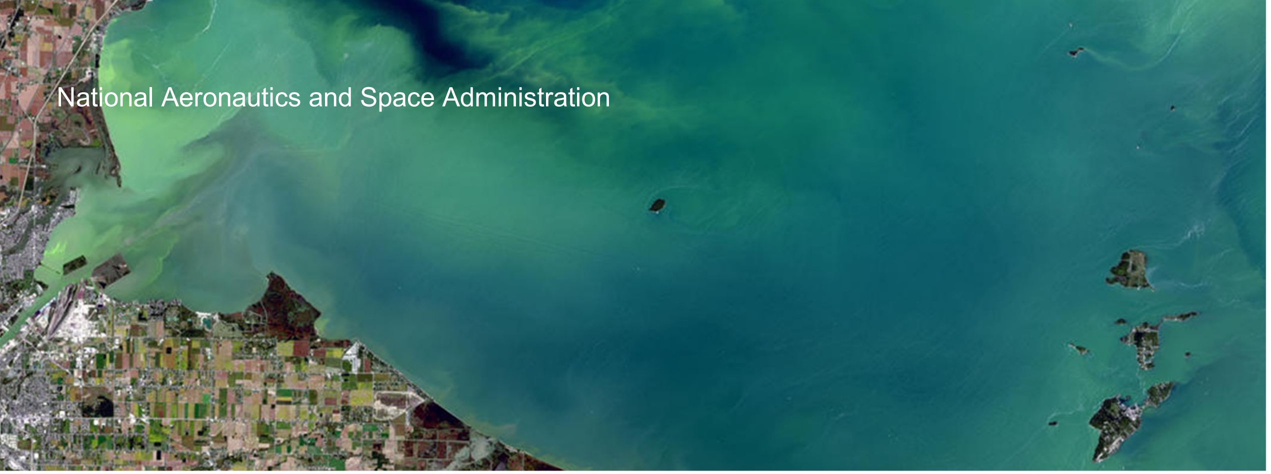
National Aeronautics and Space Administration



Monitoring Water Quality of Inland Lakes using Remote Sensing

Part 3: Assess Water Quality using Satellite and In Situ Observations

Amita Mehta and Sean McCartney

July 25, 2023

Training Outline

Part 1

Overview of Remote Sensing Observations to Assess Water Quality

July 18, 2023

Part 2

Cyanobacteria Assessment Network (CyAN)

July 20, 2023

Part 3

Assess Water Quality using Satellite and In Situ Observations

July 25, 2023

Homework

Opens July 25 – Due August 8 – Posted on Training Webpage

A **certificate of completion** will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

Training Learning Objectives

By the end of this training, participants will be able to:

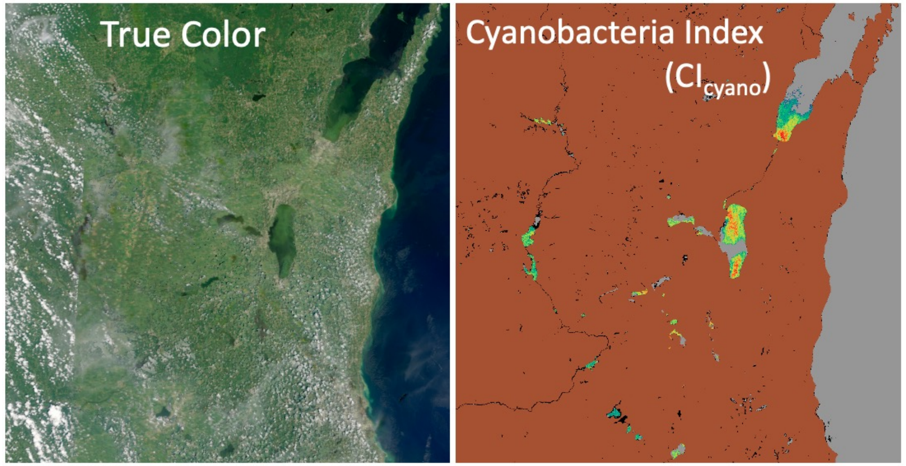
- Identify remote sensing observations useful for assessing water quality parameters in inland lakes.
- Recognize the importance of *in situ* measurements together with satellite observations in developing methodologies for operational water quality monitoring.
- Obtain an overview of Cyanobacteria Assessment Network (CyAN), an early warning system to assess algal blooms in freshwater lakes.
- Access satellite data and develop methodologies to assess water quality parameters.

Review of Part 1

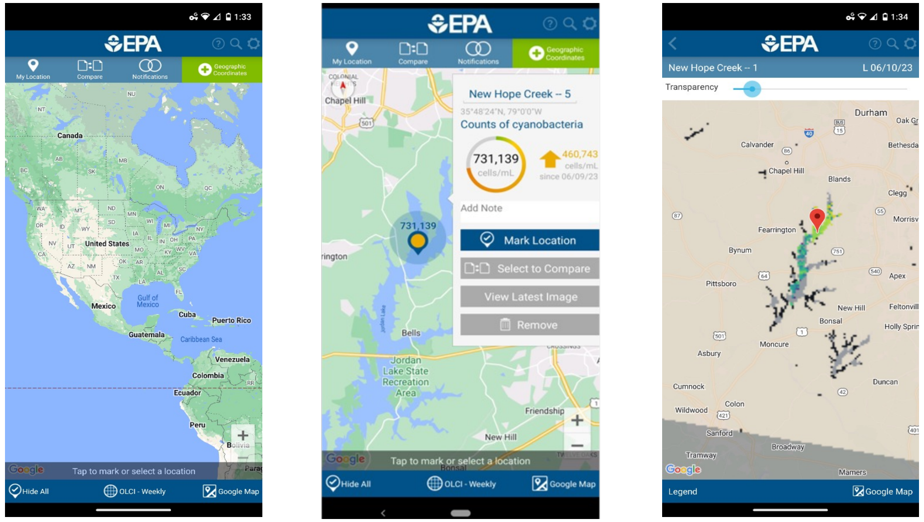
- Described state-of-the art, high spatial and spectral resolution observations from Landsat-8, Sentinel-2, and Sentinel-3 for water quality remote sensing.
- Described selected, open source, in situ measurements of water quality parameters including from USGS Water Dashboard and Lake Water Quality Portal, National Harmonized Chlorophyll Data, UNEP GEMStat, and GLORIA.
- Reviewed algorithm development requirements for remote sensing of water quality parameters.
- Explored and downloaded GLORIA in situ measurements of Chlorophyll-a concentration, Total Suspended Solids, and Secchi Depth for Lake Erie.
- Searched and identified optical surface reflectance data from Landsat-8 and Sentinel-2 collocated with in situ measurements for Lake Erie using Google Earth Engine (GEE).

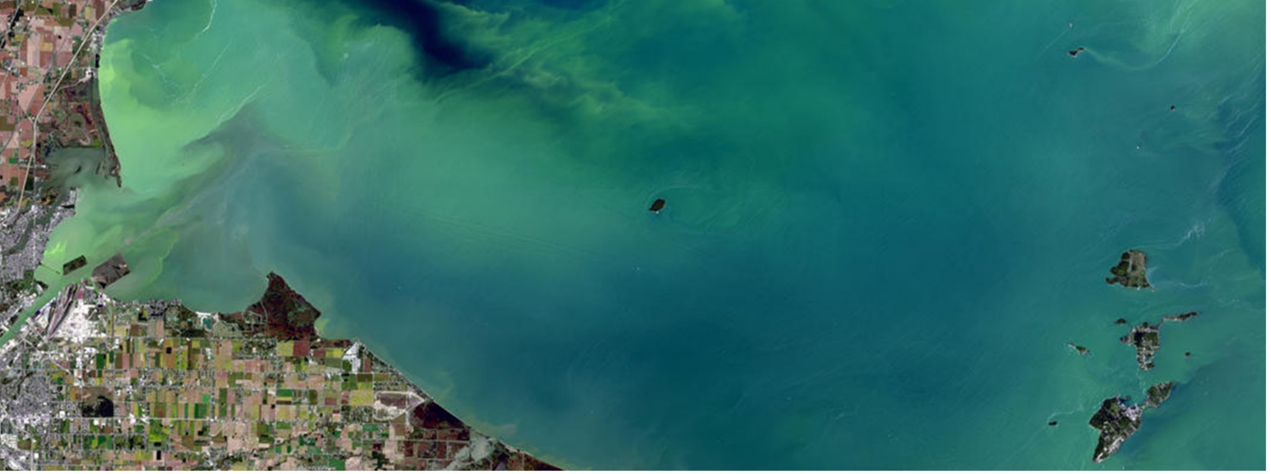
Review of Part 2

- Description of Cyanobacteria Assessment Network (CyAN).
  - Cyanobacteria Index (CI) data products are available daily and at 7-day maximum value composites from MERIS-Envisat (2002–2012), OLCI-Sentinel-3A (2016–present), and OLCI-Sentinel-3B (2018–present).
- Demonstration and application of CyAN Web-App.



CyAN app demo






Part 3: Assess Water Quality using Satellite and In Situ Observations

Part-3: Trainers

Amita Mehta

Instructor, Water & Disasters

Sean McCartney

Instructor, Water & Disasters

Part 3 Objectives

By the end of Part 3, participants will be able to:

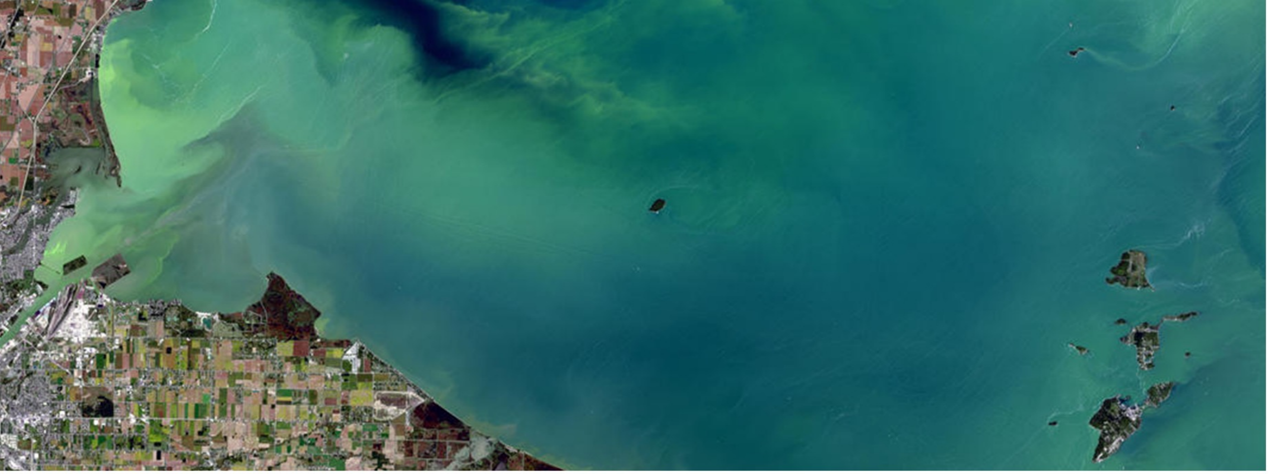
- Identify NASA image processing software for water quality (WQ) monitoring
- Understand strengths and limitations of remote sensing and available in situ data for inland WQ monitoring
- Describe upcoming NASA missions relevant for WQ monitoring
- Derive statistical algorithm coefficients for getting chlorophyll concentration (Ch-a), total suspended solids (TSS), and water clarity using satellite spectral reflectance and in situ WQ measurements, using GEE

Part 3 Outline

- NASA image processing software for WQ monitoring
- Strengths and limitations of observations for WQ monitoring
- Overview of upcoming NASA missions relevant for WQ monitoring

Demonstration and Exercise:

- Derive statistical algorithm coefficients for getting water quality parameters (Chlorophyll-a [Ch-a] and Total Suspended Solids [TSS]) using GEE
- Summary

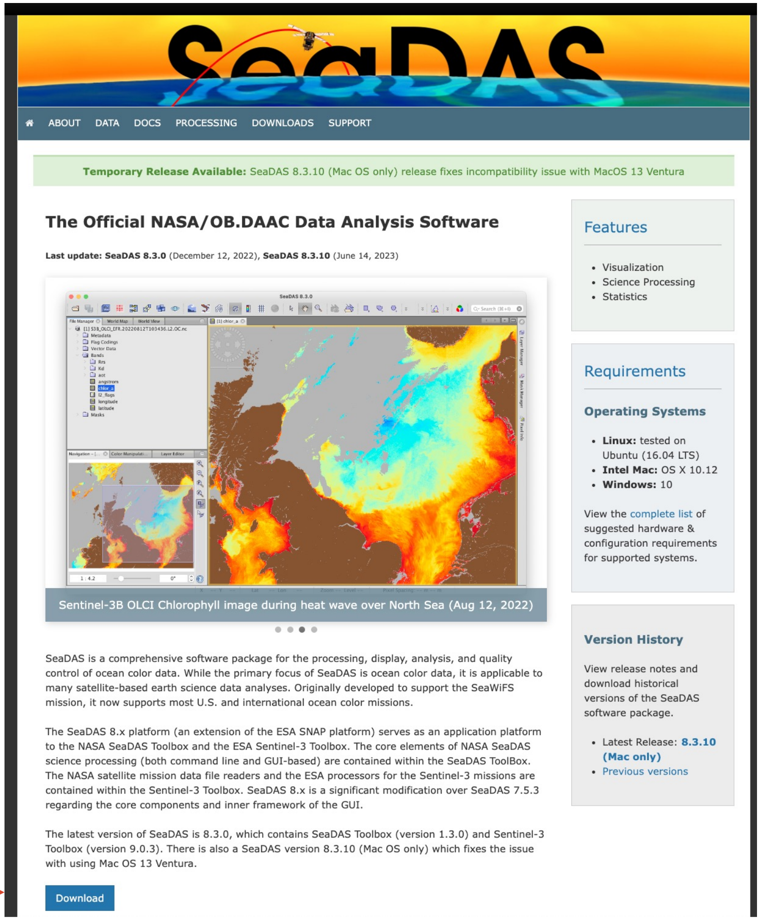



NASA Image Processing Software for WQ Monitoring

SeaDAS

https://seadas.gsfc.nasa.gov/

- NASA Ocean Biology official data processing and analysis software
- Latest Version: 8.3.10
- There is a Graphical User Interface (GUI) version.
- It is open source and can be downloaded from https://seadas.gsfc.nasa.gov/downloads/
- Can also download code and use the command line version



SeaDAS

https://seadas.gsfc.nasa.gov/

- Available for Windows, Mac OS, and Linux operating systems
- **Requires:**
  - Bash
  - Python 3.6 or later
  - Python requests package v2.18.0 or later

To learn about the latest changes to the software, please see our announcement of SeaDAS 8.1.0 release.

SeaDAS Installers and Source Code

Visualization Installers

Filename	Version	Size
seadas_8.1.0_windows64_installer.exe	8.1.0	487 MB
seadas_8.1.0_mac_installer.sh	8.1.0	608 MB
seadas_8.1.0_linux64_installer.sh	8.1.0	630 MB

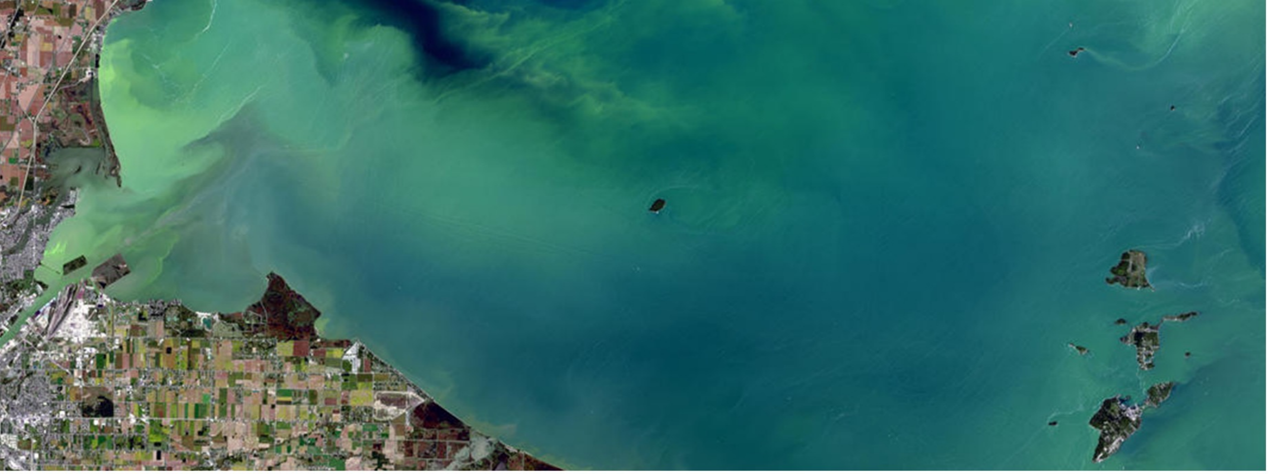
SeaDAS

https://seadas.gsfc.nasa.gov/

- The SeaDAS GUI can be used for:
  - Visualization, processing, and analysis of images
  - Installation of Ocean Color Science Software (OCSSW)
  - Running OCSSW to get Level-2 and Level-3 data from Level-1
  - Accessing available in situ data from SeaBASS[1]
- SeaDAS 8.3.10 contains SeaDAS Toolbox that includes Sentinel-3 Toolbox
- SeaDAS/OCSSW can allow atmospheric correction options
- **Requires downloading Level-1 satellite images for processing**

For SeaDAS demonstration see:
Monitoring Coastal and Estuarian Water Quality Using Remote Sensing and In Situ Data

[1]The SeaWiFS Bio-optical Archive and Storage System (SeaBASS), is publicly shared archive of in situ oceanographic and atmospheric data maintained by the NASA Ocean Biology Processing Group (OBPG). (https://seabass.gsfc.nasa.gov/)




Strengths and Limitations of Observations for WQ Monitoring

Advantages of Remote Sensing for Freshwater Systems

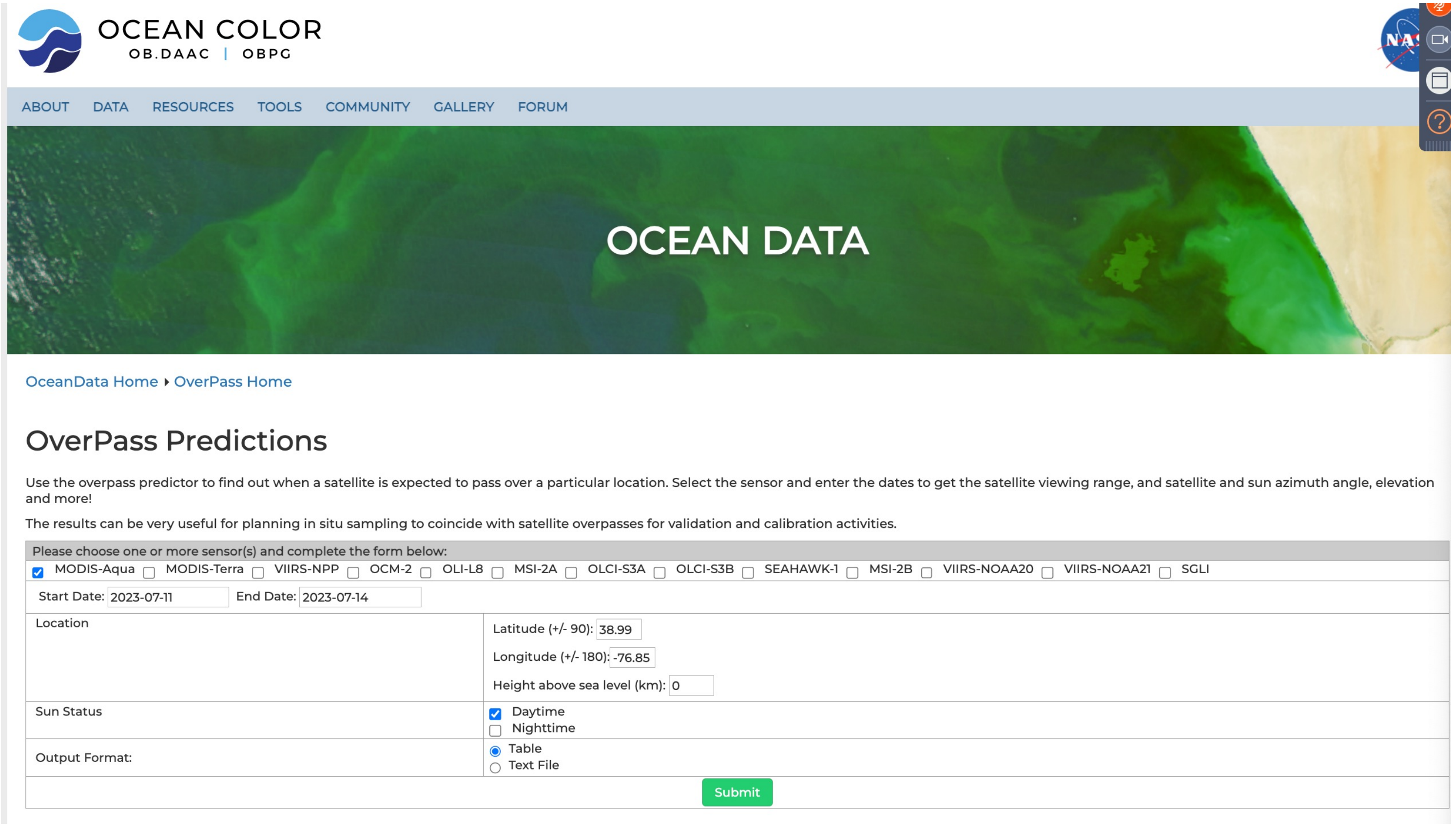
- Longtime satellite imagery record for time series analysis
- Ongoing commitment from space agencies to continue data collection
- Reliable data for operational early warning and forecasting systems
- Landsat and Sentinel-2 have sensors with moderate to high spatial resolution appropriate for lakes
- Open-source data availability

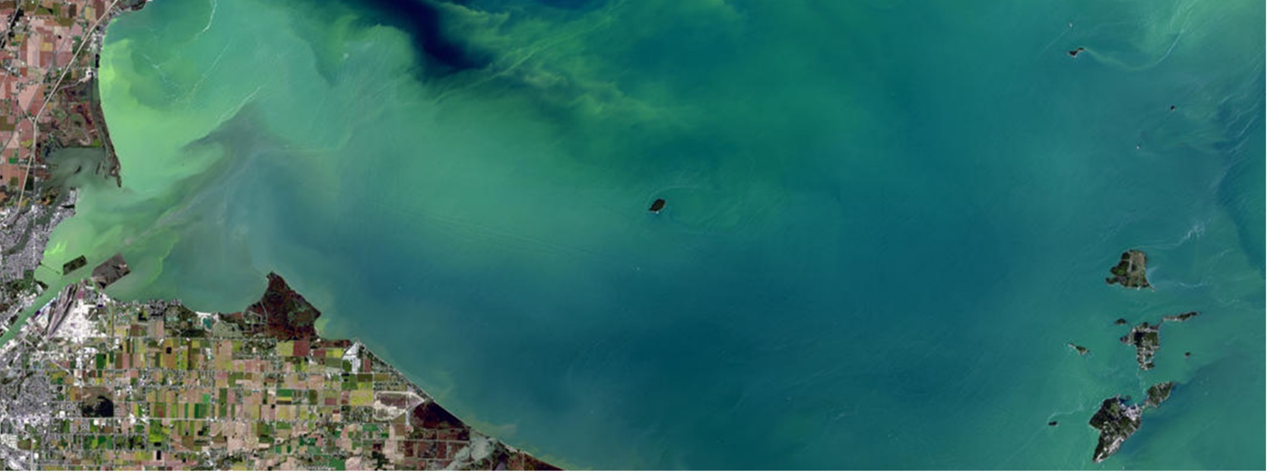
Limitations of Remote Sensing for Freshwater Systems

- Shallow water – interference from the bottom
- Water bodies too small for the spatial resolution of some sensors
- Limited number of standard algorithms for these optically complex waters
- Optical sensors can not see through clouds – missing data in cloudy conditions
- Atmospheric correction is a challenge
- Ground truthing is costly
- **Collocations of satellite observations and surface measurements in space and time required for algorithm development and accurate retrievals of water quality parameters**

Recommendation for In Situ Data Collection

- NASA Ocean Color provides overpass time for various satellites for a selected geographic region.
- Collecting in situ water samples within 2 to 4-hour window of the satellite overpass would greatly benefit algorithm development and activities.






Upcoming NASA Missions for Water Quality Monitoring

Future Satellite Missions for Water Quality Monitoring

PACE: Plankton, Aerosol, Cloud, ocean Ecosystem

https://pace.oceansciences.org/mission.htm

- Planned for launch in 2024
- Advanced optical spectrometer, Ocean Color Instrument (OCI)
  - Hyperspectral measurements for water quality products (ultraviolet to near-infrared range)

SBG: Surface Biology and Geology

- Launch in 2027-28

https://sbg.jpl.nasa.gov/

- In the initial phase of development
  - Hyperspectral imagery in the visible and shortwave infrared; multi-or hyperspectral imagery in the thermal IR

Future Satellite Missions for Water Quality Monitoring

GLIMR: The Geostationary Littoral Imaging and Monitoring Radiometer
https://eos.unh.edu/glimr

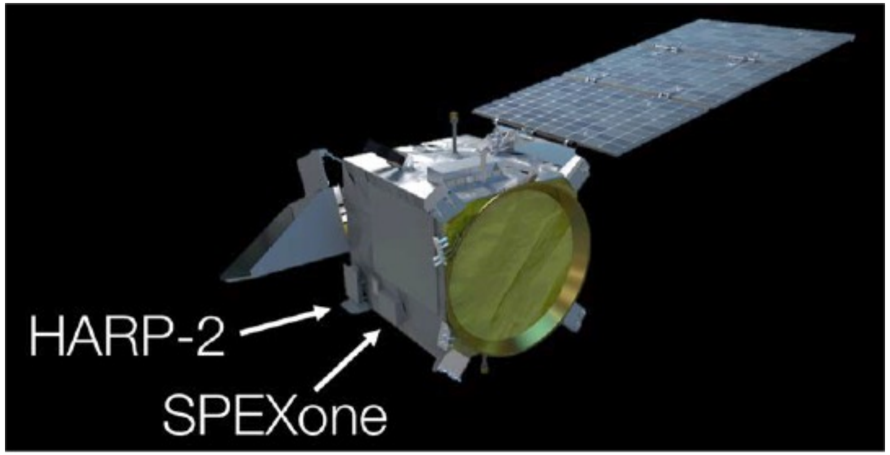
- Planned for launch in 2026-27
- Will be in a geostationary orbit, providing frequent observations – will be placed between 88 to 108 degree west
- Hyperspectral Imager (HSI), Landmark Imager (LMI)
- Will provide information on harmful algal bloom, oil spills, Sargassum accumulation

Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE)

PACE is NASA's next great investment in hyperspectral Earth imagery and multi-angle polarimetry.

- Launch Date: **Jan. 2024**
- 3-year design life; 10-year propellant

- Hyperspectral Imager: **Ocean Color Instrument (OCI)**
    - Spectral Resolution: UV to SWIR (340–890 nm every 2.5 nm, with 940, 1038, 1250, 1378, 1615, 2130, & 2250 nm)
    - Temporal Resolution: 2 days
    - Spatial Resolution: 1-km^2 at nadir
- Two Multi-Angle Polarimeters
    - **HARP-2**: Wide swath, hyper-angular, 4 bands across the VIS & NIR
    - **SPEXone**: Narrow swath, hyperspectral (UVNIR), 5 viewing angles



PACE information from: Natasha Sadoff, PACE Applications Deputy Coordinator | NASA-GSFC Ocean Ecology Lab
Contact: natasha.sadoff@nasa.gov

Extend key systematic **ocean** biological, ecological, & biogeochemical climate data records, as well as **cloud** & **aerosol climate data records**

Make **new global measurements of ocean color** that are essential for understanding the global carbon cycle & ocean ecosystem responses to a changing climate

Collect **global observations of aerosol & cloud properties**, focusing on reducing the largest uncertainties in climate & radiative forcing models of the Earth system

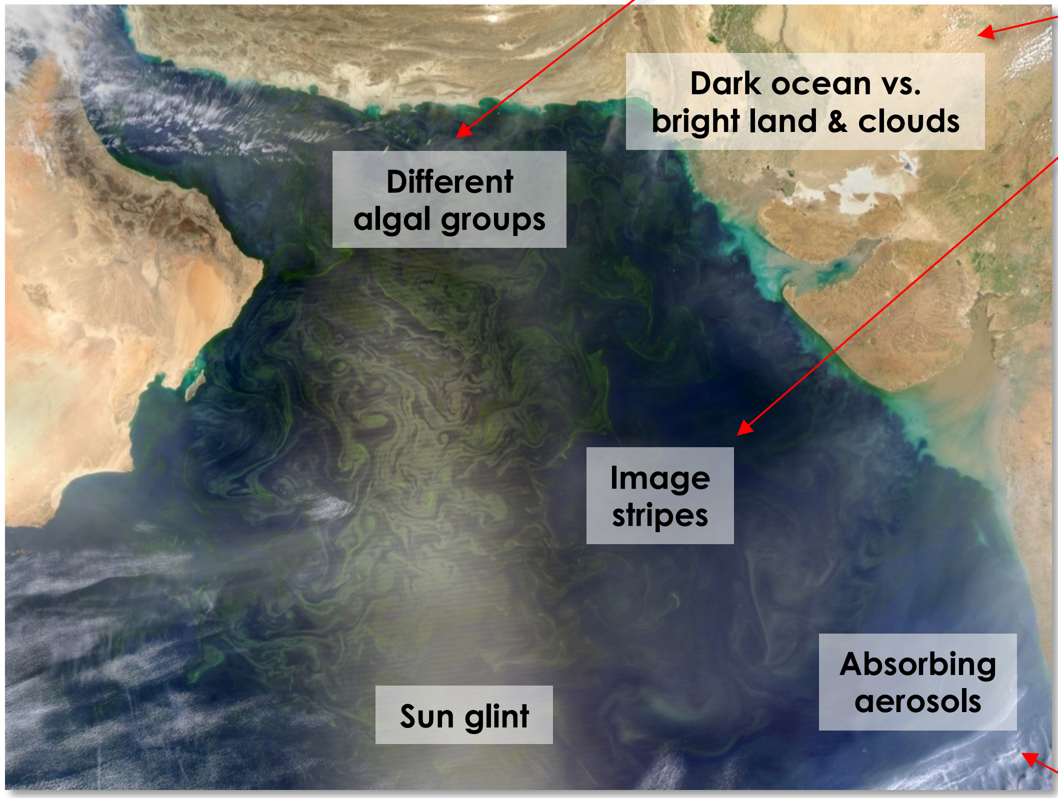
GSD of 1 ± 0.1 km^2 at nadir

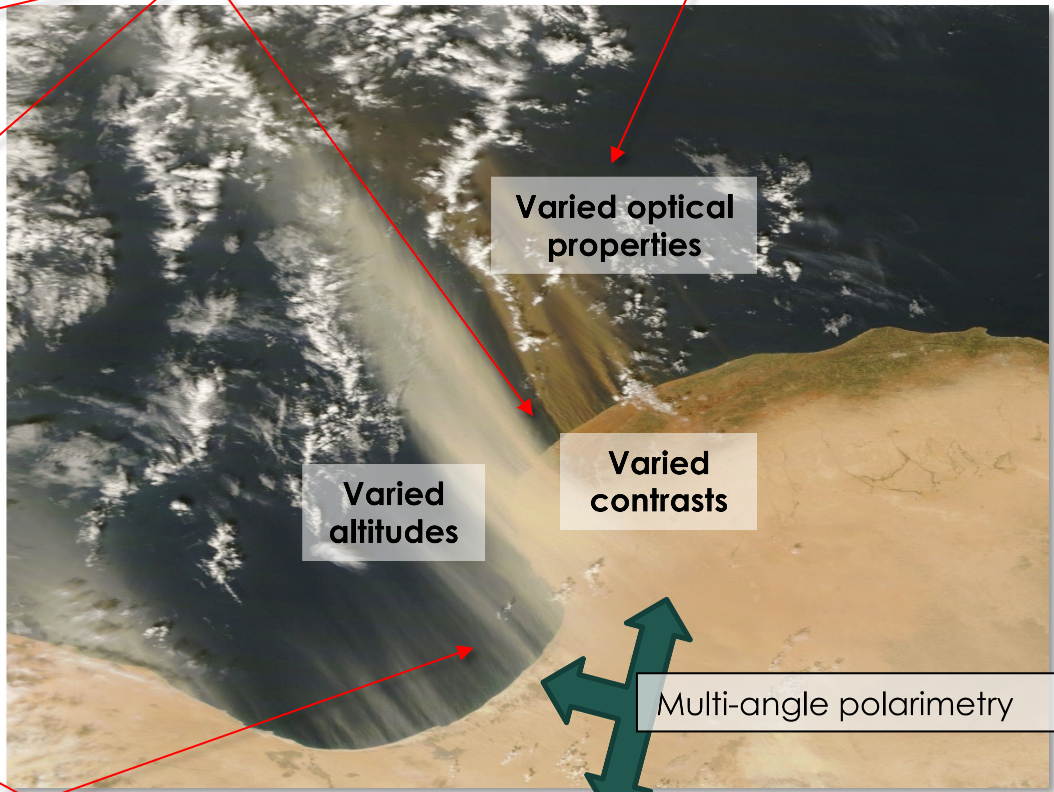
Spectral range from 350–865 @ 5 nm

940, 1038, 1250, 1378, 1615, 2130, 2260 nm

Twice-monthly lunar calibration & onboard solar calibration (daily, monthly, dim)

Instrument performance requirements





Multi-angle polarimetry

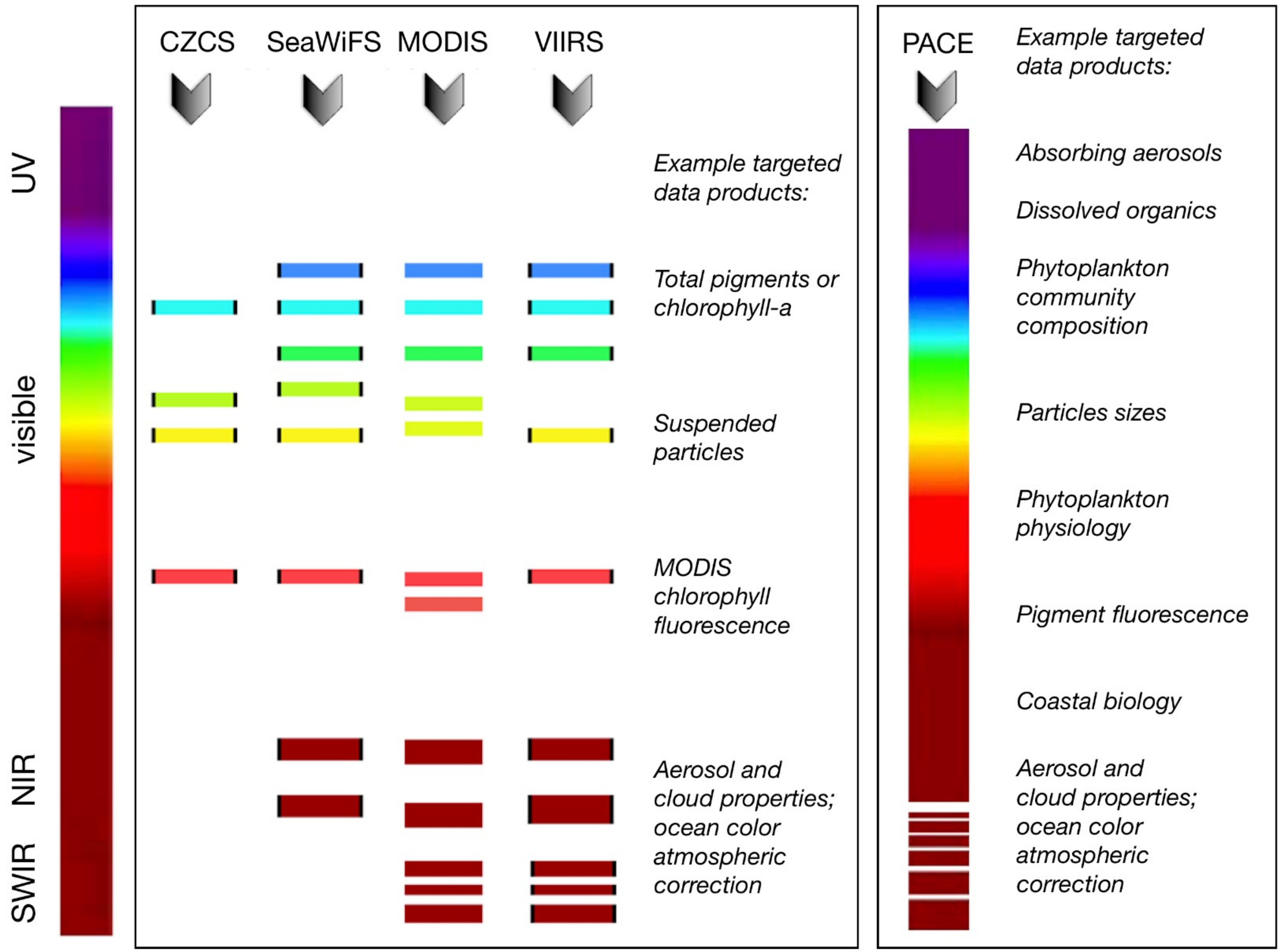
Tilt ± 20°

Spectral range goal of 320-865 @ 5 nm

Improve our understanding of how **aerosols influence ocean ecosystems & biogeochemical cycles** and how **ocean biological & photochemical processes affect the atmosphere**

Moving from multi-spectral radiometry to spectroscopy

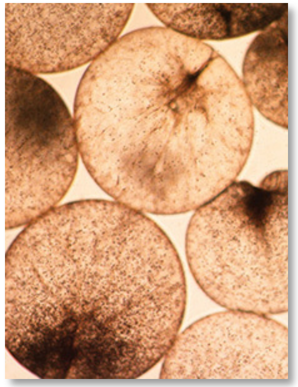
1978-1986 1997-2010 1999-pres. 2012-pres.



Example diatom

Linda Armbrecht, abc.com.au

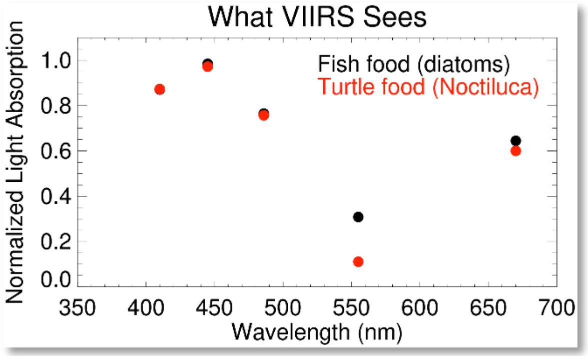
Example Noctiluca

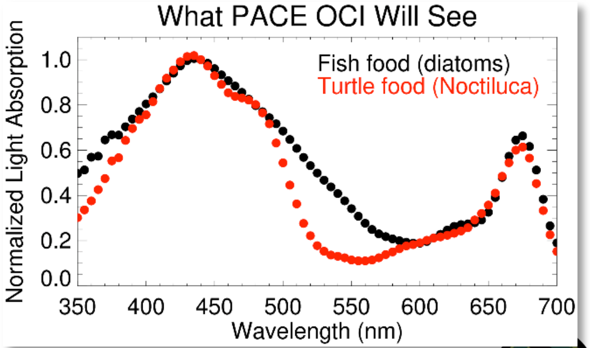


1 mm

Joaquim Goes, LDEO

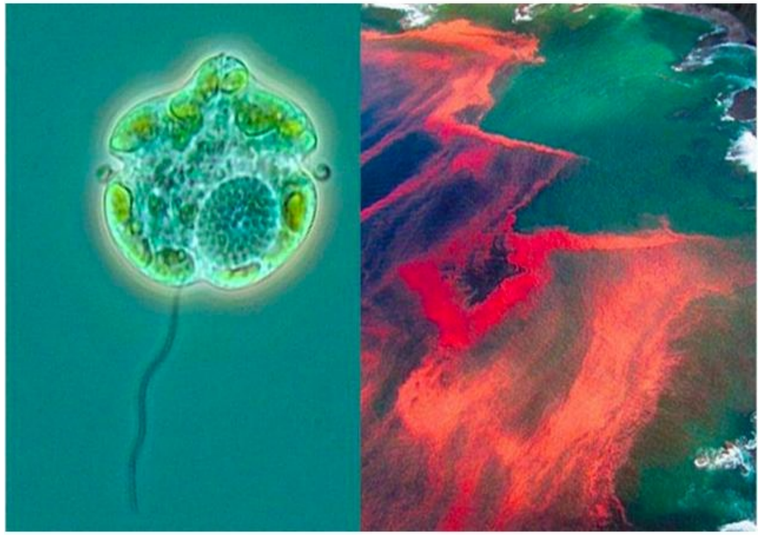
Signals from the ocean are small & differentiating between constituents requires additional information relative to what we have today





PACE Water Resources Data Products

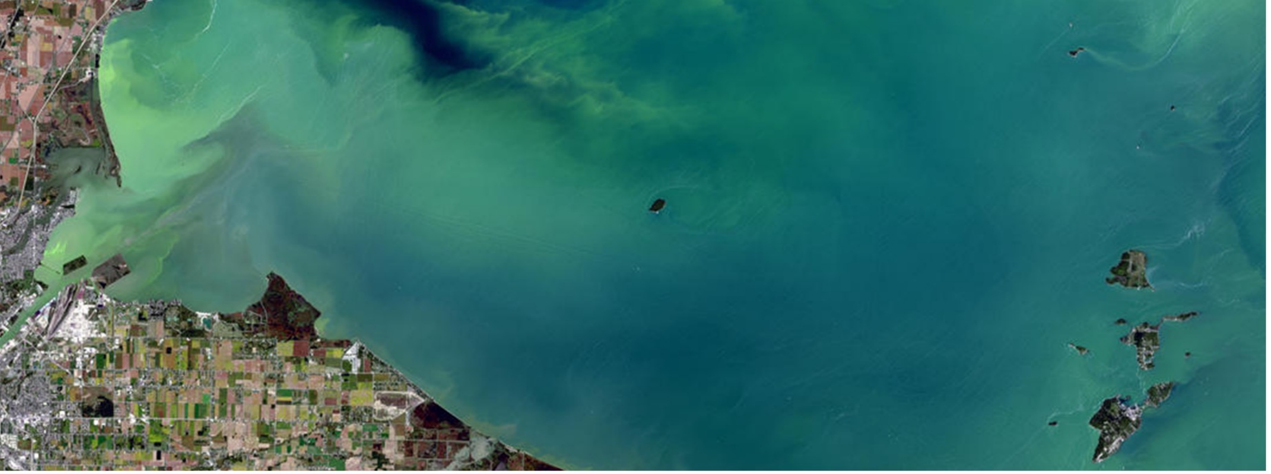
- **Standard products**
  - Chlorophyll *a*
  - Diffuse attenuation coefficient 400–700 nm [Kd(PAR)]
  - Absorption coefficient of colored dissolved organic matter plus depigmented particles at 440 nm [$a_{dg}(440)$]
  - Particle backscatter coefficient at 440 nm [$b_{bp}(440)$]
  - Phytoplankton Carbon
  - Apparent visible wavelength
- **Provisional products**
  - Suspended particulate matter
  - Absorption coefficient of colored dissolved organic matter
  - Phycocyanin (cyanobacteria)
  - Floating algae flag
  - Other pigments
  - Phytoplankton community composition
- **Water Quality product suite (tentative)**



Get involved with the PACE mission as we near launch!

Register for the 2023 PACE Applications Workshop

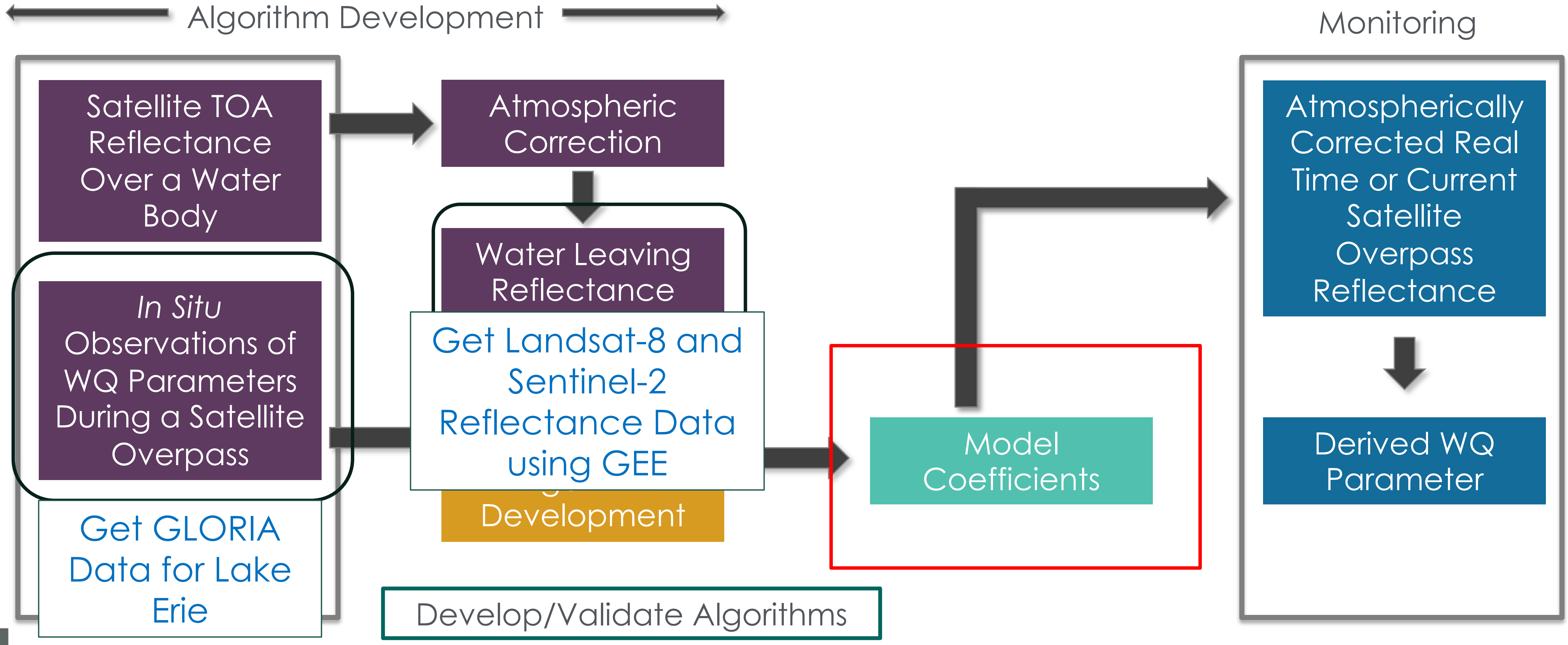
Join the PACE CoP and/or Early Adopters Program!




Statistical Algorithms for Acquiring Water Quality Parameters

Water Quality Parameters from Remote Sensing Observations

Quantitative Technique



Atmospheric Correction for Water Quality Monitoring

- Satellite observations of reflectance must be corrected for atmospheric effects for acquiring water surface reflectance.
- Various techniques exist for the atmospheric corrections.
- Requires radiative transfer modeling along with atmospheric conditions, clouds, and aerosol information.

*Vermote, E.E., D. Tanré, J.L. Deuzé, M. Herman and J.-J. Morcrette, Second Simulation of the Satellite Signal in the Solar Spectrum, 6S: An Overview, *IEEE Transactions on Geoscience and Remote Sensing, Vol. 35, No. 3, p. 675-686., 1997.* r12_Stumpf_Tomlinson.pdf

Examples:

- NASA Ocean Biology Processing Group Algorithm: https://oceancolor.gsfc.nasa.gov/docs/technical/NASA-TM-2016-217551.pdf
- *6S: Second Simulation of the Satellite Signal in the Solar Spectrum: http://6s.ltdri.org/#
- ACOLITE: https://odnature.naturalsciences.be/remsem/software-and-data/acolite
- HydroLight: http://www.oceanopticsbook.info/view/radiative_transfer_theory/level_2/hydrolight

Models for Chlorophyll-a (Cha)

https://oceancolor.gsfc.nasa.gov/resources/atbd/chlor_a/

For low chlorophyll-a (Cha), the following Color Index (CI) index is used:

- CI = Rrs(λgreen)−[Rrs(λblue)+(λgreen−λblue)/(λred−λblue)∗(Rrs(λred)−Rrs(λblue))]
- Regression coefficients between **observed** log10(cha) and CI are obtained
- $Cha=10^{(a_0 CI+a_1 CI*CI)}$
  - Rrs represents spectral water-leaving reflectance
  - a_0 and a_1 are intercept and slope of linear regression fit
- For high Cha, 4th order polynomial fit is used for blue and green spectral band ratios:

$$\log_{10}(chlor\_a) = a_0 + \sum_{i=1}^{4} a_i\left(\log_{10}\left(\frac{R_{rs}(\lambda_{blue})}{R_{rs}(\lambda_{green})}\right)\right)^i$$

Hu et al., 2019: Improving satellite global chlorophyll a data products through algorithm refinement and data recovery. Journal of Geophysical Research: Oceans, 124(3), 1524-1543, doi: 10.1029/2019JC014941

Models for Total Suspended Solid (TSS) and Secchi Depth (SD)

- Band ratio of Sentinel-2/MSI Near Infrared (Rrs_{815}) and Red (Rrs_{655}) is used to estimate TSS[1]
  - Rrs_{815}/Rrs_{655}
- Regression coefficients between **observed** TSS and the band ratios are obtained

Similarly,

- Band ratio of Sentinel-2/MSI Blue (Rrs_{490e}) and Red edge (Rrs_{709}) is used to estimate SD[2]
  - Rrs_{490e}/Rrs_{709}
- Regression coefficients between **observed** SD and the band ratios are obtained

[1]Ha NTT et al., 2022: Retrieval of total suspended solids from remote sensing reflectance in highly eutrophic lakes in Hanoi (Vietnam), INTERNATIONAL JOURNAL OF REMOTE SENSING, 43, 6936-6956, DOI:0.1080/01431161.2022.2150100.

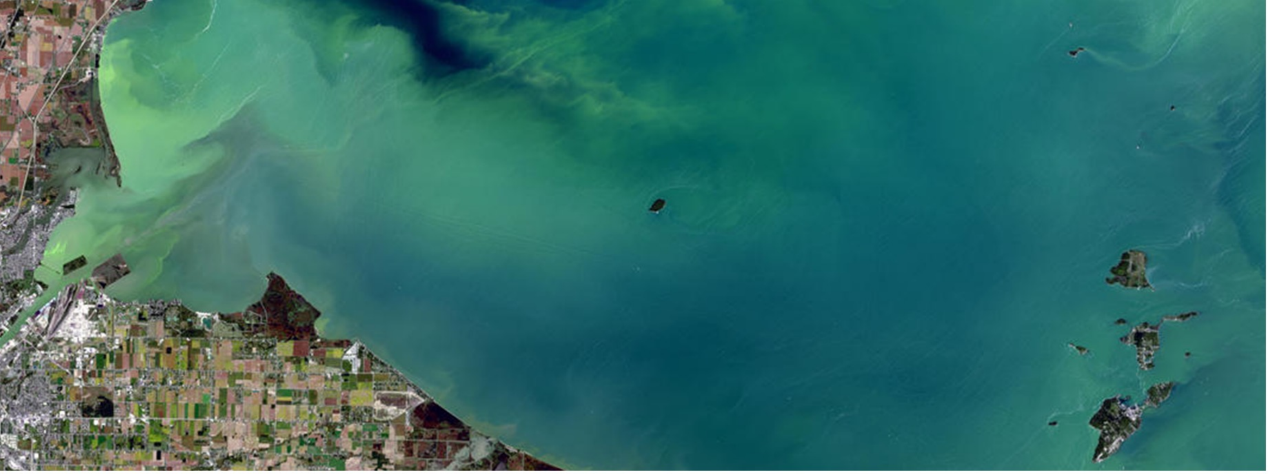
[2]Pereira-Sandova et al. 2019: Calibration and validation of algorithms for the estimation of chlorophyll-a concentration and Secchi depth in inland waters with Sentinel-2, LIMNETICA, 38, 471-487, DOI:10.23818/limn.38.27

Caution Regarding Model Selection and Usage

- We have selected simple models for the water quality parameters, but a vast literature exists with a variety of models, linear and non-linear, single bands, band ratios, and multi-band combinations.
- Each water body is different in characteristics, it is recommended to explore, develop, and apply model algorithms for each sensor for the lake of your interest.
- Advanced and more complex models for water quality parameters based on neural network[1] and Artificial Intelligence and Machine Learning[2] are developed and tested by many researchers.
- As many collocated points between *in situ* measurements and satellite observations should be used for developing the models.
- Models should be validated by using independent *in situ* data.

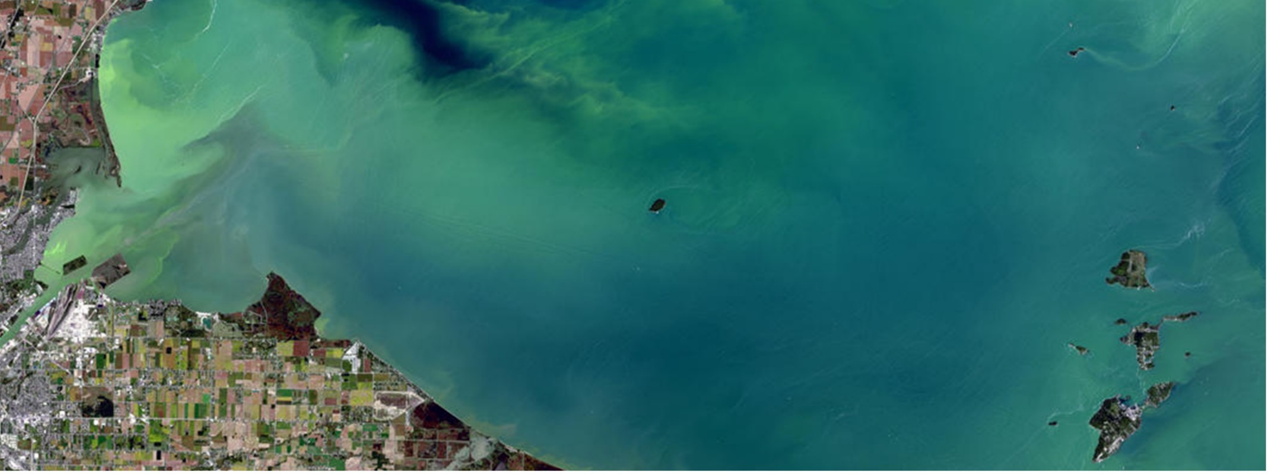
[1]Peterson et al., 2018: Suspended Sediment Concentration Estimation from Landsat Imagery along the Lower Missouri and Middle Mississippi Rivers Using an Extreme Learning Machine, Remote Sensing 10(1503), DOI:10.3390/rs10101503.

[2]Zhu et al., 2022: A review of the application of machine learning in water quality evaluation, Eco-Environment & Health, 1, 107-116, https://doi.org/10.1016/j.eehl.2022.06.001.




Demonstration

Derive Statistical Algorithm Coefficients for Acquiring Water Quality Parameters (Ch-a and TSS) using GEE




Summary

Training Summary

In this training, we learned:

- Current and upcoming remote sensing observations useful for assessing water quality parameters in inland lakes.
- Selected in situ water quality parameter measurements to be used with satellite observations to maximize accuracy.
- Explored Cyanobacteria Assessment Network (CyAN), an early warning system to assess algal blooms in freshwater lakes.
- Used GEE to access Landsat-8, Sentinel-2, and Sentinel-3 optical reflectance data for water bodies of interest.
- Explored GLORIA water quality measurements and their access
- Walked through algorithm development for water quality parameters (Ch-a, TSS, Water Clarity) based on remote sensing and in situ measurements.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on July 25, 2023
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by August 8, 2023**
  - There will be hands-on exercises in all sessions. **You will be instructed to submit results of these exercises to a Google Drive folder.**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

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- DEVELOP
- SERVIR

Questions and Answers

- Please put your questions in the Questions box
- We will try to get to all of the questions during the Q&A session
- Any remaining questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

Thank You!