The Calibration/Validation of a Mississippi Sound/Bight Model

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ABSTRACT

A regional scale forecast modeling system of the Mississippi Sound/Bight and adjoining estuaries and bays has been developed as part of the Northern Gulf of Mexico Littoral Initiative (NGLI), a multi-agency program spearheaded by NAVOCEANO and USEPA Office of Gulf of Mexico Program. The system, based on the model, called ECOMSED, provides a reliable means of predicting the littoral circulation and, the salinity and temperature structure of the region. The modeling framework adopts a high-resolution orthogonal curvilinear grid which resolves the relevant bathymetric and coastline features, especially in the vicinity of the barrier islands and ship channels. In order to ensure that the model is capable of predicting the oceanography of the Mississippi Sound/Bight, a thorough calibration and validation effort has been conducted against field observations during September 2000. Point-to-point and spatial comparisons of sea surface elevation, temperature, salinity and water currents have been conducted.

The calibration and validation efforts have been supplemented by rigorous analyses to understand the sensitivity of the model predictions to various forcing functions. The estuarine processes controlled by winds and freshwater discharges have been identified and quantified for Mobile Bay, Biloxi Back Bay, Bay St. Louis and Mississippi Sound/Bight through a series of model sensitivity simulations. Estimates of the variances in model prediction have been made using a First Order Variance Analysis (FOVA) method. Percent contribution of bathymetry, temperature and salinity boundary conditions, meteorological conditions and freshwater inflows to variances in model prediction has been determined. The bathymetry and freshwater flows are found to contribute most in the variances in temperature, salinity and transport in the Mississippi sound area. Where as wind plays a major role in the variances in model prediction in the Mississippi Bight (mid shelf) region. The ECOM model, calibrated and validated in this study, is currently in operational mode in the Major Shared Resource Center (MRSC) of NAVOCEANO at Stennis Space Center, MS and the model results are available in the NGLI website at www.navo.navy.mil/NGLI.

I. INTRODUCTION

A sustained comprehensive modeling and observation system for the Mississippi Bight area has been established through a partnership between the Commander, Naval Meteorology and Oceanography Command (CNMOC) and the Environmental Protection Agency's Gulf of Mexico Program Office. This multi-agency partnership is called the Northern Gulf of Mexico Littoral Initiative (NGLI). The system functions as both an operational Navy product and a research tool used to foster the economic and environmental well being of the Gulf Coast. The NGLI program integrates a calibrated/validated coastal ocean modeling system and timely meteorological forecasts with in-situ and remotely sensed observations. It is organized around four functional components: modeling, in-situ and remote sensing observations, data distribution and outreach. The products of the program are available to a wide range of users in near-real time. Information on the overall NGLI program can be found in Carroll and Szczechowski (2001).

The Mississippi Sound/Bight model, ECOMSED, the core component of the forecast modeling system, represents the highest spatial resolution component of a triple-nested series of three-dimensional circulation models for the North Atlantic Ocean, Gulf of Mexico and Mississippi Bight (Ahsan et al., 2001). The ability to nest model operations, cascading information through models of differing resolution, is a particularly important goal of NGLI circulation and wave forecasting.

II. HYDRODYNAMIC MODELING FRAMEWORK

The Mississippi Sound/Bight model, ECOMSED, consists of a three-dimensional circulation model, a cohesive and non-cohesive sediment transport model, and a fate and transport model, provides a reliable means to forecast littoral circulation, sediment suspension and transport, and conservative and non-conservative water quality constituents. The model is driven by mechanisms that include hydrographical (freshwater inflow), meteorological (surface wind), open ocean (large-scale ocean circulation), astronomical (tides), and internal (density gradients) forcing functions. It has most recently been used to simulate the dynamics of two estuaries nearby to the littoral waters considered by the NGLI, St. Andrew Bay, FL (Blumberg and Kim, 2000) and Pensacola Bay, FL (Ahsan et al., 2002). The components of the ECOMSED modeling framework designed for the NGLI are illustrated in Fig. 1.

The hydrodynamic component of ECOMSED is the three-dimensional, time-dependent, estuarine and coastal circulation model whose origin can be traced to the model developed by Blumberg and Mellor (1987). It incorporates the Mellor-Yamada 2.5 level turbulent closure model that provides a realistic parameterization of vertical mixing processes. A system of curvilinear coordinates is used in the horizontal direction, allowing for a smooth and accurate representation of variable shoreline geometry. In the vertical, the model uses a σ-coordinate system to permit better representation of bottom topography. Water surface elevation, water velocity (in three dimensions), temperature, salinity, and water turbulence are calculated in response to meteorological conditions, freshwater inflows, tides, and temperature and salinity at the open boundaries. The model solves a coupled system of differential, prognostic equations describing the conservation of mass, momentum, temperature, salinity, turbulent energy, and turbulence macroscale. A detailed description of the model governing equations can be found in Blumberg et al. (1999) and HydroQual (2001).

III. MODELING CONFIGURATION

The morphology of the Mississippi Sound and Bight tends to divide the area into two regions with markedly different bathymetric features. The northern and western regions are very shallow, with depths ranging from 1 to 3m, and are separated from the deeper shelf by barrier islands. The shelf area deepens to 200m and is open to the Gulf of Mexico. The Mississippi River delta is located in the southwestern part of the area. Due to the complex bathymetric features of the Mississippi Bight, the circulation and tidal regimes are also significantly complex.

For this application of ECOMSED to the Mississippi Sound and Bight, a practical, numerically efficient, yet accurate approach has been taken in order to discretize the entire Mississippi Sound and Bight and the adjoining bays. As a result a variable-resolution orthogonal curvilinear grid in the horizontal and 11 σ-levels in the vertical planes has been developed. Fig. 2 illustrates the 170 x 122 orthogonal curvilinear grid and bathymetric features of the Mississippi Sound/Bight and adjoining bay systems. The

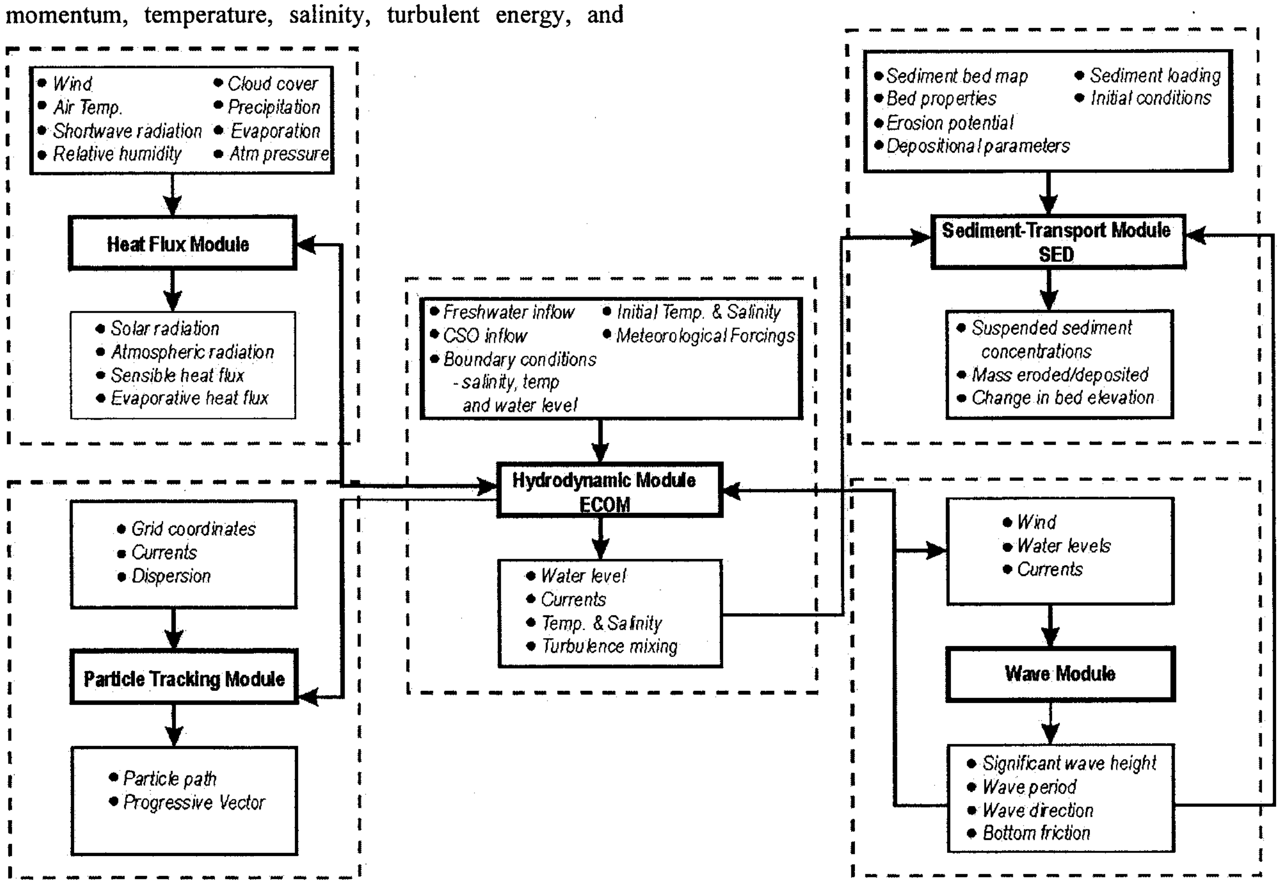

Fig. 1. Components of ECOMSED modeling framework. Hydrodynamic module ECOM, the core of the modeling system, is dynamically coupled with other modules.

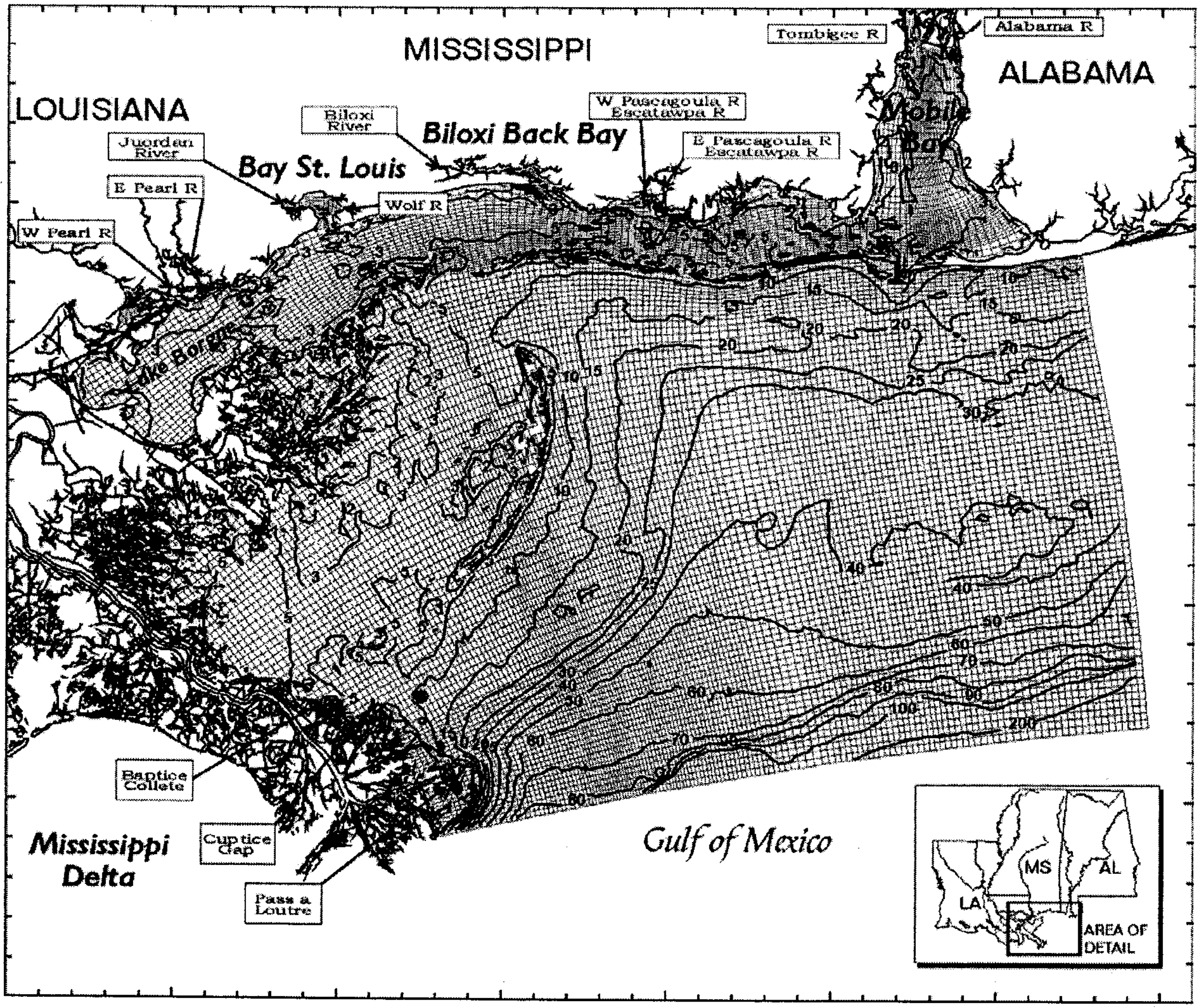

Fig.2. Mississippi Sound and Bight System including Mobile Bay and Bay St. Louis. The contours shown in (m) describe the bathymetric feature of the system. The model is configured with 170 x 122 orthogonal curvilinear grid that resolves the complicated coastline and bathymetry. Note the model has a very high resolution grid in Mississippi Sound and in the Mobile Bay area to resolve their unique coastline and bathymetric features.

grid resolves the bathymetric and coastline features of the region. It permits much finer grid resolution in areas of high interest such as the Mississippi Sound, the bays adjacent to the Sound, and the passes between the barrier islands. This curvilinear grid allows for the design of an efficient and computationally time-effective modeling framework. The southern boundary of the model domain follows the 200m isobath, a natural dynamical barrier between the Mississippi Bight and the rest of the Gulf of Mexico. The eastern boundary is placed perpendicular to the coastal bathymetry.

IV. OBSERVATIONAL PROGRAM AND SIMULATION PERIOD

The NGLI has developed and maintained an operational ocean observing system that is designed to support multi-disciplinary ocean modeling systems. In the current study the modeling simulation period was chosen from July through September of 2000. This time period corresponds to a four-day intensive CTD field observations conducted in September 5-8, 2000 across the Mississippi Sound. The observations conducted during this survey include vertical cast data of temperature and salinity at various locations along five transects across the Mississippi Sound. Fig. 3 illustrates the location and sections at which these CTD field survey were conducted. The present simulation period also spans a Pelican Cruise field program conducted during August 31 through September 14, 2000, covering a much wider spatial domain. These data can be used for model skill assessment for a future study

V. MODEL FORCING CONDITIONS

The forcing data sets that are required by ECOMSED for the calibration period of July through September 2002 come from a variety of sources. The required time-

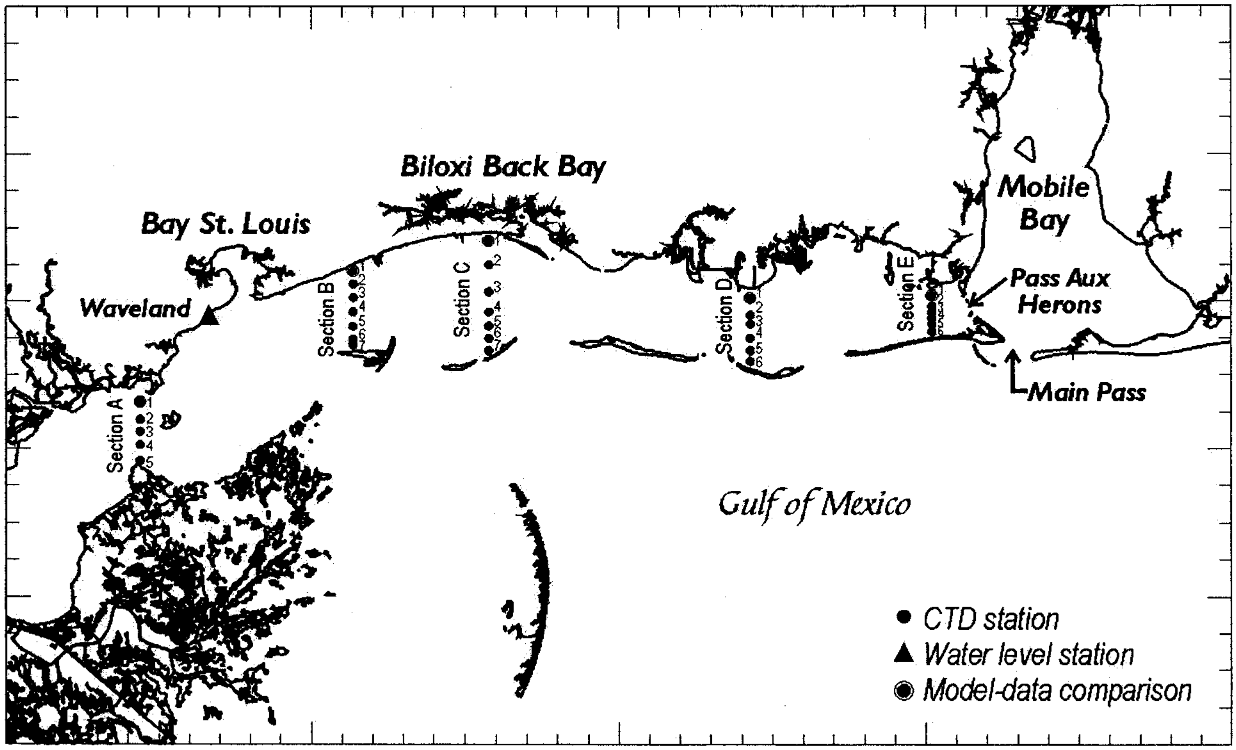

Fig. 3. Four-day intensive CTD survey conducted during Sept. 5-8, 2000 at 31 stations along five sections across the Mississippi Sound. These data form the basis of calibration and validation of the ECOMSED model.

dependent sea surface elevation data at all open boundary locations are specified through a combination of a reconstructed tide levels using the tidal harmonics of the six predominant tidal constituents provided by OSU (Oregon State University tidal model) and the low frequency observed water level variations at Waveland, MS (see Fig. 3 for location). The low frequency water level data measured at Waveland was translated to the open boundary at a reduced factor of 0.75. This factor was determined by performing model simulations to achieve best calibration results against the observed water level data at Waveland.

Time varying temperature and salinity distributions along the open boundaries at depths are derived from the Modular Ocean Data Assimilation System (MODAS) provided by the Naval Oceanographic Office (NAVOCEANO). Freshwater discharges are specified from measurements for the Mississippi River, Mobile River, Pearl River, Pascagoula River, and a few smaller rivers that enter the region. The source of freshwater in the system is illustrated in Fig. 2.

Meteorological forcing is provided by COAMPS, the Coupled Ocean Atmospheric Mesoscale Prediction System (Hodur, 1997). The Mississippi Sound/Bight system retrieves the COAMPS 27-Km forecasts twice daily; uses the micrometeorological atmospheric data fields to compute the heat exchanges, wind stresses and the atmospheric pressures to prescribe surface conditions. COAMPS predicted meteorological parameters such as wind speed and direction, air temperature, relative humidity, were compared against the observed data at Mobile Airport. They were found very consistent during the simulation period.

VI. MODEL CALIBRATION

The aims of this study are to assess the performance of the model to identify the dominant physical processes. Another focus is to assess the model's sensitivity to variations of various modeling input variables such as bathymetry, freshwater flows, wind forcing, temperature and salinity boundary conditions. A series of model simulations were performed for three months from July through September 2000. In order to firmly establish the credibility and robustness of the model, calibration and skill assessment of the model was accomplished by comparing model results with the observed water levels at Waveland, MS and temperature and salinity at five near coast stations at five CTD sections shown in Figure 3. Comparisons of the instantaneous, the low frequency (34-hour low pass filtered), and the tidal band water levels are shown in Figure 4. The model does a good job in predicting the sea level variations at this location. Times of high and low tide, as well as the spring and neap tidal variations are predicted well by the model. Good agreement can be found in water level at different spectral ranges. Harmonic decomposition of model computed and observed water levels at Waveland suggests that the model performance in reproducing each resolvable frequency is good as can be seen in Table 1. It is evident from the table that the model performed very well

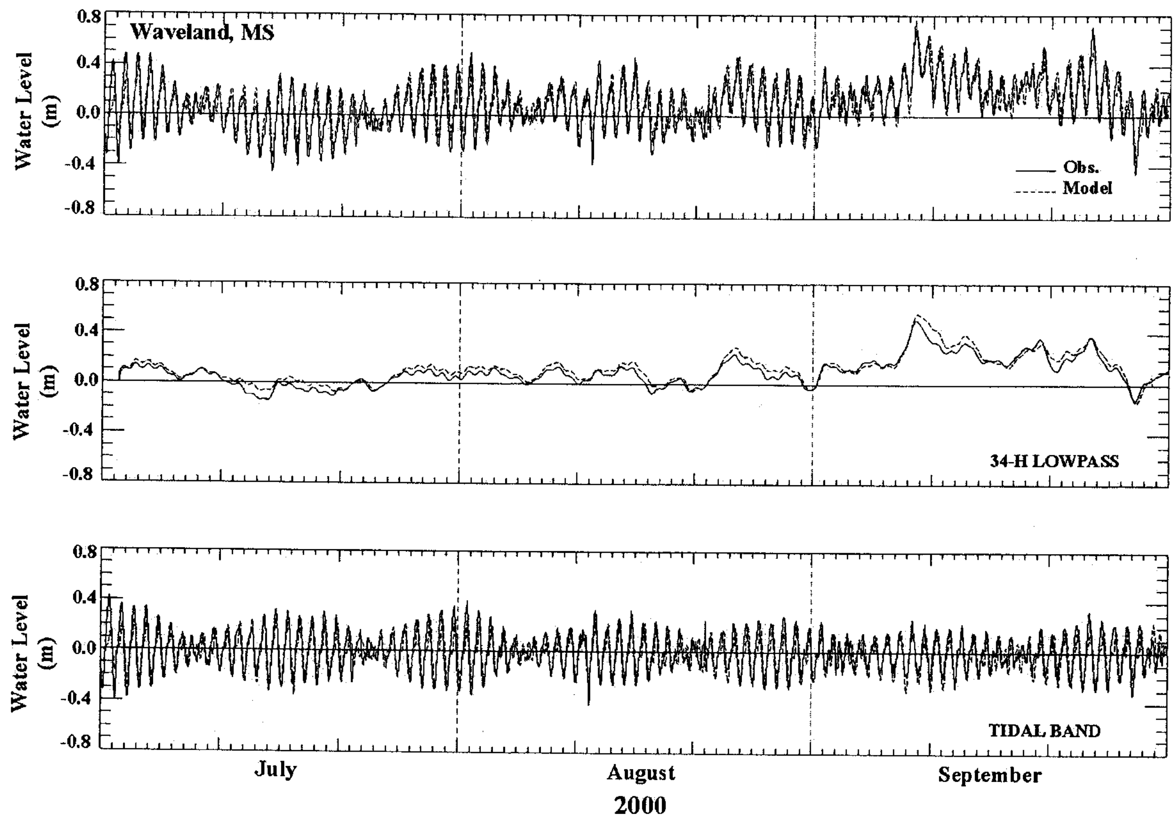

Fig. 4. Comparison of model computed water level against observed data at Waveland, MS. The model seems to predict low frequency (34 hr low pass) and tidal frequency signals very well.

TABLE 1
COMPARISON OF MODEL-DATA TIDAL HARMONICS
(Waveland, MS)

Tidal Constituents	Data		Model	
	Amplitude (cm)	Phase (deg)	Amplitude (cm)	Phase (deg)
K1	14	81	11	95
O1	15	47	14	73
N2	1	199	2	250
M2	3	205	7	260
S2	3	246	2	285

in reproducing diurnal signals, although the model underestimating the low energy semidiurnal signals.

The ability of the model to reproduce the detailed description of the three-dimensional, time-varying circulation and transport of salinity and temperature field is assessed by comparing the model results against the observed CTD data in the Mississippi Sound. The CTD data used for this purpose were collected at five sections during September 5-8, 2002 as shown in Fig. 3. Observed surface and bottom temperature and salinity data at all stations in five sections are compared against the model results. The modeled temperature and salinity fields show good quantitative agreement with observed fields at all five sections as demonstrated by the regression analysis shown in Fig. 5a and Fig. 5b. The model computed temperature and salinity seem to correlate with the observed data very well. In most cases the correlation coefficients (R^2) are 0.8 or more for temperature. For salinity, the correlation coefficients are a bit lower, especially for Sections B, C and E, but are still sufficiently high to establish the credibility of a model. Sections A and D exhibit very low correlations and the model is fresh than the observed data. These two sections are located near freshwater sources for which the model input flow could possibly be overestimated. This underscores the need for a re-evaluation of the procedure adopted for estimating ungaged flow.

Fig. 6a and Fig. 6b illustrate the model temperature and salinity comparisons in a temporal scale during September 1 through 10. The model-data comparisons are shown at five near-coast stations at all five sections. The bottom panel of the plots shows wind vectors. The model seems to reproduce both the temperature and salinity very well. During September 1 through 5 the model reproduces the day and night heating and cooling very well as can be seen in Fig. 6a. During the day time the surface temperature

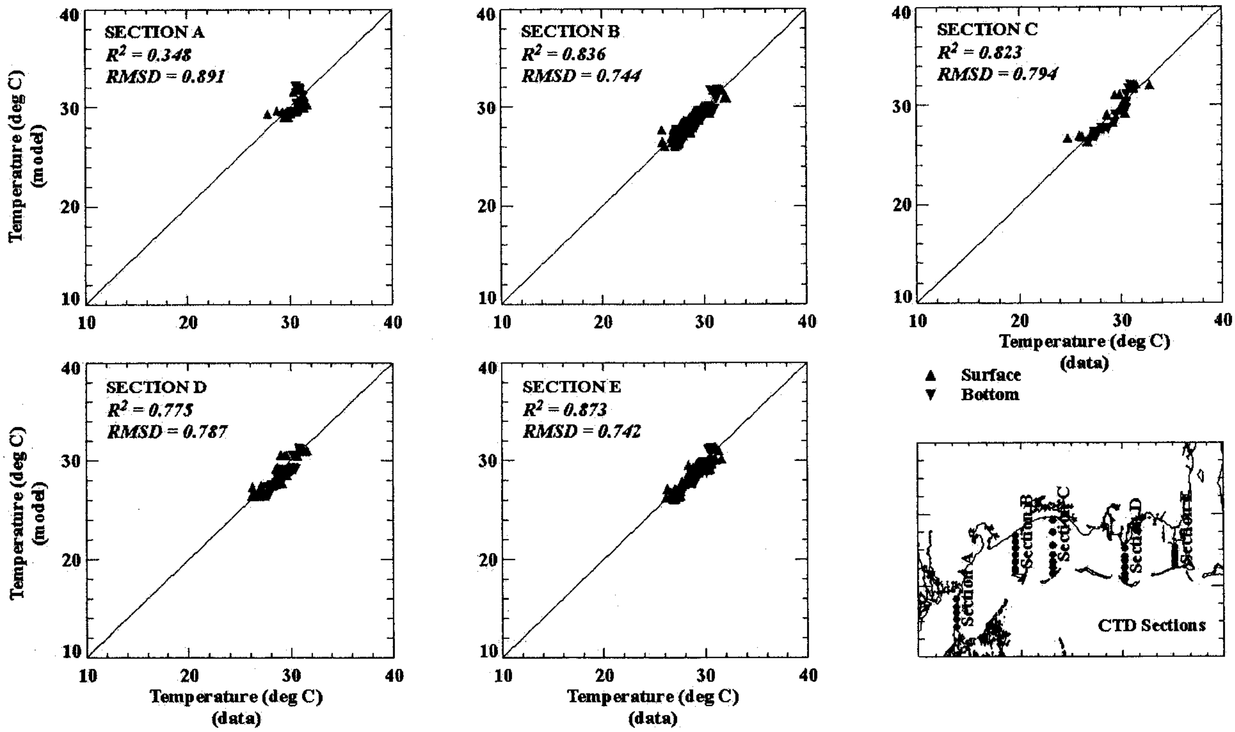

Fig. 5a. Regression of model computed temperature against the observed data at all CTD stations. The regression coefficients (R^2)are generally very high (~0.80), except for section A. The root mean square differences (RMSD) are generally less than 1.0.

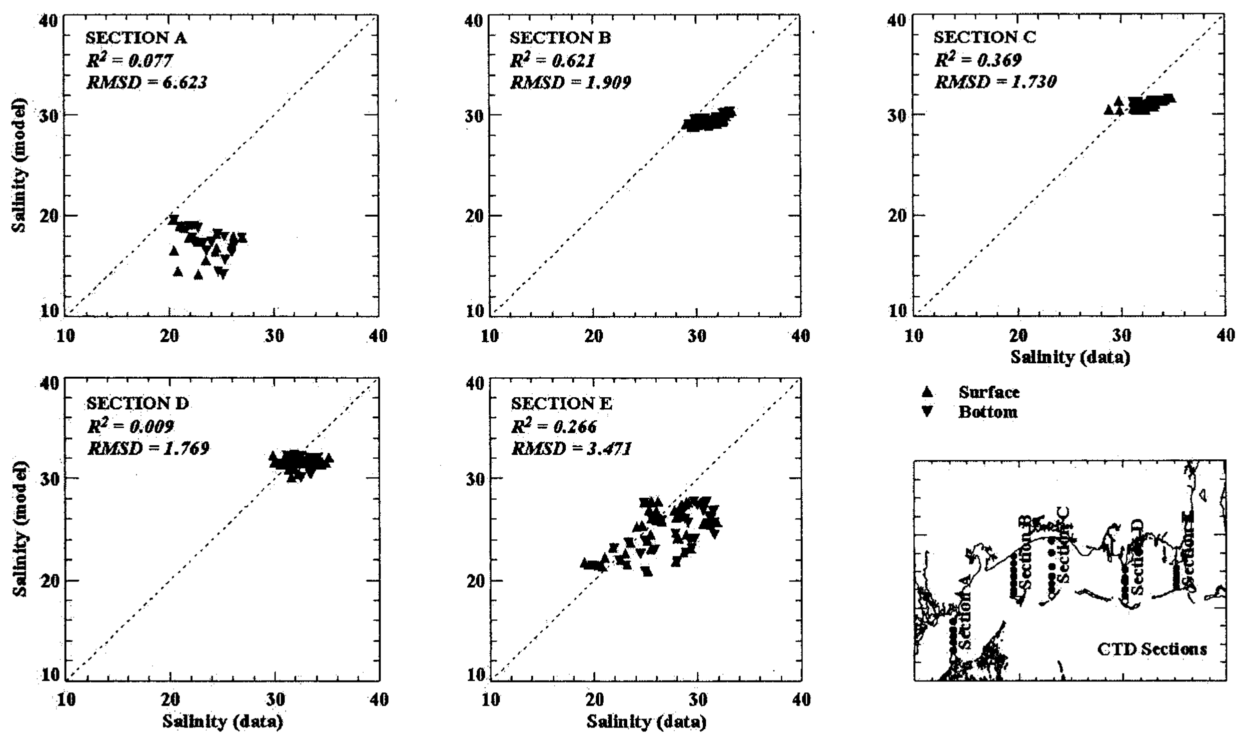

Fig. 5b. Regression of model computed salinity against the observed data at all CTD stations. The root mean square differences (RMSD) are generally less than 2.0 except sections A and E.

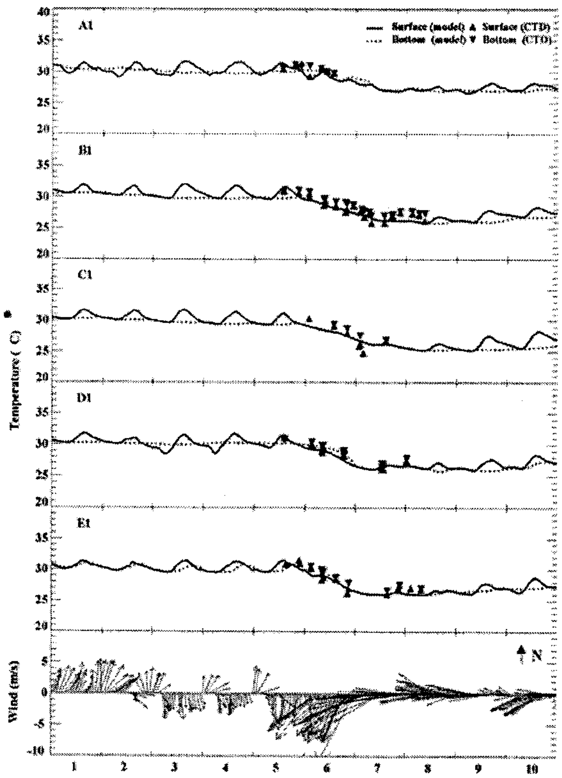

Fig. 6a. Model temperature comparison against observed surface and bottom temperature at selected CTD stations. The bottom panel illustrates the wind vectors during September 1 through 10, 2000. a strong cooling event associated with strong north northeast wind mix the water column top to bottom and drops the temperature over 5°C as can be seen both in observed data and model results.

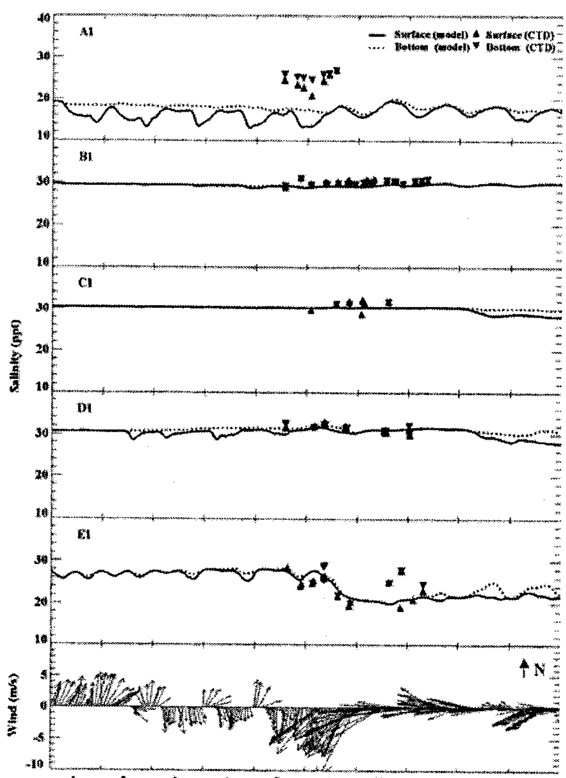

Fig. 6b. Model computed salinity compared against surface and bottom observed salinity at selected coastal stations. Model is very fresh at Station A1 indicating the freshwater inflow through Pearl River is excessive. Cool weather event during September 5-8, 2000 made the water column pretty well mixed.

becomes higher and a strong stratification in temperature develops. However, at night the temperature cools down and the water column becomes well mixed. Some times the surface temperature becomes much cooler than the bottom when the surface heat loss is excessive. There was an intense cooling weather event occurred during September 5 through 8, 2000. During this period the strong north and north-east wind mixed the water column rapidly as can be seen both in the observed data and the model results. During this cooling event the water temperature dropped almost 5°C and the model seems to reproduce this event very well.

The model also seems to reproduce the salinity fairly well as shown in Fig. 6b although the model is fresh near station A1. The model probably is getting excessive freshwater flows from the nearby Pearl River, indicating a need for further investigation on USGS flow measurement and the estimation of flows for un-gauged area. For other stations the model seem to reproduce the data fairly well, especially for the station E1. During September 5-8, 2000 the north and north-east wind event brought the relatively fresher Mobile Bay water in the Mississippi Sound through the Pass Aux Herons (See Fig. 3 for location), which significantly drops the salinity (about 10 ppt) near station E1 as can be seen in the data. The model seems to reproduce the response of the salinity to this event very well.

VII. SENSITIVITY ANALYSIS

Collection of meaningful data sets describing the physical processes of the Mississippi Sound and Bight is expensive and requires a great deal of efforts and resources. These data are required to force and validate the model and therefore reliable and meaningful data sets are vital to the success of the modeling analysis. One of the most important issues that has been focused upon the present study is to develop a mechanism that provides the level of certainty required for the observed data used for driving the model. A highly sensitive parameter that is known with greater certainty may have much less effect on the uncertainty of model results than a much less sensitive parameter with high degree of uncertainty. A first-order variance analysis (FOVA) is applied to analyze the model predicted variances in various parameters due to uncertainty in model input parameters (basic variables).

FOVA application provides insight to the model performance in terms of key parameters and the overall model prediction uncertainty. This analysis is based on an established methodology used by a number of researchers (Porter et al., 1999; Melching et al., 1996). The methodology determines the sensitivity of model results in terms of the variances in model predictions due to a perturbation introduced in each basic variable, which is the input to the model. The variances in model output is determined as follows:

$$\mathrm{Var}(C) = \sigma_c^2 = \sum_{i=1}^{p}\left[\left(\frac{\Delta g}{\Delta x_i}\right)_{X_m}\sigma_i\right]^2 \qquad (1.1)$$

Var = Variance

C = Concentration of the parameter simulated in the model;

σ_c = Standard deviation of C;

g = Functional representation of the procedures simulating constituent C in the model;

x_i = Basic variable;

σ_i = Standard deviation of basic variable x_i;

p = Number of basic variables x_i;

X_m = Vector of mean values of the basic variables

$$\frac{\Delta g}{\Delta x_i} = \frac{g_{sensitivity} - g_{base}}{x_{i,sensitivity} - x_{i,base}} \qquad (1.2)$$

term $\frac{\Delta g}{\Delta x_i}$ represents temporal and spatial average.

The base case for this analysis is one that provides the highest degree of model calibration using the best known model forcing functions. Three-dimensional, time-varying circulation, temperature and salinity fields, and fluxes across some selected transects were archived. A series of model simulations are then performed allowing small perturbations in the basic variables. The basic variables considered are winds, river flows, bathymetry, boundary temperature and salinity. A total of eleven experiments with small perturbations in basic variables have been considered. Among these, three simulations were conducted using 25% more winds, 25% less winds and 25% random winds; two simulations with reduced and increased freshwater flows by a factor of two; two simulations using ETOP05 (5′ resolution) and 2 km resolution bathymetry; two simulations, each for salinity and temperature, prescribing boundary conditions flipped in time, i.e., from September to July backward and using the levitus climatology. The details of the perturbation introduced in the basic variables are listed in Table 2. In all these eleven experiments model simulations were performed for the same period as the base case and all the three-dimensional descriptions of circulations and temperature and salinity fields were archived. Using the results from these series of model simulations, variances in model prediction in temperature and salinities at seven regions representing different hydraulic regimes across the Mississippi Sound, Mobile Bay and Mississippi Bight were calculated using (1.1). These regions are shown in Fig. 7. Fig. 7a and Fig. 7b show the percent contribution of variances in temperature and salinity predicted by the model at various regions due to the perturbations introduced in the basic variables.

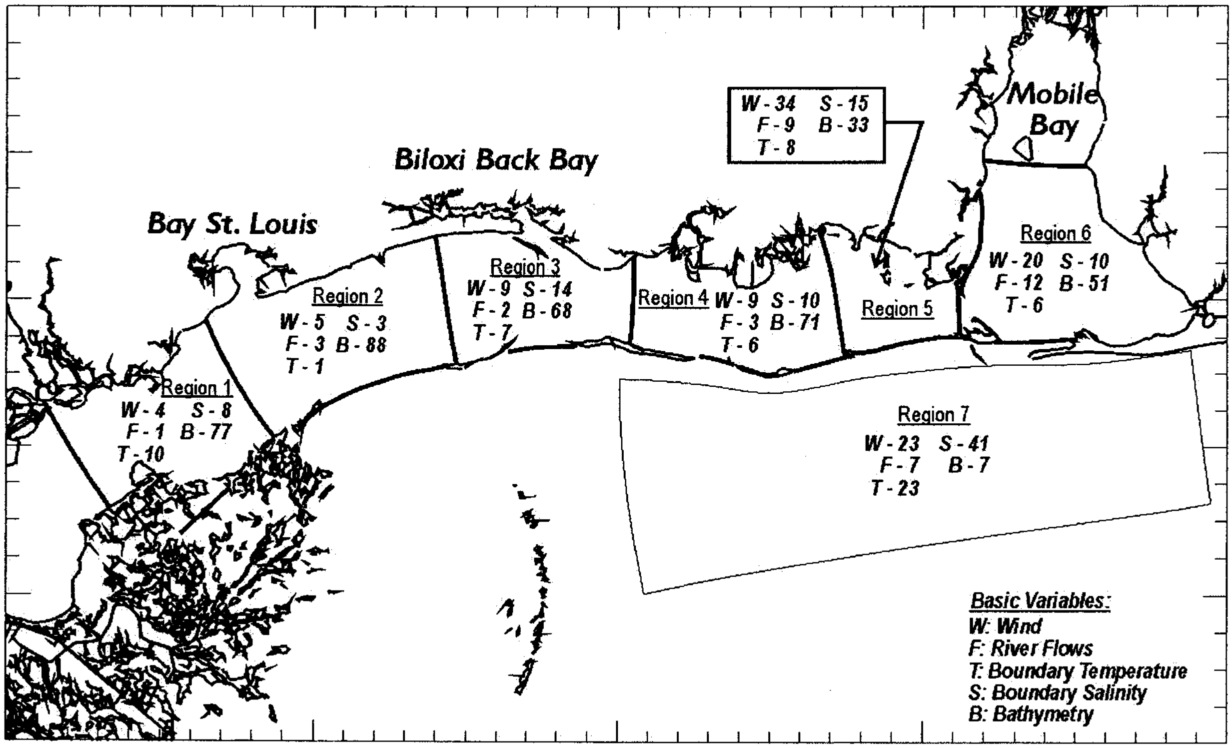

Fig. 7a. Percent contributions of basic variables (indicated by numbers against basic variables) to variances in model temperature in August-September, 2000 at various regions representing Mississippi Sound, Bight and Mobile Bay.

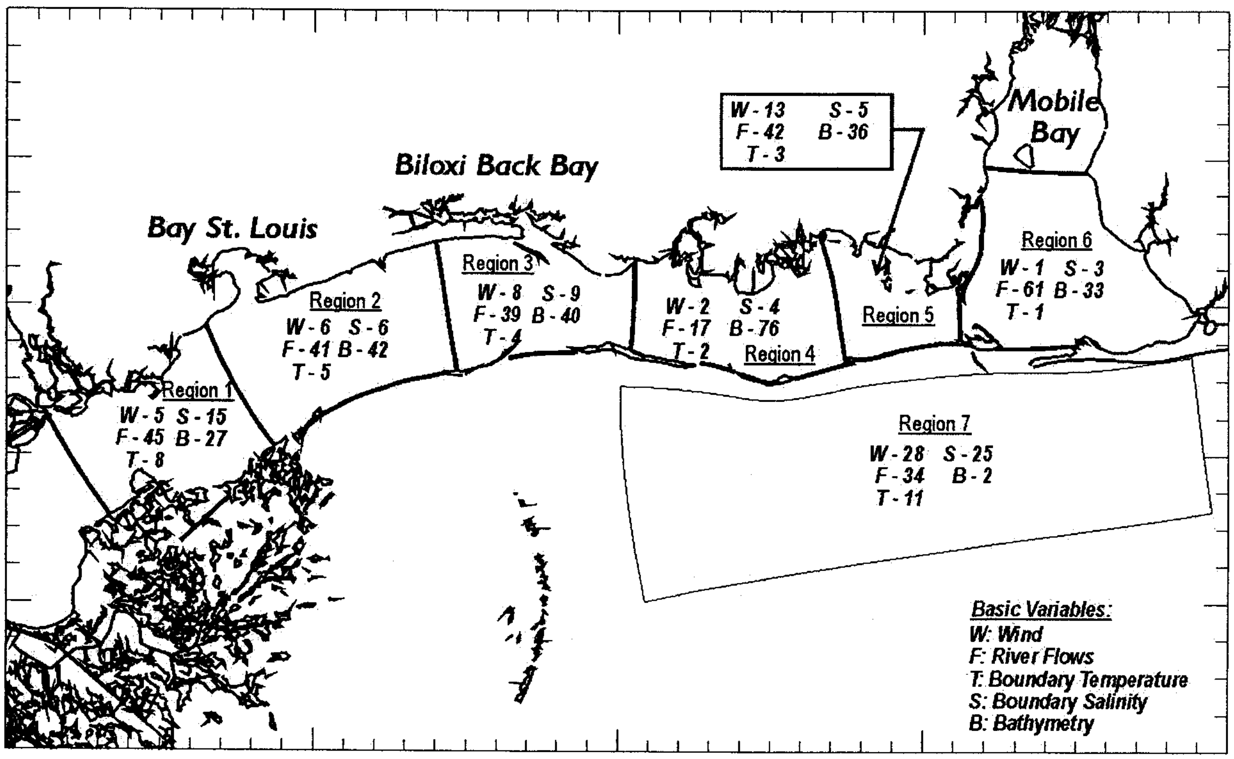

Fig. 7b: Percent contributions of basic variables (indicated by numbers against basic variables) to variances in model salinity in August-September, 2000 at various regions representing Mississippi Sound, Bight and Mobile Bay.

TABLE 2
SENSITIVITY ANALYSIS OF MODEL PREDICTION TO VARIOUS FORCING FUNCTIONS

No	Basic Variables	Perturbation
1	Winds	a) 25% More Wind
		b) 25% Less Wind
		c) 25% Random Wind
2	Flows	a) Half of USGS Flows
		b) Double of USGS Flows
3	Bathymetry	a) ETOPO5 (5' Resolution)
		b) 2 Km Resolution
4	Boundary Conditions (Temp)	a) Flip in Time
		b) Levitus Climatology
5	Boundary Conditions (Salinity)	a) Flip in Time
		b) Levitus Climatology

The model seems to be extremely sensitive to the bathymetry and freshwater flows. In particular in the shallower Mississippi Sound area the model is extremely sensitive to bathymetry and its contribution to variances both in temperature and salinity could be as high as 88% among other basic variables. Temperature in the Mississippi Sound does not seem to be sensitive to the freshwater flows. However, salinity is found to be very sensitive. For example, contribution of freshwater flow to variances in salinity could be as high as 61% among other basic variables in Mobile Bay region and as high as 45% in the Mississippi Sound region. Sensibility of the model prediction to the wind is very low in the Mississippi Sound region. Sensitivity of various basic variables in the offshore region 7 (See Fig. 7) is, however, quite different than the shallower Mississippi Sound regions. Winds, freshwater flows, boundary salinity and temperature play significant roles in the variances in temperature and salinity in the offshore region 7. On the other hand the model prediction is found to be less sensitive to the bathymetry in the offshore region 7 (Fig. 7).

VIII. CONCLUSIONS

The time variable, three-dimensional hydrodynamic model ECOMSED has been configured to the Mississippi Bight and Sound and adjoining estuaries and bays. A fairly high resolution NGLI domain has been configured. The Mississippi Bight/Sound model seems to reproduce the overall circulation and mixing characteristics of the area based on the reasonably good model result to data comparisons. The sensitivity analyses reveal that the model is very sensitive to the bathymetric resolution and the freshwater inflows. Therefore careful consideration should be given to model inputs especially for bathymetry and freshwater inflows. The calibrated and validated Mississippi Sound/Bight model is capable of predicting the oceanographic conditions of the Mississippi Sound, Bight, adjoining bays and rivers.

ACKNOWLEDGMENTS

This work was supported through cooperative programs for coastal ocean research and management at the University of Southern Mississippi and by joint funding from the Gulf of Mexico Program Office of the USEPA (Cooperative Agreement No. MX984633-99-0) and the Commander, Naval Meteorology and Oceanography Command, Stennis Space Center, MS, (Contract No. N62306-01- D-BOO01-0002). The authors thank Carl Szczechowski of NAVOCEANO and Robert Willems of the University of Southern Mississippi for sharing their insight into the dynamics of littoral waters and for their dutiful project management.

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