

**AUTOMATED EVALUATION OF WATER LEVEL FORECAST
GUIDANCE FROM NWS AND EXTRAMURAL REAL TIME OCEAN
FORECAST SYSTEMS**

**Silver Spring, Maryland
January 2011**



noaa National Oceanic and Atmospheric Administration

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National Ocean Service
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**Office of Coast Survey
National Ocean Service
National Oceanic and Atmospheric Administration
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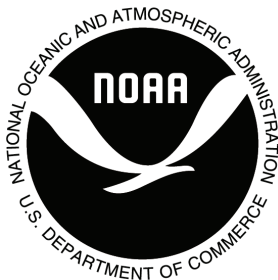
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Richard A. Schmalz, Jr. and Philip H. Richardson
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Silver Spring, MD

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TABLE OF CONTENTS

LIST OF FIGURES	iv
LIST OF TABLES	viii
ABSTRACT	ix
1. INTRODUCTION	1
2. AUTOMATED WATER LEVEL EVALUATION	7
3. ETSS MODEL MONTHLY ANALYSIS	17
4. RTOFS MODEL SEASONAL ANALYSIS	31
5. ETSS, RTOFS, AND G-NCOM MODELS ANNUAL ANALYSIS	41
6. ADDITIONAL STATISTICAL MEASURES	53
7. CONCLUSIONS AND RECOMMENDATIONS	67
ACKNOWLEDGMENTS	68
REFERENCES	68

LIST OF FIGURES

Figure 1.1. RTOFS Grid with spacing from 5 to 17 km	3
Figure 1.2. ADCIRC Western North Atlantic Grid along the East Coast with resolution ranging from 0.5 to 44.5 km	3
Figure 1.3. ETSS East Coast Grid with order 10 km coastal resolution	4
Figure 1.4. High Resolution ~6 km ETSS East Coast Grid in the Vicinity of Chesapeake and Delaware Bays	4
Figure 1.5. ETSS Gulf of Mexico Grid with order 10 km coastal resolution	5
Figure 1.6. G-NCOM Grid in the Atlantic Region 1/8 degree ~ 10km	5
Figure 2.1. RTOFS Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.....	9
Figure 2.2. RTOFS Total Water Level Forecast Guidance against NOS Observations for November 2008	10
Figure 2.3. ETSS Subtidal Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008....	11
Figure 2.4. ETSS Subtidal Water Level Forecast Guidance against NOS Observations for November 2008	12
Figure 2.5. G-NCOM Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008....	13
Figure 2.6. G-NCOM Total Water Level Forecast Guidance against NOS Observations for November 2008	14
Figure 2.7. ADCIRC Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008....	15
Figure 2.8. ADCIRC Total Water Level Forecast Guidance against NOS Observations for November 2008	16
Figure 3.1. ETSS Subtidal Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for February 2009	20
Figure 3.2. ETSS Subtidal Water Level Forecast Guidance against NOS Observations for February 2009	21

LIST OF FIGURES (Cont.)

Figure 3.3. ETSS Subtidal Water Level Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for May 2009	21
Figure 3.4. ETSS Subtidal Water Level Forecast Guidance against NOS Observations for May 2009.....	24
Figure 3.5. ETSS Subtidal Water Level Guidance RMSE (meters) for East Coast Stations (a)and for Gulf of Mexico Stations (b) for August 2009	26
Figure 3.6. ETSS Subtidal Water Level Forecast Guidance against NOS Observations for August 2009	27
Figure 4.1. RTOFS Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for February 2009	32
Figure 4.2. RTOFS Total Water Level Forecast Guidance against NOS Observations for February 2009	33
Figure 4.3. RTOFS Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for May 2009	35
Figure 4.4. RTOFS Total Water Level Forecast Guidance against NOS Observations for May 2009.....	36
Figure 4.5. RTOFS Total Water Level Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for August 2009	38
Figure 4.6. RTOFS Total Water Level Forecast Guidance against NOS Observations for August 2009	39
Figure 5.1. RTOFS Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2009...	43
Figure 5.2. RTOFS Total Water Level Forecast Guidance against NOS Observations for November 2009	44
Figure 5.3. ETSS Subtidal Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2009...	46
Figure 5.4. ETSS Subtidal Water Level Forecast Guidance against NOS Observations for November 2009	47

LIST OF FIGURES (Cont.)

Figure 5.5. G-NCOM Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2009	49
Figure 5.6. G-NCOM Total Water Level Forecast Guidance against NOS Observations for November 2009	50
Figure 6.1. RTOFS Total Water Level Forecast Guidance Relative Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	55
Figure 6.2. RTOFS Total Water Level Forecast Guidance Relative RMSE (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	56
Figure 6.3. RTOFS Total Water Level Forecast Guidance CF (15 cm reference level) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	57
Figure 6.4. ETSS Subtidal Water Level Forecast Guidance Relative Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	58
Figure 6.5. ETSS Subtidal Water Level Forecast Guidance Relative RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	59
Figure 6.6. ETSS Subtidal Level Forecast Guidance CF (15 cm reference level) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	60
Figure 6.7. G-NCOM Total Water Level Forecast Guidance Relative Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	61
Figure 6.8. G-NCOM Total Water Level Forecast Guidance Relative RMSE Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	62
Figure 6.9. G-NCOM Total Water Level Forecast Guidance CF (15 cm reference level) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	63

LIST OF FIGURES (Cont.)

Figure 6.10. ADCIRC Total Water Level Forecast Guidance Relative Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	64
Figure 6.11. ADCIRC Total Water Level Forecast Guidance Relative RMSE Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	65
Figure 6.12. ADCIRC Total Water Level Forecast Guidance CF (15 cm reference level) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008	66

LIST OF TABLES

Table 2.1. ETSS, RTOFS, ADCIRC, and G-NCOM Forecast Guidance Monthly Water Level Comparisons to NOS Observations for November 2008 (RMSE[meters])	7
Table 3.1. ETSS Monthly Subtidal Water Level Forecast Guidance Comparisons to NOS Observations for December 2008 – November 2009 (RMSE[meters])	17
Table 3.2. ETSS December 2008 – November 2009 Monthly Subtidal Water Level Forecast RMS Errors (cm): Minimum, Maximum, and Range	29
Table 4.1. RTOFS Seasonal Water Level Forecast Guidance Comparisons to NOS Observations (RMSE[meters])	31
Table 5.1. ETSS, RTOFS, and G-NCOM Forecast Guidance Monthly Water Level Comparisons to NOS Observations for November 2008 and 2009 (RMSE[meters])	41

ABSTRACT

The previous water level forecast guidance evaluation procedures (Richardson and Schmalz, 2009) were streamlined by combining into a single program the following separate programs: read, reformat, filter, adjust, and analysis programs. The plot program was modified to be run within a script to further simplify the evaluation process. The National Weather Service (NWS) Real Time Ocean Forecast System (RTOFS), NWS Extra-Tropical Storm Surge (ETSS) Model, United States Navy (USN) global Navy Coupled Ocean Model (G-NCOM), and University of North Carolina (UNC) Western North Atlantic Forecast System Advanced Circulation (ADCIRC) Model water level forecasts were compared with the observations at 24 National Ocean Service (NOS) water level stations on the U.S. East Coast and along the Gulf of Mexico shoreline using the new automated procedures. Because the ETSS model is subtidal, the ETSS forecast water levels were compared with observed subtidal water levels. The observed subtidal water levels were obtained using a 30 hour low pass Fourier filter. Because the RTOFS, ADCIRC, and G-NCOM models include tides, their forecast water levels were compared with the total observed water level. RTOFS, ETSS, ADCIRC, and G-NCOM model results were evaluated with the new procedures for November 2008 to verify that the results were consistent with the original evaluation. In addition, the new streamlined procedures were tested for monthly (ETSS), seasonal (RTOFS), and yearly (ETSS, RTOFS, and G-NCOM) water level evaluation. As a further enhancement, additional statistical measures of relative RMSE, Willmott et al. (1985) relative error, and central frequency were incorporated.

1. INTRODUCTION

Coastal ocean and estuarine nowcast/forecast systems require specification of the offshore boundary conditions for water level, density, and currents. These boundary conditions must be provided from basin scale or global numerical models, since observation density is insufficient in time and space to meet the necessary requirements. We consider here the evaluation of water level forecast guidance and to facilitate the discussion briefly review the characteristics of the ocean forecast models considered.

The Real Time Ocean Forecast System (RTOFS) Atlantic application run at the National Centers for Environmental Prediction (NCEP) uses the Hybrid Coordinate Ocean Model (HYCOM) with 1200 x 1684 points in the horizontal as shown in Figure 1.1 and 18 isopycnal and 7 z-levels in the vertical. Surface forcings, in the form of 10-m winds and sea-level atmospheric pressure, are from the 3-hour NCEP Global Forecast System (GFS), a numerical weather prediction modeling system. The open boundaries are relaxed to NCEP climatology. Tides are included in terms of tidal potential and boundary tides specified in terms of the M_2 , S_2 , N_2 , K_2 , K_1 , P_1 , O_1 , and Q_1 tidal constituents. River inputs are specified from US Geological Survey (USGS) daily streamflow data and climatology. In the previously analyzed operational version (Richardson and Schmalz, 2007; Richardson and Schmalz, 2009), SST data from the GOES AVHRR are assimilated in RTOFS. In the November 2009 operational version, improvements to the tidal dynamics have been made and SSH data assimilation has been incorporated. Refer to Bleck et al. (2002) for further details regarding the HYCOM model development and computational algorithms. River inflow data for U.S. rivers are from the USGS and from the RivDIS climatology (<http://www.rivdis.sr.unh.edu/>) for foreign rivers. Surface forcing is provided by the NCEP Global Forecast System (GFS) 3 hourly model output. Each cycle produces a 24 hour nowcast, and a 120 hour forecast forced by the NWS NAM model.

The University of North Carolina (UNC) ADCIRC western North Atlantic forecast model is a two-dimensional vertically integrated finite element model. The domain covers the western Atlantic Ocean from 60 degrees West longitude and contains the Gulf of Mexico and spans 7.9 to 45.8 degrees North latitudes. A region of the grid along the East Coast is shown in Figure 1.2. Tidal forcings include the M_2 , S_2 , N_2 , K_2 , K_1 , $2N_2$, O_1 , and Q_1 tidal constituents (Edwards and Blain, 2002). See Luetich et al. (1992) and Kolar et al. (1994) for computational details. The system is run four times a day and is forced by the NWS North American Mesoscale (NAM) 10-meter winds. Each cycle produces a 24 hour nowcast, and an 84 hour forecast forced by the NWS NAM model.

NOS/Coast Survey Development Laboratory (CSDL) has utilized the subtidal water level forecast guidance produced by the NWS Meteorological Development Laboratory (MDL) Extra-Tropical Storm Surge (ETSS) Model for offshore water level boundary conditions for the New York Harbor /Port of New Jersey, Chesapeake Bay, and Galveston Bay operational forecast systems. Separate domains are run for the East Coast as shown in Figures 1.3 and 1.4, West Coast, Alaskan Coast, and Gulf of Mexico as via finite differences on an elliptical grid. See Chen et al. (1993) for additional model shown in Figure 1.5. The NWS GFS is used to provide the meteorological forcings. The two-

dimensional depth averaged shallow water equations are solved in complex variables details. The system is run four times a day with each forecast cycle extending to 96 hours.

The U.S. Navy (USN) Global Coastal Ocean Model (G-NGOM) system in Region 1 contains the western North Atlantic and Gulf of Mexico and is run on a $1/8$ by $1/8$ degree grid as shown in Figure 1.6 based on the Princeton Ocean Model (POM) using 41 layers. See Blumberg and Mellor (1987) and Blumberg and Herring (1987) for computational details and Martin (2000) for operational implementation. The daily 00Z forecast cycle has a horizon out 72 hours and is forced by U.S. Navy Operational Global Atmospheric Prediction System (NOGAPS) winds and Multi-Channel Sea Surface Temperature (MCSST). Barotropic tides are added from the Oregon State global $1/4$ by $1/4$ degree TPXO6.2 tidal model (Egbert and Erofeeva, 2002) for the same eight constituents used in RTOFS as well as two long period constituents (M_f , M_m).

Here, we automate the evaluation of the above ocean nowcast/forecast models to assess their ability to provide water level boundary conditions. The previous water level forecast guidance evaluation procedures (Richardson and Schmalz, 2009) were streamlined into a single analysis program for each of the ocean models, the previous separate read, reformat, filter, adjust, and analysis programs. The plot program was modified to be run within a script to further simplify the evaluation process.

For November 2008, we evaluated daily forecast/nowcast results of both subtidal (ETSS) and total water level response (RTOFS, G-NCOM, and ADCIRC) along the East coast and along the Gulf of Mexico coast from hours 6-36 for all models using the new automated procedures. Results are compared in Chapter 2 to the previous results obtained by Richardson and Schmalz (2009) to verify the automated water level procedures.

Chapter 3 presents a monthly evaluation of the ETSS water level forecast guidance over the period December 2008 – October 2009. In Chapter 4, a seasonal analysis of the RTOFS forecast guidance is performed by adding the analysis for the months February, May, and August 2009 to the November 2008 analysis of Chapter 1. In Chapter 5, an annual analysis of ETSS, RTOFS, and G-NCOM is performed by comparing the November 2008 results of Chapter 1 to an analysis of results for November 2009. In Chapter 6, we present the extension of the evaluation procedures to include the additional statistical measures of relative RMSE, Willmott et al. (1985) relative error, and central frequency (Hess et al., 2003). Chapter 6 presents some conclusions drawn from the work as well as recommendations for routine ocean model water level evaluation.

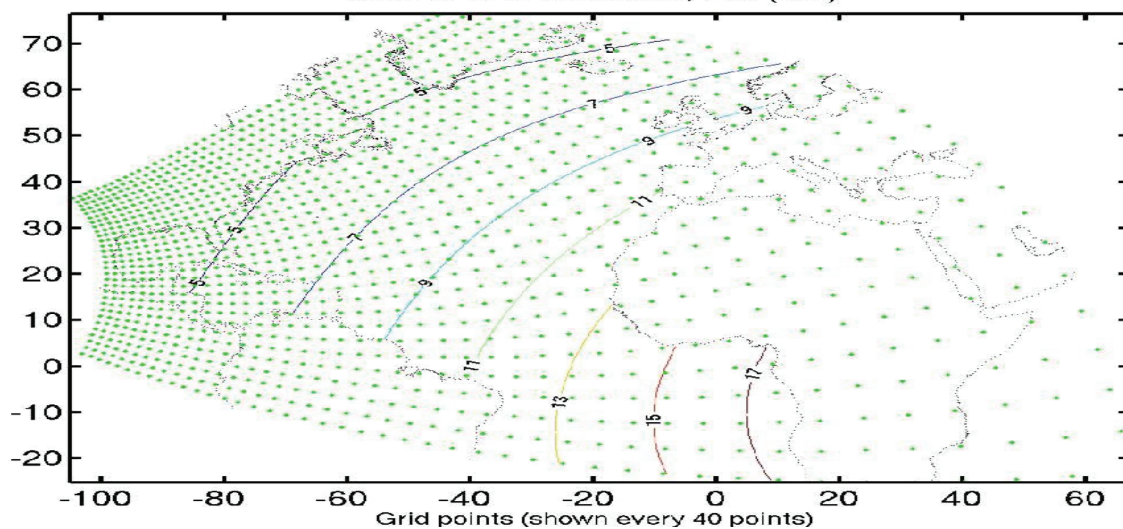


Figure 1.1. RTOFS Grid with spacing from 5 to 17 km.

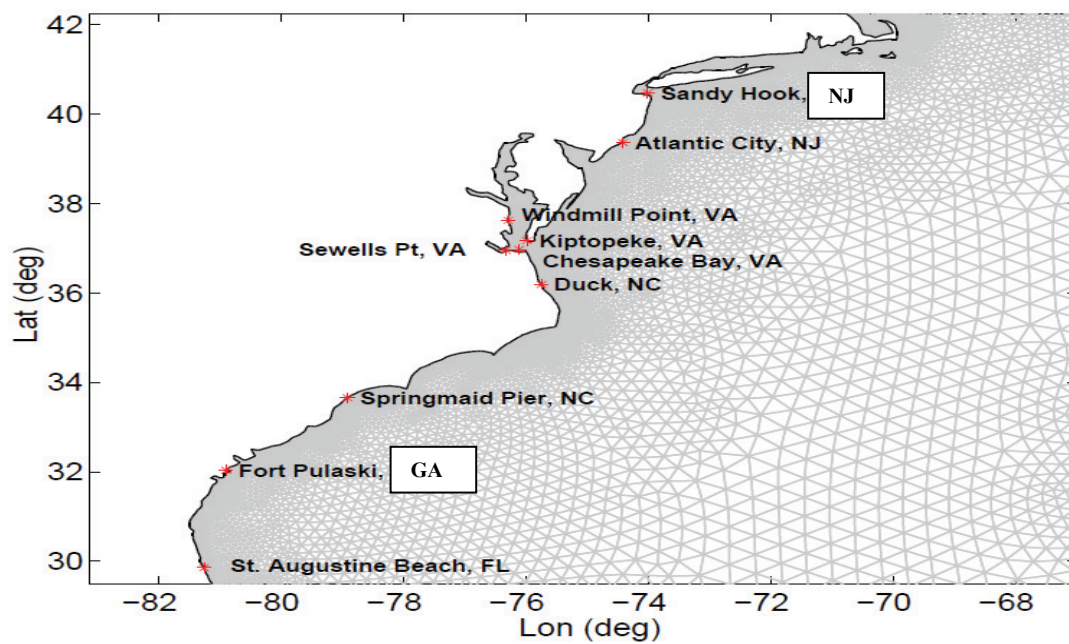


Figure 1.2. ADCIRC Western North Atlantic Grid along the East Coast with resolution ranging from 0.5 to 45 km. The Gulf of Mexico and Caribbean regions are not shown.

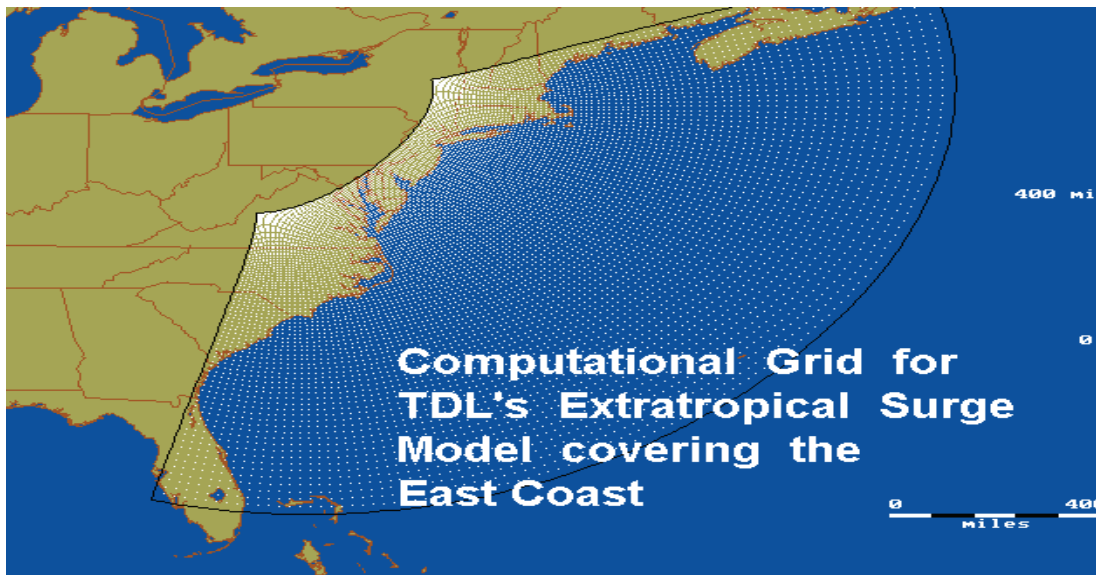


Figure 1.3. ETSS East Coast Grid with order 10 km coastal resolution. Area coverage is the same for the present order 5 km coastal resolution model, which is analyzed in this report.

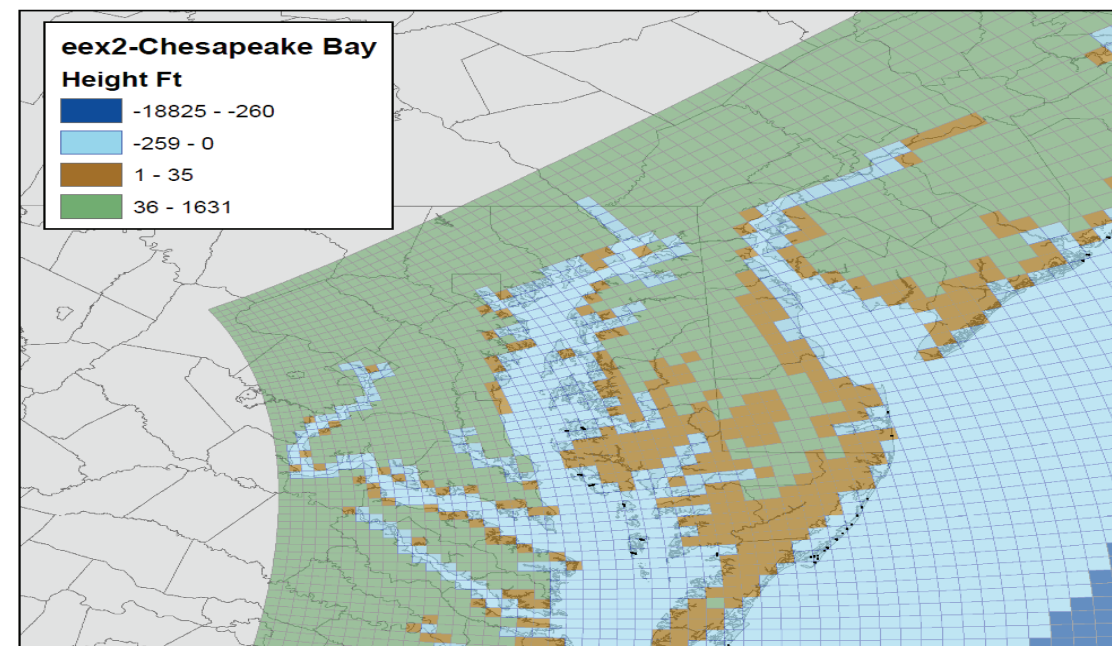


Figure 1.4. High Resolution ~6 km ETSS East Coast Grid in the Vicinity of Chesapeake and Delaware Bays. The high resolution ETSS model is analyzed in this report.

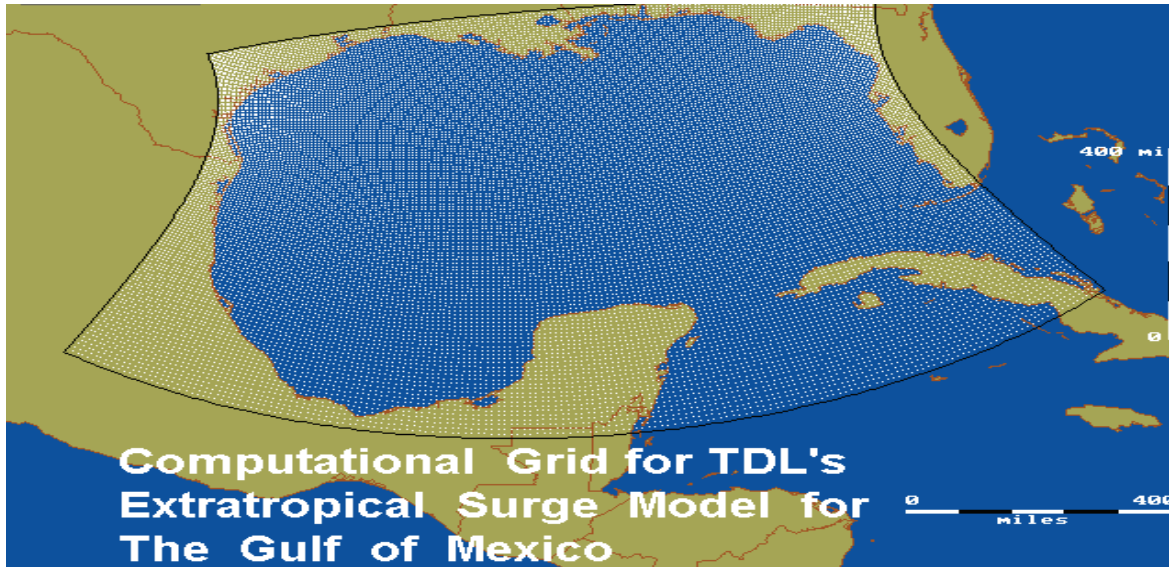


Figure 1.5. ETSS Gulf of Mexico Grid with order 10 km coastal resolution, which is analyzed in this report.

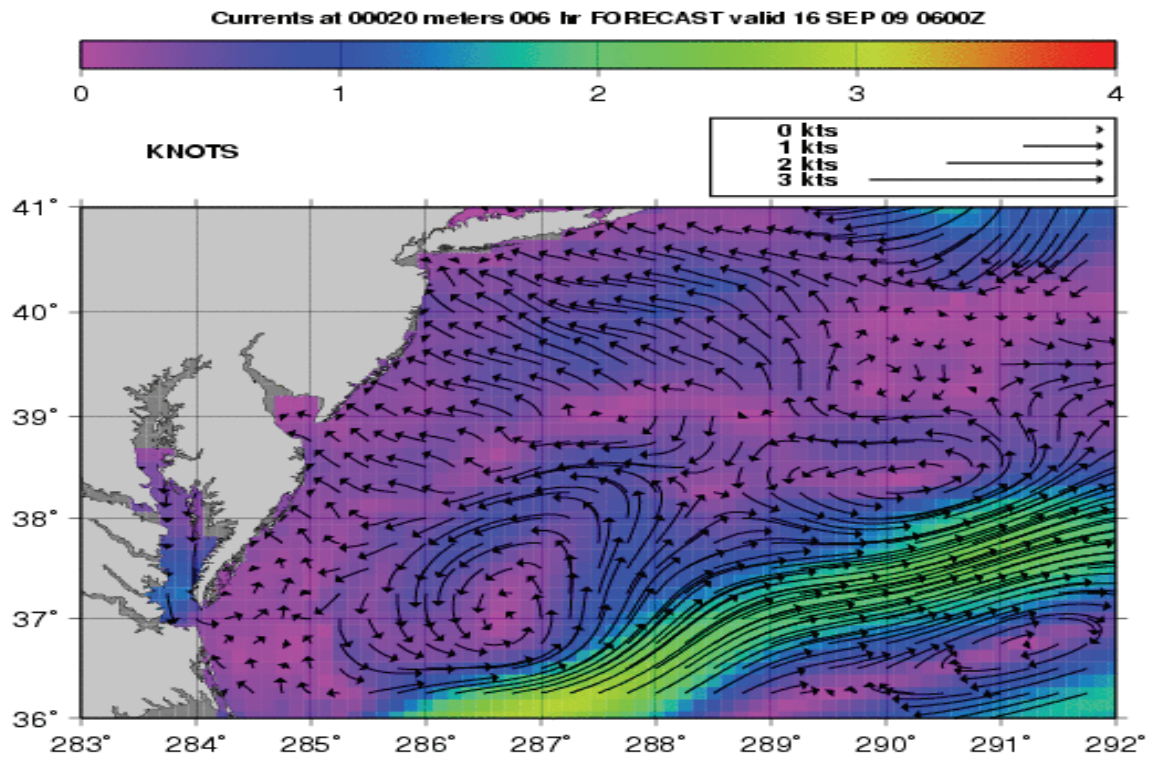


Figure 1.6. G-NCOM Grid in the Mid-Atlantic Region 1/8 degree ~ 10km. Current speeds and directions are shown for 16 September 2009 at each grid cell to illustrate the grid resolution. Gulf of Mexico and other regions are not shown.

2. AUTOMATED WATER LEVEL EVALUATION

An automated water level evaluation procedure has been developed by streamlining the previous water level forecast guidance evaluation process (Richardson and Schmalz, 2009). For each of the ocean forecast models a single analysis program was developed by combining the previous separate read, reformat, filter, adjust, and analysis programs. The plot program was modified to be run within a script environment to allow passing as an argument the ocean model to be considered. This further simplifies the evaluation plot process. Water level data acquisition was also simplified by using STEP 2 of the NOS skill assessment software (Zhang et al., 2006) to automatically download the water level data for all stations at once. Previous efforts relied on acquiring for each station the data from the CO-OPS website, reformatting the data to remove the HTML tags, and then transferring the individual station files to the Linux servers for analysis. The root mean square errors (RMSEs) from the automated water level evaluation are given in Table 2.1 for each of the ocean model forecast systems and are identical to those obtained previously by Richardson and Schmalz (2009) verifying the new automated procedures.

Table 2.1. ETSS, RTOFS, ADCIRC, and G-NCOM Forecast Guidance Monthly Water Level Comparisons to NOS Observations for November 2008 (RMSE[meters]). Forecast hours 6-36 are used in the comparisons. ETSS water levels are subtidal, while the other three forecasts include the tide.

Station	ETSS	RTOFS	ADCIRC	G-NCOM
Eastport, ME	0.078	3.476	0.644	1.044
Portland, ME	0.076	1.870	0.288	0.184
Boston, MA	0.074	1.890	0.302	0.376
Woods Hole, MA	0.064	0.320	0.183	0.118
Sandy Hook, NJ	0.094	0.968	0.236	0.196
Atlantic City, NJ	0.083	0.770	0.100	0.131
Cape May, NJ	0.228	1.042	0.335	0.435
Lewes, DE	0.072	0.865	0.109	0.276
Duck, NC	0.056	0.622	0.111	0.220
Wilmington, NC	0.058	1.099	0.670	0.632
Springmaid Pier, SC	0.050	1.042	0.131	0.136
Charleston, SC	0.053	1.191	0.239	0.237
Fort Pulaski, GA	0.054	1.638	0.286	0.326
Fernandina Beach, FL	0.056	1.546	0.356	0.272
Naples, FL	0.044	0.645	0.156	0.126
St Petersburg FL	0.098	0.750	0.271	0.399
Clearwater, FL	0.049	0.789	0.173	0.243
Apalachicola, FL	0.101	0.210	0.129	0.166
Panama City, FL	0.036	0.137	0.121	0.097
Pensacola, FL	0.033	0.207	0.085	0.153
Sabine Pass, TX	0.084	0.618	0.181	0.121
Galveston Pleasure Pier, TX	0.065	0.470	0.120	0.083
Freeport, TX	0.060	0.217	0.125	0.099

RTOFS

The RMSE results for RTOFS from the modified plotting procedures are shown in Figure 2.1 for both Atlantic and Gulf of Mexico stations. One notes the large RMSEs on the order of 80 cm for the East Coast stations due to the errors in the tidal dynamics. To further verify the automated results, plots are shown in Figure 2.2 of RTOFS forecast water levels versus observations for an Atlantic station (Sandy Hook, NJ) and a Gulf of Mexico station (Clearwater, FL). Both of these plots indicate an issue with the tide.

ETSS

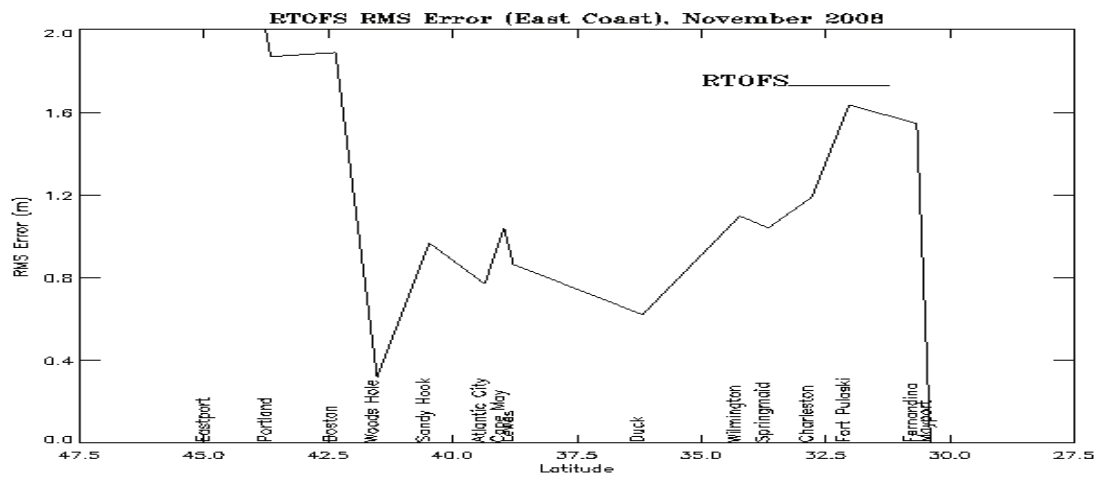
The RMSE results for ETSS are shown in Figure 2.3 and indicate errors in water level levels on the order of 10 cm for both Atlantic and Gulf of Mexico stations. To further verify the automated results, plots) are shown in Figure 2.4 of ETSS forecast subtidal water levels versus observations for an Atlantic station (Sandy Hook, NJ) and a Gulf of Mexico station (Clearwater, FL. Both of these plots indicate an excellent agreement between ETSS subtidal water level forecasts and observations.

G-NCOM

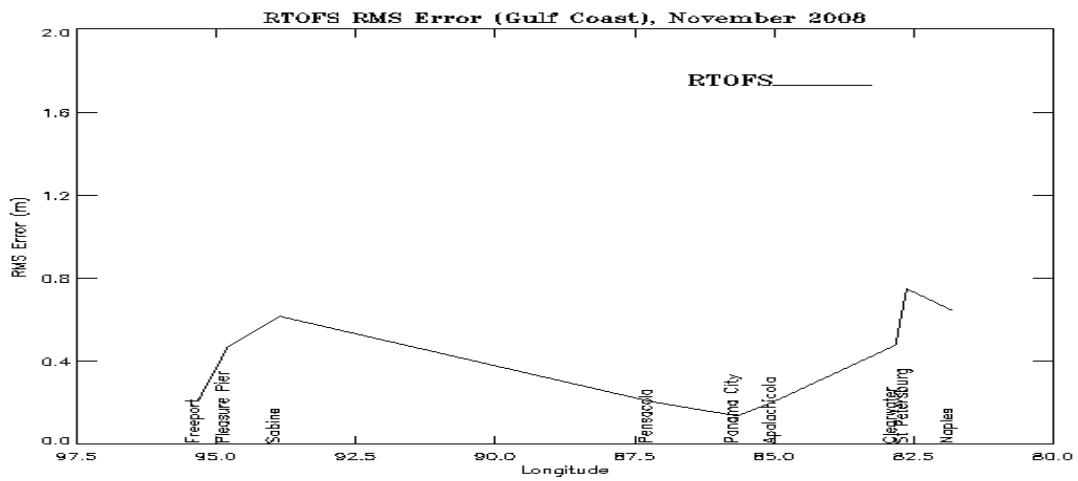
The RMSE results for G-NCOM are shown in Figure 2.5 and indicate errors in water levels on the order of 20 cm for the Atlantic and 10 cm for Gulf of Mexico stations. To further verify the automated results, plots are shown in Figure 2.6 of G-NCOM forecast water levels versus observations for an Atlantic station (Sandy Hook, NJ) and a Gulf of Mexico station (Clearwater, FL). Both of these plots indicate a reasonable agreement between G-NCOM total water level forecasts and observations. While forecasts are at three hour intervals, the tidal dynamics seem to be reasonably captured.

ADCIRC

The RMSE results for UNC ADCIRC are shown in Figure 2.7 and indicate errors in water levels on the order of 10 cm for both Atlantic and Gulf of Mexico stations. To further verify the automated results, plots of ADCIRC forecast water levels versus observations for an Atlantic station (Sandy Hook, NJ) and a Gulf of Mexico station (Clearwater, FL) are shown in Figure 2.8. Both of these plots indicate an excellent agreement between the ADCIRC total water level forecasts and observations.

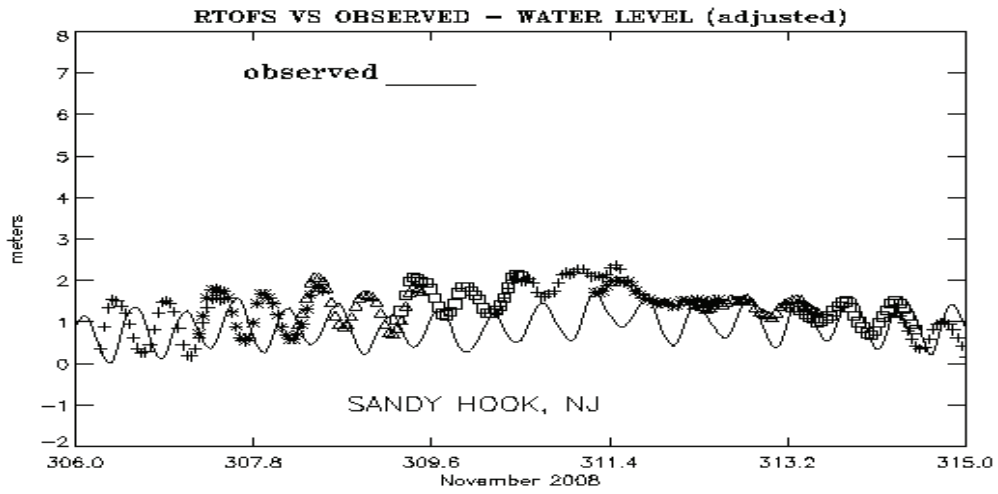


(a)

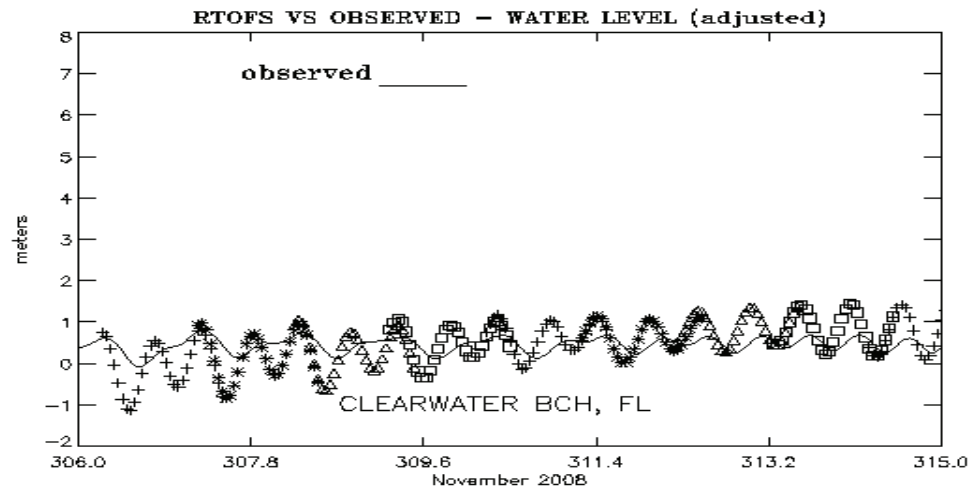


(b)

Figure 2.1. RTOFS Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008. Note there are no observations at Mayport, FL.

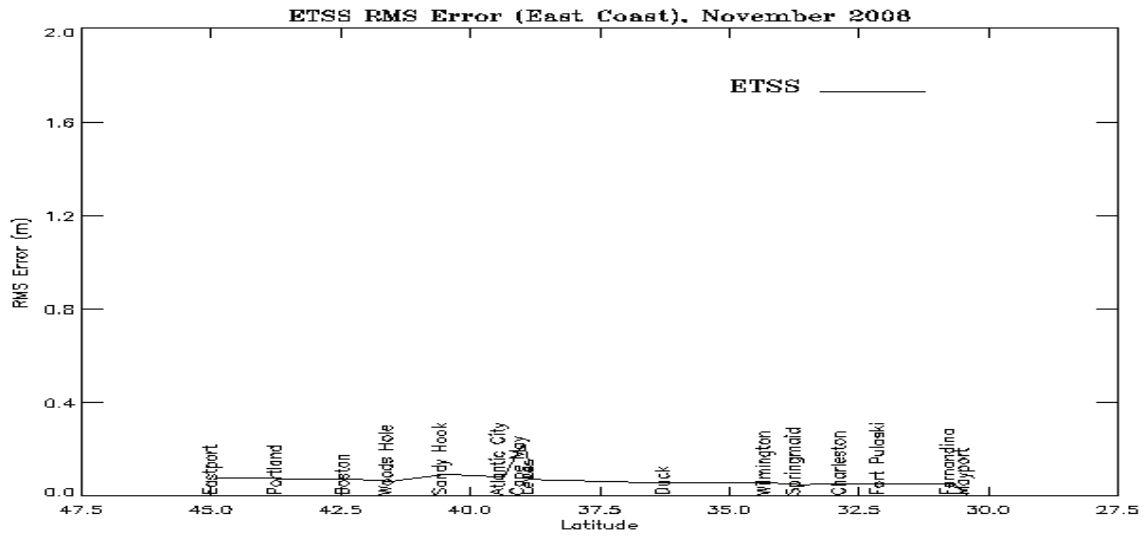


(a)

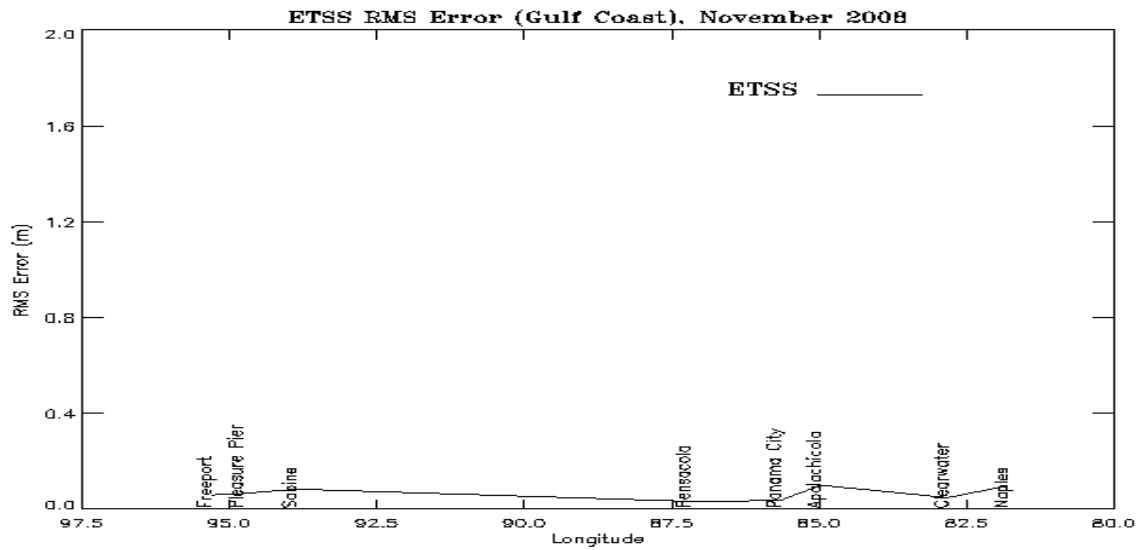


(b)

Figure 2.2. RTOFS Total Water Level Forecast Guidance against NOS Observations for November 2008. Sandy Hook, NJ (a) Clearwater Beach FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+ , * , Δ , and $\square$).

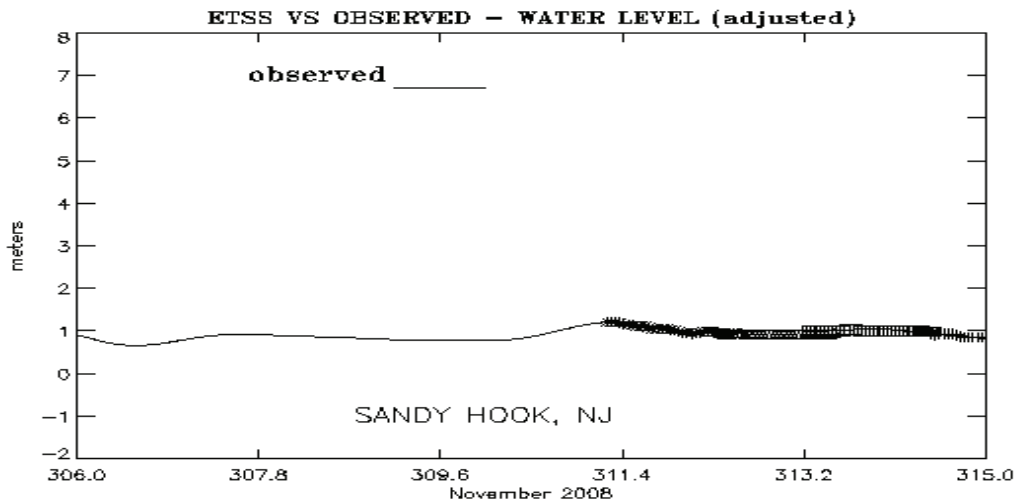


(a)

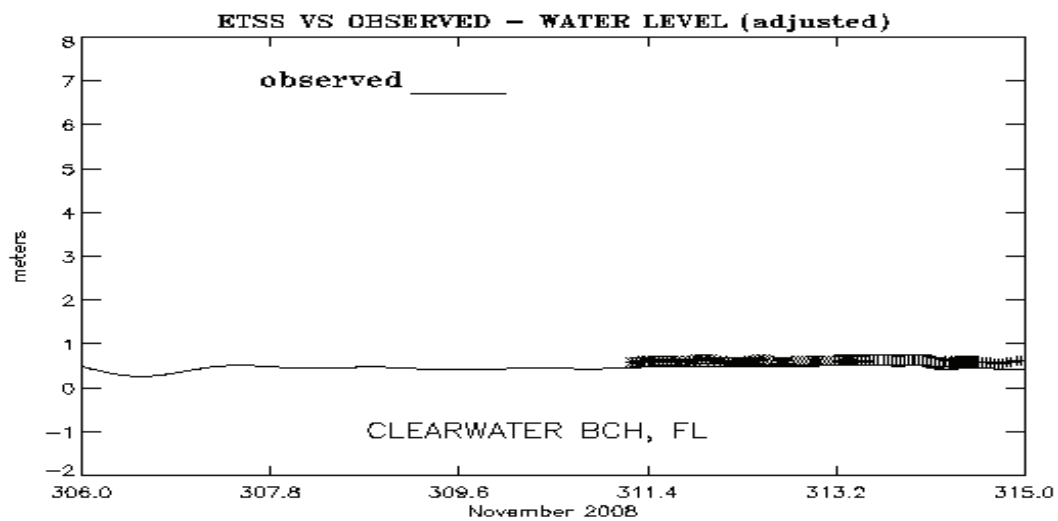


(b)

Figure 2.3. ETSS Subtidal Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008. Note there are no observations at Mayport, FL.

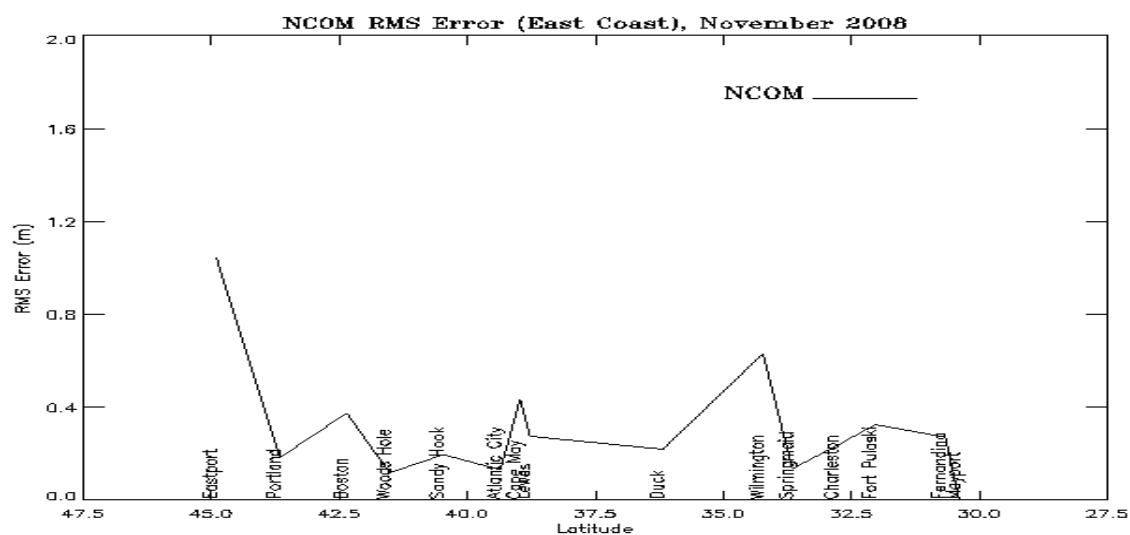


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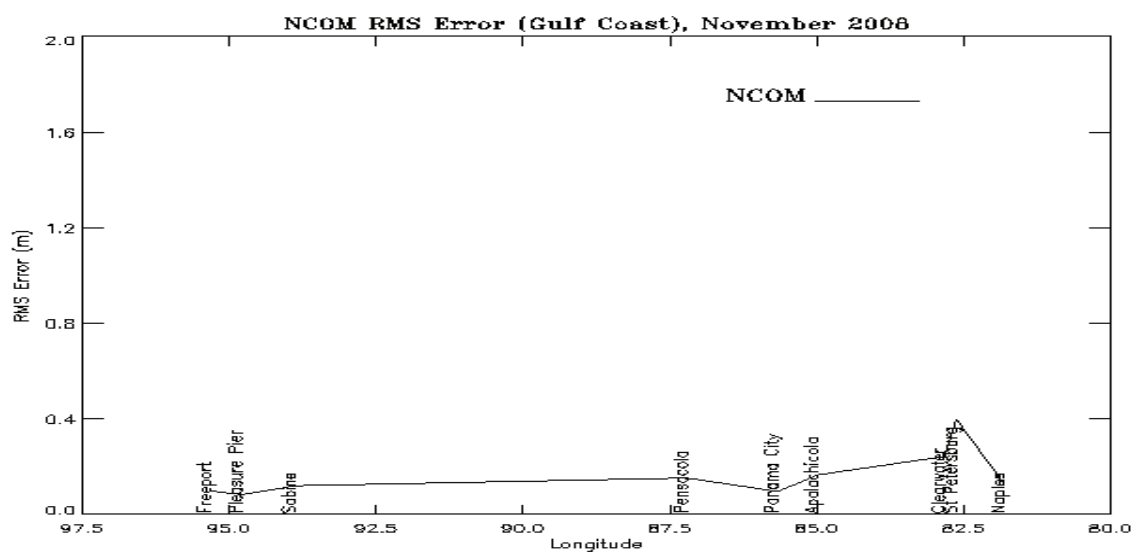


(b)

Figure 2.4. ETSS Subtidal Water Level Forecast Guidance against NOS Observations for November 2008. Sandy Hook, NJ (a) Clearwater Beach, FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+ , * , Δ , and $\square$). At this vertical scale the model results appear to be represented by +.

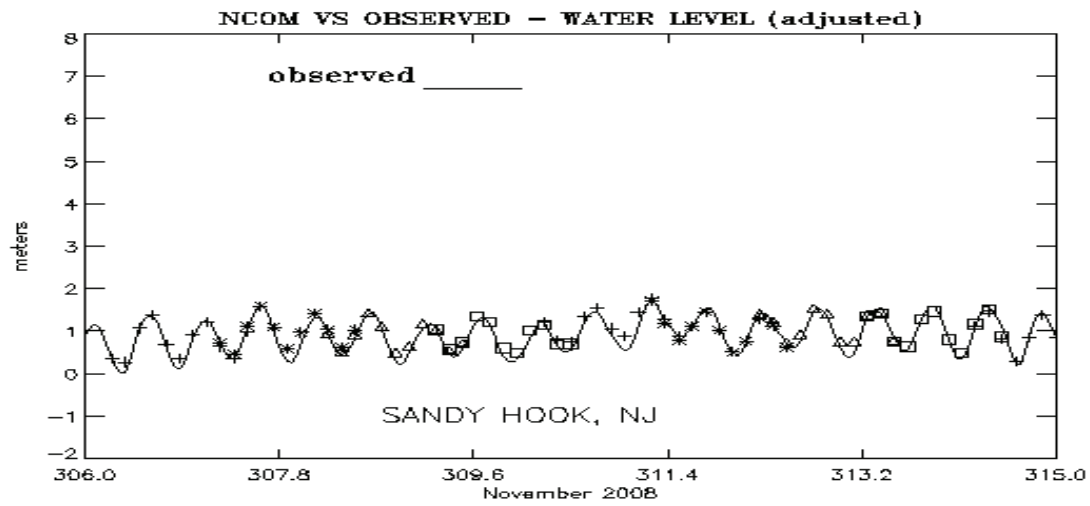


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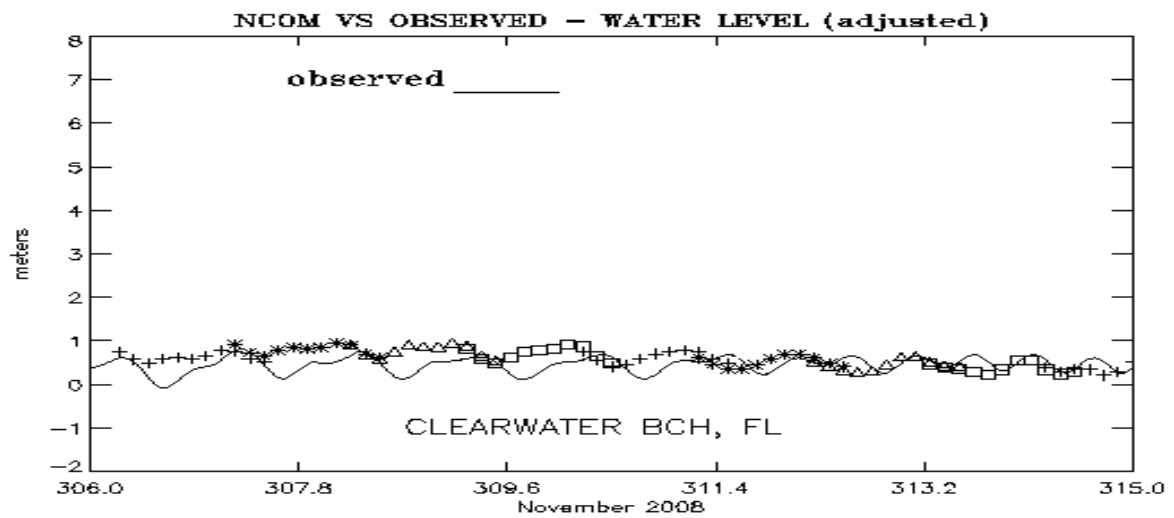


(b)

Figure 2.5. G-NCOM Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008. Note there are no observations at Mayport, FL.

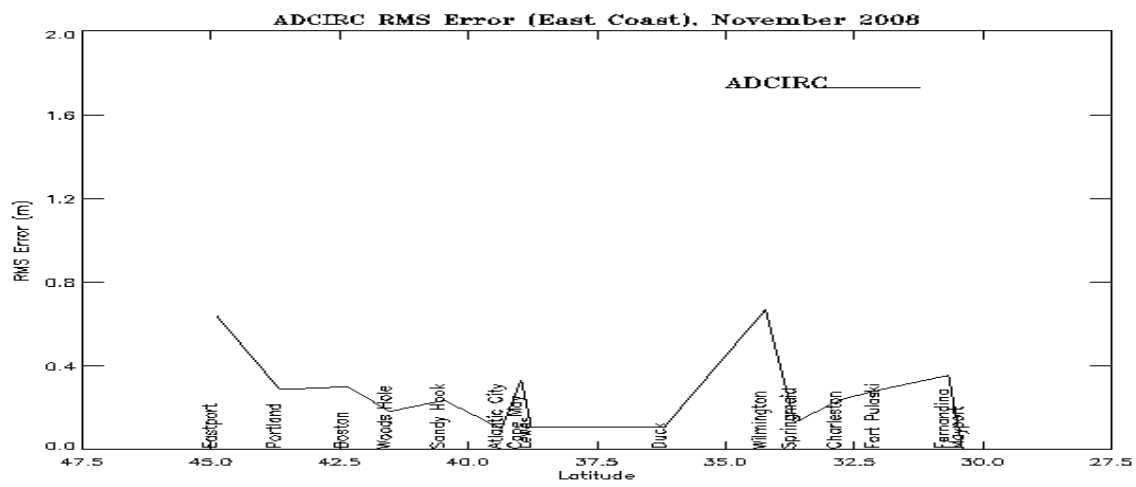


(a)

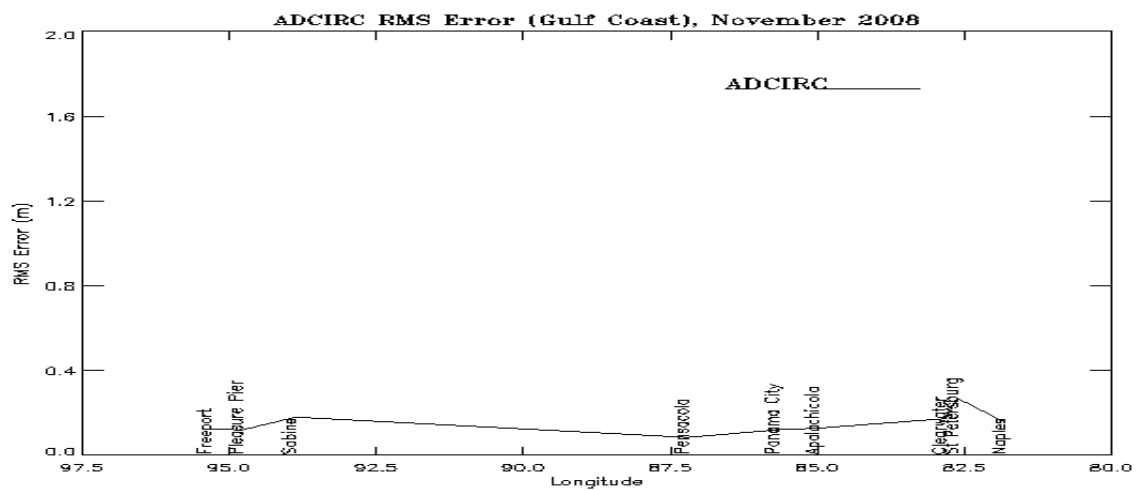


(b)

Figure 2.6. G-NCOM Total Water Level Forecast Guidance against NOS Observations for November 2008. Sandy Hook, NJ (a) Clearwater Beach FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+ , * , Δ , and □).

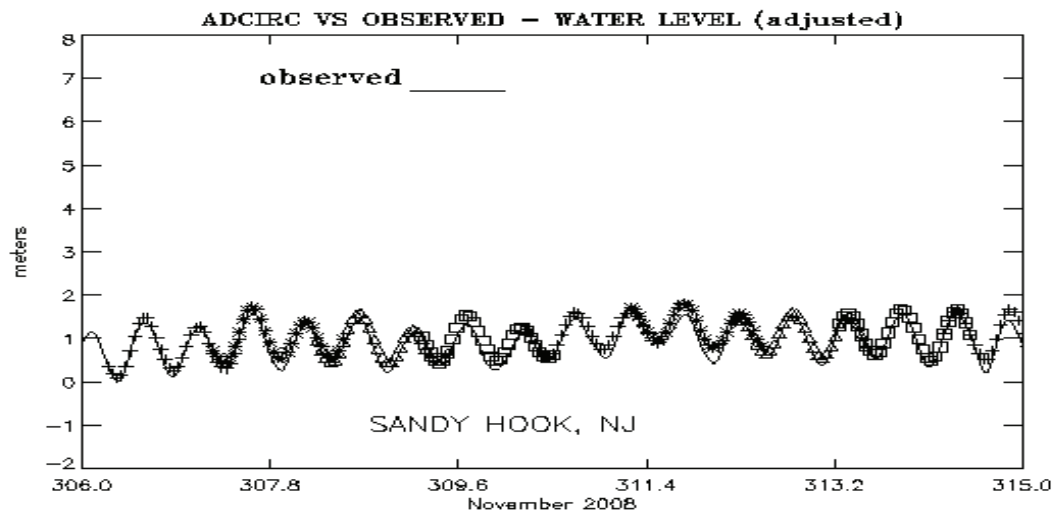


(a)

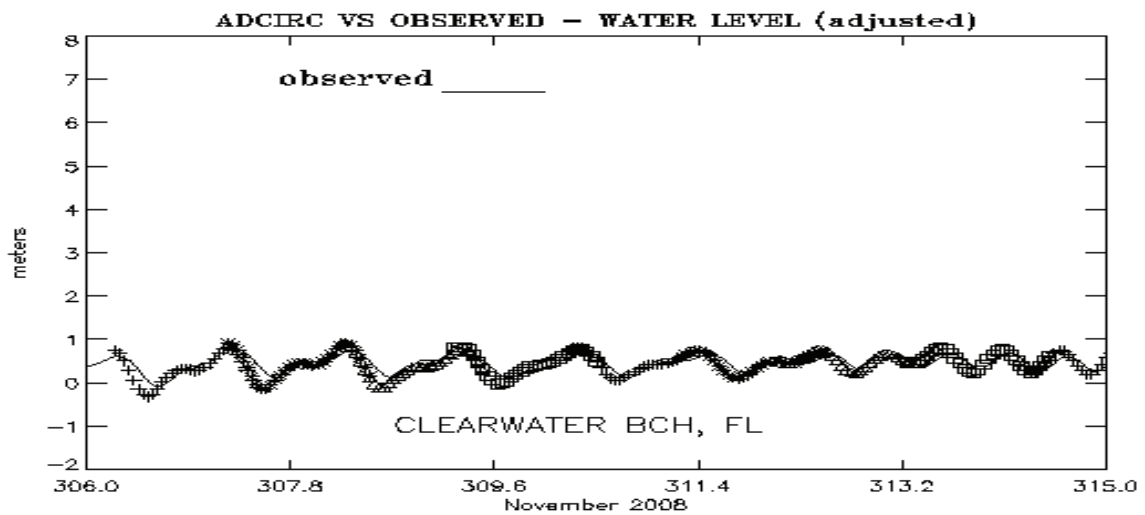


(b)

Figure 2.7. ADCIRC Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008. Note there are no observations at Mayport, FL.



(a)



(b)

Figure 2.8. ADCIRC Total Water Level Forecast Guidance against NOS Observations for November 2008. Sandy Hook, NJ (a) Clearwater Beach, FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □).

3. ETSS MODEL MONTHLY ANALYSIS

To further exercise the automated water level evaluation procedures, ETSS was evaluated on a monthly basis over the period December 2008 to November 2009. The major issue in the timeliness of the evaluation is the availability of the NOS verified hourly data. It usually is available for all 24 stations at the middle of the following month. Monthly RMSEs are given in Table 3.1 and exhibit very little change from month to month. There is some indication that along the northeast Atlantic coast, the errors are largest during the winter season. To further investigate the ETSS subtidal water level response, RMSE error plots for the Atlantic and Gulf of Mexico stations as well as time series plots at two Atlantic coast stations (Sandy Hook, NJ and Mayport, FL) and two Gulf of Mexico stations (Clearwater Beach, FL and Galveston Pleasure Pier, TX) are shown in Figure 3.1 and Figure 3.2 for February 2009, in Figure 3.3 and Figure 3.4 for May 2009, and in Figure 3.5 and 3.6 for August 2009. Excellent agreement in the predicted subtidal water levels is achieved during all months.

Table 3.1. ETSS Monthly Subtidal Water Level Forecast Guidance Comparisons to NOS Observations for December 2008 – March 2009 (RMSE[meters]). Blanks indicate months for which observations were not available, while * denotes problems with water level observations.

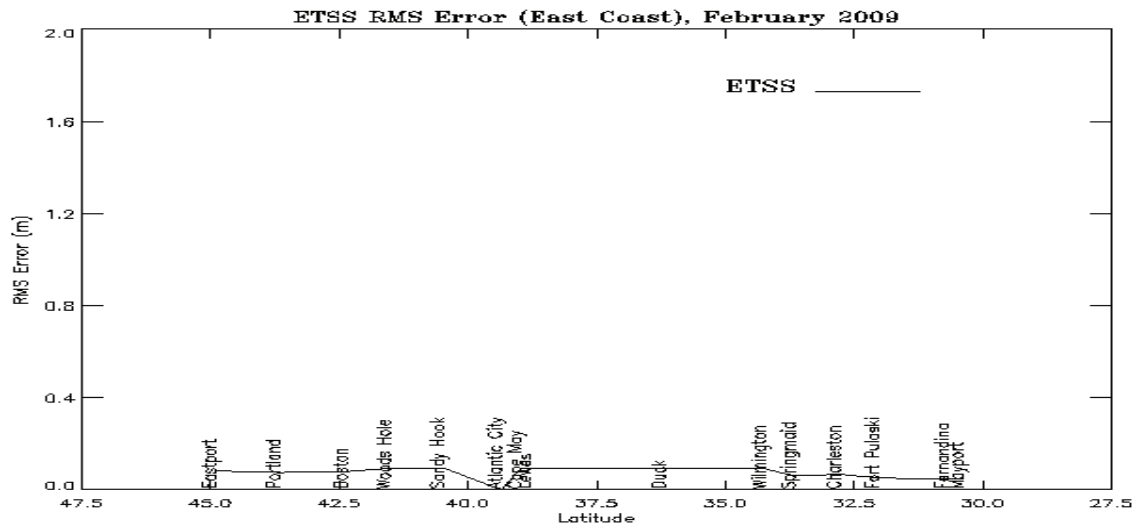
Station	December 2008	January	February	March
Eastport, ME	0.102	0.838*	0.082	0.055
Portland, ME	0.095	0.084	0.075	0.047
Boston, MA	0.105	0.085	0.079	0.051
Woods Hole, MA	0.156	0.089	0.094	0.060
Sandy Hook, NJ	0.099	0.108	0.095	0.066
Atlantic City, NJ	0.102	0.103		0.060
Cape May, NJ	0.099	0.098	0.094	0.066
Lewes, DE	0.092	0.097	0.094	0.061
Duck, NC	0.065	0.080	0.093	0.061
Wilmington, NC	0.106	0.110	0.091	0.073
Springmaid Pier, SC	0.060	0.069	0.061	0.064
Charleston, SC	0.065	0.072	0.068	0.087
Fort Pulaski, GA	0.065	0.051	0.052	0.080
Fernandina Beach, FL	0.043	0.051	0.046	0.063
Mayport, FL	0.052	0.045	0.046	0.048
Naples, FL	0.059	0.053	0.042	0.056
St Petersburg FL	0.139	0.117	0.094	0.088
Clearwater, FL	0.091	0.064	0.052	0.063
Apalachicola, FL	0.128	0.116	0.119	0.096
Panama City, FL	0.067	0.063	0.046	0.049
Pensacola, FL	0.067	0.059	0.055	0.055
Sabine Pass, TX	0.117	0.074	0.087	0.100
Galveston Pleasure Pier, TX	0.095	0.066	0.065	0.085

Table 3.1. (Cont.) ETSS Monthly Subtidal Water Level Forecast Guidance Comparisons to NOS Observations for April through July 2009 (RMSE[meters]).

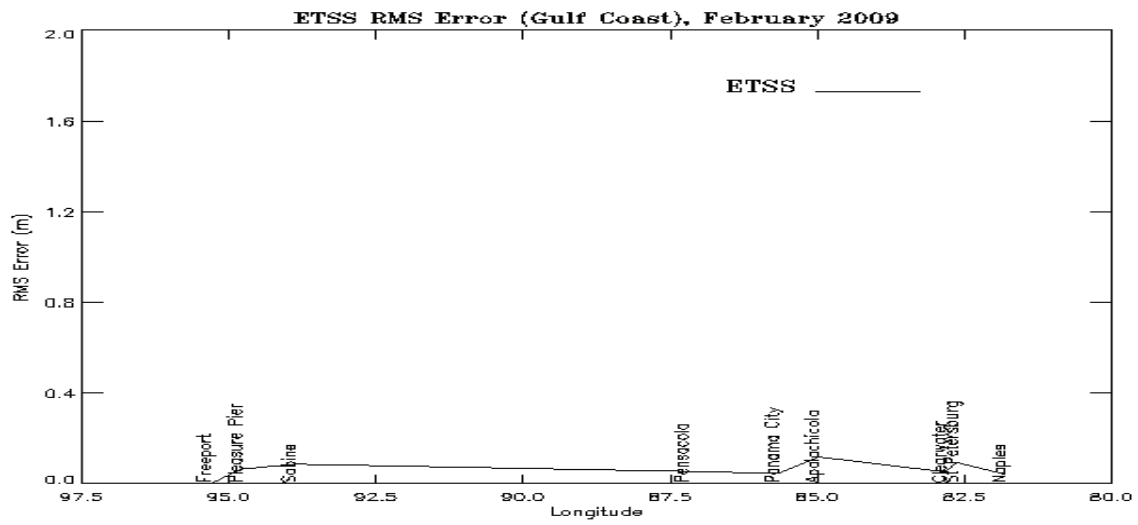
Station	April	May	June	July
Eastport, ME	0.065	0.043	0.029	0.049
Portland, ME	0.052	0.041	0.030	0.035
Boston, MA	0.053	0.043	0.028	0.039
Woods Hole, MA	0.063	0.044	0.041	0.038
Sandy Hook, NJ	0.061	0.042	0.042	0.047
Atlantic City, NJ	0.066	0.044	0.047	0.058
Cape May, NJ	0.071	0.040	0.047	0.058
Lewes, DE	0.076	0.042	0.047	0.059
Duck, NC	0.078	0.055	0.039	0.042
Wilmington, NC	0.101	0.072	0.044	0.050
Springmaid Pier, SC	0.066	0.055	0.045	0.048
Charleston, SC	0.078	0.069	0.049	0.058
Fort Pulaski, GA	0.065	0.070	0.047	0.059
Fernandina Beach, FL	0.063	0.078	0.049	0.060
Mayport, FL	0.053	0.056	0.039	0.049
Naples, FL	0.044	0.042	0.030	0.033
St Petersburg FL	0.078	0.056	0.034	0.030
Clearwater, FL	0.060	0.067	0.027	0.032
Apalachicola, FL	0.079	0.082	0.028	0.025
Panama City, FL	0.043	0.047	0.026	0.029
Pensacola, FL	0.047	0.047	0.025	0.022
Sabine Pass, TX	0.117	0.048	0.040	0.037
Galveston Pleasure Pier, TX	0.091	0.047	0.043	0.035

Table 3.1. (Cont.) ETSS Monthly Subtidal Water Level Forecast Guidance Comparisons to NOS Observations for August through November 2009 (RMSE[meters]).

Station	August	September	October	November
Eastport, ME	0.052	0.053	0.079	0.059
Portland, ME	0.040	0.044	0.063	0.051
Boston, MA	0.249*	0.248*	0.067	0.055
Woods Hole, MA	0.035	0.043	0.069	0.054
Sandy Hook, NJ	0.042	0.045	0.087	0.066
Atlantic City, NJ	0.040	0.045	0.069	0.070
Cape May, NJ	0.045	0.050	0.069	0.072
Lewes, DE	0.043	0.071	0.078	0.076
Duck, NC	0.040	0.058	0.066	0.090
Wilmington, NC	0.036	0.068	0.033	
Springmaid Pier, SC	0.044	0.055	0.060	0.071
Charleston, SC	0.051	0.050	0.065	0.075
Fort Pulaski, GA	0.041	0.053	0.066	0.076
Fernandina Beach, FL	0.045	0.052	0.065	0.068
Mayport, FL	0.036	0.041	0.053	0.053
Naples, FL	0.035	0.026	0.038	0.046
St Petersburg FL	0.037	0.031	0.063	0.082
Clearwater, FL	0.038	0.031	0.108	0.056
Apalachicola, FL	0.092	0.029	0.084	0.107
Panama City, FL	0.050	0.028	0.041	0.064
Pensacola, FL	0.040	0.032	0.042	0.066
Sabine Pass, TX	0.036	0.039	0.075	0.090
Galveston Pleasure Pier, TX	0.038	0.043	0.068	0.083

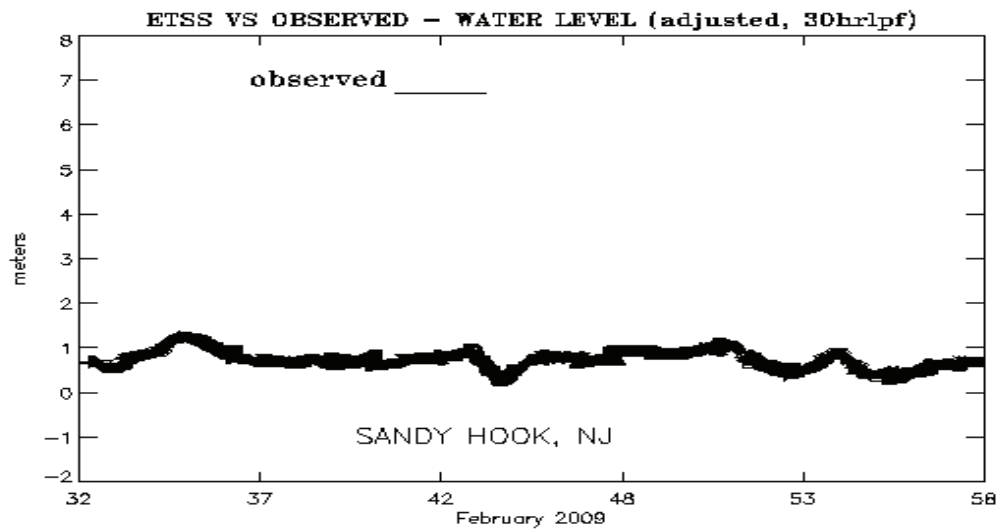


(a)

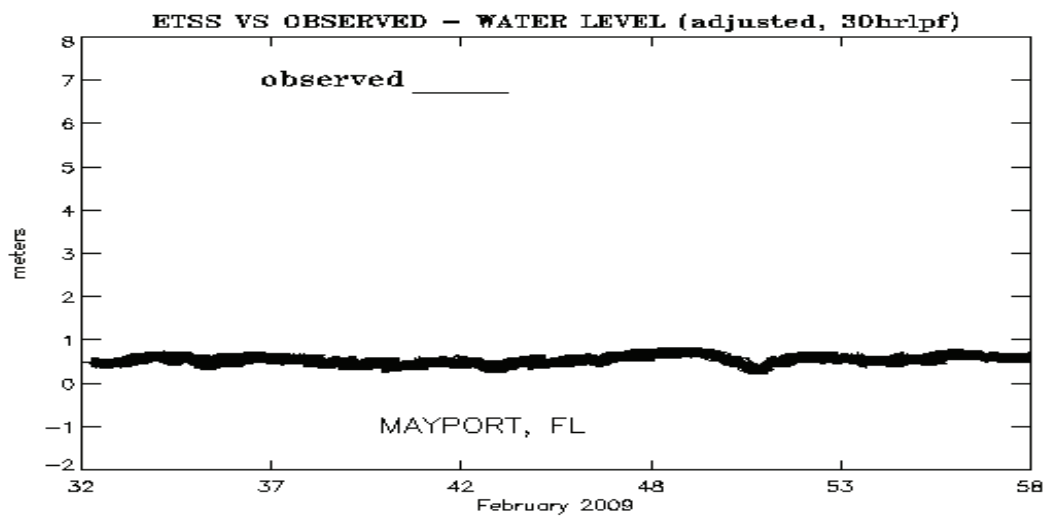


(b)

Figure 3.1. ETSS Subtidal Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for February 2009. Note there are no observations at Atlantic City, NJ and Freeport, TX.

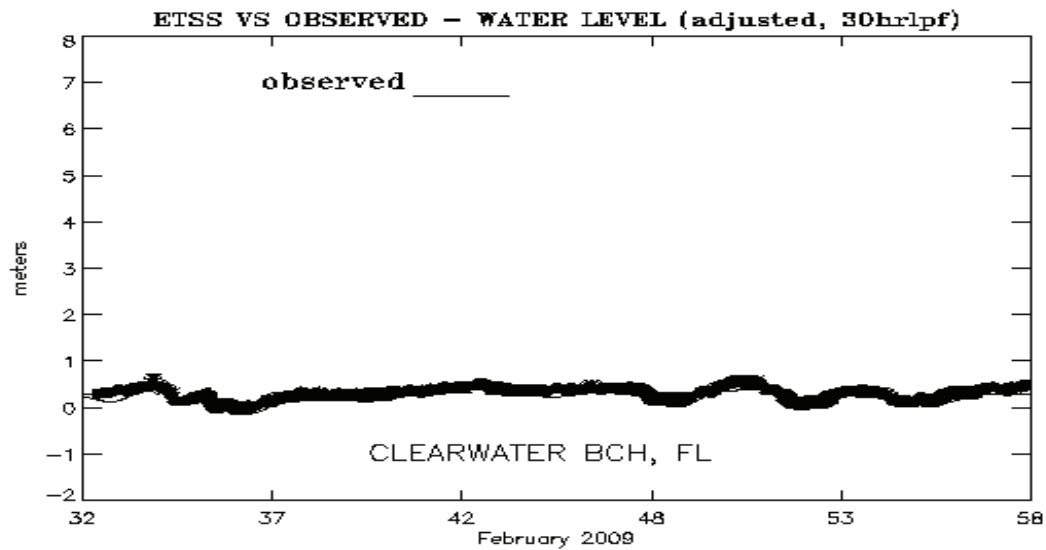


(a)

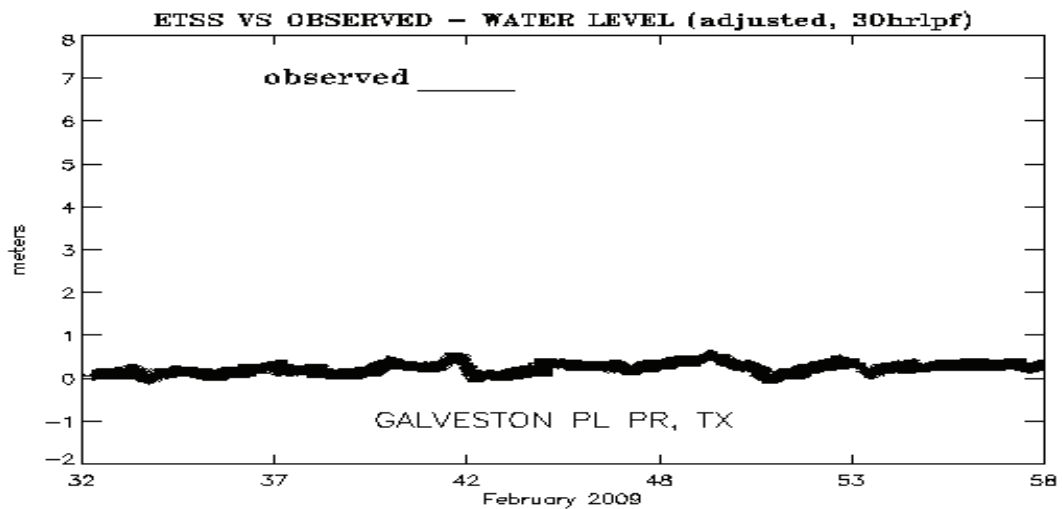


(b)

Figure 3.2. ETSS Subtidal Water Level Forecast Guidance against NOS Observations for February 2009. Sandy Hook, NJ (a) Mayport, FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □). At this vertical scale the model results appear to be represented by +.

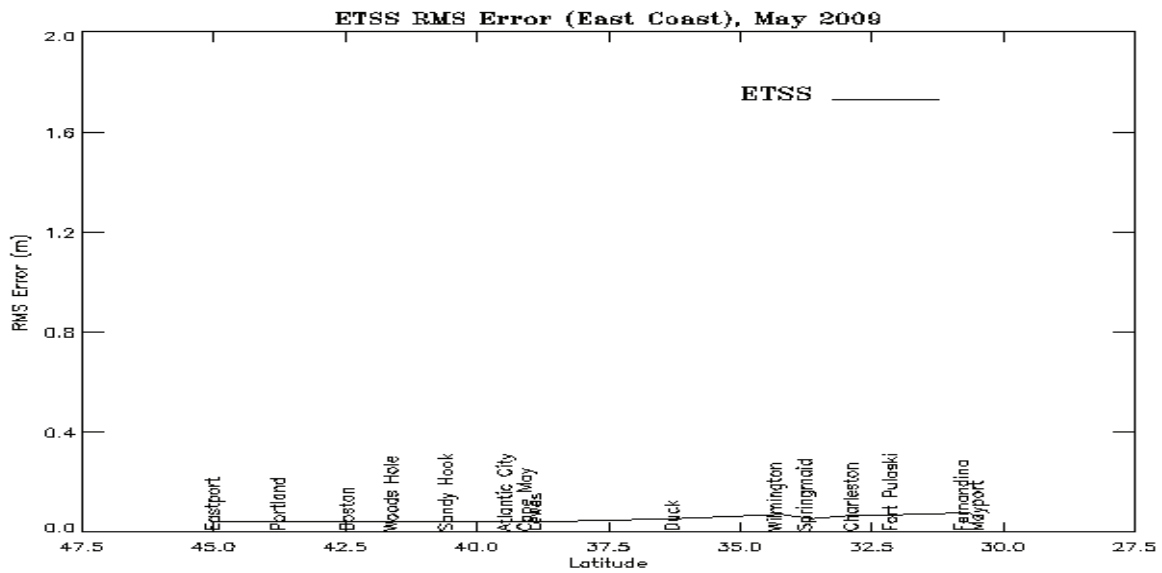


(c)

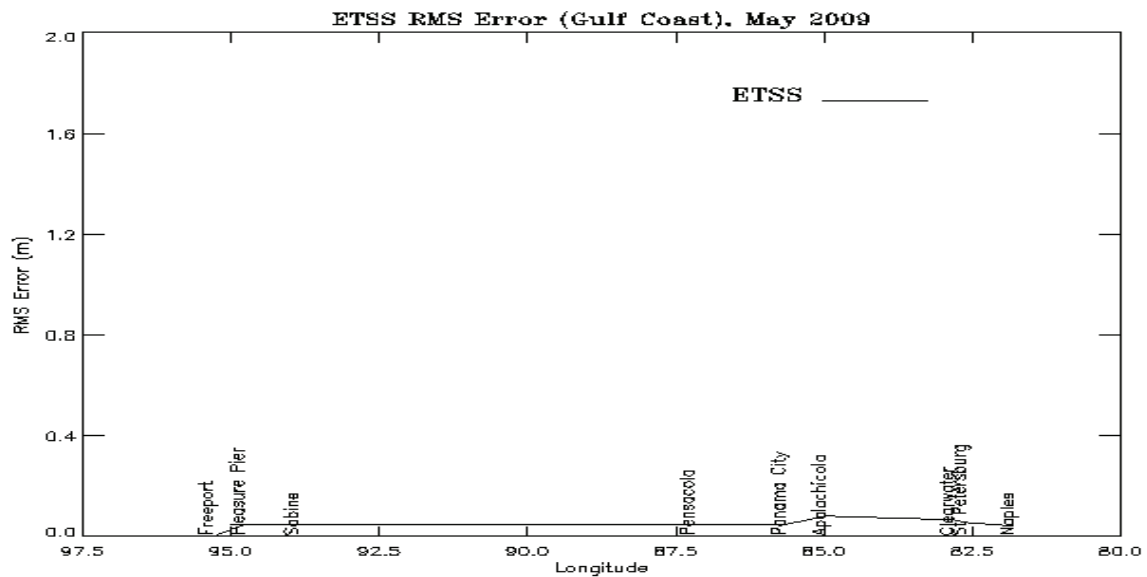


(d)

Figure 3.2. (Cont.) ETSS Subtidal Water Level Forecast Guidance against NOS Observations for November 2009. Clearwater Beach, FL (c) Galveston Pleasure Pier, TX. Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □). At this vertical scale the model results appear to be represented by +.

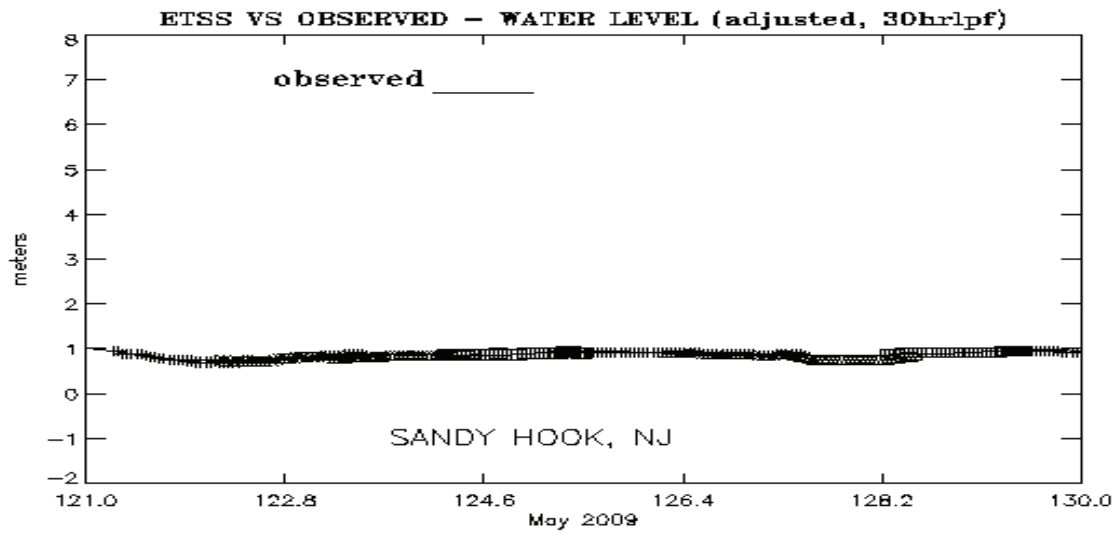


(a)

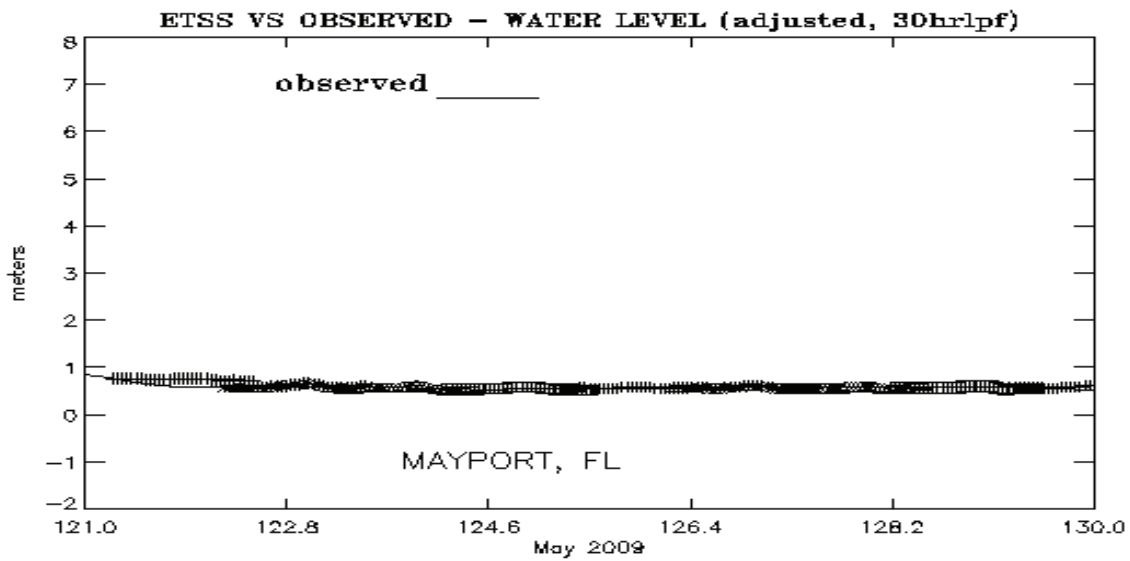


(b)

Figure 3.3. ETSS Subtidal Water Level Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for May 2009. Note there are no observations at Freeport, TX.

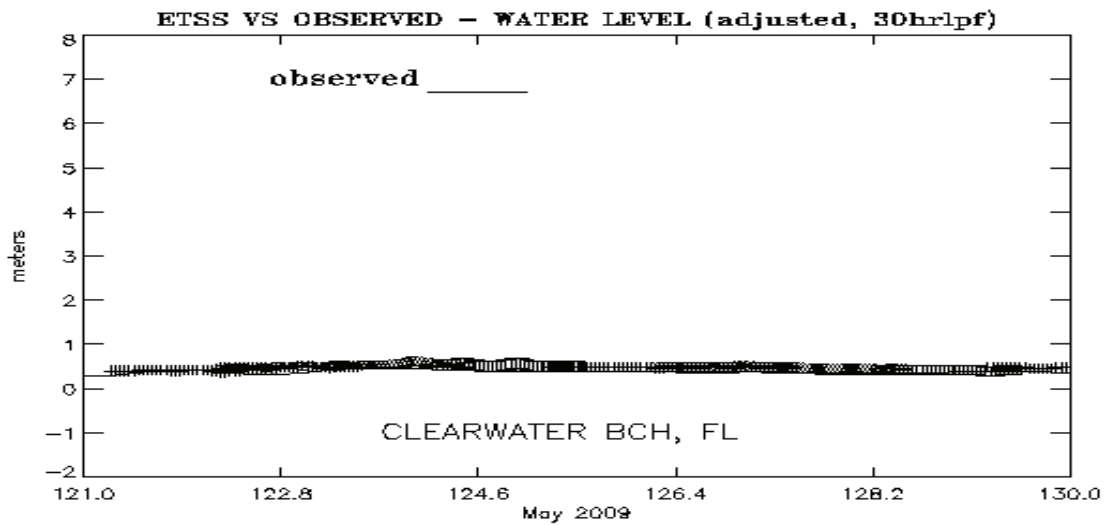


(a)

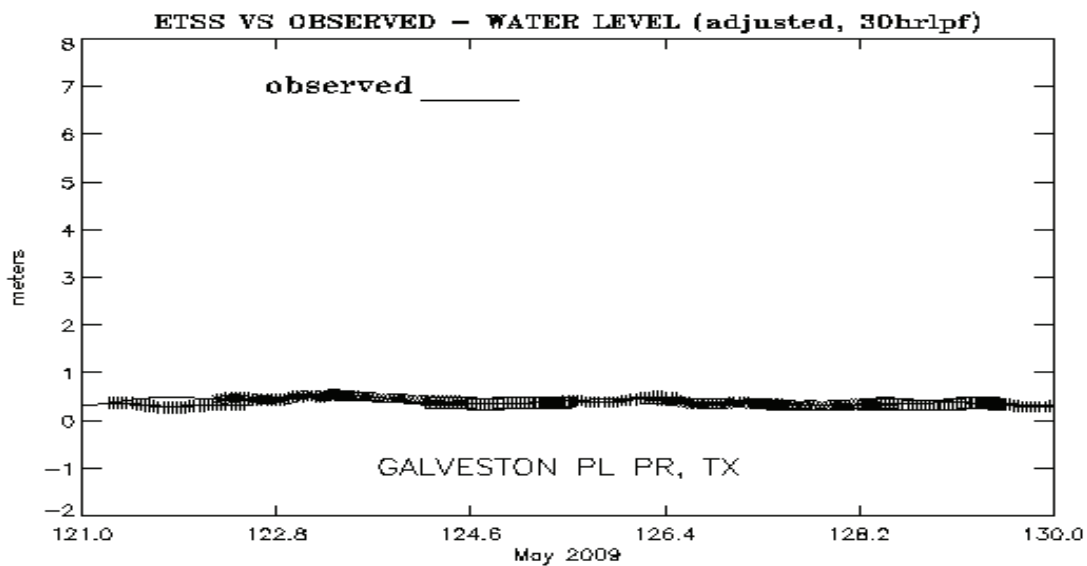


(b)

Figure 3.4. ETSS Subtidal Water Level Forecast Guidance against NOS Observations for May 2009. Sandy Hook, NJ (a) Mayport, FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □). At this vertical scale the model results appear to be represented by +.

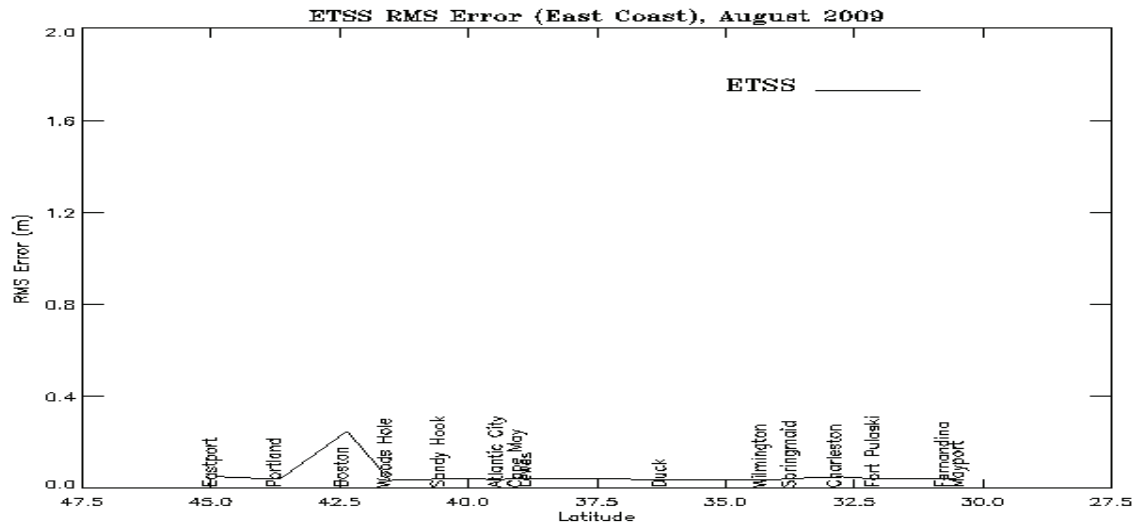


(c)

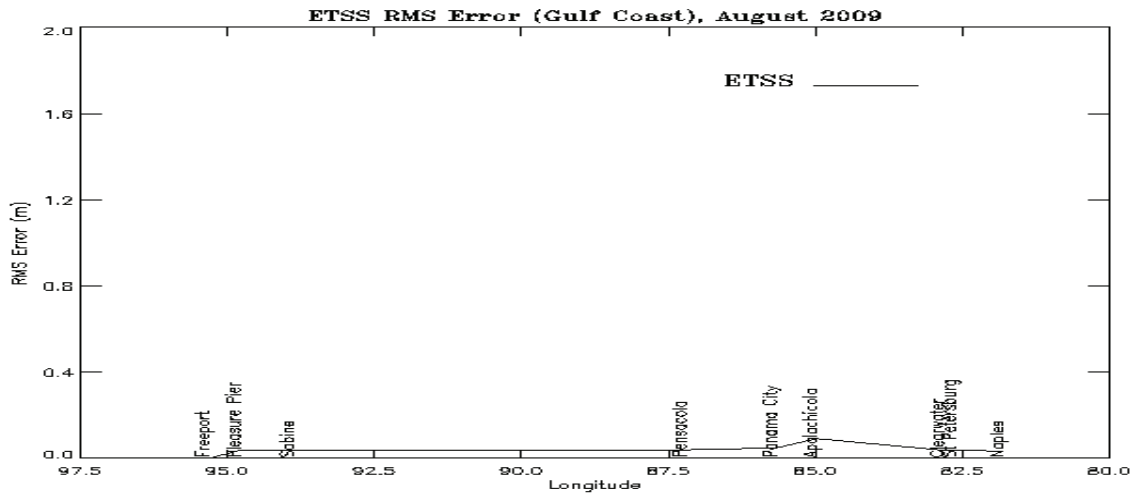


(d)

Figure 3.4. (Cont.) ETSS Subtidal Water Level Forecast Guidance against NOS Observations for May 2009. Clearwater Beach, FL (c) Galveston Pleasure Pier, TX (d). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □). At this vertical scale the model results appear to be represented by +.

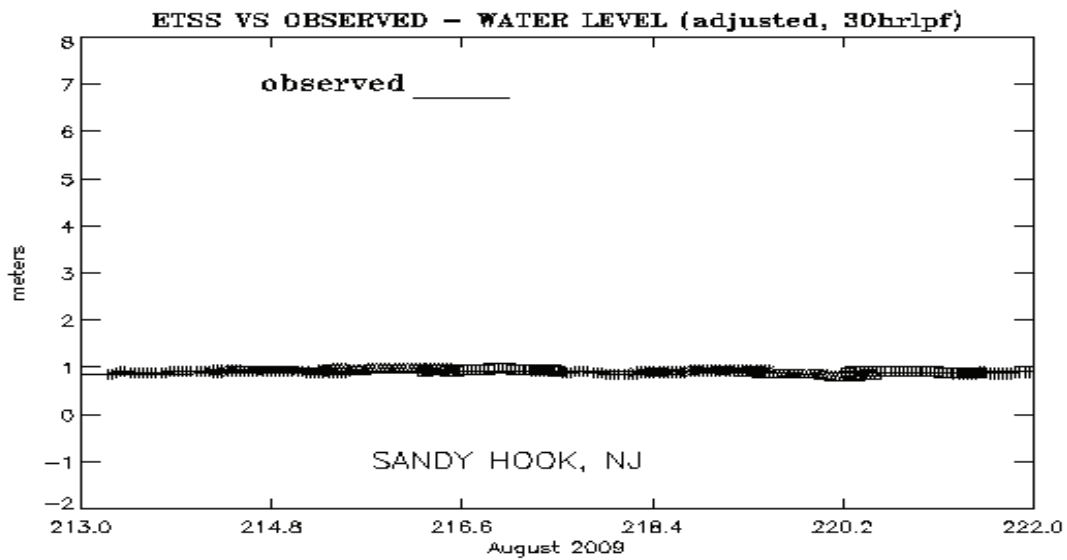


(a)

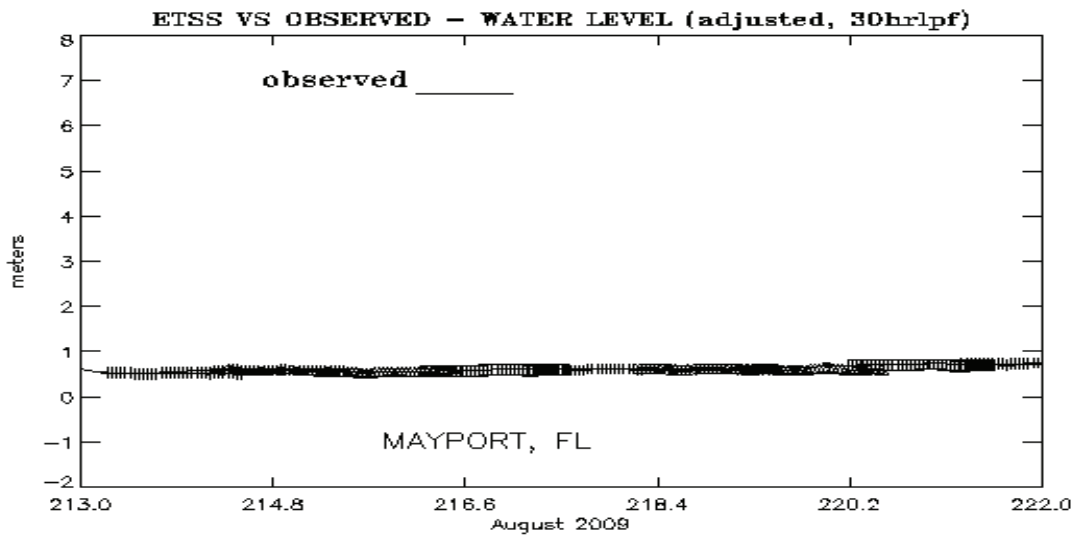


(b)

Figure 3.5. ETSS Subtidal Water Level Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for August 2009. Note there are no observations at Mayport, FL and Freeport, TX.

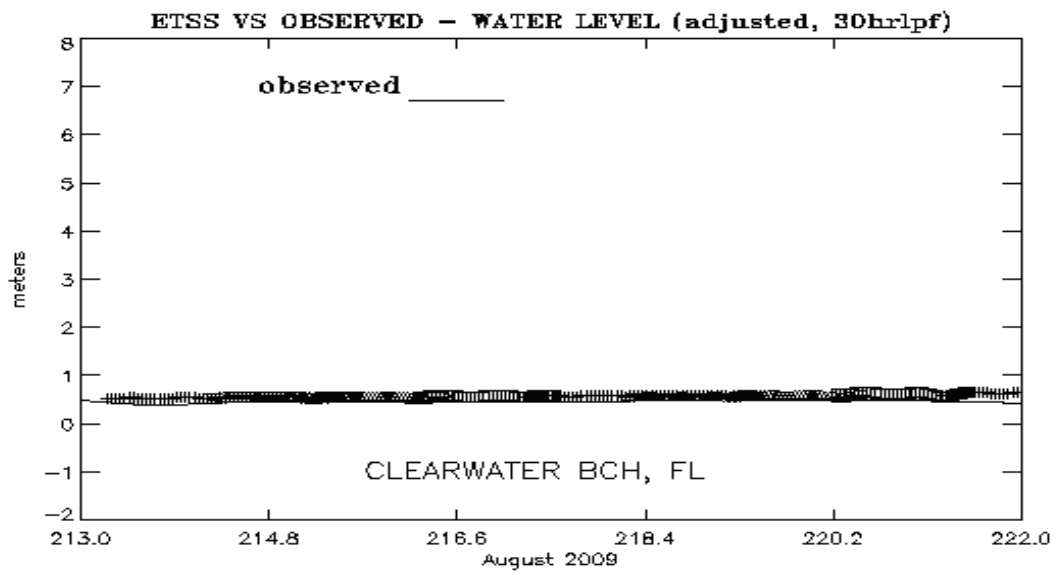


(a)

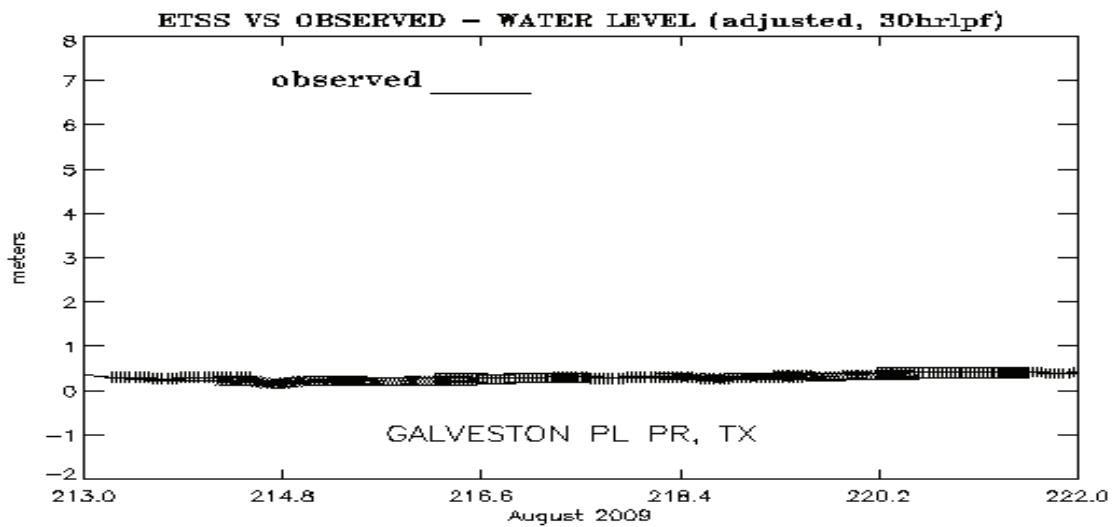


(b)

Figure 3.6. ETSS Subtidal Water Level Forecast Guidance against NOS Observations for August 2009. Sandy Hook, NJ (a) Mayport, FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □). At this vertical scale the model results appear to be represented by +.



(c)



(d)

Figure 3.6. (Cont.) ETSS Subtidal Water Level Forecast Guidance against NOS Observations for August 2009. Clearwater Beach, FL (c) Galveston Pleasure Pier, TX (d). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □). At this vertical scale the model results appear to be represented by +.

In Table 3.2, the minimum, maximum, and range of the monthly RMSEs over the entire one year period from December 2008 through November 2009 are examined. All maximum RMSE errors are below 15 cm except at Woods Hole, MA and the majority are on the order of 10 cm and generally occur during the winter. Minimum RMSEs are on the order of 4 cm and occur during the late spring and summer.

Table 3.2. ETSS December 2008 – November 2009 Monthly Subtidal Water Level Forecast RMS Errors (cm): Minimum, Maximum, and Range. *Denotes problems in water level observations for some months.

Station	Maximum-Month	Minimum-Month	Range
Eastport, ME	10-December	3-June	7*
Portland, ME	10-December	3-June	7
Boston, MA	11-December	3-June	8*
Woods Hole, MA	16-December	4-June	12
Sandy Hook, NJ	11-January	4-May	7
Atlantic City, NJ	10-January	4-August	6
Cape May, NJ	10-December	4-May	6
Lewes, DE	10-January	4-May	6
Duck, NC	9-February	4-June	5
Wilmington, NC	11-January	4-June	7
Springmaid Pier, SC	7-November	4-August	3
Charleston, SC	9-March	5-June	4
Fort Pulaski, GA	8-March	4-August	4
Fernandina Beach, FL	8-May	4-December	4
Mayport, FL	6-May	4-August	2
Naples, FL	6-December	3-September	3
St Petersburg FL	14-December	3-July	11
Clearwater, FL	11-October	3-June	8
Apalachicola, FL	13-December	3-July	10
Panama City, FL	7-December	3-June	4
Pensacola, FL	7-December	3-September	4
Sabine Pass, TX	12-December	4-August	8
Galveston Pleasure Pier, TX	10-December	4-July	6

It should be noted that by performing a yearly analysis, one learns the error behavior at each station. If in one month, the results are drastically different, plotting the time series of water levels and observations usually indicates a problem with the water level observations. In Table 3.1 problems were noted at Eastport, ME in January 2009 and at Boston, MA during August and September 2009.

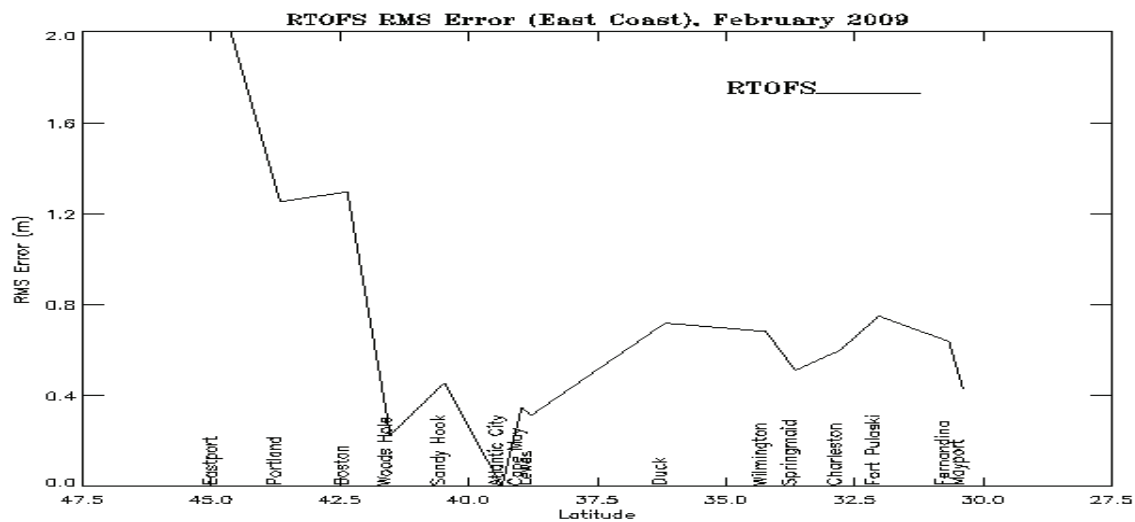
Based on these results, the behavior of the monthly RMSEs associated with the ETSS subtidal water level forecasts have been well established. It may not be necessary to continue to evaluate this ocean forecast system, unless updates are made to the system. To our knowledge, no updates in the near future are planned.

4. RTOFS MODEL SEASONAL ANALYSIS

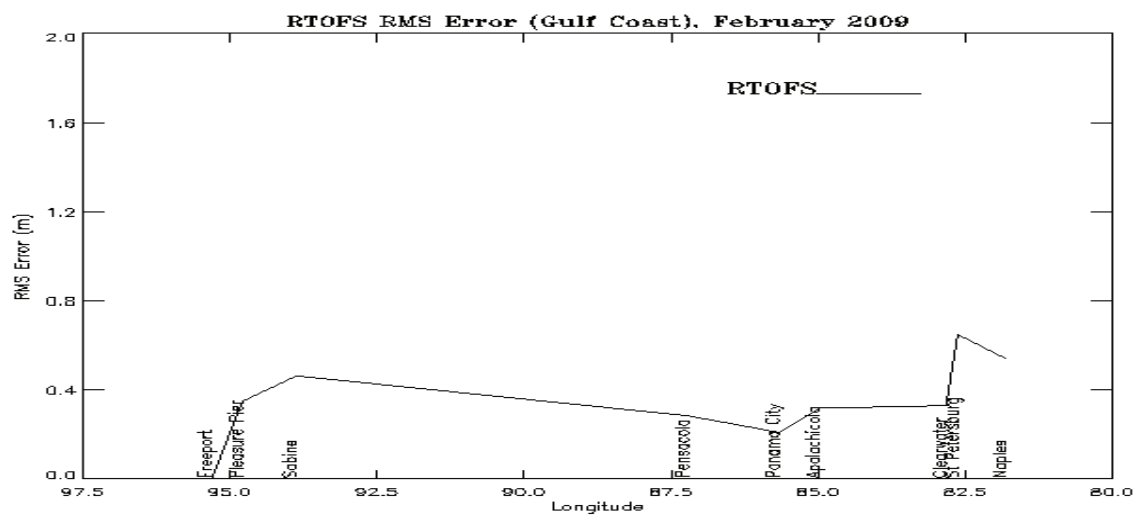
To further exercise the automated water level evaluation procedures, RTOFS was evaluated on a seasonal basis for the months of February, May, August, and November 2009. Monthly RMSEs are given in Table 4.1 and exhibit very little change from month to month. To further investigate the RTOFS total water level response, RMSE error plots for the Atlantic and Gulf of Mexico stations as well as time series plots at two Atlantic coast stations (Sandy Hook, NJ and Mayport, FL) and two Gulf of Mexico stations (Clearwater Beach, FL and Galveston Pleasure Pier, TX) are shown in Figure 4.1 and Figure 4.2 for February 2009, in Figure 4.3 and Figure 4.4 for May 2009, and in Figure 4.5 and Figure 4.6 for August 2009. One notes in these time series plots the improvement in the tidal dynamics from the results for November 2008 given in Figure 2.2.

Table 4.1. RTOFS Seasonal Water Level Forecast Guidance Comparisons to NOS Observations (RMSE[meters]). Blanks indicate no observations are available.

Station	February 2009	May 2009	August 2009	November 2009
Eastport, ME	2.227	2.500	2.356	2.035
Portland, ME	1.254	1.421	1.307	1.161
Boston, MA	1.297	1.456	1.418	1.215
Woods Hole, MA	0.227	0.221	0.301	0.245
Sandy Hook, NJ	0.457	0.447	0.463	0.379
Atlantic City, NJ		0.329	0.297	0.336
Cape May, NJ	0.348	0.335	0.367	0.263
Lewes, DE	0.314	0.295	0.293	0.229
Duck, NC	0.720	0.704	0.639	0.620
Wilmington, NC	0.683	0.660	0.591	
Springmaid Pier, SC	0.511	0.501	0.492	0.469
Charleston, SC	0.601	0.587	0.553	0.560
Fort Pulaski, GA	0.750	0.767	0.709	0.682
Fernandina Beach, FL	0.639	0.633	0.617	0.541
Mayport, FL	0.430	0.421	0.429	0.360
Naples, FL	0.541	0.414	0.405	0.533
St Petersburg FL	0.649	0.588	0.629	0.576
Clearwater, FL	0.330	0.264	0.290	0.303
Apalachicola, FL	0.318	0.354	0.344	0.304
Panama City, FL	0.210	0.178	0.176	0.209
Pensacola, FL	0.284	0.221	0.230	0.262
Sabine Pass, TX	0.464	0.437	0.496	0.420
Galveston Pleasure Pier, TX	0.349	0.368	0.379	0.318

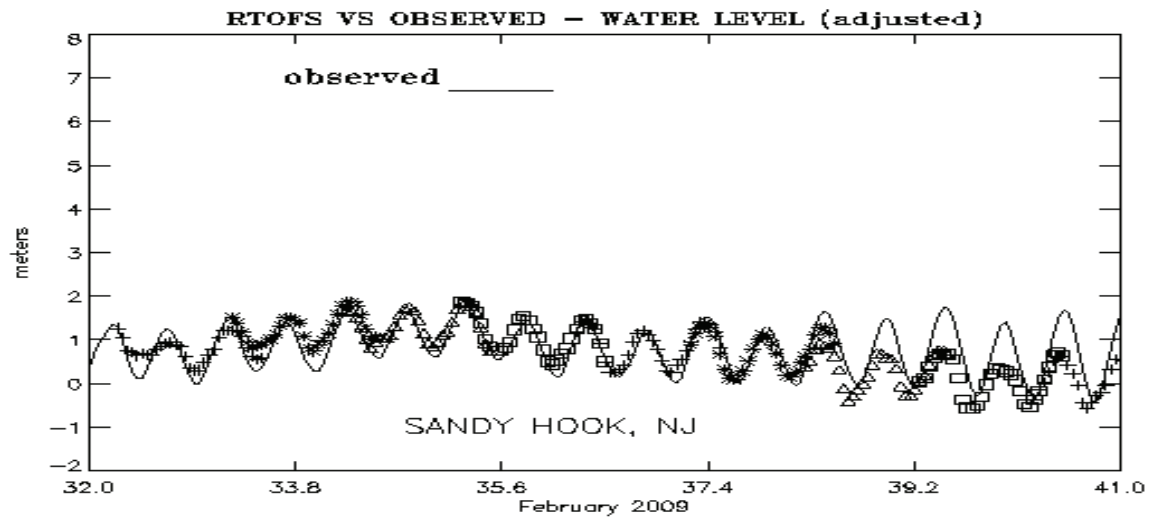


(a)

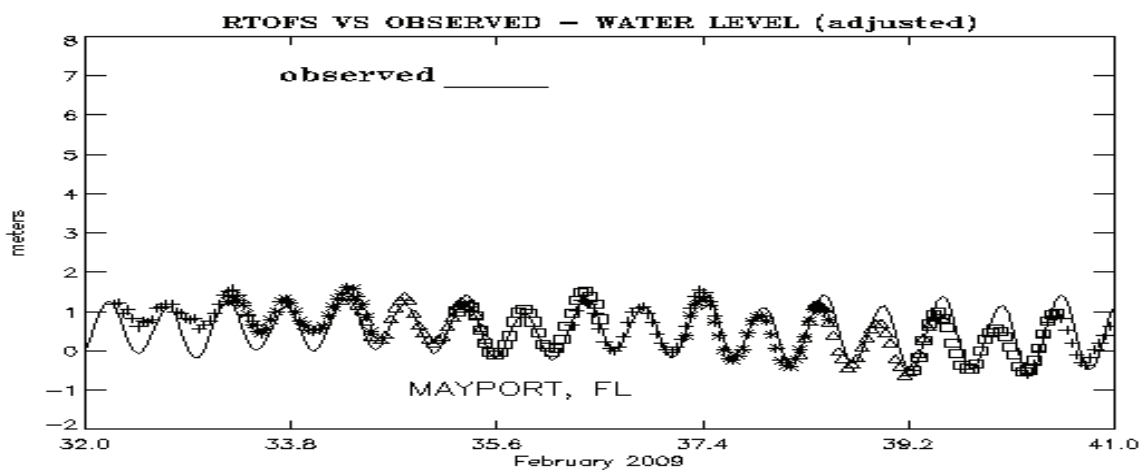


(b)

Figure 4.1. RTOFS Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for February 2009. Note no observations were available at Atlantic City, NJ.

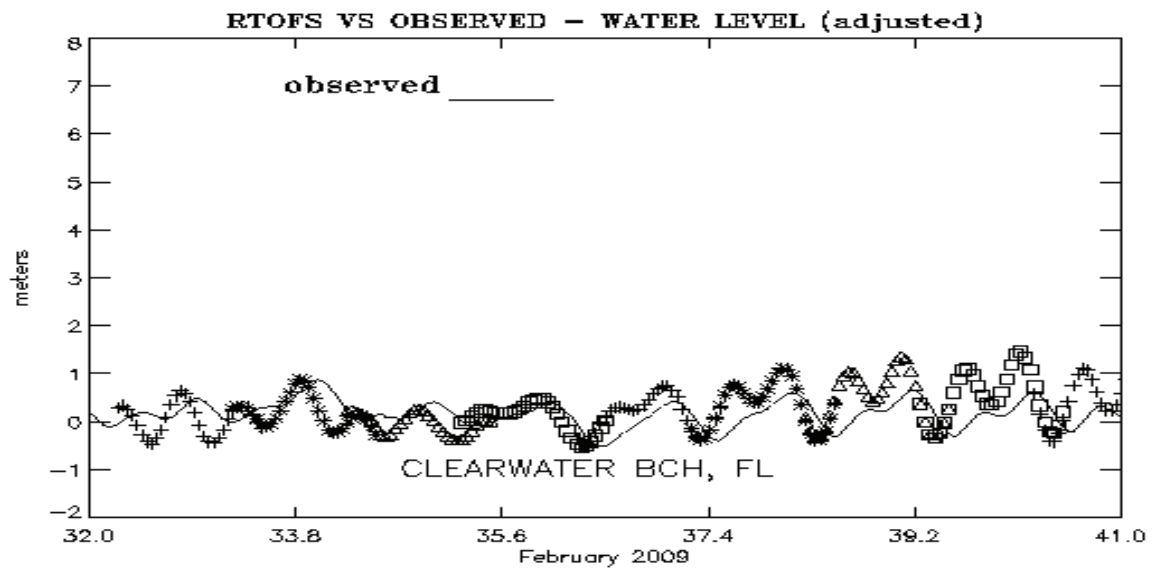


(a)

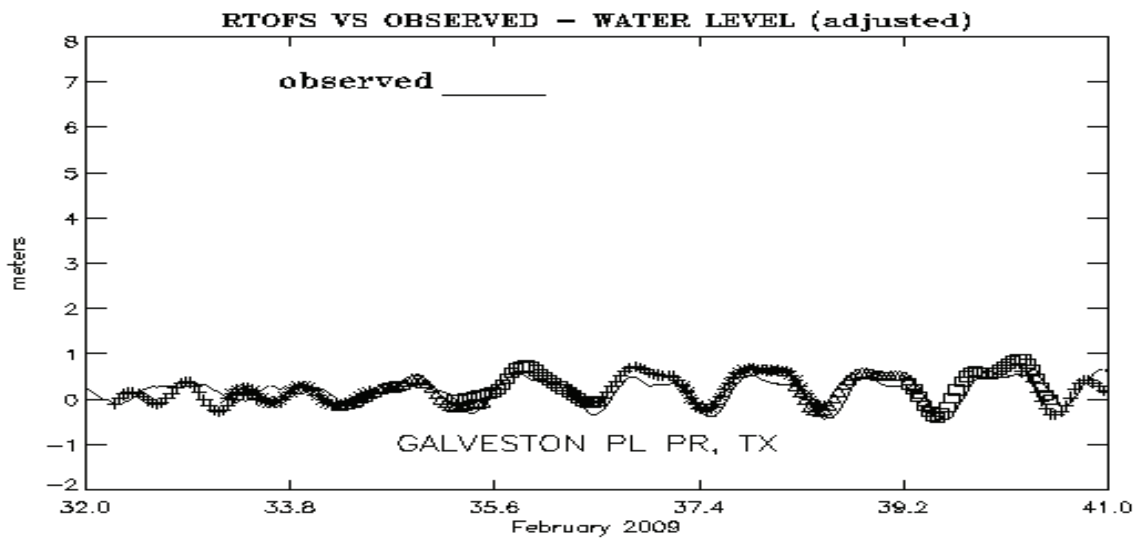


(b)

Figure 4.2. RTOFS Total Water Level Forecast Guidance against NOS Observations for February 2009. Sandy Hook, NJ (a) Mayport, FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+ , * , Δ , and $\square$).

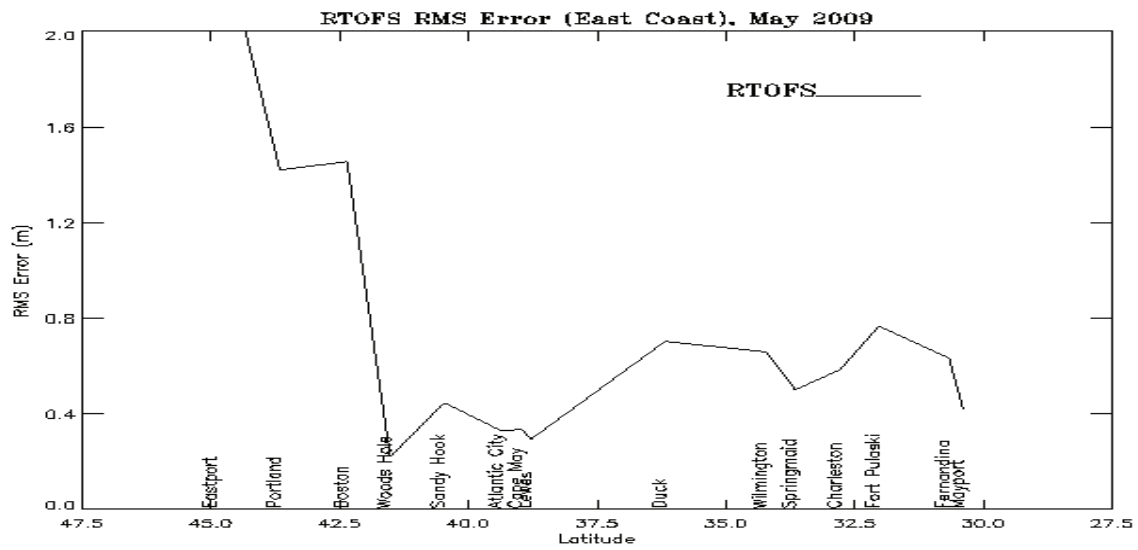


(c)

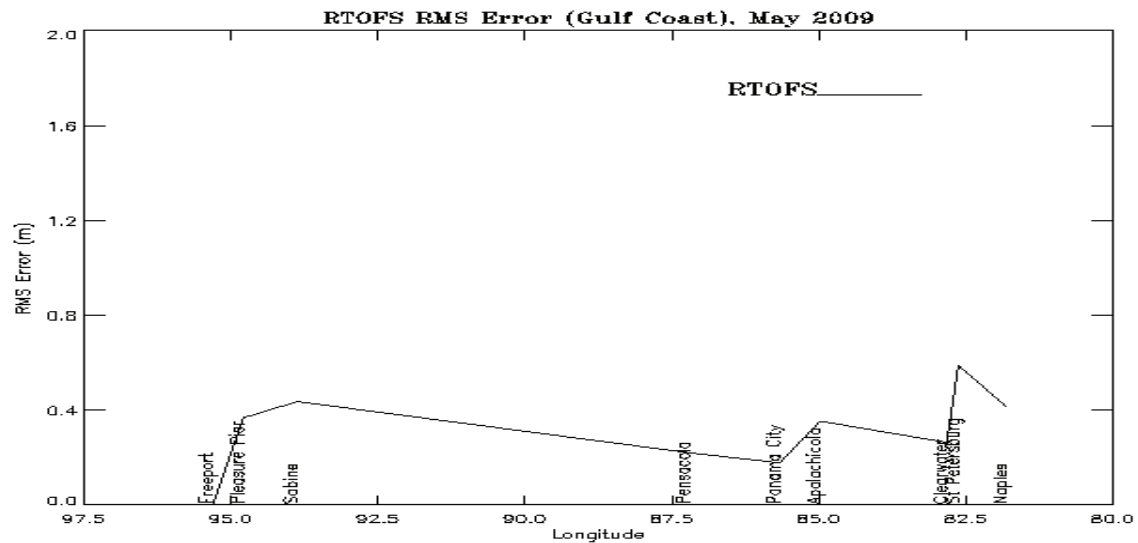


(d)

Figure 4.2. (Cont.) RTOFS Total Water Level Forecast Guidance against NOS Observations for February 2009. Clearwater Beach, FL (c) Galveston Pleasure Pier, TX (d). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+ , * , Δ , and □).

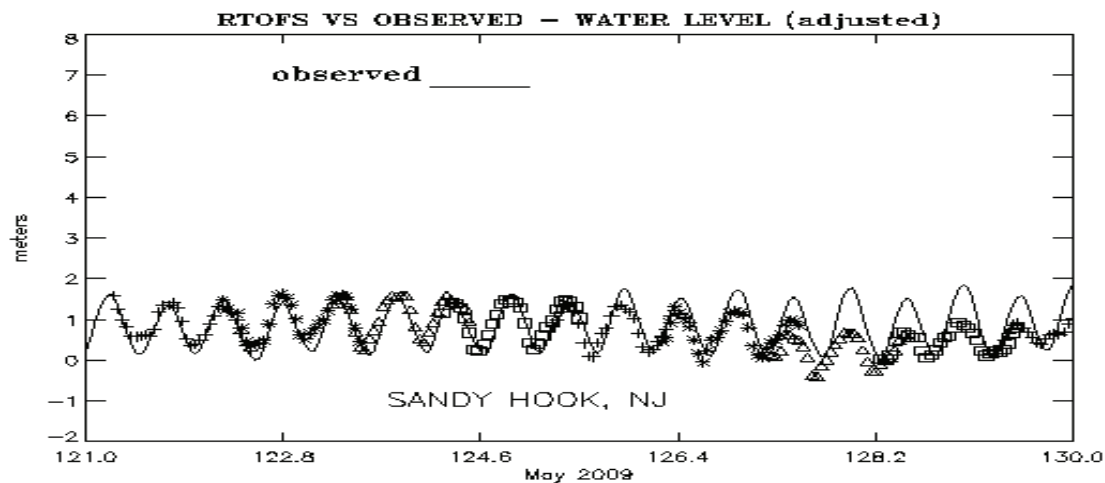


(a)

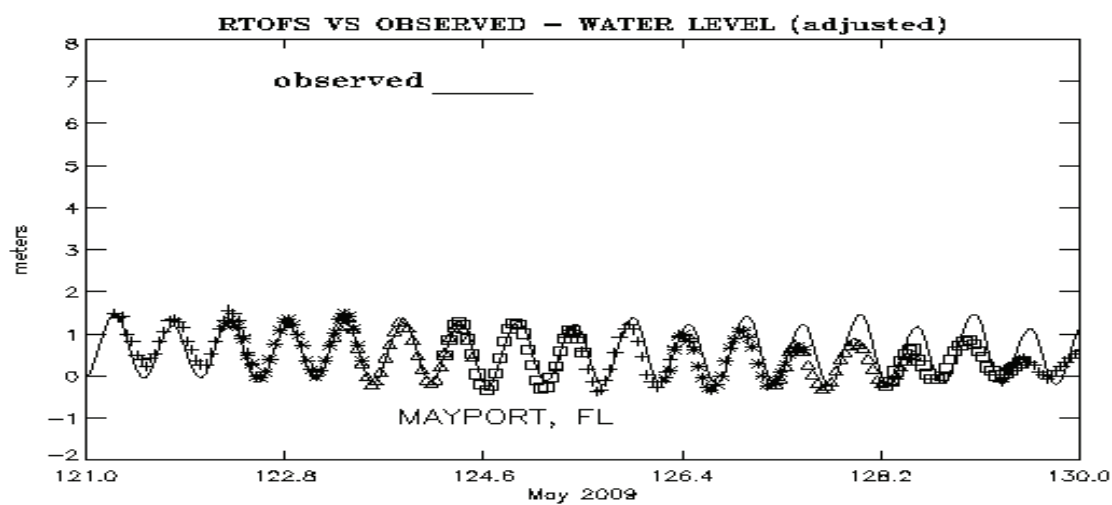


(b)

Figure 4.3. RTOFS Total Water Level Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for May 2009. No observations were available at Freeport, TX.

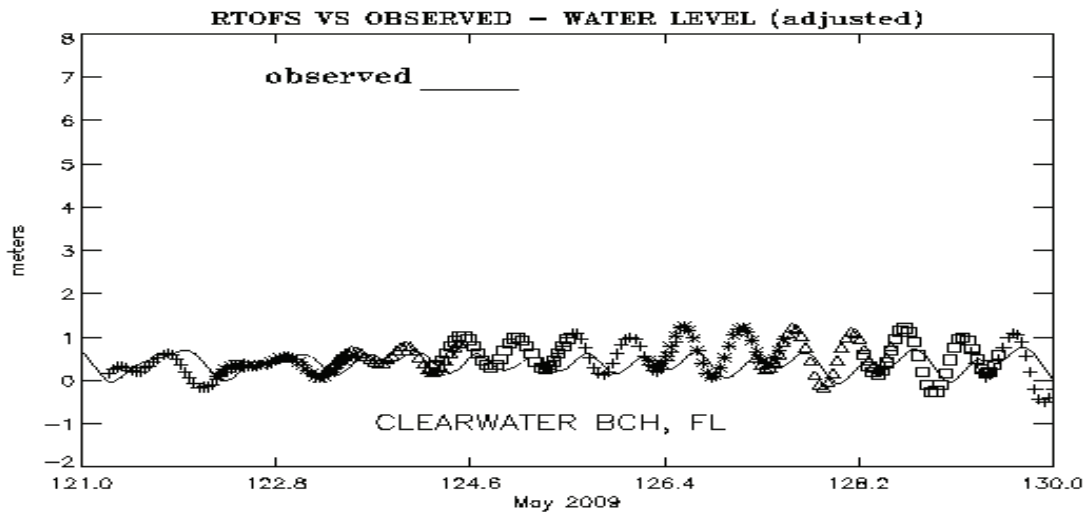


(a)

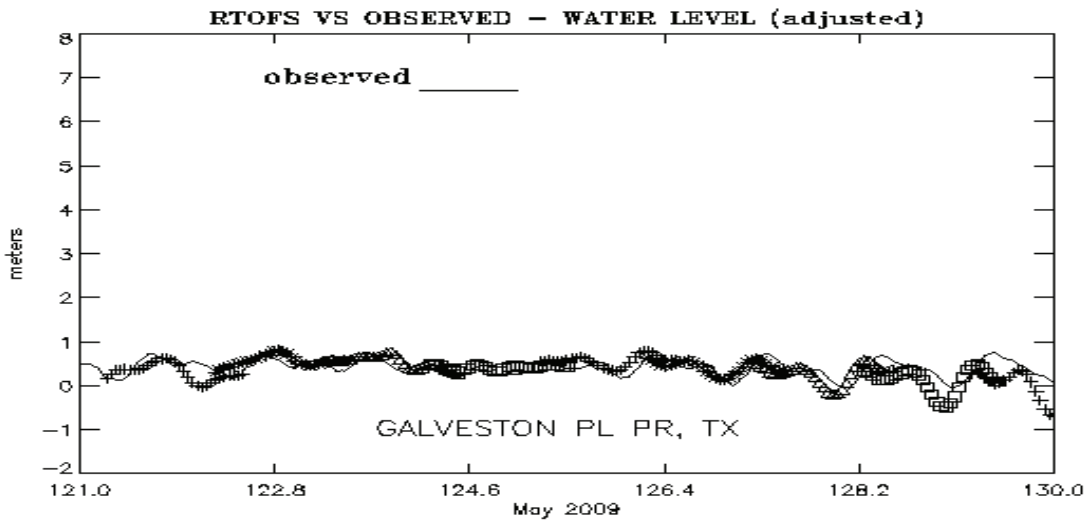


(b)

Figure 4.4. RTOFS Total Water Level Forecast Guidance against NOS Observations for May 2009. Sandy Hook, NJ (a) Mayport, FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □).

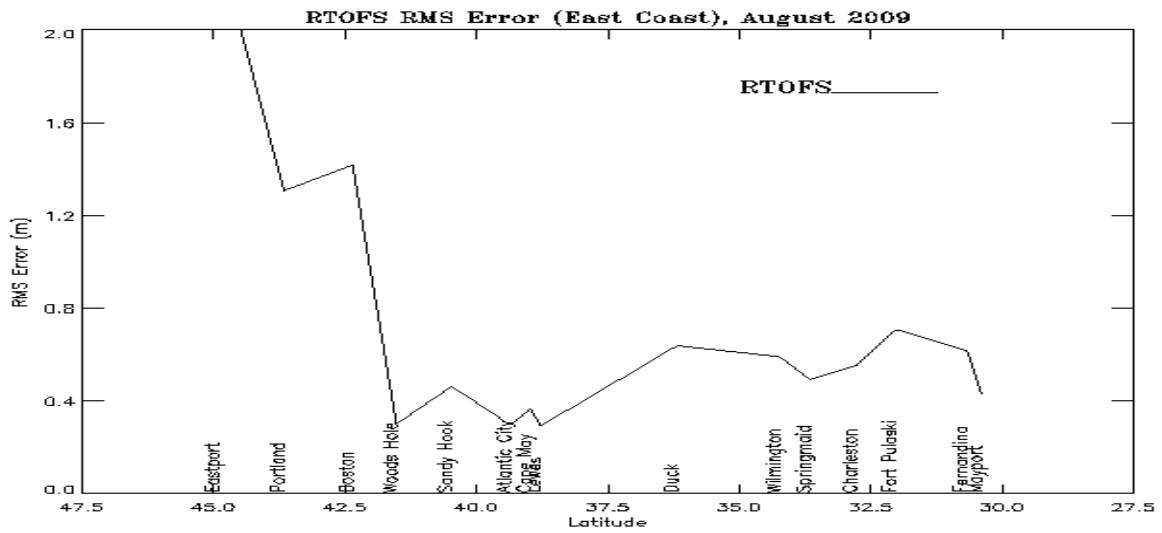


(c)

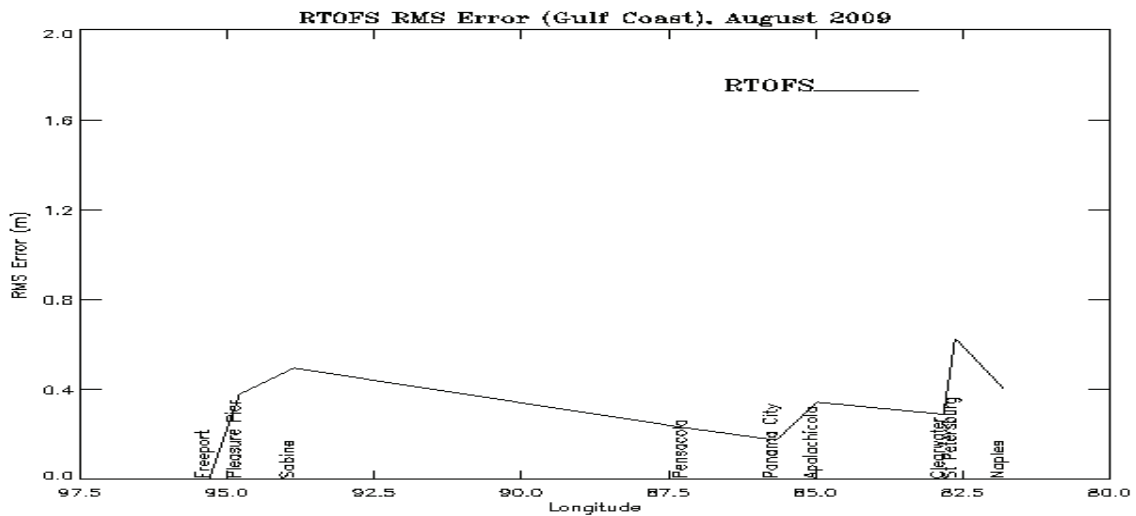


(d)

Figure 4.4. (Cont.) RTOFS Total Water Level Forecast Guidance against NOS Observations for May 2009. Clearwater Beach, FL (c) Galveston Pleasure Pier, TX (d). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+ , * , Δ , and $\square$).

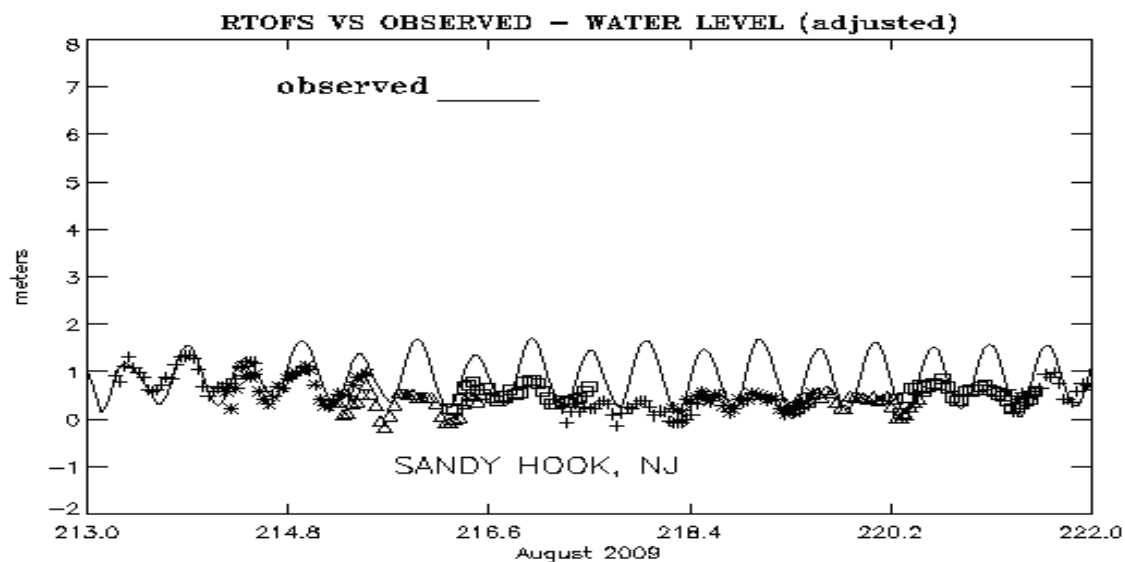


(a)

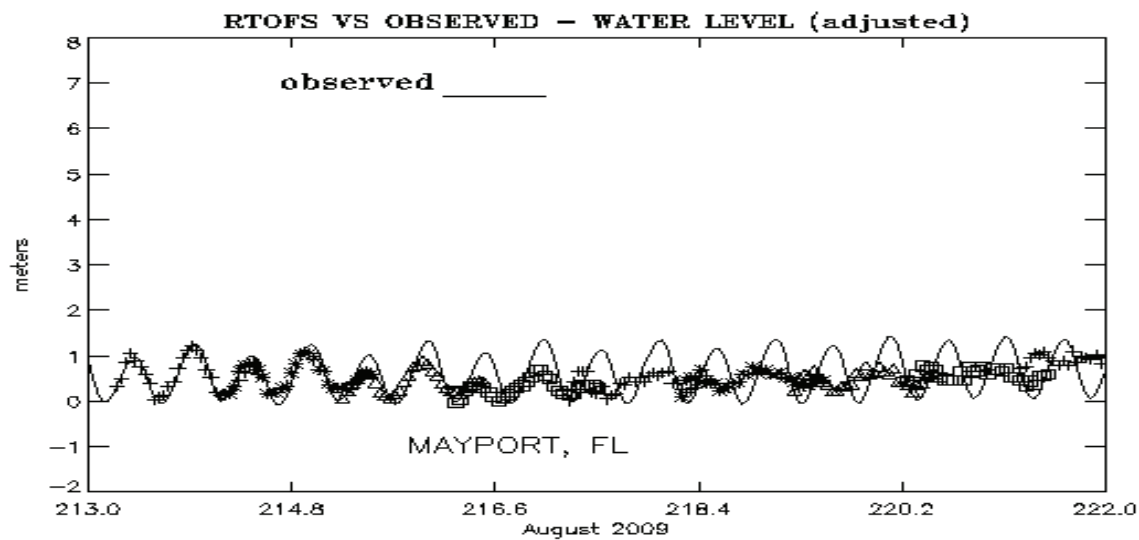


(b)

Figure 4.5. RTOFS Total Water Level Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for August 2009. No observations were available at Freeport, TX.

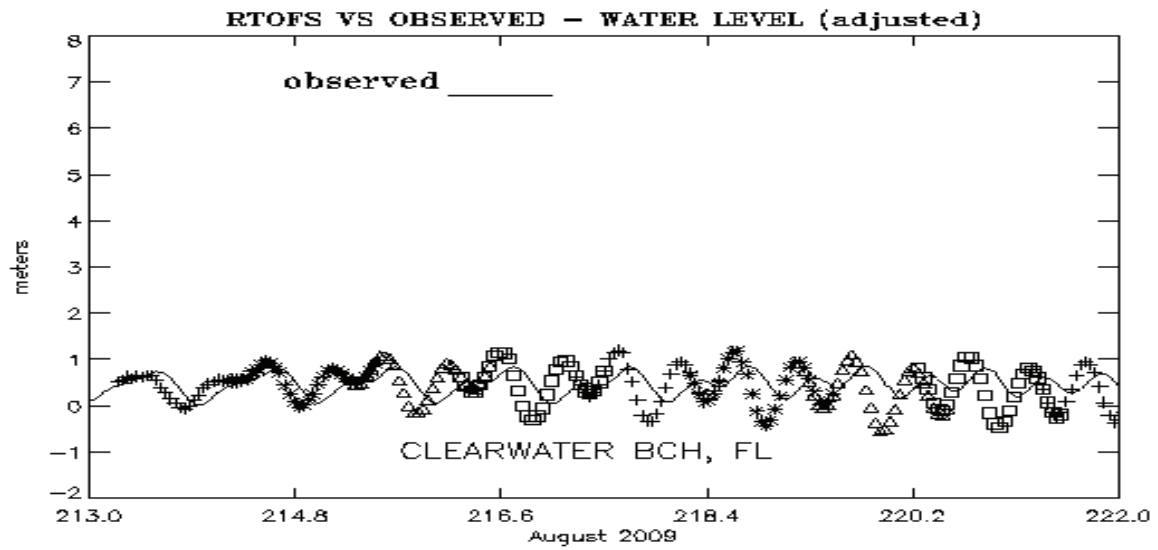


(a)

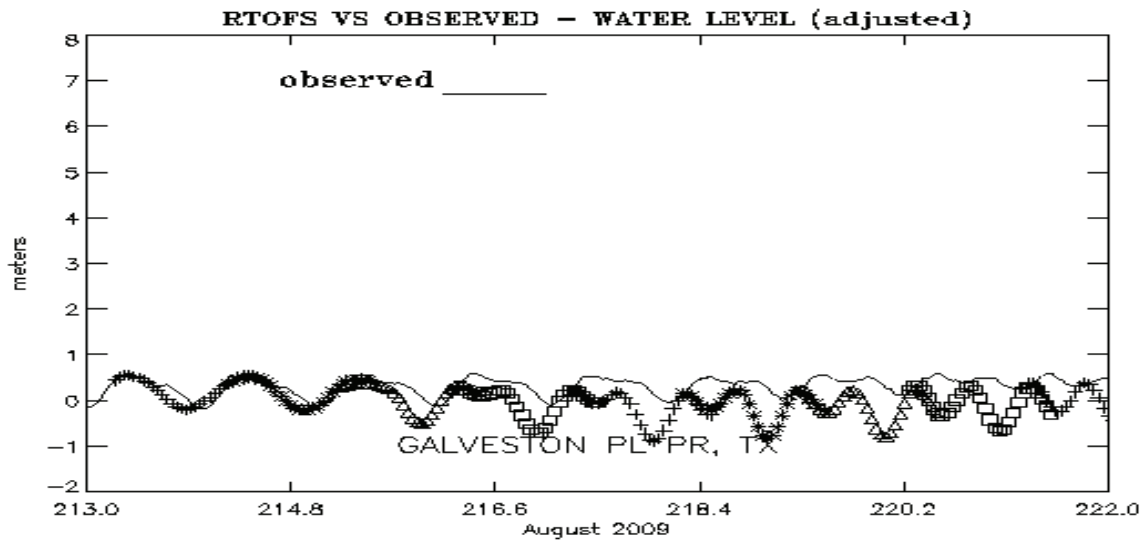


(b)

Figure 4.6. RTOFS Total Water Level Forecast Guidance against NOS Observations for August 2009. Sandy Hook, NJ (a) Mayport, FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+ , * , Δ , and $\square$).



(c)



(d)

Figure 4.6. (Cont.) RTOFS Total Water Level Forecast Guidance against NOS Observations for August 2009. Clearwater Beach, FL (c) and at Galveston Pleasure Pier, TX (d). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+ , * , Δ , and □).

5. ETSS, RTOFS, AND G-NCOM MODELS ANNUAL ANALYSIS

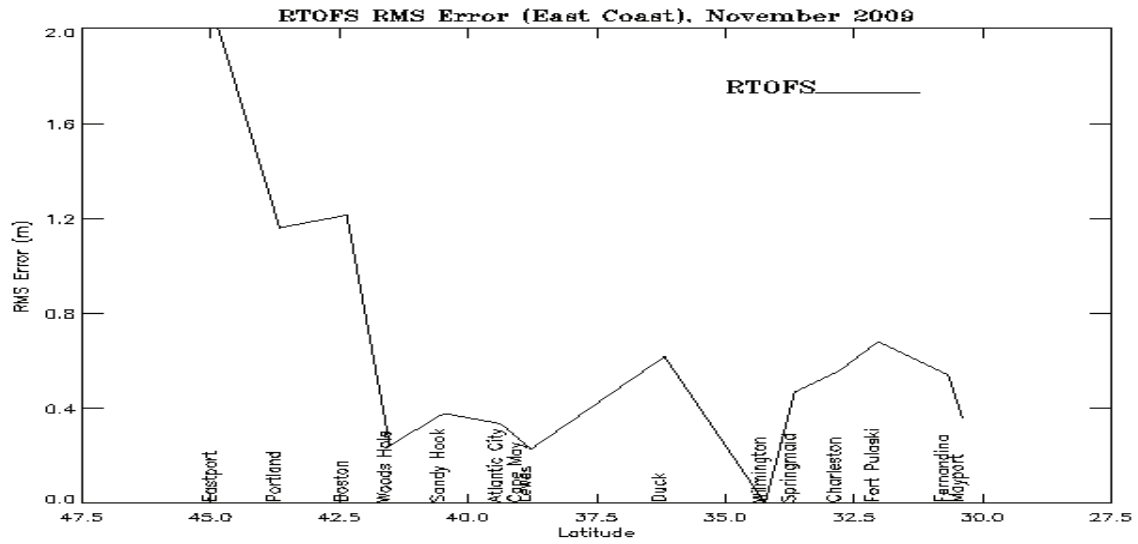
Here, we compare the results of Chapter 2 for November 2008 with those obtained a year later for November 2009 for all of the ocean models in Table 5.1 except UNC ADCIRC, whose forecasts were not available during November 2009. Note the inconsistency in RMSE at Cape May, NJ between November 2009 and November 2008 for both ETSS and G-NCOM. An examination of the times series plots for November 2008 indicated an issue with the Cape May, NJ water level observations.

Table 5.1 ETSS, RTOFS, and G-NCOM Forecast Guidance Monthly Water Level Comparisons to NOS Observations for November 2008 and 2009 (RMSE[meters]). ETSS water levels are subtidal, while RTOFS and G-NCOM water levels are total. Blanks indicate no observations are available.

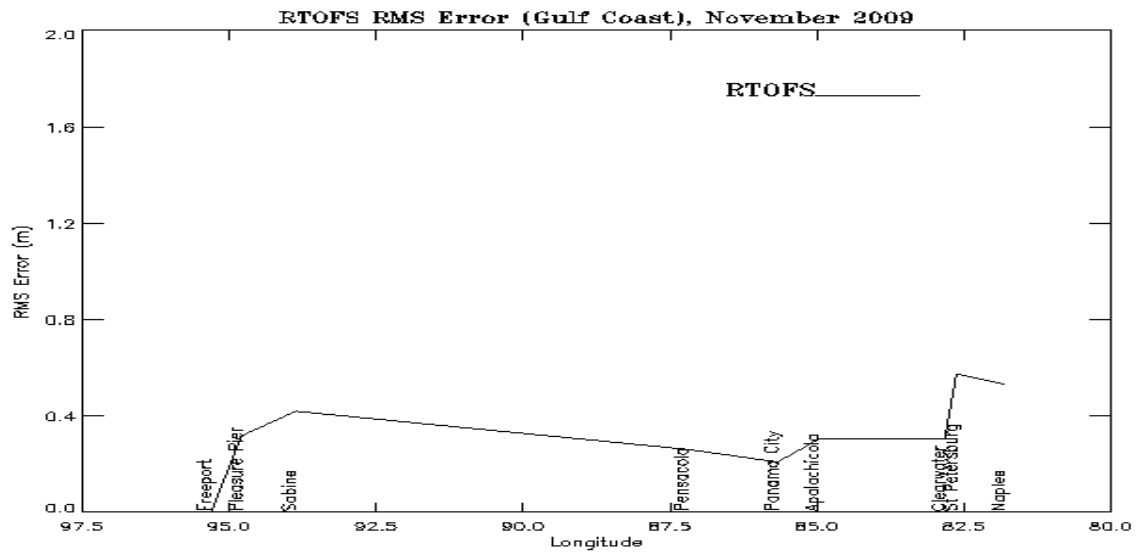
Station	ETSS		RTOFS		G-NCOM	
	11/ 2009	11/2008	11/ 2009	11/2008	11/ 2009	11/2008
Eastport, ME	0.059	0.078	2.035	3.476	1.041	1.044
Portland, ME	0.051	0.076	1.162	1.870	0.151	0.184
Boston, MA	0.055	0.074	1.215	1.890	0.378	0.376
Woods Hole, MA	0.054	0.064	0.245	0.320	0.124	0.118
Sandy Hook, NJ	0.066	0.094	0.379	0.968	0.199	0.196
Atlantic City, NJ	0.070	0.083	0.336	0.770	0.121	0.131
Cape May, NJ	0.072	0.228	0.263	1.042	0.348	0.435
Lewes, DE	0.076	0.072	0.229	0.865	0.295	0.276
Duck, NC	0.090	0.056	0.619	0.622	0.222	0.220
Wilmington, NC		0.058		1.099		0.632
Springmaid Pier, SC	0.071	0.050	0.469	1.042	0.115	0.136
Charleston, SC	0.075	0.053	0.560	1.191	0.258	0.237
Fort Pulaski, GA	0.076	0.054	0.682	1.638	0.329	0.326
Fernandina Beach, FL	0.068	0.056	0.541	1.546	0.302	0.272
Mayport, FL	0.053		0.360		0.244	
Naples, FL	0.046	0.044	0.535	0.645	0.139	0.126
St Petersburg, FL	0.082	0.098	0.576	0.750	0.409	0.399
Clearwater, FL	0.056	0.049	0.303	0.789	0.225	0.243
Apalachicola, FL	0.107	0.101	0.304	0.210	0.164	0.166
Panama City, FL	0.064	0.036	0.209	0.137	0.099	0.097
Pensacola, FL	0.066	0.033	0.262	0.207	0.148	0.153
Sabine Pass, TX	0.090	0.084	0.420	0.618	0.113	0.121

Galveston Pleasure Pier, TX	0.083	0.065	0.318	0.470	0.088	0.083
Freeport, TX		0.060		0.217		0.099

RMSE error plots are given in Figure 5.1, Figure 5.3, and in Figure 5.5, for ETSS, RTOFS, and G-NCOM for November 2009 and may be compared with those in Chapter 2 for November 2008. Time series plots for November 2009 at two Atlantic coast stations (Sandy Hook, NJ and Mayport, FL) and two Gulf of Mexico stations (Clearwater Beach, FL and Galveston Pleasure Pier, TX) are shown in Figure 5.2, Figure 5.4, and Figure 5.6 for ETSS, RTOFS, and G-NCOM, respectively, and may be compared with those of Chapter 2. While one notes the improvement in the RTOFS tidal dynamics in the November 2009 forecasts, there is still room for improvement compared to UNC ADCIRC and G-NCOM.

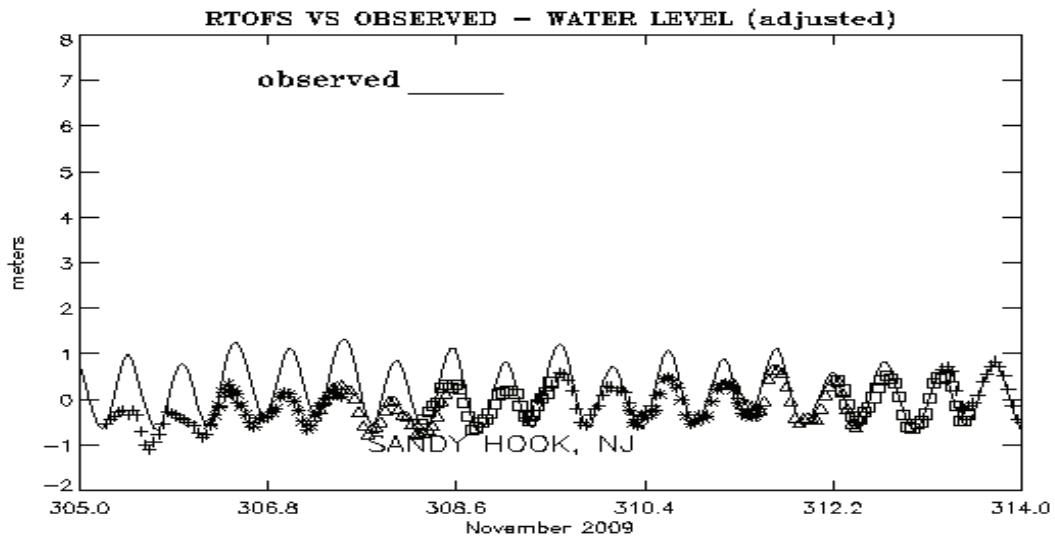


(a)

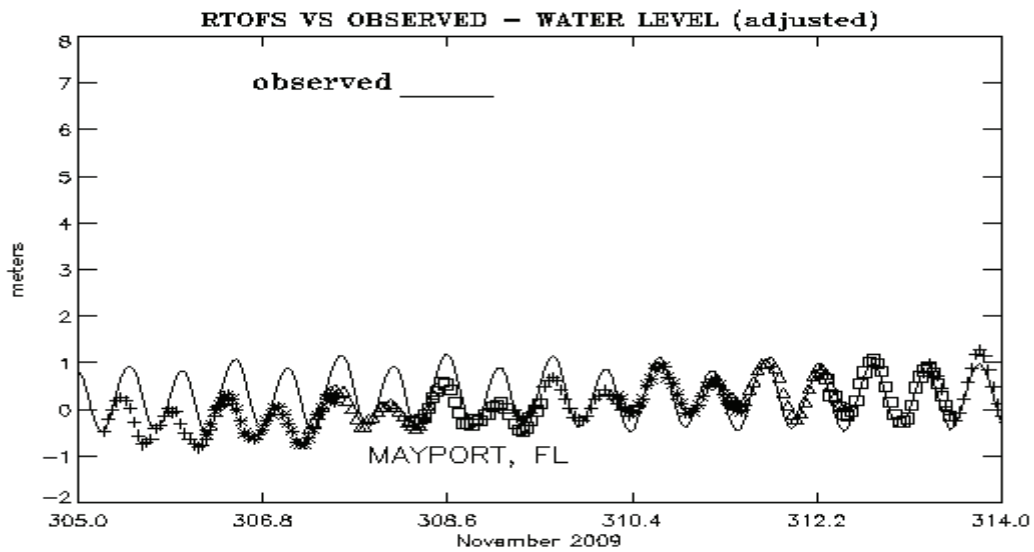


(b)

Figure 5.1. RTOFS Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2009.

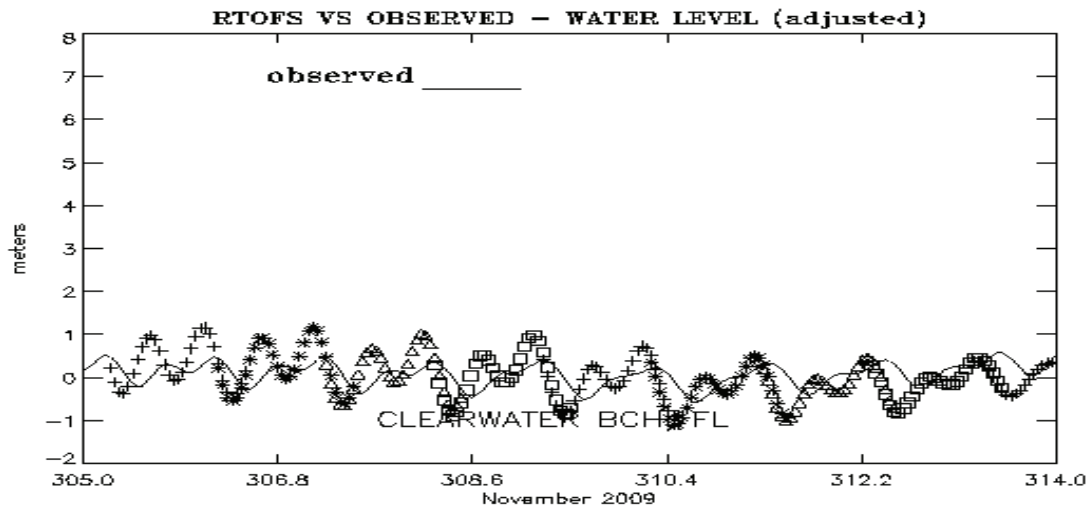


(a)

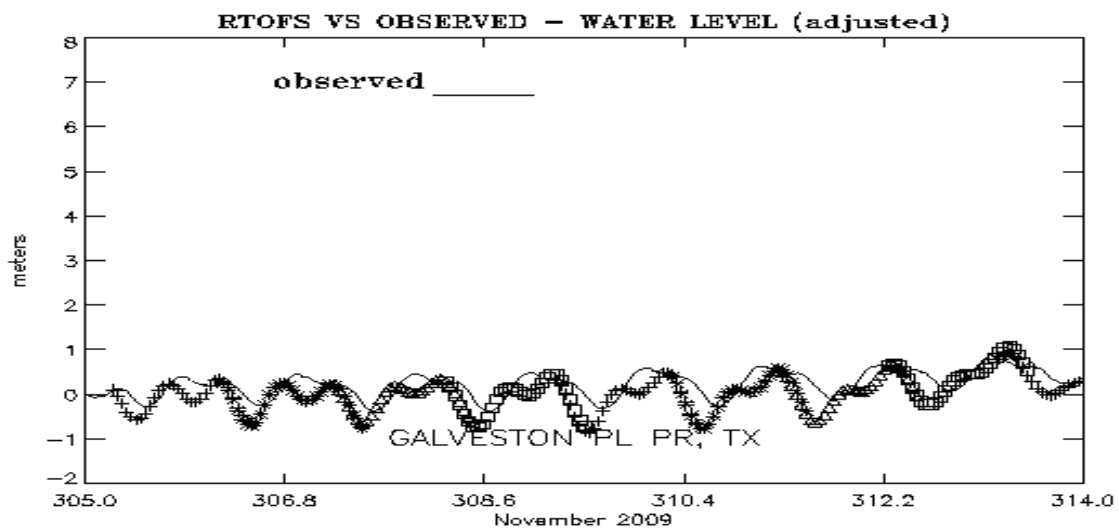


(b)

Figure 5.2. RTOFS Total Water Level Forecast Guidance against NOS Observations for November 2009. Sandy Hook, NJ (a) Mayport, FL (b). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+ , * , Δ , and $\square$).

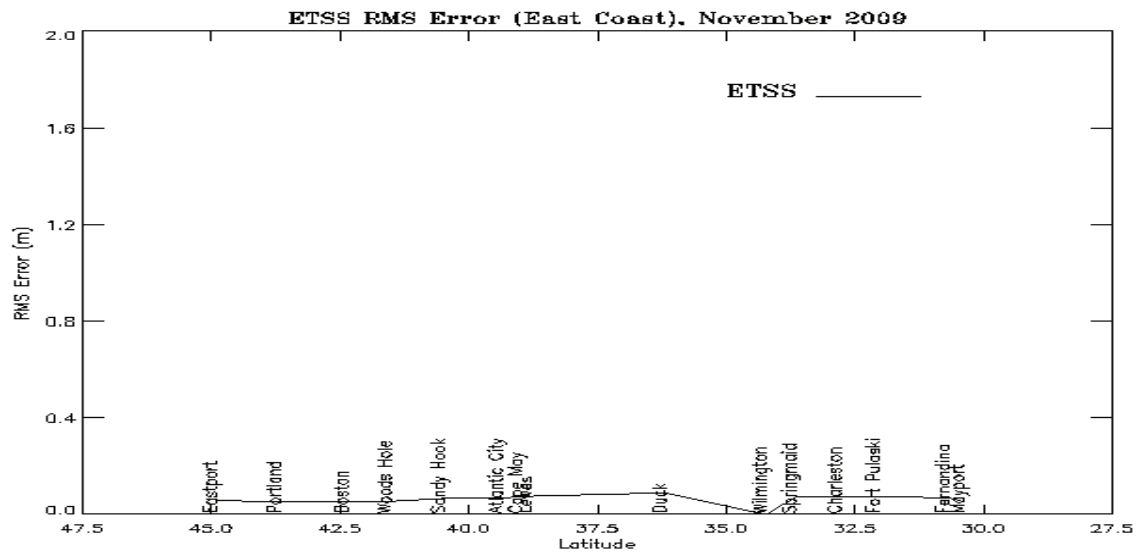


(c)

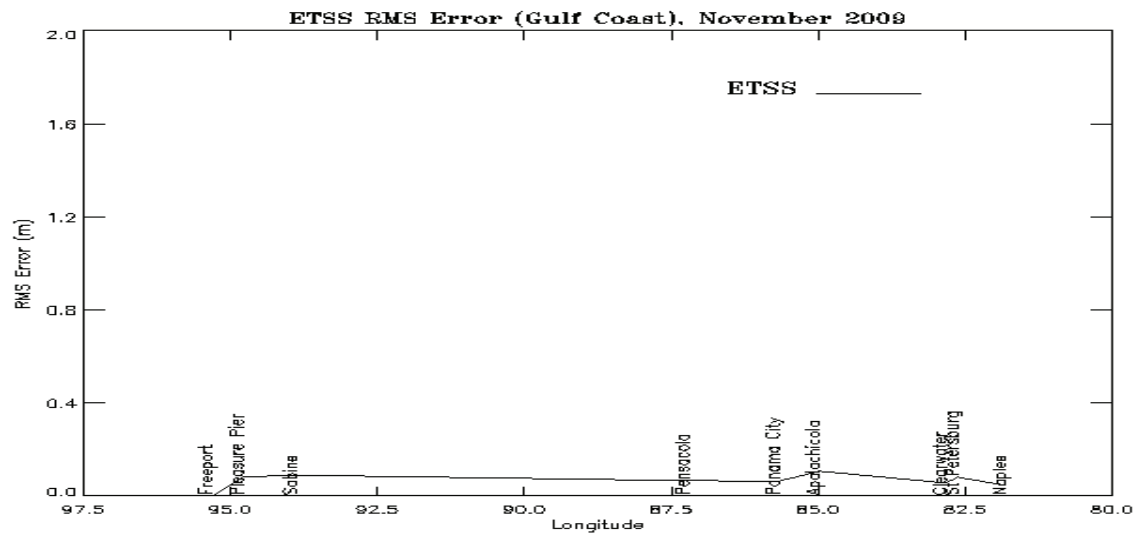


(d)

Figure 5.2. (Cont.) RTOFS Total Water Level Forecast Guidance against NOS Observations for November 2009. Sandy Hook, NJ (c) Clearwater Beach, FL (d). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □).

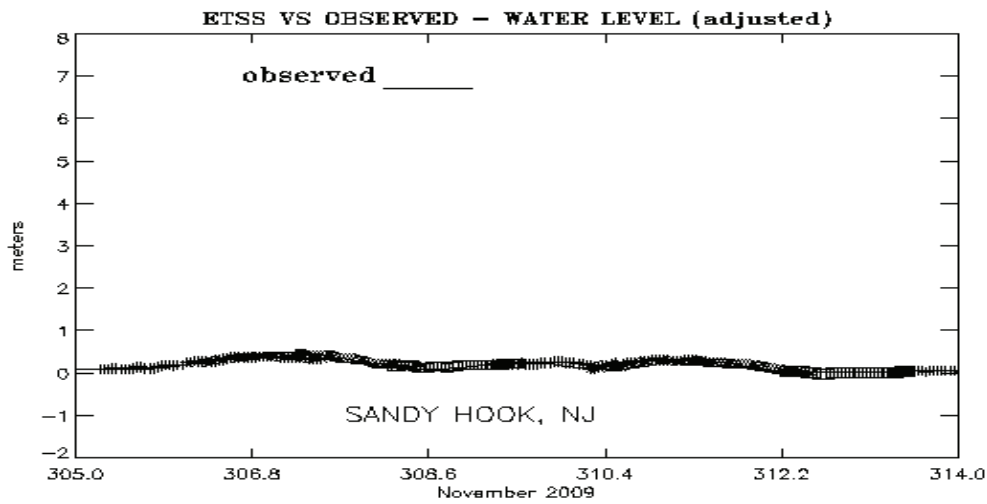


(a)

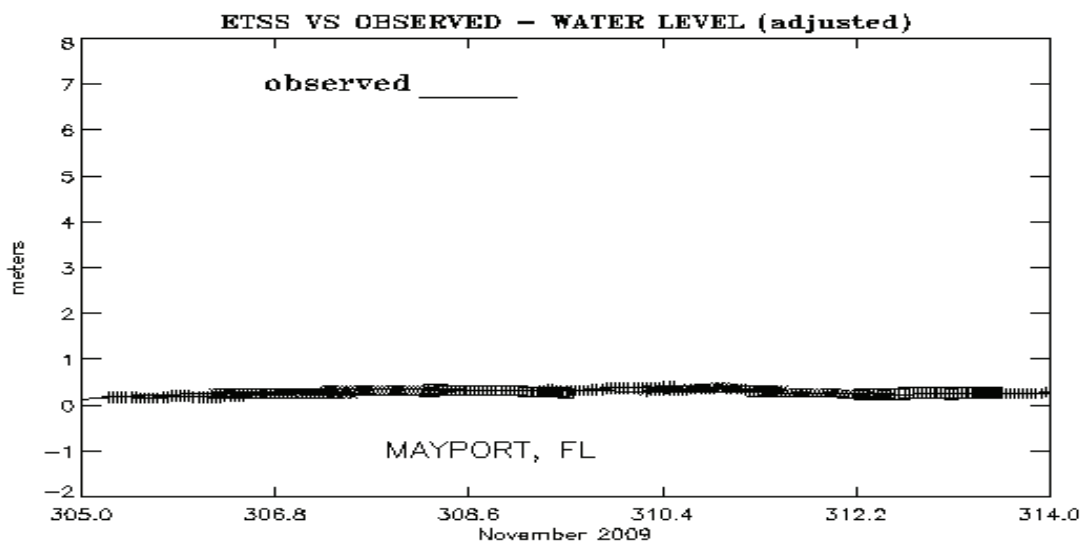


(b)

Figure 5.3. ETSS Subtidal Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2009.

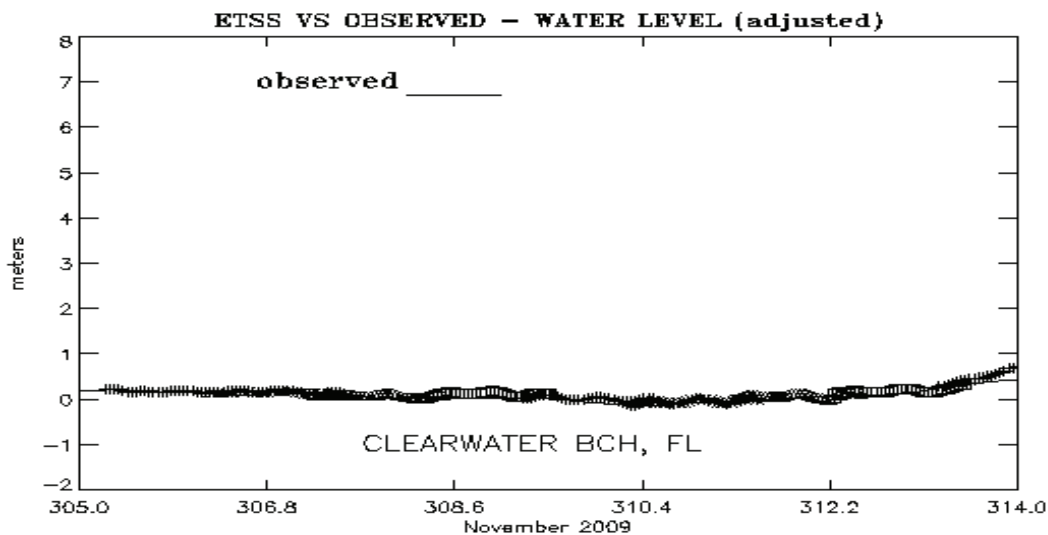


(a)

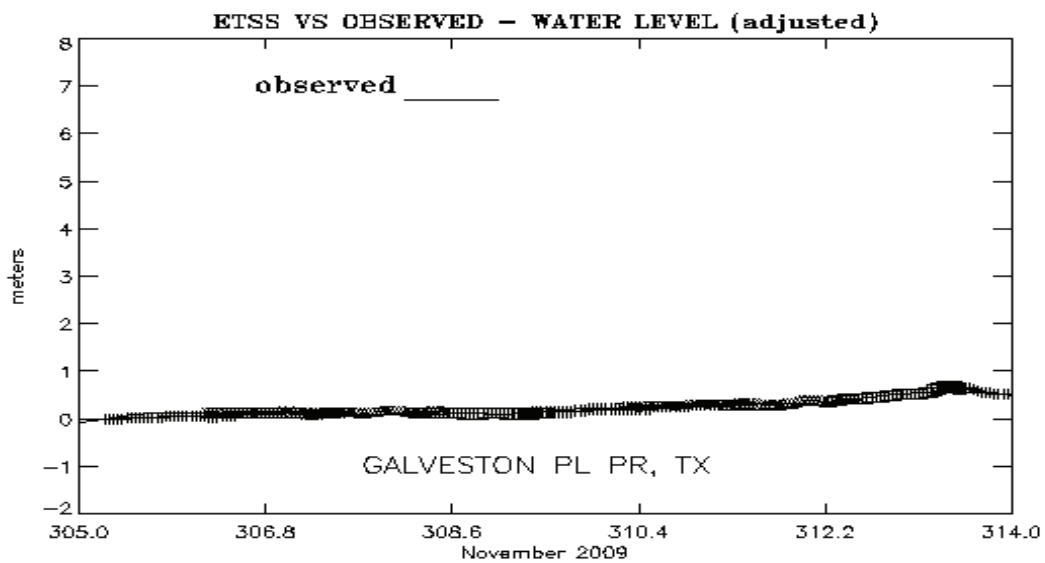


(b)

Figure 5.4. ETSS Subtidal Water Level Forecast Guidance against NOS Observations for November 2009. Sandy Hook, NJ (a). Mayport, FL (b) Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □). At this vertical scale the model results appear to be represented by +.

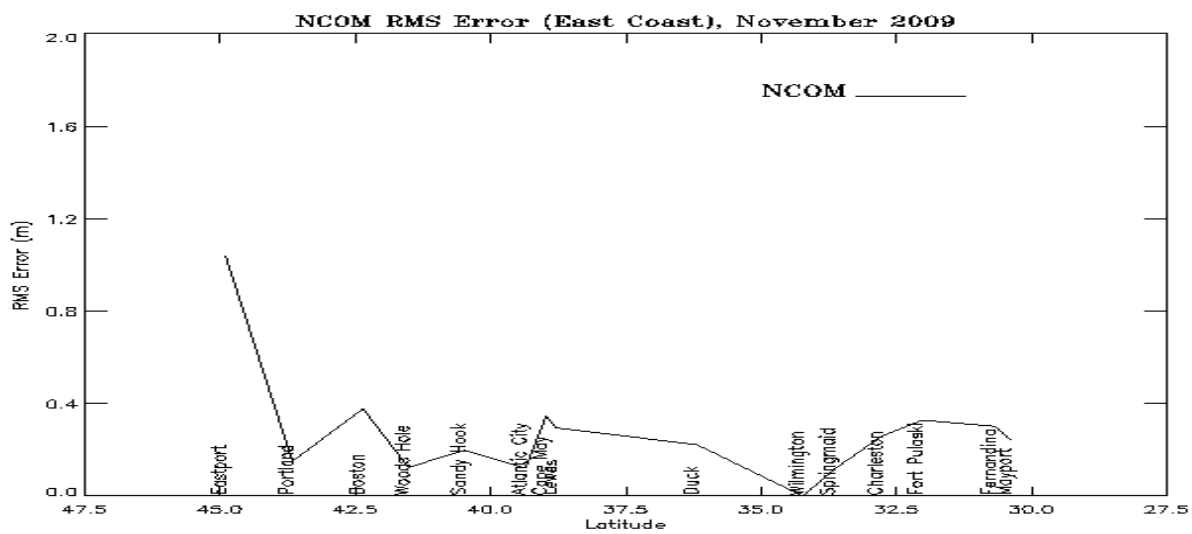


(c)

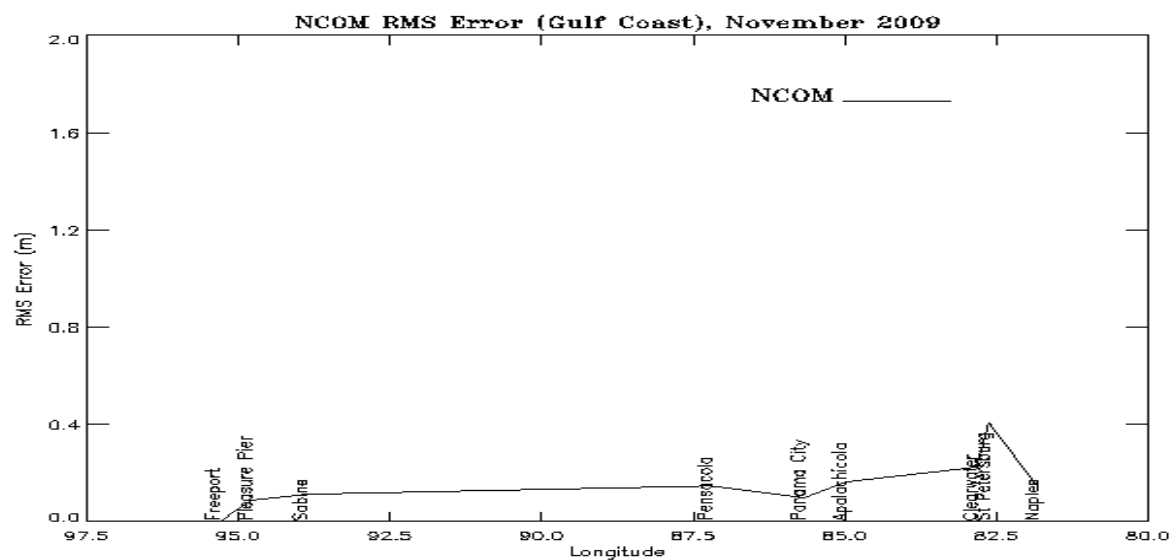


(d)

Figure 5.4. (Cont.) ETSS Subtidal Water Level Forecast Guidance against NOS Observations for November 2009. Clearwater Beach, FL (c) Galveston Pleasure Pier, TX (d). Note sequential forecasts hours 6 to 36 are illustrated at hourly intervals by a repeating sequence of symbols (+, *, Δ, and □). At this vertical scale the model results appear to be represented by +.

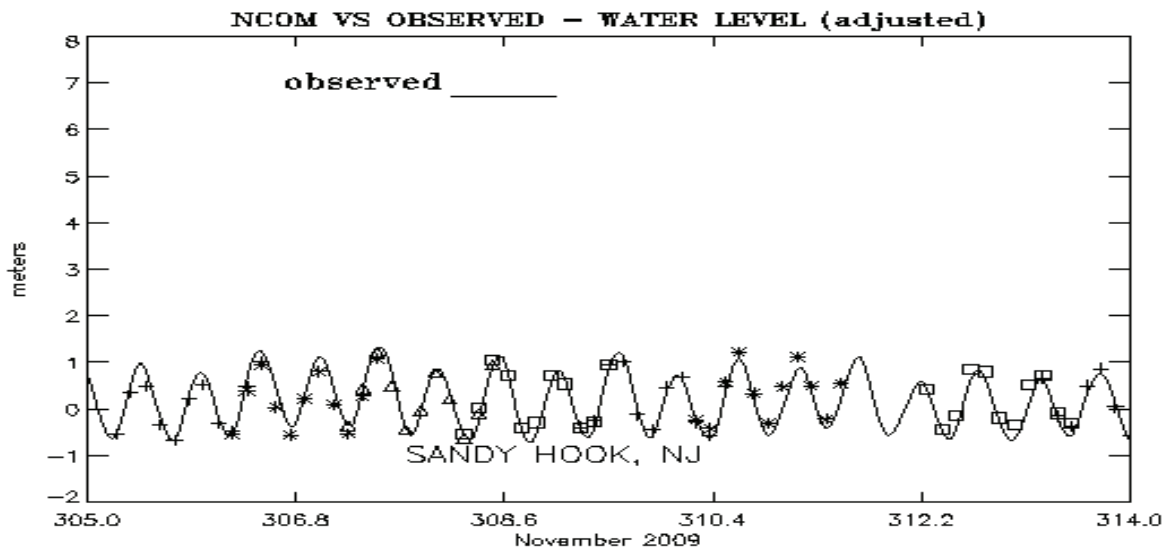


(a)

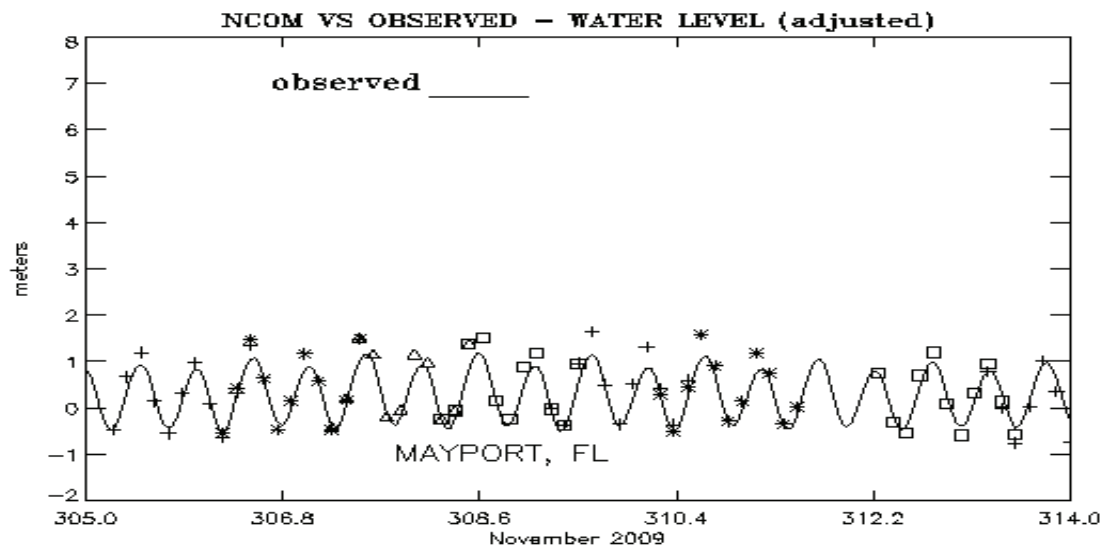


(b)

Figure 5.5. G-NCOM Total Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2009.

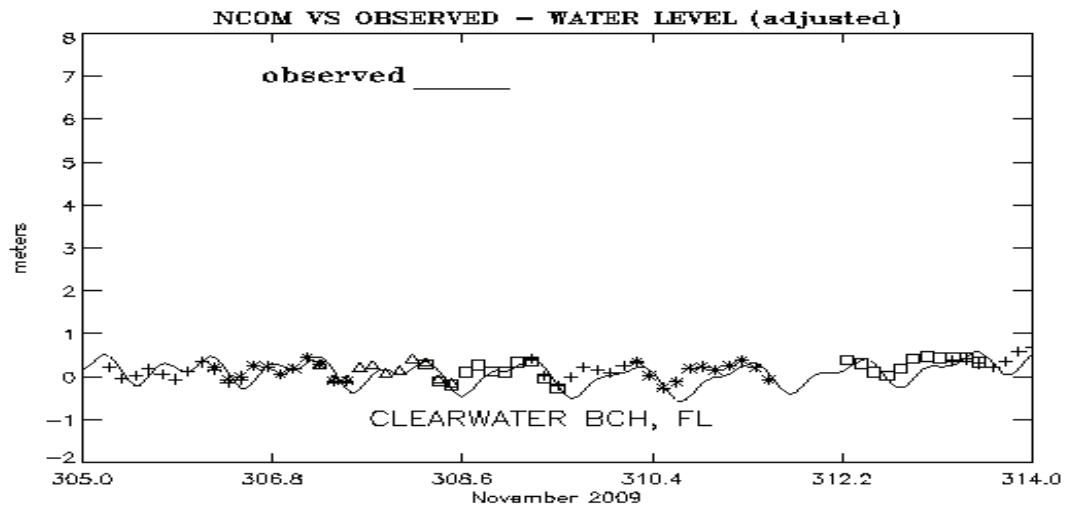


(a)

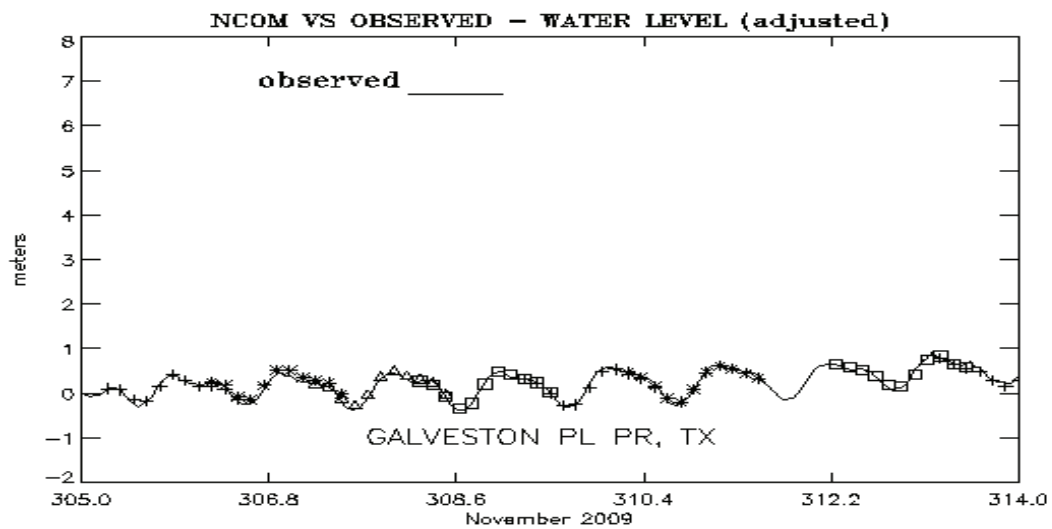


(b)

Figure 5.6. G-NCOM Total Water Level Forecast Guidance against NOS Observations for November 2009. Sandy Hook, NJ (a) Mayport FL (b). Note sequential forecasts hours 6 to 36 are illustrated at 3-hour intervals by a repeating sequence of symbols (+, *, Δ, and □).



(c)



(d)

Figure 5.6. (Cont.) G-NCOM Total Water Level Forecast Guidance against NOS Observations for November 2009. Clearwater Beach, FL (c) Galveston Pleasure Pier, TX (d). Note sequential forecasts hours 6 to 36 are illustrated at 3 hour intervals by a repeating sequence of symbols (+ , * , Δ , and □).

6. ADDITIONAL STATISTICAL MEASURES

To further aid in the evaluation, several additional statistical measures have been computed. The Willmott et al. (1985) dimensionless (0-1) relative error is computed as follows, $\langle (Y - X)^2 \rangle / \langle (|Y - \langle X \rangle| + |X - \langle X \rangle|)^2 \rangle$ where Y is the prediction and X the observation, with zero representing perfect agreement. While this statistic can be used to represent the overall agreement in shape of the model prediction time series curve to the observation time series curve, a difference in means will also affect the value. In fact, if both Y and X are constant and $Y \neq X$ then the relative error is 1. Therefore, it is possible for the relative error to be large when the RMSE is small. In general, we desire a value less than 0.05. In addition, a relative RMSE is computed as the RMSE divided by the standard deviation of the observations. It is desirable for this statistic to be less than one. Following NOS standard skill assessment procedures (Hess et al., 2003), the central frequency (CF) is also computed at a reference level of 15 cm. We desire a CF value greater than 0.9. The results for November 2008 are presented in turn below for each ocean model.

6.1. RTOFS

The relative error is shown for RTOFS in Figure 6.1. It is above 0.5 at all the East Coast stations, and is below 0.5 only at Panama City, FL and Freeport, TX along the Gulf of Mexico coast. The relative RMSE is shown in Figure 6.2. It is above 1.0 at all the East Coast stations, and is below 1.0 only at Panama City, FL and Freeport, TX along the Gulf of Mexico coast. The central frequency at a reference level of 15 cm is shown in Figure 6.3. It is near 0.2 for most stations along the East Coast, and between 0.2 and 0.8 (Panama City, FL) for the Gulf of Mexico coastal stations. These statistics confirm the findings, that there is significant error in the RTOFS November 2008 total water level forecasts, primarily due to the errors in the astronomical tide.

6.2. ETSS

The relative error is shown for the ETSS subtidal water level forecast in Figure 6.4. It is below 0.1 at all the East Coast stations, and is above 0.1 only at Apalachicola, FL and St. Petersburg, FL along the Gulf of Mexico coast. The relative RMSE is shown in Figure 6.5. It is below 0.8 at all the East Coast stations except Cape May, NJ (data problem), and is below 0.8 along the Gulf of Mexico coast. The central frequency at a reference level of 15 cm is shown in Figure 6.6. It is above 0.9, meeting the NOS standard from Hess et al. (2003) for all stations along the East Coast and Gulf of Mexico. These statistics confirm the findings that the quality of the ETSS subtidal water level forecasts serves as a benchmark for other ocean models to meet.

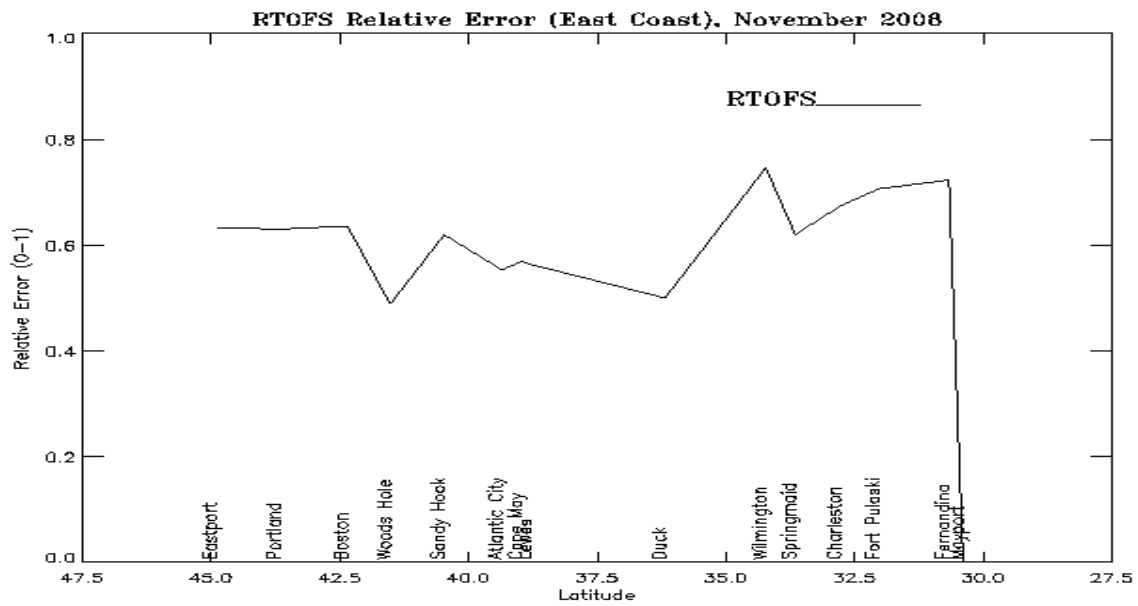
6.3. G-NCOM

The relative error is shown for the G-NCOM total water level forecasts in Figure 6.7. It is below 0.1 at all the East Coast stations except Cape May, NJ (data problem) and at Wilmington, NC (station located within the Cape Fear estuary), and is above 0.2 only at

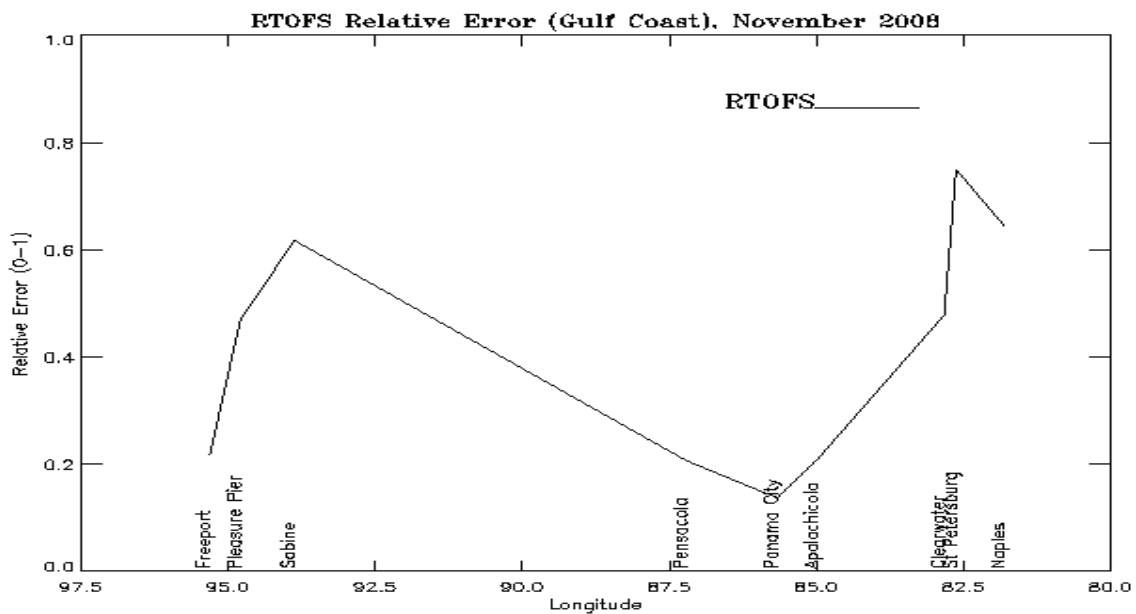
St. Petersburg, FL along the Gulf of Mexico coast. The relative RMSE is shown in Figure 6.8. It is below 0.5 at all the East Coast stations except at Cape May, NJ (data problem) and at Wilmington, NC (station located within the Cape Fear estuary), and is below 0.4 along the Gulf of Mexico coast. The central frequency at a reference level of 15 cm is shown in Figure 6.9. It is above 0.6 for all stations along the East Coast and Gulf of Mexico. At Freeport, TX and Galveston Pleasure Pier, TX, it exceeds 0.9, meeting the NOS standard. These statistics confirm the findings, that the quality of the G-NCOM total water level forecasts is substantially better than RTOFS. However, water levels are available only at a 3-hour data interval.

6.4. ADCIRC

The relative error is shown for the UNC ADCIRC total water level forecast in Figure 6.10. It is below 0.1 at all the East Coast stations except at Wilmington, NC (station located within the Cape Fear estuary), and is above 0.2 only at St. Petersburg, FL along the Gulf of Mexico coast. The relative RMSE is shown in Figure 6.11. It is below 0.8 at all the East Coast stations except at Wilmington, NC (station located within the Cape Fear estuary), and is below 0.8 along the Gulf of Mexico coast except at St. Petersburg, FL. The central frequency at a reference level of 15 cm is shown in Figure 6.12. It is above 0.8 for all stations along the mid-Atlantic coast degrading to near 0.4 at each end and it is above 0.8 except for the stations between the panhandle and Naples, FL in the Gulf of Mexico. These statistics confirm the findings that the quality of the ADCIRC total water level forecasts is substantially better than RTOFS and is improved relative to G-NCOM at only the mid-Atlantic coast stations.

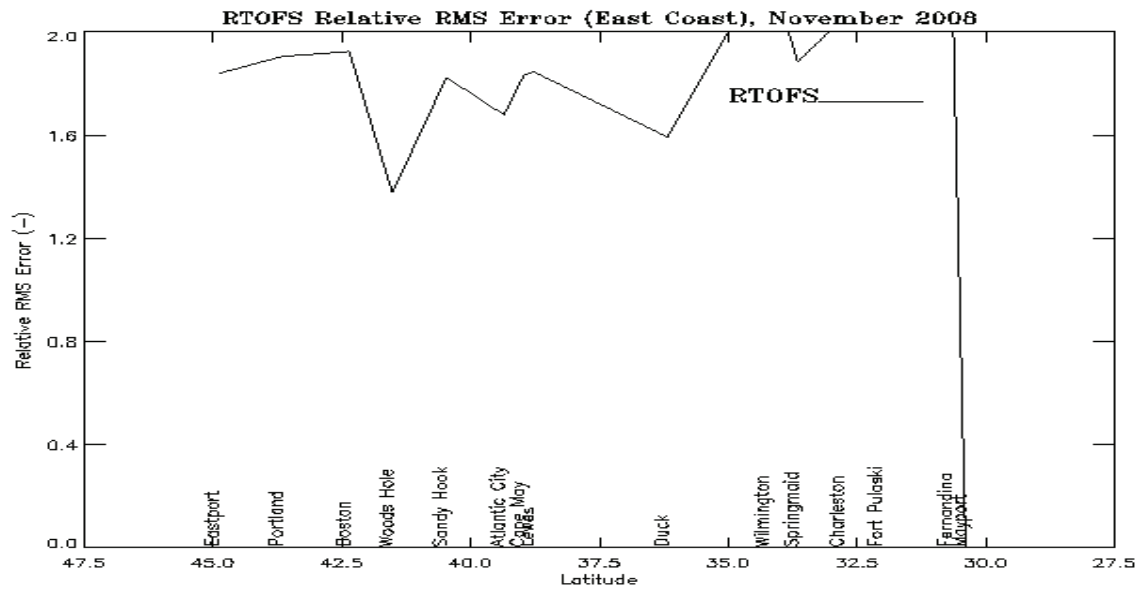


(a)

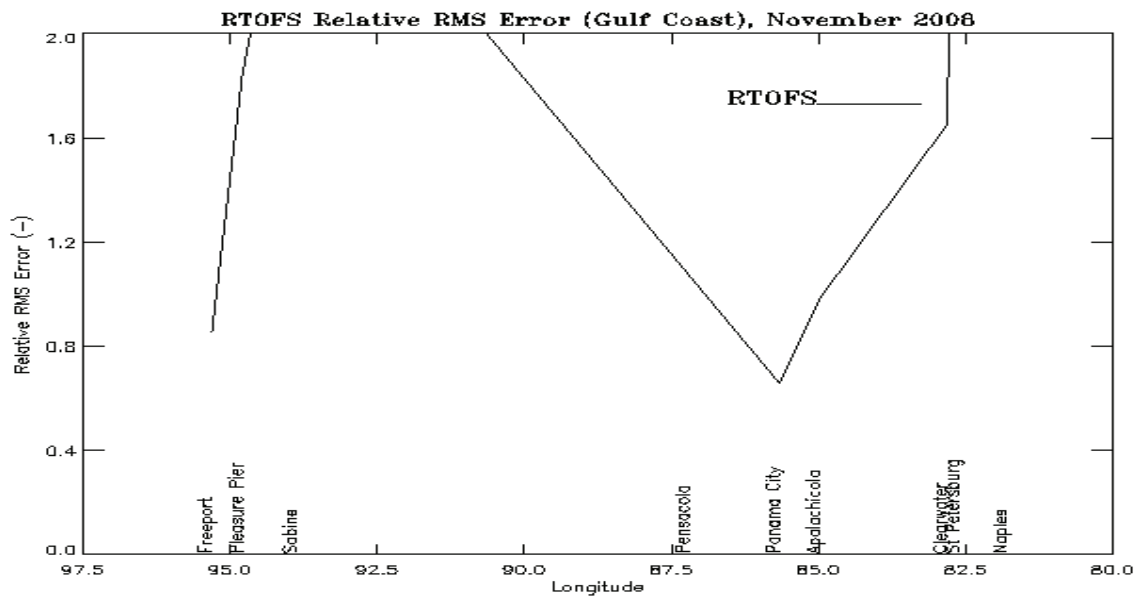


(b)

Figure 6.1. RTOFS Total Water Level Forecast Guidance Relative Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

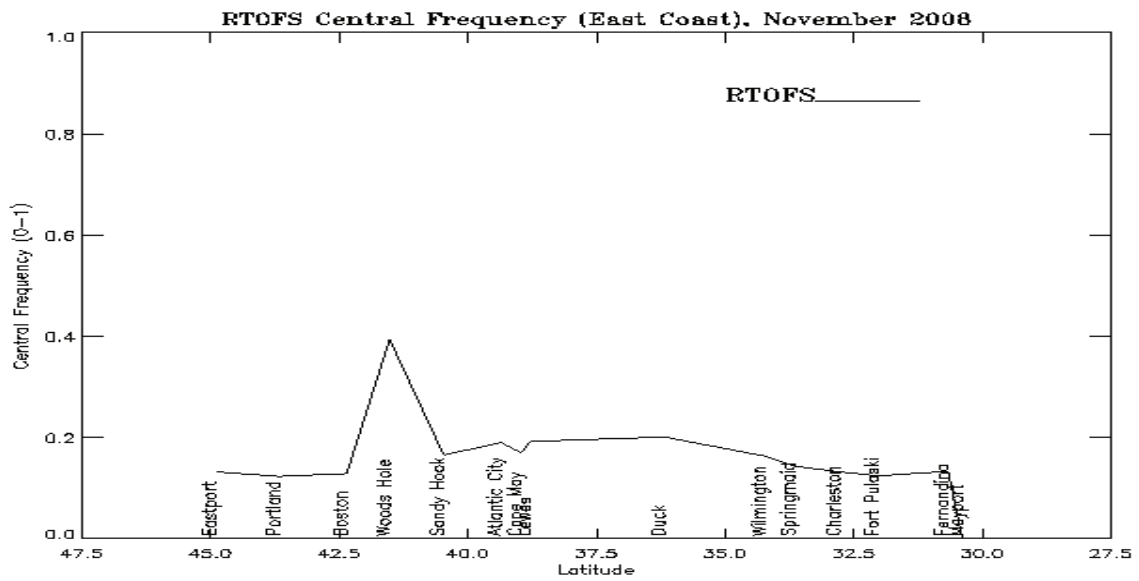


(a)

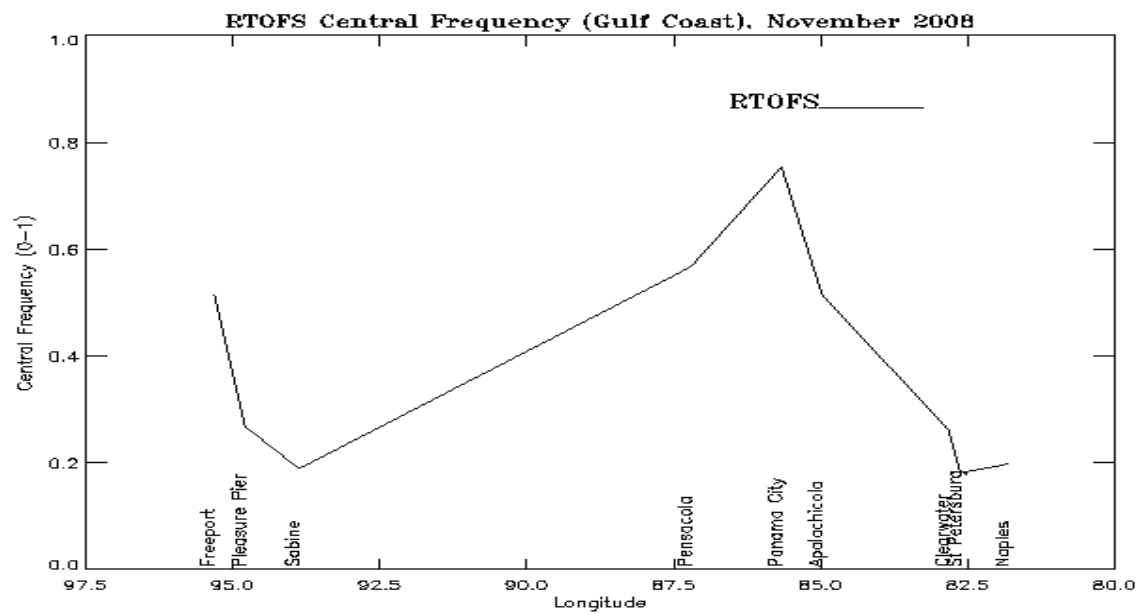


(b)

Figure 6.2. RTOFS Total Water Level Forecast Guidance Relative RMSE (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

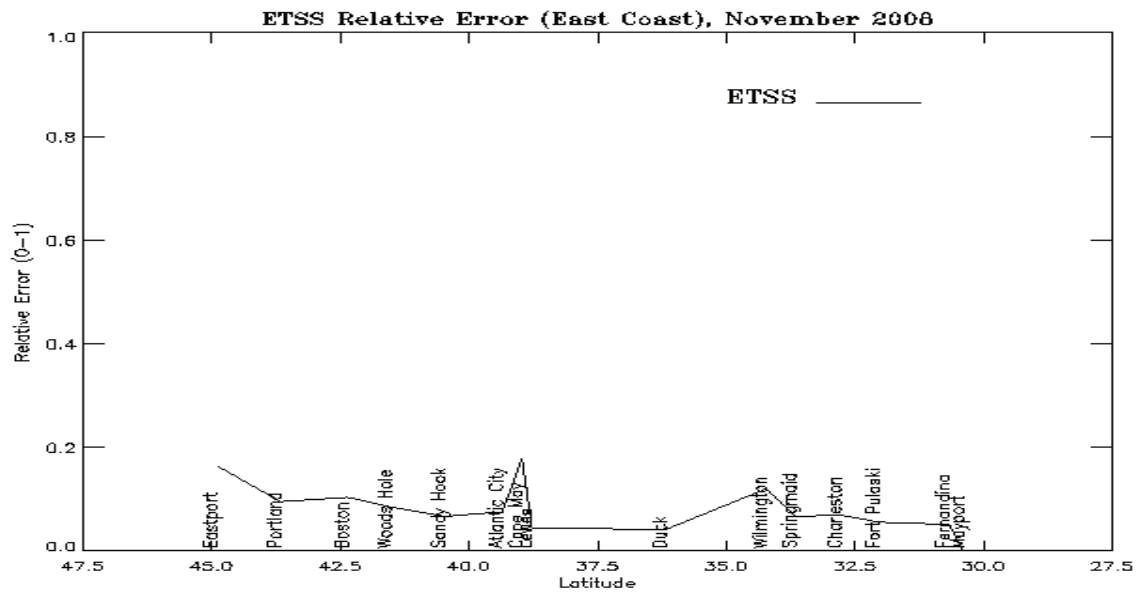


(a)

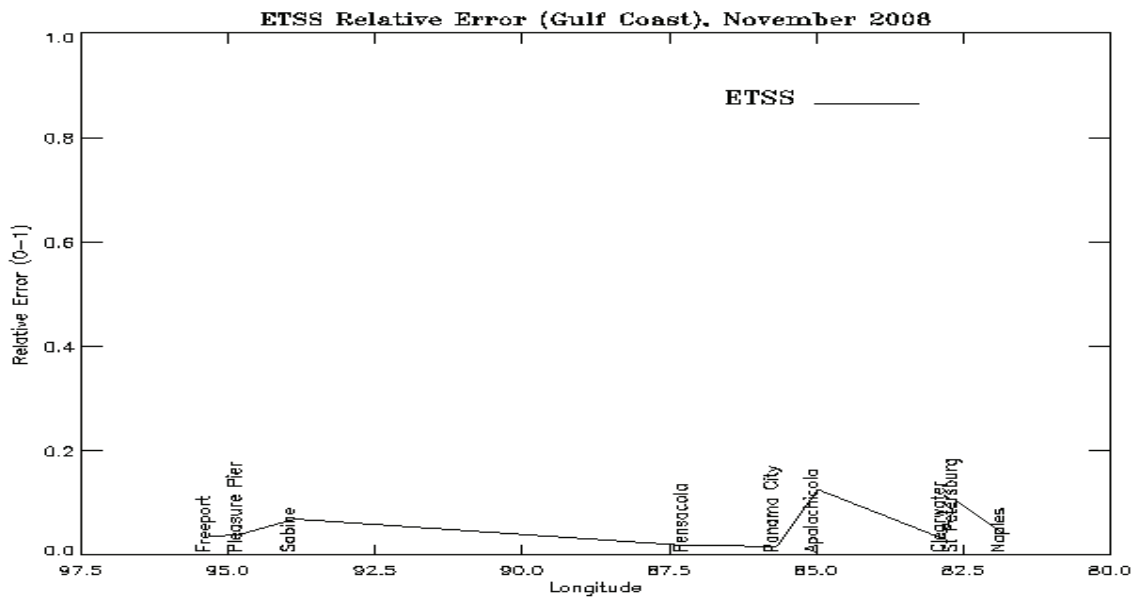


(b)

Figure 6.3. RTOFS Total Water Level Forecast Guidance CF (15 cm reference level) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

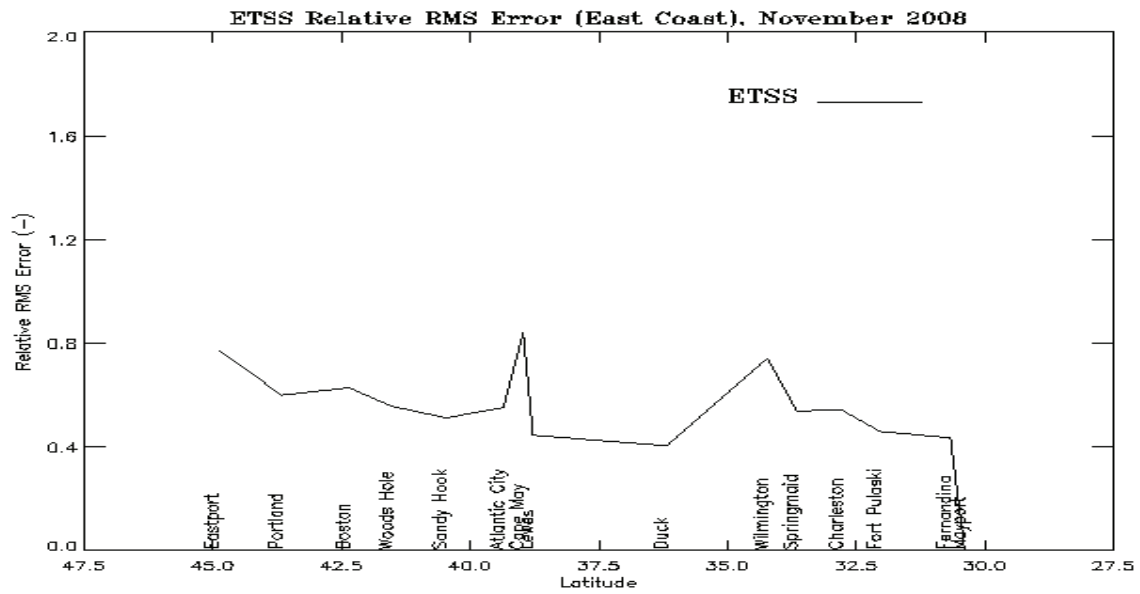


(a)

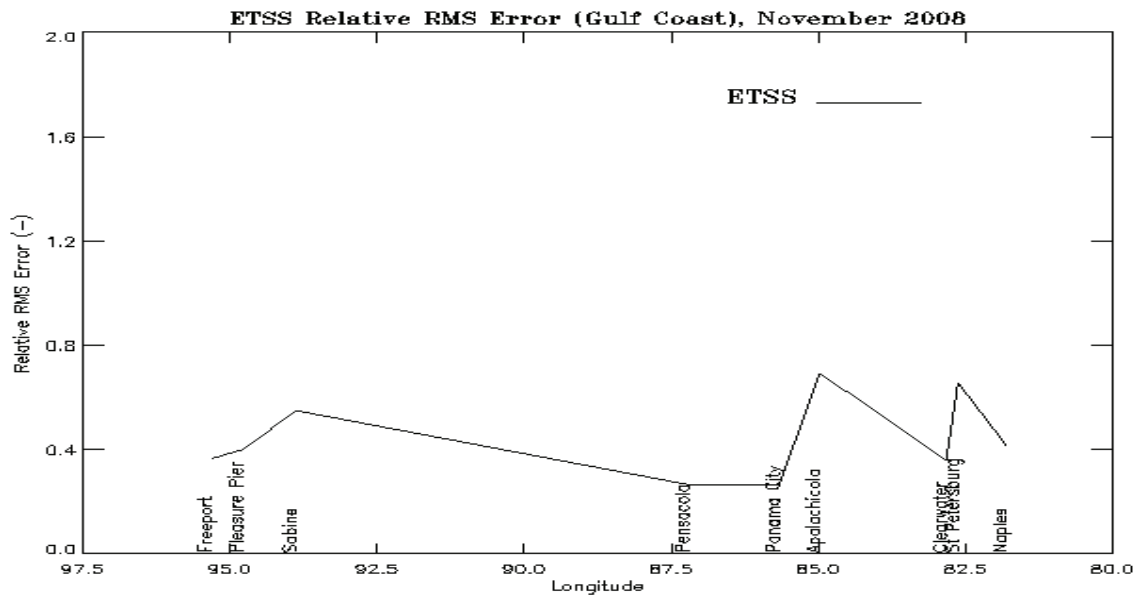


(b)

Figure 6.4. ETSS Subtidal Water Level Forecast Guidance Relative Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

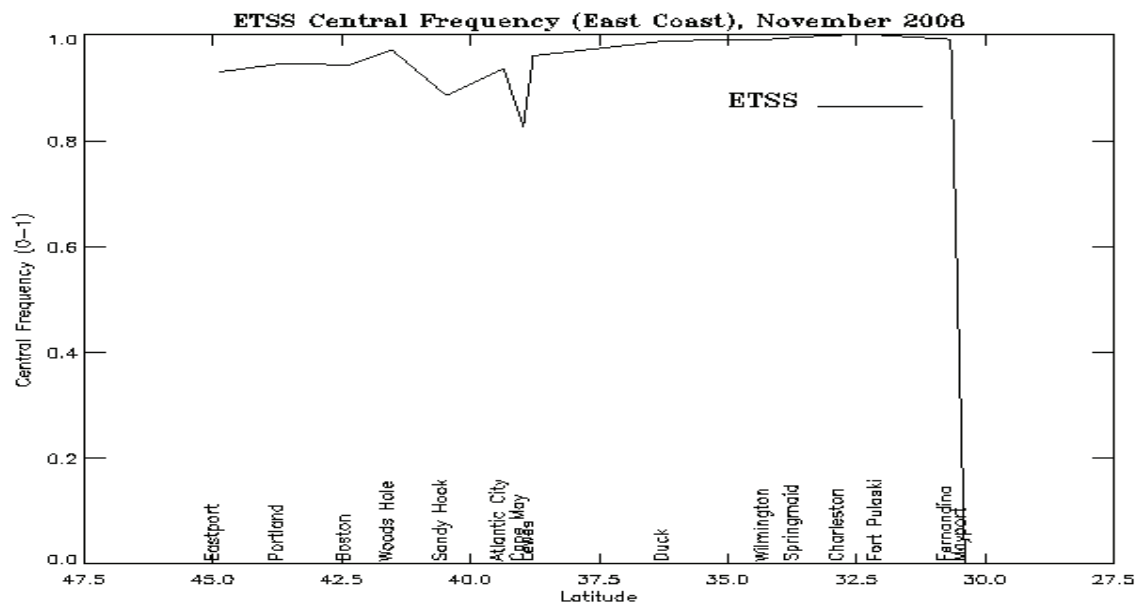


(a)

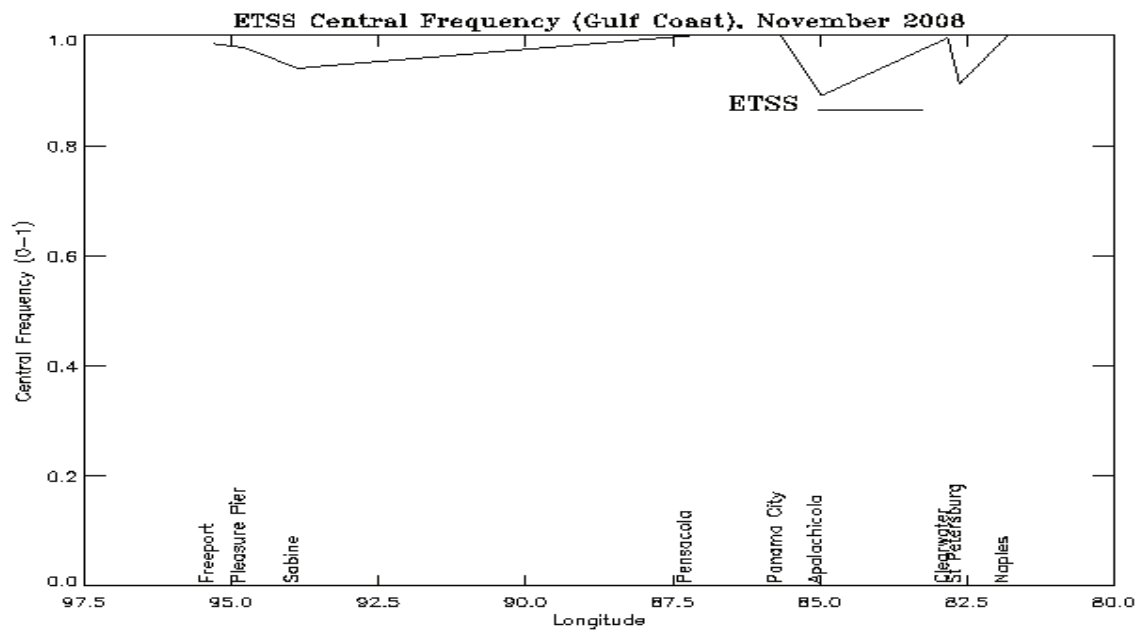


(b)

Figure 6.5. ETSS Subtidal Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

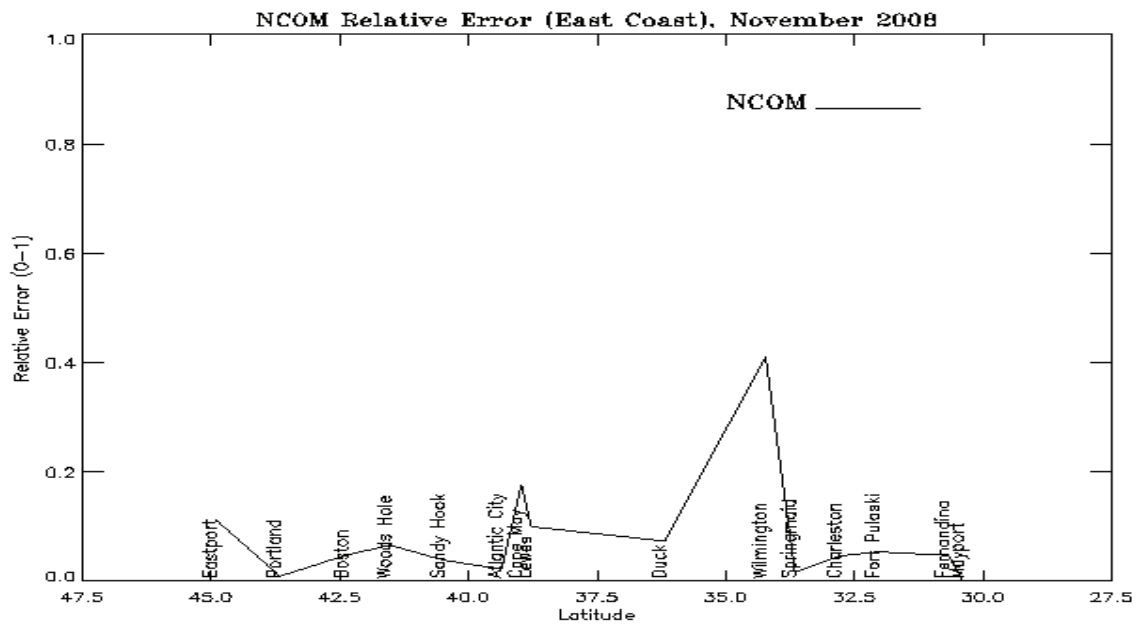


(a)

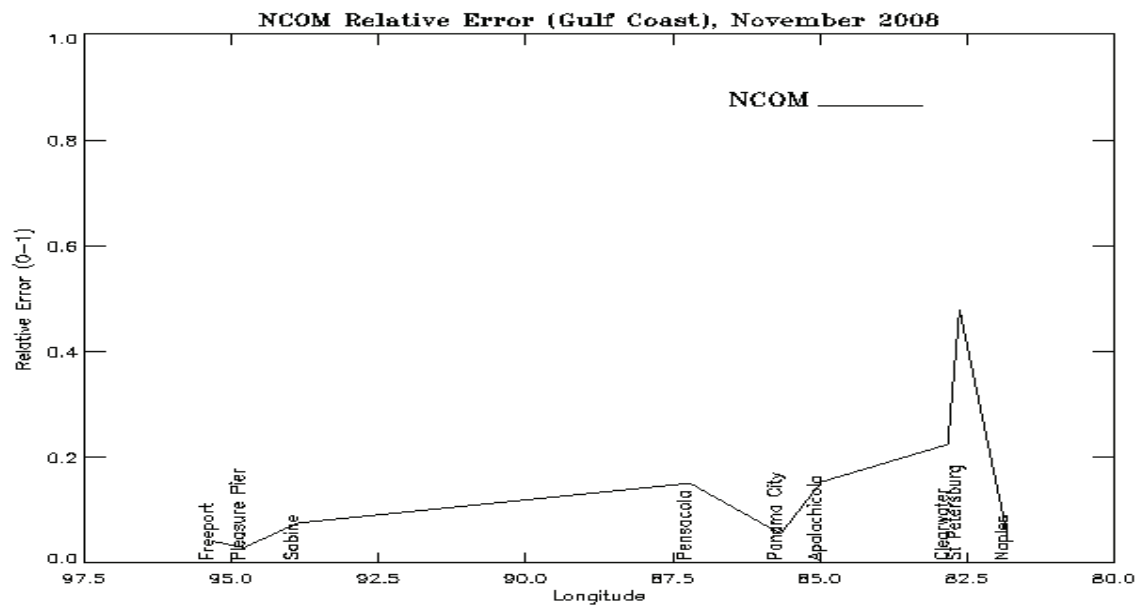


(b)

Figure 6.6. ETSS Subtidal Water Level Forecast Guidance RMSE (meters) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

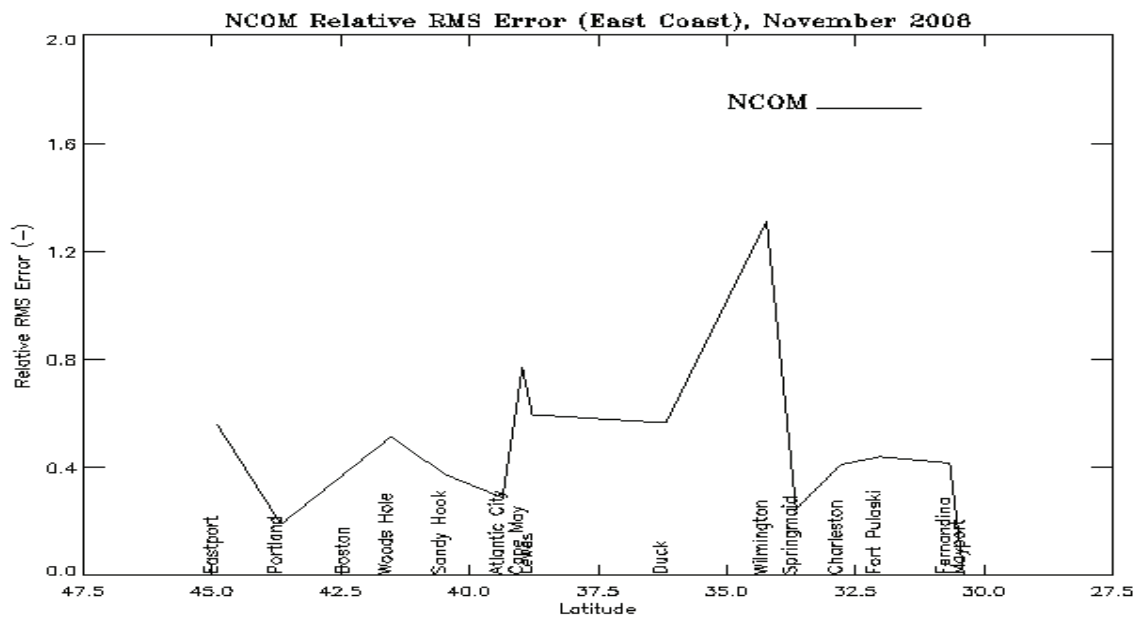


(a)

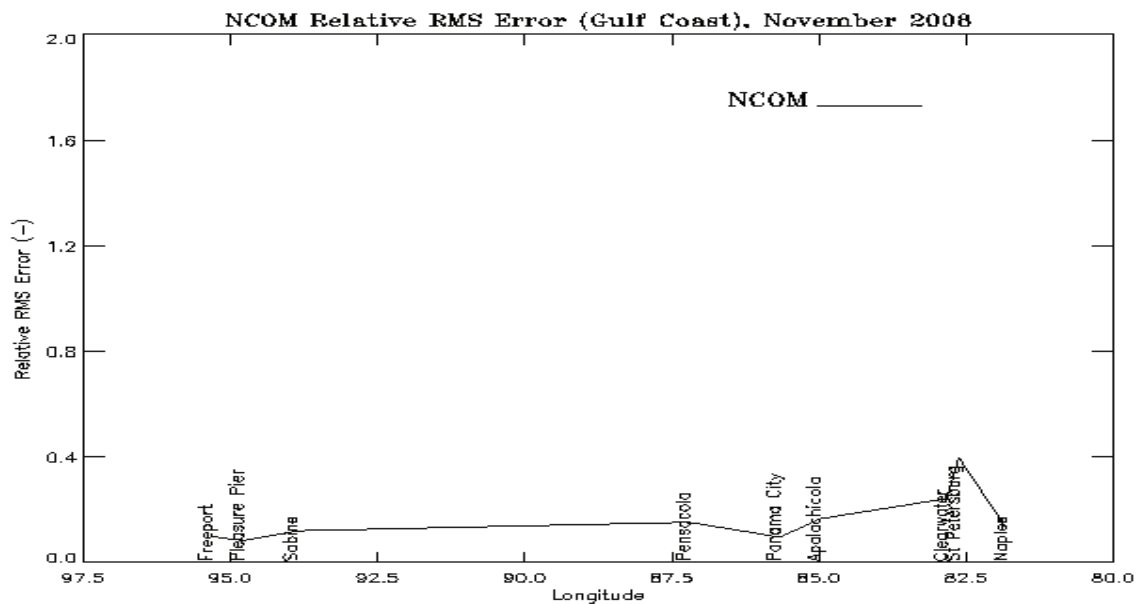


(b)

Figure 6.7. G-NCOM Total Water Level Forecast Guidance Relative Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

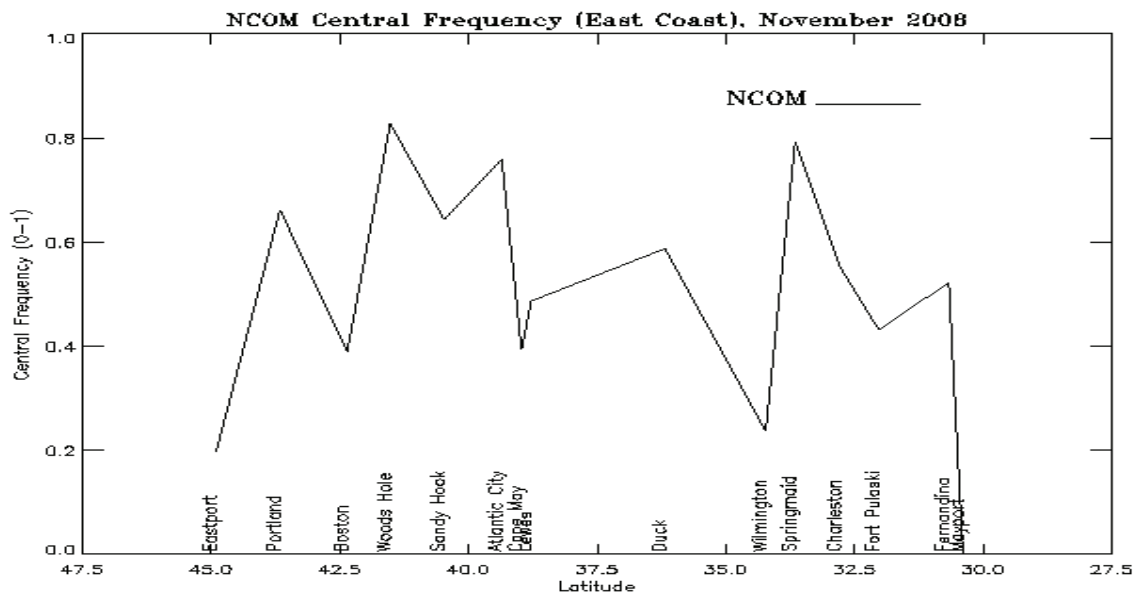


(a)

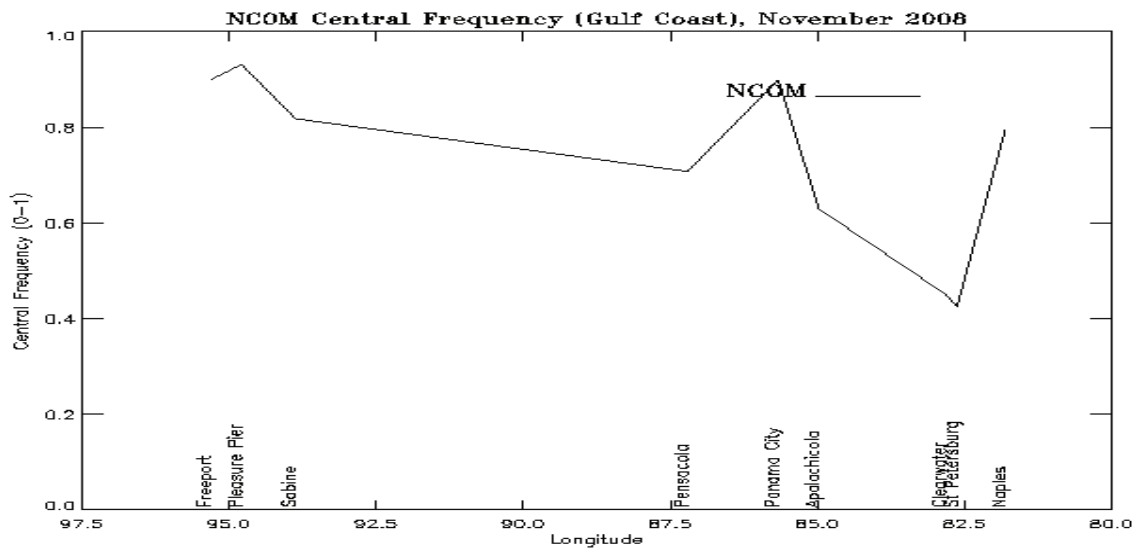


(b)

Figure 6.8. G-NCOM Total Water Level Forecast Guidance Relative RMSE Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

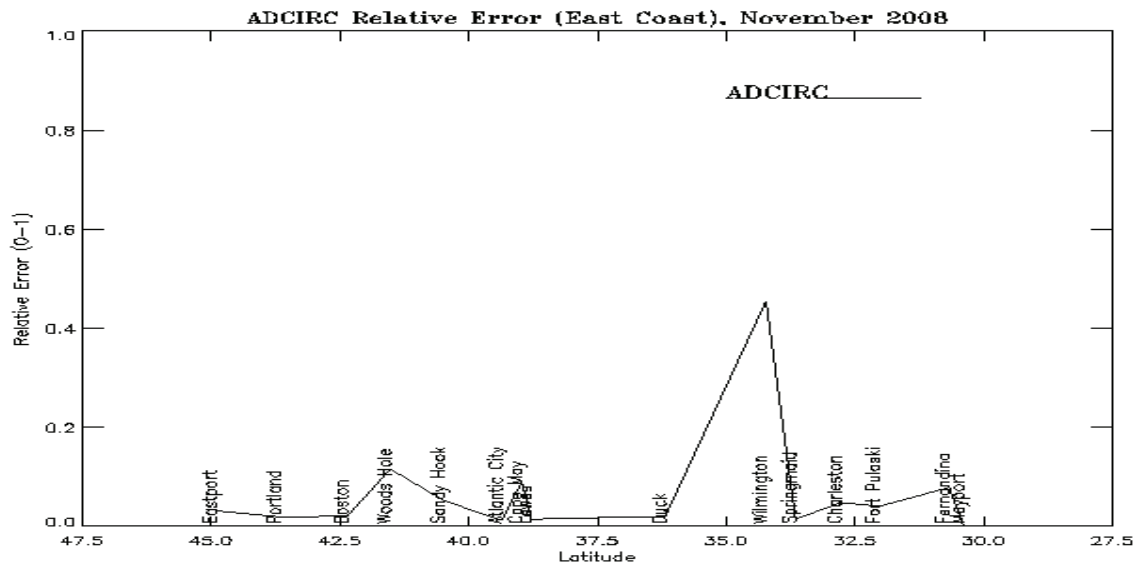


(a)

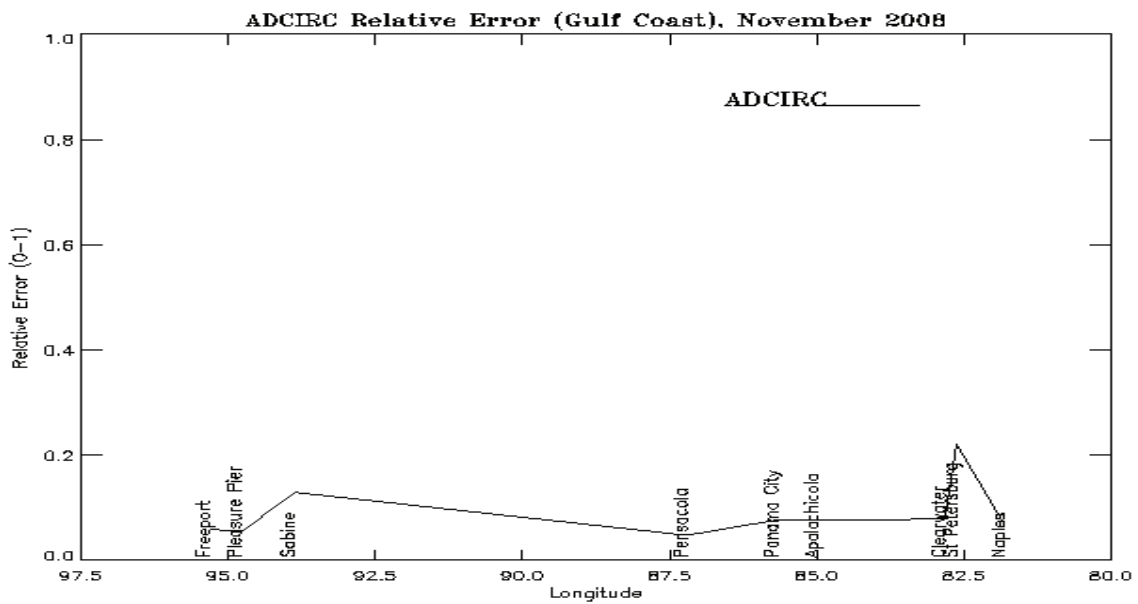


(b)

Figure 6.9. G-NCOM Total Water Level Forecast Guidance Relative RMSE Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

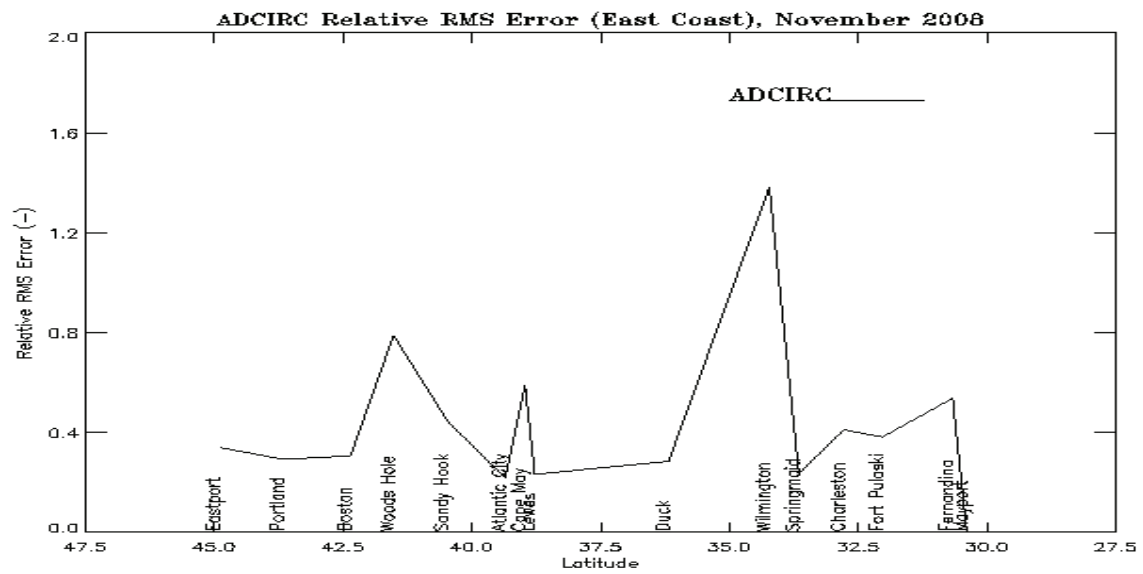


(a)

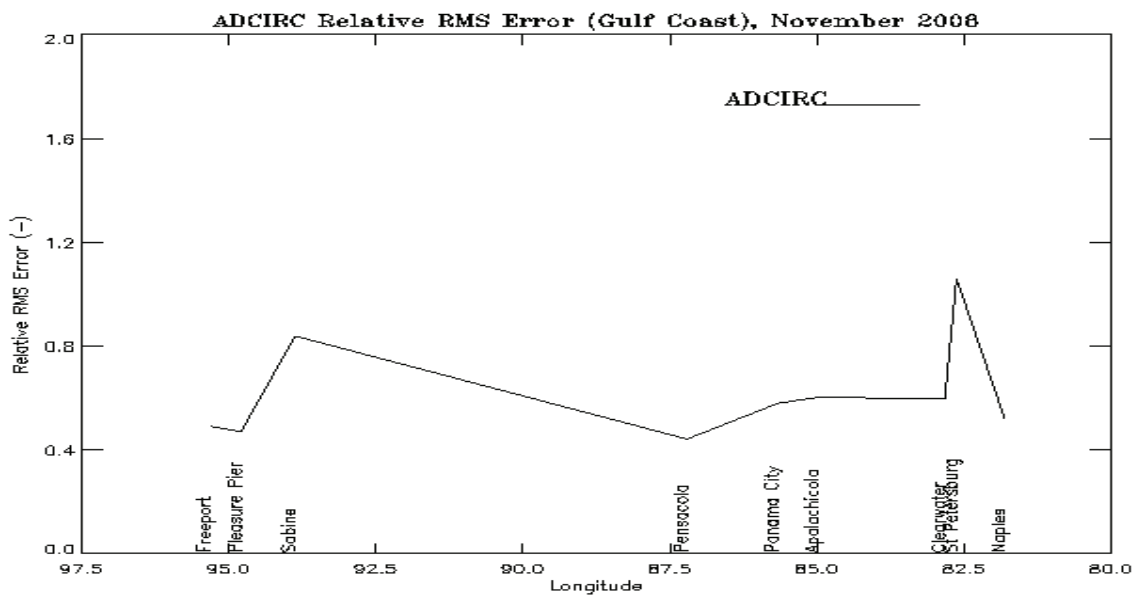


(b)

Figure 6.10. ADCIRC Total Water Level Forecast Guidance Relative Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

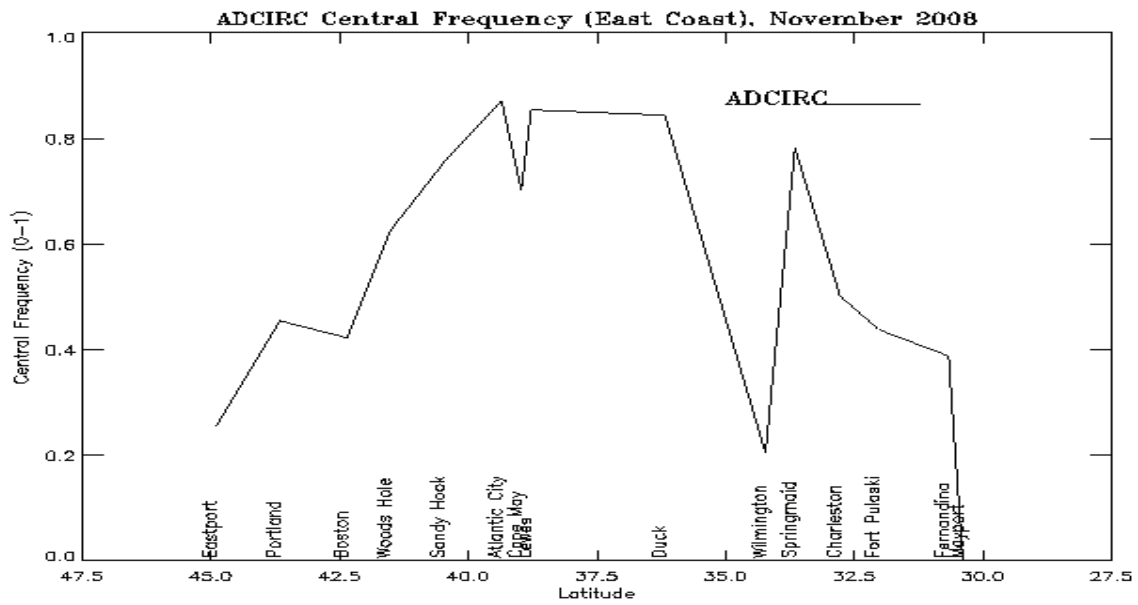


(a)

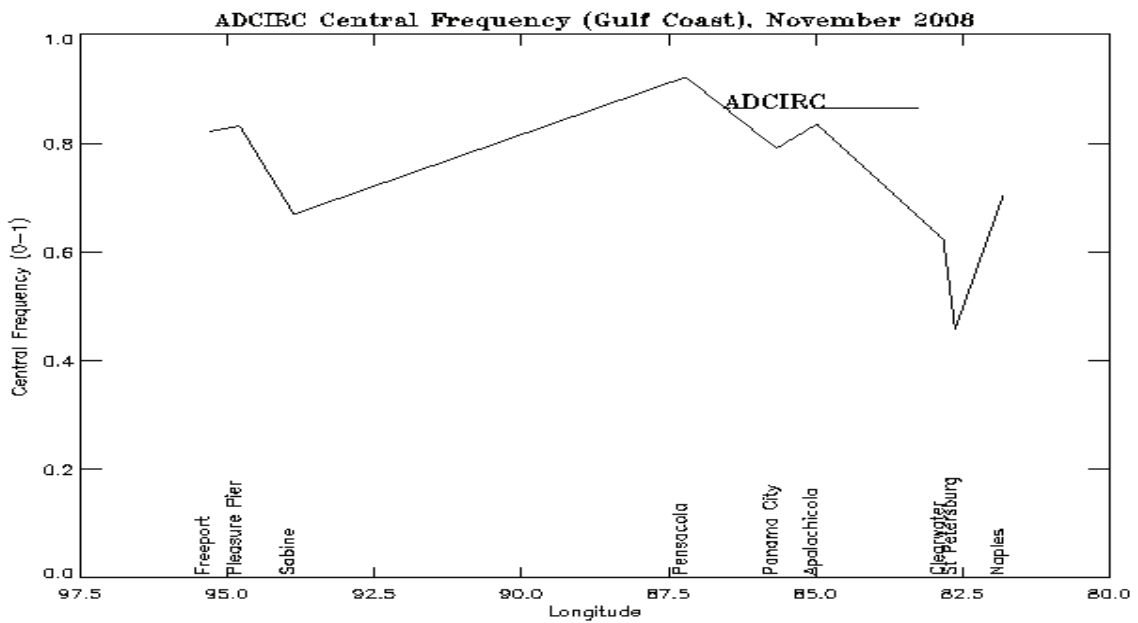


(b)

Figure 6.11. ADCIRC Total Water Level Forecast Guidance Relative RMSE Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.



(a)



(b)

Figure 6.12. ADCIRC Total Water Level Forecast Guidance Relative RMSE Error (-) for East Coast Stations (a) and for Gulf of Mexico Stations (b) for November 2008.

7. CONCLUSIONS AND RECOMMENDATIONS

The previous water level forecast guidance evaluation procedures (Richardson and Schmalz, 2009) were streamlined by combining into a single analysis program for each ocean model, the read, reformat, filter, adjust, and analysis programs. The plot program was modified to be run within a script to further simplify the plotting process. Water level data acquisition was also simplified by using STEP 2 of the NOS skill assessment software (Zhang et al., 2006) to automatically download the water level data for all stations at once.

For November 2008, daily 00Z forecast results of both subtidal (ETSS) and total water level response (RTOFS, G-NCOM, and ADCIRC) along the East coast and throughout the Gulf of Mexico from hours 6-36 for all models were evaluated using the new automated procedures. Results were compared to the previous results obtained by Richardson and Schmalz (2009) to verify the automated water level evaluation procedures.

A monthly evaluation of the ETSS water level forecast guidance over the period December 2008 – October 2009 was performed. Next, a seasonal analysis of the RTOFS forecast guidance was performed by adding the analysis for the months February, May, and August 2009 to the November 2008 analysis. Finally, an annual analysis of ETSS, RTOFS, and G-NCOM was performed by comparing the November 2008 results to an analysis of results for November 2009. The evaluation procedures were extended to include the additional statistical measures of relative RMSE, Willmott et al. (1985) relative error, and central frequency (Hess et al., 2003) as illustrated for November 2008.

While the ETSS model is subtidal only, the quality of the ETSS hourly subtidal water level forecasts serves as a benchmark for other total water level ocean forecast models to meet. To date, the quality of the total water level forecast models is not as good as the ETSS subtidal water level forecast model. For the total water level forecast models, the quality of the G-NCOM forecasts is substantially better than RTOFS. However, water levels are available only at a 3-hour data interval. The quality of the ADCIRC total water level hourly forecasts is substantially better than RTOFS and is improved relative to G-NCOM at only the mid-Atlantic coast stations. It is anticipated that the horizontal resolution in both the weather prediction models and ocean models will continue to increase leading to improvements in the atmospheric forcings as well as in the representation of the hydrodynamics; all leading to improved water level forecast guidance. Therefore it is necessary to evaluate the ocean models as they continue to evolve.

The automated analysis procedures developed here are sufficiently general to evaluate both subtidal and total water level forecast models. Additional comparisons of the total and subtidal water level forecasts to observations should be performed on a routine monthly basis using this automated software package. Specifically, it is recommended

that the automated water level evaluation procedures be transferred to CO-OPS and run on a monthly basis with results posted on the CO-OPS operational forecast system website.

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