CyanoSCape

Freshwater Phytoplankton and Floating Aquatic Vegetation Biodiversity

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CyanoSCape Importance

- The phytoplankton biodiversity of SA freshwater systems is not well characterized. Anthropogenic practices have compromised riverine and aquatic ecosystems.
- The biodiversity of freshwater phytoplankton includes cyanobacteria, some that are harmful.
- 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.
- Eutrophic conditions are also conducive to invasive floating aquatic vegetation (FAV), like water hyacinth.

CyanoSCape Goal

Goal: Utilize hyperspectral data with recently developed and next-generation algorithms to:

- Determine the biodiversity of freshwater systems phytoplankton assemblage with emphasis on genus level distinction, including potentially toxic cyanobacteria and;
- Monitor the prevalence and diversity of FAV that favor these environments.

CyanoSCape Objectives

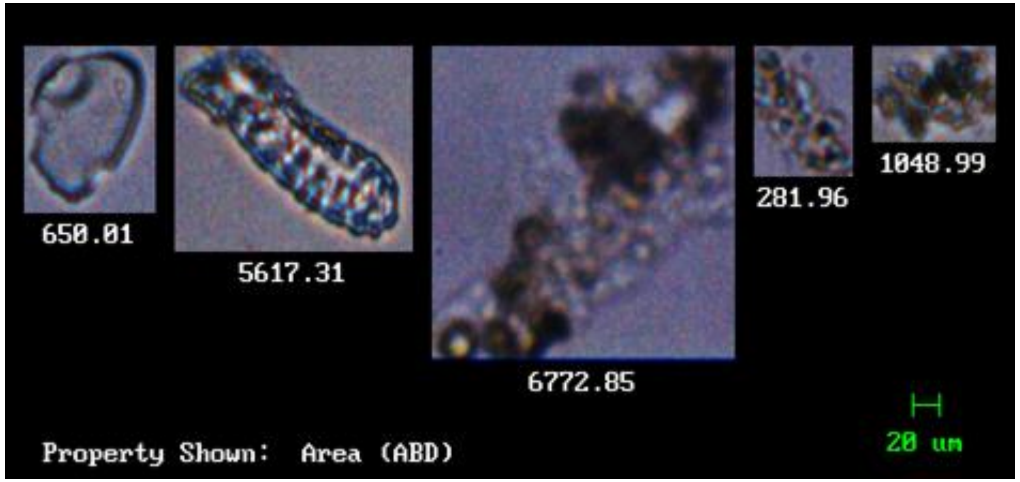
Objective 1: Apply and test the capability of published and next-generation algorithms for hyperspectral delineation of the phytoplankton assemblage and FAV biodiversity

- Remote sensing
  - **Seasonality of phytoplankton and FAV.** Build on historic time series (MERIS, Mathews 2014) with Landsat 8 OLI, and Sentinel 2 MSI, Sentinel 3 OLCI. Review MODIS, VIIRS for scale.
  - **Opportunistic satellite data collection during airborne campaign** (+/- 1 hr of airborne flight over field sites) Landsat and Sentinel (possibly MODIS, VIIRS).
  - **AVIRIS-NG and PRISM hyperspectral data.**
- Radiative Transfer Modeling will produce a synthetic dataset to train an emulator to output water quality and Phytoplankton Functional Type (PFT) products
- Machine learning and artificial neural network will be used for Phytoplankton Class/PFT level
- Mapping floating aquatic vegetation and connection with cyanobacteria blooms
- Errors and uncertainties

CyanoSCape Objectives

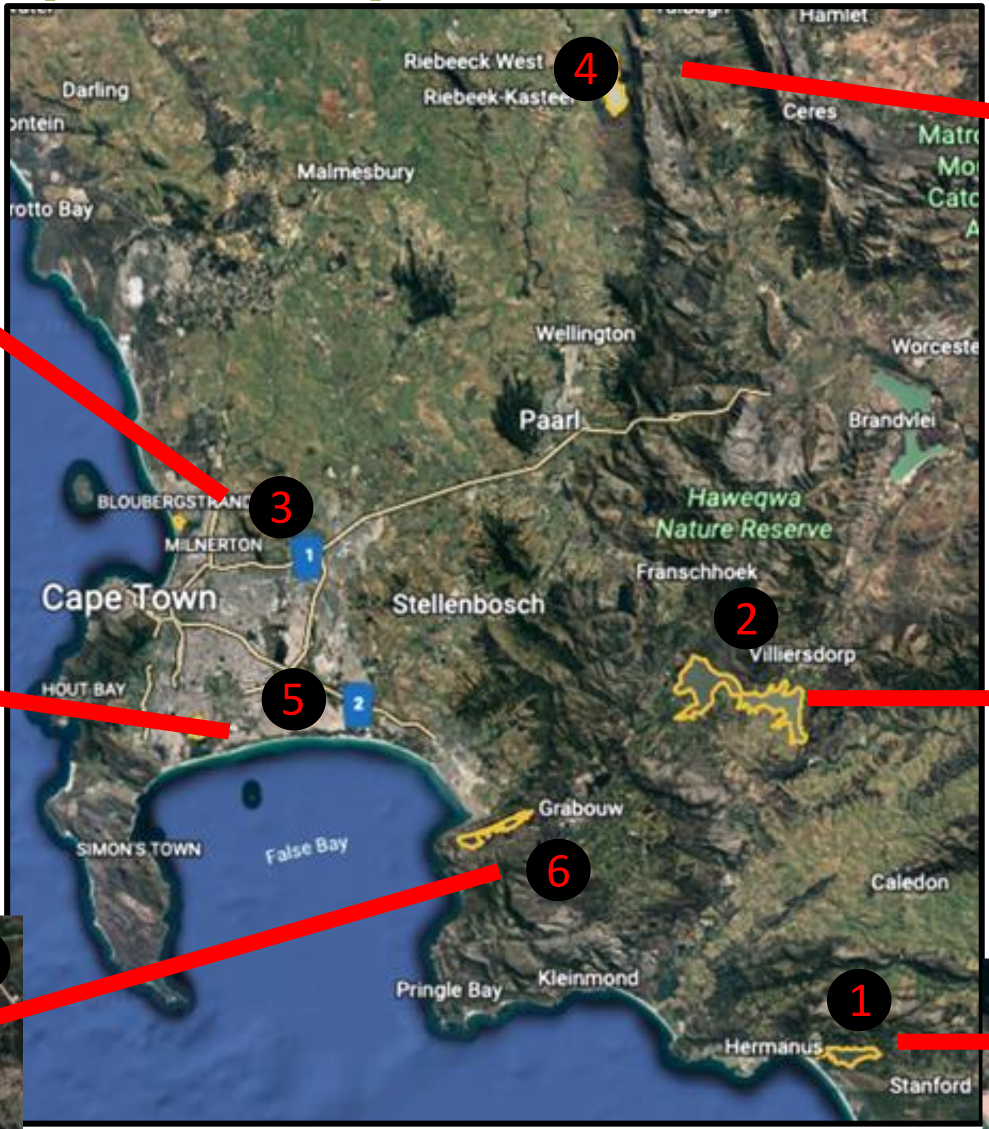
Objective 2: Phytoplankton community and FAV diversity

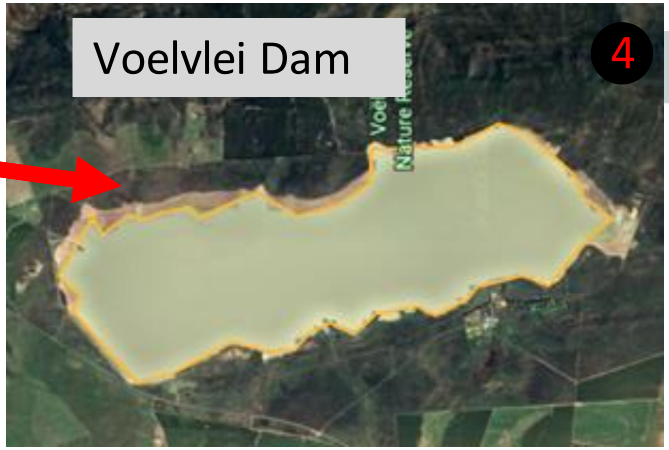
- Field - 4-5 stations during overflights:
  - Field spectroscopy
  - Apparent optical properties (AOPs)
  - Water sampling for microscopic analysis of phytoplankton and cyanobacteria
  - Aerosol optical thickness (AOT) for atmospheric correction
- Flow imaging microscopy (FlowCAM)
  - Phytoplankton enumeration and cyanobacterial identification
- Chlorophyll a fluorometric and HPLC pigment analysis

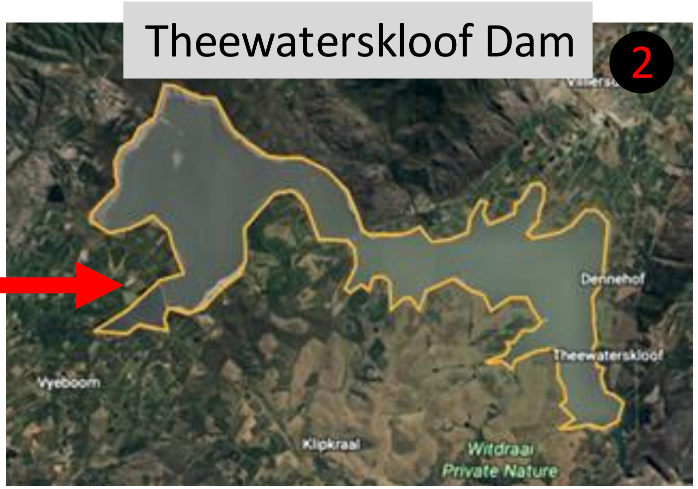


Example of harmful cyanobacteria identified using FlowCam microscopy: *Anabaena* (650.01); Dinoflagellate spp. (5617.31); *Microcystis* (6772.85, 281.96, 1048.99). Credit: Univ. of Venda.

CyanoSCape Sites



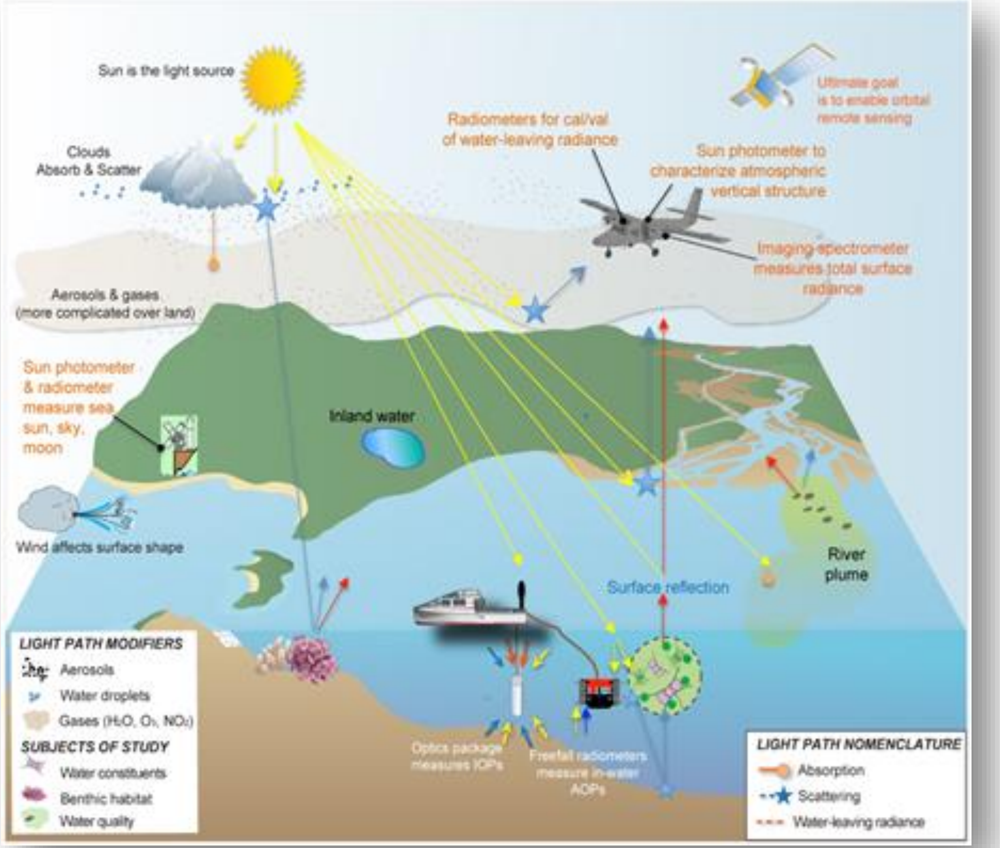




Note: Numbers in order of priority.

Flight Planning

- Avoidance of sunglint
- Avoidance of rough waters with white caps
- Cloud-free data, or nearly so
- Optimizing flight lines for science quality data
- Other considerations
  - Satellite matchup: overpass timing aligned with +/- 1 hr of aquatic field sampling
  - Satellite overpass prediction tool: [Overpass Predictions Home (nasa.gov)]

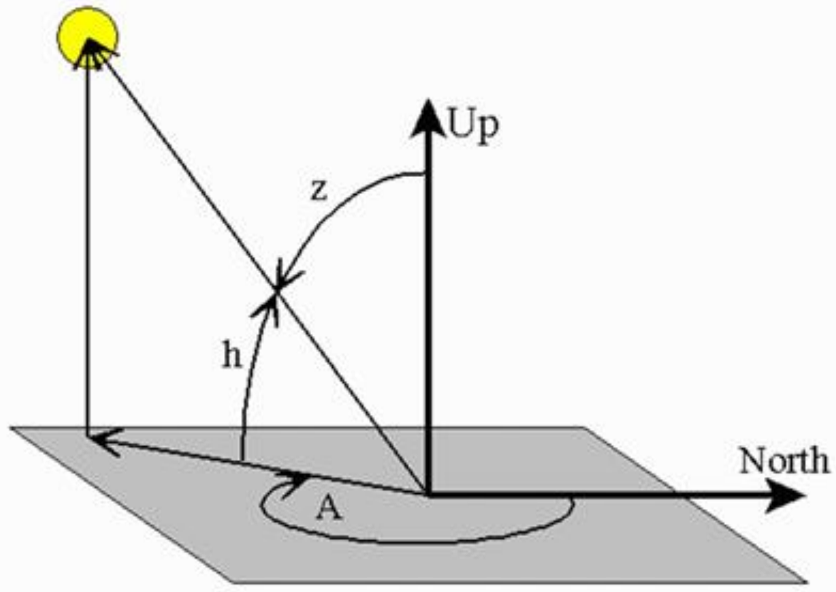


Concept of operations. Credit: Raphe Kudela (UC Santa Cruz)

Credit: Guild et al (2020), Airborne Radiometry for Calibration, Validation, and Research in Oceanic, Coastal, and Inland Waters. Front. Environ. Sci. 8:585529. DOI: 10.3389/fenvs.2020.585529.

Flight Planning

- Consider solar geometry
- Aircraft flying the nose of the aircraft into and out of the Sun mitigates sunglint
- Aircraft pitch (nose up/down), roll (wings up/down), and yaw (aircraft heading and influenced by wind) may impact some airborne sensor performance.



Credit: Guild et al (2020), Airborne Radiometry for Calibration, Validation, and Research in Oceanic, Coastal, and Inland Waters. Front. Environ. Sci. 8:585529. DOI: 10.3389/fenvs.2020.585529.

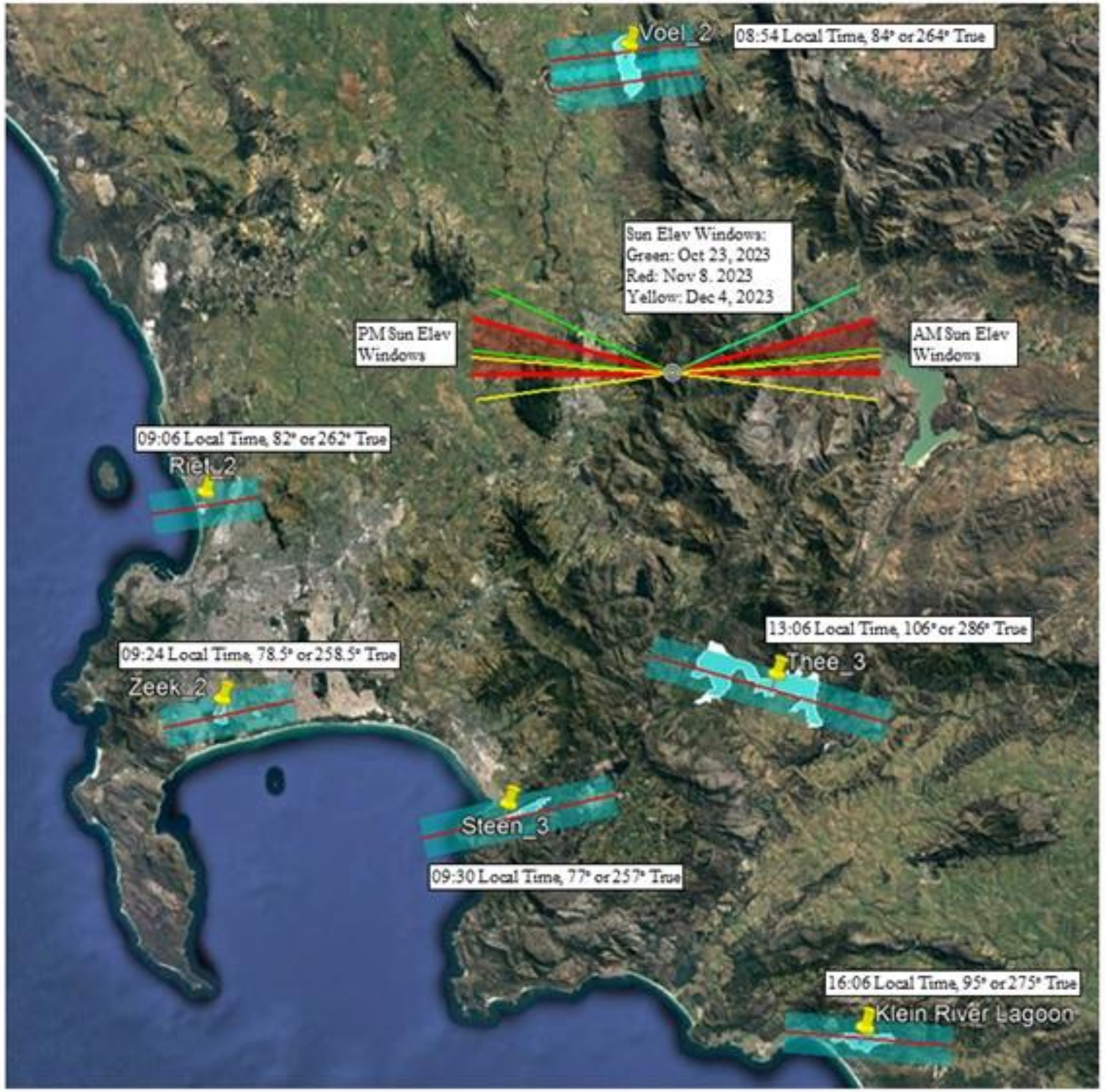
Flight Planning Window

Acceptable Sun Elevation Range: 30 to 50 deg.

Example dates: 23 Oct (green), 8 Nov (red), & 4 Dec 2023 (yellow)
Magnetic Variation Used: 25 deg W

Morning Sun Elevation Window using 8 Nov:
- Start: 08:12 Local Time, Solar Az = 89.83 True, 114.83 Magnetic
- End: 09:42 Local Time, Solar Az = 75.08 True, 100.08 Magnetic

Afternoon Sun Elevation Window:
- Start: 15:06 Local Time, Solar Az = 285.96 True, 310.96 Magnetic
- End: 16:42 Local Time, Solar Az = 270.0 True, 295.0 Magnetic



Credit: Jim Eilers (NASA Ames)

Flight Planning by Date

Acceptable Sun Elevation Range: 30 to 50 deg.

Example date: 15 Oct 2023
Magnetic Variation Used: 25 deg W

Morning Sun Elevation Window:

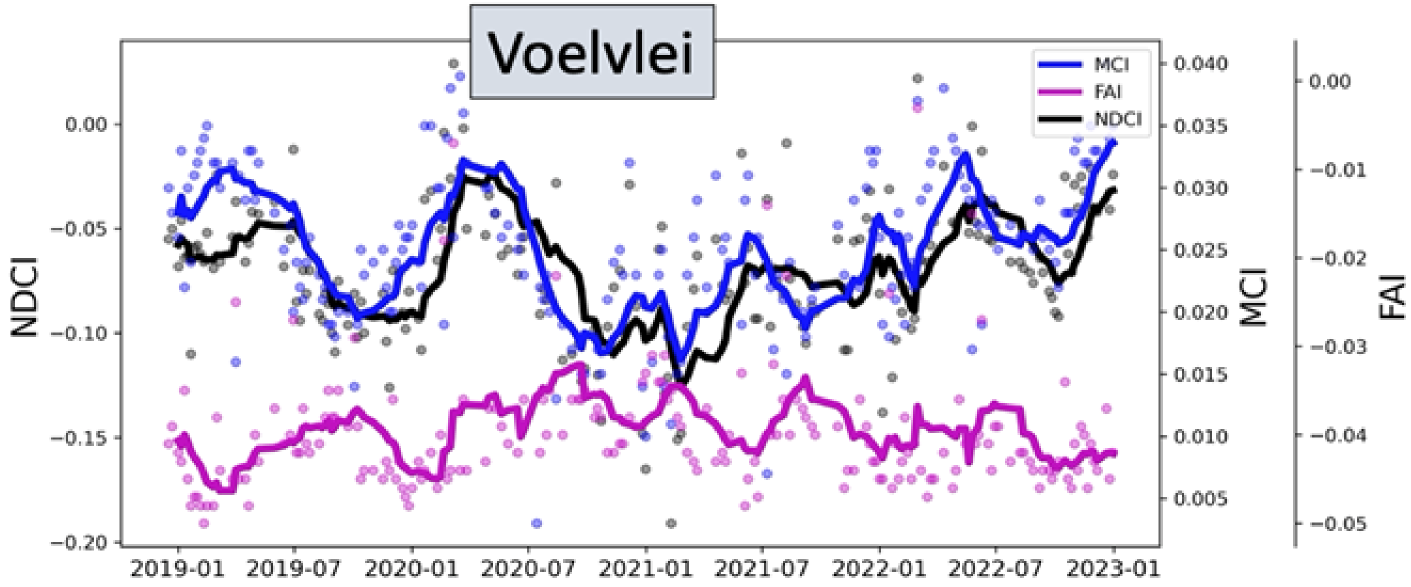
- Start: 08:36 Local Time, Solar Az = 78.58 True, 103.58 Magnetic
- End: 10:12 Local Time, Solar Az = 58.90 True, 83.90 Magnetic

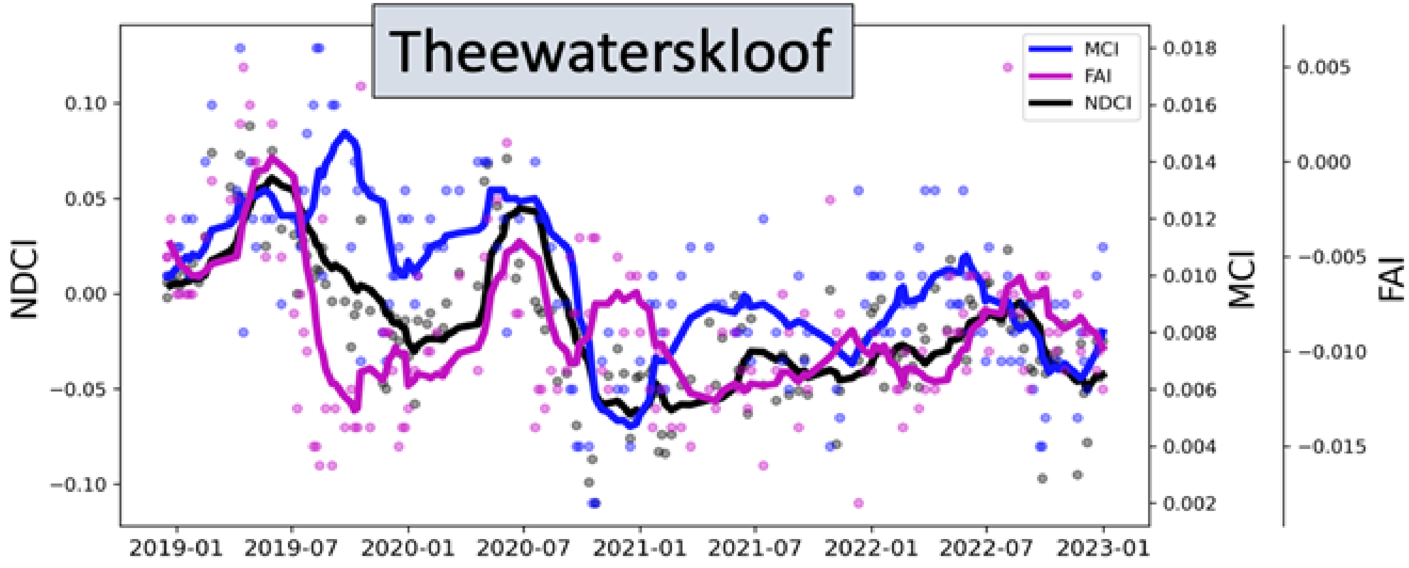
Afternoon Sun Elevation Window:

- Start: 12:48 Local Time, Solar Az = 300.46 True, 325.46 Magnetic
- End: 16:24 Local Time, Solar Az = 280.95 True, 305.95 Magnetic

Credit: Jim Eilers (NASA Ames)

Rationale for sites selection





Normalized Difference Chlorophyll Index (NDCI)

$$\text{NDCI} = \frac{\text{Red edge 1} - \text{Red}}{\text{Red edge 1} + \text{Red}}$$

Maximum Chlorophyll Index (MCI)

Floating algal Index (FAI)

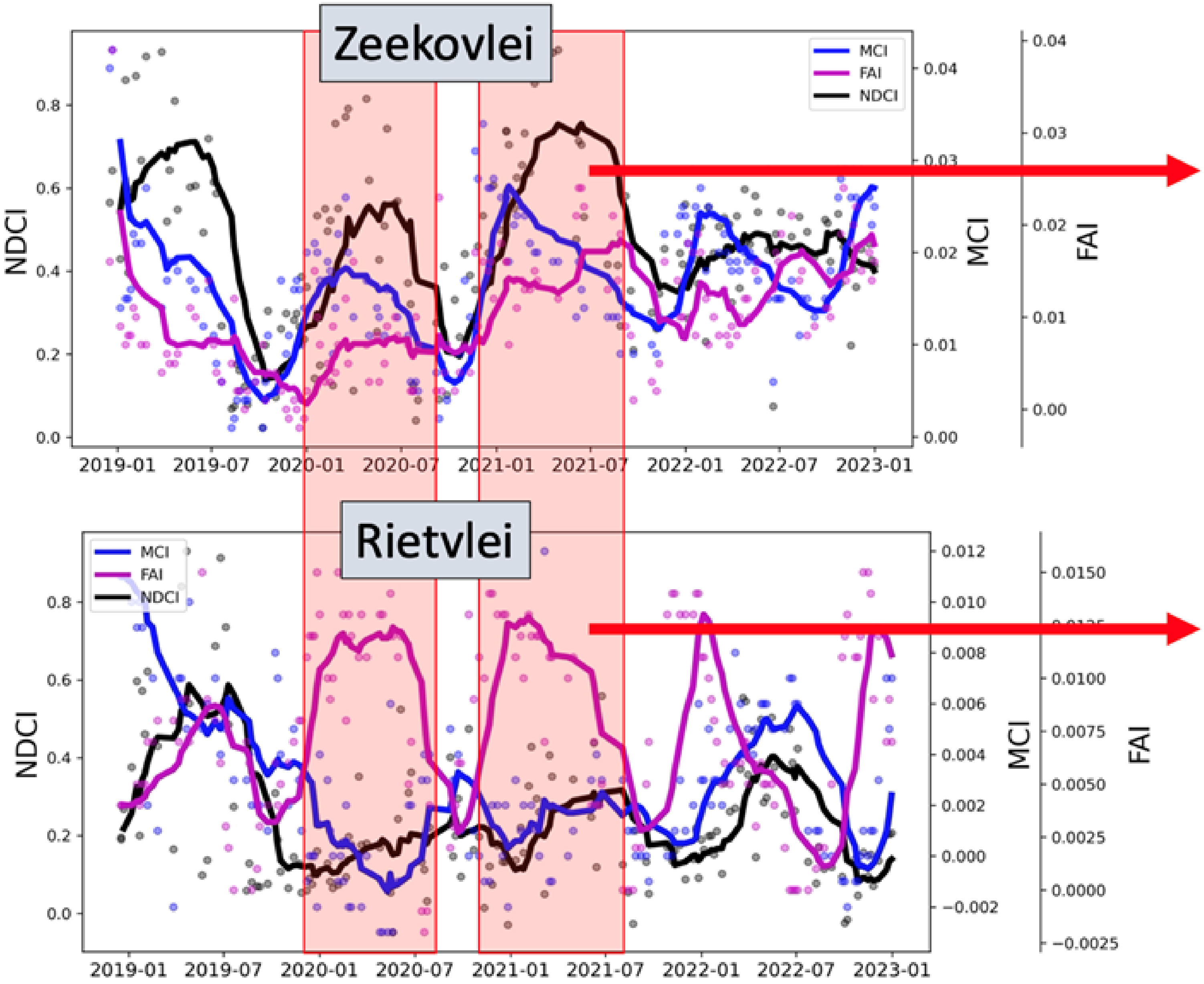
MCI bands : B4, B5, B6

FAI bands : B4, B6, B8

$$\text{Chl} - \text{a} \propto R(\lambda_2) - R(\lambda_1) + \left(R(\lambda_1) - R(\lambda_3)\frac{(\lambda_2 \_ \lambda_1)}{(\lambda_3 - \lambda_1)}\right)$$

- Four year time series (2019- 2022) of algal indices for all 6 potential sites.
- Average value of entire dam for each overpass
- Cloud and land masked

Credit: Kravitz (unpublished)

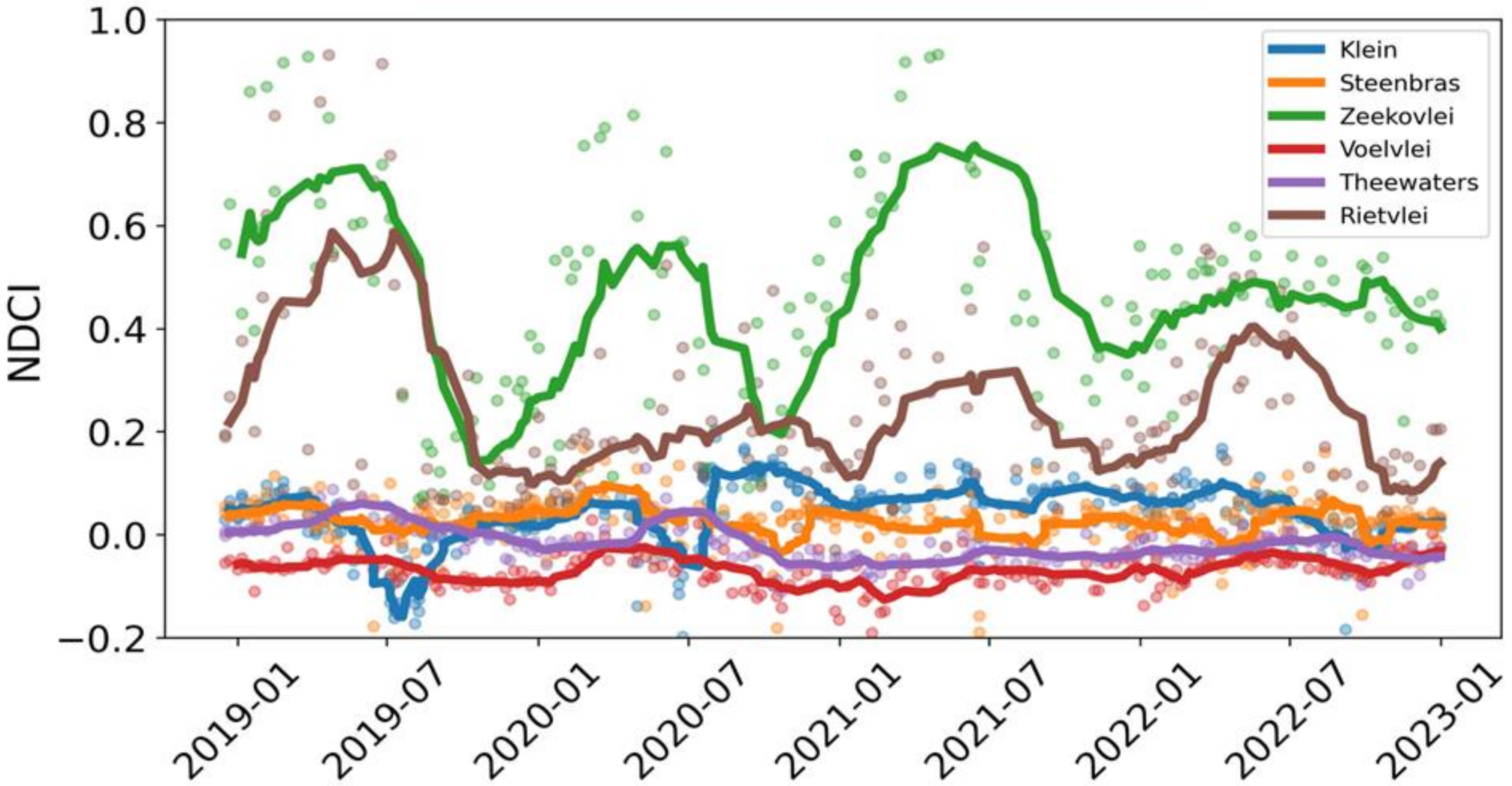


Algal blooms during and after the hot summer months and receding into the rainy winter season.

FAI only bloom could imply floating vegetation or benthic influence from water level change

Credit: Kravitz (unpublished)

NDCI Comparison of All Dams



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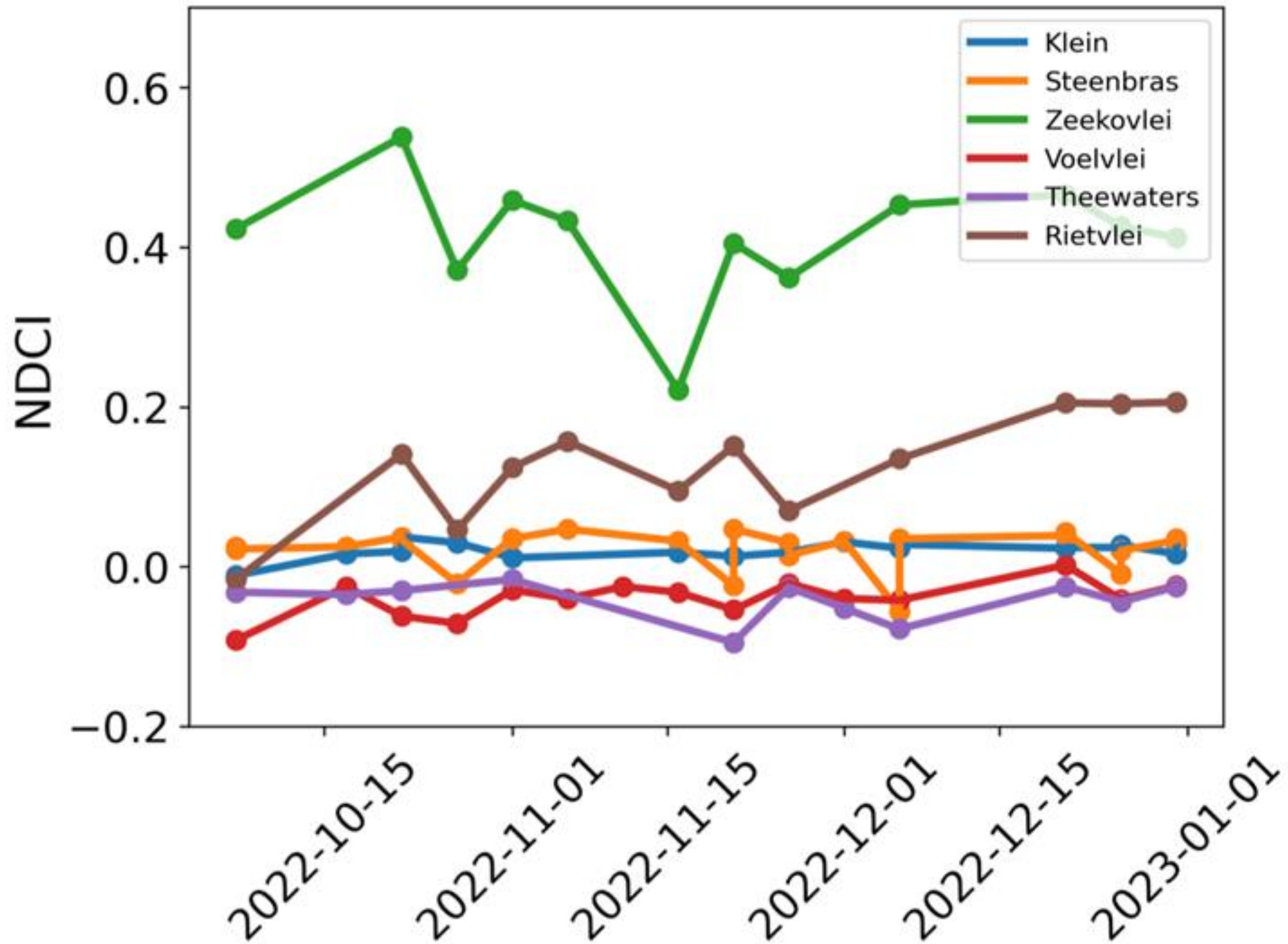


Short time series for timeframe of Airborne campaign in 2023

Credit: Kravitz (unpublished)

Fieldwork During Sensor Overpass

Sample Collection

- Inland: 4-5 stations, water collection by bucket/sample bottles

Matchups

- +/- 1 hour of overpass (PRISM, AVIRIS-NG)
- Solar elevation angle of 30-50 deg to avoid sunglint
- Nose of aircraft to fly into and out of solar azimuth

Radiometric Validation

- Simultaneous radiometric measurements with diverse instruments
- Mooring systems: Trios Ramses radiometers

Pigments:

- Chl-a, Phycocyanin

Optics

- Field: ACS, BB9 – Absorption, Attenuation, Backscatter
- Lab: Particulate/Dissolved Absorption with spectrophotometry

Phytoplankton ID

- Inland: FlowCam flow cytometry

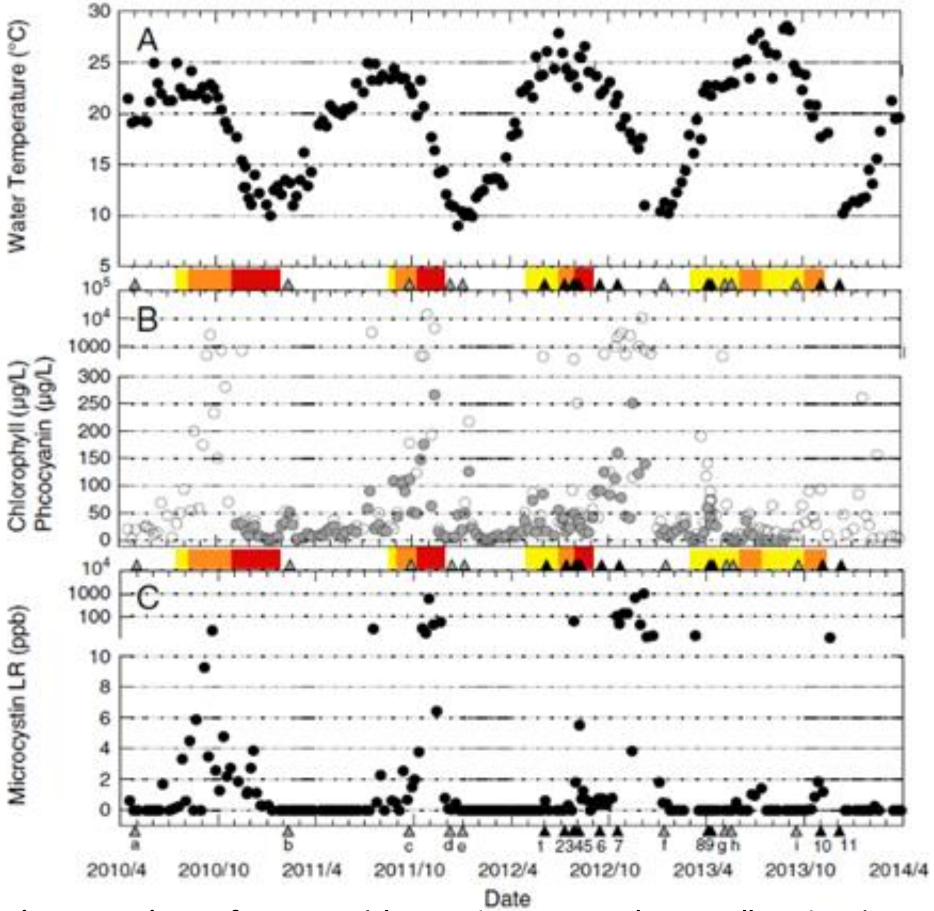
Pinto Lake, California.
Credit L. Guild & S. Palacios.

Example of previous Hyperspectral Coastal Observations with Hyperspectral Imagery - Pinto Lake, CA, USA

Algorithms developed/applied to spectral data.
CI = Cyanobacteria Index, SLH = Scattering Line Height,
AMI = *Aphanizomenon-Microcystis* Index. Kudela et al. 2015.

Algorithm	Formulation
CI	$CI = -SS(681)$
	$SS(681) = Rrs_{681} - Rrs_{665} - [Rrs_{709} - Rrs_{665}] \times \frac{(681\ \text{nm} - 665\ \text{nm})}{(709\ \text{nm} - 665\ \text{nm})}$
SLH	$SLH = Rrs_{714} - [Rrs_{654} + \frac{Rrs_{754} - Rrs654}{754nm - 654nm}(714\ \text{nm} - 654\ \text{nm})]$
AMI	AMI = peak width/dip width = [640 – 510 nm] / [652 – 625 n

Cyanobacterial layer formed at the water surface in Pinto Lake, CA. Credit: Liane Guild (NASA Ames)



Time series of ~ weekly water samples collected showing (A) water temp, (B) chlorophyll (open circles) and phycocyanin (shaded circles) concentration, and microcystin LR concentrations. Kudela et al. 2015

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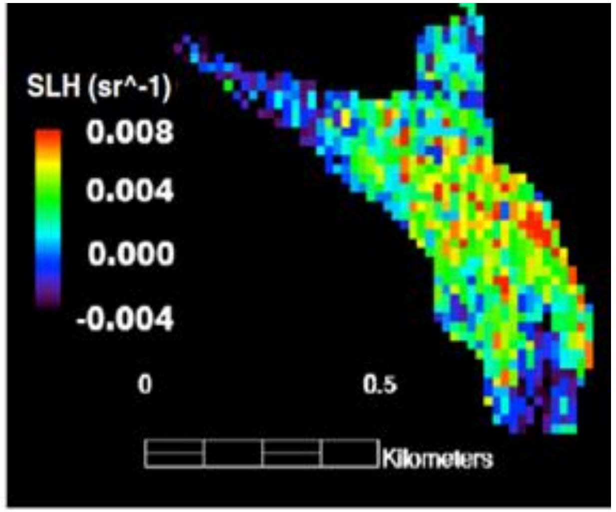
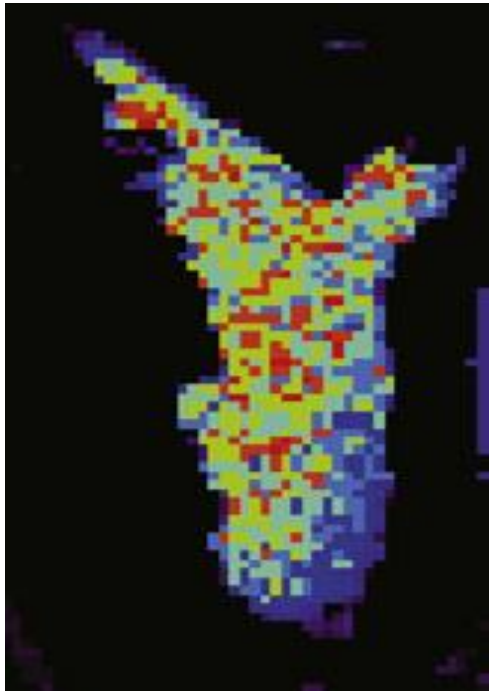


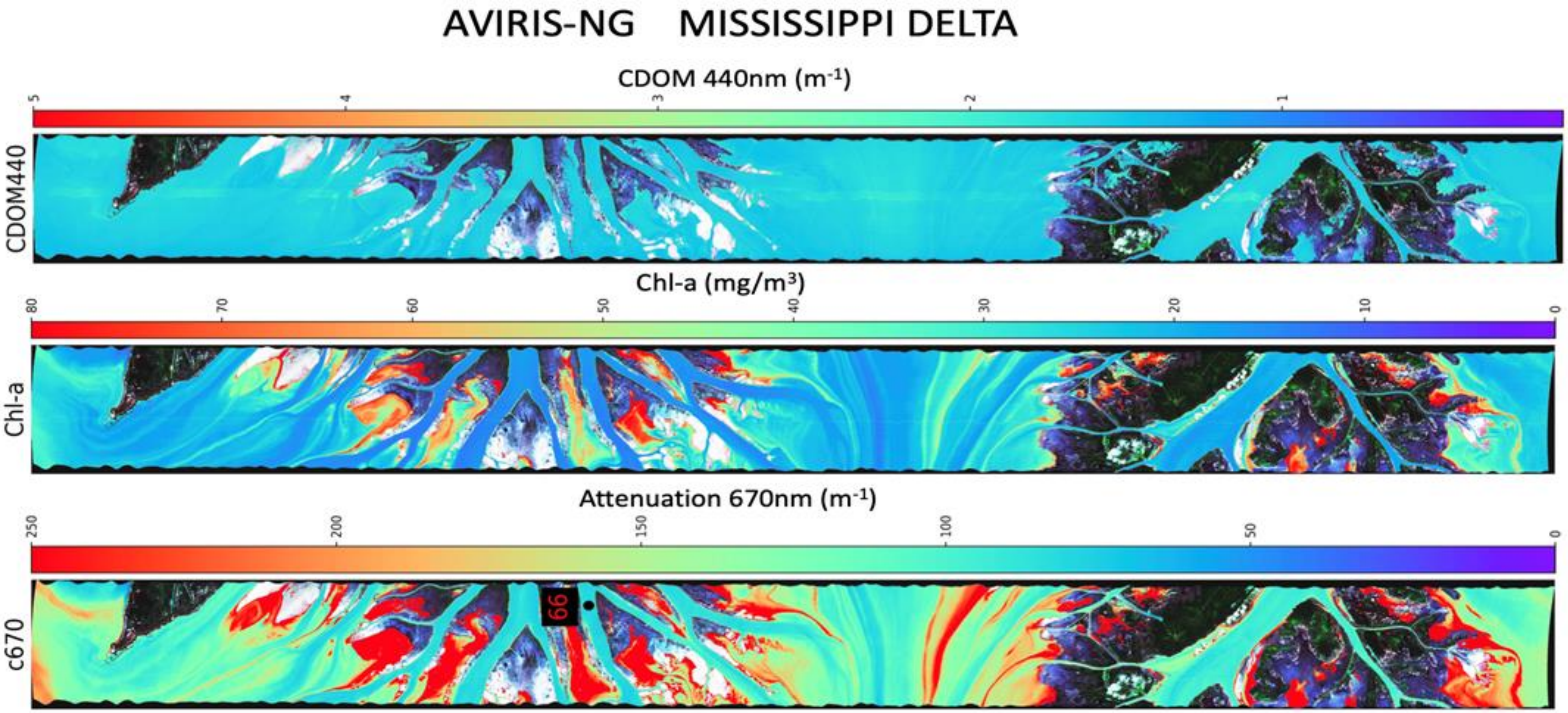
Scattering Line Height (SLH) for Pinto Lake, CA. Warm colors indicate the probability of a cyanobacterial bloom and validated with in situ observations. Kudela et al. 2015.



Cyanobacteria Index (CI) for Pinto Lake, CA using AVIRIS imagery for 31 October 2013. Kudela et al. 2015.

Credit: Kudela, Raphael M., Sherry L. Palacios, David C. Austerberry, Emma K. Accorsi, Liane S. Guild, Juan Torres-Perez, 2015, *Application of Hyperspectral Remote Sensing to Cyanobacterial Blooms in Inland Waters*, Remote Sensing of Environment, DOI: 10.1016/j.rse.2015.01.025.

Example of previous Airborne Hyperspectral Coastal Observations with AVIRIS-NG



Credit: Kravitz, Simard, Thompson, Brodrick, et al. (unpublished)

Modeling of Laboratory Data for PFTs Derivation

75 species of laboratory Culture Measurements of chl-a Specific absorption

↓

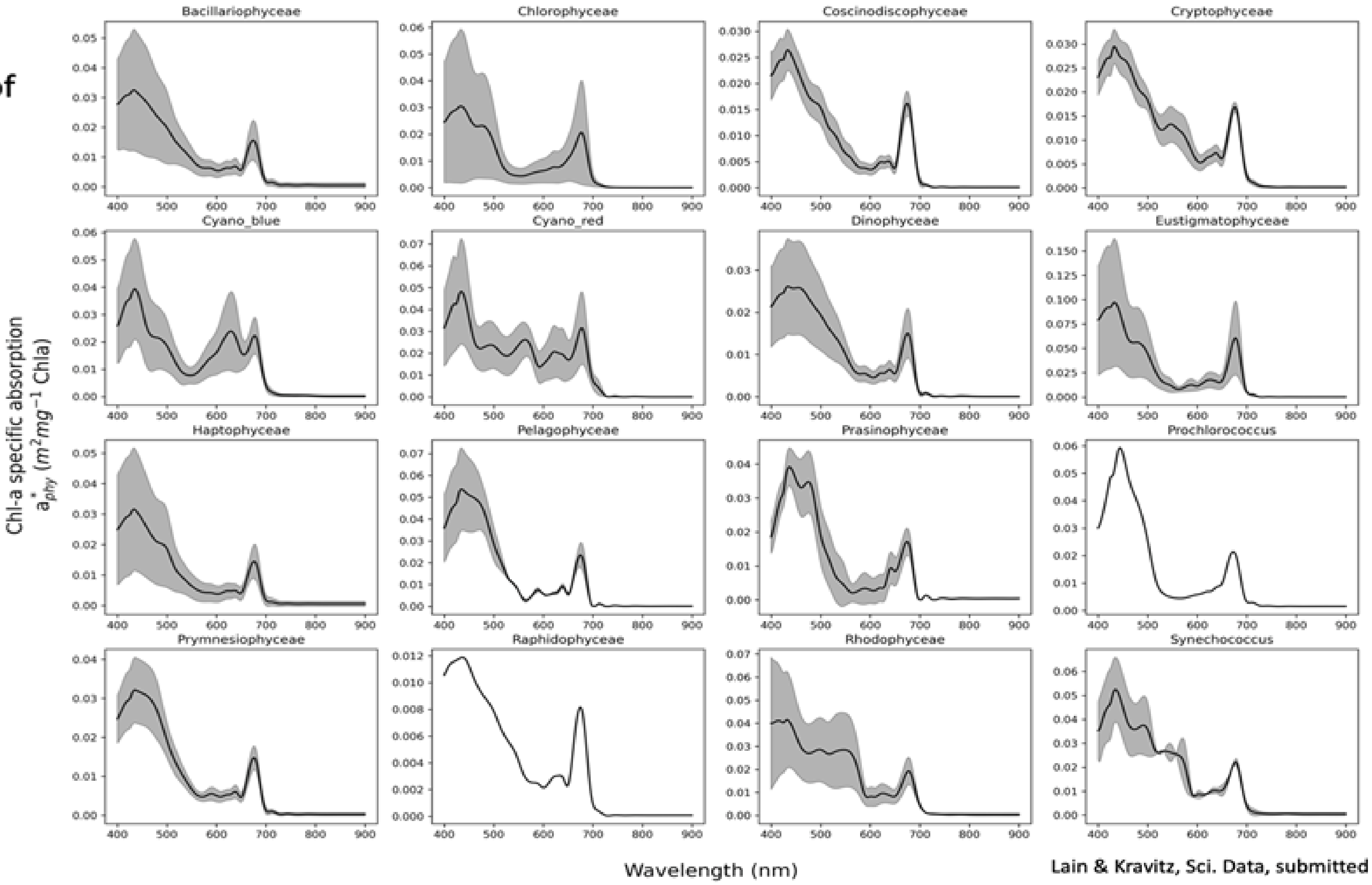
Calculate imaginary Refractive indices (absorption)

↓

Kramers-Kronig Eqs. Derive real Refractive indices (scatter)

↓

Derive species Specific IOPs (absorption, scatter, Backscatter)

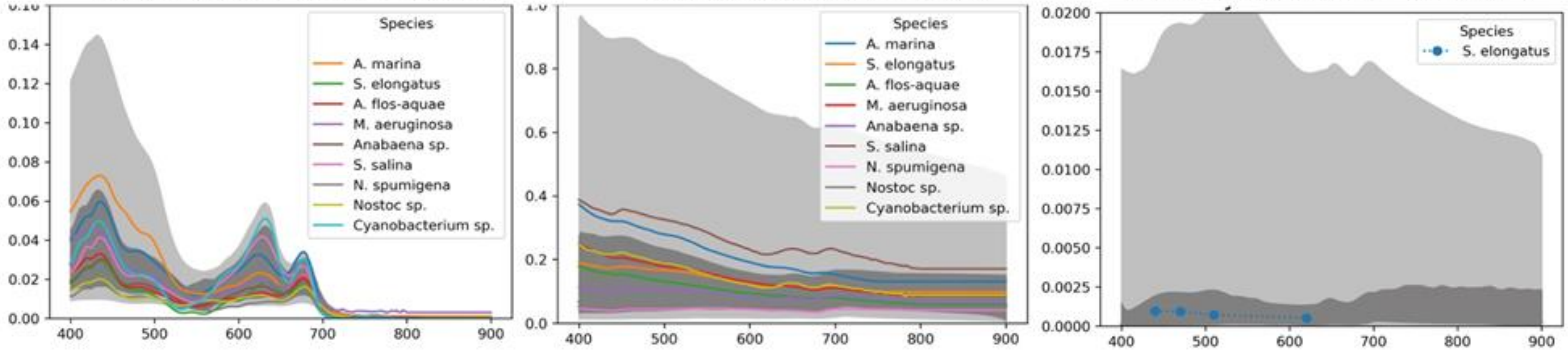


Lain & Kravitz, Sci. Data, submitted

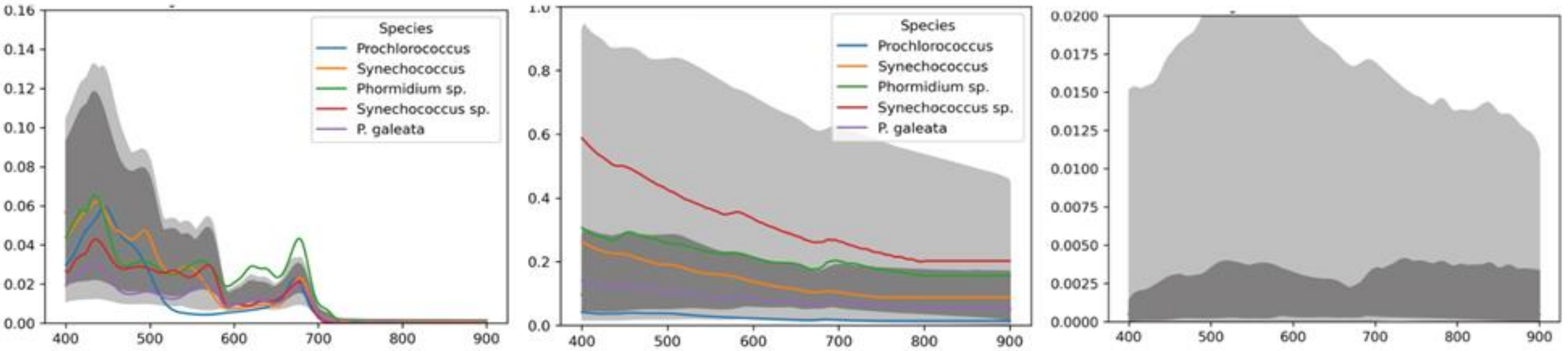
Identification of Dominant Cyanobacterial Groups

Cyanobacteria – "Blue mode" – Phycocyanin dominant

Specific absorption (m^2/mg^{-1}) | Specific scatter (m^2/mg^{-1}) | Specific backscatter (m^2/mg^{-1})

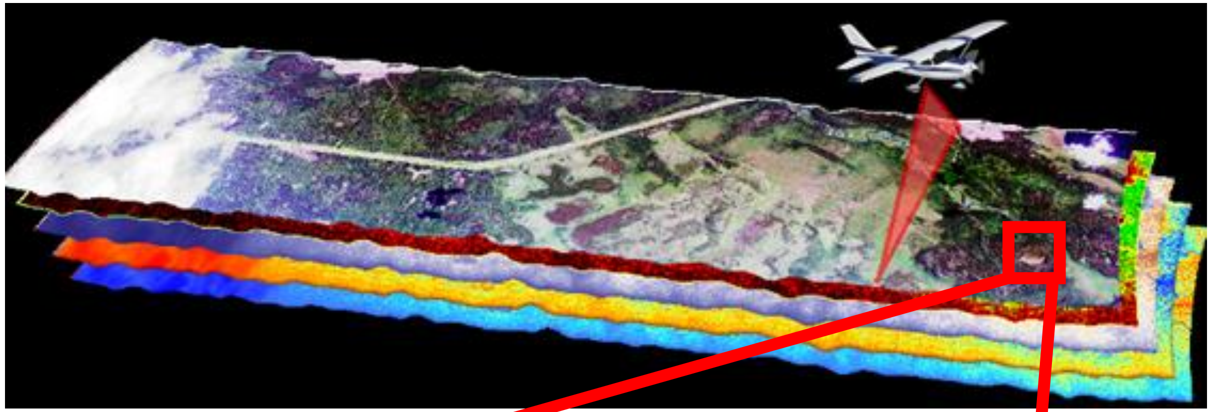


Cyanobacteria – "Red mode" – Phycoerythrin dominant

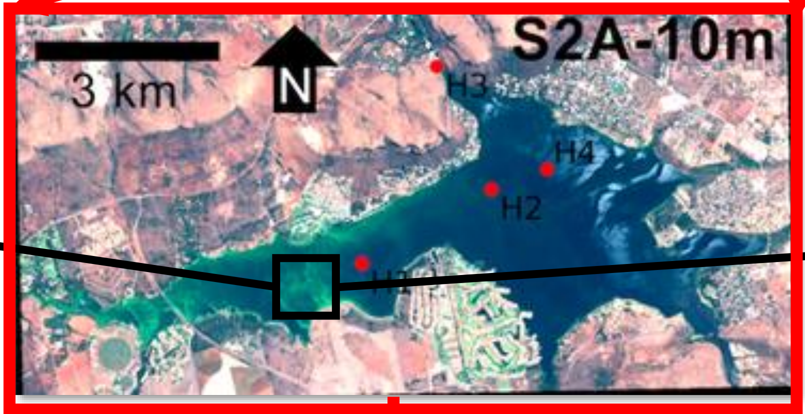


Credit: Kravitz (unpublished)

Hartbeespoort Dam, SA

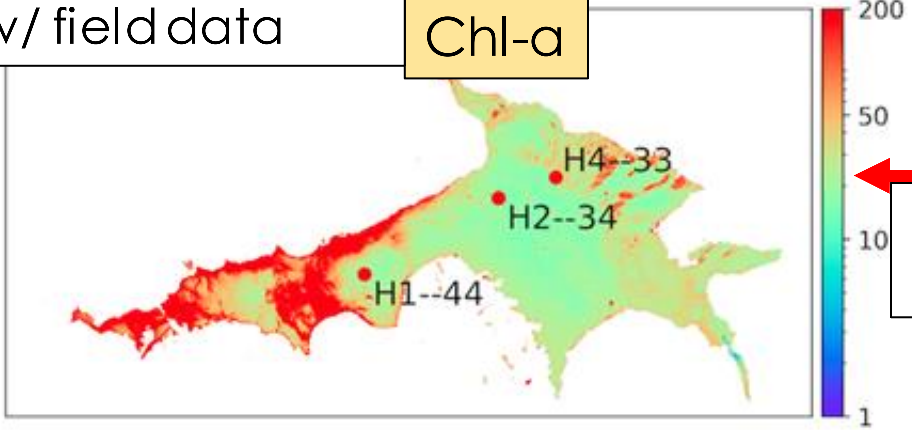


Airborne Data



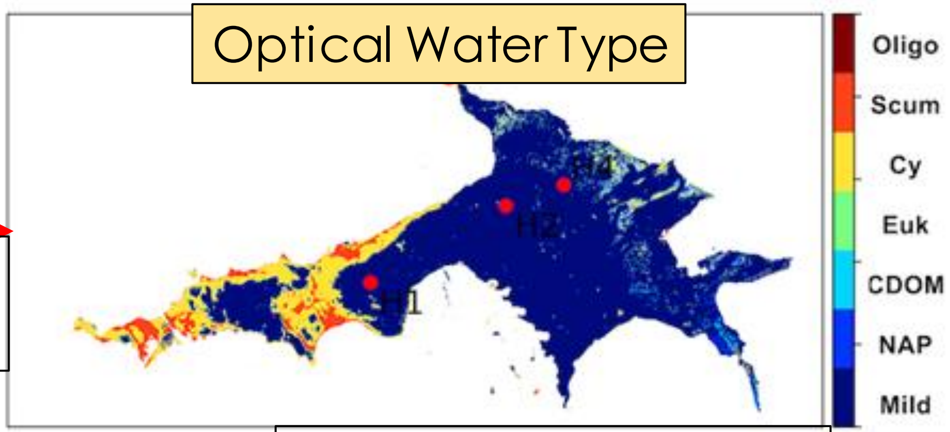
Matchup validation w/ field data

Chl-a



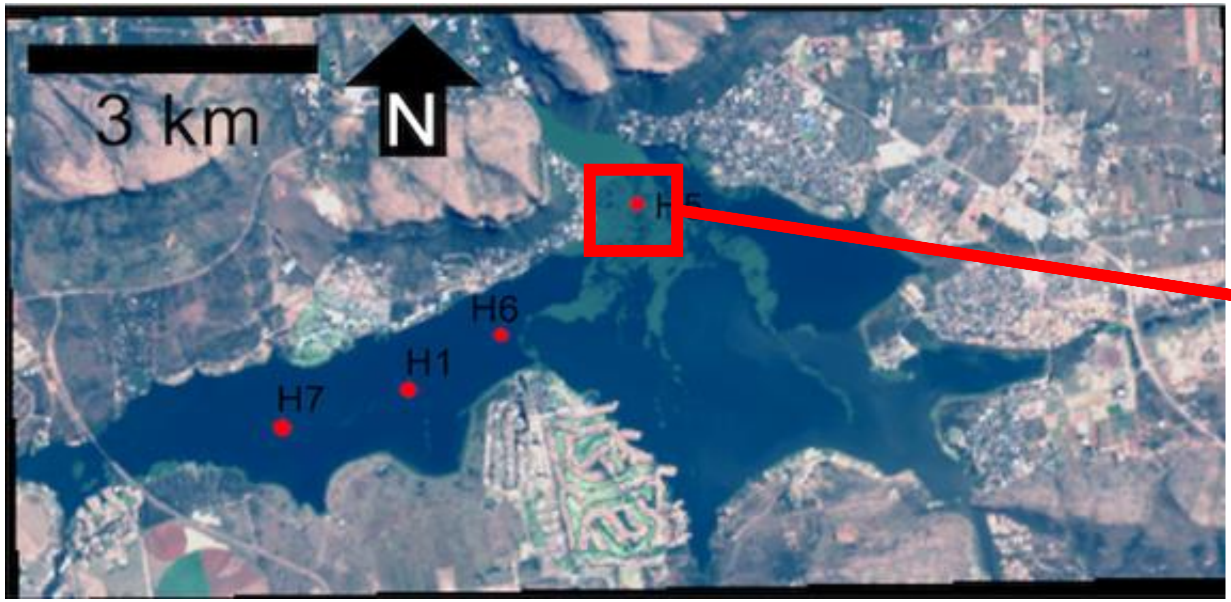
Machine Learning

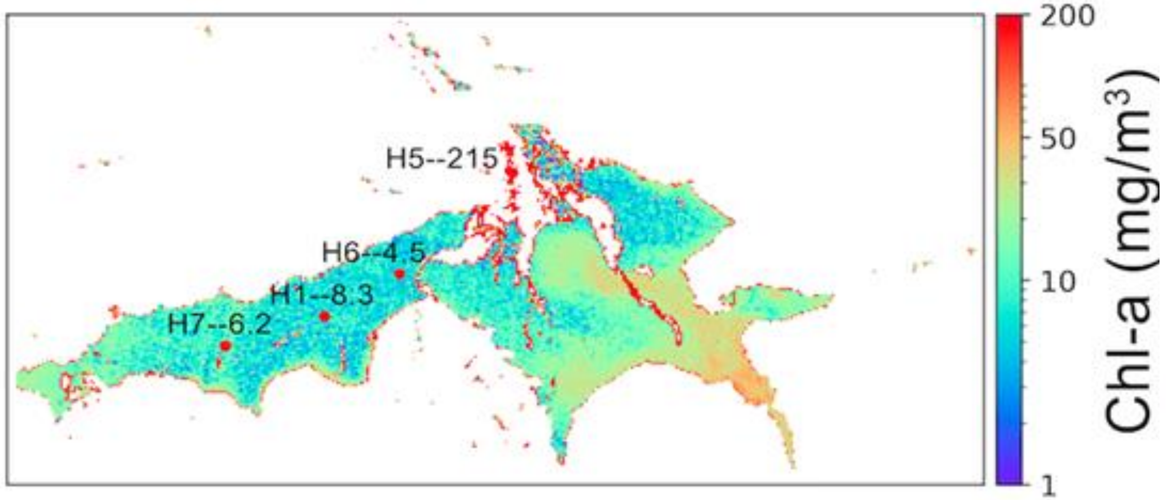
Optical Water Type

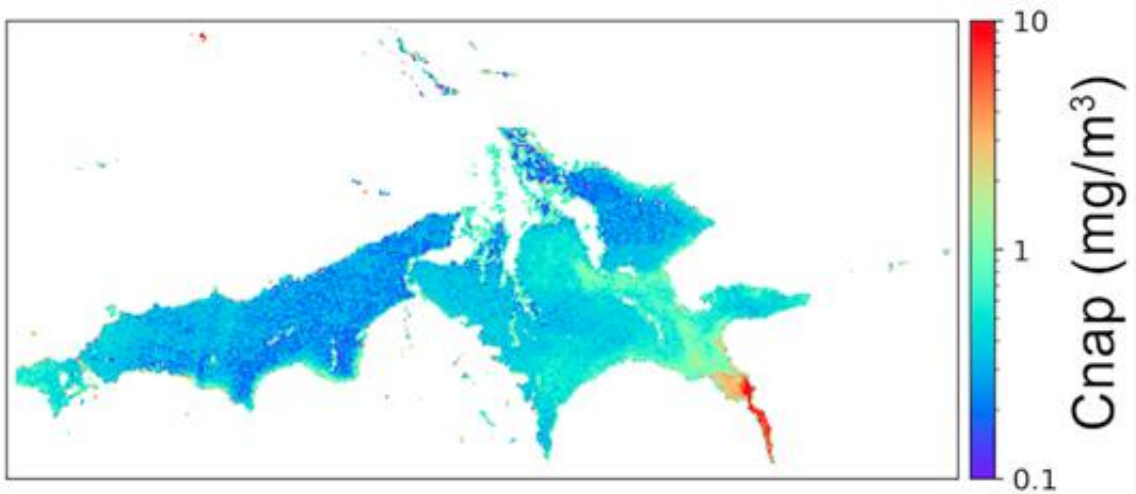


Credit: Kravitz et al. (2021)

Mapping Floating Aquatic Vegetation and Cyanobacterial Blooms







Credit: Kravitz et al. (2021)

Summary

- Airborne campaigns tied with intensive field efforts provide unique opportunities for the characterization of terrestrial and aquatic ecosystems.
- Sites selection are usually based on needs and accessibility.
- Flight Planning is critical as it may present particular challenges especially for aquatic targets.
- Consideration of phenology, seasonality, atmospheric conditions, etc.
- For aquatic targets, the fieldwork needs to be aligned with the airborne campaign and opportunistic satellite overpasses due to the constant changes in water column composition.
- Analyses and modeling facilitated by machine learning techniques help processing such large datasets collected by airborne sensors.