Cooperative Institute for Great Lakes Research

Performance Progress Report

NA17OAR4320152

July 1, 2017- March 31, 2018
Year One (9-month report)

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Cooperative Institute for Great Lakes Research
CIGLR
Great Lakes Science for Society

Table of Contents

Executive Summary

As we approach the one year anniversary of the new CIGLR Cooperative Agreement, we are measuring our impact by evaluating our grant success, research outcomes, collaborations with NOAA and our partners, and ECO program activities. During the first 9 months of the 2017-2022 Cooperative Agreement, CIGLR received $4.2 million in NOAA funding, supplemented by $480,000 in support from the University of Michigan. We immediately began building a stronger set of research partnerships across the Great Lakes, sub-awarding nearly one-third ($1.2 million; 30%) of our funding outside of the University of Michigan to foster career training opportunities and collaborative research with NOAA. Eighteen research projects underway have laid a solid foundation for scientific output, with new cutting-edge models and tools under development to support NOAA's mission in the Great Lakes. Activities during the first year of the Cooperative Institute for Great Lakes Research (CIGLR) Cooperative Agreement reflect our broader vision for multidisciplinary research, meaningful partnerships, and impactful programs that advance NOAA's mission in the Great Lakes.

Research

In our proposal to form a new Cooperative Institute in the Great Lakes, we outlined a research program that emphasized early detection and warning systems for a weather-ready nation and the integration of social science research into our already-established natural science research portfolio.

Within the first months of the new CIGLR Cooperative Agreement, we hired three social scientists to join our harmful algal bloom (HAB) and invasive species research teams, to integrate human dimensions of two of the most perplexing issues facing the Great Lakes. We are placing a major emphasis on the co-design of research and products with the stakeholders who will ultimately use them. As a result of a CIGLR Summit

CIGLR research technician Emily Davenport, left, NOAA's Timothy Davis and Roman Marin of Monterey Bay Aquarium Research Institute prepare to deploy the autonomous laboratory ESPniagara in western Lake Erie.

on the valuation of ecosystem services, we are taking lead role in organizing an effort to develop comprehensive accounting of the benefits that the Great Lakes provide.

New research projects have positioned us in the forefront of early warning and detection of human hazards in the Great Lakes. Our HAB research team deployed the first-ever "lab-in-a-can" in the Great Lakes, the ESPniagara, to measure real-time concentrations of algal toxin in western Lake Erie and provide essential information to drinking water plant managers for the protection of public health. At the same time, we developed a miniature prototype of the ESPniagara that will be contained in an autonomous underwater vehicle (AUV), thus enabling targeted mobile measurements of algal toxin concentration. Our modeling team made new advances in developing Great Lakes ice and lake effect snow forecasts, for use by the US Coast Guard and the National Weather Service to safeguard human life and property.

Partnerships

In an effort to broaden NOAA's research capacity, intellectual expertise, and geographic scope across the Great Lakes, CIGLR formed a new Regional Consortium with the award of our new Cooperative Agreement. Nine universities and five private sector organizations are partnering with CIGLR and NOAA GLERL to conduct research, transition research to operations and applications, and engage with stakeholders. The nine partner universities have all agreed to reduced indirect cost rates (26%) on sub-awards from CIGLR, ensuring NOAA a uniformly-low cost of research across the Great Lakes. In addition to five R1 institutions, our Regional Consortium partners include the first Canadian university to join a Cooperative Institute. Our private business and non-government organization partners are a major expansion of the traditional NOAA concept of partnerships.

With greater commitment to CIGLR from the University of Michigan, we are investing in our new network of partners throughout the Great Lakes by offering competitive programs that connect our Regional Consortium with NOAA scientists to broaden research capacity and facilitate co-design. During the first year of the Cooperative Agreement, we dedicated $258,000 in cost share funding from the University of Michigan to fund three postdoctoral fellowships, two graduate student fellowships, and three summits that involve collaboration between our partners and NOAA. These programs are designed to build a strong network of partners that contribute directly to NOAA's priorities in the Great Lakes. Less than three months in to the new Cooperative Agreement we held our first annual All Partners Meeting at NOAA GLERL, which afforded each partner and NOAA GLERL scientist to give a short oral and/or poster presentation. This highly successful first meeting included one-on-one and research team meetings to develop new research collaborations.

Programs

Implementation of the new Engagement, Career Training, and Outreach & Communications (ECO) Program has increased the impact of CIGLR's research by extending our reach to stakeholders, policy makers, and the public. The ECO Program also strengthens our long-standing commitment to training the next generation of Great Lakes scientists, with 29 students and postdocs supported by a CIGLR fellowship or project during the 9-month reporting period. Within the ECO Program, we strive to increase diversity, equity, and inclusion in the STEM disciplines and have developed recruiting plans to encourage fellowship applicants from a wide variety of backgrounds. Our ECO Program has also boosted public education about NOAA research and Great Lakes science, reaching thousands of people through multiple platforms including social media (>4,000 followers), e-newsletters (>500 subscribers), and interactive tables at outreach events (>3,000 participants). We are engaging the end users of our products, from resource managers to elected officials, to ensure they have the information needed to make decisions that support sustainability and protect human health in the Great Lakes.

CIGLR Summer Fellows engage a local family with an interactive Great Lakes map and talk about invasive species during a community outreach event.

Introduction

Beginning with the first Cooperative Agreement in 1989 that established the Cooperative Institute for Limnology and Ecosystems Research (CILER), the University of Michigan has partnered with the NOAA Great Lakes Environmental Research Laboratory to advance NOAA's mission in the Great Lakes. NOAA has awarded 7 consecutive multi-year Cooperative Agreements to the University of Michigan since the inception of CILER, with the most recent in 2017 marking the formation of a new, re-envisioned Great Lakes CI. The inception of the Cooperative Institute for Great Lakes Research (CIGLR) brings an increasing breadth of research, which has evolved from the original focus on natural science (limnology and ecosystem ecology) to interdisciplinary work that includes social science, engineering, and design. While CIGLR builds on the strong foundation laid by CILER, the new institute differs from its predecessor in several ways: greater investment by the University of Michigan and our partners, more impactful partnerships, more interdisciplinary research, greater focus on co-design, and quicker transitions from research to application.

CIGLR Assistant Research Scientist Dr. Mark Rowe discusses the 2017 Lake Erie algal bloom with charter boat captains.

During Year 1 of the CIGLR 2017 Cooperative Agreement, we received $4.22 million in NOAA funding for 20 research projects, education and outreach programs, and administrative costs. The EPA-administered Great Lakes Restoration Initiative (GLRI) continued to support a significant proportion of CIGLR's activities through collaborative projects with NOAA GLERL. In FY18, 32% ($1.33 million) of CIGLR's research was funded by GLRI through the Cooperative Agreement. The University of Michigan contributed $257,782 of its $2.53 million cost share commitment plus $224,318 in in-kind support during Year 1, to fund programs that foster partner collaborations, including Summits and Working Groups, graduate student and postdoctoral fellowships, and outreach and engagement activities.

Mission and Goals

CIGLR's mission is to lead exciting new research, train the next generation of scientists, and turn research

into action for safe and healthy Great Lakes communities. To achieve this mission, all CIGLR activities revolve around 6 goals:

1. Research institute. CIGLR operates a productive research institute that complements NOAA-GLERL's workforce with a highly-skilled, permanent group of research scientists, technicians, and staff that acts as a fully-integrated part of GLERL's scientific enterprise and serves to expand GLERL's research expertise.

2. Regional consortium. CIGLR expands GLERL's intellectual capacity and research infrastructure by building strong partnerships with universities, NGOs, and private-sector partners throughout the Great Lakes basin who share similar research and management goals in the Great Lakes.

3. Science translation. CIGLR helps translate NOAA research in the Great Lakes into action-oriented, science-based products that meet the needs of end-user stakeholders like natural resource managers, businesses, public utilities, and citizen users of data.

4. Engagement. CIGLR supports informed decision making by working directly with legislators, resource managers, and other stakeholders to develop the research programs, tools, and information needed for decision making that promotes sustainability in the Great Lakes.

5. Career development. CIGLR fosters the development of a diverse, skilled workforce by providing career training for undergraduates, graduate students, and postdoctoral fellows who will become the next generation of NOAA and Great Lakes scientists.

6. Outreach & communications. CIGLR advances Great Lakes environmental literacy by communicating the value, importance, and usefulness of NOAA's research to the general public at local, state, and regional levels.

Organization

The organization and operation of CIGLR is formatted in accordance with the NOAA CI Handbook, which outlines procedures for establishing and maintaining CIs. The University of Michigan School for Environment and Sustainability (SEAS) serves as the host and administrative lead for the CI, and bears responsibility for CIGLR operations and management. Consisting of a Research Institute and a Regional Consortium, CIGLR is a partnership between NOAA, universities, non-governmental organizations, and businesses (Figure 1). We work together to achieve environmental, economic, and social sustainability in the Great Lakes.

Administrative leadership consists of a Director, Associate Director, and a Program Manager who oversee and manage both the Research Institute and Regional Consortium (Figure 1). CIGLR administration is located at both NOAA GLERL and SEAS.

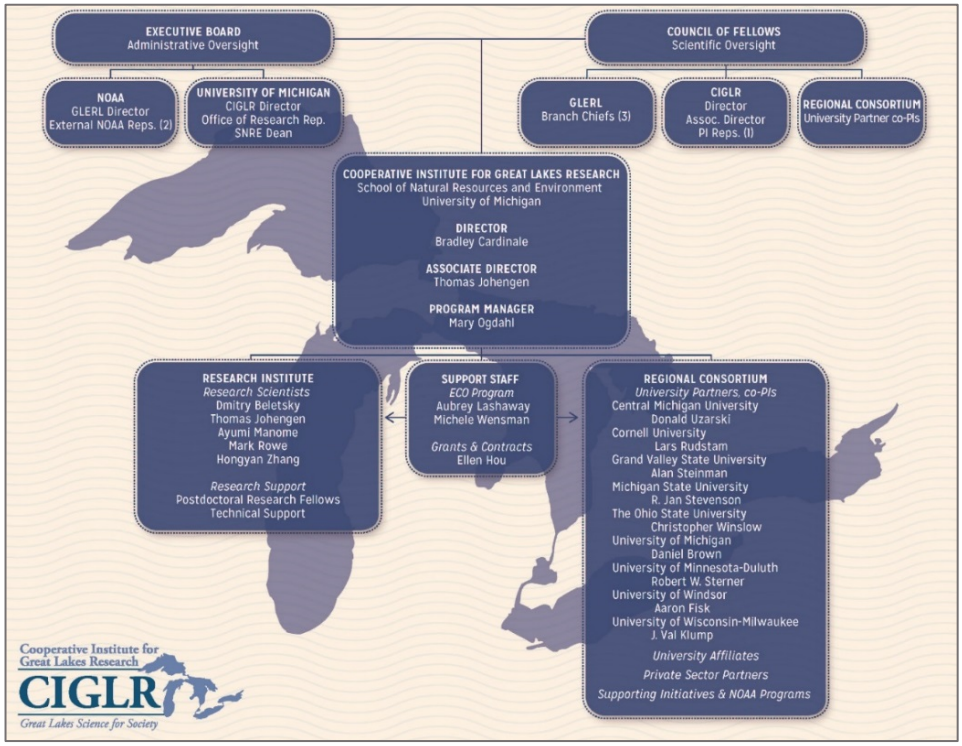


Figure 1. The organizational structure of CIGLR consists of a Research Institute and a Regional Consortium, which are overseen by an administrative leadership team and governed by an Executive Board and Council of Fellows.

The CIGLR Research Institute complements NOAA's workforce with a highly-skilled, permanent group of research scientists, postdoctoral fellows, technicians, and staff that expands NOAA's research expertise and is fully-integrated into NOAA's scientific enterprise. All CIGLR Research Institute personnel hold appointments at the University of Michigan and are collocated with NOAA GLERL. CIGLR Research Scientists serve as principal investigators on CIGLR Cooperative Agreement (NOAA) and external proposals, engage in collaborative research with NOAA scientists and Regional Consortium partners, and mentor undergraduates, graduate students, and postdoctoral fellows. CIGLR postdoctoral fellows work with CIGLR and GLERL Research Scientists to receive early career training in NOAA mission-related research topics in the Great Lakes. CIGLR research support staff work with CIGLR and GLERL principal investigators on technical aspects of their research projects.

The Regional Consortium (Figure 2) broadens our research capacity, intellectual expertise, and geographic scope across the Great Lakes. Consortium partners include nine universities and five private sector organizations that collaborate with CIGLR and NOAA GLERL to conduct research, transition research to operations, and engage with stakeholders. University partners function to expand NOAA's intellectual and geographic research capacity, while non-governmental organization partners bring their expertise with

engagement, and private sector business partners help facilitate the transition of research to application. Regional Consortium partners include: Central Michigan University, Cornell University, Grand Valley State University, University of Michigan, Michigan State University, University of Minnesota-Duluth, Ohio State University, University of Windsor, University of Wisconsin-Milwaukee, Fondriest Environmental, Great Lakes Environmental Center, LimnoTech, Michigan Environmental Council, The Nature Conservancy - Great Lakes, National Wildlife Federation - Great Lakes Regional Center.

Figure 2. CIGLR Regional Consortium, including University Partners, University Affiliates, Private Sector Partners, and Supporting Programs and Initiatives.

Together with our partners, CIGLR excels in both research and programs to advance NOAA's mission in the Great Lakes. CIGLR's research is focused on four themes that directly align with NOAA-GLERL research areas:

- Theme 1. Observing systems and advanced technology: monitoring environmental change to help society navigate the Anthropocene.
- Theme 2. Invasive species and food-web ecology: tracking the dynamics and functioning of Great Lakes ecological communities.
- Theme 3. Hydrometeorological and ecosystem forecasting: modeling physical and biological processes to help predict the Great Lakes health and future.
- Theme 4. Protection and restoration of resources: safeguarding habitats, natural capital, and ecosystem services throughout the Great Lakes

Our programmatic activities are designed to transition research into action, thus producing Great Lakes science for society. The components of our ECO Program include:

- Engagement. *Support informed decision making* by advising local, state, and federal policymakers and elected officials about the importance of the Great Lakes' ecosystem services for national security and prosperity.

- Career Training. *Promote a skilled and diverse workforce* by providing career training for undergraduates, graduate students, and postdoctoral fellows who will become the next generation of Great Lakes and NOAA scientists.
- Outreach & Communications. *Advance environmental literacy* by communicating the value, importance, and usefulness of NOAA's Great Lakes research to the general public at local, state, and regional levels.

Governance

Executive Board: administrative oversight

- Responsibilities:
  - Reviewing, providing recommendations on, and approving CIGLR's Strategic Plan.
  - Making recommendations to CIGLR's Director concerning the administrative budget.
  - Approving appointments for the Council of Fellows.
  - Reviewing the annual budget and progress report of the CI.
  - Reviewing agreements or addenda to CIGLR's Cooperative Agreement, as may be entered into in the future, and making recommendations about such agreements to the Director.
  - Reviewing general policies of CIGLR and initiating appropriate recommendations.
  - Assuring that CIGLR maintains a basin-wide approach in the Great Lakes and fully engages the Regional Consortium in research, outreach, education, and communications.
- Meeting frequency: Once per year
- Members:
  - Bradley Cardinale – Director, CIGLR, University of Michigan (Ex-Officio)
  - Carl Gouldman – Director, U.S. IOOS Office, NOAA National Ocean Service
  - Deborah Lee – Director, NOAA GLERL (Ex-Officio)
  - Jonathan Overpeck – Samuel A. Graham Dean, School for Environment and Sustainability, University of Michigan
  - Volker Sick – Associate Vice-President for Research, University of Michigan
  - Steven Thur – Director, National Centers for Coastal Ocean Science, NOAA National Ocean Service
- Meeting Dates:
  - May 30, 2018 (*upcoming*)

Council of Fellows: scientific oversight

- Responsibilities:
  - Providing leadership in maintaining high standards of research for the CI.
  - Analyzing the CI's programs and science direction, identifying critical research needs, and recommending new research foci.
  - Advising CIGLR's Director on selection of new Council of Fellows members and reappointment of current Fellows.

- Making recommendations to the CIGLR Director on the selection of Visiting Fellows.
- Reviewing grants and applications from Task IB non-administrative programs, including the Postdoctoral Fellowships, Visiting Fellows, and Graduate Research Fellowships, and making recommendations to the CIGLR Director about priority applicants.

- Meeting frequency: twice per year
- Members:
  - Bradley Cardinale – Director, CIGLR, University of Michigan (Ex-Officio)
  - John Bratton – Senior Scientist, LimnoTech
  - Philip Chu – Physical Scientist, NOAA GLERL
  - Patrick Doran – Associate State Director for Michigan, The Nature Conservancy
  - Aaron Fisk – Professor, Great Lakes Institute for Environmental Research, University of Windsor (CIGLR co-PI)
  - Steve Fondriest – President, Fondriest Environmental
  - Brad Garmon – Director of Conservation and Emerging Issues, Michigan Environmental Council
  - Tom Johengen – Associate Director, CIGLR, University of Michigan
  - J. Val Klump – Director, Great Lakes Water Institute, University of Wisconsin-Milwaukee (CIGLR co-PI)
  - Maria Lemos – Associate Dean for Research, School for Environment and Sustainability, University of Michigan (CIGLR co-PI)
  - Dennis McCauley – President and Principal Research Scientist, Great Lakes Environmental Center
  - Steve Ruberg – Group Leader, Marine Instrumentation Lab, NOAA GLERL
  - Lars Rudstam – Director, Shackelton Point Field Station, Cornell University (CIGLR co-PI)
  - Mike Shriberg – Regional Executive Director, National Wildlife Federation Great Lakes Regional Center
  - Al Steinman – Director, Annis Water Resources Institute, Grand Valley State University (CIGLR co-PI)
  - Robert W. Sterner – Director, Large Lakes Observatory, Univ. Minnesota-Duluth (CIGLR co-PI)
  - R. Jan Stevenson – Director, Center for Water Sciences, Michigan State University (CIGLR co-PI)
  - Donald Uzarski – Director, Biological Station and Institute for Great Lakes Research, Central Michigan University (CIGLR co-PI)
  - Hank Vanderploeg – Research Ecologist, NOAA GLERL
  - Chris Winslow – Director, Stone Laboratory, Ohio Sea Grant, Ohio State University (CIGLR co-PI)
  - Hongyan Zhang – Assistant Research Scientist, CIGLR, University of Michigan
- Meeting Dates:
  - September 25-26, 2017 – Annual Partners Meeting & In-Person Council of Fellows Meeting
  - May 10, 2018 (*upcoming*) – Semi-annual Council of Fellows Video Conference

Funding Distribution

The total funding received by CIGLR from July 1, 2017 through March 31, 2018 was $4,472,999. This amount includes $257,782 in cost share contributions from the University of Michigan. An additional $224,318 in in-kind support from University of Michigan includes IDC waivers, Research Scientist salary support, administrative support, and office space, for a total of $482,100 in University of Michigan support during the first 9 months of the Cooperative Agreement. Indirect cost rate reductions included 0% IDC on Task I funds and 0% IDC on subawards to Regional Consortium partners.

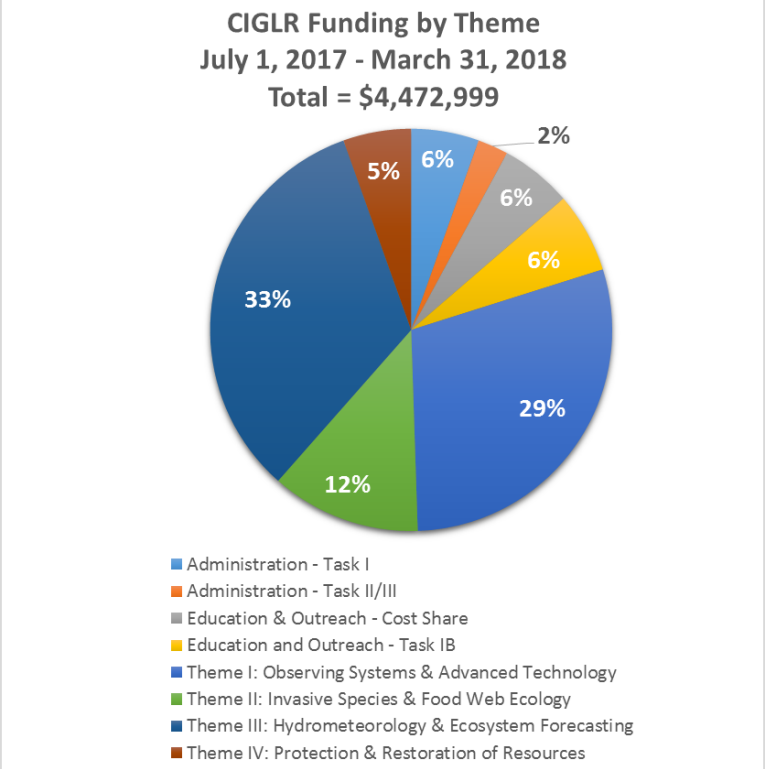


Figure 3. Funding distribution by CIGLR theme during the current Cooperative Agreement (July 1, 2017 through March 31, 2018). University of Michigan cost-share funding ($257,782) is included in this summary.

During the reporting period, funding supported 18 research projects across CIGLR Themes I-IV (80%), education and outreach activities (12%), and administration (8%) (Figure 3, Tables 1 & 3). Nearly one third ($1.2 million; 30%) of our Task IB and Task II/III funding was subawarded outside of the University of Michigan. Of these subawards, 43% went to members of our Regional Consortium to foster collaborative research with NOAA throughout the Great Lakes region (Table 2). The distribution of Task I funds is described in the following section.

Table 1. Summary of funding, by task and CIGLR theme, awarded to during the current Cooperative Agreement Award NA17OAR4320152, July 1, 2017 – March 31, 2018. Task I funds were used to support administration (Task IA) and education and outreach programs (Task IB). Administrative costs were further supported by Task II/III funding.

Task/Source	Theme	Funding ($)	Funding (%)
IA	Administration	$ 243,903	8%
II/III	Administration	$ 109,969	
Cost Share	Education & Outreach	$ 257,782	12%
IB	Education and Outreach	$ 289,108	
II	Theme I: Observing Systems & Advanced Technology	$ 1,312,351	29%
II	Theme II: Invasive Species & Food Web Ecology	$ 537,965	12%
II	Theme III: Hydrometeorology & Ecosystem Forecasting	$ 1,477,477	33%
II	Theme IV: Protection & Restoration of Resources	$ 244,445	5%
TOTAL		**$ 4,472,999**	**100%**

Table 2. Summary of sub-award funding by institution for NOAA Award NA17OAR4320152, 7/1/17-3/31/18.

Institution	Type	Parent PG	SUBK Number	PO Number	Amount ($)	Amount (%)
Grand Valley State University	Partner	F047962	SUBK00007903	3004700819	$ 66,993	34%
Michigan State University	Partner	F047732	SUBK00008550	3004875740	$ 96,642	
The Ohio State University	Partner	F048084	SUBK00007900	3004715115	$ 245,000	
University of Wisconsin	Affiliate	F047710	SUBK00007901	3004702271	$ 110,000	9%
Michigan Technological University	Other	F047997	SUBK00007909	3004701270	$ 125,000	57%
Monterey Bay Aquarium Research Institute	Other	F048082	SUBK00007876	3004716165	$ 276,680	
Pennsylvania State University	Other	F047644	SUBK00007885	3004628721	$ 99,500	
University of Illinois - Urbana Champaign	Other	F047695	SUBK00007916	3004658790	$ 183,048	
Total					**$1,202,863**	100%

Table 3. List of all project numbers for NOAA Award NA17OAR4320152, 7/1/17-3/31/18.

Task	Theme	Amend-ment No.	Title	NOAA Technical Lead/Sponsor	Total Dollars	Start Date	End Date
N/A	Parent	0	The Cooperative Institute for Great Lakes Research (CIGLR): A Proposal to the Office of Oceanic and Atmospheric Research, NOAA, for a new Regional Research Institute	GLERL: D. Lee	$100	07/01/2017	06/30/2022
II	III	1	Implementation of a 3D HAB forecast model for Lake Erie using FVCOM	GLERL: E. Anderson	$89,990	07/01/2017	06/30/2018
II	III	2	Improving Water level models for application to decision making	GLERL: B. Lofgren	$25,000	07/01/2017	06/30/2018
II	III	3	Development of a Coupled Hydrodynamic-Wave Model using FVCOM and WAVEWATCH III	GLERL: P. Chu, J. Wang	$39,993	07/01/2017	06/30/2018
II	I	4	Great Lakes CoastWatch Research Assistant for NOAA CoastWatch Program Element	GLERL: G. Leshkevich	$127,061	07/01/2017	06/30/2018
II	III	5	Development and Optimization of the NGGPS-FV3 Model and Ensemble-based Data Assimilation for Convection-permitting Hurricane Analysis and Prediction	GFDL: L. Harris, S.J. Lin	$116,527	07/01/2017	06/30/2018
II	III	6	Improved Ice Modeling for the Great Lakes	GLERL: J. Wang	$142,988	07/01/2017	06/30/2018
II	III	7	Implementation of the FVCOM-Ice model for the Great Lakes Operational Forecasting System (GLOFS)	GLERL: E. Anderson, J. Wang	$118,970	09/01/2017	08/31/2018
IB	ECO	8	Using a Teacher Mentor Model to Expand the Impact of the Center for Great Lake Literacy's Community of Practice	GLERL: D. Mason	$201,700	12/01/2017	11/30/2019
II	III	9	Water level forecasts: Improving water level models for shipping and commerce	GLERL: D. Gronewold	$68,019	07/01/2017	06/30/2018
IB	ECO	10	CIGLR Education and Outreach: Fellowship Program, Seminar Series, and Vessel Support	GLERL: D. Lee	$114,284	07/01/2017	06/30/2019
II	III	11	Assessment of contaminated sediment (sawdust) transport in Manistique River, MI	GLERL: E. Anderson, C. Wu	$128,129	05/01/2018	11/30/2018
II	II	12	Coordination & leadership of the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)	GLERL: F. Martinez	$227,199	07/01/2017	06/30/2018
II	I	13	2017 Implementation of the GLOS Buoy and Mobile Platform Observing Systems	GLERL: S. Ruberg	$151,923	07/01/2017	06/30/2018
III	III	14	Water Level Forecasting Improvements	GLERL: D. Gronewold	$40,300	07/01/2017	06/30/2018
II	III	15	Improving Lake-Effect Snow and Cloud Forecast Capability for the Great Lakes Region	GLERL: P. Chu	$121,301	08/01/2017	07/31/2019
II	II	16	Great Lakes Long-term Ecological Research Program	GLERL: A. Elgin, H. Vanderploeg, E. Rutherford	$358,111	07/01/2017	06/30/2018
II	I,IV	17	2017 Synthesis, Observations, and Response (SOAR)	GLERL: E. Anderson, S. Ruberg	$531,488	07/01/2017	06/30/2018
II	I,III	18	HABs Monitoring, Forecasting and Genomics for the Great Lakes	GLERL: E. Anderson, H. Vanderploeg	$899,496	07/01/2017	06/30/2018
II	I	19	Advancement of Mobile, In-situ HAB Toxin Warning and Genomic Observation for Great Lakes Decision Support Tools	GLERL: S. Ruberg	$432,500	10/01/2017	09/30/2018
III	III	20	Evaluating Water Quality Impacts of the Runoff Risk Advisory Forecast (RRAF)	NWS: D. Goering	$280,238	09/01/2017	08/31/2020
				Total	**$4,215,217**		

Task I Activity

The Task I funding received by CIGLR from July 1, 2017 through March 31, 2018 was $533,001 to support the following activities: Great Lakes Summer Fellows Program (10%), Graduate Research Fellowships (9%), Postdoctoral Fellowships (9%), Great Lakes Seminar Series (0.1%), an Illinois-Indiana Sea Grant outreach and education project (35%; Center for Great Lakes Literacy support), and salaries and fringe benefits for administrative personnel (36%) (Figure 4, Table 1).

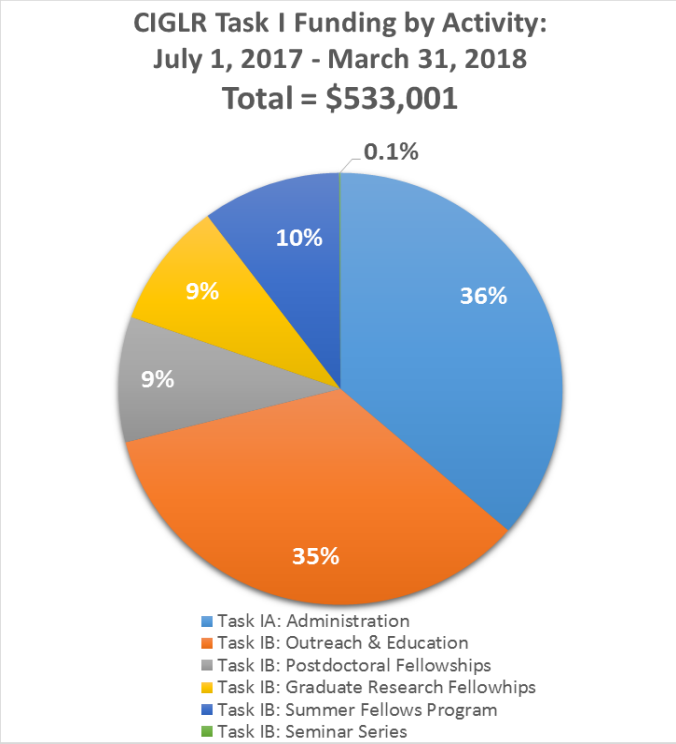


Figure 4. Task I funding distribution by activity during the CIGLR Cooperative Agreement (July 1, 2017 through March 31, 2018).

Administrative: Task IA

The primary role of CIGLR administration (Task IA) is to support research and the Engagement, Career Training, and Outreach and Communications (ECO) Program. Specific activities include facilitating financial elements of the CI; developing, implementing, and coordinating multi-university research programs; coordinating with NOAA research and administrative staff; and providing administrative support for CIGLR postdoctoral fellows, student fellows, visiting scientists, and research staff.

Non-administrative: Task IB

CIGLR's career training and outreach activities are jointly supported by Task IB and University of Michigan cost share funds. NOAA-funded Task IB activities include Graduate Research Fellowships, Great Lakes Summer Fellows Program, and Great Lakes Seminar Series. These programs are summarized along with the cost-share-funded activities in the ECO Program section below.

ECO Program Activity

Since the start of the new CIGLR Cooperative Agreement, we have focused on the development and implementation of a comprehensive Engagement, Career Training, and Outreach & Communications (ECO) Program. The ECO Program is supported by a combination of Task IB and University of Michigan cost share funds. With the University of Michigan's greater cost share commitment to CIGLR, we have been able to greatly expand our ECO Program activities, many of which are implemented with our Regional Consortium partners. In addition to the ECO Program elements, all CIGLR Task II/III research projects are required to

have an outreach or engagement component. Details on education and outreach activities associated with funded research projects can be found throughout the Research Reports by Theme section. Progress to date on ECO Program activities is summarized in the tables below. A full description of the ECO Program can be found in Appendix B.

Highlights

[E]ngagement

Support informed decision making **by working with legislators, resource managers, and stakeholders to develop the tools and information needed to promote sustainability in the Great Lakes.**

- Hired a full time Stakeholder Engagement Specialist to implement stakeholder engagement and foster co-design within our research projects.
- Held one summit and awarded two more summits on pressing research management needs to achieve sustainability in the Great Lakes. See Summits and Working Groups section for details.

[C]areer Training

Promote a skilled and diverse workforce **by providing career training for undergraduates, graduate students, and postdoctoral fellows who will become the next generation of Great Lakes and NOAA scientists.**

- Provided competitive fellowship experiences to 5 undergraduates, 8 graduate students, and 5 postdocs.
- Supported an additional 11 students and postdocs to participate in NOAA research with NOAA, CIGLR, and Regional Consortium partner scientists.

[O]utreach & Communications

Advance environmental literacy **by communicating the value, importance, and usefulness of NOAA's Great Lakes research to the general public at local, state, and regional levels.**

- Published 3 quarterly e-newsletters during the reporting period, with an average open rate of 40%.
- Launched the new CIGLR website concomitant with the start of the CIGLR Cooperative Agreement, with an average of 29,000 hits and 4,200 visitors per month during the reporting period.
- Featured in 110 news media articles and broadcasts highlighting CIGLR research and activities.

Tables 4-6 below provide a comprehensive summary of the ECO Program activities during the reporting period, followed by brief reports on specific components of the program.

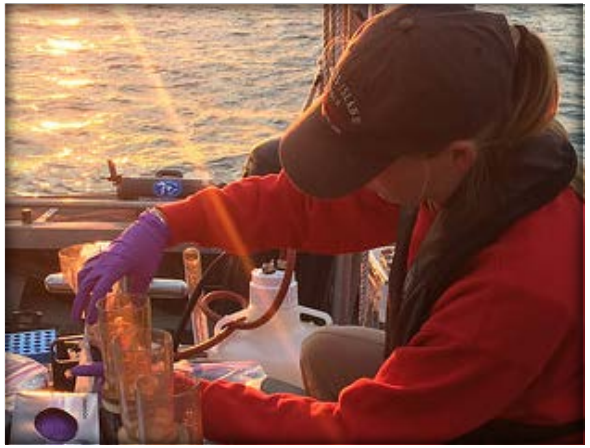
Table 4. **Engagement** activity summary, 7/1/17-3/31/18.

Activity	Description	Progress (2017-2018)
Summits & Working Groups	Host meetings with invited experts and stakeholders, focused on identifying the most pressing research and management needs to achieve sustainability in the Great Lakes. Products include peer-reviewed articles and white papers that develop an agenda for the future of Great Lakes research that are used to educate elected officials.	• 1 summit held, resulting in: o Two special sessions at scientific conferences o Two scientific presentations o One journal special issue • 2 summits awarded (June & July 2018)
Legislative Interaction	Lead and participate in interactions with local, State, and Federal legislators to inform about our work and express the Great Lakes region's priorities for legislation and appropriations to protect our environment and support our economy.	• Michigan Representative Yousef Rabhi attended CIGLR holiday reception as a special guest. • Co-hosted a visit to NOAA GLERL by Senator Gary Peters, which included a facility tour and Town Hall meeting. • Met with staff from Senator Debbie Stabenow's office in Washington, D.C.
Science-Policy Nexus Event	Host one event annually that brings together scientists, stakeholders, and Great Lakes elected officials. The focus will be outlining a vision for Great Lakes research, through identifying critical next steps and funding needs.	• Co-hosting the 2018 Science-Policy Confluence Conference, May 2018, with the Environmental Law Policy Center. The conference will focus on harmful algal blooms. Planning for this event occurred over most of the reporting period.
Great Lakes Advocacy	Communicate with local, state, and Federal policy makers with written letters and phone calls when pending legislation or appropriations have potential to impact the health and safety of the Great Lakes and the communities that rely on them.	• Take Action webpage: Launched a new Take Action portal on the CIGLR website, where the public can get informed about the Great Lakes, sign a stewardship pledge, and write to Congress. • Postcard signing event: Held a 3-day postcard writing event at University of Michigan. 90 postcards were sent to Congressional representatives in support of Great Lakes science and restoration. CIGLR provided postcards, addresses, potential talking points, and postage.
Stakeholder Engagement	Facilitate the co-production of information and tools with stakeholders to support sustainable resource management in the Great Lakes.	• Hired a Stakeholder Engagement Specialist to work within our research teams on identifying stakeholder needs and perceptions related to our work. • Held 7 focus group meetings with stakeholders to discuss user needs and HAB forecast development and dissemination.

Table 5. **Career Training** activity summary, 7/1/17-3/31/18.

Activity	Description	Progress (2017-2018)
Great Lakes Summer Fellows Program	Upper level undergraduate and graduate students work with CIGLR and NOAA GLERL mentors on Great Lakes research projects.	9 fellowships issued
Graduate Research Fellows Program	Graduate students receiving their degrees at Regional Consortium universities work on projects in collaboration with a NOAA GLERL or CIGLR scientist.	4 fellowships awarded
Postdoctoral Fellows Program	Salary and research support are provided for postdoctoral fellows to work with a CIGLR Regional Consortium university mentor and NOAA GLERL or CIGLR scientist.	5 postdocs funded
Graduate Student Projects	CIGLR research scientists serve as mentors for University of Michigan graduate students completing thesis/dissertation or professional projects.	2 students supported
Project-Funded Postdocs and Students	Undergraduates, graduate students, and postdoc support is included in annual research proposal budgets. Students and postdocs are mentored by leading research scientists at CIGLR, GLERL, or collaborating institutions/organizations.	9 students and postdocs funded

CIGLR Director Brad Cardinale (2nd from right) pictured with Senator Gary Peters during a 2018 visit to NOAA GLERL.



CIGLR Summer Fellow Deanna Fyffe gaining valuable shipboard research experience

CIGLR Summer Fellow Verena Lucke teaching engaging the public during a community event.

Table 6. **Outreach and Communications** activity summary, 7/1/17-3/31/18.

Activity	Description	Progress (2017-18)
Great Lakes Seminar Series	Joint seminar series between CIGLR and NOAA GLERL that features invited experts on a variety of Great Lakes research topics.	5 seminars hosted
CIGLR website	CIGLR's main public platform for facilitating science translation, fostering engagement, and informing Regional Consortium partners, stakeholders, students, and the public about events and opportunities.	• Launched CIGLR website in July 2017 • 29,073 avg hits per month • 4,200 avg visitors per month
Social media	CIGLR engages the public, stakeholders, scientists, and NOAA on social media through our on Facebook (@CIGLR.Umich), Twitter (@CIGLR_UM), Instagram (CIGLR_UM), and Flikr (CIGLR_UM) accounts.	• Twitter: 2,327 followers; 596,400 impressions during reporting period; 437 mentions • Facebook: 853 followers; 58,377 total reach during reporting period • Instagram: 983 followers • Flikr: 780 online photos with captions in 14 albums
News media	CIGLR produces press releases on research results and notifies news media contacts when news-worthy stories arise.	110 media stories (articles & videos) featured CIGLR during the reporting period
NOAA OAR Hot Items	CIGLR contributes Hot Item articles to NOAA OAR promoting CIGLR research outcomes and events.	3 Hot Items contributed
NOAA GLRCT Regional Highlights	CIGLR contributes articles to the Great Lakes Regional Collaboration Team (GLRCT) for publishing on the Regional Highlights portion of their website.	3 articles contributed
Quarterly e-newsletter	Email and web-based quarterly e-newsletters highlighting CIGLR research, partner interactions, opportunities, and events.	• 3 issues during reporting period • 550-person email distribution list • 40% average open rate
CIGLR Minute Video Series	CIGLR produces a monthly video series featuring research projects and staff profiles. The videos will be posted on social media, on the CIGLR website, and included in the quarterly e-newsletter	• 3 videos produced during the reporting period
Community outreach events	CIGLR students and staff interact with the public at informational tables at community events, university outreach events, and at scientific conferences. CIGLR also provides resources to Regional Consortium partners for use at events in their locations.	• 6 events during the reporting period • 3,000 interactions with students, scientists, and the public
Promotional materials	Produce compelling promotional materials that highlight CIGLR research and programs.	• Developed a new impacts poster • Published a new CIGLR brochure

Summits and Working Groups

CIGLR convenes top experts from Great Lakes universities, NGOs, government agencies, and businesses to participate in summits and working groups (SWGs) focused on identifying the most pressing research and management needs to achieve sustainability in the Great Lakes. Summits convene groups of 20-30 invited experts meeting for 2-3 days to summarize the state of knowledge and recommend future directions on Great Lakes problems that span decadal time-scales. Working groups bring together smaller groups (8-12) for up to one week to make detailed progress on more narrow Great Lakes issues with solutions on the time scale of months to years. Summits and working groups are led by Regional Consortium partners (academic or private sector), centered on CIGLR's research themes, and include NOAA GLERL scientists on the steering committees.

Participants of the 2017 summit on Great Lakes meteotsunamis.

In FY18, we issued a call to our 9 Regional Consortium universities to request proposals for up to 3 summits or working groups. Proposals were reviewed by members of the Council of Fellows and judged on the 1) scientific merit of the proposed topic, 2) applications to management needs in the Great Lakes, 3) alignment with CIGLR's mission, 4) impact and feasibility of the proposed products, 5) opportunities to forge new, cross-disciplinary partnerships, and 6) involvement of members from multiple Regional Consortium institutions or organizations. Recipients of SWG funding are required to report planned products and outcomes to CIGLR within 60 days after the summit, and submit a final report of products and outcomes one year after the summit.

The following two SWGs were selected for funding:

- Dr. Michael Murray, National Wildlife Federation: Revisiting the Prescription: Assessing Recent Progress, Understanding of Stresses and Responses, and Needs Concerning Restoring and Protecting the Great Lakes. With steering committee members David Allan (University of Michigan), John Bratton (LimnoTech), Jan Ciborowski (University of Windsor), Lucinda Johnson (University Minnesota-Duluth), Alan Steinman (Grand Valley State University), and Craig Stow (NOAA GLERL), this summit will review the current state of knowledge regarding ecosystem responses to major anthropogenic stresses, and what research and tools are needed to advance Great Lakes protection and restoration efforts.
- Brad Garmon, Michigan Environmental Council**:** *Improving Nutrient-Loading/Algal-Growth Modeling through a Watershed-Scale Approach that Emphasizes Soil Health & Upland Farming Practices.* This

summit will convene leading academic researchers, federal scientists, agricultural stakeholders, and environmental/conservation advocates to focus on improving predictive models for harmful algae blooms (HABs) in Lakes Erie and Huron (Saginaw Bay), through watershed-level approaches that incorporate a range of soil-health measures and adoption of soil-health best management practices (BMPs).

CIGLR held 5 SWGs prior to the start of the CIGLR Cooperative Agreement in July 2017. More information can be found on the CIGLR website: https://ciglr.seas.umich.edu/opportunities/summits-working-groups/

Great Lakes Summer Fellows Program

The Great Lakes Summer Fellows Program has been a cornerstone of our career training program since the CILER's inception in 1989. Each year this program places highly qualified undergraduate and graduate students with both academic and federal research mentors. Through this program, students get the opportunity to work on substantive research issues in the Great Lakes that, in turn, support CIGLR's and NOAA's research missions in the region. The fellowship program includes educational events to help the students explore topics ranging from career options across sectors to how to look for funding for graduate school. We provide fellows with an exit survey each year to assess the quality of their fellows experience and to evaluate ways to improve the program in the future. The summer fellowship program is supported by Task 1B and Task II funds.

Although the program primarily places students with research mentors at NOAA GLERL, CIGLR has also placed students at partnering universities and organizations. Beginning in 2018, we invited our academic and private sector Regional Consortium partners to propose fellowship positions that would involve co-mentoring by GLERL or CIGLR scientists. With our first year of Task IB funding, we have offered nine summer fellowships for the summer of 2018, which will all be placed at NOAA GLERL.

2017 Summer Fellows participating in a community outreach event.

In order to ensure we are recruiting a broad range of student applicants in terms of diversity, geography, and STEM disciplines, CIGLR developed and implemented a recruiting plan to reach the following priority sectors:

- Under-represented student groups: to increase diversity, equity, and inclusion in STEM disciplines
- National & scientific outlets: to provide broad, nationwide exposure
- CIGLR partners: to provide Great Lakes regional emphasis and enhance partner interactions

CIGLR is committed to supporting diversity in an inclusive environment, in alignment with the 2016 Diversity, Equity, and Inclusion Strategic Plans issued by the University of Michigan and the School for Environment and Sustainability. Thus, a major focus of the summer fellowship recruiting plan is increasing diversity among applicants to the program. As part of the recruiting plan, we began collecting optional data on applicants' race/ethnicity and gender in 2016. These data are being used to gauge our success in reaching under-represented groups with our recruitment. Since 2016, the proportion of applicants that self-identified as non-white or Caucasian has ranged from 22-29%, and that of the accepted cohort has ranged from 20-50% (Figure 5, Table 7). The proportion of applicants and the accepted cohort that identified themselves as female or transgender has been greater than 55% since 2016 (Figure 5, Table 7). The overall number of applicants has consistently risen over this period, from 58 in 2016 to 159 in 2018 (Table 7). A complete description of the Great Lakes Summer Fellows recruiting plan can be found in Appendix C.

	2016		2017		2018	
	Applied	**Accepted**	**Applied**	**Accepted**	**Applied**	**Accepted**
Number of Individuals	58	10	120	12	159	8
University Affiliations	26	7	63	9	89	8
University of Michigan	42%	40%	29%	33%	13%	6%
External	58%	60%	71%	67%	87%	94%
Female or transgender	56%	60%	61%	67%	64%	67%
Non-white or Caucasian	22%	20%	29%	25%	24%	50%

Table 7. Summary information for the 2016-2018 applicants and accepted cohorts of the Great Lakes Summer Fellows Program.

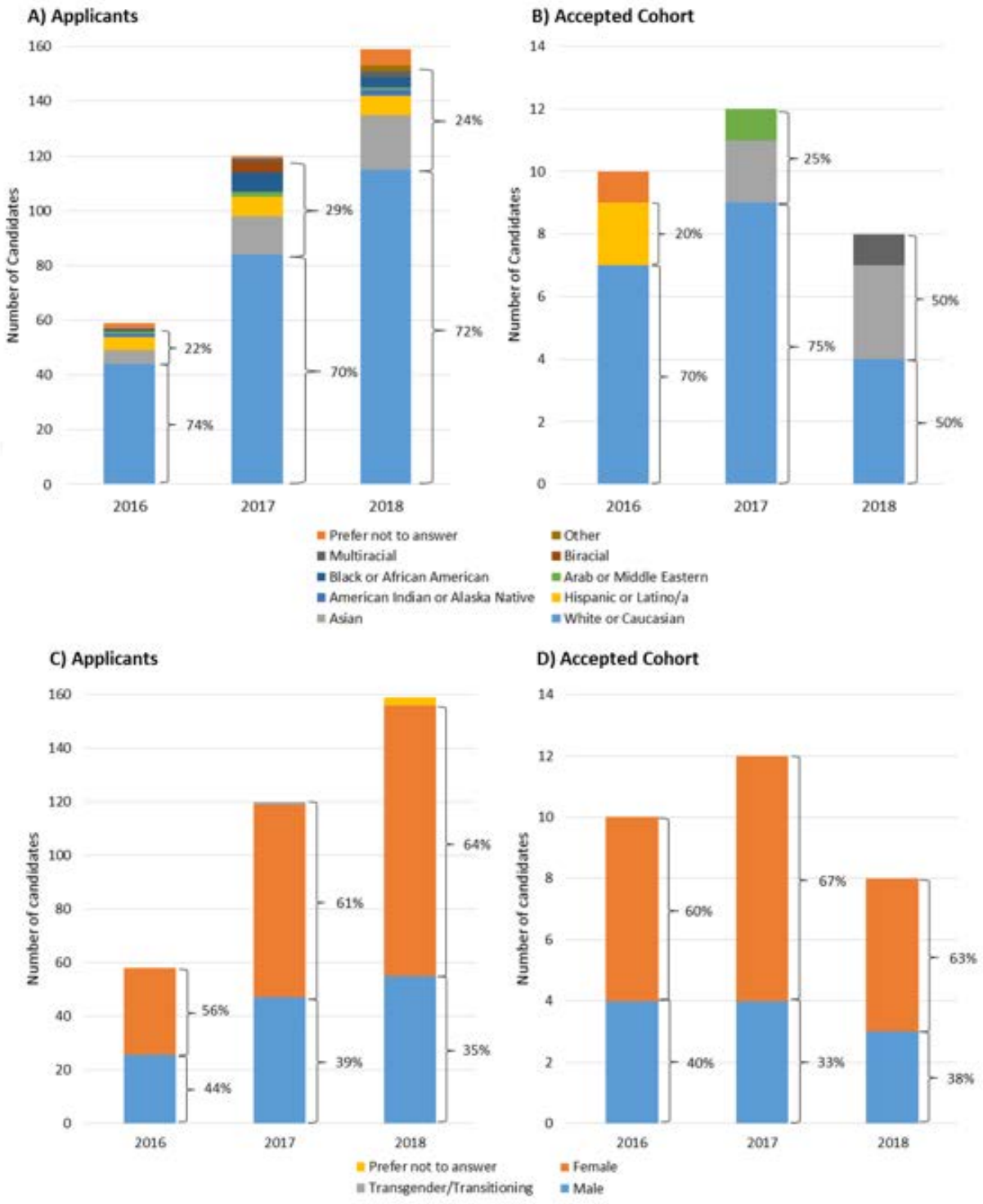


Figure 5. Self-reported race/ethnicity (A-B) and gender (C-D) data for applicants (A,C) and the accepted cohort (B,D) of the Great Lakes Summer Fellows program, 2016-2018.

Graduate Research Fellowship Program

CIGLR receives Task IB funding to administer a Graduate Research Fellowship Program that provides career training opportunities to master's or doctoral students that are located at one of CIGLR's Regional Consortium universities. The goals of these fellowships are to: 1) provide training and educational opportunities for students who will become the next generation of Great Lakes researchers, 2) enhance collaborations between CIGLR's Regional Consortium partners and PIs at NOAA GLERL and CIGLR, and 3) increase student retention within the freshwater aquatic sciences. We also seek to use these fellowships to increase diversity in STEM disciplines (science, technology, engineering and math), and thus, strongly encourage proposals that support students from groups which have been traditionally underrepresented in government and academic workforces. Graduate students or their faculty advisors affiliated with a CIGLR Regional Consortium university are eligible to compete for the fellowships. Fellowship projects must address at least one of CIGLR's research themes and require co-mentoring by a NOAA GLERL or CIGLR researcher.

Graduate Research Fellow Katie Knapp is an M.S. student at Grand Valley State University, advised by Dr. Bopi Biddanda and co-mentored by Steve Ruberg (NOAA GLERL).

In FY18, we issued a call to our 9 Regional Consortium universities to request proposals for two Graduate Research Fellowships. Proposals were scored and ranked by the Council of Fellows based on 1) the quality of the science, 2) potential for the research to make a societal impact, 3) consistency with CIGLR and NOAA GLERL's research mission and themes, 4) level of commitment to the dual mentorship of the student and student training, 5) potential to foster interaction between NOAA GLERL and CIGLR's partners.

The Graduate Research Fellowships were awarded to:

- Dr. Lars Rudstam, Cornell University. *Using size spectrum modeling to understand spatial and temporal variability in food web structure in the Laurentian Great Lakes.* Dr. Rudstam and a Cornell postdoctoral fellow will advise a graduate student on a project involving the use of a size-based ecological modeling approach to relate changes in the food web to primary productivity and anthropogenic disturbance across a range of Great Lakes ecosystems. The graduate fellow will be co-mentored by Dr. Doran Mason of NOAA GLERL.
- Dr. Aaron Fisk, University of Windsor. *Understanding the influence of environmental variation and anthropogenic stressors on fish movements and migration in Lake Erie through novel technology.* Dr. Fisk and University of Windsor postdoctoral fellow Dr. Jordan Matley will advise the graduate fellow on a project to assess the impact of environmental variability and proposed wind

turbines on walleye behavior in Lake Erie using acoustic telemetry. The graduate fellow will be co-mentored by Tom Johengen of CIGLR.

The previous Graduate Research Fellowships were awarded by CILER, prior to the start of the CIGLR Cooperative agreement. Final reports for those fellowships will be included in the Performance Progress Report for award NA12OAR4320071 (CILER, Year 6).

Postdoctoral Fellowship Program

In addition to supporting postdoctoral positions through Task II research projects, CIGLR also administers a competitive Postdoctoral Fellowship program that is supported by University of Michigan cost share funds. This program provides salary and research support for a postdoctoral fellow to work closely with a faculty mentor at a CIGLR Regional Consortium university on a project of mutual interest to CIGLR and NOAA. The goals of the Postdoctoral Fellowship Program are to 1) expand research training opportunities for postdoctoral scientists working in the area of freshwater sustainability, and 2) enhance collaborations between CIGLR's Regional Consortium partners and PIs at NOAA GLERL and CIGLR. We also seek to use these fellowships to increase diversity in STEM disciplines (science, technology, engineering and math), and thus, strongly encourage proposals that support postdocs from groups which have been traditionally underrepresented in government and academic workforces. Postdoctoral scholars or their faculty advisors affiliated with a CIGLR Regional Consortium university are eligible to compete for the fellowships. Fellowship projects must address at least one of CIGLR's research themes and require co-mentoring by a NOAA GLERL or CIGLR researcher.

In FY18, CIGLR issued a call to our 9 Regional Consortium universities to solicit proposals for two 12-month postdoctoral fellowships. The request for proposals encouraged applicants to provide matching funds. Proposals were judged by members of the CIGLR Council of Fellows based on: 1) the quality of the science, 2) potential for the research to make a societal impact, 3) consistency with CIGLR and NOAA GLERL's research mission and themes, 4) potential to foster interaction between NOAA GLERL and CIGLR's partners. Three proposals received enthusiastic support from the Council and CIGLR administration for high ranks in each of the evaluation categories. CIGLR awarded Postdoctoral Fellowship awards to three Regional Consortium partners, rather than two, for FY18. The proposals selected for funding were:

- Dr. Lars Rudstam, Cornell University. *Using size spectrum modeling to understand spatial and temporal variability in food web structure in the Laurentian Great Lakes.* With co-mentor Dr. Doran Mason of NOAA GLERL, Dr. Rudstam and a postdoctoral fellow (to be recruited) will use a size-based ecological modeling approach to relate changes in the food web to primary productivity and anthropogenic disturbance across a range of Great Lakes ecosystems.
- Dr. Aaron Fisk, University of Windsor. *Understanding the influence of environmental variation and anthropogenic stressors on fish movements and migration in Lake Erie through novel technology.* Dr. Fisk will team up with co-mentor Tom Johengen of CIGLR and postdoctoral fellow Dr. Jordan Matley to assess the impact of environmental variability and proposed wind turbines on walleye behavior in Lake Erie using acoustic telemetry.

- Dr. Greg Dick, University of Michigan. *Development of a gene-based model of toxin production by* Microcystis aeruginosa *in Lake Erie.* Postdoctoral fellow Dr. Kevin Meyer will work with Dr. Dick and NOAA GLERL co-mentor Dr. Craig Stow to develop a model that uses environmental genetic data to explicitly predict toxin production by cyanobacterial harmful algal blooms.

The previous Postdoctoral Fellowships were awarded by CILER, prior to the start of the CIGLR Cooperative agreement. Final reports for those fellowships will be included in the Performance Progress Report for award NA12OAR4320071 (CILER, Year 6).

Great Lakes Seminar Series

CIGLR continues to coordinate the joint CIGLR-GLERL Great Lakes Seminar Series, which brings in regional, national, and international researchers to talk about pertinent new and emerging scientific issues in the Great Lakes. These events facilitate collaborations between researchers, provide an educational opportunity for NOAA and university scientists, and serve as an outreach forum for stakeholders and the general public to attend. Seminars are held at NOAA GLERL or the University of Michigan and are broadcast via webinar for remote participation. Webinar recordings are available to the public on the CIGLR website and YouTube channel.

CIGLR hosted the following seminars during the reporting period:

July 27, 2017
Speaker: Yi Chao, Seatrec, Inc. and Remote Sensing Solutions, Inc.
Title**:** Ocean Observing and Modeling Technology to Enable Operational Forecasting

August 15, 2017
Speaker: Yushun Chen, Chinese Academy of Sciences
Title: Ecological responses to water diversion of the eastern route of the South-to-North Water Diversion Project (SNWDP) of China

October 25, 2017
Speaker: Hongsheng Bi, University of Maryland
Title: Seeing the invisible in coastal waters: imaging systems for ecological monitor and forecasts

November 2, 2017
Speaker: Christopher Spence, Environment and Climate Change Canada
Title: Ten years of the Great Lakes Evaporation Network: Progress Made and Opportunities for the Future

March 26, 2018
Speaker: Thomas Hamill, NOAA Earth System Research Lab
Title: Improved Statistical Postprocessing of Precipitation for the NWS Forecasts and Hydrologic Applications

Center for Great Lakes Literacy Support

In an effort funded through the Great Lakes Restoration Initiative, the Center for Great Lakes Literacy members are increasing Great Lakes literacy by developing a group of Mentor Teachers to serve as "Great Lakes Ambassadors" by 1) disseminating Great Lakes learning and stewardship practices, and 2) providing support to CGLL workshop participants for post-workshop implementation of projects, professional development, and/or knowledge dissemination. This Task IB activity is being led by Dr. Kristin TePas at University of Illinois Extension, Illinois-Indiana Sea Grant.

Throughout the Great Lakes basin, CGLL staff from each state will facilitate additional professional development with up to 10 exemplary teachers – a potential total of 70 CGLL Mentor Teachers – who have attended either CGLL's Shipboard Science or Shoreline Science workshops. These educators will learn and share (1) techniques for integrating Great Lakes materials into their classrooms, (2) examples of successful stewardship activities, (3) strategies for interacting with the Great Lakes research community, and (4) methods for overcoming barriers to incorporating Great Lakes science into K-12 education. During these trainings, Mentor Teachers will also increase their Great Lakes content knowledge by interacting with scientists (academic, agency, EPA, National Parks, NOAA, etc.) at labs, in the field, or aboard ships. As an indirect outcome, Great Lakes scientists will also learn about the broader impacts of their work and best practices for mentoring teachers and students. The Mentor Teachers are expected to reach 350 to 700 additional teachers basin-wide to further strengthen the Community of Practice that CGLL is dedicated to creating. These teachers could share their knowledge and expertise with potentially 10,000 additional elementary or secondary students.

The specific objectives of this effort are to:

1. Expand and strengthen our core network of experienced educators and scientists through additional training. Those experienced educators will mentor a cadre of new educators participating in future CGLL events.
2. Further promote Great Lakes literacy by providing support to educators who want to extend learning and stewardship opportunities to students or colleagues.

During the reporting period, the following progress was made toward these objectives:

- Illinois-Indiana Sea Grant hosted a proposal kick-off/planning meeting for all those on the grant (sub-awardees include all the other Great Lakes Sea Grant programs). This 2-day meeting took place at the end of January, 2018.
- CGLL members developed a Participant Expectations document to use to recruit mentor teachers.
- CGLL members also developed a Mentor Projects and Activity Report Form which will record the activities the mentor teachers agree to for their mentor year and then also will be used to track the completion of those activities for the final evaluation.
- CGLL members are currently developing a more formal evaluation as well to conduct at the end.
- MI Sea Grant was the first to conduct their training for their mentor teachers.

Task II/III Research Activity

Theme I: Observing Systems and Advanced Technology

Great Lakes CoastWatch Research Assistant for NOAA CoastWatch Program Element

Principal Investigator(s): Bradley Cardinale and Thomas Johengen (University of Michigan-CIGLR)
NOAA Technical Lead(s): George Leshkevich and Philip Chu (NOAA GLERL)
NOAA Sponsoring Office: OAR, NOAA Great Lakes Environmental Research Laboratory
Budget Amount: $127,061

NOAA Strategic Goal:
Goal 1 - Healthy Oceans
Goal 2 - Weather-Ready Nation
Goal 3 - Climate Adaptation and Mitigation
Goal 4 - Resilient Coastal Communities and Economies

Overview:
To address critical coastal environmental problems, the National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) has established the NOAA Ocean Remote Sensing (NSORS) Program. Within NSORS, CoastWatch is a NOAA-wide program designed to provide a rapid supply of up-to-date, coordinated, environmental (remotely sensed, chemical, biological, and physical) information to support Federal and state decision makers and researchers who are responsible for managing the Nation's living marine resources and ecosystems. NOAA CoastWatch focuses on specific regional priorities, such as unusual environmental events (e.g., harmful algal blooms), accumulating algal biomass, mapping wetland change (e.g., change detection), and mapping ice cover/ice thickness (e.g., hazard mitigation).

The goal of the CoastWatch Great Lakes program is to develop and deliver environmental data and products for near real-time monitoring of the Great Lakes for support of environmental science and decision making. One of the objectives of CoastWatch is to provide access to near real-time and retrospective satellite observations and derived products of the Great Lakes for Federal, state, and local decision making and supporting research, as well as for educational and recreational activities.

This project focuses on research and applications development utilizing CoastWatch imagery and imagery from new satellite sensors such as synthetic aperture radar (SAR) for ice classification and mapping and ocean color sensors such as the Moderate-Resolution Imaging Spectroradiometer (MODIS) and the NPOESS Preparatory Project (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) for lake color (chlorophyll) products. These sensors/imagery will enhance the CoastWatch Great Lakes product suite by enabling development regional products and applications for the Great Lakes that will

contribute to the operational responsibilities of sister agencies such as the U.S. Coast Guard and NOAA National Weather Service.

Regional products delivered in an untimely fashion or in an unusable format, whether to land- or ship-based users, defeat the objectives and goals of the program. Therefore, the development of tools to effectively and efficiently deliver these products to regional users in near real-time and in a useable format is of great importance. This will foster additional research applications by regional data users employing the processed satellite data, such as detection and tracking of thermal fronts and analysis of circulation patterns and upwelling (e.g., fish recruitment studies) and modeling and forecasting Great Lakes parameters (e.g., Great Lakes Coastal Forecasting System).

Objective(s):
A primary objective of CoastWatch is to provide access to near real-time and retrospective satellite observations and derived products of the Great Lakes for Federal, state, and local decision making and supporting research, as well as for educational and recreational activities.

Milestones:
We met milestones for developing Great Lakes regional mapping products from remotely sensed data; facilitated the dissemination of CoastWatch managed data, products, and information for research, operational, and/or educational purposes; and conducted research on algorithm development of remotely sensed data. Additional included assisting with development of project reports and scientific presentations, and providing the necessary computer system and software support to facilitate these activities.

Accomplishments:

A. Monitored, developed, and improved the operational program to receive, process, analyze, and archive the CoastWatch data.
    a. Finished the program (Unix script) to download the data from PDA (switched download data from DDS to PDA server).
    b. Finished the program (Unix script) to use SFTP to download the AVHRR, VIIRS, GOES16 SST, ICE CLASS, SAR WINDS data files.
    c. Finished the program (Unix script, and IDL) to process ICE CLASS, SAR WINDS, CPA data files
B. Maintain and improve the CoastWatch Great Lakes Node web server; design and develop the web site.
    a. Updated the THREDDS server, including adding more CPA data files to the server and made the yearly aggregated data file available.
    b. Finished set up LAS server for THREDDS server, and made the CPA data files available on LAS.
    c. Finished the PHP program to make the ICE CLASS, SAR WINDS available on CoastWatch web site.
    d. Made the whole set of GLSEA data (1995-current) include ice concentration and temperature available on THREDDS server.

e. Made GOES 16 SST image for Great Lakes region available on CoastWatch Great Lakes web site.
    i. Modified the Perl program to download the subset for Great Lakes region.
    ii. Wrote Unix script, IDL, and PHP program to processing the data and make the data available online.
    iii. Regularly updated the CoastWatch web page (other links and gallery).

C. Designed, modified, and developed the software to analyze and process the CoastWatch data.
    a. Finished the program (Unix script) to reprecess the CPA data files to make the data files available on both LAS and ERDDAP server.
        i. Converted the geotif file from projected system (X, Y) to geodetic system (Lat, Lon).
        ii. Converted the files from geotif format to netCDF format.
        iii. Added the attributes that required by both LAS and ERDDAP.

D. Participated in CoastWatch related research and prepare presentations for meetings.
    a. Assisted with presentation for the CoastWatch Node Manager Meeting: "CoastWatch Great Lakes Node Summary."
    b. Attended the Cooperative Institute for Great Lakes Research Annual Partners Meeting.
    c. Regularly wrote the program (IDL and Python program) to make the Great Lakes long term SST or ice concentration chart for "Great Lakes Region Quarterly Climate Impacts and Outlook. "

Results and Products:

Presentations

- "CoastWatch Great Lakes Node Summary", CoastWatch Node Manager Meeting. July 31-August 3, 2017, Santa Cruz.CA
- "CoastWatch Great Lakes New Products", Great Lakes Environmental research Laboratory, Feb 23, 2018. Ann Arbor, MI

Tools, maps, or models

All Coastwatch Great Lakes regional products are available at https://coastwatch.glerl.noaa.gov. Specific products developed during the reporting period include:

- Color Producing Agent (CPA) products (water quality) – image maps.
- Ice Type Classification (ICECON) and SAR winds - image map from satellite synthetic aperture radar (SAR) data – image map.
- Upwellings for Lake Michigan – image map from GLSEA composite chart.

Outreach and Engagement Activities:

Community outreach events

Presentation at Earth Day event, Washtenaw Community College (April 6, 2017)

Theme I: Observing Systems and Advanced Technology

2017 Implementation of the GLOS Buoy and Mobile Platform Observing Systems

Principal Investigator(s): Bradley Cardinale and Thomas Johengen (University of Michigan-CIGLR)
NOAA Technical Lead(s): Steve Ruberg (NOAA GLERL)
NOAA Sponsoring Office: OAR, NOAA Great Lakes Environmental Research Laboratory
Budget Amount: $151,923

NOAA Strategic Goal(s):
Goal 1 - Healthy Oceans
Goal 2 – Weather-Ready Nation
Goal 3 - Climate Adaptation and Mitigation
Goal 4 - Resilient Coastal Communities and Economies

Overview:
The Great Lakes Observing System Regional Association (GLOS-RA) is implementing key observing system and modeling improvements over the 2016-21 period that focus on critical needs of the Great Lakes region as identified through an extensive needs assessment process. The focus of the observing system team within GLOS is to provide for improved spatial and temporal coverage of key meteorological, hydrodynamic, and biological variables throughout all of the Great Lakes to support the development of improved databases and forecasts within four priority areas, including climate change impacts, ecosystem and food web dynamics, protection of public health, and navigation safety and efficiency. Critical information needs for these priority areas are being addressed by implementation of an array of integrated observations, including buoy observations and mobile observing systems.

Although offshore and nearshore moorings are essential to monitoring of thermal dynamics of the lakes, changes in physical and biological processes often require better spatial and vertical resolution than fixed moorings can provide. Hence, the buoy observations are supplemented by both autonomous underwater vehicle (AUV) and glider surveys to measure temperature, conductivity, chlorophyll, phycocyanin, dissolved oxygen, CDOM, turbidity and PAR. The dimensions of the Great Lakes (width and depth) are ideally suited for operational AUV transects. With typical cross-lake dimensions on the order of 100 km and typical depths on the order of 300 meters, our Iver-2 AUVs and Slocum glider can easily navigate these ranges. These systems, previously purchased in 2010, are operated and maintained by CIGLR in collaboration with each of the academic partners within the GLOS-RA to conduct missions in each lake to serve local needs.

Stakeholder audiences are made up of a variety of public mission agencies that operate in a diverse range of disciplines, in multiple geographic locations, and in various organizations, including U.S. and Canadian federal government agencies; state, regional, local, and tribal government agencies; NGOs and partner initiatives; academic institutions; and private business, industries, and consultants. GLOS targets communications, membership, outreach, and engagement towards those departments, agencies, and individual staff that can contribute to and/or benefit from GLOS programming and that share common goals, objectives, and strategies with GLOS. This includes formal and informal educators, modelers, and researchers who serve as target users in all of the GLOS focus areas.

Objective(s):
Within this project, CIGLR is contributing to the implementation of both moored and mobile observing activities that will help to establish, maintain, and develop operational capabilities for the GLOS-RA during project year five of the IOSS Cooperative Agreement, which include this reporting period of July 1, 2017 – March 31, 2018.

Milestones:

A. Management of Autonomous Observation Platforms

The following milestones were met within this task during the reporting period:

- Conducted glider operations in Lake Huron as part of the EPA-led Coordinated Science and Monitoring Initiative (CSMI). CIGLR worked with GLOS and NOAA-GLERL to operate the glider across the boundary between Saginaw Bay and the open Lake Huron to help examine the exchange of nutrients and primary production from the Bay to the Lake. Glider surveys helped fill in spatial and temporal gaps of core physical and biological conditions within the water column to support detailed week-long diel spatial surveys conducted by GLERL.
- Supported the ongoing development of a wave glider as a potential new mobile observing platform for the Great Lakes. NOAA-GLERL has recently received two surplus units that are being serviced for pilot missions in 2018.

B. Operational Support of Lake Michigan GLOS Buoys

The following milestones were met within this task during the reporting period:

- Oversaw the operation of two standard GLOS observing buoys in Lake Michigan, as well as supported a third buoy that is operated within the University of Michigan Biological Station in Douglas Lake.
- Deployed, operated, maintained, and retrieved a real-time TIDAS 900 buoy with a meteorological package, directional wave sensor, and thermistor string along the coast of Ludington, Michigan, in Little Traverse Bay, Michigan and in Douglas Lake, Pellston, Michigan.
- Operated all buoys throughout the major boating and recreational season, from May through November.

Accomplishments:

A. Management of Autonomous Observation Platforms

The Slocum glider operated for 74 days in two deployments between June 21 and Oct 6, 2017. The glider was recovered, along with all of its data. This work was coordinated with the EPA CSMI effort on Lake Huron and intended to show nearshore-offshore coupling between Saginaw Bay and the open lake. GLERL supported the deployment with vessel support and a lithium battery set valued at approximately $15k. In addition to the normal CTD, fluorometer and PAR instrument load, the glider also carried a Vemco acoustic fisheries tag receiver for the USGS Great Lakes Science Center to evaluate the detection efficiency of the glider platform. For this test the GLSC deployed tags transmitting at various power levels at known locations near the glider transect. The data from those deployments are currently being analyzed. An underway sampling system was installed on the NOAA research vessel in Lake Erie to support the harmful algal bloom (HAB) program. This system was used in lieu of AUVs to collect data during normal HAB sampling cruises, allowing for much more data to be collected than would be possible with the AUVs. These data have been used for comparison to hyperspectral flights and satellite data.

B. Operational Support of Lake Michigan GLOS Buoys

The Ludington buoy's modem was replaced and the wiring was overhauled reducing power consumption by 20%. 2017 was the most reliable and longest season to date for this buoy. The buoy was deployed April 23, 2017 and was retrieved November 27, 2017. The Little Traverse Bay Buoy was rewired for the same power reductions as the Ludington buoy. Our local partners, Irish Boat Shop, deployed the buoy on May 9, 2017 and recovered it on October 26, 2017. The buoy operated without incident until two days prior to recovery, when the temperature string failed during a storm with waves measuring 13 ft. During this winter season, both Ludington and Little Traverse Bay buoys had the battery tubes and charging systems updated for increased battery capacity and reduced replacement cost. The temperature string, surface temperature sensor, and cell modem were replaced on the Little Traverse Bay buoy. Work is currently ongoing to update the modem on the University of Michigan Biological Station buoy. The SOAR program that CIGLR also supports provided buoy data from four Western Lake Erie real time buoys to the GLOS HABS data portal and the GLERL real-time website. These buoys provide continuous meteorological, water quality and nutrient (phosphate and nitrate) data from May to October each year. The data streams sent from these buoys to GLOS and GLERL had additional QA checks added to the transmission program so out of range data points are not transmitted.

Results: None to report. Data analysis is underway.

Products: None

Outreach Activities:

<u>Community outreach events</u>

On March 16, 2018, the CIGLR Director, Associate Director and Engineer supported the University of Windsor's Public Launch of its new $16 million dollar initiative, Real-time Aquatic Ecosystem Observation Network (RAEON). We set up posters, a visual display of our buoyancy gliders, and gave an overview of the value of new collaborations being supported through our partnership with the University of Windsor. CIGLR has funded a competitively awarded post-doctoral fellowship to the University of Windsor and will be collaborating on the applications and missions of a new fleet of gliders to be operated within the RAEON.

Theme I: Observing Systems and Advanced Technology

2017 Synthesis, Observations, and Response (SOAR)

Principal Investigator(s): Bradley Cardinale and Thomas Johengen (University of Michigan-CIGLR)
NOAA Technical Lead(s): Steve Ruberg and Eric Anderson (NOAA GLERL)
NOAA Sponsoring Office: OAR, NOAA Great Lakes Environmental Research Laboratory
Budget Amount: $531, 488

NOAA Strategic Goal(s):
Goal 1 - Healthy Oceans
Goal 4 - Resilient Coastal Communities and Economies

Overview:

Project I: Development of Decision Support Tools for HABs and Hypoxia

The implementation of the Great lakes Synthesis, Observations and Response System (SOAR) program is designed to coordinate and integrate regional coastal observations that support national and regional priorities, including Great Lakes restoration. SOAR activities include the deployment and support of on-water and remote sensing platforms, where observations from these systems are used to create database products for assessment and decision support through an up-to-date (including real-time data) web distribution. The SOAR system provides real-time ecosystem information to help public utility managers maintain high quality drinking water and informs the general public on current water quality conditions through observations, data management, and forecast model development.

Observations of environmental parameters are used to develop decision support tools to provide warnings to regional managers regarding phosphorous loads, hypoxia and harmful algal blooms, and to support adaptive management process decisions. These decision support tools include real-time observing system components (buoys) deployed at Maumee Bay, Saginaw Bay, Lake Michigan and Lake Erie; a web-based data management system; synthesized remote sensing products for predicting harmful algal blooms (HABs); and coupled physical-chemical-biological models for Saginaw Bay and western Lake Erie. Instrumentation deployed in and near designated Areas of Concern provides observations of the timing of hypoxia, nutrient concentrations, and detection of harmful algal blooms.

Project 2. Remote Sensing Observations

The Michigan Tech Research Institute (MTRI) and NOAA GLERL have worked together over the last decade on the development of satellite based algorithms that specifically address water quality issues in the Great Lakes. The current project further supports the generation of additional satellite retrievals (2017 and forward in time) needed by GLERL and other Great Lakes stakeholders, as well as continues the successful 2015 and 2016 optical property measurements program. Another important part of this effort is the deployment of an upward and downward looking set of spectroradiometers at the NOAA Lake Erie Light #2 site.

CIGLR's support of field characterization of inherent and apparent optical properties (IOP/AOP), along with detailed water quality characterizations provided by continuous monitoring buoys and underway surface mapping, are providing the fundamental databases for the development of improved algorithms for using remote sensed observations to characterize densities of specific algal groups of interest. Phytoplankton functional type (PFT) algorithms (e.g., PHYSAT (Alvain et al. 2005)) currently operate using multi-spectral satellite imagery from the SeaWiFS, MODIS, and MERIS sensors and also imaging spectrometry ("hyperspectral") data from satellite (HICO) and airborne (e.g., AVIRIS, PRISM, and Resonon Pika II) sensors. Imaging spectrometry data has greater degrees of freedom to permit the discrimination of more spectral features that may otherwise be neglected in multispectral data. For this reason, hyperspectral data lends itself well to discriminating multiple water types or taxonomic groups. This discrimination aids the HAB Tracker model development, which aims to be a fully functional biophysical model, with predation and vertical buoyancy of phytoplankton groups. The algorithm chosen to best model a Great Lakes PFT discrimination is the Phytoplankton Detection with Optics (PHYDOTax) PFT algorithm. This algorithm creates a spectral library for phytoplankton taxa by modeling remote sensing reflectance using laboratory measurements of backscattering and absorption. It is possible to develop a region-specific spectral-library for phytoplankton. Past attempts at determining PFTs for Lake Erie and other regions have used phytoplankton absorption curves (i.e., Moisan et al., 2011; Wang et al., 2016) to discriminate phytoplankton types. The PHYDOTax is uniquely able to increase accuracy by incorporating both absorption and backscattering, which permits further differentiation of phytoplankton that contain similar pigments but belong to different taxonomic groups (Palacios, 2012).

Objective(s):
The implementation of the SOAR program is designed to coordinate and integrate regional coastal observations that support national and regional priorities, including Great Lakes restoration. The overall objective of SOAR is to provide real-time ecosystem information to maintain high quality drinking water and bathing beaches through observations, data management, and forecast model development.

Milestones:

The following milestones were met during the reporting period:

- Provided real-time, quality assured, phosphorus, nitrate and optical data for the web-based decision support system disseminated through GLERL and Great Lakes Observing System (GLOS) web portals.

- Provided data for satellite ground-truth and contributed to HAB forecast information for beach and water intake managers.
- Gained better understanding of the causes of nutrient-related nearshore biological impairments and contributed the necessary lake ecosystem data to assess the effectiveness of watershed remedial actions.
- Incorporated improved remotely sensed estimations, including airborne hyperspectral observations, into daily forecasts for use in decision support tools and for adaptive management
- Using the color producing agent algorithm (CPA-A), generated the suite of derived satellite products for each Great lake on each cloud free day. Also used the particle tracking data assimilation technique to generate daily HABs estimates in the western basin of Lake Erie, which will be used to calculate the annual HABs statistics for the EPA.
- Continued the transition of the color producing agent (CPA) algorithm for experimental use within NOAA's Great Lakes CoastWatch.
- Generated time series water quality data sets to support NOAA and CIGLR studies.
- Collected near-time continuous radiometer data at Light #2 and from the MTRI R/V Husky traveler to support atmospheric correction of remote sensing hyperspectral and satellite data as well as observe changes in surface reflectance as a function of water quality.
- In partnership with NOAA scientists and field technicians, collected additional inherent optical property (IOP) data to further refine CPA-A HO Model performance; observed seasonal and spatial changes in IOPs due to shifts in phytoplankton composition, and quantified nearshore and offshore IOP gradients.
- Processed the field collected IOP data and further populate the Great Lakes Optical Properties Geospatial Database (GLOPGD).
- Developed a hyperspectral algorithm to detect phytoplankton functional types (PFTs) in Lake Erie and other Great Lakes using the theoretical framework of PHYDOTax, which allow for:
    - Taxon-specific biomass estimates for cyanobacteria and other bloom forming species (green algae, diatoms/dinoflagellates and cryptophytes)
    - Assessment of the role of chromophoric dissolved organic material (CDOM) and non-algal particles within the PFT retrieval
    - Testing of the hyperspectral PFT algorithm on sensors with fewer spectral bands
    - Uncertainty estimate of the PFT algorithm and for varying inherent optical properties

Accomplishments:

- Deployed, serviced, and retrieved four instrumented buoys in western Lake Erie, which operate from May through October of each year.
- Collected and analyzed ground truth samples for instrument and model validations.
- Sent data to GLERL and GLOS throughout the entire operating season. Manufacturer instrument servicing issues (Cycle P) delayed phosphorus measurements at station WE8 and precluded phosphorus measurements at WE13, but all other instruments were deployed as planned.

- Performed QC checks on WLE data to share with Limnotech for the GLOS OTT program and with Tim Moore for a remote sensing paper for SOAR.
- Upgrades to WLE buoys including new cell modems on the for updated security and connectivity, modifications to accommodate new nutrient sensors provided by the National Oceanographic Center at Southampton, England under the recently awarded Nutrient Sensor Challenge project, and a new wave sensor on the WE4 buoy to provide real-time observations to recreational boaters. Higher efficiency solar charge controllers have been installed in WE2 and WE4 to handle higher instrument power loads.
- Implementation of internal QARTOD-based QA/QC reports with data passing percentages and parameters for failed data.
- Established SOAR buoy interface for western Lake Erie data acquisition.
- Generation of hyperspectral imagery maps for web viewing.
- Web-based generation of WetLABS Cycle P diagnostic plots to conduct real-time evaluation of system performance and quality control.
- Web upgrade to SOAR buoy interface for WLE now allows user to download data displayed. Top of page displays latest numerical data points.

During the reporting period, MTRI continued to generate color producing agent algorithm (CPA-A) derived products for all MODIS images intersecting the Great Lakes and disseminated these products for all high quality (relatively cloud-free) images to data portals maintained by MTRI, GLOS, and NOAA (CoastWatch). An analysis was undertaken comparing the CPA-A's performance on NESDIS-generated VIIRS imagery, leading to the transfer of the algorithm to NESDIS in order to have them generate and post derived products on CoastWatch. External requests for CPA-A derived products were fulfilled, including requests for Thunder Bay chlorophyll and light attenuation (Kd) time series (Ed Rutherford, NOAA GLERL), annual primary production data (Tony Marshak, NOAA National Fisheries), and chlorophyll and HAB products for western basin Lake Erie (Nathan Manning, UM Water Center).

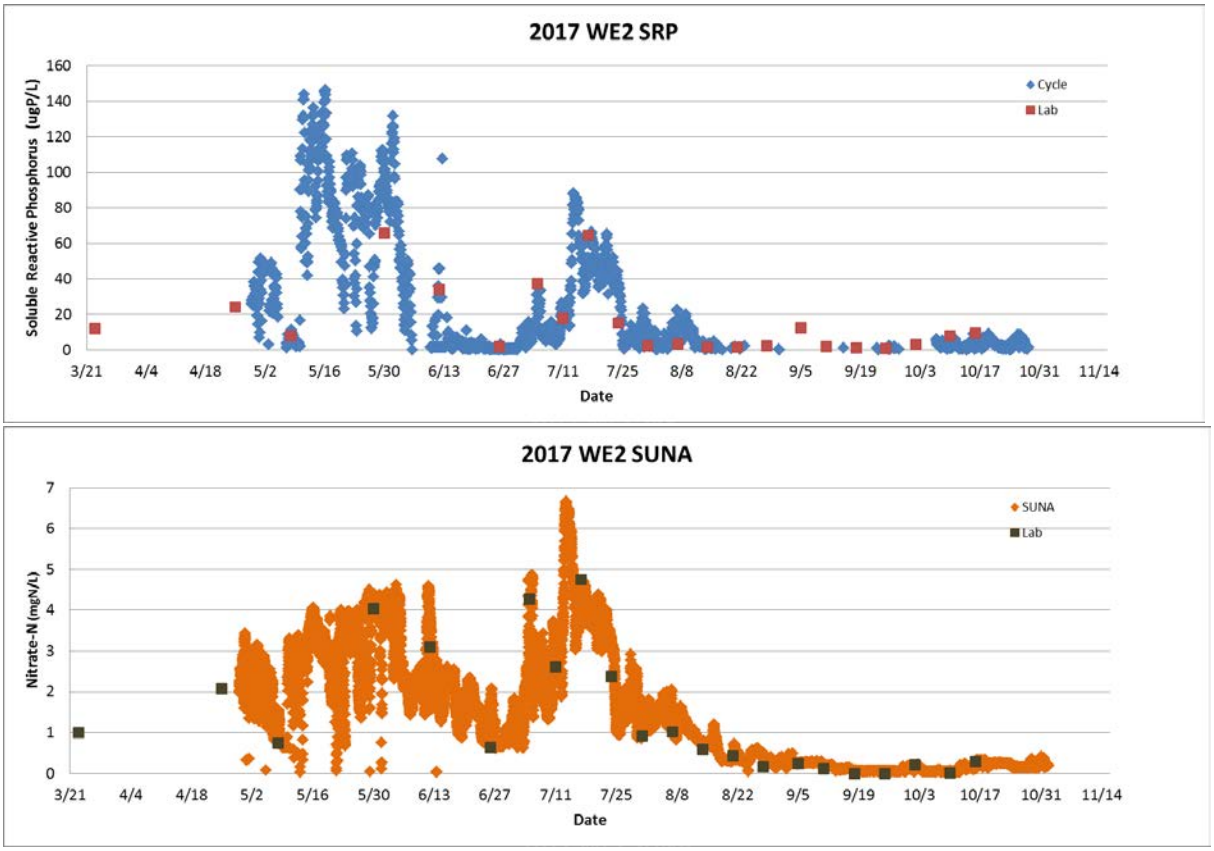
Field data collection was also a key part of MTRI's 2017-2018 activity. MTRI supported NOAA GLERL in the collection of inherent optical property (IOP) data throughout the year in western Lake Erie, Saginaw Bay, and Lake Michigan. IOP data were collected for the first time in Lake Ontario since 2008. MTRI processed all IOP data to final form which will be uploaded to the Great Lakes Optical Properties Geospatial Database (GLOPGD) following additional quality checks. Along with IOP data, Secchi disk data were collected using varying disk sizes and color patterns to guide future water clarity modeling. Hyperspectral radiometric data were collected in western Lake Erie throughout summer and fall 2017: ASD spectroradiometer data were collected on a near-weekly basis at seven stations from July through September and Lightweight Portable Radiometer (LPR) data were collected every minute at Toledo Light 2 from August through October.

Hyperspectral flyover PFT maps are being evaluated against on-water measurements of inherent optical properties (IOP) and apparent optical properties (AOP). The on-water measurements are used as validate phytoplankton functional type (PFT) algorithms based on remote sensing reflectance (AOP), such as PHYDOTax, and a comparison to additional semi-analytical PFT algorithms that rely on the

absorption and backscattering properties of phytoplankton (IOPs). Beyond the IOP and AOP, the nutrient, temperature, and wind measurements made at the fixed moorings are crucial ancillary data for knowing the timing and drivers of blooms in the Great Lakes.

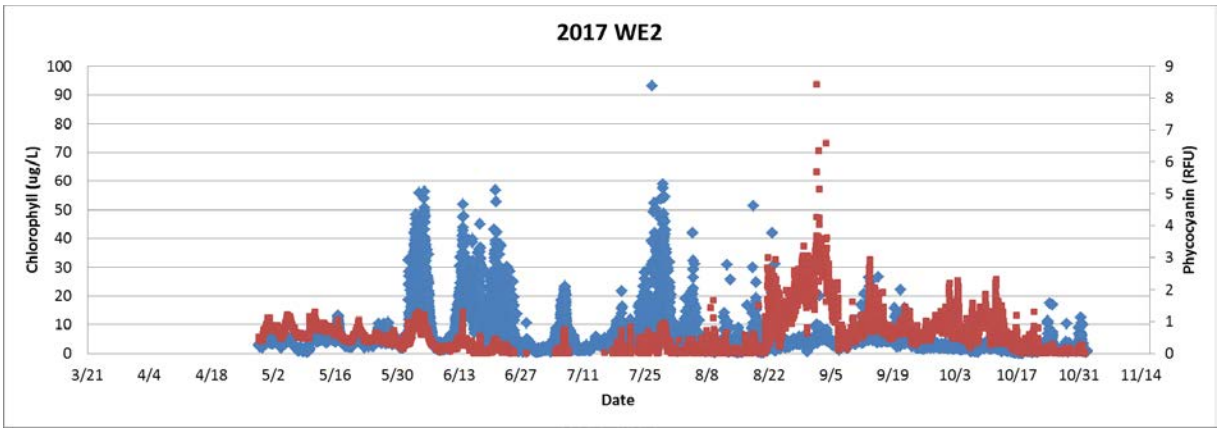
Results:

Continuous monitoring buoys were deployed for 205 days of operation in 2017 and provided over 3200 and 1900 measurements of soluble reactive phosphorus and nitrate, respectively (see below). Comparative grab sampling and lab-based analysis from our 20 weekly cruises is over-laid on the buoy data showing quite good agreement and providing high confidence in the *in situ* continuous observations. The continuous observing system data capture the significant temporal variability that can occur within the western basin due to pulses of tributary loadings and internal resuspension. These detailed observations will be critical for developing a better mechanistic understanding of the drivers and dynamics of the development of harmful algal blooms.



Soluble reactive phosphorus (top) and nitrate (bottom) data from measured continuous monitoring buoys in western Lake Erie for 205 days in 2017 [diamonds] compared with lab-measured samples [squares].

Continuous *in situ* fluorometry was able to capture detailed seasonal patterns of phytoplankton dynamics including the transition to the dominance of harmful cyanobacterial species as noted by observations of its accessory pigment, phycocyanin (see below). Weekly monitoring data confirmed



Chlorophyll (blue) and phycocyanin (red) data from measured by *in situ* fluorometers on continuous monitoring buoys in western Lake Erie in 2017.

that HABs species and toxin concentrations began to be elevated around July 21st with peak concentrations near the end of August and early September.

MTRI's analysis for NESDIS found that the CPA-A performance on VIIRS Science Quality imagery was comparable to results with MODIS imagery and compared well with *in situ* values, but that CPA-A retrievals compared poorly to *in situ* values when using Near Real Time VIIRS imagery. Having facilitated the transfer of the CPA-A to NESDIS, daily derived products for all Great Lakes are slated to be posted to CoastWatch beginning in late April 2018. MTRI will continue answering questions from NESDIS pertaining to the transition and will help with any further analyses as needed. CPA-A derived products from April through October 2017 were posted to each of the data portals with the total counts varying by lake (from 29 for Lake Superior to 45 for Lake Erie).

Products:

Peer-reviewed publications

Smith, J.P., Miller, R.J., Muzzi, R.W., Constant, S.A., Beadle, K.S., Palladino, D., Johengen, T.H., and Ruberg, S.A. (2017) Implementation of a Database Management System for Real-Time Large-Lake Observations. Marine Technology Society Journal 51 (6): 5-9.

Sayers, M.J., Grimm, A.G., Shuchman, R.A., Bosse, K.R., Leshkevich, G.A., Ruberg, S.A., and G.L. Fahnenstiel. Satellite monitoring of harmful algal blooms in the Western Basin of Lake Erie: a 20-Year History. Journal of Great Lakes Research Special Issue on HABs. *In Review*.

Bosse, K.R., Sayers, M.J., Shuchman, R.A., Fahnenstiel, G.L., Ruberg, S.A., Fanslow, D.L., Stuart, D.G., Johengen, T.H., and A.M. Burtner. Spatial-temporal variability of cyanobacteria vertical structure in western Lake Erie: implications for remote sensing observations. Journal of Great Lakes Research Special Issue on HABs. *In Review*.

Sawtell, R.W., Anderson, B., Sayers, M.J., Tokars, R., Lekki, J., and R.A. Shuchman. Real time HABs mapping using NASA Glenn Hyperspectral Imagery. Journal of Great Lakes Research Special Issue on HABs. *In ITAR Review*.

Moore, T.S., Hui Feng, Steven A. Ruberg, Kyle Beadle, Stephen A.Constant, Russell Miller, Ronald W. Muzzi, Thomas H. Johengen, Paul DiGiacomo, Veronica P. Lance, Brent N. Holben, Menghua Wang. SeaPRISM observations in the western basin of Lake Erie in the summer of 2016. Journal of Great Lakes Research. *In Review.*

Non-peer-reviewed publications

Shuchman, R.A., K. Bosse, M.J. Sayers, G. Fahnenstiel, and G. Leshkevich. "Satellite Observed Water Quality Changes in the Laurentian Great Lakes Due to Invasive Species, Anthropogenic Forcing, and Climate Change." 37th International Symposium on Remote Sensing of Environment (ISRSE-37) (2017). *Conference Paper*. https://doi.org/10.5194/isprs-archives-XLII-3-W2-189-2017

News articles or broadcasts

Chicago Tribune, October 7, 2017: "Study: Lakes Michigan, Huron top Superior in water clarity" (https://tinyurl.com/ydcgwgjb)

Chicago Tribune, January 26, 2018: "Lake Michigan has become dramatically clearer in last 20 years — but at a steep cost" (https://tinyurl.com/y6u24vb3)

February 12, 2018 Michael Sayers Interview on KMOX Radio St. Louis regarding Lake Michigan water clarity

Presentations

Stuart, D.G., A.M. Burtner, T.H. Johengen, R.J. Miller, D.A. Palladino, and S.A. Ruberg. Trends in Nitrate, Phosphate and Bloom Indicators During The 2016 Western Lake Erie Field Season. 60th Annual Meeting, International Association for Great Lakes Research. Detroit, Michigan. May 15-19, 2017.

Davis, T.W., T.H. Johengen, G. Doucette, C.M. Mikulski, A.A. Ritzenthaler, S.B. Watson, J.H. Ciborowski, G.S. Bullerjahn, R.M. McKay, J. Chaffin, M.D. Rowe, E.J. Anderson, D.C. Gossiaux, A.M. Burtner, and D.A. Palladino. Combining advanced molecular techniques and near real-time instrumentation to monitor cyanoHABs and microcystins in the lower Great Lakes. Milton, Ontario. April 26-27, 2017.

Ruberg, S.A., T.H. Johengen, A.J. Vander Woude, T. Moore, T.W. Davis, D.A. Palladino, R.J. Miller, R.W. Muzzi, S.A. Constant and K. Beadle. Emerging solutions supporting ecosystem research, monitoring and forecasting. Lake Erie Millenium Network. Windsor, Ontario, Canada. February 21-23, 2017.

Sayers, M.J., Ruberg, S.A., Leshkevich, G., Stuart, D.G., Shuchman, R.A., and K.R. Bosse. "Spatial and Temporal Patterns of Inherent Optical Properties in Western Lake Erie for 2015 and 2016 with Implications for Satellite Remote Sensing." (Ocean Sciences 2018). *Poster.*

Tools, maps, or models

Hyperspectral imagery maps have been generated for viewing at: https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/airSatelliteMon.html

MTRI maintains a website hosting CPA-A derived products for all five lakes (http://greatlakesremotesensing.org/) and HAB maps for WBLE, Green Bay, and Saginaw Bay (http://webserver.mtri.org/wordpress/habsmapping/)

MTRI maintains the GLOPGD (glopgd.org) containing historic Great Lakes IOP data

Outreach and Engagement Activities

Student mentoring
Mike Sayers is actively pursuing his PhD from Michigan Technological University, with partial support from this project.

Congressional visits
Briefed Sen. Peters on Great Lakes water quality

Theme I: Observing Systems and Advanced Technology

HABs Monitoring, Forecasting and Genomics for the Great Lakes

Principal Investigator(s): Bradley Cardinale and Thomas Johengen (University of Michigan-CIGLR)
NOAA Technical Lead(s): Henry Vanderploeg and Eric Anderson (NOAA GLERL)
NOAA Sponsoring Office: OAR, NOAA Great Lakes Environmental Research Laboratory
Budget Amount: $899,496

NOAA Strategic Goal(s):
Goal 1 - Healthy Oceans
Goal 4 - Resilient Coastal Communities and Economies

Overview:

CIGLR supports NOAA-GLERL's operational development of the Lake Erie and Saginaw Bay harmful algal bloom (HAB) forecasts and direct monitoring of microcystin concentrations within these ecosystems. We conduct research to support the evaluation, validation, and modification of the Lake Erie HAB Bulletin being operated within NOAA National Ocean Service (NOS) and the development of an improved forecasting model and dissemination plan. We conduct field sampling in Lake Erie and Saginaw Bay, Lake Huron and have expanded our efforts with both experimental work and the development of a coupled hydrodynamic-biological mechanistic model. We are using both historical and currently evolving environmental data sets to construct statistical models delineating factors regulating phytoplankton and *Microcystis* abundance patterns throughout western Lake Erie. We are developing and evaluating 'user-friendly' models (i.e., incorporating readily-obtained hydrological-meteorological variables) for predicting *Microcystis* biomass. We are engaging with end users to ensure

that the development of these new tools and forecasting products are meeting the needs of the local managers and stakeholders. This approach aligns with CIGLR's goal of facilitating the translation of research into more effective decision-making and public education. The potential impact of HABs on human health and economies magnifies importance of interpreting HAB research information in a useful and understandable manner. CIGLR's HABs Stakeholder Engagement program serves three functions: 1) identifying and assessing user needs related to HAB data and information for decision making; 2), guiding the development of future HAB research; and 3) disseminating CIGLR and GLERL HAB research tools and forecasts.

Objective(s):

The objectives of the CIGLR HABs program are to: 1) determine whether significant amounts of the HAB toxin, microcystin (MC), are entering the drinking water supplies, 2) post field sampling results to a publically-accessible website on a weekly basis, 3) elucidate the main drivers determining the timing and extent of bloom development, and the subsequent bloom movements through the western and central basins of Lake Erie, and 4) share field sampling results with NOAA NOS to assist in validating and improving the current Lake Erie HAB Bulletin.

Milestones:

Harmful Algal Bloom Modeling and Forecasting

- Ran a new 3D version of the forecast model in real time, including buoyancy parameterization of *Microcystis* for the 2017 HAB season. Skill assessment was also conducted for additional years.
  - Evaluated and improved the vertical distribution component of the model using observational data collected in 2015 and 2016, including vertical profiles of cyanobacterial abundance (Fluoroprobe casts and continuous profiler), colony size distributions (FlowCam), and measurements of colony buoyancy as a function of light and nutrients.
  - Investigated means to incorporate toxin concentrations from the weekly monitoring program and to evaluated the ability of the forecast model to predict the probability of exceeding specified toxin thresholds corresponding to exposure guidelines.
  - Used drifter studies and other observations to investigate the skill of the Lake Erie Operational Forecast System (LEOFS) model in simulating circulation patterns in the western basin of Lake Erie.
- Developing a coupled physical-biological deterministic model to examine relationships between key environmental factors (e.g., water temperature, river flows, nutrient loads, water column mixing, and sediment resuspension) on the *Microcystis* blooms on a fine spatial and temporal scale.
  - Updating a previous mass-balance Nutrient Phytoplankton Zooplankton Detritus (NPZD) model applied to Lake Michigan which includes Dreissenid mussels (Rowe et al. 2015) and coupling it with an updated hydrodynamics model (FVCOM, Anderson et al., 2010, Anderson and Schwab 2011).
  - Calibrating and verifying the model with weekly and continuous *in situ* datasets derived for this project.

- Initiated a statistical modeling approach to improve our understanding nutrient inputs and prediction of algal development, transport, and impact on human health in the Great Lakes.

Harmful Algal Bloom Monitoring and Environmental Sample Processer

Operated field monitoring programs within western Lake Erie and Saginaw Bay, Lake Huron, to provide weekly dissemination of results to local stakeholders, and maintain a publically available database of results to aid in assessment of trends.

- Collected samples and analyzed for the following: temperature, secchi disk transparency, total phosphorus, total dissolved phosphorus, nitrate and ammonia, colored dissolved organic matter, particulate carbon and nitrogen, microcystins, chlorophyll, phycocyanin, phytoplankton abundance, and potential microcystin/noduarin, cylindropsermopsin, and saxitoxin-producing cyanobacterial populations.
- Supported NOAA GLERL in the development and deployment of the Environmental Sample Processor (ESP) to detect HAB toxicity in near real-time.
    - Worked with NOAA CCEHBR to apply a multiplex microcystin/saxitoxin assay during its first ever operational deployment.
    - Compared weekly monitoring results using the Abraxis ELISA kits.
    - Worked with a senior research technician at Monterey Bay Aquarium Research Institute (MBARI) on the 2017 ESP deployments to ensure that the real-time communications between the ESP and GLERL functioned properly.

Experimental and Genomic Studies to Link P Reductions to HABs and Source Water Protection

- Supported genomic studies to assess total and toxic populations of *Microcystis*, plus total and toxic *Planktothrix* using qPCR.
- Screened monthly DNA samples from Lake Erie and Saginaw Bay for the genetic potential for the production of saxitoxins and cylindrospermopsins.
- Selected samples for high-throughput sequencing and metagenomic analysis in order to further understand how the bloom-associated community is responding to changes in physiochemical conditions as the bloom progresses.

Accomplishments:

Harmful Algal Bloom Modeling and Forecasting

The 3D harmful algal bloom forecast model (Lake Erie HAB Tracker) was run to provide a real-time nowcast and five-day forecast of HAB extent and movement during the 2017 bloom season (July through October). Efforts to further evaluate and improve the model were as follows:

- The model was updated to incorporate the newly-available high-resolution cyanobacterial index data product provided by NOAA NOS, derived from the European Space Agency Sentinel-3 Ocean and Land Colour Instrument (OLCI).

- New data collected in 2016 on the relationship between *Microcystis* colony buoyant velocity and colony diameter were used to confirm that the buoyancy parameterization used in the model, originally based on data from Japan, was appropriate for Lake Erie.
- Data from the CIGLR western Lake Erie monitoring program were used to develop statistical models of light attenuation as a function of water quality variables (manuscript submitted by former Summer Fellow, Chelsea Weiskerger). These statistical models will contribute to incorporation of light-dependent buoyancy in the model.
- Skill assessment of the HAB Tracker model was conducted for 2014-2017 (postdoc Qianqian Liu).
- In collaboration with LimnoTech, a database of Lake Erie microcystin toxin measurements was compiled from multiple agencies and universities. This database will be used to evaluate concepts for extending the HAB Tracker forecast to predict toxin concentrations. HAB Tracker forecasts for the 2016 and 2017 seasons were shared with LimnoTech. LimnoTech is evaluating the utility of the HAB Tracker for identifying high toxin areas, which will be targeted for adaptive monitoring and research through the NOAA-funded ECOHAB project led by The Ohio State University in 2018.
- A postdoc was recruited to develop a statistical modeling approach to improve our understanding of algal growth and toxicity. She will start in FY18.
- HAB Tracker forecasts for the 2016 and 2017 seasons were shared with NOAA NOS to develop a method to incorporate the information into the operational Lake Erie HAB Bulletin.
- We are running the coupled physical-biological deterministic model for multiple years (2011-2015). Monitoring data from EPA GLNPO, NOAA GLERL, and drinking water treatment plants are under compiling. These data will and have been used to carry out model skill assessment at different temporal and spatial resolutions.

Harmful Algal Bloom Monitoring and Environmental Sample Processer

Since July 2017 we completed 16 monitoring cruises in western Lake Erie. We made a total of 135 site visits, collecting 210 discrete samples including surface, bottom, and scum portions of the water column. Those samples were processed and analyzed for 20 different parameters including: temperature, secchi disk transparency, total phosphorus, total dissolved phosphorus, nitrate and ammonia, colored dissolved organic matter (CDOM), particulate carbon and nitrogen, microcystins, chlorophyll, phycocyanin, phytoplankton abundance, and potential microcystin/noduarin, cylindropsermopsin, and saxitoxin-producing cyanobacterial populations. A subset of our data, including pigment and toxin concentrations, was distributed on a weekly basis to 48 stakeholders and local water intake managers. Particulate and total microcystin concentrations were determined using the Abraxis ELISA kits within 2 days of sampling. We also completed 13 monitoring cruises in Saginaw Bay, Lake Huron. We completed 64 site visits and only surface water was sampled. The same 20 parameters were analyzed. All 2017 Lake Erie weekly monitoring analyses have been completed and the data is compiled. All 2017 Saginaw Bay weekly monitoring analyses have been completed but the data has not been finalized.

After finalizing quality control experiments of the biochemical assay used on board of the ESPniagara, the first bloom-monitoring deployments of ESPniagara took place in western Lake Erie in the summer of 2017. The goal of these deployments was to capture as much of the bloom season as possible by

programing the ESP to collect samples at gradually increasing intervals and depths in order to sustain deployment periods. The first deployment occurred from mid-July to mid-August, roughly 4 weeks, with a total of 41 full samples taken. By spacing sample collection in July every other day, the ESP was able to remain deployed in the lake, monitoring the beginning of the bloom and remaining functional into daily August sampling. Preliminary results showed that the ESPniagara was capable of measuring the toxicity of blooms within the range of lab measurements taken from weekly sampling. However, some samples in August did not reflect the toxicity of the bloom, which may have resulted from the congregation of cells at the surface, out of reach of the surface sample intake, which is located one meter below the surface to prevent the intake of air. We retrieved the ESP in August and serviced the unit for re-deployment in September to monitor the end of the bloom season. The second deployment lasted 4 weeks, collecting samples every other day due to a limitation in remaining battery power. A total of 24 samples were taken during the September deployment, with varying levels of toxins being measured at both depths, and periods of time where toxins were below detection or quantification. We are trying to improve the biochemical assay for the 2018 deployment season to produce greater sensitivity of detection and the stability of antibodies during the deployment period. We also plan to conduct better paired sampling with our ongoing weekly monitoring to provide validation data of lab determined toxin concentrations.

Experimental and Genomic Studies to link P reductions to HABs and source water protection

High-throughput sequencing samples were analyzed to study *Microcystis sp.* and associated bacterial communities for:

- Gene content and expression in different bloom stages (comparative genomics analysis)
- Transcriptional links between nutrient concentrations and toxin production
- Transcriptional regulation of nutrient transport and metabolic genes

High-throughput sequences were then used to create a native graph database of the *Microcystis* pan-genome and Lake Erie community for rapid identification of novel genes, *in situ* community gene content and expression, and hypothesis testing of links between nutrients and toxicity. Laboratory experiments using cultured isolates of Lake Erie cyanobacteria are being used to provide physiological rates to this database and verify genetic results.

Results:

Remote sensing data from the NASA MODIS satellite was used to monitor the intensity and distribution of the western Lake Erie 2017 harmful algal bloom. Analysis of the images indicated that HAB conditions were present for 83 days with an onset of July 25th and a disappearance on October 16th. At its peak intensity the bloom covered 1606 square kilometers, equivalent to 54% of the western basin area (figure 1).

Weekly monitoring results for 2017 summarizing particulate and dissolved concentration of the toxin microcystin, along with biomass proxies of phototrophic pigments phycocyanin and chlorophyll are presented in Table 1. Mean concentrations of particulate microcystin exceeded the World Health Organization drinking water guidelines of 1.0 ug/L for much of the season.

Figure 1. Satellite remote sensed image of HABs distribution in Western Lake Erie on September 26, 2017 taken from the NASA Modis-Aqua satellite.

Measureable toxin levels were present in the lake from early July to mid-October. The exact timing of when a given station saw maximum biomass or toxicity levels was dependent on its distance from the coast and the prevailing circulation patterns that varied with wind speed and direction (Figure 2). When winds came from the north and kept the Maumee River outflow trapped within the Bay, exceeding high concentrations of biomass (CHL > 500 ug/L) and toxin level (Part Microcystin = 289 ug/L) were able to develop > 200 Maximum concentrations were present on August 14, 2017 at a station located near the mouth of the Maumee River.

	Particulate Microcystin (ug/L)	Dissolved Microcystin (ug/L)	Phycocyanin (ug/L)	Chlorophyll (ug/L)
Min	0.1	0.1	0.0	1.2
Max	289	0.6	538	532
Mean	5.1	0.2	25.2	29.9

Table 1. Min, mean, max concentration of particulate and dissolved concentration of the toxin microcystin, along with biomass proxies of phototrophic pigments phycocyanin and chlorophyll during the 2017 GLERL-CIGLR western Lake Erie weekly monitoring program covering the period from May 8th – October 10th.

Weekly monitoring results have been combined with Remote sensing data from Modis, MERIS and Sentinel color sensors to produce a digitized image of the intensity of the HAB scaled to a derived unit called the Cyanobacteria index (figure 3). The low, detectable level of the HAB is calibrated to represent a cyanobacterial density of 20,000 cells per ml. The Bulletin is updated with every new clear image (potentially every other day) and is run in conjunction with a particle tracking model and the Great Lakes Coastal Forecasting System hydrodynamic model to produce 3-5 day forecasts of bloom movement and density. Monitoring results are helping to validate new algorithms that are being developed for newer ocean color sensors on the Sentinel 2 satellites.

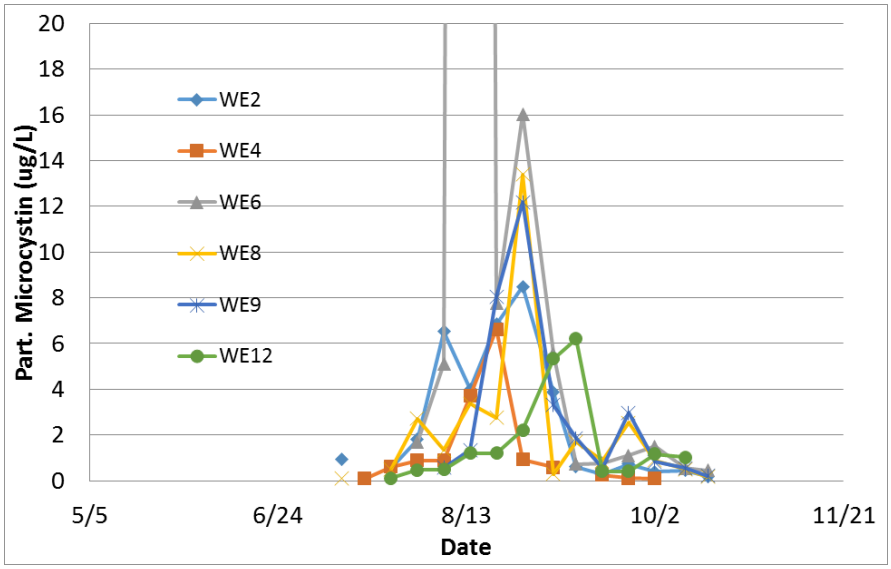


Figure 2. Particulate microcystin concentrations at six of the eight monitoring sites in western Lake Erie measured on a weekly basis using vessel based surveys.

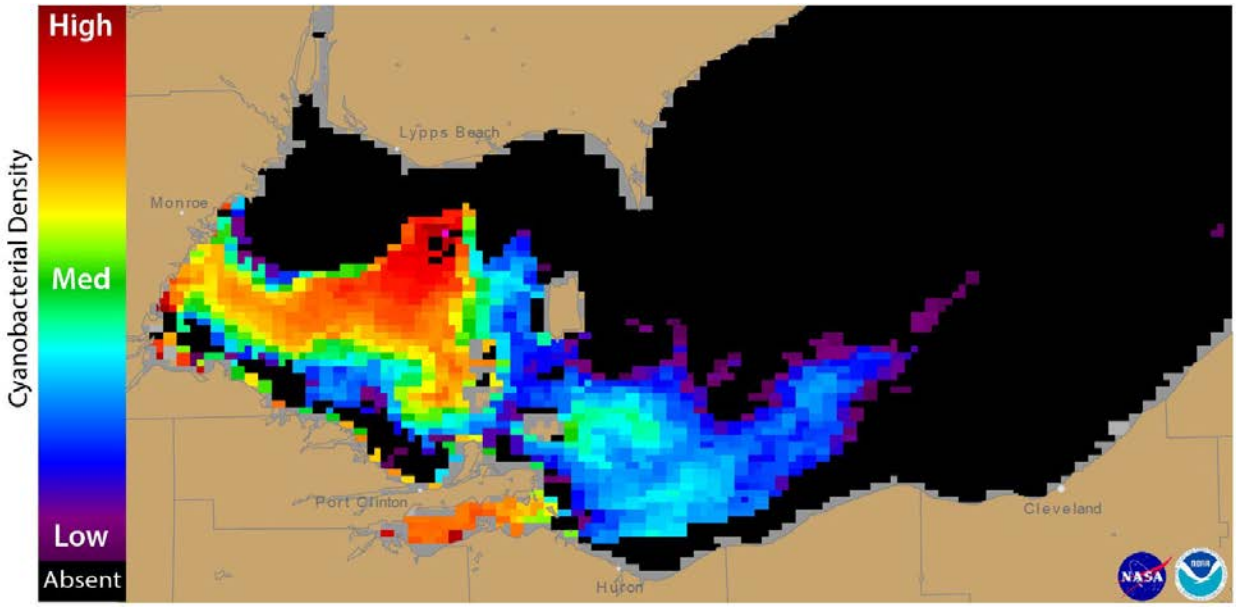


Figure 3. The NOAA HAB forecast bulletin showing the distribution of the HAB on September 17, 2017.

Products:

Peer-reviewed publications [*student co-authors]

Moore, T. S., Mouw, C. B., Sullivan, J. M., Twardowski, M. S., Burtner, A. M., Ciochetto, A. B., & Johengen, T. H. (2017). Bio-optical Properties of Cyanobacteria Blooms in Western Lake Erie. *Frontiers in Marine Science*, *4*, 300. https://www.frontiersin.org/article/10.3389/fmars.2017.00300/full

Smith, J. P., Miller, R. J., Muzzi, R. W., Constant, S. A., Beadle, K. S., Palladino, D. A., and Ruberg, S. A. (2017). An Implementation of a Database Management System for Real-Time Large-Lake Observations. *Marine Technology Society Journal*, *51*(6), 5-9.

D. Gill*, M. D. Rowe, and S. Joshi. 2018. Fishing in greener waters: understanding the impact of harmful algal blooms on Lake Erie anglers and the potential for adoption of a forecast model. Journal of Environmental Management, *submitted*.

C.J. Weiskerger*, M.D. Rowe, C.A. Stow, D. Stuart, and T. Johengen. 2018. Application of the Beer-Lambert model to attenuation of photosynthetically active radiation in a shallow, eutrophic lake. Water Resources Research, *submitted*.

Kramer, B.J.*, T.W. Davis, B.H. Rosen, G. Oh, K.A. Meyer, C.J. Gobler. Nitrogen limitation, toxicity, and toxin synthesis potential of cyanobacterial populations in Lake Okeechobee and the St. Lucie River Estuary during the 2016 State of Emergency event. *In review*

News articles or broadcasts

The HAB Tracker and related Lake Erie angler stakeholder engagement efforts were highlighted in the following media coverage:

- (July 10, 2017) Article in the International Joint Commission's newsletter, "New Tool for the Tackle Box: An Algal Bloom Tracker" (http://ijc.org/greatlakesconnection/en/2017/07/new-tool-tackle-box-algal-bloom-tracker/?mc_cid=3dc3cd5934&mc_eid=3c4d9be7c7)
- (July 11, 2017) News update on "The Afternoon News", a radio program hosted by AM 800 CKLW in Windsor, Ontario
- (August 4, 2017) Devin Gill participated in a press event held by the Toledo Drinking Water System. In the event attended by local media outlets, Gill shared prepared words regarding the development of the HAB Tracker forecast model and other efforts by CIGLR and NOAA GLERL to monitor and forecast harmful algal blooms in Western Lake Erie.
- (October 10, 2017) Article in the Erie Times published in Erie, Pennsylvania, "Staying on Track: New tools alert public to dangers of toxic HABs."

Presentations [*student co-authors]

Davis, T.W., Rowe, M.D., Anderson, E.J., Vanderwoude, A., Johengen, T.H., Ruberg, S., Stumpf, R.P., and Doucette, G. Combining advanced technologies to develop an early warning system for HABs in western Lake Erie. 60th Annual Conference on Great Lakes Research, Detroit Michigan, May 15-19, 2017.

Gill, D.G., Joshi, S.J., and Rowe, M. Understanding the Potential Utility of the HAB Tracker Forecast Model for Western Lake Erie Anglers. 60th Annual Conference on Great Lakes Research, Detroit Michigan, May 15-19, 2017.

Ming, T., Vanderploeg, H.A., Rowe, M.D., Fanslow, D.L., Strickler, J.R., Miller, R.J., Johengen, T.H., Davis, T.W., and Gossiaux, D.C. Effect of light exposure and nutrients on buoyancy of *Microcystis* colonies. 60th Annual Conference on Great Lakes Research, Detroit Michigan, May 15-19, 2017.

Ouyang, W., Rowe, M.D., and Zhang, H. Skill Assessment of the Lake Erie HAB Tracker Forecast Model using Variable Spatial Neighborhoods. 60th Annual Conference on Great Lakes Research, Detroit Michigan, May 15-19, 2017.

Zhang, H., Rowe, M.D., Johengen, T.H., Anderson, E.J., and Ruberg. Modeling succession of algal functional groups associated with Lake Erie harmful alga blooms. 60th Annual Conference on Great Lakes Research, Detroit Michigan, May 15-19, 2017.

Meyer, K.A., T.W. Davis, S.B. Watson, and G.J. Dick. Abundance and expression of nitrogen uptake and metabolic genes in a Lake Erie Microcystis bloom demonstrate a shift in community nitrogen metabolism. 9th US Symposium on Harmful Algae, Baltimore, MD

Schissler, K.*, K.A. Meyer, D.J. Smith*, T.W. Davis, S.B. Watson, and G.J. Dick. Impact of Synechococcus sp. on nitrogen and reactive oxygen species dynamics surrounding blooms of Microcystis in Lake Erie. 9th US Symposium on Harmful Algae, Baltimore, MD

Meyer, K.A., D.J. Smith*, K. Buffin*, K. Schmidt*, V.J. Denef, and G.J. Dick. Microbial interactions are a key to understanding algal bloom dynamics. 2017 MCubed Symposium, Ann Arbor, MI.

Meyer, K.A., T.W. Davis, S.B. Watson, and G.J. Dick. The impact of nitrogen form and availability on the toxicity of Microcystis blooms in Lake Erie. 60th Annual Conference on Great Lakes Research, Detroit, MI., May 15-19, 2017.

Meyer, K.A. and G.J. Dick. Developing a user-driven Great Lakes genomics graph database for collaborative data query and hypothesis testing. CIGLR Annual Partners Meeting, Ann Arbor, MI. October 2017.

Steffen, M.M., T.W. Davis, J.A. Stough, R.M. McKay, G.S. Bullerjahn, L.E. Krausfeldt, G.L. Boyer, T.H. Johengen, D.C. Gossiaux, A. Burtner, D. Palladino, M.D. Rowe, G.J. Dick, K.A. Meyer, S. Levy, B. Boone, S.W. Wilhelm. Transcriptional profiles of the 2014 Lake Erie Microcystis bloom. ASLO Aquatic Sciences Meeting, Honolulu, HI. Feb. 2017.

<u>Proposals for leveraged funding</u>

ECOHAB 2017 Linking process models and field experiments to forecast algal bloom toxicity in Lake Erie: Supplemental Funds Proposal: Chaffin, J., T.W. Davis, J. Westrick, T. Bridgeman, G.J. Dick, K.A. Meyer (Funding agency: NOAA NCCOS).

Tools, maps, and models

- The Lake Erie HAB Tracker
  - Provided a daily nowcast and five-day forecast of the extent and movement of the harmful algal bloom (HAB) in Lake Erie during the HAB season in 2017 (July through October). A map was included in 2017 to show the most recent toxin concentration measurements from the CIGLR weekly monitoring program.
  - In 2017, the HAB Tracker webpage was updated to increase accessibility and utility for targeted users. These updates were based on recommendations identified during a 2016 study to assess stakeholder needs targeting Lake Erie recreational anglers and charter boat captains. The evaluation of these updates is ongoing.
  - Website: https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/habTracker.html
  - Demonstration version showing how the website appeared during the 2017 bloom season: https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/habTracker2017.html
- Neo4j-based graph database of *Microcystis* comparative genomics and transcription of genes in Lake Erie
- A metagenomics pipeline for taxonomic identification of potential toxin producers and potential toxins (In collaboration with Stonybrook University & USGS).
- Hyperspectral imagery maps have been generated for viewing here: https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/airSatelliteMon.html

Outreach and Engagement Activities

Student mentoring

- Chelsea Weiskerger, a doctoral student at Michigan State University, was mentored through the CIGLR Summer Fellows program. Chelsea analyzed data from the CIGLR monitoring program in western Lake Erie to develop statistical models of the light attenuation coefficient for photosynthetically active radiation as a function of water quality variables, which will contribute to forecast model development. A journal article is in preparation.
- Kendall Schissler, a UM undergraduate, was mentored through the Department of Earth and Environmental Sciences. Kendall analyzed metagenomic and metatranscriptomic data from Lake Erie samples and isolated cultures from Lake Erie to understand the role of non-toxic cyanobacteria present in *Microcystis* blooms. A poster of her research was presented at the 9th Symposium on Harmful Algae. Laboratory experiments are in preparation.
- Michael Rader, a UM undergraduate, was mentored through the Department of Earth and Environmental Sciences. Michael worked on isolating new strains of the cyanobacteria *Synechococcus* from Lake Erie weekly monitoring samples. Michael also conducted a laboratory experiment on the impact of hydrogen peroxide and temperature on the growth of these *Synechococcus* isolates.
- Kirsten Nelson, a UM undergraduate, was mentored through the Undergraduate Research Opportunity Program (UROP) working on the project "The role of hydrogen peroxide in toxic cyanobacterial blooms." Kirsten isolated several strains of the cyanobacteria *Synechococcus* and is

conducting co-culture laboratory experiments with these isolates and axenic *Microcystis aeruginosa* isolates.

Public education presentations

Meetings with stakeholders to discuss user needs and HAB forecast development and dissemination:

- June 30, 2017 - Mark Rowe and Devin Gill visited the Toledo drinking water treatment plant with representatives from NOAA and LimnoTech ahead of the 2017 HAB season. Management personnel attended.
- August 10, 2017 - Mark Rowe presented at the annual meeting of the Lake Erie Water Group (a professional association of public water systems).
- August 17, 2017 - Devin Gill presented at the monthly meeting of the Lake Erie Charter Boat Association. Approximately 30 captains attended.
- September 20, 2017 – Devin Gill presented at a monthly meeting of the Owosso Rotary Club. Approximately 40 members attended.
- September 26, 2017 – Devin Gill presented at a monthly meeting of the Downriver Bass Association. Approximately 15 members attended.
- March 6, 2018 - Devin Gill was a featured presenter at the Great Lakes Conference held by Michigan State University's Department of Fisheries and Wildlife. Approximately 160 environmental professionals and public stakeholders attended.
- August 17, 2017 – Devin Gill attended a stakeholder workshop held by Donna Kashian, where she presented the Lake Erie HAB Tracker and discussed stakeholder interest in developing a similar product for Saginaw Bay.

Community outreach events

- September 27, 2017 - Devin Gill attended the Saginaw Bay Watershed Conference to learn more about stakeholder interest in Saginaw bay, and further assess interest in the development of a Saginaw Bay HAB forecast.

Factsheets or other public education materials

In response to the 2016 stakeholder needs assessment, an updated HAB Tracker FAQ webpage was developed with input from CIGLR staff (Devin Gill, Mary Ogdahl, Joe Smith), the GLERL Communications team (Margaret Lansing and Nicole Rice), and HAB forecast model developers (Mark Rowe and Eric Anderson). The FAQs sought to answer salient questions raised by focus group participants in the 2016 stakeholder needs assessment, while serving as a reference for common media inquiries and other HAB Tracker users. https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/habTracker_about.html

Other

- 9th US Symposium on Harmful Algae Student presentation Judge
- 2017 IAGLR Student presentation Judge, 60th Annual Conference on Great Lakes Research, Detroit, MI
- HABs Collaboratory meeting Organizing Committee Member

Theme I: Observing Systems and Advanced Technology

Advancement of Mobile, In-situ HAB Toxin Warning and Genomic Observation for Great Lakes Decision Support Tools

Principal Investigator(s) and Affiliation(s): Bradley Cardinale and Thomas Johengen (University of Michigan-CIGLR)
NOAA Technical Lead(s): Steve Ruberg (NOAA GLERL)
NOAA Sponsoring Office: OAR, NOAA Great Lakes Environmental Research Laboratory
Budget Amount: $432,500

NOAA Strategic Goals:
Goal 1 - Healthy Oceans
Goal 4 - Resilient Coastal Communities and Economies

Overview:

NOAA GLERL, through the Great Lakes Restoration Initiative, and in collaboration with the Cooperative Institute for Great Lakes Research (CIGLR) has significantly advanced weekly ship-based surveillance and near-real time water quality assessments in western Lake Erie, including continuous monitoring for algal pigments, nutrients, turbidity, DO, and other parameters. Furthermore, in 2016 GLERL deployed the first 2nd Generation Environmental Sample Processor (2G ESP) for autonomous, near-real time monitoring of microcystins and sampling for advanced biological analysis ('omics) in a freshwater system. These efforts advanced two of NOAA's important decision support tools -- the Western Lake Erie Experimental HAB Bulletin and the Western Lake Erie Experimental 3D HAB Tracker. While these widely adopted NOAA products provide tracking of bloom biomass and areal coverage, they do not fully meet the demands of regional stakeholders, such as drinking water intake managers, who call for forecasts of bloom toxicity. Furthermore, holistic understanding of bloom initiation, toxicity, and persistence is lacking.

In response to these needs, a project team consisting of CIGLR, NOAA GLERL, NOAA National Centers for Ocean Coastal Science (NCCOS), and Monterey Bay Aquarium Research Institute (MBARI) is developing new mobile, *in-situ* HAB detection technology to facilitate toxin forecasting and genomic observations at much improved temporal and spatial scales in support of informed decision making. Engineering advances for the third generation ESP (3G ESP) underway at MBARI include miniaturizing the *in situ* sample processing capabilities of the 2G ESP for algal toxin detection and DNA archival to fit into the payload of a Tethys-class long-range autonomous underwater vehicle (LRAUV). The resulting 3G ESP-LRAUV ("eAUV") prototype enables adaptive biological sampling over weeks-long targeted missions.

Objective(s):

Develop eAUV sample processing protocols for particulate microcystin by transferring the current 2G ESP MC extraction protocol to the new 3G ESP bench top unit and ensuring inter-comparability between the 3G ESP instrument and GLERL's traditional weekly sampling methods.

Milestones:

- Lead deployment of the new eAUV in western Lake Erie during July 2018. The deployment will consist of a one-week mission in which the onboard 3G-ESP will collect, extract, and analyze microcystin samples at each of the eight GLERL weekly sampling stations. In parallel, samples will be collected and archived onboard the eAUV for comparison of CHAB strain abundance with bloom toxicity. Fine-scale resolution of both parameters is critical for the advancement of the aforementioned forecasting tools. The goal is to capture bloom development when toxicity generally increases rapidly.
- Manage sample processing for metagenomic extraction and DNA sequencing (16S, 18S, shotgun).
- Analyze samples for microcystin genes and CHAB community composition using qPCR and DNA barcoding, respectively. qPCR will be conducted using GLERL's digital PCR (dPCR) assay for easy transition to the eAUV prototype equipped with on-board dPCR to provide gene quantification in near-real time via the 3G ESP-long range AUV (LRAUV) mobile platform.

Accomplishments:

In the first 4 months of this project, we have focused on showing comparability between the 3G ESP instrument and GLERL's traditional weekly sampling methods (Milestone #1). For instance, it is not known whether the lysis protocol normally used in the 3G ESP would be effective on the more robust cell walls of the cyanobacteria, *Microcystis*. Thus, we proceeded with several experiments to compare traditional manual vs. 3G ESP lysis methods.

Results:

Matched samples (i.e., same water mass) were collected in duplicate from the 3G ESP and a bench filtration system. One set of filters was immediately frozen, one set was preserved with RNALater and frozen, and one set was preserved with RNALater and held at room temperature for seven days, then frozen. The latter condition emulates an LRAUV mission, with recovery being somewhat delayed after sample collection.

We have also begun construction of a bench-top instrument that mimics the performance of the 3G ESP, but is designed primarily for laboratory use. This bench-top instrument (which we call the 'tackle-box', because the instrument is fitted inside a standard size fishing tackle box) will be used to refine assay development. We expect completion of this instrument by late April, 2018.

Products:

Peer-reviewed publications

Scholin, C., Birch,J., Jensen, S., Marin III, R., Massion, E., Pargett, D., Preston, C., Roman, B., Ussler III, W. 2018. The quest to develop ecogenomic sensors: A 25-year history of the Environmental Sample Processor (ESP) as a case study. Oceanography 30:100-113. https://doi.org/10.5670/oceanog.2017.427

Presentations

- Scholin—Oceanology International, London UK. March 2018
- Scholin-USGS Headquarters, Reston, VA. February 2018

Proposals for leveraged funding

- NOPP 2018 N00014-17-S-B016
- NOAA-OAR-OER-2018-2005296

Outreach and Engagement Activities: None

Theme II: Invasive Species and Food-web Ecology

Coordination & leadership of the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)

Principal Investigator(s) and Affiliation(s): Bradley Cardinale and Hongyan Zhang (University of Michigan-CIGLR), Heather Triezenberg (Michigan State University-Michigan Sea Grant, MSU Extension)
NOAA Technical Lead(s): Felix Martinez (NOAA NCCOS), Ed Rutherford (NOAA GLERL)
NOAA Sponsoring Office: GLERL
Budget Amount: $227,199

NOAA Strategic Goals:
Goal 1 - Healthy Oceans
Goal 4 - Resilient Coastal Communities and Economies

Overview:

Aquatic nonindigenous species (ANS) are perhaps the greatest stressor currently facing the Great Lakes aquatic ecosystem, altering energy pathways, lowering food web and fisheries productivity, and costing millions of dollars annually in control and mitigation. NOAA's Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) is a searchable database with fact sheets, threat assessments, and maps designed to improve stakeholder education and inform prevention, management and control of ANS. GLANSIS currently serves information relating to 182 established nonindigenous species, 12 range expansion species, and 67 watchlist species. However, these core lists were developed in approximately 2010, and have been updated only on an ad hoc basis. Because GLANSIS serves a clearinghouse role by compiling information on ANS in the Great Lakes, the project engages academic researchers from across the basin to collect the most relevant, up-to- date data on these species. In the course of providing the most current information on ANS, GLANSIS staff perform data synthesis research that leads to a better understanding of current and potential impacts of ANS to the Great Lakes ecosystems. The information served through GLANSIS helps managers make informed decisions when devising and implementing strategies to prevent, control, and mitigate the introduction and impacts of

ANS and thus protect the natural resources and economic well-being of the Great Lakes. As a database and information clearinghouse, GLANSIS's main function is to disseminate scientific information to both the science and public sectors, and in the process highlight the scientific role that NOAA can play at the regional level.

Objective(s): The goal of this project is to update, improve, and enhance GLANSIS to better inform managers of current and future threats from nonindigenous species.

Milestones:

Milestones and Deliverables for this reporting period	Anticipated completion	Completion
GLANSIS Project Manager hired	FY17 Q4	√
Report backlog (>10,000 individual reports/references) reduced by 25%	FY18 Q1	√
Literature review for revised Watchlist completed and candidate list made available	FY18 Q1	
Suggestions for re-categorizations identified (e.g., a species moved from Watchlist to established, identification of new invaders, new range expanders, shifts in taxonomy, etc.)	FY18 Q2	√
Candidate list of species for piloting advanced demographic and control information identified (based in part on availability of information)	FY18 Q1	√
Full bibliographic information made more readily accessible via programming changes.	FY18 Q2	√

Accomplishments and Results:

GLANSIS Program Manager and full-time Research Associate positions were filled (November 2017 and January 2018, respectively). Three student research associates/summer fellows were hired for work during summer 2017.

Programming needs associated with the GLANSIS website, planned additions to mapping capability, planned additions to reference capability and the first stages of planned additions to risk assessment clearinghouse capability were assessed and found to fall within the requested CIGLR expertise with the possible exception of GIS-related programming. This need was taken into consideration in the hiring of the full-time CIGLR research associate. The scientist survey is in draft form and is on target to be launched in June.

Hundreds of new (to the system) reports of ANS were added to GLANSIS and thousands more were organized and sent to USGS NAS for bulk upload to the system. Approximately 12 species profiles were updated in 2017 and more than 20 additional profiles have been completed and are pending final review. More than 350 species have been identified for possible addition to the system, 132 of these have been eliminated by rapid screening and about 5 targeted to be added (profiles in progress), the remaining approximately 230 species have been categorized based on screening but require additional assessment prior to final determination whether to list or not.

A link has been embedded within each GLANSIS fact sheet (heading the literature cited) allowing access to the full NAS-GLANSIS references tagged to the particular species, including grey literature not explicitly cited in the profile.

Species have been identified to pilot the enhanced demographic and control options. These will be presented to the Great Lakes Panel on ANS for confirmation at their spring meeting.

The mapping interface was created and launched in June 2017. Currently it can map the distribution of all species in our system, and imports select relevant environmental data layers from the Great Lakes Aquatic Habitat Framework (GLAHF). Two habitat suitability maps, courtesy of CIGLR work on Asian carp, are in development and will be tested to ensure the interface will be able to serve this type of information.

Products:

Non-peer-reviewed publications

Sturtevant, RA. 2017. *Impacts of Aquatic Invasive Species sub-indicator report.* In *State of the Great Lakes 2017 Technical Report.* 2017. Cat No. En161- 3/1E-PDF. EPA 905-R-17-001.

State of the Great Lakes 2017: *Highlights Report*. https://binational.net/wp-content/uploads/2017/06/SOGL_17-EN.pdf

News articles or broadcasts

Sturtevant, RA and E. Lower. (February 25, 2018). *GLANSIS: a "one-stop shop" for information on aquatic invaders.* Michigan State University Extension. http://msue.anr.msu.edu/news/glansis_one_stop_shop_information_on_aquatic_invaders_msg18_sturtevant18

NOAA Hot Item Article re: the soft-launch of the new website. June 2017.

Presentations

Sturtevant, R. A., Martinez, F., Rutherford, E., Elgin, A., Smith, J., Alsip, P*. (May 18, 2017) *Update on the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)*. Presented paper at International Association of Great Lakes Research Annual Conference, IAGLR, Detroit, MI, United States.

Alsip, P.*, Rice, N., Iott, S.*, Sturtevant, R. A., Martinez, F., Rutherford, E. (May 18, 2017) *The Great Lakes Aquatic Nonindigenous Species Information System Watchlist*. Presented poster at International Association of Great Lakes Research Annual Conference, IAGLR, Detroit, MI, United States.

Martinez, F. Conference/Meeting, *Fall Extension Conference*, Detroit, MI. (October 23, 2017 - October 25, 2017). Sea Grant World Café: Part 1

Lower, E., Sturtevant, R., Martinez, F. (February 8, 2018). *GLANSIS Project Status and Planning 2018*. Great Lakes Restoration Initiative.

Sturtevant, R., Lower, E. (May 30, 2018). *GLANSIS Project Updates 2018.* MSU Great Lakes Policy Forum.

Conferences or working groups

- Binational Great Lakes AIS Forum –11/8/17 hosted at GLERL
- 2nd Annual Great Lakes Aquatic Invasive Species Surveillance Planning – hosted at GLERL by Martinez 1/18-19/18

Tools, maps, models, etc

- Website overhaul. https://www.glerl.noaa.gov/glansis/
- Map Explorer Interface: https://www.glerl.noaa.gov/glansis/mapExplorer.php
- Risk Assessment Clearinghouse: https://www.glerl.noaa.gov/glansis/riskAssessment.html

Outreach and Engagement Activities:

Student mentoring

3 summer student projects:

- Kylan Hopper focused on developing/revising species profiles
- Peter Alsip focused on development of Habitat Suitability Maps and pilot testing of the new GLANSIS Map Explorer
- Thomas Makled focused on framing the new (proposed) GLANSIS Risk Assessment portal

Factsheets or other public education materials

GLANSIS Watchlist Factsheet: https://www.glerl.noaa.gov/glansis/GLANSISwatchlist.pdf

Theme II: Invasive Species and Food-web Ecology

Great Lakes Long-term Ecological Research Program

Principal Investigator(s) and Affiliation(s): Brad Cardinale and Thomas Johengen (University of Michigan-CIGLR)

NOAA Technical Lead(s): Henry Vanderploeg, Ashley Elgin, Ed Rutherford (NOAA GLELR)
NOAA Sponsoring Office: OAR, NOAA-Great Lakes Environmental Research Lab
Budget Amount: $358,111

NOAA Strategic Goals:

Goal 1 - Healthy Oceans
Goal 4 - Resilient Coastal Communities and Economies

Overview:

CIGLR is collaborating with the Ecosystem Dynamics branch at NOAA GLERL to continue their collection of long-term ecological data and conduct targeted fundamental research on ecosystem processes critical to understanding ecosystem structure and function for managing water quality, fisheries, and other ecosystem services in the Great Lakes. Specifically, CIGLR supports the NOAA GLERL Long-Term Ecological Research (LTER) program in Lake Michigan to integrate a core set of long-term observations on biological, chemical, and physical variables, with short-term process-based studies for understanding ecosystem change. In addition, CIGLR works with GLERL to support ecological research within each of the other four Great Lakes on a rotational basis in support of the U.S. EPA led Coordinated Science Monitoring Initiatives (CSMI). Efforts within the CSMI program apply similar spatial observations, analysis, and process studies conducted for the Lake Michigan LTER program. Such information is essential for the development of new concepts, models, and forecasting tools to explore impacts of various stressors on the ecosystem. This research contributes to CIGLR and GLERL core missions by providing data and understanding for the development of models and forecasting capabilities, and the application of new sampling technologies.

Objective(s):

The overarching goal of this program is to improve the understanding of the structure and function of Great Lakes food webs from viruses to fishes in response to both natural and human-induced stressors. A) Specific objectives of the Lake Michigan Long-Term Ecological Research program include:

- Examine the structure and function of the open water food web, including how it relates to tributary inputs and spatial distribution of dreissenid mussels.
- Maintain the long-term monitoring program for benthic organisms in southern Lake Michigan
- Advance our understanding of dreissenid mussel population dynamics.

B) Specific objectives of the 2017 Lake Huron CSMI project include:

- Expand upon our recent work in Lake Michigan (CSMI 2015) and past work in Lake Huron (2012) to determine fine-scale food-web structure and function from phytoplankton to fishes. A
- Maintain the long-term monitoring program for benthic organisms in southern Lake Huron, advance our understanding of dreissenid mussel population dynamics, and provide estimates of dreissenid condition and growth in Lake Huron.

Milestones:

Subproject A: Whole lake benthic survey will be conducted in 2017
Subproject A: Sample analysis and data analysis will begin after survey and continue into 2018
Subproject A: Data report and papers will be written during 2019
Subproject B: Field sampling and experiments will be carried out in 2017
Subproject B: Sample and data analysis will begin in 2017 and continue through 2018
Subproject B: Presentations will be made during 2018 and 2019
Subproject B: Papers will be written during 2019

Accomplishments:

Lake Michigan LTER: *Benthic Surveys and Dreissenid Population Dynamics*

- A benthic survey at 40 established sites was conducted in the southern region of Lake Michigan during late summer. Four new deeper water sites were added during this 2017 survey. At each site, ponar grabs were collected in triplicate. During the survey, additional mussels were collected from five sites to generate depth-specific length-weight (ash free dry weight) regressions, which indicate the condition of the mussels.
  - Over 85% of samples have been processed. In the laboratory, all dreissenid mussels were measured to produce a length distribution, which is necessary for calculating mussel biomass using the length-weight regressions.
- Regular surveys along the Muskegon transect were conducted to assess condition and reproductive status of mussels at three representative depths. Samples were at three different times during the open water season. All data has been collected and processed.

Lake Huron CSMI Studies: *Benthic Surveys and Mussel Growth Experiments*

- A benthic survey was conducted sampling 100+ sites in Lake Huron, including the Main Basin, Georgian Bay, North Channel, and Saginaw Bay onboard the R/V Lake Guardian in September 2017.
  - Sample processing is 75% complete. All Ponar samples have been processed and delivered to our collaborators at Buffalo State. Only diver collected samples remain. All dreissenid mussels were measured to produce length distributions. Oligochaetes and chironomids were mounted on slides so that they can be identified and their lengths measured.
- Additional mussels were collected at 12 sites of sites in order to prepare depth-specific, length-weight (ash free dry weight) regressions, which are necessary to determine biomass. All data has been collected and processed.

- Underwater video was collected during each of the Ponar grabs and benthic sled tows in the main basin, to increase the spatial interpretation of the individual sampling results.
- For the field growth experiment, one mussel mooring has been established in the outer portion of Saginaw Bay (~20m), and one mooring further out into the Main Basin (~45m). Growth experiment moorings were also set up at two sites in the Thunder Bay area, one at 45 m and one at 90 m.
- The moorings were set up in June 2017, select cages were removed and measured in October 2017, and will be retrieved again in April 2018 to conclude the experiment.
- Results from benthic surveys are being summarized and will be contributed for inclusion in the next EPA State of the Lakes Ecosystem Conference (SOLEC) report. The raw data will be made available via a GLERL Technical Memo and also analyzed and reported in peer-reviewed publications.

Lake Huron CSMI Studies: *Does spatial structure of the aquatic food web differ between nutrient rich and nutrient poor areas of Lake Huron?*

- CIGLR and GLERL expanded upon recent work in Lake Michigan (CSMI 2015) and past work in Lake Huron (2012) to determine fine-scale food-web structure and function from phytoplankton to fishes along a nutrient-rich transect (from inner Saginaw Bay out to the 65-m deep Bay City Basin) and along a nutrient-poor transect (from inner Thunder Bay out to the Thunder Bay basin) during May, July, and September onboard the R/V Laurentian. Additional samples of fish larvae and zooplankton were collected along both transects in June to help estimate larvae growth, diet, density and mortality and to identify recruitment bottlenecks.
    - As permitted by weather, plankton survey system (PSS)/acoustics runs (day and night) were successfully completed on all long nearshore-offshore transects and at master stations to tie in with diel distribution of zooplankton, Mysis and larval fish. The PSS transects indicated low productivity in Thunder Bay's nearshore zone in early May.
    - Slocum Glider was successfully deployed on Saginaw Bay to Bay City Basin Transect for 74 days of operation over two deployments between June 21 and October 6
    - UV radiometer was used 11 times throughout the season at 6 different sites. All data had been processed and graphed.
    - MOCNESS (Multiple Opening-Closing Net Environmental Sampling System) with strobe was used to increase sampling efficiency of *Bythotrephes*, *Mysis*, and larval fishes. Larval fishes were sampled in the inner bay, outer bay and Lake Huron proper along both transects.
    - FluoroProbe (*in situ* spectral fluorometer) was used to measure vertical profiles of algal classes.
    - Grab samples were taken to analyze nutrients, C:N:P seston ratios, dissolved organic carbon, and size fractioned chlorophyll (to evaluate size structure of phytoplankton available to zooplankton). Differences in water quality (chlorophyll a, nutrients, transparency) were summarized for Saginaw Bay and Thunder Bay.

- All CTD data has been processed and graphed; developed a regression relationship between chlorophyll fluoresce measured on the CTD fluorometer and chlorophyll measured in grab samples
- Bottom and mid-water trawls were deployed to sample fishes, calibrate acoustics, and for diet and energy density estimates (focus will be a deep site in the Thunder Basin and Bay City Basins and in inner and outer Saginaw Bay).
- Completed field sampling of fish larvae and zooplankton in nearshore-offshore transects in Thunder Bay and Saginaw Bay.
- Sorted and identified larvae from samples from Thunder Bay from April through June. Lake whitefish larvae were measured, and daily growth rates estimated from increment analysis of fish otoliths. Lake Whitefish larvae densities were estimated and compared with zooplankton densities as an index of potential survival and year class strength. These results are being used in a journal manuscript to understand effects of food web disruption on lake whitefish recruitment and population decline in Thunder Bay.
- Completed bomb calorimetry on CSMI rainbow smelt collected in Lakes Huron and Erie in 2017.
- Partial completion of 2017 benthic ponars from Lakes Michigan and Huron including picking all mussels, chironomids, and amphipods, as well as, conducting length/weight measurements on sub-sets of mussels to determine biomass.
- Prepped instruments for field moorings to be deployed in spring 2018.

MOCNESS Surveys

- Conducted surveys using the MOCNESS (Multiple Opening Closing Nets Environmental System Sampler) sampling gear to selectively sample fine-scale (<5 m) vertical structure of the water column to capture densities and food web interactions of the lower food web in Lake Huron. As part of the Spatial Studies and Microbes project, in May, July and September, sampling with the MOCNESS was conducted during week-long surveys in Lake Huron to sample the fine-scale vertical structure of the food web at shallow, mid-depth and offshore stations.
    - Supported the laboratory analysis of collected samples which includes: 1) sorting, identification, measurement of fish larvae; 2) extraction and preparation of otoliths for aging; 3) estimation of fish age (days) and growth rates (mm/d); 4) identification and weighing of larvae diet contents (g prey/g fish); 5) estimation of fish larvae consumption rate (g/g/d) using available bioenergetics software; 6) data entry and quality control of fish numbers by species, volume filtered by mesh net to estimate fish density; and 7) hands-on supervision of a CIGLR summer fellow who will participate on cruises.
- Conducted gear efficiency tests to compare catches of plankton and larvae in the MOCNESS with those collected with traditional gears (bongo sampler, Tucker trawl).

Results:

- After the first 4 months incubation period of the mussel growth experiment in Thunder Bay and Saginaw Bay, we found mussels at SB12 had the highest growth rate at about 4 mm, compared to

growth of 1 mm at TB45 and only 0.5 mm at SB45. Growth at the most offshore, nutrient deplete site (TB90) was negligible over this period. Overall, for this early period of incubation, mussel growth was higher than that observed within a comparable study conducted in Lake Michigan.

- Chlorophyll remained low throughout our sampling in Thunder Bay, reaching a maximum of 2.26 μgL^{-1} in the deep chlorophyll layer at our mid-depth (46 m) site in September. Average nearshore (18 m) chlorophyll was 0.76 μgL^{-1}, while average offshore (82 m) chlorophyll was 0.80 μgL^{-1}. Preliminary analysis shows there was no significant difference ($p=0.75$) in near surface (5 m) chlorophyll measurements between nearshore and offshore sites.
- Mean near surface chlorophyll measurements in inner Saginaw Bay, mid depth (23 m), and offshore (65 m) sites were 9.81, 0.58, and 0.47 μgL^{-1}, respectively. Preliminary analysis shows near surface chlorophyll in inner Saginaw Bay was significantly higher than both our mid-depth ($p<0.01$) and offshore ($p<0.01$) sites. There was no significant difference ($p=0.96$) between mid-depth and offshores sites.
- In examining preliminary chlorophyll trends between Saginaw Bay and Thunder Bay, there was no significant difference between offshore sites ($p=0.72$); however, inner Saginaw Bay chlorophyll was significantly higher ($p<0.01$) than all other sites sampled.
- Preliminary analysis of extinction coefficients shows that UV radiation is able to penetrate further in Lake Huron as compared to Lake Michigan, with UV-B (305 nm) wavelengths penetrating through the upper 5 m of the water column. Mean extinction coefficients were 0.981±0.067, 1.028±0.131, and 1.632±0.162 m^{-1} along transects in Saginaw Bay, Thunder Bay, and Lake Michigan (Muskegon transect, 2013-2016 average), respectively.
- Preliminary comparisons of catch-efficiency results indicate that catch rates for the MOCNESS were significantly higher (7.44 mysis/m^3±1.38) than in traditional gear types(2.55 mysis/m^3±0.91, $p=0.02$)
- Ages and growth rate of 115 Lake Whitefish larvae were collected in, Thunder Bay Lake Huron during April-May 2017. Growth rates did not vary between years even when adjusted for differences in length. The average growth rate of whitefish larvae was 0.37 ±0.03 mm/d ($F=193.86$, $p<0.0001$, $R^2 = 0.63$)
- Since 2015, Thunder Bay Lake Whitefish larvae densities have declined from 165 fish per 1000 m^3 to 49 fish per 1000 m^3 in 2017.
- In May 2017, mean biomass of zooplankton taxa at nearshore stations in Thunder Bay were dominated by calanoid copepods (42mg/m^3) compared to cyclopoids (1.27mg/m^3) and nauplii (0.52mg/m^3).

Products

Presentations

Wells et al. Spatial and temporal variation in Lake Whitefish larvae growth and density in Thunder Bay (IAGLR 2018, Scarborough,ON). Abstract submitted and accepted.

Cavaletto et al. Spatio-Temporal Organization of the Pelagic Food Web in Northern and Central Lake Huron in 2017. (IAGLR 2018, Scarborough,ON). Abstract submitted and accepted.

Tools, maps, models, etc

Dreissenid Density and Biomass Maps for Lake Michigan 2015 have been prepared.

Outreach and Engagement Activities

Student mentoring

CIGLR Summer Fellow Program: Angelika Kurthen (UM).
Doris Duke Fellowship: Jenny Par from Loyola University.

Community outreach events

Participated in the Muskegon County Water Festival in September 2017. We taught more than 300 8th grade students about aquatic food webs and the impacts of invasive species.

Factsheets or other public education materials

Dreissenid mussel density maps will be used in Grand Valley State University educational materials for school tours.

Other

Results of spatial food web and benthic surveys were shared with the Great Lakes Fishery management technical committees to help assess lower food web status and trends and aid in management stocking decisions.

Theme III: Great Lakes Hydrometeorological and Ecosystem Forecasting

Implementation of a 3D HAB forecast model for Lake Erie using FVCOM

Principal Investigator(s) and Affiliation(s): Brad Cardinale (University of Michigan-CIGLR) and Qianqian Liu (Grand Valley State University-CIGLR Fellow)
NOAA Technical Lead(s): Eric Anderson (NOAA GLERL)
NOAA Sponsoring Office: NWS, Office of Science and Technology Integration
Budget Amount: $89,990

NOAA Strategic Goals:
Goal 4 - Resilient Coastal Communities and Economies

Overview:

In 2014, NOAA GLERL began developing the 3D Finite Volume Community Ocean Model (FVCOM)-based Lagrangian particle trajectory model for 3D Harmful Algal Bloom (HAB) transport simulation. This approach was implemented into the HAB Tracker, an experimental forecast model that used NOS NCCOS cyanobacteria maps and Lake Erie Operational Forecasting System (LEOFS) currents to drive daily short-term 5-day forecasts. In 2015, the HAB Tracker and FVCOM particle model were updated to simulate buoyancy of the algal colonies and included an improved vertical mixing scheme to reduce surface and boundary artifacts that could result in artificial scums. The current research demonstration system was implemented into operational demonstration in CO-OPS in FY16. This project accelerates the implementation of a 3D HAB forecast model for Lake Erie by at least two years, providing decision makers with unprecedented real-time information on HAB extent, vertical distribution, and concentration. CIGLR's role is to expand development capacity and skill assessments, enabling an expedited transition and implementation of operational forecast systems.

Objective(s):

The objective of this project is to upgrade the existing Lake Erie HAB operational forecast system (OFS), currently in demonstration, to produce daily forecasts of 3D HAB movement and concentration for decision makers (e.g., public health officials, drinking water intake managers, etc.) and the public.

Milestones:

1) Implement more accurate HAB advection and mixing
2) Improve vertical distribution of HAB concentration
3) Improve surface concentration predictions
4) Improve predictions of coastline HAB concentration
5) Potentially provide total biomass calculation

Accomplishments

Based on the HAB tracker simulation in 2011, we developed the HAB tracker hindcast simulation for 2014, 2015 and 2016:

- Skill assessment for the hindcast of 2014, 2015 and 2016 HABs to evaluate the spatial distribution of HABs by the HAB tracker model.
- Calculated the total biomass for the 2017 season, and examined how the change of satellite data from MODIS to SENTINEL-3 OLCI affect the total biomass estimate.
- Used field data from Lake Erie and the HAB tracker model to estimate the toxicity in HAB seasons.
- A peer-reviewed manuscript describing the toxicity estimate by the HAB tracker model is under preparation.

Results:

- The HAB tracker model gives the present location and extent of HABs based on satellite imagery, and predicts the surface and vertical movements of HABs due to currents and buoyant velocity. Comparing the spatial distribution of the modeled HABs in 2014, 2016 and 2017 with satellite imagery (Figures 1-3), we found the model well captures some observed events that may be attributed to advection.
- The model may underestimate the HAB distribution when strong winds occur during the initialization of the model and lower the surface chlorophyll concentration below the detection threshold.
- After incorporating SENTINEL-3 OLCI data from the end of July 2017, the total biomass estimated by the HAB tracker model is obviously different from the model using only MODIS satellite data (Figure 4). More work is needed to assess the changes.
- The ratio between microcystin and extracted chlorophyll has an obvious seasonal variability, while relatively spatially concentrated. We can use the ratio and the HAB tracker model to estimate toxicity in HAB season.

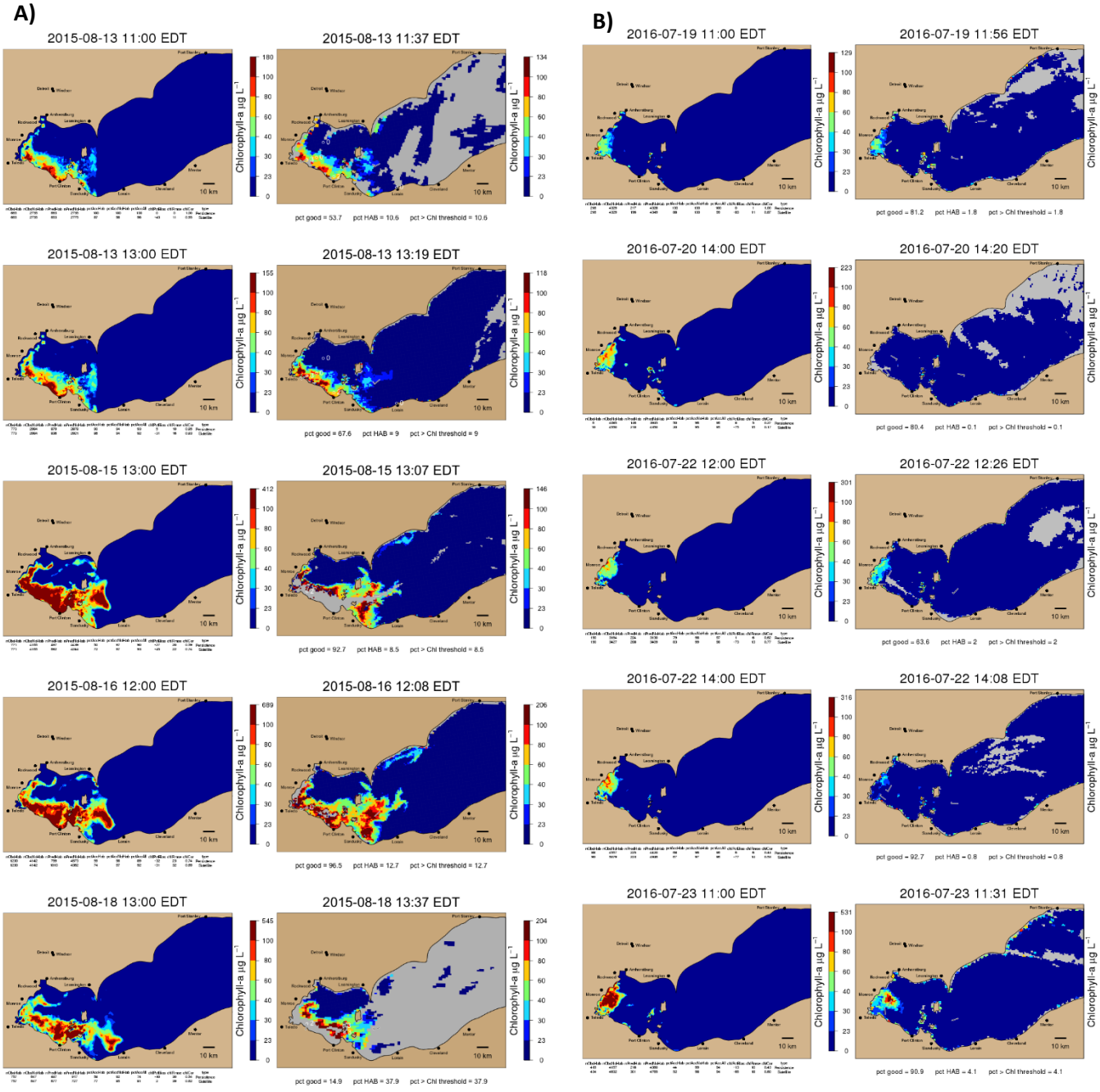


Figure 1. Comparison of (left) 3D hindcast simulations initialized from satellite-derived cyanobacterial chlorophyll concentration and (right) the corresponding satellite images in A) 2015 and B) 2016.

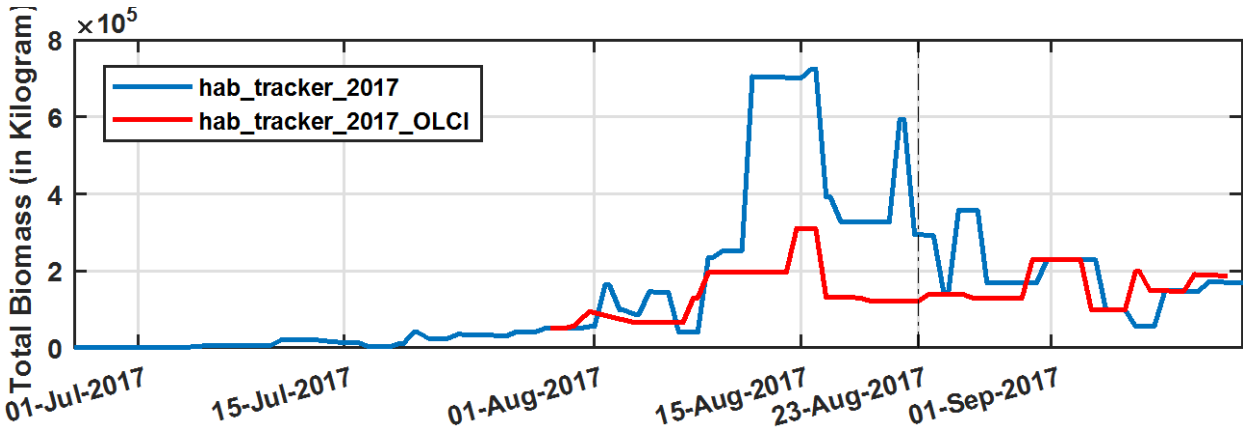


Figure 2. The estimate of total biomass by the HAB tracker model using the satellite data (blue line) from MODIS only and (red line) incorporating MODIS and SENTINEL-3 OLCI from the end of July 2017.

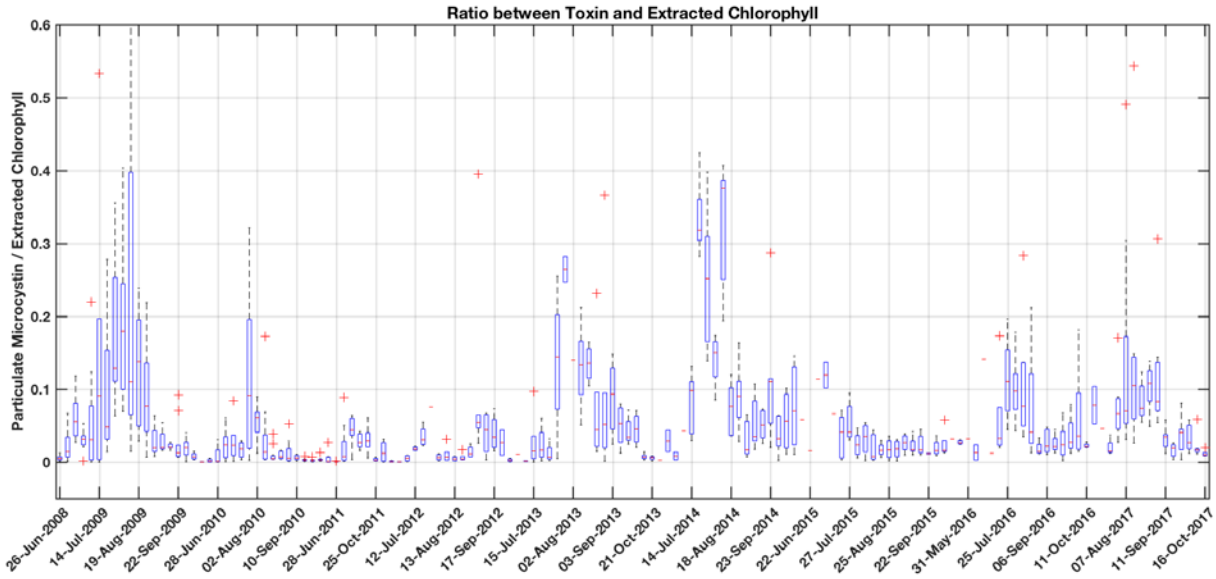


Figure 3. Boxplot for the ratio between microcystin and extracted chlorophyll, from Lake Erie field samples collected from 2008 to 2017.

Products

In development

Outreach and Engagement Activities

None

Theme III: Great Lakes Hydrometeorological and Ecosystem Forecasting

Improving Water Level Models for Application to Decision Making

Principal Investigator(s) and Affiliation(s): Brad Cardinale and Chuliang Xiao (University of Michigan-CIGLR)
NOAA Technical Lead(s): Brent Lofgren (NOAA GLERL)
NOAA Sponsoring Office: OAR, NOAA-Great Lakes Environmental Research Lab
Budget Amount: $25,000

NOAA Strategic Goals:

Goal 3 - Climate Adaptation and Mitigation
Goal 4 - Resilient Coastal Communities and Economies

Overview:

The Great Lakes play a crucial role in shaping the local and regional hydroclimate, and have generated significant interest in potential climate change effects such as rising air and lake temperatures, diminishing lake ice, increasing severe precipitation, changing water levels response, and associated socioeconomic impacts. Indeed, the implications of water level change on shipping, commerce, and human safety has been magnified by the persistently low lake levels in the Great Lakes during 1999–2012, the recent rebound since 2014, and coastal flooding of Lake Ontario in 2017. The efforts toward a fully coupled atmospheric-hydrodynamic modeling system in this project will enhance the capability to simulate climate change scenarios on a regional scale. This project informs the lake management process through the quantitative results that facilitate restoration and protection of critical natural resources, help guide management decisions, and support sustainable economic development in the region. This project is also useful to the scientific community through the methods developed that improve understanding of the fundamental physical, chemical, and biological processes operating in the Great Lakes region.

Objective(s):

The objective of this project is to improve Great Lakes water budget estimates and water level simulations in light of future climate scenarios. This is being accomplished by:

- Applying an advanced regional model, the Weather Research and Forecasting (WRF) model, and conducting a dynamical downscaling study in the Great Lakes region with a historical retrospective simulation from 1975 to 2005 and continuous future projections from 2006 to 2100 in two (high and moderate) greenhouse gas emission scenarios.

- Using the WRF downscaling output to calculate Net Basin Supplies (NBS) for each lake basin, to further drive a routing model, the Coordinated Great Lakes Regulation and Routing Model (CGLRRM) and project lake water level changes in prescribed climate scenarios.

Milestones:

1. Post-process WRF-based dynamical downscale outputs for the historical simulation and future projection.
2. Calculate and calibrate NBS using WRF outputs.
3. Project lake water levels from the CGLRRM routing model.

Accomplishments:

A dynamical downscaling study in the Great Lakes region has been conducted, using an advanced regional model, the Weather Research and Forecasting (WRF) model, with a historical retrospective simulation from 1975 to 2005 and continuous future projections from 2006 to 2100 in two (high and moderate) greenhouse gas emission scenarios.

Results:

Based on the downscaling results, a hydrologic routing model, Coordinated Great Lakes Regulation and Routing Model (CGLRRM), is performed to project the Great Lakes' water level changes in 21st century using net basin supply (NBS, calculated as the sum of over-lake precipitation, basin-wide runoff, and lake evaporation) as an input. As lakes warm and lake ice diminishes, the lake water levels are not likely having a significant trend in the future. Meanwhile, water levels are projected to have persistent and enhanced oscillations with a period around 6-10 year in the presumed climate change, raising the potential risk for socioeconomic impacts in the Great Lakes region.

Products:

Peer-reviewed publications

Fujisaki-Manome, A., L. E. Fitzpatrick, A. D. Gronewold, E. J. Anderson, B. M. Lofgren, C. Spence, J. Chen, C. Shao, D. M. Wright, and C. Xiao, 2017: Turbulent heat fluxes during an extreme lake effect snow event. *J. Hydrometeor.*, 18(12), 3145-3163, doi: 10.1175/JHM-D-17-0062.1.

Presentations

Xiao, C., B. M. Lofgren, A. Gronewold, D. J. Gochis, L. Mason, L. Pei, and K. Sampson. *Implementing the WRF-Hydro Modeling System in the Great Lakes Region*. American Meteorological Society Annual Meeting, Austin, TX, January 7-11, 2018.

Outreach and Engagement Activities:

Student mentoring

2017 Great Lakes Summer Fellow Program: Tom Hercula

Theme III: Great Lakes Hydrometeorological and Ecosystem Forecasting

Development of a Coupled Hydrodynamic-Wave Model using FVCOM and WAVEWATCH III

Principal Investigator(s) and Affiliation(s): Bradley Cardinale Ayumi and Fujisaki-Manome (University of Michigan-CIGLR)
NOAA Technical Lead(s): Philip Chu and Jia Wang
NOAA Sponsoring Office: OAR, NOAA-Great Lakes Environmental Research Lab (GLERL)
Budget Amount: $39,993

NOAA Strategic Goals:
Goal 2 - Weather-Ready Nation
Goal 3 - Climate Adaptation and Mitigation
Goal 4 - Resilient Coastal Communities and Economies

Overview:

Wave modeling is an important research and application topic in the Great Lakes. Existing wave models are inadequate because they are typically run separately from circulation models. Thus, the mixing effect caused by waves is either not included or not parameterized into the circulation model. High performance and parallel computers make it possible to couple two models and include all the wave effects into an ice-circulation model. Furthermore, the wave-ice-current interaction is not yet included in exciting ice-ocean/lake models.

WAVEWATCH III (WWIII, Tolman 2009) is a third generation wave model developed at the NOAA Centers for Environmental Protection (NCEP). It differs from its predecessors in many important points such as the governing equations, the model structure, the numerical methods, and the physical parameterizations. The current version is evolving from a wave model into a wave modeling framework, which allows for easy development of additional physical and numerical approaches to wave modeling.

Objective(s):

The objective of this project is to use WWIII and the Finite Volume Community Ocean Model (FVCOM) to develop a wave–ice-current model for Lake Erie, in which wave, ice, and currents are coupled to each other. The model will predict the distribution of wave energy and the resulting currents, temperature and ice distribution simultaneously, which should produce better ice-circulation simulations. Potential users of the models are commercial fishing operators who can predict potential catch according to circulation and temperature; US Navy, business, and nonbusiness ships who plan their sailing routes

according ice and wave conditions; and public interested in ice-related recreation who can find ideal and safe ice conditions.

Milestones:

- Study the WWIII model documents and attend a wave model workshop at the NCEP Environmental Monitoring Center (EMC).
- Prepare grids and meteorology data for the WWIII model.
- Set up the model according to the FVCOM-Erie model. Test structured and unstructured grid system and stability.
- Run the wave model stand-alone and validate the results.
- Couple FVCOM with WWIII.
- Conduct the coupled model to improve the top layer mixing, vertical temperature structure, and wave-current interaction.
- Using the coupled model to study wave-ice-current interaction.
- Peer-reviewed journal article on a coupled wave-ice-current model for Lake Erie.

Accomplishments:

The following goals have been completed during the reporting period:

1) Study the WWIII model documents and attended a wave model workshop at the NCEP Environmental Monitoring Center (EMC).
2) Prepare grids and meteorology data for the WWIII model.
3) Set up the model according to the FVCOM-Erie model. Test structured and unstructured grid system and stability.
4) Run the wave model stand-alone and validate the results.

Results:

An unstructured WaveWatch III (WW3) model was implemented in the Lake Erie for simulating wind waves. The preliminary results were compared with wave height from NOAA/GLERL Great Lakes Coastal Forecasting System. WW3 results are also compared with buoy data from Lake Erie. Errors analysis showed that the errors are mainly caused by errors in wind data. The mean absolute error of wave height was 0.16, variance is 0.06, skewness =1.72, and kurtosis = 9.29.

A novel machine learning method was introduced for data analysis and for model training. We used 2010-2015 data for training a model, and use the trained model to predict 2016 wave features. The results were inspiring. The mean absolute error of wave height is 0.19, variance is 0.09, skewness =1.57, and kurtosis = 6.36.

Products:
In development

Outreach and Engagement Activities:
None

Theme III: Great Lakes Hydrometeorological and Ecosystem Forecasting

Development and Optimization of the NGGPS-FV3 Model and Ensemble-based Data Assimilation for Convection-permitting Hurricane Analysis and Prediction

Principal Investigator(s) and Affiliation(s): Bradley Cardinale (University of Michigan-CIGLR) and Fuqing Zhang (Penn State University)
NOAA Technical Lead(s): Shian-Jiann Lin and Lucas Harris (GFDL)
NOAA Sponsoring Office: NWS, Office of Science and Technology Integration
Budget Amount: $116,527

NOAA Strategic Goals:
Goal 2 - Weather-Ready Nation

Overview:

In the continuing effort to build a new state-of-the art weather model to replace the current U.S. Global Forecasting System (GFS), scientists from Penn State University and NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) are collaborating on a project to evaluate the performance of the new dynamic core, the Finite-Volume on a Cubed-Sphere (FV3), for high-impact weather prediction such as hurricanes and severe storms. A dynamic core is the engine of a numerical weather prediction model. The new FV3 dynamic core, along with the newest modeling techniques, will produce a more accurate and reliable global weather model that is used as the basis for all weather forecasts in the U.S. In particular, the FV3 core brings an increased accuracy and numeric efficiency to the weather model's representation of atmospheric processes (e.g., air motions), making high-resolution simulations of clouds and storms possible. This work will contribute to NOAA's efforts to develop the Next Generation Global Prediction System (NGGPS) and the goals of the NOAA Hurricane Forecast Improvement Program (HFIP).

Objective(s):

The objective of this project is to evaluate the performance of the FV3 model and an ensemble Kalman filter (EnKF) data assimilation system with efficient filter algorithms and configurations in support of convection-permitting hurricane analysis and prediction. The focus is on an FV3-based model configuration and EnKF algorithms that are likely to be useful for any future NGGPS high-resolution prediction of high-impact weather (hurricanes and severe storms).

Milestones:

(1) Systematically evaluate the performance of a regional-global nested (or standalone version when available) of FV3 versus Hurricane Weather Research and Forecasting (HWRF) models at convection-permitting resolutions (~3 km) for selected past events. [Year 1, first 3 months]

(2) Examine the sensitivity and uncertainty of FV3 forecasts to different physics configurations in particular with regards to the planetary boundary layer (PBL) and surface flux parameterization schemes. [Year 1, first 3-9 months]

(3) Explore the use of a FV3-native cubed-sphere-based EnKF in convection-permitting simulations for hurricanes with simulated observations (OSSEs). [Year 1, 6-12 months]

Accomplishments:

The performance of regional-global nested FV3 model was systematically evaluated at convection-permitting resolutions (~3 km) for hurricane Harvey. The model was initialized with the GFS analysis. To evaluate the potential impacts of satellite data assimilation on hurricane forecast in FV3 model, sensitivity experiments were also conducted with enhanced inner-core initialization using a regional-scale ensemble data assimilation system ingesting the GOES-16 all-sky radiances. The forecasts of both FV3 experiments have been compared with the GFS and ECMWF operational tropical cyclone forecasts. The related results have been organized into a paper that is in review for *the Bulletin of the American Meteorological Society (BAMS).* Research is also underway to test the convection-permitting prediction with the FV3 model for other hurricanes during the busy 2017 Atlantic season. We also tested the sensitivity of model configurations and physics to the hurricane prediction performance.

Results:

Hurricane Harvey brought catastrophic destruction and historical flooding to the Gulf Coast region in late August 2017. Guided by numerical weather prediction models, operational forecasters at NOAA provided outstanding forecasts of Harvey's future path and potential for record flooding days in advance. These forecasts were valuable to the public and emergency managers in protecting lives and property. The current study shows the great potential for further improving Harvey's analysis and prediction using regional-global nested FV3 model that has embedded a convection-permitting nested domain over the hurricane with enhanced inner-core initialization ingesting the GOES-16 all-sky radiances. The global-nested FV3 model not only improves over the current-generation operational models' track prediction but also provides accurate forecasts of the storm's structure, its rapid intensification to a major hurricane, and total rainfall along the Gulf Coast region. This study highlights the potential and need for improving hurricane prediction through the nation's further investments in advanced observing systems such as those from weather satellites, comprehensive data assimilation methodologies that can more effectively ingest existing and future observations, higher-resolution weather prediction models with more accurate numerics and physics, and high-performance computing facilities that can perform advanced analysis and forecasting in a timely manner.

Products:

Peer-reviewed publications [*student co-authors]

F. Zhang, M. Minamide*, X. Chen, R. G. Nystrom*, S.-J. Lin, L. M. Harris, 2018: Improving Harvey forecasts with next-generation weather satellites and numerical models: Advanced hurricane analysis and prediction with assimilation of GOES-R all-sky radiances, *submitted to Bull. Amer. Meteor. Soc.*

Presentations

Findings from the funded project have contributed to about 10 presentations by PI Zhang at different institutions, which include as part of a US Senate hearing panel organized by UCAR in November 2017, seminars at Univ of Maryland, NCEP, Chinese Academy of Meteorological Sciences, Nanjing University, UC Irvine, Sun-Yat Sun University, etc.

Outreach and Engagement Activities:

Congressional visits

US congressional hearing in November 2017 organized by UCAR.

Theme III: Great Lakes Hydrometeorological and Ecosystem Forecasting

Improved Ice Modeling for the Great Lakes

Principal Investigator(s) and Affiliation(s): Bradley Cardinale and Ayumi Fujisaki-Manome (University of Michigan-CIGLR)
NOAA Technical Lead(s): Jia Wang (NOAA GLERL)
NOAA Sponsoring Office: OAR, Great Lakes Environmental Research Lab
Budget Amount: $142,988

NOAA Strategic Goals:
Goal 1 - Healthy Oceans
Goal 2 - Weather-Ready Nation
Goal 4 - Resilient Coastal Communities and Economies

Overview:

Great Lakes ice cover is highly sensitive to varying atmospheric conditions, resulting in a large degree of interannual variability that makes accurate forecasts challenging (Wang et al. 2012; Mason et al. 2016). For example, in the last decade, annual maximum ice cover exceeded 90% some years, but fell below 20% in others. CIGLR is addressing the need for improved Great Lakes ice forecasts by continuing our ongoing efforts to understand lake/sea ice circulation and ice-ocean-ecosystem dynamics using techniques of numerical and regression modeling. By also modeling the Arctic Ocean, a region with

perhaps the most extreme changes in sea ice (Stocker et al. 2013), we gain insight into how a changing climate might impact future Great Lakes ice. Due to the relatively abundant observational data, the Arctic is also an ideal domain to validate models that can later be applied to the Great Lakes region. The project consists of:

I. Numerical ice-hydrodynamic modeling of the Great Lakes region using the modified Finite-Volume Community Ocean Model (FVCOM) for Great Lakes ice circulation (FVCOM+ice)
II. Updating Great Lakes Ice Atlas and seasonal forecasting based on regression modeling
III. Bering-Chukchi-Beaufort Seas (Arctic Ocean) Ice-Ocean-Ecosystem Modeling

Objective(s):

The objective of this project is to develop and assess FVCOM+ice and regression models to the improve forecasts and hindcasts of Great Lakes and Arctic ice.

Milestones:
Milestones consist of short-term (within project period) goals to complete (1-4) and long-term goals to begin working toward (5-7).

1. Update Great Lakes ice atlas for 2018 and post the new data to the web
2. Analyze lake ice responses to ENSO and NAO for high ice years of 2014-2015, and low ice years of 2016-2017
3. Provide seasonal ice projections using a new statistical model in December 2017
4. Provide seasonal ice projections using the FVCOM+ice model in December 2017
5. Conduct FVCOM+ice simulation of Great Lakes ice in response to climate change, using a modified numerical scheme and ice model for the period 1993-present.
6. Conduct FVCOM+ice modeling in the Arctic for the period 2010-present.
7. Validate FVCOM+ice model using data from RASALCA and PAG cruises.

Accomplishments:

- (1) has been completed with the help of summer fellow Franky Hang.
- (2) and (3) have been completed by Wang and Kessler.
- (4) has been delayed due to lack of atmospheric seasonal forecast data availability (required as boundary conditions for FVCOM+ice model), once data are available the projection will be done retroactively (reforecast) to assess what the skill of the forecast would have been.
- (5) FVCOM+ice simulation has been completed for 1993-2017 using a modified time-integration scheme for the hydrodynamics but not for the ice model. A more accurate comparison between observed and modelled ice cover has been developed regarding the weighting of the model's grid-cells. Code development and testing for the ice code will begin soon in order to make significant progress toward this long-term goal.
- (6) and (7): An unstructured FVCOM model was developed and implemented in the Arctic Ocean for simulating sea ice. The preliminary results were compared with sea ice data from National Snow and Ice Data Center.

Results:

- In (1), our summer fellow processed and analyzed 6 full seasons of ice data to append to our historical ice records which are contain more than a half-century of ice data. The analysis included seasonal cycle/variations, interannual variability, long-term linear trends, and decadal variability. Additionally, the scripts used (R software) to process and analyze data have been archived and documented in order to streamline the process for future years.
- (3) Resulted in a skillful forecast. The regression model projected maximum ice cover (in percentage) for each of the 5 Great Lakes and an overall maximum for the Great Lakes Basin. For Superior, Michigan, Erie, Ontario and the GL Basin, the observed maximum ice cover was within 10% absolute error of the projected value (e.g., model projected Michigan: 43%; observed Michigan: 51%).
- (7) The simulated sea ice cover is agreed with the data on melting and freezing time frame and distribution. The sea ice basically moves following wind and mostly flows from Siberian coast to Greenland coast and Canadian coast, it makes ice thicker in this area than in other area.

Products:

Peer-reviewed publications:

Wang, J., J.A. Kessler, X. Bai, A. Clites, B. Lofgren, A. Assuncao, J. Bratton, P. Chu, G. Leshkevich, (in review). Decadal variability of Great Lakes ice cover in response to AMO and PDO, 1963-2017.

Non-peer-reviewed publications [* student co-authors]

Wang, J., J. Kessler, F. Hang, H. HU, A.H. CLITES, and P. CHU. Great Lakes Ice Climatology Update of Winters 2012-2017: Seasonal Cycle, Interannual Variability, Decadal Variability, and Trend for the period 1973-2017. NOAA Technical Memorandum GLERL-170. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI (2017). https://www.glerl.noaa.gov/pubs/tech_reports/glerl-170/tm-170.pdf*

Wang, J., J. Kessler, F. Hang, H. HU, A.H. CLITES, and P. CHU. Analysis of Great Lakes Ice Cover Climatology: Winters 2012-2017. NOAA Technical Memorandum GLERL-171. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 25 pp. (2017). https://www.glerl.noaa.gov/pubs/tech_reports/glerl-171/tm-171.pdf*

Presentations

Kessler, J.A., J. Wang, A. Manome, P. Chu. Modeling Great Lakes Ice Cover using FVCOM and UG-CICE (poster). CIGLR Annual Partners Meeting, Ann Arbor, MI, September 25-26, 2017.

Fujisaki-Manome, Ayumi. Impacts of shelf-basin exchange on water properties in the East Siberian Sea shelf seen in a historical ice-ocean simulation (poster). 6th Annual Meeting of Forum for Arctic Modeling & Observational Synthesis, Woods Hole, MA, October 24-27, 2017.

Tools, maps, models, etc

Great Lakes Historical Ice Cover webpage: historical ice data, plots, and analysis

Outreach and Engagement Activities:

Student mentoring

Franky Hang was a Great Lakes Summer Fellow who worked on the Great Lakes Ice Climate Study, under mentorship by James Kessler, Jia Wang, and Haoguo Hu to process and analyze the last 6 winters of ice data. This resulted in two technical memorandums (listed above.)

Factsheets or other public education materials

CIGLR Winter 2018 eNewsletter, Featured Research, "Predicting Great Lakes Ice", https://ciglr.seas.umich.edu/winter-2018-e-newsletter/featured-research-lake-ice/

Theme III: Great Lakes Hydrometeorological and Ecosystem Forecasting

Implementation of the FVCOM-Ice model for the Great Lakes Operational Forecasting System (GLOFS)

Principal Investigator(s) and Affiliation(s): Brad Cardinale and Ayumi Fujisaki-Manome (University of Michigan-CIGLR)
NOAA Technical Lead(s): Eric J. Anderson and Jia Wang (NOAA GLERL)
NOAA Sponsoring Office: NWS, Office of Science and Technology Integration
Budget Amount: $118,970

NOAA Strategic Goals:
Goal 2 - Weather-Ready Nation
Goal 4 - Resilient Coastal Communities and Economies

Overview:

The Finite Volume Community Ocean Model (FVCOM) was developed in the early 2000's by Changshen Chen (U. Mass. Dartmouth) and has been selected by the NOAA Center for Operational Oceanographic Products and Services (CO-OPS) as one of the two core hydrodynamic models by NOAA's National Operational Coastal Modeling Program (NOCMP) for National Ocean Service (NOS) hydrodynamic operational forecasting systems (OFS). The FVCOM model has since been applied to develop the upgraded next-generation Lake Erie Operational Forecast System (LEOFS), which was transitioned to operations on NOAA's Weather and Climate Operational Supercomputing System (WCOSS) in 2016 by NOS/CO-OPS. In addition, the Los Alamos Sea Ice Model (CICE) has been incorporated into FVCOM as a module by the developer (Chen). Since this release, the FVCOM-CICE (or FVCOM-Ice) model has been

calibrated and implemented into Lake Erie by GLERL and CIGLR for short-term ice forecasting. Until recently this model was not applied to ice formation in freshwater lakes. In the past few years, extensive validation and tuning of the FVCOM-Ice model has been carried out for the Great Lakes by GLERL and CIGLR. Adequate values for dynamic and thermodynamic parameters.

For Lake Erie, model performance has been evaluated in comparison with observations and previous model results using a Princeton Ocean Model (POM) coupled ice model, which has been run in real-time at GLERL for the past several years. FVCOM-Ice outperformed POM in simulating winter water temperature profile at thermistor stations during the International Field Year on Lake Erie (IFYLE) and currents. Additionally, FVCOM-predicted lake-average ice extent matches well with satellite-derived ice extent. As a result of these preliminary hindcast simulations, the FVCOM-Ice model yields improved predictions of winter and early spring hydrodynamics (water temperature and currents) and also produces reasonable predictions of ice concentration, thickness, and velocity.

The remaining steps to transition of the FVCOM Ice model to operations include hindcast simulations for recent years for LEOFS and Lake Michigan-Huron Operational Forecast System (LMHOFS), evaluation of the hindcast simulations, and development of ice initialization and assimilation methods.

Objective(s):

The goal of this project is to transition to operational implementation of an ice forecasting capability for the NOCMP. This capability will be applied through an implementation of a FVCOM-Ice forecasting model in the Great Lakes Operational Forecast System (GLOFS).

Milestones:

1. ***FVCOM-Ice model development***
    a. Finalize development of the FVCOM ice model code for the Great Lakes, in collaboration with NOAA GLERL.
    b. Carry out hindcast validation for Lake Michigan-Huron and Lake Erie for the recent years.
    c. Calibrate ice albedo, turning angle, time-integration, and freshwater ice categories.
    d. Evaluate hindcast model performance against water levels, water temperature, currents, lake-average ice extent from the National Ice Center (NIC), satellite-derived ice concentration, and ice thickness measurements.
2. ***Development of ice initialization and assimilation methods:***
    a. Optimize model initialization and assimilation based on previous and current work at NOAA GLERL.
    b. Develop real-time initialization and assimilation methods that use previous model ice conditions and the daily coordinated ice charts from NIC.

Accomplishments:

- Hindcast simulations of the FVCOM ice model were conducted for LEOFS for the period 2004-2017 and LMHOFS for the period 2015-2017.
- Two different heat flux calculation algorithms, SOLAR and COARE-Met Flux algorithms, were tested to evaluate the impacts on simulated water temperature and ice extent.
- Results of hindcast simulations were evaluated against water levels, currents, lake-average ice extent, ice thickness, and water temperature data.
- The FVCOM ice model code was finalized and sent to the developer group of Dr. Chen. The version will be released as FVCOM version 4.2 in early 2018.
- A skill assessment script for ice simulations was created. Seasonal mean root mean square errors (RMSEs) based on three different methods were included in the script to evaluate simulated ice concentration. The script was sent to NOA/CO-OPS for their reference.

Results:

- Water levels, currents, lake-average ice extent, ice thickness, and water temperature from the hindcast simulations reasonably agreed with the available observations.
- Based on the skill assessment script, the COARE algorithm notably outperformed the SOLAR algorithm in simulating ice conditions for LMHOFS while in the low ice coverage year (2016-2017) the RMSE difference between the results with the two algorithms were smaller.

Products

Presentations

Fujisaki-Manome, A., E.J. Anderson, J.A. Kessler, G. Lang, P. Chu, "Great Lakes (Lake Michigan-Huron) ice-hydrodynamic simulations with FVCOM", NOAA FVCOM Workshop, Silver Spring, MD, 28-29 September 2017.

Kessler, J.A., A. Fujisaki-Manome, E.J. Anderson, G. Lang, J. Wang, and P. Chu, "High Resolution Coupled Lake-Ice Modeling of Lakes Erie, Michigan, and Huron", American Geophysical Union Ocean Sciences Meeting 2018, Portland, OR, 11-16 February 2018. Oral presentation.

Tools, maps, models, etc

FVCOM version 4.2, which incorporated the updates for freshwater applications made in this project, has been released from University of Massachusetts-Dartmouth.

Outreach and Engagement Activities

Factsheets or other public education materials

CIGLR Winter 2018 eNewsletter, Featured Research, "Predicting Great Lakes Ice", https://ciglr.seas.umich.edu/winter-2018-e-newsletter/featured-research-lake-ice/

Theme III: Great Lakes Hydrometeorological and Ecosystem Forecasting

Water Level Forecasts: Improving Water Level Models for Shipping and Commerce

Principal Investigator(s) and Affiliation(s): Brad Cardinale (University of Michigan-CIGLR), Branko Kerkez (University of Michigan-Civil and Environmental Engineering)
NOAA Technical Lead(s): Andrew Gronewold (NOAA GLERL)
NOAA Sponsoring Office: OAR, Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $68,019

NOAA Strategic Goals:
Goal 2 - Weather-Ready Nation
Goal 3 - Climate Adaptation and Mitigation
Goal 4 - Resilient Coastal Communities and Economies

Overview:

In support of the International Joint Commission's (IJC) need for understanding water levels and future water supplies in the Great Lakes, CIGLR developed new models to improve Great Lakes water balance estimates and water level simulations. We created a robust historical dataset for each Great Lake that explains changes in observed water levels based on the relative importance of each component of the water balance (i.e., runoff, over-lake evaporation, over-lake precipitation, and connecting channel flows). Using a novel statistical model, we produced the first comprehensive water balance estimate for the Great Lakes system that systematically closes the entire water balance, while addressing both measurement bias and uncertainty. Resolving the regional water balance across monthly and inter-annual time scales represents an important stepping stone towards addressing a long-standing need in the Great Lakes for clear and defensible differentiation between hydrological, climatological, geological, and anthropogenic drivers behind seasonal and long-term changes in Great Lakes water levels.

We also developed a new, authoritative, coordinated numerical model that efficiently and accurately simulates water levels and connecting channel flows in the Great Lakes system given user-specified net basin supply (NBS) scenarios. We provided a relatively simplified water level modeling framework designed to meet current and future needs of Great Lakes regulatory authorities (e.g., Great Lakes Boards of Control). The new model will replace the current Coordinated Great Lakes Regulation and Routing Model (CGLRRM), which has been employed since the 1990s, but which is poorly documented and becoming increasingly outdated and difficult to use.

Objective(s):

The objectives of this project are to improve water balance models and water level models used by the International Joint Commission for water level regulation in the Great Lakes. These modeling products are primarily intended for members of the IJC's Great Lakes-St. Lawrence River Adaptive Management (GLAM) Committee, the Boards of Control, water resources management staff from NOAA, USACE, and Environment Canada, and members of the Coordinating Committee on Great Lakes Basic Hydrologic & Hydraulic Data. Results will be included in NOAA's Great Lakes Water Level Dashboard.

Milestones:

For the water balance, specific milestones included:

1. Recoding the existing Great Lakes water balance model to improve computational efficiency (Aug 2017)
2. Soliciting and incorporating input from regional stakeholders and project partners on *a priori* beliefs regarding bias and uncertainty associated with existing measurement-based and process model-based estimates (Sept 2017)
3. Running the model over a period dating back several decades across all of the Great Lakes (Jan 2018)
4. Effectively communicating the new results to the Great Lakes water resources management community and other interested stakeholders (Feb 2017)

For the water level model, specific milestones included:

1. Building an understanding of the current modeling system and goals of the new design (July 2017)
2. Developing an updated design documentation (Aug 2017)
3. Coding of first draft framework and submission to technical partners for review (Sept-Jan, 2018)
4. Developing and implementing test scenarios to verify correct operation (Dec-Feb 2018)
5. Revising to address any issues from testing and technical partner feedback (Jan-May 2018)
6. Developing technical documents and reports (Apr-Jun 2017)

Accomplishments:

- **Water Balance Model:** successful recoding of pre-existing water balance model for computational efficiency, worked with regional stakeholders and project partners on model configurations, successful generation of new monthly historical record of the Great Lakes water balance for all Great Lakes (and Lake St. Clair) from 1950-2015, communicated results to stakeholders and partners in webinar.
- **Water Level Model:** built a detailed understanding of previous Coordinated Great Lakes Regulation and Routing Model (CGLRRM) and developed new design framework with input from partners, began writing technical documents (will need to be revisited once code is finalized), bulk of the code (data handler, input/output routines) has been written and is in a semi-working state, formatting of data files (Net Basin Supply, over-lake precipitation, etc.) has been determined and test data has been generated.

Results:

- **Water Balance Model:** satisfactory closure of water balance, across all components and lakes, for monthly, 12-month, and 60-month periods; experimental set of models differ in inferences of water balance components by no more than 10 mm per month on average, which is the precision of coordinated water level estimates; cumulative differences between component and residual net basin supplies additionally average to less than 10 mm per month.
- **Water Level Model:** successful development of modeling framework using python software which has been rigorously tested for style and readability in order to make it easy to understand/modify for future users, successful reading in of data files in both old (CGLRRM) and new-formatting to allow for backwards compatibility, efficient use of object-oriented programming to make data input/output convenient and intuitive for the model user.

Products:

Peer-reviewed publications

Smith, J.P. and Gronewold, A.D. Development and analysis of a Bayesian water balance model for large lake systems. eprint arXiv:1710.10161 (2017) Link: https://arxiv.org/abs/1710.10161, re-submitted to the Journal of Applied Statistics

Non-peer-reviewed publications

Summary Report - A Large Lake Statistical Water Balance Model (L2SWBM) and A New L2SWBM-Generated Historical Record of the Water Balance for the Period 1950 through 2015; Submitted to: The International Watersheds Initiative of the International Joint Commission. Submitted by: NOAA Great Lakes Environmental Research Laboratory, The Cooperative Institute for Great Lakes Research, and Environment and Climate Change Canada. Andrew Gronewold, Joeseph Smith, Lauren Fry, Jacob Bruxer, and Frank Seglenieks. Currently under in-house review

Presentations

Gronewold, A.D., and J.P. Smith. Great Lakes water budget modelling and uncertainty estimation under a Bayesian MCMC framework. IAGLR 2017, 60th Annual Conference on Great Lakes Research, Detroit, MI, May 15-19, 2017 (2017).

Tools, maps, models, etc

- An operational and research version of the model package has been developed and distributed to project partners. Project partners with versions of the model are Lauren Fry (USACE), Frank Seglenieks (ECCC), and Scott Steinschnieder (Cornell).
- Water balance model code and data for Lakes Superior and Michigan-Huron are available on the following links:
  - https://www.glerl.noaa.gov/data/WaterBalanceModel/
  - http://www-personal.umich.edu/~joeseph/iaglr.html

Outreach and Engagement Activities:

- Webinar communicating project results to project partners, the Great Lakes water resources management community, and other interested stakeholders. *"Large lake statistical water balance model (L2SWBM), Fall 2017 End-of-Project Summary."* (December 8, 2017)

Theme III: Great Lakes Hydrometeorological and Ecosystem Forecasting

Assessment of Contaminated Sediment (Sawdust) Transport in Manistique River, MI

Principal Investigator(s) and Affiliation(s): Bradley Cardinale (University of Michigan-CIGLR), Chin Wu (University of Wisconsin-Madison)
NOAA Technical Lead(s): Eric Anderson (NOAA GLERL)
NOAA Sponsoring Office: OAR, Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $128,129

NOAA Strategic Goals:
Goal 1 - Healthy Oceans

Overview:

The Manistique River Area of Concern (AOC) covers the last 1.7 miles of the Manistique River. This area has a legacy of contamination from industrial waste (oils and combined sewer overflows), as well as debris and sawdust from more than a century of logging and milling. Currently, two beneficial use impairments (BUIs) still remain, including a restriction on dredging and on fish consumption. A multi-agency and multidisciplinary effort is underway in order to understand and remediate the Manistique River. The Cooperative Institute for Great Lakes Research (CIGLR), USEPA, NOAA Great Lakes Environmental Research Laboratory (GLERL), US Geological Survey Water Resources of Michigan, National Marine Fisheries Service, and the University of Wisconsin-Madison have worked together with the ultimate goal of delisting Manistique River from being an AOC. Extensive field measurements have been conducted to assess effective remediation actions plans (RAP). In particular, detailed atmospheric, flow, and sediment parameters have been employed to reveal the role of the physical processes on the fate and transport of contaminated sediments. Additionally, the hydrodynamics and sediments data have been used to estimate contaminated sediment residence time, and help identify potential contaminant sources in Manistique River, MI. While a great deal of effort has been put on the contaminated sediments, the legacy of contaminated sawdust/woodchip debris and deposits has not been addressed.

Sawdust and other wood waste deposits blanket Lake Michigan beaches near Manistique. The history of these deposits can be traced back to the beginning of the 1890s when the abundant white pine in the region was capitalized. Near the mouth of the Manistique River was the strategic location for logs being sawn into lumber and transported. Part of the legacy of the lumbering industry was the tons of sawdust, which now wash onto the shore around the Manistique area. Based upon available data, it was estimated that over 5.1 million tons of sawdust were produced in the Manistique area between 1863 and 1912. General milling practices of the time were to dump unwanted sawdust into the Manistique River and transport it out on barges to dump into Lake Michigan. To date, little information on the risk of the contaminated sawdust debris is Manistique River is available.

Objective(s):

The objective of this project is to address the knowledge gaps regarding risk of contaminated sawdust debris transport in the Manistique River.

Milestones:

1. Characterize the erodibility of sawdust/woodchip substrates and their physical properties in the river and harbor using laboratory sediment erosion testing system – *May-September, 2018*
2. Quantify the transport of sawdust/woodchip debris from upstream, the harbor, and nearshore beach of inner harbor under different physical flow forcings (floods, seiches, meteorology-induced flows-meteotsunamis) using field GPS-based neutrally buoyant objects and floating buoys – *May-September, 2018*
3. Assessment of re-distribution and fate of contaminated sawdust/woodchip debris in the AOC of the Manistique River using the "coupled" *surface wave* and hydrodynamic current model with a "*Particle Carrying Properties*" (PCP) tracking model under a set of scenarios of most vulnerable conditions - *August– November, 2018*

Accomplishments:

Transport of sawdust/woodchip debris from upstream, harbor, and nearshore beach has been assessed with the use of a high-resolution "coupled" *surface wave* and hydrodynamic current model under different flow forcing conditions. Bottom shear stress maps obtained with this model reveal potential sawdust/woodchip depositional and erosional areas. The following conclusions have been reached: (1) High river flow, typically observed during the Spring melt and Fall storms, is the major sediment resuspension mechanism in the main channel; (2) High frequency water level oscillations (Period < 2 h) are responsible of sediment resuspension in low-flow areas. Specifically, water level oscillations with amplitudes of 0.3 m, recurrently observed throughout the year, are sufficient to induce resuspension of sawdust in Manistique River. (3) Meteorologically-induced water level oscillations, similarly to tides in the ocean, exhibit larger upstream velocities than downstream velocities (flow asymmetry), which can induce upstream transport of sawdust/woodchips when the river flow is low, such as during the summer. Additionally, modeling results indicated that interactions between water level oscillations and river flow can substantially change bottom shear stress, thus affecting transport time scales of contaminated sediment in Manistique, which is summarized in the next section.

Results:

We have developed a novel "*Particle Carrying Properties*" (PCP) tracking model to examine the re-distribution and fate of contaminated sawdust/woodchip debris in Manistique River. The PCP model consists of particles with resuspension (critical shear stress), deposition (settling velocity), and contamination (initial PCB concentration and dissipation rate) properties. This model is run under a Monte Carlo simulation framework to account for the uncertainties inherent in the transport processes of particles, obtaining probabilistic results of the residence time in Manistique River. Preliminary results indicate that: (1) Meteorologically-induced water level oscillations can resuspend the surficial particles located in low flow areas, such as sawdust/woodchips (Figure 1b). As a result, water level oscillations dictate residence time of contaminated material in low flow areas of Great Lakes estuaries; (2) while residence time of surficial contaminated sawdust/woodchips located in main river channels is of the order of months, the maximum spring flow and storms significantly reduces contaminated residence time to the order of hours (Figure 1a). We also investigated how long-term hydrodynamic conditions (e.g., lake level changes) may affect contaminated sediment distributions in Manistique River. Our results suggest that long-term residence time of contaminated sawdust/woodchips is predicted to increase/decrease if Lake water level increases/decreases. Overall, we have improved our understanding of contaminated sawdust/woodchips pathways and help reveal sources of contaminants in Manistique River. This work provides valuable insights to help the sustainable remediation of the Great Lakes AOCs.

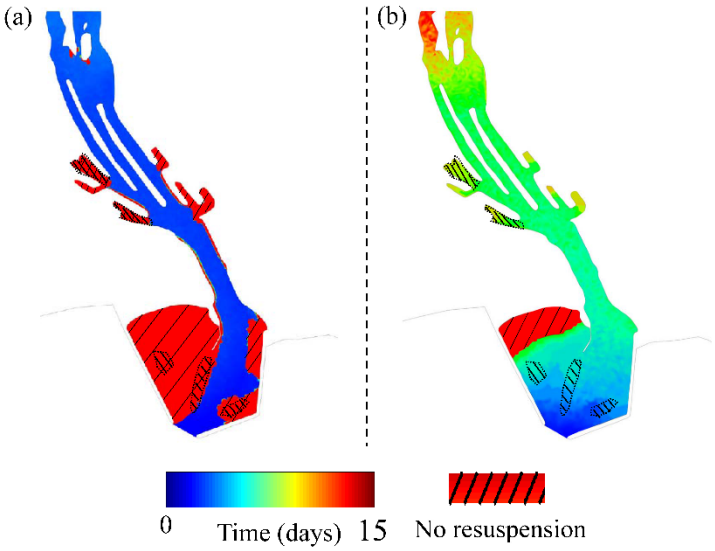


Figure 1. Mean residence time maps induced by (a) river flow and (b) High-frequency water level oscillations.

Products:

Peer-reviewed publications

Linares, Á., Wu, C.H., Anderson E.J., and Chu P. (2018). Role of Meteorologically induced water level oscillations on bottom shear stress in fresh water estuaries in the Great Lakes. *Journal of Geophysical Research: Oceans.* Under review.

Linares, Á., Bechle, A.J., and Wu, C.H. (2016) Characterization and Assessment of the meteotsunami hazard in northern Lake Michigan, *Journal of Geophysical Research: Oceans*, doi:10.1002/2016JC011979.

Presentations

Linares, Á., Bechle, A.J., Wu, C.H., Rapid forecasting of the meteotsunami hazard in the Great Lakes, Meteotsunami Summit, Ann Arbor, Michigan, June 19-21, 2017.

Linares, Á., Wu, C.H., Anderson E.J., Chu P., Role of *High Frequency Water Level Oscillations* and *Flood Flows* on contaminated Sediment Transport in the Manistique River, Michigan, IAGLR, Detroit, Michigan, May 15-19, 2017.

Linares, Á., Roles of water level oscillations and flood flows on contaminated sediment transport in the Great Lakes estuaries, Water Resources Engineering Seminar, Madison, March 3rd, 2017

Anderson, E.A., Wu, C.H., and Linares, Á. Hydrodynamic Modeling in Manistique River, the Manistique AOC group, Manistique, MI, September 6, 2016.

Outreach Activities: None

Theme III: Great Lakes Hydrometeorological and Ecosystem Forecasting

Water Level Forecasting Improvements

Principal Investigator(s) and Affiliation(s): Bradley Cardinale (University of Michigan-CIGLR)
NOAA Technical Lead(s): Drew Gronewold (GLERL)
NOAA Sponsoring Office: GLERL
Budget Amount: $40,300

NOAA Strategic Goals:
Goal 3 - Climate Adaptation and Mitigation

Overview:

The Great Lakes Advanced Hydrologic Prediction System (AHPS) is a cornerstone of the US Army Corps of Engineers (USACE) Detroit District's operational forecasting protocol. The AHPS is a comprehensive modeling package designed to forecast individual components of the Great Lakes hydrologic cycle across seasonal time scales. Over the past several years, NOAA GLERL and USACE have collaborated on improvements to the AHPS package including assessments of skill in simulating runoff (Fry et al., 2014, 2013), over-lake precipitation (Holman et al., 2012), and evaporation (Gronewold and Stow, 2014). This collaboration has also resulted in improvements to (and applications of) the Great Lakes water balance historical record (Hunter et al., 2015; Gronewold et al., 2016), a dataset that is critical to the forecasting decision-making pathway.

With so many advancements being made in Great Lakes science and updated regulation plans for the lakes, it is imperative that these changes are incorporated into the AHPS package to produce the most useful water level predictions. This work leverages additional ongoing efforts including the recoding of the Coordinated Great Lakes Regulation and Routing Model (CGLRRM), modifications to the evapotranspiration algorithms within the LBRM (large basin runoff model) following recommendations of Lofgren et al. (2011, 2013), and coordination with partners from Environment and Climate Change Canada on bi-national aspects of the project work (Gronewold and Fortin, 2012).

Objective(s):

The objective of this project is to improve water level prediction in the Great Lakes by updating the Great Lakes Advanced Hydrologic Prediction System (AHPS) with hydrometeorological data and new information about the Great Lakes water balance.

Milestones:

1. Develop a process for retrieving hydrometeorological data to drive AHPS model.
2. Develop a processes for quality control and assurance of hydrometeorological data.
3. Coordinate datasets with Canadian counterparts used in water level forecasting and analysis.
4. Execute directed improvements to improve functionality of AHPS in USACE long-range forecasts.
5. Document all developed products and analyses.

Accomplishments:

A process for retrieving hydrometeorological data to run the Large Lake Statistical Water Balance Model (L2SWBM) has been implemented. The resulting input datasets for the model are currently available to model users. This model will eventually be run operationally, but tests are still being conducted at this time, so it has not yet been made publically available. Monthly mean lake levels, beginning of month lake levels, and precipitation have all been coordinated through 2017 with Canadian counterparts. Some of the lake diversions, outflows, and net basin supplies have been coordinated, but not all of the lakes are completed yet. Work has begun on the skill assessment for the long range forecast. We are looking at the results from the contingency tables and the Heidke Skill scores of the forecasts on an individual month basis, 6 month cumulative values, and seasonality to assess the skill of the forecasts.

Results:

In analyzing the skill of the long range forecast, it has come to attention that while models are suggesting above, below, or near normal net basin supplies, forecasters are not always forecasting in the above and below categories when the models predict them. This is more evident in recent years. However, while the net basin supply forecasts may not always be spot on, once the flows are routed through the routing and regulation model, the resulting lake levels match within a couple centimeters. We are now looking at what would happen to the lake levels if we put more stock into the models and forecasted supplies that deviated more from the normal range. One hesitation results from the fact that the models could be wrong. If the models forecast wetter/drier conditions than normal conditions and they are wrong, how would that affect the lake levels that are forecasted. Tests will be run using past

forecasts to see how the resulting lake levels would have differed if the forecasters had chosen to go with an above or below supply forecast when predicted by the models.

Products: None

Outreach and Engagement Activities: None

Theme III: Great Lakes Hydrometeorological and Ecosystem Forecasting

Improving Lake-Effect Snow and Cloud Forecast Capability for the Great Lakes Region

Principal Investigator(s) and Affiliation(s): Bradley Cardinale and Ayumi Fujisaki-Manome (University of Michigan-CIGLR)
NOAA Technical Lead(s): Philip Chu (NOAA GLERL)
NOAA Sponsoring Office: Office of Weather and Air quality
Budget Amount: $ 121,301

NOAA Strategic Goals:
Goal 2 - Weather-Ready Nation

Overview:

As numerical models move toward higher temporal and spatial resolutions, the challenge remains to properly forecast mesoscale extreme events. Lake-effect snow (LES) is one of the most hazardous events in the Great Lakes region, yet it is extremely challenging to forecast such events accurately, both in the timing and amount of snow. Accurate forecasts of severe ice cover on the lakes are also critical for ship navigation, but currently no short-term forecasted ice information is available for the Great Lakes.

This project aims to provide National Weather Service (NWS)/Weather Forecast Office (WFO) forecasters with improved lake effect snow forecasts, ice predictions, and visibility forecasts by reducing uncertainties of numerical forecast models through rigorous validation and improvement of model-simulated turbulent heat fluxes, lake ice conditions, lake surface temperature, and heat flux calculation algorithms. We are working with the atmospheric model developers of High Resolution Rapid Refresh (HRRR, Benjamin et al. 2016ab) and operational forecasters (WFO Detroit, etc.) to incorporate these improvements into short-term weather forecasts by validating weather and hydrodynamic models. Evaluation of the model-simulated latent and sensible heat fluxes in comparison with the direct flux measurements over the lake surface from the Great Lakes Evaporation Network (GLEN, Lenters et al. 2013) provides a novel and rigorous validation of models in addition to the validations based on the meteorological observations and radar. This project will lead to timely and accurate forecasts that improve the preparedness for severe winter weather events.

Objective(s):

The objective of this project is to provide National Weather Service (NWS)/Weather Forecast Office (WFO) forecasters with improved lake effect snow forecasts, ice predictions, and visibility forecasts by reducing uncertainties of numerical forecast models through rigorous validation and improvement of model-simulated turbulent heat fluxes, lake ice conditions, lake surface temperature, and heat flux calculation algorithms.

Milestones:

- Evaluate the latent and sensible heat fluxes simulated by FVCOM-Ice to evaluate its three different flux calculation algorithms and possibly improve it. Simulated ice conditions, lake surface temperature, and currents will be also evaluated in comparison with the available observations. The impacts of ice conditions on the latent and sensible heat fluxes will be evaluated, as well.
- Provide temporally evolving, high spatial resolution of lake surface temperature to the Weather Research Forecasting (WRF) model from FVCOM-Ice outputs and evaluate the impacts of updated surface boundary conditions on LES forecasts. In addition, the FVCOM-Ice operational outputs will be ingested into HRRR as part of the hydrometeorology testbed.

Accomplishments

Several WRF and FVCOM runs have been conducted using a similar configuration to HRRR's to analyze four separate significant lake effect snow events, November 2014, December 2016, December 2017, and January 2018. In addition to reference WRF runs with the static lake surface temperature, experimental WRF runs with temporally evolving (dynamic) lake surface temperature from FVCOM simulations were conducted.

The latent and sensible heat fluxes from the WRF and FVCOM simulations were compared with direct observations at the GLEN sites. Wind speed, air temperature, and humidity were also compared with the observations at buoys and coastal stations.

Results:

Dynamic lake surface temperature from FVCOM simulations notably improved lake effect snow simulations with WRF for the four events compared with static lake surface temperature. Biases of wind speed, air temperature, and dew point were also reduced.

The simulated heat fluxes mostly agreed with direct observations at the GLEN sites. On the other hand, there was notable underestimation of the latent heat flux by the models, which likely influenced snow fall simulation downwind.

Products

<u>Peer-reviewed publications</u>

Umarporn C., Fujisaki-Manome, A., A.D. Gronewold, B.M. Lofgren, E.J. Anderson, P.D. Blanken, C. Spence, J.D. Lenters, C. Xiao, L.E. Fitzpatrick, and G. Cutrell (2018), Validating modeled turbulent heat fluxes across large freshwater surfaces, *Hydrol. Earth Syst. Sci. Discuss*., https://doi.org/10.5194/hess-2017-725, in review.

Fujisaki-Manome, A. L. Fitzpatrick, A.D. Gronewold, E.J. Anderson, C. Spence, J. Chen, C. Shao, D. Wright, C. Xiao, and B.M. Lofgren (2017), Turbulent Heat Fluxes during an Extreme Lake Effect Snow Event, *J. Hydrometeorology*, *18*(12), pp. 3145–3163.

News articles or broadcasts

- Imagine a Great Lakes weather forecaster who's always right, Great Lakes Echo, 11/20/2017
- Better lake-effect forecasts are coming, The Buffalo News, 11/24/2017
- Building a better lake-effect snow forecast, GoErie.com, 12/1/2017
- November 2014 storms become case study for better lake-effect forecasting, The Buffalo News, 12/9/2017
- Forecasting the Future of Lake Effect Snow, CIGLR Winder 2018 Newsletter, 2/28/2018

Presentations

Fujisaki-Manome, A., A.D. Gronewold, B.M. Lofgren, E.J. Anderson, P.D. Blanken, C. Spence, J.D. Lenters, C. Xiao, L.E. Fitzpatrick, G. Cutrell, and Umarporn C, Validating modeled turbulent heat fluxes across large freshwater surfaces, American Geophysical Union Fall Meeting, New Orleans, LA, December 11-15, 2017 (poster presentation).

Fitzpatrick, L. E., A. Fujisaki-Manome, A.D. Gronewold, E.J. Anderson, C. Spence, J. Chen, C. Shao, D. Posselt, D. Wright, B. Lofgren, D. Schwab, Reconstructing Heat Fluxes Over Lake Erie During the Lake Effect Snow Event of November 2014, American Geophysical Union Fall Meeting, New Orleans, LA, December 11-15, 2017 (poster presentation).

Outreach and Engagement Activities

Student mentoring

Currently mentoring University of Michigan grad student, Kyle Klein

Appendix A: Performance Measures – July 1, 2017-March 31, 2018

Grant Success			
Measure	**Target**	**Interval**	**Achieved**
Total NOAA grant funding awarded to CIGLR through CA	$4 M	per year	$4,215,217
Total number of amendments awarded to CIGLR through CA	20	per year	20
External (non-NOAA) funds awarded to CIGLR PIs	$500k	per year	$0
Number of CIGLR Research Institute personnel supported through CA and external funding	25		38
NOAA-University Partnership			
Measure	**Target**	**Interval**	**Achieved**
CIGLR contribution to GLERL scientific workforce, as percentage of research personnel	60%		65%
Percentage of publications and technical reports co-authored by Research Institute or Regional Consortium members	60%		58%
University of Michigan cost share and in-kind support	≥$511k	per year	$482,100
Number of NOAA, CIGLR, and Regional Consortium scientists performing visiting research at a NOAA-GLERL or Regional Consortium facility	2	per year	3
Regional Collaboration			
Measure	**Target**	**Interval**	**Achieved**
Amount of funding sub-awarded to Regional Consortium members (partners or affiliates)	$1.4 M	per year	$518,635
Proportion of sub-award funding issued to Regional Consortium partners	80%		57%
Number of Regional Consortium PIs receiving sub-awards	≥50	5-year CA	3
Number of Regional Consortium-affiliated students receiving support	40	per year	14
Research Outcomes			
Measure	**Target**	**Interval**	**Achieved**
Number of peer-reviewed publications resulting from CIGLR funding	40	per year	15
Number of peer-reviewed publications with CIGLR-funded first authors	20	per year	6
Number of news media stories related to CIGLR research	100	per year	110
Engagement			
Measure	**Target**	**Interval**	**Achieved**
Number of products resulting from Summits and Working Groups	6	per year	5
Number of meetings with legislators	2	per year	3
Number of science-policy events hosted	1	per year	1 (5/1/18)
Number of advocacy actions (i.e., letters or postcards sent)	80	per year	90
Number of stakeholder focus group meetings held	5	per year	7
Career Training			
Measure	**Target**	**Interval**	**Achieved**
Number of undergraduates, graduate students, and postdocs supported	40	per year	29
Number of students and postdocs located at GLERL	20	per year	16
Number of student and postdoctoral fellowships awarded	12	per year	18
Number of university affiliations of supported students	20	per year	20
Percentage of self-identified non-white/Caucasian summer fellowship applicants	>25%		29%
Percentage of female summer fellowship applicants	>45%		61%
Outreach & Communications			
Measure	**Target**	**Interval**	**Achieved**
Number of website hits	20,000	avg per month	29,073
Number of social media followers	4,000	total	4,163
Number NOAA OAR Hot Item articles submitted	4	per year	3
Number of e-newsletter subscribers	>500	total	553
Percentage of e-newsletter opens/views	>50%	average	40%

Appendix B: Engagement, Career Training, and Outreach & Communications (ECO) Program

CIGLR's Engagement, Career Training, and Outreach & Communications (ECO) Program facilitates the transfer of Great Lakes research and knowledge into actionable science. With financial support from the University of Michigan, our network of 9 University Partners, and NOAA GLERL, CIGLR strives to achieve 3 goals through the ECO Program:

Engagement – *Support informed decision making* by working with legislators, resource managers, and stakeholders to develop the tools and information needed to promote sustainability in the Great Lakes.

Career Training – *Promote a skilled and diverse workforce* by providing career training for undergraduates, graduate students, and postdoctoral fellows who will become the next generation of Great Lakes and NOAA scientists.

Outreach & Communications – *Advance environmental literacy* by communicating the value, importance, and usefulness of NOAA's Great Lakes research to the general public at local, state, and regional levels.

The University of Michigan has committed $1.2 million in cost-share funding over the next five years to support CIGLR's ECO Program. ECO Program funding will also come from NOAA GLERL, which has historically provided ~$100K annually in Task IB funds to support student fellowships and the Great Lakes seminar series. In addition, individual Task II/III research projects are all required to have a science translation component and encouraged to include postdoctoral and student support in their budgets.

The ECO Program is implemented by CIGLR's Program Manager, with support from the CIGLR Communications Specialist, Stakeholder Engagement Specialist, and Outreach Specialists, and guidance from the CIGLR Director. The sections that follow detail activities to achieve each of the ECO Program goals.

Engagement – ***Supporting Informed Decision Making***

CIGLR will work directly with legislators, resource managers, and other stakeholders to develop the research programs, tools, and information needed for decision making that promotes sustainability in the Great Lakes. CIGLR aims to take a leadership role in guiding the wise management and protection of the Great Lakes by translating research findings, providing NOAA's tools and data products, and identifying critical research needs to Great Lakes decision makers. Our **legislative engagement** activities will target appropriators and decision makers from the following offices: Great Lakes and St. Lawrence Cities Initiative, Michigan Office of the Great Lakes, Conference of Great Lakes and St. Lawrence Governors and Premiers, Great Lakes Congressional Task Forces, U.S. EPA Great Lakes National Program Office (GLNPO), and the International Joint Commission (IJC). At the Federal level, we will focus on success stories of projects from the Great Lakes Restoration Initiative (GLRI) to advocate for continued legislative support for this program. Our **stakeholder engagement** activities will target resource managers and others who rely on our research tools and products for decision-making, with the goal to facilitate the co-production of research outcomes. Stakeholder engagement will be implemented as part of our research programs focused on harmful algal blooms, hypoxia, ice and snow forecasting, and real-time observations.

To accomplish our engagement goals, CIGLR will collaborate with Private-sector partners (the Nature Conservancy, and the National Wildlife Federation Great Lakes Regional Center), and supporting initiatives (Great Lakes Commission, International Joint Commission) who represent the strongest advocates for science-based decision making in the Great Lakes. In addition, we will work with other CI Directors to share the importance of our work with NOAA on Capitol Hill, at the Department of Commerce, and in the Office of Management and Budget.

Specific engagement activities within the ECO Program include:

- Summits and Working Groups (3-5 per year). CIGLR will convene top experts from Great Lakes universities, NGOs, government agencies, and businesses to participate in Summits and Working Groups (SWGs) that focus on the most pressing research and management needs to achieve sustainability in the Great Lakes. SWGs are centered on CIGLR's research themes, and are designed to advance Great Lakes science and contribute to NOAA GLERL's research capacity across the Great Lakes through the co-design of research priorities. Summits comprise groups of 20-30 experts meeting for 2-3 days to summarize the state of knowledge and recommend future directions on Great Lakes problems that span decadal time scales. Working groups bring together smaller groups (8-12) for up to one week to make detailed progress on more narrow Great Lakes issues with solutions on the time scale of months to years. Regional Consortium partners (academic and private sector) will be invited to submit proposals to an annual call for funding of SWGs. CIGLR will facilitate the review and selection process, giving priority to proposals involving NOAA scientists, and host SWGs at the University of Michigan-Ann Arbor. The ultimate goal for SWGs is to produce an agenda for the future of Great Lakes research that is co-designed by researchers and end-users of NOAA data. Written products will include peer-reviewed publications and white papers. The resulting written products will be used as a

platform to make the case for increased funding for Great Lakes research, and used to drive research that provides key information for decision makers.

- Legislative interaction (3-5 per year). The CIGLR Director and Program Manager will lead and participate in interactions with local, State, and Federal legislators to inform about our work and express the Great Lakes region's priorities for legislation and appropriations to protect our environment and support our economy. Activities will include meeting with Federal legislators and their staff on Capitol Hill and local offices; inviting State and Federal legislators to visit NOAA GLERL, University of Michigan, and special events; testifying at State Senate and House Natural Resources Committee hearings; and nominating CIGLR or Regional Consortium representatives to serve on a Federal Advisory Committee.

- Science-Policy Nexus event (1 per year). CIGLR will host one event annually hat brings together scientists, stakeholders, and Great Lakes elected officials. The focus will be outlining a vision for Great Lakes research, through identifying critical next steps and funding needs. Examples of science-policy nexus events are a hosting Great Lakes Vision reception featuring invited keynote speakers that include legislators, scientists, and stakeholders; and co-hosting the annual Science-Policy Confluence conference with the Environmental Law Policy Center.

- Great Lakes policy advocacy (ongoing). CIGLR and our Regional Consortium members will communicate with local, state, and Federal policy makers with written letters and phone calls when pending legislation or appropriations have potential to impact the health and safety of the Great Lakes and the communities that rely on them. We will urge them to consider science in their decision making and highlight the economic benefit of protecting and restoring Great Lakes ecosystem services. We will facilitate Great Lakes advocacy in the University of Michigan campus community by holding postcard writing events at least once per year. CIGLR will facilitate public Great Lakes advocacy by maintaining a Take Action portal on our website, where the public can get informed about the Great Lakes, sign a stewardship pledge, and write to Congress. https://ciglr.seas.umich.edu/take-action/

- Stakeholder Engagement focus groups (10 per year). CIGLR will engage stakeholders related to our harmful algal blooms, hypoxia, ice and snow forecasting, and real-time observations research to facilitate the co-production of research outcomes. We will hold focus group meetings to introduce research goals, gather feedback on information needs and user experiences, and present project updates. Research teams will use this information to tailor their products to stakeholder needs to support sustainable resource management in the Great Lakes.

Career Training – *Promoting a skilled and diverse workforce*

CILGR will continue the highly successful career training program that has a proven track record for producing Great Lakes and NOAA scientists and professionals. Along with NOAA GLERL, our Regional Consortium members, and the University of Michigan, we provide NOAA-mission related research

experience and career training to undergraduates, graduate students, and postdoctoral research fellows. Since 2008, we have provided research training to more than 579 students and postdocs, 158 of whom were awarded graduate or postdoctoral fellowships. CIGLR students, postdocs, and staff progressed to GLERL positions (i.e., federal hire or government contractor) 7 times over the same period, fulfilling the program's ultimate goal of producing the next generation of NOAA scientists in the Great Lakes. Two of the federal hires, Drs. Ashley Elgin and Eric Anderson, advanced from CILER postdoctoral fellows to be GLERL principal investigators.

We strive to shape a workforce that is not only skilled in NOAA mission-related research priorities, but also one that is diverse. CIGLR is committed to supporting diversity in an inclusive environment, in alignment with the 2016 Diversity, Equity, and Inclusion Strategic Plans issued by the University of Michigan and SNRE. We will continue our ongoing efforts to actively encourage students from groups traditionally underrepresented in the aquatic sciences workforce to participate in our fellowship programs. We accomplish this by directly communicating our fellowship opportunities to program officers, professors, and group leaders that have contact with students from traditionally underrepresented backgrounds. Examples include the University of Michigan Office of Multi-Ethnic Student Affairs, Hampton University (historically black university), American Indian Science and Engineering Society (AISES), and Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS). We receive guidance in this effort from the SEAS Diversity, Equity, and Inclusion Office and the NOAA Equal Employment Opportunity (EEO)/Diversity Program Office. Asking optional questions on race/ethnicity and gender on the fellowship applications allows us to track our success in reaching students from underrepresented groups. We will continue to build relationships with diversity leaders and expand our list of contacts for distributing fellowship announcements to students from underrepresented backgrounds. We will also work with fellowship mentors to develop student projects that could benefit from traditional knowledge or cultural perspectives. In addition to our fellowship recruitment efforts, CIGLR research scientists will continue to mentor students in the University of Michigan's Doris Duke Conservation Scholars Program, which aims to diversify the conservation workforce.

The CIGLR Associate Director and Program Manager are responsible for implementing the career training activities described below. Specific activities include:

- Great Lakes Summer Fellowships (8-12 per year): CIGLR will continue to administer the annual Great Lakes Summer Fellows Program, which is a partnership with NOAA GLERL and helps place promising young undergraduate and graduate students with both university and Federal research mentors. Through this program, students get the opportunity to work on substantive research issues in the Great Lakes that, in turn, support CIGLR's and NOAA's research mission in the region. These fellowships are supported by Task IB and Task II funds.

- Great Lakes Graduate Research Fellowships (2 per year): CIGLR will administer a fellowship program provides career training opportunities to master's or doctoral students that are located at one of CIGLR's Regional Consortium universities. The goals of these fellowships are to: 1) provide training and educational opportunities for students who will become the next

generation of Great Lakes researchers, 2) enhance collaborations between CIGLR's Regional Consortium partners and PIs at NOAA GLERL and CIGLR, and 3) increase student retention within the freshwater aquatic sciences. These fellowships are supported by Task IB.

- Postdoctoral Fellowships (1-2 per year): In addition to supporting postdoctoral positions through Task II research projects, CIGLR also administers a competitive Postdoctoral Fellowship program that is supported by University of Michigan cost share funds. This program provides salary and research support for a postdoctoral fellow to work closely with a faculty mentor at a CIGLR Regional Consortium university on a project of mutual interest to CIGLR and NOAA. The goals of the Postdoctoral Fellowship Program are to 1) expand research training opportunities for postdoctoral scientists working in the area of freshwater sustainability, and 2) enhance collaborations between CIGLR's Regional Consortium partners and PIs at NOAA GLERL and CIGLR.

- Graduate Student Projects: As Task II research grant funding allows, CIGLR research scientists will continue to serve as mentors for University of Michigan graduate students completing Master of Science (M.S.) research projects.

- Doris Duke Conservation Scholars Program (2 per year): CIGLR research scientists will mentor at least 2 undergraduate students per year participating in University of Michigan's Doris Duke Conservation Scholars Program. The goal of the program is to introduce greater diversity into the environmental conservation workforce and teach an approach to conservation in which diversity and inclusion are integral. As part of the program, students complete an 8-week internship at an environmental organization. Students mentored by CIGLR scientists will complete this requirement at NOAA GLERL.

- Project-specific Student and Postdoc Experience (25-40 per year): CIGLR and Regional Consortium members routinely hire undergraduates, graduate students, and postdocs to fulfill CIGLR research project needs. These students and postdocs are mentored by leading research scientists at CIGLR, GLERL, or collaborating institutions/organizations, gaining valuable experience and career training. CIGLR will continue to include student and postdoc support in our annual Task II research proposal budgets.

Outreach & Communications – *Advancing environmental literacy*

CIGLR's outreach and communications activities are designed to translate and promote NOAA research in the Great Lakes at local, state, regional, national, and international levels. We work with our Regional Consortium partners to expand our outreach efforts across the basin. Our key messages relating to CIGLR and our research are formulated using input gathered from CIGLR leadership and principal investigators, and modified as needed for specific target audiences. CIGLR's target audiences include internal and external groups. Internal audiences are SEAS, the CIGLR Regional Consortium, NOAA GLERL, NOAA CI Program Office, NOAA GLRCT, and NOAA senior leadership. External audiences include the

general public, media, and stakeholders (e.g., resource managers; industry; local, state, and federal government officials; NGOs).

Our continued participation in NOAA communications and outreach groups at multiple levels allows us to coordinate communications and outreach efforts with NOAA programs across the basin, resulting in broader impact, cohesive messaging, and increased visibility for NOAA in the Great Lakes. We are active members of the GLERL Information Services (IS) Communications Group. During biweekly IS meetings, we coordinate and strategize CI and GLERL communications and outreach activities, share successes and ideas for improvement, and receive guidance on working with the larger NOAA communications network. We also participate in monthly meetings of the NOAA Great Lakes Regional Collaboration Team (GLRCT) Communications and Outreach Working Group, composed of representatives from the CI, NOAA Line Offices, Great Lakes Sea Grant Network, and the Great Lakes Observing System (GLOS). We are also connected with the OAR Communications and Outreach Working Group, and participate in their monthly nationwide conference calls.

At the university level, CIGLR has ongoing relationships with key communications offices at the University of Michigan that increase our exposure from department level up to global scale. We have a well-developed relationship with the science writer and videographer for Michigan News (the university's news and media office), as well as the SEAS Communications Office. Michigan News produces feature stories and videos that are picked up by the press worldwide.

The CIGLR Program Manager, Outreach Specialist, and Communications Specialist are responsible for implementing the activities described below:

- Great Lakes Seminar Series (8-12 per year): CIGLR will co-sponsor and coordinate the joint CIGLR-GLERL Great Lakes Seminar Series, which brings in regional, national, and international researchers to talk about pertinent new and emerging scientific issues in the Great Lakes. These events facilitate collaborations between researchers, provide an educational opportunity for NOAA and university scientists, and serve as an outreach forum for stakeholders and the general public to attend. Seminars are held at NOAA GLERL or the University of Michigan and are broadcast via webinar for remote participation. Webinar recordings are available to the public on the CIGLR website and YouTube channel.

- Website (weekly): CIGLR remains committed to a strong web presence that facilitates effective science translation, provides visibility to CIGLR and NOAA research, and informs stakeholders, students, and the public about events and opportunities. We use Google analytics to track website usage and popular products. The website continually updated and under active management. The website address is https://ciglr.seas.umich.edu/.

- Social Media (daily): CIGLR will continue to connect with the public, stakeholders, scientists, and NOAA on social media through our on Facebook (@CIGLR.UMich), Twitter (@CIGLR_UM), Instagram (CIGLR_UM), YouTube (CIGLR_UM), and Flikr (CIGLR_UM) accounts. The CIGLR Communications Specialist holds primary responsibility for maintaining a strong and active

presence on social media. CIGLR posts 8+ times per day on Twitter, 3+ times per week on Instagram, and 3-4 times per week on Facebook. We are committed to increasing our social media reach and engagement with our followers.

- News Media (4 per year): CIGLR will continue to produce press releases on research results and contact Michigan News and other local/regional news contacts with media-worthy stories. News articles will be available on the CIGLR website and promoted on social media.

- NOAA OAR Hot Items (4 per year): CIGLR will contribute Hot Item articles to NOAA OAR promoting CIGLR research results, news updates, and important events. OAR Hot Items articles are accessible only to the internal NOAA community. GLERL IS will assist CIGLR in this effort.

- NOAA GLRCT Regional Highlights (3 per year): CIGLR will contribute articles to the Great Lakes Regional Collaboration Team (GLRCT) for publishing on the Regional Highlights portion of their website. These articles will use CIGLR research results to address one of the GLRCT goals for the region: address regional challenges by connecting people and resources, exchange both national and regional insights that inform action, and improve understanding of and respect for NOAA's broad mission and regional capabilities.

- Quarterly E-newsletters (4 per year): CIGLR will publish quarterly e-newsletters highlighting CIGLR research, partner interactions, opportunities, and events. Quarterly e-newsletters are directly emailed to a wide audience, including CIGLR Regional Consortium members, NOAA (OAR Communications Office, CI Program Office, GLERL), University of Michigan (UM Water Community [listserv], SEAS faculty/staff/students), NOAA UM Programs (GLISA, NERRS, Michigan Sea Grant), Great Lakes Information Network (GLIN; listserv), and the CIGLR Executive Board. They are also posted on social media and the CIGLR website. We use analytics included with our newsletter delivery service to track e-newsletter reach and interest.

- CIGLR Minute Videos (12 per year): CIGLR will produce a monthly video series featuring research projects and staff profiles. The videos will be posted on social media, on the CIGLR website, and included in the quarterly e-newsletter.

- Outreach Events (8-12 per year): CIGLR will continue to have informational tables at community outreach events, university outreach events, and scientific conferences. Community/university events include Ann Arbor Mayor's Green Fair, Huron River Day, UM Student Visit Day, UM Green Career Fair, and the State of Michigan Earth Day Event. Scientific conferences include the International Association for Great Lakes Research (IAGLR) Conference and the Healing Our Waters-Great Lakes Coalition (HOW) Annual Great Lakes Restoration Conference. We will also continue to coordinate participation in outreach events with other NOAA programs, such as Great Lakes Sea Grant, GLOS, NOAA GLRCT, and NOAA GLERL. To broaden CIGLR's outreach across the Great Lakes, we will provide Regional Consortium partners with funds to support undergraduate or graduate research students who incorporate a public outreach or education component into their work. The student's education and outreach efforts must highlight NOAA,

CIGLR, and Regional Consortium contributions to research and management of the Great Lakes. Examples include K-12 education activities, community outreach events, public education talks, social media communication, factsheets, newsletters, and magazines. Participation in outreach events and outreach funding for partners is from University of Michigan cost share.

- Research Project-Related Outreach: All CIGLR research projects will be required to define an outreach component and report on progress in annual project reports. Our ongoing harmful algal bloom (HAB) and hypoxia research in Lake Erie is a prime example of effective project-supported outreach to end users of the data (i.e., drinking water intake managers), which has helped inform and tailor our research products.

Appendix C: Great Lakes Summer Fellowship Recruiting Plan

Each summer, CIGLR collaborates with NOAA-GLERL to provide hands-on training and research experiences to a number of highly qualified students with great potential to become the next generation of Great Lakes scientists. CIGLR's recruiting strategy involves 3 focus areas:

- Under-represented student groups: to increase diversity, equity, and inclusion in STEM disciplines
- National & scientific outlets: to provide broad, nationwide exposure
- CIGLR partners: to provide Great Lakes regional emphasis and enhance partner interactions

Under-represented Student Groups

CIGLR strives to increase diversity, equity, and inclusion in the STEM disciplines, and considers the Summer Fellows program a primary opportunity to accomplish this goal. The following steps are taken to encourage applicants from a wide variety of backgrounds:

- Race/ethnicity & gender questions are included on the application form, including options for a preference not to answer.
- The program description states "We seek to use these fellowships to increase diversity in STEM disciplines (science, technology, engineering and math) and strongly encourage applications from students who identify with groups that have been traditionally underrepresented in government and academic workforces." This statement is included on the announcement and on the CIGLR Summer Fellows webpage.
- Advertising to student groups and universities that serve under-represented student groups:
  - University of Michigan
    - Office of Academic Multicultural Initiatives (OAMI)
    - Multi-Ethnic Student Affairs (MESA)
    - Women in Science and Engineering (WISE)
    - Undergraduate Research Opportunity Program (UROP)
    - La Casa Latinx Student Organization
    - Department of American Culture: Latina/o Studies
    - American Indian Student Association (NASA)
    - American Indians at the University of Michigan
    - American Indian Science and Engineering Society (AISES), UM Chapter
    - National Society of Black Engineers
  - Minority Serving Institutions
    - Hampton University
    - Claflin University
    - Xavier University of Louisiana
    - Our Lady of the Lake University

        - Florida International University
        - University of New Mexico
        - Delaware State University
        - The University of Texas at San Antonio
        - Howard University
        - Morehouse College
        - Spelman College
        - University of the Incarnate Word
        - North Carolina Central University
        - Florida Agricultural & Mechanical University
        - Alcorn State University
    - Native American student groups
        - Keweenaw Bay Ojibwa Community College
        - College of the Menominee Nation, Sustainability Development Institute
        - Menominee Indian Tribe of Wisconsin
        - Lake Superior State University
        - Tribal College Journal job board
        - American Indian Science and Engineering Society (AISES)
        - Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS)
        - Institute for Tribal Environmental Professionals (ITEP)
        - Society of American Indian Government Employees (SAIGE)
        - Great Lakes Indian Fish and Wildlife Commission
    - NOAA Environmental Cooperative Science Center
    - NOAA OAR EEO/Diversity Program Office
    - Minorities in Agriculture, Natural Resources, and Related Sciences – Job Board
    - Brazil Scientific Mobility Program

National & Scientific Outlets

The following resources are used to advertise the Great Lakes Summer Fellows program to the broader national-level STEM community:

- Great Lakes Information Network (GLIN) Jobs listserv
- International Association for Great Lakes Research (IAGLR) Job Board
- Association for the Sciences of Limnology and Oceanography (ASLO) Student Opportunities
- Society for Freshwater Science (SFS) classified ads
- Ecological Society of America (ESA) Ecolog listserv
- American Geophysical Union (AGU) jobs website
- University Corporation for Atmospheric Research (UCAR) Earth Sciences listserv
- Handshake recruiting system: 300+ university career centers across the country

CIGLR Partners

CIGLR distributes the Great Lakes Summer Fellows announcement to its Consortium partners via email. Additional advertising is done at the University of Michigan, including:

- Participation in the annual Green Career Fair, which draws ~600 students each year
- Direct emails to contacts in STEM departments: Climate and Space Sciences and Engineering (CLaSP), Earth and Environmental Science (EES), Civil and Environmental Engineering (CEE), Ecology and Evolutionary Biology (EEB), School for Environment and Sustainability (SEAS)
- Posting on the School of Literature, Science, and the Arts (LSA) Opportunity Hub

Appendix D: Employee Count

Summary of CIGLR staff and students by head count from July 1, 2017 – March 31, 2018. Counts of Research Scientists, Research Support Staff, and Administrative staff include only University of Michigan employees. Counts of Postdoctoral Research Fellows and students include subcontracts.

		Terminal Degree		
Category	**Number**	**B.S.**	**M.S.**	**Ph.D.**
Research Scientists	6	0	0	6
Visiting Scientists	0	0	0	0
Postdoctoral Research Fellows	9	0	0	6
Research Support Staff	22	4	17	1
Administrative	3	0	3	0
Total ≥ 50% support (NOAA)	37			
Total < 50% support	3			
Undergraduate Students	6	0	0	0
Graduate Students	14	9	5	0
Located at NOAA Lab	43			
Obtained NOAA employment	0			

Appendix E: Publication Count

Summary of peer-reviewed and non-peer-reviewed publications related to CILER- and CIGLR-funded research from FY2003-FY2018, with summaries based on the last CILER 5-year Cooperative Agreement renewal (FY2013-2017), and 10-year CILER Cooperative Agreement (FY2008-2017), and the new CIGLR Cooperative Agreement (FY18). Publications attributed to CI lead authors include those led by any University of Michigan author. Publications attributed to "other" lead authors are all those with a non-UM or non-NOAA lead author, including subcontracts.

Lead	FY	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	CILER Y5-10 Total (FY13-17)	CILER Y1-10 Total (FY08-17)	CIGLR Y1 (FY18)
CIGLR	Peer-rev.	16	8	7	10	10	12	19	14	36	15	8	8	10	14	16	6	56	152	6
	Non peer-rev.	7	1	2	1	0	6	0	3	6	2	0	3	5	2	3	0	13	30	0
NOAA	Peer-rev.	5	2	4	7	3	4	33	24	10	7	6	7	6	7	2	0	28	106	0
	Non peer-rev.	4	6	1	0	2	1	0	3	0	0	0	4	2	1	5	2	12	16	2
Other	Peer-rev.	0	12	10	3	6	13	29	38	0	20	5	9	28	21	36	9	99	199	9
	Non peer-rev.	0	0	0	0	0	0	0	11	0	0	0	2	1	0	16	4	19	30	4
Total	Peer-rev.	21	22	21	20	19	29	81	76	46	42	19	24	44	42	54	15	183	457	15
	Non peer-rev.	11	7	3	1	2	7	0	17	6	2	0	9	8	3	24	6	44	76	6

Appendix F: Publications

Peer-Reviewed Publications

Cable, R.N., D. Beletsky, R. Beletsky, B.W. Locke, K. Wigginton and M.B. Duhaime. 2017. Distribution and modeled transport of plastic pollution in the Great Lakes, the world's largest freshwater resource. *Frontiers in Environmental Science*. 5(45):1-18. (DOI:10.3389/fenvs.2017.00045).

Carrick, H.J.; E. Cafferty; A. Ilacqua; S. Pothoven and G.L. Fahnenstiel. 2017. Seasonal Abundance, Biomass and Morphological Diversity of Picoplankton in Lake Superior: Importance of Water Column Mixing. *International Journal of Hydrology*. 1(6):00034.

Chiang, E.; M. Schmidt; M. Berry; B. Biddanda; A. Burtner; T. Johengen; D. Palladino and V. Denef. 2018. Verrucomicrobia are prevalent in north-temperate freshwater lakes and display class-level preferences between lake habitats. *PlosOne*. 13(3):e0195112. (DOI:10.1371/journal.pone.0195112).

Fujisaki-Manome, A.; L.E. Fitzpatrick; A.D. Gronewold; E.J. Anderson; B.M. Lofgren; C. Spence; J. Chen; C. Shao; D.M. Wright and C. Xiao. 2017. Turbulent Heat Fluxes during an Extreme Lake-Effect Snow Event. *Journal of Hydrometeorology*. 18:3145-3163. (DOI:10.1175/JHM-D-17-0062.1).

Grand, M; G. Clinton-Bailey; A. Beaton; A. Schaap; T. Johengen; M. Tamburri; D. Connelly; M. Mowlem and E. Achterberg. 2017. A Lab-On-Chip Phosphate Analyzer for Long-term In Situ Monitoring at Fixed Observatories: Optimization and Performance Evaluation in Estuarine and Oligotrophic Coastal Waters. *Frontiers in Marine Science*. 4(255):1-16. (DOI:10.3389/fmars.2017.00255).

Kramer, A.M., G. Annis, M.E. Wittmann, W.L. Chadderton, E.S. Rutherford, D.M. Lodge, L.A. Mason, D. Beletsky, C. Riseng and J.M. Drake. 2017. Suitability of Great Lakes for aquatic invasive species based on global species distribution models and local aquatic habitat. *Ecosphere*. 8(7). (DOI:10.1002/ecs2.1883).

Liu, Y., B.A. Engel, P.D. Collingsworth and B.C. Pijanowski. 2017. Optimal implementation of green infrastructure practices to minimize influences of land use change and climate change on hydrology and water quality: Case study in Spy Run Creek watershed, Indiana. *Science of the Total Environment*. 601:1400-1411. (DOI:10.1016/j.scitotenv.2016.02.116).

Meyer, K.A.; T.W. Davis; S.B. Watson; V.J. Denef; M.A. Berry and G.J. Dick. 2017. Genome sequences of lower Great Lakes Microcystis sp. reveal strain-specific genes that are present and expressed in western Lake Erie blooms. *PlosOne*. 2(10):e0183859. (DOI:10.1371/journal.pone.0183859).

Moore, T.S.; C.B. Mouw; J.M. Sullivan; M.S. Twardowski; A.M. Burtner; A.B. Ciochetto; M.N. McFarland; A.R. Nayak; D. Paladino; N.D. Stockley; T.H. Johengen; A.W. Yu; S. Ruberg and A. Weidemann. 2017. Bio-optical Properties of Cyanobacteria Blooms in Western Lake Erie. *Frontiers in Marine Science*.4(300):1-20. (DOI:10.3389/fmars.2017.00300).

Props, R.; M.L. Schmidt; J. Heyse; H.A. Vanderploeg; N. Boon and V.J. Denef. 2017. Flow cytometric monitoring of bacterioplankton phenotypic diversity predicts high population-specific feeding rates by invasive dreissenid mussels. *Environmental Microbiology*. 20(2):521-534. (DOI:10.1111/1462-2920.13953).

Scavia, D., I. Bertani, D.R. Obenour, R.E. Turner, D.R. Forrest and A. Katin. 2017. Ensemble modeling informs environmental policy making: The case of hypoxia in the northern Gulf of Mexico. *Proceedings of the National Academy of Sciences.* 114(33):8823-8828. (DOI:10.1073/pnas.1705293114).

Scholin, C.; J. Birch; S. Jensen; R. Marin III; E. Massion; D. Pargett; C. Preston; B. Roman and W. Ussler III. 2018. The quest to develop ecogenomic sensors: A 25-year history of the Environmental Sample Processor (ESP) as a case study. *Oceanography*. 30:100-113. (DOI:10.5670/oceanog.2017.427).

Smith, J. and A. Gronewold. 2018. Development and analysis of a Bayesian water balance model for large lake systems. arXiv preprint arXiv:1710.10161.

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Testa, J.M., J.B. Clark, W.C. Dennison, E.C. Donovan, A.W. Fisher, W. Ni, M. Parker, D. Scavia, S.E. Spitzer, A.M. Waldrop, V.M.D. Vargas and G. Ziegler. 2017. Ecological Forecasting and the Science of Hypoxia in Chesapeake Bay. *BioScience*. 67(7):614-626. (DOI:10.1093/biosci/bix048).

Non-Peer-Reviewed Publications

Lance, V. and H. Gu. 2017. Results of analysis comparing CPA-A retrievals on MODIS and VIIRS as a precursor to the transfer of the CPA-A to NESDIS.

Shuchman, R; K. Bosse, M. Sayers; G. Fahnenstiel and G. Leshkevich. 2017. Satellite Observed Water Quality Changes in the Laurentian Great Lakes Due to Invasive Species, Anthropogenic Forcing, and Climate Change. 37th International Symposium on Remote Sensing of Environment (ISRSE-37). (DOI:10.5194/isprs-archives-XLII-3-W2-189-2017).

Sturtevant, R. 2017. Impacts of Aquatic Invasive Species sub-indicator report. In State of the Great Lakes 2017 Technical Report. State of the Great Lakes 2017 Technical Report. Cat No. En161- 3/1E PDF. EPA 905-R-17-001.

Sturtevant, R. 2017. State of the Great Lakes: *Highlights Report*. An overview of the status and trends of the Great Lakes ecosystem. (https://binational.net/wp-content/uploads/2017/06/SOGL_17-EN.pdf).

Wang, J.; J. Kessler; F. Hang; H. Hu; A.H. Clites and P. Chu. 2017. Analysis of Great Lakes Ice Cover Climatology: Winters 2012-2017. NOAA Technical Memorandum GLERL-171. (https://glerl.noaa.gov/pubs/tech_reports/glerl-171/tm-171.pdf).

Wang, J.; J. Kessler; F. Hang; H. Hu; A.H. Clites and P. Chu. 2017. Great Lakes Ice Climatology Update of Winters 2012-2017: Seasonal Cycle, Interannual Variability, Decadal Variability, and Trend for the period 1973-2017. NOAA Technical Memorandum GLERL-170. (https://www.glerl.noaa.gov/pubs/tech_reports/glerl-170/tm-170.pdf).