

Optical characteristics of harmful algal blooms in western Lake Erie: impacts on bio-optical algorithms and ocean color remote sensing

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Background

Harmful algal blooms (HABs) have been increasing in intensity and duration in western Lake Erie in the last 10 years, adversely impacting water quality for the region. These blooms typically initiate in July near Maumee Bay, and can last through September/October. HABs are dominated by the colony-forming cyanobacteria *Microcystis* but other are often accompanied by other toxic species (*Planktothrix*, *Anabaena*).

The use of ocean color remote sensing for the detection and quantification of these HABs is subject to a number of special considerations. *Microcystis* can form long, clustered colony chains. They also contain gas vacuoles which help regulate vertical position with a tendency to form dense surface mats in low winds. The vacuoles and the vertical distributions of the colonies exert a strong influence on backscattering properties. In the summer of 2013 and 2014, we collected in situ data in western Lake Erie to assess and understand HAB distributions and their optical properties in the context of remote sensing algorithms.

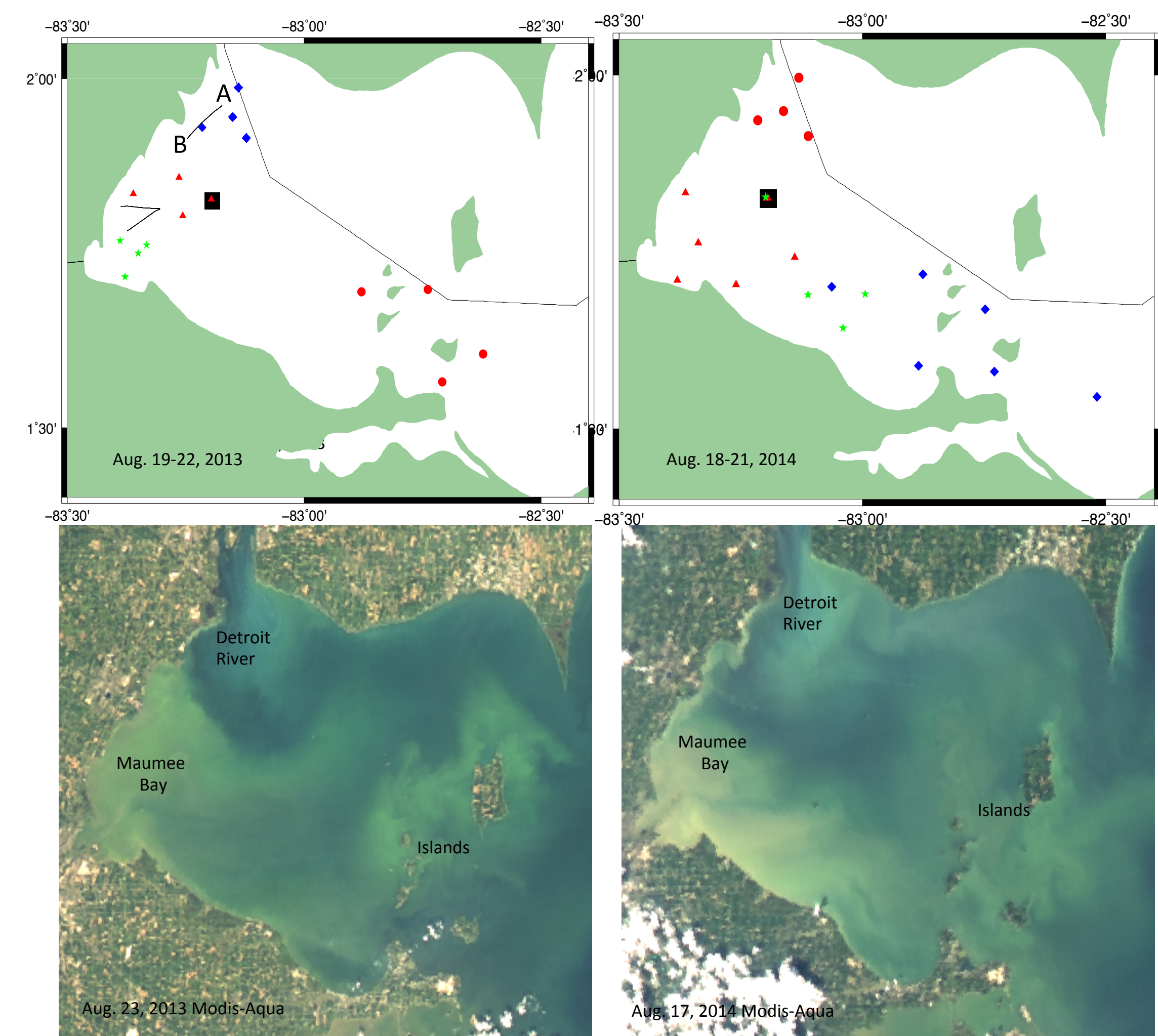


Figure 1. Map of western Lake Erie data collection sites. Top Left: Station locations in 2013 (Dolphin tows solid lines, LOBO black square); Bottom Left: MODIS-Aqua True color from Aug. 23, 2013; Top Right: station locations for 2014; Bottom Right: MODIS-Aqua True color from Aug. 17, 2014. Modis images from Chuanmin Hu's website (<http://optics.marine.usf.edu/>).

Data Collection

Field data were collected during 2 cruises from Aug. 19-22, 2013 and Aug. 18-21, 2014 in western Lake Erie at 16 and 20 stations respectively during the peak HAB period (Figure 1). Station locations were chosen to maximize environmental gradient in and out of bloom patches, and included Detroit River water, Maumee Bay, and island region (summarized in Table 1).

Data measurements encompassed:

- Discrete water sample analysis included chlorophyll, phycocyanin, microcystin and nutrient concentrations, CDOM, and particulate absorption measurements.
- Above-water Reflectance (Rrs) were measured with a hand-held ASD (courtesy of H. Dierssen).
- A WET Labs MASCOT vertical profiling system measured absorption, scattering, backscattering, fluorescence, volume scattering and particle size.
- A WET Labs towed Dolphin package at surface, measuring Chl, PC and CDOM fluorescence, absorption, scattering and backscattering (2013 only).
- A profiling WET Labs Holocam, measuring particle size, shape and orientation as well as digital imagery (2014 only).
- A Satlantic/WET Labs Land/Ocean Biogeochemical Observatory (LOBO) buoy deployed in western Lake Erie from June through October, 2013 & 2014 (<http://algae.loboviz.com/>).

Table 1. Data set sources and station distribution for analysis. All station data contained hyperspectral above-water reflectance and chlorophyll measurements.

Region	Depth	Plankton	Optical description	Secchi Depth (m)
Maumee Bay	3-5m	Microcystis	shallow, turbid HAB region	<0.5
Detroit River	4-8m	Sparse	clear, no HAB	3+
Islands West	7-8m	Microcystis	HAB	1-2
Islands East	7-8m	Planktothrix	HAB	2+

Spatial Backscattering Characteristics

- Surface Dolphin tow (with WET Labs ACS, bb9, phycocyanin (PC) and Chl fluorometers) was made from clear Detroit River water across front and into *Microcystis* HAB patch (Figure 1, from position A to B).
- Microcystis* dominated waters show much higher levels of backscattering and backscattering ratio compared to non-bloom waters (Figure 2).
- Backscattering ratio was 3-5 times higher in *Microcystis* patch compared to Detroit River water.
- Total scattering increased significantly at frontal boundary where a Chl maximum was encountered, but without a major increase in backscattering and PC indicating another algal type accumulating at front.
- Impacts on Rrs are most pronounced from ~530 to 800 nm, with very little change from 400 to ~530nm.
- Microcystis* waters show high peaks at 550 and 709 nm, and troughs at 620 and 680nm. These features are important to bio-optical algorithms.

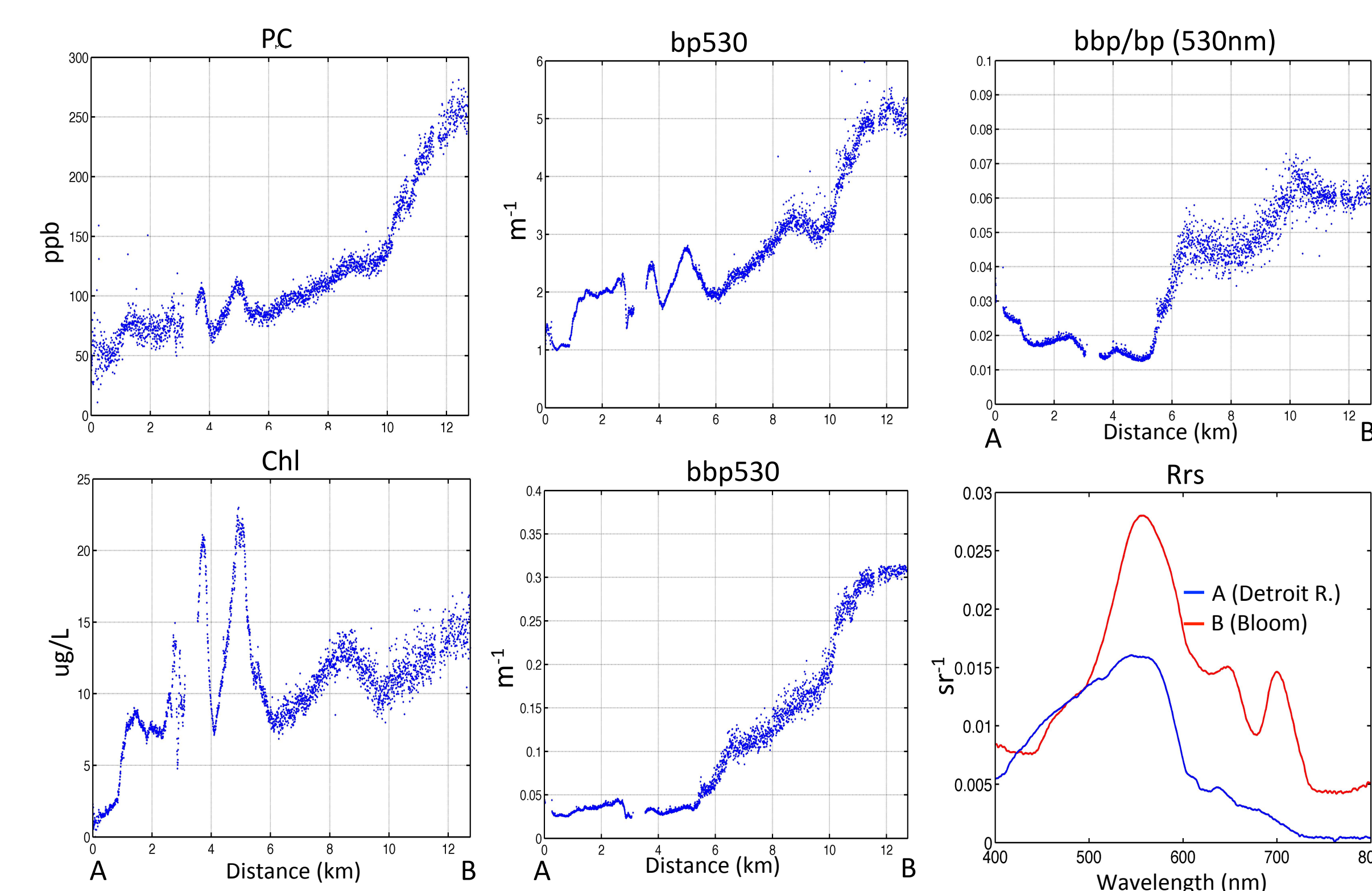


Figure 2. Dolphin transect data from 2013 across a gradient from clear, non-HAB water (position A) into a HAB patch in western Lake Erie (position B) (See Figure 1). Phycocyanin, scattering, backscattering and backscattering ratio increase dramatically across the front. Lower Right: Rrs spectra from Detroit River (blue) at beginning of Dolphin tow and in bloom patch near end of Dolphin tow (red) show the impacts of the IOPs on Rrs spectra.

Temporal Biological Characteristics

- Development of high biomass blooms typically begin in July (Figure 3).
- Pre-bloom chlorophyll levels can range from 1 to 30 ug/L, while phycocyanin levels rarely rise above 1ug/L.
- Basin-wide bloom events are reflected in high biomass (typically higher than 10 and into the 100's ug/L chlorophyll a) and phycocyanin levels (which can match or exceed Chl levels).
- The concentration levels can vary as a function of vertical distribution, significantly impacted by wind conditions and bloom stage, with a direct impact on optical conditions.
- The result is a wide range in chlorophyll and IOP levels across space (Figure 2) and time (Figure 3).
- Appropriate bio-optical algorithms (and satellite applications) are needed to accommodate this large range in conditions.
- Chlorophyll and PC algorithms are both needed to observe environmental change and to identify eutrophic HAB events from eutrophic non-HAB events.

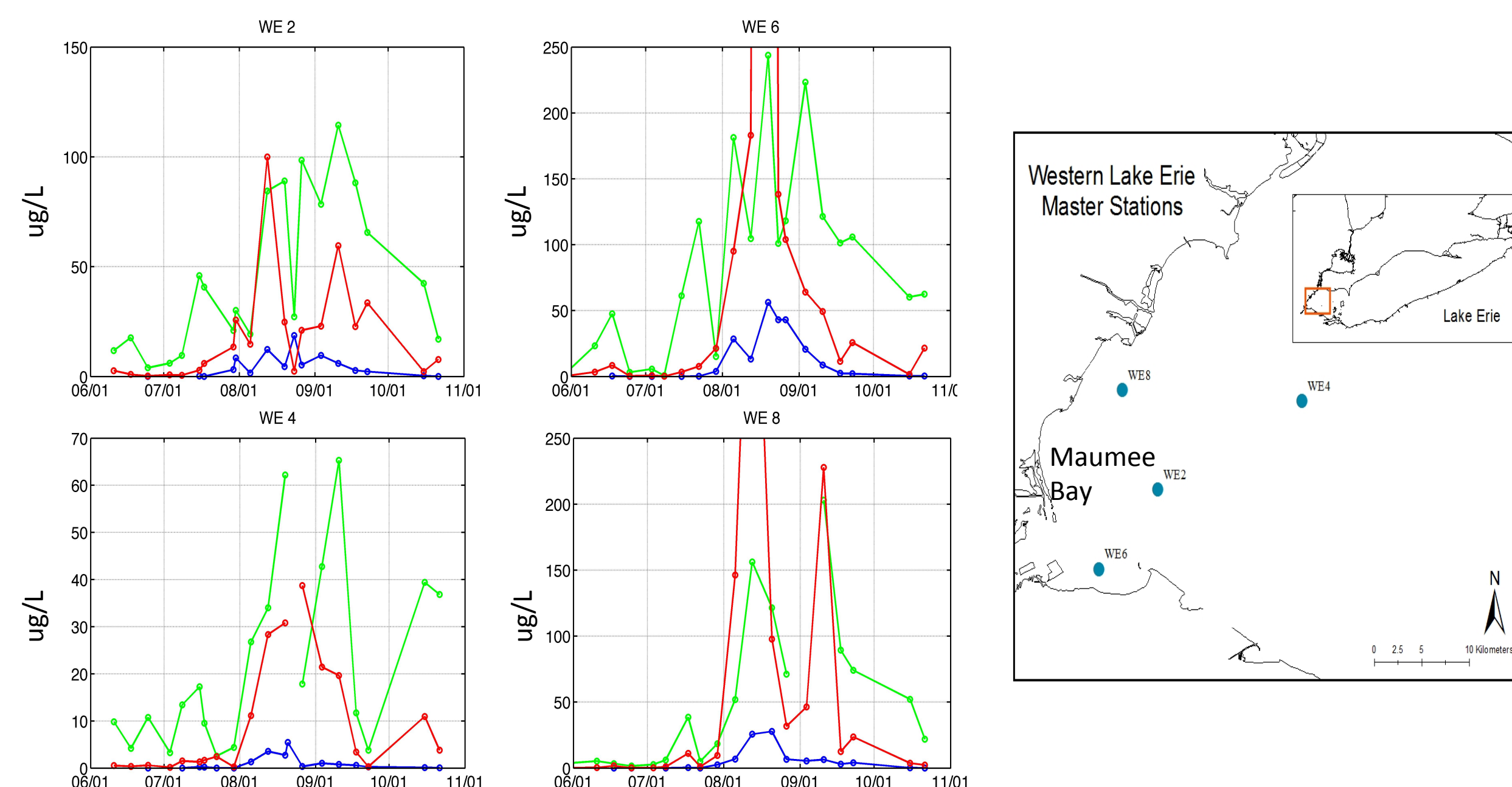


Figure 3. Time series of Chl, PC and microcystin concentrations from NOAA weekly stations in 2013. Chlorophyll ranged from 1 to over 200 mg/m³ (typical summer/fall progression). Data courtesy of NOAA/GLERL.

Impacts on Bio-optical algorithms

- Traditional OCX algorithms underestimate Chl in eutrophic waters when Chl > 10 mg/m³ (Figure 4).
- The MERIS 3-band Chl algorithm (Gitelson et al., 2011) works well above 10 mg/m³.
- Below 10 mg/m³, the MERIS 3-band algorithm can produce negative Chl values.
- A modification of the MERIS 3-band algorithm, using curvature or derivative principles, shows improved performance overall and does not produce negative Chl (Figure 4).
- Phycocyanin – an indicator pigment of cyanobacteria – can be retrieved from Rrs.
- A new PC algorithm of Mishra et al. (2013) was applied, which uses output from a modified version of QAA adapted to eutrophic waters incorporating Rrs data from 620 and 709nm (Figure 5).
- Eutrophic QAA has slight improved retrievals compared to oceanic QAA for total absorption (in situ absorption components not yet ready from our field data).
- The Simis et al (2005) PC algorithm shows the better performance (Figure 5), although both the Simis and Mishra algorithms should improve with regional tuning.

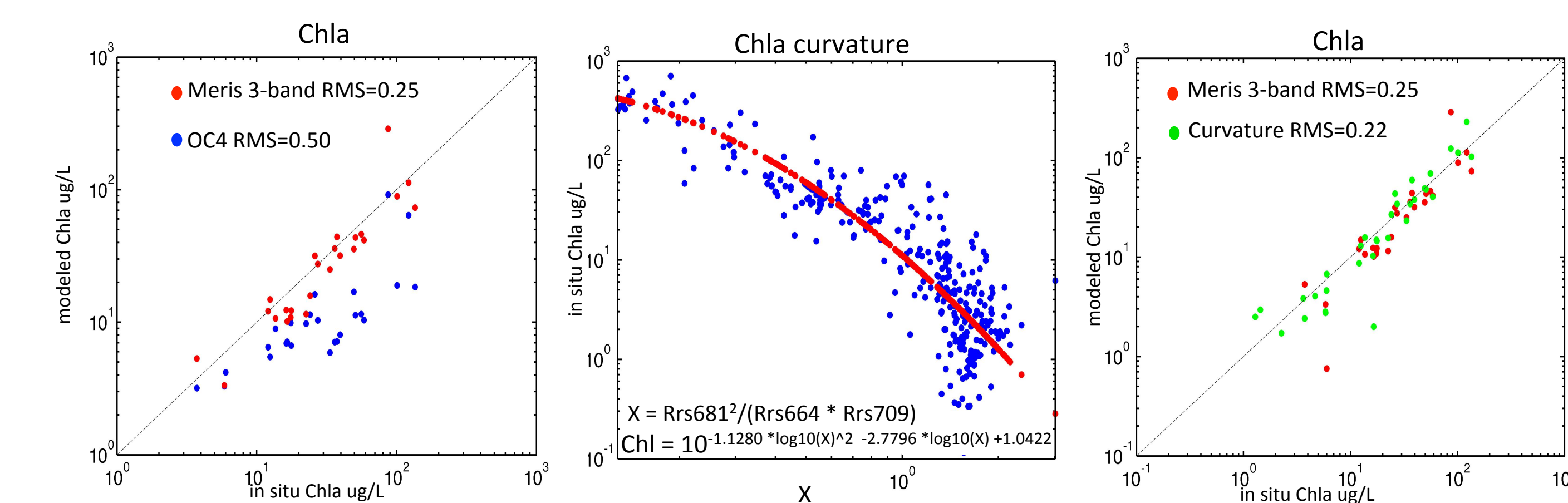


Figure 4. Chlorophyll algorithm performance based on the 2013/2014 data set. Left: Modeled OC4 Chl (blue) shows systematic low retrievals, while MERIS 3-band (red) Chl algorithm performs better at higher ranges (but returned negative Chl at levels < 10 ug/L). Middle: Development of an alternative 3-band Chl algorithm based on curvature (manuscript in prep) using a separate lake data set (Moore et al, 2014). Right: Curvature algorithm outperforms MERIS 3-band, and captures lower Chl range.

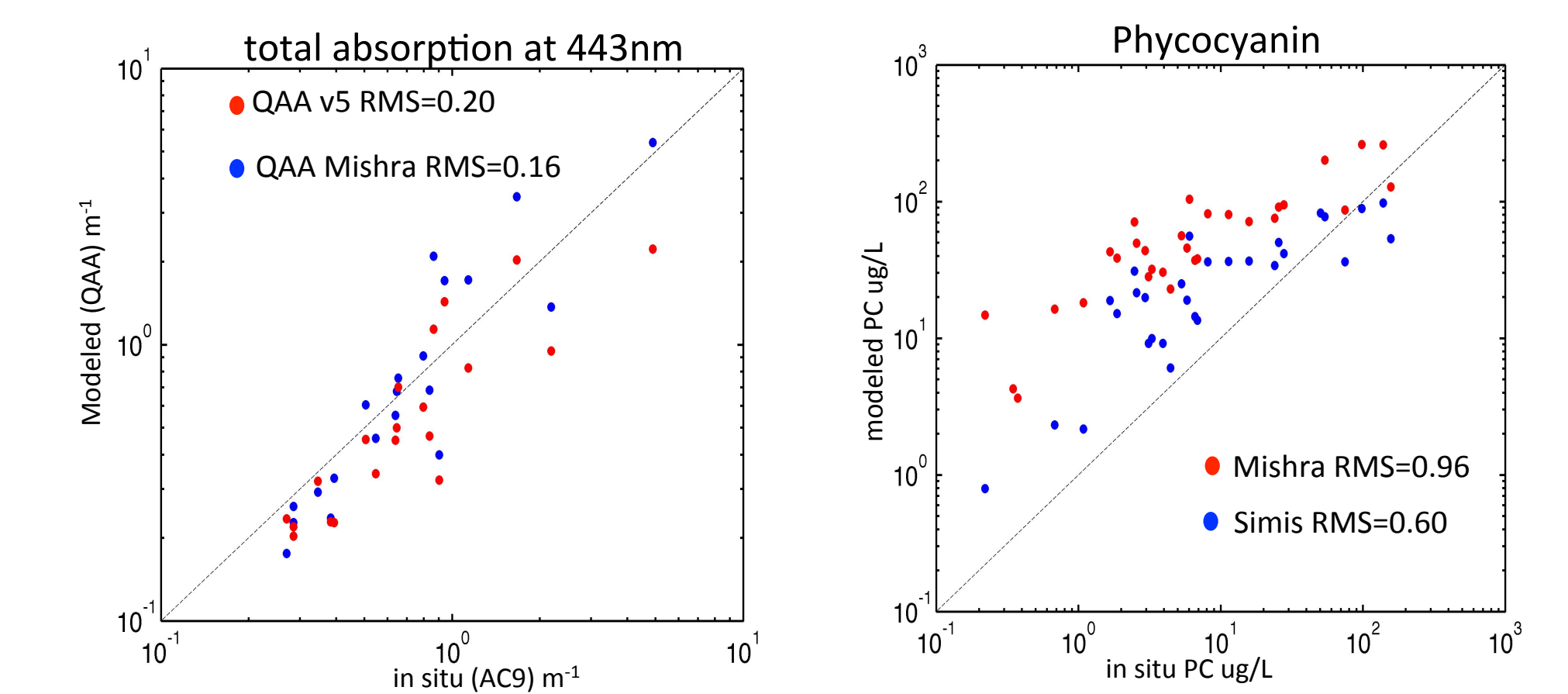


Figure 5. Left: Application of adapted QAA to eutrophic waters to retrieve absorption at 620/709 bands, needed for PC algorithms. Eutrophic QAA total absorption shows slight improvement over QAA v5 at 443nm (similar at other bands). Right: PC retrievals for Simis et al (2005), and Mishra et al (2013) using QAA phytoplankton absorption products at 620 and 709nm.

Summary

- Western Lake Erie experiences a wide range of chlorophyll concentrations, including eutrophic summertime conditions dominated by *Microcystis* blooms.
- High backscattering properties of *Microcystis* blooms impact Rrs in the green/red/NIR region (between 550 and 800 nm).
- The wide range requires algorithms that can accurately retrieve in moderate and high chlorophyll concentration, for which the blending approach of Moore et al (2014) is suited.
- The MERIS 3-band chlorophyll algorithm performs very well with *Microcystis* blooms across a large range of chlorophyll concentrations beginning around 10 mg/m³.
- A new chlorophyll algorithm adapted from the MERIS 3-band algorithm, based on curvature principles, has advantages in 1) avoiding negative retrievals and 2) producing the lowest RMS compared to the other chlorophyll algorithms.
- Phycocyanin retrievals can help distinguish HAB from non-HAB high chlorophyll events. The Simis et al (2005) and Mishra et al (2013) show good potential for PC retrieval from Rrs in western Lake Erie.

References

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