Integrated Physical & Ecological Modeling & Forecasting
Advancing understanding to improve NOAA forecasts.

The Integrated Physical and Ecological Modeling and Forecasting (IPEMF) branch conducts innovative research and develops numerical models to predict the physical, chemical, biological, and ecological response of the Great Lakes due to weather, climate, and human-induced changes.
IPEMF addresses issues identified in NOAA’s research plans and guiding documents.

See review website “Documents” tab for more.
IPEMF works to understand how atmospheric, lake, and land processes are mutually affected by conditions across time scales.

How do we improve our understanding of physical processes to support coastal resiliency and ecological forecasting?

How do we improve our ability to forecast extreme conditions?

How do we translate innovative research into useful products for the public?

- Climate and weather modeling
- Hydrological modeling
- Hydrodynamic modeling and forecasting
- Wave and meteotsunami research
- Particle tracking, oil spill simulation
- Ice modeling
- Probabilistic modeling
- Data management
The Great Lakes are a unique watershed.

- Largest surface freshwater system on Earth.
- The Great Lakes drainage basin has a vast surface area.
IPEMF develops and applies advanced models of Great Lakes and coastal systems to make real-time, near-term, and long-term predictions and forecasts.

- Working to develop an integrated Great Lakes modeling system to improve forecast capability of lake hydrodynamics, lake ice, hydrological response, ecological processes, water quality, climatic variability and trends across spatial and temporal scales.
- Working to create linkages to the NOAA Earth system modeling initiative and Unified Forecast System (UFS).
GLERL contributes to NOAA operational forecasts.

- Global Forecast System (FV3)
- Regional weather, High-Resolution Rapid Refresh (HRRR)
- Wave Watch 3 (WW3)
- Great Lakes Operational Forecast System (GLOFS) - ICE
- Lake Hydro-Ice-Wave
- Water / Ecology, Harmful Algal Bloom (HAB) Forecast
- Streamflow / Groundwater, National Water Model (NWM)
IPEMF collaborates within NOAA and beyond…

Within NOAA

- National Ocean Service Center for Operational Oceanographic Products and Services (NOS/CO-OPS) transitioning Next-Gen Great Lakes Operational Forecast System (GLOFS)
- Global Systems Laboratory (GSL) and National Weather Service Weather Forecast Offices (NWS/WFO) to transition coupled High-Resolution Rapid Refresh-Finite Volume Community Ocean Model (HRRR-FVCOM) to Environmental Modeling Center (EMC)
- Physical Sciences Laboratory (PSL), National Water Center (NWC), National Center for Atmospheric Research (NCAR) to upgrade National Water Model
- Pacific Marine Environmental Laboratory (PMEL) and National Weather Service (NWS) on meteotsunami detection/modeling/warning system
- Geophysical Fluid Dynamics Laboratory (GFDL) on climate, ocean and ecological models
- National Centers for Environmental Prediction/Environmental Modeling Center (NCEP/EMC) on wave modeling, AI/machine learning algorithms
- Weather Forecast Office, National Ocean Service, EMC on Lake Champlain Richelieu River Flooding Forecast System

Inter-Agency and International

- U.S. Army Corps of Engineers (USACE): Great Lakes seasonal hydrological prediction; Coastal resilience and wave climate
- Department of Energy (DOE): Integrated Hydro-Terrestrial Modeling (IHTM), Argonne National Laboratory
- Environmental Protection Agency: Multiple Great Lakes Restoration Initiative (GLRI) focus area projects
- U.S. Geological Survey (USGS): Powell Center Project on Great Lakes groundwater; Coastal change hazards,
- International Joint Commission: Lake Champlain-Richelieu River Flooding Forecast System, Great Lakes Adaptive Management Committee (GLAM)
- Environment Canada Climate Change (ECCC): NOAA-ECCC bilateral; Great Lakes Evaporation Network (GLEN)

Academia & Private Partners

- Cooperative Institute for Great Lakes Research (CIGLR) consortium universities and non-profit organizations.
- High-tech firms through Small Business Innovation Research (SBIR) programs.
- Collaborative R&D agreement (CRADA) with Viking Cruises.
Great Lakes climate modeling and long-term temperature trends
Brent Lofgren and Eric J. Anderson
Great Lakes climate modeling at GLERL

Goals:

Increase representation of the Great Lakes in global models of climate

Increase representation of the Great Lakes with continental-scale limited-area models, leveraging projects like North American - Coordinated Regional Downscaling Experiment (NA-CORDEX)

Add newer climate scenarios for basin-wide modeling and analysis

Key concept: Climate is not about what the atmosphere does to the surface. Surface exchanges of energy and water are at least as important to climate as atmospheric processes. The atmosphere is heated from below.

Climate results from the balance between heat in (sun intensity as affected by time of year) and the degree of difficulty of getting heat back out of the Earth-atmosphere system (affected by greenhouse gases).

Weather focuses on the atmosphere, because it is the most quickly changeable and chaotic part of the system.
Simplified lake coupled to an atmospheric model: Influence on lake thermal structure.

Lake energy and temperature: vertical water temperature profiles averaged over all years from the same simulations

- Future scenario: thermocline begins forming earlier in the year
- Red ovals highlight stronger temperature gradient in the future
- Thermocline is same depth


Xiao et al. 2018, Atmospheric Research.
What effect does ice have on lake evaporation when averaged over entire years?

Results—Latent heat flux (proportional to evaporation)
Long term temperature trends: 30 years of Lake Michigan hourly temperatures show changes in subsurface climate trends.

- Longest record of its kind
- Warming occurring year-round, greatest in winter
- Warming trends down to 100 meters deep
- Confirms “the road” to thermal regime change by 2100


Diagram of temperature mooring used.  

Deploying temperature mooring, June 1990.  

Long-term records of water temperature in southern Lake Michigan, both on the lake’s surface (top) and 110 meters or 361 feet deep (bottom).

30-year temperature profile of Southern Lake Michigan created with GLERL’s long-term temperature data.
Long-term physical observations: Subsurface climate trends

- Deep winter warming
- Extended Summer (spring warming)
- Where most studies look.
- Extended Summer (fall warming)
- Delayed turnover

Hydrodynamic modeling

Philip Chu
Where GLERL fits into the NOAA operational landscape.
Great Lakes Operational Forecast System (GLOFS) models support forecasts of lake conditions.

<table>
<thead>
<tr>
<th>GLOFS V1 2003</th>
<th>GLOFS V2 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Princeton Ocean Model (POM)</td>
<td>FVCOM</td>
</tr>
<tr>
<td>Structured grid</td>
<td>Unstructured grid</td>
</tr>
<tr>
<td>5km-10km spatial resolutions</td>
<td>200m resolution nearshore</td>
</tr>
<tr>
<td>48-hour forecasts</td>
<td>120-hour forecast horizon</td>
</tr>
<tr>
<td>No river discharge</td>
<td>Connecting channel flows</td>
</tr>
<tr>
<td>No Ice forecast</td>
<td>Built-in CICE ice model</td>
</tr>
</tbody>
</table>
GLOFS models support stakeholders in the commercial shipping industry, search and rescue operations, safe drinking water, oil spill response, and recreational use.

- Provides improved predictions (guidance) of water levels, water currents and water temperatures for all five lakes.
- Generates hourly nowcast guidance (analyses) and four times daily forecast guidance of total water level, current speed and direction, and water temperature.
- Predictions enable users to increase the margin of safety and maximize the efficiency of commerce throughout the Great Lakes.
  - Navigation safety
  - Commercial shipping & fishing
  - Search and Rescue (SAR) operations
  - Recreational boating, fishing & surfing
  - Coastal and offshore structure planning
  - Environmental protection
  - Shoreline erosion & coastal flooding simulation
  - Biology, ecology, fishery, food web & hypoxia research
  - Climate change impact studies
Transitioning the Great Lakes Coastal Forecasting System (GLCFS) to Great Lakes Operational Forecast System (GLOFS)

- Improved marine forecasts
- Coupling with HRRR for improved weather forecast
- First ever ice forecasts

The current 3rd generation of the GLCFS is run in near real-time at NOAA’s Great Lakes Environmental Research Laboratory (GLERL), and operationally at NOAA’s National Ocean Service (NOS) under the name Great Lakes Operational Forecast System (GLOFS).

2017: Department of Commerce Bronze Medal: For successful transition of LEOFS to NOAA Operations

2018: Outstanding Exhibition of Unified Modeling Award: Developing Ecological Forecasts and Applications Linked to the Great Lakes Operational Forecast System models.

See Supporting Documents on review website “Documents” tab for more award details.
Improving Forecasting of Extreme Events: Case Studies

Eric J. Anderson
Meteotsunamis: an overlooked public safety hazard.

What drives meteotsunami formation in Great Lakes?
- Complex/Linear convection (wind + pressure)
- Wave reflection/focusing

What coastal communities are vulnerable?
- Hot spots along southern L. Michigan & Erie

Why don’t present forecast models resolve them?
- Gaps in observations
- Atmospheric forecast limitations
- Hydrodynamic limitations

Why are they dangerous?
- Like seismic tsunamis, they become decoupled from the source mechanism (e.g. convective storm)
- In Great Lakes (and other areas), reflected waves can appear “out of nowhere”
- No forecasts are available for meteotsunami waves, and in Great Lakes no detection network exists
- Can create rip currents, inundation, etc.
The perfect storm: Forecasting a subset of meteotsunamis may be near.

On the afternoon of April 13, 2018, a large wave of water surged across Lake Michigan and flooded the shores of the picturesque beach town of Ludington, Michigan, damaging homes and boat docks, and flooding intake pipes.

Thanks to a local citizen’s photos and other data, GLERL scientists reconstructed the event in models and determined this was the first ever documented meteotsunami in the Great Lakes caused by an atmospheric inertia-gravity wave.

Anderson and Mann, *Natural Hazards*, 2020
Refined models will help us understand the coastal impacts of meteotsunamis.

- High-resolution models can capture the mechanisms behind some meteotsunami formation.
- Even “medium” resolution models capture general dynamics.
- Atmospheric forcing conditions are crucial.
- Shoaling, run-up could explain eyewitness wave heights.
- Advanced weather forecast products can resolve spatio-temporal features of meteotsunami-inducing storms.
- Need refined coastal approaches to characterize coastal hazards.

Huang et al. 2021, *Natural Hazards*
Advancing meteotsunami research: Collaborative scientific leadership and fostering an environmentally literate society.

Co-hosted 2017 CIGLR Meteotsunami Warning System for the Great Lakes Summit.
Participants: National Weather Service (NWS), NOAA Center for Tsunami Research, Great Lakes Observing System (GLOS), NOAA Great Lakes Environmental Research Laboratory, U.S. and international universities.

2018 AGU Ocean Sciences Meeting
Meteotsunami Session and Press Conference
NOAA NOS - Greg Dusek
NOAA OAR - Eric J. Anderson, Philip Chu

Expanding reach to non-scientific audiences: NOAA Web story, social media led to international media coverage

“More meteotsunamis occur on Lake Michigan than any other Great Lake. New research may lead to lifesaving warnings about the potentially destructive waves.”

“Scientists Document First-Of-Its-Kind Meteotsunami That Was Caused Without Any Tremors...”

Co-Organized 1st World Conference on Meteotsunamis, held in Split, Croatia in May 8-11, 2019

Co-edited Natural Hazards Special Issue on the global perspective on meteotsunami science, 3 GLERL papers

Chicago Tribune

New study shows promise of forecasting meteotsunamis...
Predicting Currents in the Straits of Mackinac

- Connects Lakes Michigan & Huron to form largest lake in the world.
- Most “dynamic” area in the Great Lakes
- Crucial waterway for commercial shipping and home to two underwater oil pipelines
- Current speeds up to 2 m/s
- Flow oscillations (change of direction) every 2-3 days
- Strong currents make navigation difficult
- Variable currents pose issues to spill response
Illustrating the uniqueness of this oscillating flow and how it affects the potential transport of a substance.

- Modeled scenarios illustrate the uniqueness of this oscillating flow and how it affects pollutant transport
- Modeled currents show materials in the water to disperse far more quickly than in other locations in the Great Lakes.
- Model validation from moored observations and drifter buoys are periodically released.

Modeled dispersion of *surface* and *subsurface* particles after 1 hour.
Coupling lake models with NOAA’s weather models

- Addressing NOAA mission of building a Weather-Ready-Nation to save lives and properties
- Improves NOAA weather forecast model model High Resolution Rapid Refresh (HRRR) capability, specifically on extreme lake-effect snow events
- Improves timing, amounts, locations and bands of lake-effect snow events
- Transitioned to National Weather Service/National Centers for Environmental Prediction (NWS/NCEP) operations in December 2020
- Collaboration among GLERL, CIGLR, National Weather Service Weather Forecast Offices (NWS WFOs), NOAA Earth System Research Lab (ESRL), and Cooperative Institute for Research in Environmental Sciences (CIRES)

On Nov 17 - 20, 2014, Nearly 10 feet of snow dropped on Buffalo, NY. There were 14 fatalities.

Animation showing snow accumulation during the lake-effect snow event in 2014.
Coupling with the High Resolution Rapid Refresh (HRRR) model improves lake-effect snow forecasts.

1st-ever coupling between hydrodynamic and weather forecast models.

Fine tuning locations of snow bands.

More accurate forecasts can save lives during lake effect snow events.

Better lake-representation improves NOAA operational models.

Fujisaki-Manome et al., *Journal of Hydrometeorology*, 2020
Ice modeling and forecasting
James Kessler, Ayumi Fujisaki-Manome, Jia Wang
GLERL is studying the relationships between ice cover, lake temperatures, and regional climate through models based on observations of variables, such as ice cover and surface water temperature.

- Observing current ice cover conditions
- Analyzing and hosting historical ice cover data
- Modeling and forecasting research

Societal Impacts:
- Presence of ice impedes commercial shipping and fishing industries
- Complex relationship between ice and evaporation → water levels, lake effect precip.
- Safety: recreation on ice, search and rescue
- Land-fast ice protects coasts from storm damage (via wave damping)
Inter-agency coordination on historical Great Lakes ice data

GLERL has been monitoring and documenting Great Lakes ice cover since the mid 1970's using the ice products developed by the U.S. National Ice Center (USNIC) and the Canadian Ice Service.

GLERL re-processes ice data from the USNIC into more accessible file formats.

Recent efforts include standardizing multiple existing formats of historic ice cover data. Historical data is critical to predictive modeling and climate analysis.

- Ice data files (txt, shp, netCDF)
- Ice statistics
- Ice charts (jpg)

GLERL Historical Ice Cover: https://www.glerl.noaa.gov/data/ice/#historical
NCEI database: https://nsidc.org/data/G10029/versions/1

2021: Lake Erie ice cover increased from 10-80% in four days in February.
Advancing Great Lakes ice forecasting on short-term and seasonal time scales

- **Seasonal ice forecasting:**
  - Prediction of annual maximum ice cover (AMIC)
  - Statistical approach based on physical analysis

- **Short-term (5 day) ice forecasting:**
  - High resolution 3D ice model coupled to hydrodynamic model
  - Supplying NWS/USNIC with ice forecasting capability (in demonstration mode at NOAA CO-OPs).

- Ice improvement: Coupling lake-ice-wave models.
- Conducting stakeholder engagement.

Improved models and forecasts provide vital information for a variety of stakeholders, such as emergency responders, shipping industries, and fishermen.
Working to improve Great Lakes seasonal ice forecasting

- The interannual variability of Great Lakes ice cover is heavily influenced by four large-scale climate patterns referred to as teleconnections: North Atlantic Oscillation (NAO), the Atlantic Multidecadal Oscillation (AMO), the El Niño/Southern Oscillation (ENSO), and the Pacific Decadal Oscillation (PDO).
- These teleconnection patterns impact Great Lakes regional climate and ice cover by influencing the location of the westerly jet stream over North America.
- The temperature and moisture content of these air masses play a key role in determining ice cover.

GLERL is working on a statistical model that predicts annual maximum ice cover.

Continuing to refine the model:
- Update the forecast every two weeks throughout the ice season.
- Each forecast iteration will reflect the latest surface air temperature data which is a primary driver of ice formation.

Our projection:
Annual Maximum Ice Cover = 38% (Observed 45%)

Implementing ice models into the Great Lakes Operational Forecast System (GLOFS)

Ice physics has been added based on Los Alamos Sea Ice Model (CICE).

The verified model provides:
- The first ever short-term ice forecast guidance for the Great Lakes region.
- A basis for advanced coupling with weather forecast models and processes studies.

Left: FVCOM-CICE model results.
Right: National Ice Center analysis.
GLERL and CIGLR conducted a needs assessment to inform the design and future development of the ice forecast guidance features in GLOFS.

Meeting with Great Lakes shipping and navigation community, U.S. & Canadian Coast Guards, and NOAA at a facilitated workshop, conducted interviews and focus groups to learn about their perspectives on ice forecasting needs and incorporate their feedback into the design process.

Key Needs Identified:
- Near-real-time information with specific temporal frequencies.
- Ability to focus in on critical geographic areas, e.g. connecting waterways.
- Coordination with existing ice information products.
- Fine tuning shipping season start / stop predictions.

Expanding ice forecasting beyond the Great Lakes

Jia Wang
Developing coupled lake-wave-ice models in the Great Lakes

Ice cover interacts with waves, storm surge, and lake currents in a highly complex way.

Great Lakes offer an ideal place to examine ice physics models that take these interactions into account because of relatively rich winter measurements.

Examined models and knowledge gained in the Great Lakes research can be applied to ice forecast models in the Great Lakes and beyond, such as Alaska’s coast and Arctic Ocean.

Simulated wave height (m): upper left, without ice model; upper right: with ice model; lower: wave height difference between without ice and with ice model (contours), and ice concentration (0-100%). Ice cover significantly dampens significant wave height (Hs).

Hawley et al. 2018, Journal of Great Lakes Research
Bai et al. 2020, Ocean Dynamics
Sharing our ice modeling expertise

Building a coupled storm surge and wave operational forecasting capacity for western Alaska

- Storm surges and flooding events are hazardous phenomena along Alaska’s coasts.
- Challenges in assessing risks and decision making (e.g. warning issuance).
- Complex interactions among atmosphere, waves, ocean circulation, and ice.
- Observations are sparse (only 4 year-round water level stations).
- High-resolution, coupled surge, wave, and ice forecast model system will fill in gaps.

Arctic-Sea Routes Nowcast/Forecast System (GCAS)

- Shipping route connecting Bering Strait and Barents Sea along the Russian coast.
- Drastic cut in travel time between far east and western Europe during ice free season: 1/3 savings on distance, oil, time, etc.
- Potential economic benefits, but environmental and resources challenges
Alaska Coastal Ocean Forecast System (ALCOFS)

Deliver an improved coupled surge, wave and ice forecasting capacity to NOAA National Centers for Environmental Protection (NCEP) and NOAA National Ocean Service (NOS) Coastal Survey Development Lab.

CIGLR and GLERL lead the advancement of a sea ice model component based on the Los Alamos Sea Ice Model (CICE).

- 5-day forecast: ice distribution using newest CICE6.
- Will enable detailed representation of nearshore and offshore sea ice behavior such as landfast ice and ridging, which impact surge and wave intensity.
- Adequately depicting these processes is critical for accurate storm surge forecasting when the ocean is covered with ice.

Hu et al. 2016, *Journal of Geophysical Research: Oceans*
Li et al. 2016, *Journal of Geophysical Research*
Arctic-Sea Routes Nowcast/Forecast System (GCAS)

Investigate mechanisms leading to accelerating decline in Arctic summer sea ice and the possible responses of the Arctic ecosystem.

Predict the Northern Sea Route opening and closing with the diminishing summer ice conditions will provide the information to guide commercial shipping, oil/gas exploration, and environmental protection.

- 5-day forecast for sea ice and ocean conditions, since August 2020.
- Based on ICEPOM (parallelized version of Princeton Ocean Model coupled with an ice model)
- The existing pan-Arctic model is 25 km resolution.
- Our 4 km resolution model covering the Northern Sea Route is now nested into the pan-Arctic model.
- This new product can provide a 5 day forecast.

Lei et al. 2019, *International Journal of Climatology*  
Hydrologic modeling
Lauren Fry
GLERL is a leader in advancing Great Lakes water level forecasting.

GLERL has a long standing critical role in the development of tools required for seasonal to interannual water level forecasts, long term monitoring of the components of net basin supply to the Great Lakes, and water management activities in the Great Lakes.

GLERL research focuses on better understanding and predicting the key factors driving Great Lakes seasonal to interannual water level changes:

- Precipitation that falls on the lake surfaces,
- Evaporation that occurs from the lake surface, and
- Runoff of water from land, rivers.

See Water Levels in the Great Lakes story map on review website.
Management challenge: Great Lakes water levels fluctuate dramatically.

Unlike ocean coasts, both low water levels and high water levels may occur in the future due to changes in the counteracting components of precipitation and evaporation.

Over the last 2 decades, there was a dramatic shift from an extended period of low water levels to a rapid multiyear rise culminating in record high water levels.
Supporting bi-national Great Lakes water management through partnerships

Seasonal water supply forecasts

- Net Basin Supply forecast developed at GLERL provides guidance to U.S. Army Corps of Engineers (USACE) contribution to internationally coordinated 6-month forecast
- Developed the Great Lakes Seasonal Hydrologic Forecasting System (GLSHFS)
- Developed under project funded by New York Power Authority and Ontario Power Generation to provide long-term forecasts of variability in water levels and flows in the Niagara and St. Lawrence Rivers
- This forecast is currently operational at USACE.

New binational precipitation product

- Binational collaboration reduces international data discrepancies.
- Blends National Weather Service Multisensor Precipitation Estimates with the Canadian Precipitation Analysis
- Expected to become the main source of precipitation estimates for coordination of data between U.S. and Canada

Fry et al. 2020, Journal of Water Resources Planning and Management
Do et al. 2020, Scientific Data

See “Documents” tab on review website for more information about bi-national committee collaboration.
Over-lake evaporation: a critical Great Lakes water budget measurement.

Understanding how changes in regional climate translate to evaporation and ultimately water levels is limited to models relying on extremely scarce overlake observations.

GLERL has taken a leadership role in the establishment Great Lakes Evaporation Network (GLEN), an informal collaboration of research scientists from NOAA, academia, and Environment Canada Climate Change.

GLEN measurements are incorporated into water budget estimates and operational forecasting systems.

Charsombat et al. 2018, *Hydrology and Earth System Sciences*
National Water Model - Developing Applications

GLERL is working with CIGLR, National Center for Atmospheric Research, and NOAA’s Office of Water Prediction, to develop National Water Model applications for the Great Lakes.

Calibration of National Water Model v2.1 for Canadian watersheds.
- Provides opportunity for new predicting total runoff into the Great Lakes.

Runoff Risk Advisory Forecast (v3.0)
- Data driven approach to predicting runoff risk at edge-of-field using National Water Model output.
- Enhanced decision-making with respect to nutrient application, ultimately resulting in improved water quality.

Runoff Risk Advisory Forecast

NWMv2.1 over the Great Lakes, including the Canadian portion (red).
Coastal coupling and flood forecasting

James Kessler and Dan Titze
Coastal coupling in large lakes for total water prediction

**Goal:** Customized coupled hydrodynamic Great Lakes Operational Forecast System (GLOFS) - hydrologic National Water Model (NWM) modeling system for the Great Lakes basin to provide accurate total water prediction capability.
Coastal coupling in large lakes for total water prediction

- Collaboration with National Water Model team (NWM) at National Center for Atmospheric Research (NCAR).
- Inundation information passed from GLOFS to NWM via restart file.
- Experimental results indicate improvement in streamflow near the coast (no upstream/backwater effects).

Future work:

- Iterative coupling with river inflows to Finite Volume Community Ocean Model.
- Alternative configuration of NWM to represent backwater effects.
Collaborative bi-national multi-agency program to develop a flood forecasting model for the Lake Champlain-Richelieu River basin.

Major Lake Champlain flooding in 2011 resulted in a Reference issued by the US and Canada to the International Joint Commission (IJC) to study the flooding and make recommendations.

NOAA GLERL is playing a leadership role in this major five year collaborative effort by bi-national, federal, and university partners.

Project is a part of the International Lake Champlain-Richelieu River Study, https://www.ijc.org/en/lcrr
Improving real-time prediction of Lake Champlain floods and waves.

- 3D hydrodynamic model (FVCOM) predicts water levels and currents driven by winds, precipitation, and river inflows from NWM.
- Wave model (WAVEWATCH III) is informed by water levels from FVCOM to predict waves in flood areas.
- Lake conditions updated every 6 hours in nowcast mode.
- Forecast provided every 24 hours with hourly output out to 5 days.
- In process of transition to operations at NOAA.

Significance and impacts

- Real-time flood forecasting system addresses one objective of the IJC study: developing improved forecasts in Lake Champlain.
- First lake flood forecasting system that uses NWM inflows. New NWM version 2.1 has domain extended to Canada based on work by the project team.
- Floodplain is included in the FVCOM domain to model both seasonal and short-term water level variations.
- First Lake Champlain wave model capable of predicting waves in flood areas.

NOAA GLERL’s OSAT team, in collaboration with partners at University of Vermont’s Forest Ecosystem Monitoring Cooperative (FEMC), deployed this wave buoy in Lake Champlain in May, 2021. Photo credit: University of Vermont FEMC staff.
Probabilistic Modeling
Craig Stow

Bayes Theorem

\[ p(\theta \mid x) = \frac{\pi(\theta) f(x \mid \theta)}{\int \pi(\theta) f(x \mid \theta) \, d\theta} \]
Addressing a binational mandate to improve Lake Erie water quality

GLERL provides scientific expertise to support the 10 Annexes in Great Lakes Water Quality Agreement. Each Annex addresses a key challenge (e.g. invasive species, oil spills, nutrients); a binational subcommittee of subject matter experts develops strategies to manage each challenge.

The Annex 4 (nutrients) subcommittee set a phosphorus load target for Lake Erie, with a 40% reduction goal.

GLERL is using probabilistic and causality approaches to study nutrient loading from major tributaries.
Why is it difficult to assess our progress toward a 40% phosphorus load reduction in Lake Erie?

Discerning Loading Patterns Using Flow Normalization

Year to year variability in precipitation can cause year to year variability in the tributary flow and can obscure what you are observing.

Figure on right contrasts the actual load with the flow normalized load of three tributaries that drain into Lake Erie.

- Actual flow: blue dots
- Flow normalize load: white dots actual load blue dots

Flow normalization removes variability due to flow and makes progress towards phosphorus load reduction goal easier to discern.

Rowland, Stow, et al., 2021, Ecological Indicators
Using probabilistic approaches to discern how we can better address the changes that will occur in the Great Lakes under climate change.

Using causal inference
- Tributary load is not causal
- Components of tributary load: concentration and flow are independently causal
- To predict how lake will respond under climate change: need to focus on changes in tributary flow that might occur.

Observing changes in Lake Erie:
- Long-term precipitation increasing
- Long-term Maumee River discharge increasing

Paper by colleagues: Milly et al., 2008, Science
Conclude stationarity is not a good assumption

Stow et al., 2015, Environmental Science & Technology
Stow, Liu, and Anderson, 2019, Wiley Interdisciplinary Reviews: Water
Data Management

Lacey Mason
Improving discovery, access, usability, and archiving of NOAA data for societal benefit

Taking a leadership role in managing data
- Member of NOAA Environmental Data Management Committee (EDMC)
- Co-organizer for the 2020 NOAA Environmental Data Management Workshop
- Co-convener of the OAR Data Management Working Group
- Leads GLERL Data Management Committee

NAO 212-15
This policy provides high-level direction that guides procedures, decisions, and actions regarding environmental data and information management throughout NOAA. This governs six environmental data procedural directives.

FAIR Data Practices
FAIR data practices (Wilkinson et al. 2016) are widely adopted by scientific community starting a series of policy changes by peer-reviewed journals and data repositories.

Public Access To Research Results (PARR)

Federal Data Strategy → NOAA Data Strategy
The NOAA Data Strategy is designed to serve as a framework for consistency that builds upon existing laws and regulations related to how NOAA uses and manages data, while being flexible and adaptable to external influences such as new policies, Executive Orders, stakeholder input, and new technologies that drive innovation within the agency.
Curating public access to data

GLERL Website
- Great Lakes Coastal Forecasting System
- Great Lakes Ice Cover Database
- Great Lakes CoastWatch
- Real-time Coast Observations Network
- HABs & Hypoxia Water Quality Monitoring & Forecasting
- Water Levels

Data Repositories
- A place that holds data, makes data available for use, and organizes data in a logical manner. Often have published procedures.
- Examples include NOAA/National Center for Environmental Information (NCEI) & National Snow and Ice Data Center (NSIDC)
- Metadata: who, what, when, where, why via ISO standards
- Data formatting standards are required
- Data are discoverable across the web - data.gov
Tracking progress and moving forward with data management

- Data management at GLERL is tied to our annual research project proposal and evaluation process (Annual Execution Process = AEP).

- Each research project has data management plan.

- GLERL data management processes are serving as a model for other OAR Laboratories.

- 204 GLERL datasets available through data.gov.
Effective data management leads to great science

- Recent manuscripts highlight historic data:
  - Ice grid standardization
  - Lake Michigan long-term temperature mooring
  - Phosphorus loading from sediments in Lake Erie

- Journals are requiring public data access, in a data repository with a DOI, prior to review.

- Plans for the future:
  - Tracking data DOIs
  - Improved workflows
  - Annual updates
Looking Forward
Looking forward: Improving weather forecasts by coupling weather modeling benefits extend beyond the Great Lakes.

The lakes can impact weather in both big and small ways.
Looking forward: Improving ice prediction

Research is underway to incorporate unique winter processes in freshwater lakes into the models.

Studying impacts of precipitation on ice forecasting.

Studying impacts of ocean mixing algorithms on ice prediction.

Lin et al. in prep.
Summary

Philip Chu
In summary, IPEMF...

Conducts innovative research and develop hydrologic (water cycle), hydrodynamic (circulation of water), wave and ice models in the prediction of runoff, nutrient loads, lake levels, currents, water temperature, inundation, waves, and ice cover.

Advances integrated environmental modeling systems for the Great Lakes to improve forecasts of physical, ecological, biological and chemical parameters at various time and space scales.

Conducts coastal dynamics research addressing water quality problems as well as physical threats to public safety on both a localized and lake-wide basis. The length of time for these problems ranges from hours to days.

Addresses problems involving water resource management, human health, and ecology, improving seasonal forecasts of Great Lakes water levels and ice cover, and linking physical conditions (air and water temperature, wind, ice cover) to ecological responses.

Transitions models and system to NOAA NWS, NOS operations and other applications.

Shares the knowledge, data and model outputs to researchers, managers and stakeholders.
IPEMF works to achieve NOAA’s mission by . . .

Furthering our understanding of over-water meteorology and hydrodynamic processes including extreme storm conditions (weather & water); mixing processes and thermal structure.

Converting data and model into useful and actionable information.

Integrating physical & ecological models to improve forecasting capabilities.

Transitioning cutting-edge science and models to NOAA operations and applications.

Fostering partnerships within Great Lakes basin, across NOAA and with other Federal Agencies.

Share our research results, disseminate data, model outputs to managers, stakeholders, and mentor future STEM scientists for NOAA workforce.
Thank you for your attention!
Thank you for agreeing to serve as a member of the GLERL five-year science review panel!

We look forward to talking with you during the live Q & A sessions.

Review criteria:
Quality: The merit of our research and development within the scientific community.
Relevance: The value of our research and development to users beyond the scientific community.
Performance: The effectiveness and efficiency with which our research and development activities are organized, directed, funded, and executed.

Review week highlights:
- In-depth Q&A/discussions of the overview presentation each theme presentation.
- Meetings with GLERL stakeholders.
- Meetings with GLERL leadership and new staff.

All supporting documents can be found on the GLERL 2021 Review website at: www.glerl.noaa.gov/review2021/#documents