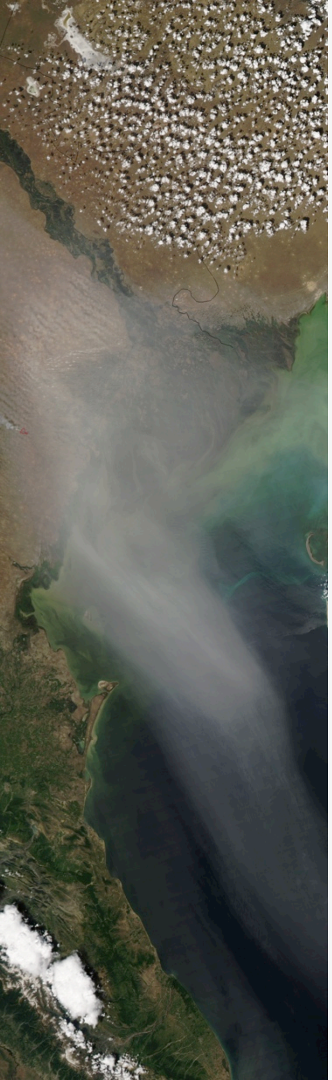


National Aeronautics and
Space Administration

ARSET
Applied Remote Sensing Training
http://arset.gsfc.nasa.gov
@NASAARSET

Using Satellite Data for the Prediction and Detection of Harmful Algal Bloom Outbreaks

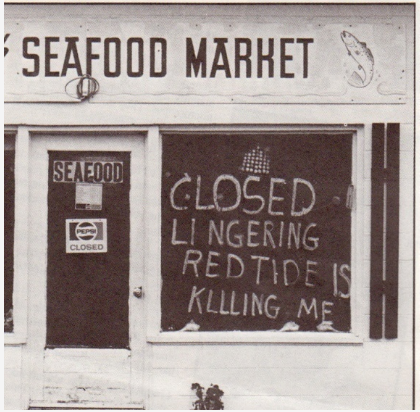
Richard Stumpf, NOAA National Centers for Coastal Ocean Science

Fundamentals of Satellite RS for Health Applications, Week 4

Outline

Harmful algal blooms (HABs)

- What are HABs
  - Cyanobacterial HABs specifically
    - The problem
- Satellites and cyano HABs
- Algorithms
- Applications



URGENT NOTICE TO RESIDENTS

DO NOT DRINK THE WATER
DO NOT BOIL THE WATER

California sea lion undergoing stomach pumping after poisoning (photo courtesy Dr. Francis Gulland, Marine Mammal Center, Sausalito, CA)

Marine HABs

HAB Occurrences Worldwide

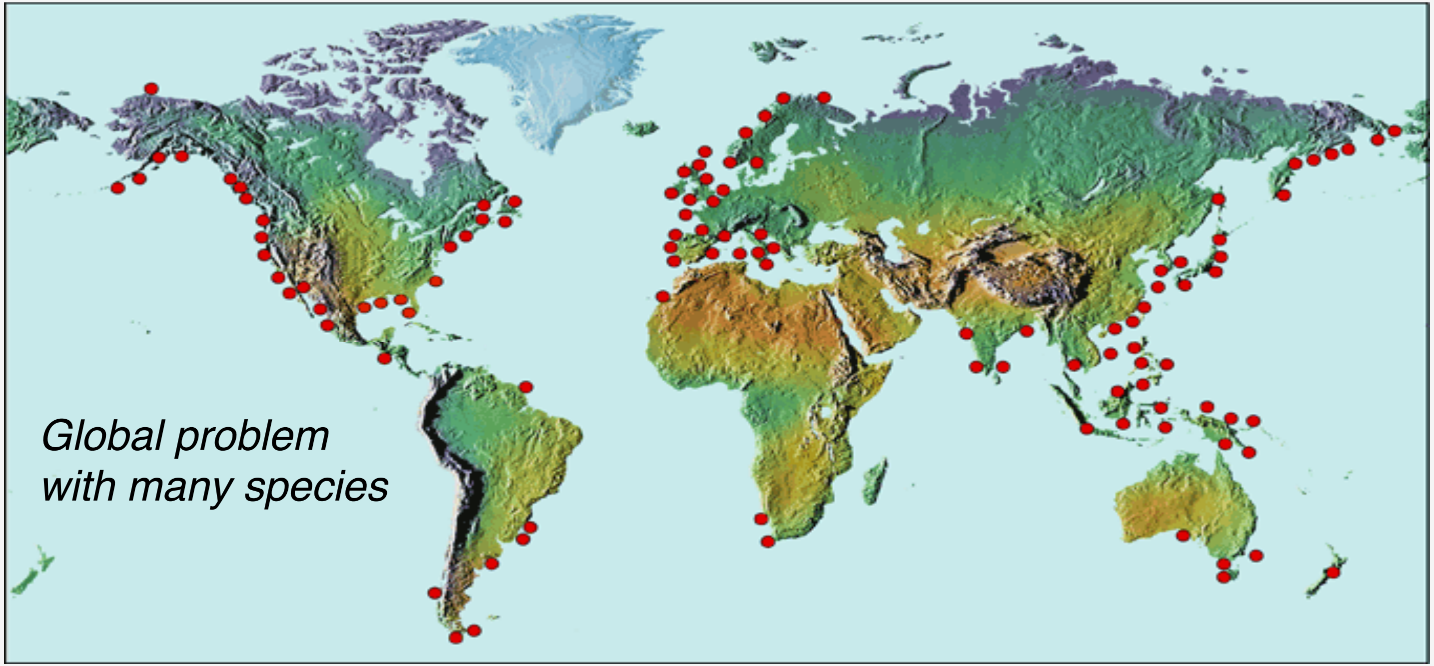


Image from whoi.edu/redtide

Impacts of Harmful Algal Blooms

- Molluscan shellfish losses
- Fish kills (threat to aquaculture)
- Endangered species
- Tourism
- Public health
- US $1 billion in loss over 10 years
- $1 billion industries at risk in East Asia, Europe, South America.


User: JesseW900 / WikiCommons / CC BY-SA 4.0

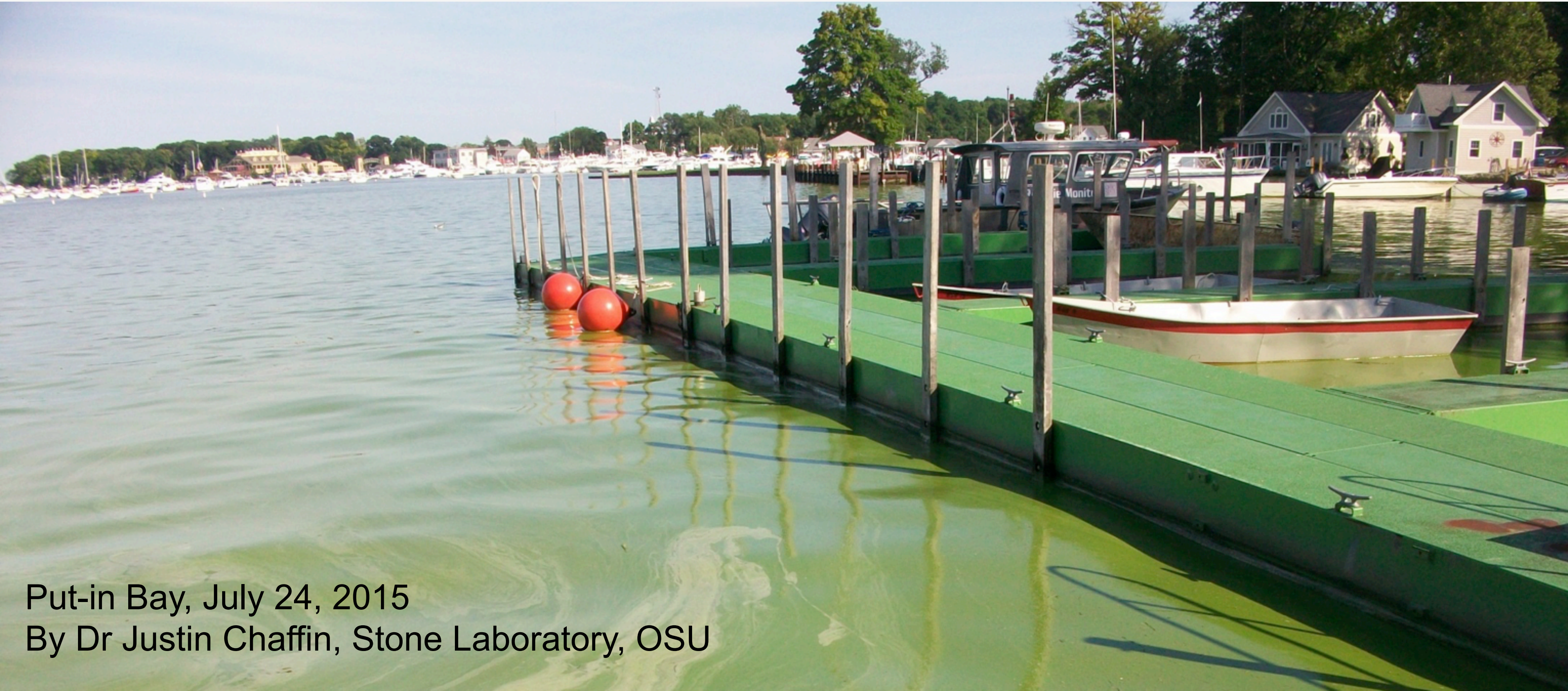

U.S. Fish & Wildlife Service

Marine HABs

Species monitoring and response can be helped by Remote Sensing

HAB Species	Region	Sensing Type	Impact
Pseudo-nitzschia spp.	Upwelling regions	SST, chlorophyll	**ASP, variable**
Karenia brevis	Gulf of Mexico	Chlorophyll, optical ratio, absorption spectra	**NSP, respiratory, fish toxin**
Karenia mikimotoi	Coastal ocean (Hong Kong, Ireland, New Zealand)	SST chlorophyll	NSP
Gymnodinium catenatum	Estuaries, coastal ocean, upwelling	SST chlorophyll	PSP
Alexandrium spp.	Coastal ocean (Gulf of Maine, Gulf of Alaska)	SST	**PSP**
Gonyaulax	Upwelling regions	Chlorophyll, possible UV absorption	**Fish toxin**
Cochlodinium	Coastal ocean (British Columbia, Korea)	SST, color	Shellfish toxin
Nodularia, Microcystis	Enclosed Brackish	Color	Hepatotoxin
Dinophysis (not monitored by RS)	Ireland, Portugal, Norway	Maybe SST, however, optical in situ	Shellfish toxin

Freshwater Cyanobacterial “HABs”

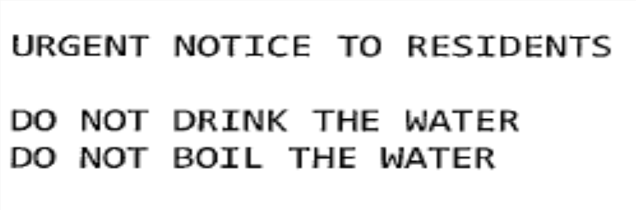


Put-in Bay, July 24, 2015
By Dr Justin Chaffin, Stone Laboratory, OSU

Issues with cyano blooms

Deaths at dialysis center in Brazil in 1996

Drinking water issue, cyano-toxins must be removed, risk of liver & kidney damage


URGENT NOTICE TO RESIDENTS

DO NOT DRINK THE WATER
DO NOT BOIL THE WATER

Bottom Left: Ohio Sea Grant, Brenda Culler, ODNR Coastal Management; Right: Tom Feran, The Plain Dealer

Risks to Pets and Animals

- Dog & cattle deaths occur annually in U.S. **Toxins!**
- Novel Marine Harmful Algal Bloom: Cyanotoxin (Microcystin) transfer from land (freshwater) to sea otters

Credit: James Brooks / Flickr / CC BY-2.0

Credit: Centers for Disease Control and Prevention

Microcystins and cylindrospermopsins

US EPA Drinking Water Guidelines

- Technical guidance (10-day average):
- Microcystins: 0.3 µg/L (ppb) for children under 6, 1.6 ppb for older and adults
- Cylindrospermopsins: 0.7 ppb for children under 6, 3 ppb for older and adults

EPA United States Environmental Protection Agency

Office of Water
820F15003
June 2015

2015 Drinking Water Health Advisories for Two Cyanobacterial Toxins

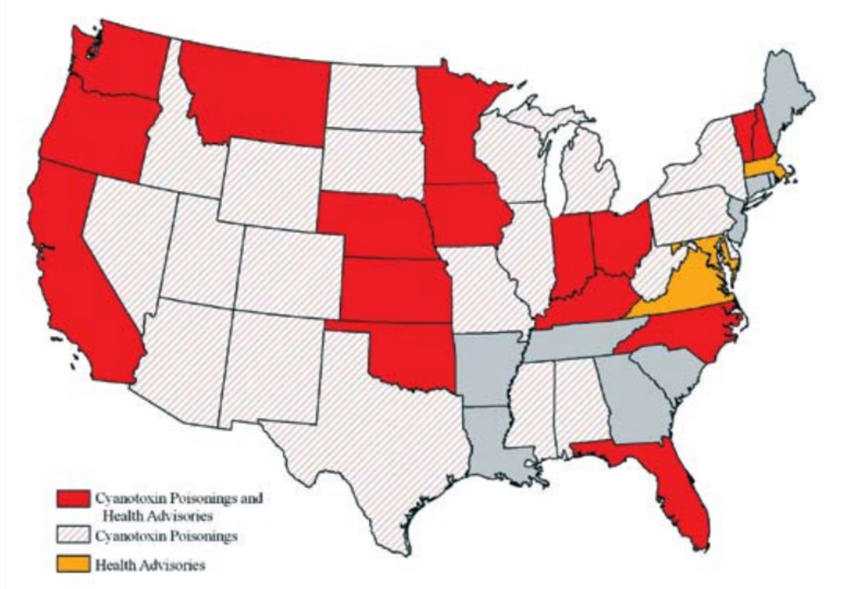
Recreational

- WHO Recommendations
- Microcystin-LR:

	Microcystin	chlorophyll-a
Low	<10 ppb	<10 µg/L
Moderate	10-20	10-50
High	20-2,000	50-5,000
Very High	>2,000	>5,000

- Different states have variations

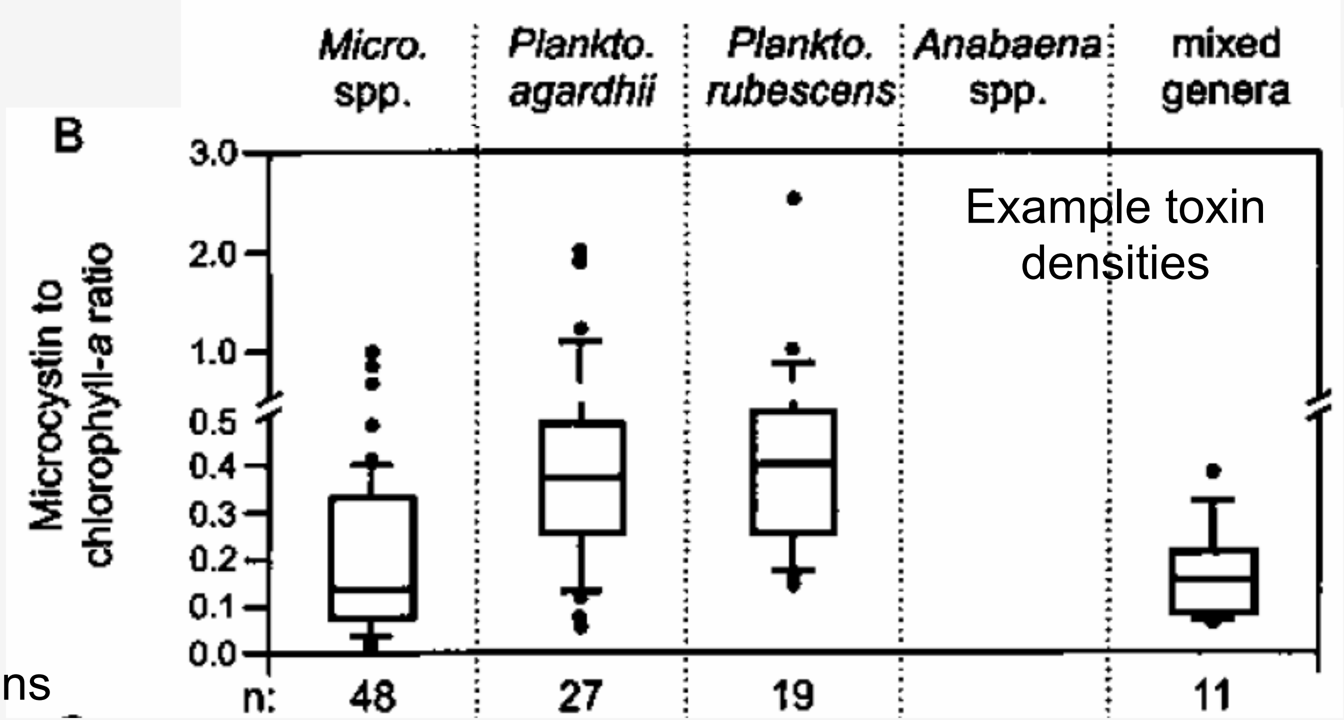
2009 Documented States



Graham et al., 2009, Lakelines

Toxicity varies across species and within species

From WHO (Chorus and Bartram, 1999 after Fastner, 1998)



Example toxin densities

Satellites cannot detect toxins

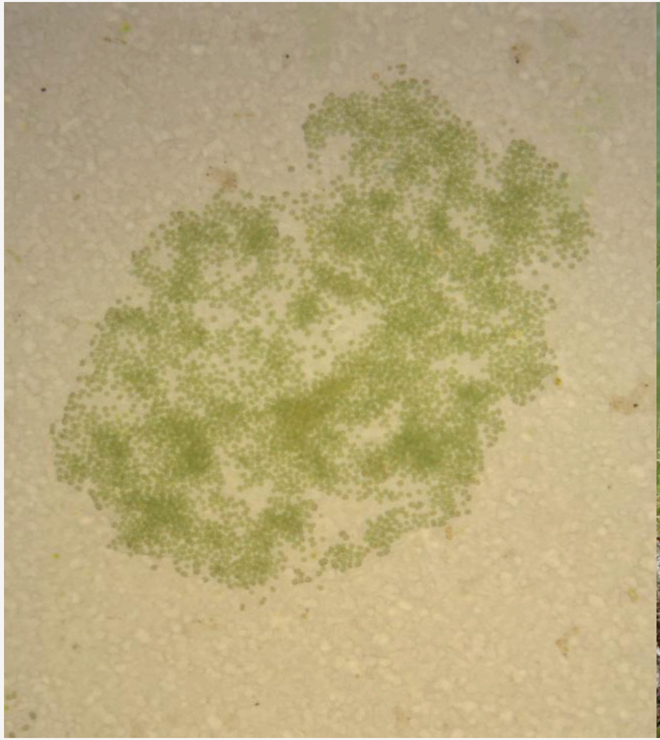
Cyanos of Concern for toxicity

Heterocysts: **nitrogen fixing do not require abundant nitrogen**
Gas Vacuoles: **flotation, concentrate at surface or mix with winds**

- ***Microcystis***
  - Colony, no heterocysts, gas vac., T&O, toxins
- ***Aphanizomenon***
  - Filament, heterocysts (N-fixer), gas vac., T&O, toxins
- ***Dolichospermum*** *(Anabaena)*
  - Filament, heterocysts, gas vac., T&O, toxins
- ***Planktothrix*** (Oscillatoria)
  - Filament, no heterocysts, gas vac. ?, T&O, toxins
- ***Cylindrospermopsis***
  - Filament, heterocysts, no gas vac.?, no T&O, toxins
- ***Lyngbya (sometimes attached)***
  - Filament, no heterocysts, no gas vac., no T&O, toxins

Microcystis most common toxic cyanobacteria

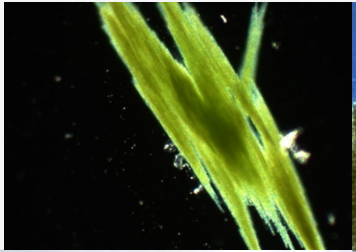
Lake Erie, Aug 2010

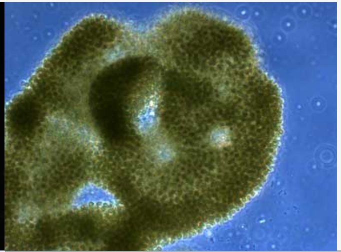


Aphanizomen and Microcystis examples

California

Aphanizomenon flos-aquae



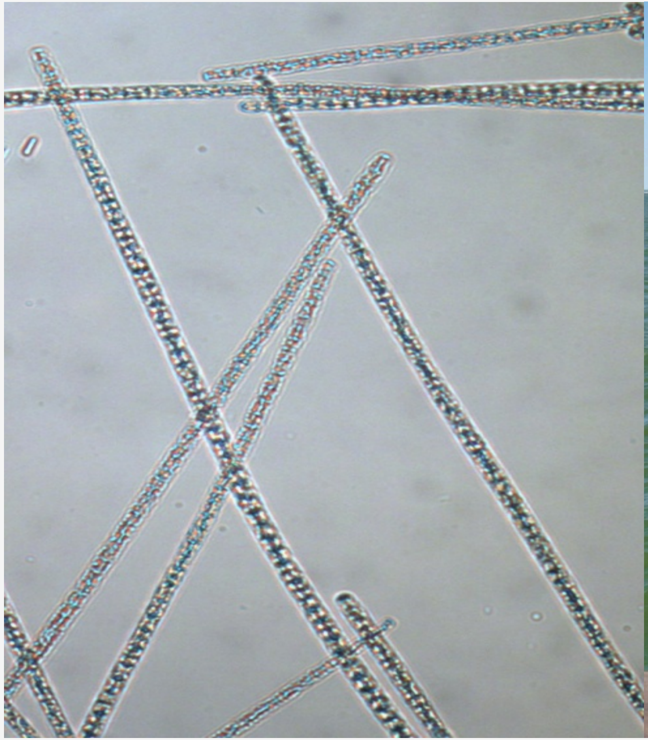


Microcystis spp.

Photos from R. Kudela, UCSC

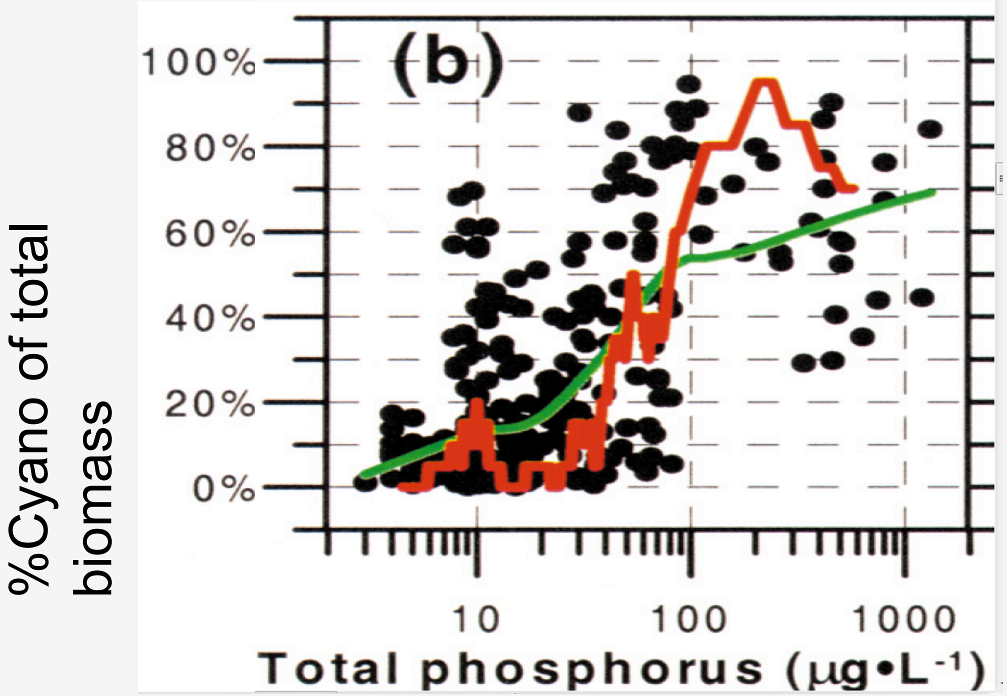
Planktothrix argardhii

Ohio, consistently dispersed




Environmental Factors

Nutrients, freshwater is usually phosphorus-limited
> 100 µg/L phosphorus associated with cyano blooms



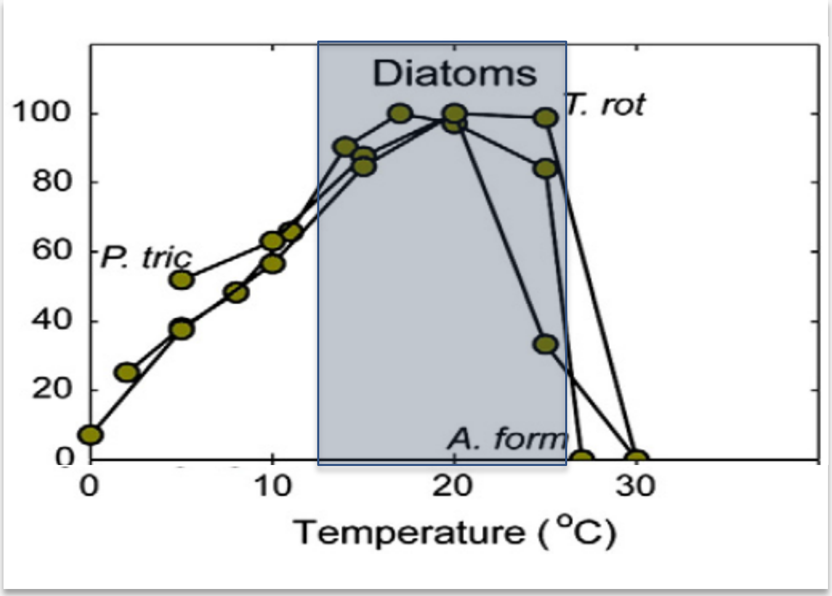
Intensity of toxicity may be influenced by nitrogen,

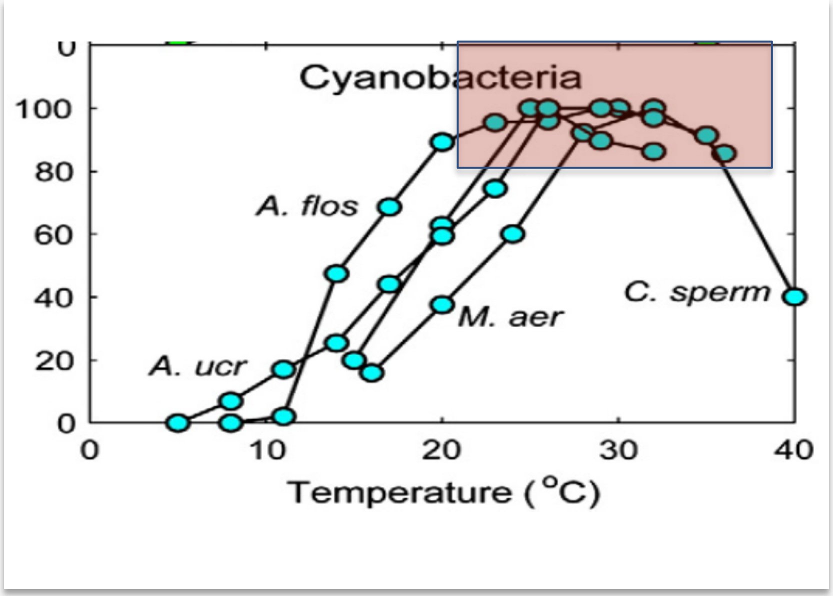
but also by turbidity and other factors still being determined

Downing et al. 2001

Cyanobacteria Like Warm Water, unlike "good" algae

Many have strongest growth > 20ºC and minimal growth < 15ºC





Paerl et al., 2011 (Science of the Total Environment)

Wind Matters for Buoyant Blooms, identified in the earliest remote sensing studies.

Verh. Internat. Verein. Limnol.	19	784 – 791	Stuttgart, Oktober 1975

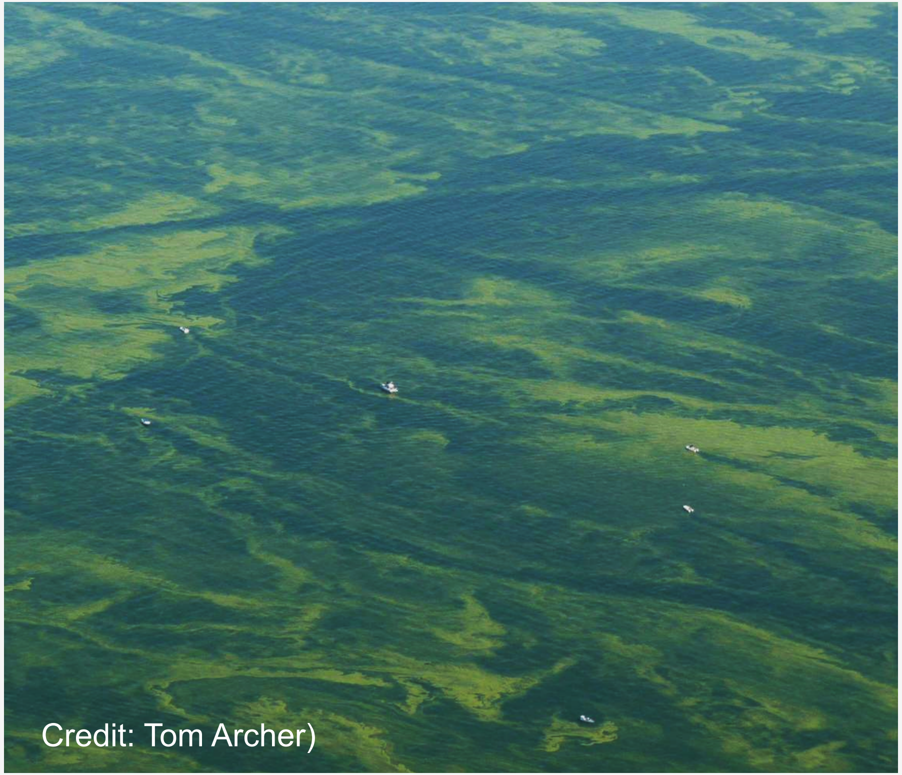
The use of remote sensing to detect how wind influences planktonic blue-green algal distribution

A. J. Horne and R. C. Wrigley

With 4 figures in the text

Cyanos thrive in low wind, many float to the surface.

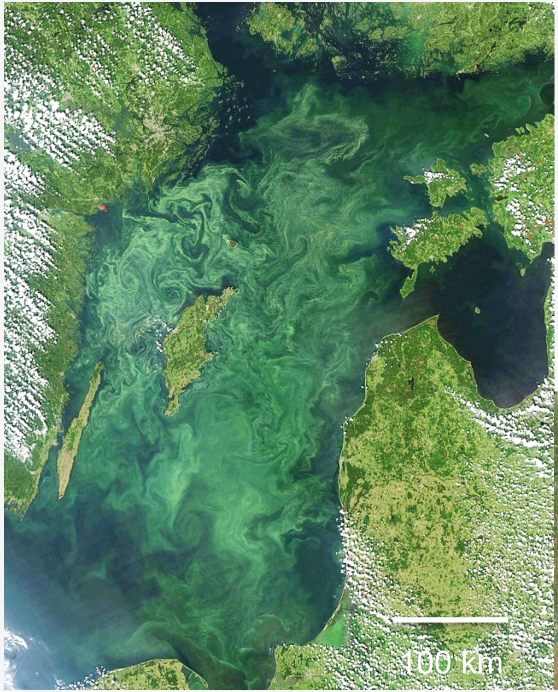
- Cyanos (*Microcystis* in this case) tend to float (green)
- Diatoms sink (olive)



Satellite Remote Sensing

Where We Are With Satellites

- We can find algal blooms
- Cyano blooms are detectable, but usable methods currently produce many false positives
  - We are examining strategies to reduce these
  - We bias against false negatives
- All sensors can find scum
- Most sensors have limitations
  - Resolution trade-offs: spatial, spectral, temporal



Left: Baltic Sea, Nodularia, Aqua MODIS, 5 July 2005.
Right: Lake Erie Microcystis, MERIS, 8 Oct 2011

Satellite Imagery. True color is useful but not best.

Two severe blooms that look different in true color

Lake Erie, 28 July 2015, Landsat OLI

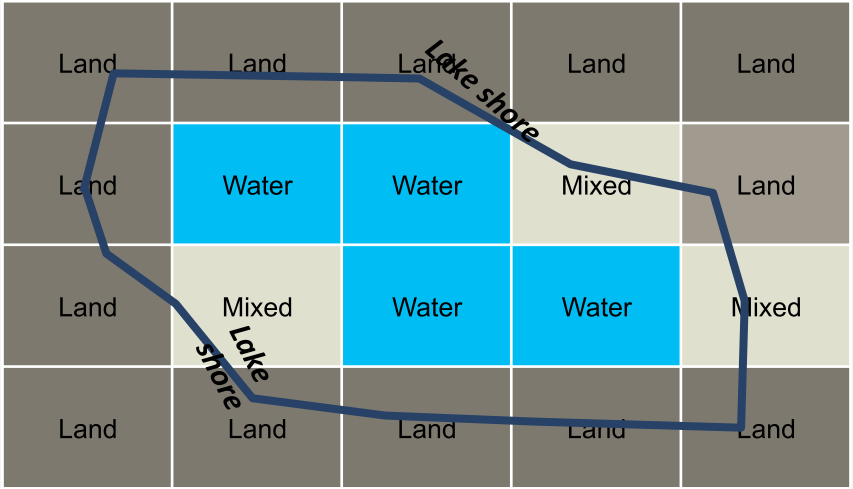
Lake Erie, 5 October 2011, Landsat 5 TM

Satellite Comparison for Cyano Applications

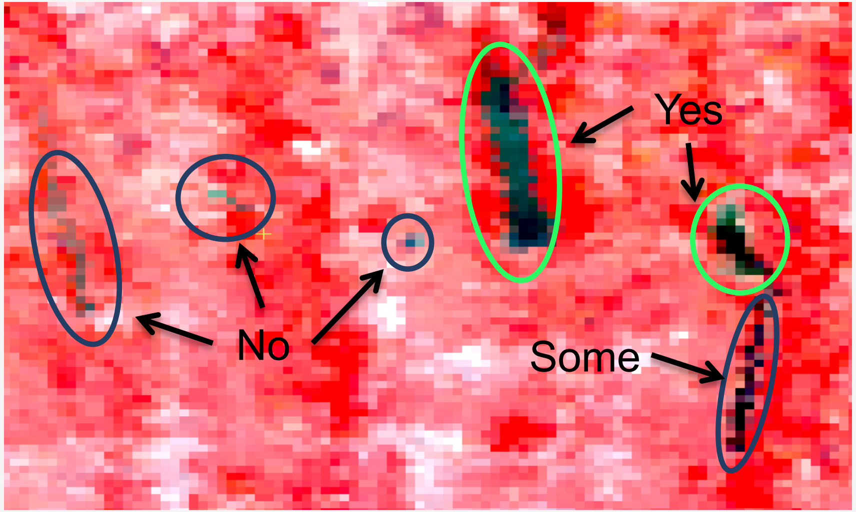
Satellite	Spatial	Temporal	Key Spectral
MERIS (2002-12) OLCI Sentinel-3, 2016	300m *ok*	2 day *good*	10 (5 in red edge) *good*
MODIS high res Terra, 1999; Aqua 2002	250/500m *ok*	1-2 day *good*	4 (1 red, 1 NIR) *marginal*
MODIS low res Sea WiFS	1km *poor*	1-2 day *good*	7-8 (2 in red edge) *ok*
Landsat	30m *good*	8 or 16 day *poor*	4 (1 red, 1 NIR) *marginal*
Sentinel-2	20m *good*	10 day (5 day with 2nd satellite in 2017) *Potential with 2nd satellite*	5 (1 red, 2 NIR, 1 in red edge) *potential*

Radiation and Water Bodies

- False color sharpens distinction between land and water
- Reddish pixels at right include land



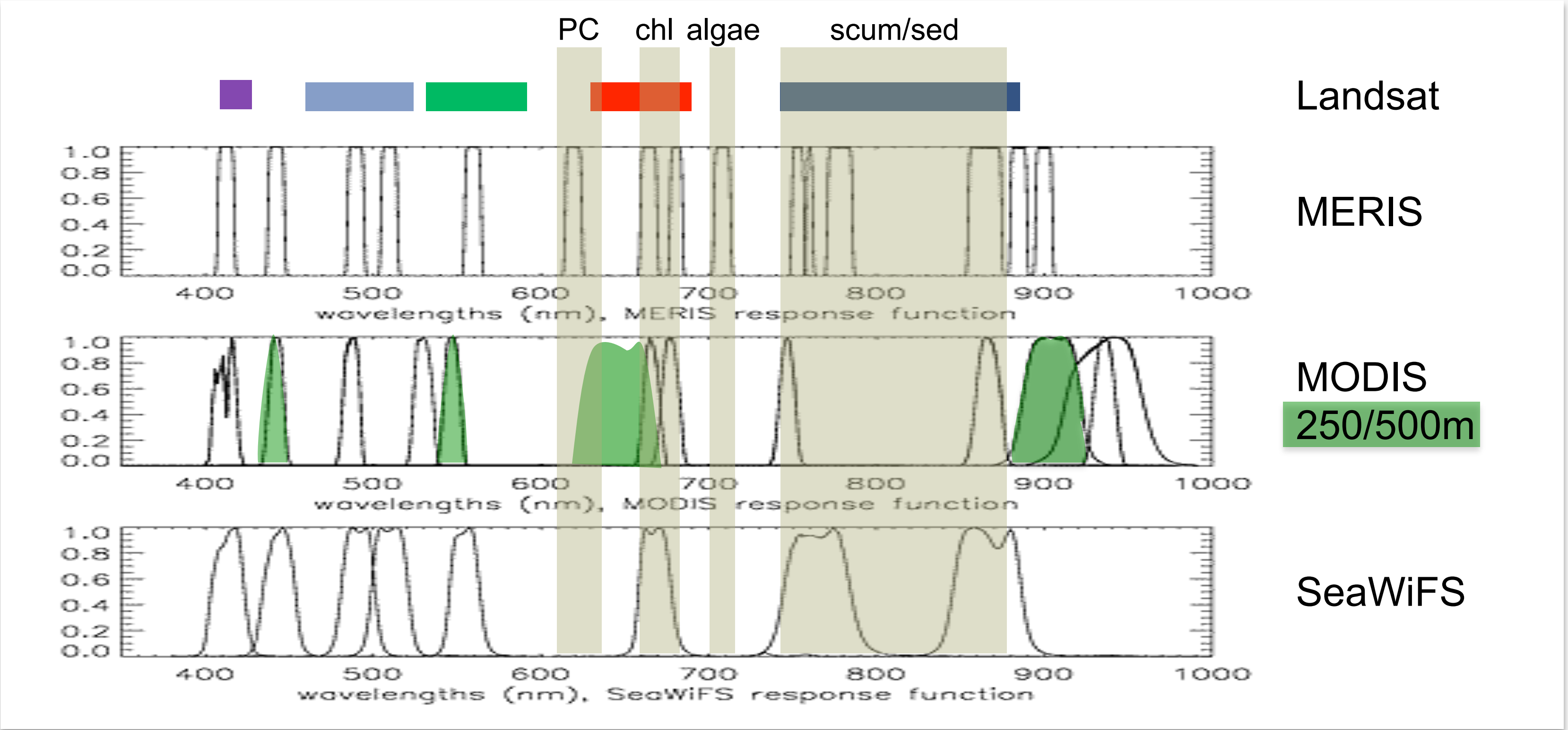
- Mixed pixels limit our ability to monitor small water bodies
- 3 pixel rule for individual scenes



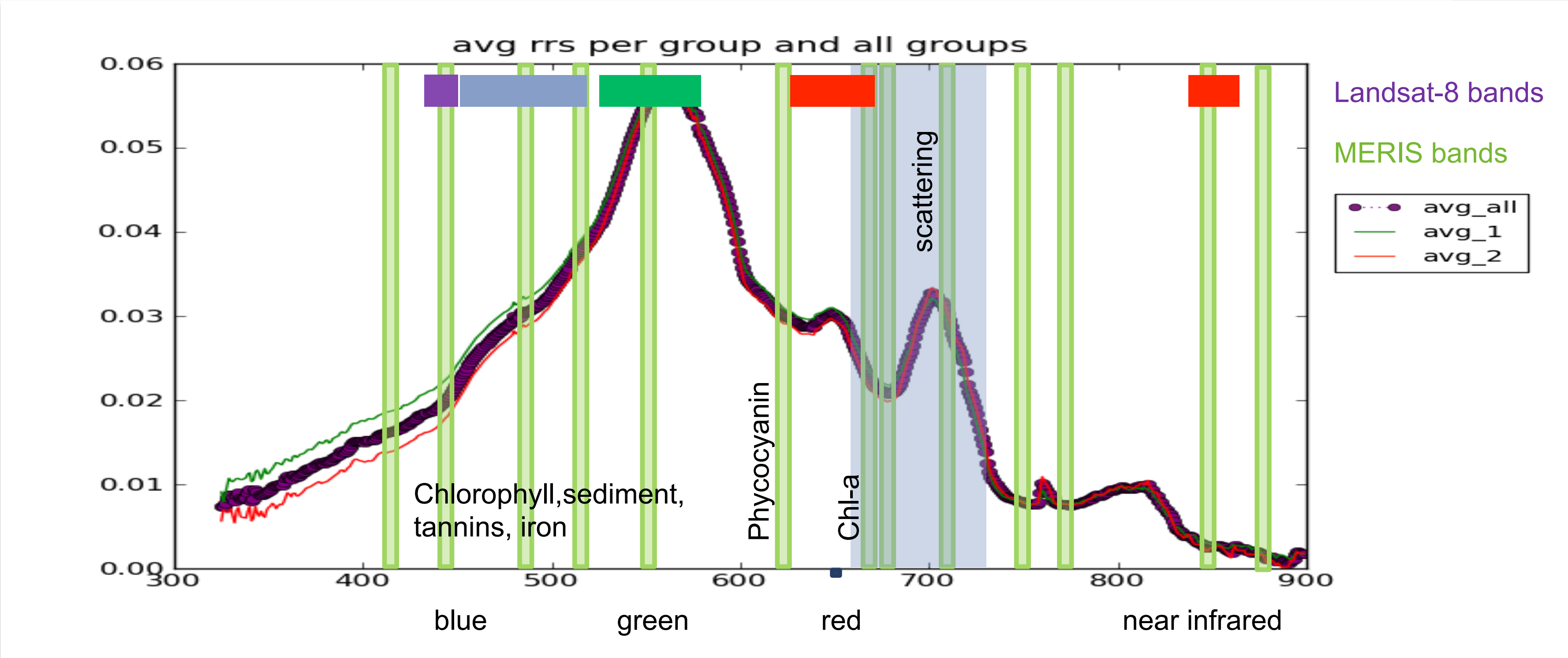
A different resolution factor: sampling scale

- Field samples against satellite have some uncertainty:
- Compare the contents of any cup at random to the average of all cups in San Francisco Stadium
- Satellites tell you the average in the entire stadium; a water sample is akin to one cup

Spectral resolution: Satellite spectral bands & turbid blooms



MERIS (and Landsat) Bands on Water Spectra for *Microcystis* phycocyanin (indicator) absorbs about 620 nm; Chl-a about 680 nm.



Types of Algorithms, I

Analytical, Semi-Analytical (Ratio), Biological-Empirical

Analytical (based on solving simple physics equations)

Water Reflectance ~ $a/(b_b + a)$ where a is absorption and b_b is backscatter

- Phycocyanin absorption at 620 nm;
- Chl-a absorption at 667 nm;
- Backscatter at 709 nm and 779 nm.
- Studies by Simis, Gons, Mithra and others
- Also QAA for absorption (Lee and others)

If water reflectance is retrieved and accurate, quite effective; demonstrated to work with in situ radiometry

HOWEVER: satellites depend on excellent atmospheric correction

Types of Algorithms, II

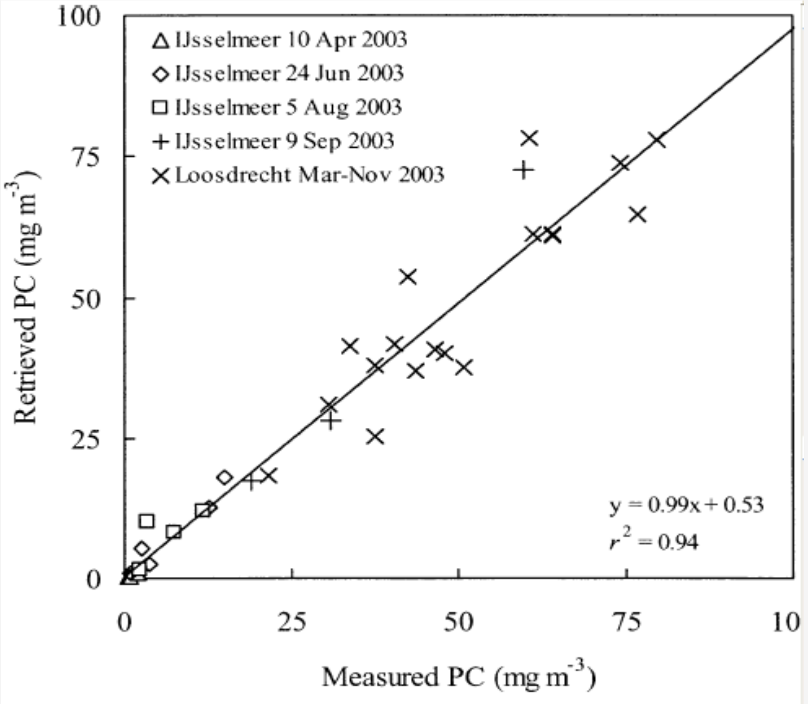
Analytical, Semi-Analytical (Ratio), Biological-Empirical

Semi-analytical (ratio, changes in absorption change ratios)

- Ratios such as 709 nm to 620 nm for PC, 709 to 665 for chl-a

With good data, quite effective; demonstrated to work with radiometry

HOWEVER: satellite depends on excellent atmospheric correction



Types of Algorithms III

Spectral Shape Biological-Empirical

Spectral shape (derivative), based on biological characteristics, but empirical

- CI (Wynne and Stumpf; Lunetta)
- MCI (Gower et al.)
- MPH (Matthews and Odermatt)

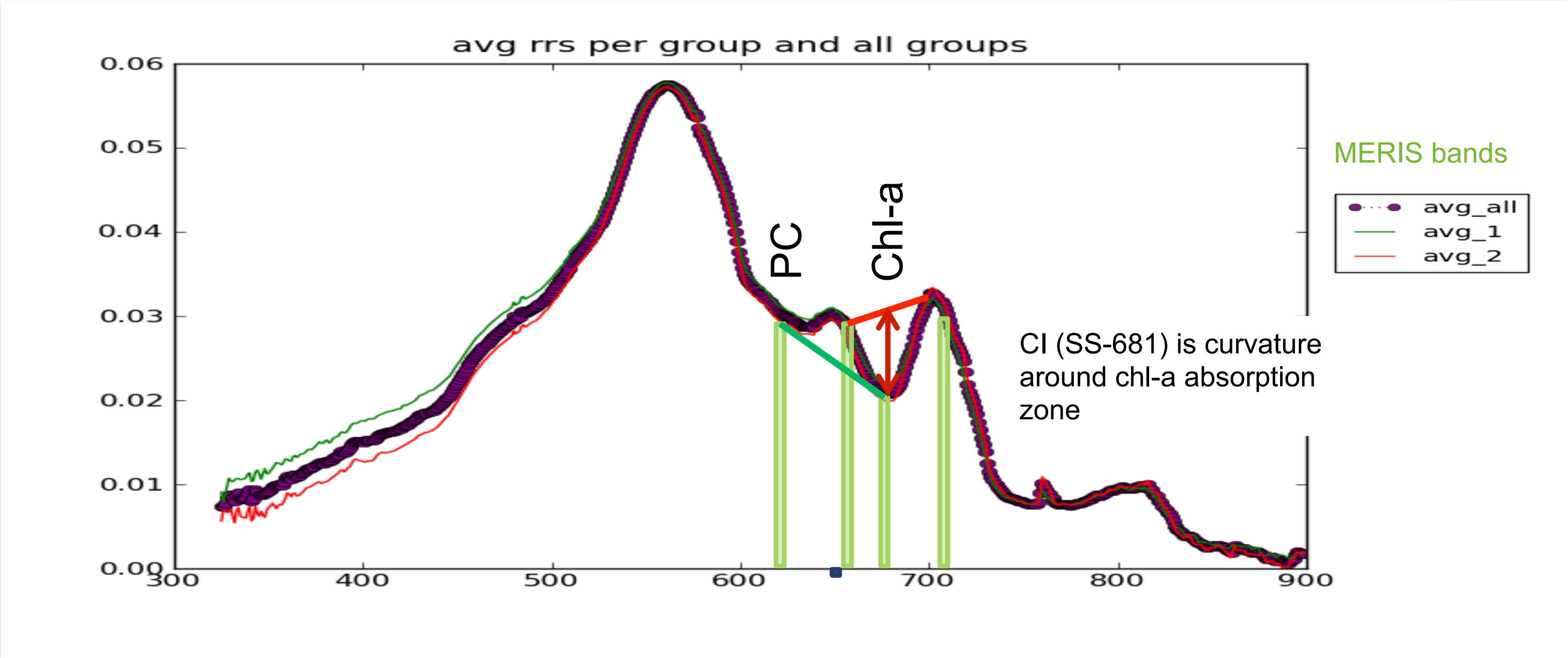
Can be used without atmospheric correction, do not require water "reflectance".

These are currently the most robust for routine monitoring.

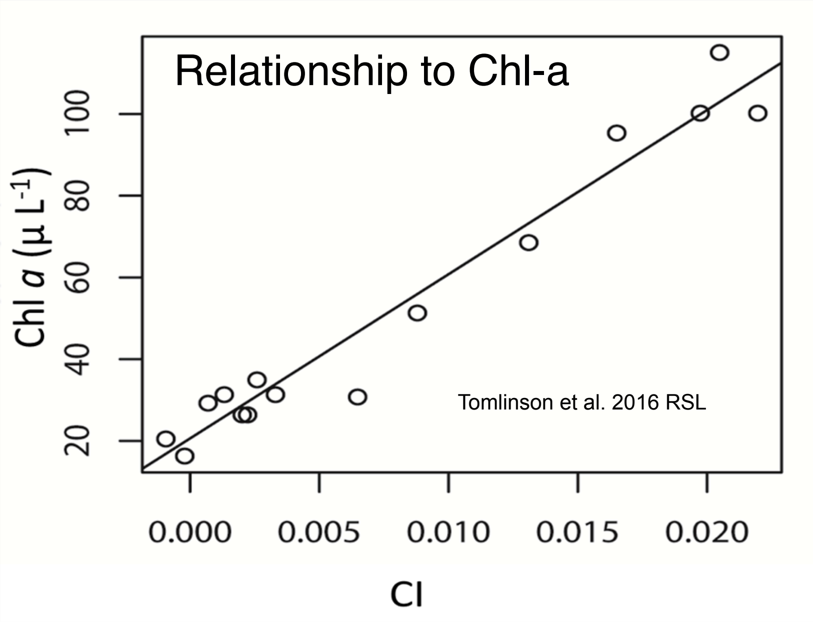
We use CI as it may be less sensitive to sediment and water vapor.

"CI" Derivative for Intense Blooms, More Cyano Sensitive

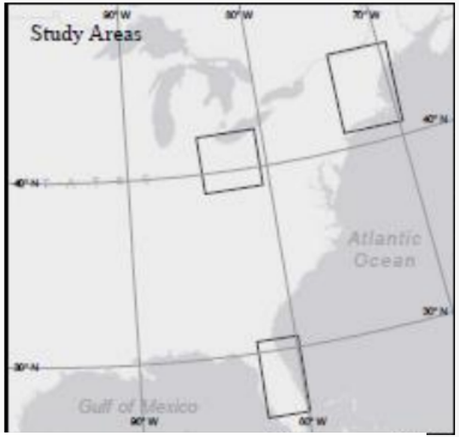
- Chl-a biomass, phycocyanin (PC) as indicators.

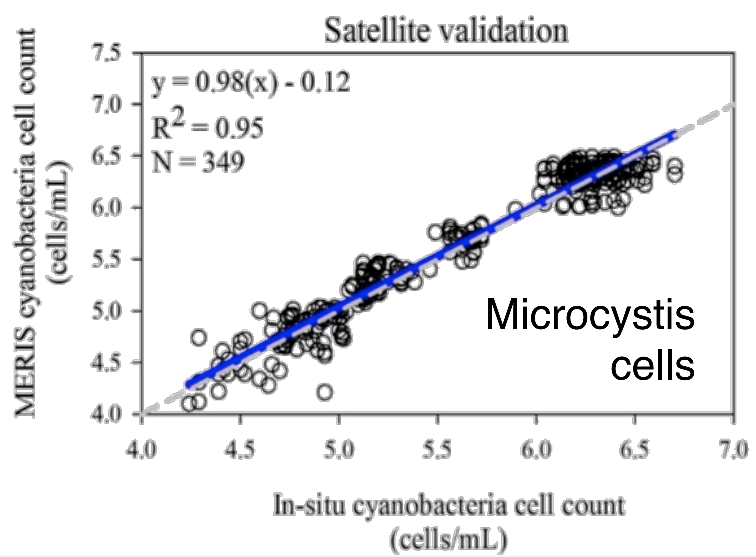


Example quantification for CI



Lake Erie Transferred to Many Other US Lakes



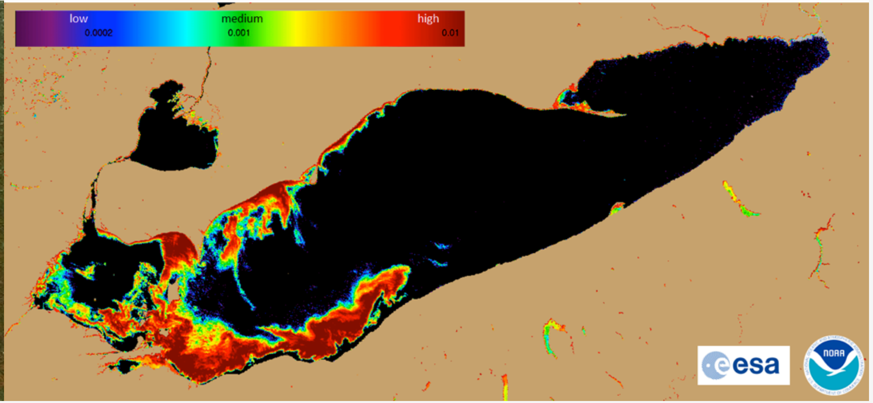


Method also used for lakes in Europe and in Caspian Sea

Cyanobacteria Index “CI”

Extra Wavelengths Give CI – Equates to Concentration

MODIS True Color, 9 Oct 2011

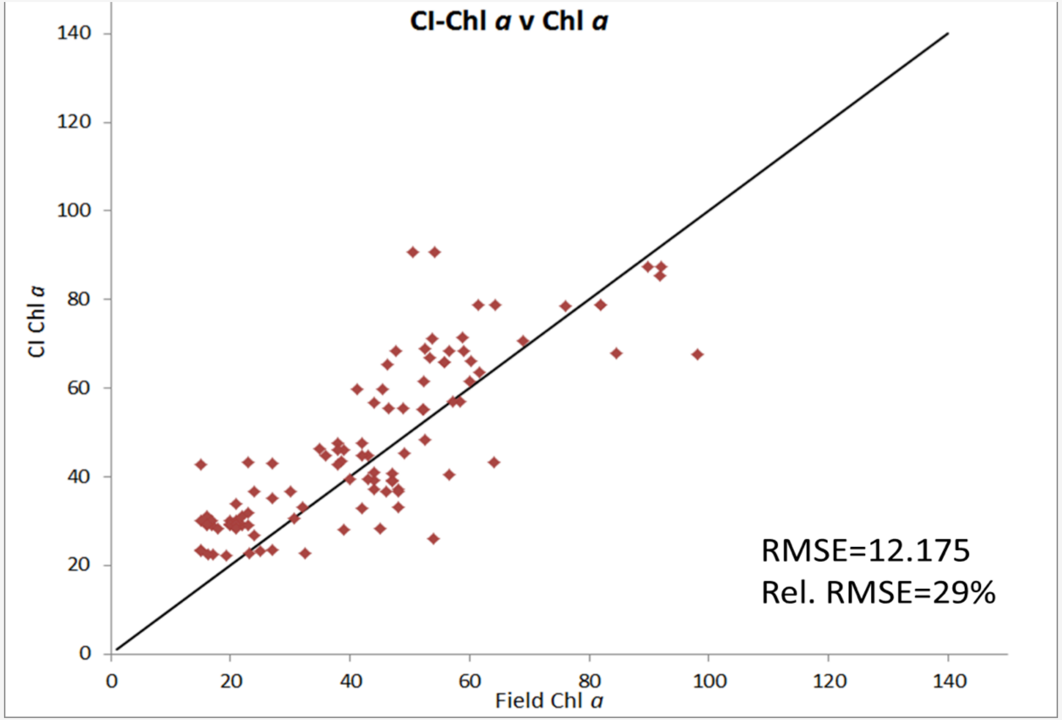


Cyano Index (CI) 8 Oct 2011

Surface concentration (up to 1 m).
Does not require scum, and works with scum

Biomass Indicator, comparison to satellite data

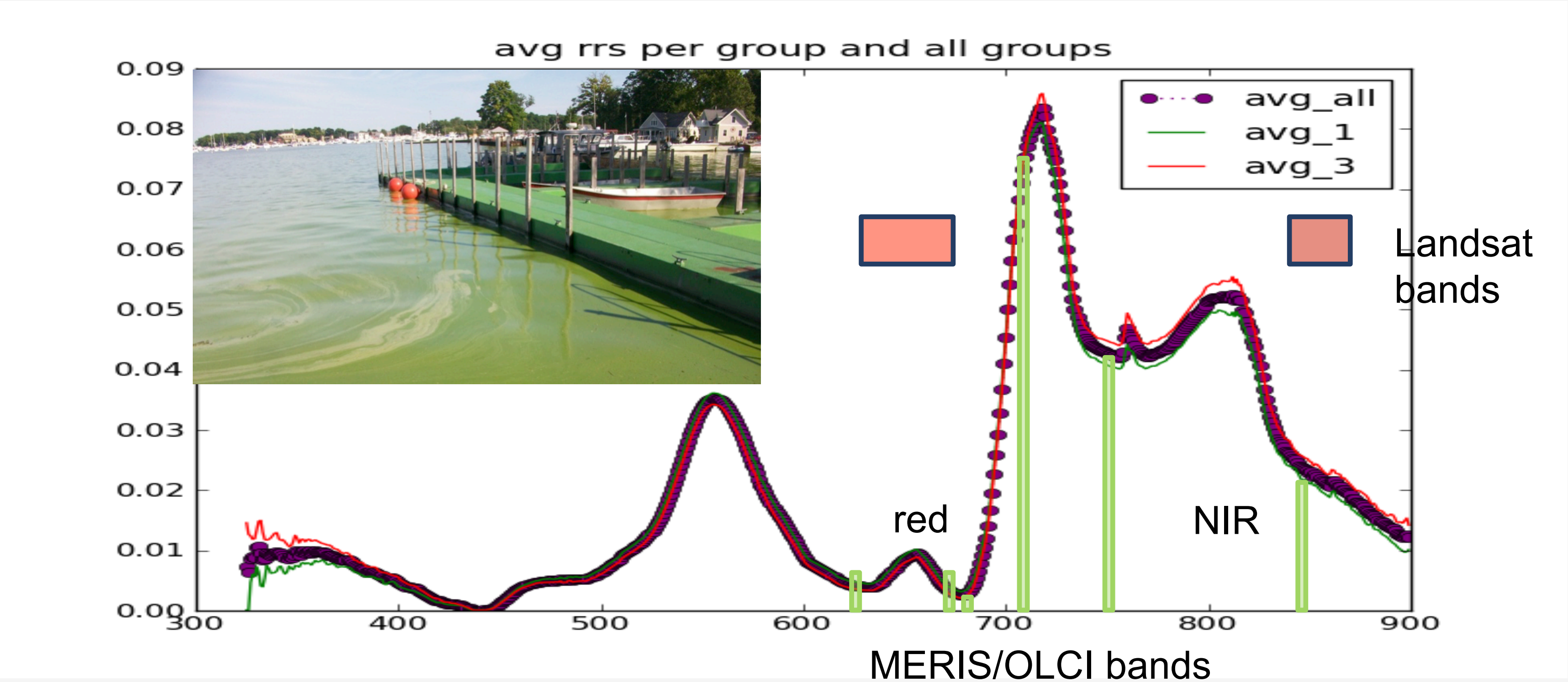
Florida Lakes, remember water sample against 300 m satellite pixel.



Data from LakeWatch and MERIS
Tomlinson et al., 2016

What about Scum? Spectra of *Microcystis* "Scum"

High in NIR, Low in Red; useful with all "color" satellites. Calm wind needed.



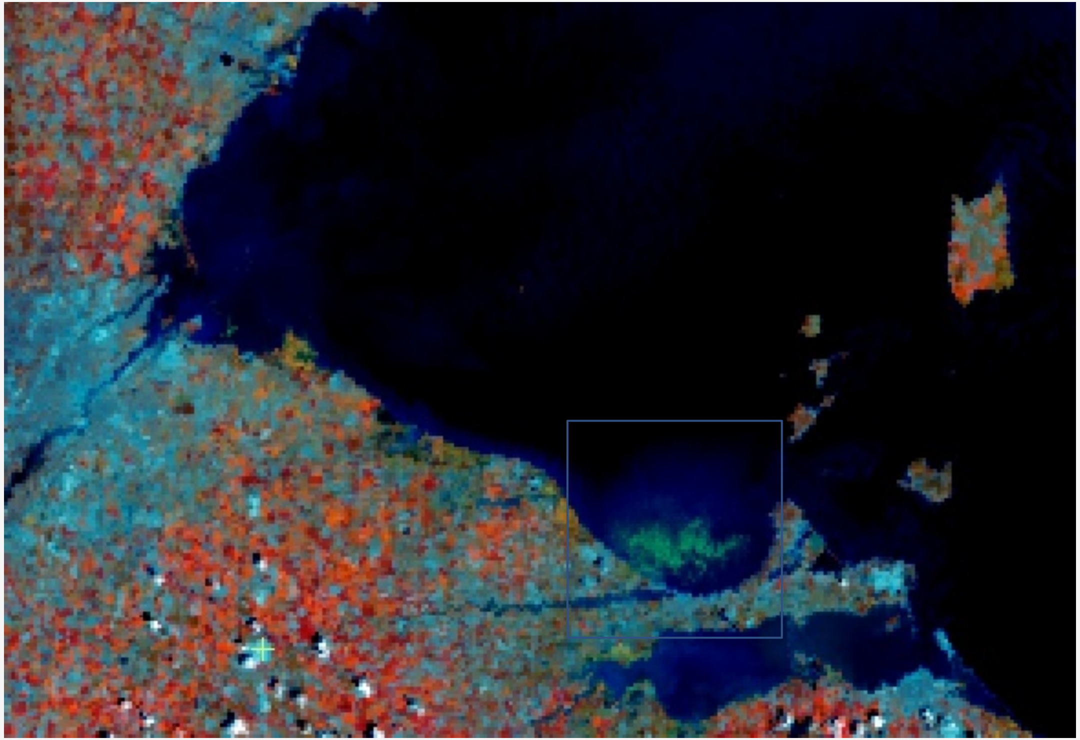
True Color

Find the Scum

- Side Note: true color is valuable but hard to interpret

MODIS True Color, 28 Aug 2010

NIR band reveals the scum



Applications

Monitoring cyano blooms in real time. Lake Erie twice/weekly

Experimental Lake Erie Harmful Algal Bloom Bulletin

National Centers for Coastal Ocean Science and Great Lakes Environmental Research Laboratory

27 July 2015, Bulletin 04

The Microcystis cyanobacteria bloom continues in the western basin. The bloom extends from west of West Sister Island, veering southward to the coast, then curving to the northeast through the islands toward the central basin and up to the Canadian coast

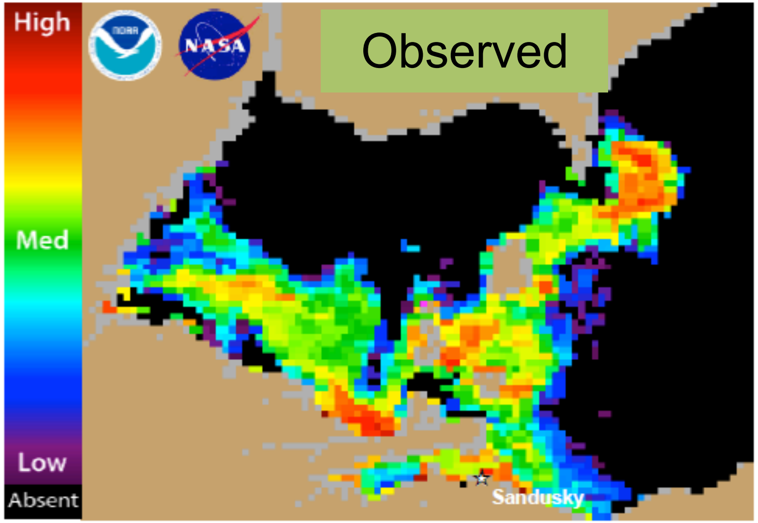


Figure 1. Cyanobacterial Index from NASA's MODIS-Terra data collected 24 July 2015 at 12:00 pm EDT. Grey indicates clouds or missing data. Black

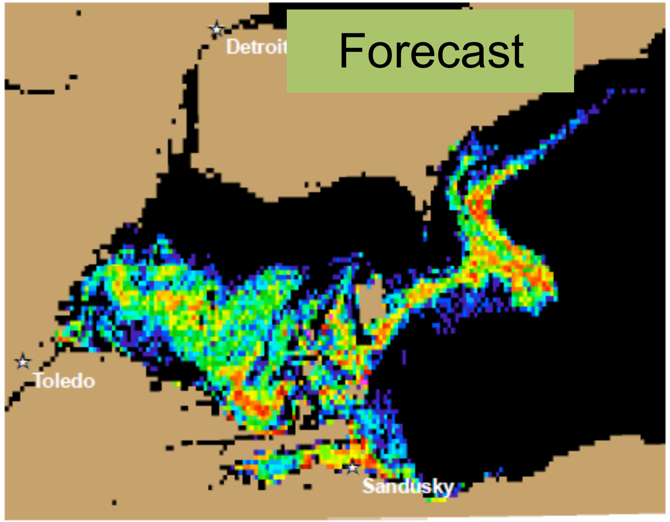
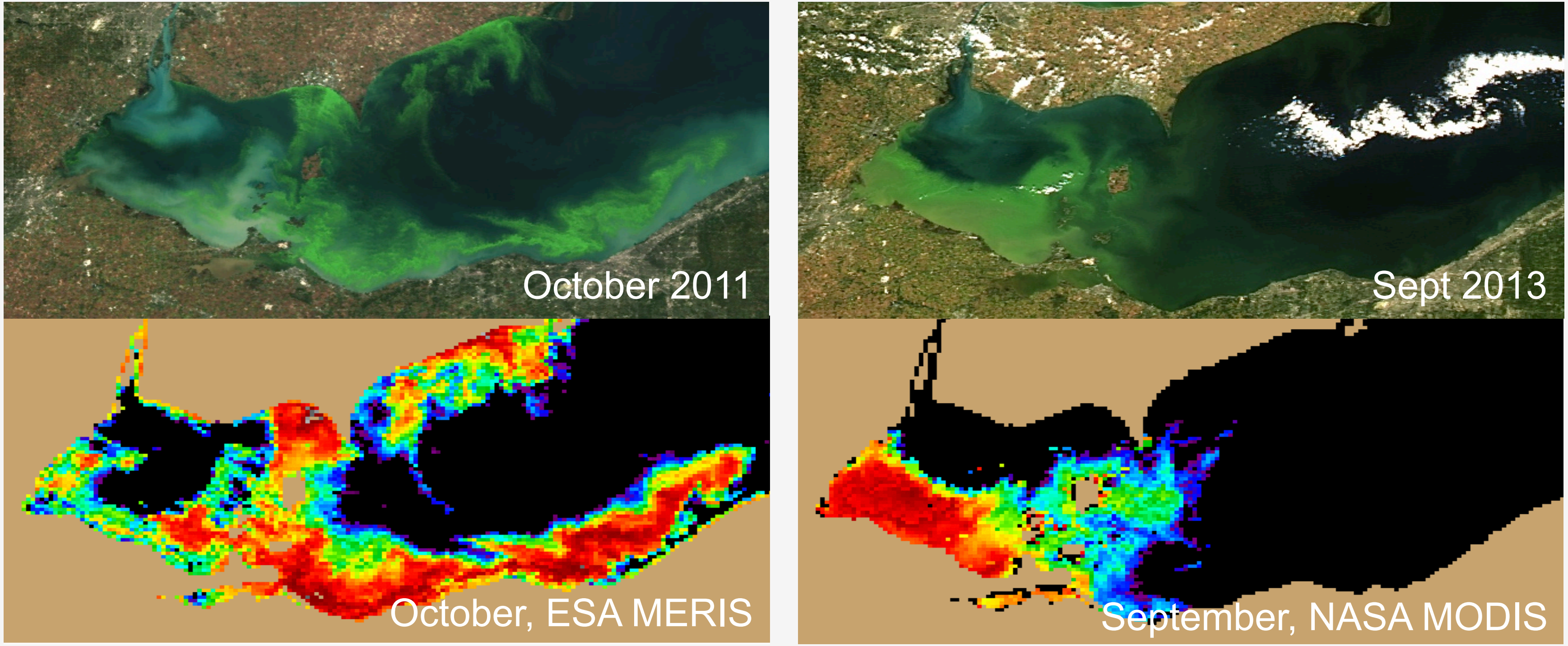


Figure 2. Nowcast position of bloom for 27 July 2015 using GLCFS modeled currents to move the bloom from the 24 July 2015 image.

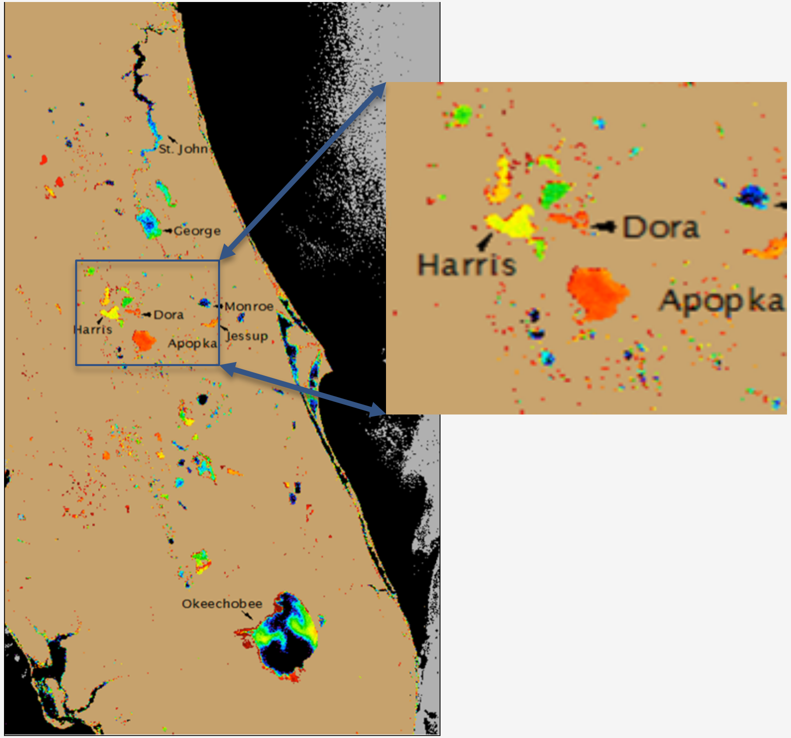
http://coastalscience.noaa.gov/research/habs/forecasting

Bloom Analysis



Tracking biomass in Florida

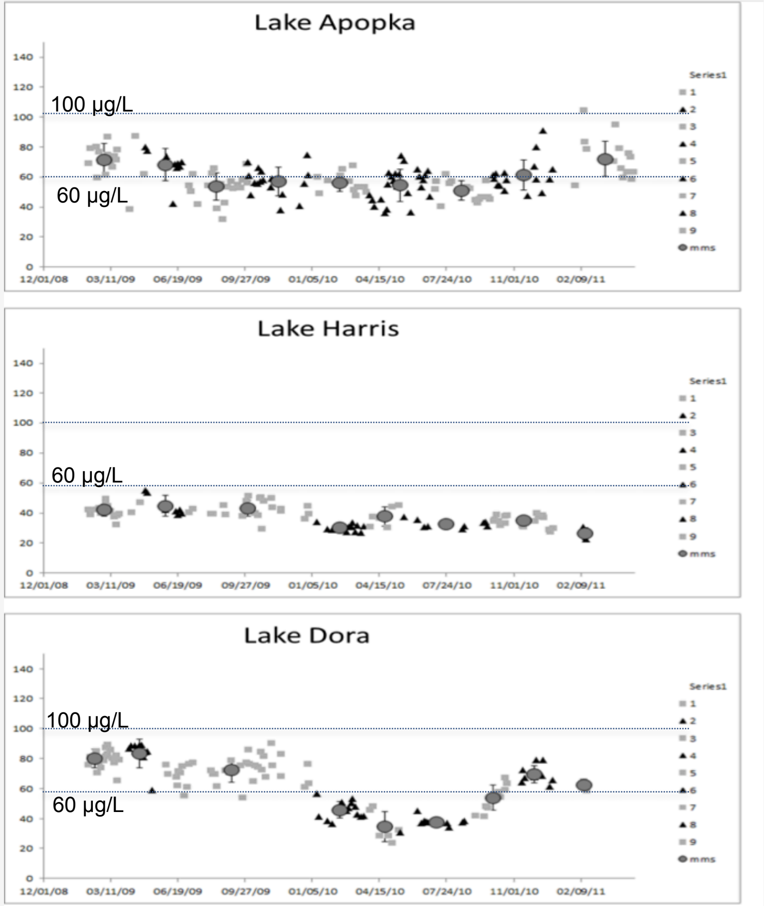
Over 3 Years



High

Med-Low

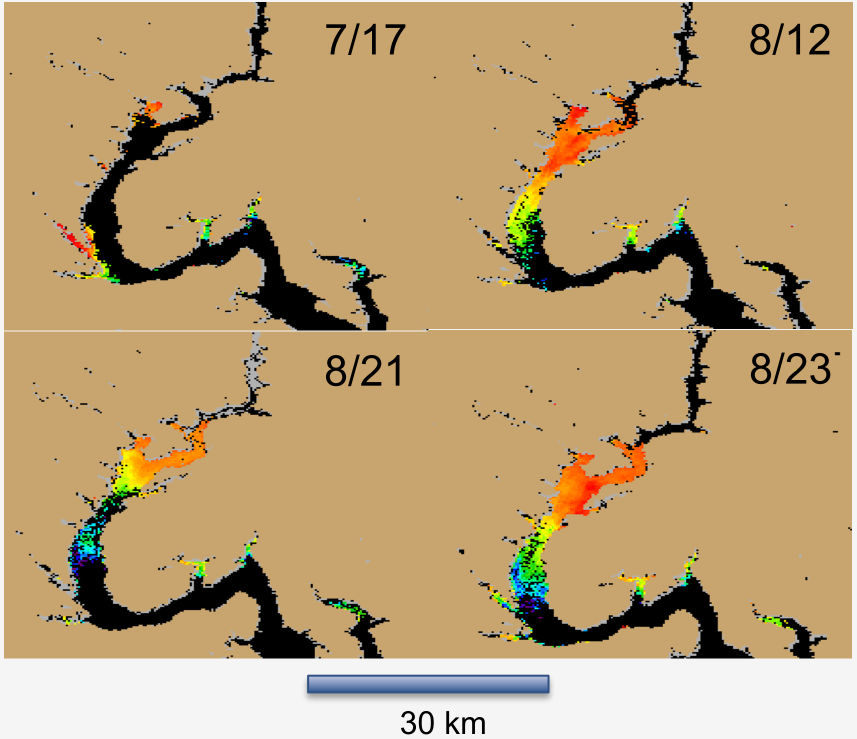
Variable

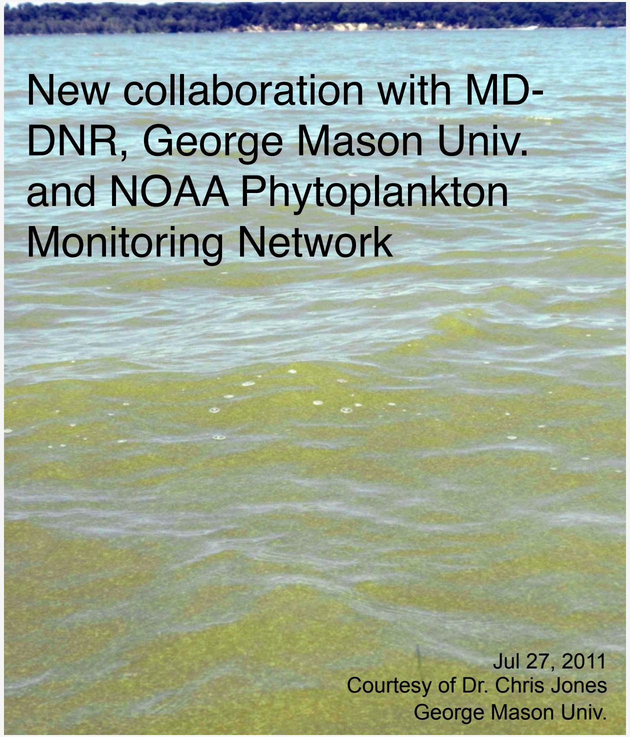


2009 2011

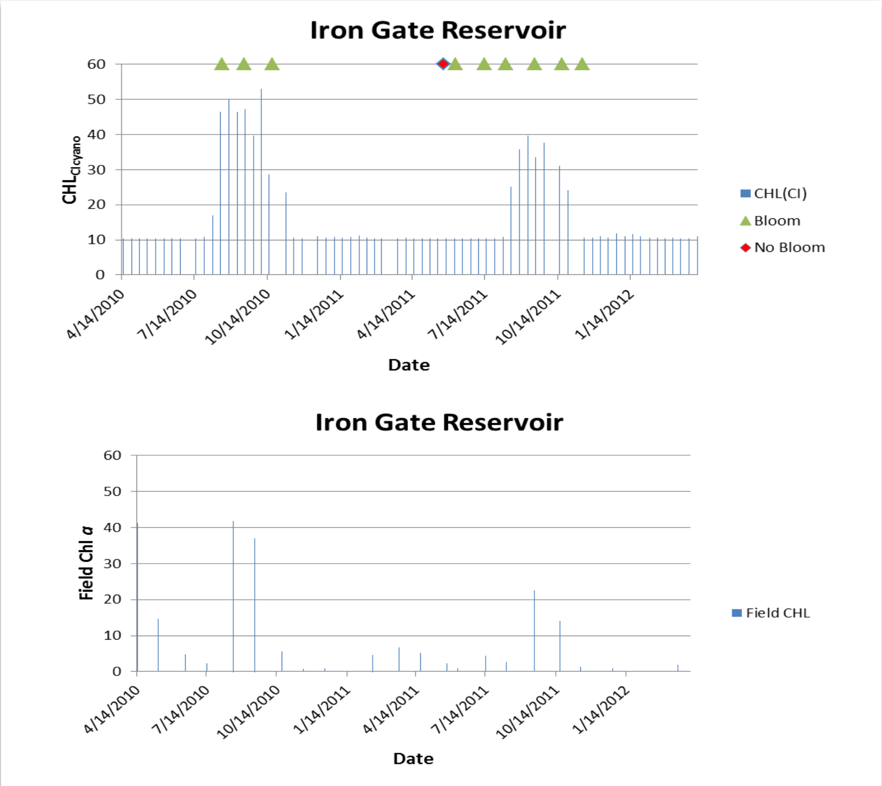
Potomac River, Maryland, extent of *Microcystis* bloom, 2011

Improved CI

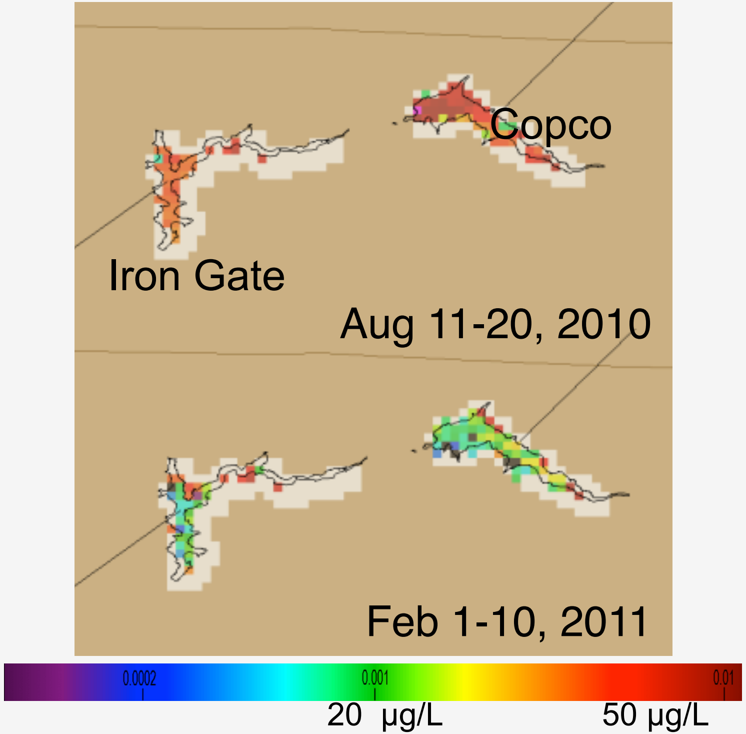




Phenology, Klamath River (CA) Reservoirs



MERIS Composites



Wind Matters for Buoyant Blooms

Verh. Internat. Verein. Limnol.	19	784 – 791	Stuttgart, Oktober 1975

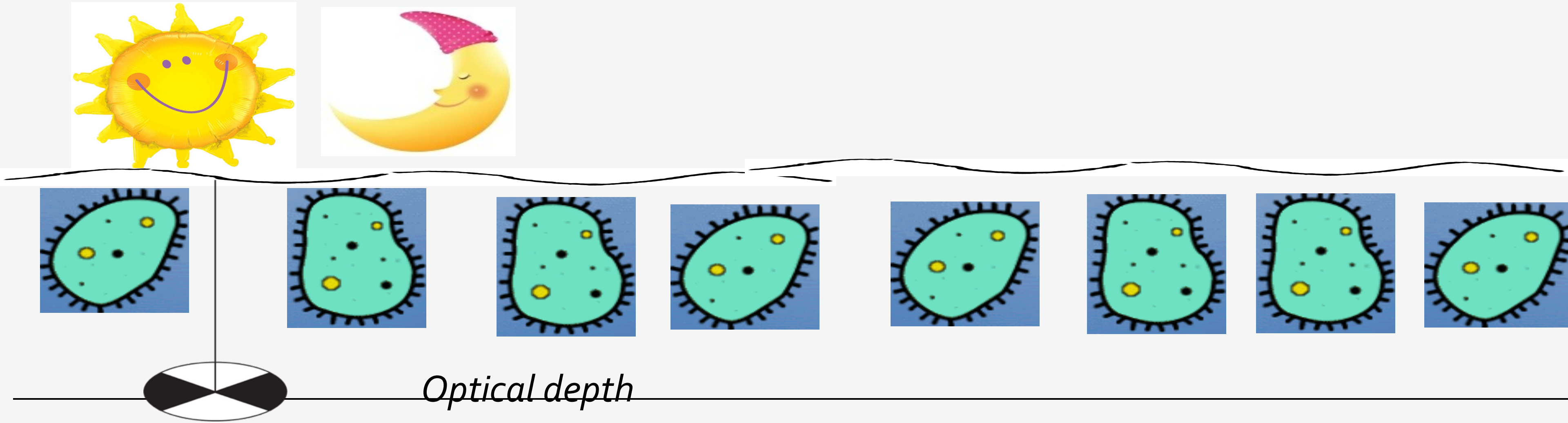
The use of remote sensing to detect how wind influences planktonic blue-green algal distribution

A. J. Horne and R. C. Wrigley

With 4 figures in the text

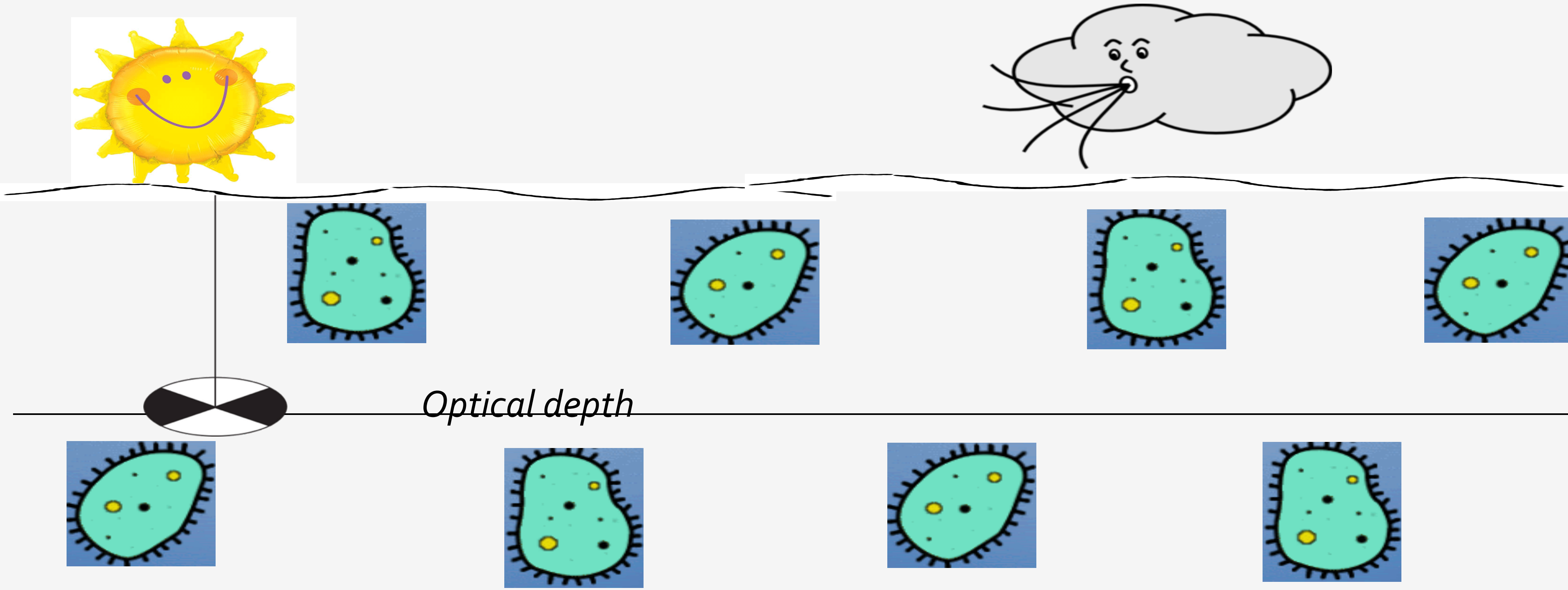
Conceptual Diagram

No Wind



Conceptual Diagram

With Wind



Lake Erie Bloom

- Satellites see either surface scum or surface concentration
- Caution on "averaging" buoyant blooms

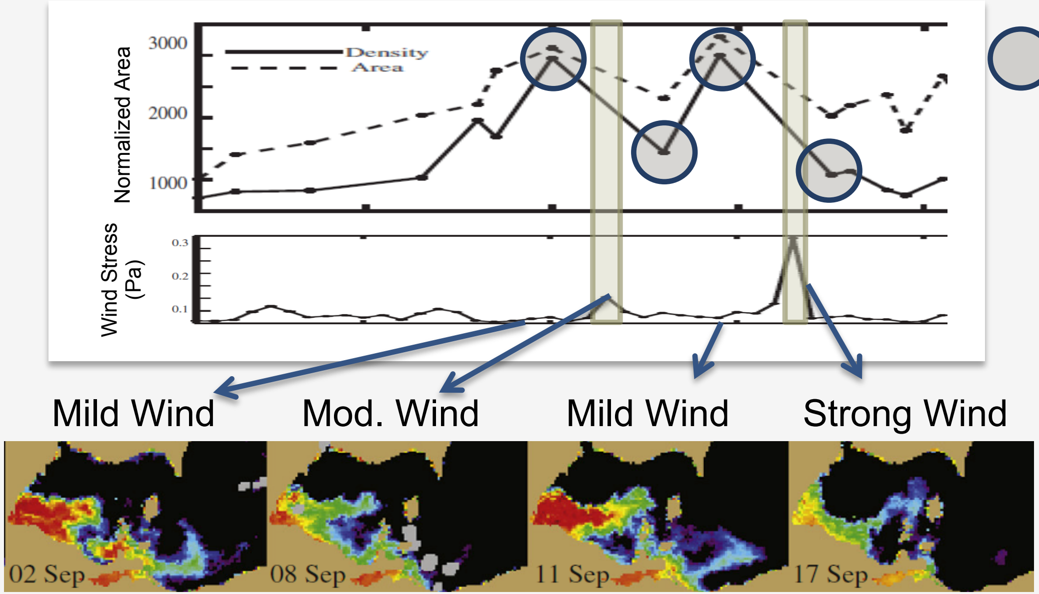
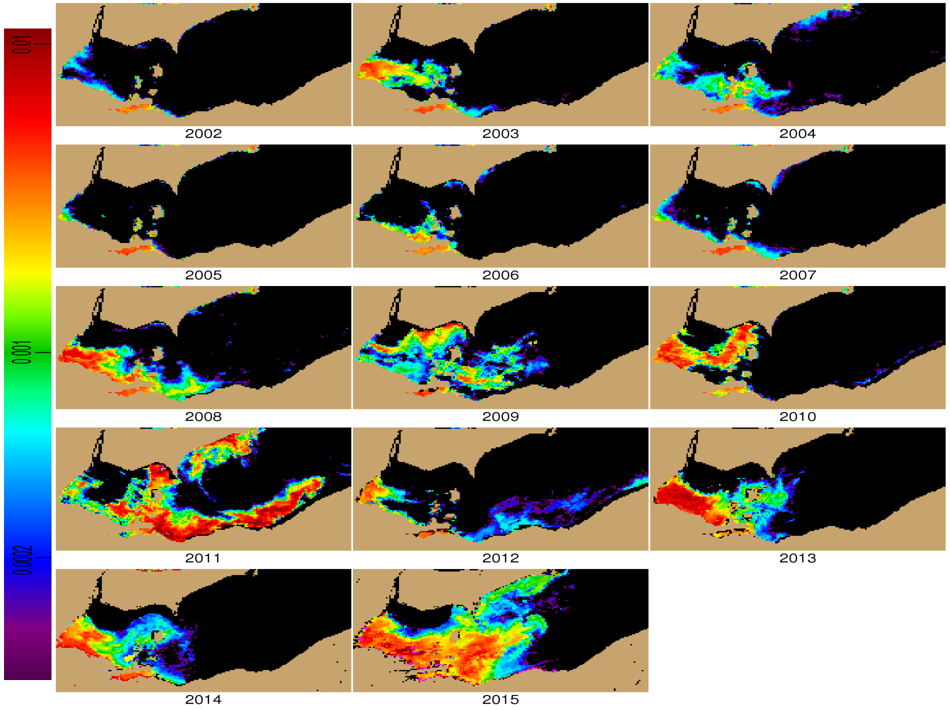


Image totals

Figure from Wynne et al., 2013

Use of Long-term patterns. Lake Erie 2015 Was Bad



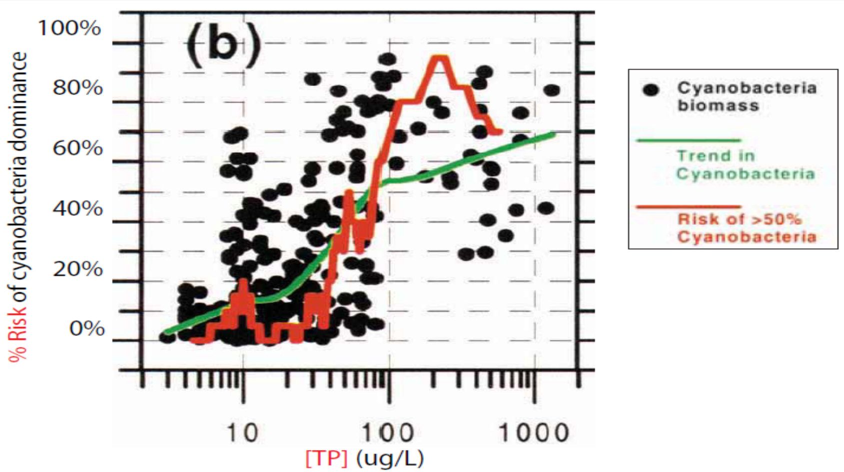
The Columbus Dispatch

Lake Erie's green monster returns

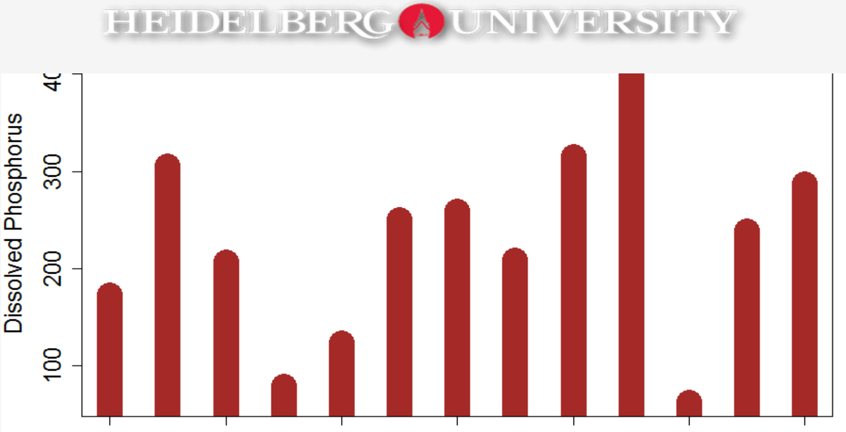
Algae back with a vengeance in Lake Erie a year after Toledo's water crisis; prognosis poor

Phosphorus as a Driver of Cyano Blooms in Lakes

Lake Erie, Spring Load from Maumee River

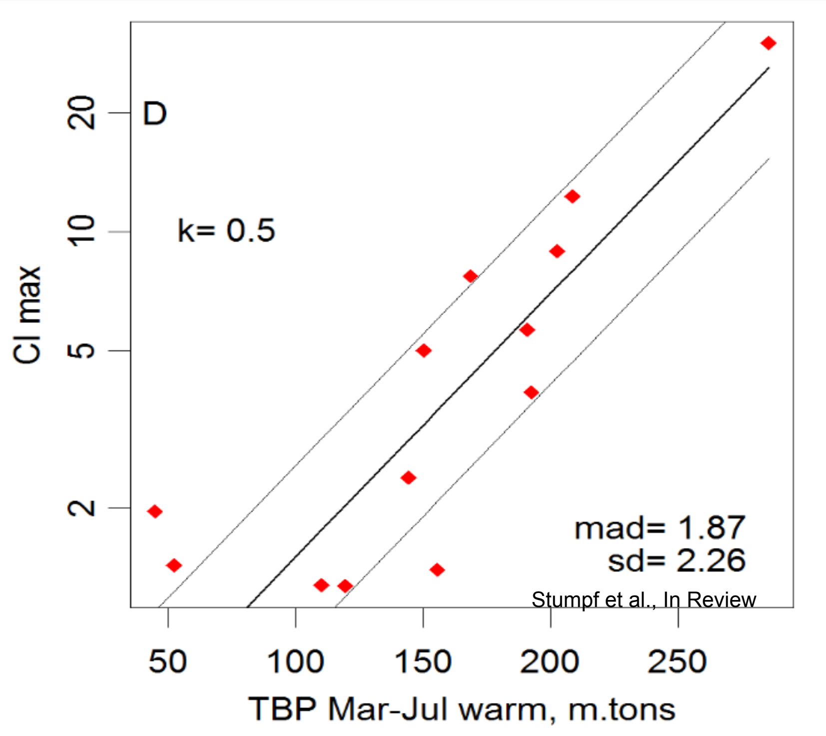


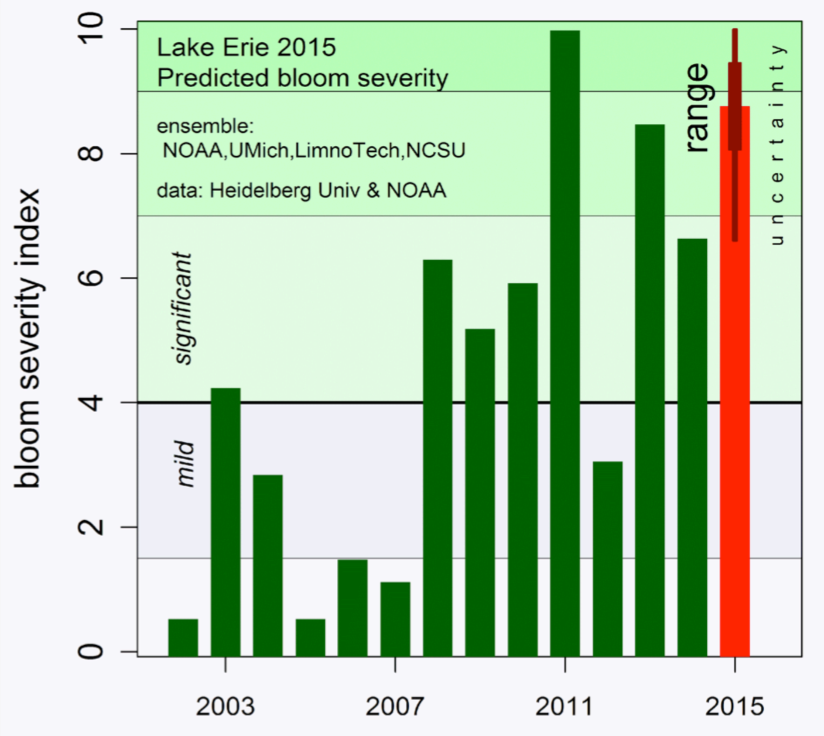
Downing et al., 2011



Lauran Johnson, NCWQR

Cyanobacterial Biomass Related to Total Bio-Available Phosphorus (TBP) Load from Maumee River, Lake Erie. Allows forecasts.





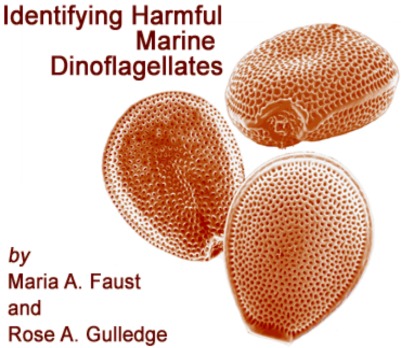
Last information

Some last thoughts on freshwater cyanobacterial blooms

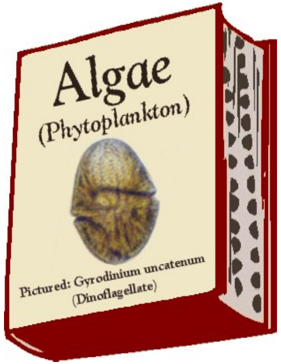
- Cyanobacterial blooms occur in eutrophic waters, they usually have high Chl-a.
- Not all satellites are the same.
  - Algorithms need to be suitable for cyanobacteria (MERIS & new OLCI are best)
    - Need algorithms as robust as the application (monitoring or characterization?)
    - Need other environmental information for other sensors (Landsat, Sentinel-2, etc.)
    - Scum is easiest to see (near infrared vs red), but only works with calm winds
- Not all blooms are toxic.
  - Satellite cannot detect toxicity.
    - (See Stumpf et al. 2016 Harmful Algae, on strategies for toxin mapping)
- Other insights can be gained
  - Monitoring blooms in real-time
  - Which lakes have problems and when
  - Role of nutrients in producing blooms
  - Inter-annual variability

Places for Information on Phytoplankton

http://oceandatacenter.ucsc.edu/PhytoGallery/index.html



http://botany.si.edu/references/dinoflag/



http://www.dnr.state.md.us/bay/cblife/algae/index.html

https://pubs.er.usgs.gov/publication/ofr20151164/