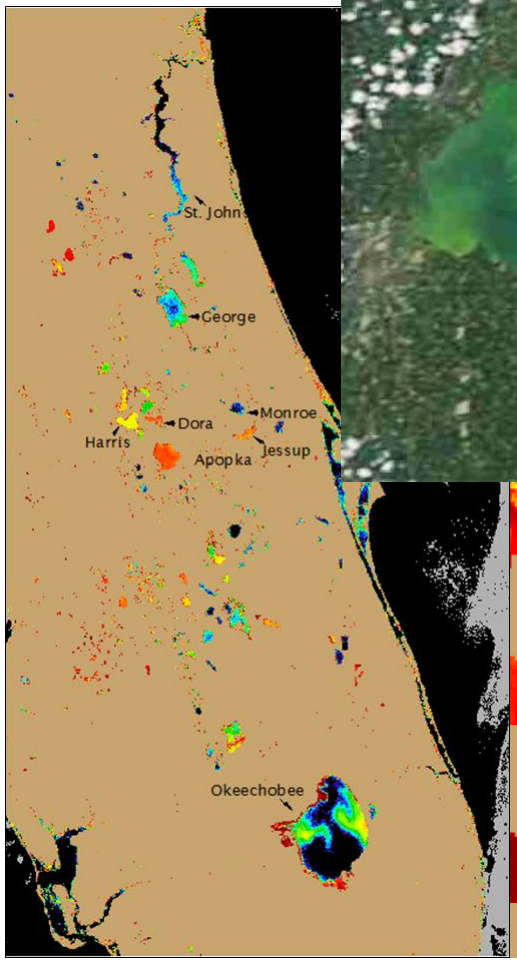
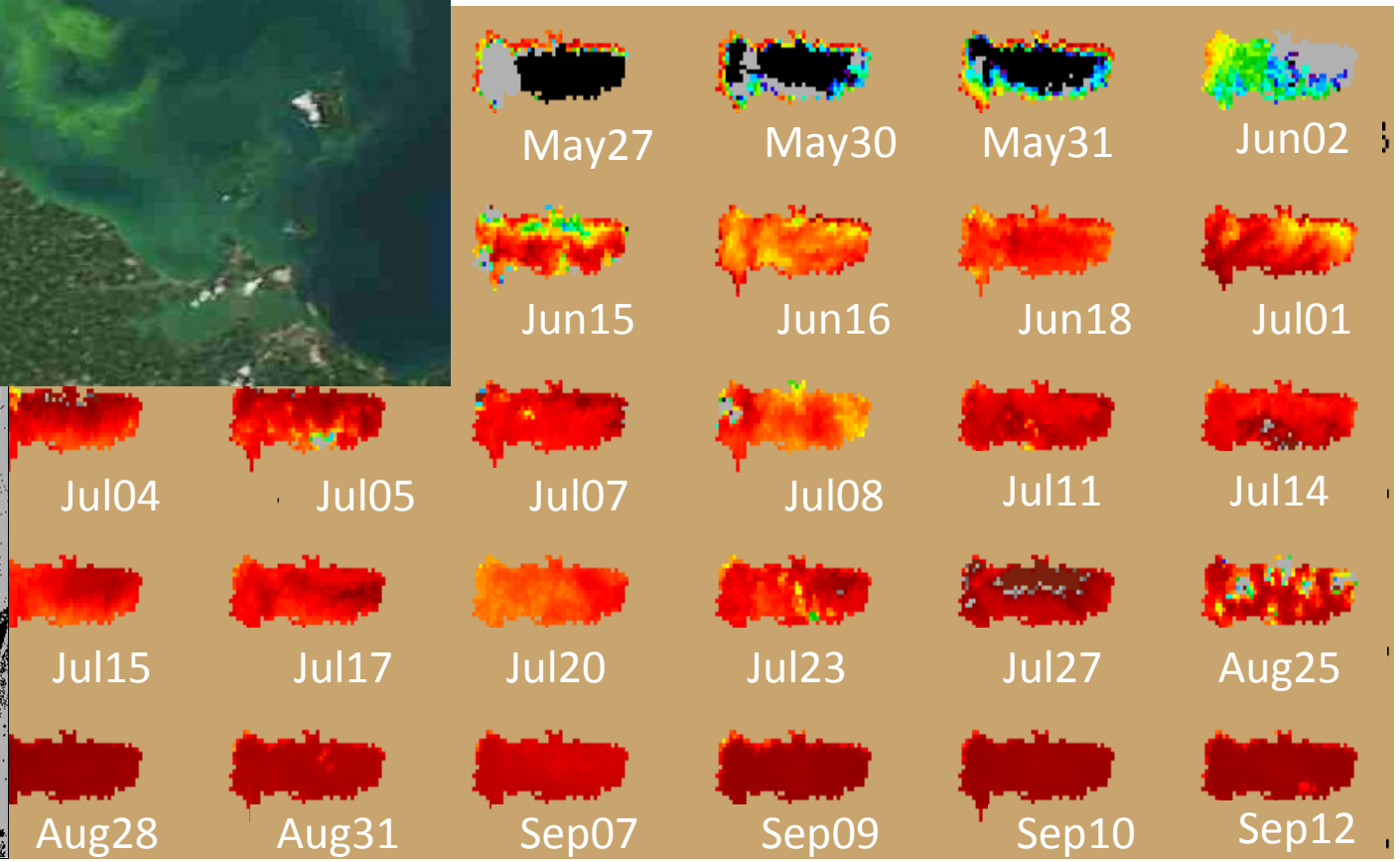
Remote Sensing of Lake Harmful Algal Blooms, What we've Learned

Rick Stumpf

NOAA National Ocean Service





Harmful Algal Blooms (HAB's)

- Bloom – increase in concentration & mass development of algal & cyanobacterial cells
- Some blooms can rise to surface (cyanos need vacuoles)
- Typical conditions:
  - Warm temperature
  - Sunlight
  - Nutrients – phosphorus
  - Calm lake conditions
- Last days to several months
- Not necessarily single species, and typically multiple strains

Floating bloom,
Microcystis scum

Where are we with satellite

- All sensors can find scum
- All sensors can find turbid “eutrophic” water
  - Defining the right answer for mgmt is the problem
- We can find cyanobacteria blooms (with MERIS)
- All usable methods produce false positives
    - Some produce false negatives
- All sensors have limitations (time, space, spectra)
- MERIS was the best sensor for cyano detection,
  - Several bands in red and near-IR, 2-day repeat
  - 300 m and 1.2 km
- The future is OLCI on Sentinel-3 (2015)
  - Replaces MERIS

Current satellite status

- MERIS (300 m) ended April 2012, 2-day
  - Used for climatologies (300 m from 2009 to 2012, 1 km from 2002 to 2012)
- MODIS (1 km) used 2012 (to 2014), 1-2 day
  - On two satellites
  - Usable but noisy, less sensitive
  - Scum/turbidity at 250 to 500 m.
- OLCI (Sentinel-3), MERIS replacement, 2-day
  - launch late 2014 early 2015
- Landsat (30 m). 1 ½ sensors, 8-day repeat.

MERIS, what does every two days mean?

"Swaths" move around

Full Swath
1150 km

No Coverage
Aug 30

Satellite Comparison for cyano applications

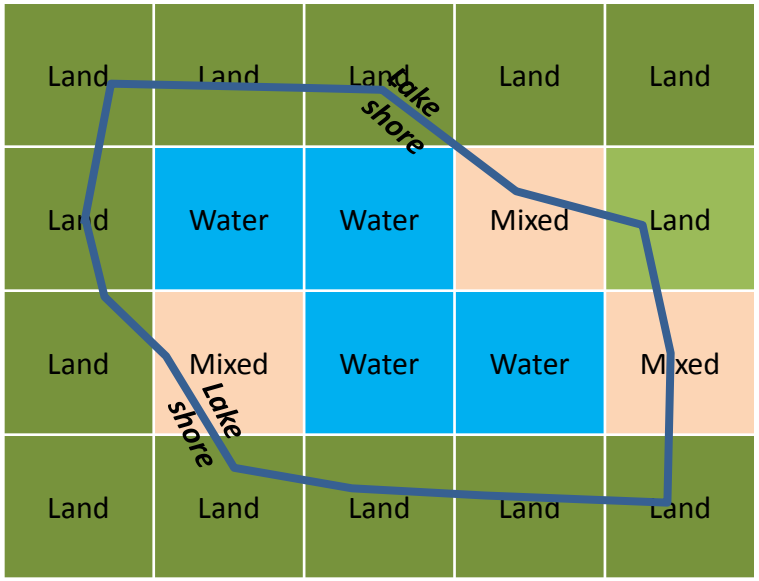
Satellite	Spatial	Temporal	Key Spectral
MERIS (& OLCI)	300 m *OK*	2 day *good*	10 (5 on red edge) *good*
MODIS high res	250/500 m *OK*	1-2 day *good*	4 (1 red, 1 NIR) *marginal*
MODIS low res SeaWiFS	1 km *poor*	1-2 day *good*	7-8 (2 in red edge) *OK*
Landsat	30 m *good*	8 or 16 day *poor*	4 (1 red, 1 NIR) *marginal*
Very high res (IKONOS, etc.)	1-4 m *good*	Variable (must be ordered) *marginal*	4 (1 red, 1 NIR) *marginal*

Clouds take out 1/2 to 2/3 of imagery

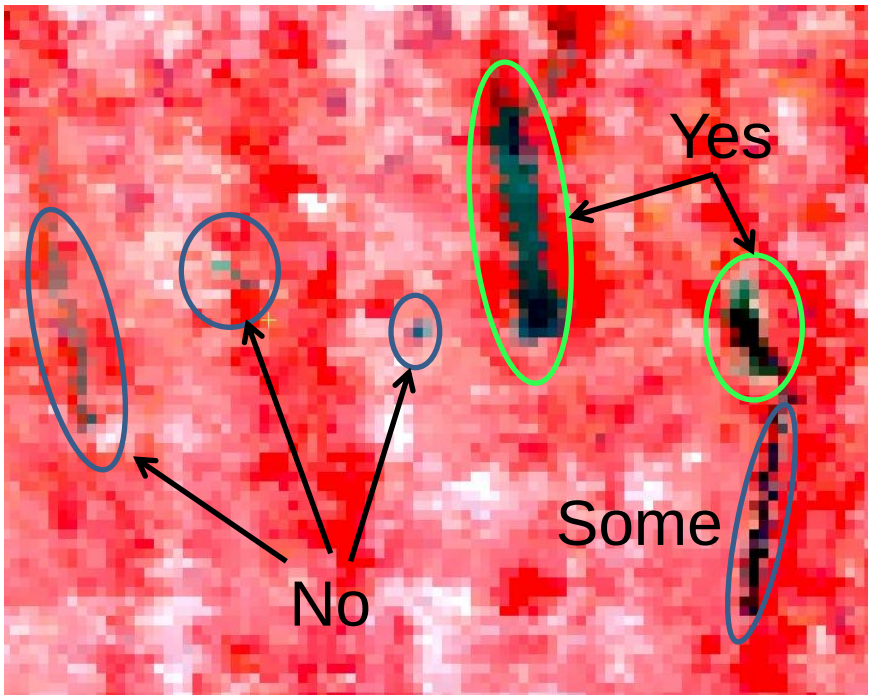
Sunglint is not a problem for our algorithms

Minimum resolution, 3 pixels across (2 mixed land/water)

Resolution and water bodies

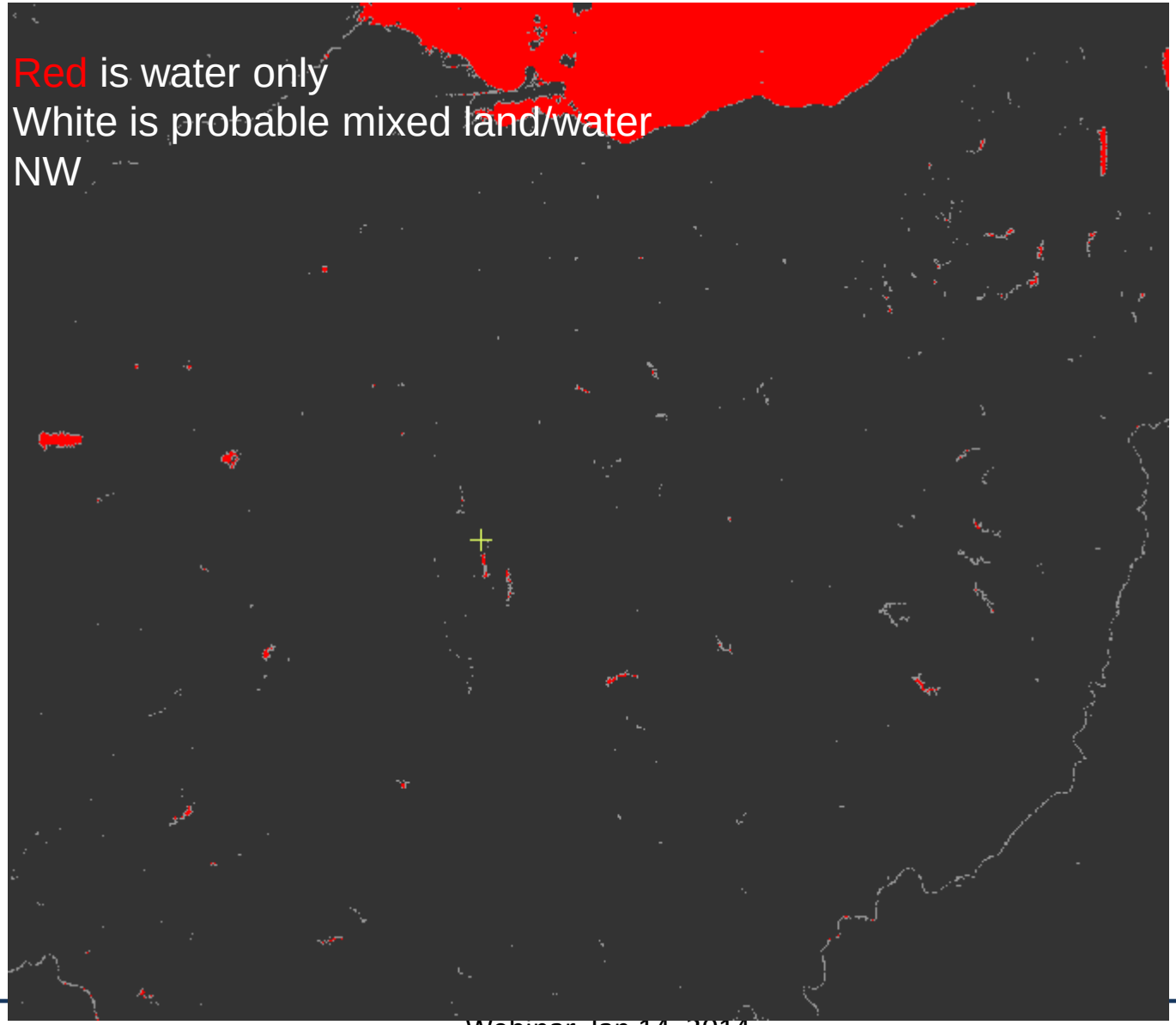


Mixed pixels limit our ability to monitor small water bodies

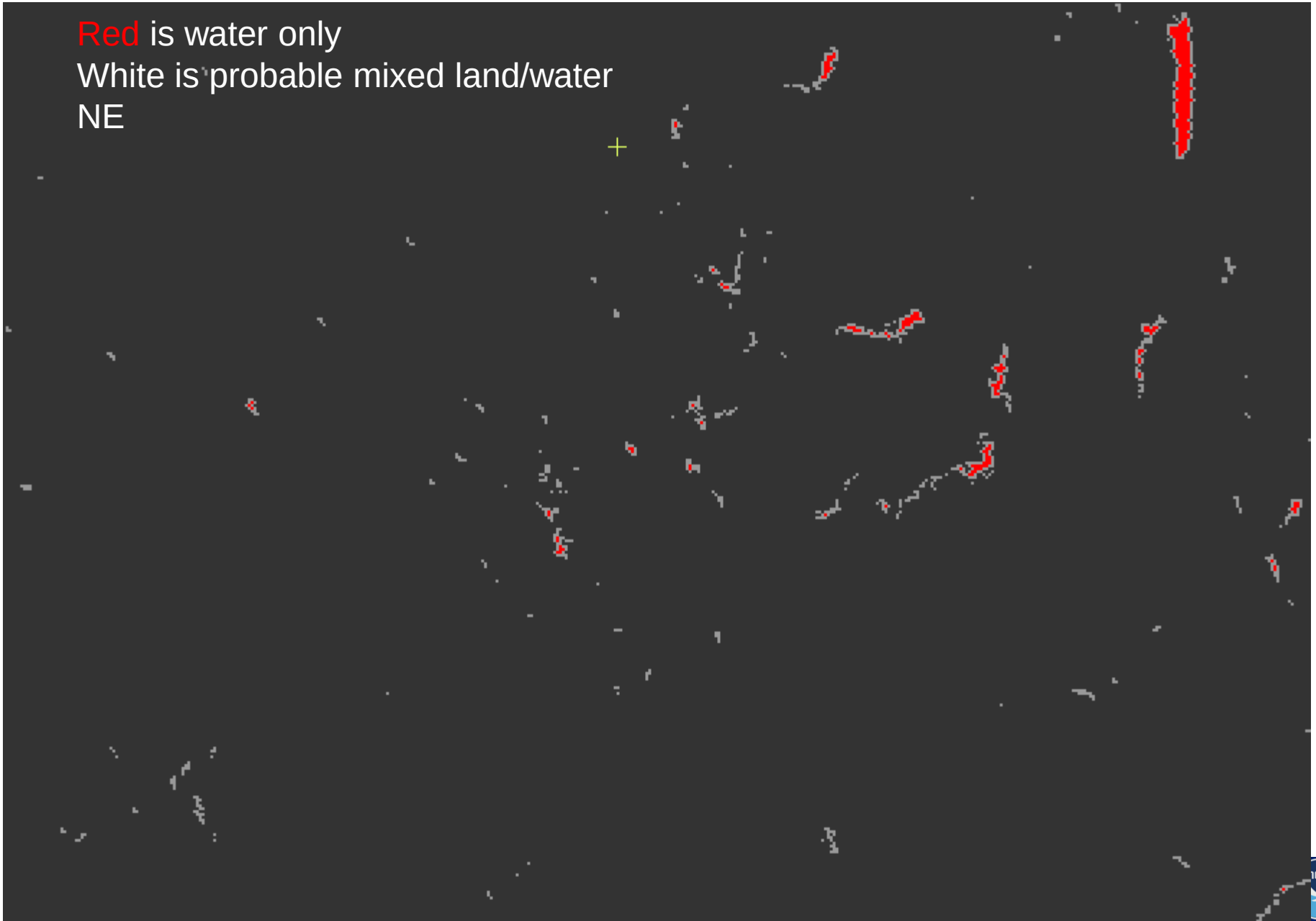


Note: false color sharpens distinction between land and water.
Reddish pixels at right include land.

Areas potentially monitored by MERIS and MODIS



Areas potentially monitored by MERIS/OLCI



Analyzing this should be a science

Context:

- Optical patterns
- Ecological context
- Temporal context
- Spatial context

These are all “rules” to interpret imagery

“Green” does not necessarily mean cyanobacteria

It's hard to be correct

- 90-95% of the light at the satellite is atmosphere or surface reflectance
- Trade-offs on resolution: spectral, spatial, temporal.
- Algae is not the only thing in the water
- Must understand sources of error to use the data correctly
- There is no magic satellite calculation: All bloom algorithms depend on some ecological information, sometimes it's easy.

Remote sensing is hard, several materials in the water absorb or scatter light

Remote sensing reflectance

$$R = f\, b_b / a$$

[absorption] $$a = a_w + a_{phyto} + a_{sed} + a_{dissolved}$$

water

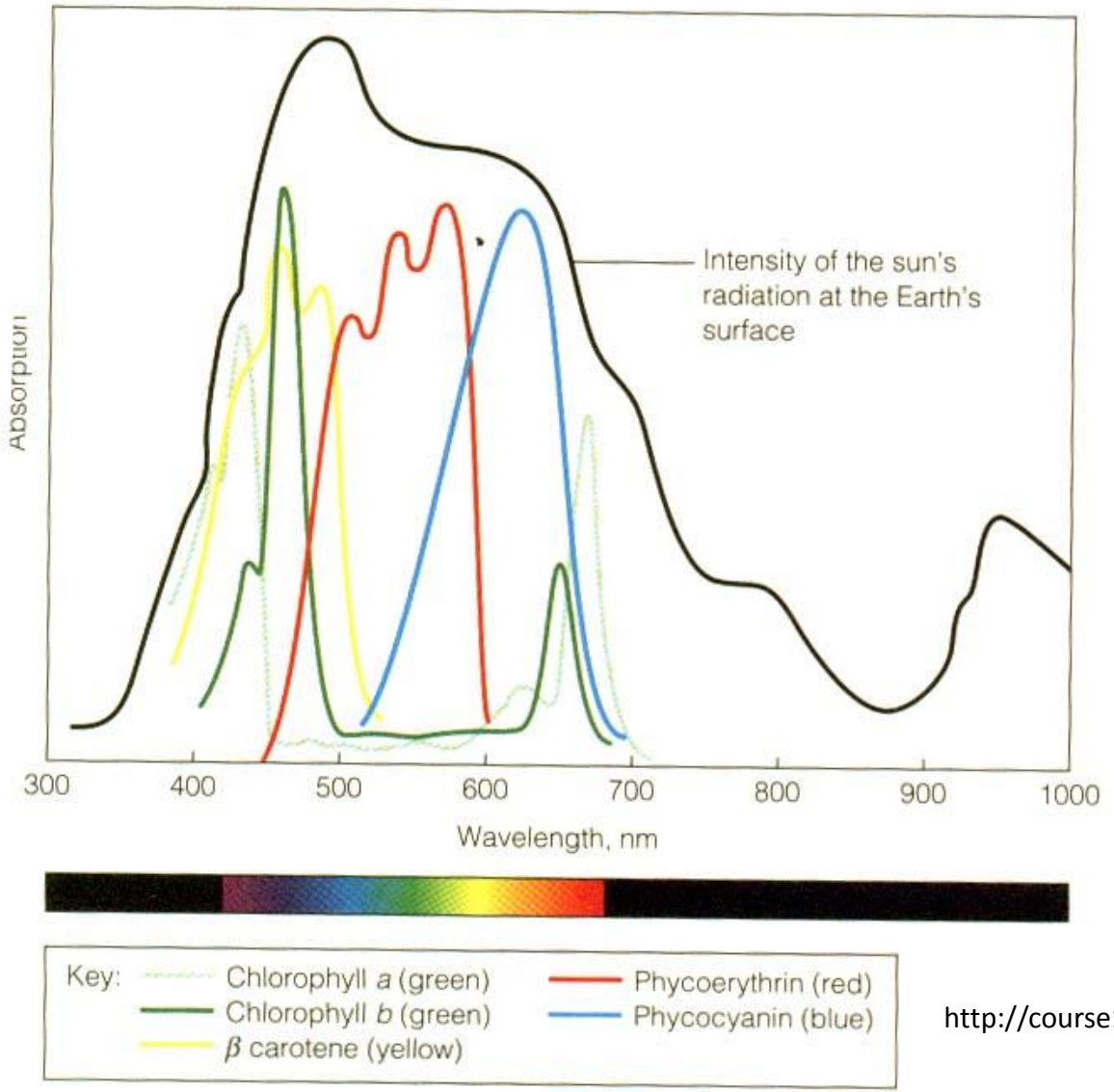
algae

sediment-detritus

dissolved

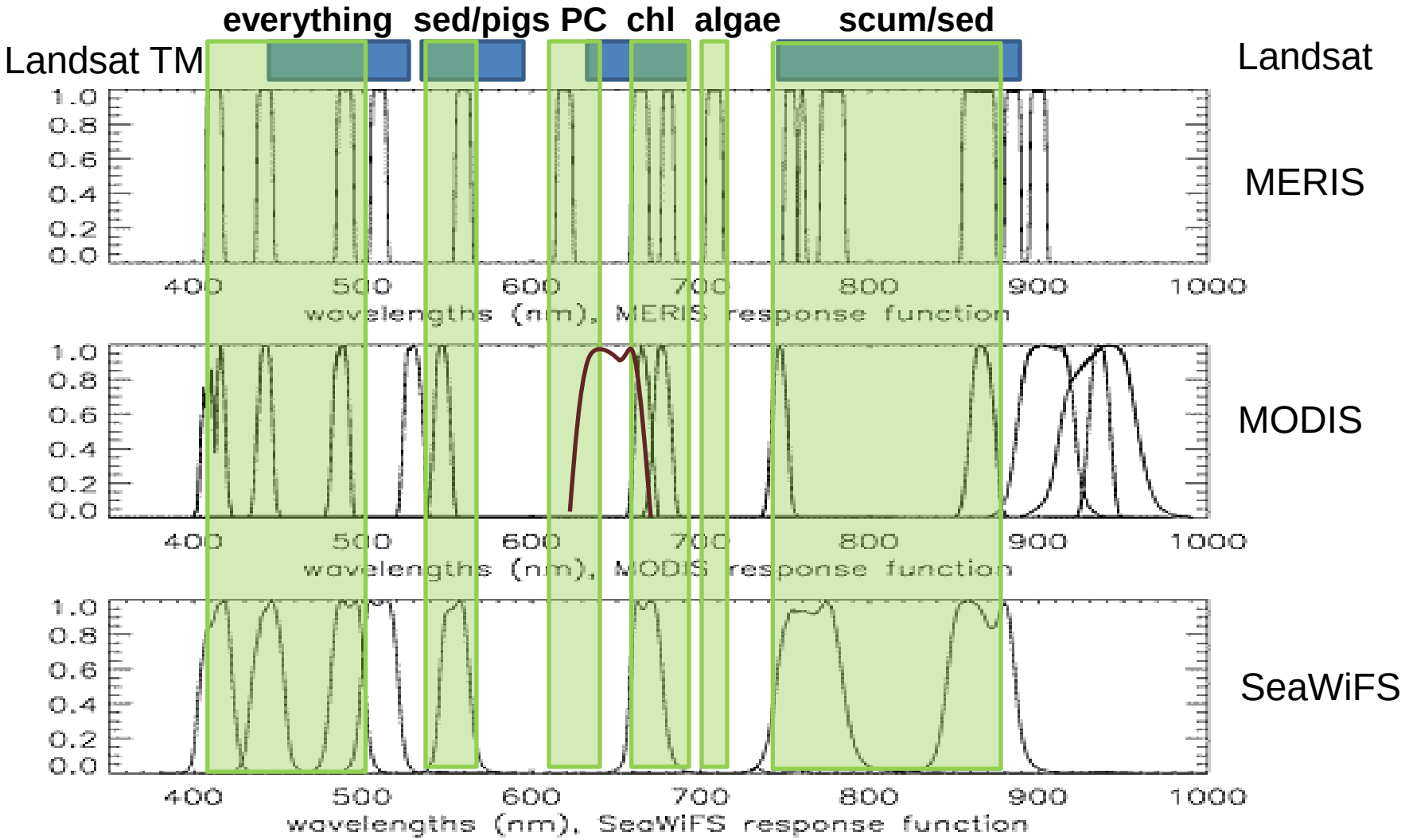
[backscatter] $$b_b = b_w + b_{phyto} + b_{sed}$$

More about spectra: various pigments in algae



S. Berg Winona State
http://course1.winona.edu/sberg/Fac_sb.htm

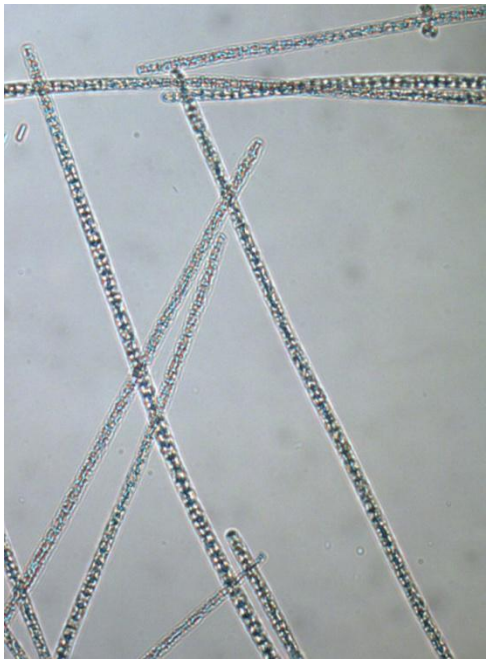
Satellite bands and sensitivity to materials in the water



“Cyanobacteria” (cyano is blue green)

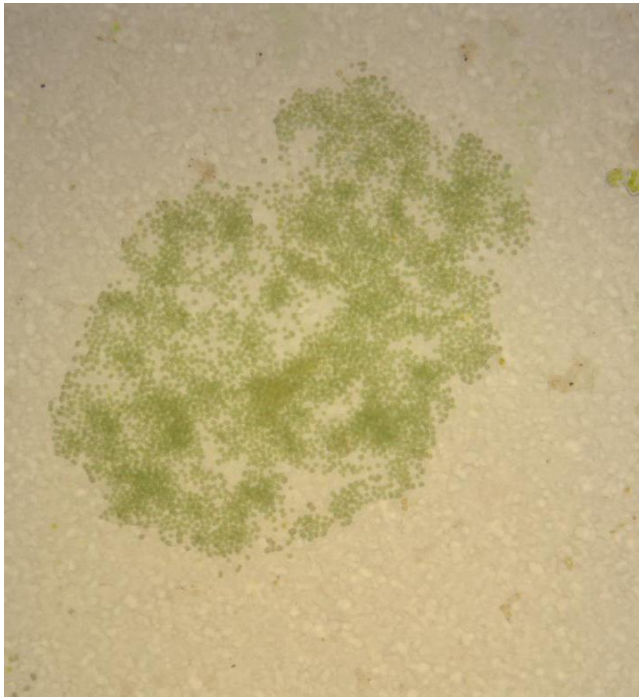
Planktothrix example

- Sandusky Bay, dispersed

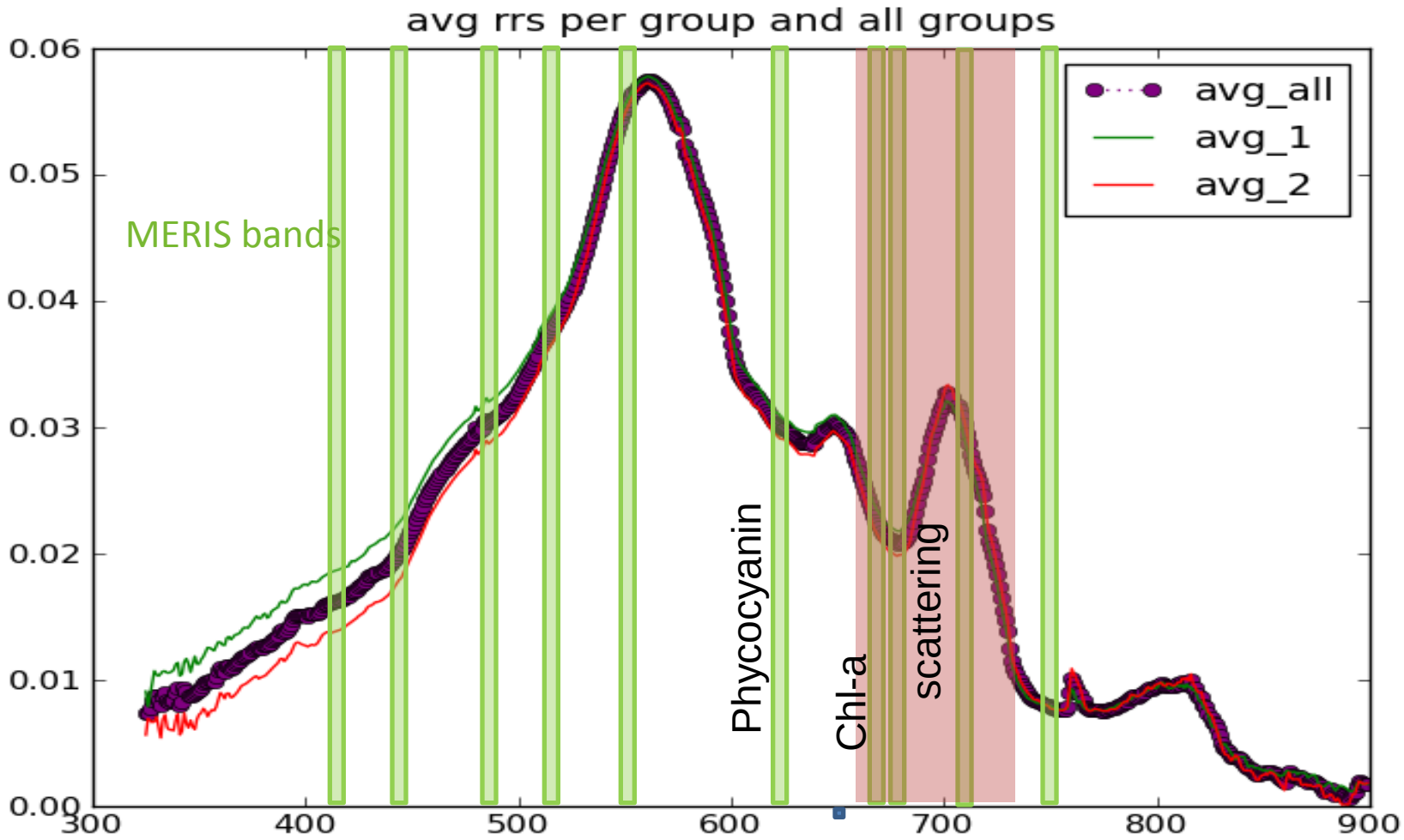


Microcystis example

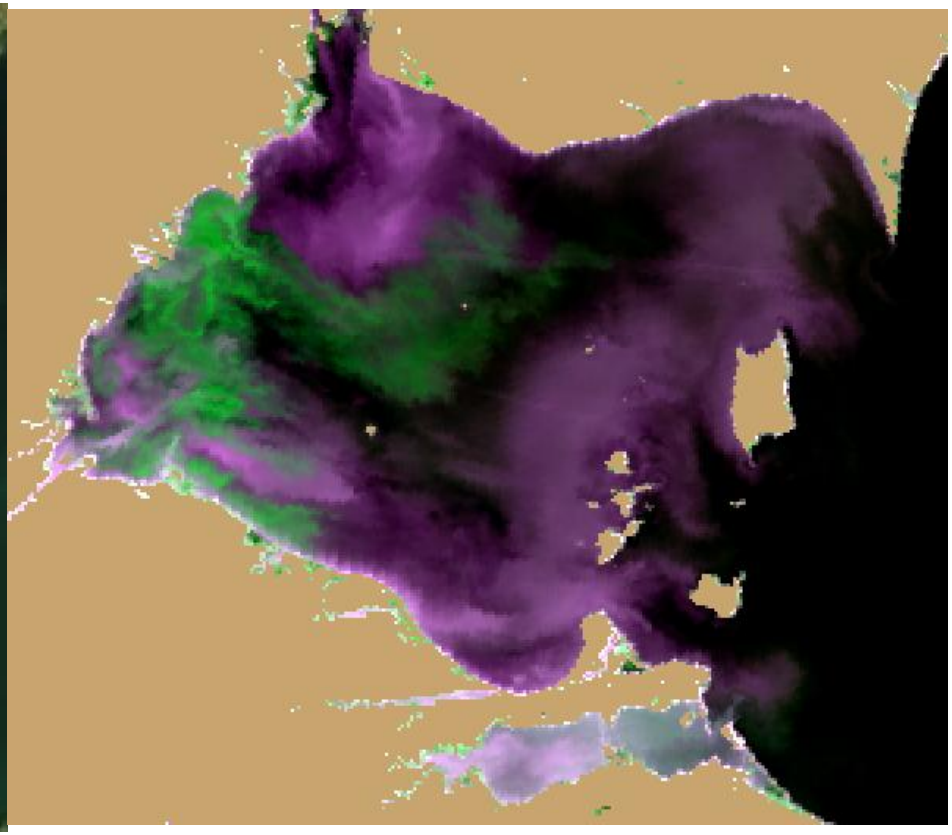
- Aug 2010, Lake Erie



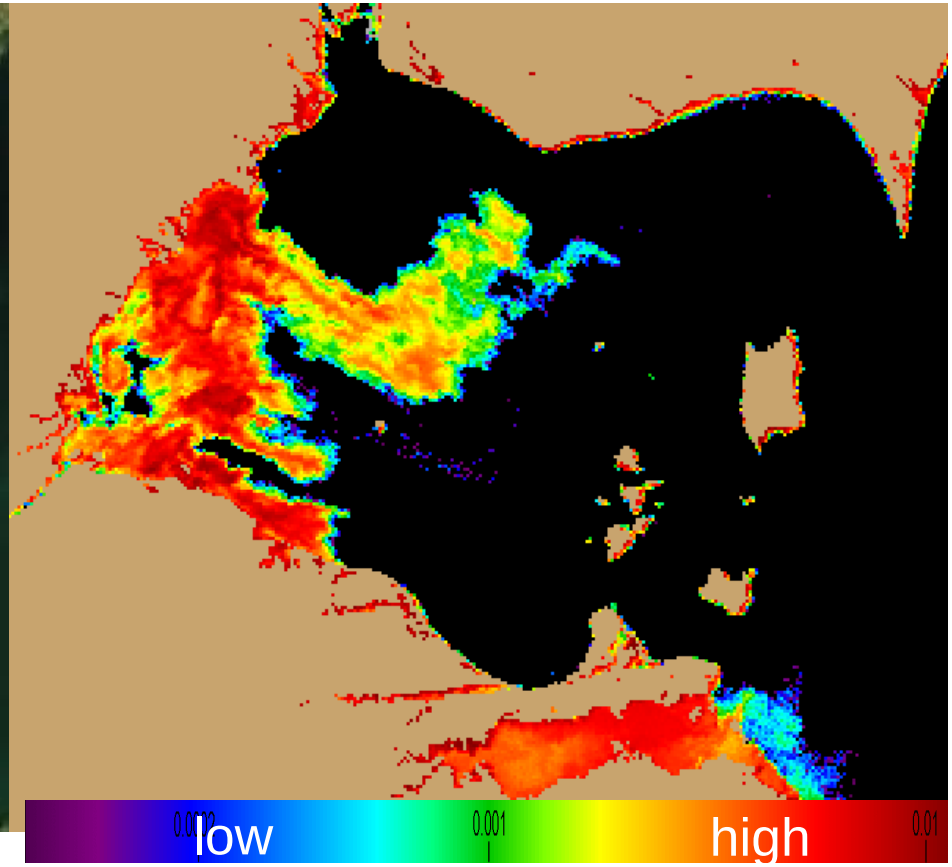
MERIS Bands on actual spectra



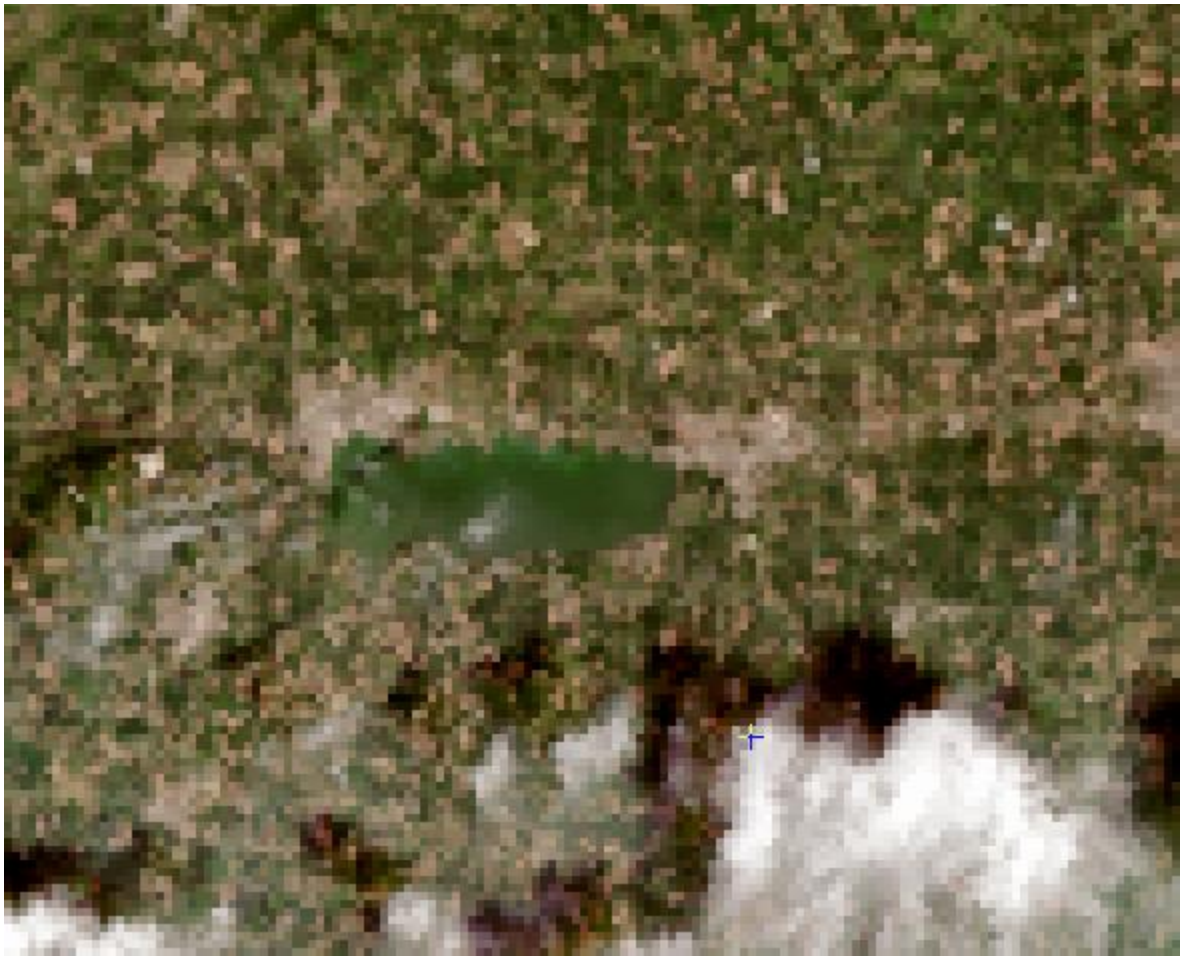
MERIS can see more wavelengths of light, allowing us to detect and quantify blooms



The extra wavelengths give a cyanobacteria index, “CI”, which equates to concentration

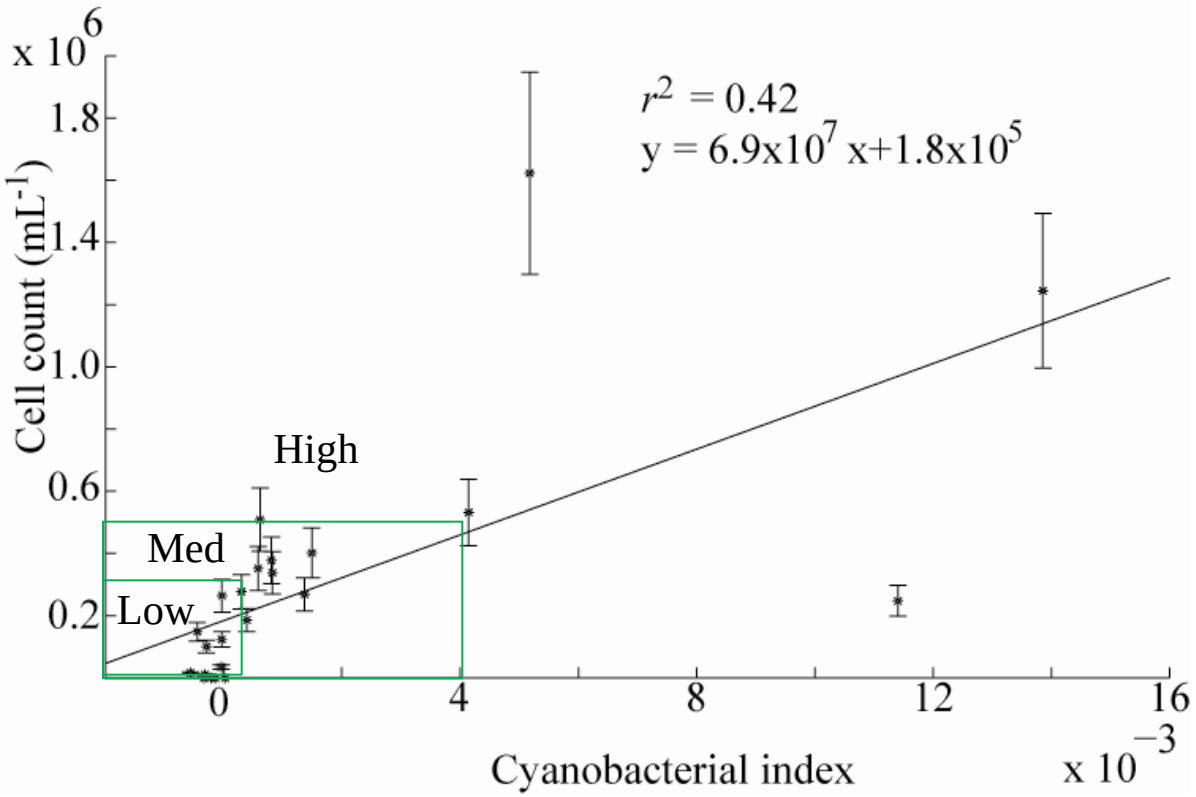


Visual interpretation is difficult;
MERIS 2010 July 27, true color
how bad is the bloom compared to Lake Erie?



Estimated cyano index, much more severe than Lake Erie Grand Lake St Marys, Ohio

Relating cell counts to satellite



Satellite against field cell counts

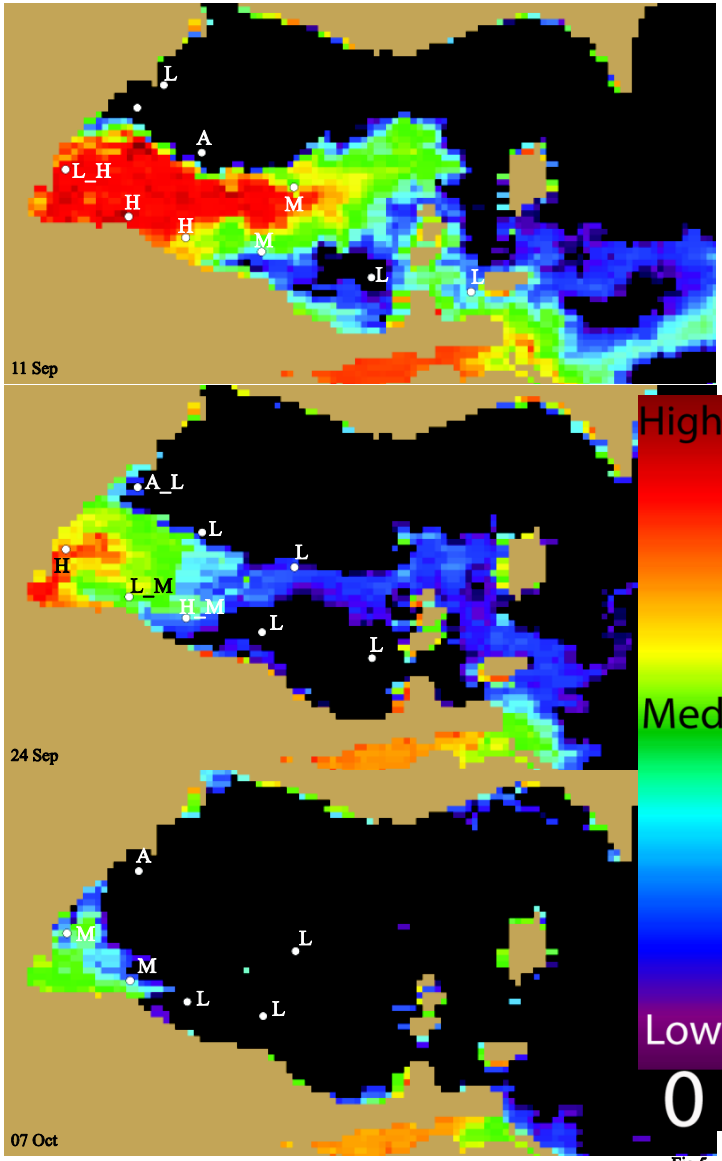
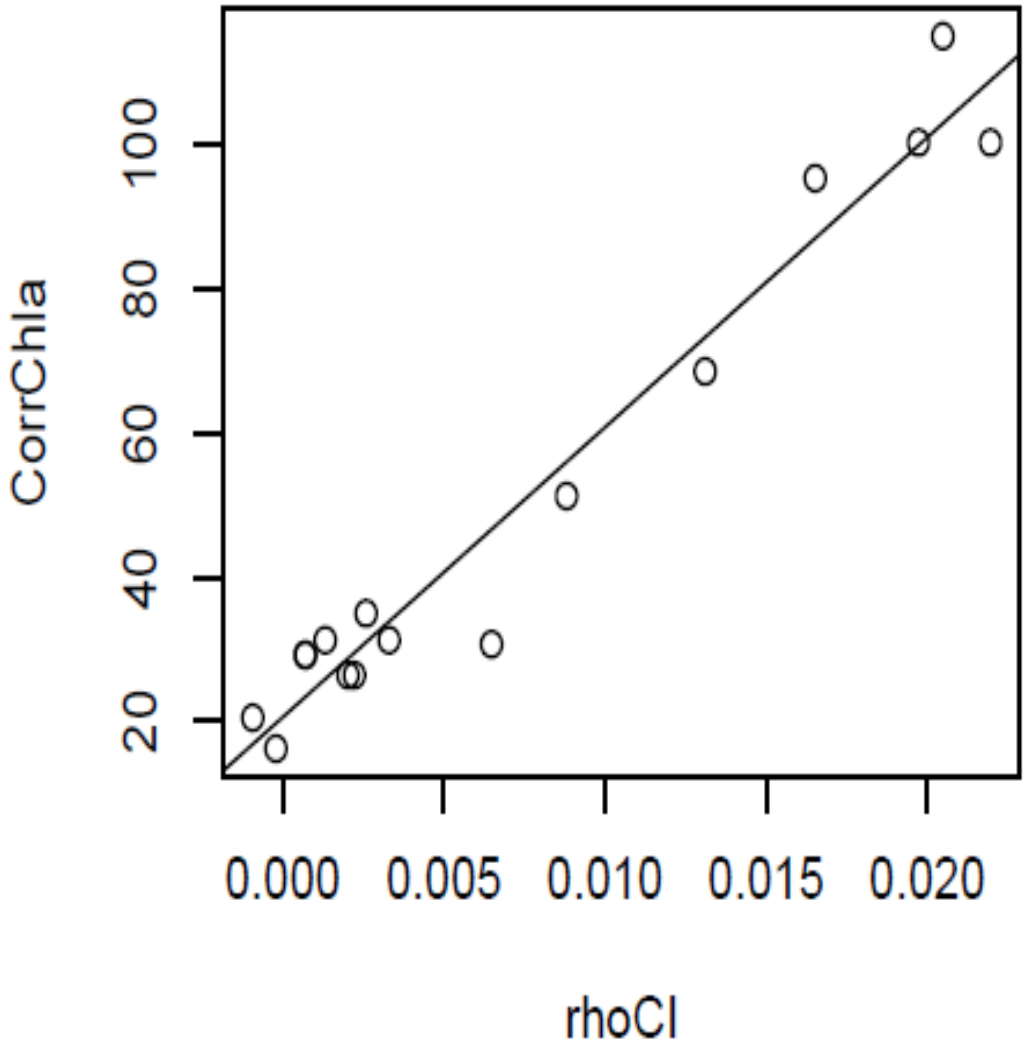


Fig 5

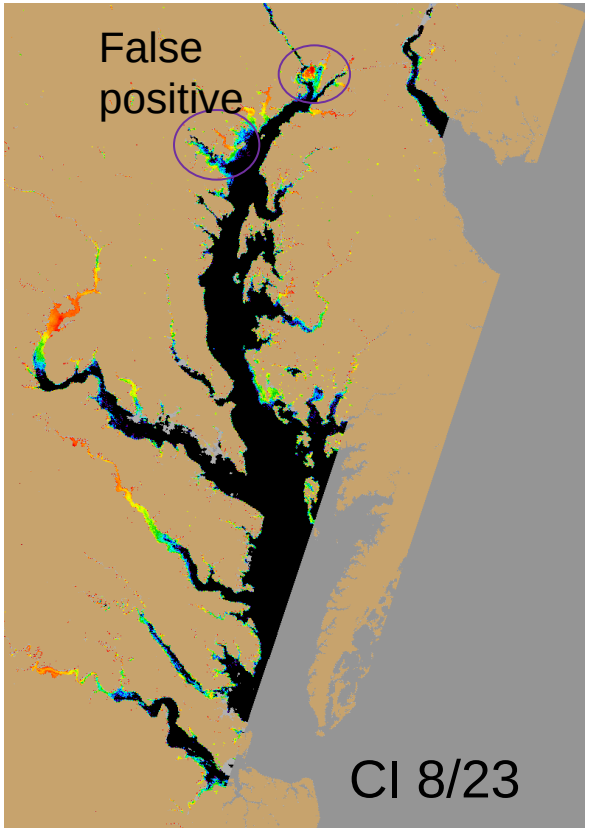
And Between Cl and chl-a from Florida (St Johns River WMD)

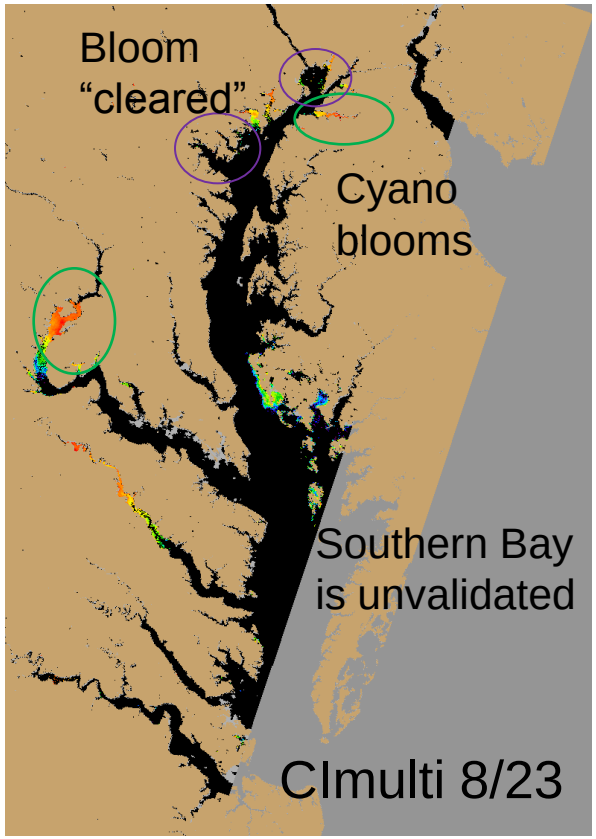
- r^2=0.96
- *Est chl* a =
- 4020*(*Cl*) + 20
- Detection of chlorophyll > 20 µg/L
  - (working on > 10 µg/L)



Bloom Detection and Description for MERIS

- CI to id high chlorophyll areas, rather than just cyanos
- CI-multi adds bands to be more specific to cyanos (phycocyanin sensitive), may still have some false +

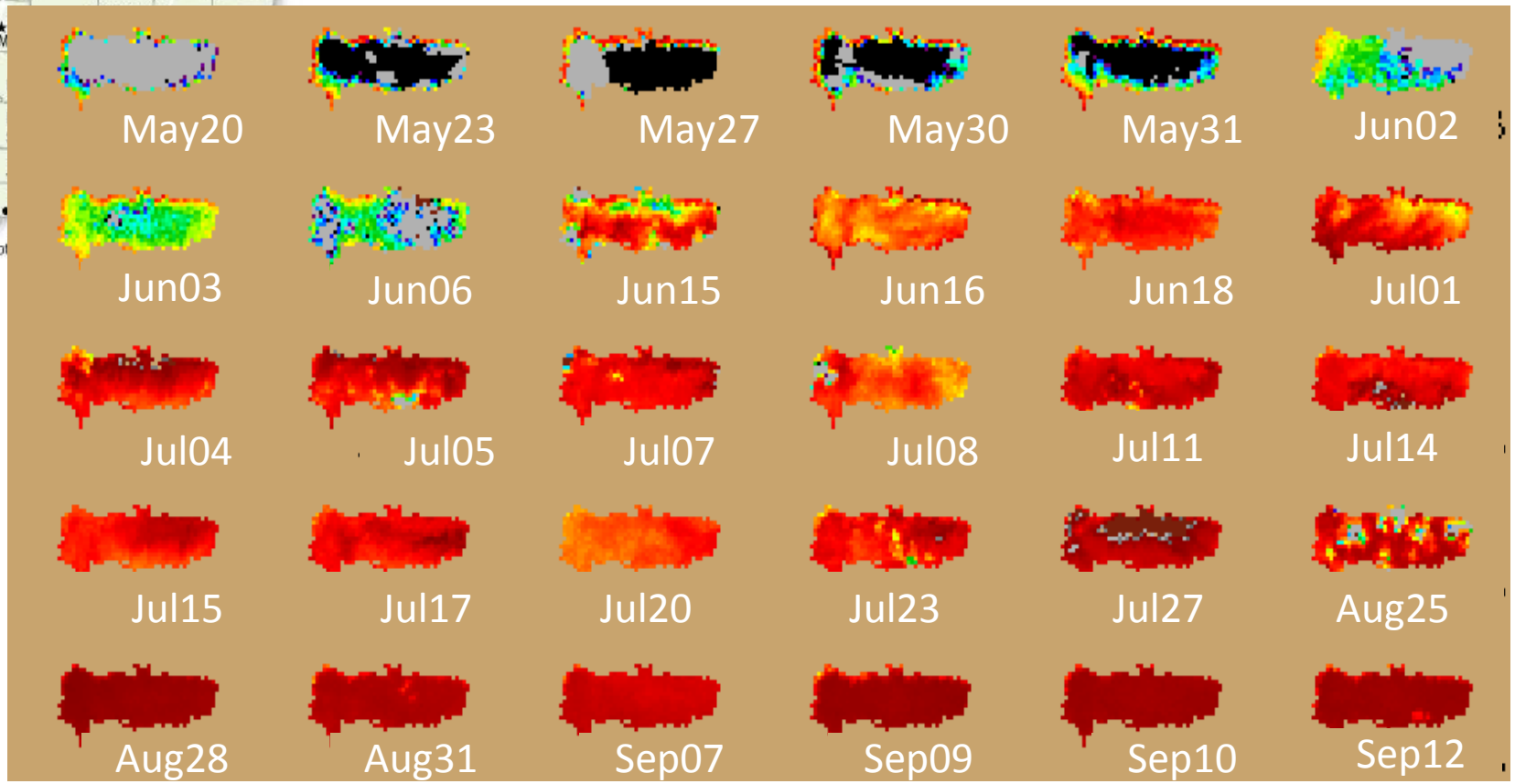




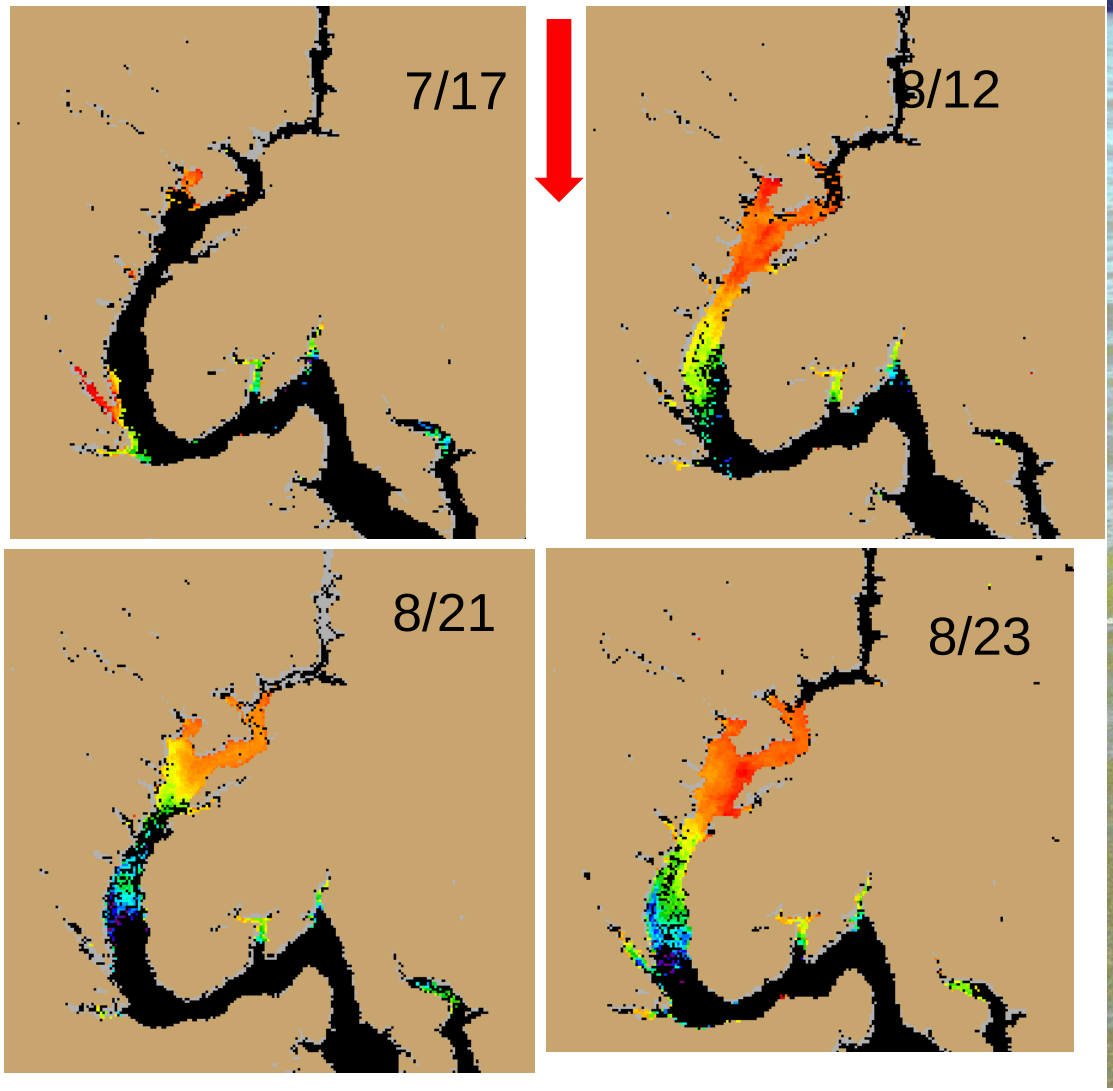
Look for likely PC absorption and keep.

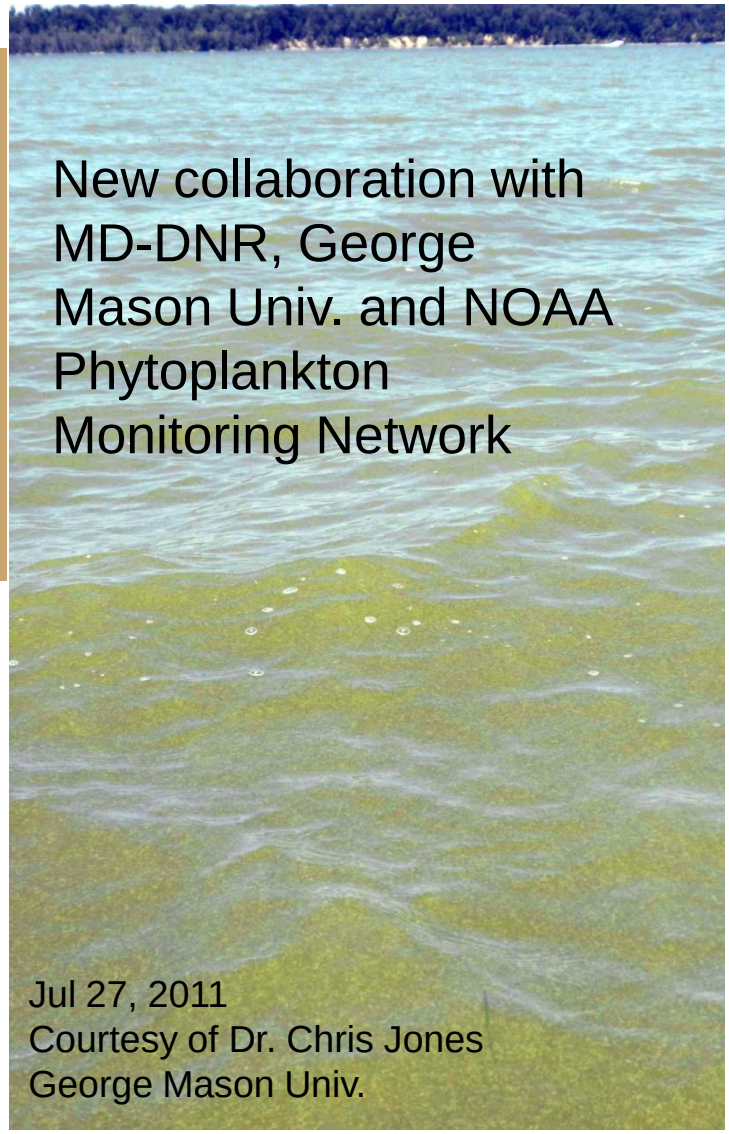
Temporal Patterns, when does bloom start? Grand Lake St Marys, Ohio

- Cyano index for 2010

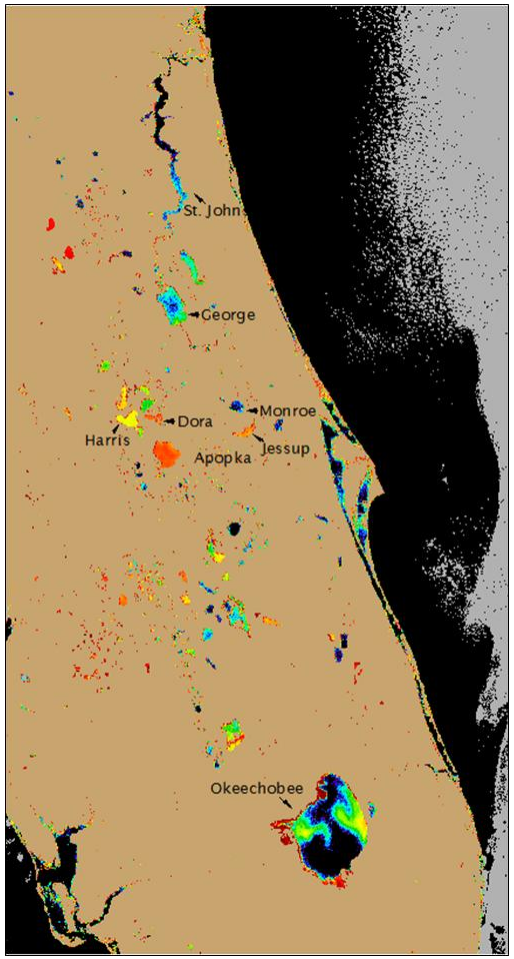


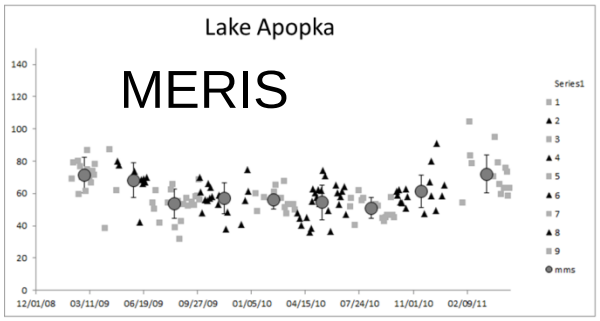
Potomac River *Microcystis* bloom

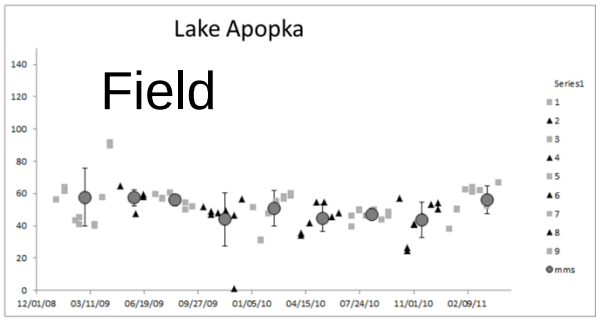


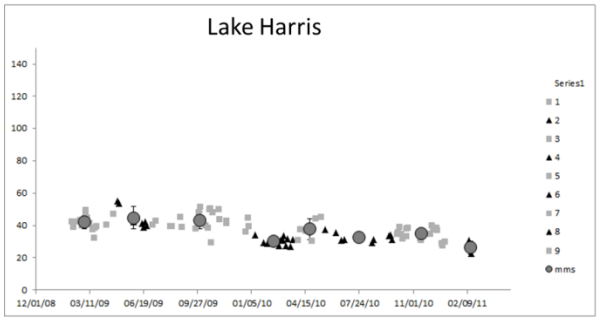


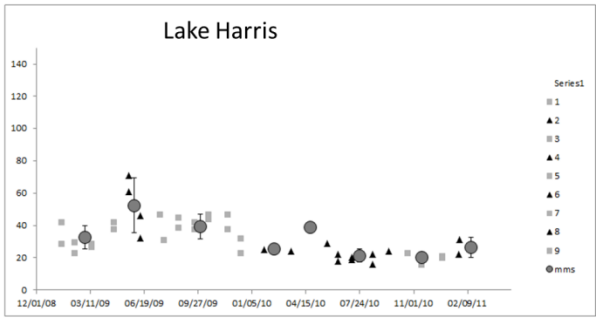
Compare chl-a in lakes over time (2 ½ years)

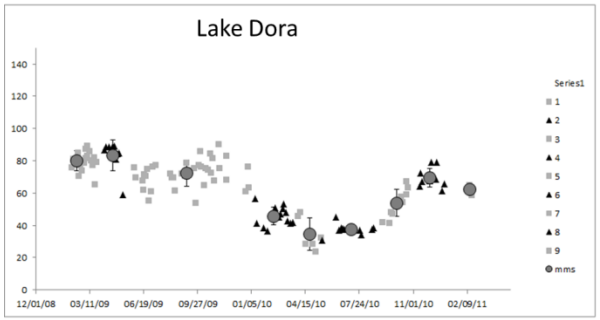


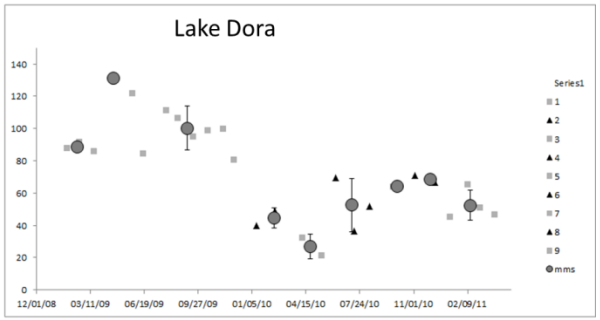


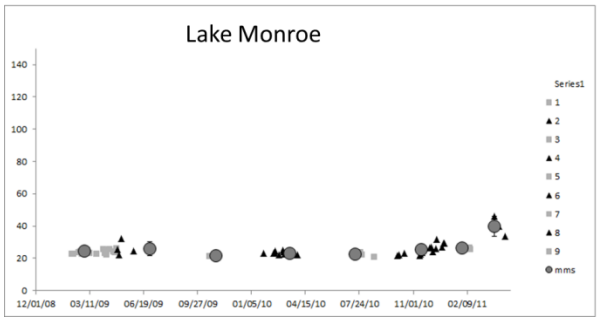


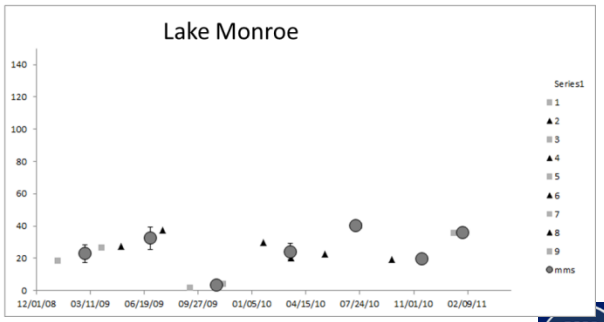




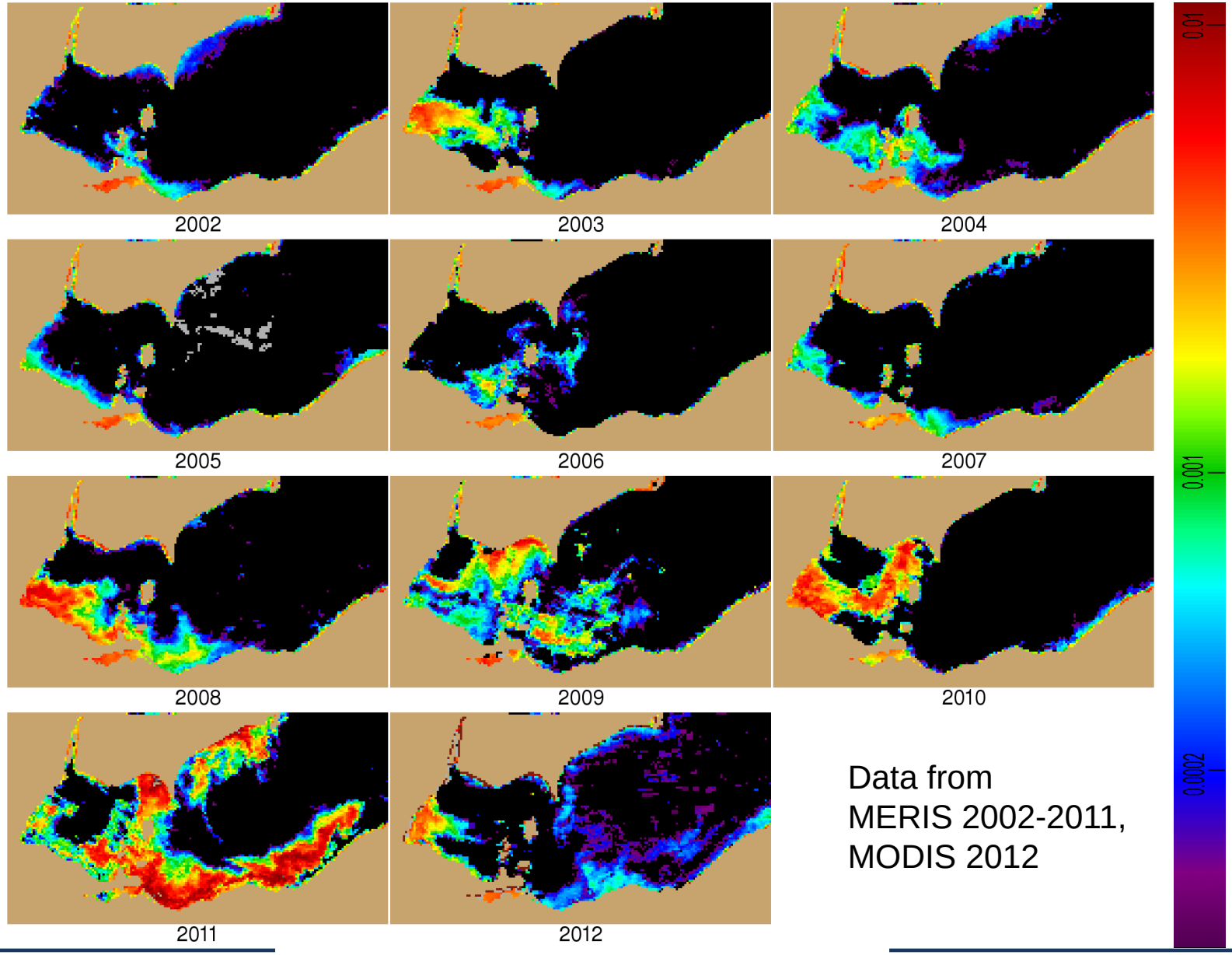






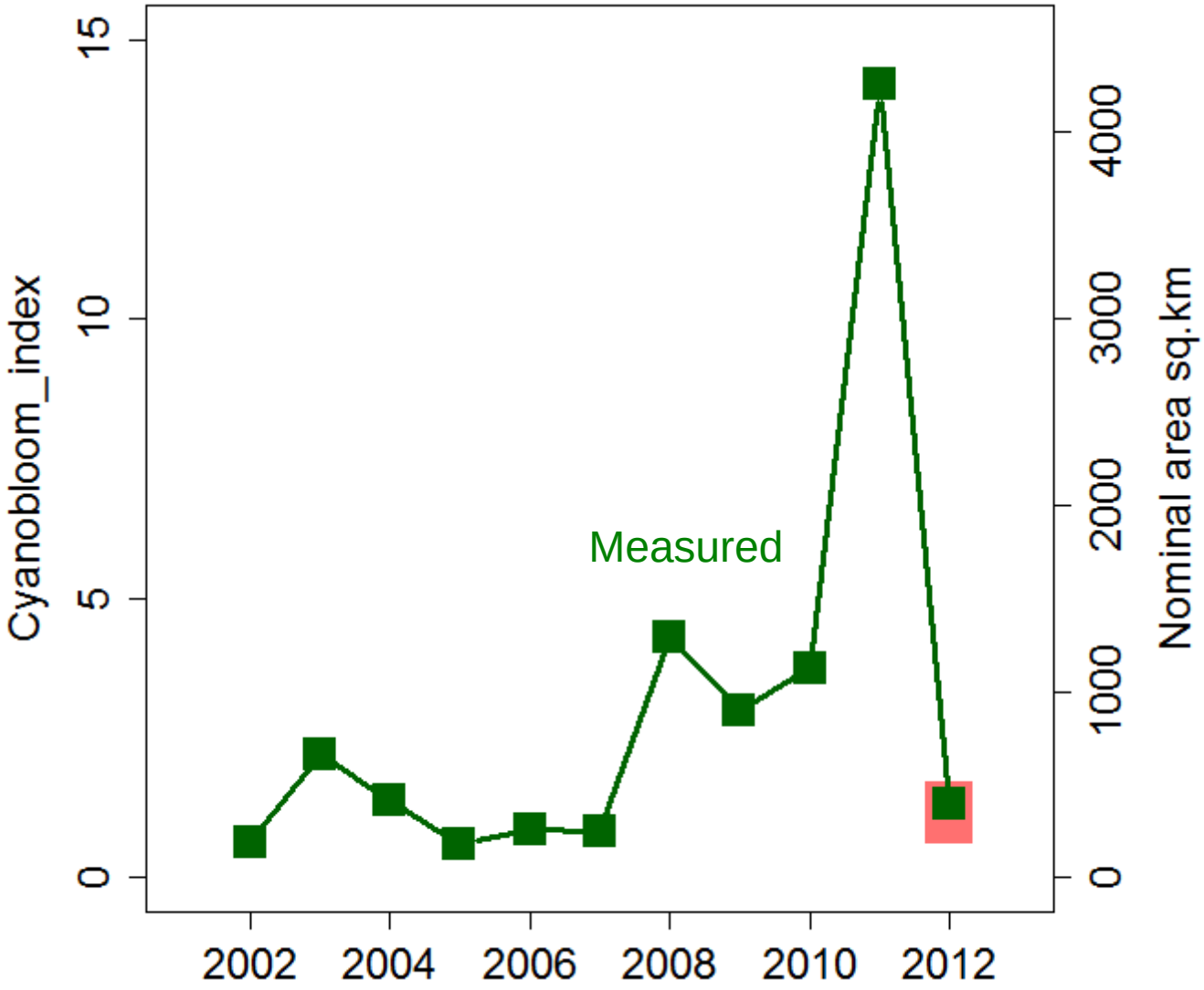


11 years of satellite data provide bloom extent

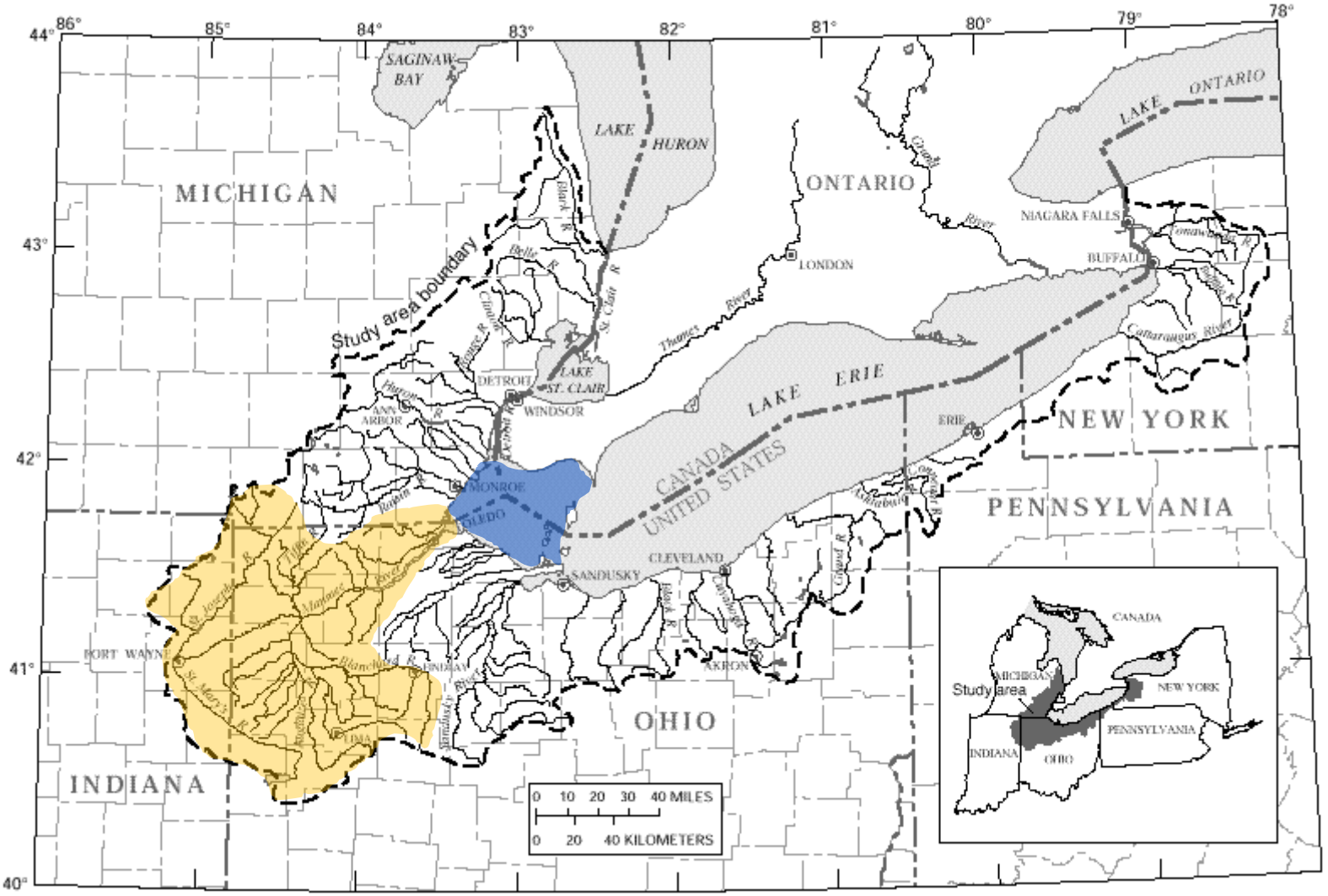


Data from
MERIS 2002-2011,
MODIS 2012

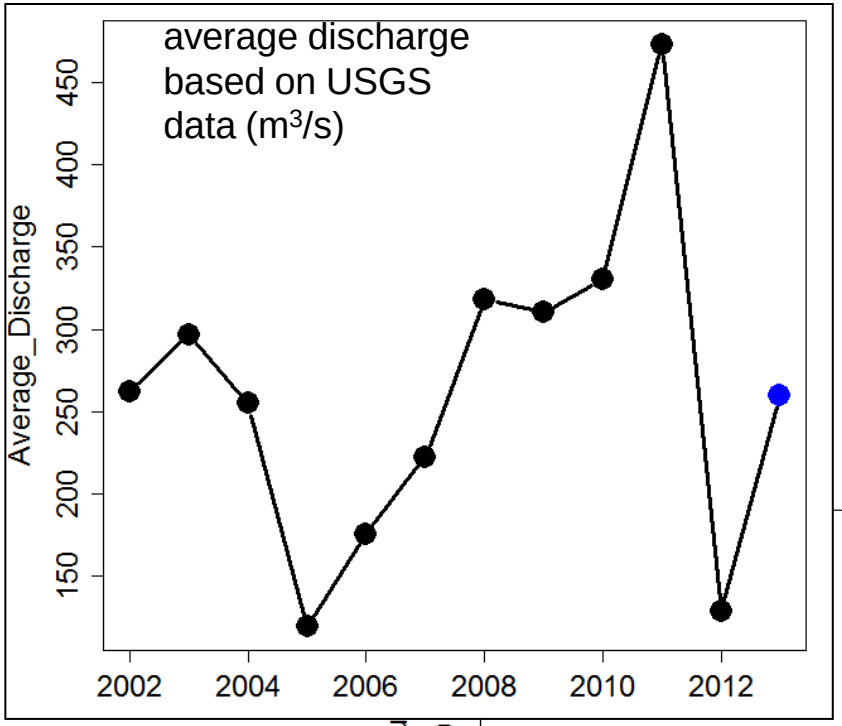
Quantify annual severity in Lake Erie. (Index is 10^{20} cells)

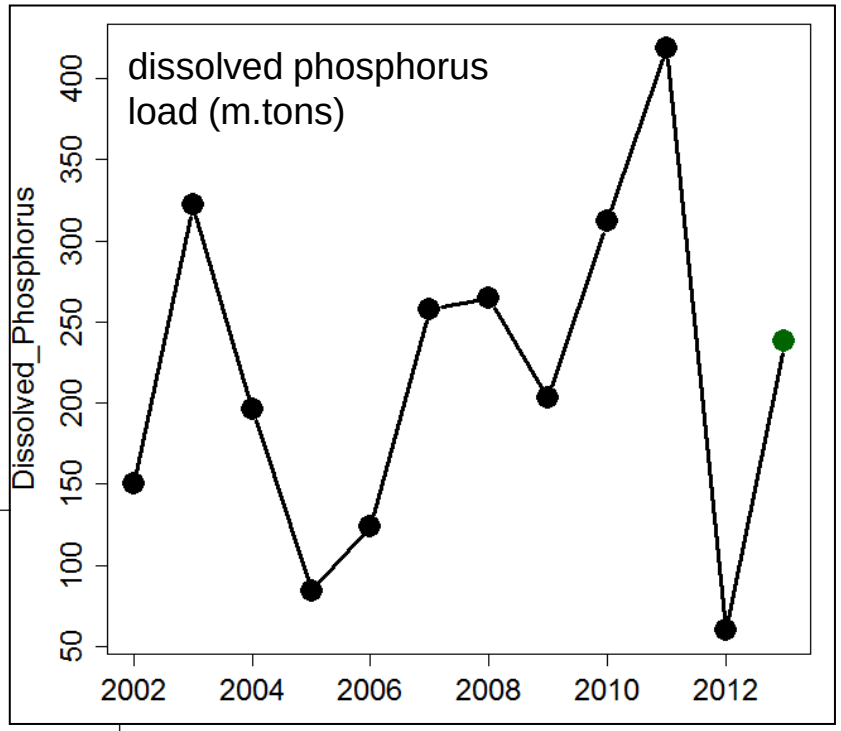


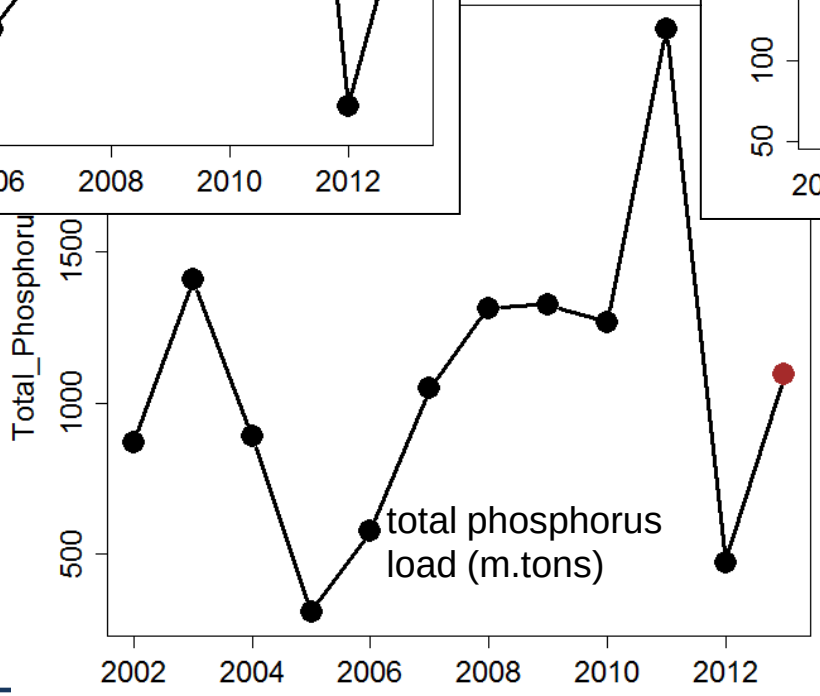
Use Maumee River Discharge to make seasonal predictions; largest tributary to Lake Erie.



2013: model uses Maumee River spring loads (2013 load falls between 2012 & 2011)



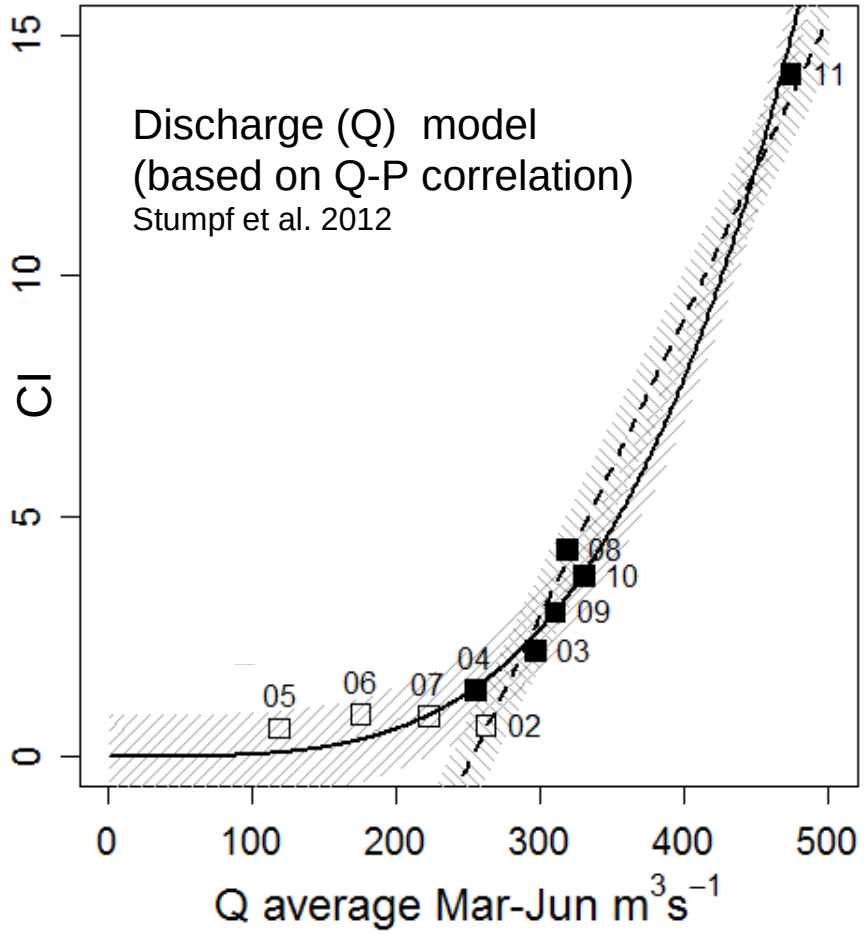


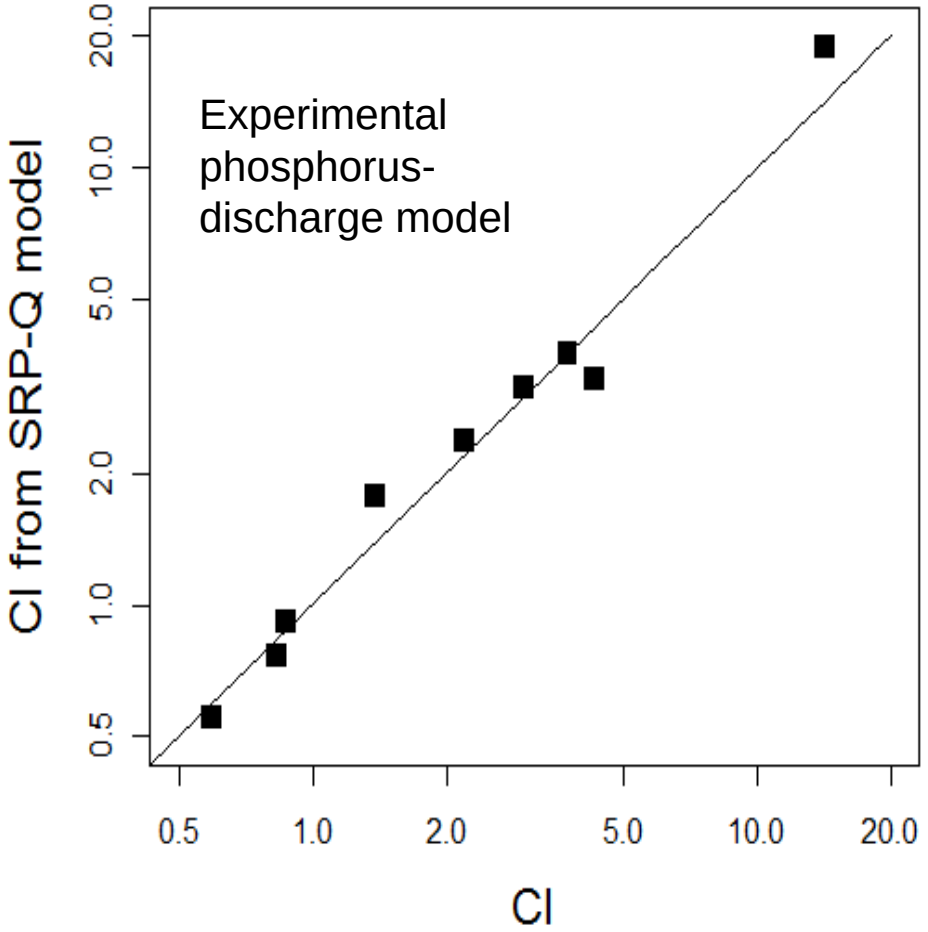


- Data from National Center for Water Quality Research

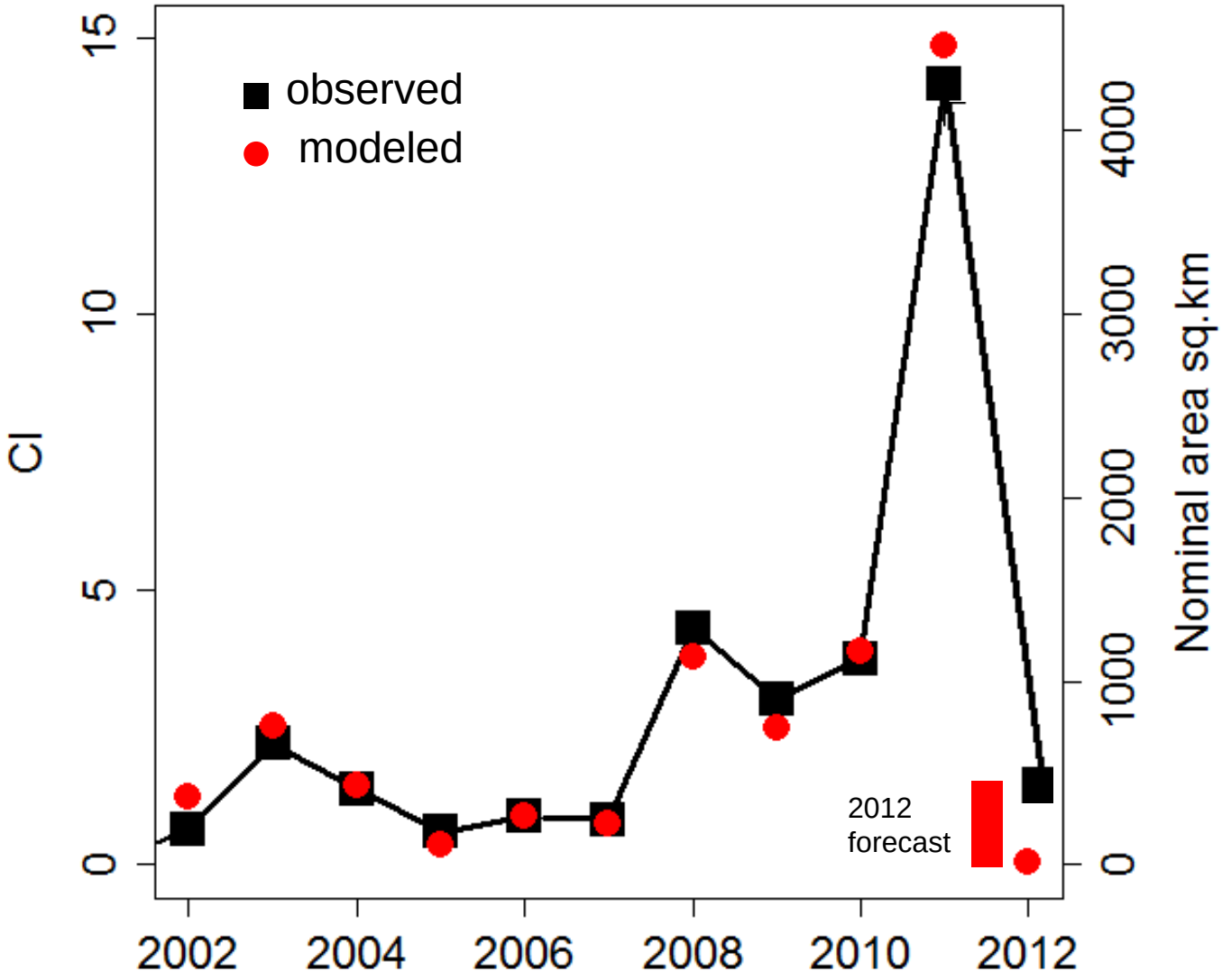
HEIDELBERG UNIVERSITY

We have a model that involves bloom severity and spring discharge & loads. See Stumpf et al., PLoSONE 2012





Observed against model (and 2012 forecast). Forecast model helps evaluate nutrient loading, rainfall impacts, ice, climate variation, etc.



What about monitoring?
If we build it*, will they come?

*If we figure out what “they”need and “it” is a useful and accurate product that meets that need.

If we do it right, we get busier because more people ask for more.

(If we don’t, we hear nothing.)

Current (2013) bulletin (700 subscribers)

To get bulletin, search for “NOAA Lake Erie bloom bulletin”

Transports with the NOAA Great Lakes Coastal Forecast System

Experimental Lake Erie Harmful Algal Bloom Bulletin

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

12 September 2013; Bulletin 19

The area of most intense bloom remains in the far western part of Lake Erie and Maumee Bay. Scum may be seen in pockets in the western basin near Maumee Bay.

Slight south-eastern transport is forecasted for the next few days. Winds tomorrow could exceed >15 knots, possibly mixing the bloom. Low winds (<8 knots) are expected over the weekend which could cause the bloom to intensify at the surface and produce patchy areas of scum.

- Dupuy, Stumpf

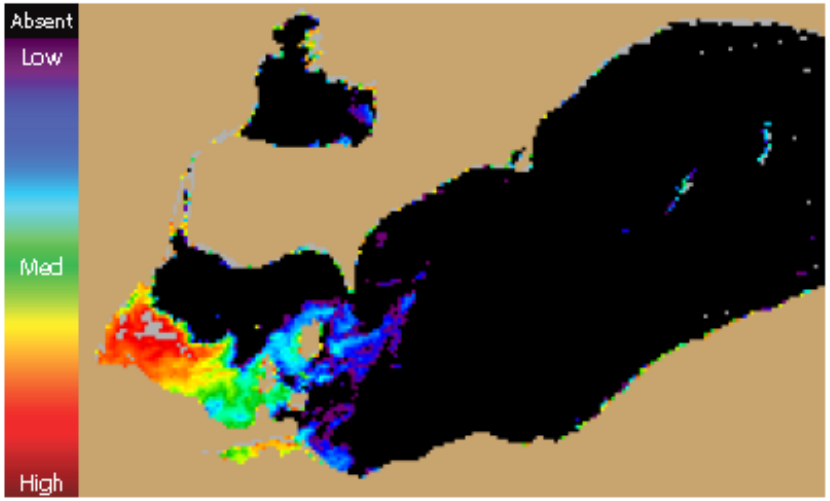


Figure 1. MODIS Cyanobacterial Index from 10 September 2013. Grey indicates clouds, or missing data. Black represents no cyanobacteria detected

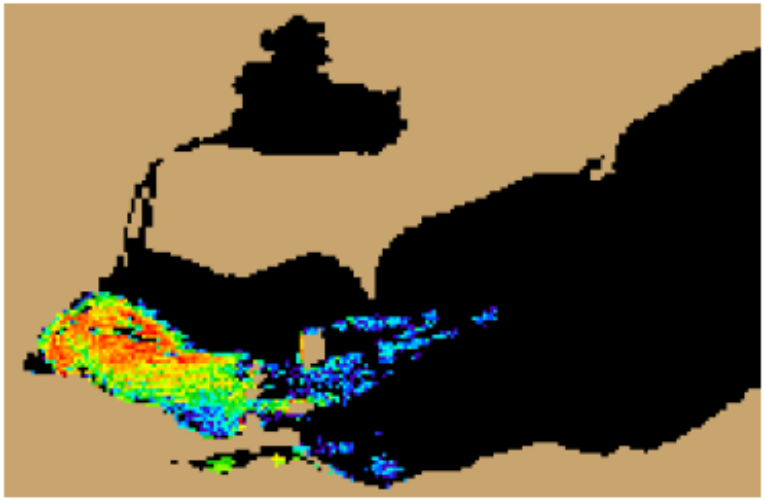
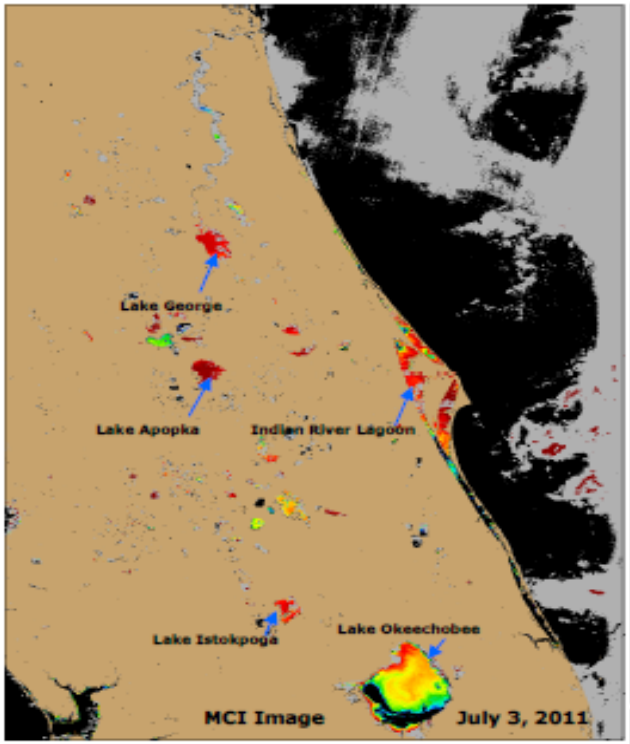


Figure 2. Nowcast position of bloom for 12 September 2013 using

Example: Satellite Health Bulletin

Experimental Cyanobacteria Bulletin: July 3, 2011

To report an illness related to a marine toxin or algal bloom please contact the FL Department of Health Aquatic Toxins Hotline at 1-888-232-8635.
For questions about the report: please contact Becky Lazensky, FL-DOH, at 352-955-1900. Images/data were obtained from Florida Water Management Districts, The National Oceanic and Atmospheric Administration (NOAA), NOAA National Climatic Data Centers and National Weather Centers. Support to produce this report was received through a NOAA/NASA Agreement (Number: NNH08ZDA001N)



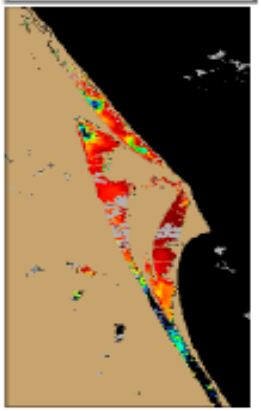
The MERIS Satellite Images above display a cyanobacteria index generated with a Medium Resolution Imaging Spectrometer (MERIS) satellite provided by the European Space Agency & NOAA.

- Very low likelihood of a bloom.
- May indicate clouds or missing data.
- Low cyanobacteria concentrations.
- Medium cyanobacteria concentrations.
- Probable bloom or higher cyanobacteria concentrations.

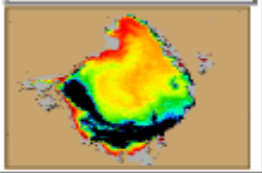
Conditions Report: July 3, 2011

- Cyanobacteria estimates were remarkably elevated in several lakes, including an ongoing detection in Lake George, Lake Apopka, Lake Istokpoga, and Lake Okeechobee.
- The Indian River Lagoon has recently begun showing an increase in estimated cyanobacteria concentrations.
- An ongoing bloom has been reported in the Caloosahatchee River (Lee County). Lake Okeechobee (photo on right) supplies water to the Caloosahatchee.

Indian River Lagoon



Lake Okeechobee



Recent Blooms

Caloosahatchee River
June 22
Photo by FL DEP

Coordinates: 26.7123, -81.6098
City: LaBelle
Confirmed Species: Anabaena flosaquae
Limnothrix, Pseudanabaena cf minima
Sample Collection Date: June 2, 2011
Bloom continuing as of June 22, 2011

St Johns River Field Brief
By: Robert Burks, St Johns River Water Management District, June 20-23

Surface Water quality: Lower Basin river continues to show high salinities through Hibernia Point (near Black Creek)

Weather/Rainfall: Hot and humid. Well above average day temps (+47F for week) and night (+ 16F for week). Rainfall at 1.21 inches on 6/17, and 1.78 inches for 6/23

Algal/HAB: No bloom or scum formations observed from Astor to Mayport, with the exception of some filamentous formations near shore at Black Creek on 6/22. HAB species were identified in samples from Doctors Lake, Mandarin Pt, & Plummers Cove

For a full report:
Email Robert Burks
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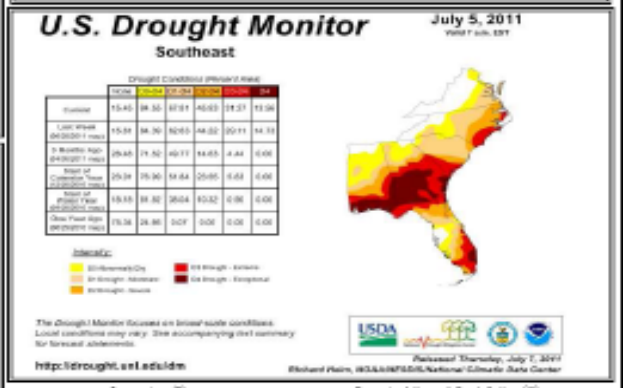

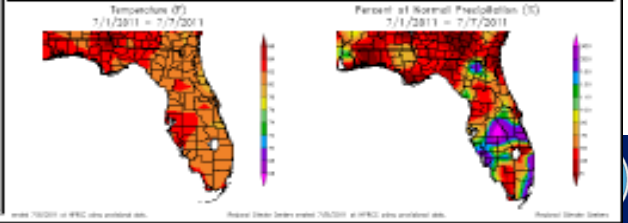

Where are we with satellite

- All sensors have limitations (time, space, spectra)
- All satellites can find turbidity and scum (although not shown here)
- Algorithms are hard and imperfect, adding ecology allows doing more with what is available (we've done this with MODIS)
- We can quantify dense blooms, and find cyanobacteria blooms with MERIS
- We can find
  - the start of blooms
  - Extent of blooms
  - Monitor
  - Look at trends, compare lakes
  - Develop climatologies
  - Examine models of causes
- The future is OLCI on Sentinel-3 (2015)

The lessons we've learned over many years

1. Just because we have a product that we like doesn't mean it addresses what a manager needs.

2. If we ask managers what they **want**, their response will sound like Star Trek. This is not the same as what they **need**. (is toxins measured in every every pond every day, with drones deploying advisory signs a want or a need?).

3. Managers know what meets their needs when they see it, but not before.

4. The best way to find out what managers need is to observe their work. Managers are friendly (usually).

5. It's easier and more fun to make an algorithm that doesn't solve a manager problem than to make one that does. Hard work, however, is far more productive, useful, and rewarding.

6. Most managers are really polite when they are not going to use a satellite product

7. Managers usually have very little time, too few people, and no money. If they offer any of these, they want the product—or at least think it may be useful.

Address

Web search for NOAA Lake Erie Bulletin

or

http://www.glerl.noaa.gov/res/Centers/HABS/lake_erie_hab/lake_erie_hab.html

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