Evaluation of unoccupied aircraft system (UAS) remote sensing reflectance retrievals for water quality monitoring in coastal waters

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FRM4DRONES
fiducial reference measurements for water using drones

SSAI

Outline

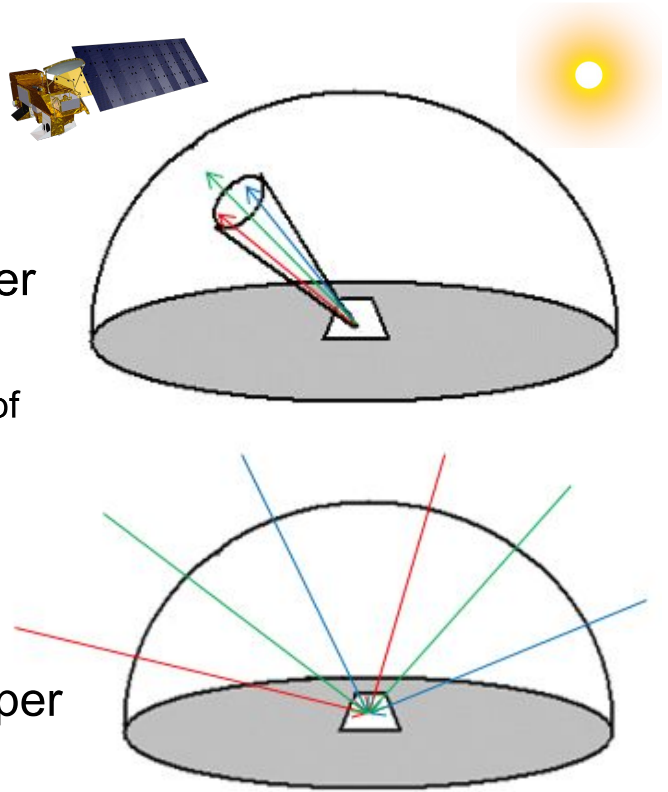
- Theory on above-water remote sensing
- Methods to remove surface reflected light
  - Windle & Silsbe, 2021
- DroneWQ Python package
- Future directions

Radiometric measurements

- Remote sensors measure **radiance**: radiant flux per unit of solid angle
  - Typical units: W m^{-2} sr^{-1}, where sr is steradian, a measure of a solid angle

- Radiance is dependent on the illumination of observed area, or the hemispherical downwelling solar **irradiance:** radiant flux incident on a surface per unit area
  - Typical units: W m^{-2}

$$surface\,reflectance\,(sr^{-1}) \approx \frac{radiance}{irradiance}$$



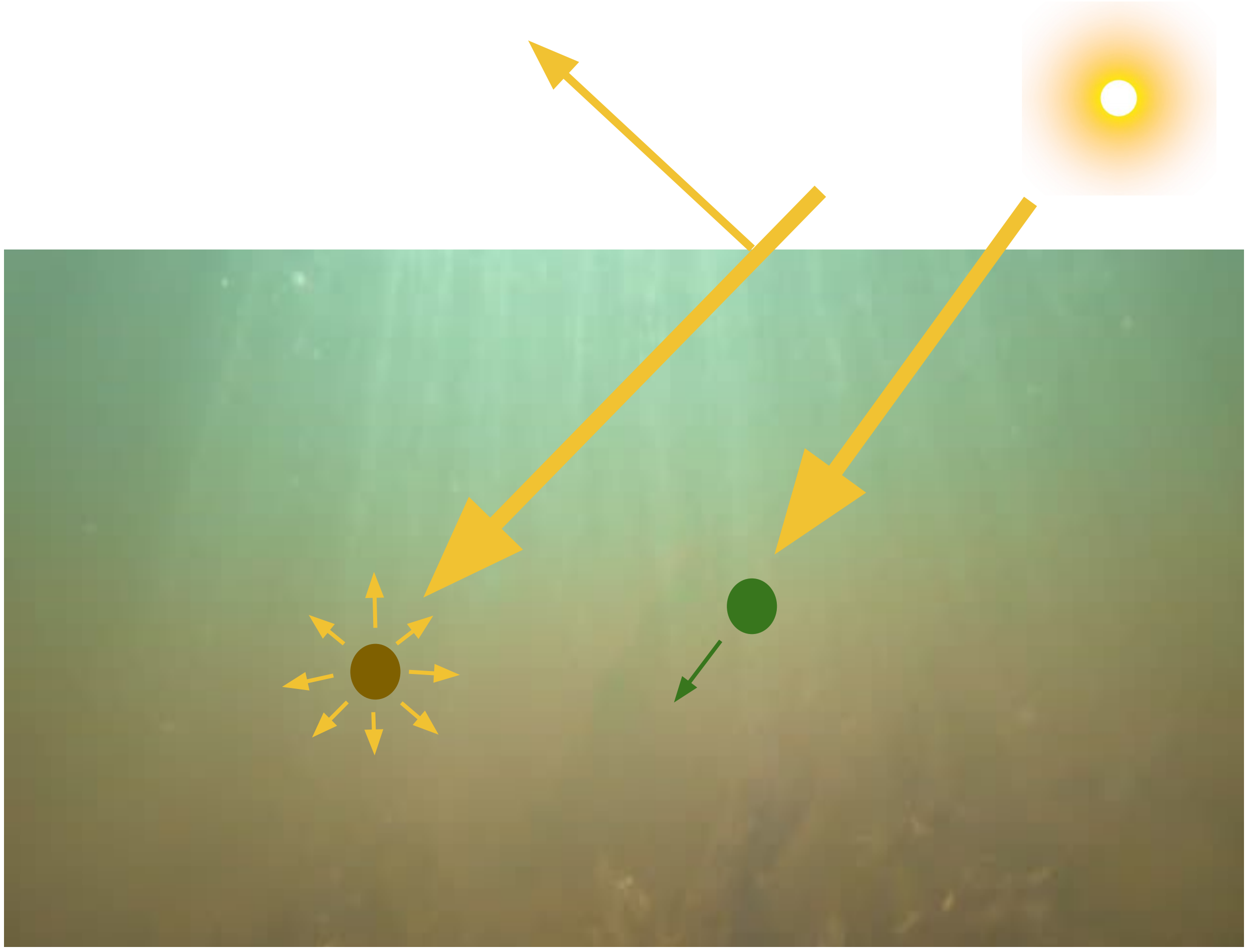
Credit: Anders Knudby, CC BY 4.0.

Light in water

Two important processes determine fate of light in water:

1) **Absorption**: light is taken up by molecules or optically active constituents

2) **Scattering**: light is redirected with no loss

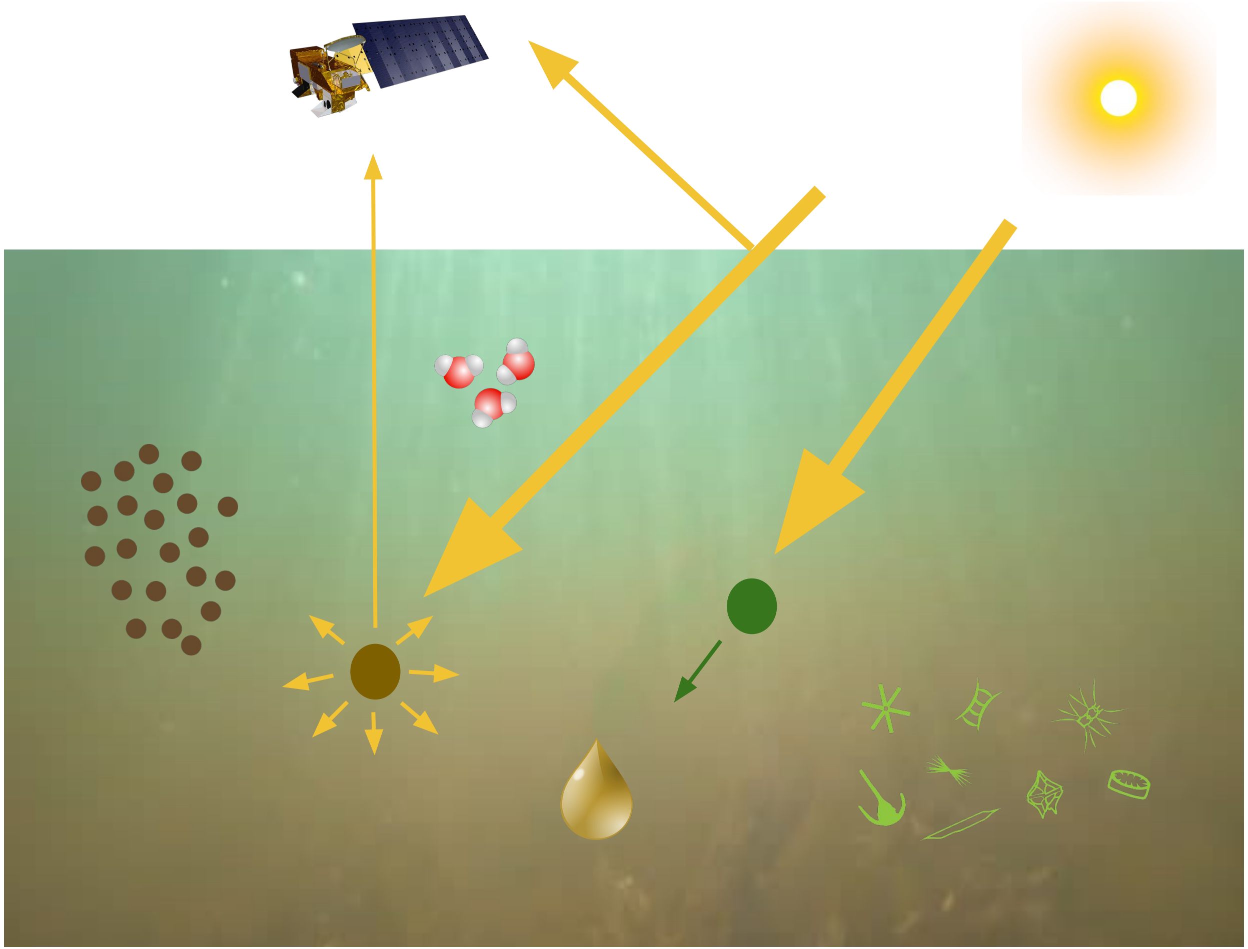


Light in water

Two important processes determine fate of light in water:

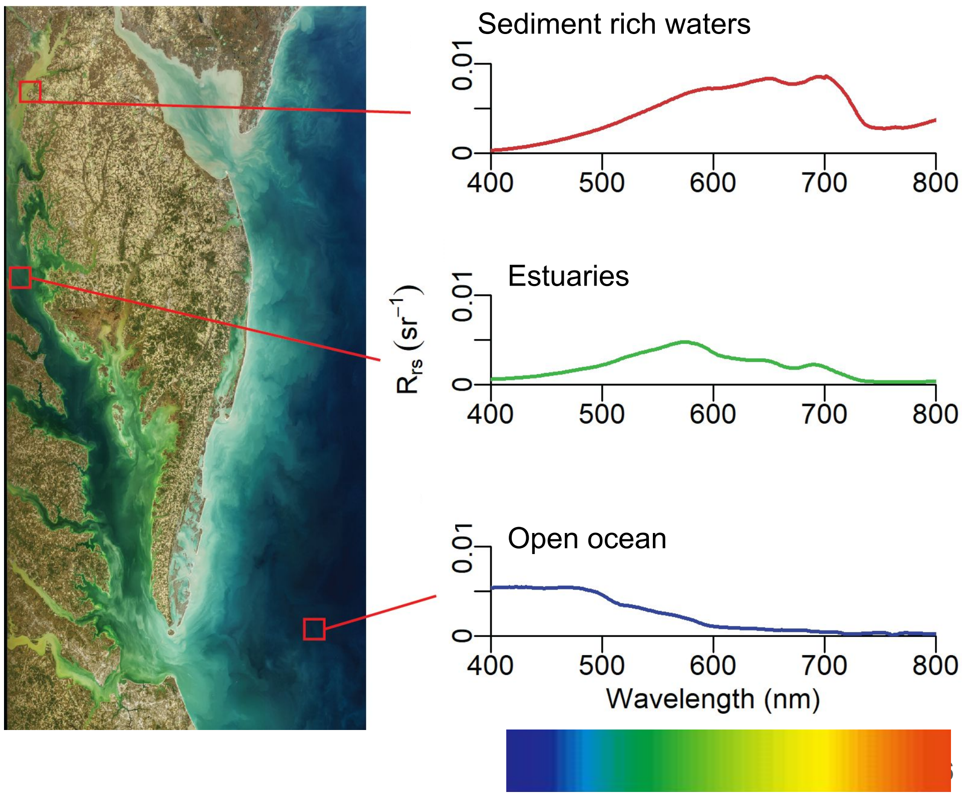
1) **Absorption**: light is taken up by molecules or water matter

2) **Scattering**: light is redirected with no loss



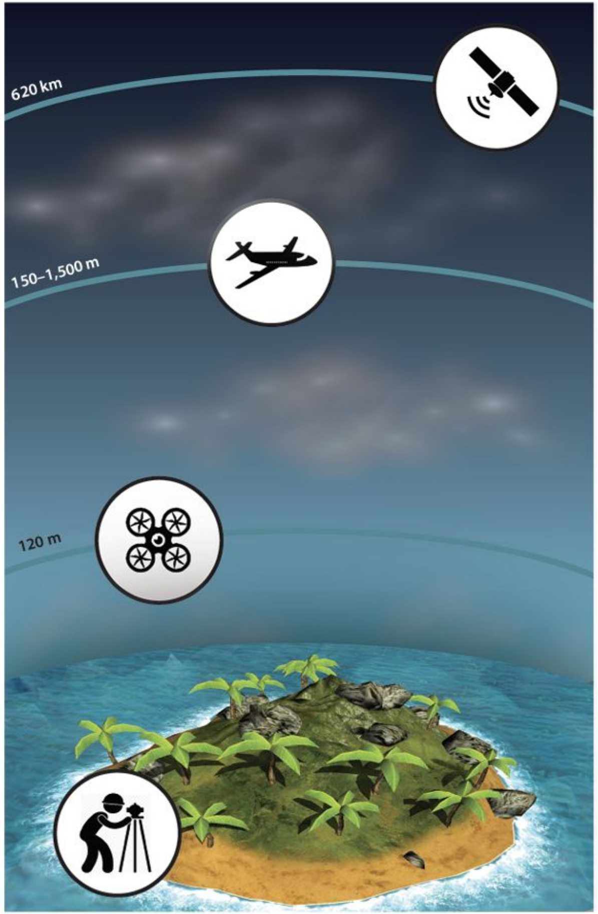
Remote sensing reflectance (R_{rs})

Absorption and backscattering of optically active constituents determines color of water -> can be used to infer what's in the water



UAS fill a gap

Photo credit: Matt Pluta, ShoreRivers

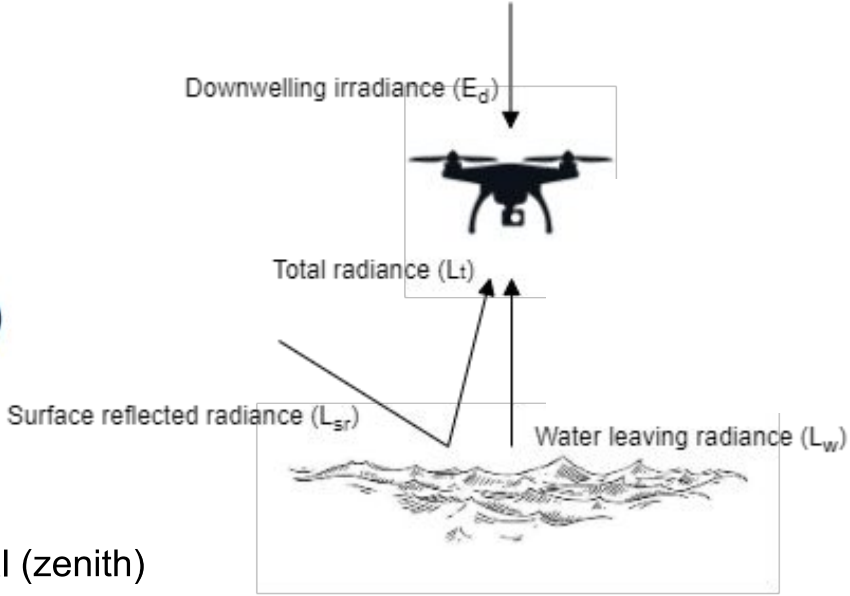


Johnston, 2019

UAS seek to measure remote sensing reflectance (R_{rs})

$$R_{rs}(\theta, \Phi, \lambda) = \frac{L_W(\theta, \Phi, \lambda)}{E_d(\lambda)}$$

$$L_T(\theta, \Phi, \lambda) = L_W(\theta, \Phi, \lambda) + L_{SR}(\theta, \Phi, \lambda)$$



θ is sensor viewing angle between the sun and the vertical (zenith)

ϕ is the angular direction relative to the sun (azimuth)

λ represents wavelength

Research motivation and question

M: UAS equipped with optical sensors offer on-demand, highly resolved data not amenable to satellite remote sensing. Aquatic UAS applications are in their infancy, and the removal of light reflected directly off the skin of water has received little attention in the literature.

Q: *How can sun glint and surface reflected light be removed from UAS imagery to obtain accurate water leaving radiance?*

Reference	UAS sensor(s)	Radiometric quantity	Removal of L_{SR}?	WQ parameter(s)
Zeng et al. (2017)	Ocean optics STS-VIS spectrometers (hyperspectral)	R_{UAS}	No	Chl *a*, CDOM, turbidity
Shang Z. et al. (2017)	AvaSpec-dual spectroradiometers (hyperspectral)	R_{rs}	Yes	Chl *a*
Su, (2017)	Canon powershot S110 RGB and NIR sensors	R_{UAS}	Yes	Chl *a*, secchi disk depth, turbidity
Choo et al. (2018)	MicaSense RedEdge and DLS (multispectral)	R_{UAS}	No	Chl *a*
Baek et al. (2019)	MicaSense RedEdge and DLS (multispectral)	R_{rs}	Yes	Chl *a*
Becker et al. (2019)	Ocean optics STS-VIS spectrometers (hyperspectral)	R_{UAS}	No	Cyanobacteria index, chl *a* TSS
Arango and Nairn. (2019)	MicaSense RedEdge and DLS (multispectral)	R_{UAS}	No	Secchi disk depth, chl *a*, TSS, TN, TP
Olivetti et al. (2020)	Parrot sequoia (multispectral)	R_{UAS}	No	TSS
McEliece et al. (2020)	Sentera multispectral sensor (4 visible bands)	R_{UAS}	No	Chl *a*, turbidity
Kim et al. (2020)	MicaSense RedEdge-M and DLS (multispectral)	R_{rs}	Yes	Chl *a* (but not focus of paper)
Castro et al. (2020)	MicaSense RedEdge and DLS (multispectral)	R_{rs}	No	Chl *a*
O'Shea et al. (2020)	Resonon Pika L spectrometer (hyperspectral) *deployed on a tower, not UAS	R_{rs}	Yes	Chl *a*

Windle & Silsbe, 2021

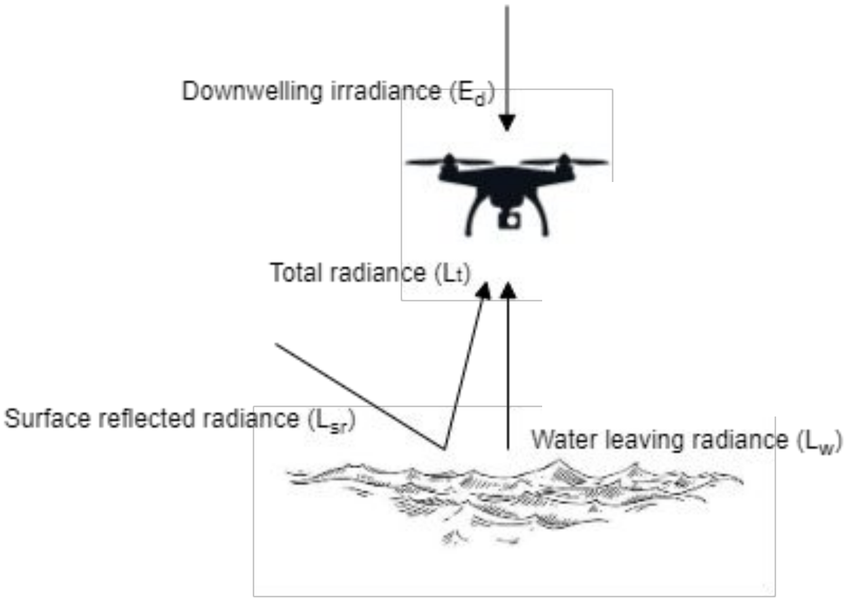
We want…

$$R_{rs}(\theta, \Phi, \lambda) = \frac{L_W(\theta, \Phi, \lambda)}{E_d(\lambda)}$$

But, a UAS measures L_T…

$$L_T(\theta, \Phi, \lambda) = L_W(\theta, \Phi, \lambda) + L_{SR}(\theta, \Phi, \lambda)$$

How do we account for L_{SR}?



Modelling surface reflectance radiance (L_{SR})

Estimation of the remote-sensing reflectance from above-surface measurements

Curtis D. Mobley

APPLIED OPTICS / Vol. 38, No. 36 / 20 December 1999

"The numerical simulations suggest that a viewing direction of 40 deg from the nadir and 135 deg from the Sun is a reasonable compromise among conflicting requirements. For this viewing direction, a value of ϱ ***= 0.028*** *is acceptable only for wind speeds less than 5 m* s^{-1}*"*

$$L_{SR}(\theta, \Phi, \lambda) = \rho(\theta, \Phi, \lambda) * L_{sky}(\theta, \Phi, \lambda)$$

(effective sea surface reflectance of the wave facet = 0.028)

(Pic of sky)

Surface reflected light (L_{SR}) can vary across pixels

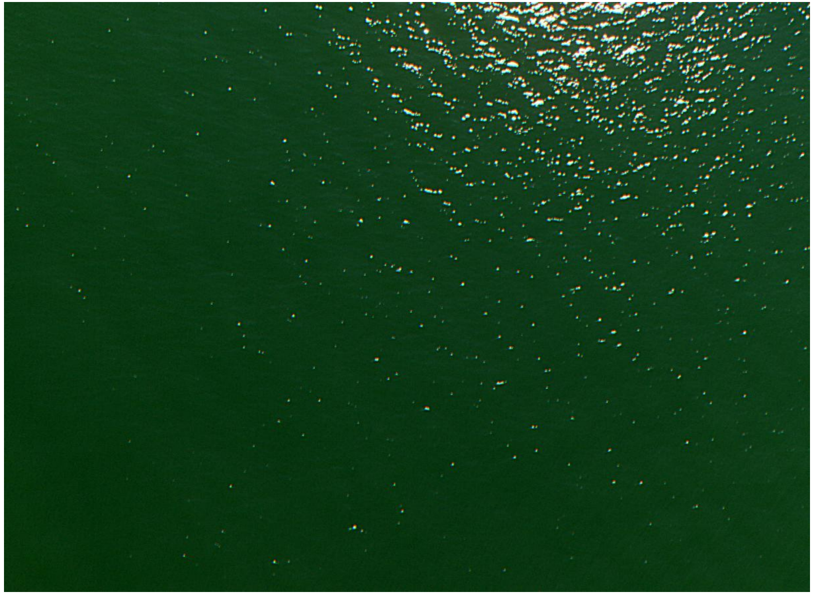


Photo credit: Anna Windle

Photo credit: Patrick Gray

Surface reflected light (L_{SR})

frontiers in Environmental Science

ORIGINAL RESEARCH
published: 26 May 2021
doi: 10.3389/fenvs.2021.674247

Evaluation of Unoccupied Aircraft System (UAS) Remote Sensing Reflectance Retrievals for Water Quality Monitoring in Coastal Waters

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Methods


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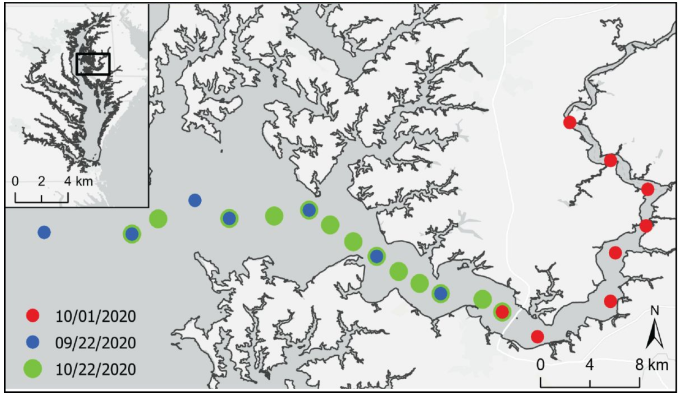
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09/22/2020
10/22/2020
N
0 4 8 km


Choptank RIVERKEEPER


Downwelling
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DJI
RGB
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MicaSense
RedEdge-MX
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camera
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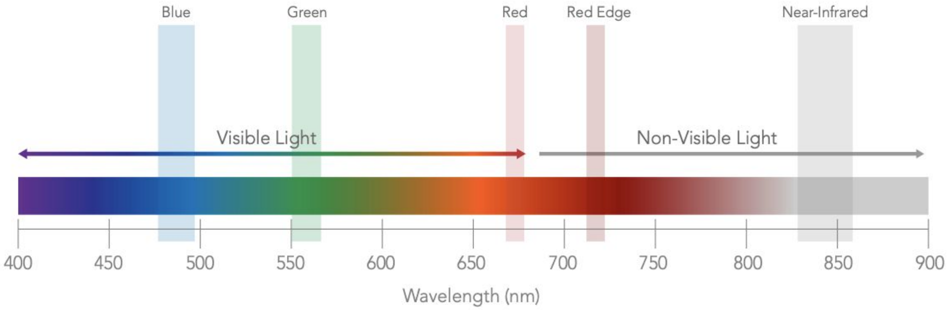
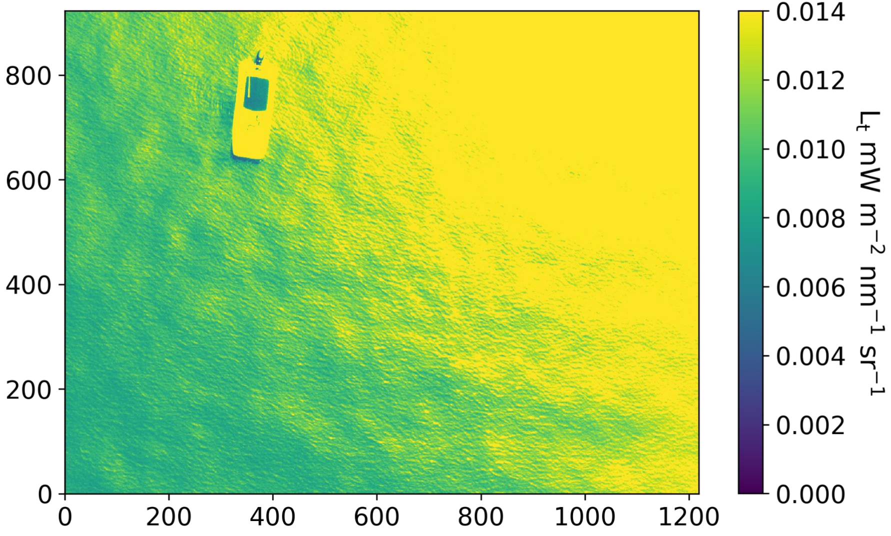

Blue
Green
Red
Red Edge
Near-Infrared
Visible Light
Non-Visible Light
400
450
500
550
600
650
700
750
800
850
900
Wavelength (nm)

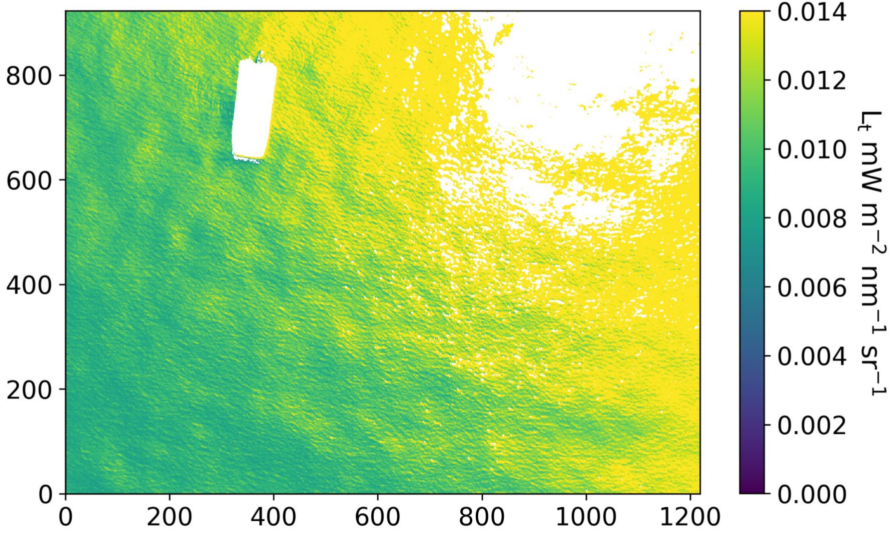
Multispectral UAS image processing

Step 1. Pre-processing to remove specular sun glint and non-water

Before filtering procedure



After filtering procedure



Multispectral UAS image processing

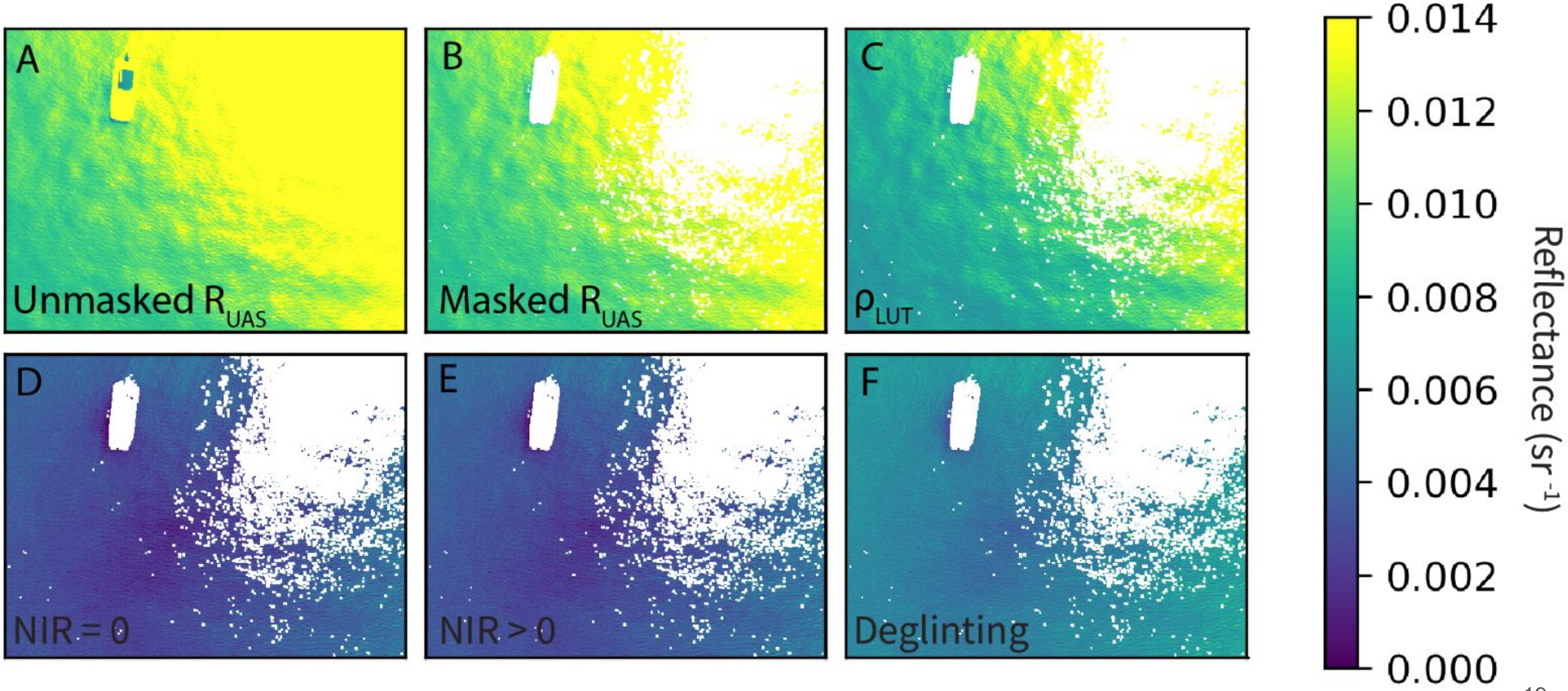
Step 2. Apply method* to remove surface reflected light ($L_{SR} = L_{sky}{}^{*}\ \rho$)

1. ρ_{LUT}
2. NIR = 0
3. NIR > 0
4. Deglinting

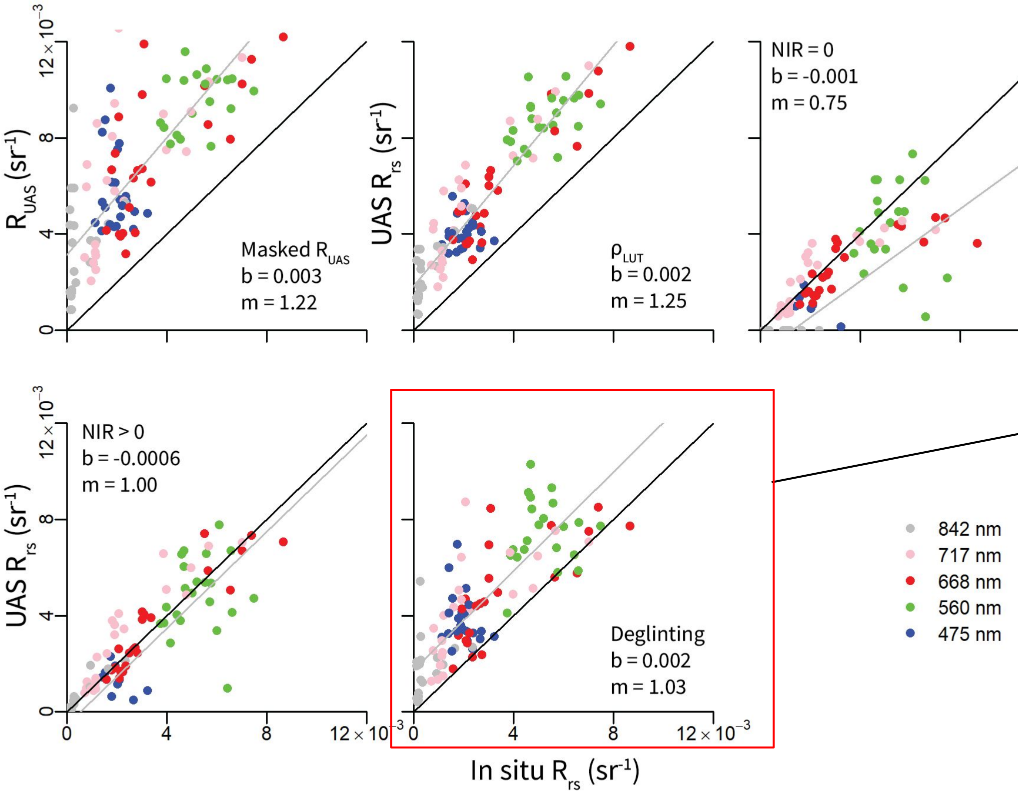
$$R_{rs}(\theta, \Phi, \lambda) = R_{UAS}(\theta, \Phi, \lambda) - \frac{L_{sky}(\theta, \Phi, \lambda) * \rho(\theta, \Phi, \lambda)}{E_d(\lambda)}$$

*See Windle & Silsbe, 2021 for more details on each method

Removing L_{sr} lowers reflectance values

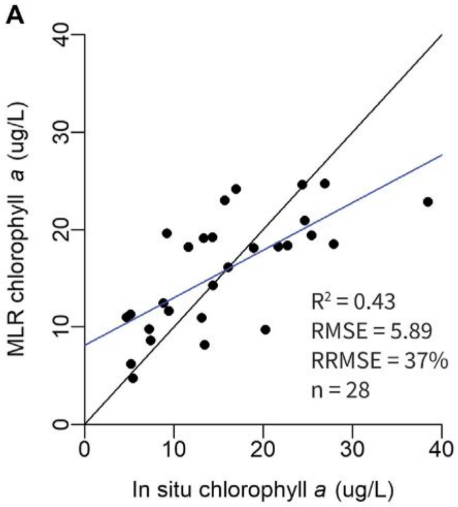


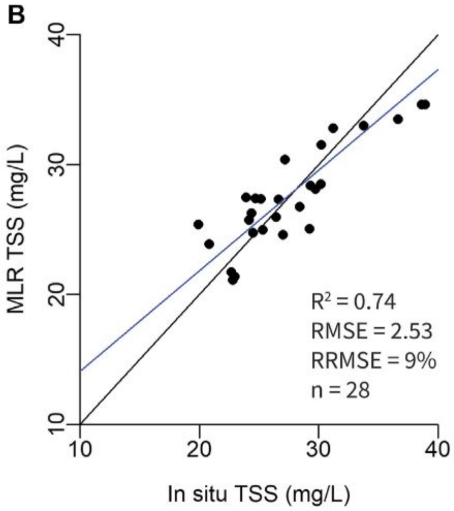
UAS vs in situ R_{rs} values

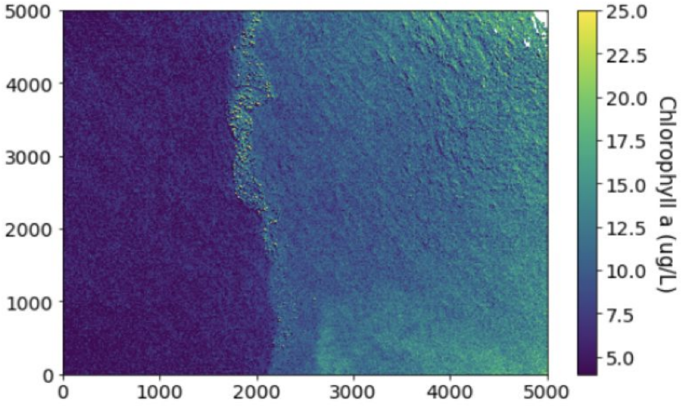


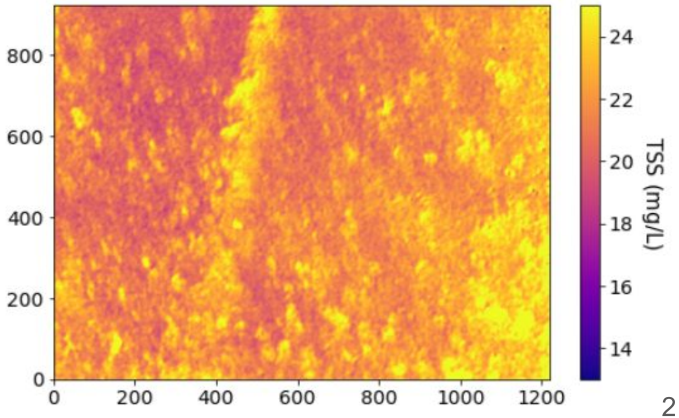
Method 4 performed best (lowest error): pixel-based approach that exploits the high absorption of water at NIR wavelengths to estimate and remove L_{sr}

High resolution water quality retrievals



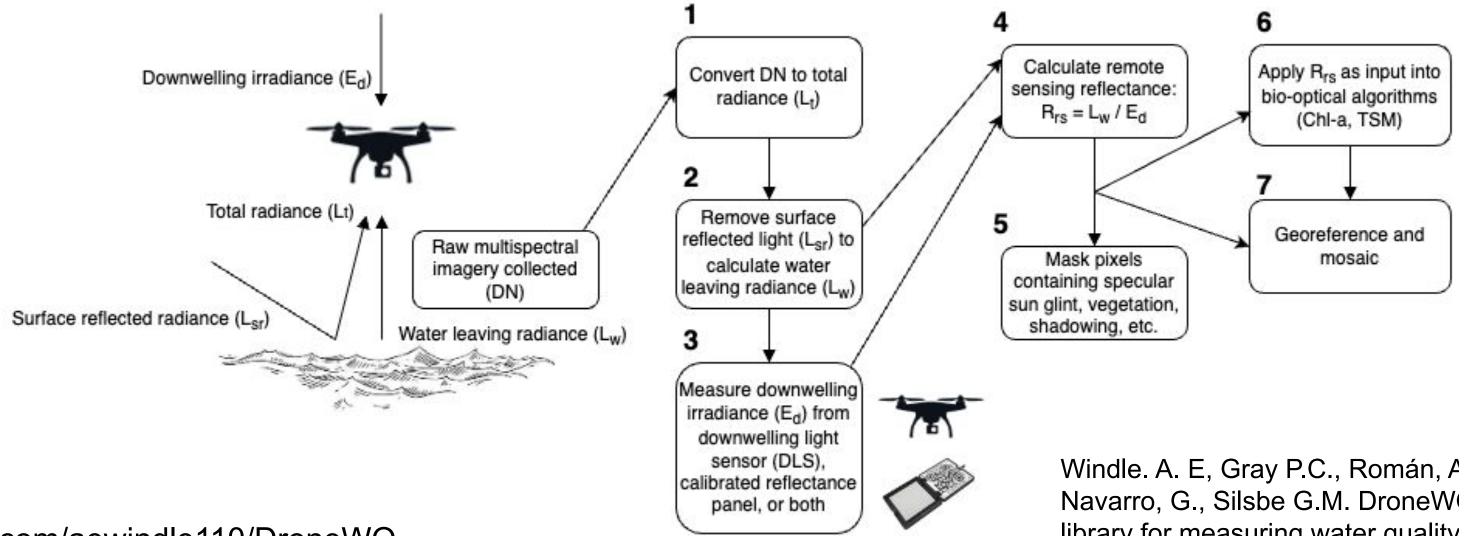






DroneWQ

Python package that can be used to analyze multispectral data collected from a drone to derive ocean color radiometry and water quality properties. Scripts are specific for the MicaSense RedEdge and Altum cameras.



https://github.com/aewindle110/DroneWQ
https://dronewq.readthedocs.io/

Windle. A. E, Gray P.C., Román, A., Heredia, S, Navarro, G., Silsbe G.M. DroneWQ: A Python library for measuring water quality with a multispectral drone sensor. *Submitted: Journal of Open Source Software*.

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Demonstration of DroneWQ f ×

https://dronewq.readthedocs.io/en/latest/primary_demo.html

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dronewq

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Demonstration of DroneWQ functions and processing code | View page source

Demonstration of `DroneWQ` functions and processing code

Summary

This notebook provides an example workflow of DroneWQ using multispectral images collected by the MicaSense RedEdge-MX sensor over western Lake Erie on August 17, 2022. The workflow processes raw imagery to remote sensing reflectance and applies bio-optical algorithms to retrieve chlorophyll a concentrations. It georeferences the images producing a final chlorophyll a mosaic of the full dataset.

The Lake Erie drone dataset can be found in the Zenodo DOI, please note it is 5.84 GB unzipped. Depending on computer speed, you may need to subset the data before running the code workflow shown here.

Contents

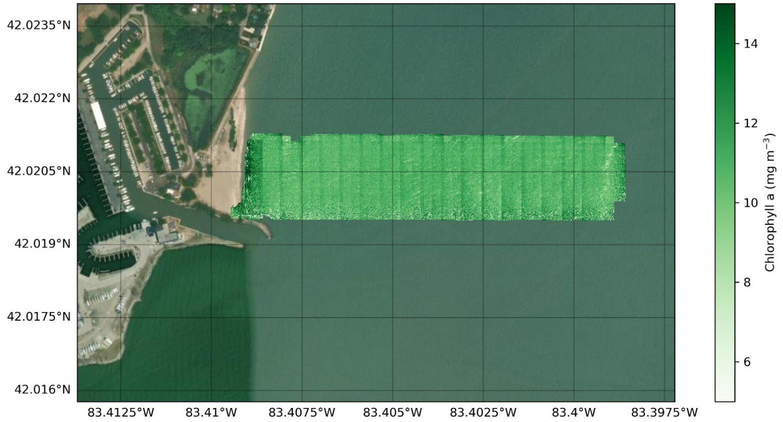
1. Setup

Pull in all the libraries needed for this notebook.

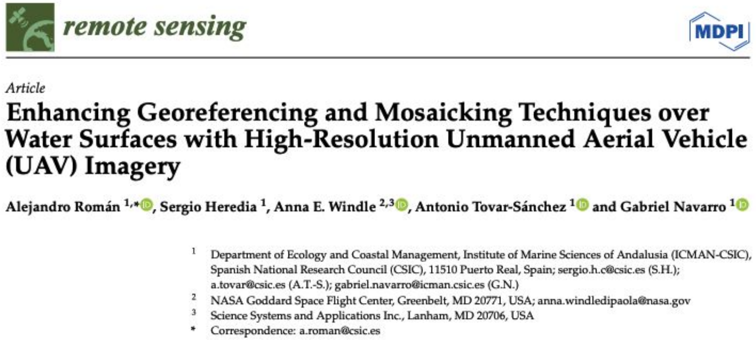
```
[1]: import os
```

latest

Georeferencing and mosaicking is challenging



Processed with DroneWQ



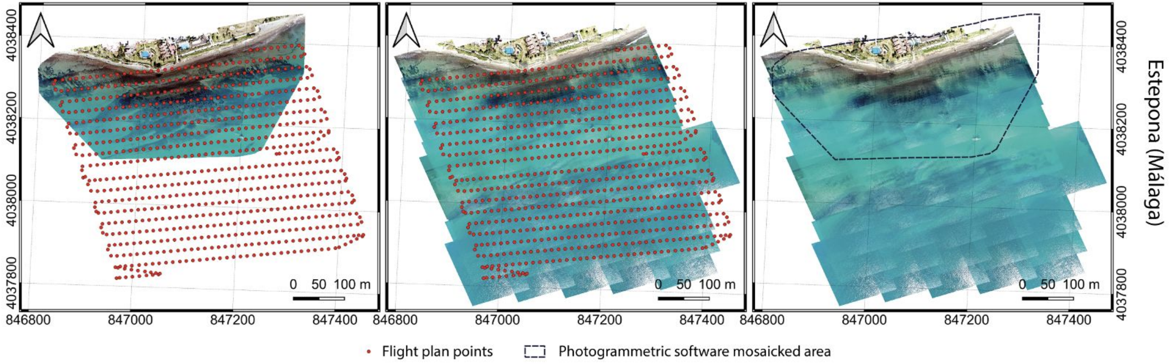
remote sensing
MDPI

Article

Enhancing Georeferencing and Mosaicking Techniques over Water Surfaces with High-Resolution Unmanned Aerial Vehicle (UAV) Imagery

Alejandro Román [1,*], Sergio Heredia [1], Anna E. Windle [2,3], Antonio Tovar-Sánchez [1] and Gabriel Navarro [1]

1 Department of Ecology and Coastal Management, Institute of Marine Sciences of Andalusia (ICMAN-CSIC), Spanish National Research Council (CSIC), 11510 Puerto Real, Spain; sergio.h.c@csic.es (S.H.); a.tovar@csic.es (A.T.-S.); gabriel.navarro@icman.csic.es (G.N.)
2 NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA; anna.windledipaola@nasa.gov
3 Science Systems and Applications Inc., Lanham, MD 20706, USA
* Correspondence: a.roman@csic.es



Aquatic drone pubs

- Windle & Silsbe, 2021
  - doi: 10.3389/fenvs.2021.674247
- Román et al., 2024:
  - doi: 10.3390/rs16020290
- Gray et al., 2022:
  - doi: 10.1002/fee.2472
- Gray et al., 2022
  - doi: 10.1002/lom3.10511

FRONTIERS IN ECOLOGY *and the* ENVIRONMENT

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Drones address an observational blind spot for biological oceanography

Patrick Clifton Gray, Gregory D Larsen, David W Johnston

First published: 15 February 2022 | https://doi-org.proxy-um.researchport.umd.edu/10.1002/fee.2472 | Citations: 3

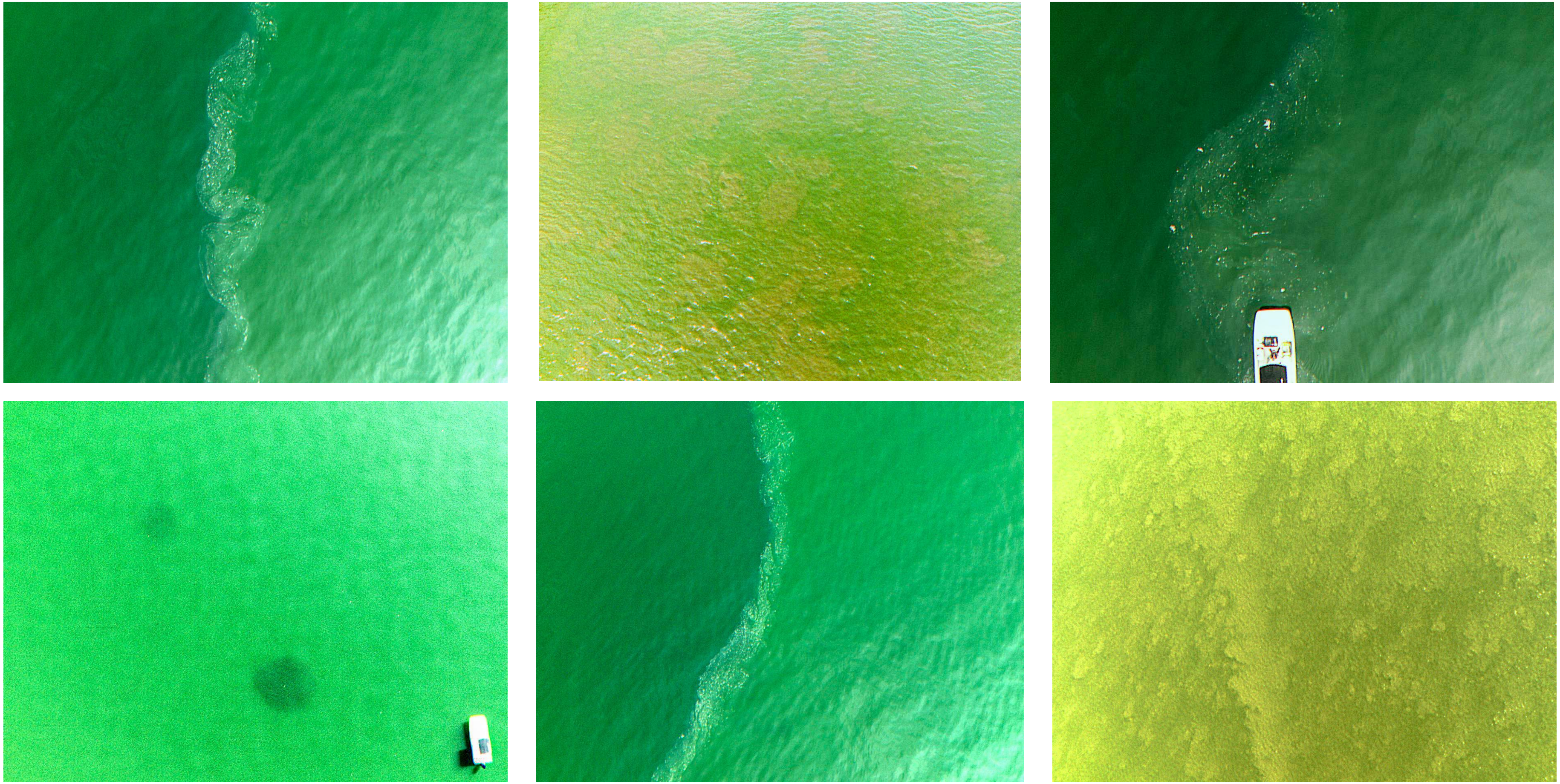
LIMNOLOGY AND OCEANOGRAPHY **Methods** ASLO Association for the Sciences of Limnology and Oceanography

New Methods

Robust ocean color from drones: Viewing geometry, sky reflection removal, uncertainty analysis, and a survey of the Gulf Stream front

Patrick Clifton Gray, Anna E. Windle, Julian Dale, Ivan B. Savelyev, Zackary I. Johnson, Greg M. Silsbe, Gregory D. Larsen, David W. Johnston

Fine-scale observations from UAS imagery



Future directions

- Collect hyperspectral UAS data
  - Point spectrometer vs push-broom/line scan camera

- Apply semi-analytical methods to derive phytoplankton community composition metrics
  - Assist with harmful algal bloom identification and monitoring

- Using UAS R_{rs} to validate ocean color satellites


Thanks for listening! Questions?
anna.windledipaola@nasa.gov