1st INIOAS Training Course on Ocean Remote Sensing, 2023

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Monitoring of Coastal and Lakes from Space

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Objectives

- Identify major coastal and lakes ecosystems
- Identify the main geological features of shorelines, including beach environments
- Identify the main satellites and sensors used for studying coastal and lakes ecosystems

Major Factors Affecting Coastal Ecosystems

Climate

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

Local

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

Most Common Temperate and Tropical Coastal Ecosystems

- Rocky Shores
- Kelp Forests
- Coral Reefs
- Seagrass Meadows
- Mangrove Forests

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

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)
- Grow well in turbulent waters, as wave action and ocean currents supply nutrients for their development and dispersion of propagules

Coastal Ecosystems

Coral Reefs

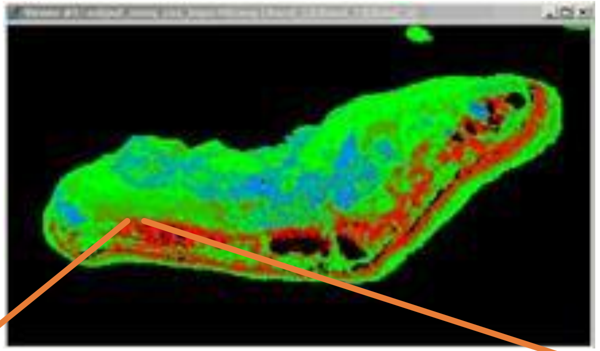
- Probably the most diverse ecosystem on the planet
- Typically exist between 30°N and 30°S of the equator
- Develop in clear, relatively warm waters (25 -29°C)
- Particularly challenging to map due to their high heterogeneity
- Usually extend beyond the depths that we can reliably use remotely-sensed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

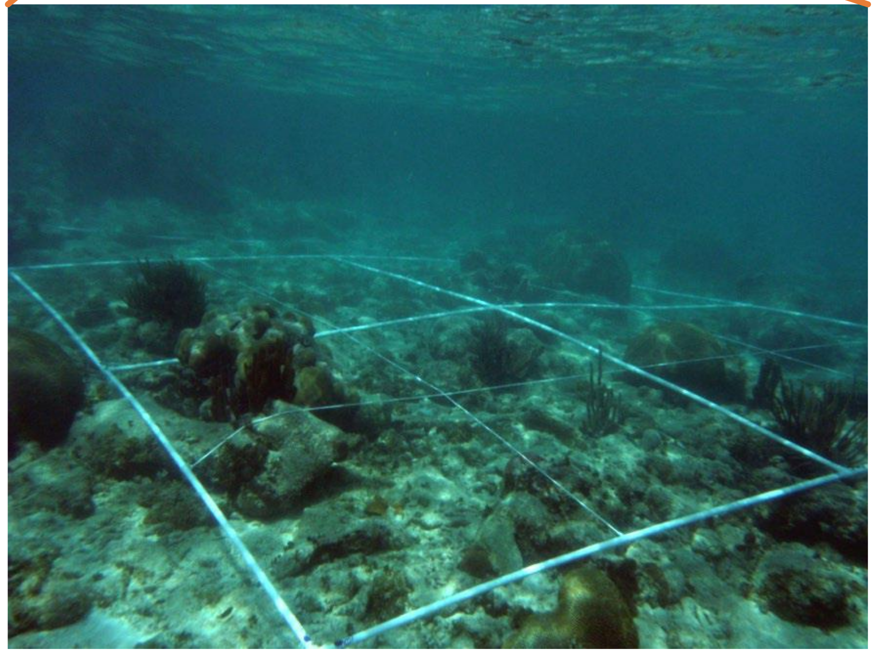
- Corals owe their ability to create complex ecosystems to their symbiotic relationship with a microscopic, photosynthetic dinoflagellate commonly known as zooxanthellae.
- Provides most (80-90%) of the coral's nutrition requirements
- Many other organisms within the coral reef ecosystem are also photosynthetic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

Coral Reefs – Within Pixel Complexity

Within any pixel, there might be:

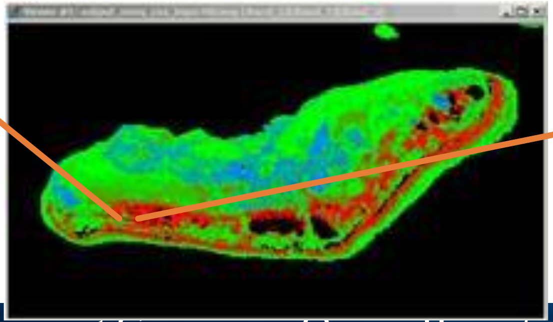
- Hard Corals
- Seagrass
- Algae
- Dead Coral Rubble
- Sand
- Sponges
- Etc.

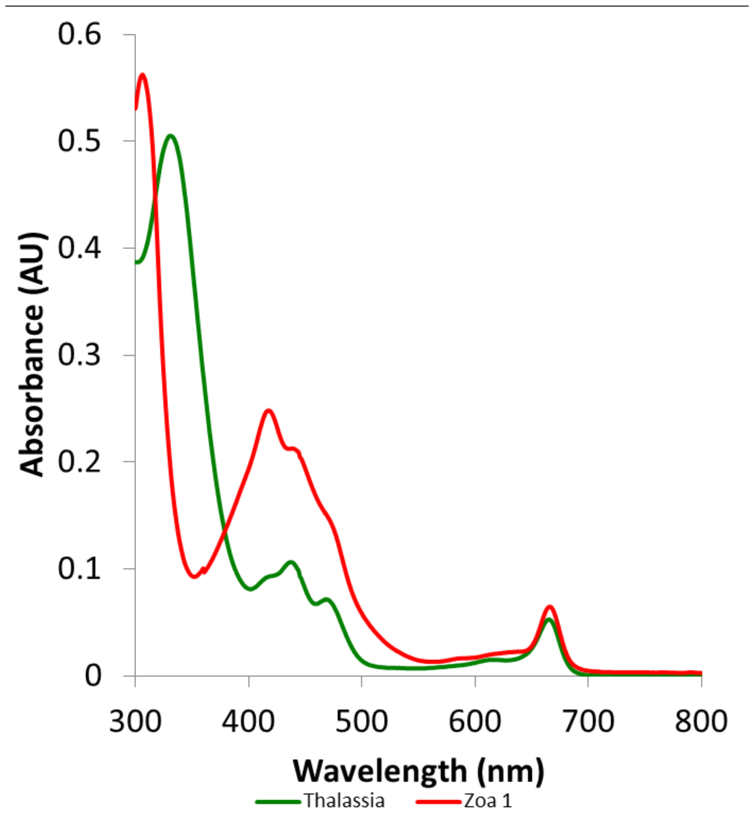




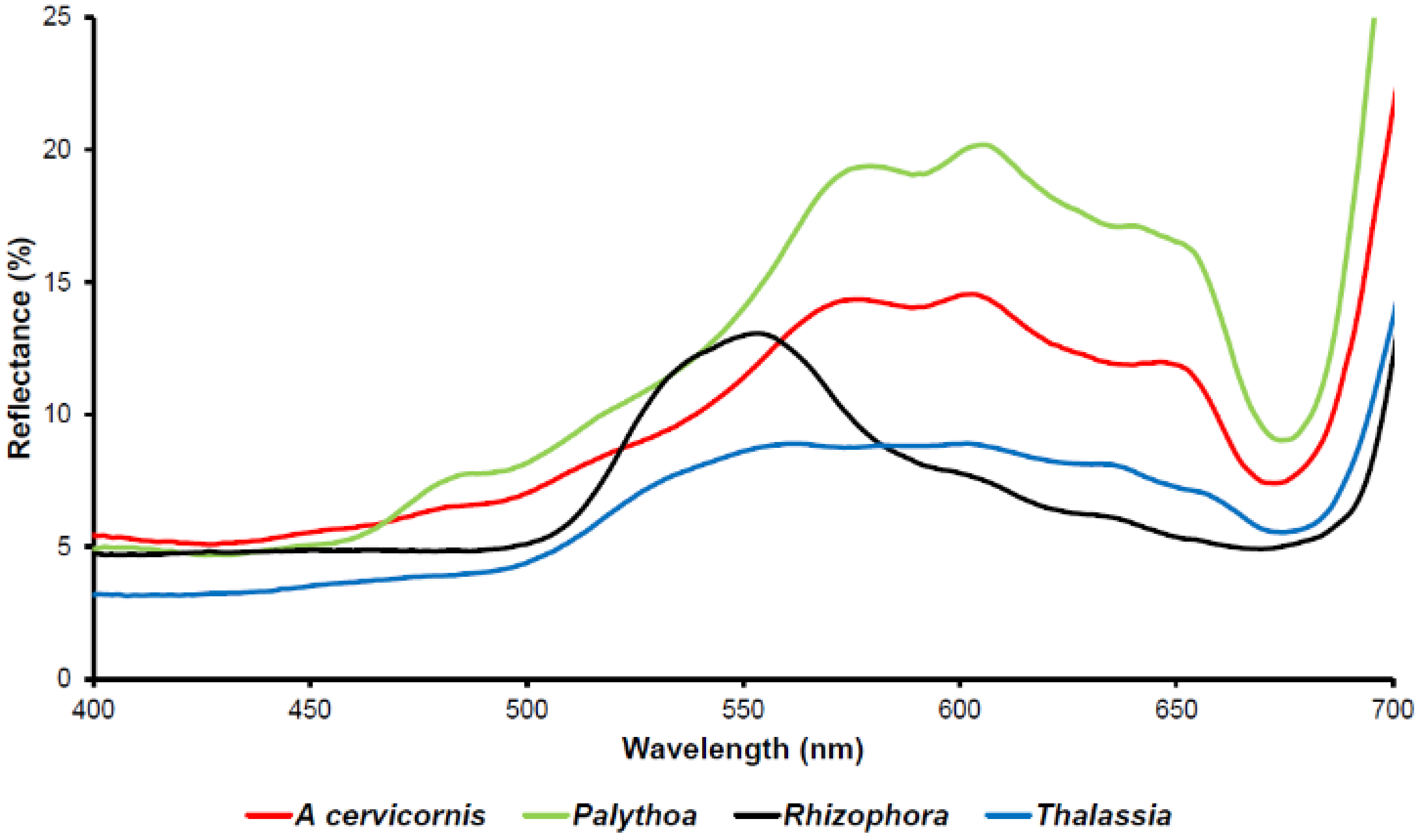
The Contents of 1 Pixel

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



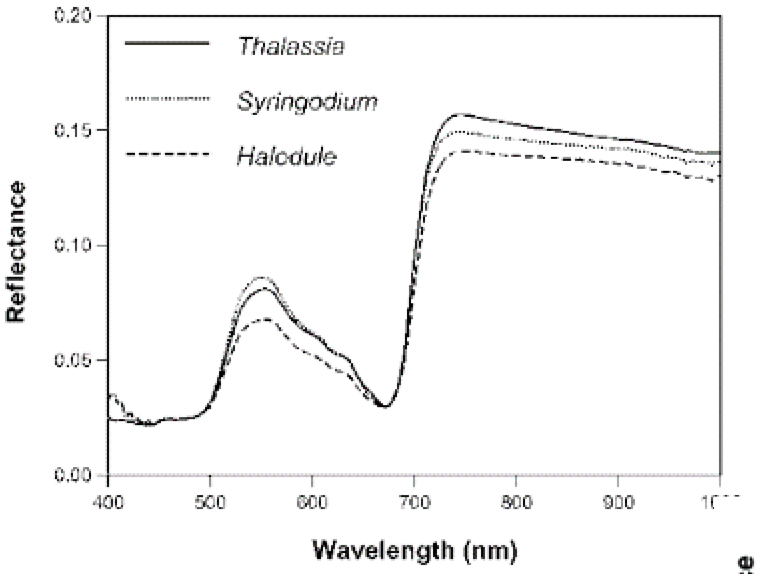


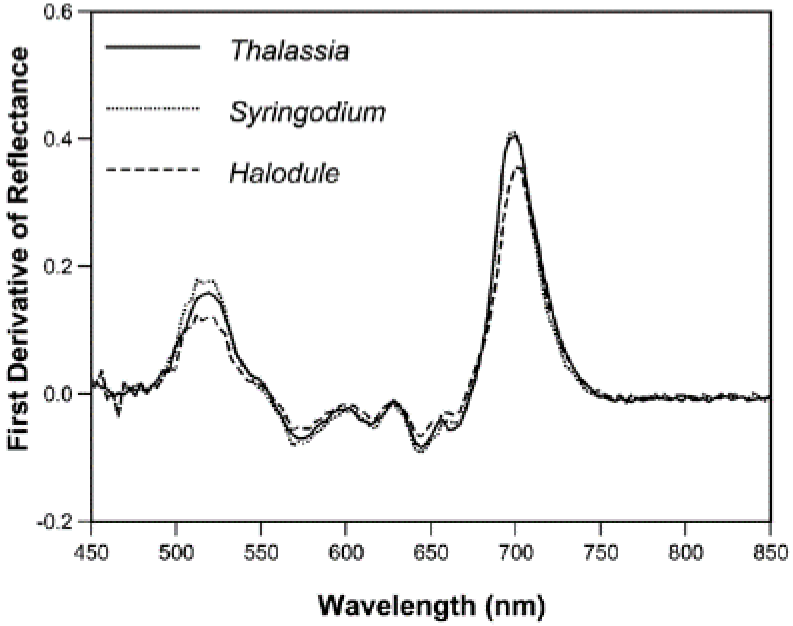
Spectral Comparison of Different Coral Reef Components



Seagrass

- Extremely important shallow-water ecosystems
- Important in carbon sequestration
- The root systems aid in sediment and nutrient stabilization
- Provide habitat for reproduction
- direct food source for commercially and ecologically important fish and shellfish

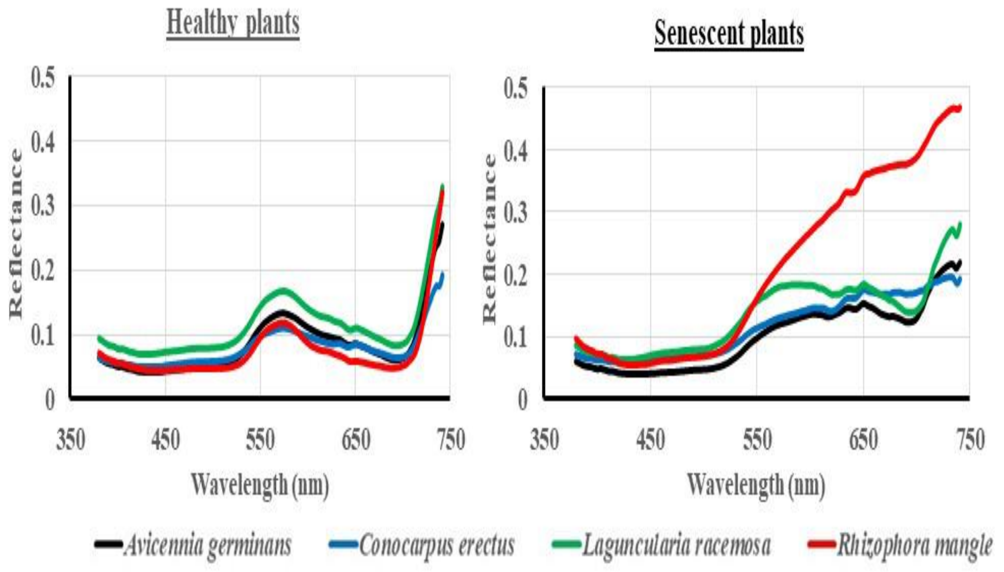




Mangrove

- Mangroves are halophytes (salt-tolerant plants) adapted to live in coastal areas.
- 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.

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



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
  - 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

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

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, incidence and penetration in the water column, aerosols, etc.

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.

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

RGB Image

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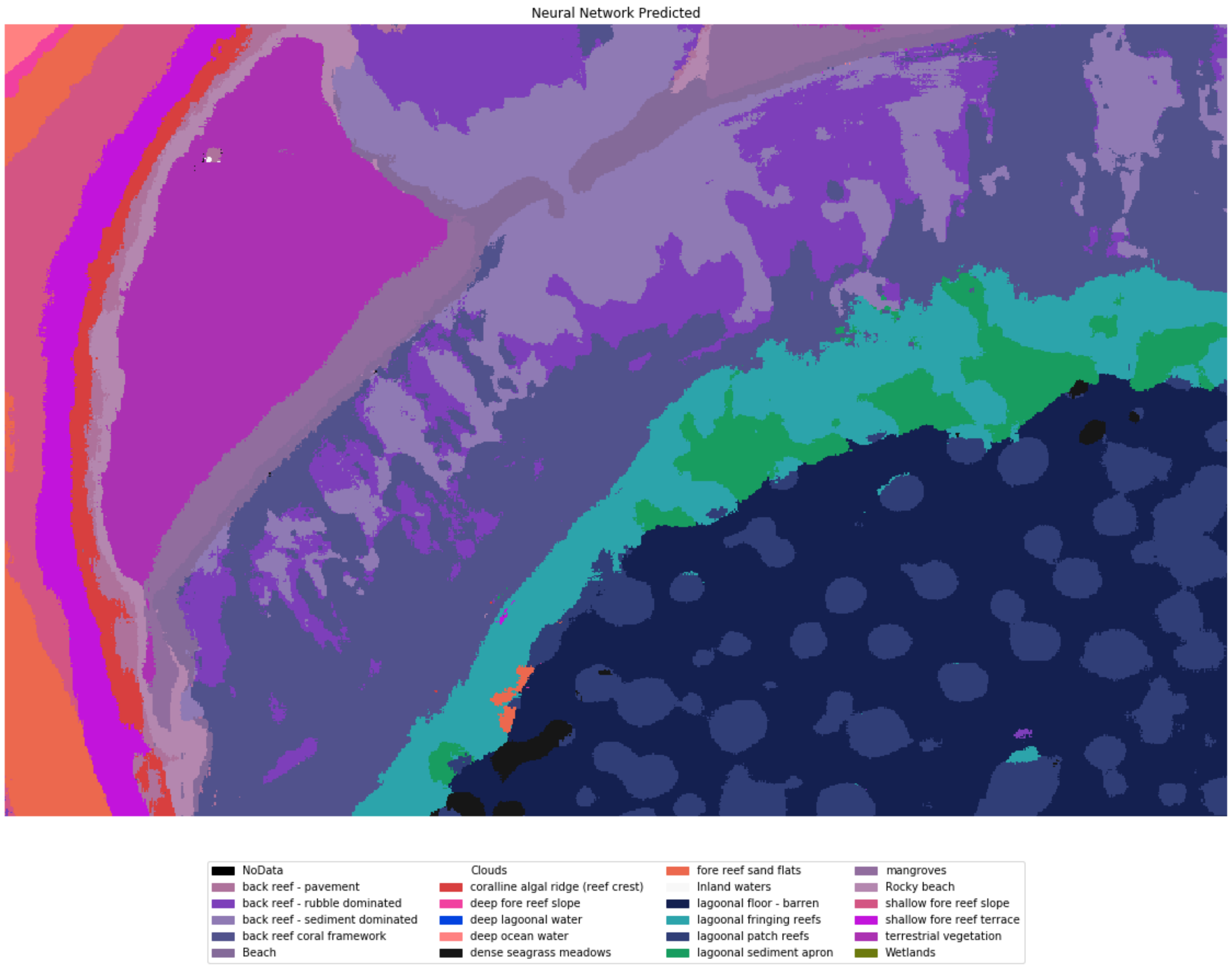

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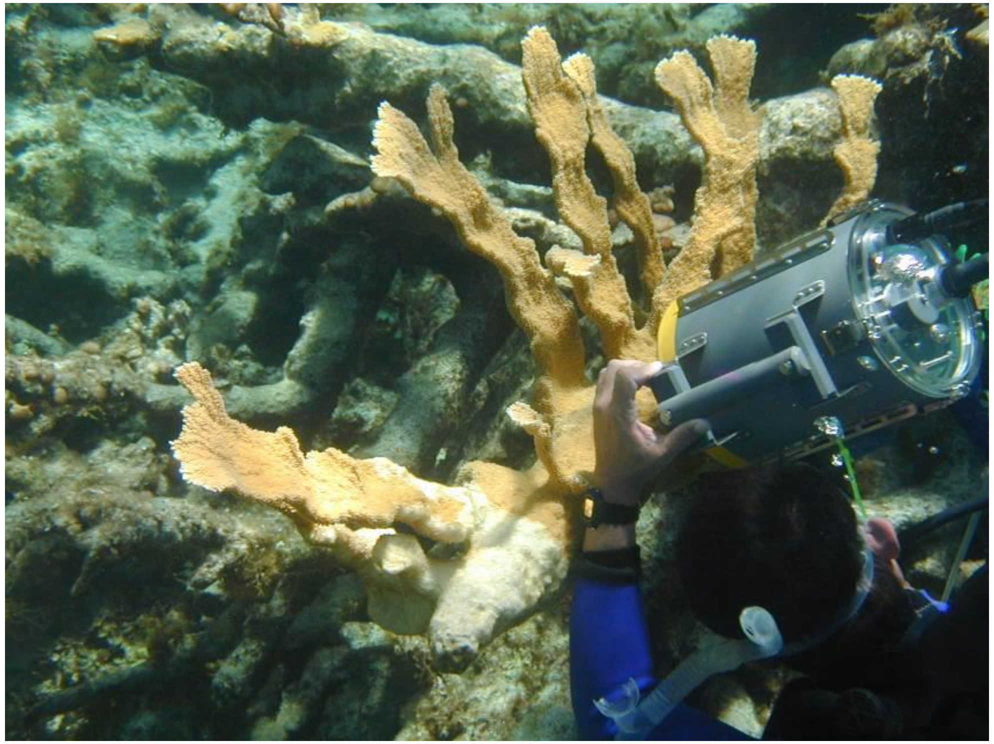
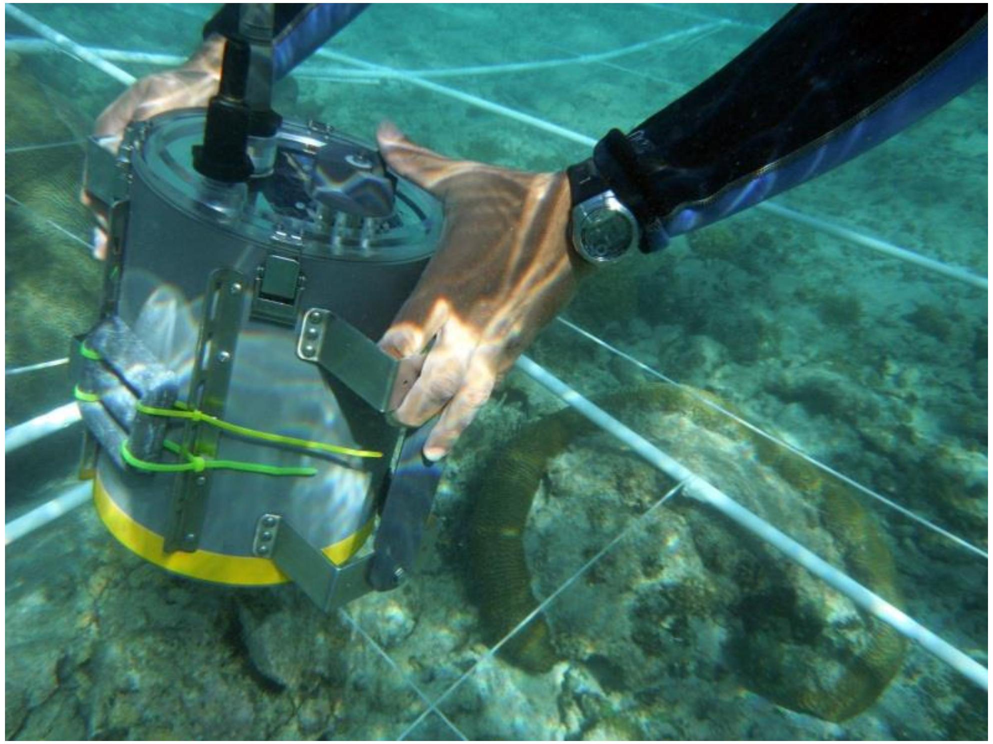
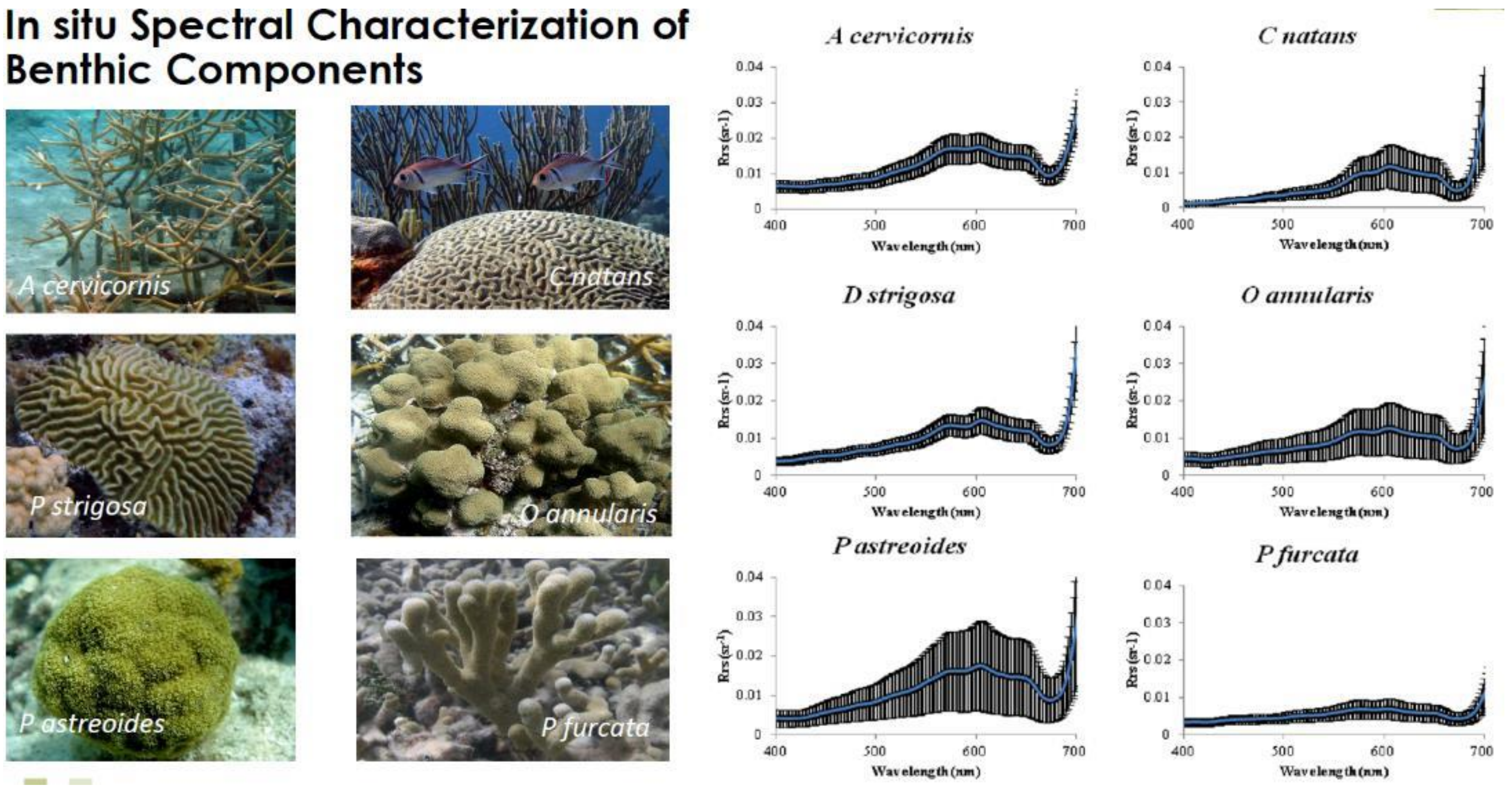
In situ Spectral Characterization of Benthic Components

- 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

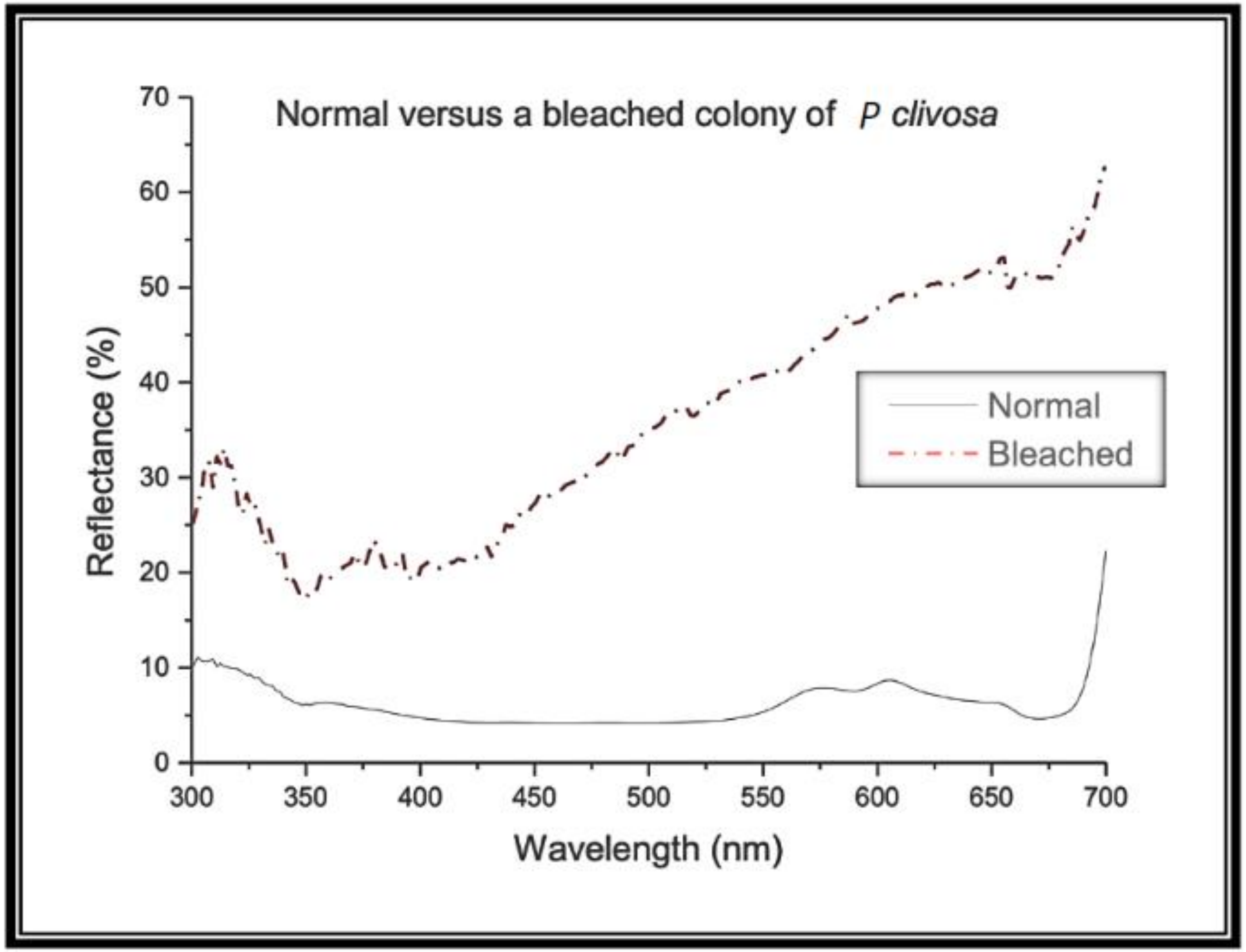


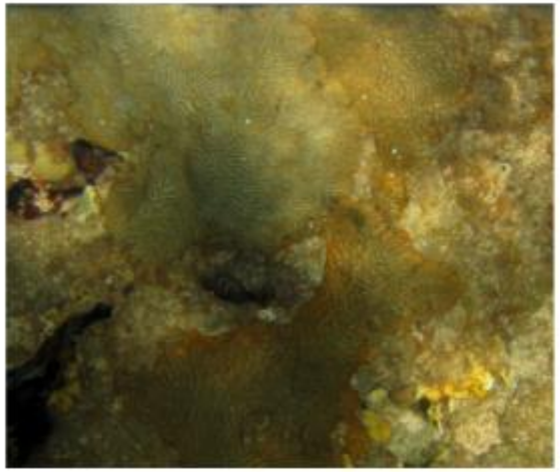


In situ Spectral Characterization of Benthic Components



In situ Spectral Characterization of Benthic Components





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

Indirect Monitoring of Benthic Ecosystems

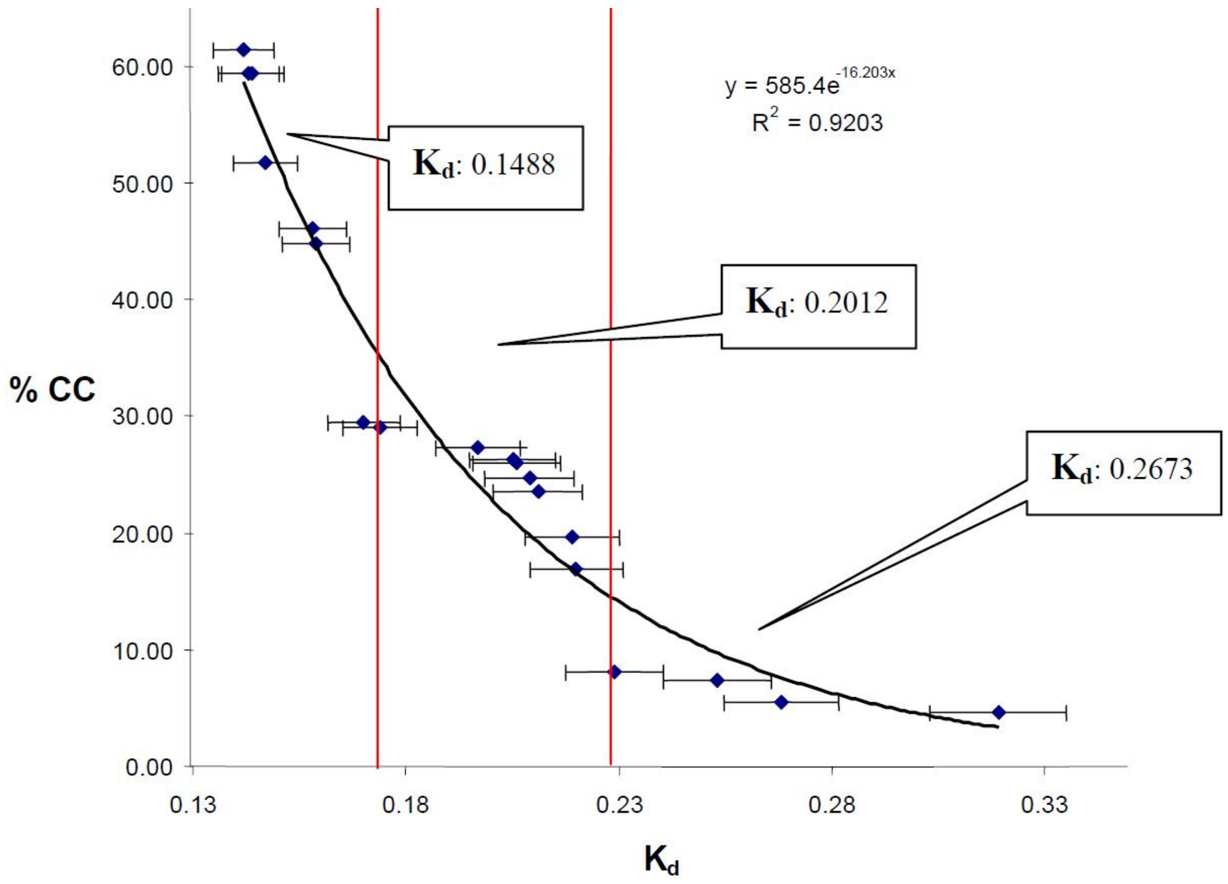
• Kd can be used to estimate ecological indicators (percent cover of dominant groups/species, species diversity and richness).

– 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.

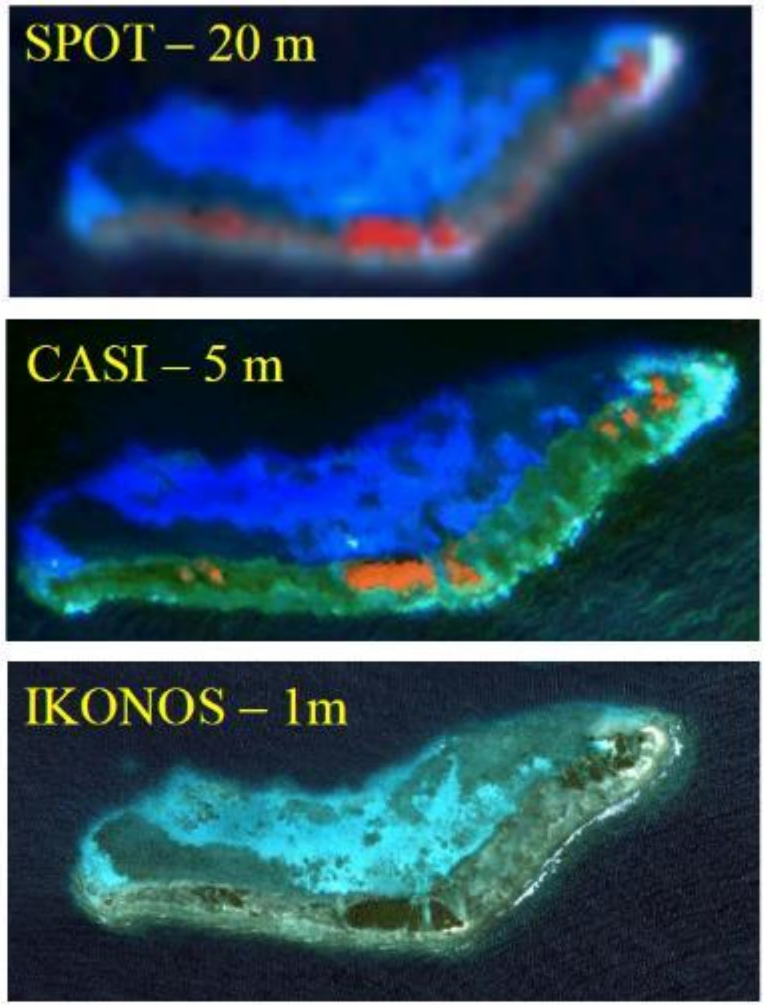
• UV radiation is directly correlated with a reduction in coral growth and reproduction.



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

Limitations of Satellite Imagery for Complex Coastal Ecosystems

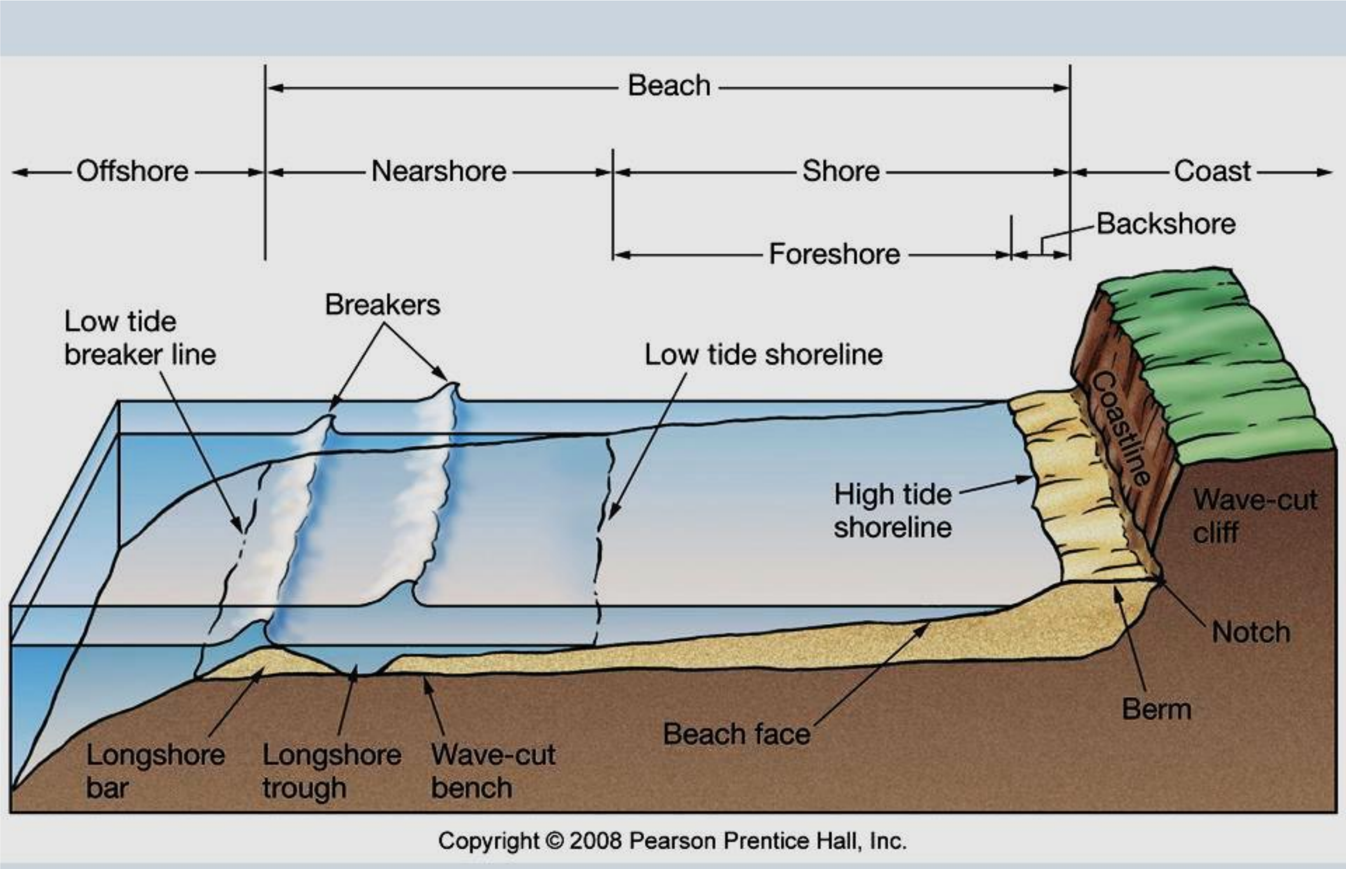
- The presence of land-derived, suspended or dissolved constituents in coastal waters makes it difficult to use remote sensing data to study shallow to moderate depth ecosystems.

- The color of the water provides a lot of information on the composition of dissolved and suspended materials in the water column.

- 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.

Major Components of a Shoreline



Major Components of a Shoreline

Shores are Classified in Two Major Types

Erosional Shores

•Have well-developed cliffs and are common in coastlines affected by tectonic activity

•Some features include coves, sea stacks, sea arches, and headlands.

Depositional Shores

•Are typical of passive margins and show areas with large deposits of sediment (sandy beaches)

•Some features include river deltas, barrier islands, and lagoons.

Shoreline Morphology Characterization

- Identification of the type of coastline (rocky, beach, vegetated)
- Identification of areas of erosion vs areas of accretion
- Identification of sediment types and composition
- Provides information on weathering patterns in other parts of the watershed
- Combines remote sensing with in situ techniques to study historical and present changes in the extension of a particular coastline type
- Identifies the distribution and current status of natural or man-made physical barriers

Shoreline Monitoring

Advantages of Using Remote Sensing to Study Shoreline Changes

- Allows for assessment of the current state of the shoreline at the time of the image capture
- Allows for a quantitative and qualitative evaluation of the shoreline components
- Allows for comparisons between different time periods or sites
    - With satellite series like Landsat you can do time series analyses

- May combine diverse tools depending on the goal of the project
    - Optical and radar
    - Satellite and airborne
    - Unmanned Aerial Systems
    - Different spatial scales

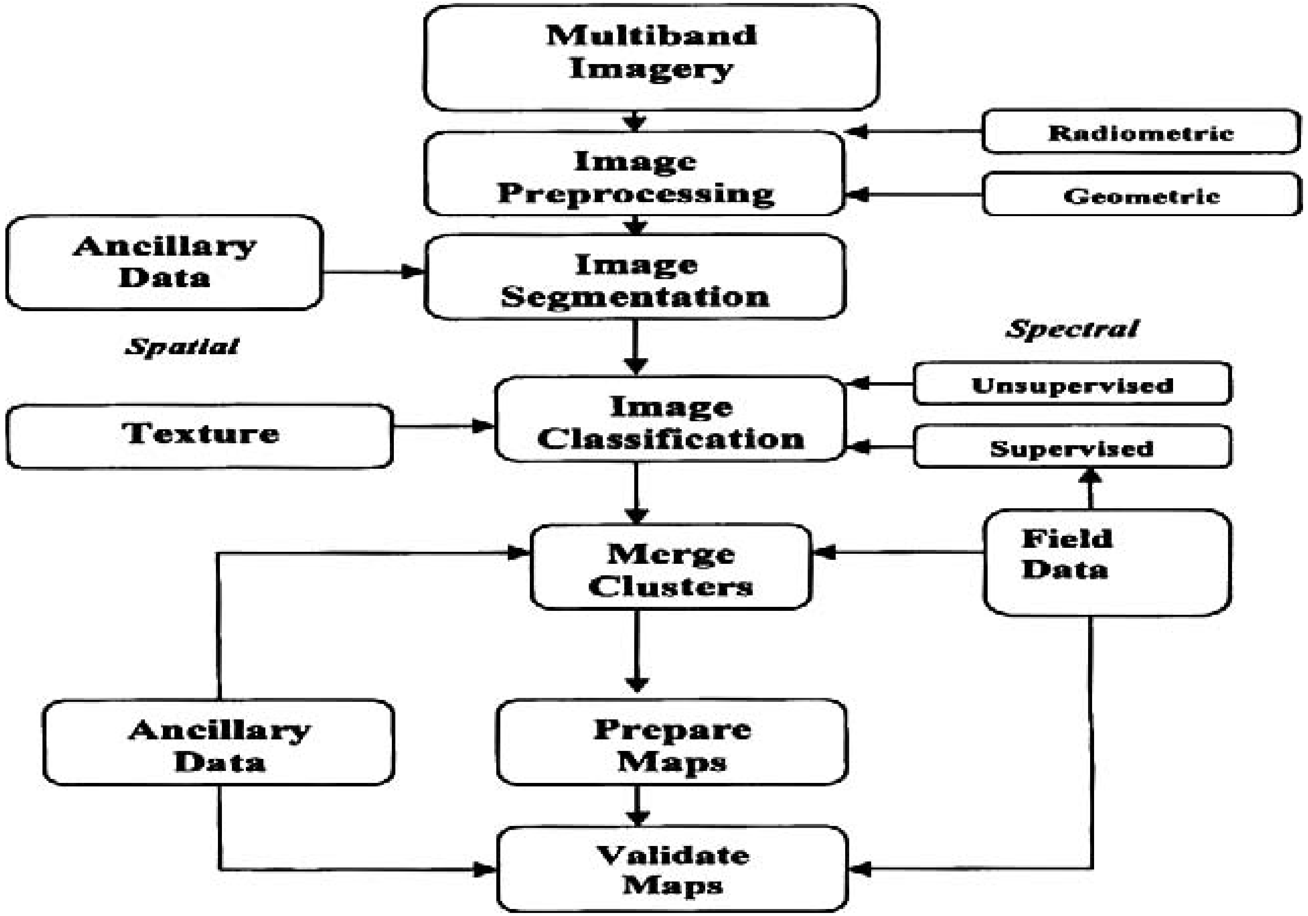
Coastal Wetlands

Salt Marshes

Mangrove Forests

Typical Image Analysis Approach for Coastal Wetlands

1. Radiometric and Geometric Correction
2. Image Segmentation
3. Supervised and Unsupervised Classification
4. Cluster Analysis
5. Final Image Classification



Coastal Wetlands

Vegetation indices and biophysical parameters used for inland areas are also useful for coastal wetlands.

Vegetation/Greenness Indices

•NDVI-Normalized Difference Vegetation Index

•EVI-Enhanced Vegetation Index

•SAVI-Soil-Adjusted Vegetation Index

•MSAVI-Modified Soil-Adjusted Vegetation Index

•SATVI-Soil-Adjusted Total Vegetation Index

Biophysical Parameter Estimates

•PAR-Fraction of Photosynthetically Active Radiation

•Fractional Cover

•GPP and NPP-Gross and Net Primary Productivity or Biomass

•LAI -Leaf Area Index

Shoreline Topography and Bathymetry

•Topography and hydrography are basic elements needed for studying nearshore processes

This includes information on:

- –Long-and short-term changes
- –Beach profiles
- –Erosional or depositional events
- –Wetland changes
- –Changes in local vegetation structure and health

Methods for Mapping Bathymetry of Shallow Waters and Topography of Adjacent Beaches

Methods	Sensors	Area	Strengths	Limitations	Accuracy or Relative Error (%)	References
Stereoscopy	Stereo Optical Imagery	Beach	High horizontal resolution; capable of capturing local beach features	Depend on ground control points to correct the vertical offset	RMSE of 0.35-0.48m	Almeida et al (2019)
Water Line	SAR and Optical	Intertidal	Increasing number of sensors in orbit allows for better sampling of intertidal zone	Assumes stable topography during acquisition time	RMSE of 0.20m	Li (2014)
InSAR	SAR	Intertidal	No field data required	High temporal decorrelation	RMSE of 0.20m	Lee & Ryu (2017)
Radar Altimetry	Radar and Laser Altimeters	Intertidal	Can provide very accurate measurements	Generate only intertidal topography profiles	RMSE of 0.23 m	Salameh et al (2018, 2019)
Aquatic Color Radiometry	Multispectral and Hyperspectral	Nearshore	No field data required	Sensitive to heterogeneity of water column and surface effects	Depends on IOPs and bottom substrate	Lee et al (1999); Capo et al (2014)

Stereoscopy for Bathymetry and Coastal Topography

- Provides high spatial resolution (sub-meter)
- The Satellite SPOT was the first constellation of civilian satellites to acquire stereoscopic images.
- The Pleiades 1A-1B constellation CNES collects stereoscopic imagery at 0.7m spatial resolution and has the ability to revisit any place in the world in one day.
    - Useful for monitoring of rapid coastal processes such as erosion caused by a storm

Waterline for Bathymetry and Coastal Topography

•The name refers to the land-sea boundary, or the shoreline, in the intertidal zone.

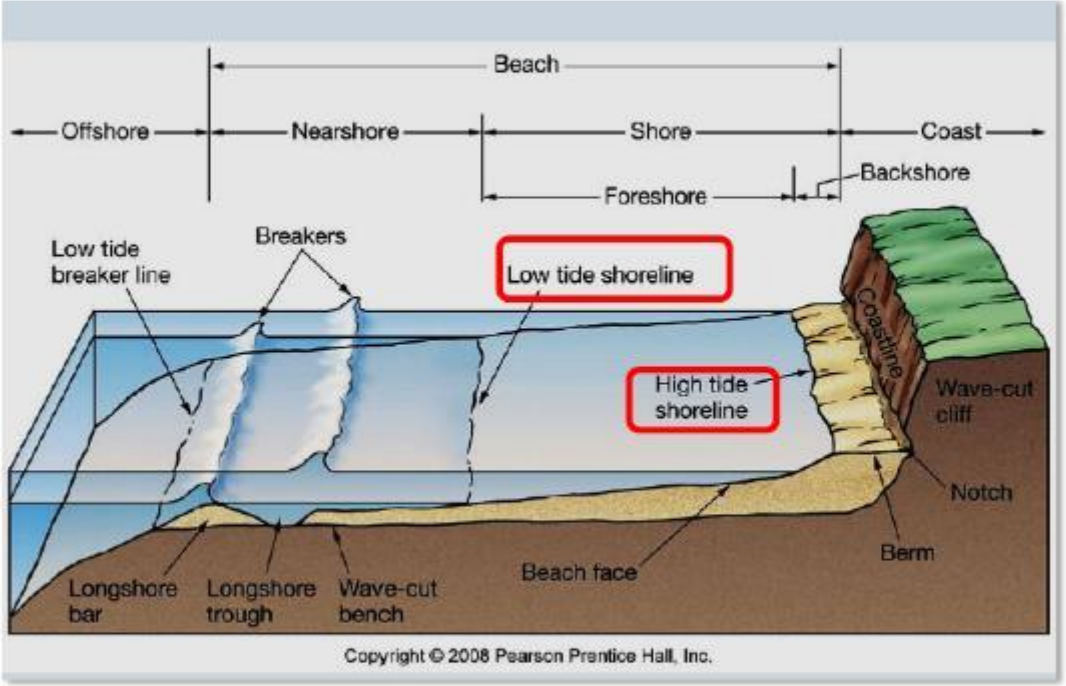
•Is the most widely used technique for constructing intertidal digital elevation models (DEMs)

•Combines remote sensing with hydrodynamic modeling

•Uses a series of images covering the whole tidal range to form a gridded DEM

•Assumes no major changes in the topography of the intertidal zone during the image acquisition period

•Typically uses SAR images, but optical can also be used



Shoreline Topography and Bathymetry

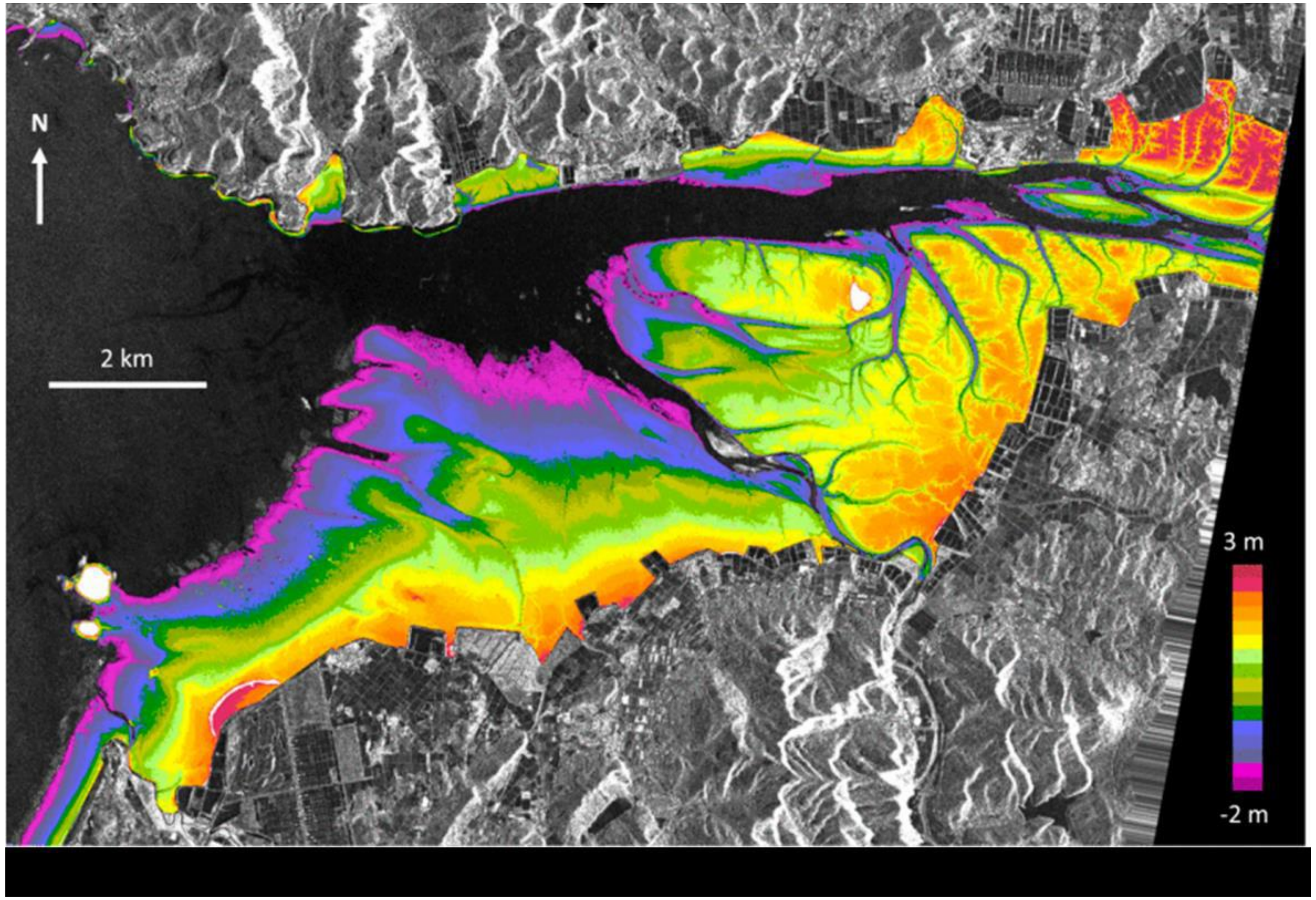
InSARfor Bathymetry and Coastal Topography

•Interferometric SAR (InSAR)

•Uses two or more SAR images taken from different positions, different times, or both to extract topography information from their phase difference

•Like other uses of SAR, one image is called the "Master" and the other ones the "Slaves"

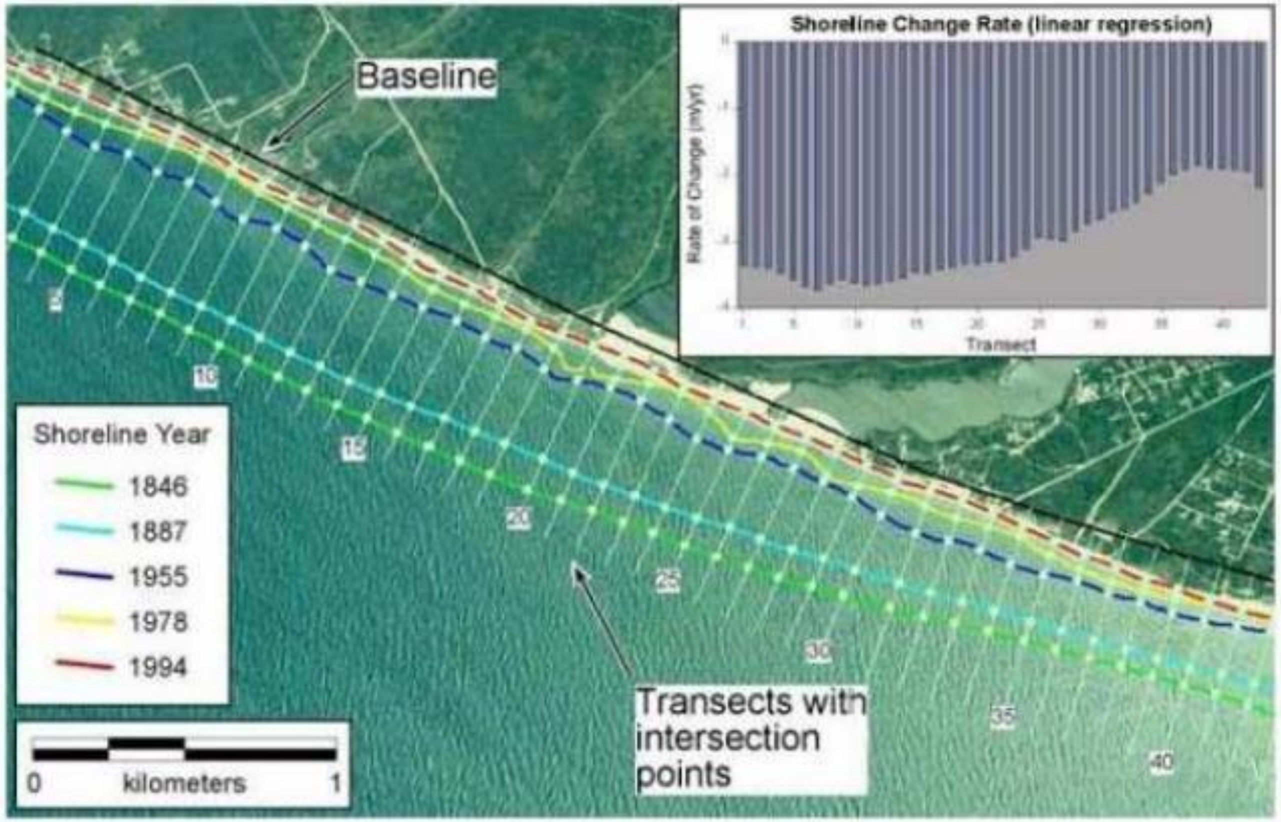
•Best to use single-pass interferometry (two antennas in the same platform) systems with no temporal baseline to obtain accurate DEMs

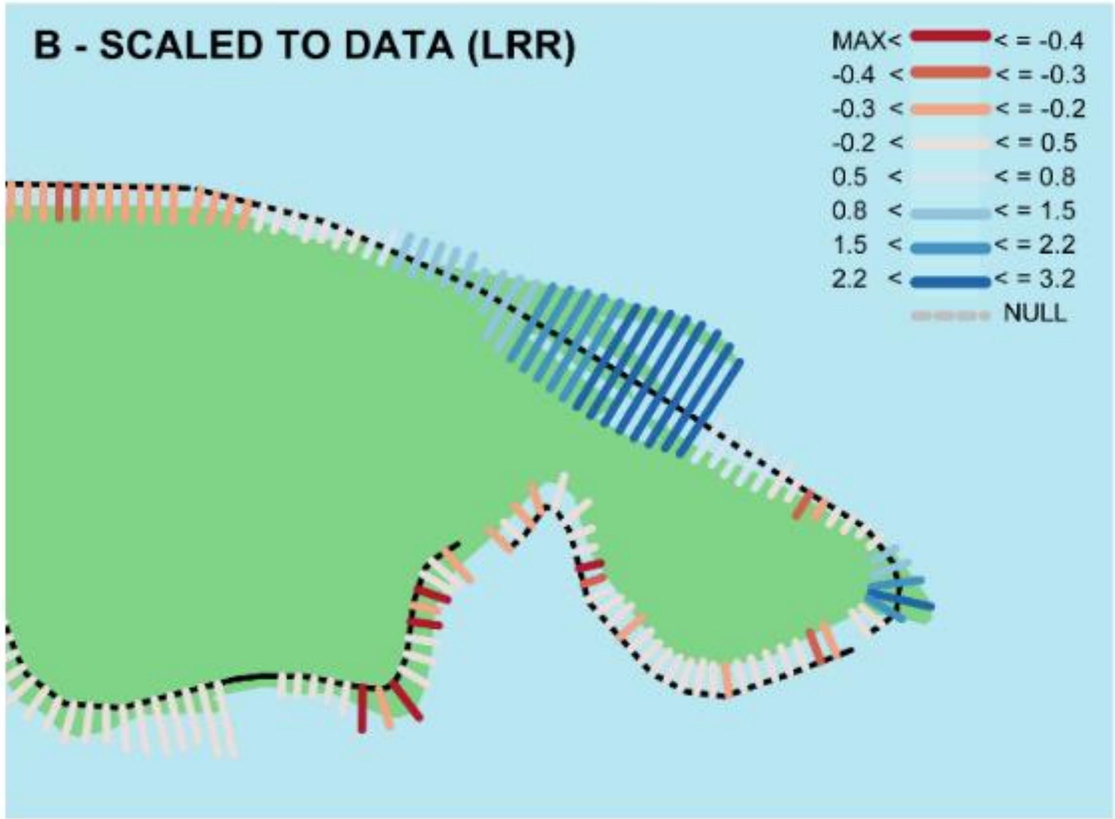


Aquatic Color Radiometry for Bathymetry and Coastal Topography

- Uses remote sensing reflectance (Rrs) as a function of:
  - Bottom albedo in optically shallow waters
  - The concentration of water column components
  - The vertical attenuation coefficient (Kd)
- Requires hyperspectral data unless the bottom topography variability is small, then multispectral data (preferably high spatial resolution) can also be useful

Digital Shoreline Analysis System (DSAS)





https://www.usgs.gov/centers/whcmsc/science/digital-shoreline-analysis-system-dsas

Lakes Monitoring

• Water volume or storage in lakes is influenced by watershed processes such as precipitation, topography, soil and vegetation cover, runoff, population density, and water consumption rate.

• Climate variability and change, land use, and water demands can impact both water inflow and outflow and influence the volume of lakes and reservoirs.

• Sediments brought to lakes and reservoirs by streams can alter their physical and chemical characteristics.

• Both the horizontal extent and water depth of lakes are influenced by the above factors.

*Water quality management is an integral part of lake management.

For sustainable and efficient water resources and ecosystem management, monitoring lake area and depth is very important.

Lakes Monitoring

• Water volume in a lake can be estimated as:

(Average Lake Area) x (Average Water Depth)

• Shoreline length (or width and length) and bathymetry information help in deciding the average volume of lakes.

Water level is required to estimate the volume of water in lakes.

• Lake bathymetry describes bottom topography or depth within the lake.

Monitoring Lakes Using Remote Sensing

• Satellite remote sensing provides global, timely, consistent observations.

• Satellites observe lakes and reservoirs and monitor surface area, water level, and bathymetry

acquired August 30, 2001 - August 20, 2006

Satellites and Sensors for Lakes

Lake Parameter	Satellites	Sensors	Spectral Measurements
Surface Water Extent	Terra & Aqua	MODIS	Optical
Surface Water Extent	Landsat 7, 8, and past data from Landsat 5	ETM+, OLI TM, MSS	Optical
Lake Level Height	Jason 2, 3, and multiple past satellites	Altimeter	C-Band and Ku-Band
Lake Level Height and Bathymetry	ICESat-2	ATLAS	Laser
Lake Polygons	SRTM	Radar	C-Band Synthetic Aperture Radar

Satellites and Sensors for Lakes

Surface Water Extent	Satellites	Spatial Resolution	Temporal Coverage and Resolution
Surface Water Extent	*Terra & Aqua	250 m	12/1999 – Present 05/2002 – Present Annual
Surface Water Extent	*Landsat 5, 7, 8	30 m	04/1999 – Present 02/2013 – Present Annual
Lake Level Height	[2]Jason 2, 3	Lakes > 100 km^2	06/2008 – Present 01/2016 – Present 10-day & 35-day
Lake Level Height and Bathymetry	[3]ICESat-2	Lakes > 0.1 km^2	9/2018 – Present 91-day
Lake Polygons	*SRTM	30 m	2/2000

Global Lake Polygons: HydroLAKES

- https://www.hydrosheds.org/pages/hydrolakes

- HydroLAKES database provides shoreline polygons of global lakes of 10 hectares and larger.

Data Download:

The data can be downloaded in 4 different formats:

1. Lake polygons (including all attributes) in an ESRI Geodatabase (727 MB zip-file)
2. Lake pour points (including all attributes) in an ESRI Geodatabase (78 MB zip-file)
3. Lake polygons (including all attributes) in a Shapefile (782 MB zip-file)
4. Lake pour points (including all attributes) in a Shapefile (75 MB zip-file)

Global Surface Water

http://global-surface-water.appspot.com/#

- Developed by the European Commission’s Joint Research Center (JRC)
- Based on entire archive of Landsat 5, 7, and 8 imagery

- Surface Water data available at 30 m resolution.

- Currently available from 1984 to 2019.

- Data available from Global Surface

Altimeter-based Lake Level Height Data

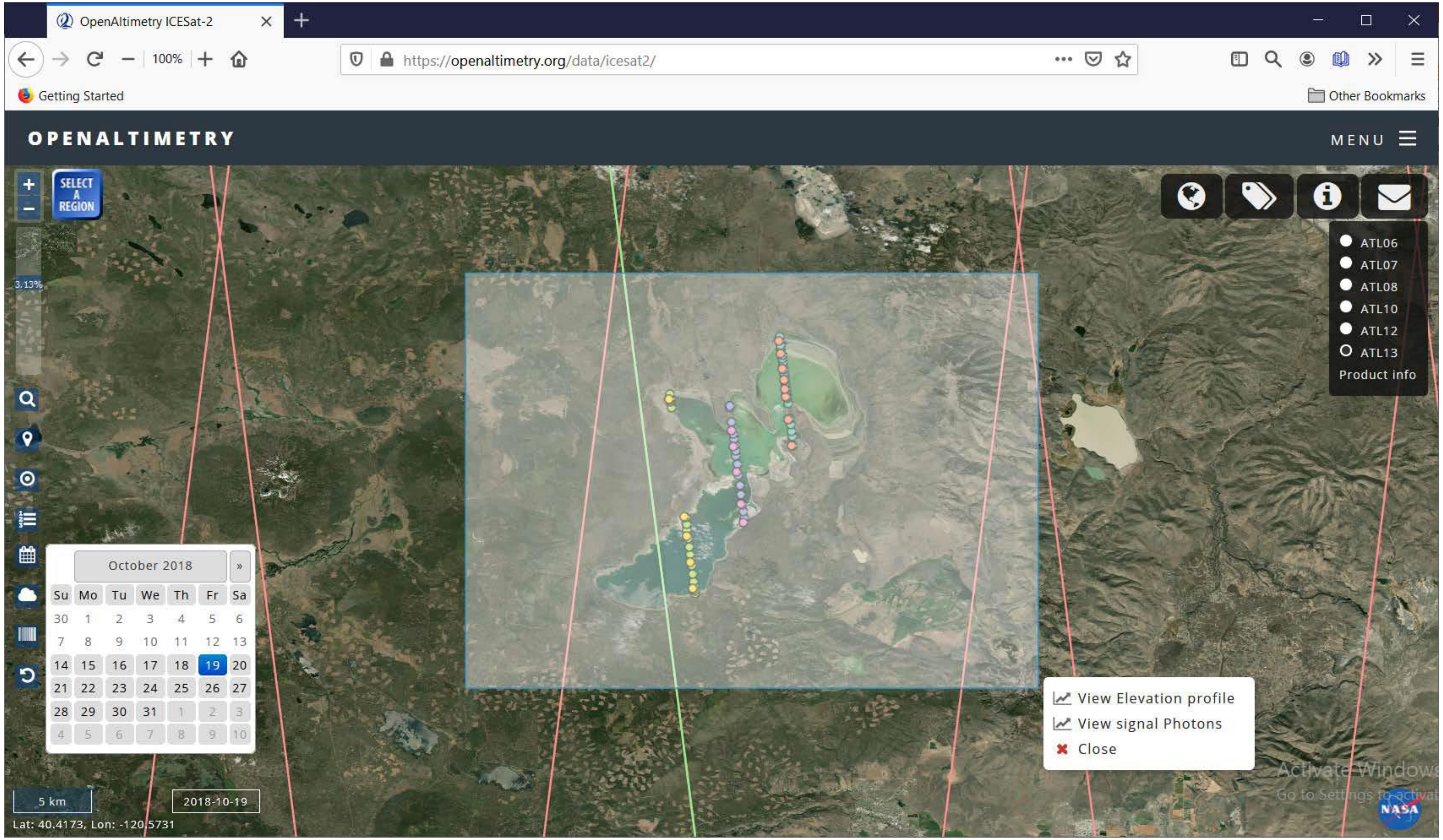
Global Reservoirs and Lakes Monitoring (G-REALM)

https://ipad.fas.usda.gov/cropexplorer/global_reservoir/

ICESat-2 Analysis Tools

Data Access:

https://openaltimetry.org/



Thank You