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IMPLEMENTATION OF THE UPGRADED LAKE ONTARIO OPERATIONAL FORECAST SYSTEM AND LAKE SUPERIOR OPERATIONAL FORECAST SYSTEM AND THE SEMI-OPERATIONAL NOWCAST/FORECAST SKILL ASSESSMENT

Silver Spring, Maryland
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noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

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National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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EXECUTIVE SUMMARY

The Lake Ontario Operational Forecast System (LOOFS) and Lake Superior Operational Forecast System (LSOFS), with the Finite Volume Community Ocean Model (FVCOM) as their hydrodynamic core, have been implemented to provide users with nowcasts (analyses of near present) and forecast guidance out to 120 hours of the 3-D physical conditions of Lakes Ontario and Superior—including surface water levels, 3-D water currents, and water temperature. LOOFS and LSOFS are two separate operational forecast systems set up in a similar way. The upgrade of LOOFS and LSOFS to FVCOM was the result of a collaborative project between the NOAA Office of Oceanic and Atmospheric Research (OAR) Great Lakes Environmental Research Laboratory (GLERL) and the National Ocean Service's (NOS) Coast Survey Development Laboratory (CSDL) and Center for Operational Oceanographic Products and Services (CO-OPS).

By increasing horizontal resolution and invoking advanced model schemes and algorithms, LOOFS and LSOFS are expected to provide more accurate predictions than the previous namesake forecast systems, which used the Great Lakes version of the Princeton Ocean Model (POMGL) as their core. The old versions of LOOFS and LSOFS were based on the Great Lakes Forecasting System developed by Ohio State University and the GLERL in the late 1980s and 1990s, using a customized POM hydrodynamic grid for each of the Great Lakes.

The final code version of the new LOOFS and LSOFS has been running reliably with no instability issues since the nowcast/forecast runs started in July 2021. Standard model skill assessment of the 12-month (August 1, 2021-August 1, 2022) semi-operational runs indicates that most targeted variables meet the NOS model skill criteria. The successful implementation of the new LOOFS and LSOFS on the NOAA Weather and Climate Operational Supercomputing System (WCOSS2) provides reliable forecast guidance on water levels, currents, and water temperatures to support NOS navigation customers.

In addition, the FVCOM ice module with Sea Ice Model (CICE) algorithms is incorporated into the latest Coastal Ocean Model Framework (COMF). As a result, ice coverage and thickness and velocity forecast capability can be turned on in all Great Lakes forecast systems, including the new LOOFS and LSOFS. The National Ice Center within the National Weather Service/National Center for Environmental Prediction's (NCEP) Ocean Prediction Center is in charge of integrating the Great Lakes Operational Forecast System (GLOFS) ice forecast guidance into a future official ice forecast for the Great Lakes. Ice-related model skill assessment, therefore, is not considered in this report.

This technical report documents how the NOS CO-OPS builds the control and static files for the High-Performance Computing (HPC) COMF to generate the required model forcing files to drive LOOFS and LSOFS. The nowcast and forecast guidance skill assessment is then presented. As the model's physics and the setups of LOOFS and LSOFS are the same, the implementation and skill assessments of the two forecast systems are documented in this single technical report.

1.0 INTRODUCTION

The National Ocean Service (NOS) had been running two namesake legend Operational Forecast Systems (OFS) since 2006 until the successful implementation of the new Finite Volume Community Ocean Model (FVCOM)-based Lake Ontario Operational Forecast System (LOOFS) and Lake Superior Operational Forecast System (LSOFS). The old models used the Great Lakes version of the Princeton Ocean Model (POMGL) as their core and had four daily nowcast and forecast cycles, which generated forecasts out to 60 hours. The horizontal grid resolutions of the old LOOFS and LSOFS were 5 km and 10 km, respectively. The nowcast cycles were forced by surface meteorological analyses of near real-time meteorological observations from over water and over land platforms, which were used to provide heat and radiation fluxes and wind stress to POMGL. The forecast cycles were forced by gridded surface wind and air temperature forecasts (2.5 km resolution) from the National Weather Service (NWS) National Digital Forecast Database (NDFD).

The old LOOFS and LSOFS nowcast and forecast guidance of water levels generally met the NOS-accepted criteria, which will be elaborated on in Section 3.3. However, due to low resolutions of model grid and out-of-date bathymetric data, the LOOFS and LSOFS underperformed in water levels at certain locations and times. In addition, they could not fully reproduce water levels under severe weather conditions for a nowcast cycle because the complexity of a weather system could not be completely represented with the low density of the meteorological observations. Generally, the surface water temperature nowcasts of the LOOFS and LSOFS exhibited an unrealistic high-frequency oscillation, possibly due to the coarse model grid resolution. Ice was not considered in the old LOOFS and LSOFS, which led to surface water temperature bias in the winter season.

In 2013, NOS and the Great Lakes Environmental Research Laboratory (GLERL) began a project to upgrade all Great Lakes Operational Forecast Systems (OFS) to provide improved lake predictions and guidance out to 120 hours. The FVCOM, with ice prediction capability from the Los Alamos Sea Ice Model (CICE), was selected as the core of the models due to its unstructured mesh design that would allow for higher horizontal resolution along the shore, as well as its incorporation of more advanced algorithms to improve heat flux boundary conditions.

The new FVCOM-based LOOFS and LSOFS, coupled with CICE, invokes more advanced model schemes and algorithms (e.g., Coupled Ocean-Atmosphere Response Experiment [COARE] 2.6 Bulk Algorithm [Fairall et al. 1996]) for surface heat flux. NOAA’s 3 arc-second bathymetry data are applied to delineate the land boundary. The horizontal model mesh of the LOOFS is composed of 64,000 triangular elements and 34,000 nodes (Figure 1), and the LSOFS is composed of 174,000 triangular elements and 91,000 nodes (Figure 2). The spatial resolution for both OFS varies from approximately 100 m near the shore to about 2.5 km offshore.

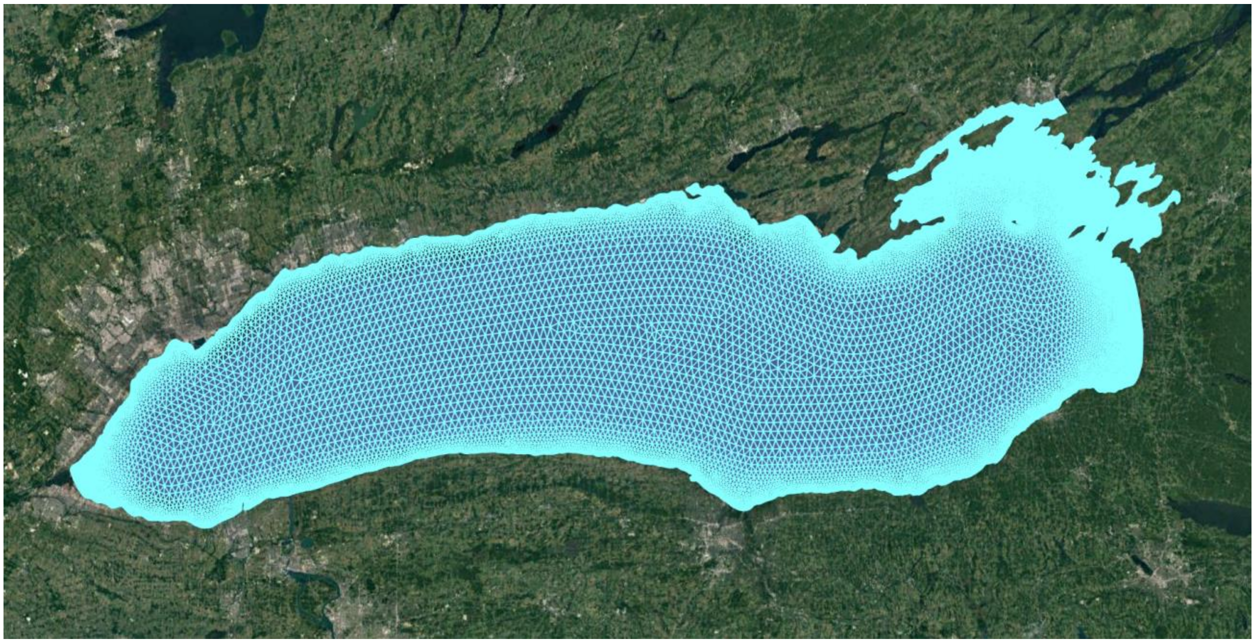

Figure 1. The Lake Ontario Operational Forecast System (LOOFS) domain and its high-resolution mesh.

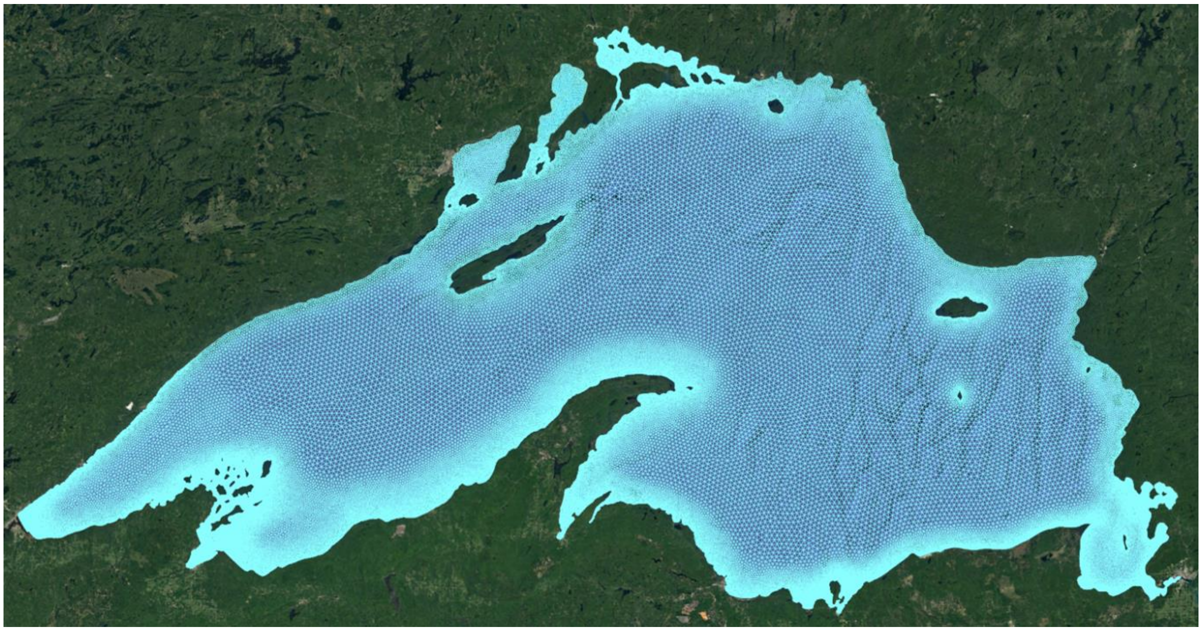

Figure 2. The Lake Superior Operational Forecast System (LSOFS) domain and its high-resolution mesh.

The grid generation module of the Surface-Water Modeling System software was used by GLERL to generate the unstructured model mesh. The model bathymetry was obtained by interpolating the GLERL digital bathymetry onto each unstructured FVCOM model mesh node, referenced to the International Great Lakes Datum. The model bathymetry of LOOFS and LSOFS is shown respectively in Figure 3 and Figure 4.

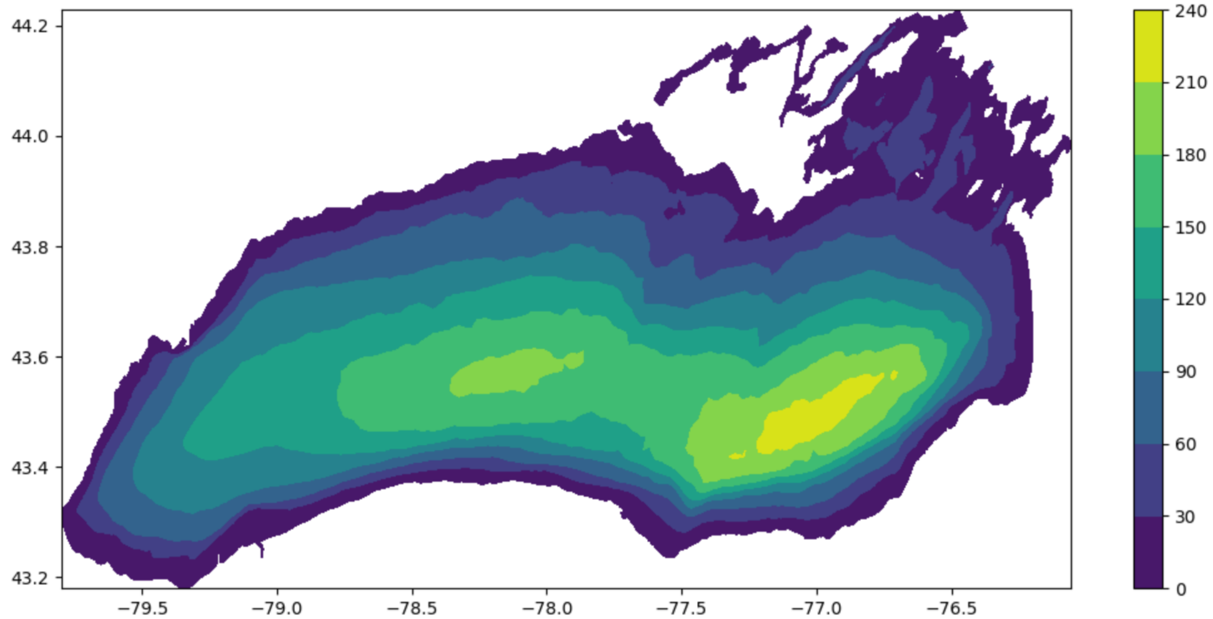

Figure 3. The Lake Ontario Operational Forecast System (LOOFS) bathymetry (in m).

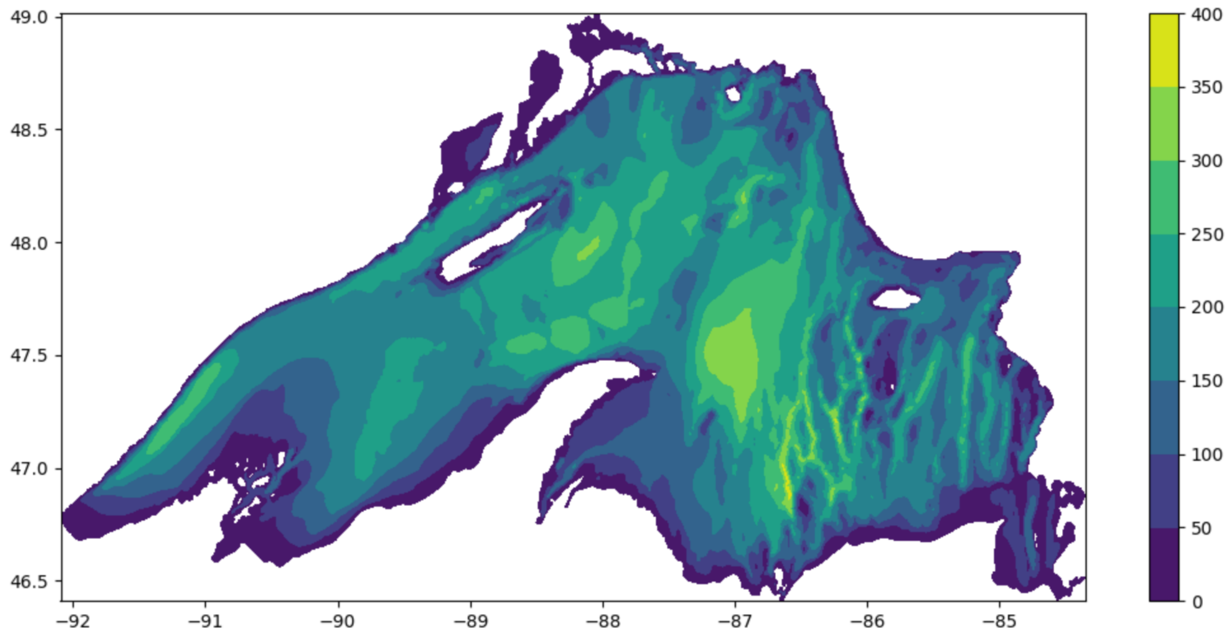

Figure 4. The Lake Superior Operational Forecast System (LSOFS) bathymetry (in m).

The LOOFS and LSOFS, with their forecast window extended to 120 hours, generate more accurate predictions than the previous namesake models. The successful implementation and operation of the new LOOFS and LSOFS provides more reliable information to help pilots and mariners safely and efficiently navigate through Lakes Ontario and Superior and also provides support for coastal zone management and hazard mitigation in the two lakes.

The model codes of the LOOFS and LSOFS were finalized in July 2021, and the models have since been running reliably in near real-time with no instability issues. A standard model skill assessment based on model results in a one year period indicates that predictions have improved for targeted variables, including water level and temperature.

This technical report documents how the NOS Center for Operational Oceanographic Products and Services (CO-OPS) creates the control and static files for the High-Performance Computing-Coastal Ocean Modeling Framework (HPC-COMF), which supports the LOOFS and LSOFS and other NOS forecast systems to generate the required model forcing files that are used to drive the LOOFS and LSOFS (Section 2). A nowcast and forecast skill assessment for the period of August 1, 2021-August 1, 2022, is then presented (Section 3).

2.0 MODEL NOWCAST/FORECAST CONFIGURATION

This section describes the generation of (1) meteorological surface forcing conditions, (2) river forcing conditions, (3) water level control, and (4) initial conditions for the LOOFS and LSOFS nowcast/forecast predictions. All these forcing condition files and the control are automatically generated by the HPC-COMF.

2.1 Meteorological Forcing Conditions

Meteorological forcing conditions for the LOOFS and LSOFS are generated by the HPC-COMF, similar to other existing NOS operational forecast systems. The **nos.loofs.ctl, nos.lsofs.ctl** files in **/nosofs.vx.x.x/fix/loofs/** and/**nosofs.vx.x.x/fix/lsofs/** control which NOAA numerical weather prediction model (or models) is used. For the LOOFS and LSOFS, the High-Resolution Rapid Refresh (HRRR) with 3 km resolution and NDFD with 5 km resolution are used by specifying the following two parameters in the **nos.loofs.ctl/nos.lsofs.ctl** control files:

export DBASE_MET_NOW=HRRR
export DBASE_MET_FOR=HRRR:NDFD

These control files indicate that HRRR is used for the nowcast and a hybrid of HRRR and NDFD is used for the forecast meteorological forcing conditions. The shell scripts of **exnos_ofs_prep.sh** within **/nosofs.vx.x.x/scripts/** and **nos_ofs_create_forcing_met.sh** within **/nosofs.vx.x.x/ush/** are launched to generate **nos.lxofs.met.nowcast.yyyymmdd.tccz.nc** and **nos.lxofs.met.forecast.yyyymmdd.tccz.nc** (where yyyy, mm, dd, and cc in “tccz” indicate the year, month, day, and cycle of the nowcast/forecast, respectively, and lxofs stands for loofs or lsofs). The required HRRR and NDFD model output files exist in the Weather and Climate Operational Supercomputing System (WCOSS) data tank.

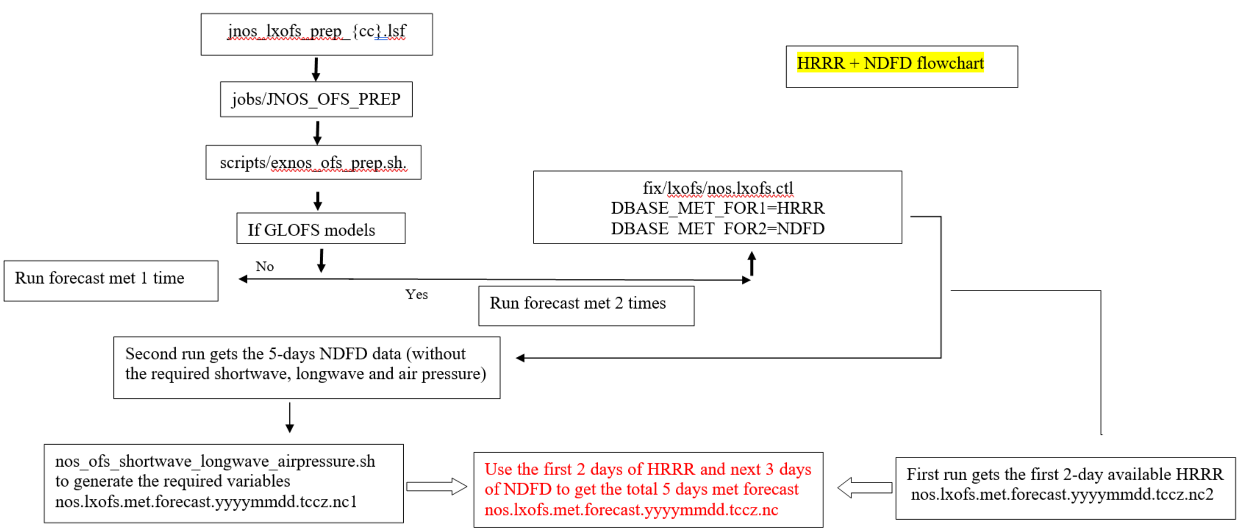

Figure 5. Flowchart of the High-Resolution Rapid Refresh (HRRR) and National Digital Forecast Database (NDFD) hybrid to generate a Lake Ontario Operational Forecast System (LOOFS) and Lake Superior Operational Forecast System (LSOFS) met forecast forcing file.

The reasons for using hybrid HRRR and NDFD for forecast met forcing are: (1) HRRR provides only 48 hours forecast, and (2) NDFD does not provide the FVCOM-model required air pressure or longwave and shortwave radiations.

As shown in Figure 5, first the COMF is to find all available HRRR forecast guidance, which can be up to 48 hourly grib2 files. All model required variables for the rest of the 120-hour forecast window, except for the 3 listed in the above (2), are available in the NDFD forecast output. Persistent air pressure, with the value from the last available hourly HRRR file, is enforced for the remaining of the 120 hours. Longwave and shortwave radiations for the remaining hours are derived from other available variables such as solar time, hour angle, and air temperature, among others (Parkinson and Washington 1979). The details of the calculation of longwave and shortwave radiations and the hybrid process to get air pressure for the forecast met forcing can be found in **nos_ofs_shortwave_longwave_airpressure.sh.**

For consistency in all Great Lakes, the existing Lake Erie Operational Forecast System (LEOFS) and Lake Michigan and Huron Operational Forecast System (LMHOFS) are also upgraded with the same method to get their forecast met forcing; ice forecast capability is also enabled in the two OFS.

2.2 River Forcing Conditions

The NWS National Water Model (NWM) analyses and predictions are, by default, used for the LOOFS and LSOFS river forcing conditions for the eight rivers of each model for both the nowcast and forecast cycles. The NWM analyses are used for the LOOFS and LSOFS nowcast cycles while the NWM predictions are used for the forecast cycles. The eight rivers of the LOOFS are the Niagara River (large inflow), Genesee River, Oswego River, Black River, Salmon River, St. Lawrence River (outflow), Humber River, and Don River. The eight rivers of the LSOFS are the St. Louis River, Bad River, Ontonagon River, Kaministiquia River, Black Sturgeon River, Nipigon River, Pic River, and St. Marys River (outflow). The NWM control files are **nos.loofs.nwm.reach.dat** and **nos.lsofs.nwm.reach.dat** (Table 1) for the LOOFS and LSOFS, respectively. The flag value 1 in Table 1 indicates the river in NWM domain and 0 means out of domain.

```
8                   8
15568145 0            1777788 1
15537927 1            1813329 1
21972746 1           11947179 1
15506742 1          904020529 1
21624085 1           41042723 1
25293362 0           41039850 1
41027973 1           41038175 1
41027941 1           41041390 1
```

Figure 6. The National Water Model (NWM) reach ID and Flag for the Lake Ontario Operational Forecast System (LOOFS; left) and the Lake Superior Operational Forecast System (LSOFS; right).

Real-time river discharge observations at a U.S. Geological Survey (USGS) river gauge are used as backup in the nowcast cycle when NWM predictions are not available for a river. In the forecast cycle, persistent river discharge and river water temperature will be used with the corresponding latest measured value. Table 2 and Table 3 show parts of the LOOFS and LSOFS river control files. If neither NWM predictions or USGS observations are available, climatological river discharge and water temperature will be employed for this river.

```
Section 1: Information about USGS or NOS gauges where real-time discharges and/or water temperature observations are available
 22    8  1.0   !! NIJ NRIVERS DELT
RiverID STATION_ID NWS_ID AGENCY_ID Q_min Q_max Q_mean  T_min  T_max  T_mean  Q_Flag TS_Flag   River_Name
  1   0421964005   YNTN6    USGS 5000.0 30000.0 5800.0   0.0    28.0   12.0      1      1      "Niagara River"
  2     04231600   ROHN6    USGS    0.0   603.0  400.0   0.0    28.0   12.0      1      1      "Genesee River"
  3     04249000   OSON6    USGS    0.0   365.0  114.0   0.0    28.0   12.0      1      1      "Oswego River"
  4     04260500   ARTN6    USGS    0.0   271.0  125.0   0.0    28.0   12.0      1      1      "Black River"
  5     04250200   PNVN6    USGS    0.0   271.0  125.0   0.0    28.0   12.0      1      1      "Salmon River"
  6     04260901   BRKQ6    USGS 5000.0 30000.0 7800.0   0.0    28.0   12.0      1      1      "St Law River"
  7      02HC003   XXXXX    ECCC    0.0   271.0  125.0   0.0    28.0   12.0      1      1      "Humber River"
  8      02HC024   XXXXX    ECCC    0.0   271.0  125.0   0.0    28.0   12.0      1      1      "Don River"
Section 2: Information of FVCOM grids/locations to specify river inputs
 GRID_ID NODE_ID ELE_ID DIR     FLAG RiverID_Q  Q_Scale RiverID_T    T_Scale         River_Basin_Name
  1        1586    1586   0        3     1         0.25      1          1.0         "Niagara River "
  2        1588    1588   0        3     1         0.25      1          1.0         "Niagara River"
  3        1589    1589   0        3     1         0.25      1          1.0         "Niagara River"
  4        1591    1591   0        3     1         0.25      1          1.0         "Niagara River"
  5       19606   19606   0        3     2         1.00      2          1.0         "Genesee River"
  6       37420   37420   0        3     3         1.00      3          1.0         "Oswego River"
  7        1403    1403   0        3     4         1.00      4          1.0         "Black River"
  8       26075   26075   0        3     5         1.00      5          1.0         "Salmon River"
  9       28863   28863   0        3     6        -0.083     6          1.0         "St Law US River"
 10       28862   28862   0        3     6        -0.083     6          1.0         "St Law US River"
 11       28861   28861   0        3     6        -0.083     6          1.0         "St Law US River"
 12       39695   39695   0        3     6        -0.083     6          1.0         "St Law CAN River"
 13       40323   40323   0        3     6        -0.083     6          1.0         "St Law CAN River"
 14       40925   40925   0        3     6        -0.083     6          1.0         "St Law CAN River"
 15       41493   41493   0        3     6        -0.083     6          1.0         "St Law CAN River"
 16       41495   41495   0        3     6        -0.083     6          1.0         "St Law CAN River"
 17       42033   42033   0        3     6        -0.084     6          1.0         "St Law CAN River"
 18       42035   42035   0        3     6        -0.084     6          1.0         "St Law CAN River"
 19       42547   42547   0        3     6        -0.084     6          1.0         "St Law CAN River"
 20       42550   42550   0        3     6        -0.084     6          1.0         "St Law CAN River"
```

Figure 7. Part of the Lake Ontario Operational Forecast System (LOOFS) river control file.

```
Section 1: Information about USGS or NOS gauges where real-time discharges and/or water temperature observations are available
 20    8  1.0   !! NIJ NRIVERS DELT
RiverID STATION_ID NWS_ID AGENCY_ID Q_min Q_max Q_mean  T_min  T_max  T_mean  Q_Flag TS_Flag   River_Name
  1     04024000   SCNM5    USGS    0.0  5000.0 3115.0   0.0    28.0   12.0      1      1      "St. Louis River"
  2     04027000   ODAW3    USGS    0.0  6003.0 4955.0   0.0    28.0   12.0      1      1      "Bad River"
  3     04040000   RKLM4    USGS    0.0   365.0  114.0   0.0    28.0   12.0      1      1      "Ontonagon River"
  4     04127885   XXXXX    USGS    0.0   271.0  125.0   0.0    28.0   12.0      1      1      "St. Marys River"
  5      02AB006   XXXXX    ECCC    0.0   271.0  125.0   0.0    28.0   12.0      1      1      "Kaministiquia River"
  6      02AC002   XXXXX    ECCC    0.0   271.0  125.0   0.0    28.0   12.0      1      1      "Black Sturgeon River"
  7      02AD012   XXXXX    ECCC    0.0   271.0  125.0   0.0    28.0   12.0      1      1      "Nipigon River"
  8      02BB003   XXXXX    ECCC    0.0   271.0  125.0   0.0    28.0   12.0      1      1      "Pic River"
Section 2: Information of FVCOM grids/locations to specify river inputs
 GRID_ID NODE_ID ELE_ID DIR     FLAG RiverID_Q  Q_Scale RiverID_T    T_Scale         River_Basin_Name
  1        6507    6507   0        3     1         0.50      1          1.0         "St Louis River "
  2        4848    4848   0        3     1         0.50      1          1.0         "St Louis River "
  3       17383   17383   0        3     2         1.00      2          1.0         "Bad River"
  4       50785   50785   0        3     3         1.00      3          1.0         "Ontonagon River"
  5       56316   56316   0        3     5         0.33      5          1.0         "Kaministiquia River"
  6       56313   56313   0        3     5         0.33      5          1.0         "Kaministiquia River"
  7       56307   56307   0        3     5         0.33      5          1.0         "Kaministiquia River"
  8       42987   42987   0        3     6         1.00      6          1.0         "Black Sturgeon River"
  9       43543   43543   0        3     7         0.33      7          1.0         "Nipigon River"
 10       43545   43545   0        3     7         0.33      7          1.0         "Nipigon River"
 11       43546   43546   0        3     7         0.33      7          1.0         "Nipigon River"
 12       99022   99022   0        3     8         0.33      8          1.0         "Pic River"
 13      173932  173932   0        3     4        -0.12      4          1.0         "St Marys River"
 14      173950  173950   0        3     4        -0.12      4          1.0         "St Marys River"
 15      173967  173967   0        3     4        -0.12      4          1.0         "St Marys River"
 16      173982  173982   0        3     4        -0.12      4          1.0         "St Marys River"
 17      173994  173994   0        3     4        -0.13      4          1.0         "St Marys River"
 18      174003  174003   0        3     4        -0.13      4          1.0         "St Marys River"
 19      174010  174010   0        3     4        -0.13      4          1.0         "St Marys River"
 20      174013  174013   0        3     4        -0.13      4          1.0         "St Marys River"
```

Figure 8. Part of the Lake Superior Operational Forecast System (LSOFS) river control file.

The temperature of waters flowing into Lakes Superior and Ontario are specified at USGS station 04024000 (St. Louis River) and USGS station 0421964005 YNTN6 (Niagara River), respectively.

For the LOOFS, a special river discharge calculation is executed for the Niagara River and St. Lawrence River. As NWM does not provide reliable discharge values for these 2 rivers, and USGS only provides their river flow and river stage data in the National Center for Environmental Prediction (NCEP) data tank, an experimental formula is employed to derive discharge from flow and stage values. It should be noted that each river has its own experimental parameters for the calculation. The calculation details can be found in **nos_ofs_create_forcing_river.f**.

2.3 Water Level Control

Unaccounted inflow/outflow due to inflow from additional tributaries, runoff, and over-lake precipitation and evaporation is determined via FVCOM's precipitation and evaporation parameters. Artificial "precipitation" or "evaporation" is calculated based on the difference between the modeled spatially-averaged water level and the average of measured water level over the previous five days at six stations for the LSOFS and four stations for the LOOFS from CO-OPS' National Water Level Observation Network (NWLON) and Canadian water level observation system. The details on how to calculate the artificial precipitation and evaporation in each cycle can be found in the Lakes Michigan and Huron technical report (Peng et al. 2019).

2.4 Initial Conditions

In COMF, **nos_ofs_read_restart_fvcom.f** is used to read the FVCOM-based OFS model initial/restart file. If the values and attributes of the variable "time" are correct, then the initial file is not changed. Otherwise, the following actions may be conducted if needed:

(1) Change the reference time (the attribute of "units" in the initial NetCDF file) of the variables "time" and "Itime" in the initial file if the reference time is different from ${BASE_DATE} specified in the control file, such as "**nos.loofs.ctl**."
(2) Recompute the values of the variables "time" and "Itime" using ${BASE_DATE} as the reference time in the initial file if (1) is conducted.
(3) If the "time" is 48 hours less than ${time_nowcastend}, then the nowcast cycle is terminated. An initial condition file has to be constructed manually with 0 surface elevation, 0 velocity, and reasonable water temperature and salinity.

For additional information, see Zhang and Yang (2014).

In the case of the LOOFS or LSOFS, the output restart file from the nowcast of the last cycle is used to generate the initial condition for the nowcast of the current cycle. For example, **nos.loofs.rst.nowcast.YYYYMMDD.t00z.nc** from the nowcast at 00z will be renamed (after minor "time" and "Itime" related revision) to **nos.loofs.init.nowcastYYYYMMDD.t06z.nc** for the nowcast at 06z. The restart file from the 06z cycle nowcast (**nos.loofs.rst.nowcast.YYYYMMDD.t06z.nc renamed to nos.loofs.init.nowcastYYYYMMDD.t12z.nc**) will be used for the 06z forecast cycle, and so on.

3.0 NOWCAST/FORECAST MODEL SKILL ASSESSMENT

The LOOFS and LSOFS performed robustly, producing reasonable predictions from their nowcast and forecast cycles for water level and temperature over the model's skill assessment period of August 1, 2021-August 1, 2022. This is visually validated by the cycle-by-cycle nowcast and forecast results as shown in Figures 6-7. However, to provide more scientific and objective analysis of the model performance, documented skill assessment metrics (Zhang et al. 2009) were used. Section 3.1 describes the cycle-by-cycle nowcast and forecast results. Section 3.2 briefly reviews the basics of skill assessment statistics, followed by the results of the LOOFS and LSOFS nowcast and forecast skill assessment in Section 3.3.

3.1 Nowcast and Forecast Results

The latest cycle's nowcast and forecast predictions are displayed on the LOOFS and LSOFS operational websites: https://tidesandcurrents.noaa.gov/ofs/loofs/loofs.html and https://tidesandcurrents.noaa.gov/ofs/lsofs/lsofs.html. The cycle-by-cycle results (Figures 6-7) show the water level, surface currents, and water temperature in nowcast and forecast time windows. Generally, the model results agree well with observations where measurements are available. The results of the standard NOS model skill assessment and a further model evaluation for a winter storm event can be found in Section 3.3.

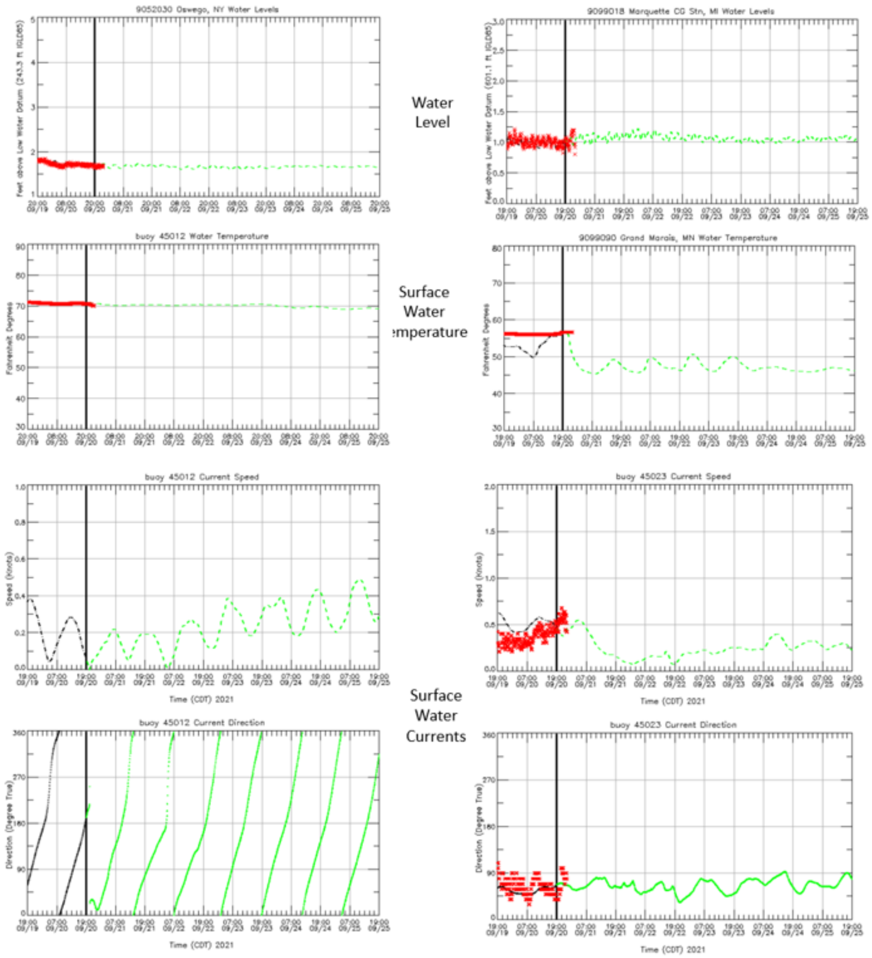

Figure 9. Examples of time series of water level, surface water temperature, and surface current at selected stations of the Lake Ontario Operational Forecast System **(**LOOFS) and the Lake Superior Operational Forecast System (LSOFS).

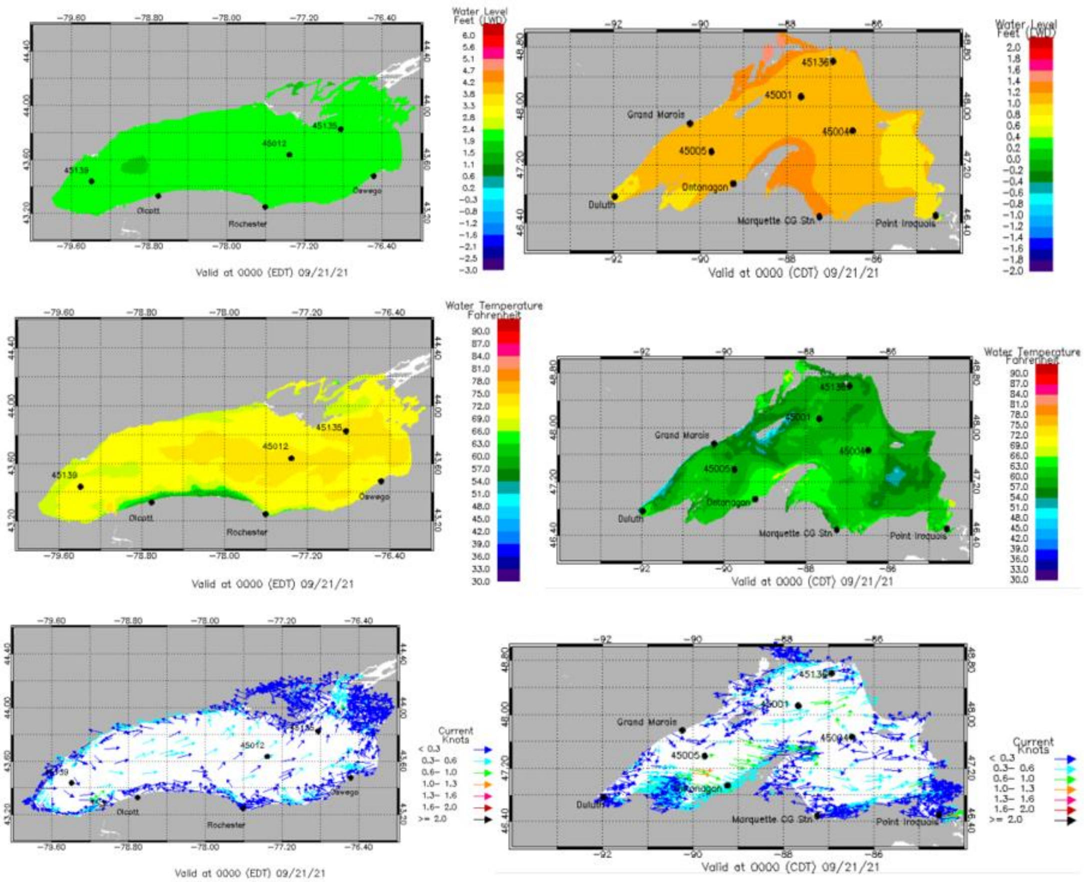

Figure 10. Examples of fields of water level, surface water temperature, and surface current at selected time of the Lake Ontario Operational Forecast System (LOOFS) and the Lake Superior Operational Forecast System (LSOFS).

3.2 Skill Assessment Software System and Data Source

This section provides an overview of the NOS model skill assessment statistics and software, and discusses the data sources used for the nowcast and forecast model skill assessment.

3.2.1 Skill assessment statistics

Skill assessment is an objective measurement of the performance of a model when systematically compared with observations. NOS skill assessment criteria were created for evaluating the performance of circulation models (Hess et al. 2003), and a software package was subsequently developed to compute these criteria using standard file format output from the models (Zhang et al. 2009). The software computes the skill assessment scores automatically using files containing observations and nowcast and forecast model results. A standard suite of skill assessment statistics is defined in Table 1.

Table 1. Skill assessment statistics (Hess et al. 2003).

Variable	Explanation
Error	The error is defined as the predicted value, p, minus the reference (observed or astronomical tide value, r : $e_i = p_i - r_i$.
SM	Series Mean. The mean value of a series y. Calculated as: $\overline{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$.
RMSE	Root Mean Square Error. Calculated as: $RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} e_i^2}$.
SD	Standard Deviation. Calculated as: $SD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N} (e_i - \overline{e})^2}$
CF(X)	Central Frequency. Fraction (percentage) of errors that lie within the limits $\pm$X.
POF(X)	Positive Outlier Frequency. Fraction (percentage) of errors that are greater than X.
NOF(X)	Negative Outlier Frequency. Fraction (percentage) of errors that are less than -X.
MDPO(X)	Maximum Duration of Positive Outliers. A positive outlier event is two or more consecutive occurrences of an error greater than X. MDPO is the length of time (based on the number of consecutive occurrences) of the longest event.
MDNO(X)	Maximum Duration of Negative Outliers. A negative outlier event is two or more consecutive occurrences of an error less than -X. MDNO is the length of time (based on the number of consecutive occurrences) of the longest event.

The target frequencies of the associated statistics based on navigation requirements are:

$$CF(X) \geq 90\%, \quad POF(2X) \leq 1\%, \quad NOF(2X) \leq 1\%, \quad MDPO(2X) \leq N, \quad MDNO(2X) \leq N$$

The NOS-accepted error criteria (X) are: 0.15 m for water level, 3.0 °C for surface water temperature, and 0.26 m per second (m/s) for surface currents. As the surface currents measurement was only available at one station, Buoy 45023, for a short period of time which did not meet the assessment requirement, this report only performs model skill assessments for water level and surface water temperature.

3.2.2 Data sources

As shown in Tables 5-6 and Figures 8-9, the observed data were collected from 2 NOAA entities—CO-OPS and the NWS National Data Buoy Center (NDBC)—and Environment and Climate Change Canada (ECCC). Real-time measurements of water level and surface water temperature were compared with the model results, and model skill assessments were performed to evaluate the model skill statistics. Observed data at some stations were not available for certain periods. The missing data periods (in days) are indicated in the headers of the corresponding model skill assessment tables in Appendices A and C.

Table 2. The observation stations used for skill assessment of the Lake Ontario Operational Forecast System (LOOFS). In the table, WL and T represent water level and water temperature, respectively.

Owner	Station ID	Lat	Lon	Station Name	Variables
CO-OPS	9052030	43.340	-78.730	Olcott	WL
CO-OPS	9052058	43.270	-77.630	Rochester	WL
CO-OPS	9052030	43.460	-76.510	Oswego	WL
CO-OPS	9052000	44.130	-76.340	Cape Vincent	WL
ECCC	13590	43.950	-78.170	Coburg	WL
ECCC	13988	44.220	-76.520	Kingston	WL
NDBC	45012	43.620	-77.410	East Lake Ontario	T
NDBC	45139	43.240	-79.540	West Lake Ontario	T
NDBC	45135	43.790	-76.870	Prince Edward Pt	T
NDBC	45159	43.770	-78.980	NW Lake Ontario	T

Figure 11. The locations of observation stations used for the Lake Ontario Operational Forecast System (LOOFS) model skill assessment. Water level stations are in white, and water temperature stations are in red.

Table 3. The observation stations used for skill assessment of the Lake Superior Operational Forecast System (LSOFS). In the table, WL and T represent water level and water temperature, respectively.

Owner	Station ID	Lat	Lon	Station Name	Variables
CO-OPS	9099004	46.490	-84.630	Point Iroquois	WL
CO-OPS	9099090	47.750	-90.300	Grand Marais	WL,T
CO-OPS	9099044	46.880	-89.300	Ontonagon	WL
CO-OPS	9099018	46.550	-87.300	Marquette	WL
CO-OPS	9099064	46.780	-92.000	Duluth	WL,T
ECCC	10750	47.956	-84.898	Michipicoten	WL
ECCC	10220	48.830	-87.500	Rossport	WL
ECCC	10050	48.400	-89.200	Thunder Bay	WL
NDBC	45023	47.270	-88.610	North Entry Buoy	T
NDBC	45004	47.585	-86.585	East Superior	T
NDBC	45001	48.060	-87.780	Middle Superior	T
NDBC	45006	47.300	-89.800	West Superior	T

Figure 12. The locations of observation stations used for the Lake Superior Operational Forecast System (LSOFS) model skill assessment. Water level stations are in white, and water temperature stations are in red. Yellow indicates that the station has both water level and water temperature observations.

3.3 Nowcast and Forecast Skill Assessment

The LOOFS and LSOFS semi-operational nowcast and forecast assessment period was from August 1, 2021-August 1, 2022, and the results from these simulations were organized into time series for analysis using the skill assessment software. The Canadian data were manually processed due to their special format. Generally, root mean square error (RMSE), central frequency (CF), negative outlier frequency (NOF), positive outlier frequency (POF), maximum duration of negative outliers (MDNO), and maximum duration of positive outliers (MDPO) at each station satisfy the error criteria for most variables in both nowcast and forecast scenarios. The results of the skill assessment for water level and temperature are discussed in the following subsections.

3.3.1 Results of water level skill assessment

The skill assessment used six water level stations (Table 2 and Figure 8) in Lake Ontario and eight stations (Table 3 and Figure 9) in Lake Superior. Modeled water levels generally agree well with observations. A typical cycle of nowcast/forecast (N/F) results is shown in Figure 6.

The RMSEs of nowcast water levels at all stations are less than 0.15 m, the accepted error criteria for navigation applications. While the RMSE of water level in all stations of LOOFS is less than 0.04 m (Figure 10), the maximum RMSE of LSOFS can be around 0.06 m at Point Iroquois and Duluth (Figure 11).

The RMSEs of forecast water levels at all stations are less than the NOS accepted error criteria (0.15 m). The skill assessment results for both lakes can be found in Figures 12-13. In general, RMSE increases as forecast lead times increase from 6 hours to 120 hours. The maximum water level RMSEs are 0.05 m and 0.09 m, respectively, for LOOFS and LSOFS.

The tables in Appendix A show details of water elevation model skill assessment results at all stations of both OFS for all skill metrics. Generally, nowcast and forecast CF values at all locations range from 91.3% to 100.0% (where ≥90% is the accepted error criteria). With no tide, the high CF values indicate that the meteorological forcing used in the model is reliable so the subsequent modeled water levels are synchronized, in magnitude and timing, with observations.

NOF and POF are much less than 1% (the NOS accepted error criteria) at all stations for both nowcast and forecast scenarios. The values are 0.0 at most stations. The maximum NOF and POF occurs at Duluth with 0.4% and 0.3%, respectively.

Both MDNO and MDPO at all stations are much less than the required 24-hour criteria for both scenarios. At most stations, the values are 0.0 hours for both MDNO and MDPO.

Time series comparisons of modeled and observed water levels at all 14 stations are shown in Appendix B, and the old POMGL-based model results are also shown for evaluation. Generally, both FVCOM- and POMGL-based models agree well with the observations at every station, and no conclusion can be straightforwardly made as to if the new models outperform the old ones.

For further model skill evaluation, Figure 14 shows the water level nowcast RMSE comparisons between the new LOOFS and LSOFS and the old ones at the 14 stations. FVCOM-based new models outperformed POMGL-based models at most stations except for Duluth, Ontonagon, and Rossport, which are all in Lake Superior. A possible reason for the downgrade of the FVCOM-based models at some locations lies in the fact that POMGL-based models used sporadic measured meteorological forcing to drive the model in the nowcast cycle which might be more accurate at certain locations than the HHHR results which are used to drive FVCOM-based models.

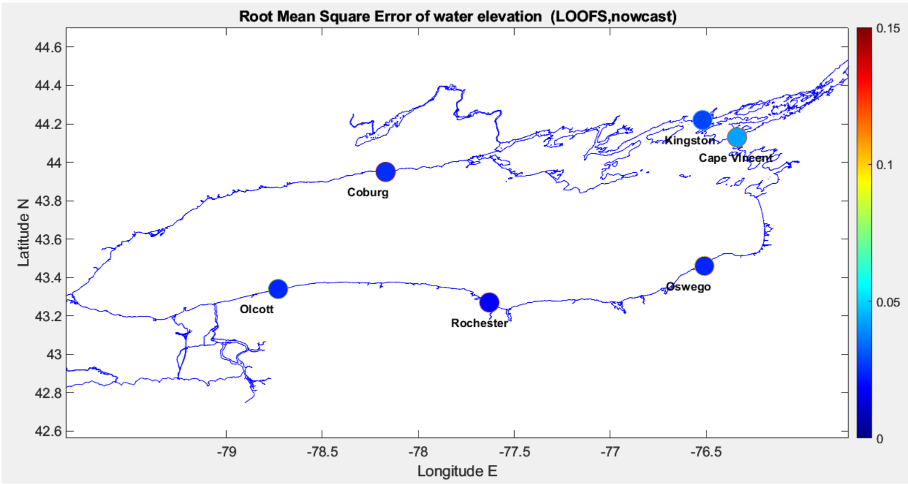

Figure 13. Nowcast root mean square error (RMSE; in m) of water level for the Lake Ontario Operational Forecast System (LOOFS).

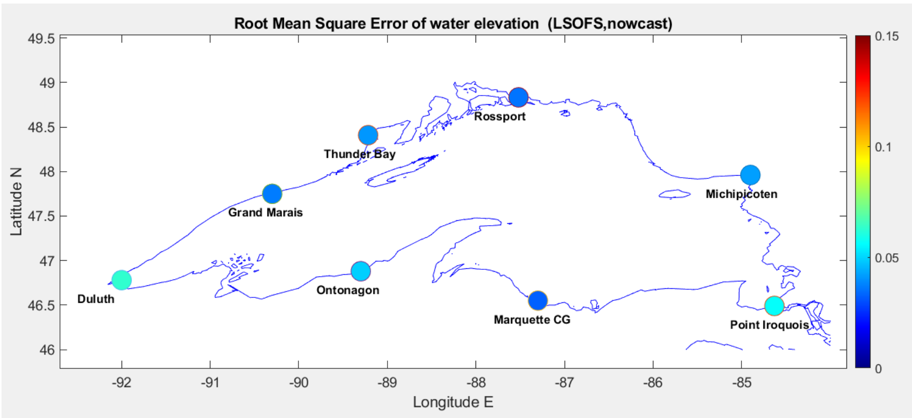

Figure 14. Nowcast root mean square error (RMSE; in m) of water level for the Lake Superior Operational Forecast System (LSOFS).

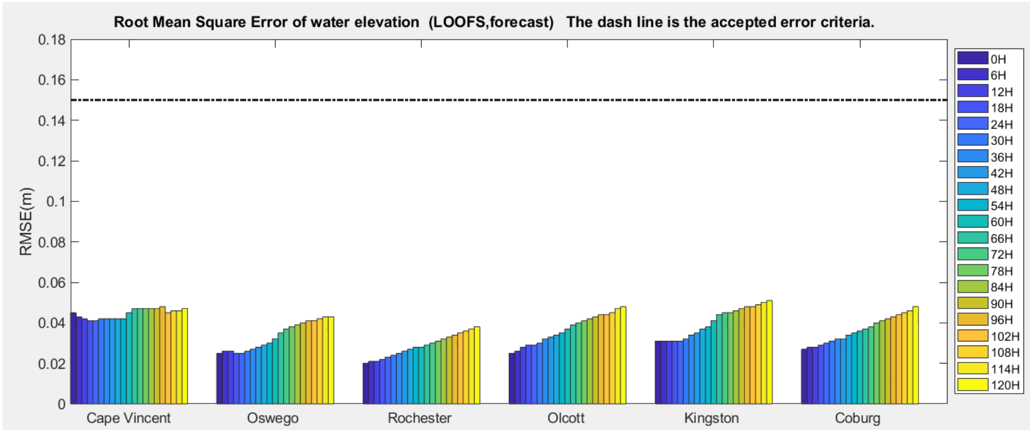

Figure 15. Forecast root mean square error (RMSE; in m) of water level for the Lake Ontario Operational Forecast System (LOOFS).

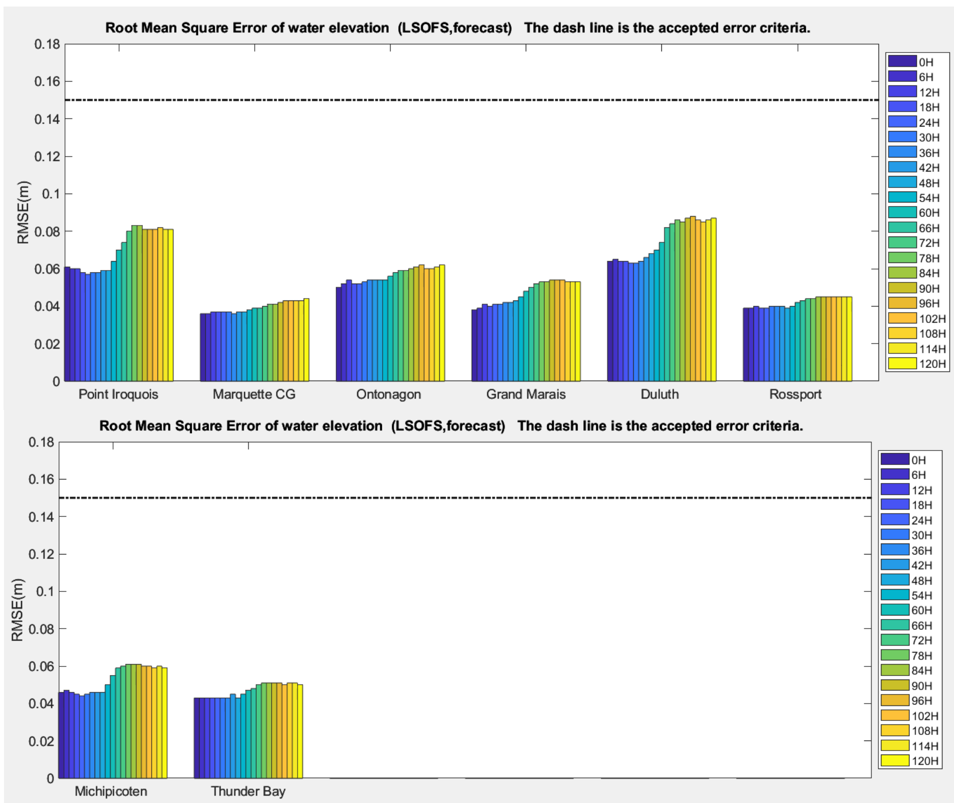

Figure 16. Forecast root mean square error (RMSE; in m) of water level for the Lake Superior Operational Forecast System (LSOFS).

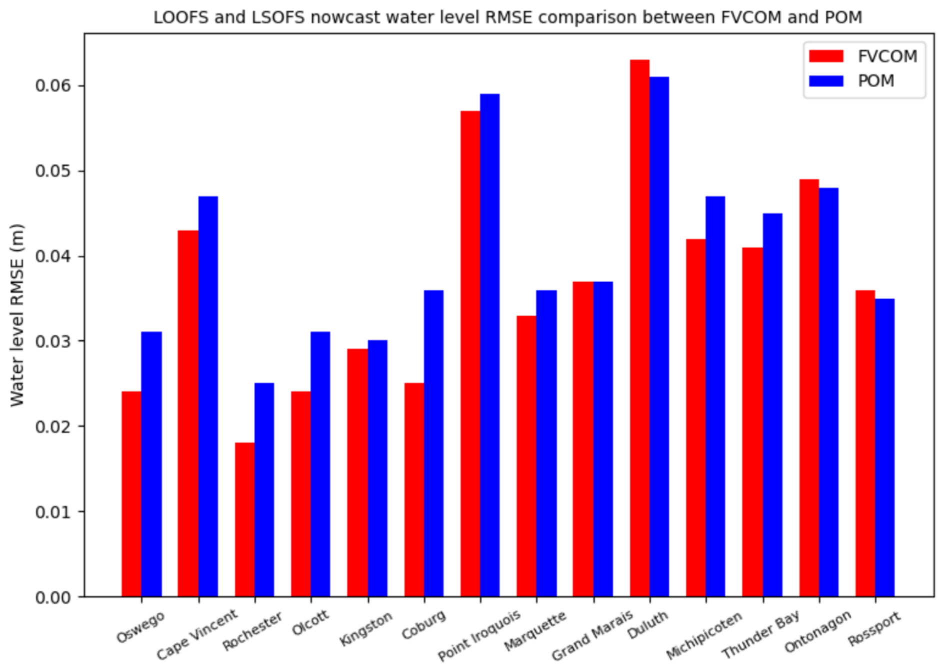

Figure 17. Nowcast water level root mean square error (RMSE) comparison between Finite Volume Community Ocean Model (FVCOM) and Princeton Ocean Model (POM) models at all stations.

It should be noted that the original observed water levels at all stations were adjusted with the consideration of the glacial isostatic rebound process of the region. This is because the water level measurement is currently still referred to the International Great Lakes Datum (IGLD) 1985, which needs to be updated approximately every 25-30 years due to isostatic rebound. Figure 15 shows the tilting speed (mm/year) of the Great Lakes region determined by high-accuracy GPS measurements. Details of the IGLD and the glacial isostatic rebound adjustment can be found at **https://tidesandcurrents.noaa.gov/datum-updates/igld/**.

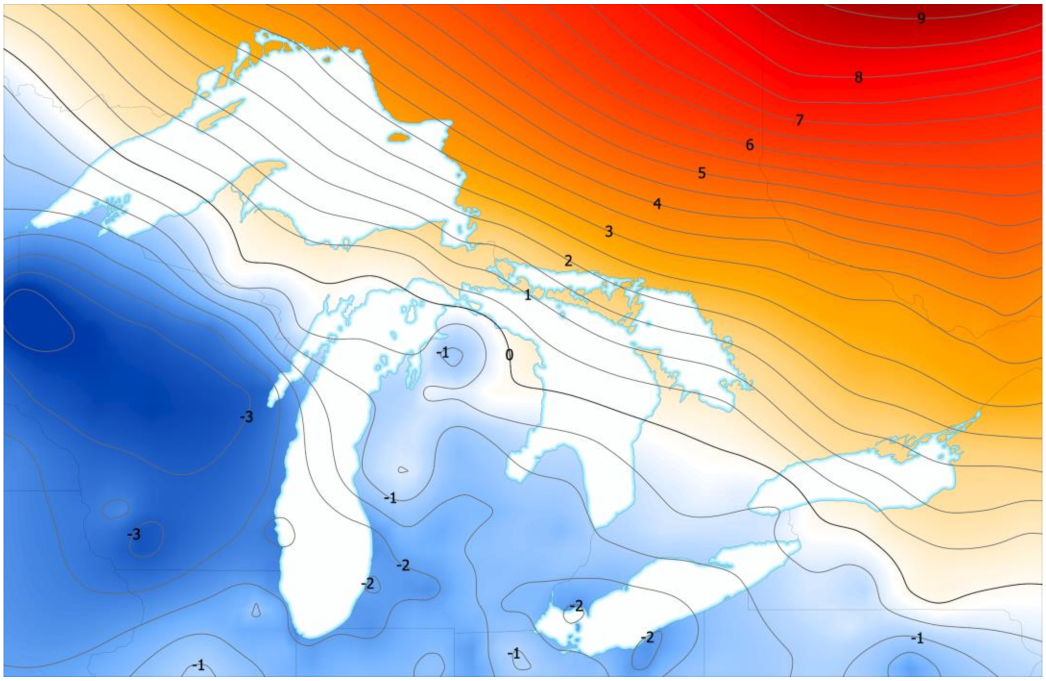

Figure 18. The vertical velocities (mm/year) across the Great Lakes region due to glacial isostatic rebound. Positive indicates upward movement.

3.3.2 Results of surface water temperature skill assessment

Model evaluation and skill assessment for surface water temperature were conducted at four LOOFS stations and six LSOFS stations. Their locations can be found in Tables 5-6 and Figures 8-9. Two are CO-OPS year-round NWLON stations, five are NDBC seasonal buoys, and three are ECCC stations.

Nowcast RMSEs of surface water temperature are illustrated in Figures 16 and 17 respectively, for LOOFS and LSOFS. Corresponding RMSEs of forecast are shown in Figures 18 and 19. By comparison, the model's skill in predicting water temperature is not as good as the water level skill described previously. However, the RMSEs of most stations are close to 3.0 °C, which is the NOS water temperature accepted error criteria for navigation applications. The RMSEs at four stations in Lake Superior are 1~2 °C larger than the criteria. The fact that the skill assessment of surface water temperature in Lake Superior is lower than in Lake Ontario is also found in the previous hindcast skill assessment from GLERL, and the root reason is still under investigation. Appendix C indicates that the error is the lowest at North Entry Buoy, whose RMSE value is only 1.51 °C, and the error is the highest, with 4.94 °C, at Duluth. It should be noted that the water temperature observation is not available in the winter season for all stations, and NOS model skill assessment software is designed in such a way that it selects only the longest continuous time period to perform the skill assessment in which both observed and modeled data are available.

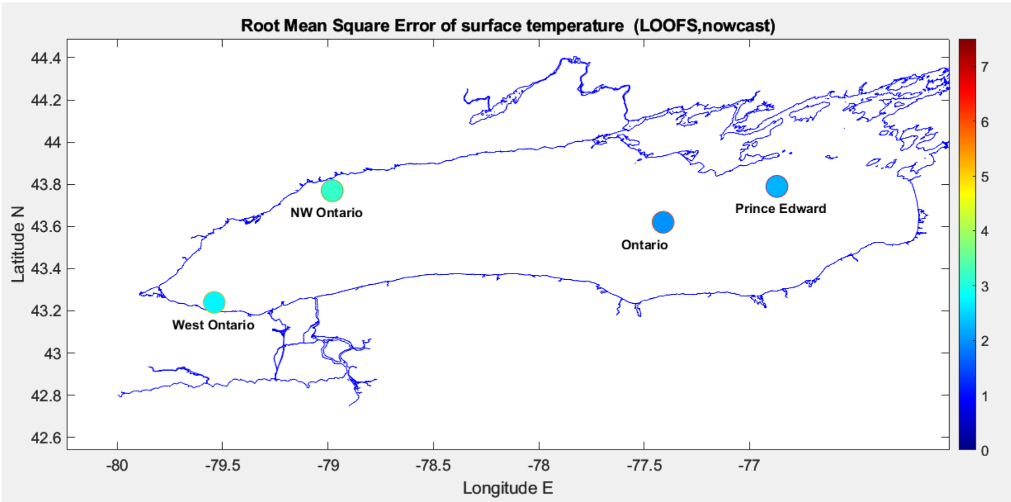

Figure 19. Nowcast root mean square error (RMSE) of surface water temperature for the Lake Ontario Operational Forecast System (LOOFS).

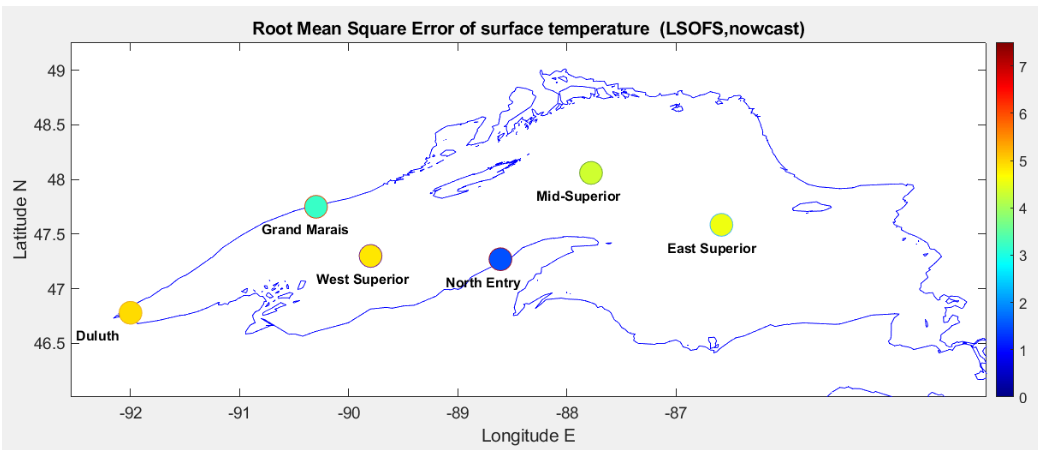

Figure 20. Nowcast root mean square error (RMSE) of surface water temperature for the Lake Superior Operational Forecast System (LSOFS).

Further details of model skill assessment results at all stations can be found in the tables in Appendix C. As shown in the tables, CF did not meet the required 90% criterion at most stations, most notably at Duluth (26.5% for nowcast). NOF meets the criterion at all stations except for Duluth where the value is as large as 9.0% for nowcast. POF fails criteria at almost all stations. This is especially the case for the three deep water stations in Lake Superior—East Superior, Mid Superior, and West Superior—where the POF are 23.8%, 19.3%, and 19.2%, respectively, for the nowcast scenario. This is a strong indication that modeled surface water temperature is much higher than observations. The huge MDPO values at these three stations (over 1000 hours at East Superior) are clear evidence that the model overpredicts water temperature in the warm-up season of 2022 as will be described in detail later.

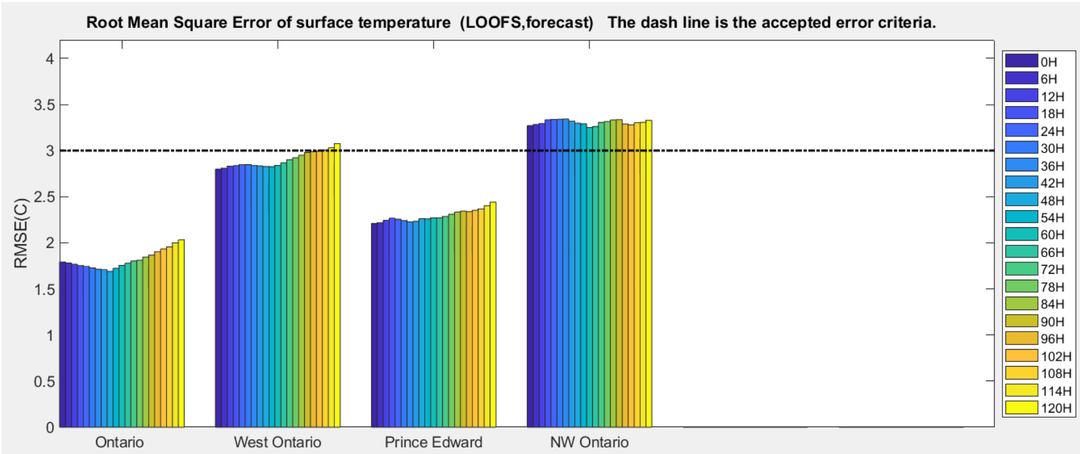

Figure 21. Forecast root mean square error (RMSE) of surface water temperature for the Lake Ontario Operational Forecast System (LOOFS).

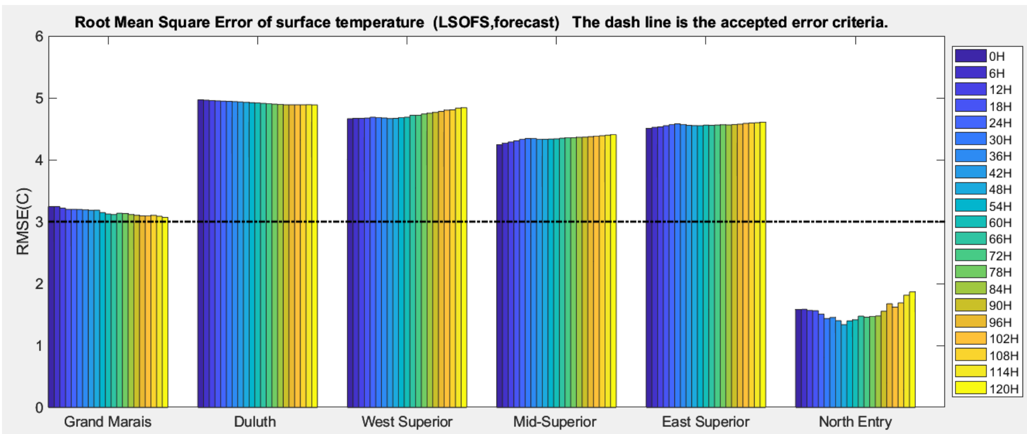

Figure 22. Forecast root mean square error (RMSE) of surface water temperature for the Lake Superior Operational Forecast System (LSOFS).

Time series comparisons of modeled versus observed surface water surface temperature are shown in Appendix D. Modeled results generally agree with the observations at most locations, except for East Superior, Mid Superior, and West Superior in the 2022 warming up season (Figures D-8, D-9, and D-10). POM-based model results are also shown in these figures for comparison purposes. The issue of water temperature overprediction in the 2022 spring season is clearly displayed in the time series of these three stations.

Lake Superior had the coldest spring-to-summer season of 2022 for the past 25 years. Local newspapers and TV channels had reported this event, and GLERL attributed this extreme cold surface water temperature to the extreme cold air temperature over Lake Superior. The air temperature used in the nowcast cycles of the model is found to be much higher than observations. Figure 20 shows two time series of air temperatures, observed versus the one that is fed into the model at Mid Superior (Buoy 45001) and East Superior (45004). The nowcast model air temperature, obtained from HRRR, is about 7.0~8.0 °C higher than observed at the end of July. This is the main reason why the modeled surface water temperature is vastly higher than observed in Figures D-8, D-9, and D-10 and for the subsequent huge POF and MDPO results in the model skill assessment as mentioned previously.

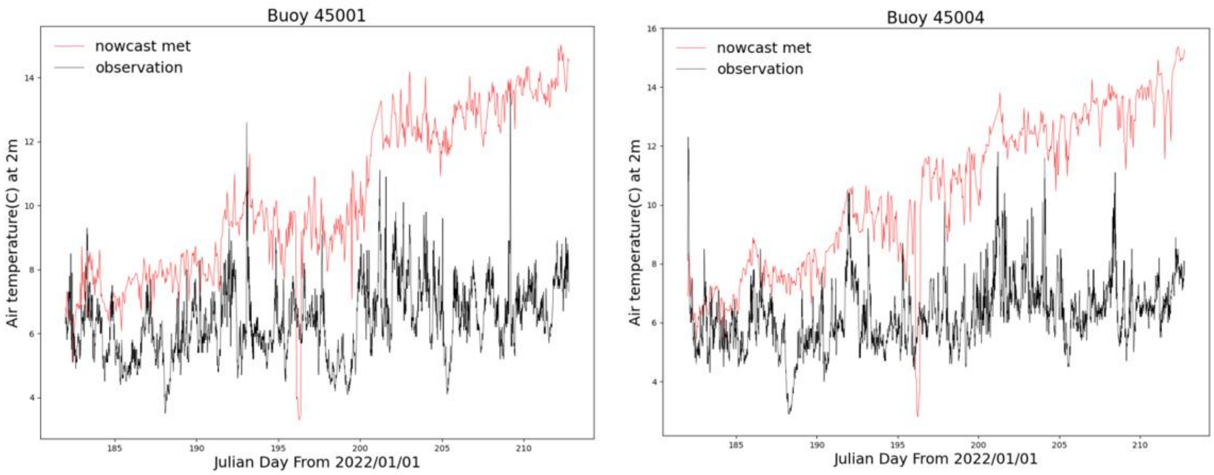

Figure 23. The comparison of observed and High-Resolution Rapid Refresh (HRRR) modeled air temperature in July 2022 at 2 National Data Buoy Center (NDBC) buoys in Lake Superior.

The nowcast RMSE comparison between FVCOM- and POM-based models are shown in Figure 21. For LOOFS, as expected, the new model's RMSE is lower than the previous POMGL-based model at most stations. But in Lake Superior, in terms of RMSE, the new FVCOM-based model's water temperature skill is lower than the previous POMGL-based LSOFS. The skill downgrade does not stem from the FVCOM model itself, but rather from the inferior surface heat flux results from HRRR as previously mentioned. This indicates that the hourly surface meteorological observations from land, coastal, and over water observing platforms which are used in POM based LSOFS are seemingly more reliable than HRRR forecast guidance during the 2022 warming up season. The reason why HRRR's heat flux's calculation is inferior only in Lake Superior is still under investigation by the model's development groups.

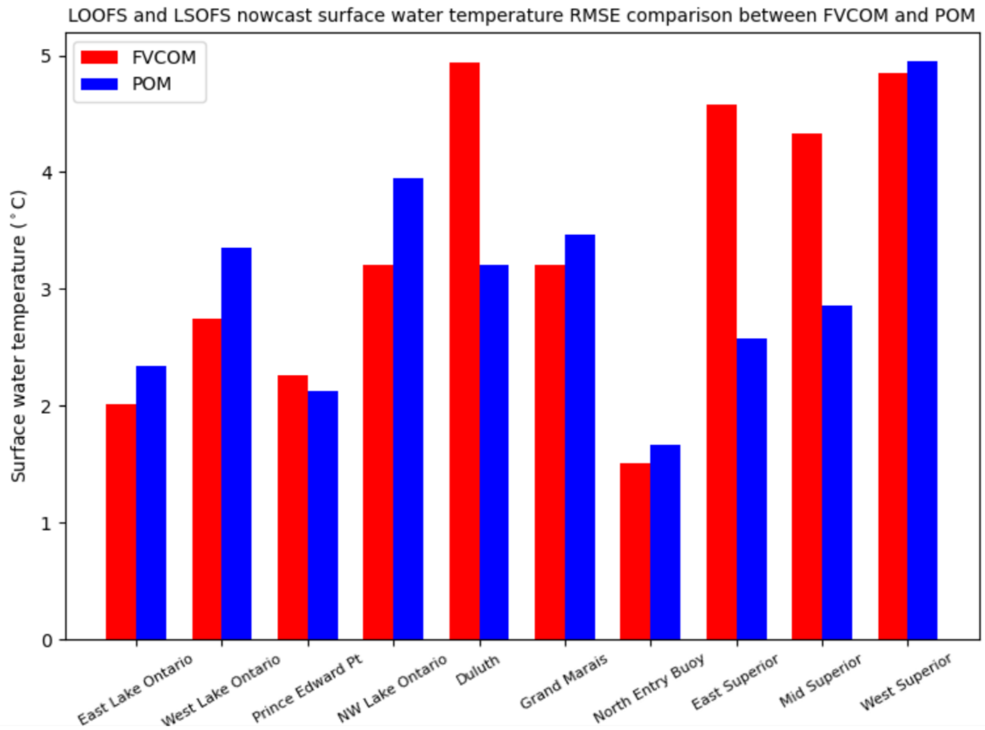

Figure 24. Root mean square error (RMSE) comparison between Finite Volume Community Ocean Model (FVCOM)- and Princeton Ocean Model (POM)-based models at ten stations.

3.3.3 Further water level model evaluation during a winter storm event

As previously described, we have evaluated and compared FVCOM-based and POM-based models' water level skill assessments with respect to statistics. The comparative performance of FVCOM vs. POM was also investigated for a strong winter storm event.

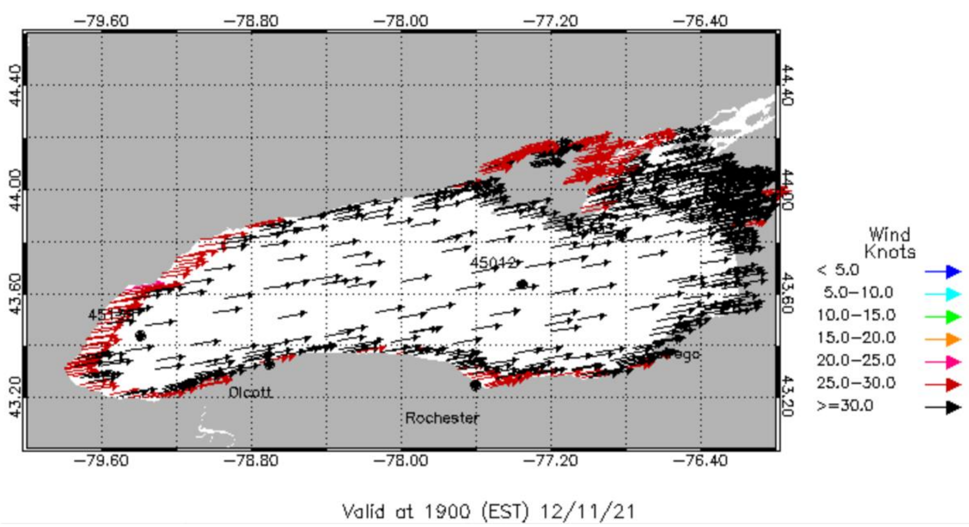

Figure 25. Strong westerly wind across Lake Ontario at 12/12/21/00Z.

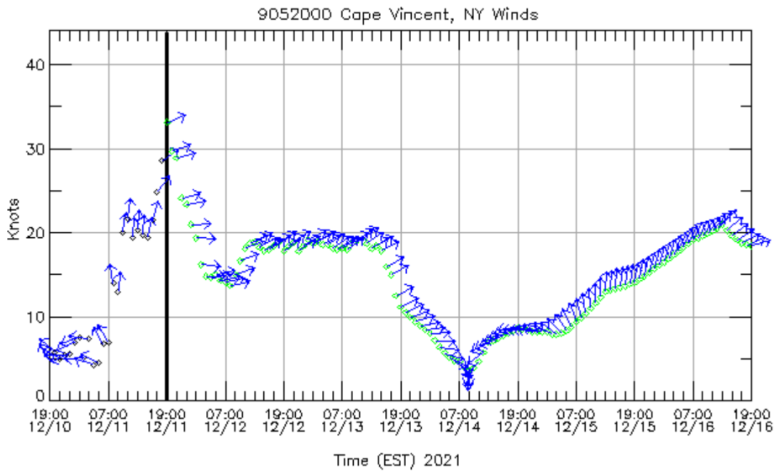

Figure 26. Wind time series at Cape Vincent for the Lake Ontario Operational Forecast System (LOOFS) 12/12/21/00Z cycle.

The Great Lakes area experienced a severe winter storm on December 11-13, 2021. This event can be seen in Figure B-2 (Appendix B) where a strong positive storm surge exists at Cape Vincent and in Figure B-4 (Appendix B) where a corresponding negative surge occurs at the opposite shore station Olcott. Strong westerly wind across the whole Lake Ontario is shown in Figure 22, and the wind time series at Cape Vincent during the event can be found in Figure 23.

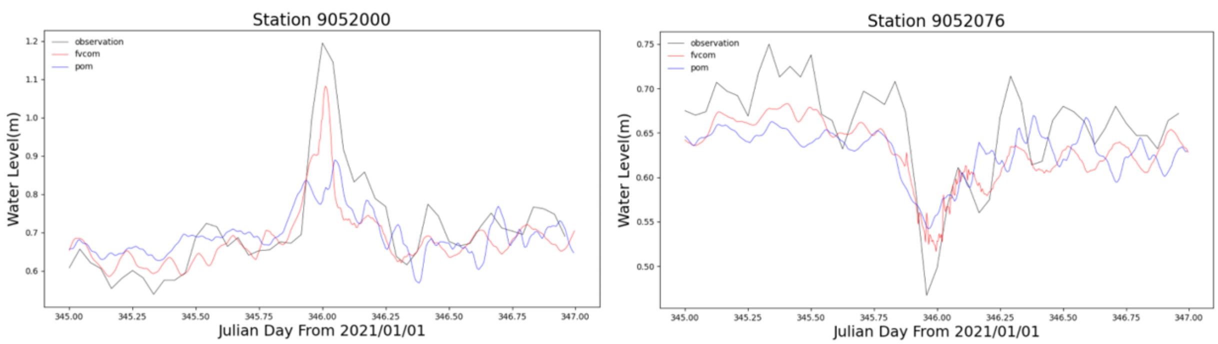

Figure 27. Finite Volume Community Ocean Model (FVCOM)- vs. Princeton Ocean Model (POM)-based Lake Ontario Operational Forecast System (LOOFS) water level comparison. The left panel shows a strong positive surge at Cape Vincent, and the right panel shows a corresponding negative surge at Olcott.

Figure 24 is the zoomed-in of Figures B-2 and B-4 (Appendix B) with December 12, 2021, as the storm's peak. The FVCOM-based model outperforms the POM-based model for both positive and negative surges at different locations. It is demonstrated that the high-resolution gridded HRRR, though still having some issues in heat flux calculation as mentioned previously, indeed provides the FVCOM-based models with more reliable meteorological momentum than the sporadic observations in the POMGL based models.

4.0 CONCLUSIONS

GLERL developed and tested the updated LOOFS and LSOFS, and the NOS/Office of Coast Survey conducted hindcast skill assessment (Kelley et al. 2022). CO-OPS successfully implemented this OFS using the HPC-COMF on WCOSS. The COMF automatically generates all necessary forcing files for nowcast and forecast predictions in real-time mode. The quasi-operational run of the LOOFS and LSOFS, with their final version, began in July 2021, and their outputs for the period of August 1, 2021-August 1, 2022, were used for the OFS's nowcast and forecast guidance skill assessment.

The results indicate that all water level skill metrics passed NOS assessment criteria. For example, RMSEs at all stations were less than 0.15 m, the accepted error criteria for navigation applications. CFs for both nowcast and forecast were larger than 90.0%, and NOF and POF were less than 1% at all stations.

The surface water temperature predictions agree well with observations except for the warming season of 2022 in Lake Superior when the HRRR's air temperature is much higher than observations. For the skill assessment period, the surface temperature RMSE is below or close to its criterion threshold (3.0 °C) at most stations. Most other variables (CF, NOF, POF, MDNO, and MDPO) also meet the NOS-accepted skill assessment criteria at most stations. This is especially the case in Lake Ontario where there were no HRRR air temperature issues.

Water level and surface temperature comparisons were made between FVCOM-based and the POM-based LOOFS and LOOFS. The new models outperform the previous models at almost all stations for water level prediction and at most stations for water temperature prediction. The water temperature skill downgrade at some stations of the FVCOM-based model in Lake Superior does not stem from the FVCOM model itself, but rather from the inferior heat flux results from HRRR which is used to feed into LSOFS.

Also, FVCOM-based LOOFS and LSOFS outperform their POM-based namesakes in water level prediction during a strong winter storm within the skill assessment period. The higher resolution of the FVCOM-based models and more reliable hourly HRRR meteorological momentum forcing are the main contributing factors.

LOOFS and LSOFS became operational at NWS/NCEP/NCEP Central Operations (NCO) in October 2022 (NOS 2022). The successful implementation of this new OFS provides reliable forecast guidance on water level, currents, and water temperature to support NOS' navigation customers and serves as the hydrodynamic basis for operational ice modeling and other applications in the region.

ACKNOWLEDGEMENTS

The development and implementation of the updated LSOFS and LOOFS models is a joint effort of GLERL, OCS, CO-OPS, and NWS/NCEP/NCO.

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For CO-OPS, thanks to Carolyn Lindley and Paul Bradley for their general management and guidance of the project; thanks to the whole modeling team for their technical suggestion and support in the nowcast/forecast model development phase; and special thanks to John Cassidy, Nicholas Allhoff, and Rita Adak for their respective support of web page development, servers' Linux support, and servers' THREDDS support, and Nicole Kruz for the models' outreach support.

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ACRONYMS

CF	central frequency
COMF	Coastal Ocean Modeling Framework
CO-OPS	Center for Operational Oceanographic Products and Services
COARE	Coupled Ocean Atmosphere Response Experiment
FVCOM	Finite Volume Community Ocean Model
GFS	Global Forecast System
GLERL	Great Lakes Environmental Research Laboratory
h	hour
HPC	High Performance Computing
HRRR	High Resolution Rapid Refresh
LHOFS	Lake Huron Operational Forecast System
LMHOFS	Lakes Michigan and Huron Operational Forecast System
LMOFS	Lake Michigan Operational Forecast System
m/s	meters per second
m	meters
MDPO	maximum duration of positive outliers
MDNO	maximum duration of negative outliers
NCEP	National Centers for Environmental Prediction
NDBC	National Data Buoy Center
N/F	Nowcast/Forecast
NOAA	National Oceanic and Atmospheric Administration
NOF	negative outlier frequency
NOS	National Ocean Service
NWS	National Weather Service
POF	positive outlier frequency
POM	Princeton Ocean Model
POMGL	Great Lakes version of the Princeton Ocean Model
RMSE	root mean square error
SM	series mean
USGS	U.S. Geological Survey
WCOSS	Weather and Climate Operational Supercomputing System

LIST OF APPENDICES

APPENDIX A. WATER LEVEL MODEL SKILL ASSESSMENT TABLES

Table A-1. Water level skill assessment at Oswego (Lake Ontario Operational Forecast System [LOOFS]).

Station:		Oswego												
Observed data time period from 8/1/2021 to 8/3/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			85931	0.738										
h			85931	0.730										
H-h	15 cm	24h	85931	0.008	0.024	0.022	0.0	100.0	0.0	0.0	0.0	0.0	0.99	0.99
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1252	0.008	0.025	0.024	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H006-h006	15 cm	24h	1252	0.006	0.026	0.025	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H012-h012	15 cm	24h	1252	0.006	0.026	0.025	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H018-h018	15 cm	24h	1252	0.005	0.025	0.025	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H024-h024	15 cm	24h	1252	0.004	0.025	0.025	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H030-h030	15 cm	24h	1252	0.003	0.026	0.026	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H036-h036	15 cm	24h	1251	0.002	0.027	0.027	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H042-h042	15 cm	24h	1250	0.001	0.028	0.028	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H048-h048	15 cm	24h	1249	-0.000	0.029	0.029	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H054-h054	15 cm	24h	1248	-0.001	0.030	0.030	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H060-h060	15 cm	24h	1247	-0.002	0.032	0.032	0.0	99.9	0.0	0.0	0.0	-99.9	0.97	
H066-h066	15 cm	24h	1246	-0.003	0.035	0.035	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H072-h072	15 cm	24h	1245	-0.004	0.037	0.036	0.0	99.9	0.0	0.0	0.0	-99.9	0.97	
H078-h078	15 cm	24h	1244	-0.005	0.038	0.038	0.0	99.9	0.0	0.0	0.0	-99.9	0.96	
H084-h084	15 cm	24h	1243	-0.006	0.039	0.039	0.0	99.9	0.0	0.0	0.0	-99.9	0.96	
H090-h090	15 cm	24h	1242	-0.006	0.040	0.040	0.0	99.9	0.0	0.0	0.0	-99.9	0.96	
H096-h096	15 cm	24h	1241	-0.007	0.041	0.040	0.0	99.9	0.0	0.0	0.0	-99.9	0.96	
H102-h102	15 cm	24h	1240	-0.008	0.041	0.040	0.0	100.0	0.0	0.0	0.0	-99.9	0.96	
H108-h108	15 cm	24h	1239	-0.009	0.042	0.041	0.0	100.0	0.0	0.0	0.0	-99.9	0.96	
H114-h114	15 cm	24h	1238	-0.010	0.043	0.042	0.0	99.8	0.0	0.0	0.0	-99.9	0.96	
H120-h120	15 cm	24h	1237	-0.011	0.043	0.042	0.0	99.8	0.0	0.0	0.0	-99.9	0.96	

Table A-2. Water level skill assessment at Cape Vincent (Lake Ontario Operational Forecast System [LOOFS]).

Station:		Cape Vincent												
Observed data time period from 8/1/2021 to 1/27/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			85644	0.738										
h			85644	0.706										
H-h	15 cm	24h	85644	0.032	0.043	0.029	0.0	99.9	0.0	0.5	0.0	0.0	0.98	0.98
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1249	0.033	0.045	0.030	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H006-h006	15 cm	24h	1249	0.030	0.043	0.030	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H012-h012	15 cm	24h	1248	0.030	0.042	0.030	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H018-h018	15 cm	24h	1249	0.029	0.041	0.029	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H024-h024	15 cm	24h	1249	0.029	0.041	0.029	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H030-h030	15 cm	24h	1249	0.029	0.042	0.030	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H036-h036	15 cm	24h	1249	0.028	0.042	0.031	0.1	99.8	0.0	0.0	0.0	-99.9	0.97	
H042-h042	15 cm	24h	1247	0.027	0.042	0.032	0.1	99.8	0.0	0.0	0.0	-99.9	0.97	
H048-h048	15 cm	24h	1246	0.025	0.042	0.034	0.1	99.8	0.0	0.0	0.0	-99.9	0.97	
H054-h054	15 cm	24h	1245	0.025	0.042	0.034	0.1	99.9	0.0	0.0	0.0	-99.9	0.97	
H060-h060	15 cm	24h	1243	0.024	0.045	0.038	0.1	99.8	0.0	0.0	0.0	-99.9	0.96	
H066-h066	15 cm	24h	1243	0.023	0.047	0.041	0.1	99.5	0.0	0.0	0.0	-99.9	0.96	
H072-h072	15 cm	24h	1242	0.021	0.047	0.042	0.1	99.5	0.0	0.0	0.0	-99.9	0.95	
H078-h078	15 cm	24h	1241	0.021	0.047	0.042	0.1	99.7	0.0	0.0	0.0	-99.9	0.95	
H084-h084	15 cm	24h	1240	0.020	0.047	0.043	0.1	99.4	0.0	0.0	0.0	-99.9	0.95	
H090-h090	15 cm	24h	1238	0.019	0.047	0.043	0.1	99.4	0.0	0.0	0.0	-99.9	0.95	
H096-h096	15 cm	24h	1237	0.018	0.048	0.044	0.1	99.6	0.0	0.0	0.0	-99.9	0.95	
H102-h102	15 cm	24h	1236	0.017	0.045	0.042	0.0	99.7	0.0	0.0	0.0	-99.9	0.96	
H108-h108	15 cm	24h	1235	0.016	0.046	0.043	0.0	99.5	0.0	0.0	0.0	-99.9	0.95	
H114-h114	15 cm	24h	1234	0.015	0.046	0.044	0.0	99.5	0.1	0.0	0.0	-99.9	0.95	
H120-h120	15 cm	24h	1233	0.015	0.047	0.045	0.0	99.4	0.1	0.0	0.0	-99.9	0.95	

Table A-3. Water level skill assessment at Rochester (Lake Ontario Operational Forecast System [LOOFS]).

Station:	Rochester													
Observed data time period from 8/1/2021 to 8/3/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			85931	0.735										
h			85931	0.735										
H-h	15 cm	24h	85931	0.000	0.018	0.018	0.0	100.0	0.0	0.0	0.0	0.0	0.99	1.00
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1252	0.001	0.020	0.020	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H006-h006	15 cm	24h	1252	-0.000	0.021	0.021	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H012-h012	15 cm	24h	1252	-0.001	0.021	0.021	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H018-h018	15 cm	24h	1252	-0.002	0.022	0.022	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H024-h024	15 cm	24h	1252	-0.003	0.023	0.023	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H030-h030	15 cm	24h	1252	-0.004	0.024	0.024	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H036-h036	15 cm	24h	1251	-0.005	0.025	0.024	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H042-h042	15 cm	24h	1250	-0.006	0.026	0.025	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H048-h048	15 cm	24h	1249	-0.007	0.027	0.026	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H054-h054	15 cm	24h	1248	-0.008	0.028	0.026	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H060-h060	15 cm	24h	1247	-0.009	0.028	0.027	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H066-h066	15 cm	24h	1246	-0.010	0.029	0.027	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H072-h072	15 cm	24h	1245	-0.011	0.030	0.028	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H078-h078	15 cm	24h	1244	-0.012	0.031	0.029	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H084-h084	15 cm	24h	1243	-0.013	0.032	0.029	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H090-h090	15 cm	24h	1242	-0.014	0.033	0.030	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H096-h096	15 cm	24h	1241	-0.015	0.034	0.030	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H102-h102	15 cm	24h	1240	-0.016	0.035	0.031	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H108-h108	15 cm	24h	1239	-0.017	0.036	0.032	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H114-h114	15 cm	24h	1238	-0.017	0.037	0.033	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H120-h120	15 cm	24h	1237	-0.018	0.038	0.033	0.0	100.0	0.0	0.0	0.0	-99.9	0.97	

Table A-4. Water level skill assessment at Olcott (Lake Ontario Operational Forecast System [LOOFS]).

Station:	Olcott													
Observed data time period from 8/1/2021 to 8/3/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			85931	0.732										
h			85931	0.748										
H-h	15 cm	24h	85931	-0.016	0.024	0.018	0.0	100.0	0.0	0.0	0.0	0.0	0.99	0.99
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1252	-0.016	0.025	0.020	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H006-h006	15 cm	24h	1252	-0.016	0.026	0.020	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H012-h012	15 cm	24h	1252	-0.017	0.028	0.021	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H018-h018	15 cm	24h	1252	-0.018	0.029	0.022	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H024-h024	15 cm	24h	1252	-0.019	0.029	0.022	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H030-h030	15 cm	24h	1252	-0.020	0.030	0.023	0.0	100.0	0.0	0.0	0.0	-99.9	0.99	
H036-h036	15 cm	24h	1251	-0.021	0.032	0.024	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H042-h042	15 cm	24h	1250	-0.022	0.033	0.024	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H048-h048	15 cm	24h	1249	-0.022	0.034	0.025	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H054-h054	15 cm	24h	1248	-0.023	0.035	0.026	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H060-h060	15 cm	24h	1247	-0.025	0.037	0.028	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H066-h066	15 cm	24h	1246	-0.025	0.039	0.030	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H072-h072	15 cm	24h	1245	-0.026	0.040	0.030	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H078-h078	15 cm	24h	1244	-0.027	0.041	0.031	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H084-h084	15 cm	24h	1243	-0.028	0.042	0.032	0.0	100.0	0.0	0.0	0.0	-99.9	0.97	
H090-h090	15 cm	24h	1242	-0.029	0.043	0.032	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H096-h096	15 cm	24h	1241	-0.029	0.044	0.032	0.0	99.9	0.0	0.0	0.0	-99.9	0.97	
H102-h102	15 cm	24h	1240	-0.030	0.044	0.033	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H108-h108	15 cm	24h	1239	-0.031	0.045	0.033	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H114-h114	15 cm	24h	1238	-0.032	0.047	0.034	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H120-h120	15 cm	24h	1237	-0.033	0.048	0.034	0.0	99.6	0.0	0.0	0.0	-99.9	0.97	

Table A-5. Water level skill assessment at Kingston (Lake Ontario Operational Forecast System [LOOFS]).

Station:		Kingston												
Observed data time period from 8/1/2021 to 3/29/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			85341	0.738										
h			85341	0.745										
H-h	15 cm	24h	85341	-0.007	0.029	0.028	0.0	99.9	0.0	0.0	0.0	0.0	0.98	0.99
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1245	-0.007	0.031	0.030	0.0	99.9	0.0	0.0	0.0	-99.9	0.97	
H006-h006	15 cm	24h	1245	-0.010	0.031	0.030	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H012-h012	15 cm	24h	1243	-0.010	0.031	0.030	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H018-h018	15 cm	24h	1241	-0.011	0.031	0.029	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H024-h024	15 cm	24h	1239	-0.011	0.031	0.029	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H030-h030	15 cm	24h	1237	-0.011	0.032	0.030	0.0	99.9	0.0	0.0	0.0	-99.9	0.97	
H036-h036	15 cm	24h	1235	-0.012	0.034	0.032	0.0	99.9	0.0	0.0	0.0	-99.9	0.97	
H042-h042	15 cm	24h	1233	-0.013	0.035	0.032	0.0	99.9	0.0	0.0	0.0	-99.9	0.97	
H048-h048	15 cm	24h	1231	-0.015	0.037	0.034	0.1	99.8	0.0	0.0	0.0	-99.9	0.97	
H054-h054	15 cm	24h	1229	-0.015	0.038	0.035	0.1	99.9	0.0	0.0	0.0	-99.9	0.97	
H060-h060	15 cm	24h	1228	-0.016	0.041	0.038	0.1	99.8	0.0	0.0	0.0	-99.9	0.96	
H066-h066	15 cm	24h	1227	-0.017	0.044	0.040	0.1	99.8	0.0	0.0	0.0	-99.9	0.96	
H072-h072	15 cm	24h	1226	-0.019	0.045	0.041	0.1	99.7	0.0	0.0	0.0	-99.9	0.96	
H078-h078	15 cm	24h	1225	-0.019	0.045	0.041	0.1	99.5	0.0	0.0	0.0	-99.9	0.96	
H084-h084	15 cm	24h	1224	-0.020	0.046	0.042	0.1	99.8	0.0	0.0	0.0	-99.9	0.95	
H090-h090	15 cm	24h	1223	-0.021	0.047	0.042	0.1	99.7	0.0	0.0	0.0	-99.9	0.95	
H096-h096	15 cm	24h	1222	-0.022	0.048	0.043	0.1	99.8	0.0	0.0	0.0	-99.9	0.95	
H102-h102	15 cm	24h	1221	-0.023	0.048	0.042	0.0	99.7	0.0	0.0	0.0	-99.9	0.96	
H108-h108	15 cm	24h	1220	-0.024	0.049	0.043	0.0	99.5	0.0	0.0	0.0	-99.9	0.95	
H114-h114	15 cm	24h	1219	-0.025	0.050	0.043	0.0	99.5	0.0	0.0	0.0	-99.9	0.95	
H120-h120	15 cm	24h	1218	-0.025	0.051	0.044	0.0	99.1	0.0	0.0	0.0	-99.9	0.95	

Table A-6. Water level skill assessment at Coburg (Lake Ontario Operational Forecast System [LOOFS]).

Station:		Coburg												
Observed data time period from 8/1/2021 to 3/29/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			84621	0.726										
h			84621	0.737										
H-h	15 cm	24h	84621	-0.011	0.025	0.023	0.0	100.0	0.0	0.0	0.0	0.0	0.99	0.99
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1233	-0.010	0.027	0.025	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H006-h006	15 cm	24h	1233	-0.010	0.028	0.026	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H012-h012	15 cm	24h	1232	-0.011	0.028	0.026	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H018-h018	15 cm	24h	1231	-0.013	0.029	0.026	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H024-h024	15 cm	24h	1230	-0.013	0.030	0.027	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H030-h030	15 cm	24h	1229	-0.015	0.031	0.027	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H036-h036	15 cm	24h	1228	-0.016	0.032	0.027	0.0	99.9	0.0	0.0	0.0	-99.9	0.98	
H042-h042	15 cm	24h	1227	-0.017	0.032	0.028	0.0	100.0	0.0	0.0	0.0	-99.9	0.98	
H048-h048	15 cm	24h	1226	-0.018	0.034	0.028	0.1	99.9	0.0	0.0	0.0	-99.9	0.98	
H054-h054	15 cm	24h	1225	-0.019	0.035	0.029	0.1	99.9	0.0	0.0	0.0	-99.9	0.98	
H060-h060	15 cm	24h	1224	-0.020	0.036	0.029	0.1	99.9	0.0	0.0	0.0	-99.9	0.98	
H066-h066	15 cm	24h	1223	-0.021	0.037	0.030	0.1	99.9	0.0	0.0	0.0	-99.9	0.98	
H072-h072	15 cm	24h	1222	-0.022	0.038	0.031	0.1	99.9	0.0	0.0	0.0	-99.9	0.97	
H078-h078	15 cm	24h	1221	-0.023	0.040	0.032	0.1	99.9	0.0	0.0	0.0	-99.9	0.97	
H084-h084	15 cm	24h	1219	-0.025	0.041	0.032	0.1	99.9	0.0	0.0	0.0	-99.9	0.97	
H090-h090	15 cm	24h	1217	-0.026	0.042	0.033	0.1	99.9	0.0	0.0	0.0	-99.9	0.97	
H096-h096	15 cm	24h	1215	-0.027	0.043	0.033	0.1	99.9	0.0	0.0	0.0	-99.9	0.97	
H102-h102	15 cm	24h	1213	-0.028	0.044	0.034	0.0	99.9	0.0	0.0	0.0	-99.9	0.97	
H108-h108	15 cm	24h	1211	-0.029	0.045	0.035	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H114-h114	15 cm	24h	1209	-0.030	0.046	0.036	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H120-h120	15 cm	24h	1207	-0.031	0.048	0.036	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	

Table A-7. Water level skill assessment at Point Iroquois (Lake Superior Operational Forecast System [LSOFS]).

Station:	Point Iroquois													
Observed data time period from 8/1/2021 to 8/3/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			86409	0.231										
h			86409	0.234										
H-h	15 cm	24h	86409	-0.003	0.057	0.057	0.0	98.4	0.0	1.1	0.0	0.0	0.94	0.97
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1300	-0.007	0.061	0.060	0.1	98.1	0.0	0.0	0.0	-99.9	0.93	
H006-h006	15 cm	24h	1300	-0.003	0.060	0.059	0.1	97.9	0.0	0.0	0.0	-99.9	0.94	
H012-h012	15 cm	24h	1300	-0.005	0.060	0.060	0.2	98.2	0.0	0.0	0.0	-99.9	0.94	
H018-h018	15 cm	24h	1300	-0.006	0.058	0.058	0.2	98.7	0.0	0.0	0.0	-99.9	0.94	
H024-h024	15 cm	24h	1300	-0.007	0.057	0.057	0.2	98.4	0.0	0.0	0.0	-99.9	0.94	
H030-h030	15 cm	24h	1300	-0.006	0.058	0.058	0.2	98.5	0.0	0.0	0.0	-99.9	0.94	
H036-h036	15 cm	24h	1299	-0.003	0.058	0.058	0.2	98.6	0.0	0.0	0.0	-99.9	0.94	
H042-h042	15 cm	24h	1298	-0.005	0.059	0.058	0.2	97.6	0.0	0.0	0.0	-99.9	0.94	
H048-h048	15 cm	24h	1297	-0.008	0.059	0.059	0.2	97.8	0.0	0.0	0.0	-99.9	0.94	
H054-h054	15 cm	24h	1296	-0.009	0.064	0.064	0.2	96.8	0.0	0.0	0.0	-99.9	0.93	
H060-h060	15 cm	24h	1295	-0.006	0.070	0.070	0.3	96.3	0.0	0.0	0.0	-99.9	0.91	
H066-h066	15 cm	24h	1294	-0.006	0.074	0.074	0.2	94.6	0.0	0.0	0.0	-99.9	0.90	
H072-h072	15 cm	24h	1293	-0.008	0.080	0.079	0.3	93.7	0.0	0.0	0.0	-99.9	0.88	
H078-h078	15 cm	24h	1292	-0.009	0.083	0.083	0.3	92.9	0.0	0.0	0.0	-99.9	0.87	
H084-h084	15 cm	24h	1291	-0.008	0.083	0.082	0.2	93.0	0.0	0.0	0.0	-99.9	0.87	
H090-h090	15 cm	24h	1290	-0.007	0.081	0.081	0.2	93.3	0.0	0.0	0.0	-99.9	0.88	
H096-h096	15 cm	24h	1289	-0.009	0.081	0.081	0.3	93.6	0.0	0.0	0.0	-99.9	0.88	
H102-h102	15 cm	24h	1288	-0.011	0.081	0.080	0.2	93.7	0.0	0.0	0.0	-99.9	0.88	
H108-h108	15 cm	24h	1287	-0.012	0.082	0.081	0.4	93.1	0.0	0.0	0.0	-99.9	0.88	
H114-h114	15 cm	24h	1286	-0.011	0.081	0.080	0.3	93.9	0.0	0.0	0.0	-99.9	0.88	
H120-h120	15 cm	24h	1285	-0.011	0.081	0.080	0.4	94.4	0.0	0.0	0.0	-99.9	0.88	

Table A-8. Water level skill assessment at Marquette (Lake Superior Operational Forecast System [LSOFS]).

Station:	Marquette CG Stn													
Observed data time period from 8/1/2021 to 7/30/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			86139	0.232										
h			86139	0.239										
H-h	15 cm	24h	86139	-0.007	0.033	0.032	0.0	99.7	0.0	0.1	0.0	0.0	0.98	0.99
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1293	-0.009	0.036	0.035	0.0	99.7	0.0	0.0	0.0	-99.9	0.98	
H006-h006	15 cm	24h	1293	-0.008	0.036	0.035	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H012-h012	15 cm	24h	1293	-0.008	0.037	0.036	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H018-h018	15 cm	24h	1293	-0.009	0.037	0.036	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	
H024-h024	15 cm	24h	1293	-0.011	0.037	0.036	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H030-h030	15 cm	24h	1293	-0.011	0.037	0.035	0.0	99.7	0.0	0.0	0.0	-99.9	0.98	
H036-h036	15 cm	24h	1292	-0.010	0.036	0.035	0.0	99.7	0.0	0.0	0.0	-99.9	0.98	
H042-h042	15 cm	24h	1291	-0.010	0.037	0.035	0.0	99.7	0.0	0.0	0.0	-99.9	0.98	
H048-h048	15 cm	24h	1290	-0.011	0.037	0.035	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H054-h054	15 cm	24h	1289	-0.012	0.038	0.036	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	
H060-h060	15 cm	24h	1288	-0.011	0.039	0.037	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	
H066-h066	15 cm	24h	1287	-0.011	0.039	0.037	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H072-h072	15 cm	24h	1286	-0.012	0.040	0.038	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	
H078-h078	15 cm	24h	1285	-0.014	0.041	0.038	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H084-h084	15 cm	24h	1284	-0.014	0.041	0.039	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H090-h090	15 cm	24h	1283	-0.014	0.042	0.040	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H096-h096	15 cm	24h	1282	-0.014	0.043	0.040	0.1	99.6	0.0	0.0	0.0	-99.9	0.97	
H102-h102	15 cm	24h	1281	-0.016	0.043	0.040	0.0	99.4	0.0	0.0	0.0	-99.9	0.97	
H108-h108	15 cm	24h	1280	-0.016	0.043	0.040	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H114-h114	15 cm	24h	1279	-0.015	0.043	0.041	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	
H120-h120	15 cm	24h	1278	-0.016	0.044	0.041	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	

Table A-9. Water level skill assessment at Grand Marais (Lake Superior Operational Forecast System [LSOFS]).

Station:	Grand Marais													
Observed data time period from 8/1/2021 to 8/3/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			86409	0.228										
h			86409	0.238										
H-h	15 cm	24h	86409	-0.010	0.037	0.036	0.0	99.8	0.0	1.4	0.0	0.0	0.98	0.99
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1300	-0.010	0.038	0.037	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	
H006-h006	15 cm	24h	1300	-0.013	0.039	0.037	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H012-h012	15 cm	24h	1300	-0.014	0.041	0.038	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H018-h018	15 cm	24h	1300	-0.012	0.040	0.039	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H024-h024	15 cm	24h	1300	-0.011	0.041	0.039	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H030-h030	15 cm	24h	1300	-0.013	0.041	0.039	0.0	99.3	0.0	0.0	0.0	-99.9	0.97	
H036-h036	15 cm	24h	1299	-0.015	0.042	0.039	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H042-h042	15 cm	24h	1298	-0.014	0.042	0.040	0.0	99.6	0.0	0.0	0.0	-99.9	0.97	
H048-h048	15 cm	24h	1297	-0.013	0.043	0.041	0.0	99.3	0.0	0.0	0.0	-99.9	0.97	
H054-h054	15 cm	24h	1296	-0.013	0.045	0.043	0.0	98.9	0.0	0.0	0.0	-99.9	0.96	
H060-h060	15 cm	24h	1295	-0.016	0.048	0.045	0.0	99.2	0.0	0.0	0.0	-99.9	0.96	
H066-h066	15 cm	24h	1294	-0.017	0.050	0.047	0.0	98.9	0.0	0.0	0.0	-99.9	0.96	
H072-h072	15 cm	24h	1293	-0.016	0.052	0.050	0.0	98.8	0.0	0.0	0.0	-99.9	0.95	
H078-h078	15 cm	24h	1292	-0.015	0.053	0.051	0.1	98.6	0.0	0.0	0.0	-99.9	0.95	
H084-h084	15 cm	24h	1291	-0.017	0.053	0.050	0.1	98.5	0.0	0.0	0.0	-99.9	0.95	
H090-h090	15 cm	24h	1290	-0.018	0.054	0.050	0.0	98.8	0.0	0.0	0.0	-99.9	0.95	
H096-h096	15 cm	24h	1289	-0.018	0.054	0.051	0.0	98.7	0.0	0.0	0.0	-99.9	0.95	
H102-h102	15 cm	24h	1288	-0.017	0.054	0.051	0.1	98.7	0.0	0.0	0.0	-99.9	0.95	
H108-h108	15 cm	24h	1287	-0.017	0.053	0.051	0.1	98.8	0.0	0.0	0.0	-99.9	0.95	
H114-h114	15 cm	24h	1286	-0.019	0.053	0.049	0.1	98.9	0.0	0.0	0.0	-99.9	0.95	
H120-h120	15 cm	24h	1285	-0.019	0.053	0.050	0.1	98.9	0.0	0.0	0.0	-99.9	0.95	

Table A-10. Water level skill assessment at Duluth (Lake Superior Operational Forecast System [LSOFS]).

Station:	Duluth													
Observed data time period from 8/1/2021 to 8/3/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			86409	0.223										
h			86409	0.230										
H-h	15 cm	24h	86409	-0.007	0.063	0.063	0.0	97.6	0.0	1.8	0.0	0.0	0.93	0.97
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1300	-0.004	0.064	0.064	0.0	97.3	0.0	0.0	0.0	-99.9	0.93	
H006-h006	15 cm	24h	1300	-0.009	0.065	0.064	0.0	96.6	0.0	0.0	0.0	-99.9	0.93	
H012-h012	15 cm	24h	1300	-0.008	0.064	0.064	0.1	97.2	0.1	0.0	0.0	-99.9	0.93	
H018-h018	15 cm	24h	1300	-0.009	0.064	0.064	0.0	96.7	0.0	0.0	0.0	-99.9	0.93	
H024-h024	15 cm	24h	1300	-0.007	0.063	0.062	0.0	97.5	0.0	0.0	0.0	-99.9	0.94	
H030-h030	15 cm	24h	1300	-0.010	0.063	0.063	0.0	96.8	0.0	0.0	0.0	-99.9	0.94	
H036-h036	15 cm	24h	1299	-0.016	0.064	0.062	0.0	96.8	0.0	0.0	0.0	-99.9	0.94	
H042-h042	15 cm	24h	1298	-0.014	0.066	0.065	0.0	96.5	0.0	0.0	0.0	-99.9	0.93	
H048-h048	15 cm	24h	1297	-0.013	0.068	0.067	0.2	96.5	0.0	0.0	0.0	-99.9	0.93	
H054-h054	15 cm	24h	1296	-0.012	0.070	0.069	0.1	95.9	0.0	0.0	0.0	-99.9	0.92	
H060-h060	15 cm	24h	1295	-0.017	0.074	0.072	0.1	95.4	0.1	0.0	0.0	-99.9	0.91	
H066-h066	15 cm	24h	1294	-0.019	0.082	0.080	0.0	93.3	0.0	0.0	0.0	-99.9	0.89	
H072-h072	15 cm	24h	1293	-0.017	0.084	0.083	0.1	91.7	0.2	0.0	0.0	-99.9	0.88	
H078-h078	15 cm	24h	1292	-0.016	0.086	0.084	0.1	91.8	0.3	0.0	0.0	-99.9	0.88	
H084-h084	15 cm	24h	1291	-0.017	0.085	0.084	0.4	91.6	0.1	6.0	0.0	-99.9	0.88	
H090-h090	15 cm	24h	1290	-0.020	0.087	0.085	0.3	91.3	0.1	0.0	0.0	-99.9	0.88	
H096-h096	15 cm	24h	1289	-0.018	0.088	0.086	0.2	91.3	0.1	0.0	0.0	-99.9	0.88	
H102-h102	15 cm	24h	1288	-0.016	0.086	0.085	0.1	91.4	0.1	0.0	0.0	-99.9	0.88	
H108-h108	15 cm	24h	1287	-0.016	0.085	0.083	0.1	92.4	0.0	0.0	0.0	-99.9	0.88	
H114-h114	15 cm	24h	1286	-0.019	0.086	0.084	0.4	92.1	0.0	6.0	0.0	-99.9	0.88	
H120-h120	15 cm	24h	1285	-0.020	0.087	0.085	0.4	91.7	0.0	12.0	0.0	-99.9	0.88	

Table A-11. Water level skill assessment at Michipicoten.

Station:			Michipicoten											
Observed data time period from 8/1/2021 to 3/29/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			84041	0.233										
h			84041	0.223										
H-h	15 cm	24h	84041	0.011	0.042	0.041	0.0	99.7	0.0	0.0	0.0	0.0	0.97	0.98
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1258	0.014	0.046	0.044	0.0	99.4	0.0	0.0	0.0	-99.9	0.96	
H006-h006	15 cm	24h	1258	0.017	0.047	0.044	0.0	99.5	0.0	0.0	0.0	-99.9	0.96	
H012-h012	15 cm	24h	1257	0.016	0.046	0.044	0.0	99.4	0.0	0.0	0.0	-99.9	0.96	
H018-h018	15 cm	24h	1255	0.014	0.045	0.043	0.0	99.6	0.0	0.0	0.0	-99.9	0.97	
H024-h024	15 cm	24h	1255	0.013	0.044	0.042	0.0	99.6	0.0	0.0	0.0	-99.9	0.97	
H030-h030	15 cm	24h	1254	0.015	0.045	0.043	0.0	99.4	0.0	0.0	0.0	-99.9	0.97	
H036-h036	15 cm	24h	1253	0.015	0.046	0.044	0.0	99.4	0.0	0.0	0.0	-99.9	0.96	
H042-h042	15 cm	24h	1252	0.014	0.046	0.044	0.0	99.7	0.0	0.0	0.0	-99.9	0.96	
H048-h048	15 cm	24h	1251	0.012	0.046	0.045	0.0	99.3	0.0	0.0	0.0	-99.9	0.96	
H054-h054	15 cm	24h	1250	0.011	0.050	0.049	0.0	98.8	0.0	0.0	0.0	-99.9	0.95	
H060-h060	15 cm	24h	1249	0.013	0.055	0.053	0.0	98.8	0.0	0.0	0.0	-99.9	0.94	
H066-h066	15 cm	24h	1248	0.012	0.059	0.058	0.0	98.0	0.0	0.0	0.0	-99.9	0.94	
H072-h072	15 cm	24h	1247	0.011	0.060	0.059	0.0	97.8	0.0	0.0	0.0	-99.9	0.93	
H078-h078	15 cm	24h	1246	0.010	0.061	0.060	0.0	98.0	0.0	0.0	0.0	-99.9	0.93	
H084-h084	15 cm	24h	1245	0.010	0.061	0.060	0.0	97.8	0.0	0.0	0.0	-99.9	0.93	
H090-h090	15 cm	24h	1244	0.010	0.061	0.060	0.0	98.0	0.0	0.0	0.0	-99.9	0.93	
H096-h096	15 cm	24h	1243	0.008	0.060	0.060	0.0	98.1	0.0	0.0	0.0	-99.9	0.93	
H102-h102	15 cm	24h	1242	0.007	0.060	0.060	0.0	98.2	0.0	0.0	0.0	-99.9	0.93	
H108-h108	15 cm	24h	1241	0.006	0.059	0.059	0.0	98.2	0.0	0.0	0.0	-99.9	0.93	
H114-h114	15 cm	24h	1240	0.006	0.060	0.059	0.0	98.3	0.0	0.0	0.0	-99.9	0.93	
H120-h120	15 cm	24h	1239	0.006	0.059	0.059	0.0	98.3	0.0	0.0	0.0	-99.9	0.93	

Table A-12. Water level skill assessment at Thunder Bay (Lake Superior Operational Forecast System [LSOFS]).

Station:			Thunder Bay											
Observed data time period from 8/1/2021 to 3/29/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			85700	0.234										
h			85700	0.244										
H-h	15 cm	24h	85700	-0.011	0.041	0.039	0.0	99.6	0.0	0.8	0.0	0.0	0.97	0.98
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1285	-0.007	0.043	0.042	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H006-h006	15 cm	24h	1285	-0.010	0.043	0.042	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H012-h012	15 cm	24h	1284	-0.011	0.043	0.041	0.0	99.6	0.0	0.0	0.0	-99.9	0.97	
H018-h018	15 cm	24h	1283	-0.010	0.043	0.042	0.1	99.5	0.0	0.0	0.0	-99.9	0.97	
H024-h024	15 cm	24h	1282	-0.010	0.043	0.042	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H030-h030	15 cm	24h	1281	-0.012	0.043	0.041	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H036-h036	15 cm	24h	1280	-0.013	0.043	0.041	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H042-h042	15 cm	24h	1279	-0.015	0.045	0.042	0.0	99.2	0.0	0.0	0.0	-99.9	0.97	
H048-h048	15 cm	24h	1278	-0.013	0.043	0.041	0.0	99.4	0.0	0.0	0.0	-99.9	0.97	
H054-h054	15 cm	24h	1277	-0.013	0.045	0.043	0.0	99.4	0.0	0.0	0.0	-99.9	0.97	
H060-h060	15 cm	24h	1276	-0.015	0.047	0.045	0.0	99.4	0.0	0.0	0.0	-99.9	0.96	
H066-h066	15 cm	24h	1275	-0.017	0.048	0.045	0.0	99.2	0.0	0.0	0.0	-99.9	0.96	
H072-h072	15 cm	24h	1274	-0.017	0.050	0.047	0.0	99.3	0.0	0.0	0.0	-99.9	0.96	
H078-h078	15 cm	24h	1273	-0.018	0.051	0.048	0.0	99.0	0.0	0.0	0.0	-99.9	0.96	
H084-h084	15 cm	24h	1272	-0.018	0.051	0.048	0.0	99.1	0.0	0.0	0.0	-99.9	0.96	
H090-h090	15 cm	24h	1271	-0.019	0.051	0.048	0.0	98.9	0.0	0.0	0.0	-99.9	0.96	
H096-h096	15 cm	24h	1270	-0.019	0.051	0.047	0.0	99.2	0.0	0.0	0.0	-99.9	0.96	
H102-h102	15 cm	24h	1269	-0.018	0.050	0.047	0.0	99.1	0.0	0.0	0.0	-99.9	0.96	
H108-h108	15 cm	24h	1268	-0.018	0.051	0.047	0.0	99.0	0.0	0.0	0.0	-99.9	0.96	
H114-h114	15 cm	24h	1267	-0.020	0.051	0.047	0.0	99.1	0.0	0.0	0.0	-99.9	0.96	
H120-h120	15 cm	24h	1266	-0.020	0.050	0.046	0.0	99.1	0.0	0.0	0.0	-99.9	0.96	

Table A-13. Water level skill assessment at Ontonagon (Lake Superior Operational Forecast System [LSOFS]).

Station:				Ontonagon										
Observed data time period from 8/1/2021 to 8/3/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			86409	0.235										
h			86409	0.262										
H-h	15 cm	24h	86409	-0.026	0.049	0.042	0.0	98.1	0.0	1.1	0.0	0.0	0.97	0.98
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1300	-0.028	0.050	0.042	0.0	97.5	0.0	0.0	0.0	-99.9	0.97	
H006-h006	15 cm	24h	1300	-0.031	0.052	0.042	0.0	97.5	0.0	0.0	0.0	-99.9	0.97	
H012-h012	15 cm	24h	1300	-0.032	0.054	0.043	0.0	97.4	0.0	0.0	0.0	-99.9	0.96	
H018-h018	15 cm	24h	1300	-0.031	0.052	0.042	0.1	97.5	0.0	0.0	0.0	-99.9	0.96	
H024-h024	15 cm	24h	1300	-0.030	0.052	0.042	0.0	97.5	0.0	0.0	0.0	-99.9	0.96	
H030-h030	15 cm	24h	1300	-0.032	0.053	0.042	0.0	97.6	0.0	0.0	0.0	-99.9	0.97	
H036-h036	15 cm	24h	1299	-0.033	0.054	0.042	0.0	97.5	0.0	0.0	0.0	-99.9	0.97	
H042-h042	15 cm	24h	1298	-0.033	0.054	0.043	0.0	97.6	0.0	0.0	0.0	-99.9	0.96	
H048-h048	15 cm	24h	1297	-0.032	0.054	0.044	0.1	97.2	0.0	0.0	0.0	-99.9	0.96	
H054-h054	15 cm	24h	1296	-0.033	0.054	0.043	0.0	97.8	0.0	0.0	0.0	-99.9	0.96	
H060-h060	15 cm	24h	1295	-0.036	0.056	0.043	0.0	98.2	0.0	0.0	0.0	-99.9	0.96	
H066-h066	15 cm	24h	1294	-0.036	0.058	0.045	0.0	98.1	0.0	0.0	0.0	-99.9	0.96	
H072-h072	15 cm	24h	1293	-0.036	0.059	0.047	0.2	98.2	0.0	6.0	0.0	-99.9	0.96	
H078-h078	15 cm	24h	1292	-0.035	0.059	0.047	0.1	98.3	0.0	0.0	0.0	-99.9	0.96	
H084-h084	15 cm	24h	1291	-0.037	0.060	0.047	0.1	98.5	0.0	0.0	0.0	-99.9	0.96	
H090-h090	15 cm	24h	1290	-0.039	0.061	0.048	0.0	98.0	0.0	0.0	0.0	-99.9	0.95	
H096-h096	15 cm	24h	1289	-0.038	0.062	0.049	0.1	98.1	0.0	0.0	0.0	-99.9	0.95	
H102-h102	15 cm	24h	1288	-0.037	0.060	0.048	0.1	97.6	0.0	0.0	0.0	-99.9	0.95	
H108-h108	15 cm	24h	1287	-0.037	0.060	0.047	0.1	97.4	0.0	0.0	0.0	-99.9	0.95	
H114-h114	15 cm	24h	1286	-0.039	0.061	0.047	0.0	97.4	0.0	0.0	0.0	-99.9	0.95	
H120-h120	15 cm	24h	1285	-0.039	0.062	0.048	0.1	97.6	0.0	0.0	0.0	-99.9	0.95	

Table A-14. Water level skill assessment at Rossport (Lake Superior Operational Forecast System [LSOFS]).

Station:				Rossport										
Observed data time period from 8/1/2021 to 8/1/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			86359	0.231										
h			86359	0.211										
H-h	15 cm	24h	86359	0.020	0.036	0.030	0.0	99.8	0.0	0.0	0.5	0.0	0.98	0.99
SCENARIO: SEMI-OPERATIONAL FORECAST														
H000-h000	15 cm	24h	1296	0.021	0.039	0.032	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H006-h006	15 cm	24h	1296	0.022	0.039	0.033	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H012-h012	15 cm	24h	1295	0.021	0.040	0.034	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H018-h018	15 cm	24h	1294	0.021	0.039	0.034	0.0	99.7	0.0	0.0	0.0	-99.9	0.98	
H024-h024	15 cm	24h	1293	0.020	0.039	0.034	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H030-h030	15 cm	24h	1292	0.020	0.040	0.034	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H036-h036	15 cm	24h	1291	0.020	0.040	0.034	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H042-h042	15 cm	24h	1290	0.020	0.040	0.035	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H048-h048	15 cm	24h	1289	0.019	0.039	0.034	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H054-h054	15 cm	24h	1288	0.019	0.040	0.035	0.0	99.8	0.0	0.0	0.0	-99.9	0.98	
H060-h060	15 cm	24h	1287	0.019	0.042	0.038	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H066-h066	15 cm	24h	1286	0.018	0.043	0.039	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H072-h072	15 cm	24h	1285	0.017	0.044	0.040	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H078-h078	15 cm	24h	1284	0.017	0.044	0.041	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H084-h084	15 cm	24h	1283	0.017	0.045	0.042	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	
H090-h090	15 cm	24h	1282	0.016	0.045	0.042	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	
H096-h096	15 cm	24h	1281	0.015	0.045	0.042	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	
H102-h102	15 cm	24h	1280	0.014	0.045	0.042	0.0	99.5	0.0	0.0	0.0	-99.9	0.97	
H108-h108	15 cm	24h	1279	0.014	0.045	0.043	0.0	99.7	0.0	0.0	0.0	-99.9	0.97	
H114-h114	15 cm	24h	1278	0.014	0.045	0.043	0.0	99.8	0.0	0.0	0.0	-99.9	0.97	
H120-h120	15 cm	24h	1277	0.013	0.045	0.043	0.0	99.6	0.0	0.0	0.0	-99.9	0.97	

APPENDIX B. TIME SERIES OF MODELED WATER LEVEL VERSUS OBSERVATIONS

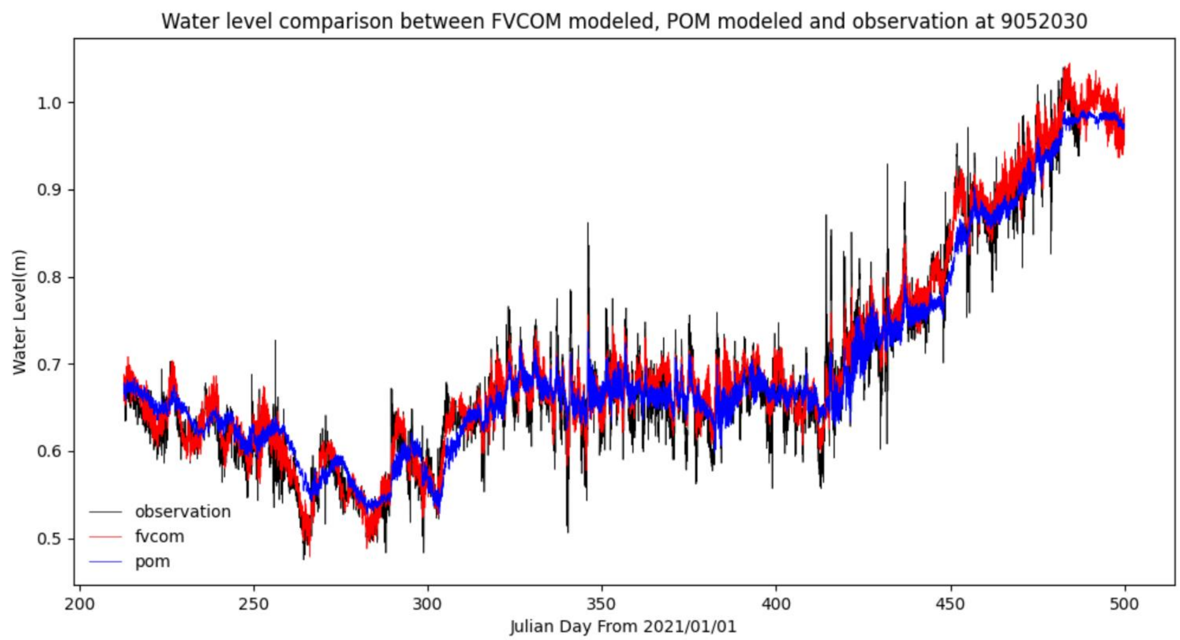

Figure B-1. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Oswego.

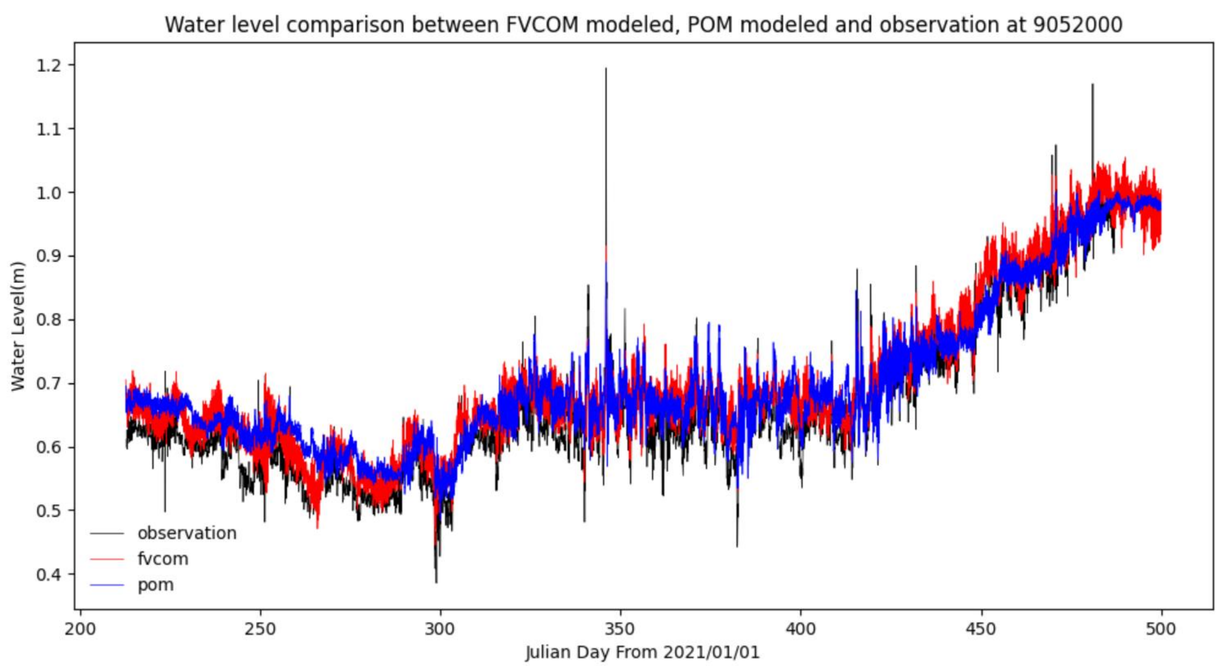

Figure B-2. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Cape Vincent.

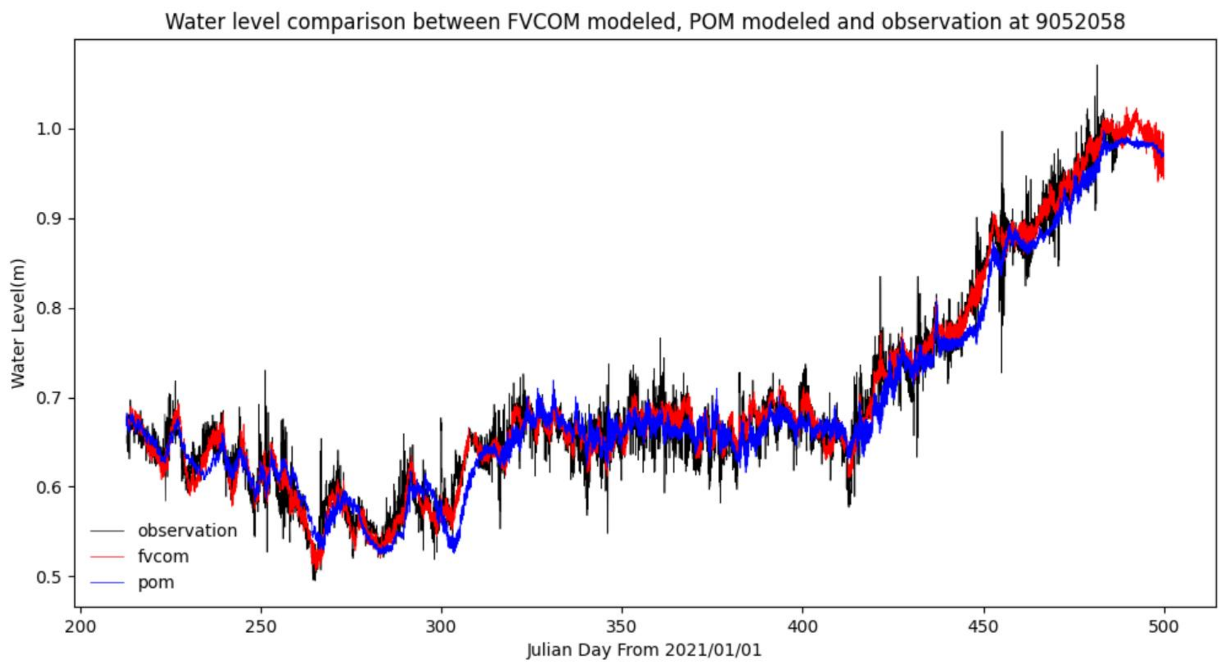

Figure B-3. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Rochester.

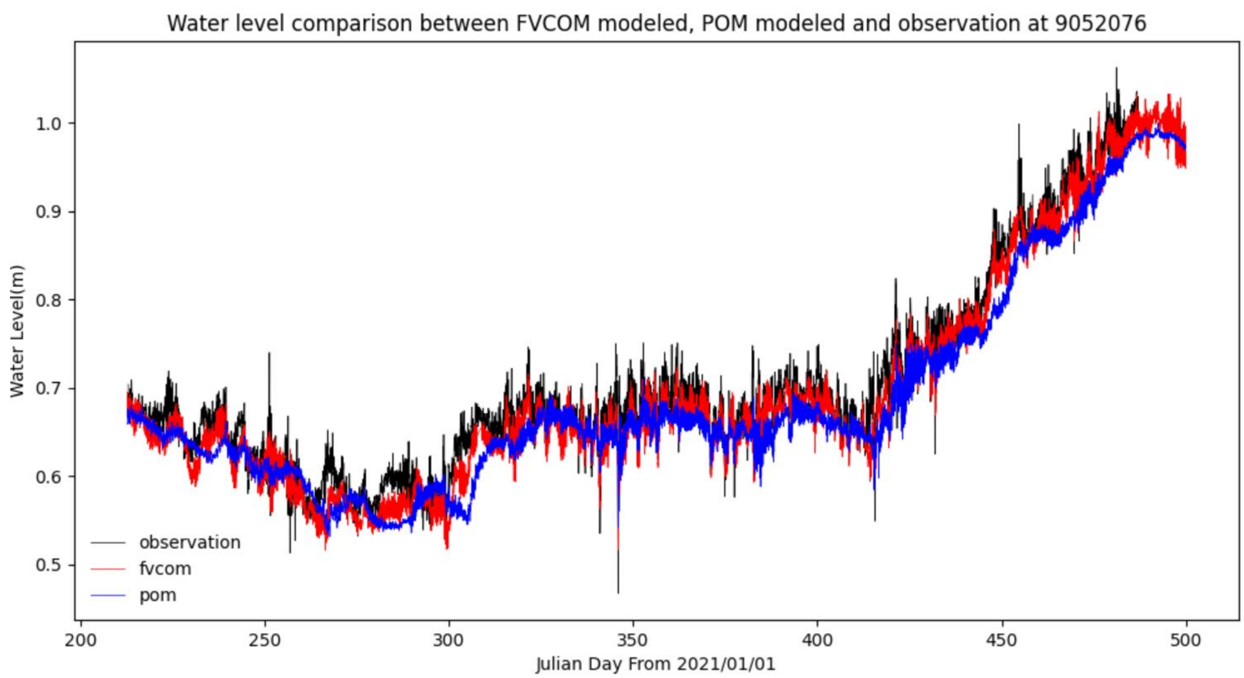

Figure B-4. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Olcott.

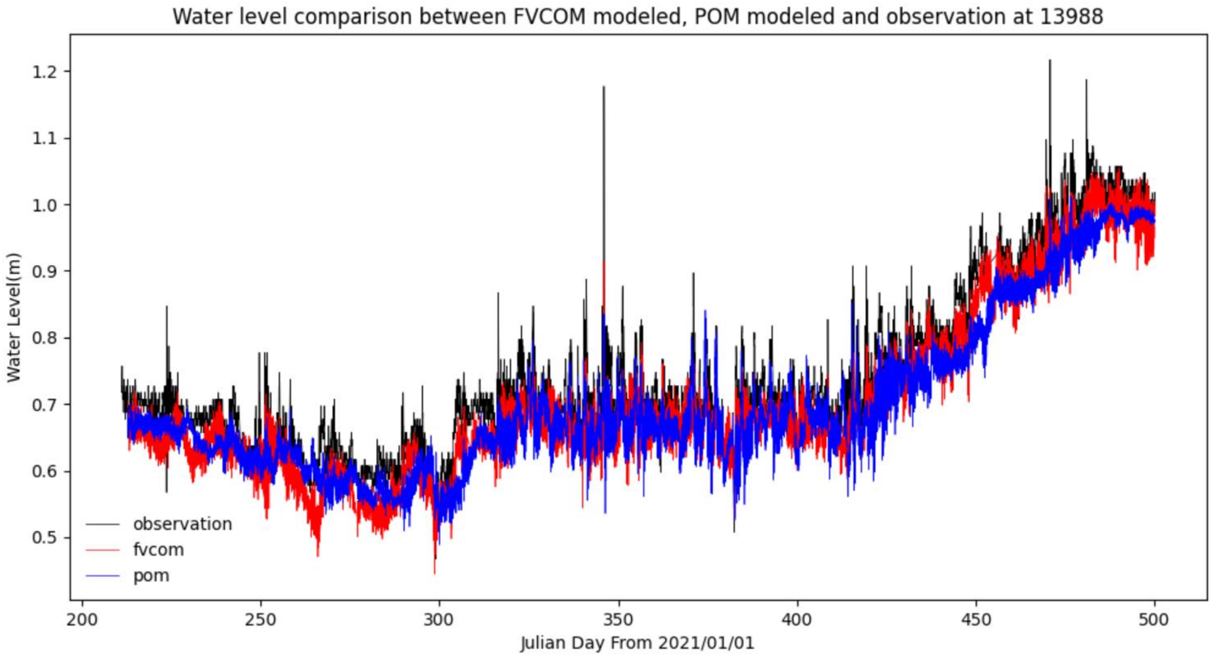

Figure B-5. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Kingston.

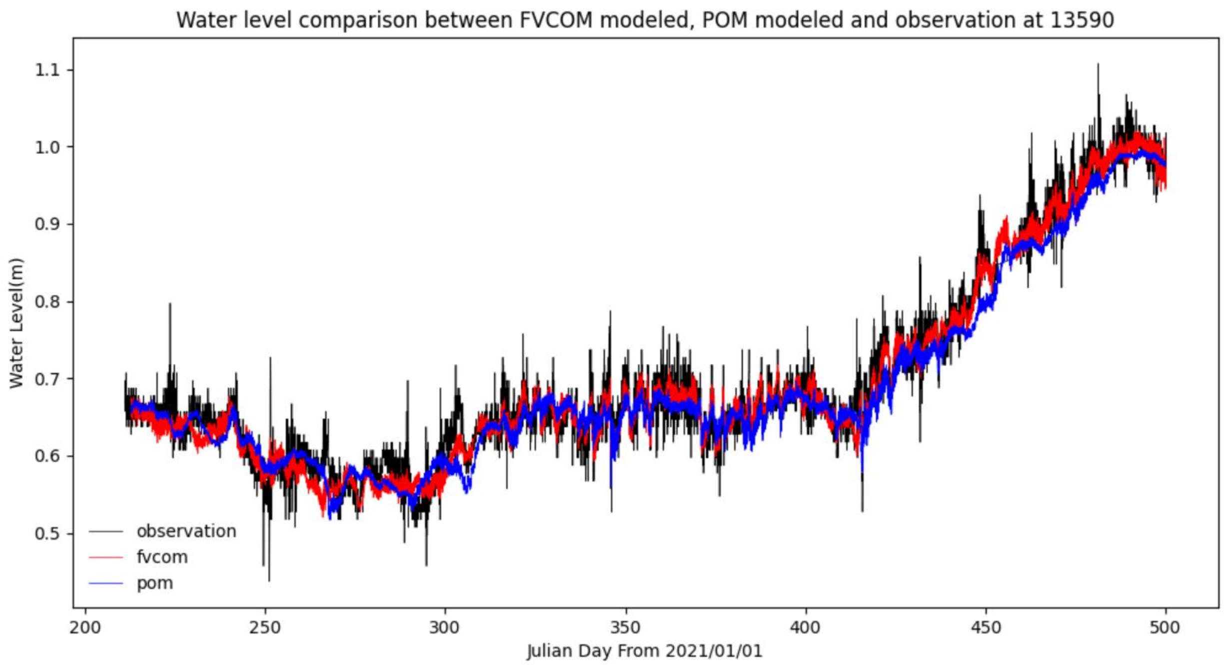

Figure B-6. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Coburg.

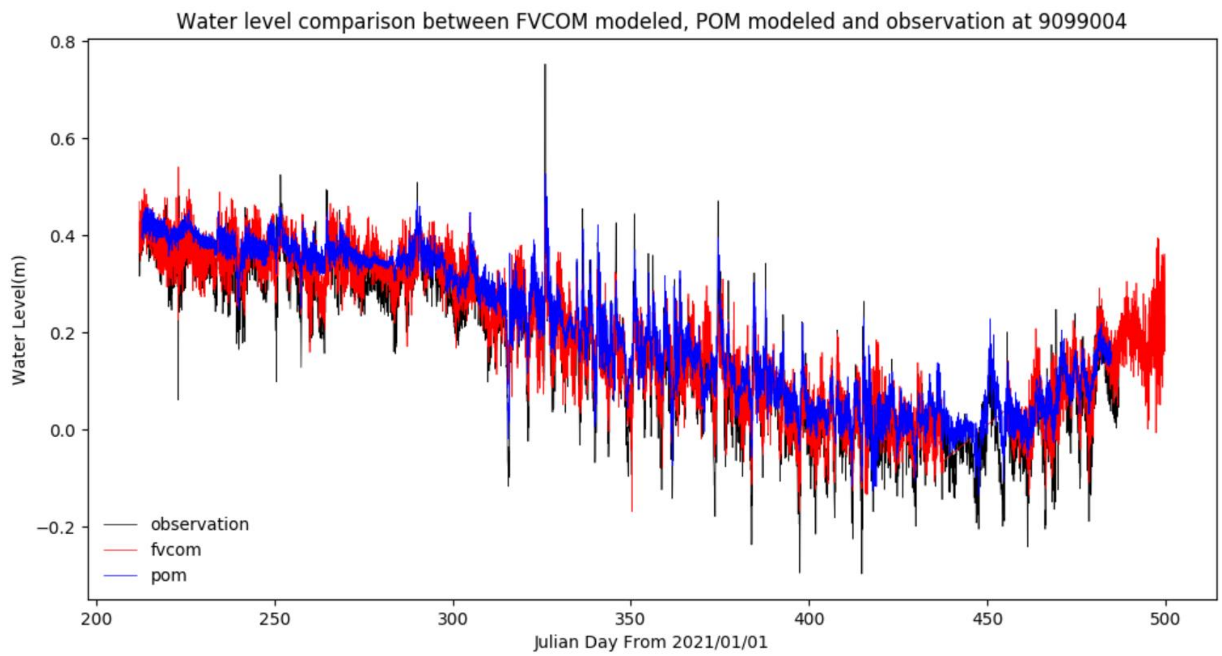

Figure B-7. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Point Iroquois.

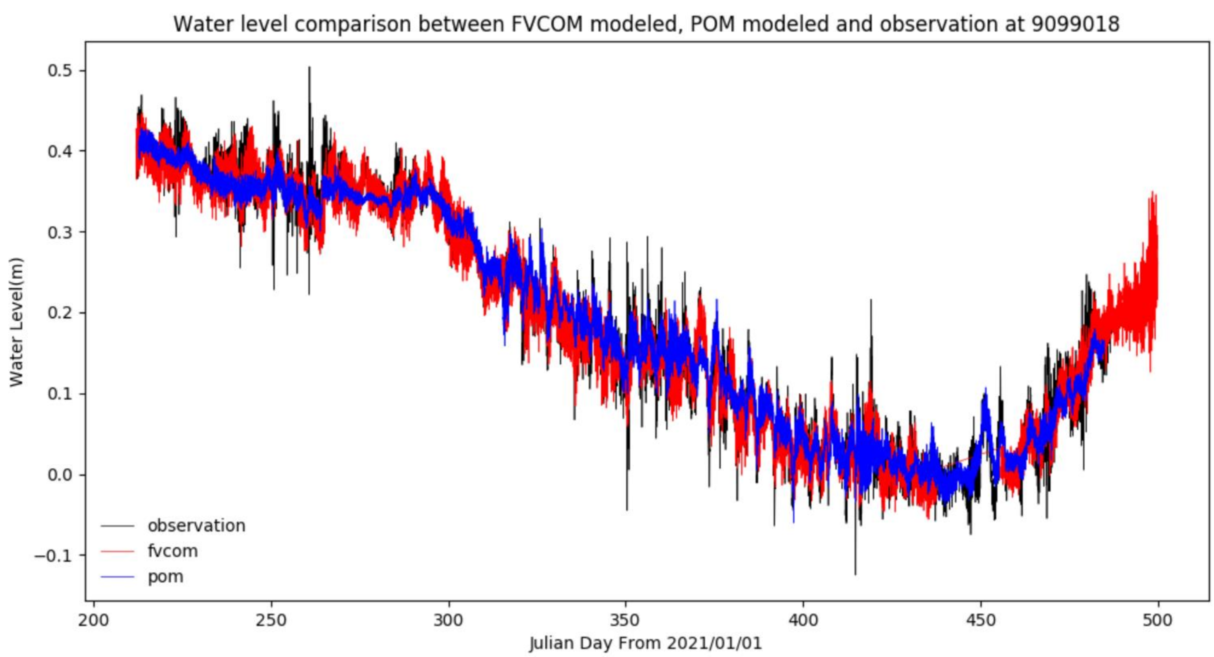

Figure B-8. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Marquette.

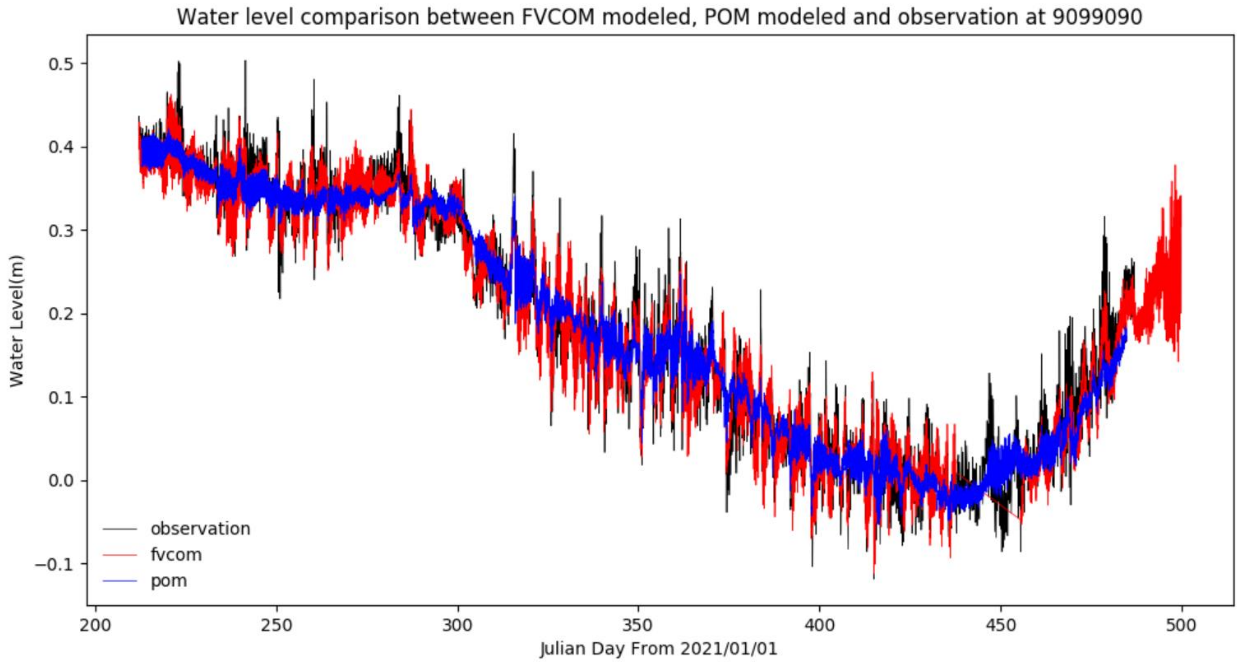

Figure B-9. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Grand Marais.

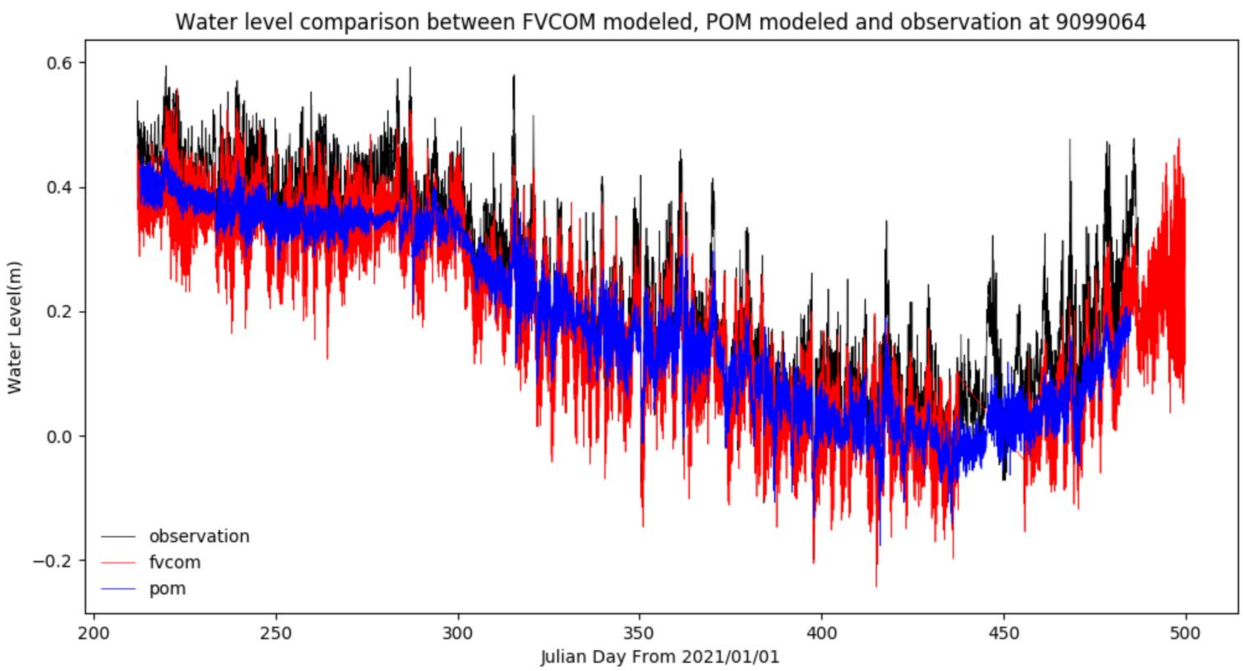

Figure B-10. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Duluth.

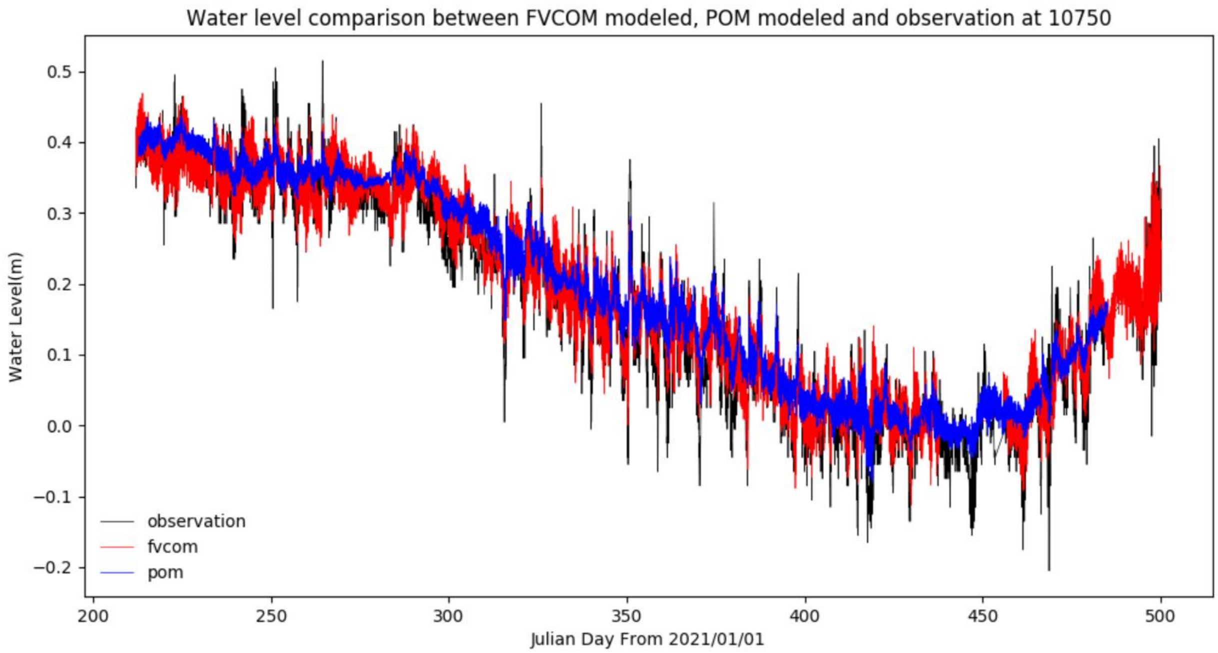

Figure B-11. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Michipicoten.

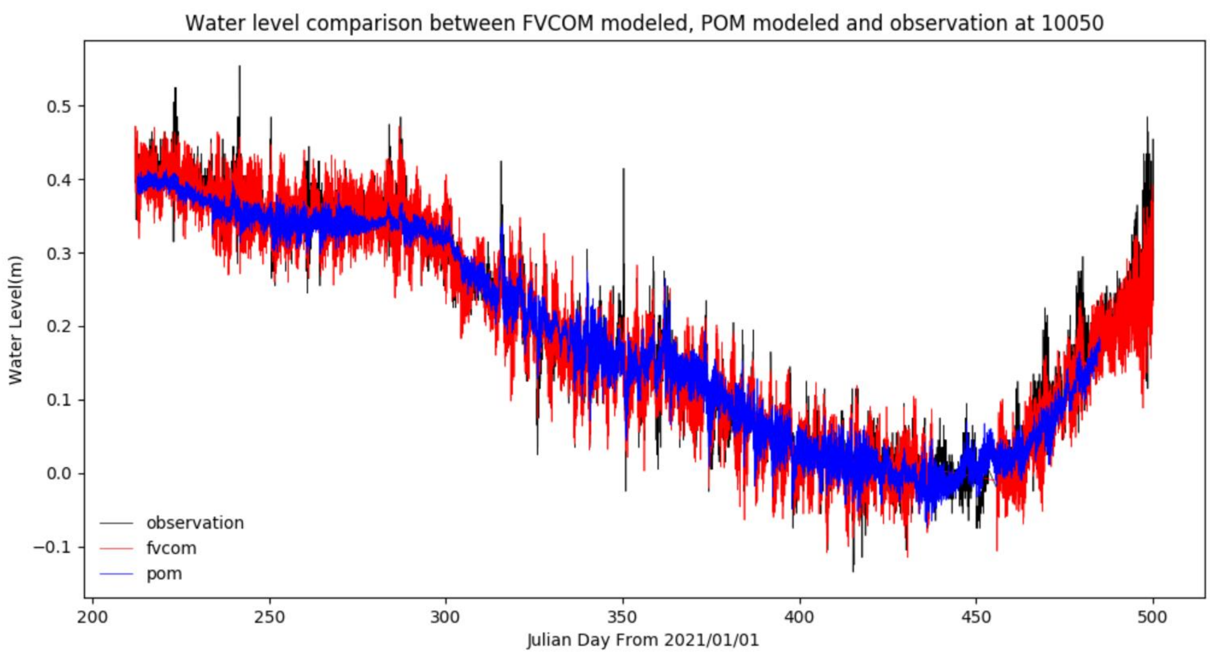

Figure B-12. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Thunder Bay.

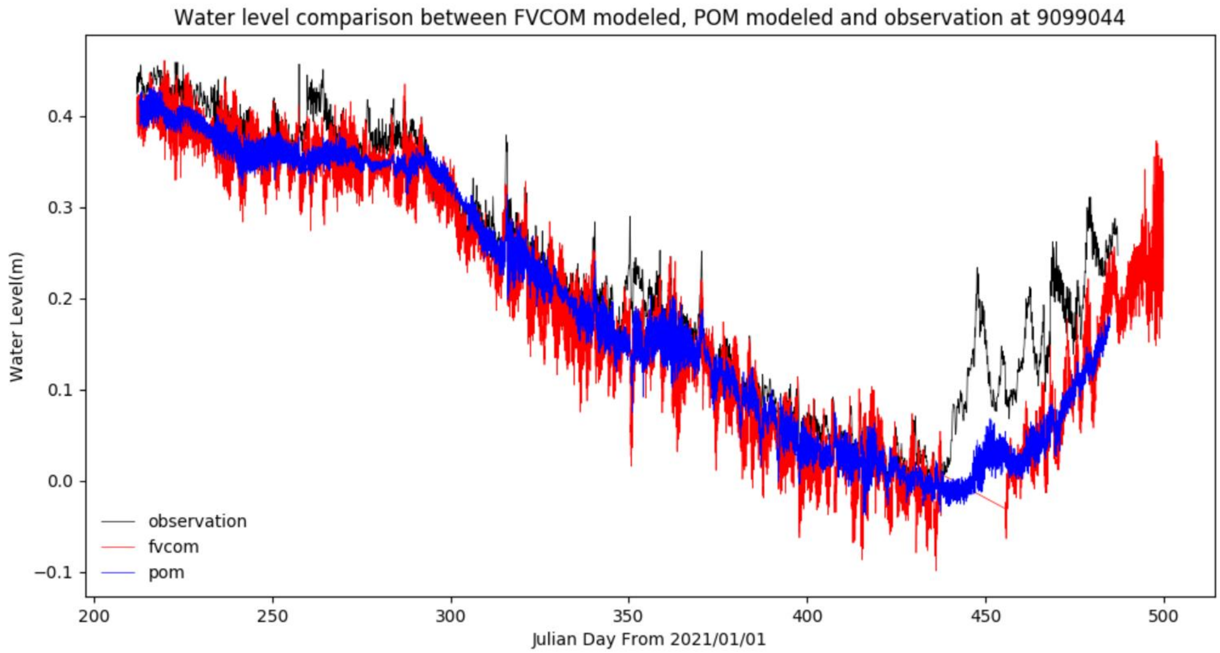

Figure B-13. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Ontonagon.

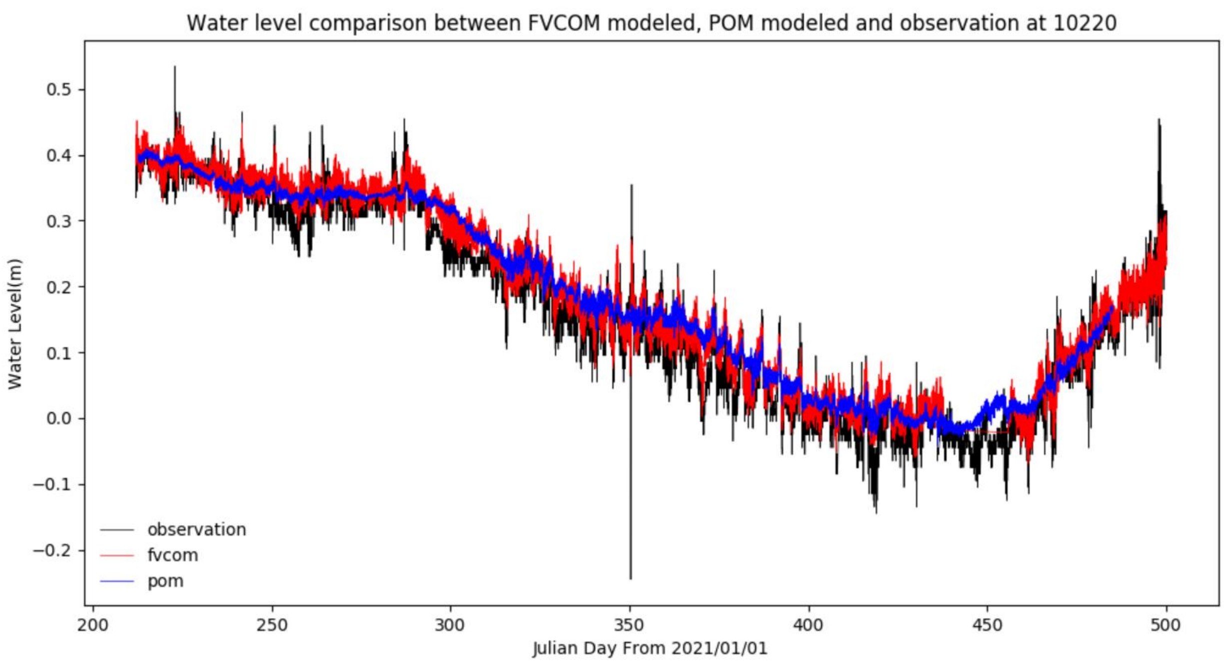

Figure B-14. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) water levels at Rossport.

APPENDIX C. SURFACE WATER TEMPERATURE SKILL ASSESSMENT TABLES

Table C-1. Water surface temperature skill assessment at East Lake Ontario.

Station:	East Lake Ontario													
Observed data time period from 8/1/2021 to 11/28/2021														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			54104	17.083										
h			54104	15.551										
H-h	3.0 c	24h	54104	1.532	2.013	1.306	0.0	87.2	0.1	0.0	2.6	-99.9	0.98	0.98
SCENARIO: SEMI-OPERATIONAL FORECAST														
T000-t000	3.0 c	24h	772	1.373	1.792	1.153	0.0	91.3	0.1	0.0	0.0	-99.9	0.99	
T006-t006	3.0 c	24h	772	1.360	1.782	1.152	0.0	91.3	0.1	0.0	0.0	-99.9	0.99	
T012-t012	3.0 c	24h	772	1.349	1.767	1.141	0.0	91.6	0.1	0.0	0.0	-99.9	0.99	
T018-t018	3.0 c	24h	772	1.340	1.752	1.130	0.0	91.8	0.1	0.0	0.0	-99.9	0.99	
T024-t024	3.0 c	24h	772	1.321	1.744	1.139	0.0	92.1	0.1	0.0	0.0	-99.9	0.99	
T030-t030	3.0 c	24h	772	1.306	1.729	1.134	0.0	92.2	0.1	0.0	0.0	-99.9	0.99	
T036-t036	3.0 c	24h	771	1.284	1.714	1.136	0.0	92.2	0.1	0.0	0.0	-99.9	0.99	
T042-t042	3.0 c	24h	770	1.274	1.709	1.140	0.0	92.2	0.0	0.0	0.0	-99.9	0.99	
T048-t048	3.0 c	24h	769	1.251	1.690	1.137	0.0	92.2	0.0	0.0	0.0	-99.9	0.99	
T054-t054	3.0 c	24h	768	1.286	1.724	1.149	0.0	91.9	0.0	0.0	0.0	-99.9	0.99	
T060-t060	3.0 c	24h	767	1.322	1.755	1.155	0.0	91.9	0.0	0.0	0.0	-99.9	0.99	
T066-t066	3.0 c	24h	766	1.352	1.778	1.156	0.0	92.2	0.0	0.0	0.0	-99.9	0.99	
T072-t072	3.0 c	24h	765	1.384	1.804	1.158	0.0	91.8	0.0	0.0	0.0	-99.9	0.99	
T078-t078	3.0 c	24h	764	1.390	1.811	1.161	0.0	91.1	0.0	0.0	0.0	-99.9	0.99	
T084-t084	3.0 c	24h	763	1.422	1.845	1.177	0.0	90.8	0.0	0.0	0.0	-99.9	0.99	
T090-t090	3.0 c	24h	762	1.445	1.866	1.182	0.0	91.2	0.1	0.0	0.0	-99.9	0.99	
T096-t096	3.0 c	24h	760	1.482	1.902	1.192	0.0	90.3	0.1	0.0	0.0	-99.9	0.99	
T102-t102	3.0 c	24h	758	1.520	1.934	1.196	0.0	89.3	0.1	0.0	0.0	-99.9	0.99	
T108-t108	3.0 c	24h	756	1.539	1.957	1.210	0.0	88.6	0.3	0.0	0.0	-99.9	0.99	
T114-t114	3.0 c	24h	754	1.570	2.000	1.239	0.0	88.2	0.4	0.0	0.0	-99.9	0.98	
T120-t120	3.0 c	24h	753	1.590	2.032	1.265	0.0	87.5	0.5	0.0	6.0	-99.9	0.98	

Table C-2. Water surface temperature skill assessment at West Lake Ontario.

Station:	West Lake Ontario													
Observed data time period from 8/1/2021 to 11/28/2021														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			32037	17.296										
h			32037	15.787										
H-h	3.0 c	24h	32037	1.509	2.751	2.300	0.0	82.9	7.5	0.9	55.2	-99.9	0.96	0.95
SCENARIO: SEMI-OPERATIONAL FORECAST														
T000-t000	3.0 c	24h	487	1.545	2.799	2.337	0.2	82.5	7.6	0.0	84.0	-99.9	0.96	
T006-t006	3.0 c	24h	485	1.545	2.809	2.349	0.2	82.3	7.6	0.0	84.0	-99.9	0.96	
T012-t012	3.0 c	24h	483	1.539	2.831	2.379	0.2	82.2	7.7	0.0	84.0	-99.9	0.96	
T018-t018	3.0 c	24h	481	1.543	2.837	2.384	0.2	82.5	8.1	0.0	84.0	-99.9	0.96	
T024-t024	3.0 c	24h	479	1.554	2.847	2.388	0.2	82.3	8.1	0.0	84.0	-99.9	0.96	
T030-t030	3.0 c	24h	478	1.534	2.849	2.404	0.2	81.8	8.2	0.0	84.0	-99.9	0.96	
T036-t036	3.0 c	24h	477	1.526	2.841	2.399	0.2	81.1	8.0	0.0	84.0	-99.9	0.96	
T042-t042	3.0 c	24h	476	1.529	2.834	2.389	0.2	81.9	8.0	0.0	84.0	-99.9	0.96	
T048-t048	3.0 c	24h	475	1.504	2.827	2.396	0.2	82.3	8.0	0.0	84.0	-99.9	0.96	
T054-t054	3.0 c	24h	474	1.531	2.826	2.378	0.2	81.9	7.8	0.0	84.0	-99.9	0.96	
T060-t060	3.0 c	24h	473	1.592	2.840	2.355	0.2	81.8	7.4	0.0	84.0	-99.9	0.96	
T066-t066	3.0 c	24h	472	1.649	2.868	2.349	0.2	82.0	7.6	0.0	84.0	-99.9	0.95	
T072-t072	3.0 c	24h	471	1.679	2.901	2.369	0.2	81.5	7.9	0.0	84.0	-99.9	0.95	
T078-t078	3.0 c	24h	470	1.709	2.923	2.373	0.2	81.9	8.3	0.0	84.0	-99.9	0.95	
T084-t084	3.0 c	24h	469	1.735	2.950	2.389	0.2	81.9	8.3	0.0	84.0	-99.9	0.95	
T090-t090	3.0 c	24h	468	1.746	2.979	2.416	0.2	81.4	8.8	0.0	84.0	-99.9	0.95	
T096-t096	3.0 c	24h	467	1.791	2.988	2.394	0.0	80.9	8.8	0.0	84.0	-99.9	0.95	
T102-t102	3.0 c	24h	466	1.821	2.995	2.380	0.0	81.3	8.6	0.0	84.0	-99.9	0.96	
T108-t108	3.0 c	24h	465	1.853	3.006	2.369	0.0	80.4	8.6	0.0	84.0	-99.9	0.96	
T114-t114	3.0 c	24h	464	1.905	3.031	2.360	0.0	80.6	9.1	0.0	84.0	-99.9	0.96	
T120-t120	3.0 c	24h	463	1.938	3.075	2.389	0.2	79.5	9.1	0.0	84.0	-99.9	0.95	

Table C-3. Water surface temperature skill assessment at Prince Edward Pt.

Station:	Prince Edward Pt													
Observed data time period from 8/28/2021 to 10/18/2021														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			29967	18.446										
h			29967	16.973										
H-h	3.0 c	24h	29967	1.473	2.259	1.713	0.0	92.5	4.7	0.0	30.9	-99.9	0.96	0.96
SCENARIO: SEMI-OPERATIONAL FORECAST														
T000-t000	3.0 c	24h	454	1.450	2.209	1.668	0.0	92.5	4.2	0.0	42.9	-99.9	0.96	
T006-t006	3.0 c	24h	454	1.457	2.217	1.673	0.0	92.5	4.2	0.0	42.9	-99.9	0.96	
T012-t012	3.0 c	24h	453	1.461	2.245	1.706	0.0	92.5	4.4	0.0	24.0	-99.9	0.96	
T018-t018	3.0 c	24h	451	1.469	2.267	1.729	0.0	92.5	4.7	0.0	24.0	-99.9	0.96	
T024-t024	3.0 c	24h	451	1.455	2.256	1.725	0.0	92.5	4.7	0.0	24.0	-99.9	0.96	
T030-t030	3.0 c	24h	450	1.437	2.241	1.722	0.0	92.7	4.7	0.0	24.0	-99.9	0.96	
T036-t036	3.0 c	24h	449	1.423	2.227	1.715	0.0	93.1	4.5	0.0	24.0	-99.9	0.96	
T042-t042	3.0 c	24h	451	1.419	2.233	1.725	0.0	92.9	4.4	0.0	24.0	-99.9	0.96	
T048-t048	3.0 c	24h	450	1.425	2.263	1.760	0.0	92.7	4.7	0.0	24.0	-99.9	0.96	
T054-t054	3.0 c	24h	448	1.439	2.260	1.745	0.0	92.4	4.7	0.0	24.0	-99.9	0.96	
T060-t060	3.0 c	24h	447	1.465	2.271	1.738	0.0	91.9	4.7	0.0	24.0	-99.9	0.96	
T066-t066	3.0 c	24h	444	1.480	2.271	1.725	0.0	91.9	4.5	0.0	24.0	-99.9	0.96	
T072-t072	3.0 c	24h	442	1.503	2.285	1.723	0.0	91.4	4.5	0.0	24.0	-99.9	0.96	
T078-t078	3.0 c	24h	441	1.521	2.310	1.740	0.0	91.8	4.5	0.0	30.0	-99.9	0.96	
T084-t084	3.0 c	24h	440	1.546	2.334	1.751	0.0	90.7	4.5	0.0	36.0	-99.9	0.96	
T090-t090	3.0 c	24h	439	1.560	2.344	1.752	0.0	90.0	4.6	0.0	42.0	-99.9	0.96	
T096-t096	3.0 c	24h	438	1.568	2.338	1.736	0.0	90.6	4.3	0.0	42.0	-99.9	0.96	
T102-t102	3.0 c	24h	436	1.596	2.353	1.731	0.0	89.9	4.4	0.0	42.0	-99.9	0.96	
T108-t108	3.0 c	24h	434	1.615	2.366	1.731	0.0	90.1	4.4	0.0	42.0	-99.9	0.96	
T114-t114	3.0 c	24h	432	1.639	2.402	1.758	0.0	90.0	4.6	0.0	42.0	-99.9	0.96	
T120-t120	3.0 c	24h	430	1.670	2.441	1.783	0.0	89.8	4.9	0.0	42.0	-99.9	0.96	

Table C-4. Water surface temperature skill assessment at NW Lake Ontario.

Station:	NW Lake Ontario													
Observed data time period from 9/2/2021 to 11/28/2021														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			35179	14.982										
h			35179	12.948										
H-h	3.0 c	24h	35179	2.034	3.207	2.480	0.3	64.3	7.2	10.4	40.9	-99.9	0.96	0.95
SCENARIO: SEMI-OPERATIONAL FORECAST														
T000-t000	3.0 c	24h	528	2.090	3.271	2.519	0.4	63.8	8.3	0.0	72.0	-99.9	0.96	
T006-t006	3.0 c	24h	526	2.095	3.284	2.530	0.4	63.7	8.4	0.0	72.0	-99.9	0.96	
T012-t012	3.0 c	24h	524	2.094	3.293	2.545	0.4	63.5	8.2	0.0	72.0	-99.9	0.96	
T018-t018	3.0 c	24h	522	2.119	3.334	2.577	0.4	62.8	8.6	0.0	72.0	-99.9	0.96	
T024-t024	3.0 c	24h	520	2.124	3.338	2.578	0.4	63.3	8.5	0.0	72.0	-99.9	0.96	
T030-t030	3.0 c	24h	520	2.111	3.340	2.591	0.4	62.7	8.3	0.0	72.0	-99.9	0.96	
T036-t036	3.0 c	24h	520	2.082	3.343	2.618	0.4	62.9	7.9	0.0	72.0	-99.9	0.96	
T042-t042	3.0 c	24h	520	2.061	3.318	2.603	0.4	63.3	7.9	0.0	72.0	-99.9	0.96	
T048-t048	3.0 c	24h	520	2.001	3.298	2.623	0.4	63.3	7.7	0.0	72.0	-99.9	0.96	
T054-t054	3.0 c	24h	520	2.011	3.291	2.608	0.4	62.9	7.9	0.0	72.0	-99.9	0.95	
T060-t060	3.0 c	24h	520	1.973	3.252	2.588	0.4	63.7	7.3	0.0	72.0	-99.9	0.96	
T066-t066	3.0 c	24h	520	1.991	3.262	2.586	0.4	63.7	7.3	0.0	66.0	-99.9	0.96	
T072-t072	3.0 c	24h	520	2.011	3.306	2.626	0.4	62.5	7.1	0.0	72.0	-99.9	0.95	
T078-t078	3.0 c	24h	520	1.978	3.315	2.663	0.4	63.5	7.1	0.0	48.0	-99.9	0.95	
T084-t084	3.0 c	24h	520	1.966	3.333	2.694	0.4	61.2	7.7	0.0	66.0	-99.9	0.95	
T090-t090	3.0 c	24h	520	1.966	3.336	2.698	0.4	61.9	7.3	0.0	66.0	-99.9	0.95	
T096-t096	3.0 c	24h	520	1.947	3.289	2.653	0.2	62.5	7.1	0.0	66.0	-99.9	0.95	
T102-t102	3.0 c	24h	519	1.930	3.279	2.653	0.6	62.0	7.1	6.0	48.0	-99.9	0.95	
T108-t108	3.0 c	24h	518	1.884	3.302	2.715	0.6	61.8	7.1	6.0	24.0	-99.9	0.95	
T114-t114	3.0 c	24h	517	1.873	3.306	2.726	0.4	62.5	7.5	6.0	30.0	-99.9	0.95	
T120-t120	3.0 c	24h	516	1.814	3.327	2.792	0.6	61.6	6.8	6.0	24.0	-99.9	0.95	

Table C-5. Water surface temperature skill assessment at Duluth.

Station:			Duluth											
Observed data time period from 8/1/2021 to 10/30/2021														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			45698	16.314										
h			45698	15.318										
H-h	3.0 c	24h	45698	0.995	5.326	5.232	17.2	24.1	15.6	429.7	196.7	-99.9	0.64	0.66
SCENARIO: SEMI-OPERATIONAL FORECAST														
T000-t000	3.0 c	24h	672	0.924	5.357	5.281	18.0	24.0	15.3	276.0	198.0	-99.9	0.64	
T006-t006	3.0 c	24h	672	0.924	5.352	5.276	18.0	24.6	15.0	270.0	198.0	-99.9	0.64	
T012-t012	3.0 c	24h	672	0.924	5.345	5.269	18.0	25.1	14.9	264.0	198.0	-99.9	0.64	
T018-t018	3.0 c	24h	672	0.924	5.340	5.263	18.0	25.6	14.7	258.0	198.0	-99.9	0.64	
T024-t024	3.0 c	24h	672	0.926	5.337	5.260	18.0	26.0	14.6	252.0	198.0	-99.9	0.65	
T030-t030	3.0 c	24h	672	0.928	5.333	5.256	18.0	26.3	14.6	246.0	198.0	-99.9	0.65	
T036-t036	3.0 c	24h	671	0.923	5.329	5.252	18.0	26.7	14.5	240.0	198.0	-99.9	0.64	
T042-t042	3.0 c	24h	670	0.916	5.325	5.249	18.1	26.9	14.3	234.0	192.0	-99.9	0.64	
T048-t048	3.0 c	24h	669	0.909	5.319	5.245	18.1	27.1	14.1	228.0	186.0	-99.9	0.64	
T054-t054	3.0 c	24h	668	0.902	5.314	5.241	18.1	27.2	13.9	222.0	180.0	-99.9	0.64	
T060-t060	3.0 c	24h	667	0.896	5.308	5.236	18.1	27.4	13.8	216.0	174.0	-99.9	0.64	
T066-t066	3.0 c	24h	666	0.891	5.302	5.230	18.2	27.6	13.7	216.0	168.0	-99.9	0.64	
T072-t072	3.0 c	24h	665	0.886	5.295	5.225	18.2	27.8	13.8	222.0	162.0	-99.9	0.64	
T078-t078	3.0 c	24h	664	0.882	5.289	5.219	18.2	28.0	14.0	228.0	156.0	-99.9	0.65	
T084-t084	3.0 c	24h	663	0.878	5.284	5.214	18.3	28.2	14.0	234.0	150.0	-99.9	0.65	
T090-t090	3.0 c	24h	662	0.874	5.280	5.211	18.3	28.2	14.0	240.0	144.0	-99.9	0.65	
T096-t096	3.0 c	24h	662	0.859	5.279	5.213	18.4	28.2	13.9	246.0	138.0	-99.9	0.65	
T102-t102	3.0 c	24h	662	0.843	5.279	5.215	18.6	28.2	13.7	252.0	132.0	-99.9	0.65	
T108-t108	3.0 c	24h	662	0.827	5.280	5.219	18.7	28.2	13.7	258.0	126.0	-99.9	0.65	
T114-t114	3.0 c	24h	662	0.811	5.281	5.222	18.9	28.2	13.7	264.0	120.0	-99.9	0.65	
T120-t120	3.0 c	24h	661	0.808	5.278	5.220	18.9	28.1	13.8	264.0	114.0	-99.9	0.65	

Table C-6. Water surface temperature skill assessment at Grand Marais.

Station:			Grand Marais											
Observed data time period from 8/1/2021 to 11/22/2021														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			46182	8.216										
h			46182	10.498										
H-h	3.0 c	24h	46182	-2.281	3.209	2.257	0.0	48.7	0.8	0.0	11.7	-99.9	0.72	0.74
SCENARIO: SEMI-OPERATIONAL FORECAST														
T000-t000	3.0 c	24h	680	-2.320	3.244	2.270	0.0	47.9	1.2	0.0	18.0	-99.9	0.71	
T006-t006	3.0 c	24h	680	-2.318	3.244	2.272	0.0	47.4	1.0	0.0	6.0	-99.9	0.71	
T012-t012	3.0 c	24h	680	-2.231	3.221	2.325	0.1	47.4	1.5	0.0	48.0	-99.9	0.71	
T018-t018	3.0 c	24h	680	-2.194	3.198	2.329	0.0	47.5	1.0	0.0	18.0	-99.9	0.71	
T024-t024	3.0 c	24h	680	-2.173	3.198	2.348	0.1	48.5	0.7	0.0	18.0	-99.9	0.71	
T030-t030	3.0 c	24h	680	-2.185	3.197	2.335	0.0	48.5	0.9	0.0	18.0	-99.9	0.71	
T036-t036	3.0 c	24h	679	-2.161	3.190	2.347	0.0	49.5	0.7	0.0	18.0	-99.9	0.71	
T042-t042	3.0 c	24h	678	-2.167	3.184	2.334	0.1	48.8	0.9	0.0	6.0	-99.9	0.71	
T048-t048	3.0 c	24h	677	-2.163	3.186	2.341	0.0	48.3	1.0	0.0	18.0	-99.9	0.71	
T054-t054	3.0 c	24h	676	-2.085	3.147	2.359	0.0	52.1	1.0	0.0	24.0	-99.9	0.71	
T060-t060	3.0 c	24h	675	-2.085	3.123	2.327	0.0	51.9	0.7	0.0	6.0	-99.9	0.71	
T066-t066	3.0 c	24h	674	-2.052	3.115	2.346	0.0	52.8	0.9	0.0	6.0	-99.9	0.70	
T072-t072	3.0 c	24h	673	-2.047	3.136	2.377	0.0	53.6	0.9	0.0	12.0	-99.9	0.70	
T078-t078	3.0 c	24h	672	-2.053	3.131	2.366	0.0	52.5	0.6	0.0	6.0	-99.9	0.69	
T084-t084	3.0 c	24h	671	-2.052	3.115	2.346	0.0	51.6	0.4	0.0	0.0	-99.9	0.70	
T090-t090	3.0 c	24h	670	-2.040	3.103	2.340	0.0	53.1	0.4	0.0	0.0	-99.9	0.70	
T096-t096	3.0 c	24h	669	-2.037	3.095	2.332	0.0	54.1	0.4	0.0	0.0	-99.9	0.70	
T102-t102	3.0 c	24h	668	-2.018	3.092	2.344	0.0	53.1	0.3	0.0	0.0	-99.9	0.70	
T108-t108	3.0 c	24h	667	-2.011	3.102	2.363	0.0	51.9	0.1	0.0	0.0	-99.9	0.69	
T114-t114	3.0 c	24h	666	-2.002	3.087	2.351	0.0	53.6	0.3	0.0	0.0	-99.9	0.70	
T120-t120	3.0 c	24h	665	-1.989	3.068	2.338	0.2	54.6	0.3	0.0	0.0	-99.9	0.70	

Table C-7. Water surface temperature skill assessment at North Entry Buoy.

Station:			North Entry Buoy											
Observed data time period from 8/28/2021 to 10/15/2021														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			19037	18.985										
h			19037	18.317										
H-h	3.0 c	24h	19037	0.668	1.511	1.356	0.0	98.0	0.6	0.0	3.1	-99.9	0.79	0.83
SCENARIO: SEMI-OPERATIONAL FORECAST														
T000-t000	3.0 c	24h	289	0.757	1.581	1.390	0.0	98.3	1.0	0.0	0.0	-99.9	0.77	
T006-t006	3.0 c	24h	289	0.752	1.585	1.398	0.0	98.3	1.0	0.0	0.0	-99.9	0.76	
T012-t012	3.0 c	24h	289	0.738	1.565	1.382	0.0	97.9	1.0	0.0	0.0	-99.9	0.77	
T018-t018	3.0 c	24h	289	0.724	1.561	1.386	0.0	97.9	0.7	0.0	0.0	-99.9	0.76	
T024-t024	3.0 c	24h	288	0.697	1.504	1.335	0.0	98.3	0.7	0.0	0.0	-99.9	0.78	
T030-t030	3.0 c	24h	287	0.639	1.435	1.288	0.0	98.6	0.7	0.0	0.0	-99.9	0.80	
T036-t036	3.0 c	24h	286	0.591	1.452	1.328	0.0	98.3	0.3	0.0	0.0	-99.9	0.78	
T042-t042	3.0 c	24h	284	0.531	1.400	1.298	0.0	98.6	0.4	0.0	0.0	-99.9	0.79	
T048-t048	3.0 c	24h	283	0.462	1.336	1.256	0.0	98.2	0.4	0.0	0.0	-99.9	0.81	
T054-t054	3.0 c	24h	282	0.530	1.397	1.295	0.0	98.9	0.4	0.0	0.0	-99.9	0.81	
T060-t060	3.0 c	24h	280	0.552	1.414	1.304	0.0	98.2	0.4	0.0	0.0	-99.9	0.82	
T066-t066	3.0 c	24h	279	0.592	1.473	1.351	0.0	97.8	0.4	0.0	0.0	-99.9	0.83	
T072-t072	3.0 c	24h	278	0.598	1.457	1.331	0.0	97.8	0.0	0.0	0.0	-99.9	0.86	
T078-t078	3.0 c	24h	277	0.630	1.467	1.327	0.0	98.2	0.0	0.0	0.0	-99.9	0.87	
T084-t084	3.0 c	24h	276	0.700	1.476	1.302	0.0	98.2	0.0	0.0	0.0	-99.9	0.87	
T090-t090	3.0 c	24h	275	0.760	1.553	1.357	0.0	97.1	0.4	0.0	0.0	-99.9	0.84	
T096-t096	3.0 c	24h	273	0.816	1.674	1.464	0.0	96.0	0.7	0.0	0.0	-99.9	0.79	
T102-t102	3.0 c	24h	271	0.833	1.619	1.391	0.0	97.0	0.4	0.0	0.0	-99.9	0.83	
T108-t108	3.0 c	24h	269	0.872	1.688	1.447	0.0	95.2	0.4	0.0	0.0	-99.9	0.81	
T114-t114	3.0 c	24h	267	0.927	1.813	1.561	0.0	95.1	1.1	0.0	0.0	-99.9	0.78	
T120-t120	3.0 c	24h	265	0.955	1.866	1.607	0.0	91.3	0.8	0.0	0.0	-99.9	0.78	

Table C-8. Water surface temperature skill assessment at East Superior.

Station:			East Superior											
Observed data time period from 4/13/2022 to 8/3/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE	X	N	IMAX	SM	RMSE	SD	NOF	CF	POF	MDNO	MDPO	WOF	CORR	SKILL
CRITERION	-	-	-	-	-	-	<1%	>90%	<1%	<N	<N	<.5%		
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			46969	11.156										
h			46969	8.391										
H-h	3.0 c	24h	46969	2.765	4.583	3.655	0.0	71.1	23.8	0.0	*****	-99.9	0.84	0.88
SCENARIO: SEMI-OPERATIONAL FORECAST														
T000-t000	3.0 c	24h	698	2.691	4.507	3.618	0.0	72.8	23.8	0.0	420.0	-99.9	0.85	
T006-t006	3.0 c	24h	698	2.701	4.523	3.631	0.0	72.6	23.6	0.0	420.0	-99.9	0.85	
T012-t012	3.0 c	24h	697	2.709	4.532	3.636	0.0	72.5	23.5	0.0	420.0	-99.9	0.85	
T018-t018	3.0 c	24h	696	2.714	4.550	3.655	0.0	72.3	23.6	0.0	420.0	-99.9	0.84	
T024-t024	3.0 c	24h	695	2.726	4.567	3.667	0.0	72.1	23.5	0.0	420.0	-99.9	0.84	
T030-t030	3.0 c	24h	694	2.729	4.583	3.685	0.0	72.0	23.6	0.0	420.0	-99.9	0.84	
T036-t036	3.0 c	24h	693	2.711	4.567	3.678	0.0	71.9	24.0	0.0	420.0	-99.9	0.84	
T042-t042	3.0 c	24h	692	2.702	4.558	3.673	0.0	72.0	23.6	0.0	420.0	-99.9	0.84	
T048-t048	3.0 c	24h	691	2.688	4.551	3.674	0.0	71.9	23.0	0.0	420.0	-99.9	0.84	
T054-t054	3.0 c	24h	690	2.700	4.550	3.665	0.0	72.0	23.6	0.0	420.0	-99.9	0.84	
T060-t060	3.0 c	24h	689	2.724	4.559	3.659	0.0	72.0	23.7	0.0	420.0	-99.9	0.84	
T066-t066	3.0 c	24h	688	2.738	4.558	3.647	0.0	71.9	23.7	0.0	420.0	-99.9	0.84	
T072-t072	3.0 c	24h	688	2.752	4.561	3.640	0.0	71.9	23.8	0.0	420.0	-99.9	0.84	
T078-t078	3.0 c	24h	688	2.770	4.566	3.633	0.0	71.9	24.4	0.0	420.0	-99.9	0.84	
T084-t084	3.0 c	24h	688	2.776	4.563	3.625	0.0	71.8	24.4	0.0	420.0	-99.9	0.84	
T090-t090	3.0 c	24h	688	2.792	4.571	3.621	0.0	71.5	24.7	0.0	420.0	-99.9	0.84	
T096-t096	3.0 c	24h	687	2.811	4.575	3.612	0.0	71.5	25.2	0.0	420.0	-99.9	0.85	
T102-t102	3.0 c	24h	686	2.827	4.587	3.615	0.0	71.3	24.9	0.0	420.0	-99.9	0.85	
T108-t108	3.0 c	24h	685	2.852	4.596	3.606	0.0	71.2	25.4	0.0	420.0	-99.9	0.85	
T114-t114	3.0 c	24h	684	2.865	4.599	3.600	0.0	70.9	25.0	0.0	420.0	-99.9	0.85	
T120-t120	3.0 c	24h	683	2.884	4.608	3.597	0.0	70.9	25.2	0.0	426.0	-99.9	0.85	

Table C-9. Water surface temperature skill assessment at Mid Superior.

Station:		Mid Superior												
Observed data time period from 4/12/2022 to 8/3/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			46534	10.321										
h			46534	7.953										
H-h	3.0 c	24h	46534	2.368	4.326	3.621	0.0	72.3	19.3	0.0	870.3	-99.9	0.84	0.89
SCENARIO: SEMI-OPERATIONAL FORECAST														
T000-t000	3.0 c	24h	691	2.290	4.245	3.577	0.0	72.8	18.7	0.0	420.0	-99.9	0.84	
T006-t006	3.0 c	24h	691	2.305	4.267	3.594	0.0	72.8	18.8	0.0	420.0	-99.9	0.84	
T012-t012	3.0 c	24h	691	2.314	4.287	3.611	0.0	72.8	19.0	0.0	420.0	-99.9	0.84	
T018-t018	3.0 c	24h	691	2.327	2.307	3.627	0.0	72.8	19.0	0.0	420.0	-99.9	0.84	
T024-t024	3.0 c	24h	691	2.340	4.330	3.646	0.0	72.8	19.4	0.0	420.0	-99.9	0.84	
T030-t030	3.0 c	24h	692	2.334	4.344	3.667	0.0	72.8	19.5	0.0	420.0	-99.9	0.84	
T036-t036	3.0 c	24h	692	2.330	4.342	3.667	0.0	73.0	19.1	0.0	420.0	-99.9	0.84	
T042-t042	3.0 c	24h	692	2.314	4.329	3.661	0.0	73.1	19.4	0.0	420.0	-99.9	0.84	
T048-t048	3.0 c	24h	692	2.307	4.333	3.670	0.0	73.3	19.1	0.0	420.0	-99.9	0.84	
T054-t054	3.0 c	24h	691	2.328	4.334	3.659	0.0	73.4	19.5	0.0	420.0	-99.9	0.84	
T060-t060	3.0 c	24h	690	2.338	4.338	3.657	0.0	73.5	20.1	0.0	420.0	-99.9	0.84	
T066-t066	3.0 c	24h	689	2.368	4.349	3.650	0.0	73.6	20.2	0.0	420.0	-99.9	0.84	
T072-t072	3.0 c	24h	688	2.388	4.354	3.643	0.0	73.5	20.2	0.0	420.0	-99.9	0.84	
T078-t078	3.0 c	24h	688	2.397	4.358	3.642	0.0	73.4	20.8	0.0	420.0	-99.9	0.84	
T084-t084	3.0 c	24h	688	2.417	4.363	3.635	0.0	73.4	20.6	0.0	420.0	-99.9	0.84	
T090-t090	3.0 c	24h	688	2.426	4.366	3.632	0.0	73.3	20.8	0.0	420.0	-99.9	0.84	
T096-t096	3.0 c	24h	688	2.444	4.373	3.629	0.0	73.3	20.9	0.0	420.0	-99.9	0.84	
T102-t102	3.0 c	24h	687	2.463	4.380	3.625	0.0	73.2	20.7	0.0	420.0	-99.9	0.84	
T108-t108	3.0 c	24h	686	2.483	4.388	3.620	0.0	72.9	21.0	0.0	420.0	-99.9	0.84	
T114-t114	3.0 c	24h	685	2.504	4.397	3.627	0.0	72.6	20.9	0.0	420.0	-99.9	0.84	
T120-t120	3.0 c	24h	684	2.531	4.405	3.608	0.0	72.5	21.1	0.0	426.0	-99.9	0.84	

Table C-10. Water surface temperature skill assessment at West Superior.

Station:		West Superior												
Observed data time period from 4/10/2022 to 8/3/2022														
Data gap is filled using SVD method														
Data are not filtered														
VARIABLE CRITERION	X -	N -	IMAX -	SM -	RMSE -	SD -	NOF <1%	CF >90%	POF <1%	MDNO <N	MDPO <N	WOF <.5%	CORR	SKILL
SCENARIO: SEMI-OPERATIONAL NOWCAST														
H			48012	10.780										
h			48012	8.522										
H-h	3.0 c	24h	48012	2.258	4.873	4.319	0.0	71.2	19.2	0.0	822.3	-99.9	0.80	0.87
SCENARIO: SEMI-OPERATIONAL FORECAST														
T000-t000	3.0 c	24h	711	2.122	4.663	4.155	0.0	73.1	18.8	0.0	420.0	-99.9	0.82	
T006-t006	3.0 c	24h	711	2.123	4.670	4.162	0.0	73.0	18.8	0.0	420.0	-99.9	0.82	
T012-t012	3.0 c	24h	711	2.131	4.669	4.157	0.0	73.0	18.7	0.0	420.0	-99.9	0.82	
T018-t018	3.0 c	24h	711	2.131	4.673	4.162	0.0	72.9	19.0	0.0	420.0	-99.9	0.82	
T024-t024	3.0 c	24h	711	2.146	4.687	4.170	0.0	72.9	19.4	0.0	420.0	-99.9	0.82	
T030-t030	3.0 c	24h	711	2.147	4.680	4.162	0.0	72.7	19.7	0.0	420.0	-99.9	0.82	
T036-t036	3.0 c	24h	710	2.139	4.675	4.160	0.0	72.8	19.6	0.0	420.0	-99.9	0.82	
T042-t042	3.0 c	24h	709	2.133	4.665	4.151	0.0	72.5	19.7	0.0	420.0	-99.9	0.82	
T048-t048	3.0 c	24h	708	2.131	4.669	4.157	0.0	72.3	20.2	0.0	420.0	-99.9	0.82	
T054-t054	3.0 c	24h	707	2.152	4.679	4.157	0.0	72.1	20.2	0.0	420.0	-99.9	0.82	
T060-t060	3.0 c	24h	705	2.190	4.687	4.147	0.0	71.9	21.3	0.0	420.0	-99.9	0.82	
T066-t066	3.0 c	24h	703	2.233	4.718	4.159	0.0	71.8	21.2	0.0	420.0	-99.9	0.82	
T072-t072	3.0 c	24h	701	2.262	4.718	4.143	0.0	71.8	22.1	0.0	420.0	-99.9	0.82	
T078-t078	3.0 c	24h	699	2.295	4.741	4.152	0.0	71.2	22.6	0.0	420.0	-99.9	0.82	
T084-t084	3.0 c	24h	698	2.322	4.752	4.149	0.0	71.5	22.8	0.0	420.0	-99.9	0.82	
T090-t090	3.0 c	24h	697	2.356	4.766	4.146	0.0	71.3	23.1	0.0	420.0	-99.9	0.82	
T096-t096	3.0 c	24h	696	2.388	4.782	4.145	0.0	71.1	22.8	0.0	420.0	-99.9	0.82	
T102-t102	3.0 c	24h	696	2.419	4.801	4.151	0.0	71.0	23.1	0.0	420.0	-99.9	0.81	
T108-t108	3.0 c	24h	696	2.446	4.807	4.141	0.0	70.3	23.1	0.0	420.0	-99.9	0.82	
T114-t114	3.0 c	24h	696	2.482	4.834	4.151	0.0	69.8	23.1	0.0	420.0	-99.9	0.81	
T120-t120	3.0 c	24h	696	2.517	4.841	4.138	0.0	69.5	23.1	0.0	426.0	-99.9	0.81	

APPENDIX D. TIME SERIES OF MODELED SURFACE WATER TEMPERATURE VERSUS OBSERVATIONS

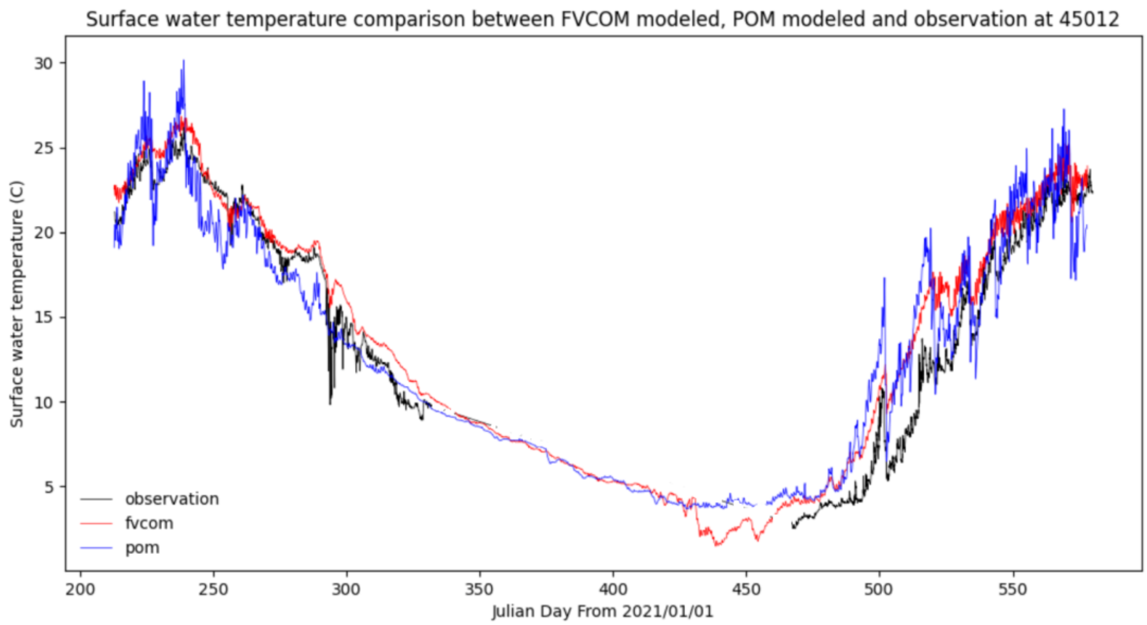

Figure D-1. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) surface water temperature at East Lake Ontario.

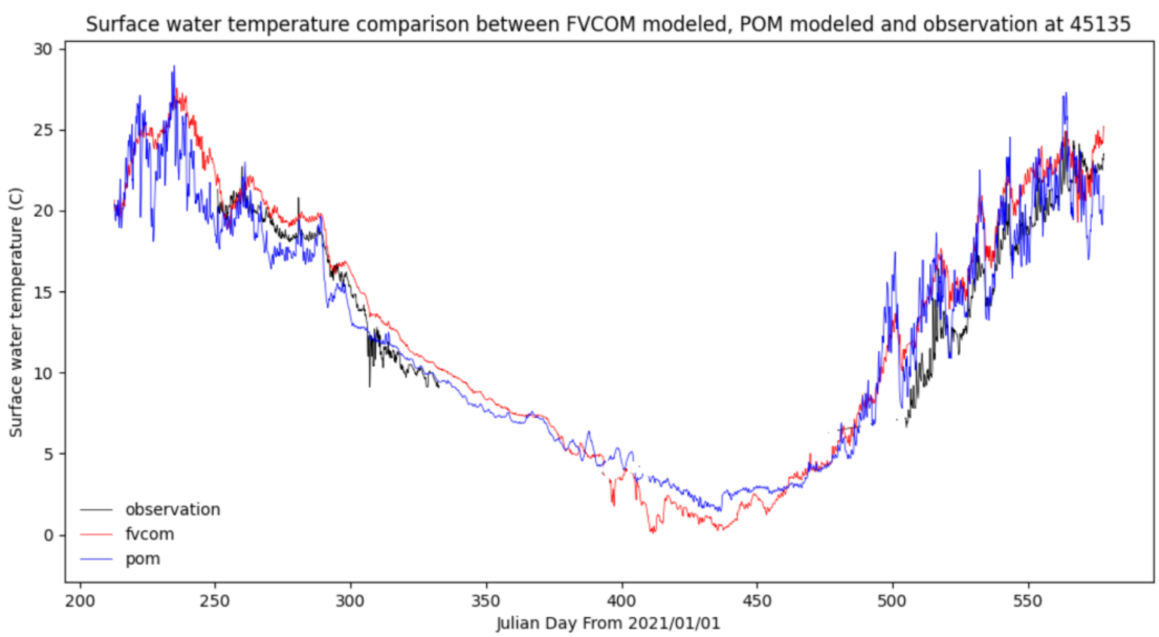

Figure D-2. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) surface water temperature at West Lake Ontario.

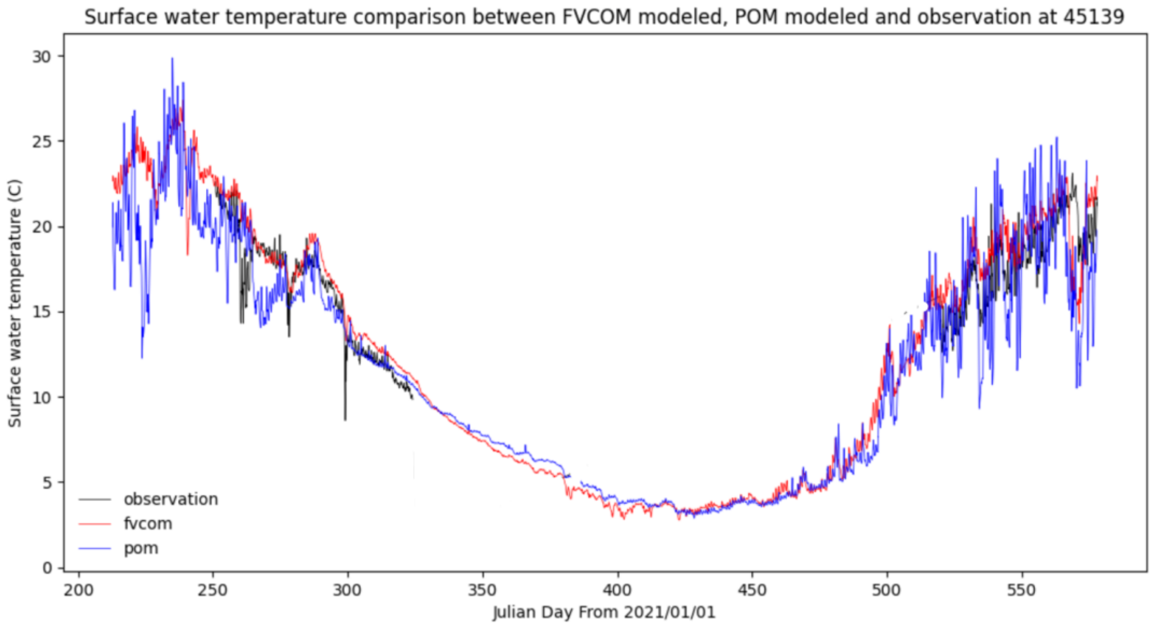

Figure D-3. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) surface water temperature at Prince Edward Pt.

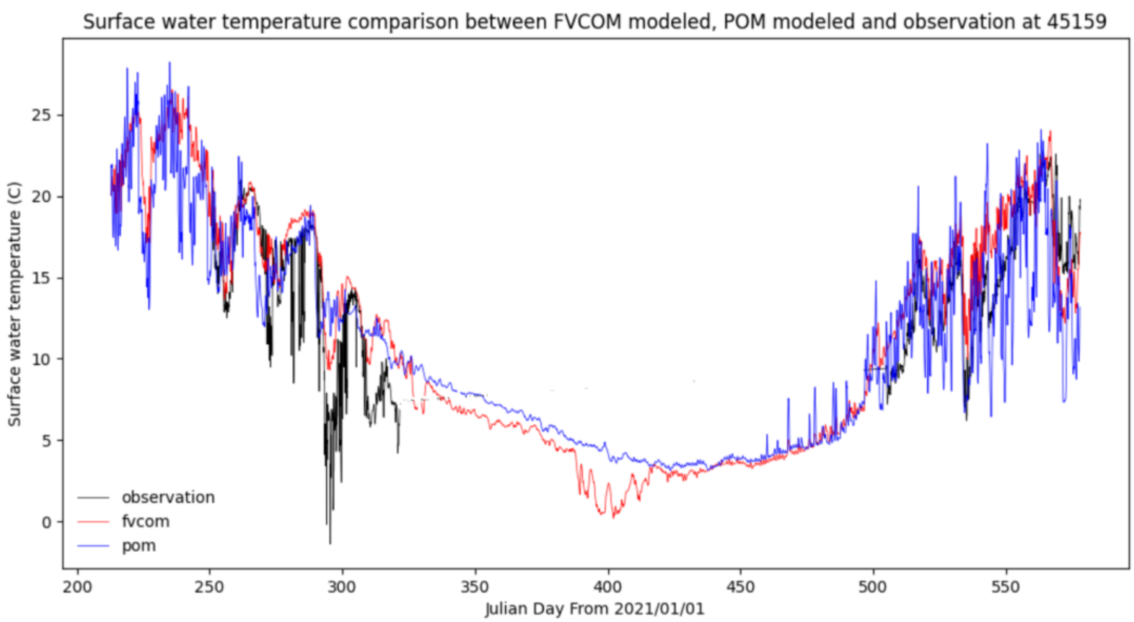

Figure D-4. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) surface water temperature at NW Lake Ontario.

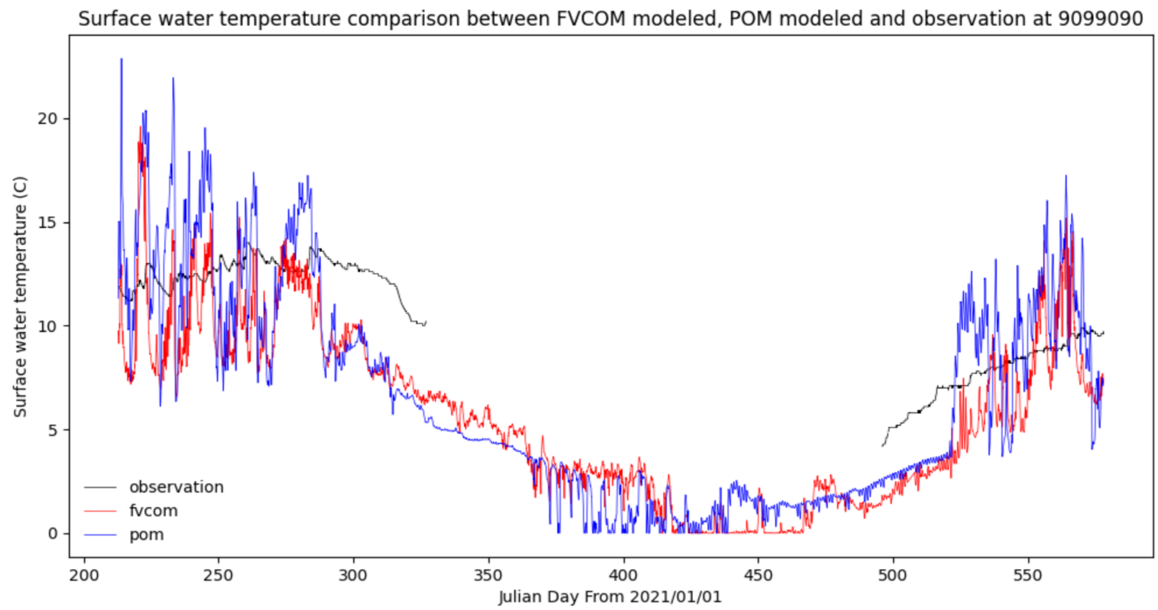

Figure D-5. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) surface water temperature at Grand Marais.

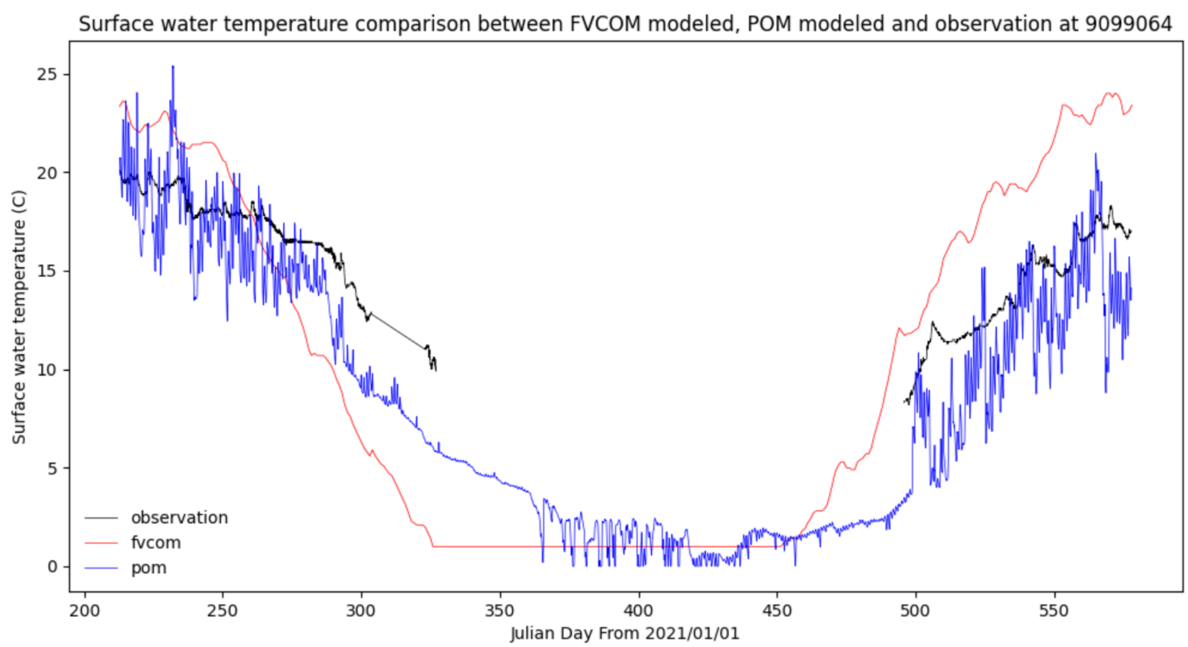

Figure D-6. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) surface water temperature at Duluth.

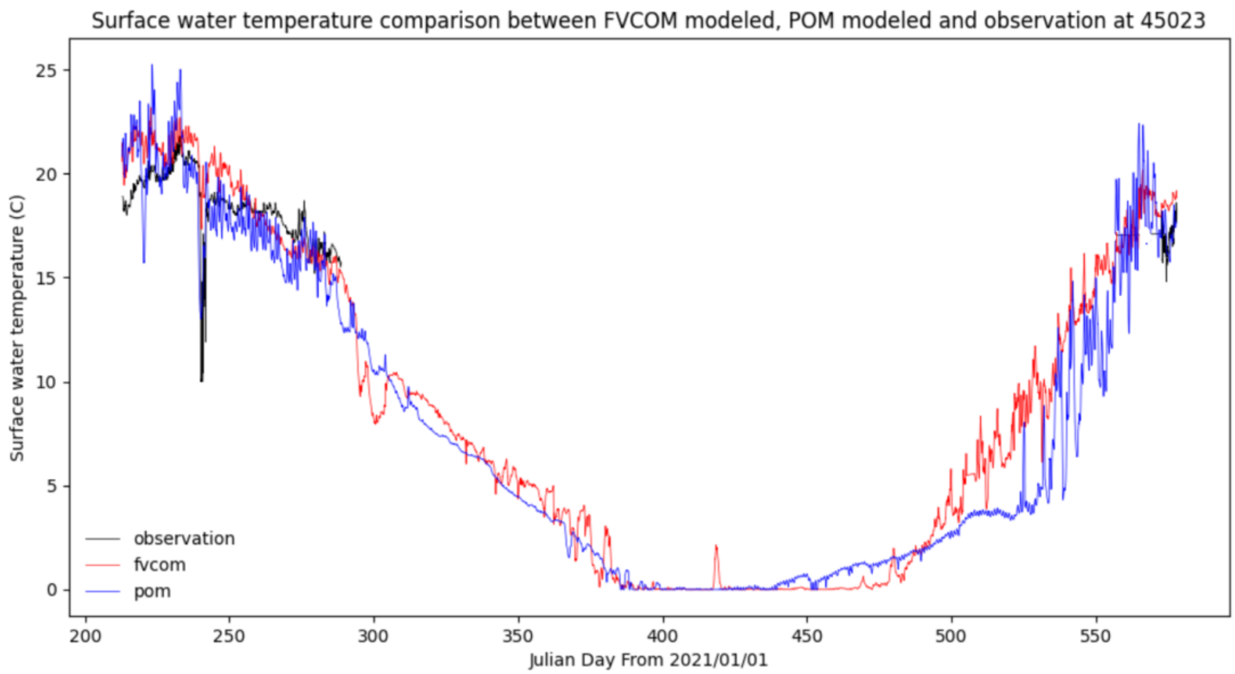

Figure D-7. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) surface water temperature at North Entry Buoy.

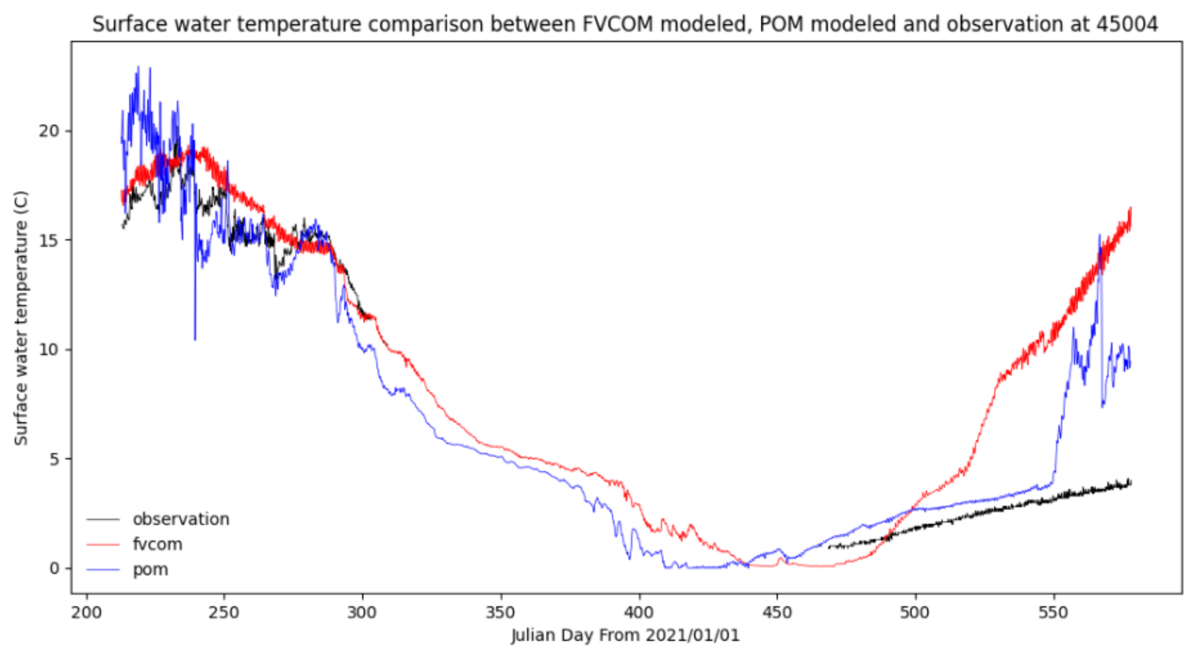

Figure D-8. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) surface water temperature at East Superior.

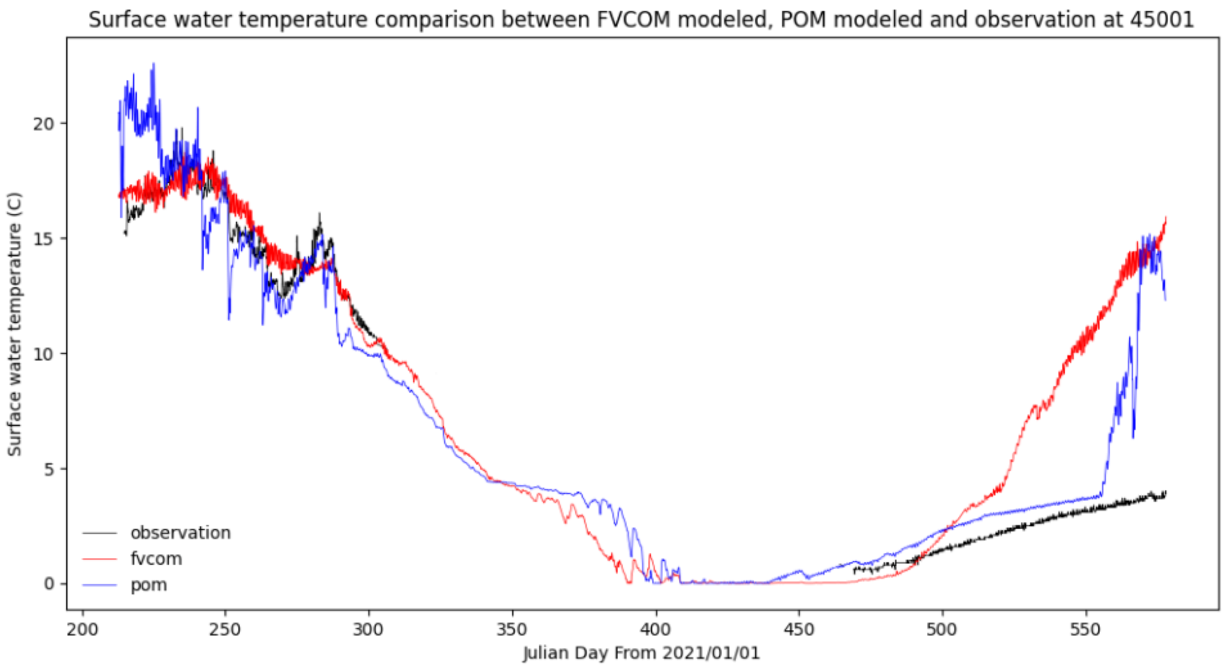

Figure D-9. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) surface water temperature at Mid Superior.

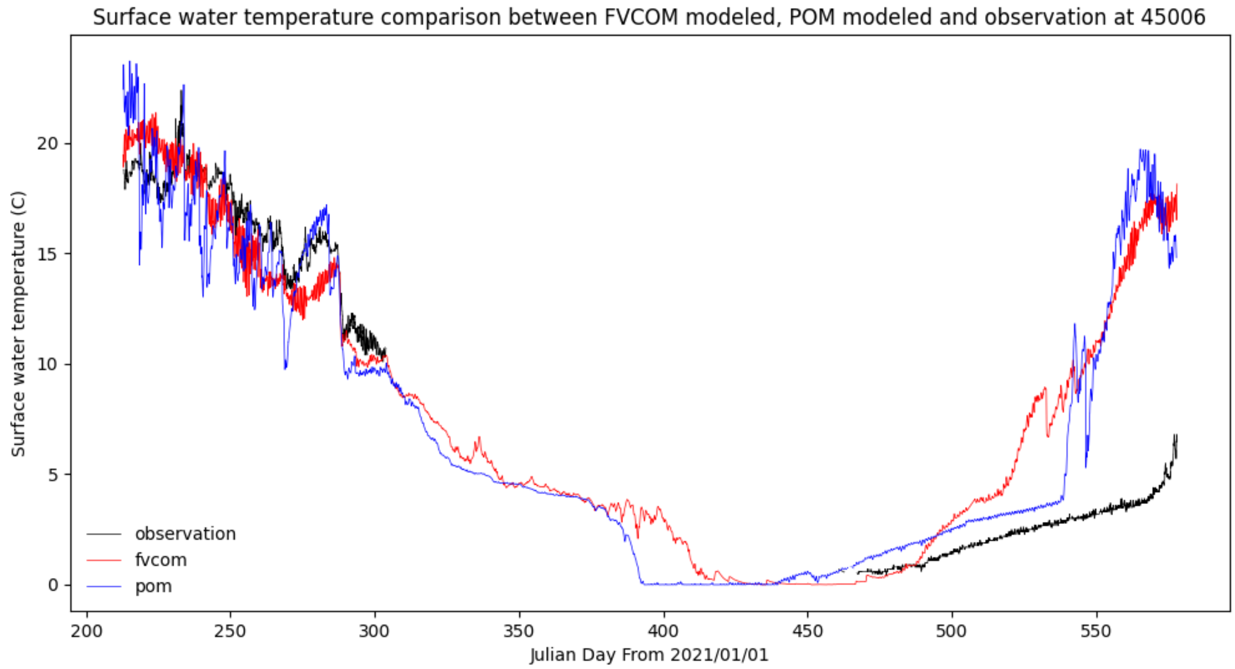

Figure D-10. Finite Volume Community Ocean Model (FVCOM; red), Princeton Ocean Model (POM; blue), and observed (black) surface water temperature at West Superior.