NOAA Technical Report NOS CS 35

THE NESTED NORTHWEST AND NORTHEAST GULF OF MEXICO OPERATIONAL FORECAST SYSTEMS (NWGOFS AND NEGOFS): MODEL DEVELOPMENT AND HINDCAST SKILL ASSESSMENT

Silver Spring, Maryland
July 2015

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Coast Survey Development Laboratory

Office of Coast Survey
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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

There are four components of OCS:

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

NOAA Technical Report NOS CS 35

THE NESTED NORTHWEST AND NORTHEAST GULF OF MEXICO OPERATIONAL FORECAST SYSTEMS (NWGOFS AND NEGOFS): MODEL DEVELOPMENT AND HINDCAST SKILL ASSESSMENT

Eugene Wei, Zizang Yang, and Yi Chen
Office of Coast Survey, Coast Survey Development Laboratory
Silver Spring, Maryland

John G.W. Kelley
Office of Coast Survey, Coast Survey Development Laboratory
Durham, New Hampshire

Aijun Zhang
Center for Operational Oceanographic Products and Services
Silver Spring, Maryland

July 2015

noaa National Oceanic and Atmospheric Administration

U. S. DEPARTMENT OF COMMERCE Penny Pritzker, Secretary	National Oceanic and Atmospheric Administration Dr. Kathryn D. Sullivan, Under Secretary	National Ocean Service Dr. Holly A. Bamford, Assistant Administrator

Office of Coast Survey
Rear Admiral Gerd F. Glang

Coast Survey Development Laboratory
Captain Richard T. Brennan

NOTICE

Mention of a commercial company or product does not constitute an endorsement by NOAA. Use for publicity or advertising purposes of information from this publication concerning proprietary products or the tests of such products is not authorized

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The NOAA National Ocean Service's (NOS) Northern Gulf of Mexico Operational Forecast System (NGOFS) has been operational since April 2012 using the Finite Volume Coastal Ocean Model (FVCOM) (Chen et al., 2007) as the core hydrodynamic model. Designed as a regional scale system, NGOFS lacks sufficient spatial coverage and/or resolution to fully resolve hydrodynamic features in critical ports and estuaries [i.e., where NOS Physical Oceanographic Real-Time Systems (PORTS) exist in the region] including Lake Charles, Sabine Neches, Houston/Galveston Bay, Mobile Bay, Pascagola and Morgan City areas. To overcome this shortcoming and better support the needs for marine navigation, emergency response, and effective environmental management, NOS has developed two FVCOM-based, high-resolution, estuary-scale nested forecast models, namely the Northwest and Northeast Gulf Of Mexico Operational Forecast Systems (NWGOFS and NEGOFS). NWGOFS and NEGOFS are coupled with NGOFS through one-way nesting, i.e., NGOFS produces the open ocean boundary forcing (water levels and currents) for NWGOFS and NEGOFS without receiving feedback from the latter. The unstructured model grid was constructed and populated with bathymetry obtained from NOS hydrographic survey soundings and U.S. Army Corps of Engineers survey data. NWGOFS and NEGOFS were calibrated and evaluated with observed data obtained from various government agencies and private companies. The two high-resolution model systems became operational September 2014.

The hindcast simulation was conducted by NOS/CSDL/Marine Modeling and Analysis Programs for the period from September 2010 to April 2011, the same as NGOFS 2nd hindcast to validate the model (Wei et al., 2014a). The NGOFS hindcast simulation was conducted to save simulated water levels, current velocity, salinity and water temperature at the nested NWGOFS and NEGOFS grid open boundary as the open boundary condition. The NWGOFS and NEGOFS hindcast simulations were then forced with the open ocean boundary condition from NGOFS, the atmospheric wind and heat flux analysis at the air-sea interface from the National Weather Service (NWS)/North America Mesoscale (NAM) Model, and the river discharge and temperature data from United States Geological Survey (USGS) observations.

The hindcast simulation skills were evaluated using NOS skill assessment software (Zhang et al., 2006). By comparing with hourly station observations, a set of performance statistics as described in the NOS skill assessment procedures for operational forecast systems (Hess et al., 2003; Zhang et al., 2006; and Zhang et al., 2010) for variables of water level, current, salinity and water temperature was obtained.

The hindcast skills are summarized in two statistical variables, Central Frequency (CF) and Root-Mean-Squared-Error (RMSE), of four parameters: water level, current velocity, salinity, and temperature. The skills obtained at stations spatially distributed over the NGOFS model domains are presented as skill maps shown in Figures E1 to E3.

Most of the CF skill assessment results show satisfactory or excellent skill, and exceed the NOS criteria with the exception of skills for currents at few stations.

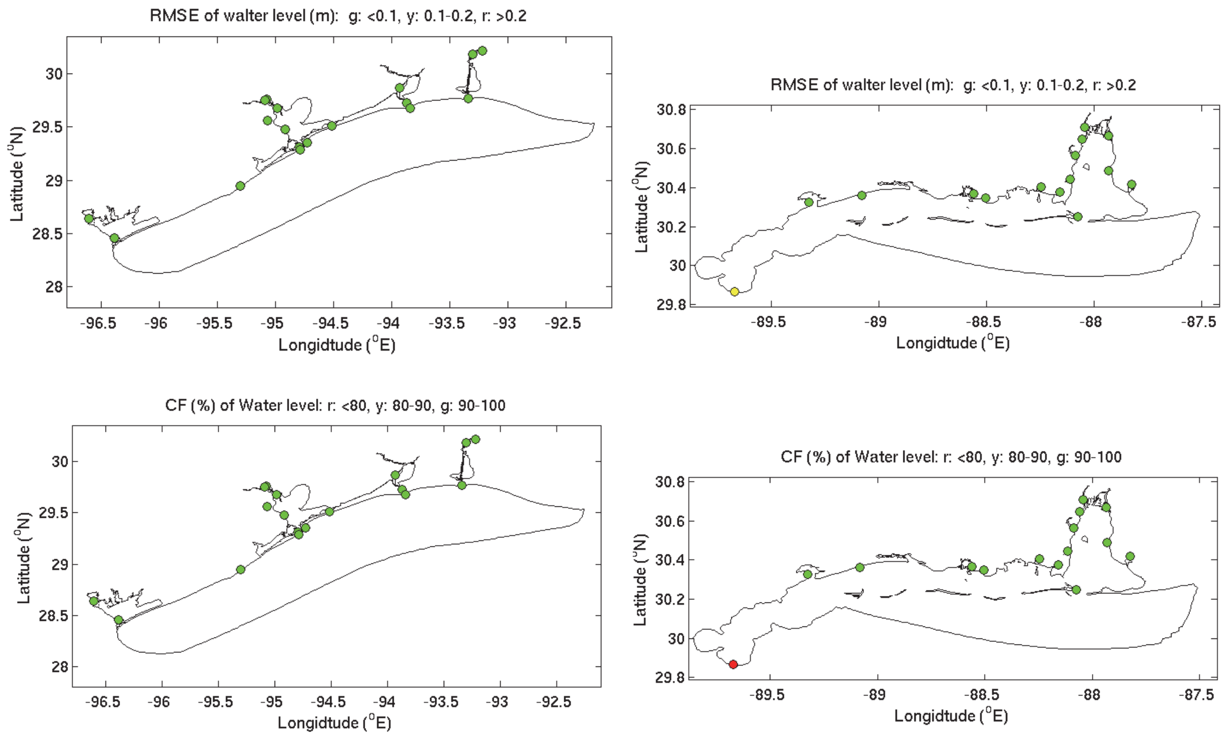

Figure E.1. Hindcast water level RMSE and CF skill assessment summary map for NWGOFS (left column) and NEGOFS (right column).

The variable shapes are circles (water level), squares (current velocity), triangles (temperature), and diamonds (salinity) and the skill range color in the plots are defined as:

CF: Green > 90%; 90% ≥ Yellow ≥ 80%; Red <80%
RMSE for water levels (m): 0< Green ≤ 0.1; 0.1 ≤ Yellow ≤ 0.2; 0.2 < Red
RMSE for currents (m/s): 0 <Green ≤ 0.26; 0.26 ≤ Yellow ≤ 0.4; 0.4 < Red
RMSE forwater temperature/salinity (^{0}C, PSU): 0 < Green ≤ 3; 3 ≤ Yellow ≤ 5; 5 < Red

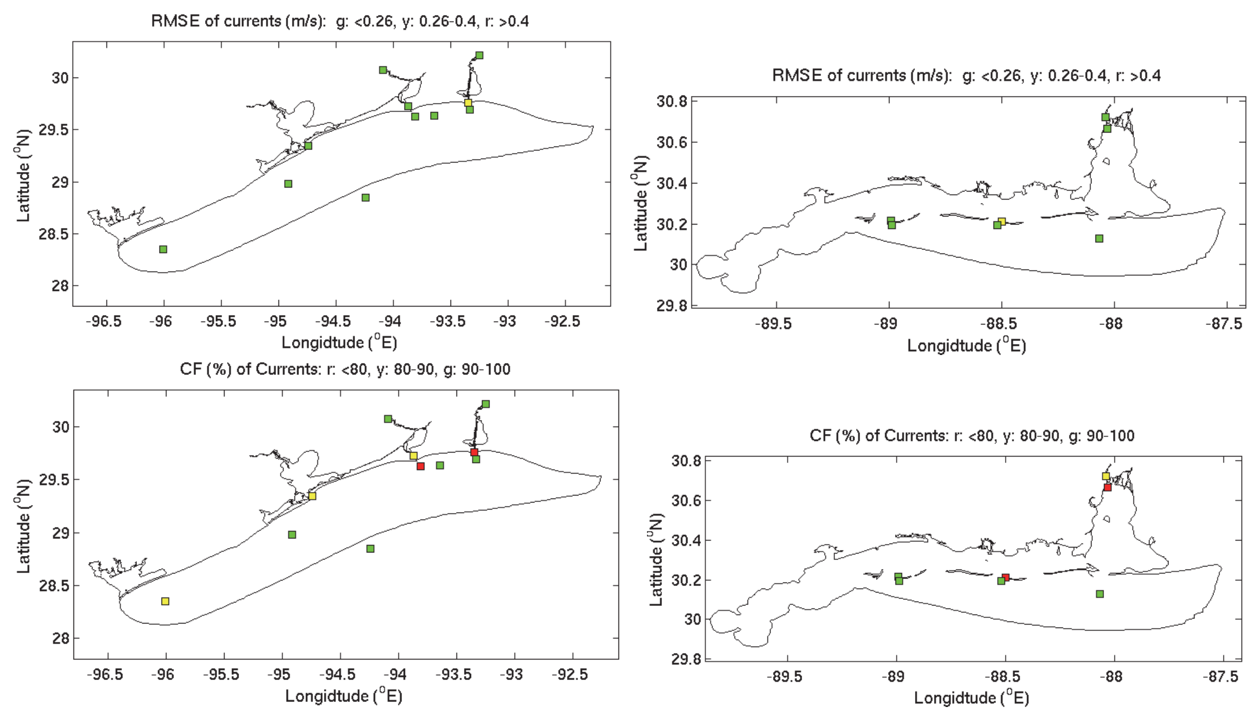

Figure E.2. Hindcast current velocity RMSE and CF skill assessment summary map for NWGOFS (left column) and NEGOFS (right column).

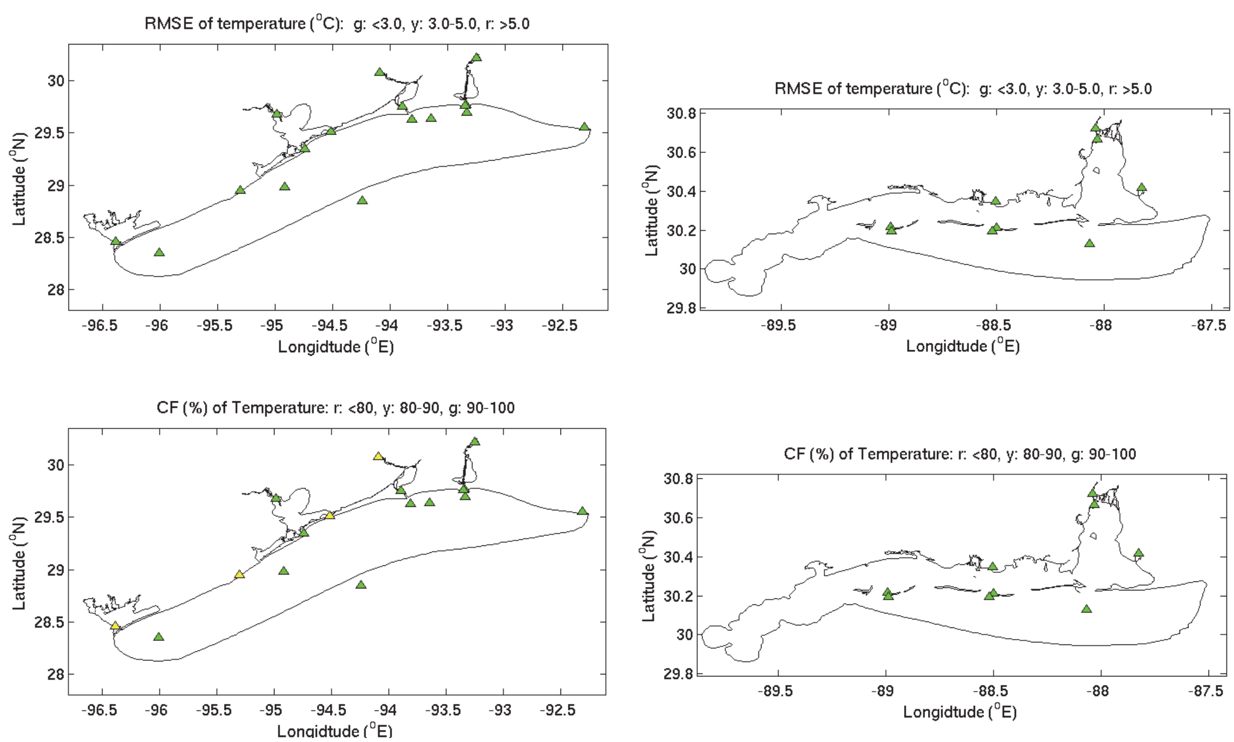

Figure E.3. Hindcast temperature RMSE and CF skill assessment summary map for NWGOFS (left column) and NEGOFS (right column).

1. INTRODUCTION

The NOAA National Ocean Service's (NOS) Northern Gulf of Mexico Operational Forecast System (NGOFS) has been operational in April 2012 (Wei et al., 2014a). Implemented with the Finite Volume Coastal Ocean Model (FVCOM) (Chen et al., 2003) as its core three-dimensional oceanographic circulation model, NGOFS produces a real-time nowcast (-6 hours to zero) and six-hourly, two-day forecast guidance for water levels and 3-dimensional currents, water temperature and salinity over the northern Gulf of Mexico continental shelf. Designed as a regional scale prediction system, NGOFS lacks sufficient spatial coverage and/or resolution to fully resolve hydrodynamic features in critical seaports and estuaries. To overcome this shortcoming and better support the needs of marine navigation, emergency response, and environmental management, two FVCOM-based, high-resolution, estuary-scale nested forecast modeling systems, namely the Northwest and Northeast Gulf of Mexico Operational Forecast Systems (NWGOFS and NEGOFS) have been developed through one-way nesting in NGOFS. Using the atmospheric forecast guidance from the NOAA (National Oceanic and Atmospheric Administration)/NWS (National Weather Services) North American Mesoscale (NAM) Forecast Modeling System, U.S. Geological Survey (USGS) river discharge observations, and the NGOFS water level, current, water temperature and salinity as the surface, river, and open ocean boundary forcing, respectively, a six-month model hindcast for the period October 2010-March 2011 was conducted. Modeled water levels, currents, salinity, and water temperature are compared with observations using the NOS standard skill assessment software. Skill assessment scores indicated that NWGOFS and NEGOFS demonstrate improvement over NGOFS. The NWGOFS and NEGOFS were transferred to NOS's Center for Operational Oceanographic Products and Services (CO-OPS) for real-time nowcast/forecast test and evaluation in October 2013. The validated forecast systems were then implemented by NWS's National Centers for Environmental Protection (NCEP) operationally on NOAA Weather and Climate Operational Supercomputer System (WCOSS) on September 16, 2014.

The NOS's Physical Oceanographic Real-Time Systems (PORTS) along the northern coast of the Gulf of Mexico (GOM) provide real-time oceanographic data to promote safe and efficient navigation. The NWGOFS covers Lake Charles, Sabine Neches, Houston/Galveston Bay, and the proposed Matagorda Bay PORTS. The NEGOFS covers Mobile Bay, Pascagoula, and Gulfport (Morgan City) PORTS (Figure 1).

The FVCOM model numerically solves momentum, continuity, water temperature, salinity, and density equations and is available with different turbulent closure sub-models (Chen et al., 2003, 2007, 2013). The irregular bottom slope is represented using a generalized vertical coordinate transformation, and the horizontal grid comprises unstructured triangular cells. The FVCOM has been successfully applied in several coastal ocean regions to simulate the hydrodynamics using an unstructured grid.

This report documents the development of the NWGOFS and NEGOFS as well as the model hindcast skill assessment. The NWGOFS and NEGOFS model systems and set-up are discussed in Chapter 2 including the model grid coverage and FVCOM application general requirements such as the set-up of the initial conditions, surface and boundary forcing, and river forcing. The model calibration using the tidal simulations and the model evaluation using two hindcast simulations are described in Chapter 3. Model simulation skill assessment results from the model hindcast are described in Chapter 4. The salinity and temperature vertical profiles from the NOS Tri-Office Mobile Bay conductivity-temperature-depth (CTD) survey (Patchen et al., 2012) are compared with the model hindcast and included in Chapter 4. Finally, conclusions are summarized in Chapter 5.

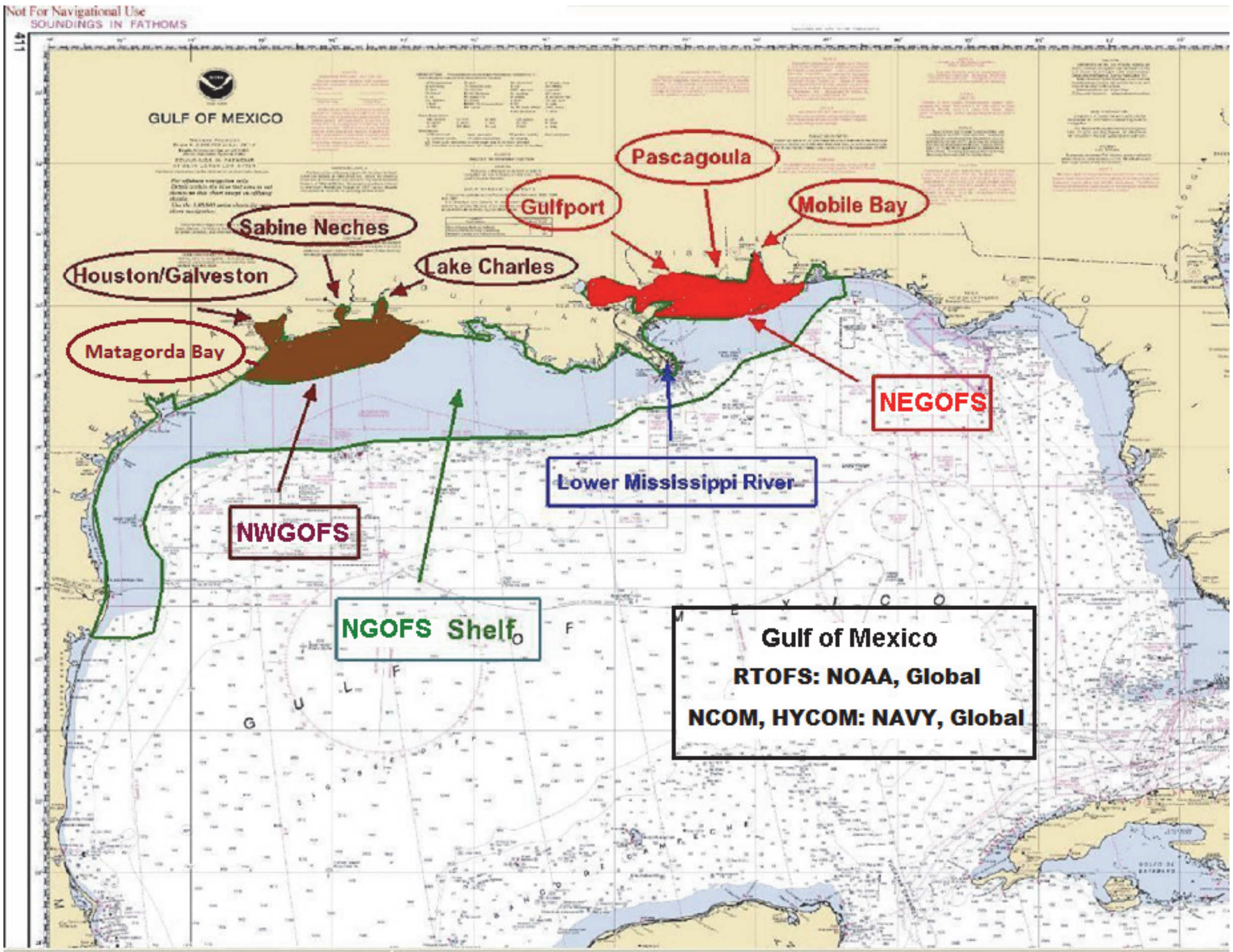

Figure 1. Schematic depicting the locations of NOS PORTS along with NGOFS and nested NWGOFS and NEGOFS grid domains.

2. MODEL SYSTEM AND SET-UP

The FVCOM has been successfully applied in several coastal ocean regions to simulate the hydrodynamics using an unstructured grid. The governing equations and detail formulation has been documented in Chen et al. (2003; 2007) and on the web page: http: //fvcom.smast.umassd.edu/index.html. Publications based on FVCOM applications can be found from this web page: http://fvcom.smast.umassd.edu/Extra/publication.html. In particular, the Northeast Coastal Ocean Forecast System (NECOFS) has been implemented by the University of Massachusetts at Dartmouth (UMASSD) in a real-time mode since 2007 (http://fvcom. smast.umassd.edu/research_projects/NECOFS/index.html) with high resolution grid nesting functionality. The FVCOM applied in the NOAA's operational NGOFS regional shelf modeling system (Wei et al., 2014a, 2014b) has also been used in NWGOFS and NEGOFS to simulate the wind-driven coastal circulation and the smaller scale inland estuary hydrodynamics associated with complex shorelines, topography, tide, and fresh water inputs.

Note that the FVCOM model requires an input model grid information file in ASCII format for a cold start run and NetCDF format in subsequent runs. For surface forcing, open boundary forcing (if the nesting approach is selected), and the river forcing, the FVCOM requires the input files in NetCDF format.

2.1. Model Grid

The NWGOFS and NEGOFS are designed for resolving detail dynamics in the shallow near-shore and inland navigational channels. The grid generation module of the Surface-Water Modeling System (SMS - http://www.aquaveo.com/sms) software for generating the NGOFS model grid was also used for creating the NWGOFS and NEGOFS model grids. When the coarse grid NGOFS (Wei et al., 2014a) was constructed, two grid generation control lines were defined as the nesting interface for NWGOFS and NEGOFS shown in Figures 2.1 and 2.2, respectively. Two shoreward rows of nodes from the NGOFS model grid along each control line with the corresponding elements are defined as the nesting boundary for the nested models. For NWGOFS, the nesting boundary node near NOS's National Water Level Observation Network (NWLON) gage locations Port O'Connor, Texas (NOS ID 8773701) on the west and Freshwater Canal Locks, Louisiana (8766072) on east were selected as the nested boundary locations (Figure 2.1). For NEGOFS, the nested boundary locations selected were near the Shell Beach, Louisiana (8761305) gage on the west and Pensacola, Florida (8729840) gage on the east (Figure 2.2). The grid size distribution is configured as dependent on the bathymetry which was generated from the most recent NOAA hydrographic survey. High resolution NOAA coastline data have been applied to delineate the land boundary. The shoreline data are taken from NOAA's National Geophysical Data Center (NGDC) high resolution shoreline/coastline resources data base (http://www.ngdc.noaa.gov/mgg/shorelines/). The nested model domains with corresponding NOS PORTS are shown as Figures 2.3 and 2.4. Note that the smallest grid size has been set to 60 m and 45 m for NWGOFS and NEGOFS, respectively. The model bathymetry is obtained by interpolating the most recent NOAA hydrographic survey data and US Army Corps of Engineers (USACE) bathymetric database onto each unstructured NWGOFS and NEGOFS model grid node. The minimum water depth (for wetting and drying) of the grid is defined as 0.3 m below mean sea level and the land topography is not considered. The deepest water depths are 37 m and 25 m for NWGOFS and NEGOFS, respectively, shown as bathymetric plots in Figures 2.5 and 2.6 The most recent bathymetry from NOAA's Vertical Datum (VDatum) projects and USACE's channel and beach restoration project information (e.g., Lake Calcasieu Channel) was also used to update the nest model bathymetry.

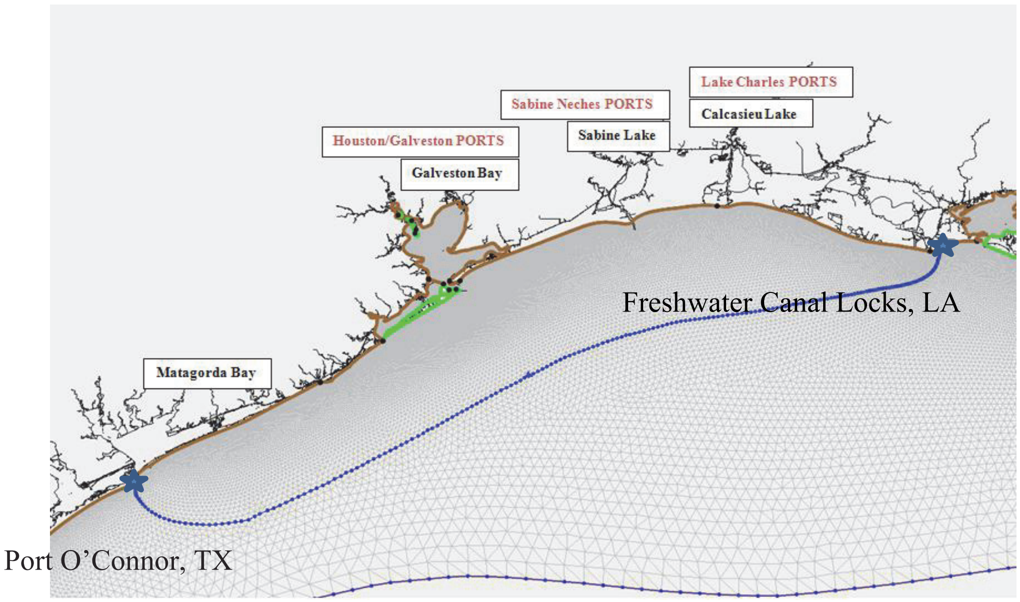

Figure 2.1. Control line (blue) in NGOFS model grid for NWGOFS open boundary.

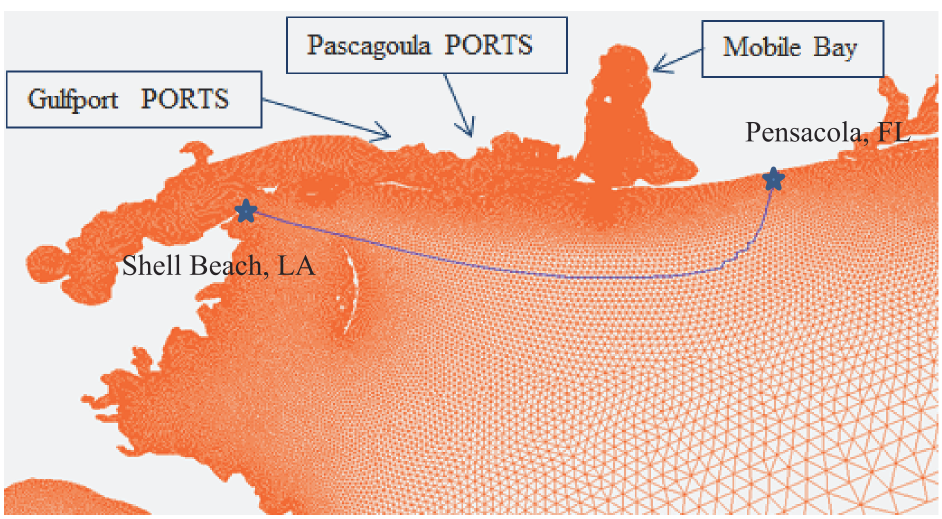

Figure 2.2. Control line (blue) in NGOFS model grid for NEGOFS open boundary.

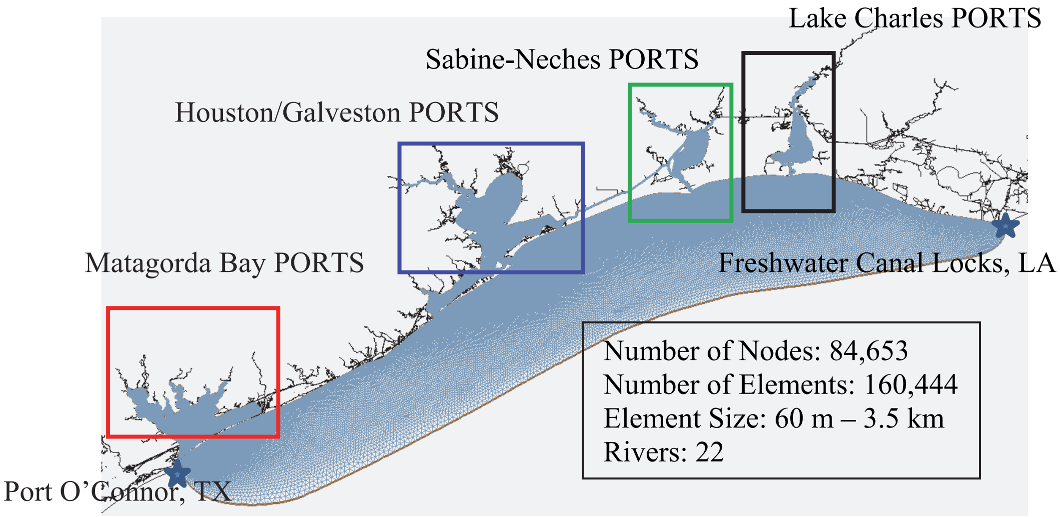

Figure 2.3. NWGOFS model grid.

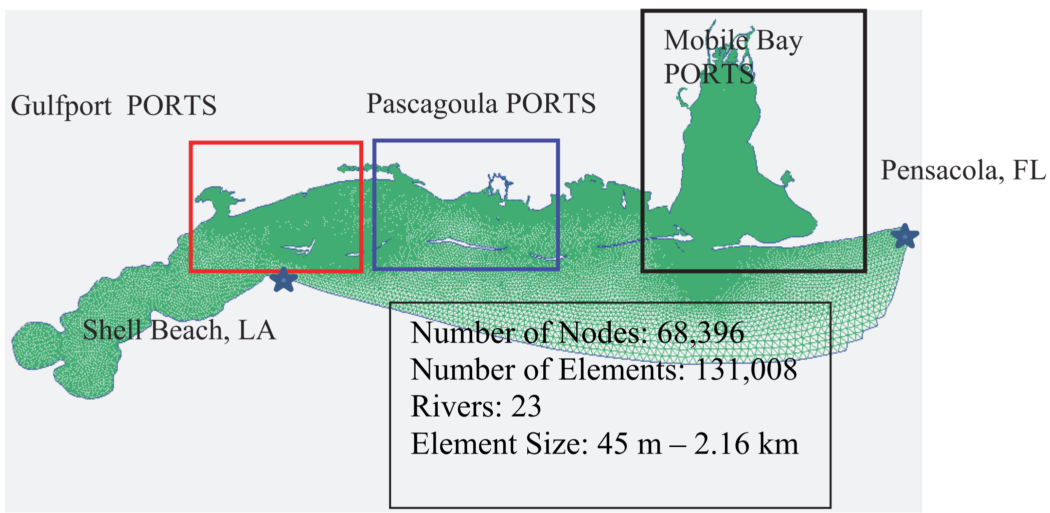

Figure 2.4. NEGOFS model grid.

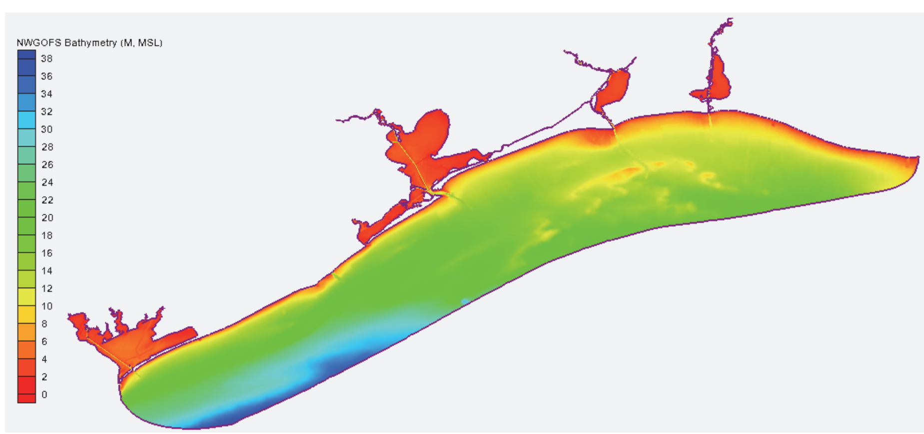

Figure 2.5. NWGOFS bathymetric map.

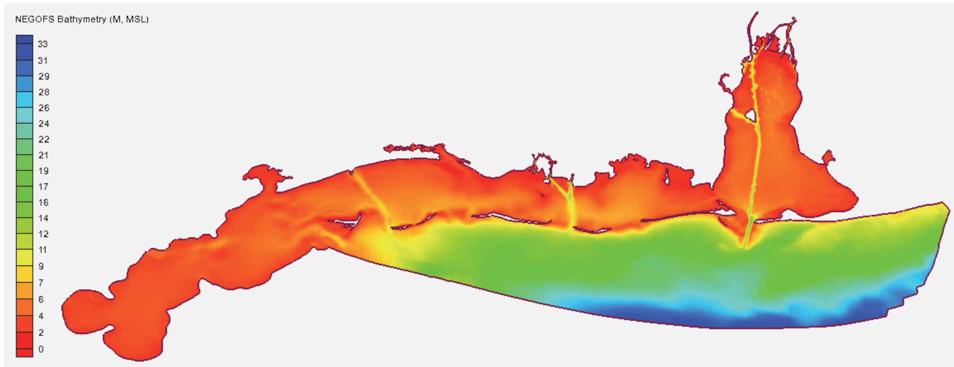

Figure 2.6. NEGOFS bathymetric map.

2.2. Nesting Boundary Forcing

The NWGOFS and NEGOFS are nested with the NGOFS through a one-way nesting boundary interface. The FVCOM nesting module requires that both the coarse and nested model grids be unstructured with the same nodes at the open boundary. Zheng and Weisberg (2012) defined a five-tier buffer zone and a weighting factor γ for determining the direct influence of the coarse model on a state variable of the nested model within the buffer zone, i.e.,

$$Q^{n+l} = \gamma Q_H^{n+1} + (1-\gamma) Q^n{}_F$$

where Q is a nested state variable, Q_H is the value of that variable interpolated from the Global HYCOM, Q_F is the value of that variable computed by FVCOM, the superscript n represents the current model time step and (n+1) represents the next time step. The forcing variables used for the nesting include water elevation, the vertically averaged and three-dimensional velocity components, and the three-dimensional temperature and salinity. A two-tier buffer zone test for the nested boundary interface in this study (with the same node location and water depth between coarse and nested grids in the buffer zone) shows a smooth state variable field near the boundary.

2.3. Surface Forcing

The air-water surface boundary forcing for NWGOFS and NEGOFS comes from several components of the numerical weather prediction model outputs: the wind stress (calculated from the wind velocity), the atmospheric pressure, and the heat flux through the water-air interface. Although the FVCOM accepts uniform forcing (from observations) over the model domain, we use the forcing from the NOAA/NWS North America Regional Re-analysis (NARR) (Mesinger et al., 2006) and North America Mesoscale Forecast System (NAM) (http://www.emc.ncep.noaa.gov/index.php?branch=NAM) for NWGOFS and NEGOFS hindcasts.

The heat flux calculation requires input from the NARR, including surface wind velocity, surface air pressure, upward and downward short wave radiation, upward and downward short long wave radiation, surface air temperature, and surface relative humidity. The bulk parameterization scheme computes the sensible heat, the latent heat, and the net heat flux on the ocean surface for the temperature equation. Net short wave radiation is also required for the heat penetration into the water column and was computed by taking an algebra sum between the upward and downward short wave radiation.

2.4. Thin_Dam Numerical Approach

Navigation channels of four bays within NWGOFS (Matagorda Bay, Galveston Bay, Sabine Lake, and Lake Calcasieu) are protected by solid jetties at the entrance. The flow near the entrance is regulated by these jetties. Although the circulation pattern at the bay entrance may not have an effect on the far field circulation, it does play an important role in the navigation and circulation induced sediment transportation in the local area, especially when the jetties are submerged due to a high wind or storm event. The “Thin_Dam” numerical approach (Ge et al., 2012) in FVCOM to the coastal jetty is therefore applied to NWGOFS at the entrance of these four bays to accurately simulate the flow at and near the entrance channel. Duplicated nodes are added to the model along the jetty to separate the elements inside and outside the channel, thus the water surface elevation may be different and no flow crosses the emerged jetty. When the jetty submerges the flow is free for crossing over the top portion of the submerged jetty. The sensitivity test shows the flow at the entrance is confined within the emerged jetties while the velocity vectors are along the shoreline without the jetties presence (Figure 2.7).

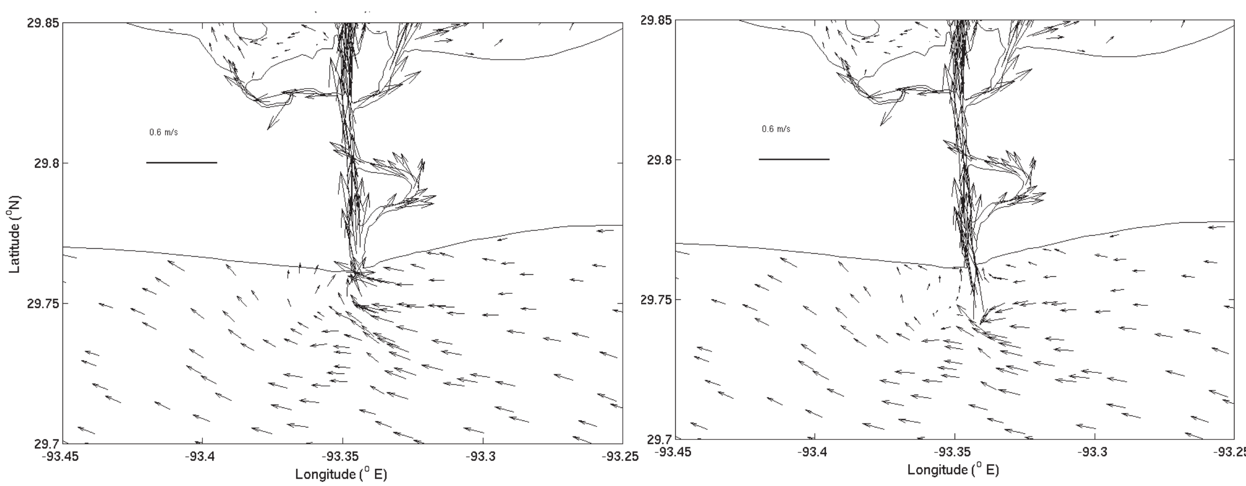

Figure 2.7. Velocity vectors at Lake Calcasieu entrance without (left) and with (right) jetties.

2.5. River Forcing

The FVCOM accepts the river discharge and the tracer concentration (water temperature and salinity in the NGOFS application) input to the model grid domain at the shoreline location. The model calculates the equivalent surface elevation changes based on the input discharge. A method for the tracer concentration boundary condition has been used for the NWGOFS and NEGOFS application to prevent unrealistic buoyance gradient near the discharge source (Chen et al., 2013).

The river forcing information for NWGOFS and NEGOFS hindcasts are based on the river forcing data configured for NGOFS (Wei et al., 2014a and 2014b). Since there is more detailed coverage in the inland estuarine area for the nested model grids than the shelf model grid, the river forcing location to the model is modified to further upstream for better representing the actual location where the tidal effect becomes insignificant.

3. MODEL HINDCAST

3.1. Hindcast Set-Up

Hindcast Period

The NWGOFS and NEGOFS model verification has been conducted using a similar approach to the NGOFS hindcast simulation. The 2nd hindcast simulation period for NGOFS from 14 September 2010 to 1 April 2011 has been repeated to provide open ocean boundary conditions for the nested model hindcasts. During this period an extensive survey was performed by the NOS Tri-Office (OCS, National Geodetic Survey, and CO-OPS) project in Mobile Bay, Alabama, to collect water levels, currents, salinity and water temperature data (Patchen et al., 2012). The survey data, along with other long-term observations, are then used for model verification.

Nesting Boundary Conditions

The NGOFS hindcast (Wei et al., 2014) was repeated and output variables determined at the NWGOFS and NEGOFS nesting boundary as the boundary forcing for the hindcast. The forcing variables used for the nesting include water elevation, the vertically averaged and three-dimensional velocity components, and the three-dimensional temperature and salinity. Due to the shallower water of NWGOFS and NEGOFS, the number of vertical sigma layer is set as half of that of NGOFS, i.e., 20 layers. The state variables from every other sigma level/layer are selected from the nesting boundary for NWGOFS and NEGOFS.

Initial Conditions

The initial conditions for the NWGOFS and NEGOFS hindcasts were created based on the NGOFS initial condition at hour zero Universal Time Coordinate (UTC) September 14, 2010. For inland areas and bays (Matagorda Bay, Sabine Lake, and Lake Calcasieu) not covered by NGOFS, the initial salinity and water temperature fields created by extrapolation from the NGOFS hindcast initial field resulted in high salinity. For NWGOFS, observed salinity at 14 stations [from USGS, Texas Water Development Board (TWDB), and NOS] as listed on Table 3.1 were nudged to correct the initial salinity field. These stations cover NWGOFS inland bays: Matagorda Bay, Galveston Bay, Sabine Lake and Lake Calcasieu as shown in Figure 3.1. For NEGOFS, observed salinity at 11 stations, as listed on Table 3.2 and shown in Figure 3.2, in Mobile Bay (from Dauphin Sea Laboratory [DISL]) and east Mississippi Sound (from USGS) were used for correcting the initial salinity field.

Table 3.1. Observation stations for NWGOFS correcting initial salinity condition.

Station	Longitude	Latitude	Station Name
1	-96.59555	28.65333	Lavaca Bay at causeway, TX
2	-96.35555	28.44583	Matagoda Bay, GB, TX
3	-95.01667	29.70833	Baytown, GB, TX
4	-94.98500	29.68167	Morgans Pt, TX
5	-94.85333	29.67000	Fishers Reef, GB, TX
6	-94.74667	29.66167	Trnity Bay, GB, TX
7	-94.91833	29.48000	Eagle Pt, TX

8	-94.87500	29.50833	Mid Galveston Bay, TX
9	-94.78333	29.34167	Pelican Is, GB, TX
10	-93.85731	29.94952	N Sabine LK,USCG marker, TX
11	-93.89011	29.75808	S Sabine LK, nr MK C, TX
12	-93.24722	30.23694	USGS Calc R at I-10, LA
13	-93.29944	30.03166	USGS N Calc Lake,HCKB,LA
14	-93.34888	29.81555	USGS Calc at Cameron, LA

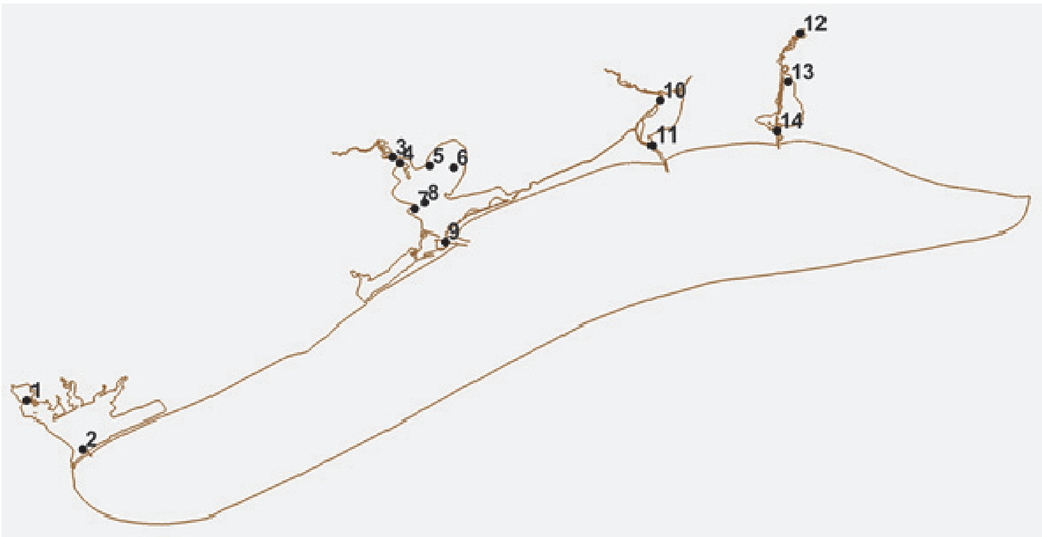

Figure 3.1. Observed salinity station locations applied to correct NWGOFS salinity initial field.

Table 3.2. Observation stations for NEGOFS correcting initial salinity condition

Station	Longitude	Latitude	Station Name
1	-88.04333	30.70833	Mobile St Dock, AL
2	-87.82833	30.32833	Bon Secour, AL
3	-88.07833	30.25167	Dauphin Island, AL
4	-88.01167	30.43667	Mid-Mobile Bay, AL
5	-88.01167	30.66667	Meaher_Park, AL
6	-88.58389	30.30806	Round Island Light, MS
7	-88.86889	30.25444	East Ship Island Light, MS
8	-88.86444	30.38833	Biloxi Bay, MS
9	-88.97222	30.31861	Gulfport Light, MS
10	-89.24278	30.23806	Merrill Shell, MS
11	-89.42222	30.19083	Joseph Island Light, MS

Figure 3.2. Observed salinity station locations applied to correct NEGOFS salinity initial field.

Atmospheric Surface Boundary Conditions

The surface forcing data required for the NWGOFS and NEGOFS hindcast simulations consists of meteorological parameters from NAM model. Forecast guidance from 12-km NAM model at three-hour time interval including surface wind velocity at 10 m above ground level (AGL), air pressure at mean sea level, surface air temperature at 2 m AGL, surface relative humidity at 2 m AGL, and short- and long-wave radiation are interpolated onto the NWGOFS and NEGOFS model domains at each node. The sensible heat, latent heat, and the net heat flux at each model grid node are then calculated based on the bulk flux parameterization empirical formula. The net heat flux, surface wind velocity, and surface air pressure are the atmospheric forcings for NWGOFS and NEGOFS.

River Open Boundary Conditions

Detailed river station information used for NWGOFS and NEGOFS river boundary forcings are listed in Tables 3.3 and 3.4. Sources of discharge and temperature are identified with gage number and the agency that maintains the gage. Depending on the river cross-section dimension, river input location to the model grid can be configured at multiple model nodes. For instance, Sabine River (#19 and #20 of Table 3.3) enters into Sabine Lake at nodes 80850 and 80887. Several tributaries can be combined as one flow entering into at one model grid such as #4 of Table 3.3 where discharges from four tributaries are combined and entered at node 59034. River boundary locations for NWGOFS and NEGOFS are shown as Figures 3.3 and 3.4. Most rivers entering into NEGOFS model grid domain carry larger discharges and require multiple river input nodes (Table 3.4).

Table 3.3. River information for NWGOFS hindcasts

#	River Input Name	Node #	USGS ID	Station Name	Discharge (hindcast)	Water Temperature (hindcast)
1	Placedo_TX	57503.nc	08164800	Placedo Ck nr Placedo, TX	USGS_08164800	TCOON/COOPS_ 87732591
2		57504.nc	08164600	Garcitas Ck nr Inez, TX	USGS_08164600	
3	Lavaca_TX	59033.nc	08164000	Lavaca Rv nr Edna, TX	USGS_08164000	TCOON/COOPS_ 87732591
4		59034.nc	08164390	Navidad Rv at Strane Pk nr Edna, TX	USGS_08164390	
			08164450	Sandy Ck nr Ganado, TX	USGS_08164450	
			08164503	W Mustang Ck nr Ganado, TX	USGS_08164503	
			08164504	E Mustang Ck nr Louise, TX	USGS_08164504	
5	Colorado_TX	20977.nc	08162500	Colorado Rv nr Bay City, TX	USGS_08162500	TCOON_87731461
6	Brazos_TX	19173.nc	08116650	Brazos Rv nr Rosharon, TX	USGS_08116650	COOPS_8772447
7	Houston_West_TX	85567.nc	08075000	Brays Bayou at Houston, TX	USGS_08075000	TCOON_87707771
8		85566.nc	08074500	Whiteoak Bayou at Houston, TX	USGS_08074500	
9		85571.nc	08073700	Buffalo Bayou at Piney Point, TX	USGS_08073700	
10	Sims_TX	85430.nc	08075400	Sims Bayou at Hiram Clarke St, Houston, TX	USGS_08075400	TCOON_87707771
11	Houston_North_TX	83773.nc	08076000	Greens Bayou nr Houston, TX	USGS_08076000	TCOON_87707771
12		83749.nc	08076180	Garners Bayou nr Humble, TX	USGS_08076180	
			08076500	Halls Bayou at Houston, TX	USGS_08076500	
13	Cypress_Spring_TX	82138.nc	08069000	Cypress Ck nr Westfield, TX	USGS_08069000	USGS_08068000
14		82139.nc	08068500	Spring Ck nr Spring, TX	USGS_08068500	
15		82116.nc	08068000	W Fk San Jacinto Rv nr Conroe, TX	USGS_08068000	
			08070200	E Fk San Jacinto Rv nr New Caney, TX	USGS_08070200	
16	Trinity_TX	70248.nc	08066500	Trinity Rv at Romayor, TX	USGS_08066500	USGS_08067100
17		72607.nc				
18	Neches_TX	85403.nc	08041780	Neches Rv Saltwater Barrier at Beaumont, TX	USGS_08041780	COOPS_8770570
19	Sabine_TX	80850.nc	08030500	Sabine Rv nr Ruliff, TX	USGS_08030500	COOPS_8770570
20		80887.nc				
21	Calcasieu_LA	85424.nc	08015500	Calcasieu River near Kinder, LA	USGS_08015500	USGS_08017044
22	Nezpique_LA	24258.nc	08012000	Nezpique near Basile, LA		
			08010000	Bayou Des Cannes near Eunice, LA		

TCOON: Texas Coastal Ocean Observation Network
USGS: US Geological Survey
CO-OPS: NOAA/NOS Centers for Operational Oceanographic Products and Services

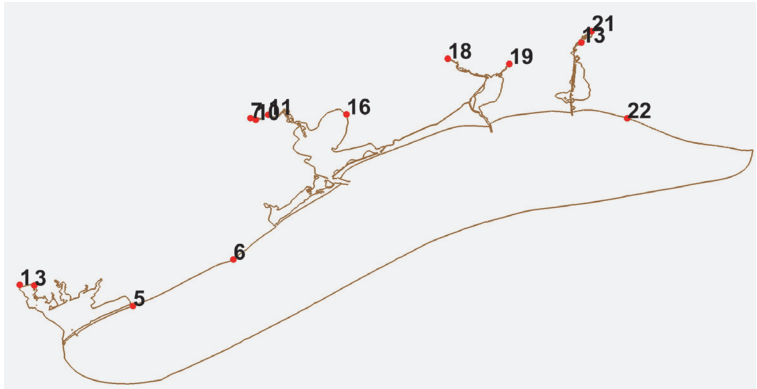

Figure 3.3. River location for NWGOFS.

Table 3.4. River information for NEGOFS hindcasts.

#	River Input Name	Node #	USGS ID	Station Name	Discharge (hindcast)	Water Temperature (hindcast)
1	Tangipahoa, LA	26462.nc	07375500	Tangipahoa River at Robert, LA	USGS_07375500	USGS_301001089442600
2	Chitto, LA	21423.nc	02492000	Bogue Chitto River near Bush, LA	USGS_02492000	USGS_301141089320300
3	Pearl, LA	20905.nc	02489500	Pearl River near Bogalusa, LA	USGS_02489500	USGS_301141089320300
4	Bay St Louis, MS	34125.nc	02481510	Wolf Rv Nr Landon, MS	USGS_02481510	USGS_02481660
5		34126.nc				
6		34127.nc				
7	Pascagoula Bay west, MS	48344.nc	02479000	PASCAGOULA RIVER AT MERRILL, MS	USGS_2479000	USGS_02480285
8		48345.nc				
9		48346.nc				
10		48347.nc				
11	Pascagoula Bay east, MS	54044.nc	02479560	Escatawpa River near Agricola, MS	USGS_02479560	COOPS_8741533
12		54221.nc				
13		54222.nc				
14		54223.nc				
15	Mobile Bay west	68358.nc	02470629	Mobile River near Landon, MS	USGS_02470629	COOPS_8737048
16		68359.nc				
17		68360.nc				
18		68361.nc				
19	Mobile Bay east	68450.nc	02471019	Tensaw River near Mount Vernon, AL	USGS_02471019	COOPS_8737048
20		68451.nc				
21		68452.nc				
22		68453.nc				
23		68454.nc				
24	Perdido, FL	555.nc	02376500	Perdido River at Barrineau Park, FL	USGS_02471019	COOPS_8729840

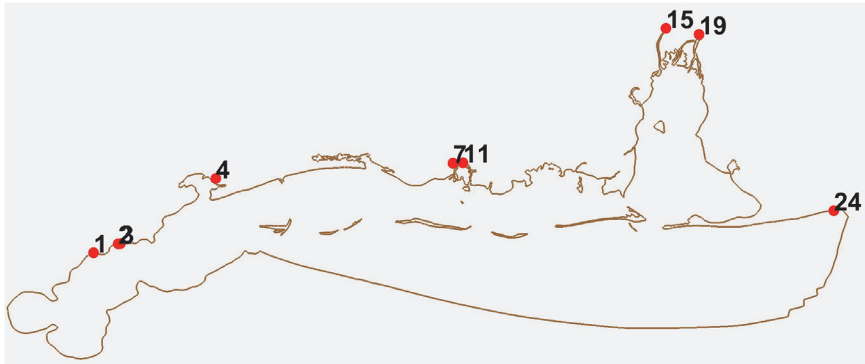

Figure 3.4. River location for NEGOFS.

__Sensitivity Tests__

Several sensitivity tests have been conducted to calibrate parameters in the FVCOM applied to the NWGOFS and NEGOFS. The constant and variable bottom roughness logarithm scale length (z_{0b}) (Cheng et al., 1993; Schmalz, 2013) and bottom friction coefficient (C_d) were tested and found to have insignificant effect to the surface elevations and velocity compared with observations. The NGOFS uses 41 sigma levels to resolve the vertical structure in the shelf and shelf break areas. For shallow water NWGOFS and NEGOFS, both 41 and 21 sigma levels are tested to evaluate the effect of the number of vertical layers to water level and velocity at stations with observations. Test results also show insignificant differences (less than 0.01 m in surface elevation and 0.02 ms^{-1} in horizontal velocity at all levels). Therefore, the nested models use 21-sigma level in the vertical. The information of velocity, salinity, and temperature from NGOFS at every other layer are extracted as the nesting boundary conditions for NWGOFS and NEGOFS.

3.2. Hindcast Model-Data Comparison

The hindcast starts at hour 0, 14 September 2010. Forced with nesting open ocean boundary information from NGOFS, the NWGOFS and NEGOFS take about seven days for water levels and tidal currents to spin-up and about 1.5 months for salinity and temperature to reach quasi-equilibrium. Simulated water level, current, salinity and temperature are saved at stations for model verification with observations. Surface elevation and three-dimensional fields for the entire NWGOFS and NEGOFS domains are also outputs for model verification.

The comparisons of model simulated water level, temperature, current velocity and salinity time series with observations at representative locations are shown in Figures 3.5–3.8. The skill assessment of the time series will be discussed in Chapter 4.

Water level time series show predominant diurnal and mixed tide with wind event effect (Figure 3.5). Simulated water levels follow the observation tidal and event signal very well except that the model underestimates the low surge from a storm event by approximately 0.4 m at NWGOFS coast and 0.2 m at NEGOFS coast on 13 December 2010.

The simulated near surface water temperature matches with observations throughout the 2010–2011 winter (Figure 3.6). This agreement can also be seen in the NGOFS temperature hindcast from August 2008 to August 2009 (Wei et al., 2014a) which indicates the surface heat flux calculation accuracy. The temperature at each station near the river mouth shows the response to the river temperature input. However, the heat flux controls the model surface temperature for the rest of the area.

Model simulated and observed current speed time series at station g0601 (Galveston Bay entrance, Galveston, TX, USA) and sn0201 (USCG Sabine, Sabine, LA, USA) are shown in Figure 3.7. The maximum currents over 1.0 m s^{-1} at the bay entrance of NWGOFS are shown in Figure 3.7 left column. Weaker currents are observed at Gulfport PORTS in NEGOFS domain (gp0401, Figure 3.7 right column). At the Mobile Bay entrance (mb0101), the model underestimated the peak current speed.

Salinity time series at selected stations are shown in Figure 3.8. Observed salinity data quality deterioration by the bio-fouling is very common especially in northern Gulf of Mexico inland bays. The estuary salinity is also sensitive to freshwater river input. Simulated surface salinity for NWGOFS (Figure 3.8 left column) follows the observation trend during the hindcast period but fails to capture the high frequency fluctuation. For Meaher Park, AL of NEGOFS (top of Figure 3.8 right column), the simulated surface salinity overestimated the rate of salinity decrease due to increased river inflow to Mobile Bay. At Mobile Bay entrance, the salinity time series at Dauphin station shows strong tidal flushing signals matching with the range of observations.

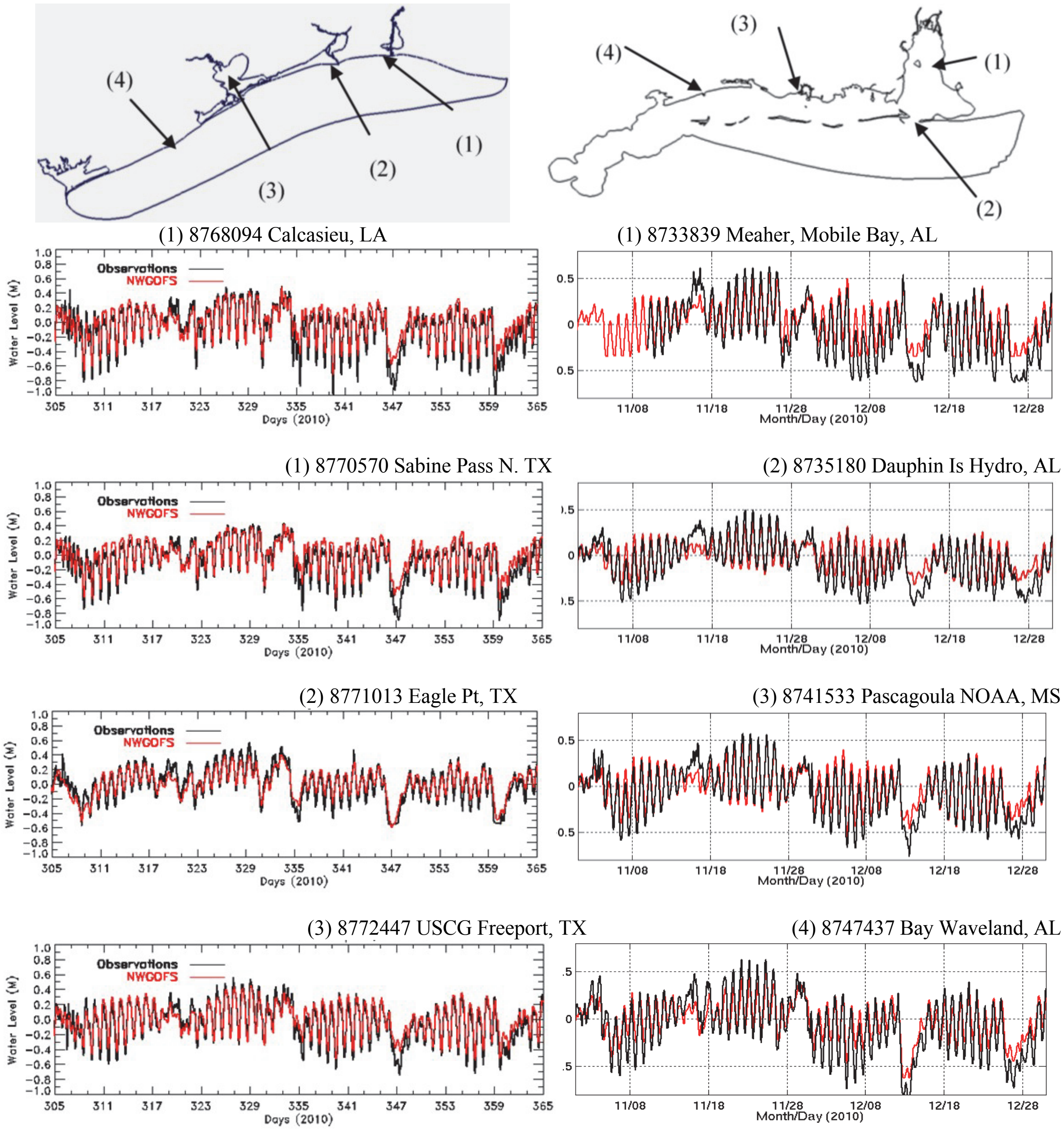

Figure 3.5. Simulated (red) and observed (black) water level time series at stations in NWGOFS (left column) and NEGOFS (right column) from 1 November 2010 to 31 December 2010.

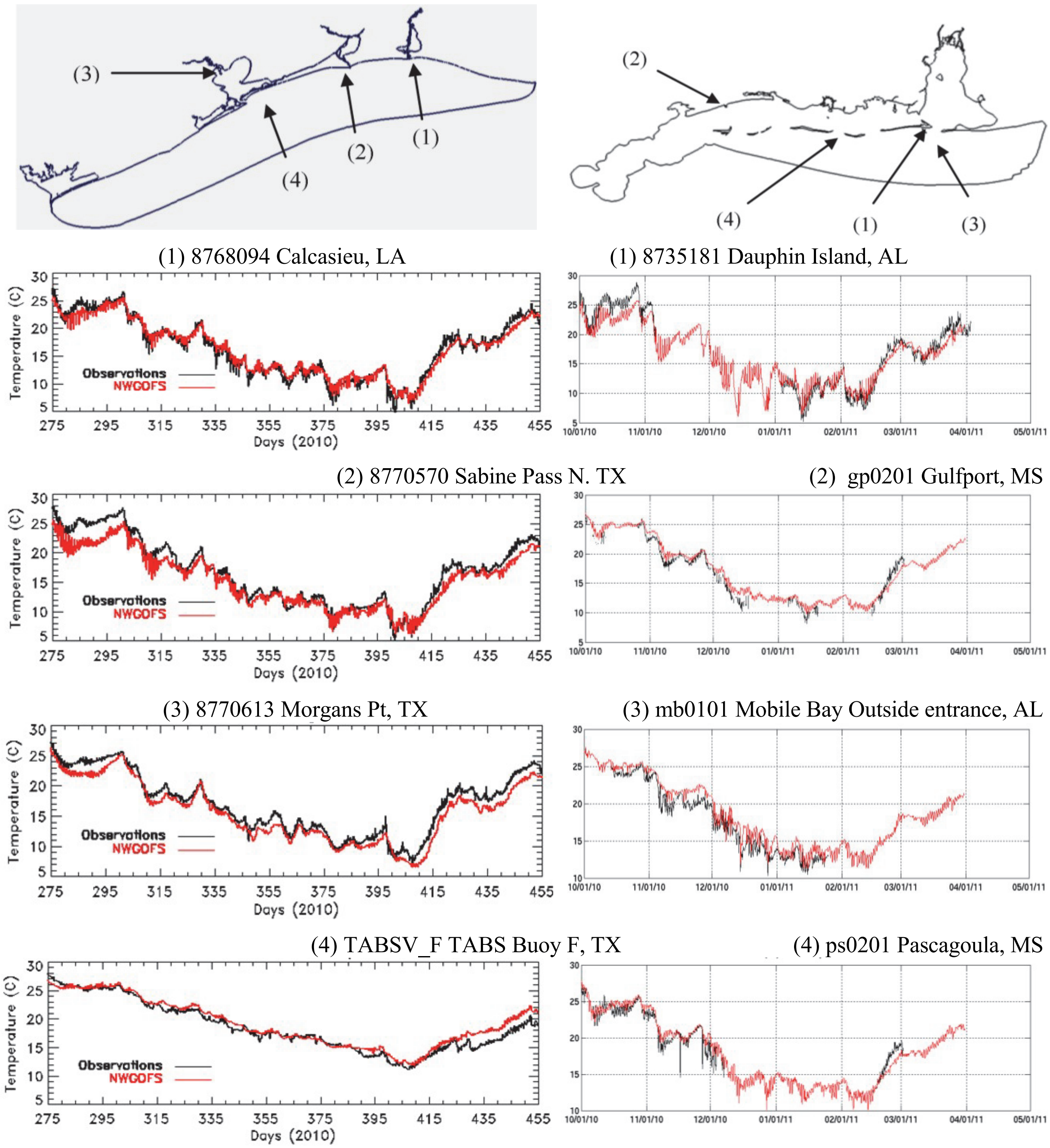

Figure 3.6. Simulated (red) and observed (black) temperature time series at stations in NWGOFS (left column) and NEGOFS (right column) from 1 October 2010 to 1 April 2011.

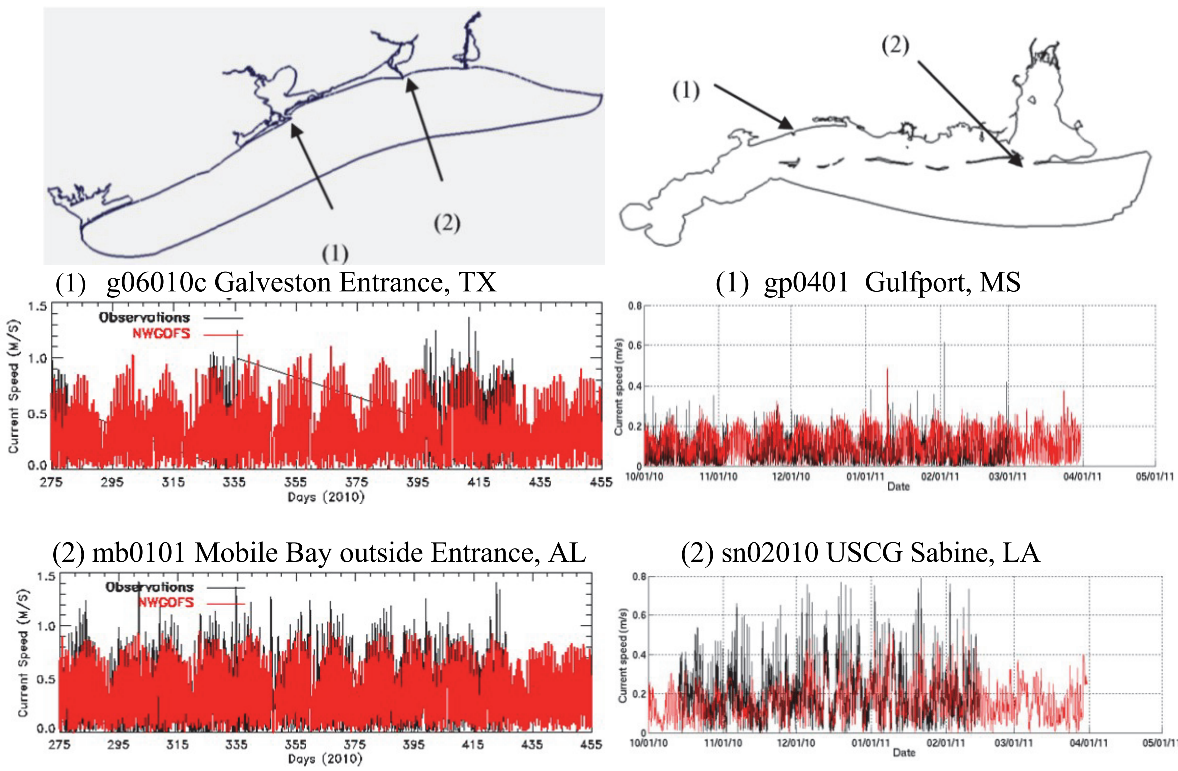

Figure 3.7. Simulated (red) and observed (black) near surface current speed time series at stations in NWGOFS (left column) and NEGOFS (right column) from 1 October 2010 to 1 April 2011.

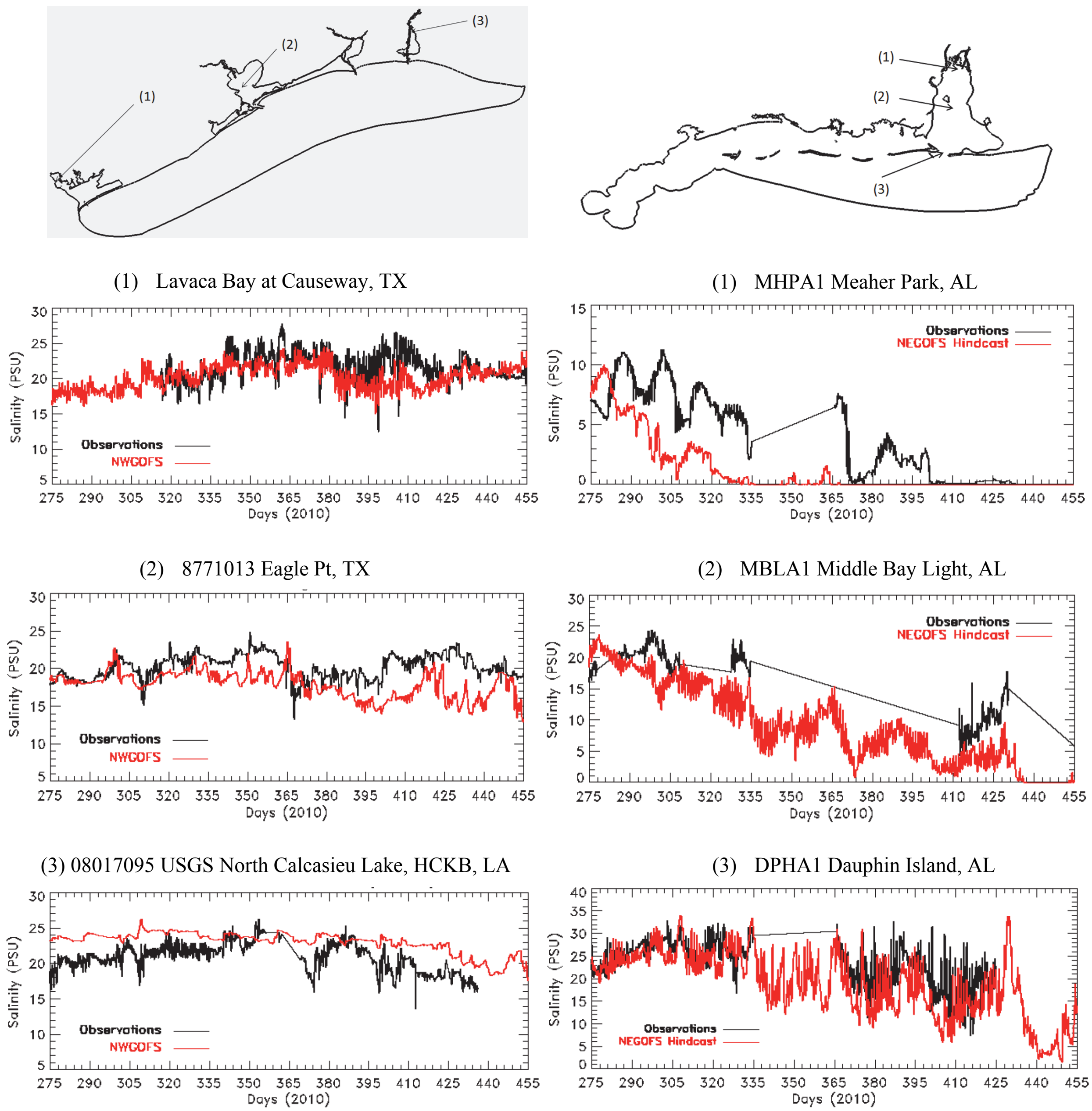

Figure 3.8. Simulated (red) and observed (black) surface salinity time series at stations in NWGOFS (left column) and NEGOFS (right column) from 1 October 2010 to 1 April 2011.

4. MODEL HINDCAST SKILL ASSESSMENT

Model simulated results for water levels, currents, salinity, and temperature from the hindcast have been compared with observations using NOS standard skill assessment software (Zhang et al., 2006; Zhang et al., 2010) to further quantify the model performance. Statistic parameters in the NOS skill assessment procedures for operational forecast system development (Hess et al, 2003; Zhang et. al., 2006; Zhang et al., 2010) are computed. These parameters include: Root Mean Squared Error (RMSE), Central Frequency (CF), and Positive Outlier Frequency (POF), and Negative Outlier Frequency (NOF). The NOS standard criteria (0.15 m for water level, 0.26 m s^{-1} for current speed, 3.0 ^{0}C for water temperature, and 3.5 PSU for salinity) are greater than 90% for CF and less than 1% for NOF and POF. More detailed definitions of the above parameters can be found in Hess et al., (2003).

The hindcast performance skills are presented as Taylor diagrams and the skill maps described in this chapter.

4.1. Hindcsat Skill Taylor Diagrams

Model skill assessment results from the hindcast as a series of tables for each station in NWGOFS and NEGOFS contain variables from the skill assessment software based on NOS model skill criterion. In summary, the RMSD, Standard Deviation, and Correlation Coefficient are calculated and plotted as concise Taylor Diagrams for water level, current speed, temperature, and salinity shown in Figure 4.1. The Root-Mean-Squared-Deviation (RMSD) for water level is less than 10 cm for both NWGOFS and NEGOFS except at three locations. High correlation over around 0.95 for water level and temperature indicates good model hindcast skills. The current velocity correlation coefficient is under-performed compared to the water level and temperature. Salinity skills are over 4 PSU for both NWGOFS and NEGOFS. Part of the reason is the deterioration of observation accuracy due to bio-fouls accumulation on the sensors.

NWGOFS: Water level (m) NWGOFS: Current speed (m s^{-1})

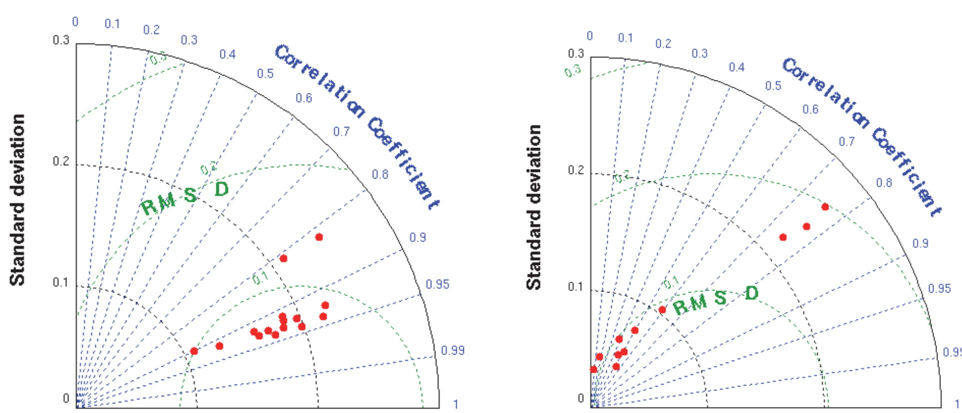

Figure 4.1. Taylor Diagrams of water level, current speed, and water temperature for NWGOFS and NEGOFS. Standard deviation, correlation coefficient, and the Root Mean Squared Deviation (RMSD) are presented in one diagram.

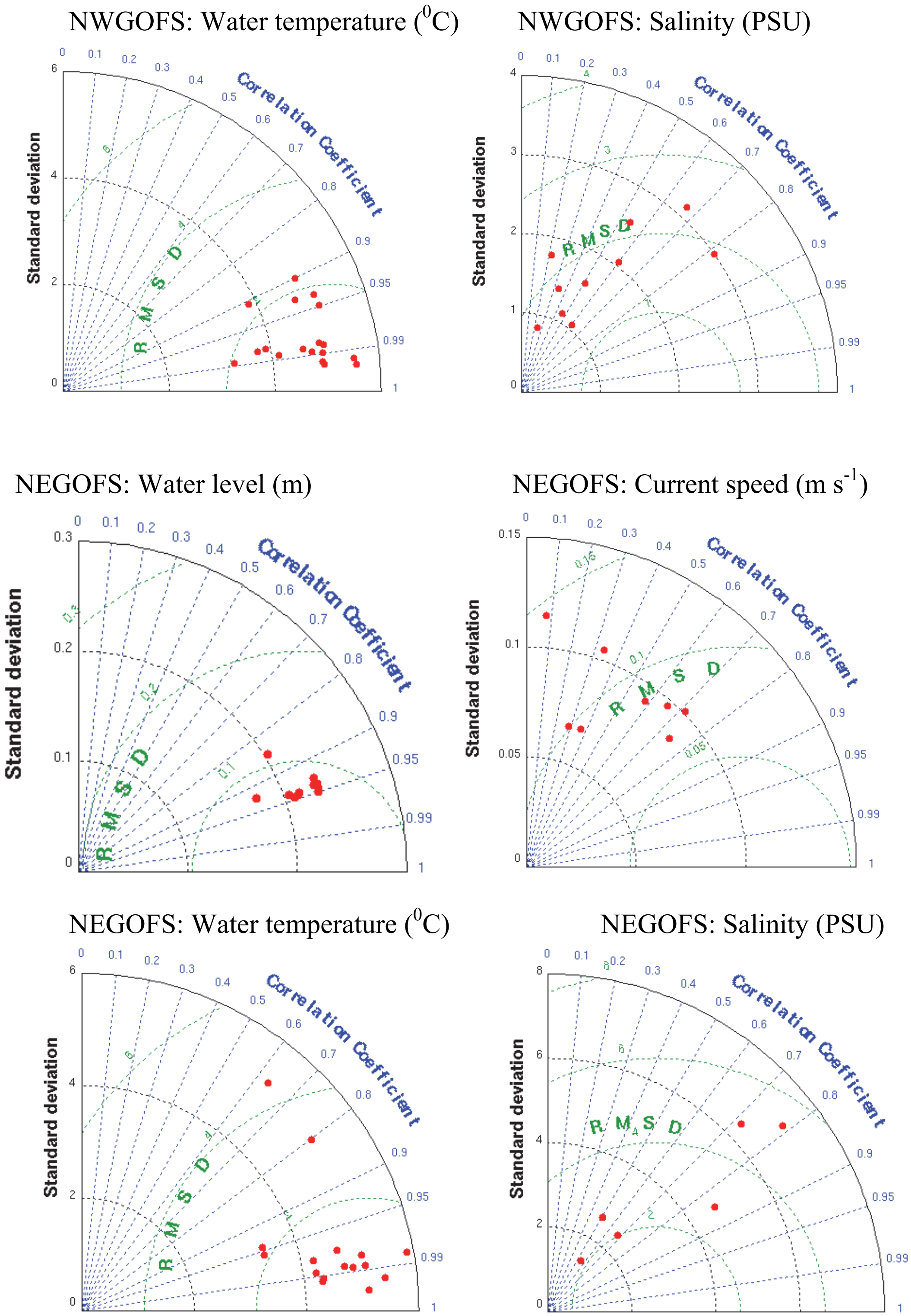

Figure 4.1. (Continued)

4.2. Hindcast Skill Maps

The RMSE and CF for water level, current, and temperature extracted from the detail skill assessment report can be presented as a skill summary map as shown in Figure 4.2 which convenient for users and decision makers. The range of RMSE and CF are presented in three color categories; green (g), yellow (y), and red (r) with corresponding skill ranges shown in the figure. The water level CF satisfies the 90% NOS criteria except for one location west of Mississippi Sound where the sounding data are sparse. The temperature CF also exceeds 90%. The salinity skill maps are not satisfactory (as shown in Taylor diagrams - Figure 4.1), and therefore, are not shown here.

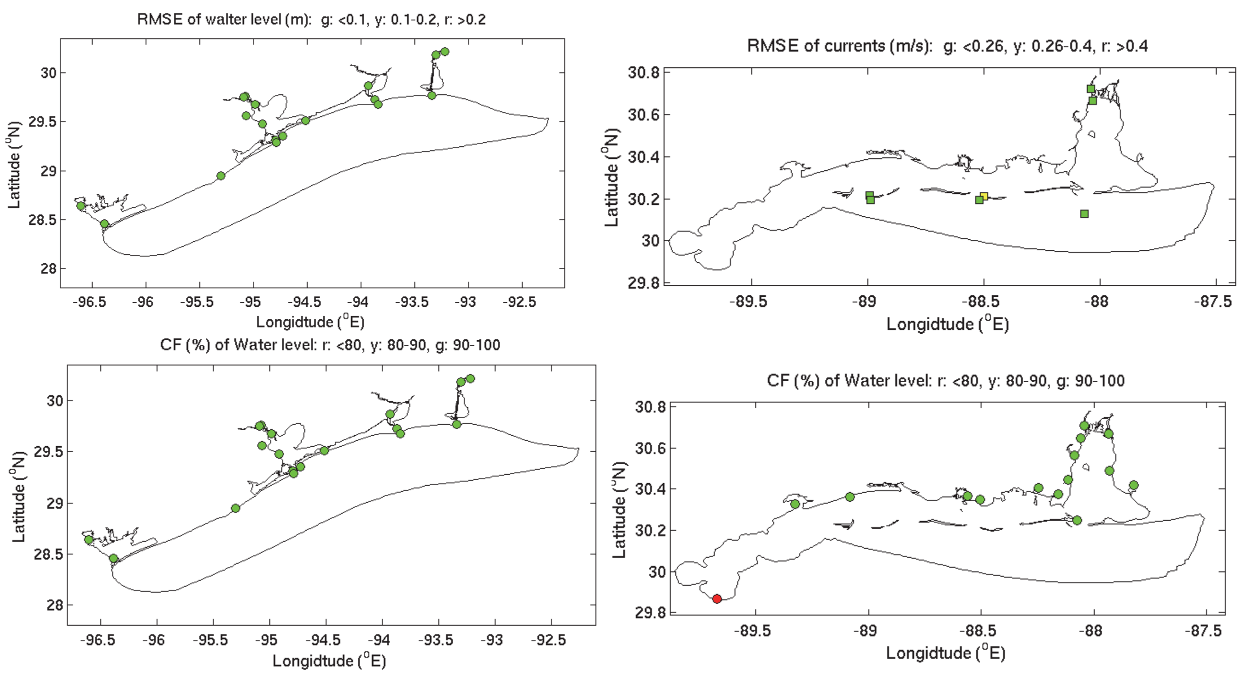

Figure 4.2. Hindcast water level RMSE and CF skill assessment summary map for NWGOFS (left column) and NEGOFS (right column).

4.3. NGOFS and Nested NGOFS Skill Comparisons

The water level, current, water temperature, and salinity skill assessments from the nested NGOFS (NWGOFS and NEGOFS) hindcast are compared at common locations of the parent model system NGOFS (Wei et al., 2014b) and listed in Tables 4.1 to 4.4. The station locations are shown in Figures 4.5 to 4.8. The NWGOFS and NEGOFS water level RMSEs (Table 4.1) are either comparable with or slightly better than the parent NGOFS. No significant difference was noticed between the nested model current and temperature skills (Tables 4.2 and 4.3) and the parent model. Due to the accuracy of observed salinity, only two salinity skill stations are reliable.

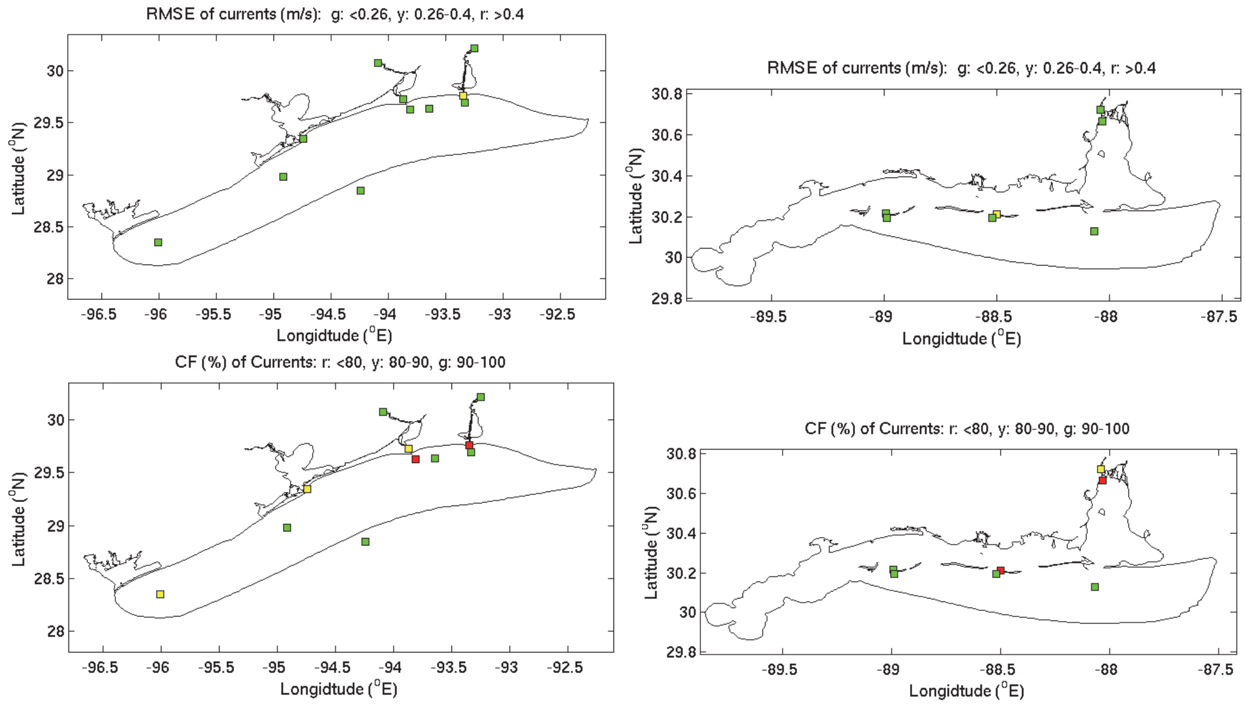

Figure 4.3. Hindcast current velocity RMSE and CF skill assessment summary map for NWGOFS (left column) and NEGOFS (right column).

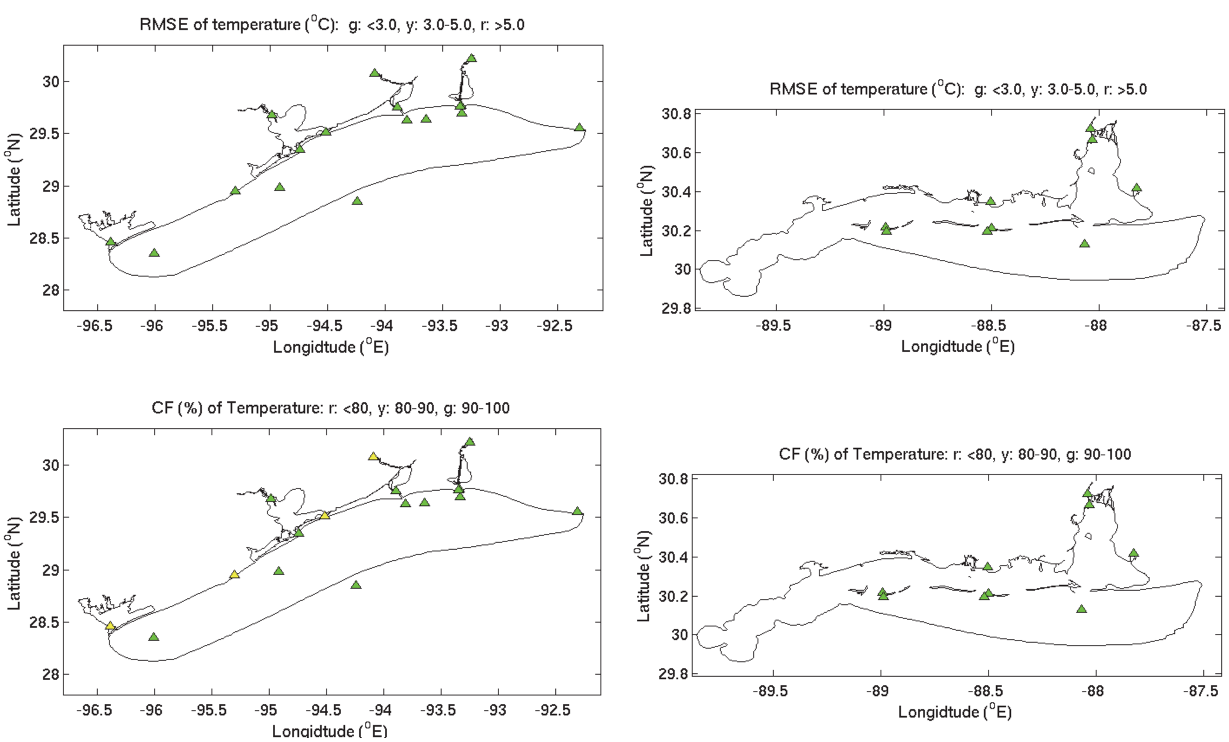

Figure 4.4. Hindcast temperature RMSE and CF skill assessment summary map for NWGOFS (left column) and NEGOFS (right column).

Table 4.1. Water level hindcast skill comparison between nested NGOFS and NGOFS.

	RMSE (m)			CF (%)		
Station Name	NWGOFS	NGOFS	NWGOFS-NGOFS	NWGOFS	NGOFS	NWGOFS-NGOFS
1. Freshwater Canal Docks, LA	0.12	0.12	0.00	80.6	82.0	-1.4
2. Calcasieu Pass, LA	0.12	0.12	0.00	81.0	79.9	1.1
3. Sabine Pass North, TX	0.11	0.13	-0.02	83.6	73.0	10.6
4. Morgans Point, TX	0.13	0.14	-0.01	75.3	69.5	5.8
5. Rollover Pass, TX	0.11	0.10	0.01	82.5	84.5	-2.0
6. Eagle Point, TX	0.10	0.08	0.02	85.0	95.6	-9.4
7. Galveston Pleasure Pier, TX	0.11	0.10	0.01	80.3	85.5	-5.2
8. USCG Freeport, TX	0.10	0.09	0.01	86.6	90.5	-5.9
	NEGOFS	NGOFS	NEGOFS-NGOFS	NEGOFS	NGOFS	NEGOFS-NGOFS
9. Weeks Bay, AL	0.10	0.12	-0.02	85.7	76.9	8.8
10. CG Mobile, AL	0.12	0.15	-0.03	79.8	67.7	12.1
11. Mobile St Dock, AL	0.13	0.15	-0.02	73.8	68.3	5.5
12. Pascagoula Dock, MS	0.08	0.10	-0.02	95.1	88.6	6.5
13. Pascagoula NOAA, MS	0.08	0.10	-0.02	94.0	89.7	4.3
14. Gulfport Harbor, MS	0.09	0.12	-0.03	92.0	80.7	11.3
15. Bay Waveland, MS	0.10	0.14	-0.04	88.8	70.9	17.9
16. Shell Beach, LA	0.12	0.16	-0.04	79.0	62.1	16.9

Table 4.2. Current speed hindcast skill comparison between nested NGOFS and NGOFS.

	RMSE (ms^{-1})			CF (%)		
Station Name	NWGOFS	NGOFS	NWGOFS - NGOFS	NWGOFS	NGOFS	NWGOFS - NGOFS
1. Galveston Bay Entr Channel, TX	0.192	0.182	0.100	82.2	84.6	-2.4
2. Calcasieu Channel LB 36, TX	0.106	0.102	0.004	96.5	97.1	-0.6
3. Sabine Bank Channel LBB 34, TX	0.169	0.203	-0.046	99.6	98.7	0.9
	NEGOFS	NGOFS	NEGOFS-NGOFS	NEGOFS	NGOFS	NEGOFS-NGOFS
4. Gulfport Ship Channel LB 22, MS	0.094	0.098	-0.040	99.4	99.0	0.4
5. Gulfport Ship Channel LB 26, MS	0.100	0.113	-0.013	98.2	97.3	0.9
6. West Pier, MS	0.092	0.070	0.022	99.9	99.0	0.0
7. Pascagoula Harbor LB 17, MS	0.333	0.281	0.052	70.4	71.8	-1.4
8. Mobile Bay Buoy M, AL	0.111	0.123	-0.012	96.9	95.6	1.3
9. Mobile Container Terminal, AL	0.213	0.267	-0.046	79.5	71.2	8.3

Table 4.3. Surface water temperature hindcast skill comparison between nested NGOFS and NGOFS.

	RMSE (^0C)			CF (%)		
Station Name	NWGOFS	NGOFS	NWGOFS-NGOFS	NWGOFS	NGOFS	NWGOFS-NGOFS
1. Calcasieu Pass, LA	1.01	0.96	0.05	99.2	99.6	-0.4
2. Sabine Pass North, TX	1.23	1.06	0.17	90.6	98.8	-8.2
3. Morgans Point, TX	1.42	1.62	0.20	99.6	98.7	0.9
4. Galveston Bay Chan LB 11, TX	0.73	0.71	0.02	100.0	100.0	0.0
5. USCG Freeport, TX	2.26	2.32	-0.06	89.4	87.9	1.5
6. Calcasieu Chan LB 36, TX	0.94	1.20	-0.26	100.0	99.9	0.1
7. Sabine Channel LBB 34, LA	1.84	1.05	0.79	86.4	100.0	-13.6
	NEGOFS	NGOFS	NEGOFS-NGOFS	NEGOFS	NGOFS	NEGOFS-NGOFS
8. CG Mobile, AL	3.51	3.74	-0.23	37.7	50.0	-12.3
9. Mobile St Dock, AL	1.95	2.22	-0.27	89.0	81.0	8.0
10. Pascagoula Dock, MS	2.85	2.41	0.44	61.2	71.4	-10.2
11. Pascagoula NOAA, MS	1.12	1.21	-0.09	100.0	98.6	1.4
12. Bay Waveland, MS	1.24	1.69	-0.45	97.7	94.4	3.3
13. Shell Beach, LA	1.07	1.37	-0.30	99.8	96.5	3.3
14. Gulfport,LB22 MS	0.93	0.84	0.09	99.7	100.0	-0.3
15. Gulfport,LB26 MS	1.03	1.19	-0.16	99.5	99.2	0.3
16. GP Harbor WP, MS	0.83	1.45	-0.62	99.4	98.6	0.8
17. MB Buoy M, AL	1.49	1.44	0.05	96.9	98.0	-1.1
18. MB Container Term, AL	1.28	1.76	-0.48	98.1	99.8	-1.7
19. Pascagoula, LB17, MS	0.86	1.06	-0.20	100	99.4	0.6

Table 4.4. Surface salinity hindcast skill comparison between nested NGOFS and NGOFS.

	RMSE (PSU)			CF (%)		
Station Name	NWGOFS	NGOFS	NWGOFS-NGOFS	NWGOFS	NGOFS	NWGOFS-NGOFS
1. Eagle Point, TX	3.04	8.09	-4.95	74.5	28.7	25.8
2. TABS Buoy B, TX	2.57	2.36	0.21	82.4	84.6	-1.8
	NEGOFS	NGOFS	NEGOFS-NGOFS	NEGOFS	NGOFS	NEGOFS-NGOFS
3. Dauphin Island, AL	5.30	5.32	-0.02	54.1	44.1	10.0
4. Meaher Park, AL	3.28	2.36	0.92	68.6	84.6	-16.0

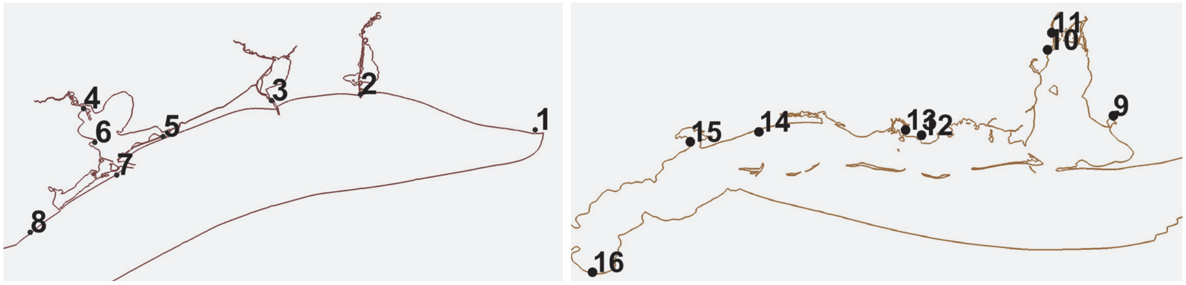

Figure 4.5. Locations for water level skill comparison between NGOFS and nested NGOFS.

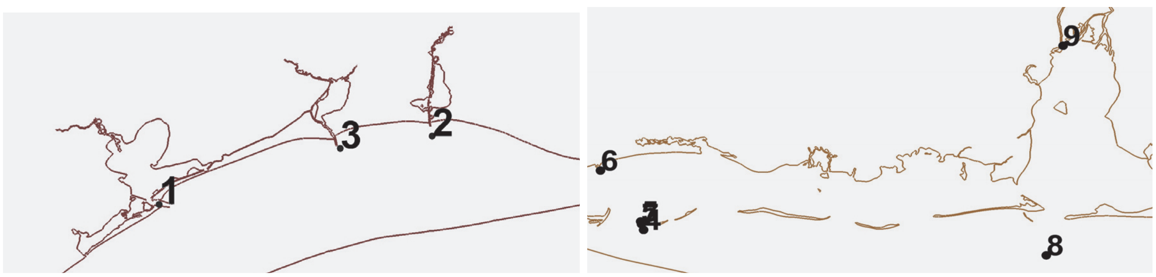

Figure 4.6. Locations for current speed skill comparison between NGOFS and nested NGOFS.

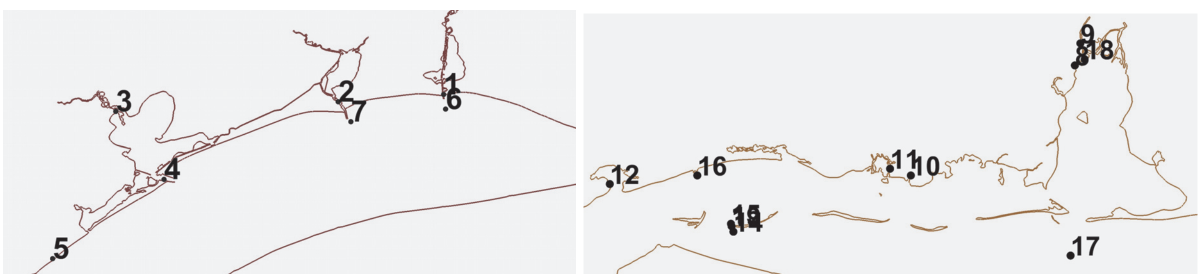

Figure 4.7. Locations for temperature skill comparison between NGOFS and nested NGOFS.

Figure 4.8. Locations for salinity skill comparison between NGOFS and nested NGOFS.

4.4. NGOFS and NEGOFS Mobile Bay Transect Skill Comparisons

The NWGOFS and NEGOFS 6-months hindcast covers the NOS Tri-Office Mobile Bay survey time period (Patchen et al., 2012). The conductivity-temperature-depth (CTD) measurements were conducted using the Automus Underwater Vehicle (AUV) along several transects crossing the ship channel in Mobile Bay as shown in Figure 4.9. An example of typical AUV survey data of temperature and salinity along a transect is plotted as Figure 4.10.

The AUV-CTD measurements along transect were made at various time, geographical locations, and depths. To foster model-data comparisons, NEGOFS' six-minute interval temperature and salinity fields were interpolated onto time instances and spatial locations coincident with the CTD measurements. Along each transect, the model water temperature/salinity were compared with observations to form a model error series. The mean, minimum, maximum, and RMSE were then computed from the error series along each transect. The error statistics from NEGOFS are listed with NGOFS (Wei et al., 2014b) in Tables 4.5 and 4.6 for temperature and salinity, respectively.

From Tables 4.5 and 4.6, mean errors from the nested model NEGOFS simulated water temperature and salinity are less than the parent model NGOFS for all transects although NEGOFS maximum water temperature difference is greater than NGOFS for transects 3,4,6, and 7. The NEGOFS salinity mean errors are also less than NGOFS; however, the errors are still not satisfactory.

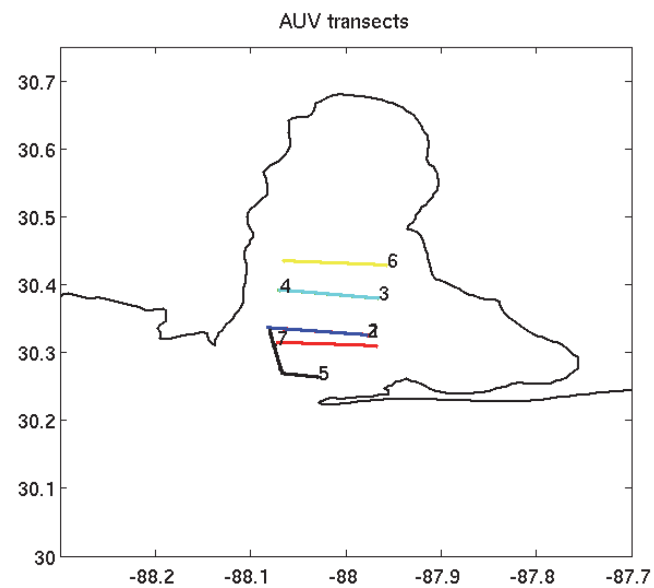

Figure 4.9. Transects of AUV-CTD measurements (Patchen et al., 2012). Note that two pairs of AUV-CTD transects were overlapped: transects 1 and 2 and transects 3 and 4. A number labeled at one end of a transect line denotes the survey's ID and its launch point.

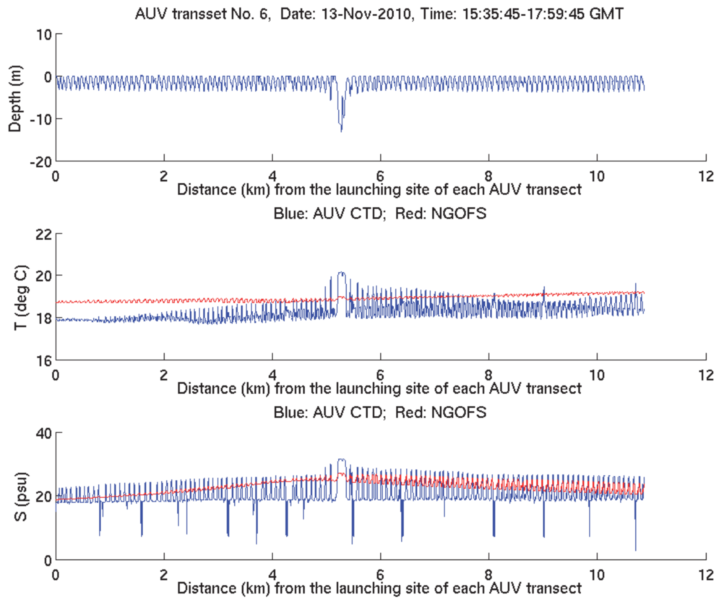

Figure 4.10. Salinity, temperature, and depth data along AUV transect 6.

Table 4.5. Statistics of model water temperature errors comparison for NGOFS and NEGOFS along seven AUV-CTD transects.

	NGOFS				NEGOFS			
Transect ID	mean(Δ_T) (^oC)	min($\lvert\Delta_T\rvert$) (^oC)	max($\lvert\Delta_T\rvert$) (^oC)	RMSE (Δ_T) (^oC)	mean(Δ_T) (^oC)	min($\lvert\Delta_T\rvert$) (^oC)	max($\lvert\Delta_T\rvert$) (^oC)	RMSE (Δ_T) (^oC)
1	1.137	0.001	2.127	1.297	0.520	0.000	1.477	0.604
2	1.003	0.001	1.869	1.142	0.395	0.000	1.775	0.496
3	1.351	0.008	2.004	1.427	0.266	0.000	2.159	0.366
4	1.169	0.039	1.975	1.242	0.345	0.001	2.475	0.463
5	1.924	0.004	3.197	2.156	0.888	0.000	2.422	1.030
6	0.62	0.004	1.203	0.735	0.857	0.208	2.201	0.921
7	0.446	0.000	1.191	0.611	0.858	0.072	2.340	0.979

Table 4.6. Statistics of model salinity errors comparison for NGOFS and NEGOFS along seven AUV-CTD transects.

	NGOFS				NEGOFS			
Transect ID	mean(Δ_S) (psu)	min($\lvert\Delta_S\rvert$) (psu)	max($\lvert\Delta_S\rvert$) (psu)	RMSE (Δ_S)(psu)	mean(Δ_S) (psu)	min($\lvert\Delta_S\rvert$) (psu)	max($\lvert\Delta_S\rvert$) (psu)	RMSE (Δ_S)(psu)
1	6.274	0.006	10.22	6.784	5.337	0.003	9.516	5.942
2	6.27	0.006	10.519	6.795	5.339	0.011	9.796	5.927
3	4.127	0.021	8.471	4.663	4.036	0.007	8.300	4.515
4	3.918	0.006	8.26	4.466	3.799	0.003	7.782	4.283
5	7.122	0.016	12.659	7.763	6.046	0.006	12.068	6.639
6	2.157	0.013	6.665	3.476	3.074	0.018	6.762	3.471
7	5.88	0.041	10.236	6.408	5.325	0.017	9.662	5.900

5. SUMMARY AND CONCLUSIONS

The nested NOGFS models, NWGOFS and NEGOFS, have been developed at NOS to provide 2 days short term nowcast and forecast guidance of water level, current velocity, salinity and water temperature over the model grid domain of the northwest and northeast Gulf of Mexico inland and coastal. The combined NWGOFS and NEGOFS cover six NOS PORTS systems (Houston/Galveston, Sabine/Neches, Lake Charles, Gulfport, Pascagoula, and Mobile Bay) and one proposed PORTS (Matagorda Bay) where NOS provides real-time information to the navigation community. The NWGOFS and NEGOFS are two nested forecast systems using the unstructured grid FVCOM developed by UMASS Dartmouth. A synoptic hindcast simulation covering the period of September 2010 to April 2011 has been conducted.

The performance of NWGOFS and NEGOFS model hindcasts were evaluated through the NOS skill assessment software to compare the model simulated water level, current, water temperature and salinity with the observations available from NOAA, Texas Automated Buoy System (TABS), and US Integrated Ocean Observing System (IOOS). The skill assessment has been briefly synthesized in graphics and presented in this report. In general, the simulated water levels, current velocity, and water temperature meet the skill requirement of NOS. The average RMSE ranges from: 0.07 to 0.12 m for water level, 0.06 to 0.26 m s^{-1} for current speed, and 0.5 to 3.8 °C for water temperature, respectively. The salinity skills are not satisfactory for both nested model system.

The skill assessment results comparison between NWGOFS and NEGOFS hindcasts and NGOFS's hindcast for the same period indicates a slight skill edge to the nested models over the parent NGOFS model. However, the nested models' higher resolution assists resolving detailed features that were unable to be resolved in NGOFS. Since the nesting approach in this application requires more computation resources to maintain three model systems, an alternative approach is to replace three models with a large domain model covering the entire nested and the parent model domain with same grid resolution. A future study will be carried out to evaluate the computation resource and skill differences between two approaches.

The NWGOFS and NEGOFS were delivered to NOS Centers for Operational Oceanographic Products and Services (CO-OPS) for setting up a real-time nowcast/forecast test on NOAA's High Performance Computers (HPC) in November 2013. After evaluating the systems real-time nowcast/forecast performance (Peng and Zhang, 2014), the systems were then delivered to NOAA's National Centers for Operation (NCO) for parallel testing before implementing operationally on the NOAA HPC on 16 September 2014.

ACKNOWLEDGEMENT

We thank the FVCOM developers Drs. Changsheng Chen and Jianhua Qi of the University of Massachusetts-Dartmouth for their support in providing the FVCOM code and upgrade in addition to the FVCOM model application assistance. Dr. Frank Aikman, Chief of Marine Modeling and Analysis Program (MMAP), provided project guidance; our colleagues, Dr. Richard Schmalz and Degui Cao, provided many suggestions and comments; and Dr. Lei Shi helped create initial salinity fields for the hindcast. Their help was greatly appreciated. We are grateful to Jianzhong Ge of East China Normal University, China, for providing information, suggestions, and discussion on the dike-groyne algorithm in the thin_dam representation of jetties. Solomon Negusse and Junji Matsumoto of Texas Water Development Board (TWDB) kindly provided salinity and temperature observations in Galveston Bay, Matagorda Bay, and Sabine Lake for hindcast verification and are greatly appreciated. We also thank Tara Wallace of NOS Office of Coast Survey for providing a Lake Calcasieu nautical chart with updated shoreline and bathymetric information.

REFERENCES

Chen C, H. Liu, and R. Beardsley, 2003. An Unstructured Grid, Finite-Volume, Three-Dimensional Primitive Equations Ocean Model: Application to Coastal Ocean and Estuaries. *J. Atmos. Oceanic Technol.*, **20**, 159-186.

Chen C, H. Huang, R. Beardsley, H. Liu, Q. Xu, and G. Cowles, 2007. A finite volume numerical approach for coastal ocean circulation studies: Comparisons with difference models. *J. Geophys. Res.*, **112**, C03018.

Chen C, R. Beardsley, G. Cowles, J. Qi, Z. Lai, G. Gao, D. Stuebe, Q. Xu, P. Xue, J. Ge, S. Hu, R. Tian1, H. Huang, L. Wu, and H. Lin, 2013. An Unstructured Grid, *Finite-Volume Coastal Ocean Model FVCOM User Manual*, UMASSD, New Bedford, MA. 416 pp.

Cheng, R.T., V. Casulli, and J.W. Gartner, 1993. Tidal, Residual, Intertidal Mudflat (TRIM) Model and Its Applications to San Francisco Bay California. *Estuar. Coast. Shelf Sci.*, **36**, 235–280.

Ge, J, C. Chen, J Qi, P Ding, and R. C. Beardsley, 2012. A dike–groyne algorithm in a terrain-following coordinate ocean model (FVCOM): Development, validation and application. Ocean Modeling, *J. Geophys. Res.*, **47**, 26–40.

Hess, K. T. Gross, R. Schmalz, J. Kelley, F. Aikman, E. Wei, and M. Vincent, 2003. NOS Standards for Evaluating Operational Nowcast and Forecast Hydrodynamic Model Systems. *NOAA Tech Report NOS CS 17*, Silver Spring, Maryland, 47 pp.

Mesinger, F., G. DiMego, E. Kalnay, K. Mitchell, P. C. Shaftran, W. Ebisuzaki, D. Jovic, J. Woollen, E. Rogers, E.H. Berbery, E.Y. Fan, R. Grumbine, W. Higgins, Y. Lin, G. Manikin, D. Parrish, and W. Shi, 2006. North American Regional Reanalysis. *Bull. Amer. Meteor. Soc.*, **87**, 343-360.

Patchen, R., Z. Yang, S. Brodet, P. Fink, J. Riley, P. Turner, T. Landon, and C. Paternostro, 2012. Mobile Bay Collaborative Survey: 2010 -2011. *NOAA Tech. Memo NOS CS 28*, Silver Spring, Maryland, 49 pp.

Peng, M. and A. Zhang, 2014. San Francisco Bay Operational Nowcast and Forecast System and Skill Assessment. *NOAA Technical Report NOS CO-OPS 078*, Silver Spring, Maryland, 2014, 90 pp.

Schmalz, R., 2013. Three-Dimensional Hydrodynamic Model Developments for the San Francisco Bay Nowcast/Forecast System; *NOAA Technical Report NOS CS33*, Silver Spring, Maryland, 314 pp.

Warner, J., W.R. Geyer, and J. Lerczak, 2005. Numerical modeling of an estuary: A comprehensive skill assessment. *J. Geophys. Res.*, **110**, C05001.

Wei, E., Z. Yang, Y. Chen, J.W. Kelley, and A. Zhang, 2014a. The Northern Gulf of Mexico Operational Forecast System (NGOFS): Model Development and Skill Assessment. *NOAA Technical Report NOS CS33*, Silver Spring, Maryland, 190 pp.

Wei, E., A. Zhang, Z. Yang, Y. Chen, G.W. Kelley, F. Aikman, and D. Cao, 2014b. NOAA's Nested Northern Gulf of Mexico Operational Forecast Systems Development. *J. Mar. Sci. Eng.*, **2**(1), 1-17.

Zhang, A., K.W. Hess, E. Wei, and E. Myers, 2006. Implementation of Model Skill Assessment Software for Water Level and Current. *NOAA Technical Report NOS CS 24*, Silver Spring, Maryland, 61 pp.

Zhang, A., K.W. Hess, and F. Aikman, 2010. User-based Skill Assessment Techniques for Operational Hydrodynamic Forecast Systems, *J. Oper. Oceanogr.*, **3**(2), 11-24.

Zheng, L. and R.H. Weisberg, 2012. Modeling the West Florida Coastal Ocean by downscaling from the deep ocean, across the continental shelf and into the estuaries. *Ocean Model.*, ***48***(May), 10–29.