National Aeronautics and Space Administration

Monitoring Aquatic Vegetation with Remote Sensing

Juan L. Torres-Pérez, Amber McCullum, Roy Armstrong, William Hernández

July 19, 2022

Course Structure and Materials

- Three, 1-hour sessions on July 12, 14, and 19
- The same content will be presented at two different times each day:
  - Session A: 11:00-12:30 EDT (UTC-4) (English)
  - Session B: 14:00-15:30 EDT (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/arset-monitoring-aquatic-vegetation-remote-sensing
- 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 August 2nd**

- **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/arset-monitoring-aquatic-vegetation-remote-sensing

Learning Objectives

By the end of this session, you will become familiarized with:

- The *Sargassum* seaweed, its benefits, importance, and impacts
- The Caribbean/Atlantic *Sargassum* Patch: The world's largest harmful algal bloom
- Remote sensing and in situ sampling for mapping the extent and prevalence of the *Sargassum* patch
- Multiscale sensors and algorithms to detect *Sargassum*
- The *Sargassum* Watch System (SaWS)

Sargassum mat washing ashore in La Parguera, PR.
Credit: Juan L. Torres-Pérez

Overview of the Caribbean/Atlantic *Sargassum* Patch

Sargassum: The World's Largest Harmful Algal Bloom

Roy A. Armstrong, Ph.D. (Presenter), Professor, University of Puerto Rico at Mayaguez

Co-Authors: Yasmin Detrés, William J Hernández, and Emmanuel Arzuaga

Sponsored by NASA MUREP OCEAN Program (80NSSC21K1701)

July 19, 2022

What is *Sargassum*?

- The genus *Sargassum* contains about 150 different species of brown macroalgae (Phaeophyte) which are generally attached to rocks along temperate coasts or as pelagic (free-floating) algae in the open ocean.
- *Sargassum* multiplies by vegetative fragmentation. The thallus breaks into fragments due to mechanical injury or death and decay of older parts.
- Most species reproduce sexually, but the pelagic species reproduce by fragmentation. The largest members can reach several meters in length.

Photo Courtesy of JP Segarra

Morphological Characteristics

- Highly branched thallus
- Small and leaf-like fronds with toothed edges
- Pneumatocysts: Berry-like floats to help the seaweed float
- These “berries” are actually gas-filled structures that are filled mostly with oxygen.
- Pneumatocysts add buoyancy to the plant structure allowing it to float on the surface.

Photo courtesy of Jenniffer Pérez Pérez

Species of *Sargassum* found in the Caribbean

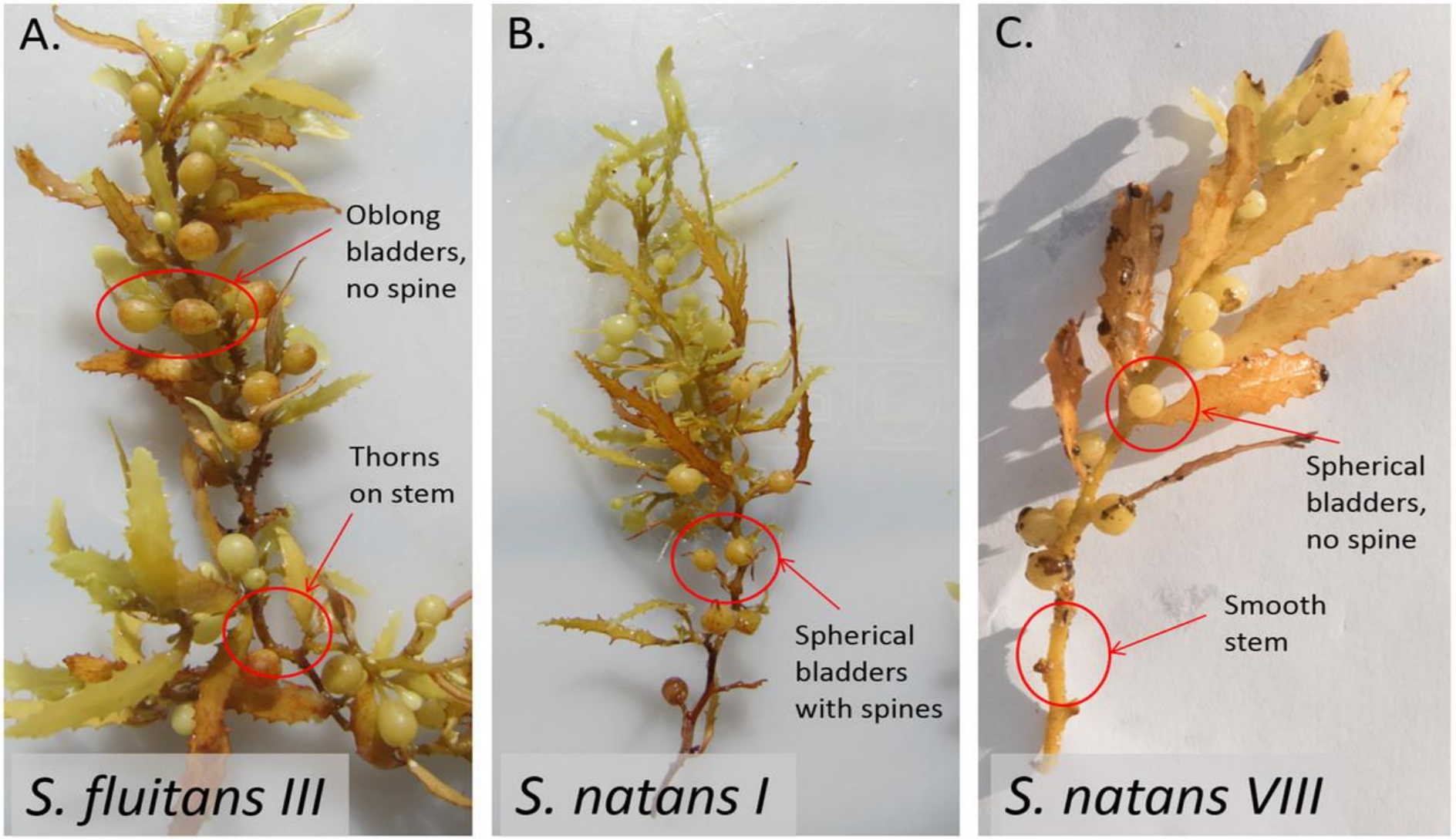
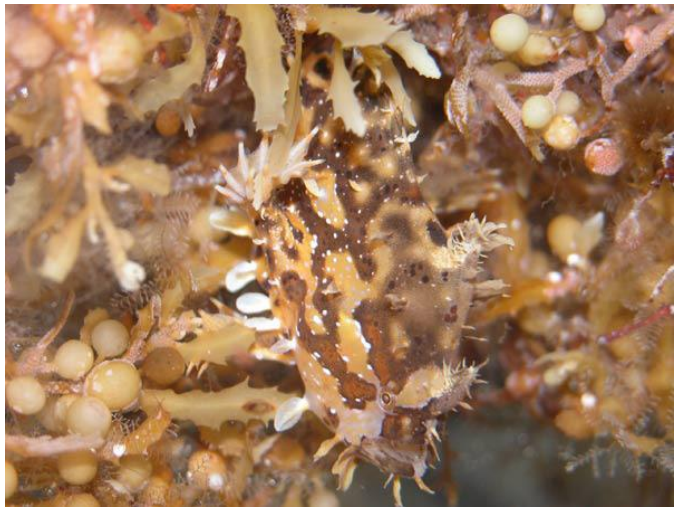


Image Credit: DOI: 10.7717/peerj.7814/fig-1

Sargassum as Essential Habitat

- Floating rafts of *Sargassum* can stretch for miles across the ocean.
- This floating habitat provides food, refuge, and breeding grounds for an array of animals such as fish, sea turtles, marine birds, crabs, shrimp, and more.
- Some animals, like the *Sargassum* fish, live their entire lives within this habitat.
- *Sargassum* serves as a primary nursery area for a variety of commercially important fish such as mahi mahi, jacks, and amberjacks.

Photo Credit: Roy Armstrong



The *Sargassum* Fish, *Histrio histrio*. *Image courtesy of Art Howard/Ross et al., NOAA-OE*

Sargassum as Essential Habitat

- Because of its ecological importance, in 2003, *Sargassum* within U.S. Exclusive Economic Zone off the southern Atlantic states was designated as Essential Fish Habitat, which affords these areas special protection.
- *Sargassum* provides refuge for migratory species and essential habitat for some 120 species of fish and more than 120 species of invertebrates.

Image courtesy of the Life on the Edge Exploration, NOAA Ocean Explorer

Sargassum Floating Mats

- Some of these *Sargassum* "islands" or floating mats can be a mile wide and several feet deep.
- When *Sargassum* loses its buoyancy after about a year, it sinks to the seafloor and provides energy to ocean life on the seafloor.
- *Sargassum* can survive a wide range of temperatures and salinity.

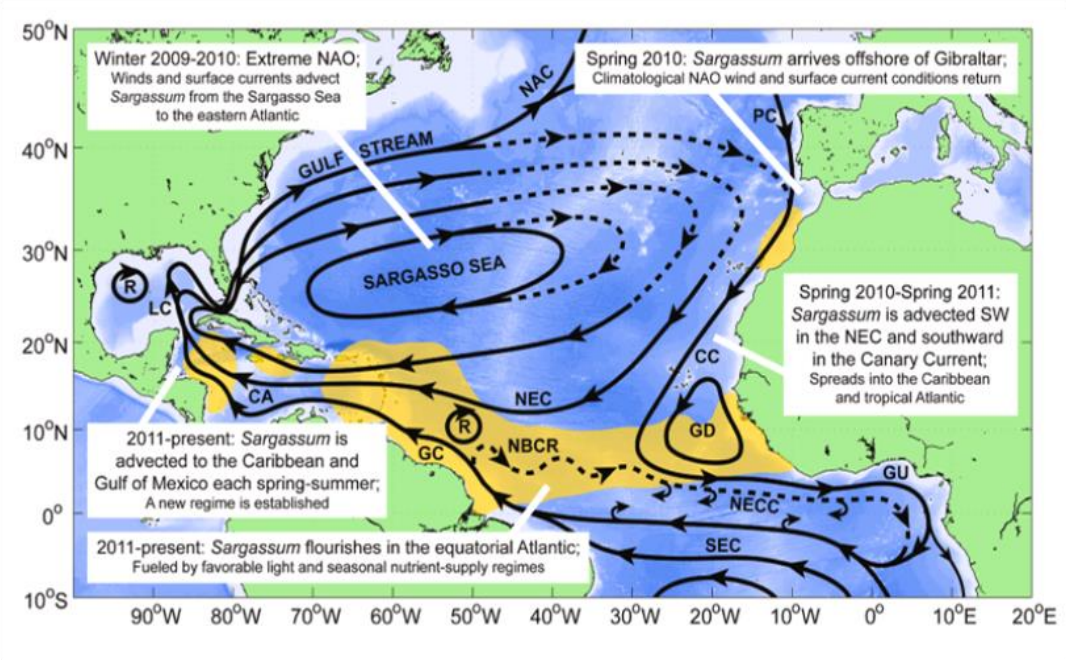
Photo Credit: Omar Lopez

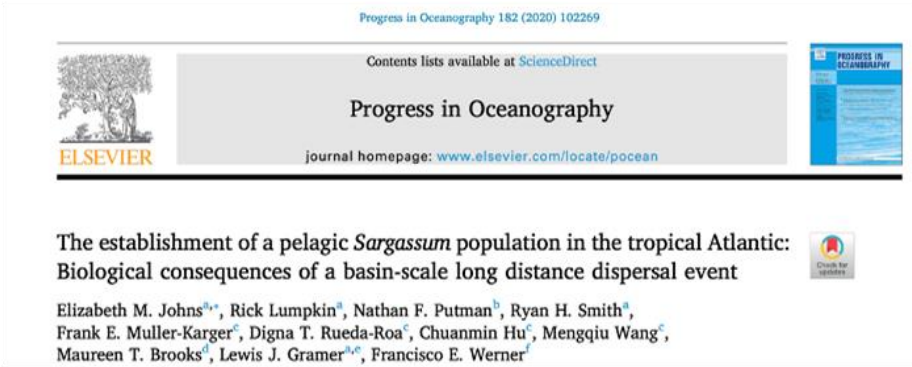
Benefits of *Sargassum*

- *Sargassum* acts as an oasis in an otherwise desolate environment and supports a high level of biodiversity.
- *Sargassum* contributes an estimated 60% of the total primary production in the upper 1m of the water column.
- The egg and larval stages of fish, some crustaceans, and juvenile sea turtles are particularly dependent upon the pelagic *Sargassum* habitat for survival.
- *Sargassum* is a good plant fertilizer, but it should be tested for heavy metals before using in home gardens and food crops.
- Good source of alginates, which are used in the food, cosmetic, medical, and pharmacological industries.
- Alginates can be converted into biofuels and bioplastics.

Photo Credit: Roy Armstrong

New Source of *Sargassum* in the Tropical Atlantic Ocean




Progress in Oceanography 182 (2020) 102269

Contents lists available at ScienceDirect

Progress in Oceanography

journal homepage: www.elsevier.com/locate/pocean

ELSEVIER

The establishment of a pelagic *Sargassum* population in the tropical Atlantic: Biological consequences of a basin-scale long distance dispersal event

Elizabeth M. Johns[a,*], Rick Lumpkin[a], Nathan F. Putman[b], Ryan H. Smith[a], Frank E. Muller-Karger[c], Digna T. Rueda-Roa[c], Chuanmin Hu[c], Mengqiu Wang[c], Maureen T. Brooks[d], Lewis J. Gramer[a,e], Francisco E. Werner[f]

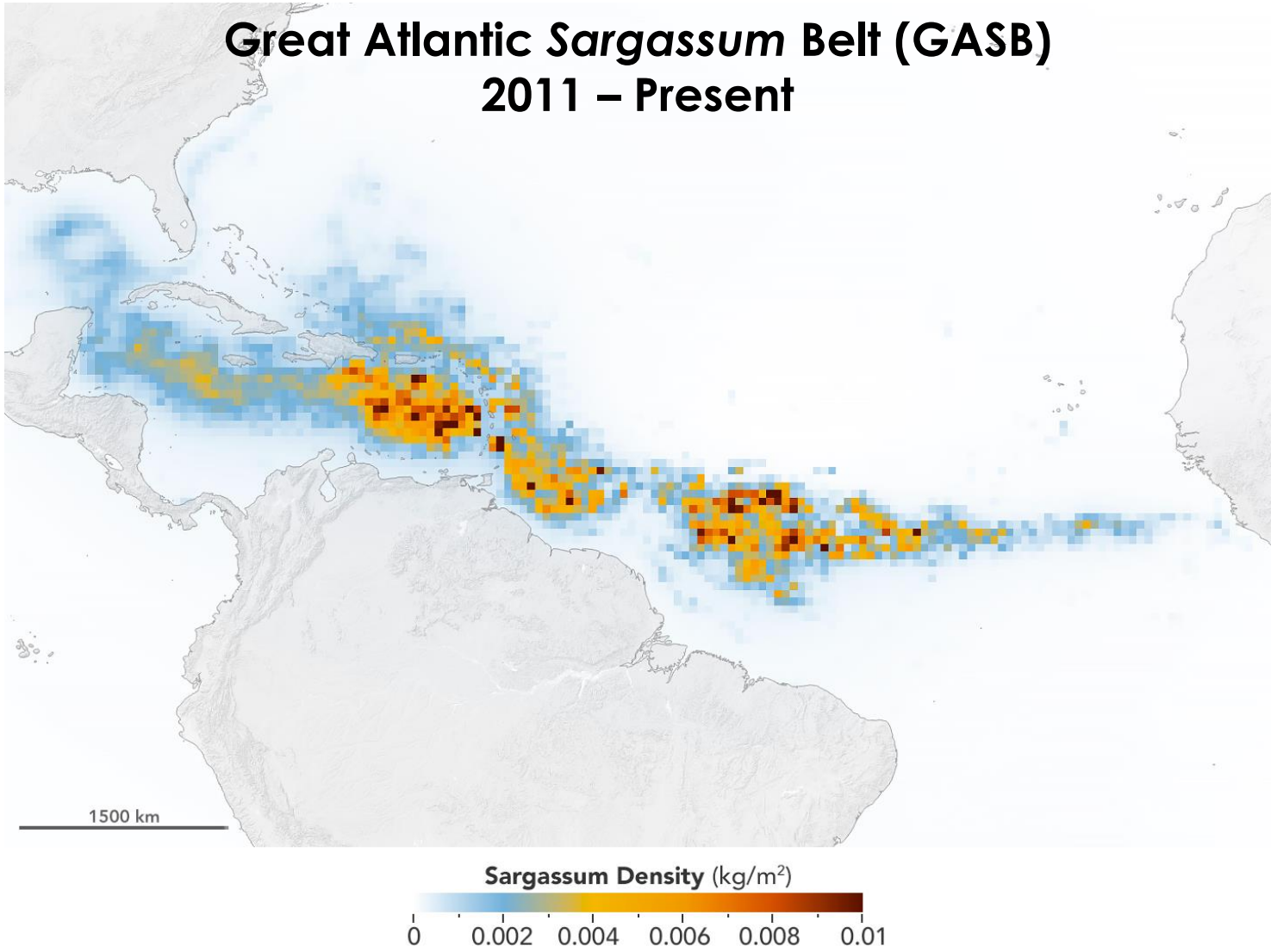
2009-2010: Changing wind patterns associated to extreme North Atlantic Oscillation (NAO) advected Sargassum to the Eastern Atlantic – Johns et al., 2020

2010-2011 (Spring): *Sargassum* was transported to the Caribbean by the North Equatorial Current and southward in the Canary Current.

2011-Present: *Sargassum* is advected to the Caribbean and Gulf of Mexico each spring-summer

NASA Satellites Find Biggest Seaweed Bloom in the World

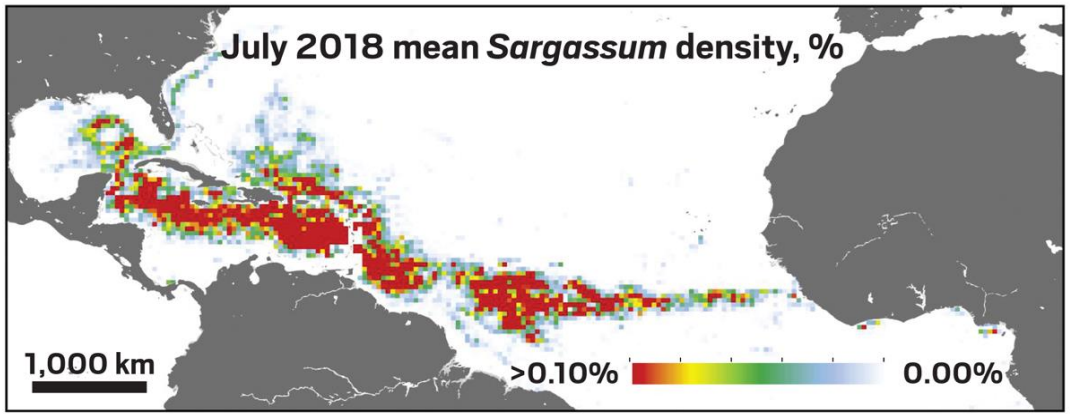
NASA News Jul 8, 2019

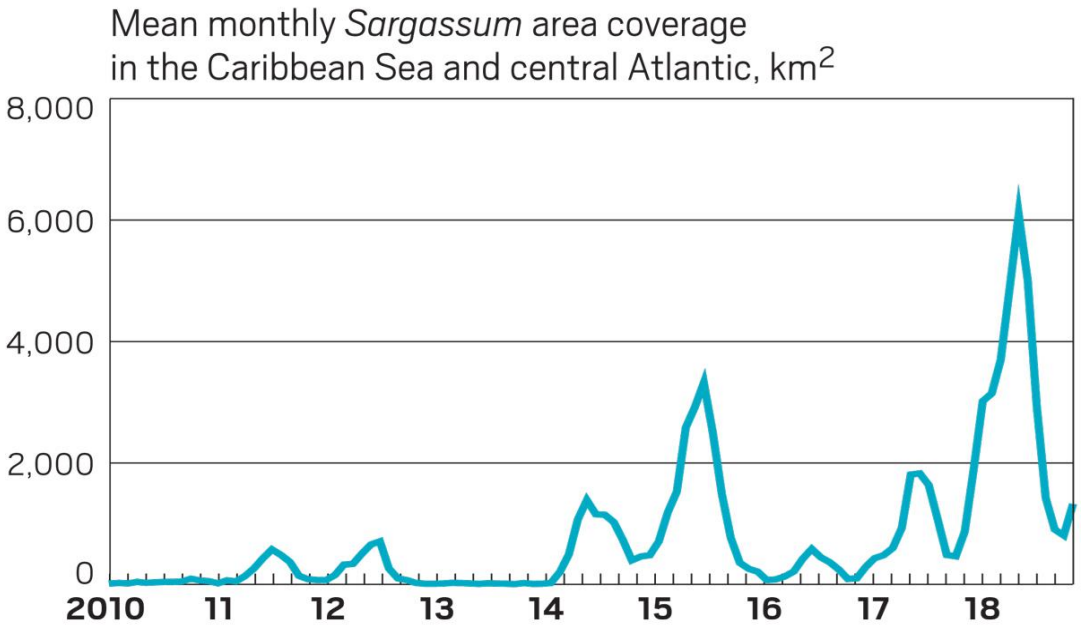


Credits: NASA/Earth Observatory. Data provided by Mengqiu Wang and Chuanmin Hu, USF College of Marine Science

2018: Largest *Sargassum* Bloom Ever Reported in History

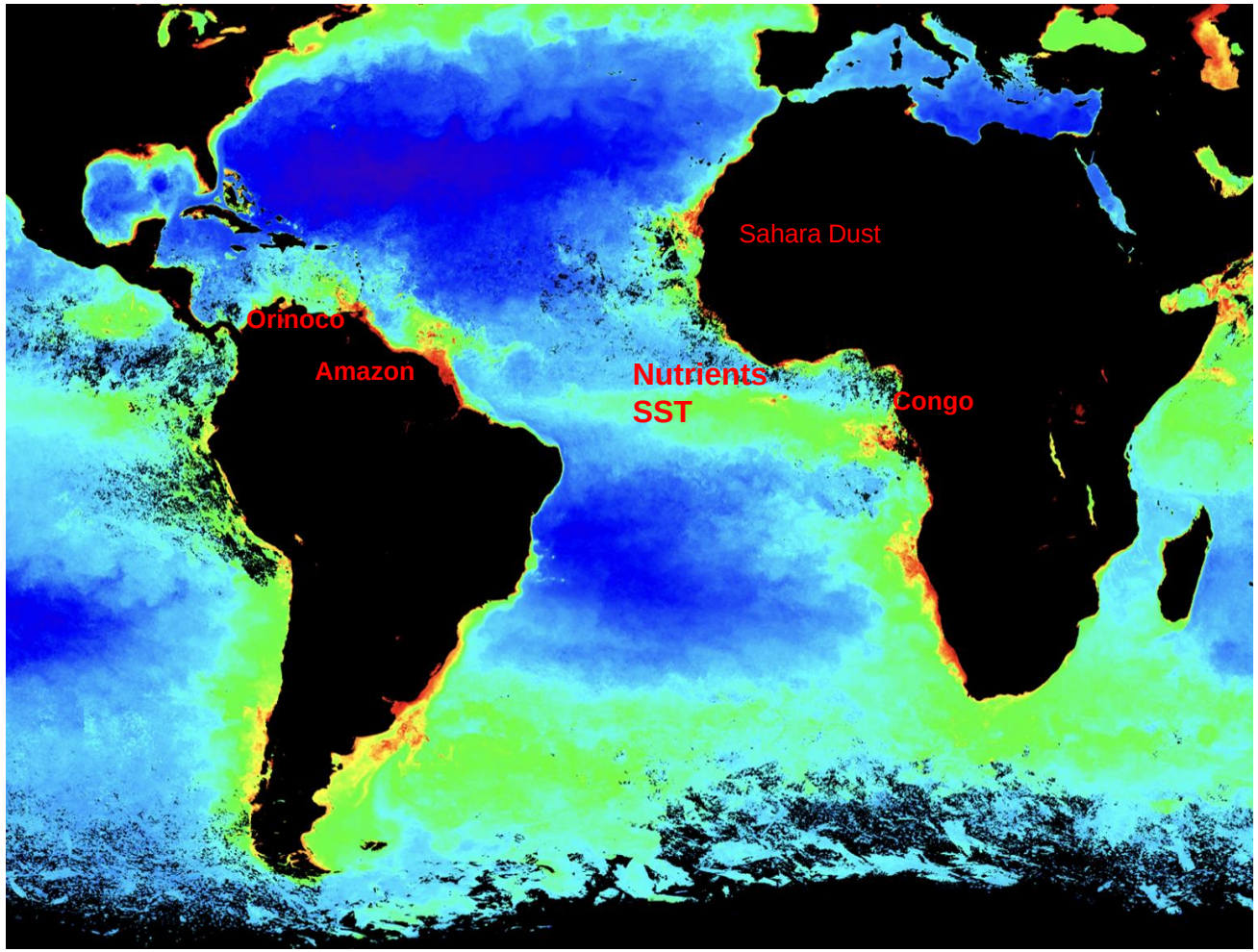
- Scientists found *Sargassum* in record-high amounts in the Caribbean, central west Atlantic Ocean, and Gulf of Mexico.
- First instance of year-round occurrence of *Sargassum* blooms in the Caribbean Sea
- > 20 million tons of *Sargassum*
- The world's largest HAB at over 6,000km^2





Drivers of GASB

- **Nutrient Enrichment:** Amazon, Orinoco, and Congo Rivers
  - Agriculture (i.e., fertilizers)
  - Poor land-use (deforestation)
- **Sahara Dust Plumes**: Input of iron and phosphates
- **Climate Variability**: Higher water temperatures, heavier rainfall events, rougher winter seas



Sargassum Stranding on Beaches and Coastal Areas

Photo Credits: William Hernandez and Roy Armstrong

Sargassum Accumulation Impacts on Tropical Coastlines

- Releases hydrogen sulfide and ammonia
- Heavy metals: Arsenic and Cadmium
- Reduced or depleted oxygen
- Fish mortalities due to anoxic conditions
- Threat to turtle nesting in beaches
- Reduced light penetration
- Biodiversity loss in coastal marine ecosystems

Sargassum accumulation in SW Puerto Rico fringing mangrove coastlines
Photo by William Hernandez

Accumulation of *Sargassum* on Shallow Coral Reef Areas

Sargassum Accumulation in SW Puerto Rico Coral Reefs
Photos by Roy Armstrong (left) and Omar Lopez (right)

Sargassum Accumulation: Impacts on Tourism and Economy

- Declined tourism
- Disrupted coastal operations (i.e., ports, marinas, power plants)
- Disrupted recreation and fishing
- Ecosystem services
- High clean up cost

Impacts of "Beached" *Sargassum* on Human Health

Prolonged contact with *Sargassum*, or inhaling the hydrogen sulfide gas can cause:

- Irritation of respiratory tract
- Shortness of breath
- Dizziness, vertigo
- Nausea
- Headache
- Skin rashes
- Neurological and cardiovascular changes

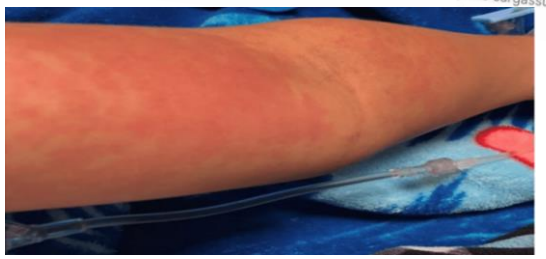
Heavy metals (including arsenic, aluminum, and boron) are toxic in high concentrations.


SEAWEED 2022

A rare case of irritant dermatitis due to exposure to sargassum in Puerto Rico

Algal dermatitis is a little-studied problem that has been gaining more and more relevance in Puerto Rico. Check out what is going on there.

The municipality of Guánica requested help from the DNER to clean up the sargassum on Playa Santa. Image: El Vocero



Remote Sensing and In Situ Techniques for Assessing *Sargassum* in the Caribbean

Sargassum Observations and Analysis using Remote Sensing

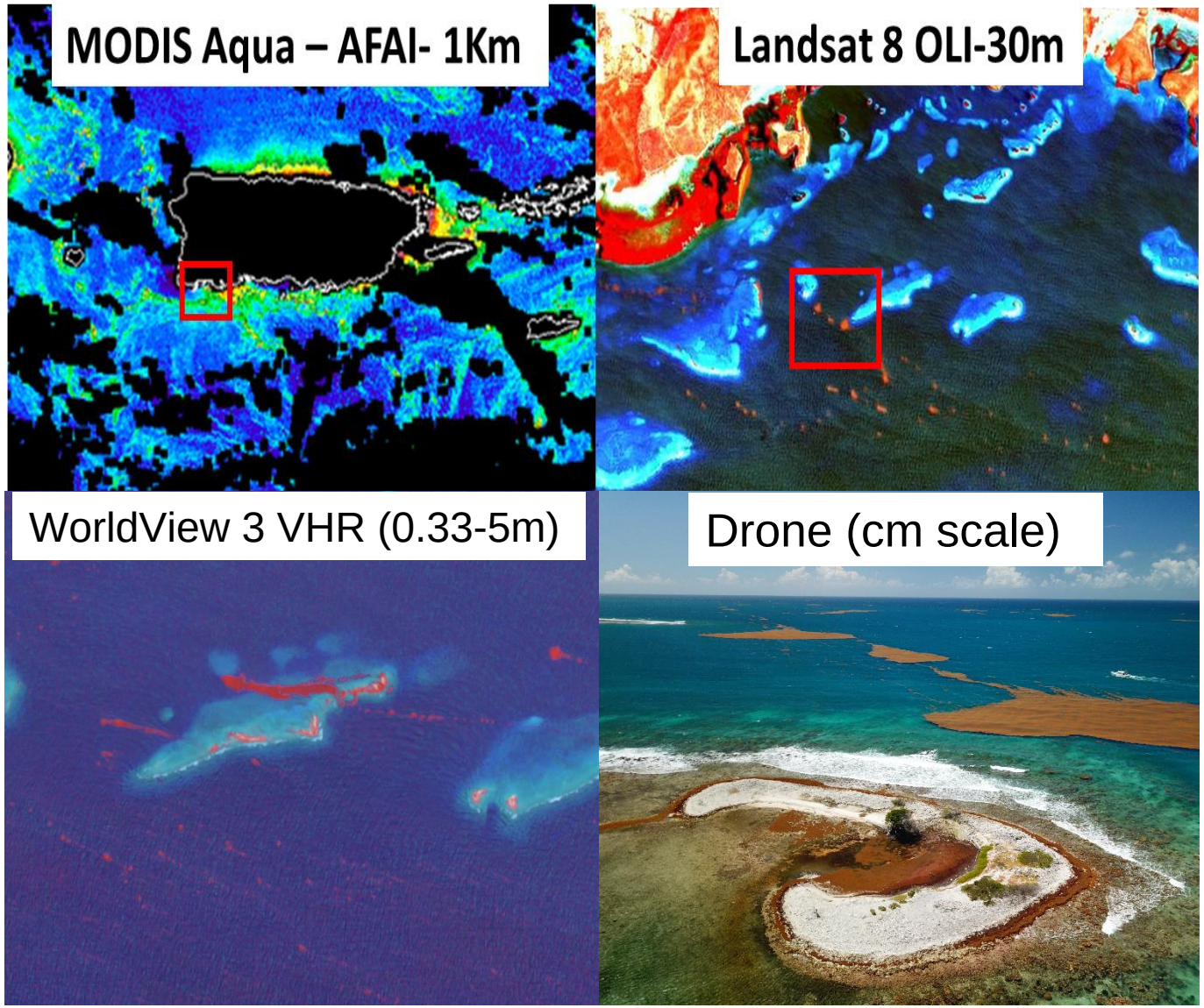
William J Hernández *Ph.D.* (Presenter), Researcher, UPR-Mayaguez

william.hernandez@upr.edu

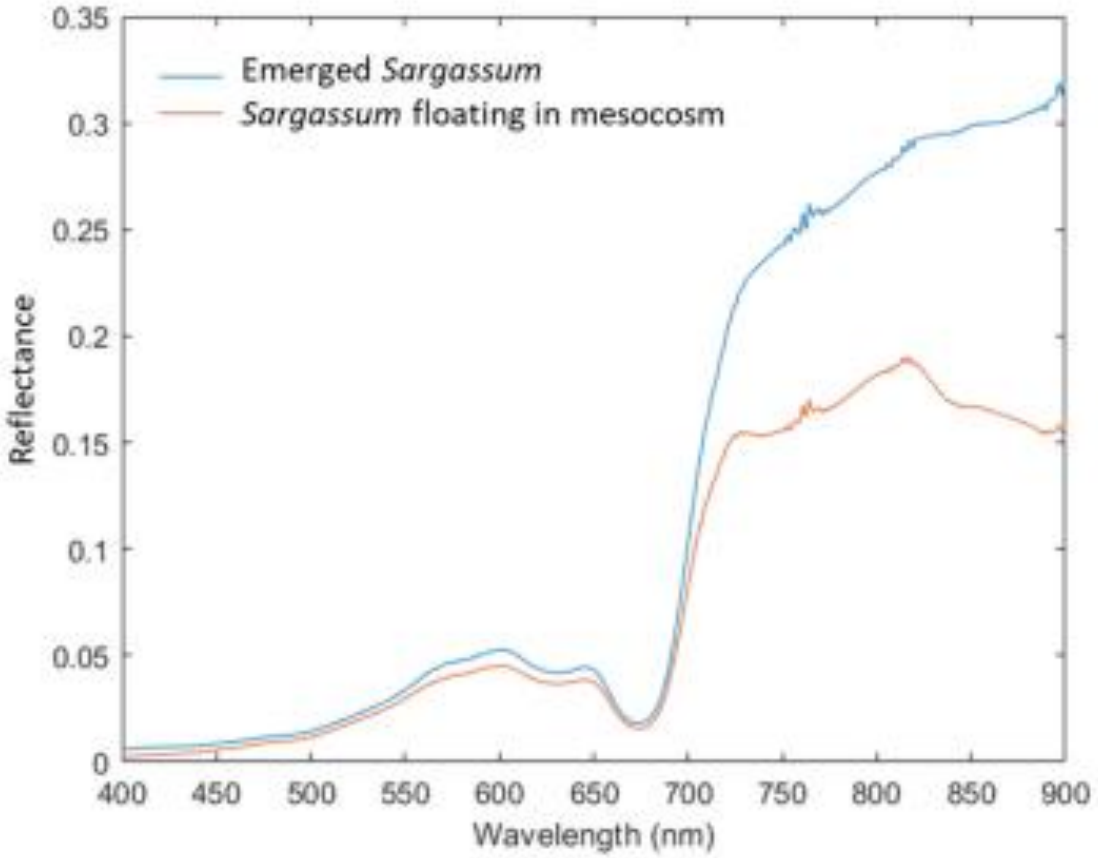
Co-Authors: Roy A. Armstrong, Emmanuel Arzuaga, Yasmin Detrés.

July 19, 2022

Sargassum Detection at Various Spatial Scales



Exploiting Vegetation Spectral Signature to Detect *Sargassum*



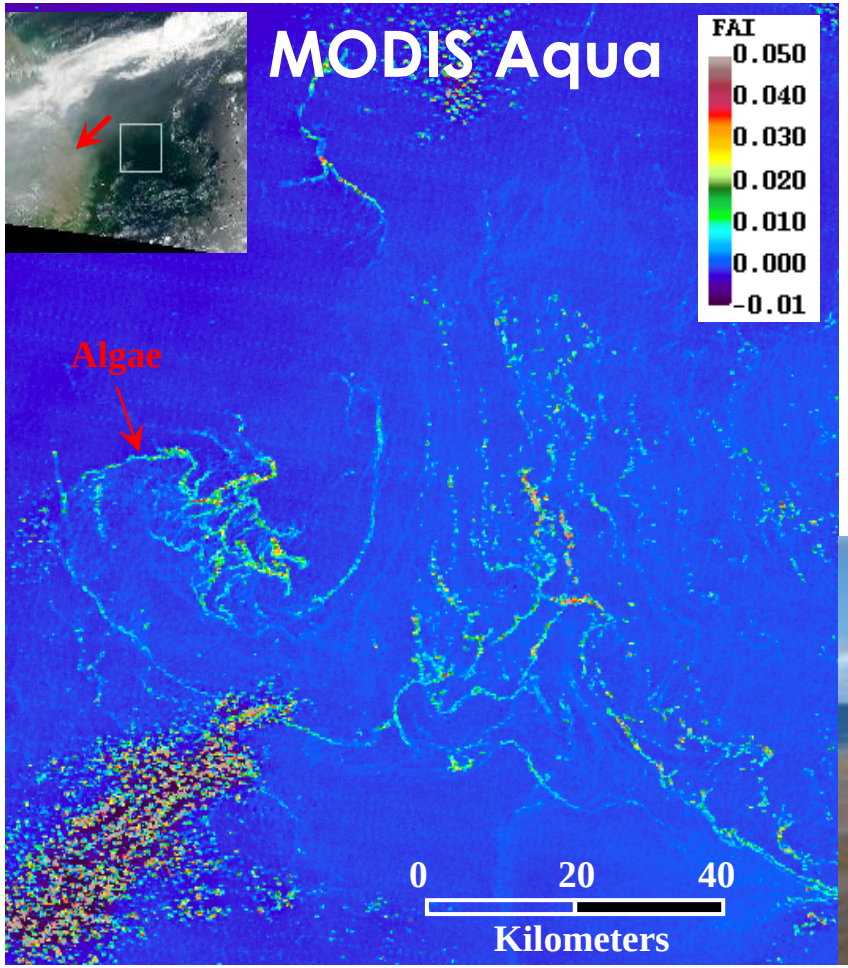
From: Descloitres et al. (2021)

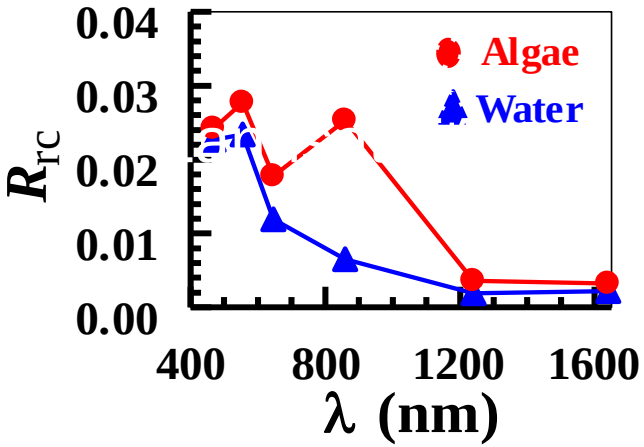
Moderate Resolution Sensors for *Sargassum*

	MODIS (A & T)	VIIRS
Spatial Resolution	1 km	750 m
Temporal Resolution	1 day	1 day
Cross Track	2 330 km	3 040 km
Algae Index	AFAI[1]	AFAI[1]
Radiometric data*	Rayleigh-corrected reflectance**	Rayleigh-corrected reflectance**
Wavebands	$\lambda_1 = 667$ nm	$\lambda_1 = 671$ nm
	$\lambda_2 = 748$ nm	$\lambda_2 = 745$ nm
	$\lambda_3 = 869$ nm	$\lambda_3 = 862$ nm

From: Ody et al. (2019)

Floating Algae Index (FAI)



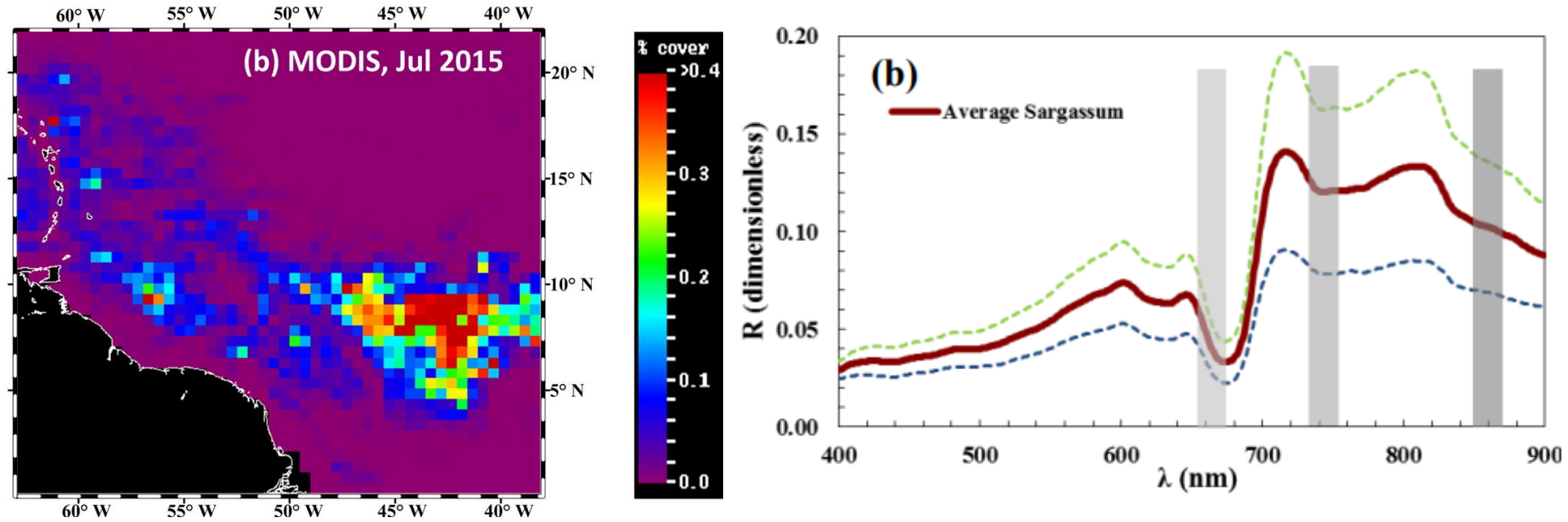


From: Hu (2009)

FAI Spectral Bands: λRED =645nm, λNIR =859nm, λSWIR =1240nm

Hu, C. (2009). A novel ocean color index to detect floating algae in the global oceans. Remote Sensing of Environment, 113, 2118–2129.

Alternate Floating Algae Index (AFAI)

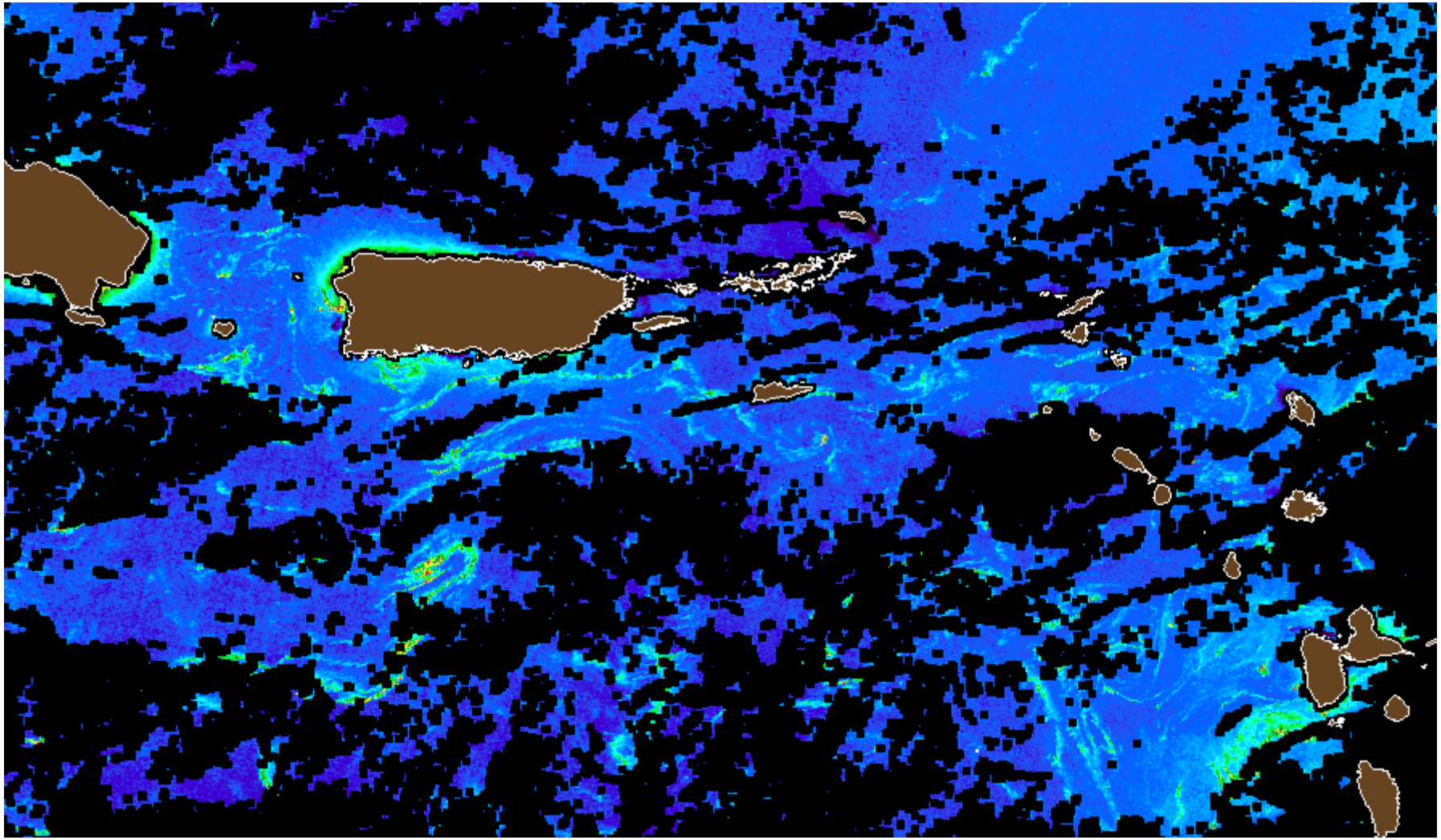


Adapted from Wang & Hu 2016

AFAI Spectral bands: (λRED =667nm, λNIR =748nm, λSWIR =869nm)

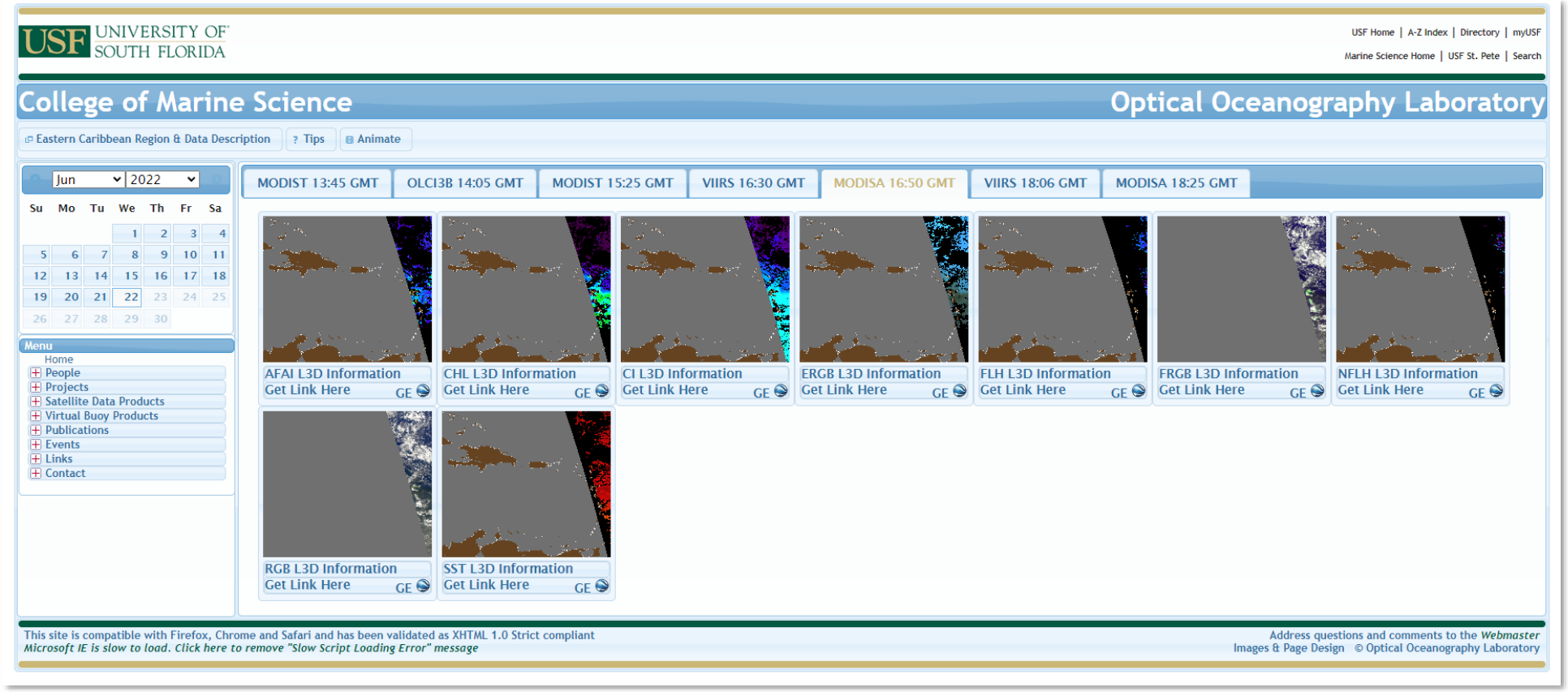
Wang, M and Hu, C. Mapping and quantifying Sargassum distribution and coverage in the Central West Atlantic using MODIS observations, Remote Sensing of Environment, Volume 183, 2016, Pages 350-367, ISSN 0034-4257, https://doi.org/10.1016/j.rse.2016.04.019.

Alternate Floating Algae Index (AFAI)



May 4, 2022, Courtesy of: https://optics.marine.usf.edu/projects/SaWS.html

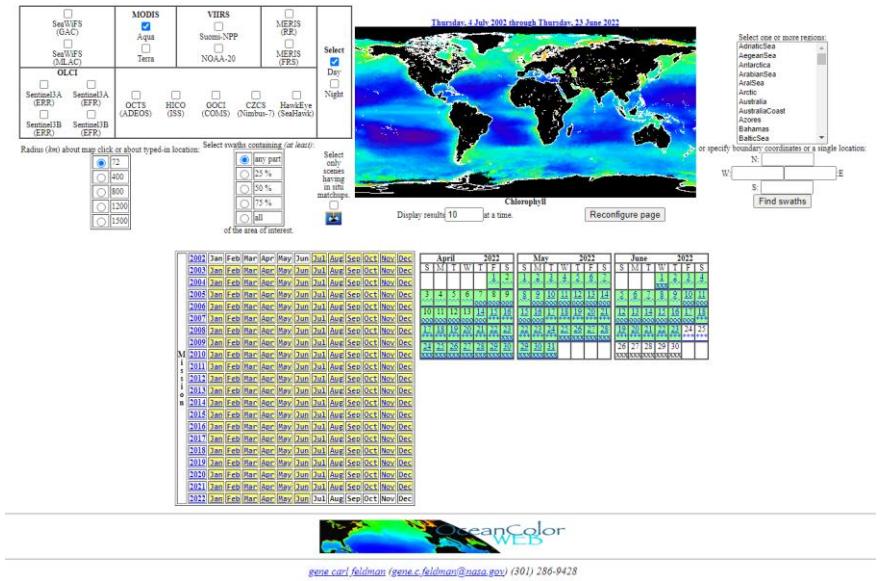
Sargassum Watch System (SaWS)



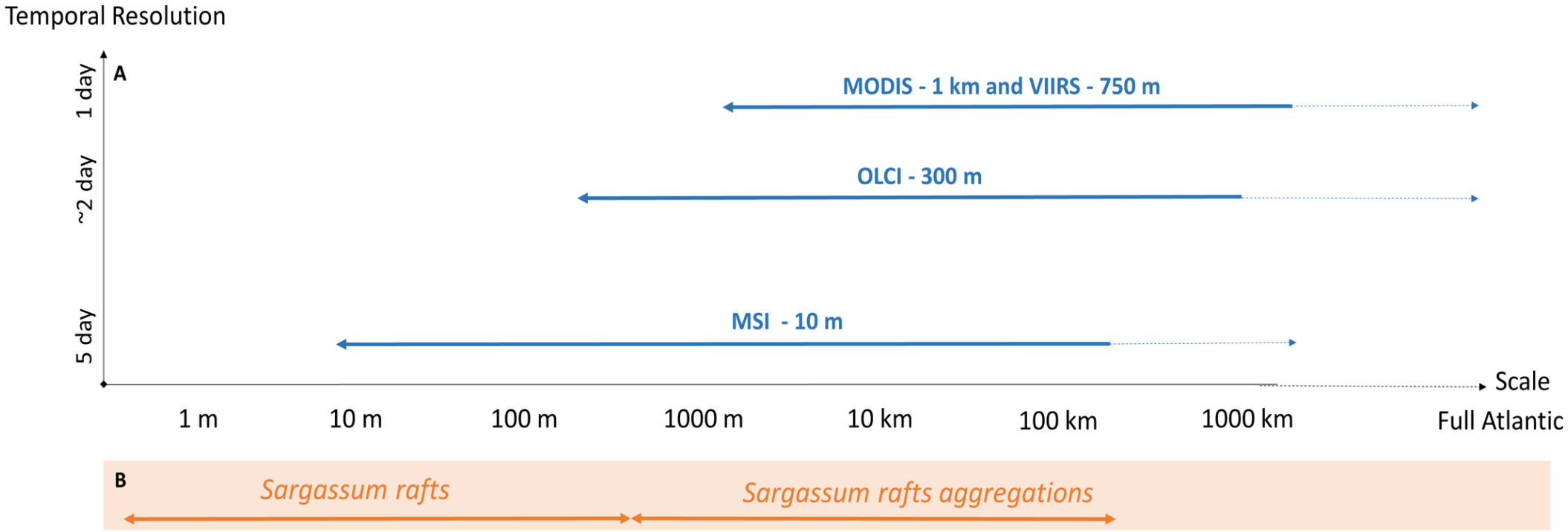
https://optics.marine.usf.edu/projects/SaWS.html

Additional Data Sources

- MODIS/VIIRS
  - NASA's Ocean Color Web Level 2 Browser
  - Processed with SEADAS using L2 gen
  - https://oceancolor.gsfc.nasa.gov/
- Sentinel-3 OLCI
  - Level-2 products
  - Processed with SNAP processing software
  - https://scihub.copernicus.eu/

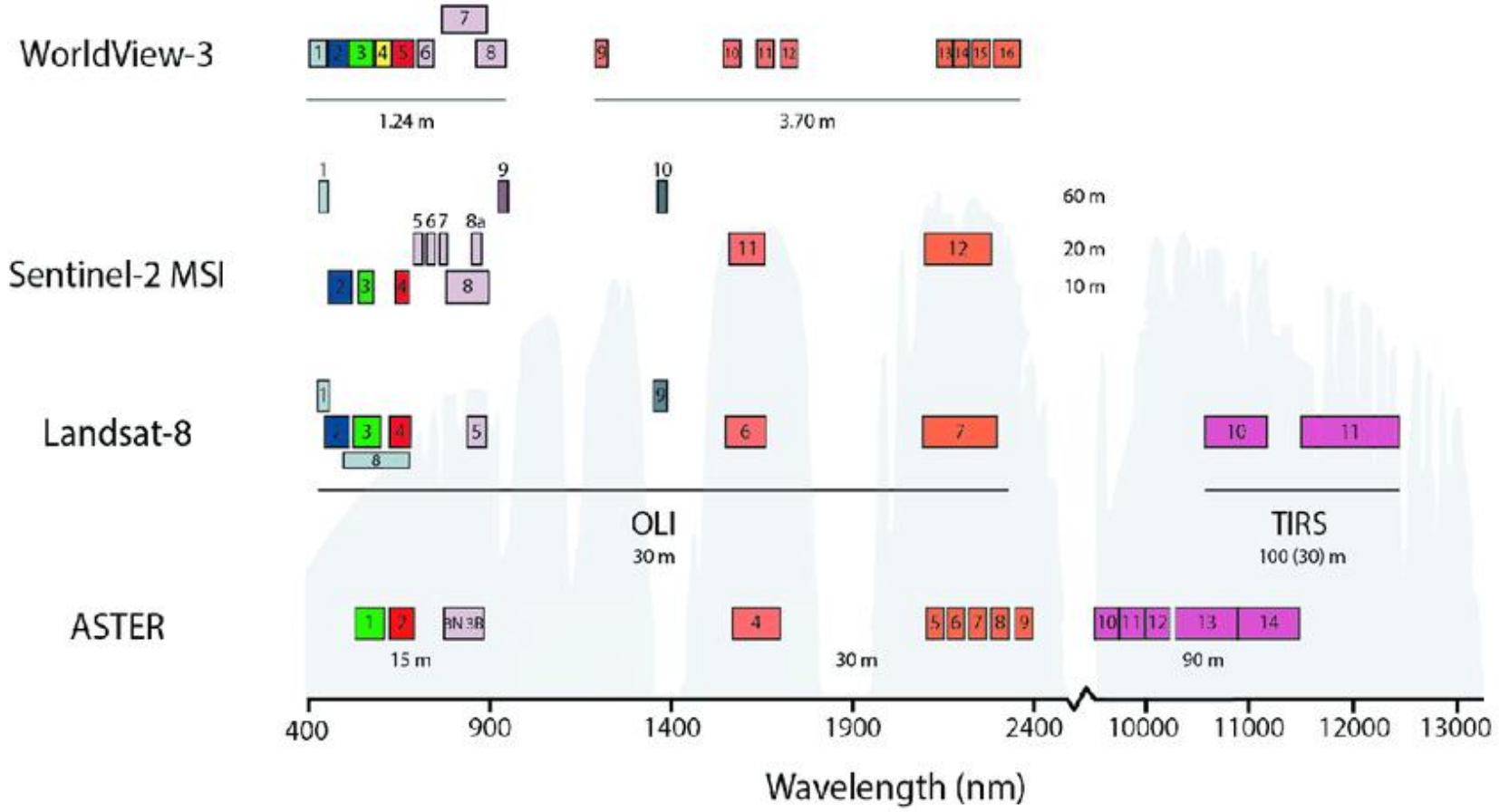


Limitations for *Sargassum* Detection



Ody, A.; Thibaut, T.; Berline, L.; Changeux, T.; André, J.-M.; Chevalier, C.; Blanfuné, A.; Blanchot, J.; Ruitton, S.; Stiger-Pouvreau, V.; et al. From In Situ to Satellite Observations of Pelagic Sargassum Distribution and Aggregation in the Tropical North Atlantic Ocean. PLoS ONE 2019, 14, e0222584.

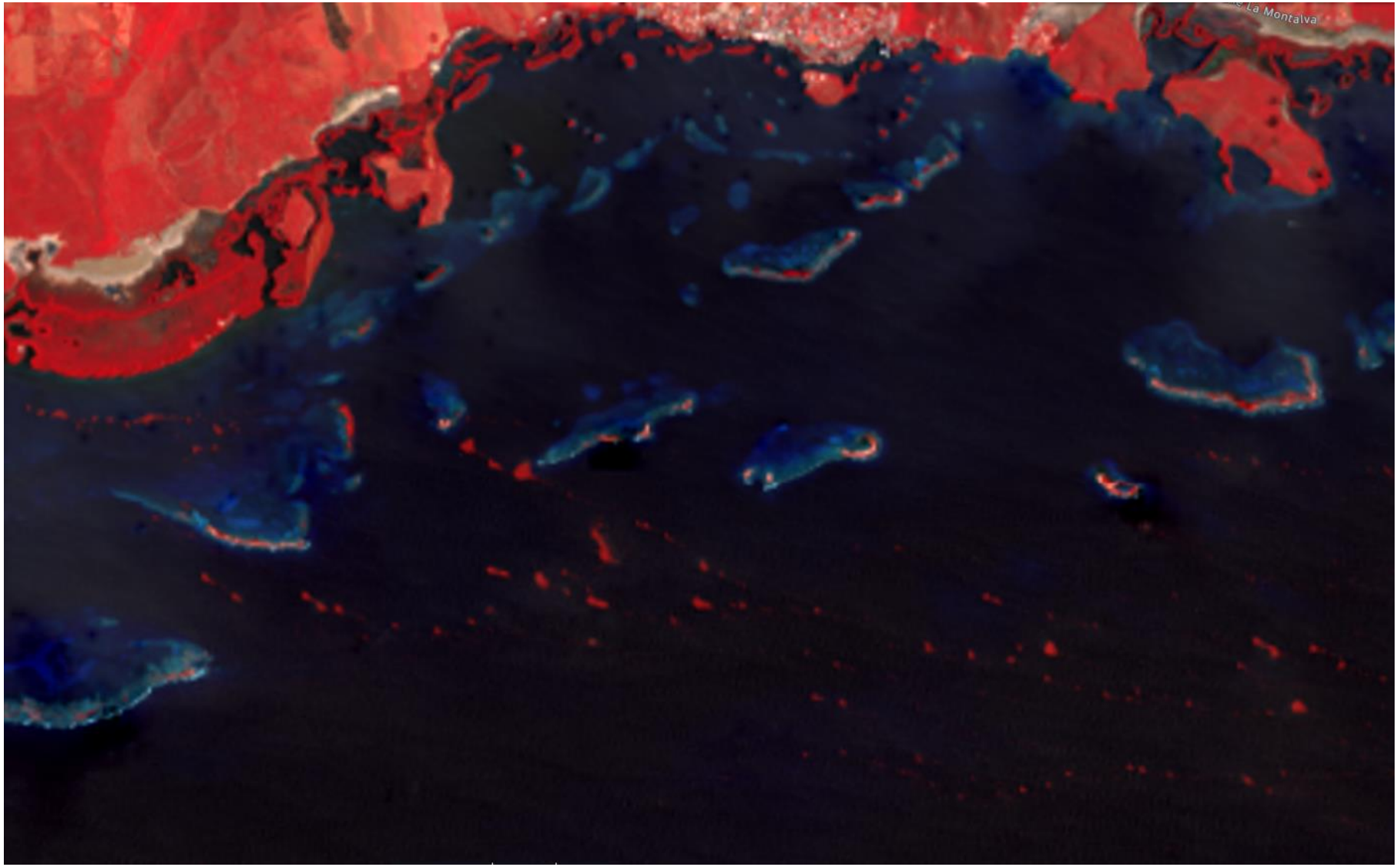
High-Resolution Sensors for *Sargassum* Detection



Cardoso-Fernandes, Joana Teodoro, A.Lima, A. Perrotta, Mônica Roda-Robles, Encarnacion. 2020. Detecting Lithium (Li) Mineralizations from Space: Current Research and Future Perspectives. Vol- 10.-10.3390app10051785 Applied Sciences.

Landsat 8 (30m) True Color, La Parguera, SWPR

Landsat 8 (30m) False Color, La Parguera, SWPR



Sentinel 2 MSI (10m) FAI, La Parguera, SWPR

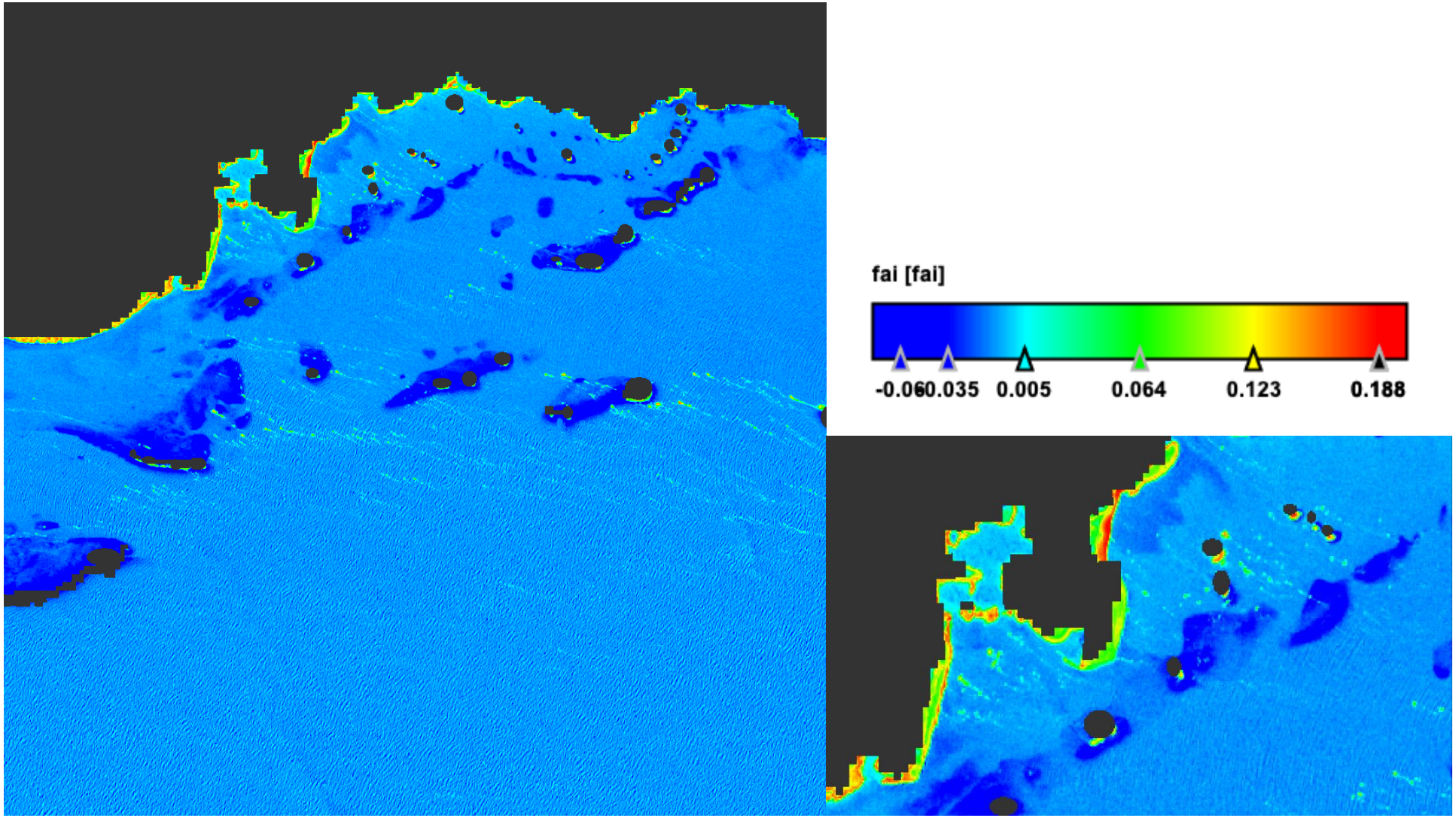
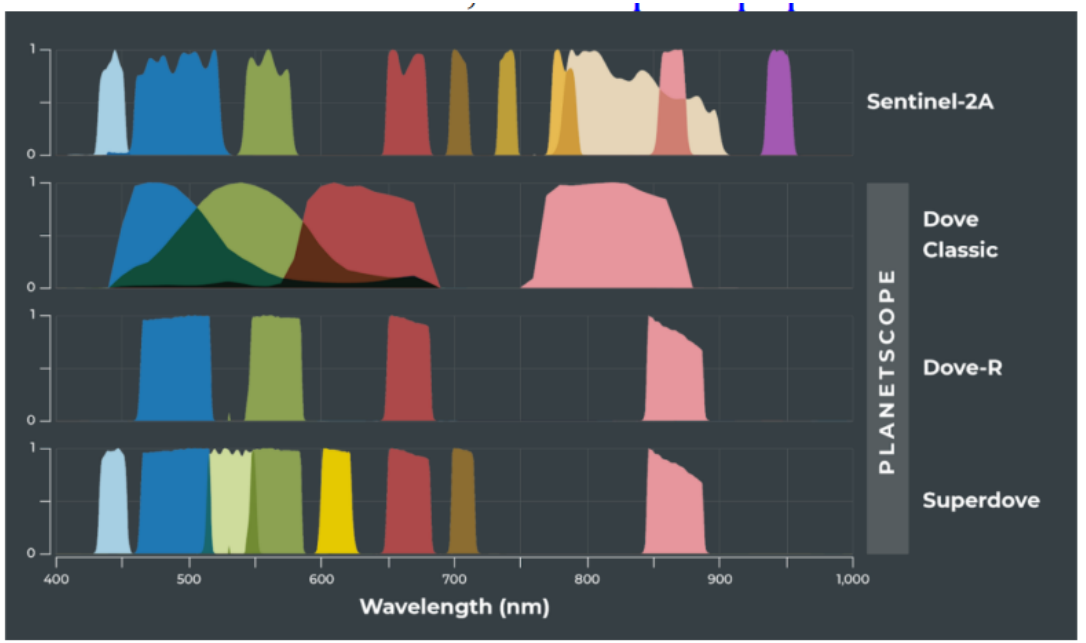


Image Credit: Jennifer Perez UPRM

Very High-Resolution Sensors for *Sargassum* Detection

Benefit from NASA's Commercial Smallsat Data Acquisition (CSDA) Program

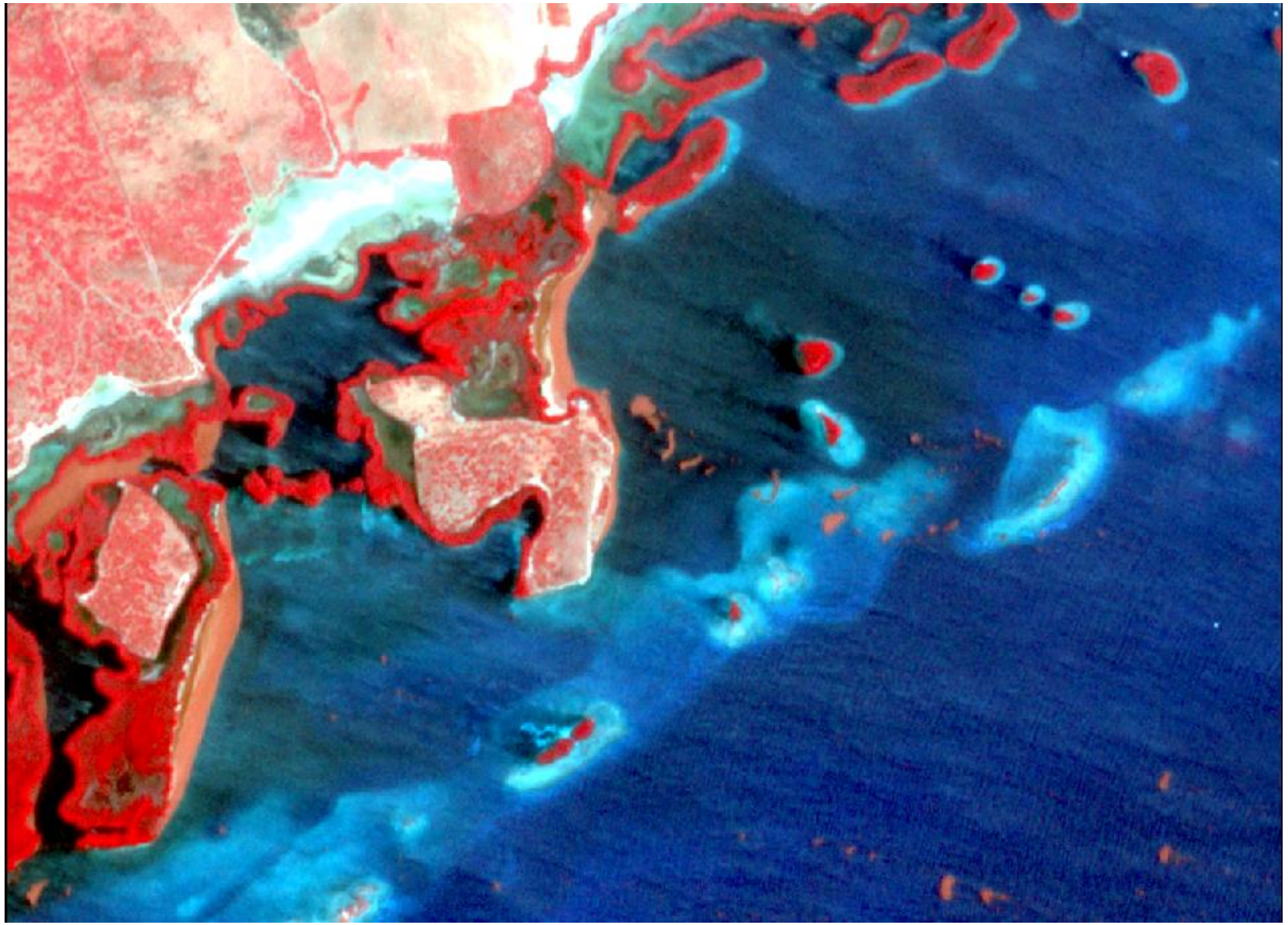
- Access to PlanetScope data (1-3m)
  - Multispectral (Superdove)
- Maxar/Digital Globe Data (WorldView 1-4) (0.33-2m).
  - Multispectral
- Excellent for change detection studies (impacts from *Sargassum*)



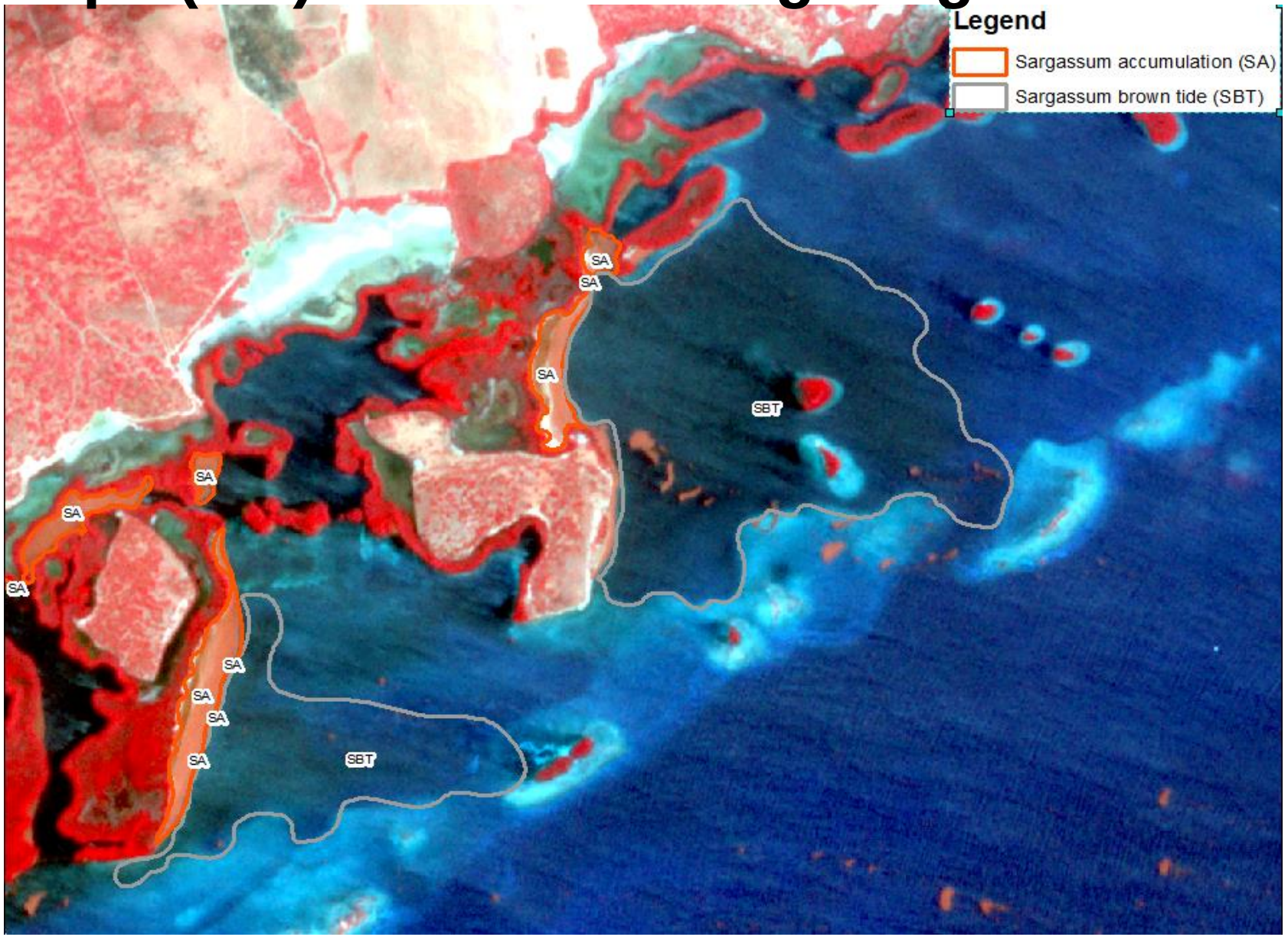
Harrison T. N. et al. (2017) AGU Fall Meeting 2017, P43C-2297. [2] Planet Team (2017) Planet Application Program Interface: In Space for Life on Earth. San Francisco, CA. https://api.planet.com.

Planet Scope (3m)True Color Image

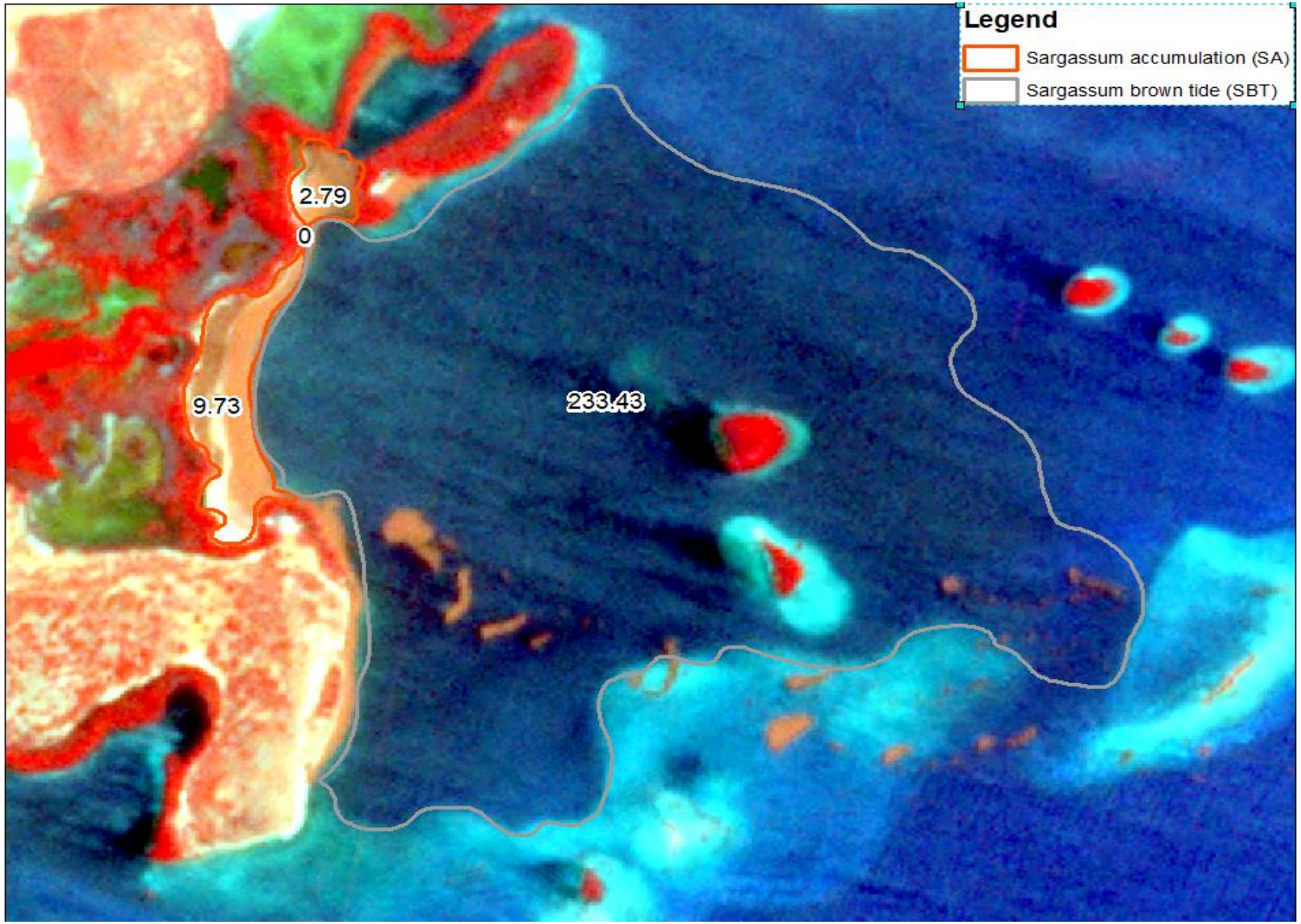
Planet Scope (3m)True Color Image



Planet Scope (3m)True Color Image Digitized



Planet Scope (3m) Image Area (Acres)

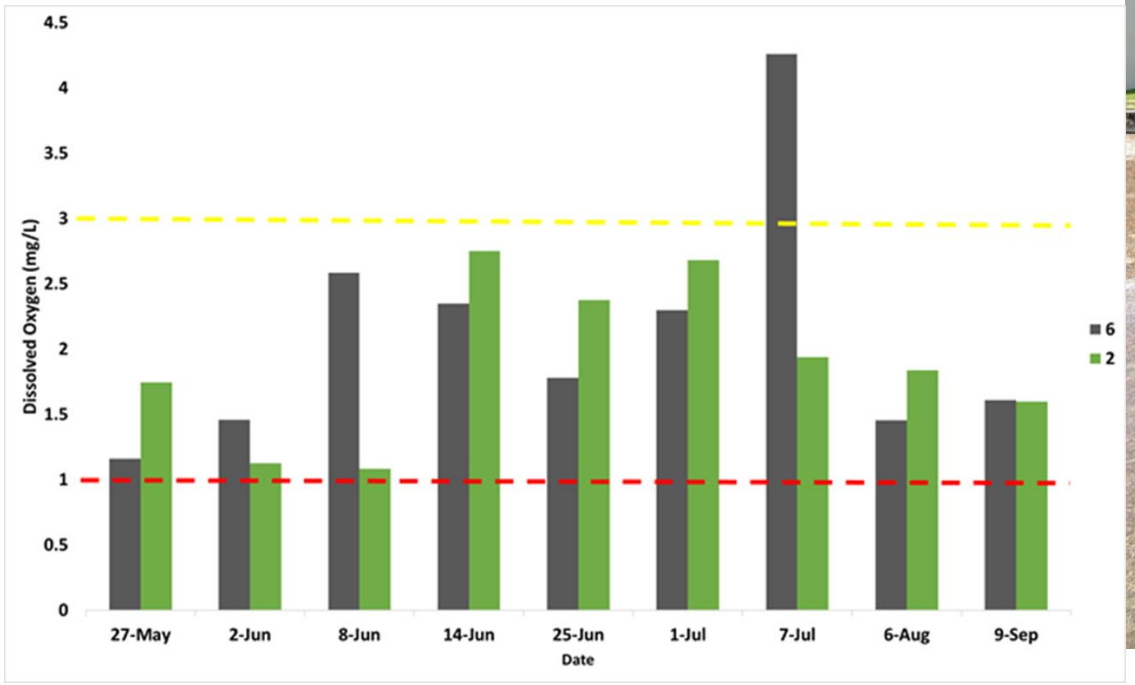


WorldView 3 (0.33m) True Color Image

WorldView 3 (0.33m) False Color Image

Field *Sargassum* Observations

- Water Quality Impacts:
  - pH, temperature, conductivity, dissolved oxygen (DO), and turbidity profiles
- Fish and marine life mortality

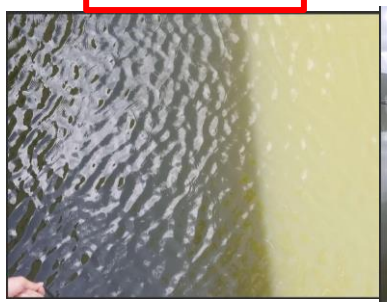


Field *Sargassum* Observations

- Location, accumulation level, sea turtle presence, debris, etc.
- ArcGIS Survey 123 App via smartphones
- Collect photos and geolocation

Palmas del Mar, Humacao

Station 2



May 27, 2021

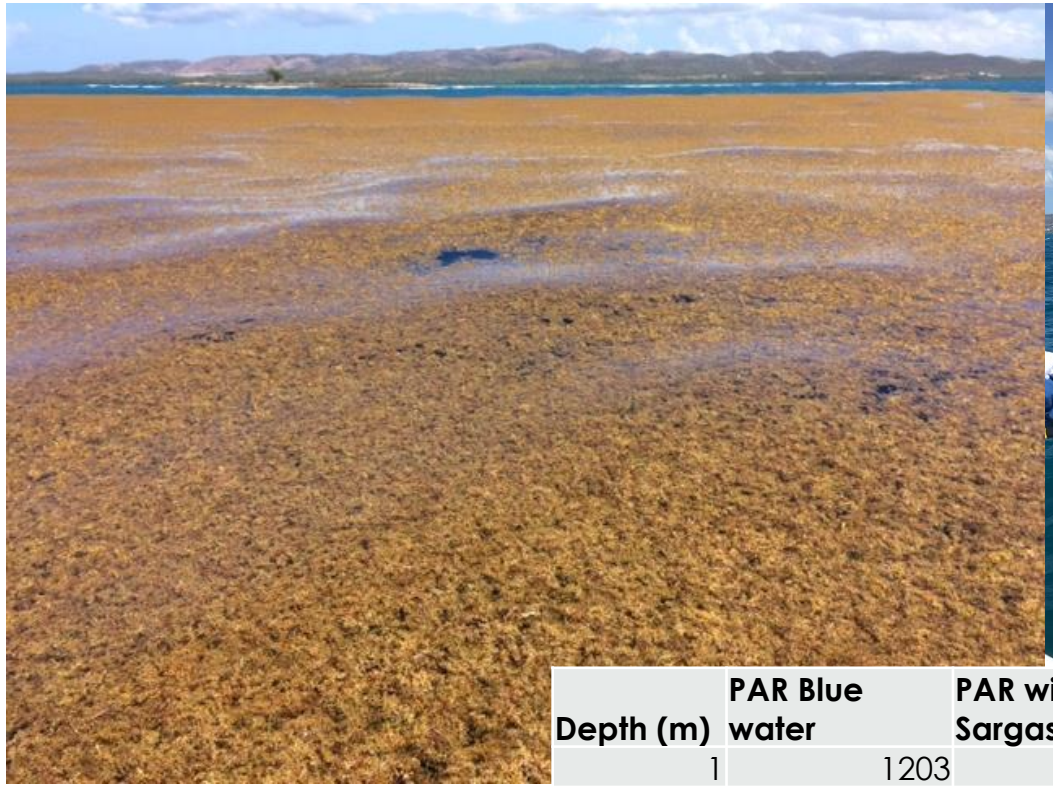
Station 6

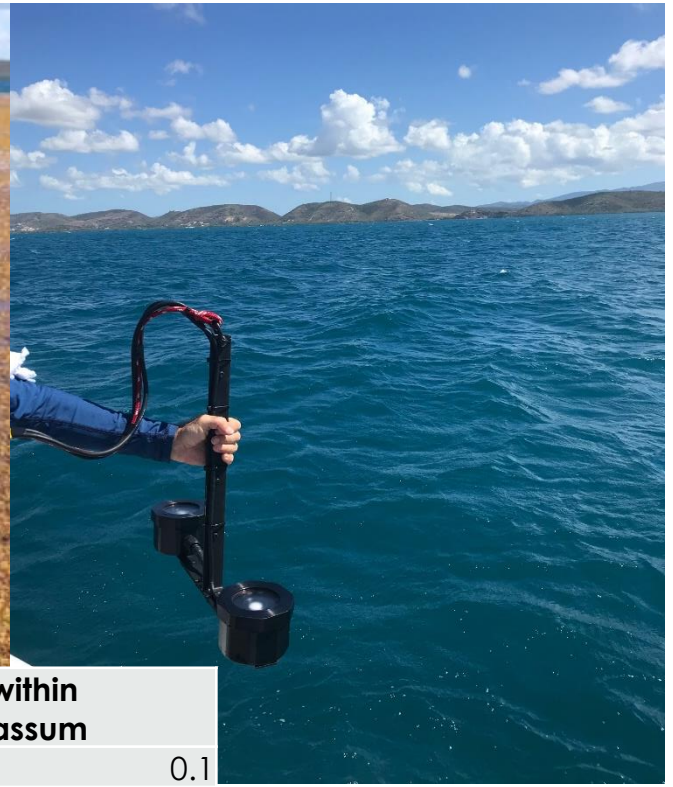
May 27, 2021

Jun 8, 2021

Jun 8, 2021

Impact of Large *Sargassum* Patch on the Underwater Light Field





Depth (m)	PAR Blue water	PAR within Sargassum
1	1203	0.1
2	902	0
3	760	0
4	603	0.2
5	572	0.3
6	464	0.3
7	401	0.3
8	342	1.8
9	297	2.7
10	272	0.9

Solar Light Submersible Radiometer
PAR Attenuation (Kd_{PAR})
(quanta * m2 * s-1)

Remote Cameras to Monitor *Sargassum*

- Record *Sargassum* observations
- Estimate *Sargassum* accumulation.
- Validation of *Sargassum* observations for satellite imagery

Remote Cameras to Monitor *Sargassum*

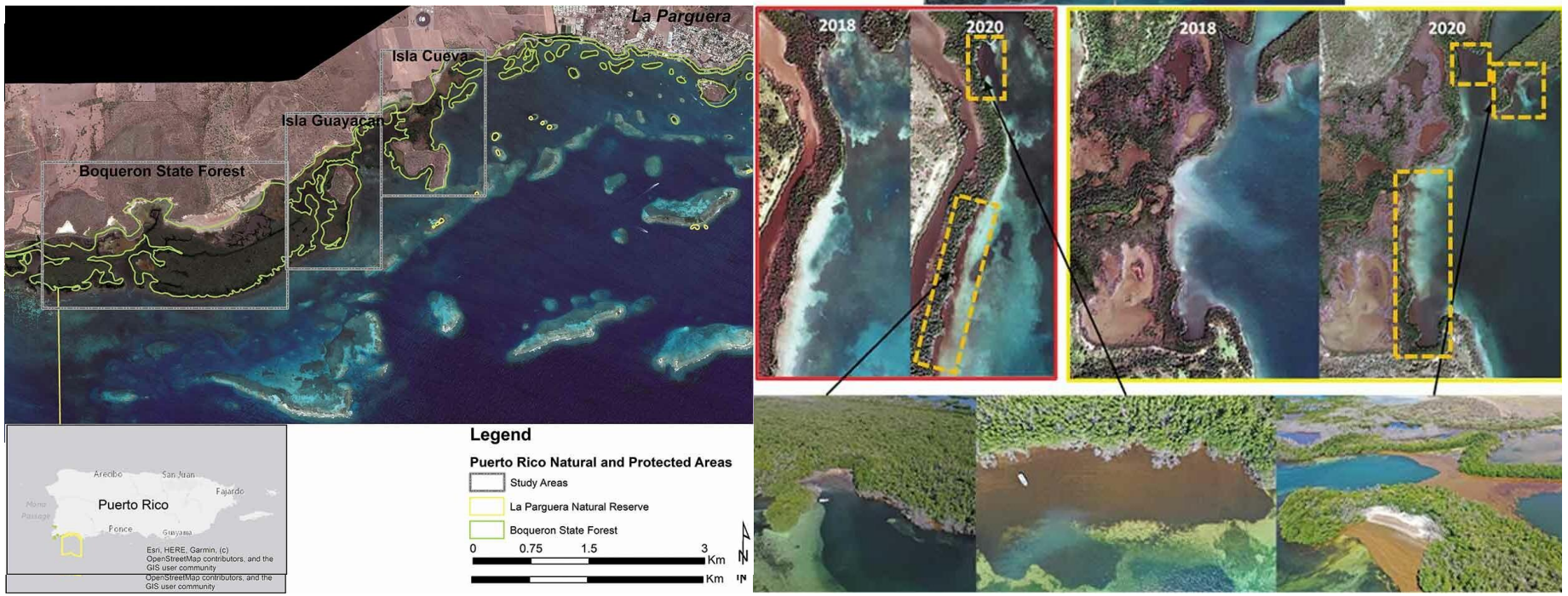
Drone Surveys

Drone Surveys

Drone Surveys

Using High-Resolution Satellite Imagery to Assess the Impact of *Sargassum* Inundation on Coastal Areas

- Hernández, WJ, Morell, JM & Armstrong, RA. (2021)
- Suggests accelerated impacts to the fringing mangroves via an NDVI analysis since 2018, especially to Isla Cueva site.
- https://doi.org/10.1080/2150704X.2021.1981558



Concluding Remarks

- *Sargassum* is an essential ecosystem in the open ocean, but these new inundations of *Sargassum* are negatively impacting coastal resources and ecosystems.
- Remote sensing tools can be used to observe, detect, and analyze *Sargassum* using band combinations and algorithms.
- Combining multi-scale remote sensing imagery with field observations can provide a better understating of the acute and chronic effect of *Sargassum* impacts to the coastal ecosystems.

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