National Aeronautics and Space Administration

Part 2: Water Quality of Larger Inland Water Bodies

Instructors: Sherry L. Palacios, PhD & Amita Mehta, PhD

Guest Speaker: Daniela Gurlin, PhD, Wisconsin Department of Natural Resources

Training Objectives

Learn to:

- Understand which data products are used for water quality monitoring
- Follow rigorous practices for obtaining and processing aquatic remote sensing data
- Build skills in image processing for water quality monitoring for coastal and inland water bodies using NASA's SeaDAS image processing software

Training Outline

June 5

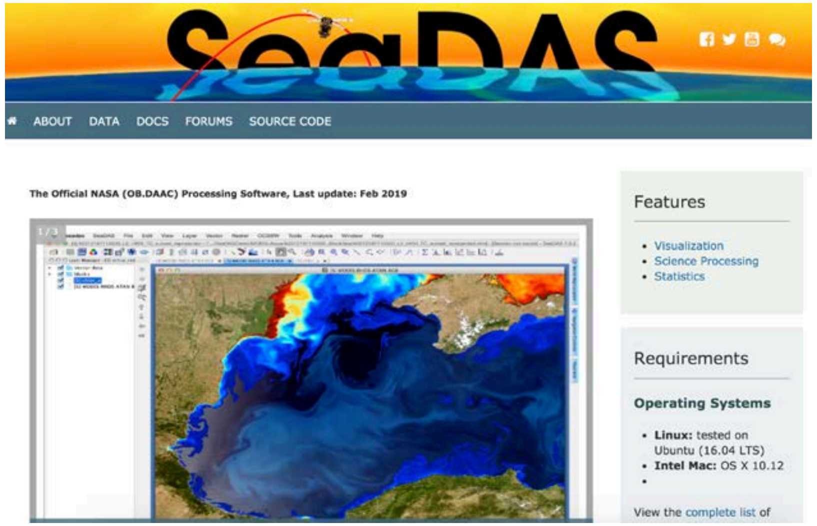
Water Quality in the Coastal Zone

June 12

Water Quality of Larger Inland Water Bodies

June 19

Aquatic Remote Sensing Skill Development and Best Practices



Outline for Part 2

- Review Part 1
- Water Quality Monitoring in Freshwater Systems
- Sensors & Data Products for Freshwater Systems
- Examples of Freshwater WQ Monitoring Programs
- Guest Speaker:

  Integrating Remote Sensing into a Water Quality Monitoring Program

  Dr. Daniela Gurlin, Wisconsin Department of Natural Resources
- Demonstration of Landsat 8 OLI Image Data Access, Atmospheric Correction, Processing to Level 2 Products

Review of Part 1

NASA's Applied Remote Sensing Training Program (ARSET)

http://arset.gsfc.nasa.gov/

- Empowering the global community through remote sensing training
- Seeks to increase the use of Earth science in decision-making through training for:
  - policy makers
  - environmental managers
  - other professionals in the public and private sector
- Training topics focus on:
  - air quality
  - disasters
  - land
  - water

Helping Professionals Solve Problems Including…

How *In Situ* and Satellite Observations Roughly Correspond

In Situ	Satellite
Water Temperature	Sea Surface Temperature (SST)
Colored Dissolved Organic Matter (CDOM)	Absorption by CDOM (adg_443_giop)
Suspended Solids – Turbidity	Diffuse attenuation of light at 490 nm (Kd_490)
Water Clarity	Chlorophyll-a, Normalized Fluorescence Line Height (nFLH)
Cyanobacteria	Cyanobacteria Index (CI)
Algal Pigments	Euphotic Zone Depth (Z_{eu}) Experimental Phytoplankton Functional Type Algorithms

Current Satellite Missions for Water Quality Monitoring

- Landsat 7 (4/15/1999 – present)
- Landsat 8 (2/1/2013 – present)
- Terra (12/18/1999 – present)
- Aqua (5/4/2002 – present)
- Suomi National Polar Partnership (SNPP) (11/21/2011 – present)
- Sentinel-2A (6/23/2015 - present)
- Sentinel-2B (3/7/2017 – present)
- Sentinel-3A (2/16/2016 – present)

Water Quality Monitoring Program Workflow

Identify Water Quality Problem

Evaluate if Remote Sensing can Complement *In Situ* Sampling Effort

Choose Sensor(s) & Data Product(s) Appropriate for Problem

Build Sampling Strategy for Coincident *In Situ* & Remote Sensing Monitoring

In Situ

collect sample data within 2 hours of aircraft or satellite overpass

collect field samples

process field samples

QA/QC data

Remote Sensing

identify aircraft or satellite overpass dates/times

download imagery

pre-process imagery & derive L2 data product

extract pixel values at sample site locations

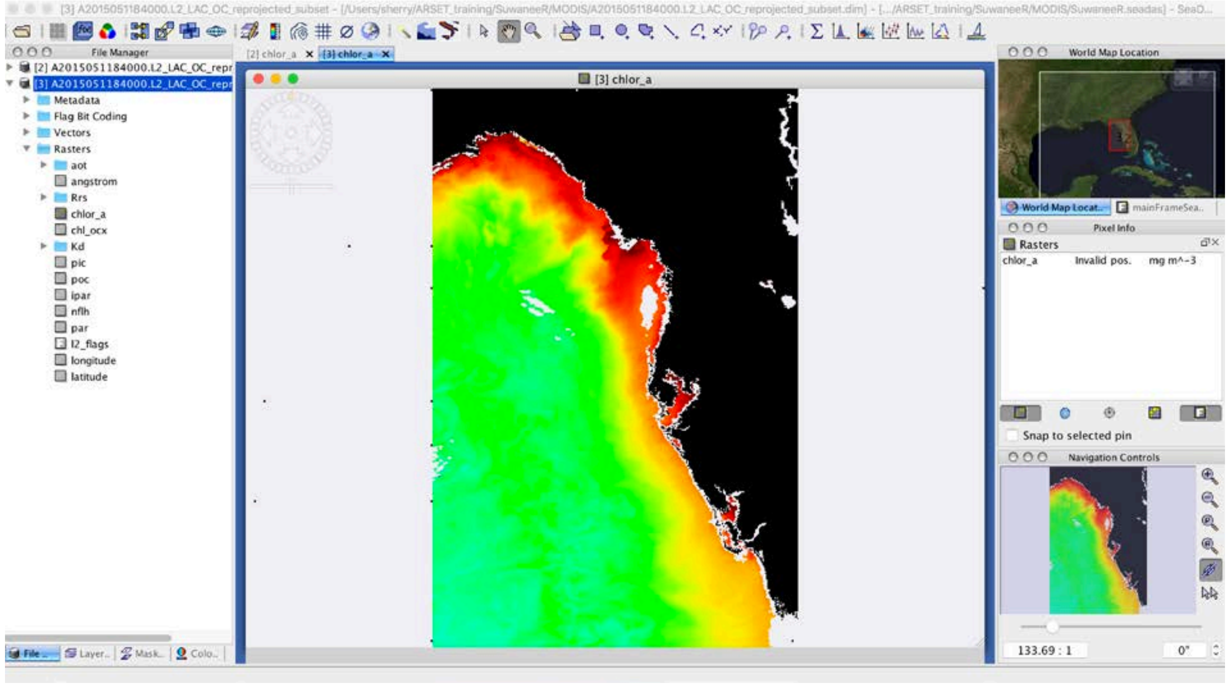
Compare *In Situ* & Remote Sensing Matchups & Run Statistics

Communicate Results to Stakeholders

Part 1 Homework Reminder

https://forms.gle/Uw9dTtfktm2iy45Q9

- Complete the exercise from Part 1
- Some of the data saved in the Part 1 exercise will be used for Part 3, be sure to process data for chlor_a, sst, and adg_443_giop and to crop all images to the same geographic coordinates
- Your answers to Part 1 Homework are due on June 21st



Water Quality in Freshwater Systems

What are Some Goals of Monitoring in Freshwater Systems?

To Monitor for…

- cyanobacteria
- pathogens
- man-made pollutants
- nutrient inputs
- water clarity

Why? Impacts to…

- drinking water
- domestic animals
- wildlife
- ecosystems

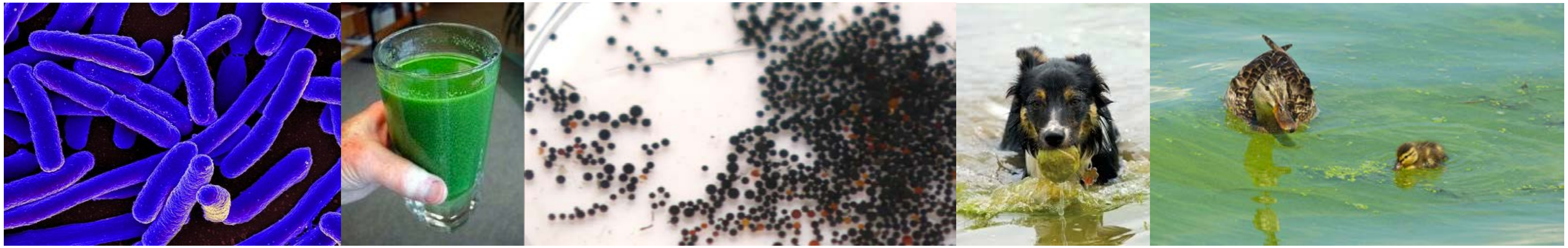


Image Credits: *E. coli*, cyanobacteria, plastic microbeads, domestic animals, wildlife

What Are Typical *In Situ* Observations for Monitoring in Freshwater Systems?

- chlorophyll concentration
- temperature
- water clarity
- nutrients
- metals
- pH & alkalinity
- dissolved organic matter
- phytoplankton taxonomy
- cyanobacteria
- condition of indicator species
- suspended sediments
- *E. coli*
- plastics

Which Remote Sensing Data Products Are Relevant for Freshwater Systems?

- chlorophyll
- water surface temperature
- absorption of light by CDOM
- diffuse attenuation coefficient
- water clarity
- cyanobacterial index
- light absorption and scattering at wavelengths diagnostic of particular algal taxa
- user-defined, custom algorithms developed for specific use and particular region

Which Sensors are Best for Monitoring in Freshwater Systems?

- Considerations depend on the problem
- Sensor choice is based on:
  - spatial resolution
  - temporal resolution
  - spectral resolution and data products

Why Are Cyanobacteria Such a Problem?

- Toxin producers
- Excessive biomass
- Thrive in warm waters, so blooms will likely increase with warming climate

Genus	Colony or Filament	Surface Scum?	Toxin(s)
Microcystis	Colony	yes	Microcystin, Anatoxins
Aphanizomenon	Filament	yes	Cylindrospermopsin, Anatoxins, Saxitoxins
Anabaena	Filament	yes	Microcystin, Cylindrospermopsin, Anatoxins, Saxitoxins
Planktothrix (Oscillatoria)	Filament	no	Microcystin, Anatoxins, Saxitoxins
Cylindrospermopsis	Filament	no	Cylindrospermopsin, Anatoxins
Lyngbya	Filament	no	Cylindrospermopsin, Saxitoxins

Credit: R. Stumpf, EPA

Cyanobacteria and Satellite Remote Sensing

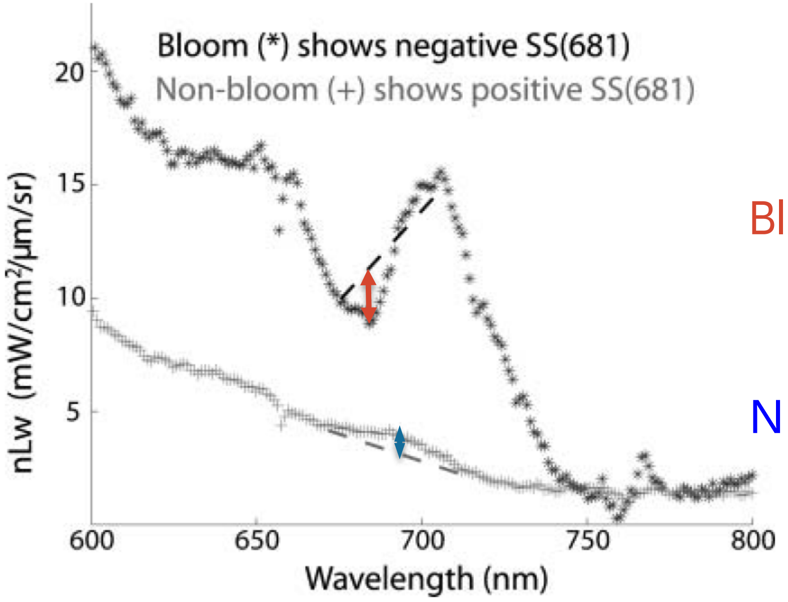
- Satellites cannot detect toxins
- Taxa that form surface scums are readily detected in most satellite imagery
- Spectral features at particular wavelengths can be diagnostic of cyanobacteria
  - phycocyanin absorption at 620 nm
  - chlorophyll-a absorption at 667 nm
  - backscattering at 709 and 779 nm
- Variations in spectral signature can be used to distinguish cyanobacteria
  - Cyanobacteria Index (CI) (Wynne et al. 2008)
  - Maximum Chlorophyll Index (MCI) (Gower et al. 2008)
  - Maximum Peak Height (MPH) (Matthews & Odermatt 2016)

Work fine without atmospheric correction

Credit: R. Stumpf, EPA

Cyanobacteria Index (CI)

- Does not require surface scum, but also works with scum
- Less sensitive to sediment and water vapor in atmosphere
- CI equates to cell concentration
- CI is equivalent to the spectral shape at 681 nm



Bloom: curve of spectrum is below baseline (-)

Non-bloom: curve of spectrum is above baseline (+)

Credit: Wynne et al. 2008

CI Gives an Estimate of Cyanobacteria Cell Concentration

https://tidesandcurrents.noaa.gov/hab/lakeerie_bulletins/HAB20180813_2018016_LE.pdf

The images below are "GeoPDF". Please visit https://go.usa.gov/xReTC for instructions on viewing longitude and latitude.

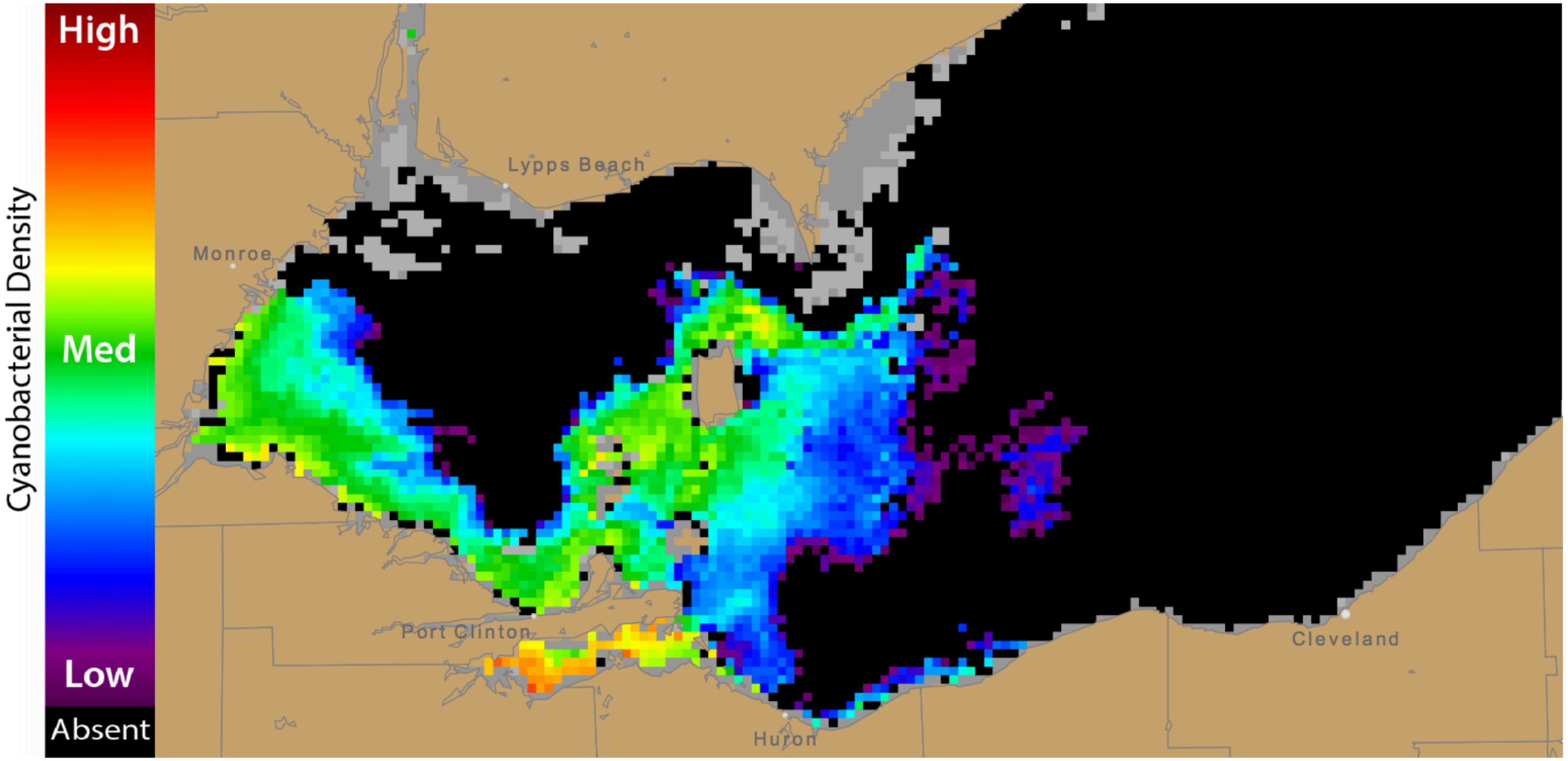


Figure 1. Cyanobacterial Index from NASA MODIS-Aqua data collected 11 August, 2018 at 14:21 EST. Grey indicates clouds or missing data. The estimated threshold for cyanobacteria detection is 20,000 cells/mL.

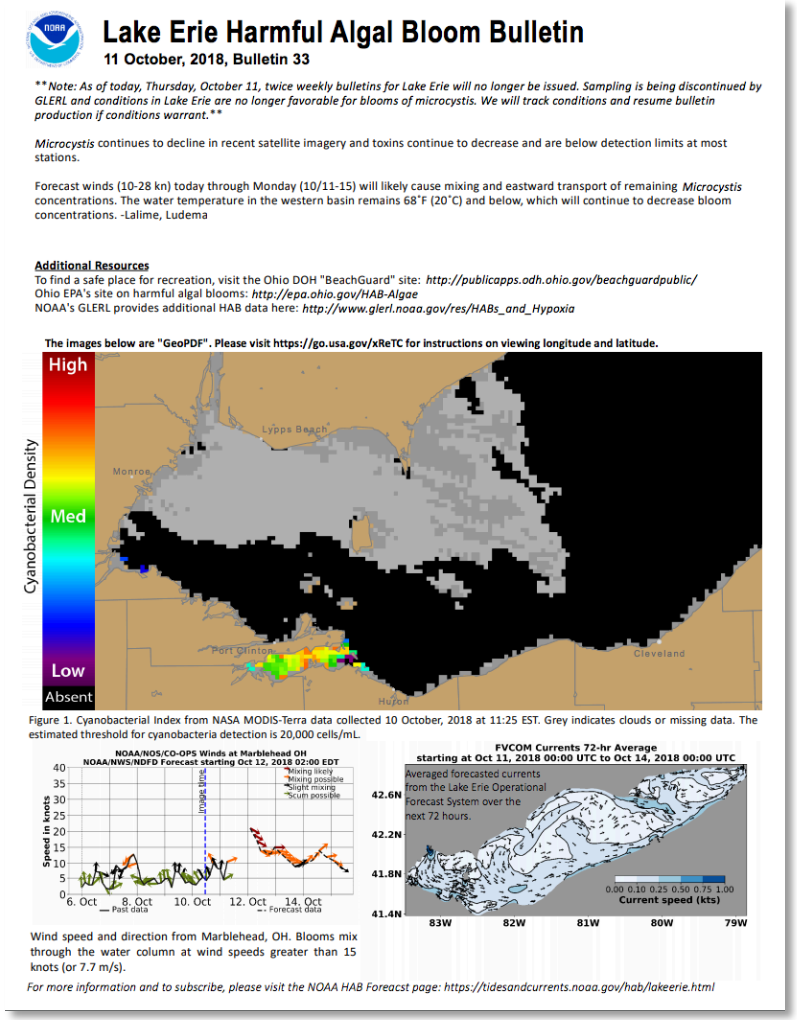
Credit: NOAA Lake Erie Harmful Algal Bloom Bulletin, 13 Aug 2018

Cyanobacterial Harmful Algal Bloom Monitoring Programs

NOAA Operational Great Lakes HAB Bulletin

https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/bulletin.html

- Operational Harmful Algal Bloom Bulletin
- Issued twice weekly when conditions warrant – typically in the summer and early autumn
- Reports Cyanobacterial Index (CI)



Lake Erie Harmful Algal Bloom Bulletin

11 October, 2018, Bulletin 33

Note: As of today, Thursday, October 11, twice weekly bulletins for Lake Erie will no longer be issued. Sampling is being discontinued by GLERL and conditions in Lake Erie are no longer favorable for blooms of microcystis. We will track conditions and resume bulletin production if conditions warrant.

Microcystis continues to decline in recent satellite imagery and toxins continue to decrease and are below detection limits at most stations.

Forecast winds (10-28 kn) today through Monday (10/11-15) will likely cause mixing and eastward transport of remaining *Microcystis* concentrations. The water temperature in the western basin remains 68˚F (20˚C) and below, which will continue to decrease bloom concentrations. -Lalime, Ludema

Additional Resources

To find a safe place for recreation, visit the Ohio DOH "BeachGuard" site: *http://publicapps.odh.ohio.gov/beachguardpublic/*
Ohio EPA's site on harmful algal blooms: *http://epa.ohio.gov/HAB-Algae*
NOAA's GLERL provides additional HAB data here: *http://www.glerl.noaa.gov/res/HABs_and_Hypoxia*

The images below are "GeoPDF". Please visit https://go.usa.gov/xReTC for instructions on viewing longitude and latitude.

Figure 1. Cyanobacterial Index from NASA MODIS-Terra data collected 10 October, 2018 at 11:25 EST. Grey indicates clouds or missing data. The estimated threshold for cyanobacteria detection is 20,000 cells/mL.

Wind speed and direction from Marblehead, OH. Blooms mix through the water column at wind speeds greater than 15 knots (or 7.7 m/s).

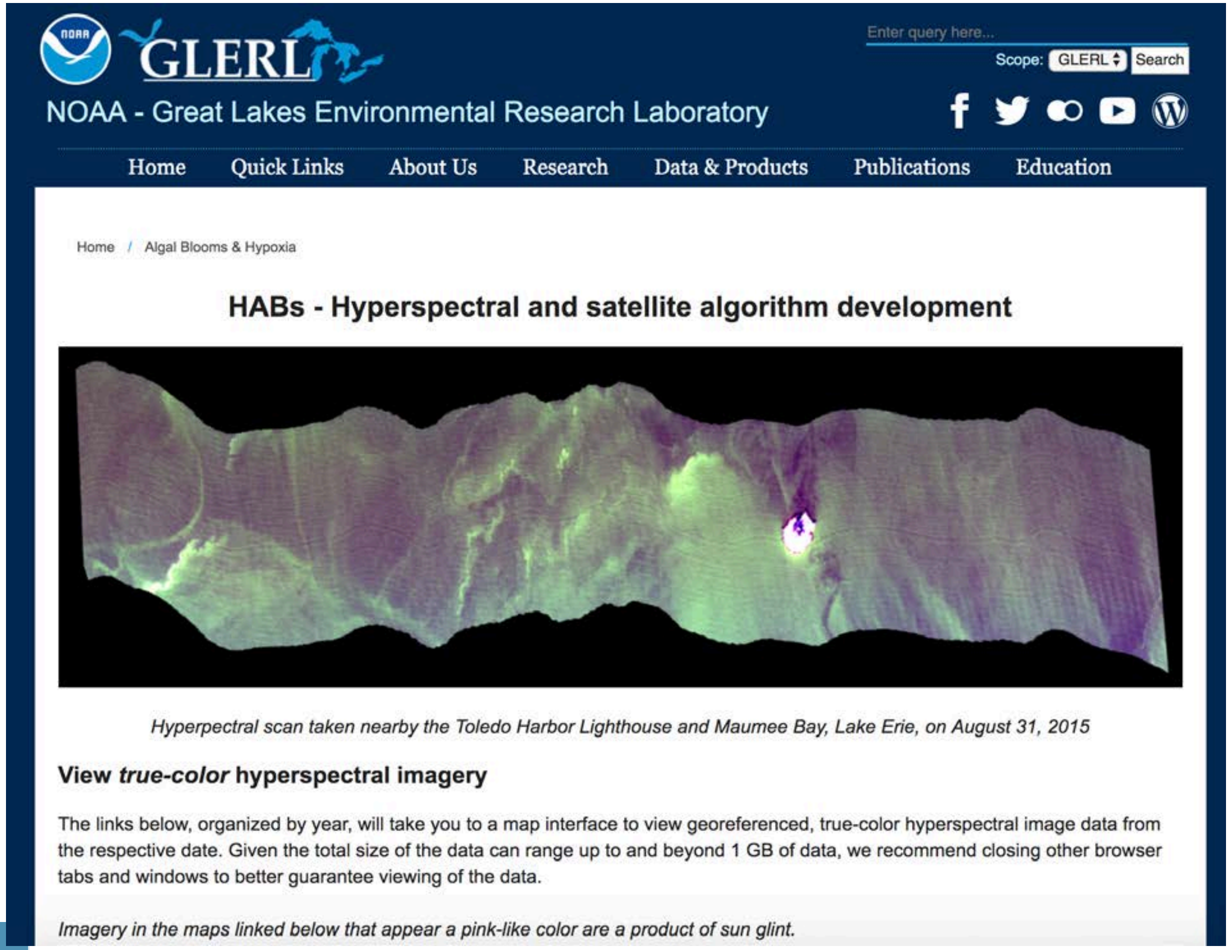
For more information and to subscribe, please visit the NOAA HAB Foreacst page: https://tidesandcurrents.noaa.gov/hab/lakeerie.html

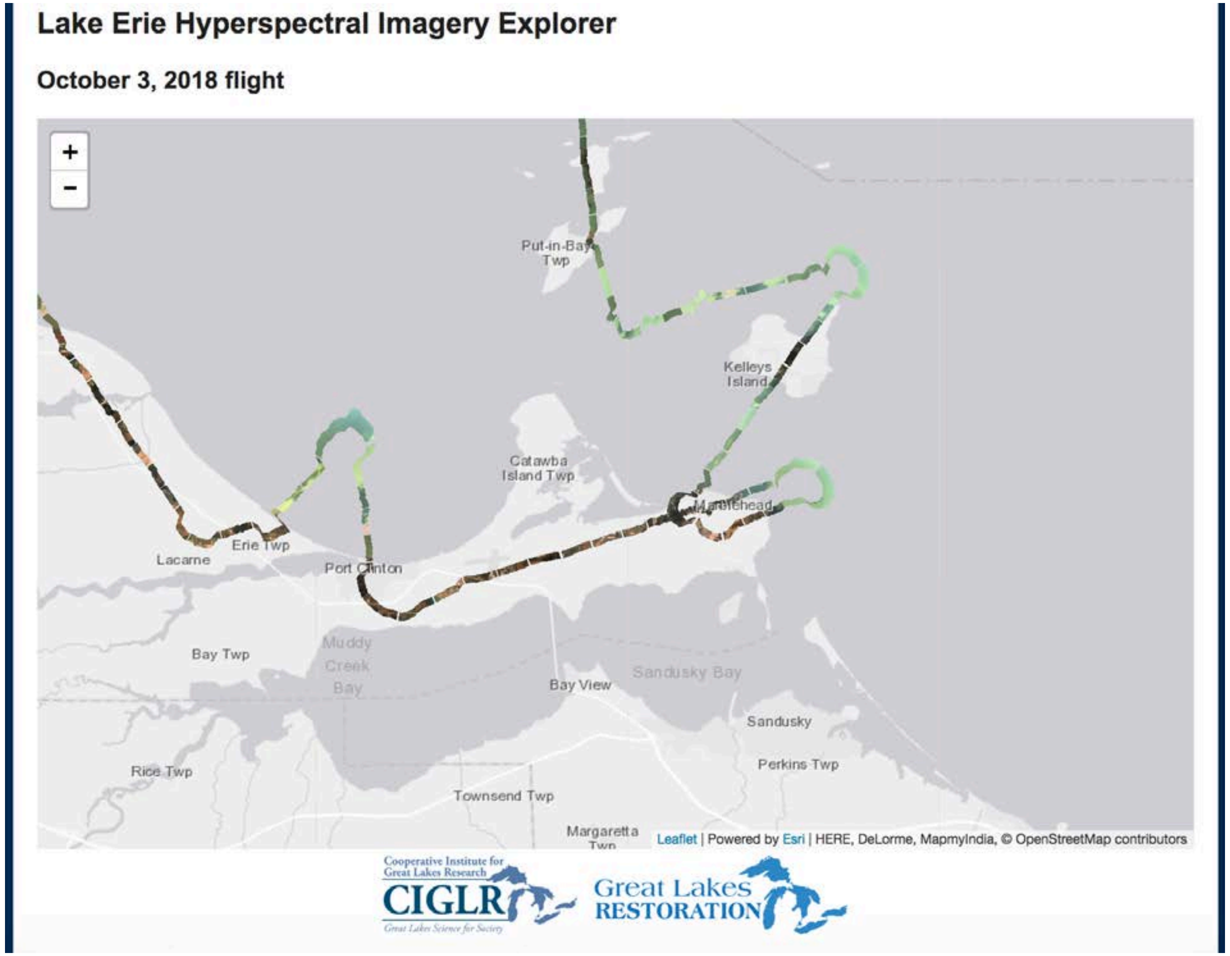
NOAA Experimental Lake Erie HAB Tracker

https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/habTracker.html

NOAA Great Lakes Hyperspectral Monitoring

https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/airSatelliteMon.html

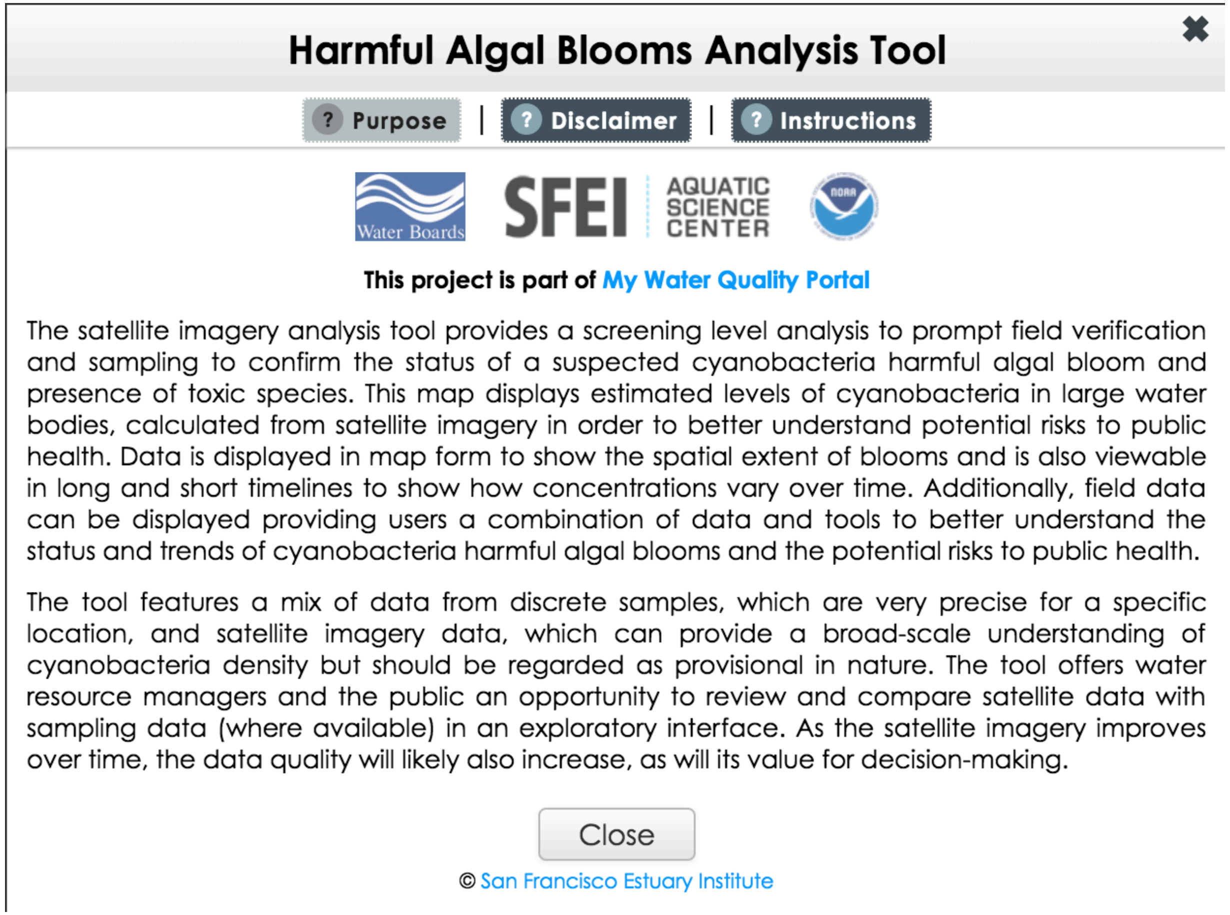




Harmful Algal Blooms Analysis Tool

https://cchab.sfei.org/

- Screening level analysis tool to prompt field verification and sampling to confirm suspected cyanoHAB
- Browser provides map view of blooms to show spatial extent of bloom and time series at particular pixel location
- Region includes US States California and parts of Oregon and Nevada

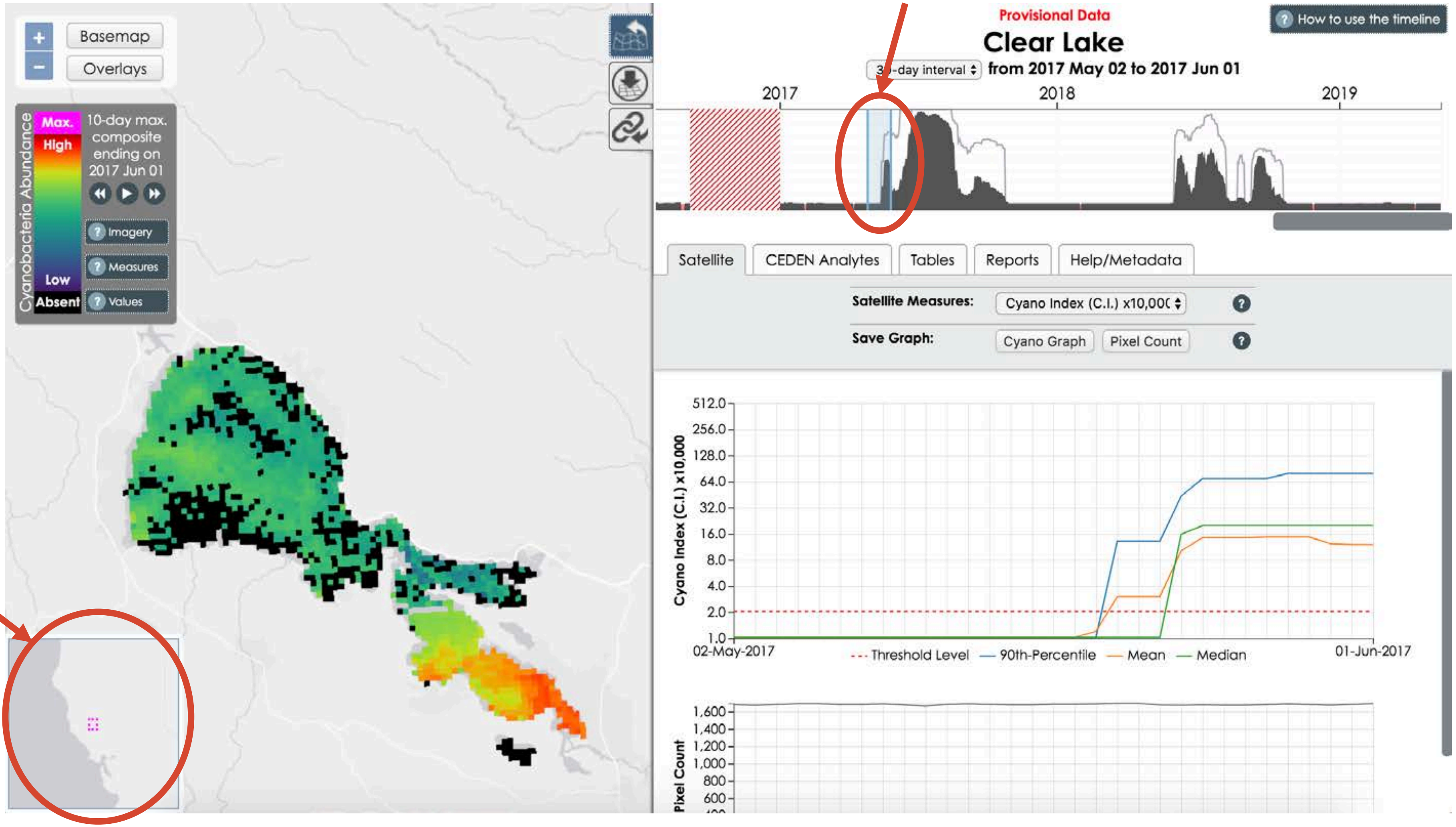


Harmful Algal Blooms Analysis Tool

https://cchab.sfei.org/

Time Period of Interest

Location of Interest



Considerations When Using Remote Sensing for Freshwater Water Quality Monitoring

Advantages of Remote Sensing for Freshwater Systems

- Longtime imagery record for time series analysis
- Ongoing commitment from space agencies to continue data collection
- Reliable data for operational early warning and forecasting systems
- Some sensors have spatial resolution appropriate for lakes
- Imagery is typically freely available and of high quality

Disadvantages of Remote Sensing for Freshwater Systems

- Shallow water – interference from the bottom
- Water bodies too small for the spatial resolution of sensors
- Limited number of standard algorithms for these optically complex waters
- Atmospheric correction
- Highly variable systems
- Ground truthing is costly

Dr. Daniela Gurlin
Wisconsin Department of Natural Resources

National Aeronautics and Space Administration

Integrating Remote Sensing into a Water Quality Monitoring Program

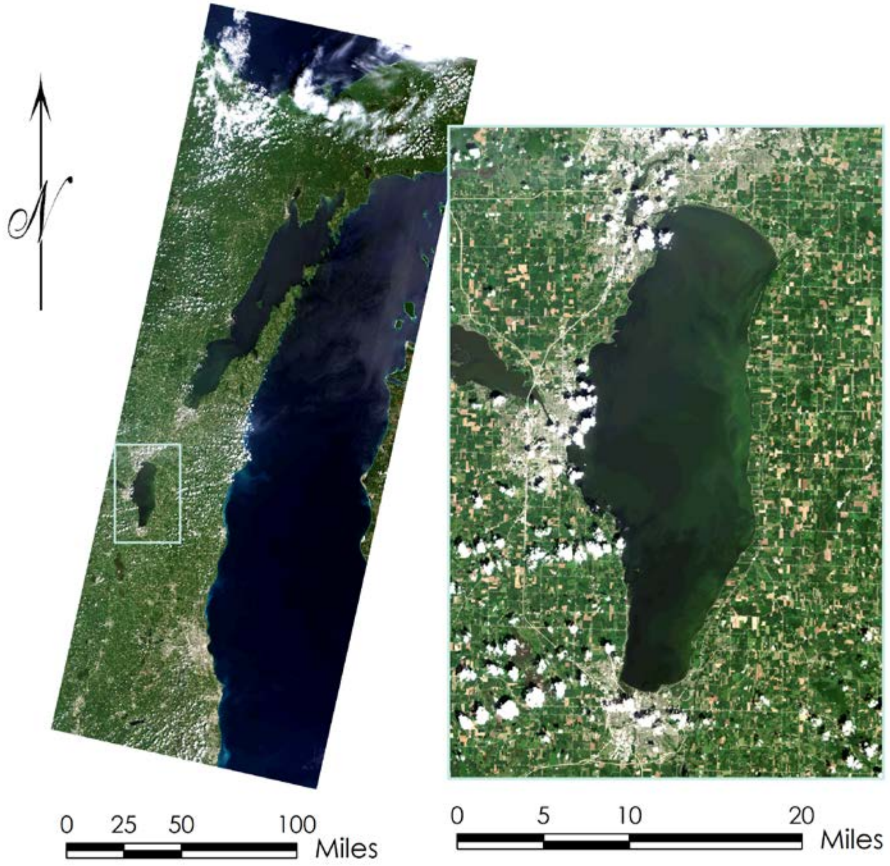
Daniela Gurlin (Wisconsin Department of Natural Resources)

12 June 2019

Outline

- Remote Sensing Challenges
- Earth Observation Sensors
- Remote Sensing Activities
- Satellite Water Clarity Monitoring
- Data Use for Integrated Reporting
- Data Dissemination
- Remote Sensing Research Projects

Algal bloom in Lake Winnebago



Algal bloom in eastern Lake Winnebago as seen by Landsat 8 OLI on 07/26/2016 (Source of Landsat 8 OLI data: USGS).

Remote Sensing Challenges

Advantages

- Data with a high spatial and temporal resolution
- Evaluation of environmental problems and potential health risks
- Historical data for studies of trends in water quality
- Data for integration into early warning systems

Disadvantages

- Optically complex conditions in lakes and reservoirs
- Interference from the lake bottom
- Dynamic water quality changes
- Limited number of water quality parameters
- Collection of ground-truth data required

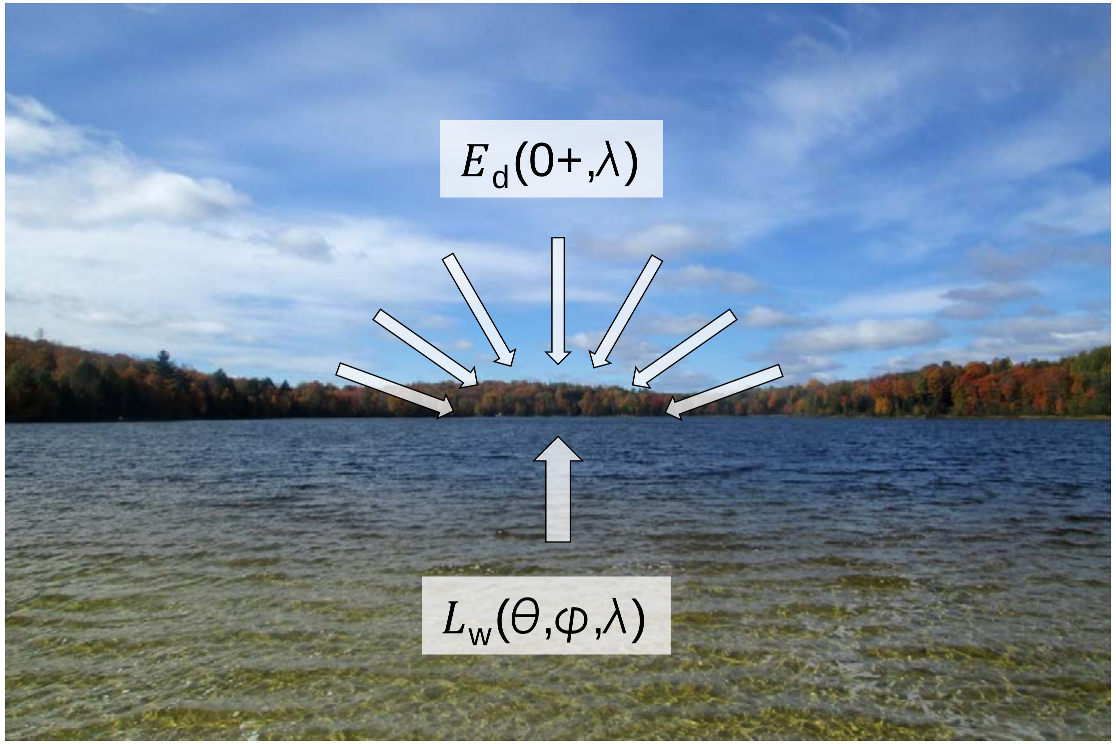
Earth Observation Sensors

	Landsat 7	Landsat 8	Sentinel-2A	Sentinel-2B	Sentinel-3A	Sentinel-3B
Satellite Sensor System	ETM+	OLI/TIRS	MSI	MSI	OLCI	OLCI
Spatial Resolution (m)	15, 30, 60	15, 30, 100	10, 20, 60	10, 20, 60	300	300
Spectral Bands	8	11	13	13	21	21
Revisit Cycle (days)	16	16	5	5	2	2
Swath Width (km)	183	183	290	290	1270	1270
Launch Date	April 1999	February 2013	June 2015	March 2017	February 2016	April 2018
Years in orbit/minimum design life (years)	20/5	6/5	3/7	2/7	3/7	1/7
Example Data Sources	U.S. Geological Survey EarthExplorer (https://earthexplorer.usgs.gov/)			Copernicus Open Access Hub (https://scihub.copernicus.eu/)		

Satellite Sensor Abbreviations
Landsat 7: Enhanced Thematic Mapper Plus (ETM+)
Landsat 8: Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)
Sentinel-2: Multispectral Instrument (MSI)
Sentinel-3: Ocean and Land Color Instrument (OLCI)

Earth Observation Sensors

What is remote sensing reflectance?



$$R_{rs}(\theta,\varphi,\lambda) = \frac{L_w(\theta,\varphi,\lambda)}{E_d(0^+,\lambda)}$$

- $R_{rs}(\theta,\varphi,\lambda)$: remote sensing reflectance
- $L_w(\theta,\varphi,\lambda)$: water leaving radiance
- $E_d(0+,\lambda)$: downwelling irradiance
- θ: solar zenith angle
- φ: solar azimuth angle
- λ: wavelength

Calculation of the remote sensing reflectance of waterbodies. This equation relates the ratio of the water leaving radiance and the downwelling irradiance ($L_w(\theta,\varphi,\lambda)$ and $E_d(0^+,\lambda)$) to the remote sensing reflectance ($R_{rs}(\theta,\varphi,\lambda)$).

Earth Observation Sensors

What is remote sensing reflectance?

Sensitivity of the reflectance to variations in the solar zenith angle

$$R_{rs}(\theta, \varphi, \lambda) = \frac{f(\lambda)}{Q(\lambda)} \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

Bidirectional properties of the reflectance

Absorption coefficient

Backscattering coefficient

$$a(\lambda) = a_{\varphi}(\lambda) + a_{NAP}(\lambda) + a_{CDOM}(\lambda) + a_w(\lambda)$$

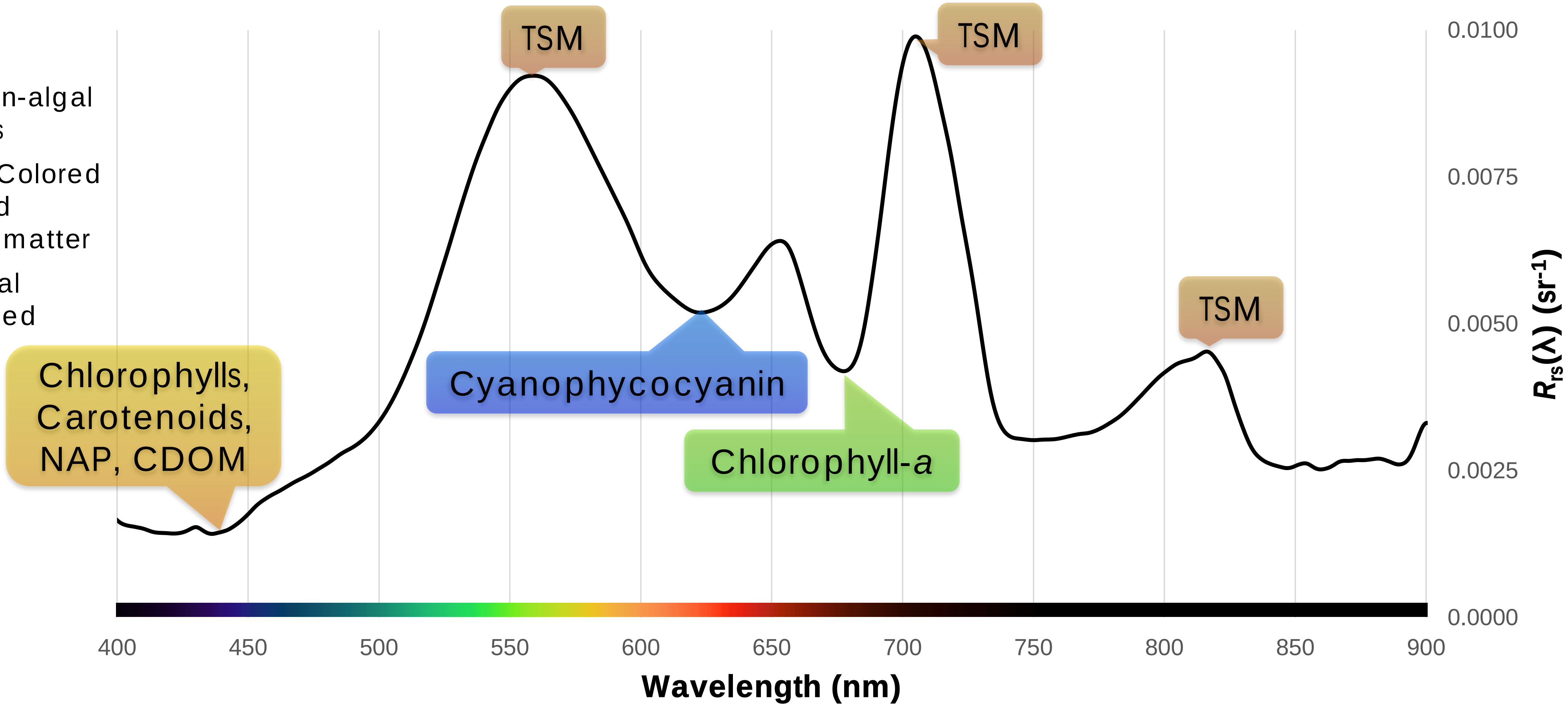
φ: Phytoplankton, NAP: Non-algal particles, CDOM: Colored dissolved organic matter, w: water

Earth Observation Sensors

NAP: Non-algal particles

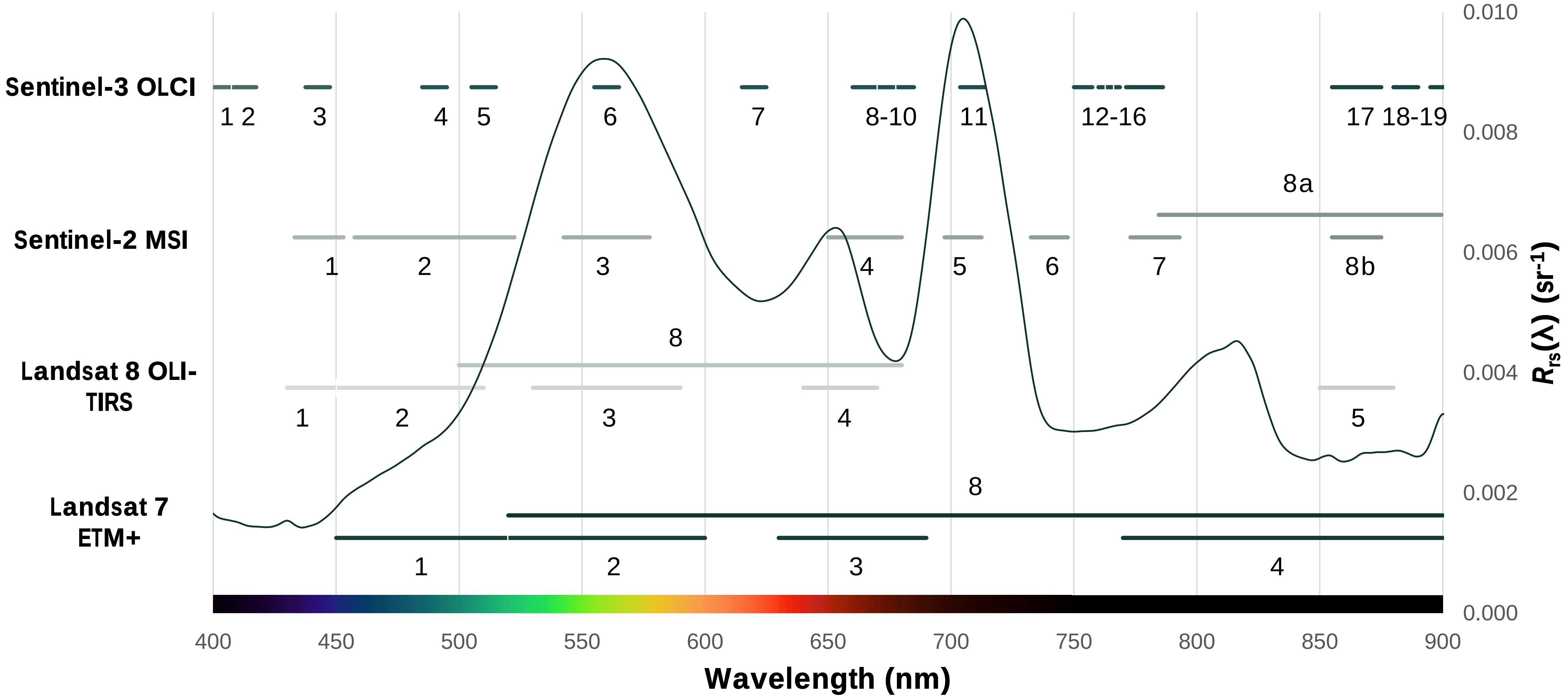
CDOM: Colored dissolved organic matter

TSM: Total suspended matter



Remote Sensing Reflectance Spectrum for Lake Winnebago, Acquired 09/21/2015

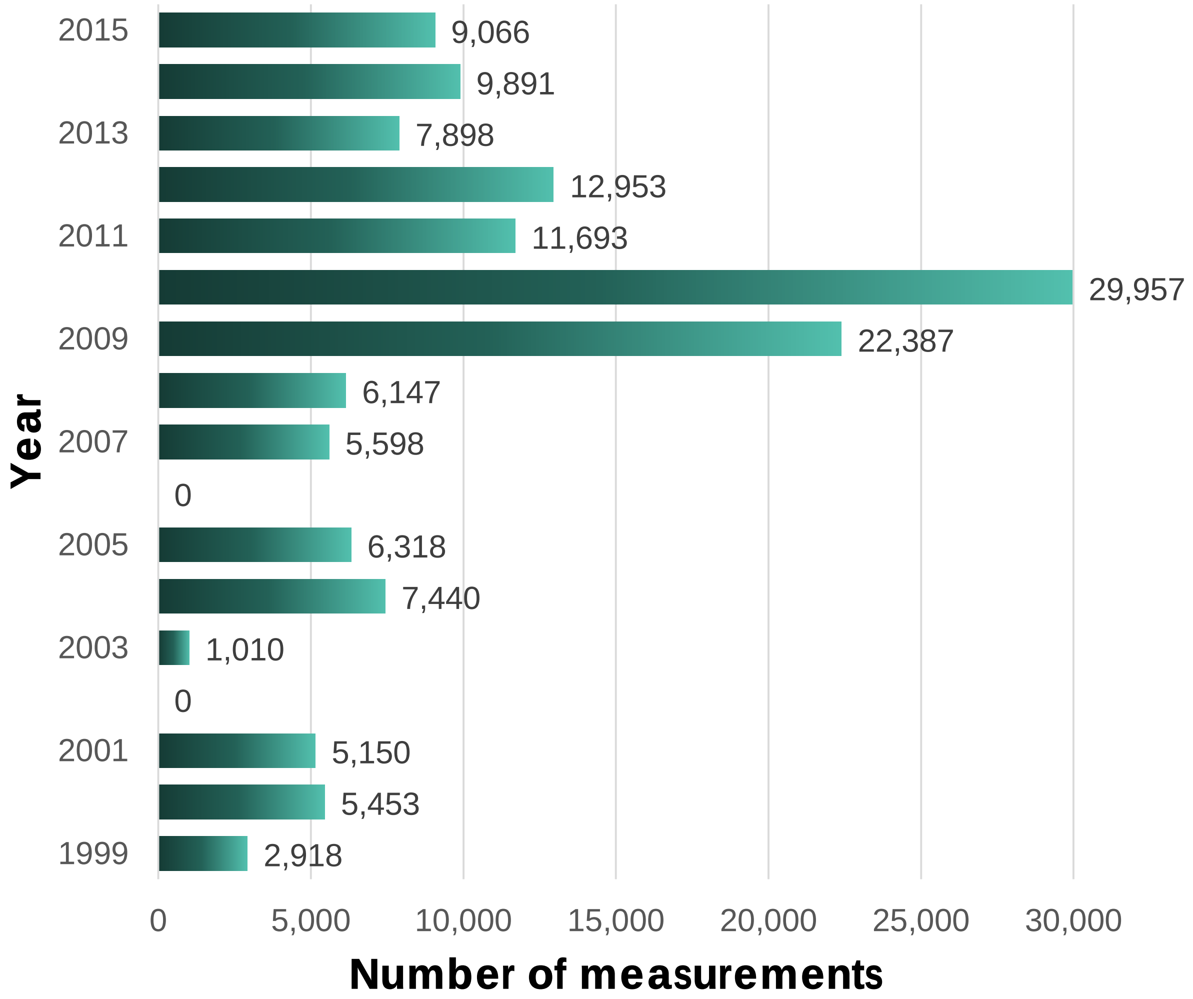
Earth Observation Sensors



Remote Sensing Reflectance Spectrum for Lake Winnebago, Acquired 09/21/2015

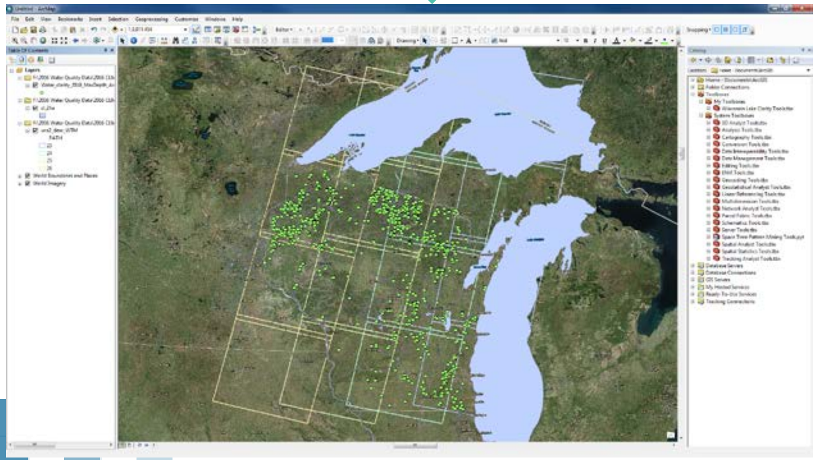
Remote Sensing Activities

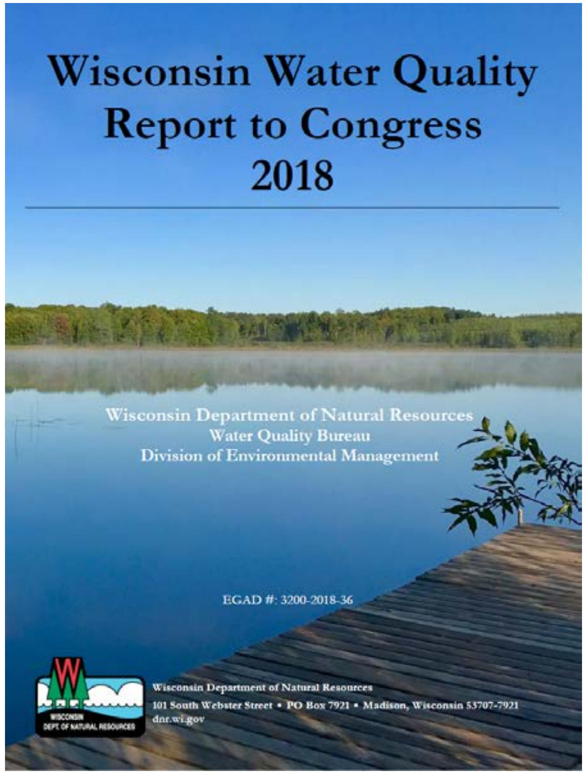
- Systematic retrieval of the water clarity from Landsat 7 ETM+ and Landsat 8 OLI-TIRS data
- Studies of the major drivers of lake water clarity
- Increase in Earth observation monitoring capabilities

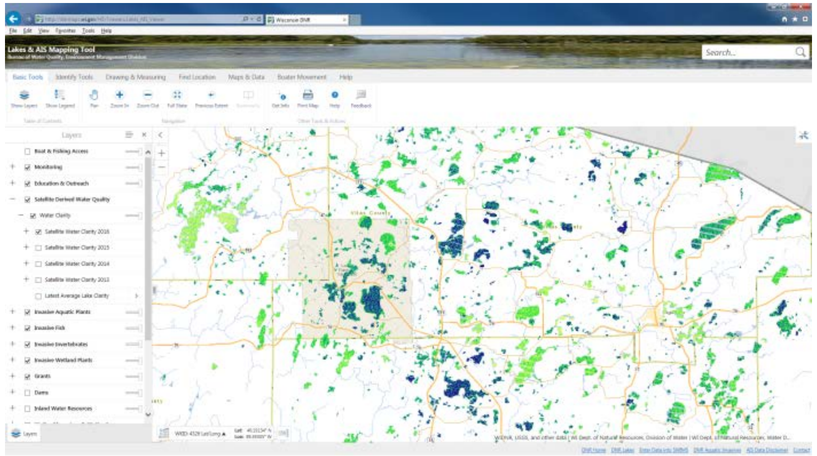


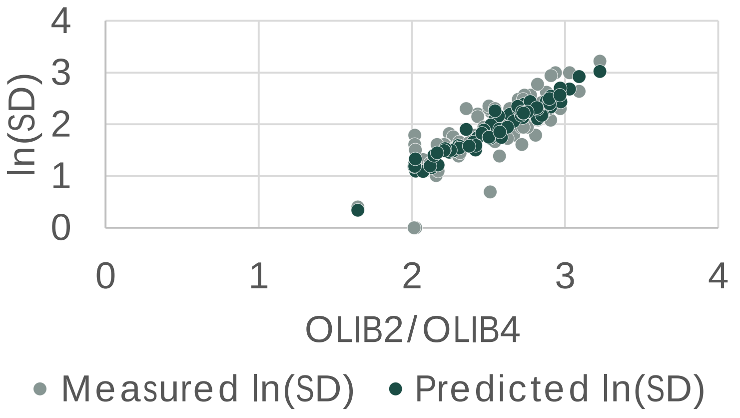
Satellite Water Clarity Monitoring

Photo credit: Amy Kowalski









Satellite Water Clarity Monitoring

2016 Satellite Retrieval of Water Clarity

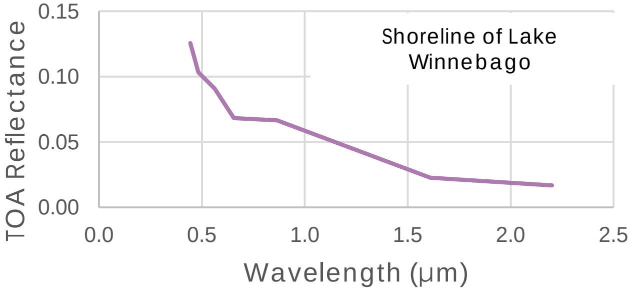
- Pre-processing and mosaicking of Landsat Images
- Extraction of field data signatures from Landsat images
- Multiple linear regression of field and satellite data
- Retrieval of water clarity from Landsat images
- Software packages used include ArcGIS 10.4.1 for Desktop, ENVI 5.4.0, IDL 8.6.0, R for Windows 3.3.1, and RStudio

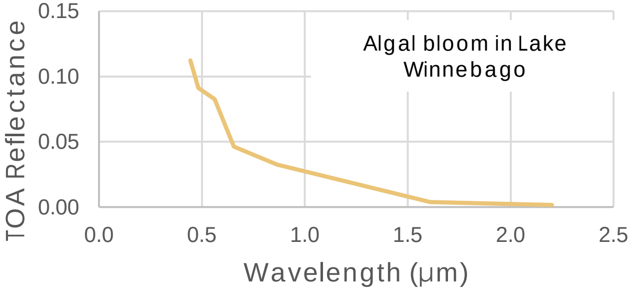
1. Download of Landsat images and ancillary data (Landsat Collection 1 Level-1 data)
2. Conversion of image digital numbers (DN) to top of atmosphere (TOA) reflectance
3. Removal of clouds and cloud shadows
4. Reprojection of images
5. Removal of land and residual clouds
6. Identification and removal of shallow water, aquatic vegetation, and lake edges
7. Building of mosaic rasters for images from the same image acquisition dates

Satellite Water Clarity Monitoring

2016 Satellite Retrieval of Water Clarity

Removal of edge effects
for Lake Winnebago
07/26/2016





Differentiation of the shoreline and an algal bloom for the Landsat 8 OLI images acquired on 07/26/2016 (Source of Landsat 8 OLI data: USGS).

$$\ln(SD) = a + b \times \frac{OLI_{B2}}{OLI_{B4}} + c \times OLI_{B2}$$

ln(SD) – Natural logarithm of the Secchi depth

OLIB2 - Operational Land Imager Band 2

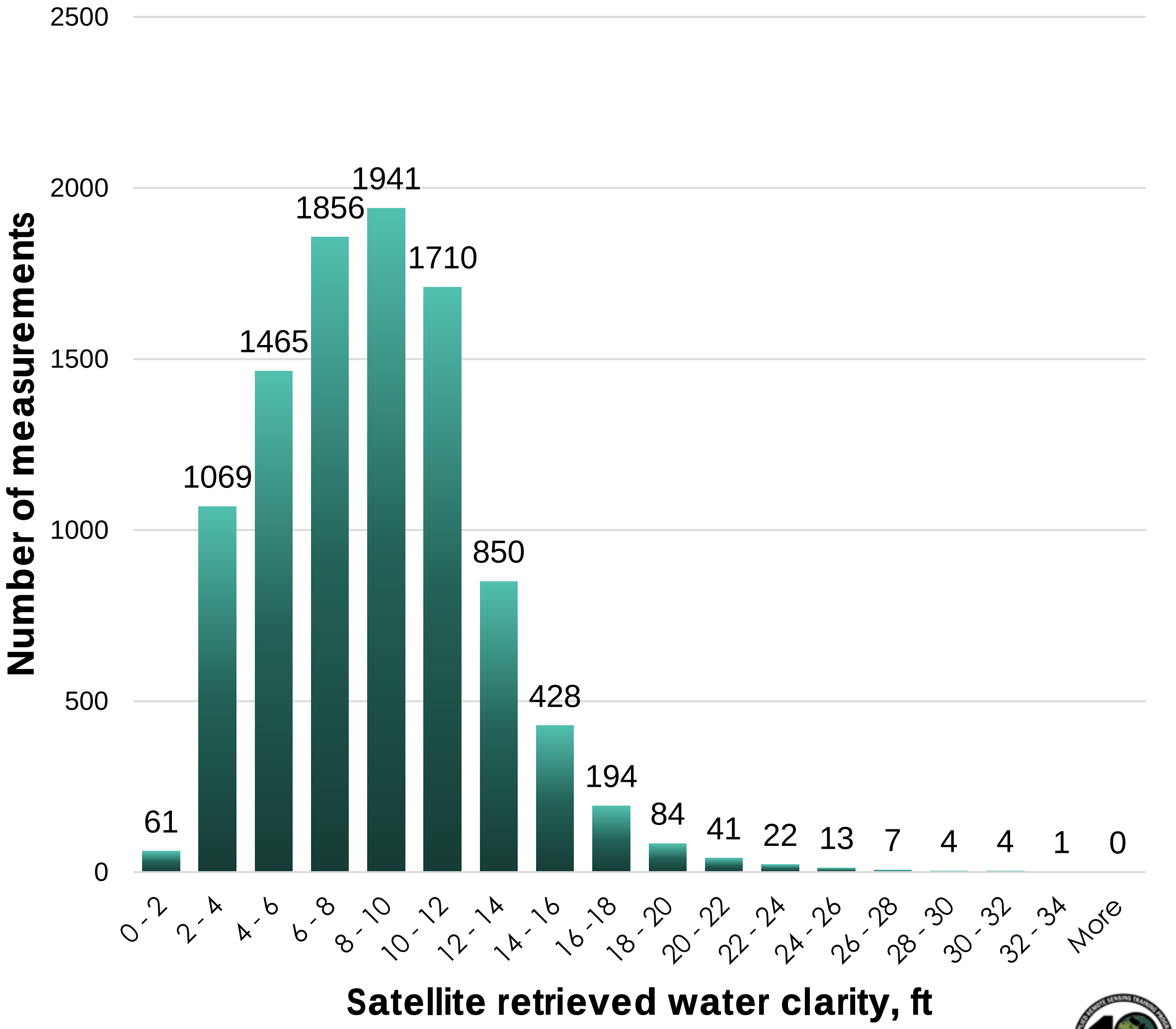
OLIB4 – Operational Land Imager Band 4

- 76 Landsat 7 and 8 images
- 11 image mosaics for algorithm development
- 608 ground-truth measurements for algorithm development

Satellite Water Clarity Monitoring

2016 Satellite Retrieval of Water Clarity

- 9750 water clarity estimates
- 4500 water bodies
- Average mean normalized absolute error of 2.0 ft (0.6096 m)



Data Use for Clean Water Act "Integrated Reporting"

What is integrated reporting?

- Fulfill federal reporting requirements for statewide water quality conditions
- Water quality standards are used to define goals for a waterbody through use designations, use protection, and water quality protection
- Water quality monitoring data is used to assess the current status of the waterbody
- General and specific assessments
- Designated uses are classified into four categories


Aquatic Life


Recreation


Public Health & Welfare


Wildlife

Data Use for Integrated Reporting

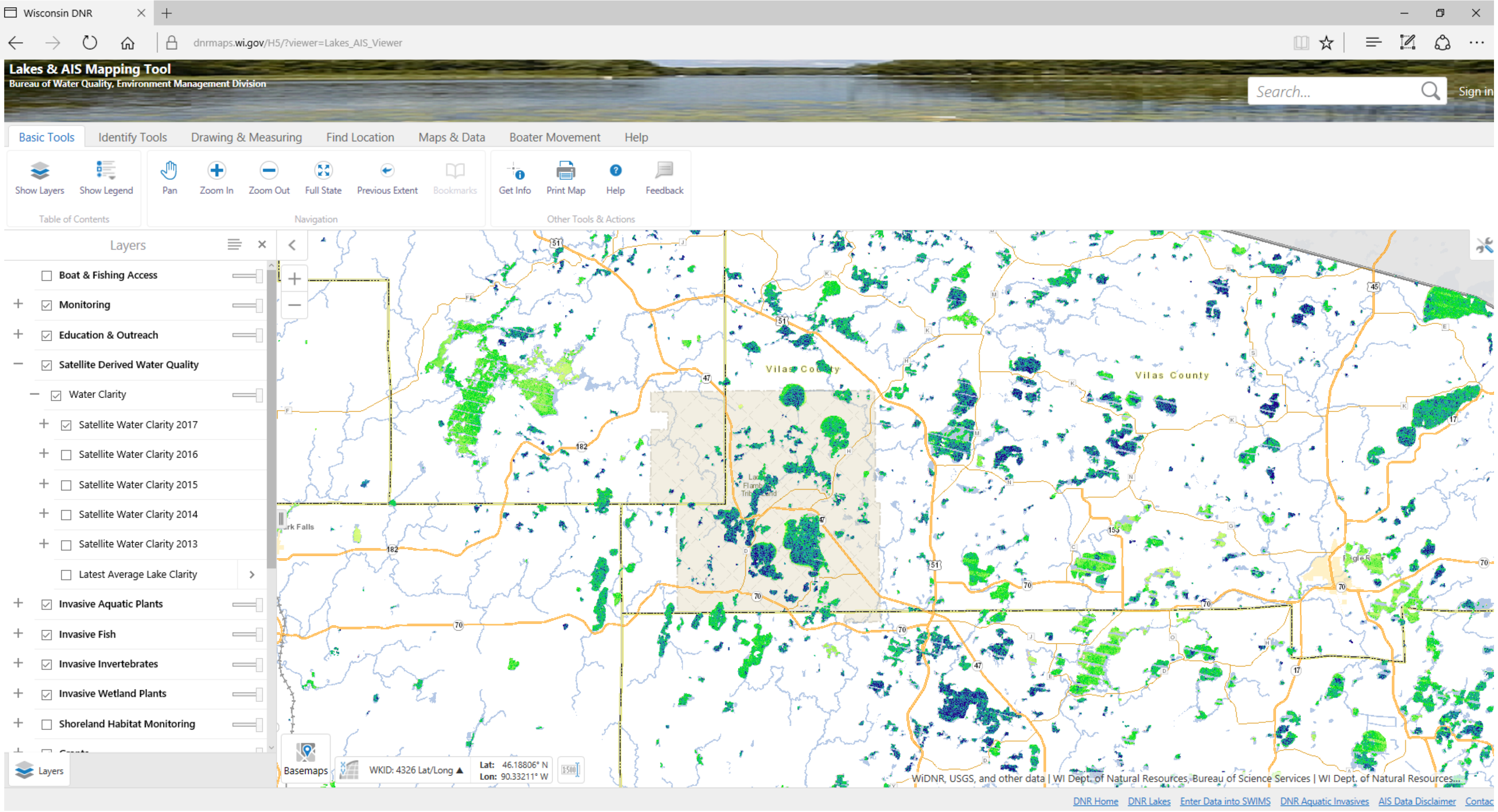
- General condition assessments include multiple metrics
- Carlson Trophic State Index is the most commonly used index of lake productivity
- Calculated from chlorophyll-*a* or Secchi depth which includes satellite inferred Secchi depth
- Calculated automatically with a programming package

$$TSI_{SD} = 60 - 14.41 \ln(SD)$$

- TSI – Trophic State Index
- SD – Secchi depth (m)
- Ln – Natural logarithm

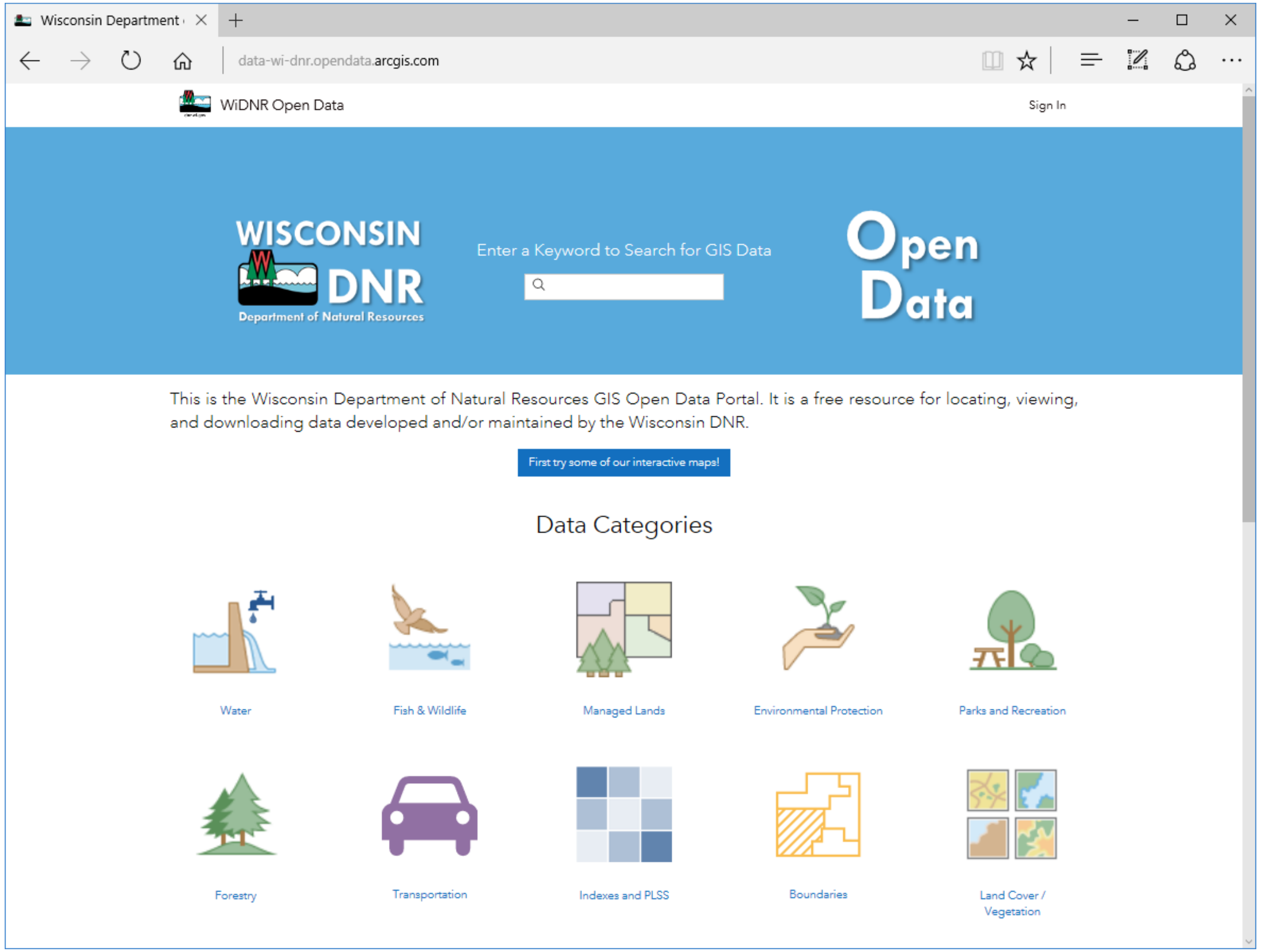
Data Dissemination

https://dnr.wi.gov/lakes/viewer/



Data Dissemination

http://data-wi-dnr.opendata.arcgis.com/



Remote Sensing Research Projects

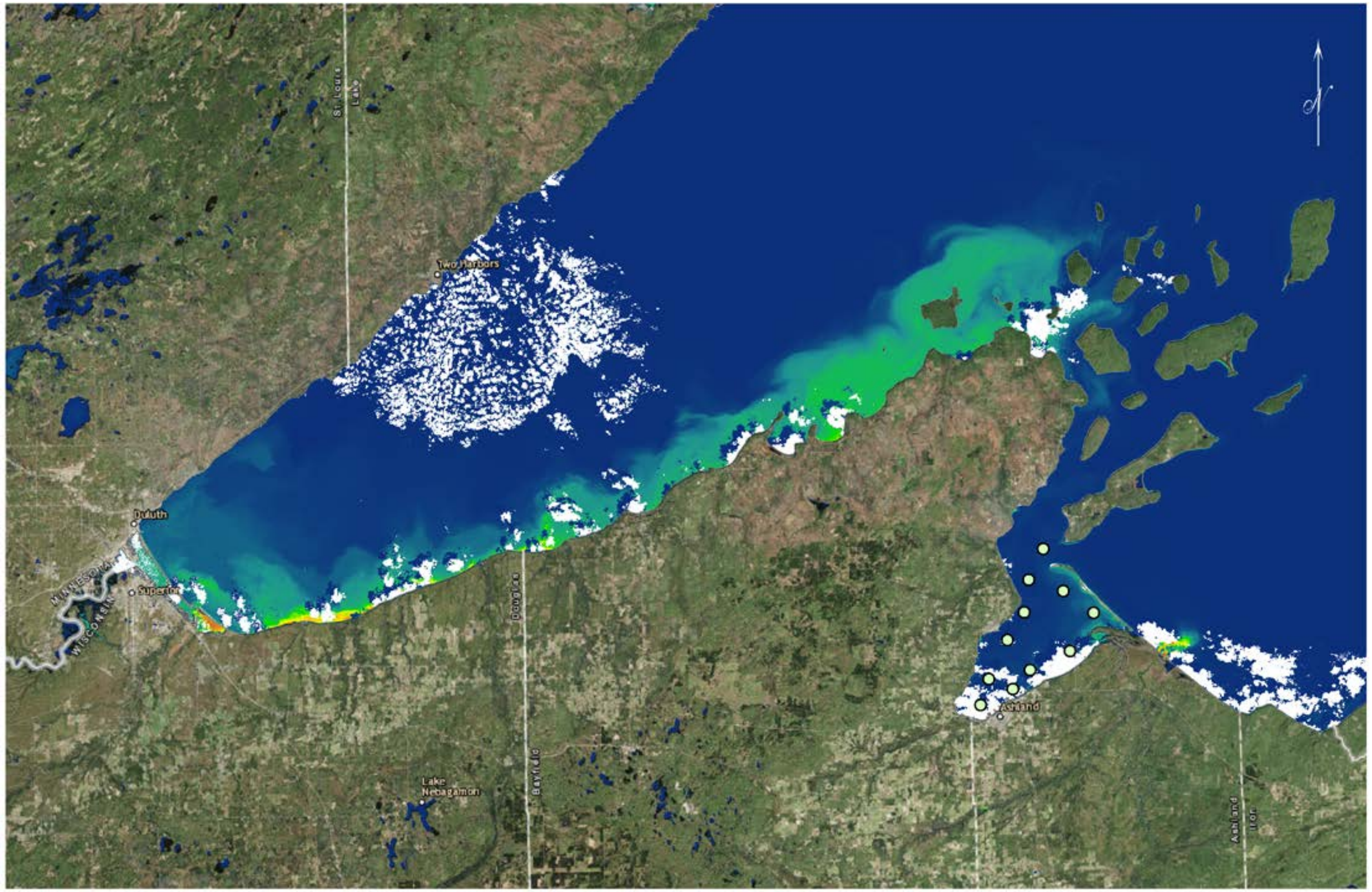
- Field data collection in summer and fall 2014 and 2015 for algorithm development
- 32 lakes in Wisconsin
- Standard water quality data
- Radiometric data
- Absorption and backscattering data

- Additional field data collection to support partnerships in summer 2016 and 2018

Regretting the decision to collect field data...

Field data collection completed...

Remote Sensing Research Projects



Retrieval of TSM concentration for the Lake Superior nearshore from Landsat 8 OLI data acquired on 07/10/2014 (C2RCC)

○ Northland College stations TSM concentration 0.10 mg L⁻¹ – 158.60 mg L⁻¹ 0 5 10 20 Miles

Basemap credits: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Dr. Amita Mehta
Demonstration of Landsat Download and Processing