solutions has lead to substantial revisions of and enhancements to the model system protocols. This paper will provide an overview of the present status of the nowcast and forecast models, as well as results of water level calibration and validation and a performance audit of the automated nowcast model.

Study Area

Tampa Bay is located on the west central coast of Florida, and is the largest port and estuary in the state. It has been classified as a coastal plain estuary with mixed semi-diurnal tides with less than a one meter tide range. The bay covers approximately one thousand square kilometers with a average depth of four meters.

Real-time data acquisition

A total of ten real-time telemetered data acquisition stations are located within the bay. These are comprised of eight Tampa Bay Physical Oceanographic Real-time System (PORTS) stations and two Coastal Oceanographic Monitoring System (COMPS) stations (Vincent et al., 1997). The station locations are provided in Figure 1. Two of the stations, Egmont Key (EGK) and Anna Maria Island (ANM) provide water level, salinity and temperature data for the model open boundary conditions. Wind data from three of the stations, CCUT, VMAN and EGK, are used to provide the surface wind stress forcing.

Real-time or recent river discharge and meteorological data are derived from the US Geological Survey (USGS) and National Weather Service (NWS) ftp internet sites respectively. After proper amplification for ungaged basins and curve number adjustment, the river discharge data are used to provide real-time boundary conditions for a total of 31 river and stream sources within the nowcast model. Regional and local daily meteorological data are used to provide surface mass sink and source fluxes due to precipitation and evaporation.

The Numerical Model

In Tampa Bay, the Blumberg-Mellor ECOM-3D model was initially deployed in work by Galperin et. al, (1992). Salient features of the model include: vertical sigma coordinates, boundary fitted curvilinear grid, a split time step for the solution of the baroclinic 3-D mode and the barotropic 2-D mode, and an embedded second order turbulence closure model to provide vertical mixing coefficients. Details of the model can be found in Blumberg and Mellor (1987) and Blumberg (1990). This new nowcast-forecast phase uses a high resolution grid with 70 by 100 cells in the horizontal and 11 layers in the vertical. The average dimension of the horizontal grid

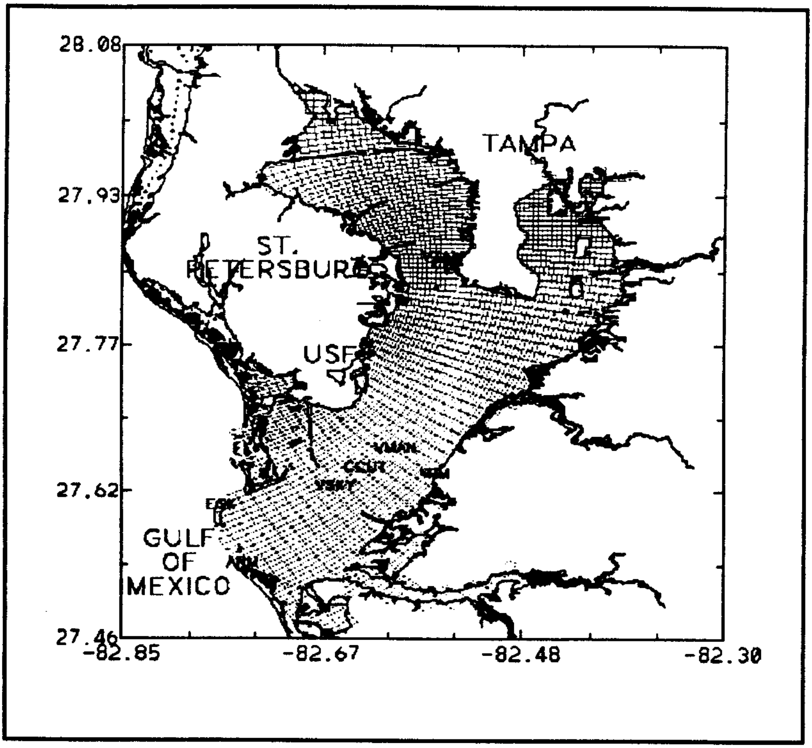

Figure 1 Model Grid and Data Stations

face is on the order of 640 meters. The split time step is 60 seconds for the internal mode and 6 seconds for the external mode. During hundreds of simulations, model input parameters have been tuned to provide good agreement with observations. A noteworthy adjustment of the new higher resolution configuration has been the reduction of the Smagorinsky horizontal diffusivity coefficient (HORCON) to 0.02 from the value of 0.2 used for the old coarser model grid.

Several experiments and investigations have shown that the baroclinic or density driven circulation of Tampa Bay is on the order of ten percent of the total flow (Galperin et al., 1992; Burwell et al., 1999). To account for this important forcing, proper hydrologic source and sink terms must be included. This has been accomplished by the 31 real-time fresh water lateral sources discussed above, as well as the addition of evaporation and precipitation physics to the ECOM-3D model. Recent investigations have shown that these terms do seasonally modulate the bay salinity, thus influencing the baroclinic circulation.

For spill, search and rescue and dispersal studies, passive tracer and an internal Lagrangian particle model have been added (Burwell et al, 1999).

Model Protocols

Three parallel model protocols (hindcast, nowcast and medium range forecast) are currently being tested. The primary engine of the system is the nowcast model protocol. Using real-time data as boundary conditions, this model is updated in time every twelve minutes. Using the output fields from the last nowcast run (restart file), the model is run forward to the most recent boundary conditions received. The current nowcast protocol has been significantly enhanced to provide redundant tidal open boundary conditions (EGK and ANM) as well as a preferred hierarchy of wind stations. This redundancy helps ensure the continued model performance during periods of station failure.

Archived nowcast restart files and the most recent restart files serve as the initialization fields for hindcast and forecast runs respectively. The hindcast protocol has been developed specifically to allow the rapid simulation of hindcast to forecast simulations for purposes of spill response and search and rescue operations.

The forecast model protocols are by far the most difficult, owing to the uncertainty and error of the forecast boundary conditions. The short range forecast protocol uses the National Weather Service (NWS) Nested Grid Model (NGM) Model Output Statistics (MOS) wind fields. The predicted open boundary water level is provided by a signal composed of the tidal harmonics with a super-imposed subtidal component that is a function of the past twenty four hour setup, the setup at the last recorded water level, and the prediction from the NWS Storm Surge Gulf Model (SSGM).

Calibration and Validation of Nowcast Model Water Levels

The nowcast model outputs time series data of water levels, currents and salinities at the grid cells that contain COMPS or PORTS observing stations. This information, which is output every internal time step (1 minute), is used for real-time dissemination as well as archiving for subsequent analysis. Calibration and validation of the nowcast model produced water levels was performed for the periods February 1, 2000 to February 20, 20000, and February 21, 2000 to March 10, 2000 respectively. During both of these phases, the nowcast model protocol was fully automated. Both of these periods were characterized by the passage of strong winter fronts which resulted in large non-tidal water level fluctuations, thereby providing a challenging time frame for skill assessment.

Model output (1 minute frequency) was tested against six minute frequency data obtained from the four PORTS water level stations (i.e. St. Petersburg, Port Manatee, Old Port Tampa, and Port Tampa). During the calibration phase, Port Tampa experienced two periods of down time, therefore had a reduced data set for comparison.

Various methods were employed to compare the nowcast model and observed PORTS water levels. These included skill assessment tests and as well as cross correlation, cross covariance and difference histograms. Tabulated results of nowcast water level calibration are provided in Table 1. Columns one through four of Table 1 contain the PORTS station abbreviation, the lag of highest correlation, the cross covariance and cross correlation. Columns five through eight contain the mean extrema (R), the rms difference between the model and data (Drms), the rms nondimensionalized by the extrema (Dp=Drms/R), the gain ratio of model extrema to data extrema (Gw), the rms difference of extrema values (Arms), the mean lag of extrema (Lm), and rms extrema lag (Lrms). In these computations, developed by Hess and Bosely (1994), extrema is defined as a parameter maxima or minima that is separated by at least two hours. The summary products of this method are SD (six minute difference skill), SA (extrema amplitude skill) and SL (the extrema lag skill).

The nowcast water levels during the calibration phase were in good agreement with the PORTS data. The cross correlation and cross covariance coefficients exceeded 0.99, with lags of less than 6 minutes. The global gain ratio (Gw) was almost unity (i.e. 0.999)

Time series plots of water level comparisons at each of the four PORTS stations are provide in Figures 2 to 5, which again show the close agreement in phase and amplitude. The phase of model extrema was in excellent agreement with the observations at three of the PORTS stations (i.e. SP, PM, OPT) with less than one minute of lead. Port Tampa (PT), located in a narrow channel at the head of the bay, recorded the worst extrema lag rating (Lm=0.154), which still only equates to a 9.24 minute model lag. All three of the global skill scores (SD, SA, and SL) were very close to the maximum, with scores of 96.2%, 97.2% and 96.3% respectively. The individual station and the global Drms values were all less than 2.3 centimeters, indicating very close agreement between the 6 minute PORTS data and model output.

As required, all tuneable model parameters (friction coefficients etc.) were held constant for the subsequent twenty day nowcast validation period. Similar to the calibration period, the nowcast model was fully automated during this period, requiring no intervention by the model managers.

station	grid cell	num. of Data	lag (hr)	cross covar	cross corr	R	Drms	Dp	num. of extrema	Gw	Arms (m)	Lm (hr)	Lrms (hr)
PM	e45,30	5039	0.000	0.998	0.998	0.473	0.014	0.030	59	1.004	0.011	0.210	0.293
SP	e15,37	5039	0.000	0.998	0.997	0.491	0.015	0.031	60	1.014	0.013	0.093	0.265
OPT	e27,54	5038	0.100	0.998	0.998	0.542	0.013	0.024	61	1.000	0.013	0.048	0.209
PT	e55,66	5038	0.000	0.997	0.995	0.592	0.022	0.038	59	1.012	0.018	0.164	0.255
Global Values							0.016	0.030		1.007	0.013	0.128	0.255
Skill Parameters							SD=97.0%			SA=97.5%		SL=95.9%	

Table 1 Water Level Calibration Statistics

station	grid	num. of cell	lag Data	cross (hr)	cross covar	R corr	Drms	Dp	num. of extrema	Gw (m)	Arms (hr)	Lm (hr)	Lrms
PM	e45,30	4794	0.100	0.996	0.996	0.560	0.021	0.037	54	1.008	0.015	0.098	0.259
SP	e15,37	4764	0.000	0.995	0.995	0.563	0.023	0.041	55	1.009	0.017	0.005	0.245
OPT	e27,54	4792	0.100	0.996	0.996	0.614	0.023	0.037	55	0.975	0.018	-0.009	0.185
PT	e55,66	814	0.100	0.997	0.994	0.645	0.022	0.034	11	1.018	0.015	0.154	0.219
Global Values							0.022	0.038		0.999	0.016	0.039	0.229
Skill Parameters							SD=96.2%			SA=97.2%		SL=96.3%	

Table 2 Water Level Validation Statistics

Output from the model was obtained at one minute intervals and compared to the six minute interval PORTS water level data. Validation statistics are provided in Table 2, which follows the same format described for Table 1.

Cross correlation and cross covariance coefficients exceeded 0.994, with zero lag occurring at three of the stations (SP, PM, PT) and only a six minute lag at station OPT. For the validation time period, the individual station and the global model gain was almost identically unity, indicating there was not any amplification or damping of the model extrema relative to the observation extrema. The six minute PORTS data agreed closely with the model output, with a station averaged Drms value of 1.6 cm. The station averaged mean lag (Lm) indicated a slight model lag of 0.128 hours or 7.68 minutes. The skill scores SD, SA and SL were again very high, with values of 97.0%, 97.5% and 95.9% respectively. Relative to the calibration results, two of the three skill scores were higher (SD and SA), and the average of the three scores increased to 96.80% from 96.56%. All three primary skill scores increased from the validation conducted for the previous model configuration, which had an average skill score of 95.46% (Vincent et al., 1997).

Useful information on the distribution of model errors can be gleaned from histogram plots of model-observation differences. Such information facilitates the identification of extreme failures, if any, which could eliminate certain model configurations. Histograms of the differences between model output and observation data at each of the four PORTS stations are provided in Figure 6 and 7 for the calibration and validation periods respectively. The data for these plots is divided into bins centered from -0.15 meters to 0.15 meters, on 0.01 meter increments. The height of each of the rectangles in the histogram corresponds to the number of values in that interval. A tight unimodal spread centered around the 0.0 meter difference interval indicates that a station has low model - observation differences and is relatively immune from problematic outliers. Such is the case for all four stations in the calibration plot (Figure 6) and the validation plot (Figure 7). For the calibration phase, 94.5% of the differences were within plus or minus 0.045 meters (4.5 cm) and 100% of the differences were within the range of -0.105 meters to 0.145 meters. Agreement was even better for the validation phase, within 97.64% of the differences were within plus or minus 0.045 meters (4.5 cm) and 100% of the differences were within the range of -0.065 meters to 0.095 meters.

Preliminary Audit of Nowcast Model

The previous section detailing calibration and validation indicates that the automated model performs relatively well at reproducing the the water level physics of Tampa Bay. However, this is only part of the challenge in developing an operational system. Specifically, in addition to being accurate, a nowcast (and forecast) system must provide prompt, dependable and useful information. Significant modifications and revisions have been incorporated into the new model protocols in order to immunize them from events of boundary condition station failures, interruption of data transmission, spurious data, power failures and computer shutdown and restarts. The current model protocols have implemented contingencies for these cases.

To test the reliability of the nowcast model protocol, a preliminary performance audit was performed concurrent with the twenty day water level validation phase. During this period, the nowcast model protocol was fully automated. The key measure of the model system reliability was the delay time for the model products to be available via the the project www site (http://ompl.marine.usf.edu/TBmodel). A unix cron job was scheduled to run every six minutes to plot and disseminate the most recent model water levels. This program recorded the computer system date and time, the most recent nowcast model date and time, and the skill assessment of the last twenty four hours of the model forecast. Figures 8 A and B provide a plot of the product delay time versus calender days of the validation and audit period, and a plot of the skill scores (SD,SA, SL) versus days of the validation and audit period. The mean and maximum product delay times during the audit period was 0.22 hours and 0.56 hours. Since this process is called every six minutes, the average and maximum age of the posted internet data is 0.32 hours and 0.66 hours.

As indicated by Figure 8 B, skill scores were very high during this period, with average values for SD, SA and SL of 97.05%, 97.5% and 95.9% respectively.

Summary

A prototype nowcast forecast circulation model was developed and tested for a one year period. Based upon a critical evaluation of the system, the model; model protocols; real-time forcing data and forecast forcing products were revised. The new system incorporates enhanced real-time hydrologic forcing via the inclusion of evaporation and precipitation physics to the model, as well as the addition of 31 real-time freshwater stream and river sources. The nowcast model protocol has also been redesigned to be much more robust, incorporating redundancy where possible. Example nowcast water level comparisons are provided in Figures 9-12. The nowcast model conducts updates every twelve minutes. Calibration and validation of water levels for the automated nowcast model indicated very good agreement with PORTS observation data. For the water level validation, rms values were 1.6 centimeters with lags of less than six minutes. Additional skill assessment of water levels as well as currents is ongoing. The medium range forecast protocol conducts 24 hour forecast simulations every four hours. This protocol is currently automated and is being evaluated for water level and current prediction skill. Model and data products from this system can be reviewed online at ompl.marine.usf.edu

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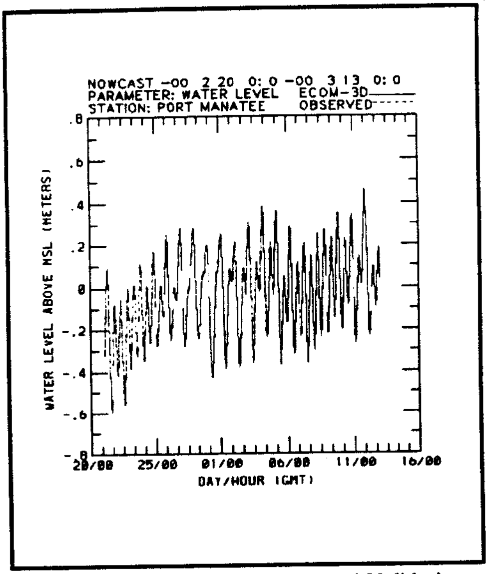

Figure 2 Port Manatee Water Level Validation

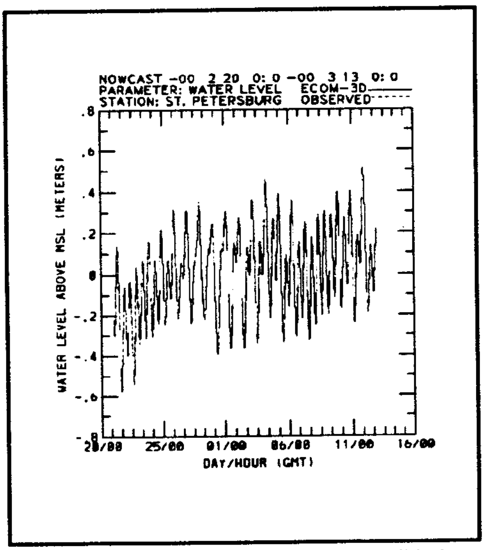

Figure 3 St. Petersburg Water Level Validation

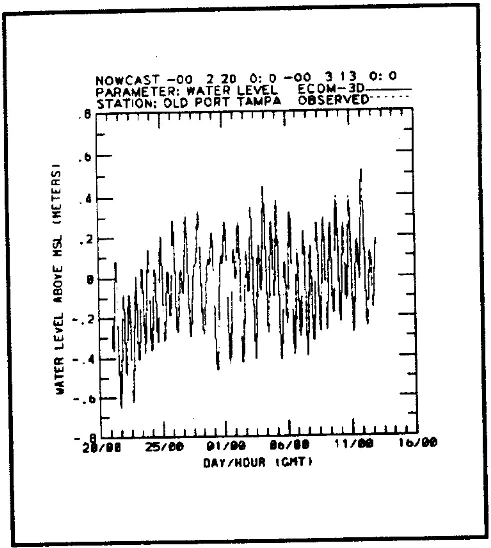

Figure 4 Old Port Tampa Water Level Validation

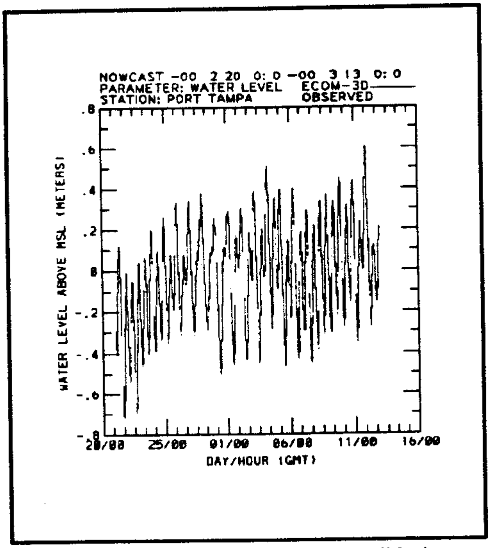

Figure 5 Port Tampa Water Level Validation

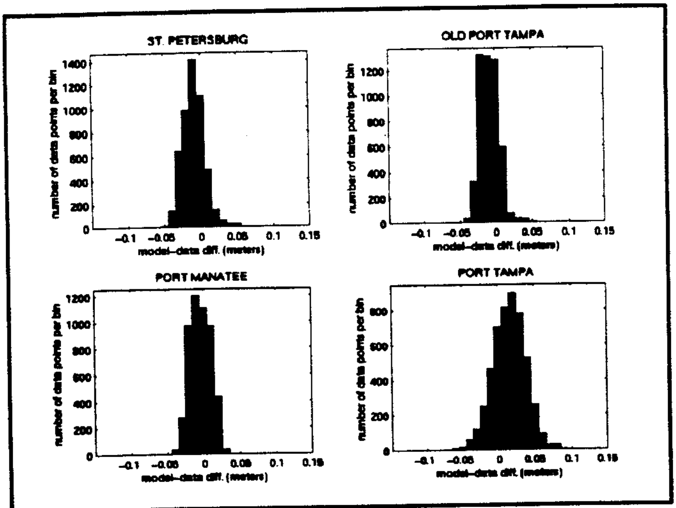

Figure 6 Water Level Validation Difference Histograms

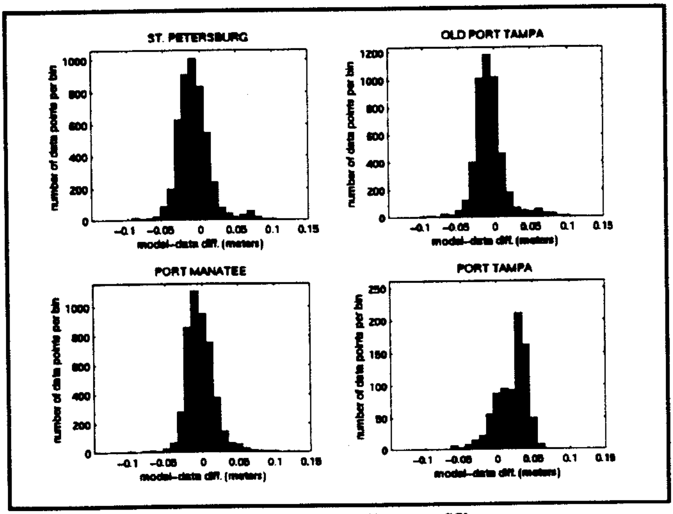

Figure 7 Water Level Calibration Difference Histograms

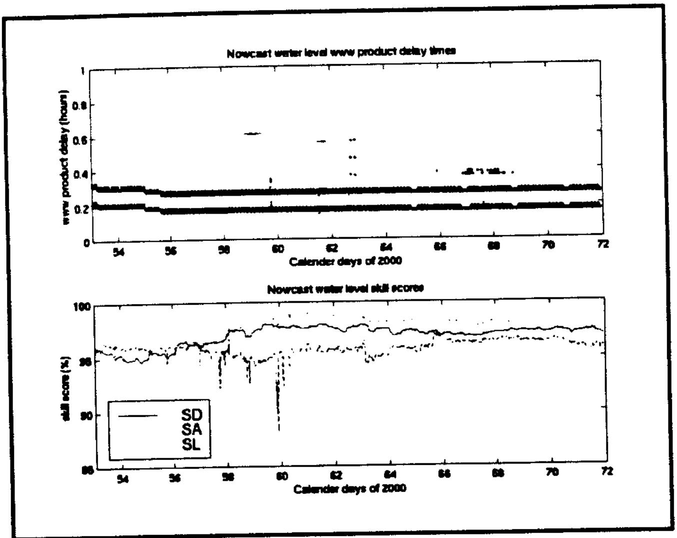

Figure 8 Validation Product Delay and Skill Scores

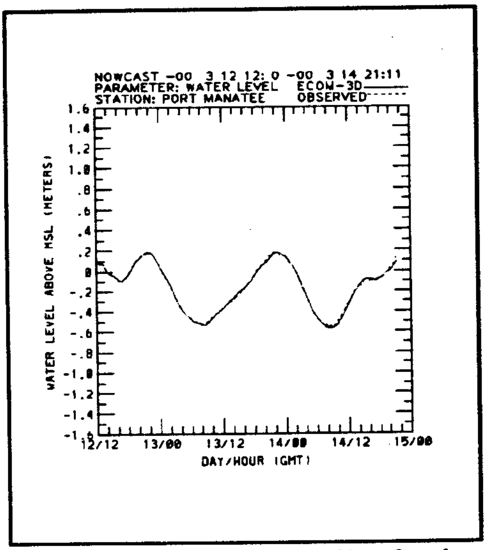

Figure 9 Port Manatee Nowcast Water Levels

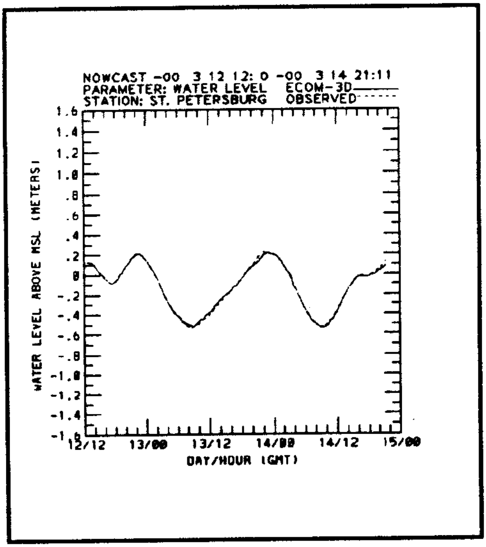

Figure 10 St. Petersburg Nowcast Water Levels

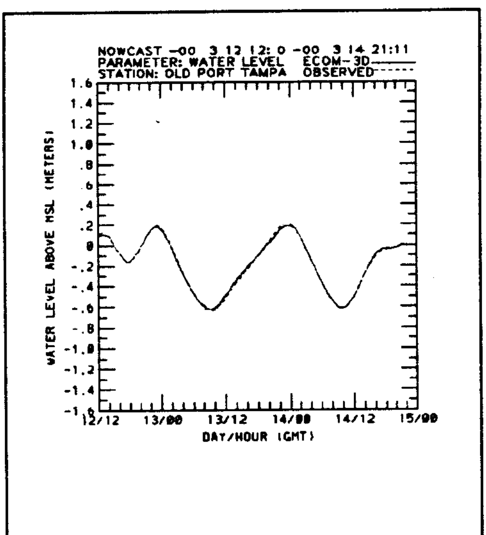

Figure 11 Old Port Tampa Nowcast Water Levels

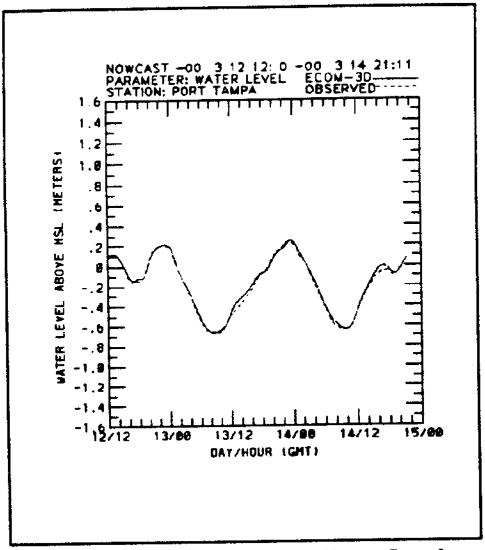

Figure 12 Port Tampa Nowcast Water Levels