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Customizing WRF-Hydro for the Laurentian Great Lakes Basin

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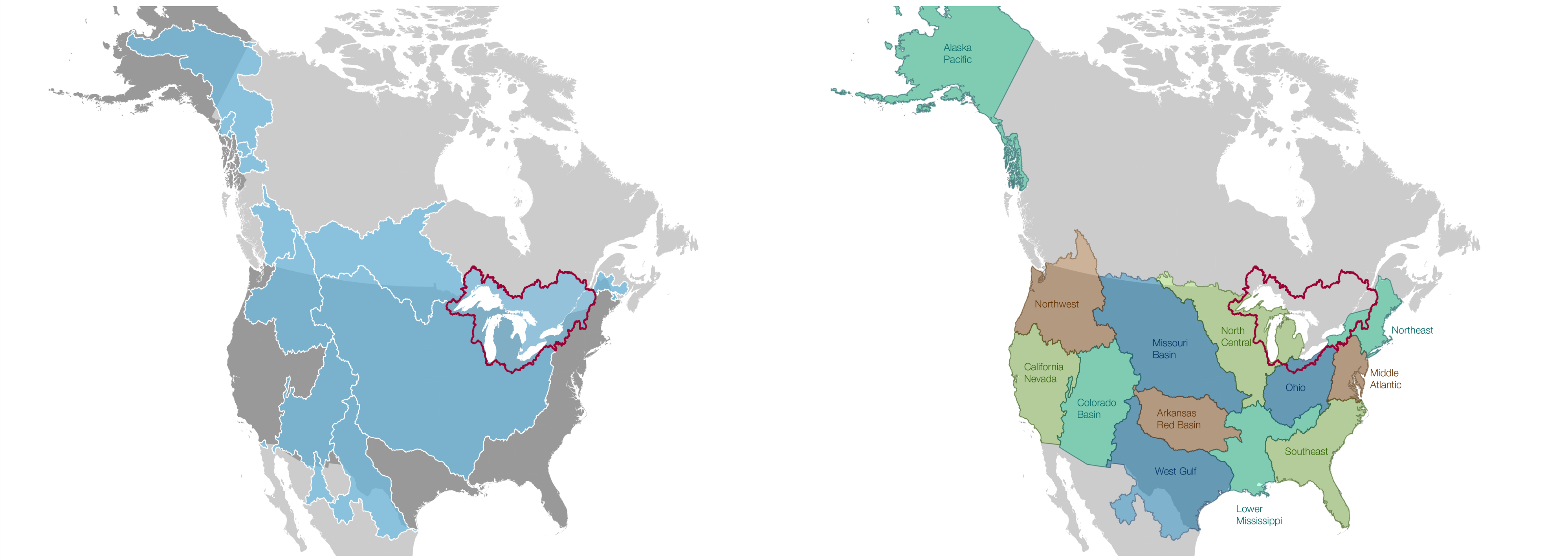
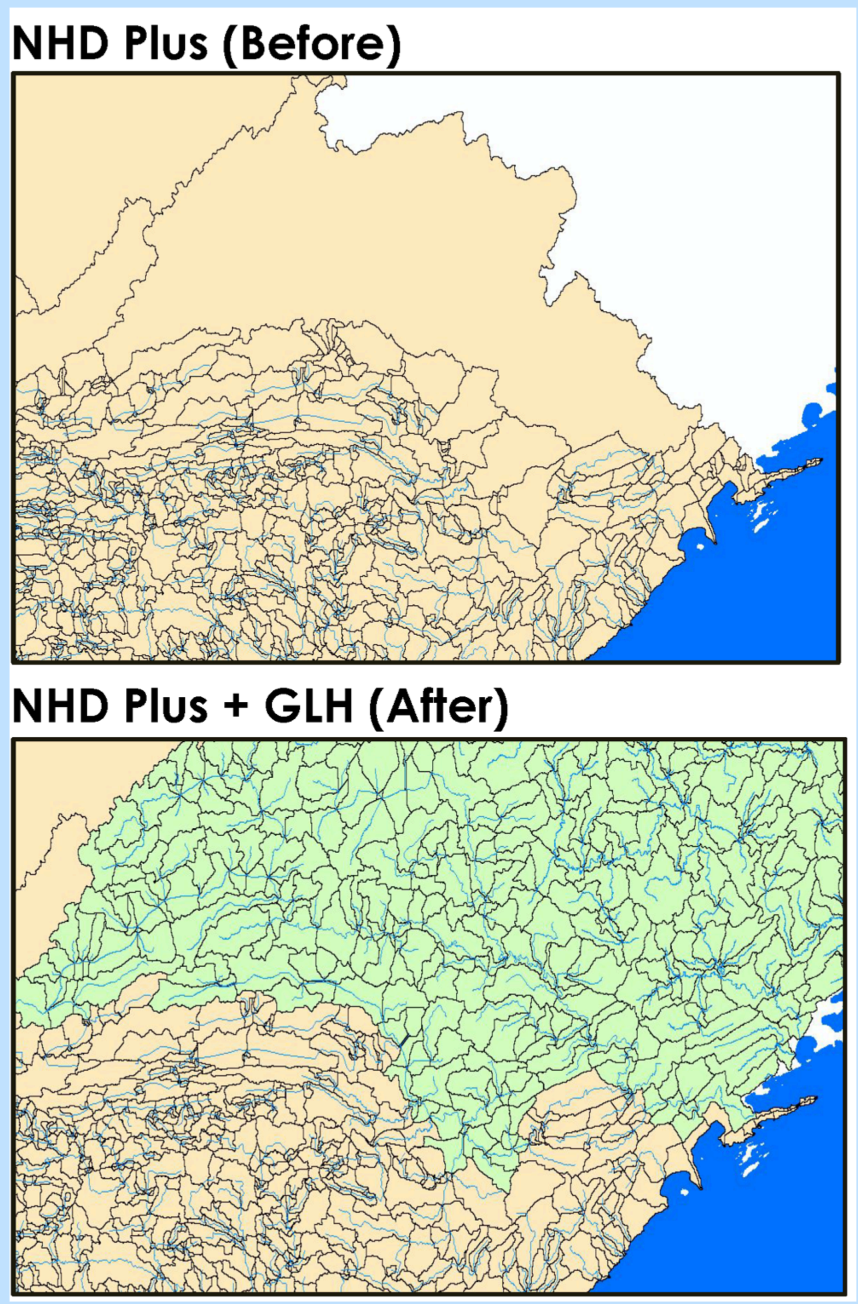
Abstract

To advance the state of the art in regional hydrological forecasting, and to align with operational deployment of the National Water Model, a team of scientists has been customizing WRF-Hydro (the Weather Research and Forecasting model - Hydrological modeling extension package) across the binational land and lake surfaces of the Laurentian Great Lakes and St. Lawrence River basin. Objectives of this customization project include operational simulation and forecasting of the Great Lakes water balance and development of research-oriented insights into modeling one- and two-way coupled lake-atmosphere and near-shore processes. Initial steps in this project have focused on overcoming inconsistencies in land surface hydrographic datasets and meteorological forcings along the international border between the United States and Canada. Improvements in the model's current representation of lake physics and stream routing are also critical components of this effort.



Boundary (red line) of the Great Lakes and St. Lawrence River Basin (GLSLRB) superimposed on (left) transboundary river basins of lower North America and (right) jurisdictional bounds of the NOAA National Weather Service (NWS) River Forecasting Centers (RFCs). The RFC jurisdictional bounds have historically defined the geographic extent of NOAA operational hydrological forecasting products. One of the goals of our project is to fill the gap left by this protocol over the lake and land surfaces of the GLSLRB (figure reproduced from Gronewold et al., in press, BAMS).

Development of new hydrography



In initial configurations of the National Water Model, WRF-Hydro was built on the medium resolution (1:100,000 scale) National Hydrography Dataset Plus Version 2 (NHDPlus V2). To date, however, NHDPlus V2 has not been extended across the Canadian land surface of the Great Lakes and St. Lawrence River basin. Through a partnership between the NOAA Great Lakes Environmental Research Laboratory (GLERL), the University of Michigan Cooperative Institute for Great Lakes Research (CIGLR), and the National Center for Atmospheric Research (NCAR), a new hydrography dataset has been developed for this region (Figs. 1 and 2) that combines NHDPlus V2 and the Great Lakes Hydrography Dataset (GLHD). This new product leverages previous efforts to resolve the binational watersheds of the Great Lakes in the GLHD, while also employing features of NHDPlus V2 that facilitate expansion of WRF-Hydro across the Canadian land surfaces of the basin.

FIGURE 1. Evolution of new Great Lakes hydrography data sets including detailed perspective of the original NHDPlus (top panel) with noticeable discontinuity across the US-Canada border, and new combined product (bottom panel) with discontinuities resolved.

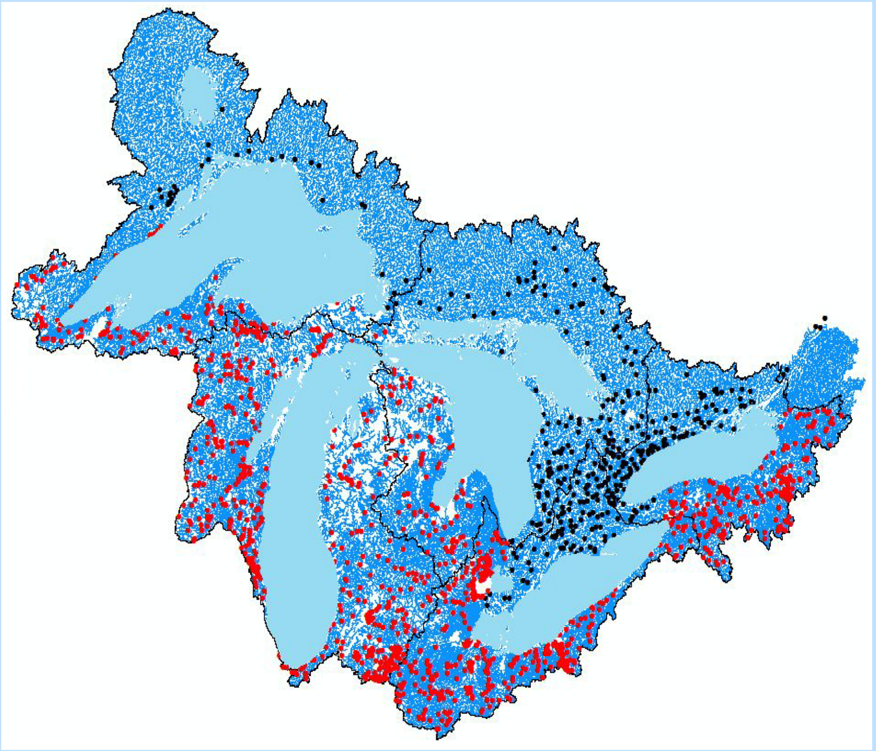


FIGURE 2. Complete new hydrography dataset for the Laurentian Great Lakes basin based on combination of NHDPlus V2 and the Great Lakes Hydrography Dataset (GLHD). This new hydrography serves as a cornerstone for expanding WRF-Hydro across the entire land surface of the Laurentian Great Lakes basin. Dots indicate locations of gauges for assimilating Canadian (black) and US (red) streamflow data. One of the challenges of implementing WRF-Hydro over the Great Lakes basin is customization of operational protocols for assimilating Canadian streamflow data.

Evaluating meteorological forcings

Developing spatially and temporally consistent meteorological forcings along the binational land and lake surfaces of the Great Lakes basin is a major challenge. Our research indicates that conventional meteorological data products, such as the North American Land Data Assimilation System (NLDAS), have severe biases along the US-Canada border (Fig. 3). At present, members of this research team are evaluating the skill of a suite of operational and experimental products over the land surfaces of the basin, and over the vast surfaces of the Great Lakes as well.

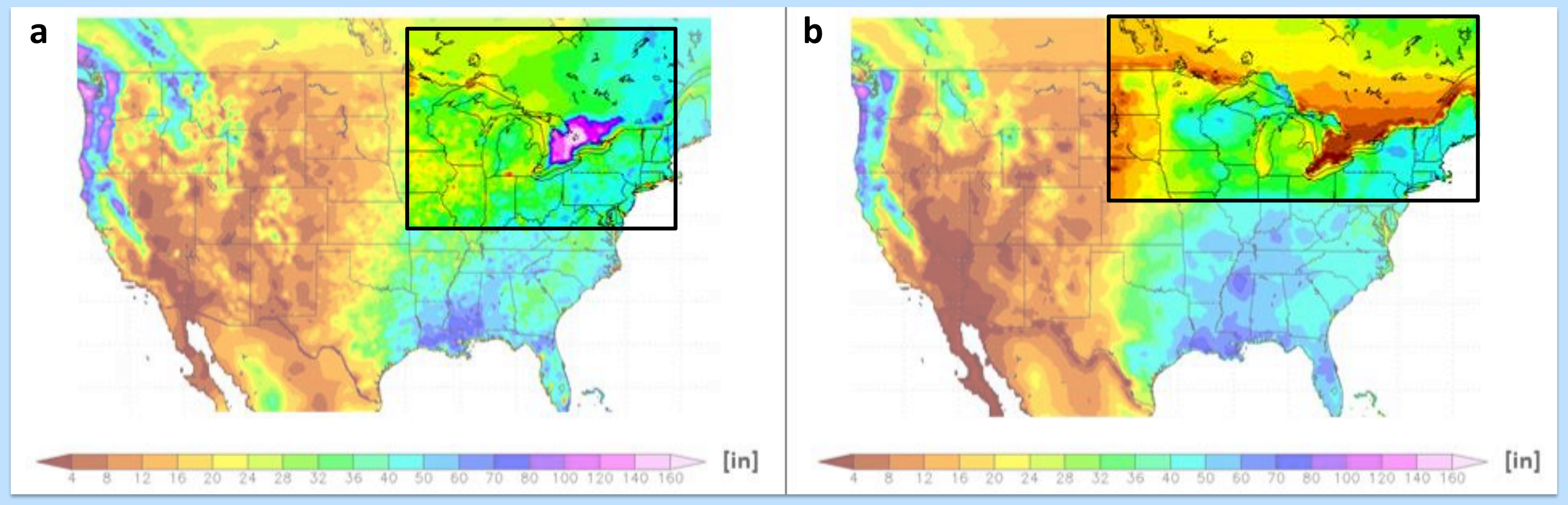
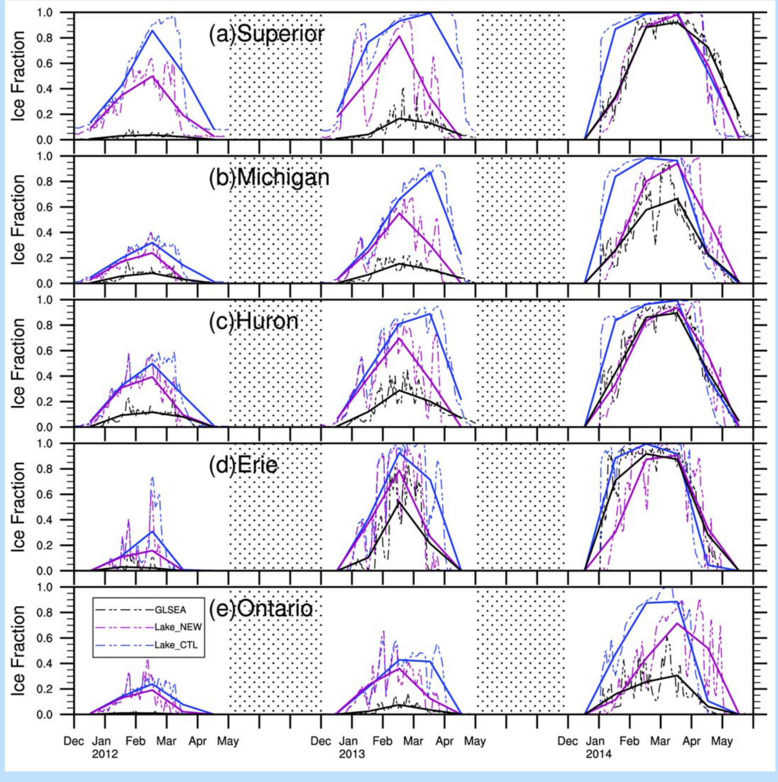


FIGURE 3. One of the biggest challenges facing Great Lakes regional hydrological modeling is development of consistent hydrometeorological forcings along the international border. Above, North American Land Data Assimilation System (NLDAS) cumulative precipitation for a) 2012, and b) 2002 both indicate unrealistic gradients along the US-Canadian international border (adapted from Gronewold et al., in press, BAMS).

Development and testing of a coupled WRF-Lake model



Representing lake physical processes, including seasonal fluctuations in heat content, ice formation, and latent and sensible heat fluxes, is critical to simulating and forecasting the short- and long-term water balance of the Great Lakes system. Recent research (Fig. 4) indicates potential improvements in the WRF-Lake model based largely on sophisticated treatment of lake surface albedo, and underscores the importance of accurately representing ice melt and snow accumulation across the lake surfaces. This research also serves as a foundation for improving the lake scheme within the WRF-Hydro system for other smaller lakes across the continental United States.

FIGURE 4. Seasonal lakewide-average ice cover for the Laurentian Great Lakes from 2012 through 2014 based on the original (default) configuration of WRF-Lake (blue), the new configuration of WRF-Lake (purple), and observations (black). Dashed lines represent daily values, solid lines represent monthly averages (from Xiao et al., 2016).

Runoff simulation—calibration and testing

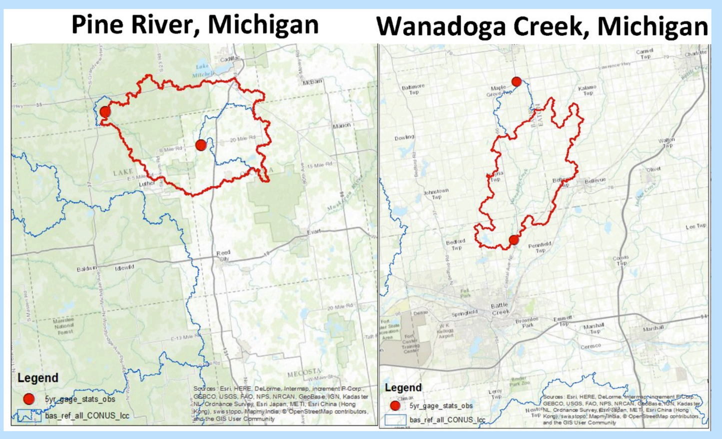


FIGURE 5. Location map of the Pine River and Wanadoga Creek watersheds.

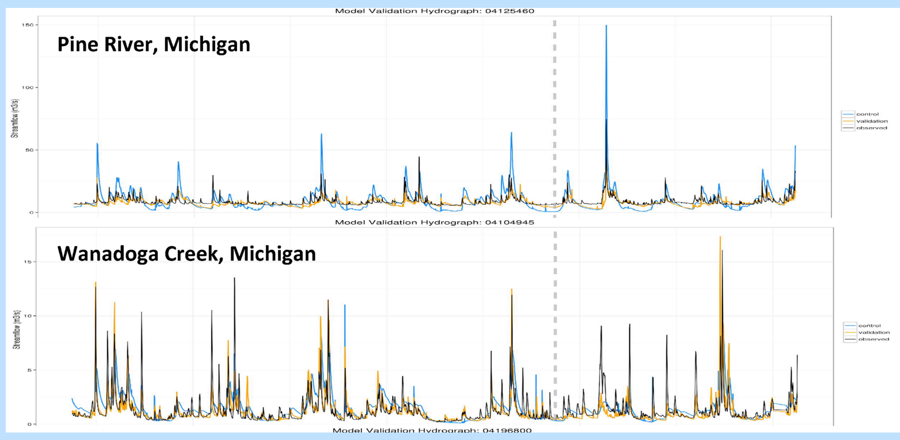
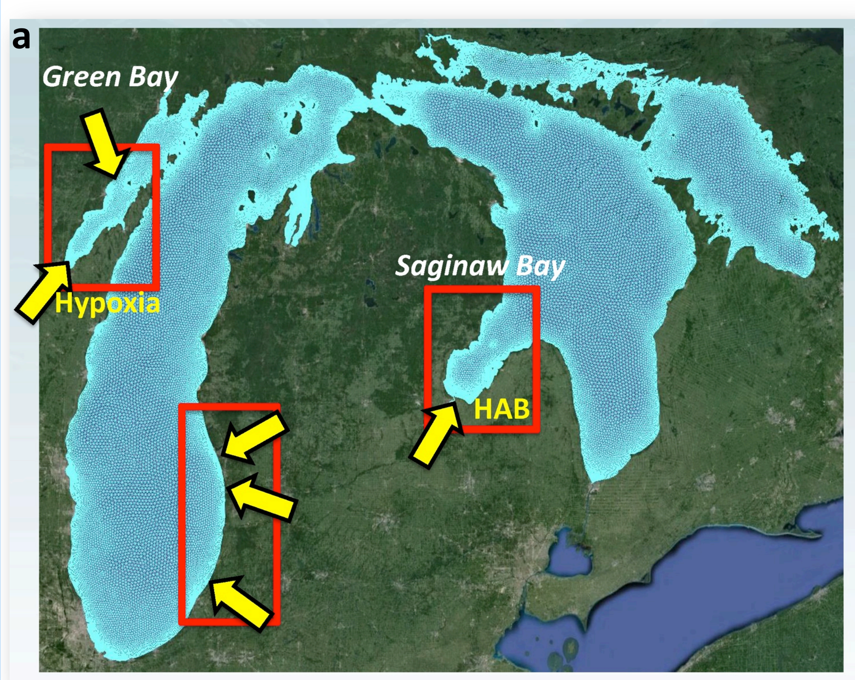


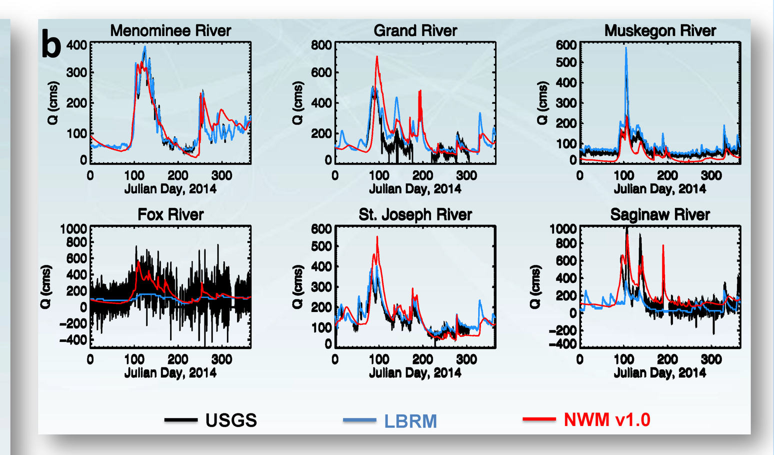
FIGURE 6. Streamflow hydrographs in Pine River and Wanadoga creek from observations, raw WRF-Hydro simulations, and post-calibration WRF-Hydro simulations.

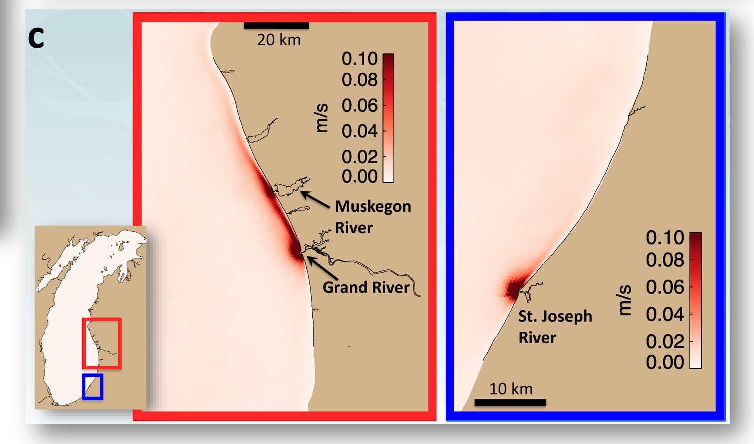
Routine protocols for calibrating and testing WRF-Hydro across the entire United States have been developed by NCAR, and are being leveraged in our ongoing regional application of WRF-Hydro to the Laurentian Great Lakes. Preliminary results (Figs. 5 and 6), based on testing in watersheds in Michigan's lower peninsula, indicate reasonable model performance, including a noticeable improvement in skill after calibration.

Coastal coupling and related future work

The next phases of this work will include continued model calibration and verification across the US and Canadian land surfaces of the Great Lakes basin, and intercomparison of different meteorological forcings. Preliminary tests indicate that lake circulation and pollutant fate and transport processes in existing operational lake physics models are sensitive to lateral tributary flow inputs, and underscore the importance of implementing a coastal coupling scheme between WRF-Hydro and the lake models. We expect the capabilities of the new National Water Model to include improved ability to forecast and understand Great Lakes basin flooding events, including the recent historical flooding across much of the Lake Ontario basin.







Detailed image (a) of the unstructured grids of the Finite-volume community ocean model (FVCOM) for Lakes Michigan and Huron, along with critical tributary inputs (yellow arrows) known to contribute to hypoxia events, harmful algal blooms (HABs), and beach closures due to contaminated runoff. A comparison (b) between simulated flow from a legacy model (the Large Basin Runoff Model, or LBRM), the National Water Model (NWM), and observations (USGS gages) indicates that version 1.0 of the NWM provides reasonable simulations of flow, but that further calibration will likely be needed. Importantly, these tributary inputs have a significant impact on nearshore circulation and pollutant fate and transport patterns, as indicated by plots of velocity differences (c) between lake models run with and without lateral tributary flow inputs.

Acknowledgements

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For additional reading

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Forsyth, D.K., et al. (2016). The Great Lakes hydrography dataset: consistent, binational watersheds for the Laurentian Great Lakes basin. JAWRA, 52, 1068-1088.

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