

Monitoring and Forecasting Cyanobacterial Blooms for Public Health Protection and Response

NASA - Decision Support through Earth Science
NNH08ZDA001N-Decisions

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Sonia Joseph-Joshi, Michigan Sea Grant and Center of Excellence for Great Lakes and Human Health

Juli Dyble-Bressie, NOAA Great Lakes Environmental Research Lab

Lorrie Backer, Centers for Disease Control, Environmental Health

Team

NOAA/NOS Center for Coastal Monitoring and Assessment: *Rick Stumpf, Tim Wynne, Shelly Tomlinson*

Overall project coordination, satellite remote sensing for detection of cyanobacteria, forecast system development, overseeing the transition of research capabilities into operations and skill assessment

Center of Excellence for Great Lakes and Human Health (and Sea Grant): *Sonia Joseph*

Leads the education and outreach component in the Great Lakes

NOAA Great Lakes Environmental Research Lab : *Juli Dyble-Bressie*
Evaluate the ecological models for detection and forecasts and assist in field data collection

Florida Department of Health: *Andrew Reich, Becky Lazensky*
Leads user interaction in Florida and develop plans that integrate the forecasts into response systems, and aid in identifying appropriate products

Center for Disease Control and Prevention: *Lorraine Backer*
To incorporate products into the HAB Illness Surveillance System (HABISS) to make them available to the user community

Goals of Project

Help managers with public health and safety

Reduce cost of impact

Educate the public

Reduce impacts to the public

Establish procedures for routine support and for an operational capability

Cyanobacterial blooms



In waters used for drinking, fishing, recreation

Why worry about cyano HABs?

- ❖ Degrades water quality
 - ❖ Taste/odor issues
 - ❖ Loss of recreational and fishing value to affected waters
 - ❖ Hypoxia/anoxia, may lead to mortality in benthic invertebrate community and fish kills
- ❖ Alters food webs
 - ❖ Unpalatable to many zooplankton grazers
- ❖ Toxin producer
(neurotoxins, hepatotoxins, dermatotoxins)
 - Toxic to zooplankton, shellfish, fish, animals, humans

Dogs have been known to die of renal failure within hours of drinking water with microcystins.

Exposure to toxic cyanobacteria.....



Boating/ recreation



Drinking water reservoirs



Bioaccumulation

Algae supplement
is latest 'miracle'

SPIRULINA
Green Superfood For Life



Health food supplements

Microcystis in the Great Lakes



**Lake Erie, Put-In-Bay,
Sept 2006**



**Lake Erie, South Bass Island,
Sept 2006**

Great Lakes as an aquatic resource

- ❖ Largest supply of freshwater in the world
 - ◆ 80% of US freshwater supply
 - ◆ Drinking water supply for 40 million US and Canadian citizens
 - ◆ Used extensively for recreation



Microcystin

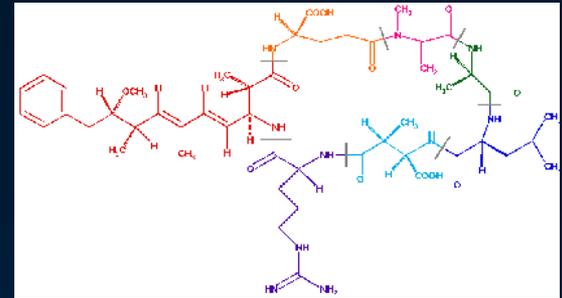
❖ Hepatotoxin

❖ Health effects

- Animal mortality: livestock, wildlife, birds, pets
- Human illness:
 - ❖ gastrointestinal illness (nausea, diarrhea, cramps)
 - ❖ eye and skin irritation
 - ❖ Liver damage (chronic exposure)

❖ WHO recommended exposure limits

- 20 $\mu\text{g}/\text{L}$ – recreational exposure
- 1 $\mu\text{g}/\text{L}$ – drinking water
- EPA has not developed an equivalent standard in this country





**Experimental
Lake Erie Harmful Algal Bloom Bulletin**
2011-007
22 July 2011
National Ocean Service
Great Lakes Environmental Research Laboratory
Last bulletin: 14 July 2011

Conditions: There appears to be a bloom of cyanobacteria in western Lake Erie. The bloom has not been validated with in situ sampling.

Analysis: This image is from Saturday. The wind stress has been low and water temperature has been high so the bloom is most likely still at the surface and conditions are favorable to gain biomass. Forecast transport shows a slight NE movement.

-Wynne

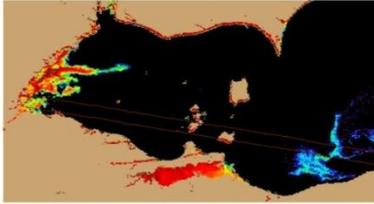


Figure 1. MERIS image from the European Space Agency. Imagery shows the spectral shape at 681 nm from July 16, where colored pixels indicate the likelihood of the last known position of the *Microcystis* spp. bloom (with red being the highest concentration). *Microcystis* spp. abundance data from shown as white squares (very high), circles (high), diamonds (medium), triangles (low), + (very low) and X (not present).

Successfully identified intensifying *Microcystis* bloom and initiated bloom sampling; Impacting Michigan coastline, toxins >1000 ug/L in late July (50x higher than moderate recreational risk)



Figure 2. Nowcast position of *Microcystis* spp. bloom for July 22 using GLCFS modeled currents to move the bloom from the July 16 image.



Figure 3. Forecast position of *Microcystis* spp. for July 25 using GLCFS modeled currents to move the bloom from July 16 image.

Please note:

- MERIS imagery was distributed by the NOAA CoastWatch Program and provided by the European Space Agency
- http://www.glerl.noaa.gov/res/Centers/HABS/lake_erie_hab/lake_erie_hab.html
- Cell counts were collected by the Great Lakes Environmental Research Laboratory
- The wind data is available through the National Data Buoy Center and the National Weather Service
- Modeled currents were provided through the Great Lakes Coastal Forecasting System



22 July 2011, western Lake Erie



West Lake Erie again fighting bloom of algae – Toledo Blade 8/7/2011

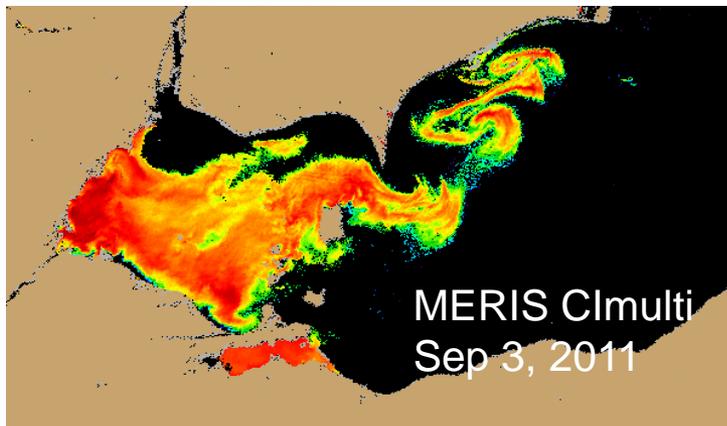


Figure 1. MERIS image from the European Space Agency. Imagery shows the spectral shape at 681 nm from August 28, where colored pixels indicate the likelihood of the last known position of the *Microcystis* spp. bloom (with red being the highest concentration). *Microcystis* spp. abundance data from shown as white squares (very high), circles (high), diamonds (medium), triangles (low), + (very low) and X (not present). Please note: Colored pixels in Sandusky Bay are due to a mixed bloom dominated by *Planktothrix* spp.

Conditions: A confirmed *Microcystis* bloom persists in Western Lake Erie.

Analysis: The large *Microcystis* bloom continues in Western Lake Erie. Imagery is from August 28 and due to a large cloud present the models do not show the potential full extent of the bloom. Wind conditions and high temperatures are conducive for bloom intensification.

-Neff, Briggs

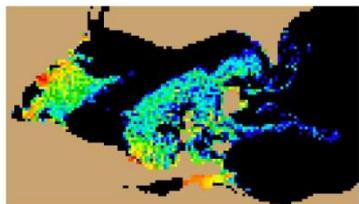
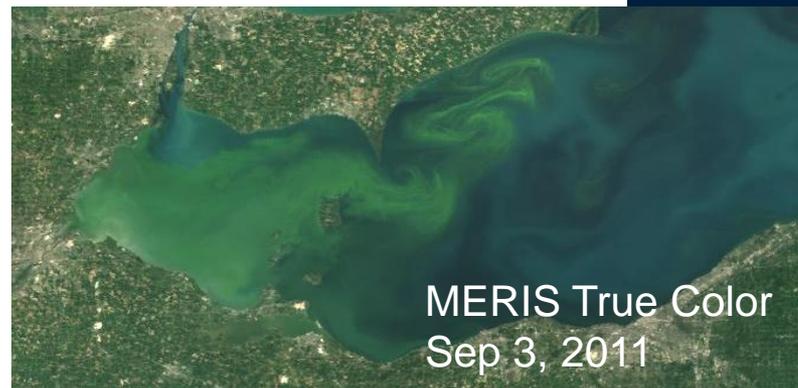


Figure 2. Nowcast position of *Microcystis* spp. bloom for September 01 using GLCFS modeled currents to move the bloom from the August 28 image. Please note: Colored pixels in Sandusky Bay are due to a mixed bloom dominated by *Planktothrix* spp.

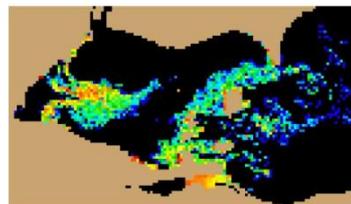


Figure 3. Forecast position of *Microcystis* spp. for September 04 using GLCFS modeled currents to move the bloom from August 28 image. Please note: Colored pixels in Sandusky Bay are due to a mixed bloom dominated by *Planktothrix* spp.

Please note:

- MERIS imagery was distributed by the NOAA CoastWatch Program and provided by the European Space Agency
- Cell counts were collected by the Great Lakes Environmental Research Laboratory
- The wind data is available through the National Data Buoy Center and the National Weather Service
- Modeled currents were provided through the Great Lakes Coastal Forecasting System

Forecast on 9/8/2011



Experimental Lake Erie Harmful Algal Bloom Bulletin

2011-014

08 September 2011

National Ocean Service

Great Lakes Environmental Research Laboratory

Last bulletin: 01 September 2011

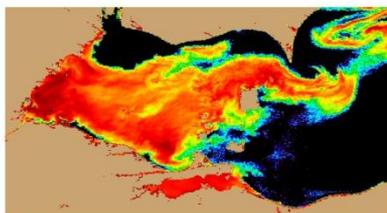


Figure 1. MERIS image from the European Space Agency. Imagery shows the spectral shape at 681 nm from September 03, where colored pixels indicate the likelihood of the last known position of the *Microcystis* spp. bloom (with red being the highest concentration). *Microcystis* spp. abundance data from shown as white squares (very high), circles (high), diamonds (medium), triangles (low), + (very low) and X (not present).

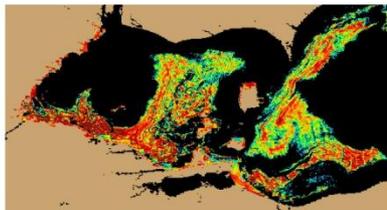


Figure 2. Nowcast position of *Microcystis* spp. bloom for September 08 using GLCFS modeled currents to move the bloom from the September 03 image.

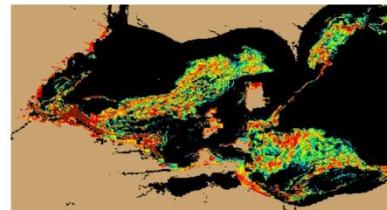


Figure 3. Forecast position of *Microcystis* spp. for September 11 using GLCFS modeled currents to move the bloom from September 03 image.

Conditions: A massive *Microcystis* bloom persists throughout most of Lake Erie's Western Basin.

Analysis: As indicated in satellite imagery from Saturday (9/3/2011), an enormous *Microcystis* bloom was present in western Lake Erie. The southern extent of the bloom was remotely observed along the coast of Ohio from Maumee Bay to Catawba Island. The northern extent of the bloom was observed to be consistent along the Michigan coast from Northern Maumee Bay to the mouth of the Detroit River. The eastern-most portion of the bloom was observed past Point Pelee and to the northeast up in to Rondeau Provincial Park.

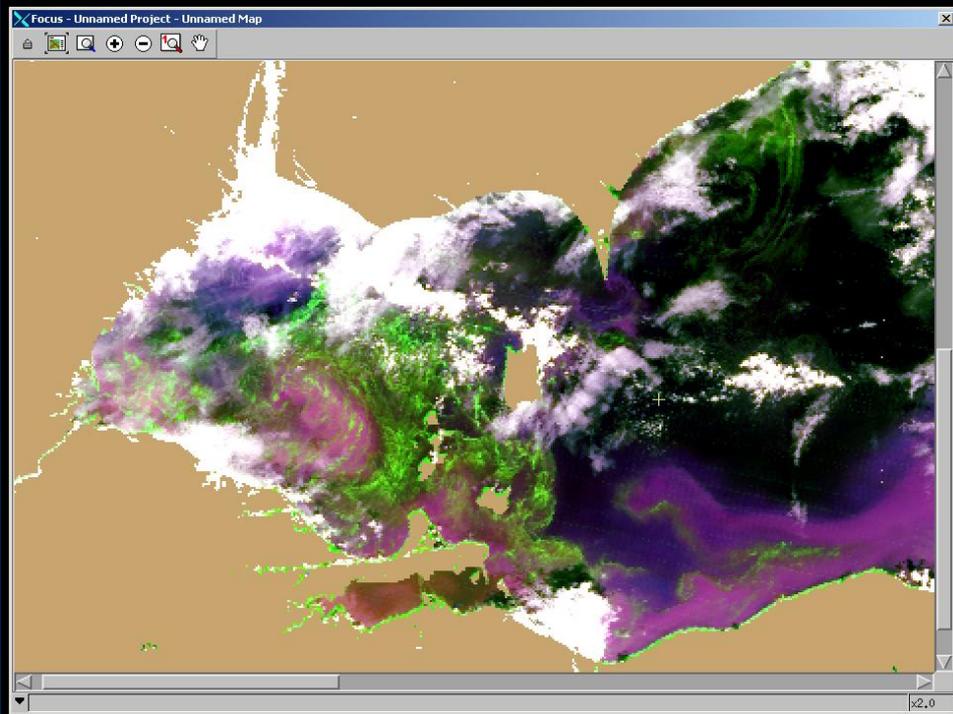
At the mouth of the Detroit River, a five day nowcast shows a southward suppression of the western-most portions of the bloom. However, the bloom is likely to still persist in much of the Western Basin. The nowcast also suggest the bloom has spread to the east of Sandusky and into the Cleveland area. **(Note: Due to a lack of clear imagery the bloom has not been remotely observed in the Cleveland area.)** A three day forecast also suggests that the bloom will persist to the north of Cleveland through the weekend. Water temperatures remain above 20 degrees Celsius and are forecast to decrease into the weekend; however, conditions remain favorable for bloom growth.

Briggs, Wynne

Please note:

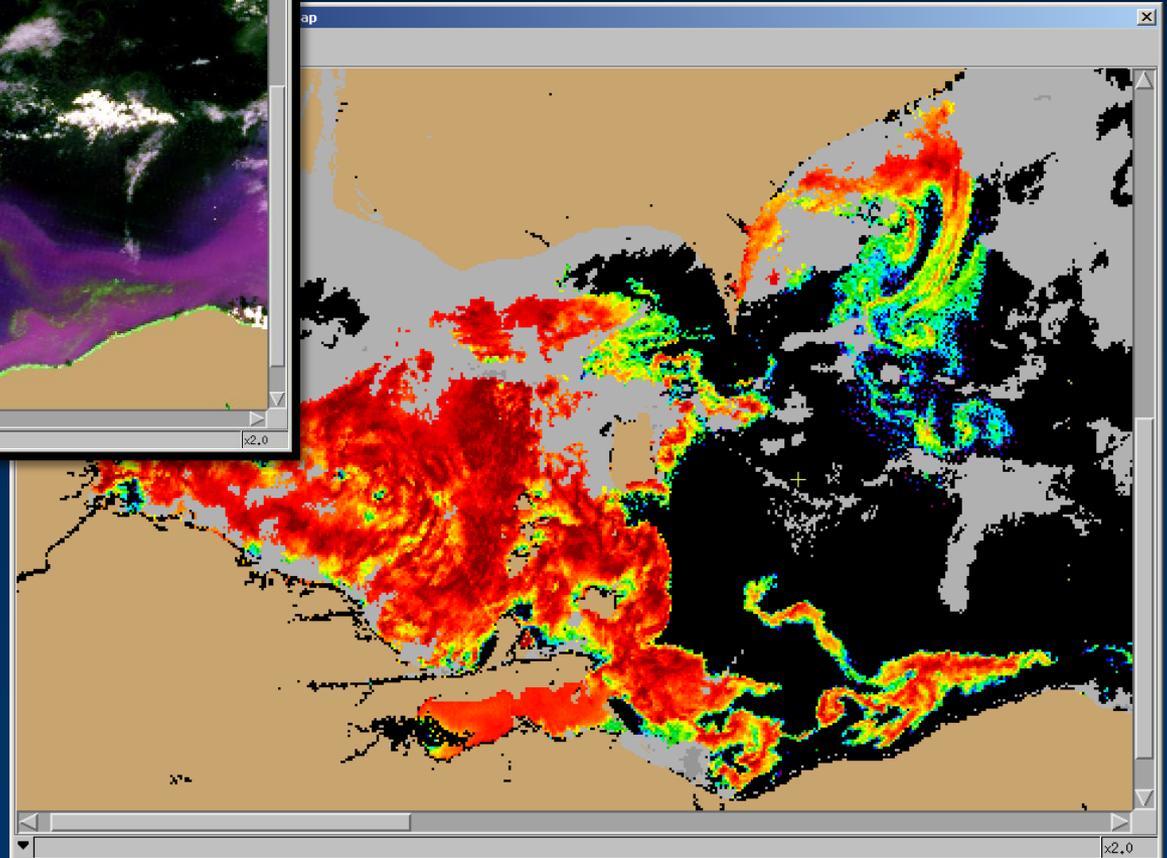
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- Cell counts were collected by the Great Lakes Environmental Research Laboratory
- The wind data is available through the National Data Buoy Center and the National Weather Service
- Modeled currents were provided through the Great Lakes Coastal Forecasting System

Sep 11 images confirm southeastern expansion



MODIS Terra image
False color showing scum in green

MERIS CImulti showing
extent of bloom



Media hits

GREAT LAKES ECHO

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Satellite system warns swimmers, treatment plants of harmful algae

JUL 12 2011 SHAHEEN KANTHAWALA 3 COMMENTS

Satellite images of Lake Erie sent right to your inbox can warn you about harmful algae in the lake before you decide to visit.

People can sign up for the emailed bulletin that was developed at the Center of Excellence for Great Lakes in Human Health at the National Oceanic and Atmospheric Administration.

They'll learn where waves, winds and currents are expected to move algal blooms, said Sonia Joseph Joshi, Sea Grant extension outreach coordinator at the Center of Excellence for Great Lakes in Human Health at the National Oceanic and Atmospheric



Satellite images of Lake Erie on June 07, 2011, from MERIS - the European Space Agency. The different colors show the likelihood of the last known position of the Microcystis bloom (where red- highest, white squares -very high, circles -high, diamonds -medium, triangles -low, + -very low and X -not present). Image: National Oceanic and Atmospheric Administration.

PortClinton NewsHerald.com

Algae makes its way to Kelleys Island

Aug 27, 2011

KELLEYS ISLAND --The Kelleys Island State Park's public beach includes a posted warning about the algae bloom that has made its way to the island's north side.

"They are a blue-green algae, and we call them harmful algae blooms because they produce a toxin called microcystin," said Sonia Joseph-Joshi, outreach coordinator for the National Oceanic and Atmospheric Administration's Center of Excellence for Great Lakes and Human Health.

In Asia and South America, she said, the toxins in blue-green algae have caused deaths after being ingested.

At an Ohio Lake Erie Commission meeting in June, researchers predicted a thicker, longer-lasting algal bloom than seen in past years, because of heavier than normal rains. Those rains are blamed for transporting high levels of fertilizer and phosphorous from agricultural fields into small streams and, eventually, into Lake Erie.

"There are three major rivers," Joseph-Joshi said, "the Maumee, Detroit and Sandusky, and they all converge in western Lake Erie."

According to researchers, those rivers and others are pouring tens of thousands of tons of nutrients into the lake each year, feeding the algae blooms.

Mike Libben, a technician with the Ottawa Soil and Water Conservation District, said his organization works hard to educate and help change the habits of people who work in agriculture.

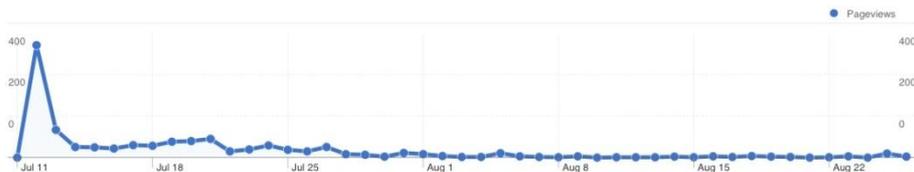
greatlakesecho.org

Content Detail:

/2011/07/12/satellite-system-warns-swimmers-treatment-plants-of-harmful-algae/

Jul 11, 2011 - Aug 26, 2011

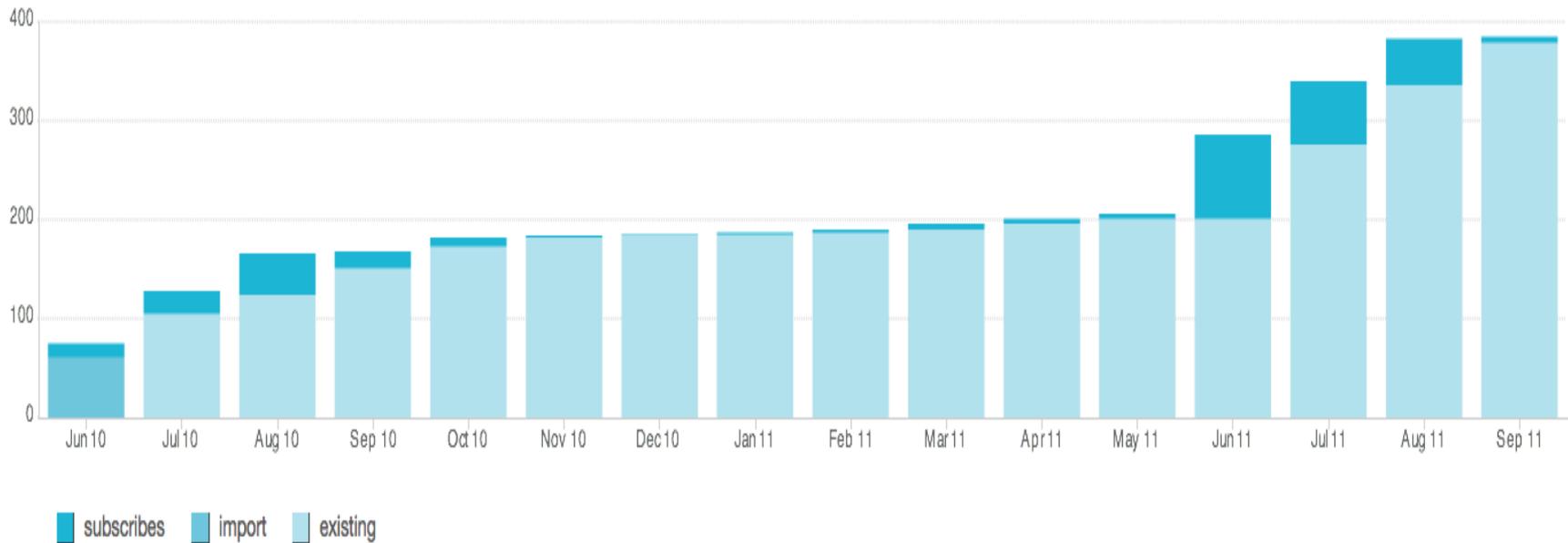
Comparing to: Site



This page was visited 1,079 times via 54 regions

Bulletin Subscriber Growth

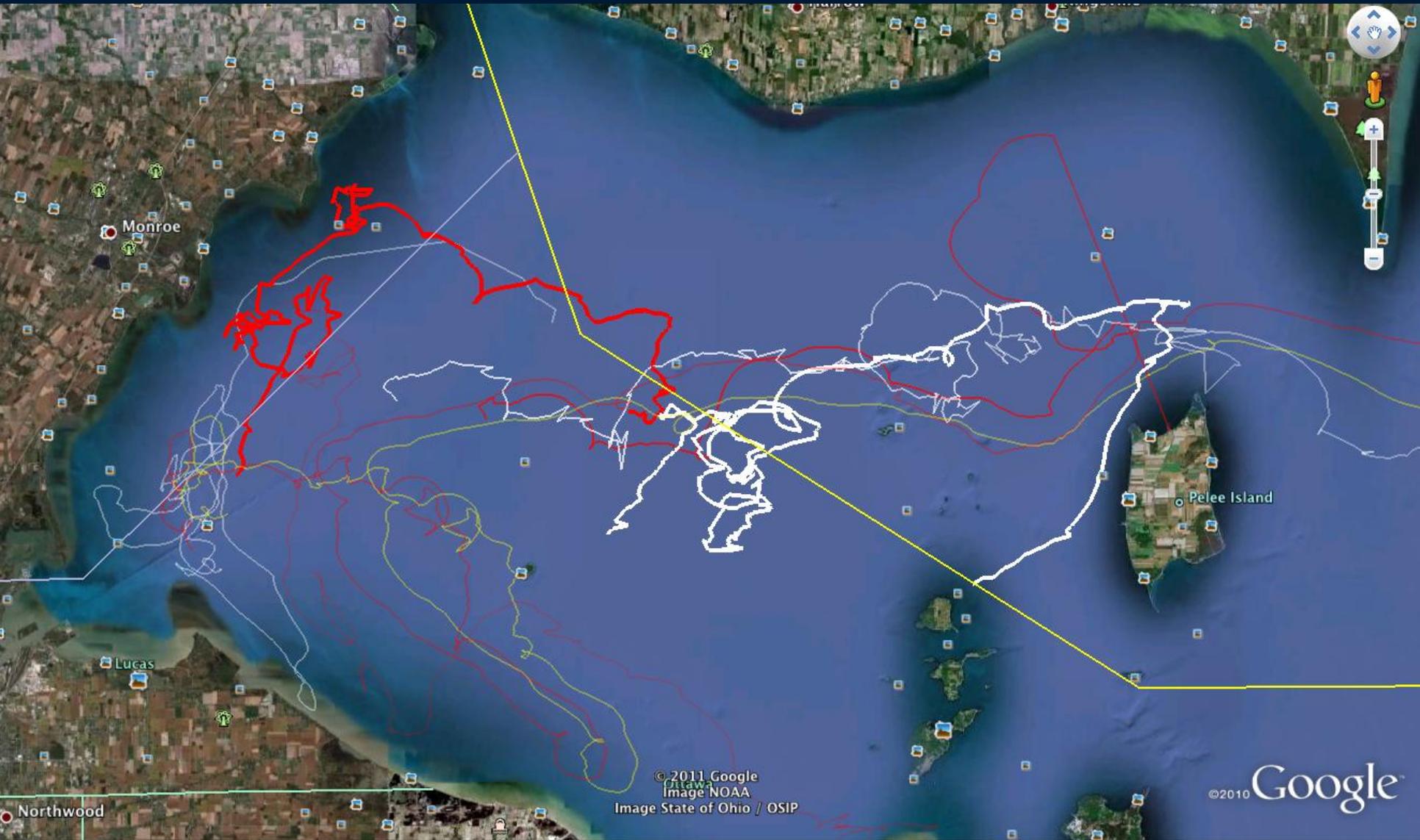
List Growth



Lake Erie HAB Bulletin List

- Subscribers range from Canada, Wisconsin, to California and Washington, even Germany
- Ohio municipal drinking water managers use Bulletin to determine treatment strategies.
- Working with Michigan to determine when and how to post advisories at beaches for 2012
- Released drifters on two occasions (July and August) in the summer
 - Tracking drifter movement and transferring information to Google Earth

Lake Erie HAB Drifter Tracks



© 2011 Google
Image NOAA
Image State of Ohio / OSIP

© 2010 Google

Field sampling

- ❖ 2011 sampling
 - ❖ Monthly and event response
 - ❖ Stations throughout western Lake Erie, including drinking water intakes
- ❖ Samples collected
 - ❖ Cell counts – major HAB species
 - ❖ Microcystin
 - ❖ Phycocyanin (pigment indicator of cyanobacterial HABs)
 - comparing PC fluorescence sensor and extracted PC
 - ❖ Chlorophyll a, Secchi depth, CDOM

Florida Department of Health (FDOH) Aquatic Toxins Disease Prevention Program

Satellite Health Bulletin

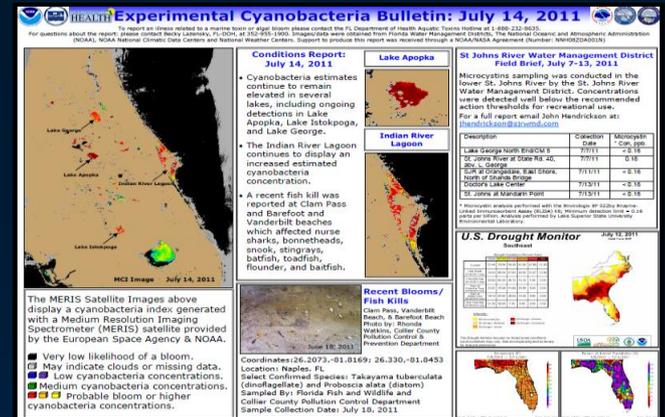
Becky Lazensky, MPH

Andrew Reich, MS, MSPH

- FDOH developed a satellite health bulletin to disseminate satellite imagery data and interpretation to users on a routine basis
- Bulletins contain MERIS satellite images with interpretation, a section on recent algae blooms, a HABs and health section, and field observations
- Reports are produced on a bi-weekly basis when MERIS satellite images are available



Satellite Health Bulletins



The bulletin's distribution list includes these state and local agencies:

- FDOH -FL-DEP
- CHDs -SJRWMD

A total of 57 persons currently receive the satellite health bulletin

4 bulletins have been distributed so far

Example: Satellite Health Bulletin

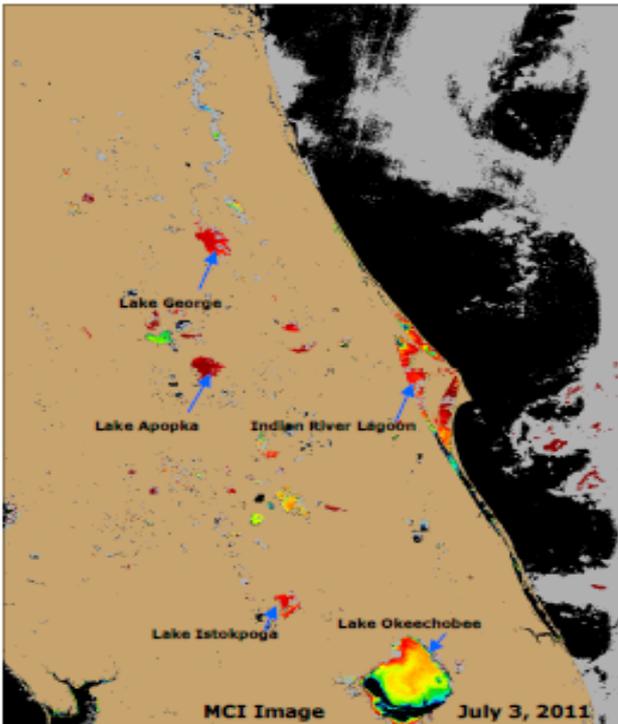


Experimental Cyanobacteria Bulletin: July 3, 2011



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.

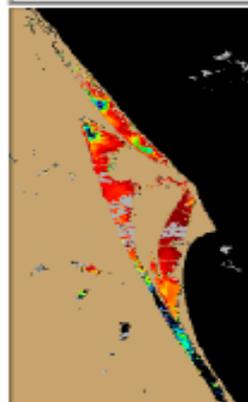
For questions about the report: please contact Becky Lazensky, FL-DOH, at 352-955-1900. Images/data were obtained from Florida Water Management Districts, The National Oceanic and Atmospheric Administration (NOAA), NOAA National Climatic Data Centers and National Weather Centers. Support to produce this report was received through a NOAA/NASA Agreement (Number: NNN082DA001N)



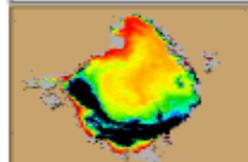
Conditions Report: July 3, 2011

- 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



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
rburks@sinwmd.com



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.



Recent Blooms

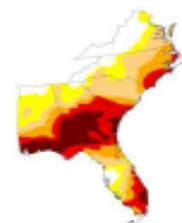
**Caloosahatchee River
June 22
Photo by FL DEP**

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

U.S. Drought Monitor Southeast

July 5, 2011
V007 F.000.001

Station	Drought Conditions (Percent Area)					
	Very Dry	Dry	Mod. Dry	Wet	Very Wet	Ext. Wet
Atlanta	15.00	84.00	0.00	0.00	0.00	0.00
Charlotte	15.00	84.00	0.00	0.00	0.00	0.00
Dallas	15.00	84.00	0.00	0.00	0.00	0.00
Denver	15.00	84.00	0.00	0.00	0.00	0.00
Houston	15.00	84.00	0.00	0.00	0.00	0.00
Los Angeles	15.00	84.00	0.00	0.00	0.00	0.00
Miami	15.00	84.00	0.00	0.00	0.00	0.00
Minneapolis	15.00	84.00	0.00	0.00	0.00	0.00
New York	15.00	84.00	0.00	0.00	0.00	0.00
San Francisco	15.00	84.00	0.00	0.00	0.00	0.00

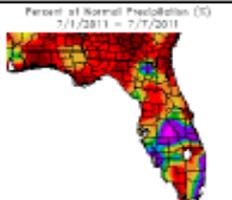
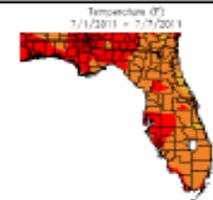


Legend:
 ■ Very Dry (Yellow)
 ■ Dry (Orange)
 ■ Moderate Dry (Red)
 ■ Wet (Green)
 ■ Very Wet (Dark Green)
 ■ Extreme Wet (Blue)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text for more information.

<http://drought.unl.edu/dm>

Released Thursday, July 7, 2011
Richard Peters, NOAA/NCEP/National Climatic Data Center



Satellite Imagery Guide for CHDs

A user guide on how data can be applied to public health practice was developed

Examples of possible uses:

- Epidemiologists can include water sites with high a cyanobacteria index when interviewing ill persons about their recent recreational water exposures
- Environmental Health programs may rely upon satellite imagery data when deciding where to conduct field assessments of public swimming areas
- State and local agencies can use imagery to target sampling and educational health interventions

Applications of Satellite Imagery Data

- Informing Public Health Investigations
- Increasing Surveillance
- Identifying Toxin Producing Blooms
- Targeting Sampling Efforts
- Protecting Public Drinking Water

Cyanobacteria Satellite Imagery Uses for County Health Departments

1. **Provides Increased Situational Awareness:** Satellite imagery can provide County Health Departments (CHDs) with a picture of environmental conditions in their county and a view of what is happening statewide. This information can serve as part of an early-warning system to notify counties when conditions are favorable for bloom formation and provides valuable time to prepare education and risk communications materials and inform key stakeholders. Satellite information may be useful during large-scale event planning such as before holidays or events that include recreational water activities to allow for early precautionary measures to be taken like testing the water body before the event.

2. **Informing Public Health Investigations:** Satellite bloom detection will allow CHDs to make important linkages between health complaints in their community and specific health threats. When they know locations of ongoing blooms, CHDs are better equipped to associate illnesses with cyanobacteria exposures. Identifying areas with active algae blooms encourages epidemiologists to inquire whether symptomatic persons swam in the affected water source. While some blooms are considered nuisance blooms, others can cause respiratory, gastrointestinal, and neurological symptoms within a short time following an exposure.

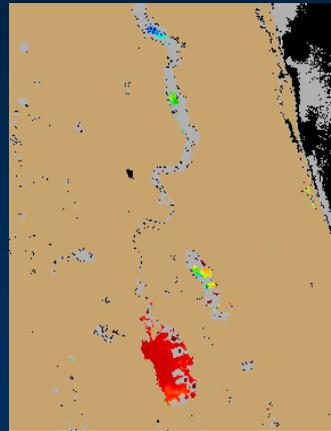
3. **Increasing Surveillance Efforts:** CHDs may share details of recent cyanobacteria blooms with local healthcare providers to improve case finding. When blooms are associated with health effects, CHDs often increase surveillance efforts to identify additional illnesses and implement response activities aimed at reducing health impacts.

4. **Identifying Toxic Blooms by Targeting Sampling Activities:** Satellite imagery can assist in identifying areas which are at an increased risk of cyanobacteria blooms and guide field sampling efforts more effectively. Blooms can then be assessed for toxins which pose a threat to human and animal health. Environmental Health programs can rely upon imagery to provide timely oversight of public swimming areas. Field assessments of permitted freshwater bathing sites can be done when satellite imagery indicates there may be high cyanobacteria concentrations. Collaboration between CHDs and partner agencies such as the Florida Fish and Wildlife Conservation Commission, Florida's five Water Management Districts, and the Department of Environmental Protection) encourages using the appropriate agency's resources to test whether blooms are composed of toxin-producing algal species.

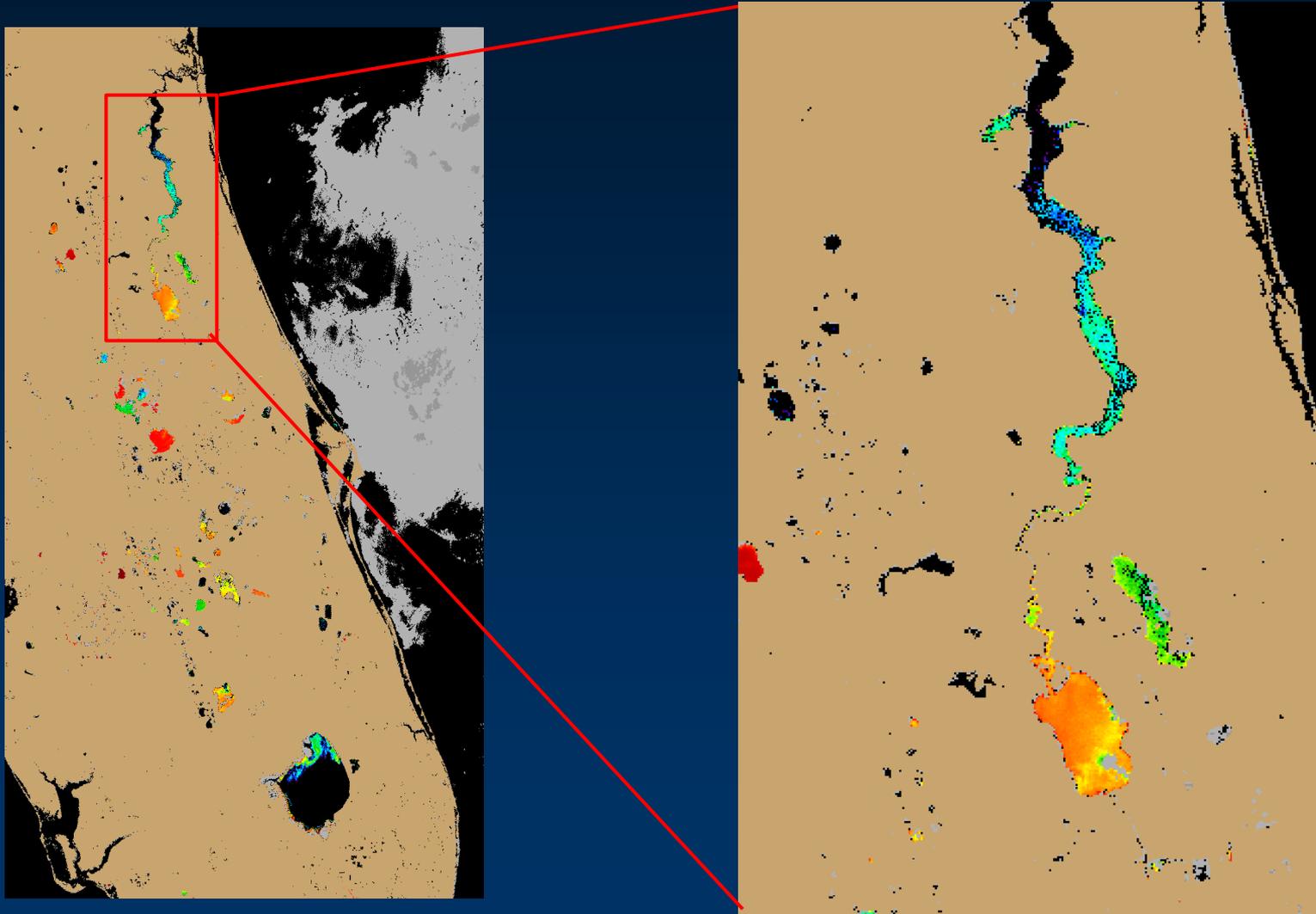
5. **Protecting Public Drinking Water:** Surface water treatment facilities can use satellite imagery as a mechanism to identify blooms that have the potential to affect their source water. The imagery, together with NOAA predictive modeling, provides water facilities time to develop contingency plans for alternate sources of potable water. This would reduce the likelihood that cyanotoxins will enter the public drinking water supply.

Partnering with the St Johns River Water Management District

- ◆ In 2011-NOAA conducted 2 radiometer trainings w/6 SJRWMD and 1 FDOH scientist in March and June
- ◆ Radiometer data were collected from the St Johns River, Lake Apopka, Newnans Lake, Bivens Lake, Lake George, & Crescent Lake
- ◆ *Microcystis* blooms indicated in NOAA satellite imagery were confirmed by local sampling efforts in Crescent & George Lakes

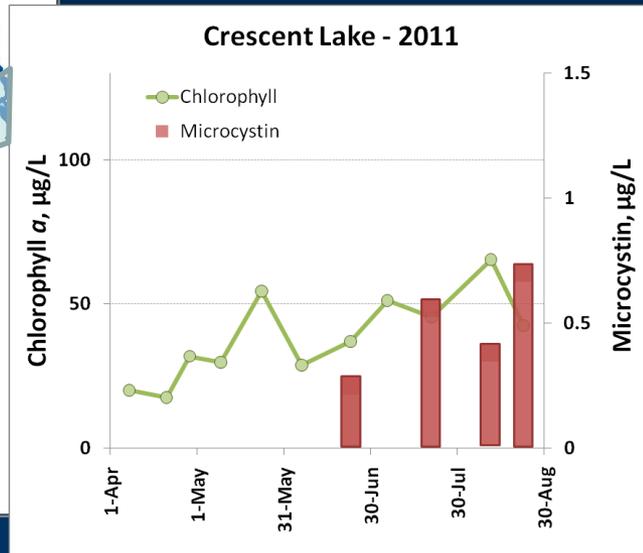
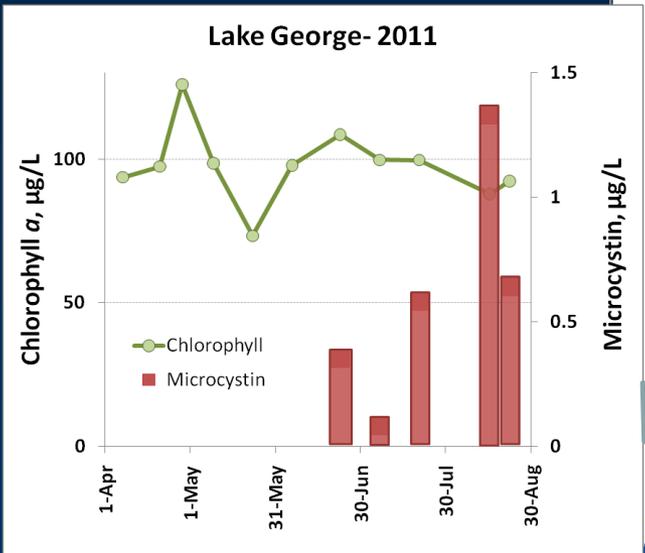
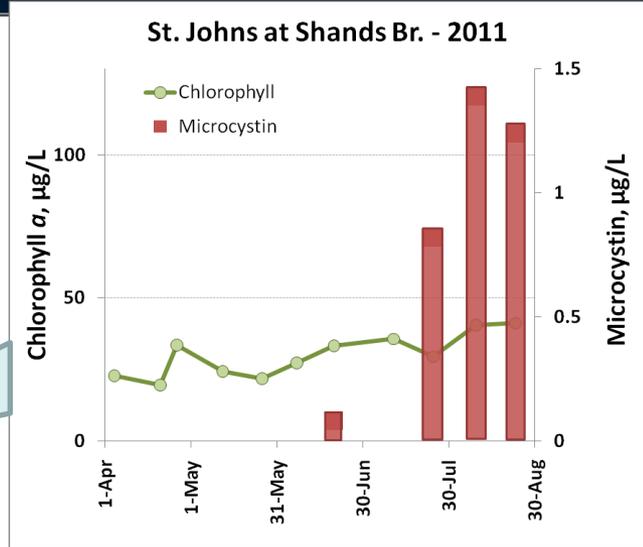
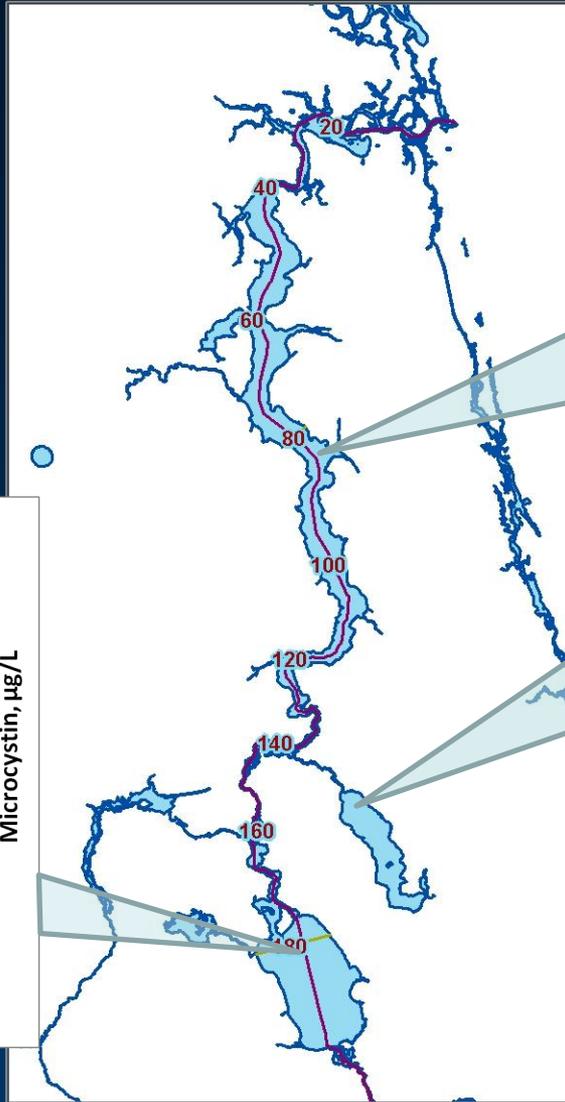


July 19, 2011



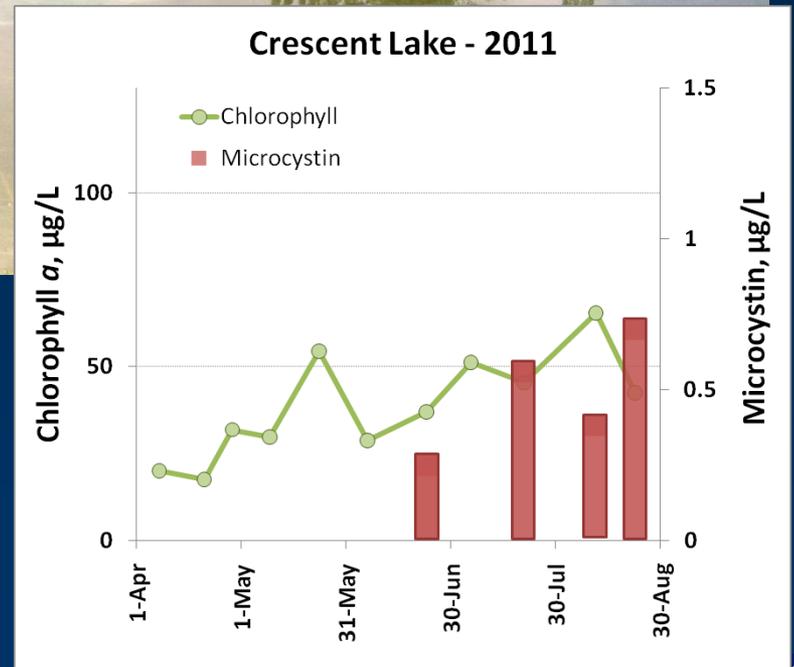
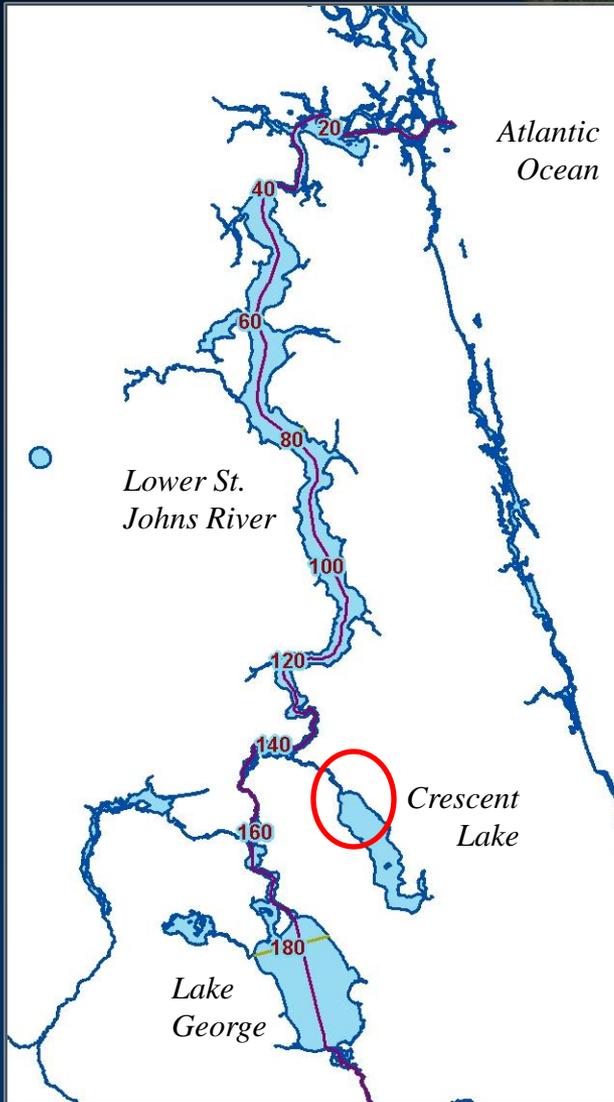
St. Johns River Estuary Cyanobacteria Blooms 2011

Microcystin concentration
more a function of
composition than density.



Slide courtesy of John Hendrickson, SJWMD

Crescent Lake, August 3, 2011
 Photo courtesy of Robert Burks

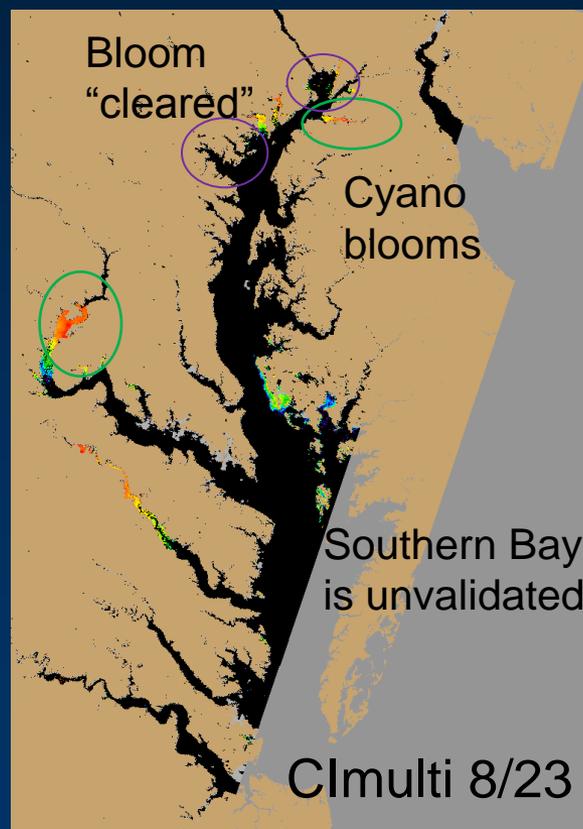
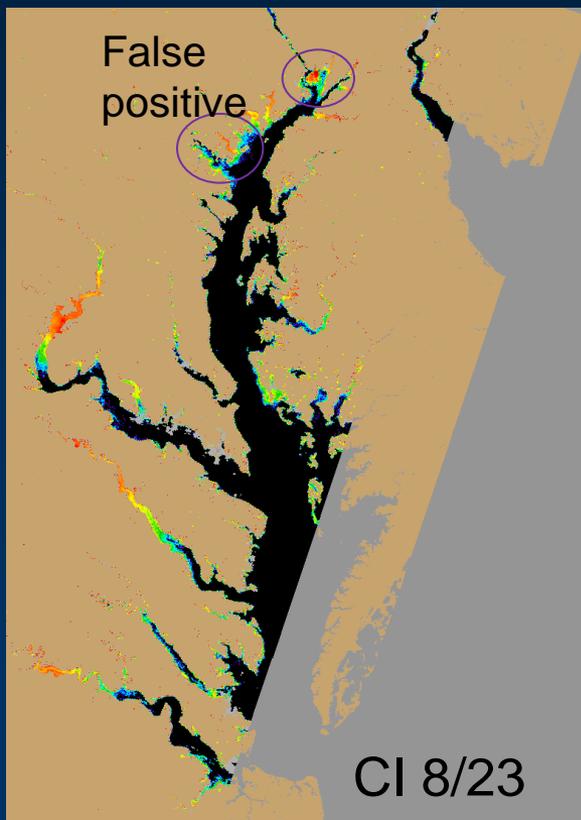


Slide courtesy of John Hendrickson,
 SJWMD



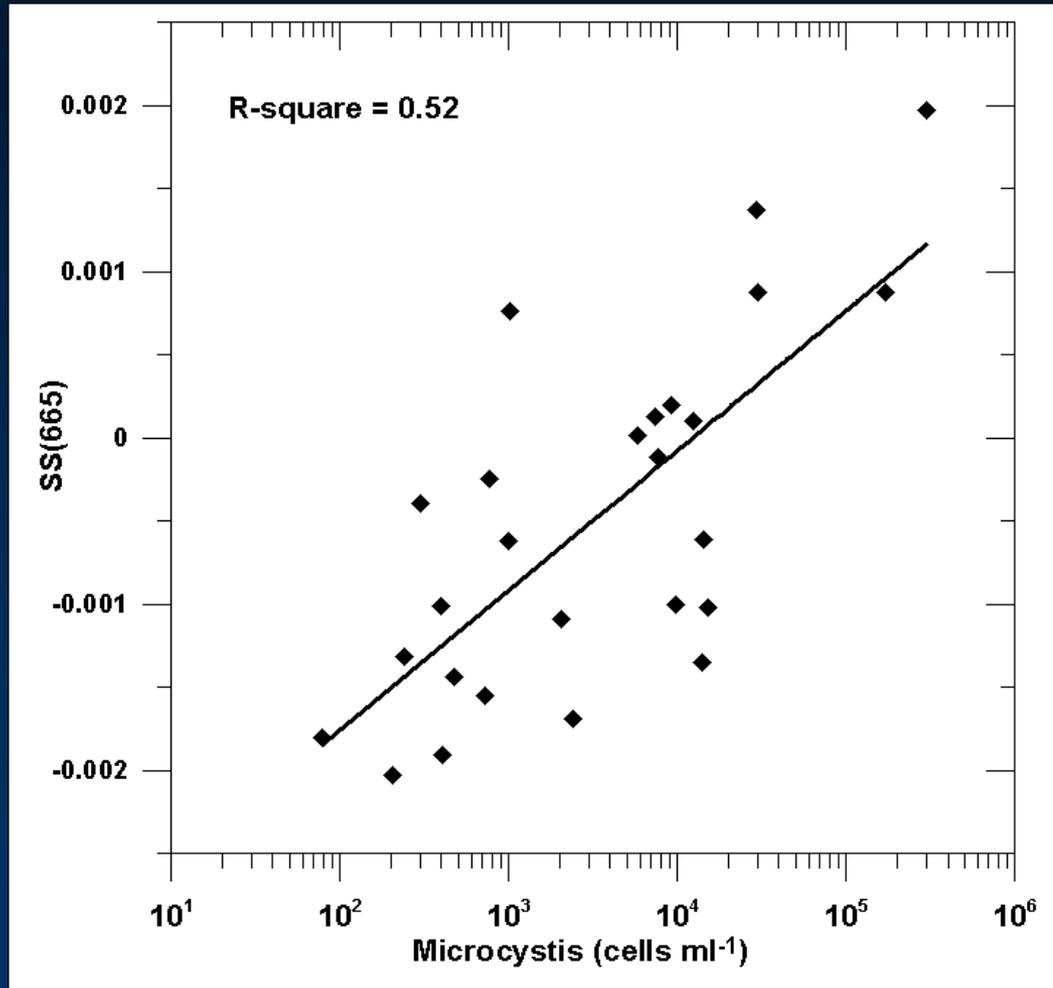
Chesapeake Bay- need for revised algorithm

- CI from Lake Erie produced false positives in Chesapeake
- Need for revised algorithm which considers SS665 (which relates to phycocyanin concentration)



Discards areas where $SS665 < 0$ (corresponding to lower phycocyanin)

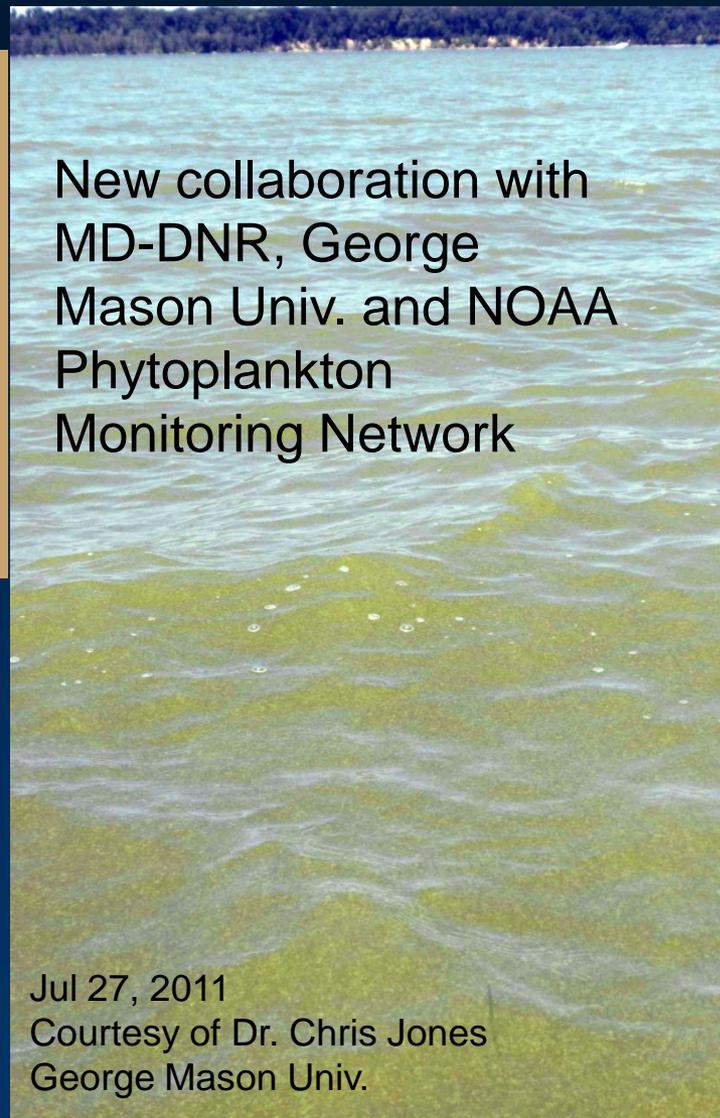
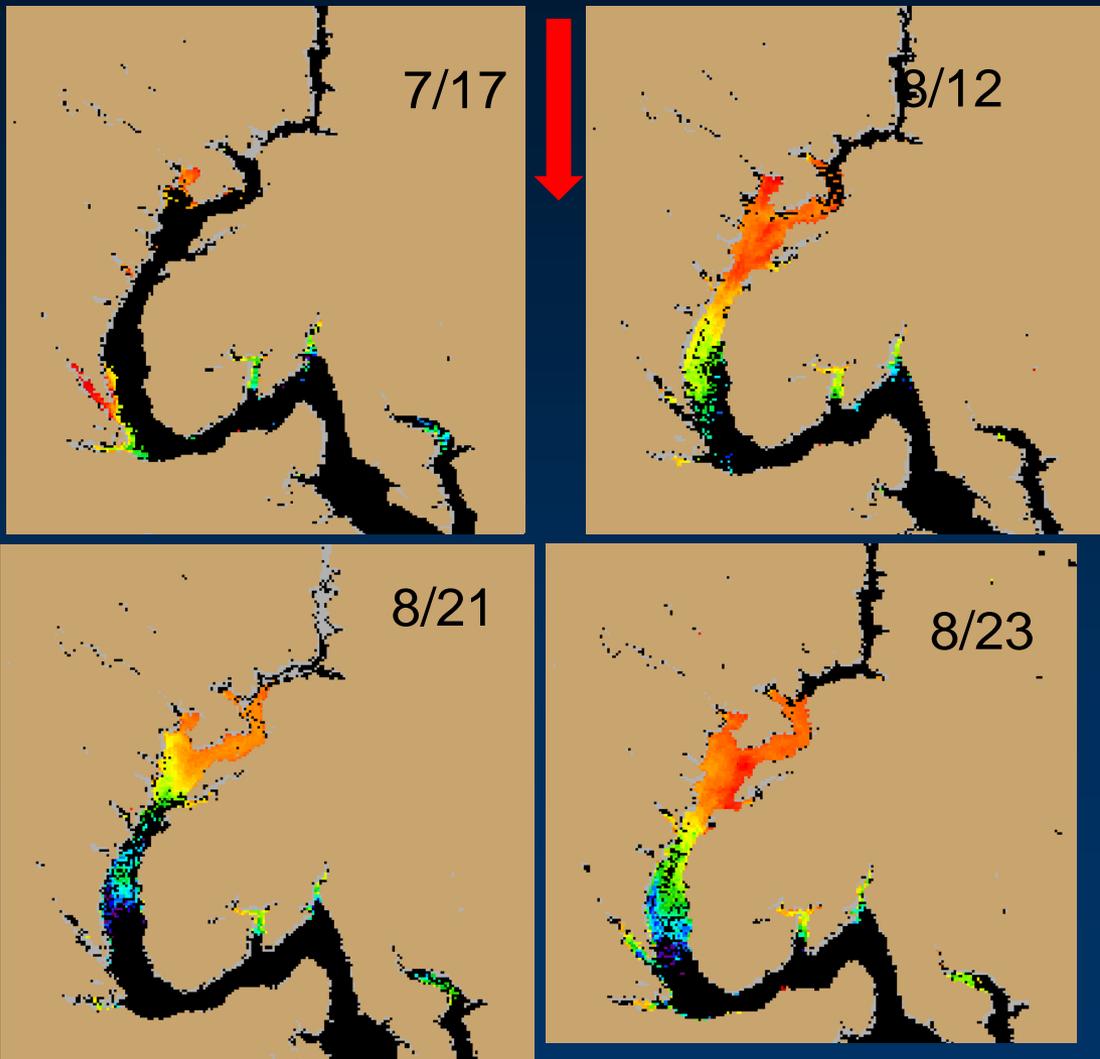
Part of the cyano algorithm; effective with sunglint



Potomac River *Microcystis* bloom

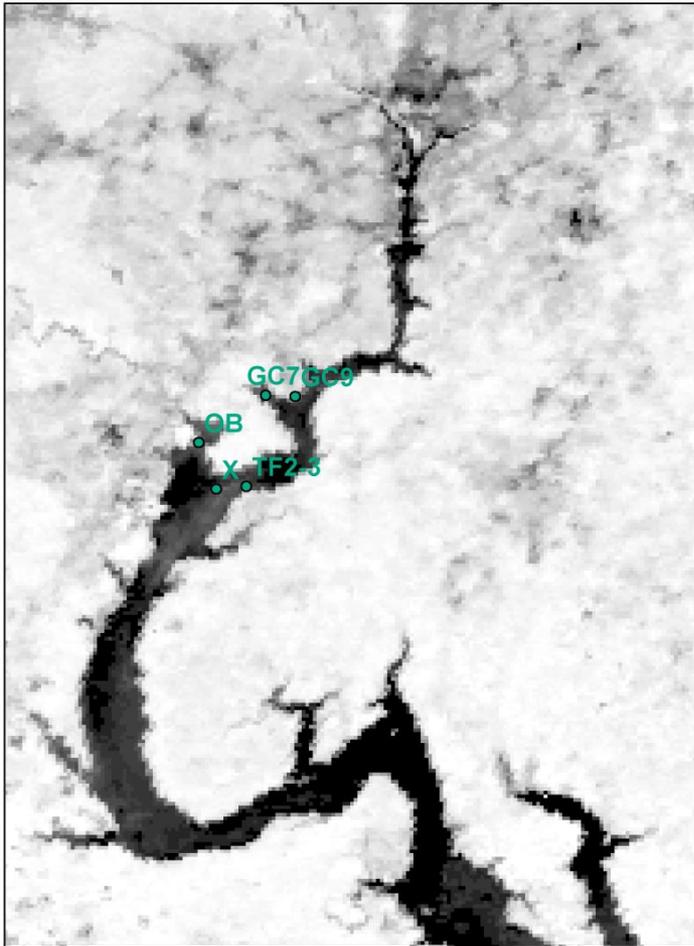
Improved CI

Loss of MERIS



MODIS as Backup for MERIS

MODIS SS645 (red shape)



7/27/2011

Brighter (higher SS645) areas
seems to indicate bloom

Station TF 2.3

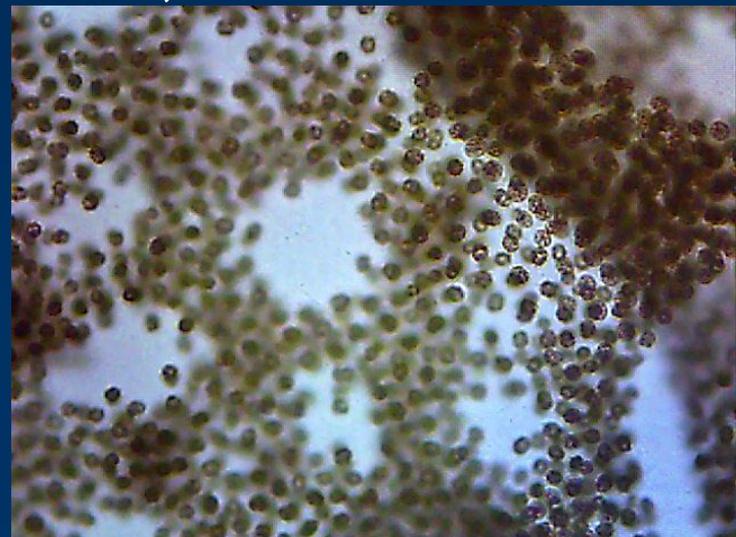
2.1 ppb microcystin

171,958 cells/ml

Station X:

6.3 ppb microcystin

171,958 cells/ml



Response from customers

“Looking at the MODIS imagery from today it was a pretty good forecast for the movement of the bloom.

Sure wish you guys could do this several times each week instead of just once, especially this time of year”

Brenda Snyder
Chief Chemist
Toledo Water Treatment

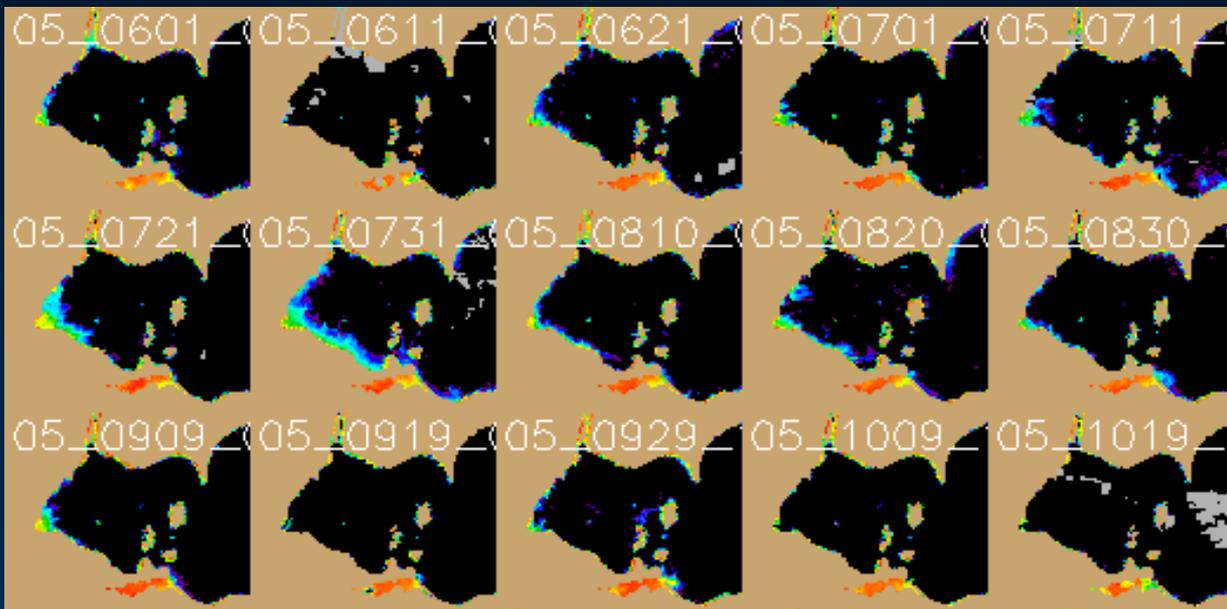
NOAA’s product “ will minimize resources necessary for large scale surveillance. It will help us focus our resources.”

Linda Merchant-Masonbrink
Ohio EPA, Div of Surface Waters. Aug 2011

“The satellite data should provide us with a new way to track the Potomac bloom (spatially and temporally) as it progresses this year.”

Cathy Wazniak, Maryland DNR

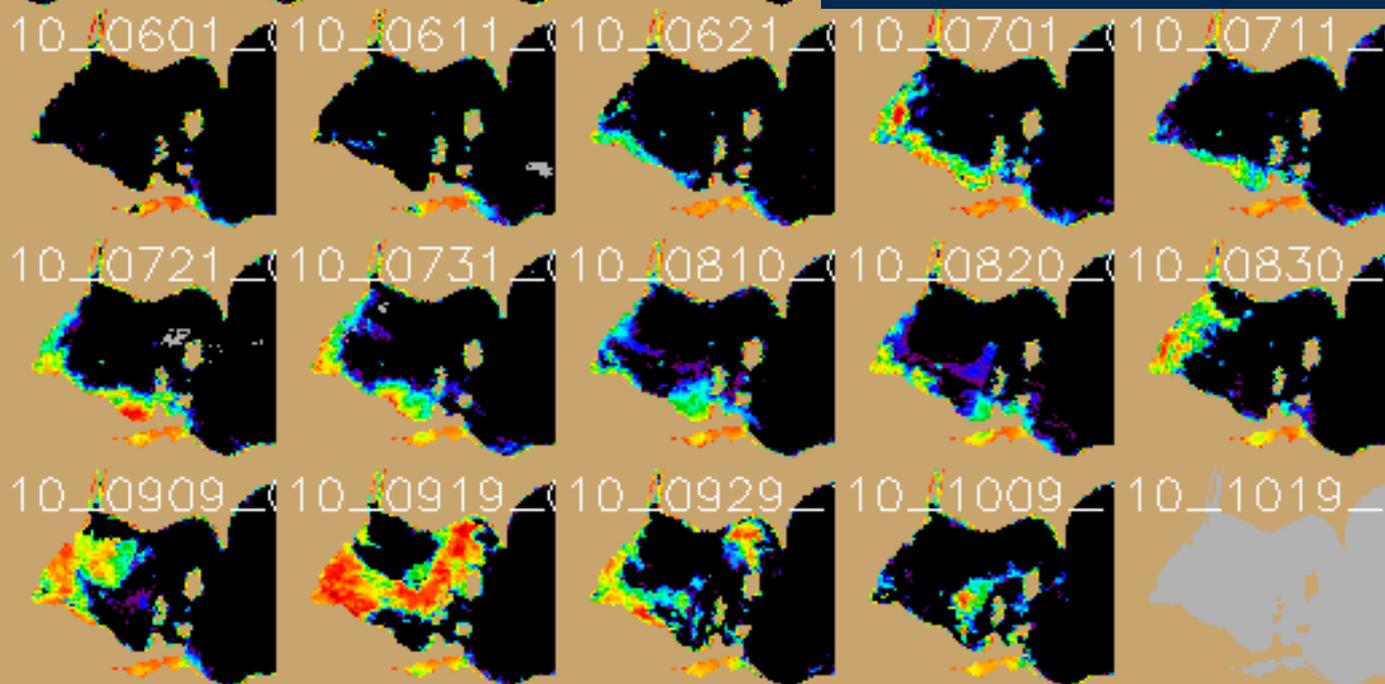
Development of climatology to assess bloom



2005 mild

- Ten day composites (highest pixel) to remove gaps in data coverage
- Shows variability between years
- Reduces mixing events

2010 severe



To consider:

- Maumee River Discharge
- Wind events
- Temperature
- Precipitation

2nd Year Successes

- Applied improved cloud mask to image products; improved cyanobacterial index (CImulti)
- Partnered with SJWMD and FDOH, provided training on radiometry; extensive field radiometry, water samples were collected this summer
- Satellite Health bulletin for Northern Florida water management districts
- Regular delivery of high resolution MERIS products in Florida, Chesapeake, Ohio
- Produced weekly forecasts for western Lake Erie blooms (June 9-present); imagery indicates start of massive bloom on 22 July, and is confirmed by GLERL.
- Training workshop on the use of MERIS products presented to Ohio EPA in Columbus, May 4, 2011
- Participated in HABISS User meeting, Atlanta, 2011

2nd Year Challenges

- Although improved cloud mask, sunglint still poses an issue
- MERIS hi-res was unreliable for real-time delivery in August due to dropped scans at Gatineau receiving station

Publications, Presentations

- Wynne, T.T., R.P. Stumpf, M.C. Tomlinson, J. Dyble, 2010. Characterizing a cyanobacterial bloom in western Lake Erie using satellite imagery and meteorological data. *Limnology and Oceanography*, v. 55, No. 5, pp. 2025-2036.
- Wynne, T.T., R.P. Stumpf, M.C. Tomlinson, D.J. Schwab, G.Y. Watabayashi, J.D. Christensen, 2011 Estimating cyanobacterial bloom transport by coupling remotely sensed imagery and a hydrodynamic model. *Ecological Applications* [doi:10.1890/10-1454.1].
- Stumpf, R.P., M.C. Tomlinson, T.T. Wynne, S. Joseph-Joshi, J. Dyble. 2010. Using models to forecast Harmful Algal Blooms, an example from Lake Erie. The Modeling for Public Health Action: From epidemiology to operations, conference. Atlanta, GA Dec 9-10 2010.
- Tomlinson, M.C., R.P. Stumpf, and T.T. Wynne. 2011. Finding and Forecasting Harmful Algal Blooms. The National Shellfisheries Association 103rd Annual Meeting. March 27-31, 2011. Baltimore, MD.

Goals for 2011-2012

- Continue outreach: Host two user workshops in North, South Florida and Ohio to provide information on how environmental managers, public health programs, and water treatment facilities can use bulletins for management
- Increase the numbers of users who receive the satellite health bulletin
- Continue to ground-truth blooms using radiometers and water testing, and aquafluor to screen for increases in chl *a* and phycocyanin
- Improved algorithms for all regions
- Expand climatological study in Lake Erie

