National Aeronautics and Space Administration

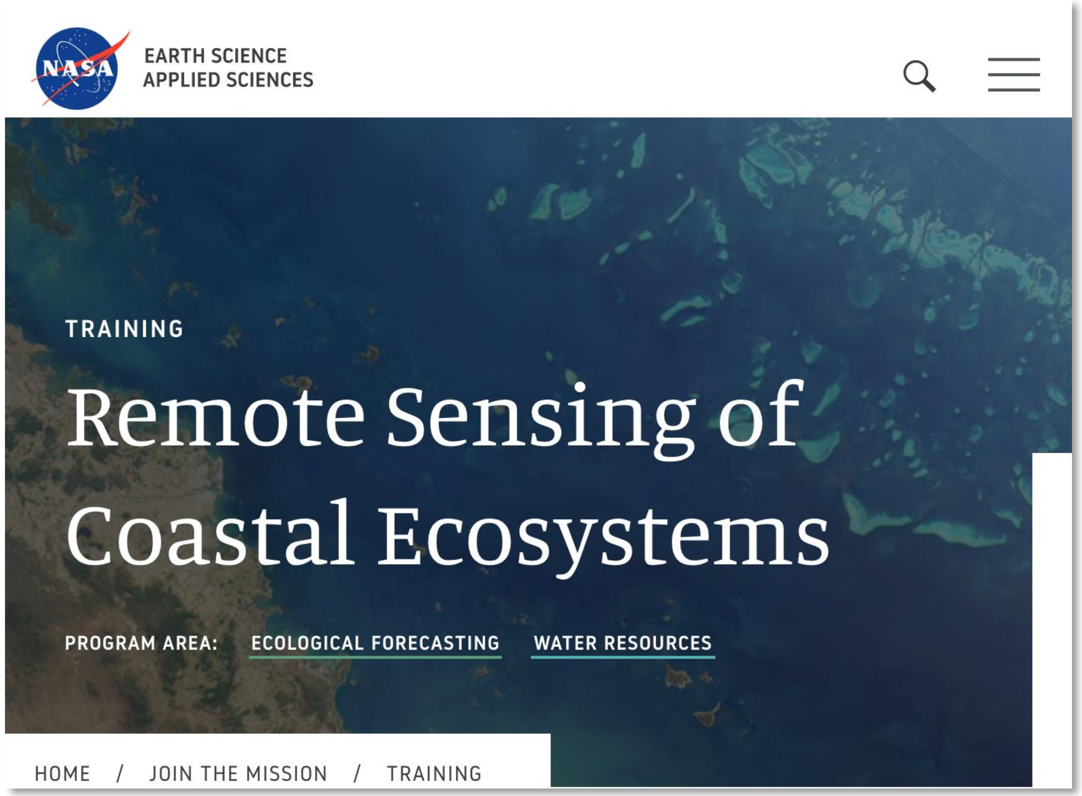
# Remote Sensing of Coastal Ecosystems

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

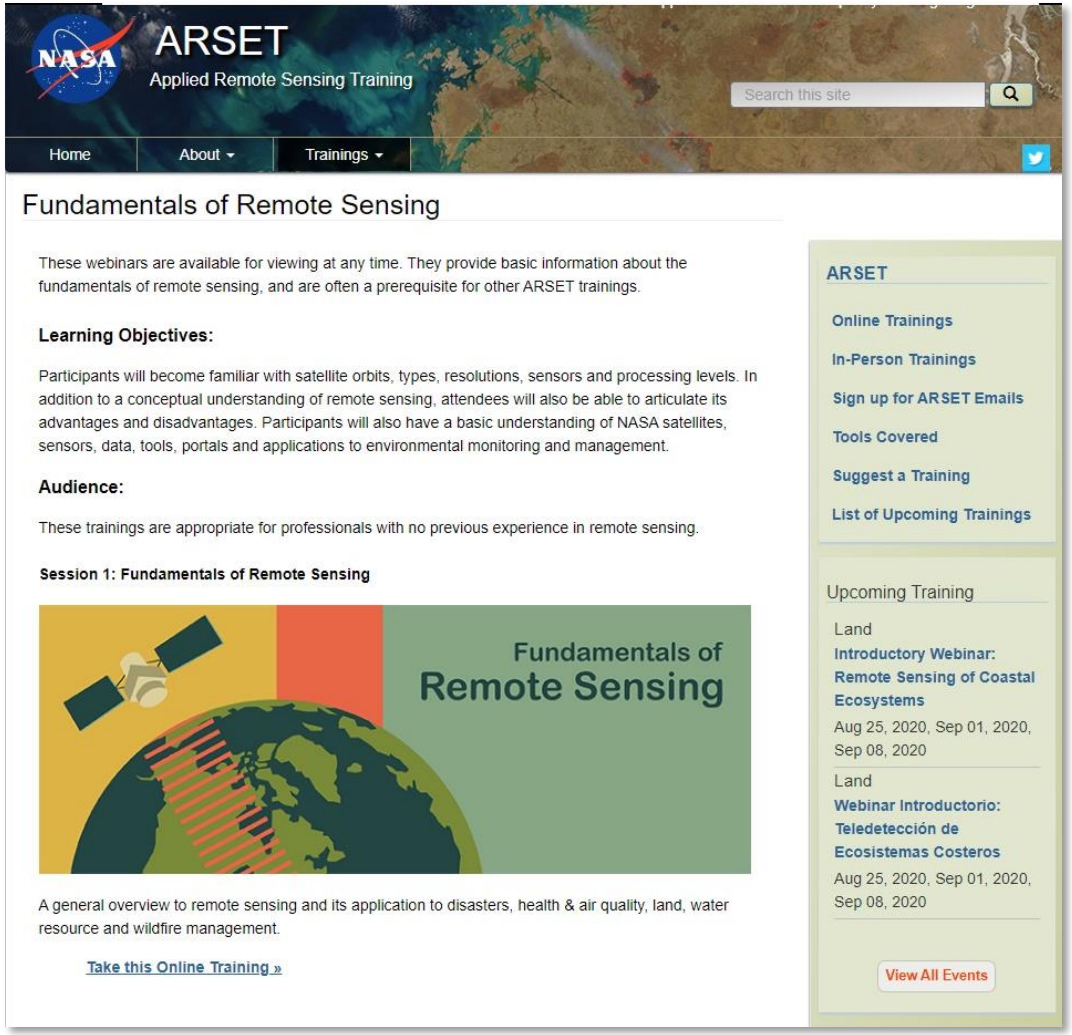
- **Homework:**
  - One homework assignment
  - Answers must be submitted via Google Forms
  - **HW Deadline: Tuesday Sept 22**

- **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

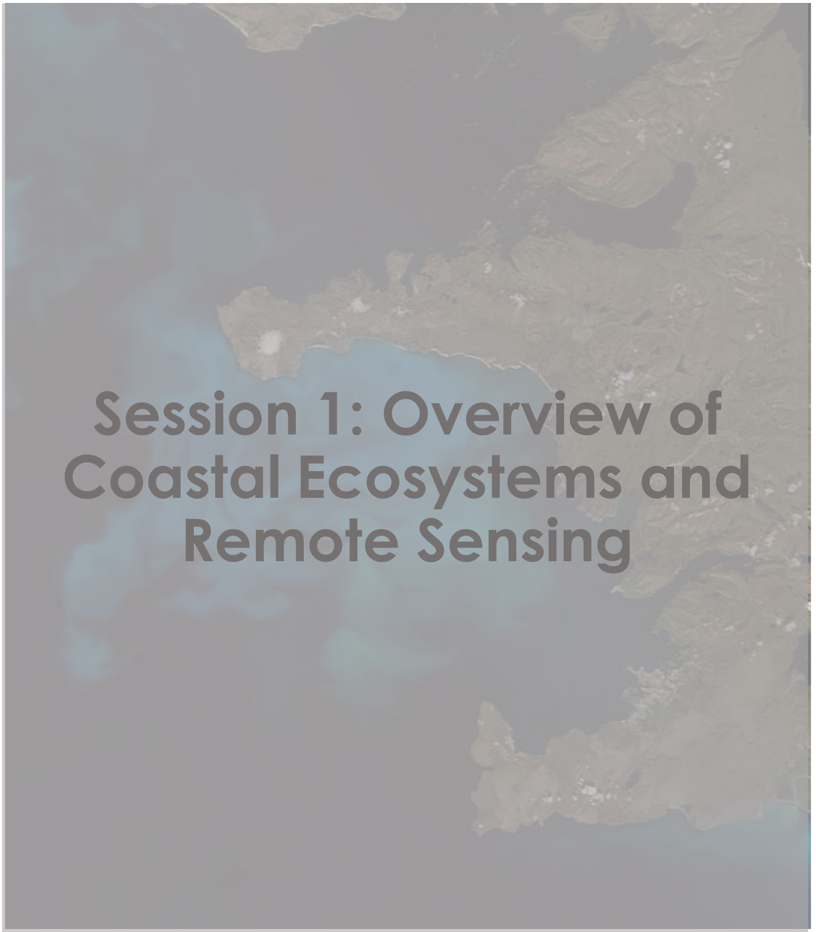
# Prerequisites

- **Prerequisites:**
  - Please complete Sessions 1 & 2A of Fundamentals of Remote Sensing or have equivalent experience.

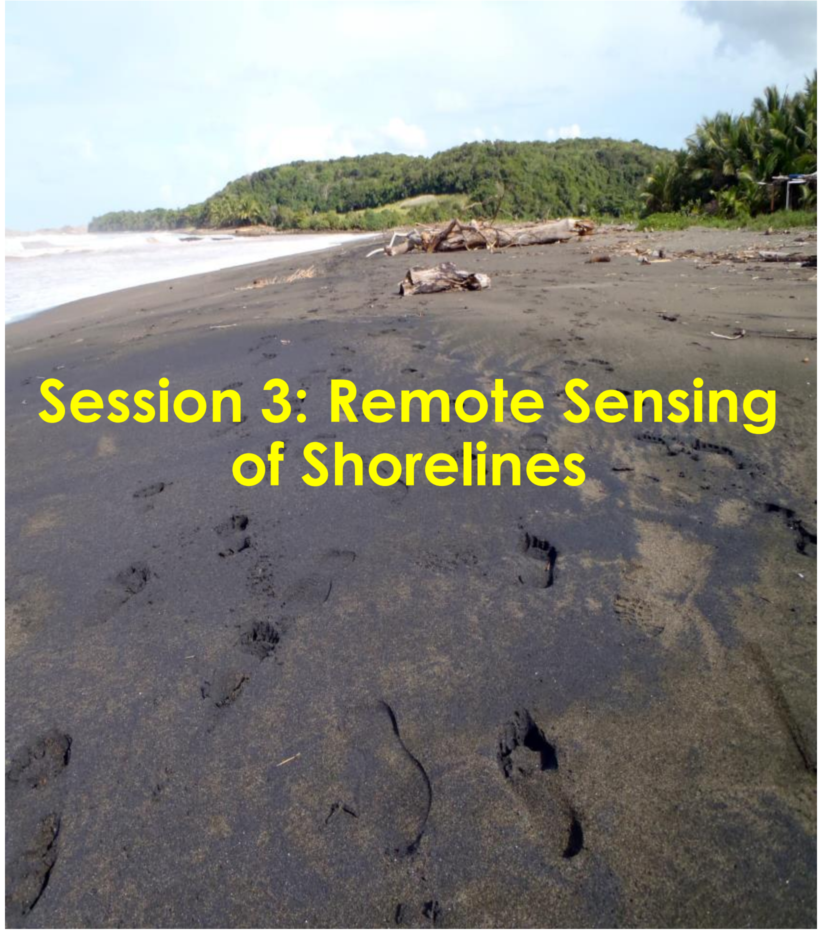
- **Course Materials:**
  - https://appliedsciences.nasa.gov/join-mission/training/english/remote-sensing-coastal-ecosystems



# Course Outline







# Learning Objectives

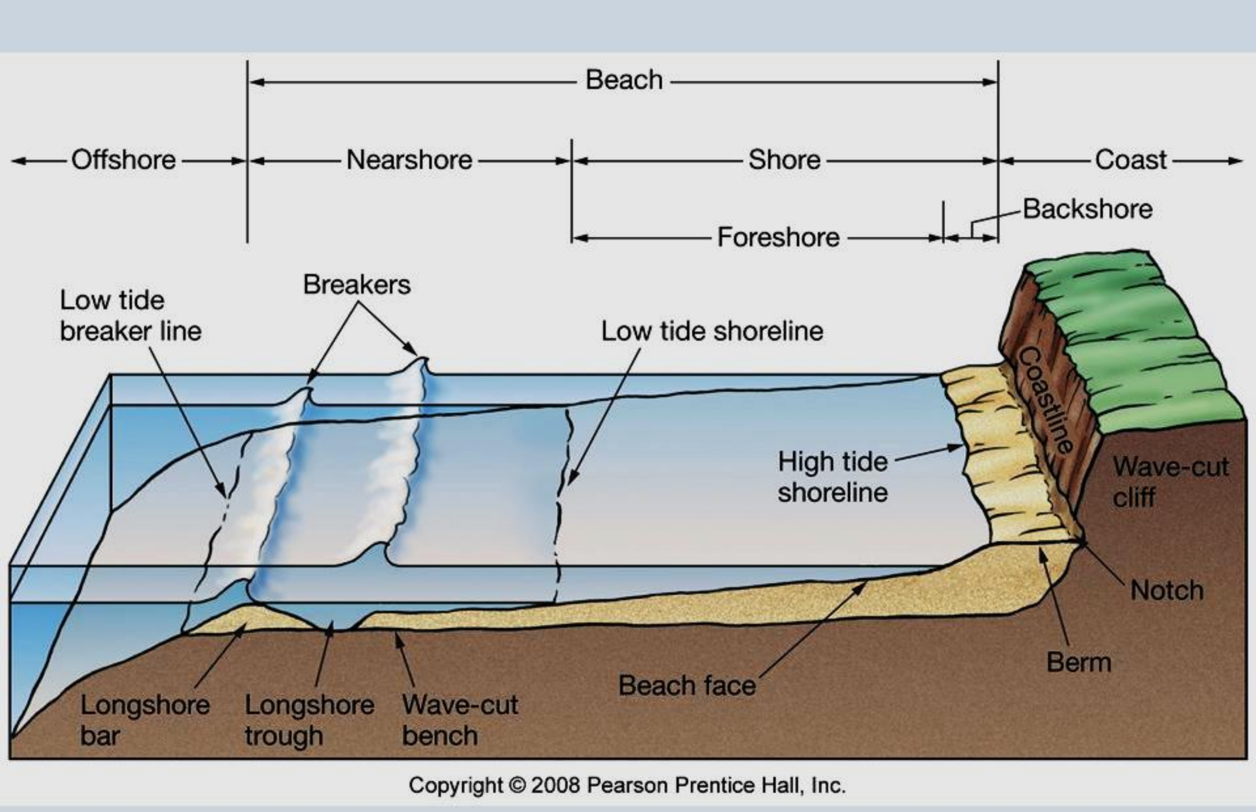
By the end of this session, you will be able to:

- Identify the main geological features of shorelines, including beach environments
- Summarize techniques used for shoreline characterization with remotely-sensed data

Tómbolo Beach in the north coast of Puerto Rico. Credit: Juan L. Torres-Pérez

# Major Components of a Shoreline

Credit: Dr. Maritza Barreto, Univ. of PR



# 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.
    - Ex: West Coast of US

## Depositional Shores

- Are typical of passive margins and show areas with large deposits of sediment (sandy beaches)
- Some features include river deltas, tombolos, barrier islands, and lagoons.
    - Ex: East Coast of the US

Credit: Dr. Maritza Barreto, Univ. of PR

# 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

Credit: Dr. Maritza Barreto, Univ. of PR

# Causes for Shoreline Changes

- Occurrence and magnitude of tropical or temperate systems
- Hurricanes
- Cold fronts
- Wave action/cyclonic waves
- Tidal range
- Tectonic activity
- Climate change events such as variations in sea surface temperature, sea level rise, etc.
- River discharge
- Human activities such as sand removal or constructions

Differences in beach width.
Credit: Dr. Maritza Barreto, Univ. of PR

# Effects of Sea Level Rise on Coastlines

Credit: www.ejatlas.org

Credit: Dr. Maritza Barreto, Univ. of PR

# Effects of Sea Level Rise on Coastlines

March 2018

February 2020

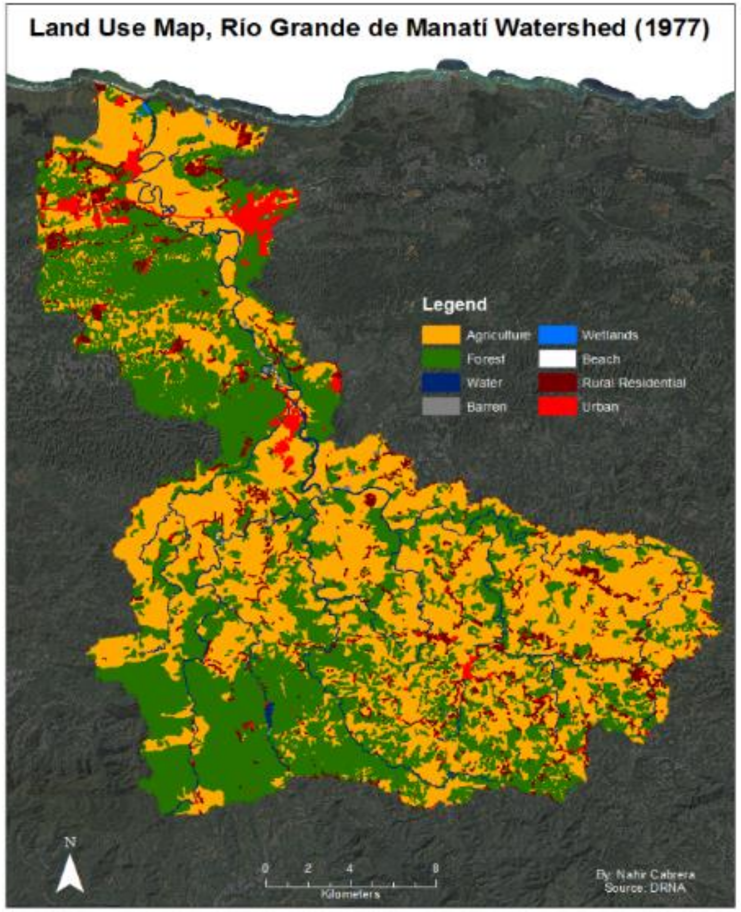


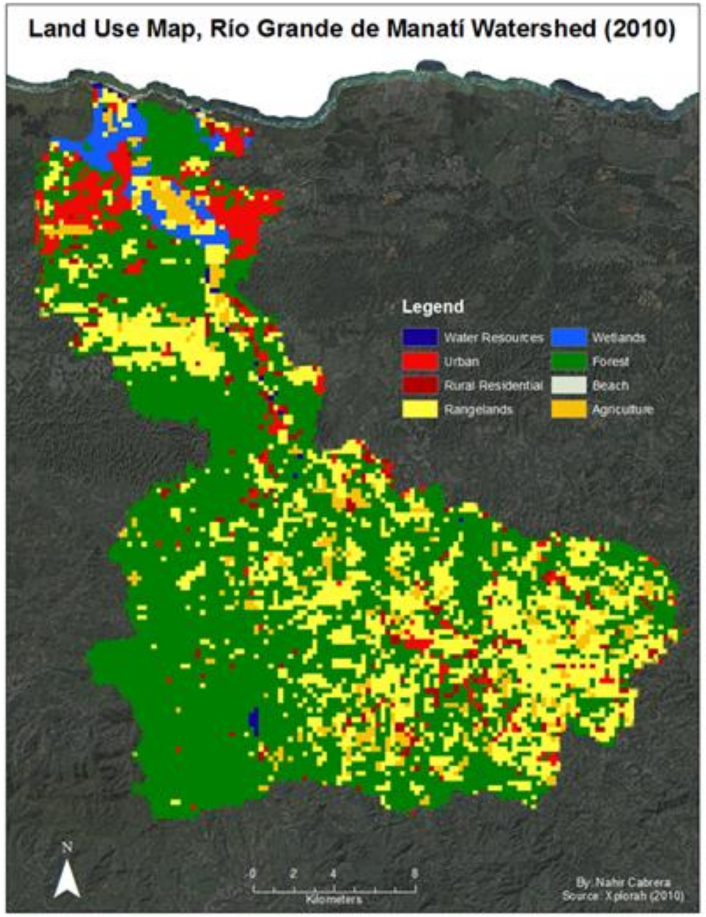
Credit: Prof. Aurelio Mercado, Univ. of PR

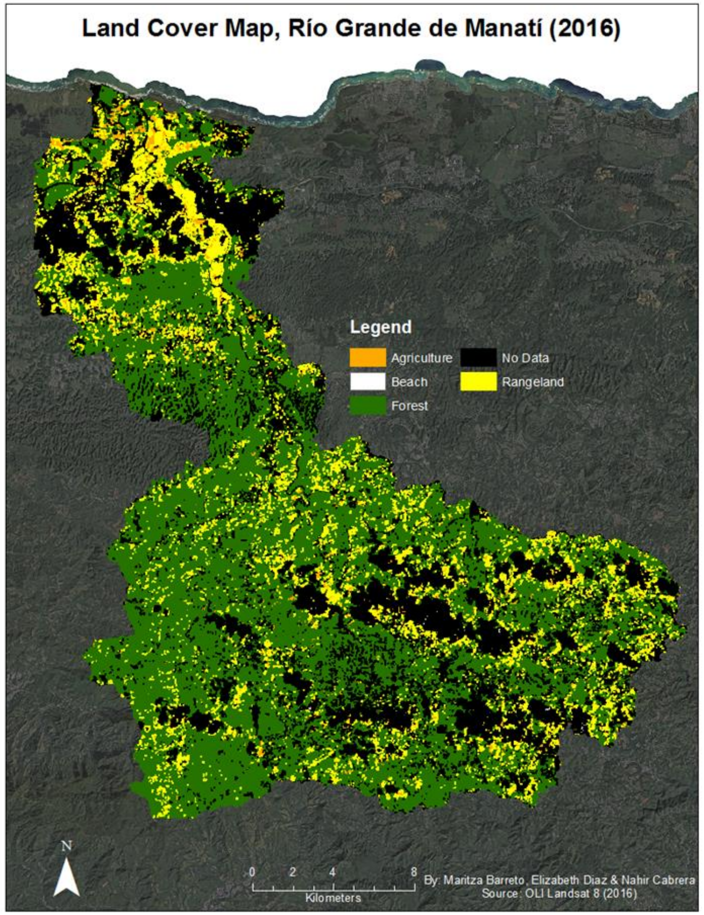
# Advantages of Using Remote Sensing to Study Shoreline Changes

- 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 on some sites for almost 50 years!
- May combine diverse tools depending on the goal of the project
  - Optical and radar
  - Satellite and airborne
  - Unmanned Aerial Systems (UAS; drones)
  - Different spatial scales

# Landsat Imagery for Shoreline and Watershed Changes



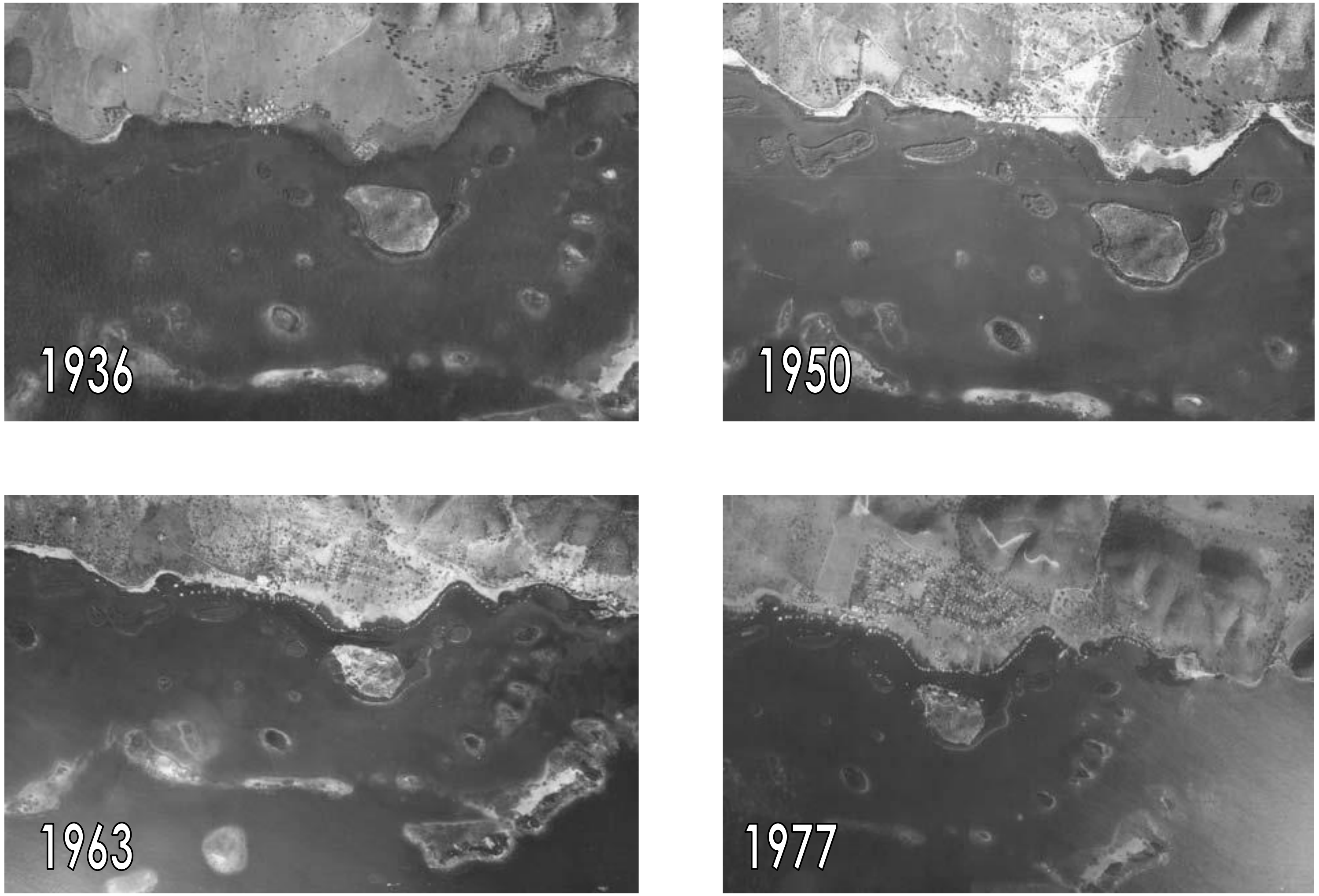

Credit: Dr. Maritza Barreto, Univ. of PR

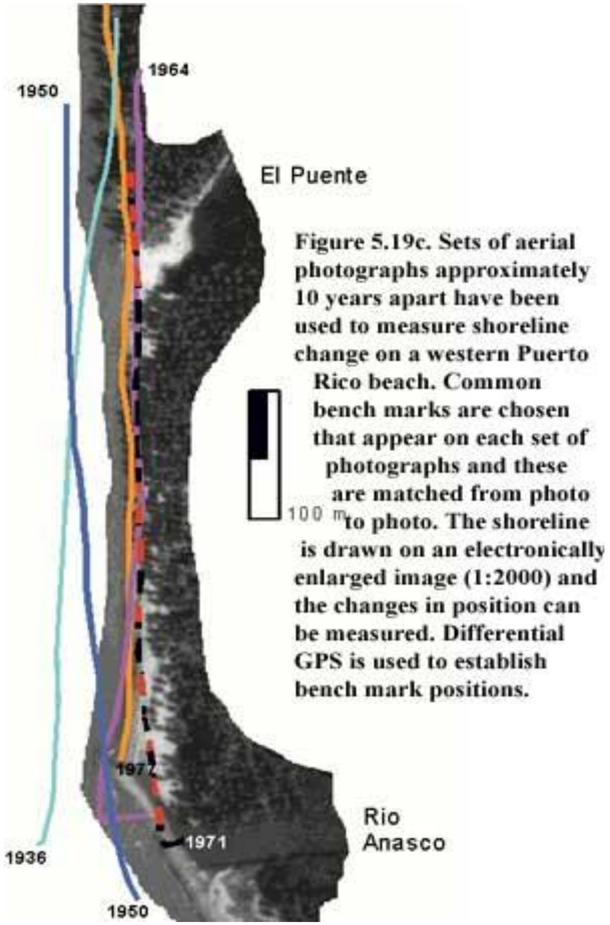
# Advantages of the Coastal Band in Landsat 8 for Shoreline Features

Lagoa Dos Patos, Brazil

Congo River Delta

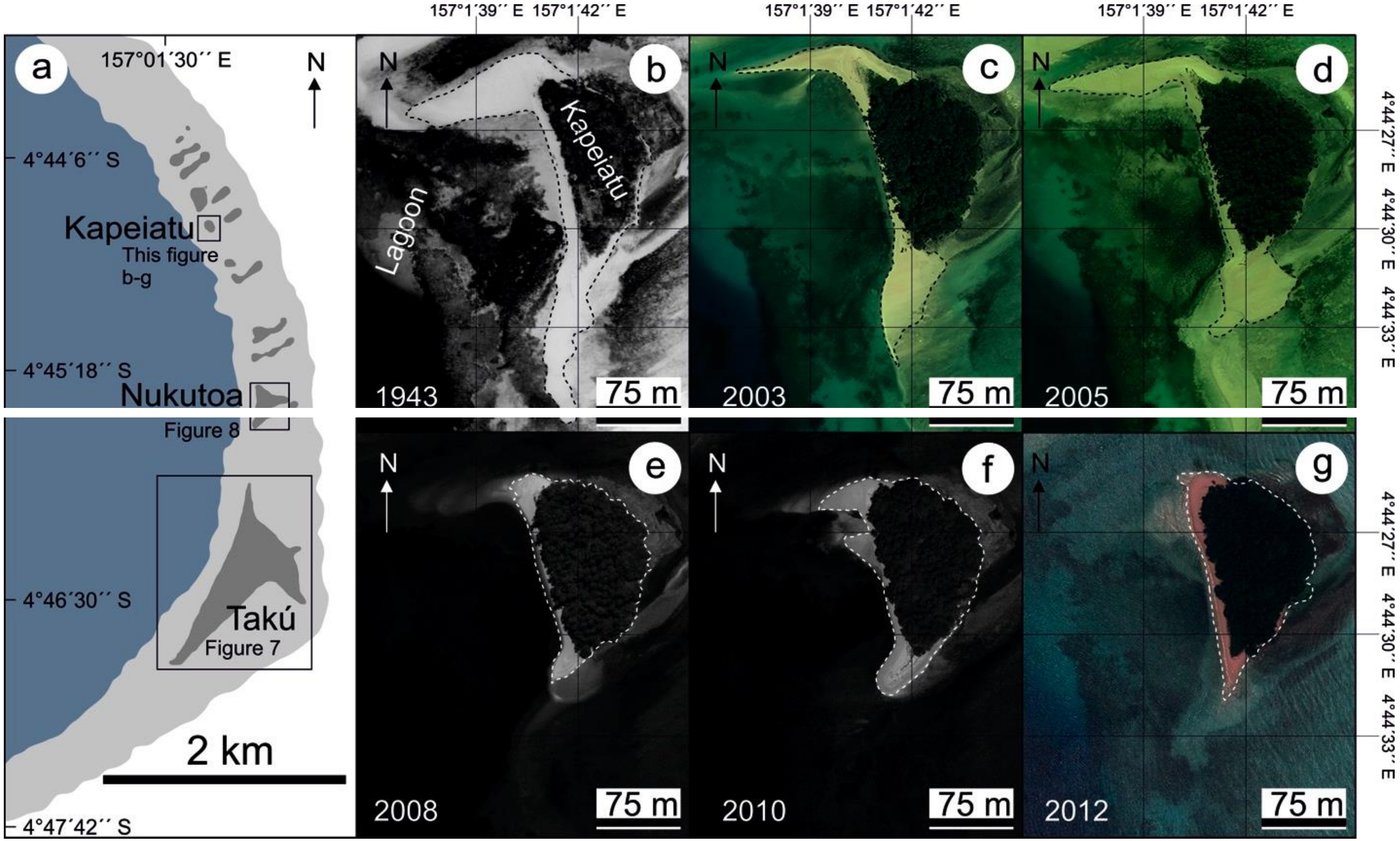
# Use of Historical Aerial Photographs to Quantify Shoreline Changes




Credit: Dr. Maritza Barreto, Univ. of PR

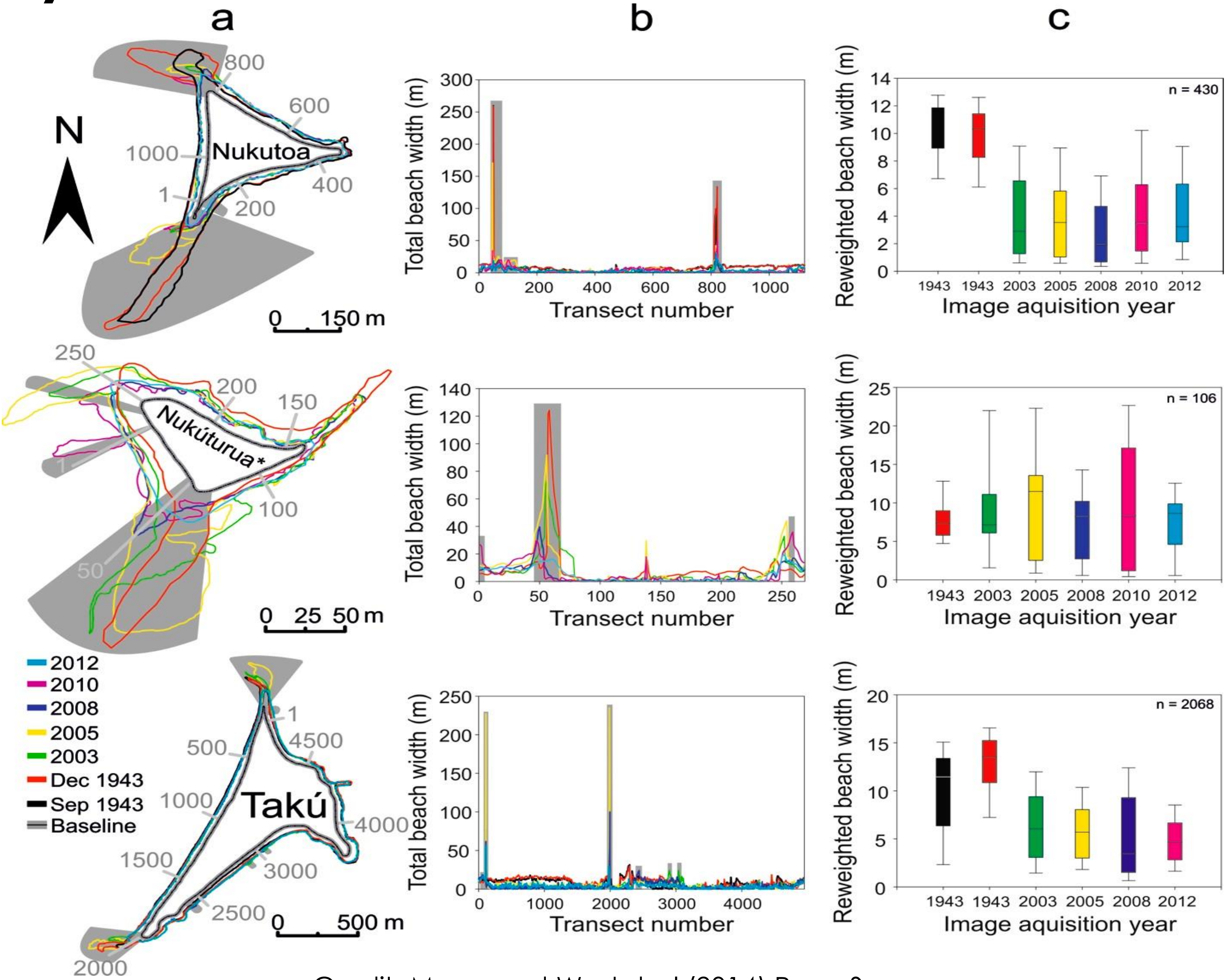
# Combined Aerial and High-Resolution Satellite Data for Shoreline Change Analysis




Credit: Mann and Westphal (2014) Rem. Sens.

# Combined Aerial and High-Resolution Satellite Data for Shoreline Change Analysis

Historical aerial data can be combined with satellite imagery to assess for shoreline changes as a result of sea level rise or other climate- or human-related factors.




Credit: Mann and Westphal (2014) Rem. Sens.

# Dunes, Beaches, and Wetlands

# Coastal Dunes

- Occur where there is a supply of sand, wind to move it, and a place for it to accumulate
- Occur above the spring high tide line and the back-beach forms the seaward boundary of the dunes and the supply of sand
- Classified in two general types:
  - Vegetated Dunes – Form ridges parallel to the beach which are anchored by vegetation
  - Transverse Dunes – Lack vegetation and generally migrate

Credit: www.geology.uprm.edu/MorelockSite

Credit: www.commons.Wikimedia.org

# Beach Types (Dissipative vs. Reflective Beaches)

## Dissipative Beaches

- Develop under high wave conditions where there is an abundant supply of medium to fine sands
- The surf zone is wide with a gentle slope (<5 degrees)
- More dominated by wave action
- Wide beach face
- Usually lack a berm

## Reflective Beaches

- Form during low to medium wave conditions
- Coarser sands
- Have a steeper slope (>10 degrees)
- Are more dominated by tides

Dissipative (left) and Reflective (right) beaches in Australia. Image credit: www.ozcoasts.org.au

# Beaches are highly dynamic environments.

- Beach extension and width can change in short periods of time.
- This can be part of the natural beach cycle or as a consequence of a major natural event (hurricane).
- This makes local knowledge and the collection of in situ data during the satellite overpass key steps for accurate image processing and analysis.


Changes in beach width (San Juan, PR). Credit: Dr. Maritza Barreto, Univ. of PR

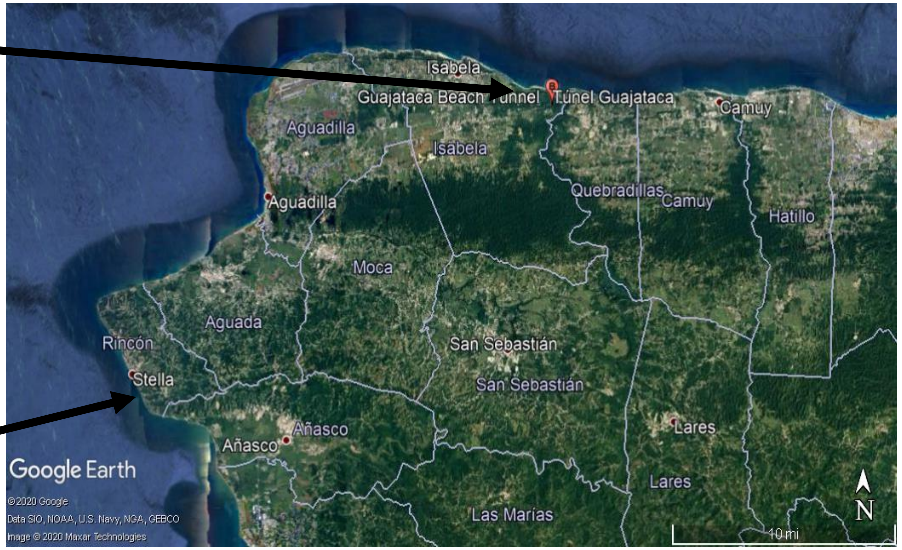
# Beaches are highly dynamic environments.

Guajataca Beach, Northwest PR

Sept 2009

Oct 2009

Nov 2009




Rincon Beach, Northwest PR

Sept 2009

Oct 2009

Nov 2009

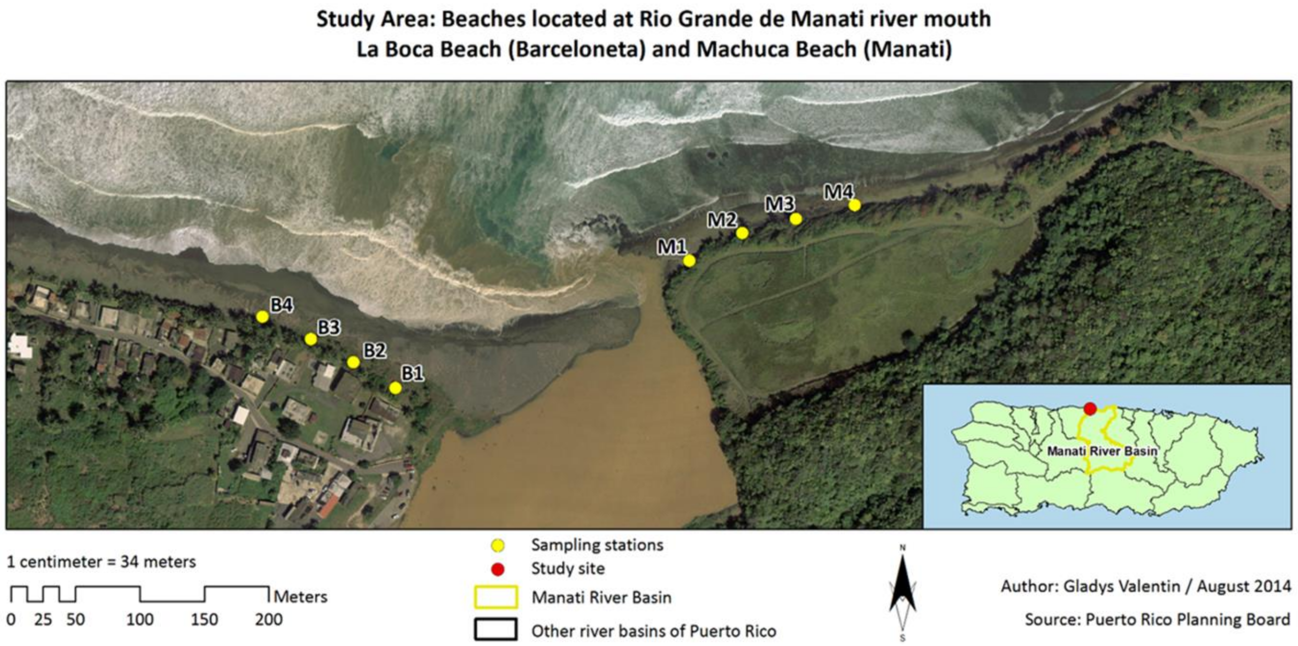
Dynamics of sediment composition in two beaches in PR. Credit: Dr. Maritza Barreto, Univ. of PR

# Beaches are highly dynamic environments.

La Selva Beach, Luquillo, PR (Sept 2009) (Transition)

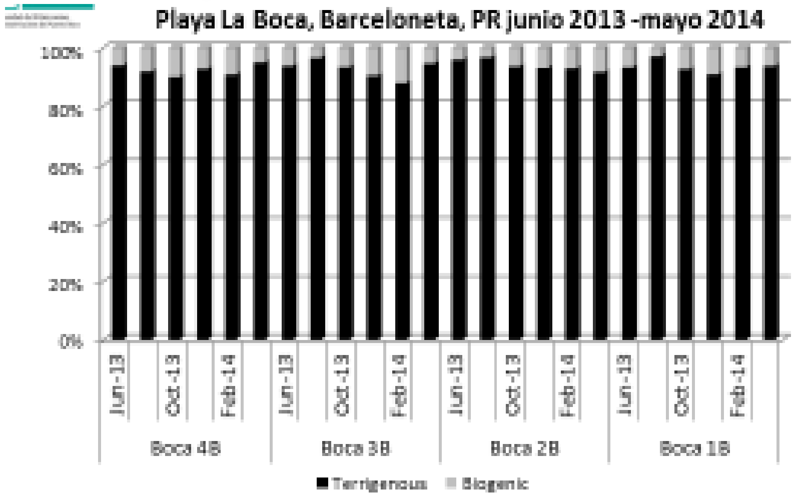
Same beach in October 2009 (Dissipative Beach)

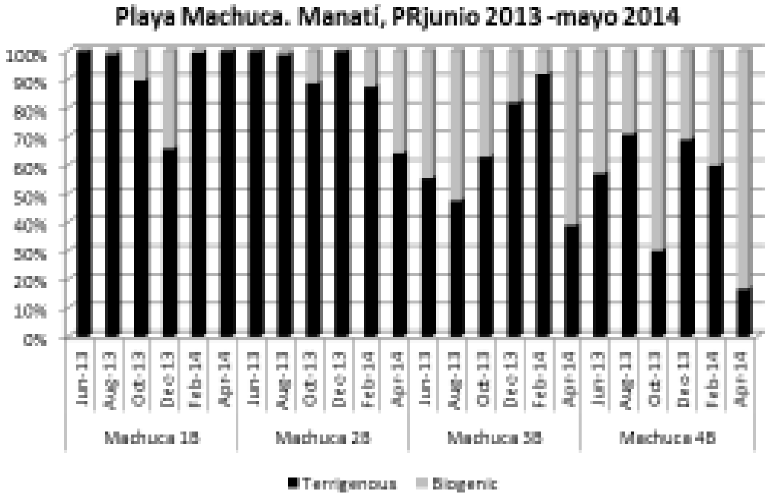
# Beaches are highly dynamic environments.




Sediment composition (and hence, the spectral signature) can change in a short period of time depending on the dynamics of the physical processes acting upon them.

Credit: Dr. Maritza Barreto, Univ. of PR



# Coastal Wetlands

**Salt Marshes** – More typical of mid latitudes

Cumberland Island, Georgia USA. Credit: www.flickr.com

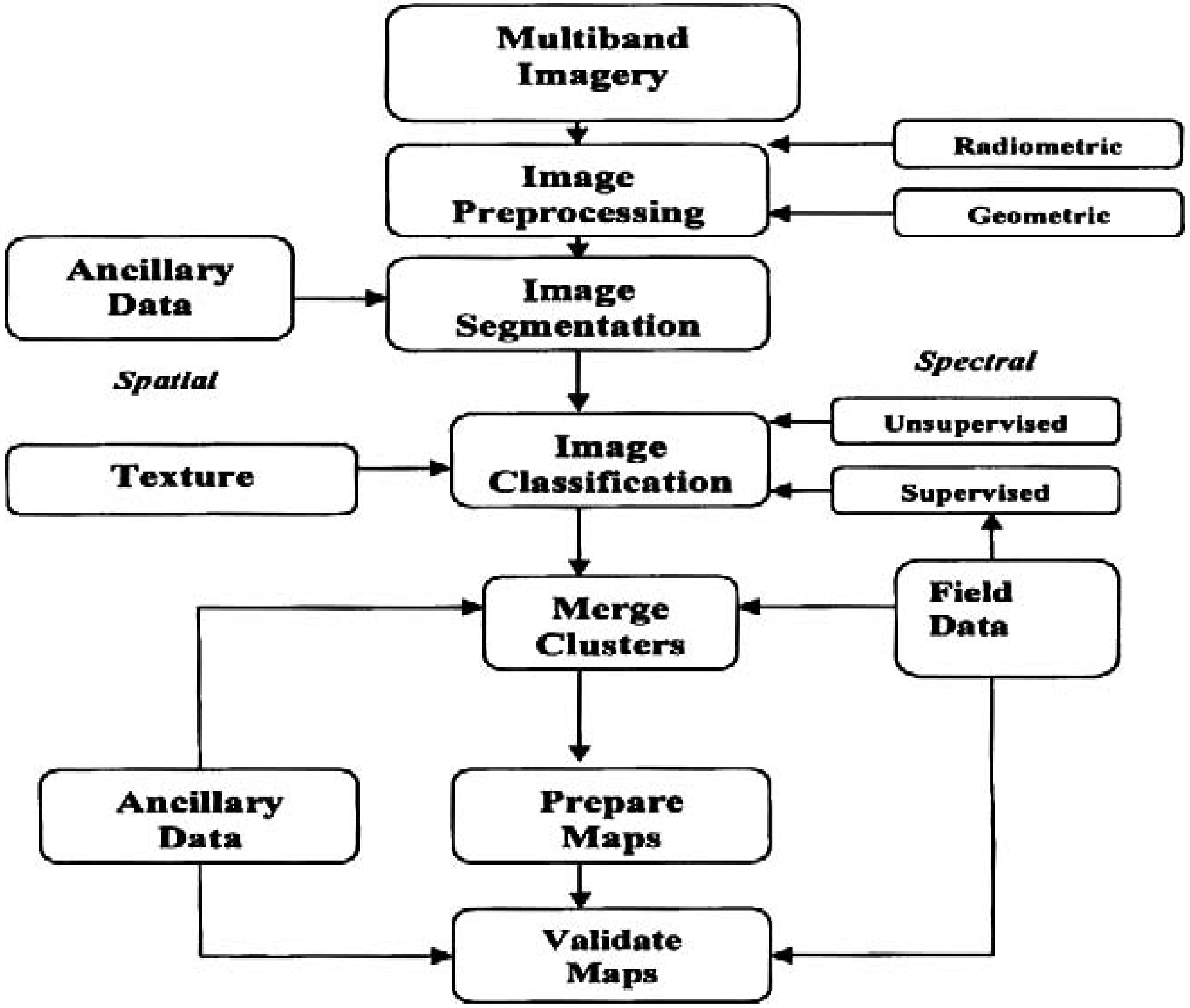
**Mangrove Forests** – more typical of low latitudes (tropics)

Black mangrove forest – Southwest PR. Credit: Juan L. Torres-Pérez

# 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

**Note:** Ancillary data can be used whenever available; field data aids in image validation.




Credit: Klemas (2011) J Coastal Res

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

## Vegetation/Greenness Indices

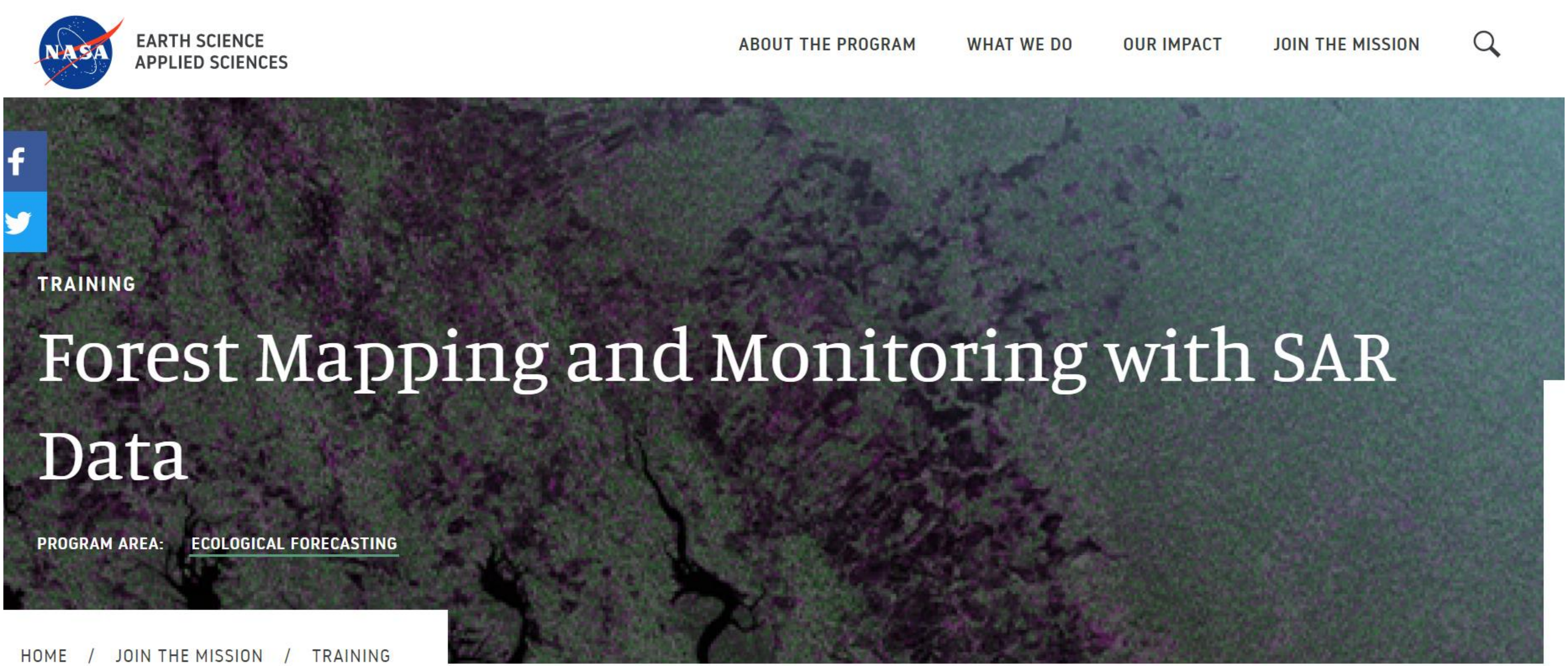
- NDVI - Normalized Difference Vegetation Index
- EVI - Enhanced Vegetation Index
- SAVI - Soil-Adjusted Vegetation Index
- MSAVI - Modified Soil-Adjusted Vegetation Index
- SATVI - Soil-Adjusted Total Vegetation Index
- Normalized Burn Ratio (NBR)

## Biophysical Parameter Estimates

- fPAR - Fraction of Photosynthetically Active Radiation
- Fractional Cover
- GPP and NPP - Gross and Net Primary Productivity or Biomass
- LAI - Leaf Area Index

https://appliedsciences.nasa.gov/join-mission/training/english/understanding-phenology-remote-sensing

# Monitoring Mangroves Using Synthetic Aperture Radar (SAR)




https://appliedsciences.nasa.gov/join-mission/training/english/forest-mapping-and-monitoring-sar-data

# Shoreline Topography and Bathymetry

# 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


Credit: Dr. Maritza Barreto, Univ. of PR

# 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) |

RMSE = Root Mean Square Error

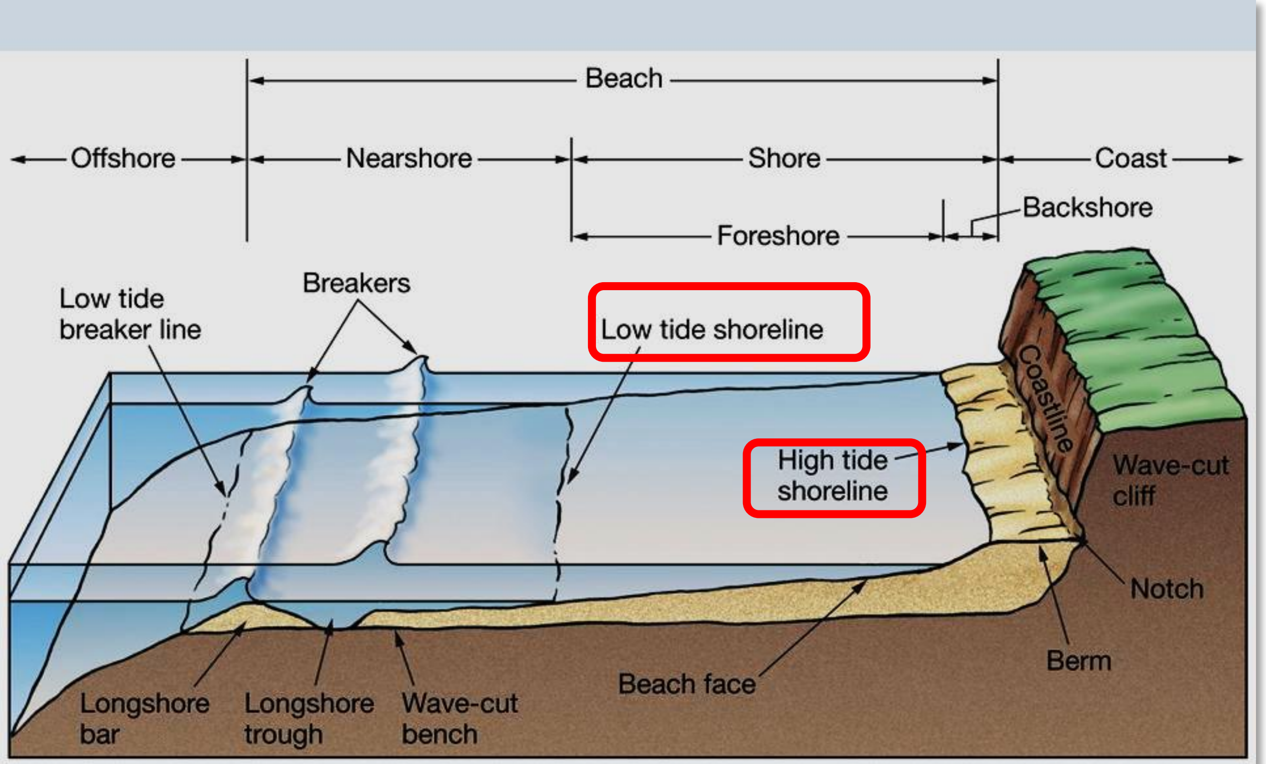
# Stereoscopy for Bathymetry and Coastal Topography

- Provides high spatial resolution (sub-meter)
- The Satellite Pour l'Observation de la Terre (SPOT) was the first constellation of civilian satellites to acquire stereoscopic images.
- The Pleiades 1A-1B constellation (Centre National d'Etudes Spatiales [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

Pleiades 1A image of the island of Bora Bora in Polynesia. Credit: CNES

# 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



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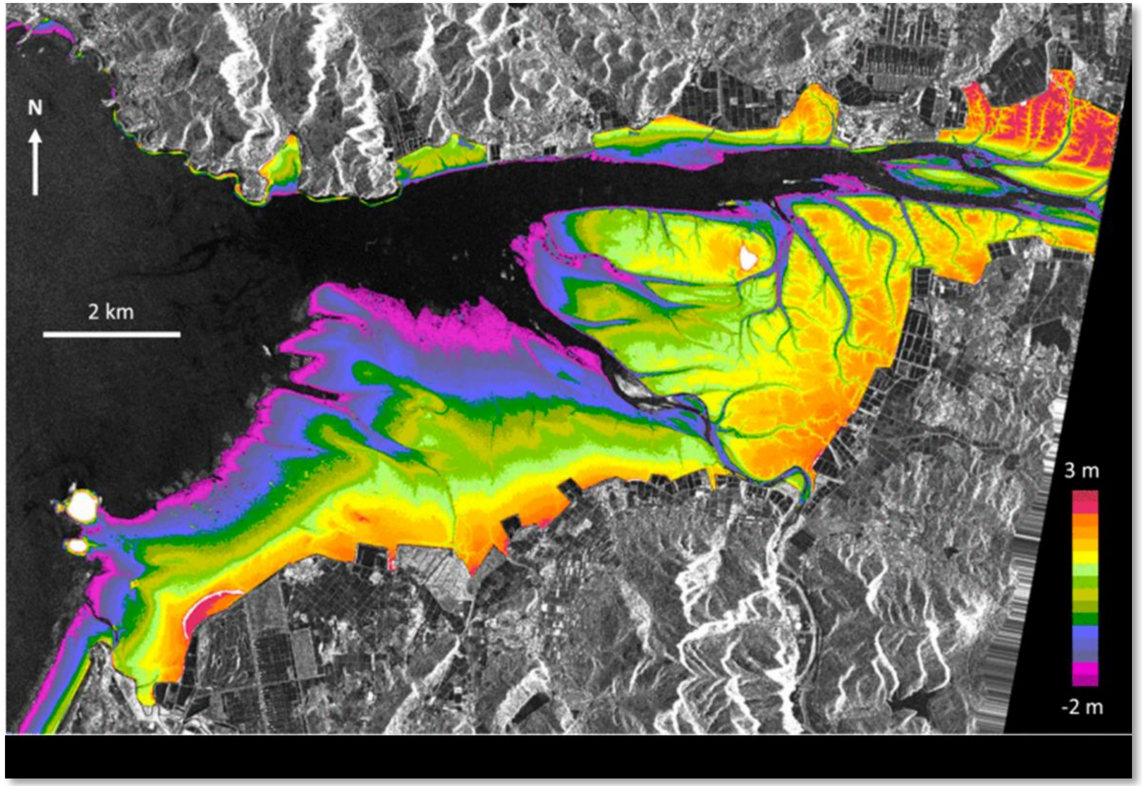
# InSAR for Bathymetry and Coastal Topography

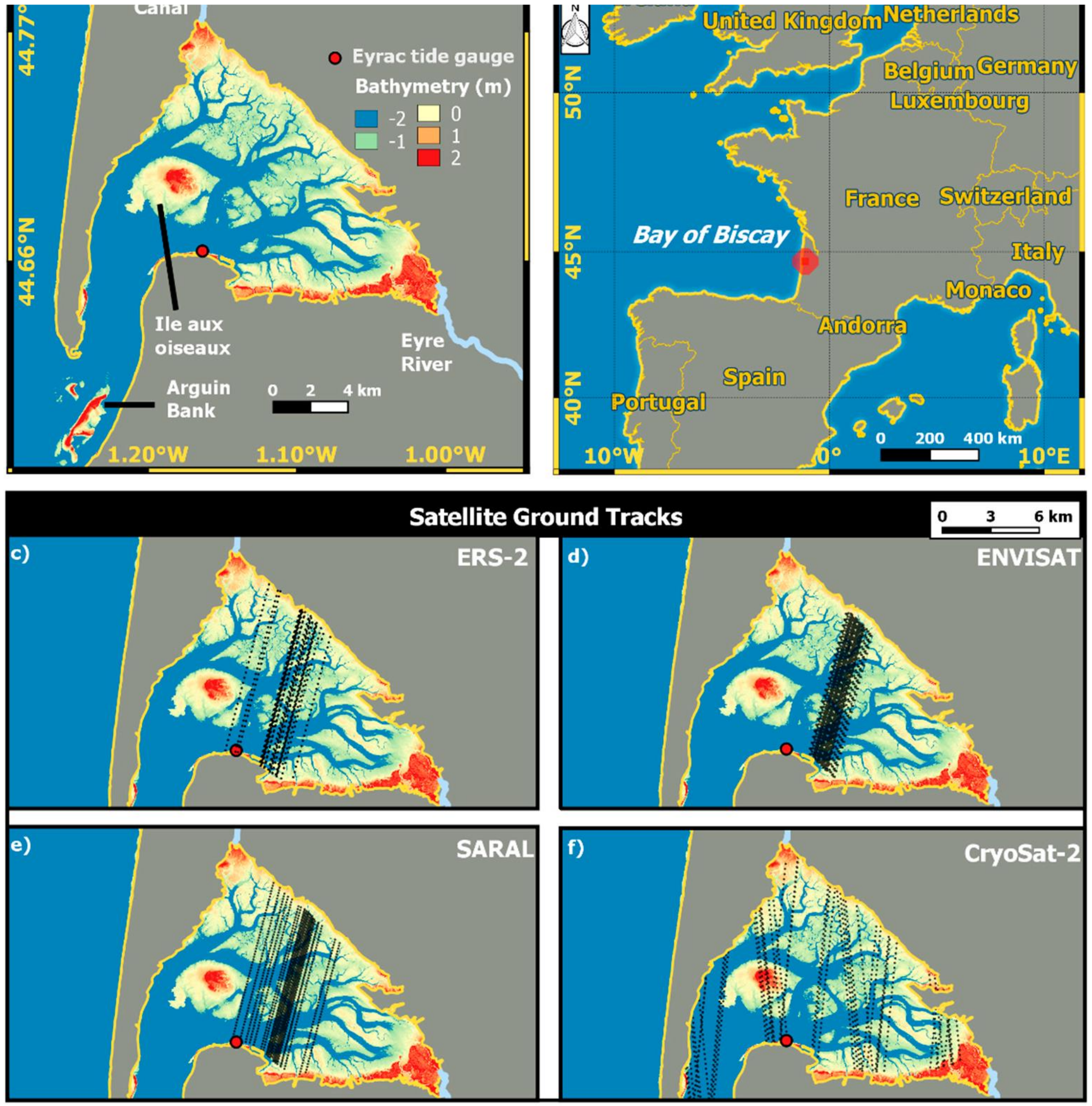
- Interferometric SAR (InSAR)
- Uses two or more SAR images taken from different positions, different times, or both to extract topography information from their phase difference
- Like other uses of SAR, one image is called the "Master" and the other ones the "Slaves"
- Best to use single-pass interferometry (two antennas in the same platform) systems with no temporal baseline to obtain accurate DEMs




InSAR DEM for the Gomso Bay, South Korea (spatial resolution = 5m).
From: Lee et al (2017) IEEE

# Radar Altimetry for Bathymetry and Coastal Topography

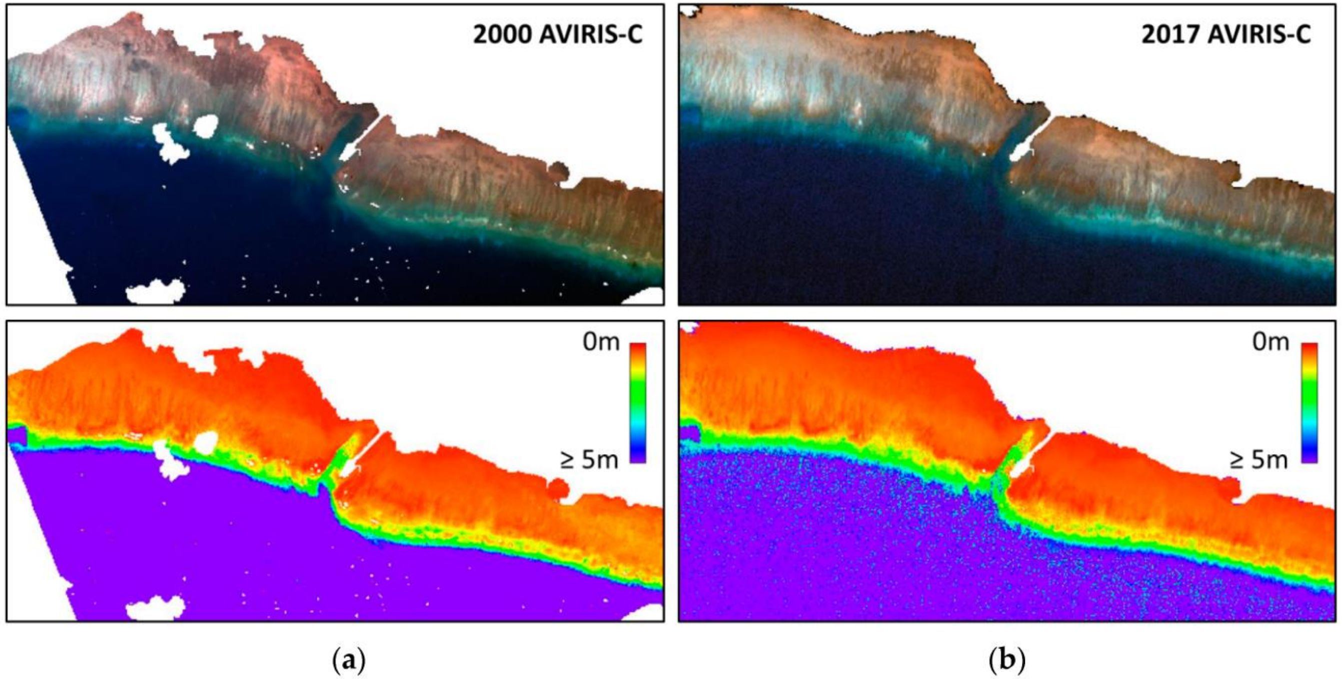
- Can also be used to derive direct estimates of bottom topography over intertidal zones during low tide
- Can combine data from multiple satellite-based radars:
  - ERS-2 (1995-2003)
  - ENVISAT (2002-2010)
  - Cryosat-2 (since 2010)
  - SARAL (2013-2016)




Arcachon Lagoon, Bay of Biscay, France. Credit: Salameh et al (2018) Remote Sensing

# 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




Derived bathymetry for Molokai (Hawaii) obtained with the AVIRIS-C hyperspectral sensor. From: Goodman et al (2020) Remote Sens

# Remote Sensing of Marine Debris on Shorelines

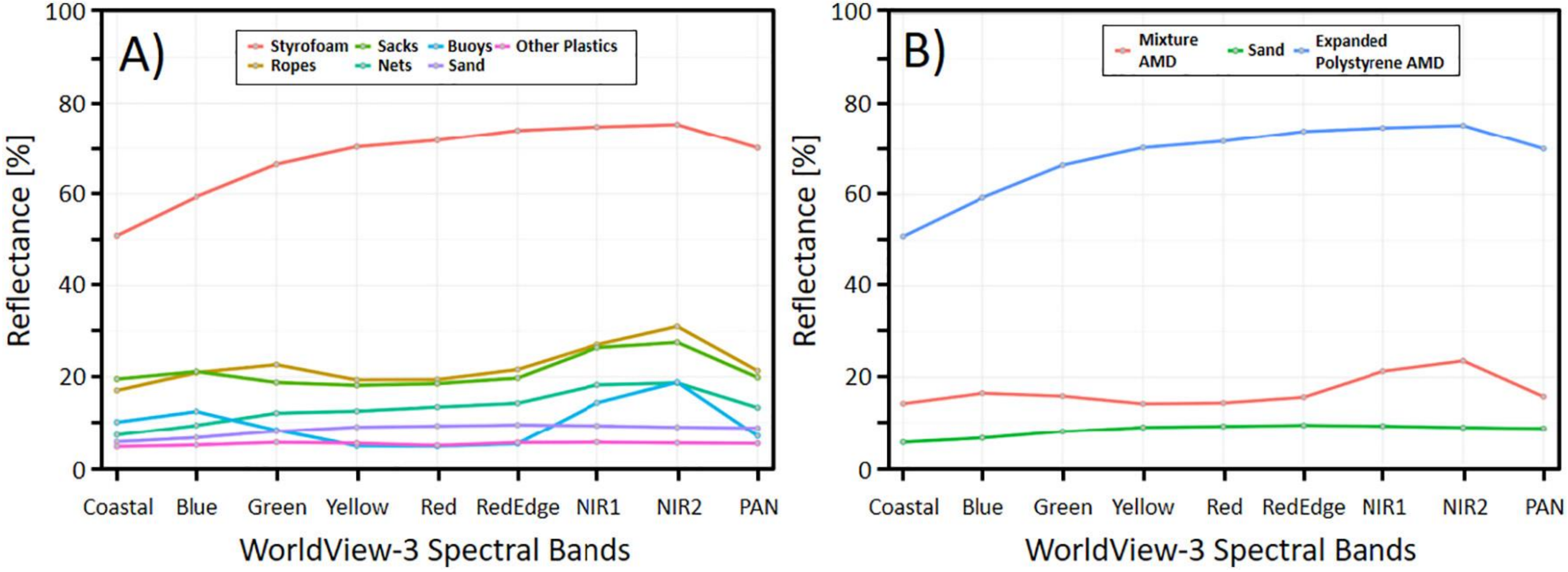
# Marine Debris

- It is occurring from pole to pole.
- 50-90% are plastics
- Micro (<5mm) to macro plastics (>25mm)
- Impacts include fauna entanglement and ingestion, effects on gas exchange between the water column and the seafloor sediment, displacement of many benthic species, and loss of aesthetic value and activity.
- Usual survey methods can provide for debris removal, but it is limited and costly for remote areas.
- Remote sensing can practically assess the presence of marine debris on all shorelines.

Top: Pieces of an old cellphone found in a reef site. Bottom: Anthropogenic marine debris washed ashore on a beach in West PR. Image Credit: Juan L. Torres-Pérez

# Remote Sensing of Marine Debris

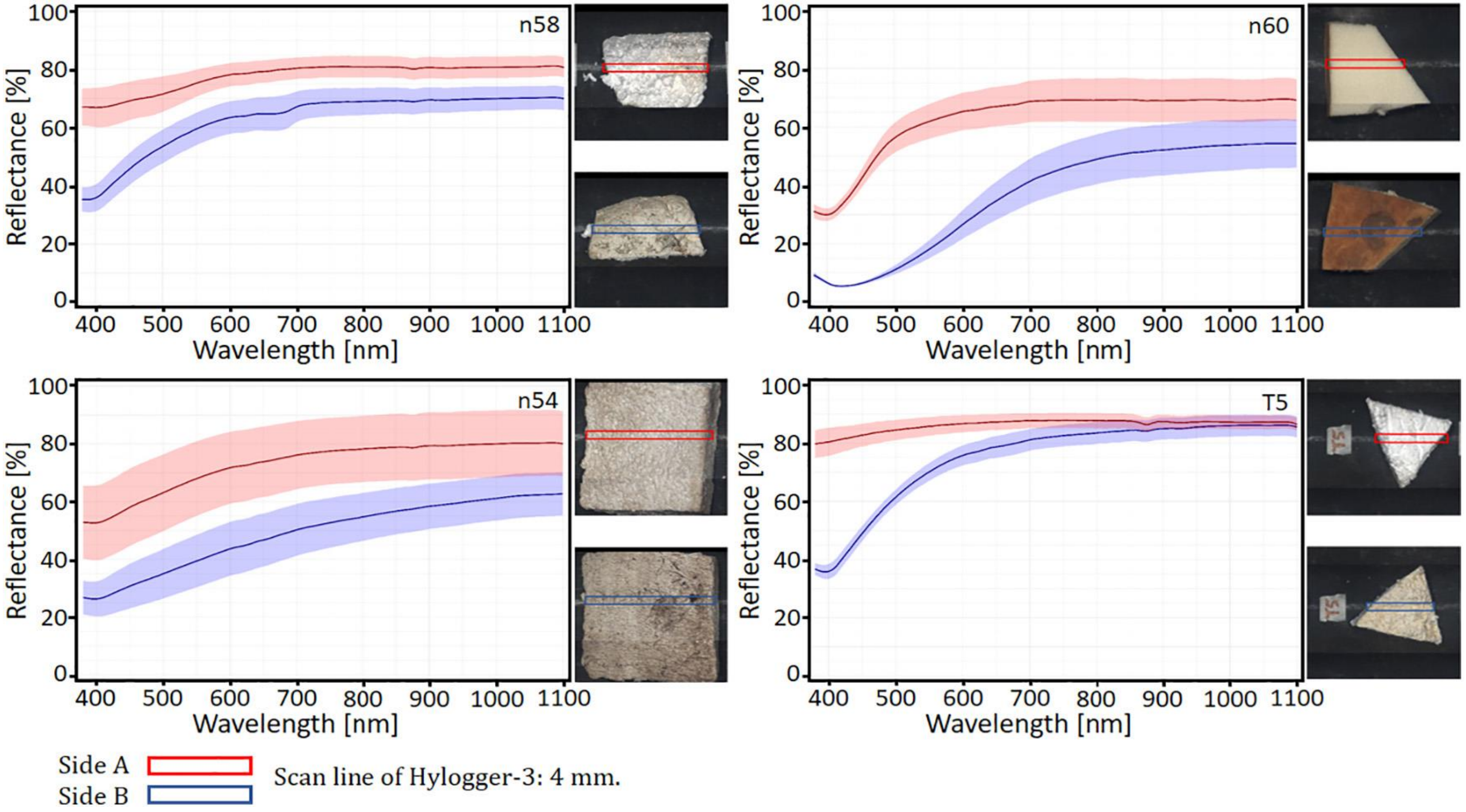
- Challenging due to size and variety (plastics beads, cigarette butts, derelict fishing and nautical gear, macro plastics, Styrofoam, bags of different types/sources, etc.)
- Lately, some researchers have attempted to create spectral libraries of major marine debris categories and have shown spectral differences among these (Garaba and Dierssen 2018 RSE; Acuña-Ruz et al 2018 RSE).




Credit: Acuña-Ruz et al (2018) Remote Sens Environ

# Remote Sensing of Marine Debris

- The spectral signal of the material is altered depending on the time exposed to environmental conditions (weathering, UV, biofouling, sediments, etc.).




From: Acuña-Ruz et al (2018) Remote Sens Environ

# In Summary

- Shorelines are highly dynamics areas dominated by climate and/or anthropogenic factors.
- Shoreline topography and bathymetry can be obtained by a number of remote sensing methods and diverse imagery sources.
- Remotely-sensed data allows for short- and long-scale time series analysis of shoreline features and provides valuable information for decision-making processes.
- This may include the combination of historical aerial and recent satellite-based imagery.

# 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!