Ice Model Development for Great Lakes Operational Forecast System (GLOFS)

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GLERL
Great Lakes Environmental Research Laboratory

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

Coast Guards Icebreaking Conference
October 26, 2021

Acknowledgements

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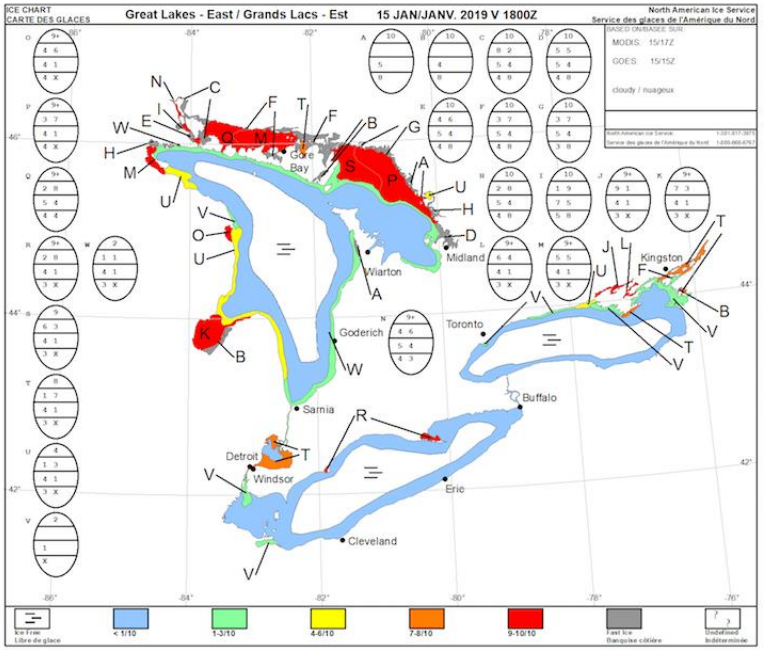
NOAA National Ocean Service
John Kelley, Yi Chen, Ilya Rivin, Machuan Peng, Mojgan Rostaminia

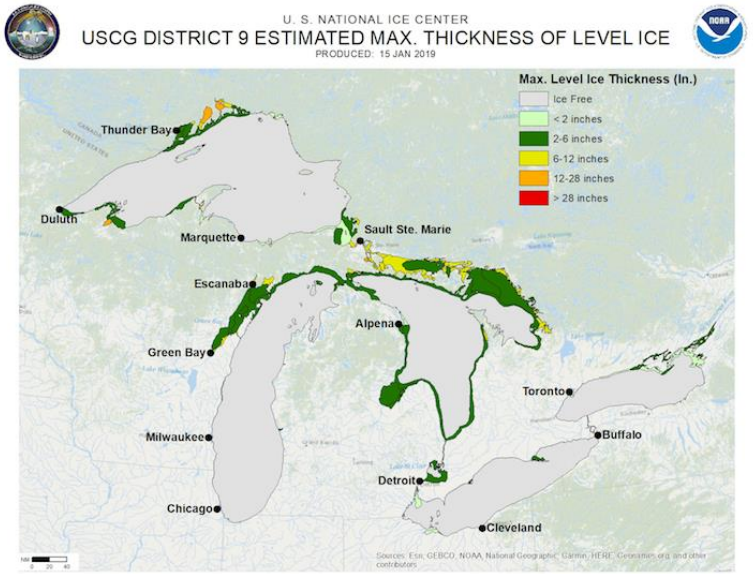
Cooperative Institute for Great Lakes Research, University of Michigan
Yu-chun Lin, Devin Gill,

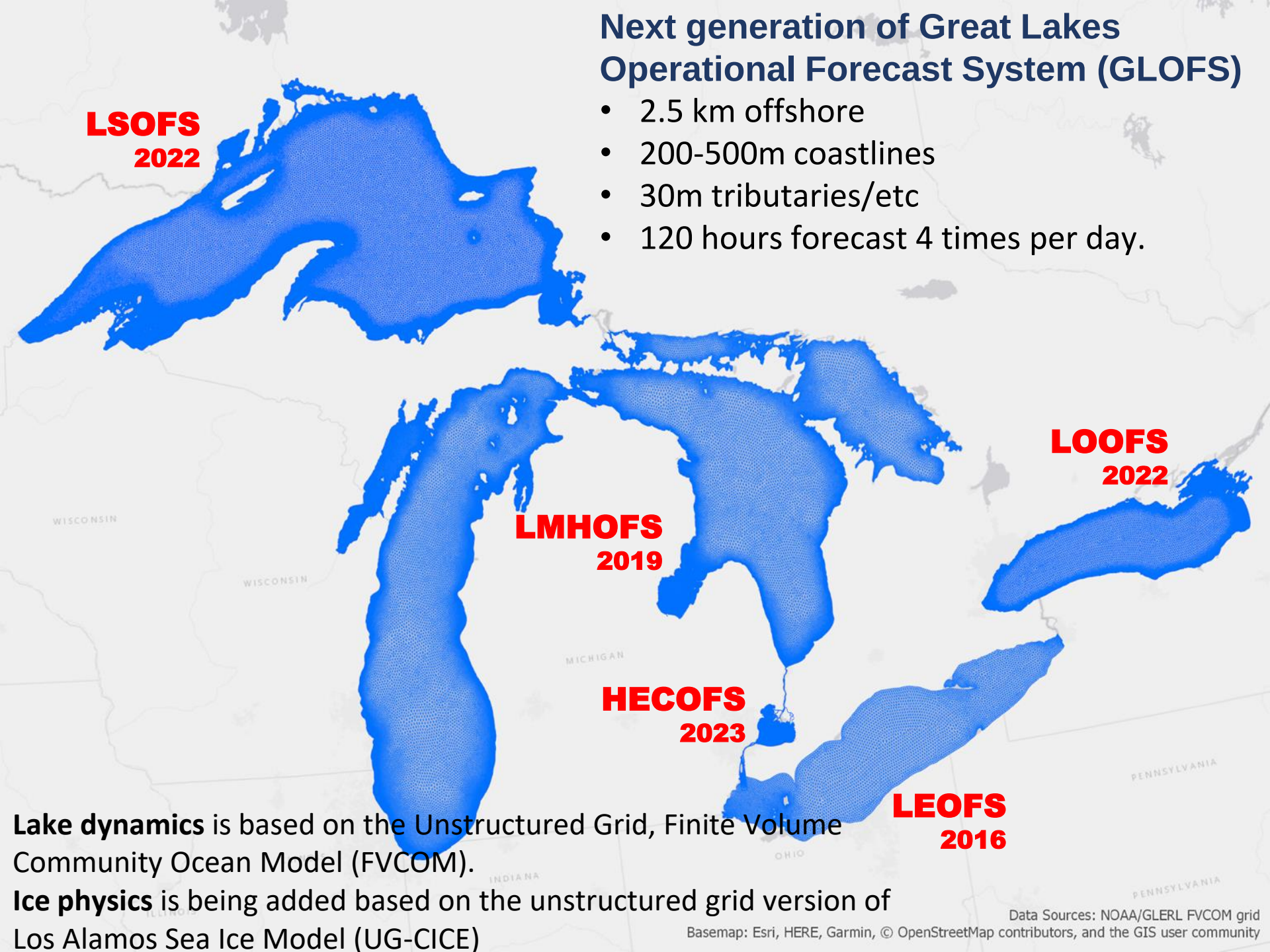
School for Environment and Sustainability, University of Michigan
Maria Lemos, Kimberly Channell, Victoria Graves

Background

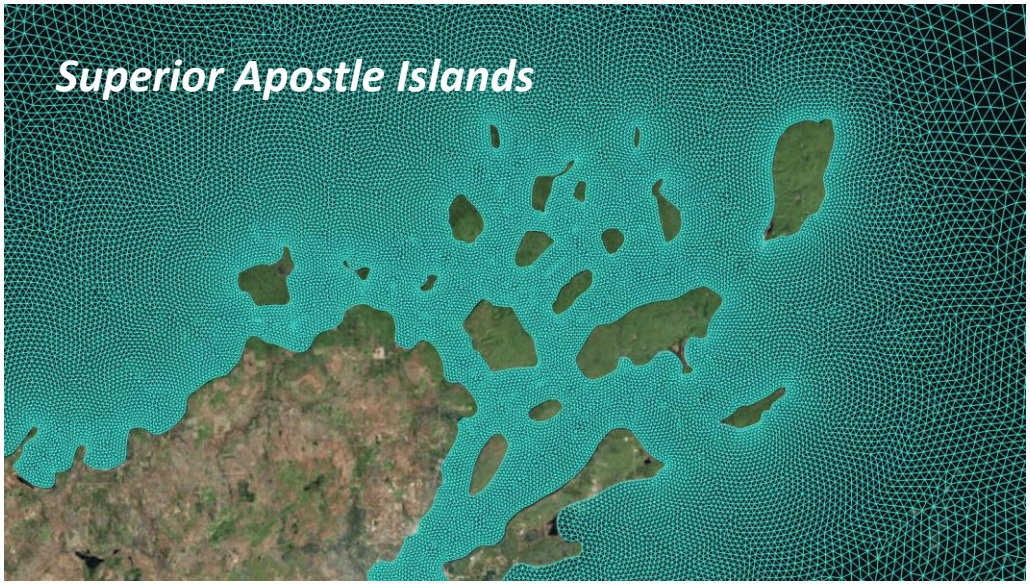
- Real-time information of lake ice conditions is critical for navigational safety and planning ice breaking operations.
- Short-term forecast capability can complement the existing products such as USNIC/CIS daily ice charts.
- Implementation of ice forecast to the existing Great Lakes Operational Forecast System (GLOFS) is underway.

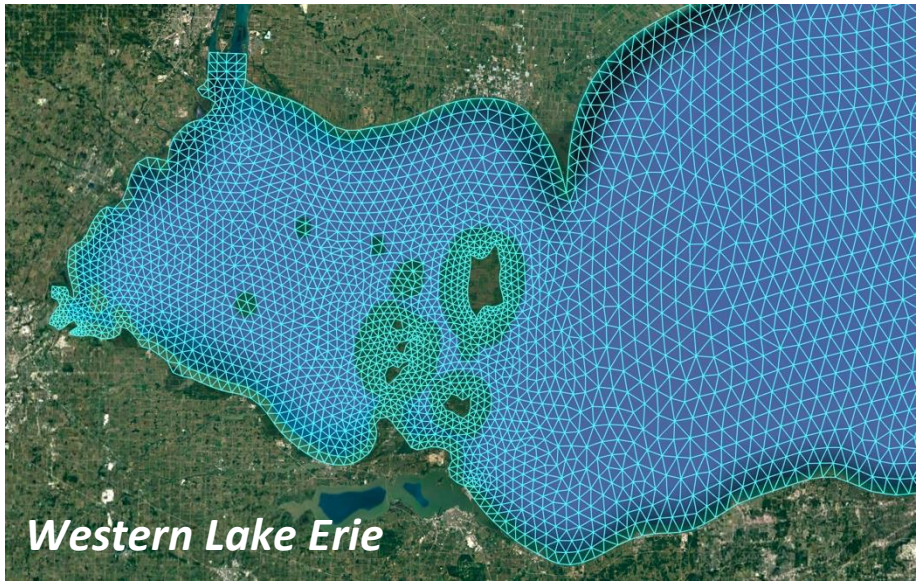


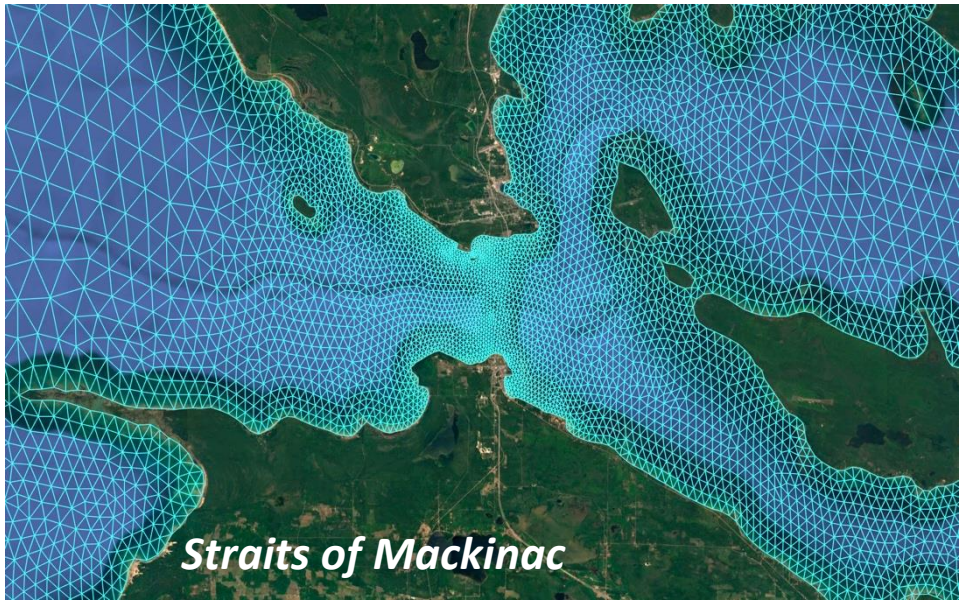



Next generation of Great Lakes Operational Forecast System (GLOFS)
• 2.5 km offshore
• 200-500m coastlines
• 30m tributaries/etc
• 120 hours forecast 4 times per day.
LSOFS
2022
LMHOFS
2019
LOOFS
2022
HECOFS
2023
LEOFS
2016
WISCONSIN
MICHIGAN
INDIANA
OHIO
PENNSYLVANIA
Lake dynamics is based on the Unstructured Grid, Finite Volume Community Ocean Model (FVCOM).
Ice physics is being added based on the unstructured grid version of Los Alamos Sea Ice Model (UG-CICE)
Data Sources: NOAA/GLERL FVCOM grid
Basemap: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Unstructured grid snapshots





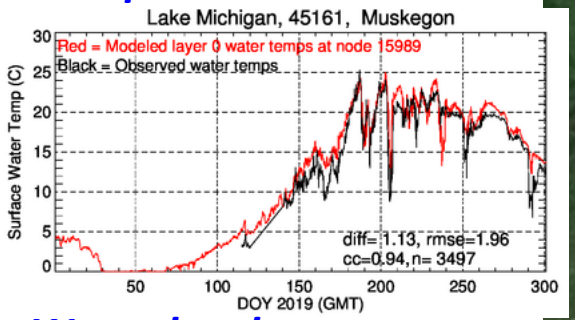


The models are driven by weather forecast inputs.

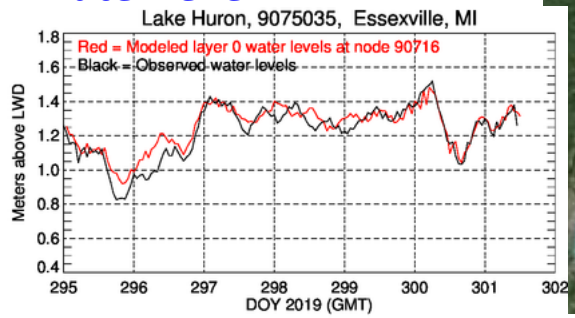
- Winds, Air Temperature, Humidity, Cloud Cover, Radiations

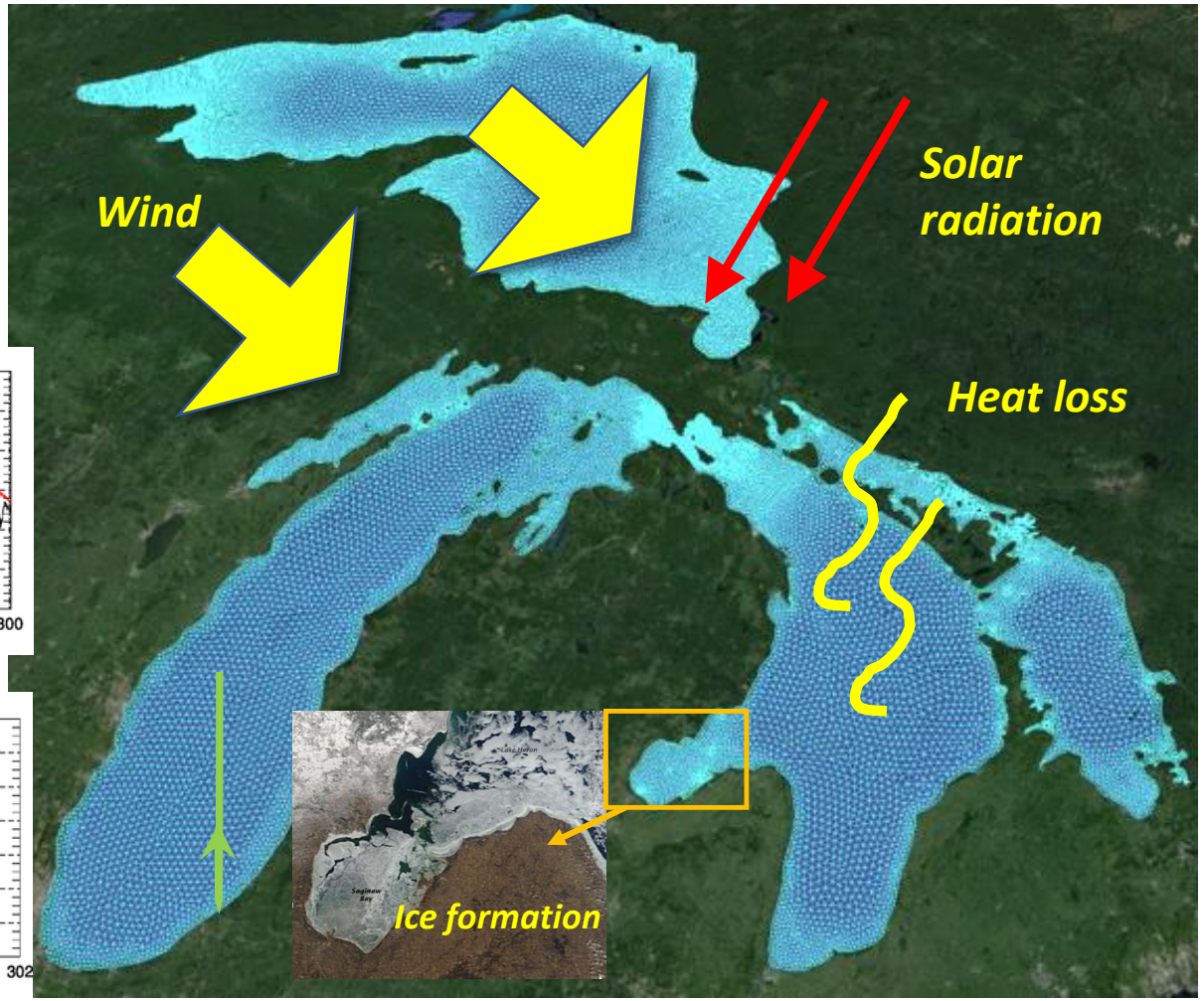
Predicts Lake Currents, Temperature, Water Levels, Ice Cover

Water temperature



Water level





Ice physics is being added based on the unstructured grid version of Los Alamos Sea Ice Model (UG-CICE)

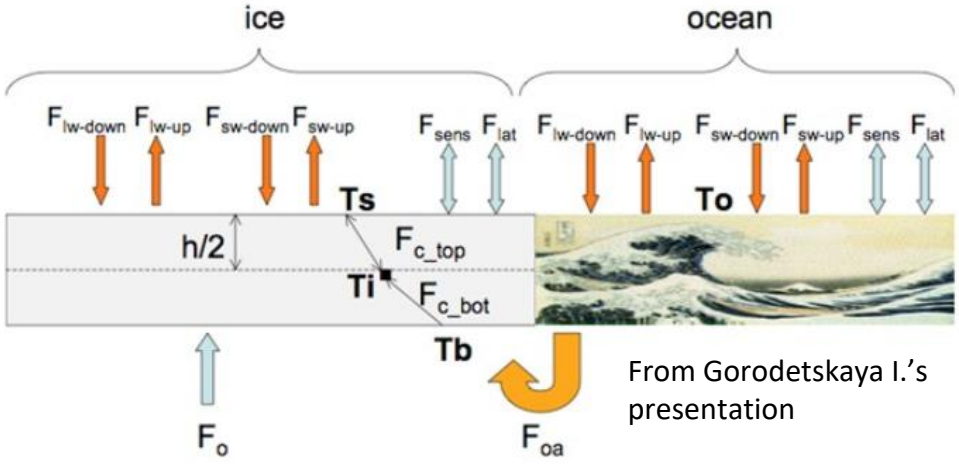
1979 SSMI Composite Data. Credit: NASA

Dynamics

- motion
- deformation

Thermodynamics

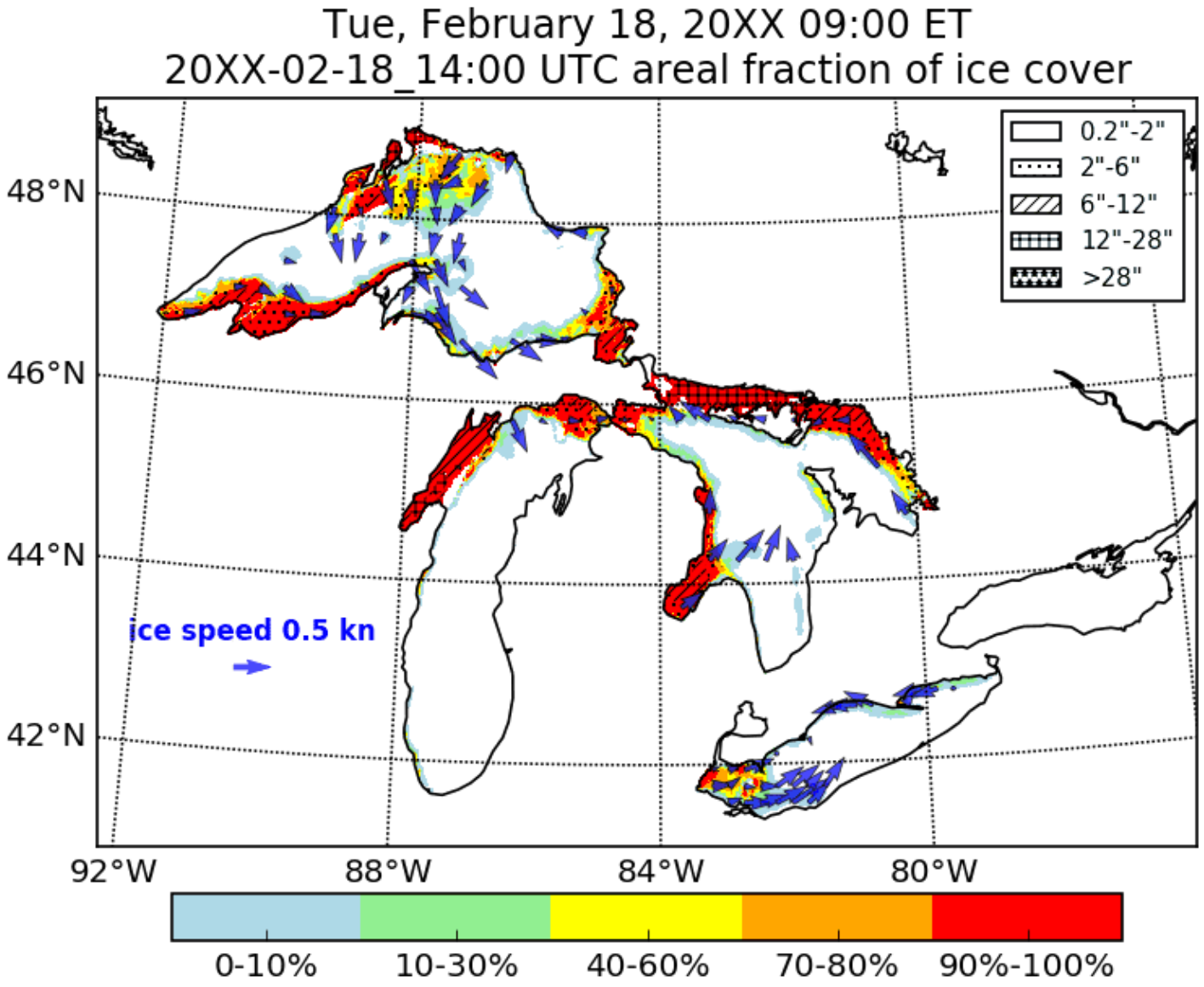
- new ice formation
- growth
- melting



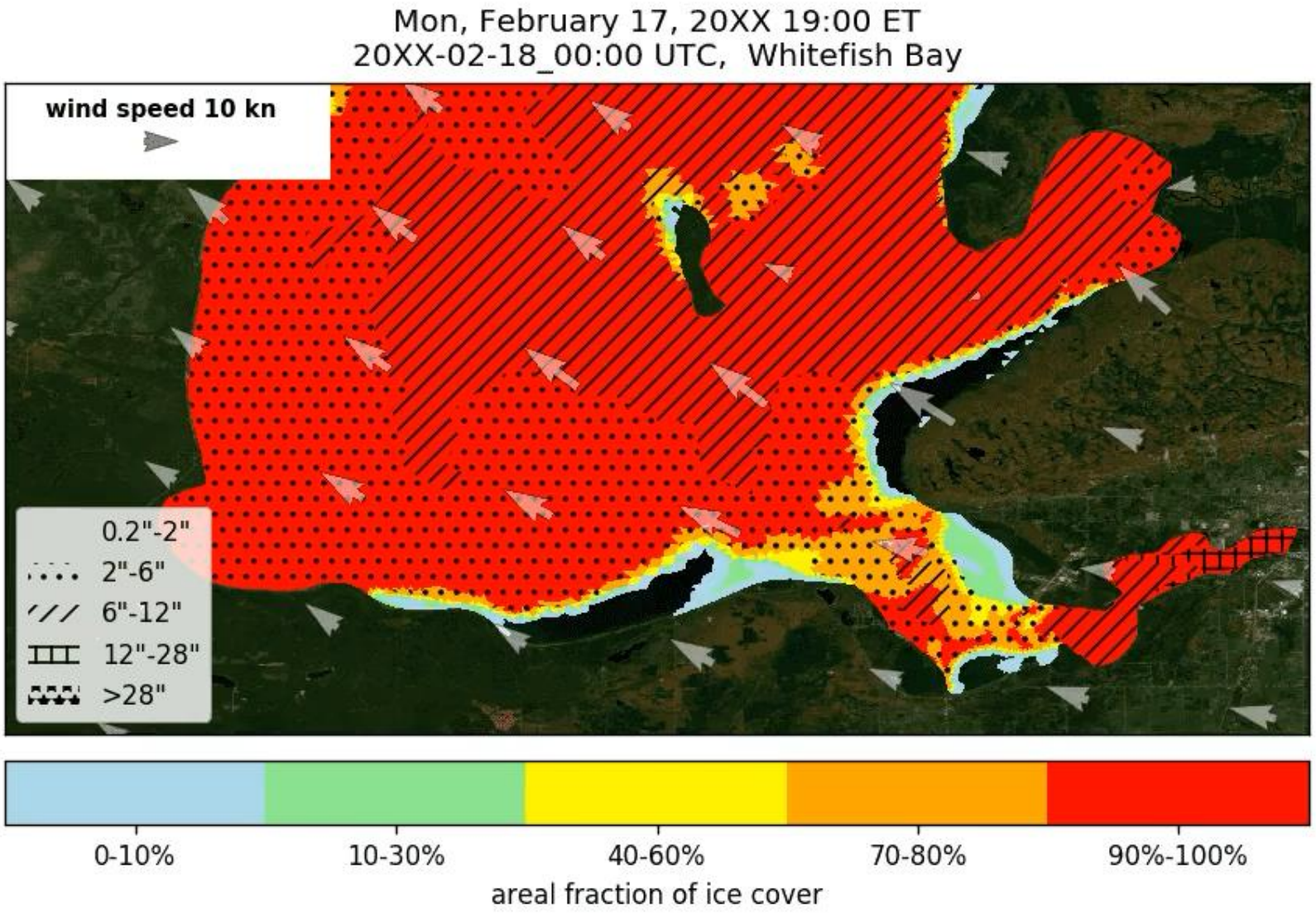
From Gorodetskaya I.'s presentation

Brash ice in northern Green Bay March 4,

An example of what model can produce…



Another example. Zoomed over Whitefish Bay.

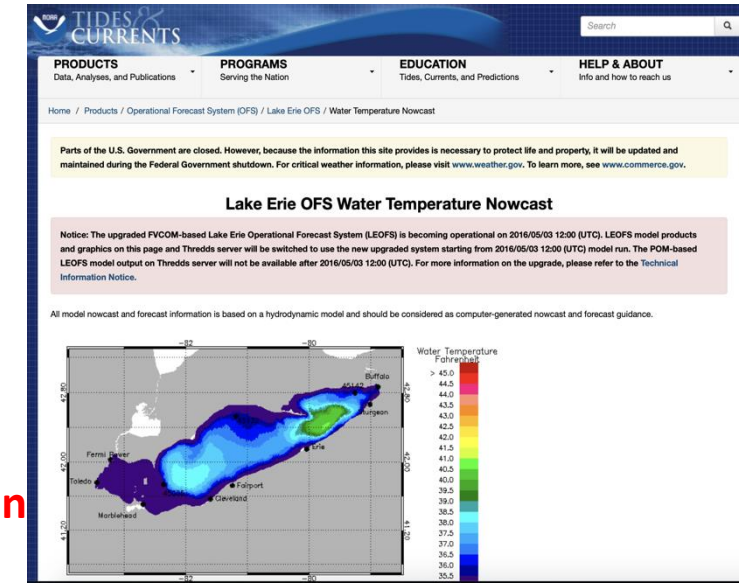


Great Lakes Operational Forecast System (GLOFS) Research-to-Operation (R2O) flow

Research & Development (*CIGLR, GLERL*)

Demonstration at quasi-operational environment (*GLERL*)

At the time of 2019 presentation



Formal Skill Assessment (*National Ocean Service Coastal Survey Development Lab*)

From NOAA GLERL website

Demonstration at operational environment (*National Ocean Service, CO-OPS*)

Ice product is here now in 2021

Operations to provide short term forecast (*National Ocean Service, U.S. National Ice Center*)

Great Lakes Operational Forecast System (GLOFS) Research-to-Operation (R2O) flow

4 New Research & Development (*CIGLR, GLERL*)

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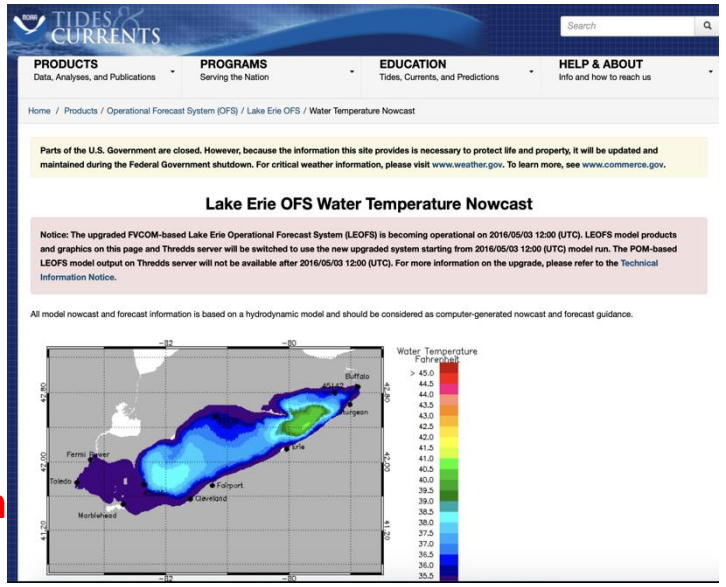

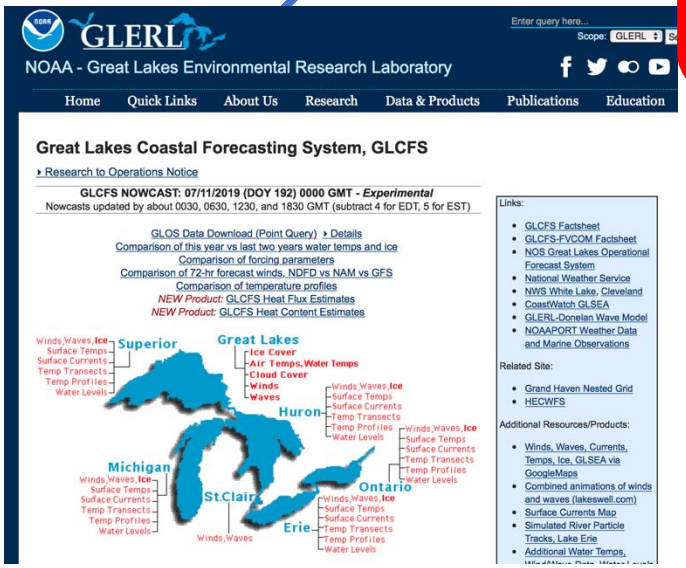

From NOAA GLERL website

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From NOAA GLERL website

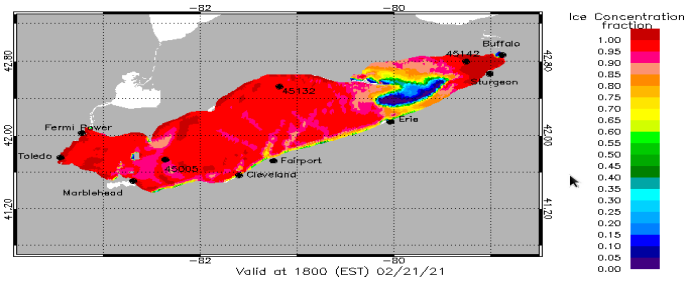
NOAA/NOS/CO-OPS Great Lake Ocean Forecast System (GLOFS)

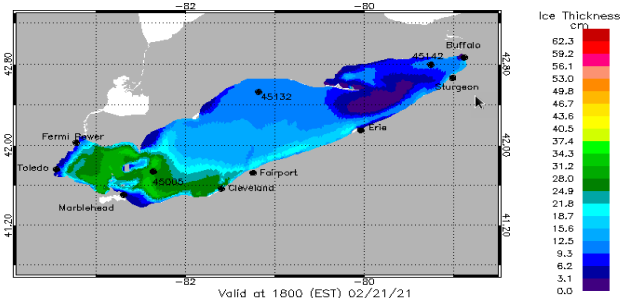
- **PRODUCTION:** GLOFS runs daily four times per day with 6-hour nowcast and 120-hour forecast guidance for total water level, currents, and water temperature for each of the Great Lakes
- **DEVELOPMENT**: produce guidance of ice concentration, ice thickness, and ice velocity. Implementation (tentative): fall 2022.
- **GLOFS COMPONENTS**:
  - Model: FVCOM coupled with CICE
  - Surface forcing:
    - *Nowcast*: NCEP's hourly updated High-Resolution Rapid Refresh (HRRR)
    - *Forecast*: NCEP's Global Forecast System (GFS) in production and NOAA's National Digital Forecast Database (NDFD) in development
  - Rivers: Real-time river discharge observations

- GLOFS development monitoring websites are
  - https://tidesandcurrents.noaa.gov/ofs/dev/loofs/loofs.html
  - https://tidesandcurrents.noaa.gov/ofs/dev/lsofs/lsofs.html
  - https://tidesandcurrents.noaa.gov/ofs/dev/leofs/leofs.html
  - https://tidesandcurrents.noaa.gov/ofs/dev/lmhofs/lmhofs.html

NOS GLOFS 2020-2021 Ice Season Snapshots

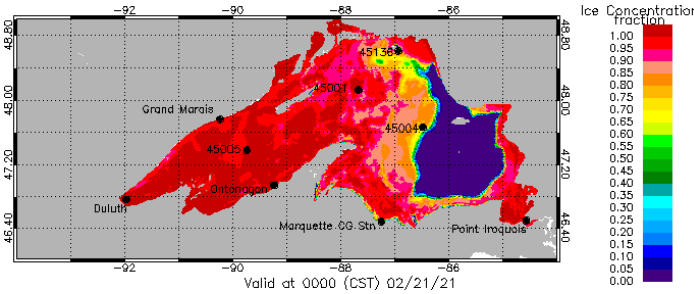
LEOFS concentration

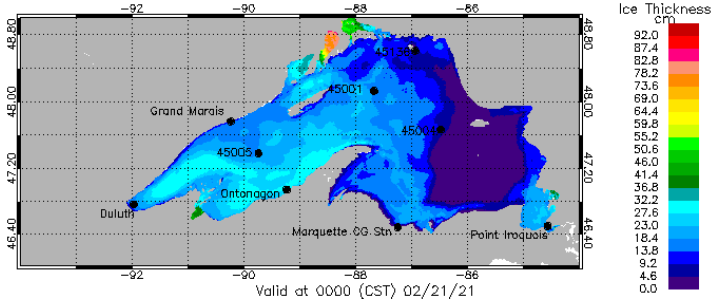




LEOFS thickness

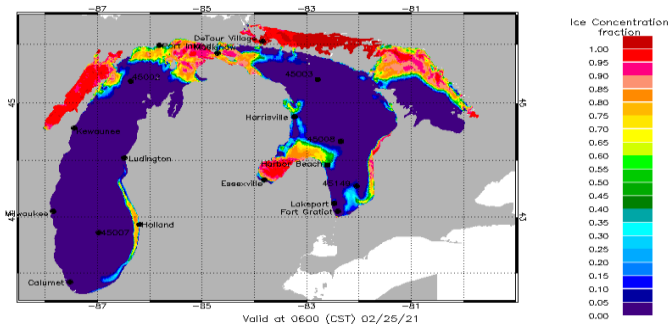
LSOFS concentration

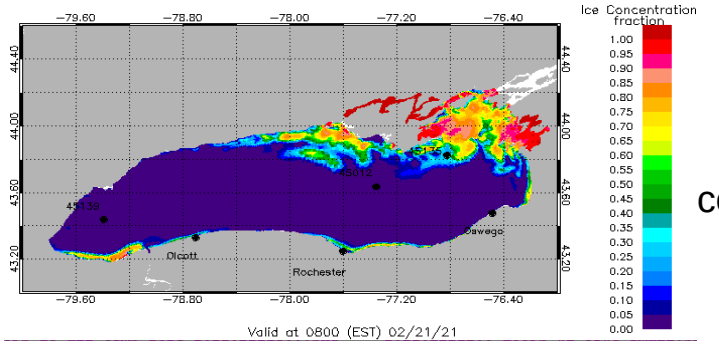




LSOFS thickness

LMHOFS concentration





LOOFS concentration

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From NOAA GLERL website

Skill Assessment of GLOFS Ice Forecast Guidance

- NOS conducts skill assessments of nowcasts and forecast guidance of water temperatures, water levels, & currents when GLOFS is upgraded

- NOAA (CSDL,CO-OPS,GLERL, & CIGLR) is *now* developing capability to skill assess GLOFS predictions of ice concentration & thickness

  - Ice Concentration Assessments:

    - Spatial pattern comparations of averaged ice concentration for
      - Freezing Period (Dec. 1 – Jan. 15)
      - Mid-Season (Jan. 16 – Mar. 15)
      - Melting Period (Mar. 16 – Apr. 30)
      - Entire Ice Season (Dec. 1 – Apr. 30)

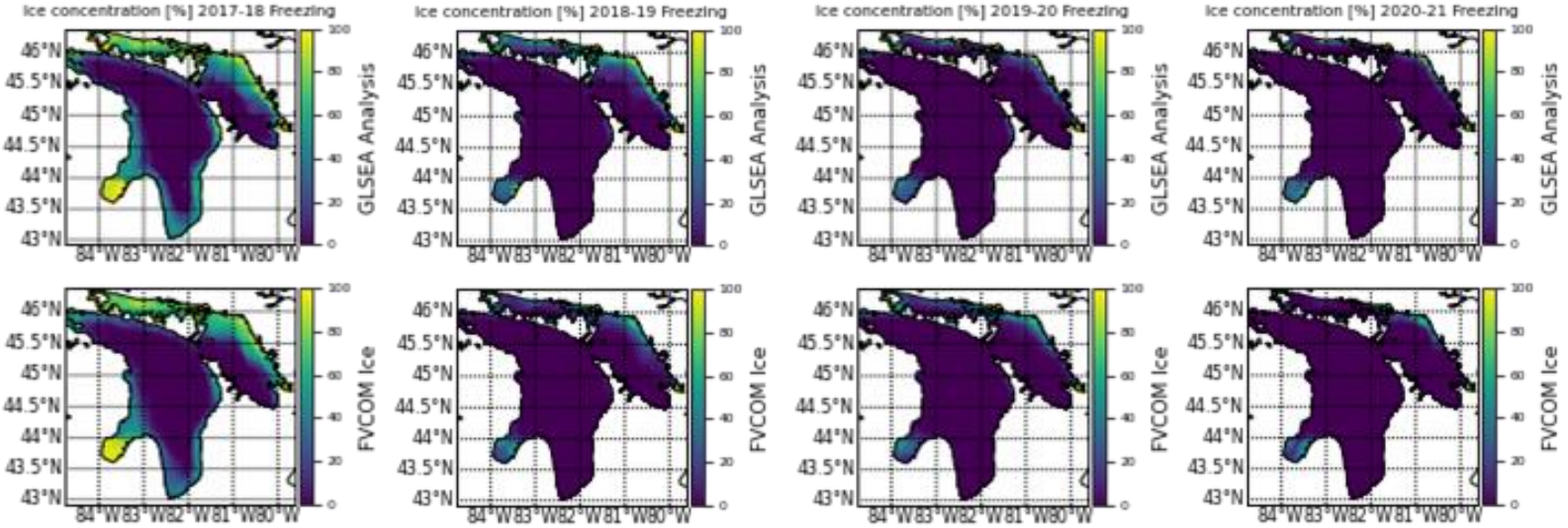
    - Spatial distribution of averaged seasonal ice concentration
      Root Mean Square Error (RMSE)

    - Time series of normalized ice concentration and ice extent
      (Normalized over total number of lake pixels)

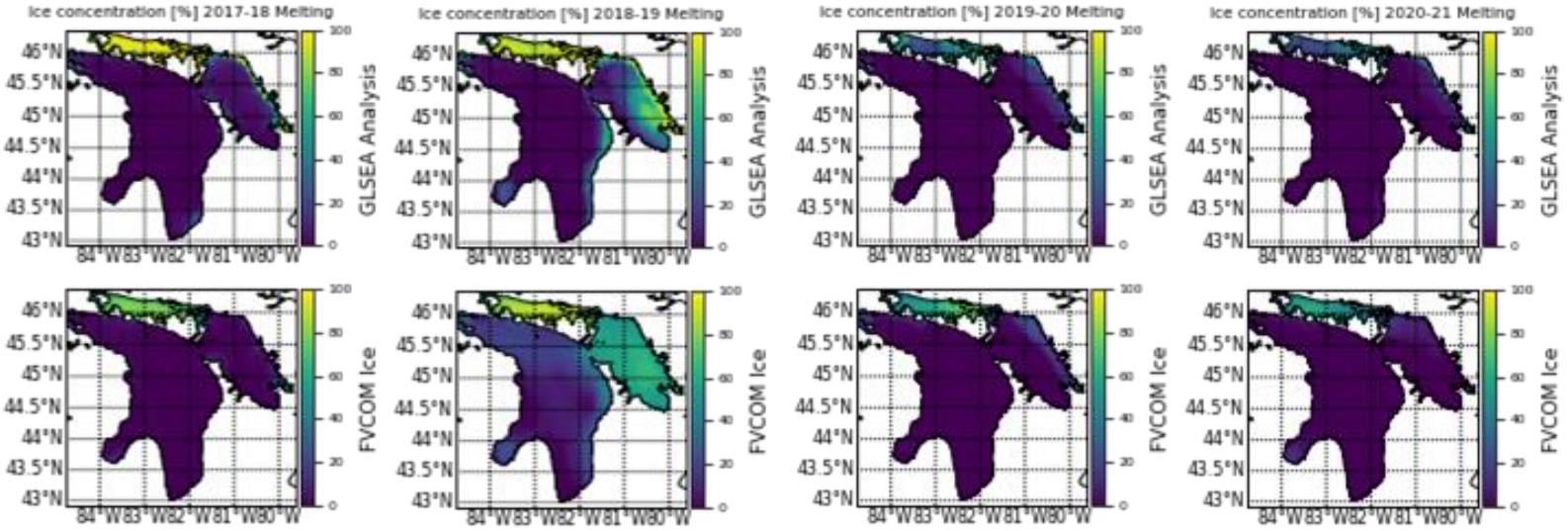
    - Daily and seasonal skill scores of ice concentration and extent

Example:
Spatial Pattern Comparisons of Avg. Ice Conc. for Lake Huron (GLSEA vs. GLOFS-FVCOM Predictions)

2017 – 2021 (Freezing Period)

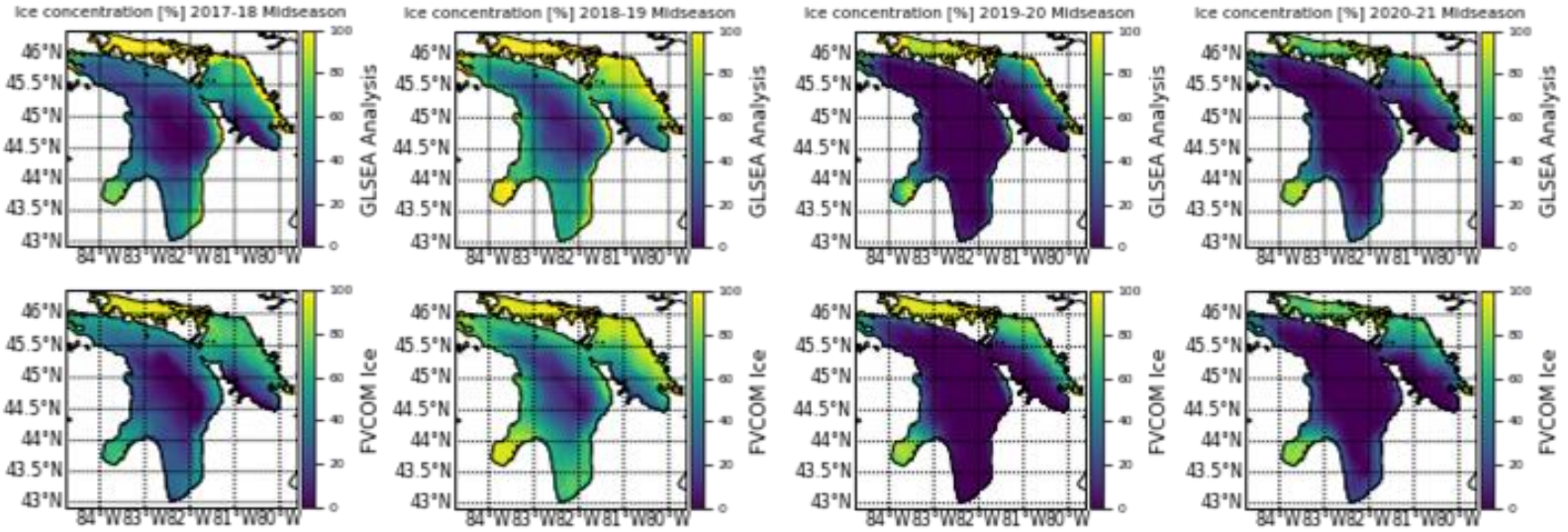


2017 – 2021 (Melting Period)

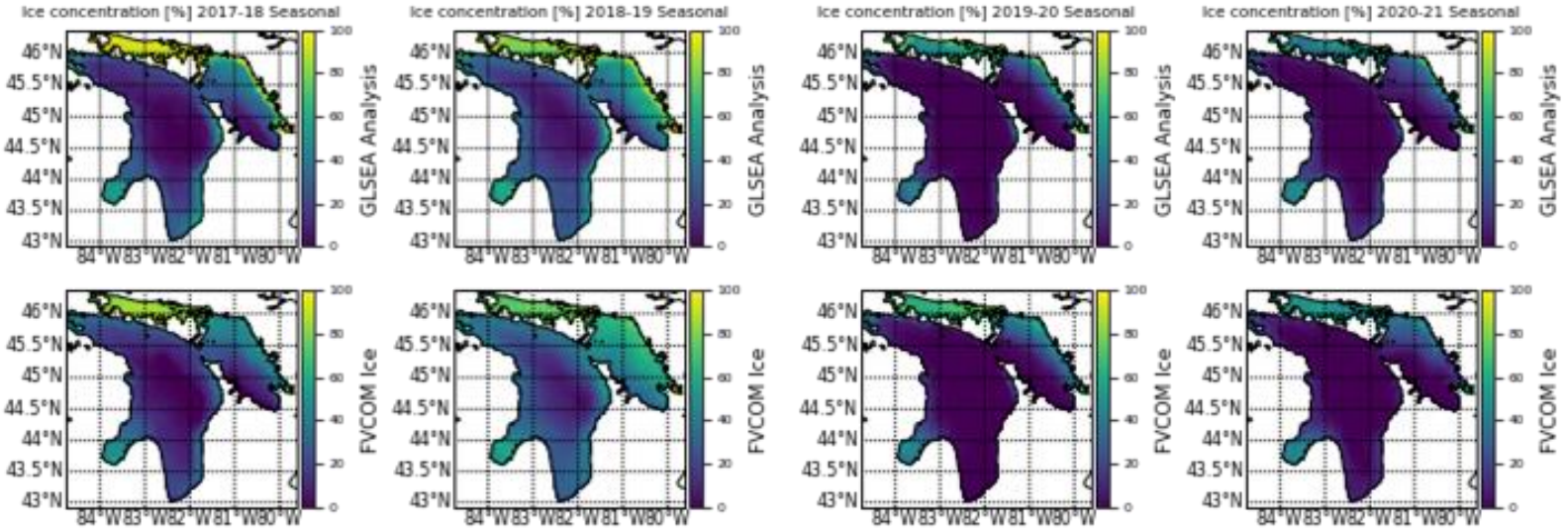


Example:
Spatial Pattern Comparisons of Avg. Ice Conc. for Lake Huron (GLSEA vs. GLOFS-FVCOM Predictions)

2017 – 2021 (Mid-season)

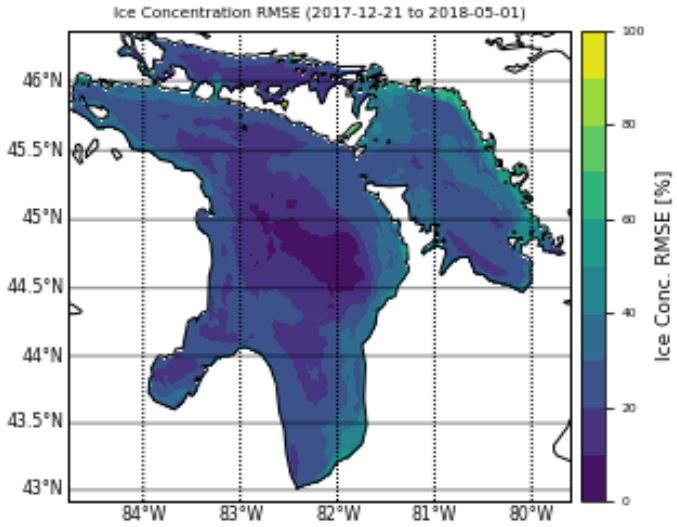


2017 – 2021 (Entire Season)

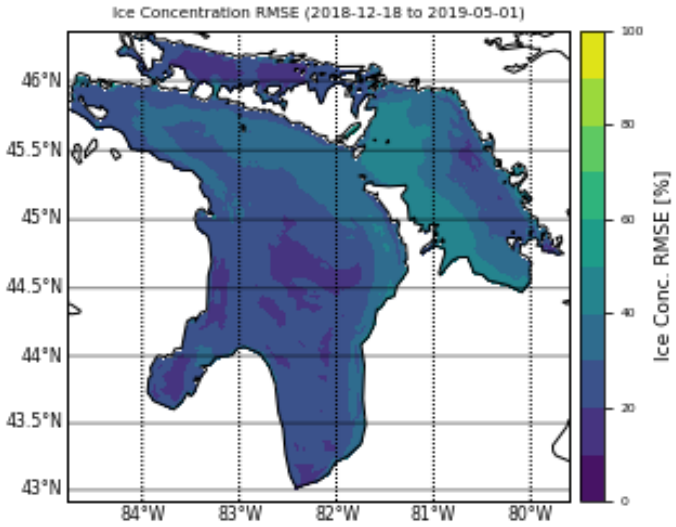


Example: Ice Concentration RMSE* for Entire Season - Lake Huron

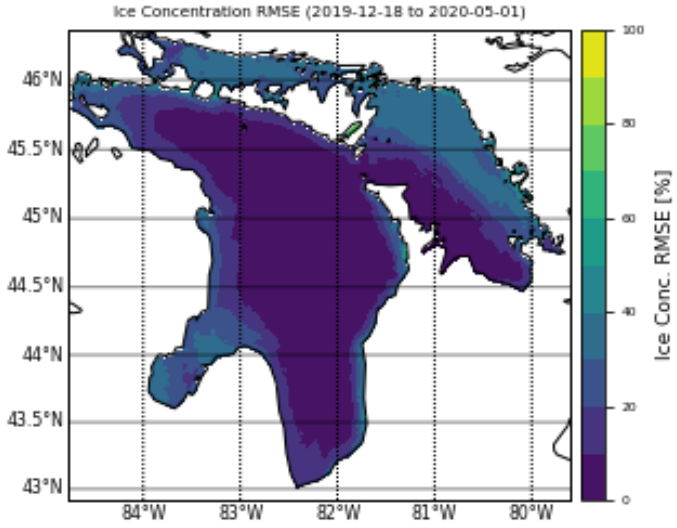
2017-2018



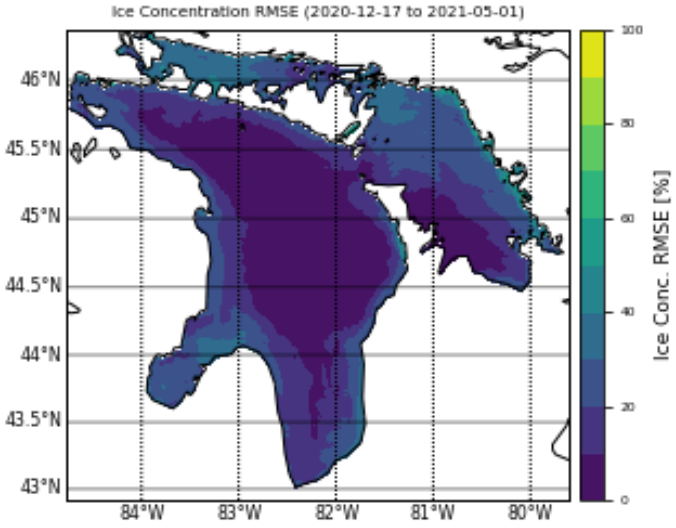
2018-2019



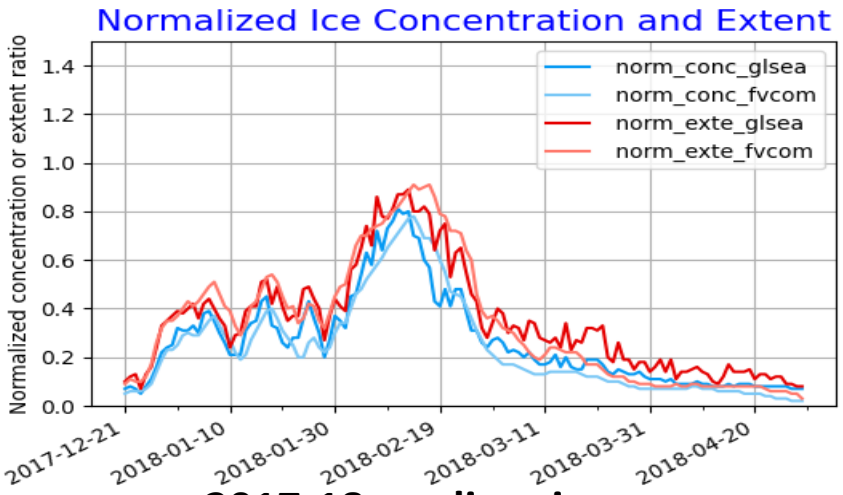
2019-2020



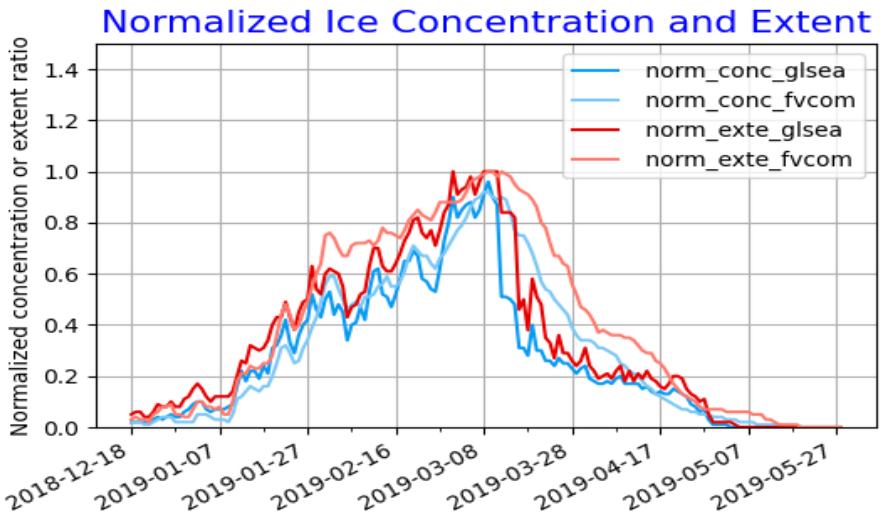
2020-2021



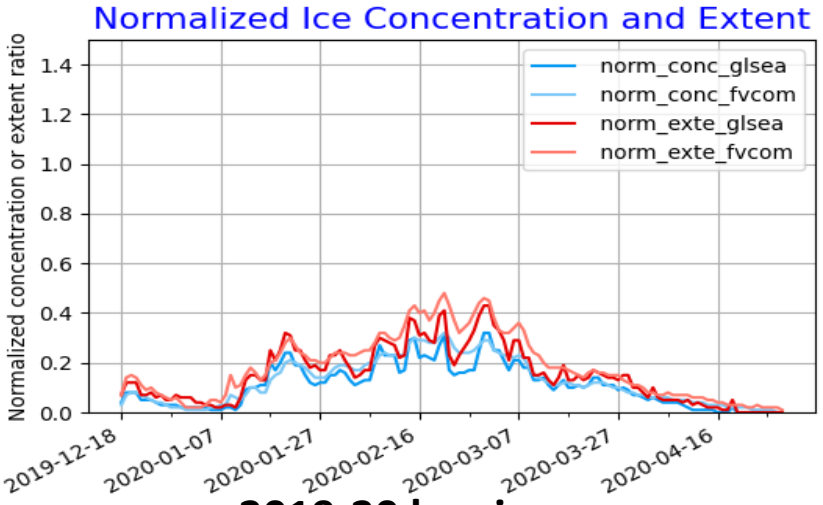
Example: Time Series of Ice Concentration and Extent GLSEA vs. GLOFS-FVCOM Predictions for Lake Huron



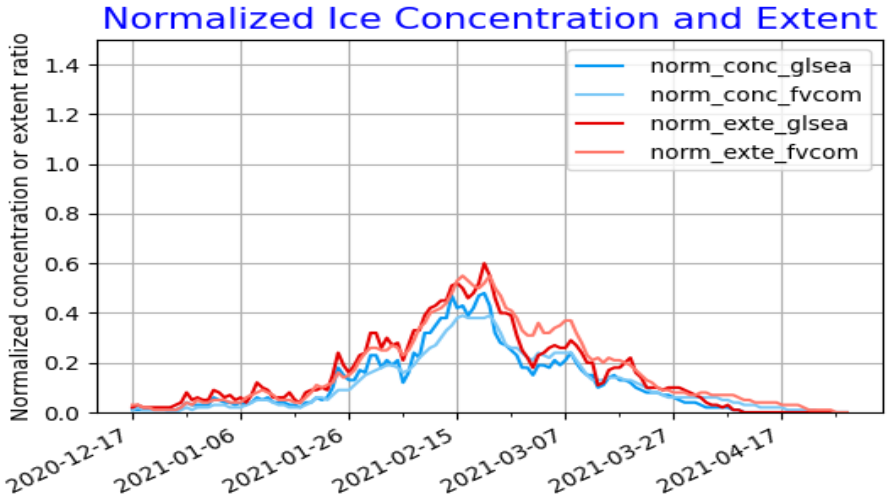
2017-18 medium ice year



2018-19 medium ice year



2019-20 low ice year



2020-21 low ice year

Skill Assessment of GLOFS Ice Forecast Guidance

- NOAA (CSDL,CO-OPS,GLERL, & CIGLR) **plans to finish the development and testing of its skill assessment code & procedures and skill assess GLOFS-FVCOM hindcasts of ice concentration for all five lakes for the four ice seasons by early 2022**

- **NOAA will also develop capability to skill assess GLOFS-FVCOM ice thickness predictions** (i.e. compare thickness predictions vs. NIC ice thickness analysis)

- **NOAA will publish the ice skill assessment results in a NOS technical report in FY21**

- **NOS/CO-OPS will use the ice skill assessment code & procedures to assess their GLOFS-FVCOM semi-operational runs for the upcoming 2021-2022 ice season**

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At the time of 2019 presentation

Ice product is here now in 2021

From NOAA GLERL website

GLERL's quasi-operational product

https://www.glerl.noaa.gov/res/glcfs/

- Upgraded to use FVCOM from the old model (POM) for all of the Great Lakes
- Include ice model
- Will be available in parallel with CO-OPS demonstration
- Periodical updates informed by new research

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New Research

- Improving landfast ice representation
- Coupling with a NOAA weather model
- Ice-wave interactions
- Snow accumulation on the ice
- Ice modeling in the river corridors.
  - Huron-Erie river corridor, St. Marys River
- Stakeholder engagement

New Research

- **Improving landfast ice representation**
- Coupling with a NOAA weather model
- Ice-wave interactions
- Snow accumulation on the ice
- **Ice modeling in the river corridors.**
  - **Huron-Erie river corridor, St. Marys River**
- **Stakeholder engagement**

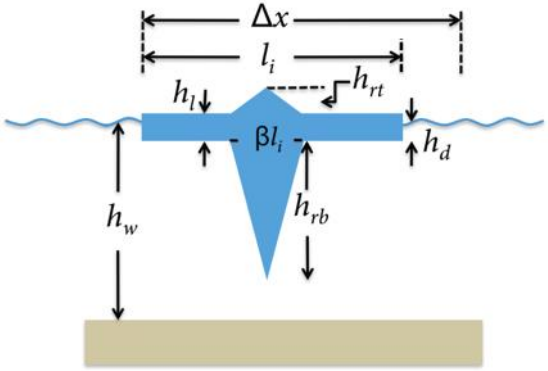
Improving Landfast Ice Representation

Basal stress term was added to the sea ice momentum equation [Lemieux et al., 2015]

$$m\frac{D\boldsymbol{u}}{Dt} = -k\times mf\boldsymbol{u} + \boldsymbol{\tau_a} + \boldsymbol{\tau_w} + \boldsymbol{\tau_b} + \boldsymbol{\nabla}\cdot\boldsymbol{\sigma} - mg\boldsymbol{\nabla}\boldsymbol{H_o}$$

Basal stress term due to grounded ridges

$$\boldsymbol{\tau_b} = \begin{cases} 0 & if\ h \le h_c \\ k_2\left(\frac{-\boldsymbol{u}}{|\boldsymbol{u}| + u_0}\right)(h - h_c)exp^{-\alpha_b(1-A)} & if\ h > h_c \end{cases}$$

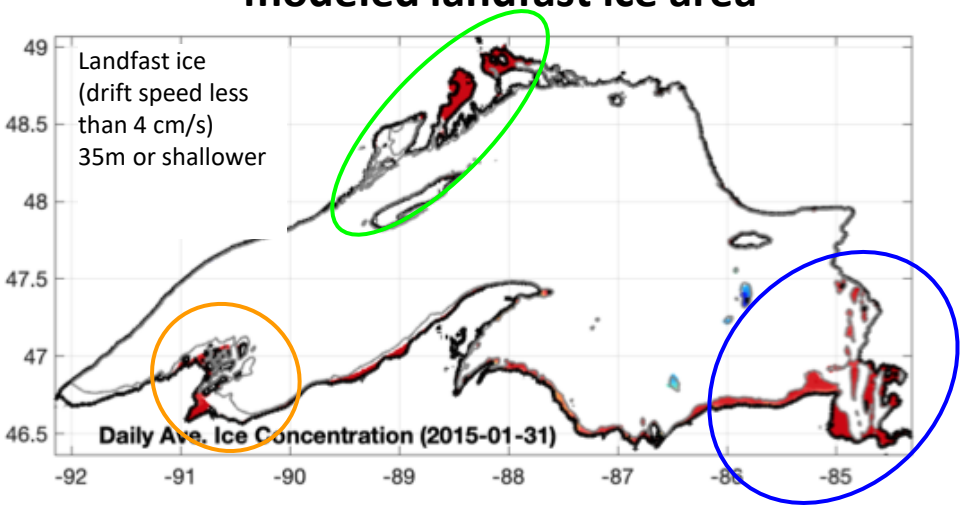


h: mean ice thickness
$h_c = Ahw/k_1$: critical mean ice thickness
h_w: bathymetry
k_1: critical thickness parameter (=8)
k_2: free parameter that determines maximum basal stress (=15)

$|\mathbf{u}|$: ice velocity
u_0: a small velocity parameter
α_b: basal stress ice concentration parameter

Verification of modeled landfast ice

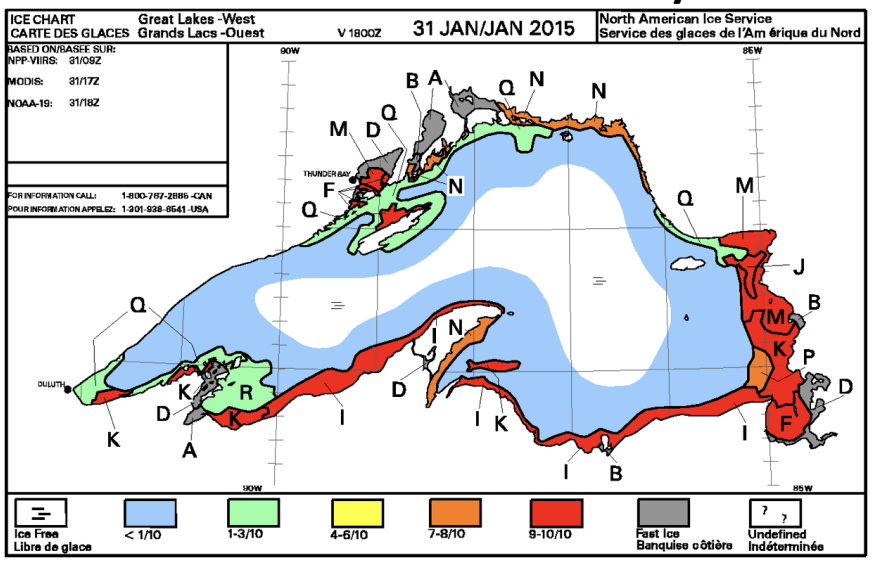
modeled landfast ice area

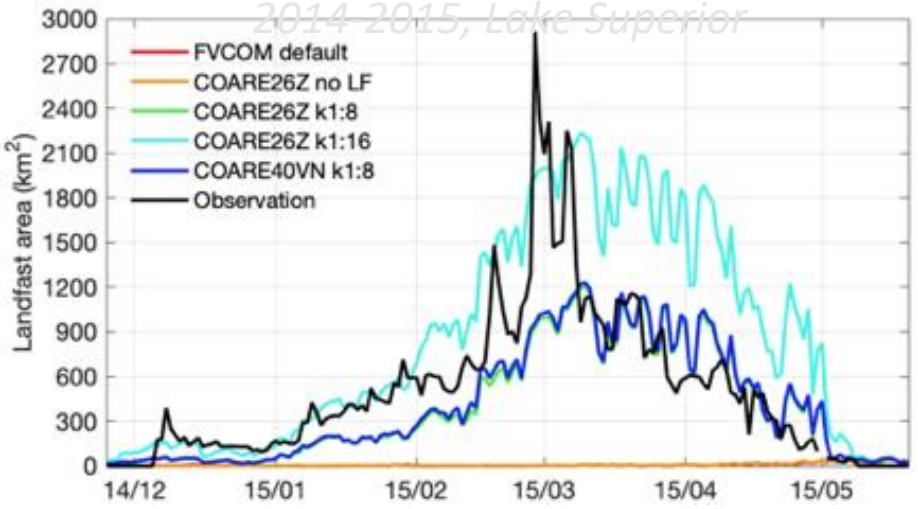


Good representation of landfast ice in Black Bay, Nippigon Bay, and Apostle Islands.

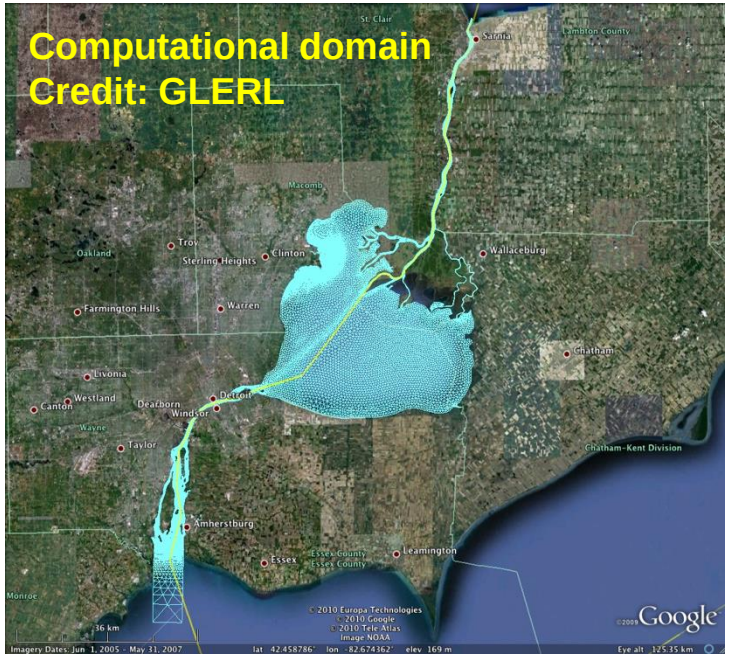
Some overestimation in Whitefish Bay and underestimation in Thunder Bay.

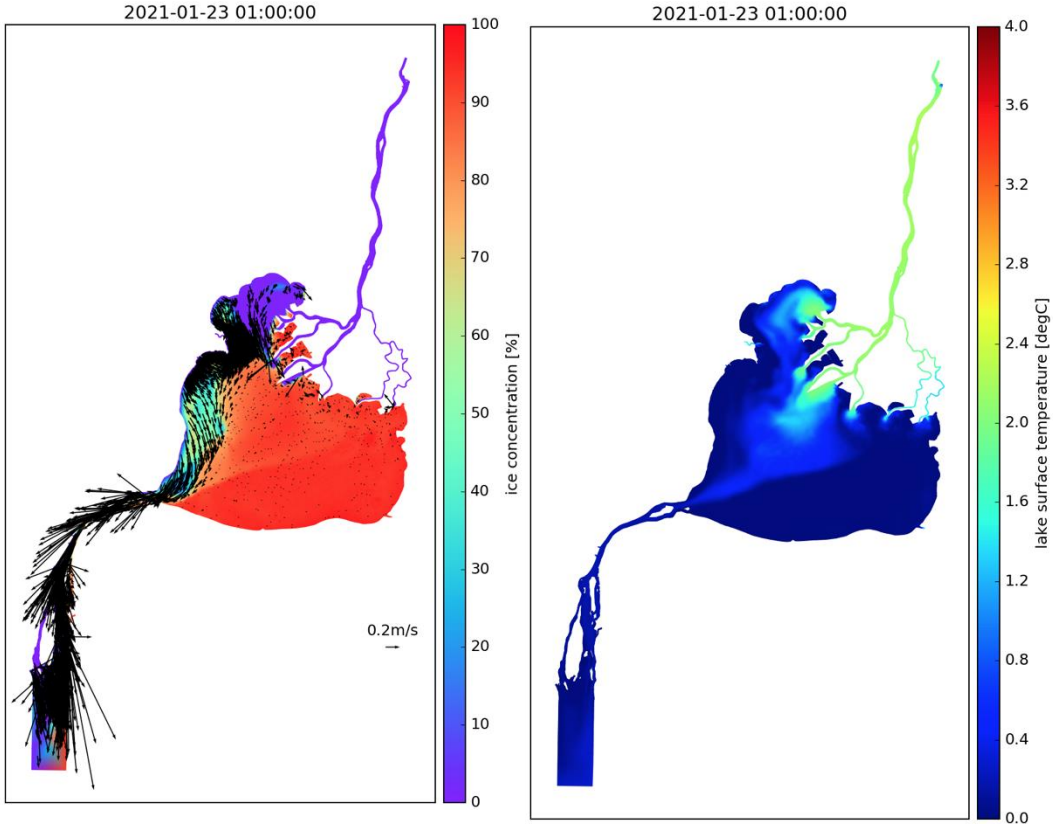
Ice chart on the same day

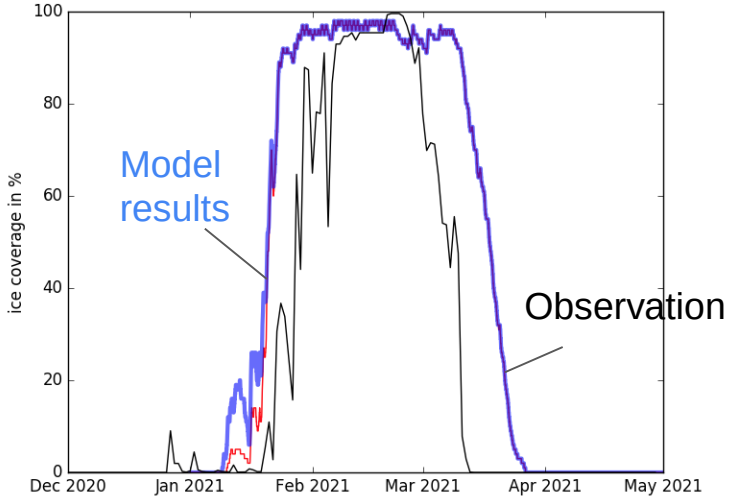




Testing the ice model in the Huron-Erie river corridor system





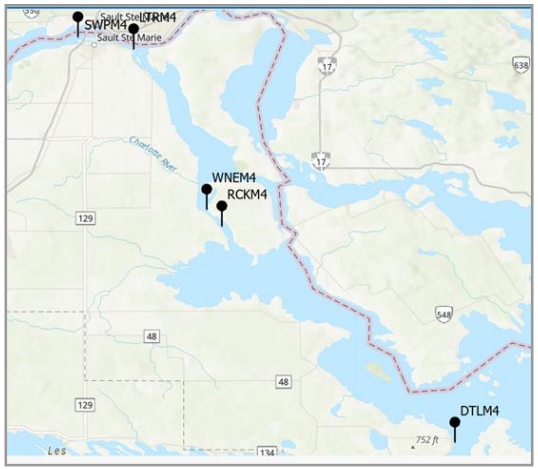


Timeseries of Lake St. Clair wide ice coverage

Machine Learning modeling application for St. Marys River

UM SEAS capstone project

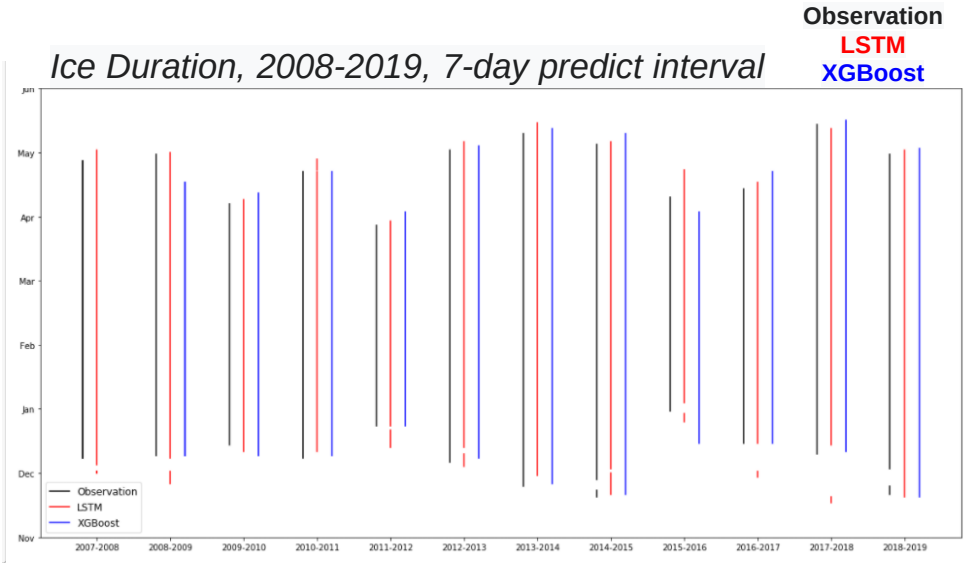
USCG Cutters break ice in the lower end of the Rock Cut in the St. Mary's River in Michigan. (Credit: USCG)



5 Weather Stations over St. Marys River. Data was used to train and test the models for ice forecasting.

- St. Marys River ice prediction using two machine learning models (LSTM, XGBoost)
- Addressing gap in GLOFS
- Train the models with 5 weather station data and ice chart.

Ice Duration, 2008-2019, 7-day predict interval

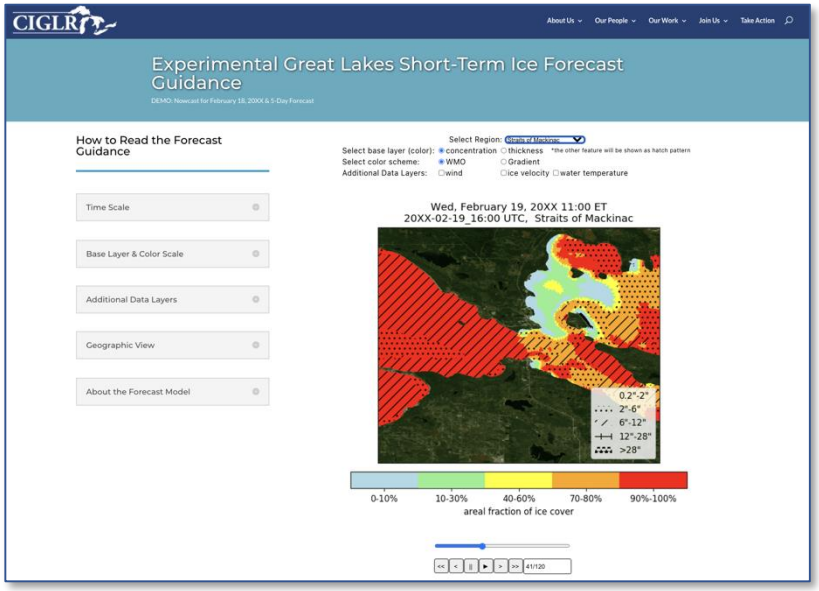


Error Statistics Table

	Mean Absolute Error			Root Mean Square Error		
	XGBoost	LSTM	Baseline	XGBoost	LSTM	Baseline
Freezing Phase	6.0%	7.5%	9.5%	9.8%	15.2%	17.2%
Mid Winter	5.2%	2.9%`	10.3%	7.7%	3.4%	10.5%
Melting Phase	4.5%	7.1%	9.3%	7.8%	12.4%	16.2%

Stakeholder engagement

- Goal is to form recommendations on the user interface of the ice forecast product.
- Workshop in July 2019
- 11 interviews in 2020
- 2 focus groups in June 2021.
- With Coast Guards, Shipping industry, USACE, and NOAA



Experimental website being used for focus groups to evaluate the graphic. Date does not specify any real day not to confuse this as an actual product.

Workshop in Cleveland OH, July 11, 2019
Report available at
http://graham.umich.edu/activity/43899

Stakeholder engagement

The team is working on the final report.
After review by the participants and NOAA collaborators, the report will be finalized.

Recommendations to the user interface of forecast guidance

Learning about what motivates decision making in our user group, and understanding how users responded to initial prototypes of the short-term ice forecast guidance allows us to present a number of recommendations to improve the user interface of forecast guidance before it is officially deployed.

Feature	Issue	User Recommendation
Geographic Scale	Users need to be able to view all details present in the map	• Focus on enhancing zoomed-in maps that provide necessary detail for decision making • Make the map graphic larger in proportion to the rest of the web platform
Geographic View Selection	View selection was sufficient, however more options would be useful	• Place highest priority on adding river corridors (i.e., St. Clair River / Lake St. Clair, Detroit River, St. Mary's River, Saginaw River) • Expand lake views (i.e., expand Straits of Mackinac further west, add Southern Lake Huron and Lake St. Clair) • Other interesting additions, but less critical included certain lake views (i.e., Lake Michigan, Lake Erie) and ports or harbors (i.e., Duluth, Superior, Thunder Bay, Whitefish Bay, Green Bay)
Ice Concentration and Thickness	While color gradient with a hatch overlay was familiar and intuitive to some, others took more time to comprehend	• Provide the option to turn off simultaneous view of ice concentration and thickness so as to simplify the view if desired • Concentration and thickness determine if ice will move or not, therefore it is not necessary to view concentration once it reaches a steady

Snapshot of the recommendation section of the draft report.

Great Lakes Operational Forecast System (GLOFS) Research-to-Operation (R2O) flow

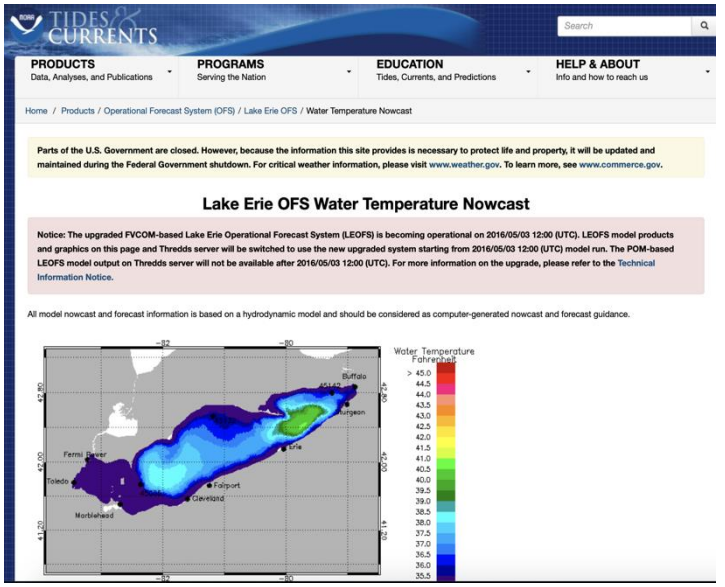
Research & Development (*CIGLR, GLERL*)

Demonstration at quasi-operational environment (*GLERL*)

Formal Skill Assessment *(National Ocean Service Coastal Survey Development Lab)*

Demonstration at operational environment *(National Ocean Service, CO-OPS)*

Operations to provide short term forecast *(National Ocean Service, U.S. National Ice Center)*



From NOAA GLERL website

Summary

- Operational implementation of the ice model at NOS CO-OPS is tentatively scheduled in fall 2022.
- GLERL implements a quasi-operational version of the ice model, which is available now.
- Multiple entities are involved at multiple stages of the R2O process from academia at research end to NOAA operations at the operational end.
- New research continuously develops and periodically pushed to the operational end through the R2O pathway.
- Stakeholder engagement at each level is important. The Great Lakes shipping community helps this a lot.


Thank you!
Any questions?