Evaluating SeaHawk Ocean Color CubeSat Data: challenges, opportunities and lessons learned

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Outline

- **Becoming a PI and starting a lab**
- **Seahawk CubeSat Mission**
- **Motivation to do satellite validation**
- **Work done by my lab:**
  - In situ (South Atlantic Bight)
  - MOBY + Cross-validation,
  - AERONET OC,
  - PLOCAN gliders
- **Rivero Lab instruments available**

SKIDAWAY INSTITUTE of Oceanography

Bio-Optical and Satellite OCEANOGRAPHY LAB

Starting a New Research Lab at UGA

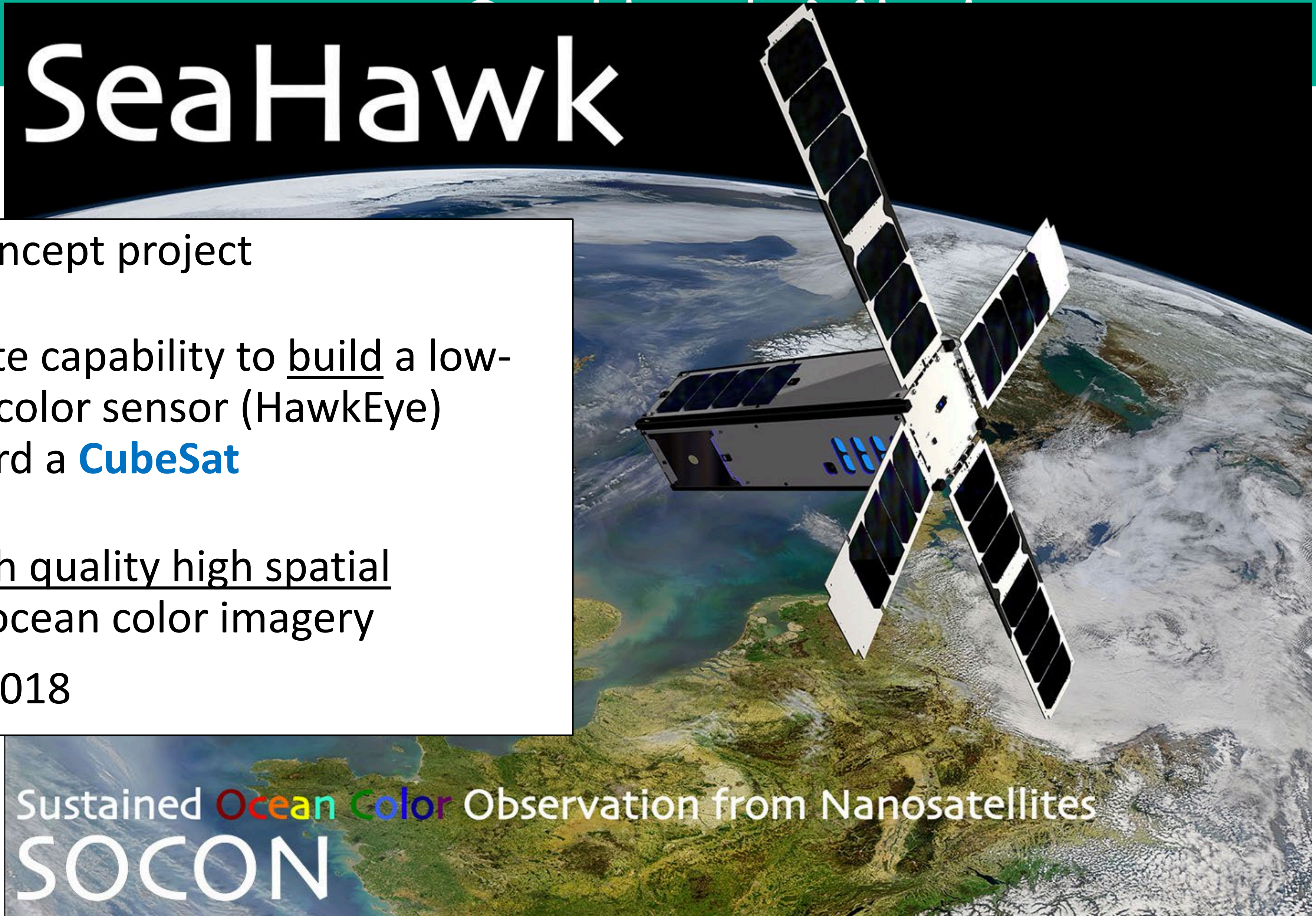
Year 2020

pandemic + supply chain issues

Go!

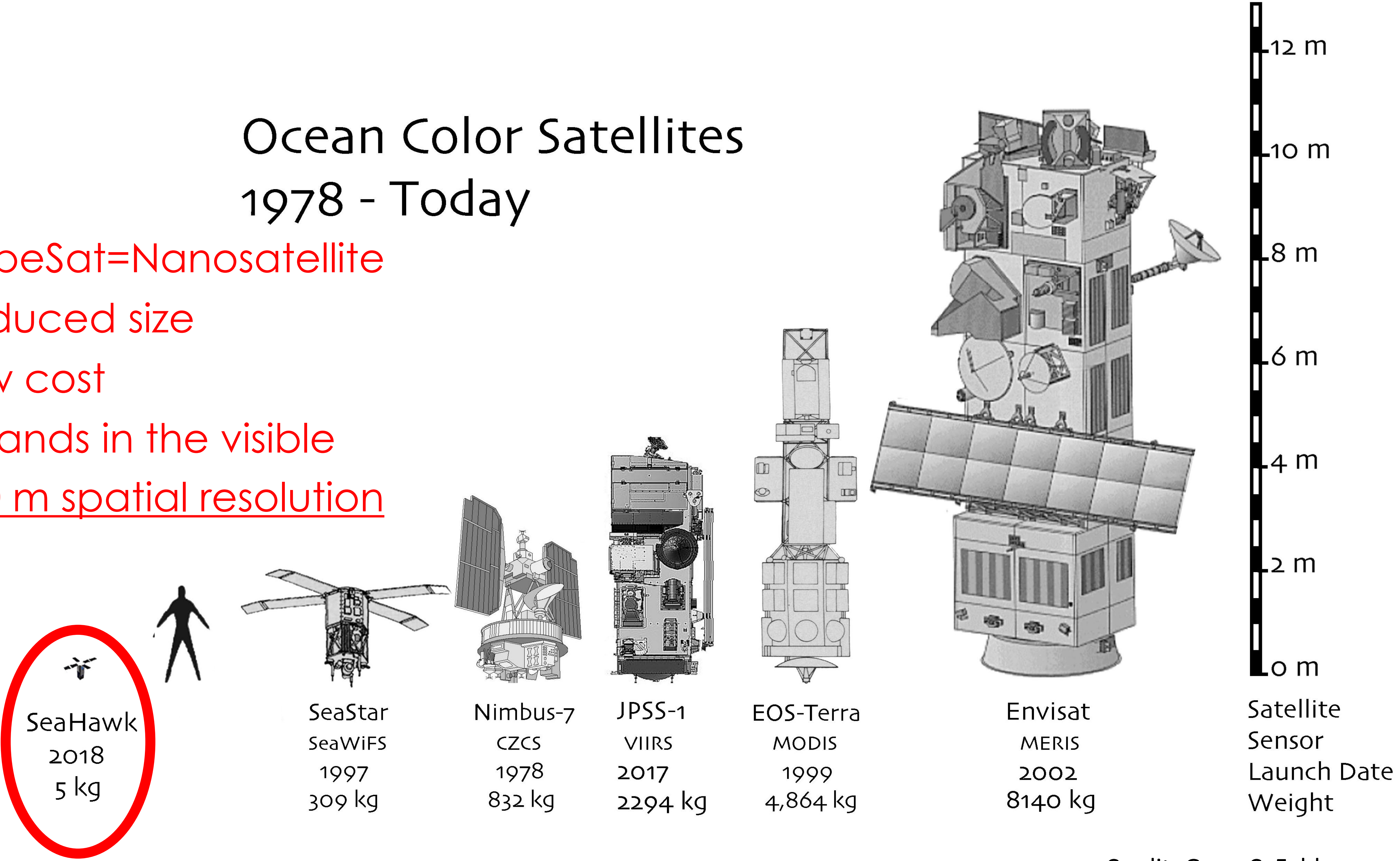
- Write proposals
- Recruit students
- Buy equipment
- Publish!

- Proof-of-concept project
- Demonstrate capability to build a low-cost ocean color sensor (HawkEye) flown aboard a **CubeSat**
- Provide high quality high spatial resolution ocean color imagery
- Launched 2018



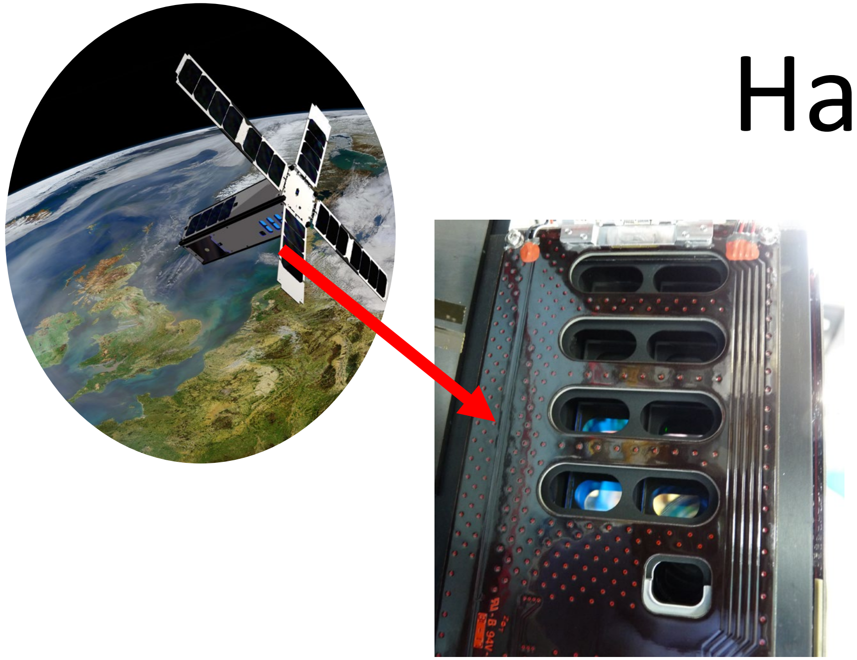
Ocean Color Satellites
1978 - Today

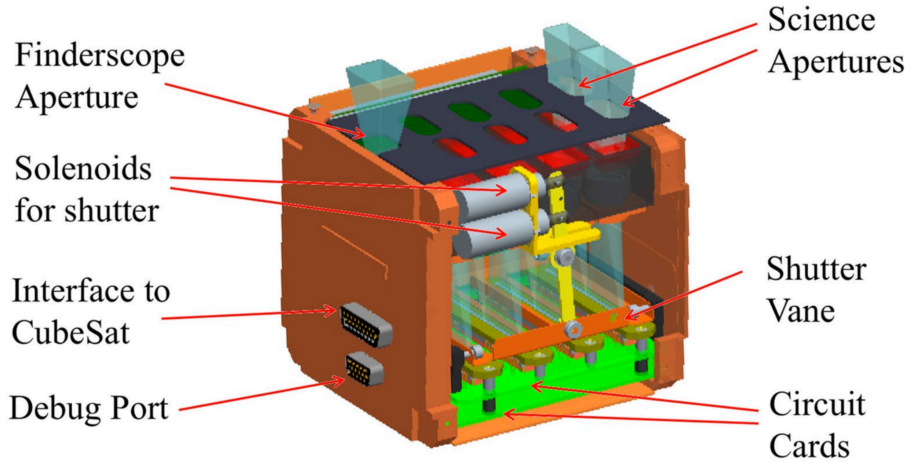
- CubeSat=Nanosatellite
- Reduced size
- Low cost
- 8 bands in the visible
- 120 m spatial resolution

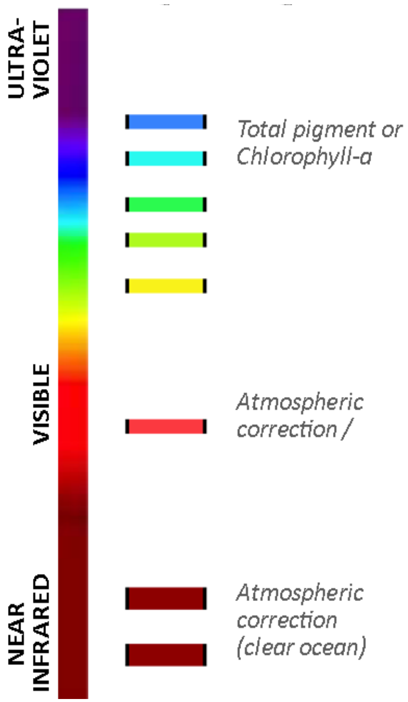


Credit: Gene C. Feldman

HawkEye Sensor



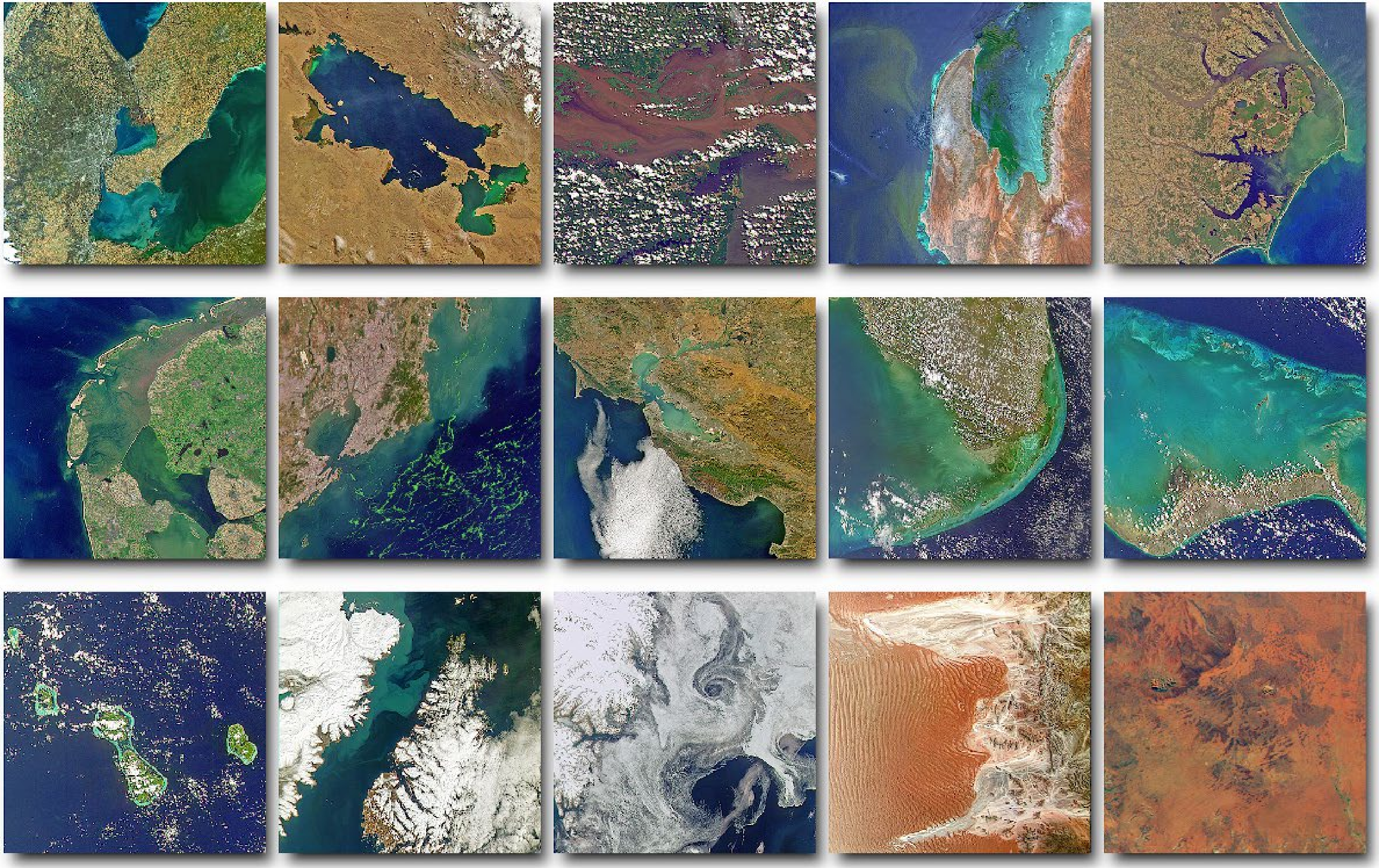




Band #	Wavelength (nm)	Band width (nm)
Band 1	412	20
Band 2	443	20
Band 3	490	20
Band 4	510	20
Band 5	555	20
Band 6	670	20
Band 7	750.9	14.7
Band 8	865	40

← same design as SeaWiFS except for band 7

SeaHawk-HawkEye Mission



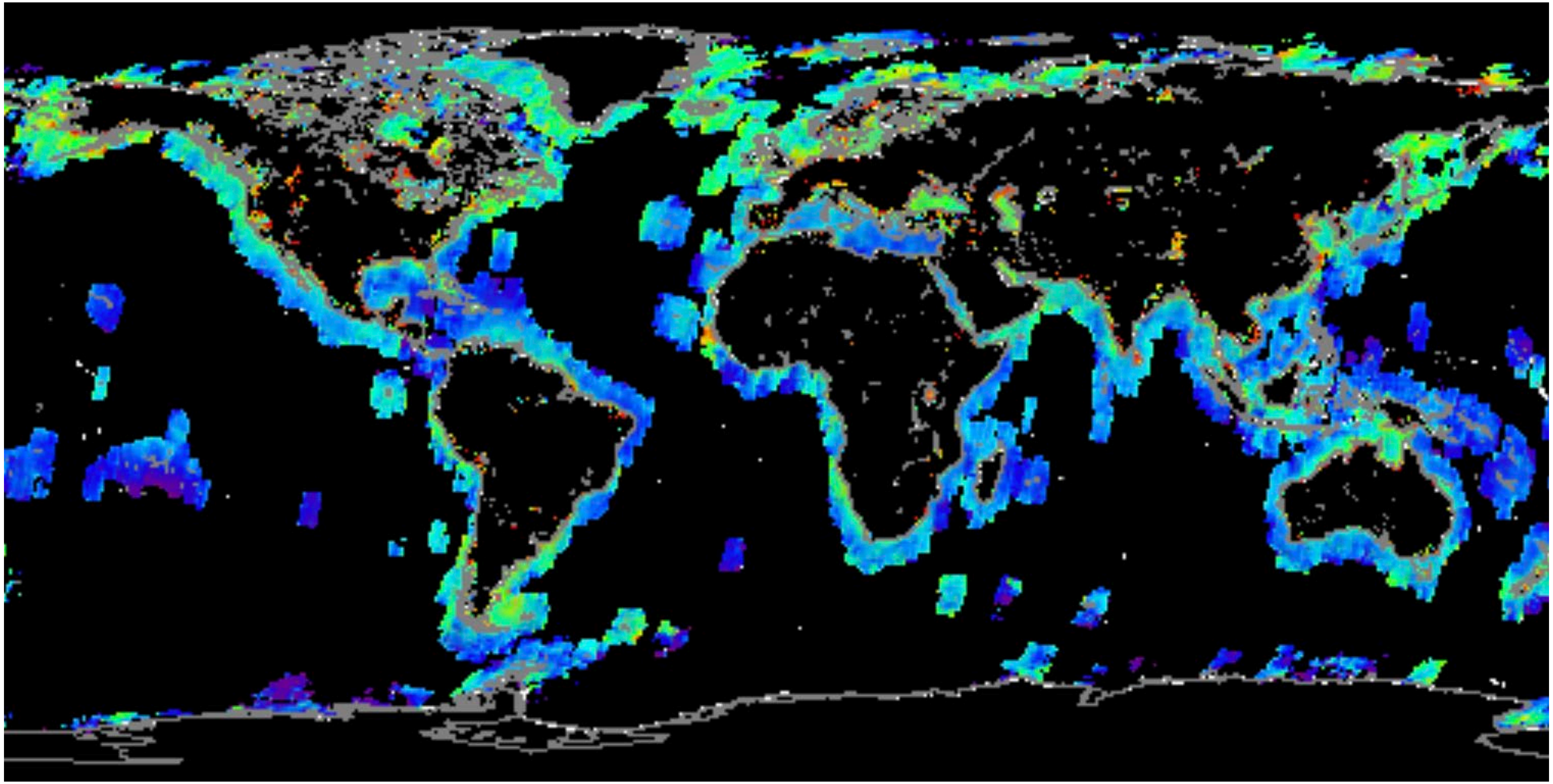
~9,000 images collected 2021-2023

@seahawk_hawkeye

SeaHawk-HawkEye Mission

Evaluating its Performance

200 km



Chl-a a collage of SeaHawk-HawkEye data 2021-2023

Original cal-val plan

- Lunar Calibrations
- Vicarious calibration: MOBY
- Cross-validation with NASA OC missions

Bio-Optical and Satellite
Oceanography Lab

Fieldwork: South Atlantic Bight
- Validation with *in situ* data
- Regional Algorithm Development

Comparison with MODIS+OLCI+VIIRS
Glider collaboration
AERONET OC

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Getting the Instruments

STARTUP PURCHASES

Hyperpro II
+T, S,
+ triplets
(bb, chla, PE, PC)

(~$105k)

SpectraVista Radiometer
+ spectralon panel
(~$18k)

Proposed Equipment in May 2022

~~SeaBird HyperSAS (~$60k)~~
Computer Node (~$10k)

Water Quality and Satellite Data Validation in Coastal and Inland Waters Workshop (June 2022)

Giuseppe Zibordi
Juan Gossn
Igor Igoshawara
John Schalles…
HyperCP!

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TRiOS G2 + SoRAD
(~$30k + ~$5k) ordered Fall 2022

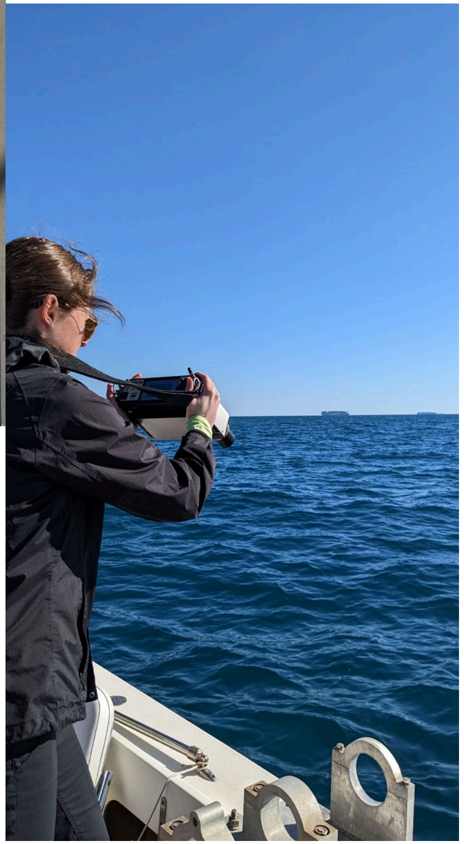
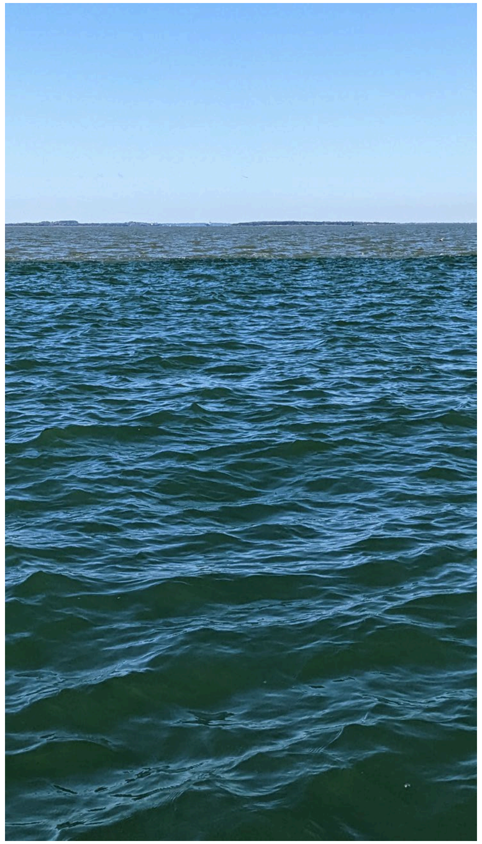
1. In situ data collection 2022-2023



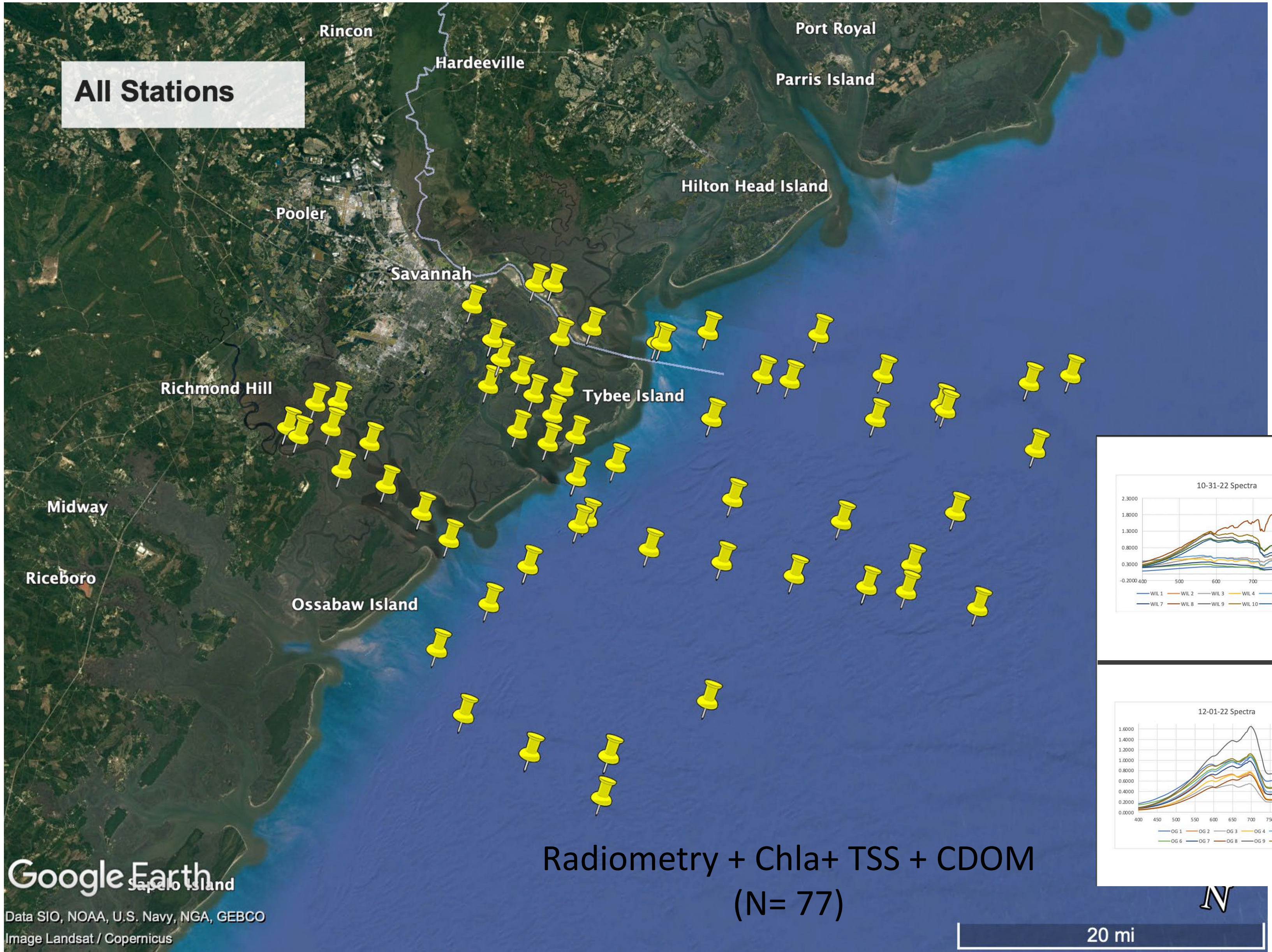
Collected:

- SVC radiometry and water samples
- Wind
- Temp and salinity of water with HANA instrument (~1.5k)

<u>In the lab</u>: a_{CDOM}, chlorophyll a concentration, suspended sediments

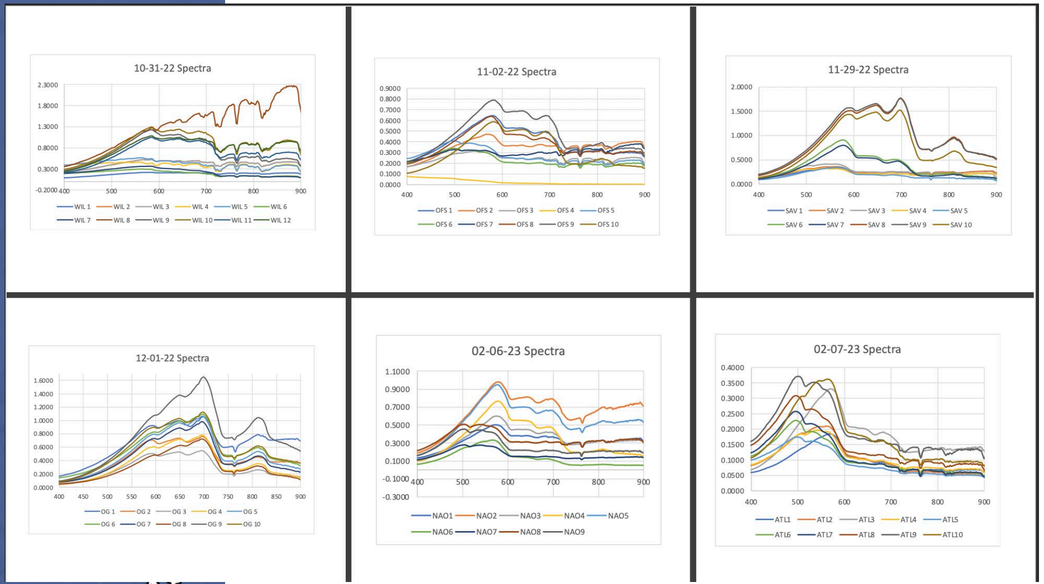





1. In situ data collection SAB



Goal: acquire validation data in SAB and build regional algorithms

8 field days
77 matchups
Data on radiometry and water quality (Chla+ TSS + CDOM)



1. In situ data collection SAB

Unexpected Delays….

- Supply chain issues
- HyperSAS discontinued
- Issues buying from TRIOS
- R/V Savannah mid life refit
- R/V Blanton broke down
- SeaHawk increasing revisit time
- SeaHawk instabilities
- Cloud cover over the summer
- Technician moves

MANY lessons learned….

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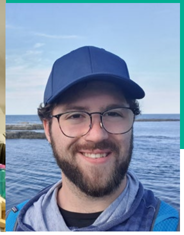
1. In situ data collection SAB





Achievements:

- Acquired equipment and supplies
- Developed lab protocol for radiometry
- Developed lab protocol for water sample collection and processing (chla, TSS, aCDOM)
- Intercomparison with Dr. John Schalles (GLORIA)
- Generated Matchups with SeaHawk
- Produced SeaBASS files
- Trained students and technicians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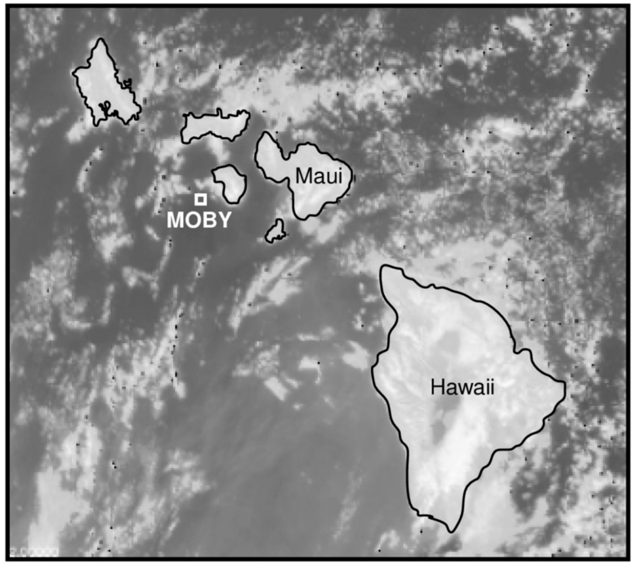
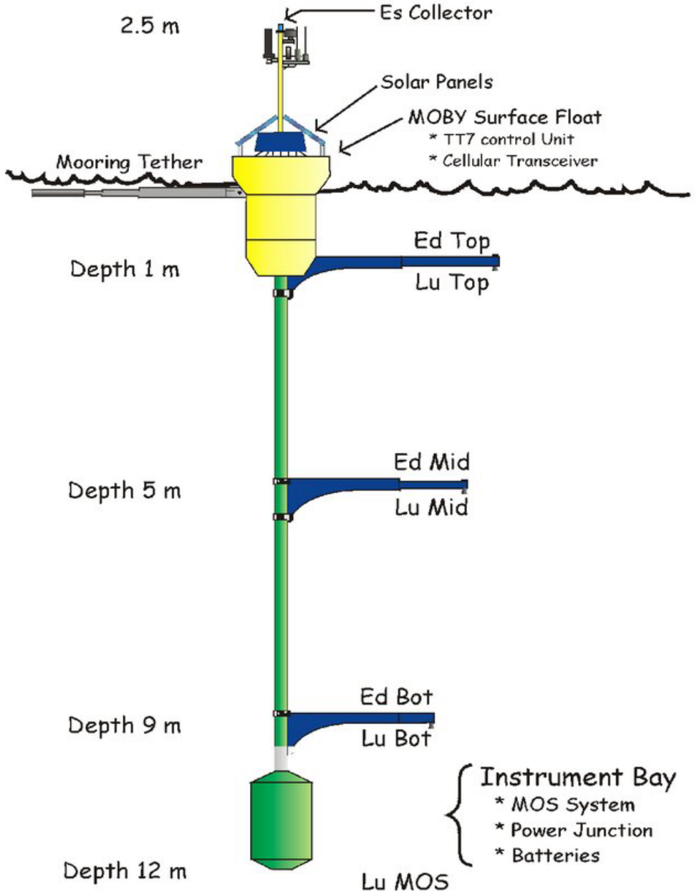
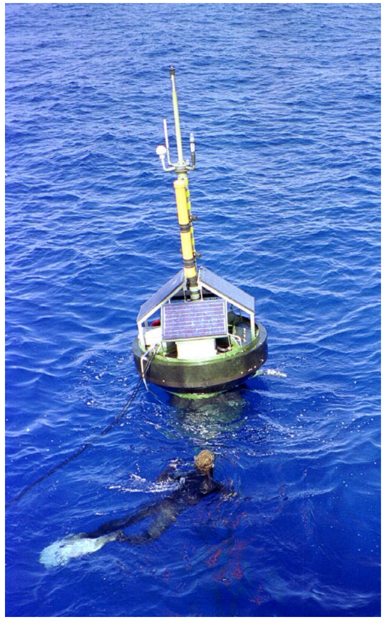
2. The Marine Optical BuoY (MOBY)



MOBY station in Hawaii





Only 2 matchups

Why? ☹

- Clouds
- Conflict with downlink of imagery in Alaska ground station

Masud-Ul- Alam et al., in prep. *"SeaHawk Low-Cost Ocean Color CubeSat Produces High Spatial Resolution and High-Quality Data: A Comparison with NOAA-20 VIIRS, NASA MODIS-Terra and MODIS-Aqua"* (in prep.)

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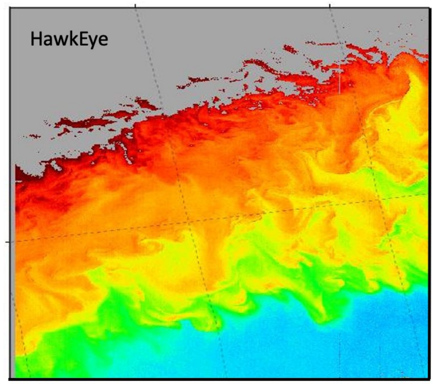
3. Cross-comparison study

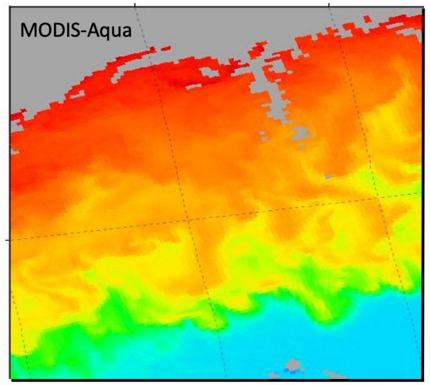
QUESTIONS

1. Can we evaluate SeaHawk-HawkEye Performance on a GLOBAL SCALE?
2. Will our matchups improve or worsen with SeaHawk-HawkEye HIGHER SPATIAL RESOLUTION???



resolution

120m	300m	750m	1000m
HawkEye	OLCI	VIIRS	MODIS Aqua Terra



What is the information gain??

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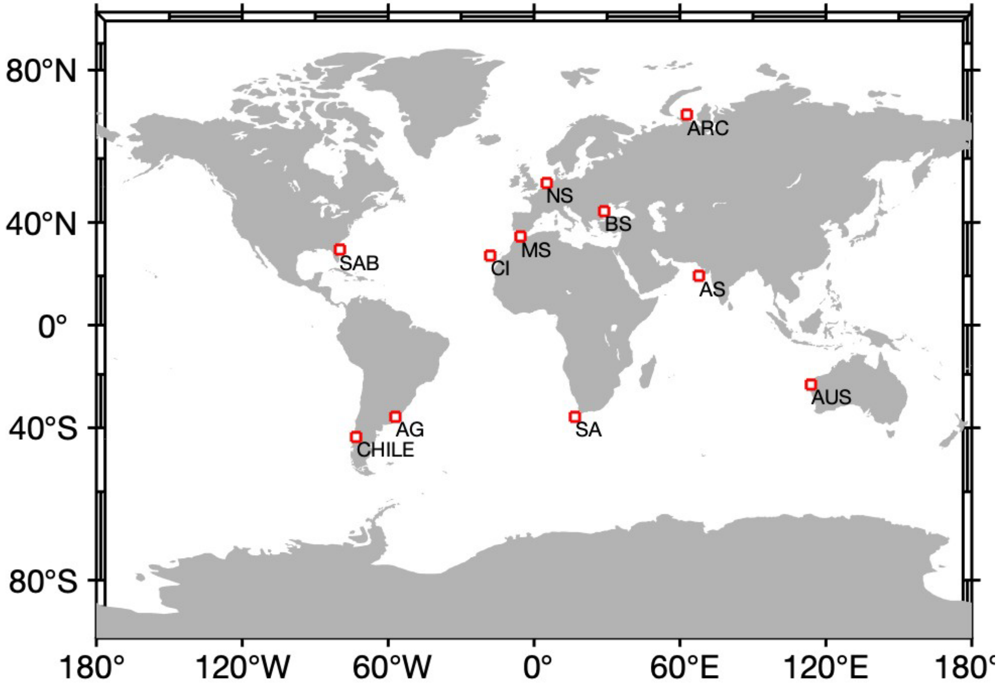
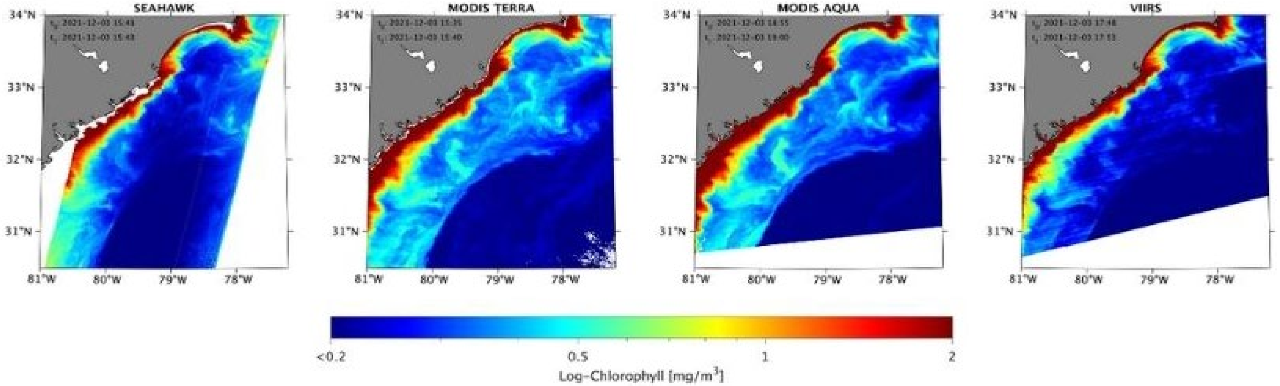
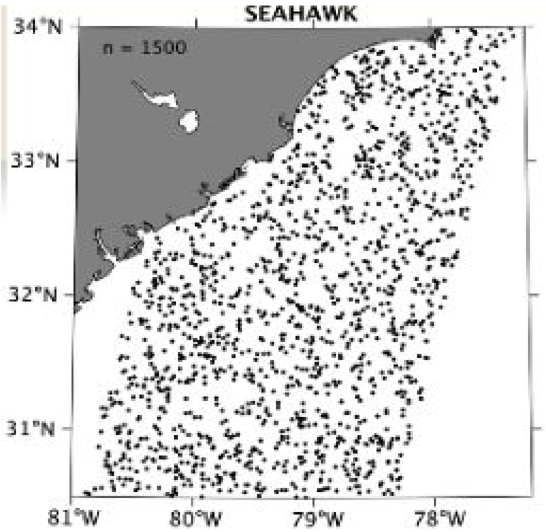
3. Cross-comparison study

4 sensors: HawkEye, Terra, Aqua, VIIRS



First SeaHawk performance study
11 locations + MOBY in situ data





5 bands
3 processing levels
5 statistical methods:

- R^2
- bias,
- RMSE,
- d-index
- CCC

Masud-Ul- Alam et al., in prep. "*SeaHawk Low-Cost Ocean Color CubeSat Produces High Spatial Resolution and High-Quality Data: A Comparison with NOAA-20 VIIRS, NASA MODIS-Terra and MODIS-Aqua*" (in prep.)

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3. Cross-comparison study

Results:

(yellow)	> 20%
(light blue)	20% or less

Top of the atmosphere (TOA) reflectance (% difference)

Bands	MT-SH	MA-SH	VIIRS-SH	MT-MA	MT-VIIRS	MA-VIIRS
412 nm	-5	0	-5	5	0	-5
447 nm	-4	2	-5	6	-1	-6
488 nm	-5	0	-4	5	0	-5
555 nm	-7	-2	-7	5	0	-5
670 nm	-18	-3	-4	15	14	200

Less than 7%

Remote sensing reflectance (Rrs) (% difference)

Bands	MT-SH	MA-SH	VIIRS-SH	MT-MA	MT-VIIRS	MA-VIIRS
412 nm	66	60	20	-6	-47	-40
447 nm	10	17	[illegible]	-7	-2	5
488 nm	8	2	3	-7	-6	1
555 nm	-5	10	7	15	12	-3
670 nm	117	131	118	23	1	-21

17% or less

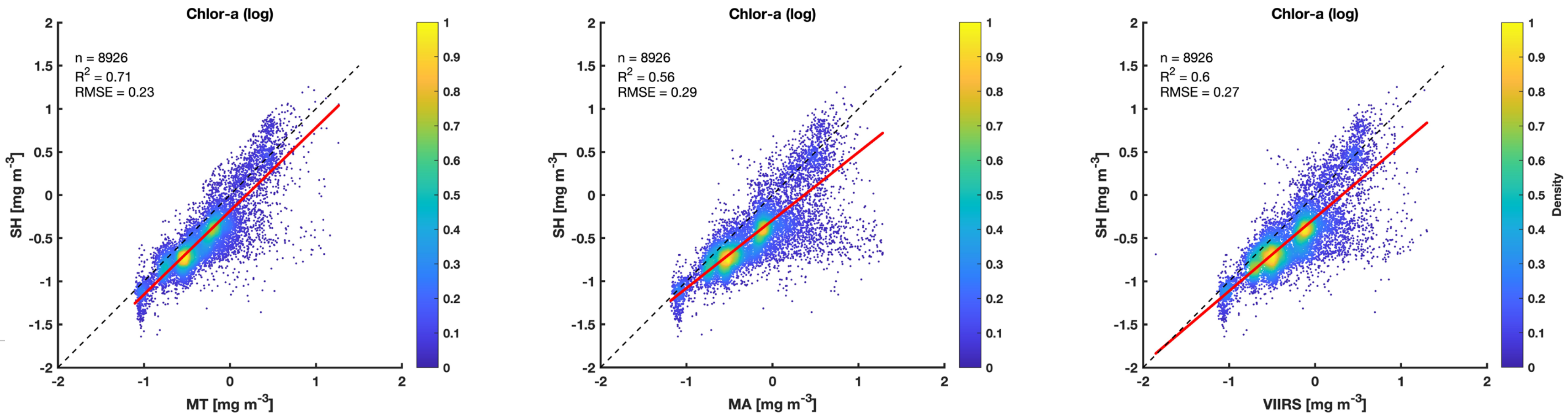
Sources of uncertainty

TOA
- 90% of signal is from the atmosphere

Rrs
- Atmospheric correction algorithms
- Aerosol models

Chl-a
- Algorithm is sensor-dependent
- Not regionally tuned (global)

Chlorophyll a



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Masud-Ul- Alam et al., in prep. *"SeaHawk Low-Cost Ocean Color CubeSat Produces High Spatial Resolution and High-Quality Data: A Comparison with NOAA-20 VIIRS, NASA MODIS-Terra and MODIS-Aqua"* (in prep.)

3. Cross-comparison and MOBY

Conclusions and Lessons Learned:

- Difficult to find concurrent imagery for all sensors
- HawkEye performs comparably to other OC sensors
- Time of overpass, Geometry and Atmospheric Correction play an important role
- Very location-dependent
- worse performance in the blue (412nm)band for ALL sensors
- Chlorophyll comparison is similar among sensors

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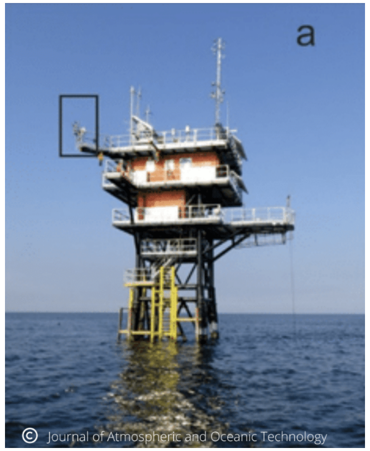
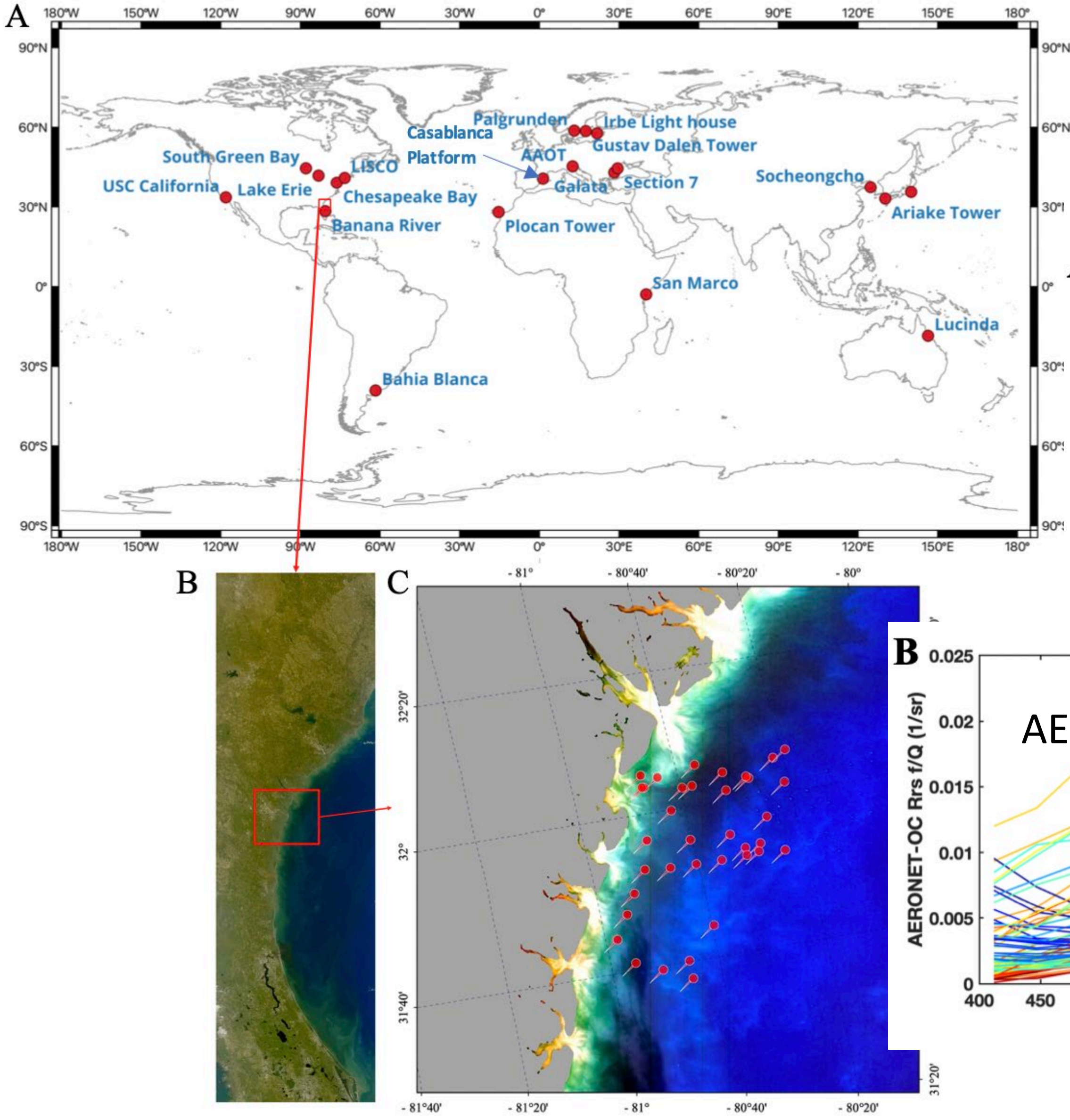
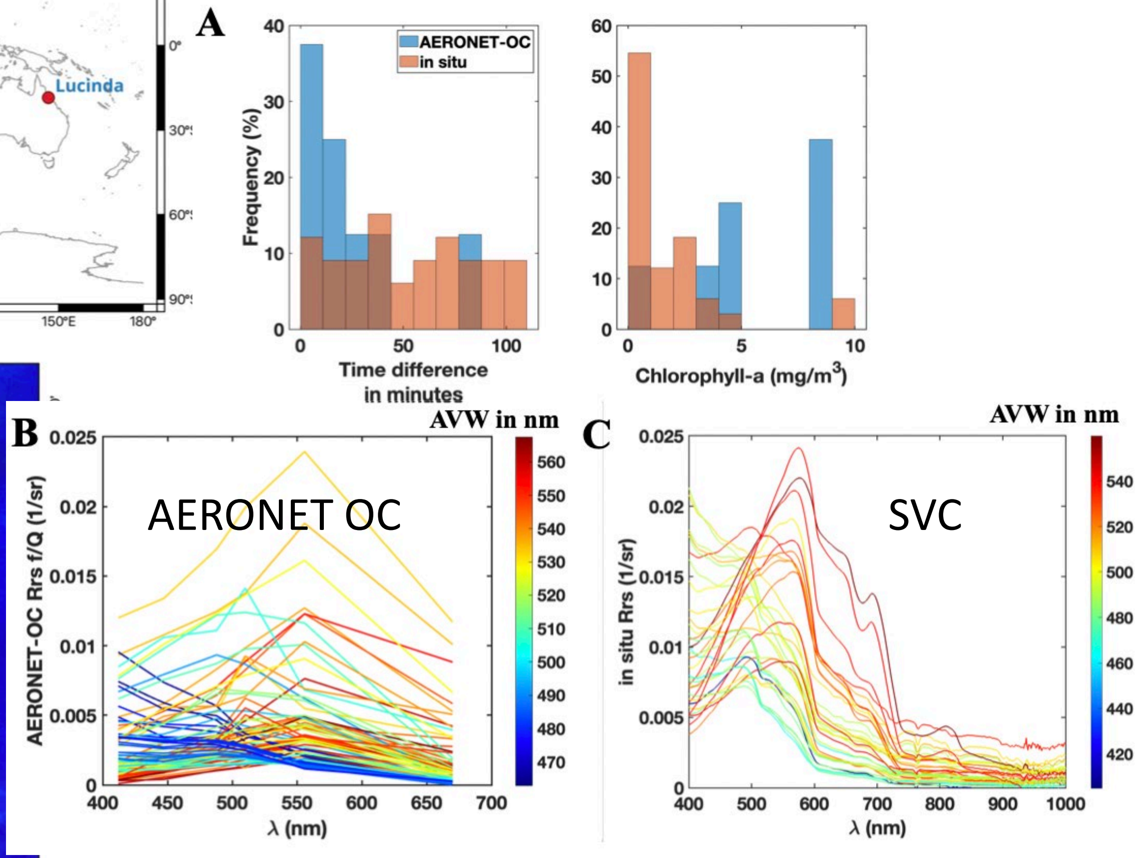
Masud-Ul-Alam, Rivero-Calle et al. (in prep.)

4. AERONET OC + SVC







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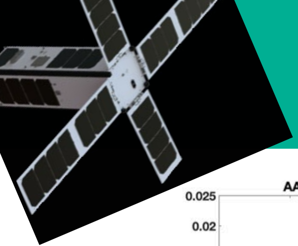
Kolluru, Rivero-Calle et al. (in prep.)

2. AERONET OC :Global Network



AERONET-OC

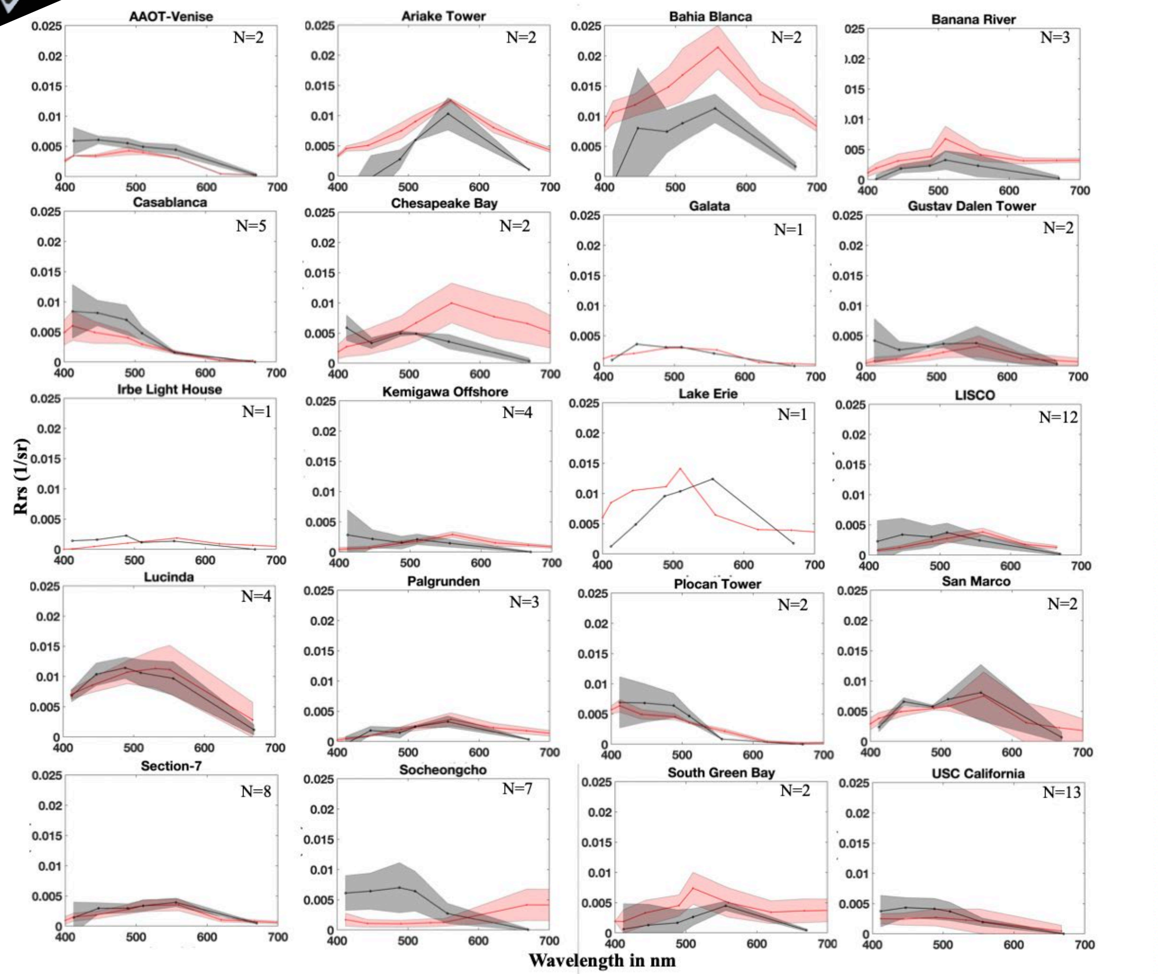


Fig. 3. Comparisons of mean SeaHawk R_{rs} and AERONET-OC R_{rs} (f/Q) data. The variability in the mean spectra of SeaHawk R_{rs} in a black curve with a shaded gray area representing one standard deviation. The equivalent AERONET-OC R_{rs} (f/Q) are shown in red. Galata, Irbe Light ; and Lake Erie have only one match-up point, hence shaded area was absent.

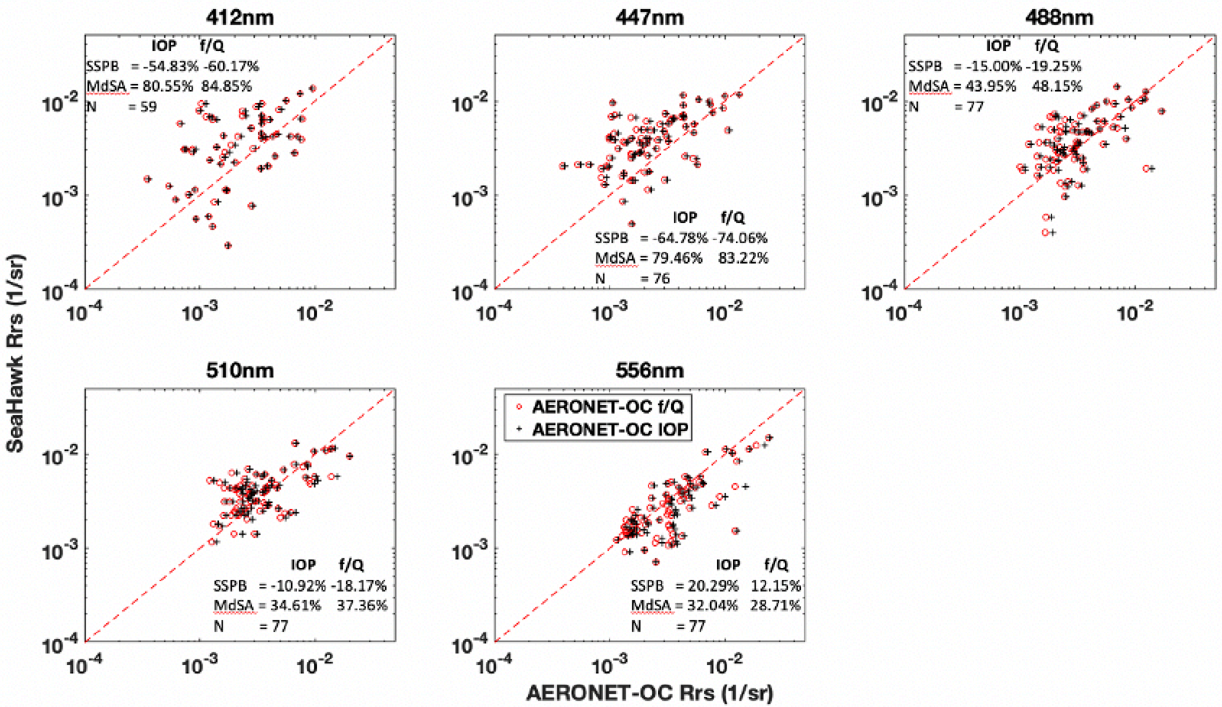


Fig. 4. Scatter plots between SeaHawk Rrs and AERONET-OC Rrs (f/Q and IOP) at five wavelengths for 77 matchups over the twenty locations. Statistics presented in each subplot correspond to SeaHawk Rrs and AERONET-OC IOP Rrs (f/Q and IOP).

Kolluru, Rivero-Calle et al. (in prep.)

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4. AERONET-OC: Georgia

Rivero Lab

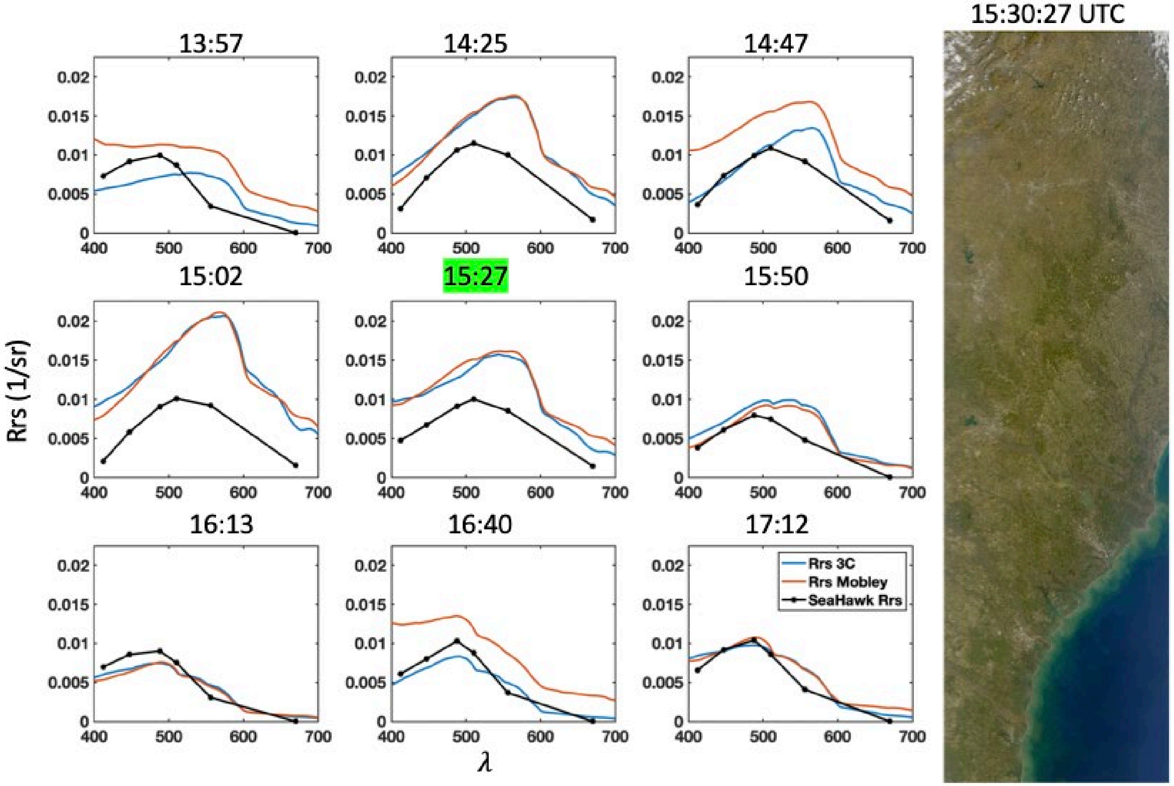

Fig. 5. Comparison of SeaHawk R_{rs} and hyperspectral *in situ* R_{rs} data processed with Mobley's and 3C method acquired on 06 Feb 2023 in coastal Georgia, USA. The title of each subplot indicates the local time in Hours and Minutes. The highlighted time was closest to SeaHawk (true color image on the right) overpass, i.e., at 5:30 local time.

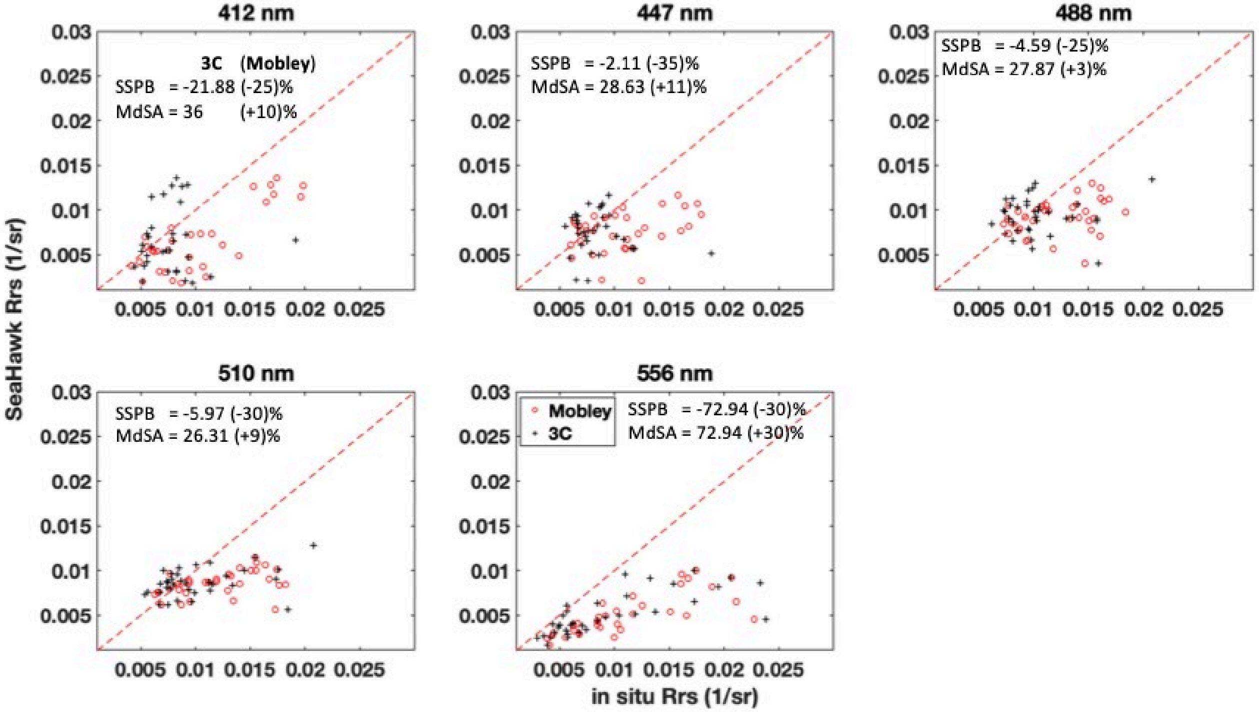

Fig. 6. Scatter plots between SeaHawk R_{rs} (L2gen) and *in situ* R_{rs} (Mobley) at five wavelengths for 34 matchups.

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Kolluru, Rivero-Calle et al. (in prep.)

4. AERONET-OC

Conclusions and Lessons Learned:

- AERONET-OC was very useful!
- SeaHawk performed well
- Disagreement between sensors
- Blue region issue
- Atmospheric correction is a big issue
- Complex waters are difficult to work with

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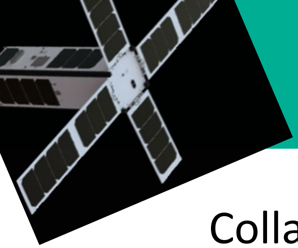
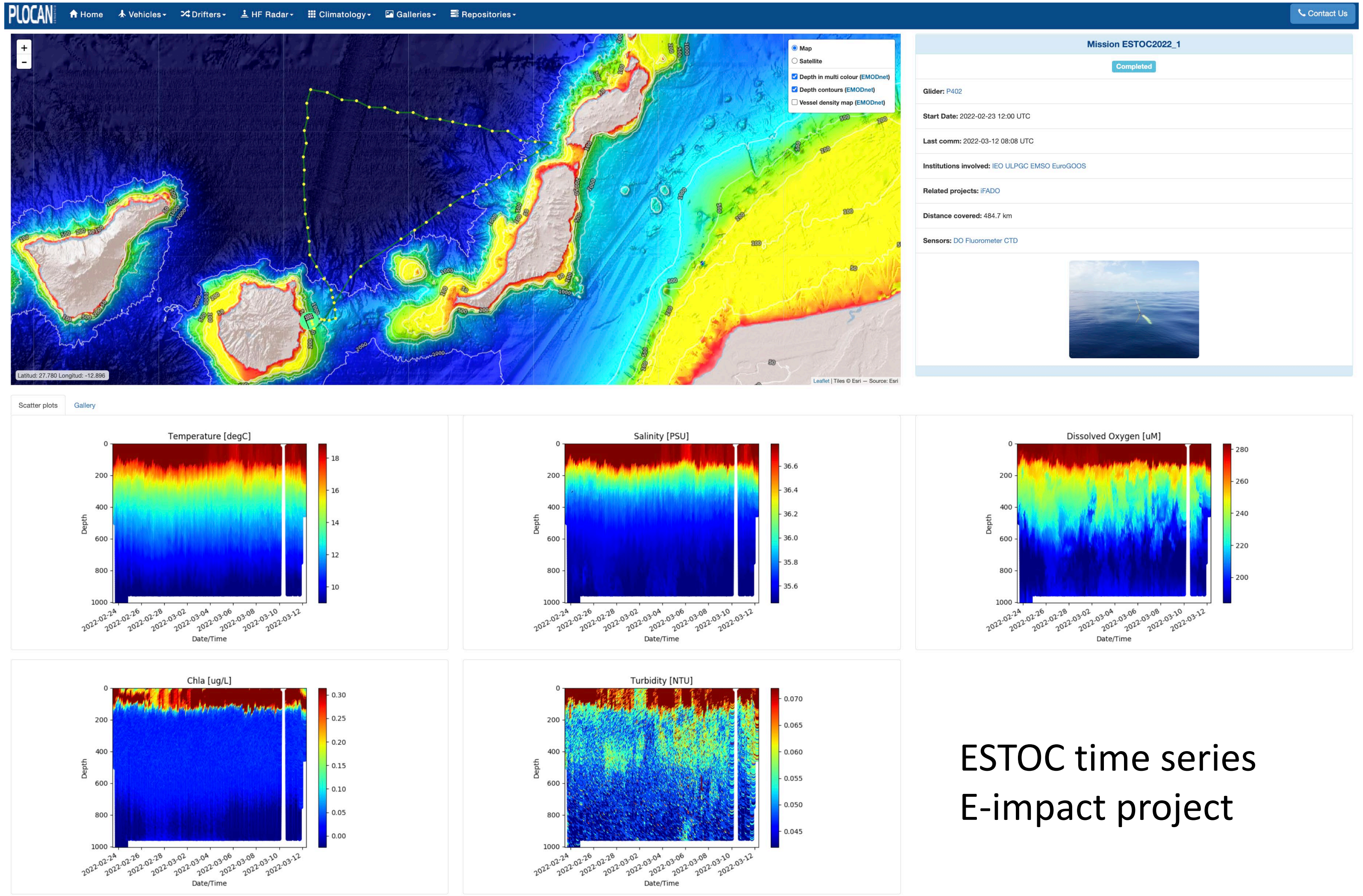
Kolluru & Rivero-Calle (in prep.)



5. PLOCAN GLIDERS

Collaboration with PLOCAN

- Compare chl-a from gliders with SeaHawk + OLCI
- Explore the vertical component using gliders



Plataforma Oceánica de Canarias

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ESTOC time series

E-impact project

Lowin , Rivero-Calle, et al. (in prep.)

Future Plans

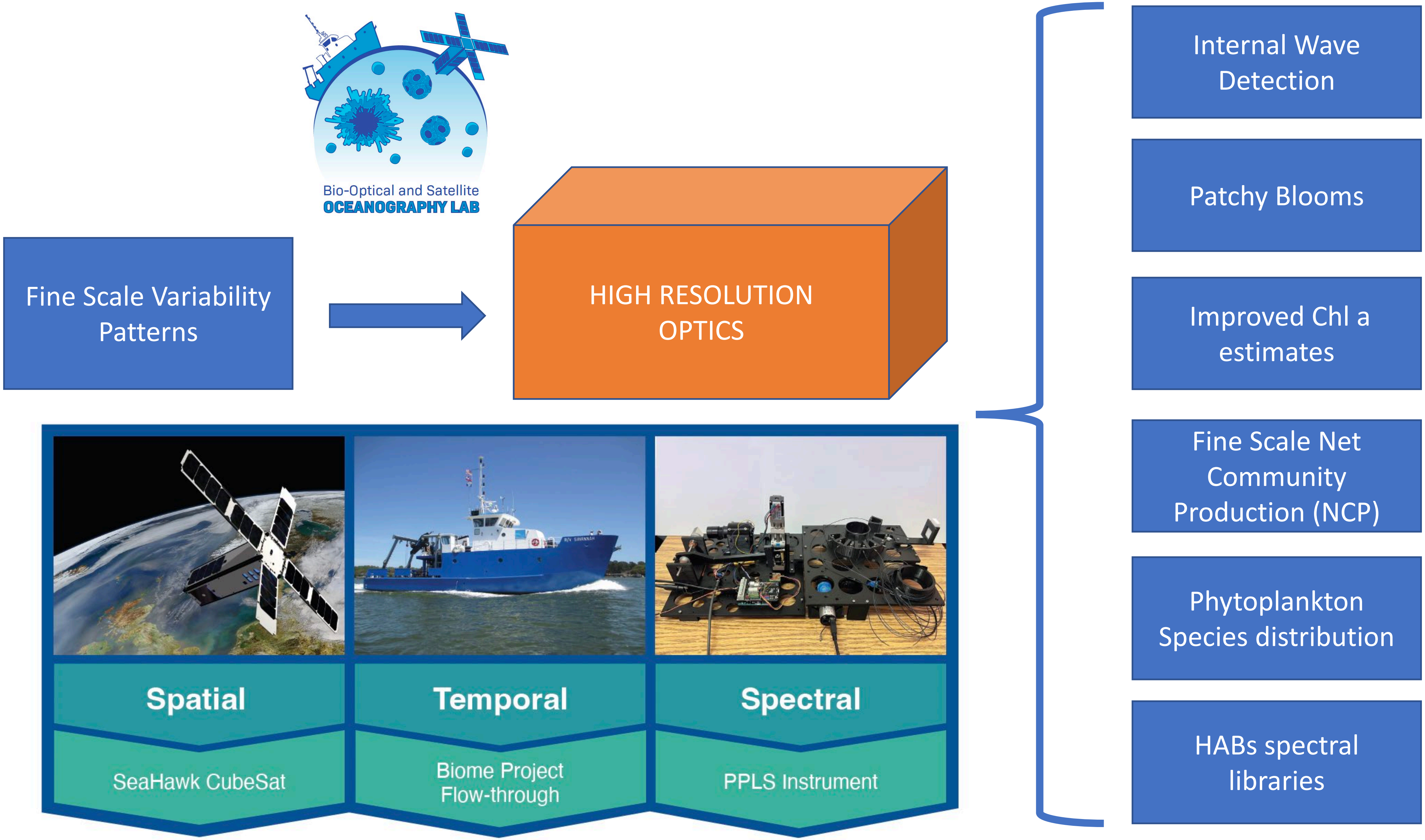
Trios G2 + So-Rad
SVC + Hyperpro II

Using the RV Savannah as ship of opportunity

Regional Algorithms for:

- Net Community Production (NCP)

- Total Suspended Sediments (TSS)


Bio-Optical and Satellite
OCEANOGRAPHY LAB
Fine Scale Variability Patterns
HIGH RESOLUTION OPTICS
Spatial
SeaHawk CubeSat
Temporal
Biome Project Flow-through
Spectral
PPLS Instrument
Internal Wave Detection
Patchy Blooms
Improved Chl a estimates
Fine Scale Net Community Production (NCP)
Phytoplankton Species distribution
HABs spectral libraries

Rivero Lab Instruments

AOPs

TRiOS G2 + SoRAD

SpectraVista Radiometer

Hyperpro II
+T, S,
+ triplets
(bb, chla, PE, PC)

IOPs

AC-S

TRiOS OSCAR

Hyper-bb

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Bio-Optical and Satellite OCEANOGRAPHY LAB

Grazie!

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Skidaway Institute of Oceanography

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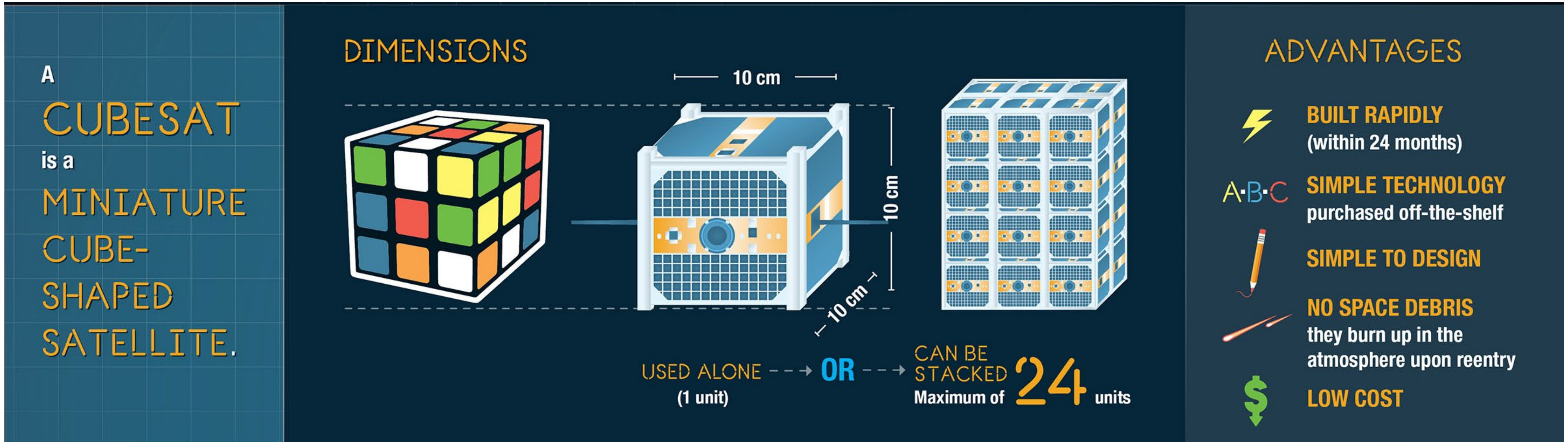
NASA

FULBRIGHT

GEORGIA Space Grant Consortium

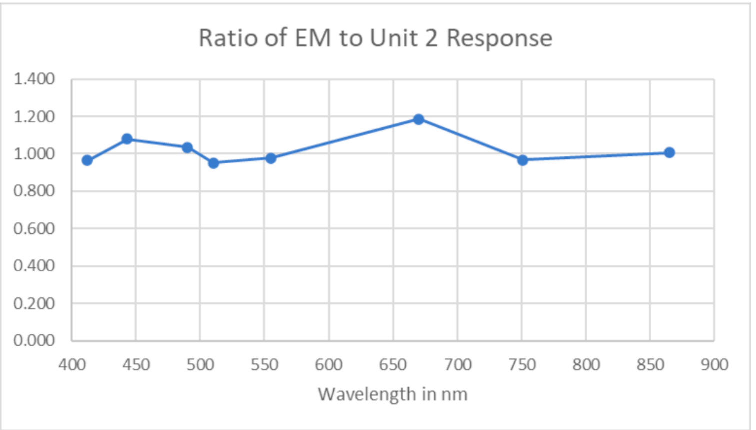

A
CUBESAT
is a
MINIATURE
CUBE-
SHAPED
SATELLITE.
DIMENSIONS
10 cm
10 cm
10 cm
USED ALONE
(1 unit)
OR
CAN BE
STACKED
Maximum of 24 units
ADVANTAGES
BUILT RAPIDLY
(within 24 months)
A·B·C
SIMPLE TECHNOLOGY
purchased off-the-shelf
SIMPLE TO DESIGN
NO SPACE DEBRIS
they burn up in the
atmosphere upon reentry
LOW COST

Lunar calibrations

Figure Two: Image of Moon from Lunar Calibration in Orbit using Unit 2

Figure Three: Image from Ground-Based Lunar Calibration using EM

Figure One: Relative Sensitivity of EM unit to Unit 2



Using that data, in Table One I show the signal counts (ADU) that were expected from the orbital collection, assuming an identical moon phase and such as in 2017.

Table One: Expected Signal Counts

Lunar Cal Band	Exposure Time	EM Total Counts per ms at 35 C	EM Peak Pixel Counts/ms	Ratio, EM/Unit 2	Unit 2 Peak Pixel Counts/ms	Expected Peak Counts	Expected Total Counts
1	4.1	1.308E+06	1647	0.965	1707	6999	5.557E+06
2	4.1	2.112E+06	2659	1.080	2463	10097	8.017E+06
3	4.1	3.595E+06	4528	1.035	4373	17929	1.424E+07
4	4.1	3.487E+06	4392	0.951	4617	18931	1.503E+07
5	3.4	4.310E+06	5428	0.979	5547	18858	1.497E+07
6	3.4	4.722E+06	5947	1.185	5017	17057	1.354E+07
7	4.1	2.363E+06	2976	0.968	3074	12602	1.001E+07
8	4.1	3.174E+06	3998	1.007	3970	16275	1.292E+07

In the image of 4/14/2022 the moon was quite a bit away from full, with a phase angle near 36 degrees, in order to simplify the pitch maneuver in orbit. Figure Two shows the resulting image from Band 4, and Figure Three the ground-based image.

Figure Two: Image of Moon from Lunar Calibration in Orbit using Unit 2

Figure Three: Image from Ground-Based Lunar Calibration using EM

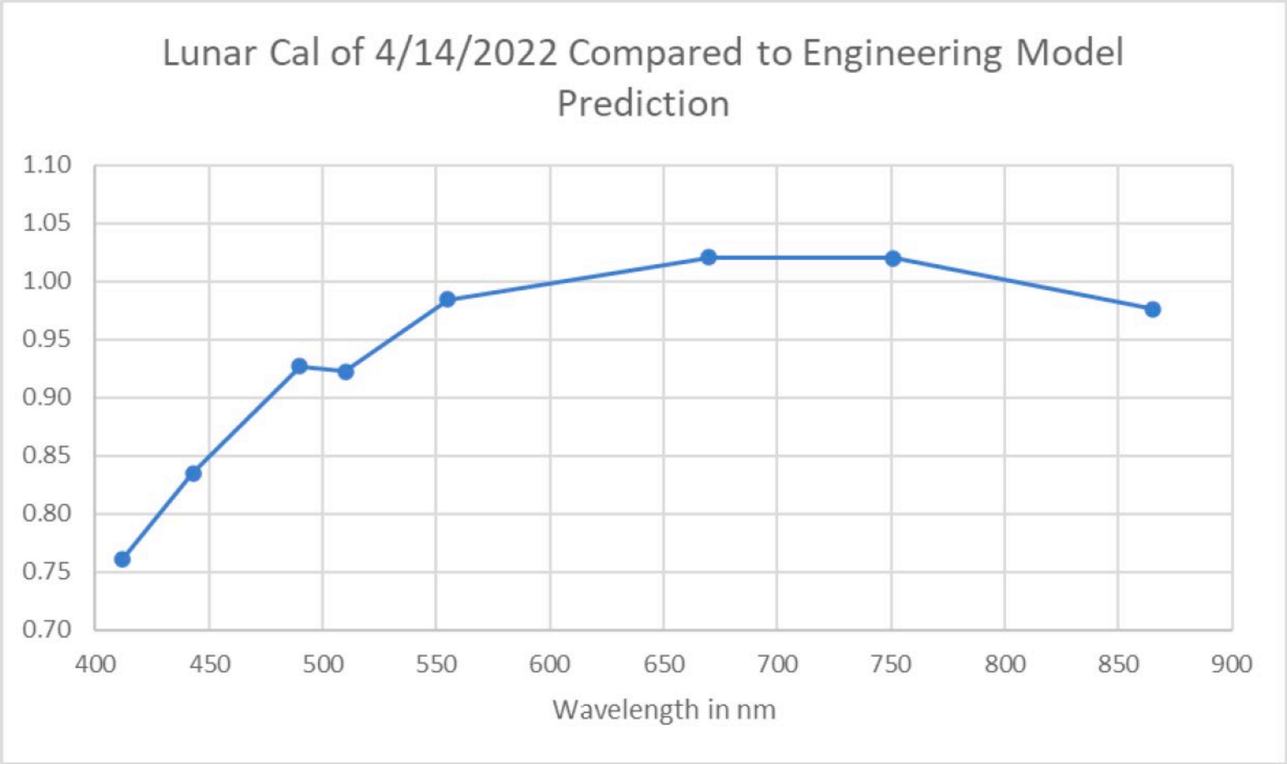
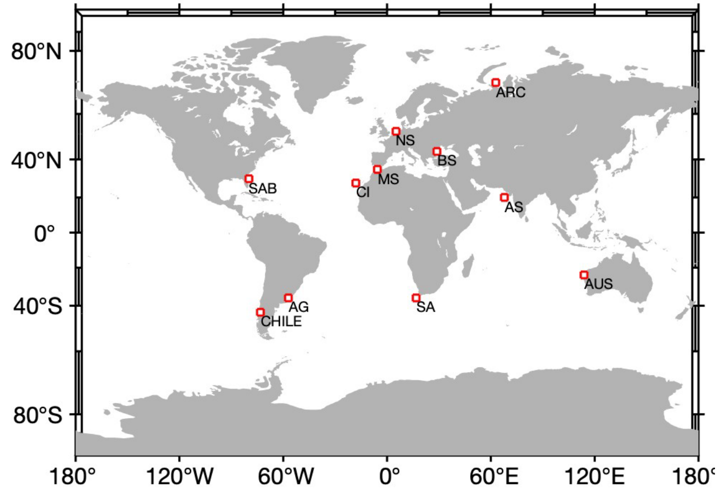


Table One: Preliminary Instrument Degradation Model

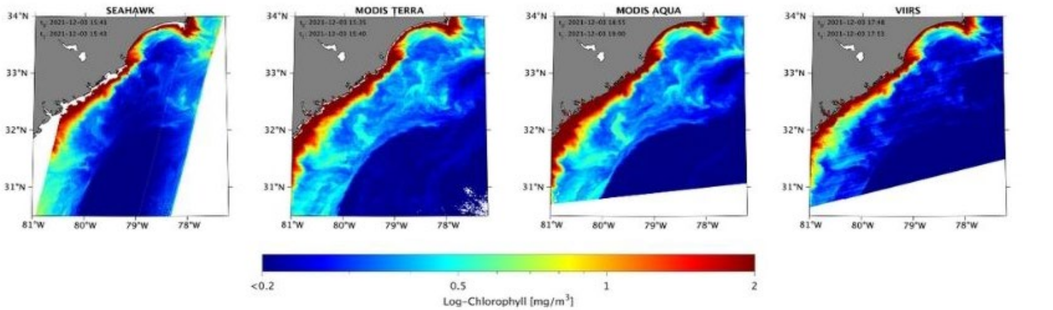
Band	Wavelength	Degradation
1	413	0.780
2	447	0.842
3	488	0.935
4	510	0.924
5	557	0.964
6	670	1.000
7	751	0.991
8	866	0.959

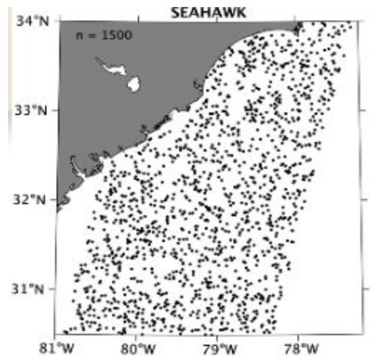
1. Cross-comparison study



First SeaHawk performance study
11 locations + MOBY in situ data

4 sensors: HawkEye, Terra, Aqua, VIIRS





5 bands
3 processing levels
5 statistical methods:

- R^2
- bias,
- RMSE,
- d-index
- CCC

Top of the Atmosphere: *d-index*

Location	MODIS-Terra	MODIS-Aqua	VIIRS
Rhot-412nm	0.8049	0.5351	0.6049
Rhot-447nm	0.8049	0.5351	0.6049
Rhot-488nm	0.8049	0.5351	0.6049
Rhot-555nm	0.7799	0.5301	0.5833
Rhot-670nm	0.8049	0.5351	0.6049

Rrs *d-index*

Bands	MT	MA	VIIRS
Rrs-412nm	0.57	0.53	0.58
Rrs-447nm	0.63	0.55	0.56
Rrs-488nm	0.70	0.62	0.60
Rrs-555nm	0.68	0.64	0.63
Rrs-670nm	0.46	0.41	0.43

Chlorophyll a

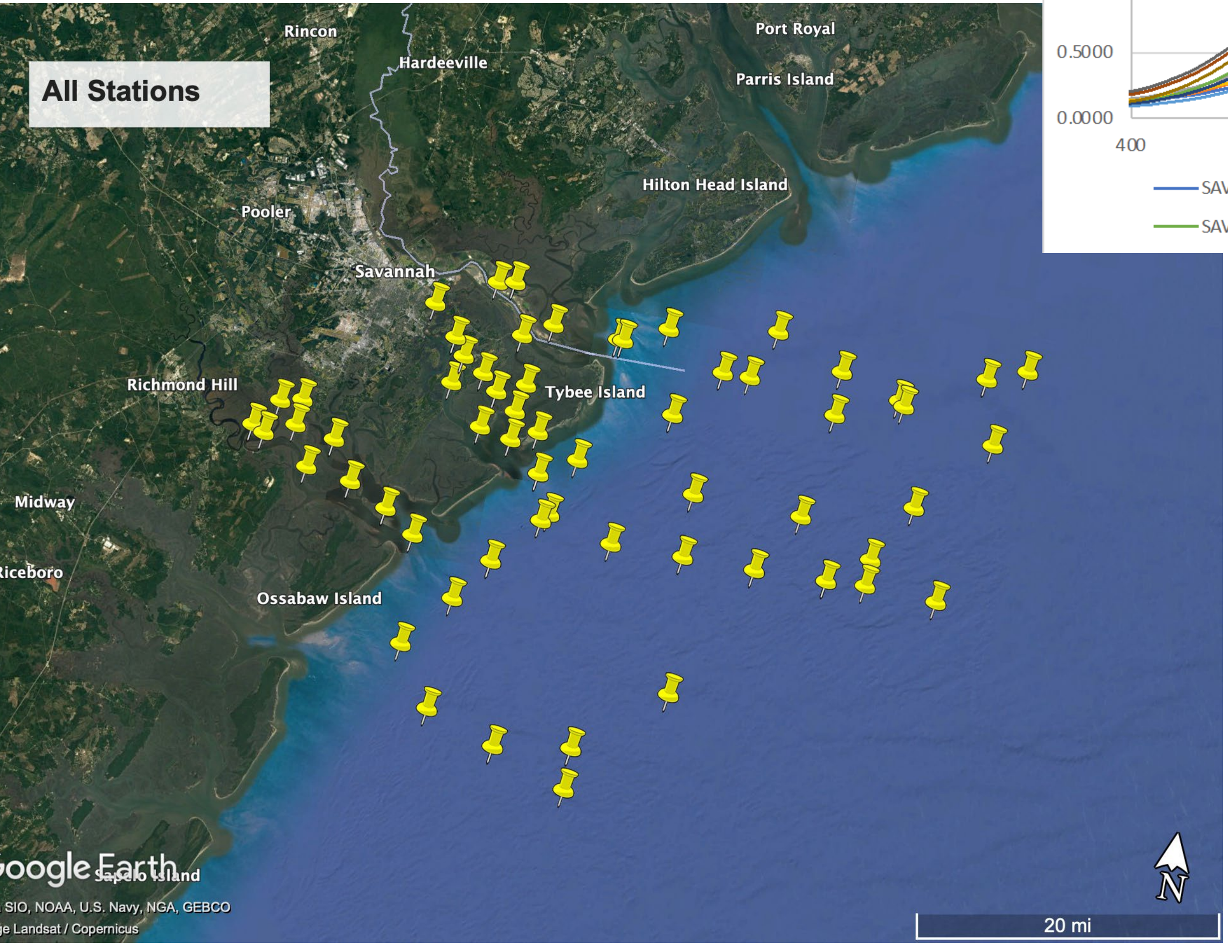
Stats	MT	MA	VIIRS
RMSE	8.73	4.72	5.02
d-index	0.31	0.4	0.33
CCC	0.59	0.77	0.58
Bias	-0.32	-0.75	-0.11
R-sq	0.38	0.42	0.4

Legend	
	Min
	Max

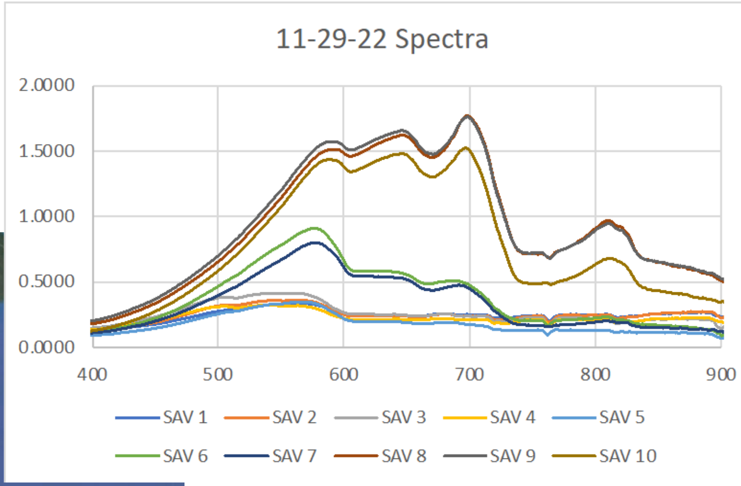
Masud-Ul- Alam et al., in prep. *"SeaHawk Low-Cost Ocean Color CubeSat Produces High Spatial Resolution and High-Quality Data: A Comparison with NOAA-20 VIIRS, NASA MODIS-Terra and MODIS-Aqua"*

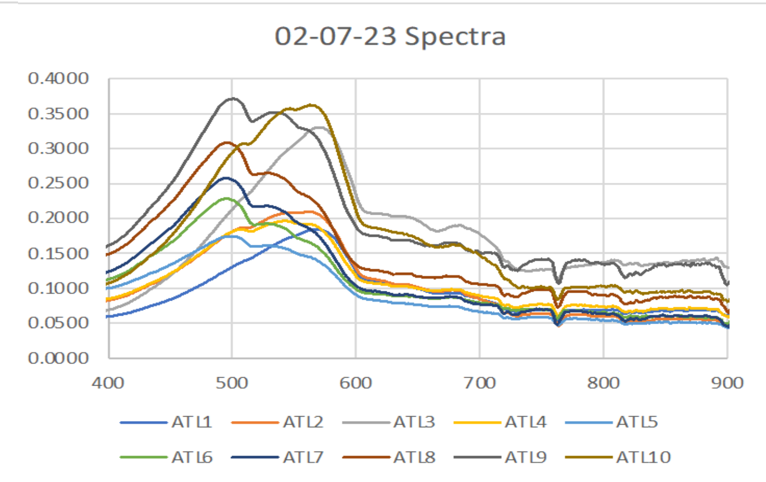
Fieldwork in SAB

8 out of 24 completed outings
61 matchups
Collecting data on radiometry and water quality
Goal: build regional algorithms



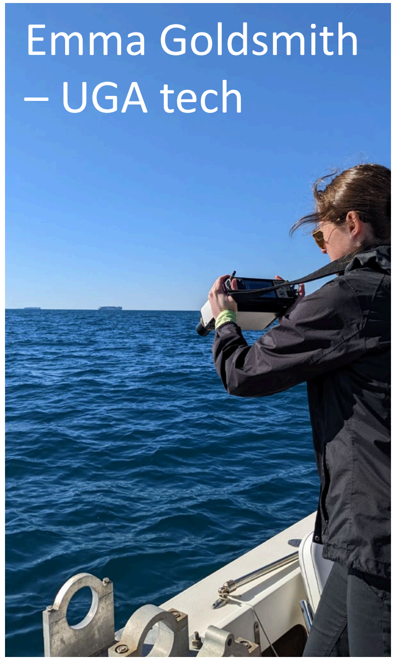
Remote Sensing Reflectance (Rrs)



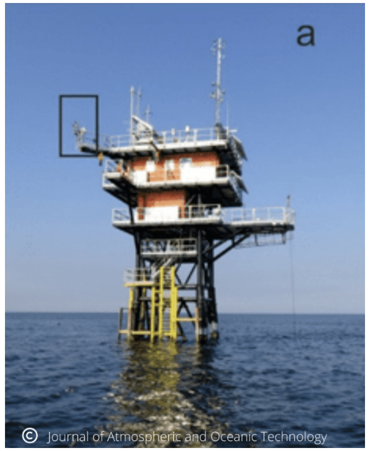


Chlorophyll a, suspended sediments and colored dissolved organic matter

	Chl-a	TSS	CDOM
Min	0.15	13.84	0.027
Max	9.65	64.82	1.52
Mean	2.93	28.43	0.43
Sd	2.39	9.53	0.35
CV	0.816	0.335	0.797



2. AERONET OC + SVC



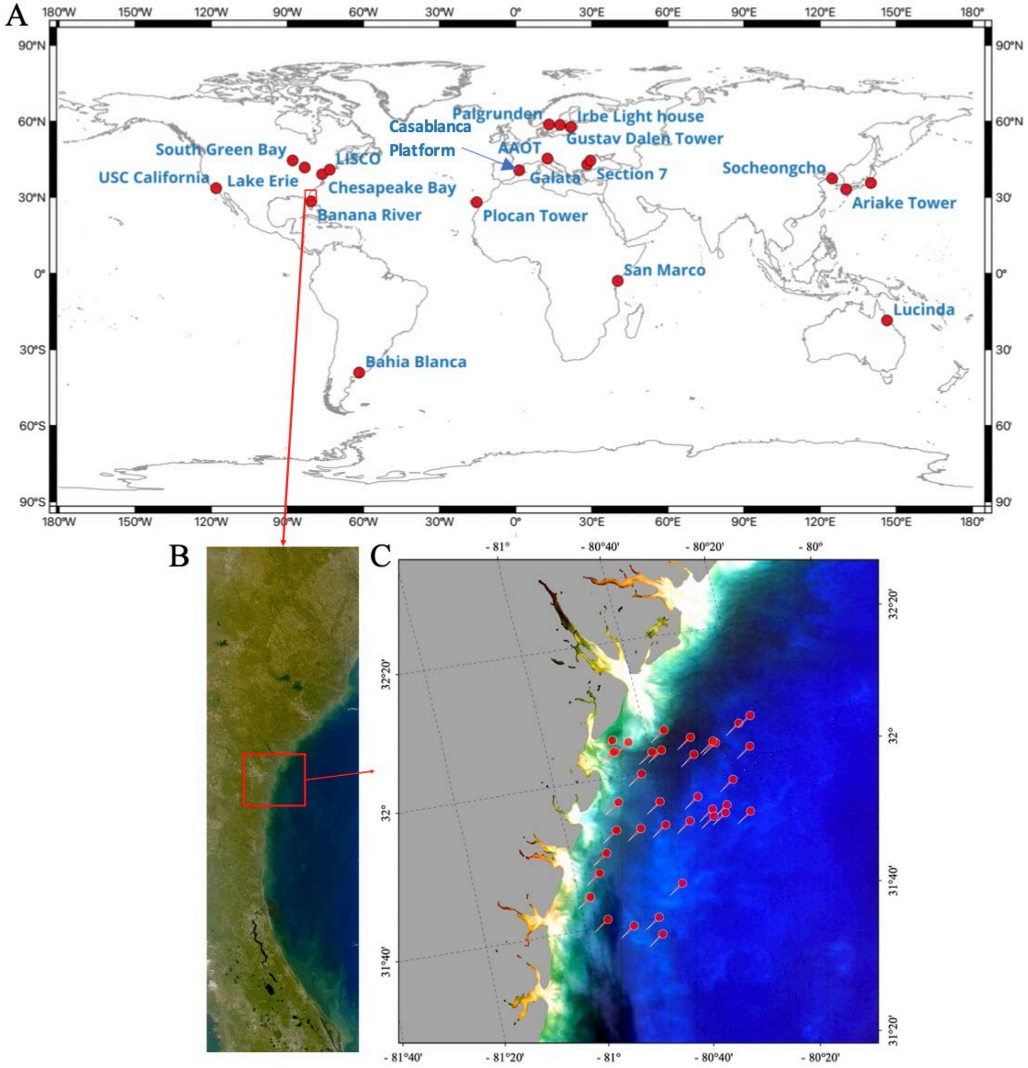


Fig. 1A. Location of the twenty AERONET-OC sites used in this study, **B**. SeaHawk over over Georgia coast, 29 November 2022, **C**. Sampling locations (N=34) concurrent with SeaHawk overpass over Georgia coast, USA.

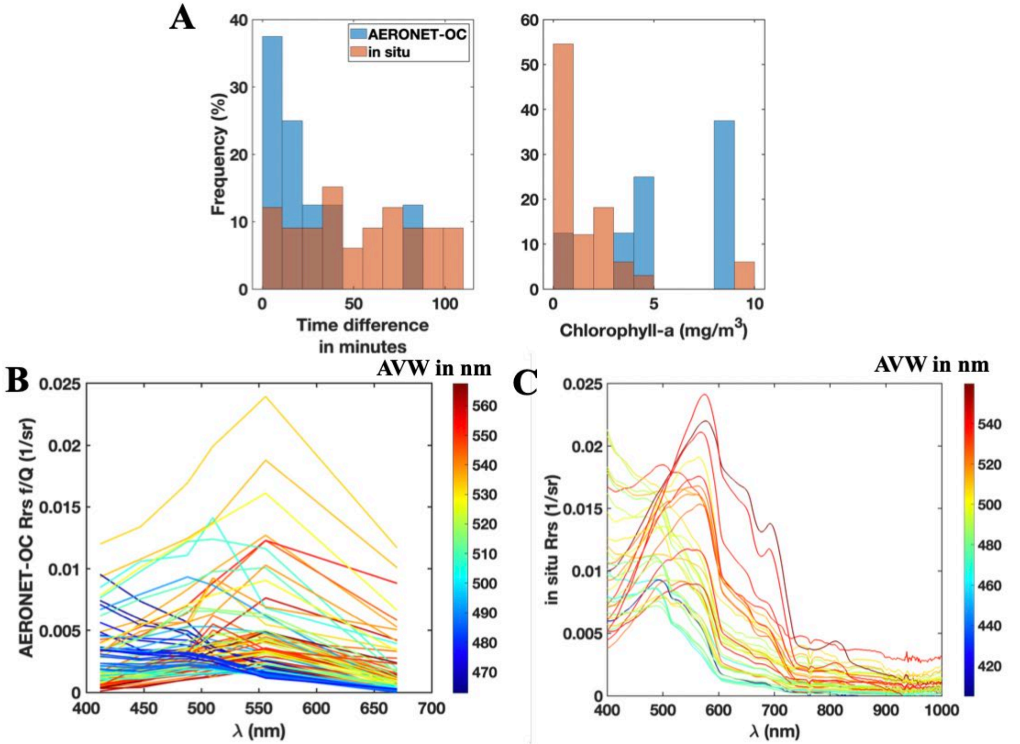


Fig. 2A. Ancillary information from twenty AERONET-OC locations and *in situ* location Georgia coastal waters, USA; Time difference in minutes indicates the difference betwee *situ*/AERONET-OC measurements and SeaHawk acquisition time. **B**. $R_{rs}(\lambda)$ AERONET (f/Q) spectra used in the study (N=78) with colors indicating Apparent Visible Wavelen (AVW in nm) **C**. Above-water *in situ* hyperspectral R_{rs} spectra from Georgia coastal wa

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Kolluru & Rivero-Calle (in prep.)

3. Cross-comparison study

Sources of uncertainty

- **TOA**
  - 90% of signal is from the atmosphere
- **Rrs**
  - Atmospheric correction algorithms
  - Aerosol models
- **Chl-a**
  - Algorithm is sensor-dependent
  - Not regionally tuned (global)

Results:

Legend	
Yellow	> 20%
Light blue	20% or less

Top of the atmosphere (TOA) reflectance (% difference)

Bands	MT-SH	MA-SH	VIIRS-SH	MT-MA	MT-VIIRS	MA-VIIRS
412 nm	-5	0	-5	5	0	[illegible]
447 nm	-4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
488 nm	-5	0	-4	5	0	[illegible]
555 nm	-7	-2	-7	5	0	[illegible]
670 nm	-18	-3	-4	15	14	200

Less than 7%

Remote sensing reflectance (Rrs) (% difference)

Bands	MT-SH	MA-SH	VIIRS-SH	MT-MA	MT-VIIRS	MA-VIIRS
412 nm	66	60	20	-6	-47	-40
447 nm	[illegible]	[illegible]	[illegible]	-7	-2	5
488 nm	8	2	3	-7	-6	[illegible]
555 nm	-5	10	7	15	12	-3
670 nm	117	131	118	23	1	-21

17% or less

Legend: Min, Max

Top of the Atmosphere: *d-index*

Location	MODIS-Terra	MODIS-Aqua	VIIRS
Rhot-412nm	0.8049	0.5351	0.6049
Rhot-447nm	0.8049	0.5351	0.6049
Rhot-488nm	0.8049	0.5351	0.6049
Rhot-555nm	0.7799	0.5301	0.5833
Rhot-670nm	0.8049	0.5351	0.6049

Rrs *d-index*

Bands	MT	MA	VIIRS
Rrs-412nm	0.57	0.53	0.58
[illegible]	[illegible]	[illegible]	0.56
Rrs-488nm	[illegible]	[illegible]	0.60
Rrs-555nm	0.68	0.64	0.63
[illegible]	[illegible]	[illegible]	0.43

			VIIRS
[illegible]	[illegible]	[illegible]	.02
[illegible]	[illegible]	[illegible]	.33
[illegible]	[illegible]	[illegible]	.58
Bias	-0.32	-0.75	-0.11
R-sq	0.38	0.42	0.4

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Masud ... Alam et al., in prep: "Seahawk Low Cost Ocean Color C... *Produces High Spatial Resolution and High-Quality Data: A Comparison with NOAA-20 VIIRS, NASA MODIS-Terra and MODIS-Aqua"* (in prep.)

2. AERONET OC

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1. Outline