NOAA Technical Memorandum NOS CS 23

SKILL ASSESSMENT OF NOS LAKE HURON OPERATIONAL FORECAST SYSTEM (LHOFS)

Silver Spring, Maryland
October 2010

noaa National Oceanic and Atmospheric Administration

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

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

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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
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
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 Huron Operational Forecast System (LHOFS) 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 Huron.

LHOFS is the result of technology transfer of the Great Lakes 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.

The model system skill assessment of LHOFS 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 Huron as was the case for Lakes Michigan and Erie. Therefore, no hindcast scenario skill assessment was done for LHOFS.

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 Huron 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 Huron.

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 all six NOS gauges in Lake Huron used in the evaluation. In terms of other statistics, the mean algebraic error or difference (MAE) ranged between -4 and 11 cm. The root mean square error (RSME) ranged from 4 to 7 cm.

The nowcast predictions of *high water level events* passed the NOS criteria for amplitude at all six gauges. In terms of timing, the nowcasts failed to meet the NOS acceptance criteria. The nowcasts of low water events met the NOS criteria for amplitude at six gauges but did not pass the criteria in terms of timing at any of the gauges.

Forecast Guidance:

The *hourly forecast guidance* met the NOS criteria for predicting water level amplitude at the six gauges. In terms of other statistics, the MAE ranged between -4.7 and 4.0 cm and RSME ranged from 3.8 to 6.1 cm. The forecast guidance was similar to the nowcasts in that the greatest errors were at the Essexville gauge located in the southern end of Saginaw Bay and at the Mackinaw City gauge at the extreme western edge of the model domain.

The forecast guidance of high water events passed the NOS criteria for amplitude at three of the six gauges. The forecast guidance failed to meet NOS criteria in predicting the times of these extreme events at all gauges. The guidance of low water events passed the NOS criteria for amplitude at all gauges but failed the criteria in predicting the times of these extreme events at all gauges.

Surface Water Temperatures:

Nowcasts:

The hourly surface water temperature nowcasts were evaluated at the northern and southern NDBC buoys in Lake Huron. The water temperature nowcasts passed the NOS acceptance criteria at the southern buoy but failed to pass 3 of the 5 criteria statistics at the northern buoy. The nowcasts overpredicted temperatures at both bouys, with the greatest differences occurring at the northern buoy. The MAE range from 0.8 to 1.9^{o}C and RMSE ranged from 1.7 to 2.8^{o}C. The greatest positive departure between the nowcasts and observations at both buoys occurred from mid May, when water temperature rose above 4^{o}C, till early July.

Forecast Guidance:

The hourly surface water temperature forecast guidance at the 24-hr projection passed the NOS acceptance criteria at the southern buoy. The MAE and RSME at this buoy were 0.5^{o}C and 1.4^{o}C, respectively. The hourly guidance at the northern buoy failed the majority of the criteria statistics. At this buoy, the MAE and RSME were 1.8^{o}C and 2.7^{o}C, respectively. The MAE and RMSE values for 24-hr forecast projection were slightly higher than for the nowcast comparisons. The MAE decreased by 0.15^{o}C to 0.35^{o}C as the forecast projection increased from 0 to 24 hours.

Surface Currents:

Due to the lack of water current observations, no quantitative assessment could be conducted for LHOFS. However, animation of surface current nowcasts and forecast guidance indicated that LHOFS 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, oceanographic forecast systems, Lake Huron, 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, as well as 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 Huron since August 2002. GLCFS for Lake Huron 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 Coastal Ocean 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 Huron was renamed as the Lake Huron Operational Forecast System (LHOFS). LHOFS began making routine operational lake nowcasts and forecasts for Lake Huron on March 30, 2006 at CO-OPS during the ice-free season. The forecast systems for Lake Ontario and Superior were also implemented on this date.

The predictions from LHOFS, similar to those from NOS estuarine forecast systems, must be evaluated to inform users about the skill of the nowcasts and forecasts. In evaluating LHOFS, 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 Huron 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 LHOFS. 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 Huron and an overview of LHOFS are given first.

2. LAKE HURON

Lake Huron is the second largest of the Great Lakes in terms of surface area (59,565 sq. km and the fourth largest lake in the world. The lake has a breadth of 295 km (183 mi) and a length of 332 km (206 mi). It has an average depth of 59 m (195 ft) with a maximum of 229 m (750 ft). Lake Huron, similar to other Great Lakes, has a pronounced annual thermal cycle ranging from vertically well-mixed water body in late autumn to thermal stratification across the entire lake with a well-developed thermocline by August (Boyce et al. 1989).

Lake Huron, as all the Great Lakes, experiences two types of water level fluctuations. Short-term changes occur due to surface winds and changes in atmospheric pressure. Seasonal changes occur with the lowest water levels occurring during the winter and the highest levels occurring during the early autumn (GLIN 2006).

The mean large-scale circulation in Lake Huron is cyclonic both in summer and winter but stronger during the winter (Beletsky et al. 1999). A persistent feature during both winter and summer is the surface flow into Georgian Bay which implies a return flow at deeper depth (Beletsky et al. 1999). Beletsky et al. (1999) states that the strong cyclonic circulation in the winter may be due to lake-induced mesoscale vorticity in the wind field caused by the lake's large surface area and stronger lake-atmosphere temperature gradients.

On a short time period (less than a day), Lake Huron 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 LHOFS. 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 LHOFS 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 model for the Great Lakes will be referred to as POMGL. Lake Huron, 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 Huron consists of a rectangular grid with a 5-km horizontal resolution in both the x- and y-directions. The domain has a total of 6075 grid points with 81 points in the x-direction and 75 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 maintain stability and 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.

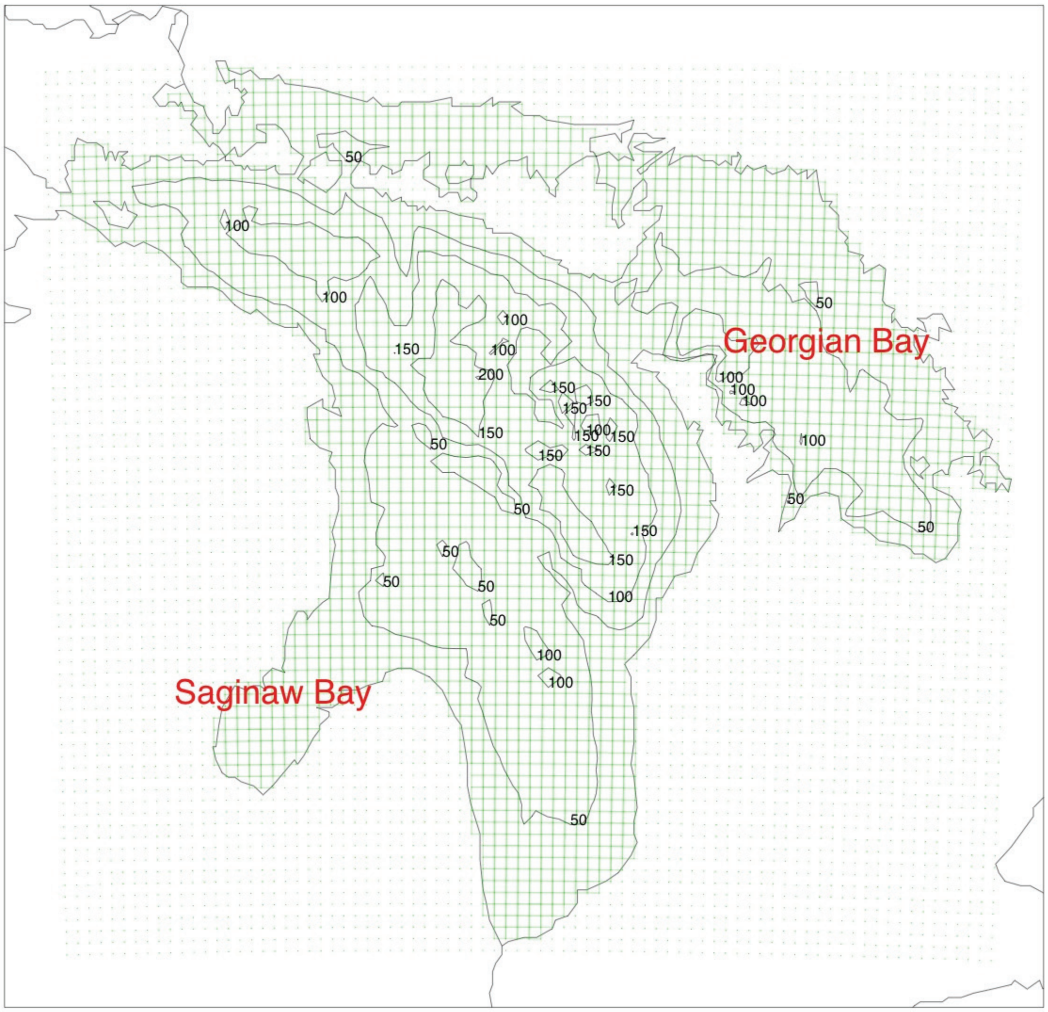

Figure 1. Map depicting the POMGL grid domain (5 km spatial resolution) used by NOS' Lake Huron Operational Forecast System along with model bathymetry contoured at 50 m intervals.

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 meteorological data format, but are decoded and written out to a text file for use by LHOFS and other NOS operational forecast systems. The surface observation text file is available to LHOFS 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 Huron. 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 any of the individual nowcast/forecast systems for the Great Lakes.

3.4 Nowcast Cycle

The nowcast cycle of LHOFS is run hourly at NOS to generate updated nowcasts of the 3-D state of Lake Huron, 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). This is accomplished by 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 (10m AGL). 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's 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 (AVHRR) on board NOAA's polar-orbiter satellites. The adjustments to the observations along with simple quality control checks are done 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 surface water temperature predictions from POMGL are used by a heat flux scheme (McCormick and Meadows 1988) to estimate the net rate of heat transfer for the lake at each 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 LHOFS is run four times per day to generate forecast guidance of the 3-D state of Lake Huron. 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 National Digital Forecast Database (NDFD). The NDFD fields are obtained from the NWS Weather Forecast Office (WFO) in Cleveland, OH by CO-OPS four times/day in netCDF format. The gridded forecasts have a spatial resolution of 5km and cover both the U.S. and Canadian Great Lakes waters. The NAM guidance is used as backup forcing if the NDFD forecasts are not available.

3.6 Operational Environment and Scheduling

LHOFS is run operationally on a Linux workstation at NOS/CO-OPS in Silver Spring, MD. Each hourly nowcast cycle is launched at 52 minutes past the top of the hour to ensure a sufficient amount of surface meteorological observations from both Canadian and U.S. networks are received at NCEP and then processed at CO-OPS.

The forecast cycle of LHOFS is run four times per day at 0000, 0600, 1200, and 1800 UTC at 52 minutes past the top of these hours. The forecast horizon of each forecast cycle is 30 hours.

LHOFS and the operational forecast systems for Lakes Ontario 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 and be evaluated in a 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 a semi-operational nowcast scenario (Hess et al. 2003). 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."

LHOFS, as described in Chapter 2, is based on NOAA/GLERL's Great Lakes Coastal Forecast System (GLCFS) for Lake Huron. Both LHOFS and GLCFS-Lake Huron 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 (MAREPS), whereas LHOFS does not include these. However, this difference was not expected to cause a significant difference in the nowcasts.

Due to the similar characteristics of LHOFS and GLCFS, the assessment of the LHOFS 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 Huron, and the other four Great Lakes, year round. The POMGL used by each forecast system are not reinitialized each spring. The surface forcing for the nowcast cycles are provided by objective analyses 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. 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 LHOFS 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 (Time Series)	Water level Water temperature	H, h T, t
Group 2 (Values at Extreme Event)	Amplitude of high water Amplitude of low water Time of high water Time of low water	AHW, ahw ALW, ahw THW, thw TLW, tlw
Group 3 (Values from a Forecast)	Water level at forecast projection time of nn hrs Water temperature at forecast projection time of nn hrs	Hnn, hnn 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^oC*	24

Notes: $^+$1.0 hour for tidal regions, *7.7^oC 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/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 six NOS NWLON stations along the Lake Huron shore line (Table 4). A map depicting the locations of the six NOS stations, whose data were used in the evaluation, is given in Fig. 2. (The NOS gauges at Rock Cut and Fort Gratiot, MI were not used.)

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 LHOFS 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 Huron 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 statistical 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.

Nowcasts of Surface Water Temperatures

The evaluation of GLCFS nowcasts of surface water temperatures was based on comparisons of time series of model-predicted temperatures vs. observations at two 3-m fixed disk buoys in the lake. The buoys are operated by NOAA/National Data Buoy Center (NDBC). Information on the buoys 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 it is sampled once per hour. The point evaluations were conducted by comparing surface (1st sigma layer) temperature nowcasts at the nearest grid points to surface observations from the buoys. A map depicting the locations of the NDBC fixed buoys is given in Fig. 3.

The evaluation of GLCFS surface water temperature nowcasts for Lake Huron 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 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 4. Information on NOAA/NOS/CO-OPS NWLON stations whose observations were used to evaluate LHOFS 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
DeTour Village	MI	9075099	DTLM4	45.99	83.90	15	67
Mackinaw City	MI	9075080	MACM4	45.78	84.72	2	64*
Harrisville	MI	9075059	NA	44.66	83.29	25*	38
Essexville	MI	9075035	NA	43.64	83.85	15	16*
Harbor Beach	MI	9075014	HRBM4	43.85	82.64	35*	20
Lakeport	MI	9075002	LPNM4	43.14	82.49	37	4

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

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

Buoy Name	Agency	Prov. or State	WMO Buoy ID	Geographic Coordinates		Corresponding LHOFS Grid Point Coordinates	
				Latitude (deg N)	Longitude (deg W)	I	J
45003- North Huron	NWS/ NDBC	MI	45003	45.35	82.84	31	53
45008 – South Huron	NWS/ NDBC	MI	45008	44.28	82.42	38	29

Figure 2. Map depicting locations of NOS/CO-OPS NWLON stations in Lake Huron used in the skill assessment.

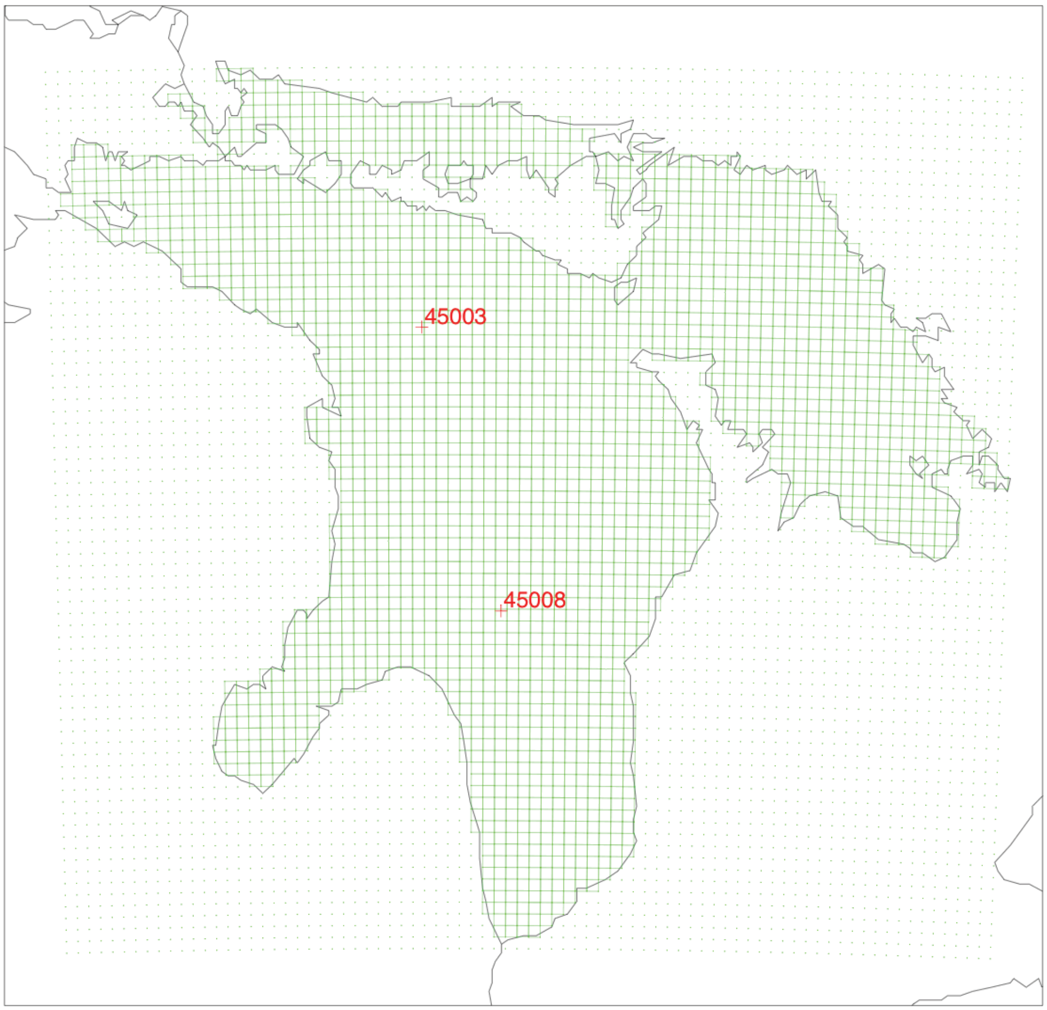

Figure 3. Map depicting location of NWS/NDBC fixed buoys in Lake Huron.

5.3 Assessment 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 six NOS gauges from 15 April to 17 December 2004 are given in Appendix A. Time series plots of the nowcasts compared with 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 -4 and 11 cm and the RMSE ranged between 4 and 7 cm. The greatest RMSE was at Essexville gauge located at the extreme southern part of Saginaw Bay (Fig. 2). The nowcasts generally over predicted the water levels but under predicted levels at Essexville, Harbor Beach and Lakeport.

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

Statistic, Acceptable Error [ ], and Units ( )	DeTour Village, MI	Mackinaw City, MI	Harrisville, MI	Essexville, MI	**NOS Accept. Criteria**
Mean Diff. (m)	0.111	0.041	0.001	-0.042	na
RMSE (m)	0.043	0.055	0.036	0.073	na
SD (m)	0.042	0.037	0.036	0.061	na
NOF [2x15cm] (%)	0.0	0.0	0.0	0.0	≤ 1%
CF [15 cm] (%)	99.4	99.4	100.0	95.3	≥ 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 6 (continued)

Statistic, Acceptable Error [ ], and Units ( )	Harbor Beach, MI	Lakeport, MI	**NOS Accept. Criteria**
Mean Diff. (m)	-0.011	-0.018	na
RMSE (m)	0.043	0.052	na
SD (m)	0.042	0.048	na
NOF [2x15cm] (%)	0.0	0.0	< 1%
CF [15 cm] (%)	99.9	99.1	> 90%
POF [2x15 cm] (%)	0.0	0.0	< 1%
MDPO [2x15 cm] (hour)	0.0	0.0	< 24 hours
MDNO [2x15 cm] (hour)	0.0	0.0	< 24 hours

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 high water level nowcasts passed the NOS acceptance criteria for amplitude at four of the six gauges, failing at Harbor Beach and Lakeport. The nowcasts ability to simulate the timing of these events did not pass the NOS acceptance at any of the six gauges.

Table 7. Summary of Standard Statistics Evaluating the Ability of the *Semi-Operational Nowcasts* to Predict Extreme High Water Level Events at NOS NWLON stations in Lake Huron 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 ( )	DeTour Village N=12		Mackinaw City N=25		Harrisville N=5	
	Amp.	Time	Amp.	Time	Amp.	Time
Mean Diff. (m) (min)	-0.077	1.250	-0.002	-1.520	-0.083	0.600
RMSE (m) (min)	0.090	5.694	0.039	4.940	0.084	2.408
SD (m) (min)	0.049	5.802	0.040	4.797	0.017	2.608
NOF [2x15cm or 90min] (%)	0.0	25.0	0.0	32.0	0.0	0.0
CF [15 cm or 90 min] (%)	91.7	33.3	100,0	36.0	100.0	20.0
POF [2x15 cm or 90 min] (%)	0.0	25.0	0.0	20.0	0.0	20.0
MDPO [2x15 cm or 90 min] (#)	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

Table 7 (continued)

Essexville N=22		Harbor Beach N=17		Lakeport N=28		NOS Accept. Criteria
Amp.	Time	Amp.	Time	Amp.	Time	
-0.158	0.909	-0.087	-0.647	-0.111	-0.464	na
0.167	4.442	0.096	4.734	0.124	4.508	na
0.055	4.450	0.43	4.834	0.054	4.566	na
0.0	4.5	0.0	29.4	0.0	25.0	≤ 1%
54.5	13.6	100.0	23.5	82.1	50.0	≥ 90%
0.0	13.6	0.0	23.5	0.0	14.3	≤ 1%
0.0	0	0.0	0.0	0.0	0.0	≤ 24 hrs
0.0	0	0.0	0.0	0.0	0.0	≤ 24 hrs

Notes: na = not applicable

The skill statistics to predict *extreme low water level events* at the six NOS gauges during 2004 are given together in Table 8. Depending on the gauge, there were 11 to 46 events during the time period, with the greatest number of events at Lakeport located in southern most part of the lake. The extreme low water level nowcasts passed NOS acceptance criteria for amplitude at the six gauges. The nowcasts' ability to simulate the timing of these events did not pass the NOS acceptance criteria at any of the gauges.

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 Huron 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 ( )	DeTour Village N=24		Mackinaw City N=31		Harrisville N=11	
	Amp.	Time	Amp.	Time	Amp.	Time
Mean Diff. (m) (min)	0.088	1.000	0.089	-0.129	0.085	1.455
RMSE (m) (min)	0.094	2.483	0.098	3.398	0.089	3.104
SD (m) (min)	0.033	2.322	0.042	3.452	0.027	2.876
NOF [2x15cm or 90min] (%)	0.0	4.2	0.0	25.8	0.0	9.1
CF [15 cm or 90 min] (%)	95.8	62.5	93.5	38.7	100.0	36.4
POF [2x15 cm or 90 min] (%)	0.0	12.5	0.0	16.1	0.0	27.3
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 (continued)

Essexville N=37		Harbor Beach N=21		Lakeport N=46		NOS Accept. Criteria
Amp.	Time	Amp.	Time	Amp.	Time	
0.051	-1.270	0.081	1.190	0.069	-0.022	na
0.076	3.089	0.088	3.619	0.079	2.463	na
0.058	2.854	0.035	3.502	0.039	2.490	na
0.0	24.3	0.0	14.3	0.0	15.2	≤ 1%
94.6	43.2	95.2	38.1	95.7	63.0	≥ 90%
0.0	2.7	0.0	38.1	0.0	4.3	≤ 1%
0.0	0.0	0.0	0.0	0.0	0.0	≤ 24 hrs
0.0	0.0	0.0	0.0	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 semi-operational nowcasts to predict hourly lake surface water temperatures at the two NWS/NDBC fixed buoys in Lake Huron, 45003 in the northern part and 45008 in the southern part, from mid-April to early December 2004 are given in Appendix D. Time series plots of the nowcasts (1st sigma level) vs. observations at the buoy are given in Appendix E.

The time series plots indicate that the nowcasts were in close agreement to observations 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). The difference between observations and nowcasts during this period ranged from 1.5^{o}C at 45003 and 1^{o}C at 45008.

However, when the surface water temperature nowcasts reached 4^{o}C around May 10th (JD 130-135), the temperature of maximum density for fresh water, the nowcasts at both bouys began to deviate from the observations by +2-3^{o}C, with the greatest difference occurring at approximately in mid-June (JD 165-170). This continued until approximately July 4th (JD 185-190).

Overall, nowcasts from early July until mid November closely matched observations at both buoys. The difference between nowcasts and observations varied between $\pm$ 0.5 – 1^{o}C. However, there were short time periods when the nowcasts deviated from the observations. At the northern buoy 45003 during mid-Aug (JD 235) to early September (JD250), the nowcasts were 1 - 2^{o}C cooler than observations while nowcasts at 45008 matched the observations within $\pm$0.5^{o}C. This corresponded with arrival of significant cold air mass in the Great Lakes and New England regions following a cold front passage on August 21st. Morning minimum temperatures on August 22nd dropped below 10^{o}C over Michigan. Although, both nowcasts and observations also decreased at 45008 during this time, the nowcasts continued to match the observations within +0.5^{o}C.

From late September until mid Novermber, the nowcasts very closely matched observations. 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 1-1.5^{o}C warmer than observations until the buoys were removed from the lake by NDBC for the winter, similar to what occurred in the early Spring.

The skill statistics assessing the ability of LHOFS to predict hourly surface water temperatures at the NDBC buoys are given together in Table 9 along with the NOS acceptance criteria. The hourly water temperature nowcasts passed the NOS criteria at southern buoy 45008 but failed to pass 3 of the 5 criteria statistics at the northern buoy 45003. The nowcasts over predicted lake surface temperatures at both buoys with the greatest departure at the northern buoy where the MAE and RMSE were 1.9^{o}C and 2.8^{o}C, respectively.

Table 9. Summary of Skill Assessment Statistics of the *Semi-Operational Nowcasts* of Hourly Surface Water Temperatures at two NWS/NDBC fixed buoys in Lake Huron 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 ( )	45003 North - Lake Huron N=5036	45008 South – Lake Huron N=5152	NOS Acceptance Criteria
Time Period	29 July to 1 Dec 2004	20 April to 20 Nov. 2004	365 days
Mean Difference (°C)	1.89	0.80	na
RMSE (°C)	2.79	1.65	na
SD (°C)	2.06	1.44	na
NOF [2x3°C] (%)	0.0	0.0	≤ 1%
CF [3°C] (%)	79.7	94.4	≥ 90%
POF [2x3°C] (%)	8.1	0.0	≤ 1%
MDNO [2x3°C] (hours)	0.02	0.0	≤ 24 hrs
MDPO [2x3°C] (hours)	45.0	0.0	≤ 24 hrs

Notes: na = not applicable

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 Hess et al. (2003), 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." (Similar to the nowcast scenario, the data streams for the Great Lakes could include wind stresses, surface heat flux, and river flows.)

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

6.1 Description of Forecast Cycles

GLCFS performs twice/day 60-hr forecast cycles for Lake Huron. 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 valid time of the nowcasts 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 surface water temperatures at NWS/NDBC fixed buoys from mid-April to early November. 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 was based on comparisons of time series of observed vs. model-predicted temperatures at the same NWS/NDBC fixed buoys 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 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 are 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 six NOS gauges are presented together in Table 10 along with the NOS acceptance criteria. The hourly forecasts passed all the criteria statistics at all gauge locations except for NOF at Essexville. The forecast guidance overpredicted water levels at the northern and central gauge locations and underpredicted at the southern gauges. The MAE ranged between -4.7 cm at Essexville to +4.0 cm at Mackinaw City and the RMSE ranged between 3.8 cm at Harrisville to 6.1 cm at Mackinaw City, similar to the statistics for the nowcast evaluation. In addition, the nowcasts were similar to the forecast guidance in that the greatest errors were at the Essexville gauge located at southern end of Saginaw Bay and at the Mackinaw City gauge at the extreme western edge of the model domain. There was no significant increase in the mean differences, RMSE values, or CF as forecast projection increased (Appendix A).

The skill statistics to assess the ability of the forecast guidance to predict *extreme high water level events* at six NOS water levels gauges during 2004 are given together in Table 11. There were between 4 and 82 extreme high water level events depending on location.

The forecasts of extreme high water level passed NOS acceptance criteria for amplitude at three gauges, DeTour Village, Harbor Beach, and Harrisville. However, it should be noted these three gauges had the lowest number of high water events. The forecasts' ability to simulate the timing of these events did not pass NOS acceptance criteria at any of the gauges.

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

Statistic, Acceptable Error [ ], and Units ( )	DeTour Village	Mackinaw City	Harrisville	Essexville	NOS Accept. Criteria
Mean Diff. (m)	0.005	0.040	0.001	-0.047	na
RMSE (m)	0.049	0.061	0.038	0.083	na
SD (m)	0.049	0.046	0.039	0.069	na
NOF [2x15cm] (%)	0.0	0.0	0.0	0.2	≤ 1%
CF [15 cm] (%)	98.8	97.6	100.0	90.8	≥ 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

Table 10. (continued)

Statistic, Acceptable Error [ ], and Units ( )	Harbor Beach	Lakeport	NOS Accept. Criteria
Mean Diff. (m)	-0.009	-0.014	na
RMSE (m)	0.044	0.051	na
SD (m)	0.043	0.050	na
NOF [2x15cm] (%)	0.0	0.0	≤ 1%
CF [15 cm] (%)	100.0	99.0	≥ 90%
POF [2x15 cm] (%)	0.0	0.0	≤ 1%
MDPO [2x15 cm] (hour)	0.0	0.0	≤ 24 hours
MDNO [2x15 cm] (hour)	0.0	0.0	≤ 24 hours

The skill statistics to assess the ability of the forecast guidance to predict *extreme low water level events* at the six NOS gauges in 2004 are given together in Table 12. The number of events ranged from 11 to 47 with the greatest number of events at Essexville and Lakeport.

The forecasts of extreme low water level passed NOS acceptance criteria for amplitude at all six gauges. The forecasts' ability to simulate the timing of these events did not pass all the NOS acceptance criteria at any of the gauges.

Table 11. Summary of Skill Assessment Statistics Evaluating the Ability of 24-hr *Semi-Operational Forecast Guidance* to Predict Extreme High Water Level Events at NOS NWLON Stations in Lake Huron 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 ( )	DeTour Village N=11		Mackinaw City N=82		Harrisville N=4	
	Amp.	Time	Amp.	Time	Amp.	Time
Mean Diff. (m) (min)	-0.083	-1.455	0.063	-0.036	-0.088	-2.250
RMSE (m) (min)	0.092	4.786	0.108	5.729	0.091	5.809
SD (m) (min)	0.043	4.782	0.089	5.834	0.026	6.185
NOF [2x15cm or 90min] (%)	0.0	36.4	0.0	35.7	0.0	25.0
CF [15 cm or 90 min] (%)	100.0	36.4	82.1	17.9	100.0	25.0
POF [2x15 cm or 90 min] (%)	0.0	9.1	0.0	25.0	0.0	0.0

Table 11 (cont.)

Essexville N=24		Harbor Beach N=15		Lakeport N=35		NOS Accept. Criteria
Amp.	Time	Amp.	Time	Amp.	Time	
-0.116	1.500	-0.088	1.000	-0.117	-0.171	na
0.129	4.311	0.095	4.389	0.133	5.860	na
0.058	4.128	0.037	4.424	0.064	5.943	na
0.0	12.5	0.0	20.0	0.0	31.4	≤ 1%
66.7	20.8	100.0	26.7	77.1	25.7	≥ 90%
0.0	29.2	0.0	33.3	0.0	25.7	≤ 1%

Notes: na = not applicable

Table 12. Summary of Skill Assessment Statistics Evaluating the Ability of 24-hr *Semi-Operational Forecast Guidance* to Predict Extreme Low Water Level Events at NOS NWLON Stations in Lake Huron 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 ( )	DeTour Village N=23		Mackinaw City N=30		Harrisville N=11	
	Amp.	Time	Amp.	Time	Amp.	Time
Mean Diff. (m) (min)	0.082	0.913	0.070	0.467	0.080	1.727
RMSE (m) (min)	0.089	3.000	0.088	3.337	0.085	2.780
SD (m) (min)	0.036	2.922	0.054	3.360	0.031	2.284
NOF [2x15cm or 90min] (%)	0.0	8.7	0.0	16.7	0.0	0.0
CF [15 cm or 90 min] (%)	91.3	47.8	93.3	43.3	100.0	45.5
POF [2x15 cm or 90 min] (%)	0.0	17.4	0.0	20.0	0.0	18.2

Table 12 (continued)

Essexville N=38		Harbor Beach N=20		Lakeport N=47		NOS Accept. Criteria
Amp.	Time	Amp.	Time	Amp.	Time	
0.018	1.158	0.074	1.000	0.061	-0.149	na
0.077	3.095	0.080	4.389	0.072	2.764	na
0.075	2.909	0.032	4.424	0.038	2.790	na
0.0	7.9	0.0	20.0	0.0	14.9	≤ 1%
92.1	26.3	100.0	26.7	97.9	51.1	≥ 90%
0.0	21.1	0.0	33.3	0.0	10.6	≤ 1%

Notes: na = not applicable

6.4 Assessment 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 Huron fixed buoys 45003 and 45008 from mid-April to early December 2004 is given in Appendix D. Tables therein provide skill statistics at the forecast projections 0, 6, 12, 18, and 24 hours. Time series plots of the forecasts (1st sigma level) from the 0000 UTC forecast cycle compared with buoy observations are given in Appendix E.

The time series plots indicate that the forecast guidance from the 0000 UTC forecast cycle resembles the nowcasts 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 values are 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 two NDBC buoys are given in Table 13 along with the NOS criteria. The hourly forecast guidance at the southern buoy passed all the criteria. The MAE and RSME at this buoy were 0.5°C and 1.4°C, respectively. However, the hourly guidance at the northern buoy failed all the criteria statistics except for MDPO. For this buoy, the MAE and RSME were 1.8°C and 2.7°C, respectively. 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 only decreased by 0.15°C and 0.35°C at 45003 and 45008, respectively as the forecast projection time increased from 0 to 24 hours (Table D.1).

Table 13. Summary of Skill Assessment Statistics for *Semi-Operational Forecast Guidance* to Predict Surface Water Temperatures 24 hours in advance at NWS/NDBC fixed buoys in Lake Huron 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 ( )	45003 North - Lake Huron N=416	45008 South – Lake Huron N=426	NOS Acceptance Criteria
Time Period	29 July to 1 Dec 2004	20 Apr to 20 Nov 2004	365 days
Mean Difference (°C)	1.77	0.50	na
RMSE (°C)	2.65	1.37	na
SD (°C)	1.97	1.27	na
NOF [2x3°C] (%)	0.0	0.0	≤ 1%
CF [3°C] (%)	82.2	97.7	≥ 90%
POF [2x3°C] (%)	7.5	0.0	≤ 1%
MDPO [2x3°C] (hours)	0.24	0.0	≤ 24 hrs
MDNO [2x3°C] (hours)	40.0	0.0	≤ 24 hrs

Notes: na = not applicable

7. SUMMARY

NOS' Lake Huron Operational Forecast System (LHOFS) 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.

LHOFS 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, LHOFS 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 LHOFS 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 Huron from 15 April to 17 December 2004. Unfortunately, neither GLERL nor OSU conducted comparisons between POMGL output with field data for Lake Huron which could be used to fulfill the hindcast scenario.

The semi-operational nowcasts and forecast guidance were compared to water level observations at six NOS NWLON stations and surface temperatures at two NWS/NDBC fixed buoys, 45003 in northern part of the lake and buoy 45008 in the southern part. Due to the lack of sub-surface water temperatures and current observations, no quantitative assessment of these variables was conducted for LHOFS.

Water Levels

The hourly nowcasts of water level for amplitude met the NOS acceptance criteria at the six NOS gauges in Lake Huron. The mean algebraic error or difference (MAE) ranged between -4 and + 11 cm and the RSME ranged from 4 and 7 cm. The nowcast of high water events passed the NOS criteria for amplitude at the six NOS gauges but did not meet the NOS criteria for timing. Similarly, the nowcasts of low water events met the NOS criteria for amplitude, but did not pass the criteria in terms of timing at any of the gauges.

The hourly forecast guidance met the majority of NOS criteria for predicting water level amplitude at all six gauges. The MAE ranged between -4.7 and +4.0 cm and the RMSE ranged between 3.8 cm and 6.1 cm. There was no significant increase in the error as forecast projection increased from 0 to 24 hours. The forecast guidance of *high water events* passed the NOS criteria for amplitude at the three of the six gauges. The guidance failed to meet NOS criteria in predicting the times of these extreme events at all six gauges. The guidance of *low water events* passed the NOS criteria for amplitude at all locations but failed to meet NOS criteria in predicting the times of these extreme events at the gauges.

Surface Water Temperatures

The hourly water temperature nowcasts passed NOS criteria at the NDBC southern buoy 45008 located in 50 m deep water but not at the northern buoy 45003 situated in 150 m water. For the two buoys, the MAE ranged from 0.8 to 1.9°C and the RMSE ranged from 1.7 to 2.8°C. The nowcasts deviated from observations the most during the period from mid May, when the water temperature reached 4°C until early July. During this period, nowcasts were generally 2 to 3°C too warm, especially at the northern buoy.

The hourly water temperature forecast guidance at 24 hours passed NOS criteria at the southern buoy but not the northern buoy. The MAE and RMSE values for 24-hr forecast projection were slightly higher than for the nowcast comparisons. The MAE decreased by 0.15°C and 0.35°C at the northern and southern buoys, respectively as the forecast projection increased from 0 to 24 hours.

Surface Currents

Due to the lack of water current observations, no quantitative assessment could be conducted for LHOFS. However, animation of surface current nowcasts and forecast guidance indicated that LHOFS 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 Huron buoys indicate a potential over prediction of surface water temperature predictions, from mid May till early July. A similar problem occurred with LSOFS, LMOFS, and LEOFS. Since surface water temperature comparisons were done only at two buoys, it is difficult to conclude whether this is an issue over the entire model grid domain. Therefore, it is recommended that in the future, LHOFS SST nowcasts and forecast guidance also be evaluated at the Canadian fixed buoys: Southern Lake Huron (45149), Northern Channel East (45154), Georgian Bay (45137), and South Georgian Bay (45143).

Recommendation #2:

The comparisons of the semi-operational nowcasts and forecast guidance of surface water temperature to observations indicate a potential overestimation of the surface heat flux during the nowcast cycle. An improved specification of cloud cover via GOES analyses instead of interpolation of airport cloud cover observations may improve radiation flux estimations and reduce the surface water temperature overprediction similar to work done by Chu (1998). The overprediction may be also be reduced by nudging the water temperature nowcasts towards GLERL's GLSEA daily lake wide average surface water temperature.

Recommendation #3:

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 in the lake. This would likely involve sensitivity tests with POMGL using higher grid resolution and incorporating atmospheric pressure forcing.

Recommendation #4:

The under prediction of water levels at Essexville, MI could be due to a combination of a) model grid resolution, b) bathymetric data resolution in the Saginaw Bay and c) physical location of the NOS water level gauge. POMGL sensitivity tests should be conducted to determine the impact of improved model grid resolution and higher resolution bathymetry on water level predictions.

Possible research topics for improving LHOFS predictions include incorporating ice dynamics, using a coupled lake system, and using hydrologic inputs.

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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.

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

Table A.1. Skill Assessment Statistics of Semi-Operational Predictions at the NOS DeTour Village, MI Gauge (NOS ID 9075099) for 2004.

```
Station:           DeTour Village, Lake Huron, MI
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	176.205							
h			5832	176.194							
H-h	15 cm	24h	5832	0.011	0.043	0.042	0.0	99.4	0.0	0.0	0.0
AHW-ahw	15 cm	24h	12	-0.077	0.090	0.049	0.0	91.7	0.0	0.0	0.0
ALW-alw	15 cm	24h	24	0.088	0.094	0.033	0.0	95.8	0.0	0.0	0.0
THW-thw	1.50 hr	25h	12	1.250	5.694	5.802	25.0	33.3	25.0	0.0	0.0
TLW-tlw	1.50 hr	25h	24	1.000	2.483	2.322	4.2	62.5	12.5	0.0	0.0
SCENARIO: SEMI-OPERATIONAL FORECAST											
H00-h00	15 cm	24h	494	0.007	0.042	0.042	0.0	99.8	0.0	0.0	0.0
H06-h06	15 cm	24h	490	0.014	0.045	0.043	0.0	99.4	0.0	0.0	0.0
H12-h12	15 cm	24h	490	0.005	0.047	0.047	0.0	99.0	0.0	0.0	0.0
H18-h18	15 cm	24h	490	0.014	0.048	0.046	0.0	99.2	0.0	0.0	0.0
H24-h24	15 cm	24h	490	0.005	0.049	0.049	0.0	98.8	0.0	0.0	0.0
AHW-ahw	15 cm	24h	11	-0.083	0.092	0.043	0.0	100.0	0.0		
ALW-alw	15 cm	24h	23	0.082	0.089	0.036	0.0	91.3	0.0		
THW-thw	1.50 hr	25h	11	-1.455	4.786	4.782	36.4	36.4	9.1		
TLW-tlw	1.50 hr	25h	23	0.913	3.000	2.922	8.7	47.8	17.4		

Table A.2. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Mackinaw City, MI Gauge (NOS ID 9075080) for 2004.

```
Station:         Mackinaw City, Lake Michigan, MI
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	176.243							
h			5832	176.202							
H-h	15 cm	24h	5832	0.041	0.055	0.037	0.0	99.4	0.0	0.0	0.0
AHW-ahw	15 cm	24h	25	-0.002	0.039	0.040	0.0	100.0	0.0	0.0	0.0
ALW-alw	15 cm	24h	31	0.089	0.098	0.042	0.0	93.5	0.0	0.0	0.0
THW-thw	1.50 hr	25h	25	-1.520	4.940	4.797	32.0	36.0	20.0	0.0	0.0
TLW-tlw	1.50 hr	25h	31	-0.129	3.398	3.452	25.8	38.7	16.1	0.0	0.0
SCENARIO: SEMI-OPERATIONAL FORECAST											
H00-h00	15 cm	24h	494	0.033	0.050	0.037	0.0	99.4	0.0	0.0	0.0
H06-h06	15 cm	24h	490	0.052	0.067	0.042	0.0	97.8	0.0	0.0	0.0
H12-h12	15 cm	24h	490	0.039	0.056	0.041	0.0	98.2	0.0	0.0	0.0

H18-h18	15 cm	24h	490	0.050	0.065	0.042	0.0	98.0	0.0	0.0	0.0
H24-h24	15 cm	24h	490	0.040	0.061	0.046	0.0	97.6	0.0	0.0	0.0
AHW-ahw	15 cm	24h	28	0.063	0.108	0.089	0.0	82.1	0.0		
ALW-alw	15 cm	24h	30	0.070	0.088	0.054	0.0	93.3	0.0		
THW-thw	1.50 hr	25h	28	-0.036	5.729	5.834	35.7	17.9	25.0		
TLW-tlw	1.50 hr	25h	30	0.467	3.337	3.360	16.7	43.3	20.0		

Table A.3. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Harrisville, MI Gauge (NOS ID 9075059) for 2004.

Station: Harrisville, Lake Huron, MI
Observed data time period from: 4/15/2004 to 12/3/2004
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			5818	176.208							
h			5818	176.208							
H-h	15 cm	24h	5818	0.001	0.036	0.036	0.0	100.0	0.0	0.0	0.0
AHW-ahw	15 cm	24h	5	-0.083	0.084	0.017	0.0	100.0	0.0	0.0	0.0
ALW-alw	15 cm	24h	11	0.085	0.089	0.027	0.0	100.0	0.0	0.0	0.0
THW-thw	1.50 hr	25h	5	0.600	2.408	2.608	0.0	20.0	20.0	0.0	0.0
TLW-tlw	1.50 hr	25h	11	1.455	3.104	2.876	9.1	36.4	27.3	0.0	0.0
SCENARIO: SEMI-OPERATIONAL FORECAST											
H00-h00	15 cm	24h	493	0.002	0.036	0.036	0.0	100.0	0.0	0.0	0.0
H06-h06	15 cm	24h	489	-0.001	0.038	0.038	0.0	100.0	0.0	0.0	0.0
H12-h12	15 cm	24h	489	0.001	0.037	0.037	0.0	100.0	0.0	0.0	0.0
H18-h18	15 cm	24h	489	-0.001	0.038	0.038	0.0	100.0	0.0	0.0	0.0
H24-h24	15 cm	24h	489	0.001	0.038	0.039	0.0	100.0	0.0	0.0	0.0
AHW-ahw	15 cm	24h	4	-0.088	0.091	0.026	0.0	100.0	0.0		
ALW-alw	15 cm	24h	11	0.080	0.085	0.031	0.0	100.0	0.0		
THW-thw	1.50 hr	25h	4	-2.250	5.809	6.185	25.0	25.0	0.0		
TLW-tlw	1.50 hr	25h	11	1.727	2.780	2.284	0.0	45.5	18.2		

Table A.4. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Essexville, MI Gauge (NOS ID 9075035) for 2004.

Station: Essexville, Lake Huron, MI
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	176.197							
h			5832	176.238							
H-h	15 cm	24h	5832	-0.042	0.073	0.061	0.0	95.3	0.0	0.0	0.0
AHW-ahw	15 cm	24h	22	-0.158	0.167	0.055	0.0	54.5	0.0	0.0	0.0
ALW-alw	15 cm	24h	37	0.051	0.076	0.058	0.0	94.6	0.0	0.0	0.0
THW-thw	1.50 hr	25h	22	0.909	4.442	4.450	4.5	45.5	13.6	0.0	0.0
TLW-tlw	1.50 hr	25h	37	-1.270	3.089	2.854	24.3	43.2	2.7	0.0	0.0
SCENARIO: SEMI-OPERATIONAL FORECAST											
H00-h00	15 cm	24h	494	-0.049	0.078	0.061	0.0	94.3	0.0	0.0	0.0

H06-h06	15 cm	24h	490	-0.026	0.066	0.061	0.0	96.5	0.0	0.0	0.0
H12-h12	15 cm	24h	490	-0.047	0.080	0.065	0.4	93.5	0.0	0.0	0.0
H18-h18	15 cm	24h	490	-0.028	0.070	0.065	0.0	94.9	0.0	0.0	0.0
H24-h24	15 cm	24h	490	-0.047	0.083	0.069	0.2	90.8	0.0	0.0	0.0
AHW-ahw	15 cm	24h	24	-0.116	0.129	0.058	0.0	66.7	0.0		
ALW-alw	15 cm	24h	38	0.018	0.077	0.075	0.0	92.1	0.0		
THW-thw	1.50 hr	25h	24	1.500	4.311	4.128	12.5	20.8	29.2		
TLW-tlw	1.50 hr	25h	38	1.158	3.095	2.909	7.9	26.3	21.1		

Table A.5. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Harbor Beach, MI Gauge (NOS ID 9075014) for 2004.

Station: Harbor Beach, Lake Huron, MI
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	176.211							
h			5832	176.221							
H-h	15 cm	24h	5832	-0.011	0.043	0.042	0.0	99.9	0.0	0.0	0.0
AHW-ahw	15 cm	24h	17	-0.087	0.096	0.043	0.0	100.0	0.0	0.0	0.0
ALW-alw	15 cm	24h	21	0.081	0.088	0.035	0.0	95.2	0.0	0.0	0.0
THW-thw	1.50 hr	25h	17	-0.647	4.734	4.834	29.4	23.5	23.5	0.0	0.0
TLW-tlw	1.50 hr	25h	21	1.190	3.619	3.502	14.3	38.1	38.1	0.0	0.0
SCENARIO: SEMI-OPERATIONAL FORECAST											
H00-h00	15 cm	24h	494	-0.008	0.042	0.042	0.0	100.0	0.0	0.0	0.0
H06-h06	15 cm	24h	490	-0.014	0.045	0.042	0.0	99.8	0.0	0.0	0.0
H12-h12	15 cm	24h	490	-0.008	0.043	0.042	0.0	100.0	0.0	0.0	0.0
H18-h18	15 cm	24h	490	-0.013	0.045	0.043	0.0	99.8	0.0	0.0	0.0
H24-h24	15 cm	24h	490	-0.009	0.044	0.043	0.0	100.0	0.0	0.0	0.0
AHW-ahw	15 cm	24h	15	-0.088	0.095	0.037	0.0	100.0	0.0		
ALW-alw	15 cm	24h	20	0.074	0.080	0.032	0.0	100.0	0.0		
THW-thw	1.50 hr	25h	15	1.000	4.389	4.424	20.0	26.7	33.3		
TLW-tlw	1.50 hr	25h	20	0.350	3.248	3.313	20.0	25.0	15.0		

Table A.6. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Lakeport, MI Gauge (NOS ID 9075002) for 2004.

Station: Lakeport, Lake Huron, MI
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	176.214							
h			5832	176.233							
H-h	15 cm	24h	5832	-0.018	0.052	0.048	0.0	99.1	0.0	0.0	0.0
AHW-ahw	15 cm	24h	28	-0.111	0.124	0.054	0.0	82.1	0.0	0.0	0.0
ALW-alw	15 cm	24h	46	0.069	0.079	0.039	0.0	95.7	0.0	0.0	0.0
THW-thw	1.50 hr	25h	28	-0.464	4.508	4.566	25.0	50.0	14.3	0.0	0.0
TLW-tlw	1.50 hr	25h	46	-0.022	2.463	2.490	15.2	63.0	4.3	0.0	0.0
SCENARIO: SEMI-OPERATIONAL FORECAST											

H00-h00	15 cm	24h	494	-0.013	0.050	0.048	0.0	99.2	0.0	0.0	0.0
H06-h06	15 cm	24h	490	-0.022	0.052	0.047	0.0	98.6	0.0	0.0	0.0
H12-h12	15 cm	24h	490	-0.012	0.051	0.049	0.0	99.0	0.0	0.0	0.0
H18-h18	15 cm	24h	490	-0.023	0.055	0.050	0.0	98.4	0.0	0.0	0.0
H24-h24	15 cm	24h	490	-0.014	0.051	0.050	0.0	99.0	0.0	0.0	0.0
AHW-ahw	15 cm	24h	35	-0.117	0.133	0.064	0.0	77.1	0.0		
ALW-alw	15 cm	24h	47	0.061	0.072	0.038	0.0	97.9	0.0		
THW-thw	1.50 hr	25h	35	-0.171	5.860	5.943	31.4	25.7	25.7		
TLW-tlw	1.50 hr	25h	47	-0.149	2.764	2.790	14.9	51.1	10.6		

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

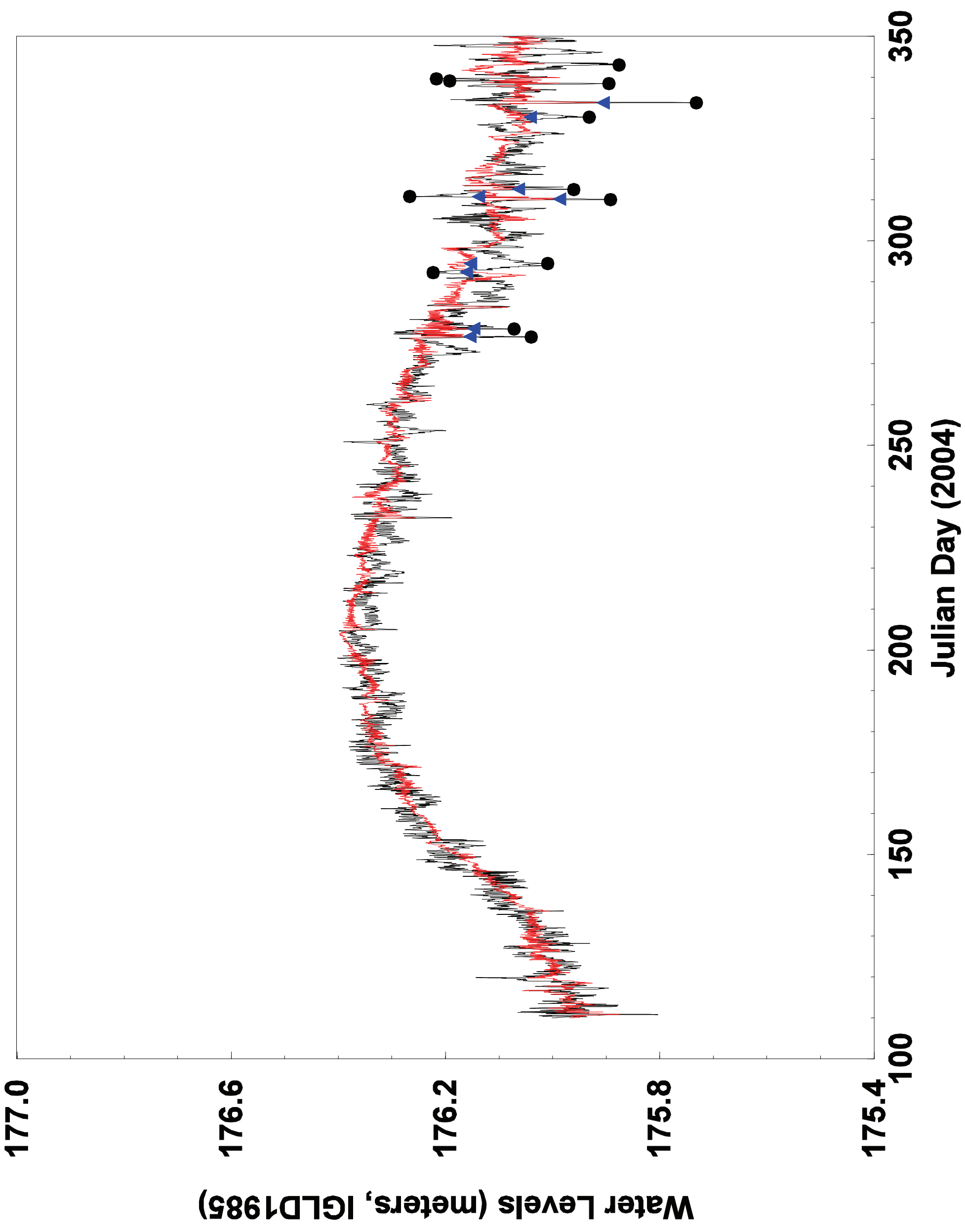

Fig. B.1. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at NOS DeTour Village, MI, NY Gauge during 2004.

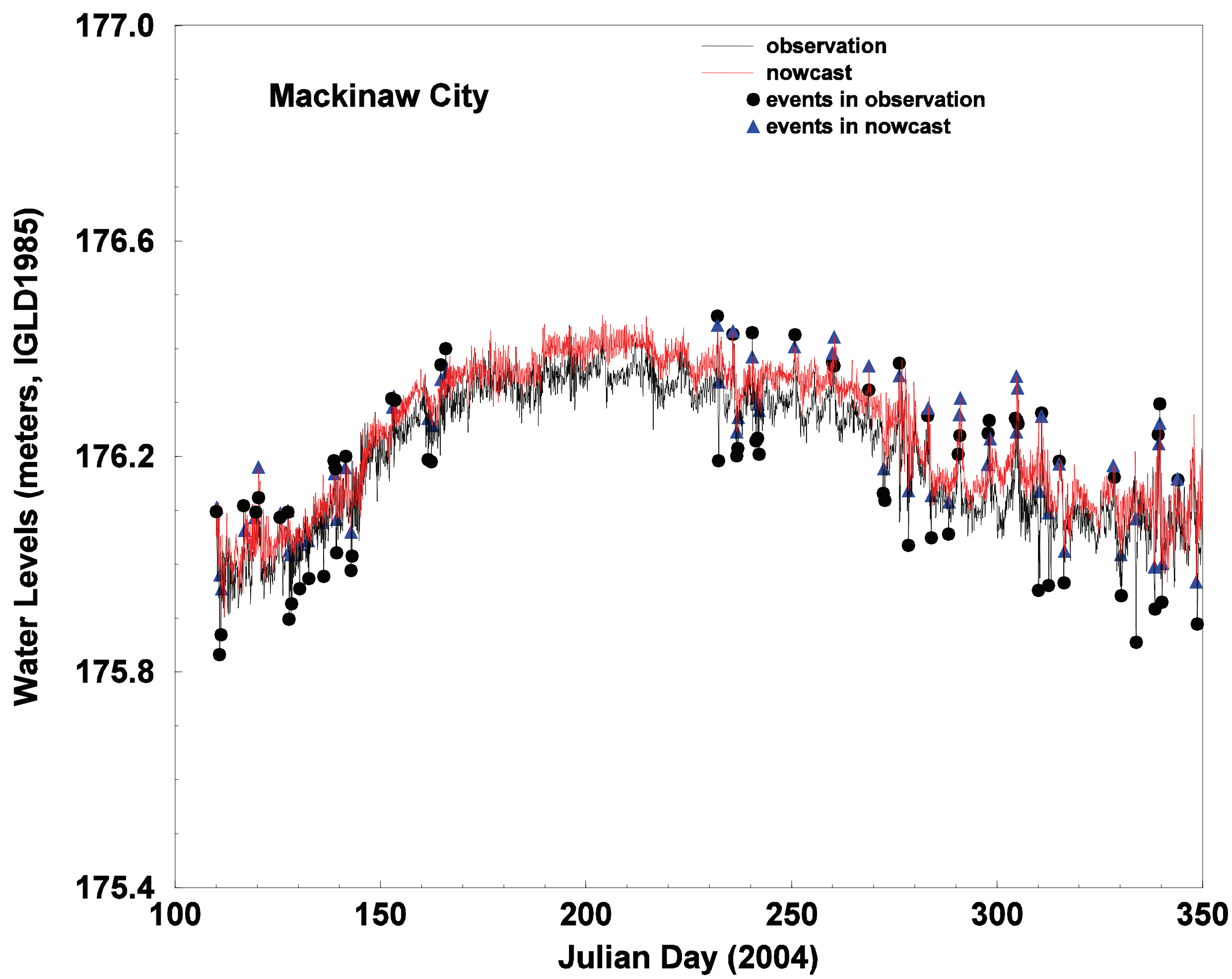

Fig. B.2. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at NOS Mackinaw City, MI, NY Gauge during 2004.

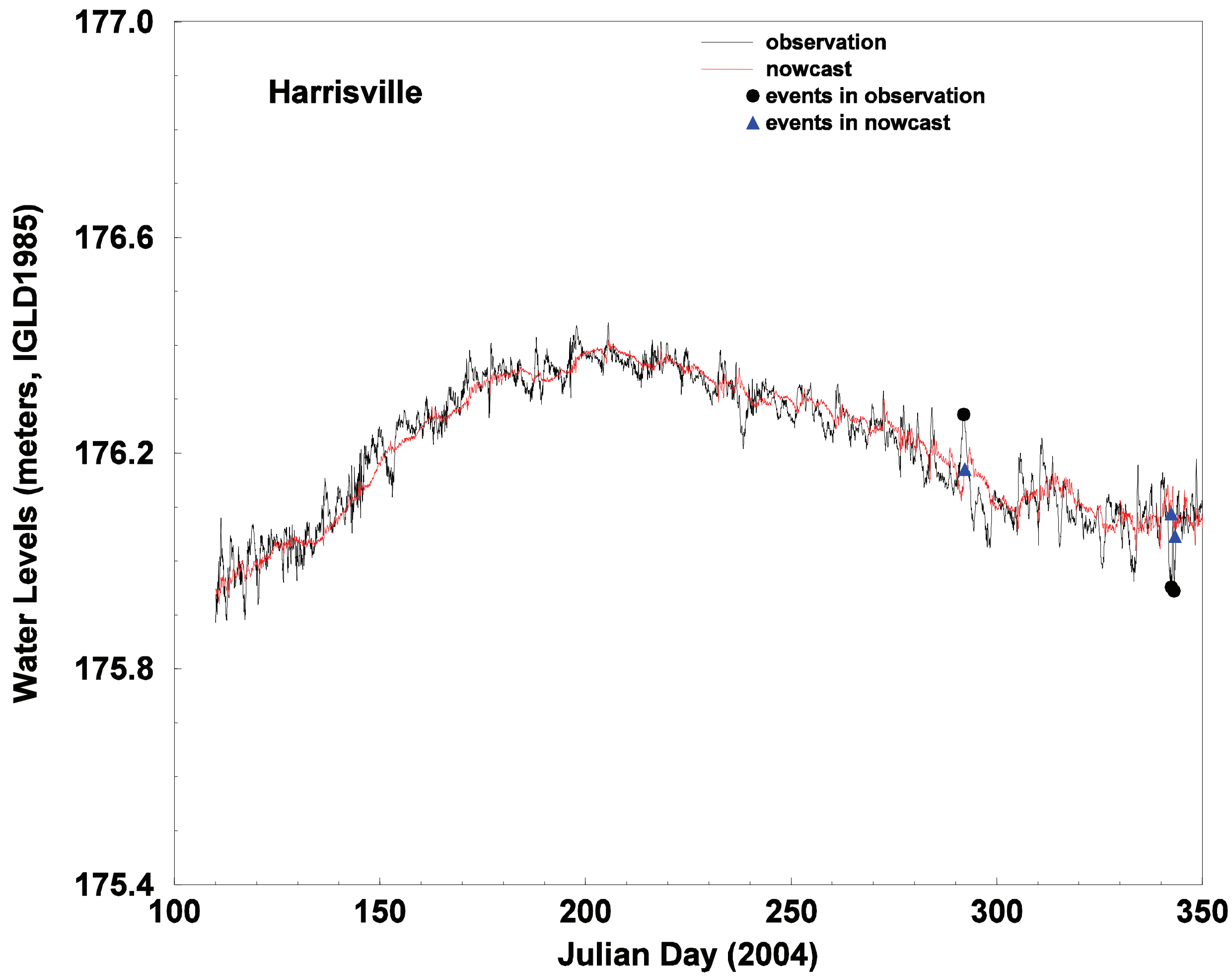

Fig. B.3. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at NOS Harrisville, MI Gauge during 2004.

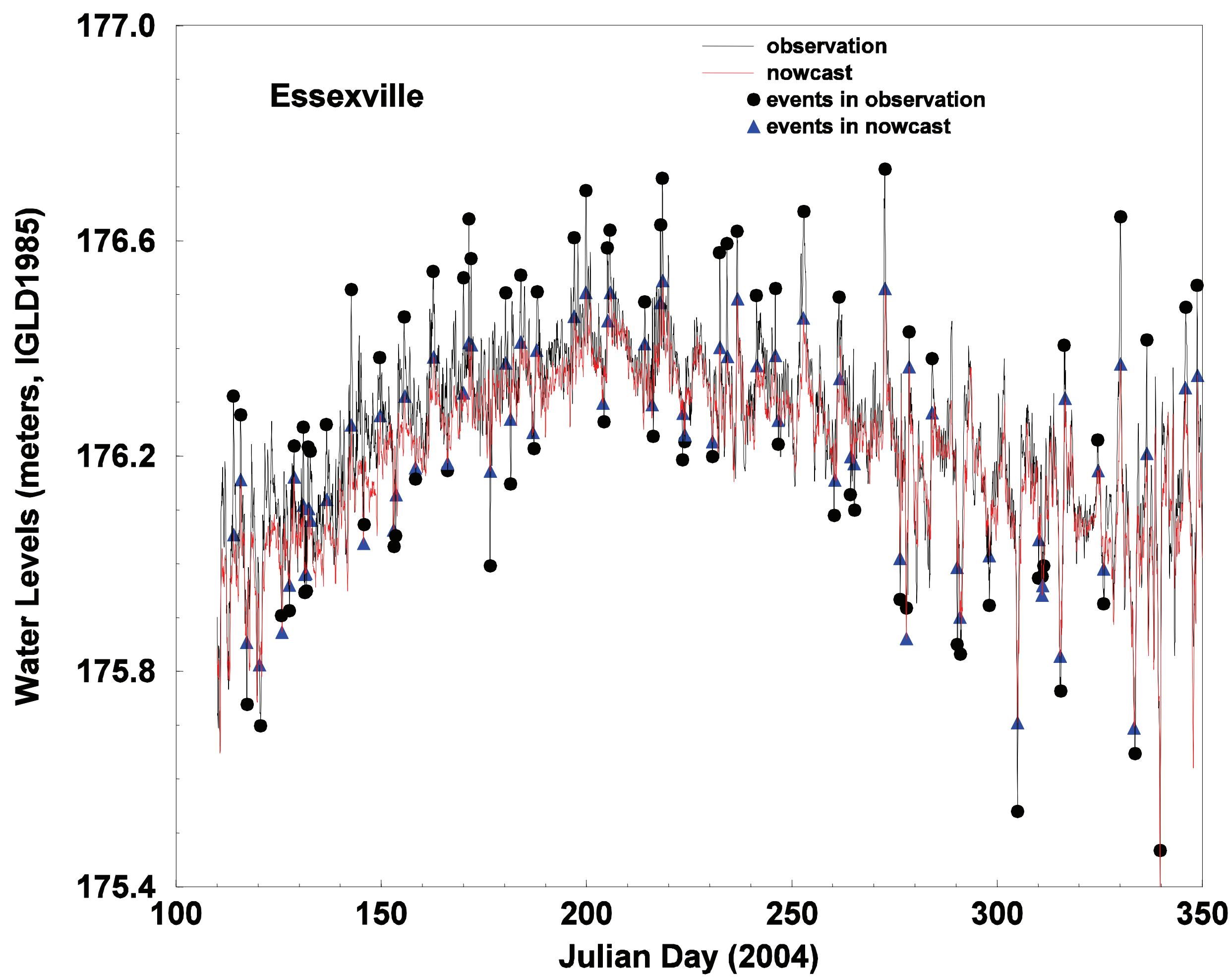

Fig. B.4. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at NOS Essexville, MI Gauge during 2004.

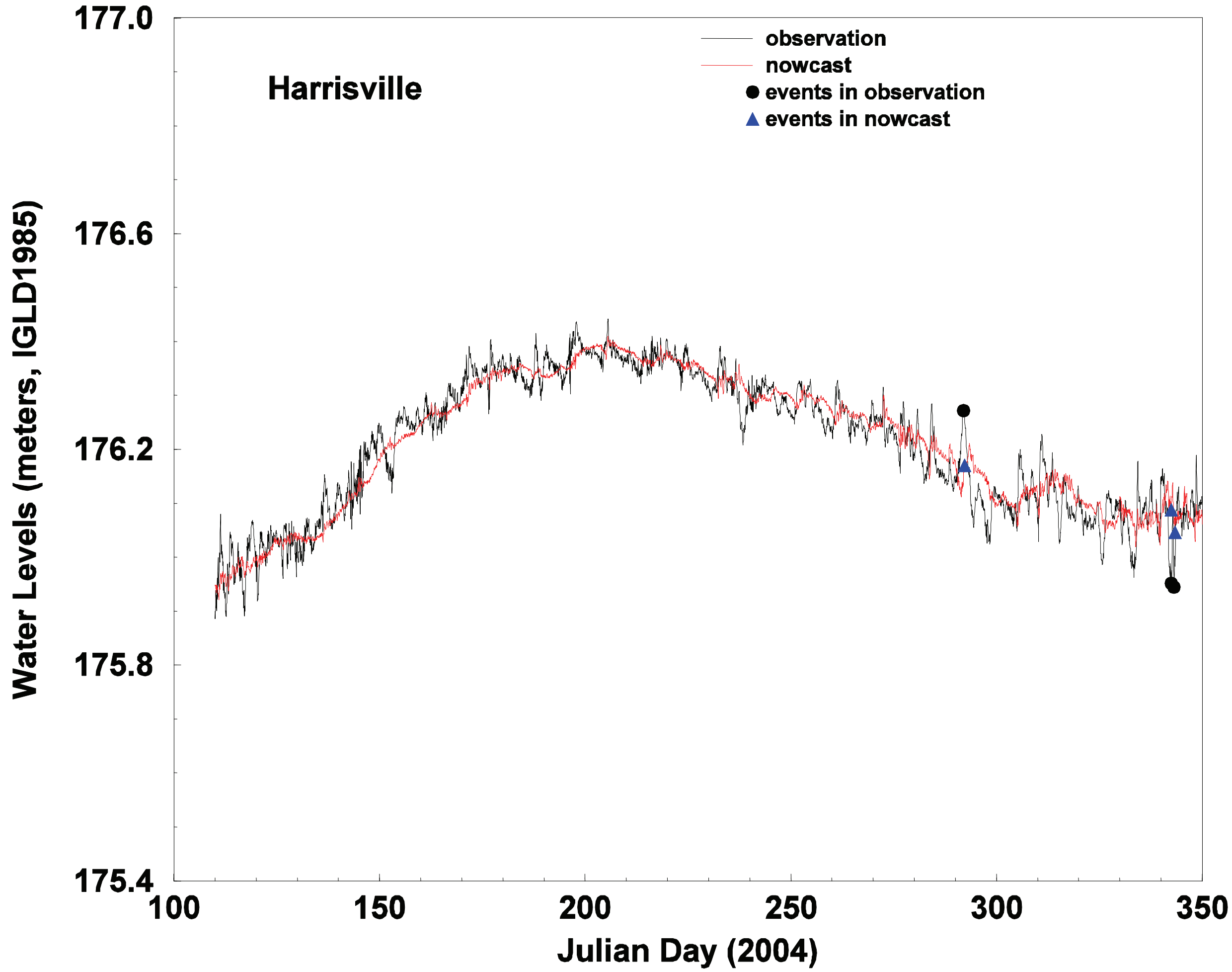

Fig. B.5. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at NOS Harbor Beach, MI Gauge during 2004.

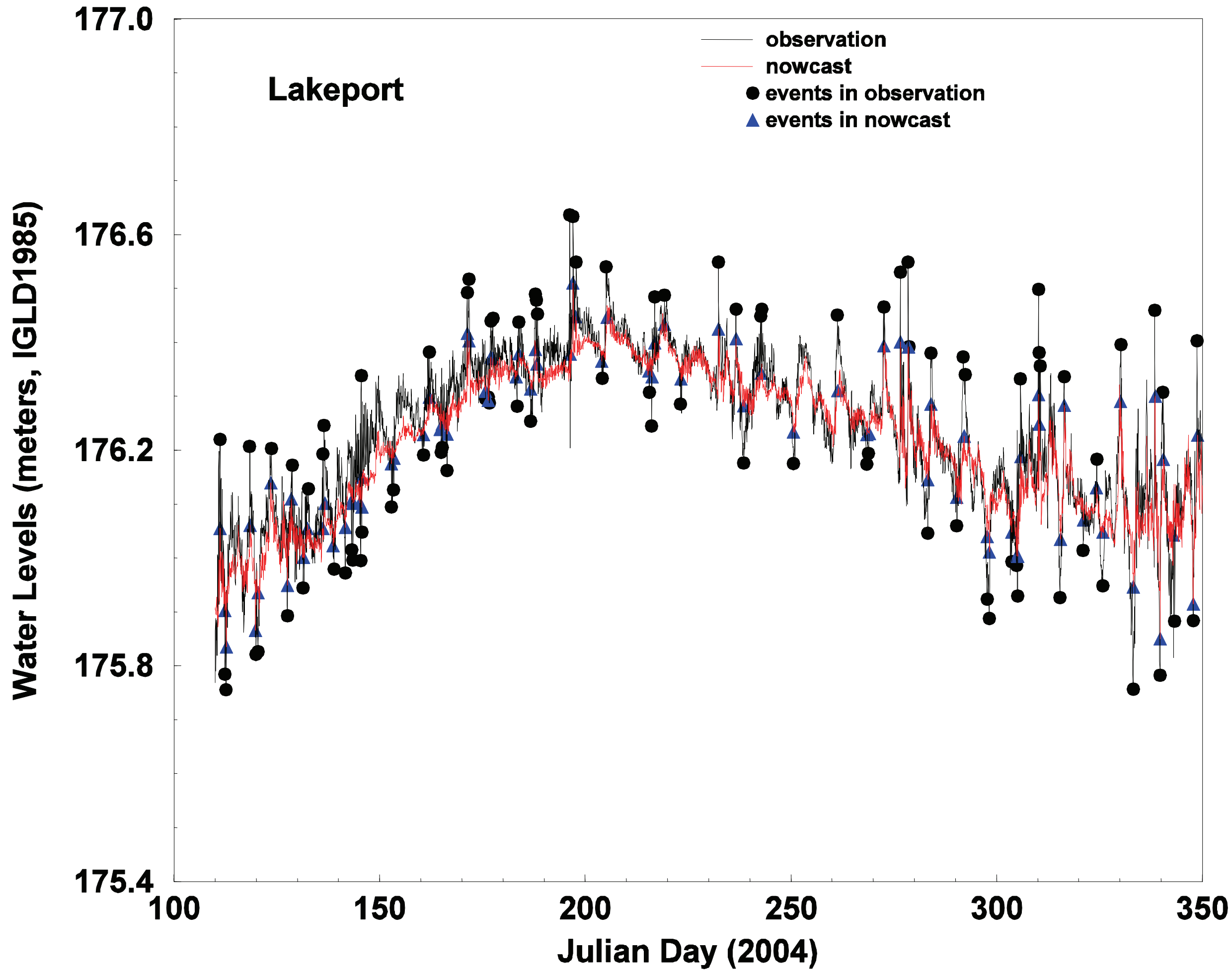

Fig. B.6. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at NOS Lakeport, MI Gauge during 2004.I Gauge during 2004.

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

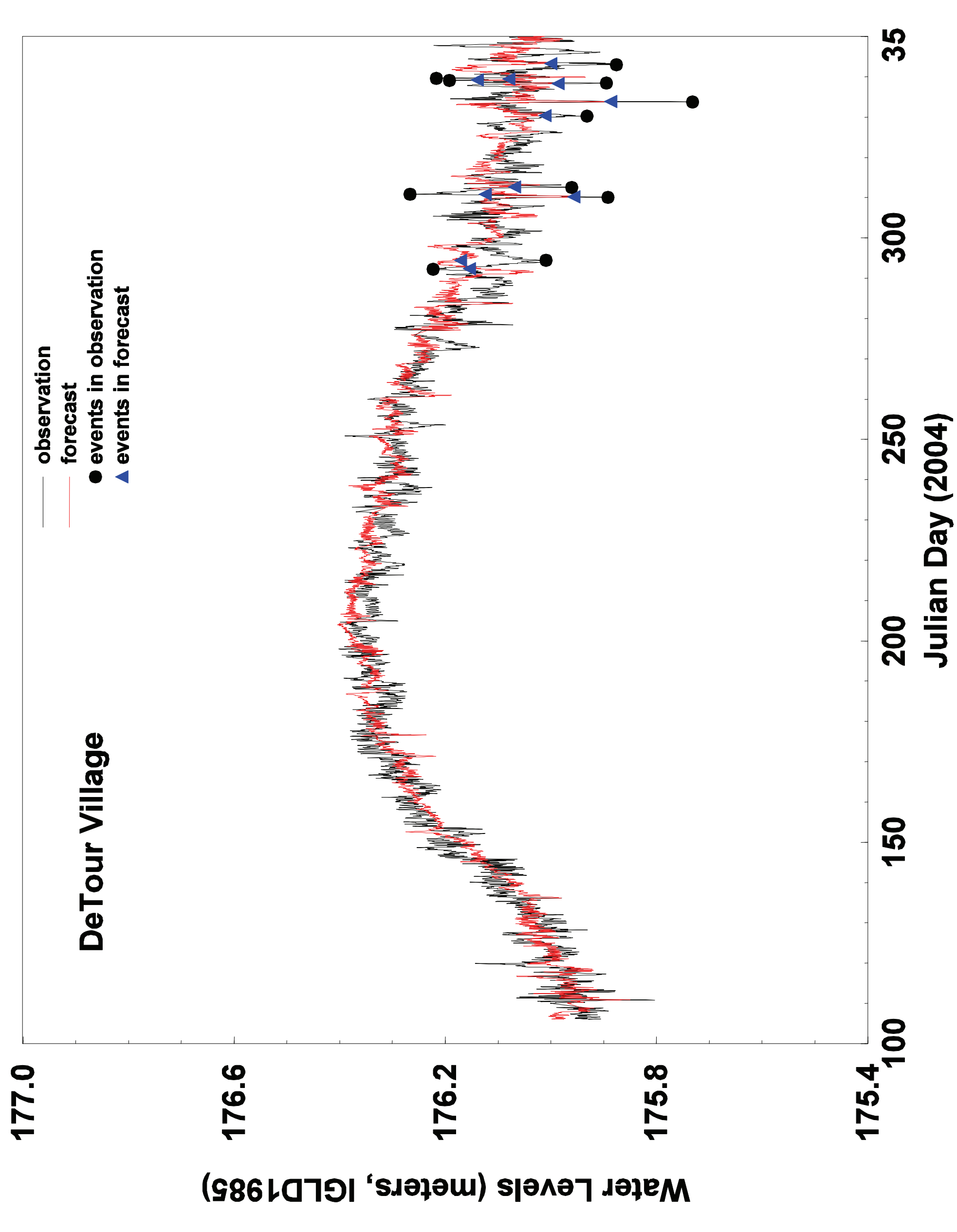

Fig. C.1. Time Series Plot of Semi-Operational Water Level Forecast Guidance vs. observations at NOS DeTour Village, MI Gauge during 2004.auge during 2004.I Gauge during 2004.

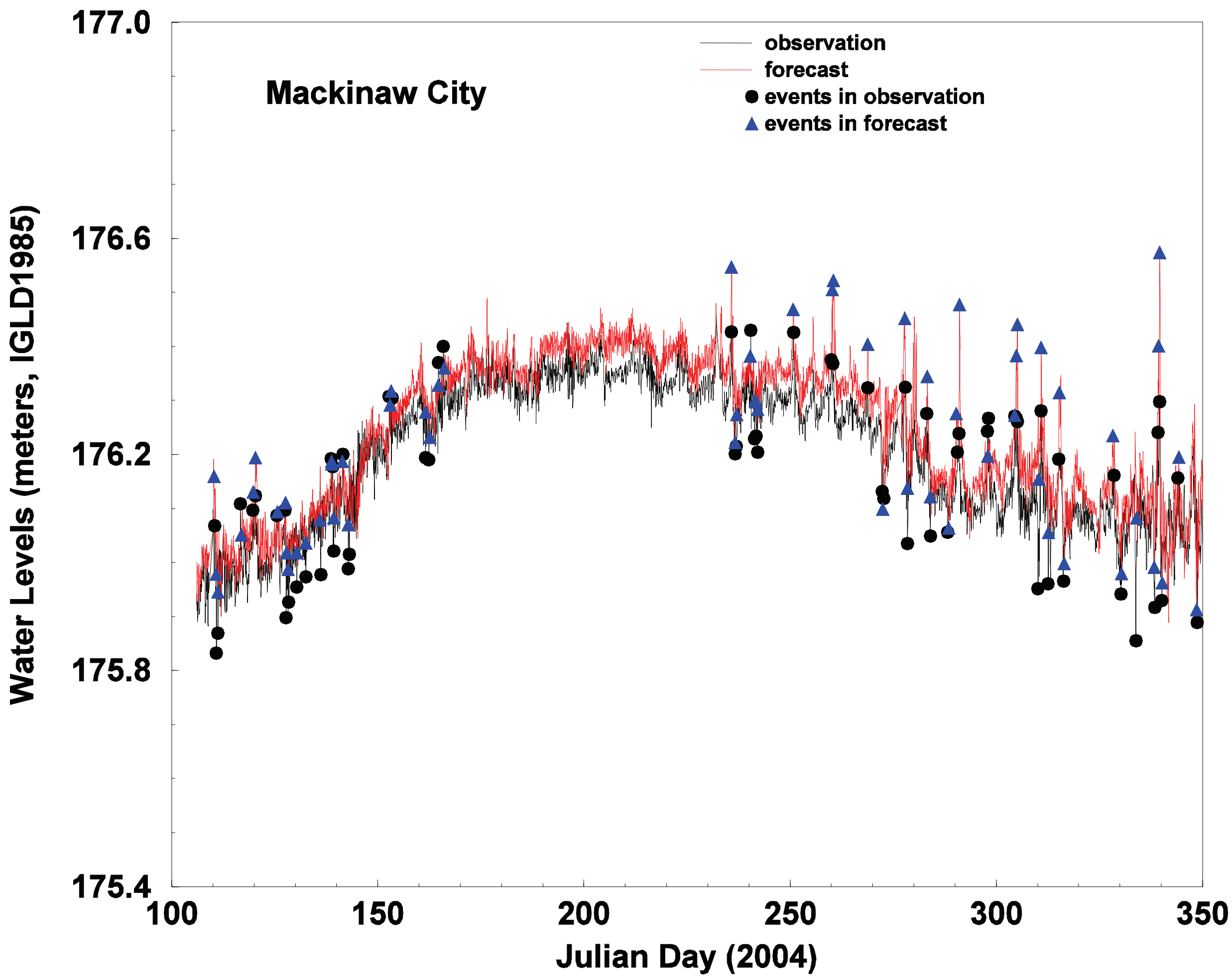

Fig. C.2. Time Series Plot of Semi-Operational Water Level Forecast Guidance vs. Observations at NOS Mackinaw City, MI Gauge during 2004.

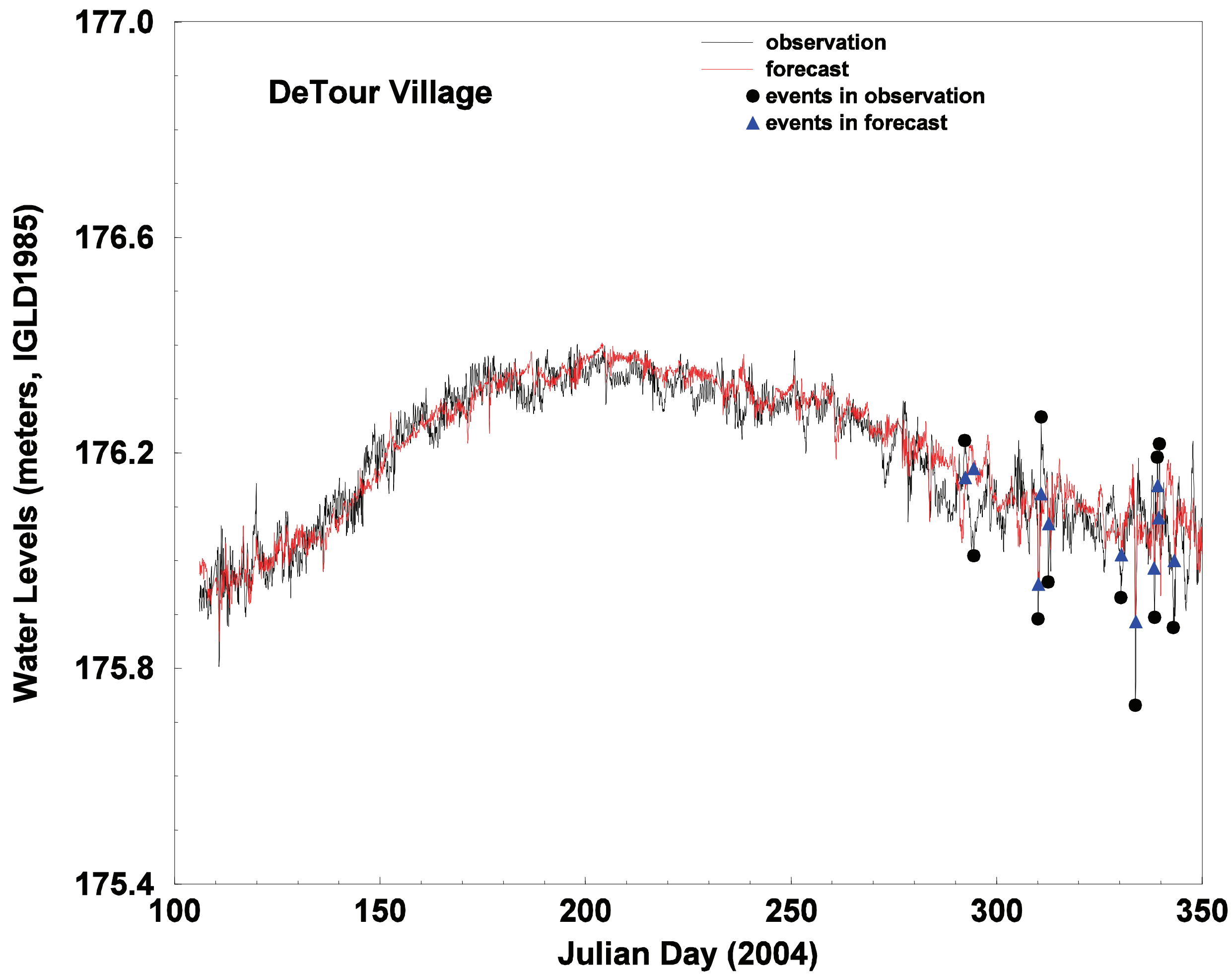

Fig. C.3. Time Series Plot of Semi-Operational Water Level Forecast Guidance vs. Observations at NOS Harrisville, MI Gauge during 2004.

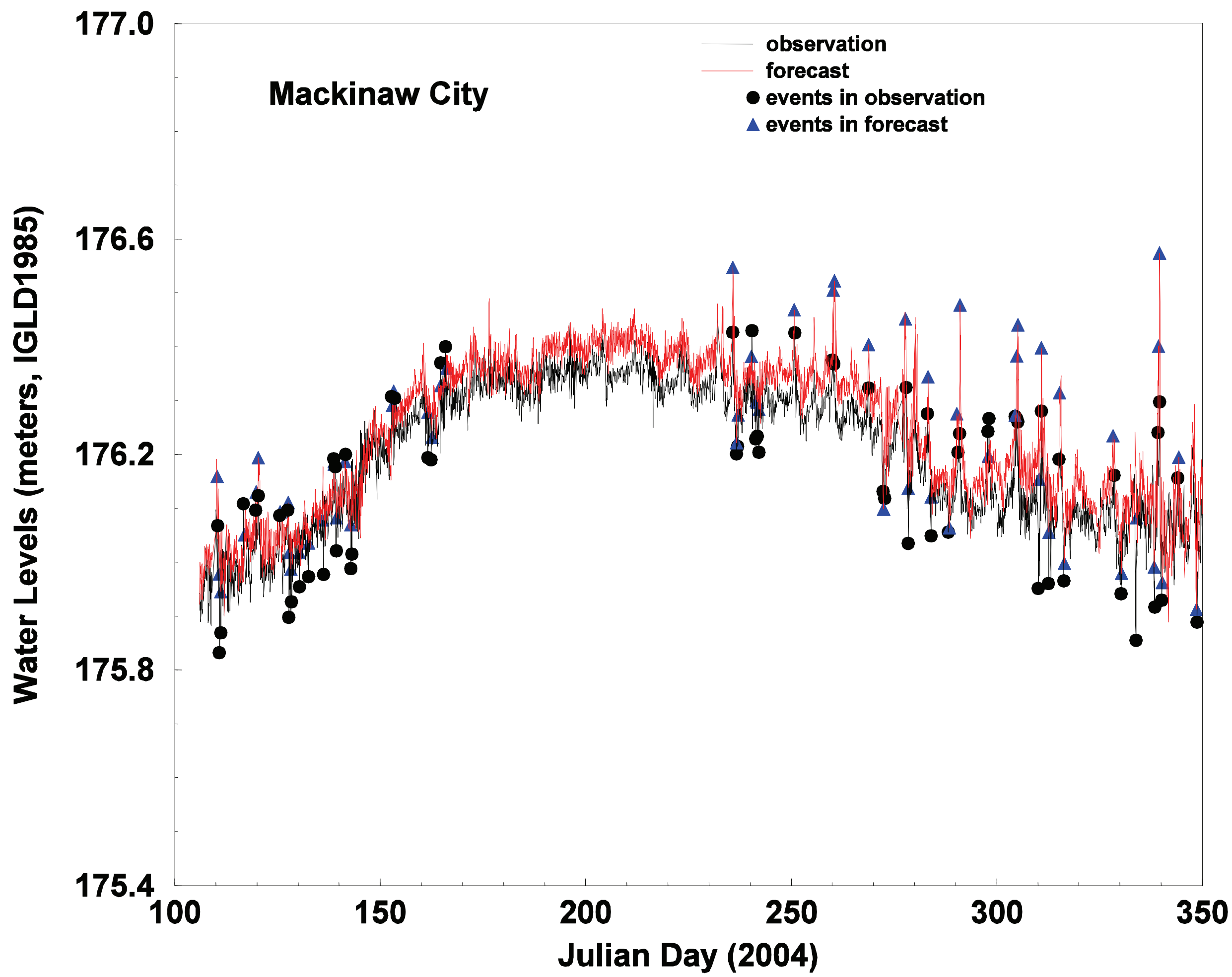

Fig. C.4. Time Series Plot of Semi-Operational Water Level Forecast Guidance vs. Observations at NOS Essexville, MI Gauge during 2004.

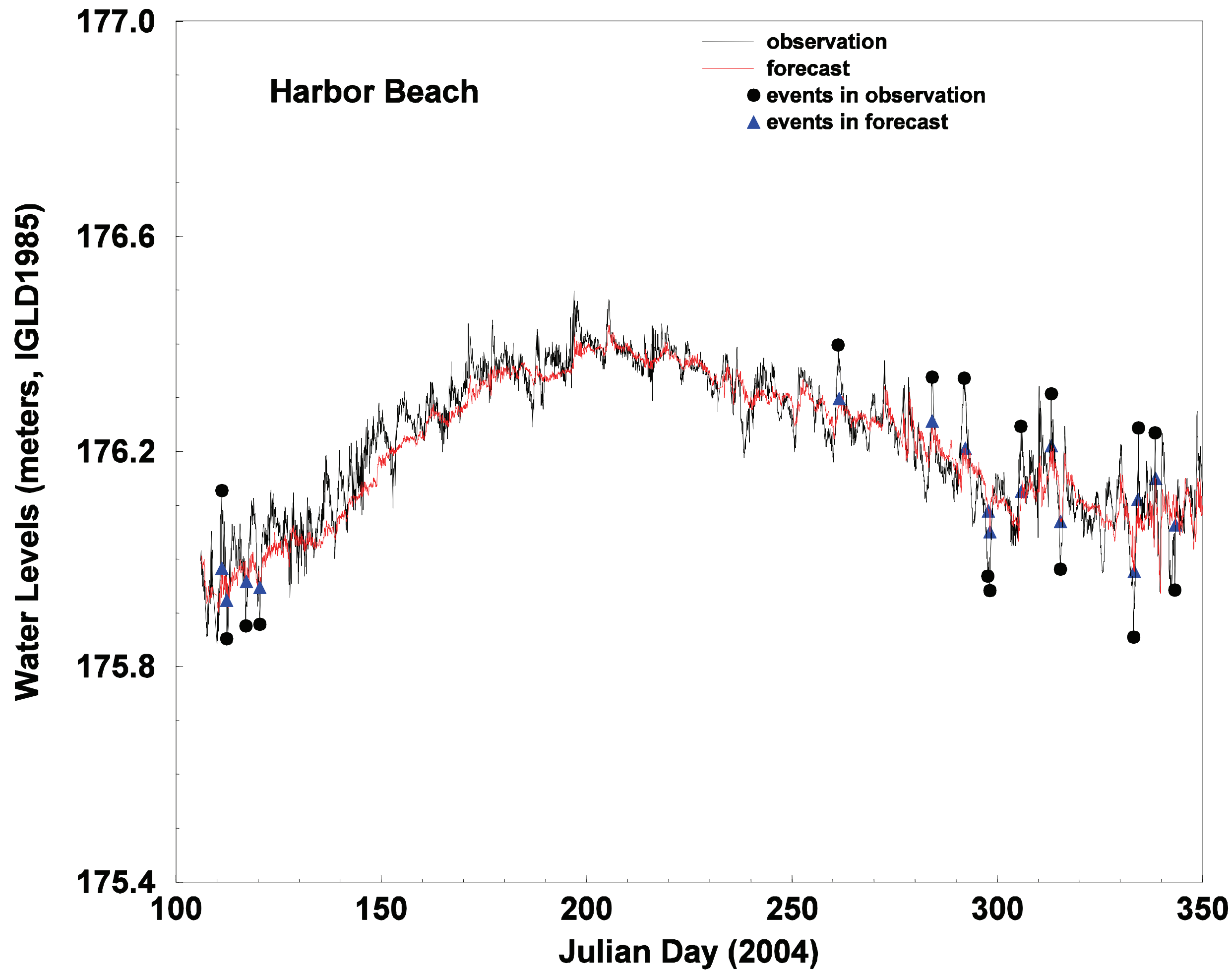

Fig. C.5. Time Series Plot of Semi-Operational Water Level Forecast Guidance vs. Observations at NOS Harbor Beach, MI Gauge during 2004.

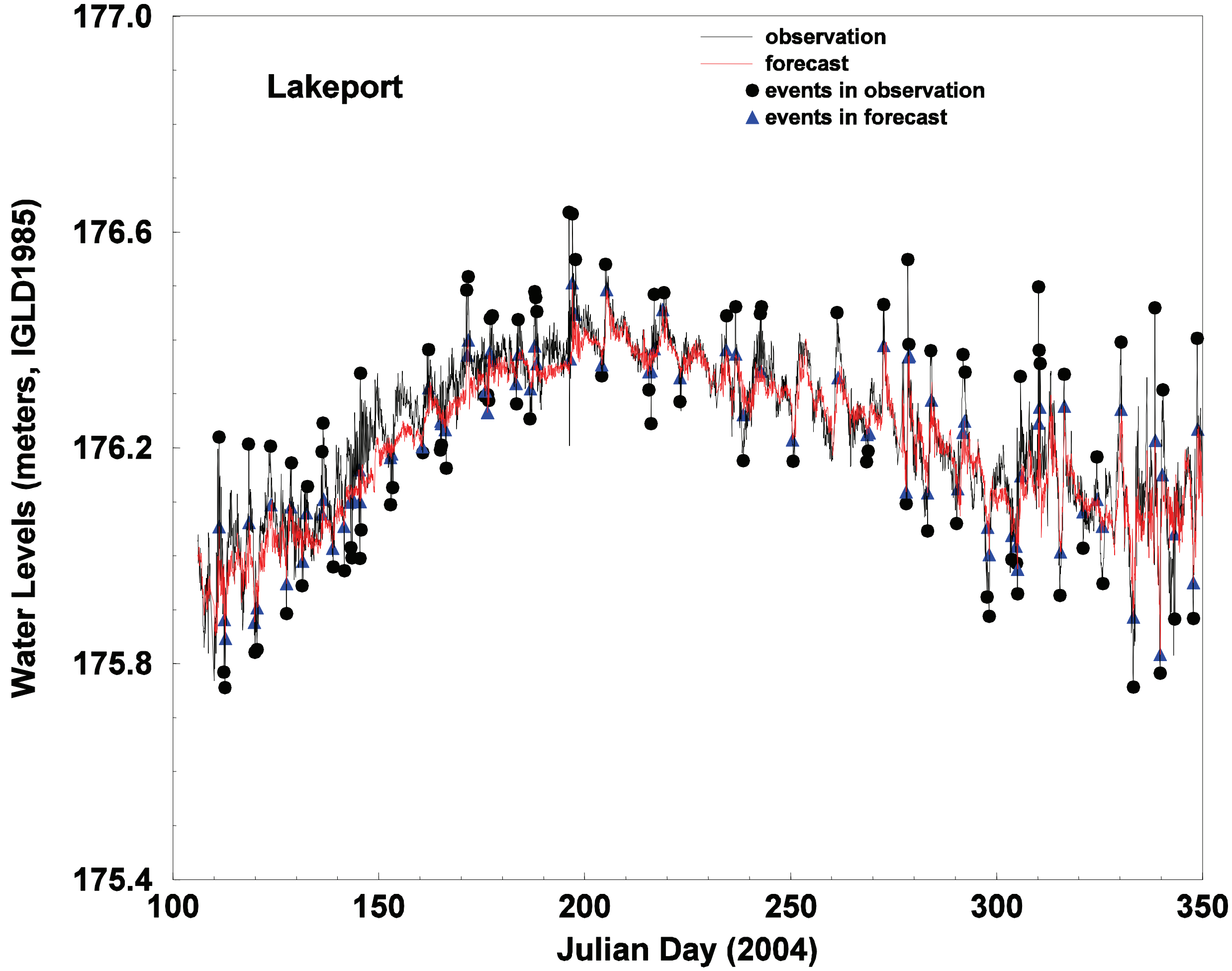

Fig. C.6. Time Series Plot of Semi-Operational Water Level Forecast Guidance vs. Observations at NOS Lakeport, MI Gauge during 2004.

APPENDIX D. Skill Assessment Statistics of Semi-Operational Surface Water Temperature Nowcasts and Forecast Guidance at NWS/NDBC Fixed Buoys in Lake Huron 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 45003 (North Lake Huron) for the Period July 29, 2004 to December 1, 2004.

Station: NDBC Buoy 45003 in Lake Huron
Observed data time period from: 7/29/2004 to 12/ 1/2004
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			5036	11.638							
t			5036	9.752							
T-t	3.0 c	24h	5036	1.886	2.792	2.059	0.0	79.7	8.1	0.0	245.0
SCENARIO: SEMI-OPERATIONAL FORECAST											
T00-t00	3.0 c	24h	420	1.923	2.821	2.066	0.0	80.0	8.3	0.0	360.0
T06-t06	3.0 c	24h	415	1.849	2.761	2.052	0.0	80.0	8.0	0.0	204.0
T12-t12	3.0 c	24h	416	1.857	2.767	2.054	0.0	80.5	8.2	0.0	240.0
T18-t18	3.0 c	24h	415	1.754	2.642	1.978	0.0	81.9	7.0	0.0	228.0
T24-t24	3.0 c	24h	416	1.774	2.649	1.969	0.0	82.2	7.5	0.0	240.0

Table D.1. Skill Assessment Statistics of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperatures at the NWS/NDBC Fixed Buoy 45008 (South Lake Huron) for the Period April 20, 2004 to November 20, 2004.

Station: NDBC Buoy 45008 in Lake Huron
Observed data time period from: 4/20/2004 to 11/20/2004
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											
T			5152	12.992							
t			5152	12.196							
T-t	3.0 c	24h	5152	0.796	1.645	1.440	0.0	94.4	0.0	0.0	0.0
SCENARIO: SEMI-OPERATIONAL FORECAST											
T00-t00	3.0 c	24h	430	0.845	1.684	1.459	0.0	93.0	0.0	0.0	0.0
T06-t06	3.0 c	24h	425	0.731	1.613	1.439	0.0	95.1	0.0	0.0	0.0
T12-t12	3.0 c	24h	426	0.654	1.573	1.432	0.0	95.5	0.0	0.0	0.0
T18-t18	3.0 c	24h	425	0.552	1.397	1.285	0.0	97.9	0.0	0.0	0.0
T24-t24	3.0 c	24h	426	0.504	1.369	1.274	0.0	97.7	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 NWS/NDBC fixed buoys in Lake Huron during 2004.

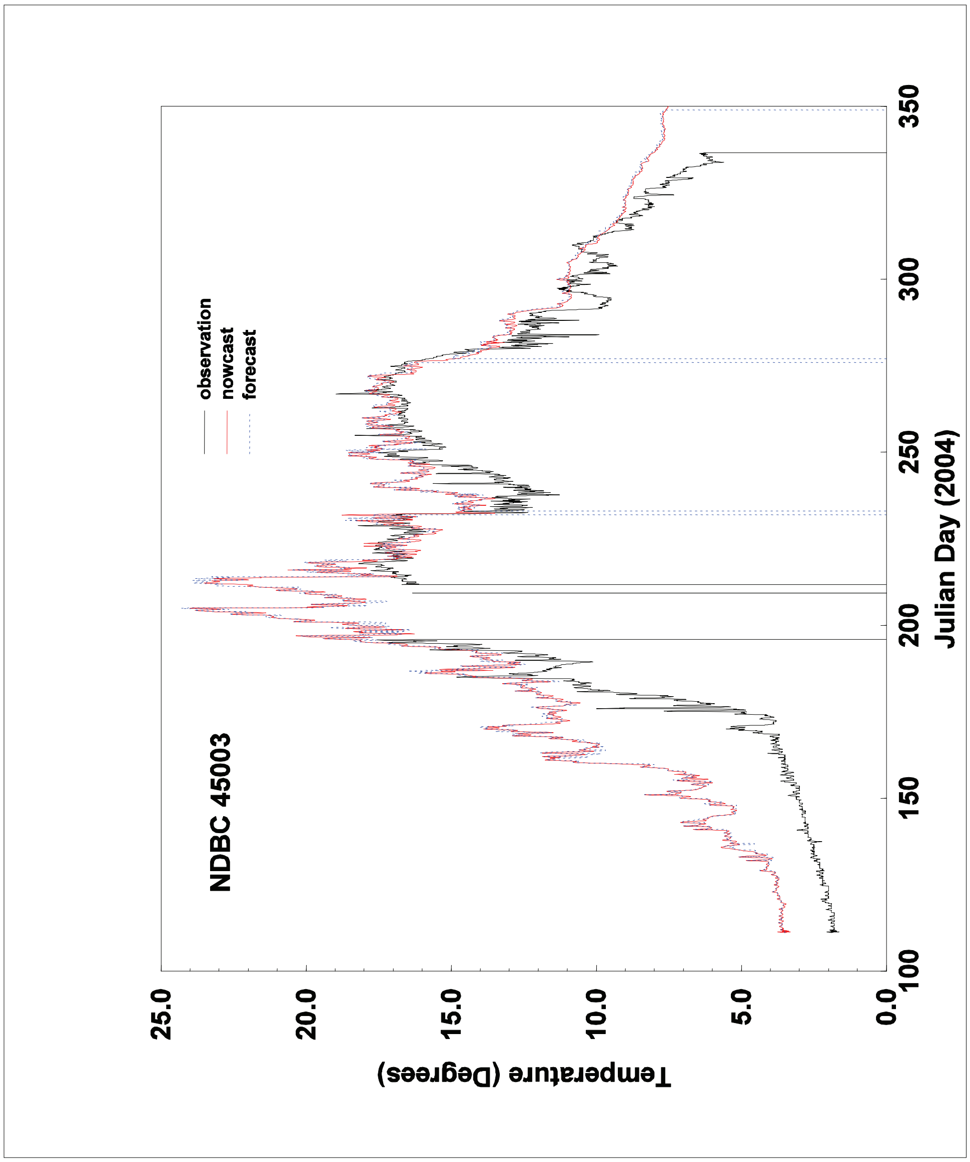

Figure E.1. Time Series of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperature (^{o}C) vs. Observations at the NWS/NDBC Fixed Buoy 45003 (North Lake Huron) for the Period July 29, 2004 to December 1, 2004. The forecast values depicted on the plots are from the 0000 UTC forecast cycle.

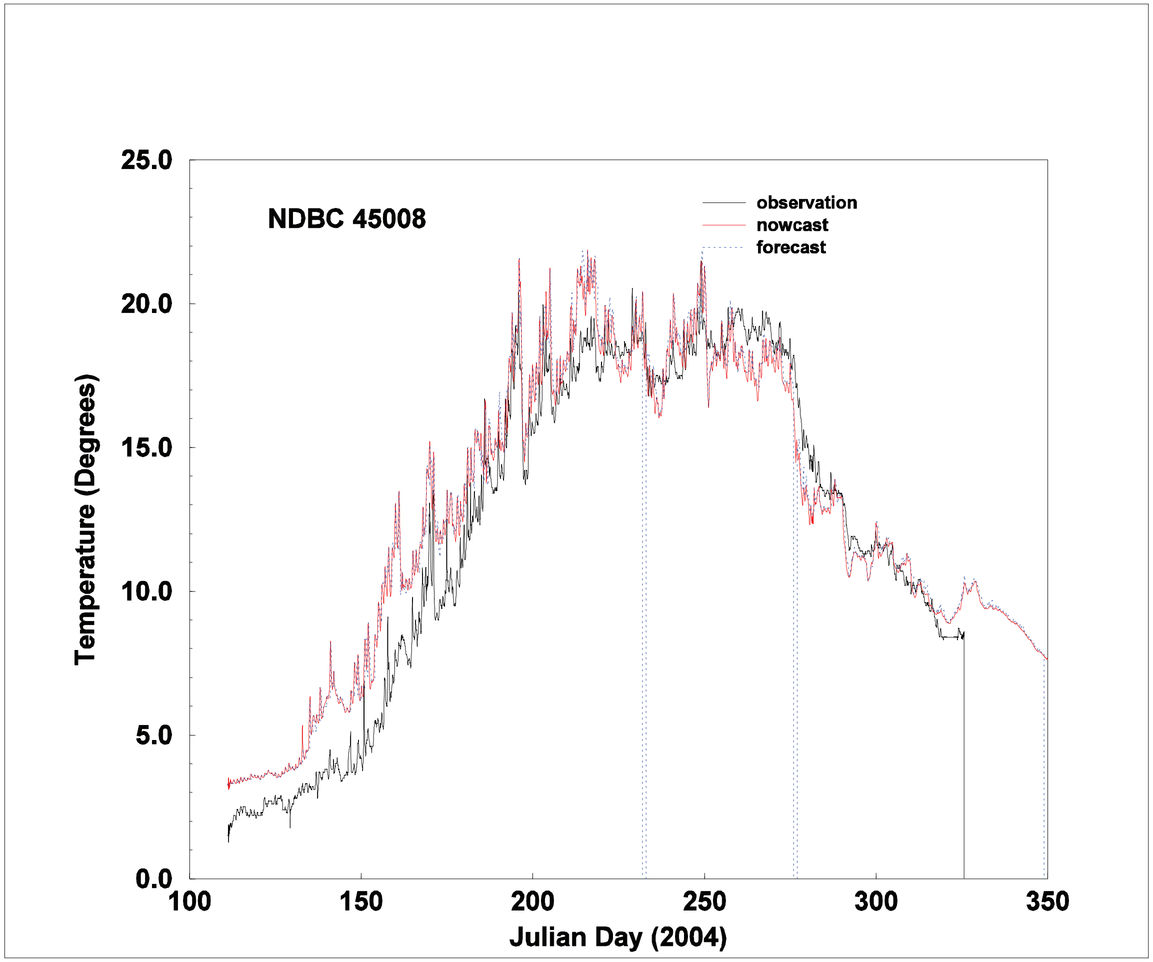

Figure E.2. Time Series of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperature (^{o}C) vs. Observations at the NWS/NDBC Fixed Buoy 45008 (South Lake Huron) for the Period April 20, 2004 to November 20, 2004. The forecast values depicted on the plots are from the 0000 UTC forecast cycle.