2016-2017

Performance Progress Report

Cooperative Institute for Limnology and Ecosystems Research (CILER)

University of Michigan

NA12OAR4320071 – Year Five

UNIVERSITY OF MICHIGAN

Bradley J. Cardinale
Director

Thomas H. Johengen
Associate Director

Mary E. Ogdahl
Program Manager

CILER
Cooperative Institute for Limnology and Ecosystems Research

G110 Dana Building
440 Church Street
Ann Arbor, MI 48109-1041
734-763-3010
www.ciler.snre.umich.edu

Cooperative Institute for Limnology and Ecosystems Research – CILER

Bradley J. Cardinale, Director
Thomas H. Johengen, Associate Director
Mary Ogdahl, Program Manager
University of Michigan
Ann Arbor, Michigan

Annual Report for NA12OAR4320071
Year Five (12 months): July 1, 2016 – June 30, 2017

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Cover photo: Mike Wood/Michigan News

Executive Summary

Activities during the fifth year of CILER's Cooperative Agreement reflect our continued commitment to excel in ongoing core collaborative research activities that strengthen NOAA's mission in the Great Lakes, as well as a strong vision for the future with the launch of our new Engagement, Career Training, and Outreach & Communications (ECO) Program. As we complete activities proposed under the CILER 2012-2017 Cooperative Agreement, we are measuring our impact by evaluating our grant success, research outcomes, collaborations with NOAA and academic partners, and career training and outreach programs.

CILER has received $16.8 million in NOAA funding through the 2012-2017 Cooperative Agreement, supplemented by $4.5 million in external awards and $2.02 million in support from the University of Michigan. Nearly one-third ($5.12 million; 32%) of our Task Ib and Task II funding has been sub-awarded to our partners throughout the Great Lakes region to foster collaborative research with NOAA and career training through graduate student and postdoctoral fellowships. CILER's scientific productivity is reflected in part by its sustained high rate of peer-reviewed publication. For three consecutive years, CILER and our partners have published more than 40 journal articles each year on research supported by CA funding. We have also maintained our strong commitment to training the next generation of Great Lakes scientists, with 52 undergraduates, graduate students, and postdocs supported by a CILER fellowship or project during FY17; 237 students have received support during the CA period. CILER's new ECO Program has boosted public education about NOAA research and Great Lakes science, reaching an estimated 14,000 people during public outreach events in FY17 and launching our first quarterly newsletter. More ECO Program highlights for FY17 can be found in the ECO Program Activities section below.

CILER will continue to operate through August 2018 under a one-year no-cost time extension, while we concurrently begin new research within our Research Institute, build partnerships across our Regional Consortium, and enhance the impact of NOAA science through our ECO program under our newly awarded Cooperative Institute for Great Lakes Research.

Research Highlights (FY17)

Harmful Algal Bloom Monitoring & Forecasting

CILER continues to partner with NOAA GLERL to understand and forecast harmful algal blooms (HABs) and their toxins in Lake Erie and Saginaw Bay of Lake Huron. Through monitoring, modeling, and experimentation, the CILER-GLERL research team is focused on predicting when the HAB toxin microcystin threatens drinking water supplies, understanding factors that affect HAB development and movement, providing HAB data to the public, and assisting NOAA National Ocean Service with the operational Lake Erie HAB forecast (Lake Erie HAB Bulletin, https://tidesandcurrents.noaa.gov/hab/lakeerie#).

Key accomplishments in FY17 included advances in monitoring technology, improvements to the experimental short-term HAB forecast, outreach to end users of our data products, and the use of metagenomics to understand HAB toxicity. NOAA GLERL's Environmental Sample Processor (ESP) brings new technology to the Great Lakes for detecting and quantifying HAB toxins directly in the water column in near-real time, rather than traditional laboratory methods that take days to complete. During FY17, CILER partnered with Dr. Tim Davis (NOAA GLERL) and Dr. Greg Doucette (NOAA-CCEHBR) to develop a microcystin assay for use on the robotic ESPniagara and performed systems operation testing in preparation for its first operational deployment in 2017. Data from the ESPniagara are being used to give drinking water managers advance warning when algal toxins reach dangerous levels near intakes.

New research was conducted this year to improve specific aspects of the short-term HAB forecast model, HAB Tracker (www.glerl.noaa.gov/res/HABs_and_Hypoxia/habTracker.html). Advised by CILER scientists, three University of Michigan Master's students formed an interdisciplinary team to elucidate how light and nutrients affect the buoyancy of bloom-forming algae, how spatial smoothing affects model skill, and how stakeholders use and perceive the HAB Tracker tool. The outcome of this team project was improved HAB Tracker accuracy, estimates of spatial uncertainty in the HAB Tracker forecast, and recommendations for improved HAB Tracker presentation, content, and communication to better reflect stakeholder needs and interests. In addition, the work fulfilled the professional project requirements for three Master's degree candidates.

Metagenomic sequencing was completed on bloom-forming *Microcystis*, giving new capabilities to investigate relationships between bloom toxicity, genomic content and expression, and nutrient availability in Lake Erie.

Empowering Communities with Online Action Planning Tools: Tipping Points and Indicators for Improving Water Quality across the Great Lakes

With a multi-disciplinary research team that includes Illinois Sea Grant, Michigan State University, Purdue University, and NOAA GLERL, CILER received funding through the Great Lakes Restoration Initiative (GLRI) from 2010-2012 to develop an interactive decision support system (DSS) (http://tippingpointplanner.org) to help watershed managers identify land-based activities that threaten ecosystem sustainability. The Tipping Point Planner (TPP) DSS provides extension specialists, coastal managers, and consultants with a facilitated forum to explore policy and management interventions needed to keep ecosystems from crossing a "tipping point" and moving to an unstable condition.

The Tipping Points team re-grouped in FY17 to make improvements to the TPP DSS by including nutrient source data for select Area of Concern (AOC) watersheds and models that relate nutrient sources to multiple ecological outcomes. An additional goal of the new work was to engage communities in targeted watersheds to identify restoration and conservation opportunities, and expand the use and adoption of the TPP system. The Tipping Points team accomplished the integration of phosphorus and nitrogen loading simulations that are linked to land use change forecasts into the TPP assessment tool. Users are now able to identify if there is a nutrient loading issue within a watershed of interest and what is causing the issue. Future work during the no-cost time extension will include the incorporation of models that simulate food web changes in response to phosphorus loads. The team also seeks to expand the use and adoption of the TPP DSS by holding a workshop at the 2017 State of Lake Michigan conference in November 2017. Attendees will include the watershed planning officials around Lake Michigan.

The improved Tipping Point Planner will ultimately improve sustainable land management decision making and restoration at the sub-watershed level by targeting nutrient loading and land use practices that impact Great Lakes food webs, coastal algal blooms, and tributary fishery values. It will inform Best Management Practice (BMP) selection, location and action prioritization, and help Sea Grant facilitators select target watersheds for facilitation and/or assistance.

Great Lakes Synthesis, Observations and Response System (SOAR

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. The SOAR project provides real-time ecosystem information to maintain high quality drinking water and bathing beaches through observations, data management, and forecast model development. SOAR activities include the deployment and support of on-water and remote sensing platforms. Observations from these systems are used to create database products for assessment and decision support, providing an up-to-date (including real-time data) public web data presence. The decision support tools developed from these observations provide warnings to regional managers regarding phosphorous loads, hypoxia and harmful algal blooms, and support adaptive management process decisions.

As part of the SOAR project, CILER continues to partner with Grand Valley State University (GVSU) to support the operation of the Muskegon Lake Observatory (MLO) within the Muskegon Lake Area of Concern (AOC). The MLO project utilizes GVSU-Annis Water Resources Institute (AWRI) and NOAA GLERL resources, building a key regional infrastructure that supports students, scientists, resource managers, and policy makers. Initially developed with funding from EPA's GLRI program (2011-2014), the MLO provides observations of hypoxia and soluble reactive phosphorous and supports the detection of harmful algal blooms, in support of restoration goals for the Muskegon Lake AOC. Data from the MLO are being used by GVSU to examine linkages between hypoxia and fish abundance, phosphorus generation, and HABs, and gather lake-wide flow measurements to better understand how lake hydrodynamics affect the distribution and intensity of hypoxia. MLO infrastructure and findings have been successfully leveraged to develop a CILER Graduate Research Fellowship focused on quantifying the carbon cycle in Muskegon Lake. The MLO has also been leveraged to support the data needs of a CILER Postdoctoral Fellow working with NOAA GLERL to develop a 3-D hydrodynamic model for the Muskegon Lake AOC that when linked to a watershed model, will help evaluate the impacts of land use practices and restoration activities on Muskegon Lake.

Administrative Summary

The primary roles of CILER administration are to support the research carried out under the auspices of the Cooperative Institute, implement CILER's Engagement, Career Training, and Outreach & Communications (ECO) Program, and manage the financial elements of the CI. CILER administrative leadership consists of a Director, Associate Director, and a Program Manager who oversee and manage the CI. CILER administration is located at both the NOAA Great Lakes Environmental Research Laboratory (GLERL) and the University of Michigan School for Environment and Sustainability (SEAS). CILER administration is supported by a Grants and Contracts Specialist, Outreach and Communications Specialist, and Outreach Assistant.

Dr. Bradley Cardinale serves as the CILER Director and chief executive officer, reporting to the Dean of SEAS. Dr. Cardinale's responsibilities are to: (a) oversee the administration and budget, (b) serve as CIGLR's chief science advisor, (c) develop and maintain CILER's programmatic activities, (d) build research and development partnerships between Regional Consortium members and CILER and GLERL scientists, (e) mentor CILER's Research Scientists and Research Fellows, and (f) serve as CILER's primary spokesperson to university leadership, NOAA leadership, media outlets, and the public.

Dr. Thomas Johengen serves as the CILER Associate Director. Dr. Johengen's responsibilities are to: (a) co-manage CILER's research activities, (b) foster partnerships between Regional Consortium members and CIGLR and GLERL scientists, (c) lead CIGLR's career training activities, and (d) on behalf of the Director, serve as a spokesperson for CIGLR to university leadership, NOAA leadership, media outlets, and the public.

Ms. Mary Ogdahl serves as the CILER Program Manager. Ms. Ogdahl's responsibilities are to (a) lead implementation of the Engagement, Career Training, and Outreach & Communications (ECO) Program, (b) create and maintain research and administration budget projections, (c) conduct CILER hiring and manage personnel research project assignments, (d) oversee research proposal development, and (e) lead the preparation of CILER's annual Performance Progress Report.

Ms. Aubrey Lashaway & Michele Wensman provide support for the ECO Program. Their responsibilities are to (a) manage and maintain the CILER website, (b) lead the preparation of quarterly and annual newsletters, (c) interact with CILER and Regional Consortium researchers to generate project updates for ECO Program activities and performance tracking, (d) lead CILER community outreach activities, (e) manage CILER social media accounts, and (f) maintain a database of CILER's products and performance tracking metrics.

Ms. Ellen Hou is the CILER Grants and Contracts Specialist. Ms. Hou's responsibilities are to (a) process all Cooperative Agreement and external grant proposal submissions, (b) perform post-award grant management, (c) establish and monitor sub-awards, and process invoices, (d) prepare quarterly budget reports, and (e) ensure compliance with University of Michigan financial policies and procedures.

Executive Board, Management Council, and Council of Fellows

CILER Executive Board

The Executive Board makes recommendations concerning CILER's administration, budget, future Cooperative Agreements, and Management Council members.

The Executive Board last met on August 21, 2015. The Board did not meet in 2016 due to the competition for the new Great Lakes Cooperative Institute.

The members of the Executive Board include:

Allison Allen (Portfolio Manager, NOAA Ecological Forecasting Roadmap, NOAA-NOS)
Dan Brown (Interim Dean, UM-SNRE)
Bradley Cardinale (CILER Director, Ex-Officio)
Deborah Lee (Director, NOAA GLERL, Ex-Officio)
Volker Sick (Associate Vice-President for Research, UM)
Richard Wagenmaker (Meteorologist in Charge, NOAA – National Weather Service)

CILER Management Council

The Management Council provides reviews and recommendations of the scientific direction of the CI, and includes directors of the Great Lakes Sea Grant programs, with additional representation by NOAA and university scientists.

This Council last met on May 7, 2015. The Council did not meet in 2016 due to the competition for the new Great Lakes Cooperative Institute.

The members of the Management Council are:

Jay Austin, Assistant Professor, University of Minnesota-Duluth, Department of Physics and the Large Lakes Observatory
Jim Diana, Director, University of Michigan, Michigan Sea Grant Program
Andrew Gronewold, Physical Scientist, NOAA GLERL
Tomas Hook, Associate Director of Research, Illinois-Indiana Sea Grant
Donna Kashian, Assistant Professor, Wayne State University, Department of Biological Science
Val Klump, Director, University of Wisconsin-Milwaukee, Great Lakes Water Institute
Stu Ludsin, Associate Professor, Ohio State University, Evolution, Ecology & Organismal Biology
Doran Mason, Research Ecologist & CILER Program Manager, NOAA GLERL
Peter McIntyre, Assistant Professor, University of Wisconsin-Madison, Department of Zoology
Cheryl Murphy, Assistant Professor, Michigan State University, Department of Fisheries & Wildlife
Steve Ruberg, Group Leader, Marine Instrumentation Lab, NOAA GLERL
Al Steinman, Director, Grand Valley State University, Annis Water Resources Institute
Carol Stepien, Director, University of Toledo, Lake Erie Center
Craig Stow, Aquatic Ecosystem Modeler, NOAA GLERL

Donald Uzarski, Director, Biological Station and Institute for Great Lakes Research, Central Michigan University
William Wise, Interim Director, New York Sea Grant, Stony Brook, NY

Council of Fellows

The CILER Council of Fellows includes over 30 Great Lakes academic and federal researchers willing to engage in CILER research activities, including collaboration on our Task II and III research projects, as well as mentoring of graduate and postdoctoral fellows. Identified members include:

James Ammerman, Director, New York Sea Grant
Joe Atkinson, Professor, State University of New York – University at Buffalo
Jay Austin, Asst. Professor, University of Minnesota-Duluth, Large Lakes Observatory
Stuart Batterman, Professor, University of Michigan, School of Public Health
Dima Beletsky, Research Scientist, CILER
Bopi Biddanda, Research Scientist, Grand Valley State University, Annis Water Resources Institute
Harvey Bootsma, Associate Professor, University of Wisconsin-Milwaukee
Greg Boyer, Professor, SUNY-College of Environmental Science and Forestry
Thomas Bridgeman, Associate Professor, University of Toledo
Rose Cory, Assistant Professor, University of Michigan, Earth and Environmental Sciences
Greg Dick, Associate Professor, University of Michigan, Earth and Environmental Sciences
Hunter Carrick, Professor, Central Michigan University
Steve Colman, Professor, University of Minnesota-Duluth, Large Lakes Observatory
Jim Cotner, Professor, University of Minnesota
Vincent Denef, Assistant Professor, University of Michigan, Ecology and Evolutionary Biology
Melissa Duhaime, Assistant Research Scientist, University of Michigan, Ecology and Evolutionary Biology
Mark Flanner, Assistant Professor, University of Michigan, Climate and Space
Joseph Johnson, Assistant Professor, University of Minnesota-Duluth
Branko Kerkez, Assistant Professor, University of Michigan, Civil and Environmental Engineering
George Kling, Professor, University of Michigan, Ecology and Evolutionary Biology
Peter Lavrentyev, Professor, University of Akron
Brent Lofgren, Physical Scientist, NOAA GLERL
Nancy Love, Professor, University of Michigan
Rex Lowe, Professor, Bowling Green State University
Phanikumar Mantha, Associate Professor, Michigan State University
Guy Meadows, Professor Michigan Technological University
Brian Miller, Director, Illinois-Indiana Sea Grant
Cheryl Murphy, Asst. Professor, Michigan State University
Scott Peacor, Associate Professor, Michigan State University
Lutgarde Raskin, Professor, University of Michigan
Jennifer Read, Director, University of Michigan, Water Center
Richard Rood, Professor, University of Michigan, Climate and Space
Carl Ruetz III, Associate Professor, Grand Valley State University, Annis Water Resources Institute

Ed Rutherford, Research Fishery Biologist, NOAA GLERL
David Schwab, Research Scientist, University of Michigan, Water Center
Paul Seelbach, Eco. Hlth. & Restor. Branch Chief, USGS-Great Lakes Science Center
Bob Shuchman, Co-Director, Michigan Technological University, Michigan Tech Research Institute
Allison Steiner, Associate Professor, University of Michigan, Climate and Space
Robert Sterner, Professor, University of Minnesota
R. Jan Stevenson, Professor, Michigan State University
Henry Vanderploeg, Research Ecologist, NOAA GLERL
Mike Wiley, Professor, University of Michigan, School of Natural Resources and Environment
Chin Wu, Professor, University of Wisconsin-Madison

Introduction

The Cooperative Institute for Limnology and Ecosystems Research (CILER) was established in 1989 with an MOU between the University of Michigan and the Undersecretary of Oceans and Atmosphere in the U.S. Department of Commerce. Since the inception of CILER, NOAA has awarded 6 consecutive multi-year Cooperative Agreements (CAs) to the University of Michigan to help NOAA accomplish its mission in the Great Lakes region. The last CILER Cooperative Agreement went into effect in July of 2012 and will continue through August 2018, under a one-year no-cost time extension. During the extension period, the new Cooperative Institute for Great Lakes Research (CIGLR) will operate concurrently and begin research, outreach, communications, and career training activities under the 2017-2022 Cooperative Agreement. The last CILER Cooperative Agreement was awarded to the University of Michigan (host institution) and nine partner universities (Grand Valley State University, Michigan State University, Michigan Technological University, Penn State University, State University of New York at Stony Brook, University of Illinois at Urbana Champaign, University of Minnesota-Duluth, University of Toledo, and University of Wisconsin). Over the course of the last CA, CILER had a significant impact on Great Lakes science, as demonstrated by overall grant funding, the level of NOAA and academic partnership, research outcomes, and career training activities.

Since 2012, CILER received $16.8 million in NOAA Cooperative Agreement funding for 83 research projects, education and outreach programs, and administrative costs. The EPA-administered Great Lakes Restoration Initiative (GLRI) continued to support a significant proportion of CILER’s research activity through collaborative projects with NOAA GLERL. In FY17, 39% ($1.65 million) CILER’s research was funded by GLRI. The University of Michigan has contributed $2.02 million in cost sharing ($589,272) and in-kind support ($1,483,303) since 2012, to fund programs that foster partner collaborations, postdoctoral fellowships, and administrative costs. CILER principal investigators have been successful in securing external funding over this period, receiving $4.5 million in research awards to supplement NOAA CA funding.

CILER’s Vision, Mission, and Goals

CILER’s Vision

To enhance the quality of the Great Lakes and its related ecosystem services, through a partnership of universities, NOAA scientists, and other stakeholders.

CILER’s Mission

- Advance our understanding of, and ability to predict, complex ecosystem processes, responses, and dynamics in the Great Lakes.
- Identify and characterize emerging areas of concern for the Great Lakes ecosystem, with applications to all coastal ecosystems.
- Provide a forum for better linking ecosystem responses, sustainable ecosystem services, and decision-making in the Great Lakes.

- Translate research into productive outcomes for stakeholders in the region through outreach and education.
- Improve effectiveness of education and expand research training opportunities for students and postdoctoral fellows.

CILER's Goals

- Advance the science of Great Lakes ecosystem forecasting by integrating physical, chemical, and biological components to allow for more effective responses and management of invasive species, climate change, habitat alteration, and contaminants.
- Facilitate the translation of research into more effective decision-making and public education.
- Support NOAA's mission and strategic goals.
- Facilitate research in the Great Lakes region.
- Mentor and train the next generation of scientists through research and educational opportunities.

CILER Organization

The organization and operation of CILER is formatted in accordance with NOAA's CI Handbook, which outlines procedures for establishing and maintaining CIs. The University of Michigan serves as the host and administrative lead for CILER and bears responsibility for CILER operations and management. CILER is located in the School for Environment and Sustainability (SEAS) (formerly the School of Natural Resources and Environment (SNRE)). CILER administrative leadership consists of a Director, Associate Director, and a Program Manager, who are supported by outreach and communications and grants and contracts staff (Figure 1). CILER complements NOAA GLERL's workforce with a highly-skilled, permanent group of research scientists, research support staff, and postdoctoral fellows that expands GLERL's research expertise and fully-integrates into GLERL's scientific enterprise (Figure 1).

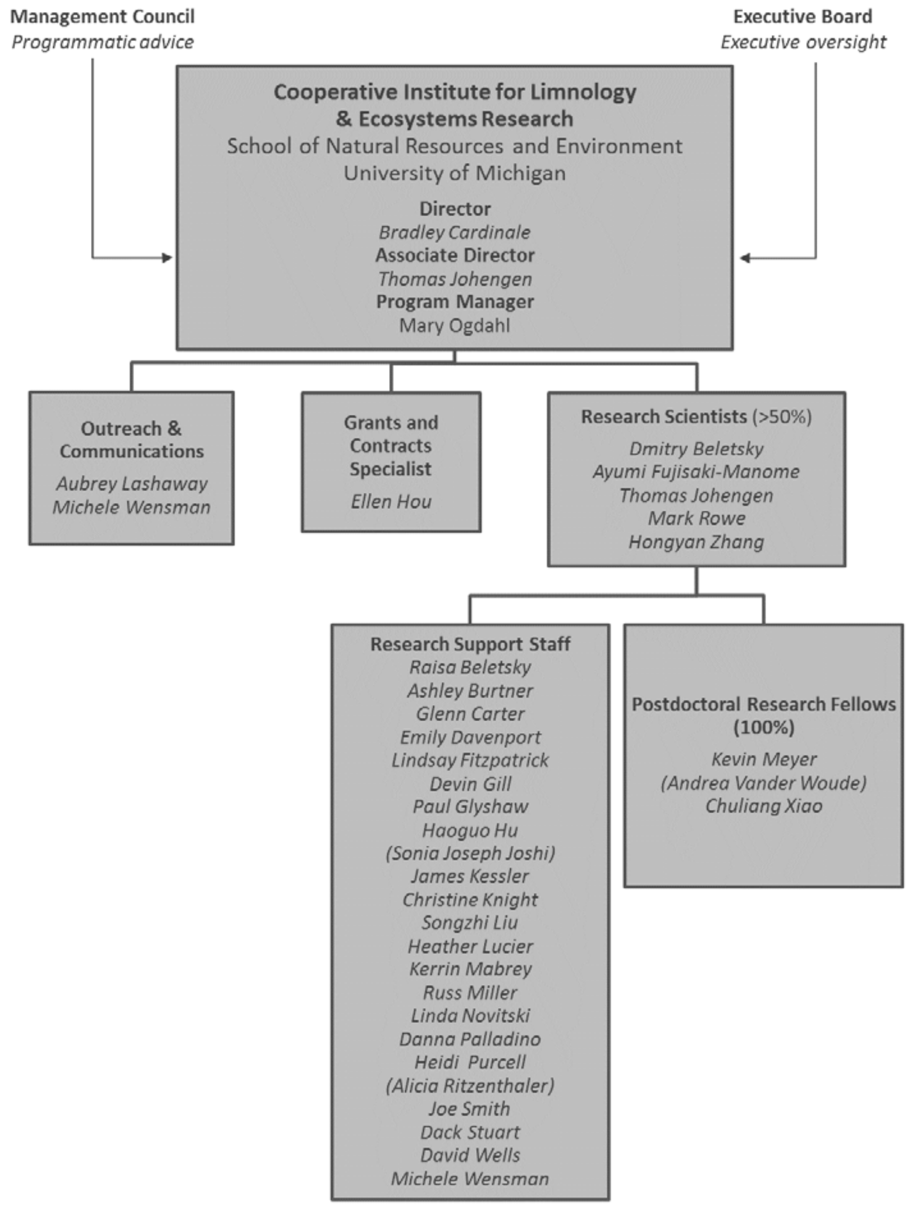


Figure 1: CILER's organizational structure with 2016-2017 personnel. Parentheses indicate staff that departed during the reporting period.

Funding Distribution

The total funding received by CILER from July 1, 2012 through June 30, 2017 was $17,351,782. This amount *includes* $589,272 in cost-share contributions from the University of Michigan. An additional $1,430,099 in in-kind contributions from University of Michigan including IDC reduction, Research Scientist salary support, administrative support, and office space, for a total of $2,019,371 in University of Michigan support during the Cooperative Agreement. Indirect cost rate reductions included 0% IDC on Task I, 0% IDC on pass-through awards, and a 4.5% IDC reduction on Task II and III funding from FY13-15.

During the Cooperative Agreement period, funding was used to support 83 Task II research projects across CILER Themes I-IV (85%), education and outreach activities within Task Ib and Task II -Theme V (6%), and Task Ia administration (9%) (Figure 2, Tables 1 & 2). Nearly one-third ($5.12 million; 32%) of our Task Ib and Task II funding has been sub-awarded to our partners throughout the Great Lakes region to foster collaborative research with NOAA and career training through graduate student and postdoctoral fellowships (Table 3). The distribution of Task I funds is described in the following section.

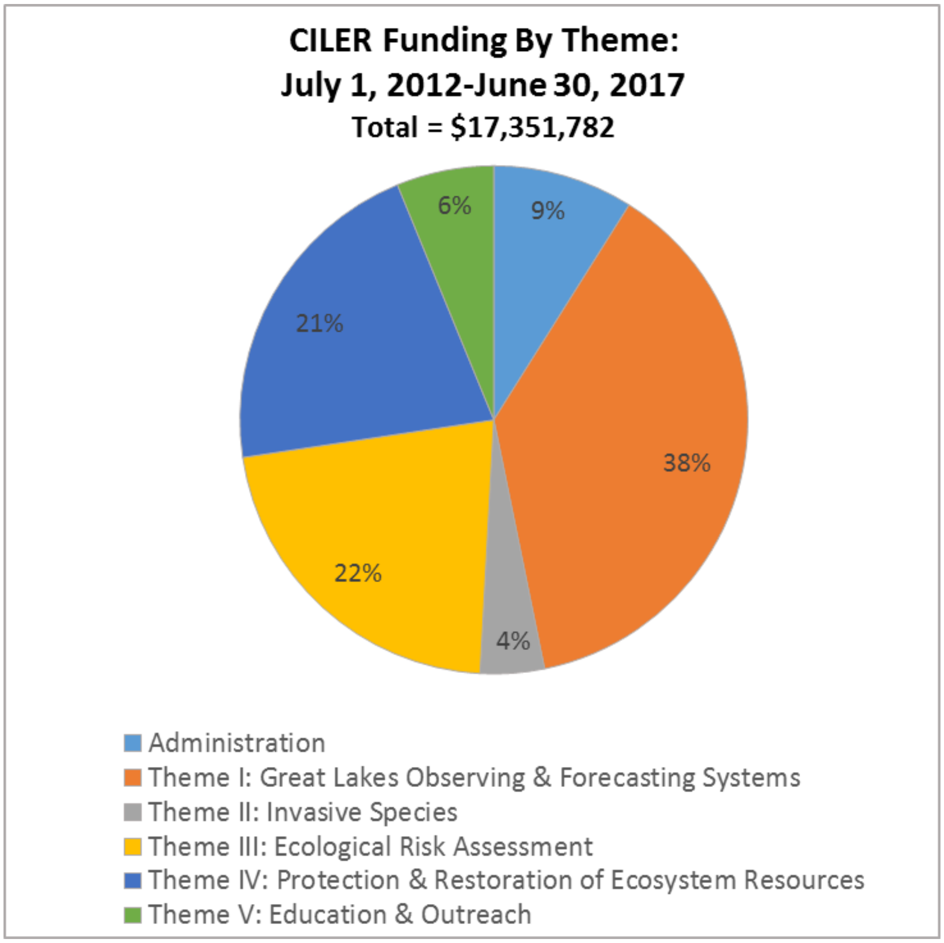


Figure 2: Funding distribution by CILER theme during the current Cooperative Agreement (July 1, 2012 through June 30, 2017). University of Michigan cost-share funding ($589,272) is included in this summary.

Table 1: Summary of funding, by task and CILER theme, awarded to CILER during the current Cooperative Agreement Award NA12OAR4320071, July 1, 2012 – June 30, 2017. Task I funds were used to support administration (Task Ia) and education and outreach programs (Task Ib). Administrative costs were further supported by University of Michigan cost share and Task II funding.

Task/Source	Research Theme	Funding ($)	Funding (%)
Cost share	Administration	$457,772	9%
Ia	Administration	$689,802	
II	Administration	$316,148	
II	Theme I: Great Lakes Observing & Forecasting Systems	$6,604,461	38%
II	Theme II: Invasive Species	$709,265	4%
II	Theme III: Ecological Risk Assessment	$3,799,349	22%
II	Theme IV: Protection & Restoration of Ecosystem Resources	$3,693,378	21%
Cost share	Theme V: Education & Outreach	$131,500	6%
Ib	Theme V: Education & Outreach	$793,501	
II	Theme V: Education & Outreach	$156,607	
TOTAL		**$17,351,782**	**100%**

Table 2: List of all project numbers for NOAA Award NA12OAR4320071, 7/1/12-6/30/17.

2016-2017 Report	Task	Theme	Amendment Number	Title	NOAA Technical Lead/Sponsor	Total Budget	Start Date	End Date
	Ia	Admin	0	CILER 5-year Renewal Proposal - July 1, 2012 through June 30, 2017	GLERL: D. Lee	$135,380	07/01/2012	06/30/2017
	II	V	1	NOAA Emergency Response Protocols	GLERL: J. Day	$5,702	07/01/2012	06/30/2013
	II	II	2	Assessing risk of Asian carp invasion and impacts on Great Lakes food webs and fisheries	GLERL: E. Rutherford, D. Mason	$294,048	07/01/2012	06/30/2013
	II	II	3	Improving runoff estimates in the Great Lakes basin	GLERL: A. Gronewold	$6,008	07/01/2012	06/30/2013
	II	III	4	Lakewide Assessment of Lake Ontario Benthic Macroinvertebrate Communities	GLERL: H. Vanderploeg	$29,225	07/01/2012	06/30/2013
	Ib	V	5	CILER summer student fellowship program	GLERL: D. Lee	$81,500	07/01/2012	06/30/2013
✓	II	V	6	Global Interoperability Program (GIP) Introducing Shared Software Infrastructure into the Climate Model Curriculum	GLERL: D. Mason	$75,000	07/01/2012	06/30/2017
	II	V	7	PSU SeaBASS 2012: A Marine BioAcoustics Summer School	GLERL: D. Mason	$20,486	07/01/2012	06/30/2013
	II	I	8	How will the Great Lakes Water Levels Respond to Climate Change Year 3: Regional Modeling for Application to Decision-making	GLERL: B. Lofgren, A. Gronewold, J. Wang	$376,622	07/01/2012	06/30/2017
	II	IV	9	Identify Land Use Indicators and Tipping Points that Threaten Great Lakes Ecosystems	GLERL: E. Rutherford, D. Mason	$309,745	07/01/2012	06/30/2013
	II	I	10	Hydrodynamic Modeling and Observation in Support of GLRI Decision Support Tools	GLERL: S. Ruberg	$144,107	07/01/2012	06/30/2013
	II	I	11	Great Lakes CoastWatch Research Assistant for NOAA CoastWatch Program Element	GLERL: G. Leshkevich	$92,520	07/01/2012	06/30/2013
	II	I	12	Modeling sea ice-ocean-ecosystem changes, and Great Lakes ice modeling, measurement, and climate change.	GLERL: J. Wang	$104,161	07/01/2012	06/30/2013
	II	II	13	Larval Dispersal, habitat classification and food web modeling	GLERL: E. Rutherford	$227,874	07/01/2012	08/31/2014
	II	IV	14	Implementation of the Great lakes Synthesis, Observations and Response System (SOAR)	GLERL: S. Ruberg	$356,375	07/01/2012	06/30/2013
	II	I	15	Great Lakes Restoration Initiative Climate Project	GLERL: J. Day	$8,078	07/01/2012	06/30/2013
	II	III	16	The effects and impacts of hypoxia on production potential of ecologically and commercially important living resources in the northern Gulf of Mexico	GLERL: C. Stow, D. Mason	$113,041	07/01/2012	06/30/2013
	II	IV	17	2012 Monitoring Activities for the Lake Huron CSMI and Lake Michigan Long-term Ecological Research programs	GLERL: C. Stow, H. Vanderploeg	$267,053	07/01/2012	06/30/2013
	II	I	18	Implementation of 2012 GLOS Nearshore Observing Network	GLERL: D. Schwab, S. Ruberg	$597,000	07/01/2012	06/30/2013
	II	III	19	2012 OHH: HABS Beach and Quality Forecasting	GLERL: M. McCormick, A. Gronewold	$602,668	11/01/2012	10/31/2013
	II	I	20	Hydrodynamic Modeling for the Manistique River Area of Concern	GLERL: E. Anderson	$51,534	01/01/2013	12/31/2013
	II	V	21	NOAA Great Lakes Strategies, Forecasts & Responses	GLERL: A. Gronewold, J. Day, D. Mason	$19,267	07/01/2013	06/30/2014
	II	I	22	Great Lakes CoastWatch Research Assistance for NOAA CoastWatch Program Element	GLERL: G. Leshkevich	$92,000	07/01/2013	06/30/2014
	Ia	Admin	23	CILER 5-year Renewal Proposal - July 1, 2012 through June 30, 2017	GLERL: D. Lee	$140,118	07/01/2012	06/30/2017
	Ib	V	24	2013 Administrative Supplement, Great Lakes & Summer Student Fellowship Program	GLERL: D. Lee	$102,171	07/01/2013	06/30/2014
	II	I	25	Implementation of 2013 GLOS Nearshore Observing Network	GLERL: S. Ruberg	$586,322	06/01/2013	05/31/2014
	II	III	26	2013 Monitoring Activities for the Lake Huron CSMI & Lake Michigan Long-term Ecological Research Programs	GLERL: H. Vanderploeg	$83,988	07/01/2013	12/31/2014
	II	IV	27	2013 Implementation of the Great Lakes Synthesis, Observations & Response System (SOAR)	GLERL: E. Anderson, S. Ruberb	$412,331	09/01/2013	12/31/2014
	II	I	28	Modeling sea ice-ocean-ecosystem changes, and Great Lakes ice modeling, measurement, and climate change	GLERL: J. Wang	$227,281	07/01/2013	06/30/2014
	II	III	29	2013 HABS, Bacteria & Beach Quality Forecasting	GLERL: A. Gronewold, S. Ruberg	$497,810	10/01/2013	12/31/2014
	II	I	30	How will the Great Lakes Water Levels Respond to Climate Change Year 4: Regional Modeling for Application to Decision-making	GLERL: B. Lofgren	$367,000	07/01/2013	06/30/2014
	II	IV	31	Weather Ready Nation	GLERL: J. Day	$54,000	05/01/2013	04/30/2015
	II	IV	32	2014 Remote Sensing of Algal Blooms in support of the GLRI Synthesis, Observations & Response (SOAR) Program	GLERL: E. Anderson, S. Ruberg	$242,507	03/01/2014	12/31/2015
	II	V	33	PSU SeaBASS 2014: A Marine BioAcoustic Summer School	GLERL: D. Mason	$15,365	07/01/2014	04/30/2015

Table 2, cont.: List of all project numbers for NOAA Award NA12OAR4320071, 7/1/12-6/30/17.

2016-2017 Report	Task	Theme	Amendment Number	Title	NOAA Technical Lead/Sponsor	Total Budget	Start Date	End Date
	II	I	34	Lake Sentinel: Observatory for Ecosystem Changes in Muskegon Lake AOC	GLERL: S. Ruberg	$51,215	09/01/2014	02/28/2015
	II	III	35	2014 Monitoring Activities for the Lake Michigan & Lake Huron Long-term Ecological Research Programs	GLERL: H. Vanderploeg	$101,000	07/01/2014	12/31/2015
	II	I	36	Great Lakes CoastWatch Research Assistant for NOAA CoastWatch Program Element	GLERL: G. Leshkevich	$99,612	09/01/2014	08/31/2015
	II	V	37	NOAA Great Lakes Strategies & Response	GLERL: J. Day	$62,000	05/01/2014	04/30/2015
✓	II	IV	38, 52	A Metagenomic-Based Approach to Determine Microbial Pollution Sources in South Florida Coral Reefs	AOML: C. Sinigalliano	$24,999	08/01/2014	07/31/2016
	Ib	V	39	CILER Summer Fellowship Program	GLERL: D. Lee	$95,920	07/01/2014	06/30/2017
	II	I	40	A high-resolution atmospheric, wave and circulation model guidance system for the Great Lakes Region	GLERL: E. Anderson	$127,937	09/01/2014	08/31/2016
	II	I	41	Year 4 Implementation of the GLOS-RA Nearshore Observing System Network	GLERL: S. Ruberg	$605,000	08/01/2014	07/31/2015
	II	I	42	Modeling sea ice-ocean-ecosystem changes, and Great Lakes ice modeling, measurements and climate changes	GLERL: J. Wang	$113,000	07/01/2014	06/30/2015
✓	II	IV	43	Decision Support of Western Lake Erie Phosphorus Concentrations to Mitigate Harmful & Nuisance Algal Blooms	GLERL: C. Stow	$177,706	09/01/2014	06/30/2017
✓	II	IV	44, 73, 74	FATE Proposal: Incorporating an environmental index into the Southern New England Mid-Atlantic yellowtail flounder stock assessment with potential predictability.	NMFS: L. Alade	$197,115	07/01/2014	06/30/2017
	Ia	Admin	45	CILER 5-year Renewal Proposal - July 1, 2012 through June 30, 2017	GLERL: D. Lee	$99,982	07/01/2012	06/30/2017
	II	IV	46	2014 Synthesis, Observations and Response (SOAR)	GLERL: E. Anderson, S. Ruberg	$252,681	09/01/2014	12/31/2015
	II	II	47	Larval Dispersal, Habitat Classification and Food Web Modeling	GLERL: E. Rutherford	$98,214	07/01/2014	06/30/2015
	II	III	48	HABS, Bacteria & Beach Quality Forecasting for the Great Lakes Ocean & Human Health Center	GLERL: T. Davis, E. Anderson	$653,097	09/01/2014	12/31/2015
	II	I	49	How will the Great Lakes Water Levels Respond to Climate Change Year 5	GLERL: J. Wang, B. Lofgren	$321,448	07/01/2014	06/30/2015
	Ia	Admin	50	CILER 5-year Renewal Proposal - July 1, 2012 through June 30, 2017.	GLERL: D. Lee	$2,342	07/01/2012	06/30/2017
	Ia	Admin	53	CILER 5-year Renewal Proposal - July 1, 2012 through June 30, 2017.	GLERL: D. Lee	$43,864	07/01/2012	06/30/2017
	Ia	Admin	54	CILER 5-year Renewal Proposal - July 1, 2012 through June 30, 2017.	GLERL: D. Lee	$97,352	07/01/2012	06/30/2017
	II	I	55	Lake Circulation and GLCFS: Can HRRR meteorological forcing conditions be used to improve hydrodynamic forecasting skill?	GLERL: E. Anderson	$29,000	07/01/2015	06/30/2017
	II	III	56	2015 Monitoring Activities for the Lake Michigan Long-Term Ecological Research Program	GLERL: H. Vanderploeg	$89,700	07/01/2015	12/31/2016
	II	I	57	Dynamical Core Selection for the Next Generation Global Prediction System (NGGPS)	NWS: I. Stajner	$46,863	04/01/2015	06/30/2017
✓	Ib	V	58	CILER Summer Fellowship Program	GLERL: D. Lee	$95,920	07/01/2015	06/30/2017
	Ib	V	59	Hosting 2016 23rd IAHR Ice Symposium in UofM	GLERL: J. Wang	$39,190	07/01/2015	06/30/2016
	II	I	60	Great Lakes Heat Budget - Water Budget Connections	GLERL: B. Lofgren, E. Anderson, A. Gronewold, C. Stow, J. Wang	$22,000	07/01/2015	12/31/2016
	II	V	61	NOAA Great Lakes Policy Coordination & Communications Intern	GLERL: J. Day, F. Martinez	$12,999	09/01/2015	08/31/2016
✓	Ib	V	62	Task 1C Support of CILER's Education & Outreach Programs	GLERL: D. Lee	$90,000	09/01/2015	06/30/2017
	Ia	Admin	63	CILER 5-year Renewal Proposal - July 1, 2012 through June 30, 2017	GLERL: D. Lee	$64,584	07/01/2012	06/30/2017
	II	I	64	Great Lakes CoastWatch Research Assistant for NOAA CoastWatch Program Element	GLERL: G. Leshkevich	$109,553	09/01/2015	08/31/2016
✓	II	I	65	Great Lakes water budget uncertainty assessment	GLERL: A. Gronewold	$25,000	05/01/2015	04/30/2016
	II	I	66	Data Management, Handling & Analysis of Great Lakes Time Series	GLERL: A. Gronewold, B. Lofgren	$74,954	09/01/2015	08/31/2016
	II	I	67	High-resolution atmospheric, wave, ice and circulation model guidance system for the Great Lakes region	GLERL: J. Wang, E. Anderson	$146,567	09/01/2015	08/31/2016
	II	I	68	Modeling sea ice-ocean-ecosystem changes, and Great Lakes ice modeling, measurements and climate changes	GLERL: J. Wang	$156,408	07/01/2015	06/30/2016
	II	IV	69	2015 Synthesis, Observations & Response (SOAR)	GLERL: S. Ruberg	$480,289	07/01/2015	12/31/2016

Table 2, cont.: List of all project numbers for NOAA Award NA12OAR4320071, 7/1/12-6/30/17.

2016-2017 Report	Task	Theme	Amendment Number	Title	NOAA Technical Lead/Sponsor	Total Budget	Start Date	End Date
	II	I	70	Year 5 Implementation of the GLOS-RA Nearshore Observing System Network	GLERL: S. Ruberg	$572,000	06/01/2015	06/30/2017
✓	II	IV	71	2015 Lake Michigan Monitoring Activities for the Coordinated Science Monitoring Initiative	GLERL: H. Vanderploeg	$204,825	03/01/2015	06/30/2017
✓	II	I	72, 82	Transitioning to Operations NOAA-Supported Statistical Hypoxia Models and Forecasts in the Gulf of Mexico and Chesapeake Bay	GLERL: D. Mason	$206,100	07/01/2015	08/31/2018
✓	II	III	75	MOCNESS in the Great Lakes: Gear Efficiency Comparisons and Estimates of Fine-Scale Vertical Spatial Structure of the Food Web	GLERL: E. Rutherford	$66,447	04/01/2016	03/31/2017
✓	II	I	76	Evaluation of the evaporation and heat flux algorithms for the Great Lakes based on the eddy covariance measurements	GLERL: A. Gronewold	$116,605	04/01/2016	03/31/2017
✓	II	III	77	2016 Monitoring Activities for the Lake Michigan Long-term Ecological Research program	GLERL: H. Vanderploeg, A. Elgin	$162,918	04/01/2016	03/31/2017
✓	II	I	78	Assessment of contaminated sediment transport in Manistique River, MI	GLERL: E. Anderson	$179,724	05/01/2016	04/30/2017
✓	II	I	79	How will the Great Lakes Water Levels Respond to Climate Change: Regional Modeling for Application to Decision-Making (FY2015)	GLERL: B. Lofgren, J. Wang	$340,666	07/01/2016	06/30/2017
✓	II	III	80	HABS Monitoring, Forecasting and Genomics for the Great Lakes	GLERL: E. Rutherford	$648,914	07/01/2016	06/30/2017
✓	II	II	81	Impacts of Asian carp on Great Lakes food webs and R2X transition to USACE	GLERL: E. Rutherford, D. Mason	$20,371	07/01/2016	06/30/2017
✓	II	I	83	High-resolution atmospheric, wave, ice and circulation model guidance system for the Great Lakes region	GLERL: E. Anderson	$69,929	07/01/2016	06/30/2017
✓	II	I	84	2016 Implementation of the GLOS Buoy and Mobile Platform Observing Systems	GLERL: S. Ruberg	$151,979	06/01/2016	05/31/2017
✓	II	I	85	Lake Circulation and GLCFS: Can HRRR meteorological forcing conditions be used to improve hydrodynamic forecasting skill?	GLERL: E. Anderson	$30,762	07/01/2016	06/30/2017
✓	II	I	86	Integration of GLAHF with WRF-Hydro	GLERL: P. Chu	$21,425	05/01/2016	04/30/2017
✓	II	IV	87	NOAA Regional Team Great Lakes Policy Support	GLERL: J. Day	$19,591	04/01/2016	03/31/2017
✓	Ib	V	88	CILER Education and Outreach: Fellowship Program and Seminar Series	GLERL: D. Lee	$117,771	07/01/2016	06/30/2017
✓	II	I	89	Data Management, Handling & Analysis of Great Lakes Time Series	GLERL: E. Anderson, B. Lofgren	$33,952	07/01/2016	06/30/2017
✓	II	I	90	Modeling sea ice-ocean-ecosystem changes, and Great Lakes ice modeling, measurements, and climate changes	GLERL: J. Wang	$96,392	07/01/2016	06/30/2017
✓	II	I	91	Great Lakes Heat Budget-Water Budget Connections	GLERL: E. Anderson, B. Lofgren, A. Gronewold	$18,897	07/01/2016	06/30/2017
✓	II	I,IV	92	Development of a PostgreSQL database for accessible research, operations, and communications of real-time Harmful Algal Bloom data	GLERL: S. Ruberg	$49,000	07/01/2016	06/30/2017
✓	II	II	93	GLANSIS: Science and Management Support	GLERL: E. Rutherford, F. Martinez	$73,554	07/01/2016	06/30/2017
✓	II	I	94	GLRI Nearshore: Circulation and Thermodynamics	GLERL: E. Anderson	$163,307	07/01/2016	06/30/2017
✓	II	I	95	Dynamical Core Implementation for the Next Generation Global Prediction System (NGGPS)	NWS: I. Stajner	$181,520	07/01/2016	08/31/2018
✓	II	I	96	Great Lakes CoastWatch Research Assistant for NOAA CoastWatch Program Element	GLERL: G. Leshkevich	$121,561	07/01/2016	06/30/2017
✓	II	IV	97	2016 Synthesis, Observations, and Response (SOAR)	GLERL: S. Ruberg	$496,751	07/01/2016	06/30/2017
✓	II	III	98	HABs Monitoring, Forecasting and Genomics for the Great Lakes	GLERL: T. Davis, E. Anderson	$724,492	07/01/2016	06/30/2017
✓	II	IV	99	Empowering Communities with Online Action Planning Tools: Tipping Points and Indicators for Improving Water Quality across the Great Lakes	GLERL: E. Rutherford	$394,943	07/01/2016	06/30/2017
✓	II	V	100	The 2016 Dynamical Core Model Intercomparison Project (DCMIP-2016) and Summer School	GLERL: D. Mason	$32,633	06/01/2016	05/31/2017

Table 3: Summary of subcontract funding by institution for NOAA Award NA12OAR4320071, 7/1/12-6/30/17.

Institution	Funding
Central Michigan University	$ 59,798
Grand Valley State	$ 280,000
Indiana-Illinois Sea Grant	$ 5,264
Louisiana State University	$ 34,054
Michigan State University	$ 547,162
Michigan State University Sea Grant	$ 2,731
Michigan Tech University	$ 670,549
MTRI (Michigan Tech University)	$ 350,000
New York Sea Grant (Cornell)	$ 5,829
North Carolina State University	$ 50,035
Palm Island Environmental	$ 128,240
Penn State University	$ 35,000
Purdue University	$ 196,220
Ohio State University	$ 100,000
State University of New York	$ 392,600
Stony Brook University	$ 193,227
University of Maryland	$ 34,012
University of Illinois	$ 188,401
University of Minnesota-Duluth	$ 464,566
University of Minnesota Sea Grant	$ 4,171
University of Toledo	$ 197,544
University of Wisconsin	$ 349,443
University of Wisconsin – Madison	$ 346,898
University of Wisconsin – Milwaukee	$ 395,249
Virginia Institute of Marine Science	$ 34,055
Wayne State University	$ 30,000
Wisconsin Sea Grant	$ 22,479
Total	**$ 5,117,527**

The Task I funding received by CILER from July 1, 2012 through June 30, 2017 was $1,483,303 to support the following activities: Great Lakes Summer Student Fellows Program (17%), Graduate Research Fellowship Program (17%), Postdoctoral Fellowship Program (16%), Great Lakes Seminar Series (0.3%), international conference hosting (23rd IAHR Symposium on Ice; 3%), and salaries and fringe benefits for administrative personnel (47%) (Figure 3, Table 1).

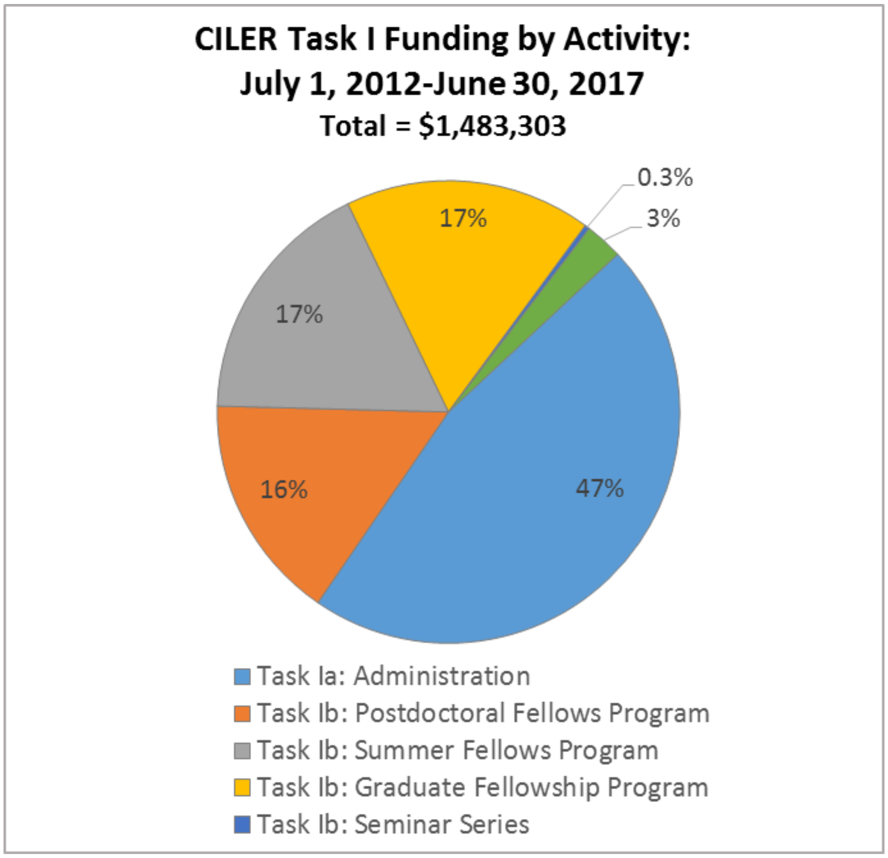


Figure 3: Task I funding distribution by activity during the current Cooperative Agreement (July 1, 2012 through June 30, 2017).

Engagement, Career Training, and Outreach & Communications (ECO) Program Activities

Over the past year, CILER built upon its previous Education and Outreach Program to develop a more comprehensive and focused Engagement, Career Training, and Outreach & Communications (ECO) Program. Although the new ECO Program was created as part of the new CIGLR vision, it was implemented immediately during the CILER CA. Progress to date on ECO Program activities is summarized in the tables below. The ECO Program is supported by a combination of Task Ib and cost share funds. Most career training activities are funded through Task Ib, such as the Great Lakes Summer Fellows Program, the Graduate Research Fellowship program, the CILER Postdoctoral Fellowship program, and the CILER-GLERL Great Lakes Seminar series; detailed information about these program activities can be found after the ECO Program progress summary tables below. In addition ECO Program activities, several of CILER's Task II research projects are within Theme V: Education and Outreach. Furthermore, all CILER Task II research projects are required to have an outreach or educational component. Details on education and outreach activities associated with funded research projects can be found throughout the Research Reports by Theme section and the Theme V subsection.

A full description of the ECO Program can be found in Appendix A.

Highlights (FY17)

Engagement

- Held a postcard writing event at University of Michigan that resulted in 93 postcards being sent to Congressional delegates emphasizing the importance of Great Lakes science and restoration.
- Sponsored 2 applicants to attend the March for Science in Washington, D.C., to advocate for Great Lakes science and restoration. Follow-up letters were sent to 80 Congressional delegates from Great Lakes states.
- Held 5 summits on pressing research management needs to achieve sustainability in the Great Lakes.

Career Training

- Advanced a CILER postdoctoral fellow to Assistant Research Scientist within University of Michigan, becoming CILER's fifth principal investigator (Dr. Ayumi Fujisaki-Manome).
- Provided competitive fellowship experiences to 11 undergraduates, 13 graduate students, and 2 postdocs.
- Supported an additional 26 students and postdocs to participate in NOAA research with NOAA, CILER, and regional academic partner scientists.

Outreach & Communications

- Hired a 0.5 FTE Education and Communications Specialist, a 0.5 FTE Outreach Assistant, and a temporary hourly Communications Assistant to assist with implementing the new ECO Program.
- Gained 12 times greater social media followers during FY17, for a total of 3,490 followers across Facebook, Twitter, and Instagram.
- Initiated a quarterly newsletter and published 3 issues during FY17.
- Created an entirely new website that gives greater visibility to our academic and NOAA partnerships, research, news and events, and programs.
- Featured in 100 news media articles and videos highlighting CILER research and activities.
- Held informational tables at 10 community/university outreach events and scientific conferences, resulting in interactions with 13,000-14,000 people.

Engagement. The goal of CILER's engagement activities is to *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.

Activity	Description	**Progress (2012-2017)**
Summits and Working Groups	2- 5 day meetings with invited experts 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	• 5 summits held • 2 peer-reviewed publications • 2 international conference special sessions • 2 white papers in preparation • 1 manuscript in preparation • Several manuscripts in preparation for journal special issue

	of Great Lakes research that are used to educate elected officials.	
Great Lakes Day	Participate in the annual Great Lakes Day on Capitol Hill. The event is hosted by the Great Lakes Commission and the Northeast-Midwest Institute to convey a unified message to Congress expressing the Great Lakes region's priorities for legislation and appropriations to protect our environment and support our economy.	Participation planned for March 2018
Great Lakes Vision Reception	Host an annual reception for Great Lakes elected officials at the local, state, and Federal level to showcase NOAA's impact in the Great Lakes. The focus will be outlining a vision for Great Lakes research, through identifying critical next steps and funding needs.	• In preparation for 2018
Great Lakes Advocacy	Communicate with local, state, and Federal policy makers with written letters and phone calls when pending legislation has potential to impact the health and safety of the Great Lakes and the communities that rely on them.	• **March for Science**: Sponsored 2 applicants to attend the March for Science in Washington, D.C., on April 22, 2017. In addition to marching, individuals wrote op-ed articles for local newspapers and sent letters advocating for continued Great Lakes restoration funding to 80 Congressional delegates from Great Lakes states. • **Postcard signing event**: Held a 3-day postcard writing event at University of Michigan. 93 postcards were sent to Congressional representatives in support of Great Lakes science and restoration. CILER provided postcards, addresses, potential talking points, and postage.

Career Training. The goal of CILER's career training activities is to p*romote 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.

Activity	**Description**	**Progress (2012-17)**
CILER Summer Fellows Program	Upper level undergraduate and graduate students work with CILER and GLERL mentors on Great Lakes research projects.	71 students funded
CILER Graduate Research Fellows Program	Graduate students receiving their degrees at Consortium Partner universities work on projects in collaboration with a GLERL scientist.	10 students funded
CILER Postdoctoral Fellows Program	Salary and research support are provided for postdoctoral fellows to work with a CILER Consortium Partner university and GLERL scientist.	18 postdocs funded

Graduate Student Projects	CILER research scientists serve as mentors for University of Michigan graduate students completing thesis/dissertation or professional projects.	19 students funded
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 CILER, GLERL, or collaborating institutions/organizations.	119 students and postdocs funded
Doris Duke Conservation Scholars Program	CILER provides undergraduate summer research internships in collaboration with the University of Michigan's Doris Duke Conservation Program, which is designed to enhance diversity in the STEM topics and promote inclusion in the environmental conservation workforce.	3 students mentored (new program in 2016)

Outreach & Communications. The goal of CILER's outreach and communications activities is to *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.

Activity	Description	**Progress (2012-17)**
Great Lakes Seminar Series	Joint seminar series between CILER and GLERL that features invited experts on a variety of Great Lakes research topics.	30 seminars funded and hosted
CILER website	CILER's main public platform for facilitating science translation, providing visibility to CILER and NOAA research, and informing stakeholders, students, and the public about events and opportunities.	• New website in December 2016 • 23,567 avg hits per month • 6,088 avg visitors per month
Social media	CILER engages the public, stakeholders, scientists, and NOAA on social media through our on Facebook (@CILER.Umich), Twitter (@CILER_UM), and Instagram (CILER_UM) accounts.	• Twitter: 1,875 followers; 489,688 impressions in FY17 • Facebook: 635 followers; 76,972 impressions in FY17 • Instagram: 980 followers
News media	CILER produces press releases on research results and notifies news media contacts when news-worthy stories arise.	253 media stories (articles & videos) feature CILER; 100 in FY17
Fact sheets	CILER co-produces a series of fact sheets with GLERL on Great Lakes topics that highlight CILER and GLERL research. The fact sheets are posted on the CILER and GLERL websites and used for informational tables at outreach events.	4 completed; 2 in preparation
NOAA OAR Hot Items	CILER contributes Hot Item articles to NOAA OAR promoting CILER research outcomes and events.	10 Hot Items featured CILER
NOAA GLRCT Regional Highlights	CILER contributes articles to the GLRCT for publishing on the Regional Highlights portion of their website. These articles CILER research results to address one of the GLRCT goals for the region.	4 articles contributed
Annual news magazine	Full-color publication featuring CILER research and event highlights each year, geared toward the general public; the first issue is scheduled for late 2017.	In preparation for December 2017 publication
Quarterly e-newsletter	Email and web-based quarterly e-newsletters highlighting CILER research, partner interactions, opportunities, and events.	• Publication began in 2016 • 3 issues in FY17 • 520-person email distribution list

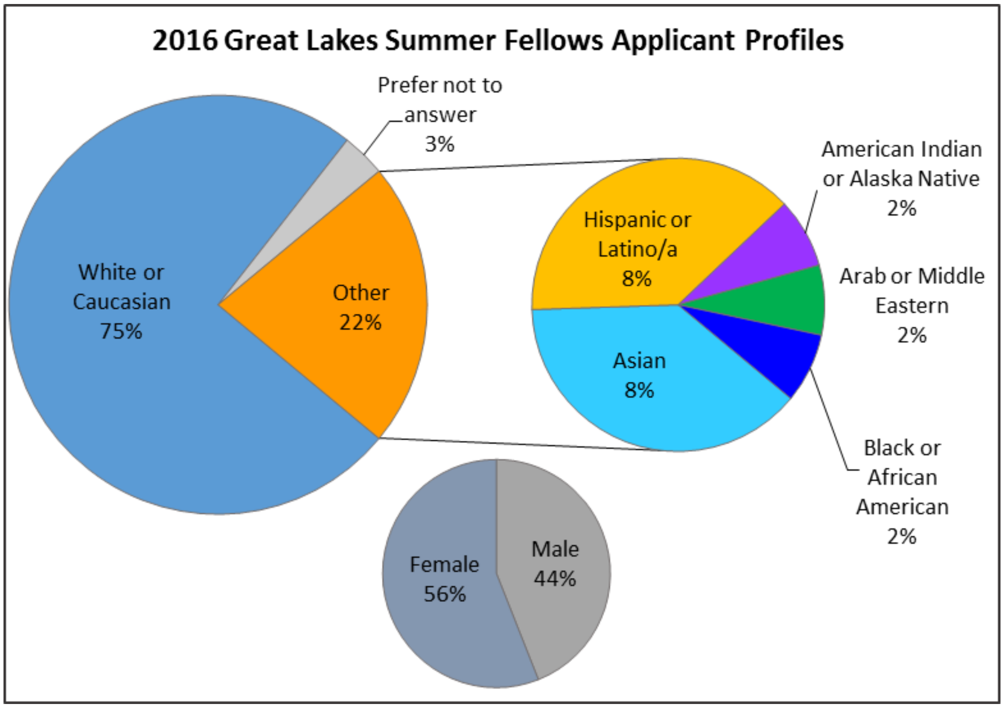
Community outreach events	CILER students and staff interact with the public at informational tables at community and university outreach events, and at scientific conferences. CILER also provides resources to Consortium Partners for use at events in their locations.	>40 events; 10 events in FY17

2016 and 2017 Great Lakes Summer Student Fellows Program

As part of its efforts to educate and train a new generation of research scientists, CILER has administered Great Lakes Summer Student Fellows Program since 1989. Each year this program places highly qualified 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 CILER's and NOAA's research missions in the region. Although the program primarily places students with research mentors at NOAA GLERL, CILER has also placed students at partnering universities. CILER will continue to build upon the success of the current program by continuing to promote it throughout the Great Lakes region to other institutes. The program is supported by Task 1b and Task II funds.

We offered 10 positions in 2016 and 12 positions in 2017. All fellows in 2016 were placed at NOAA GLERL. In 2017, one student was placed at a location other than NOAA GLERL – the Midwestern Regional Climate Center in Champaign, Illinois. 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.

In advance of the 2016 Summer Fellows advertisement, we developed a recruiting plan (Appendix B) for the program to establish our recruitment priorities and develop a strategy to accomplish our recruitment goals. A major focus of the 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. These data are being used to gauge our success in reaching under-represented groups with our recruitment. In 2017, the proportion of applicants that self-identified as non-white or Caucasian was 29%, a 7% increase from 2016 and 8% higher than the University of Michigan campus community (https://diversity.umich.edu/our-commitment) (Figure 4, Table 4). The proportion of applicants that identified themselves as female or transgender was 61% in 2017, a 5% increase from 2016 and 19% higher than the University of Michigan campus community (Figure 4, Table 4). The overall number of applicants more than doubled from 2016 to 2017 (Table 4).



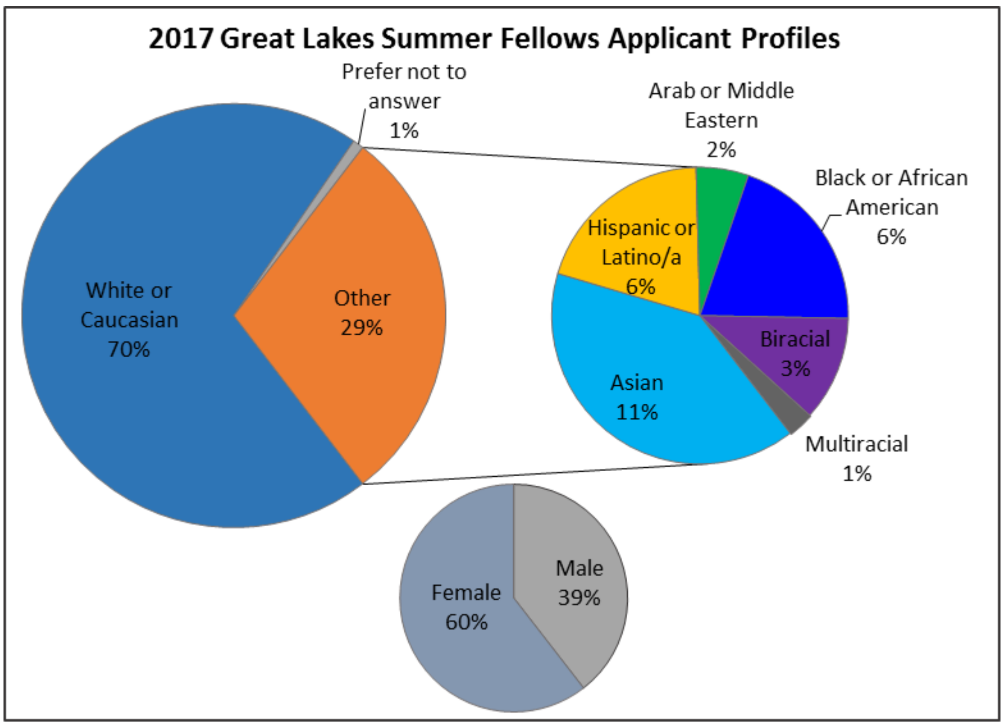


Figure 4: Applicant profiles for the 2016 and 2017 Great Lakes Summer Fellows program, using data collected during the application process. Responses to all profile information were optional.

Table 4: Summary information for the 2016 and 2017 applicants and accepted cohorts of the Great Lakes Summer Fellows Program.

	2016		2017	
	Applied	**Accepted**	**Applied**	**Accepted**
Number of Individuals	58	10	120	12
University Affiliations	26	7	63	9
University of Michigan	42%	40%	29%	33%
External	58%	60%	71%	67%
Female or transgender	56%	60%	61%	67%
Non-white or Caucasian	22%	20%	29%	25%

2016 Great Lakes Summer Student Fellows Cohort (May 2016-August 2016)

Fellow	Affiliation	Project	Mentor(s)
Alex Assuncao	Wayne State University	Great Lakes ice data ArcGIS scripting	Jia Wang (NOAA GLERL) Anne Clites (NOAA GLERL)
Kim Channell	University of Michigan	Hydroclimatological modeling	Chuliang Xiao (UM-CILER) Brent Lofgren (NOAA GLERL)
Tiffany Chin	Dickinson College	Invasive species, fisheries and foodweb dynamics	Ed Rutherford (NOAA GLERL)
Peter Goodspeed	University of Michigan	Spatial analysis of dreissenid mussel populations	Ashley (Baldridge) Elgin (NOAA GLERL) Mark Rowe (UM-CILER)
Maria Hernandez	Brown University	Using an ecosystem-based model to study the impacts of remediation on the food webs	Doran Mason (NOAA GLERL) Ed Rutherford (NOAA GLERL) Hongyan Zhang (UM-CILER)
Etienne Herrick	University of Michigan	Safety and environmental management system	Kim Kulpanowski (NOAA GLERL)
Susannah Iott	Eastern Michigan University	GLANSIS (Great Lakes Aquatic Nonindigenous Species Information System)	Rochelle Sturtevant (Sea Grant) Ed Rutherford (NOAA GLERL)
Logan Lee	University of North Dakota	Meteorological data analysis	Ayumi Manome (UM-CILER) Eric Anderson (NOAA GLERL)
Zoe Psarouthakis	Lawrence University	Invasive species, fisheries and foodweb dynamics	Ed Rutherford (NOAA GLERL)
Cody Yarbrough	University of Michigan	Modeling food web interactions	Doran Mason (NOAA GLERL)

2017 Great Lakes Summer Student Fellows Cohort (May 2017-August 2017)

Fellow	Affiliation	Project	Mentor(s)
Kennedy Connolly	Oakland University	Safety and Environmental Management System	Kim Kulpanowski (NOAA GLERL)
Rachel Fadlovich	Arizona State University	Ecosystem Modeling	Ed Rutherford (NOAA GLERL) Hongyan Zhang (UM-CILER)
Deanna Fyffe	Miami University	In situ fluorometers for detection of harmful algal blooms (HABs)	Tom Johengen (UM-CILER) Tim Davis (NOAA GLERL)
Franky Hang	University of Michigan	Great Lakes Ice Climate Study	Jia Wang (NOAA GLERL) James Kessler (UM-CILER)
Thomas Makled	University of Michigan-Dearborn	Intercomparison of Precipitation Datasets in the Great Lakes Region	Chuliang Xiao (UM-CILER) Brent Lofgren (NOAA GLERL)
Kylan Hopper	Western Washington University	Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)	Rochelle Sturtevant (Sea Grant)
Angelika Kurthen	University of Michigan	Invasive Species, Fisheries, and Foodweb Dynamics	Ed Rutherford (NOAA GLERL) Hongyan Zhang (UM-CILER)
Verena Lucke	Indiana University	Biotic and Abiotic Drivers of Diel Vertical Migration in Post-dreissenid Lakes Michigan and Huron	Hank Vanderploeg (NOAA GLERL)
Thomas Hercula	University of Michigan	Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)	Rochelle Sturtevant (Sea Grant)
Mary Grace Thibault	The Ohio State University	Climate Decision Support Services (DSS) Workshop Coordinator, NOAA Great Lakes Regional Collaboration	Beth Hall (University of Illinois) Jennifer Day (NOAA GLERL)
Chelsea Weiskerger	Michigan State University	Water Quality Statistical Modeling	Mark Rowe (UM-CILER)
Huayun Zhou	University of Michigan	Data Analysis / Hydrodynamic Modeling	Dima Beletsky (UM-CILER) Eric Anderson (NOAA GLERL)

2016-2017 Graduate Research Fellowships

CILER administers a Graduate Research Fellowship Program (formerly called the Long-Term Fellowship Program) that is supported by Task Ib funding. The goals of this program are to: 1) increase training and educational opportunities for students in Great Lakes research; 2) enhance academic and NOAA collaborations to improve research effectiveness; and 3) increase student retention within the freshwater aquatic sciences. The competitive fellowships are available to faculty researchers affiliated with CILER's Consortium Partner universities to collaborate with a NOAA GLERL researcher in supporting a graduate student on a joint research project.

In FY17, we issued a call to our 9 Consortium Partner universities to request proposals for two CILER Graduate Research Fellowship positions. Proposals were scored and ranked by CILER administration (Director, Associate Director, Program Manager), based on research quality, student opportunity, quality of interactions, and advancing research. The Graduate Research Fellowships were awarded to:

- Ms. Kaitlin Reinl, a first year Ph.D. student at the University of Minnesota-Duluth, advised by Dr. Robert Sterner and co-mentored by Dr. Tom Johengen (CILER). The goal of her fellowship research is to evaluate algal bloom response time to changes in temperature and nutrients in three different Great Lakes ecosystems.
- Ms. Katie Knapp, an M.S. student at Grand Valley State University, advised by Dr. Bopi Biddanda and co-mentored by Steve Ruberg (NOAA GLERL). The goal of her fellowship research is to provide a better understanding of carbon cycling in Great Lakes coastal ecosystems, such as lakes and estuaries, and ultimately apply her methods and results globally.

Ms. Reinl and Ms. Knapp's Graduate Research Fellowship reports will be included in the FY18 Annual Progress Report.

CILER awarded one Graduate Research Fellowship in 2016 to Ms. Sarah Bartlett, a doctoral student advised by Dr. Todd Miller at the University of Wisconsin-Milwaukee. The final report for this fellowship can be found in Appendix C.

Postdoctoral Fellowship Program

In addition to supporting postdoctoral positions through Task II research projects, CILER also administers a competitive Postdoctoral Fellowship program. This program provides salary and research support for a postdoctoral fellow to work closely with a CILER Consortium Partner on a project of mutual interest to CILER and NOAA. The program is administered as a Task Ib activity, because they are competitively awarded positions based on funds that are not associated with a specific research project.

In FY17, CILER issued a call to our 9 Consortium Partner universities to solicit proposals for an 18-month postdoctoral fellowship position. The request for proposals stated that preference would be given to a suitable project that included 6 months of matching support, for a total of a 2-year funded position. The award was granted to Dr. C.K Shum at Ohio State University, who is co-mentoring Dr. Yuanyuan Jia with Dr. Philip Chu (NOAA GLERL) on a project investigating the use of satellite data products to improve Great Lakes observing and forecasting systems. Annual progress will be reported on Dr. Jia's fellowship in FY18, and a final fellowship report will be included in the FY19 Annual Progress Report.

A postdoctoral fellowship was awarded to Dr. Bopi Biddanda at Grand Valley State University's Annis Water Resources Institute in FY16, to co-mentor a postdoc with Dr. Eric Anderson (NOAA GLERL) on a project that will result in a three-dimensional hydrodynamic model for the Muskegon Lake Area of Concern. CILER is funding 18 months of the position and GVSU is providing a matching 6 months, for a 2 year total appointment. During FY17, GVSU recruited and hired Dr. Qianqian Liu for the postdoctoral fellowship. Dr. Liu is located at GLERL and AWRI, although GLERL is the primary work location. An annual progress report for Dr. Liu's fellowship is included in Appendix D.

2015-2016 Great Lakes Seminar Series

CILER continues to coordinate the joint CILER-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 CILER website and YouTube channel.

CILER sponsored the following 10 seminars in FY17:

July 20, 2016
Speaker: Jim Richman, Florida State University
Title: Internal tides and waves in the global ocean

August 17, 2016
Speakers: Drs. John Iames and Ross Lunetta, U.S. Environmental Protection Agency, National Exposure Research Laboratory
Title: Cyanobacteria Assessment Network (CyAN) for freshwater systems: an early warning indicator for toxic and nuisance blooms using ocean color satellites

September 14, 2016
Speakers: Dr. Andre Erler, Aquanty Inc.
Title: High-resolution Dynamically Downscaled Climate Projections for the Great Lakes Region

October 19, 2016
Speaker: Dr. Jesse Feyen, NOAA Great Lakes Environmental Research Laboratory
Title: Delivering Impactful Coastal Science Services to Strengthen Communities

December 6, 2016
Speakers: Dr. Silvia Newell, Wright State University
Title: Nitrogen cycling in eutrophic systems: Case studies in Lakes Erie and Taihu

January 25, 2017
Speaker: Dr. Galen McKinley, University of Wisconsin
Title: Spatio-temporal Variability in Great Lakes Biogeochemistry

February 16, 2017
Speaker: Dr. Mark Rowe, University of Michigan, CILER
Title: Looking at Lake Erie Hypoxia From a Different Point of View

March 21, 2017
Speaker: Dr. Chris Winslow, Ohio Sea Grant
Title: Lake Erie HABs and current research efforts: bloom behavior, producing safe drinking water, public health impacts, and nutrient load reduction

April 10, 2017
Speaker: Dr. Robert Sterner, University of Minnesota-Duluth Large Lakes Observatory
Title: Lake Superior: A warming ecosystem

May 11, 2017
Speaker: Dr. Bopi Biddanda, Grand Valley State University, Annis Water Resources Institute
Title: Finding and Tracking the "Goldilocks Zone" for Carbon Cycling in a Great Lakes Watershed

Research Reports by Theme

Theme I: Great Lakes Observing and Forecasting Systems

Great Lakes Water Budget Uncertainty Assessment

Principal Investigator(s): Brad Cardinale (CILER), Allison Steiner (University of Michigan), Nik Katopodes (University of Michigan)
NOAA Technical Lead(s): Andrew Gronewold (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory
Budget Amount: $25,000

NOAA Strategic Goal:
Goal 3 – Climate Adaptation and Mitigation
Goal 4 – Resilient Coastal Communities and Economies
Goal 5 – NOAA Enterprise-wide Capabilities: Science and Technology Enterprise, Engagement Enterprise, Organization and Administration Enterprise.

Overview:
Monitoring and modeling the major components of the Great Lakes water budget (including over-lake evaporation, over-lake precipitation, tributary inflows, and interconnecting channel flows) requires an explicit acknowledgement of measurement- and forecast-based uncertainty. To date, however, historical records of the Great Lakes water budget have rarely included an estimate of uncertainty, and have instead relied on mostly empirically-derived deterministic values. Consequently, it has been difficult to differentiate drivers of water budget and water level change in the Great Lakes, particularly when water level fluctuations coincide with both engineered modifications (such as dredging of the interconnecting channels) and regional climate perturbations (including the strong 1997-1998 El Nino, and the recent Arctic polar vortex anomaly).

In this project, we intend to better quantify the uncertainties associated with Great Lakes water budget historical estimates and forecasts. Our project will focus specifically on using both statistical models, and novel atmospheric modeling tools, to achieve this goal.

Objectives:
The objective of this study is to characterize the relationship between runoff estimates and the other components of the water budget – precipitation, evaporation, channel inflows and outflows, diversions, and change in lake storage of water – develop new estimates of runoff with respect to those variables, and quantify the uncertainty for those estimates.
We intend on extending the draft statistical model across all Great Lakes, and generating monthly estimates with quantified uncertainty for the period 1950 to present. The resulting database would be the first ever to effectively close the Great Lakes water balance while also reconciling different sources of data.

Specific Aims/Milestones:

- Improve draft statistical model for expansion by finding ways to make it more efficient.

- Use new model to produce a new historical record of monthly hydrological component estimates with quantified uncertainty for the period 1950 to present.

Accomplishments:

- Designed experiment to identify model structure(s) that would produce new estimates that close the water balance in an efficient manner.
- Established framework such that additional estimates of water balance components can be incorporated into the model, and operational entities may run a version as well.
- Set stage to evaluate multiple versions of new historical water balance record.

Peer-Reviewed Publications:

Smith, J.P, Gronewold, A.D. Development and analysis of a Bayesian water balance model for large lake systems. *Environmental Modelling and Software.* (Submitted)

Non-Peer-Reviewed Publications:

None

Presentations:

Gronewold, A. and J. Smith. 2017. Great Lakes water balance modelling and uncertainty estimation under a Bayesian MCMC framework. International Association for Great Lakes Research Annual Meeting. (http://www-personal.umich.edu/~joeseph/docs/IAGLR2017_L2SWBM.pdf)

Outreach Activities:

Workshop coinciding with the 102nd meeting of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data in Burlington, ON, Canada.

Theme I: Great Lakes Observing and Forecasting Systems

Transitioning to Operations NOAA-Supported Statistical Hypoxia Models and Forecasts in the Gulf of Mexico and Chesapeake Bay

Principal Investigator(s): Donald Scavia (University of Michigan), Daniel Obenour (North Carolina State University), Isabella Bertani (University of Michigan), David Forrest (Virginia Institute of Marine Science), Gene Turner (Louisiana State University), Jeremy Testa (University of Maryland Center for Environmental Science)
NOAA Technical Lead(s): Alan Lewitus
NOAA Sponsoring Office: NOS, National Centers for Coastal Ocean Science (NCCOS)
Budget Amount: $200,000

NOAA Strategic Goal:
Goal 1 – Healthy Oceans
Goal 4 – Resilient Coastal Communities and Economies
Goal 5 – NOAA Enterprise-wide Capabilities: Science and Technology Enterprise, Engagement Enterprise, Organization and Administration Enterprise

Overview:

The Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) mandates the development of scientific tools for managers addressing hypoxia in coastal systems. In response, NOAA has supported development of scenario forecast models in many U.S. coastal regions with serious hypoxia problems, with the most mature of these efforts being focused in the northern Gulf of Mexico and the Chesapeake Bay. In both regions, statistical models are being used to inform regional management entities of progress toward hypoxia reduction goals. They also play a crucial role in raising public and stakeholder awareness of the hypoxia problems and the actions needed to address them which is an essential element of a successful management plan. For the Northern Gulf of Mexico, these statistical models are the primary management tool to set nutrient loading targets to reach the interagency Hypoxia Task Force goal to reduce the size of the hypoxic zone to 5,000 square kilometers.

The suite of forecast models currently used to produce the annual Gulf of Mexico dead zone forecast and to support long-term management decisions of the Gulf Hypoxia Task Force, as well as development of statistical models for the Chesapeake Bay, have been the product of competitive research funding from NOAA's National Centers for Coastal Ocean Science. Finalizing the transition to NOAA of the models developed, providing training on their operation, and simultaneously ensuring that the forecast outputs are produced during the period of transition, is a critical next step. In addition, the production of the forecasts and press releases support regional interagency management efforts through: 1) deliverables for the National Ocean Policy Implementation Plan for the Water Objective, 2) a FY15 Milestone for the Coastal Intelligence Priority of the NOS Roadmap, 3) Actions in the NOAA Ecological Forecast Roadmap Action Plan, and 4) an NCCOS FY15 milestone.

Objectives:

The main objective of this project is to finalize the transition to NOAA of the models developed, provide training on their operation, and simultaneously ensure that the forecast outputs are produced during the period of transition.

Specific Aims/Milestones:

The purpose of this project is to develop and implement a plan for transition to "sustained operations" of an ensemble-based, statistical modeling framework for hypoxia forecasting and assessment in the Gulf of Mexico and Chesapeake Bay that is capable of addressing NOAA's responsibilities to the Gulf Hypoxia Task Force and regional management entities. The developed system provides a template for application to other regions (e.g., Great Lakes), applications (e.g., living resources impacts, watershed linkages), and capabilities (e.g., coupled modeling platforms, and scenario-based management questions). The 3 main focal areas of activity are outlined below.

Activity Area 1: Produce the annual dead zone forecasts for the Gulf of Mexico hypoxic zone size (area and volume) and Chesapeake Bay (anoxic and hypoxic zone volume) in coordination with NOAA.

Activity Area 2: Provide technical assistance in coordination with NOAA staff for Gulf of Mexico hypoxia-related questions from the Gulf Hypoxia Task Force which are amenable to, or can be aided by, statistical modeling approaches.

Activity Area 3: In coordination with NOAA staff, develop the requirements and conduct the training required for NOAA to maintain an operational scenario forecasting capability to address the management and public information needs related to hypoxia in the Gulf of Mexico and Chesapeake Bay, with expandability to other systems around the U.S. experiencing hypoxia.

Accomplishments:

- Drafted a Preliminary Transition Plan in collaboration with NOAA staff.
- Provided model code, documentation, computing requirements, and forecasting protocols to NOAA staff.
- Deployed the new probabilistic approach for generating the Gulf Ensemble forecast considering the past performance of individual models; provided code and documentation to NOAA staff.
- Published paper in *Proceedings of the National Academy of Sciences* on the method and application of the ensemble modeling.
- Published a new paper in *BioScience* that reviewed the success and impact of the Chesapeake Bay hypoxia and anoxia forecasts
- Provided code and documentation for Gulf geostatistical model so NOAA can provide a statistically-based estimate of hypoxia area based on LUMCON cruise data.
- Generated 2017 hypoxia and anoxia forecasts for Gulf of Mexico and Chesapeake Bay.
- Collaborated with NOAA staff to issue an official NOAA press release for each system.
- Used the newly developed ensemble approach to answer questions raised by the Gulf Hypoxia Task Force. Specifically, we quantified: 1) the nitrogen load reduction necessary to achieve the long-term goal of a 5,000 km^2 hypoxic area, and 2) the expected response of hypoxic area to an interim 20% reduction in nitrogen load.

Peer-Reviewed Publications:

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, G. Ziegler. 2017 Ecological Forecasting and the Science of Hypoxia in Chesapeake Bay. BioScience. Doi:10.1093/biosci/bix048

Turner, R.E. 2017. The Dead Zone as a downstream prelude to the upstream consequence. P. 59-60, 'The True Cost of American Agriculture, San Francisco', CA. 15-16 April 2016. *In press.*

Scavia, D., I. Bertani, D. R. Obenour, R. E. Turner, D. R. Forrest, A. Katin 2017 Ensemble modeling informs environmental policy making: The case of hypoxia in the northern Gulf of Mexico. *Proc. Nat. Acad. Sci. in press*

Presentations:

Obenour, D.R. and J.K. Craig, "Synthesis and Integrated Modeling of Long-term Data Sets to Support Fisheries and Hypoxia Management in the Northern Gulf of Mexico. Hypoxia Effects on Fisheries Workshop, New Orleans, LA., February 2017.

Turner, R.E. "Corn-Soy, Landscapes, and the Hypoxia of the Gulf of Mexico" The True Cost of American Agriculture, San Francisco, CA. 15-16 April 2016.

Turner, R.E. "Gulf Hypoxia Task Force – Science Approach" Illinois Association of Wastewater Agencies – Mini Conference, Springfield, IL. 24 March 2016.

Non-Peer-Reviewed Publications:

- Gulf of Mexico Hypoxia Forecast U-M)
- Gulf of Mexico Hypoxia Forecast (LSU/LUMCON)
- Gulf of Mexico Hypoxia Forecast (VIMS)
- Chesapeake Bay Hypoxia (U-M)

- Chesapeake Bay Anoxia (UMCES)
- Chesapeake Bay Summer Review Report (UMCES, U-M)

Outreach Activities:

- Chesapeake Bay Hypoxia/Anoxia Forecast Press Release: Coverage: > 50 articles, including those in the Baltimore Sun, Washington Post, USA Today, US News and World Report, AP, and UPI
- Chesapeake Bay Summer Review webpage (http://tinyurl.com/y7ymhz9l), December 2016
- Chesapeake Bay Hypoxia/anoxia forecast webpage (http://tinyurl.com/ycby578j) 6/14/17
- Gulf of Mexico Hypoxia Forecast Press Release: Coverage: > 50 articles, including those in the Times Picayune, NY Times, Chicago Tribune, Washington Post, USA Today, Smithsonian Magazine, AP, and UPI

Theme I: Great Lakes Observing and Forecasting Systems

Evaluation of the Evaporation and Heat Flux Algorithms for the Great Lakes Based on Eddy Covariance Measurements

Principal Investigator(s): Brad Cardinale (CILER), Ayumi Fujisaki-Manome (CILER)
NOAA Technical Lead(s): Drew Gronewald (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $116,605

NOAA Strategic Goal:
Goal 2 – Weather-Ready Nation

Overview:
GLERL has participated in the efforts of the Great Lakes evaporation network, where the direct flux measurements are continuously conducted at offshore stations using the eddy covariance technique. The efforts have been made by U.S. and Canadian investigators to understand the cause of water level change (Lenters et al. 2013). Since the first year-round station at Stannard Rock Light that started in June of 2008 (Blanken et al. 2011), additional sites have followed across the Great Lakes including Granite Island (Van Cleave et al. 2014), White Shoal Light, Spectacle Reef, and Long Point.

Given the record of these direct flux measurements to present, an important outcome of this evaporation network is the input to the assessment of the existing bulk flux algorithms that are used in Great Lake forecast models.

NOAA-GLERL Great Lakes Evaporation Model, which estimates lake-wide average evaporation and provides the inputs to GLERL's hydrologic forecast, uses a lumped-parameter surface flux and heat-storage model. It uses air temperature, wind speed, humidity, precipitation and cloud cover averaged over area (Croley 1989). This model is applied on a one-dimensional basis in a vertical direction and represents the lake-wide average evaporation. In the current Great Lakes Coastal Forecasting System (GLCFS), where the three-dimensional hydrodynamic variables are simulated, surface sensible and latent heat fluxes are calculated using bulk formulae with stability-dependent heat transfer coefficients in the Princeton Ocean Model (POM) framework. In the next generation GLCFS, whose physical core is based on the unstructured-grid Finite Volume Community Ocean Model (FVCOM), three different options are available: 1) TOGA COARE-Met flux (COARE, hereafter) algorithm version 2.6, 2) an iterative method developed for the Great Lakes, and 3) an iterative method included in the ice module by Kauffman and Large (2002). Atmospheric models that are often used to provide external forcing to GLCFS have different algorithms for surface flux calculations (e.g. MM5, Eta).

Objectives:

The purpose of this project was to enhance the forecast capability for the Great Lakes by evaluating and improving the current technique to estimate sensible and latent heat fluxes based on the comparison with direct flux measurements. These fluxes had never been inter-compared mainly because there has been no direct flux measurement to be referenced. Another important aspect is that the year-round station data allow us to evaluate winter evaporation and heat fluxes; the former is great unknown in terms of impacts on water levels and the latter is critical to predicting ice production.

Specific Aims/Milestones:

The specific goal of this project was to improve the flux algorithm for heat and evaporation in the operational Great Lakes forecasts by evaluating model-predicted heat flux and evaporation. Focus was given to Lakes Michigan and Huron, where the eddy covariance measurements are available at offshore lighthouses. The final product was intended to be an improved COARE algorithm in the FVCOM framework, which is to replace the physical model in the next generation Great Lakes Coastal Forecasting System.

Specific milestones included:

1. Investigate surface flux algorithms used in atmospheric and hydrodynamic models that will be used for inter-comparison with direct flux measurements. The targets for comparison include the lumped-parameter method of Great Lakes Evaporation Model, COARE algorithm used in FVCOM, and the stability-dependent method used in POM-based GLCFS, but other candidates that could be applicable to lakes will be searched and included.
2. Obtain the processed eddy covariance measurements data from White Shoal Light (Michigan) and Spectacle Reef Light (Huron) from 2013 to 2015 from Dr. Peter Blanken at University of Colorado-Boulder. A data sharing agreement has been executed.
3. Calculate sensible and latent heat fluxes at the eddy covariance stations based on different bulk algorithms. Compare them with the direct flux measurements from the eddy covariance method.
4. Evaluate the model-produced surface sensible and latent heat fluxes from FVCOM, Great Lakes Evaporation model at GLERL (one-dimensional framework), Weather Research and Forecasting (WRF) Model in comparison with the eddy covariance measurements.
5. Evaluate the performance within each season based on quantitative analysis (e.g., root mean square values). Suggest improvements to the existing COARE algorithm used in the FVCOM-based operational forecast model.
6. Highlight the importance of offshore stations that operate year round, as well as the importance of continuous direct flux measurements in the Great Lakes Evaporation Network.

Accomplishments:

1. Bulk heat flux algorithms from the unstructured grid Finite Volume Community Ocean Model (FVCOM), Weather Research and Forecasting (WRF) model, and Large Lake Thermodynamic

Model (LLTM) were examined in terms of their formulations as well as heat flux simulations driven by the observed meteorological data from the flux towers.

2. Data were received from White Shoal Light and Spectacle Reef Light as well as data from Long Point Light and the Toledo Water Crib. This allowed us to study cases outside of Lake Michigan – Huron such as Lake Erie during the historic lake effect snow event of 2014 that occurred near Buffalo, NY.
3. Many FVCOM simulations were conducted using different combinations of flux algorithms and meteorological forcings. The calculated sensible and latent heat fluxes were then compared to eddy covariance stations from the above locations.
4. In association with 1., heat flux simulations were evaluated in comparison with direct flux measurements. This was done for a) a case study during an extreme lake effect snow over Buffalo NY in November 2014 and b) a longer-term period from 2012-2014.
5. For a), the heat flux simulations from the NAM and CFSv2 weather models were also examined. Both comparisons showed that overall the simulated heat fluxes with the COARE algorithm (included in FVCOM) presented the best agreement with the direct flux observations.
6. The above results were presented at several scientific conferences and are being documented in two papers, one of which is under revision (J. Hydrometeorology) and the other is to be submitted in a few weeks.

Publications:

Fujisaki-Manome, A., Fitzpatrick, L., Gronewold, A., Anderson, E., Lofgren, B., Spence, C., Chen, J., Shao, C., Wright, D., Xiao, C., Turbulent Heat Fluxes during an Extreme Lake Effect Snow Event (in revision).

Charusombat, U., Manome, A., Lofgren, B., Anderson, E., Gronewold, A., Blanken, P., Spence, C., Lenters, J., Xiao, C., Fitzpatrick, L., Validation and intercomparison of turbulent heat fluxes from the lake surface in physical modeling (in preparation).

Presentations:

Fitzpatrick, L., Reconstructing evaporation over Lake Erie during the historic November 2014 lake effect snow event, American Meteorological Society, Seattle, WA, January 22 – 27, 2017 (Poster).

Fitzpatrick, L. and Manome, A., Reconstructing evaporation over Lake Erie during the historic November 2014 lake effect snow event, Inaugural MUSE Conference, Ann Arbor, MI, February 9 – 10, 2017 (Poster).

Fitzpatrick, L., Reconstructing evaporation over Lake Erie during the historic November 2014 lake effect snow event, International Association for Great Lakes Research, Detroit, MI, May 15 – 19, 2017 (Poster).

Fujisaki-Manome, A. Reconstructing turbulent heat fluxes over Lake Erie using an unstructured grid model – extreme lake effect snow, FVCOM Users Workshop 2016, Bedford Institute of Oceanography, October 18-20, 2016

Gronewold, A.D., Improving NOAA's Great Lakes forecasting models with off-shore monitoring platforms. University of Michigan Great Lakes Adaptation Forum, Ann Arbor, MI, October, 2016.

Outreach Activities:

None.

Theme I: Great Lakes Observing and Forecasting Systems

Assessment of Contaminated Sediment Transport in Manistique River, MI

Principal Investigator(s): Brad Cardinale (CILER), Chin H. Wu (University of Wisconsin-Madison)
NOAA Technical Lead(s): Eric Anderson
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $179,724

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

Overview:
Manistique River, located in the Upper Peninsula of Michigan, is a 114-km-long river within a 3,742 km^2 watershed flowing into Lake Michigan. The lower 1.7 km of the Manistique River is listed as one of the Great Lakes Area of Concern due to sediment contamination with polychlorinated biphenyls. The legacy contamination comes from industrial waste (oils and combined sewer overflows) as well as debris and sawdust from more than a century of logging and milling. Currently, there still remains two beneficial use impairments that include 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 Limnology and Ecosystems Research (CILER), US-EPA, Great Lakes Environmental Research Laboratory (GLERL), US Geological Survey Water Resources of Michigan, National Marine Fisheries Service and the University of Wisconsin-Madison are working together with the ultimate goal of delisting Manistique River from being an Area of Concern. In particular, during 2012 and 2016, comprehensive field campaigns were conducted by the University of Wisconsin-Madison to characterize sediment properties, atmospheric, and hydrodynamic conditions in order to assess effective remediation actions plans (RAP). In particular, detailed atmospheric and hydrodynamic observations together with sediment characteristics were employed to validate a hydrodynamic and sediment particle tracking model in Manistique River (Figure 1). Additionally, sediments and hydrodynamic data and modeling were used to determine critical hydrodynamic conditions (e.g., seiche amplitude, flow

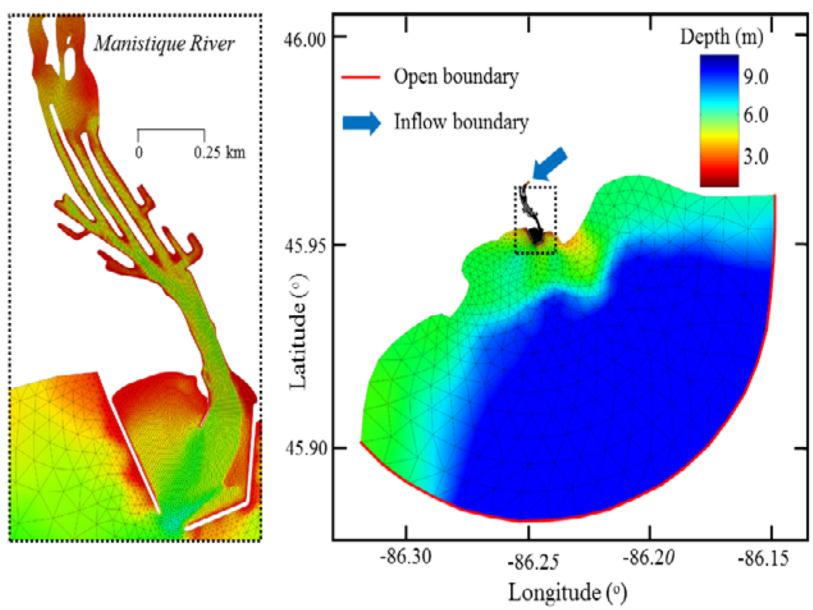


Figure 1. *Unstructured mesh for Manistique River*

discharge, or combinations) that induce sediment mobility. Ultimately, the particle tracking model is employed to help identify potential contaminant sources, and to estimate contaminated residence time under a variety of recurrent and extreme hydrodynamic conditions.

Objectives:

The specific objectives of the project were to:

- Understand surface sediment mobility, including overall depositional/erosional zones, in the harbor and navigation channel.
- Predict how sediment contamination distribution is affected by recurrent (e.g., seiches or normal flow) and singular extreme events (e.g., meteotsunamis or floods). This would allow us to answer the following questions: (i) How long does it take for the contaminated sediments to be flushed out of Manistique River under different hydrodynamic condition? (ii) How would a storm affect the distribution of contaminated sediments, and in turn, remediation efforts?

Specific Aims/Milestones:

To address the above objectives, we conducted the following tasks:

(A) Conduct field measurements to obtain critical shear stress and associated sediment and flow for addressing the roles of erosion and deposition zone during ice-off and spring storm periods;

(B) Provide physical forcing (spring ice off floods, summer stratifications, and fall wind storms and measured parameters for hydrodynamic and particle tracking models;

(C) Construct a set of scenarios to assess the resident time of the Manistique River AOC.

Accomplishments:

Detailed hydrodynamic modeling has provided bottom shear stress maps to assess overall depositional and erosional zones, as well as the hydrodynamic thresholds that induce sediment mobility (see Figure 2). Particle tracking model was employed to predict contaminated sediment residence time in Manistique River. The following conclusions have been reached: (1) During Spring, the river flow is the major sediment resuspension mechanism in the main channel (Figure 2a); (2) High frequency water level oscillations (period < 2 h) are responsible for sediment resuspension in low-flow areas. Amplitudes of 0.2 m, recurrently observed throughout the year, are sufficient to induce contaminated sediment resuspension in Manistique river; (3) While residence time of surficial contaminated sediments is of the order of months, storms can significantly reduce contaminated residence time to the order of hours; (4) Long-term residence time of contaminated sediments is predicted to increase/decrease if Lake water level increases/decreases.

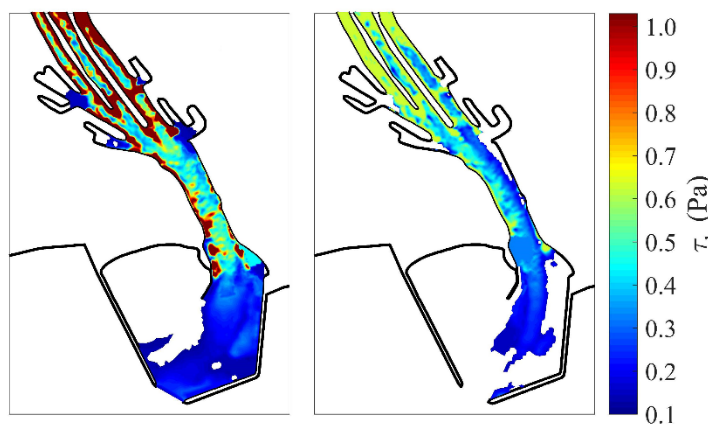


Figure 2. *Bottom shear stress map induced by (a) High-frequency water level oscillations and (b) river flow.*

NOAA and UW-Madison scientists have collaborated in modeling the sediment transport and conducting the field campaign. During the project period, we had several meetings with Dr. Eric Anderson at the

NOAA Great Lake Environmental Research Laboratory, and at the International Association of Great Lakes Conference. Weekly discussions via email and phone conversations have led to the success of the development of a novel sediment transport modeling approach.

A comprehensive field campaign was conducted during June – September 2016 to characterize in detail the hydrodynamic conditions and bottom shear stress in Manistique River. In particular, five water level gages, one acoustic Doppler current profiler (ADCP), and one acoustic Doppler velocimeter (ADV) were deployed with 1-minute temporal resolution were deployed. This 2016 field campaign provided essential information to enhance the data analysis and previous numerical modeling efforts. Specifically, a novel adaptive particle tracking algorithm was developed and data assimilation techniques were employed to set the model parameters so that the hydrodynamics and the transport processes are accurately captured. The new modeling tools were used to reveal how water level oscillations, river flow, and their interactions affect contaminated sediment transport in Manistique River. We also aimed to address time scales of contaminated sediment transport through the different periods (spring, summer, and fall seasons), and distribution of contaminated sediments after storm events. Results indicated that interactions between water level oscillations and river flow can dramatically change bottom shear stress, thus affecting transport time scales of contaminated sediment in the Manistique River. We also investigated how long-term atmospheric (e.g., air temperature warming) and hydrodynamic conditions (e.g., lake level changes) may affect contaminated sediment distributions in the Manistique River. Overall, we have improved forecasting of contaminated sediment pathways and help reveal sources of contaminants in Manistique River, and apply this knowledge to sustainably remediate the Great Lakes AOCs.

Publications:

Linares, Á., Bechle, A.J., and Wu, C.H. (2016) Characterization and Assessment of the 41ortune41etics hazard in northern Lake Michigan, *Journal of Geophysical Research: Oceans*, doi:10.1002/2016JC011979.

Linares, Á., Wu, C.H., Anderson E.J., and Chu P. (2017). Role of Meteorologically induced water level oscillations on bottom shear stress in fresh water estuaries in the Great Lakes. To be submitted to *Journal of Geophysical Research: Oceans.*

Effects of High-Frequency Water Level Oscillations and Flood Flows on contaminated sediment residence time in the Manistique River, Michigan, to be submitted to *Journal of Great Lakes Research*.

Presentations:

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

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

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., Bechle, A.J., Wu, C.H., Rapid forecasting of the 41ortune41etics hazard in the Great Lakes, Meteotsunami Summit, Ann Arbor, Michigan, June 19-21, 2017.

Outreach Activities:

None.

Theme I: Great Lakes Observing and Forecasting Systems

How will the Great Lakes Water Levels Respond to Climate Change: Regional Modeling for Application to Decision-Making

Principal Investigator(s): Brad Cardinale (CILER), Ayumi Fujisaki-Manome (CILER) Phanikumar Mantha (Michigan State University), Michael Notaro (University of Wisconsin-Madison)
NOAA Technical Lead(s): Brent Lofgren (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $340,666

NOAA Strategic Goal:
Goal 3 – Climate Adaptation and Mitigation
Goal 4 – Resilient Coastal Communities and Economies

Overview:
Research by GLERL and CIGLR scientists has made initial steps toward development of a Great Lakes Earth System Model (GLESM). The eventual goal is to have an integrated model of the Great Lakes physical environment system, including the atmosphere, hydrologic system, 3-dimensional lake dynamics, and lake ice formation, transport, and ablation, as well as coupling these into models of lake primary productivity. The coupling effort that has been advanced so far has mainly concentrated on interaction between 3-D lake dynamics and ice as represented by the Great Lakes Ice-Circulation Model (GLIM). Over the past three years, Dr. Ayumi Fujisaki-Manome (CILER) has carried out extensive validation and tuning of the unstructured grid Finite Volume Community Ocean Model (FVCOM), which is a physical core in GLIM. FVCOM facilitates coupling to the Weather Research and Forecasting (WRF) and also includes a nutrient-phytoplankton-zooplankton-detritus (NPZD) model as a biological sub-module. Dr. Chuliang Xiao (CILER) has configured a Great Lakes regional implementation of WRF, as a replacement of the older Coupled Hydrosphere-Atmosphere Research Model (CHARM). Preliminary simulations using WRF have been conducted.

Objectives:
During the final phase of this multi-year project, the dynamical downscaling was used to explore several avenues of climate change impact research. In particular, the objectives were to answer what are the projected 21st century changes in weather severity across the Great Lakes region, in terms of means and extremes of air temperature, lake-effect snow, and water levels, and how will that affect the timing of dabbling duck migration?

Specific Aims/Milestones:
1. Run the WRF model with general circulation models (GCMs) from the Coupled Model Intercomparison Project Phase Five (CMIP5) dataset as lateral boundary forcing. Perform analysis on the results.
2. Complete projections of lake dynamics, ice cover, and chemical concentrations in the lakes under the same scenarios using GLIM.
3. Complete all above projections for three more scenarios, with possible inclusion of Lake Erie loadings and concentrations.
4. Link WRF to the Oasis coupler.

Accomplishments:

Accomplishments related to the above milestones are listed below.

- Improve the 1-D lake Model in WRF. With an updated lake surface albedo scheme in WRF/Lake model, the simulation of lake temperature and ice coverage was improved (Xiao et al., 2016). After calibrations of the 1-D lake model, the coupled WRF/Lake model was used to conduct regional climate simulation in the Great Lakes region. Related to milestones 1 and 4.
- The Great Lakes Water Level Projection in 21st Century. The historical simulation and future projections were completed using the coupled WRF/Lake model driven by GFDL-CM3 outputs with two future scenarios, RCP8.5 in a high emission and RCP4.5 in a medium emission. The lake water levels were calculated by a routing model forced by the WRF/Lake outputs (Xiao et al., 2017 AMS presentation). Related to milestone 2.
- Midwestern Lake and Stream Temperature Modeling. To better understand the diversity of lake and stream responses to climate change and give managers insight on individual lakes, we modelled daily water temperature profiles for 8,903 lakes in Michigan, Minnesota, and Wisconsin and 38,532 stream segments in Wisconsin for contemporary (1979–2015) and future (2020–2040 and 2080–2100) time periods with climate models based on the RCP8.5. Related to milestone 2.
- Elucidating the Drivers of Rapid Great Lakes' Warming. The primary drivers of the recent accelerated warming of the Great Lakes from 1982 to 2012 were explored through observations, remote sensing, and regional climate model experiments. The study focused on the abrupt warming from 1997 to 1998 as a proxy for the long-term warming trend. Related to milestone 3.
- Changing Winter Severity and Wildlife Implications. Projected changes in the relative abundance and timing of autumn-winter migration were assessed for seven dabbling duck species across the Mississippi and Atlantic Flyways for the mid- and late 21st century. Related to milestone 2.

Peer-Reviewed Publications:

Winslow, L. A., G. J. A. Hansen, J. S. Read, and M. Notaro, 2017: Large-scale modeled contemporary and future water temperature estimates for 10774 Midwestern U.S. lakes. *Nature Scientific Data*, doi:10.1038/sdata.2017.53.

Zhong, Y., M. Notaro, and S. J. Vavrus, 2016: Recent accelerated warming of the Laurentian Great Lakes: Physical drivers. *Limnology and Oceanography*, **61**, 1762-1786.

Notaro, M., Y. Zhong, S. Vavrus, M. Schummer, L. Van Den Elsen, J. Coluccy, and C. Hoving, 2016: Projected influences of changes in weather severity on autumn-winter distributions of dabbling ducks in the Mississippi and Atlantic Flyways during the twenty-first century. *Plos One*, **11**(12), e0167506.

Xiao, C., B. M. Lofgren, J. Wang, and P. Y. Chu, 2016: Improving the lake scheme within a coupled WRF-lake model in the Laurentian Great Lakes. *J. Adv. Model. Earth Syst.*, **8**, 1969–1985, doi:10.1002/2016MS000717.

Non-Peer-Reviewed Publications:

None

Presentations:

Notaro, M., Projected climatic and limnological changes and their potential implications for the spread of aquatic invasive species in the Upper Midwest United States, March 2017, webinar to Department of Environmental Quality, Department of Natural Resources, and United States Geological Survey, Madison, WI.

Notaro, M., Overview of observed and projected climate change and its implications, March 2017, St. Maria Goretti School, Madison, WI.

Notaro, M., Climate change projections and implications for the Great Lakes region, October 2016, University of Wisconsin-Madison, Weston Roundtable lecture, Madison, WI.

Notaro, M., Overview of observed and projected climate change and its implications, October 2016, University of Wisconsin-Madison InterAg 155 class, Madison, WI.

Notaro, M., Historical and future projected climate change in the Upper Midwest United States, as Relevant to Plant Communities, September 2016, Wisconsin Initiative on Climate Change Impacts (WICCI) Adaptation Workshop: Preparing Wisconsin's Plant Communities for an Uncertain Future, Madison, WI.

Notaro, M., Projected changes in winter severity for the 21st century and implications for the migratory behavior of dabbling ducks in eastern North America, July 2016, North American Congress for Conservation Biology, Madison, WI.

Xiao, C., B. M. Lofgren, J. Wang, P. Y. Chu, and A. D. Gronewold, Projecting Water Levels of the Laurentian Great Lakes in the 21st Century from a Dynamical Downscaling Perspective. *97th American Meteorological Society Annual Meeting* (AMS), Seattle, WA, January 23-27, 2017.

Xiao, C., and B. M. Lofgren, A. D. Gronewold, D. J. Gochis, L. Mason, and L. Pei, Implementing the WRF-Hydro Modeling System in the Great Lakes Region. *60th Annual Conference of the International Association for Great Lakes Research* (IAGLR), Detroit, MI, May 15-19, 2017.

Outreach Activities:

- Xiao, C., volunteer in *the Great Lakes Ocean Sciences Bowl* (February, 2017).
- Notaro, M., member of the Advisory Board for the Great Lakes Integrated Sciences and Assessment (GLISA), NOAA RISA
- News articles:

  Sturgis Journal, Prepare for climate change, 2017.
  Capital News Service, 5 things to prepare for climate change, 2017.
  Weather Channel, Climate change could bring more lake-effect snow – for a few decades, 2017.
  NOAA climate.gov, The paradox of lake effect snow: global warming could bring the Great Lakes more of it, at least for a while, 2017.

Related website:

- Great Lakes Ice Atlas:
  http://www.glerl.noaa.gov/data/pgs/glice/glice.html

Theme I: Great Lakes Observing and Forecasting Systems

High-resolution Atmospheric, Wave, Ice and Circulation Model Guidance System for the Great Lakes Region

Principal Investigator(s): Brad Cardinale, Ayumi Fujisaki-Manome
NOAA Technical Lead(s): Eric J. Anderson (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL) and Coastal Storms Program (CPO)
Budget Amount: $69,929

NOAA Strategic Goal:
Goal 2 – Weather-Ready Nation

Overview:
The Great Lakes region currently has no model guidance capacity regarding the combined wind and wave-induced coastal surge events, including meteotsunamis/seiches. In addition, the inclusion of ice processes in the model guidance is required to predict rapidly changing events, including ice break-up (lead formation) and ice jams. To address this omission, a three-year across-NOAA collaborative effort under NOAA's Coastal Storm Program aimed to develop a combined circulation, ice, and wave model on an unstructured grid that will be forced by a high-resolution atmospheric model. In the past two years of the collaborative work, a number of historical extreme storms were selected, with particular focus on key problem areas, including the shallow regions of the open waters (e.g., western Lake Erie, west arms of Lake Superior, Lake St. Clair basin) and the transition zones in and near larger bays (e.g., Saginaw Bay, Green Bay, Grand Traverse Bay). In the third year of the project, we worked on the two-way coupling of WAVEWATCH III (WW3) and Finite-Volume Community Ocean Model (FVCOM), as well as initiated the inclusion of ice physics into the modeling system.

Objectives:
The overall objective of this project was to improve the current wave, hydrodynamics, and ice guidance at NOS and NWS. We conducted and evaluated high-resolution wave-hydrodynamic simulations for the Great Lakes using atmospheric, wave, ice, and hydrodynamic models, as well as evaluated impacts of wave-hydrodynamic interaction on hazardous events (e.g., surges, meteotsunamis) using the two-way coupling WW3-FVCOM.

Specific Aims/Milestones:

1. Conduct additional high-resolution Weather Research and Forecasting (WRF) simulations for the selected extreme events.

2. Set up a two-way coupling system between WW3 and FVCOM using the file-based method.

3. Conduct WW3-FVCOM coupled simulations for the selected events, for which the WW3 and FVCOM uncoupled simulations were conducted in the past two years. Evaluate the impacts of two-way coupling on significant wave height, water level fluctuation, and current in comparison with the uncoupled runs.

4. Incorporate ice processes in the FVCOM framework using the validated parameter setting under development by project lead Dr. Manome and NOAA collaborator Dr. Jia Wang. Test runs will be conducted with a WW3-FVCOM-ice system.

Accomplishments:

Milestone 1: Additional WRF simulations for a few storm cases were conducted. FVCOM and WW3 simulations forced by the WRF-simulated meteorological data were also conducted. The results were evaluated with buoy observations.

Milestone 2: Two-way coupling between FVCOM and WW3 was set up based on a file-transfer method.

Milestone 3: Two-way coupled simulations were conducted for selected storm cases. The comparison the uncoupled results showed notable difference in water levels and significant wave heights at buoy locations.

Milestone 4: Ice processes based on the unstructured grid version of Los Alamos Sea Ice Model (UG_CICE) were incorporated in the Great Lakes FVCOM. The results were validated based on the comparison with observations of ice concentration and ice thickness.

Peer-Reviewed Publications:

Anderson, E.J., and D.J. Schwab. Meteorological influence on summertime baroclinic exchange in the Straits of Mackinac. *Journal of Geophysical Research: Oceans* (DOI:10.1002/2016JC012255) (2017).

Bechle, A., C.H. Wu, D.A.R. Kristovich, E.J. Anderson, D.J. Schwab, and A.B. Rabinovich. Meteotsunamis in the Laurentian Great Lakes. *Scientific Reports* (DOI:10.1038/srep37832) (2016).

Linares, Á., Bechle, A.J., and Wu, C.H. (2016) Characterization and Assessment of the 46ortune46etics hazard in northern Lake Michigan, Journal of Geophysical Research: Oceans, doi:10.1002/2016JC011979.

Mao, M. Van der Westhuysen, A.J., Xia, M., Schwab, D.J., and Chawla, A., Modeling wind waves from deep to shallow waters in Lake Michigan using unstructured SWAN, J. Geophs. Res., 121(6), 3836-3865, (2016).

Non-Peer-Reviewed Publications:

None.

Presentations:

Anderson, E.J., Lang, G.A., Chu, P., Fujisaki-Manome, A. and Wang, J., Development of the Next-Generation Lake Michigan-Huron Operational Forecast System (LMHOFS), International Association for Great Lakes Research annual conference, May 15th-19th, 2017, Cobo Hall, Detroit, MI.

Fujisaki-Manome, A., Wang, J. and Anderson, E.J., Modeled ice thickness in Lake Erie with different parameterizations of the ice strength, International Association for Great Lakes Research annual conference, May 15th-19th, 2017, Cobo Hall, Detroit, MI.

Kuang, J., Van der Westhuysen , A.J., Anderson, E.J., Mann, G., Fujisaki-Manome, A., and Kelly, J.G.W., Coupling Effects Between Unstructured WAVEWATCH III and FVCOM in Shallow Water Regions of the Great Lakes, Joint Session "Regional and Coastal Hydrodynamic Model Coupling, Including Hydrological Impacts" at 97th American Meteorological Society annual meeting, Seattle, WA, January 22-26, 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

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.

Wu, C.H. and Anderson, J.D, Freak Waves in the Apostle Islands, Lake Superior: Characteristics and Occurrence, International Association for Great Lakes Research annual conference, May 15th-19th, 2017, Cobo Hall, Detroit, MI.

Outreach Activities:
None.

Theme I: Great Lakes Observing and Forecasting Systems

2016 Implementation of the GLOS Buoy and Mobile Platform Observing Systems

Principal Investigator(s): Brad Cardinale and Thomas Johengen (CILER)
NOAA Technical Lead(s): Steve Ruberg (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory
Budget Amount: $572,000

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

Overview:
The Great Lakes Observing System Regional Association (GLOS-RA) proposes to implement key observing system and modeling improvements over the 2011-2016 period that focus on critical needs of the Great Lakes region as identified through an extensive needs assessment process. The focus of this work will be on supporting observations and developing new products related to four priority issue affecting the health, well-being and economic viability of the region, 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 will be addressed by implementation of an array of integrated observations including new moorings and additional sensors to measure temperature and current profiles. AUV/glider technologies would be initiated to collect critical transect information. Cross-lake ferries and other vessels of opportunity will be instrumented to collect repetitive observations of surface chemistry. Satellite remote sensing products would be derived to begin daily monitoring of lake surface loadings of nutrients and sediments. Our 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, and Local Government Agencies and Tribes; 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 which serve as target users in all the GLOS focus areas.

Objectives:
The objective of this project is to oversee the implementation of planned activities for the open-lake observing team that will help to establish, maintain, and develop operational capabilities for the GLOS-RA during the project period of June 1, 2016 – May 31, 2017.

Specific Aims/Milestones:

<u>I. Cooperative Institute for Limnology and Ecosystems Research (PI: Thomas Johengen)</u>

A. Project Management

1. Manage and execute the sub-awards for each of the academic institutional participants on the project. The sub-awards are executed through the existing Cooperative Agreement with host lab NOAA-GLERL. Partner institutions include: CILER-University of Michigan, University of Wisconsin-Milwaukee, University of Minnesota-Duluth Large Lakes Laboratory, Great Lake Regional Consortium-SUNY Environmental Sciences and Forestry, Michigan Technological University (MTU), and Michigan Technological Research Institute (MTRI).
2. Facilitate and oversee delivery all progress reporting requirements to the Integrated Ocean Observing System (IOOS).

B. Management of Autonomous Observation Platforms

1. Support up to 150 days of glider observations in Lake Michigan as part of the 2015 Coordinated Science and Monitoring Initiative (annual bi-national lake-by-lake effort) in conjunction with NOAA, USGS, and EPA. Disseminate the mission data into the IOOS National Glider Data Assembly Center (DAC), as well as disseminate to all of the participating project scientists from the various Federal agencies.
2. Complete three AUV missions in Lake Erie to support ongoing CILER and NOAA efforts to monitor and forecast toxic cyanobacterial algal blooms. Complete a fourth mission planned to support hypoxia monitoring and modeling in Green Bay along with our University of Wisconsin-Milwaukee partner.

1. Operational Support of Lake Michigan GLOS Buoys

1. Deploy, operate, maintain, and retrieve a real-time TIDAS 900 buoy with meteorological package, directional wave sensor, currents and thermistor along the coast of Ludington, Michigan.
2. Work with MTU to deploy, operate, maintain and retrieve a real-time TIDAS 900 buoy in Little Traverse Bay with meteorological package, directional wave sensor and thermistor string.
3. Operate and maintain these buoys during the navigational season of Lake Michigan, reporting all data real-time to GLOS, the National Data Buoy Center (NDBC), and the MTRI website.
4. Support the operation of a research buoy at the UM Biological station to provide continuous long-term water quality data for support of student research projects and serve as a platform to R&D application of new sensor technologies.
5. Provide limited QA/QC and archive all collected data.
6. Ensure that both GLOS buoys are reporting data real-time every ten minutes, and transmitting to GLOS, MTRI and NDBC, and that the data are available to the general public via their websites.

<u>II. University of Wisconsin-Milwaukee School of Freshwater Sciences (SFS), Great Lakes WATER Institute (GLWI) (Pis: Val Klump and Harvey Bootsma)</u>

Real-time Buoy and Vessel of Opportunity Underway Observing Systems, Lake Michigan

1. Deploy and maintain two standard GLOS open water monitoring buoys in Lake Michigan off Milwaukee and in Green Bay, Lake Michigan and a third GLWI-designed nearshore buoy in the waters of Lake Michigan in the vicinity of the Milwaukee Bight.

2. Operate the buoy monitoring systems during the recreational season in the bay (June – October), with the aim of extending this period from May to November. Interface GLOS real time data collection with other ongoing monitoring and research efforts in the Milwaukee region.
3. Collaborate with the National Park Service Lake Michigan monitoring program, an objective of which is the identification of conditions that lead to avian botulism outbreaks.
4. Continue to assist in the development of long-term forecast systems and models for the prediction of future conditions.
5. Operate and maintain the high-speed ferry vessel of opportunity monitoring program (Lake Express).
6. Support research projects funded from other sources, e.g., impact of invasive dreissenids on Lake Michigan carbon and phosphorus dynamics, supported by Wisconsin Sea Grant and GLRRIN; research on seasonal hypoxia, watershed impacts and climate change in Green Bay supported by NOAA CSCOR CHRP, the Michigan Water Center and the Wisconsin Sea Grant program.

III. University of Minnesota, Duluth (PI: Jay Austin)

Real-time Meteorological Buoy Glider Deployments and Harbor Instrumentation

1. Deploy two meteorological buoys in the western arm of Lake Superior with NDBC designations 45027 and 45028. Measurements include wind speed and direction, air temperature, relative humidity, water temperature at ten depths, solar radiation, downward longwave radiation, precipitation, and wave height, period, and direction. Data is downloaded periodically to a lab at UMD for QA/QC and archiving. Data is ported directly to NDBC and GLOS every 10 minutes.
2. Deploy the glider for 4 separate transects (one each in June, July, August, and September) between the Keweenaw Peninsula and Isle Royal Continue in collaboration with MTU. This transect takes six days to complete. The glider measures temperature, conductivity, chlorophyll a fluorescence, CDOM fluorescence, backscatter, and dissolved oxygen.
3. Deploy automated water quality sensors (a) in the Superior Inlet (SI) of the St. Louis River (SLR) to Lake Superior; (b) on a mid SLR channel range cell near the Blatnik Bridge, in the connecting channel between the Duluth Harbor/Duluth Bay and the lower reaches of the St Louis Estuary; and (c) at the Duluth Inlet (DI) to Lake Superior. Measurements include flow, temperature, DO, EC25, turbidity, and chlorophyll fluorescence.

IV. Great Lakes Research Consortium (GLRC), State University of New York College of Environmental Science and Forestry (PI: Gregory L. Boyer)

Real Time Meteorological Buoy Deployments

1. Deploy a TIDAS 9000 series buoy off Oswego, NY with a full meteorological suite, a thermistor string running surface to bottom at 2 m intervals, and YSI or HydroLab multi-parameter sonde with T, μ, DO, and pH sensors.
2. Use the current GLRC website to provide easy access to basic water quality information, the temperature profile, and meteorological information, as well as support transfer of that information to GLOS Data Management and Communications (DMAC).
3. Validate this information through biweekly or monthly grab samples collected at the buoy location in conjunction with SUNY- Oswego. Comparison of buoy data with ship-based measurements conducted through the US-EPA and Environment Canada bi-national sampling program in Lake Ontario as well as with riverine measurements collected by USGS and the Upstate Freshwater Institute.

4. Develop an outreach and education program in consultation with the H. Lee White Maritime Museum in the City of Oswego to co-support at least one internship from SUNY-Oswego in science education and outreach.
5. Deploy a TIDAS 900 series buoy in eastern Lake Ontario and transfer the data to the H. Lee White Maritime museum and to the GLOS DMAC system.

V. Michigan Technological University (Pis: Guy Meadows and Robert Shuchman)

A. Nearshore Buoys, Keweenaw Waterway Observatory, and Glider Support Activities

1. Deploy and operate three GLOS buoys: two off the north and south entrances to the Keweenaw Waterway of Lake Superior and one in Little Traverse Bay of Lake Michigan from late May to late October 2015. A microcontroller-based power management system has been designed, built and tested and will be added to the north Keweenaw buoy on an experimental basis for this deployment year. All buoys will transmit data every ten minutes and be available near-real time via the GLOS, NDBC and UGLOS (uglos.mtu.edu) web sites. Develop and test novel power generation methods designed to harvest energy from wave action.
2. Deploy two separate thermistor chains at the north and south entries of the Keweenaw Waterway. The temperature sensors will be located at six, one meter intervals (surface to bottom) and will remain deployed from late May to October. After QA/QC, 2010-2015 data will be provided to the GLOS information system.
3. Continue to host the interactive UGLOS website that reports the real-time observations.
4. Continue to maintain equipment, and archive video stills and meteorological data for three GLRC rooftop HD web cameras.
5. Continue to work with University of Minnesota-Duluth Large Lakes Observatory to deploy, recover, and support additional GLOS trans-lake glider missions. Up to four round-trip missions to Isle Royal will be conducted in the 2015 season.

B. MTRI – GLOS Remote Sensing Activities

1. In support of remote sensing product continuity for the Great Lakes, MTRI will continue using the MODIS and its follow-on sensor VIIRS to generate weekly CPA-A products. MODIS is operating beyond its expected operational lifetime. Both satellite products will be delivered to the GLOS DMAC team.
2. Generate satellite retrieval products (chlorophyll (chl), dissolved organic carbon (doc), cdom, suspended minerals(sm), extinction coefficients (kd), KPAR, photic depth, and lake surface temperatures (LST)) for the times and areas that the University of Minnesota-Duluth glider operated in 2014. The surface satellite observations will be compared with Dr. Austin's glider measurements. A co-authored note on the joint analysis will result.
3. Using data assimilation techniques developed by Drs. Dave Schwab and Eric Anderson, satellite derived products of chl will be combined with particle tracking models to show the utility of combining satellite maps on non-cloudy days with a hydrodynamic model to capture a more robust understanding of the Great Lake processes.
4. Continue to update the Great Lakes Optical Properties Geospatial Database (GLOPGD) as more data sets are collected this summer field season.

Accomplishments:

I. Cooperative Institute for Limnology and Ecosystems Research – University of Michigan

1. The Ludington buoy was deployed 5-11-16, operating normally until it was struck by a vessel early in the morning on 7-16-16. The buoy was recovered with the aid of the local charter fishermen partners. Upon retrieval, it was discovered that the buoy mast and all the instruments mounted on the mast were lost in the collision (anemometer, barometer, air temperature/humidity probe, radiometer and GPS). To aid in a quick repair and redeployment, a mast was borrowed from Limnotech and instruments were borrowed from GLERL. The buoy was redeployed with a limited meteorological package with the assistance of GLERL on 8-8-16. The buoy operated without incident for the rest of the season and was retrieved on 10-19-17. All data were transmitted to NDBC, GLOS, and the UGLOS websites for the deployment period. Over the winter the damaged fiberglass was repaired, the instruments were replaced, and the datalogger was refurbished for lower power consumption and higher reliability. The old CDMA modem was replaced with a new 4G cell modem.
2. During winter of 2016 the Little Traverse Bay buoy was transitioned to CILER from MTU. It was deployed 5-6-16, and was fully operational, transmitting data to NDBC, GLOS and the UGLOS websites until retrieval by our partners with Irish Boat on 11-2-16. Over the winter, power reduction modifications were made to save approximately 20%. Power disconnect and external winter charging capability were also added. The buoy was serviced, checked, and a new mooring line was installed. The buoy was redeployed on 5-9-17 by Irish Boat, and has operated continuously throughout the season, transmitting data to NDBC, GLOS and the UGLOS websites.
3. The glider was deployed from 6-22-16 to 7-29-16 and then again from 8-12-16 to 8-16-16 in the nearshore of Lake Michigan off of the mouth of Muskegon Lake, Michigan. The glider flew over GLERL long-term research (LTR) transects to supplement diel sampling data taken from the R/V Laurentian over the same transects. A third deployment was attempted but issues with the pump and a leak terminated the mission. Over the winter the glider was returned to the manufacturer to replace an instrument that was causing the glider to take on water. While at the manufacturer, the glider CTD was recalibrated, the pumps were serviced and new equipment was added to better ballast the glider in fresh water. In May of 2017 the glider was fitted with a USGS fish tag receiver for deployment this summer in Saginaw Bay. This deployment will be part of work for the CSMI for Lake Huron, and will be used not only to supplement one of GLERL's transects, as well as flow across the mouth of Saginaw Bay, but also to assess the range a glider would need to receive fish tag data.
4. The AUVs were deployed in support of two diel surveys done in western Lake Erie to help verify the HABs model for Lake Erie. The AUVs were launched and recovered from the NOAA 41 foot boat and flew between 2 sampling stations to provide continuous spatial data to compliment the water sampling at each station.

II. University of Wisconsin-Milwaukee (UWM)

1. Serviced, upgraded, and deployed two nearshore buoys at depths of 10 m and 20 m north of Milwaukee, a buoy in Green Bay at 13 m and a monitoring system on the high-speed Lake Express ferry that operates between Milwaukee WI and Muskegon MI for the 2016 and 2017 navigational seasons. The Lake Michigan GLOS buoys contribute to a larger Lake Michigan nearshore monitoring effort that is coordinated among UWM-School of Freshwater Sciences (SFS), the Wisconsin Department of Natural Resources which operates a monitoring station near Kewaunee, WI, and the National Park Service (NPS) which contracts SFS to operate a monitoring station near Sleeping Bear Dunes National Lakeshore. Buoy data from the 2016 season was compiled and analyzed during the winter.

2. Through NPS funding, developed a real-time monitoring buoy with benthic camera system for outreach and research at Sleeping Bear Dunes National Lakeshore. Data from the buoy will be integrated into the GLOS data buoy system and NDBC. Deployment scheduled for August 2017.
3. The water monitoring system operated in collaboration with the North Shore Water Commission (NSWC) in Whitefish Bay was deployed November 4th 2016 and continues to operate. The system required weekly maintenance and has been fully functional throughout its deployment. One of the shortcomings of traditional water monitoring systems has been the inability to collect data during the winter months. To address this challenge, SFS installed a monitoring system at a water intake, immediately north of Milwaukee, that measured lake water temperature, CO_2 concentration, and chlorophyll *a* concentration. The system remains deployed to compare data collected with that of the Milwaukee 10m buoy.
4. The inertial wave sensor (IWS) from Seaview Systems added to the Milwaukee 20m buoy in winter 2015-2016 failed to collect data one month into the 2016 season. After undergoing troubleshooting and repair the following winter the system has operated without issue throughout the 2017 season. The IWS provides wave height, period, and direction measurements that are currently undergoing validation. These parameters will be included in reporting to GLOS and the NDBC once validation is complete.
5. Real-time images from the Milwaukee 20m and Green Bay buoys continue to be hosted on the SFS website www.uwm.edu/GLOS. There has been strong interest from Green Bay and Milwaukee broadcasters for access to buoy imaging for local broadcasts. The site continues to host historical and recent data from non-real-time SFS monitoring assets.
6. The high-speed ferry monitoring system was installed on May 5th 2017. The system has occasional service requirements which resulted in minimal data gaps for the 2016 ferry operating season (May-Oct). Some of these data have been used to calibrate and validate a Lake Michigan hydrodynamic / biogeochemical model.
7. For the 2017 season, observing systems have been deployed operable during the following times:
    a. Milwaukee Endurance Buoy (10m): Deployed 5/10/2017. Meteorological stations and sonde are fully operational. Endurance pCO2 system, overhauled in winter 2016-2017, continued to experience monitoring issues into the 2017 season. A new pCO2 sensor (LiCor) was installed 7/2017 resolving all issues.
    b. Milwaukee 45013 (20m): Deployed 5/03/2017 with meteorological station, sonde, current meter, temperature string, wave sensor, and camera. Fully operational.
    c. Green Bay 45014: Deployed 5/31/2017 with meteorological station, sonde, current meter, temperature string, and camera. Fully operational. Surface water oxygen sensor data combined with meteorological data from this buoy are producing the first continuous estimates of oxygen exchange across the air-water interface, water column gross primary production (GPP), and net ecosystem production (NEP) in Green Bay. These data are contributing to a larger effort to understand the drivers of hypoxic and anoxic conditions in the bay.
    d. Lake Express High-Speed Ferry: Deployed 5/05/2016. The high-speed ferry monitoring systems data have been used to calibrate and validate a Lake Michigan hydrodynamic / biogeochemical model.
    e. Northshore Water Monitoring: The over-winter nearshore monitoring system was deployed 10/2016 and continued to monitor through the reporting period.

III. University of Minnesota-Duluth (UMD)

1. **Real-time buoys**: Two meteorological buoys, deployed previous to the period of activity (deployed 14 April 2016) were recovered on 25 October 2016. Measurements include wind speed and direction, air temperature, relative humidity, water temperature at ten depths, solar radiation, downward longwave radiation, precipitation, and wave height, period, and direction. Data are downloaded periodically to a lab at UMD for QA/QC and archiving. Data are ported directly to NDBC and GLOS every 10 minutes. The buoys were redeployed on 9 May 2017, and are deployed as of the writing of this report.
2. **Glider deployments**: Two deployments in 2016, for a total of 22 days, were made from 9-19 August and 8-21 September. Both occupied our traditional western arm transect, and the second deployment included an extensive along-shore transect, from the far western portion of the lake past the Apostle Islands, including several cross-shelf transects. In 2017, two deployments totaling roughly 9 days were made (two more deployments, totaling another 9 days, have been made since 30 June). Both of these include our western arm transect, and the second of these also included a cross-lake transect further downlake.
3. Three **synergistic activities** not directly funded by the project have occurred during the period of performance. First, a winter mooring was deployed at the LLO2 location that carried a hydrophone, in a continued effort to characterize the acoustic environment of the lake. Developing a better understanding of both the ambient acoustic environment of large lakes and propagation characteristics is going to be important as acoustic tagging becomes a more widespread technique. Second, our lab is part of a large NSF-sponsored project to study internal wave generation on coastal boundaries. The project includes significant oceanographic instrumentation that is new to the lakes that could be incorporated into future observing systems, such as wave-driven profilers (profiling instruments that use wave power for propulsion) and a variety of turbulence-measuring instrumentation. Finally, our lab has been working on understanding plume dynamics in the western arm of the lake, using, in part, data from GLOS-sponsored buoys and gliders to inform the research. Developing a better understanding of plume dynamics will help us to better understand cross-shelf transport processes, which likely have a non-trivial impact on fisheries.

IV. Great Lakes Research Consortium, SUNY-ESF

1. A TIDAS buoy deployed off of Oswego harbor in 2016 was likely hit by a ship in the second week of October 2016. All assets were lost. We spent the winter months reconfiguring our second TIDAS buoy, last used in 2013, for deployment in 2017. As of June 30th, we were unable to get all electronic systems to function properly.
2. Deployment of the eastern Lake Erie TIDAS buoy operated by the Buffalo State College was delayed due to mechanical issues with the boat but was be deployed for the remainder of 2016 season. They have been having continuing problems with the YSI sonde but the buoy was deployed in May 2017 with the weather station, wave height, and temperature string.
3. In the summer of 2016, three MB300 Bay buoys were deployed in Sodus Bay Lake Ontario specifically to monitor for harmful algal blooms. The three MB300 Bay buoys were deployed again in May/June 2017. This effort is jointly funded by the Great Lakes Restoration Initiative and New York Sea Grant. The center buoy is equipped with full meteorological stations, thermistor string, and a Turner Designs C6 sensor (chlorophyll, phycocyanin, phycoerythrin, colored dissolved organic matter, and turbidity) and hypo- and epilimnetic YSI sondes on the center buoy. The north and south buoys are equipped with water level and conductivity sensors in 2017, wind speed and direction (south buoy only) to look at the impact of in-bay seiche on HAB formation. Analysis of last summer's data showed very low algal productivity in the center

of the bays. Analysis of prior year's data shows that the center of the bay goes periodically anoxic. We are working with the University of Buffalo to model the impact of this anoxia and seiche on nutrient release and HAB formation within the bay.

4. The weather station on LeRoy Island (Sodus Bay, Lake Ontario) functioned year-round and was popular among sailors and ice fisherman. We need a better data portal to make the information available to these users via their smart phones.
5. We have been working with the H. Lee White maritime museum to install a permanent exhibit featuring the Oswego Buoy information. That exhibit is up and running pending our data feed from the Oswego buoy. We also deployed a buoy in the Great New York State Fair in August 2016 as part a cooperative project with New York Sea Grant, Lake Champlain Maritime Association, Coast Guard Auxiliary, and Sea Way Trails. This buoy broadcasts weather live from the New York State Park reflecting pool and was viewed by nearly 1 million visitors (www.esf.edu/shipwreck). We are currently evaluating next steps for that aspect of the project.

V. Michigan Technological University

Buoy and Other Physical Observations

1. Integrated and deployed an additional TIDAS buoy in the Straits of Mackinac mid-season (August – October, 2015). This platform includes the only near real-time, ADCP data in the Straits. The buoy was leveraged from non-IOOS industrial funding.
2. Optimized GLOS-wide acoustic Doppler current profiler (ADCP) code for improved accuracy. Shared this optimization with all GLOS partners using ADCP's.
3. Upgraded battery capacity on two Lake Superior buoys. This resulted in fewer power issues during the late fall, low incident solar radiation season at high latitudes.
4. Continued work and deployed buoy energy management systems (on 45025) and exploration of potential power generation via wave induced buoy motions.
5. Completed QA/QC for all buoy sites.
6. Recovered at end of the navigation season and refurbished/calibrated each buoy (3) and redeployed in early May 2016. Little Traverse Bay buoy was recovered, and will be maintained in the future, by CILER.
7. Monitored and maintained new mooring design for all four (4) buoys.
8. Continued analysis of ADCP and sonde measurements made from the North Keweenaw and Mackinac Straits buoy.
9. Continued to maintain and operate GLRC roof top/waterfront meteorological data station (also reporting to Michigan Tech and GLOS).
10. Continued co-located live video to support the waterfront meteorological station at the GLRC (supported by funding from Michigan Tech).
11. Launched, recovered, and delivered the LLO Slocum glider three times in cooperation with Dr. Jay Austin of LLO (using supplemental GLOS funding).
12. GLRC mentored a student group, MTU Robotics Systems Enterprise, who developed a power management solution for the GLOS/Michigan Tech Research buoys. The solution was a culmination of electronics hardware construction and software programming efforts put forth by the eleven member student group. Structure, including regular project meetings, documentation and budgeting was enforced by GLRC technical staff members. Following rigorous testing, the power management solution is successfully deployed on the GLOS Michigan Tech "South" buoy (45025) beginning spring 2016. This buoy power management system has been operational in full autonomous mode without issue. It is

expected that this new system will extend buoy life in low solar environments (high latitudes, extended cloud cover) for all GLOS buoys.

13. Analyzed coastal temperature data for the last 15 years on Lake Superior for a paper on "indirect food web effects" of increasing temperature. The paper uses sediment core data, coastal sampling, and long-term temperature records (temperature probe, GLOS) to discuss changes in zooplankton community structure and predator-prey relationships associated with near-shore temperature shifts.

Remote Sensing Observations

1. Continued to update the GLOPGD website (www.glopgd.org) with additional data sets collected during 2016 and 2017 in collaboration with CILER and NOAA GLERL. The new IOP measurements include time series in Lakes Erie, Michigan, and Huron (Saginaw Bay).
2. Finalized the monthly retrievals for 2016 of chl, doc, and sm, cdom, kPAR, and photic zone for all three upper Great Lakes.
3. Generated additional example remote sensing data products for GLOS DMAC.
4. Continued transitioning the CPA-A chl, doc, and sm retrieval algorithm to NOAA for operational use in the NOAA Great Lakes CoastWatch system.

Publications:

Troy, C., D. Cannon, Q. Liao, H. Bootsma. 2016. Logarithmic velocity structure in the deep hypolimnetic waters of Lake Michigan. Journal of Geophysical Research: Oceans. 121:949-965.

Bullerjahn, G. S., R.M. McKay, T.W. Davis, D.B. Baker, G.L. Boyer, L.V. D'Anglada, G.J. Doucette, J.C. Ho, E.G. Irwin, C.L. Kling, R.M. Kudela, R.Kurmayer, J.D. Ortiz, T.G. Otten, H.W. Paerl, B. Qin, B.L. Sohngen, R.P. Stumpf, P.M. Visser and S.W. Wilhelm (2016) Global solutions for regional problems: collecting global expertise to address the problem of harmful algal blooms. A Lake Erie case study. Harmful Algae, 54:223-238 doi.org/10.1016/j.hal.2016.01.003

Carmichael, W.W. and G.L. Boyer (2016) Health impacts from cyanobacteria harmful algae blooms: Implications for the North American Great Lakes, Harmful Algae, 54:194-212doi.org/10.1016/j.hal.2016.02.002

Watson S.B., C. Miller, G. Arhonditsis, G.L. Boyer, W. Carmichael, M. Charlton, R. Confesor, D. C. Depew, T.O. Höök, S. Ludsin, G. Matisoff, S.P. McElmurry, M.W. Murray, P. Richards, Y. R. Rao, M. Steffen, and S. Wilhelm (2016) The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia. Harmful Algae, 56 (2016) 44–66. DOI:10.1016/j.hal.2016.04.010

Weber, S. (2017) Contribution of External Phosphorus Loads from Sodus Creek East to the phosphorus budget of Sodus Bay, MPS dissertation report, Department of Chemistry, SUNY-College of Environmental Science and Forestry, May 2017.

Kerfoot, W.C., S.C. Savage. 2016. Multiple inducers in aquatic foodwebs: Counter-measures and vulnerability to exotics. Limnol. Oceanogr. 61:382-406.

Kerfoot, W.C., N. R. Urban, C.P. McDonald, R. Rossmann, H. Zhang. 2016. Legacy mercury releases during copper mining near Lake Superior. J. Great Lakes Res. 42:50-61.

Kerfoot, W.C., M.M. Hobmeier, F. Yousef, B M. Lafrancois, R.P. Maki, J.K. Hirsch. 2016. A plague of waterfleas (Bythotrephes): impacts on microcrustacean production in a large inland-lake complex. Biol. Invasions 18: 1121-1145.

Fahnenstiel, M.J. Sayers, R.A. Shuchman, F. Yousef, S.A. Pothoven. 2016. Lake-wide phytoplankton production and abundance in the Upper Great Lakes: 2010-2013. J. Great Lakes Res. 42(3):619-629.

Presentations:

Bisgrove, J., G.L. Boyer and M. Satchwell (2016) Communicating Water Quality Parameters Through Maps, Abstracts, Student Spotlight on Research and Outreach, SUNY-ESF, summer 2016.

Miller, R., T. H. Johengen, H.A. Vanderploeg, J. Hoffman, T. Hollenhorst, L. Fiorentino, and J. Austin. Application of GLIDERs to map nearshore-offshore gradients in thermal structure, coastal inputs and biological distributions during 2015 Lake Michigan CSMI, IAGLR, Guelph, Ontario, CA. 6-10 June, 2016.

Kerfoot, W.C., M.M. Hobmeier, F. Yousef, BM Lafrancois, R.P. Maki, J.K. Hirsch. A plague of waterfleas (Bythotrephes): Impacts on community structure and secondary production. 2016 ASLO meeting Santa Fe, NM.

Bootsma, H. A.; Turschak, B. A.: High resolution carbon dioxide dynamics in Lake Michigan over a 10-year period. 2017. ASLO 2017 Aquatic Sciences Meeting (Presentation), Honolulu, HI. 26 February – 3 March, 2017.

Johengen, T.H , Paige, K., Ruberg, S.A., Twiss, M.R. , and R. Pearson. State of the Science for Great Lakes Observations: Conclusions from the 2016 CILER Symposium. 60th IAGLR Conference, Detroit, MI. May 2017.

Austin, J. US Glider Operators meeting: “Gliders on the Great Lakes: data distribution and early results”. January 2017.

Fai, G., Austin, J.A. and McKinney, P.J. Formation of a wind-drive cross-shelf sediment plume in a large lake. 60th IAGLR Conference, Detroit, MI. May 2017.

McKinney, P.J., Austin, J.A. and Fai, G. Remote sensing and underwater glider observations of a springtime plume in western Lake Superior. 60th IAGLR Conference, Detroit, MI. May 2017.

Outreach Activities:

UMD has worked diligently over the last year to improve our public outreach, so that local mariners and interested citizens are aware of our data and use it to inform decisions they make.

- They have redesigned their webpage (http://www.d.umn.edu/buoys/) to display real-time data from both meteorology buoys, provide maps of measured Lake Superior winds, and information about the overall observing program. In addition, the web page links to a similarly themed page showing glider progress, and real-time glider data when available. This page has been designed to be readable on desktop computers and, importantly, mobile devices.
- They have initiated an active Facebook presence (UMDbuoys), which has a small but growing number of followers, and use this to post information about recent meteorological events, glider deployments and recoveries, and other milestones within the lab group.
- “Rack cards” were printed up and have been distributing these at the Great Lakes Aquarium, local marine supply stores, marinas, and public outreach events.
- They continue to work closely with both Minnesota Sea Grant and the Environmental Protection Agency mid-continent Ecology Division Laboratory co-located in Duluth.

CILER collaborated with NOAA GLERL and GLOS to run a 2-day workshop on State of the Science for Great Lakes Observations that involved 30 participants from the US and Canada, including federal and state agencies, research labs, and academia. Results are being used by GLOS to help develop future observing system priorities and to help the region promote future resources and support for the development of critical early warning systems to better assess and monitor ecosystem health.

MTU continues to maintain UGLOS website for public data dissemination.

Austin, J. Featured Speaker, North House Folk School, Northern Landscapes Festival. 3 June 2017
Austin, J. Featured Speaker, Propeller Club, "Ice on the open lake: Observations and Implications". Superior, WI. 27 January 2017.

Theme I: Great Lakes Observing and Forecasting Systems

Lake Circulation and GLCFS: Can HRRR Meteorological Forcing Conditions be used to Improve Hydrodynamic Forecasting Skill?

Principal Investigators: Brad Cardinale (CILER), Dmitry Beletsky (CILER)
NOAA Technical contacts: Eric Anderson (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $30,762

NOAA Strategic Goal:
Goal 1 – Health Oceans
Goal 4 – Resilient Coastal Communities and Economie*s*

Overview and Objectives:

This project evaluates the new National Centers for Environmental Prediction (NCEP) High-Resolution Rapid Refresh (HRRR) model output for the Great Lakes. The HRRR model is a rapid update weather model that uses radar and other observations to improve forecasted weather conditions. Currently, the operational forecasting systems (OFS) including GLOFS and the GLCFS do not use radar data as part of the surface marine observations that drive the hydrodynamic simulations. In addition, the existing OFS use hourly, interpolated meteorological observations to determine over-lake conditions and as a result are unable to resolve fine-scale convective processes and some coarse-scale over-water wind conditions (see Beletsky et al., 2013). Currently, the next generation of the GLCFS is under development using the Finite Volume Coastal Ocean Model (FVCOM), with the first model, Lake Erie Operational Forecasting System (LEOFS), scheduled to transfer from GLERL to CO-OPS for operational implementation by August 2015. The HRRR model has be identified as a candidate for meteorological forcing conditions needed by the FVCOM Lake Erie model (LEOFS), however no study of hydrodynamic response on any body of water has been carried out. Although the potential for HRRR to improve meteorological outlooks is known, we do not know how well the HRRR resolves over-water conditions for the Great Lakes (at 3km scale) or how hydrodynamic models will respond to the implementation of rapid-update weather forcing.

Objectives:

The objective of this project is to determine the suitability of HRRR for hydrodynamic OFS implementation and improvement to model skill.

Specific Aims/Milestones:

Prepare hindcast output (hourly) from the HRRR model (covering Lake Erie) obtained NOAA Earth System Research Laboratory (ESRL) for April 2012-December 2014 period to drive FVCOM. Analyze wind fields in HRRR and interpolation-based dataset. Simulate Lake Erie hydrodynamics with FVCOM model to evaluate lake response to HRRR forcing. Analyze hydrodynamic conditions in Lake Erie to evaluate model skill.

Accomplishments:

Hindcast output from the HRRR model was obtained from NOAA ESRL for 2013 and 2014 (in addition to previously analyzed 2012 data set). Original HRRR output files were converted to netCDF format; quality control conducted, data edited as needed. HRRR data were re-gridded to FVCOM grid for subsequent model runs and to 2 km regular grid for vorticity calculations; time gaps filled with observed data (INTERP). Monthly wind and wind vorticity fields and time-series of lake-average wind vorticity were calculated for detailed comparison of HRRR and INTERP data. FVCOM was run for 2012-2014 with HRRR and INTERP forcing. FVCOM output (depth-averaged currents) was interpolated to 2 km regular grid for vorticity calculation. Monthly current and vorticity fields and time-series of lake-average current vorticity were computed.

Comparison of FVCOM currents driven by HRRR and INTERP forcing showed more anticyclonic circulation in the Lake Erie central basin in summer when HRRR forcing was used. This is in line with known observations and is an improvement in hydrodynamic forecasting, and in particular in GLCFS predictions. Time-series of current vorticity and lake area occupied by currents with anticyclonic vorticity showed correlation with wind vorticity and more pronounced anticyclonic vorticity in HRRR winds in summer than in INTERP winds.

Peer-Reviewed Publications:

Hawley, N., D. Beletsky and J. Wang. 2017. Ice thickness measurements in Lake Erie during the winter of 2010-2011, *J. Great Lakes Res (submitted)*

Cable, R. N., D. Beletsky, R. Beletsky, K. Wigginton, B.W. Locke 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 (in press*)

Presentations:

Beletsky, D., E. Anderson, R. Beletsky. Hydrodynamics of western Lake Erie. IAGLR, May 15-19, 2017, Detroit, MI.

Hawley, N., D. Beletsky, J. Wang, and P. Chu. 2017. Ice thickness measurements in Lake Erie during the winter of 2010-2011. IAGLR, May 15-19, 2017, Detroit, MI.

Beletsky, D., Beletsky, R., Wang, J., Hawley, N. Observations and Modeling of Physical Processes in Lake Erie in Winter. ASLO Aquatic Sciences meeting. Feb 26-Mar 3, 2017, Honolulu, Hawaii.

Beletsky, D., Beletsky, R., Wang, J. and N. Hawley. 2016. Hydrodynamics of Lake Erie in winter. The 33rd SIL Congress, July 31- August 5, Turin, Italy.

Beletsky, R., D. Beletsky, J. Wang and N. Hawley. 2016. Winter Circulation in the Presence of Ice in Lake Erie. The 23nd IAHR International Symposium on Ice, May 31 – June 3, 2016, Ann Arbor, MI.

Beletsky, D., R. Beletsky, N. Hawley and J. Wang. Seasonal Circulation and Thermal Structure of Lake Erie. 18th Workshop on Physical Processes in Natural Waters, Landau, Germany, August 25-28, 2015.

Beletsky, D., R. Beletsky, N. Hawley and J. Wang. Interannual variability of winter circulation and ice in Lake Erie. IAGLR, May 25-29, 2015, Burlington, VT.

Outreach Activities:

None.

Theme I: Great Lakes Observing and Forecasting Systems

Integration of GLAHF with WRF-Hydro

Principal Investigator(s): Brad Cardinale (CILER), Catherine Riseng (University of Michigan)
NOAA Technical Lead(s): Philip Chu (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $21,425

NOAA Strategic Goal:
Goal 3 – Climate Adaptation and Mitigation
Goal 4 – Resilient Coastal Communities and Economies
Goal 5 – NOAA Enterprise-wide Capabilities: Science and Technology Enterprise, Engagement Enterprise, Organization and Administration Enterprise.

Overview:
GLERL is working with the National Center for Atmospheric Research (NCAR) and NOAA National Water Center (NWC) to develop and improve the Weather Research and Forecasting model hydrological modeling extension package (WRF-Hydro) for the Great Lakes Region. The existing hydrologic, land surface and watershed data used in WRF-Hydro require reprocessing to standardize data across the basin because the existing data was 1) incomplete, (e.g., missing the Canadian portion), 2) contains inadequate spatial resolution to simulate the channel routing module of the hydrologic model, or 3) comprises data sets in different spatio-temporal resolution and in different formats.

Objectives:
In order to accelerate WRF-Hydro model development, this project developed standardized and harmonized input data files available from the Great Lakes Aquatic Habitat Framework (GLAHF) database to be used in WRF-Hydro simulations in the Great Lakes region. We processed data at different spatial resolutions and in various data formats including netCDF, ASCII, and shapefiles, with appropriate metadata to meet NOAA environmental data archiving requirements. These data serve as the foundation for GLERL's GIS data warehouse, and will be made available to all scientists at GLERL. The newly created high-resolution datasets provide the required input to configure and test WRF-Hydro, thus accelerating GLERL's capability to develop and improve WRF-Hydro in the Great lakes region. This project also created many critical datasets and data layers in uniform format that can be used for future development of the Great Lakes Forecasting System and serve the Great Lakes community.

Specific Aims/Milestones:

Working with GLERL staff we created, processed, and post-processed data needed for WRF-Hydro. Data processing tasks included:

- Prepared and re-sampled Great Lakes data sets at various spatial resolution and file format (ASCII, netCDF, shapefile, and mxd files)
- Post-processed, regridded, and resampled to different spatial resolutions and file formats as needed

- Created appropriate metadata that meet NOAA environmental data requirement for all files generated
- Added/deleted/joined/fixed files as necessary

Accomplishments:

- Completed the seamless geospatial hydrography ("hydrofabric") for the Great Lakes basin across the US and Canada to Cornwall, Ontario.
- Built necessary stream attributes (e.g., elevation, slope) for the Canadian stream network.
- Built WRF-Hydro input files, in netCDF format, from the geospatial hydrography.

Peer-Reviewed Publications:

Mason, L.A., A.D. Gronewold, M. Laitta, D. Gochis, K. Sampson, E. Klyszejko, J. Kwan, L. Fry, K. Jones, P. Steeves, A. Pietroniro, M. Major, Development of a transboundary hydrographic dataset for the Laurentian Great Lakes, *Bull. Amer. Meteor. Soc.* (in review).

Presentations:

Riseng, C.M., The Great Lakes Aquatic Habitat Framework: a spatial framework, database and tools for Great Lakes management and research. June 2016. Great Lakes Basin-Wide Binational Hydrological Forecasting Stakeholder Exchange and Model Development Workshop, Ann Arbor, MI.

Mason, L.A., Geofabric for operational Great Lakes basin WRF Implementation. June 2016. Great Lakes Basin-Wide Binational Hydrological Forecasting Stakeholder Exchange and Model Development Workshop, Ann Arbor, MI.

Mason, L.A., Geospatial Data in the Great Lakes. December 2016. NOAA GLERL Brown Bag Seminar, Ann Arbor, MI.

Mason, L.A., K. Sampson, A. Dugger, D. Gochis, C.M. Riseng, A.D. Gronewold. Development of a new geospatial hydrofabric to support advanced hydrological modeling. May 2017. International Association for Great Lakes Research, Detroit, MI.

Outreach Activities:

None.

<u>Theme I: Great Lakes Observing and Forecasting Systems</u>

Data Management, Handling & Analysis of Great Lakes Time Series

Principal Investigator(s): Brad Cardinale and Ayumi Manome (CIGLR)
NOAA Technical Lead(s): Brent Lofgren and Eric Anderson (NOAA-GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $33,952

NOAA Strategic Goal:
Goal 2 – Weather-Ready Nation
Goal 3 – Climate Adaptation and Mitigation

Overview:
GLERL has benefited from enhanced data management of existing datasets, and those generated in the past year. This took the form of cataloguing, archiving, and serving both data and metadata. The cataloguing effort made awareness of existing datasets more accessible by users internal to GLERL and CIGLR. The serving effort made the data more available and usable. Also, within the scope of this project was the handling of data being generated by modeling activities and field measurements (e.g., Acoustic Doppler Current Profiler [ADCP] data) that was done cooperatively by CILER and GLERL, to analyze, reduce, and transfer these results to long-term archive.

Objectives:
The objective of this project was to support the data management needs of all projects at CILER and GLERL. The enhanced and lab-wide coordinated data management efforts have been highlighted by NOAA mandates, and by the activities of other Great Lakes organizations such as USGS Great Lakes Science Center and the Great Lakes Observing System. Our scientific efforts were accompanied by a need to catalog, document, standardize, and serve internal data products to the appropriate extent. Although some GLERL and CILER projects and products with more advanced data management schemes in place, others need more work. This CILER project took steps to upgrade the level of data management by assigning personnel resources dedicated to this task.

This project aimed to satisfy these goals:

1. Collect and make available information on the existence and attribution of datasets at CILER and GLERL on a systematic basis, to raise awareness among internal users.
2. Manage the work burden for satisfying data management requirements in proportion to the effort required to generate the data and its general usefulness, and within GLERL's role as a research laboratory rather than a data center.
3. Provide necessary data processing, management, and analysis for data collection during the 2016 field season.

Specific Aims/Milestones:

1. Catalog—Document the existence of datasets.
2. Metadata—Make the strongest practical effort at documenting the method of generating the data. Include the information on where, when, and how it was generated, along with links to peer-reviewed and other literature, and practical considerations of parsing the data.
3. Data format—Standardize datasets that will be served to external users, using current formatting standards acceptable to the broader scientific community. This should make them usable off the shelf by standard analysis software such as ArcGIS.
4. Serving—Guidance and standards from NOAA are largely geared toward data that will be served to the public, especially through dedicated data centers. However, in order to keep the data-related workload within bounds, we will need to be selective about which datasets to make available on servers, with the associated user support that might be necessary.

Accomplishments:

- Created metadata for existing datasets that complies with the International Organization for Standardization (ISO) standards for metadata and those datasets were then added to the data server.
- GeoNetwork was updated to the latest version and the most current set of ISO metadata standards were added.
- Data management plans were created for all of the 2016 projects so that progress can be tracked and can be added to GeoNetwork when they are ready.
- ADCP data that was collected last year was processed, quality checked, and put into NetCDF format.

Peer-Reviewed Publications: None

Non-Peer-Reviewed Publications: None

Presentations: None

Outreach Activities: None

Theme I: Great Lakes Observing and Forecasting Systems

Modeling Sea Ice-ocean-ecosystem Changes, and Great Lakes Ice Modeling, Measurements, and Climate Changes

Principal Investigator(s): Brad Cardinale, Ayumi Fujisaki-Manome (CILER)
NOAA Technical Lead(s): Jia Wang (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $96,392

NOAA Strategic Goal:
Goal 3 – Climate Adaptation and Mitigation

Overview:
Advancing ice-ocean/lake-ecosystem modeling is critical to provide better guidance in climate adaptation and mitigation. GLERL and CILER have worked on the development of a Coupled Ice-Ocean Model (CIOM) that includes a 3-D, 9-compartment, Physical-Ecosystem Model (PhEcoM), and the Finite-Volume Community Ocean Model (FVCOM) coupled with an unstructured grid version of Los Alamos Sea Ice Model (UG-CICE). In this project we further improved CIOM-PhEcoM and FVCOM-Ice in applications to the Bering-Chukchi-Beaufort Seas and the Great Lakes, respectively.

Objectives:

I) *Bering-Chukchi-Beaufort Seas Ice-Ocean-Ecosystem Modeling*
Conduct CIOM-PhEcoM simulations for years covered by the Russian-American Long-term Census of the Arctic (RUSALCA) moorings. Conduct model-observation comparison.

II) *FVCOM-ice*
Test a central time differencing scheme in 1996-2005 simulations.

III) *2016 Great Lakes Ice Atlas Update*
Complete the annual update of the Great Lakes Atlas.

Specific Aims/Milestones:

1) Synthesis studies using the coupled CIOM-PhEcoM-PROFS model system for the period of 1990-present. Reconstruction of the realistic circulation and plankton dynamics in the Bering-Chukchi-Beaufort Seas will be accomplished.
2) Assimilation of RUSALCA-observed biogeochemical data into PhEcoM. Conduct simulations covering the same RUSALCA surveys, and prepare and process the data assimilation of SIC, SSH, and RUSALCA moorings. Our synthesis goal was to compare the simulation and assimilation results using the CIOM-PhEcoM-PROFS system with the RUSALCA and other observations in terms of reconstruction of ocean circulation and ecosystem dynamics in the RUSALCA.
3) Analyze data from T/S Oshoro-maru, RUSALCA, and Pacific Arctic Group (PAG) cruises.
4) Conduct FVCOM-ice simulation of Great Lakes ice in response to climate change, using a modified numerical scheme and ice model for the period 1996-2005.
5) Update Great Lakes ice atlas for 2016 and provide seasonal ice projections.

Accomplishments:

Milestone 1-3:

- CIOM-PhEcoM simulations for the Bering-Chukchi-Beaufort Seas were conducted.
- The simulation results were compared with the RUSALCA observations.
- The analyses were documented into a peer-reviewed paper (Hu et al. 2016).
- Configured FVCOM in the Arctic Ocean, succeed in setting up rotating system for the model.
- A closed boundary case was tested and succeeded.
- The problem of (FVCOM) ice accumulation at open boundary was solved.
- Major bug in FVCOM for gravity was found and reported.

Milestone 4:

- Hindcast completed for the period 1994-2016 using said model combination.
- Validation with regards to annual maximum ice cover (AMIC).
    - 17/23 simulated years: <15% absolute error compared to observations. (Indication of model capturing interannual variability.)
- Validation of daily time series for select years showed good qualitative agreement.

Milestone 5:

- Seasonal Ice Projections: November 2016, projections made for the coming 2017 winter using two methods:
    - 1) regression model using four teleconnection indices as regressors
    - 2) FVCOM-ICE projection using CFS 9-Month seasonal forecast.
    - Unfortunately, both methods showed little skill during the anomalous low-ice year. The projection methods will be improved for next year.

Peer-Reviewed Publications:

Hu, H., J. Wang, H. Liu, and J. Goes (2016), Simulation of phytoplankton distribution and variation in the Bering-Chukchi Sea using a 3-D physical-biological model, J. Geophys. Res. Oceans, 121, 4041–4055, doi:10.1002/2016JC011692.

Non-Peer-Reviewed Publications:

None.

Presentations:

Fujisaki-Manome, A., Wang, J. and Anderson, E.J., Modeled ice thickness in Lake Erie with different parameterizations of the ice strength, International Association for Great Lakes Research annual conference, May 15th-19th, 2017, Cobo Hall, Detroit, MI.

Hu, H., Wang, J., Liu, H. and Goes, J., Simulation of Phytoplankton Distribution and Variation in the Bering-Chukchi Sea using a 3D Physical-biological model, International Association for Great Lakes Research annual conference, May 15th-19th, 2017, Cobo Hall, Detroit, MI.

Kessler, J., J. Wang, *Validation of Interannual Variability of Great Lakes Ice Cover, 1994-2008.* Lake Workshop: Improving Weather Forecasting Models with Satellite Data Assimilation, April 11th, 2017, University of Waterloo, Waterloo, ON, Canada.

Kessler, J., J. Wang, A. Manome, P. Chu, *Modeling Great Lakes Ice Cover using FVCOM and UG–CICE.* International Association for Great Lakes Research annual conference, May 15th-19th, 2017, Cobo Hall, Detroit, MI.

Wang, J., Kessler, J.A., Hu, H.[2], Fujisaki-Manome, A., Clites, A., Lofgren, B.M. and Chu, P., Seasonal forecast of Great Lakes ice cover using multi-variable regression and FVCOM+ice models, International Association for Great Lakes Research annual conference, May 15th-19th, 2017, Cobo Hall, Detroit, MI.

Outreach Activities:

None.

Theme I: Great Lakes Observing and Forecasting Systems

Great Lakes Heat Budget-Water Budget Connections

Principal Investigators: Brad Cardinale and Dmitry Beletsky (CILER)
NOAA Technical contacts: Brent Lofgren (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $18,897

NOAA Strategic Goal:
Goal 1 – Health Oceans
Goal 4 – Resilient Coastal Communities and Economies

Overview and Objectives:
This project draws on various GLERL modeling and data resources that have not previously been used in combination. It expands on recent work at GLERL on quantifying heat storage in the Great Lakes and connecting this to over-lake evaporation and the general water budget of the lakes. It capitalizes on modeled (NARR, HRRR, etc.) and observed meteorological datasets, and especially on the more recent advent of eddy covariance-based observations of evaporative and sensible heat fluxes from the Great Lakes Evaporation Network (GLEN). These datasets were used to drive hindcast simulations from the suite of models that exist at GLERL. Use of these models augments the observational dataset with more spatial richness in the information about lake surface heat and moisture fluxes, lake thermal structure, lake effect precipitation, and coastal processes.

Objectives:

Main objective of this project is to compare alternative meteorological forcing used by hydrodynamic models and compare heat fluxes computed by the hydrodynamic model with observations.

Specific Aims/Milestones:

Coordinate with GLERL scientists on estimates of over-lake precipitation. Compare lake-atmosphere turbulent heat fluxes (with proper allowance for spatial resolution) based on eddy covariance stations, Large Lakes Thermodynamic Model (LLTM), Coupled Hydrosphere-Atmosphere Research Model (CHARM), Weather Research and Forecasting (WRF), Finite Volume Coastal Ocean Model (FVCOM), and Princeton Ocean Model (POM). Evaluate the influence of lake heat storage on evaporation under all of these modeling and observation systems. Complete a retrospective run of FVCOM and interface results with this project. Analyze meteorological observations and turbulent heat fluxes produced by FVCOM.

Accomplishments:

Bulk parameterizations used by FVCOM for surface heat flux calculations involve air temperature and wind speed, therefore we tested accuracy of the High-Resolution Rapid Refresh (HRRR) atmospheric model alternative forcing used by FVCOM by comparing HRRR output to observations made at several meteorological buoys in Lake Erie. Results show that HRRR model predicted air temperature over lake rather accurately with RMSE of about 1^{o}C and wind speed with RMSE of about 1 m/s. We also found that HRRR model predictions improved in 2014 compared with 2012-2013.

Next, FVCOM was run with HRRR (atmospheric model) and INTERP (observation-based) forcing and surface flux components were saved for comparison with Lake Erie eddy covariance flux observations during 2012-2014. In comparison with observations, we coordinated and shared results with GLERL-CILER researchers who used the same measurements for testing the accuracy of different flux parameterizations in FVCOM in the NOAA Coastal Storms project. In particular, we used the same model node for comparison with Long Point observations that GLERL-CILER researchers identified while investigating flux footprint. For statistical analysis, only data during ice-free period were employed because the model was run without ice. Overall sensible and latent heat fluxes calculated by the model matched observations reasonably well while the fluxes in the HRRR case were slightly more accurate in most years. Influence of lake heat storage on evaporation was investigated in case of Lake Michigan (Gronewald et al, 2015).

Peer-Reviewed Publications:

Hawley, N., D. Beletsky and J. Wang. 2017. Ice thickness measurements in Lake Erie during the winter of 2010-2011, *J. Great Lakes Res (submitted)*

Non-Peer-Reviewed Publications:

None.

Presentations:

Hawley, N., D. Beletsky, J. Wang, and P. Chu. 2017. Ice thickness measurements in Lake Erie during the winter of 2010-2011. IAGLR, May 15-19, 2017, Detroit, MI.

Beletsky, D., Beletsky, R., Wang, J. and N. Hawley. Observations and Modeling of Physical Processes in Lake Erie in Winter. ASLO Aquatic Sciences meeting. Feb 26-Mar 3, 2017, Honolulu, Hawaii.

Beletsky, D., Beletsky, R., Wang, J. and N. Hawley. 2016. Hydrodynamics of Lake Erie in winter. The 33rd SIL Congress, July 31- August 5, Turin, Italy.

Outreach Activities:

None.

Theme I: Great Lakes Observing and Forecasting Systems

GLRI Nearshore: Circulation and Thermodynamics

Principal Investigators: Brad Cardinale and Dmitry Beletsky (CILER)
NOAA Technical contacts: Eric Anderson (NOAA-GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $163,307

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

Overview:
In 2016-2017, CILER continued to support GLERL on the operational development of the Lake Erie harmful algal bloom (HAB) forecasts. These forecasts are based on Great Lakes Coastal Forecasting System (GLCFS) output, in particular circulation and thermal structure produced by the Finite Volume Coastal Ocean Model (FVCOM, Anderson et al., 2010). The Lake Erie Operational Forecasting System (LEOFS, part of the Great Lakes Operational Forecasting System [GLOFS]) became operational in 2015. Comparison of model results with the first long-term current observations conducted in Lake Erie's western basin in 2015 will be very beneficial for additional testing of model skill. In addition, unlike the research version of FVCOM, neither of the existing hydrodynamic forecasting systems (GLCFS run by GLERL; GLOFS run by NOS CO-OPS) include the Maumee River flow in their predictions. Maumee River flow may not only influence local and regional lake hydrodynamics (especially during major run-off events), but also influence dynamics of HABs in the vicinity of Toledo, OH, and beyond (Michalak et al., 2013). Finally, the existing hydrodynamic forecasting systems use different meteorological forcing data: GLCFS uses spatially-interpolated observations in its hindcasts, while GLOFS uses output from the new

National Centers for Environmental Prediction (NCEP) High-Resolution Rapid Refresh model (HRRR). While spatial interpolation is done with the natural neighbor method (Beletsky et al., 2003), the HRRR model is a rapid update weather model that uses radar and other observations to improve forecasted weather conditions at a 3-km scale. Although the potential for meteorological models to improve outlooks is known (Beletsky et al., 2003; Beletsky et al., 2013), no systematic study of hydrodynamic response to HRRR forcing on any body of water has been carried out.

Objectives:

Main objective of this project is to investigate hydrodynamics and the accuracy of hydrodynamic modeling in the western basin of Lake Erie and how they relate to the inclusion of Maumee River and the choice of meteorological forcing functions.

Specific Aims/Milestones:

Analyze ADCP data collected by GLERL in the western basin of Lake Erie during summer 2015. Prepare two versions of meteorological forcing functions will to drive FVCOM: hourly observation-based data and output from the HRRR model. Run the baseline version of FVCOM using a single tributary in the western basin (Detroit River) and observed meteorology. Evaluate model skill using ADCP data. Make an identical model, but with Maumee River flow included in simulations, and check improvements in accuracy. Use observations of lake temperature for additional model validation. Repeat both model scenarios using the HRRR forcing and check improvement to model skill.

Accomplishments:

ADCP data in the western basin of Lake Erie in 2015 (4 ADCP moorings) were analyzed and several strong wind events in summer and early fall were identified as focus of model validation. Surface drifter observations made in August in the northern part of western basin were also analyzed and compared with HAB movement. Two versions of meteorological forcing functions were prepared to drive FVCOM in 2015: hourly observation-based interpolated data and output from the HRRR model. In addition, Maumee River flow measurements in 2015 were analyzed, missing data filled and prepared for FVCOM run. The baseline version of FVCOM, i.e., with a single tributary in the western basin (Detroit River) – configuration currently used by both GLCFS and GLOFS, was run for 2015, using observed meteorology (INTERP case). Both observations and model showed well mixed water column most of the time and seasonal cycle was well predicted by the model although with a slight warm bias.

An identical to INTERP case model run but with Maumee River flow included was conducted and results showed that the area affected by Maumee River flow was restricted to the Maumee Bay and changes in circulation only occurred during strong runoff events. Both model scenarios described above were repeated using the HRRR forcing. Circulation patterns changed substantially due to differences in spatial variability in HRRR forcing. Comparison with ADCP observations showed mixed results: during some months and strong wind events the HRRR forcing produced more accurate circulation patterns and timing/magnitude of wind-driven events, while during other months and events the INTERP forcing produced superior results.

Peer-Reviewed Publications:

Hawley, N., D. Beletsky and J. Wang. 2017. Ice thickness measurements in Lake Erie during the winter of 2010-2011, *J. Great Lakes Res (submitted).*

Cable, R. N., D. Beletsky, R. Beletsky, K. Wigginton, B.W. Locke 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 (in press*).

Non-Peer-Reviewed Publications:

None.

Presentations:

Beletsky, D., E. Anderson, R. Beletsky. Hydrodynamics of western Lake Erie. IAGLR, May 15-19, 2017, Detroit, MI.

Hawley, N., D. Beletsky, J. Wang, and P. Chu. 2017. Ice thickness measurements in Lake Erie during the winter of 2010-2011. IAGLR, May 15-19, 2017, Detroit, MI.

Beletsky, D., Beletsky, R., Wang, J. and N. Hawley. Observations and Modeling of Physical Processes in Lake Erie in Winter. ASLO Aquatic Sciences meeting. Feb 26-Mar 3, 2017, Honolulu, Hawaii.

Beletsky, D., Beletsky, R., Wang, J. and N. Hawley. 2016. Hydrodynamics of Lake Erie in winter. The 33rd SIL Congress, July 31- August 5, Turin, Italy.

Outreach Activities:

None.

Theme I: Great Lakes Observing and Forecasting Systems

Dynamical Core Implementation for the Next Generation Global Prediction System (NGGPS)

Principal Investigator(s): Richard B. Rood
NOAA Technical Lead(s): Ivanka Stajner (NOAA)
NOAA Sponsoring Office: National Weather Service, Next Generation Global Prediction System Program Office
Budget Amount: $181,520

NOAA Strategic Goal:
Goal 2 – Weather-Ready Nation
Goal 5 – NOAA Enterprise-wide Capabilities: Science and Technology Enterprise, Engagement Enterprise, Organization and Administration Enterprise

Overview:

The NOAA National Weather Service is developing a Next Generation Global Predication System (NGGPS) that will replace the currently-used Global Forecast System (GFS), with NGGPS-GFS parallel forecast tests planned to begin in early 2018. This project extends previous work by Dr. Rood for the

NOAA-funded project *Dynamical Core Selection for the Next Generation Global Prediction System (NGGPS)*, in which the project team participated in test design, sensitivity studies, interpretation of results, and assured the objectivity of the testing protocol.

The project covered NGGPS's pre-implementation and development testing phase, during which the dynamical core was integrated together with the physics parameterizations, the data assimilation system, and the other subsystems that compose the end-to-end forecast system. Additional tasks for the pre-implementation and development testing phase will focused on the physics-dynamics coupling strategy and the characteristics of the variable-resolution technique of the selected dynamical core. The investigations took advantage of the upcoming Dynamical Core Model Intercomparison Project (DCMIP-2016) that also focused on these aspects. DCMIP-2016 thereby informed and advanced the NGGPS development process. At the end of the development test phase, NGGPS is expected to be ready for parallel testing and final-stage development and testing in an operational weather-forecasting framework.

Objectives:
Serve as an external expert on planning and guidance of the implementation of NOAA's Next Generation Global Prediction System

Specific Aims/Milestones:

Participate in regular meetings with NOAA and external teams to develop community governance models, and to provide external expert guidance to program managers on the Next Generation Global Prediction System. Participate in face-to-face meetings as scheduled by program mangers.

Accomplishments:

The NGGPS Dynamical Core Test Group provided a final report to the NGGPS Program Office on dynamical core evaluation September 22, 2016.

We developed the first version of a community governance model that was presented at the National Centers for Environmental Predictions (NCEP), Strategic Implementation Plan (SIP), Community Meeting during the first week of August 2017.

We participated in the SIP Dynamics and Nesting Working Group.

Publications:

Dynamical Core Evaluation Test Report for NOAA's Next Generation Global Prediction System (NGGPS) (https://www.earthsystemcog.org/site_media/projects/dycore_test_group/20160922_Final_Report_NGGPS_Dycore_Phase_2_Test_Report_website.pdf)

Draft: Governance Model for Unified Forecast System for NCEP's Product Suite (https://docs.google.com/document/d/1dpm9U1wR0-bZHTrCP0Tl4BCF0leXfV50I9V7Xncct8Y/edit)

Presentations:

Presentations at NCEP SIP Community meetings, April and August 2017.

Outreach Activities:

PI Rood maintains the public website for the group:
https://www.earthsystemcog.org/projects/dycore_test_group/
https://www.earthsystemcog.org/projects/communitygovernance/
https://www.earthsystemcog.org/projects/umac_model_advisory/

Theme I: Great Lakes Observing and Forecasting Systems

Great Lakes CoastWatch Research Assistant for NOAA CoastWatch Program Element

Principal Investigator(s): Brad Cardinale and Thomas Johengen (CILER)
NOAA Technical Lead(s): George Leshkevich (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $121,561

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
Goal 5 – NOAA Enterprise-wide Capabilities: Science and Technology Enterprise, Engagement Enterprise, Organization and Administration Enterprise

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).

Objectives:

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.

Specific Aims/Milestones:

This project is a continuation of CILER's collaboration in the activities of the CoastWatch Great Lakes Regional Node at the NOAA Great Lakes Environmental Research Laboratory within the project period. Specific activities included:

- Continue participation in the development of Great Lakes regional products from remotely sensed data and dissemination of CoastWatch managed data, products, and information for research, operational, and/or educational purposes.
- Assist in research on algorithm development of remotely sensed data.
- Assist in development of project reports and scientific presentations.
- Provide the necessary computer system and software support to facilitate these activities.
- Complete products including upwelling, color producing agents (chlorophyll, CDOM, suspended mineral), and ice type mapping.
- Transfer the Great Lakes CoastWatch web site to a new server and the implement the Thematic Real-time Environmental Distributed Data Services (THREDDS) server with ERDDAP (Environmental Research Division's Data Access Program) as an optional server on the CoastWatch Great Lakes website. This will entail installation on the new server and testing within the project period. Future plans include implementing LAS (Live Access Server) as image display server for THREDDS.

Accomplishments:

A. Monitored, developed, and improved the operational program to receive, process, analyze, and archive the CoastWatch data.
    a. Finished the program (Unix script, PHP and IDL program) to download the new ocean color products (CPA) includes:
        i. Wrote Unix script to download the CPA files in geotif format.

ii. Made the new data file format (png with color bar).

b. Wrote the Unix script and modified the IDL program to process the Great Lakes Surface Environmental Analysis (GLSEA) files to make Lake Michigan upwelling products.

c. Recalculated the daily lake average surface water temperature (1995-2013) from GLSEA with Ice overplayed. The pixels covered with ice were considered to be 0.2 degrees.

B. Maintained and improved the CoastWatch Great Lakes Node web server, designed and developed the web site:

a. Finished the THREDDS set up and made the CoastWatch data files (hdf, png, jpg, asc, tif, …) available on the THREDDS server.

b. Finished the ERDDAP server set up and made the Ocean color files (nc) available on ERDDAP server.

c. Finished the program (Unix script and IDL program) to make the new file format (GLSEA geotif) for RealEarth server and made the data file available on CW web page.

d. Wrote the Unix script and modified the IDL program to make the Lake Michigan upwelling program available online.

e. Wrote PHP program to make the CPA data files available on CoastWatch web site.

f. 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 convert the CPA data files format from geotif to netCDF format, which include:

i. Converted the geotif files from projected system (X,Y) to geodetic system (Lat, Long)

ii. Converted files from geotif to nc format.

iii. Added the attributes that required by ERDDAP (time, color bar range, etc.

D. Participated in CoastWatch related research and prepare presentations for meetings:

a. Wrote and modified the IDL program to assist to GLERL scientist (Anne H. Clites) to make the graph to display the Great Lakes long term sea surface temperature (SST) compare to current year SST.

b. Assisted with presentation for the 60th annual meeting of the International Association for Great Lakes Research (IAGLR): "Great Lakes CoastWatch – New Data Sets and New Data Servers"

c. Wrote the programs (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."

d. Assisted in the mentorship of a Great Lakes summer fellow:

i. Assistant to GLERL summer student to convert 12x512 ice chart to 1024x1024 chart, which requires the shore line of the chart match the GLSEA shore line.

Peer-Reviewed Publications:

None.

Non-Peer-Reviewed Publications:

None.

Presentations:

G. Leshkevich and S. Liu, Great Lakes CoastWatch – New Data Sets and New Data Servers, IAGLR 2017, 60th Annual Conference on Great Lakes Research Detroit, Michigan, May 15-19, 2017

G. Leshkevich and S. Liu, CoastWatch Great Lakes Node Summary, CoastWatch Node Managers Meeting, SWFSC, Santa Cruz, Ca, July 31-August 3, 2017

Outreach Activities:

- Implemented daily, cloud-free Great Lakes CoastWatch GLSEA SST data on the RealEarth map server hosted by SSEC, University of Wisconsin.
- Contributed Great Lakes SST/ice cover analysis to the 2017 quarterly issues of the Great Lakes Climate Quarterly Reports.
- Great Lakes CoastWatch booth/display at the Washtenaw Community College Earth Day Event.
- Provided data and information to support media interview and data/information requests.

Theme II: Invasive Species

Impacts of Asian Carp on Great Lakes Food Webs and R2X Transition to USACE

Principal Investigator(s): Brad Cardinale and Hongyan Zhang (CILER)
NOAA Technical Lead(s): Doran Mason and Ed Rutherford (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $20,371

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

Overview:
Bighead (*Hypophthalmichthys nobili*) and silver (*H. molitrix*) carp (Asian carps) threaten to invade the Great Lakes and disrupt aquatic food webs and fisheries through their consumption of lower trophic levels. Asian carps can potentially cause shifts in phytoplankton and zooplankton species composition and relative abundances resulting in potential changes up the food web. In river and lake ecosystems in North America, Asia, and Europe, the introductions of Asian carps have resulted in the decline of many native fish species, with planktivorous fish and fish with planktivorous stages being particularly affected. Some of our modeling results in Lake Erie suggest that if Asian carps can reach a high biomass, there could be consequences to important recreational and commercial fish species. However, Asian carp impacts may differ between ecosystems, including amongst the individual Great Lakes, as the overall impacts are likely driven by lake productivity and fish community structures. Ecosystem-level and habitat-specific analyses of Asian carp impacts on the Great Lakes are not available (except our Lake Erie results), and they are urgently needed for management decisions. In this project, we complete the spatially-explicit ecosystem models for Lake Michigan, and transition our results to the U.S. Army Corps of Engineers (USACE) to support their reporting requirements for the Great Lakes and Mississippi River Interbasin Study (GLMRIS).

Objectives:

Our overall goals were to 1) assess the ability of bighead and silver carps to survive and grow (using ambient plankton and benthos prey densities, hydrodynamics, and thermodynamics) in Lake Michigan, 2) determine the potential impacts of Asian carps on the Lake Michigan food web and fisheries, and 3) to transition our results to management agencies that rely on scientific information of invasive species impacts to make policies and management priorities.

Specific Aims/Milestones:

Specific milestones include model calibration, impacts assessment, comparison between models, and engaging in stakeholder interactions.

Accomplishments:

1) We have run the Atlantis ecosystem model for Lake Michigan and the results are consistent from what we have found for Lake Erie. We are working to link this model with an economic model to asses Asian carp effects on regional economy.

2) We are running bioenergetic models to determine growth potential for Asian carp in Lake Michigan. This effort involves using output from Mark Rowe's (2015) 3-dimensional biophysical model with spatially explicit data on zooplankton biomass, chlorophyll a, and temperature by depth for Lake Michigan. As our effort includes zooplankton biomass, and higher estimates of chlorophyll a in the deep chlorophyll max layer, it should improve upon predictions made by Anderson et al. (2017) who used remote sensing data on surface water temperature and chlorophyll a to predict growth potential of Asian carp in a few places in Lake Michigan.

3) We are revising our manuscript on individual-based modeling of Asian carp impacts on the Saginaw Bay food web. We anticipate submitting it for review in fall 2017.

4) We are drafting a manuscript comparing Asian carp impacts on 3 Great Lakes (Lake Erie, Michigan, and Huron) using the Ecopath with Ecosim food web model.

Peer-Reviewed Publications:
None.

Non-Peer-Reviewed Publications:
None.

Presentations:
Zhang, H., Rutherford, E.S, Mason, D. M., Ivan, L., Campbell-Arvai, V., Beletsky, D., Hoff, M., and Fulton, E. Ecosystem and Fisheries Impacts of Asian Carp on Lake Michigan – the Atlantis Ecosystem Model Approach. The 2016 annual meeting of American Fisheries Society, Kansas City, MO, August 21-26, 2016.

Outreach Activities:
Invited webinar. Zhang, H., Mason, D., Ivan, L., and Rutherford, E.S. Modeling potential effects of bighead and silver carp on Great Lakes food webs. Canada AIS Centre. Mar 28, 2017.

Theme II: Invasive Species

GLANSIS: Science and Management Support

Principal Investigator(s): Brad Cardinale (CILER)
NOAA Technical Lead(s): Felix Martinez (NCCOS)
NOAA Sponsoring Office: NCCOS, Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $73,554

NOAA Strategic Goal:
Goal 1 – Healthy Oceans

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 aquatic nonindigenous species (ANS). In this project, we proposed to maintain, improve, and enhance GLANSIS to better inform managers of current and future threats from ANS.

Objectives:
1. Maintain and update GLANSIS with new reports of ANS (currently documented and new) in unique locations, along with new research, case studies, and information for management.
2. Improve information extraction capability by improving existing interfaces and implementing a new "Map Explorer" which will allow users to search for ANS and view their geospatial distribution in and around the Great Lakes Basin. The map interface will also allow for the overlaying of said distributions on top of relevant environmental and habitat suitability layers from the Great Lakes Aquatic Habitat Framework (GLAHF).

Specific Aims/Milestones:

- Work with the USGS Nonindigenous Aquatic Species database group in development of a new GLANSIS website and interfaces to desired data; Beta test the new interface.
- Develop new fact sheets (including risk assessments) for at least 5 species from the list (of 15) that have been 'recommended for inclusion' in the database; Review all fact sheets that are more than 5 years old and update as needed.
- Develop initial maps of ANS habitat suitability, develop protocol for serving these via the "Map Explorer" and beta test a pilot product.

Accomplishments:

- New website: https://www.glerl.noaa.gov/glansis/ soft-launched in June 2017 featuring
  - Modified Non-indigenous Species List Generator and Fact Sheet Access: https://www.glerl.noaa.gov/glansis/nisListGen.php
  - And **new** Map Explorer: https://www.glerl.noaa.gov/glansis/mapExplorer.php

    - This is the first major upgrade to the GLANSIS interface since its development (~2003) and the first major upgrade to content type since 2011 (when management fields were added to the fact sheets.
- One new factsheet (*Thermocyclops crassus*) has been added to the database and approximately 11 additional sheets are in progress. Seven older factsheets have been updated and approximately 7 additional sheets are near completion (pending review).
- Developed a suite of habitat suitability maps for Asian carp and initiated conversations with GLAHF for serving the data. We anticipate the Map Explorer interface as constructed will be able to handle this new type of data, though it remains to be tested.

Peer-Reviewed Publications:

None.

Non-Peer-Reviewed Publications*:

*(*note: these do go through an 'Expert Review' but not a blind peer review)*

Crassula helmsii USGS Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI. <https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?SpeciesID=69&Potential=Y&Type=2&HUCNumber=> Revision Date: 2/10/2017

Cherax destructor USGS Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI. <https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?SpeciesID=58&Potential=Y&Type=2&HUCNumber=> Revision Date: 2/21/2017

Osmerus eperlanus USGS Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI. <https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?SpeciesID=63&Potential=Y&Type=2&HUCNumber=> Revision Date: 3/15/2017

Limnoperna 76ortune USGS Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI. <https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?SpeciesID=68&Potential=Y&Type=2&HUCNumber=> Revision Date: 3/9/2017

Pistia stratiotes USGS Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI. <https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?SpeciesID=15&Potential=Y&Type=2&HUCNumber=> Revision Date: 4/13/2017

Pseudorasbora parva USGS Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI. <https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?SpeciesID=64&Potential=Y&Type=2&HUCNumber=DGreatLakes> Revision Date: 4/3/2017

Stratiotes aloides USGS Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI. <https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?SpeciesID=70&Potential=Y&Type=2&HUCNumber=DGreatLakes> Revision Date: 5/11/2017

Thermocyclops crassus USGS Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI.

<https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?SpeciesID=2793&Potential=N&Type=0&HUCNumber=DGreatLakes> Revision Date: 6/19/2017

Presentations:

Alsip, P., Rice, N., Iott, S., Sturtevant, R.A., Martinez, F., and Rutherford, E. The Great Lakes Aquatic Nonindigenous Species Information System Watchlist. IAGLR 2017.

Sturtevant, R.A., Martinez, F., Rutherford, E.S., Elgin, A.K., Smith, J.P., and Alsip, P. Update on the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS). IAGLR 2017.

Outreach Activities:

- GLANSIS is a publicly-available outreach product.
- Participated in Huron River Days outreach event. Handed out GLANSIS flyers and engaged the public in discussions about Great Lakes ANS.

THEME III: Ecological Risk Assessment

MOCNESS in the Great Lakes: Gear Efficiency Comparisons and Estimates of Fine-Scale Vertical Spatial Structure of the Food Web

Principal Investigator(s): Brad Cardinale (CILER)
NOAA Technical Lead(s): Ed Rutherford (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $66,447

NOAA Strategic Goal:
Goal 1 – Healthy Oceans

Overview:

Recent studies at NOAA GLERL (Vanderploeg et al. 2015) have shown that there is extreme diel vertical migration of zooplankton, micronekton, and fishes, and their densities are highly concentrated in relatively thin layers associated with thermal structure and phytoplankton concentrations that can be sampled well only by new technology. Despite extensive sampling of the food web by traditional methods, critical nagging questions remain regarding vertical position and movement of zooplankton, *Bythotrephes*, *Mysis*, larval fish, and fish predators relative to light, temperature, and chlorophyll. Precise definition and quantification of spatial structure and density are critical to understanding food web structure and function, and for ecosystem forecasting. New sampling equipment is needed to sample the food web at fine horizontal and vertical scales. To address this gap in our understanding of the spatial distribution of lower food web organisms, the MOCNESS (Multiple Opening Closing Nets Environmental System Sampler) was purchased by NOAA GLERL to sample fine-scale (<5 m) vertical and horizontal distributions of mesozooplankton, *Bythotrephes*, and micronekton including *Mysis* and larval fishes.

In FY 2016-2017, CILER supported NOAA GLERL in the use of the MOCNESS 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 Michigan. Gear efficiency tests also were conducted to compare catches of plankton in the MOCNESS with those collected with traditional gears.

Objectives:
1. Evaluate efficiency of MOCNESS for sampling Mysis and fish larvae.
2. Characterize densities of organisms in fine vertical layers of offshore food web.

Specific Aims/Milestones:

Aims:

1. Characterize fine spatial structure of the lower food web and its relationship to physical variables and invasive species.
2. Compare gear efficiencies of traditional (Tucker trawl, bongo sampler) and new (MOCNESS) sampling gears.
3. Continue monitoring densities of fish larvae and zooplankton in nearshore and offshore areas.

Milestones:
1. Densities of plankton and fish larvae are sampled in April, July, and September to characterize spatial structure of food web.
2. Plankton and fish larvae are sampled by MOCNESS and traditional gears during night and day at the offshore site.
3. Densities of plankton and fish larvae in MOCNESS and traditional gears are estimated and compared to evaluate gear efficiency.
4. Otoliths are extracted and diets analyzed for alewife and bloater larvae.
5. Write and submit annual report summarizing results.

Accomplishments:

Characterize fine spatial structure of the lower food web:
In July and September 2016 in Lake Michigan, and in May 2017 in Lake Huron, we deployed the MOCNESS to characterize fine-scale vertical structure of the lower food web. In Lake Michigan, densities of fish larvae at the 110 m offshore site were higher at night compared to day, and higher in the metalimnion compared to the epilimnion. Analysis is underway of larval fish species composition and growth rates for Lake Michigan in 2016 and Lake Huron in 2017. In April and May 2017, preliminary results indicate coregonid larvae were abundant at nearshore sites in Thunder Bay, but absent at offshore sites in the main basin of Lake Huron.

Gear Efficiency Studies:
- *Mysis diluviana* (opossum shrimp) is a key member of Great Lakes aquatic food webs and an important prey for pelagic fish. We evaluated catch efficiency of Mysis collected in June, July and September 2016 in MOCNESS with LED strobe lighting that is used to sample Euphausid shrimp (krill), plankton, and fish larvae in marine waters. We made replicate tows in thermally stratified depth layers during night, and compared Mysis densities sampled with the LED strobe on vs strobe off. There were no significant differences in Mysis density or size in samples with strobe on or off in any month. Mysis densities were highest in the metalimnion at night. We

concluded that the strobe flash light had no effect on catch avoidance by Mysis. (Detailed results are presented in Wells et al. 2017).

In June 2017, we compared catch efficiency of Mysis in MOCNESS tows to catch efficiency of Mysis caught in a 1.0 diameter lift net used to monitor Mysis density. Replicate tows were made at night at an 82-m depth site offshore of Thunder Bay, Lake Huron. Mysis densities were significantly higher (Wilcoxon test Chi-Square = 4.17, p=0.04) and more variable in MOCNESS (mean = 6.7/m3, s.d. = 6.3) compared those in the 1-m lift net (mean = 1.0/m3, s.d. = 0.3).

- We also compared catch efficiency of larval fish collected at the 45 m depth station in June and July 2016 in MOCNESS with LED strobe lighting. Fish larvae were sampled in thermally stratified depth layers at night, and densities were compared with LED strobe on vs off. Fish larvae densities were significantly higher with strobe on compared to strobe off (Chi-square = 7.969, d. f.=1, p<0.005) overall and in the epilimnion (Chi-square = 10.631, d.f.=1, p<0.002), but were not significantly different in the metalimnion (ANOVA F=1.187, p=0.31).

Peer-Reviewed Publications:
None

Non-Peer-Reviewed Publications:
None

Presentations:
Wells, D., Psarouthakis, Z., Rutherford, E., Chin, T., Vanderploeg, H., Cavaletto, J., Glyshaw, P. and Mason, D. Shock and Awe! Estimating Mysis Density and Catch Avoidance using the MOCNESS in SE Lake Michigan. May 16, 2017. IAGLR conference, Detroit, Michigan.
Psarouthakis, Z. Evaluation of Mysis catch avoidance using the MOCNESS along with strobe-LED light comparison. August 18, 2016. NOAA GLERL. CILER summer fellow research presentation.

Outreach Activities:
Conducted tours of the wet lab to demonstrate otolith extraction and aging techniques for fish larvae.

THEME III: Ecological Risk Assessment

2016 Monitoring Activities for the Lake Michigan Long-term Ecological Research program

Principal Investigator(s): Brad Cardinale and Thomas Johengen (CILER)
NOAA Technical Lead(s): Henry Vanderploeg and Ashley Baldridge Elgin (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $162,918

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

Overview:

CILER supports the Ecosystem Dynamics branch at NOAA GLERL to continue its 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. Toward this goal, NOAA GLERL has developed a Long-Term Research (LTR) program that integrates a core set of long-term observations on biological, chemical, and physical variables, with short-term process-based studies for understanding ecosystem change. 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 will contribute to GLERL's core mission by providing data and understanding for the development of models and forecasting capabilities, and the application of new sampling technologies.

Our research activities are organized into two general projects: LTR observations and process-based studies. It is implicitly understood that all process studies are targeted to understand critical processes affecting Great Lakes LTR sites or ecosystems. It is our ultimate goal to understand structure and function of Great Lakes food webs from viruses to fishes. The single most important stressor in the system remains dreissenid mussels, and our team recognizes that observation of the pelagic realm alone is no longer an option. Dreissenid mussels, because of their high filtration rates and high abundance in all depth zones of the lake, have decimated the spring phytoplankton bloom and have decreased the abundance of phytoplankton in the hypolimnion and deep chlorophyll layer during the stratified season. They have also reengineered the ecology of the entire food web by increasing water clarity and altering nutrient cycling. It is believed they have had a negative effect on the food web, which is putting the valuable sport fishery at risk and is exacerbating nuisance growths of algae in the nearshore. We believe it is possible that dreissenid populations may be poised for a correction or crash.

Objectives:

Collect 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.

Specific Aims/Milestones:

Project 1: Long-term Ecological Observations

The ultimate goal of our LTR program is to have long-term observations of core variables across Lakes Michigan, Huron, and Superior. The focus of this CILER/GLERL effort for FY16 was to provide support for the following projects in Lake Michigan. In 2017, we will work in Lake Michigan as always, but in addition it is likely we will participate in CSMI spatial studies in Lake Huron

1.1. Dreissenid Abundance and Condition

Continue long-term observations of dreissenid abundance and condition in the Southern Lake Michigan basin A benthic survey at 40 sites in the southern basin will be made in late summer, and monthly collections of mussels at our shallow, mid-depth, and deep sites along our Muskegon transect will be examined quarterly for condition (based on weight). This project, along with the proposed feeding and nutrient excretion subproject (see below), will work together to develop models of mussel population growth and bioenergetics and to develop models of mussel impacts to the food web.

1.2. Spatial Studies and Microbes

As part of the CSMI Years of Lake Michigan (2010 and 2015), and CSMI Year of Lake Huron (2012), we have been examining structure and function of the open water food web, including how it relates to tributary inputs and spatial distribution of dreissenid mussels**.** In cooperation with USEPA, USGS-GLSC, and Michigan DNR, we have been examining horizontal and vertical distribution of plankton, larval fish, juvenile fish, adult fish, and the opossum shrimp *Mysis*, and relating them to changes in phytoplankton and light caused by invasive quagga mussels. We had major cruises in April, July, and September in each Lake. This work was continued in 2013 along the Muskegon transect, adding new measurements of the microbial food web and primary productions. University of Michigan and Central Michigan University scientists have partnered with CILER and GLERL to examine the structure and function of communities of microbes in Lake Huron and Lake Michigan. In 2013, we discovered that the phytoplankton community has shifted to picoplankton, which affects function of the entire food web. We suspect this is a consequence of mussel grazing. This intensive field sampling is starting to provide new insights on the importance of spatial coupling of the food webs within each of these two Lakes, and has raised many questions that have to be attacked with even more sophisticated technologies than we brought to bear so far on the field efforts. The focus in 2014 was the same as 2013 and as mentioned above, we greatly expanded our efforts to include all months from April through October in CSMI 2015. The work in 2016 was very similar to the seasonal work conducted on Lake Michigan in 2010, 2011, 2013, and 2014.

Project 2: Process-based Studies

In addition to maintaining core monitoring of key variables these LTR sites at appropriate time scales, conducted targeted process research to get at root causes of the changes, necessary for development of new concepts and forecasting capabilities. Research in this project area is concerned with process studies involving the main biotic driver of the system, the quagga mussel, and attacks the most critical issues concerning their interactions with the ecosystem. The subproject deals with the contentious problem as to the connection of the mussels with the overlying water column. Research also supports the development of a new *Dreissena* impacts model in Lake Michigan using the FVCOM framework and ties into the research on abundance and condition of mussels in Lake Michigan. Measurement of the chlorophyll at the benthic boundary layer and exchange are important not only for understanding impact of the mussels on the water column but also for understanding mussel condition and growth to understand their population dynamics. We also collected mussels and water from Lake Michigan to check on nutrient excretion interactions there. We have previously defined grazing on phytoplankton (using the chlorophyll techniques), but have not looked at nutrient excretion nor considered interactions in the benthic boundary layer.

2.1 Mussel Feeding and Nutrient Excretion

- Continue to determine selective feeding on the whole spectrum of seston (from bacteria to microplankton), quantify nutrient recycling, and examine factors limiting growth of mussels in Lake Michigan.
- Conduct experiments over a range of habitats and trophic gradients along a nearshore-offshore gradient ranging from 25m to 110m in water column depth.

2.2 Mussel Growth Experiments

- Assess quagga mussel growth under different levels of food quantity and quality, and in different temperatures. Experiments will be conducted in the field using mussel cages at two depths (45m and 90m). We will also conduct complementary growth experiments in lab incubators.

Accomplishments:

1.1. Lake Michigan – Dreissenid Abundance and Condition

Biomass estimates of mussels were completed up through 2015 and presented at IAGLR in May 2017. Mussel condition was measured three times during the 2016 season, the values from which will be used to calculate the 2016 dreissenid biomass estimates for southern Lake Michigan. Benthic invertebrates were collected during the CSMI Lake Michigan survey in July 2016 (further details included in CSMI report). Some of the sample processing was supported by LTR funds. The 2016 benthic samples from the southern region of Lake Michigan have all been processed and data analysis is in progress.

1.2. Lake Michigan – Spatial Study and Microbes

Data analysis is continuing and manuscripts are continuing to be prepared and published. A number of presentations were made at national meetings (see below)

2.1. Mussel Feeding and Nutrient Excretion

We examined results of feeding experiments that were carried out in summer and fall of 2013 and August 2014 on nutrient excretion and fate of pico-plankton and the microbial food web by feeding quagga mussels. As part of this experiment, Vincent Denef (EEB, UM) examined changes in the microbial community using molecular techniques and Hunter Carrick (CMU) examined fate of the MFW using microscopy. As a result of these experiments we are modifying experimental approach to focus on pico-plankton and new methods for measuring excretion. No additional experiments were carried out during this project year. Efforts focused on data analysis and finalizing manuscripts.

2.2 Mussel Growth Experiments

We successfully concluded the 2016-2017 Field Cage Mussel Growth Experiment in March 2017. All mussels have been weighed and measured, preliminary analysis is complete, and a manuscript is in preparation. The 2017-2018 experiment has been moved to Thunder Bay and Saginaw Bay to correspond with the Lake Huron CSMI and to allow for cross lake comparison with previous data collected in Lake Michigan

Publications:

Denef, V.J., H.J. Carrick, J. Cavaletto, E. Chiang, T.H. Johengen, H.A. Vanderploeg (2017). Lake bacterial assemblage composition is sensitive to biological disturbance caused by an invasive filter feeder. *mSphere* 2(3)(DOI:10.1128/mSphere.00189-17) (2017).

Vanderploeg, H.A., O. Sarnelle, J.R. Liebig, N.R. Morehead, S.D. Robinson, T.H. Johengen and G.P. Horst. (2017). Seston nutrient stoichiometry drives feeding, tissue nutrient stoichiometry, and excretion in zebra mussels. *Freshwater Biology* 62:664-680. DOI:10.1111/fwb.12892.

Presentations:

Glyshaw, P., Vanderploeg, H.A., Cavaletto, J.F., Rutherford, E.S., Wells, D.J., Nash, R.D.M. , and Geffen, A.J. May 2017. Potential effects of UV radiation on vertical distribution of zooplankton in Southeast Lake Michigan. 60th Annual Conference of the International Association of Great Lakes Research. Detroit, MI.

Elgin, A.K., Burlakova, L.E., Karatayev, A.Y., Mehler, K. and Nalepa, T.F. May 2017. Quagga Mussel Body Condition and Size Distribution Inform Recent Lake Michigan Population Trends. 60th Annual Conference of the International Association of Great Lakes Research. Detroit, MI.

Mabrey, K., Glyshaw, P., and Elgin, A.K. May 2017. Using the Fluoromarker Calcein to Assess Growth Rates of Quagga Mussels in situ. 60th Annual Conference of the International Association of Great Lakes Research. Detroit, MI.

THEME III: Ecological Risk Assessment

HABs Monitoring, Forecasting and Genomics for the Great Lakes

Principal Investigator(s): Tom Johengen, Mark Rowe (CILER)
NOAA Technical Lead(s): Tim Davis, Eric Anderson (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $724,492

NOAA Strategic Goal 1: Healthy Oceans
NOAA Strategic Goal 3: Resilient Coastal Communities and Economies

1. Sub-Project: HABs Monitoring, Forecasting and Genomics for the Great Lakes

Overview:
CILER continues to support 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. This involves evaluation, validation, and modification of the preliminary Lake Erie HAB Bulletin being operated within NOAA National Ocean Service (NOS) and conducting research toward an improved forecasting model and dissemination plan. We continue to conduct field sampling in Lake Erie and Saginaw Bay, Lake Huron and expand our efforts with both experimental work and development of a coupled hydrodynamic-biological mechanistic model. Collectively, these efforts are used to: 1) determine whether significant amounts of the HAB toxin, microcystin (MC), are entering the drinking water supplies, 2) 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, 3) post field sampling results to a publically-accessible website, and 4) share field sampling results with NOS to assist in validating and improving the current Lake Erie HAB Bulletin. We use both historical and our current evolving environmental data sets to construct statistical models delineating factors regulating phytoplankton and *Microcystis* abundance patterns throughout western Lake Erie. We also develop and evaluate 'user-friendly' models (i.e., incorporating readily-obtained hydrological-meteorological variables) for predicting *Microcystis* biomass.

To ensure development of user-needed tools and technology for local managers, interfacing with end users is critical and falls in line with CILER'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. CILER's HABs Communications and Outreach program serves two functions: 1) identifying and assessing user needs related to HAB data and information for decision making, which helps guide the development of HAB research 2) disseminating CILER and GLERL HAB research tools and forecasts.

Objectives:

1. Develop an improved nowcast-forecast model for Lake Erie harmful algal blooms that shows the spatial extent of the bloom in near real-time and predicts transport of the bloom over a five-day forecast period.
2. Monitor the environmental conditions, extent and toxicity of *Microcystis* blooms in Lake Erie and Saginaw Bay.

Specific Aims/Milestones:

1. Develop an updated short-term HAB forecast model that is linked to the FVCOM-based Lake Erie Operational Forecasting System model, and provide the model to NOAA GLERL for real-time use during the 2016 HAB season.
2. Develop a 3-D version of the short-term HAB forecast model that simulates vertical distribution of buoyant *Microcystis* colonies, conduct hindcast skill assessment, and provide the model to NOAA GLERL for real-time use during the 2016 HAB season.
3. Monitor hydrodynamic and water quality conditions and associated metagenomic variables to help understand environmental drivers determining timing, extent, and toxicity of HAB biomass, location, and toxicity.

Accomplishments:

Weekly monitoring for HABs, toxins, and water quality conditions was conducted in western Lake Erie at eight fixed stations from July through mid-October until no toxins were detected for two consecutive weeks. Similarly, a biweekly monitoring effort was conducted at five stations in Saginaw Bay. We conducted 18 surveys with a total of 236 discrete samples in western Lake Erie and 9 surveys with a total of 45 discrete samples in Saginaw Bay. Each sample was analyzed for over a dozen parameters, most significantly particulate and dissolved microcystin levels. Results were actively shared with over 60 stakeholders including water intake managers and State water quality managers. In addition, results were made publically available through data portals maintained by NOAA GLERL and the Great Lakes Observing System (GLOS) Regional Association. In 2017, several early pre-bloom sampling events were conducted to see how the algal community responded to major river discharge events and to provide an initial look into the community composition against which the HABs become dominant in July.

Three new profiling instruments first deployed in 2015, were used throughout the 2016 and initial 2017 Lake Erie and Saginaw Bay monitoring efforts to improve our understanding of the vertical distribution and composition of the phytoplankton community and to characterize the inherent optical properties (IOP) of the water column to improve satellite estimations of HABs abundance and type. Phytoplankton composition throughout the water column was measured with the BBE FluoroProbe, which provides estimates of 5 distinct phytoplankton classes along with background DOM. IOP instruments include the ACS and BB9. Preliminary data analysis shows that surface concentrations of *Microcystis* can be elevated between 2 – 50X due to their buoyancy during calm conditions. Enhanced surface concentrations tend to occur below a critical windspeed threshold of 8 mph.

During the 2016 HAB season, a new version of the short-term HAB forecast model (HAB Tracker) was run in real-time and output was made available to the public through the NOAA GLERL website (www.glerl.noaa.gov/res/HABs_and_Hypoxia/habTracker.html). The model was initialized using satellite-derived cyanobacterial index imagery that was used by NOAA NOS for the Lake Erie HAB Bulletin. The model included updates developed in 2015: 1) use of the FVCOM offline Lagrangian particle model linked to output from the Lake Erie Operational Forecasting System, 2) filling in cloud-covered areas in satellite images with model data from a previous run, and 3) an updated buffering procedure to eliminate remote-sensing artifacts near land. An additional update in 2016 was the use of the 3-D version of the model, including a method to simulate the vertical distribution of buoyant *Microcystis* colonies. Hindcast skill assessment for the record 2011 HAB season, showed that the 3-D model had greater skill than the 2-D model and a persistence forecast (Rowe et al., 2016, J. Geophys. Res. – Oceans).

In 2016, additional research was conducted on three themes with the goal of improving the forecast model: 1) Influence of light and nutrients on the buoyancy of *Microcystis* colonies, 2) Influence of spatial smoothing on model skill, and 3) Lake Erie angler perceptions of HABs and the HAB Tracker. This work was conducted by University of Michigan Master's students Tonghui Ming, Wanqi Ouyang, and Devin Gill as a Master's project, advised by Mark Rowe, Hongyan Zhang, and Sonia Joshi (final report: http://hdl.handle.net/2027.42/136562).

1) *Microcystis* colony rising/sinking (buoyant) velocity, a parameter in the HAB Tracker model, was measured using an improved method. Statistical relationships were obtained between buoyant velocity and environmental variables, showing lower buoyancy associated with greater light exposure, smaller colony size, and deficient nutrient levels.
2) Model skill was assessed in comparison to satellite-derived HAB distributions using a neighborhood-based spatial smoothing method. Model skill was improved after spatial smoothing using a 3-km neighborhood size, giving an estimate of the spatial uncertainty of the model forecast.
3) A series of focus group interviews was conducted with Lake Erie fishing charter captains and recreational anglers to evaluate perceptions of HABs and the HAB Tracker. Results indicated that the majority of anglers seek to avoid fishing in HABs, but beliefs vary regarding the impact of HABs on fish and human health. Anglers were unfamiliar with the HAB Tracker and had not used it during a bloom, but results indicated that anglers may find the HAB Tracker to be useful. Changes were recommended to improve the presentation of information on the HAB Tracker web site, in addition to improved content and methods of communication to better reflect angler concerns and interests.

Metagenomic sequencing was completed on three isolate cultures of *Microcystis,* as well as 34 samples from Lake Erie bloom monitoring efforts. In addition, seven metatranscriptomes from Lake Erie samples were also sequenced. All sequences have been assembled into contigs and scaffolds and binned to isolate sequences for individual species communities (e.g., *Microcystis*). Isolate *Microcystis* sequences were then annotated (via JGI IMG/MER) and compared to 17 publically available *Microcystis* strains (Meyer et al., accepted, PLOS One). These data were then used to build a graph-database using Neo4j

(Community Edition) which allows for comparative genomics data, gene annotation data (from IMG), and meta –genomic & -transcriptomic sequences to be linked and compared against environmental metadata from bloom monitoring efforts. This database is being used to investigate links between nutrient availability in Lake Erie (nitrogen and phosphorus), bloom toxicity, and *Microcystis* genomic content and expression.

2. Sub-Project: Harmful Algal Blooms Outreach and Research to Users Program

Overview and Objectives:

The goal of this sub-project is to assess public health, drinking water quality, and natural resource managers' and decision-makers' research and information needs in order to improve harmful algal blooms research development and forecasts, to ensure successful technology transfer. Developing user friendly, timely products, tools and services requires stakeholders involvement in determining research priorities and providing stakeholders with research materials that are translated into a concise, easily understood formats to assist in local decision-making and education.

The objectives of this work are to identify and assess user needs (related to harmful algal blooms) and disseminate scientific information, technology, and research materials to aid health officials, local governments, and communities in making sound environmental decisions.

Accomplishments:

1) As a component of the CILER HABs SNRE Master's project, a series of 7 focus groups with 41 participants representing 10 different fishing organizations was held to assess the impact of HABs on Lake Erie anglers, and receive feedback on the utility of the HAB Tracker forecasting tool. As a result of this study, recommendations were made to increase the accessibility and utility of the HAB Tracker. These recommendations will be reviewed and implemented in the summer of 2017. (August – November 2016)
2) Presented the findings of the CILER HABs SNRE Master's project at events including the Ohio Charter Captain Conference (March 2017), the University of Michigan School of Natural Resources and Environment's Master's Project Symposium (April 2017), and the International Association of Great Lakes Research Annual Conference (May 2017).

3. Sub-Project: Near-real time, *in situ,* microcystin detection in Lake Erie using the Environmental Sampler Processor (ESP)

Overview and Objectives:

The goal of the Environmental Sample Processor (ESP) sub-project is to focus on developing the ability to detect and quantify cyanotoxins *in situ*, in near-real time. The ESP is a robotic, electromechanical instrument capable of acquiring, processing, and analyzing samples for molecular-based detection and measurement of organisms and their metabolites (e.g., toxins) *in situ*, in near real-time. Although the ESP has been deployed numerous times in marine coastal waters, this technology has not been utilized in the Great Lakes to monitor HAB produced toxins.

Accomplishments:

CILER supported NOAA-GLERL in the final development of a microcystin assay for the ESPniagra. CILER supported a systems operation test during a one-week deployment at Ohio State University's Stone Laboratory at Put-in-Bay and a two-week pilot deployment in Lake Erie during the 2016 field year. During spring of 2017 the ESP was prepped and deployed for its first month-long fully operational unit in July of 2017.

Peer-Reviewed Publications:

Rowe, M. D., E. J. Anderson, T. T. Wynne, R. P. Stumpf, D. L. Fanslow, K. Kijanka, H. A. Vanderploeg, J. R. Strickler, and T. W. Davis (2016), Vertical distribution of buoyant *Microcystis* blooms in a Lagrangian particle tracking model for short-term forecasts in Lake Erie, J. Geophys. Res.: Oceans, 121, doi:10.1002/2016JC011720.

Berry, M.A., T.W. Davis, R.M. Cory, M.B. Duhaime, T.H. Johengen, C.L. Kling, J.A. Marino, P.A. Den Uyl, D.C. Gossiaux, G.J. Dick, and V.J. Denef. Cyanobacterial harmful algal blooms are a biological disturbance to western Lake Erie bacterial communities. Environmental Microbiology 19 (Thematic Issue on Environmental Glycerol Metabolism):1149-1162 (DOI:10.1111/1462-2920.13640) (2017).

Berry, M.A., J.D. White, T.W. DAVIS, S. Jain, T.H. Johengen, G.J. Dick, O. Sarnelle, and V.J. Denef. Are oligotypes meaningful ecological and phylogenetic units? A case study of *Microcystis* in freshwater lakes. Frontiers in Microbiology 8:Article 365 (DOI:10.3389/fmicb.2017.00365) (2017). https://www.glerl.noaa.gov/pubs/fulltext/2017/20170006.pdf

Steffen, M.M., T.W. Davis, R.M. McKay, G.S. Bullerjahn, L.E. Krausfeldt, J.M.A. Stough, M.L. Neitzey, N.E. Gilbert, G.L. Boyer, T.H. Johengen, D.C. Gossiaux, A.M. Burtner, D. Palladino, M.D. ROWE, G.J. Dick, K.A. Meyer, S. Levy, B.E. Boone, R.P. Stumpf, T.T. Wynne, P.V. Zimba, D. Gutierrez, and S.W. Wilhelm. Ecophysiological Examination of the Lake Erie *Microcystis* Bloom in 2014: Linkages between Biology and the Water Supply Shutdown of Toledo, OH. Environmental Science & Technology (DOI:0.1021/acs.est.7b00856).
(2017). https://www.glerl.noaa.gov/pubs/fulltext/2017/20170017.pdf

Meyer, K.A., T.W. Davis, S.B. Watson, V.J. Denef, M. Berry, G.J. Dick (accepted). Genome sequences of lower Great Lakes *Microcystis* sp. Reveal strain-specific genes that are present and expressed in western Lake Erie blooms. PLOS One.

Non Peer-Reviewed Publications:

Gill, D., Ming, T., & Ouyang, W. (2017). Improving the Lake Erie HAB Tracker: A Forecasting & Decision Support Tool for Harmful Algal Blooms. Master's project report. University of Michigan. http://hdl.handle.net/2027.42/136562

Presentations:

Rowe, M. D, E. J. Anderson, T. T. Wynne, R. P. Stumpf, D.L. Fanslow, H. A. Vanderploeg. Advection and vertical distribution of buoyant cyanobacterial colonies in a Lagrangian particle model for short-term forecasts of harmful algal blooms in Lake Erie, American Geophysical Union Ocean Sciences Meeting, 21-26 February, 2016, New Orleans, LA.

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

Meyer, K.A. *Meta-omics analysis of Lake Erie Microcystis strains and blooms.* Invited Presentation, HABs State of the Science webinar series: HABs Bloom detection, composition & effects, Great Lakes HABs Collaboratory, Ann Arbor. MI. 2016.

Meyer, K.A. *Combining comparative genomics and graph databases to improve and streamline population and ecosystem meta-omics analyses.* Invited Presentation, Tools and Technology Series, Department of Computational Medicine and Bioinformatics, Ann Arbor, MI, November 2016

Meyer, K.A. *Combining comparative genetics and graph databases to improve harmful algal bloom analysis*. Invited Presentation, Water@Michigan Forum, Graham Sustainability Institute, Ann Arbor, MI, 2017

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

Meyer, K.A. *Combining comparative genomics and graph databases to improve and streamline population and ecosystem meta-omics analyses.* Invited Presentation, Water, microbes, and human health: pre-meeting workshop, Center for Epidemiology of Infectious Diseases, Ann Arbor, Michigan 2017

Meyer, K.A., T.W. Davis, S. B. Watson, G.J. Dick. *The impact of nitrogen form and availability on the toxicity of* Microcystis *blooms in Lake Erie*. 2017 IAGLR Meeting, Detroit, MI May 15-19, 2017

Smith, D., T.W. Davis, M. Berry, R.M. Cory, V.J. Denef, T.H. Johengen, G.W. Kling, K.A. Meyer, G.J. Dick *Metagenome and transcriptomic evidence suggests* Microcystis *is dependent on heterotrophic bacteria for mitigation of oxidative stress caused by exogenous hydrogen peroxide.* 2017 ESA Meeting, Portland, OR, August 6-11, 2017

Ritzenthaler, A.A., C.M. Mikulski, R. Marin, B. Roman, J. Michett, C. Siani, G. Doucette, and T.W. Davis. Development of the first autonomous, *in-situ* microcystin immunoassay for the inaugural freshwater deployment on the robotic Environmental Sample Processor. Oceans 2016, September 19-23, 2016. MTS/IEEE (2016).

Outreach Activities:

- Presented an overview of the HAB Tracker to representatives of six drinking water treatment plants that draw water from Lake Erie at a hypoxia workshop, Baldwin Water Treatment Plant, Cleveland, Ohio, May 24, 2017.
- Presented an overview of the HAB Tracker to representatives of the Toledo drinking water treatment plant, Toledo, Ohio, June 30, 2017.
- Detroit Public Television interview on Lake Erie harmful algal blooms for a segment on Blue Economy, December 16, 2016.

THEME IV: Protection and Restoration of Ecosystem Resources

Development of a PostgreSQL Database for Accessible Research, Operations, and Communications of Real-time Harmful Algal Bloom Data

Principal Investigator(s): Brad Cardinale and Tom Johengen (CILER)
NOAA Technical Lead(s): Steve Ruberg (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)

Budget Amount: $49,000

NOAA Strategic Goal:
Goal 1 – Healthy Oceans
Goal 4 – Resilient Coastal Communities and Economies
Goal 5 – NOAA Enterprise-wide Capabilities: Science and Technology Enterprise, Engagement Enterprise, Organization and Administration Enterprise

Overview:

In August 2014, a harmful algal bloom (HAB) contaminated the water supply of Toledo, OH, leaving over 400,000 residents without drinking water for 2 days. Real-time observations of temperature, HAB-related optical parameters (chlorophyll, phycocyanin, turbidity) and nutrients (phosphorus, nitrogen) are important components of HAB modeling and forecasting efforts serving Lake Erie drinking water managers but have been traditionally stored in plain-text format representing a data management challenge. Such a setup does not allow for expedient querying, analysis, or quick visualization of parameters of interest. In support of **Scientific, Workflow, and Data Analytics tools** for the NOAA High Performance Computing and Communications Program, we proposed the development of a database using the robust and industry standard PostgreSQL database management system to archive and let users access the real-time observations with ease.

Objectives:

1. Develop database prototype using archival real-time data from the Western Lake Erie (WLE) Harmful Algal Blooms (HABs) Monitoring Program (transmitted from buoys via cellular service as a CR1000 data acquisition system data table, which are ingested by Campbell Scientific's LOGGERNET data acquisition system); produce interface to data on a website.
2. Design a workflow to archive data as they come in and allow their access on the website.
3. Employ recommended required Quality Assurance of Real Time Ocean Data, or QARTOD, checks on the data, store results in database for future analysis

Specific Aims/Milestones:

1. A portable database system that could be cloned for operations at an operational entity such as the GLOS RA and partners contributing data.
2. A web interface to the database.
3. Peer-reviewed manuscript or technical memorandum.

Accomplishments:

Database is up and running, and an interface to the data is available here →
https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/rtMonSQL.php

Peer-Reviewed Publications:

"An implementation of a database management system for real-time large-lake observations" Marine Technology Society Journal. *(submitted)*

Non-Peer-Reviewed Publications:

None.

Presentations:

Ruberg, S., Constant, S., Muzzi, R., Miller, R. and J. Smith. Utilization of PostgreSQL Database for Real-Time Western Lake Erie Data Storage and Dissemination. International Association for Great Lakes Research annual conference, May 15th-19th, 2017, Detroit, MI.

Outreach Activities:

None.

THEME IV: Protection and Restoration of Ecosystem Resources

A Metagenomic-Based Approach to Determine Microbial Pollution Sources in South Florida Coral Reefs

Principal Investigator(s): Brad Cardinale (CILER), Chan Lan Chun (University of Minnesota-Duluth), and Michael J. Sadowsky (University of Minnesota-Twin Cities)
NOAA Technical Lead(s): Chris Sinigalliano (AOML)
NOAA Sponsoring Office: Atlantic Oceanographic and Meteorological Laboratory (AOML)

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

Overview:

Microbial contaminants from land-based sources of pollution (LBSP) are considered to be major threats to coral reef ecosystems. Particularly, coastal inlets and treated wastewater effluents are recognized as major pathways for transporting contaminants from lands to costal water, which has significant impact on coral reef ecosystem and human health. These LBSP discharges can contain a variety of microbial contaminants, including fecal indicator bacteria, fecal host marker bacteria, and pathogens to both humans and coral ecosystems. Likewise, such microbial contaminants have been measured in coral reef waters of Florida's Southeastern coast (from Broward to Palm Beach) using both culture-based methods and the amplification of source-specific genetic makers These contaminants may potentially impact the health of corals in this region. Thus, understanding the sources of land-based pollution on coral reef mucus or tissues is essential to assess the microbial loading of such contaminants to coastal waters of coral reefs, as well as develop effective mitigation strategies in a cost-effective manner. In this study we characterized total microbial community structure in coastal inlets and treated wastewater effluents and in the tissues of coral from Florida's Southeastern coastal marine ecosystem using a Next-Generation Illumina sequencing approach. We compared community structure between inlets, effluents, and coral microbial populations and examined the host-specificity and temporal and spatial stability of LBSP in coastal waterways and coral reef mucus or tissues. This work will help inform management as to the degree that LBSP bacterial contaminants may be influencing coral reef microbial communities and how coral symbiont populations may be reacting to LBSP exposure.

Objectives:

The study aimed to investigate the impacts of various LBSPs on microbial (prokaryotic and fungal) communities in nearby coral reefs and tissue samples in Florida's Southeastern coastal marine ecosystem and to evaluate the relative degree of source impacts based on exchange between microbial communities from LBSP and reef waters or coral tissues and demographic and hydrological differences associated with sampling sites.

Specific Aims/Milestones:

- Characterization of total microbial community structure in coastal inlets and treated wastewater effluents and in the tissues of the coral reefs of Florida's Southeastern coastal marine ecosystem quarterly in 2015-2016 by using Next-Generation Illumina sequencing analyses.
- Comparison of microbial (bacterial, archaeal, and fungal) community structure, diversity, and relative abundance between inlets, effluents, and coral microbial populations.
- Determine what degree LBSP microbial contaminants may be influencing coral reef microbial communities and how coral symbiont populations may be reacting to LBSP exposure by correlating patterns of pollutant exposure with microbial community composition.

Accomplishments:

This work utilized an Illumina-based next-generation sequencing approach to characterize prokaryotic and fungal communities from samples collected off the southeast coast of Florida. Water samples from coastal inlet discharges, oceanic outfalls of municipal wastewater treatment plants, treated wastewater effluent before discharge, open ocean samples, and coral tissue samples (mucus and polyps) were characterized to determine the relationships between microbial communities in these matrices and those in reef water and coral tissues. Significant differences in microbial communities were noted among all sample types but varied between sampling areas. Contamination from outfalls was found to be the greatest potential source of LBSP influencing native microbial community structure among all reef samples, although pollution from inlets was also noted. Notably, reef water and coral tissue communities were found to be more greatly impacted by LBSP at southern reefs, which also experienced the most degradation during the course of the study. The results of this work provide new insights into how microbial communities from LBSP can impact coral reefs in southeast Florida and suggest that wastewater outfalls may have a greater influence on the microbial diversity and structure of these reef communities than do contaminants carried in runoff, although the influences of runoff and coastal inlet discharge on coral reefs are still substantial.

Peer-Reviewed Publications:

Staley, C., Kaiser, T., Gidley, M.L., Enochs, I.C., Jones, P.R., Goodwin, K.D., Sinigalliano, C.D., Sadowsky, M.J. and Chun, C.L., 2017. Differential impacts of land-based sources of pollution on the microbiota of southeast Florida coral reefs. Applied and environmental microbiology, *83:*10, e03378-16.

Presentations:

Lee, H.W., Gidley, M.L., Lopez, J., Staley, C., Chun, C.L., Sadowsky, M.J., Gramer, L. and, Sinigalliano, C.D., 2017. Next-Generation-Sequencing and Microbial Source Tracking to Investigate Associations between Reef Microbiome Community Structure, Land-Based Sources of Pollution, and Physical Habitat Characteristics. 2017 US Coral Reef Task Force meeting in Fort Lauderdale, FL.

Outreach Activities:

Press release of the publication:

- https://www.asm.org/index.php/newsroom/item/6274-land-based-microbes-may-be-invading-and-harming-coral-reefs
- https://phys.org/news/2017-03-land-based-microbes-invading-coral-reefs.html

THEME IV: Protection and Restoration of Ecosystem Resources

Decision Support of Western Lake Erie Phosphorus Concentrations to Mitigate Harmful & Nuisance Algal Blooms

Principal Investigator(s): Thomas Johengen (CILER), Hongyan Zhang (CILER), Song Qian (U. Toledo)
NOAA Technical Lead(s): Craig Stow (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Lab (GLERL)
Budget Amount: $177,706

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

Overview:

In 2011, Lake Erie experienced a cyanobacterial bloom of unprecedented proportion (Michelak et al. 2013). This event, though noteworthy, was only one recent example of eutrophication symptoms that reappear in some areas of the Great Lakes more than 35 years after the establishment of phosphorus reduction targets under the 1978 Great Lakes Water Quality Agreement (GLWQA). Recognizing these enduring problems, the updated 2012 GLWQA calls for a reevaluation of the 1978 phosphorus targets. Additionally, the revised protocol directs Canada and the United States to "develop Substance Objectives for phosphorous concentrations for nearshore waters, including embayments and tributary discharge for each Great Lake" and to "complete this work for Lake Erie within three years of entry into force of this Agreement." Thus, there is an imperative to focus attention on management actions that will reduce ongoing eutrophication problems, which include extensive hypoxia, in Lake Erie.

While the fundamental drivers of algal proliferation in temperate lakes have been understood since the 1970s (Schindler 1977), there are lake-specific processes that influence the relationship between phosphorus and measures of algal productivity (Pace 1984, Stauffer 1991, Kamarainen 2008). Additionally, the Great Lakes have experienced profound changes since the initial phosphorus targets were developed in the 1970s. Most notably, invasive dreissenid mussels, which became abundant in the 1990s, have altered phosphorus cycling, promoted cyanobacterial growth (Vanderploeg et al. 2001) and altered the relationship between chlorophyll a and total phosphorus (Cha et al. 2013). Concurrently, phosphorus inputs to Lake Erie have changed with bioavailable phosphorus concentration increases in the western tributaries since the 1990s (Daloglu et al. 2012).

Objectives:

The objective of this study is to provide information to support pending decision-making for Lake Erie nutrient and harmful algal bloom (HAB) management by developing predictive models that describe the relationship between phosphorus concentration and other logical predictor variables, and endpoints associated with algal production including cyanobacteria, Microcystis, and total algal biovolume, and chlorophyll a. Additionally, we explore relationships between phosphorus inputs and in-lake phosphorus concentrations to examine whether the existing data support development of a simple network linking measures of algal concentration to watershed loads. Because phosphorus load is composed of tributary flow and phosphorus concentration, which have distinct effects on the distribution and concentration of in-lake phosphorus, we consider these two drivers separately in the model development.

Specific Aims/Milestones:

1. Development of predictive phosphorus models using a Bayesian hierarchical framework (Borsuk et al. 2001). This approach allows the models to capture relationships between predictor and response variables that differ spatially and temporally if the data indicate such differences. Additionally, the Bayesian framework provides probabilistic quantification of the uncertainty in these relationships as well as the predictive uncertainty between the predictor and response variables.
2. A second approach is to develop a coupled physical-biological deterministic model to examine relationships between key environmental factors (water temperature, river flows, nutrient loads, water-column mixing and sediment resuspension) on the *Microcystis* blooms on a fine spatial and temporal scale. We are updating a previous mass-balance nutrients-phytoplankton-zooplankton-detritus (NPZD) model (EcoLE, Zhang et al. 2008) and coupling it with an updated hydrodynamics model (FVCOM, Anderson et al., 2010; Anderson and Schwab 2011). The horizontal resolution of the model ranges from 1.5 km in the central basin of the lake to 30 m in complex nearshore regions and near tributary mouths. Vertical resolution is provided by 21 terrain-following sigma layers, with a higher density of layers in shallow water columns. The updated model is calibrated and verified with the same existing database used for the statistical modeling approach. Model projection of the spatial extent and intensity of HABs and in-lake phosphorus distributions is compared under various potential phosphorus loading scenarios, and used to develop relationships between nutrient loads and HABs (spatial extent and total *Microcystis* biomass) in the western Lake Erie.

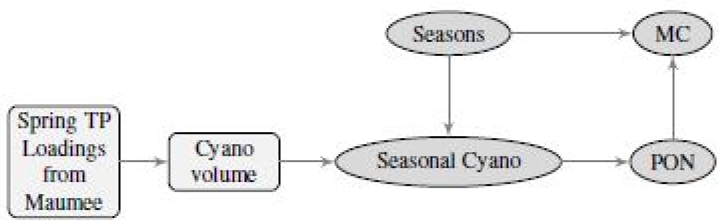
Accomplishments:

<u>Task 1: Bayesian hierarchical modeling</u>

Research activities led by the University of Toledo focused on developing models for forecasting cyanobacteria toxin (microcystin) concentrations in western basin of Lake Erie (WBLE) using NOAA HAB monitoring data from 2008 to 2015. The project used a Bayesian hierarchical modeling approach for linking Lake Erie phosphorus and nitrogen concentrations to harmful and nuisance algal blooms, by using Lake Erie monitoring data from NOAA-GLERL (NOAA data) and nutrient loading data from Maumee River. As part of the research, we published a review and justification of the Bayesian hierarchical modeling approach (Qian, et al, 2015b). We also proposed to use a large cross-sectional data from Canada to expand the spatial coverage of the resulting model. Prior to the start of the project, our preliminary analysis of a large database of lakes in southern Canada suggests that indictors of harmful algal bloom (e.g., microcystin, or MC, concentrations) are related to both in-lake N:P ratio and the trophic status of the lake. This feature is also present in the U.S. EPAs national lake survey data. Based on this preliminary finding, we proposed to explore the NOAA GLERL Lake Erie monitoring data in conjunction with the analysis of two cross-sectional data to develop predictive models of harmful and nuisance algal bloom using in-lake nutrient concentrations and climate and surrounding watershed environmental predictors. From August 2015 to March 2016, we analyzed the NOAA data collected from

2008 to 2014. The initial exploratory data analysis showed a link between nutrient (especially TP) concentration and a variable representing phytoplankton abundance (particular organic carbon or nitrogen, POC or PON), and MC concentration is directly related to POC/PON. We also learned the difference between intensively sample data from one lake and data from multiple lakes (each with sparse sampling). From March to July, 2016, we included data collected in 2015. A noticeable difference between the two sets of exploratory analyses is the role of inorganic nitrogen. In analyzing data without observations made in 2015, one model seems to suggest that high MC concentrations are associated with high inorganic nitrogen (NH4 and NO3). This connection disappeared when data from 2015 were included. After reexamining the data and plots, we believe that the link is an artifact.

Using a series of exploratory plots, we established the following causal diagram.



The underlying causal model is parameterized using a Bayesian Networks (BN) modeling approach. The resulting model connects spring TP loading from Maumee to predict the annual bloom size (cyanobacterial index, CI) by using current NOAA models. Using the monitoring data, we convert the predicted annual maximum CI to monthly cyanobacterial volume through a Bayesian ANOVA model. A second model connects monthly volumes to POC/PON; while a third model connects PON/POC to MC concentrations. By using the BN modeling approach for continuous variables (the cBN model) of Qian and Miltner (2015), we combine these three sets of models into a package that can be used for forecasting the seasonal (monthly) risk of high MC concentration in the WBLE. The initial version of the cBN model is presented at the 2016 IAGLR annual conference in Guelph, Canada. A model assessment and update procedure was developed and presented at the 2017 IAGLR annual conference in Detroit, MI.

During the course of the project, we completed additional research activities, including:

- Developed a framework for including the MC risk assessment in conjunction with NOAA’s annual bloom size prediction. Under a Bayesian framework, the cBN model can be updated annually, where model parameters estimated each year can be used to develop prior distributions. Annual NOAA forecast of WBLE bloom size can be used to forecast monthly MC concentrations distributions. These distributions can be used to calculate the risk (or probability) of high MC concentration events. Once the year’s monitoring data are available, the cBN model can be updated. The updated model will then be used for next year’s forecasting. As of June 2016, we were unable to complete the structure of the model because large portion of cyanobacterial volume data from the NOAA monitoring program are not yet ready. An alternative model is developed with the cyanobacterial volume node removed. The alternative model is ready for testing when the 2016 and 2017 monitoring data are available.
- Calculated cumulative TP loadings from Maumee River. In order to calculate the annual cumulative TP loadings, daily TP loadings must be present without missing days. The best data we had were from the long-term monitoring program at Waterville Ohio, maintained by

Heidelberg University. The Heidelberg monitoring program has nearly daily nutrient concentration and flow measurements, however, there are occasional missing days and some days with more than one measurement. A short computer program was written to process the data for calculating mean daily loads. Missing days are imputed using median-polishing (Qian et al., 2000).

- Analyzed annual cumulative TP loading patterns. As a by-product of the project, we noticed a distinct pattern of annual cumulative TP loadings. When the daily cumulative TP loadings are graphed against Julian days, the cumulative loadings increased rapidly initially. Once passing a temporal threshold, the rate of increase reduced. The cumulative loadings plot resembles a hockey stick model with two line segments. The first segment starts at Julian day 1 (January 1) and with a larger slope than the slope of the second segment. These two segments join at a change point (or a temporal threshold). Given the distinct pattern of the cumulative load, we hypothesis that the annual WBLE bloom size not only is related to the amount of spring TP loadings from Maumee River, but also related to the temporal threshold. We plan to develop a Bayesian hierarchical model to test this hypothesis.
- An important issue of modeling microcystin concentration is the high level of uncertainty associated with the measurement method. During the course of the project, we studied statistical means for improving the statistical calibration process of the standard measurement method, ELISA. Two undergraduate students and one graduate student conducted two sets of experiments to obtain needed data and explored alternative statistical calibration methods. The work resulted in one manuscript currently in review by the journal *MethodsX*, a conference presentation (the 48th Central Regional Meeting of the American Chemical Society in Dearborn, MI, June 6-9, 2017), and two undergraduate research reports as part of the NSF funded Research Experience for Undergraduates (REU) program at the Lake Erie Center of the University of Toledo. One manuscript is currently under preparation based on these two reports.

<u>Task II: Physical-biological deterministic modeling</u>

We used EcoLE (a two-dimensional, vertical-longitudinal, hydrodynamic and ecological model) to compare the effects of phosphorus loads from different sources on water quality and phytoplankton dynamics. Our simulations showed that both external and internal phosphorus loads were distributed homogeneously in the water column in Lake Erie's western basin. Simulated reductions in external phosphorus loads decreased individual phytoplankton groups most at times when they were normally most abundant, e.g., *Microcystis* decreased the most during September. Phosphorus was the main limiting factor over the simulation periods, but water temperature and light conditions also played critical roles in phytoplankton succession. While phosphorus pools in the water column responded quickly to external phosphorus reduction, a pulse of phosphorus (riverine input or sediment resuspension) occurring immediately before the *Microcystis* bloom period could allow *Microcystis* to bloom despite long-term external phosphorus load reduction. We also analyzed the turbidity in the western basin of Lake Erie of 2011-2014, and found that river loads and wind speed are two predominant factors that can predict most of the high turbidity events. Currently, we are working on differentiating the high water-turbidity events due to sediment resuspension versus riverine loads. We have used FVCOM-GEM to simulation algal dynamics in the western Lake Erie with algae being one model group. We are working on separate algae into three model groups, green algae, diatoms and *Microcystis*. Inorganic matter will be added to the model as a state variable to simulate water turbidity.

We added two more algal groups into the FVCOM-GEM, thus our FVCOM-GEM simulates the dynamics of three algal groups (diatoms, *Microcystis* and other algae). The simulated seasonal patterns for the three groups showed that diatoms were abundant during spring and early summer, while *Microcystis* population started to build up during early summer and became abundant during August and September. The group of other algae showed much lower biomass compared to diatoms and *Microcystis*. Sensitivity analysis of algal succession indicated that in addition to nutrient concentration and water temperature, zooplankton grazing could significantly affect the algal succession. Model calibration with the Chlorophyll data of 2011 indicated that model caught the right level of total algal biomass. We are working on using FVCOM-GEM to simulate water quality of 2016, when had biomass data for all three modeled groups. The simulated detritus concentrations were higher than observations, which further affected the simulation of TP. We are checking parameters that affect the detritus dynamics in the model and find the settling rates are a critical parameter.

Publications:

Zhang, H., Boegman, L., Scavia, D., Culver, D.A., 2016. Spatial distributions of external and internal phosphorus loads in Lake Erie and their impacts on phytoplankton and water quality. Journal of Great Lakes Research, 42:1212-1227.

Nummer, S.A., A.J. Weeden, C. Shaw, N.K. Snyder, T.B. Bridgeman, and S.S. Qian. Modifying ELISA standard curve fitting process to reduce uncertainty in estimated microcystin concentrations. *MethodsX* (in review)

Presentations:

Zhang, H., Rowe, M.D., Johengen, T.H., Anderson, E.J., and Ruberg, S.A. Modeling succession of algal functional groups associated with Lake Erie harmful algal blooms. IAGLR 2017 From Cities to Farms: Shaping Great Lakes Ecosystems. Detroit, MI. May 15-19, 2017. (Oral)

Ouyang, W., Rowe, M.D., and Zhang, H. Skill assessment of the Lake Erie HAB Tracker Forecast Model using variable spatial neighborhoods. IAGLR 2017 From Cities to Farms: Shaping Great Lakes Ecosystems. Detroit, MI. May 15-19, 2017. (Poster)

Nummer, S.A., A.J. Weeden, and S.S. Qian (2017) Modifying ELISA standard curve fitting process to reduce uncertainty in estimated microcystin concentrations. The 48th Central Regional Meeting of the American Chemical Society, June 2017, Dearborn, MI. (Oral)

Outreach Activities:

As of June 2016, the project supported one MS student for two summers and provided research opportunity for two undergraduate students (supported by NSF-REU program).

THEME IV: Protection and Restoration of Ecosystem Resources

FATE Proposal: Incorporating an Environmental Index into the Southern New England Mid-Atlantic Yellowtail Flounder Stock Assessment with Potential Predictability

Principal Investigator(s): Brad Cardinale (CILER), Janet Nye (Stony Brook University)
NOAA Technical Lead(s): Larry A. Alade, PhD (NMFS), Doran Mason (GLERL)
NOAA Sponsoring Office: NOAA National Marine Fisheries Service (NMFS) Fisheries and the Environment

Budget Amount: $197,115

NOAA Strategic Goal:
Goal 3 – Climate Adaptation and Mitigation

Overview:

Southern New England- Mid Atlantic (SNEMA) yellowtail flounder comprised one of the most important groundfish fisheries in the Northeast United States. High fishing pressure particularly during the 1960s through the 1970s reduced the abundance of SNEMA yellowtail flounder significantly. Since 1992, strict regulations have been put in place along with closed areas, but the stock has not recovered in twenty years and recruitment has remained low. The low recruitment trend over the last twenty years is a major source of uncertainty in the most recent benchmark assessment of SNEMA yellowtail flounder that occurred in 2012.

Objectives:

- Investigate the physical linkage between changes in atmospheric indices, temperature regime and yellowtail flounder recruitment and productivity for several years after a fluctuation in the Azores High pressure.
- Develop predictive relationships between environmental indices and recruitment and SSB and assess the skill of such a prediction scheme.
- Incorporate the environmental indicator into the stock assessment in one of three ways.

Specific Aims/Milestones:

The deliverables for this project were:

- An analysis of environmental factors affecting not only recruitment, as represented by Age-1 fish, but also subsequent year class strength (up to Age 6 fish).
- A better understanding of oceanographic and atmospheric processes influencing environmental conditions (particularly temperature) in the Northeast US continental shelf, including the SNE area.
- Incorporation of an environmental variable into a statistical catch at age model in potentially three ways that could potentially be used to inform future stock assessment of SNEMA yellowtail flounder.
- A potentially novel way of using predictability within the climate system to forecast future recruitment and SSB to help set ACLs.
- Several peer-reviewed publications and presentations at national and international meetings.

Accomplishments:

We have accomplished all of the goals for the project. We have incorporated the Gulf Stream Index (GSI) into two stock assessment models for SNE Yellowtail Flounder, a state-space model and an age-structured forward-projecting model called ASAP (Age-Structured Assessment Program) that was used in the last stock assessment. We have fully evaluated the model skill and forecast ability of the state-space model. The model fits the data better when the Gulf Stream Index is incorporated into the stock-recruit function than when it is not or when other environmental variables are incorporated. However, the forecasting skill of the model with the Gulf Stream Index incorporated was highly variable. Comparison of the retrospective prediction patterns clearly demonstrated that the prediction skill of recruitment in the environmentally-explicit model, on average, is improved for the first two prediction years. For a specific near-term recruitment prediction, however, the prediction skill is largely affected by the predictive performance of the incorporated environmental covariate in the state-space model. In conclusion, incorporating environmental covariates explicitly in a stock assessment model may result in a better fit but does not necessarily lead to higher prediction skill. The model and forecast performance for the state space model has been published (Xu et al. accepted).

We have also incorporated the Gulf Stream Index into an ASAP model. In accordance with the results from the state-space model, the stock-recruit function in which the GSI is incorporated as a limiting factor is also the best for SNE yellowtail flounder in ASAP, further supporting the conclusion that the shelf environmental conditions, indicated by the meridional position of the Gulf Stream, have substantial influenced SNE yellowtail flounder recruitment by modulating the carrying capacity of the ecosystem. Recruitment of SNE yellowtail flounder is negatively affected by the position of the Gulf Stream (GSI), and the unfavorable environmental condition caused by a northward shift of the Gulf Stream plays a major role in keeping the productivity of the stock to a low level after 1990. Moreover, the state-space model which can separately model process error and observation error outperforms statistical catch-age-age model (e.g., ASAP) which assumes no process error, especially when large retrospective bias exists in population estimates. It indicates that the large retrospective bias recently emerged in the updated assessment in 2015 is partially due to assuming no process error in ASAP. However, other kinds of structural error such as time-invariant M and closed population assumption also contribute to the emergence of large retrospective bias, which should be a high research priority for SNE yellowtail flounder in the next benchmark assessment.

Publications:

Xu H, Kim H-M, Nye JA, Hameed S (2015) Impacts of the North Atlantic Oscillation on sea surface temperature on the Northeast US Continental Shelf. Continental Shelf Research 105:60-66

Xu, H., T. J. Miller, S. Hameed, L. A. Alade, and J. A. Nye. (accepted Fisheries Oceanography). Evaluating the utility of the Gulf Stream Index for predicting recruitment of Southern New England-Mid Atlantic yellowtail flounder.

Xu, H., T.J, Miller, J.T. Thorson, J.A. Nye." (in preparation). Consequences of implementing a 2D survival smoother into a state-space assessment model for Southern New England-Mid Atlantic yellowtail flounder. (to be submitted to Fisheries Research).

Presentations:

Xu, Haikun. "Improving Southern New England yellowtail flounder assessment by using a state-space age-structured assessment model." Quantitative Seminar, University of Washington, WA, USA (April 2017)

Xu, Haikun, Timothy J. Miller, Sultan Hameed, Larry A. Alade, and Janet A. Nye. "Evaluating the utility of the Gulf Stream Index for predicting recruitment of Southern New England-Mid Atlantic yellowtail flounder." 31st Wakefield Symposium, Anchorage, AK, USA (May 2017)

Xu, Haikun, Timothy J. Miller, Sultan Hameed, Larry A. Alade, and Janet A. Nye. "Evaluating model fit and forecast performance after incorporating the Gulf Stream Index into Southern New England yellowtail flounder state-space age-structured assessment model." Fisheries and the Environment Annual Meeting, La Jolla, CA (January 2016)

Xu, Haikun, Hye-Mi Kim, Janet A. Nye, and Sultan Hameed. "Impacts of the North Atlantic Oscillation on sea surface temperature on the Northeast US Continental Shelf." Ocean Sciences Meeting, New Orleans, LA (poster)

Outreach Activities:

- Janet Nye briefed US Congressional staff and Research Service about the need to address climate in fisheries assessment and management based on this and other research on fisheries and climate issues (COMPASS: Tides of Change, June 2016).
- This grant has supported the dissertation research of one PhD student, Haikun Xu, who graduated in December 2016 from Stony Brook University.

THEME IV: Protection and Restoration of Ecosystem Resources

2015 Lake Michigan Monitoring Activities for the Coordinated Science Monitoring Initiative

Principal Investigator(s): Brad Cardinale and Thomas Johengen (CILER), Tom Nalepa (University of Michigan, Hunter Carrick (Central Michigan University)
NOAA Technical Lead(s): Henry Vanderploeg and Ashley Baldridge Elgin (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Lab (GLERL)
Budget Amount: $204,825

NOAA Strategic Goal:
Goal 1 – Healthy Oceans

Overview and Objectives:

This project is collaboration between CILER, NOAA GLERL, EPA, and USGS as part of the Coordinated Science and Monitoring Initiative (CSMI) Program to describe the status of Lake Michigan and understand its capacity to deliver important ecological services. The work consists of two subprojects that **examine spatial distributions and interaction of benthic and pelagic components of the food web to better understand the movement of nutrients from inshore to offshore and spatial coupling of the food web that has been disrupted by dreissenid mussels.**

Specific Aims/Milestones:

1. Benthic Surveys for Lake Michigan

CILER has worked with NOAA GLERL to document trends in dreissenid populations and the keystone amphipod *Diporeia* in the main basin of Lake Michigan every 5 years since 1994/1995. Samples have been collected in triplicate at 130 sites in 1994/1995, 2000, 2005, and 2010. In addition, we have collected samples for these two taxa at a subset on 40 sites in the southern basin every year since 1998. Further, the total benthic community (all taxonomic groups) have been sampled/analyzed at these southern basin sites for two consecutive years every five years since 1980-81 (i.e., 1980-81. 1986-87, 1992-93, 1998-99, 2004-05, and 2010-2011). This is the longest data set of benthic populations in the Great Lakes that has been consistently collected at the same sites using the same methods. To maintain consistency in both the whole lake data set and the data set in the southern basin, in 2015 GLERL in cooperation with EPA, USGS and academic partners collected samples at the same 130 sites that were sampled in previous years (1994/1995, 2000, 2005, and 2010) and processed in whole the benthic collections in the southern basin and do analysis of mussels and Diporeia in all collections from all sites.

In addition to densities, a key component of assessing trends in dreissenid populations is accurate estimates of biomass. To estimate biomass, we have developed length-weight regressions and determined size-frequencies of populations during the whole-lake surveys. In addition to documenting temporal trends in biomass, we used statistical tools to take into account the natural variance of biomass with depth to create better estimates of spatial distributions and total abundance. We have used these new tools to reexamine spatial patterns of biomass in 2000, 2005, and 2010. We applied these statistical tools to biomass estimates in 2015: one method based on organizing stations into transects and fitting depth-dependent models, and a second method based on universal Kriging. These methods will allow us to infer whether there are significant trends in biomass over time, not only at specific stations, but lakewide and within sub-regions of the lake. Again, as with density estimates, it is critical that biomass is determined exactly the same way as in previous years.

Milestones:

- Whole lake benthic survey will be conducted in 2015
- Sample analysis and data analysis will start immediately and continue through 2016
- Data report and papers will be written during 2016

Outcomes:

- We will provide lake-wide abundance estimates of the most important invasive species in Lake Michigan and compare it with past abundance to describe population trends necessary for adaptive management of the Great Lakes.
- By providing a framework for understanding the effects of nearshore to offshore lower trophic measures and inter-basin trophic measures this work supports focus areas 2, 4, and 5 Great Lakes Action Plan.

2. Temporal and spatial coupling of nutrients and food web—microbes to fish

In support of EPA/USGS efforts to sample food web components at multiple transects around the periphery of the Lake during two seasons, conducted more intensive temporal (including diel sampling) and fine-scale spatial sampling across seasons— nearly monthly—in the Muskegon/Grand River Region of Lake Michigan so we can project EPA/USGS results across time for greater generalization of results and development of spatially explicit ecosystem models incorporating nutrient movement from inshore to offshore, and impacts of dreissenids and other stressors. Moreover, we incorporated the microbial food web (MFW) as part of our study to fully describe connections of the food web. Our approach was similar to Year of Lake Michigan 2010 and Lake Huron 2012, where we have been examining detailed diel spatial coupling seasonally (April, July, and September) of the food web using a variety of advanced tools including plankton survey system that we tow-yow behind our vessel simultaneously with fisheries acoustics (in moon pool shipboard). We examined spatial coupling of the food web during May and June to augment our standard seasonal sampling in April, July, and September to understand nutrient flow from inshore to offshore in the Muskegon and Grand River, the largest source of nutrient loading directly into Lake Michigan.

Limited seasonal studies in 2013 indicated that ~ 80% of primary production is now in the picophytoplankton (< 2 µm), which is not available to most mesozooplankton; in contrast in earlier years it constituted ~ 20-30%. However, there is evidence that ciliates, a preferred prey of copepods, are still abundant. Therefore we evaluated the sustainability of the pelagic food web in Lake Michigan, with particular emphasis on measuring the link between the MFW and crustacean zooplankton that directly feed fish and the role of mussels in affecting that link. We predicted the MFW is resilient to the quagga mussel-induced ecosystem changes, due to the fast growth rates and ecological plasticity of its major components, so that it may act to stabilize the pelagic system towards a new steady state. Several outcomes will result from this work. First, we will assess the relative importance of the MFW in Lake Michigan by comparing our data collected with measurements made pre-driessenid in 1980-90 and 1998-2000. Second, we will help revise water quality models under development at GLERL by incorporating the MFW into it. Last, we will augment GLERL monitoring of plankton assemblages in 2015 Year of Lake Michigan to fully describe the pelagic system.

*Field Sampling***-** Sampling will be conducted at three stations in Lake Michigan (nearshore M15, mid-depth M45, and offshore M110) monthly between March to October 2015. Surveys will be used to estimate the standing stock of plankton at each site, while intensive experiments will be carried in spring (April) and summer (July or August) and possibly fall (October/November) to evaluate rates of carbon flux through the MFW to higher trophic levels.

Experiments **–** Experiments will be carried at all three stations on two or three dates (April, August, and possibly October) and three depths (epi, meta, and hypolimnion); we will collect water and animals to determine the rates of picoplankton growth and loss, microzooplankton growth and grazing. Size fractionated primary production and chlorophyll a concentrations will be measured. Rates of primary production will be measured in duplicate bottle using a clean 14-carbon technique (Fitzwater et al. 1982) that will be post fractionated to determine size specific production rates (Fahnenstiel and Carrick 1992).

Milestones:

- Field sampling and experiments will be carried out in 2015
- Sample and data analysis will begin and continue through 2016
- Presentations will be made during 2016
- Papers will be written during 2016

Outcomes:

This project provides detailed seasonal information and spatio-temporal connections of the entire food web and movement of nutrient through it in the Muskegon/Grand River region of Lake Michigan so we can project EPA/USGS results across time for greater generalization of results and development of spatially explicit ecosystem models incorporating nutrient movement from inshore to offshore, and impacts of dreissenids and other stressors. Describing the current state of lower food web is paramount to facilitate our understanding, management, and restoration of the Lake Michigan ecosystem. In particular our study of the MFW is addressing a major research gap because we believe the MFW is exerting a stabilizing influence on the pelagic food web.

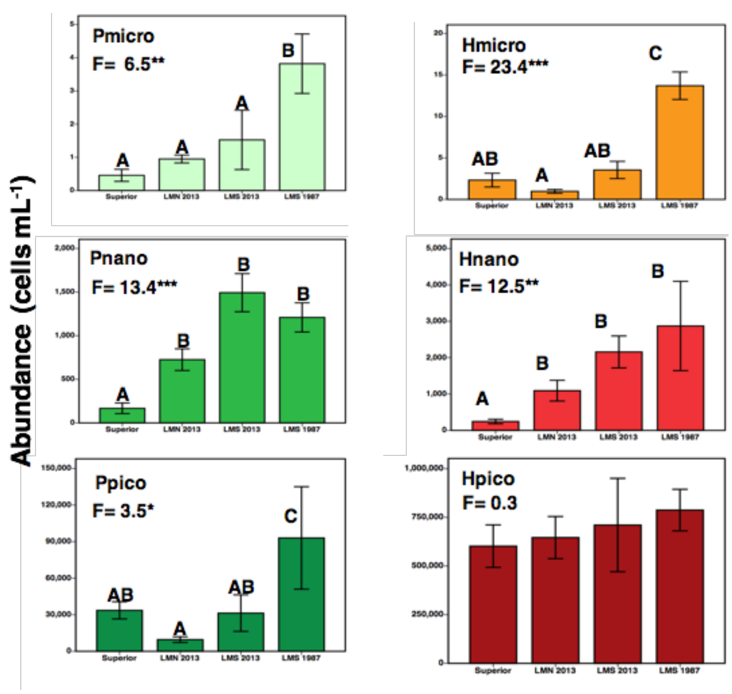
Accomplishments:

<u>Project 1: Benthic Surveys for Lake Michigan</u>

- Coordinated with collaborators from EPA and Buffalo State College (BSC) to collect samples on board the R/V Lake Guardian in July 2015
- Samples from the southern region of Lake Michigan were picked at GLERL by CILER employees and at the University of Michigan by a work study student, under supervision by Elgin (Baldridge) and Nalepa. We then transferred the picked organisms to BSC, where they are in process of being identified and measured.
- We finished picking samples ahead of schedule and had enough time to conduct our own measurements on the mussels from our annual survey sites before turning the samples over to BSC.
- Preliminary estimates of mussel biomass for the southern region are complete and were presented at IAGLR in June 2016.
- We have received all data from our BSC collaborators and whole lake analyses is now in progress.

Project 2: Temporal and spatial coupling of nutrients and food web

Research activities focused on the sustainability of the pelagic food web in Lake Michigan, with particular emphasis on measuring the link between the MFW and crustacean zooplankton that directly feed fish and the role of mussels in affecting that link. Our objectives were: 1) census the complete MFW assemblage along a near to offshore gradient in Lake Michigan, 2) determine simultaneous rate measurements of picoplankton (bacteria and cyanobacteria) growth and loss rates, and 3) determine loss rates for MFW components using the feeding experiments of Vanderploeg et al. (2001, 2009). Quagga mussels and lake water will be collected from our mussel collection sites in Lake Michigan (M45). We have accomplished objectives 1 and 2, and are in the process of completing objective 3 this year.



Objective 1, MFW Assemblage: Ppico numbers (i.e., picocyanobacteria) in 2013 were lower compared with those in the 1980's; however, the percent contribution of the <2µm fraction increased 2-fold (> 50% of total chlorophyll, Fig. 1). The abundance of small, pigmented chrysomonads and cryptomonads (Pnano size category) were not significantly different between 1987 and 2013 at the same time Pmicro did decline; this shift towards Ppico and Pnano dominance may be related to the recent oligotrophication of Lake Michigan. The abundance of ciliated protists (Hmicro size class) was 3-fold lower in 2013 compared with levels in 1987, while the abundance of both Hpico (eubacteria, range 0.24-1.36 x 10^6 cells • mL^{-1}) and Hnano (mainly colorless chrysomonads; range 0.11-6.4 x 10^3 cells • mL^{-1}) remained stable and reflected the resilience of bacteria-flagellate trophic linkage.

Objective 2, Picoplankton Population Dynamics: Bottle experiments were performed during major thermal periods to estimate both Hpico (bacteria) and Ppico (picocyanobacteria) growth and grazing in Lake Michigan (May, July, October 2013, n=30 experiments) and these were compared against estimates in Lake Superior. Interestingly, Hpico loss rates were higher than growth rates in Lake Superior, while rates were balance in Lake Michigan. Ppico loss and growth were lower than rates for Hpicos and were balanced in both lakes. Our results suggest that high grazing losses balance both Hpico and Ppico growth rates in Lake Michigan, but the pattern is not the same in Lake Superior.

Lake	No. Exps	Hpico Growth Per day	Hpico Loss Per day	Ppico Growth Per day	Ppico Loss Per day
Superior Epi, Meta	33	0.515	-0.963	0.215	-0.203
Michigan North	6	0.589	-0.513	0.383	-0.232
Michigan South	11	0.535	-0.458	0.188	-0.328

Publications:

Butts, E., and H.J. Carrick. 2017. Phytoplankton seasonality along a gradient of temperate lakes: Convergence in taxonomic composition during winter ice-cover. *Northeastern Naturalist*. 24: 167-187 (IGLR # 82).

Denef, V., H.J. Carrick, J.F. Cavaletto, E. Chiang, T.H. Johengen, and H. Vanderploeg. 2017. Lake bacterial assemblage composition is sensitive to biological disturbance caused by an invasive filter feeder. mSphere 2: e00189-17 (IGLR # 81).

Presentations:

Carrick, H., L. Rudstam, D. Warner, and H. Vanderploeg. Plankton dynamics along a near to offshore gradient in Lake Michigan. 60th Annual Conference- *International Association for Great Lakes Research*, Cobo Center, Detroit, Michigan, 16 May, 2017. Invited

Carrick, H.J. Importance of the microbial food web in Lake Michigan. *Bowling Green State University*, Bowling Green, Ohio, 19 October, 2016. Invited.

Carrick, H.J. Role of microbes in regulating ecosystem-level dynamics in lakes and streams, *Central Michigan University*, Mt. Pleasant, Michigan, 13 January, 2017. Invited

Dart, A., A. Robb, H. Vanderploeg, and H. Carrick. Picoplankton dominant the particulate P pool along a near to offshore gradient in Lake Michigan. 60th Annual Conference- *International Association for Great Lakes Research*, Cobo Center, Detroit, Michigan, 19 May, 2017. Invited.

Dart, A. and H. Carrick. Variation in phosphorus concentrations along a near to offshore gradient in southern Lake Michigan: Importance of picoplankton storage of polyphosphates, Dept. of Biology. Institute for Great Lakes Research Student Symposium, *Central Michigan University*, Mt. Pleasant Michigan, 28 February, 2017.

Outreach Activities:

We participated in public outreach events (e.g., the Ann Arbor Mayor's Green Fair) and volunteered for student science competitions (e.g., National Ocean Science Bowl and a local science fair). Summaries of our activities were posted on GLERL and CILER's Facebook, YouTube channel, and Twitter accounts.

THEME IV: Protection and Restoration of Ecosystem Resources

NOAA Regional Team Great Lakes Policy Support

Principal Investigator(s): Brad Cardinale (CILER)
NOAA Technical Lead(s): Jennifer Day (GLRCT), Felix Martinez (NCCOS)
NOAA Sponsoring Office: NOAA Great Lakes Regional Collaboration Team
Budget Amount: $19,591

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:

The National Oceanic and Atmospheric Administration (NOAA) seeks to strengthen and leverage public-private partnerships to provide the nation with the best available science and high quality environmental information. The NOAA Great Lakes Regional Collaboration Team is interested in exploring innovative and non-traditional public-private partnership opportunities that are strategically aligned with NOAA's current priorities and mission critical work. With guidance from NOAA personnel, a student team focused on a strategic partnership analysis of NOAA's current priorities and how those align with private and public interest organizations across the Great Lakes region. Completion of this project will assist NOAA's Great Lakes Regional Team in exploring partnership opportunities throughout the region, as well as assist in garnering public and private interest in mutually-identified priority projects.

Objectives:

- Produce methodology criteria rubric that is used for evaluating potential partners in this project and can be used for reference in the future.
- Generate recommendation list of organizations that we recommend NOAA consider partnering with in the future.

Specific Aims/Milestones:

- Conduct research on Great Lakes environmental issues and NOAA's capabilities to address those issues through partnerships.
- Use interviews, literature reviews, and other research methods to identify areas of need and criteria for evaluation.
- Discuss project plans and progress in meetings and conferences with NOAA team leads in the Great Lakes region.

Accomplishments:

Methodology
Our methodology rubric is a form that allows us to efficiently gauge a potential partner organization's performance. Based on major environmental issues in the Great Lakes region and NOAA's capabilities, we defined collaboration topics including invasive species, harmful algal blooms, green infrastructure, customized weather service, coastal management, coastal navigation, habitat restoration and economic development in the Great Lakes region. For each of these topics, we considered whether potential partner organizations would fill the role of information producer, information distributor, information end-user, or some combination.

We divided potential partners into 6 categories which are industries, foundations, coastal management, education, restoration, and conservation. We created separate criteria for the evaluation of partners in each category. We defined a set of criteria which would quantitatively and qualitatively evaluate potential partner organizations that we felt would be a good fit with NOAA's current partnership needs in the Great Lakes region. The separate criteria items within each partner category were each assigned a different weight. Some criteria items have greater weight, such as 20% of the total, while other criteria items may only have 5% or 10% weight. We based the weights of the criteria items on how important we felt a specific criteria item was to ensuring an effective partnership between NOAA and the prospective partner organization within a topic. The importance we placed on each criteria item stemmed from our previous research, case studies, and interviews.

Recommendation list
We identified a list of partner organizations, using our general methodology as a resource and ensuring the partner fits in one of the seven major environmental issues and topics. The list of partners includes potential collaborations in areas of industry, foundation, coastal management, education, restoration, and conservation. The list of organizations we reviewed using our methodology can be viewed in the final report of this project (https://drive.google.com/file/d/0B8cwAwoy-5P6czQ0aUxYUWdfQWc/view?usp=sharing).

Peer-Reviewed Publications:

None.

Non-Peer-Reviewed Publications:

None.

Presentations:

Presentation in Erie, Pennsylvania (August 2016). This presentation took place at the annual GLRCT meeting. The presentation provided an early overview of the project, and covered our methods (interviews, literature reviews, methodology model, identifying new partnership opportunities). In addition, the presentation outlined several cooperation areas in the environmental topics of invasive species, customized weather service, green infrastructure, harmful algal blooms, coastal navigation, coastal management, coastal health, and dams/other barriers.

Presentation in Washington, D.C. (March 2017). In this presentation at the NOAA Central Library, we focused on partnership selection. The presentation provided backgrounds for each of the six major partnership categories (industries, foundations, coastal management, education, restoration conservation), as well as a criteria rubric and candidate list for each partnership category.

Presentation at SNRE Capstone Conference (April 2017). This presentation took place at the annual SNRE Capstone Conference. The presentation provided an overview of the project, and showed some of the deliverables, including methodology rubrics for the partnership categories and a potential recommendation list for each category.

Outreach Activities:

None.

THEME IV: Protection and Restoration of Ecosystem Resources

2016 Synthesis, Observations, and Response (SOAR)

Principal Investigator(s): Thomas Johengen (CILER), Robert Shuchman (MTRI), Bopaiah Biddanda (GVSU)
NOAA Technical Lead(s): Steve Ruberg (*GLERL*)
NOAA Sponsoring Office: OAR, NOAA Great Lakes Environmental Research Lab
Budget Amount: $496,751

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

Overview and Objectives:

The implementation of the Great lakes Synthesis, Observations, and Response System program (SOAR) 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 providing an up-to-date (including real-time data) web presence. **The overall objective of the SOAR project is to provide real-time ecosystem information to maintain high quality drinking water and bathing beaches through observations, data management, and forecast model development.** Observations of environmental parameters will be 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, Muskegon Lake Area of Concern (AOC), Lake Michigan and Lake Erie; a web-based data management system; synthesized remote sensing products for predicting HABs; and coupled physical-chemical-biological models for Green Bay, Saginaw Bay, and western Lake Erie. Instrumentation deployed in and near AOCs will provide observations of hypoxia and soluble reactive phosphorous, and support detection of harmful algal blooms. Specific components of these research activities are led by CILER Partners at Michigan Tech Research Institute (MTRI) and Grand Valley State University (GVSU), as defined below.

MTRI has worked together with NOAA GLERL and CILER over the last decade on the development of satellite-based algorithms that specifically address water quality issues in the Great Lakes. An important component of this work is the measurement of backscatter and absorption coefficients of nearshore and offshore waters in all five Great Lakes. Accurate backscatter and absorption coefficients are necessary inputs into Great Lakes satellite-based algorithms that provide chlorophyll, DOC, CDOM, TSM, HABs, water clarity, and photic zone estimates. Previous *in situ* optical property measurements collected by NOAA GLERL, MTRI, and UFI are located in the Great Lakes Optical Properties Geospatial Database (GLOPGD) which can be found on line at http://glopgd.org/. This project supports the generation of additional satellite image retrievals (2016 and forward in time) needed by GLERL and other Great Lakes stakeholders, as well as continue the successful optical property measurements program started in 2015. The satellite image retrievals utilize both MODIS and VIIRS data. An element of the satellite image retrieval task is the generation and evaluation of 7-10 day composite maps that are created using data from the useful portions of partially cloudy images. Additional efforts focus on near real-time continuous radiometer data collected at Lighthouse 2 in western Lake Erie to support atmospheric correction of remote sensing data. Handheld ASD data are collected to help calibrate aircraft-based hyperspectral data.

GVSU continues to operate the Muskegon Lake Observatory (MLO), which was initially developed under funding from EPA's GLRI program (2011-2014). The current project continues building much-needed long-term time series data for this Great Lakes AOC, and enables new scientific discoveries such as detection of hypoxia and CyanoHABs with management implications. The MLO project utilizes GVSU-Annis Water Resources Institute (AWRI) and NOAA GLERL resources, building a key regional infrastructure that supports students, scientists, resource managers, and policy makers.

Project I: Development of Decision Support Tools (PI: Dr. Thomas Johengen, CILER)
Specific Aims/Milestones:

1. Develop and operate observing systems within western Lake Erie that include:
    - Deploy four instrumented moorings that contain the following instrumentation: WETLabs CYCLE-P nutrient analyzer, Turner Designs C6 fluorometer, and a YSI multi-parameter sonde. All moorings will be designed to transmit the data in real-time via GLERL's ReCON data management system.
    - Use collected ground truth samples to validate and refine remotely-sensed determinations of sediment plumes and nuisance algal blooms using discrete measurements of chlorophyll, total suspended matter, and CDOM.
    - Conduct profiles to measure inherent optical properties using the Satlantic hyperspectral profiler, the Satlantic hand-held hyperspectral imager, and WETLabs acs and bb9 absorption and backscatter instruments to aid in algorithm development and validation of remote sensing estimations of color producing agents (chlorophyll, total suspended matter, and CDOM).
    - Conduct 2-3 detailed 3-dimensional surveys with our existing IVER-2 Autonomous Underwater Vehicles to map spatial distributions of the Maumee River plume and harmful algal blooms.
    - Initiate the collection of airborne hyperspectral data using manned and unmanned aerial systems (UAS).
2. Develop and operate a field program for Saginaw Bay to collect ground truth samples to help compare and refine various remote sensed determinations of sediment plumes and nuisance algal blooms.

3. Deploy a real-time buoy in Saginaw Bay to aid in the detection of harmful algal blooms and episodic hypoxia events.
4. Conduct QA/QC sampling monthly in Saginaw Bay, western Lake Erie, and Lake Michigan to help evaluate the accuracy and consistently of ReCON instrumented moorings.
5. Initiate an inter-comparison of various remote sensed products and estimations of algal bloom and sediment plume concentrations and areal extent for western Lake Erie and compare these estimates against field data.

Accomplishments:

The SOAR western Lake Erie buoys were deployed starting at the end of May and operated continuously until final retrieval in October and November (Table 1). Stations WE2 and WE4 were outfitted with WETLabs Cycle P, Turner C6 and YSI EXO units. Stations WE8 and WE13 were equipped with Cycle P and EXO units only. Total number of days of continuous monitoring across the four sites ranged from 117 to 161, with a total of 616 days for all stations. All four stations were real-time and being reported to the GLOS and GLERL HABs websites. Buoys were serviced at 4-6 week intervals with clean instruments.

Table 1. Deployment schedule for western Lake Erie buoys providing continuous, near-realtime monitoring of water quality conditions, nutrient concentrations, and HAB development.

Site	Initial Deployment	Final Retrieval	Days Deployed
WE2	5/20/16	10/28/16	161
WE4	5/20/16	11/21/16	185
WE8	6/2/16	11/2/16	153
WE13	6/30/16	10/25/16	117
TOTAL			616

CILER also supported the deployment and operation of a NOAA GLERL ReCon buoy in Saginaw Bay, Lake Huron throughout the 2016 field season to aid in the detection of harmful algal blooms and episodic hypoxia events. Monthly vessel surveys were performed at the buoy to re-service instruments and provide QA/QC checks with independent profiles and laboratory analysis of discrete samples.

<u>Project II: Remote Sensing and Optical Property Measurements of Great Lakes Water (PI: Dr. Robert Shuchman, MTRI)</u>

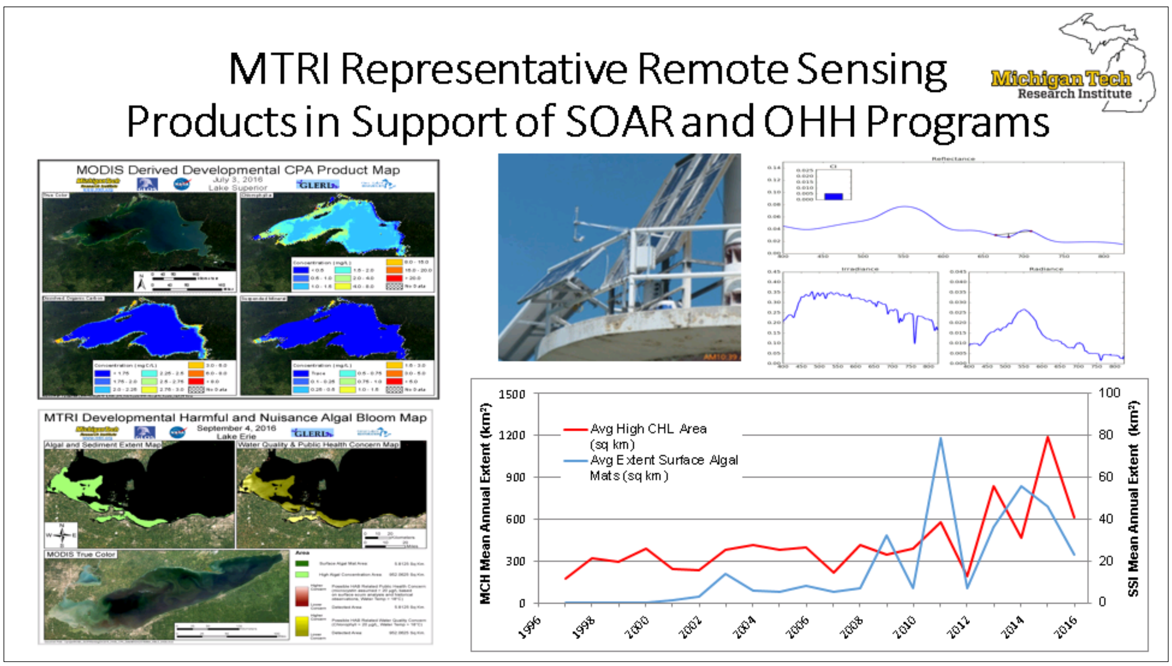
Specific Aims/Milestones:

Remote Sensing Observations Program Objectives:

1. Collect near real-time continuous radiometer data at Lighthouse 2 to support atmospheric correction of remote sensing data and observe changes in surface reflectance as a function of water quality,
2. Collect ASD data at MBSP to support vicarious calibration of aircraft hyperspectral data,
3. Generate the suite of derived satellite products for each Great lake on each cloud free day, and
4. Demonstrate the robustness of a 7-10 day composite image of the suite of derived products.

Optical Property Measurement Program Objectives:
1. Generate updated inherent optical property (IOP) data to further refine CPA-A hydro-optical (HO) model performance,
2. Observe seasonal and spatial changes in IOPs due to shifts in phytoplankton composition,
3. Quantify nearshore and offshore IOP gradients,
4. Determine HO model parameters in Lake Erie for two dominating sediment types (calcite and red clay), and
5. Generate HABs-specific HO models for more robust HABs satellite retrievals.

Accomplishments:
During the July 2016 to June 2017 project period, MTRI continued to develop and disseminate new and refined remote sensing products in support of the current SOAR monitoring and public warning activities that included: 1.) Additional weekly HABs concentrations in the Western Basin of Lake Erie as well as Saginaw Bay in Lake Huron and Green Bay in Lake Michigan; 2.) Updates of the annual extent of HABs in



the Western Basin and Saginaw Bay; 3.) Weekly derived Great Lakes water quality parameters (chlorophyll (chl), dissolved organic carbon (doc), and suspended mineral (sm) concentrations; cdom absorption; Kd attenuation, Photosynthetically Active Radiation (PAR), photic zone depth, backscatter, and absorption); and 4.) Satellite-derived time series of stakeholder-requested products of interest (i.e., pp and HABs). The attached figure summarizes example derived remote sensing satellite products being generated under this SOAR initiative.

MTRI researchers contributed to a paper which demonstrated a method to generate high temporal resolution, spatially continuous composites of chlorophyll for Lake Superior by coupling the CPA-A with a hydrodynamic model (Xue et al., 2017). This approach resulted in hourly and daily chlorophyll maps. Comparing the algorithm's output to *in situ* data, Xue et al. found strong correlation even when there was no valid satellite retrieval within 24 hours of the *in situ* data. MTRI researchers extended this approach to work on other lakes, to interpolate other remote-sensing derived water quality products (whether from the CPA Algorithm or otherwise), to run without the particle-driven spatial interpolation, and to allow users to set a limit on the age of data being included in the interpolations. Initial tests on Lake Erie have shown promise in circumventing cloud issues as well as HABs-driven atmospheric correction failures.

In addition to the derived remote sensing products, MTRI scientists and engineers are assisting GLERL personnel in the collection of Inherent Optical Properties (IOP) and Apparent Optical properties (AOP) measurements of Great Lakes water. These IOP and AOP measurements will be imported into the GLOPGD.org and support the refinement of the derived satellite products as well as provide insight into how lake constituents (algae, sediment, and doc) are changing due to invasive species, climate change and anthropogenic forcing.

A paper is nearing completion using these time-series observations to document the spatio-temporal variations in IOPs due to prolific blooms of harmful cyanobacteria (cyanoHABs) in Lake Erie. Significant differences in absorption spectra were observed throughout the observation period and between years. These observed differences are attributed to fluctuations in cyanoHAB extent and concentration but also from the periodic occurrence of large sediment plumes from the Maumee River. These measurements were able to capture the differences in IOPs resulting from a severe cyanoHAB event in 2015 and a mild event in 2016. These measurements are critical for the refinement, calibration, and validation of remote sensing water quality algorithms. Specifically, these new IOP measurements are being used to update the HO models utilized by the CPA Algorithm which is now being utilized to generate experimental products within the NOAA Great Lakes CoastWatch system.

Project III: Observatory for Ecosystem Changes in Muskegon Lake AOC (2016-17) (PI: Bopi Biddanda, GVSU)

Specific Aims/Milestones:

The goal of this project is a robust 7-yr time-series of meteorological and water quality data for the Muskegon Lake AOC that will be universally accessible on the project website. The MLO engages the wider Great Lakes community to carry out research, education, and outreach including engagement with GVSU researchers, students, and the public year round. MLO data are openly accessible on the project website and the GLOS website, advancing ecosystem science in the Great Lakes. Monitoring and research focus during the reporting period included:

- Monitor in support of restoration goals for the Muskegon Lake Area of Concern.
- Comparative analysis of seasonal hypolimnetic hypoxia through the monitoring years and investigation of key drivers.
- Analyze the role of intrusions of cold and oxygenated Lake Michigan water into Muskegon Lake during summer time coastal upwelling events in alleviating hypoxia.
- Examine linkages between hypoxia and fish abundance, P-regeneration, and HABs.
- Initiate lake-wide ADCP flow measurements, and made plans for additional T-profile moorings to better understand lake hydrodynamics.

Accomplishments:

Project activities and milestones for the MLO during the reporting period include:

- MLO was in operation from July 1, 2016 through November 15, 2016 after which it was recovered for the winter with support from NOAA-GLERL.

- MLO was serviced during the winter months; sensors were bench checked and serviced; buoy infrastructure was cleaned, serviced; solar tower was strengthened; surface and subsurface buoys painted with ablative paint. New batteries were purchased and installed. All buoy components were serviced.
- A subsurface YSI Sonde and sturgeon acoustic receiver were deployed January 3, 2017 for deployment during winter and early spring. Recovered March, 28 2017.
- MLO was again deployed in May 2017 and operated through the reporting period.
- Time-series data was processed for data quality, disseminated and archived.
- Supported 1 buoy technician to manage operations and gathered data for supporting projects of 3 Graduate Students and 1 Post-doctoral Associate to develop a working hydrodynamic model of Muskegon Lake.
- Supported 3 MLO-based Master's degree thesis projects and their professional development.
- Supported 5 MLO-based undergraduate interns in their training and professional development.
- Made 7 presentations at forums ranging from classrooms to international conferences.
- Generated 5 peer-reviewed journal publications, with 1 in review and 3 more under preparation.
- Published 1 popular science article in a regional STEM education newsletter and 1 Photo from the Field in a global Earth science Newsmagazine based on MLO findings (please see under Publications and Outreach, below).
- Shared observatory science findings with >1,000 K-12 students and >100 teachers.
- Leveraged MLO infrastructure and findings to apply for and obtain funding for a graduate fellowship position focused on quantifying the carbon cycle in Muskegon Lake.
- Leveraged MLO infrastructure and findings to seek funding to Postdoctoral researcher focused on developing a 3-D hydrodynamic model for the Muskegon Lake AOC.
- Additional time-series instrumentation to support graduate and post-doctoral studies: Constructed and equipped 5 additional sensor strings in Muskegon Lake to better understand spatial heterogeneity of ecosystem changes within the lake. Deployed Early August 2016 through January 3, 2017. Recovered and serviced system during Winter 2017. Redeployed in early June 2017 and operated through the reporting period.

Peer-Reviewed Publications:

Biddanda, B. A. 2017. Global significance of the changing carbon cycle. Eos- Earth and Space News, American Geo[physical Union 98 (6): 15-17. https://eos.org/opinions/global-significance-of-the-changing-freshwater-carbon-cycle

Defore, A. D., A. Weinke, M. Lindback, and B. Biddanda (2016). Year-round Measures of Planktonic Metabolism Reveal Net Autotrophy in Surface Waters of a Great Lakes Estuary. Aquatic Microbial Ecology 77: 139-153. http://www.int-res.com/articles/ame_oa/a077p139.pdf

Salk, K. R., Ostrom, P. H., Biddanda, B. A., Weinke, A. D., Kendall, S. T., and Ostrom, N. E. 2016. Ecosystem metabolism and greenhouse gas production in a mesotrophic northern temperate lake experiencing seasonal hypoxia. *Biogeochemistry*. 131:303-319. https://link.springer.com/content/pdf/10.1007%2Fs10533-016-0280-y.pdf

Weinke, A. D. and Biddanda, B. A. (In Press, 2017). From bacteria to fish: ecological consequences of seasonal hypoxia in a Great Lakes estuary. Ecosystems. https://link.springer.com/content/pdf/10.1007%2Fs10021-017-0160-x.pdf

Cotner, J. B., Weinke, A. D. and Biddanda, B. A. (In Press, 2017). Great Lakes: Science can keep them great. http://www.sciencedirect.com/science/article/pii/S0380133017301107

Biddanda, B. A., A. D. Weinke, S. T. Kendall, L. C. Gereaux, T. M. Holcomb, M. J. Snider, D.K. Dila, S. A. Long, C. VandenBerg, K. Knapp, D. J. Koopmans, K. Thompson, J. H. Vail, M. E. Ogdahl, Q. Liu, T. J. Johengen, E. J. Anderson, and S. A. Ruberg (Submitted, In Review). Chronicles of Hypoxia: Time-series buoy observations reveal annually recurring seasonal basin-wide bottom water hypoxia in Muskegon Lake Area of Concern – a Great Lakes estuary. J. Great Lakes Res.

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*

Sayers, M.J., G. Fahnenstiel, R.A. Shuchman, and K. Bosse. "Spatial and Temporal Patterns of Inherent Optical Properties in Western Lake Erie for 2015 and 2016." *In Progress*

Xue, P., D.J. Schwab, R.W. Sawtell, M.J. Sayers, R.A. Shuchman, and G.L. Fahnenstiel. "A particle-tracking technique for spatial and temporal interpolation of satellite images applied to Lake Superior chlorophyll measurements." *Journal of Great Lakes Research, 43(3)* (2017): 1-13.

Non Peer-Reviewed Publications:

Lekki, J., G. Leshkevich, S.A. Ruberg, D. Stuart, and A. Vander Woude, et al. Airborne Hyperspectral Sensing of Harmful Algal Blooms in the Great Lakes Region: System Calibration and Validation, From Photons to Algae Information: The Processes In-Between. NASA –Technical Memorandum NASA/TM—2017-219071. NASA, (2017). https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170002298.pdf

Biddanda, B. and A. Weinke. 2016. Finding a Lake's Productivity Peak and Nap Time. In InterChange, Stem Connections for the Classroom, Newsmagazine of the Regional Science and Math Center, GVSU. http://www.gvsu.edu/rmsc/interchange/2016-november-connections-1188.htm

Biddanda, B., A. Weinke and S. Kendall (2017). Michigan's Muskegon Lake Observatory Buoy. Postcards from the Field. Eos-Earth and Space News, AGU, March 1, 2017. Eos 98 (3): 48. https://eos.org/wp-content/uploads/2017/02/Mar-17_magazine.pdf?x35494

Presentations:

Biddanda, B. (March 1, 2017). Finding the "Goldilocks Zone" for Carbon Cycling in a Great Lakes Watershed. Departmento de Ecologia, University of Granada, Granada, Spain. (Oral)

Weinke, A., Biddanda, B., Knapp, K., and Kendall, S. (March 11, 2017). Muskegon Lake Observatory 2011-2017: Its use to boaters, fishermen, and scientists. Spring Thaw Open House Event at Torresen Marine, Muskegon, Michigan (Oral).

O'Brien, Z. and Biddanda, B. (April 12, 2017). Exploring the changing thermal structure and primary production of a Great Lakes estuary. GVSU Student Scholarship Day. (Poster).

Biddanda, B. (May 11, 2017). Finding and tracking a "Goldilocks Zone" of net productivity in a Great Lakes watershed. CILER Seminar, GLERL, Ann Arbor, Michigan. (Oral)

Knapp, K., Weinke, A., and Biddanda, B. (May 17, 2017). Carbon cycling in Muskegon Lake estuary AOC using time-series data. IAGLR 60th Annual Conference of the International Association for Great Lakes Research, Detroit, Michigan (Poster).

Liu, Q, E. Anderson and Biddanda B. (May 17, 2017). A physical-Biogeocheimcal Simulation of Muskegon Lake. 60th Annual Conference of the International Association for Great Lakes Research, Detroit, Michigan. (Oral)

Weinke, A., Knapp, K., and Biddanda, B. (May 18, 2017). Time-series and discrete data reveal dynamics and consequences of hypoxia in Muskegon Lake, Michigan. IAGLR 60th Annual Conference of the International Association for Great Lakes Research, Detroit, Michigan (Oral).

Billmire, M., C. Brooks, K. Bosse, M. Sayers, R.A. Shuchman, A. Grimm, and R. Sawtell. "Enabling Increased Sharing of Great Lakes Remote Sensing Data." IAGLR 60th Annual Conference on Great Lakes Research (IAGLR 2017) (2017). (Oral)

Bosse, K.R., R.A. Shuchman, M.J. Sayers, D.J. Schwab, and G. Leshkevich. "Developing A Daily Composite Product for Water Quality Parameters in the Great Lakes." IAGLR 60th Annual Conference on Great Lakes Research (IAGLR 2017 (2017). (Oral)

Sawtell, R.W., M.J. Sayers, R.A. Shuchman, K.R. Bosse, B.E. Hart, and J. Lekki. "Near Real Time HABs Observations in Lake Erie Using a Lightweight Portable Radiometer." IAGLR 60th Annual Conference on Great Lakes Research (IAGLR 2017) (2017). (Oral)

Sayers, M.J., J. Lekki, L. Liou, R.A. Shuchman, R.W. Sawtell, R.C. Anderson, and G. Aden. "Next day generation of cyanoHAB water quality products to support NASA Hyperspectral Imaging of Lake Erie." Ocean Optics XXIII Conference (2016). (Poster)

Sayers, M.J., S. Ruberg, G. Leshkevich, D.G. Stuart, R.A. Shuchman, and S.T. Aden. "Spatial and Temporal Patterns of Inherent Optical Properties in Western Lake Erie for 2015 and 2016." IAGLR 60th Annual Conference on Great Lakes Research (IAGLR 2017) (2017). (Oral)

Shuchman, R.A., M.J. Sayers, K. Bosse, 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). (Oral)

Rowe, M.D., E.J. Anderson, S.A. Ruberg, E.M. Verhamme, D. Beletsky, H. Zhang, T.H. Johengen, and C.A. Stow. Investigation of a hydrodynamic forecast model as a predictor of dissolved oxygen dynamics near public water system intakes in the central basin of Lake Erie. ASLO 2017, Honolulu, Hawaii, February 26-March 3 (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 Millennium Network, Windsor, Ontario, Canada, February 21-23 (2017).

Outreach Activities:

Data for the MLO project are maintained at www.gvsu.edu/buoy/ where current and historical data are accessible to researchers and the public. Select data feeds into the Integrated Ocean Observing System through the Great Lakes Observing System portal at http://glos.us/.

Made time-series data for 2016 and 2017 from Muskegon Lake Observatory available for ship-board instruction and comparisons during W.G. Jackson K-12 educational trips on the lake.

Published a popular science article in a regional STEM education newsletter (please see link under non-peer-reviewed publications, above) and a Postcard from the Field in a global Earth science Newsmagazine based on MLO findings.

Data from RECON buoys are currently displayed on the Real-time Coastal Observation Network web display and data management system, as well as the GLOS DMAC web portal to be made available for access by GLRI managers, municipal water managers, beach managers, and researchers.

Data from the western Lake Erie buoys are displayed on the GLERL HABs and Hypoxia website as well as through the IOOS GLOS data portal.

THEME IV: Protection and Restoration of Ecosystem Resources

Empowering Communities with Online Action Planning Tools: Tipping Points and Indicators for Improving Water Quality across the Great Lakes

Principal Investigator(s): Brad Cardinale (CILER), Hongyan Zhang (CILER), Brian Miller (IL Sea Grant), Dave Hyndman (MSU), and Bryan Pijanowski (Purdue University)
NOAA Technical Lead(s): Edward Rutherford (NOAA GLERL)
NOAA Sponsoring Office:
Budget Amount: $394,943

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
Goal 5 – NOAA Enterprise-wide Capabilities: Science and Technology Enterprise, Engagement Enterprise, Organization and Administration Enterprise

Overview:
In order for coastal communities to achieve ecosystem sustainability, they must first know what land and habitat components are necessary to sustain their ecosystems. When communities are armed with science-based environmental limits or "tipping-points," they are able to institute land use policies and restoration plans that ensure critical green infrastructure and habitat-sustaining Great Lakes ecosystems are maintained. For example, the Sea Grant Sustainable Coastal Community Development network has used a 10% impervious cover tipping point to work with communities to measure their existing impervious surface cover, and implement land use change policies, ordinances, cois developinmprehensive plans, and smart growth strategies necessary to keep a community's impervious surface cover below levels that impact their streams.

With Great Lakes Restoration Initiative (GLRI) funding from FY2010-2012, our Tipping Points project team identified watershed-scale land use tipping points that affect ecosystem health in selected Great Lakes tributary and near shore areas. We developed an interactive decision support system (DSS) (http://tippingpointplanner.org), based on extensive research, as a facilitation tool for extension specialists, coastal managers, and consultants who work with land use commissions and watershed planning committees. This tool helps watershed leaders identify land-based activities that result in nutrient loading, increased runoff, nonpoint source pollution, threatening the sustainability of ecosystems in their watershed. The tool provides a facilitated forum to explore policy and management interventions necessary to keep ecosystems from crossing a tipping point and moving to an unstable condition. Communities may use the tool develop sustainable action plans for their watershed or community.

Objectives:

Our overall objective is to improve sustainable land management decision making and restoration at the sub-watershed level by targeting nutrient loading and land use practices that impact Great Lakes food webs, coastal algal blooms, and tributary fishery values. We seek to enhance the Tipping Point Planner (TPP) DSS with high resolution data for nutrient sources in selected Area of Concern (AOC) watersheds and with models relating nutrient sources to multiple endpoints. Our work will inform Best Management Practice (BMP) selection, location and action prioritization, and will help Sea Grant facilitators select target watersheds for facilitation and/or assistance.

Specific Aims/Milestones:

Goal 1. Identify sources of nutrient loading that cause ecosystem impacts and evaluate costs/benefits of management in priority basins (Research Team)

- Task 1.1. Expand Tipping Point Planner maps
- Task 1.2 Fine-scale data and model analysis of nutrient-related impacts

Goal 2. Community Engagement in Targeted Watersheds (Outreach Team)

- Task 2.1. Identify restoration and conservation opportunities
- Task 2.2. Facilitate action register development and plan implementation
- Task 2.3. Expand use and adoption of the Tipping Point Planner system
- Task 2.4. Evaluate impact and environmental outcomes

Goal 3. Decision Support System Improvement and Upgrades (All teams)

- Task 3.1. System upgrade maintenance

Accomplishments:

Task 1.1. TPP map expansion (Purdue University and Michigan State University [MSU] teams)
We have completed the input of phosphorus loading simulations based on the USGS SPARROW model also linked to land change forecasts to 2050. These simulations are now included as part of the Tipping Point Planner assessment tool.

The Purdue, NOAA, and MSU research team met at the Kellogg Biological Station June 28th to discuss how to integrate all nutrient loading models into the TPP DSS tool. We also discussed data sharing, future research projects and coordination of research and outreach across the project. The team also started a catalogue of models that are incorporated into TPP so that the outreach team can determine which model fits outreach needs the best.

Task 1.2 Fine-scale data and model analysis of nutrient-related impacts (Purdue, MSU, and University of Michigan [UM] teams)

Task 1.2.a *Refine nutrient loading model*

Task 1.2.b *Model analysis of nutrient-related impacts*

Great Lakes Basin scale SENSMaps (Spatially Explicit Nutrient Source Maps) are nearing completion. SENSMaps accounts for point sources and 6 specific nonpoint nutrient sources at 30m cell resolution across the Great Lakes Basin (GLB): atmospheric deposition, septic systems, chemical non-agricultural fertilizer, nitrogen fixation, chemical agricultural fertilizer, and manure. Atmospheric deposition has been completed for the GLB (N and P). P deposition uses extensive literature review to improve data coverage and reliability compared to other P deposition models. Septic loading has been completed for the GLB (N and P) and updated to use an automated waste water treatment plant (WWTP) service area delineation script based on drinking water wells, US Census population, and existing WWTP locations. Chemical non-agricultural fertilizer has been completed for the GLB (N and P). Nitrogen fixation from legumes has been completed for the GLB. This model uses relationships reported in the literature to calculate fixation as a function of yield. We used the relationship found between USDA Ag Census reported yield and remotely sensed vegetation indices to model yield at the cell level and improve spatial variability in fixation prediction. Manure, point sources, chemical agricultural fertilizer (N and P) are in progress and near completion. We are using the relationship between county USGS N fertilizer application, soil, and crop type to improve cell level spatial variability. We anticipate these datasets will be ready for integration to Tipping Point Planner by September 2017.

Following the work of Luscz et al. (2017), completed for the lower peninsula of Michigan, we will be applying the soon-to-be completed SENSMaps to predict in-stream nutrient loads for each of the HUC-12 scale watersheds in the US Great Lakes Basin. This effort will use publically-available stream nutrient concentration data from EPA's STORET database to provide the calibration dataset for the model. This same approach will be used, along with a simplified nutrient load model, to run forecasts of in-stream nutrient loads based on the land use forecasts out to 2050. We anticipate this effort to be complete by early Spring of 2018.

Work has commenced to provide basin-wide maps of average groundwater recharge. We are using the Landscape Hydrology Model (LHM) to compute average recharge based on climate, land use, and soil characteristics. LHM is a spatially-explicit, hourly, process-based hydrologic model. Average annual recharge, computed by LHM, will then be integrated into the TPP later this year.

Simulations of nitrogen loading, based on farmer fertilizer schedules, land use forecasts (to 2050), soils and crop rotation (corn-soybean versus corn-corn monoculture) options was completed by Purdue. Paper documenting the nitrogen loading was submitted to *Journal of Environmental Management* (minor revisions required). We have also updated the Land Transformation Model to include forecasts of urban subclasses as this is required for LTHIA-LID simulations in the Fort Wayne case study area. Two papers have been prepared that document this work (both are in review, one at *Computers, Environment and Urban Systems* and the second with *Land Use Policy*). Simulations of future land use, constrained by the quality of agricultural soils, were recently published in *Data* by the Purdue-MSU team. A fourth paper has been completed that extends the current Land Transformation Model by incorporating a multi-labeling concept so that multiple models can link to one set of simulations. It was recently published in *GISci and Remote Sensing*. We plan to submit another paper that describes how this affects spatial data and modeling to *International Journal of Geographical Information Science* by August 1.

Food web responses to phosphorus loads in the Saginaw Bay, Lake Huron showed that with phosphorus load decreased from high to low, most of the fish species biomass decreased, but the biomass decreased sharply if phosphorus loads below the current loading level, indicating the system is approaching to a nutrient loading tipping point. These data were ready to be incorporated into the Tipping Point Planner. Food web model for western Lake Erie had been developed and currently under model calibration and scenario simulation for phosphorus loading. Changes in food web structure (especially fish community composition) due to phosphorus loads are also under development based on literature review.

Task 2.1. Identify restoration and conservation opportunities

Two papers that describe low-impact development and green infrastructure planning options (e.g., rain barrels) were published in *Science of the Total Environment* by the Purdue team. Simulations took into consideration future land use change and climate change comparing the cost of implementations and nutrient reductions of over 20 low-impact development options across the entire simulation area over a 50-year period. Simulations required several weeks of optimization runs on a supercomputer. We have identified Sea Grant facilitators to lead community workshops in: Saginaw Bay (MI), Green Bay (WI), Maumee Basin (Toledo, OH), Maumee Basin (Fort Wayne, IN). We have been holding regular meetings with the facilitators in preparation for community deployment.

Task 2.2. Facilitate action register development and plan implementation (Outreach team)
Stakeholder and advisory member discussions have resulted in suggestions for best practice additions for suggested action strategy development. Preliminary dialogue has been conducted with candidate communities in the four watersheds identified above. Final communities will be selected and plans for implementation will be developed it the next quarter.

Task 2.3. Expand use and adoption of the DSS system
Candidate communities and facilitators participated in the April 2017 workshop to learn more about the decision support system, program implementation and discuss community locations for action planning. We will present a four-hour workshop at the 2017 IAGLR State of Lake Michigan conference in November in Green Bay, WI. Attendees will include the watershed planning officials around Lake Michigan. We are coordinating efforts with the LAMP manager for Lake Michigan and Lake Erie to determine how tipping point planner might help in the creation and prioritization of LAMP planning in the future. Meetings with the LAMP groups is scheduled for August 2017.

Task 2.4. Evaluation of impact and environmental outcomes
The outreach team is working with the research team to tie action register strategies to STEP-L to calculate load reductions.

Task 3.1. System upgrade maintenance
The Tipping Point Planner website has been redesigned and now features a modern style, more intuitive user interface with a built-in, professionally produced introduction video. This video gives the user an immediate understanding of what the decision support tool does, and draws the user's attention with audio and visual communication. Additional site improvements were initiated this year that include decision support system module development and integration within the website's modular framework. Additional video support materials were also developed for integration with the site in the second half of 2017. These videos will add to the user's experience while increasing the user-friendliness of the site from a program partner or co-facilitator's perspective.

The SPARROW dataset has been incorporated into the website so as to provide users with information on nutrient loading within a watershed of interest. The SPARROW data is hosted in the Nutrient Loading module, a module designed to guide users through identifying nutrient loading sources and using tools to reduce nutrient loading and promote a sustainable future. The website utilizes the latest web interface components to increase the functionality for users to interact with data and information. The SPARROW section is a crucial element to the Nutrient Loading module since it is a multifaceted set of information. The SPARROW section contains information for the user to explore current nutrient loading metrics as well as future nutrient loading metrics forecasted out to 2040. In addition, SPARROW provides the ability for users to identify nutrient loading sources within the watershed through percent contribution broken down into six sources. With this multifaceted set of information provided by the SPARROW dataset, Tipping Point Planner users are provided with data and information, in a user friendly interface, to identify if there is a nutrient loading issue within a watershed and what is causing the issue.

Peer-Reviewed Publications:

Liu, Y., Theller, L. O., Pijanowski, B. C., & Engel, B. A. (2016). Optimal selection and placement of green infrastructure to reduce impacts of land use change and climate change on hydrology and water quality: An application to the Trail Creek Watershed, Indiana. *Science of the Total Environment*, *553*, 149-163.

Omrani, H., Tayyebi, A., & Pijanowski, B. (2017). Integrating the multi-label land-use concept and cellular automata with the artificial neural network-based Land Transformation Model: an integrated ML-CA-LTM modeling framework. *GIScience & Remote Sensing*, *54*(3), 283-304.

Liu, Y., Engel, B. A., Collingsworth, P. D., & Pijanowski, B. C. (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.

Tayyebi, A., Smidt, S. J., & Pijanowski, B. C. (2017). Long-Term Land Cover Data for the Lower Peninsula of Michigan, 2010–2050. *Data*, *2*(2), 16.

Luscz, E. C., Kendall, A. D., & Hyndman, D. W. (2017). A spatially explicit statistical model to quantify nutrient sources, pathways , and delivery at the regional scale. *Biogeochemistry*, 133(1), 37–57. https://doi.org/10.1007/s10533-017-0305-1

Hamlin, Q F., Kendall, A.D., Martin, S.L., Whitenack, H. D., Roush, J. A., Hannah, B. A., & Hyndman, D.W. Quantifying the Magnitude and Variability of Source Specific Landscape Nutrient Loads across the US Great Lakes Basin. *Journal of Great Lakes Research.* In prep.

Non-Peer-Reviewed Publications:

None.

Presentations:

Hamlin, Q. F., Kendall, A. D., Martin, S. L., Hyndman, D. W. Mapping Wastewater Treatment Plant Service Areas in the Great Lakes Basin. Mid-Michigan Symposium for Undergraduate Research Experiences. 27 July 2016.

Hamlin, Q. F., Kendall, A. D., Martin, S. L., Whitenack, H. D., Hyndman, D. W. Spatially-Explicit Modelling of Nutrient Loading to the Landscape in the Great Lakes Basin. American Geophysical Union Fall Meeting. 12 December 2016.

Utley, L., Salazar, K., Walker, D., Doucette, J., Pijanowski, B., Miller, B. Assisting Great Lakes Communities in Creating Watershed Action Plans. Coastal GeoTools Conference. 8 February 2017.

Utley, L., Salazar, K., Walker, D., Doucette, J., Pijanowski, B., Miller, B. Tools to Help Communities Plan for a Sustainable Future. Esri User Conference. 13 July 2017.

Miller, B., Utley, L., Salazar, K., Walker, D., Doucette, J., Pijanowski, B., Assisting Great Lakes Communities in Creating Watershed Action Plans. NOAA regional team meeting, Washington, DC. 1-3 May 2017.

Outreach Activities:

Spring workshop, April 19-20, 2017
Thirty-eight researchers, stakeholders, partner agency representatives, and Sea Grant staff attended a two day meeting April 19-20, 2017 at Purdue University to discuss new research updates and applications for water quality issues facing partner communities. Focused discussion included updates on the new structure for the Tipping Point Planner decision support system to address community needs, including the inclusion of SPARROW models and soundscapes applications. Participants included IN Department of Environmental Management watershed managers, The Nature Conservancy staff, Alliance for the Great Lakes, EPA Region 5 staff, WI, MI and OH Sea Grant staff to provide training and discussion for integration in coastal community planning efforts for Saginaw Bay (MI), Green Bay (WI) and Western Lake Erie Basin (OH and IN).

Advisory Board Workshop, August 5, 2016
An advisory board has been formed for NE Indiana in Lake Erie's Maumee River Watershed as part of the new collaboration between US EPA and the Tipping Points and Indicators team. The advisory board comprised of municipal officials, government organizations, conservation professionals and nonprofit organizations met with the Tipping Points and Indicators team August 5, 2016 in Fort Wayne to provide feedback on nutrient models and local deployment. The advisory board will continue to meet for three years to further nutrient modeling development and targeted community implementation projects.

Research team workshops, November 10-11, 2016 and June 27-28, 2017
Research and outreach team members met twice to plan for decision support system updates for nutrient and food web modeling and outreach applications. We developed story boards for the website, plans and timelines to integrate research into the website. Additionally, the team began planning for a tipping point planner workshop to be held at the IAGLR State of the Lake Michigan conference November 6-9, 2017.

Project website
http://www.tippingpointplanner.org/

THEME V: Education and Outreach

Global Interoperability Program (GIP) Introducing Shared Software Infrastructure into the Climate Model Curriculum

Principal Investigator(s): Brad Cardinale (CILER), Christiane Jablonowski (Climate and Space Sciences and Engineering, University of Michigan)
NOAA Technical Lead(s): Cecelia DeLuca (NOAA Earth System Research Laboratory, NOAA Environmental Software Infrastructure and Interoperability (NESII) group)
NOAA Sponsoring Office: NOAA Climate Program Office
Budget Amount: $75,000 total budget

NOAA Strategic Goal:
Goal 3 - Climate Adaptation and Mitigation

Overview:

Next-generation weather and climate models put strong demands on computing capabilities, transparent software designs with exchangeable components, self-explanatory descriptions of data and models, online gateways and portals for data exchanges, and shared online workspaces for both tight and loose science collaborations. Such challenges demand a highly versatile and interdisciplinary workforce. This project trains graduate students and postdoctoral researchers in climate modeling and the shared software infrastructure tools that aid the model development. A novel course 'The Art of Climate Modeling' has been developed at the University of Michigan and was taught in the fall of 2010, 2013 and 2016. In addition, this project supports the evaluation of dynamical cores for atmospheric General Circulation Models (GCMs), the Dynamical Core Model Intercomparison Project (DCMIP) series and its associated summer schools. These were held in 2008, 2012 and 2016, and were supported by shared software infrastructure developed by NOAA.

Objectives:

The major objective of this project is to introduce the future generation of atmospheric scientists to modern, shared and enabling software tools and modeling practices for weather and climate models.

Specific Aims/Milestones:

This project has two specific aims. First, we are an educator for the future generation of atmospheric modelers. This is accomplished by teaching graduate-level climate modeling courses at the University of Michigan (UM) and organizing international climate modeling summer schools at the National Center for Atmospheric Research (NCAR). Second, we are a communicator who provides feedback on the shared software infrastructure Earth System CoG (https://www.earthsystemcog.org/projects/cog/) that has been developed by the NOAA NESII group. An example project page is: https://www.earthsystemcog.org/projects/dcmip-2016/

Accomplishments:

During the reporting period (7/1/2016-6/30/2017) the PI further enhanced and taught the hands-on driven course 'The Art of Climate Modeling' (September-December 2016) at the University of Michigan. The course trains graduate students in the newest climate modeling techniques. It surveys the many design decisions in atmospheric General Circulation Models (GCMs), the trends in GCM and dynamical core modeling and how GCMs are coupled to land, ocean and ice components in Earth System Models (ESM). Furthermore, next-generation ESMs will require greater computing capabilities, transparent software designs with exchangeable model components, self-explanatory (metadata) descriptions of data and models, online gateways and portals for data exchanges, and shared online workspaces for both tight and loose science collaborations. Therefore, the course reviewed and utilized a variety of computational tools that enable students to work effectively with the most modern software infrastructure for the climate and weather sciences. In particular, the course explored how the computational tools aid the model developments, evaluations and collaborations. The class thereby provides feedback on the ease of use, quality, enhancements, and usability of the shared modeling infrastructure. The class and its course projects are documented on the page https://sites.google.com/a/umich.edu/aoss589-f16/ (open to all UM affiliates, access permission for others is granted upon request).

Furthermore, this project supported the scientific evaluation of the Dynamical Core Model Intercomparison Project (DCMIP-2016) & Summer School which was held at the National Center of Atmospheric Research (NCAR) in Boulder, CO, in June 2016. This included the quality control and compliance checks of the DCMIP database, as well as the preparation of four journal papers. These will be published in the special issue of the European Geophysical Union (EGU) journal 'Geoscientific Model Development (GMD).

Peer-Reviewed Publications:

Ullrich, P. A., C. Jablonowski, J. Kent, P. H. Lauritzen, R. Nair, K. A. Reed, C. M. Zarzycki, D. M. Hall, D. Dazlich, R. Heikes, C. Konor, D. Randall, T. Dubos, Y. Meurdesoif, X. Chen, L. Harris, C. Kühnlein, V. Lee, A. Qaddouri, C. Girard, M. Giorgetta, D. Reinert, J. Klemp, S.-H. Park, W. Skamarock, H. Miura, T. Ohno, R. Yoshida, R. Walko, A. Reinecke and K. Viner (2017), DCMIP2016: A Review of Non-hydrostatic Dynamical Core Design and Intercomparison of Participating Models, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2017-108, in review

Gross, M., H. Wan, P. J. Rasch, P. M. Caldwell, D. L. Williamson, D. Klocke, C. Jablonowski, D. R. Thatcher, N. Wood, M. Cullen, B. Beare, M. Willett, F. Lemarie, E. Blayo, S. Malardel, P. Termonia, P. Bechtold, A. Gassmann, P. H. Lauritzen, H. Johansen, C. M. Zarzycki, K. Sakaguchi and R. Leung (2017), Recent Progress and Review of Physics Dynamics Coupling in Geophysical Models, Reviews of Geophysics, revised version in review

Peer-Reviewed Publications in Preparation for the Journal 'Geoscientific Model Development'

Jablonowski, C. and co-authors (2017), DCMIP2016, Part 2: Moist BaroclinicWave
Reed, K. A. and co-authors (2017), DCMIP2016, Part 3: Idealized Tropical Cyclone
Zarzycki, C. M. and co-authors (2017), DCMIP2016, Part 4: Splitting Supercell
(see also the github repository: https://github.com/DCMIP2016 for the manuscripts)

Non-Peer-Reviewed Publications:

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Presentations:

Jablonowski, C., P. A. Ullrich, K. A. Reed, C. M. Zarzycki, J. Kent, P. H. Lauritzen and R. Nair (2017), Highlights from the 2016 Dynamical Core Model Intercomparison Project (DCMIP-2016), poster presentation at the European Geophysical Union (EGU) General Assembly, Austria, April 24-28, 2017

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Jablonowski, C., P. A. Ullrich, C. M. Zarzycki, K. A. Reed, J. Kent, P. H. Lauritzen and R. Nair (2017), Lessons learned from the Dynamical Core Model Intercomparison Project (DCMIP-2016), oral presentation at the CESM Atmosphere Model Working Group (AMWG) Meeting, Boulder, CO, USA, February 27 – March, 1, 2017

Jablonowski, C., C. M. Zarzycki, K. A. Reed, P. A. Ullrich, J. Kent, P. H. Lauritzen and R. D. Nair (2016), The Dynamical Core Model Intercomparison Project (DCMIP-2016): Results of the Moist Baroclinic Wave Test Case, poster presentation at the American Geophysical Union (AGU) Fall Meeting, Abstract A31A-0001, San Francisco, CA, USA, December 12-16, 2016

Reed, K. A., C. Jablonowski, C. M. Zarzycki, P. A. Ullrich, J. Kent, P. H. Lauritzen and R. D. Nair (2016), The Dynamical Core Model Intercomparison Project (DCMIP-2016): Results of the Tropical Cyclone Test Case, poster presentation at the American Geophysical Union (AGU) Fall Meeting, Abstract A31A-0002, San Francisco, CA, USA, December 12-16, 2016

Zarzycki, C. M., K. A. Reed, C. Jablonowski, P. A. Ullrich, J. Kent, P. H. Lauritzen and R. D. Nair (2016), The Dynamical Core Model Intercomparison Project (DCMIP-2016): Results of the Supercell Test Case, poster presentation at the American Geophysical Union (AGU) Fall Meeting, Abstract A31A-0003, San Francisco, CA, USA, December 12-16, 2016

Jablonowski, C. and W. Yao (2016), In-depth Assessments of Dynamical Phenomena via an Ensemble of Idealized Dynamical Cores, poster presentation at the Modeling Hierarchies Workshop, Princeton, NJ, November 2-4, 2016

Outreach Activities:

The project is focused on educational and outreach activities. The university course and the DCMIP-2016 summer school taught multi-disciplinary students, postdocs and young researchers how today's and future atmospheric models are or need to be built. The project webpage for DCMIP-2016 is: https://www.earthsystemcog.org/projects/dcmip-2016/

The project webpage for the university course is: https://sites.google.com/a/umich.edu/aoss589-f16/ (open to all UM affiliates, access permission for others is granted upon request).

THEME V: Education and Outreach

The 2016 Dynamical Core Model Intercomparison Project (DCMIP-2016) and Summer School

Principal Investigator(s): Brad Cardinale (CILER), Christiane Jablonowski (Climate and Space Sciences and Engineering, University of Michigan)
NOAA Technical Lead(s): Doran Mason (GLERL)
NOAA Sponsoring Office: National Weather Service (Fred Toepfer), NOAA Climate Program Office (CPO) Modeling, Analysis, Predictions and Projections (MAPP) Program (Annarita Mariotti), NOAA Oceanic and Atmospheric Research (OAR) Office of Weather and Air Quality (OWAQ) (John Cortinas)
Budget Amount: $32,633

NOAA Strategic Goal:
Goal 3 - Climate Adaptation and Mitigation

Overview:

This project supported the multidisciplinary 2016 Dynamical Core Model Intercomparison Project (DCMIP-2016) and two-week summer school, which was held at the National Center for Atmospheric Research (NCAR) in Boulder, CO, from June/6-17/2016. DCMIP-2016 brought together graduate students, postdocs, atmospheric modelers, expert lecturers and computer specialists, and created a stimulating, unique and hands-on driven educational environment. DMIP-2016 was built upon previous dynamical core model intercomparison efforts (DCMIP-2012 and NOAA's High Impact Weather Prediction Project [HIWPP]). It addressed key outstanding issues in global atmospheric climate and weather models, incorporated the international modeling community, and provided a unique training experience for the future generation of climate modelers and scientists. Special attention was paid to the role of simplified physical parameterizations, physics-dynamics coupling, non-hydrostatic atmospheric modeling, and variable-resolution global modeling. The summer school and model intercomparison project promoted active learning, innovation, discovery, mentorship, and the integration of science and education. DCMIP-2016 was endorsed by the WMO Working Group on Numerical Experimentation (WGNE).

Objectives:

The major objective of this project is to educate the future generation of atmospheric scientists about emerging scientific frontiers in weather and climate modeling.

Specific Aims/Milestones:

The 2-week summer school and model intercomparison project highlighted the newest modeling techniques for climate and weather models. The specific aims of the summer school were (1) to teach a group of about 45 multi-disciplinary students and postdocs about the development process for atmospheric models, and the outstanding needs of the atmospheric modeling community, (2) to host about 12 dynamical core model developers at NCAR for a hands-on student-run model intercomparison project, (3) to establish new atmospheric model test cases of intermediate complexity incorporating simplified physics parameterizations, (4) to invite keynote speakers to NCAR that will give lectures on modern modeling techniques and innovative computational tools, and (5) to utilize the DCMIP-2016 results for scientific studies.

Accomplishments:

During the reporting period (7/1/2016-6/30/2017), this project supported the scientific evaluation of the DCMIP-2016 model intercomparison results and the administrative close-out of the DCMIP-2016 summer school. In particular, this included the quality control and compliance checks of the DCMIP database, presentations of the DCMIP-2016 results at scientific conferences and workshops, as well as the preparation of four journal papers. These will be published in the special issue of the European Geophysical Union (EGU) journal 'Geoscientific Model Development (GMD)' in 2017/2018.

DCMIP-2016 brought together an international group of about 75 graduate students, postdocs, atmospheric modelers, expert lecturers and computer specialists and created a stimulating, unique and hands-on driven learning environment. It led to a student-run model intercomparison project, and thereby trained the future generation of scientists engaged in global atmospheric model developments. Special attention was paid to the role of emerging non-hydrostatic global atmospheric models, the physics-dynamics interactions with simplified moisture processes and models with variable-resolution grids. We hosted twelve dynamical cores (some of them remotely) that represent a broad spectrum of the modeling approaches in the international weather and climate modeling community. One of the DCMIP-2016 models was the non-hydrostatic NOAA-GFDL dynamical core FV3 that selected in 2016 as the new dynamical core for NOAA's Next Generation Global Prediction System (NGGPS) and the National Weather Service. The summer school and model intercomparison project promoted active learning, innovation, discovery, mentorship and the integration of science and education. The DCMIP-2016 project page is: https://www.earthsystemcog.org/projects/dcmip-2016/

Peer-Reviewed Publications:

Ullrich, P. A., C. Jablonowski, J. Kent, P. H. Lauritzen, R. Nair, K. A. Reed, C. M. Zarzycki, D. M. Hall, D. Dazlich, R. Heikes, C. Konor, D. Randall, T. Dubos, Y. Meurdesoif, X. Chen, L. Harris, C. Kühnlein, V. Lee, A. Qaddouri, C. Girard, M. Giorgetta, D. Reinert, J. Klemp, S.-H. Park, W. Skamarock, H. Miura, T. Ohno, R. Yoshida, R. Walko, A. Reinecke and K. Viner (2017), DCMIP2016: A Review of Non-hydrostatic Dynamical Core Design and Intercomparison of Participating Models, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2017-108, in review

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Test Case, poster presentation at the American Geophysical Union (AGU) Fall Meeting, Abstract A31A-0002, San Francisco, CA, USA, December 12-16, 2016

Zarzycki, C. M., K. A. Reed, C. Jablonowski, P. A. Ullrich, J. Kent, P. H. Lauritzen and R. D. Nair (2016), The Dynamical Core Model Intercomparison Project (DCMIP-2016): Results of the Supercell Test Case, poster presentation at the American Geophysical Union (AGU) Fall Meeting, Abstract A31A-0003, San Francisco, CA, USA, December 12-16, 2016

Outreach Activities:

The project is focused on educational and outreach activities. The DCMIP-2016 summer school taught multi-disciplinary students, postdocs and young researchers how today's and future atmospheric models are or need to be built. The project webpage for DCMIP-2016 is: https://www.earthsystemcog.org/projects/dcmip-2016/

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

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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 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.

The University of Michigan has committed $1.2 million in cost-share funding over the next five years to support CIGLR's ECO Program (Attachment A. Budget narrative). 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 CA research projects (Task II/III) 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 Outreach and Communications Specialist and guidance from the CIGLR Director. The sections that follow detail activities to achieve each of the ECO Program goals.

Engagement – ***Supporting Informed Policy and Decision Making***

CIGLR will advise local, state, and federal policymakers and elected officials about the economic, environmental, and societal value of the Laurentian 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 key Great Lakes decision makers. 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 engagement activities will target Federal and State 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).

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.

The CIGLR Director and Program Manager will be responsible for implementation of the engagement activities within the ECO Program, which 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. University Partners within the Regional Consortium will be invited to submit proposals to an annual call for funding of SWG's. CIGLR will facilitate the review and selection process, giving priority to proposals involving NOAA scientists, and will then 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 an annual Great Lakes Vision white paper that includes results and recommendations from all SWGs held that year. 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.

- Great Lakes Day (1x per year). The CIGLR Director and Program Manager will participate in the annual Great Lakes Day in Washington, D.C. This event is hosted by the Great Lakes Commission and the Northeast-Midwest Institute to convey a unified message to Congress expressing the Great Lakes region's priorities for legislation and appropriations to protect our environment and support our economy. It includes a Congressional breakfast reception and visits to Capitol Hill. CIGLR's message to Great Lakes policy makers will center on our annual Great Lakes Vision white paper, produced as part of our SWGs.

- Great Lakes Vision Reception (1x per year). With our University Partners, CIGLR will host an annual reception for Great Lakes elected officials at the local, state, and Federal level. We will showcase NOAA's impact in the Great Lakes and highlight the CIGLR Regional Consortium's contributions to Great Lakes science. The focus will be outlining a vision for Great Lakes research, through identifying critical next steps and funding needs.
- Great Lakes policy advocacy. CIGLR and our Regional Consortium members will communicate with local, state, and Federal policy makers with written letters and phone calls when pending legislation has 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. In addition to letters and phone calls, CIGLR will actively provide input to the International Joint Commission (IJC) as members of Participate IJC, an online democracy forum for contributing to the assessment of progress by U.S. and Canadian governments under the 2012 Great Lakes Water Quality Agreement.

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 CILER-GLERL graduate or postdoctoral fellowships. CILER 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 SNRE 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. In 2016, 22% of applicants identified themselves as non-white or Caucasian and 44% identified themselves as female. These ratios are slightly higher than the 21% and 42%, respectively, among the University of Michigan campus community (https://diversity.umich.edu/our-commitment/). 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. CIGLR will continue to support 8-12 upper level undergraduate and graduate students per summer.

- Great Lakes Graduate Research Fellowships (2 per year): CIGLR will administer a year-long fellowship program that funds graduate students (Master and Ph.D.) to work with CIGLR University Partner PIs on important topics for the Great Lakes region, in collaboration with GLERL or CIGLR scientists. The goals are to: 1) increase training and educational opportunities for students in Great Lakes research; 2) enhance academic and NOAA collaborations to improve research effectiveness; and 3) increase student retention within the freshwater aquatic sciences. CIGLR will support 2 Graduate Research Fellowships per year.

- CIGLR Postdoctoral Fellowships (1-2 per year): CIGLR will provide salary and research support for postdoctoral fellows who will work closely with a CIGLR University Partner PI and a CIGLR or GLERL scientist on a project of mutual interest. In the past, these fellowships have been offered opportunistically, as research funds allowed. However, with additional support from the University of Michigan, we are now able to competitively fund 1-2 postdoctoral fellows per year under a cost matching agreement. CIGLR will provide 1 year of funds and University Partners will provide a matching 2nd year of funds, and agree to a reduced 10% IDC.

- Graduate Student Projects: As 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 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, and national levels. We work with our University 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 SNRE, 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 weekly 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 SNRE Communications Office. Michigan News produces feature stories and videos that are picked up by the press worldwide.

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

- Great Lakes Seminar Series (8-12x 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 ciler.snre.umich.edu.

- Social Media (daily): CIGLR will continue to connect with the public, stakeholders, scientists, and NOAA on social media through our on Facebook (@CILER.UMich), Twitter (@CILER_UM), Instagram (CILER_UM), and YouTube (CILER_UM) accounts. Collectively, CIGLR has 2,737 followers in these social media outlets. The CIGLR Outreach and Communications Specialist holds primary responsibility for maintaining a strong and active presence on social media. CIGLR posts 3+ times per day on Twitter, 3+ times per week on Instagram, and 1-2 times per week on Facebook. We are committed to increasing our social media reach and engagement with our followers.

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

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

- NOAA GLRCT Regional Highlights (3x per year): CIGLR will contribute articles to the 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 (4x per year): CIGLR will continue publishing 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], SNRE 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.

- Annual News Magazine (1x per year): CIGLR will publish an annual news magazine featuring our accomplishments over the year, promoting student opportunities, and highlighting research collaborations. The news magazine will be distributed via direct mail to those who request hard copy, and electronically to the same recipients as our quarterly e-newsletters. Hard copies will also be used to promote CIGLR and NOAA at outreach events.
- Fact Sheets (6-8): CIGLR will update and co-produce with GLERL a series of fact sheets on Great Lakes topics that highlight CIGLR and GLERL research. The updated fact sheets will be posted on the CIGLR website and used for informational tables at outreach events.
- Outreach Events (8-12x per year): CIGLR will continue to have informational tables at community and university outreach events, and at 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 University 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 University Partner 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.
- 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 B: Great Lakes Summer Fellowship Recruiting Plan

Each summer, CILER 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. CILER's recruiting strategy involves 3 focus areas:

- Scientific outlets to provide national-level exposure
- CILER partners – for Great Lakes regional emphasis
- Under-represented student groups

Scientific Outlets

The following resources are used to advertise the Great Lakes Summer Fellows program to the broader national-level aquatic science 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

CILER Partners

CILER distributes the Great Lakes Summer Fellows announcement to its Consortium partners and Affiliate partners, via an email list that is kept current with all of CILER's academic partners in the Great Lakes basin. Additional advertising is done at the University of Michigan, through participation in the School of Natural Resources and Environment's annual Green Career Fair, which draws ~600 students each year.

Under-represented Student Groups

CILER strives to create an inclusive environment within the Summer Fellows program. The following steps are taken to encourage applicants from a wide variety of backgrounds, with a goal of increasing diversity among the applicants.

- Race/ethnicity & gender questions are included on the application form, including options for a preference not to answer.
- The program description states "We are seeking a diverse group of students; thus, we encourage students from groups traditionally underrepresented in the aquatic sciences discipline and workforce to apply." This statement is included on the announcement and on the CILER 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)
    - Hampton University (historically African-American university, Virginia)
    - Eastern Michigan University
    - Wayne State University

- NOAA Environmental Cooperative Science Center (goal to increase scientists from under-represented groups in environmental, coastal, and oceanic sciences)
- Native American student groups
  - Lake Superior State University (large Native American student population)
  - Tribal College Journal - Job Board
  - Disseminate flyers at American Indian Science and Engineering Society (AISES) conference
  - Announcements posted through the following, courtesy of Georgia Madrid, OAR EEO/Diversity Program Office:
    - 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, Jennifer Vanator, Great Lakes Program Coordinator
- Link to the Doris Duke Conservation Scholars Program, and vice versa, on the Summer Fellows webpage

Appendix C: Graduate Research Fellowship Final Report – Sarah Bartlett, University of Wisconsin-Milwaukee

Cyanobacterial Harmful Algal Bloom Ecology and Cyanotoxin Production in Green Bay, Lake Michigan

Graduate Fellow: Sarah Bartlett (University of Wisconsin-Milwaukee)
Mentors: Todd Miller (University of Wisconsin-Milwaukee), Timothy Davis (GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $25,000

NOAA Strategic Goal:
Goal 1 - Healthy Oceans
Goal 3 - Climate Adaptation and Mitigation

Overview:

Cyanobacterial harmful algal blooms, or cyanoHABs, are a growing problem in freshwater systems worldwide including the Laurentian Great Lakes due to excess nutrient pollution. CyanoHABs have significant impacts on ecological health, as well as on the socioeconomics and human health of surrounding regions. Every year, toxins produced by cyanoHABs are responsible for animal death, including pets and livestock and in some cases have caused human fatalities. Furthermore, decaying cyanoHAB biomass creates hypoxic/anoxic conditions harmful to fish and other aquatic life. Despite decades of research, the causes, consequences and complexities of HABs remain too poorly understood to fully inform remediation, management and policy. For example, most cyanoHAB forming genera have strains capable of producing one or more cyanotoxins including microcystins (MCs), anatoxins, saxitoxins, cylindrospermopsins. However, those strains are morphologically identical to other strains of the same genera that cannot produce cyanotoxins. This is troublesome for predicting cyanoHAB toxicity because not only are blooms often comprised of more than one genus, which have toxic and non-toxic strains that co-bloom, but structural variations within cyanotoxin groups are numerous, with varying toxicity among toxin congeners. Notably, more than 100 different MC congeners have been detected. Developing tools to predict cyanoHAB dynamics and toxicity to protect ecosystem and human health (CILER Themes I, III, IV) is critical as these events are expected to become more frequent and toxic in the coming decades.

Within the Great Lakes, most studies have focused on cyanoHAB ecology in the lower Lakes. Toxin-producing MCs are well documented in Lake Erie, Huron and Ontario, where *Microcystis* and *Planktothrix have been shown to be the major genera producing MCs.* Recent studies have suggested that while phosphorus is critical for the overall development of the bloom, nitrogen plays an important role in driving seasonal bloom toxicity in Lake Erie. Lake Erie is often used as a model ecosystem for Great Lakes cyanoHAB events. However, it is currently unknown if the results found in Lake Erie extend to other cyanoHAB impacted areas, such as Green Bay.

Green Bay, a large, shallow and eutrophic embayment in Lake Michigan, is one of the most productive regions in the Laurentian Great Lakes. Lower Green Bay (an area of 55 km^2 of southern Green Bay) is listed as an Area of Concern (AOC) by the International Joint Commission and the State of Wisconsin. It experiences persistent nutrient pollution from point and nonpoint sources including wastewater effluent and agriculture, fueling cyanoHABs. While Green Bay is not currently used as a source of drinking water, emerging contaminants in groundwater and growing populations in Wisconsin municipalities are placing greater pressures on use of Lake Michigan for drinking water production. Furthermore, the city of Green Bay plans to reopen Bay Beach in Lower Green Bay within three years. As such, there is a great need for information about cyanoHABs and cyanotoxins in this area that may pose serious recreational risk to swimmers, particularly children.

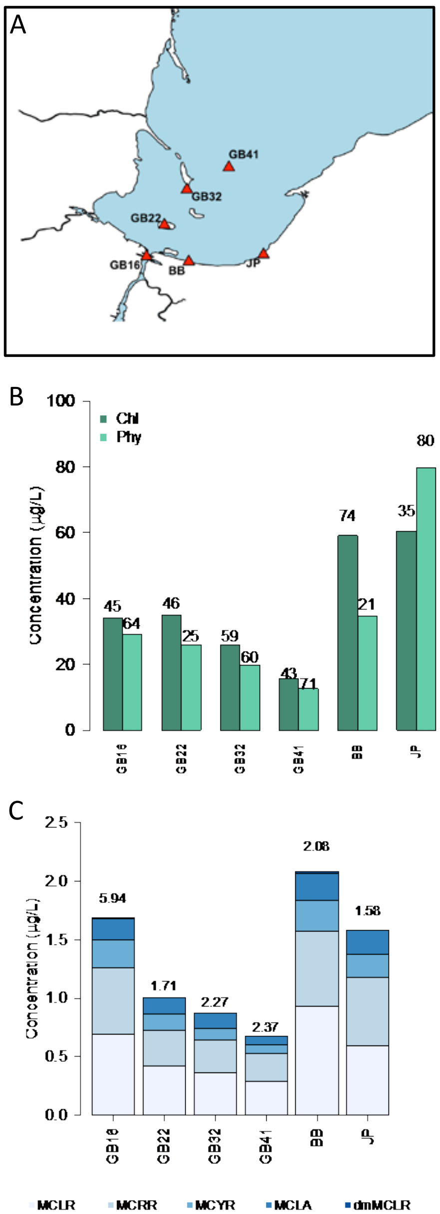

Figure 1. Map of sampling sites (A). Concentrations of chlorophyll and phycocyanin (B) and microcystins (C).

Surprisingly, there is a lack of information on cyanoHAB ecology and their toxins in Green Bay. Unlike western Lake Erie and Saginaw Bay, very little is known about the environmental drivers of bloom growth and toxicity in this system. Previous studies have shown that the Lake Winnebago – lower Fox River – to – Green Bay corridor contributes 1/3 of all phosphorus in Lake Michigan. The goal of this study was to further our understanding of cyanoHABs and their toxins in Green Bay using advanced molecular and chemical techniques in order to help develop cyanoHAB prediction tools.

Objectives:

<u>Objective 1:</u> Identify the dominant cyanotoxins produced in Green Bay. Characterize the identity and trends in cyanotoxins in Green Bay using liquid chromatography tandem (MS/MS) mass spectrometry. **<u>Objective 2:</u> Genetically identify the MC producers in Green Bay and describe drivers of percent toxicogenic taxa.** Using quantitative PCR (qPCR) we will quantify MC synthesis genes using primers directed at *mcy*E and *mcyD* genes. Our denominator for these measurements will be the concentration of 16S rRNA gene copy numbers from each of these genera. **<u>Objective 3:</u> To identify environmental drivers of MC gene transcription in Green Bay.** Limnological variables and cyanotoxins will be measured and compared to rates of MC gene (*mcy E* and *D*) transcription. The major hypothesis that will be tested is that C:N ratios drive MC transcription.

Accomplishments:

We have produced a large dataset describing cyanoHABs, their toxins, and limnological conditions associated with cyanoHABs during the 2016 season in Lower Green Bay. This is the most extensive analysis of cyanotoxins and conditions under which they occur in Green Bay. In accordance with objective 1 we described the dominant toxins in Green Bay, which were MC-LR (mean and max = 0.6 and 2.5 µg/L), and MC-RR (0.45 and 2.3 µg/L). However we also detected other MCs including MCYR, MCLA and desmethly-MCLR producing sum total concentrations of all MCs (mean and max = 1.5 and 5.6 µg/L) that were over EPA recreational guideline values on three sampling occasions. Chlorophyll concentrations in Lower Green Bay in 2016 were low (mean = 36 µg/L) compared to the historical 27- year average of 50 µg/L. Thus, 2016 was overall a mild year for cyanoHABs in Green Bay.

Previous research has shown that there is a strong trophic gradient from the Fox River northward toward the upper bay. In 2016 we observed a decreasing trend in concentrations of chlorophyll and phycocyanin from site 16 at the river mouth to site 41 (Figure 1B) just outside the AOC consistent with previous observations. We also observed a decreasing trend in concentrations of the sum total of all detected MCs (Figure 1C) where mean concentrations were 1.7 µg/L at site 16 (mouth of Fox) to 0.8 µg/L at site 41 outside the AOC. However, highest concentrations of pigments and toxins was observed outside this transect in the southeastern part of the lower bay near Bay Beach (site BB) and Joliet Park (site JP). We believe transport and entrainment of cyanobacteria and toxins in this area is due to a combination of Fox River discharge north and prevailing southeasterly winds. We are now working to incorporate transport models into our research efforts.

We have now extracted RNA and DNA from all 165 samples and are in the process of conducting RT-qPCR and qPCR for the analysis of RNA transcripts and gene copy numbers of toxin genes and genes involved in pathways we believe are important for regulating microcystin production (objective 3). We will also quantify the variability in percent toxicogenic species throughout the 2016 season at all sites (objective 2). Our goal will then be to model these attributes against the prevailing limnological conditions (wind/waves, nutrients, etc) that occur in the bay.

Peer-Reviewed Publications:

Sarah L. Bartlett, Shelby A. Brunner, J.Val Klump, Erin M. Houghton, Todd R. Miller, Spatial analysis of cyanobacterial toxins in Green Bay, Lake Michigan. Journal of Great Lakes Research. In preparation.

Non-Peer-Reviewed Publications:

None.

Presentations:

Todd Miller, Sarah Bartlett, Erin Houghton, Donalea Dinsmore, Gina La Liberte. Assessing Cyanobacterial Harmful Algal Blooms in Green Bay, HABs Collaboratory Webinar, 2017 Field Season Kickoff, July 24, 2017.

Todd Miller, Sarah Bartlett, Erin Houghton, Donalea Dinsmore, Gina La Liberte. Green Bay HABs 2016, HABs Collaboratory Webinar, End of Field Season Wrap-up, December 15, 2016.

Rachel Kutzner, Sarah Bartlett, Allison Tomczyk, Joseph Piatt, Todd Miller. Algal toxin dynamics and predictors in Green Bay, WI, American Chemical Society National Meeting, San Francisco, CA, April 2 – 6, 2017.

Outreach Activities:

Participated in the Green Bay Science Summit, Green Bay, WI, July 2017

News stories:

- "Experts Work to Save Green Bay: Up Front with Mike Gousha", WISN 12 News. http://www.wearegreenbay.com/news/local-news/algae-that-produces-toxins-shows-up-early-around-green-bay/781525416
- "Algae that produces toxins shows up early around Green Bay", Channel 5 News Green Bay. https://www.youtube.com/watch?v=4JjXyAzy9OE

Appendix D: Postdoctoral Fellowship Annual Progress Report – Qianqian Liu, Grand Valley State University

Modeling Recovery: Implementing a 3-D Hydrodynamic Model for a Recovering Great Lakes Estuary (Muskegon Lake AOC) Impacted by Eutrophication, HABs and Hypoxia

Postdoctoral Fellow: Qianqian Liu (Grand Valley State University, Annis Water Resources Institute)
Mentors: Bopi Biddanda (GVSU-AWRI), Eric Anderson (NOAA-GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory (GLERL)
Budget Amount: $135,000

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
Goal 5 - NOAA Enterprise-wide Capabilities: Science and Technology Enterprise, Engagement Enterprise, Organization and Administration Enterprise

Overview:

Muskegon Lake is a model drowned river-mouth estuary characterized not only by net primary productivity and important recreational and commercial fisheries, but also by seasonal HABs and bottom water hypoxia. It is connected with Lake Michigan through a navigation channel and, therefore, its hydrodynamic and ecological processes are affected by Lake Michigan. The complex dynamical processes can simultaneously take place, making Muskegon Lake a natural laboratory. There is an urgent need for a hydrodynamic model, which will result in a better understanding of lake function as well as better resource management of the lake. A project about the model construction was identified during two meetings involving GLERL, AWRI, and community stakeholders in 2014 and 2015. The project's main goal is to implement a 3-D hydrodynamic model for Muskegon Lake using time-series data from the Muskegon lake Observatory (www.gvsu.edu/buoy/) and all other available information.

Objectives:

The objective of this project is to build a working coupled physical-biogeochemical model to systematically investigate the physical processes and ecosystem dynamics in Muskegon Lake, which can help understanding of Muskegon Lake and assist ecosystem-based management.

Specific Aims/Milestones:

- Implement a 3-D hydrodynamic model for Muskegon Lake.
- Assemble a robust multi-year time-series data set for Muskegon Lake and construct a high-resolution 3-Dimensional hydrodynamic model compatible with the existing NOAA modeling framework.
- Provide a linked hydrodynamic-hydrologic model for a Great Lakes AOC and Habitat Blueprint area that is currently not represented by the Great Lakes Coastal Forecast System (GLCFS).
- Link the Muskegon Lake Hydrodynamic Model (MLHM) to the next-generation Lake Michigan-Huron Operational Forecast System (LMHOFS; NOAA/GLERL) for offshore open boundary

conditions, and the Megamodel for the Muskegon River Watershed (MREMS) for watershed boundary conditions, and ensure integrated operation among the 3 components.

- Describe patterns in temperature, circulation, algal production and dissolved oxygen in surface and bottom waters during recent years (e.g. 2011-2017); assess the relevance of events in this Great Lakes estuary to coastal environments elsewhere.
- Simulate relevant hind-cast years (e.g. 2011-2016) using the linked model for calibration and validation as well as analysis of thermal structure, circulation, and nutrient dynamics in Muskegon Lake, including exchange with Lake Michigan.
- Advance the suite of NOAA hydrodynamic forecast systems in the Great Lakes, currently being developed by NOAA/GLERL and CILER.

Accomplishments (12/1/16-6/30/17):

Developed a hydrodynamic model based on the unstructured grid, Semi-Implicit Cross-scale Hydroscience Integrated System Model (SCHISM). The model configuration is shown in the left panel of Figure 1.

- The model was validated by comparisons with field observations in Lake Michigan at M20 site and the data in Muskegon Lake from 2016.
- Deployed additional moorings to measure currents, water temperature, and DO in Muskegon Lake for model validation. The stations are shown in the right panel of Fig.1.
- This model was used to simulate the physical limnological processes in Muskegon Lake during 2016.
- We used the model to track and study the cold intrusion events during upwelling-favorable winds. Please see examples of modeling results below (Figure 2).
- A peer-reviewed manuscript describing the hydrodynamic model and the cold water intrusion is under preparation.

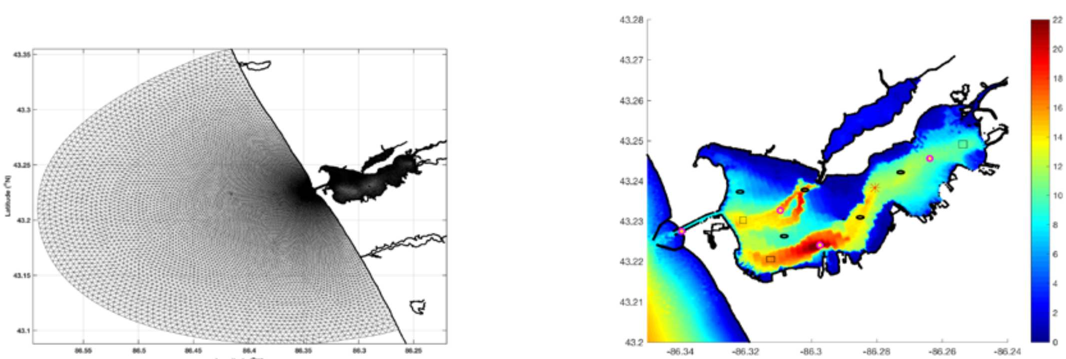

Figure 1. Left panel shows the SCHISM model configuration for Muskegon Lake and the adjacent coastal area in Lake Michigan. Right panel shows the Muskegon Lake monitoring stations with magenta circles for GVSU's stations for temperature and oxygen concentrations, squares for bottom-mounted ADCP deployed since May 2017, and ellipses for vertical transects of temperature deployed since May 2017. The red X is the Muskegon Lake Observatory (www.gvsu.edu/buoy/) with meteorological, water temperature and quality data since 2010.

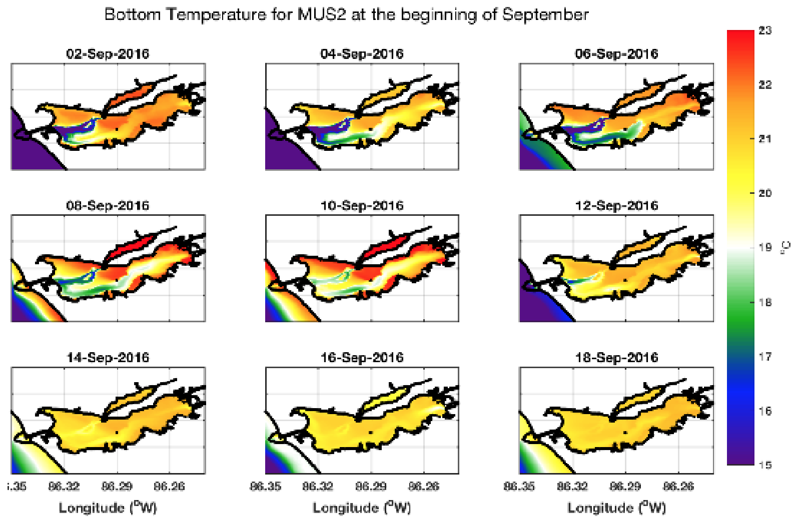

Figure 2. Daily averaged bottom temperature from September 2, 2016 to September 18, 2016 from the SCHISM model. The bottom temperature delineates the bottom coldwater intrusion from Lake Michigan to Muskegon Lake during an upwelling event along the eastern shore of Lake Michigan.

Peer-Reviewed Publications: Submitted – In Review

Biddanda, B. A., A. D. Weinke, S. T. Kendall, L. C. Gereaux, T. M. Holcomb, M. J. Snider, D. K. Dila, S. A. Long, C. VandenBerg, K. Knapp, D. J. Koopmans, K. Thompson, J. H. Vail, M. E. Ogdahl, Q. Liu, T. J. Johengen, E. J. Anderson, and S. A. Ruberg (Submitted, In Review)

Chronicles of Hypoxia: Time-series buoy observations reveal annually recurring seasonal basin-wide bottom water hypoxia in Muskegon Lake Area of Concern – a Great Lakes estuary. J. Great Lakes Res.

Non-Peer-Reviewed Publications:

None for this project period.

Presentations:

Liu, Q (Presenter), E. Anderson and B. Biddanda (Oral). A physical-Biogeocheimcal Simulation of Muskegon Lake. 60th International Association for Great Lakes Research (IAGLR) Conference; Detroit, MI. May 17, 2017.

Biddanda, B. Finding the "Goldilocks Zone" for Carbon Cycling in a Great Lakes Watershed. Departmento de Ecologia, University of Granada, Granada, Spain. March 1, 2017.

Outreach Activities:

- K-12 students (~1000) from West Michigan were introduced to Muskegon Lake Observatory time-series data and its usefulness for tracking lake phenomena and understanding lake dynamics in AWRI-GVSU shipboard and classroom activities.
- In the coming months, will construct a project webpage that features the hydrodynamic modeling of Muskegon Lake. It will be user-friendly and freely accessible to via the project webpage.

Appendix E: Employee Count

Summary of CILER staff and students by head count from July 1, 2016 – June 30, 2017. 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	10	0	0	10
Visiting Scientists	0	0	0	0
Postdoctoral Research Fellows	12	0	0	12
Research Support Staff	22	5	16	1
Administrative	5	1	3	1
Total ≥ 50% support	34			
Total ≤ 50% support	15			
Undergraduate Students	15	0	0	0
Graduate Students	25	22	3	0
Located at NOAA Lab	59			
Obtained NOAA employment	1			

Appendix F: Publication Count

Summary of peer-reviewed and non-peer-reviewed publications related to CILER-funded research from FY2003-FY2017, with summaries based on the current 5-year Cooperative Agreement renewal (FY2013-2017) and the 10-year Cooperative Agreement (FY2008-2017). Publications attributed to CILER 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	CA Renewal Total (FY13-17)	CA Total (FY08-17)
CILER	Peer-rev.	16	8	7	10	10	12	19	14	36	15	8	8	10	14	16	56	152
	Non peer-rev.	7	1	2	1	0	6	0	3	123	67	N/A	3	5	2	3	13	212
NOAA	Peer-rev.	5	2	4	7	3	4	33	24	10	7	6	7	6	7	2	28	106
	Non peer-rev.	4	6	1	0	2	1	0	3	64	30	N/A	4	2	1	5	12	110
Other	Peer-rev.	0	12	10	3	6	13	29	38	0	20	5	9	28	21	36	99	199
	Non peer-rev.	0	0	0	0	0	0	0	11	11	56	N/A	2	1	0	16	19	97
Total	Peer-rev.	21	22	21	20	19	29	81	76	46	42	19	24	44	42	54	183	457
	Non peer-rev.	11	7	3	1	2	7	0	17	198	153	0	9	8	3	24	44	419

Appendix G: Publications

Peer-Reviewed Publications

Anderson, E.J. and D.J. Schwab. 2017. Meteorological influence on summertime baroclinic exchange in the Straits of Mackinac. *Journal of Geophysical Research: Oceans*. 122(3):2171-2182. (DOI:10.1002/2016JC012255).

Baskaran, M., T. Novell, S.A. Ruberg, B.A. Biddanda, T.H. Johengen, N. Hawley and J.V. Klump. 2016. Seepage of subsurface sinkhole vent waters into Lake Huron using radium and stable isotopes of oxygen and hydrogen. *Aquatic Geochemistry.* 22(4):349-374. (DOI: 10.1007/s10498-015-9286-7).

Bechle, A., C.H. Wu, D.A.R. Kristovich, E.J. Anderson, D.J. Schwab and A.B. Rabinovich. 2016. Meteotsunamis in the Laurentian Great Lakes. *Scientific Reports*. 6:1-8. (DOI:10.1038/srep37832).

Beletsky, D., R. Beletsky, E.S. Rutherford, J.L. Sieracki, J.M. Bossenbroek, W.L. Chadderton, M.E. Wittmann and D.M. Lodge. 2017. Predicting spread of aquatic invasive species by lake currents. *Journal of Great Lakes Research.* 43(3):14-32. (DOI:10.1016/j.jglr.2017.02.001).

Berry, M.A., T.W. Davis, R.M. Cory, M.B. Duhaime, T.H. Johengen, C.L. Kling, J.A. Marino, P.A. Den Uyl, D.C. Gossiaux, G.J. Dick and V.J. Denef. 2017. Cyanobacterial harmful algal blooms are a biological disturbance to western Lake Erie bacterial communities. *Environmental Microbiology*. 19(3):1149-1162. (DOI:10.1111/1462-2920.13640).

Berry, M.A., J.D. White, T.W. Davis, S. Jain, T.H. Johengen, G.J. Dick, O. Sarnelle and V.J. Denef. 2017. Are oligotypes meaningful ecological and phylogenetic units? A case study of Microcystis in freshwater lakes. *Frontiers in Microbiology*. 8(365). (DOI:10.3389/fmicb.2017.00365).

Biddanda, B.A. 2017. Global significance of the changing freshwater carbon cycle. *EOS*. 98. (DOI:10.1029/2017EO069751).

Butts, E. and H.J. Carrick. 2017. Phytoplankton seasonality along a gradient of temperate lakes: Convergence in taxonomic composition during winter ice-cover. *Northeastern Naturalist*. 24:167-187. (IGLR # 82).

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). (DOI:10.3389/fenvs.2017.00045).

Collingsworth, P.D., D.B. Bunnell, M.W. Murray, Y.C. Kao, Z.S. Feiner, R.M. Claramunt, B.M. Lofgren, T.O. Hook and S.A. Ludsin. 2017. Climate change as a long-term stressor for the fisheries of the Laurentian Great Lakes of North America. *Reviews in Fish Biology and Fisheries*. 27(2):363-391. (DOI:10.1007/s11160-017-9480-3).

Defore, A.D., A. Weinke, M. Lindback and B. Biddanda. 2016. Year-round Measures of Planktonic Metabolism Reveal Net Autotrophy in Surface Waters of a Great Lakes Estuary. *Aquatic Microbial Ecology*. 77(3):1616-1564. (DOI:10.3354/ame01790).

Denef, V.J., H.J. Carrick, J.F. Cavaletto, E. Chiang, T.H. Johengen and H.A. Vanderploeg. 2017. Lake Bacterial Assemblage Composition Is Sensitive to Biological Disturbance Caused by an Invasive Filter Feeder. *American Society for Microbiology: mSphere*. 2(3). (DOI:10.1128/mSphere.00189-17).

Fahnenstiel, G.L., M.J. Sayers, R.A. Shuchman, F. Yousef, S.A. Pothoven. 2016. Lake-wide phytoplankton production and abundance in the Upper Great Lakes: 2010-2013. *Journal of Great Lakes Research.* 42(3):619-629. (DOI:10.1016/j.jglr.2016.02.004).

Fujimoto, M., J.F. Cavaletto, J.R. Liebig, A. McCarthy, H.A. Vanderploeg and V.J. Denef. 2016. Spatiotemporal distribution of bacterioplankton functional groups along a freshwater estuary to pelagic gradient in Lake Michigan. *Journal of Great Lakes Research*. 42(5):1036-1048. (DOI:10.1016/j.jglr.2016.07.029).

Hu, H., J. Wang, H. Liu and J. Goes. 2016. Simulation of phytoplankton distribution and variation in the Bering-Chukchi Sea using a 3-D physical-biological model. *Journal of Geophysical Research: Oceans.* 121(6):4041-4055. (DOI:10.1002/2016JC011692).

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).

Lauber, T.B., R.C. Stedman, N.A. Connelly, L.G. Rudstam, R.C. Ready, G.L. Poe, D.B. Bunnell, T.O. Hook, M.A. Koops, S.A. Lusdsin and E.S. Rutherford. 2016. Using Scenarios to Assess Possible Future Impacts of Invasive Species in the Laurentian Great Lakes. *North American Journal of Fisheries Management*. 36(6):1292-1307. (DOI:10.1080/02755947.2016.1214647).

Linares, Á., A.J. Bechle and C.H. Wu. (2016) Characterization and Assessment of the meteotsunami hazard in northern Lake Michigan. *Journal of Geophysical Research: Oceans*. 121(9):7141-7158. (DOI:10.1002/2016JC011979).

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