Ensuring Safe Drinking Water in Lake Erie: Quantifying Extreme Weather Impacts on Cyanobacteria and Disinfection By-products

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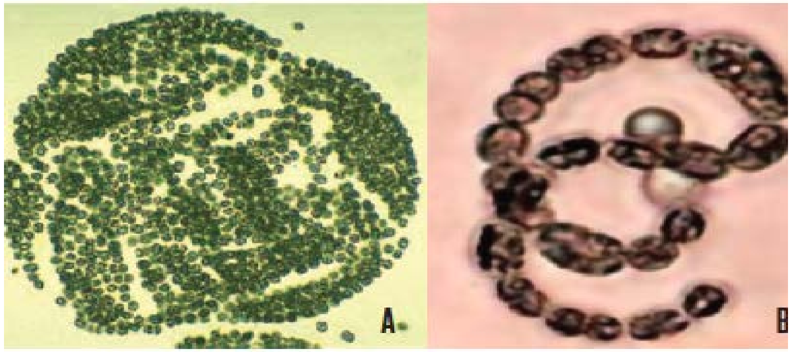
- Algal bloom: When algae grows rapidly in a confined area to form a dense population, so it is visible.
- Harmful algal bloom (HAB): A bloom of cyanobacteria (blue-green algae) that contains **toxins.**
- Appearance: Cyanobacterial blooms can appear as foam, scum, or mats on the surface of freshwater lakes and ponds.

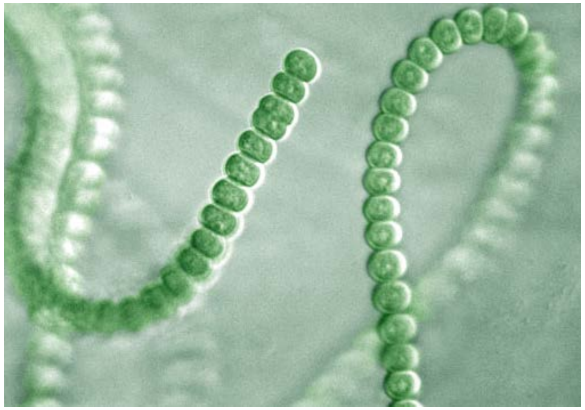
Catawaba Island, Ohio

Image Source: http://www.noaanews.noaa.gov/stories2009/images/ohiohab.jpg

Cyanobacteria

- Cyanobacteria have been around in aquatic environments for thousands of years. One of the earliest life forms on Earth.
- Photosynthetic bacteria: light + nutrients (P, N).





(Image sources: http://www.whoi.edu/redtide/page.do?pid=16142

& www.lastrefuge.co.uk

How an algal bloom forms

- The formation of a bloom is influenced by **physical, chemical, biological factors** in the water, including season.
- Favorable conditions for the bloom formation:

  - The presence of nutrients (N & P)

  - Water temperatures between 15° and 30°C (>20^{o}C).

  - pH levels between 6 and 9.

  - Late summer or early fall (temperature & light levels)

Source: The Beach Manager's Manual: Harmful Algal Bloom

Toxins in algae

- There are more than 40 freshwater species of toxic cyanobacteria. The most common species in the Great Lakes are:

  - ***Microcystis aeruginosa***

  - *Anabaena circinalis*

  - *Anabaena flos-aquae*

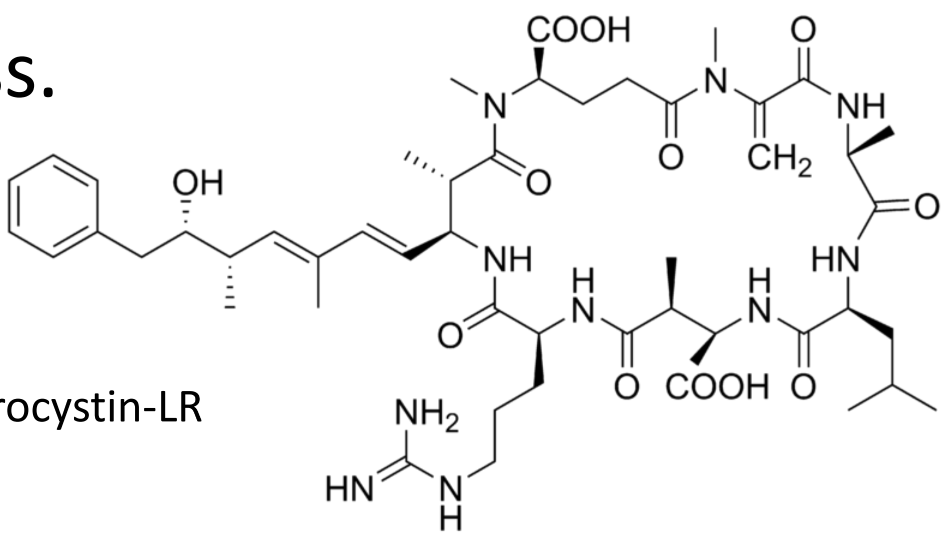
  - *Aphanizomenon flos-aquae*

  - *Cylindrospermopsis raciborskii*

Source: The Beach Manager’s Manual: Harmful Algal Bloom

Cyanotoxins

- 3 main classes of toxins:
  1) Nerve toxins: **neurotoxins**
  2) Liver toxins: **hepatotoxins**
  3) Skin toxins: **dermatotoxins**
- All cyanobacteria can generate dermatotoxins, all of these toxins may also cause gastrointestinal distress.



Microcystin-LR

Source: The Beach Manager's Manual: Harmful Algal Bloom

WHO guidelines

The World Health Organization (WHO) has guidelines for algal toxin exposure for humans, which can be translate to 1µg/L for drinking water and 20 µg/L for recreational water contact.

Table 3. WHO recreational water guidelines for human health risk (modified from WHO 2003).

Probability of adverse health effects	Cell concentration (per ml)	Chlorophyll-a concentration (µg/L)
Relatively low	<20,000 cells	<10
Moderate	20,000–100,000 cells	10–50
High	>100,000 cells (visible scum)	visible scum

Cheung, Liang, Lee (2013)

Toxicity of Cyanotoxins

Rodent 24 h intraperitoneal LD50s (µg/kg): cyanotoxins vs. other well-known toxins

Cyanotoxins	**LD_{50}**	**EPA priority**	**Comparison**	**LD_{50}**
Saxitoxins	10	Medium/high	Ricin	22
Anatoxin-a(s)	20	Medium/high	Cobra venom	185
Microcystin-LR	50	Highest	Sarin	218
Anatoxin-a	200	Highest	Curare	500
Cylindrospermopsin	300/180	Highest	Strychnine	2500/980

(Hudnell, 2010)

Climate change and HABs

Climate change may lead to warmer surface water **temperatures**, increased **nutrient** loadings, more frequent **floods** and **droughts**, changes in thermal stratification, and other environmental alterations, which will have a significant impact on algal ecology.

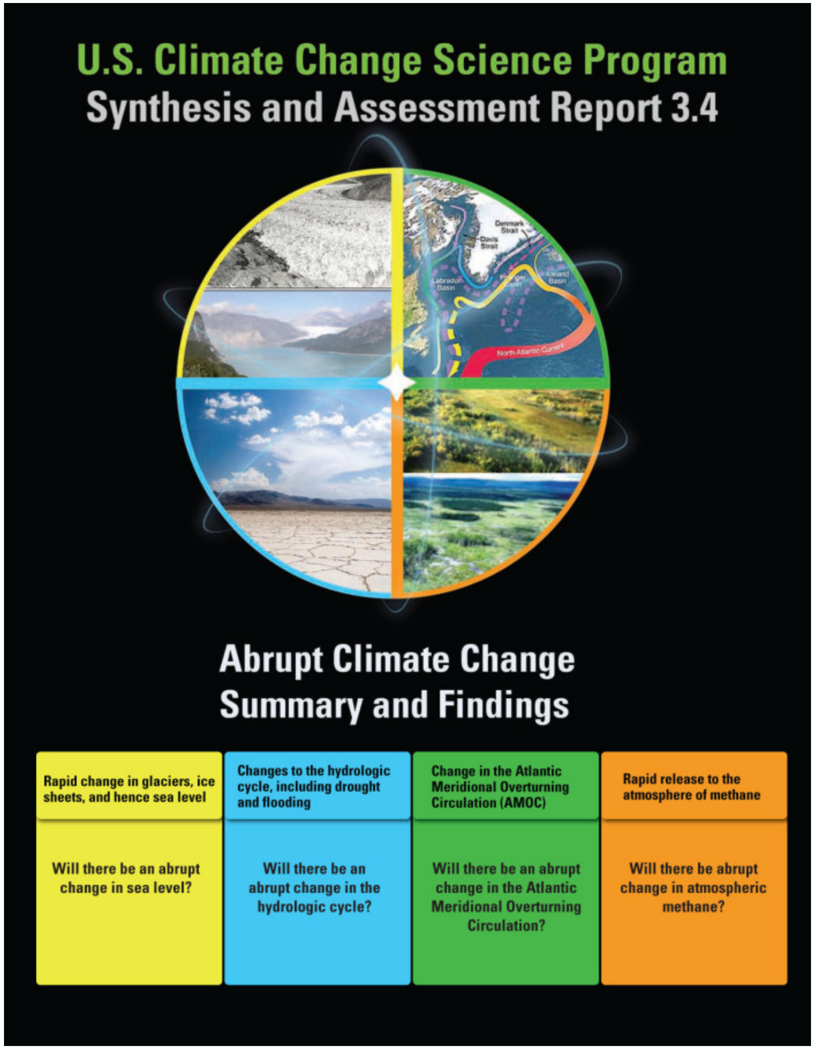


Image source: http://digital.library.unt.edu/ark:/67531/metadc29380/m1/1/

Climate change and HABs

- Cyanobacteria will show up earlier and staying longer throughout the seasons.
- The link between climate change and HABs is poorly understood.
- Cyanobacterial blooms are **worldwide risks** for the **environment**, **animal** and **human health.**

photo source: NOAA

Fish kill (photo source: USGS)

Linking satellite remote sensing to molecular detection of cyanobacteria in Lake Erie

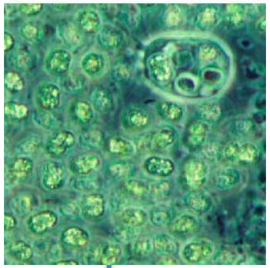
MODIS on Terra satellite acquired the image on March 21 2012.

Source: http://eoimages.gsfc.nasa.gov/images/imagerecords/77000/77506/erie_tmo_2012081_lrg.jpg

Project Objectives

- Assessment of the link between historic and current extreme weather events and water quality indicators using satellite and field work data including water color temperature, turbidity, precipitation, water level, and ice/snow/flood extents.
- Improved understanding of the links between extreme weather events and the *source* and *finished* water quality including cyanobacteria densities, cyanotoxins, DBPs, and nutrient concentrations.
- Modeling and prediction of adverse impacts to *source* and *finished* water to understand the future impact of climate-change induced extreme weather events on water safety in Lake Erie region.

The Team



<u>Jiyoung Lee</u>
Cyanobacteria, Toxin, DBPs

<u>CK Shum</u>
Satellite Remote Sensing

<u>Song Liang</u>
Modeling

Our Approach

- Quantify parameters associated with extreme weather events using satellite remote sensing (e.g. MERIS, OLIS) data and Numerical Weather Prediction reanalysis (e.g. ERA-Interim) models

- Determine the cyanobacteria profile using molecular tools, and measure chemical-physical parameters including toxins and DBPs

- Integrate the above results using empirical modeling to improve our ability to quantify risks to Lake Erie drinking water

Goals

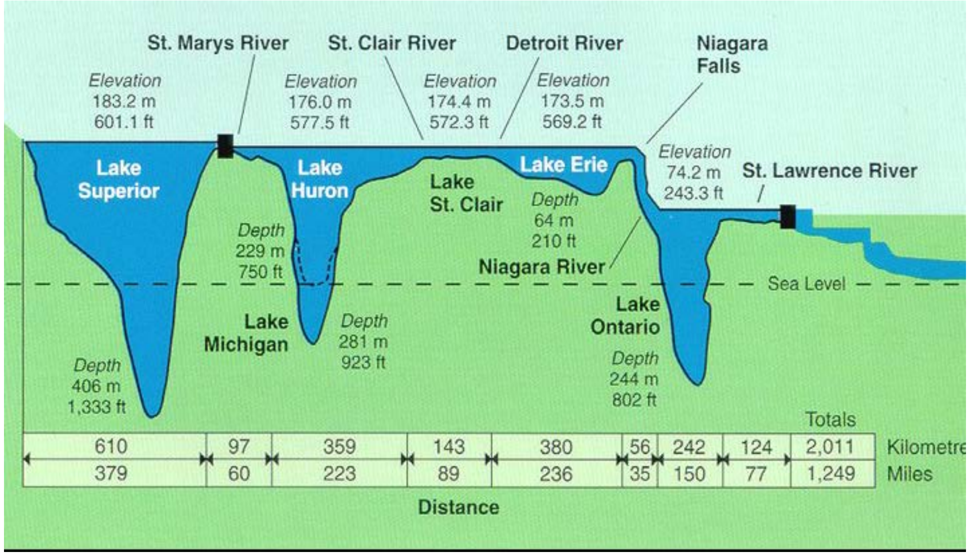
- This research will contribute to better understanding of the patterns of climate-change induced extreme weather events and their impact on Lake Erie water quality.
- This interdisciplinary approach using historic and current satellite remote sensing and geodetic data, molecular tools, and empirical modeling will result in comprehensive scientific information that can be used for sustainable solutions for drinking water safety.
- Findings are transferrable to other parts of the nation and the world.

Project Significance

- Satellite remote sensing needs **fine tuning** with *in situ* toxin, toxin-producers, and toxin-proxy factors .
- Factors that promote cyanobacterial blooms are generally well-known (e.g. excessive nutrients (N & P), sunlight, temperatures, lack of vertical mixing), but
- Factors that trigger **toxin-production** or **dominance of toxin-producing strains** are considerably less-understood.

Study Site: Lake Erie

- 12^{th} largest lake in the world
- Smallest, shallowest, warmest lake among the Great Lakes
- Retention time: 2.6 yrs



J. Lee, S. Liang, CK Shum, EPA STAR Extreme Events Research Forum, Arlington, VA, 2- 27- 2013

Lake Erie HABs

- Pollution source: agriculture, sewage and industrial wastewater
- Maumee River: the largest single contributor of non-point pollution to the lake
- Mitigation: International Joint Commission (US & Canada) spent >$7.5 billion since 1972 to bring into compliance with 1 mg/L-P.

Lake Erie Near South Bass Island, 8/5/2009 (*Microcystis*)
Photo by: Ohio Sea Grant

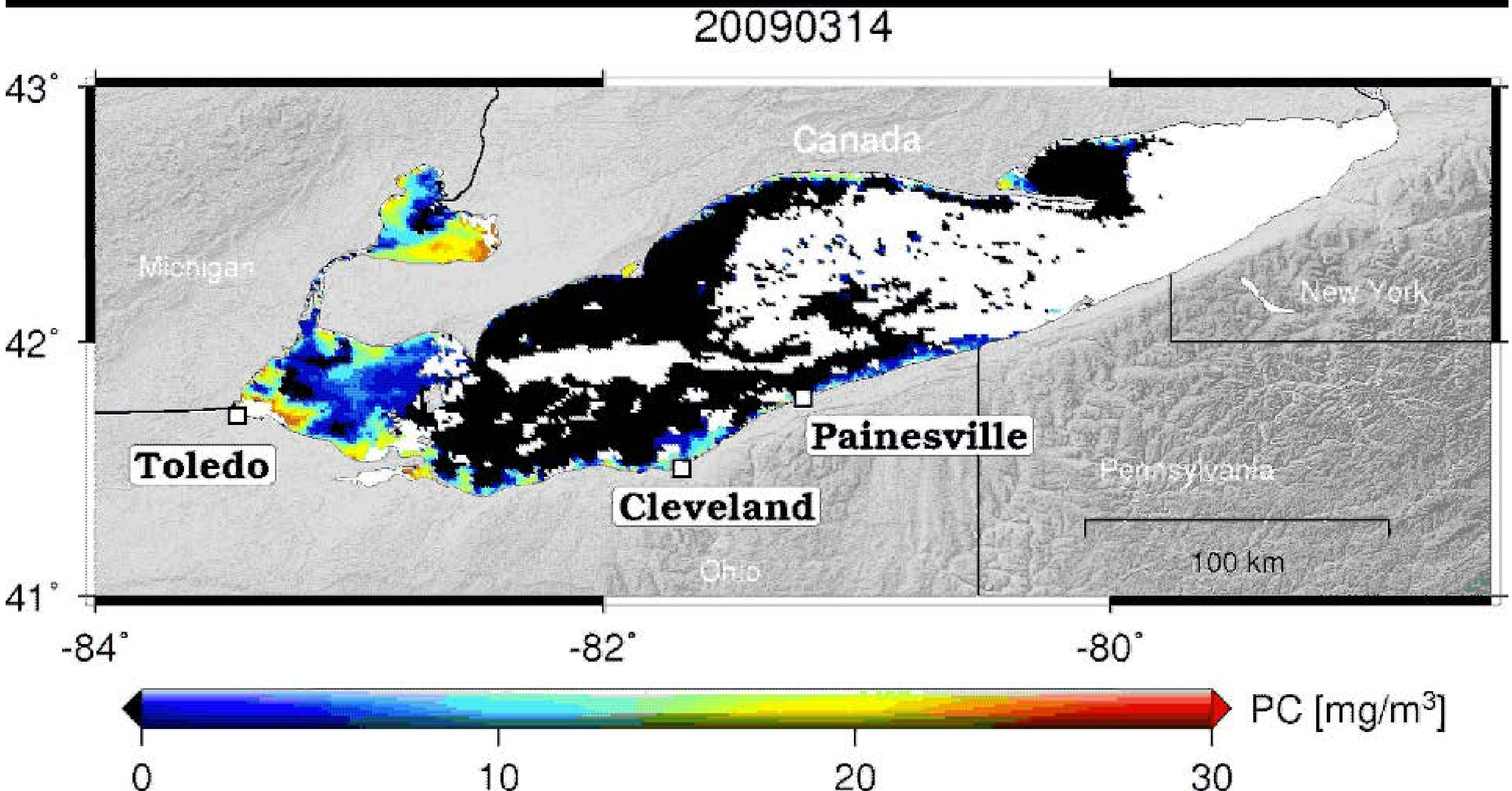
Preliminary Results

- Historical data
- Satellite remote sensing and *in situ* measurements

Satellite remote sensing

- Phycocyanin : pigment-protein complex in *Microcystis* spp. absorbing the visible light near the wavelength at 620 nm
- A nested semi-empirical model (Simis et al., 2005) for phycocyanin quantification
- MERIS onboard ESA's Envisat since March 2002: spatial resolution of 300 m; 15 spectral bands (390 nm to 1040 nm)
- Ceased its operation on in May 2012

temporal MERIS PC variation



Data span: 1/1/1979 – 12/13/2012 (as of Feb 2013)

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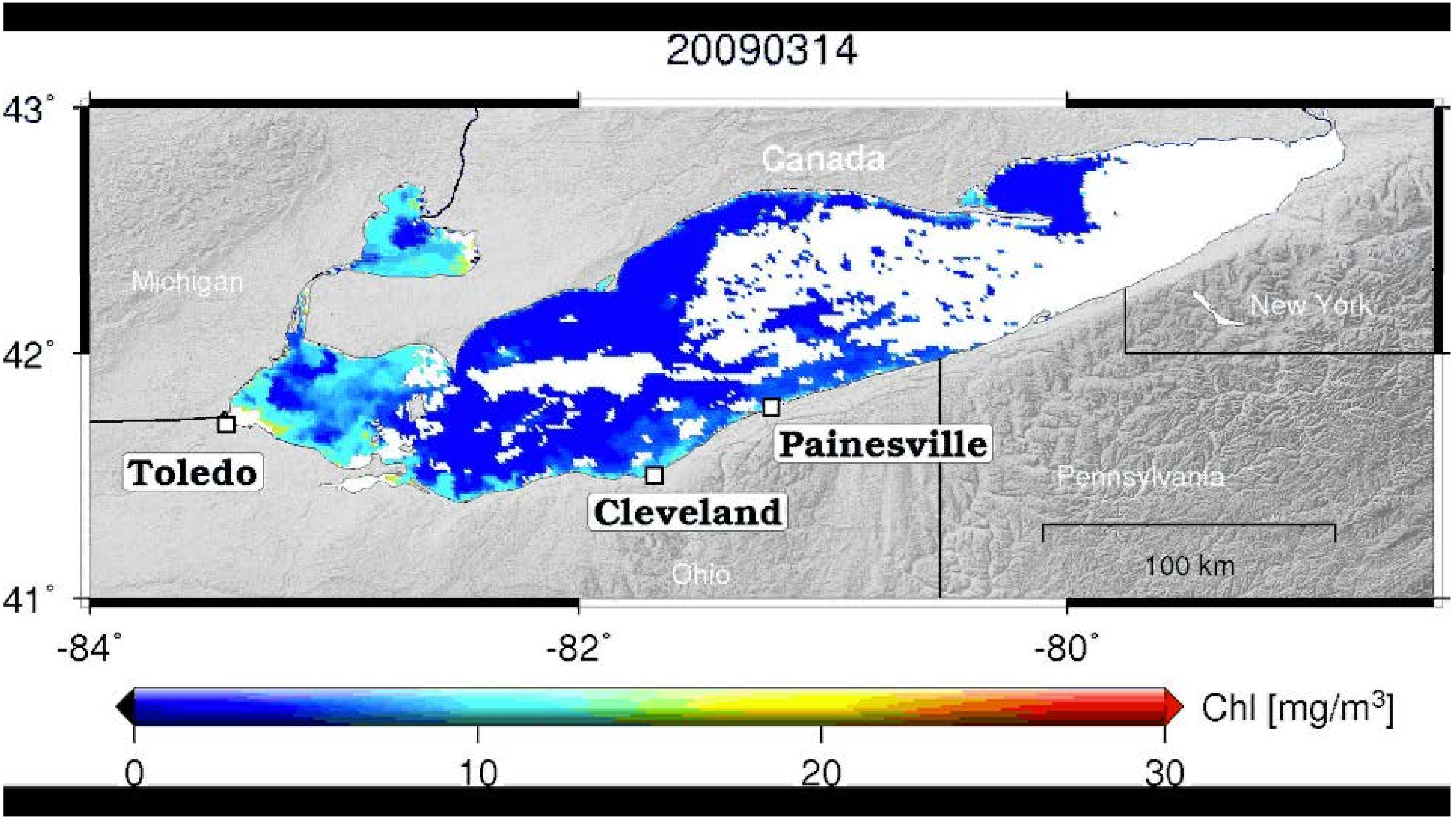
temporal MERIS Chlorophyll variation



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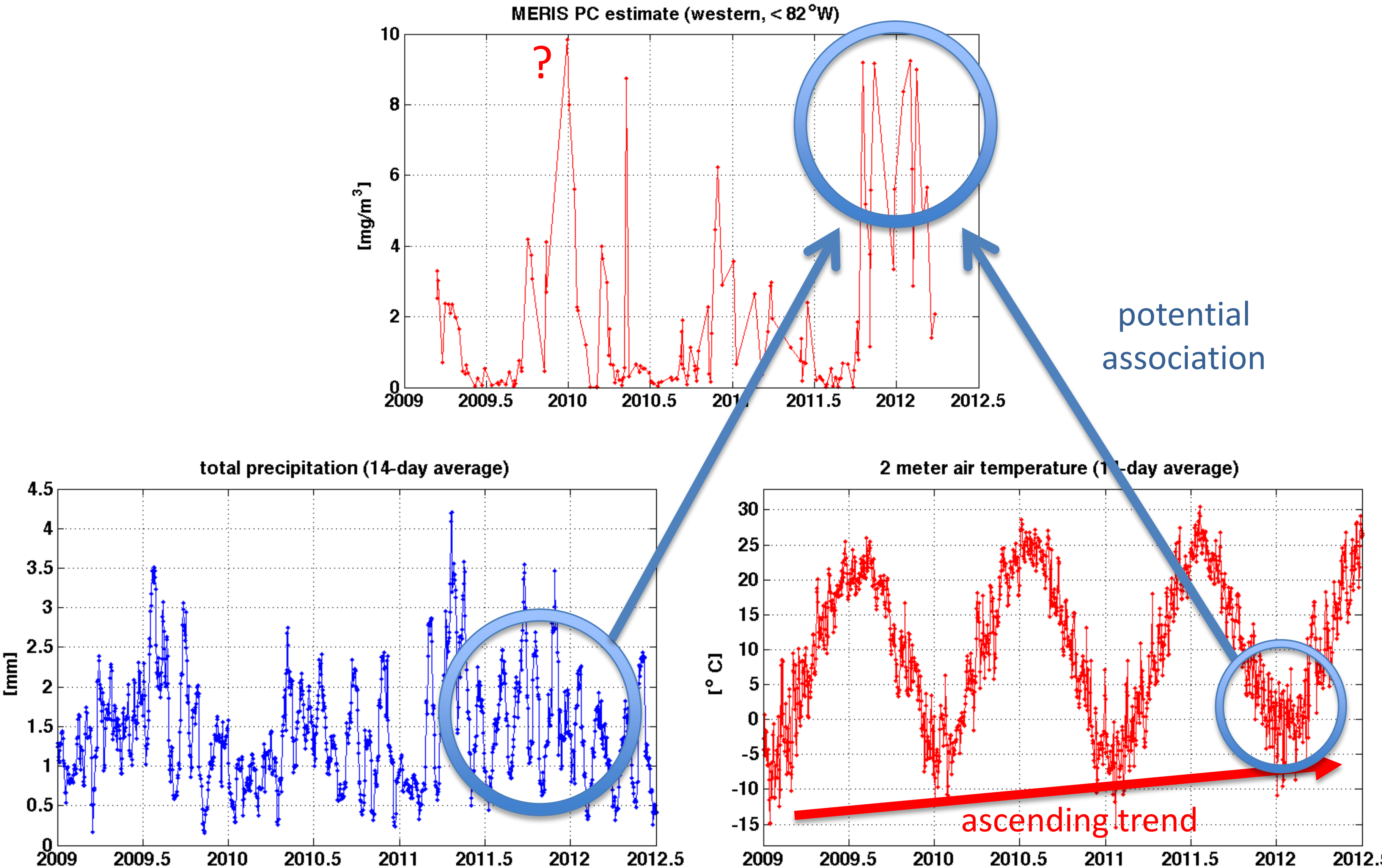

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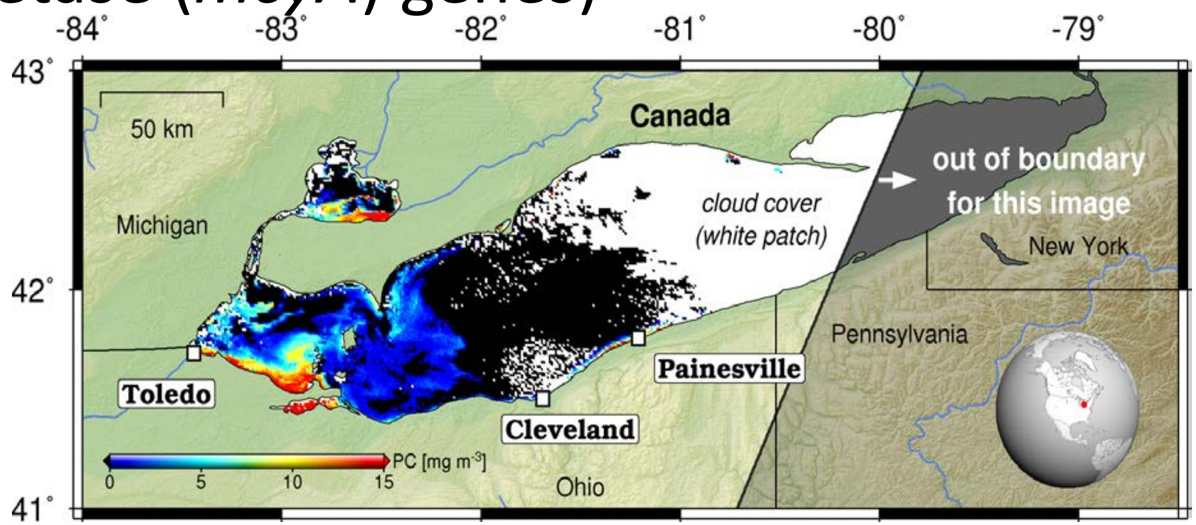
Phycocyanin: remote sensing vs. *in situ*

- By syncing both data sets in a way of linear interpolation of *in situ* quantities at the timing of MERIS's snapshots, we observed a good correlation between the two PC (in situ vs. MERIS estimates) (r= 0.84).
- The spaceborne sensors (MERIS and its its enhanced successor OLCI) can efficiently identify the pigment 'anomaly' in the cyanobacterial biomass

Lee et al. in preparation (2013)

In situ measurements

- Study site: central Lake Erie (Headlands beach)
- Sampling period: July - September, 2010
- Sample collection: 4 times per week at 2 locations
- WQ parameters, nutrients, chl-a, phycocyanin, *E. coli*
- Microcystin & qPCR measurements (phycocyanin intergenic spacer (PC-IGS) and *M. aeruginosa*-specific microcystin synthetase (*mcyA*) genes)
- Water level etc. from NOAA



Temporal variations: pigments, microcystin, mcyA and PC-IGS

- Increasing trend in PC levels
- The peaks of *mcyA* and PC-IGS occurred earlier (middle August) and were followed by the microcystin peaks (late August)

Lee et al. in preparation (2013)

HAB-associated measurements & environmental variables

	phycocyanin	chlorophyll a	PC-IGS	mcyA	microcystin
phycocyanin	1				
chlorophyll a	0.3982*	1			
PC-IGS	0.5577 *	-0.0601	1		
mcyA	0.6696*	0.0954	0.7902*	1	
microcystin	0.1361	0.0731	0.2252	0.1366	1
Water temperature	-0.3464 *	0.2837	-0.7421*	-0.5617*	-0.3474*
pH	-0.0801	0.3021*	-0.4500*	-0.2213	0.0009
dissolved oxygen	0.3619 *	0.0270	0.1925	-0.0386	-0.2529*
turbidity	0.6401 *	0.0164	0.5930*	0.5992*	-0.1221
E. coli	0.0581	0.2258	-0.1636	0.0017	-0.3412*
total phosphorus	0.0169	-0.2105	0.2918*	0.1823	0.2881*
nitrate-N	0.0114	-0.0389	0.1931	0.1385	0.0664
water level	-0.5782*	-0.0153	-0.6663*	-0.6169*	-0.4917*

Phycocyanin seems to be a better proxy predicting harmful algal blooms (HABs).

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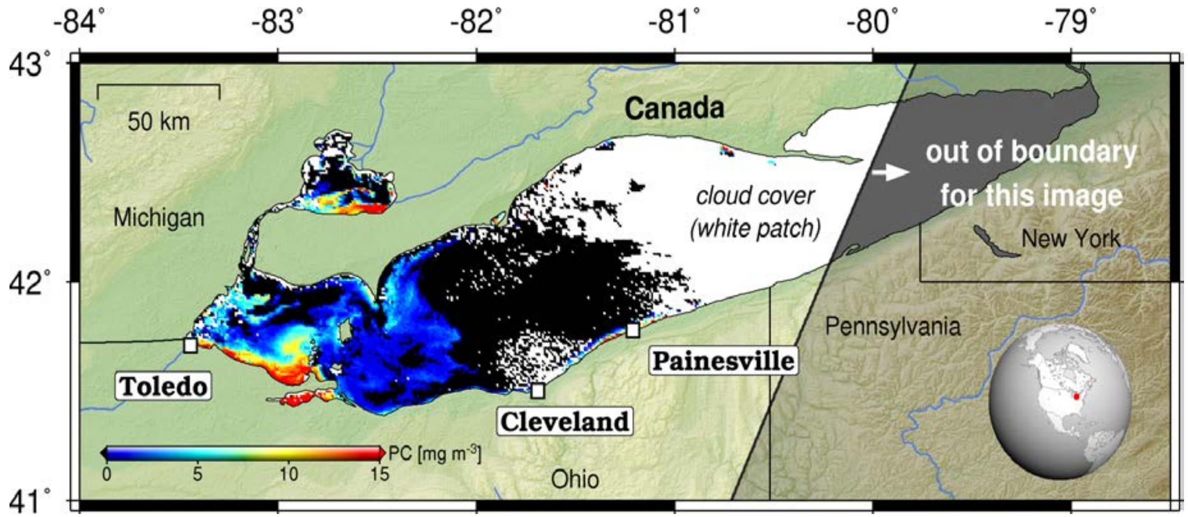
On-going work



- Source/finished water: 2013-2014 monthly (source/finished water quality including cyanobacteria, toxin, DBPs, nutrients)
- Remote sensing: Ocean and Land Colour Instrument (onboard at the Sentinent-3 satellites)
- Modeling and prediction of impact of extreme weather events on water safety in Lake Erie region

Analyzing Historical Data

- Availability of historical data

- Objectives
  - Identifying patterns
  - Exploring possible associations (e.g. between phycocyanin, chl-a, temperature, and precipitation)

Environment-HABs Linkage and Predictive Modeling

Objectives

- Identify environmental drivers underlying HABs
- Develop predictive modeling framework for impact of extreme weather events

Analysis plans

- Classification (using a machine learning algorithm)
- Main-effect log-linear model
- Variance importance (to confirm results from the above two)
- Predictive modeling

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HAB & extreme events

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