

*Reprinted from Estuarine and Coastal Modeling
Proceedings of the Seventh International Conference
American Society of Civil Engineers
Held November 5-7, 2001, St. Petersburg, Florida*

**NORTHERN GULF OF MEXICO LITTORAL INITIATIVE MODELING
PROGRAM**

Quamrul Ahsan¹, Charlie N. Barron², John Blaha³, Alan F. Blumberg^{1, 4}, Pat J. Fitzpatrick⁵, Derrick Herndon⁵, H. James Herring⁶, Y. Larry Hsu², Timothy R. Keen², Honghai Li¹, Yongzuo Li⁵, Richard C. Patchen⁶, Carl Szczechowski³, Robert Willems⁷ and Patrick Wilz⁸

ABSTRACT

The Northern Gulf of Mexico Littoral Initiative (NGLI) was established by the US Navy and the US Environmental Protection Agency to create a state-of-the-art ocean observing and forecasting system for the waters of the Mississippi Sound/Bight and adjoining estuaries and bays. The goal of NGLI is to become a sustained cooperative multi-agency effort that will use model forecasts and observational data for military training and coastal resource management. The focus forecasting system consists of triply nested, three-dimensional circulation models, a cohesive and non-cohesive sediment transport model, and a wave model. This system will provide a reliable means to forecast littoral circulation, sediment suspension and transport, surface waves and water quality constituents. The nested models begin with a global model that drives a Gulf of Mexico model which in turns drives a very high horizontal resolution Mississippi Sound/Bight model. An atmospheric circulation model provides the required meteorological forcing for the Mississippi Sound/Bight modeling system. Currents, temperature, salinity, turbidity,

¹ HydroQual, Inc., One Lethbridge Plaza, Mahwah, NJ 07430

² Oceanography Division, Naval Research Laboratory, Stennis Space Center, MS 39529

³ Naval Oceanographic Office, Bldg. 1002, Stennis Space Center, MS 39529

⁴ Corresponding author

⁵ Engineering Research Center, Mississippi State University, Stennis Space Center, MS 39529

⁶ Dynalysis of Princeton, 219 Wall Street, Princeton, NJ 08540

⁷ USM Institute for Marine Sciences, Building 1103, Stennis Space Center, MS 39529

⁸ Planning Systems, Inc., MSAAP, Bldg. 9121, Stennis Space Center, MS 39529

remotely sensed data, conventional meteorology data, and scatterometer winds are being collected for model validation via an extensive near real-time data collection network.

1.0 INTRODUCTION

The Northern Gulf of Mexico Littoral Initiative (NGLI) is a multi-agency program established through a partnership between the Commander, Naval Meteorology and Oceanography Command and the US Environmental Protection Agency's Gulf of Mexico Program Office. The goal of NGLI is to produce a sustainable comprehensive modeling and observational system for the Mississippi Sound and Bight area that functions as both an operational Navy product and a research tool used to foster a sustained economic growth with managed environmental resources of the Gulf Coast. The program integrates a calibrated/validated coastal ocean modeling system and timely meteorological forecasts with in-situ and remotely sensed observations. The products of NGLI are available to a wide range of users in near-real time.

NGLI is organized around five functional components: modeling, in-situ and remote sensing observations, data distribution and outreach. Figure 1 illustrates the functional components of the NGLI program and contains a list of all project participants. The current paper will focus only on the modeling systems. The observing system will be discussed as it applies to the model calibration/validation plan (see Section 3). Information on the overall NGLI program can be found in Carroll and Szczechowski (2001).

2.0 MODELING COMPONENTS

The NGLI modeling mission is to produce a sustainable resource for multidisciplinary ocean forecasting for the Mississippi Sound/Bight, and through this effort, to obtain a prototype for Naval marginal sea forecasting. The modeling system is designed to provide reliable and timely meteorological and oceanographic nowcasts/forecasts not only for the MS Sound/Bight but also for the adjoining rivers and estuarine systems such as Mobile Bay, Biloxi Back Bay and Bay St. Louis. The modeling suite consists of triply nested three-dimensional circulation models (global ocean, Gulf of Mexico, and Mississippi Sound/Bight), a sand-silt sediment transport model, an atmospheric model, and wave/surf models. Figure 2 illustrates the nested hierarchy of models. The various model components that form the basis for the modeling system are shown in Figure 3, each of which will be discussed herein.

2.1 Global Ocean Model

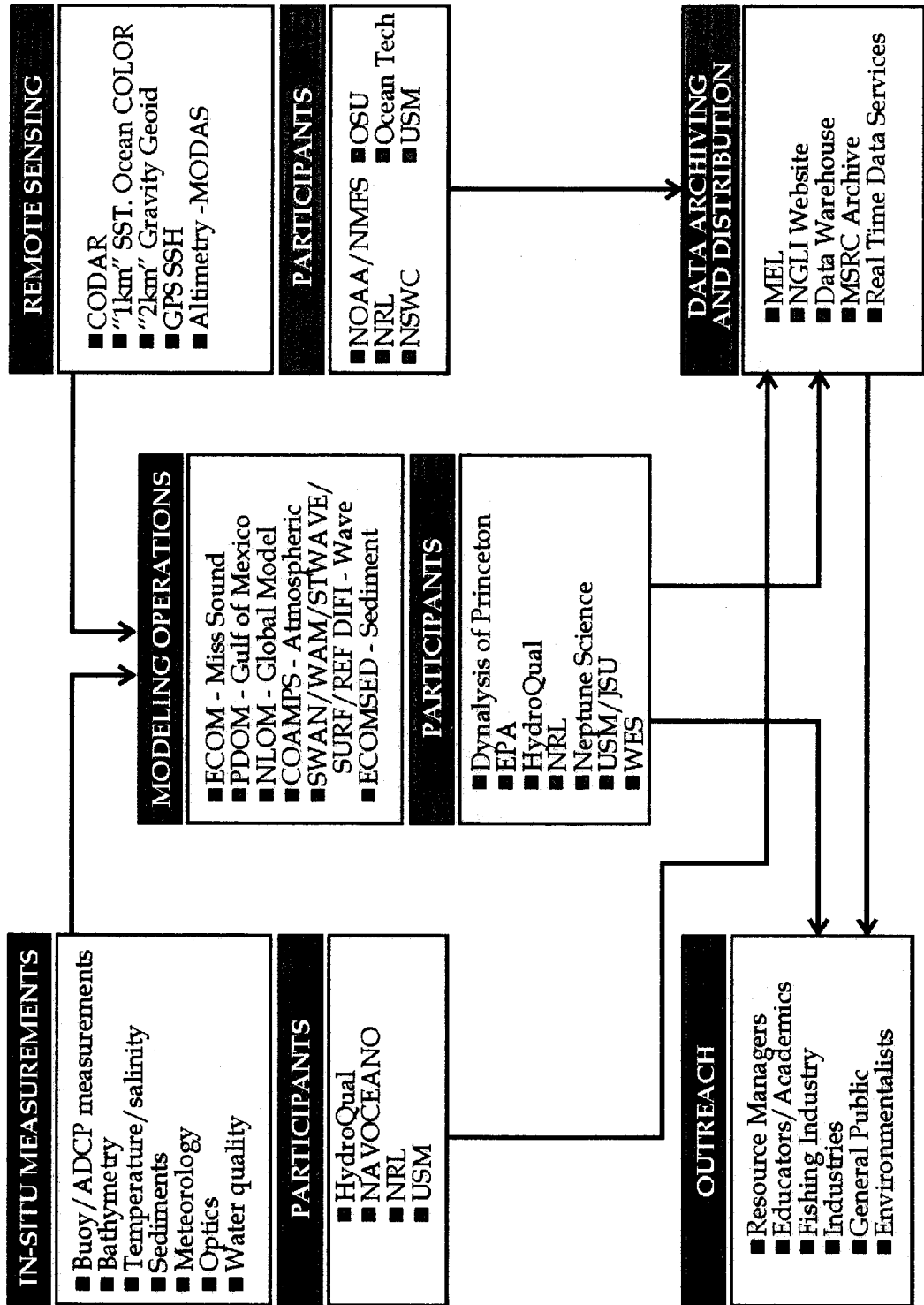


Figure 1. The five functional components of the NGLI program. The Project participants are listed under their respective component.

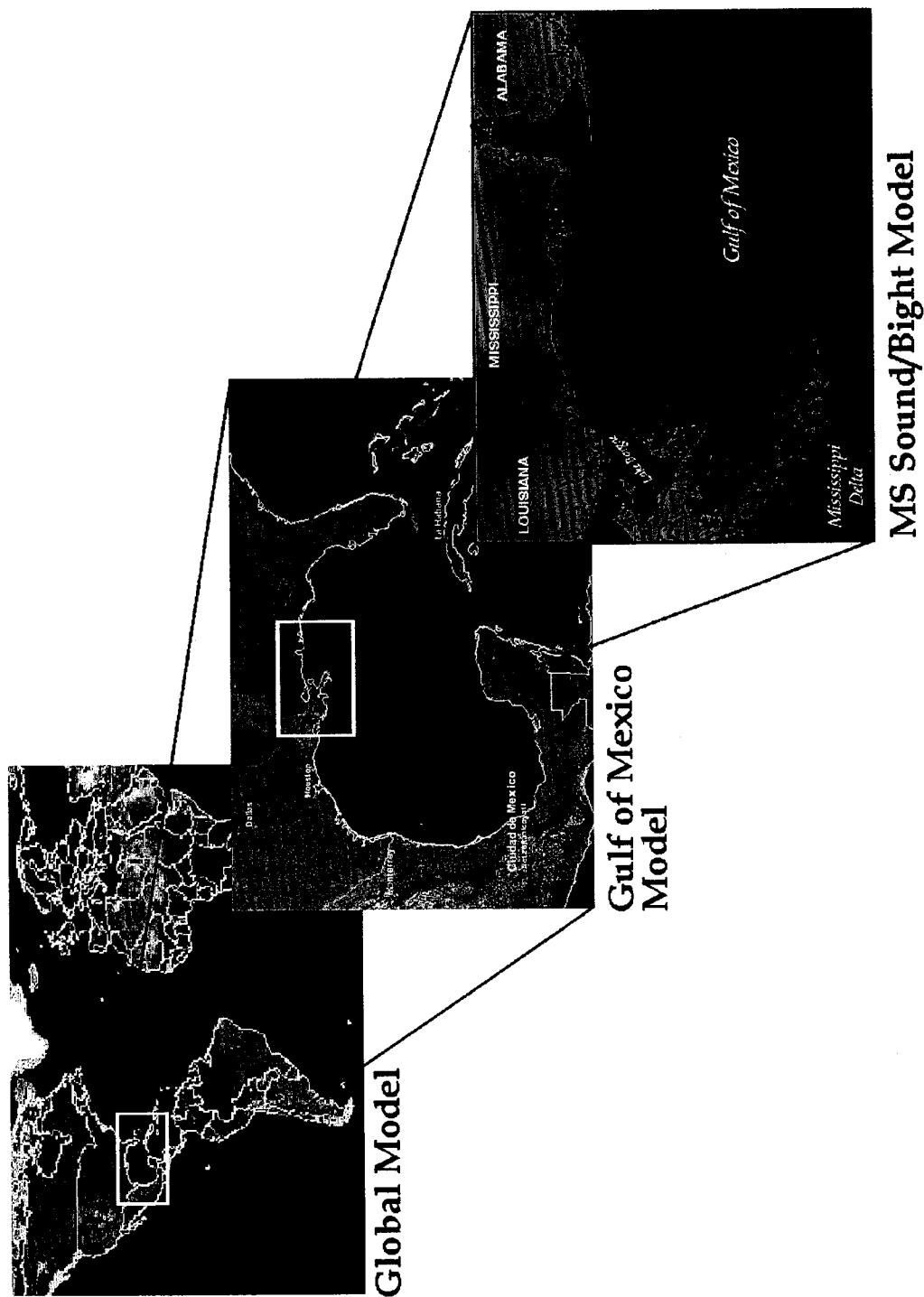


Figure 2. The triple nested hierarchy of circulation models forming the NGLI ocean modeling system.

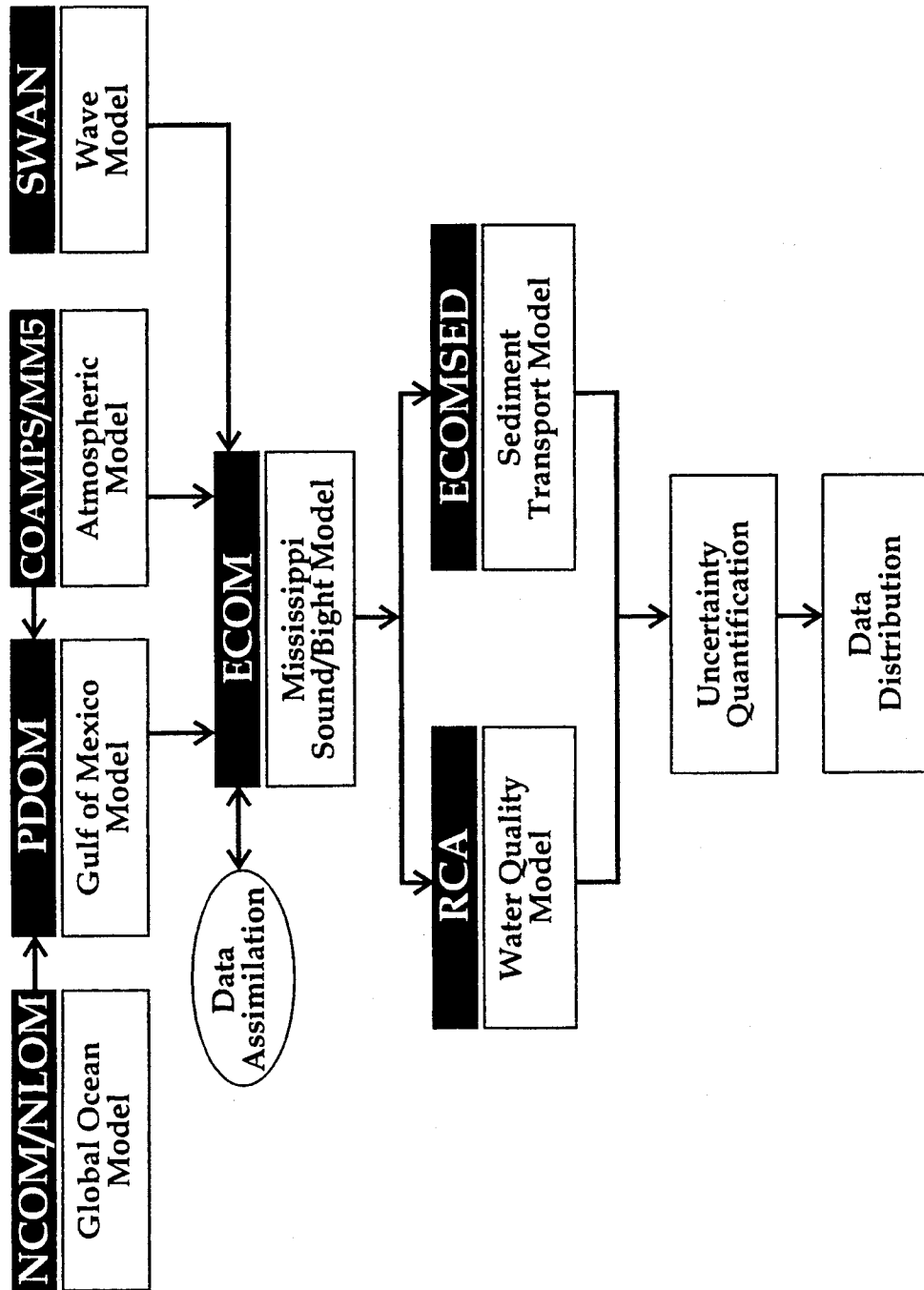


Figure 3. The various models in the NGLI ocean modeling system.

The planned global ocean model is NCOM, the Navy Coastal Ocean Model (Martin, 2000). It is presently configured on a curvilinear 2048x1280 horizontal grid that covers the global ocean to depths of 5m with nominally 1/8 degree midlatitude resolution, coarser toward the equator and finer toward the poles. The vertical implementation uses 19 sigma coordinates in the upper ocean over 22 (21 active) z-level (constant depth) coordinates in the lower ocean, with transition between sigma and z near 138m. The vertical coordinate is logarithmically stretched to provide minimum upper level thickness of 1m at maximum bottom depth of 5500m. Because global NCOM is not yet fully transitioned to operational status, NGLI will rely for the near future on NLOM, the Navy Layer Ocean Model (Hurlburt, et al., 1992). It is implemented on a grid that covers the global ocean with 1/16 degree resolution. The vertical direction is resolved with 6 equally spaced σ -levels. The global NLOM is run daily with atmospheric forcing from the Navy Operational Global Atmospheric Prediction System (NOGAPS) and assimilation of sea surface temperature data and satellite altimeter data via the Modular Ocean Data Assimilation System (MODAS) protocol (three-dimensional distribution of temperature and salinity, which are calculated from correlations of the satellite sea surface height (SSH) and sea surface temperature (SST) anomalies with the subsurface density structure, (Carnes, 1999).

2.2 Gulf of Mexico Model

A basin-wide three dimensional circulation model of the Gulf of Mexico has been developed using PDOM, the Princeton-Dynalysis Ocean Model (Herring and Patchen, 1999). The gulf domain extends into the western Caribbean and to the northern limits of the Florida Straits. The model employs an orthogonal, curvilinear grid with horizontal resolution which enables realistic simulation of eddies 50 km in diameter and larger. The model is configured with 37 sigma levels in the vertical, with sufficient resolution placed in the near-surface and near-bottom to resolve boundary layers and resolution through the remainder of the water column to resolve the MODAS profiles of temperature and salinity.

The operational Gulf-wide nowcast/forecast model produces two 48-hour forecasts a day and a month-long forecast each week. Meteorological forcing is provided by COAMPS, the Coupled Ocean/Atmospheric Mesoscale Prediction System (Hodur, 1997). The system retrieves the COAMPS 27-km forecasts twice daily; uses the fields to compute the wind stresses and the atmospheric pressures to prescribe surface conditions; and also retrieves all available real-time river discharge data along the Gulf coast from the U.S. Geological Survey (USGS) to be imposed as coastal boundary conditions. The lateral forcing functions for this model will first utilize results from the global NLOM and then the global NCOM.

Data assimilation is implemented using MODAS. While the MODAS fields are available at daily intervals everywhere in the Gulf, the correlations are less

accurate further from the center of the satellite ground track where the satellite measures the SSH and also less accurate the longer the time since the last satellite over flight. Furthermore, the SSH correlation is less accurate on the well-mixed continental shelf. A weighting function, which reflects this temporally and spatially varying confidence, is used to select the portions of the MODAS fields used for assimilation into the model, as shown in Figure 4 (Blaha et al., 2000).

2.3 Mississippi Sound/Bight Model

The Mississippi Sound and Bight model is built with the three-dimensional circulation model, ECOM (Blumberg et al., 1999). ECOM is the estuarine and coastal ocean version of the Princeton Ocean Model of Blumberg and Mellor (1987). Within ECOM are a cohesive and non-cohesive sediment transport submodel (SED), and a fate and transport capability coupled with HydroQual's state-of-the-art water quality model (RCA). Together these models are used as a basis to forecast littoral circulation, sediment suspension and transport, and water quality constituents. The model is driven by mechanisms that include hydrographical (freshwater inflow), meteorological (surface wind), and open ocean (large-scale ocean circulation) forcing functions.

The MS Sound/Bight model represents the highest spatial resolution component of the triple-nested series of three-dimensional circulation models. At its eastern and southern boundaries, the MS Sound/Bight model is coupled to the regional Gulf of Mexico model in a manner that ensures that energy transfer between the two models is consistent. Figure 5 illustrates the coupling of the MS Sound/Bight and gulf-wide computational grids.

The NGLI also utilizes the Advanced Circulation Model (ADCIRC) (Westerink et al., 1994), a finite element circulation model, to generate tidal components with a very high level of accuracy within the Mississippi Bight and Sound. This accuracy is necessary for calculating the tidal signal in airborne and satellite altimetric determinations of sea surface height, and provides a method by which to remove the effects of tidal velocity from underway Acoustic Doppler Current Profiler (ADCP) measurements.

2.4 Atmospheric Model

The meteorological forcing for the NGLI oceanographic models is provided twice a day by COAMPS. COAMPS is configured with a coarser mesh of 27-km covering much of the southern U.S. and northern Gulf of Mexico, and a higher-resolution 9-km mesh (covering the Louisiana, Mississippi, and Alabama Gulf Coast) is imbedded in the coarse mesh. Only a one-way nest is used to simplify the validation studies, and to provide faster operational runs. Initial and boundary

conditions were provided by NOGAPS in a "cold-start" mode for 0000 and 1200 hour runs. Running COAMPS in data assimilation mode, using its Multivariate Optimal Interpolation Scheme, is scheduled for December 2001. The Land-Use mask for ground wetness, albedo, and surface roughness consists of 0.01° climatological data from the U.S. Geological Survey.

Currently, COAMPS is only available for serial and shared-memory architecture, and not for distributed memory computers, restricting the scope of atmospheric modeling for mesoscale analysis. As a result, a second meteorology model, the Fifth Generation Mesoscale Model, or MM5 (Dudhia et al. 2000), is being run for additional operational and research analysis. Operational 9-km runs, covering the entire Gulf of Mexico and Caribbean Sea, are being provided to NGLI researchers.

2.5 Wave Model

The primary wave model used in the NGLI program is SWAN (Simulating Waves Nearshore), a model capable of simulating wave evolution in coastal areas (Booij et al., 1999). SWAN includes wind wave generation, wave shoaling, refraction, nonlinear interactions, depth-induced breaking, wave-current interaction, and bottom friction and whitecapping dissipation. SWAN has been shown to provide accurate wave prediction in the Mississippi Bight area (Hsu et al, 2000). SWAN is currently running twice daily for 48 hours forecast at a 500-m spatial resolution. COAMPS wind fields and regional WAM (WAve Model) directional wave spectra are used to drive SWAN.

3.0 PROGRESS

Progress achieved to date has seen significant improvements in our understanding of the Mississippi Sound/Bight oceanography and in our ability to model it. That progress will be discussed next.

3.1 Background Model Studies

Several preliminary modeling studies have been completed within the NGLI area, including circulation and sedimentation studies (Keen, 2000; Bentley et al., 2001; Keen et al., 2001). Several sediment cores have had geochemical and sedimentological examinations completed. These tests have revealed the presence of as many as two sandy layers that appear to have been deposited by hurricanes. The origin of these beds by hurricanes has been studied using a linked model system similar to ECOMSED. These studies have focused on the deposition of the sand bed during storms permitting an understanding of event sedimentation patterns within the region. A second preliminary study has examined the variability of waves and steady

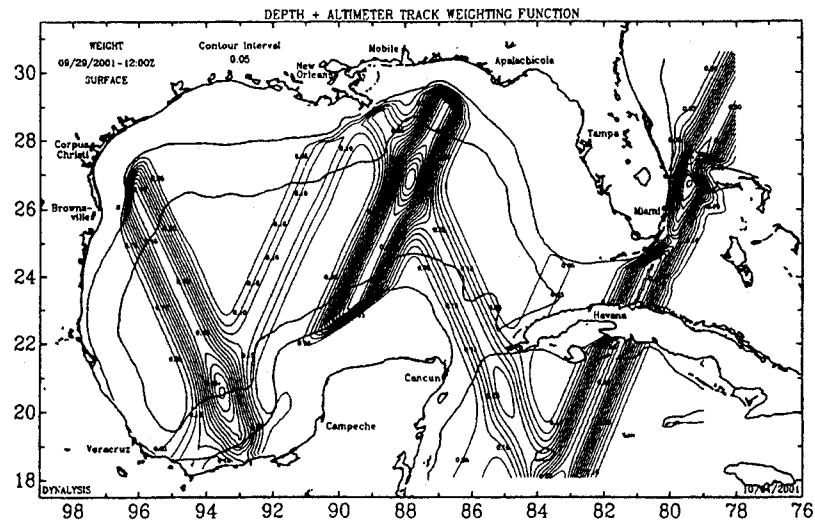


Figure 4. The spatial weighting function for the assimilation of the MODAS temperature and salinity fields for a nowcast of Sept. 29, 2001.

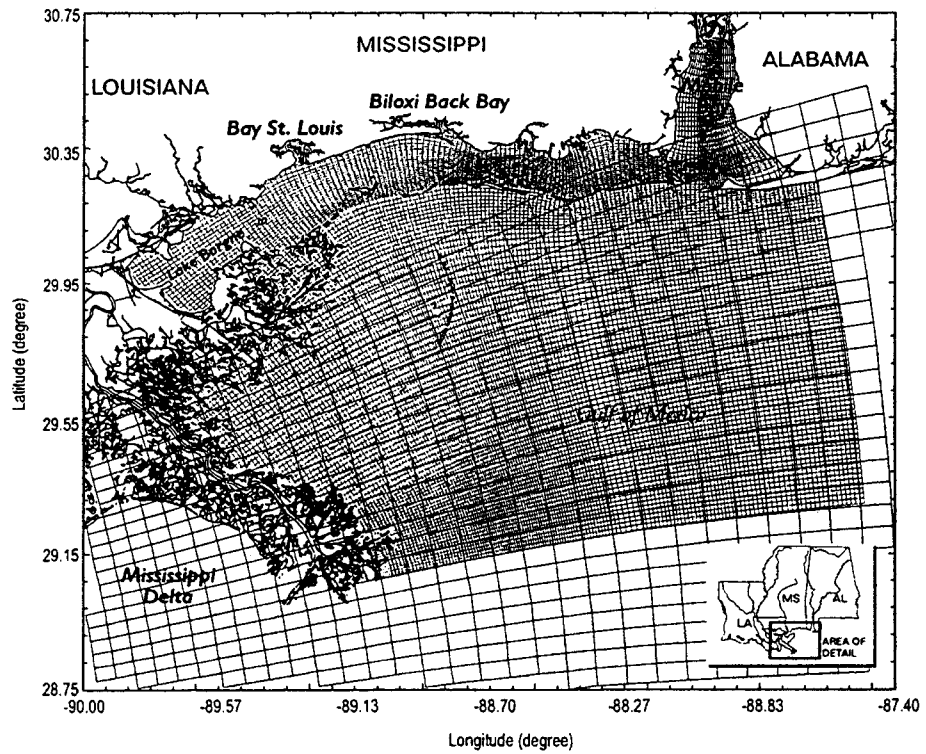


Figure 5. The computational grid of the Mississippi Sound/Bight model and the overlap portion of the Gulf of Mexico model grid. The grid alignment facilitates model information exchange.

currents within the area during a winter cold front passage (Keen, 2001). This study suggests that long-term erosion of the barrier islands is strongly influenced by episodic sedimentation during these weak meteorological systems, which erode the sound sides of the islands and deposit material in the inlets and the central part of the sounds. These modeling studies suggest that the barrier islands are in fact being removed by both catastrophic and “normal” sedimentation processes. Additional studies are examining the effect of the resuspension of mixed sand-clay sediments on the optical properties of the estuarine waters.

Studies are also in progress to determine the best way to initialize models that are set up to run in littoral waters like those of the NGLI. The idea is to use as few as one recent temperature profile or climatological profiles in conjunction with remotely sensed information to construct initial temperature fields. Since the SST can be estimated from high resolution satellite data, the following simple formula can be used to generate profiles at each model grid point and thus a three-dimensional temperature distribution:

$$T(x, y, z) = \frac{T_s(x, y) - T_B}{1 + 1.76 \cdot \exp(z/D)} + T_B \quad (1)$$

where T_s = surface temperature, T_B = bottom temperature, D = depth of mixed layer, and z = depth below surface. The surface temperature will come from the spatially abundant SST measurements, the bottom temperature and the mixed layer depths will come from the profile information or the climatological data set. Unfortunately, no similar procedure is available for salinity, and it must be estimated from available data or measured prior to model operation.

3.2 COAMPS Horizontal Resolution Sensitivity Experiments

In addition to providing meteorological forcing to the ocean and wave models, another goal of NGLI is to assess the impact of high-resolution COAMPS wind output in the littoral region compared to the coarser 27-km output. An analysis of 12 simulations during 14-20 December 2000 (Mostovoi et al., 2001), shows distinct differences in 10m model winds between the 9- and 27-km COAMPS runs along the immediate coastlines. The 27-km run overpredicts the wind speeds along the coastal interface, particularly over the mouth of the Mississippi River, and in general does not capture the transition from land to ocean as well as the 9-km run, and has a nocturnal bias. The improved 9-km coastal winds can be attributed to how COAMPS computes surface roughness values. The impact on winds is strongest at night, when the atmosphere is stable and the Richardson number is positive; during the day, when the Richardson number becomes negative, the Businger-Dyer relationships include mixing, which negates the impact of the improper roughness lengths. Other findings in the 27-km versus 9-km comparison show:

- better representation of land/sea breeze flows in the 9-km COAMPS,
- a definite tendency for speed underprediction in both models when wind speed exceeds 6 m/s. At the same time, both models demonstrate a persistent overestimation of wind speed for observed weak winds less than 2 m/s and
- an underestimate of latent and heat fluxes in deep water for both model resolutions.

3.3 Mississippi Sound/Bight Model Calibration Plan

The NGLI maintains an operational ocean observing system that is being optimized to support multidisciplinary ocean modeling. Figure 6 illustrates the nine surveys, 10 to 15 days in length, conducted in the Mississippi Bight region to collect oceanographic and geophysical data in support of the NGLI. In addition, one 3-day small-boat field campaign was conducted within Mississippi Sound during a period of low freshwater inflow conditions. Observations and samples obtained during the surveys included sediment core and grab samples, underway ADCP measurements, and profiles of conductivity and temperature. Figure 7 illustrates the observed surface salinity and temperature distribution in the Mississippi Sound during August 2000. The fields are constructed by using the modern variational interpolation method developed for the analysis of the NGLI profile data (McIntosh, 1990). The Mississippi Sound/Bight model will be run for the period encompassing the surveys of February and August 2000 and the small-boat field campaign. The observations will be then compared with the model results. A challenge for the modeling system will be to reproduce the considerable spatial structure found in Mobile Bay. Water level data from other agencies that is routinely gathered by the NGLI will also form part of the model calibration process. The calibration emphasizes on the Mississippi Sound and the passes between the barrier islands.

3.4 Wave Model Calibration Plan

The observing system has been collecting data relevant for calibrating/validating the SWAN model since September 2000. The major sources of data are the two NDBC buoys (see Figure 6) which were upgraded to directional wave sensors. They provide long term data. Short term wave data has also been gathered from various wave gages at locations inside and outside the Mississippi Sound (see Figure 6).

4.0 OPERATIONAL FORECASTING SYSTEM

All of the simulations of the NGLI models are performed and archived on the Major Shared Resource Center (MSRC) high-performance computers resident at NAVOCEANO. Model hindcasts and forecasts are produced twice daily, at 0000 and

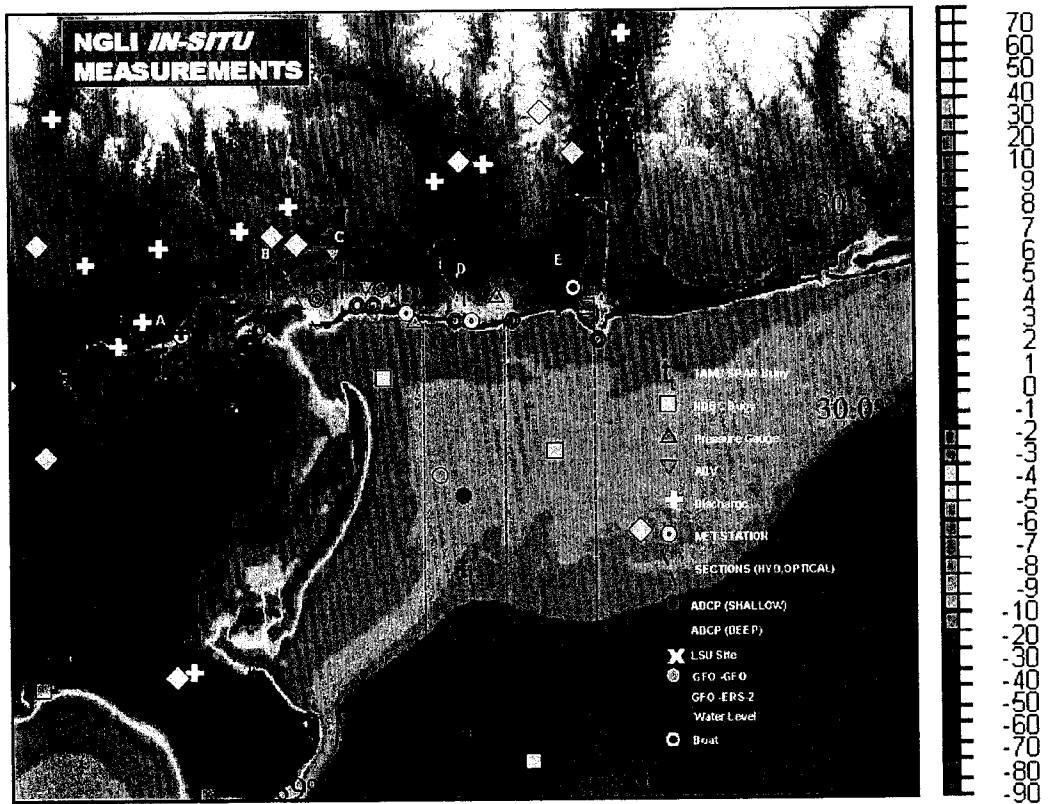


Figure 6. The instrumentation and deployment locations for the measurements obtained from the NGLI observing system.

Salinity, Aug. 2000, 0.5-2m



Temperature, Aug. 2000, 0.5-2m



Figure 7. The surface salinity and temperature distributions in the Mississippi Sound during August 2000. They are deduced from non-synoptic data and as objective analysis scheme.

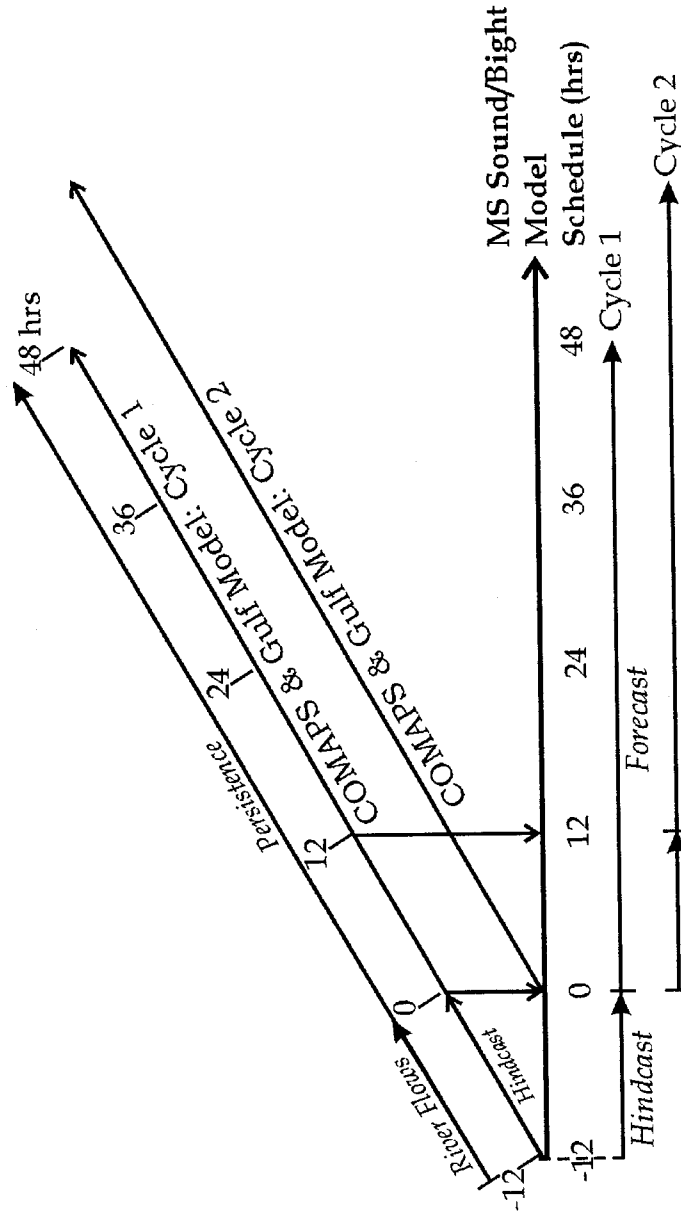


Figure 8. The operational flow data into and out of the Mississippi Sound/Bight model. A forecast cycle consists of a 12-hour hindcast followed by a 48 hour forecast.

1200 hours. The system is scheduled to run for 12 hours in a hindcast mode and then 48 hours in a forecast mode. There is a total of 60 hours of simulations, twice a day. begins at -1200 hours and ends at 4800 hours. When the system is in operation, the model results will be available on the project website (www.navo.navy.mil/NGLI).

The Mississippi Sound/Bight model, for example, begins a cycle at 0000 hour every day. It is scheduled to run at 0000 hours; first for a 12 hour hindcast simulation period and then continuing with a 48 hour forecast simulation. Model time after the 12 hour hindcast simulation, the time will be either at 0000 or 1200 hours. The Mississippi Sound/Bight model will have saved the proper hydrodynamic information for a restart. A smooth and seamless execution will thus be possible to start the next cycle, which is scheduled to start at 12 hours later (see Figure 8).

The model output fields that are archived every cycle include hourly, three-dimensional fields of salinity, temperature and currents and water level fields across the model domain. Uncertainty quantification and quality control are performed before the results go to the post-processing phase. A post-processing program which runs autonomously generates surface current, temperature and salinity distributions after the completion of each cycle of forecast. These graphics are available for display on the NGLI website (www.navo.navy.mil/NGLI) for public use. A 15 day permanent archiving protocol has been established in which model output, older than 15 days, are removed from the present directories and permanently archived in the MSRC system.

5.0 CONCLUSIONS

The nowcasting and forecasting modeling components of the NGLI are being applied to the Mississippi Sound/Bight area by cascading information from a global ocean circulation model and a Gulf of Mexico model to a shallow-water Mississippi Sound/Bight model. The ability to nest model operations, cascading information through models of differing resolution, is a particularly important goal of NGLI circulation and wave forecasting. During the initial efforts of the NGLI, significant improvements and enhancements have been made to the models and modeling system. The focus will now shift towards model calibration/validation, sensitivity analysis and maintaining the operations of the modeling system on the MSRC.

6.0 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-

B0001-0002). Key contributions to the atmospheric modeling component were provided by Nam Tranan, Gueorgui Mostovoi of Mississippi State University and Elizabeth Valenti of WorldWinds, Inc. The authors thank Suzzane N. Carroll of Planning Systems, Inc. for careful administration of the project deliverables.

7.0 REFERENCES

Bentley, S. J., T. R. Keen, C.A. Blain, W. C. Vaughan, and J. Barnes, 2001. "The Origin and Preservation of a Major Hurricane Event Bed in the Northern Gulf of Mexico: Hurricane Camille, 1969," Marine Geology, submitted.

Blaha, J. P., G. H. Born, N. L. Guinasso, Jr., H.J. Herring, G. A. Jacobs, F. J. Kelly, R. R. Leben, R. D. Martin, Jr., G. L. Mellor, P. Niiler, M. E. Parke, R. C. Patchen, K. Schaudt, N. W. Scheffner, C. K. Shum, C. Ohlmann, W. Sturges, III, G. L. Weatherly, D. Webb and H. J. White, 2000. "Gulf of Mexico Ocean Monitoring System," Oceanography, 13 (2), 10-17.

Blumberg, A. F., L.A. Khan, J. P. St. John, 1999. "Three Dimensional Hydrodynamic Model of New York Harbor Region," J. Hydraulic Engineering, 125, 8, 799 - 816.

Blumberg, A. F. and G. L. Mellor, 1987. "A Description of a Three Dimensional Coastal Ocean Circulation Model". Three Dimensional Coastal Ocean Models: Volume 4, N. Heaps, Ed., American Geophysical Union, Washington, D.C., 1 -16.

Booij, N., R.C. Ris, and L. H. Holthuijsen, 1999. "A Third-Generation Wave Model for Coastal Regions, Part 1: Model Description and Validation," J. Geophys. Res., 104, 7649-7666.

Carroll, S. and C. Szczechowski, 2001. "The Northern Gulf of Mexico Litteral Initiative." Marine Technical Society Annual Meeting, Hawaii, 1-7.

Dudhia, J., D. Gill, Y. Guo, K. Manning, W. Wang, and J. Chiszar, 2000: PSU/NCAR Mesoscale Modeling System Tutorial Class Notes and User's Guide: MM5 Modeling System Version 3. [Available from NCAR, P.O. Box 3000, Boulder, CO 80307; also available online at <http://www.mmm.ucar.edu>].

Fox, D.N., W.J. Teague, C.N. Barron, M.R. Carnes and C.M. Lee, in press. "The Modular Ocean Data Assimilation System (MODAS)," J. Atmos. Oceanic Technol.

Hodur, R.M., 1997. "The Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS)," Mon. Wea. Rev., 125, 1414-1430.

Hsu, Y. L., W.E. Erick, J.M. Kaihatu, and R.A. Allard, 2000. "Application of SWAN in Mississippi Sound" Proceedings 6th International Workshop on Wave Hindcasting and Forecasting, Monterey, CA, pp. 398-403.

Hurlburt, H.E., A.J. Wallcraft, Z. Sirkes and E.J. Metzger, 1992. "Modeling of the Global and Pacific Oceans: On the Path to Eddy-Resolving Ocean Prediction," Oceanography, 5, 9-18.

Keen, T. R., S. J. Bentley, W. C. Vaughan, and C. A. Blain, 2001. "The Generation and Preservation of Multiple Hurricane Beds in the Northern Gulf of Mexico", Marine Geology, submitted.

Keen, T.R., 2001. "Waves and Currents during a Winter Cold Front in the Mississippi Bight, Gulf Of Mexico: Implications for Barrier Island Erosion," Journal of Coastal Research, submitted.

Martin, Paul J., 2000. "An Ocean Model Applied To The Chesapeake Bay Plume," Estuarine and Coastal Modeling, ASCE, 1055-1069.

McIntosh, P.C., 1990. "Oceanographic Data Interpolation: Objective Analysis and Splines," Journal of Geophysical Research, 95 (C8), 13,529-13,541.

Mostovoi, G.V., P.J. Fitzpatrick, and Y. Li, 2001. "Comparison of 9-km Wind Forecasts Versus 27-km Wind Forecasts during the Northern Gulf Of Mexico Littoral Initiative," AMS Ninth Conference on Mesoscale Processes, Ft. Lauderdale, FL, 2001, Preprint.

Westerink, J.J., R.A. Luetich, Jr. and J. Muccino, 1994. "Modeling Tides in the Western North Atlantic Using Unstructured Graded Grids," Tellus, 46a (2), 178-199.