CyanoSCape - Freshwater Phytoplankton Biodiversity

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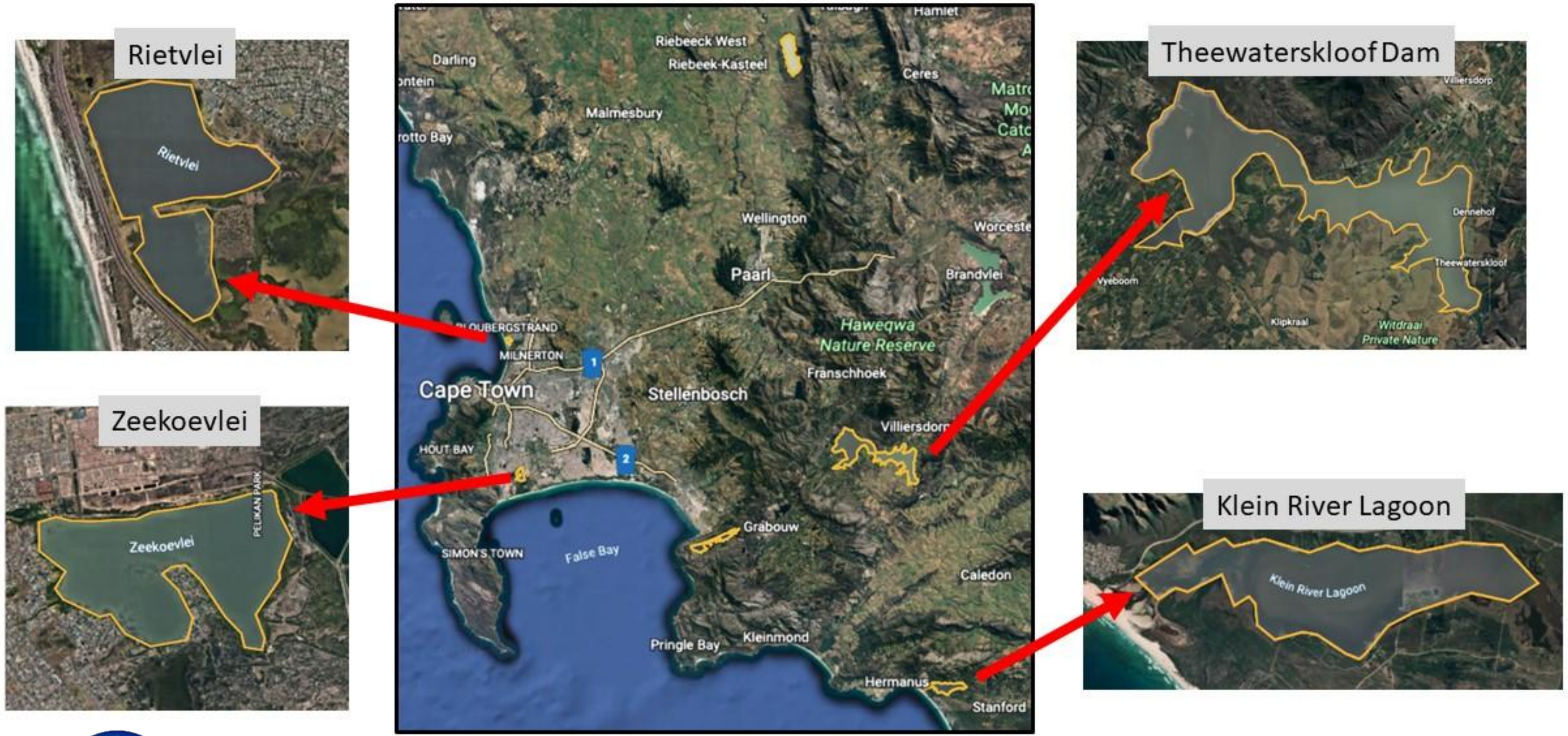
Goal: Utilize hyperspectral data with recently developed and next-generation algorithms to determine the biodiversity of freshwater systems phytoplankton assemblages with emphasis on phytoplankton functional type (PFT) level distinction, including potentially toxic cyanobacteria.

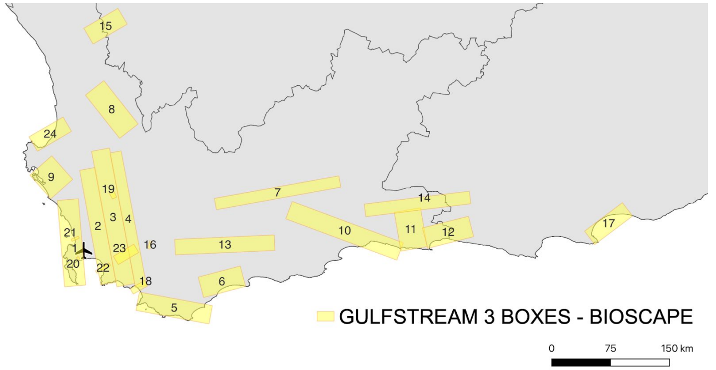


NASA
CSIR
Touching lives through innovation
University of Venda
Creating Future Leaders
BioSCape
Biodiversity Survey of the Cape

CyanoSCape Objectives

Aligned field radiometry and optics coincident with airborne/satellite observations

- Collected field radiometric and bio-optical data coincident with airborne imaging spectrometers **(PRISM, AVIRIS-NG) and/or satellites (EMIT, DESIS, PRISMA, OLCI-S3A/S3B)**
- Field spectroradiometer comparisons (**Spectral Evolution, TriOS RAMSES, Spectra Vista**)
- **BioSCape Cal/Val with hyperspectral radiometer buoy and thermal ring**
- **22 days of field data collection. 11 Gulfstream-3 flights over CyanoSCape sites**
- Assess radiometric integrity of atmospherically corrected surface reflectance over productive waters



Airborne imaging spectrometer data analyses

- **Application of published and next-generation algorithms to airborne PRISM and AVIRIS-NG for phytoplankton discrimination and spatial distribution**

Phytoplankton Community Composition (PCC)

- Characterize phytoplankton composition/diversity of example freshwater systems through aligned **field spectroscopy, water sample collection, temperature, microscopy, and HPLC analysis**

Machine Learning Derived Biogeochemical Parameters and Inherent Optical Properties (IOPs)

- Leverage pre-trained, globally applicable, machine learning algorithms (Mixture Density Networks; MDNs) to estimate biogeochemical parameters (Chlorophyll-a, total suspended solids, and phycocyanin) as well as inherent optical properties (IOPs) from hyperspectral remote sensing reflectance (Rrs)

Phytoplankton phenology of inland waters

- Leverage historic multispectral data of phytoplankton seasonality with meteorology and utilize opportunistic hyperspectral satellite matchup collection with the BioSCape hyperspectral airborne data in preparation for future missions (e.g.,Surface Biology & Geology)

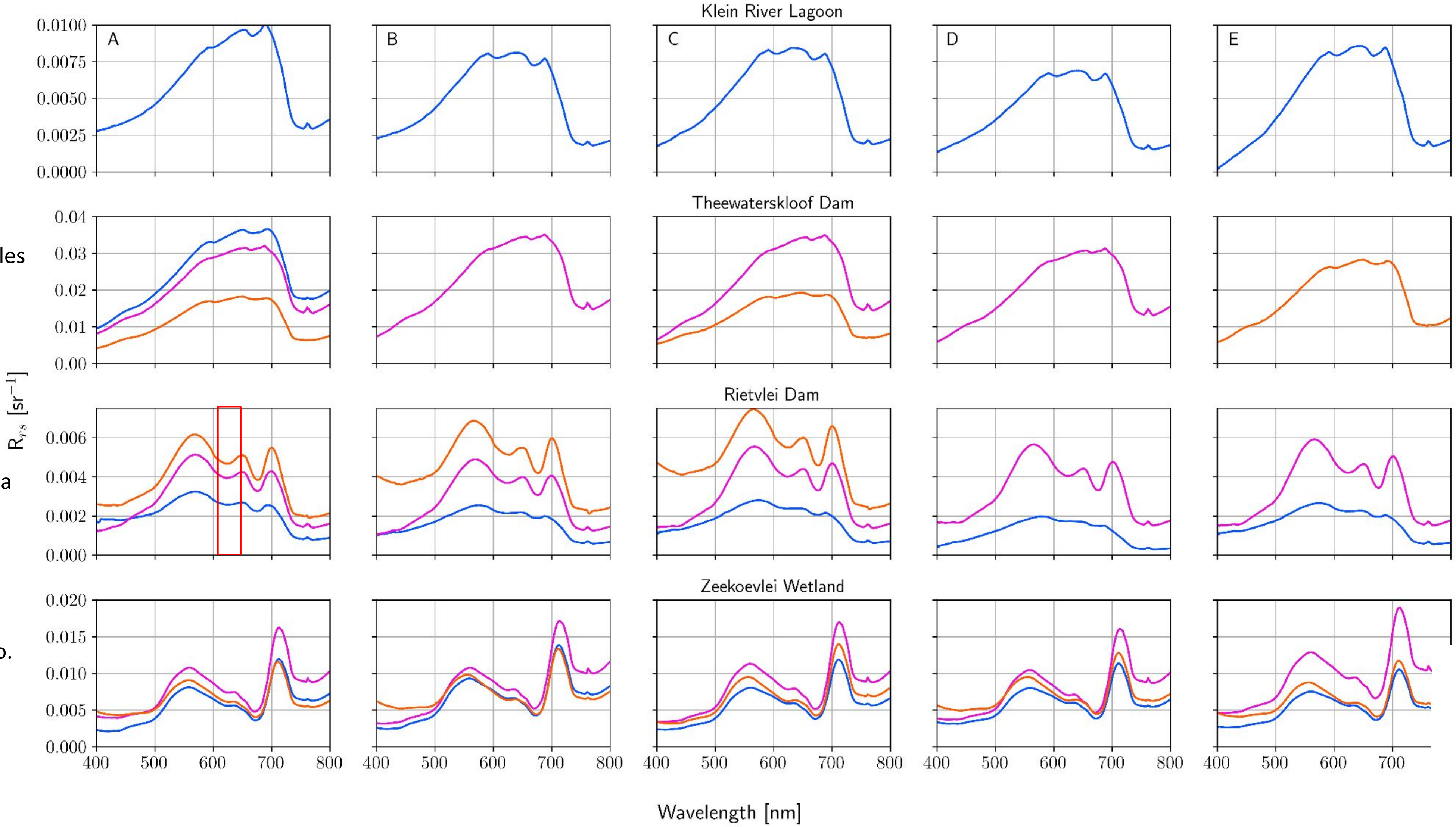
In situ Rrs per Site and Sampling Event

Mouth of river (site A) has higher chl, tss, & turbidity

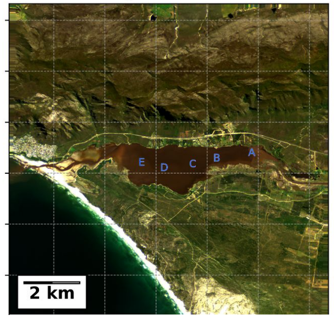
Sediment settles out of water column

Cyanobacteria bloom develops!

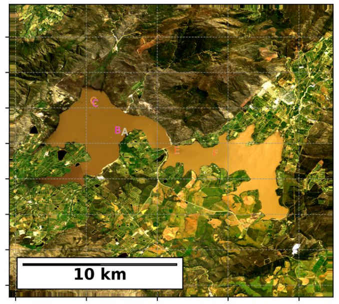
Stable cyano. bloom.



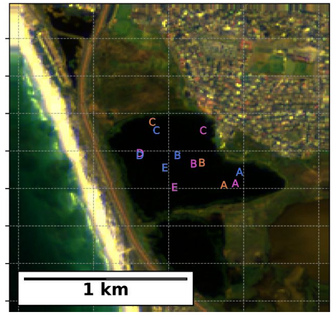
Klein River Lagoon on October 17, 2023



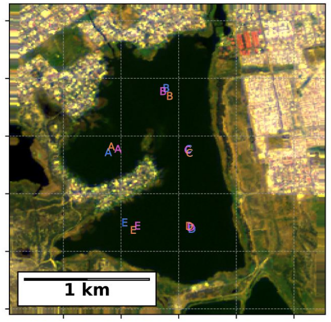
Theewaterskloof Dam on October 17, 2023



Rietvlei Dam (Urban) on October 17, 2023



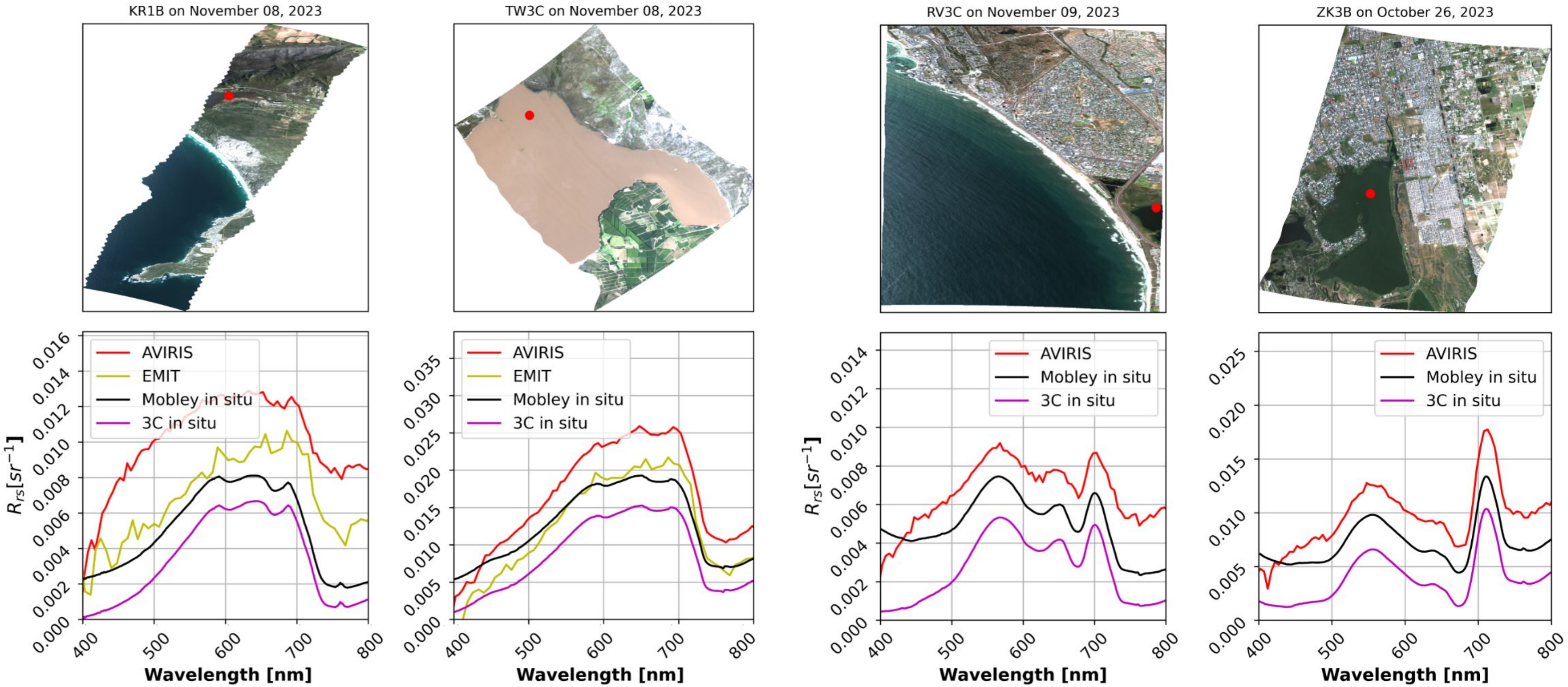
Zeekoevlei Wetland (Urban) on October 17, 2023



Sampling event order: 1, 2, 3

Ryan O'Shea, SSAI/GSFC

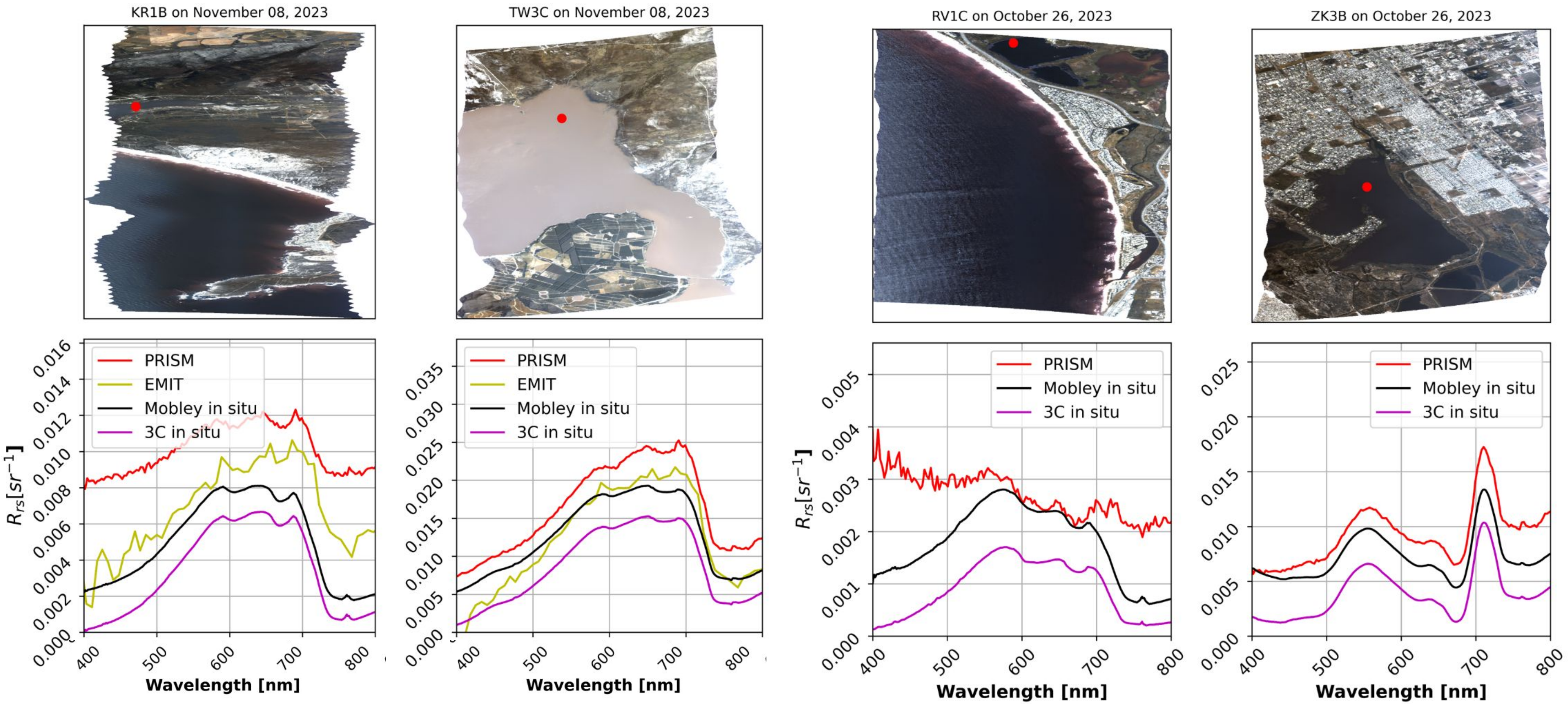
<u>AVIRIS-NG</u> Aquatic Rrs Evaluation



1. AVIRIS-NG matches spectral shape, except for 400-450 nm range, magnitude offset due to glint.
2. ACOLITE-corrected EMIT imagery matches Mobley in situ Rrs, but with sharp spectral features.

Ryan O’Shea, SSAI/GSFC

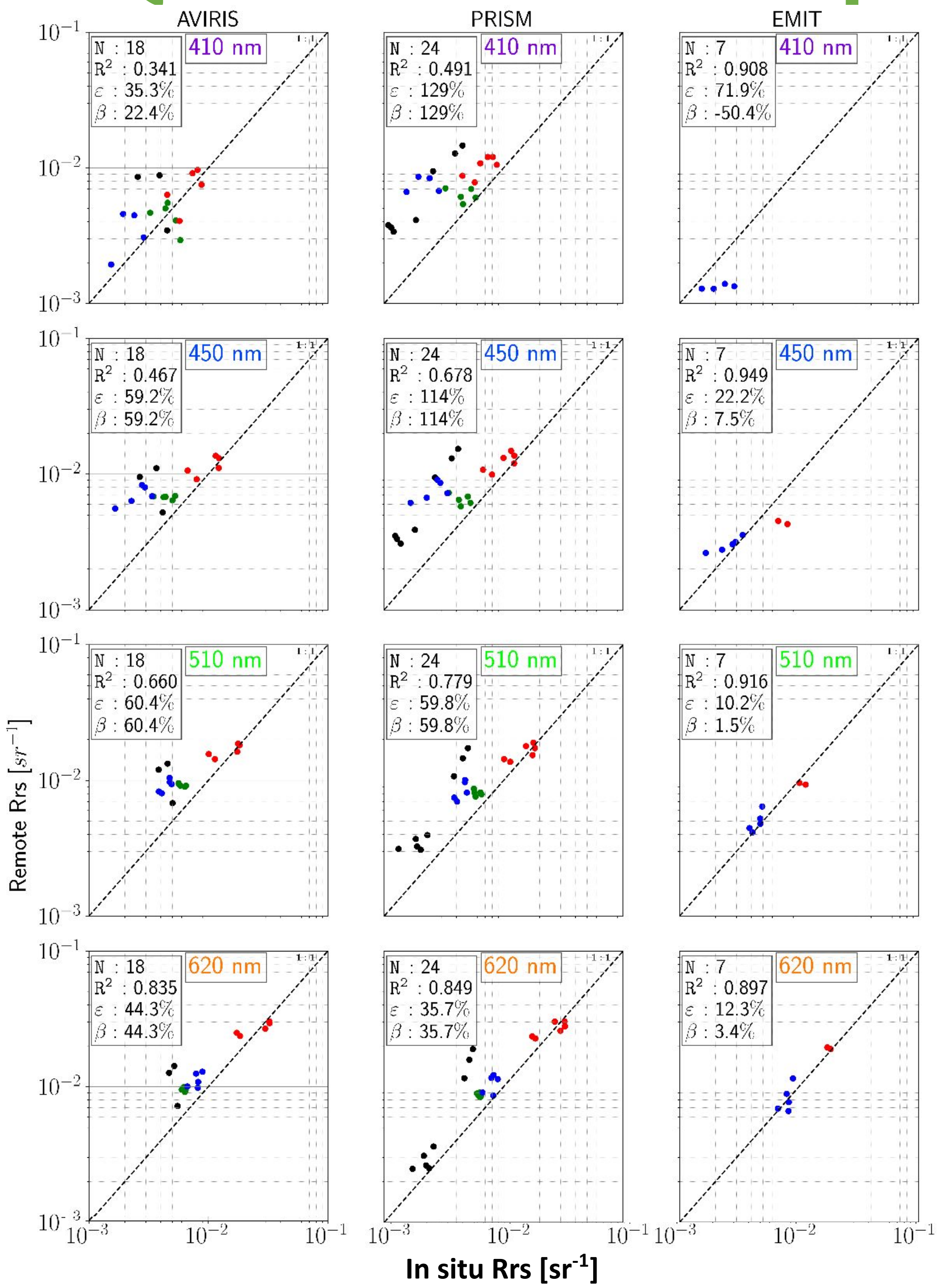
<u>PRISM</u> Aquatic Rrs Evaluation



1. PRISM has high offsets in blue and NIR (glint), but matches spectral shape in green-red
2. Noisy signal in darkest waters (RV1C)

Ryan O'Shea, SSAI/GSFC

Quantitative Comparison to In Situ R_{rs}



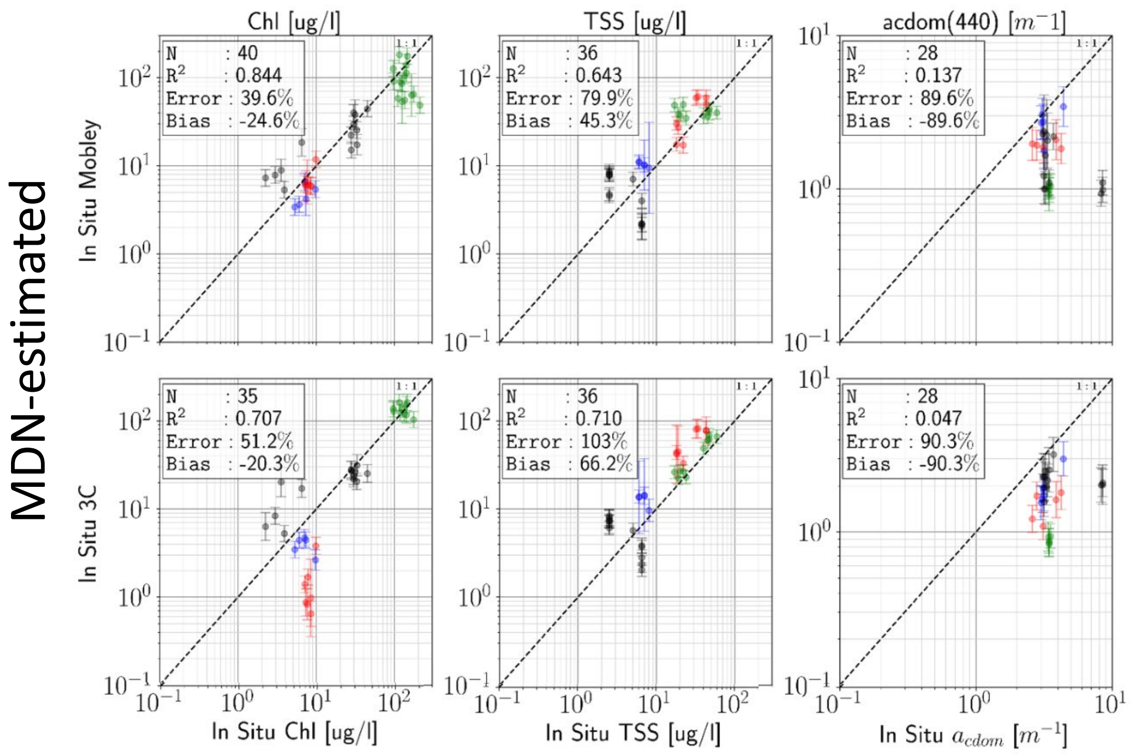
<u>Non-glint corrected</u> imagery results:

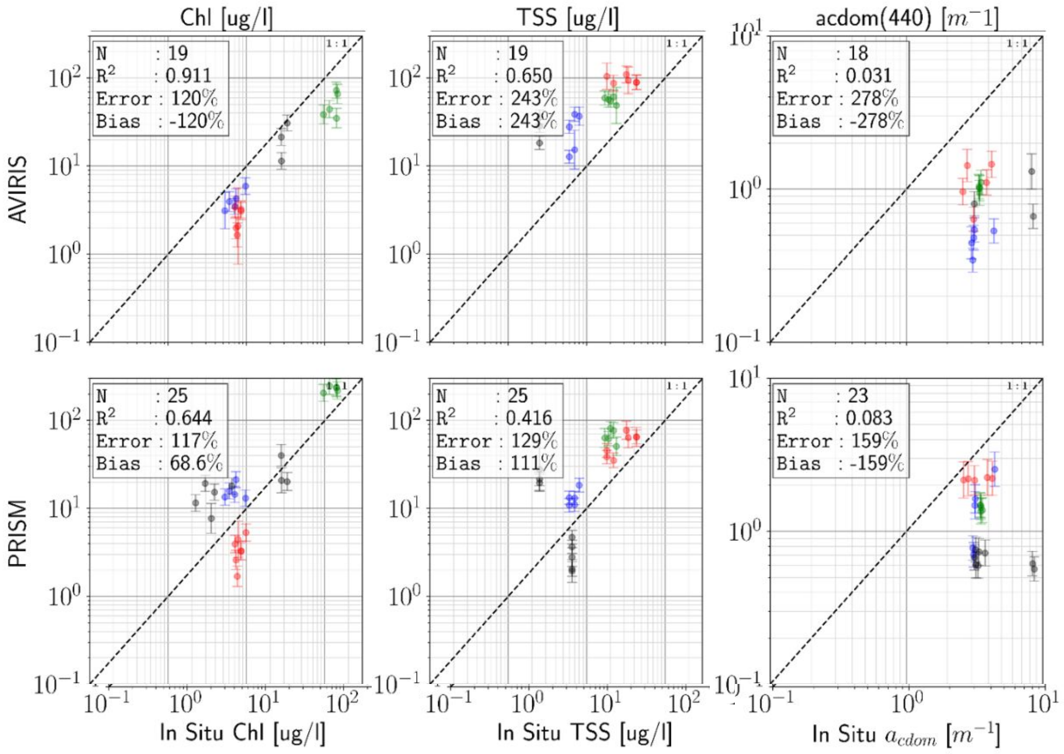
- AVIRIS-NG outperforms PRISM in blue
- Error dominated by bias across the spectrum (likely due to glint)
- EMIT has strong agreement on limited samples

ZK,RV,TW,KR

Ryan O'Shea, SSAI/GSFC

Quantitative Comparison for Downstream Products





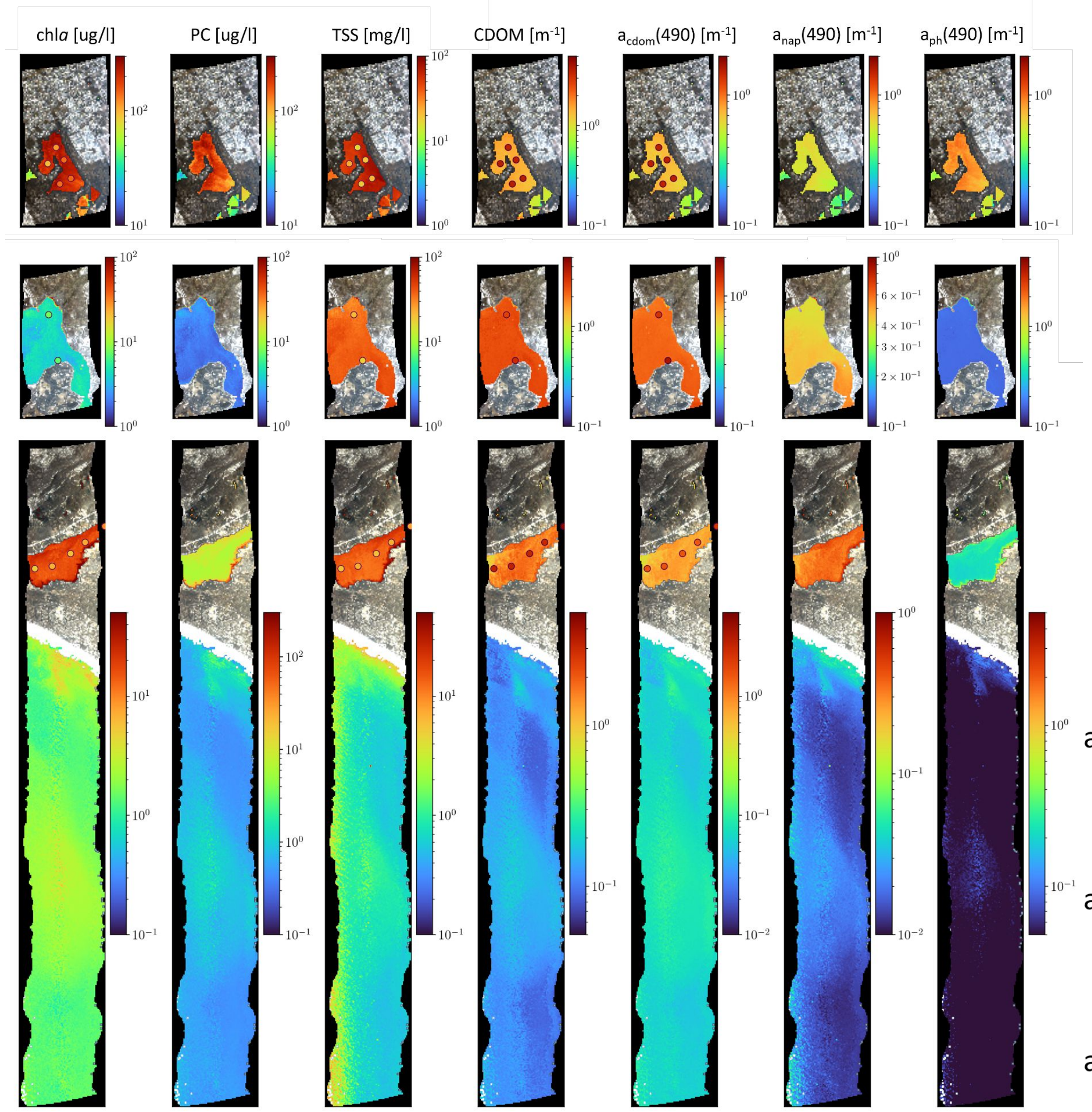
Mixed Density Networks (MDN) algorithm well represents Chl and TSS across a range of magnitudes in South African inland waters (ZK,RV,TW,KR)

Ryan O'Shea, SSAI/GSFC

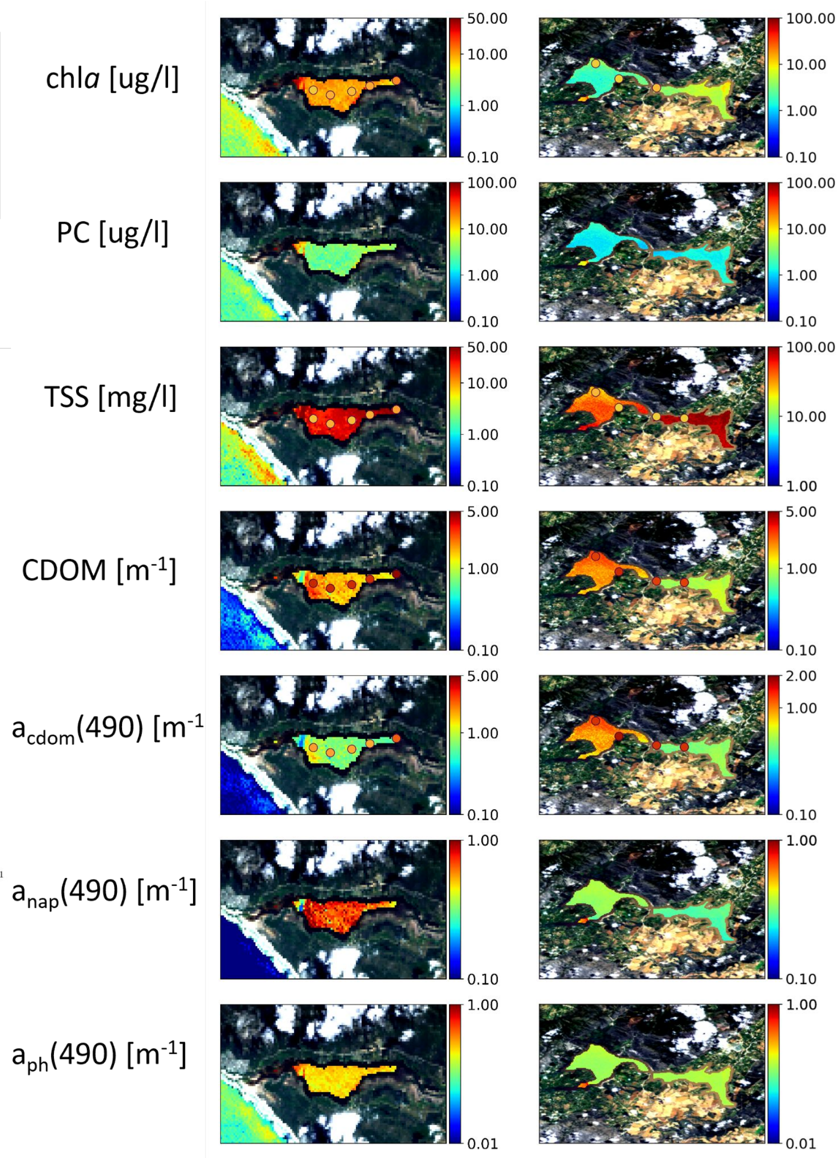
MDN Chl, TSS, and CDOM retrievals are heavily biased by atmospheric correction uncertainties and glint within AVIRIS and PRISM imagery

- results expected to improve with glint corrected imagery

PRISM



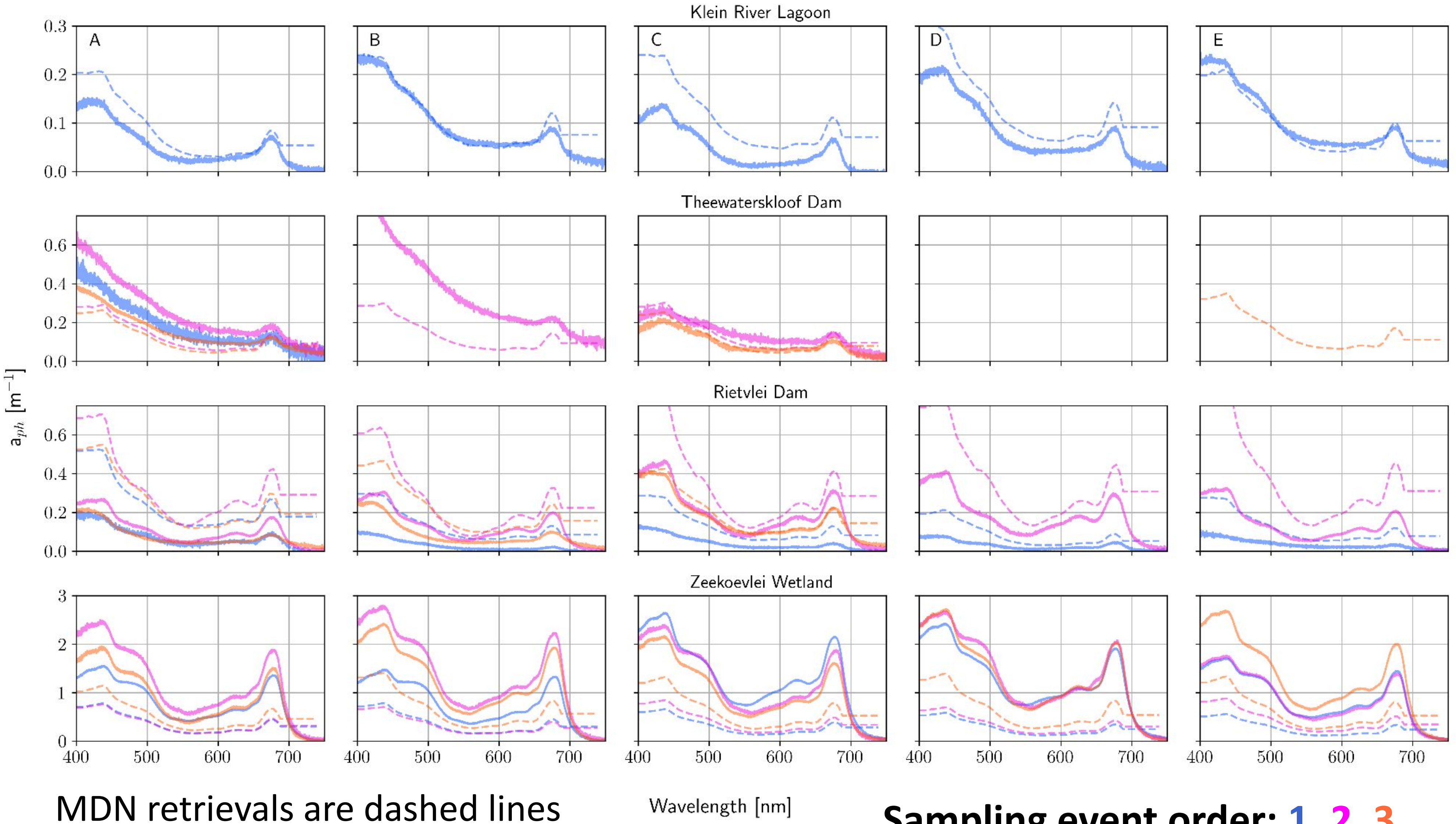
EMIT



- **MDNs produce artifact free product maps**
- **EMIT chl agrees well with in situ values**
- **Changes in CHl magnitude is well represented despite atmospheric correction uncertainties**
- **Phytoplankton absorption spectrum (a_{ph}) must be added in**

Ryan O'Shea, SSAI/GSFC

Towards PCC: Hyperspectral a_{ph} Retrieval



Magnitude and spectral shape well represented by MDN-derived aph!

Absorption peak at 620 nm well captured.

Spectral shape well captured, magnitude is higher than most training data…

MDN retrievals are dashed lines
in situ measurements are **solid** lines

Sampling event order: 1, 2, 3

Ryan O'Shea, SSAI/GSFC

Phytoplankton Community Composition (PCC)

Evaluating the performance of the PCC classification algorithm, Phytoplankton Detection with Optics (PHYDOTax)

HPLC-derived PCC

- PCC derived from HPLC pigment data using CHEMTAX and *phytoclass*
- Five phytoplankton classes common to inland water bodies were determined: Chlorophytes, Cryptophytes, Cyanophytes, Diatoms, and Dinoflagellates

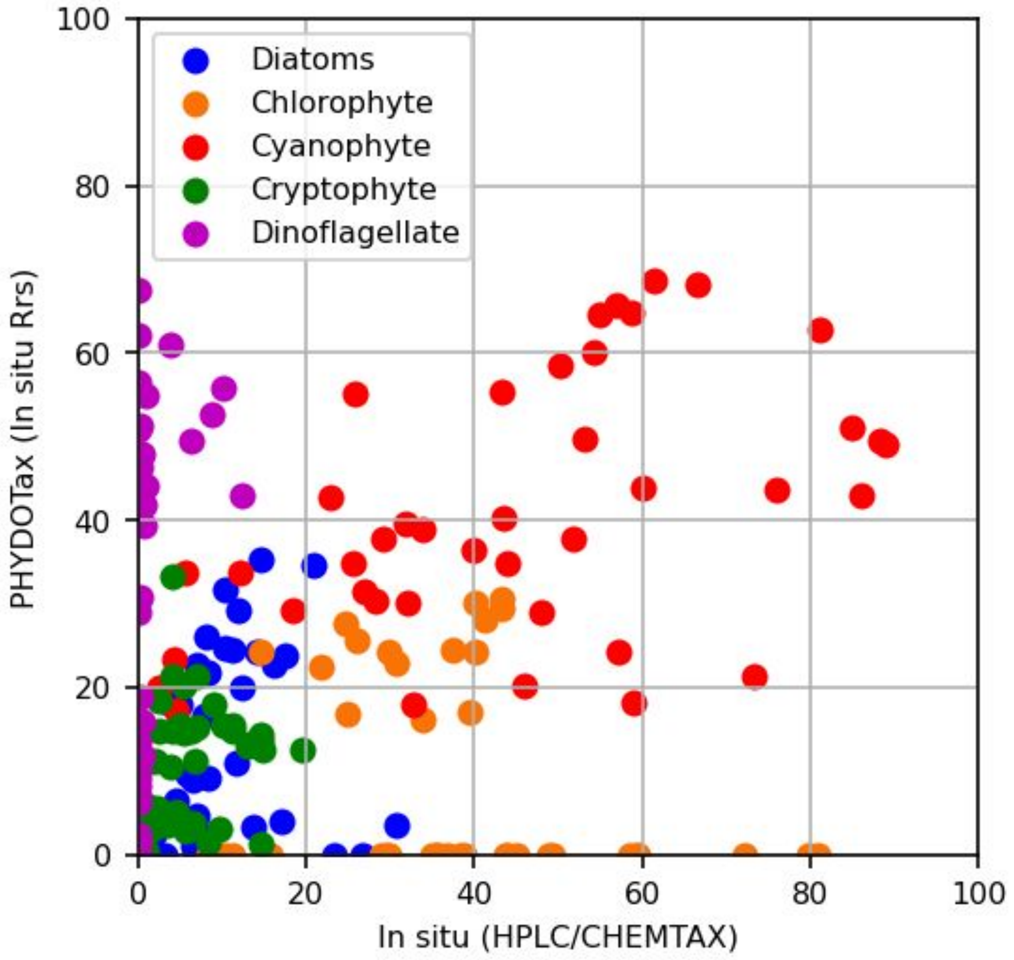
Hyperspectral imagery-derived PCC (DESIS)

- PCC derived from both the in situ R_{rs} and from the pre-processed hyperspectral scenes using the bio-optical approach PHYDOTax
- The PCC results were compared between those derived from the in situ R_{rs} and the hyperspectral imagery as well as between the PCC derived from PHYDOTax verses the in situ HPLC measurements

PHYDOTax-derived PCC from in situ R_{rs} compared with HPLC-derived PCC (CHEMTAX):

- Strongest performance with identifying Cyanobacteria

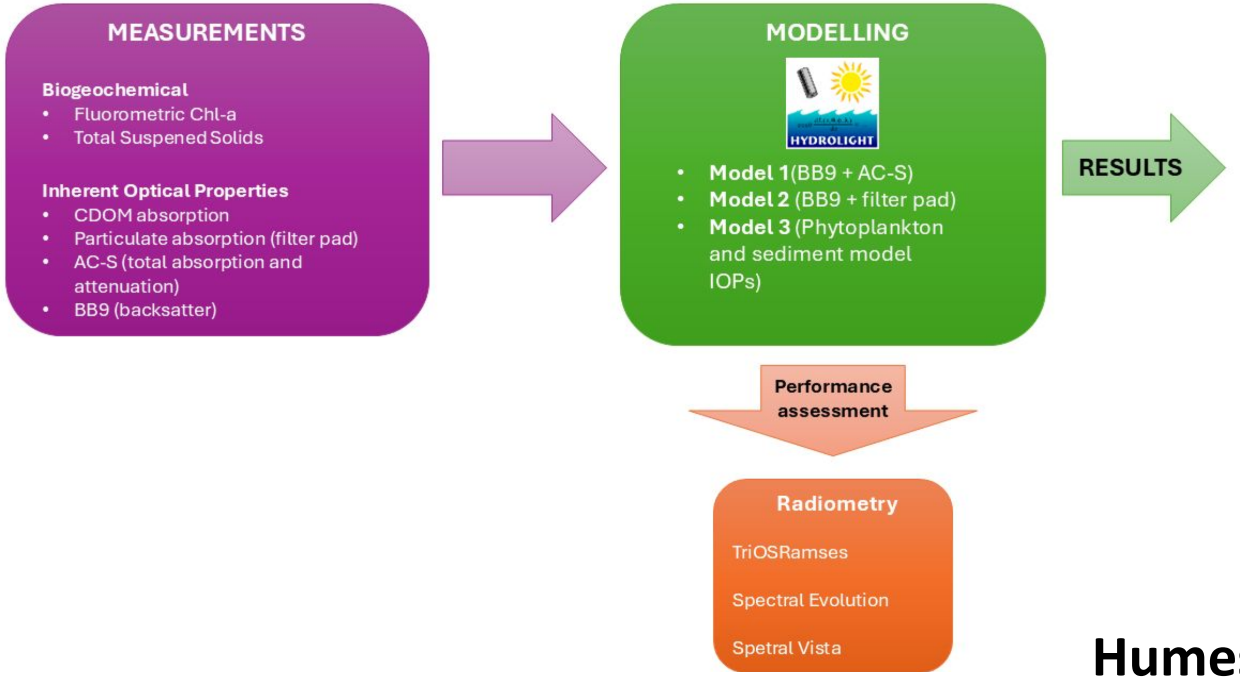
Complete analysis of PHYDOTax application to BioSCape hyperspectral imagery



Samantha Sharp, NPP/NASA ARC

Comparison of Inherent Optical Properties (IOPs): Absorption and Backscatter

Measured and modelled IOPs were input into Hydrolight with the measured constituent concentrations. The output modelled reflectances were compared to in situ measurements to determine the accuracy of the modelling methods. The uncertainties between different measuring techniques were revealed through these optical closure experiments.

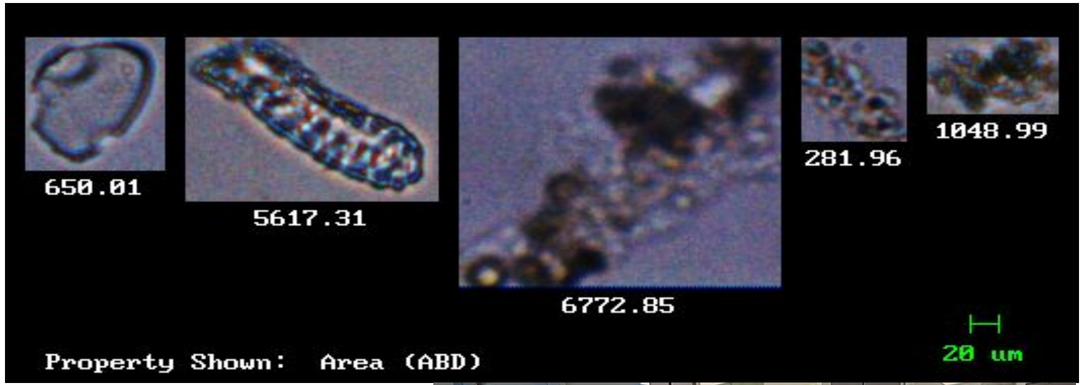


Findings: For most sites, filter pad and modelled IOPs were able to model the water-leaving reflectance for high sediment (Theewaterskloof) and Chl-a (Zeekoevlei) Inland water bodies.

We can use pre-existing models to represent the outcoming reflectances in this region.

Humeshni Pillay, Univ of Cape Town and Marie Smith, CSIR

CyanoSCape Stay Tuned

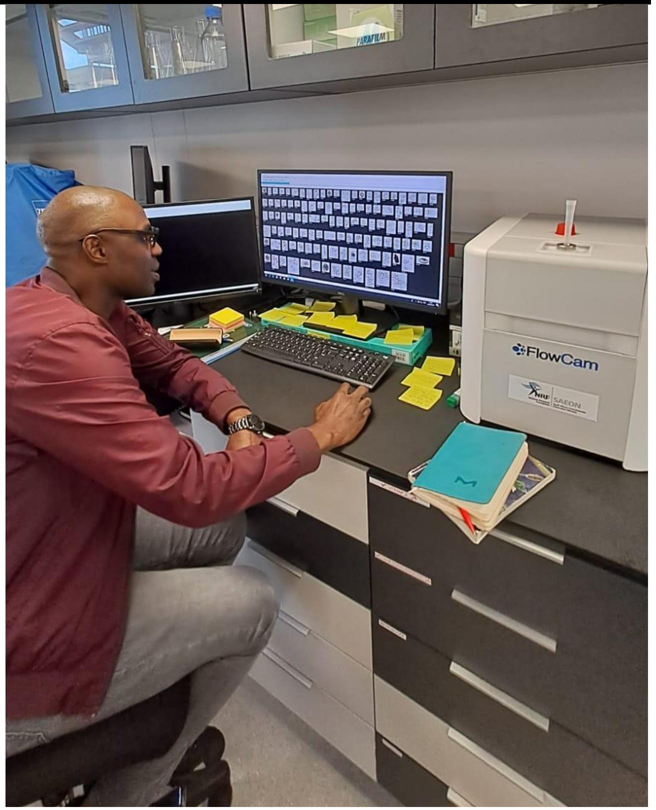


Water sample analyses

- Pigments – HPLC at GSFC (rec'd Jan 2025, behind PACE in the processing queue)
- Particulate absorption - GSFC (rec'd April 2025)
- aCDOM - CUNY (rec'd April 2024)
  - Luka Catipovic et al., in prep (CUNY)
- Nutrients, liquid carbon, particulate carbon, etc. - SAEON (rec'd April 2025)

University of Venda – Flow imaging microscopy (FlowCam)

- Phytoplankton identification (including cyanobacteria) and enumeration.



Thanks! **Woody Turner and Laura Lorenzoni,**
Phil Brodrick/JPL and Coastal PFT Team/LDEO

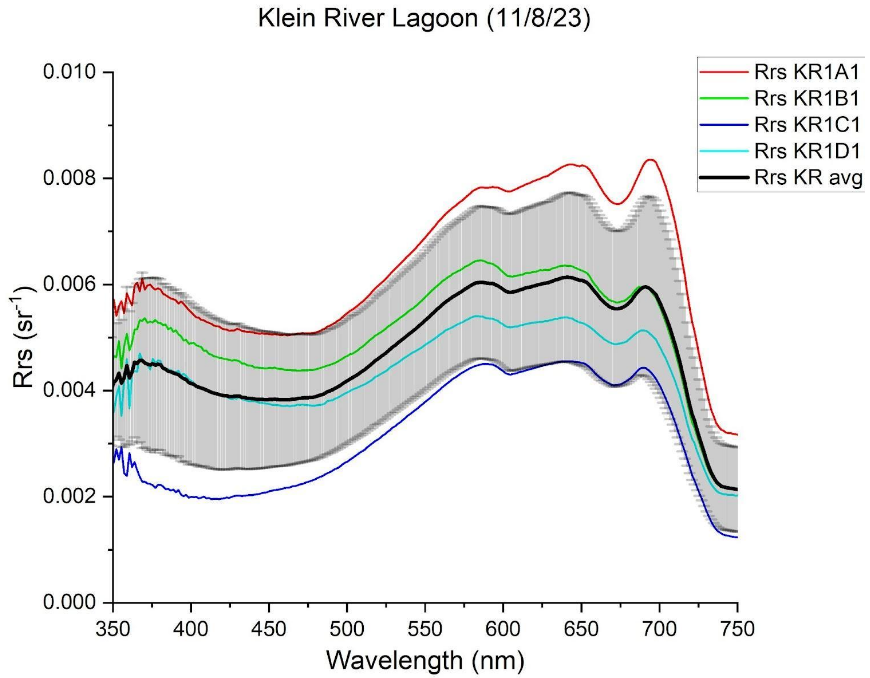
NASA CSIR Touching lives through innovation University of Venda Creating Future Leaders BioSCape Biodiversity Survey of the Cape

Backup Slides

2023-11-26 00:00 - 2023-11-26 23:59, Sentinel-2 L2A, Custom script

Mouth of the lagoon was open during the campaign as seen in the Sentinel 2 image.

Field Spectroscopy



Klein River Lagoon - Natural estuary site, with varying brackish levels depending on distance upstream from Walker Bay and tidal dynamics.

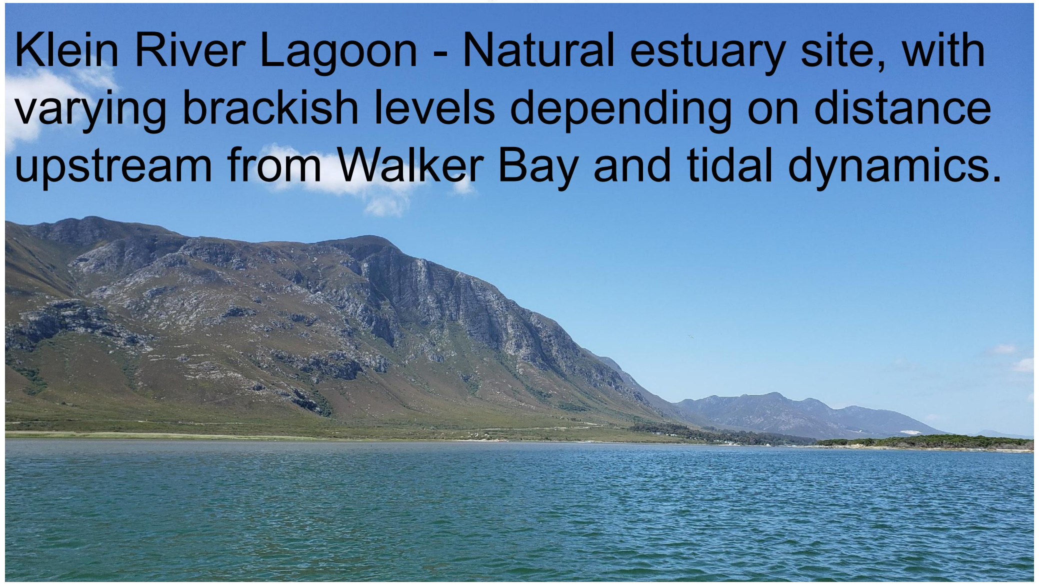
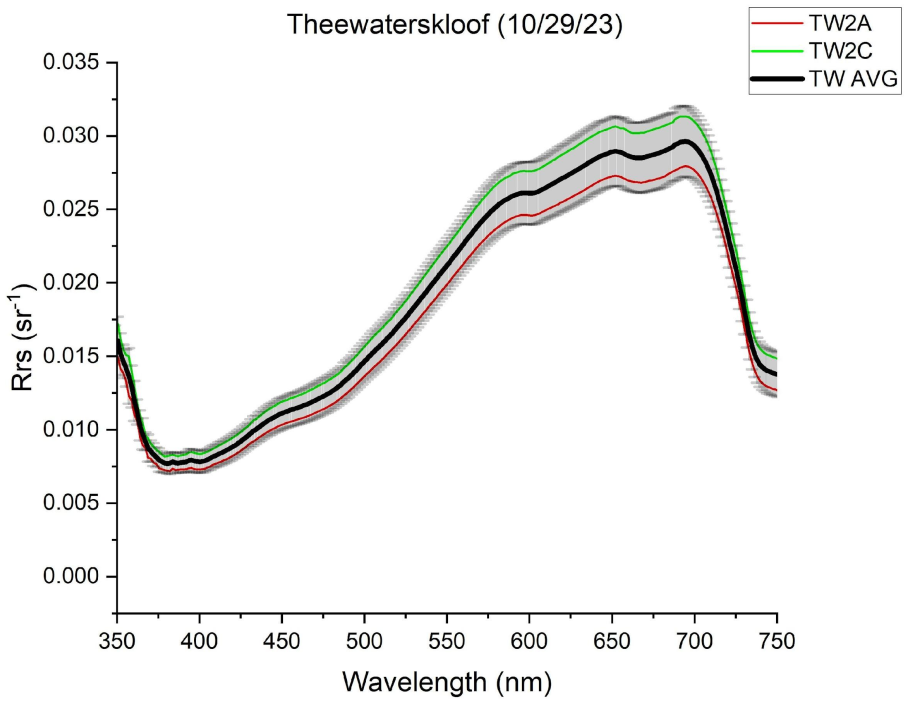


Photo credit: L. Guild.

Field Spectroscopy

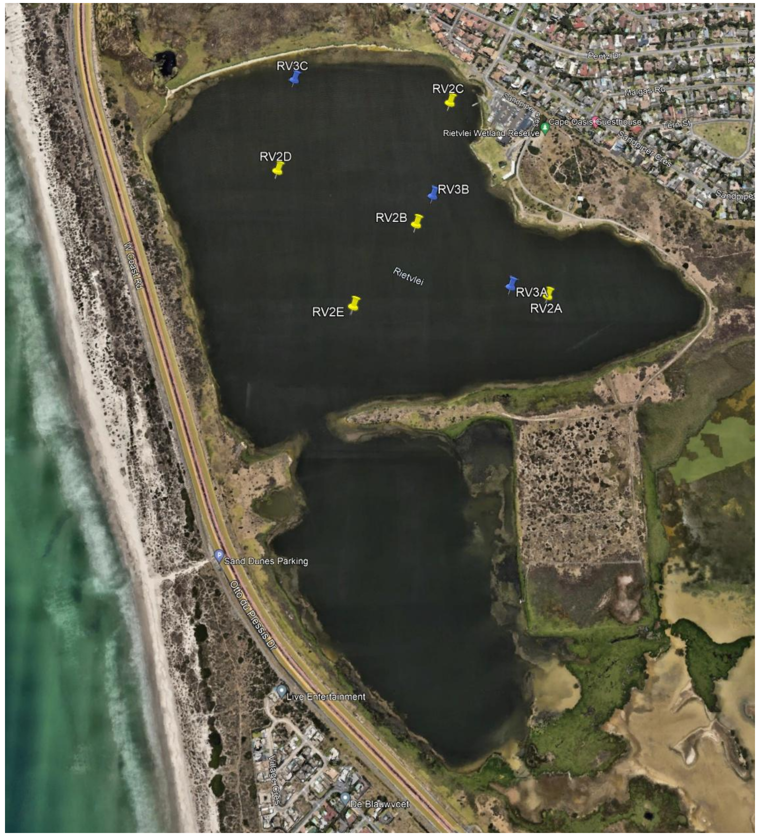


Theewaterskloof Dam – Provides most of the water supply for Cape Town.

Heavy rains at the end of September 2023 prior to the field campaign, high sediment loading was visible.

Left: CSIR TriOS RAMSES (hyperspectral) buoy with additional TriOS RAMSES and Spectral Evolution radiometers. The money shot!

Photo credit: S. Sharp.



Field Spectroscopy

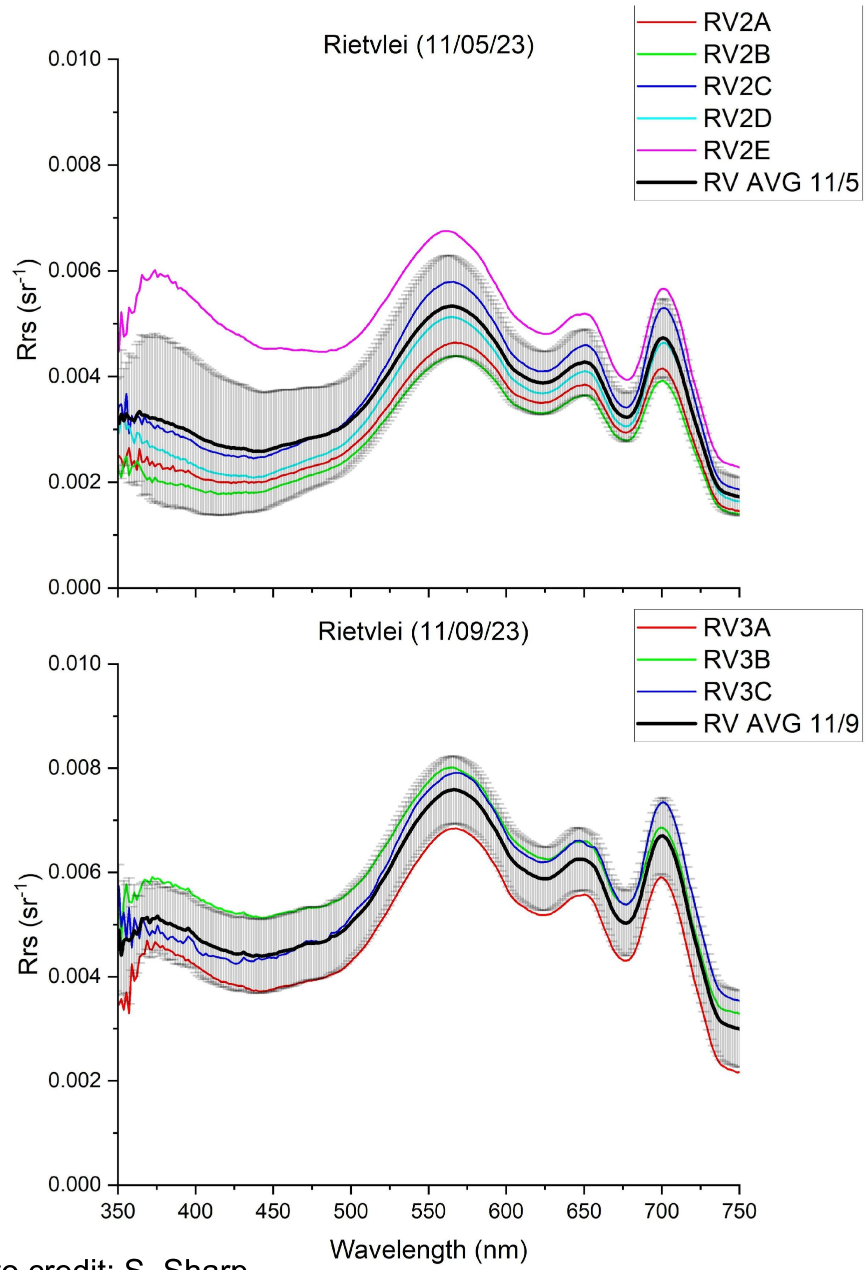


Photo credit: S. Sharp.

Rietvlei – natural freshwater site adjacent to wetland.

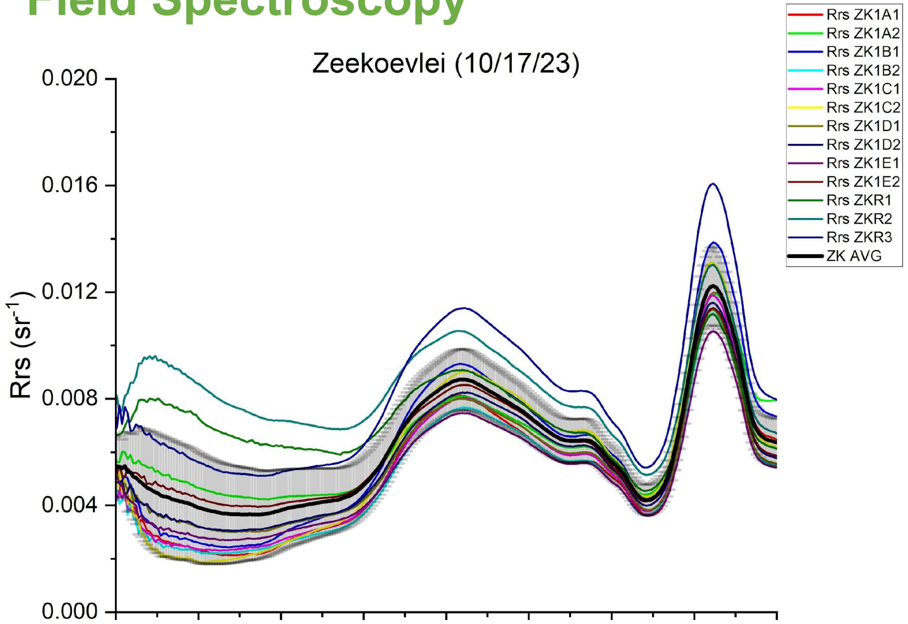
Clear water with benthic plants visible on the bottom.

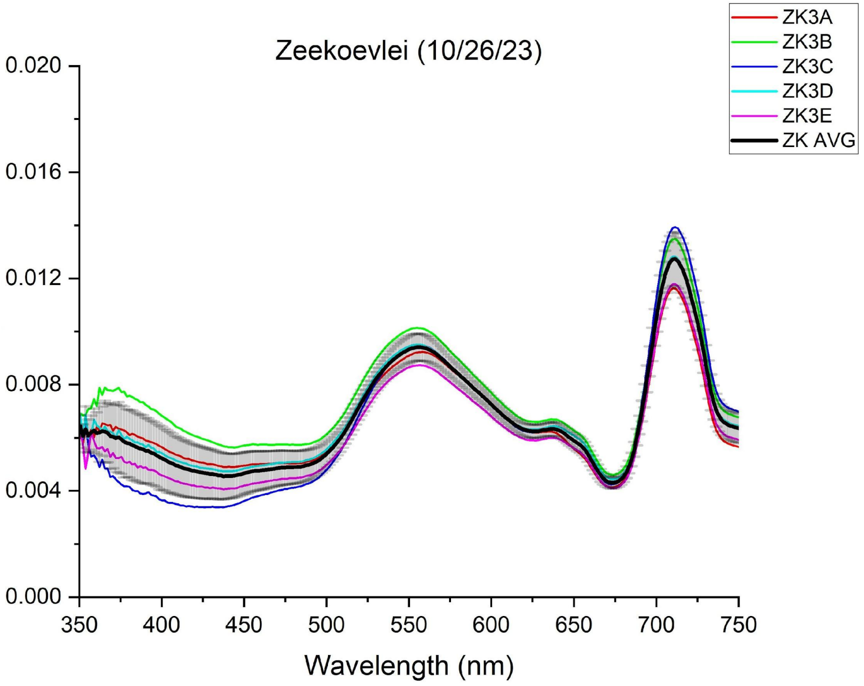
Suspecting CDOM presence but awaiting water sample results.

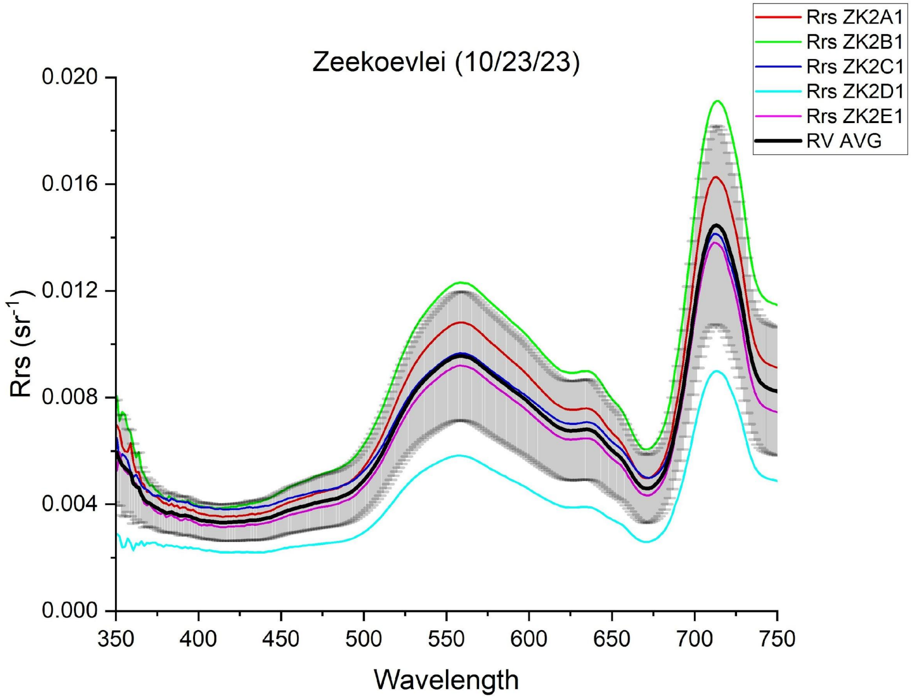
Nothing definitive without pigment data results just yet.

Field Spectroscopy

Photo credit: S. Sharp.







Zeekoevlei – urban wetland.

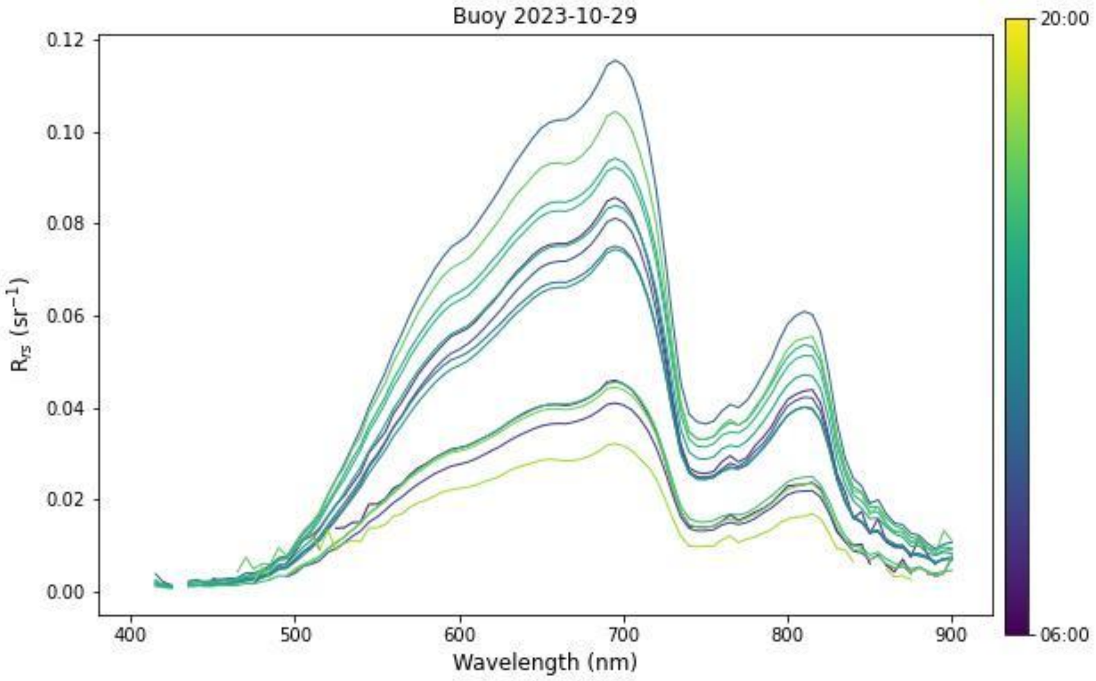
High phytoplankton – note how green it is! Still awaiting water sample results.

709 nm peaks indicative of **very** high chlorophyll concentrations.
650 nm bump is a typical high bio tension between absorption and backscatter, with pigment absorption “fighting” against both size- and biomass-driven backscatter features.

- Gizmo: CSIR hyperspectral radiometry buoy with TriOS Ramses instrument at Theewaterskloof Dam

- JPL thermal ring for HyTES cal/val

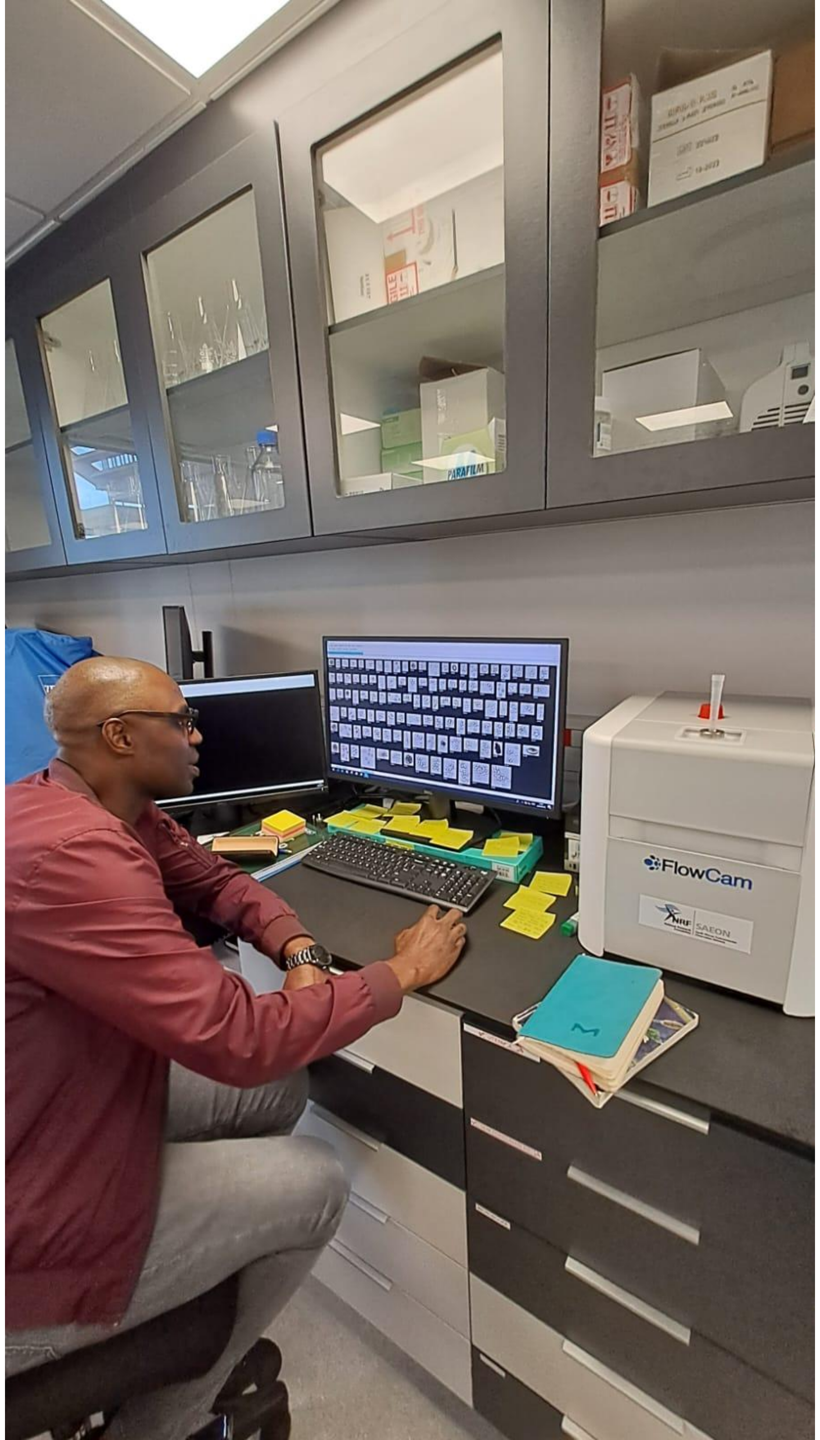
Theewaterskloof Dam. Photo credit: S. Sharp.



Hourly hyperspectral radiometry from Gizmo.

Scale from Blue (morning) to Yellow late in the day.

At least 41 days of data from 10/17/2023 to 11/29/2023



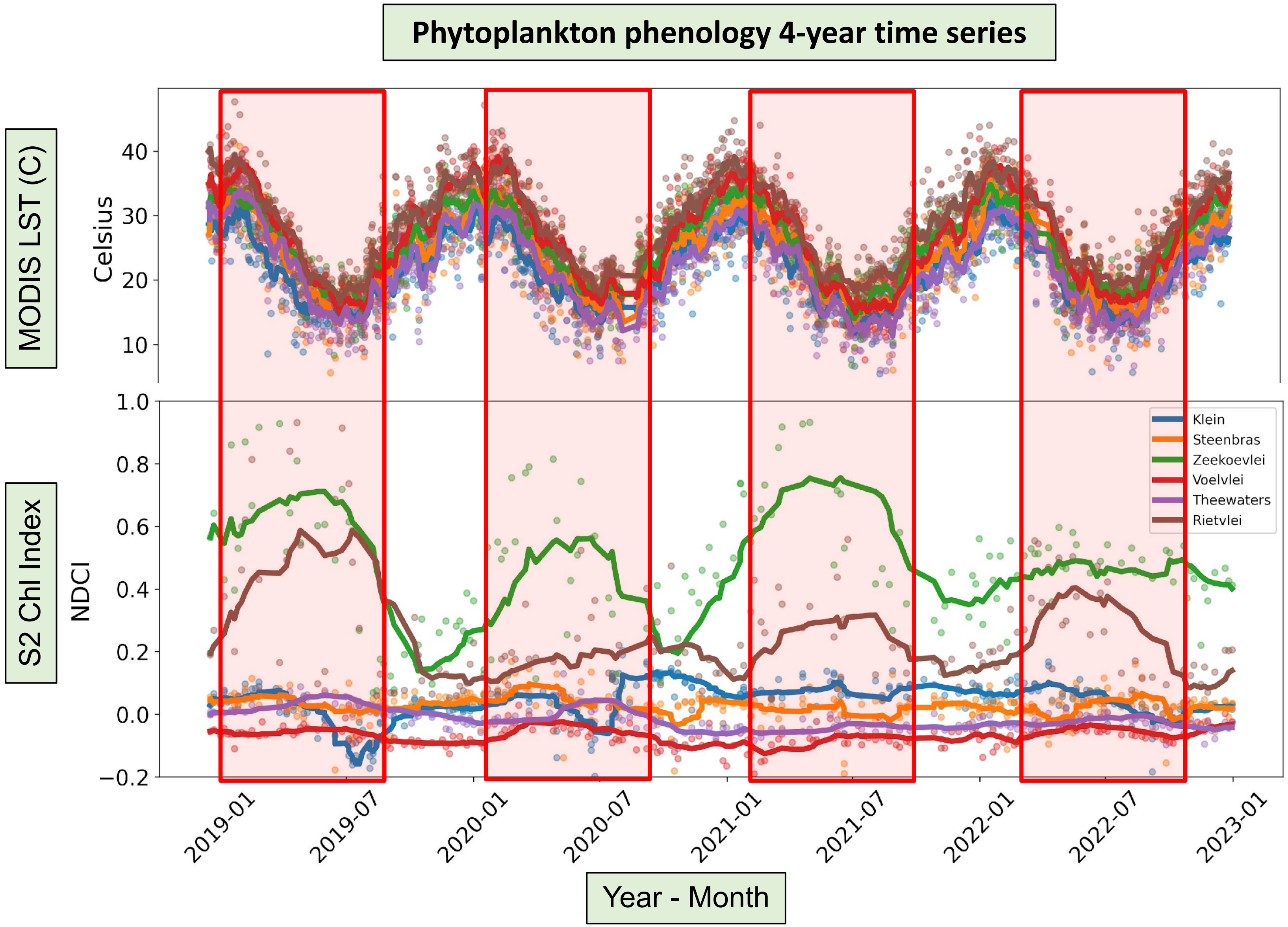
Laboratory

University of Venda – Flow imaging microscopy (FlowCam)

Phytoplankton identification (including cyanobacteria) and enumeration.

Glynn Pindihama and Rabe Mudzielwana have just started work processing water samples with the FlowCam!

Land Surface Temperature and Chlorphyll Index Analysis



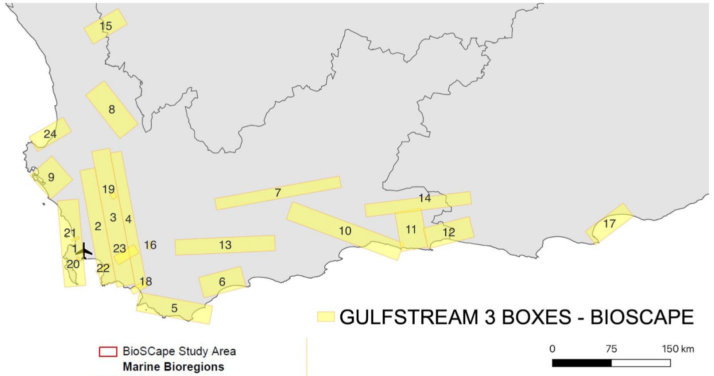
- Four-year time series of Normalized Difference Chlorophyll Index (NDCI), plotted with MODIS Land Surface Temperature (LST) product at each CyanoSCape site
- Algal blooms peak ~3 months after LST peaks at most productive sites
- Most productive sites are those closest to the Cape Town metropolitan area

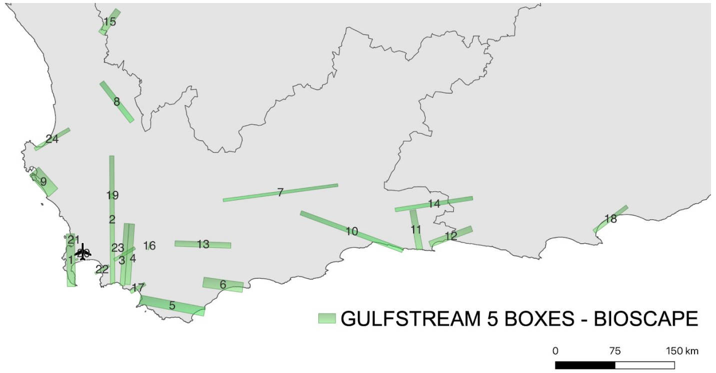
				Airborne		Satellite
Date	Site	Stations	Radiometry	AVIRIS-NG	PRISM	
10/17/2023	Zeekoevlei	A-E	✓ - Spectra Vista			OLCI-S3A/S3B
10/20/2023	Theewaterskloof Dam	A (Buoy)	✓ - Spectral Evolution			
10/23/2023	Zeekoevlei	A-E	✓ - Spectral Evolution + Spectra Vista			DESIS
10/23/2023	Klein River Lagoon, Rietvlei					DESIS
10/26/2023	Zeekoevlei	A-E	✓ - Spectra Vista	✓	✓	
10/26/2023	Rietvlei	A-E	✓ - Spectral Evolution + TriOS Ramses	✓	✓	
10/27/2023	Klein River Lagoon, Rietvlei, Theewaterskloof		✓ - TriOS Ramses on Theewaterskloof Bouy only			DESIS
10/27/2023	Theewaterskloof Dam		✓ - TriOS Ramses on Theewaterskloof Bouy			PRISMA
10/29/2023	Theewaterskloof Dam	A-C, + A (buoy)	✓ - Spectral Evolution + TriOS Ramses + Spectra Vista	✓	✓	
10/31/2023	Klein River Lagoon, Rietvlei, Zeekoevlei					DESIS
11/2/2023	Theewaterskloof Dam		✓ - TriOS Ramses on Theewaterskloof Bouy			PRISMA
11/4/2023	Rietvlei, Zeekoevlei					EMIT
11/5/2023	Rietvlei	A-E	✓ - Spectral Evolution + TriOS Ramses + Spectra Vista			OLCI-S3A/S3B
11/8/2023	Klein River Lagoon	A-E	✓ - TriOS Ramses + Spectra Vista	✓	✓	DESIS
11/8/2023	Theewaterskloof Dam	A-D	✓ - Spectral Evolution + TriOS Ramses (Buoy)	✓	✓	DESIS
11/9/2023	Rietvlei	A-C	✓ - Spectral Evolution + Spectra Vista	✓	✓	
11/10/2023	Theewaterskloof Dam	A (Buoy)	✓ - Spectral Evolution + TriOS Ramses (Buoy)	✓	✓	
11/11/2023	*Theewaterskloof Dam*	*A (Buoy)*	✓ - TriOS Ramses on Theewaterskloof Buoy	✓	✓	
11/13/2023	Theewaterskloof Dam		✓ - TriOS Ramses on Theewaterskloof Buoy			PRISMA
11/14/2023	Theewaterskloof Dam	A (Buoy)	✓ - TriOS Ramses on Theewaterskloof Buoy	✓	✓	
11/14/2023	Rietvlei, Zeekoevlei					PRISMA
11/17/2023	Rietvlei					EMIT
11/17/2023	Rietvlei, Zeekoevlei					DESIS
11/17/2023	Theewaterskloof Dam		✓ - TriOS Ramses on Theewaterskloof Buoy	✓	✓	
11/19/2023	Theewaterskloof Dam		✓ - TriOS Ramses on Theewaterskloof Buoy			PRISMA
11/21/2023	Rietvlei, Zeekoevlei					EMIT
11/22/2023	Theewaterskloof Dam		✓ - TriOS Ramses on Theewaterskloof Buoy	✓	✓	
11/25/2023	Rietvlei, Theewaterskloof, Zeekoevlei		✓ - TriOS Ramses on Theewaterskloof Bouy only			EMIT
11/25/2023	Zeekoevlei					DESIS
11/25/2023	Theewaterskloof Dam		✓ - TriOS Ramses on Theewaterskloof Bouy			PRISMA

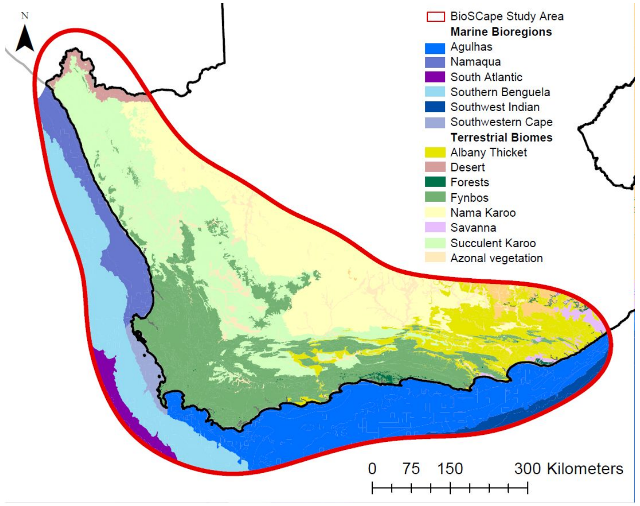
BioSCape Field Campaign (Oct-Nov 2023)

CyanoSCape:

- Successful field campaign with ~22 days of data collected (airborne/satellite coincident with field data).
- 11 (G-III) flights included CyanoSCape study sites.
- CyanoSCape's Theewaterskloof Dam site - BioSCape Cal/Val with hyperspectral radiometer buoy and thermal ring.







G-V	LVIS	Land, Vegetation, and Ice Sensor (Laser Altimeter)
	HyTES	Hyperspectral Thermal Emission Spectrometer
G-III	PRISM	Portable Remote Imaging Spectrometer
	AVIRIS-NG	Airborne Visible-Infrared Imaging Spectrometer (NextGen)


a b c d

a: Field radiometry collection at Theewaterskloof Dam by Ryan O'Shea (GSFC) and Lisl Lain (CSIR).
b: Field radiometry collection at Rietvlei by Jeremy Kravitz (SGE) skippered by Samantha Sharp (SGE).
c: Glynn Pindihama and Rabe Mudzielwana, filtering water samples at CSIR.
d: CyanoSCape team contemplating ac-s operations at CSIR.
Photos: S. Sharp, H. Pillay, L. Guild

CyanoSCape Freshwater Phytoplankton Biodiversity

Motivation:

- The **phytoplankton biodiversity of SA freshwater systems is not well characterized**.
- Anthropogenic practices have hindered hydrological processes and **compromised riverine and aquatic ecosystems**.
- These impacts are compounded by the effects of **increasingly variable rainfall and temperature fluctuations** associated with climate change.
- The biodiversity of **freshwater phytoplankton includes cyanobacteria, some that are harmful**.
- The increased incidence of cyanobacteria and harmful bloom conditions is related to **nutrient over-enrichment from agriculture, urban, and industrial practices and climate change**.
- **Harmful cyanobacteria can produce toxins** (e.g., Microsystin) that cause hepatoxic (liver disease) and neurotoxic effects in humans and animals and can lead to mortality.