NOAA Technical Report NOS OCS 15

NOS EXPERIMENTAL NOWCAST/FORECAST SYSTEM FOR THE PORT OF NEW YORK/NEW JERSEY (NYEFS): REQUIREMENTS, OVERVIEW, AND SKILL ASSESSMENT

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October, 2002

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EXECUTIVE SUMMARY

This document describes the Port of New York/New Jersey Water Level and Current Experimental Model Forecast System and an assessment of its skill. The system, based on a hydrodynamic model, uses near real-time and oceanographic and atmospheric observations and forecasts to produce water level and current nowcasts and forecasts throughout the entire model domain which includes New York Harbor and its estuarine vicinity. In addition to the near real-time information and astronomical tide predictions at a number of gauge locations, the mariners navigating in the Harbor can access the model system generated information to improve navigational safety and to optimize cargo operations.

The needs for developing such a model system are analyzed and the model system requirements are also assessed based on a survey of local maritime pilots. The model system structures and operational procedures are described in this document.

The model system skill assessment scenarios specified by NOS (1999) include the astronomical tide simulation, the model system test nowcasts and forecasts, and the pseudo-operational nowcasts and forecast. The primary statistics used to assess the model performance include: the Central Frequency (CF) - to measure the model errors from a specified target; the Positive Outlier Frequency (POF) and Negative Outlier Frequency - to describe how often the model system either over or under predicts; Maximum Duration of Positive Outliers (MDPO) and Maximum Duration of Negative Outliers (MDNO) - to describe how long the model system either over or under predicts. The skill assessment of the astronomical tide simulation and the model hindcasts (in place of test nowcasts/forecasts) are described in Wei and Chen (2001). The results from the experimental model system nowcast/forecast are summarized as follows.

(1) Water Level at Bayonne and The Battery

Nowcasts: All statistics meet NOS (1999) standard

Forecasts: Do not meet NOS (1999) but better than astronomical tide predictions

<u>Bayonne Bridge</u>:	CF > 80%, POF and NOF about 1% to hour 6
	CF about 75% at hour 24 and POF and NOF about 2%.
<u>The Battery</u>:	CF about 75%, POF < 1%, NOF about 3% to hour 6
	CF about 71%, POF about 1%, NOF about 3% to hour 24

(2) Currents

Nowcasts: Do not meet NOS (1999) at Bergen Point. Meet NOS (1999) at The Narrows

<u>Bergen Point</u>:	Speed:	CF(76%), POF(9%), NOF(0%), MDPO & MDNO < 3 hours
	Direction:	CF(86%), POF & NOF < 1%, MDPO & MDNO < 1 hour
<u>The Narrows</u>:	Speed:	CF(95%), POF & NOF< 1%, MDPO & MDNO < 3 hours
	Direction:	CF(94%), POF(2.5%), NOF<1%, MDPO & MDNO < 15 hours

Forecasts:

<u>Bergen Point</u>:	Speed:	CF(76%), POF(9%), NOF(0%), MDPO & MDNO < 22 hours
	Direction:	CF(85%), POF & NOF < 1%, MDPO & MDNO < 8 hours
<u>The Narrows</u>:	Speed:	CF(95%), POF & NOF< 1%, MDPO & MDNO < 2 hour
	Direction:	CF(94%), POF(2%), NOF < 1%, MDPO & MDNO < 14 hours

1. INTRODUCTION

Mariners navigating in New York Harbor (Figure 1) and nearby estuaries rely on astronomical tide predictions (NOS Tide and Tidal Current Tables) and real-time water level and current information (PORTS - Physical Oceanographic Real-Time System) at selected locations maintained by National Ocean Service (NOS) of NOAA. However, these gauges provide limited information to the users and the astronomical tide predictions do not account for the non-tidal signals induced either by meteorological or river discharge influences.

A numerical model-based forecast system is the most effective and accurate tool to account for the effects of the non-tidal signals on the water levels and currents in the harbor. The Port of New York/New Jersey Experimental Forecast Model System (NYEFS) is designed to provide accurate water level and current predictions to the marine community in the New York Harbor region (Figure 1.1). The needs and requirements for developing the system as a forecast component of NOS's PORTS are described in Chapter 2.

The model system includes a hydrodynamic model component and a suit of software for processing input and output data, including graphic applications. The nowcast/forecast model system operation consists of three components: input data ingest, model nowcast/forecast, and model data post-processing. Each element is controlled by automated scripts on a Unix environment. The sequential procedures include: gathering and formatting the input data for the hydrodynamic nowcast/forecast simulations, running the nowcast/forecast model, and post-processing the model output to graphically display on the Internet or for dissemination to users via ftp. The system overview is described in Chapter 3.

The hydrodynamic model of the experimental nowcast/forecast model system has been developed and calibrated (Wei and Chen, 2001) based on a three-dimensional barotropic version of the Princeton Ocean Model (POM, Blumberg and Mellor, 1987). A fine sub-grid model, covering channels and bays critical to navigation, including the Kill van Kull and Bergen Point, has been developed and embedded within and dynamically connected to the coarse grid model using a one-way coupling technique. Figure 1.2 shows the model grids. The model system provides hourly nowcasts and 36 hour forecasts of water levels and currents within the New York Harbor.

Since April of 1999, the experimental system has been implemented and run on NOS's Coastal Survey Development Laboratory (CSDL) computer. The model system has been modified to improve the accuracy and reliability. Automated scripts handling operational procedures have been modified and updated to accommodate a variety of networking and changes in data types.

This report describes the model performance based on NOS requirements for operational nowcast/forecast system (NOS, 1999). Skill assessments for tidal simulation and test nowcast assessments have been reported as part of the model documentation in Wei and Chen (2001). Due to 1997 observed data errors at The Battery, the water level test nowcast skill assessment at The Battery was based on four months of observations. A test nowcast simulation conducted using the entire1998 data shows similar results to the 1997 four month test nowcast skill assessment. Model nowcast/forecast output from the experimental system are saved for skill assessment, which is presented in Chapter 4. This report, in conjunction with the model documentation (Wei and Chen, 2001), completes the Port of New York/New Jersey skill assessment required by NOS (1999).

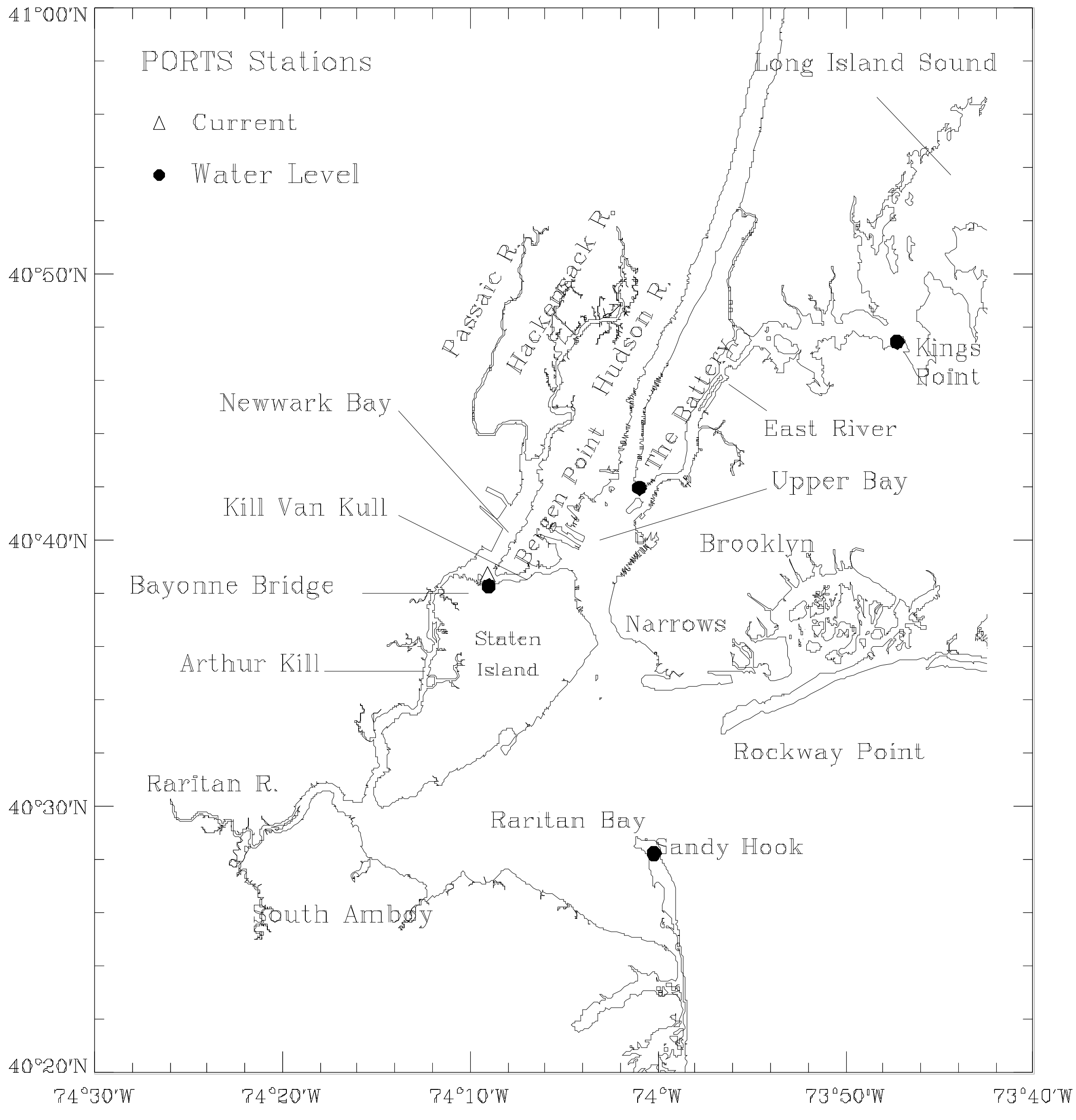

Figure 1. Map showing New York Harbor and major tributaries.

2. NEEDS ANALYSIS AND REQUIREMENTS ASSESSMENT

Much of the hydrodynamics in the harbor are determined by the coastal fluctuations propagating through the harbor entrance (Figure 1.1). The main flow goes through The Narrows; part of the flow north of The Narrows goes to the East River and the Kill van Kull, while the reminder goes to the Hudson River. When the flow through the Kill van Kull meets the flow through the Arthur Kill at Bergen Point, a tidal eddy is generated. The flow continues north to the Upper Newark Bay.

In the Harbor, NOS maintains a PORTS for navigation safety. Information provided to the users by NY PORTS includes: water level at Sandy Hook, Kings Point, The Battery, and Bayonne Bridge; meteorology at Robbins Reef, Bayonne Bridge Sandy Hook, and Kings Point; and currents at Bergen Point and The Narrows (Figure 2.1).

NOS's PORTS provides near real-time information to users only at the gauge stations. However, there is still need for information in addition to the near real-time information at PORTS stations, including:

(1) near real-time water level and current information at non-gauge locations,
(2) short term (1 to 2 days) water level and current forecast guidance information, and
(3) detailed current information in navigational channels, such as the Kill van Kull, for Coast Guard "right of way" decision making.

Figure 2.2(a) shows a water level time series at Bayonne Bridge from January 11 to 16, 2002. On January 13, due to a strong westerly wind (Figure 2.2(b)), the observed water levels (asterisks) dropped from 0.5 m above the astronomical tide prediction (solid line) to 0.8 m below the astronomical tide prediction within 24 hours. The situation poses a groundin grisk. Therefore, for navigation safety, there is the need for a more accurate tool other than just the astronomical prediction. The Port of New York/New Jersey Experimental Water Level and Current Nowcast/Forecast Model System is designed for this purpose. Figure 2.2(c) shows the model system water level nowcast and forecast for the same period. Both the model nowcast (dotted line) and the forecast (dashed line) are much closer to the observations than just the astronomical tide predictions. This example shows that an oceanographic forecast system based on a hydrodynamic model is an effective tool to make near real-time nowcasts and short term forecasts of the water levels and currents in an estuary.

Marine pilots of the Port of New York and New Jersey maritime community such as the Sandy Hook Pilot Association have participated in activities of the Harbor Navigation Committee organized by the Port Authority of New York & New Jersey. Through this Committee, representatives from NOS's Office of Coast Survey have collected the oceanographic information needs voiced by the marine pilots and other users. In May, 2001, a user needs and requirements questionnaire was distributed to the maritime community for information. The questionnaires, designed by CSDL, requested users to identify their priorities for oceanographic parameters (water level, current, salinity, and temperature), the information on necessary locations; and the information on frequency and error tolerance.

The results from returned questionnaires are summarized as follows:

(1) The oceanographic parameters of highest priority are the water level and current nowcasts and forecasts.
(2) The locations of high priority are shown in Figure 2.3. In response to the survey, NOS deployed a current meter at The Narrows in August, 2001 as part of the NY PORTS.
(3) The forecast information should be at least out to 24 hours.
(4) The forecast information report frequency should be at least hourly or shorter.
(5) The forecast information should be updated at least four times a day.
(6) The nowcast and forecast error tolerance proposed by NOS (1999) for water level and current speed are acceptable (e.g., 90% of the time the errors be less than 0.5 ft for water level and 0.5 kt for current speed).
(7) A 95% confidence limit is recommended.
(8) Dissemination methods requested include web-based time series plot, plan views, and PORTS screen display.

All of this information will be used to improve and modify the model system design before it becomes operational.

Figure 2.1. New York Harbor PORTS stations maintained by NOS.

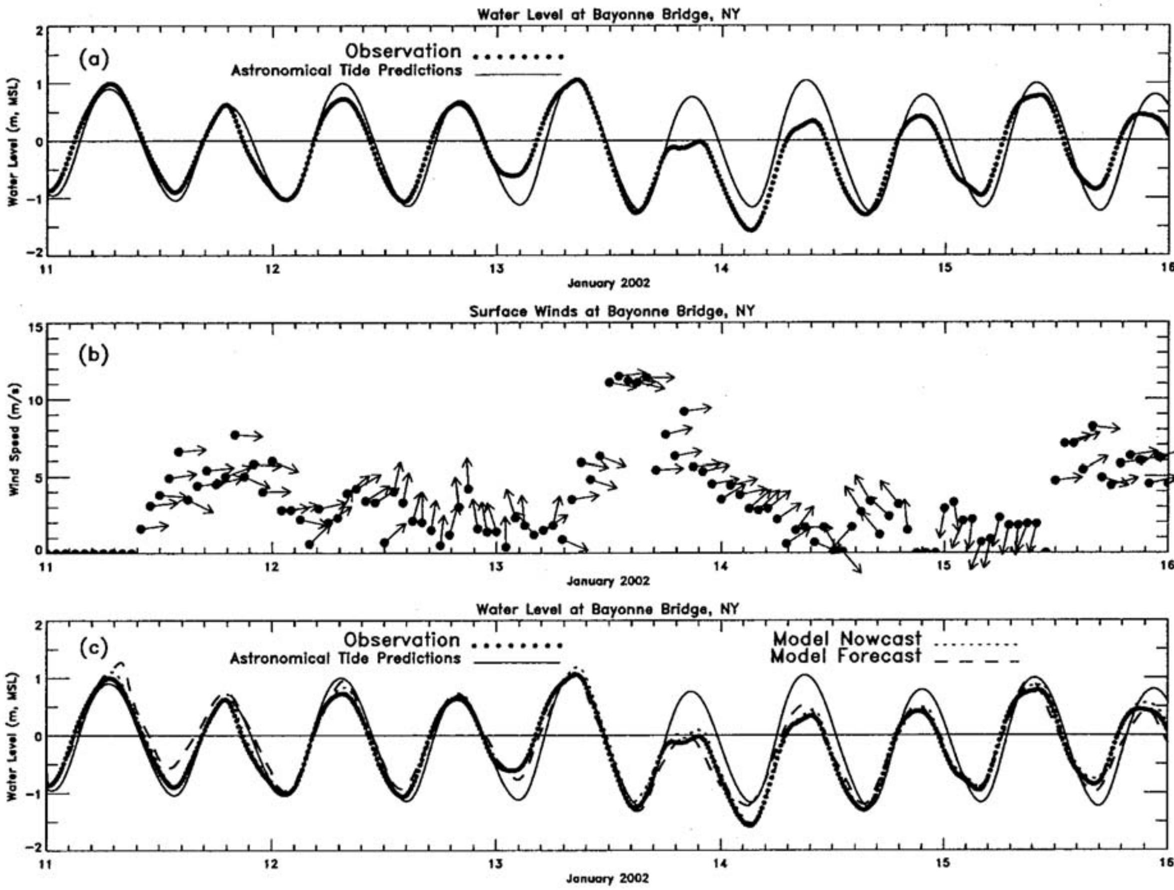

Figure 2.2. Water level at Bayonne Bridge; (a) observations and astronomical tide prediction, (b) surface wind observations, and (c) observations and astronomical tide prediction over-laid with model water level nowcast and forecasts.

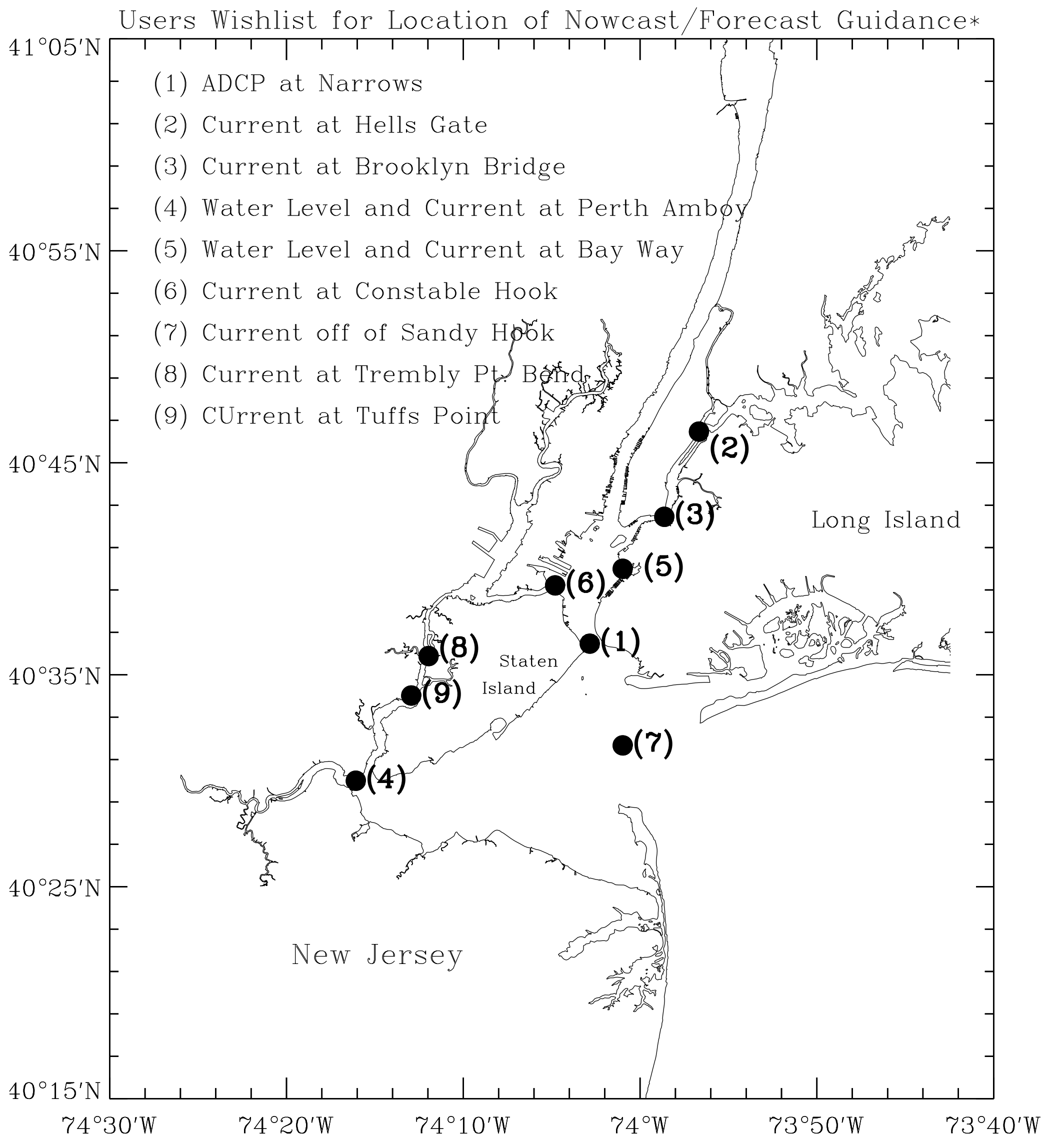

Figure 2.3. Parameters and locations that marine pilots request for navigation.

3. SYSTEM OVERVIEW

The NYEFS provides near real-time water level and current nowcasts and forecasts using a hydrodynamic model forced with water levels at the open ocean boundary and with winds on the water surface. The hydrodynamic model used for the system, as described in detail in Wei and Chen (2001), is a three-dimensional barotropic model based on the Princeton Ocean Model (POM, Blumberg and Mellor, 1987). The model requires forcing of real-time water levels and winds acquired from NOS's PORTS, water level forecasts acquired from the Extra-Tropical Storm Surge (ETSS) model (Chen et al., 1993; Kim et al., 1996), and wind forecasts acquired from the Eta (Black, 1994) model. The model grid information including bathymetry data is stored as a separate file. Data acquired are then formated to be read directly by the model. With the near real-time input data and the initial conditions created by the previous nowcast, the hourly nowcast is executed to obtain the water levels and currents throughout the entire model grid for the past hour. The nowcast model fields at 05Z and 17Z are used for the 36 hour forecast run forced with Eta wind and ETSS water level forecasts. Monthly climatological river discharges for the Raritan, Passic, Hakensack, and Hudson Rivers (Figure 1.1), generated from USGS (U.S. Geological Survey) observations are used as fresh water input to the model. The output from the nowcast and forecast runs are processed and plotted with graphic application for posting on the Internet. The NYEFS is implemented by various Unix scripts. Each script performs different operations including data gathering and quality control, executing nowcast and forecast simulations, and output data processes for product dissemination and graphic preparation. A schematic of the NYEFS system is shown in Figure 3.1 and also described in the following sections.

3.1. Data Ingest and Boundary Forcing Generation

The data required for driving the model nowcast and forecast include the water levels as lateral open boundary conditions and winds as the surface forcing. For nowcast runs, near real-time water levels and winds at National Water Level Observation Network (NWLON) stations (Figure 2.1); Sandy Hook, NJ and Kings Point, NY (switching from Willets Points, NY on November 14, 2000) and are available in PORTS Uniform Flat File Format (PUFFF) format for anonymous ftp (File Transfer Protocol) through Internet from the NYPORTS data base server in CO-OPS. The near real-time water levels are acquired every 6 minutes and are processed hourly before the nowcast run. The non-tidal water levels are obtained by subtracting the astronomical tide prediction from the observations. In the case of data interruption, such as connection failure or erroneous data values, the non-tidal water levels are persisted and added to the tide predictions as a substitute for open boundary conditions at Sandy Hook and Willets Point. Therefore, the hourly nowcast run can be continued without interruption. Except when a strong wind prevails for a long duration, the water levels within the harbor are predominately determined by the water levels at the lateral open boundary, Sandy Hook. Therefore, in the case of data interruption, the nowcast can safely run without any wind forcing.

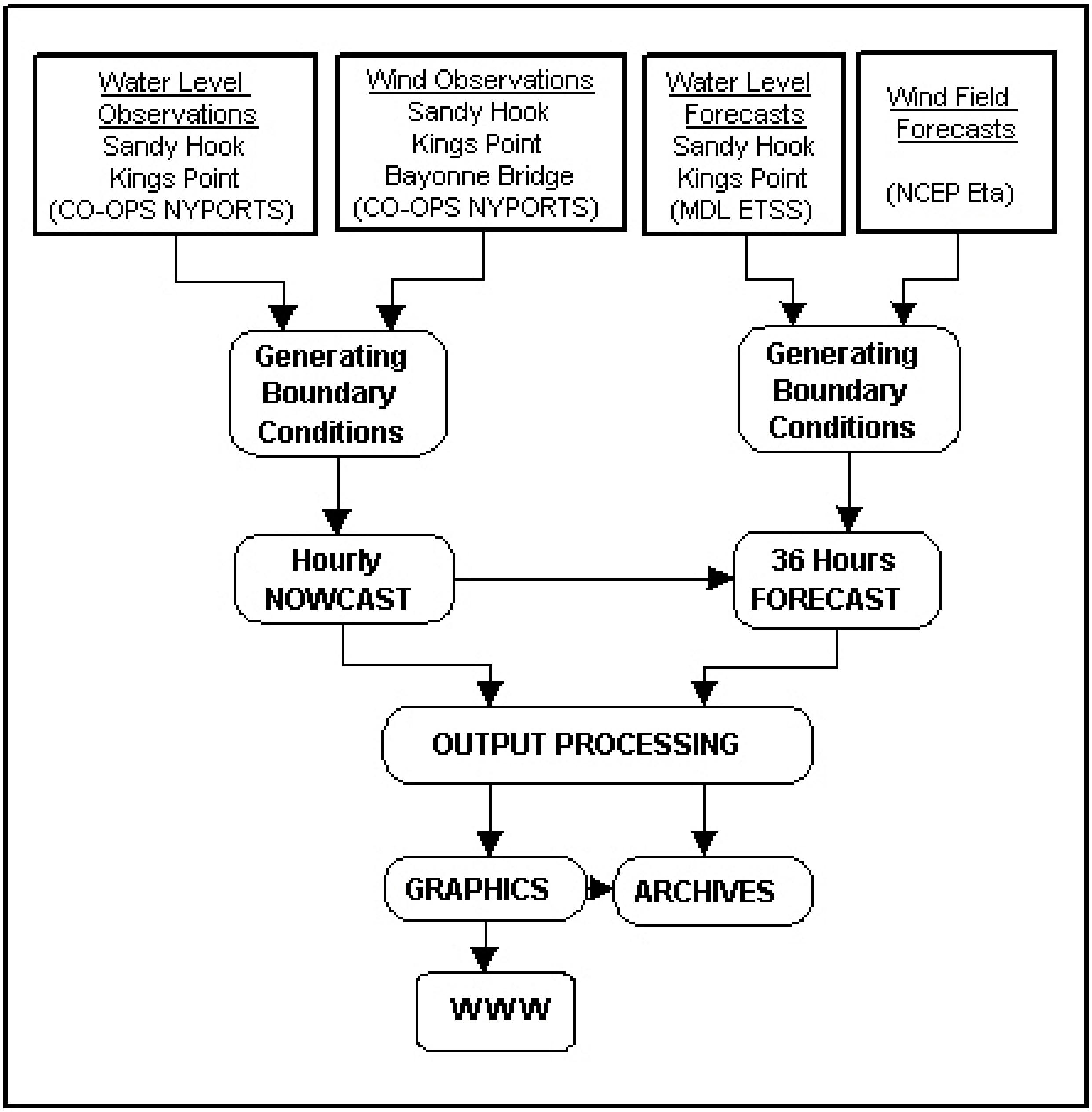

Figure 3.1. Schematic of the NYEFS system operation function element.

Winds at Bayonne Bridge are also obtained for model input. Water levels at Bayonne Bridge and The Battery, and current velocity at The Narrows (starting July, 2001) are also acquired for model verification purpose.

For the forecast, the wind-driven water level forecasts produced by NWS's Meteorological Development Laboratory (MDL) ETSS are acquired by NOS's Operational Data Acquisition and Archive System (ODAAS, Kelley et. al.,2001) as the lateral open boundary condition. Since ETSS water level forecasts have a consistent datum bias, a correction procedure has been applied to reduce the errors. The correction procedure includes two steps. First, the averaged discrepancy between the previous 24 hour forecasts and observations at the NYEFS model open boundaries: Sandy Hook, NJ and Kings Pt., NY, are calculated. The entire present 24 hour forecasts are then corrected by the averaged datum discrepancy. Even after the datum bias correction, there is a water level gap between the last observed and the first forecast water level. To prevent any model instability from occurring, the first 6 hour datum-corrected forecasts are smoothed. The smoothed water level forecasts are then added to the tide predictions at Sandy Hook, NJ and Kings Point, NY for the model lateral open boundary conditions. Wind velocity forecasts acquired by ODAAS from the Eta model are used for surface forcing. Water level and wind data ingested for nowcast and forecast model runs are also archived for further evaluation.

3.2. Nowcast Run

The water level and wind boundary forcing fields at Sandy Hook and Willets Point are used to drive the hourly nowcast run. The model is initialized with the fully developed state from the previous nowcast run. The beginning hour is determined by the restart initial file. This hourly nowcast run produces the water levels and three-dimensional currents for the entire model grid. A restart file describing the entire mode grid ocean condition is also created for the next hourly nowcast run, or for the forecast run. Water level and current at selected locations are processed for plotting the time series. Water surface elevation and currents throughout the model domain are also processed for the contour and current vectors plots, and displayed on the Internet web site. Nowcast data such as water levels at model interior NWLON locations Bayonne Bridge and The Battery, and currents at Bergen Point, Bayonne Bridge, and The Narrows (Figure 2.1), are also archived for model skill assessment. Water levels at additional locations (Figure 3.2), where no operational observations available, are also output for time series plotting.

3.3. Forecast Run

The twice a day forecast runs start when the forecast forcing input files, as described in Section 3.1, are generated. The monthly climatological river discharges that are used in the nowcast are also used for the forecast. The model forecast is initialized with the fully developed state of motion field of the model nowcast. The model runs for the 36 hour forecast and the output similar to the nowcast, i.e., water level and current throughout the entire domain and at selected locations, are processed and plotted. Model forecasts are also archived for the skill assessment.

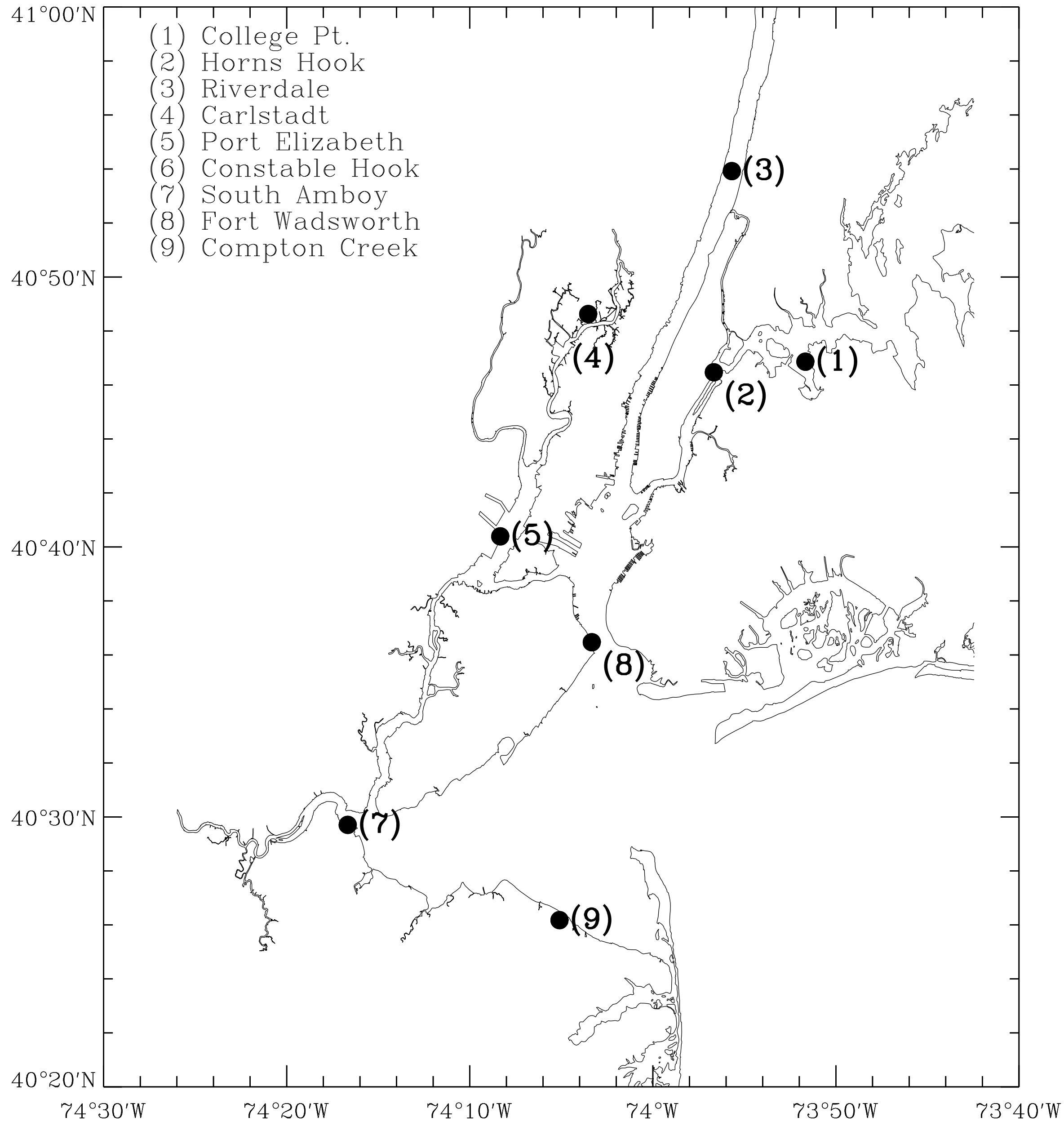

Figure 3.2. Station locations available for model system water level output.

3.4. Operational Environment and Scheduling

The NYEFS is running on two SGI (Silicon Graphic, Inc.) work stations at CSDL. The data ingest, model nowcast and forecast, and output post-processing are running on an SGI Origin 2000 computer. This server is a high-end MIPS computer equipped with eight 400 MHz (megahertz) IP27 processors and 2 GB (gigabyte) total memory and is using the IRIX 6.5 operating system. The IDL graphic software (Version 5.3) is used for generating water level and current time series, contour, and vector plots in gif or post-script format. The graphic server is an SGI Indigo2 computer equipped with a 195 MHz processor and 128 MB (megabyte) of memory. This server is also using the IRIX 6.5 operating system.

The NYEFS nowcast schedule is shown in Figure 3.3. NYEFS performs the data ingest every 6 minutes to acquire PUFFF data and process the hourly data at minute 7 each hour. The hourly model nowcast run is submitted at minute 8 each hour (or till input data process is completed). The nowcast output process is followed immediately after the nowcast completion. The 05Z and 17Z forecast runs are submitted at 0520Z and 1720Z, respectively, for a 36-hour simulation. Shown in Figure 3.4, the forecast run starts with an initial condition defined by the corresponding hourly nowcast model field. Under a machine dedicated situation (i.e., no CPU competition), the hourly nowcast requires about 67 seconds in CPU time and the 36-hour forecast requires about 33 minutes.

3.5. System Interruption and Recovery Procedure

The NYEFS is implemented with UNIX scripts to control operation procedures. The run schedule of these scripts is controlled by an UNIX crontab. These scripts have been frequently modified and updated since the system commenced in 1999. For example, a procedure has been adopted to accommodate the real-time water level interruption at Sandy Hook and Willets Point. The procedure uses the “persistent sub-tidal water level” added to the astronomical prediction to obtain the model open boundary forcing so that the nowcast run can continue without interruption. However, unexpected interruption still occurs. The interruptions result from many reasons such as server shutdowns, network breakdowns, and NWLON station switches (from Willets Point to Kings Point). The forecast run can proceed without Eta wind forecasts, but it can not run without ETSS forecasts. A system interruption would occur if ETSS is not available from ODAAS.

A manual recovery procedure has been developed for the nowcast run. The procedure is also implemented with a UNIX shell script. This script is submitted manually by entering date information including the year, month, day, and hour when the last valid coarse grid and fine grid model restart files exist. The recovery script generates water level and wind forcing from PORTS archives based on the date information entered. The model will then run in a hindcast mode to bring the nowcast up to the “now” time. After the recovery hindcast is completed the system will operate normally.

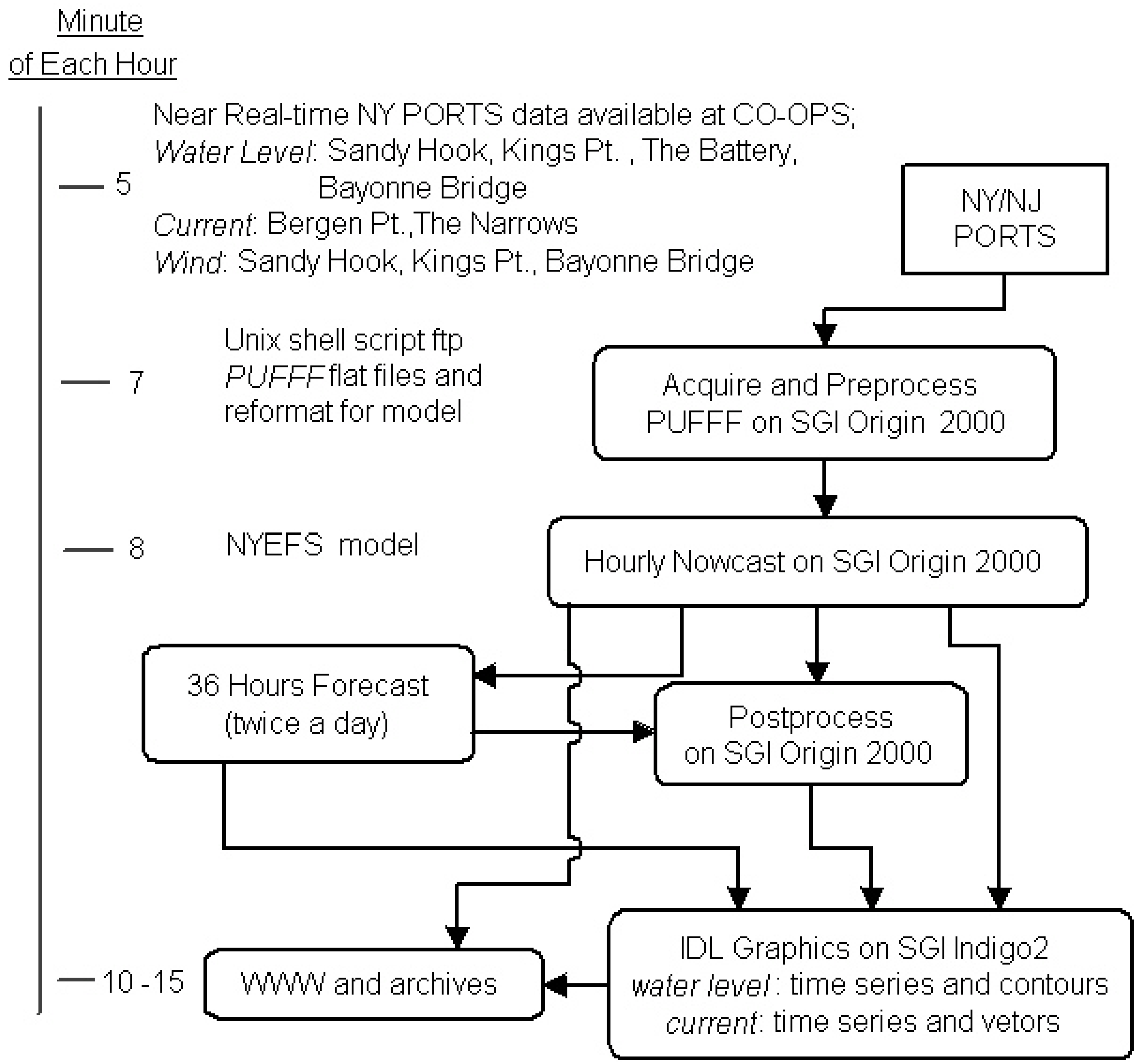

Figure 3.3. NYEFS nowcast run schedule.

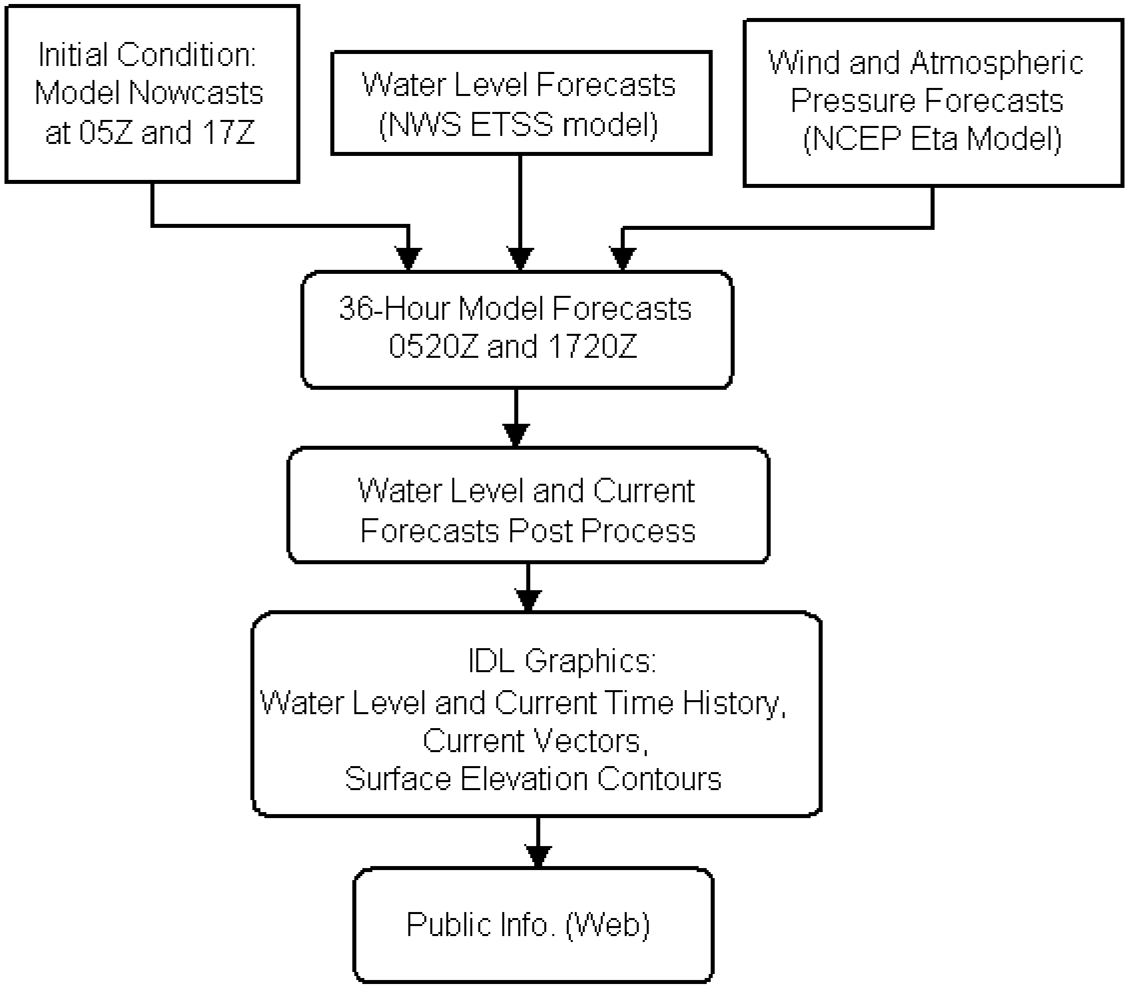

Figure 3.4. NYEFS forecast run schematic flow chart.

4. SEMI-OPERATIONAL NOWCAST/FORECAST SKILL ASSESSMENT

Skill assessments for tidal simulations and test nowcast assessments have been reported as part of the NYEFS model documentation in Wei and Chen (2001). This report describes the model system performance based on NOS requirements of an operational nowcast/forecast system (NOS, 1999). According to NOS (1999), the definition of model run scenarios for semi-operational nowcast/forecast are as follows:

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

Semi-operational Forecast: In this scenario, the model is forced with actual other model forecasts 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.

The NYEFS, as described in Chapter 3, has been implemented on CSDL's SGI computers to produce hourly water level and current nowcasts and twice daily forecasts in New York Harbor. The water level model nowcasts and forecasts at NWLON station; Bayonne Bridge and The Battery are archived for system skill evaluation. Analysis (Wei and Chen, 2001) shows water level discrepancy from the fine grid and coarse are negligible but not current velocity. Therefore, if available, outputs from the fine grid model are used in the analysis described in this Chapter.

4.1. Analysis Method

A standard suit of assessment statistics is defined in NOS (1999). Parameters in the suite are calculated based on the time series of observed and model simulated water levels at the Bayonne Bridge and The Battery. Defining the error as the observations minus the semi-operational nowcasts, these parameters are (NOS, 1999):

(1) SM: Series mean.
(2) SD: Standard deviation of the error.
(3) RMSE: Root mean squared error.
(4) CF(x): Central Frequency. Percentage of errors that lie within the limit ±x
(5) POF(x): Positive Outlier Frequency. Percentage of errors that are greater than x.
(6) NOF(x): Negative Outlier Frequency. Percentage of errors that are less than x.
(7) 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 (number of consecutive occurrences) of the longest event.

(8) 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 (number of consecutive occurrences) of the longest event.
(9) WOF(X): Worst Cas Outlier Frequency. Fraction (percentage) of errors that, given an error of magnitude exceeding X, that (1) the simulated value of water level is greater than the astronomical tide and the observed value is less thatn 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.

4.2. Skill Assessment for Water Level Nowcasts

Hourly water level model nowcasts at the Bayonne Bridge and The Battery NWLON stations have been archived daily for model system evaluations since April 1, 1999. Only data associated with normal model system operation are selected. The skill assessment described in this chapter is based on the time series archived between April 1, 1999 and July 31, 2001. Model data from April to September, 2000 were not saved and not included in the analysis. No observed water level data is available at the Bayonne Bridge station for March, 2000 and at The Battery from January to May, 2001. Simulated water levels at the Bayonne Bridge and The Battery are taken from the fine grid and coarse grid, respectively. There are 11,996 and 9,884 hourly water level data extracted from 6-minute interval model output, at the Bayonne Bridge and The Battery, respectively, included in the analysis. Figures 4.1 and 4.2 show a portion of the observed and model nowcast water level time series at the Bayonne Bridge and The battery.

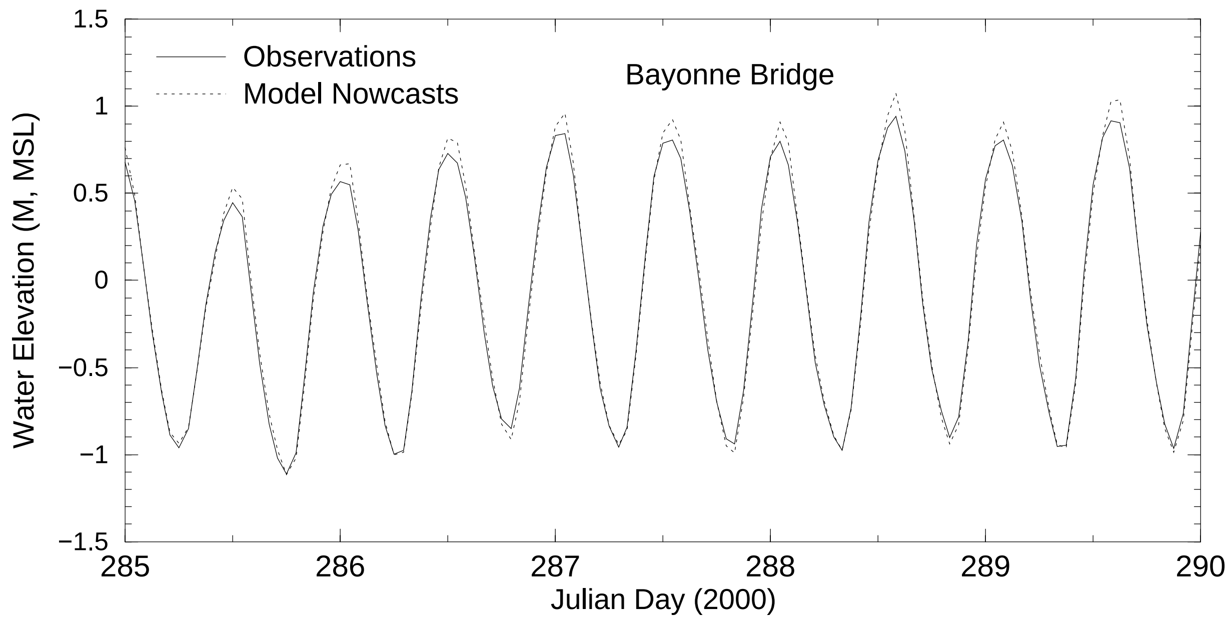

Figure 4.1. Observed and model nowcast water level time series at the Bayonne Bridge, October 12 - 17, 2000.

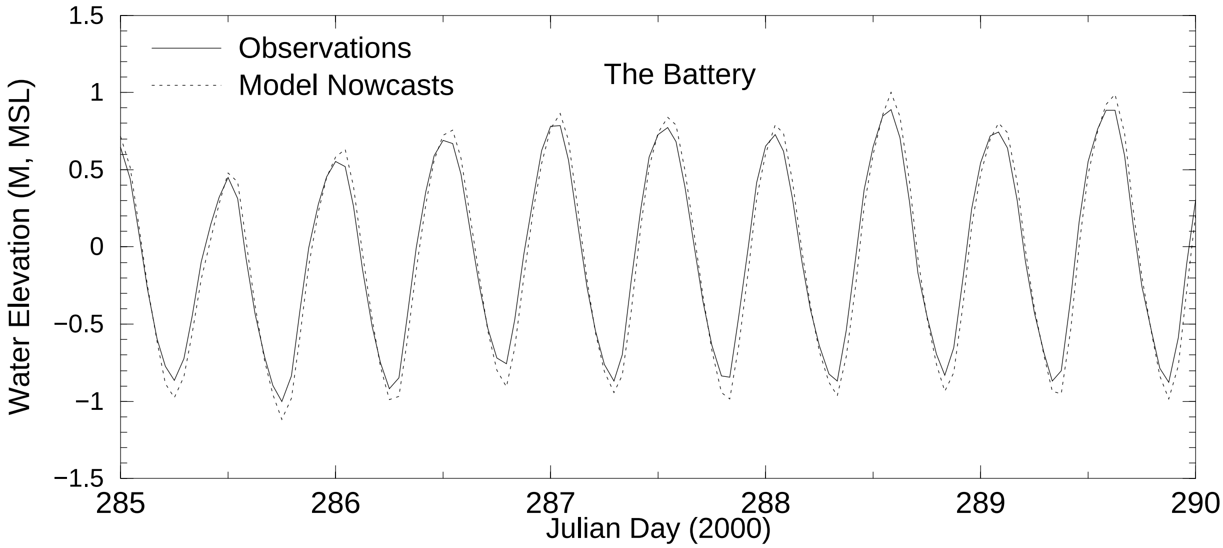

Figure 4.2. Observed and model nowcast water level time series at The Battery, October 12 - 17, 2000.

Water level semi-operational nowcast statistics at the Bayonne Bridge and The Battery are listed in Table 4.1. The criteria accepted by NOS are also included in the table. All model statistical parameters pass the criteria. The water level time series means (SM) between model simulated and observed data at both locations are very close indicating the model reference datum is correct. Time series difference root-mean-square errors (RMSE) are 7.3 cm at the Bayonne Bridge and 9.5 cm at The Battery.

A standard suite of assessment statistics for amplitude and time of high and low water are computed for the Bayonne Bridge and The Battery. Simulated water levels at the Bayonne Bridge and The Battery are taken from the fine grid and coarse grid, respectively. The high and low water time series subsets are derived from the entire 6-minute interval simulated and observed water level time series and the differences are computed.

The standard suite of statistical parameters are derived and listed in Tables 4.2 and 4.3. All statistical parameters at the Bayonne Bridge are within NOS accepted criteria. The simulated high and low water lags behind the observations about 20 minutes at both locations. At both locations, the mean model high water amplitudes are higher than the observations and the mean model low water amplitudes are lower than the observations.

Table 4.1. Model system water level nowcast skill assessment standard statistics for complete time series at Bayonne Bridge and The Battery. (Note: na = not applicable)

	Bayonne Bridge			The Battery			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm)	5.9	6.5	0.6	6.5	7.1	0.5	na
SD (cm)	na	na	7.3	na	na	9.5	na
RMSE (cm)	na	na	7.3	na	na	9.5	na
CF (15 cm) %	97.4			92.4			≥90
POF (30 cm) %	0.2			0.2			≤ 1
NOF (30 cm) %	0.1			0.1			≤ 1
MDPO (30 cm) (Hour)	5			4			≤ 24
MDNO (30 cm) (Hour)	2			2			≤ 24
WOF (30 cm) %	0.1			0.1			≤0.5

Table 4.2. High and low water level nowcast skill assessment standard suite statistics at the Bayonne Bridge. (Note: na = not applicable)

	Bayonne Bridge				NOS Accepted Criteria
	High Water		Low Water		
	Amplitude	Time	Amplitude	Time	
Difference SM (cm) (min)	4.6	15.1	-1.6	0.5	na
Difference SD (cm) (min)	6.7	15.4	4.6	12.6	na
RMSE (cm) (min)	8.1	21.6	4.9	12.6	na
CF (15 cm) (30 min) %	96.1	90.1	99.1	97.8	≥ 90
POF (30 cm) (60 min) %	0.3	0.7	0.3	0.2	≤1
NOF (30 cm) (60 min) %	0	0.3	0	0.4	≤1
MDPO (30 cm) (#)	2	1	2	1	≤ 3
MDNO (30 cm) (#)	0	1	0	1	≤ 3

Table 4.3. High and low water level nowcast skill assessment standard suite statistics at The Battery. (Note: na = not applicable)

	The Battery				NOS Accepted Criteria
	High Water		Low Water		
	Amplitude	Time	Amplitude	Time	
Difference SM (cm) (min)	8.9	14.8	-7.2	7.1	na
Difference SD (cm) (min)	4.1	12.3	4.3	11.5	na
RMSE (cm) (min)	9.8	19.2	8.4	13.5	na
CF (15 cm) (30 min) %	96.1	92.6	98.4	97.9	≥ 90
POF (30 cm) (60 min) %	0.3	0.4	0.3	0.3	≤1
NOF (30 cm) (60 min) %	0	0	0.1	0.1	≤1
MDPO (30 cm) (#)	2	1	2	1	≤ 24
MDNO (30 cm) (#)	0	0	1	1	≤ 24

4.3. Skill Assessment for Water Level Forecasts

The NYEFS makes an 36-hour forecast run twice a day. Each forecast run uses the datum-corrected ETSS subtidal water level forecasts, added to the astronomical tide predictions at Sandy Hook, NJ and Willets Pt. (Kings Point), NY as lateral open ocean boundary conditions. The other lateral open boundary condition is the climatological river flow described at river mouths. The model is forced with Eta forecasts on the surface. The forecast runs start the simulation at 05Z and 17Z and produce water level and three-dimension current forecasts over 36 hours. Hourly water level data of the first 24 hours of the forecasts, at the Bayonne Bridge and The Battery, from October, 2000 to July 2001, are used for the skill assessment. There are about 270 days (two forecast cycles each day) of valid model data. However, observed data at The Battery are not available between January1, and April 30, 2001. Figures 4.3 and 4.4 show the observed and model forecast water level time series at the Bayonne Bridge and The Battery.

According to NOS (1999), the statistic parameters including CF, POF, NOF, MDPO, MDNO and RMSE, at each forecast hour are calculated. The statistics from the 05z and 17z cycles are similar although the 05z cycle statistics are slightly better than 17z cycle in general. Tables 4.4 and 4.5 list these parameters at each forecast hour (hour 1, 6, 12, 18, and 24 are highlighted) using the two cycle model forecast data.The overall statistics are listed as Table 4.6.

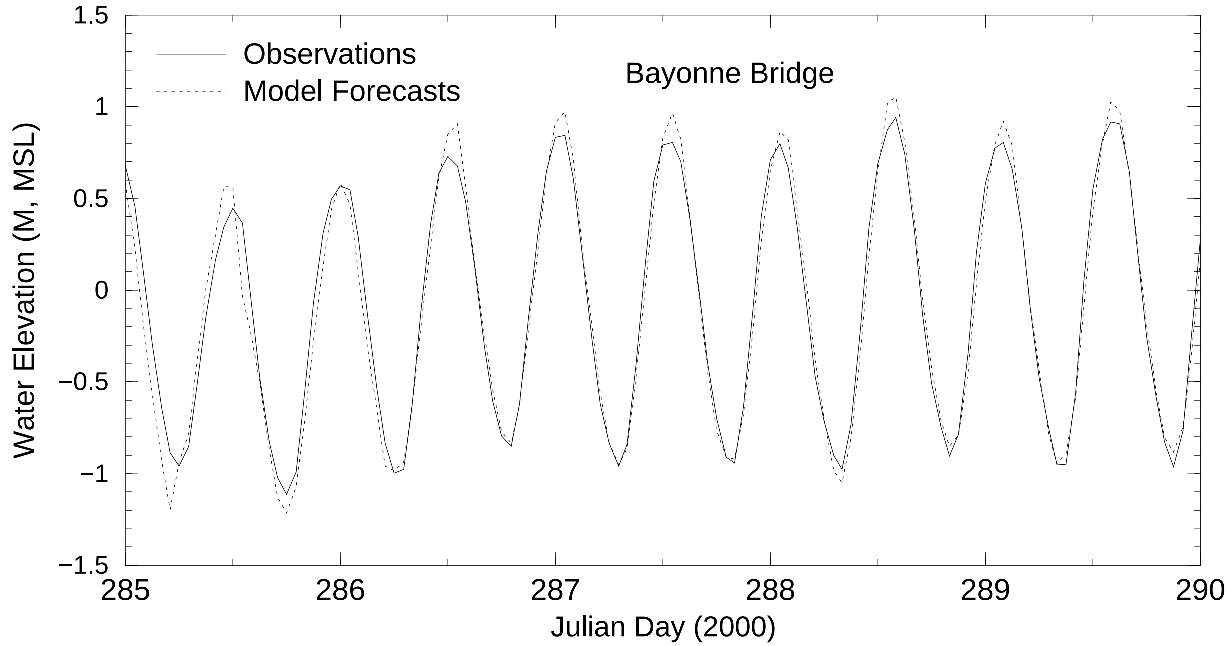

Figure 4.3. Observed and model forecast water level time series at the Bayonne Bridge, October 12 - 17, 2000.

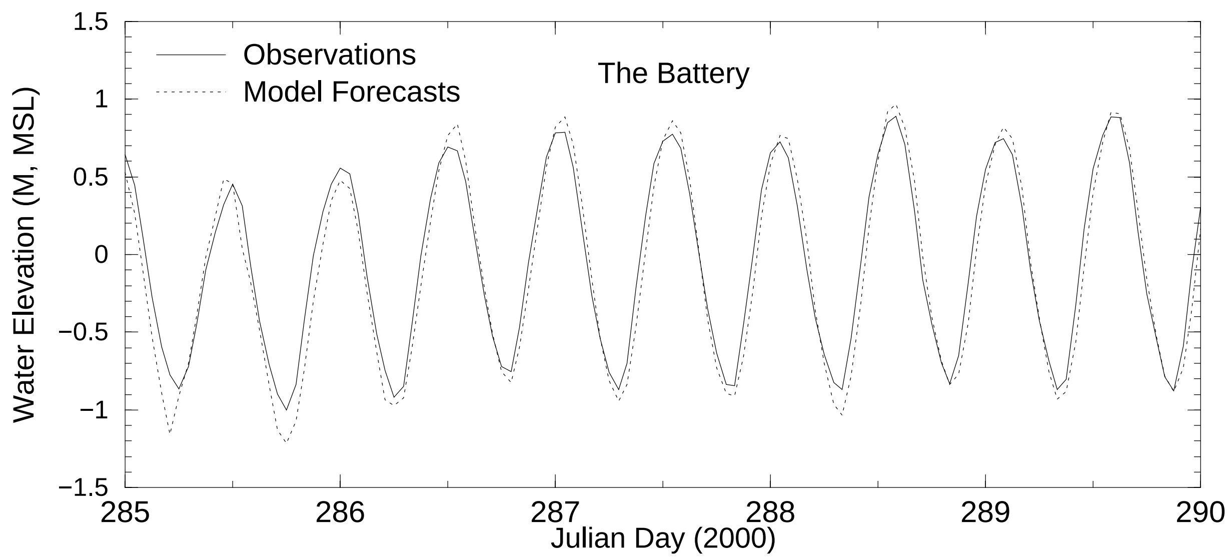

Figure 4.4. Observed and model forecast water level time series at The Battery, October 12 - 17, 2000.

Table 4.4. Model system water level forecast skill assessment standard statistics for complete time series (two cycle forecasts) at Bayonne Bridge. (Note: Overall RMSE average: 13.4 cm.)

Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMSE (cm)
1	97.2	0.4	0.0	6.9
2	86.2	0.9	0.2	10.6
3	86.8	0.6	0.4	10.7
4	84.6	0.2	0.6	10.9
5	83.8	1.1	0.4	11.8
6	79.0	1.5	0.6	12.2
7	82.5	0.9	0.9	12.0
8	66.2	5.8	3.0	16.9
9	70.1	5.0	1.1	14.9
10	79.9	1.9	0.2	12.1
11	75.8	1.9	0.7	13.1
12	79.4	2.4	0.2	12.6
13	74.7	1.5	0.4	12.7
14	73.4	2.0	1.7	13.7
15	74.3	2.0	2.4	14.0
16	68.8	1.7	2.2	14.7
17	69.1	2.8	2.2	15.2
18	70.3	3.2	2.2	15.0
19	70.6	3.0	1.9	15.1
20	68.8	3.5	2.6	15.4
21	69.5	3.2	2.4	15.1
22	72.1	2.4	1.5	14.4
23	74.2	2.0	1.7	13.7
24	75.1	2.4	1.7	13.6

Table 4.5. Model system water level forecast skill assessment standard statistics for complete time series (two cycle forecasts) at The Battery. (Note: Overall RMSE average: 14.3 cm.)

Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMSE (cm)
1	89.9	0.0	3.6	11.2
2	82.1	0.0	3.3	12.7
3	77.2	0.3	3.6	13.5
4	75.2	0.0	2.6	13.5
5	74.9	0.7	2.0	13.8
6	74.6	0.3	2.6	13.8
7	73.0	1.0	1.3	12.9
8	67.8	2.9	1.6	15.6
9	72.6	2.3	1.3	14.0
10	77.9	1.0	2.9	13.2
11	75.2	1.0	2.9	13.9
12	73.6	0.7	3.6	14.1
13	72.0	0.0	2.9	14.3
14	73.0	1.0	3.6	14.9
15	68.1	0.7	5.2	15.1
16	66.4	0.7	4.6	15.1
17	65.1	1.3	3.9	15.4
18	66.8	1.3	3.6	15.5
19	66.8	2.9	2.3	15.4
20	67.1	3.3	1.6	15.2
21	72.3	3.6	1.3	14.7
22	72.6	2.9	1.6	14.6
23	71.7	1.6	2.9	14.4
24	70.7	0.7	2.9	14.4

Table 4.6. Model system water level forecast skill assessment standard statistics for complete time series at Bayonne Bridge and The Battery. (Note: na = not applicable)

	Bayonne Bridge			The Battery			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm)	5.1	6.7	1.6	6.5	7.5	-1.5	na
SD (cm)	na	na	13.3	na	na	14.2	na
RMSE (cm)	na	na	13.4	na	na	14.3	na
CF (15 cm) %	76.4			72.8			≥90
POF (30 cm) %	2.2			1.3			≤ 1
NOF (30 cm) %	1.3			2.8			≤ 1
MDPO (30 cm) (Hour)	10			6			≤ 24
MDNO (30 cm) (Hour)	8			7			≤ 24
WOF (30 cm) %	2.0			2.2			≤ 0.5

Since the water level forecasts at Bayonne Bridge and The Battery heavily depend on the ETSS forecasts at Sandy Hook, NJ (the 00Z ETSS cycle described in Section 3.1), the accuracy of ETSS forecasts at Sandy Hook becomes important. Inter-comparison of ETSS forecasts with observations at Sandy Hook shows ETSS forecasts has consistent underestimated the sub-tidal water levels shown in Tables 4.7. Table 4.7 shows the RMSE of ETSS forecasts is 21.6 cm. The central frequency (15 cm) ranges from 30% to 50% and the NOF (30 cm) are greater than 10% and no POF. Several correction approaches have been tested, for example, corrected with the average of the discrepancy between the observations and forecasts of the previous one, five, seven, and ten days. Table 4.8 shows the statistics of ETSS forecasts after the correction procedure using the previous one-day average discrepancy approach. The RMSE has been reduced to 13.3 cm and the CF increased to greater than 90% out to forecast hour 6. The corrected RMSE using other methods are all greater than 13 cm. The water level boundary conditions for semi-operational forecast runs are based on the previous one-day descrepancy correction.

The water level forecast errors at the Bayonne Bridge and The Battery are expected to be greater than that at Sandy Hook. Shown in Tables 4.5 and 4.6 the Central Frequency CF decreases to about 80% and 74% at forecast hour 6 at the Bayonne Bridge and The Battery, respectively. At the Bayonne Bridge, the POF is greater than 1% after forecast hour 4 while the NOF is less than 1% up to forecast hour 13, except at forecast hours 8 and 9. At The Battery, the NOF is much greater than the POF for all forecast hours and the RMSE (14.3 cm) is greater than at the Bayonne Bridge.

Table 4.7. ETSS water level forecast skill assessment standard statistics at Sandy Hook. (Note: Overall RMSE average: 21.6 cm.)

Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMSE (cm)
1	30.0	0.0	16.6	25.0
2	27.9	0.0	19.1	25.5
3	31.4	0.0	15.5	24.9
4	42.8	0.4	12.4	22.1
5	49.8	0.0	10.2	20.2
6	51.2	0.0	8.1	18.9
7	49.5	0.0	9.5	19.8
8	46.3	0.0	9.9	20.2
9	39.9	0.0	13.1	21.4
10	38.5	0.0	13.8	21.7
11	42.8	0.0	11.3	20.8
12	49.8	0.0	9.2	20.4
13	55.5	0.0	9.2	21.3
14	53.4	0.0	11.0	21.5
15	54.1	0.0	11.7	21.7
16	51.9	0.0	10.6	22.1
17	53.0	0.0	13.4	21.8
18	51.9	0.0	13.8	21.4
19	49.1	0.0	14.5	21.2
20	48.8	0.0	12.7	21.6
21	50.2	0.0	14.5	20.9
22	49.8	0.0	15.2	20.3
23	50.9	0.0	15.2	20.8
24	44.9	0.0	18.7	23.5

Table 4.8. ETSS water level forecast skill assessment standard statistics at Sandy Hook **after the correction**. (Note: Overall RMSE average: 13.3 cm)

Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMSE (cm)
1	93.3	0.0	1.4	9.9
2	90.1	0.4	0.7	11.0
3	90.8	0.4	1.8	12.1
4	92.9	0.7	1.4	10.5
5	91.9	1.1	0.7	9.8
6	94.0	1.1	0.4	9.5
7	84.1	2.5	1.8	13.3
8	82.0	1.8	1.8	13.0
9	79.5	1.4	0.7	12.5
10	79.9	1.1	0.7	12.4
11	79.5	0.7	0.7	12.2
12	80.6	1.1	1.1	13.4
13	76.7	2.1	2.5	15.6
14	76.7	2.1	2.1	15.2
15	78.1	2.8	1.8	15.2
16	74.6	1.8	1.8	15.7
17	76.3	2.1	2.5	15.0
18	77.4	1.4	2.8	14.5
19	74.2	1.4	1.4	14.0
20	75.3	2.1	1.4	14.1
21	75.6	2.1	1.4	14.0
22	73.9	1.8	1.8	13.6
23	76.3	1.8	1.8	13.9
24	75.6	1.1	3.2	14.7

The NYEFS water level forecasts are then compared with astronomical tide predictions at the Bayonne Bridge and The Battery. Table 4.9 lists the skill assessment parameters for overall time series between forecasts/predictions and observations from October, 2000 to July, 2001.

At the Bayonne Bridge, the model water level forecast skills do not meet the NOS accepted criteria, however, they are still better than the astronomical tide prediction skills when the MDPO and MDNO are greater than 24 hours. At The Battery, the NYEFS forecasts only show slight accuracy improvement over astronomical tide predictions. The astronomical tide predictions at The Battery has 48 hours MDNO and negative difference series mean (SM) indicating strong subtidal signal during this period.

Table 4.9. NYEFS water level forecast and astronomical tide prediction skill assessment standard suite statistics at the Bayonne Bridge and The Battery. (Note: na = not applicable)

	Bayonne Bridge		The Battery		NOS Accepted Criteria
	NYEFS	Tide Predictions	NYEFS	Tide Predictions	
Difference SM (cm)	1.8	-6.0	-1.5	-7.9	na
Difference SD (cm)	13.3	17.3	14.2	14.4	na
RMSE (cm)	13.4	18.3	14.3	16.4	na
CF (15 cm) %	76.4	65.6	72.8	71.0	≥ 90
POF (30 cm) %	2.2	3.1	1.3	1.2	≤1
NOF (30 cm) %	1.3	5.7	2.8	5.8	≤1
MDPO (30 cm) (#)	10	26	6	7	≤ 3
MDNO (30 cm) (#)	8	47	7	48	≤ 3

A standard suite of assessment statistics for forecast water level amplitude and times of high and low water are computed for the Bayonne Bridge and The Battery. Simulated water levels at the Bayonne Bridge and The Battery are taken from the fine grid and coarse grid, respectively. The high and low water time series subsets are derived from the entire 6-minute interval simulated and observed water level time series and the differences are computed. The standard suite of statistical parameters are derived and listed in Tables 4.10 and 4.11.

Similar to the entire forecast time series skill statistics, most of the forecast high and low water skill statistics for the Bayonne Bridge and The Battery do not meet the NOS criteria (NOS, 1999). The amplitude statistics CF at both locations are low compared with the time occurrence statistics CF.

Table 4.10. High and low water level forecast skill assessment standard suite statistics at Bayonne Bridge. (Note: na = not applicable)

	Bayonne Bridge				NOS Accepted Criteria
	High Water		Low Water		
	Amplitude	Time	Amplitude	Time	
Difference SM (cm) (min)	10.4	7.3	-0.4	-5.8	na
Difference SD (cm) (min)	11.0	21.6	10.8	20.9	na
RMSE (cm) (min)	15.1	22.8	10.8	21.7	na
CF (15 cm) (30 min) %	70.2	85.3	85.8	88.4	≥ 90
POF (30 cm) (60 min) %	5.0	1.6	0.6	1.2	≤1
NOF (30 cm) (60 min) %	0	0	0.8	1.2	≤1
MDPO (30 cm) (#)	2	1	1	1	≤ 24
MDNO (30 cm) (#)	0	0	1	1	≤ 24

Table 4.11. High and low water level forecast skill assessment standard suite statistics at The Battery. (Note: na = not applicable)

	The Battery				NOS Accepted Criteria
	High Water		Low Water		
	Amplitude	Time	Amplitude	Time	
Difference SM (cm) (min)	6.6	9.9	-8.7	-0.3	na
Difference SD (cm) (min)	10.8	21.2	11.8	20.6	na
RMSE (cm) (min)	12.7	23.4	14.6	20.6	na
CF (15 cm) (30 min) %	77.5	87.8	73.4	92.1	≥ 90
POF (30 cm) (60 min) %	2.3	2	0	0.7	≤1
NOF (30 cm) (60 min) %	0	0.3	5.3	0.7	≤1
MDPO (30 cm) (#)	2	1	0	1	≤ 24
MDNO (30 cm) (#)	0	1	3	1	≤ 24

4.4. Skill Assessment for Persisted Water Level Forecasts

A forecast method which provides timely information without running a hydrodynamic modeling is the so called persisted water level forecasts. In this method, the last available observed water level offset from the astronomical tide at a location is added to the future astronomical tide predictions to obtain the water level forecasts. This section describes the persisted water level forecasts skill assessments at The Battery and the Bayonne Bridge during the same period (October 1, 2000 – July 31, 2001) of the model forecast skill assessments described in Section 4.3.

The observed water level offset from the astronomical tide predictions at The Battery and the Bayonne Bridge at 05Z and 17Z were used to added to the followed 24 hours astronomical tide predictions as tpersisted water level forecasts. The persisted water level forecasts are then compared with observations to obtain the skill assessments as listed in Table 4.12. Comparing the skill assessments for the presisted water level forecasts (Table 4.12), the model water level forecast (Table 4.6), and the astronomical tide predictions (Table 4.9) shows that the CF, POF, and NOF for the persisted water level forecasts, especially at The Battery, are better than the other methods. However, the models's MDPO and MDNO are lower than the other methods.

Table 4.12. Persisted water level forecast skill assessment standard statistics at Bayonne Bridge and The Battery. (Note: na = not applicable)

	Bayonne Bridge			The Battery			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm)	5.1	-1.1	-0.9	9.0	2.2	-0.6	na
SD (cm)	na	na	14.7	na	na	11.6	na
RMSE (cm)	na	na	14.8	na	na	11.6	na
CF (15 cm) %	78.9			87.0			≥90
POF (30 cm) %	2.9			1.4			≤ 1
NOF (30 cm) %	2.2			1.2			≤ 1
MDPO (30 cm) (Hour)	23			17			≤ 24
MDNO (30 cm) (Hour)	14			15			≤ 24
WOF (30 cm) %	2.7			1.3			≤ 0.5

4.5. Skill Assessment for Current Nowcasts

Nowcast Current Speed and Direction Skill Assessment at Bergen Point

Current observations about 4 m below the water surface (bin 8) are compared with simulated fine-grid model current speed and direction nowcasts at equivalent depth (fine-grid model layer 3) at Bergen Point from October 6 to December 3, 2000. The observations are low-passed with a 90-minute filter to remove high frequency disturbances. Selection of both the observed and modeled co-existing data results in 12,000 total valid 6-minute interval data, equivalent to about 51 days. The time difference (2 minutes) between simulated and observed data time has been neglected in calculating the statistics. The current speed time series between October 6 to 11, 2000 are shown in Figure 4.5. The maximum flood current speeds are much stronger than the maximum ebb current speeds. The parameters in the analysis are obtained based on the entire data set except for MDPO and MDNO, which are based on each continuous data segment.

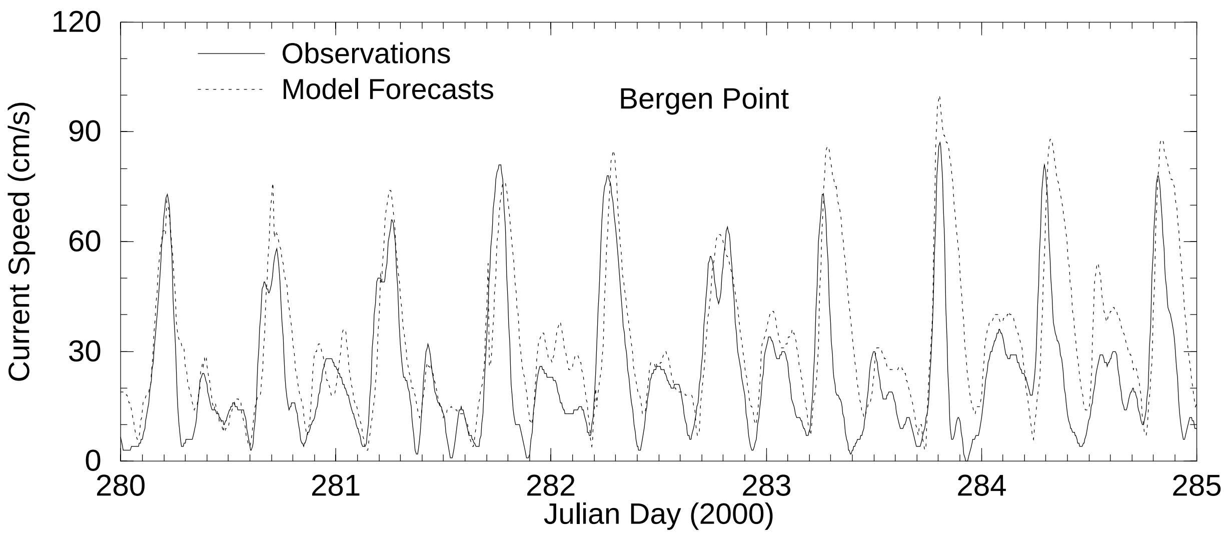

Figure 4.5. Observed and model nowcast current speed time series (low-passed) at Bergen Point, October 6 - 11, 2000.

Current speed and direction skill assessments for Bergen Point are listed in Table 4.13. The current speed CF (76.2%) is below the NOS acceptable criterion (90%). Current direction statistics (CF: 85.6%, POF: 0.7%, and NOF:0.6%) are better than the speed but CF is still below the accepted criterion. The speed RMS error of about 27 cm s^{-1} is mostly due to the phase lag of the simulated current speed. This can also be seen in the slack before flood (SBF) and slack before ebb (SBE) analysis results presented in Table 4.14.

Table 4.13. Nowcast current speed and direction skill assessment standard suite statistics at Bergen Point, based on 12,384 six minutes interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	28.3	44.7	16.3	228.7	232.3	3.5	na
SD (cm/s) (deg)	na	na	21.9	na	na	17.1	na
RMSE (cm/s) (deg)	na	na	27.0	na	na	17.5	na
CF (26 cm/s) (22.5 deg)%	76.2			85.6			≥ 90
POF (52 cm/s)(45 deg) %	8.5			0.7			≤1
NOF (52 cm/s) (45 deg)%	0			0.6			≤1
MDPO (52 cm/s) (45 deg)(Hour)	2.3			0.9			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	0			0.9			≤ 24

<u>Nowcast Current Slack Time at Bergen Point</u>

The beginning and end time of SBE and SBF are defined as at the time when current speed is less/greater 0.26 cm s^{-1}. The skill assessment for the beginning aand end time of SBE and SBF series at Bergen Point are computed. The observed and model simulated current nowcasts have 3 gaps. Therefore, the beginning and end time of SBE and SBF are selected from each of 4 continuous time series segments and then put together. Two sets of standard NOS statistics are then computed based on the differences of SBE and SBF beginning and end times between the observed and the model-based nowcast currents. Table 4.14 lists the statistical parameters for Bergen Point. The model performance does not meet NOS standards due to the complex flow pattern and horizontal current shears near Bergen Point. When the criteria were relaxed (time limit was doubled), the skills of CF, POF, and NOF are improved, although they are still below the NOS criteria (Table 4.14).

<u>Nowcast Maximum Flood and Ebb Currents at Bergen Point</u>

Although these are not required by NOS (1999), the simulated time, speed, and direction of maximum flood and ebb currents at Bergen Point are also compared with the observations to evaluate the model system performance. Table 4.15 shows the skill statistics in terms of CF, RSME, POF, and NOF.

It appears that RMSE for the speed and direction of maximum current is very low indicating the model performs well in defining the maximum current speeds and directions. However, the simulated time of maximum flood current lags behind the observations by 40 minutes (RMSE) (Figure 4.5).

Table 4.14. Skill assessment standard suite statistics for begin and end times of SBE (slack before ebb) and SBF (slack before flood) differences between current observations (at bin 8) and nowcastss (at layer 3) at Bergen Point. (Note: na = not applicable)

	Bergen Point		
	SBE	SBF	NOS Accepted Criteria
SM (minutes)	29.0	37.5	na
SD (minutes)	63.0	35.3	na
RMSE (minutes)	69.0	51.5	na
CF (15 minutes) %	10.9	25.3	≥ 90
POF (30 minutes) %	50.6	45.4	≤1
NOF (30 minutes) %	16.0	0.7	≤1
CF (30 minutes) %	33.3	53.9	
POF (60 minutes) %	37.2	22.7	
NOF (60 minutes) %	4.5	0	

Table 4.15. Skill assessment standard suite statistics for maximum current time, speed, and direction differences between current observations (at bin 8) and nowcast currents (in layer 3) at Bergen Point. (Note: na = not applicable)

	Maximum Flood Current			Maximum Ebb Current		
	Time	Speed	Direction	Time	Speed	Direction
SM (min) (cm/s) (deg)	34.8	23.3	10.7	9.3	9.5	-2.0
SD (min) (cm/s) (deg)	24.1	13.0	3.2	52.0	7.8	14.9
RMSE (min) (cm/s) (deg)	42.3	26.7	11.1	52.5	12.2	15.0
CF (30 min) (26 cm/s) (22.5 deg)%	44.4	64.7	99.0	47.5	99.0	85.9
POF (60 min) (52 cm/s)(45 deg) %	16.2	2.0	0.0	20.2	0.0	0.0
NOF (60 min) (52 cm/s) (45 deg)%	0.0	0.0	0.0	7.1	0.0	0.0

Nowcast Current Speed and Direction at The Narrows

In July, 2001, NOS installed a bottom mounted ADCP at The Narrows as part of the New York PORTS. Since August, 2001, the model system started archiving the nowcast and forecast currents from the coarse grid model at this location. Current observations about 6 m below water surface (bin 20) are compared with simulated current speed and direction nowcasts at the equivalent depth (model layer 2) from August 14 to November 19, 2001. Observations are low-passed with a 90 minute period filter to remove high frequency disturbances. Selection of both the observed and modeled co-existing data results in almost 19,000 valid 6-minute samples, equivalent to about 79 days. The difference (2 to 3 minutes) between simulated and observed data time has been neglected in calaulating the statistics. The current speed time series from August 20 to 22, 2001 are shown in Figure 4.6. The maximum flood and ebb current difference is less than that at Bergen Point (Figure 4.5). The parameters in the analysis are obtained based on the entire data set except for MDPO and MDNO (maximum duration of positive/negative outliers), which are based on each continuous data segment.

Current speed and direction skill assessments for The Narrows are listed in Table 4.16. The model simulated current speed and direction at The Narrows are more accurate than at Bergen Point because of simple geometry of the waterway. All parameters satisfy NOS criterion.

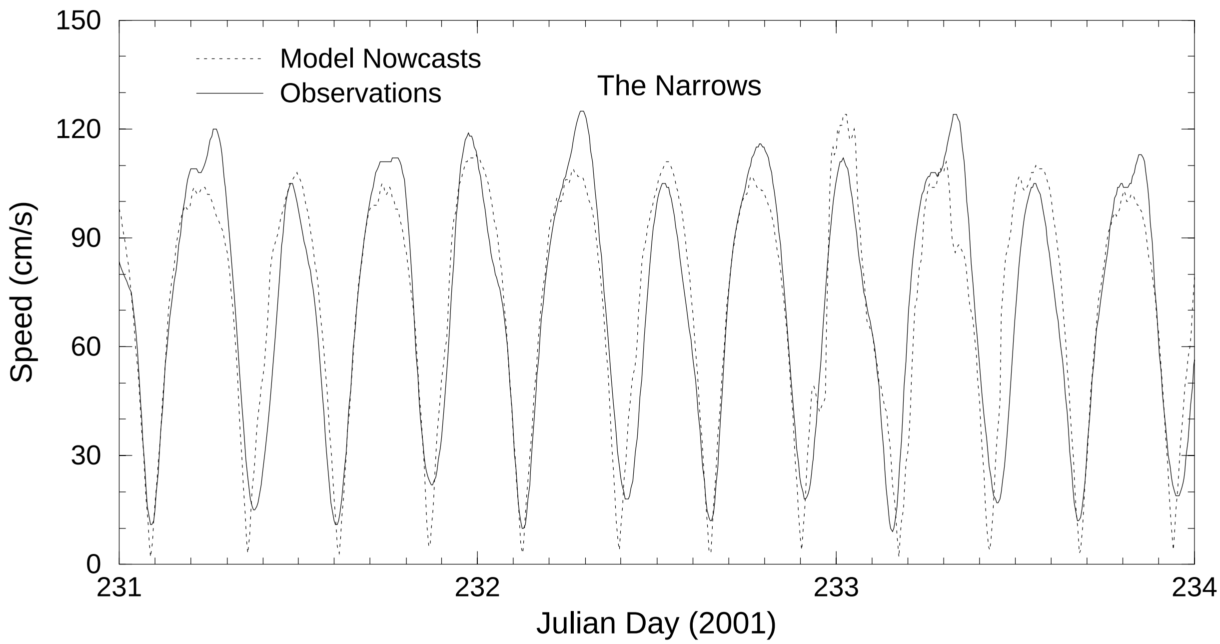

Figure 4.6. Observed and model nowcast current speed time series (low-passed) at The Narrows, August 20 - 23, 2001.

Table 4.16. Current speed and direction nowcast skill assessment standard suite statistics at The Narrows, based on 18,985 six minutes interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	58.1	57.9	-0.22	240.2	243.6	3.3	na
SD (cm/s) (deg)	na	na	13.1	na	na	11.5	na
RMSE (cm/s) (deg)	na	na	13.	na	na	12.0	na
CF (26 cm/s) (22.5 deg)%	94.7			95.2			≥ 90
POF (52 cm/s)(45 deg) %	0.0			0.8			≤1
NOF (52 cm/s) (45 deg)%	0.0			0.0			≤1
MDPO (52 cm/s) (45 deg)(Hour)	3			4			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	0			1			≤ 24

Nowcast Current Slack Time at The Narrows

The skill assessment for the beginning and end time of SBE and SBF series at The Narrows are computed. The observed and model simulated current nowcasts have 2 gaps. Therefore, the beginning and end time of SBE and SBF are selected from each of 3 continuous time series segment and then put together. Two sets of standard NOS statistics are then computed based on the differences of SBE and SBF beginning and end times between observed and model-based tidal currents. Table 4.17 lists the statistical parameters for The Narrows. Although the statistics are better than that at Bergen Point, the slack time performance is still below NOS acceptable criteria. When the criteria was relaxed (the time limit was doubled), the skills of CF, POF, and NOF are improved, although still below the criteria.

Table 4.17. Skill assessment standard suite statistics for the beginning and end times of SBE (slack before ebb) and SBF (slack before flood) differences between current observations (at bin 20) and forecasts (at layer 2) at The Narrows. (Note: na = not applicable)

	The Narrows		
	SBE	SBF	NOS Accepted Criteria
SM (minutes)	-0.2	-27.8	na
SD (minutes)	13.2	19.9	na
RMSE (minutes)	13.1	34.2	na
CF (15 minutes) %	78.2	25.5	≥ 90
POF (30 minutes) %	1.3	0.0	≤1
NOF (30 minutes) %	1.7	41.3	≤1
CF (30 minutes) %	97.0	58.7	
POF (60 minutes) %	0.0	0.0	
NOF (60 minutes) %	0.0	7.1	

Nowcast Maximum Flood and Ebb Currents at The Narrows

Although these are not required by NOS (1999), the model nowcast time, speed, and direction of maximum flood and ebb currents at The Narrows are also compared with observations to evaluate the model system performance. Table 4.18 shows the skill statistics in terms of CF, RSME, POF, and NOF. Note that the criteria variable for time has been set to 30 minutes.

Table 4.18 shows that the CF for the speed and direction of maximum currents are 100% indicating that the model performs well in defining the maximum current speeds and directions. However, the simulated time of maximum flood current lags behind the observations by about 36 minutes (RMSE) as shown in Figure 4.6.

Table 4.18. Skill assessment standard suite statistics for maximum current time, speed, and direction differences between current observations (at bin 20) and nowcasts (in layer 2) at The Narrows. (Note: na = not applicable)

	Maximum Flood Current			Maximum Ebb Current		
	Time	Speed	Direction	Time	Speed	Direction
SM (min) (cm/s) (deg)	-17.0	2.7	7.6	-9.0	-12.6	-4.0
SD (min) (cm/s) (deg)	31.9	6.7	6.5	35.3	6.8	8.9
RMSE (min) (cm/s) (deg)	36.0	7.2	10.0	36.1	14.4	9.8
CF (30 min) (26 cm/s) (22.5 deg)%	61.5	100.0	100.0	61.7	99.3	100.0
POF (60 min) (52 cm/s)(45 deg) %	0.0	0.0	0.0	1.3	0.0	0.0
NOF (60 min) (52 cm/s) (45 deg)%	0.0	0.0	0.0	7.4	0.0	0.0

4.5. Skill Assessment for Current Forecasts

Forecast Current Speed and Direction Skill Assessment at Bergen Point

ADCP current observations bout 4 m below the water surface (bin 8) are compared with simulated current speed and direction forecasts (05z cycle only) at the equivalent depth (fine-grid model layer 3) at Bergen Point from October 6 to December 3, 2000. The observations are low-passed with a 90 minute filter to remove high frequency disturbances Selection of both the observed and modeled co-existing data results in over 11,000 valid 6-minute samples, equivalent to about 48 days. The time difference (2 minutes) between simulated and observed data time has been neglected in calculating the statistics. The current speed time series between October 6 to 11, 2000 are shown in Figure 4.7. The model forecast current speed time series (Figure 4.7) are very similar to the nowcast (Figure 4.5). The parameters in the analysis are obtained based on the entire data set except for MDPO and MDNO (maximum duration of positive/negative outliers), which are based on each continuous data set.

Current speed and direction skill assessments for Bergen Point are listed in Table 4.19. The statistics ire very similar to the nowcasts (Table 4.13). The current speed CF (75.9%) is below the NOS acceptable criterion (90%). Tables 4.20 and 4.21 lists the 24 hour current speed and direction forecast statistics. The speed CF ranges from 60% to 84% throughout the 24 forecast hours, but not necessary degrading with time. The POFs are greater than 1% for all Forecast hours, however, most of the NOFs are less than 1%.

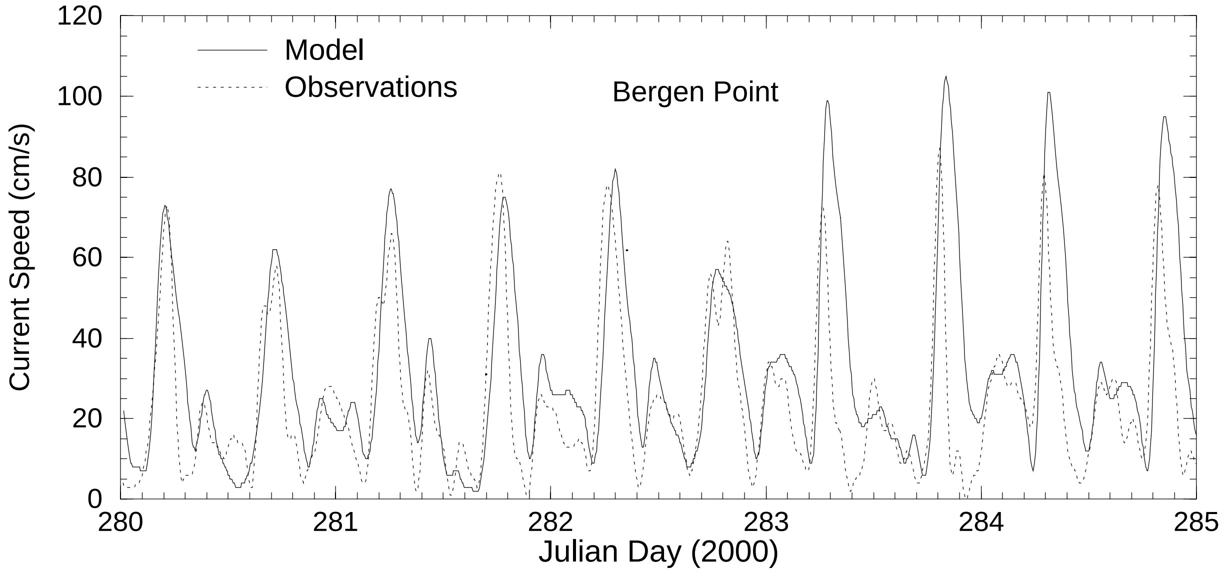

Figure 4.7. Observed and model forecast current speed time series (low-passed) at Bergen Point, October 6 - 11, 2000.

Table 4.19. Forecast current speed and direction skill assessment standard suite statistics at Bergen Point, based on 11,674 six minute interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	28.2	44.2	16.0	228.9	232.5	3.6	na
SD (cm/s) (deg)	na	na	21.2	na	na	16.4	na
RMSE (cm/s) (deg)	na	na	26.6	na	na	16.9	na
CF (26 cm/s) (22.5 deg)%	75.9			85.4			≥ 90
POF (52 cm/s)(45 deg) %	8.0			0.3			≤1
NOF (52 cm/s) (45 deg)%	0.0			0.6			≤1
MDPO (52 cm/s) (45 deg)(Hour)	22			3			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	3			8			≤ 24

Table 4.20. Model system current speed forecast statistics at each of the 24 forecast hour at Bergen Point. (Note: Overall RMSE average: 29 cm.s^{-1})

Forecast Hour	CF (26 cm s^{-1})	POF (52 cm s^{-1})	NOF (52 cm s^{-1})	RMSE (cm s^{-1})
1	81.2	2.3	0.0	20.5
2	82.7	3.8	0.0	21.9
3	73.7	6.8	0.0	25.1
4	71.4	5.3	0.0	26.2
5	68.4	9.8	0.0	29.5
6	71.4	12.8	0.8	31.4
7	65.4	15.8	0.0	33.0
8	65.4	6.0	1.5	29.8
9	72.9	9.0	0.8	27.2
10	76.7	4.5	0.8	68.7
11	81.2	1.5	0.0	22.3
12	75.2	6.8	0.0	25.7
13	78.2	2.3	0.0	22.7
14	81.2	6.0	0.0	23.0
15	75.9	5.3	0.0	23.9
16	70.7	9.0	0.0	27.2
17	68.4	11.3	0.0	30.7
18	70.7	15.0	0.0	32.4
19	69.9	11.3	0.0	29.7
20	66.2	5.3	1.5	28.4
21	75.2	9.0	1.5	26.5
22	79.7	3.8	0.0	23.9
23	82.0	2.3	0.0	21.2
24	84.2	0.0	1.5	19.3

Table 4.21. Model system current direction forecast statistics at each of 24 Forecast hour at Bergen Point. (Note: Overall RMSE average: 20.0 degrees)

Forecast Hour	CF (22 deg)	POF (45 deg)	NOF (45 deg)	RMSE (deg)
1	78.6	2.9	0.0	19.5
2	84.3	0.0	0.0	17.9
3	87.0	1.4	0.0	16.9
4	79.2	1.4	1.4	19.9
5	79.4	1.5	1.5	18.7
6	76.3	3.4	3.4	20.5
7	83.6	1.8	0.0	17.6
8	80.4	1.8	1.8	29.5
9	75.4	1.8	0.0	19.6
10	76.8	4.3	0.0	20.0
11	87.7	0.0	1.5	18.4
12	77.4	0.0	0.0	18.3
13	82.1	0.0	0.0	16.0
14	84.0	1.3	0.0	17.3
15	84.5	0.0	1.4	16.0
16	83.3	1.5	1.5	18.6
17	76.9	1.5	3.1	20.1
18	83.6	0.0	0.0	16.2
19	77.2	0.0	0.0	18.9
20	74.1	3.7	1.9	43.2
21	81.1	0.0	0.0	18.2
22	88.9	1.6	0.0	15.7
23	80.0	0.0	0.0	16.8
24	79.2	0.0	0.0	16.8

Forecast Current Slack Time at Bergen Point

The skill assessment for the beginning and end time of SBE and SBF series at Bergen Point are computed. The observed and model simulated current forecasts have 3 gaps. Therefore, the beginning and end time of SBE and SBF are selected from each of 4 continuous time series segments and then put together. Two sets of standard NOS statistics are then computed based on the differences of SBE and SBF beginning and end times between the observed and the model-based forecast currents. Table 4.22 lists the statistical parameters for Bergen Point. Similar to the nowcast, the forecast current slack time statistics do not meet NOS standards due to the complex flow pattern and horizontal current shears near Bergen Point. The skills of CF, POF, and NOF have been improved, although still below the criteria, when the criteria was relaxed.

Table 4.22. Skill assessment standard suite statistics for begin and end times of SBE (slack before ebb) and SBF (slack before flood) differences between current observations (at bin 20) and forecasts (at layer 2) at Bergen Point. (Note: na = not applicable)

	The Narrows		
	SBE	SBF	NOS Accepted Criteria
SM (minutes)	28.7	33.5	na
SD (minutes)	64.4	38.0	na
RMSE (minutes)	70.4	50.6	na
CF (15 minutes) %	8.7	24.0	≥ 90
POF (30 minutes) %	49.3	42.5	≤1
NOF (30 minutes) %	14.0	1.4	≤1
CF (30 minutes) %	36.7	56.2	
POF (60 minutes) %	37.3	21.2	
NOF (60 minutes) %	4.7	0.0	

Forecast Maximum Flood and Ebb Currents at Bergen Point

The model forecast time, speed, and direction of maximum flood and ebb currents at Bergen Point are also compared with the observations to evaluate the model system performance. Table 4.23 shows the skill statistics in terms of CF, RSME, POF, and NOF. Note that the criteria variable for time has been set to 30 minutes.

Table 4.23 shows that the CF for the speed and direction of maximum currents are near 100%, except maximum ebb direction (87.9%), indicating that the model performs well in defining the maximum current speeds and directions. However, the forecast time of maximum flood current lags behind the observations by greater than 30 minutes RMSE.

Table 4.23. Skill assessment standard suite statistics for maximum current time, speed, and direction differences between current observations (bin 20) and forecasts (fine-grid model layer 2) at Bergen Point. (Note: na = not applicable)

	Maximum Flood Current			Maximum Ebb Current		
	Time	Speed	Direction	Time	Speed	Direction
SM (min) (cm/s) (deg)	44.2	23.6	10.2	10.5	11.6	-1.9
SD (min) (cm/s) (deg)	27.4	13.4	2.4	79.2	7.1	14.5
RMSE (min) (cm/s) (deg)	52.0	27.1	10.4	79.2	13.5	14.5
CF (30 min) (26 cm/s) (22.5 deg)%	36.1	65.1	100.0	28.3	98.3	88.3
POF (60 min) (52 cm/s)(45 deg) %	31.3	2.4	0.0	36.7	0.0	0.0
NOF (60 min) (52 cm/s) (45 deg)%	0.0	0.0	0.0	18.3	0.0	0.0

Forecast Current Speed and Direction at The Narrows

The current forecasts from the experimental model system at The Narrows from August 20 to November 30, 2002 are compared with observations. Adjusting both forecasts and observations, based on data gaps, results in near 19,000 records of 6 minutes samples of forecasts in model layer 2 and observations in bin 20. The time difference for each corresponding forecast and observation record is about 2 to 3 minutes, which has been neglected in the analysis. Current speed and direction skill assessments for The Narrows are listed in Table 4.24. The statistics is very similar to the nowcasts (Table 4.16). All parameters satisfy NOS criterion except for the POF (2.2%) direction statistic.

Table 4.24. Current speed and direction forecast skill assessment standard suite statistics at The Narrows, based on 18,935 six minute interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	56.1	56.5	0.4	238.1	238.3	5.6	na
SD (cm/s) (deg)	na	na	13.1	na	na	24.1	na
RMSE (cm/s) (deg)	na	na	13.	na	na	24.1	na
CF (26 cm/s) (22.5 deg)%	95.1			92.0			$\geq$ 90
POF (52 cm/s)(45 deg) %	0.0			2.2			$\leq$1
NOF (52 cm/s) (45 deg)%	0.0			0.2			$\leq$1
MDPO (52 cm/s) (45 deg)(Hour)	2			14			$\leq$ 24
MDNO (52 cm/s)(45 deg) (Hour)	0			6			$\leq$ 24

The statistics, including CF, POF, NOF, and RMSE, for the current speed forecasts at The Narrows at each of the 24 forecast hours are calculated and listed in Table 4.25. Most of the central frequency (CF) are either exceeding or close to the NOS (1999) criteria. The outliers (POF and NOF) also pass the NOS standards, except for POF at Forecast hour 20 (1.3%). This indicates that the model forecast current speed at The Narrows is very accurate. Table 4.26 lists the 24 hour forecast statistics for the direction. The RMSE of the direction is 24.1 degrees. The statistics either exceed or are close to the NOS (1999) criteria.

Table 4.25. Model system current speed forecast statistics at each of 24 Forecast hour at The Narrows. (Note: Overall RMSE average: 13 cm.s^{-1})

Forecast Hour	CF (26 cm s^{-1})	POF (52 cm s^{-1})	NOF (52 cm s^{-1})	RMSE (cm s^{-1})
1	96.1	0.0	0.0	14.3
2	96.1	0.0	0.0	11.4
3	97.4	0.0	0.0	11.2
4	97.4	0.0	0.0	11.9
5	96.1	0.0	0.0	12.0
6	96.1	0.0	0.0	12.2
7	89.6	0.0	0.0	15.2
8	90.9	0.0	0.0	15.2
9	98.7	0.0	0.0	11.3
10	100.0	0.0	0.0	10.5
11	100.0	0.0	0.0	9.8
12	97.4	0.0	0.0	11.0
13	94.8	0.0	0.0	13.0
14	100.0	0.0	0.0	11.2
15	98.7	0.0	0.0	11.4
16	97.4	0.0	0.0	11.7
17	97.4	0.0	0.0	13.3
18	100.0	0.0	0.0	12.0
19	96.1	0.0	0.0	13.6
20	88.3	1.3	0.0	17.0
21	87.0	0.0	0.0	17.4
22	87.0	0.0	0.0	16.9
23	90.9	0.0	0.0	13.5
24	96.1	0.0	0.0	12.6

Table 4.26. Model system current direction forecast statistics at each of 24 Forecast hour at The Narrows. (Note: Overall RMSE average: 24.1 degrees)

Forecast Hour	CF (22 deg)	POF (45 deg)	NOF (45 deg	RMSE (deg)
1	90.0	3.3	0.0	38.3
2	93.1	1.7	0.0	14.2
3	88.7	1.6	0.0	17.9
4	95.1	0.0	0.0	11.3
5	95.1	0.0	0.0	10.8
6	100.0	0.0	0.0	9.0
7	95.0	1.7	0.0	12.4
8	90.2	0.0	0.0	12.4
9	88.9	1.6	0.0	25.8
10	93.7	0.0	0.0	11.7
11	89.2	3.1	0.0	26.0
12	92.1	1.6	0.0	23.8
13	92.2	0.0	0.0	13.2
14	89.2	3.1	0.0	16.5
15	87.5	3.1	0.0	17.8
16	95.1	0.0	0.0	12.3
17	90.6	4.7	0.0	16.6
18	95.3	1.6	0.0	12.7
19	96.8	0.0	0.0	11.8
20	91.7	3.3	0.0	33.6
21	89.2	4.6	0.0	39.4
22	88.5	4.9	0.0	63.7
23	88.5	1.6	0.0	27.9
24	93.0	1.8	1.8	16.6

Forecast Current Slack Time at The Narrows

The skill assessment for the beginning and end time of SBE and SBF series at The Narrows are computed. The observed and model simulated current forecasts have 3 gaps. Therefore, the beginning and end time of SBE and SBF are selected from each of 4 continuous time series segment and then put together. Two sets of standard NOS statistics are then computed based on the differences of SBE and SBF beginning and end times between observed and model-based forecast currents. Table 4.26 lists the statistical parameters for The Narrows. The statistics are better than that at Bergen Point, however, they still do not meet NOS standard. The skills would be improved dramatically if the criteria was doubled (relaxed) (below the double line in Table 4.27.

Table 4.27. Skill assessment standard suite statistics for the beginning and end times of SBE (slack before ebb) and SBF (slack before flood) differences between current observations (at bin 20) and forecasts (at layer 2) at The Narrows. (Note: na = not applicable)

	The Narrows		
	SBE	SBF	NOS Accepted Criteria
SM (minutes)	2.3	-24.2	na
SD (minutes)	16.0	22.4	na
RMSE (minutes)	16.1	33.0	na
CF (15 minutes) %	66.6	33.5	≥ 90
POF (30 minutes) %	3.3	0.3	≤1
NOF (30 minutes) %	4.6	35.2	≤1
CF (30 minutes) %	92.1	64.4	
POF (60 minutes) %	0.0	0.0	
NOF (60 minutes) %	0.0	5.0	

Forecast Maximum Flood and Ebb Currents at The Narrows

The model forecast time, speed, and direction of maximum flood and ebb currents at The Narrows are also compared with observations to evaluate the model system performance. Table 4.27 shows the skill statistics in terms of CF, RSME, POF, and NOF. Note that the criteria variable for time has been set to 30 minutes.

Table 4.28 shows that the CF for the speed and direction of maximum currents are near 100%, except maximum ebb direction (87.9%), indicating that the model performs well in defining the maximum current speeds and directions. However, the forecast time of maximum flood current lags behind the observation by greater than 30 minutes (RMSE).

Table 4.28. Skill assessment standard suite statistics for maximum current time, speed, and direction differences between current observations (at bin 20) and forecasts (in layer 2) at The Narrows. (Note: na = not applicable)

	Maximum Flood Current			Maximum Ebb Current		
	Time	Speed	Direction	Time	Speed	Direction
SM (min) (cm/s) (deg)	-19.6	9.9	0.3	-11.8	-6.3	-11.1
SD (min) (cm/s) (deg)	34.3	6.6	8.4	30.8	8.2	9.1
RMSE (min) (cm/s) (deg)	39.4	11.9	8.4	32.9	10.3	14.4
CF (30 min) (26 cm/s) (22.5 deg)%	47.6	99.3	99.3	61.1	98.7	87.9
POF (60 min) (52 cm/s)(45 deg) %	0.0	0.0	0.7	0.7	0.0	0.0
NOF (60 min) (52 cm/s) (45 deg)%	0.0	0.0	0.0	4.0	0.0	0.0

5. SUMMARY

An experimental nowcast/forecast water level and current model system for the Port of New York and New Jersey has been operational on CSDL computers since April 1999. The model system performs hourly nowcasts using observed water levels at Sandy Hook, NJ and Kings Point, NY as the lateral open boundary condition. The observed winds at Sandy Hook, NJ, Bayonne Bridge, NY, Robbins Reef, NY, and Kings Point, NY are used as model surface forcing. The nowcast model fields at 05Z and 17Z are used for 36 hours model forecast runs forced with Eta winds and ETSS water level forecasts. The modeled water levels at the Bayonne Bridge and The Battery, and the observed currents at Bergen Point, Bayonne Bridge, and The Narrows are used for the model system skill assessment.

The skill assessment results indicate that most parameters either exceed, or are close to the NOS (1999) criteria. Due to the inaccuracy of subtidal water level forecasts from ETSS at Sandy Hook and Kings Point, the CF of the model simulated water levels at most of frecast hour are below NOS (1999) criteria. The current velocity nowcasts and forecasts at The Narrows, although from the coarse grid, are better modeled than at Bergen Point from the fine grid because of geometry complexity near Bergen Point.

The model system uses the three-dimensional barotropic version of POM. Therefore the effects of density are not included. In the near future the barotropic model will be extended to include the salinity and temperature since commercial ship operations require the water density information for maximizing the cargo draft for avoiding grounding. The salinity and temperature information will not only be useful for navigational safety and efficiency but it will also be the key parametric input for water quality and environmental requirements.

ACKNOWLEDGMENT

The development of the Port of New York/New Jersey water level and current nowcast/forecast model system has been carried out in the Coast Survey Development Laboratory (CSDL) of NOS's Office of Coast Survey under the leadership of CSDL's Chief Dr. Bruce Parker. Dr. Parker suggested the development of the nested grid model in resolving detailed current patterns and structure in the Kill Van Kull. The second author, Manchun Chen, while a visiting scientist at CSDL from the National Marine Data Information Service (NMDIS) of the Peoples Republic of China's State Oceanographic Agency, developed the nested grid model coupling technique. We thank Dr. Leo Oey of Princeton University for providing guidance in the model nesting technique development. Dr. Frank Aikman, Chief of CSDL's Marine Modeling and Analysis Programs (MMAP) has provided valuable oversight and review of the project. His critical report review is acknowledged. Dr. Aijun Zhang, also a visiting scientist from NMDIS, is acknowledged for his assistance in performing many model sensitivity experiments.

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