Hydrodynamics of Western Lake Erie

Dmitry Beletsky[1], Eric J. Anderson[2], Raisa Beletsky[1]

[1]CILER, School of Natural Resources and Environment, University of Michigan, beletsky@umich.edu, raisabel@umich.edu

[2]NOAA, Great Lakes Environmental Research Laboratory, eric.j.anderson@noaa.gov

Introduction

HABs re-emerged in Lake Erie and most notably in its shallow and warm western basin (Fig. 1) in mid-1990s and became a serious enviromental and public health issue in recent years. In summer 2015, the largest HAB on record occurred, especially pronounced in late July-August (Fig. 2). It is known that on short and medium time scales dynamics of HABs depend strongly on lake circulation (Rowe et al, 2016) but the accuracy of model prediction in western basin of Lake Erie is largely unknown due to lack of long-term current measurements. Therefore, hydrodynamic model validation is essential for improving the quality of HAB forecasting.

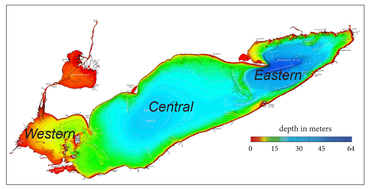

Fig. 1. Bathymetry of Lake Erie.

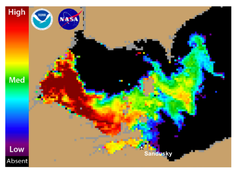

Fig. 2. NOAA/NCCOS cyanobacterial index (CI) based on NASA's MODIS data collected on 05 August, 2015.

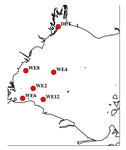

Fig. 3. Mooring locations in June-October 2015 (WE6 and DET temperature only).

Data and Methods

To investigate long-term circulation and evaluate model skill, four current profilers were deployed for the first time in western Lake Erie in June-October 2015 (Fig. 3). In addition to bottom temperature sensors at current meter locations, satellite observations of lake surface temperature were also available through the Great Lakes CoastWatch program.

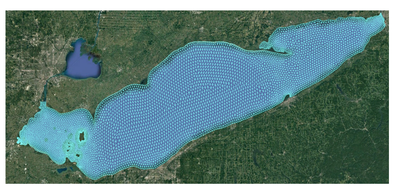

Fig. 4. FVCOM grid.

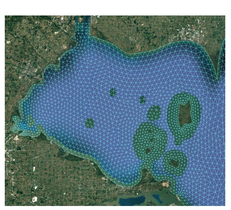

Fig. 5. FVCOM grid for Western Basin.

Circulation and thermal structure in Lake Erie in 2015 is studied with a three-dimensional hydrodynamic model (FVCOM) (Chen et al., 2003). The hydrodynamic model has 20 vertical levels and horizontal grid size that varies from 30 m nearshore to 2 km offshore (Fig. 4). Horizontal resolution is higher in the western basin (Fig. 5). The model uses time-dependent wind stress and heat flux forcing at the surface which are calculated from the hourly meteorological observations obtained from National Weather Service and Environment Canada land stations and meteorological buoys.

Results

Because western basin is shallow, wind mixing typically prevents formation of a distinct thermocline. Indeed, modeled temperature field was rather uniform both vertically and horizontally (Fig. 6). At the same time, comparison with observations showed that the model has a warm bias (Fig. 7).

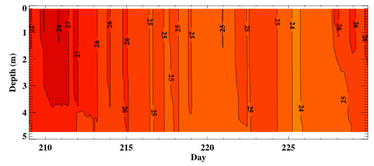

Fig. 6. Modeled temperature at mooring 8 in August 2015.

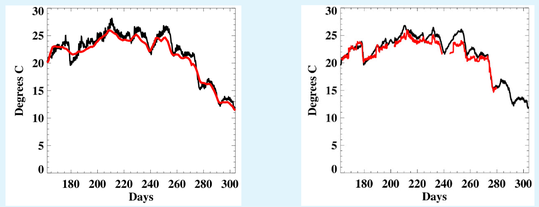

Fig. 7. Modeled (black) versus observed (red) temperature at mooring 8 in 2015. Left - surface, right - bottom temperature.

Monthly circulation was quite variable throughout the lake (Fig. 8). In western basin, mean circulation was rather weak in August (when HAB peaked in 2015). This typically leads to increased residence times of nutrient rich Maumee River waters stimulating HAB development (Michalak et al, 2013). Observations showed an anticyclonic circulation in August in the area of deployment which the model captured reasonably well (Fig. 9).

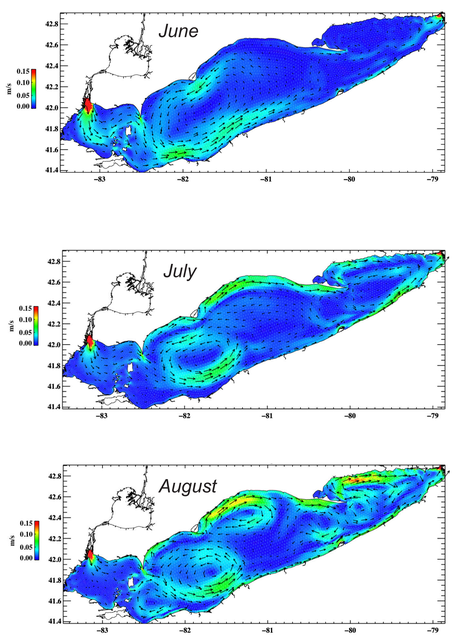

Fig. 8. Monthly depth-averaged circulation in 2015.

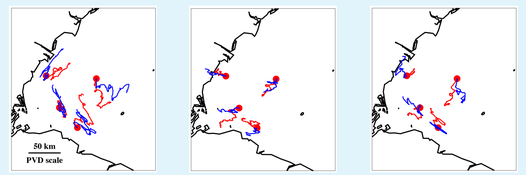

Fig. 9. Progressive vector diagram (PVD) of currents, August 2015. Modeled (blue) versus observed (red).

Notably, there was a strong westerly wind event on August 3 when wind speed reached 15 m/s (Fig. 10). According to observations, this wind event also produced waves up to 1 m (potentially capable of sediment resuspension), just before the intensification of bloom was registered in satellite imagery on August 5 (Fig. 2).

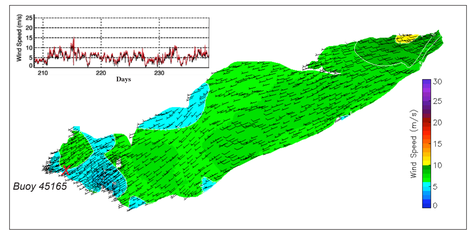

Fig. 10. Mean wind on August 3, 2015 (24 hour average). Insert shows time-series of wind speed at buoy 45165 in Western Basin.

During the August 3rd wind event, model predicted a complex circulation system with a cyclonic gyre close to Maumee Bay (in line with observations in that area) and a larger anticyclonic gyre offshore (Fig. 11). This configuration led to Maumee River waters spread both north and east coinsiding with a quick expansion of the bloom area.

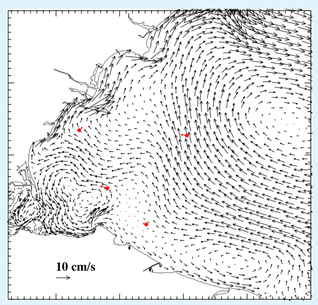

Fig. 11. Depth-averaged circulation on August 3, 2015. Modeled (black) versus observed (red).

Observed currents were remarkably uniform with depth during the event (Fig. 12) but current direction was highly variable, potentially a sign of a strong seiche activity. The model underestimated the peak current speed on August 3 and also exhibited a pronounced 2-layer structure not seen in observations (Fig. 13). Because vertical current structure influences turbulent mixing, this should have an impact on vertical modeling of HAB.

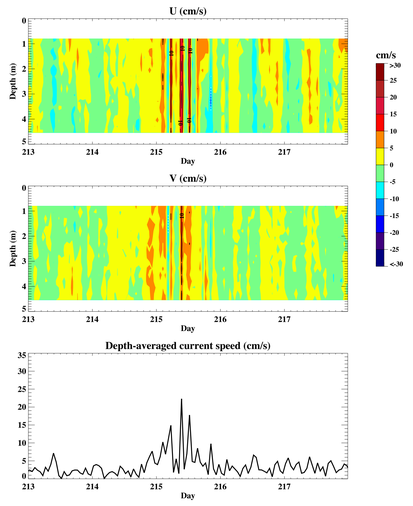

Fig. 12. Observed currents at mooring 8 on August 1-5, 2015.

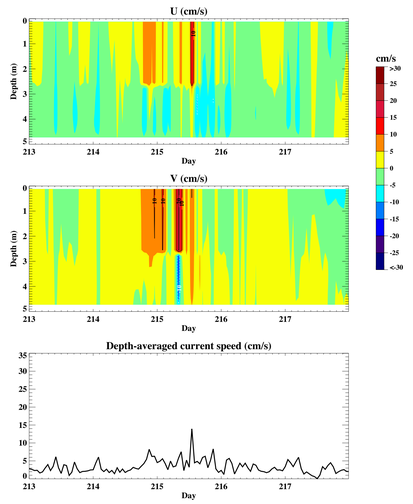

Fig. 13. Modeled currents at mooring 8 on August 1-5, 2015.

Future work

- Investigate causes of 2-layer structure in the model expanding analysis to two other strong wind events in June and October, just before the bloom start and just after its end respectively.
- Improve timing and magnitude of modeled currents by performing hydrodynamic modeling with enhanced meteorological forcing (using HRRR model output), in particular wind field that is a known potential source of model error (Beletsky et al, 2013).

References

Beletsky, D., N. Hawley, and Y. R. Rao (2013), Modeling summer circulation and thermal structure of Lake Erie, J. Geophys. Res. Oceans, 118, 6238–6252, doi:10.1002/2013JC008854.

Chen, C., H. Liu, and R. C. Beardsley (2003), An unstructured grid, finite-volume, three-dimensional, primitive equations ocean model: Appli- cation to coastal ocean and estuaries, J. Atmos. Oceanic Technol., 20(1), 159–186.

Michalak, A. M., E. J. Anderson, D. Beletsky, S. Boland, N. S. Bosch, T. B. Bridgeman, J. D. Chaffin, K. Cho, R. Confesor, and I. Daloglu (2013), Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions, Proc. Natl. Acad. Sci. U. S. A., 110(16), 6448–6452.

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.

Acknowledgments: Funding for this research was provided by EPA GLRI awarded to Cooperative Institute for Limnology and Ecosystems Research (CILER) through the NOAA Cooperative Agreement with the University of Michigan (NA12OAR4320071).