Assessing the spatial distribution and physical drivers of cyanobacterial blooms in Western Lake Erie

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Abstract: Despite efforts to reduce the occurrence of harmful algal blooms (HABs) in western Lake Erie, blooms recur annually due to agricultural runoff, storms with high winds and heavy rains, and weak lake circulation patterns. The influence from river inputs on the spatial and temporal characteristics of HABs remains relatively unknown. The Detroit River, which contributes about 80% of the basin's total inflow can have a large influence on the spatial and temporal distribution of the bloom. To understand this, optically classified imagery, *in situ* water measurements, and meteorological and river discharge observations were compiled and synthesized to examine the spatiotemporal variability of the Detroit River, HABs, and their interaction. Results indicate the presence of a defined Detroit River plume, which varies in size depending on wind and water current conditions within the lake. While the river's high discharge has an impact on the entire basin, strong winds in the spring, fall, and during summer storms pushes the Detroit River further south into the basin. This increases the spatiotemporal interaction between the Detroit River and HAB by limiting the bloom's northerly extent and diluting bloom water conditions. These results reveal the importance of the Detroit River's impact on blooms. A greater understanding of the Detroit River's role in the lake can improve the ability to predict bloom spatial variability.

Keywords: Detroit River, Lake Erie, Harmful Algal Blooms, Water Quality, Satellite Imagery

Executive Summary: Despite efforts to combat harmful algal blooms (HABs) in western Lake Erie through nutrient reduction, HABs continue to occur year after year. HABs are concerning because they can produce toxins that are dangerous to human and environmental health and local coastal economies. Excess nutrients enter into the lake from the Maumee River through fertilizer runoff from farms. Additionally, weak currents in Lake Erie's western basin are not strong enough to dilute nutrients. The height of the bloom occurs when lake water temperatures are highest in July through September.

While the Maumee River is the main culprit for feeding blooms, the Detroit River is the largest influence on water circulation in western Lake Erie. The Detroit River accounts for approximately 80% of the total river inflow into the lake, whereas the Maumee River makes up about 10% inflow. HABs do not occur near the mouth of Detroit River due to relatively low nutrient concentration and high river discharge. However, the Detroit River's seasonal influence on HAB spatial variability within the basin is relatively unknown. Continuous monitoring of Detroit River water characteristics has not been completed, limiting knowledge about how the river influences HAB conditions and how physical drivers, such as wind and the river's own discharge, affect the river plume's spatial characteristics in the lake.

These two rivers look different when monitoring western Lake Erie using satellite imagery; the Detroit River appears clearer and the Maumee River is less so. By using this information, the river and bloom can be differentiated from each other and we can begin to understand how they interact with each other. The HAB does not occur in the Detroit River plume, which moves depending on prevailing wind direction. Strong winds in the spring and fall can push the Detroit River further south, which then limits the northern extent of the bloom. The satellite imagery shows a clear boundary between where the Detroit River plume stops and where the HAB begins.

This interaction is also captured using in-water measurements, such as buoys or field measurements. Strong winds can significantly change water movement and a given water mass that a buoy is sampling at any given time. To understand these changes, satellite imagery is used to help identify if a buoy is sampling water from the Detroit River or HAB. These instances are then grouped together to help define the water quality characteristics of the river and bloom. A shift from HAB to either Detroit River or Lake Erie water typically follows a change in water direction. Buoy observations also detect this change through its water quality measurements, such as a decrease in chlorophyll-a fluorescence, indicating that the bloom has moved away from the buoy, and lower conductivity, which indicates that the buoy is most likely sampling Detroit River water.

Introduction: Harmful algal blooms (HABs) in western Lake Erie (WLE) continue to occur despite efforts to combat them via nutrient reduction. HABs in WLE are dominated by several species of *Microcystis* [2], which are cyanobacteria capable of producing microcystin, a toxin harmful to humans and wildlife. WLE is prime habitat for bloom growth due to its shallow waters and continual nutrient loading from surrounding agriculturally-impacted rivers [4]. HABs are primarily driven by weak lake wide circulation patterns and large storm events with high winds and heavy rainfall that bring agricultural fertilizer runoff into the lake from the Maumee River [5, 6, 10].

Although the Maumee River is the primary nutrient driver, the Detroit River (DR) has a significant influence on WLE's hydrodynamics [6] due its significantly higher discharge (5300 m^3 s^{-1}) compared to the Maumee River (150 m^3 s^{-1}) [1]. The DR's flow prevents blooms from occurring near the river mouth and it typically remains HAB free [9]. When the river discharge is combined with a northerly wind, the DR's influence can spread further south, impacting the HAB's spatial extent by diluting nutrient rich waters and minimizing bloom severity [5, 6]. However, the DR's direct influence on bloom spatial and temporal variability can only be inferred. There is a lack of continuous monitoring of DR water quality characteristics [3], limiting knowledge about how the biogeochemistry of the river influences bloom conditions and the plume itself.

This research integrated *in situ* measurements, optically classified satellite imagery, meteorological observations, and river discharge observations to determine the primary physical and environmental drivers of the DR plume and HAB in WLE. With these data streams, this study focused on the following goals: 1) utilize previously identified water masses within WLE to characterize spatiotemporal variability of the DR plume and HABs during a bloom growing season; 2) determine the primary physical and environmental drivers of the plume and HAB, and; 3) characterize the spatiotemporal influence the DR has on distribution of HABs in WLE.

Project Narrative: To identify and distinguish the DR and HAB from each other and the surrounding water masses, I analyzed two different optically classified satellite remote sensing products. The first is an optical water type (OWT) classification, which was used to identify and track the variability of distinct features associated with the bloom and river. Moore et al. (2014) identified seven different OWTs, which grouped optically similar waters based upon characteristics of the water itself, non-living (e.g., sediments) and living (e.g., phytoplankton) particles, and colored dissolved organic matter (CDOM). The other optically classified satellite imagery used was the cyanobacterial index (CI), which was used to analyze the spatiotemporal variability of HABs [10]. CI imagery is used to estimate the size and presence of HABs throughout the summer bloom season. Combined, both products provide a method to identify and analyze the spatial and temporal variability of different water masses within the basin.

In addition to classified satellite imagery, real time water quality data measured by a Land/Ocean Biogeochemical Observatory (LOBO) buoy was used to monitor the temporal and spatial variability of WLE waters. Located near the center of WLE, continuous observations of chlorophyll-*a* fluorescence, phycocyanin, CDOM, oxygen, phosphate, temperature, turbidity, and conductivity were recorded in the summers of 2013 and 2014. The Great Lakes Environmental Research Laboratory (GLERL) and the Cooperative Institute for Great Lakes Research (CIGLR) have an existing HAB program that collects water samples in WLE weekly throughout the summer. These water quality monitoring sites captured similar water quality parameters as the LOBO. When using buoy data, it is important to understand that this information provides a snapshot of water characteristics at time of sampling. Combining these data with physical dynamics, such as wind, provides greater context to water quality changes detected in field measurements.

Based upon OWT persistence calculations from 2002-2014, the DR plume is predominately located in the northeastern section of WLE (>80% persistence; Fig.1). Spatial variation occurs due to seasonal wind characteristics. Strong winds are more prevalent in the spring and fall, though may occur in the summer due to storm events, which pushes the DR plume further south away from the river mouth.

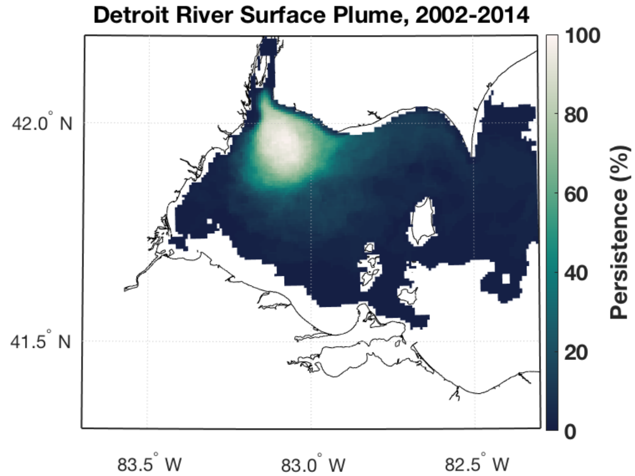

Figure 1: Average persistence of the Detroit River plume.

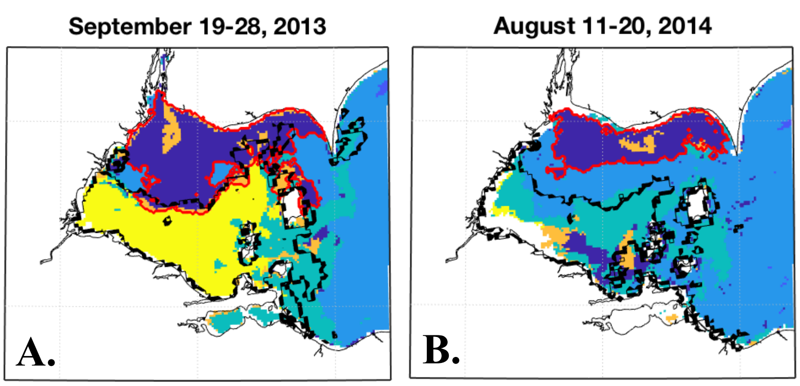

Figure 2: Detroit River (red) and HAB (black) delineations over OWT classification. Boundaries between these different masses may touch (A) or have a defined boundary (B).

While the relationship between Maumee River spring discharge and bloom intensity is exponentially strong, the DR itself does not drive bloom intensity. It does limit the northerly extent of the bloom, which is observed through the OWT imagery (Fig. 2). There is a distinct boundary between the Detroit River and the rest of WLE (Fig. 2A). Since the river "drains" the rest of the Great Lakes, the DR has a lower particulate load than the well-mixed waters of WLE. An optical gradient is present and indicates a shift from less (DR) to more optically complexity (WLE) [8] (Fig. 2B). There is a typically a band of mixed water between the DR (red) and HAB (black).

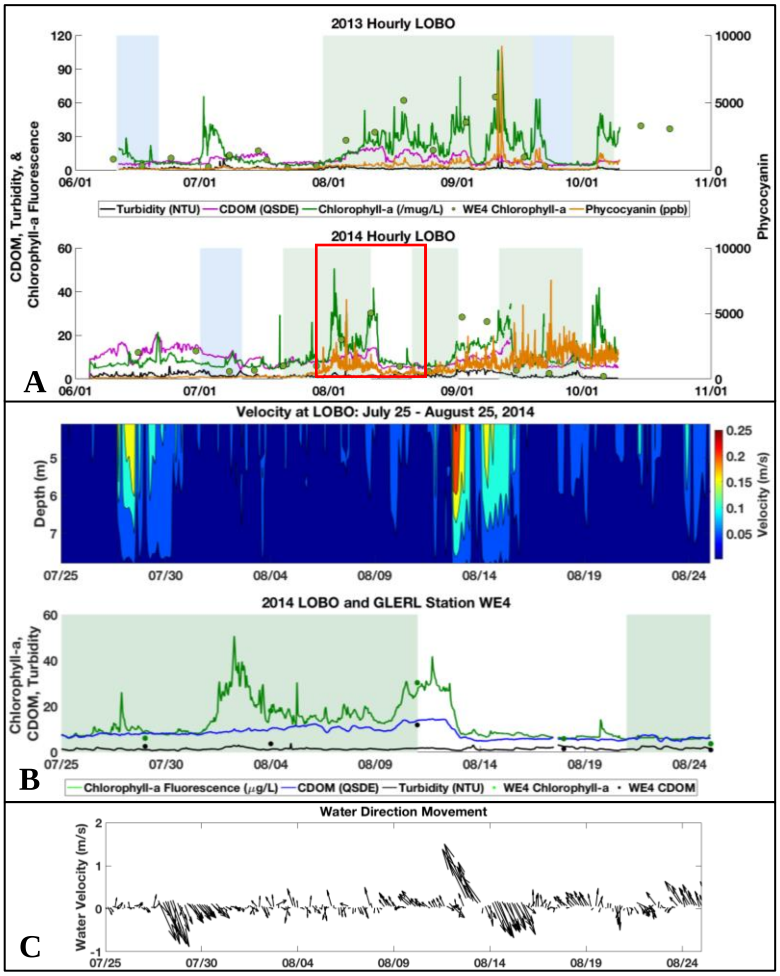

Figure 3: 2013 and 2014 LOBO time series (A) with indication of sampling in Detroit River (blue) or bloom (green). Thunderstorm winds on August 12, 2014 (red outline in A; B) is depicted, indicating a change in water mass, most likely due to Detroit River waters coming from the north (C; arrows point in direction of movement).

The OWT and CI were then used to define when the LOBO and other field measurements were sampling in either the DR or HAB. These instances were grouped together to define the water quality characteristics of the different water masses. Any changes in detection by the LOBO typically follows a wind event or directional change in water (Fig. 3 A). While DR discharge remains the same, northerly winds can change water currents (Fig. 3C), shifting water quality characteristics (Fig. 3B) in response to this event.

<u>Research Implications:</u> Multiple data streams (e.g., satellite monitoring, *in situ* observations) are needed to fully characterize not only the spatiotemporal HAB dynamics and its interaction with physical forces in the basin, but to fully characterize the DR's influence on the bloom. Recognizing the importance of the river on HAB characteristics provides a more wholistic view of WLE HAB variability. While the DR does not impact bloom intensity, it does play a role in its location, impacting the spatial variability of blooms.

Applications/Benefits: In the short term, this project can help water managers better understand water quality changes observed by in-water measurements aimed to detect bloom presence. For a longer timeframe, this research can leverage increased monitoring of the DR in the future. Even though the river itself does not contribute to bloom severity, its significant influence on the basin itself should elicit interest in DR water quality characteristics.

Research Outputs: I have given four poster presentations on this research project. I presented at the following: Ocean Sciences Meeting (2016 and 2018), International Association of Great Lakes Research Conference (2017), and at Michigan Technological University's World Water Day Poster Competition (2018). I placed third at the World Water Day original research poster competition. This research also was part of a larger project that resulted in the following publication in which I was a contributing author: Moore et al., 2017. "Bio-optical properties of cyanobacteria blooms in western Lake Erie." *Frontiers of Marine Science*.

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