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IMPLEMENTATION OF THE UPGRADED LAKE ERIE OPERATIONAL FORECAST SYSTEM (LEOFS) AND THE SEMI-OPERATIONAL NOWCAST/FORECAST SKILL ASSESSMENT

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National Ocean Service
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IMPLEMENTATION OF THE UPGRADED LAKE ERIE OPERATIONAL FORECAST SYSTEM (LEOFS) AND THE SEMI-OPERATIONAL NOWCAST/FORECAST SKILL ASSESSMENT

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EXECUTIVE SUMMARY

NOAA/National Ocean Service (NOS) collaborated with the Office of Oceanic and Atmospheric Research (OAR) Great Lakes Environmental Research Laboratory (GLERL) in developing and transitioning the new Finite Volume Community Ocean Model (FVCOM)-based Lake Erie Operational Forecast System (LEOFS) to operations. The system was implemented on NOAA’s Weather Climate Operational Supercomputing System (WCOSS), operated by the National Centers for Environmental Prediction (NCEP) Central Operations (NCO) and run within NOAA’s Coastal Ocean Modeling Framework (COMF). The LEOFS upgrade will be followed by upgrades of the remaining Princeton Ocean Model-based (POM) Great Lake Operational Forecast System (GLOFS).

The existing GLOFS is based on the Great Lakes Forecasting System developed by the Ohio State University (OSU) and NOAA/OAR/GLERL in the late 1980’s and 1990’s, which is based on a customized POM for the Great Lakes. The upgraded LEOFS uses FVCOM, which is one of the NOS selected community ocean models for NOS hydrodynamic operational forecast systems (OFS).

The existing GLOFS is operated in a unique, stand-alone environment, which greatly increases maintenance efforts and hinders efficient diagnostic analysis. It also has data dependencies on data sources outside the NCEP data tank (e.g. mean lake temperature from GLERL and mean lake level from the Center for Operational Oceanographic Products and Services (CO-OPS)). The upgraded LEOFS is implemented within the standard COMF environment and only uses operational data on WCOSS, which improves the reliability of the system and eases the operation and maintenance efforts. The upgraded LEOFS became operational on May 3, 2016.

The upgraded LEOFS provides higher resolution nowcast and forecast guidance of water levels, currents, and water temperatures for Lake Erie and extends the forecast horizon out to 120 hours to better serve the user communities. The accuracy of nowcast/forecast guidance from the upgraded LEOFS was evaluated by comparisons to observations and the existing POM-based LEOFS results. The root mean square error (RMSE) of the upgraded LEOFS for water level and water temperature is below 15 cm and 3 °C, respectively. Relative to the POM-based LEOFS, RMSE for water level is reduced in the western Erie by 2-4 cm and for water temperature reduced at all stations by up to 2 °C.

1.0 INTRODUCTION

The existing Great Lakes Operational Forecast System (GLOFS) was developed by the Ohio State University (OSU) and NOAA's Office of Oceanic and Atmospheric Research (OAR) Great Lakes Environmental Research Laboratory (GLERL) in the late 1980's and 1990's, and is based on a customized Princeton Ocean Model (POM) for the Great Lakes (Chu et al., 2007; Kelley et al.,2007a, 2007b, 2008, 2010). It has been in operation at NOAA's National Ocean Service (NOS) for Lakes Erie and Michigan since September 30, 2005 and for Lakes Ontario, Huron, and Superior since March 30, 2006. The existing GLOFS has relatively coarse resolutions. The original POM-based Lake Erie Operational Forecast System (LEOFS) utilizes an 81x24 grid with a 5 km horizontal grid size and 11 vertical layers. The model generates hourly nowcast guidance and four times daily forecast guidance out to 60 hours of water level, currents and water temperature. The water level guidance from the existing LEOFS nowcasts and forecasts generally meets the NOS acceptance criteria. However even though LEOFS predicts well the overall horizontal distribution and seasonal trend of the surface water temperature, it does not perform well in predicting water temperatures during the spring and early summer warm up and often exhibits unrealistic, high frequency water temperature oscillations.

Based on community-wide usage and support, and continuing development efforts, NOS has chosen two community ocean models as the core ocean models: the Finite Volume Community Ocean Model (FVCOM) for the unstructured grid modeling and the Regional Ocean Modeling System (ROMS) for the structured grid modeling. The POM is not a core ocean model selected by NOS for coastal ocean operational forecast systems. Furthermore, the existing GLOFS is implemented and operated under a unique operational environment that is completely separate from the standardized Coastal Ocean Modeling Framework (COMF) on NOAA's high-performance computing systems operated by the National Centers for Environmental Prediction (NCEP). This segregated model implementation caused significant difficulty in its operations and maintenance. Additionally, the existing GLOFS relies on real-time observations with no proper backup sources, which have resulted in occasional failures when the observations are missing.

The upgraded LEOFS developed by NOAA/OAR/GLERL is based on FVCOM. The triangular unstructured grid with higher resolution for the upgraded LEOFS better resolves the shoreline geometry, bathymetric features and the lake dynamics. These enhancements will provide improved forecast guidance of water level, currents and water temperature. The forecast horizon was extended out to 120 hours to meet the increasing needs from ecological applications such as harmful algal blooms (HAB) (see Kavanaugh et al., 2016 and references therein), beach hazard forecasts and water resource management. The upgraded LEOFS is also significantly more reliable than the existing version because it is operated in the standard COMF environment (Zhang and Yang, 2014), which has more comprehensive capabilities to generate all required forcing conditions.

The upgraded model development and hindcast skill assessment are detailed in a separate technical report (Kelley et al., 2018). This report will focus on the unique features of the operational LEOFS, such as model configurations and set-up used in the nowcast/forecast, and LEOFS performance in the semi-operational nowcast/forecast simulations.

2.0 MODEL NOWCAST/FORECAST CONFIGURATION

Figures 1 and 2 depict the upgraded LEOFS model grid and model bathymetry from the National Geophysical Data Center (NGDC, 1999). The new LEOFS model grid has 6,106 nodes and 11,509 elements. The cell size ranges from 400 m to 4 km, with higher resolution along the shoreline and in the shallow western basin and coarser resolution for the open waters in the mid and eastern basins. The grid has a minimum depth of 0.5 m and maximum depth of 62.7 m.

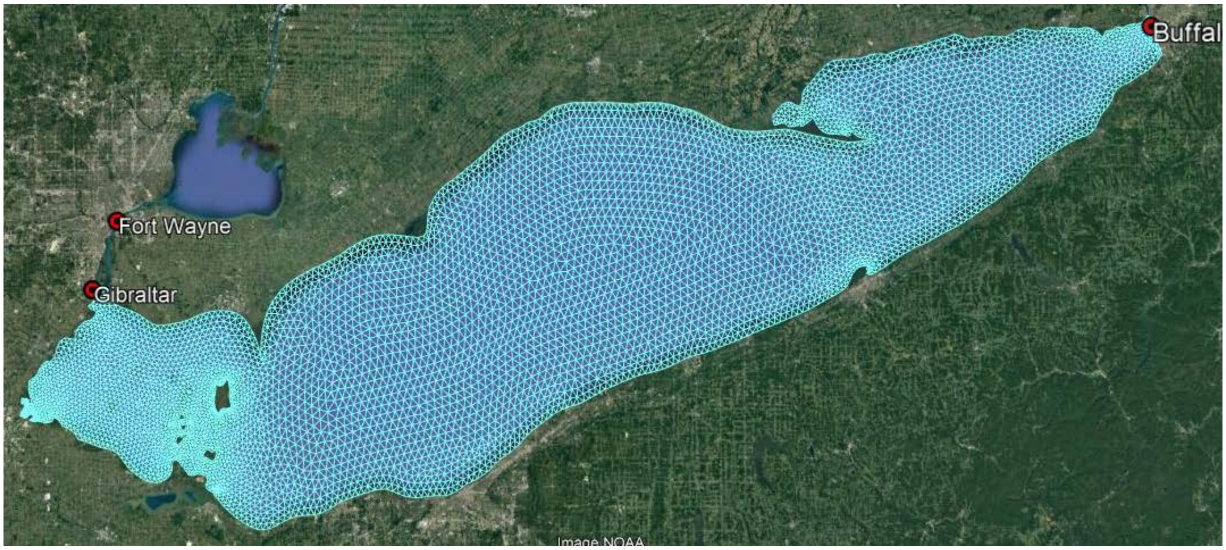

Figure 1. The upgraded LEOFS model grid and the location of stations that provide boundary conditions.

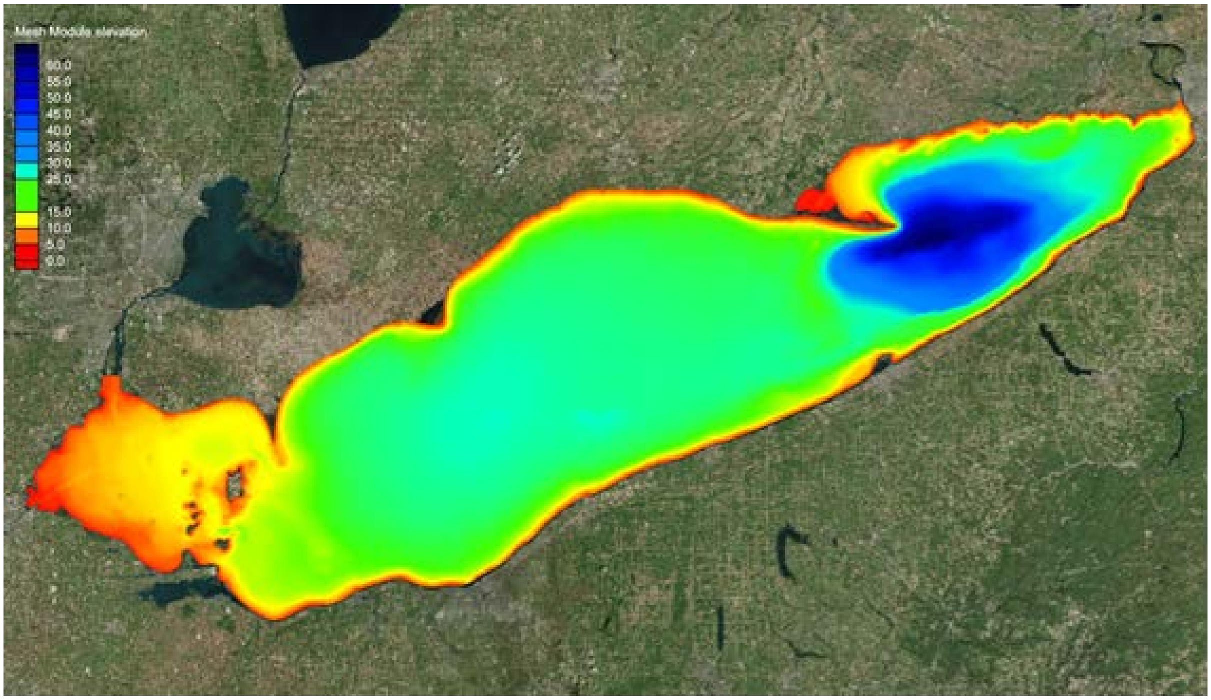

Figure 2. The bathymetry (m) on the upgraded LEOFS model grid.

In development and testing of the upgraded LEOFS, hindcast simulations were carried out for the years of 2005 and 2006. The surface forcing (wind, air temperature, dew point temperature, cloud cover) was interpolated from the surface marine observations. The upgraded LEOFS has two open boundaries: the Detroit River in the west and the Niagara River in the east. Water level and water temperature from observations were specified along the two boundaries. The details of the upgraded LEOFS configuration for the hindcast simulation can be found in the hindcast technical report (Kelley et al., 2018).

In the real-time nowcast/forecast implementation, procedures in COMF (Zhang and Yang, 2014) were followed as closely as possible to accommodate the requirements of LEOFS as well as to minimize the impact on other OFS operated within the same framework.

2.1 Configuration comparison with the POM-Based LEOFS

To ease operations and maintenance efforts and achieve consistency among all OFS products, the upgraded LEOFS run schedule was set to four cycles per day. Each cycle includes a 6-hour nowcast and a 120-hour forecast. The domain-wide fields output are available at hourly intervals, which is the same as the existing LEOFS. The change in the run schedule consisted of 1) reducing the frequency of the nowcast update from hourly to every 6 hours, and 2) increasing the forecast horizon from 60 hours to 120 hours. Because the model forecast skill is comparable to the nowcast skill (see section 4), this change does not affect meeting the requirements of the user communities. Table 1 summarizes the modeling system changes in the upgraded LEOFS.

Table 1. Model set-up and run schedule comparison between existing POM-based and the upgraded LEOFS. Data sources in parentheses serve as back up.

	Existing LEOFS	Upgraded LEOFS
Numerical Model	POM	FVCOM
Nowcast Cycle		
Run Schedule	Hourly	6-hourly
Surface Forcing	Hourly analyses of surface marine observations.	HRRR hour 2 forecast (2.5 km NDFD)
Lateral Boundary	N/A	Open boundary forced by WL at Gibraltar (Fermi) and Buffalo (Sturgeon)
Forecast Cycle		
Run Schedule	6-hourly	6-hourly
Forecast Horizon	60 hrs	120 hrs
Surface Forcing	5 km NDFD GL (12 km NAM)	2.5 km NDFD CONUS (1/4 degree GFS)
Lateral Boundary	N/A	Open boundary forced by WL persisted from previous day average

2.2 Minimum Temperature Setting

The real-time semi-operational nowcast/forecast system was initially set up and started to run in March 2015. The first issue observed was that the water temperature in the model could drop well below freezing (Fig. 3). In reality, about 60% of Lake Erie was covered by ice at that time (https://www.glerl.noaa.gov/data/ice/#historical) and the surface water temperature stayed around 0 °C. Because the model does not include an ice module and other constraints, the water temperature can theoretically drop freely given a negative surface net heat flux (heat going out of the water). To deal with this unrealistic water temperature in the cold weather, a mechanism was implemented in the FVCOM model so that when water temperature drops to -2 °C any negative net heat flux will be set to 0, which prevents further cooling of the water temperature. The choice of -2 °C was guided by a similar approach utilized in ROMS, the other NOS core ocean model. It allows for some room for the temperature to drop below 0, which acts as a proxy of the ice melting in spring warm-up by absorbing some heat for the water temperature to rise above freezing. A long-term hindcast simulation with this new minimum temperature setting was carried out by GLERL and it verified that the change did not adversely influence the timing and rate of the spring warm up.

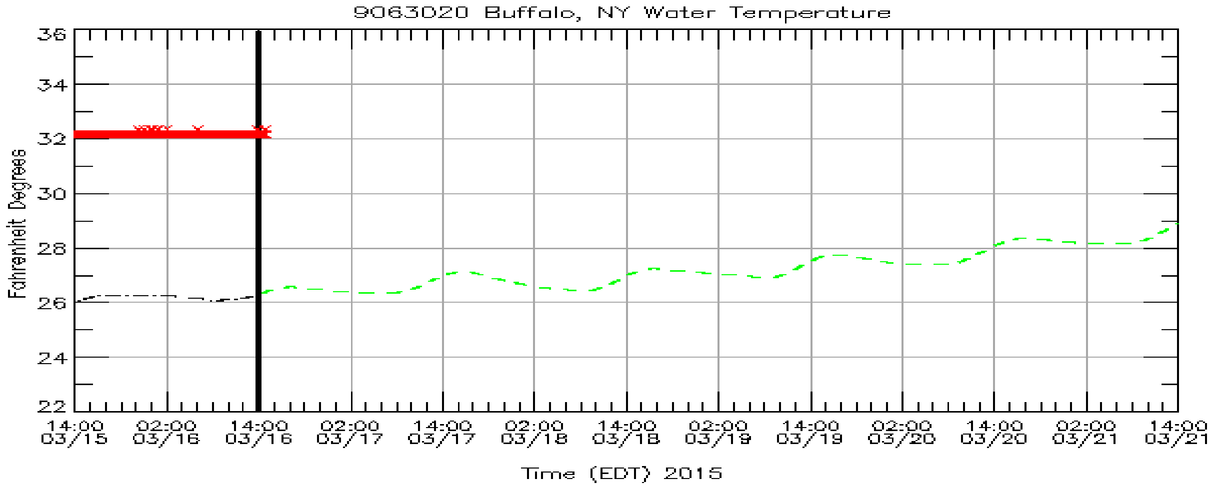

Figure 3. The surface water temperature time series at Buffalo, NY station as shown on LEOFS website. Observations (when available) are in red, model nowcast is in black and model forecast is in green. The vertical black line delineates the nowcast/forecast transition.

2.3 Lateral Boundary Conditions

2.3.1 Lateral boundary conditions: flow vs. water level

In the upgraded LEOFS, Detroit River (inflow) and Niagara River (outflow) are treated as open boundaries. The proposed lateral boundary conditions for the real-time runs were to specify water levels and water temperature from observations along the two open boundaries during nowcast simulation; for the forecast, the boundary conditions are switched to specify water flow to allow free water surface oscillation under the predicted wind conditions. For the nowcast, the real-time water level observations at the NOAA water level gauges at Gibraltar, MI (Station ID 9044020) for the Detroit River and at Buffalo, NY (Station ID 9063020) for the Niagara River are used as the primary data source to specify water levels along the boundaries. An offset adjustment of 0.6 m is applied to the observation at Buffalo, NY to account for the estimated average lake surface drop from the gauge of Buffalo, NY to the boundary location in the Niagara

River. The derivation of the offset of 0.6 m stems from water level observations at Buffalo and a historic Canadian gauge at the Peace Bridge. The value was calibrated to minimize the yearly Root Mean Square Error (RMSE) of the lake water level for the hindcast period. For the forecast, the discharge at USGS Fort Wayne (Station ID 04165710) is persisted through the forecast period. Water temperature along the open boundary is derived from real time observations at the USGS station at Fort Wayne (Station ID 04165710) during the nowcast and the water temperature observations are persisted during forecast simulation.

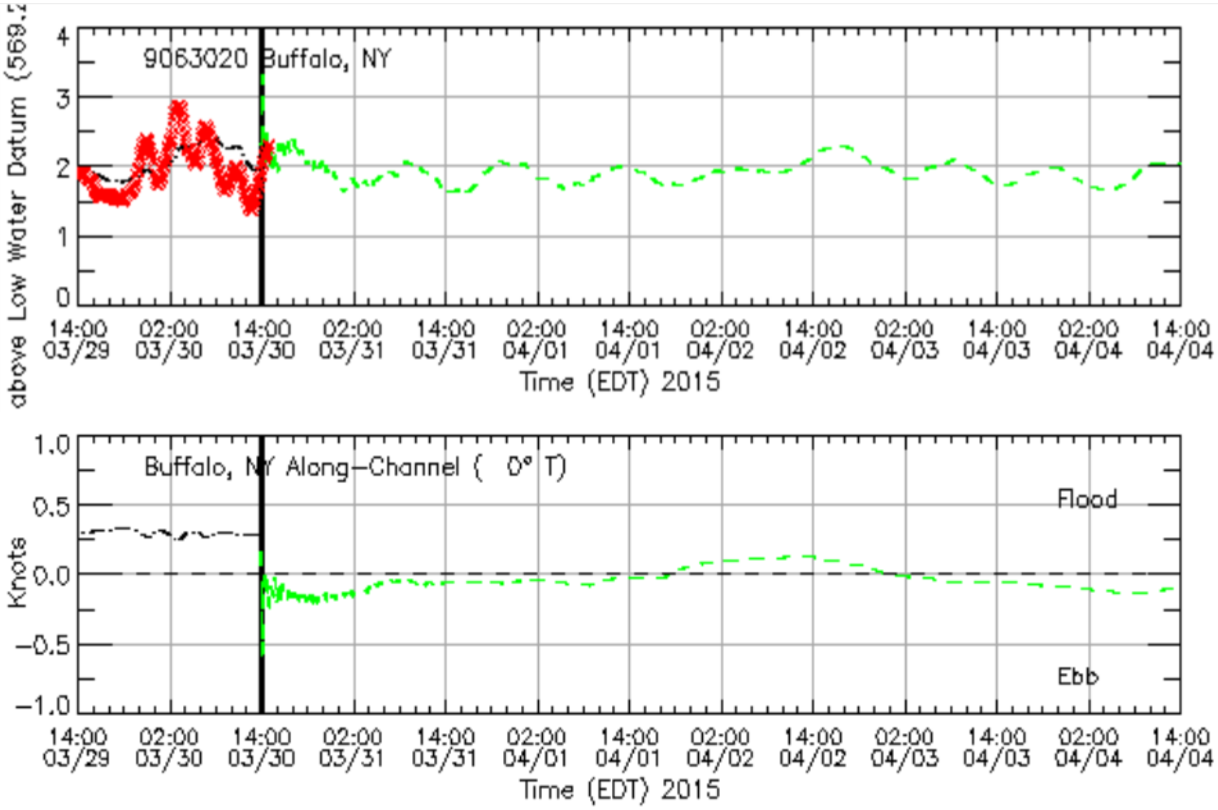

Figure 4. The water level and along channel current time series at the Buffalo, NY station as shown on the LEOFS website. Observations (when available) are in red, model nowcast is in black and model forecast is in green. The vertical black line delineates the nowcast/forecast transition.

The initial model set-up behaved reasonably well in most places. However, in the small area next to the eastern open boundary the modeled water level and currents were not smooth when transitioning from nowcast to forecast. A large discontinuity occurred at the transition and unrealistic oscillations followed, which gradually damped out in a few hours (Fig. 4). This phenomenon was persistent across all nowcast/forecast cycles. Several scenario test cases, such as increasing/decreasing flow rate based on the discharge at Fort Wayne, using the model-calculated flow rate across the boundary edges from the previous nowcast cycles, and imposing the flow conditions at either boundary nodes or boundary edges, did not resolve this discontinuity/oscillation problem. Apparently, the model adjusts itself when the model configurations for nowcast and forecast are changed from specification of water levels to specification of river flow conditions due to the different treatments of flow boundary conditions and open boundary conditions and the dynamic inconsistency during the switch. Please refer to the FVCOM User Manual (Chen et al., 2006) for details on how boundary conditions are coded.

The adjustment takes place in just a few hours, which may not be a significant problem in a long-term simulation. However, the effect occurs at the nowcast/forecast transition during every forecast cycle (four times a day) and is undesirable in the real-time environment where the maritime community relies on accurate short-term model predictions.

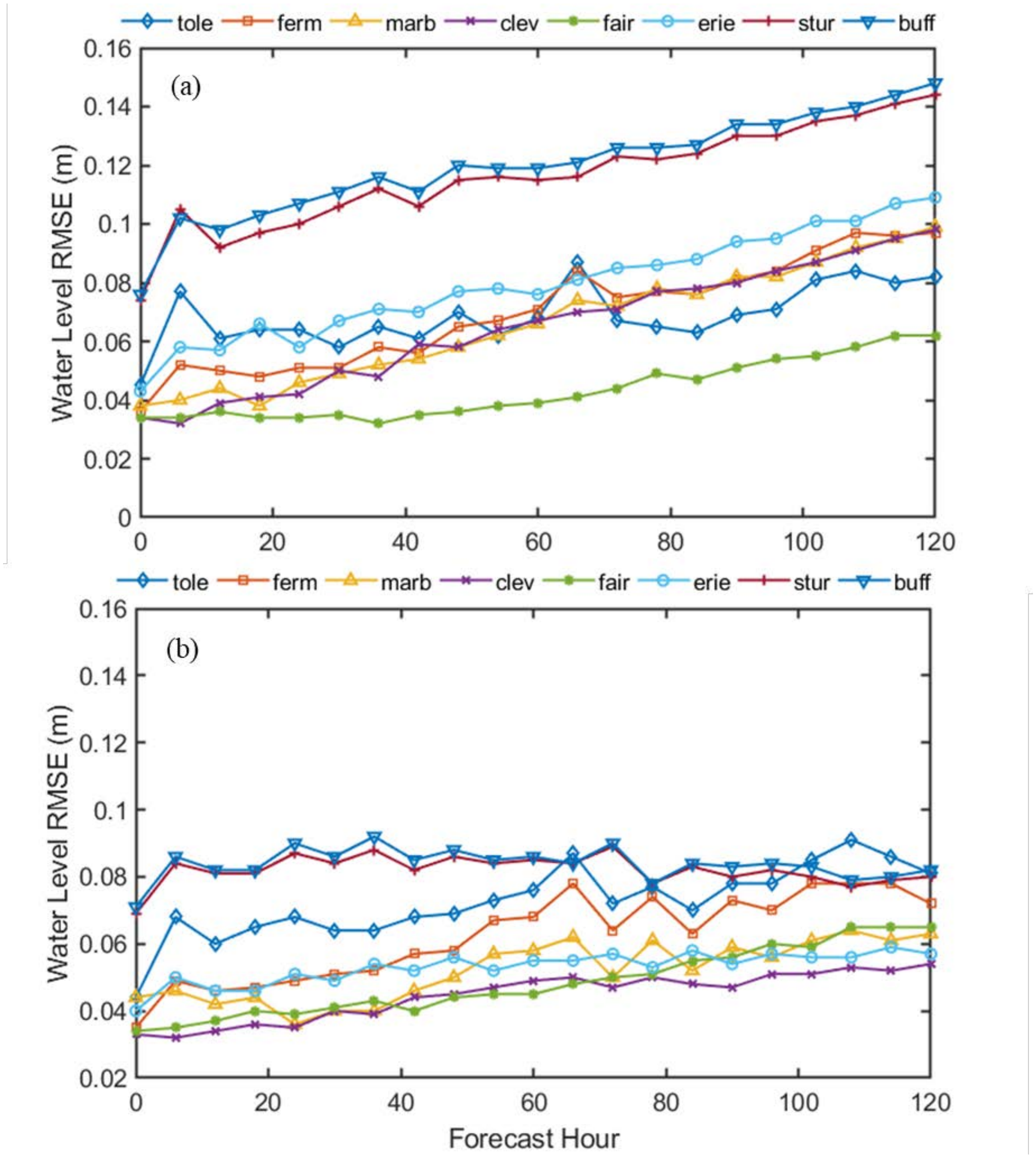

Figure 5. Water Level Forecast Skill (4/28-5/17/2015) at eight stations from (a) flow boundary conditions and (b) water level boundary conditions.

It was recommended to keep the boundary conditions consistent between nowcast and forecast even though it meant that the water levels at the two boundaries would be fixed during the forecast period. The initial attempt was to use the average of the previous day observed water level at the open boundaries. A 6-hour window was used to gradually change the lake level at the open boundary from the last available data point to the averaged value that was then persisted throughout the forecast period. This approach eliminated the discontinuity and oscillation problem and improved the water level forecast skill. Figure 5 compares the water level forecast skill at eight stations from 4/28 – 5/17/2015. With the flow boundary condition, the water level skill deteriorated considerably with RMSE increasing by more than 20% in the 120-hour forecast period (Fig. 5a). However, with the water level boundary condition, the RMSE of forecast water level was generally comparable with the nowcast water level skills (Fig. 5b). Details of the model skill assessment will be discussed in Section 4.

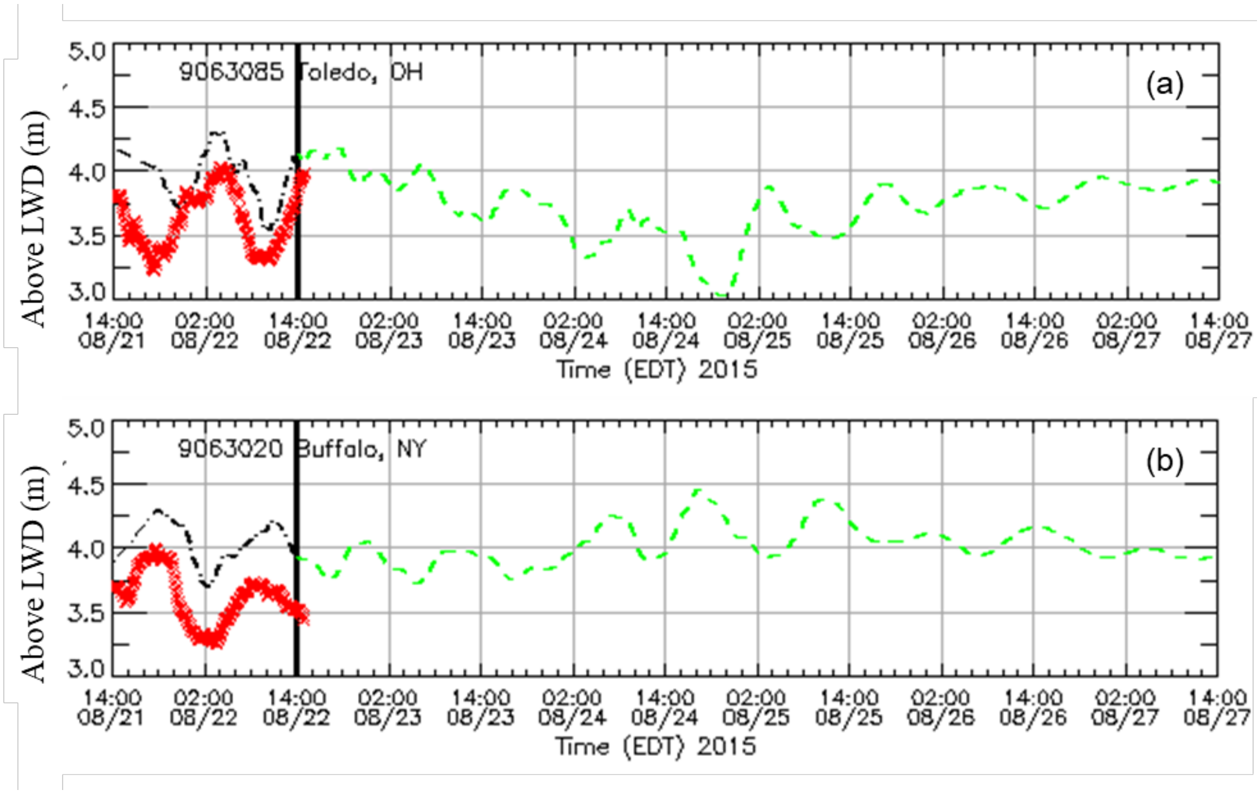

Figure 6. Water level nowcast and forecast time series at (a) Toledo, OH and (b) Buffalo, NY as shown on LEOFS website. Observations (when available) are in red, model nowcast is in black and model forecast is in green. The vertical black line delineates the nowcast/forecast transition.

2.3.2 Dynamic adjustment to the water level boundary conditions

As discussed above, the water level observations at Buffalo, NY are lowered by 0.6 m on the eastern open boundary to account for the average water level drop between the station and the boundary location. This constant offset does not take into account the short-term variability, which often results in a bias between model predictions and the observations (Fig. 6). A new approach was tested to adjust the offset based on the real-time model-observation discrepancy. The averaged differences between model results and observations at Fermi Power Plant and Buffalo over the past 5 days were calculated to make changes to the water level boundary conditions obtained in the above section to bring the model predictions closer to the observations. Figure 7 compares the nowcast water level against the observations at Fermi Power Plant and Sturgeon Point for the two approaches. The model responded to the adjustment well and compared more favorably to the observations using the dynamically-adjusted offset at the two open boundaries. The calculation of model-observation discrepancy was later changed to use the previous 2-day comparison, which reduced the data dependency and eased the operational efforts when operational runs would switch from one computing system to another at NCEP because less files would need to be copied from one machine to the other. The choice of two days was determined by a sensitivity test of the duration that the offset calculation is based on to retain the effectiveness of the adjustment while minimizing the data dependency.

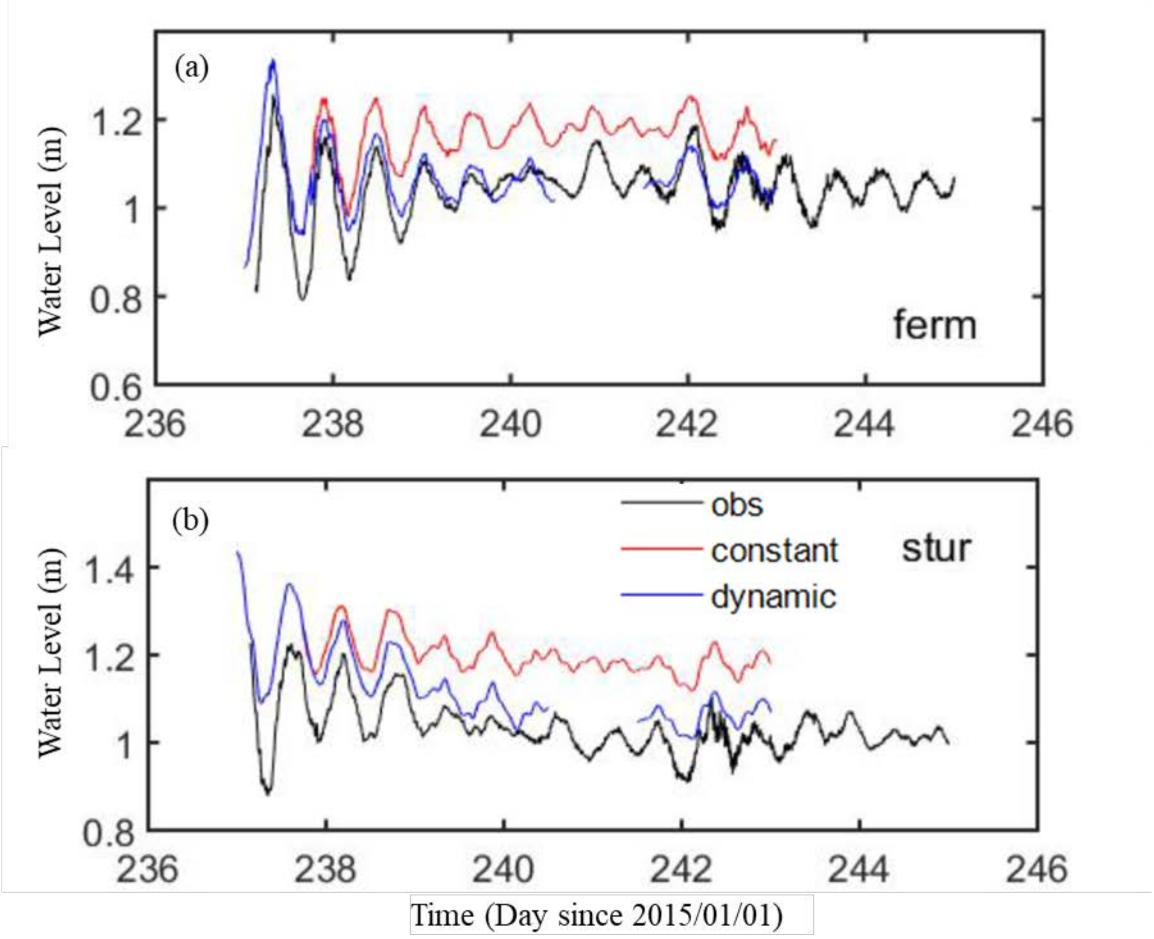

Figure 7. Nowcast water level at (a) Fermi Power Plant and (b) Sturgeon Point from 8/26 to 8/31/2015. Black lines are the observed water level; Red lines are the model prediction with constant water level offset and blue lines are with dynamic water level adjustment.

2.4 Surface Boundary Forcing

The surface forcing (wind, air temperature, dew point temperature, cloud cover) was interpolated from the surface marine observations in the hindcast simulations carried out by NOAA/OAR/GLERL. The same data source is used in the existing GLOFS as well. The interruption of the availability of the surface marine observations occasionally caused the model to fail, which led to difficulties in GLOFS operations and maintenance and adversely impacted the reliability of operational GLOFS products. Therefore, this implementation explored using NCEP's 3-km, hourly updated High-Resolution Rapid Refresh (HRRR) atmospheric model as the upstream data source for nowcast surface forcing and using the National Digital Forecast Database (NDFD) on the 2.5-km CONUS grid for forecast surface forcing.

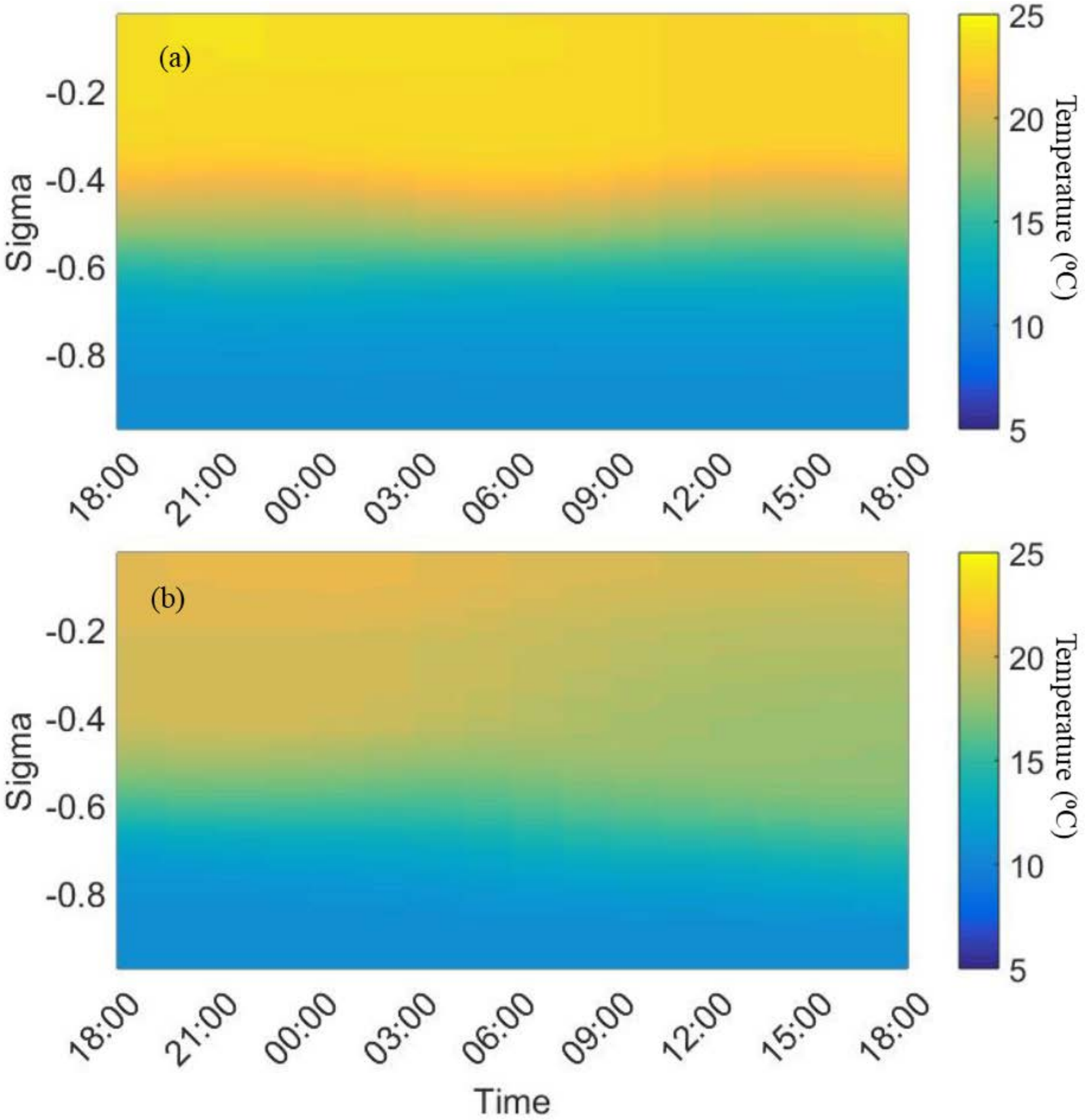

Figure 8. Nowcast water temperature vertical profile at Port Stanley from 8/17/2015 18z to 8/18/2015 18z with (a) HRRR hour 0 analysis (b) Hour 2 forecast for surface forcing.

The initial set-up used the HRRR 0 hour analysis, which seemed to overheat the surface water compared to the observations and the GLERL nowcast results. HRRR assimilates radar data every 15 min over a 1-hour period. It was later realized that the hour 0 analysis fields may best represent the observations, but the fields over the whole domain may not reach dynamic balance yet. Hence, the HRRR hour 2 forecast fields were considered instead. Figure 8 compares the nowcast water temperature vertical profiles within a 24-hour period (8/17/2015 18z – 8/18/2015 18z). With HRRR hour 0 analysis fields, the thermocline was more well-defined. However, the hour 2 forecast forcing had a more diffused thermocline and mixed the surface water deeper, which resulted in a slightly cooler water surface. Figure 9 shows the surface water temperature time series from the two simulations with different surface forcings of the HRRR hour 0 analysis and hour 2 forecasts at Marblehead, OH during 7/7/2015-8/18/2015. With the hour 2 forecast fields, the overestimate of surface water temperature appears to be up to 1 °C lower in August

(Fig. 9). The overestimation of surface temperature still observed while using HRRR hour 2 forecasts may be the residual effect of forcing the model with HRRR hour 0 analysis from March 2015.

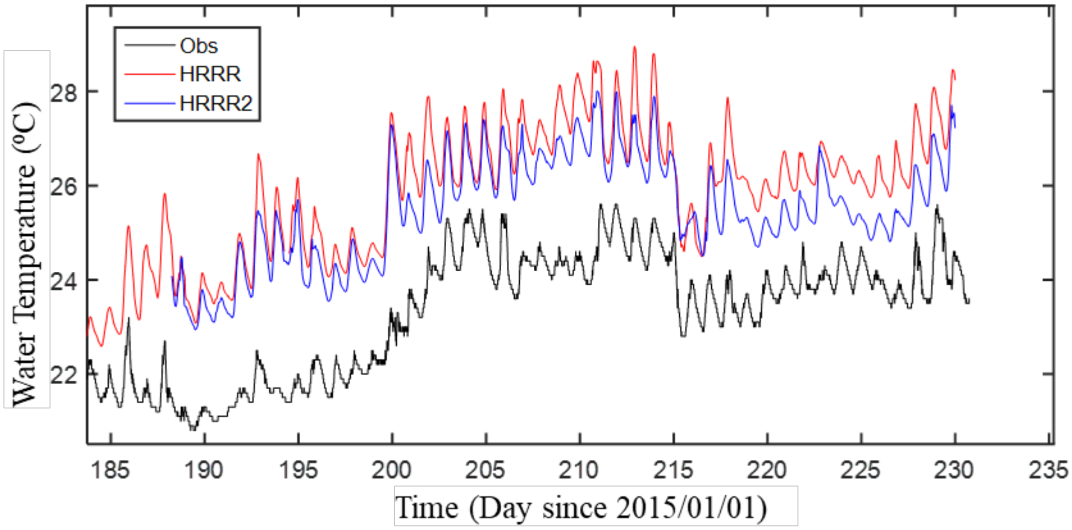

Figure 9. Nowcast surface water temperature at Marblehead, OH (7/7/2015-8/18/2015). Observed water temperature is in black, model predicted water temperature with HRRR hour 0 analysis in red and with HRRR hour 2 forecast in blue.

3.0 COMF MODIFICATIONS

The upgraded LEOFS was implemented within the standard COMF. The COMF package is available at: https://svnemc.ncep.noaa.gov/projects/nosofs_shared/trunk/. At the time of the code freeze for the upgraded LEOFS delivery, the SVN repository was at revision 71582. Please refer to Zhang and Yang (2014) for the detailed description on the COMF package. Only the changes necessary within the package to accommodate the implementation of the upgraded LEOFS are listed.

3.1 Surface Forcing Preparation

The upgraded LEOFS nowcast surface forcing is derived from the HRRR and the forecast forcing is from the NDFD. Both data sources are new for COMF. The addition of the HRRR was straightforward because its format and file structure are similar to other atmospheric models such as the North America Mesoscale (NAM) model that is already processed within COMF.

The inclusion of NDFD as a source of forcing data was more complicated. NDFD has a different file structure from the other NCEP atmospheric products previously used. NDFD has hourly output for the first 36 hours, up to 72 hours and 6 hourly for days 3 to 7. The day 1-3 forecast is updated hourly while the day 3-7 forecast is updated every 6 hours. NCEP receives NDFD products through the National Weather Service Telecommunication Gateway (NWSTG) and writes to files based on the time when the files are received. The shell script (ush/nos_ofs_create_forcing_met.sh) was re-written to handle NDFD separately and initially encountered numerous problems because the forecast length was not consistent among the files and the day 4-7 forecasts were not available in all files. After collaborating with the NCEP data flow team, it was decided to save NDFD at NCEP as a parameter by day instead of by hour. The script ush/nos_ofs_create_forcing_met.sh was updated accordingly. Finally, the script for NDFD had to be incorporated into the original script so that back-up data sources could be used if the forcing generation from NDFD failed for any reason.

The modification in COMF to process HRRR and NDFD files involved the following:

- Scripts jobs/JNOS_OFS_*: modified to define the path for HRRR and NDFD products,
- Script ush/nos_ofs_create_forcing_met.sh: modified to find the available HRRR and NDFD output files,
- Fortran code sorc/nos_ofs_met_file_search.fd/ and sorc/nos_ofs_met_file_search.f: modified to search for the most recent HRRR and NDFD files for the period of simulation.

3.2 Open Boundary Forcing Preparation

The open boundary forcing generation for the upgraded LEOFS is different from other Great Lakes and coastal OFS. The existing GLOFS treated the lakes as a fully enclosed basin. Different from coastal OFS, the upgraded LEOFS open boundary conditions are generated from observations only, with no modeling products from other larger domain regional models and there is no tide at the boundary. Therefore, a separate folder sorc/nos_ofs_create_forcing_obc_fvcom_gl.fd was created for the upgraded LEOFS and other Great Lakes OFS in the future. Within this folder, nos_ofs_create_forcing_obc_fvcom_gl.f and nos_ofs_obc_write_netcdf_fvcom_gl.f were written to create the boundary forcing in the format that FVCOM requires. To simplify code maintenance, these two programs followed the same code structure as the existing programs within nos_ofs_create_forcing_obc_fvcom.fd. Modifications were made to skip reading model products and making tide predictions, and to add code to use the previous day's average observation as backup if the primary and secondary station data sources are not available. As discussed in section 2.2.2, a dynamic water level offset was applied to the water level boundary conditions to improve the model prediction, and thus a new program nos_ofs_wlobc_offset_correction.f was put in the same folder to calculate the correction based on model-observation discrepancy.

The updates in COMF to generate open boundary condition (obc) forcing for LEOFS include the following:

- Script ush/nos_ofs_create_forcing_obc.sh: modified to add the water level correction control file to the input for the forcing generation and use the most recent correction file from the previous two days as backup.
- Fortran codes under sorc/nos_ofs_create_forcing_obc_fvcom_gl.fd/:
  - nos_ofs_create_forcing_obc_fvcom_gl.f: new code to generate the open boundary forcing based on observations only
  - nos_ofs_obc_write_netcdf_fvcom_gl.f: new code to write out needed variables in FVCOM input format
  - nos_ofs_wlobc_offset_correction.f: new code to calculate the water level correction offset
- fix/leofs/nos.leofs.ctl: added variables for the water level correction control file and the correction output file.
- fix/leofs/nos.leofs.wlobc.correction.ctl: new fix file to control the water level comparison between model and observation for boundary condition adjustment

4.0 NOWCAST/FORECAST MODEL SKILL

The model skill evaluation was conducted using the NOS standard skill assessment software (Zhang et al., 2006 and 2010), and used the standard NOS suite of skill assessment statistics. These statistics included series mean (SM), standard deviation (SD), root mean square error (RMSE), central frequency (CF), positive outlier frequency (POF), negative outlier frequency (NOF), maximum duration of positive outliers (MDPO), and maximum duration of negative outliers (MDNO). The description and criteria of the statistics are listed in Table 2. The statistics used in the skill assessment are described in more detail in Hess et al. (2003).

Table 2. Description of NOS Skill Assessment Statistics along with NOS Acceptance Criterion (Targets).

Statistic	Units	Description	NOS Acceptance Criterion
SM	Meters or Hours	Series Mean. The mean value of a series y	NA
SD	Meters or Hours	Standard Deviation	NA
RMSE	Meters or Hours	Root Mean Square Error	NA
CF(X)	%	Central Frequency. Fraction (percentage) of errors that lie within the limits ±X.	=> 90%
POF(X)	%	Positive Outlier Frequency. Fraction (percentage) of errors that are greater than X.	<= 1%
NOF(X)	%	Negative Outlier Frequency. Fraction (percentage) of errors that are less than -X.	<= 1%
MDPO(2X)	Hours	Maximum Duration of Positive Outliers. A positive outlier event is two or more consecutive occurrences of an error greater than +2X. MDPO is the length of time in hours (based on the number of consecutive occurrences) of the longest positive outlier event.	<= L
MDNO(2X)	Hours	Maximum Duration of Negative Outliers. A negative outlier event is two or more consecutive occurrences of an error less than -2X. MDNO is the length of time in hours (based on the number of consecutive occurrences) of the negative outlier longest event.	<= L
NOS Standard Criteria		where X=acceptable error magnitude (cm or minutes) X = +- 15cm for water level amplitude errors X = +- 1.5 hours (90 minutes) for water level timing errors X = +- 3.0°C for water temperature amplitude errors	where L=time limit or max. allowable duration L=24 hours

4.1 Real-Time Data Availability

During the development and testing of the upgraded LEOFS, model hindcast results were validated against observations of water level as well as surface and sub-surface water temperature (Kelley et al., 2018). Only observations of water level and surface water temperature were available during the semi-operational nowcast/forecast testing period. No water current observations are available within the model domain.

Water level observations are available from eight NOS water level stations in Lake Erie. Table 2 lists the station information and Figure 10 shows the locations of the stations. At each station, water level data is recorded every 6 minutes.

Real-time water temperature observations are available from four NOS stations and five buoys. The station information is listed in Table 3. At the NOS stations, the temperature sensors were installed ~ 1.5 m below Low Water Datum (LWD) and recorded data every 6 minutes. The five buoys are owned by different agencies (Table 3), but the real-time data are disseminated by the National Data Buoy Center (NDBC). The three buoys on the U.S. side had temperature sensors 1 m below the water surface and recorded data every 10 minutes. Sensor depth information on the two buoys owned by Environment and Climate Change Canada (ECCC) are not available and data was reported every hour. Figure 11 shows the location of the stations.

Table 3. Information on NOS water level stations with real-time observations.

Station Name	State	Station ID	Coordinates	
			Lat (deg N)	Lon (deg W)
Toledo	OH	9063085	41.693	83.471
Fermi Power Plant	MI	9063090	41.960	83.258
Marblehead	OH	9063079	41.545	82.731
Cleveland	OH	9063063	41.540	81.635
Fairport	OH	9063053	41.750	81.283
Erie	PA	9063038	42.153	80.075
Sturgeon Point	NY	9063028	42.690	79.048
Buffalo	NY	9063020	42.876	78.890

Figure 10. Locations of the water level stations with real-time observations for nowcast/forecast skill assessment.

Table 4. Information on stations with real-time water temperature observations.

Station Name	Owner	Station ID	Coordinates	
			Lat (deg N)	Lon (deg W)
Oregon, OH	Limno Tech*	45165	41.702	83.262
Marblehead, OH	NOS	9063079	41.545	82.731
West Erie, OH	NDBC	45005	41.677	82.398
Cleveland, OH	NOS	9063063	41.540	81.635
Fairport, OH	NOS	9063053	41.750	81.283
Port Stanley, ON	ECCC*	45132	42.463	81.215
Erie Nearshore Buoy, PA	Regional Science Consortium*	45167	42.186	80.137
Port Colborne, ON	ECCC*	45142	42.737	79.290
Buffalo, NY	NOS	9063020	42.876	78.890

*data downloaded from NDBC.

Figure 11. Locations of the water temperature stations with real-time observations for nowcast/forecast skill assessment.

4.2 Water Level Skill Assessment

Six-minute water level model results from the NCEP/NCO-conducted 30-day parallel evaluation runs (3/10/2016-4/10/2016) were compared with the 6-minute water level observations. The skill assessment statistics at each station are listed in Tables A1-A8 in Appendix A. The results from the upgraded LEOFS were also compared with the POM-based LEOFS to check its relative performance. Because Lake Erie is non-tidal, the low/high water events are sparse and the statistics for these events do not have sufficient samples to be significant. Therefore, we examined the events individually for their magnitude and timing.

Due to the frequent seiche events caused by the southwest wind over Lake Erie, the lake water level displayed the largest variability at the western and eastern ends of the lake and considerably less variability in the middle reach of the lake. Therefore, the RMSE of the water level were generally greater at Toledo and Fermi Power Plant in the western lake and Buffalo and Sturgeon Point, NY in the eastern lake (Fig. 12). The nowcast water level RMSE at all stations were below 15 cm. Figure 12 also compared the nowcast water level RMSE from the upgraded LEOFS (in blue) with the existing POM-based LEOFS (in red). The upgraded LEOFS performed considerably better than the POM-based LEOFS at the stations in the western lake while slightly worse at the stations near the eastern boundary. The POM-based LEOFS treated the lake as an enclosed basin with no open boundaries and the mean lake level was adjusted to the observed mean after the model run. This was done to track the seasonal variation in the lake level, which cannot be simulated with the model configuration of an enclosed basin. This process also removed any bias existing in the model. In the upgraded LEOFS, the seasonal lake level change is captured by the open boundary conditions. However, defining the eastern boundary as an outflow boundary is less effective in regulating the conditions upstream in the eastern basin of the lake. Comparison of the water level time series at Toledo, OH and Buffalo, NY show that both models generally agree well with the observations (Fig. 13). At Toledo, the upgraded LEOFS prediction followed the variation in the observations more closely. At Buffalo, the upgraded LEOFS had a small positive bias in the water level prediction even though it captured much of the variability (Fig. 13).

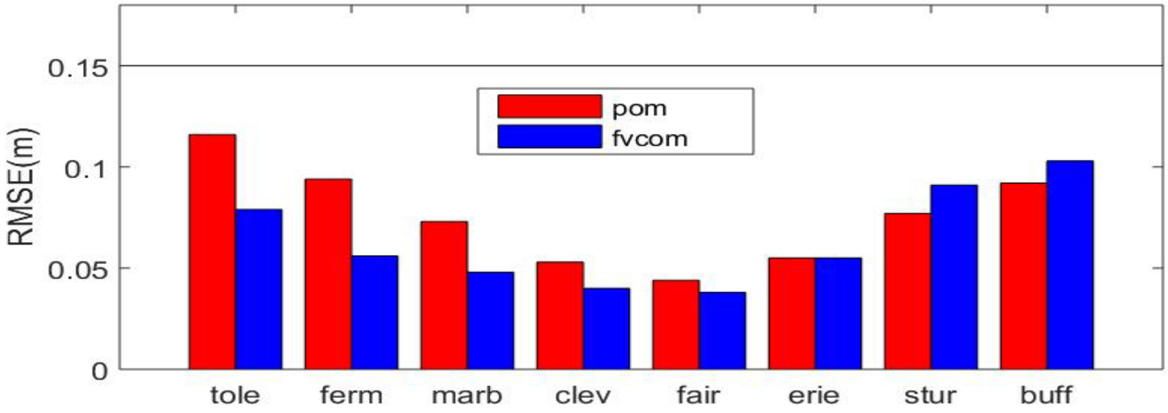

Figure 12. Water level nowcast skill comparison between the POM-based (red) and the upgraded LEOFS (blue) for the period of 3/10/2016-4/12/2016 at the eight stations listed in Table 3. The horizontal black line delineates the target RMSE value of 15 cm.

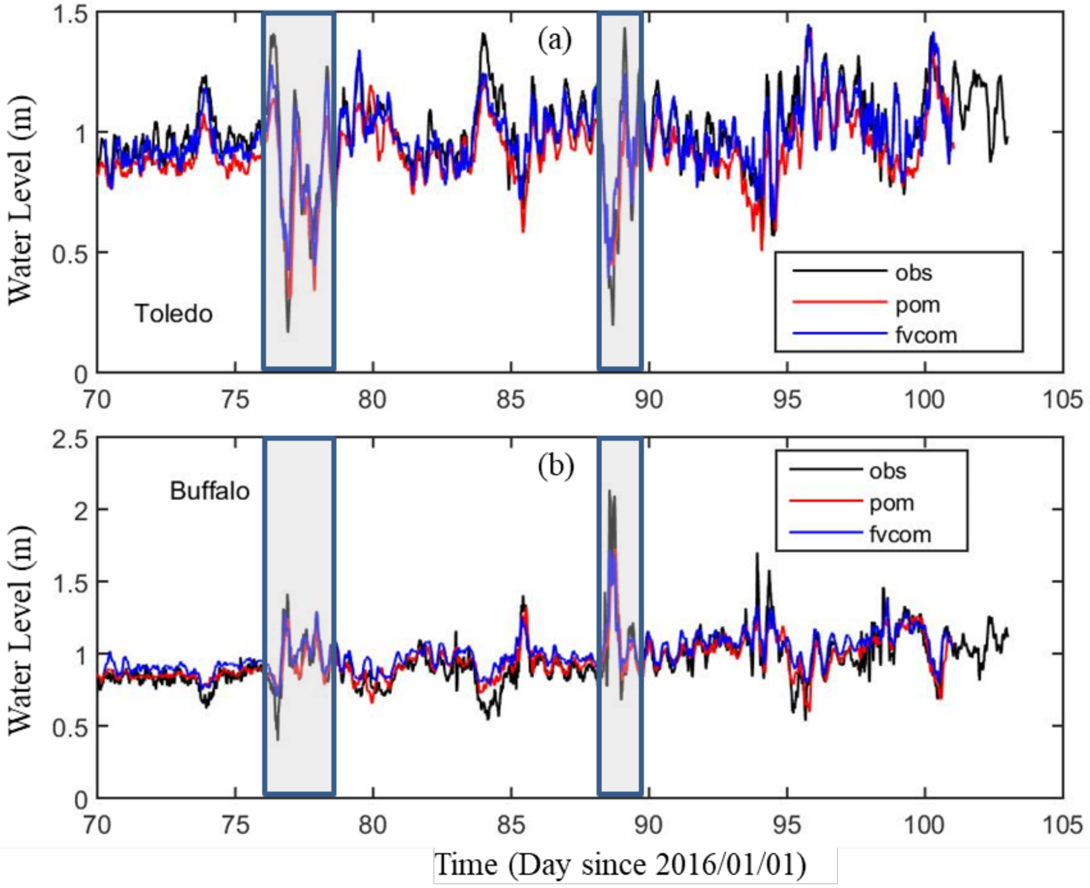

Figure 13. Time series (3/10/2016-4/12/2016) of water level at (a) Toledo, OH and (b) Buffalo, NY. Black lines are from observations, red lines are from the POM-based LEOFS and blue lines are from the upgraded LEOFS. The shaded time periods show the timing of the two strong wind events.

Within this one-month evaluation period, there were two wind events with strong W/SW wind in excess of 10 m/s that persisted for serval hours: one on March 16-18 and the other on March 28, 2016 (shown as the shaded areas in Fig. 13). Figure 14 focuses on the latter event on March 28 (day 88) to show the change in water level at Toledo and Buffalo more clearly. At both stations the water level changed by more than 1 m during the event. Both versions of LEOFS underestimated the range of water level change at Toledo during the event (~0.3 m higher at low water mark and ~ 0.2 m lower at the high water mark), but the upgraded version generally followed the observations more closely. At Buffalo, the upgraded LEOFS was able to capture the double rise-up of the water level. However, both models underestimated the water level rise by nearly 0.40 m.

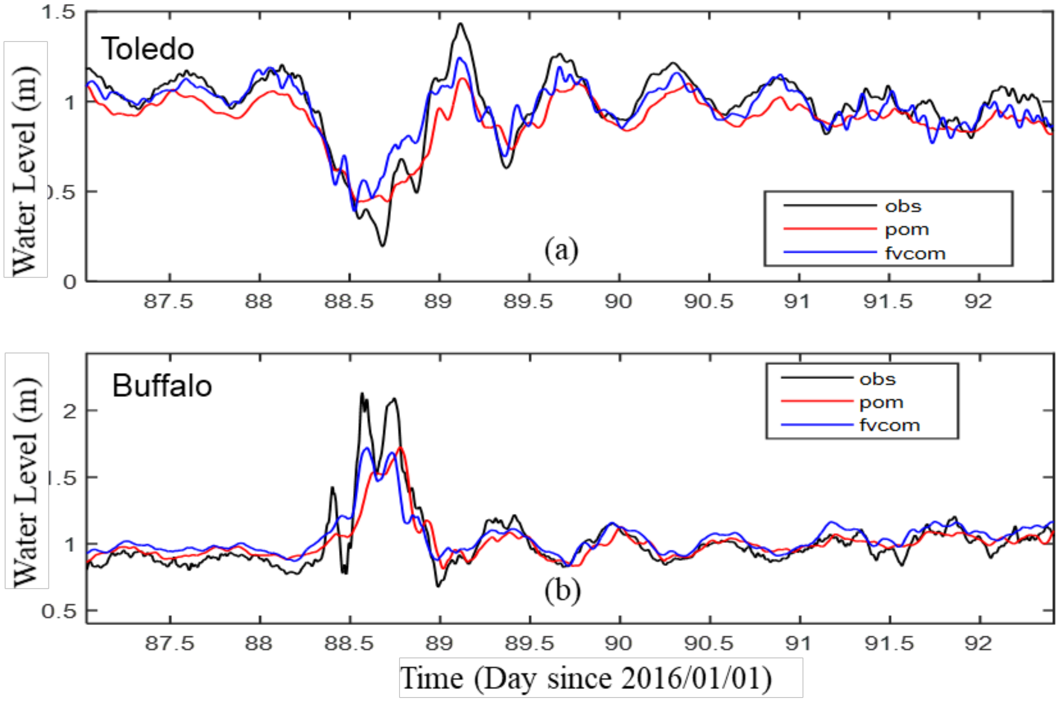

Figure 14. Water level at (a) Toledo, OH and (b) Buffalo, NY during the wind event on March 28 (day 88). Black lines are from observations, red lines are from the POM-based LEOFS and blue lines are from the upgraded LEOFS.

For the nowcast water levels, the criterion for CF (>90%), NOF (<1%), POF (<1%), MDPO (<24 hours), and MDNO (<24 hours) used in NOS OFS skill assessment were met at all stations except for Buffalo where the CF for nowcast water level was at 89.4% (Tables A1-A8 in Appendix A) due to the persistent bias at this station.

As discussed earlier, the upgraded LEOFS extended the forecast horizon to 120 hours. The water level forecast skill generally deteriorated slowly with the forecast hour (Fig. 15). The RMSE of water level remained under 0.15 m up to 60 hours into the forecast at six out of the eight stations, with RMSE at Toledo and Buffalo exceeding 0.15 m after forecast hour 30. The CF of forecast water level at Toledo, Fermi Power Plant and Buffalo did not meet the NOS criterion of 90%, while at the other five stations, CF exceeded 90% for a period of 18 – 108 hours. Tables A1-A8 in Appendix A provide a detailed summary of skill assessment statistics. Users of forecasts at Toledo, Fermi Power Plant and Buffalo need to be aware of the fact the water level response at these stations generally tend to be underestimated by more than 15 cm.

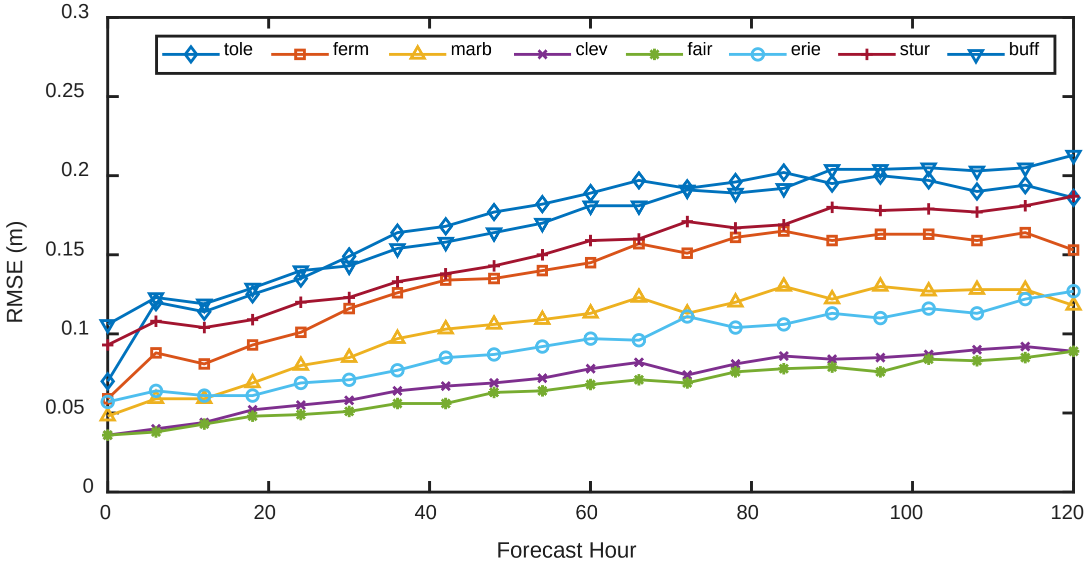

Figure 15. Water level forecast RMSE (m) from the upgraded LEOFS for the period of 3/10/2016-4/12/2016 at the eight stations listed in Table 3. The x-axis is the forecast hour.

4.3 Water Temperature Skill Assessment

The water temperature skill assessment was conducted using the nowcast/forecast simulations from April to December in 2015 because the NCO-conducted 30-day parallel test (3/10/2016-4/10/2016) occurred during the winter when minimal water temperature measurements were made. The nowcast water temperature at the surface of the model was compared with observations and the existing POM-based LEOFS. The mixed-layer depth in Lake Erie is generally deeper than 5 m even in summer when the lake is most thermally stratified (Schertzer et al., 1987). Therefore, the surface (top layer) temperature in the model is comparable to the temperature observed at depth varying from 1 to 2 m. The nowcast surface water temperature RMSE from the upgraded LEOFS at all stations was below 3 °C and compared more favorably with observations than the POM-based LEOFS (Fig. 16). Model results at the two buoy stations at Oregon, OH and Erie, PA were not saved from the POM-based LEOFS before it was decommissioned so that only the RMSE from the upgraded LEOFS were calculated. Figure 17 shows the time series of surface water temperature at Marblehead, OH and Port Colborne, ON. Both models reproduced the seasonal temperature cycle very well. The POM-based LEOFS had a warm bias of up to 2 °C during the spring warm-up and 4 °C during the fall cool-down; the upgraded LEOFS better simulated the water temperature during these transition periods by reducing the bias to less than 1 °C. The upgraded LEOFS also eliminated the spurious frequent spikes evident in the POM-based LEOFS (Fig. 17).

For the nowcast water temperature, the criterion for CF (>90%), NOF (<1%), POF (<1%), MDPO (<24 hours), and MDNO (<24 hours) used in NOS OFS skill assessment were met at five stations (Oregon, Marblehead, Erie, Port Colborne and Buffalo). However, the CF criterion was not met at West Erie, Cleveland, Fairport and Port Stanley (Tables B1-B9 in Appendix B). Examination of the time series comparison revealed that less than satisfactory skill resulted from a combination of possible observation data error (for example, the initial observation values at West Erie and Port Colborne) and the consistent positive bias in the first half of the year before switching the surface forcing from HRRR hour 0 analysis to hour 2 forecast.

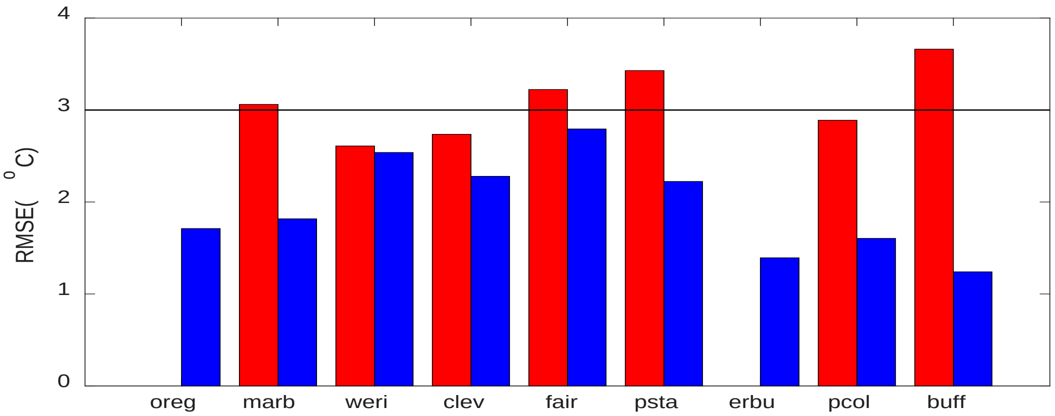

Figure 16. Nowcast surface water temperature model skill comparison between the POM-based LEOFS (in red) and the upgraded FVCOM-based LEOFS (in blue). The horizontal black line delineates the target RMSE of 3 °C.

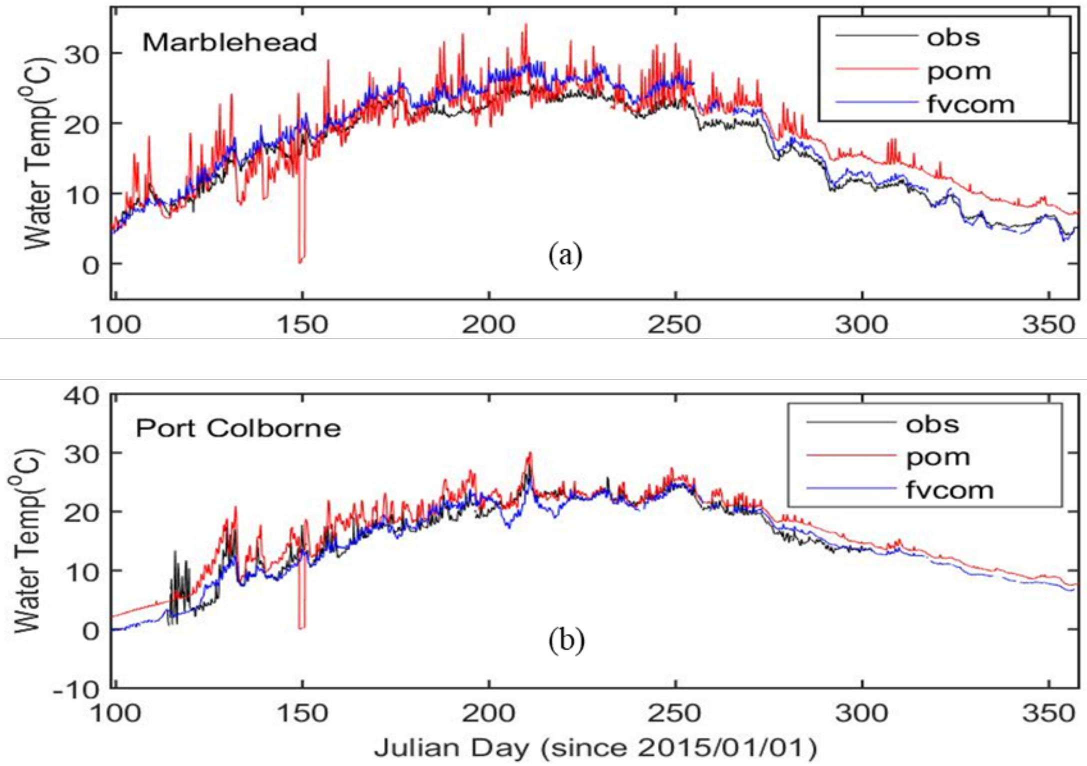

Figure 17. Time series of surface water temperature at (a) Marblehead, OH and (b) Port Colborne, ON from 3/10/2015-12/31/2015. Black lines are from observations, red lines are from the POM-based LEOFS and blue lines are from the upgraded LEOFS.

The water temperature forecast skill stayed more or less the same for the entire forecast period of 120 hours (Fig. 18). The RMSE of water temperature remained under 3 °C at all stations during the forecast. Similar to the nowcast, the CF of forecast water temperature at West Erie, Cleveland, Fairport and Port Stanley did not meet the NOS criterion of 90%, while at the other five stations, CF exceeded 90% for a period of 78-120 hours. Tables B1-B9 in Appendix B provide a detailed summary of skill assessment statistics.

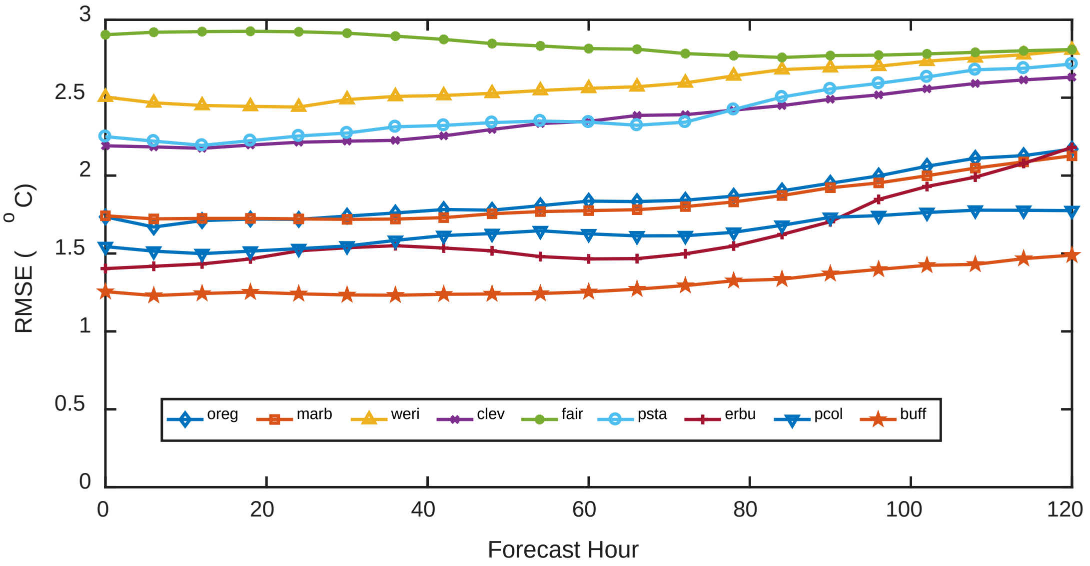

Figure 18. The surface water temperature forecast skill at the nine stations listed in Table 4.

5.0 SUMMARY AND DISCUSSION

NOAA/OAR/GLERL developed the FVCOM-based LEOFS and completed hindcast simulations for years 2005 and 2006. The real-time implementation of the upgraded system required updates to NOS' COMF and significant changes to the model configuration compared to the hindcast configuration. For the nowcast, the open boundary conditions are prescribed by the real-time water level observations from NOAA water level gauges and water temperature observations from USGS. Surface forcing conditions are derived from NCEP's 3-km, hourly-updated HRRR atmospheric model. For the forecasts, along the open boundary, water levels are specified using the previous day's average water level and persisted for the forecast period. Winds and other variables from the National Digital Forecast Database on the 2.5-km CONUS grid are used as the surface forcing for the upgraded LEOFS. The upgraded LEOFS runs four times per day with a 6-hour nowcast and 120-hour forecast. The implementation of the upgraded LEOFS within the standard COMF greatly eases maintenance and operations.

The upgraded LEOFS started its experimental nowcast/forecast run in March 2015 while changes and improvements were introduced and tested throughout the implementation. The model configuration and COMF code were finalized in November 2015. NCO started the 30-day parallel run on March 10, 2016 and the upgraded LEOFS was implemented into operations on May 3, 2016.

The water level and surface temperature from the upgraded LEOFS were compared with observations and results from the existing POM-based LEOFS. The upgraded LEOFS captured the seasonal and short-term (hours) lake level variations. During the strong wind-driven seiche events, the model tended to underestimate the magnitude of the water level change at both ends of the Lake. The upgraded LEOFS treats the Detroit River and the Niagara River as open boundaries, which eliminates the need to adjust the model results to the observed mean to track the seasonal lake level change. The water level specified along the open boundary was modified based on the model/observation discrepancy near the boundary. The model responded to the adjustment in the western boundary water level very well, which improved water level predictions in the western part of the lake (reducing RMSE at Toledo and Fermi from 0.12 m to 0.08 m and 0.09 m to 0.06 m, respectively). Therefore, at the stations in the western Erie, the upgraded LEOFS out-performed the existing LEOFS even though the existing LEOFS adjusted the lake level each cycle based on the observations. However, the upgraded LEOFS was not sensitive to the dynamic water level adjustment along the eastern boundary. It is intuitive that the model responds better to the adjustment to the inflow (upstream in the Detroit River) than the outflow (downstream in the Niagara River) boundary conditions because FVCOM uses specified open boundary conditions for inflow conditions, but uses radiation boundary conditions for outflow conditions. During the strong wind-driven seiche events, LEOFS underestimates the magnitude of the lake level response. Comparisons between the existing and upgraded LEOFS and the corresponding wind forcing demonstrate that the surface forcing plays a vital role in the water level prediction. The POM-based LEOFS nowcast was forced by the interpolated hourly analysis of observed winds from land-based, coastal, and offshore stations while the upgraded LEOFS nowcast was forced by HRRR atmospheric model 2-hr forecast guidance. The difference in the wind forcing directly affected the observed difference in the lake level in response to the strong wind events.

Compared to the POM-based LEOFS, the upgraded LEOFS reduced the RMSE of the water surface temperature predictions by up to 2 °C. It removed the warm bias in water temperature during the fall cool-down and the spring warm-up and eliminated the spurious spikes evident in the existing LEOFS.

The upgraded LEOFS is used to support the Harmful Algae Bloom (HAB) forecast in Lake Erie and also provides the infrastructure for the hypoxia forecast in Lake Erie. An ice forecasting capability is being developed by NOAA/OAR/GLERL. The ice forecast will be incorporated into upgraded future version of LEOFS, and will potentially improve the water temperature forecast during the winter and provide ice forecast guidance for ice concentration, coverage and movement.

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John Cassidy, Zhong Li, Ainsley Gibson, and Xiaoyan Li from CO-OPS' Information Systems Division helped to create the website for the upgraded LEOFS, disseminate the model output on the THREDDS server, and address data archiving and other IT-related issues. Cary Wong, Shawn Maddock, Chris DiVeglio, and Paul Fanelli from CO-OPS' Oceanographic Division tested and evaluated the website. Nicole Rice at NOAA/OAR/GLERL copyedited this report. We thank the reviewers for their helpful comments and suggestions to improve this report.

REFERENCES

Chen, C., R. C. Berardsley and G. Cowles, 2006. An unstructured Grid, Finite-Volume Coastal Ocean Model FVCOM User Manual. SMAST/UASSD-06-0602, 315 pp.

Chu P, J. G. W. Kelley, A. Zhang, G. A. Lang, and K.W. Bedford, 2007. Skill Assessment of NOS Lake Erie Operational Forecast System (LEOFS). NOAA Technical Memorandum NOS CS 12, 73 pp.

Hess, K.W., T. F. Gross, R. A. Schmalz, J. G.W. Kelley, F. Aikman III, E. Wei, and M. S. Vincent, 2003. NOS Standards for Evaluating Operational Nowcast and Forecast Hydrodynamic Model System. NOAA Technical Report NOS CS 17, 48 pp.

Kavanaugh, K., K. Derner, and E. Davis. 2016. Assessment of the Eastern Gulf of Mexico Harmful Algal Bloom Operational Forecast System (GOMX HAB-OFS): An Analysis of Forecast Skill and Utilization from May 1, 2008 to April 30, 2014. NOAA Technical Report NOS CO-OPS 082, 94 pp.

Kelley, J. G. W., P. Chu, A. Zhang, G. A. Lang, and D. J. Schwab, 2007a. Skill Assessment of NOS Lake Michigan Operational Forecast System (LMOFS). NOAA Technical Memorandum NOS CS 8, 67 pp.

Kelley, J. G. W., P. Chu, A. Zhang, and G. A. Lang, 2007b. Skill Assessment of NOS Lake Superior Operational Forecast System (LSOFS). NOAA Technical Memorandum NOS CS 9, 48 pp.

Kelley, J. G. W., A. Zhang, P. Chu, and G. A. Lang, 2008. Skill Assessment of NOS Lake Ontario Operational Forecast System (LOOFS). NOAA Technical Memorandum NOS CS 13, 40 pp.

Kelley, J.G.W., A.J. Zhang, P. Chu, and G.A. Lang, 2010. Skill Assessment of NOS Lake Huron Operational Forecast System (LHOFS). NOAA Technical Memorandum NOS CS 23, 57 pp.

Kelley, J. G. W., Y. Chen, E. J. Anderson, G. A. Lang, and J. Xu, 2018. Upgrade of NOS Lake Erie Operational Forecast System (LEOFS) To FVCOM: Model Development and Hindcast Skill Assessment. NOAA Technical Memorandum NOS CS 40, 92 pp.

National Geophysical Data Center, 1999. Bathymetry of Lake Erie and Lake Saint Clair. National Geophysical Data Center, NOAA. doi:10.7289/V5KS6PHK

Schertzer, W. M., J. H. Saylor, F. M. Boyce, D. G. Robertson, and F. Rosa, 1987. Seasonal Thermal Cycles of Lake Erie. Journal of Great Lakes Research 13 (4), 468-486.

Zhang, A., K. W. Hess, E. Wei, and E. Myers, 2006. Implementation of Model Skill Assessment Software for Water Level and Current in Tidal Regions. NOAA Technical Report NOS CS 24, 61 pp.

Zhang, A., K. W. Hess, and F. Aikman, 2010. User-based skill assessment techniques for operational hydrodynamic forecast systems, *J. Oper. Oceanogr.*, 3(2), 11-24.

Zhang, A., Z., and Yang, 2014. Coastal Ocean Modeling Framework on NOAA’s High Performance Computer (COMF-HPC). NOAA Technical Report NOS CO-OPS 069, 75pp.

APPENDIX A. WATER LEVEL SKILL ASSESSMENT TABLES

The following tables are the summary results from the standard NOS skill assessment performed for 3/10/2016 to 4/12/2016. The tables are listed in the order of the stations in Table 3.

Table A1. Water level nowcast and forecast skill table for Toledo, OH.

Station: Toledo
Observed data time period from: 3/10/2016 to 4/12/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
H			7381	0.974									
h			7381	0.993									
H-h	15cm	24h	7381	-0.018	0.079	0.077	0.0	93.8	0.3	0.0	1.3	0.00	0.94
SCENARIO: SEMI-OPERATIONAL FORECAST													
H000-h000	15cm	24h	124	-0.015	0.070	0.069	0.0	96.0	0.0	0.0	0.0		
H006-h006	15cm	24h	124	-0.048	0.120	0.111	2.4	82.3	0.0	0.0	0.0		
H012-h012	15cm	24h	124	-0.044	0.114	0.106	2.4	83.9	0.0	0.0	0.0		
H018-h018	15cm	24h	124	-0.045	0.125	0.117	2.4	77.4	0.0	0.0	0.0		
H024-h024	15cm	24h	124	-0.054	0.135	0.125	4.8	77.4	0.0	0.0	0.0		
H030-h030	15cm	24h	124	-0.059	0.149	0.137	4.8	72.6	0.8	6.0	0.0		
H036-h036	15cm	24h	123	-0.063	0.164	0.152	6.5	69.1	1.6	6.0	0.0		
H042-h042	15cm	24h	122	-0.059	0.168	0.158	6.6	63.1	1.6	6.0	0.0		
H048-h048	15cm	24h	121	-0.063	0.177	0.167	5.0	58.7	3.3	6.0	0.0		
H054-h054	15cm	24h	120	-0.062	0.182	0.172	6.7	61.7	3.3	6.0	0.0		
H060-h060	15cm	24h	119	-0.063	0.189	0.179	9.2	67.2	3.4	6.0	6.0		
H066-h066	15cm	24h	118	-0.064	0.197	0.187	9.3	64.4	5.1	6.0	6.0		
H072-h072	15cm	24h	117	-0.064	0.192	0.182	8.5	61.5	6.0	12.0	6.0		
H078-h078	15cm	24h	116	-0.055	0.196	0.188	8.6	58.6	4.3	12.0	0.0		
H084-h084	15cm	24h	115	-0.057	0.202	0.194	11.3	65.2	6.1	12.0	6.0		
H090-h090	15cm	24h	114	-0.059	0.195	0.187	7.9	62.3	5.3	6.0	6.0		
H096-h096	15cm	24h	113	-0.058	0.200	0.192	8.0	58.4	5.3	6.0	6.0		
H102-h102	15cm	24h	112	-0.059	0.197	0.188	8.9	58.0	5.4	6.0	6.0		
H108-h108	15cm	24h	111	-0.058	0.190	0.182	6.3	62.2	3.6	6.0	6.0		
H114-h114	15cm	24h	110	-0.059	0.194	0.186	10.9	63.6	3.6	6.0	6.0		
H120-h120	15cm	24h	109	-0.059	0.186	0.178	6.4	60.6	2.8	12.0	6.0		

Table A2. Water level nowcast and forecast skill table for Fermi Power Plant, MI.

Station: Fermi Power Plant
Observed data time period from: 3/10/2016 to 4/12/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
H			7263	0.982									
h			7263	0.978									
H-h	15cm	24h	7263	0.004	0.056	0.056	0.0	97.8	0.0	0.0	0.0	0.00	0.95
ALW-alw	15cm	24h	3	0.171	0.178	0.063	0.0	66.7	0.0	0.0	0.0		
TLW-tlw	0.50hr	25h	3	-0.500	1.370	1.562	33.3	33.3	0.0	0.0	0.0		
SCENARIO: SEMI-OPERATIONAL FORECAST													
H000-h000	15cm	24h	122	0.004	0.059	0.059	0.0	95.1	0	0.0	0.0		
H006-h006	15cm	24h	122	-0.016	0.088	0.087	0.8	92.6	0	0.0	0.0		
H012-h012	15cm	24h	122	-0.010	0.081	0.081	0.0	93.4	0.8	0.0	0.0		
H018-h018	15cm	24h	123	-0.011	0.093	0.092	0.0	91.9	0.8	0.0	0.0		
H024-h024	15cm	24h	124	-0.019	0.101	0.100	0.8	87.9	0.8	0.0	0.0		
H030-h030	15cm	24h	124	-0.022	0.116	0.114	2.4	83.9	1.6	0.0	0.0		
H036-h036	15cm	24h	123	-0.025	0.126	0.124	2.4	83.7	2.4	0.0	6.0		
H042-h042	15cm	24h	122	-0.024	0.134	0.132	3.3	74.6	2.5	0.0	6.0		
H048-h048	15cm	24h	121	-0.026	0.135	0.133	0.8	73.6	1.7	0.0	0.0		
H054-h054	15cm	24h	120	-0.028	0.140	0.138	0.8	70.8	2.5	0.0	6.0		
H060-h060	15cm	24h	119	-0.030	0.145	0.142	0.8	69.7	1.7	0.0	6.0		
H066-h066	15cm	24h	118	-0.032	0.157	0.154	2.5	69.5	2.5	0.0	6.0		
H072-h072	15cm	24h	117	-0.032	0.151	0.149	3.4	70.1	3.4	0.0	6.0		
H078-h078	15cm	24h	116	-0.025	0.161	0.160	4.3	70.7	2.6	6.0	0.0		
H084-h084	15cm	24h	115	-0.026	0.165	0.164	6.1	68.7	3.5	6.0	6.0		
H090-h090	15cm	24h	114	-0.027	0.159	0.157	1.8	68.4	2.6	0.0	6.0		
H096-h096	15cm	24h	113	-0.025	0.163	0.161	1.8	66.4	3.5	0.0	6.0		
H102-h102	15cm	24h	112	-0.027	0.163	0.161	1.8	68.8	3.6	0.0	6.0		
H108-h108	15cm	24h	111	-0.027	0.159	0.157	0.9	67.6	2.7	0.0	6.0		
H114-h114	15cm	24h	110	-0.027	0.164	0.162	6.4	70.9	3.6	0.0	6.0		
H120-h120	15cm	24h	109	-0.026	0.153	0.151	2.8	69.7	1.8	0.0	6.0		
ALW-alw	15cm	24h	3	0.164	0.195	0.130	0.0	33.3	00				
TLW-tlw	0.50hr	25h	3	-0.867	1.864	2.021	66.7	0.0	33.3				

Table A3. Water level nowcast and forecast skill table for Marblehead, OH.

Station: Marblehead
Observed data time period from: 3/10/2016 to 4/12/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
H			7381	0.983									
h			7381	0.974									
H-h	15cm	24h	7381	0.010	0.048	0.047	0.0	99.1	0.0	0.0	0.1	0.00	0.94
ALW-alw	15cm	24h	3	0.148	0.151	0.04	0.0	33.3	0.0	0.0	0.0		
TLW-tlw	0.50hr	25h	3	-1.000	1.757	1.769	33.3	0.0	0.0	0.0	0.0		
SCENARIO: SEMI-OPERATIONAL FORECAST													
H000-h000	15cm	24h	124	0.009	0.048	0.047	0.0	99.2	0.0	0.0	0.0		
H006-h006	15cm	24h	124	-0.001	0.059	0.060	0.0	96.0	0.0	0.0	0.0		
H012-h012	15cm	24h	124	0.000	0.059	0.059	0.0	96.0	0.0	0.0	0.0		
H018-h018	15cm	24h	124	0.000	0.069	0.069	0.0	96.0	0.0	0.0	0.0		
H024-h024	15cm	24h	124	-0.006	0.080	0.080	0.0	95.2	0.8	0.0	0.0		
H030-h030	15cm	24h	124	-0.007	0.085	0.085	0.0	92.7	0.8	0.0	0.0		
H036-h036	15cm	24h	123	-0.010	0.097	0.097	0.0	91.1	1.6	0.0	0.0		
H042-h042	15cm	24h	122	-0.008	0.103	0.103	0.0	90.2	0.8	0.0	0.0		
H048-h048	15cm	24h	121	-0.011	0.106	0.106	0.0	86.8	1.7	0.0	6.0		
H054-h054	15cm	24h	120	-0.012	0.109	0.109	0.0	84.2	0.8	0.0	0.0		
H060-h060	15cm	24h	119	-0.013	0.113	0.113	0.0	81.5	1.7	0.0	6.0		
H066-h066	15cm	24h	118	-0.015	0.123	0.122	0.8	80.5	1.7	0.0	0.0		
H072-h072	15cm	24h	117	-0.014	0.113	0.112	0.9	84.6	1.7	0.0	0.0		
H078-h078	15cm	24h	116	-0.008	0.120	0.121	0.9	80.2	1.7	0.0	6.0		
H084-h084	15cm	24h	115	-0.010	0.130	0.130	1.7	86.1	2.6	0.0	6.0		
H090-h090	15cm	24h	114	-0.011	0.122	0.122	0.9	85.1	1.8	0.0	6.0		
H096-h096	15cm	24h	113	-0.008	0.130	0.130	0.9	86.7	2.7	0.0	6.0		
H102-h102	15cm	24h	112	-0.009	0.127	0.127	0.9	83	1.8	0.0	6.0		
H108-h108	15cm	24h	111	-0.009	0.128	0.128	0.9	82.9	1.8	0.0	6.0		
H114-h114	15cm	24h	110	-0.009	0.128	0.128	1.8	85.5	1.8	0.0	0.0		
H120-h120	15cm	24h	109	-0.008	0.118	0.118	0.9	80.7	0.9	0.0	0.0		
ALW-alw	15cm	24h	3	0.167	0.169	0.027	0.0	33.3	0.0				
TLW-tlw	0.50hr	25h	3	0.000	0.638	0.781	0.0	66.7	0.0				

Table A4. Water level nowcast and forecast skill table for Cleveland, OH.

Station: Cleveland
Observed data time period from: 3/10/2016 to 4/12/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
H			7381	0.990									
h			7381	0.974									
H-h	15cm	24h	7381	0.015	0.04	0.037	0.0	99.6	0.0	0.0	0.0	0.00	0.93
SCENARIO: SEMI-OPERATIONAL FORECAST													
H000-h000	15cm	24h	124	0.013	0.036	0.034	0.0	100.0	0.0	0.0	0.0		
H006-h006	15cm	24h	124	0.013	0.040	0.038	0.0	100.0	0.0	0.0	0.0		
H012-h012	15cm	24h	124	0.012	0.044	0.042	0.0	100.0	0.0	0.0	0.0		
H018-h018	15cm	24h	124	0.011	0.052	0.051	0.0	98.4	0.0	0.0	0.0		
H024-h024	15cm	24h	124	0.009	0.055	0.054	0.0	99.2	0.0	0.0	0.0		
H030-h030	15cm	24h	124	0.009	0.058	0.057	0.0	98.4	0.0	0.0	0.0		
H036-h036	15cm	24h	123	0.007	0.064	0.064	0.0	96.7	0.0	0.0	0.0		
H042-h042	15cm	24h	122	0.007	0.067	0.066	0.0	98.4	0.0	0.0	0.0		
H048-h048	15cm	24h	121	0.006	0.069	0.069	0.0	98.3	0.0	0.0	0.0		
H054-h054	15cm	24h	120	0.004	0.072	0.073	0.0	95.0	0.0	0.0	0.0		
H060-h060	15cm	24h	119	0.003	0.078	0.078	0.0	97.5	0.0	0.0	0.0		
H066-h066	15cm	24h	118	0.001	0.082	0.082	0.0	94.1	0.0	0.0	0.0		
H072-h072	15cm	24h	117	0.000	0.074	0.074	0.0	95.7	0.0	0.0	0.0		
H078-h078	15cm	24h	116	0.003	0.081	0.081	0.0	94.0	0.0	0.0	0.0		
H084-h084	15cm	24h	115	0.002	0.086	0.087	0.0	89.6	0.0	0.0	0.0		
H090-h090	15cm	24h	114	0.002	0.084	0.084	0.0	92.1	0.0	0.0	0.0		
H096-h096	15cm	24h	113	0.004	0.085	0.085	0.0	93.8	0.9	0.0	0.0		
H102-h102	15cm	24h	112	0.004	0.087	0.087	0.0	91.1	0.9	0.0	0.0		
H108-h108	15cm	24h	111	0.005	0.09	0.091	0.0	88.3	0.9	0.0	0.0		
H114-h114	15cm	24h	110	0.005	0.092	0.092	0.0	90.9	0.9	0.0	0.0		
H120-h120	15cm	24h	109	0.005	0.089	0.089	0.0	89.0	0.0	0.0	0.0		

Table A5. Water level nowcast and forecast skill table for Fairport, OH.

Station: Fairport
Observed data time period from: 3/10/2016 to 4/12/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
H			7381	0.990									
h			7381	0.969									
H-h	15cm	24h	7381	0.021	0.038	0.032	0.0	99.9	0.0	0.0	0.0	0.00	0.93
AHW-ahw	15cm	24h	3	-0.054	0.057	0.024	0.0	100	0.0	0.0	0.0		
ALW-alw	15cm	24h	2	0.152	0.153	0.002	0.0	0.0	0.0	0.0	0.0		
THW-thw	0.50hr	25h	3	0.667	0.766	0.462	0.0	66.7	33.3	0.0	0.0		
TLW-tlw	0.50hr	25h	2	0.650	0.992	1.061	0.0	50.0	50.0	0.0	0.0		
SCENARIO: SEMI-OPERATIONAL FORECAST													
H000-h000	15cm	24h	124	0.020	0.036	0.030	0.0	100.0	0.0	0.0	0.0		
H006-h006	15cm	24h	124	0.020	0.038	0.032	0.0	100.0	0.0	0.0	0.0		
H012-h012	15cm	24h	124	0.018	0.043	0.039	0.0	100.0	0.0	0.0	0.0		
H018-h018	15cm	24h	124	0.018	0.048	0.045	0.0	99.2	0.0	0.0	0.0		
H024-h024	15cm	24h	124	0.016	0.049	0.046	0.0	100.0	0.0	0.0	0.0		
H030-h030	15cm	24h	124	0.016	0.051	0.048	0.0	100.0	0.0	0.0	0.0		
H036-h036	15cm	24h	123	0.014	0.056	0.055	0.0	99.2	0.0	0.0	0.0		
H042-h042	15cm	24h	122	0.014	0.056	0.055	0.0	99.2	0.0	0.0	0.0		
H048-h048	15cm	24h	121	0.012	0.063	0.062	0.0	100.0	0.0	0.0	0.0		
H054-h054	15cm	24h	120	0.010	0.064	0.063	0.0	99.2	0.0	0.0	0.0		
H060-h060	15cm	24h	119	0.009	0.068	0.068	0.0	100.0	0.0	0.0	0.0		
H066-h066	15cm	24h	118	0.008	0.071	0.071	0.0	97.5	0.0	0.0	0.0		
H072-h072	15cm	24h	117	0.007	0.069	0.069	0.0	98.3	0.0	0.0	0.0		
H078-h078	15cm	24h	116	0.008	0.076	0.076	0.0	97.4	0.0	0.0	0.0		
H084-h084	15cm	24h	115	0.008	0.078	0.078	0.0	95.7	0.0	0.0	0.0		
H090-h090	15cm	24h	114	0.008	0.079	0.079	0.0	90.4	0.0	0.0	0.0		
H096-h096	15cm	24h	113	0.009	0.076	0.076	0.0	94.7	0.0	0.0	0.0		
H102-h102	15cm	24h	112	0.009	0.084	0.084	0.0	92.9	0.0	0.0	0.0		
H108-h108	15cm	24h	111	0.010	0.083	0.083	0.0	93.7	0.0	0.0	0.0		
H114-h114	15cm	24h	110	0.011	0.085	0.085	0.0	88.2	0.0	0.0	0.0		
H120-h120	15cm	24h	109	0.011	0.089	0.089	0.9	90.8	0.0	0.0	0.0		
AHW-ahw	15cm	24h	2	-0.065	0.067	0.020	0.0	100.0	0.0	0.0	0.0		
ALW-alw	15cm	24h	2	0.155	0.155	0.000	0.0	0.0	0.0	0.0	0.0		
THW-thw	0.50hr	25h	2	0.500	0.640	0.566	0.0	50.0	0.0	0.0	0.0		
TLW-tlw	0.50hr	25h	2	-0.500	2.061	2.828	50.0	0.0	50.0				

Table A6. Water level nowcast and forecast skill table for Erie, PA.

Station: Erie
Observed data time period from: 3/10/2016 to 4/12/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
H			7381	0.996									
h			7381	0.966									
H-h	15cm	24h	7381	0.030	0.055	0.046	0.0	98.5	0.0	0.0	0.0	0.00	0.92
AHW-ahw	15cm	24h	3	-0.089	0.099	0.053	0.0	100.0	0.0	0.0	0.0		
THW-thw	0.50hr	25h	3	-0.833	1.731	1.858	33.3	33.3	0.0	0.0	0.0		
SCENARIO: SEMI-OPERATIONAL FORECAST													
H000-h000	15cm	24h	124	0.031	0.057	0.048	0.0	97.6	0.0	0.0	0.0		
H006-h006	15cm	24h	124	0.036	0.064	0.053	0.0	96.0	0.0	0.0	0.0		
H012-h012	15cm	24h	124	0.032	0.061	0.052	0.0	97.6	0.0	0.0	0.0		
H018-h018	15cm	24h	124	0.032	0.061	0.052	0.0	96.8	0.0	0.0	0.0		
H024-h024	15cm	24h	124	0.032	0.069	0.062	0.0	95.2	0.0	0.0	0.0		
H030-h030	15cm	24h	124	0.032	0.071	0.064	0.0	94.4	0.0	0.0	0.0		
H036-h036	15cm	24h	123	0.032	0.077	0.070	0.0	94.3	0.0	0.0	0.0		
H042-h042	15cm	24h	122	0.029	0.085	0.080	0.0	92.6	0.0	0.0	0.0		
H048-h048	15cm	24h	121	0.030	0.087	0.081	0.0	93.4	0.0	0.0	0.0		
H054-h054	15cm	24h	120	0.031	0.092	0.087	0.0	88.3	0.0	0.0	0.0		
H060-h060	15cm	24h	119	0.031	0.097	0.092	0.8	87.4	0.0	0.0	0.0		
H066-h066	15cm	24h	118	0.031	0.096	0.091	1.7	90.7	0.0	6.0	0.0		
H072-h072	15cm	24h	117	0.031	0.111	0.107	1.7	88.0	0.0	6.0	0.0		
H078-h078	15cm	24h	116	0.026	0.104	0.102	0.9	88.8	0.0	0.0	0.0		
H084-h084	15cm	24h	115	0.026	0.106	0.104	0.9	87.0	0.9	0.0	0.0		
H090-h090	15cm	24h	114	0.028	0.113	0.110	0.9	82.5	0.9	0.0	0.0		
H096-h096	15cm	24h	113	0.028	0.110	0.107	0.0	80.5	0.9	0.0	0.0		
H102-h102	15cm	24h	112	0.029	0.116	0.113	0.9	81.2	0.9	0.0	0.0		
H108-h108	15cm	24h	111	0.030	0.113	0.109	0.0	82.9	0.0	0.0	0.0		
H114-h114	15cm	24h	110	0.031	0.122	0.118	0.9	80.0	0.9	0.0	0.0		
H120-h120	15cm	24h	109	0.031	0.127	0.124	1.8	78.0	0.9	0.0	0.0		

Table A7. Water level nowcast and forecast skill table for Sturgeon, NY.

Station: Sturgeon
Observed data time period from: 3/10/2016 to 4/12/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
H			7381	1.002									
h			7381	0.944									
H-h	15cm	24h	7381	0.058	0.091	0.071	0.4	92.5	0.1	1.9	0.1	0.00	0.89
AHW-ahw	15cm	24h	2	-0.239	0.241	0.047	0.0	0.0	0.0	0.0	0.0		
THW-thw	0.50hr	25h	2	0.350	0.430	0.354	0.0	50.0	0.0	0.0	0.0		
SCENARIO: SEMI-OPERATIONAL FORECAST													
H000-h000	15cm	24h	124	0.059	0.093	0.073	0.8	95.2	0.0	0.0	0.0		
H006-h006	15cm	24h	124	0.068	0.108	0.085	0.0	84.7	0.8	0.0	0.0		
H012-h012	15cm	24h	124	0.064	0.104	0.083	0.0	84.7	0.8	0.0	0.0		
H018-h018	15cm	24h	124	0.064	0.109	0.089	0.8	81.5	0.8	0.0	0.0		
H024-h024	15cm	24h	124	0.065	0.120	0.101	0.8	82.3	0.0	0.0	0.0		
H030-h030	15cm	24h	124	0.066	0.123	0.104	0.8	83.9	0.8	0.0	0.0		
H036-h036	15cm	24h	123	0.067	0.133	0.115	0.8	82.9	2.4	0.0	0.0		
H042-h042	15cm	24h	122	0.062	0.138	0.124	0.8	81.1	1.6	0.0	0.0		
H048-h048	15cm	24h	121	0.063	0.143	0.129	0.8	81.0	3.3	0.0	0.0		
H054-h054	15cm	24h	120	0.067	0.150	0.135	0.8	74.2	5.0	0.0	6.0		
H060-h060	15cm	24h	119	0.065	0.159	0.146	0.8	76.5	4.2	0.0	0.0		
H066-h066	15cm	24h	118	0.065	0.160	0.146	0.8	74.6	5.1	0.0	6.0		
H072-h072	15cm	24h	117	0.064	0.171	0.159	0.9	69.2	5.1	0.0	0.0		
H078-h078	15cm	24h	116	0.057	0.167	0.158	0.9	74.1	3.4	0.0	0.0		
H084-h084	15cm	24h	115	0.058	0.169	0.160	1.7	72.2	5.2	0.0	6.0		
H090-h090	15cm	24h	114	0.060	0.180	0.170	3.5	66.7	4.4	0.0	0.0		
H096-h096	15cm	24h	113	0.061	0.178	0.169	2.7	67.3	5.3	0.0	0.0		
H102-h102	15cm	24h	112	0.062	0.179	0.169	2.7	67.9	7.1	0.0	0.0		
H108-h108	15cm	24h	111	0.064	0.177	0.166	0.9	65.8	8.1	0.0	12.0		
H114-h114	15cm	24h	110	0.064	0.181	0.170	1.8	66.4	6.4	0.0	6.0		
H120-h120	15cm	24h	109	0.064	0.187	0.177	2.8	66.1	5.5	6.0	0.0		

Table A8. Water level nowcast and forecast skill table for Buffalo, NY.

Station: Buffalo
Observed data time period from: 3/10/2016 to 4/12/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
H			7381	1.003									
h			7381	0.943									
H-h	15cm	24h	7381	0.060	0.103	0.084	0.7	89.4	0.4	2.2	1.2	0.00	0.89
AHW-ahw	15cm	24h	4	-0.194	0.234	0.151	25.0	50.0	0.0	0.0	0.0		
ALW-alw	15cm	24h	2	0.286	0.286	0.030	0.0	0.0	50.0	0.0	0.0		
THW-thw	0.50hr	25h	4	0.125	1.383	1.590	25.0	0.0	25.0	0.0	0.0		
TLW-tlw	0.50hr	25h	2	-0.100	0.412	0.566	0.0	50.0	0.0	0.0	0.0		
SCENARIO: SEMI-OPERATIONAL FORECAST													
H000-h000	15cm	24h	124	0.056	0.106	0.090	0.8	87.9	0.0	0.0	0.0		
H006-h006	15cm	24h	124	0.067	0.123	0.103	0.0	81.5	1.6	0.0	0.0		
H012-h012	15cm	24h	124	0.063	0.119	0.101	0.0	82.3	0.8	0.0	0.0		
H018-h018	15cm	24h	124	0.063	0.129	0.113	0.8	77.4	0.8	0.0	0.0		
H024-h024	15cm	24h	124	0.065	0.140	0.125	0.8	77.4	0.8	0.0	0.0		
H030-h030	15cm	24h	124	0.065	0.143	0.128	0.8	76.6	2.4	0.0	0.0		
H036-h036	15cm	24h	123	0.066	0.154	0.140	0.8	77.2	4.1	0.0	0.0		
H042-h042	15cm	24h	122	0.061	0.158	0.146	1.6	77.9	4.9	0.0	0.0		
H048-h048	15cm	24h	121	0.063	0.164	0.152	0.8	74.4	3.3	0.0	0.0		
H054-h054	15cm	24h	120	0.066	0.170	0.157	1.7	70.8	6.7	0.0	6.0		
H060-h060	15cm	24h	119	0.063	0.181	0.170	1.7	68.9	5.0	0.0	6.0		
H066-h066	15cm	24h	118	0.063	0.181	0.170	0.8	70.3	5.1	0.0	6.0		
H072-h072	15cm	24h	117	0.062	0.191	0.181	2.6	66.7	6.0	0.0	6.0		
H078-h078	15cm	24h	116	0.054	0.189	0.182	2.6	70.7	4.3	0.0	6.0		
H084-h084	15cm	24h	115	0.055	0.192	0.185	3.5	68.7	6.1	0.0	6.0		
H090-h090	15cm	24h	114	0.057	0.204	0.197	4.4	59.6	7.0	0.0	6.0		
H096-h096	15cm	24h	113	0.058	0.204	0.196	3.5	61.9	8.8	0.0	12.0		
H102-h102	15cm	24h	112	0.060	0.205	0.197	3.6	63.4	8.0	0.0	12.0		
H108-h108	15cm	24h	111	0.062	0.203	0.194	3.6	65.8	9.0	0.0	12.0		
H114-h114	15cm	24h	110	0.062	0.205	0.197	4.5	60.0	7.3	0.0	12.0		
H120-h120	15cm	24h	109	0.062	0.213	0.205	6.4	56.9	6.4	6.0	0.0		
AHW-ahw	15cm	24h	2	-0.391	0.407	0.156	50.0	0.0	0.0				
ALW-alw	15cm	24h	2	0.271	0.306	0.200	0.0	50.0	50.0				
THW-thw	0.50hr	25h	2	0.400	0.721	0.848	0.0	50.0	50.0				
TLW-tlw	0.50hr	25h	2	0.500	0.583	0.424	0.0	50.0	0.0				

APPENDIX B. WATER TEMPERATURE SKILL ASSESSMENT TABLES

The following tables are the summary results from the standard NOS skill assessment performed for 4/1/2015 to 12/31/2015. The exact time period for each station may differ depending on the availability of water temperature observations. The tables are listed in the order of the stations in Table 4.

Table B1. Water temperature nowcast and forecast skill table for Oregon, OH.

Station: Oregon
Observed data time period from: 6/30/2015 to 8/11/2015
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
T			35768	22.508									
t			35768	21.217									
T-t	3.0c	24h	35768	1.291	1.711	1.123	0.0	94.0	0.0	0.0	0.0		0.95
SCENARIO: SEMI-OPERATIONAL FORECAST													
T000-t000	3.0c	24h	489	1.280	1.735	1.173	0.0	93.3	0.0	0.0	0.0		
T006-t006	3.0c	24h	489	1.242	1.670	1.118	0.0	94.1	0.0	0.0	0.0		
T012-t012	3.0c	24h	489	1.266	1.711	1.152	0.0	94.1	0.0	0.0	0.0		
T018-t018	3.0c	24h	489	1.279	1.721	1.153	0.0	92.8	0.0	0.0	0.0		
T024-t024	3.0c	24h	489	1.272	1.719	1.158	0.0	93.3	0.0	0.0	0.0		
T030-t030	3.0c	24h	489	1.294	1.740	1.165	0.0	93.7	0.0	0.0	0.0		
T036-t036	3.0c	24h	489	1.306	1.760	1.181	0.0	92.8	0.0	0.0	0.0		
T042-t042	3.0c	24h	489	1.317	1.782	1.201	0.0	92.0	0.0	0.0	0.0		
T048-t048	3.0c	24h	489	1.337	1.778	1.173	0.0	92.4	0.0	0.0	0.0		
T054-t054	3.0c	24h	489	1.364	1.807	1.185	0.0	92.0	0.0	0.0	0.0		
T060-t060	3.0c	24h	489	1.385	1.836	1.206	0.0	92.4	0.0	0.0	0.0		
T066-t066	3.0c	24h	489	1.400	1.833	1.185	0.0	92.2	0.0	0.0	0.0		
T072-t072	3.0c	24h	489	1.424	1.842	1.169	0.0	91.6	0.0	0.0	0.0		
T078-t078	3.0c	24h	489	1.442	1.868	1.188	0.0	92.2	0.0	0.0	0.0		
T084-t084	3.0c	24h	489	1.469	1.902	1.210	0.0	91.2	0.0	0.0	0.0		
T090-t090	3.0c	24h	489	1.510	1.951	1.237	0.0	90.2	0.0	0.0	0.0		
T096-t096	3.0c	24h	489	1.559	1.998	1.251	0.0	89.0	0.0	0.0	0.0		
T102-t102	3.0c	24h	489	1.623	2.060	1.269	0.0	87.1	0.2	0.0	0.0		
T108-t108	3.0c	24h	490	1.676	2.111	1.284	0.0	86.3	0.4	0.0	6.0		
T114-t114	3.0c	24h	491	1.703	2.128	1.277	0.0	84.7	0.2	0.0	0.0		
T120-t120	3.0c	24h	492	1.739	2.170	1.298	0.0	84.3	0.0	0.0	0.0		

Table B2. Water temperature nowcast and forecast skill table for Marblehead OH.

Station: Marblehead
Observed data time period from: 4/1/2015 to 1/2/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
T			61880	16.603									
t			61880	15.400									
T-t	3.0c	24h	61880	1.203	1.817	1.363	0.0	90.6	0.0	0.0	0.0		0.98
SCENARIO: SEMI-OPERATIONAL FORECAST													
T000-t000	3.0c	24h	852	1.134	1.742	1.323	0.0	91.8	0.0	0.0	0.0		
T006-t006	3.0c	24h	852	1.106	1.722	1.320	0.0	92.1	0.0	0.0	0.0		
T012-t012	3.0c	24h	852	1.097	1.725	1.332	0.0	91.5	0.0	0.0	0.0		
T018-t018	3.0c	24h	852	1.086	1.725	1.341	0.0	91.8	0.0	0.0	0.0		
T024-t024	3.0c	24h	852	1.079	1.722	1.343	0.0	91.8	0.0	0.0	0.0		
T030-t030	3.0c	24h	852	1.070	1.719	1.347	0.0	91.1	0.0	0.0	0.0		
T036-t036	3.0c	24h	851	1.077	1.721	1.344	0.0	90.5	0.0	0.0	0.0		
T042-t042	3.0c	24h	850	1.079	1.730	1.353	0.0	90.8	0.0	0.0	0.0		
T048-t048	3.0c	24h	849	1.088	1.755	1.379	0.0	90.6	0.0	0.0	0.0		
T054-t054	3.0c	24h	848	1.099	1.769	1.387	0.0	90.8	0.0	0.0	0.0		
T060-t060	3.0c	24h	847	1.112	1.775	1.384	0.0	90.8	0.1	0.0	0.0		
T066-t066	3.0c	24h	846	1.122	1.781	1.384	0.0	91.0	0.1	0.0	0.0		
T072-t072	3.0c	24h	845	1.145	1.801	1.391	0.0	90.2	0.1	0.0	0.0		
T078-t078	3.0c	24h	844	1.182	1.831	1.400	0.0	90.5	0.1	0.0	0.0		
T084-t084	3.0c	24h	843	1.216	1.872	1.425	0.0	89.6	0.1	0.0	0.0		
T090-t090	3.0c	24h	842	1.247	1.922	1.464	0.0	88.6	0.2	0.0	0.0		
T096-t096	3.0c	24h	841	1.278	1.953	1.478	0.0	87.2	0.1	0.0	0.0		
T102-t102	3.0c	24h	840	1.326	1.999	1.497	0.0	86.0	0.1	0.0	0.0		
T108-t108	3.0c	24h	840	1.363	2.048	1.529	0.0	84.9	0.1	0.0	0.0		
T114-t114	3.0c	24h	840	1.389	2.088	1.560	0.0	84.3	0.1	0.0	0.0		
T120-t120	3.0c	24h	840	1.417	2.127	1.588	0.0	82.1	0.1	0.0	0.0		

Table B3. Water temperature nowcast and forecast skill table for West Erie, OH.

Station: West Erie
Observed data time period from: 7/24/2015 to 12/13/2015
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
T			51314	18.789									
t			51314	17.678									
T-t	3.0c	24h	51314	1.111	2.538	2.282	2.5	81.2	0.0	45.1	0.0		0.95
SCENARIO: SEMI-OPERATIONAL FORECAST													
T000-t000	3.0c	24h	699	1.129	2.504	2.237	2.1	79.7	0.0	30.0	0.0		
T006-t006	3.0c	24h	699	1.089	2.467	2.215	2.3	81.0	0.0	30.0	0.0		
T012-t012	3.0c	24h	699	1.070	2.450	2.206	1.9	81.8	0.0	30.0	0.0		
T018-t018	3.0c	24h	700	1.060	2.444	2.204	1.9	81.3	0.0	12.0	0.0		
T024-t024	3.0c	24h	700	1.051	2.440	2.204	2.1	81.7	0.0	12.0	0.0		
T030-t030	3.0c	24h	699	1.041	2.488	2.262	2.3	80.7	0.0	12.0	0.0		
T036-t036	3.0c	24h	698	1.045	2.508	2.282	2.6	79.9	0.0	30.0	0.0		
T042-t042	3.0c	24h	697	1.055	2.514	2.283	2.6	79.8	0.0	30.0	0.0		
T048-t048	3.0c	24h	696	1.077	2.528	2.288	2.6	78.9	0.0	30.0	0.0		
T054-t054	3.0c	24h	696	1.116	2.546	2.290	2.3	79.2	0.0	30.0	0.0		
T060-t060	3.0c	24h	697	1.144	2.560	2.291	2.2	79.3	0.0	12.0	0.0		
T066-t066	3.0c	24h	697	1.162	2.570	2.294	2.4	77.5	0.0	30.0	0.0		
T072-t072	3.0c	24h	697	1.181	2.595	2.312	2.3	77.3	0.0	30.0	0.0		
T078-t078	3.0c	24h	697	1.206	2.640	2.350	2.3	77.3	0.0	30.0	0.0		
T084-t084	3.0c	24h	697	1.231	2.680	2.382	2.3	75.5	0.0	12.0	0.0		
T090-t090	3.0c	24h	697	1.255	2.693	2.384	2.2	74.5	0.0	24.0	0.0		
T096-t096	3.0c	24h	697	1.300	2.702	2.370	2.2	74.5	0.1	18.0	0.0		
T102-t102	3.0c	24h	697	1.360	2.734	2.373	2.4	73.7	0.0	12.0	0.0		
T108-t108	3.0c	24h	697	1.407	2.756	2.372	2.2	73.0	0.0	12.0	0.0		
T114-t114	3.0c	24h	697	1.429	2.776	2.381	2.0	71.3	0.1	18.0	0.0		
T120-t120	3.0c	24h	698	1.451	2.806	2.403	1.9	71.9	0.4	24.0	0.0		

Table B4. Water temperature nowcast and forecast skill table for Cleveland, OH.

Station: Cleveland
Observed data time period from: 4/1/2015 to 1/2/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
T			61880	16.487									
t			61880	15.660									
T-t	3.0c	24h	61880	0.826	2.279	2.124	0.0	79.2	0.1	0.0	2.6		0.97
SCENARIO: SEMI-OPERATIONAL FORECAST													
T000-t000	3.0c	24h	852	0.682	2.191	2.084	0.0	80.8	0.0	0.0	0.0		
T006-t006	3.0c	24h	852	0.651	2.184	2.086	0.0	82.0	0.1	0.0	0.0		
T012-t012	3.0c	24h	852	0.624	2.175	2.084	0.0	82.9	0.0	0.0	0.0		
T018-t018	3.0c	24h	852	0.618	2.196	2.108	0.1	82.6	0.1	0.0	0.0		
T024-t024	3.0c	24h	852	0.618	2.214	2.127	0.2	81.9	0.2	6.0	0.0		
T030-t030	3.0c	24h	852	0.617	2.221	2.135	0.2	82.0	0.1	6.0	0.0		
T036-t036	3.0c	24h	851	0.630	2.226	2.136	0.4	82.3	0.4	6.0	0.0		
T042-t042	3.0c	24h	850	0.656	2.255	2.159	0.2	81.9	0.6	0.0	6.0		
T048-t048	3.0c	24h	849	0.686	2.296	2.192	0.1	80.8	0.9	0.0	6.0		
T054-t054	3.0c	24h	848	0.714	2.334	2.224	0.1	79.4	0.8	0.0	6.0		
T060-t060	3.0c	24h	847	0.740	2.348	2.229	0.0	79.8	1.1	0.0	6.0		
T066-t066	3.0c	24h	846	0.779	2.386	2.257	0.0	78.3	0.9	0.0	6.0		
T072-t072	3.0c	24h	845	0.815	2.391	2.250	0.0	78.8	0.9	0.0	6.0		
T078-t078	3.0c	24h	844	0.871	2.420	2.259	0.0	78.8	1.4	0.0	6.0		
T084-t084	3.0c	24h	843	0.924	2.449	2.269	0.0	77.7	1.3	0.0	6.0		
T090-t090	3.0c	24h	842	0.966	2.490	2.296	0.0	76.6	1.7	0.0	6.0		
T096-t096	3.0c	24h	841	1.004	2.518	2.311	0.0	76.5	1.3	0.0	12.0		
T102-t102	3.0c	24h	840	1.043	2.557	2.336	0.0	75.4	1.4	0.0	12.0		
T108-t108	3.0c	24h	840	1.077	2.591	2.358	0.0	74.5	1.5	0.0	18.0		
T114-t114	3.0c	24h	840	1.109	2.614	2.369	0.0	75.0	1.4	0.0	12.0		
T120-t120	3.0c	24h	840	1.138	2.632	2.374	0.0	74.4	1.5	0.0	6.0		

Table B5. Water temperature nowcast and forecast skill table for Fairport, OH.

Station: Fairport
Observed data time period from: 5/16/2015 to 1/2/2016
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
T			61805	15.799									
t			61805	16.679									
T-t	3.0c	24h	61805	-0.879	2.794	2.652	8.2	81.3	0.0	105.7	0		0.96
SCENARIO: SEMI-OPERATIONAL FORECAST													
T000-t000	3.0c	24h	851	-1.076	2.904	2.699	8.7	78.6	0.0	120.0	0		
T006-t006	3.0c	24h	851	-1.092	2.920	2.710	8.9	78.7	0.0	120.0	0		
T012-t012	3.0c	24h	851	-1.095	2.924	2.713	8.8	78.8	0.0	120.0	0		
T018-t018	3.0c	24h	851	-1.087	2.926	2.718	9.3	79.4	0.0	120.0	0		
T024-t024	3.0c	24h	851	-1.064	2.923	2.724	9.0	79.8	0.0	114.0	0		
T030-t030	3.0c	24h	851	-1.041	2.914	2.723	8.9	80.0	0.0	108.0	0		
T036-t036	3.0c	24h	850	-1.015	2.895	2.713	9.3	80.4	0.0	108.0	0		
T042-t042	3.0c	24h	849	-0.967	2.874	2.707	8.8	81.0	0.0	102.0	0		
T048-t048	3.0c	24h	848	-0.917	2.847	2.696	8.8	81.4	0.0	96.0	0		
T054-t054	3.0c	24h	847	-0.862	2.832	2.699	8.5	81.9	0.0	84.0	0		
T060-t060	3.0c	24h	846	-0.809	2.815	2.698	8.4	82.9	0.0	84.0	0		
T066-t066	3.0c	24h	845	-0.750	2.811	2.711	7.8	83.0	0.1	84.0	0		
T072-t072	3.0c	24h	844	-0.700	2.783	2.696	8.1	82.1	0.0	90.0	0		
T078-t078	3.0c	24h	843	-0.643	2.770	2.696	7.9	82.6	0.0	84.0	0		
T084-t084	3.0c	24h	842	-0.583	2.758	2.697	7.4	82.9	0.0	90.0	0		
T090-t090	3.0c	24h	841	-0.546	2.770	2.717	7.0	82.5	0.0	90.0	0		
T096-t096	3.0c	24h	840	-0.515	2.773	2.726	7.4	82.3	0.0	192.0	0		
T102-t102	3.0c	24h	839	-0.464	2.781	2.743	7.3	82.7	0.0	174.0	0		
T108-t108	3.0c	24h	839	-0.437	2.791	2.758	6.9	81.6	0.0	84.0	0		
T114-t114	3.0c	24h	839	-0.402	2.801	2.773	7.2	81.8	0.4	174.0	0		
T120-t120	3.0c	24h	839	-0.381	2.809	2.785	7.4	81.2	0.0	174.0	0		

Table B6. Water temperature nowcast and forecast skill table for Port Stanley, ON.

Station: Port Stanley
Observed data time period from: 4/24/2015 to 5/13/2015
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
T			42518	17.618									
t			42518	16.596									
T-t	3.0c	24h	42518	1.022	2.223	1.974	0.5	80.6	0.3	7.4	3.2		0.97
SCENARIO: SEMI-OPERATIONAL FORECAST													
T000-t000	3.0c	24h	581	1.144	2.250	1.939	0.7	78.8	0.3	0.0	0.0		
T006-t006	3.0c	24h	581	1.159	2.221	1.896	0.5	80.0	0.3	0.0	0.0		
T012-t012	3.0c	24h	582	1.166	2.194	1.860	0.5	80.4	0.2	0.0	0.0		
T018-t018	3.0c	24h	582	1.174	2.224	1.891	0.5	81.8	0.3	0.0	0.0		
T024-t024	3.0c	24h	582	1.182	2.254	1.921	0.5	79.7	0.5	0.0	6.0		
T030-t030	3.0c	24h	582	1.176	2.273	1.947	0.5	79.7	0.5	0.0	6.0		
T036-t036	3.0c	24h	583	1.179	2.313	1.992	0.5	79.6	0.7	0.0	18.0		
T042-t042	3.0c	24h	582	1.184	2.322	1.999	0.3	79.4	0.7	0.0	18.0		
T048-t048	3.0c	24h	582	1.238	2.340	1.987	0.3	79.4	0.7	0.0	18.0		
T054-t054	3.0c	24h	580	1.266	2.350	1.981	0.3	80.9	0.7	0.0	18.0		
T060-t060	3.0c	24h	576	1.307	2.343	1.946	0.3	79.0	0.7	0.0	18.0		
T066-t066	3.0c	24h	575	1.328	2.323	1.908	0.3	79.1	0.5	0.0	18.0		
T072-t072	3.0c	24h	574	1.353	2.343	1.914	0.5	79.1	0.5	0.0	18.0		
T078-t078	3.0c	24h	576	1.404	2.424	1.979	0.5	75.9	0.5	0.0	18.0		
T084-t084	3.0c	24h	578	1.461	2.504	2.036	0.5	72.7	0.5	0.0	18.0		
T090-t090	3.0c	24h	580	1.506	2.556	2.067	0.5	71.0	0.5	0.0	18.0		
T096-t096	3.0c	24h	581	1.536	2.592	2.090	0.3	70.2	0.5	0.0	18.0		
T102-t102	3.0c	24h	580	1.597	2.633	2.096	0.3	68.8	0.5	0.0	12.0		
T108-t108	3.0c	24h	580	1.651	2.679	2.111	0.3	67.1	0.7	0.0	12.0		
T114-t114	3.0c	24h	578	1.671	2.689	2.108	0.3	66.8	0.5	0.0	0.0		
T120-t120	3.0c	24h	577	1.706	2.716	2.115	0.5	65.9	0.5	0.0	0.0		

Table B7. Water temperature nowcast and forecast skill table for Erie, PA nearshore buoy.

Station: Erie
Observed data time period from: 5/26/2015 to 6/13/2015
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
T			32759	20.791									
t			32759	20.014									
T-t	3.0c	24h	32759	0.777	1.393	1.157	0.0	96.6	0.1	0.0	3.6		0.97
SCENARIO: SEMI-OPERATIONAL FORECAST													
T000-t000	3.0c	24h	447	0.749	1.403	1.188	0.0	96.0	0.2	0.0	0.0		
T006-t006	3.0c	24h	447	0.747	1.418	1.207	0.0	95.3	0.0	0.0	0.0		
T012-t012	3.0c	24h	447	0.733	1.433	1.233	0.0	94.9	0.0	0.0	0.0		
T018-t018	3.0c	24h	447	0.739	1.465	1.267	0.0	94.2	0.0	0.0	0.0		
T024-t024	3.0c	24h	447	0.758	1.517	1.316	0.0	92.8	0.0	0.0	0.0		
T030-t030	3.0c	24h	447	0.770	1.537	1.332	0.0	93.3	0.0	0.0	0.0		
T036-t036	3.0c	24h	447	0.795	1.550	1.332	0.0	92.8	0.0	0.0	0.0		
T042-t042	3.0c	24h	448	0.806	1.535	1.307	0.0	93.3	0.0	0.0	0.0		
T048-t048	3.0c	24h	447	0.792	1.517	1.295	0.0	94.0	0.2	0.0	0.0		
T054-t054	3.0c	24h	447	0.771	1.480	1.265	0.0	94.0	0.2	0.0	0.0		
T060-t060	3.0c	24h	447	0.775	1.465	1.245	0.0	94.6	0.0	0.0	0.0		
T066-t066	3.0c	24h	446	0.788	1.467	1.238	0.0	95.1	0.0	0.0	0.0		
T072-t072	3.0c	24h	446	0.821	1.498	1.255	0.0	95.3	0.0	0.0	0.0		
T078-t078	3.0c	24h	445	0.867	1.548	1.284	0.0	92.6	0.2	0.0	0.0		
T084-t084	3.0c	24h	444	0.947	1.622	1.318	0.0	92.3	0.0	0.0	0.0		
T090-t090	3.0c	24h	443	1.037	1.704	1.354	0.0	91.4	0.0	0.0	0.0		
T096-t096	3.0c	24h	442	1.129	1.847	1.463	0.0	89.6	0.5	0.0	0.0		
T102-t102	3.0c	24h	443	1.208	1.930	1.507	0.0	87.6	0.7	0.0	6.0		
T108-t108	3.0c	24h	443	1.275	1.990	1.529	0.0	86.9	0.7	0.0	6.0		
T114-t114	3.0c	24h	444	1.357	2.078	1.576	0.0	84.0	0.9	0.0	6.0		
T120-t120	3.0c	24h	444	1.427	2.181	1.652	0.0	81.1	1.4	0.0	6.0		

Table B8. Water temperature nowcast and forecast skill table for Port Colborne, ON.

Station: Port Colborne
Observed data time period from: 4/24/2015 to 5/20/2015
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
T			55146	15.060									
t			55146	15.167									
T-t	3.0c	24h	55146	-0.107	1.604	1.601	0.5	92.2	0.3	9.3	13.7		0.98
SCENARIO: SEMI-OPERATIONAL FORECAST													
T000-t000	3.0c	24h	759	-0.064	1.544	1.544	0.7	93.5	0.3	6.0	0.0		
T006-t006	3.0c	24h	758	-0.051	1.515	1.515	0.7	94.1	0.1	6.0	0.0		
T012-t012	3.0c	24h	758	-0.030	1.499	1.500	0.7	94.2	0.0	6.0	0.0		
T018-t018	3.0c	24h	756	0.000	1.515	1.516	0.5	94.7	0.1	0.0	0.0		
T024-t024	3.0c	24h	753	0.029	1.531	1.532	0.4	94.2	0.3	0.0	6.0		
T030-t030	3.0c	24h	752	0.060	1.548	1.548	0.3	93.6	0.4	0.0	12.0		
T036-t036	3.0c	24h	754	0.080	1.584	1.583	0.3	93.6	0.5	0.0	18.0		
T042-t042	3.0c	24h	753	0.091	1.615	1.614	0.4	93.2	0.7	0.0	18.0		
T048-t048	3.0c	24h	753	0.099	1.628	1.627	0.4	92.8	0.7	0.0	18.0		
T054-t054	3.0c	24h	753	0.106	1.646	1.644	0.5	93.2	0.5	0.0	18.0		
T060-t060	3.0c	24h	753	0.130	1.626	1.622	0.5	93.5	0.5	6.0	18.0		
T066-t066	3.0c	24h	752	0.145	1.613	1.607	0.4	93.0	0.5	6.0	18.0		
T072-t072	3.0c	24h	752	0.179	1.614	1.605	0.5	93.2	0.5	0.0	18.0		
T078-t078	3.0c	24h	752	0.226	1.636	1.621	0.7	92.4	0.5	6.0	18.0		
T084-t084	3.0c	24h	751	0.268	1.681	1.661	0.7	91.6	0.5	6.0	18.0		
T090-t090	3.0c	24h	752	0.313	1.732	1.705	0.7	91.6	0.5	0.0	18.0		
T096-t096	3.0c	24h	753	0.365	1.743	1.706	0.4	91.2	0.5	0.0	18.0		
T102-t102	3.0c	24h	753	0.424	1.763	1.713	0.5	91.2	0.5	0.0	18.0		
T108-t108	3.0c	24h	752	0.461	1.778	1.718	0.5	90.8	0.5	6.0	12.0		
T114-t114	3.0c	24h	751	0.481	1.777	1.712	0.4	90.4	0.4	0.0	6.0		
T120-t120	3.0c	24h	750	0.531	1.775	1.695	0.4	90.3	0.4	0.0	0.0		

Table B9. Water temperature nowcast and forecast skill table for Buffalo, NY.

Station: Buffalo
Observed data time period from: 4/25/2015 to 12/8/2015
Data gap is filled using SVD method
Data are not filtered

VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%	
SCENARIO: SEMI-OPERATIONAL NOWCAST													
T			61275	15.203									
t			61275	15.033									
T-t	3.0c	24h	61275	0.170	1.240	1.229	0.0	97.3	0.0	0.3	0.0		0.99
SCENARIO: SEMI-OPERATIONAL FORECAST													
T000-t000	3.0c	24h	846	0.166	1.255	1.245	0.0	97.5	0.0	0.0	0.0		
T006-t006	3.0c	24h	846	0.107	1.230	1.226	0.1	97.3	0.0	0.0	0.0		
T012-t012	3.0c	24h	846	0.089	1.243	1.241	0.1	97.2	0.0	0.0	0.0		
T018-t018	3.0c	24h	846	0.081	1.252	1.251	0.1	97.2	0.0	0.0	0.0		
T024-t024	3.0c	24h	846	0.082	1.241	1.239	0.0	97.3	0.0	0.0	0.0		
T030-t030	3.0c	24h	845	0.093	1.234	1.231	0.0	97.5	0.0	0.0	0.0		
T036-t036	3.0c	24h	842	0.099	1.232	1.229	0.0	97.5	0.0	0.0	0.0		
T042-t042	3.0c	24h	839	0.111	1.238	1.234	0.0	97.7	0.0	0.0	0.0		
T048-t048	3.0c	24h	837	0.120	1.240	1.235	0.0	97.0	0.0	0.0	0.0		
T054-t054	3.0c	24h	836	0.142	1.243	1.236	0.0	97.2	0.0	0.0	0.0		
T060-t060	3.0c	24h	835	0.154	1.254	1.245	0.0	97.5	0.0	0.0	0.0		
T066-t066	3.0c	24h	835	0.172	1.271	1.260	0.0	96.6	0.0	0.0	0.0		
T072-t072	3.0c	24h	835	0.196	1.294	1.280	0.0	97.0	0.0	0.0	0.0		
T078-t078	3.0c	24h	835	0.217	1.325	1.307	0.0	96.5	0.0	0.0	0.0		
T084-t084	3.0c	24h	836	0.236	1.335	1.315	0.0	96.3	0.0	0.0	0.0		
T090-t090	3.0c	24h	836	0.254	1.370	1.347	0.0	96.3	0.0	0.0	0.0		
T096-t096	3.0c	24h	835	0.285	1.398	1.369	0.0	95.8	0.0	0.0	0.0		
T102-t102	3.0c	24h	834	0.310	1.424	1.391	0.0	95.4	0.0	0.0	0.0		
T108-t108	3.0c	24h	834	0.324	1.430	1.393	0.0	95.4	0.0	0.0	0.0		
T114-t114	3.0c	24h	834	0.347	1.467	1.426	0.0	95.4	0.0	0.0	0.0		
T120-t120	3.0c	24h	834	0.373	1.489	1.442	0.0	94.7	0.1	0.0	0.0		

ACRONYMS

CF	Central Frequency
CO-OPS	Center for Operational Oceanographic Products and Services
COMF	Coastal Ocean Modeling Framework
ECCC	Environment and Climate Change Canada
FVCOM	Finite Volume Community Ocean Model
GLERL	Great Lakes Environmental Research Laboratory
GLOFS	Great Lakes Operational Forecast System
HAB	Harmful Algal Bloom
HRRR	High Resolution Rapid Refresh
LEOFS	Lake Erie Operational Forecast System
LWD	Low Water Datum
MDNO	Maximum Duration of Negative Outliers
MDPO	Maximum Duration of Positive Outliers
NAM	North America Mesoscale
NCEP	National Centers for Environmental Prediction
NCO	NCEP Central Operations
NDBC	National Data Buoy Center
NDFD	National Digital Forecast Database
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
NOF	Negative Outlier Frequency
NOS	National Ocean Service
NWS	National Weather Service
NWSTG	National Weather Service Telecommunication Gateway
OAR	Office of Oceanic and Atmospheric Research
OFS	Operational Forecast System
OSU	The Ohio State University
POF	Positive Outlier Frequency
POM	Princeton Ocean Model
ROMS	Regional Ocean Modeling System
RMSE	Root Mean Square Error
SD	Standard Deviation
SM	Series Mean
USGS	United States Geological Survey
WCOSS	Weather and Climate Operational Supercomputing System