SEA GRANT PROJECT SUMMARY FORM (90-2)

**TITLE:** Hindcasting cyanobacterial harmful algal bloom timing and extent in western Lake Erie using lake surface temperature variability  
**AFFILIATION:** Stony Brook University  
**EFFORT:** 0.18 mo

**PRINCIPAL INVESTIGATOR:** Dr. Timothy Davis  
**AFFILIATION:** Bowling Green State University  
**EFFORT:** 0.18 mo

**ASSOCIATE INVESTIGATOR:** Dr. Owen Doherty  
**AFFILIATION:** Eagle Rock Analytics  
**EFFORT:** 1.08 mo (OSG)

**ASSOCIATE INVESTIGATOR:** Dr. Chris Gobler  
**AFFILIATION:** Stony Brook University  
**EFFORT:** 0.18 mo

**PROJECT NUMBER:**

**SEA GRANT STRATEGIC PLAN CLASSIFICATION:**

**KEYWORDS:** Harmful Algal Blooms, Lake Surface Temperature, Ecosystem Modeling, Lake Erie

**OBJECTIVES:**
This project is a collaboration between Bowling Green State University, Eagle Rock Analytics and Stony Brook University and leverages the 10+ years of weekly to bi-weekly water quality data collected by NOAA-GLERL/CIGLR, OSU Stone Laboratory, BGSU and the University of Toledo. The primary objective is to understand; (1) timing of Harmful Algal Blooms in response to lake surface temperature variability, (2) phosphorus limitation and the potential for Harmful Algal Blooms and (3) decoupling responses to Maumee River discharge rates.

1. **TIMING OF HARMFUL ALGAL BLOOMS IN RESPONSE TO LAKE SURFACE TEMPERATURE VARIABILITY**
The primary objective of this project is to quantify the degree to which recent increases in the occurrence and frequency of Cyanobacterial Harmful Algal Blooms (CHABs) are driven by variability in Lake Surface Temperature (LST) in western Lake Erie (WLE). A daily model of CHABs in WLE will be used to identify bloom onset date, duration and termination over the past 15 years, and will be related to observed variability in LST. This work will test the hypothesis that the seasonality of CHABs has changed with earlier spring onset being observed. Hindcasting of prior years to validate model quality is a critical first step in model development for real-time forecasting applications, which will serve the yet unmet needs of decision makers and stakeholders.

With additional resources from Lake Erie Protection Fund to support a Master’s student, we also propose:

2. **PHOSPHORUS LIMITATION AND THE POTENTIAL FOR HARMFUL ALGAL BLOOMS**
Inclusion of field measurements in mathematical models of CHABs has been limited through irregular collections of nutrient data. Here we propose to make use of the PIs high resolution observations of phosphorus and other nutrients in our high-resolution CHAB modeling. Through inclusion of both phosphorus and LST in our CHAB growth model we will be able to quantify the contribution of each to key historical occurrences of CHAB in WLE.

3. **DECOUPLING RESPONSES TO MAUMEE RIVER DISCHARGE RATES**
In WLE a paradox exists: CHABs are increasing while total phosphorus is not. Maumee River Discharge has previously been related to occurrence of CHABs in WLE, with the associated hypothesis that riverine discharge drives CHAB occurrence through phosphorus loading. Maumee River Discharge is also associated with changes in LST, a key driver of CHAB occurrence and frequency. Our model of CHAB growth, which includes both phosphorus and temperature controls, can be applied to decouple CHAB forcing and address the paradox. We will demonstrate how WLE LST responds to changes in Maumee River discharge and how Maumee River discharge is associated with regional climate variability. This work will test the hypothesis that Maumee River discharge is a proxy for LST variability in WLE, and drives CHAB occurrence through LST anomalies.

**SEA GRANT FUNDS:**

**STATE MATCHING FUNDS:**

**PASS-THROUGH FUNDS:** $
METHODOLOGY:

1. TIMING OF HARMFUL ALGAL BLOOMS IN RESPONSE TO LAKE SURFACE TEMPERATURE VARIABILITY

**Data.** The surface area of Western Lake Erie is roughly 2980 km², including embayments (i.e. Maumee Bay and Sandusky Bay) which are ecologically and limnographically important areas to resolve. It is a remote sensing challenge to provide; the ultrahigh resolution needed to resolve the complex terrain, the daily timescale needed to understand CHAB dynamics, with a sufficiently long record to address climate variability. The GHRSST Level 4 MUR Global Foundation Sea Surface Temperature Analysis (v4.1) provides ultrahigh (1km) resolution, daily, over the period of 2002 – 2017. The 15+ year record may allow for observed trends and relationships to be quantified and understood.

**Model.** We will model the dominant open water bloom forming cyanobacterium, *Microcystis* as well as *Planktothrix*, which dominates the tributaries such as Sandusky Bay and Maumee River and a dominant summertime diatom, *Aulacoseira*. For each genus, a temperature-growth rate response curve will be generated. As the exact shape of these curves are assumed, rather than empirically determined, we rely on conservative techniques (i.e. bootstrapping) to generate the mathematical representation (fitting techniques) of the growth rate curves to be used in the model. The model successfully propagates estimated uncertainty from our conservative fitting techniques so that all results will include bounded uncertainty measures. In this way our results will be robust and resilient to choices of experimental data, growth rate curve fitting, and the distribution of observed data.

The model will produce growth rates for each genus on each day that data is available (2002 to 2017). When the growth rate exceeds 75% of the maximum potential growth for a CHAB genus, we tag this day as having the potential to experience a CHAB event. Our model tracks the first day of bloom potential, last day of bloom potential, total number of days of bloom potential and the duration of the season on an annual basis. In this way variability in the onset and duration of bloom potential are known. Insight into ecosystem dynamics will come from comparing onset and termination dates for CHAB causing genera and the genera that predate them.

Statistical analysis of model outputs will rely upon conservative, non-parametric methods. The magnitude of trends among growth, blooming season, and the timing of bloom onset or termination will be determined using the non-parametric Theil-Send magnitude estimation method. A corresponding Mann-Kendall test will determine significance of the observed trend. Non-parametric methods will be implemented to reduce the influence of: non-normality, outliers and asymmetry (skewness) in the LST products or growth-rate response data, consistent with our robust and resilient approach to model development.

If funds from Lake Erie Protection Fund are made available to support a Master’s student:

2. PHOSPHORUS LIMITATION AND THE POTENTIAL FOR HARMFUL ALGAL BLOOMS

**Data & Interpolation.** Phosphorus is well understood to be a primary limiting nutrient during CHABs as well as the nutrient that can predict seasonal bloom biomass in western Lake Erie. However, measurements of phosphorus require great effort to acquire and process, and have historically been limited in coverage and frequency. NOAA-GLERL/CIGLR has performed weekly sampling at regular locations across western Lake Erie from 2008 to the present. University of Toledo and OSU Stone Laboratory also have bi-weekly datasets that can compliment the GLERL-CIGLR weekly data. These comprehensive datasets contain physical, biological and chemical observations, including critical measurements of multiple species of phosphorus. The MS student, supervised by PI Davis will assist with compiling these data. The student will assist co-PI Doherty to conduct cubic spline interpolation of measured phosphorus (using the Akima scheme) to produce weekly maps of phosphorus across western Lake Erie. Interpolation of measurements onto the high resolution temperature grid already in the model, will allow us to produce directly comparable phosphorus limited growth rates of key phytoplankton genera.

**Threshold Limitation Model.** We will update our model to cap maximum growth rates as a function of the LST and available phosphorus. For each previously saved variable, two output variables will be saved; temperature limited and temperature-phosphorus limited. Statistical analysis will demonstrate how and where phosphorus limitation is occurring within different phytoplankton taxonomic groups, allowing for critical understanding of the interplay ecosystem dynamics and physical and chemical forcings.
3. Decoupling Discharge Rates and Harmful Algal Bloom Response

Maumee River and LST: Co-PI Doherty will work with the MS student to quantify the co-variability between discharge rate of the Maumee River and LST in WLE. Our analysis will include station based and gridded weather data. Seasonal composites will show the physical means (i.e. air temperature, precipitation rates) by which regional climate variability drives discharge and LST anomalies in WLE.

Partial Correlation Analysis. The Maumee River discharges both nutrients and warm water in WLE in the spring season. Discharge itself is a function of regional climate, with discharge increasing in seasons that are dominated by warm-humid air masses, the presence of which also warms the surface of Lake Erie. Disambiguation of these coupled processes is necessary to properly explain the role of the Maumee River in driving occurrences of CHAB, and resolve the phosphorus paradox. Co-PI Doherty and the MS student will use partial correlation analysis to control for the variability of phosphorus, in quantifying the relationship between discharge and LST (and vice versa) in both our modeled data and observation.

Ground Truth Model Output: The MS student will also assist in ground truthing model hindcasts via Fluoroprobe (BBE, Germany) data collected weekly at six to eight sites in western Lake Erie, by NOAA GLERL since 2014 and bi-weekly by the University of Toledo and The Ohio State university Stone Laboratory. This represents a unique opportunity to validate an ecosystem model on a weekly basis throughout a full growing season, a crucial step in model development which is rarely supported at such high temporal frequencies. The Fluoroprobe collects information on algal community composition based on pigment ratios and can distinguish between cyanobacteria, diatoms, green algae and cryptophytes. This high degree of discernment from the Fluoroprobe, in conjunction with a numerical model making predictions for a number of key taxa, will allow us to diagnose the skill of the model on an individual taxon basis, leading to model improvement and improved understanding of ecosystem interactions. The unique coupling of Fluoroprobe data with nutrient data will allow for improved understanding how key ecosystem processes respond to changes in nutrient concentration. This work will inform future model development, and provide baseline model skill scores which can be incorporated in future efforts to generate probabilistic forecasts of HAB outbreaks in near real-time. Finally, these all of data will be incorporated into the student’s thesis.

Rationale:
Cyanobacterial harmful algal blooms (CHABs) occur in freshwaters worldwide, including some of the most socio-economically important systems on Earth (Paerl and Otten, 2013). Nationally, CHAB events contribute to economic losses associated with drinking, recreational, and agricultural water resources that exceed $2 billion dollars annually in the U.S. (Dodds et al., 2009). The Lake Erie Basin is the most densely populated of the North American Great Lakes (IJC, 2014), and its ecosystem services include the recreational, commercial, and drinking water resources for 11.6 million people (LAMP, 2011). Western Lake Erie (WLE) experiences anthropogenic eutrophication and annual, toxic CHAB (Steffen et al. 2014). Recent blooms (in 2011 and 2014) had enormous economic impacts estimated at $65 million (Bingham et al. 2015) and caused the 2014 shutdown of Toledo, Ohio's drinking water system (Steffen et al., 2017). Shifts in regional climatology, specifically warming and more extreme hydrologic events, leading to increased nutrient loading, is predicted to exacerbate these CHAB in WLE (Michalak et al., 2013). However, one factor that is often overlooked is the potential shift in the onset of the bloom that may accompany earlier increases in water temperature. In general, cyanobacteria grow well above 15°C and reach maximum growth rates between 20 and 30°C (Konopka and Brock, 1978). Currently the western Lake Erie CHAB generally forms around mid to late-July, peaks in August and dissipates by mid-October. However, if climate shifts cause warmer springs, the timing of bloom initiation could be shifted earlier in the summer. Furthermore, warmer fall temperatures may allow the blooms to persist longer than they currently do. This is problematic for several reasons. First, it could extend the bloom season causing water treatment plants to have to treat longer which increases cost to the consumer. Second, a longer growing season extends the ‘risk period’ for a potential exceedance of Ohio’s drinking water guidelines for microcystins. Finally, if the bloom onset shifts earlier in the summer, this could be problematic for water treatment managers who may not be prepared for an early bloom which, again, can increase the risk of a Toledo water crisis repeat. Therefore, it is critical to develop a model that can aid in predicting the potential shifts in bloom dynamics associated with a changing climate and nutrient loading regimes.
References: