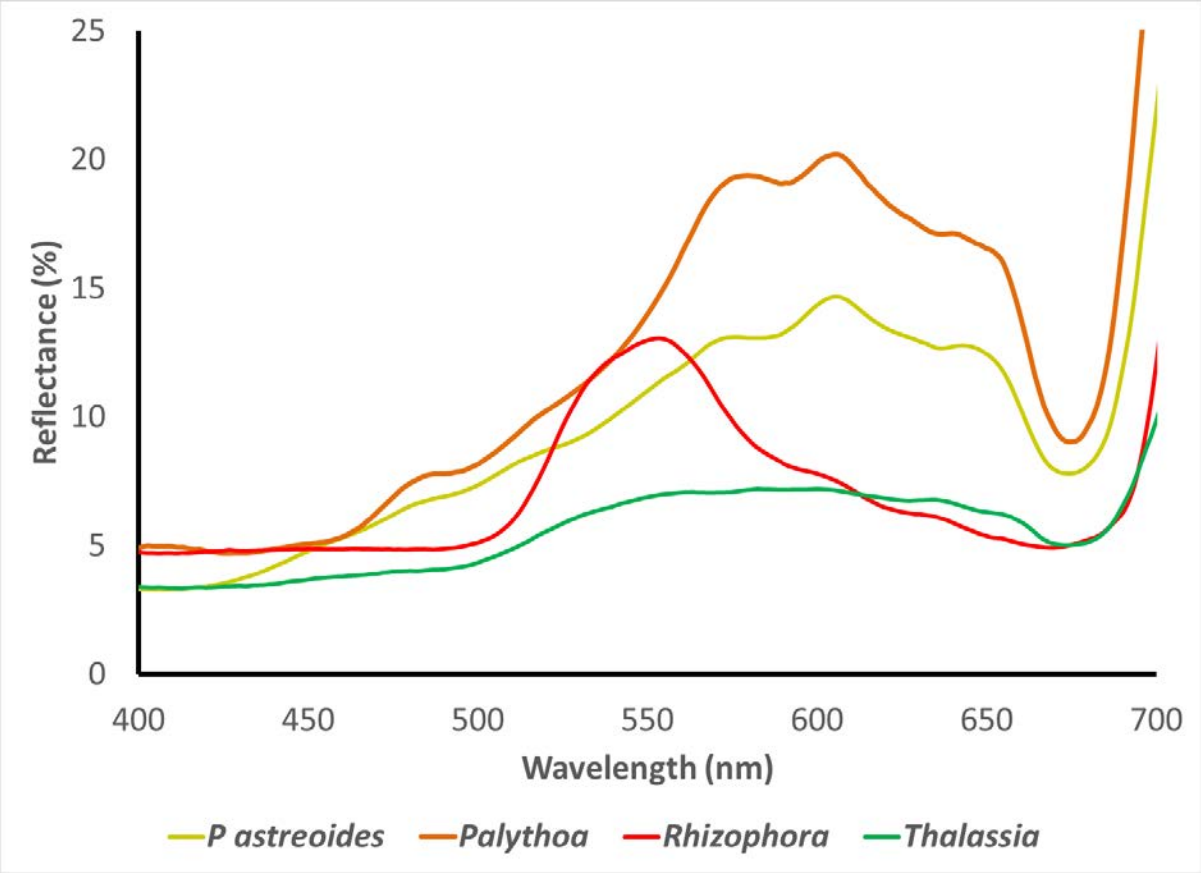
Multispectral

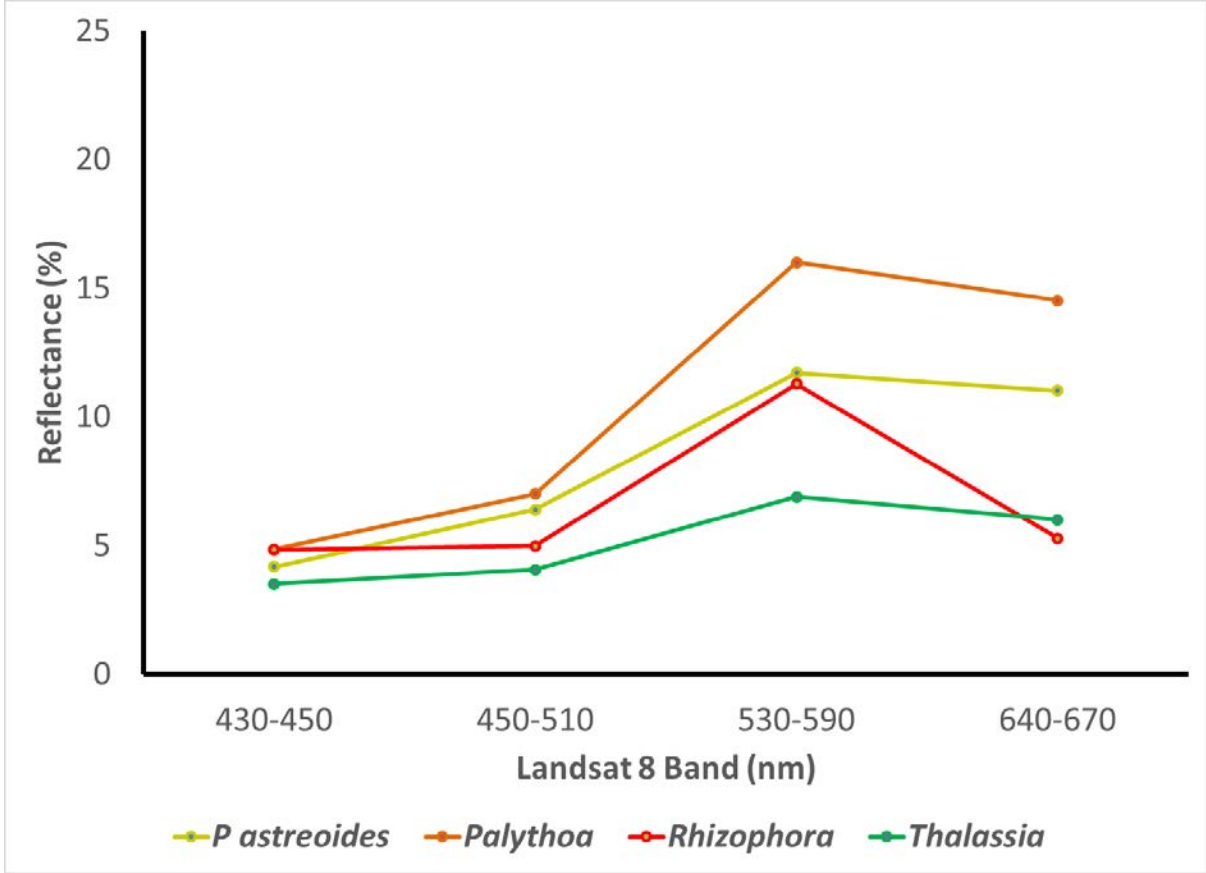
- Has been the norm with satellite sensors
- Limited in the number of spectral bands that can be used
- Has the advantage of longevity of datasets in some cases (Landsat, MODIS)
  - Landsat Series – Since 1972
  - MODIS – Since 1999 (Terra) and 2002 (Aqua)
- Fairly high temporal resolution (days to weeks)
  - Landsat – Every 16 days
  - MODIS – Every 1-2 days

Hyperspectral

- So far, very limited numbers of satellite-based sensors
- Hyperion – On board EO-1 spacecraft (data available from 2000-2017; decommissioned in 2017); 30m resolution, 220 bands @10nm bandwidth
- Some are mission specific
  - (Hyperspectral Imager for the Coastal Ocean on board the ISS); Limited data set (2009-2014)
- Airborne Sensors
  - Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)
  - AVIRIS-New Generation (AVIRIS-NG)
  - Portable Remote Imaging Spectrometer (PRISM)
- Lately, development of hyperspectral cameras for Unmanned Airborne Systems (UAS) looks promising
- Upcoming Designated Deliverables and additional satellite-based sensors
  - Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)
  - Surface Biology and Geology (SBG)

Spectral Comparison of Different Coral Reef Components (Hyperspectral vs. Multispectral)





Torres-Pérez (Unpublished)

Considerations when Processing Hyperspectral Data

- Even adjacent bands can give different results.
  - It is important to iteratively assess which band is appropriate depending on the target.
- Typical atmospheric correction algorithms might need to be modified accordingly.
- For some sensors, additional georectification might be required.

Considerations when Processing Hyperspectral Data

- For HICO:
  - Multiple images of the same target do not always cover identical spatial coordinates.
  - Images of the same area are acquired at different times of the day and different angles due to the ISS orbit and repositioning.
  - Uncertainty with overpass predictions affects the deployment of field crews for vicarious data collection.

- For Airborne (AVIRIS, PRISM):
  - Field campaigns are often costly (>$200K).
  - Typical aircraft issues (pitch, roll, yaw) affect image acquisition and require additional processing.

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 satellite imagery.
- Characterization of these deep communities is important as they can be refugia of biodiversity.
  - Usually accessible with other means:
    - Side-scan and multibeam sonars
    - Underwater autonomous vehicles

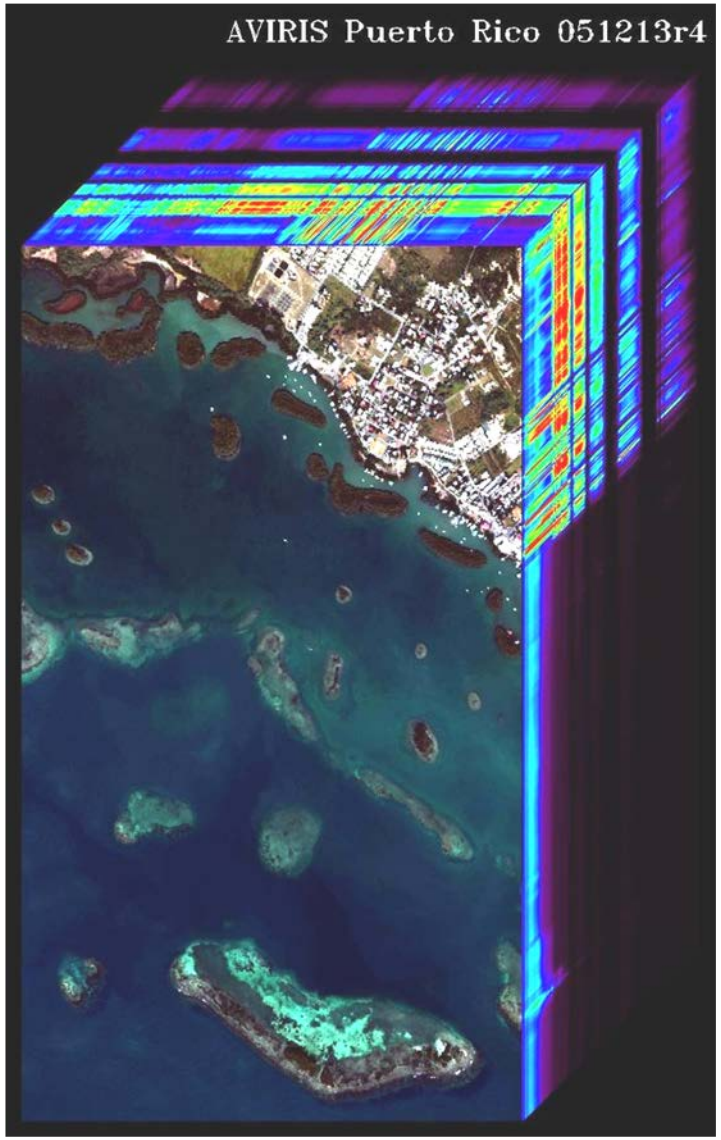
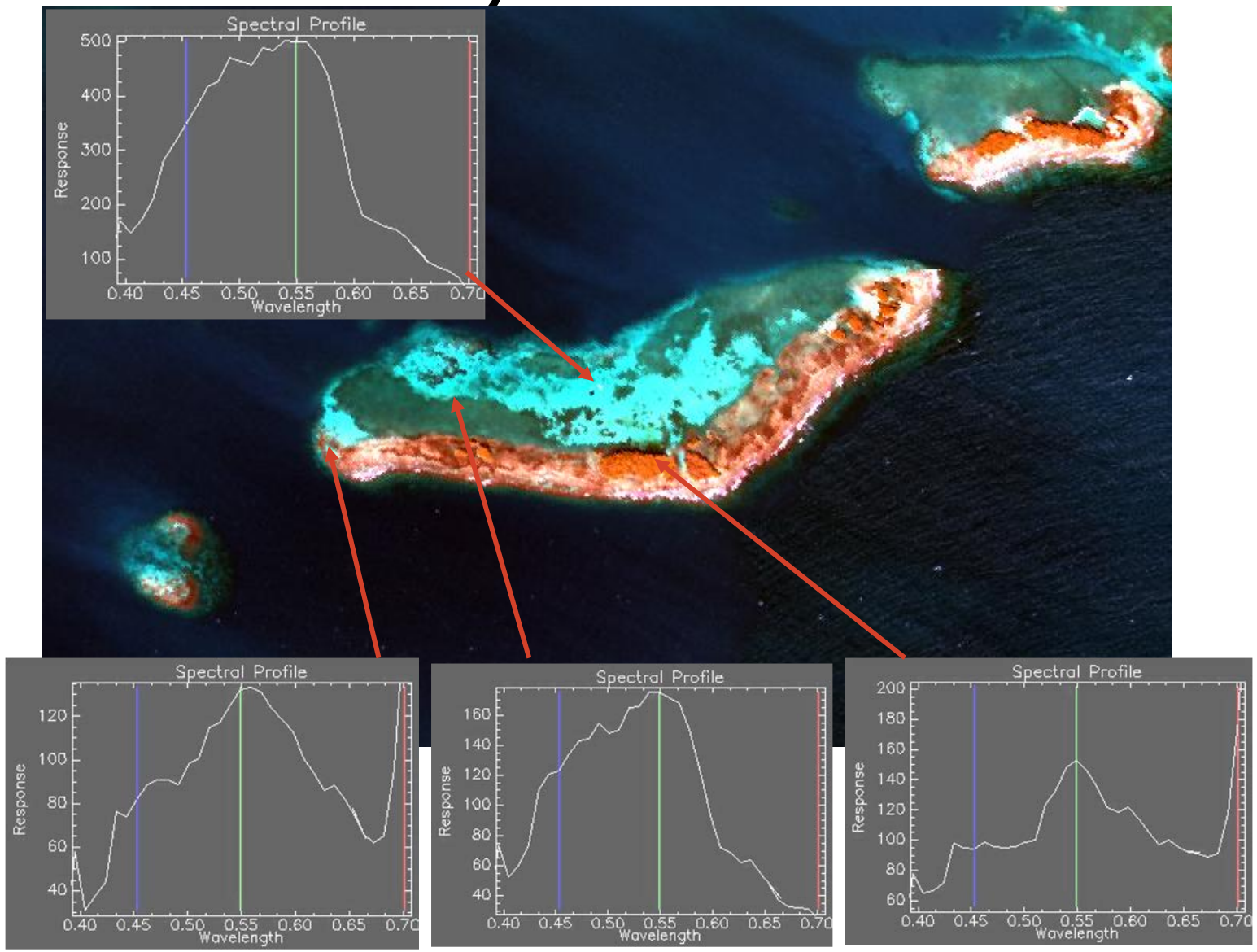


Image Credit: NASA JPL

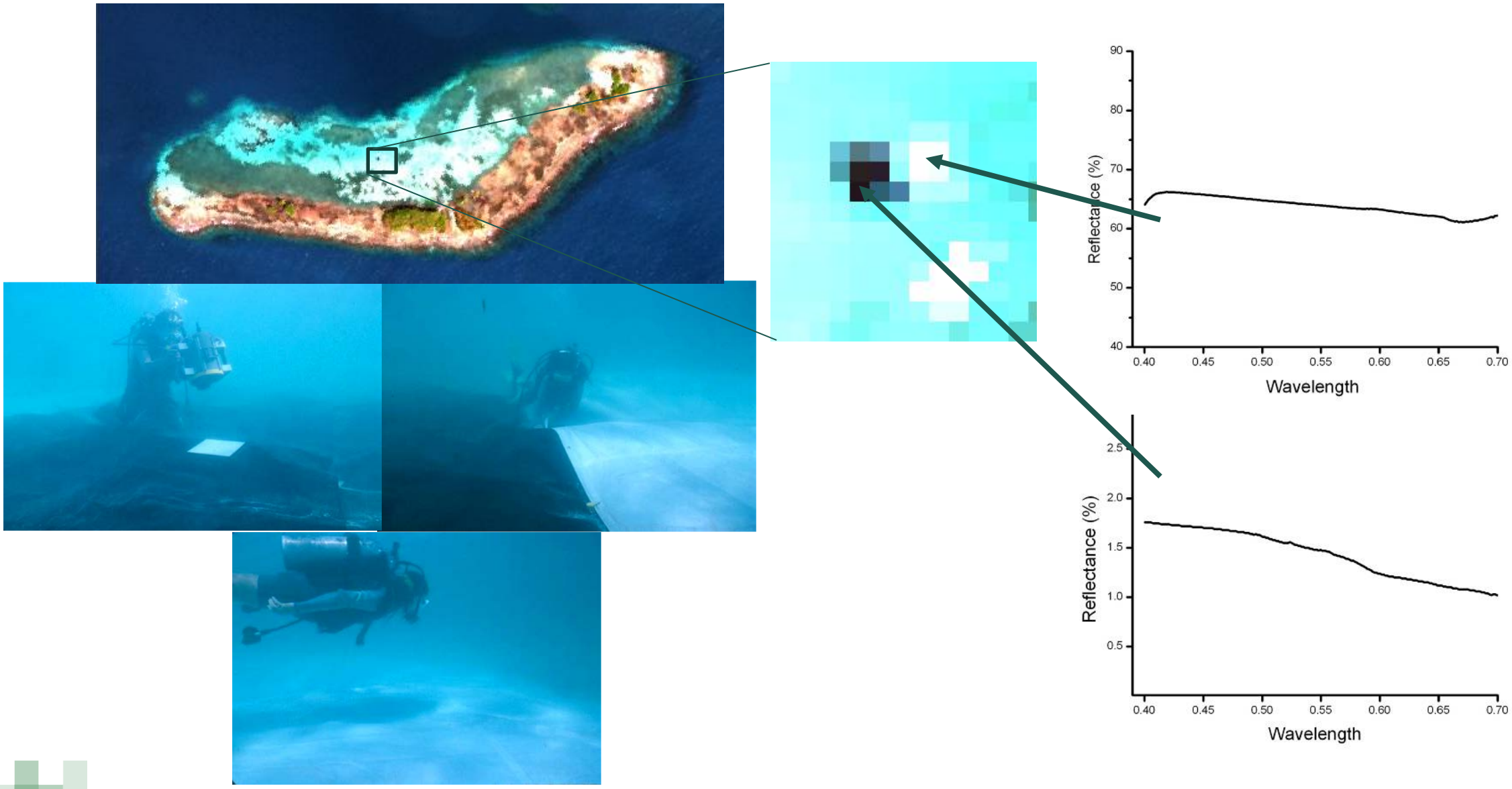
Examples of Hyperspectral Data Used for Coastal and Ocean Systems

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



Credit: Univ. PR Bio-optical Oceanography Lab

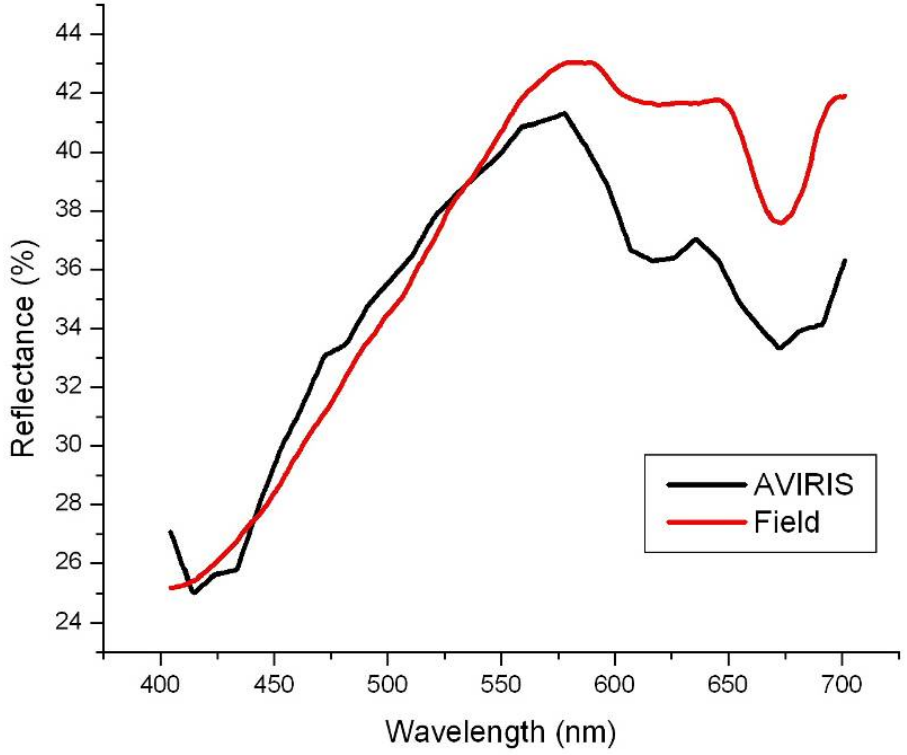
Underwater Flat-Field Calibration Targets for Water Column Correction



Credit: Univ. PR Bio-optical Oceanography Lab

Water Column Correction Validation

- AVIRIS 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.



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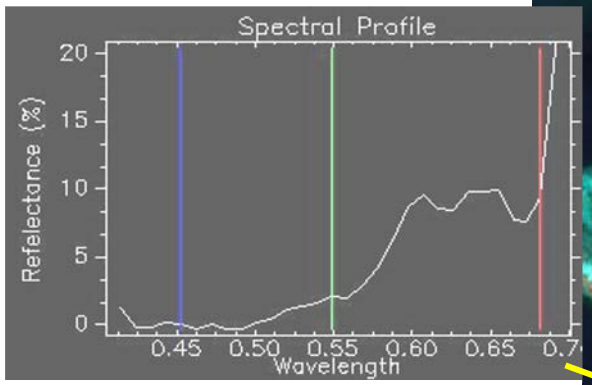
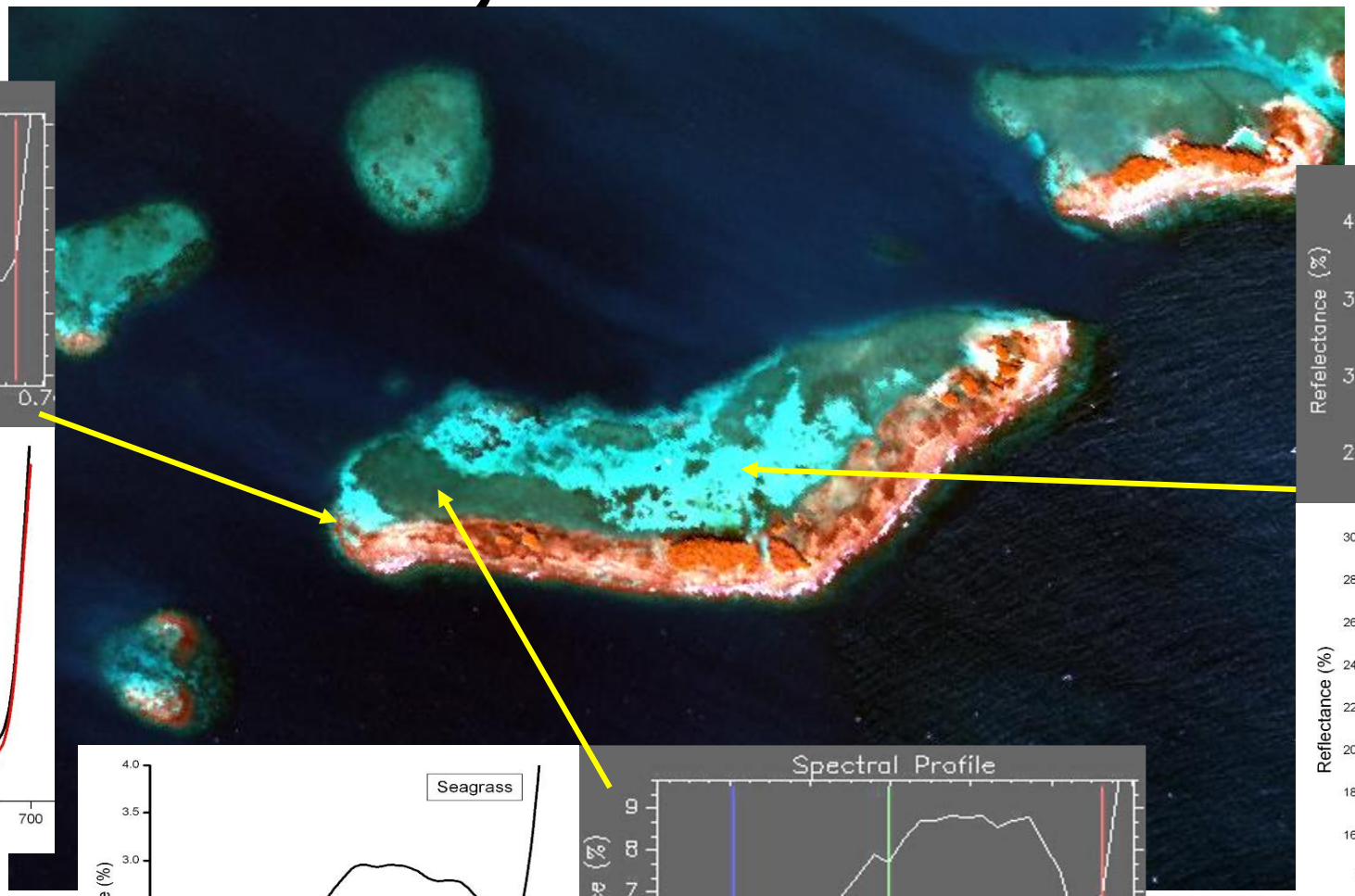
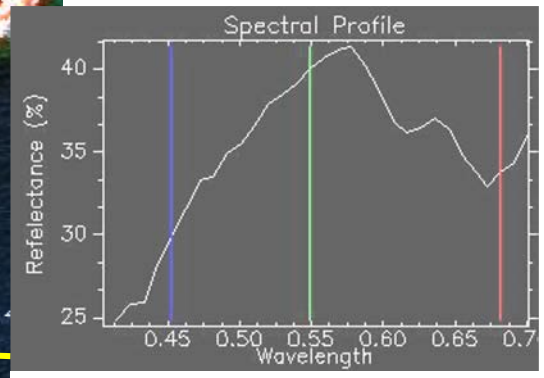
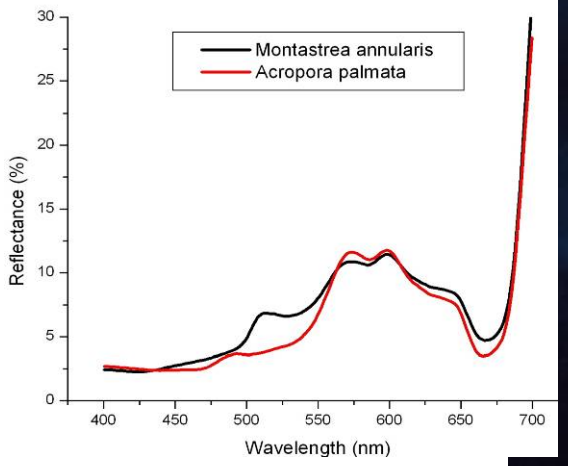
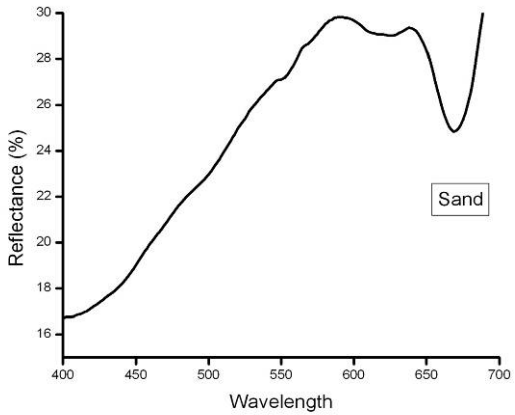
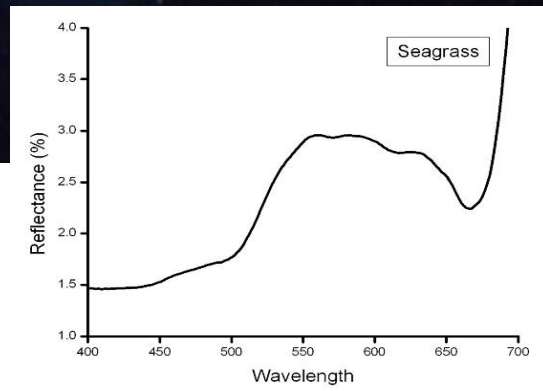


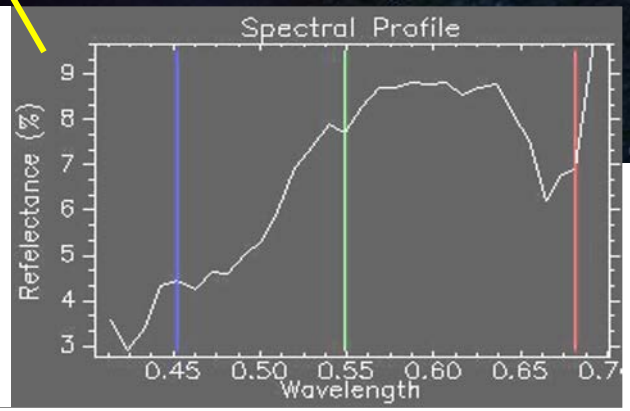












Credit: Univ. PR Bio-optical Oceanography Lab

COral Reef Airborne Laboratory (CORAL)

- Airborne mission flown using the Portable Remote Imaging Spectrometer (PRISM) to evaluate health and conditions of coral reef ecosystems
- Date Range: 2016-2019
- Spectral Resolution: 349.9-1053.5 nm (3.5 nm sampling)

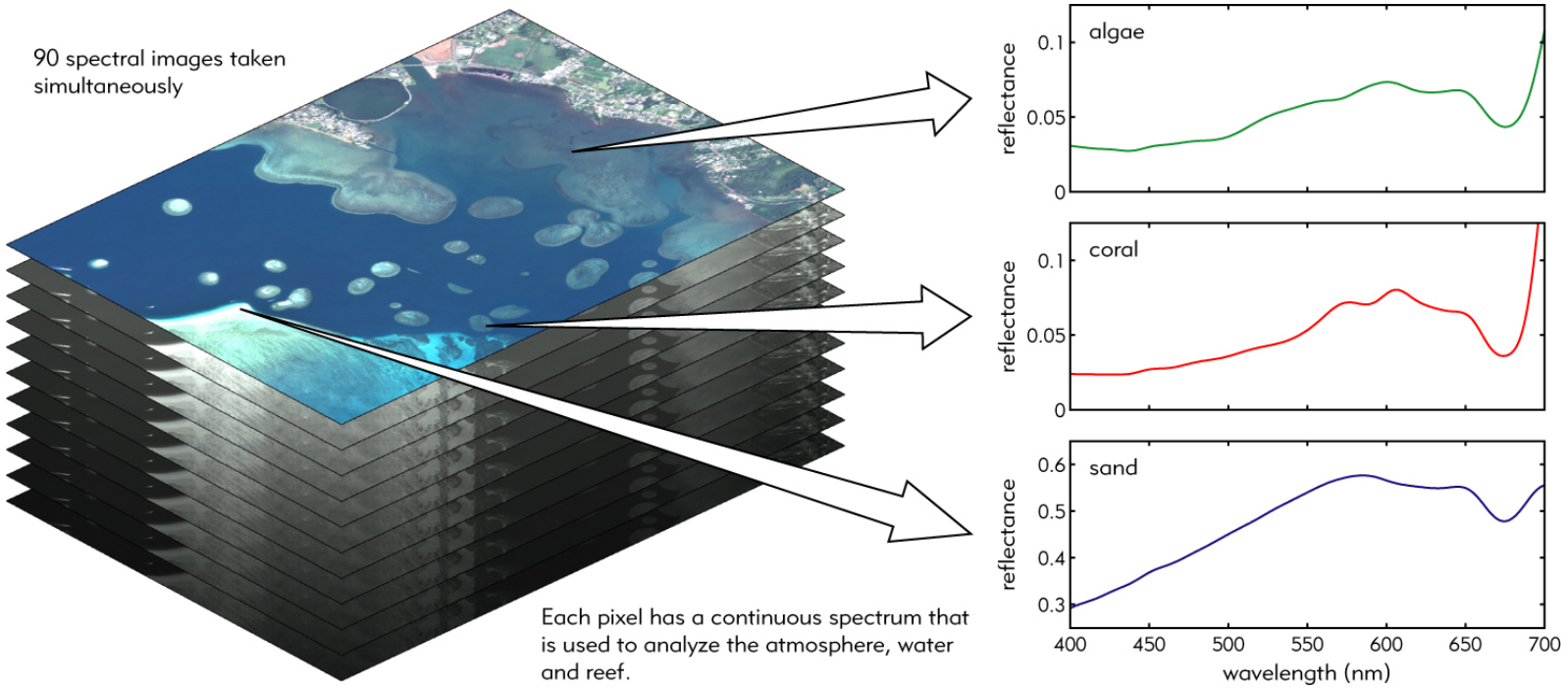
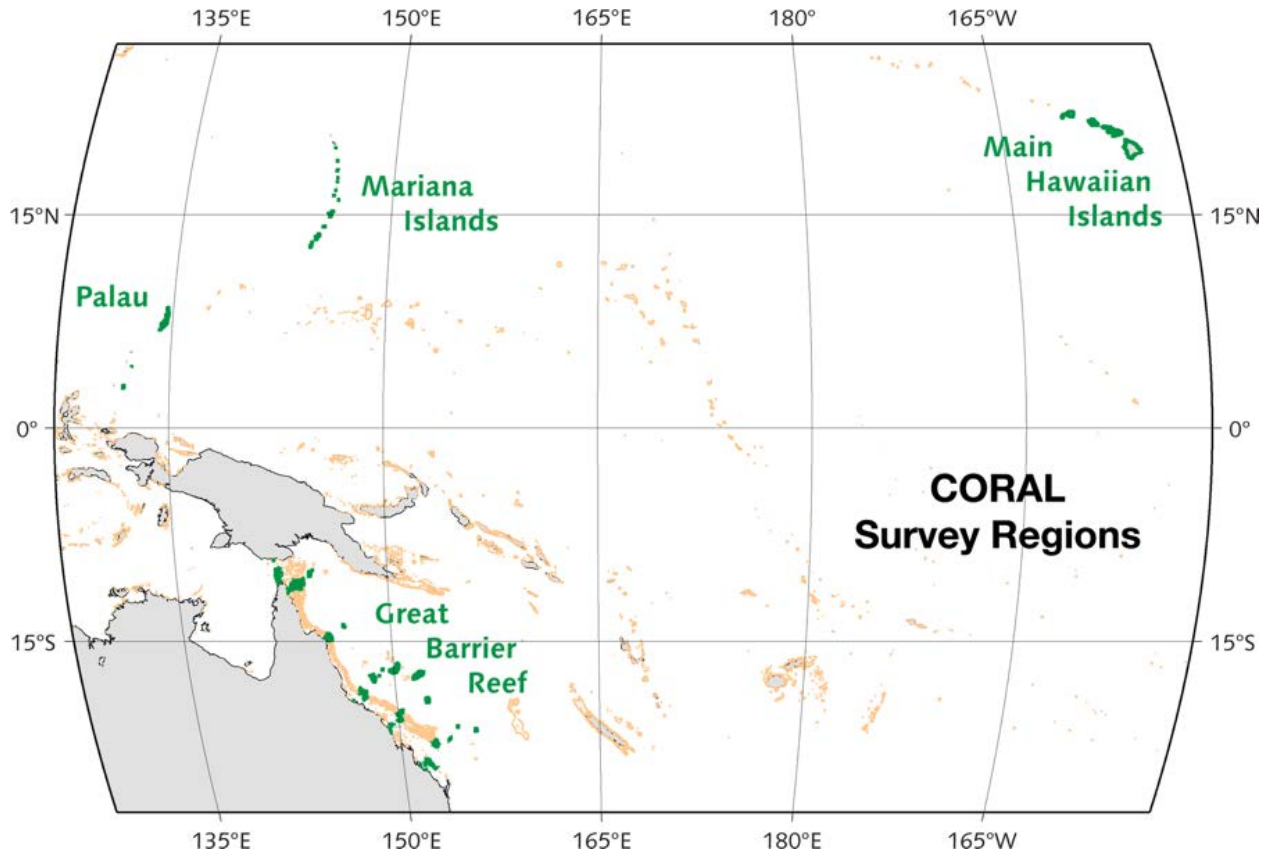
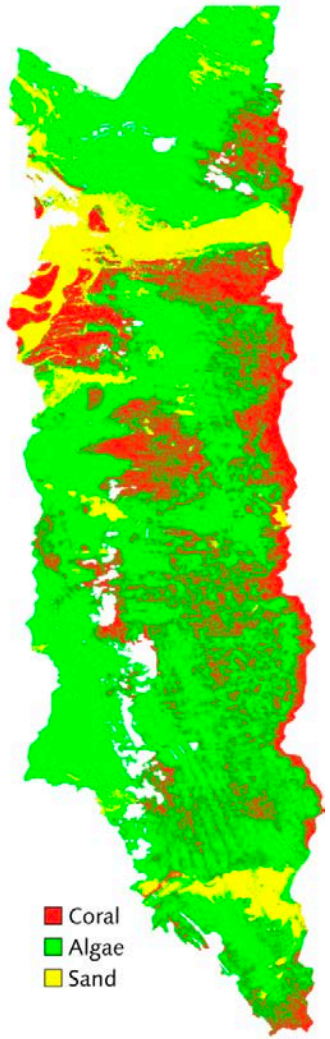


Image Credit: Eric Hochberg (CORAL PI)

COral Reef Airborne Laboratory (CORAL)

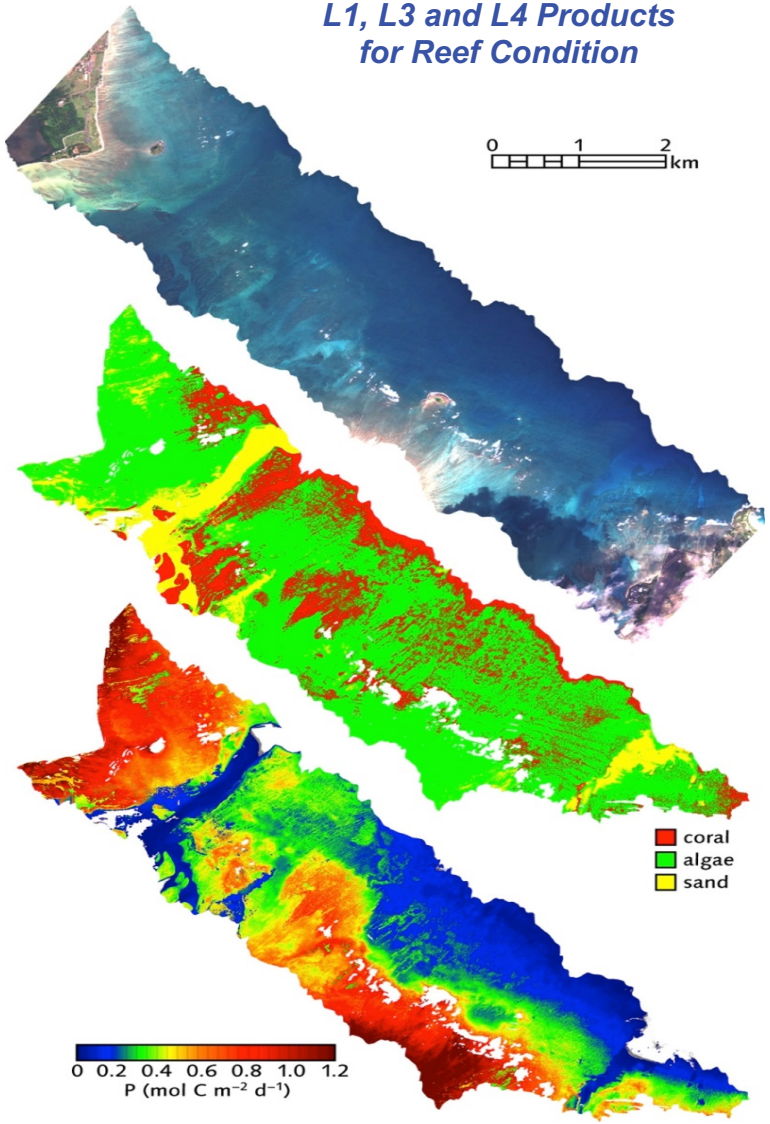




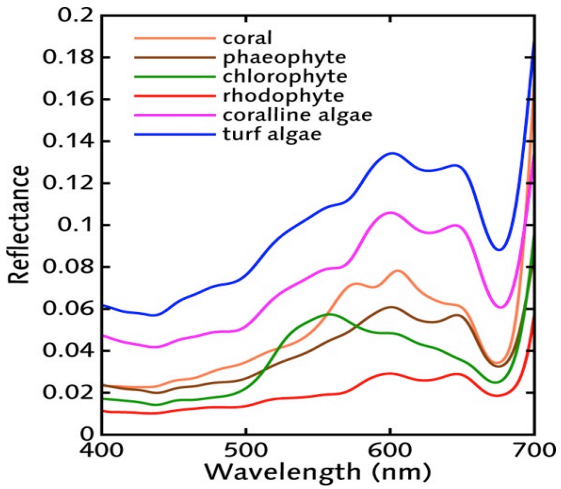
Six sub-campaigns near the Mariana Islands, Palau, portions of the Great Barrier Reef, and the Hawaiian Islands (top). CORAL image and classification (right) from the French Frigate Shoals in Northwestern Hawaii. Image Credit: NASA

COral Reef Airborne Laboratory (CORAL)

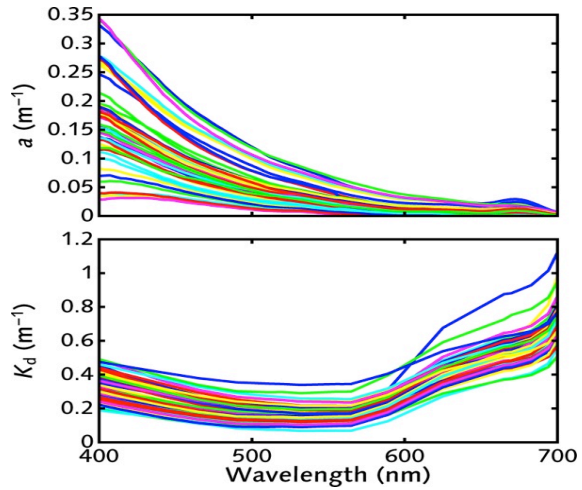
L1, L3 and L4 Products for Reef Condition



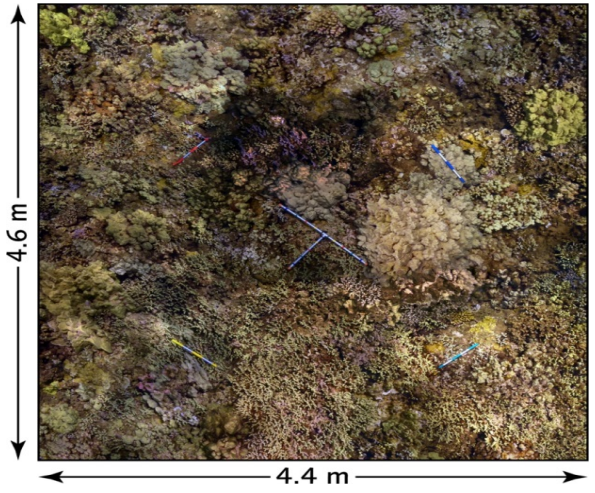
Benthic Reflectance Cal/Val



Water IOP/AOP Cal/Val



Benthic Cover Cal/Val via Photomosaic



Benthic Productivity Cal/Val via Gradient Flux

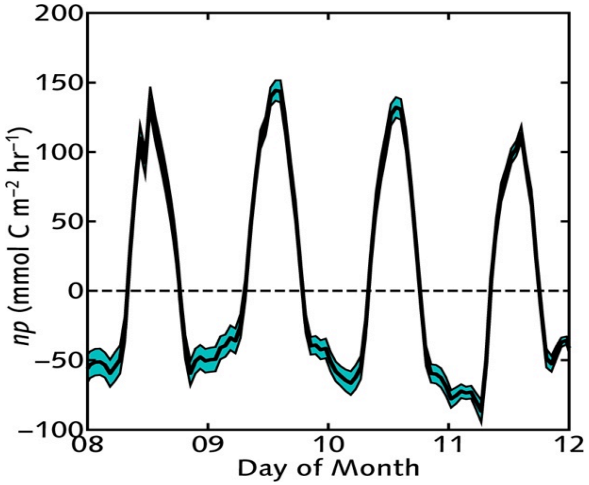
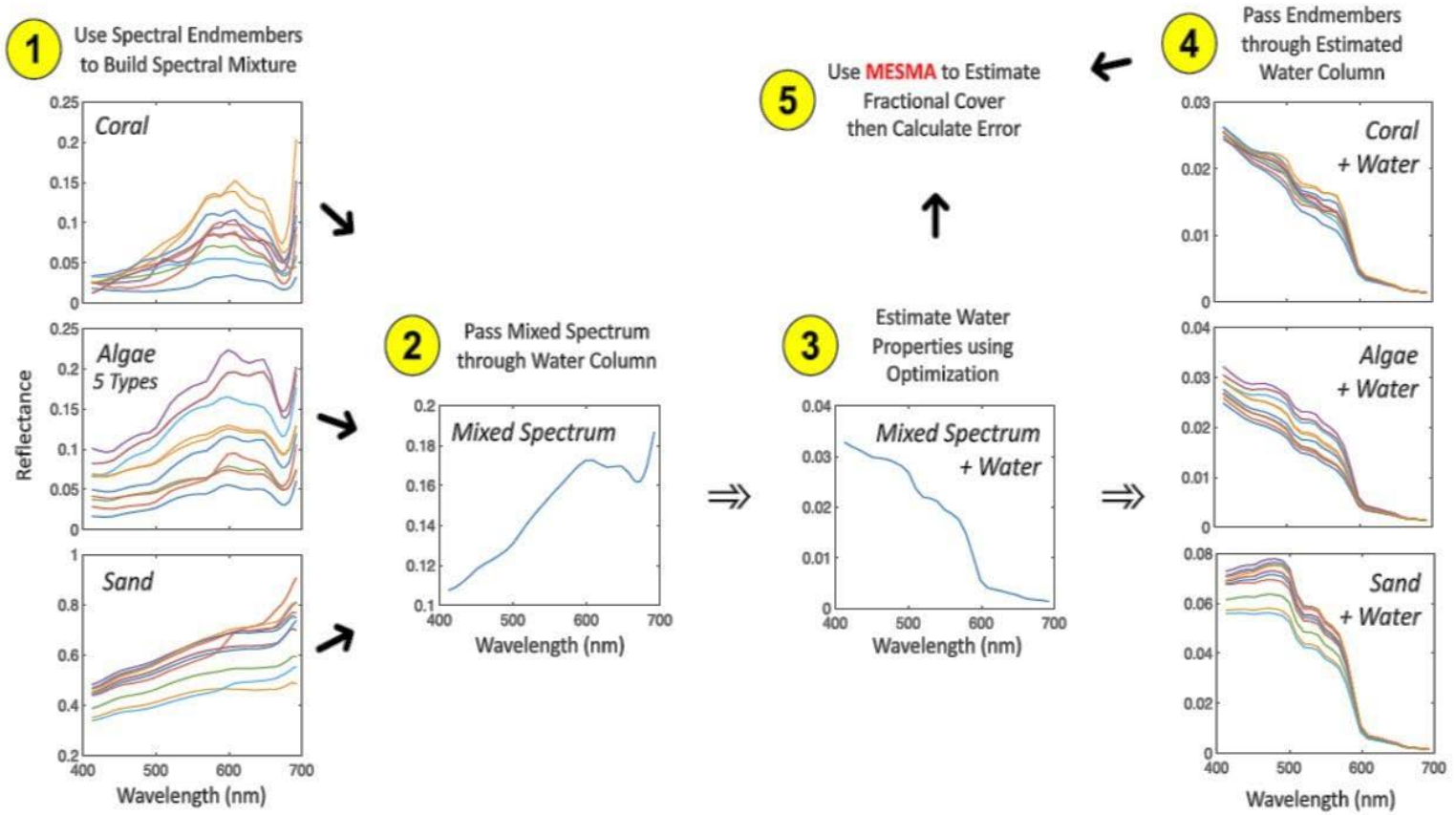


Image Credit: Eric Hochberg (CORAL PI)

Discrimination of Benthic Cover (CORAL)

- Benthic organisms have somewhat similar spectral signatures.
- Robust end-members data can aid in validating hyperspectral imagery.
- Fractional cover of coral and algae should be >25% for accurate estimates with current hyperspectral sensors.
  - Due to heterogeneity of reef substrate cover and current sensors' spatial resolutions



Credit: Bell et al (2020) RSE

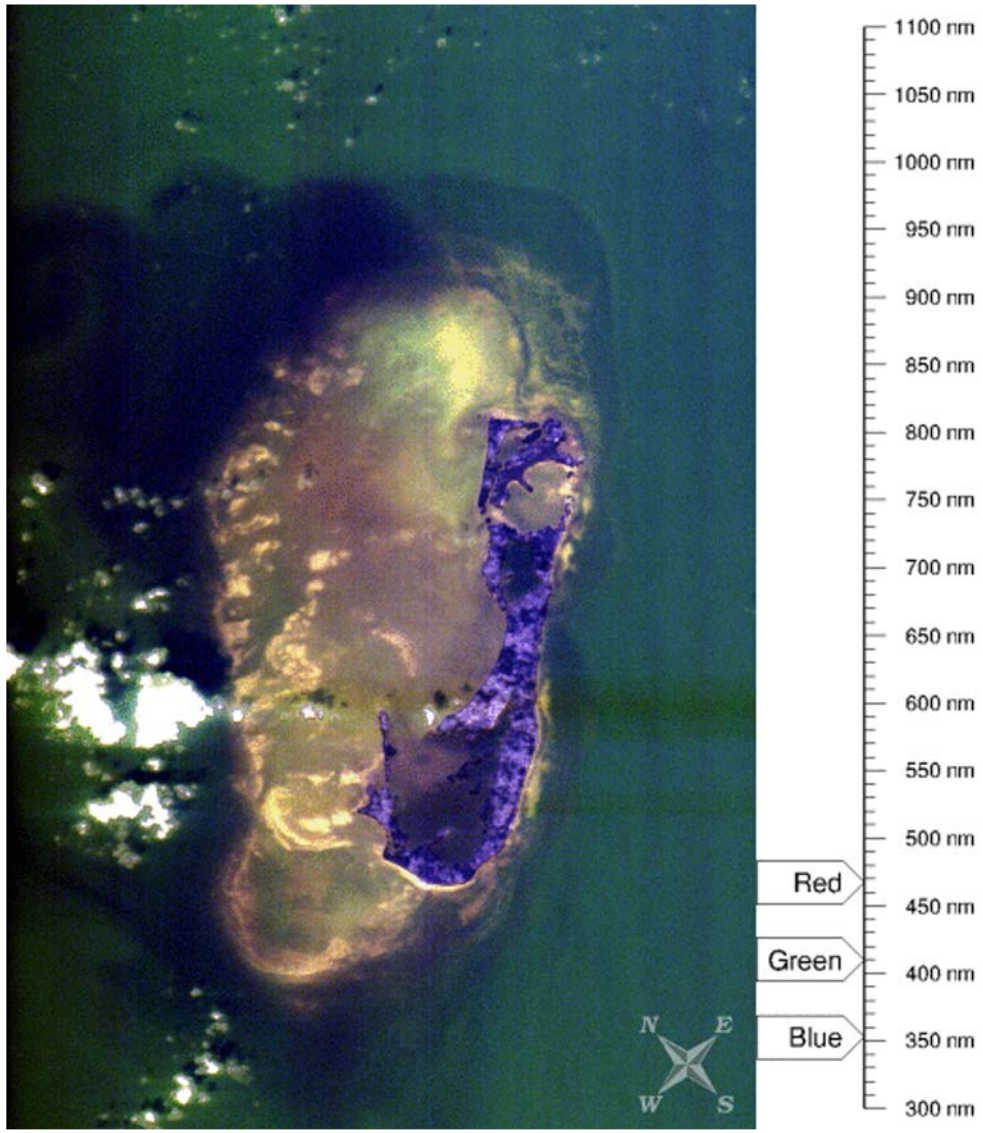
Hyperspectral Imager for Coastal Ocean (HICO)

- First spaceborne imaging spectrometer designed to sample the coastal ocean
  - Onboard the International Space Station (ISS)
- Date Range: 2009-2014
- Spatial Resolution: 90 m
- Spectral Resolution: 128 bands (400-900nm every 5.7nm)
- Temporal Resolution: ~3 days

HICO image of a massive Microcystis bloom in Western Lake Erie, Sept. 3, 2011. Image Credit: NASA

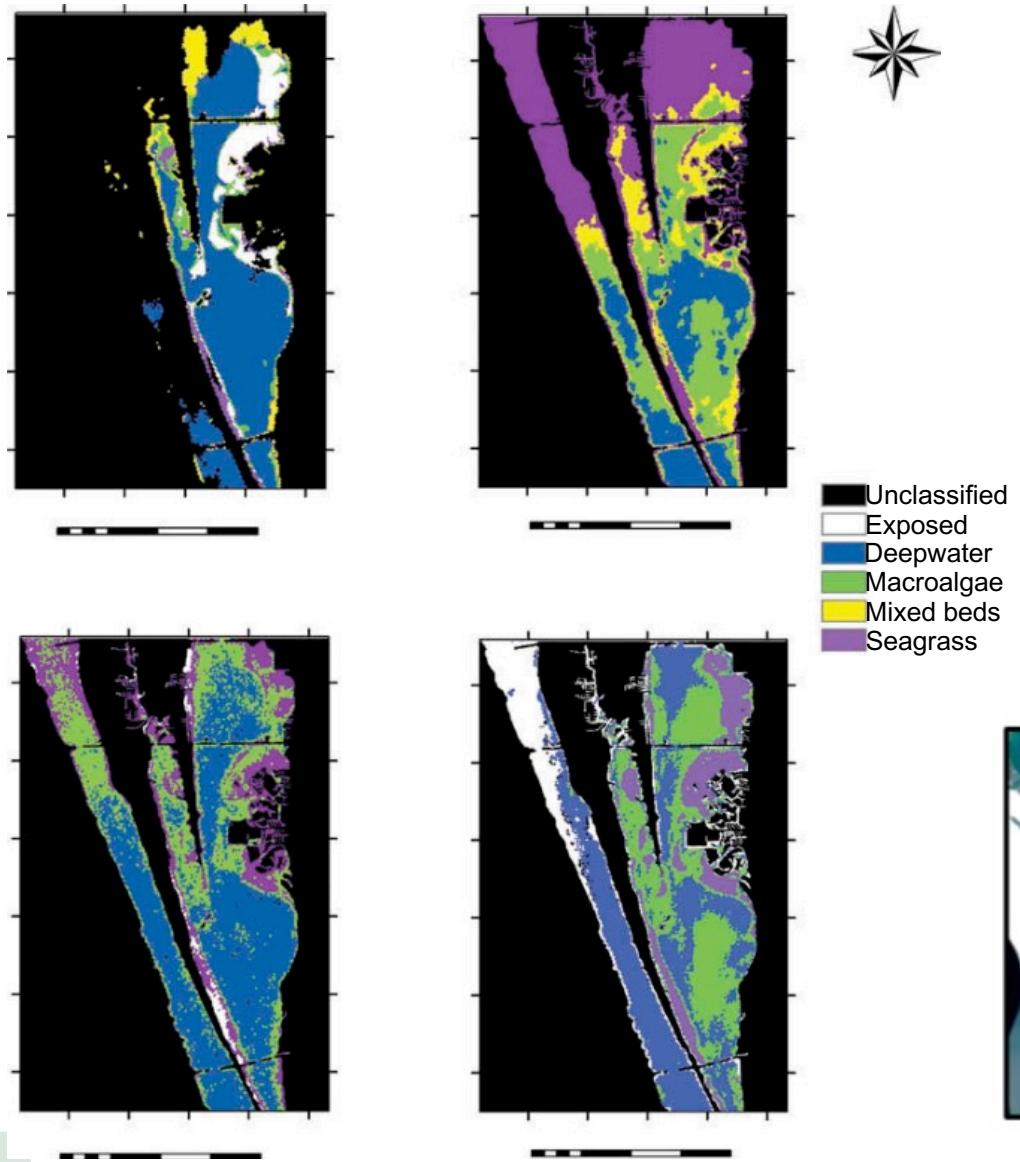
HICO

Image Credit: NASA

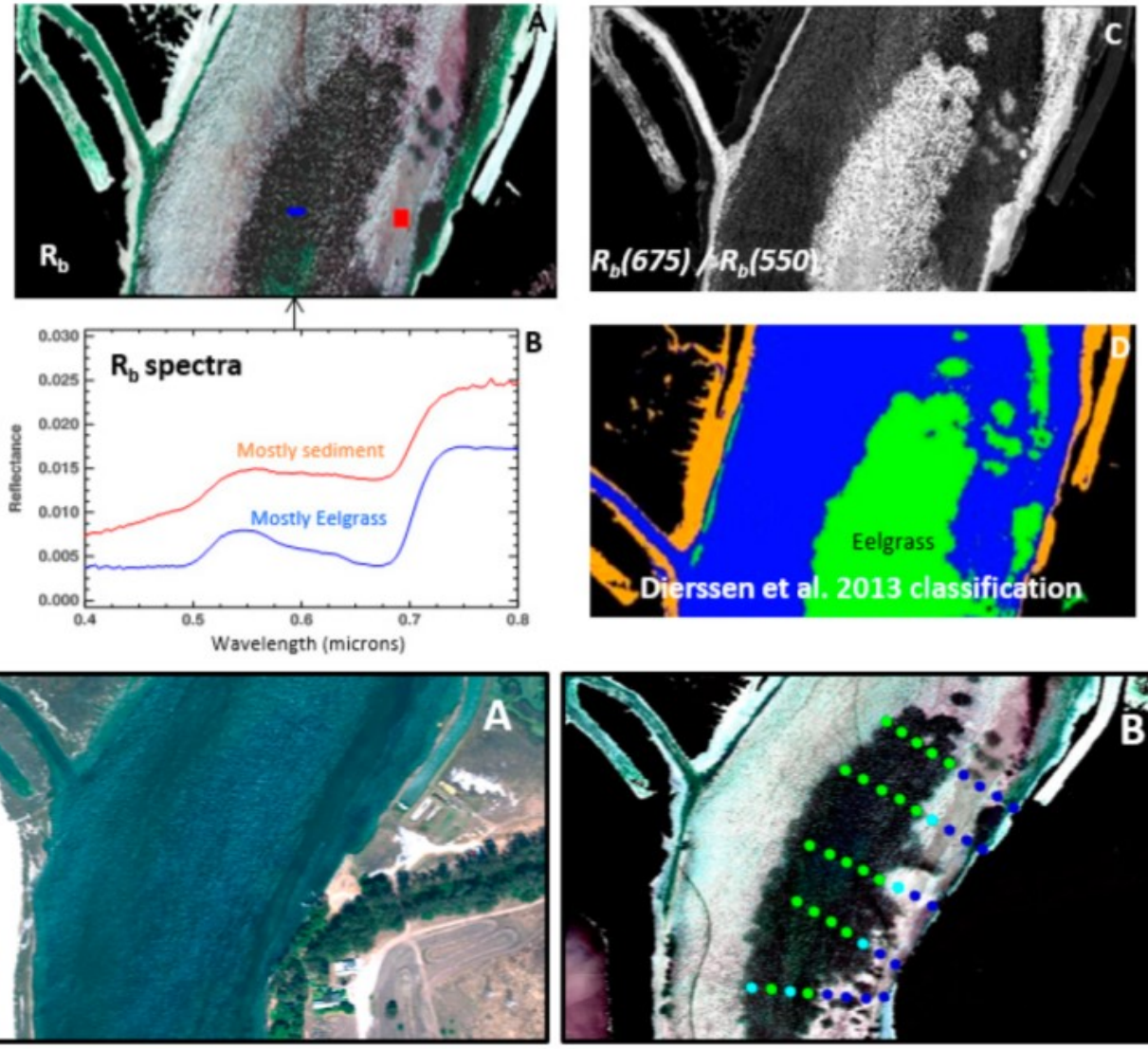


- Bermuda, August 2013
- This animation displays all 128 HICO bands, 3 at a time, to produce color.
- Island characteristics, shallow water components, and coral signatures can be examined.

Seagrass Mapping



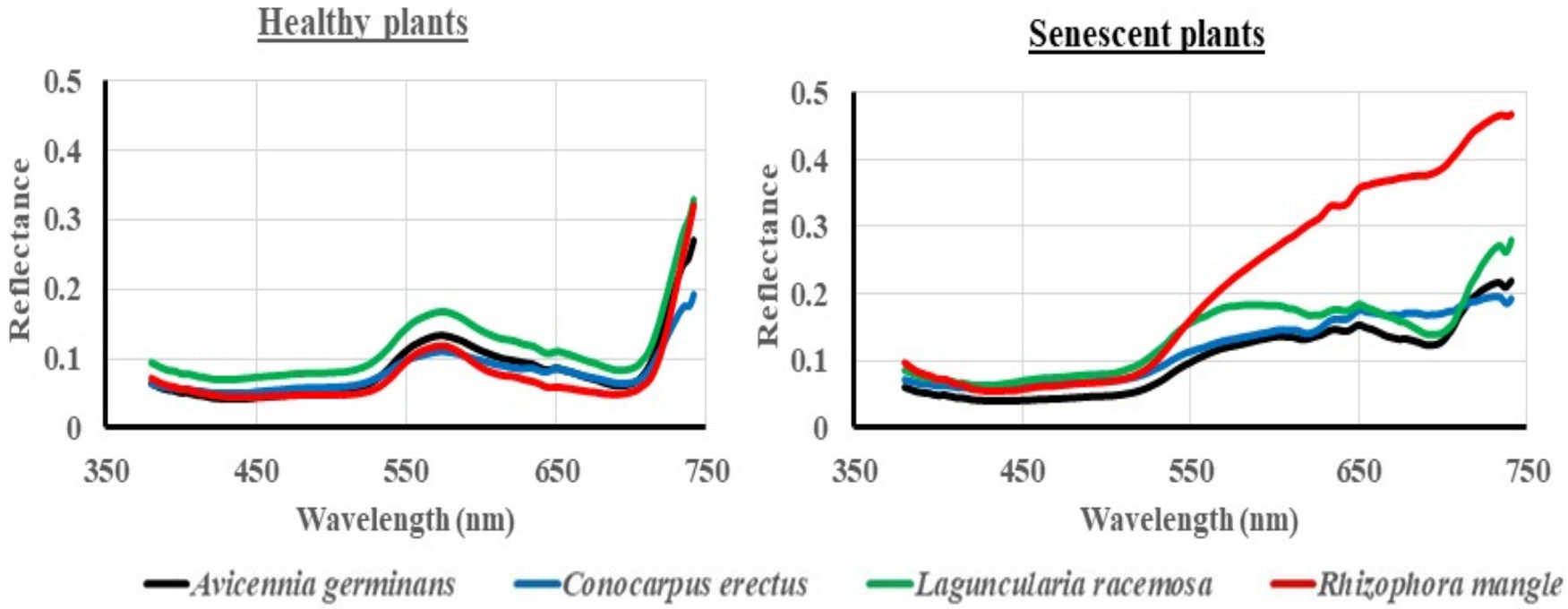
Credit: Cho et al (2013) GIScience & Rem Sens



Credit: Dierssen et al (2019) Remote Sensing

Mangrove Forests

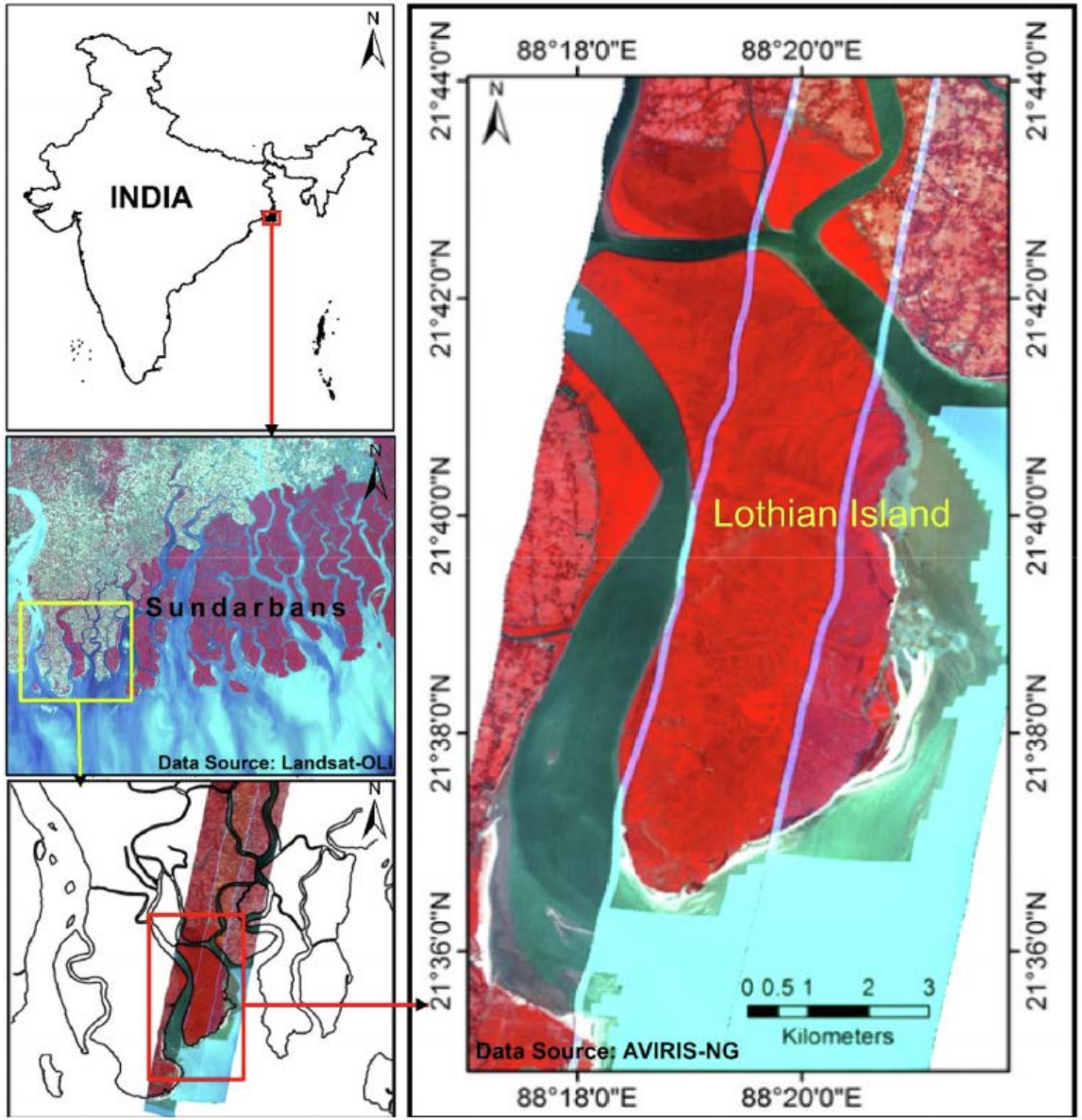
- Mangrove species are spectrally similar.
- Hyperspectral data can potentially be used for discriminating between healthy and non-healthy, or senescent, canopies.
- Depends on the spatial resolution of the imagery and the size and density of each species canopy.



Torres-Pérez (Unpublished)

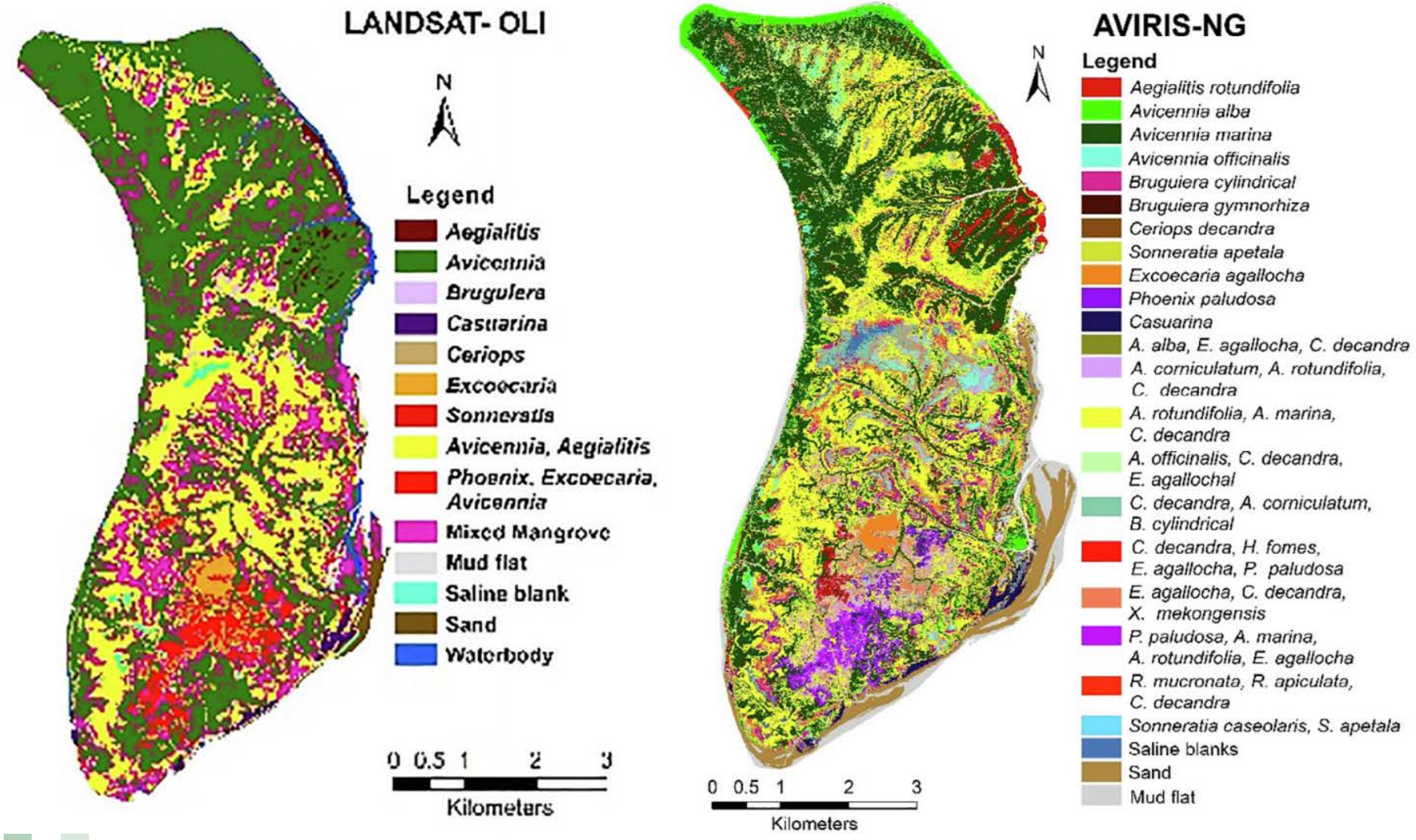
Mangrove Species Composition

- Mangrove ecosystems are vulnerable to changes in sea level and salinity.
- Some species of mangroves are more vulnerable than others.
- Preservation in the Lothian Island Wildlife Sanctuary in India relies on the monitoring of mangrove extent and species composition.
- AVIRIS-NG hyperspectral data was used to map vegetation at the genus and species level.



Credit: Hati et al. 2020

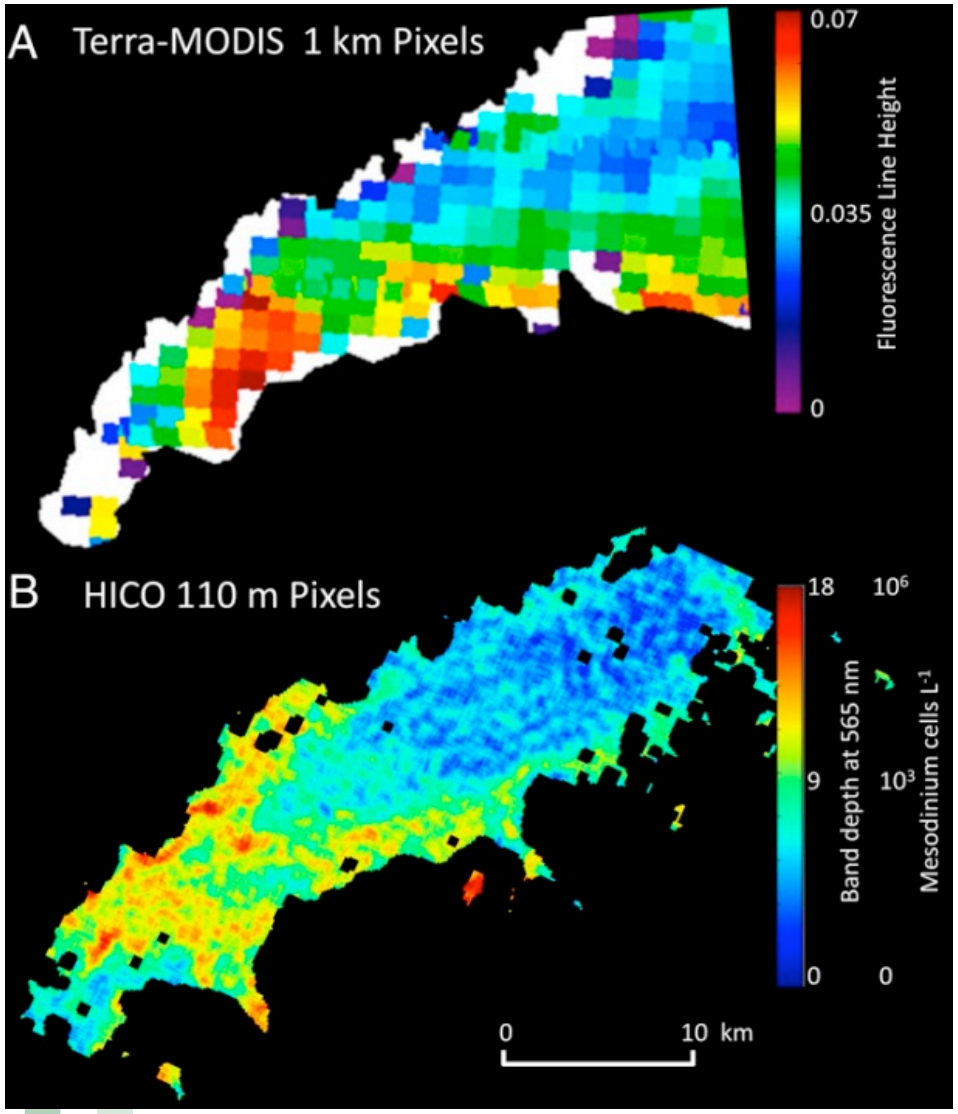
Mangrove Species Composition

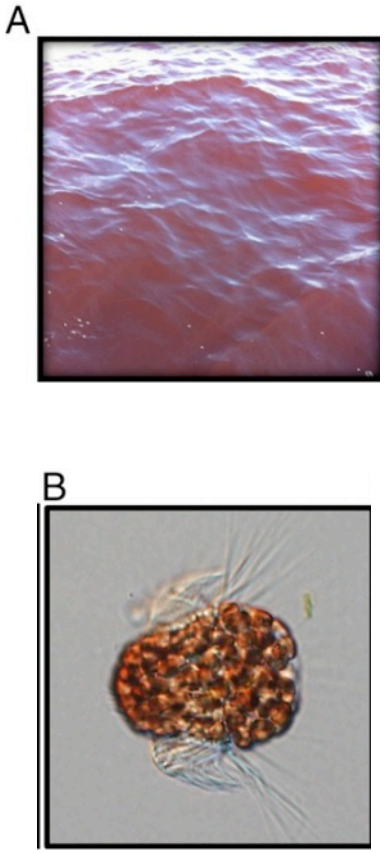


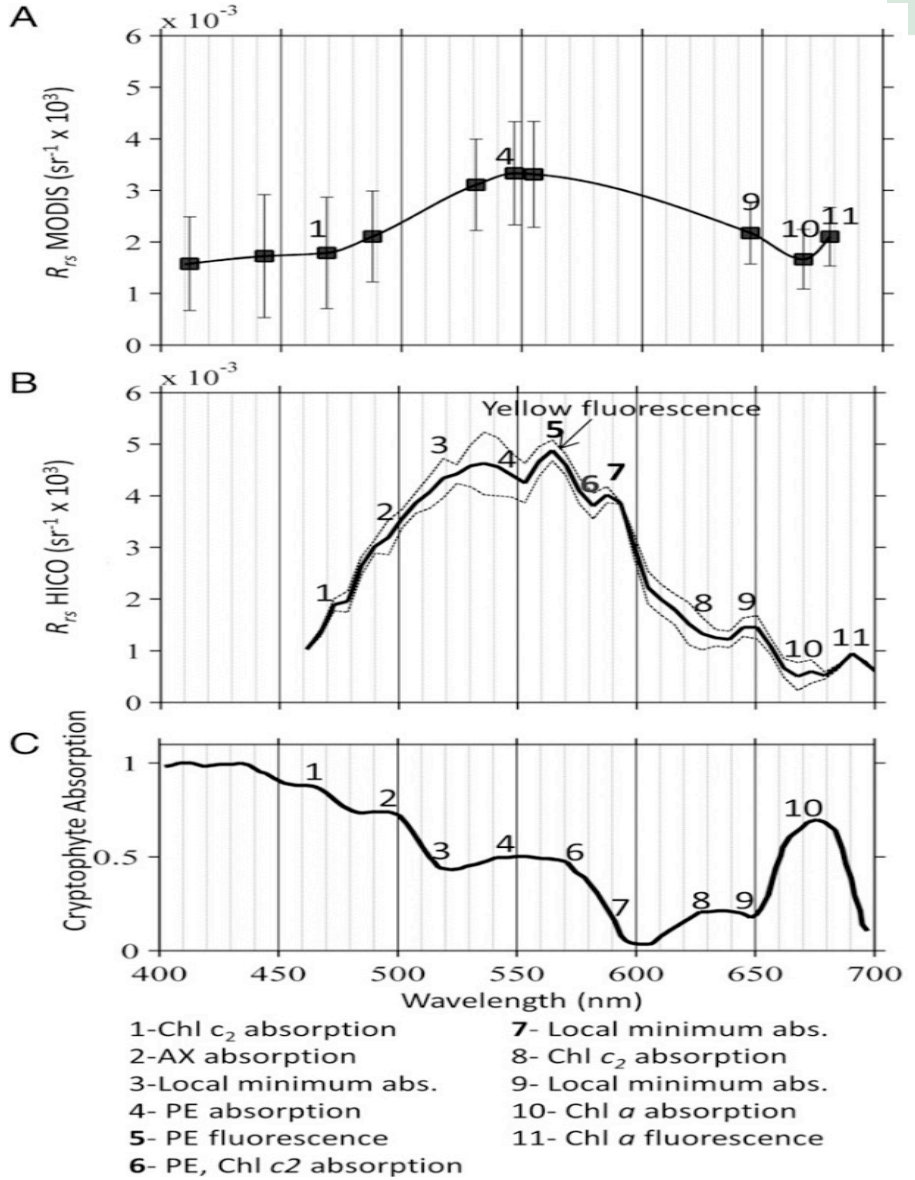
This case study compares the capabilities of multispectral (left) and hyperspectral (right) data to accurately map vegetation composition. Hyperspectral data was able to differentiate vegetation species in many cases and provided more accurate classifications.

Credit: Hati et al. 2020

Plankton Blooms

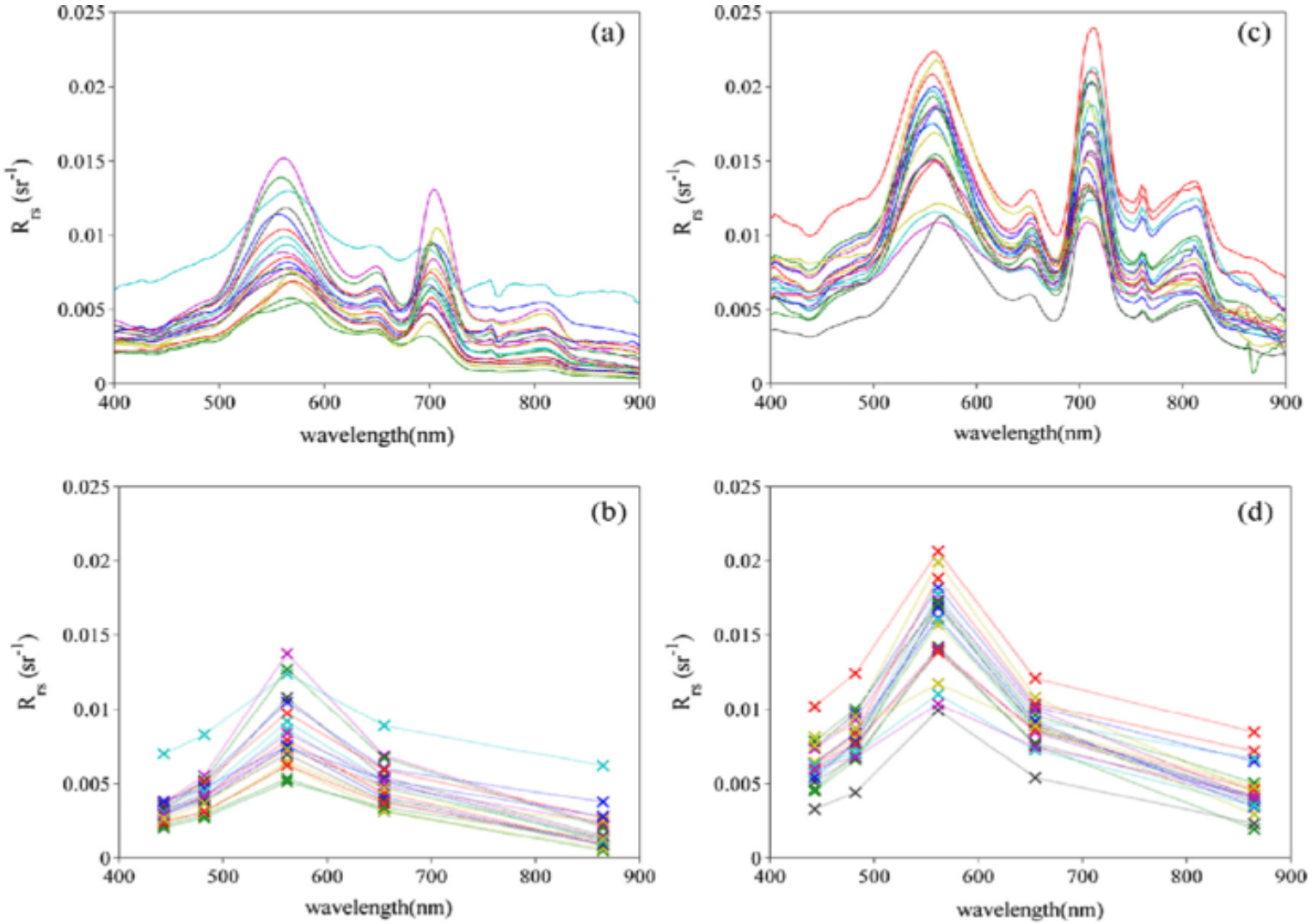






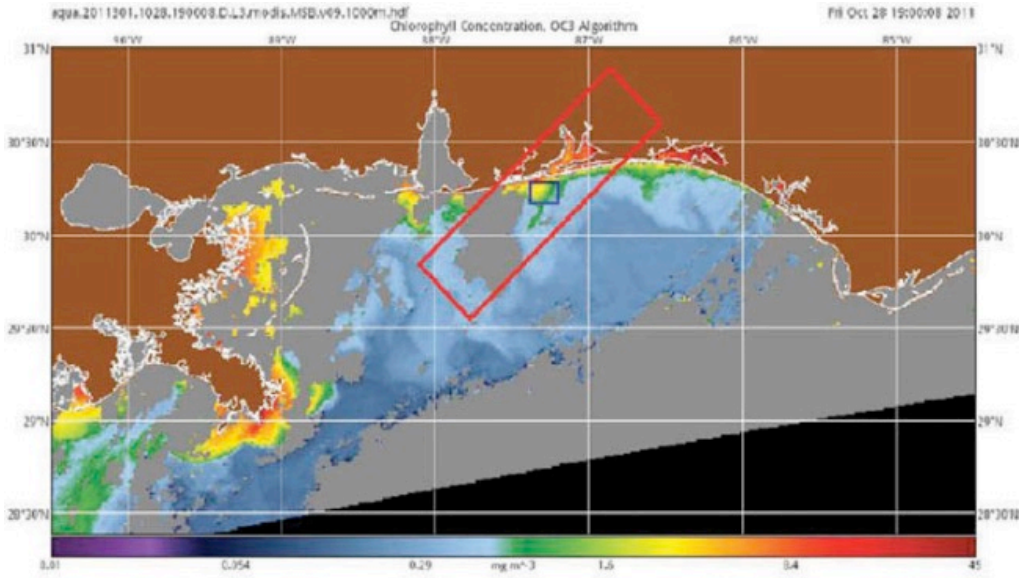
Credit: Dierssen et al (2015)

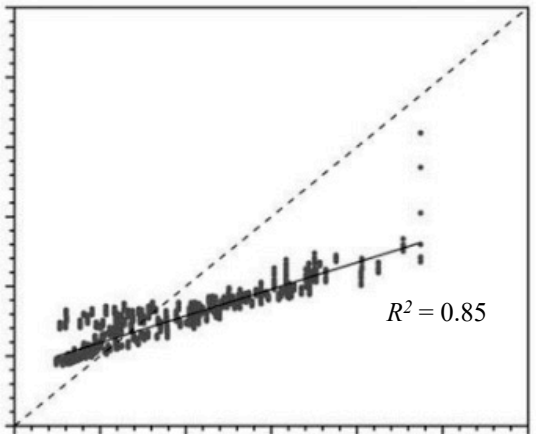
Multispectral vs. Hyperspectral for Water Quality Analysis

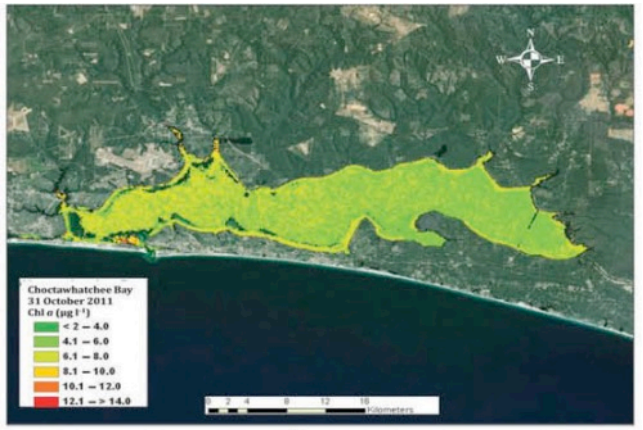


Comparison of Total Suspended Matter Concentrations. Credit: Bernardo et al 2017 Adv. Space Res.

Water Quality in a Coastal System







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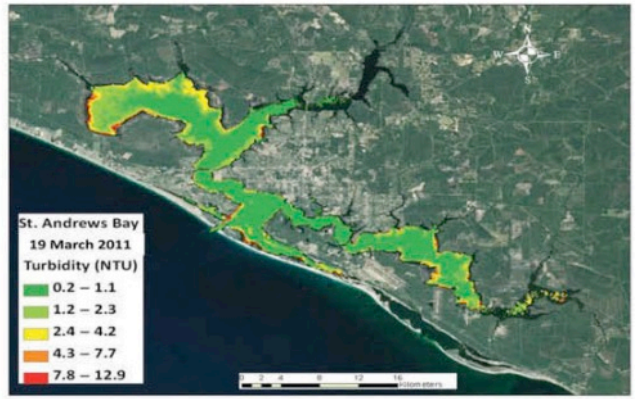
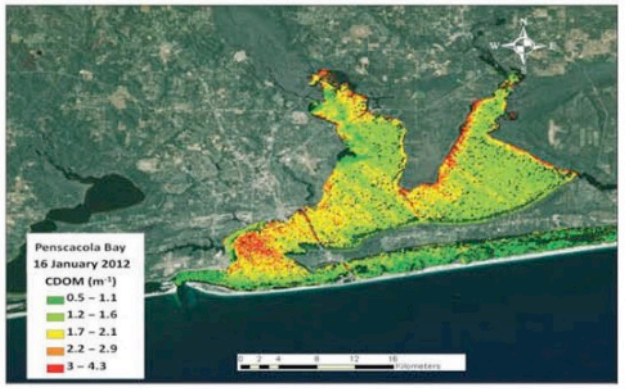
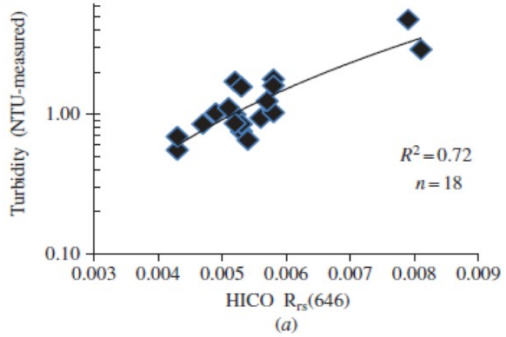


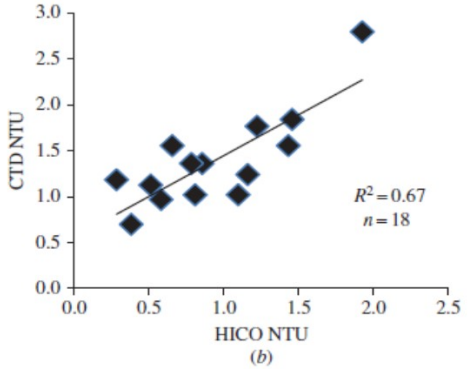
(b)



(c)



(a)



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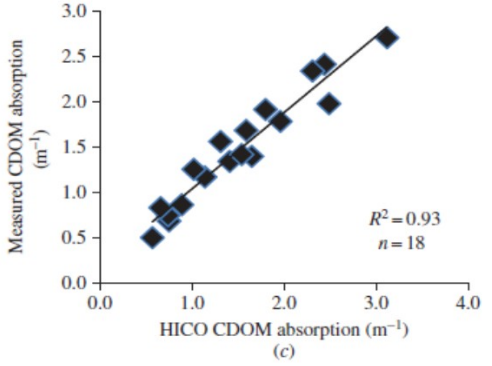


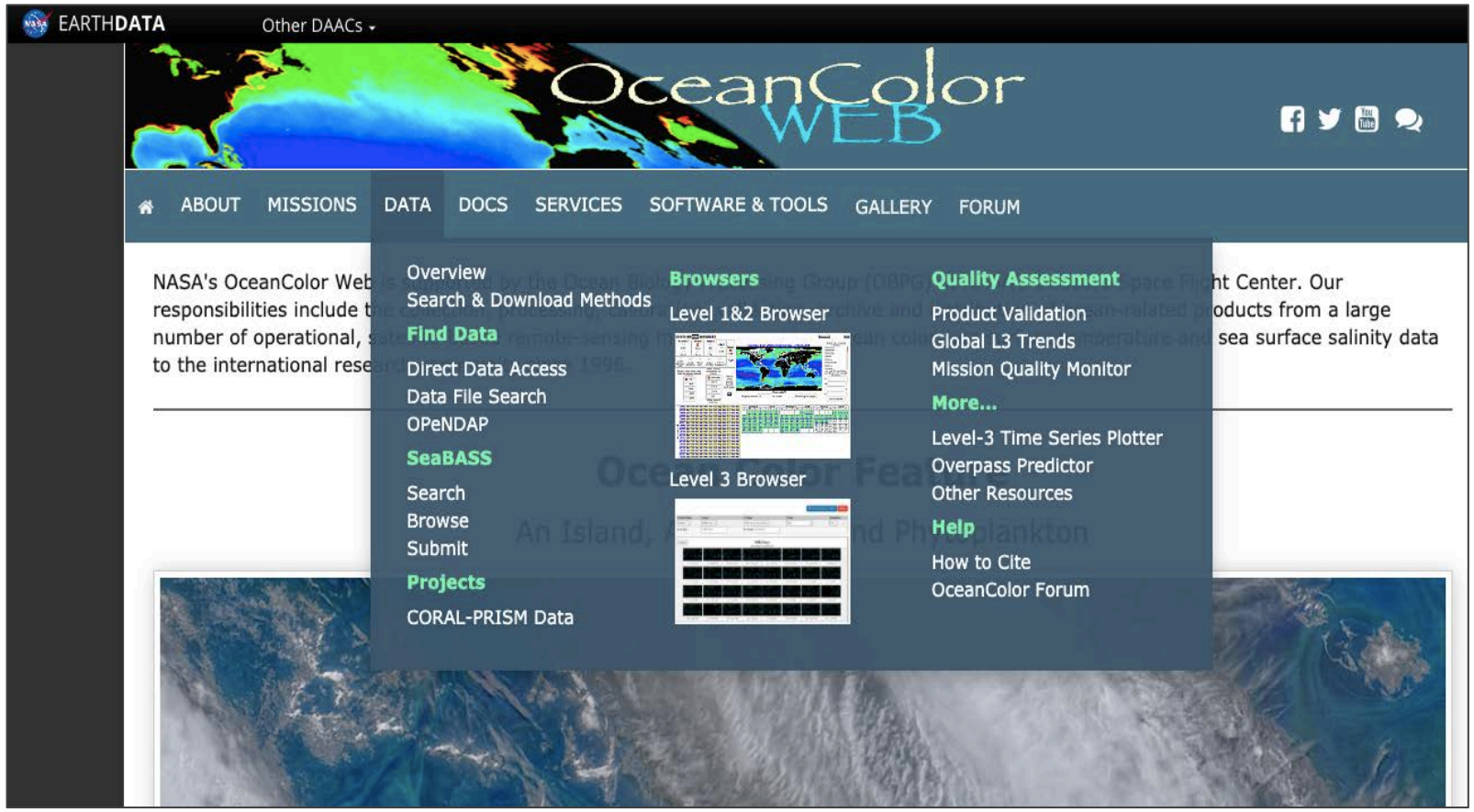
(c)

Credit: Keith et al (2014) Int J Rem Sens

Hyperspectral Data Acquisition and Display for Coastal and Ocean Systems

NASA OceanColor Web

- OceanColor Web data browsers can be used to filter and access data from ocean and coastal sensors.
- Data search criteria include…
  - Data product type
  - Sensor
  - Spatial extent
  - Date range



Link: https://oceancolor.gsfc.nasa.gov/

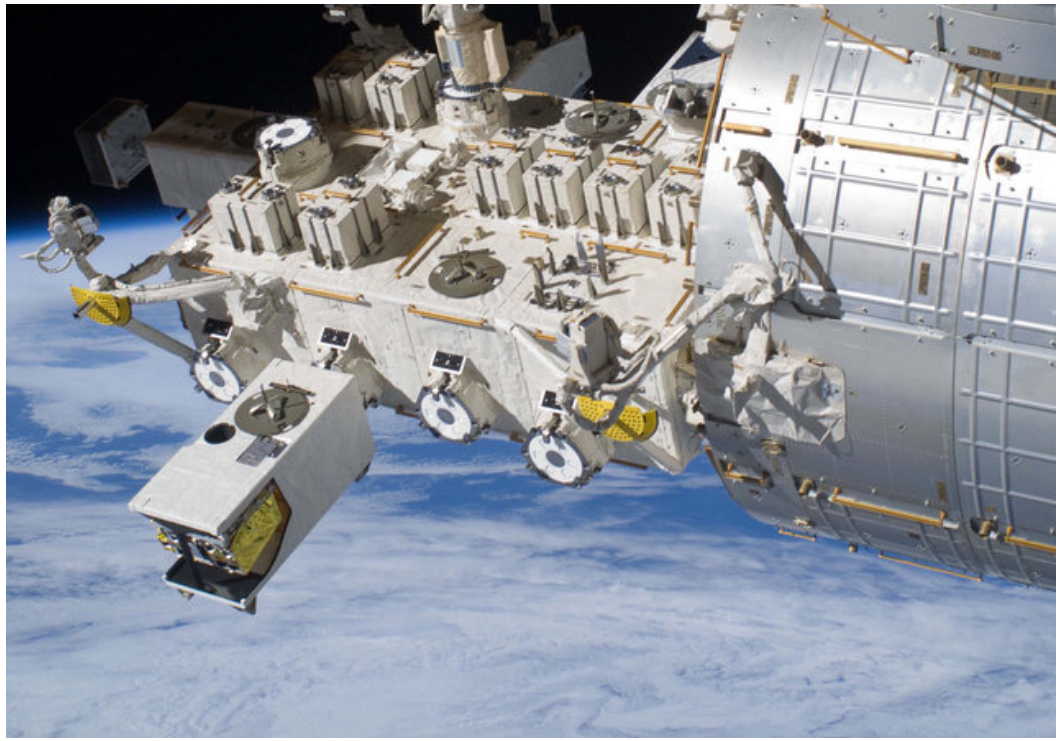
NASA OceanColor Web Login Requirements

- You will need to sign up for an account through NASA Earthdata to access data from OceanColor Web.
- Once registered with your preferred email, you will be able to access data downloads through the OceanColor Web browsers and directly download data products.

Link: https://urs.earthdata.nasa.gov/

HICO Review

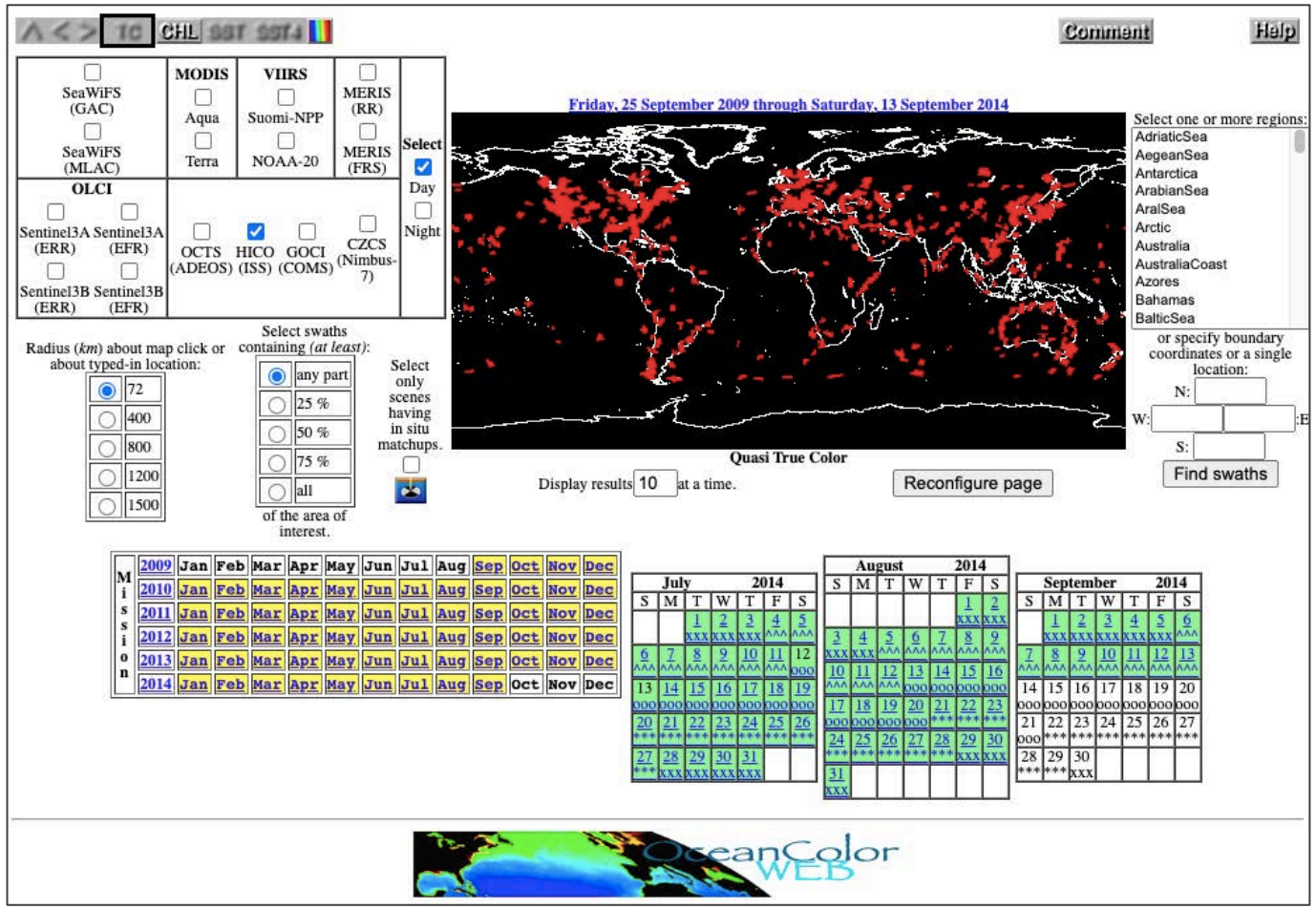
- Hyperspectral spaceborne data from **September 25th, 2009 – September 13th, 2014**
- Spatial **resolution of 90 meters** for all bands
- **128 unique spectral bands** ranging from 380 to 960 nanometers with a 5.7nm bandwidth
- Full data archive available online



Flight model HICO on the ISS.
Image Credit: Jeffrey H. Bowles, US NRL

Available HICO Data Products

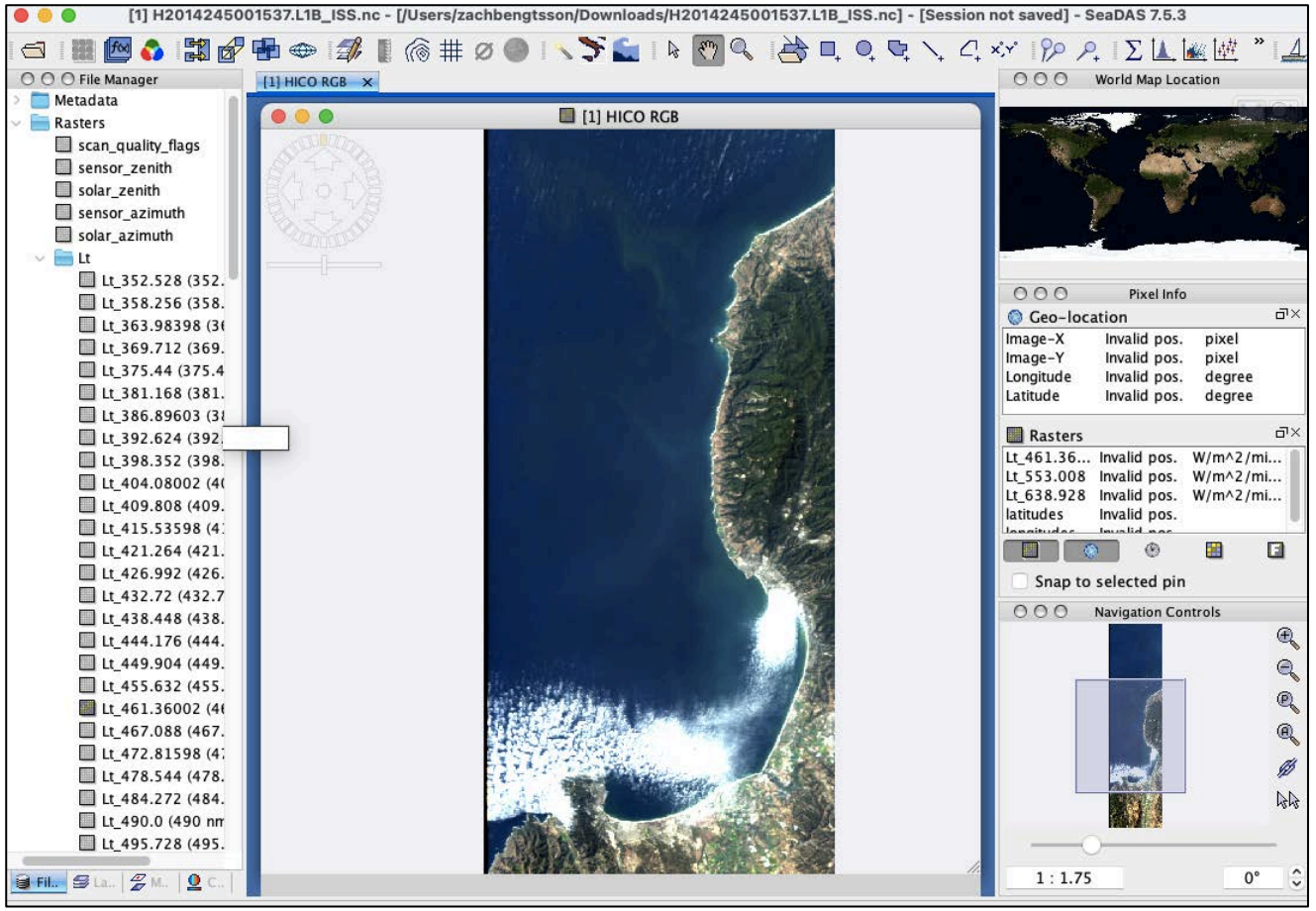
- **Level 1B**
  - Corrected radiance and geolocation
  - Displays top-of-atmosphere radiance values
- **Level 2**
  - Atmospherically corrected
  - Displays surface reflectance
  - Includes water quality layers like chlorophyll-a and Kd490 (light attenuation)
- Data products are available in **NetCDF format**



OceanColor Web Level 1 & 2 Browser
Link: https://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sen=amod

SeaDAS

- SeaDAS is a free software package for the processing, display, analysis, and quality control of remote sensing Earth data.
- Features include data reprojection, band manipulation, and visual data display.
- SeaDAS can also be used to…
  - Display spectral profiles
  - Apply algorithms to derive water quality parameters and physical features



SeaDAS interface displaying HICO Level 1B radiance data from Monterey Bay coastal area in California.

SeaDAS Download Link: https://seadas.gsfc.nasa.gov/downloads/

OceanColor Web and SeaDAS Demonstration

Summary

- Coastal-based applications of hyperspectral data include:
  - Retrieval of benthic substrates, particularly in shallow waters
  - Potential discrimination of species based on their spectral signatures and cover
  - Water quality analyses at higher spectral and spatial resolutions
- Hyperspectral data can be accessed via multiple data portals:
  - NASA's Ocean Color Data Portal (https://oceancolor.gsfc.nasa.gov)
  - For HICO Data (http://hico.coas.oregonstate.edu/index.shtml)
  - AVIRIS Data Portal (https://aviris.jpl.nasa.gov)
- Upcoming sensors (Ex., PACE) and new designated deliverables (Ex., SBG) will provide new venues for assessing coastal and ocean systems never attained before.


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!