EARTH OBSERVATION MONITORING OF ALGAL BLOOMS IN OKLAHOMA AND NORTH TEXAS RESERVOIRS

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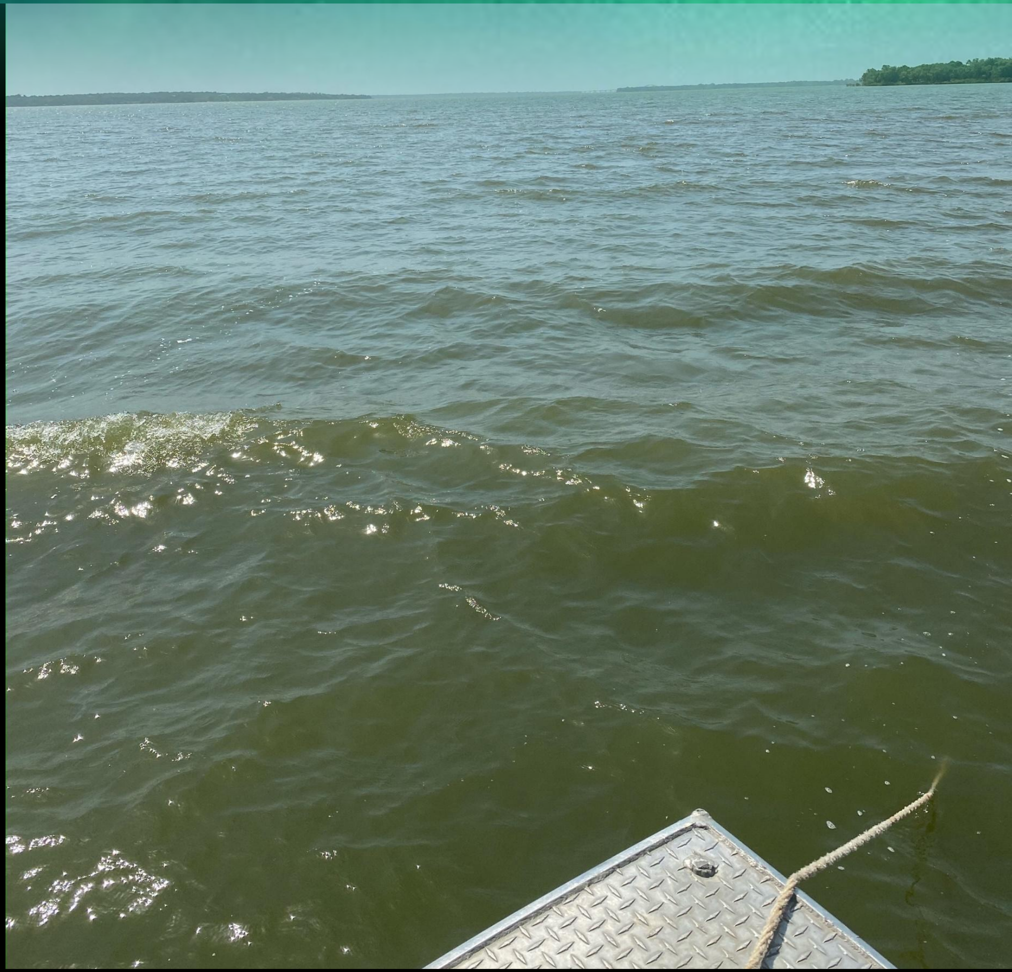
Image credit: Landsat 8 OLI imagery Sept. 26, 2017 of Lake Erie, USA. Path 20 Row 31.

PROBLEM

Harmful and/or nuisance algal and cyanobacterial blooms cause water-quality and ecological problems including health risks, such as acute and chronic toxicity, anoxia, taste-and-odor problems, and fish kills.

Current ground monitoring/data collection and analysis of water samples are often geographically limited and have a minimum of several days before results are available.



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SCIENCE OBJECTIVES

The USGS, in collaboration with North Texas water-supply reservoir managers, developed a reservoir monitoring system that incorporates imagery from ESA Sentinel-2 powered by Google Earth Engine.

Detection and concentration estimation of Chlorophyll-a, a surrogate for algae and cyanobacteria, was calibrated for ten reservoirs based on field data collected in 2020.

The web app has been developed to help monitor algae and cyanobacteria in near real-time and to study temporal trends at the regional scale.

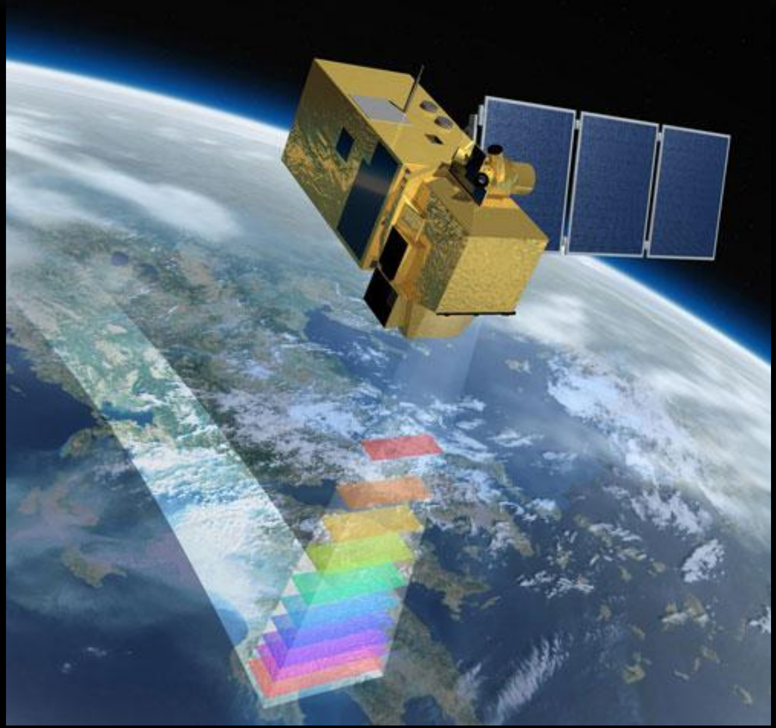
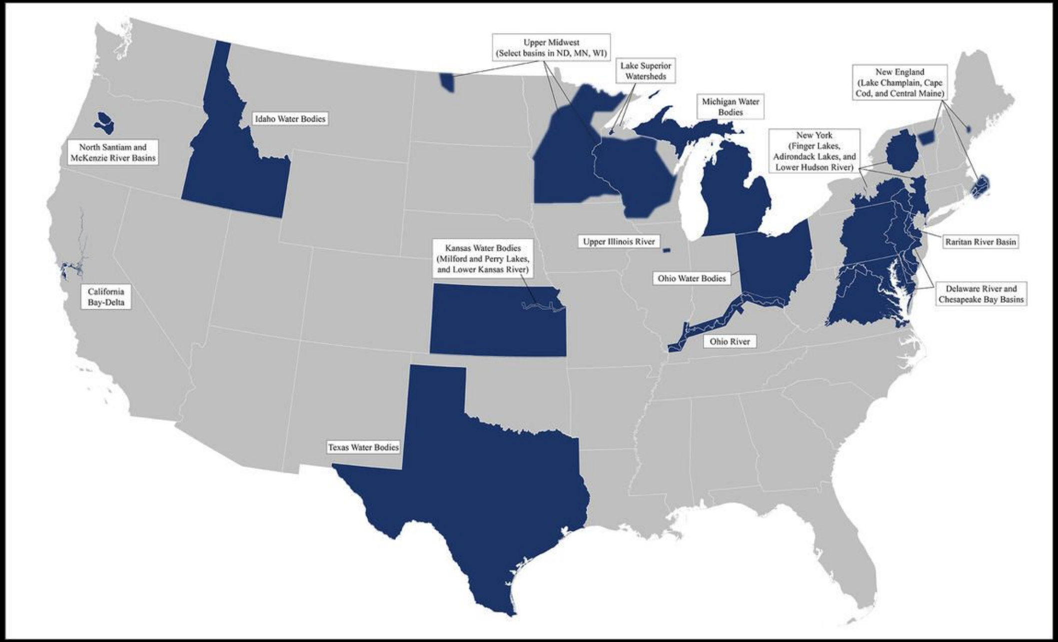


Image credit: ESA

NATIONAL COLLABORATION

Funding was provided by USGS Water Mission Area and north Texas reservoir managers.

“In Fiscal Years 2019 through 2022, Congress provided the USGS National Water Quality Program (NWQP) with additional resources to assess HABs. The NWQP is currently funding 24 projects in 15 geographic areas that advance real-time monitoring, remote sensing, and use of molecular techniques to identify and predict the occurrence of HABs and the toxins they produce.”



https://www.usgs.gov/mission-areas/water-resources/science/harmful-algal-bloom-hab-cooperative-matching-funds-projects?qt-science_center_objects=0#qt-science_center_objects

PROJECT WORKFLOW

***In situ* water-quality data collection:** Used for calibration and validation of remote sensing analysis

Chlorophyll-a concentration estimation: *In situ* data driven spectral algorithm selection

Cloud computation in Google Earth Engine: Multispectral Sentinel-2 storage, processing, and analysis

Near real-time web app hosted by GEE

Temporal analysis: Descriptive statistics revealing temporal variation of bloom activity

GEOCOMPUTATION ENVIRONMENT

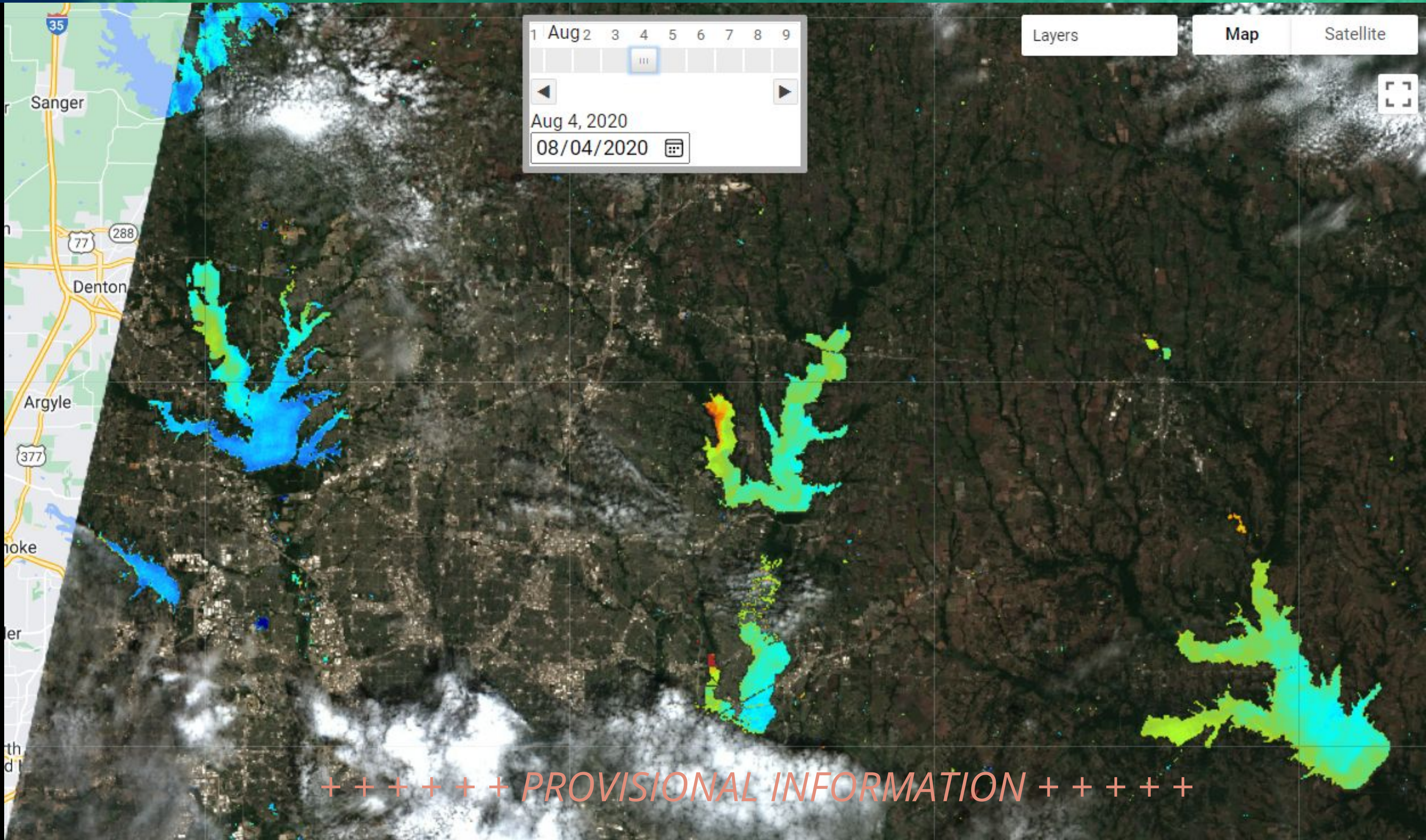
Google Earth Engine

- ✔ Delivering cloud hosted analysis ready satellite imagery to a high-performance geoprocessing platform
- ✔ Planetary-scale geospatial analysis accelerating scientific discovery (Gorelick et al., 2017).
- ✔ Facilitating a paradigm shift in the field of remote sensing and geospatial analysis from change detection to earth observation monitoring (Woodcock et al., 2020).

CHALLENGES OF NEAR REAL-TIME MONITORING

Signal interference from our rambunctious planet:

- Clouds and cloud shadows;
- An estimated average of 47% of MODIS overpasses per month observed cloud presence for study area (Wilson et al., 2016).



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CHALLENGES OF NEAR REAL-TIME MONITORING

Signal interference from our rambunctious planet:

× Glint on the water surface roughness from high wind and sun angle.

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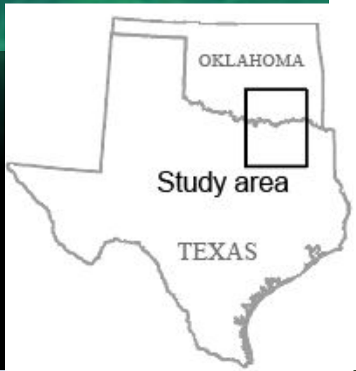
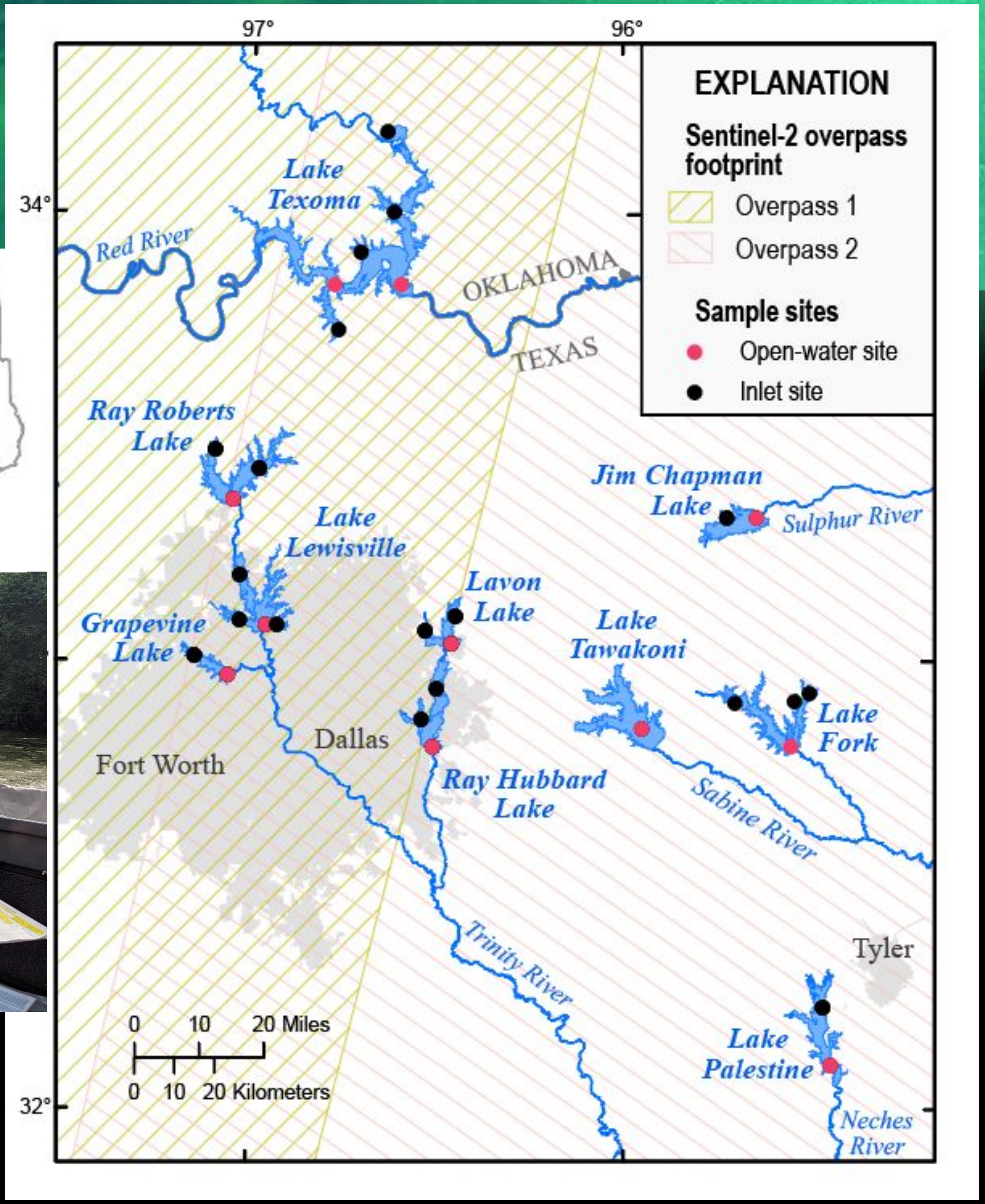
FIELD DATA COLLECTION

In situ data were collected from January - November 2020 for sites located at open water or near inlets of tributaries:

- ✔ Chlorophyll-a,
- ✔ Phycocyanin,
- ✔ Turbidity,
- ✔ Water temperature,
- ✔ Dissolved oxygen,
- ✔ Secchi disk depth,
- ✔ Wind speed,
- ✔ Phytoplankton taxonomy, and
- ✔ Hyperspectral reflectance.

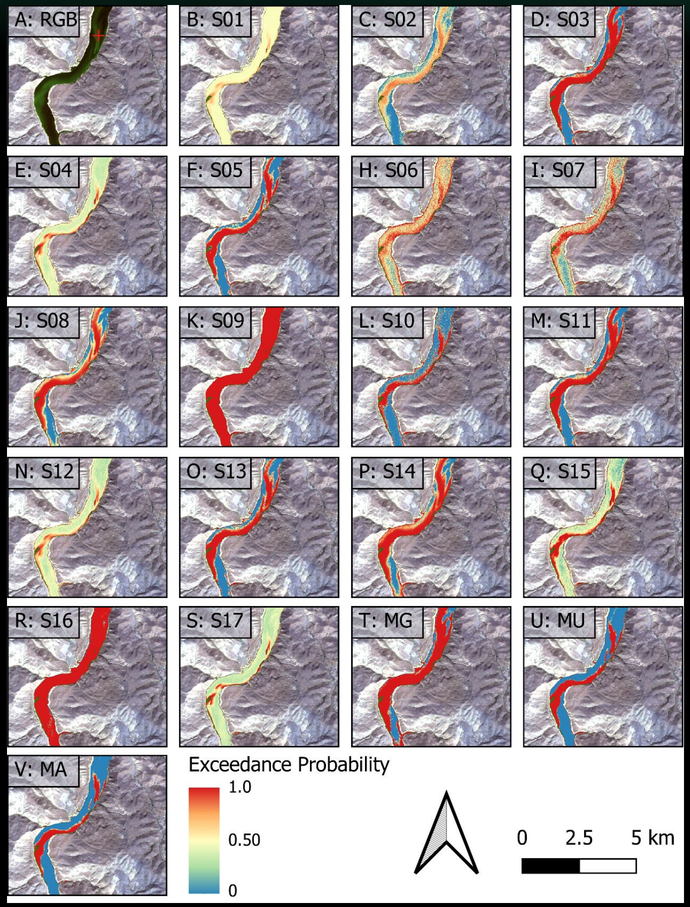




Sievers, J. M., Stengel, V. G., and Trevino, J. M. 2022. "Surface-Water Characteristics and Phytoplankton Taxonomy in Selected North Texas Reservoirs Using Biological, Hyperspectral, and Water-Quality Methods, 2019-2020." U.S. Geological Survey. https://doi.org/10.5066/P9X1R5IM .

CHLOROPHYLL-a RETRIEVAL ALGORITHMS

King, et al., 2022 (in review) collected 17 Chlorophyll-a spectral indices from the literature that were evaluated against *in situ* Chl-a concentrations.

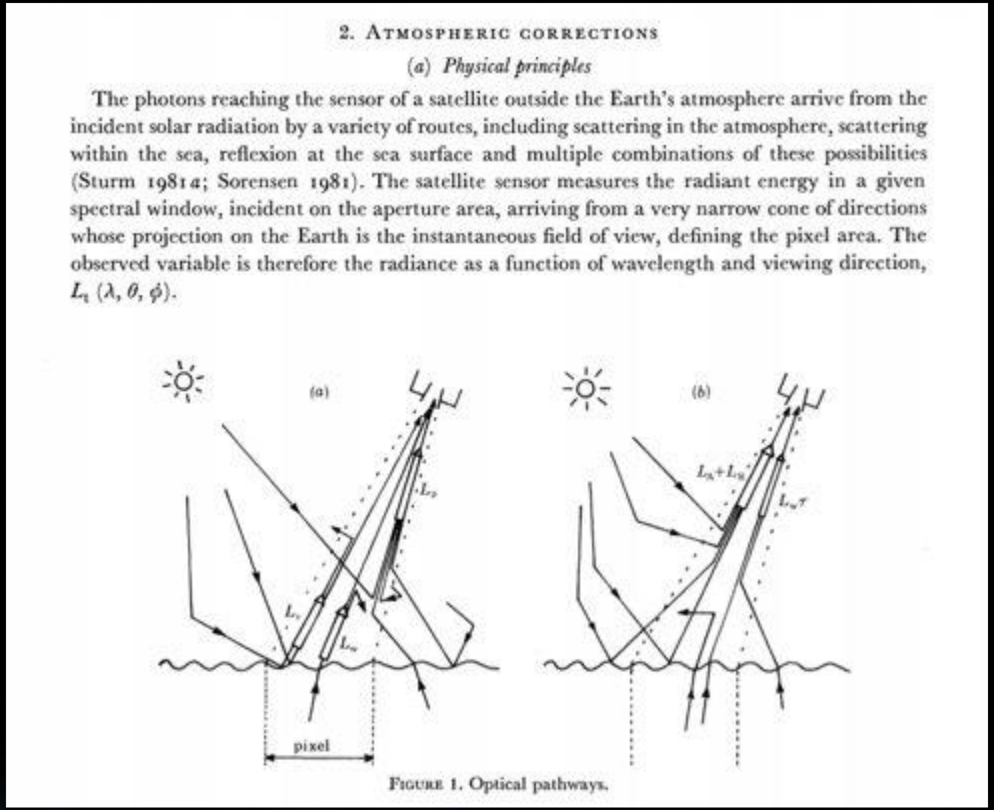


King et al., 2022; Probability to exceed 10 ug/L Chlorophyll-*a*

ATMOSPHERE CORRECTIONS

Tested index performance across 3 atmosphere corrections:

- ✔ Sen2cor surface reflectance (Main-Korne, 2017)
- ✔ ACOLITE aquatic reflectance (Vanhellemont, 2019)
- ✔ MAIN aquatic reflectance (Page, 2019)



2. ATMOSPHERIC CORRECTIONS

(a) *Physical principles*

The photons reaching the sensor of a satellite outside the Earth's atmosphere arrive from the incident solar radiation by a variety of routes, including scattering in the atmosphere, scattering within the sea, reflexion at the sea surface and multiple combinations of these possibilities (Sturm 1981*a*; Sorensen 1981). The satellite sensor measures the radiant energy in a given spectral window, incident on the aperture area, arriving from a very narrow cone of directions whose projection on the Earth is the instantaneous field of view, defining the pixel area. The observed variable is therefore the radiance as a function of wavelength and viewing direction, $L_t(\lambda, \theta, \phi)$.

FIGURE 1. Optical pathways.

Atmosphere correction, Robinson, 1983

CHLOROPHYLL-a RETRIEVAL ALGORITHMS

Consistent process applied for comparison of satellite matchups with *in-situ* samples:

- ✔ cloud filtering
- ✔ cloud masking
- ✔ water masking
- ✔ *In situ* chlorophyll-a samples within 2 days of a suitable satellite acquisition.

- × Match-ups reviewed for glint, clouds, & shadows near sample sites.
- × Images reviewed to verify positive blue band reflectance values at sample sites.

The chlorophyll-a spectral index value was retrieved using a 50 m diameter mean reducer at each sample site from January 2020 through November 2020.

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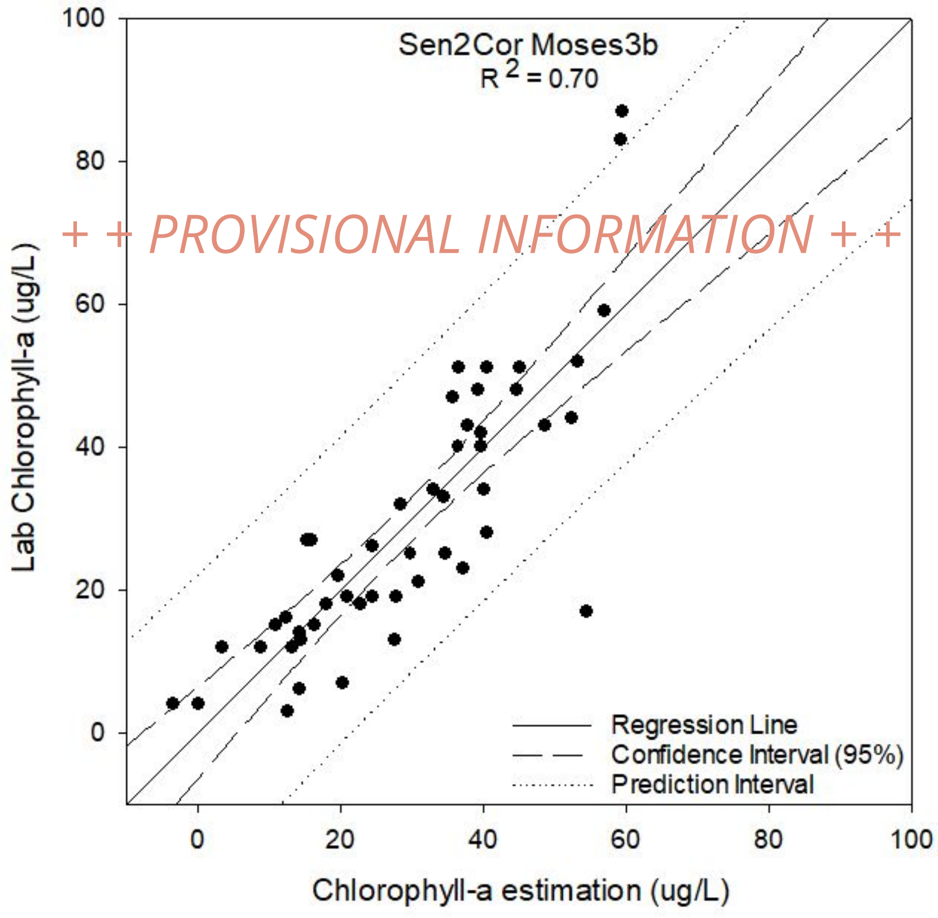
SPECTRAL ALGORITHM PERFORMANCE

- ✔ Moses 3 Band outperformed other indices across all three atmosphere corrections (Moses, et al., 2012), Sen2cor surface reflectance achieved the top performance.

$$\left(\frac{1}{b4} - \frac{1}{b5}\right) * b6$$

- ✔ Moses 3 Band was designed for Chl-a retrieval in turbid waters.



Statistic	Sen2Cor	n	Site type
R²	0.70	49	All
	0.49	23	Open water
	0.84	26	Inlet
RMSE, µg/L	10.31	49	All
	11.44	23	Open water
	9.20	26	Inlet
BIAS, µg/L	0	49	All
	3.13	23	Open water
	-2.27	26	Inlet

+ + PROVISIONAL INFORMATION + +

- ✔ Moses 3 Band Sen2cor combination performed better at inlet sites compared to open-water sites.

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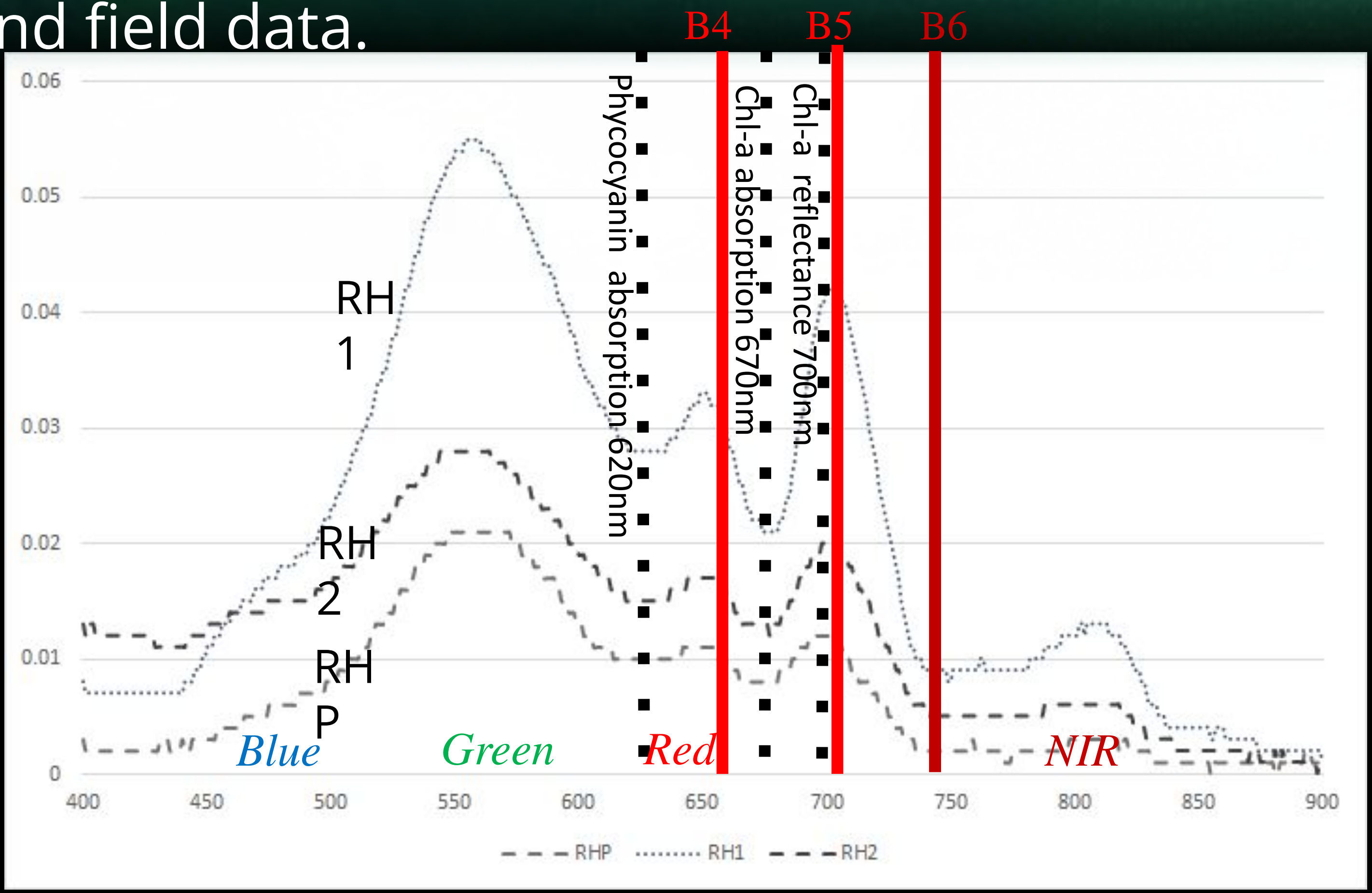
SPECTRAL ALGORITHM PERFORMANCE

Hyperspectral reflectance for open-water (RHP) and inlet (RH1, RH2) sites compared to the Moses 3 Bands and field data.

✔ Dominant Taxa at RHP: Cyanobacteria (Cyanophyta)

Lake Ray Hubbard, August 6, 2022			
Constituent	Site		
	RHP	RH1	RH2
Chlorophyll-a	30 ug/L	57 ug/L	49 ug/L
Phycocyanin	0.59 ug/L	1.39 ug/L	1.15 ug/L
Turbidity	6.75 FNU	37.29 FNU	18.4 FNU
Secchi disk depth	0.64 m	0.27 m	0.64 m



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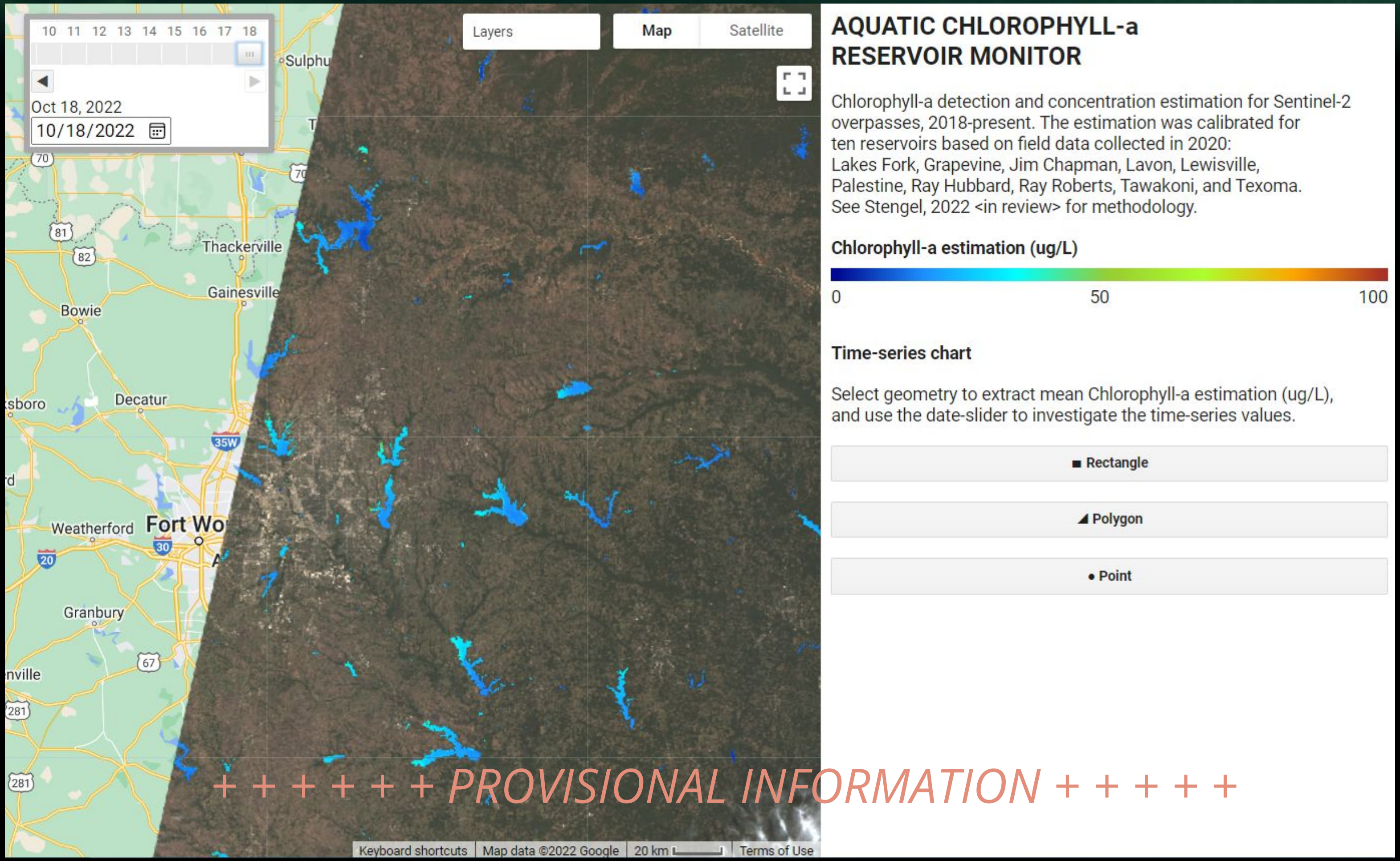
NEAR REAL-TIME MONITORING

Google Earth Engine web application estimates Chlorophyll-a concentrations using new Sentinel-2 imagery as they are ingested into GEE from the ESA.



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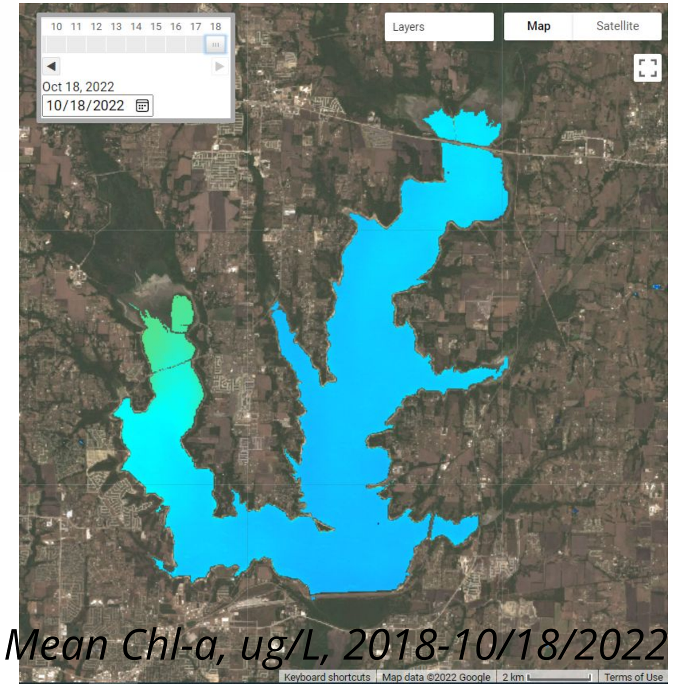
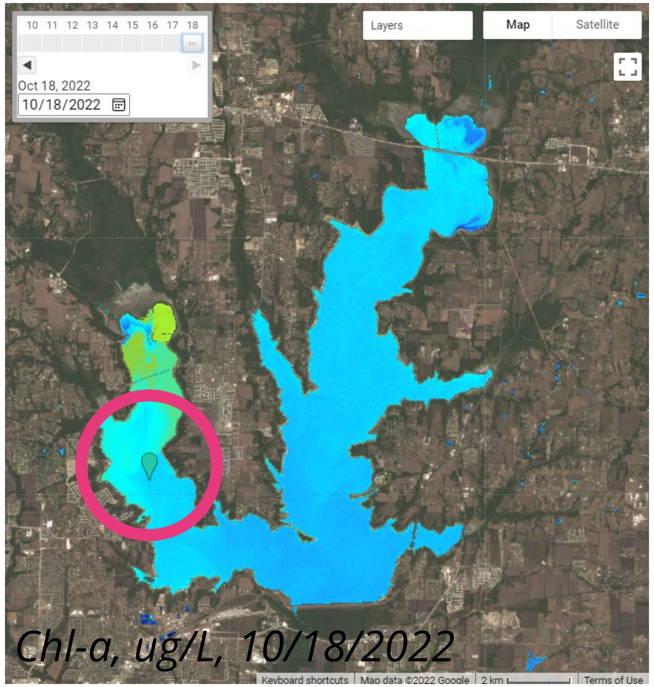
NEAR REAL-TIME MONITORING

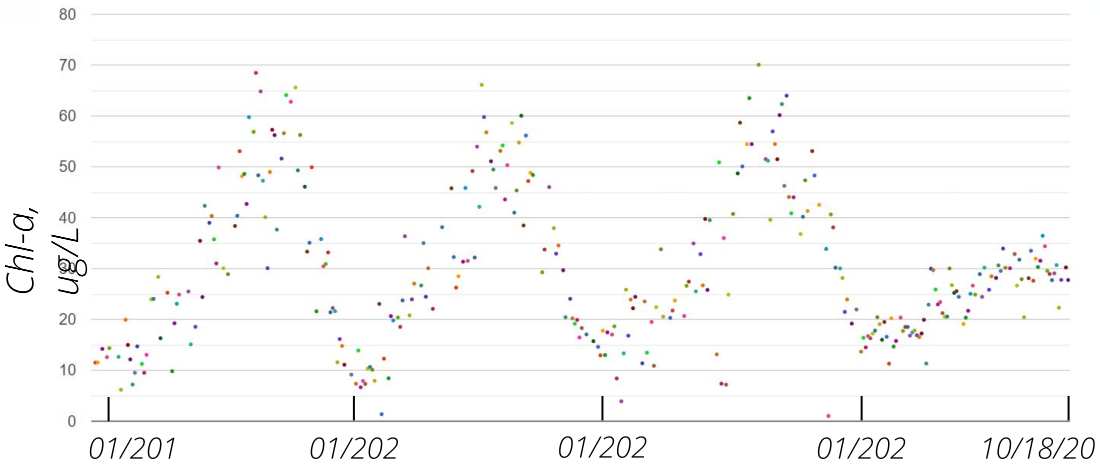
Mean and real-time visualization and time-series plot allow users to detect elevated chlorophyll-a concentrations and trends.



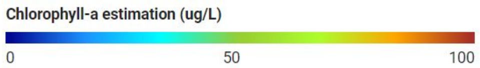
Mean Chl-a, ug/L, 2018-10/18/2022



Chl-a, ug/L, 10/18/2022



Time series for point location, Chl-a, ug/L, 12/21/2018 -10/18/2022



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TEAMWORK MAKES THE DREAM WORK

Scientists, field technicians, and developers:

USGS BIOLOGISTS: *Dr. Chris Churchill, Jessica Trevino*

USGS FIELD CREW: *Jeff Sievers, CeJay Petersen, Sarah Reynolds, MaryKate Higginbotham*

USGS REMOTE SENSING SCIENTISTS: *Victoria Stengel, Dr. Tyler King, Stephen Hundt, Scott Ducar, Dr. Konrad Hafen*

USGS WEB DEVELOPERS: *August Schultz, Joe Vrabel*

GOOGLE EARTH ENGINE DEVELOPER EXPERT: ***Dr. Samapriya Roy***

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USGS ENTERPRISE LICENSING

GOOGLE CLOUD + EARTH ENGINE

NASA EARTH SCIENCE

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