NOAA Technical Memorandum NOS CS 13

# SKILL ASSESSMENT OF NOS LAKE ONTARIO OPERATIONAL FORECAST SYSTEM (LOOFS)

Silver Spring, Maryland
April 2008

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Coast Survey Development Laboratory

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**National Ocean Service**
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# SKILL ASSESSMENT OF NOS LAKE ONTARIO OPERATIONAL FORECAST SYSTEM (LOOFS)


**John G. W. Kelley**
**Ai-Jun Zhang**
**Philip Chu**
**Office of Coast Survey, Coast Survey Development Lab, Silver Spring, MD**

**Gregory A. Lang**
**Office of Oceanic and Atmospheric Research**
**Great Lakes Environmental Research Laboratory, Ann Arbor, MI**



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| | |
|---|---|
| ASOS | Automated Surface Observing System |
| AVHRR | Advanced Very High Resolution Radiometer |
| AWOS | Automated Weather Observing System |
| BUFR | Binary Universal Form for the Representation of meteorological data |
| C-MAN | Coastal-Marine Automated Network |
| CCS | Central Computer System |
| COMF | Common Ocean Modeling Framework |
| CO-OPS | Center for Operational Oceanographic Products and Services |
| CORMS | Continuously Operating Real-Time Monitoring System |
| CSDL | Coast Survey Development Laboratory |
| DOD | Department of Defense |
| EPA | Environmental Protection Agency |
| ETA | Eta Mesoscale Numerical Weather Prediction Model |
| GLCFS | Great Lakes Coastal Forecast System |
| GLERL | Great Lakes Environmental Research Laboratory |
| GLFS | Great Lakes Forecasting System |
| GLOFS | Great Lakes Operational Forecast System |
| GLSEA | Great Lakes Surface Environmental Analysis |
| GRIB | GRIdded Binary |
| LEOFS | Lake Erie Operational Forecast System |
| LHOFS | Lake Huron Operational Forecast System |
| LMOFS | Lake Michigan Operational Forecast System |
| LOOFS | Lake Ontario Operational Forecast System |
| LSOFS | Lake Superior Operational Forecast System |
| MAREP | MARriner REPort |
| MMAP | Marine Modeling and Analysis Programs |
| NAM | North America Mesoscale Model |
| NCEP | National Centers for Environmental Prediction |
| NCOP | National Coastal Ocean Program |
| NDBC | National Data Buoy Center |
| NOAA | National Oceanic and Atmospheric Administration |
| NOS | National Ocean Service |
| NWLON | National Water Level Observation Network |
| NWS | National Weather Service |
| ODAAS | Operational Data Acquisition and Archive System |
| OSU | The Ohio State University |
| POMGL | Princeton Ocean Model – Great Lakes version |
| USCG | United States Coast Guard |
| VOS | Voluntary Observing Ship |

# EXECUTIVE SUMMARY

This document describes the Lake Ontario Operational Forecast System (LOOFS) and an assessment of its skill. The lake forecast system, based on a hydrodynamic model, uses near real-time atmospheric observations and numerical weather prediction forecast guidance to produce three-dimensional forecast guidance of water temperature and currents and two-dimensional forecasts of water levels for Lake Ontario.

LOOFS is the result of technology transfer of the Great Lake Forecasting System (GLFS) and Great Lakes Coastal Forecasting System (GLCFS) from The Ohio State University (OSU) and NOAA's Great Lakes Environmental Research Laboratory (GLERL) to NOAA's National Ocean Service (NOS).

The model system skill assessment of LOOFS follows scenarios specified by Hess et al. (2003) which are applicable to forecast systems for non-tidal water bodies. However, this is the first time that the NOS standards have been applied to these freshwater forecast systems. These scenarios include 1) hindcast, 2) semi-operational nowcast, and 3) semi-operational forecast. The hindcast is a long simulation using the best available observed meteorological observations and verification data. The semi-operational nowcast and forecast are simulations made in a real-time environment where there are occasional periods of missing inputs (i.e. meteorological observations and/or forecast guidance from atmospheric forecast models).

Unfortunately, there was no known research study comparing surface and subsurface observations to simulations from the Princeton Ocean Model for Lake Ontario as was the case for Lakes Michigan and Erie. Therefore, no hindcast scenario skill assessment was done for LOOFS.

For the semi-operational nowcast and forecast scenarios, an evaluation of GLERL's real-time four times/day nowcast and twice daily forecast cycles from GLCFS for Lake Ontario was used to satisfy Hess et al. (2003) requirements. Although Hess et al. (2003) recommends conducting evaluations for 365 days in order to capture all expected seasonal conditions, GLCFS nowcasts and forecasts were evaluated for the ice-free period from 15 April to 17 December 2004. Due to the lack of regularly monitored currents and sub-surface water temperatures, only water levels and surface water temperatures at a few sites could be evaluated for Lake Ontario.

The primary statistics used to assess the model performance for water levels and surface water temperatures are those required by Hess et al. (2003) for evaluating predicted water levels in non-tidal regions. These included Series Means (SM), Mean Algebraic Error (MAE), Root Mean Square Error (RMSE), Standard Deviation (SD), Negative Outlier Frequency (NOF), Positive Outlier Frequency (POF), Maximum Duration of Positive Outlier (MDPO), and Maximum Duration of Negative Outlier (MDNO).

The skill statistics for the semi-operational nowcast and forecast scenarios are summarized below:

Water levels:

Nowcasts:

The *hourly nowcasts* of water level for amplitude met the NOS acceptance criteria at the four NOS gauges in Lake Ontario: Cape Vincent, Oswego, Rochester, and Olcott, NY. In terms of other statistics, the mean algebraic error or difference (MAE) ranged between -1.1 and +2.6 cm. The RSME ranged from 2.9 to 4.4 cm.

The nowcast predictions of *high water level events* were assessed at two NOS gauges: Cape Vincent and Oswego, NY where there were 12 and two events, respectively. The nowcast of high water events passed the NOS criteria for amplitude at these two gauges. In terms of timing, the nowcasts met the NOS criteria at only Oswego.

The nowcast predictions of *low water level events* were assessed at the four NOS gauges: Cape Vincent, Oswego, Rochester, and Olcott, NY where there were six, five, two, and two events, respectively. The nowcasts of low water events met the NOS criteria for amplitude at the four gauges but did not pass the criteria in terms of timing at any of these gauges.

Forecast Guidance:

The *hourly forecast guidance* met the NOS criteria for predicting water level amplitude at all four locations. In terms of other statistics, the MAE ranged between -1.0 and +2.8 cm and RSME ranged from 3.4 to 4.8 cm.

The forecast guidance of *high water level events* were assessed at two NOS gauges: Cape Vincent and Oswego, NY where there were 11 and four events, respectively. The guidance of high water events passed the NOS criteria for amplitude at both locations. The forecast guidance failed to meet NOS criteria in predicting the times of these extreme events at either of the gauges.

The forecast guidance of *low water level events* were assessed at all four NOS gauges however, the number of 'events' were low ranging from two to six. The guidance of low water events passed the NOS criteria for amplitude at all gauges. The forecast guidance met NOS criteria in predicting the times of these extreme events at only one gauge.

Surface Water Temperatures:

Nowcasts:

The hourly surface water temperature nowcasts was very close to meeting the proposed NOS acceptance criteria at the NOAA/National Weather Service (NWS) buoy in Lake Ontario (45012). The CF was 88.6% slightly below the target of 90% or greater. The MAE was $0.003^{o}C$ and RMSE was $1.88^{o}C$.

Forecast Guidance:

The hourly surface water temperature forecast guidance also came very close to meeting the proposed NOS acceptance criteria at the NWS buoy. The guidance only failed to meet the CF target by 2.4%. The MAE was -0.13$^{o}$C and the RSME was 1.89 $^{o}$C. The times series plots indicated that LOOFS over predicted the SST during the Spring months and under predicted during August and September.

Surface Currents:

Due to the lack of water current observations, no quantitative assessment could be conducted for LOOFS. However, animation of surface current nowcasts and forecast guidance indicated that LOOFS did simulate the known cyclic clockwise rotation of surface currents present in the Great Lakes when the lake water is density stratified. This stratification occurs usually from May through October.

Key Words: short-term lake predictions, nowcasts, model forecast guidance, Lake Ontario, skill assessment, water levels, water currents, water temperatures, Princeton Ocean Model, North American Mesoscale weather prediction model

# 1. INTRODUCTION

The Great Lakes Forecasting System (GLFS) was developed by The Ohio State University (OSU) and NOAA's Great Lakes Environmental Research Laboratory (GLERL) in the late 1980s and 1990s to provide nowcasts and short-range forecasts of the physical conditions (temperature, currents, water level, and waves) of the five Great Lakes. The development of GLFS was directed by Drs. Keith Bedford (OSU) and David Schwab (GLERL) and involved over a dozen OSU graduate students, research assistants and post doctoral researchers at GLERL and OSU, and other OSU faculty members. The development of GLFS was funded by over 36 contracts from 25 different sources. From the start, GLERL and OSU were interested in working cooperatively with NOAA in "assessing the potential benefits [of GLFS] to NOAA's scientific and operational programs in the coastal ocean". In April 1991, Drs. Bedford and Schwab met with representatives from the National Weather Service (NWS) and the National Coastal Ocean Program (NCOP) in Silver Spring, MD to discuss how they could work with NOAA line offices (NWS, NOS, etc.) to have GLFS products carefully evaluated through a demonstration program prior to NWS adopting the products as 'guidance tools' and which products might be distributed directly to end users.

GLFS used the Princeton Ocean Model (Blumberg and Mellor 1987; Mellor 1996) and GLERL-Donelan wave model (Schwab et al. 1984). The first 3-D nowcast for the Great Lakes was made for Lake Erie in 1992 at the Ohio Supercomputer Center on the OSU Columbus campus (Yen et al. 1994; Schwab and Bedford 1994). Starting in July 1995, twice per day forecasts were made for Lake Erie. GLFS was recognized with an award in 2001 by the American Meteorological Society as the first U.S. coastal forecasting system to make routine real-time predictions of currents, temperatures, and key trace constituents.

In 1996, GLFS was ported to GLERL in Ann Arbor, MI. GLERL's workstation version of GLFS, called The Great Lakes Coastal Forecast System (GLCFS), has been running in semi-operational mode at GLERL for Lake Ontario since August 2002. GLCFS for Lake Ontario generates nowcasts four times/day and forecast guidance out to 60 hours twice per day. The predictions are displayed on the GLERL web page (http://www.glerl.noaa.gov/res/glcfs/) and digital output is made available in GRIdded Binary (GRIB) format to NWS Weather Forecast Offices in the region. GLCFS nowcasts and forecasts are archived at GLERL.

In 2004, the hydrodynamic model code of GLCFS for all five Great Lakes was ported to NOS Center for Operational Oceanographic Products and Services (CO-OPS) in Silver Spring, MD. GLCFS was reconfigured to run in the NOS Common Modeling Framework (COMF) and to use surface meteorological observations from NOS Operational Data Acquisition and Archive System (ODAAS) (Kelley et al. 2001). The CO-OPS version of GLCFS for Lake Ontario was renamed as the Lake Ontario Operational Forecast System (LOOFS). LOOFS began making routine operational lake nowcasts and forecasts for Lake Ontario on March 30, 2006 at CO-OPS during the ice-free season. The forecast systems for Lake Huron and Superior were also implemented on this date.

The predictions from LOOFS, similar to those from NOS estuarine forecast systems, must be evaluated to inform users about the skill of the nowcasts and forecasts. In evaluating LOOFS, NOS sought to take advantage of previous evaluations done by researchers at OSU and GLERL to fulfill the hindcast scenario requirements described in Hess et al. (2003). Unfortunately, there was no modeling research study for Lake Ontario using the Princeton Ocean Model adapted to the Great Lakes (POMGL), as was the case for Lakes Michigan and Erie. Therefore, no hindcast scenario skill assessment was done for LOOFS. However, NOS did utilize the routinely-produced nowcasts and forecasts produced by GLERL to fulfill the semi-operational nowcast and forecast scenarios required by Hess et al. (2003).

This report describes the model performance based on NOS requirements for operational nowcast/forecast systems (Hess et al. 2003). Brief descriptions of Lake Ontario and an overview of LOOFS are given first.

## 2. LAKE ONTARIO

Lake Ontario is the smallest of the Great Lakes in terms of surface area and the 14th largest lake in the world with a breadth of 85 km (53 mi) and a length of 311 km (193 mi). It has an average depth of 86 m (283 ft) with a maximum of 244m (802ft). Lake Ontario, similar to other Great Lakes, has a pronounced annual thermal cycle ranging from a vertically well-mixed water body in late autumn to a thermally stratified lake with a well-developed thermocline by August (Boyce et al. 1989).

Lake Ontario, as do all the Great Lakes, experiences three types of water level fluctuations. Short-term changes occur due to surface winds and changes in atmospheric pressure. Seasonal changes occur with the lowest levels during the winter and highest during the early autumn. Long term water level changes occur over consecutive years, with wet/cold years causing water levels to rise and warm/dry years resulting in lower water levels (GLIN 2006).

In terms of mean currents, the winter circulation in Lake Ontario is characterized by a two-gyre circulation pattern while summer circulation is predominantly cyclonic (Beletsky et al. 1999). On a short time period, Lake Ontario and other Great Lakes exhibit a cyclic clockwise rotation of surface currents when the lake water is density stratified during the warm season (May through October). Observational studies have found that the clockwise rotation has a near-inertial period of 18 hours (Saylor and Miller, 1987). Additional information on currents in the Great Lakes can be found in Boyce et al. (1989).

## 3. SYSTEM OVERVIEW

This section provides a brief description of the numerical hydrodynamic model used by LOOFS. Detailed descriptions of the model as it has been applied to Lake Michigan can be found in Schwab and Beletsky (1998). Similar descriptions of the model as it has been applied to Lake Erie are given by Hoch (1997), Kuan (1995), and Kelley (1995).

### 3.1 Description of Model

The core numerical model in LOOFS is the Princeton Ocean Model (POM) developed by Blumberg and Mellor (Mellor 1996). The model is a fully three-dimensional, non-linear primitive equation coastal ocean circulation model, with a second order Mellor-Yamada turbulence closure scheme to provide parameterization of vertical mixing processes. The model solves the continuity equation, momentum equation, and the conservation equation for temperature simultaneously in an iterative fashion, and the resulting predictive variables are free upper surface elevation, full three-dimensional velocity and temperature fields, Turbulence Kinetic Energy (TKE), and turbulence macroscale. Other main features of the model include: terrain following coordinate in the vertical (sigma coordinate), finite difference numerical scheme, Boussinesq and hydrostatic approximation, and mode splitting technique.

POM was modified by researchers at OSU and GLERL for use in the Great Lakes (Bedford and Schwab 1991, O'Connor and Schwab 1993). For the rest of this report, the modified version of the POM for the Great Lakes will be referred to as POMGL. Lake Ontario, like the other Great Lakes, is treated as an enclosed basin. Therefore, there are no inflow/outflow boundary conditions: no fluid exchange between the lake and its tributaries, between the lake and ground water sources, or between the lake and anthropogenic influences. Thus the model simulations do not include seasonal changes in lake wide mean water level due to precipitation and evaporation. GLERL is presently evaluating the impact of using climatological estimates of river discharge on POMGL simulations.

### 3.2 Grid Domain

The POMGL domain for Lake Ontario consists of a rectangular grid with a 5-km horizontal resolution in both the x- and y-directions. The domain has a total of 1525 grid points with 61 points in the x-direction and 25 points in the y-direction (Fig. 1). The bottom topography for the domain is based on GLERL's 2-km digital bathymetry data compiled by Schwab and Sellers (1980) but slightly smoothed to minimize the development of "two delta x noise." The model uses 20 sigma levels in the vertical, with vertical levels spaced more closely in the upper 30 m of water and near the bottom to better resolve both the seasonal thermocline and bottom boundary layer (Schwab and Beletsky, 1998). The levels are located at sigma equal to 0, -.0227, -.0454, -.0681, -.0908, -.1135, -.1362, -.1589, -.1816, -.2043, -.2270, -.2724, -.3405, -.4313, -.5448, -.6810, -.7945, -.8853, -.9534, and -1.0.

### 3.3 Data Ingest

The nowcast cycle relies on surface meteorological observations obtained from NOS' Operational Data Acquisition and Archive System (ODAAS). ODAAS acquires meteorological observations from the NWS/NCEP Central Operations (NCO) observational 'data tanks' located on NCEP's Central Computer Systems (CCS) twice per hour at approximately 25 and 48 minutes past the top of the hour. The observations are originally in unblocked Binary Universal Form of Representation (BUFR) of

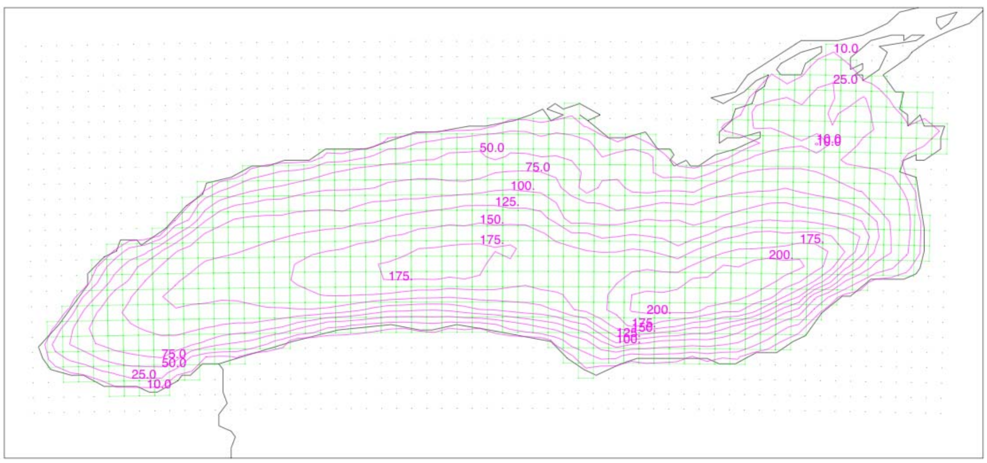


**Figure 1. Map depicting the POMGL grid domain (5 km grid increment) and bathymetry (m) (labeled contours) used by NOS' Lake Ontario Operational Forecast System.**

meteorological data format, but are decoded and written out to a text file for use by LOOFS and other NOS operational forecast systems.  The surface observation text file is available to LOOFS within a minute of receiving the observations from the CCS.

The text file includes surface observations from a variety of observing networks on and around Lake Ontario.  On land, these networks include Automated Surface Observing System (ASOS), Coastal-Marine Automated Network (C-MAN), NOS National Water Level Observing Network (NWLON), and NOAA GLERL's Real-Time Meteorological Observation Network.  Presently, the surface meteorological observations from U.S. Coast Guard (USCG) stations around the lake are not available in the NCEP's operational data tanks.  Over water, the networks include the fixed buoys operated by the NWS/NDBC and Environment Canada, as well as observations from ships participating in the Voluntary Observing Ship (VOS) program.  However, observations from VOS ships are not presently used by GLOFS due to occasional errors in observations from ships.

To support the forecast cycle, ODAAS obtains gridded forecasts from NWS/NCEP models and NWS National Digital Forecast Database (NDFD).

### 3.4 Nowcast Cycle

The nowcast cycle of LOOFS is run hourly at NOS to generate updated nowcasts of the 3-D state of Lake Ontario, including 3-D water temperatures and currents.  The cycle also generates hourly nowcasts of 2-D water levels.

The initial conditions for the nowcast cycle are provided by the previous hour's nowcast cycle.  The nowcast cycle is forced by gridded surface meteorological analyses valid at two times, one hour prior to the time of the nowcast and the current time of the nowcast.  The gridded surface meteorological analyses are generated by interpolating surface observations of wind, air temperature, dew point temperature, and cloud cover using the natural neighbor technique (Sambridge et al. 1995) using the program interpnn.f.

Before being interpolated, the surface wind and air temperature observations are adjusted to a common anemometer height of 10 m above the ground or water. Surface observations of wind direction, wind speed, air temperature, and dew point temperature from overland stations are adjusted to be more representative of overwater conditions.  Both the height adjustment correction and overland adjustment procedure use the previous day' lake average water temperature from GLERL's Great Lakes Surface Environmental Analysis (GLSEA).  The GLSEA temperature analysis is generated using SST retrievals derived from the Advanced Very High Resolution Radiometer data obtained from NOAA's polar-orbiter satellites.  The adjustments to the observations along with simple quality control checks are performed by the program edit_sfcmarobs.f

The gridded surface wind fields are then used by POMGL to calculate wind stress at each model grid point.  The surface meteorological fields along with POMGL lake surface water temperatures predictions from POMGL are used by a heat flux scheme (McCormick and Meadows 1988) to estimate the net rate of heat transfer at each lake grid point.  The heat flux scheme can be found in POMGL's subroutine FLUX1. Additional information on the wind stress and heat flux schemes can be found in Kelley (1995).

### 3.5 Forecast Cycle

The forecast cycle of LOOFS is run four times per day to generate forecast guidance of the 3-D state of Lake Ontario. The forecast cycle uses the most recent nowcast for its initial conditions. From March 2006 to March 2007, the surface meteorological forcing was provided by the latest forecast guidance of surface (10 m AGL) u- and v-wind components and surface air temperature (2 m AGL) from the 0, 6, 12, or 18 UTC forecast cycles of NWS/NCEP's North American Mesoscale (NAM) model. NAM has a spatial resolution of 12 km and uses the Weather Research and Forecast (WRF) model as its core. The surface wind velocity forecast guidance from the NAM model is valid at a height of 10 m above the ground or lake surface. However, in April 2007, CO-OPS decided to switch to using gridded forecasts of surface wind velocity and surface air temperature from the NWS NDFD. The NDFD fields are obtained from the NWS Weather Forecast Office (WFO) in Cleveland, OH by CO-OPS four times/day in netCDF. The NDFD forecasts have a spatial resolution of 5 km and cover both U.S. and Canadian waters of the Great Lakes.

### 3.6 Operational Environment and Scheduling

LOOFS is run operationally on a Linux workstation at NOS/CO-OPS in Silver Spring, MD. Each hourly nowcast cycle is launched at 56 minutes past the top of the hour to ensure that a sufficient amount of surface meteorological observations from both Canadian and U.S. networks are received at NCEP and then processed at CO-OPS by ODAAS.

The forecast cycle of LOOFS is run four times per day at 0000, 0600, 1200, and 1800 UTC at 56 minutes past the top of these hours. The forecast horizon of each forecast cycle is 30 hours.

LOOFS and the operational forecast systems for Lakes Huron and Superior were officially implemented as operational forecast systems at CO-OPS on March 30, 2006.

## 4. HINDCAST SKILL ASSESSMENT

NOS standards (Hess et al. 2003) require the hydrodynamic model of any NOS nowcast/forecast system to run in the hindcast scenario. A hindcast is defined as a long simulation using the best available gap-filled observed data for boundary water levels, wind, and river flows. Unfortunately, unlike the skill assessments of the operational forecast systems for Lake Erie and Lake Michigan, there were no field observing programs in order to compare POMGL simulations to surface and subsurface data. Therefore, no skill assessment was done to fulfill the hindcast scenario requirement.

## 5. SEMI-OPERATIONAL NOWCAST SKILL ASSESSMENT

This section describes the model system performance based on NOS requirements for semi-operational nowcast scenario (Hess et al. 2003). According to Hess et al., the definition of the model run scenario for a semi-operational nowcast is the following:

"In this scenario, the model is forced with actual observational input data streams including open ocean boundary water levels, wind stresses, river flows, and water density variations. Significant portions of the data may be missing, so the model must be able to handle this."

LOOFS, as described in Chapter 2, is based on NOAA/GLERL's Great Lakes Coastal Forecast System (GLCFS) for Lake Ontario. Both LOOFS and GLCFS-Lake Ontario have a spatial grid increment of 5 km, 20 sigma layers, and use similar surface meteorological forcing. Neither of the systems employed any river inflow or assimilated any limnological data. GLCFS used surface observations from USCG stations and cooperative marine weather observations called MARinter REPort (MAREP) unlike LOOFS which does not. However, this difference was not expected to cause a significant difference in the nowcasts due to low number of observations available from USCG and MAREP locations during any given hour.

Due to the similar characteristics of LOOFS and GLCFS, the assessment of the LOOFS semi-operational nowcasts was performed using archived nowcasts from GLCFS four times/day nowcast cycles.

This chapter describes the GLCFS nowcast cycles, the evaluation method including time period and assessment statistics, and the results of the evaluation.

### 5.1 Description of Nowcast Cycles

GLCFS performs four times/day nowcast cycles for Lake Ontario, and the other four Great Lakes, year round. The POMGL used by each forecast system are not reinitialized each spring. (GLOFS at NOS is reinitialized each spring around April using isothermal conditions based on SST from the Great Lakes Surface Environmental Analysis.) The surface forcing for the nowcast cycles are provided by objective analyses (Sambridge et al. 1995) of surface meteorological observations from land-based and overwater observing stations. The four nowcast cycles produce nowcasts valid at 0000, 0600, 1200, and 1800 UTC each day. The nowcast cycles are launched at approximately 80 minutes past the valid time of the nowcasts. For example, the nowcast cycle to generate a nowcast valid at 0000 UTC is launched at 0120 UTC to allow for observations from late reporting NDBC C-MAN stations to be received at GLERL via NOAAPORT broadcast system. Hourly model output from the four nowcast cycles are archived at GLERL.

## 5.2 Method of Evaluation

The hourly model results from the GLCFS nowcasts were compared to observations from coastal and offshore observing platforms in the lake for the period from mid-April to mid-December 2004. This was a period when there was no significant ice cover. The evaluation used the standard suite of assessment statistics, as defined in Hess et al. (2003). The standard suite of statistics is given in Table 1. The target frequencies of the associated statistics are the following:

CF(X) ≥90%, POF(2X) ≤1%, NOF(2X) ≤1%, WOF(2X) ≤0.5%
MDPO(2X) ≤ L, MDNO(2X) ≤ L

There are three types of data sets (Table 2): Group 1, a time series of values at uniform time intervals; Group 2, a set of values representing the consecutive occurrences of an event (such as high or low water); and Group 3, a set of values representing a forecast valid at a given projection time. The acceptable error limits (X) and maximum duration limits (L) for the associated variable applied to the LOOFS are presented in Table 3.

**Table 1. NOS 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 $\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$. |
| RMSE | Root Mean Square Error. Calculated as $RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} e_i^2}$. |
| SD | Standard Deviation. Calculated as $SD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N} (e_i - \bar{e})^2}$ |
| CF(X) | Central Frequency. Fraction (percentage) of errors that lie within the limits ±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. |
| WOF(X) | Worst Case Outlier Frequency. Fraction (percentage) of errors that, given an error of magnitude exceeding X, either (1) the simulated value of water level is greater than the astronomical tide and the observed value is less than the astronomical tide, or (2) the simulated value of water level is less than the astronomical tide and the observed value is greater than the astronomical tide. |

**Table 2. Data series groups and the variables in each.** Note that upper case letters indicate a prediction series (e.g., H), and lower case letters (e.g., h) indicate a reference series (observation) (Modified from Hess et al. 2003).

| Group | Variable | Symbol |
|---|---|---|
| Group 1 | Water level | H, h |
| (Time Series) | Water temperature | T, t |
| Group 2 | Amplitude of high water | AHW, ahw |
| (Values | Amplitude of low water | ALW, alw |
| at Extreme Event) | Time of high water | THW, thw |
| | Time of low water | TLW, tlw |
| Group 3 | Water level at forecast projection time of nn hrs | Hnn, hnn |
| (Values from a Forecast) | Water temperature at forecast projection time of nn hrs | Tnn, tnn |

**Table 3. Acceptance error limits (X) and the maximum duration limits (L) modified from Hess et al. (2003) for use in the Great Lakes.**

| Variables | X | L (hours) |
|---|---|---|
| H, Hnn, AHW, ALW | 15 cm | 24 |
| THW, TLW | 1.5 hours$^{+}$ | 25 |
| T, Tnn, | 3$^{o}$C* | 24 |

Notes: $^{+}$1.0 hours for tidal regions, *7.7$^{o}$C for tidal regions.

The evaluation utilized the NOS skill assessment software (Zhang et al. 2006), but was modified for use in the Great Lakes. The software computes the skill assessment scores automatically using files containing observations and nowcast or forecast guidance. Since the GLCFS output was not in netCDF, the output was reformatted to meet the text format input requirements of the skill assessment code.

Nowcasts of Water Levels

The evaluation of GLCFS nowcasts of water levels were based on time series of observed and model-based water levels at four NOS NWLON stations along the Lake Ontario shore line (Table 4). A map depicting the locations of the four NOS stations in the lake is given in Fig. 2.

Since water level nowcasts and forecasts generated by GLCFS were vertical displacements relative to the flat lake, further adjustment was necessary to bring the water levels relative to the mean lake level. An offset value based on a dynamic 7-day average mean lake water level was computed and added to the model nowcast of water level displacement from model's mean. This is the same method used by CO-OPS prior to displaying the LOOFS nowcasts on the Web. The final nowcast water levels were then compared with the observational data.

The evaluation of GLCFS water level nowcasts for Lake Ontario was done by comparing time series differences using SM, RMSE, SD, NOF, POF, MDPO, and MDNO statistics described in Hess et al. (2003). Since tides are not significant in the Great Lakes there were no comparisons of the times and amplitudes of tidally-forced high and low waters. However, significant high amplitude water events do occur in several of the Great Lakes, especially in Lake Erie. Following the recommendations of Hess et al. (2003), a method was developed and implemented in the NOS skill assessment software to analyze the nowcast/forecast system's ability to simulate large amplitude events. This is the first attempt at evaluating the ability of a NOS prediction system to simulate high and low water events in non-tidal regions. Other methods such as described by Dingman and Bedford (1986) and used by Kelley (1995) and Hoch (1997) may be considered for future versions of the NOS standards and skill assessment code.

The NOS skill assessment software identifies high and low water events in the Great Lakes using the following method.

Step 1. For the observed time series of water level, pick all high and low values. A data point is selected if it is either higher than its two neighboring points (both sides), or lower than its two neighboring points.

Step 2. For each selected peak from Step 1, a seven day window is centered on the particular peak and the mean value and standard deviation (called sigma hereafter) of the observed time series are computed within the seven day period. Upper/lower limits are then computed as the mean value +/- 2 sigma.

Step 3. The peak is identified as a high/low water level event if it exceeds the upper and lower limits. (Step 2 was performed to remove the impact of periodical variations, such as semi-diurnal and diurnal frequency signals on event selection.)

Step 4. For each high and low water level event in the observed time series, the maximum/minimum water level value and occurrence time are selected from the model simulated time series within a 12 hour window (the occurrence time of the observed event is centered), and paired with the observed events for comparison and statistic evaluation.

Step 5. The paired observed and simulated extreme events are compared to each other to assess the ability of the forecast system to simulate large amplitude events.

**Table 4. Information on NOAA/NOS/CO-OPS NWLON stations whose observations were used to evaluate LOOFS semi-operational nowcasts and forecasts of water levels.**

| Station Name | State | NOS Station ID Number | NWS Station ID | Geographic Coordinates | | Corresponding I and J model coordinates | |
|---|---|---|---|---|---|---|---|
| | | | | Latitude (deg N) | Longitude (deg W) | I | J |
| Cape Vincent | NY | 9052000 | NS | 44.13 | 76.34 | 56* | 22* |
| Oswego | NY | 9052030 | OSGN6 | 43.46 | 76.51 | 54 | 9* |
| Rochester | NY | 9052058 | NS | 43.27 | 77.65 | 36 | 4 |
| Olcott | NY | 9052076 | NS | 43.34 | 78.73 | 18 | 6* |

Notes: NS = A official NWS station ID has not been assigned to the station yet.
* = I and J coordinates assigned to nearest water grid cell.

<u>Nowcasts of Surface Water Temperatures</u>

The evaluation of GLCFS nowcasts of surface water temperatures was based on comparisons of time series of model-predicted temperatures vs. observations at a 3-m fixed disk buoy in the lake. The buoy is operated by NOAA/National Data Buoy Center (NDBC). Information on the buoy is given in Table 5. The lake surface temperatures at NDBC Buoys are measured using a Yellow-Springs thermistor sealed in epoxy in a copper slug clamped to the inside of the buoy's hull (Gillhousen 1987). The thermistor depth is 0.5 m and is sampled once per hour. The point evaluations were conducted by comparing surface (highest sigma layer) temperature nowcasts at the nearest grid point to surface observations from the buoy. A map depicting the locations of the NDBC fixed buoy is given in Fig. 3.

The evaluation of GLCFS surface water temperature nowcasts for Lake Ontario was done by comparing time series differences using SM, RMSE, SD, NOF, POF, MDPO, and MDNO statistics described in Hess et al. (2003). No attempt was made to assess the nowcast/forecast system's ability to simulate diurnal or larger temperature fluctuations. Other methods for evaluating water temperature predictions such as those used by Kelley (1995) and Hoch (1997) may be implemented in the future.

In evaluating predicted water temperature in tidal regions, NOS sets an acceptable error of 7.7$^{o}$C to meet the acceptable error of draft of 7.5 cm (3 inches), as water density is a function of temperature and salinity. Since the Great Lakes are fresh water bodies and non-tidal, there is no preset standard for a lake temperature prediction. Based on the 10 years experience of running the Great Lakes Forecasting System and input from the Great Lakes user community, Dr. David Schwab of NOAA/GLERL (Schwab 2006) suggested a 3$^{o}$C criteria for water temperature skill assessment in the Great Lakes region (personal communication). Thus, all the statistical evaluation and skill scores are based on a 3$^{o}$C criteria.

**Table 5. Information on NOAA/NWS/NDBC fixed buoy whose observations were used to evaluate LOOFS semi-operational nowcasts and forecasts of surface water temperatures.**

| Buoy Name | Agency | State | WMO Buoy ID | Geographic Coordinates and Depth | | | Corresponding LOOFS Grid Point Coordinates and Depth | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Latitude (deg N) | Longitude (deg W) | Depth (m) | I | J | Depth (m) |
| Lake Ontario Buoy (20nm NNE of Rochester, NY) | NWS/ NDBC | NY | 45012 | 45.62 | 77.41 | 145 | 40 | 11 | 150 |

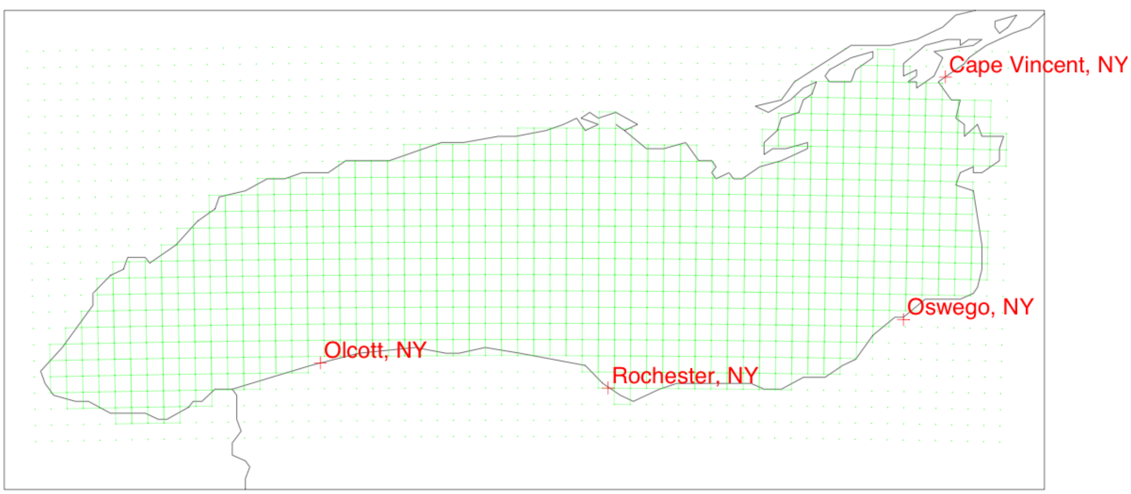


**Figure 2. Map depicting locations of NOS/CO-OPS NWLON stations in Lake Ontario along with the model grid of LOOFS.**

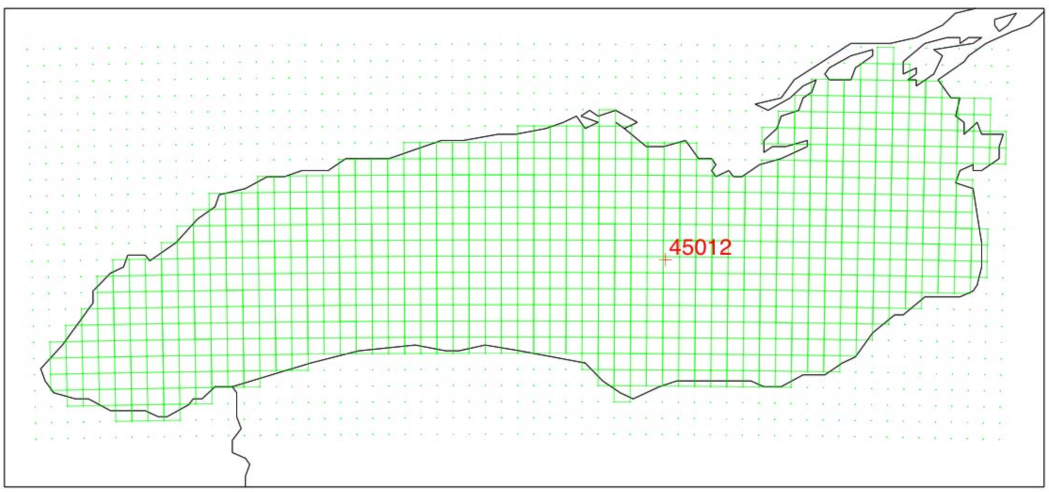


**Figure 3. Map depicting location of NWS/NDBC fixed buoy 45012 in Lake Ontario along with the model grid of LOOFS.**

## 5.3 Assessment Results of Water Level Nowcasts

The standard suite of skill assessment statistics evaluating the ability of semi-operational nowcasts and forecast guidance to predict hourly and extreme water levels at four NOS gauges from 15 April to 17 December 2004 are given in Appendix A. Time series plots of the nowcasts vs. observations at the gauges are given in Appendix B.

The skill statistics assessing the ability of the nowcasts to predict hourly water levels at the four NOS gauges are presented together in Table 6 along with the NOS acceptance criteria. The hourly nowcasts passed the criteria at all four locations. The mean algebraic errors or differences ranged between -1.1 and 2.6 cm and the RMSE ranged between 2.9 and 4.4 cm. The greatest RSME was at Cape Vincent, NY gauge located at the extreme NE part of the lake (Fig. 2). The nowcasts generally over predicted the water levels at most gauges but under predicted levels at Olcott, NY.

**Table 6. Summary of Skill Assessment Statistics of *Semi-Operational Nowcasts* of Hourly Water Levels at NOS NWLON Stations in Lake Ontario for the Period 15 April to 17 December 2004.** A total of 5757 to 5832 nowcasts were used in the assessment. Gray shading if present, indicates that the statistics did not pass the NOS acceptance criteria.

| Statistic, Acceptable Error [ ], and Units ( ) | Cape Vincent, NY | Oswego, NY | Rochester, NY | Olcott, NY | NOS Accept. Criteria |
|---|---|---|---|---|---|
| Mean Diff. (m) | 0.026 | 0.005 | 0.000 | -0.011 | na |
| RMSE (m) | 0.044 | 0.032 | 0.029 | 0.033 | na |
| SD (m) | 0.036 | 0.031 | 0.029 | 0.031 | na |
| NOF [2x15cm] (%) | 0.0 | 0.0 | 0.0 | 0.0 | ≤ 1% |
| CF [15 cm] (%) | 99.9 | 100.0 | 100.0 | 100.0 | ≥ 90% |
| POF [2x15 cm] (%) | 0.0 | 0.0 | 0.0 | 0.0 | < 1% |
| MDPO [2x15 cm ] (hour) | 0.0 | 0.0 | 0.0 | 0.0 | ≤ 24 hours |
| MDNO [2x15 cm ] (hour) | 0.0 | 0.0 | 0.0 | 0.0 | ≤ 24 hours |

Notes: na = not applicable

The skill statistics assessing the ability of nowcasts to predict *extreme high water level events* at NOS gauges during 2004 are given together in Table 7. The statistics are for only two gauges (Cape Vincent and Oswego) since no extreme high water level events occurred at Olcott or Rochester, NY based on the event definition. The high water level nowcasts at the two gauges passed the NOS acceptance criteria for amplitude. The nowcasts ability to simulate the timing of these events did not pass the NOS acceptance criteria for NOF, CF, and POF at Cape Vincent but did pass at Oswego. However, the skill assessment results of extreme water level events might be suspect due to only a few high water events occurred at Oswego. The skill statistics to predict *extreme low water level events* at the four NOS gauges during 2004 are given together in Table 8. Depending on the gauge, there were 2 to 6 events during the time period. The extreme low water level nowcasts passed NOS acceptance criteria for amplitude at the four gauges. The nowcasts ability to simulate the timing of these events did not pass the NOS acceptance criteria for one or two of the skill statistics (i.e. NOF, CF, and POF) at the four gauges

**Table 7. Summary of Standard Statistics Evaluating the Ability of the *Semi-Operational Nowcasts* to Predict <u>Extreme High Water Level Events</u> at the NOS NWLON stations in Lake Ontario during the Period 15 April to 17 December 2004.** Gray shading indicates that the statistic did not pass the NOS acceptance criteria.

| Statistic, Acceptable Error [ ], and Units ( ) | Cape Vincent, NY N=12 | | Oswego, NY N=2 | | NOS Accept. Criteria |
|---|---|---|---|---|---|
| | Amp. | Time | Amp. | Time | |
| Mean Diff. (m) (min) | -0.046 | -1.333 | -0.074 | 0.500 | na |
| RMSE (m) (min) | 0.050 | 4.472 | 0.074 | 0.707 | na |
| SD (m) (min) | 0.022 | 4.458 | 0.008 | 0.707 | na |
| NOF [2x15cm or 90min] % | 0.0 | 33.3 | 0.0 | 0.0 | ≤ 1% |
| CF [15 cm or 90 min] (%) | 100.0 | 33.3 | 100.0 | 100.0 | ≥ 90% |
| POF [2x15 cm or 90 min] (%) | 0.0 | 16.7 | 0.0 | 0.0 | ≤ 1% |
| MDPO [2x15 cm or 90 min] (#) | 0.0 | 0.0 | 0.0 | 0.0 | ≤ 24 hrs |
| MDNO [2x15 cm or 90min] (#) | 0.0 | 0.0 | 0.0 | 0.0 | ≤ 24 hrs |

Notes: na = not applicable

**Table 8. Summary of Standard Statistics Evaluating the Ability of *Semi-Operational Nowcasts* to Simulate Extreme Low Water Level Events at the NOS NWLON Stations in Lake Ontario for the Period 15 April to 17 December 2004.** Gray shading indicates that the statistic did not pass the NOS acceptance criteria.

| Statistic, Acceptable Error [ ], and Units ( ) | Cape Vincent, NY N=6 | | Oswego, NY N=5 | | Rochester, NY N=2 | |
|---|---|---|---|---|---|---|
| | Amp. | Time | Amp. | Time | Amp. | Time |
| Mean Diff. (m) (min) | 0.067 | 0.167 | 0.052 | 0.800 | 0.067 | 1.000 |
| RMSE (m) (min) | 0.069 | 1.225 | 0.053 | 3.098 | 0.067 | 3.162 |
| SD (m) (min) | 0.021 | 1.329 | 0.010 | 3.347 | 0.010 | 4.243 |
| NOF [2x15cm or 90min] (%) | 0.0 | 0.0 | 0.0 | 20.0 | 0.0 | 0.0 |
| CF [15 cm or 90 min] (%) | 100.0 | 8.3 | 100.0 | 20.0 | 100.0 | 0.0 |
| POF [2x15 cm or 90 min] (%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 50.0 |
| MDPO [2x15 cm or 90 min] (#) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| MDNO [2x15 cm or 90min] (#) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table 8 (cont.)**

| Statistic, Acceptable Error [ ], and Units ( ) | Olcott, NY N=2 | | NOS Accept. Criteria |
|---|---|---|---|
| | Amplitude | Time | |
| Mean Diff. (m) (min) | 0.001 | -3.500 | na |
| RMSE (m) (min) | 0.015 | 4.301 | na |
| SD (m) (min) | 0.021 | 3.536 | na |
| NOF [2x15cm or 90min] (%) | 0.0 | 50.0 | ≤ 1% |
| CF [15 cm or 90 min] (%) | 100.0 | 50.0 | ≥ 90% |
| POF [2x15 cm or 90 min] (%) | 0.0 | 0.0 | ≤ 1% |
| MDNO [2x15 cm or 90 min] (#) | 0.0 | 0.0 | ≤ 24 hrs |
| MDPO [2x15 cm or 90min] (#) | 0.0 | 0.0 | ≤ 24 hrs |

Notes: na = not applicable

## 5.4 Assessment of Surface Water Temperature Nowcasts

The standard suite of skill assessment statistics evaluating the ability of the semi-operational nowcasts to predict hourly lake surface water temperatures at the NWS/NDBC fixed buoy in Lake Ontario (45012) from mid-April to early December 2004 is given in Appendix D. The time series plot of the nowcasts ($1^{st}$ sigma level) vs. observations at the buoy is given in Appendix E.

The time series plots indicate that the nowcasts were in close agreement to observations (+0.5-1$^{o}$C) from mid-April until mid-May corresponding to the spring warming period. During the warming period, surface heating causes convective overturning (destabilization of the water column) over the entire lake as the water warms from temperatures close to freezing to 4$^{o}$C (Boyce et al. 1989).

However, when the surface water temperature nowcasts reached 4$^{o}$C, the temperature of maximum density for fresh water, the nowcasts deviated from the observations by +2-3$^{o}$C until mid-June at the buoy. From mid-June until approximately the beginning of August the nowcasts matched the observations. August is the time when complete thermal stratification of the lake usually occurs (Boyce et al. 1989).

From the beginning of August until late September the nowcasts were cooler than observations by 2-3$^{o}$C. The difference then declined to -1$^{o}$C or less by mid October. This corresponds to the time of the year when the vertical temperature structure becomes homogeneous through surface cooling and storm induced destabilization (Bedford 1992). However, starting in mid November the nowcasts were approximately 2-3$^{o}$C warmer than observations until the buoy was removed from the lake by NDBC for the winter, similar to what occurred in the early spring.

The skill statistics assessing the ability of LOOFS to predict hourly surface water temperatures at the NDBC buoy are given together in Table 9 along with the NOS acceptance criteria. The hourly water temperature nowcasts came close to passing the NOS criteria, failing to achieve the CF criteria by only 1.4%. The MAE for the period was 0.003$^{o}$C and the RMSE was 1.88$^{o}$C.

# 6. SEMI-OPERATIONAL FORECAST SKILL ASSESSMENT

This section describes the model system performance for a semi-operational forecast scenario based on NOS requirements (Hess et al. 2003). According to NOS requirements, the definition of the model run scenario for a semi-operational forecast is the following:

"In this scenario, the model is forced with actual forecast input data streams, including open ocean boundary water levels, wind, river flows, and water density variations. Initial conditions are generated by observed data. Significant portions of the data may be missing, so the model must be able to handle this."

For the assessment of the semi-operational forecast scenario for LOOFS, archived forecast guidance from GLCFS twice per day forecast cycles (0000 and 1200 UTC) during 2004 were compared to available observations in the lake.

This chapter provides a description of the GLCFS forecast cycles, the method of evaluation including time period and assessment statistics, and the evaluation results.

**Table 9. Summary of Skill Assessment Statistics of the *Semi-Operational Nowcasts* of <u>Hourly Surface Water Temperatures</u> at a NWS/NDBC fixed buoy in Lake Ontario for the Period from mid-April to early November 2004.** Gray shading indicates that the statistic did not pass the NOS acceptance criteria.

| Time Period, Statistic, Acceptable Error [ ], and Units ( ) | 45012 Lake Ontario N=5078 | NOS Acceptance Criteria |
|---|---|---|
| Time Period | April to Nov. 2004 | 365 days |
| Mean Difference ($^{o}$C) | 0.003 | na |
| RMSE ($^{o}$C) | 1.880 | na |
| SD ($^{o}$C) | 1.880 | na |
| NOF [2x3$^{o}$C] (%) | 0.0 | ≤ 1% |
| CF [3$^{o}$C] (%) | 88.6 | ≥ 90% |
| POF [2x3$^{o}$C] (%) | 0.1 | ≤ 1% |
| MDNO [2x3$^{o}$C] (hours) | 0.0 | ≤ 24 hrs |
| MDPO [2x3$^{o}$C] (hours) | 2.0 | ≤ 24 hrs |

Notes: na = not applicable

## 6.1 Description of Forecast Cycles

GLCFS performs twice/day 60-hr forecast cycles for Lake Ontario. The two forecast cycles are initialized at 0000 and 1200 UTC each day. The forecast cycles are launched at approximately 2 hours and 45 minutes past the start time of the cycle to allow for complete ingestion of atmospheric forecast fields. For example, the forecast cycle with initial conditions valid at 1200 UTC is launched at 1445 UTC. The initial conditions for each forecast cycle are provided by the nowcast cycle. The surface forcing for the forecast cycles consists of surface (10 m AGL) wind velocity and surface (2 m AGL) air temperatures from NWS/NCEP North America Mesoscale (NAM) Model. The wind velocity and air temperature are used to calculate surface wind stress for input into the lake model. The surface heat fluxes into the lake model during the forecast cycle are zero.

## 6.2 Method of Evaluation

The semi-operational forecast guidance at 1 hour increments from +1 to +24 hours from GLCFS were compared to water level observations from NOS NWLON stations in the lake from 15 April to 17 December 2004 and to the NWS/NDBC fixed buoy from mid-April to early November for the surface water temperature forecasts. This was a period when there was no significant ice cover on the lake.

The evaluation used the standard suite of assessment statistics as defined in Hess et al. (2003) but modified for non-tidal regions. The evaluation of GLCFS forecasts of water levels were based on time series of observed and model-based water levels at the same four NOS NWLON stations along the lake shore line used in the evaluation of the nowcasts.

The evaluation of semi-operational forecast guidance of surface water temperatures were based on comparisons of time series of observed vs. model-predicted temperatures at the same NWS/NDBC fixed buoy used in the nowcast evaluation. There are a few gaps in the record of forecast guidance due to computer, and/or network problems, or incomplete surface forcing from the NAM Model for a particular forecast cycle.

## 6.3 Assessment Results of Water Level Forecast Guidance

The standard suite of skill assessment statistics evaluating the ability of semi-operational forecast guidance to predict hourly and extreme water levels at four NOS Gauges from 15 April to 17 December 2004 is given in Appendix A. Time series plots of the forecast guidance from the 0000 UTC model forecast cycle vs. observations at the gauges are given in Appendix C.

The skill statistics assessing the ability of the forecast guidance to predict hourly water levels at the four NOS gauges are presented together in Table 10 along with the NOS acceptance criteria. The hourly forecasts passed the criteria at all gauge locations. The MAE ranged between +0.1 to + 2.8 cm and the RMSE ranged between 3.4 and 4.8 cm, very similar to the statistics for the nowcast evaluation. Similar to the nowcasts, the greatest errors were at Cape Vincent located at in the NE end of the lake. The forecasts under-predicted the water levels at Olcott but over-predicted the levels at the other gauges. There was no significant increase in the mean differences, RMSE values, or CF as forecast projection time increased (Appendix A).

The skill statistics to assess the ability of the forecast guidance to predict *extreme high water level events* at NOS Oswego and Cape Vincent gauges during 2004 are given together in Table 11. There were no extreme high water events at Rochester and Olcott based on the event selection method defined in 5.2. The forecasts of extreme high water level passed NOS acceptance criteria for amplitude at the two gauges. However, it should be noted there were only four and 11 high water level events at Oswego and Cape Vincent, respectively. The forecasts' ability to simulate the timing of these events did not pass NOS acceptance criteria for NOF and CF at the two gauges but did pass POF criteria at the Oswego gauge.

The skill statistics to assess the ability of the forecast guidance to predict *extreme low water level events* at the four NOS gauges in 2004 are given together in Table 12. The number of events ranged from two to six. The forecasts of extreme low water level passed NOS acceptance criteria for amplitude at all four gauges. The forecasts ability to simulate the timing of these events did not pass all the NOS acceptance criteria for NOF, CF, and POF except at the Rochester gauge. However, there were only two low water events at this gauge.

**Table 10. Summary of Skill Assessment Statistics of 24-hr *Semi-Operational Forecast Guidance* of Hourly Water Levels at NOS NWLON Stations in Lake Ontario for the Period 15 April to 17 December 2004.** Approximately 490 forecasts were used in the assessment. Gray shading, if present, indicates that the statistic did not pass the NOS acceptance criteria.

| Statistic, Acceptable Error [ ], and Units ( ) | Cape Vincent, NY | Oswego, NY | Rochester, NY | Olcott, NY | NOS Accept. Criteria |
|---|---|---|---|---|---|
| Mean Diff. (m) | 0.028 | 0.005 | 0.001 | -0.010 | na |
| RMSE (m) | 0.048 | 0.036 | 0.034 | 0.037 | na |
| SD (m) | 0.039 | 0.035 | 0.034 | 0.035 | na |
| NOF [2x15cm] (%) | 0.0 | 0.0 | 0.0 | 0.0 | ≤ 1% |
| CF [15 cm] (%) | 100.0 | 100.0 | 100.0 | 100.0 | ≥ 90% |
| POF [2x15 cm] (%) | 0.0 | 0.0 | 0.0 | 0.0 | ≤ 1% |
| MDPO [2x15 cm ] (hour) | 0.0 | 0.0 | 0.0 | 0.0 | ≤ 24 hours |
| MDNO [2x15 cm ] (hour) | 0.0 | 0.0 | 0.0 | 0.0 | ≤ 24 hours |

Notes: na = not applicable

**Table 11. Summary of Skill Assessment Statistics Evaluating the Ability of *Semi-Operational Forecast Guidance* (0 to 24 hours) to Predict <u>Extreme High Water Level Events</u> at NOS NWLON Stations in Lake Ontario during the Period 15 April to 17 December 2004.** Gray shading indicates that the statistic did not pass the NOS acceptance criteria.

| Statistic, Acceptable Error [ ], and Units ( ) | Cape Vincent, NY N=11 | | Oswego, NY N=4 | | NOS Acceptance Criteria |
|---|---|---|---|---|---|
| | Amp. | Time | Amp. | Time | |
| Mean Diff. (m) (min) | -0.041 | 0.545 | -0.058 | -1.250 | na |
| RMSE (m) (min) | 0.067 | 3.861 | 0.068 | 2.693 | na |
| SD (m) (min) | 0.055 | 4.009 | 0.040 | 2.754 | na |
| NOF [2x15cm or90min] (%) | 0.0 | 18.2 | 0.0 | 25.0 | ≤ 1% |
| CF [15 cm or 90 min] (%) | 90.9 | 27.3 | 100.0 | 25.0 | ≥ 90 % |
| POF [2x15 cm or 90 min] (%) | 0.0 | 27.3 | 0.0 | 0.0 | ≤ 1 % |

Notes: na = not applicable

**Table 12. Summary of Skill Assessment Statistics Evaluating the Ability of *Semi-Operational Forecast Guidance* (0 to 24 hours) to Predict <u>Extreme Low Water Level Events</u> at NOS NWLON Stations in Lake Ontario during the Period 15 April to 17 December 2004.** Gray shading indicates that the statistic did not pass the NOS acceptance criteria.

| Statistic, Acceptable Error [ ], and Units ( ) | Cape Vincent, NY N=6 | | Oswego, NY N=5 | | Rochester, NY N=2 | |
|---|---|---|---|---|---|---|
| | Amp. | Time | Amp. | Time | Amp. | Time |
| Mean Diff. (m) (min) | 0.074 | -0.667 | 0.052 | 0.800 | 0.066 | 0.500 |
| RMSE (m) (min) | 0.076 | 3.873 | 0.053 | 3.098 | 0.067 | 2.550 |
| SD (m) (min) | 0.021 | 4.179 | 0.010 | 3.347 | 0.013 | 3.536 |
| NOF [2x15cm or 90min] (%) | 0.0 | 33.3 | 0.0 | 20.0 | 0.0 | 0.0 |
| CF [15 cm or 90 min] (%) | 100.0 | 16.7 | 100.0 | 20.0 | 100.0 | 0.0 |
| POF [2x15 cm or 90 min] (%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table 12 (cont.)**

| Statistic, Acceptable Error [ ], and Units ( ) | Olcott, NY N=2 | | NOS Acceptance Criteria |
|---|---|---|---|
| | Amplitude | Time | |
| Mean Diff. (m) (min) | 0.010 | 1.500 | na |
| RMSE (m) (min) | 0.010 | 2.915 | na |
| SD (m) (min) | 0.006 | 3.536 | na |
| NOF [2x15cm or 90min] (%) | 0.0 | 0.0 | ≤1% |
| CF [15 cm or 90 min] (%) | 100.0 | 50.0 | ≥ 90% |
| POF [2x15 cm or 90 min] (%) | 0.0 | 50.0 | ≤1% |

Notes: na = not applicable

### 6.4 Assessment Results of Surface Water Temperature Forecast Guidance

The standard suite of skill assessment statistics evaluating the ability of semi-operational forecast guidance to predict hourly lake surface water temperatures at the NWS/NDBC Lake Ontario fixed buoy (45012) from mid-April to early December 2004 is given in Appendix D. Tables therein provide skill statistics at the forecast projection hours of 0, 6, 12, 18, and 24. Time series plots of the forecasts ($1^{st}$ sigma level) from the 0000 UTC forecast cycle vs. buoy observations are given in Appendix E. The time series plots indicate that the forecast guidance from the 0000 UTC forecast cycle resembles the nowcast very closely. This reflects the fact that the lake model configuration (i.e. POMGL) used for the semi-operational forecast cycles does not include any input of surface heat fluxes either directly or indirectly from the NAM-12 model forecast guidance. Specifically, the lake model uses subroutine FLUX5 in which the heat fluxes are zero.

Similar to the nowcasts, the semi-operational forecast guidance is in close agreement to observations. The skill statistics assessing the ability of semi-operational forecast guidance to predict surface water temperatures 24 hours in advance at the NDBC buoy are given in Table 13 along with the NOS acceptance criteria. The hourly forecast guidance at the buoy came close to passing all the criteria (failing to meet the CF criteria by only 2.4%). The MAE was -0.13$^{o}$C and the RMSE was 1.89$^{o}$C. The MAE and RMSE values for the forecast guidance were slightly lower than for the nowcasts. It is interesting to note that the mean differences increased and reversed sign as forecast projection time increased. The MAE was 0.08$^{o}$C at the 0-hr projection and -0.13$^{o}$C at 24-hrs (see Table D.1).

## 7. SUMMARY

NOS' Lake Ontario Operational Forecast System (LOOFS) generates hourly nowcasts and forecast guidance out to 30 hours four times per day. It is based on the Great Lakes Coastal Forecasting System (GLCFS) developed by the Ohio State University and NOAA/GLERL.

**Table 13. Summary of Skill Assessment Statistics for *Semi-Operational Forecast Guidance* (0 to 24 hours) to Predict Surface Water Temperatures at a NWS/NDBC fixed buoy in Lake Ontario during the period from mid-April to early-November 2004.** Gray shading indicates that the statistic did not pass the NOS acceptance criteria.

| Time Period, Statistic, Acceptable Error [ ], and Units ( ) | 45012 Lake Ontario N=420 | NOS Acceptance Criteria |
|---|---|---|
| Time Period | 20 April to 7 Nov. 2004 | 365 days |
| Mean Difference ($^oC$) | -0.130 | na |
| RMSE ($^oC$) | 1.891 | na |
| SD ($^oC$) | 1.889 | na |
| NOF [2x3$^o$C] (%) | 0.0 | $\leq$ 1% |
| CF [3$^o$C] (%) | 87.6 | $\geq$ 90% |
| POF [2x3$^o$C] (%) | 0.0 | $\leq$ 1% |
| MDPO [2x3$^o$C] (hours) | 0.0 | $\leq$ 24 hrs |
| MDNO [2x3$^o$C] (hours) | 0.0 | $\leq$ 24 hrs |

Notes: na = not applicable

LOOFS became operational at CO-OPS on March 30, 2006. The hourly nowcast cycles are forced by surface wind stress and surface heat flux estimated from objectively analyzed surface meteorological fields and the initial conditions are provided by the previous hour's nowcast. The four times/day forecast cycle uses the most recent nowcasts for its initial conditions and gridded NWS forecasts of surface air temperature and wind forcing from NWS/National Digital Forecast Database. Prior to April 1, 2007, LOOFS used forecast guidance from NCEP's NAM-12 weather prediction model. During the forecast cycle, the heat flux is set to zero.

An assessment of the LOOFS nowcasts and forecast guidance was conducted according to the NOS evaluation standards (Hess et al. 2003). To comply with the NOS required semi-operational nowcast and forecast scenarios, the evaluation used archived output from NOAA/GLERL's GLCFS semi-operational nowcasts and forecasts for Lake Ontario from 15 April to 17 December 2004. Unfortunately, neither GLERL or OSU conducted comparisons between POMGL output vs. field data for Lake Ontario which could be used to fulfill the hindcast scenario.

The semi-operational nowcasts and forecast guidance were compared to water level observations at four NOS NWLON stations and surface temperatures at one NWS/NDBC fixed buoy 45012 in western part of the lake. Due to the lack of sub-surface water temperatures and current observations, no quantitative assessment of these variables was conducted for LOOFS.

*Water Levels*

The hourly nowcasts of water level for amplitude met the NOS acceptance criteria at the four NOS gauges in Lake Ontario: Cape Vincent, Oswego, Rochester, and Olcott, NY. The mean algebraic error or difference (MAE) ranged between -1.1 cm at Rochester, NY and +2.6 cm at Cape Vincent, NY located at the extreme eastern end of Lake Ontario at the entrance of the St. Lawrence River. The RSME ranged from 2.9 to 4.4 cm at Rochester and Cape Vincent. The nowcasts of *high water level events* were assessed at two NOS gauges where high events occurred. The nowcast of high water events passed the NOS criteria for amplitude at the two gauges but met the NOS criteria for timing at only one gauge. The nowcasts of *low water level events* were assessed at the four NOS gauges. The nowcasts of low water events met the NOS criteria for amplitude at the four gauges, but did not pass the criteria in terms of timing at any of the gauges.

The hourly forecast guidance met the NOS criteria for predicting water level amplitude at all four locations. The MAE ranged between -1.0 cm and +2.8 cm at Olcott and Cape Vincent, respectively. The RSME ranged from 3.4 to 4.8 cm. The forecast guidance of *high water events* passed the NOS criteria for amplitude at the two gauges where high events occurred. The guidance failed to meet NOS criteria in predicting the times of these extreme events. The guidance of low water level events was assessed at all four NOS gauges. The guidance of *low water events* passed the NOS criteria for amplitude at locations but only met NOS criteria in predicting the times of these extreme events at the Rochester gauge.

*Surface Water Temperatures*

The hourly water temperature nowcasts came very close in meeting the NOS criteria at the NDBC buoy 45012, only failing to meet the CF by 1.4%. The MAE was 0.003$^{o}$C and the RMSE was 1.88$^{o}$C. The hourly water temperature forecast guidance at 24 hours came very close to meeting NOS criteria at the buoy only failing to meet the CF by 2.4%. The MAE for the period was -0.13$^{o}$C and the RMSE was 1.89$^{o}$C. The time series plots indicated that LOOFS over predicted the SST during the spring months and under predicted the SST during August and September.

*Surface Currents*

Due to the lack of water current observations, no quantitative assessment could be conducted for LOOFS. However, animation of surface current nowcasts and forecast guidance indicated that LOOFS did properly simulate the known cyclic clockwise rotation of surface currents present in the Great Lakes when the lake water is density stratified. This occurs usually from May through October. Observational studies have found that the clockwise rotation has a near-inertial period of 18 hours (Saylor and Miller, 1987).

## 8. RECOMMENDATIONS FOR FUTURE WORK

Recommendation #1:

The comparisons of the semi-operational nowcasts and forecast guidance of surface water temperature to observations at the NDBC Lake Ontario buoy (45012) indicate a potential problem with the prediction of surface water temperatures, especially during the spring and early summer. A similar problem occurred with LSOFS, LMOFS, and LEOFS. Since surface water temperatures comparisons were done only at one buoy it is difficult to conclude whether this is an issue over the entire model grid domain. Therefore, it is recommended that in the future, LOOFS SST nowcasts and forecast guidance also be evaluated at the Canadian fixed buoys: Prince Edward Point (45135) in the western end and West Lake Ontario-Grimsby (45139) in the far western end of the lake.

Recommendation #2:

A study is needed to determine the reason why POMGL was unable to better forecast the timing of water level of extreme high and low water level events and the water level amplitudes in the lake. This would likely involve sensitivity tests with POMGL using higher grid resolution and incorporating atmospheric pressure forcing.

This was our first attempt to assess extreme water level events in non-tidal freshwater regions. We currently used a so-called two-sigma rule to select extreme high and low water level events. Other approaches can be tested to define a high/low water level event more reasonably in the future.

Recommendation #3:

Investigate in cooperation with GLERL, the possibility of incorporating climatological or near-real time river discharge in the nowcoast cycle of LOOFS and surface heat flux estimates in the forecast cycle of LOOFS.

Recommendation #4:

The LOOFS surface water temperature predictions should also be evaluated at the Canadian buoys 45135 and 45139 in Lake Ontario.

## ACKNOWLEDGMENTS

The development of the Great Lakes Forecasting System was a joint effort of The Ohio State University and NOAA’s Great Lakes Environmental Research Laboratory led by Dr. Keith Bedford (OSU) and Dr. David Schwab (GLERL). During the eleven-year life of the GLFS the following OSU staff members have been associated with the development of the system: fifteen graduate students; seven faculty; six postdocs; and seven research scientists. Funding came from over 26 different sources ranging from small grants from private foundations and companies to several large federal grants. The operation and further development of GLCFS at GLERL has involved two research scientists and three support scientists.

The porting of the GLCFS from GLERL to NOS was conducted by the GLOFS System Development and Implementation Team consisting of personnel from GLERL, OSU, CO-OPS, CSDL, and Aqualinks.com. In particular, we acknowledge the hard work of Dr. Mark Vincent, Greg Mott, Zack Bronder, and others at CO-OPS.

The archived GLCFS nowcast and forecast guidance used in the skill assessment were provided by Greg Lang and David Schwab at NOAA/GLERL. The skill assessment software was modified for use in the Great Lakes based on suggestions from Drs. Kurt Hess and Eugene Wei in CSDL.

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## REFERENCES

Bedford, K.W. and D. J. Schwab, 1991: The Great Lakes Forecasting System- Lake Erie nowcasts/forecasts, *Proceedings, Marine Technology Society National Meeting*, New Orleans, LA, Marine Technology Society, 206-264.

Bedford, K.W., 1992: The physical effects of the Great Lakes on tributaries and wetlands. *J. Great Lakes Res*., **18**, 571-589.

Beletsky, D., J.H. Saylor, and D.J. Schwab, 1999: Mean circulation in the Great Lakes. *J. Great Lakes Res.*, **25**, 78-93.

Blumberg, A. F. and G. L. Mellor, 1987**:** A Description of a Three-Dimensional Coastal Ocean Circulation Model, *Three-Dimensional Coastal Ocean Models*, Vol. 4, Ed. N. Heaps, American Geophysical Union, Washington, DC, pp. 1-16.

Boyce, F. M., M. A. Donelan, P. F. Hamlin, C. R. Murthy, and T. J. Simons, 1989: Thermal structure and circulation in the Great Lakes. *Atmos.-Ocean***, 27**, 607-642.

Dingman, J.S. and K. W. Bedford, 1986: Skill tests and parametric statistics for model evaluation. *J. Hydraul. Eng*., **112**, 124-141.

Gilhousen, D.B., 1987: A field evaluation of NDBC moored buoy winds. *J. Atmos. Oceanic Technol*., **4**, 94-104.

Great Lakes Information Network (GLIN), 2006: Water Levels on the Great Lakes, (http://www.great-lakes.net/teach/envt/levels/lev_2.html).

Hess, K. W., T. F. Gross, R. A. Schmalz, J. G. W. Kelley, F. Aikman, III, E. Wei, and M. S. Vincent, 2003: NOS standards for evaluating operational nowcast and forecast hydrodynamic model systems, NOAA Technical Report NOS CS 17, 47 pp. [Available from NOAA/NOS Coast Survey Development Lab, 1315 E-W Highway, Silver Spring, MD 20910.]

Hoch, B. 1997: An evaluation of a one-way coupled atmosphere-lake model for Lake Erie. M.S. thesis, Atmospheric Sciences Program, Ohio State University, 226 ppp. [Available from Atmospheric Sciences Program, 1049 Derby Hall, 154 N. Oval Mall, Ohio State University, Columbus, OH 43210-1361.]

Kelley, J.G.W., 1995: One-way coupled atmospheric-lake model forecasts for Lake Erie. Ph.D. dissertation, Ohio State University, 450 pp. [Available from Atmospheric Sciences Program, 1049 Derby Hall, 154 N. Oval Mall, Ohio State University, Columbus, OH 43210-1361.]

Kelley, J.G.W., M. Westington, E. Wei, S. Maxwell, and A. Thomson, 2001: Description of the Operational Data Acquisition and Archive System (ODAAS) to support the NOS Chesapeake Bay Operational Forecast System (CBOFS), NOAA Technical Report NOS CS 10, 45 pp. [Available from NOAA/NOS Coast Survey Development Lab, 1315 E-W Highway, Silver Spring, MD 20910.]

Kuan, C.-F., 1995: Performance evaluation of the Princeton Circulation Model for Lake Erie. Ph.D. Dissertation, Ohio State University, 376 pp. [Available from Dept. of Civil and Environmental Engineering and Geodetic Science, 470 Hitchcock Hall, 2070 Neil Avenue, Ohio State University, Columbus, OH 43210-1275.]

McCormick, M. J. and G. A. Meadows, 1988: An intercomparison of four mixed layer models in a shallow inland sea. *J. Geophys. Res.*, **93**, 6774-6788.

Mellor, G. L., 1996: Users guide for a three-dimensional, primitive equation, numerical ocean model. Program in Atmospheric and Oceanic Sciences, Princeton University, Princeton, NJ, 39 pp. [Available from Program in Atmospheric and Oceanic Sciences, P.O. Box CN710, Sayre Hall, Princeton University, Princeton, NJ 08544-0710.]

O'Connor, W. P. and D. J. Schwab, 1993: Sensitivity of Great Lakes Forecasting System nowcasts to meteorological fields and model parameters. *Proc. ASCE Third Int. Conf. on Estuarine and Coastal Modeling*, Oak Brook, IL, Amer. Soc. Civil Eng., 149-157.

Sambridge, M., Braun, J., and H. McQueen, 1995: Geophysical parameterization and interpolation of irregular data using natural neighbors. *Geophys. J. Int.*, **122**, 837-857.

Saylor, J. H. and G. S. Miller, 1987: Studies of Large-Scale Currents in Lake Erie, 1979-80. *J. Great Lakes Res.*, **13**, 487-514.

Schwab, D. J. and K. W. Bedford, 1994:  Initial implementation of the Great Lakes Forecasting System:  A real-time system for predicting lake circulation and thermal structure.  *Water Pollution Res. J. of Canada*, **29**, 203-220.

Schwab, D. J., and D. Beletsky, 1998: Lake Michigan Mass Balance Study: Hydrodynamic Modeling Project. NOAA Technical Memorandum ERL GLERL-108,  53 pp. [Available from NOAA/Great Lakes Environmental Research Laboratory, Publications Office, 2205 Commonwealth Blvd., Ann Arbor, MI 48105-2945.]

Schwab, D. J. and D. L. Sellers, 1980:  Computerized bathymetry and shorelines. NOAA Data Rep. ERL GLERL-16, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 13 pp. [Available from NOAA/Great Lakes Environmental Research Laboratory, Publications Office, 2205 Commonwealth Blvd., Ann Arbor, MI 48105-2945.]

Schwab, D. J., J. R. Bennett, P. C. Liu, M. A. Donelan, 1984**:**  Application of a Simple Numerical Wave Prediction Model to Lake Erie, *J. Geophys. Res.***,** **89**, no. C3, 3586-3592.

Schwab, D. J.  Personal communication of May 2006.

Yen, C.C. J., J. G. W. Kelley, and K. W. Bedford, 1994:  Daily procedure for GLFS nowcasts. *Proc. National Conf. on Hydraulic Engineering*, Buffalo, NY, Amer. Soc. Civil Eng., 202-206.

Zhang, A.-J., K. W. Hess, E. Wei, and E. Myers, 2006:  Implementation of model skill assessment software for water level and current in tidal regions.  NOAA Technical Report NOS CS 24, 61 pp. [Available from NOAA/NOS Coast Survey Development Lab, 1315 E-W Highway, Silver Spring, MD  20910.]

## APPENDIX A. Skill Assessment Statistics of Semi-Operational Water Level Nowcasts and Forecast Guidance at NOS Gauges in Lake Ontario for 2004.

Table A.1. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Cape Vincent, NY Gauge (NOS ID 9052000) for 2004.

Station: Cape Vincent, Lake Ontario, NY
Observed data time period from: 5/14/2004 to 12/20/2004
Data gap is filled using SVD method
Data are filtered using 3.0 Hour Fourier Filter

| VARIABLE | X | N | IMAX | SM | RMSE | SD | NOF | CF | POF | MDNO | MDPO |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CRITERION | - | - | - | - | - | - | <1% | >90% | <1% | <N | <N |
| SCENARIO: SEMI-OPERATIONAL NOWCAST | | | | | | | | | | | |
| H | | | 5757 | 74.901 | | | | | | | |
| h | | | 5757 | 74.875 | | | | | | | |
| H-h | 15 cm | 24h | 5757 | 0.026 | 0.044 | 0.036 | 0.0 | 99.9 | 0.0 | 0.0 | 0.0 |
| AHW-ahw | 15 cm | 24h | 12 | -0.046 | 0.050 | 0.022 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| ALW-alw | 15 cm | 24h | 6 | 0.067 | 0.069 | 0.021 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| THW-thw | 1.50 hr | 25h | 12 | -1.333 | 4.472 | 4.458 | 33.3 | 33.3 | 16.7 | 0.0 | 0.0 |
| TLW-tlw | 1.50 hr | 25h | 6 | 0.167 | 1.225 | 1.329 | 0.0 | 83.3 | 0.0 | 0.0 | 0.0 |
| SCENARIO: SEMI-OPERATIONAL FORECAST | | | | | | | | | | | |
| H00-h00 | 15 cm | 24h | 488 | 0.025 | 0.045 | 0.037 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H06-h06 | 15 cm | 24h | 484 | 0.028 | 0.048 | 0.039 | 0.0 | 99.8 | 0.0 | 0.0 | 0.0 |
| H12-h12 | 15 cm | 24h | 484 | 0.027 | 0.047 | 0.038 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H18-h18 | 15 cm | 24h | 484 | 0.028 | 0.048 | 0.039 | 0.0 | 99.8 | 0.0 | 0.0 | 0.0 |
| H24-h24 | 15 cm | 24h | 484 | 0.028 | 0.048 | 0.039 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| AHW-ahw | 15 cm | 24h | 11 | -0.041 | 0.067 | 0.055 | 0.0 | 90.9 | 0.0 | | |
| ALW-alw | 15 cm | 24h | 6 | 0.074 | 0.076 | 0.021 | 0.0 | 100.0 | 0.0 | | |
| THW-thw | 1.50 hr | 25h | 11 | 0.545 | 3.861 | 4.009 | 18.2 | 27.3 | 27.3 | | |
| TLW-tlw | 1.50 hr | 25h | 6 | -0.667 | 3.873 | 4.179 | 33.3 | 16.7 | 0.0 | | |

Table A.2. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Oswego, NY Gauge (NOS ID 9052030) for 2004.

Station: Oswego, Lake Ontario, NY
Observed data time period from: 4/15/2004 to 12/20/2004
Data gap is filled using SVD method
Data are filtered using 3.0 Hour Fourier Filter

| VARIABLE | X | N | IMAX | SM | RMSE | SD | NOF | CF | POF | MDNO | MDPO |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CRITERION | - | - | - | - | - | - | <1% | >90% | <1% | <N | <N |
| SCENARIO: SEMI-OPERATIONAL NOWCAST | | | | | | | | | | | |
| H | | | 5832 | 74.896 | | | | | | | |
| h | | | 5832 | 74.891 | | | | | | | |
| H-h | 15 cm | 24h | 5832 | 0.005 | 0.032 | 0.031 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| AHW-ahw | 15 cm | 24h | 2 | -0.074 | 0.074 | 0.008 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| ALW-alw | 15 cm | 24h | 5 | 0.052 | 0.053 | 0.010 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| THW-thw | 1.50 hr | 25h | 2 | 0.500 | 0.707 | 0.707 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| TLW-tlw | 1.50 hr | 25h | 5 | 0.800 | 3.098 | 3.347 | 20.0 | 20.0 | 0.0 | 0.0 | 0.0 |
| SCENARIO: SEMI-OPERATIONAL FORECAST | | | | | | | | | | | |
| H00-h00 | 15 cm | 24h | 494 | 0.004 | 0.032 | 0.032 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H06-h06 | 15 cm | 24h | 490 | 0.006 | 0.033 | 0.032 | 0.0 | 99.8 | 0.0 | 0.0 | 0.0 |
| H12-h12 | 15 cm | 24h | 490 | 0.004 | 0.033 | 0.033 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H18-h18 | 15 cm | 24h | 490 | 0.006 | 0.035 | 0.034 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H24-h24 | 15 cm | 24h | 490 | 0.005 | 0.036 | 0.035 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| AHW-ahw | 15 cm | 24h | 4 | -0.058 | 0.068 | 0.040 | 0.0 | 100.0 | 0.0 | | |
| ALW-alw | 15 cm | 24h | 5 | 0.046 | 0.046 | 0.002 | 0.0 | 100.0 | 0.0 | | |
| THW-thw | 1.50 hr | 25h | 4 | -1.250 | 2.693 | 2.754 | 25.0 | 25.0 | 0.0 | | |
| TLW-tlw | 1.50 hr | 25h | 5 | -0.800 | 1.414 | 1.304 | 0.0 | 60.0 | 0.0 | | |

Table A.3. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Rochester, NY Gauge (NOS ID 9052058) for 2004.

Station: Rochester, Lake Ontario, NY
Observed data time period from: 4/15/2004 to 12/20/2004
Data gap is filled using SVD method
Data are filtered using 3.0 Hour Fourier Filter

| VARIABLE | X | N | IMAX | SM | RMSE | SD | NOF | CF | POF | MDNO | MDPO |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CRITERION | - | - | - | - | - | - | <1% | >90% | <1% | <N | <N |
| SCENARIO: SEMI-OPERATIONAL NOWCAST | | | | | | | | | | | |
| H | | | 5832 | 74.894 | | | | | | | |
| h | | | 5832 | 74.894 | | | | | | | |
| H-h | 15 cm | 24h | 5832 | 0.000 | 0.029 | 0.029 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| ALW-alw | 15 cm | 24h | 2 | 0.067 | 0.067 | 0.010 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| TLW-tlw | 1.50 hr | 25h | 2 | 1.000 | 3.162 | 4.243 | 0.0 | 0.0 | 50.0 | 0.0 | 0.0 |
| SCENARIO: SEMI-OPERATIONAL FORECAST | | | | | | | | | | | |
| H00-h00 | 15 cm | 24h | 494 | 0.000 | 0.029 | 0.029 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H06-h06 | 15 cm | 24h | 490 | -0.001 | 0.030 | 0.030 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H12-h12 | 15 cm | 24h | 490 | 0.000 | 0.032 | 0.032 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H18-h18 | 15 cm | 24h | 490 | -0.001 | 0.032 | 0.032 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H24-h24 | 15 cm | 24h | 490 | 0.001 | 0.034 | 0.034 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| ALW-alw | 15 cm | 24h | 2 | 0.066 | 0.067 | 0.013 | 0.0 | 100.0 | 0.0 | | |
| TLW-tlw | 1.50 hr | 25h | 2 | 0.500 | 2.550 | 3.536 | 0.0 | 0.0 | 0.0 | | |

Table A.4. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Olcott, NY Gauge (NOS ID 9052076) for 2004.

Station: Olcott, Lake Ontario, NY
Observed data time period from: 4/15/2004 to 12/20/2004
Data gap is filled using SVD method
Data are filtered using 3.0 Hour Fourier Filter

| VARIABLE | X | N | IMAX | SM | RMSE | SD | NOF | CF | POF | MDNO | MDPO |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CRITERION | - | - | - | - | - | - | <1% | >90% | <1% | <N | <N |
| SCENARIO: SEMI-OPERATIONAL NOWCAST | | | | | | | | | | | |
| H | | | 5832 | 74.892 | | | | | | | |
| h | | | 5832 | 74.903 | | | | | | | |
| H-h | 15 cm | 24h | 5832 | -0.011 | 0.033 | 0.031 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| ALW-alw | 15 cm | 24h | 2 | 0.001 | 0.015 | 0.021 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| TLW-tlw | 1.50 hr | 25h | 2 | -3.500 | 4.301 | 3.536 | 50.0 | 50.0 | 0.0 | 0.0 | 0.0 |
| SCENARIO: SEMI-OPERATIONAL FORECAST | | | | | | | | | | | |
| H00-h00 | 15 cm | 24h | 494 | -0.010 | 0.032 | 0.031 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H06-h06 | 15 cm | 24h | 490 | -0.012 | 0.034 | 0.032 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H12-h12 | 15 cm | 24h | 490 | -0.010 | 0.034 | 0.033 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H18-h18 | 15 cm | 24h | 490 | -0.011 | 0.036 | 0.034 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| H24-h24 | 15 cm | 24h | 490 | -0.010 | 0.037 | 0.035 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| ALW-alw | 15 cm | 24h | 2 | 0.010 | 0.010 | 0.006 | 0.0 | 100.0 | 0.0 | | |
| TLW-tlw | 1.50 hr | 25h | 2 | 1.500 | 2.915 | 3.536 | 0.0 | 50.0 | 50.0 | | |

**APPENDIX B. Time Series Plots of Semi-Operational Water Level Nowcasts vs. Observations at NOS Gauges in Lake Ontario during 2004.**

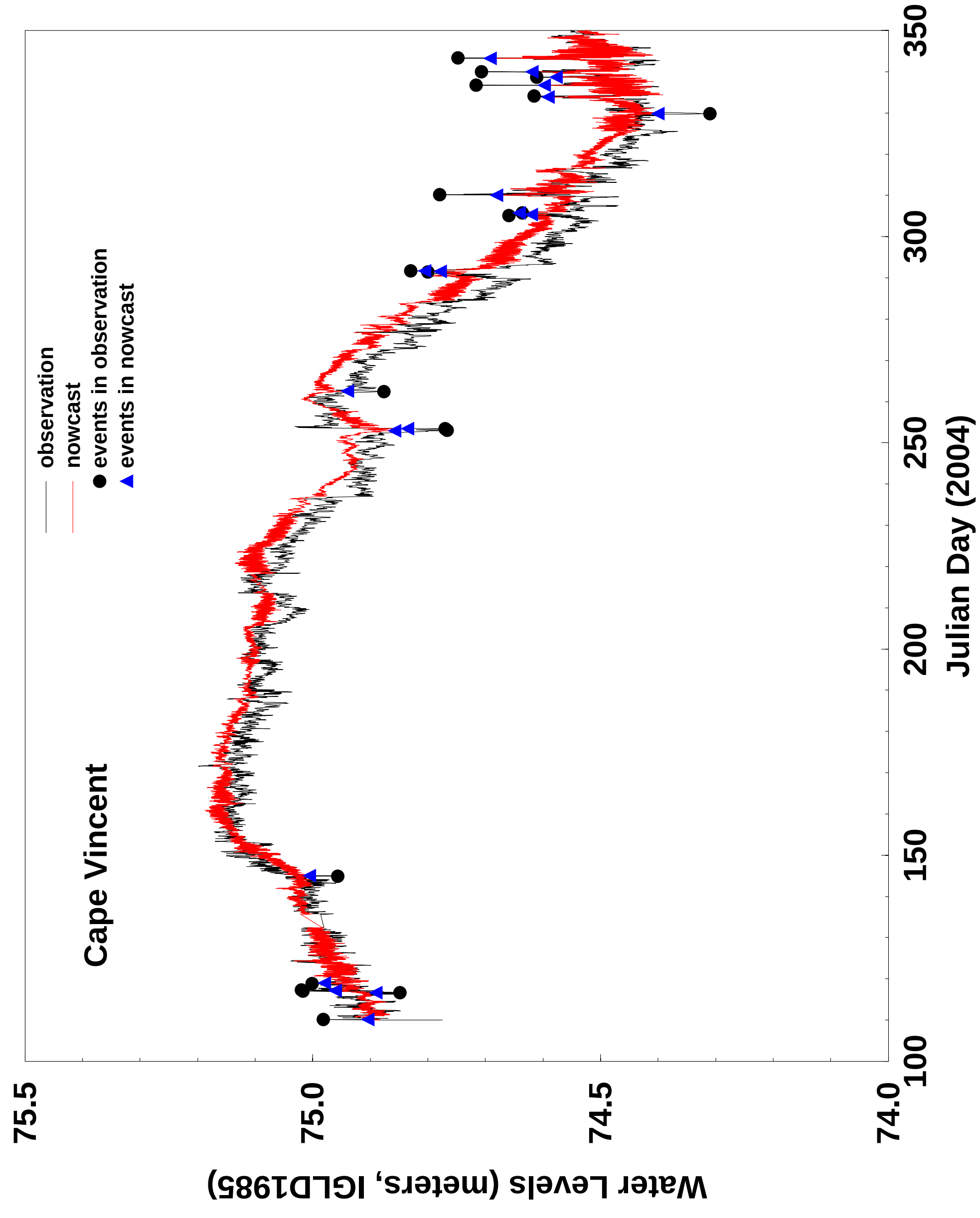


Fig. B.1. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at NOS Cape Vincent, NY Gauge during 2004.

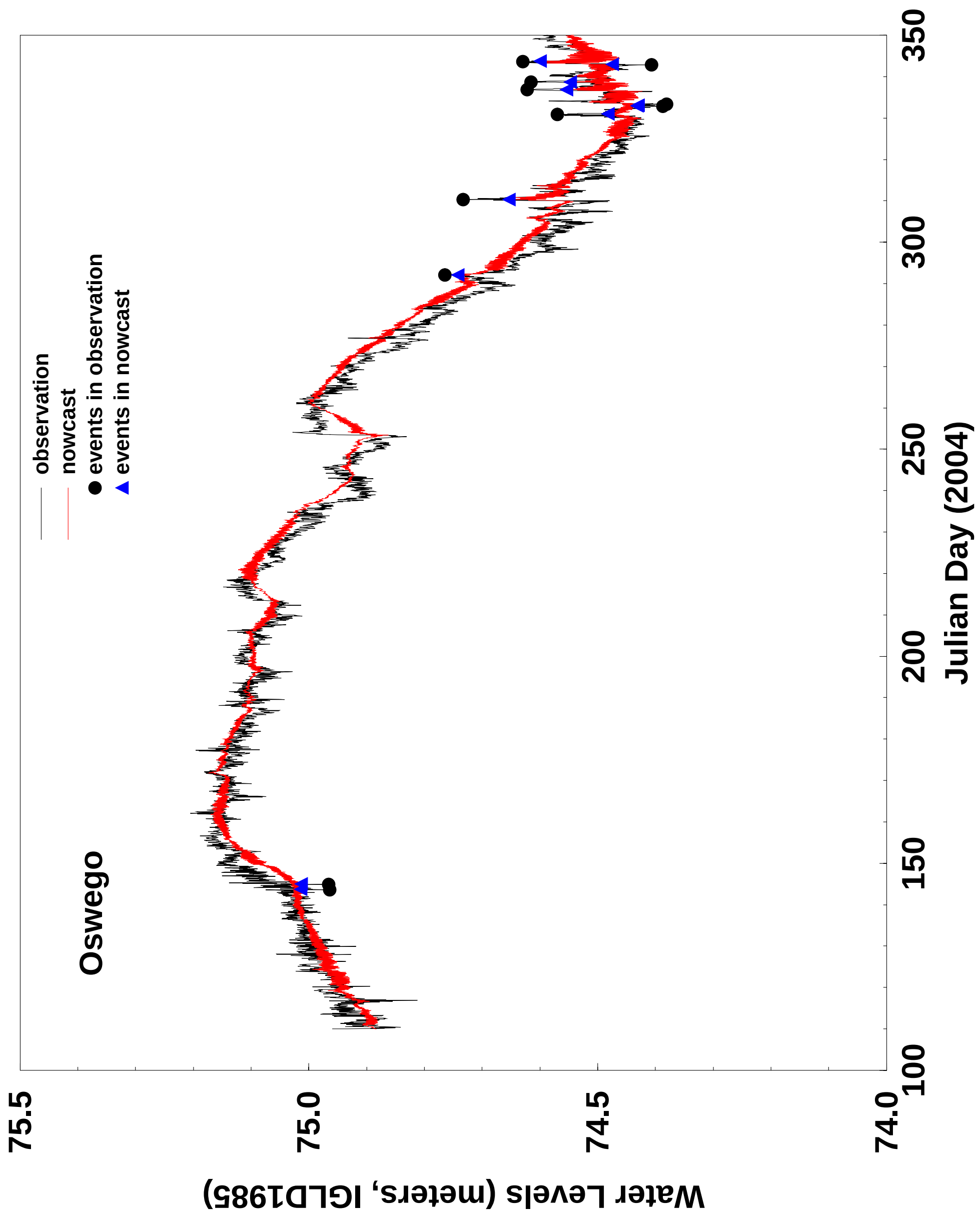


Fig. B.2. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at NOS Oswego, NY Gauge during 2004.

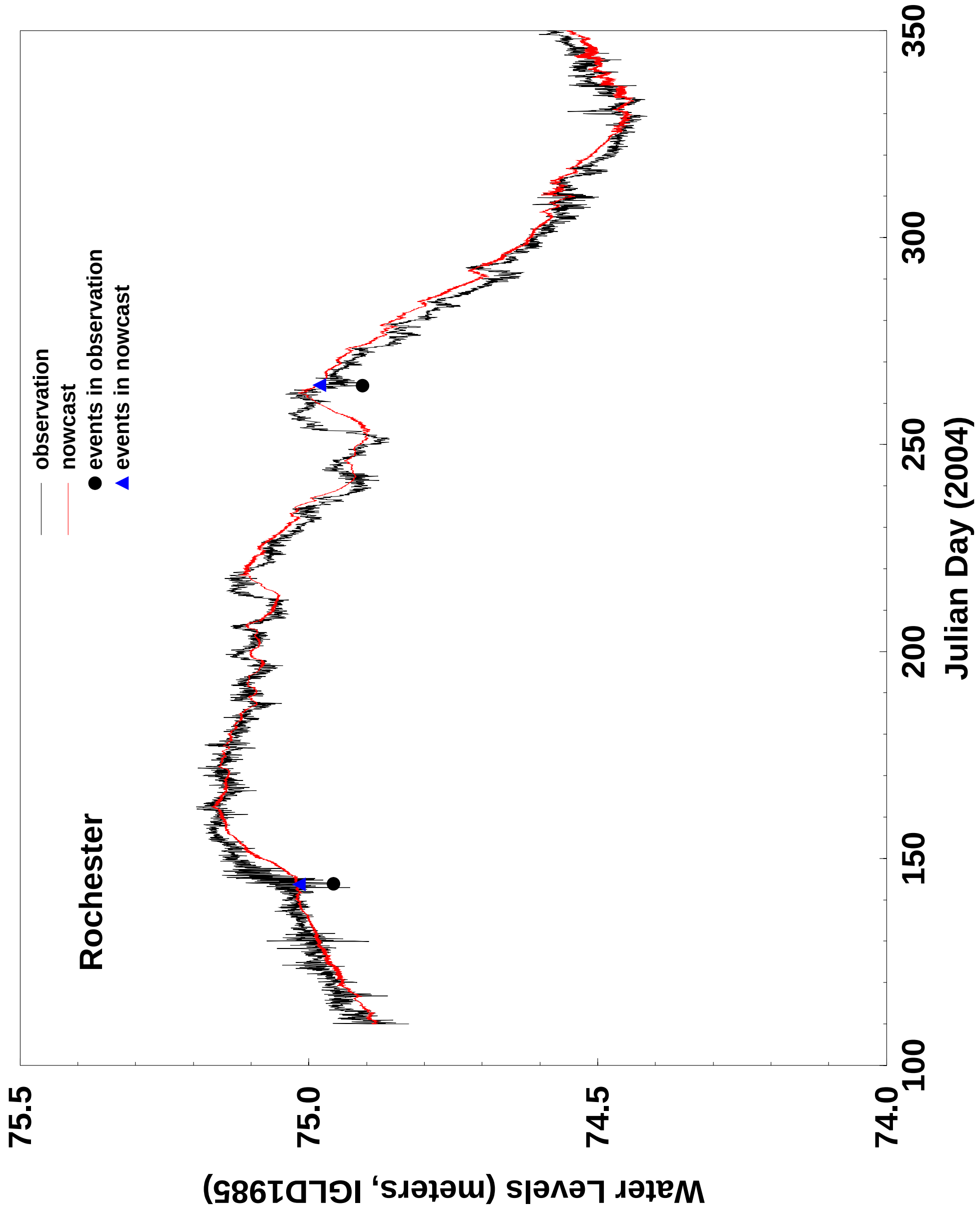


Fig. B.3. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at NOS Rochester, NY Gauge during 2004.

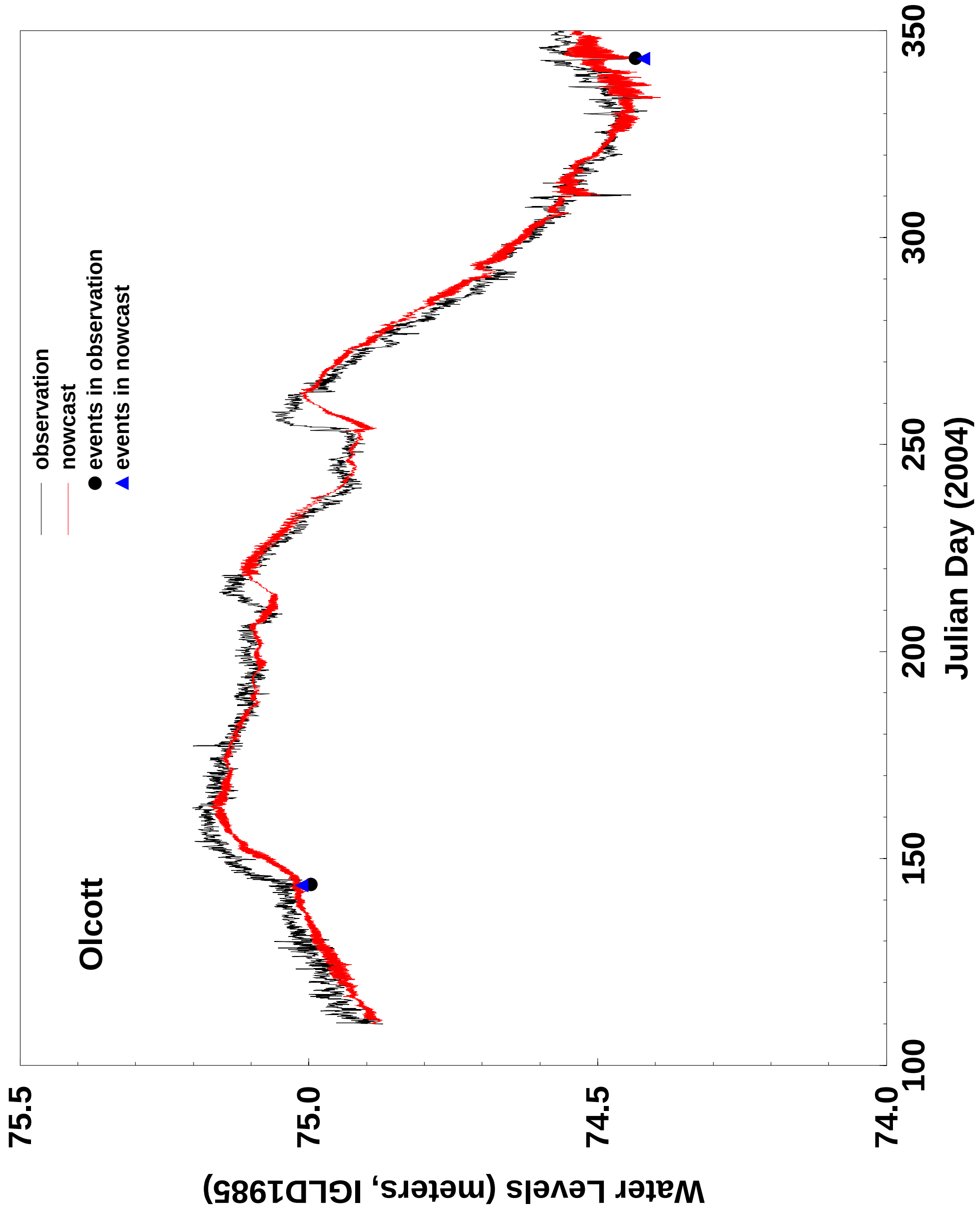


Fig. B.4. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at NOS Olcott, NY Gauge during 2004.

## APPENDIX C. Time Series Plots of Semi-Operational Water Level Forecast Guidance vs. Observations at NOS Gauges in Lake Ontario during 2004.

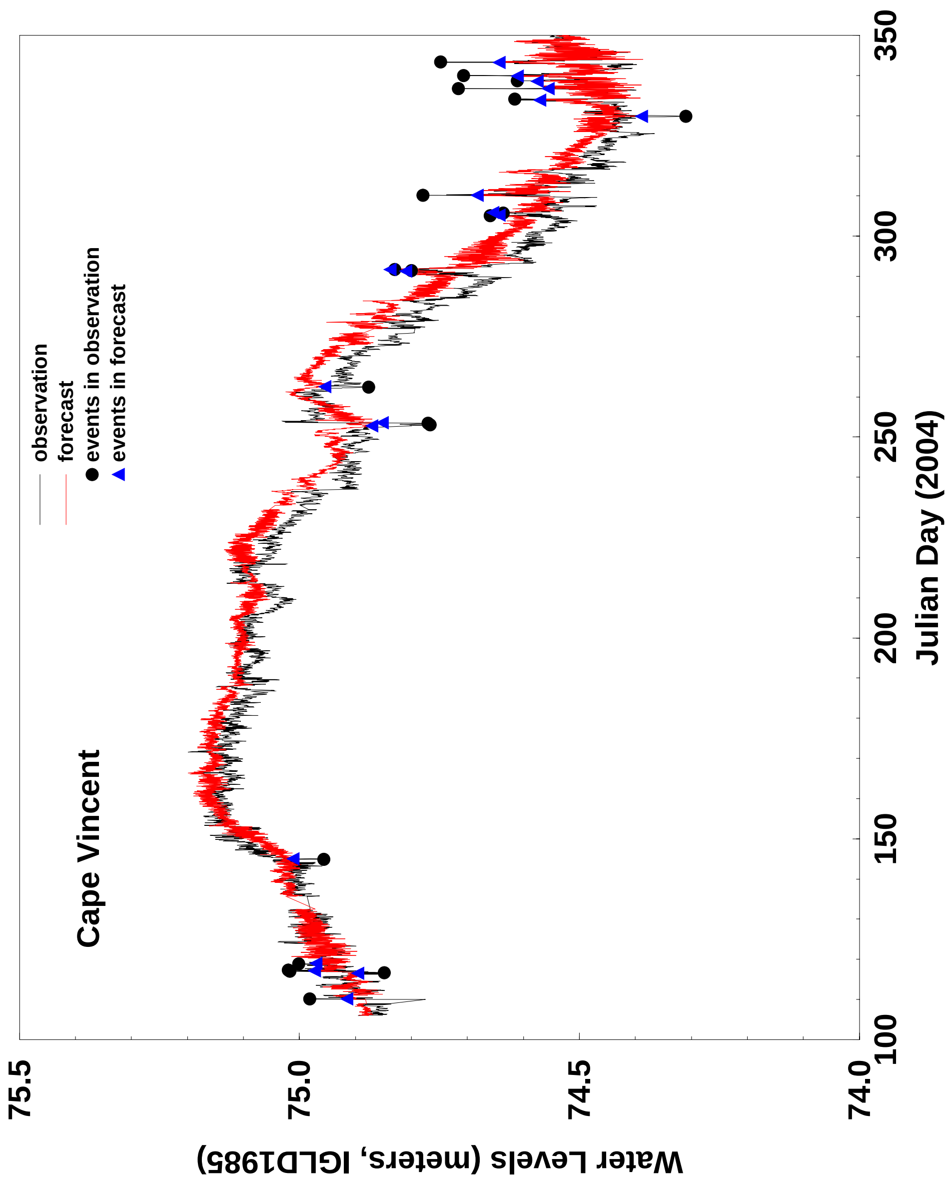


Fig. C.1. Time Series Plot of Semi-Operational Water Level Forecast Guidance vs. Observations at NOS Cape Vincent, NY Gauge during 2004.

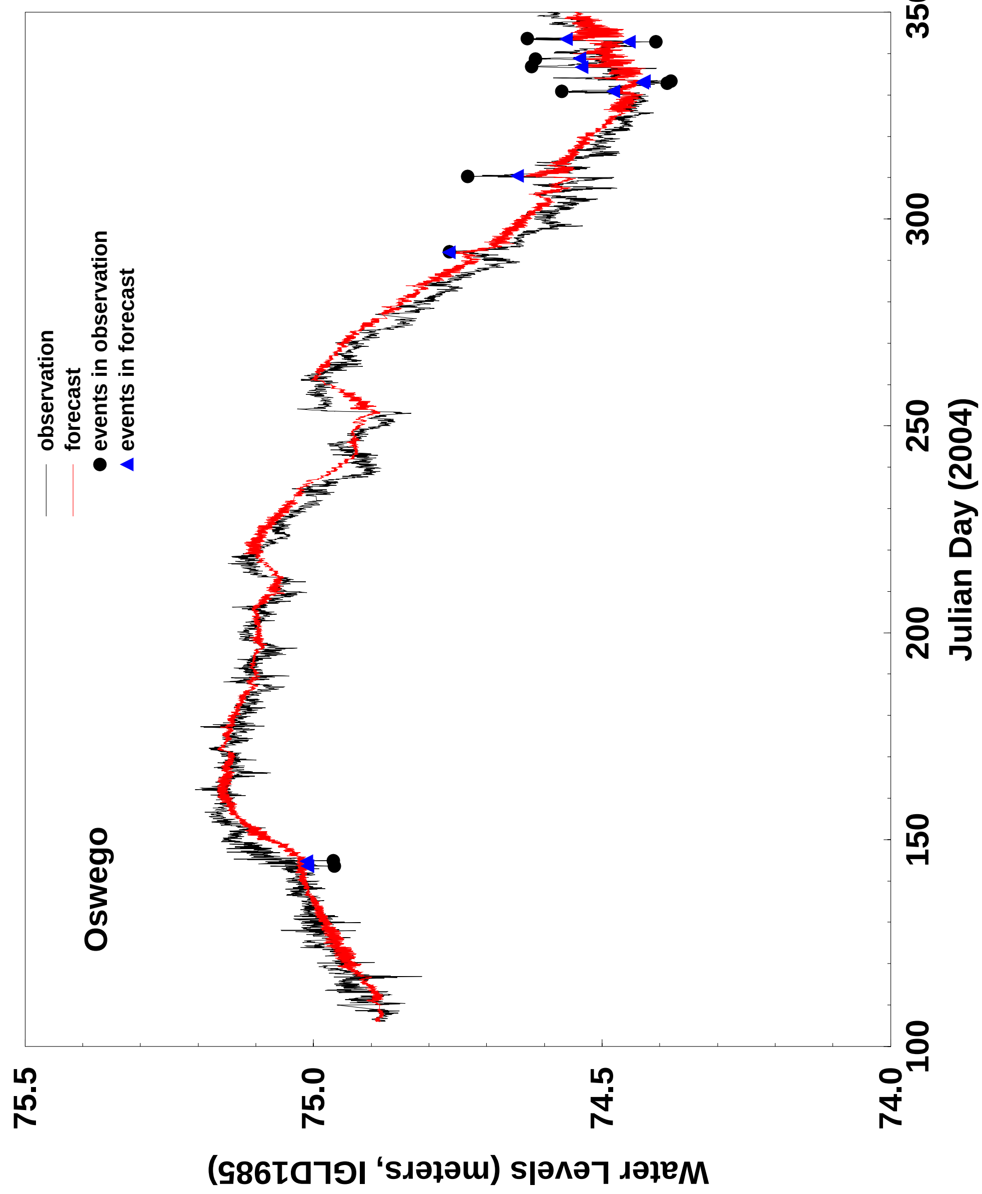


Fig. C.2. Time Series Plot of Semi-Operational Water Level Forecast Guidance vs. Observations at NOS Oswego, NY Gauge during 2004.

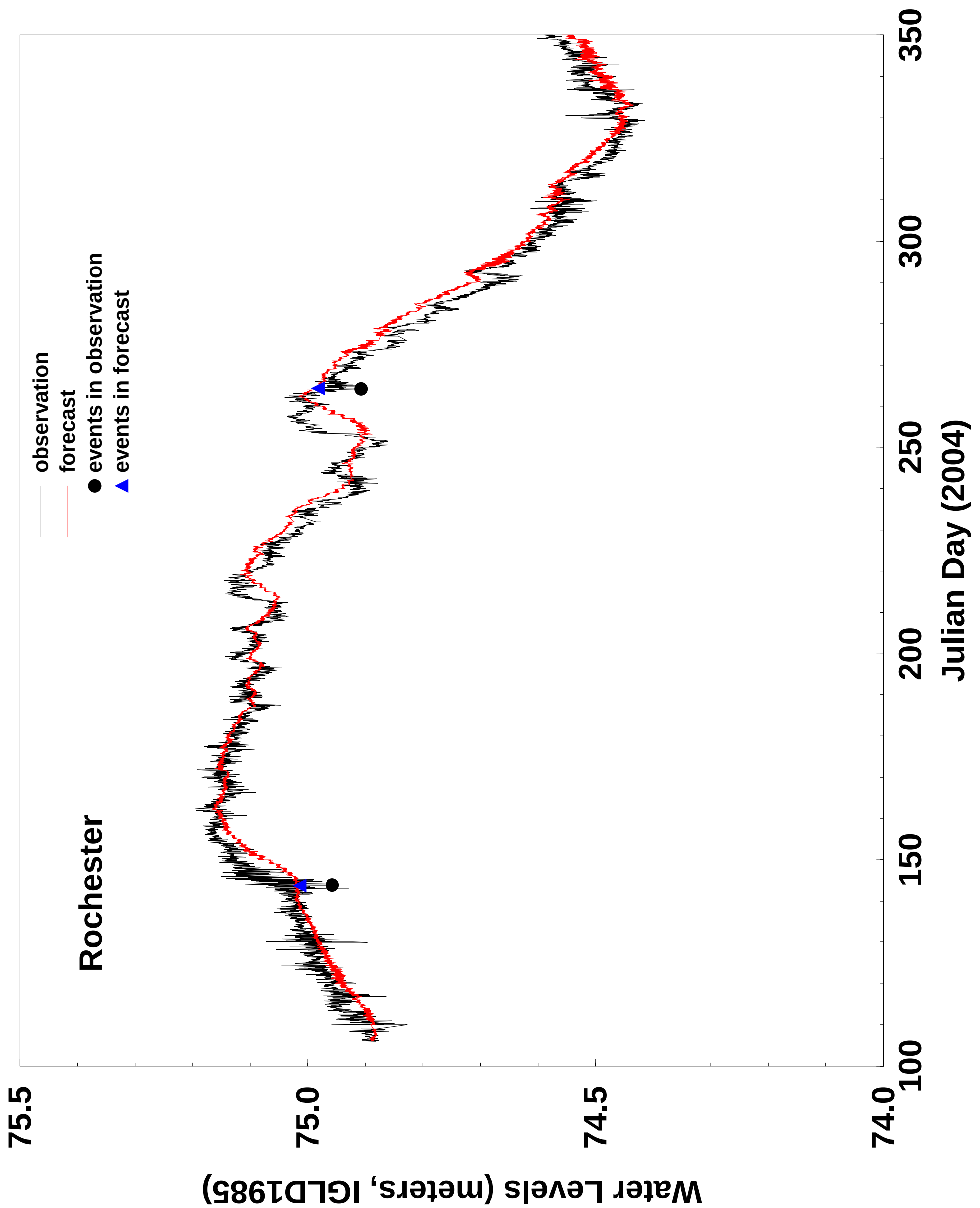


Fig. C.3. Time Series Plot of Semi-Operational Water Level Forecast Guidance vs. Observations at NOS Rochester, NY Gauge during 2004.

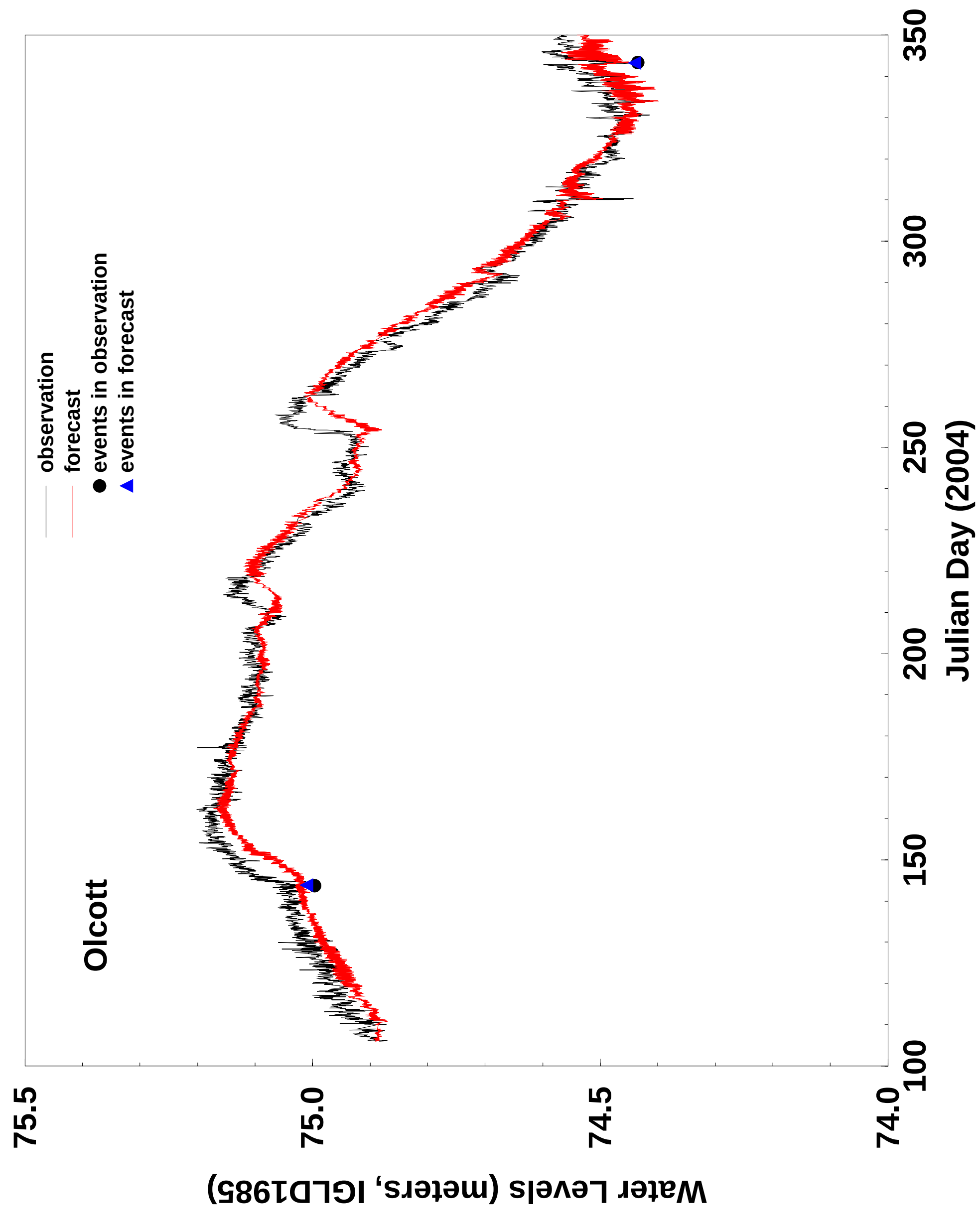


Fig. C.4. Time Series Plot of Semi-Operational Water Level Forecast Guidance vs. Observations at NOS Olcott, NY Gauge during 2004.

## APPENDIX D. Skill Assessment Statistics of Semi-Operational Surface Water Temperature Nowcasts and Forecast Guidance at the NWS/NDBC Fixed Buoy in Lake Ontario for 2004.

Table D.1. Skill Assessment Statistics of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperatures at the NWS/NDBC Fixed Buoy 45012 (Lake Ontario) for the Period 20 April to 17 November 2004.

Station: NDBC Buoy 45012 in Lake Ontario
Observed data time period from: 4/20/2004 to 11/17/2004
Data gap is filled using SVD method
Data are filtered using 3.0 Hour Fourier Filter

| VARIABLE | X | N | IMAX | SM | RMSE | SD | NOF | CF | POF | MDNO | MDPO |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CRITERION | - | - | - | - | - | - | <1% | >90% | <1% | <N | <N |
| SCENARIO: SEMI-OPERATIONAL NOWCAST | | | | | | | | | | | |
| T | | | 5078 | 13.607 | | | | | | | |
| t | | | 5078 | 13.604 | | | | | | | |
| T-t | 3.0 c | 24h | 5078 | 0.003 | 1.880 | 1.880 | 0.0 | 88.6 | 0.1 | 0.0 | 2.0 |
| SCENARIO: SEMI-OPERATIONAL FORECAST | | | | | | | | | | | |
| T00-t00 | 3.0 c | 24h | 424 | 0.082 | 1.885 | 1.886 | 0.0 | 88.7 | 0.0 | 0.0 | 0.0 |
| T06-t06 | 3.0 c | 24h | 419 | -0.080 | 1.929 | 1.930 | 0.0 | 86.9 | 0.0 | 0.0 | 0.0 |
| T12-t12 | 3.0 c | 24h | 420 | -0.036 | 1.929 | 1.931 | 0.0 | 87.6 | 0.2 | 0.0 | 0.0 |
| T18-t18 | 3.0 c | 24h | 419 | -0.169 | 1.903 | 1.898 | 0.0 | 87.6 | 0.0 | 0.0 | 0.0 |
| T24-t24 | 3.0 c | 24h | 420 | -0.130 | 1.891 | 1.889 | 0.0 | 87.6 | 0.0 | 0.0 | 0.0 |

## APPENDIX E. Time Series Plots of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperature vs. Observations at the NWS/NDBC fixed buoy in Lake Ontario during 2004.

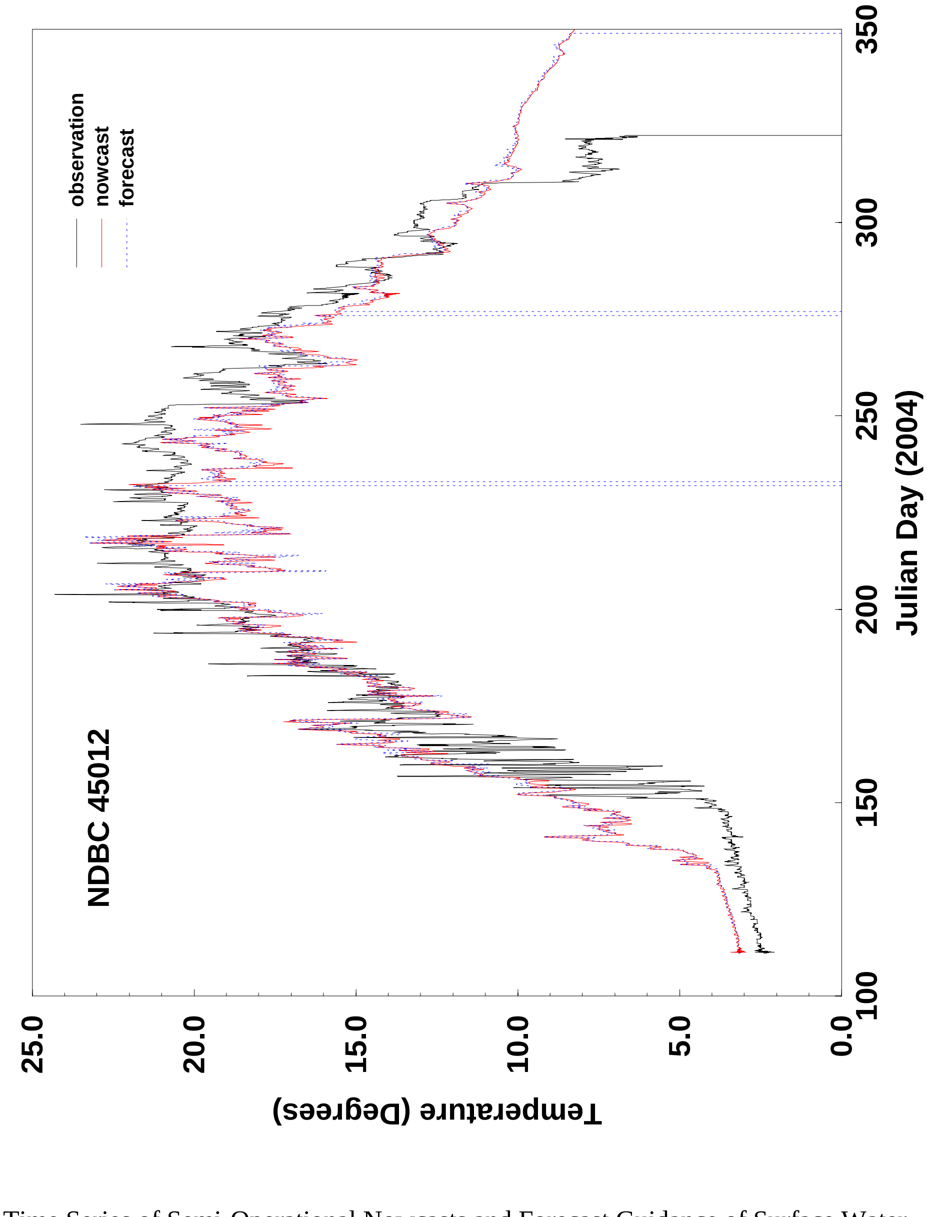


Figure E.1. Time Series of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperature ($^{o}$C) vs. Observations at the NWS/NDBC Fixed Buoy 45012 (Lake Ontario) for the Period 20 April to 17 November 2004. The forecast values depicted on the plots are from the 0000 UTC forecast cycle.