

## SMAST Technical Report 04-11- 02

# An Operational Application of the QUODDY Circulation Model for Nowcasting the Response of the Gulf of Maine/Georges Bank Region to Wind Stress and $M_2$ Tidal Forcing : July 2001

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### Abstract

This was a test of a near real-time operational application of the Dartmouth 3-dimensional finite-element circulation model QUODDY designed to nowcast the meteorologically-forced response of the Gulf of Maine region in the presence of the strong semidiurnal tide. The model is forced along the open ocean boundaries with a predicted  $M_2$  tidal sea level and at the surface with wind stress derived by an optimal interpolation of an array of NOAA National Weather Service/ National Data Buoy Center measurements that were obtained in near real-time. In this application, the model is run every  $1/16 M_2$  tidal period (i.e., 0.77625 hours) in near real-time. Because each calculation runs faster than real time, subsequent calculations are delayed until real time catches up with model time, when the model sea level results are output. A model/observation comparison of tidal sea level results at 49 observation stations throughout the Gulf indicated that  $M_2$  tidal sea level amplitude differences were typically less than  $\pm 10\%$  and phase differences less than 30 degrees, though there was a bias in the latter. The test of the operational model system was run for the month of July 2001 produced results that are sampled here. Instructions for running this operational model system in the SMAST Unix computing environment are included.

### I. Introduction

This paper describes the first real-time test of an application of the Dartmouth 3-dimensional, finite-element circulation model (QUODDY; Lynch et al. 1996, 1997) for nowcasting the sea level and current variability of the Gulf of Maine region in response to tidal and wind stress forcing. The purpose of this test was to identify the issues in running an operational model system that requires a steady and timely input of data for the model forcing fields and produces products that are accessible to others. This system is being constructed for the operational nowcasting and forecasting of the sea level response to storm forcing. This test just happened to occur during July 2001 and thus did not exhibit the robust model responses that winter storms produce (e.g., see Fan et al., 2004).

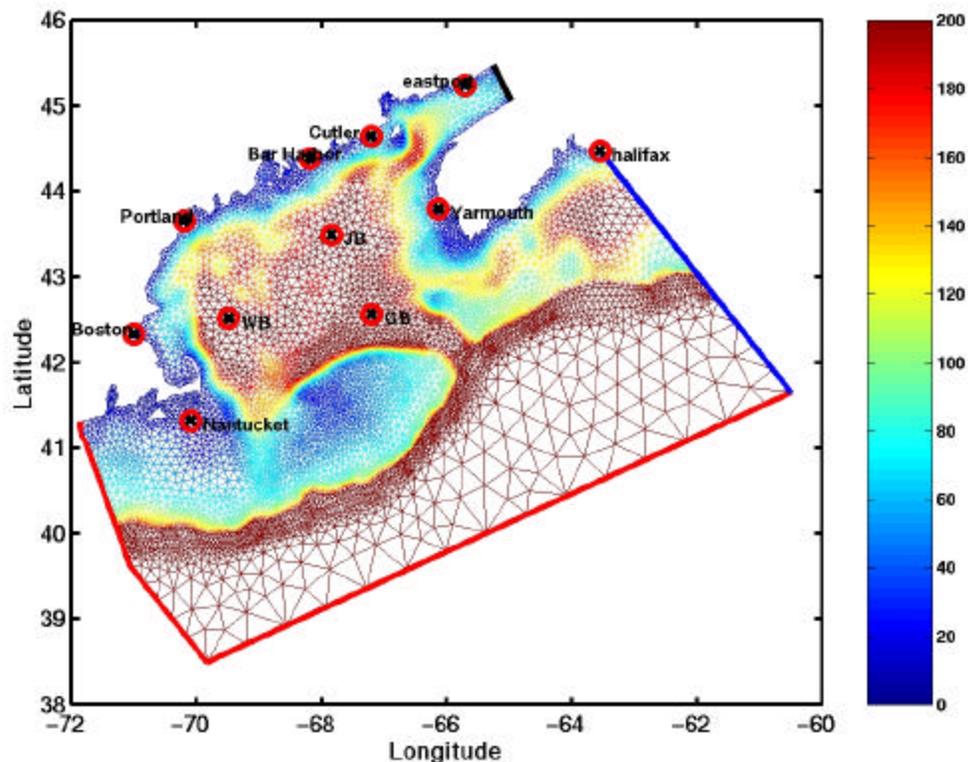
Nevertheless this test generally advanced the construction of the system and taught us a lot about how to do these kinds of calculations - as described in this report. The details of the model system setup and forcing are described in section II. The details of the model system initialization and operations are described in section III. The operational QUODDY results with  $M_2$  tidal forcing only are described in section IV. The operational QUODDY results with  $M_2$  tidal and wind forcing are described in section V. The details of the protocol for the near real-time forcing of the model open ocean boundary across the Scotian shelf are described in the section VI [Appendix A](#). A manual for operation of

the system on an SGI Inc. Origin 200 in the UNIX computing environment at the School for Marine Science and Technology (SMAST) is in the section VI [Appendix B](#).

## II. Model Setup and Forcing

**Setup:** QUODDY was run in its barotropic or constant density mode, with steady, homogeneous temperature (6.39°C) and salinity (33.47 psu). The specified temperature and salinity were based on moored measurements in Wilkinson Basin during February 1987 ([Brown and Irish, 1993](#)). A space-time independent bottom drag coefficient of 0.005 was used with the model's quadratic bottom stress.

The QUODDY model domain is the Gulf of Maine/Georges Bank region and surroundings as defined by a deep ocean along-shelf transect south of Georges Bank that is closed by a pair of cross-shelf transects that run southeastward offshore from of Halifax, NS, and Watch Hill, RI, respectively, and a short transect across the southwestern end of the Bay of Fundy. QUODDY is run on the [Holboke \(1998\)](#) finite element GHSD mesh ([Figure 1](#)), with a resolution varies from about 10km in the interior of the Gulf to about 5km near the coastlines and order 2km in the regions of steep bathymetric slopes like the north flank of Georges Bank. The mesh resolution is consistent with a  $(\Delta h)/h_{\min} < 0.5$  condition ([Naimie et al., 1996](#)) throughout the domain. A 10m depth minimum was adopted for the coastal boundary elements.



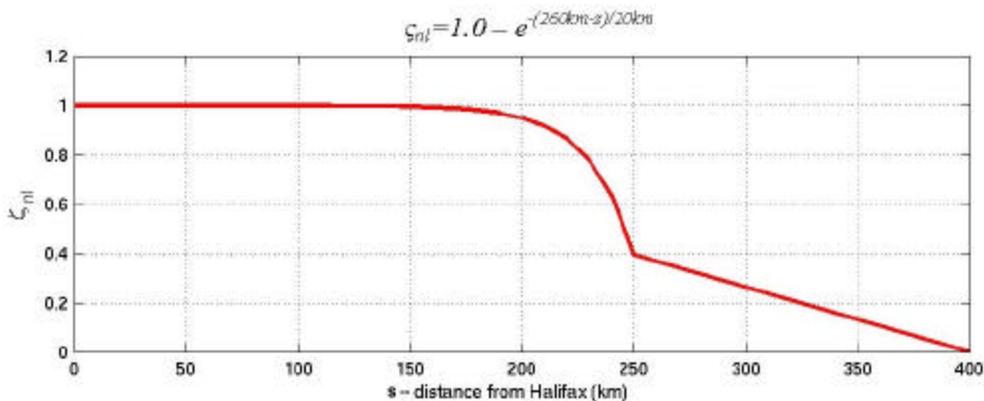
**Figure 1.** The GHSD mesh for the QUODDY model domain. Water depth (in meters) is color-coded as defined by color bar on the right. A subset of the sea level and bottom pressure observation stations used in the model/observation comparisons are located (circled cross).

**Model Lateral Boundary Conditions:** The conditions imposed along the different QUODDY open boundaries are as follows.

- The Deep Ocean and Western Cross-Shelf Sections (red line; Figure 1): The Lynch et al. (1997) predicted semidiurnal  $M_2$  tidal elevation forcing, zero steady residual elevation, and the Holboke (1999) inhomogeneous, barotropic radiation conditions were imposed.
- The Bay of Fundy Section (black line; Figure 1): The Lynch et al. (1997) predicted  $M_2$ ,  $M_4$ ,  $M_6$  normal flow, constrained by a condition of zero non-tidal transport normal to the section, was imposed.
- The Cross-Shelf Section at Halifax (blue line; Figure 1): The Lynch et al. (1997) predicted  $M_2$  tidal elevations, a zero steady residual elevation, and the Holboke (1999) radiation boundary condition were imposed. Also an *unsteady* (i.e., non-tidal) residual sea level, containing the remotely-forced sea level variability as discussed above, was imposed along this model boundary. Specifically, we used the Holboke (1999) "smooth-step model" of this residual cross-shelf sea level  $\eta_h$ , which is

$$\eta_h(s) = SL_H \zeta_{nl}$$

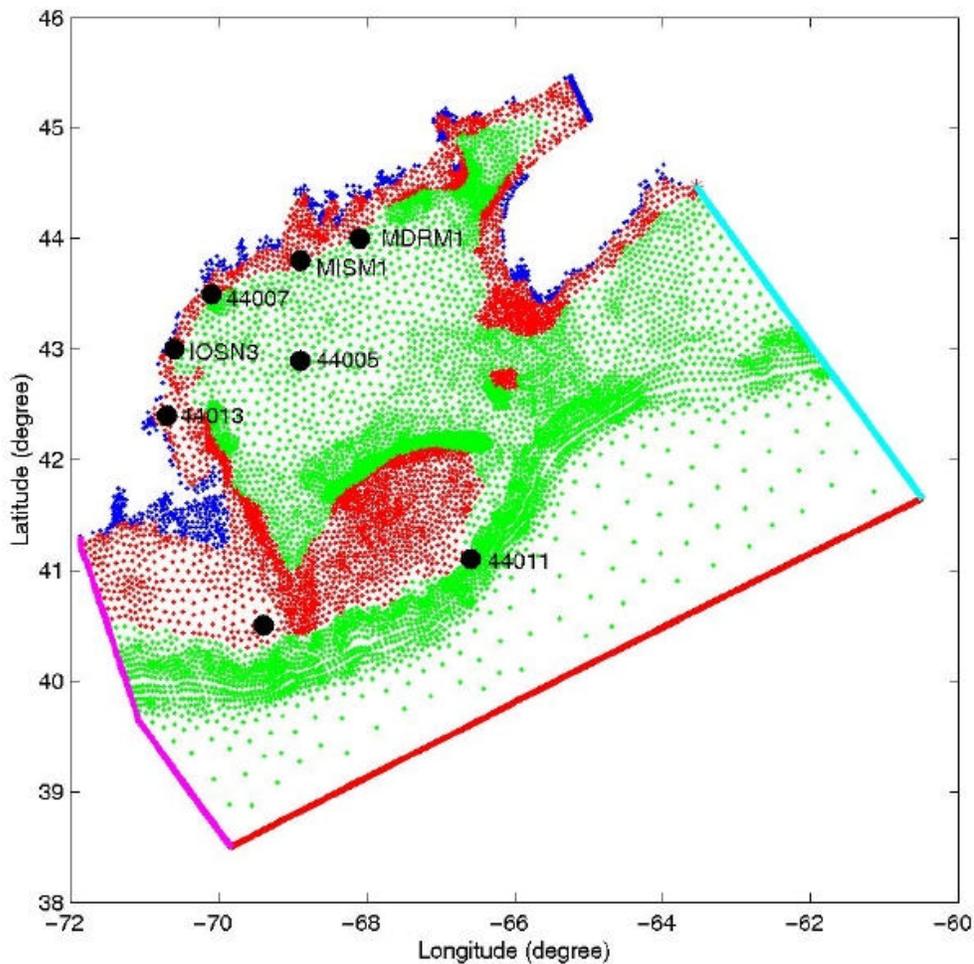
where  $SL_H$  is the measured time-varying Halifax residual sea level and  $\zeta_{nl}$  is the normalized cross-shelf structure is given by  $\zeta_{nl} = 1.0 - e^{-(260km-s)/20km}$ , in which  $s$  is the distance offshore from Halifax. As shown in Figure 2, the "smooth-step" sea level extrapolation is nearly constant across the Scotian Shelf out to the shelf break, where it decreases rapidly. This structure is consistent with the observed behavior of subtidal bottom pressure fluctuations on the northeast continental shelf (e.g. Brown et al., 1985).



**Figure 2.** The normalized cross-shelf structure of the smooth-step model for the residual (i.e., non-tidal) sea level forcing along the open cross-shelf boundary from Halifax (to the left) and deep ocean (to the right).

For this real-time application, Halifax non-tidal sea level was not available in real-time to “drive” the variable residual cross-shelf sea level protocol described above. Thus it had to be inferred (in real-time) using National Ocean Service (NOS) real-time sea level at Portland ME with an estimated statistical response function between the two stations (see the [Appendix A](#) for details of the estimation process).

The model was forced at the surface with nowcast wind stress derived from NOAA National Weather Service (NWS) and National Data Buoy Center (NDBC) measurements at the stations in [Figure 3](#). The NDBC/C-Man measurements usually arrive about 90 minutes late relative to real time. These winds are interpolated onto the GHSD mesh via an optimal interpolation scheme ([Brown et al. 2004](#)), and then the sea surface wind stress is computed ([Large and Pond, 1981](#)). The protocols for processing the atmospheric pressure measurements are described by [Fan et al. \(2004\)](#).



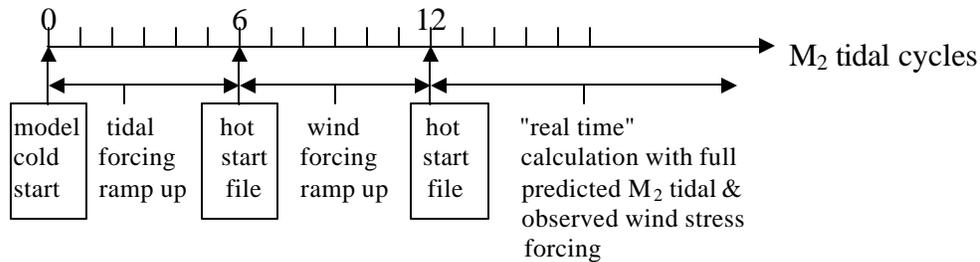
**Figure 3.** Meteorological measurement station locations relative to the GHSD mesh of nodes (Holboke, 1999) used with the QUODDY model. The depths of blue mesh nodes are less than 15m; 15m < red nodes depths < 80m; and green node depths > 80m. Meteorological measurements made at NDBC buoy stations (numbered •) and the NWS C-Man stations (lettered •) were available in near-real-time.

### III. Near Real-Time QUODDY Operations Protocols

Here we outline the protocols for the near real-time operation of the QUODDY model system described in the previous section. A detailed manual for the operation of the system on an SGI Inc. Origin 200 in a UNIX environment at SMAST is in [Appendix B](#). To initiate a near real time calculation, the model tidal is linearly increased in intensity (i.e., ramped up) from “cold-start” conditions of zero velocity and sea level during the first 6  $M_2$  tidal cycles. During the second 6  $M_2$  tidal cycles, the meteorological forcing is ramped up as indicated for wind stress according to:

$$\underset{\substack{\uparrow \\ \text{applied forcing}}}{t_x(t_y)} = \text{rampup} * \underset{\substack{\uparrow \\ \text{real wind stress}}}{t_x(t_y)};$$

where "ramp up" increases linearly from 0 to 1 (see [Figure 4](#)). At the end of the 12  $M_2$  tidal cycle model “warm-up”, the model calculation is temporally terminated and a “hot-start file” - containing the values of all of the model variable values variables - is produced. The hot-start file is used to restart the model calculation as described below.

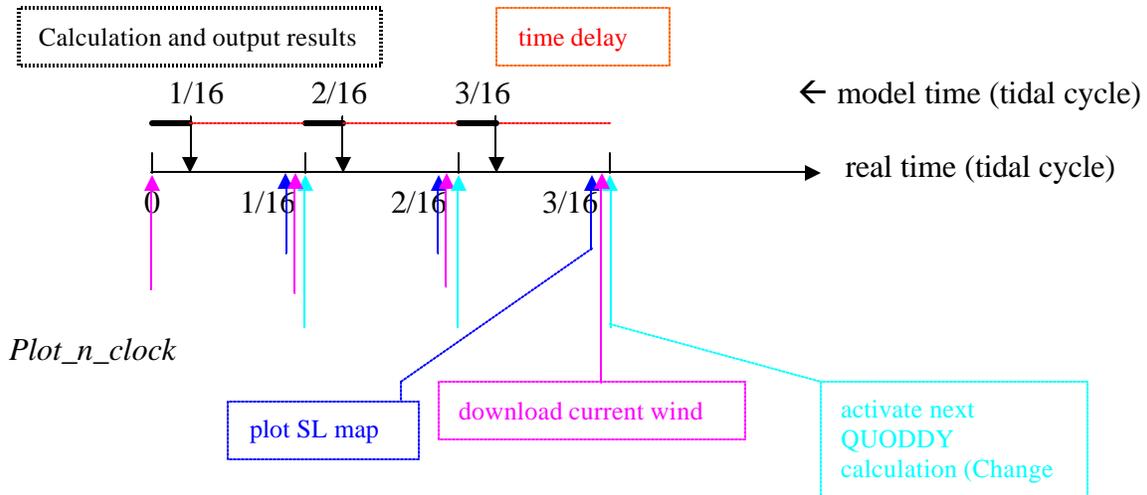


**Figure 4.** Time line of the QUODDY model initialization process for near real-time operations.

During normal operations, QUODDY is repeatedly restarted and run for 1/16 of  $M_2$  tidal period or 0.77625 hours. Each of these model run bursts consisting of 128 model time steps of 21.83203125s (or 1/2048  $M_2$  tidal period ) runs on our SGI Origin 200 in about 16 and our Dell/Linux PC in about 1 real-time minute(s) respectively; both considerably faster than real time. Thus the output of model sea level results and subsequent model calculations need to be delayed for about 30 (45) minutes until real time is able to “catch-up” to model time.

The QUODDY operations are controlled according to the timing shown in [Figure 5](#). Every 1/16  $M_2$  tidal cycles (~ 47 real time minutes), the C-language program called *plot\_n\_clock* (a) triggers the output plotting of the most recent QUODDY sea level results, (b) orchestrates the down-loading of the NDBC meteorological data, (c) “notes” real time and (d) signals the beginning of the next cycle.

The beginning of each model calculation cycle (see [Figure 6](#) flow diagram) is signaled when FLAG is set to 1. Simultaneously QUODDY is restarted and *plot\_n\_clock* triggers the output (i.e., plotting) of the QUODDY sea level maps that were computed during the previous calculation cycle.



**Figure 5.** Time line of operational QUODDY model calculations.

### QUODDY Operational Steps:

1. QUODDY runs for 128 time steps and then outputs (a) the real world GMT time corresponding to the 128<sup>th</sup> model time step to a file called "Expected\_date"; (b) the corresponding model sea level distribution to a file called "SL\_mod"; and (c) corresponding currents to a trio of files called "velu", "velv", and "velw" respectively.
2. FLAG is set to 0.
3. The QUODDY control element called "Delay Subroutine" begins checking the state of FLAG, which is normally 0, every second. When the real time, as measured by *plot\_n\_clock*, equals the time of the most recent QUODDY calculation in "Expected\_date", (a) FLAG changes from 0 to 1, (b) *plot\_n\_clock* outputs the previous QUODDY sea level results and (c) the next QUODDY calculation is activated.

### Plot\_n\_clock Operational Steps:

1. Every second "plot\_n\_clock" checks to see if its measured real time matches the calculated GMT time (in Expected\_date) of the most recent QUODDY model run. When the measured real time matches the model calculated time, "plot\_n\_clock" changes "FLAG" to 1.
2. When FLAG changes to 1, "plot\_n\_clock" starts Matlab, which plots the most recent model sea level contours and downloads the most recent (-90 minutes) wind data from the NDBC website for the next QUODDY run.
3. Goes back to step 1.

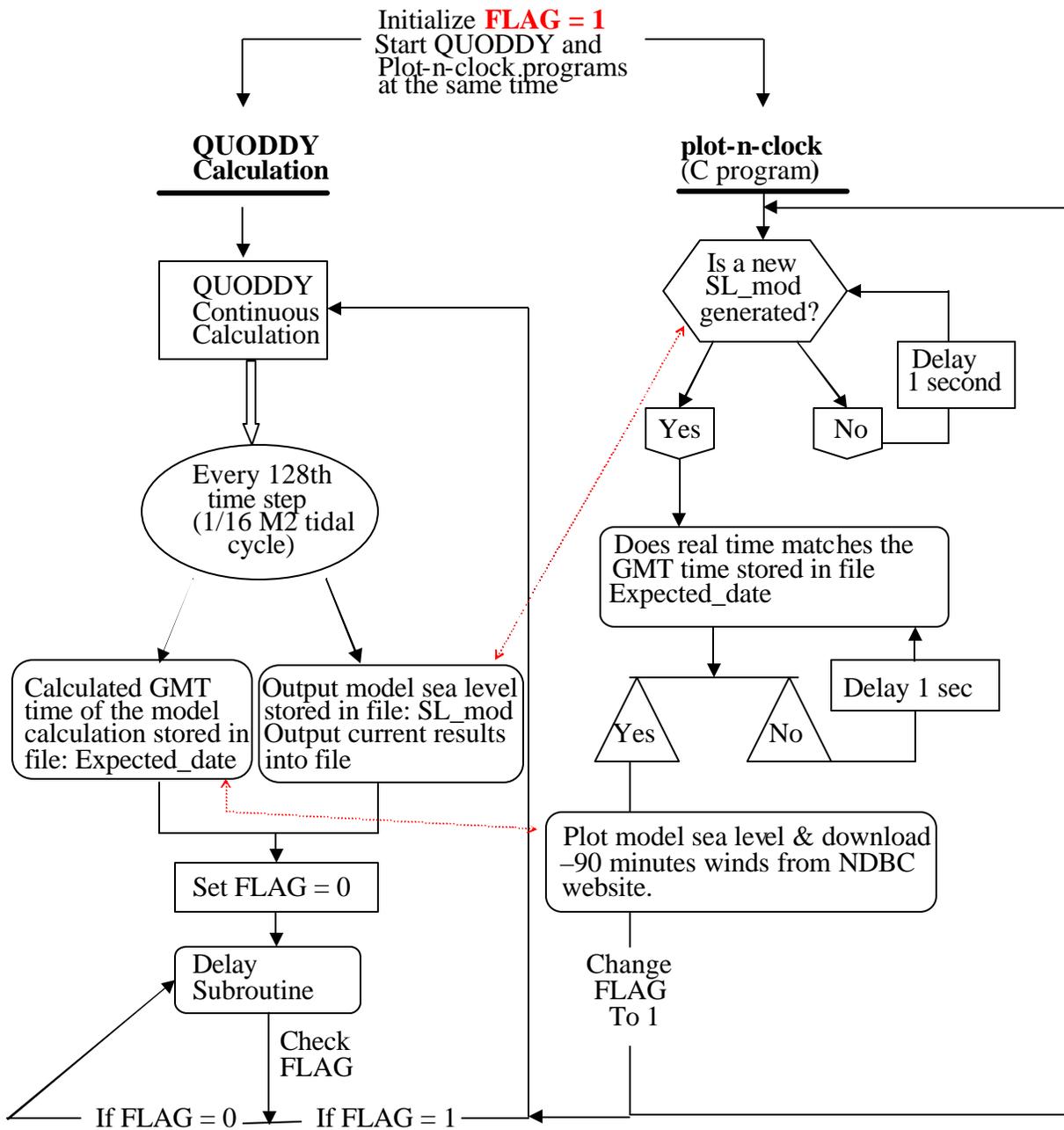
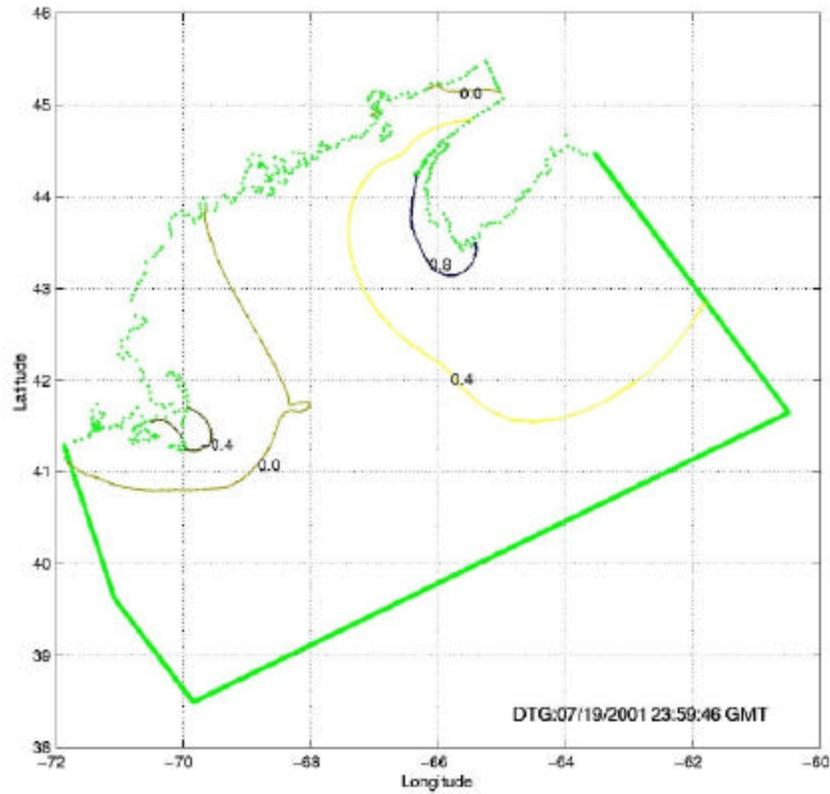


Figure 6. Flow diagram of real-time QUODDY operations (see text).

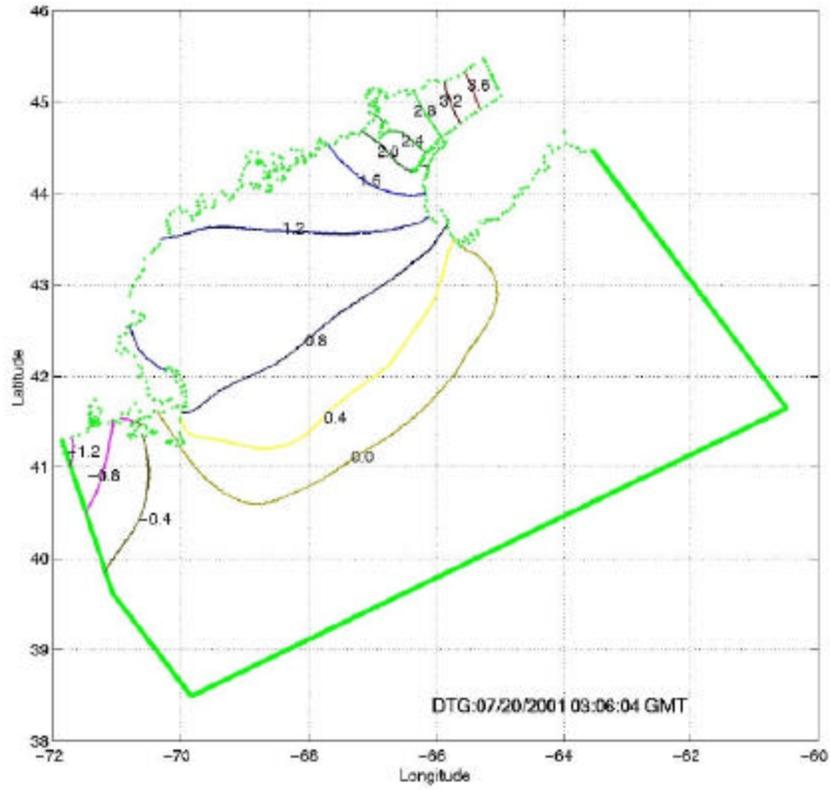
#### IV. Operational QUODDY Results: M<sub>2</sub>Tidal Forcing Only

After the initialization described above, the model, with M<sub>2</sub> tidal forcing-only, was run for 2 tidal cycles on 19-20 July, 2001. The model sea level results are displayed at 1/4 M<sub>2</sub> tidal cycle intervals in Figures 7a-d). This sequence of model tidal sea level patterns, which are very similar to those presented in Brown and Moody (1987), start nearly at

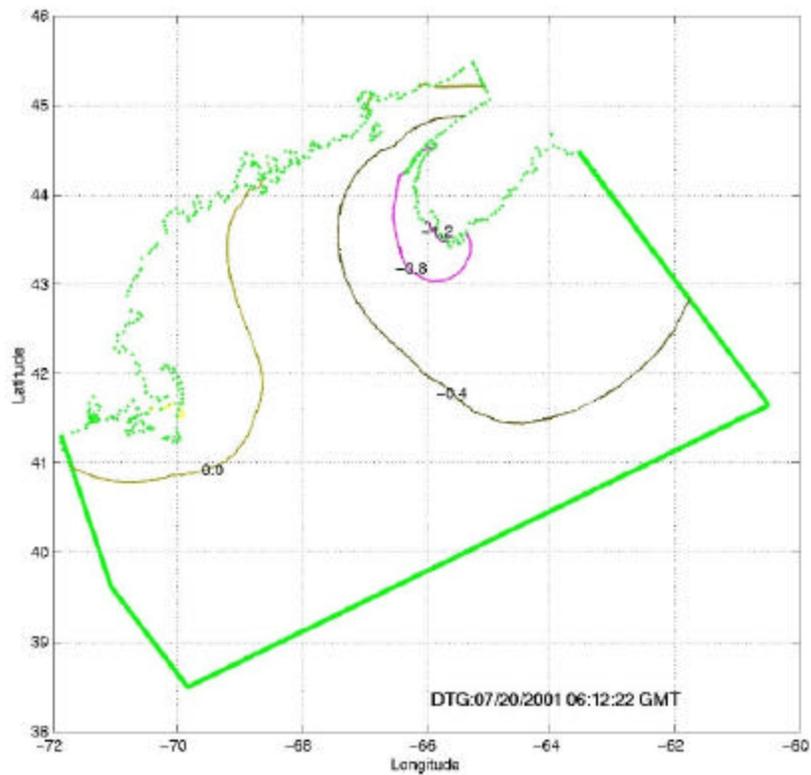
mid-tide on a rising tide (Figure 7a); progress to high tide in Figure 7b; to a falling tide mid-tide in Figure 7c; and finally to low tide in Figure 7d. The tide in the Gulf of Maine is forced by the deep ocean tidal wave that propagates into the tidal domain from the east. Note the slight upward tilt toward the east in the Figure 7a pattern. The near-resonant  $M_2$  tide displays its standing wave character with its node along the south flank of Georges Bank and amplification in the Bay of Fundy (Figure 7b). After the high tide (~ 4m) in the Bay of Fundy, the tidal sea level begins to decrease nearly in unison throughout the Gulf.



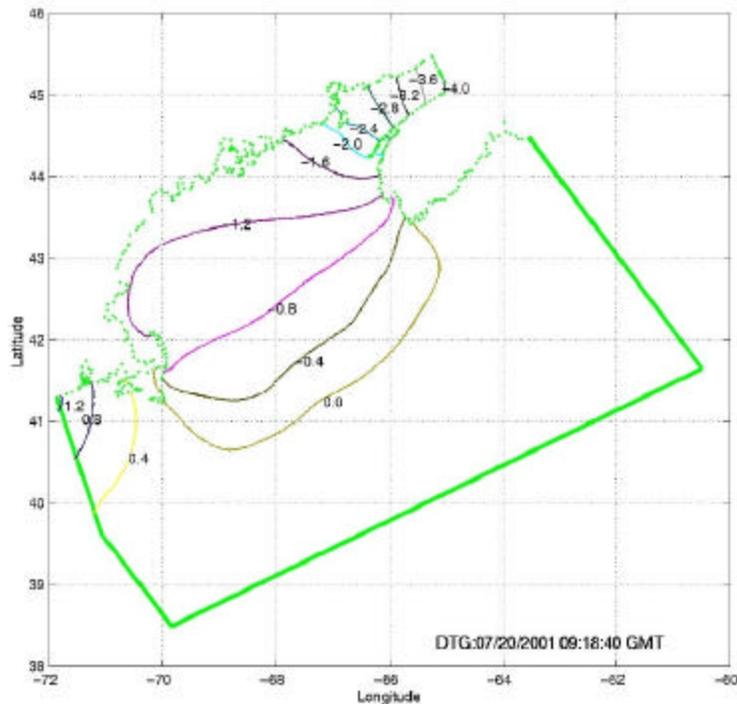
(a) 2359<sup>46</sup> GMT 19 July 2001



(b) 0306<sup>04</sup> GMT 20 July 2001



(c) 0612<sup>22</sup> GMT 20 July 2001

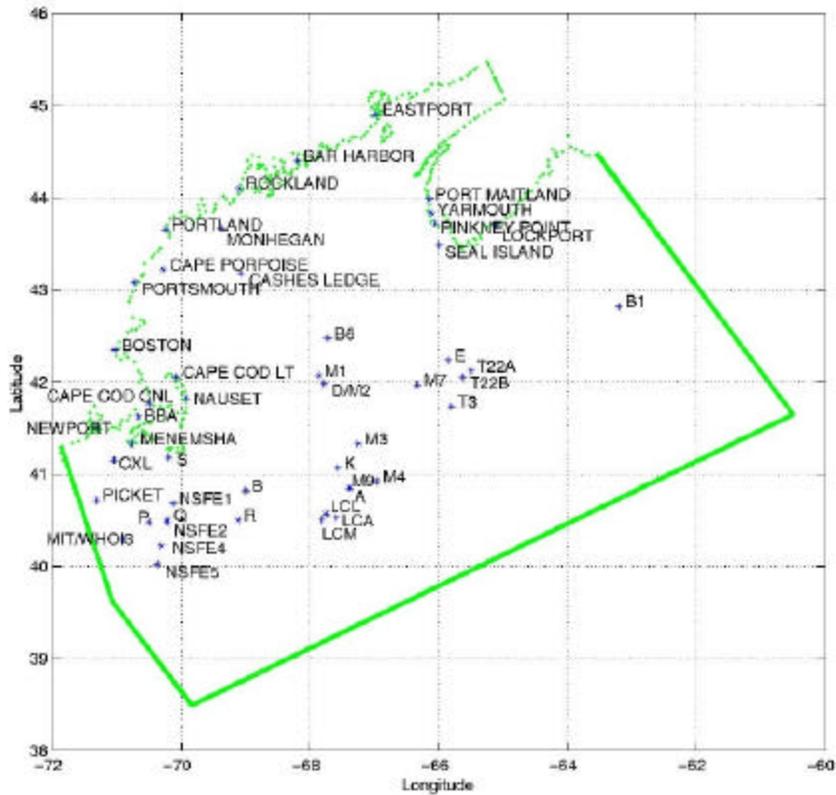


(d) 0918<sup>40</sup> GMT 20 July 2001

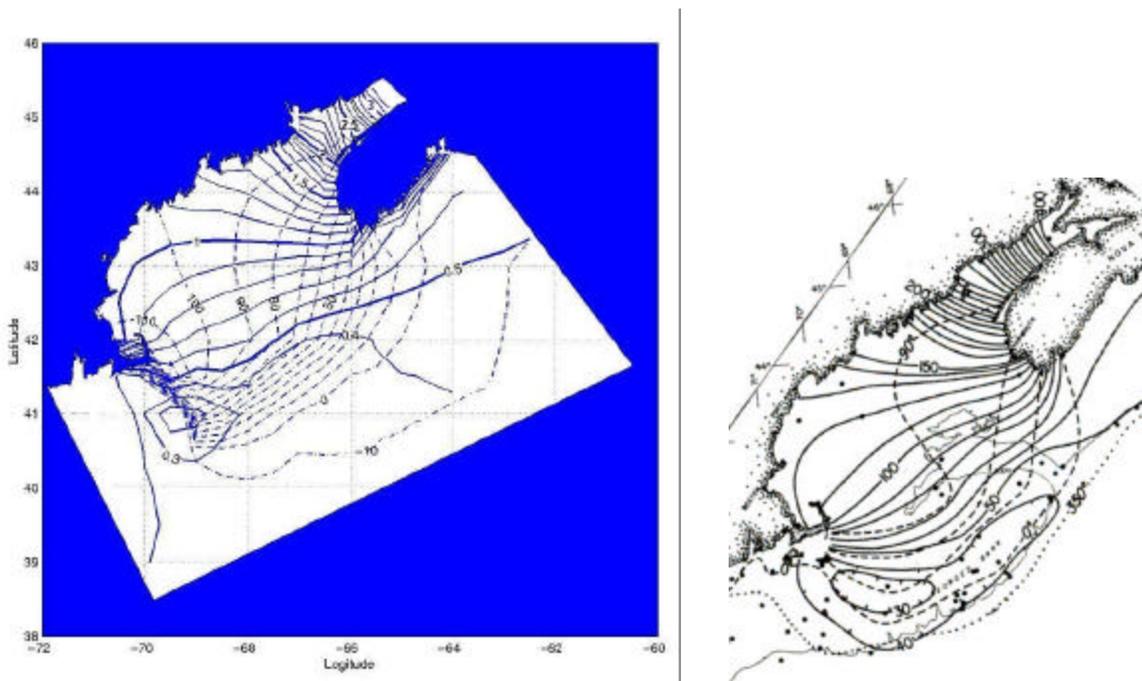
**Figure 7.** The contour plots in panels **a, b, c, d** are of QUODDY model sea level (m) at intervals of  $\frac{1}{4} M_2$  tidal period respectively between 19 July 2001 2359<sup>46</sup> GMT to 20 July 2001 1224<sup>58</sup> GMT.

The accuracy of the model  $M_2$  tidal sea level results was assessed through a comparison with the [Moody et al. \(1984\)](#) predicted  $M_2$  tidal sea level harmonic constants at the 49 locations shown in [Figure 8](#). The QUODDY model sea level harmonic constants (see [Table 1](#)) were computed from the 2-month time series that were constructed by repeatedly joining replications of the computed 2 tidal cycle (single-frequency -  $M_2$ ) segment end to end. The  $M_2$  cotidal chart pattern in [Figure 9](#) that was derived from the QUODDY sea level results is very similar to the corresponding one in [Moody et al. \(1984\)](#) that is based on observed tides. The principal discrepancies between the two patterns are in the region south of Cap Cod near an amphidromic region.

The [Table 1](#) comparisons of observed and model  $M_2$  tidal sea level harmonic amplitudes are typically within  $\pm 10\%$  at stations within the Gulf of Maine and on Georges Bank, while phase differences are typically less than 30 degrees. There is a bias in the latter results that will receive future attention.



**Figure 8** Location map for tidal sea level pressure observation sites (Moody et al., 1984) used for the model-observation comparison studies.



**Figure 9.** Cotidal chart of  $M_2$  harmonic sea level amplitude (meters, solid) and phase (Greenwich degrees, dashed) for sea levels from (left) QUODDY and (right) observations (Moody et al., 1984).

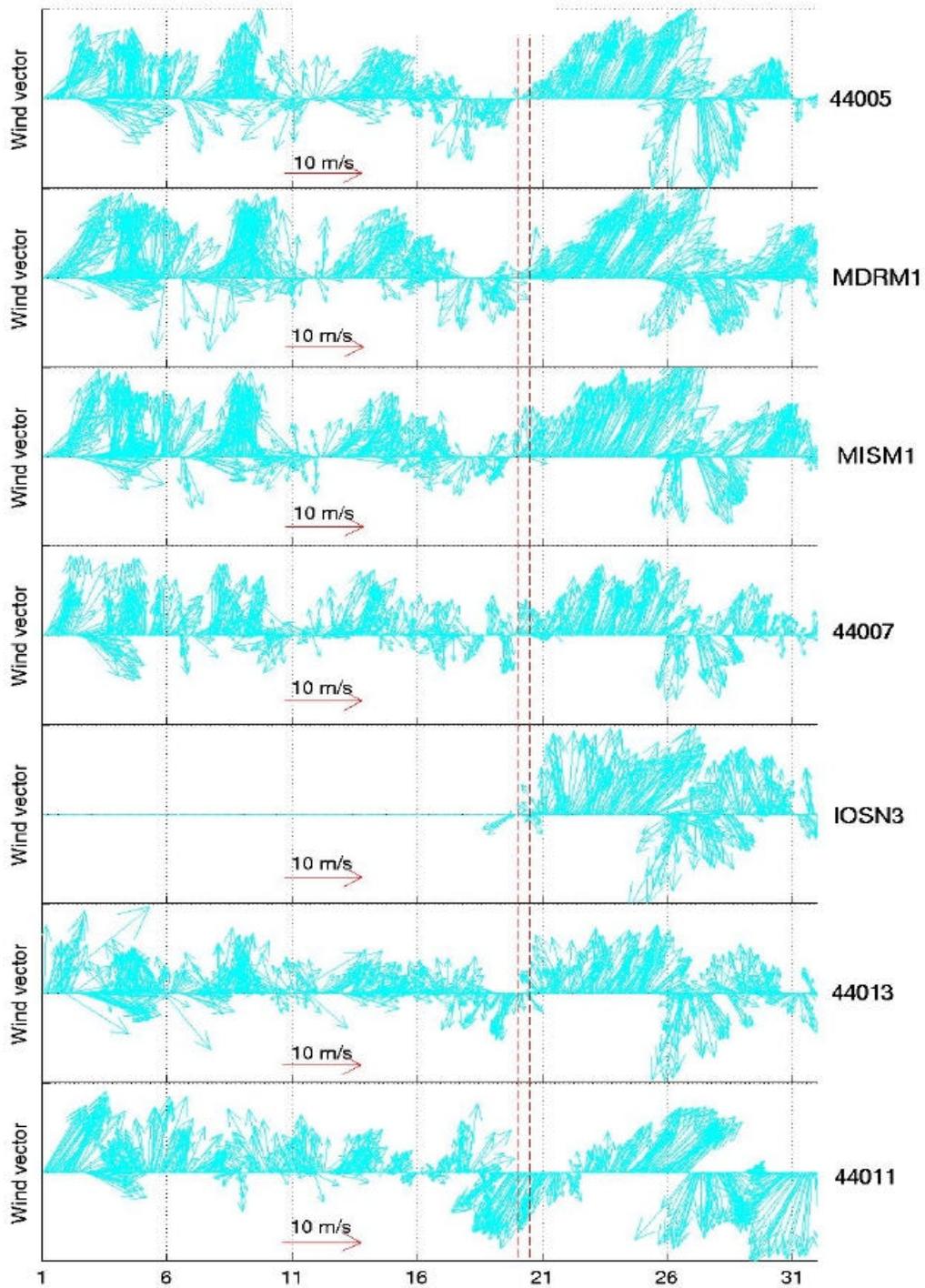
**Table 1.** Comparison of observed, model, and model-observed  $M_2$  tidal harmonic sea level amplitudes (m) and phases (Greenwich epoch $^\circ$ ) for most of the observation stations in [Figure 8](#).

Station	Observations		Model Results		Model-Observation	
	Amplitude	Phase	Amplitude	Phase	Amplitude	Phase
B1	0.482	351	0.4749	14.76	-0.0071	23.76
LOCKPORT	0.698	359	0.7339	25.03	0.0359	26.03
T22A	0.458	4	0.4295	33.35	-0.0285	29.35
T22B	0.442	9	0.4108	35.4	-0.0312	26.4
E	0.452	24	0.4323	52.01	-0.0197	28.01
T3	0.391	2	0.3728	28.46	-0.0182	26.46
M7	0.41	38	0.3558	62.22	-0.0542	24.22
M4	0.389	1	0.3665	20.7	-0.0225	19.7
M3	0.396	22	0.3086	46.62	-0.0874	24.62
D/M2	0.765	93	0.6291	122.42	-0.1359	29.42
M1	0.782	92	0.6661	122.04	-0.1159	30.04
B6	0.88	87	0.7528	114.9	-0.1272	27.9
CASHES LEDGE	1.2	98	1.0815	127.97	-0.1185	29.97
MONHEGAN	1.303	99	1.1904	129.19	-0.1126	30.19
CAPE PORPOISE	1.272	103	1.1549	133.88	-0.1171	30.88
M9	0.389	6	0.3597	26.89	-0.0293	20.89
A	0.389	5	0.3622	24.8	-0.0268	19.8
K	0.399	18	0.3433	42.03	-0.0557	24.03
LCL	0.394	354	0.3771	17.21	-0.0169	23.21
LCA	0.392	358	0.3674	20.51	-0.0246	22.51
LCM	0.394	356	0.3702	18.34	-0.0238	22.34
B	0.259	47	0.1437	75.52	-0.1153	28.52
R	0.314	3	0.2304	18.97	-0.0836	15.97
NSFE2	0.404	354	0.2978	330.9	-0.1062	-23.1
NSFE4	0.42	353	0.3388	345.34	-0.0812	-7.66
NSFE5	0.419	351	0.3653	351.81	-0.0537	0.81
P	0.416	352	0.3526	330.6	-0.0634	-21.4
Q	0.387	353	0.2978	330.9	-0.0892	-22.1
SEAL ISLAND	1.204	52	1.2078	76.62	0.0038	24.62
PINKNEY POINT	1.554	59	1.4429	83.22	-0.1111	24.22
YARMOUTH	1.632	63	1.5791	90.49	-0.0529	27.49
PORT MAITLAND	1.851	66	1.7838	96.48	-0.0672	30.48
EASTPORT	2.613	99	2.5604	128.95	-0.0526	29.95
BAR HARBOR	1.549	93	1.463	123.64	-0.086	30.64
ROCKLAND	1.5	98	1.3538	128.64	-0.1462	30.64
PORTLAND	1.33	103	1.2162	133.07	-0.1138	30.07
PORTSMOUTH	1.303	107	1.1607	135.45	-0.1423	28.45
BOSTON	1.345	111	1.1853	139.17	-0.1597	28.17
CAPE COD CNL	1.244	109	1.2246	142.72	-0.0194	33.72

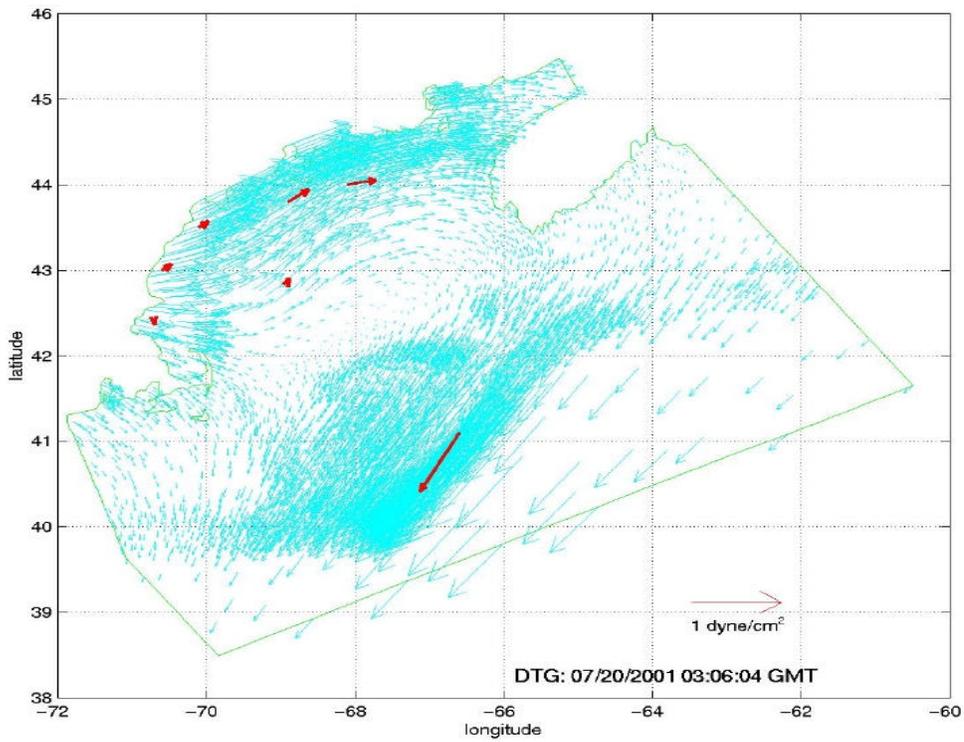
## V. Operational QUODDY Results: Tidal and Wind Forcing

For this test operational experiment, QUODDY was forced with both  $M_2$  tides and NDBC-derived wind stress fields for a 2 week period bracketing 20 July 2001. The July 2001 time series of wind vectors at the 7 NDBC stations ([Figure 10](#)) show winds that are common for the region during summer. The [Figure 11a](#) example of the optimally-interpolated wind stress for 20 July shows that the coastal wind stresses for this day is dominated by the common southwesterly (northeastward), while the wind stresses over

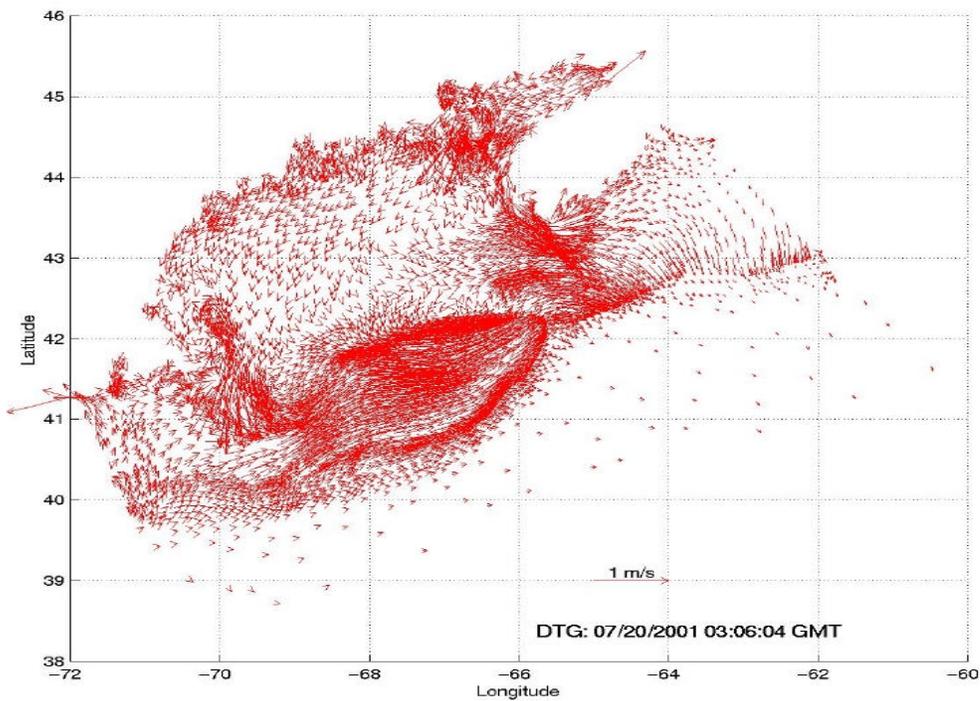
Georges Bank are northeasterly (southwestward). The corresponding pattern of model surface current at slack high tide is presented in [Figure 11b](#). The latter contrasts starkly with the [Figure 12](#) picture of surface current  $\frac{1}{4}$  tidal cycle latter at maximum ebb flow.



**Figure 10.** Hourly wind vectors at NDBC stations located in [Figure 3](#) from July 1 to July 31 2001. The tidal cycle for which the model results are presented is indicated.

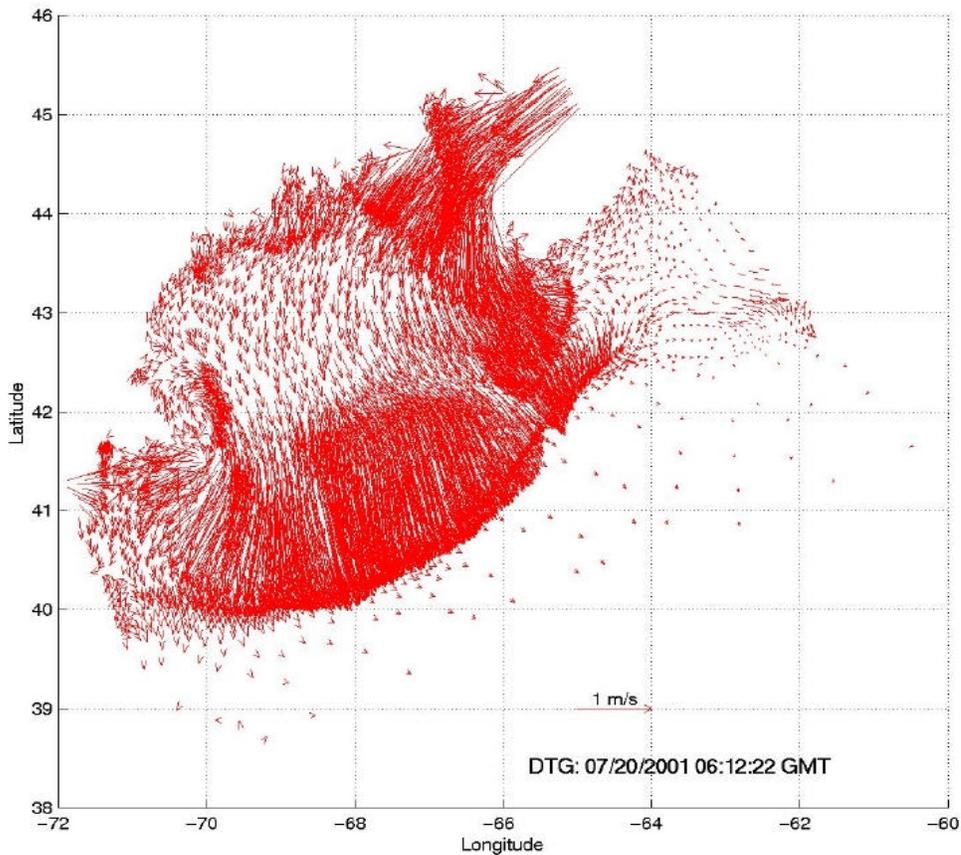


(a)



(b)

**Figure 11** The 20 July 2001 at 0306<sup>04</sup> GMT example of the (a) wind stress forcing field that was computed by optimal interpolation of the NDBC buoy-derived wind stresses (red); and (b) model surface currents at slack high water.



**Figure 12** The 0612<sup>12</sup> GMT 20 July 2001 example of the model surface currents at maximum ebb flow.

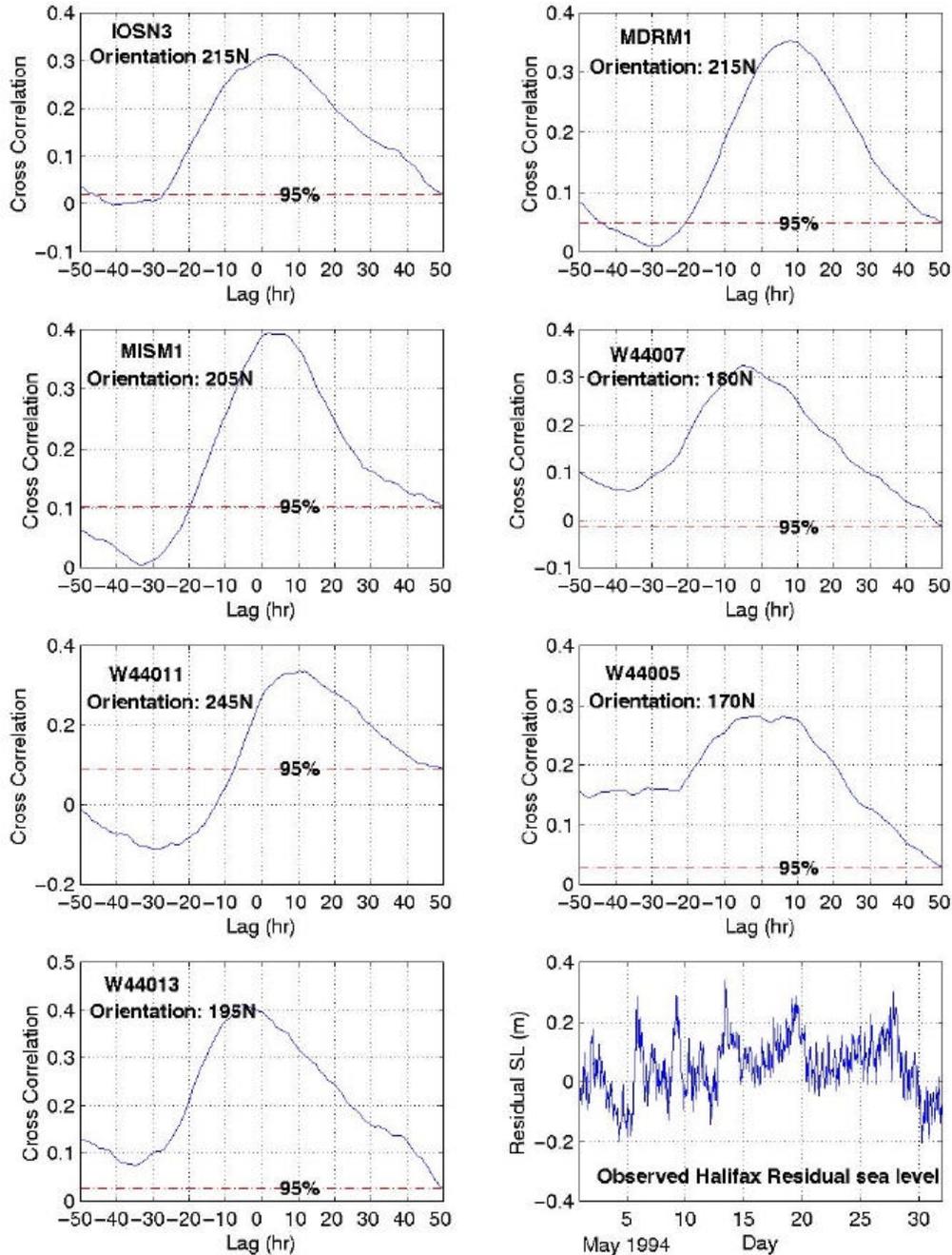
## VI. APPENDICES

### Appendix A. Real-time Halifax Residual Sea Level Protocol

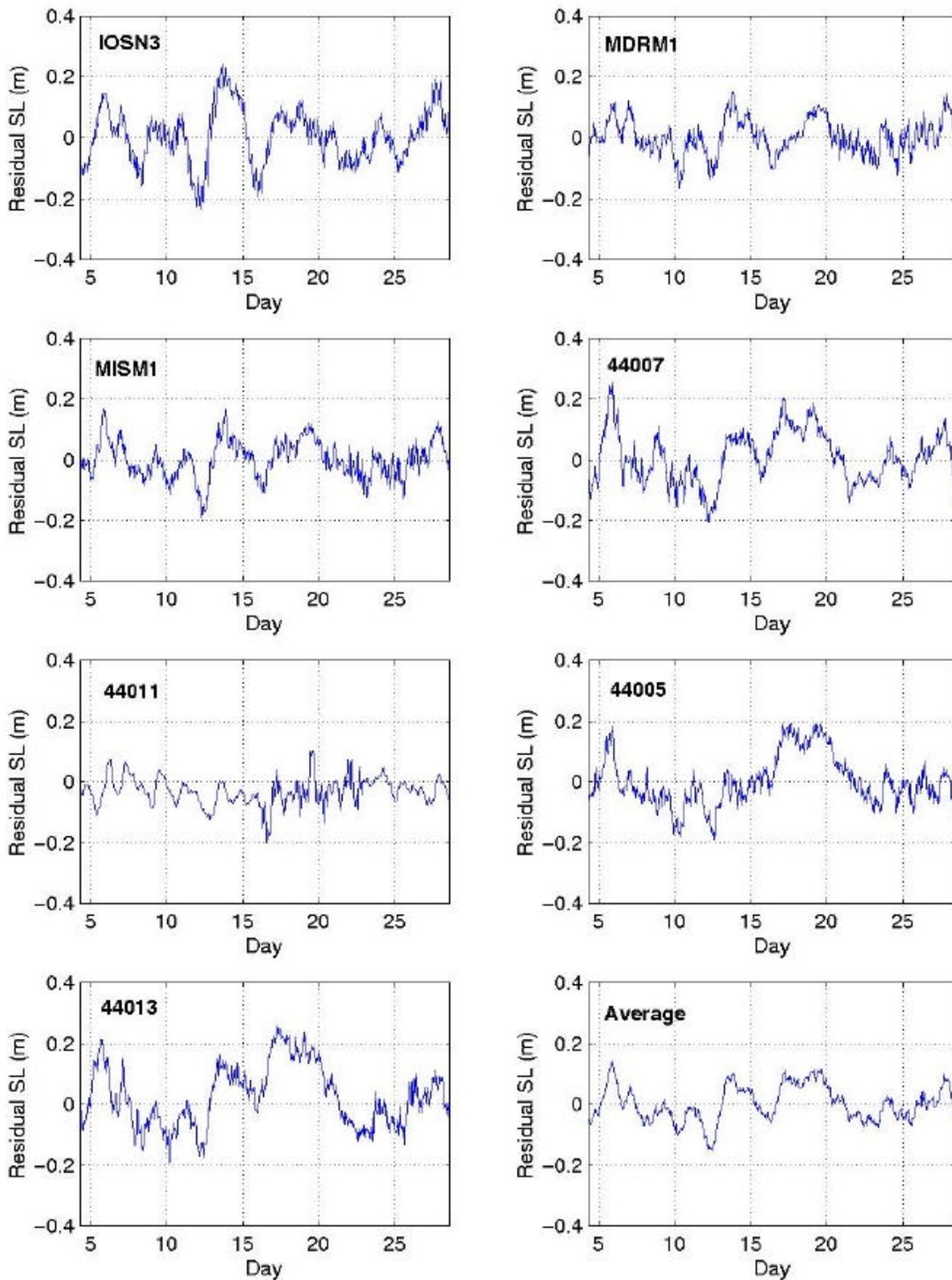
The Halifax sea level response function was calculated using an input wind stress time series derived from 7 NDBC stations and an output residual sea level time series at Halifax. First the sensitivity of the Halifax residual sea level to the orientation Gulf of Maine winds stress (as derived from NDBC buoy winds) was tested for the spring-summer 1994 (1 March to 30 September). The maximum cross-correlations between Halifax residual sea level and NDBC-derived wind stress component ( $t_{max}$ ) with the optimum orientation  $q_{max}$  were typically about 0.4 at time lags of 1 to 5 hours (see [Figure A.1](#)).

A set of frequency response functions was estimated from the different optimal NDBC wind stress components ( $t_{max}$ ) and Halifax residual sea level time series. The response functions were used to predict separate realizations of the Halifax residual sea level for

May 1994. The [Figure A.2](#) presentation of the results show predicted Halifax residual sea level records that are similar to the observed Halifax record in [Figure A.1](#), an average simulates the observations better. Thus we use the average of the 7 predicted Halifax residual sea levels.



**Figure A.1** Maximum cross correlation functions between Halifax residual sea level and the wind stress component ( $\mathbf{t}_{\max}$ ) with the optimum wind stress orientation  $\mathbf{q}_{\max}$  at respective NDBC stations. (Lower right panel) The May 1994 Halifax observed residual sea level.



**Figure A.2** Predicted Halifax residual sea level for May 1994 using frequency response functions for the different NDBC-derived wind stresses. (**lower right panel**) The average of the predicted Halifax residual sea level.

## Appendix B. Operational QUODDY Manual - Y. Fan (08/20/2003)

All the QUODDY programs are under directory  
/hosts/solomon/observer32/yfan/QUODDY/

There are three directories that you are going to use in the future.

- (1). Gulf\_Feb\_1987\_HalifResSL\_WS\_Cd005/
- (2). Gulf\_Feb\_1987\_HalifResSL\_WS\_Cd005\_AP/
- (3). Gulf\_Feb\_1987\_HalifResSL\_WS\_BBLM/

All the three directories are set up in the same way.

### Directory Gulf Feb 1987 HalifResSL\_WS Cd005/

Including the following directories:

- (a) Code/: this directory contains all the codes for the model.
- (b) INPUT/: this directory contains all the input files for the model.
- (c). GEN\_FIGURE/: this directory contains the MATLAB programs to compose model results to time series, plot results, and calculate model skill.
- (d). other directories are used to store all the model results I've generated and you'll generate some new ones once you want to run the model. The directories names that I've generated usually following the same set up: RES\_SL\_\* stands for residual sea levels, SUR\_ELE\_\* stands for surface elevations, and VEL\_UVW\_\* stands for velocities.

#### **To run the model under this directory:**

- (1). Go to the Gulf\_Feb\_1987\_HalifResSL\_WS\_Cd005/ directory

- (2). Make new subdirectories to store your files

For example: mkdir WSB\_Residual\_sl

- (3). Generate new forcing files to replace the following in the subdirectory INPUT/  
Hourly wind forcing files: U direction -- FSu7\_10m.asc, V direction -- FSv7\_10m.asc  
Every 6 hour Halifax residual sea level: HalifResSL.dat:  
Hourly Atmospheric pressure: GHSD\_AP\_BOF\_URM\_HAL\_2hr.asc

- (4). Go to subdirectory Code/, open usrsubs.f and change the following:  
go to Line 1894, which is the output for residual sea level.  
"open (19, file='RES\_SL\_CD025/reszts'//cnrvt (istart:iend)('//.s2r', "  
change the directory name RES\_SL\_CD025 to your directory name (WSB\_Residual\_sl)  
go to Line 3411, which is the output for Surface elevation  
"open (19, file='SUR\_ELE\_CD025/SURELE' "  
change the directory name SUR\_ELE\_CD025 to your directory name  
go to Line 3426, 3435, 3444, which is the output for velocities.  
"open(20,file='VEL\_UVW\_AUG11\_03/velu'//cnrvt(istart:iend)('//.v2r', "  
change the directory name VEL\_UVW\_AUG11\_03 to your directory name  
You can put c in the beginning of lines to eliminate the output that you don't need.  
Save usrsub.f

- (5). Open makefile, and change the executable file name (Feb87\_025.exe ) to the one you prefer and save the makefile, run makefile.

- (6). Go the upper directory (cd ..), open ghsd.run, and change the executable file name (Feb87\_025.exe) to the one you just compiled. And run ghsd.run by type ghsd.run& on your Unix command line, and hit enter.

#### **To generate new Atmospheric forcing:**

Go to the subdirectory LINEAR\_INTERP\_AP/

Open Linear\_interp\_GOM\_AP.m and change the AP time series as directed.

Change the file name you want to save your file (GHSD\_AP\_BOF\_URM\_HAL\_2hr.asc)

Save the matlab file and run it in matlab.

**To plot the model results:**

Go the subdirectory GEN\_FIGURE/

To generate residual sea level plot and calculate model skill.

- (1). Open PROCESS\_ResSL.c  
change the directory name (/RES\_SL\_AUG11\_03/) to your directory name  
save PROCESS\_ResSL.c  
compile PROCESS\_ResSL.c (gcc -o PROCESS\_ResSL.exe PROCESS\_ResSL.c)
- (2). open Cal\_model\_skill.m  
change the filename you want to print your figures to on the last line  
of the file, and save your file
- (3). run Cal\_model\_skill from Matlab

You will see the plot, and get the JPEG file as you defined.

You will read the model skill on the screen after the program is done.

To generate sea level time series and plots along the transect

- (1). Open PROCESS\_SL.c  
change the directory name (/SUR\_ELE\_AUG11\_03/) to your directory name  
save PROCESS\_SL.c  
compile PROCESS\_SL.c (gcc -o PROCESS\_SL.exe PROCESS\_SL.c)
- (2). open Plt\_transect\_SL.m  
change the filename you want to print your figures to on the last line  
of the file, and save your file
- (3). run Plt\_transect\_SL from Matlab

**Directory Gulf Feb 1987 HalifResSL WS Cd005 AP/**

Including the following directories:

- (a) Code/: this directory contains all the codes for the model.
- (b) INPUT/: this directory contains all the input files for the model.
- (c). GEN\_FIGURE/: this directory contains the MATLAB programs to compose model results to time series, plot results, and calculate model skill.
- (d). other directories are used to store all the model results I've generated and you'll generate some new ones once you want to run the model. The directories names that I've generated usually following the same set up: RES\_SL\_\* stands for residual sea levels, SUR\_ELE\_\* stands for surface elevations, and VEL\_UVW\_\* stands for velocities.

**To run the model under this directory:**

- (1). Go to the Gulf\_Feb\_1987\_HalifResSL\_WS\_Cd005\_AP/ directory

(2). Make new subdirectories to store your files  
for example: mkdir WSB\_Residual\_sl

(3). Generate new forcing files to replace the following in the subdirectory INPUT/  
Hourly wind forcing files: U direction -- FSu7\_10m.asc, V direction -- FSv7\_10m.asc  
Every 6 hour Halifax residual sea level: newhalsl.dat

(4). Go to subdirectory Code/, open usrsubs.f and change the following:  
go to Line 1921, which is the output for residual sea level.  
"open(19,file='RES\_SL\_AUG18\_03/reszts'//cnrvt(istart:iend)/'.s2r', "  
change the directory name RES\_SL\_AUG18\_03 to your directory name (WSB\_Residual\_sl)  
go to Line 3437, 3446, 3454, and 3462, and change the directory names as directed above.

You can put c in the beginning of lines to eliminate the output that you don't need.  
Save ussub.f

(5). Open makefile, and change the executable file name (Feb87\_LinearAP\_2hr.exe ) to the one you prefer and save the makefile, run makefile.

(6). Go the upper directory (cd ..), open ghsd.run, and change the executable file name (Feb87\_LinearAP\_2hr.exe) to the one you just compiled. And run ghsd.run by type ghsd.run& on your Unix command line, and hit enter.

### **To plot the model results and calculate model skill**

Go to the subdirectory GEN\_FIGURE/

To generate residual sea level plot and calculate model skill.

- (1). Open compose\_sl\_results.m  
change the directory name (/RES\_SL\_NEW\_HAL\_SL\_2hrAP/) to your directory name  
save compose\_sl\_results.m
- (2). open Cal\_model\_skill.m  
change the filename you want to print your figures to on the last line  
of the file, and save your file
- (3). run compose\_sl\_results from Matlab

You will see the plot, and get the JPEG file as you defined.  
You will read the model skill on the screen after the program is done.

To generate Residual sea level at Portland and Boston  
open plt\_Port\_Bos\_model\_results.m and change the filename you want to  
print your figure to on the last line and save you file  
run it in Matlab

### **Directory Gulf Feb 1987 HalifResSL WS BBLM/**

Including the following directories:

- (a) Code/: this directory contains all the codes for the model.
- (b) INPUT/: this directory contains all the input files for the model.
- (c) . GEN\_FIGURE/: this directory contains the MATLAB programs to compose model results to time series, plot results, and calculate model skill. This directory hasn't been fully set up yet, but it will be in a couple of days, and the manual will be completed by then.
- (d). other directories are used to store all the model results I've generated and you'll generate some new ones once you want to run the model. The directories names that I've generated usually following the same set up: RES\_SL\_\* stands for residual sea levels, SUR\_ELE\_\* stands for surface elevations, and VEL\_UVW\_\* stands for velocities.

## VII. ACKNOWLEDGMENTS

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