NOAA Technical Memorandum NOS CS 9

SKILL ASSESSMENT OF NOS LAKE SUPERIOR OPERATIONAL FORECAST SYSTEM (LSOFS)

Silver Spring, Maryland
June 2007

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

The Office of Coast Survey (OCS) is the Nation's only official chartmaker. As the oldest United States scientific organization, dating from 1807, this office has a long history. Today it promotes safe navigation by managing the National Oceanic and Atmospheric Administration's (NOAA) nautical chart and oceanographic data collection and information programs.

There are four components of OCS:

> **The Coast Survey Development Laboratory develops new and efficient techniques to accomplish Coast Survey missions and to produce new and improved products and services for the maritime community and other coastal users.**
>
> **The Marine Chart Division acquires marine navigational data to construct and maintain nautical charts, Coast Pilots, and related marine products for the United States.**
>
> **The Hydrographic Surveys Division directs programs for ship and shore-based hydrographic survey units and conducts general hydrographic survey operations.**
>
> **The Navigational Services Division is the focal point for Coast Survey customer service activities, concentrating predominately on charting issues, fast-response hydrographic surveys, and Coast Pilot updates.**

NOAA Technical Memorandum NOS CS 9

SKILL ASSESSMENT OF NOS LAKE SUPERIOR OPERATIONAL FORECAST SYSTEM (LSOFS)

John G. W. Kelley
Philip Chu
Ai-Jun Zhang
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

June 2007

noaa **National Oceanic and Atmospheric Administration**

U. S. DEPARTMENT OF COMMERCE Carlos Gutierrez, Secretary	**National Oceanic and Atmospheric Administration Conrad C. Lautenbacher, Jr., VADM USN (Ret.), Under Secretary**	**National Ocean Service John H. Dunnigan Assistant Administrator**

Office of Coast Survey Captain Steven R. Barnum, NOAA	**Coast Survey Development Laboratory Mary Erickson**

NOTICE

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ASOS	Automated Surface Observing System
AVHRR	Advanced 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
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 Superior Operational Forecast System (LSOFS) 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 Superior.

LSOFS 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.

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

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 Superior 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 Superior.

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 at five NOS water level gauges:

Nowcasts:

The hourly nowcasts of water level amplitude met the NOS acceptance criteria at all gauges. The mean algebraic difference (MAE) ranged between -2.9 cm at Duluth, MN and +2.4 cm at Port Iroquois, MI located at the extreme western and eastern ends of Lake Superior. The nowcast predictions of high and low water level events passed the NOS criteria for amplitude at three of five gauges and four of five gauges, respectively. In terms of timing, the nowcasts did not meet NOS criteria.

Forecast Guidance:

The hourly forecast guidance met the NOS criteria for predicting water level amplitude at all five locations. The MAE ranged between -2.9 cm at Duluth and +2.6 cm at Port Iroquois. The forecast guidance of high and low water level events passed the NOS criteria for amplitude at thee and four of the five gauges, respectively. Similar to the nowcasts, the most difficult forecast locations were at Duluth and Port Iroquois where the MAE ranged from -12.3 cm to +11.6 cm. The forecast guidance failed to meet NOS criteria in predicting the times of extreme events.

Surface Water Temperatures at three NWS fixed buoys:

Nowcasts:

The hourly surface water temperature nowcasts did not meet the proposed NOS acceptance criteria at all three buoys. The MAE ranged from 1.1 to 2.1^{o}C.

Forecast Guidance:

The hourly surface water temperature forecast guidance came very close to meeting the proposed NOS acceptance criteria at the buoys. The MAE ranged between 1.0 and 2.0^{o}C. The MAE and the RSME decreased slightly as forecast projection increased.

Key Words: short-term lake predictions, nowcasts, model forecast guidance, Lake Superior, 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 MAEe 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 MAEe 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 Superior since August 2002. GLCFS for Lake Superior 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 MAEe 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 Superior was renamed as the Lake Superior Operational Forecast System (LSOFS). LSOFS began making routine experimental lake nowcasts and forecasts for Lake Superior on March 30, 2006 at CO-OPS during the ice-free season.

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

2. LAKE SUPERIOR

Lake Superior is the largest of the Great Lakes and the second largest lake in the world with a breadth of 257 km (160 mi) and a length of 563 km (350 mi). It has an average depth of 149 m (489 ft) with a maximum of 406 m (1,333 ft). Lake Superior, 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 Superior 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. The lowest levels occur during winter when evaporation is the greatest and more water is leaving the lake than entering it. During the spring the water level begins to rise as runoff from melting snow increases, and evaporation decreases, as the air above the lake becomes warm and moist, and the lake is relatively cold. The highest levels occur in early to mid-autumn, just before the amount of water leaving the lake due to outflows and increased evaporation exceeds the amount of water entering the lake. Long term water level changes occur over consecutive years with wet and cold years causing water levels to rise, and warm and dry years resulting in levels decline (GLIN 2006).

3. SYSTEM OVERVIEW

This section provides a brief description of the numerical hydrodynamic model used by LSOFS. 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 LSOFS 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-YaMAEa 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 (Schwab and Bedford 1994, 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 Superior, 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 Superior consists of a rectangular grid with a 10-km horizontal resolution in both the x- and y-directions. The domain has a total of 1830 grid points with 61 points in the x-direction and 30 points in the y-direction (Fig. 1). Of the 1830 points, there are 807 water cells. 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 meteorological data format, but are decoded and written out to a text file for use by LSOFS and other NOS operational forecast systems. The surface observation text file is available to LSOFS within a minute of receiving the observations from the CCS.

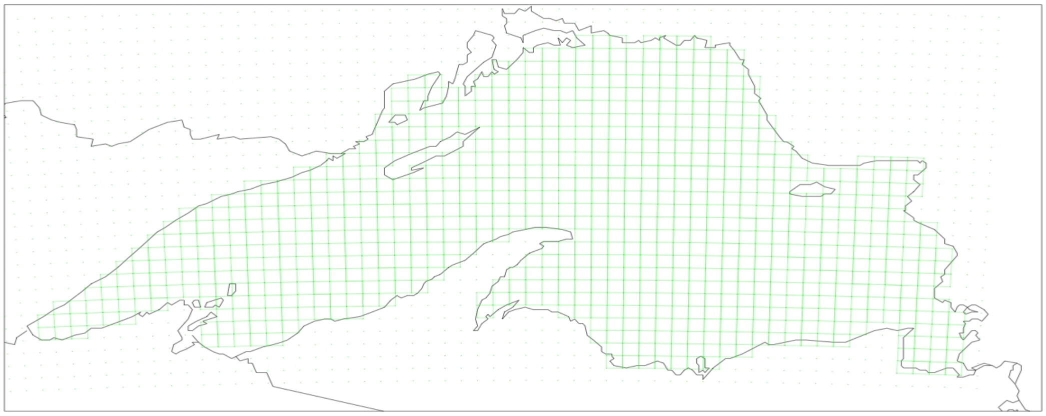

Figure 1. Map depicting the POMGL grid domain (10km spatial resolution) used by NOS' Lake Superior Operational Forecast System.

The text file includes surface observations from a variety of observing networks on and around Lake Superior. 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 LSOFS is run hourly at NOS to generate updated nowcasts of the 3-D state of Lake Superior, 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 analyses of u- and v-wind components, and total heat flux valid at two times: one hour prior to the time of the nowcast and the current hour of the nowcast. The heat flux analyses are generated by the scheme of McCormick and Meadows (1988) which uses adjusted surface meteorological observations as well as the previous day's lake surface average water temperature from GLERL's Great Lakes Surface Environmental Analysis (GLSEA). The GLSEA temperature analysis is generated using sea surface temperature (SST) retrievals derived from the Advanced High Resolution Radiometer data obtained from NOAA's polar-orbiter satellites.

3.5 Forecast Cycle

The forecast cycle of LSOFS is run four times per day to generate forecast guidance of the 3-D state of Lake Superior. The forecast cycle uses the most recent nowcast for its initial conditions. The surface meteorological forcing is 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. Presently, 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. The forecast cycle does not use surface pressure guidance from NAM in forcing POMGL.

The NAM model forecast guidance is obtained from ODAAS which acquires the NAM output from NCEP's CCS in GRIB format four times per day at 3 hour increments out to 60 hours. ODAAS decodes the GRIB files and then encodes the output into netCDF files following NOS COMF standards.

3.6 Operational Environment and Scheduling

LSOFS is run operationally on a Linux workstation at NOS/CO-OPS in Silver Spring, MD. Each hourly nowcast cycle is launched at 67 minutes past the top of the hour, 12 minutes past the time the surface meteorological observations are received and processed by ODAAS at CO-OPS.

The forecast cycle of LSOFS is run four times per day at 0000, 0600, 1200, and 1800 UTC at 67 minutes past the top of these hours. The forecast horizon of each forecast cycle is 30 hours.

LSOFS and the operational forecast systems for Lake Huron and Lake Ontario 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. (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."

LSOFS, as described in Chapter 2, is based on NOAA/GLERL's Great Lakes Coastal Forecast System (GLCFS) for Lake Superior. Both LSOFS and GLCFS-Lake Superior have a spatial grid increment of 10 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) unlike LSOFS which does not. However, this difference was not expected to cause a significant difference in the nowcasts.

Due to the similar characteristics of LSOFS and GLCFS, the assessment of the LSOFS 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 Superior, 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 on the lake.

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) $\geq$90%, POF(2X) $\leq$1%, NOF(2X) $\leq$1%, WOF(2X) $\leq$0.5%
MDPO(2X) $\leq$ L, MDNO(2X) $\leq$ 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 LSOFS 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	H, h
	Water temperature	T, t
Group 2 (Values at Extreme Event)	Amplitude of high water	AHW, ahw
	Amplitude of low water	ALW, ahw
	Time of high water	THW, thw
	Time of low water	TLW, tlw
Group 3 (Values from a Forecast)	Water level at forecast projection time of nn hrs	Hnn, hnn
	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 five NOS NWLON stations along the Lake Superior shore line (Table 4). A map depicting the locations of the five 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 LSOFS 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 Superior 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.

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 three 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 is sampled once per hour. The point evaluations were conducted by comparing surface (highest 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 Superior 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 MAEe 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 LSOFS 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
Point Iroquois	MI	9099004	PTIM4	46.49	84.63	59	2
Marquette CG Station	MI	9099018	MCGM4	46.55	87.30	38	2
Ontonagon	MI	9099044	NS	46.88	89.30	23	7
Grand Marais	MN	9099090	GDMM5	47.75	90.30	16	16
Duluth	MN	9099064	DULM5	46.78	92.00	3	6

Notes: NS = An official NWS station ID has not been assigned to the station yet.

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

Buoy ID and Name	Agency	Prov. or State	WMO Buoy ID	Geographic Coordinates		Corresponding LSOFS Grid Point Coordinates	
				Latitude (deg N)	Longitude (deg W)	I	J
45001 – Mid Superior	NWS/ NDBC	MI	45001	48.07	87.78	35	19
45004 – East Superior	NWS/ NDBC	MI	45004	47.57	86.55	44	14
45006 – West Superior	NWS/ NDBC	MI	45006	47.35	89.83	19	11

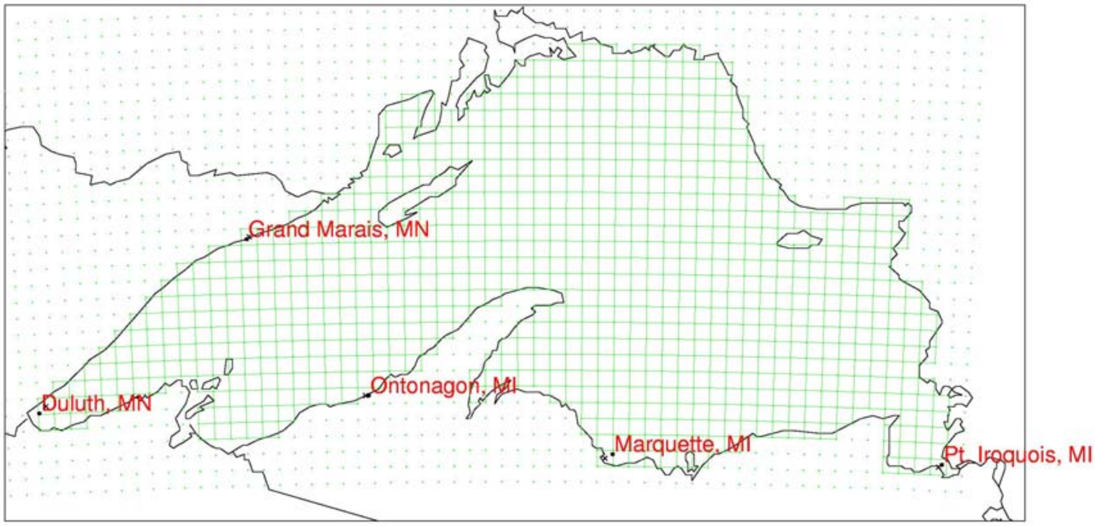

Figure 2. Map depicting locations of NOS/CO-OPS NWLON stations in Lake Superior.

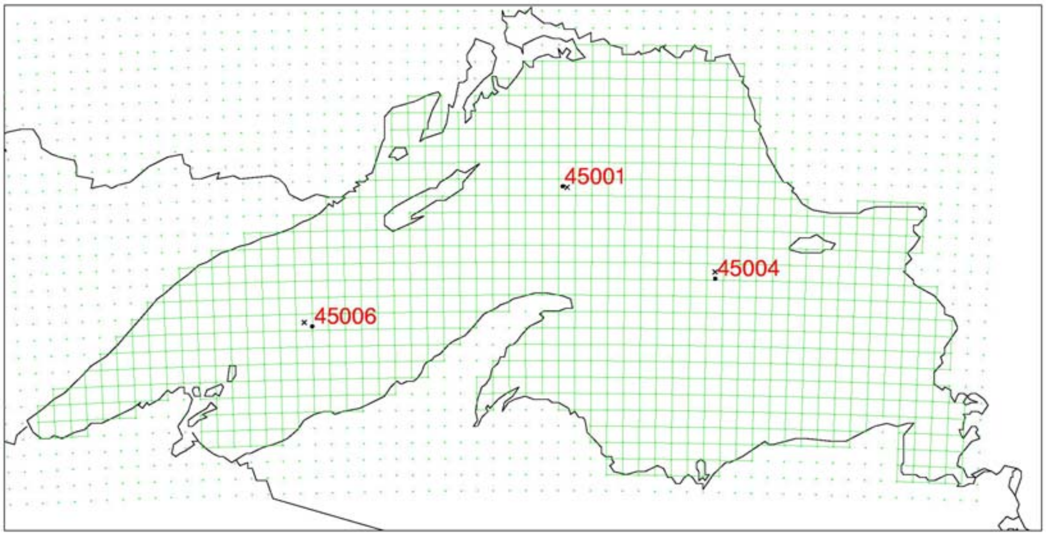

Figure 3. Map depicting locations of NWS/NDBC fixed buoys in Lake Superior.

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 five 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 five NOS gauges are presented together in Table 6 along with the NOS acceptance criteria. The hourly nowcasts passed the criteria at all five locations. The mean algebraic differences ranged between ± 3 cm and the RMSE ranged between 2.5 and 6.2 cm. The greatest errors were at Duluth and Port Iroquois gauges located at the extreme western and eastern ends of the lake, respectively (Fig. 2), which experience the greatest hourly water level variability. The nowcasts under-predicted the water levels at Duluth and over-predicted the levels at Port Iroquois.

Table 6. Summary of Skill Assessment Statistics of *Semi-Operational Nowcasts* of <u>Hourly Water Levels</u> at five NOS NWLON Stations for the Period 15 April to 17 December 2004. A total of 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 ( )	**Grand Marais, MN**	**Duluth, MN**	**Ontonagon, MI**	**Marquette, MI**	**Port Iroquois, MI**	**NOS Accept. Criteria**
Mean Diff. (m)	-0.012	-0.029	-0.002	-0.000	0.024	na
RMSE (m)	0.035	0.062	0.031	0.025	0.061	na
SD (m)	0.033	0.055	0.031	0.025	0.056	na
NOF [2x15cm] (%)	0.0	0.0	0.0	0.0	0.0	≤ 1%
CF [15 cm] (%)	100.0	98.2	99.8	100.0	98.1	≥ 90%
POF [2x15 cm] (%)	0.0	0.0	0.0	0.0	0.0	< 1%
MDPO [2x15 cm] (hour)	0.0	0.0	0.0	0.0	0.0	≤ 24 hours
MDNO [2x15 cm] (hour)	0.0	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 the five NOS gauges during 2004 are given together in Table 7. The high water level nowcasts passed the NOS acceptance criteria for amplitude at Grand Marais, Ontonagon, and Marquette, but not at Duluth and Port Iroquois. The nowcasts ability to simulate the timing of these events did not pass NOS acceptance criteria for NOF, CF, and POF at any of the five gauges.

Table 7. Summary of Standard Statistics Evaluating the Ability of the *Semi-Operational Nowcasts* to Predict Extreme High Water Level Events at the NOS NWLON stations in Lake Superior 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 ( )	Grand Marais, MN N=12		Duluth, MN N=27		Ontonagon, MI N=11	
	Amp.	Time	Amp.	Time	Amp.	Time
Mean Diff. (m) (min)	-0.081	-1.000	-0.123	-0.636	-0.085	-0.077
RMSE (m) (min)	0.087	3.440	0.136	6.695	0.094	5.211
SD (m) (min)	0.033	3.438	0.058	6.990	0.043	5.314
NOF [2x15cm or 90min] %	0.0	25.0	0.0	27.3	0.0	19.2
CF [15 cm or 90 min] (%)	100.0	16.7	57.7	27.3	90.9	30.8
POF [2x15 cm or 90 min] (%)	0.0	8.3	0.0	18.2	0.0	23.1
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

Statistic, Acceptable Error [ ], and Units ( )	Marquette, MI N=9		Port Iroquois, MI N=36		NOS Accept. Criteria
	Amplitude	Time	Amplitude	Time	
Mean Diff. (m) (min)	-0.071	1.778	-0.083	-0.306	na
RMSE (m) (min)	0.074	5.011	0.097	4.450	na
SD (m) (min)	0.023	4.969	0.050	4.503	na
NOF [2x15cm] (90min) %	0.0	11.1	0.0	22.2	≤ 1%
CF [15 cm or 90 min] (%)	100.0	22.2	83.3	27.8	≥ 90%
POF [2x15 cm or 90 min] (%)	0.0	44.4	0.0	19.4	≤ 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

The skill statistics to predict extreme low water level events at the five NOS gauges during 2004 are given together in Table 8. The extreme low water level nowcasts passed NOS acceptance criteria for amplitude at Grand Marais, Ontonagon, Duluth, and Marquette, but not at Port Iroquois where the CF was 81%. The nowcasts ability to simulate the timing of these events did not pass NOS acceptance criteria for NOF, CF, and POF at any of the five 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 Superior 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 ( )	Grand Marais, MN N=23		Duluth, MN N=48		Ontonagon, MI N=15	
	Amp.	Time	Amp.	Time	Amp.	Time
Mean Diff. (m) (min)	0.061	0.087	0.060	-0.479	0.066	-0.267
RMSE (m) (min)	0.066	3.683	0.068	2.955	0.069	3.204
SD (m) (min)	0.025	3.765	0.033	2.946	0.018	3.305
NOF [2x15cm or 90min] (%)	0.0	21.7	0.0	18.8	0.0	20.0
CF [15 cm or 90 min] (%)	100.0	26.1	100.0	47.9	100.0	46.7
POF [2x15 cm or 90 min] (%)	0.0	21.7	0.0	6.3	0.0	13.3
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

Statistic, Acceptable Error [ ], and Units ( )	Marquette, MI N=15		Port Iroquois, MI N=36		NOS Accept. Criteria
	Amplitude	Time	Amplitude	Time	
Mean Diff. (m) (min)	0.065	0.800	0.121	-0.500	na
RMSE (m) (min)	0.067	3.366	0.126	3.734	na
SD (m) (min)	0.013	3.385	0.033	3.753	na
NOF [2x15cm or 90min] (%)	0.0	13.3	0.0	25.0	≤ 1%
CF [15 cm or 90 min] (%)	100.0	33.3	80.6	13.9	≥ 90%
POF [2x15 cm or 90 min] (%)	0.0	26.7	0.0	25.0	≤ 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

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 three NWS/NDBC fixed buoys 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 buoys are given in Appendix E.

The time series plots indicate that the nowcasts were in close agreement to observations (+0.5-1°C) from mid-April until mid- to late-June 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°C (Boyce et al. 1989).

However, when the surface water temperature nowcasts reached 4°C, the temperature of maximum density for fresh water, the nowcasts began to deviate from the observations by +2-4°C until mid-July at the eastern buoy and until mid- to late-August at the mid-and western-buoys located in deeper water (+260 m). August is the usual time when the complete thermal stratification of Lake Superior occurs (Boyce et al. 1989).

From mid-July or mid- to late-August until early October, the nowcasts differed from observations by +1-2°C and then the difference generally declined to +1°C or less by the end of the evaluation period.

The skill statistics to predict hourly surface water temperatures at the three NDBC buoys are given together in Table 9 along with the NOS acceptance criteria. The hourly water temperature nowcasts at the three buoys did not pass the NOS criteria for assessment statistics of CF, POF, and MDNO. The hourly nowcasts at the Mid Superior buoy came close to passing the criteria, failing primarily in regards to CF by only 5%. The mean algebraic differences for the period ranged between 1.3 – 2.1°C and the RMSE ranged between 1.9 – 2.7°C at the three buoys.

Table 9. Summary of Skill Assessment Statistics of the *Semi-Operational Nowcasts* of Hourly Surface Water Temperatures at three NWS/NDBC fixed buoys in Lake Superior 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 ( )	45006 West Superior N=4811	45001 Mid Superior N=4831	45004 East Superior N=4814	NOS Acceptance Criteria
Time Period	23 April to 11 Nov. 2004	21 April to 11 Nov. 2004	23 April to 9 Nov. 2004	365 days
Mean Difference (^oC)	1.10	1.27	2.13	na
RMSE (^oC)	2.07	1.98	2.70	na
SD (^oC)	1.75	1.54	1.65	na
NOF [2x3^{o}C] (%)	0.0	0.0	0.0	$\leq$ 1%
CF [3^{o}C] (%)	84.9	84.9	75.9	$\geq$ 90%
POF [2x3^{o}C] (%)	0.2	1.1	4.2	$\leq$ 1%
MDPO [2x3^{o}C] (hours)	0.0	0.0	0.0	$\leq$ 24 hrs
MDNO [2x3^{o}C] (hours)	8.0	15.0	36.0	$\leq$ 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 LSOFS, 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.

6.1 Description of Forecast Cycles

GLCFS performs twice/day 60-hr forecast cycles for Lake Superior. 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 NWS/NDBC fixed buoys 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 5 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 three 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 five 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 five NOS gauges are presented together in Table 10 along with the NOS acceptance criteria. The hourly forecasts passed the criteria at all five locations. The mean algebraic differences ranged between -2.9 to + 2.6 cm and the RMSE ranged between 2.5 and 6.2 cm, very similar to the statistics for the nowcast evaluation. Similar to the nowcasts, the greatest errors were at Duluth and Port Iroquois Gauges located at the extreme western and eastern ends of the lake, respectively. The forecasts under-predicted the water levels at Duluth and over-predicted the levels at Port Iroquois. There was no significant increase in the mean differences, RMSE values, or CF as forecast projection increased (Appendix A).

Table 10. Summary of Skill Assessment Statistics of *Semi-Operational Forecast Guidance* of Hourly Water Levels at NOS NWLON Stations in Lake Superior for the Period 15 April to 17 December 2004. A total of 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 ( )	Grand Marais, MN	Duluth MN	Ontonagon MI	Marquette MI	Port Iroquois MI	NOS Accept. Criteria
Mean Diff. (m)	-0.005	-0.029	0.002	-0.001	0.026	na
RMSE (m)	0.037	0.062	0.033	0.025	0.059	na
SD (m)	0.037	0.055	0.033	0.025	0.053	na
NOF [2x15cm] (%)	0.0	0.0	0.0	0.0	0.0	≤ 1%
CF [15 cm] (%)	100.0	98.2	99.8	100.0	99.4	≥ 90%
POF [2x15 cm] (%)	0.0	0.0	0.0	0.0	0.0	≤ 1%
MDPO [2x15 cm] (hour)	0.0	0.0	0.0	0.0	0.0	≤ 24 hours
MDNO [2x15 cm] (hour)	0.0	0.0	0.0	0.0	0.0	≤ 24 hours

Notes: na = not applicable

The skill statistics to assess the ability of the forecast guidance to predict extreme high water level events at the five NOS gauges during 2004 are given together in Table 11. The forecasts of extreme high water level passed NOS acceptance criteria for amplitude at Grand Marais, Ontonagon, and Marquette, but not at Duluth and Port Iroquois where the CF was 67% and 89%, respectively. The forecasts' ability to simulate the timing of these events did not pass NOS acceptance criteria for NOF, CF, and POF at any of the five gauges.

Table 11. Summary of Skill Assessment Statistics Evaluating the Ability of *Semi-Operational Forecast Guidance* to Predict Extreme High Water Level Events at NOS NWLON Stations in Lake Superior 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 ( )	Grand Marais, MN N=13		Duluth, MN N=27		Ontonagon, MI N=11	
	Amp.	Time	Amp.	Time	Amp.	Time
Mean Diff. (m) (min)	-0.088	-0.308	-0.123	-0.407	-0.087	0.273
RMSE (m) (min)	0.092	6.239	0.135	5.168	0.095	5.402
SD (m) (min)	0.028	6.486	0.058	5.250	0.042	5.658
NOF [2x15cm or90min] (%)	0.0	30.8	0.0	25.9	0.0	18.2
CF [15 cm or 90 min] (%)	100.0	38.5	66.7	25.9	90.9	27.3
POF [2x15 cm or 90 min] (%)	0.0	23.1	0.0	22.2	0.0	18.2

Statistic, Acceptable Error [ ], and Units ( )	Marquette MI N=9		Port Iroquois MI N=36		NOS Acceptance Criteria
	Amplitude	Time	Amplitude	Time	
Mean Diff. (m) (min)	-0.050	1.889	-0.066	-0.833	na
RMSE (m) (min)	0.053	4.333	0.084	5.344	na
SD (m) (min)	0.020	4.137	0.053	5.353	na
NOF [2x15cm or 90min] (%)	0.0	11.1	0.0	27.8	≤ 1%
CF [15 cm or 90 min] (%)	100.0	44.4	88.9	22.2	≥ 90 %
POF [2x15 cm or 90 min] (%)	0.0	22.2	0.0	25.0	≤ 1 %

Notes: na = not applicable

The skill statistics to assess the ability of the forecast guidance to predict extreme low water level events at the five NOS gauges in 2004 are given together in Table 12. The forecasts of extreme low water level passed NOS acceptance criteria for amplitude at Grand Marais, Ontonagon, Duluth, and Marquette, but not at Port Iroquosis where the CF was 84%. The forecasts ability to simulate the timing of these events did not pass NOS acceptance criteria for NOF, CF, and POF at any of the five gauges.

Table 12. Summary of Skill Assessment Statistics Evaluating the Ability of *Semi-Operational Forecast Guidance* to Predict Extreme Low Water Level Events at NOS NWLON Stations in Lake Superior 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 ( )	Grand Marais, MN N=24		Duluth MN N=46		Ontonagon MI N=14	
	Amp.	Time	Amp.	Time	Amp.	Time
Mean Diff. (m) (min)	0.072	-0.292	0.061	-0.304	0.064	0.429
RMSE (m) (min)	0.075	3.857	0.071	2.670	0.066	2.449
SD (m) (min)	0.021	3.928	0.036	2.682	0.014	2.503
NOF [2x15cm or 90min] (%)	0.0	20.8	0.0	15.2	0.0	7.1
CF [15 cm or 90 min] (%)	100.0	25.0	100.0	43.5	100.0	42.9
POF [2x15 cm or 90 min] (%)	0.0	25.0	0.0	6.5	0.0	7.1

Statistic, Acceptable Error [ ], and Units ( )	Marquette MI N=15		Port Iroquois MI N=38		NOS Acceptance Criteria
	Amplitude	Time	Amplitude	Time	
Mean Diff. (m) (min)	0.060	-0.067	0.116	-0.684	na
RMSE (m) (min)	0.062	3.642	0.120	3.479	na
SD (m) (min)	0.016	3.770	0.032	3.457	na
NOF [2x15cm or 90min] (%)	0.0	26.7	0.0	21.1	≤1%
CF [15 cm or 90 min] (%)	100.0	20.0	84.2	15.8	≥ 90%
POF [2x15 cm or 90 min] (%)	0.0	20.0	0.0	18.4	≤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 three NWS/NDBC fixed buoys from mid-April to early December 2004 are 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 (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 are in close agreement to observations ($+0.5^{o}$C) from mid- April until early/mid June, but then begin to deviate from the observations by $3\text{-}4^{o}$C until mid- to late-August. After that the forecasts differ from observations by $+1\text{-}2^{o}$C until early October and then generally decline to $+1^{o}$C or less by the end of the period. The skill statistics assessing the ability of semi-operational forecast guidance to predict surface water temperatures 24 hours in advance at the three NDBC buoys are given in Table 13 along with the NOS acceptance criteria. The hourly forecast guidance at the Mid Superior buoy came close to passing all the criteria (failing to meet the CF criteria by only 2%). The forecast guidance at the East Superior buoy failed the CF criteria by approximately 10% and the POF by only 0.3%. The mean algebraic differences ranged between 1.2 and 2.0^{o}C and the RMSE ranged between 1.9 and 2.5^{o}C at the three buoys. The mean differences and RMSEs for the forecast guidance were slightly lower than for the nowcasts.

It is interesting to note that the mean differences, RMSE, and the CF and POF values decreased as forecast projection increased in time. For example, at the East Superior buoy, the RMSE was 2.7^{o}C at the 0-hr projection and 2.5^{o}C at 24-hrs (see Table D.3). This suggests that the surface heat flux is being overestimated during the nowcast cycle.

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 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 ( )	45006 West Superior N=397	45001 Mid Superior N=399	45004 East Superior N=398	NOS Acceptance Criteria
Time Period	20 April to 7 Nov. 2004	21 April to 11 Nov. 2004	23 April to 9 Nov. 2004	365 days
Mean Difference (°C)	0.960	1.16	1.96	na
RMSE (°C)	1.99	1.90	2.48	na
SD (°C)	1.75	1.51	1.52	na
NOF [2x3°C] (%)	0.0	0.0	0.0	$\leq$ 1%
CF [3°C] (%)	85.6	88.0	79.4	$\geq$ 90%
POF [2x3°C] (%)	0.5	0.5	1.3	$\leq$ 1%
MDPO [2x3°C] (hours)	0.0	0.0	0.0	$\leq$ 24 hrs
MDNO [2x3°C] (hours)	12.0	0.0	0.0	$\leq$ 24 hrs

Notes: na = not applicable

7. SUMMARY

NOS' Lake Superior Operational Forecast System (LSOFS) 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.

LSOFS 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 surface air temperature and wind forcing from NWS/NCEP's NAM-12 weather prediction model. During the forecast cycle, the heat flux is set to zero.

An assessment of the LSOFS 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 Superior from 15 April to 17 December 2004. Unfortunately, neither GLERL or OSU conducted comparisons between POMGL vs. field data for Lake Superior which could be used to fulfill the hindcast scenario.

The semi-operational nowcasts and forecast guidance were compared to water level observations at five NOS NWLON stations and surface temperatures at three NWS/NDBC fixed buoys in the lake. Due to the lack of sub-surface water temperatures and current observations, no assessment of these variables was conducted for LSOFS.

Water Levels

The hourly water nowcasts met the NOS acceptance criteria at all five NOS gauges. The mean algebraic differences ranged between -2.9 cm at Duluth, MN and +2.4 cm at Port Iroquois, MI. Thus, the nowcasts under-predicted the hourly water levels at Duluth and over-predicted the levels at Port Iroquois. The RMSE among the five gauges ranged between 2.5 and 6.2 cm.

The ability of the nowcasts to predict extreme high and low water level events was also assessed using a proposed modification to the NOS evaluation standards. The nowcast predictions of high water level events passed the NOS criteria for amplitude at three of the five NOS gauges, failing at Duluth and Port Iroquois. The predictions of low water level events passed the NOS criteria at four of the five NOS gauges, failing at Port Iroquois. The nowcasts failed to meet NOS criteria in predicting the timing of both extreme high and low water events at all the NOS gauges.

The hourly forecast guidance met the NOS criteria at all five locations. The mean algebraic differences ranged between -2.9 to + 2.6 cm and the RMSE ranged between 2.5 and 6.2 cm, very similar to the statistics for the nowcast evaluation. Similar to the nowcasts, the greatest errors were at Duluth and Port Iroquois gauges located at the extreme western and eastern ends of the lake, respectively. The forecast under-predicted the water levels at Duluth and over-predicted the levels at Port Iroquois. There was no significant increase in the mean algebraic errors or RMSE values, or CF as forecast projection increased.

The forecast guidance of extreme high and low water level events passed NOS criteria at three and four of the five gauges, respectively. Again, the least satisfactory locations for forecasts were Duluth and Port Iroquois. The highest mean algebraic differences for the forecast of extreme high and low events were -12.3 cm at Duluth and +11.6 cm at Port Iroquois, respectively. The forecast guidance failed to meet NOS criteria in predicting the timing of both extreme high and low water events at all NOS gauges.

Surface Water Temperatures

The hourly water temperature nowcasts did not meet the NOS criteria at the three buoys. The nowcasts came very close to meeting NOS criteria at the Western- and Mid-Superior buoys, failing to meet the CF by 5%. The mean algebraic errors for the period ranged between 1.1 and 2.1^{o}C and the RMSE ranged between 1.9 and 2.7^{o}C.

The hourly water temperature forecast guidance at 24 hours came very close to meeting NOS criteria at all buoys. The mean algebraic difference ranged between 1.0 and 2.0^{o}C and RMSE between 1.9 and 2.5^{o}C which were slightly lower than for the nowcasts. The

RMSE of the hourly water temperature forecasts decreased slightly as the forecast projection increased in time.

8. RECOMMENDATIONS FOR FUTURE WORK

Recommendation #1

The comparisons of the semi-operational nowcasts and forecast guidance of surface water temperature to observations at buoys, especially in the mid and eastern parts of the lake indicate a problem with surface water temperature predictions, especially during the Spring and Summer. This could be caused by the inaccuracy in the model's depiction of the three dimensional thermal structure at the start of spring warming. It is recommended that sensitivity runs be conducted to determine the impacts of 1) re-initializing the model's three-dimensional thermal structure at start of each spring based on a historical mean temperature profile and 2) using an ice module in POMGL. (GLERL is presently testing ice module in POMGL for Lakes Erie and Michigan.)

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 western and eastern ends of the lake according to NOS standards. This would likely involve sensitivity tests with POMGL using higher grid resolution and incorporating atmospheric pressure forcing.

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.

We express our thanks to Drs. Richard Schmalz, Eugene Wei, and Zhizhang Yang as well as Lorraine Robidoux in CSDL for their helpful comments and suggestions to improve this technical report.

REFERENCES

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.

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 five NOS Gauges in Lake Superior for 2004.

Table A.1. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Port Iroquois, MI Gauge (NOS ID 9099004) for 2004.

```
Station:        Point Iroquois, Lake Superior, MI
Observed data-longest continuous time segment 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 183.407
h                     5832 183.383
H-h        15 cm 24h  5832   0.024  0.061  0.056   0.0  98.1   0.0    0.0  0.0
AHW-ahw    15 cm 24h    36  -0.083  0.097  0.050   0.0  83.3   0.0    0.0  0.0
ALW-alw    15 cm 24h    36   0.121  0.126  0.033   0.0  80.6   0.0    0.0  0.0
THW-thw  1.50 hr 25h    36  -0.306  4.450  4.503  22.2  27.8  19.4    0.0  0.0
TLW-tlw  1.50 hr 25h    36  -0.500  3.734  3.753  25.0  13.9  25.0    0.0  0.0

     SCENARIO: SEMI-OPERATIONAL FORECAST
H00-h00    15 cm 24h   494   0.025  0.062  0.057   0.2  98.8   0.0    0.0  0.0
H06-h06    15 cm 24h   490   0.023  0.058  0.053   0.0  98.6   0.0    0.0  0.0
H12-h12    15 cm 24h   490   0.028  0.059  0.053   0.0  99.6   0.0    0.0  0.0
H18-h18    15 cm 24h   490   0.023  0.058  0.053   0.0  98.6   0.0    0.0  0.0
H24-h24    15 cm 24h   490   0.026  0.059  0.053   0.0  99.4   0.0    0.0  0.0
AHW-ahw    15 cm 24h    36  -0.066  0.084  0.053   0.0  88.9   0.0
ALW-alw    15 cm 24h    38   0.116  0.120  0.032   0.0  84.2   0.0
THW-thw  1.50 hr 25h    36  -0.833  5.344  5.353  27.8  22.2  25.0
TLW-tlw  1.50 hr 25h    38  -0.684  3.479  3.457  21.1  15.8  18.4
```

Table A.2. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Marquette CG Station Gauge (NOS ID 9099018) for 2004.

```
Station:  Marquette CG Station, Lake Superior, MI
Observed data-longest continuous time segment 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 183.403
h                     5832 183.403
H-h        15 cm 24h  5832   0.000  0.025  0.025   0.0 100.0   0.0    0.0  0.0
AHW-ahw    15 cm 24h     9  -0.071  0.074  0.023   0.0 100.0   0.0    0.0  0.0
ALW-alw    15 cm 24h    15   0.065  0.067  0.013   0.0 100.0   0.0    0.0  0.0
THW-thw  1.50 hr 25h     9   1.778  5.011  4.969  11.1  22.2  44.4    0.0  0.0
TLW-tlw  1.50 hr 25h    15   0.800  3.366  3.385  13.3  33.3  26.7    0.0  0.0

     SCENARIO: SEMI-OPERATIONAL FORECAST
H00-h00    15 cm 24h   494   0.000  0.026  0.026   0.0 100.0   0.0    0.0  0.0
H06-h06    15 cm 24h   490  -0.003  0.024  0.024   0.0 100.0   0.0    0.0  0.0
H12-h12    15 cm 24h   490   0.001  0.026  0.026   0.0 100.0   0.0    0.0  0.0
H18-h18    15 cm 24h   490  -0.003  0.025  0.025   0.0 100.0   0.0    0.0  0.0
H24-h24    15 cm 24h   490  -0.001  0.025  0.025   0.0 100.0   0.0    0.0  0.0
AHW-ahw    15 cm 24h     9  -0.050  0.053  0.020   0.0 100.0   0.0
ALW-alw    15 cm 24h    15   0.060  0.062  0.016   0.0 100.0   0.0
THW-thw  1.50 hr 25h     9   1.889  4.333  4.137  11.1  44.4  22.2
TLW-tlw  1.50 hr 25h    15  -0.067  3.642  3.770  26.7  20.0  20.0
```

Table A.3. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Ontonagon, MI Gauge (NOS ID 9099044) for 2004.

```
Station:             Ontonagon, Lake Superior, MI
Observed data-longest continuous time segment 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 183.401
h                     5832 183.403
H-h        15 cm 24h  5832  -0.002  0.031  0.031   0.0  99.8   0.0    0.0  0.0
AHW-ahw    15 cm 24h    11  -0.085  0.094  0.043   0.0  90.9   0.0    0.0  0.0
ALW-alw    15 cm 24h    15   0.066  0.069  0.018   0.0 100.0   0.0    0.0  0.0
THW-thw  1.50 hr 25h    11  -0.636  6.695  6.990  27.3  27.3  18.2    0.0  0.0
TLW-tlw  1.50 hr 25h    15  -0.267  3.204  3.305  20.0  46.7  13.3    0.0  0.0

     SCENARIO: SEMI-OPERATIONAL FORECAST
H00-h00    15 cm 24h   494  -0.001  0.032  0.032   0.0  99.8   0.0    0.0  0.0
H06-h06    15 cm 24h   490  -0.004  0.032  0.032   0.0  99.8   0.0    0.0  0.0
H12-h12    15 cm 24h   490  -0.003  0.032  0.032   0.0  99.8   0.0    0.0  0.0
H18-h18    15 cm 24h   490  -0.004  0.032  0.032   0.0  99.8   0.0    0.0  0.0
H24-h24    15 cm 24h   490  -0.002  0.033  0.033   0.0  99.8   0.0    0.0  0.0
AHW-ahw    15 cm 24h    11  -0.087  0.095  0.042   0.0  90.9   0.0
ALW-alw    15 cm 24h    14   0.064  0.066  0.014   0.0 100.0   0.0
THW-thw  1.50 hr 25h    11   0.273  5.402  5.658  18.2  27.3  18.2
TLW-tlw  1.50 hr 25h    14   0.429  2.449  2.503   7.1  42.9   7.1
```

Table A.4. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Grand Marais, MN Gauge (NOS ID 9000090) for 2004.

```
Station: Grand Marais, Lake Superior, MI47.750 -9
Observed data-longest continuous time segment 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 183.393
h                     5832 183.405
H-h        15 cm 24h  5832  -0.012  0.035  0.033   0.0 100.0   0.0    0.0  0.0
AHW-ahw    15 cm 24h    12  -0.081  0.087  0.033   0.0 100.0   0.0    0.0  0.0
ALW-alw    15 cm 24h    23   0.061  0.066  0.025   0.0 100.0   0.0    0.0  0.0
THW-thw  1.50 hr 25h    12  -1.000  3.440  3.438  25.0  16.7   8.3    0.0  0.0
TLW-tlw  1.50 hr 25h    23   0.087  3.683  3.765  21.7  26.1  21.7    0.0  0.0

     SCENARIO: SEMI-OPERATIONAL FORECAST
H00-h00    15 cm 24h   494  -0.012  0.035  0.033   0.0 100.0   0.0    0.0  0.0
H06-h06    15 cm 24h   490  -0.007  0.037  0.036   0.0 100.0   0.0    0.0  0.0
H12-h12    15 cm 24h   490  -0.007  0.036  0.035   0.0 100.0   0.0    0.0  0.0
H18-h18    15 cm 24h   490  -0.006  0.037  0.037   0.0 100.0   0.0    0.0  0.0
H24-h24    15 cm 24h   490  -0.005  0.037  0.037   0.0 100.0   0.0    0.0  0.0
AHW-ahw    15 cm 24h    13  -0.088  0.092  0.028   0.0 100.0   0.0
ALW-alw    15 cm 24h    24   0.072  0.075  0.021   0.0 100.0   0.0
THW-thw  1.50 hr 25h    13  -0.308  6.239  6.486  30.8  38.5  23.1
TLW-tlw  1.50 hr 25h    24  -0.292  3.857  3.928  20.8  25.0  25.0
```

Table A.5. Skill Assessment Statistics of Semi-Operational Predictions at the NOS Duluth, MI Gauge a (NOS ID 9000064) for 2004.

```
Station:                Duluth, Lake Superior, MI
Observed data-longest continuous time segment 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 183.397
h                     5832 183.426
H-h        15 cm 24h  5832  -0.029  0.062  0.055   0.0  98.2   0.0    0.0  0.0
AHW-ahw    15 cm 24h    26  -0.123  0.136  0.058   0.0  57.7   0.0    0.0  0.0
ALW-alw    15 cm 24h    48   0.060  0.068  0.033   0.0 100.0   0.0    0.0  0.0
THW-thw  1.50 hr 25h    26  -0.077  5.211  5.314  19.2  30.8  23.1    0.0  0.0
TLW-tlw  1.50 hr 25h    48  -0.479  2.955  2.946  18.8  47.9   6.3    0.0  0.0

     SCENARIO: SEMI-OPERATIONAL FORECAST
H00-h00    15 cm 24h   494  -0.028  0.061  0.055   0.0  98.4   0.0    0.0  0.0
H06-h06    15 cm 24h   490  -0.031  0.065  0.057   0.0  98.0   0.0    0.0  0.0
H12-h12    15 cm 24h   490  -0.031  0.064  0.055   0.0  98.0   0.0    0.0  0.0
H18-h18    15 cm 24h   490  -0.029  0.065  0.058   0.0  98.2   0.0    0.0  0.0
H24-h24    15 cm 24h   490  -0.029  0.062  0.055   0.0  98.2   0.0    0.0  0.0
AHW-ahw    15 cm 24h    27  -0.123  0.135  0.058   0.0  66.7   0.0
ALW-alw    15 cm 24h    46   0.061  0.071  0.036   0.0 100.0   0.0
THW-thw  1.50 hr 25h    27  -0.407  5.168  5.250  25.9  25.9  22.2
TLW-tlw  1.50 hr 25h    46  -0.304  2.670  2.682  15.2  43.5   6.5
```

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

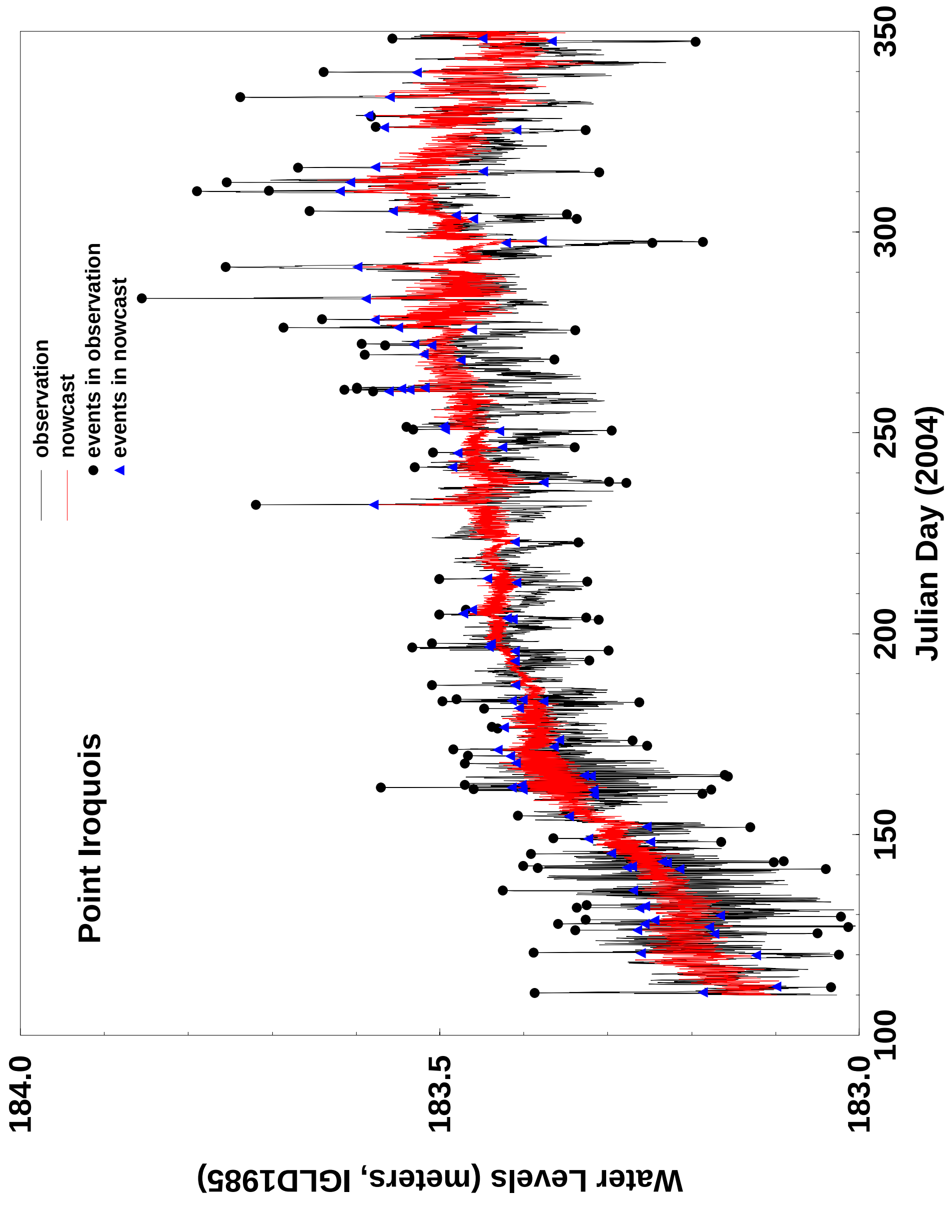

Fig. B.1. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at the NOS Port Iroquois, MI Gauge during 2004.

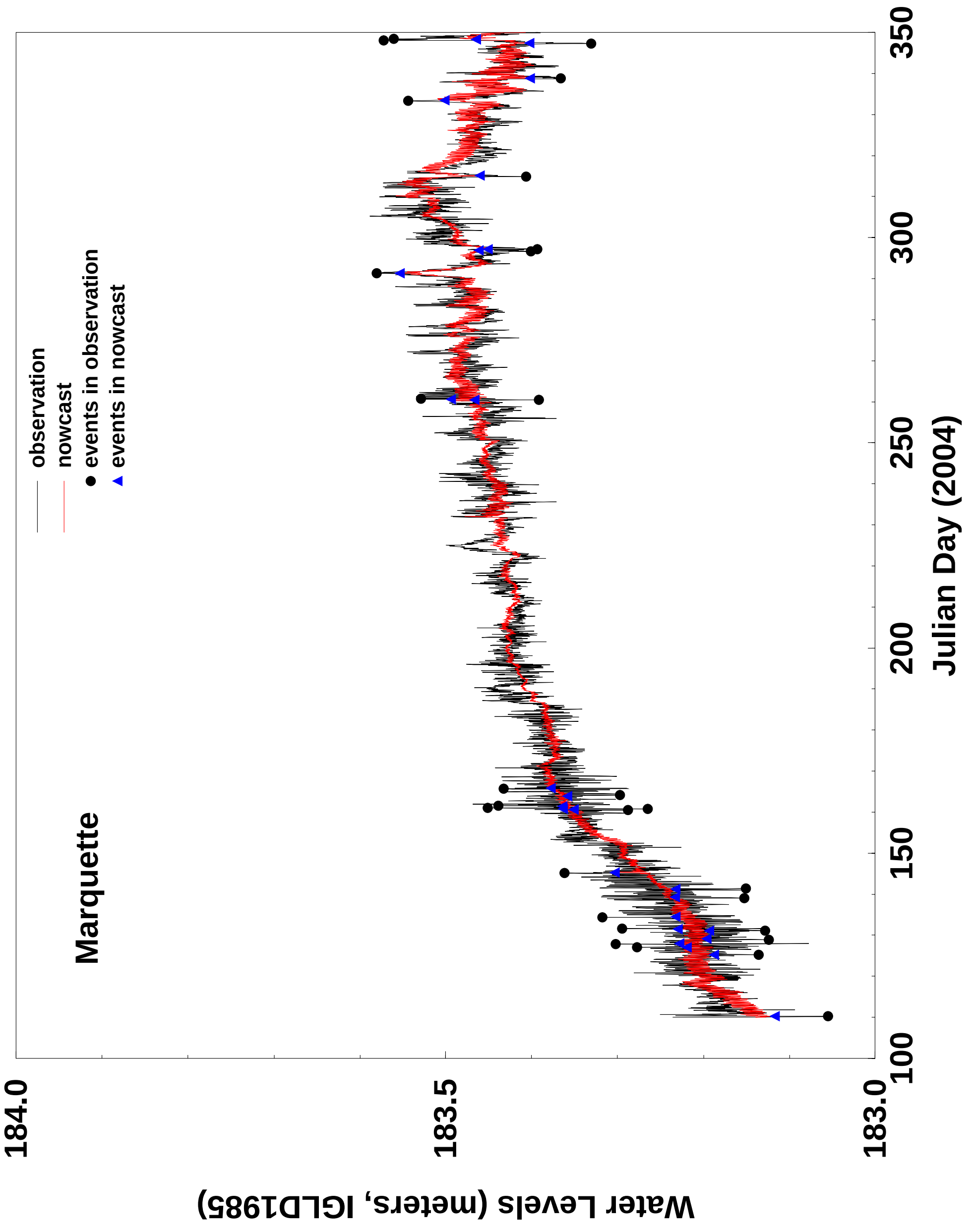

Fig. B.2. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at the NOS Marquette CG Station, MI Gauge during 2004.

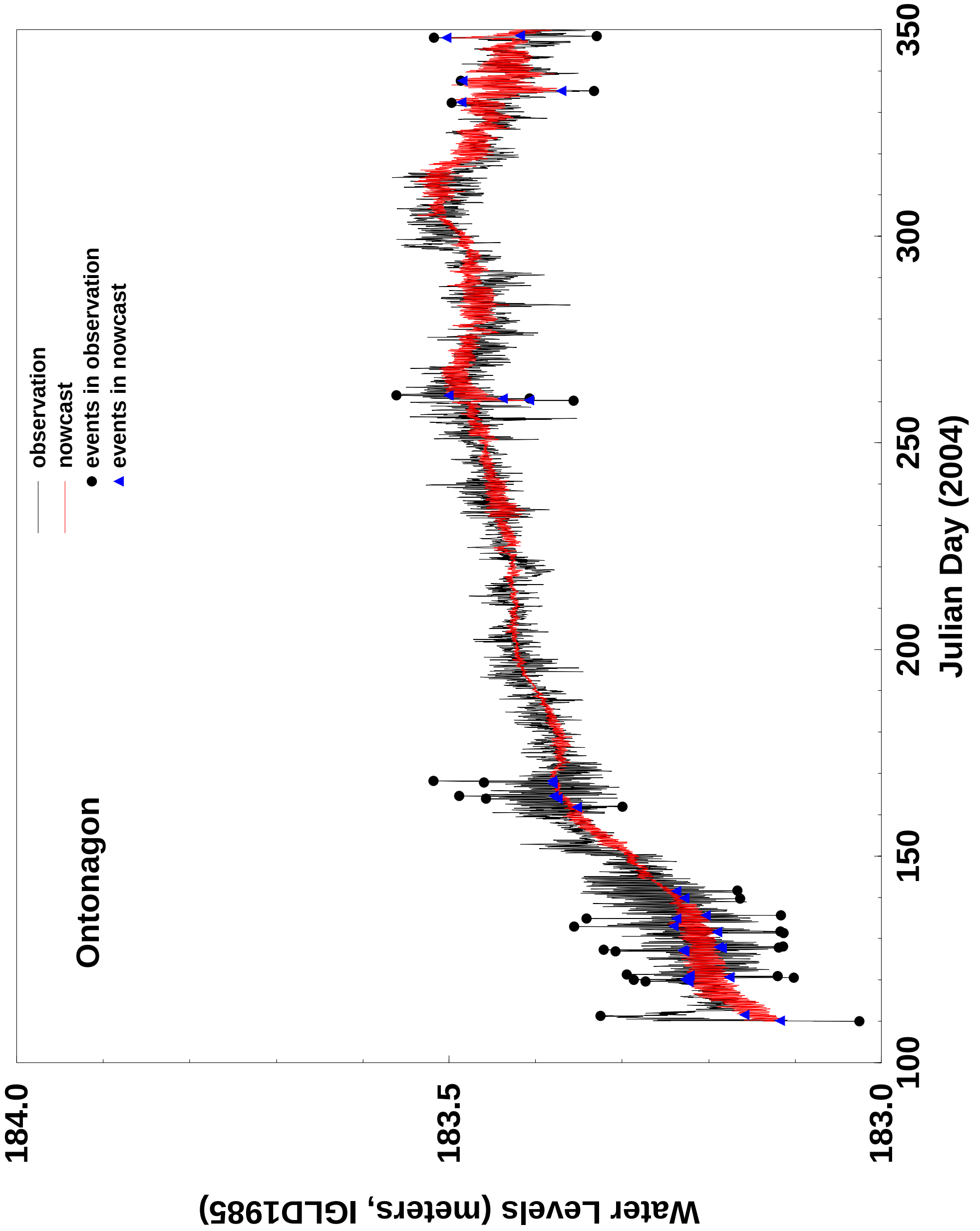

Fig. B.3. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at the NOS Ontonagon, MI Gauge during 2004.

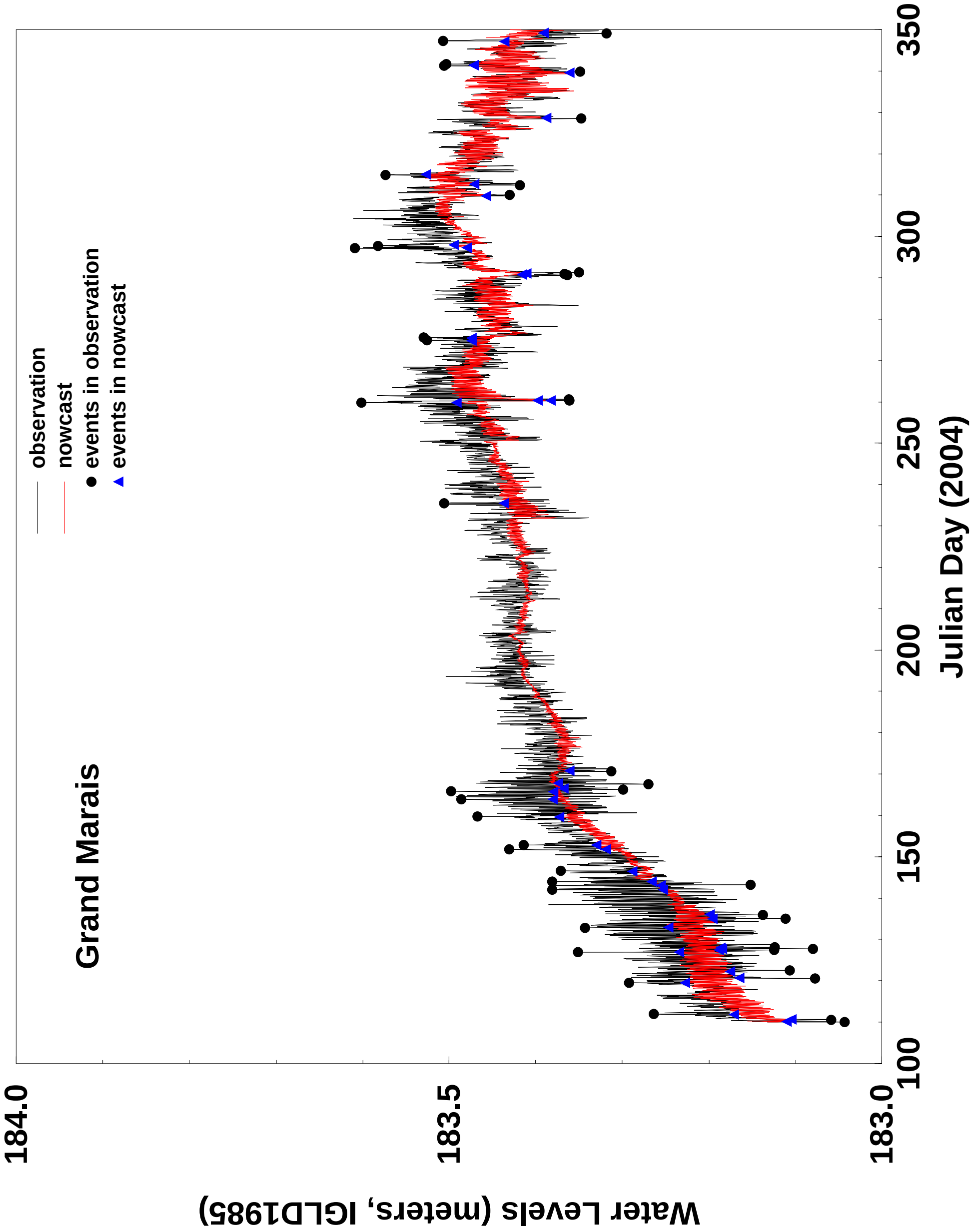

Fig. B.4. Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at the NOS Grand Marais, MN Gauge during 2004.

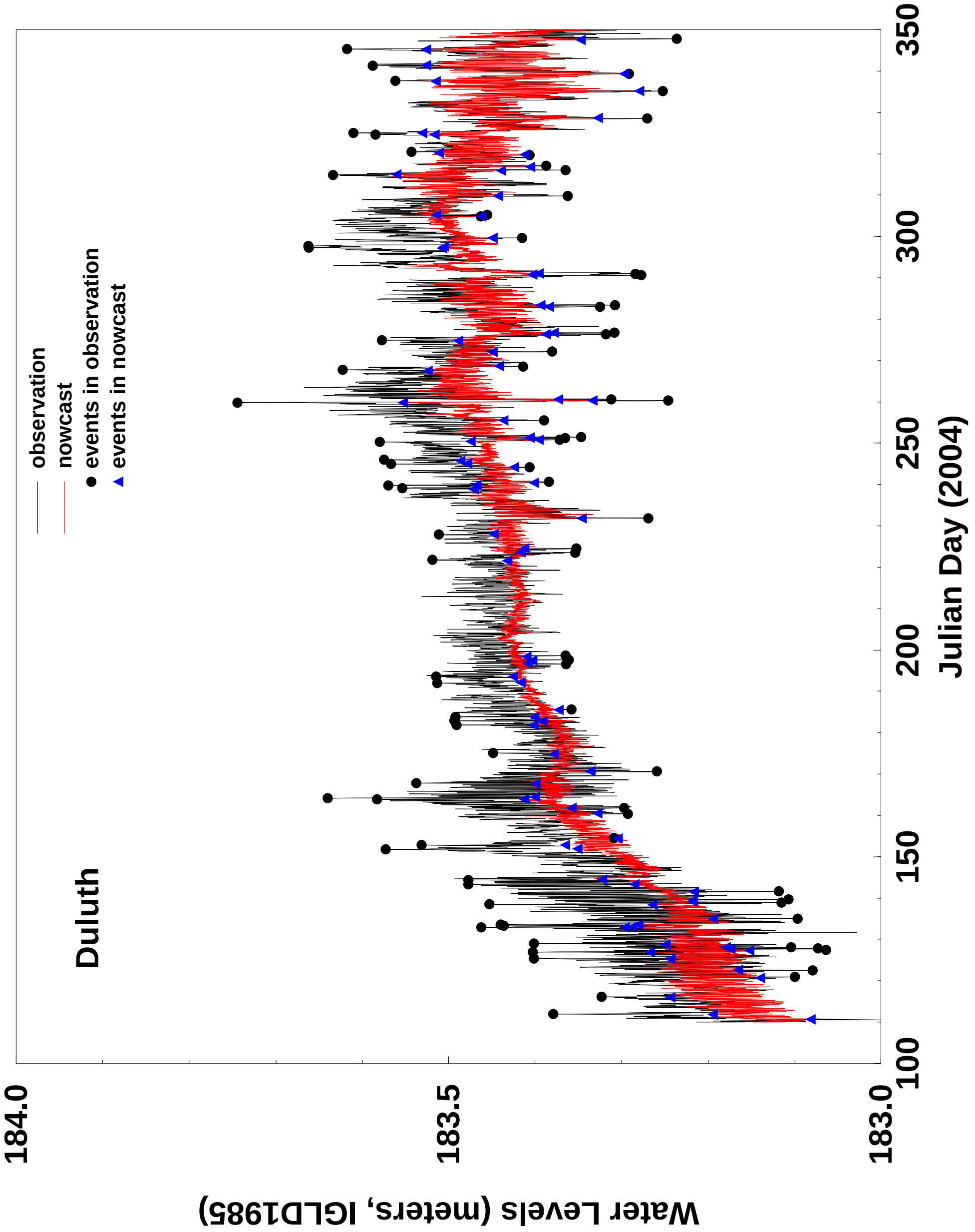

Fig. B.5 Time Series Plot of Semi-Operational Water Level Nowcasts vs. Observations at the NOS Duluth, MN Gauge during 2004.

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

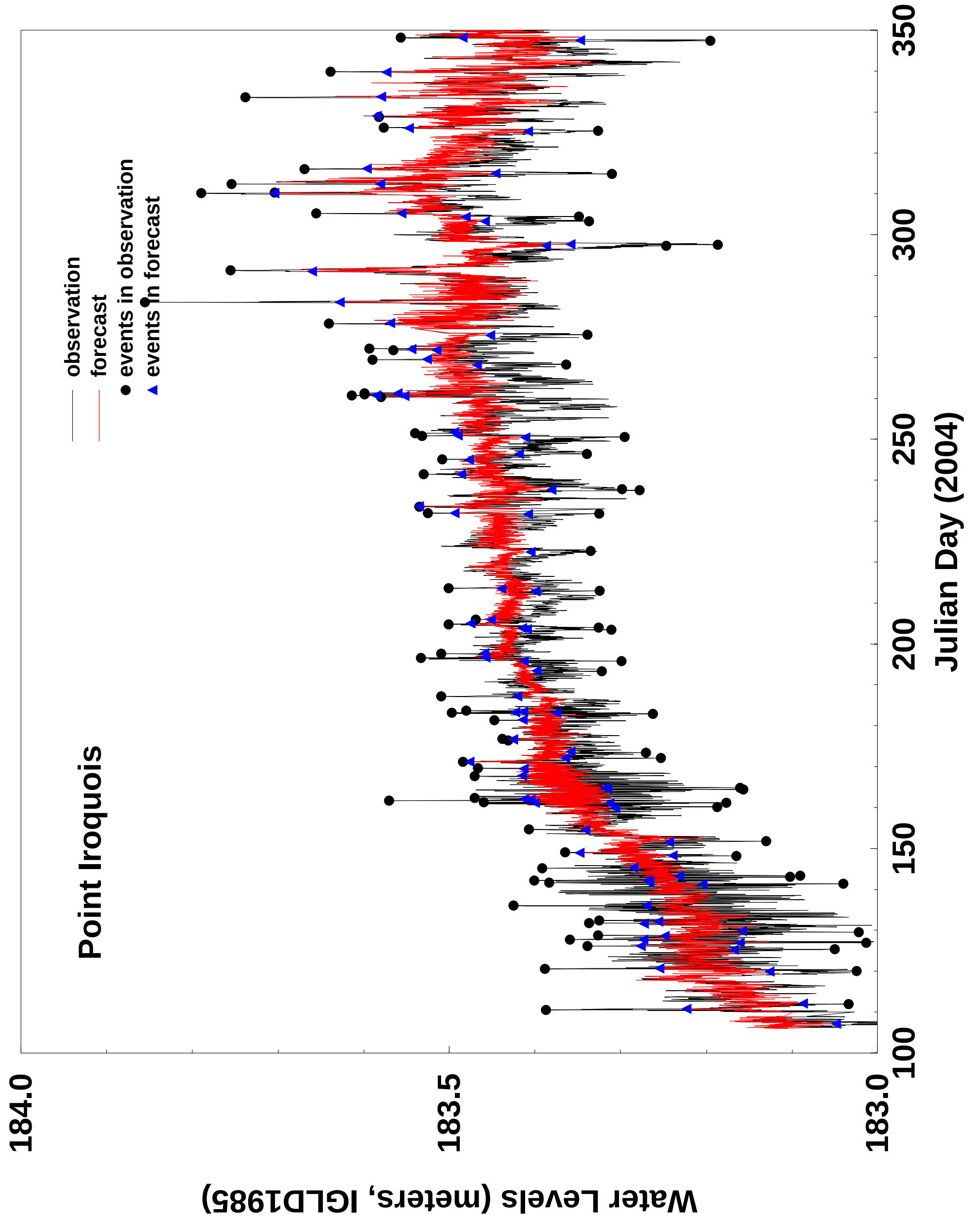

Fig. C.1. Times Series Plot of Semi-Operational Water Level Forecasts vs. Observations at the NOS Port Iroquois, MI Gauge during 2004.

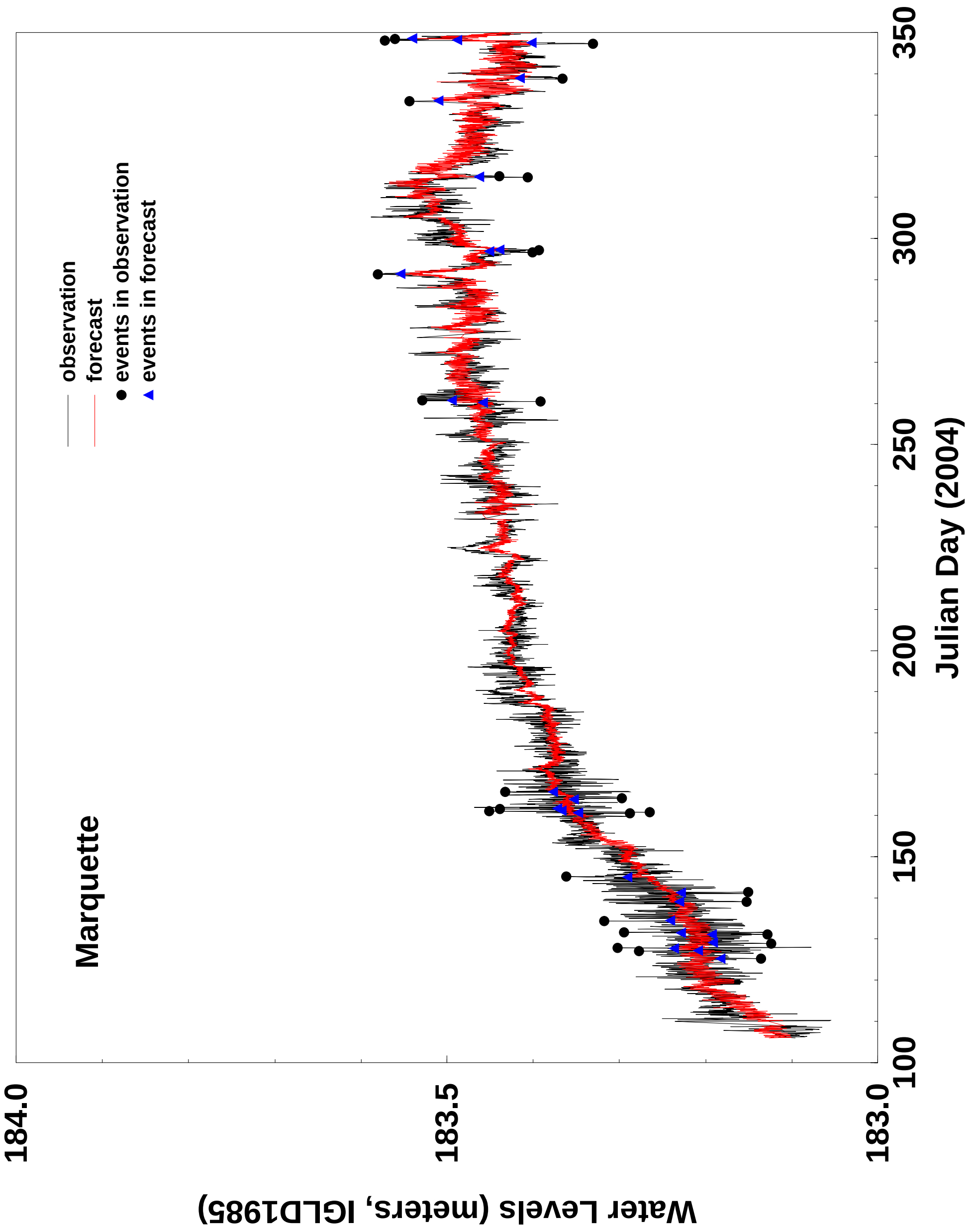

Fig. C.2. Time Series Plot of Semi-Operational Water Level Forecasts vs. Observations at the NOS Marquette CG Station, MI Gauge during 2004.

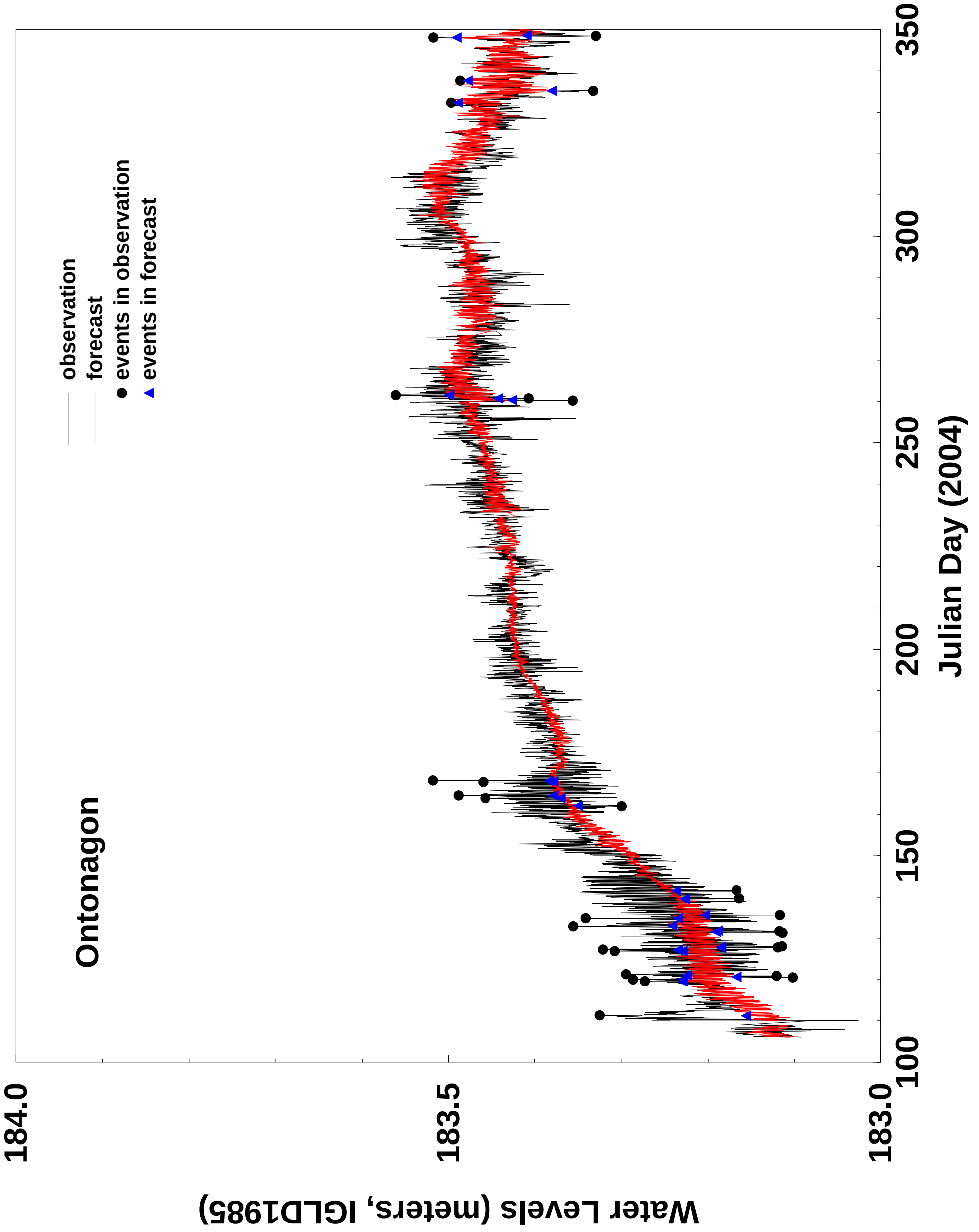

Fig. C.3. Time Series Plot of Semi-Operational Water Level Forecasts vs. Observations at the NOS Ontonagon, MI Gauge during 2004.

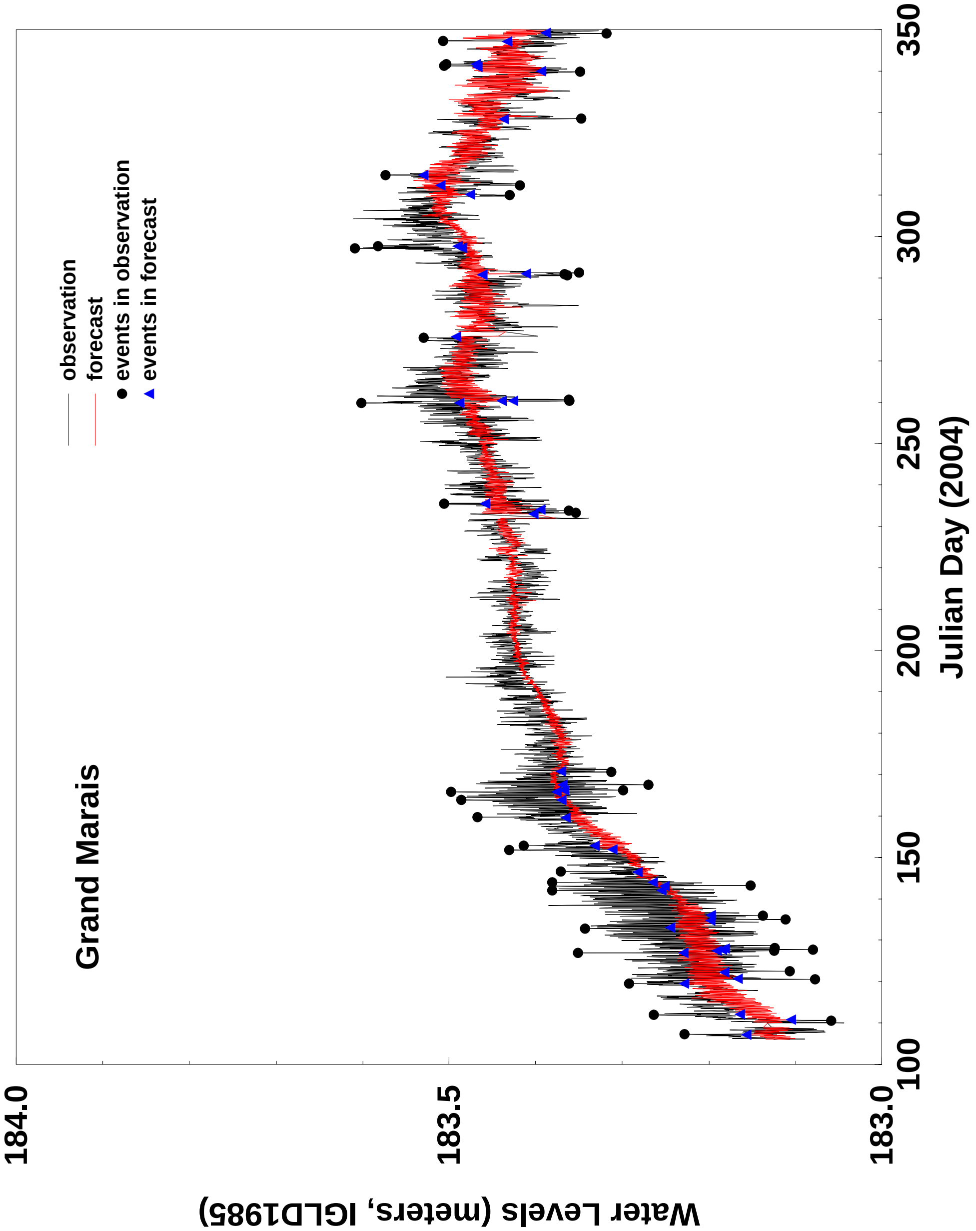

Fig. C.4. Time Series Plot of Semi-Operational Water Level Forecasts vs. Observations at the NOS Grand Marais, MN Gauge during 2004.

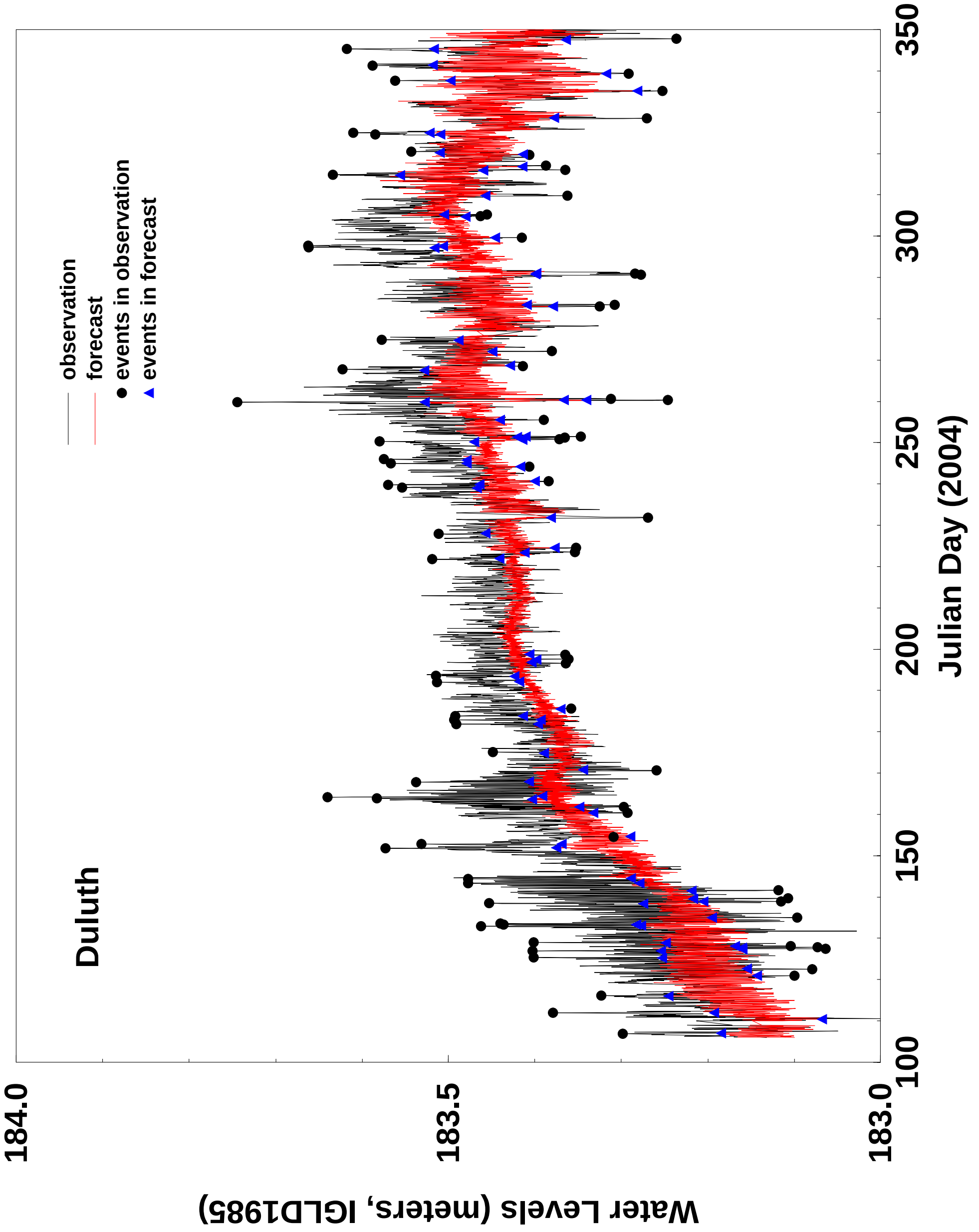

Fig. C.5 Time Series Plot of Semi-Operational Water Level Forecasts vs. Observations at the NOS Duluth, MN Gauge during 2004.

APPENDIX D. Skill Assessment Statistics of Semi-Operational Surface Water Temperature Nowcasts and Forecast Guidance at three NWS/NDBC Fixed Buoys in Lake Superior 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 45006 (Western Superior) for the Period 20 April to 7 November 2004.

```
Station:         NDBC Buoy 45006 in Lake Superior
Observed data-longest continuous time segment from:  4/20/2004 to 11/ 7/2004
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    POFMDNO  MDPO
CRITERION   -     -     -      -      -      -     <1%  >90%   <1%    <N    <N
-------------------------------------------------------------------------------

     SCENARIO: SEMI-OPERATIONAL NOWCAST
T                      4811   9.009
t                      4811   7.905
T-t   3.0 c 24h        4811   1.103  2.066  1.746   0.0  84.9   0.2    0.0  8.0

     SCENARIO: SEMI-OPERATIONAL FORECAST
T00-t00    3.0 c 24h    400   1.125  2.098  1.773   0.0  85.5   0.3    0.0  0.0
T06-t06    3.0 c 24h    398   1.080  2.040  1.733   0.0  84.4   0.5    0.0  0.0
T12-t12    3.0 c 24h    398   1.029  2.069  1.797   0.0  84.7   0.5    0.0  0.0
T18-t18    3.0 c 24h    397   1.003  1.986  1.717   0.0  85.6   0.3    0.0  0.0
T24-t24    3.0 c 24h    397   0.960  1.992  1.748   0.0  85.6   0.5    0.0 12.0
```

Table D.2. Skill Assessment Statistics of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperatures at the NWS/NDBC Fixed Buoy 45001 (Mid Superior) for the Period 21 April to 11 November 2004.

```
Station:         NDBC Buoy 45001 in Lake Superior
Observed data-longest continuous time segment from:    4/23/2004 to 11/ 9/2004
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                     4831   7.504
t                     4831   6.233
T-t        3.0 c 24h  4831   1.271  1.997  1.540   0.0  84.9   1.1    0.0 15.0

     SCENARIO: SEMI-OPERATIONAL FORECAST
T00-t00    3.0 c 24h   403   1.285  2.018  1.558   0.0  84.9   1.0    0.0 12.0
T06-t06    3.0 c 24h   399   1.237  1.951  1.510   0.0  85.7   1.3    0.0  0.0
T12-t12    3.0 c 24h   399   1.229  1.999  1.578   0.0  86.2   1.0    0.0  0.0
T18-t18    3.0 c 24h   399   1.183  1.893  1.480   0.0  85.7   0.8    0.0  0.0
T24-t24    3.0 c 24h   399   1.157  1.899  1.508   0.0  88.0   0.5    0.0  0.0
```

Table D.3. Skill Assessment Statistics of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperatures at the NWS/NDBC Fixed Buoy 45004 (Eastern Superior) for the Period 21 April to 11 November 2004.

```
Station:         NDBC Buoy 45004 in Lake Superior
Observed data-longest continuous time segment from:    4/23/2004 to 11/ 9/2004
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                     4814   8.379
t                     4814   6.245
T-t        3.0 c 24h  4814   2.134  2.700  1.654   0.0  75.9   4.2    0.0 36.0

     SCENARIO: SEMI-OPERATIONAL FORECAST
T00-t00    3.0 c 24h   402   2.137  2.696  1.646   0.0  76.9   4.2    0.0 36.0
T06-t06    3.0 c 24h   397   2.120  2.697  1.669   0.0  75.6   3.0    0.0 36.0
T12-t12    3.0 c 24h   398   2.036  2.599  1.617   0.0  78.4   4.3    0.0 24.0
T18-t18    3.0 c 24h   397   2.019  2.553  1.564   0.0  76.8   1.5    0.0 12.0
T24-t24    3.0 c 24h   398   1.959  2.478  1.519   0.0  79.4   1.3    0.0  0.0
```

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

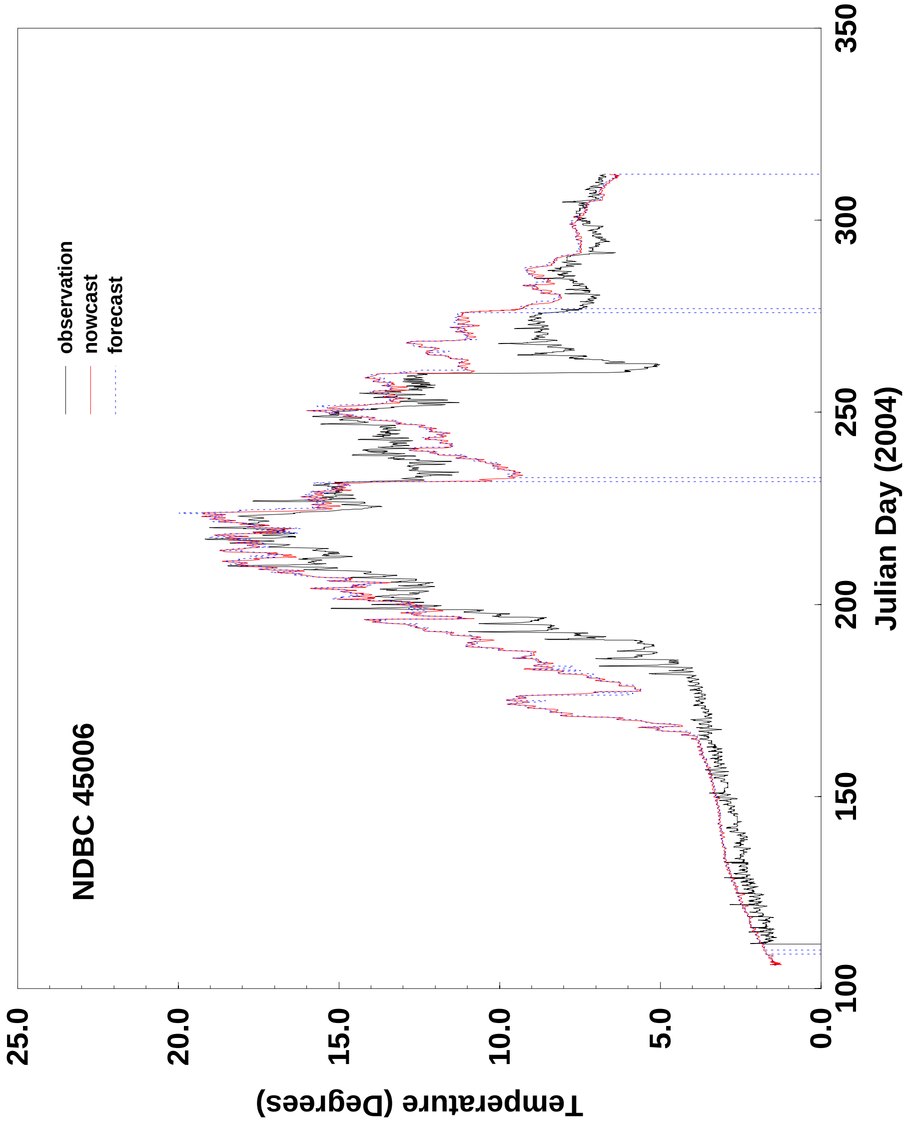

Fig. E.1. Time Series Plot of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperatures (^{o}C) vs. Observations at the NWS/NDBC Fixed Buoy 45006 (West Superior) for the Period mid-April to mid-December 2004. The forecast values depicted on the plot are from the 0000 UTC forecast cycle.

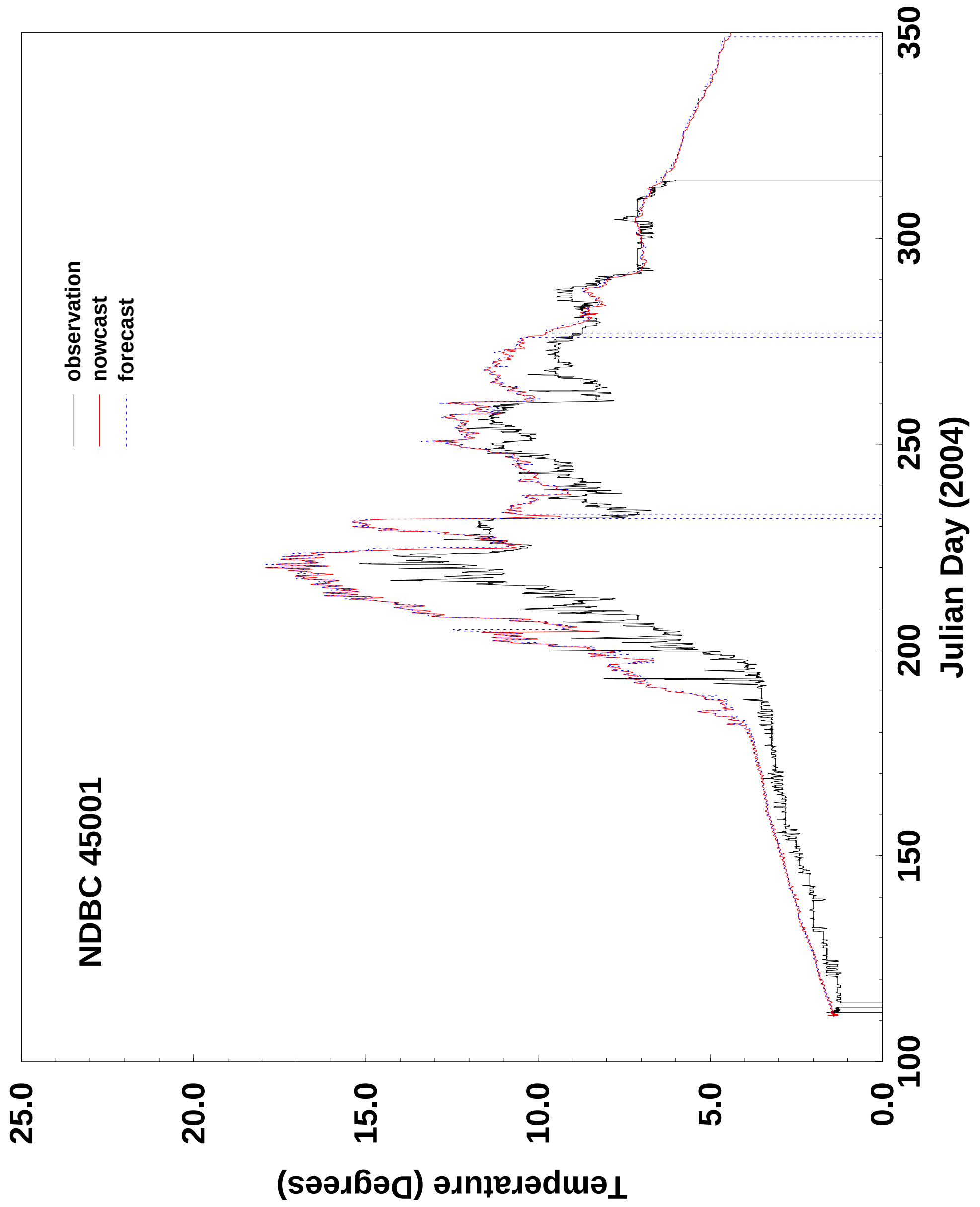

Fig. E.2. Time Series Plot of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperatures (^{o}C) vs. Observations at the NWS/NDBC Fixed Buoy 45001 (Mid Superior) for the Period mid-April to mid-December 2004. The forecast values depicted on the plot are from the 0000 UTC forecast cycle.

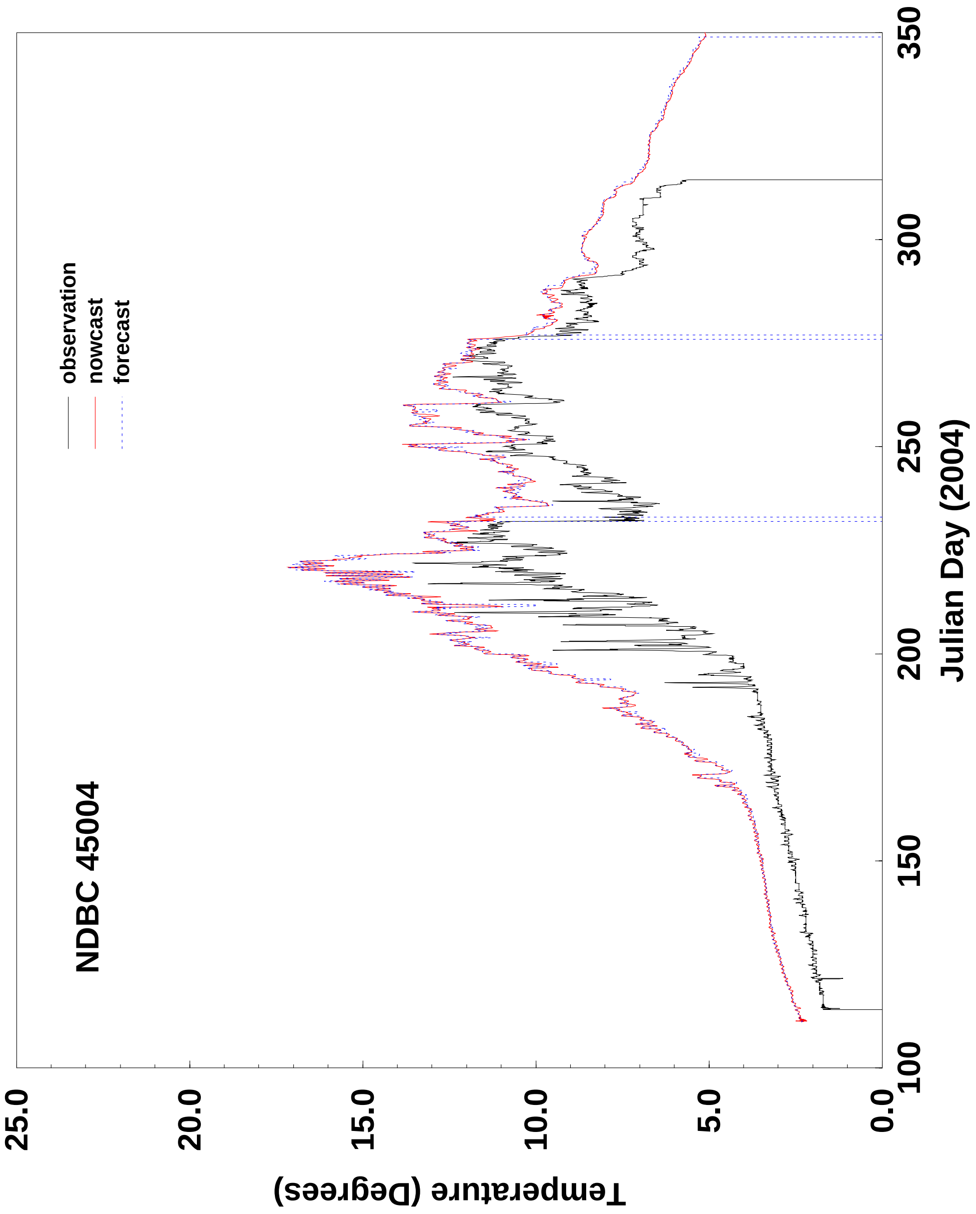

Fig. E.3. Time Series Plot of Semi-Operational Nowcasts and Forecast Guidance of Surface Water Temperatures (^{o}C) vs. Observations at the NWS/NDBC Fixed Buoy 45004 (Eastern Superior) for the Period 23 April to 9 November 2004. The forecast values depicted on the plot are from the 0000 UTC forecast cycle.