National Aeronautics and Space Administration

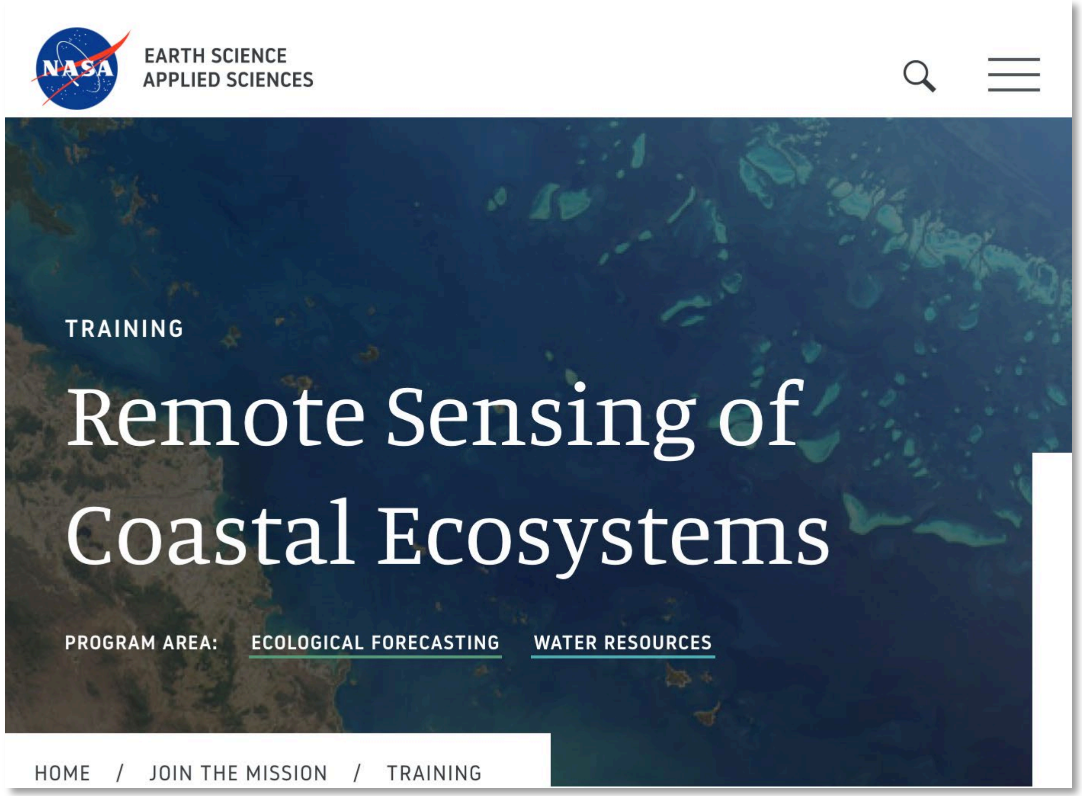
Remote Sensing of Coastal Ecosystems

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



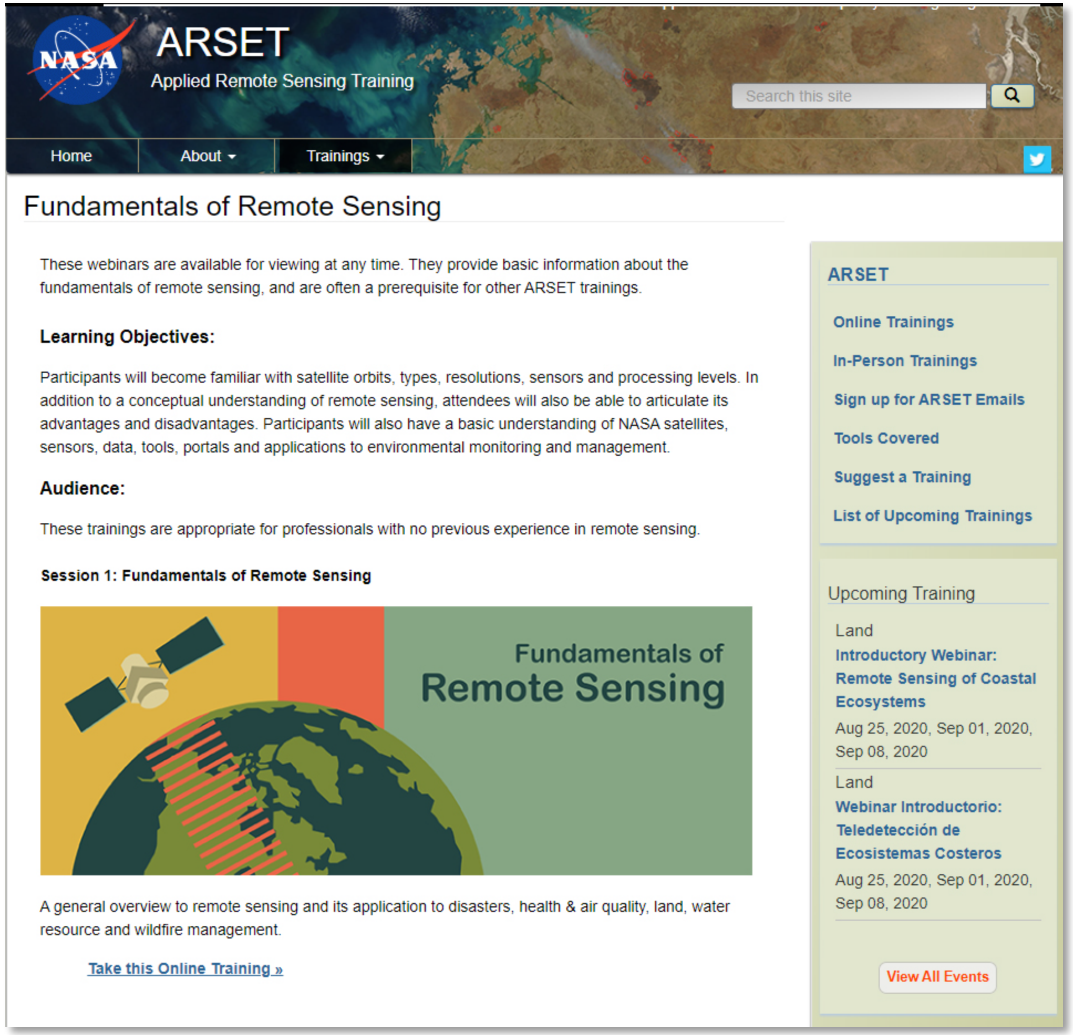
Homework and Certificates

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

- **Certificate of Completion:**
  - Attend all 3 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

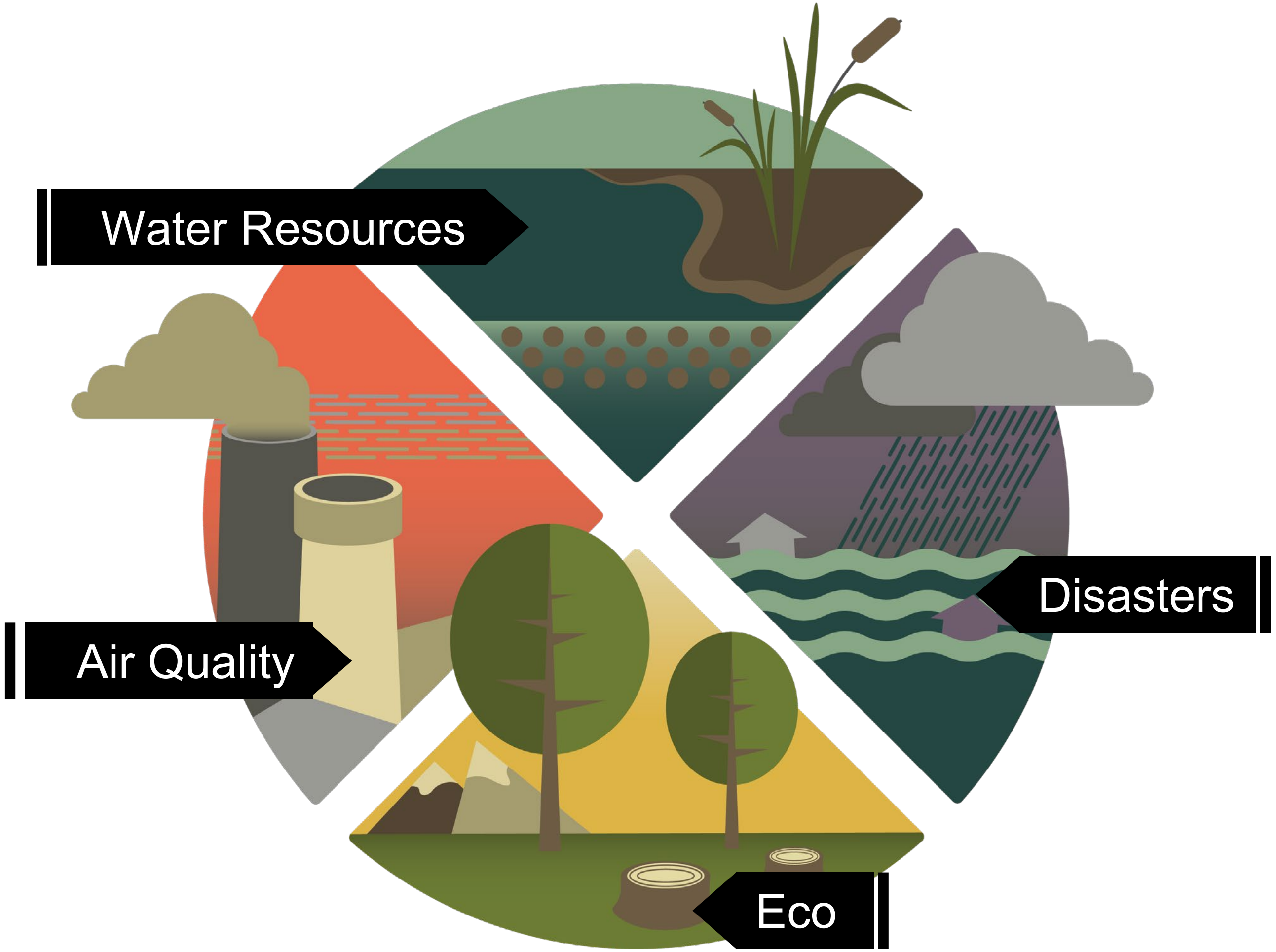
- Prerequisites:
  - Please complete [Sessions 1 & 2A of Fundamentals of Remote Sensing] or have equivalent experience.
- Course Materials:
  - https://appliedsciences.nasa.gov/join-mission/training/english/remote-sensing-coastal-ecosystems



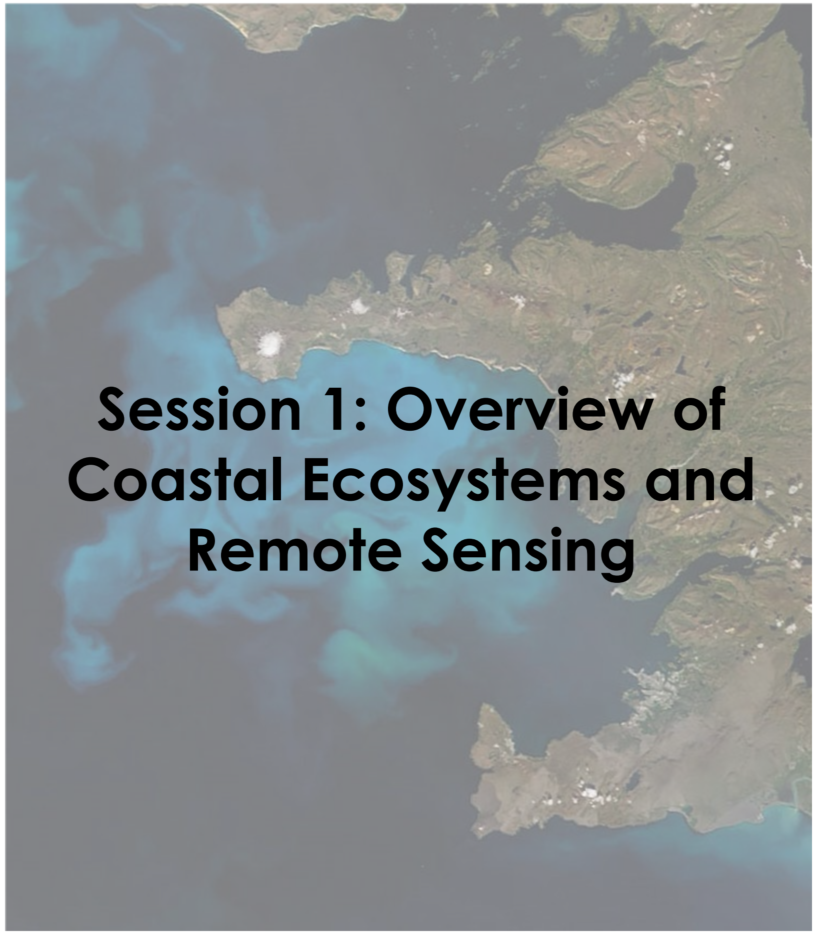
NASA's Applied Remote Sensing Training Program (ARSET)

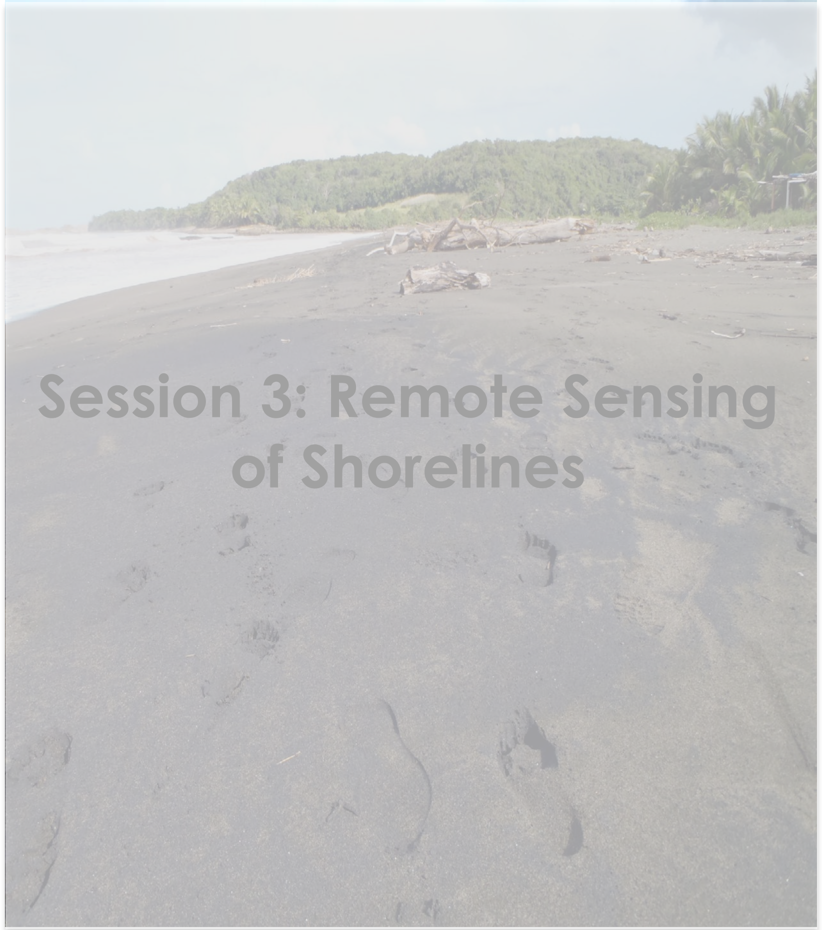
http://appliedsciences.nasa.gov/arset

- Part of NASA's Applied Sciences Program
- Empowering the global community through remote sensing training
- Seeks to increase the use of Earth science in decision-making through training for:
  - Policy makers
  - Environmental managers
  - Other professionals in the public and private sector



Course Outline





Learning Objectives

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

- Identify major coastal ecosystems, particularly from tropical and temperate regions
- Identify the main satellites and sensors used for studying coastal ecosystems

Coral reef in Papua New Guinea. Credit: USGS

Why is it important to study coastal ecosystems?

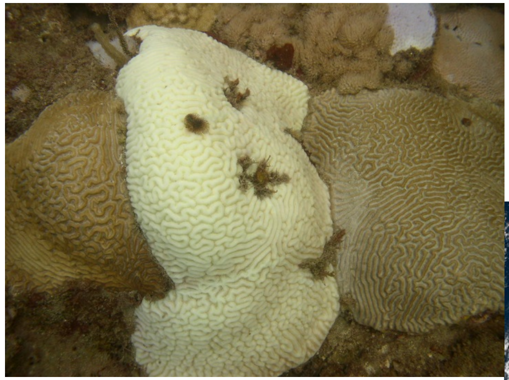
- Ecosystem Services:
  - Provide a habitat for thousands of species, including commercially important ones
  - Provide coastal protection against wave action
  - Recreational areas
  - Provide sustenance for millions of people worldwide
  - Conservation/Cultural Heritage

Image Credit: Juan L. Torres-Pérez

Major Factors Affecting Coastal Ecosystems

<u>**Climate**</u>

- Occurrence of extreme events
- Sea level rise
- Ocean acidification
- Sea surface and global temperatures
- Changes in ocean currents
- New and/or increased diseases



Bleached Coral; Image Credit: Juan L. Torres-Pérez

Hurricane Maria (2017); Image Credit: Naval Research Laboratory NOAA

Major Factors Affecting Coastal Ecosystems

<u>Local</u>

- Coastal runoff
- Mechanical damage
- Illegal dumping of waste
- Plastics
- Introduction of invasive species

Image Credit: (Left) Juan L. Torres-Pérez; (Right) Tom Moore NOAA

Most Common Temperate and Tropical Coastal Ecosystems

Temperate Zones:

- Rocky Shores
- Kelp Forests

Tropical Zones:

- Coral Reefs
- Seagrass Meadows
- Mangrove Forests

Rocky shore in New Zealand. Credit: Pixabay

Coral Reef, Kaneohe Bay, Hawaii. Credit: Juan L. Torres-Pérez

Temperate Coastal Ecosystems

Rocky Shores

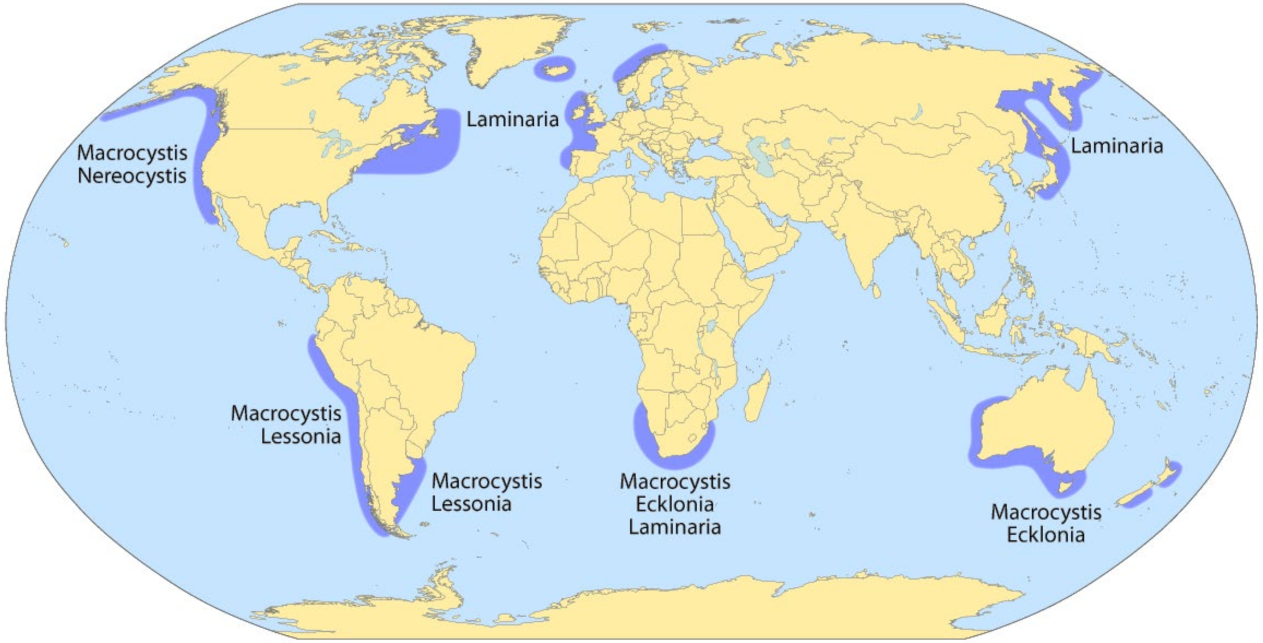
- Exposed rocky shores support some of the most diverse and productive assemblages of species in temperate zones.
- 2-5x more productive than temperate evergreen forests
- Highly heterogenic ecosystems
- More than 300 described species in the west coast of North America, particularly mollusks and other invertebrates

Credit: Juan L. Torres-Pérez

Temperate Coastal Ecosystems

Kelp Forests

- Occur in cold, nutrient-rich, shallow open waters in temperate and polar oceans
- Cover about 25% of the world's coastlines
- Like all marine photosynthetic organisms, kelp restricts its distribution to the first tens of meters (usually up to 40m), but some species have been found in up to 260m in very clear waters of the Indian Ocean and the Mediterranean.
- Grow well in turbulent waters, as wave action and ocean currents supply nutrients for their development and dispersion of propagules

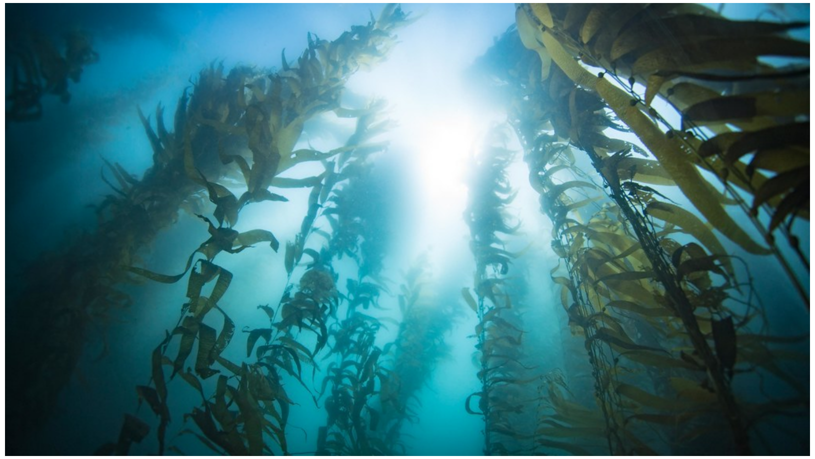


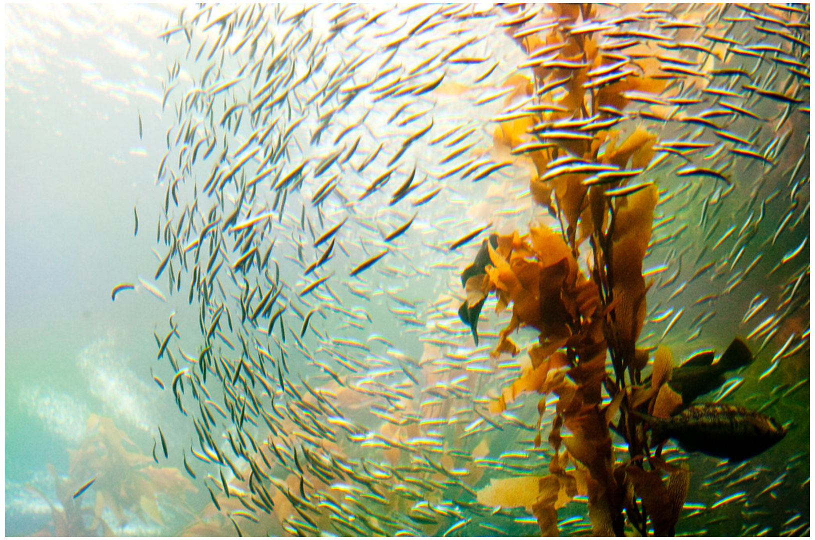
Credit: www.commons.Wikimedia.org

Temperate Coastal Ecosystems

Kelp Forests

- Under ideal conditions, individuals can grow up to 18 inches per day.
- Many species have pneumatocysts (gas-filled bladders) that aid in their buoyancy.
- They harbor a diversity of other organisms.
- Many mammals and birds use the kelp forest for protection and finding food.
- They are recognized as one of the most productive and dynamic ecosystems on the planet.

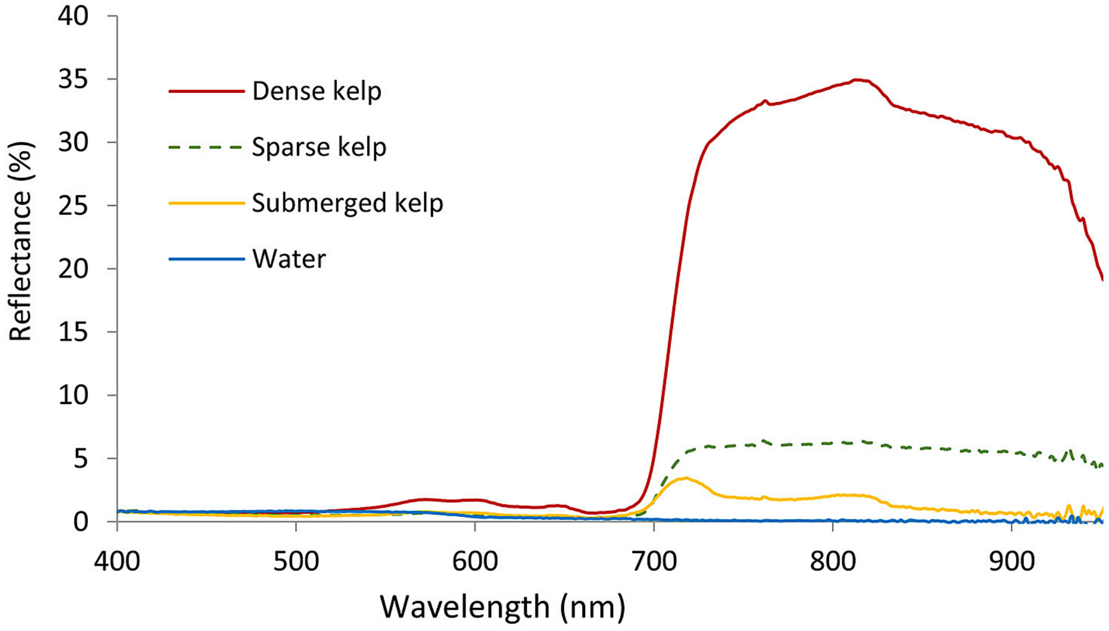


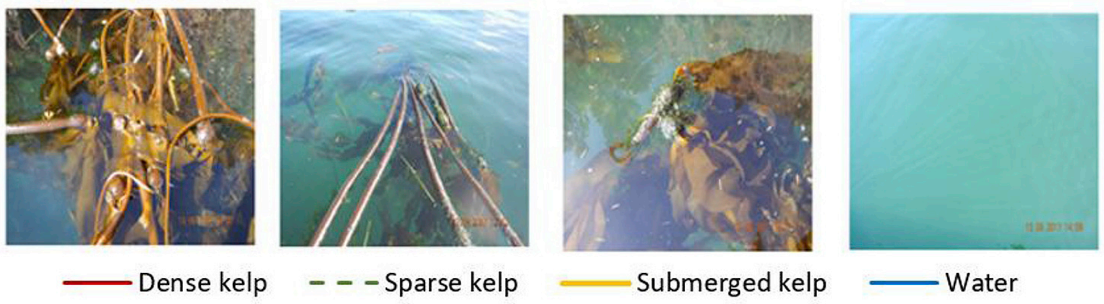


Credit: www.flickr.com

Discrimination of Kelp at the Water Surface

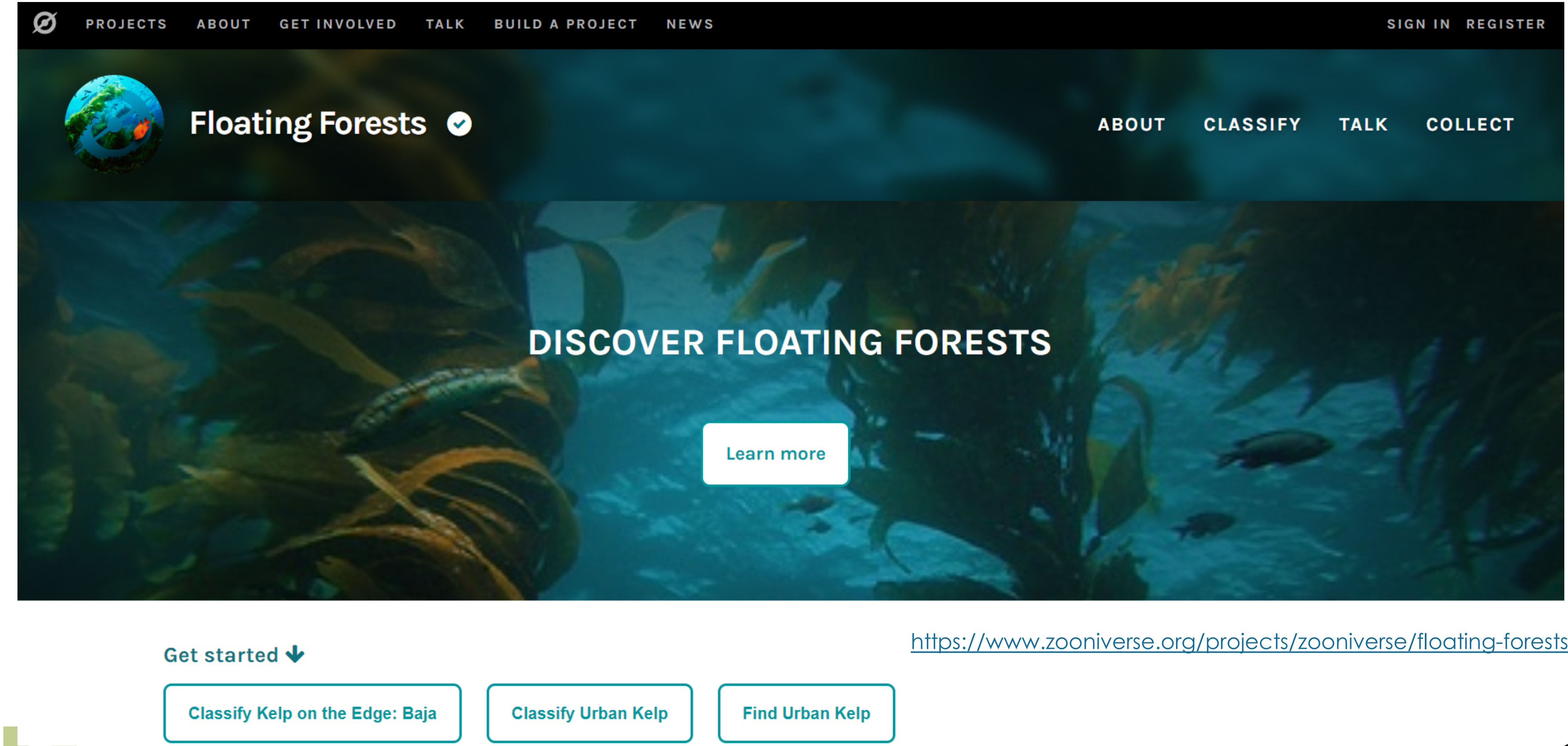
- Dense kelp at the water surface reflects strongly in the NIR.
- Sparse and submerged kelp signals reflect the high influence of the water absorption of NIR even in the first centimeters of the water column.
- Signals are also influenced by the presence of phytoplankton, suspended sediments, and Colored Dissolved Organic Matter (CDOM).





Schroeder et al (2019) Global Ecol. Cons.

Floating Forests – A NASA-Funded Citizen Science Project



https://www.zooniverse.org/projects/zooniverse/floating-forests

Tropical Coastal Ecosystems

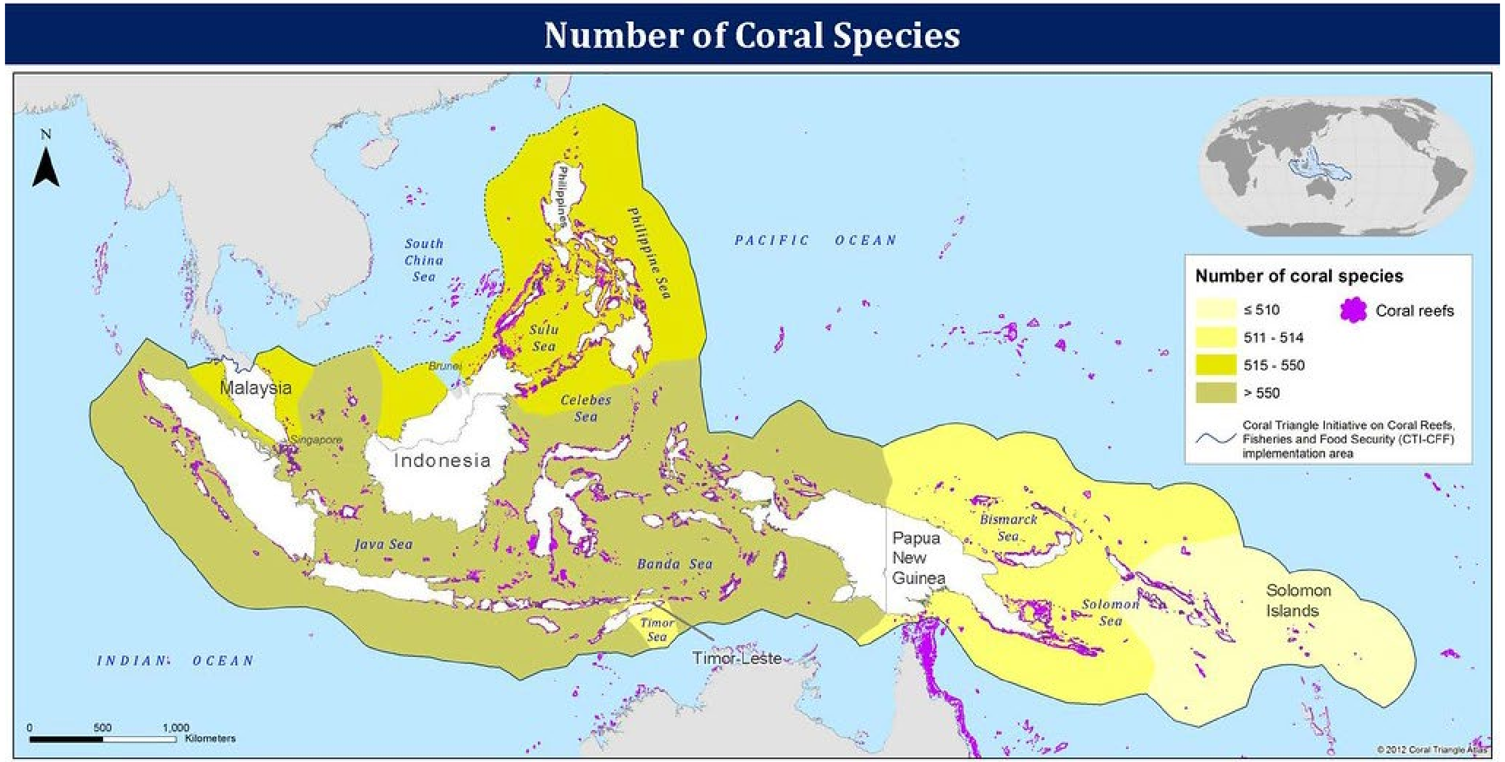
Coral Reefs

- Probably the most diverse ecosystem on the planet
- Typically exist between 30°N and 30°S of the equator
- Develop in clear, relatively warm waters (25 - 29°C)
- Particularly challenging to map due to their high heterogeneity
- Usually extend beyond the depths that we can reliably use remotely-sensed data

IKONOS image of the La Parguera Natural Reserve.
Credit: University of PR, Bio-Optical Oceanography Lab

Coral Reefs

- There are more than 700 species of hard corals described so far
- The Indo-Pacific has by far the highest number of species
- The Caribbean has about 1/10 of the number of coral species of the Indo-Pacific
  - Much younger basin
  - Closure of the Panama Isthmus in the Late Pliocene (~6-7MYA) restricted the gene flow between the Caribbean and Pacific Basins



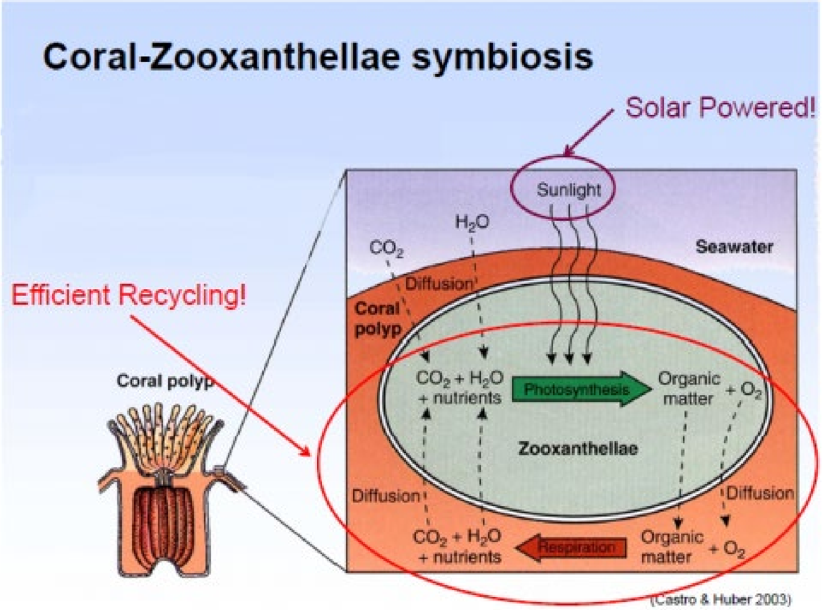
Sources: Number of coral species – Indonesia, Philippines, Papua New Guinea, Solomon Islands and Timor-Leste from Veron (2009) *Coral Geographic: a spatial database*; Malaysia from the *State of the Coral Triangle Report (SCTR) for CT countries*; Coral reefs – UNEP-WCMC (2010) *Global Distribution of Coral Reefs*.

Credit: USAID

Coral Reefs

- Corals owe their ability to create complex ecosystems to their symbiotic relationship with a microscopic, photosynthetic dinoflagellate commonly known as zooxanthellae.
  - Provides most (80-90%) of the coral's nutrition requirements
- Many other organisms within the coral reef ecosystem are also photosynthetic (i.e., algae, seagrasses) and have similar pigments.
  - i.e., chlorophylls, carotenes, and xanthophylls

Montastraea cavernosa Colony (PR)
Credit: Juan L. Torres-Pérez

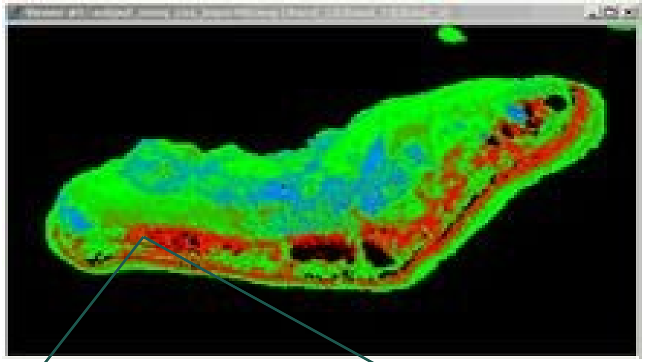


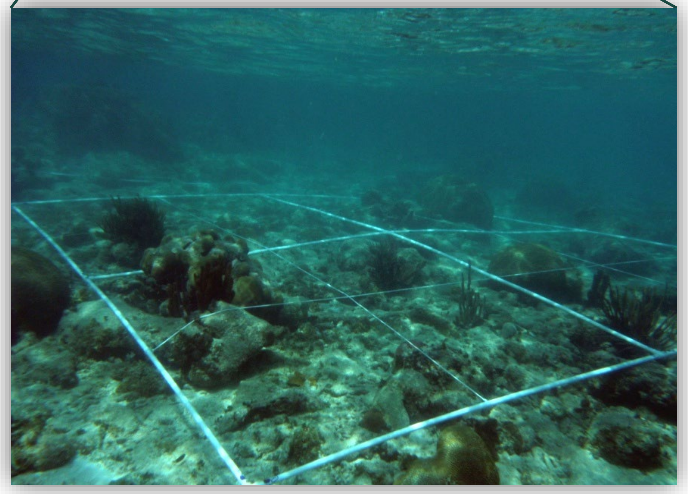
Coral Reefs – Within Pixel Complexity

Within any pixel, there might be:

- Hard Corals
- Seagrass
- Gorgonians
- Algae
- Dead Coral Rubble
- Sand
- Sponges
- Etc.

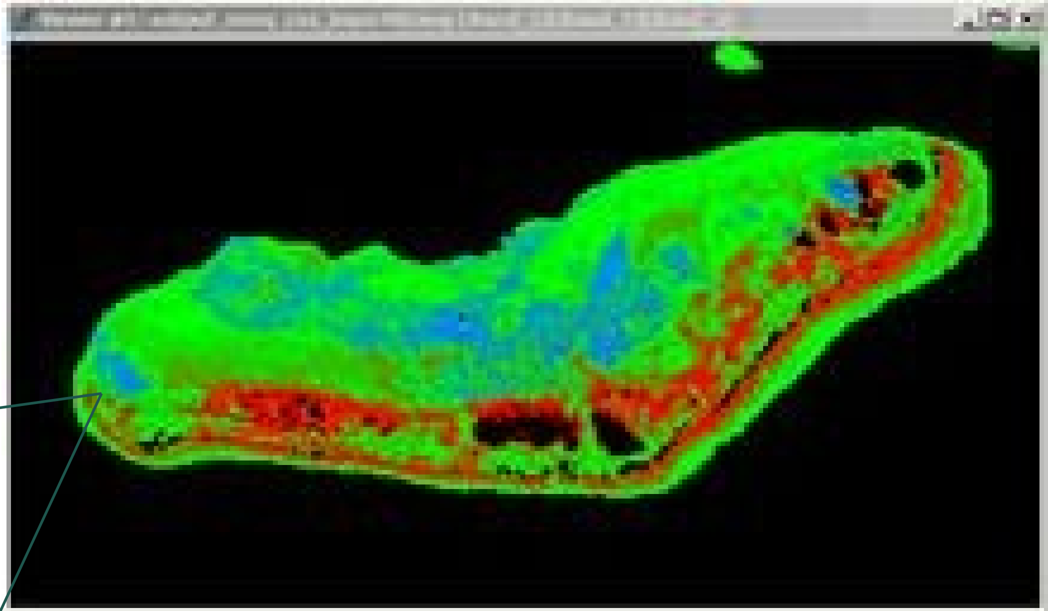
Credit: University of PR, Bio-Optical Oceanography Lab

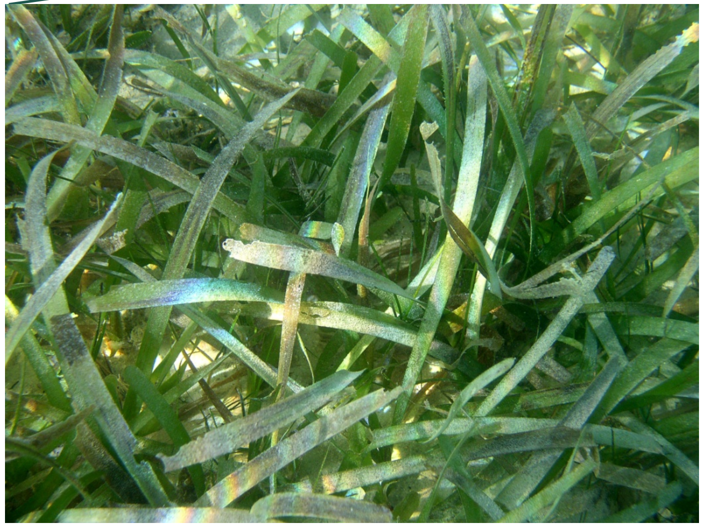


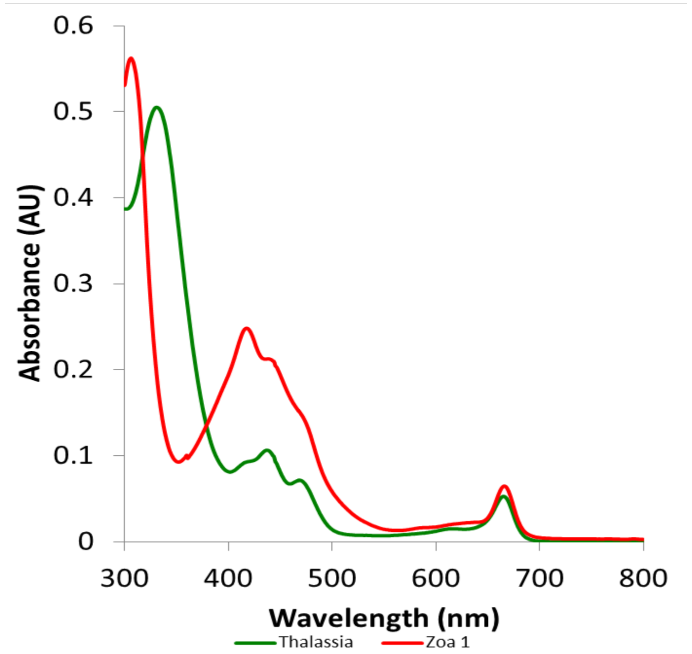


The Contents of 1 Pixel

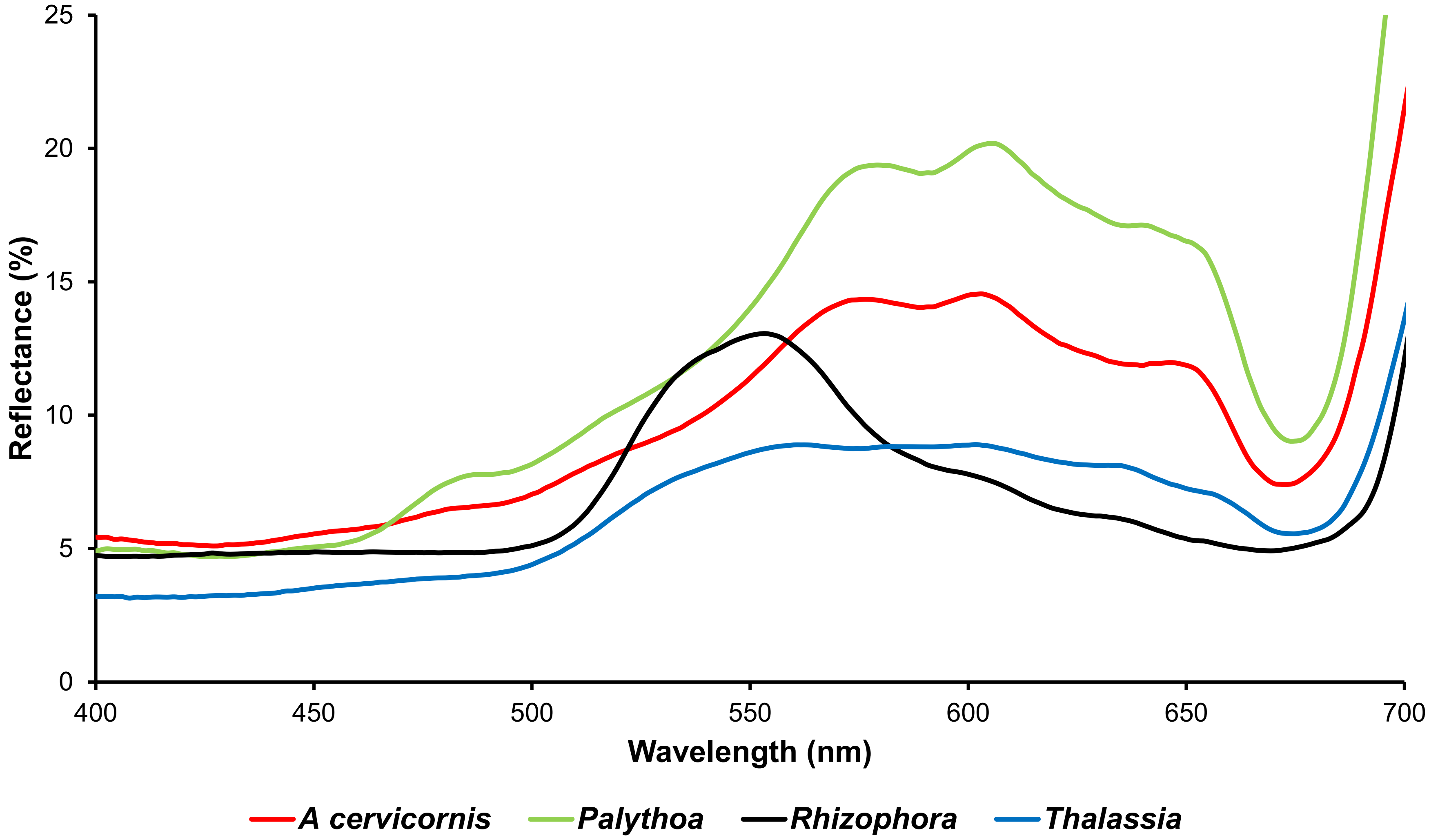
- Benthic components may have similar colors but may be spectrally different.







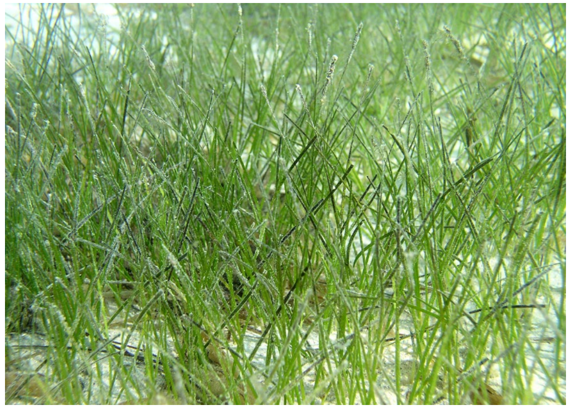
Spectral Comparison of Different Coral Reef Components



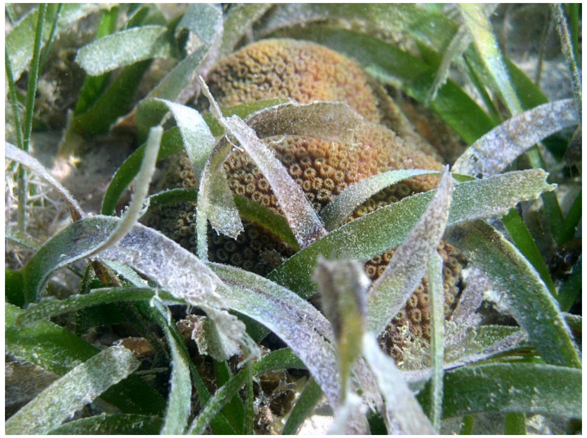
Torres-Pérez (Unpublished)

Seagrass Meadows

- Extremely important shallow-water ecosystems in the tropics
- Important in carbon sequestration
- The root systems aid in sediment and nutrient stabilization
- Provide habitat for reproduction and nursery as well as a direct food source for commercially and ecologically important fish and shellfish and endangered species

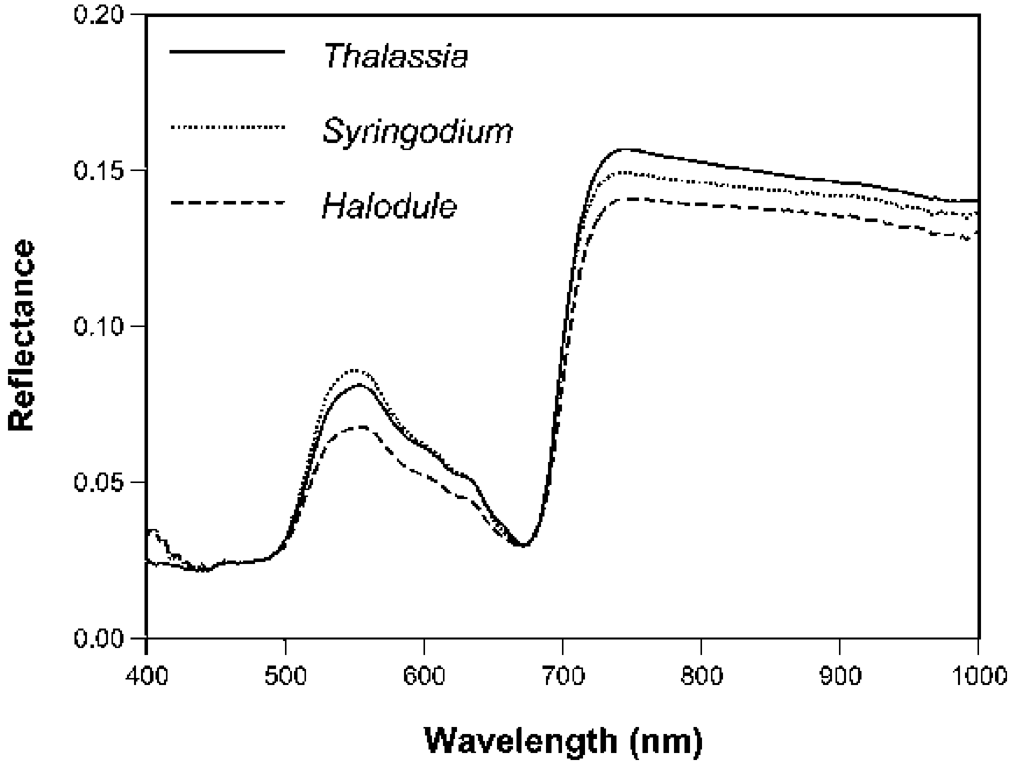



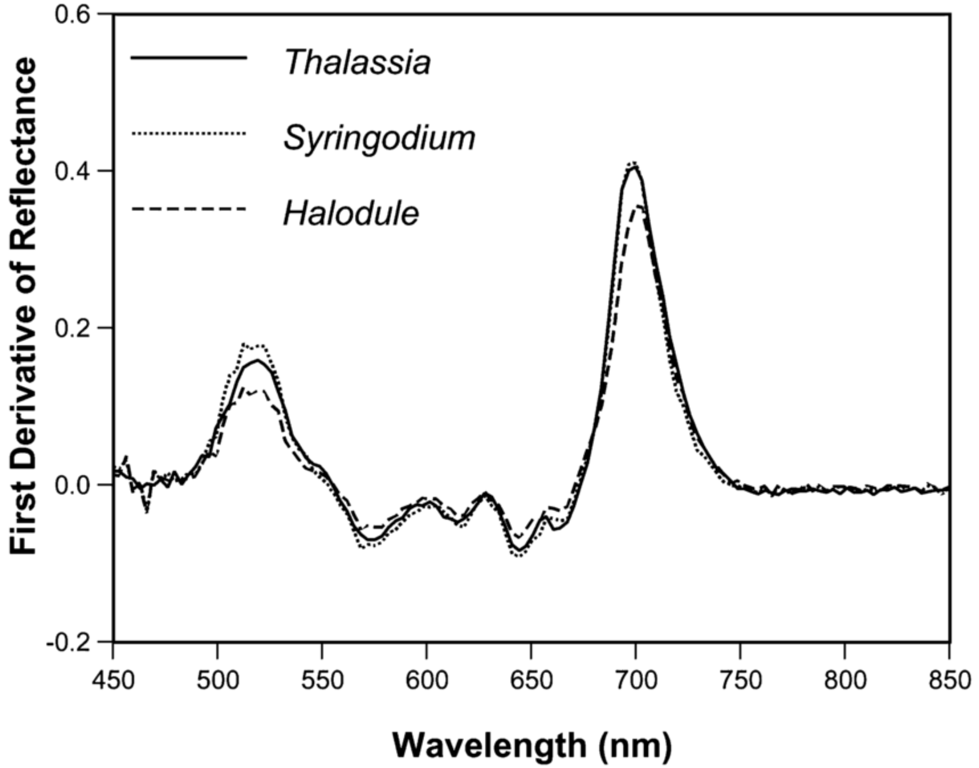
Left: Turtle Grass (*Thalassia testudinum*); Right: Manatee Grass (*Syringodium filiforme*). Credit: Juan L. Torres-Pérez




Left: Star Coral (*Orbicella annularis*); Right: Reticulated Starfish (*Oreaster reticulatus*). Credit: Juan L. Torres-Pérez

Seagrass Meadows

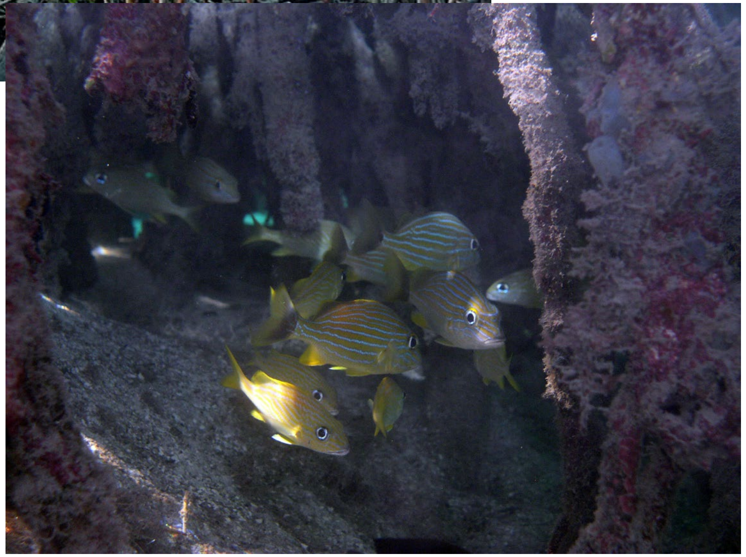




From: Thorhaug et al 2005 Int. J. Remote Sens.

Mangrove Forests

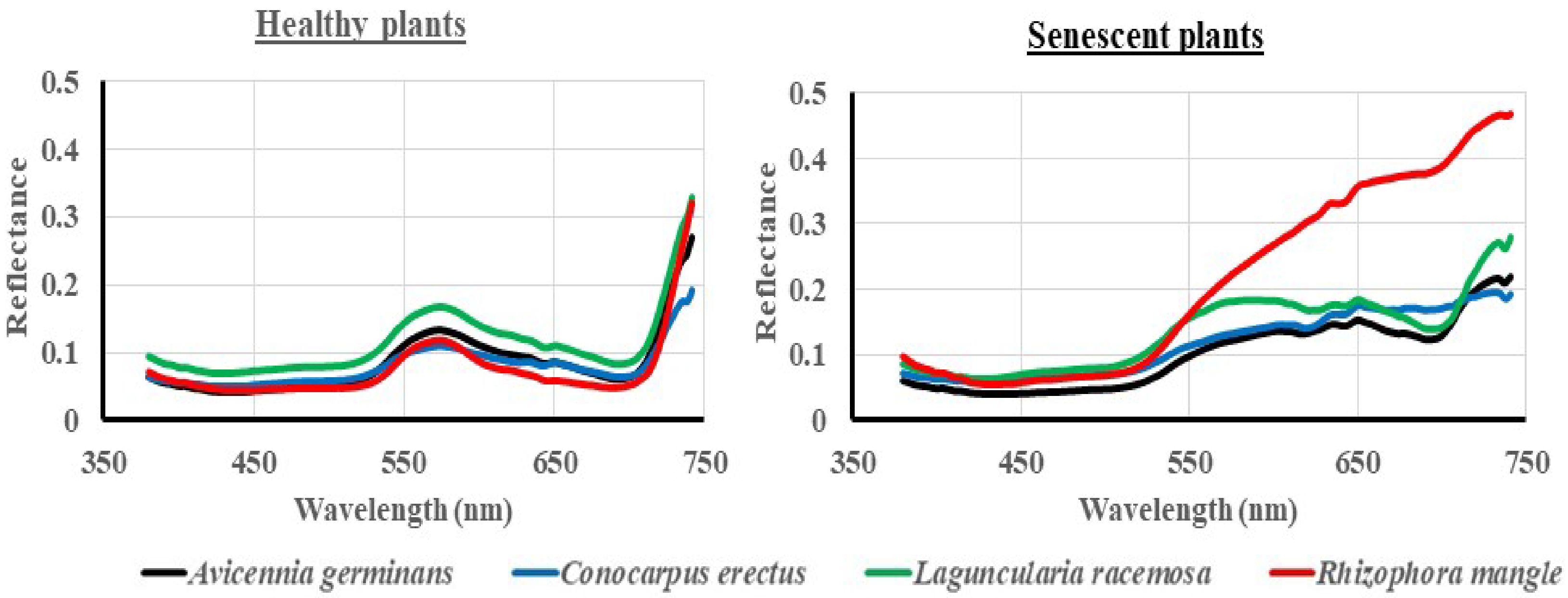
- Mangroves are halophytes (salt-tolerant plants) adapted to live in coastal areas.
- Like seagrass beds, mangroves provide many ecosystem services (sediment stabilization, nursing areas for fish and shellfish species, and protection of the coastline).
- Mangroves capture more carbon than tropical forests.
- Mangroves are typically dominated by a few species with a zonation based on resistance to salt concentration in the soil.
- Red mangrove usually lives in contact with the ocean.



Top: Red mangrove (*Rhizophora mangle*);
Bottom: fish community on mangrove roots.
Credit: Juan L. Torres-Pérez

Mangrove Forests

- Species are spectrally similar.
- Spectral data can be used for discriminating between healthy and non-healthy or senescent canopies.



Torres-Pérez (Unpublished)

Satellites Commonly Used for Coastal Ecosystems Assessment

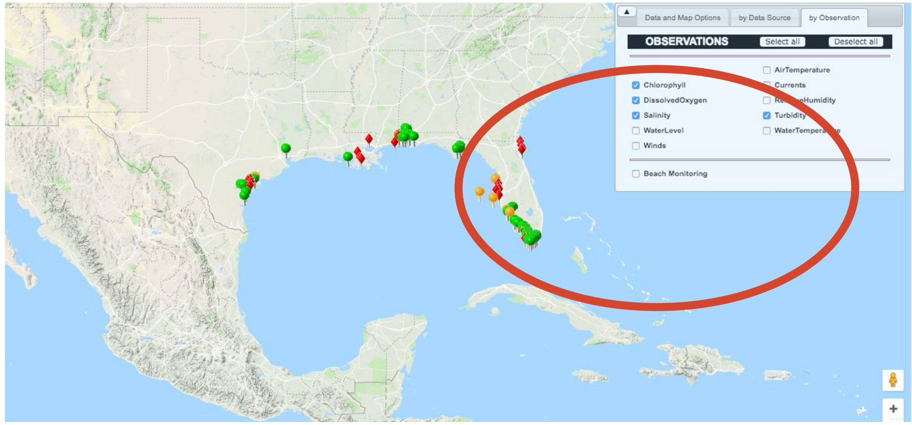
Considerations when Choosing Satellite Data

- Temporal resolution of data acquisition – Daily? Weekly? Monthly?
- Spatial Resolution – depends on the satellite: meters to km
- Spectral Resolution – multispectral vs. hyperspectral
  - Where in the electromagnetic spectrum are the satellite bands? Visible? IR? SWIR?
- Longevity of the Satellite Mission
  - Landsat has the longest record of satellite data (since 1970's).
- Geographical and Atmospheric Conditions at the Study Site
  - Coastal ecosystems in general tend to be small (seagrass beds) or narrow (beaches)
  - Tropical zones typically have more cloud cover year round
- Is the data freely available, or is there a cost associated with data acquisition?
- Are there any future missions being planned?
  - Surface Biology and Geology (SBG)
  - Plankton, Aerosol, Cloud, Ocean Ecosystem (PACE)

Advantages of Satellite Observations

- Available for large regions
  - Only source of global information for some parameters
- Long time series and data continuity
  - Tracks progress
  - Establishes baselines and trends
- Consistency and comparability
  - Among multiple countries
- Diversity of measurements
  - Many different physical parameters
- Complements traditional statistical methods
  - Cross-check with in situ data
- Mostly free and open access

Limited Water Sampling Locations



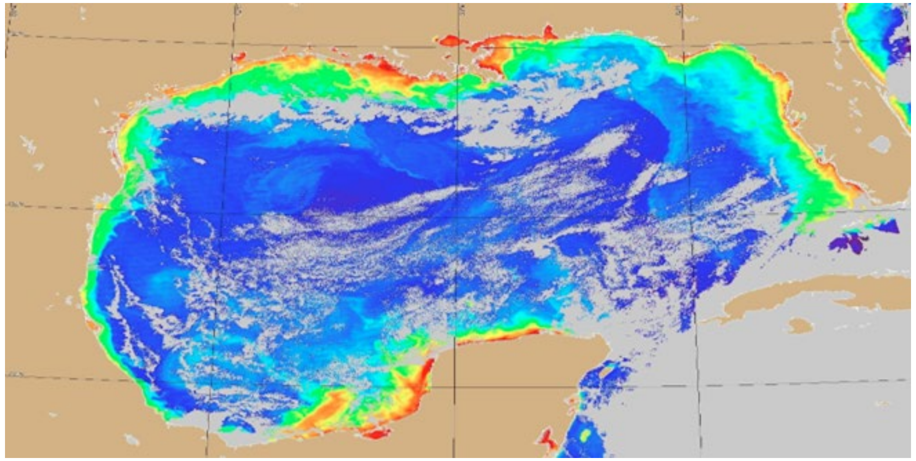


Image Credit (top) http://data.gcoos.org; (bottom) 2013 MODIS Aqua image showing elevated chlorophyll-a levels

Earlier Satellite Missions for the Coastal Zone

Coastal Zone Color Scanner (CZCS)

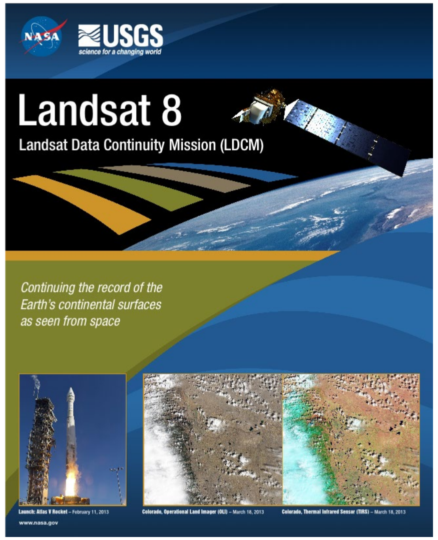
- Launched in 1978 onboard the Nimbus-7 satellite (sun-synchronous near-polar orbit)
- Up to 1986
- Specifically intended for monitoring the oceans and other water bodies
- Primarily for ocean color and temperature
- Global coverage every 6 days
- 6 bands: 4 visible, NIR, thermal
- 825m spatial resolution

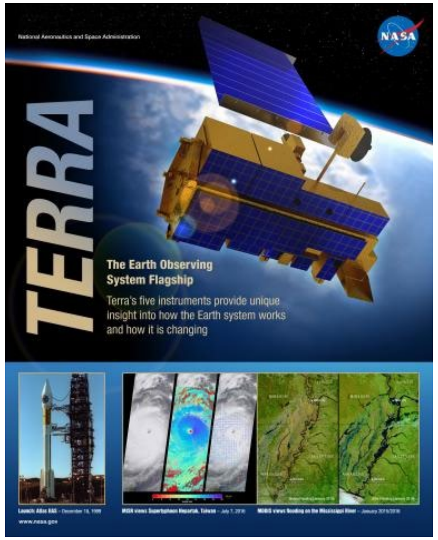
Sea-viewing Wide Field-of-view Sensor (SeaWiFS)

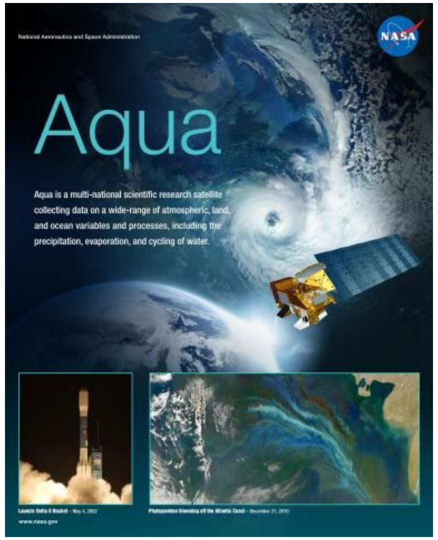
- Launched in 1997 onboard the SeaStar platform
- Mission ended in Dec 2010
- Designed for ocean monitoring
- 8 spectral bands: 6 visible (400-700nm) and 2 NIR
- Spatial resolution available at 1.1 and 4.5 km
- Revisit Time: 1 day
- Was used for estimating ocean primary production, phytoplankton processes, and others

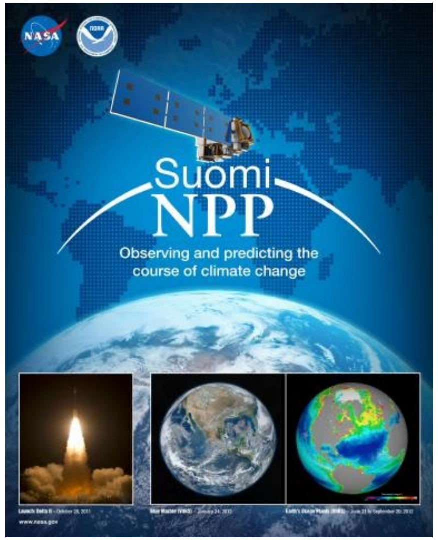
Current Satellite Missions

- Landsat 7 (4/15/1999 – Present)
- Landsat 8 (2/1/2013 – Present)
- Terra (12/18/1999 – Present)
- Aqua (5/4/2002 – Present)
- Suomi National Polar Partnership (SNPP) (11/21/2011 – Present)
- Sentinel-2A (6/23/2015 - Present)
- Sentinel-2B (3/7/2017 – Present)
- Sentinel-3A (2/16/2016 – Present)









Satellites and Sensors for Monitoring Coastal Ecosystems

Satellites	Sensors	Resolution
Landsat 7	Enhanced Thematic Mapper (ETM+)	185 km swath; 15 m, 30 m, 60 m; 16-day revisit
Landsat 8	Operational Land Imager (OLI)	185 km swath; 15 m, 30 m, 60 m; 16-day revisit
Terra & Aqua	MODerate Resolution Imaging Spectroradiometer (MODIS)	2330 km swath; 250 m, 500 m, 1 km; 1-2-day revisit
Suomi NPP	Visible Infrared Imaging Radiometer Suite (VIIRS)	3040 km swath; 375 m – 750 m; 1-2-day revisit
Sentinel 2A and 2B	Multi Spectral Imager (MSI)	290 km swath; 10 m, 20 m, 60 m; 5-day revisit
Sentinel 3A	Ocean and Land Color Instrument (OLCI)	1270 km swath; 300 m; 27-day revisit

Multispectral vs. Hyperspectral

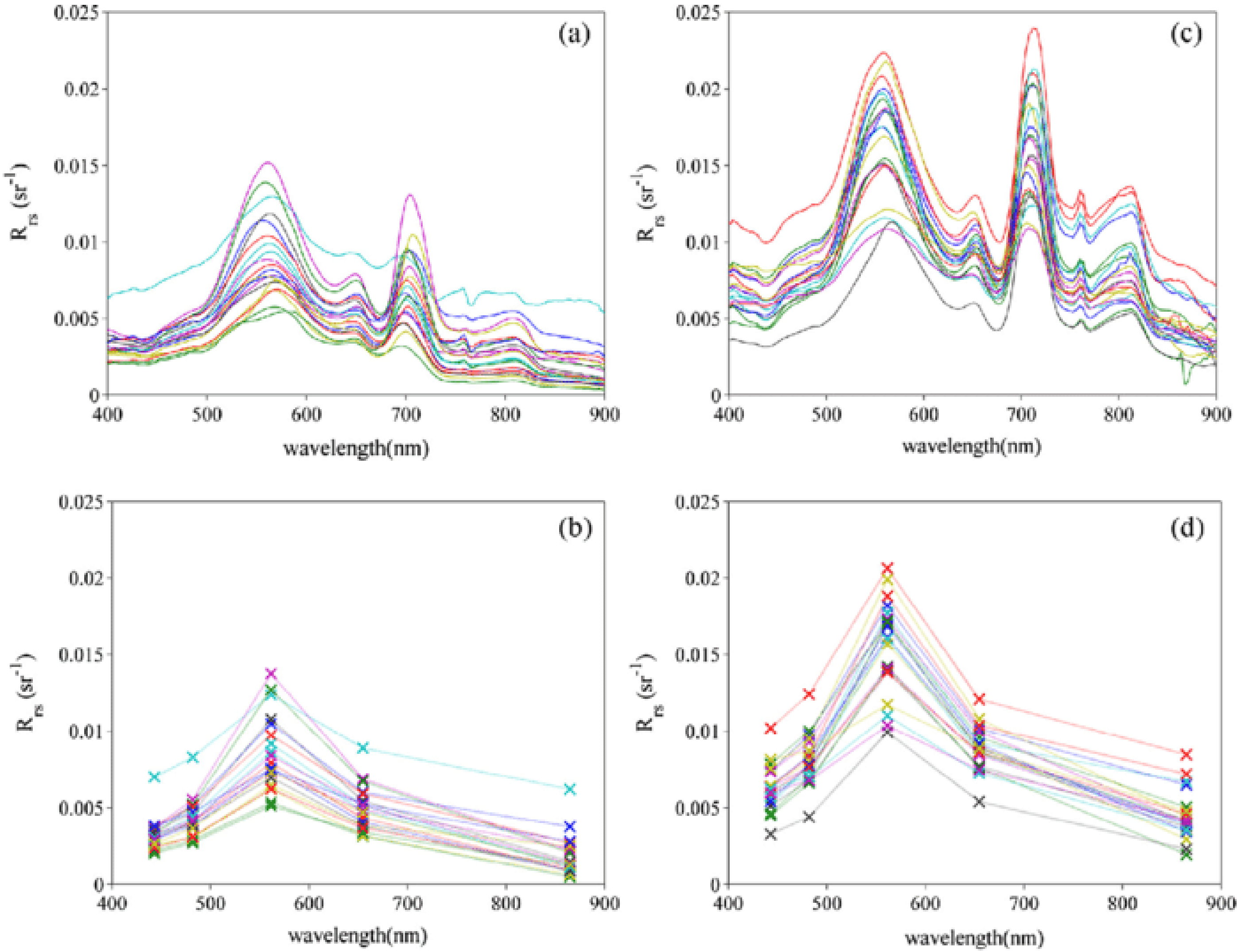
Multispectral

- 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)
- Fairly high temporal resolution (days to weeks)

Hyperspectral

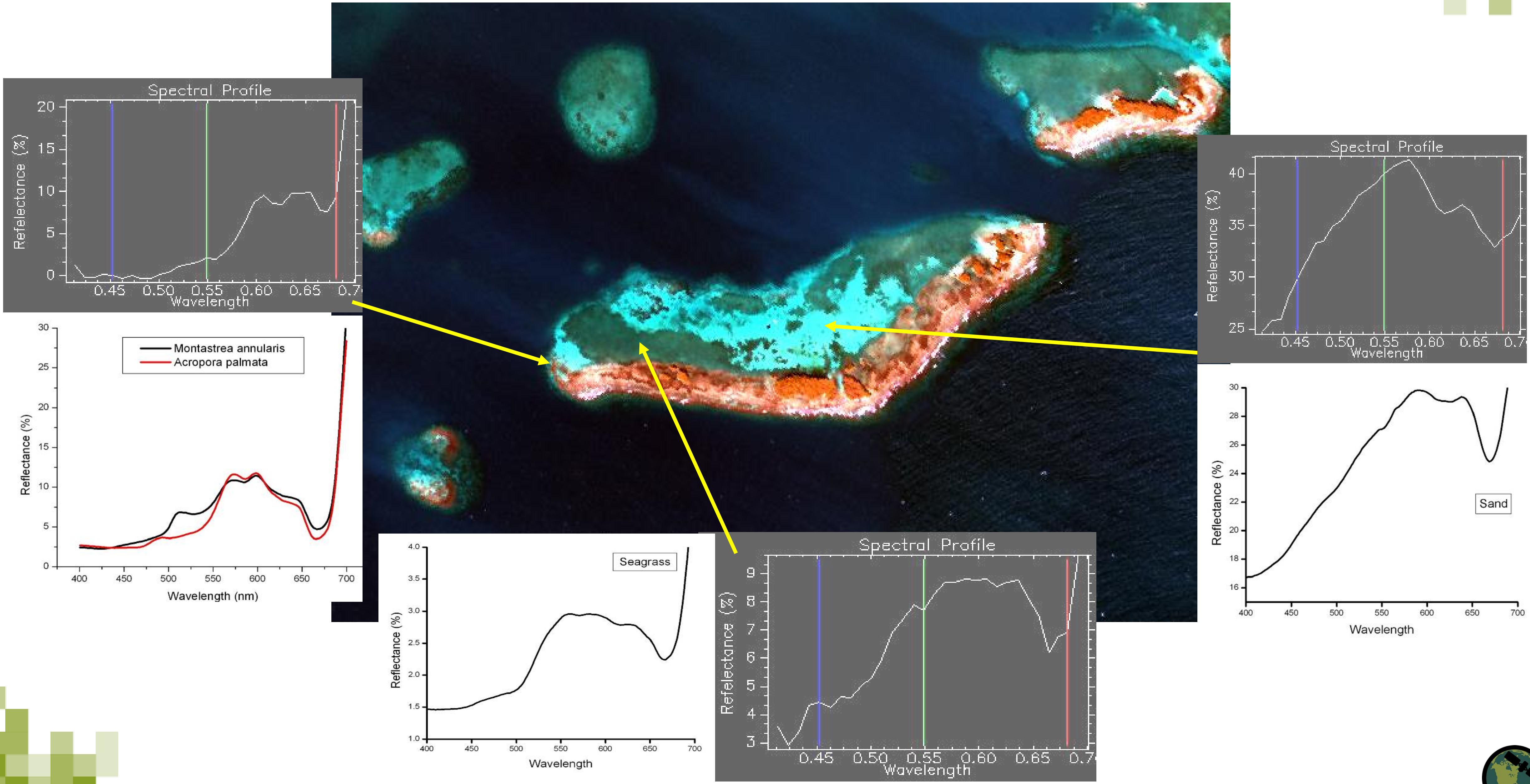
- So far, very limited in numbers of satellite-based sensors
- Hyperion – onboard EO-1 spacecraft (decommissioned in 2017); 30m resolution, 220 bands @10nm bandwidth
- Some are mission specific
  - (Hyperspectral Imager for the Coastal Ocean on board the ISS)
    - Limited data set (2009-2014)
- Airborne 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) look promising

Multispectral vs. Hyperspectral



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

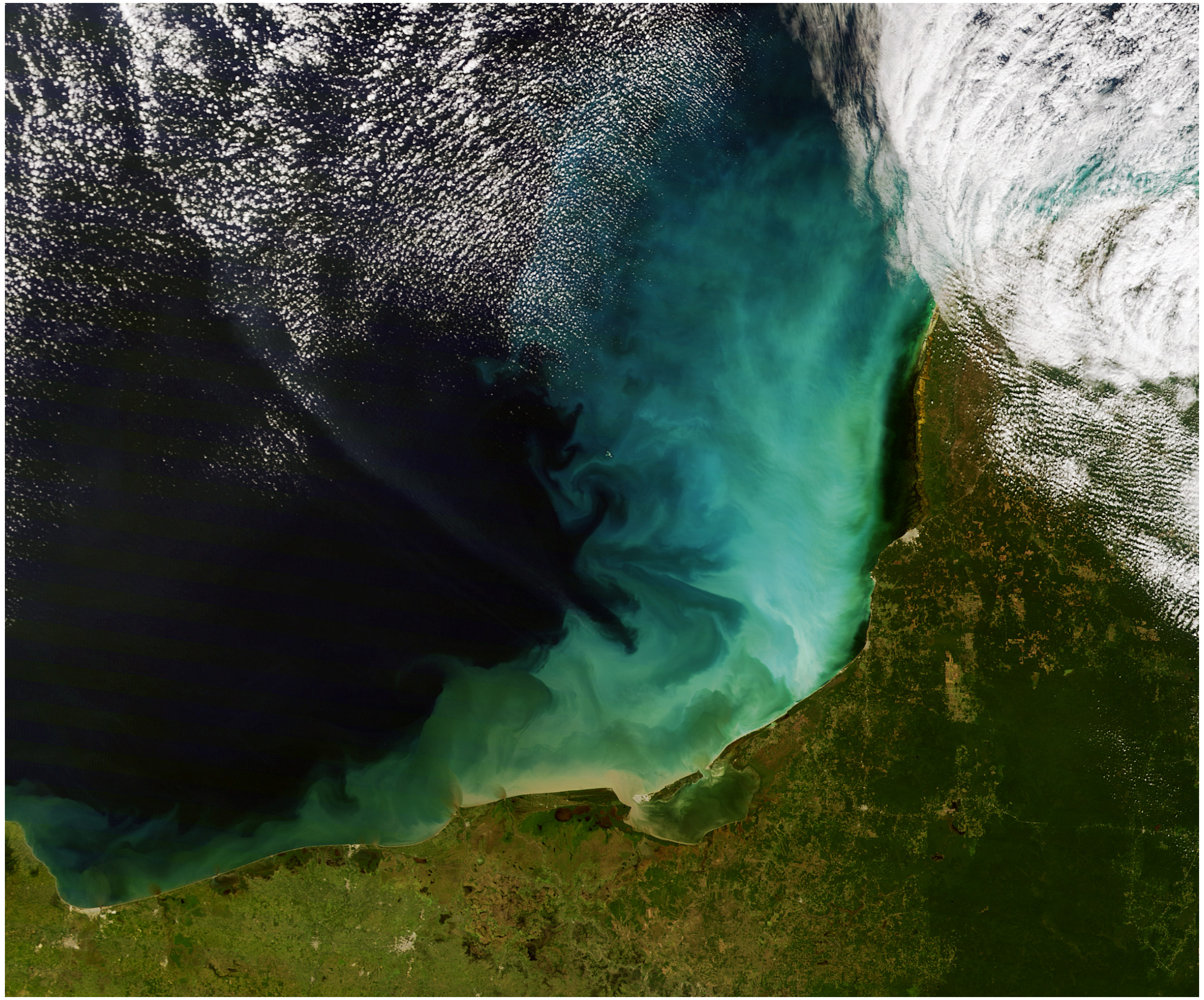
Atmospherically-Corrected AVIRIS (Hyperspectral) Image



Indirect Assessment of Submerged Ecosystems

Water Quality Indicators Measurable from Satellite Sensors

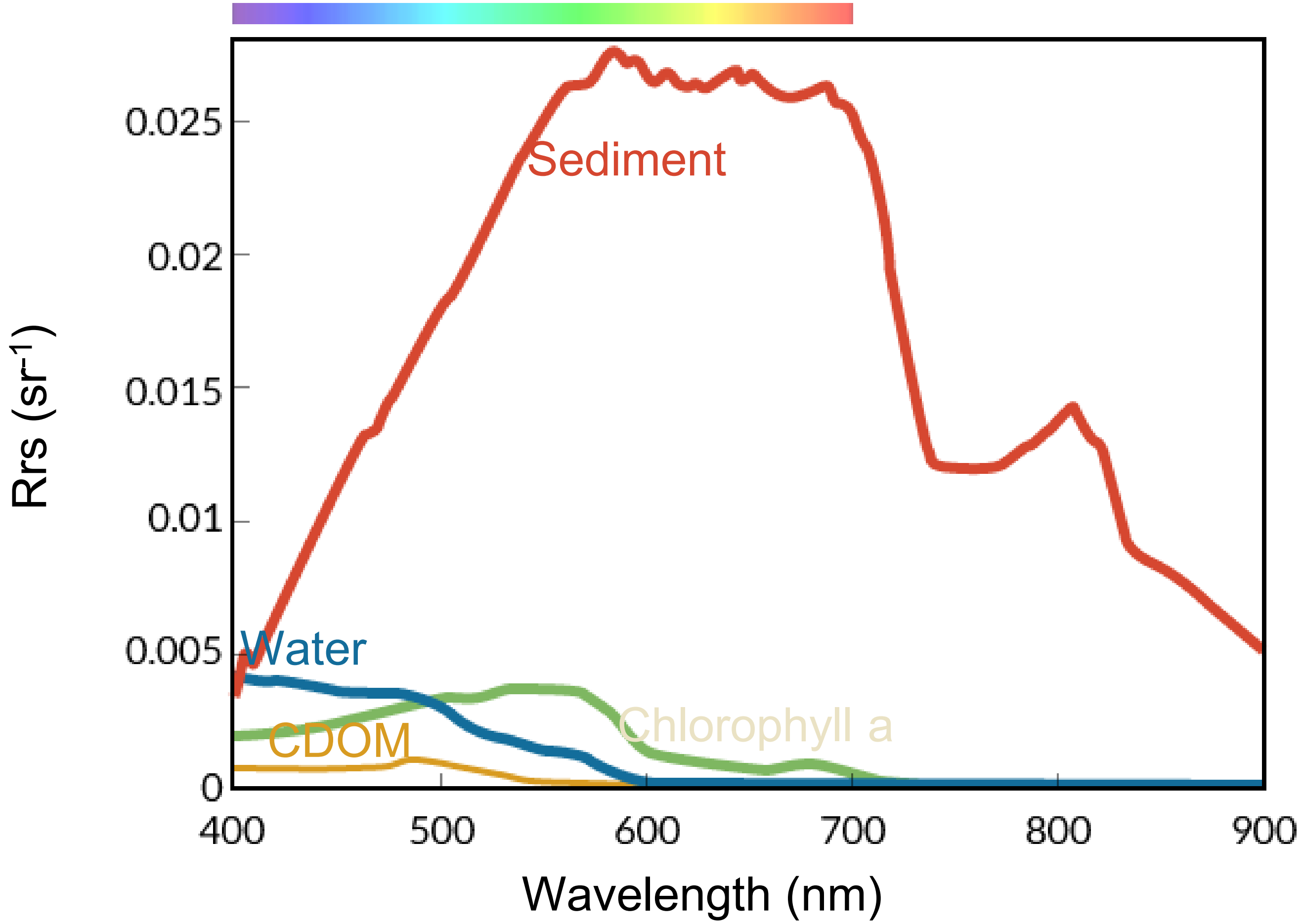
- Colored Dissolved Organic Matter (CDOM)
- Sea Surface Temperature (SST)
- Chlorophyll-a (phytoplankton)
- Salinity
- TSS (Total Suspended Solids) or Total Suspended Matter (TSM)
- Fluorescence Line Height
- Euphotic Depth



Yucatan Peninsula. Credit: GSFC

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)

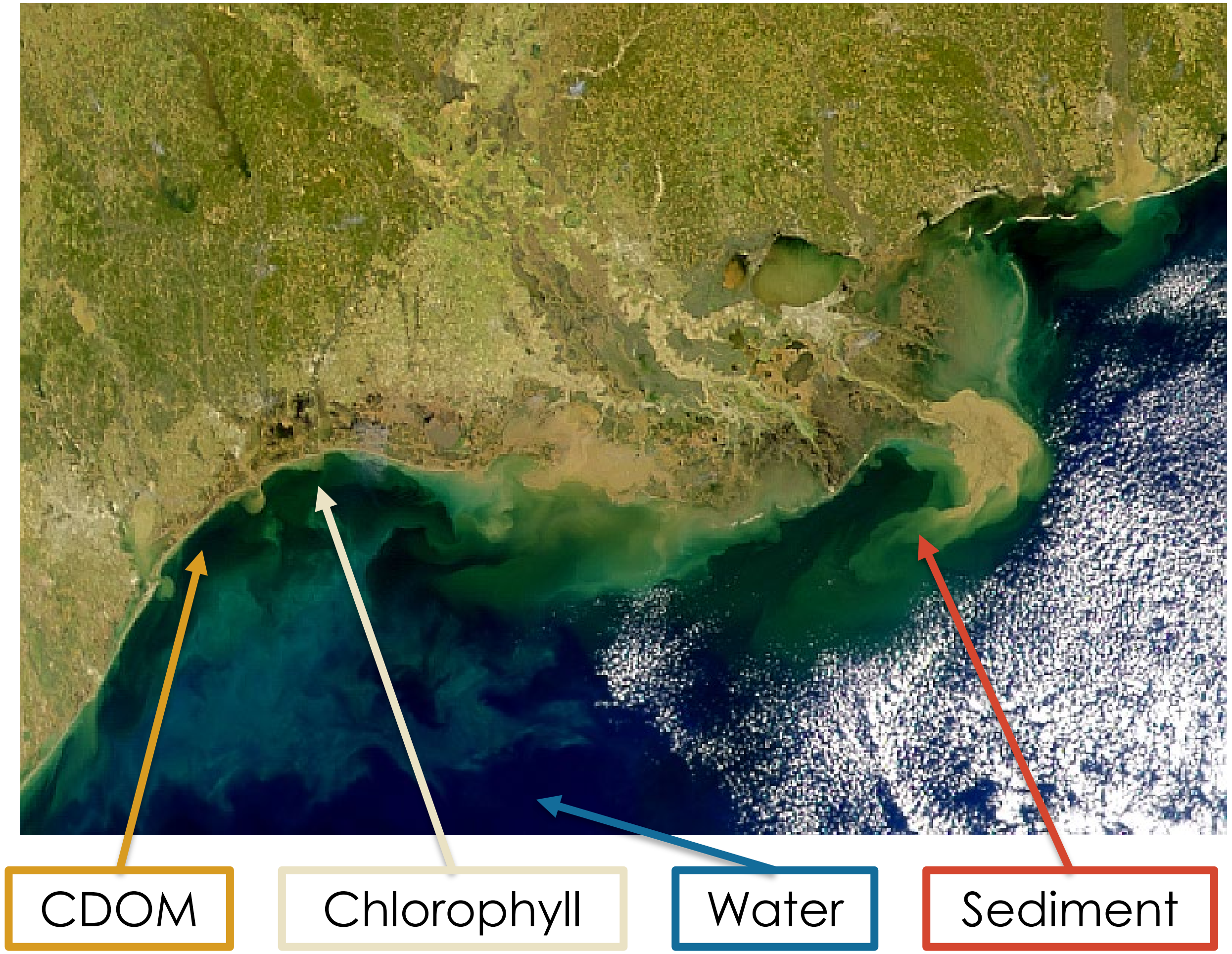


Inherent Optical Properties (IOPs) and the 'Color' of Water

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 $b = b_f + b_b$



Next Session (Sept 1): Light Penetration in the Water

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!