REAL TIME FORECASTING
OF
HURRICANE WINDS AND FLOODING

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1.0. INTRODUCTION

This report describes a real time hurricane wind and flood forecasting system developed to support emergency preparedness, evacuation and sheltering decisions in Louisiana. The hurricane storm threat includes winds and storm surge. Coping with this threat in metropolitan areas, such as New Orleans, is a particularly vexing problem. The city of New Orleans cannot be evacuated and yet there may be no true shelters available anywhere in the city during a severe storm. To deal with this dilemma, detailed information is needed about the magnitude and location of high winds and flooding. It is well known that the hurricane threat varies greatly with storm track and intensity. Thus emergency preparedness, evacuation and sheltering decisions must be guided by storm specific information. While the ability to determine the hurricane wind and flooding threat was available and was currently being used, it had not been set-up to meet the requirements of a real time application. The project described in the report addresses this need for a real time capability to forecast single hurricane storms.

In order to support emergency preparedness, evacuation and sheltering decisions for the coastal areas of Louisiana, the real time forecasting system had to meet certain performance criteria. These criteria were;

- Cover the geographic area of the north central Gulf of Mexico.
- Have a data base and forecasting resolution for the study area of 1 km, including topography, roads, levees and rivers.
- Have a hurricane forecasting model that incorporates real time data input and real time output.
- Acquire and process data from the National Weather Service (NWS) about the most probable hurricane path and intensity, and from other sources about real time wind speeds and flooding.
- Transmit the pertinent environmental information in real time to emergency managers at the Louisiana Office of Emergency Preparedness and Louisiana parishes.
- Forecast the winds and storm surge within 3 hours of receiving the NWS data,
- Assess the threat of the forecast winds and storm surge to specific buildings and locations in the study area to assist evacuation decisions and shelter selection.

2.0 REAL TIME FORECASTING AND ASSESSMENT SYSTEM

Real time forecasting requires the processing of data that will be received from a variety of sources and the integration of the data into the forecasts. The system for doing this is illustrated in Figure 1. The primary sources for the data include NWS, Louisiana State University, various parishes, and data collection platforms. The National Weather Service issues a 72 hour track forecast every six hours during a storm event. Each forecast consists of a most probable track and probabilities associated with other tracks. To fully describe the storm threat would entail running three simulations simultaneously, which consist of the most probable track and two alternate tracks forecasted by the National Weather Service.

There are several Louisiana State University facilities that directly support the modeling effort. These facilities are the Southern Regional Climate Center (SRCC), the Louisiana Office of State Climatology (LOSC) and the Earth Scan Laboratory (ESL, a NOAA satellite earth station). The SRCC is a NOAA funded facility receiving all National Weather Service data, model results and forecasts for regional distribution. The LOSC is supported by the Department of Geography and Anthropology at LSU with official ties to state government agencies. The ESL facilities were established and manned as research facilities of the Coastal Studies Institute. They will provide detailed but graphically synthesized, near real-time information on the location of storms, movement and behavior of weather systems both during training exercises and during emergencies. Additional information is acquired from the United States Geological Survey and from NWS.

In order to meet the performance criteria outlined above a real time forecasting system was established in the Natural Systems Engineering Laboratory in the Louisiana Water Resources Research Institute. The major components of the system are:

$ An extensive data base of topography, levees and cultural features in the study area,
$ A calibrated hurricane wind and storm surge model,
$ Computer hardware capable of providing real time forecasts in the needed time,
$ A real time data telecommunication system linking LSU, LaOEP, St. Bernard Parish, Jefferson Parish and Orleans Parish, to each other and data sources (i.e., NWS),
$ An automated realtime display of the input data, and forecast results.

Display and visualization of the forecast results uses a GIS and the World Wide Web (WWW). An advantage of using the WWW as the standard post processor is its ease of use and platform independence. Due to the rising popularity of the internet and the free availability of browsers almost everybody is familiar with its usage. The WWW also ensures a uniform look and feel irrespective of the underlying hardware/operating systems platform. The GIS software system being used is ARC/INFO. It is also be compatible with ARCVIEW. Using appropriate plugins for ARCVIEW, vector features like roads, evacuation routes, shelter information, etc., can be overlaid on the flood depth/elevation and wind field raster images. The real time system also integrates other data sources, like satellite images, real time stage information for rivers from USGS.

3.0. HURRICANE SIMULATION MODEL

The model used for forecasting the wind and surge had to satisfy several criteria. First it needed to involve the fundamental hydrodynamic processes occurring with the study area and explicitly incorporate the geographic properties of the coastal landforms, such as barrier islands, levees, inlets, rivers and man-made canals. Furthermore it had to be suited for application to the Louisiana coast, make quantitative predictions of know accuracy, be easily and routinely applied, and provide the kinds of information that were needed for making management decisions.

The model selected for use is the overland flooding model developed by the Federal Emergency Management Agency to predict hurricane flood elevations for the National Flood Insurance Program (FEMA, 1988)(Figure 2.). The model uses an explicit, two dimensional, spaced staggered, finite difference scheme to simulate the flow of water caused by tides and wind systems. The model forecasts these parameters over a spatial grid that incorporates land cells as they are flooded, as shown in Figure 3. The computer model solves the vertically averaged momentum and mass conservation equations using and explicit scheme, given in Figure 4. The velocities are defined on the edges of the grid cell and the elevation of the land and water are deined at the center of the cell as shown in Figure 5. The grid is rectangular and can have unequal grid sizes in the X and Y directions. Multiple grids can be nested to produce forecasts for very small grid sizes. The inputs to the model include the bathymetry, coastline configuration, boundary conditions, and bottom friction and other flow resistance coefficients. The model also includes sub-grid barriers such as islands, roadways, levees and sub-grid channels such as rivers, bayous and canals. The land grid cells can have multiple flow resistance elements. Hurricane winds speeds can be adjusted for land roughness effects. The water flow friction can be modeled as a depth variable or constant Manning's coefficient. Tides and hurricane surges can be combined non-linearly. The model has been used by FEMA to conduct flood insurance studies throughout the United States and has recently been used by the project manager to revise the Flood Insurance Rate Map for Cameron Parish, Louisiana (Suhayda and Young, 1987).

An integral component of the storm surge simulation model is a hurricane wind model. The hurricane wind model used is based on a model developed by the NWS for defining the wind field for the surge model. This wind model is used for defining the maximum sustained wind speeds, and the direction and the time of occurrence. Time variation of winds and direction at predefined locations are also available.

The hydrodynamic model was set-up to run simulations using several different resolutions. A coarse scale grid was used to generate the boundary input for a fine scale grid. The finer grid was concentrated in a particular study area. The coarse and fine scale grids are based the Universal Transverse Mercator (UTM) coordinates system. The coarse grids have cell sizes of 10,000 ft (3 km), and the fine grid has a cell size of 3,333 feet (1 km).

The sensitivity of model predictions to small variations in input conditions was evaluated. The model was run with several values of the Manning coefficient. The model was calibrated for average and extreme conditions for the time period of August 1992, which included Hurricane Andrew.

Water level data was available for several tide and river stage gauges. The tide calibration was based upon observed tide ranges and tide elevations for locations surrounding the study. The calibration also used measurements of water levels made inside the estuary complex, to verify the predictions. The model was verified using hurricane Andrew because this recent storm reflects the current geomorphic conditions of the coastal area of the state.

4.0. DATA BASE

The database needed to support the modeling effort was available from existing sources. The distribution of land within the study area was determined from a satellite image, as shown in Figures 6, 7, 8 and 9. Figure 6 shows the LANDSAT image taken in 1993 of the study area. The resolution of the image is 25 m. A blow-up of the image for the New Orleans metropolitan area is shown in Figure 7. Using this image a land water mask was developed, as shown in Figure 8. The modeling grid resolution is 1 km, so that the land water data in Figure 7 had to be coarsened by a factor of 40. This meant that individual model grid cells would contain various fractions of land and water. Figure 9 shows the resulting percentage of land in each of the model grid cells.

Topographic and bathymetric data was based upon USGS quad sheets, NOS bathymetric charts and topographic data taken by Parishes and by the State of Louisiana. Most of the roadway and upland topographic data for the study was taken from 7.5 ' and 15 ' USGS quad sheets. The marsh elevation data was taken from a recent survey funded by the Barataria/Terrebonne National Estuaries Program (Alawady and Khaldi, 1995). The topographic/bathymetric map of the study area is shown in Figure 10. The marsh elevation data set is shown in Figure 11. Additional topographic data was collected for levees and roadways. The location of these features is shown in Figure 12. Figure 13 shows the locations of the waterways used in the forecasts.

5.0. HURRICANE FORECASTS

The results of the model forecasting are presented for a category 4 storm, such as Hurricane Andrew.

The path of the storm is shown in Figure 14. This path represents a storm that swings to the east before reaching landfall and crosses south of New Orleans. The input file for the hurricane is shown in Figure 15. The file includes the time, latitude, longitude, central pressure and radius.

The output from the model includes information on winds and flooding. The wind field over the study area for two positions of the hurricane are shown in Figures 16 and 17. In each figure the direction and speed of the winds is shown, with the wind speed colored coded to give the magnitude. The circular wind pattern is obvious and the two images show the large variation of wind speed and direction associated with a hurricane.

The maximum flood elevation and flood depth are shown in Figures 18, 19 and 20. Figure 18 shows the maximum elevation of the surge over the study area. Figure 19 shows the maximum flood depth. The depth of flooding is the surge elevation minus the ground elevation. Figure 20 shows the coastal area flooded by the hurricane superimposed on the LANDSAT image to convey a sense of the large area impacted by the storm.

The distribution of maximum winds are shown in Figures 21, 22, and 23. Figure 21 shows the bands of maximum wind speed experienced during the storm. Figure 22 shows the direction of the maximum wind speed and again illustrates the complex wind patterns associated with a hurricane. Figure 23 shows the time lines of when the maximum wind speed was experienced during the simulation. The time lines are separated into 5 hour increments.

The model forecasts also include time series at selected locations in the study area. Figure 24 shows the locations of the grid cells for which time series can be generated. The point selected as an example is in the northern part of Barataria Bay at St. Mary=s point. Figure 25 and 26 show the surge elevation, and the wind speed and direction throughout the storm.

Once the storm surge model is run and the results are processed and the web server is updated, Louisiana OEP and the parish OEP=s can access these images using a terminal connected to the internet.

6.0. APPLICATION OF THE RESULTS

The results of the forecasts can be used to evaluate the treat of hurricane winds and surge to many facilities, such as shelters, evacuation routes, power stations, and haz/mat storage facilities. The data could also be integrated with the shelter database would also be available for obtaining pertinent information about shelters. This information can be used with other pertinent information to provide a more complete description the threat posed by a hurricane. Other types of information such as the variability of the forecast track and the actual track should be included in a final evaluation. The variations in NWS forecast track for Hurricane Andrew are shown in Figure 27. This information can be supplemented by actual satellite data as to the position of the storm, as shown in Figure 28.

The assessment of the hurricane flood risk is based upon both area of flooding and the depth of flooding. The area of flooding determines whether a site or building will be directly flooded or be isolated from access. If the site or structure is in a flooded area the issue is whether the flood elevation exceeds the elevation of the ground floor of the structure. If the ground floor is above the flood water elevation, the building would be safe from direct flooding, but may suffer damage from waves riding on the surge. If levees become overtopped then many areas of a city will be under water for extended periods of time, significantly reducing number of buildings available for use as long term shelters.

The assessment of the threat of wind damage to structures is dependent both on the hurricane wind speed and direction and the properties of the structure itself. Each structure is to some degree unique in it=s response to wind loading. During a hurricane the structure can be subject to extreme winds for many hours and from many directions. The wind can find a weak point in the structure, which would allow the wind and water to penetrate into the interior of the building and/or cause partial or complete structural collapse.

7.0. REFERENCES

ALAWADY, M. amd KHALED, A., 1995. Elevation data gathering report to the Barataria/Terrebonne National Estuaries Program, Dept. of Civil And Environmental Engineering, Louisiana State University, 43 p.

FEDERAL EMERGENCY MANAGEMENT AGENCY, 1988. Coastal Flooding Hurricane Storm Surge Model. Federal Insurance Administration, Washington D. C., August,.

SUHAYDA, J. N. and YOUNG, M., 1987. Simulation of hurricane surges using the new FEMA model, Proc. of Symposium on Numerical Modelling.

8.0. FIGURES

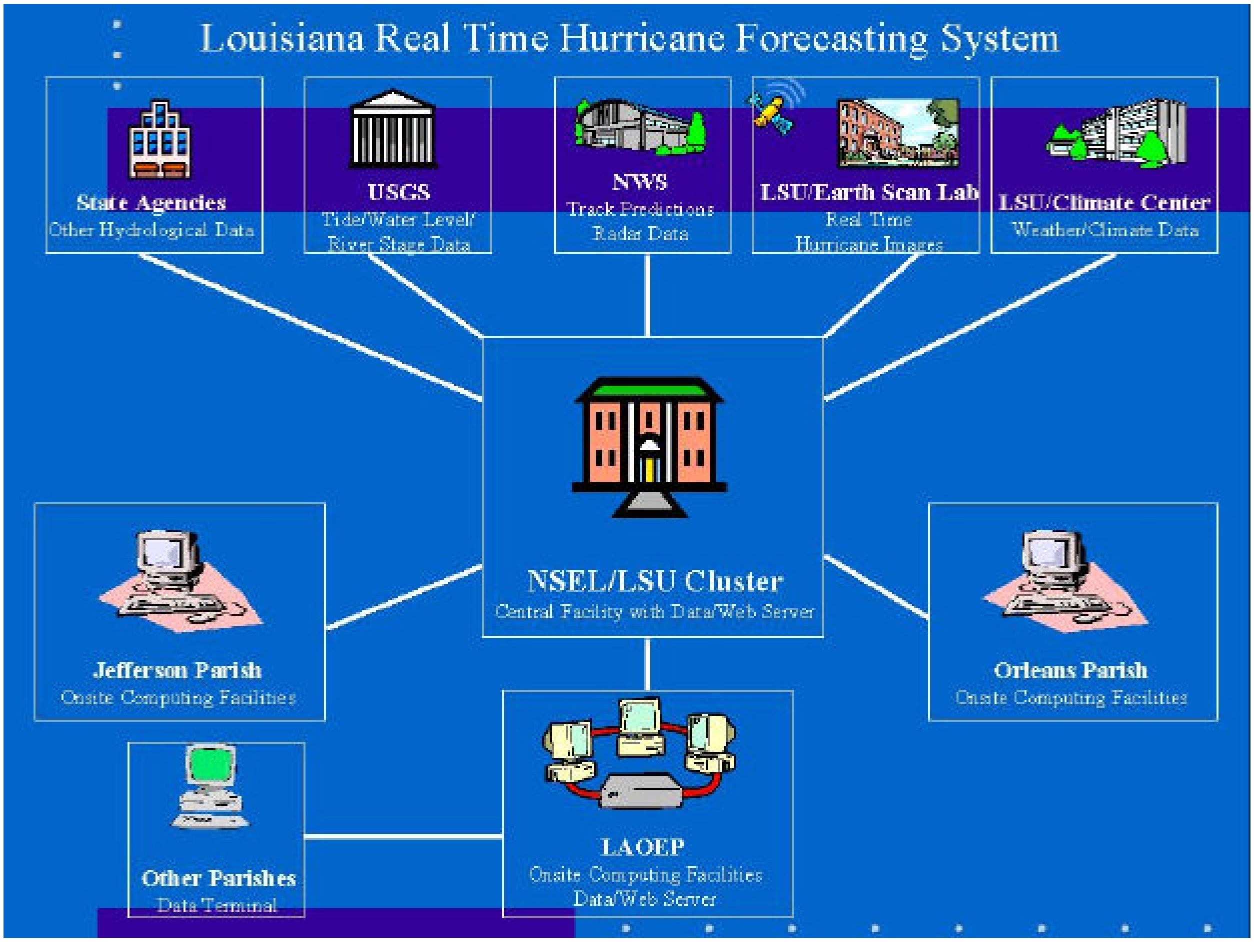


Figure.1

COASTAL FLOODING
HURRICANE STORM SURGE MODEL

VOLUME 1 METHODOLOGY

UPDATE OF SURGE MODEL VERSION DATED JUNE 1985

FEDERAL EMERGENCY MANAGEMENT AGENCY
OFFICE OF RISK ASSESSMENT
FEDERAL INSURANCE ADMINISTRATION
WASHINGTON, D.C. 20472

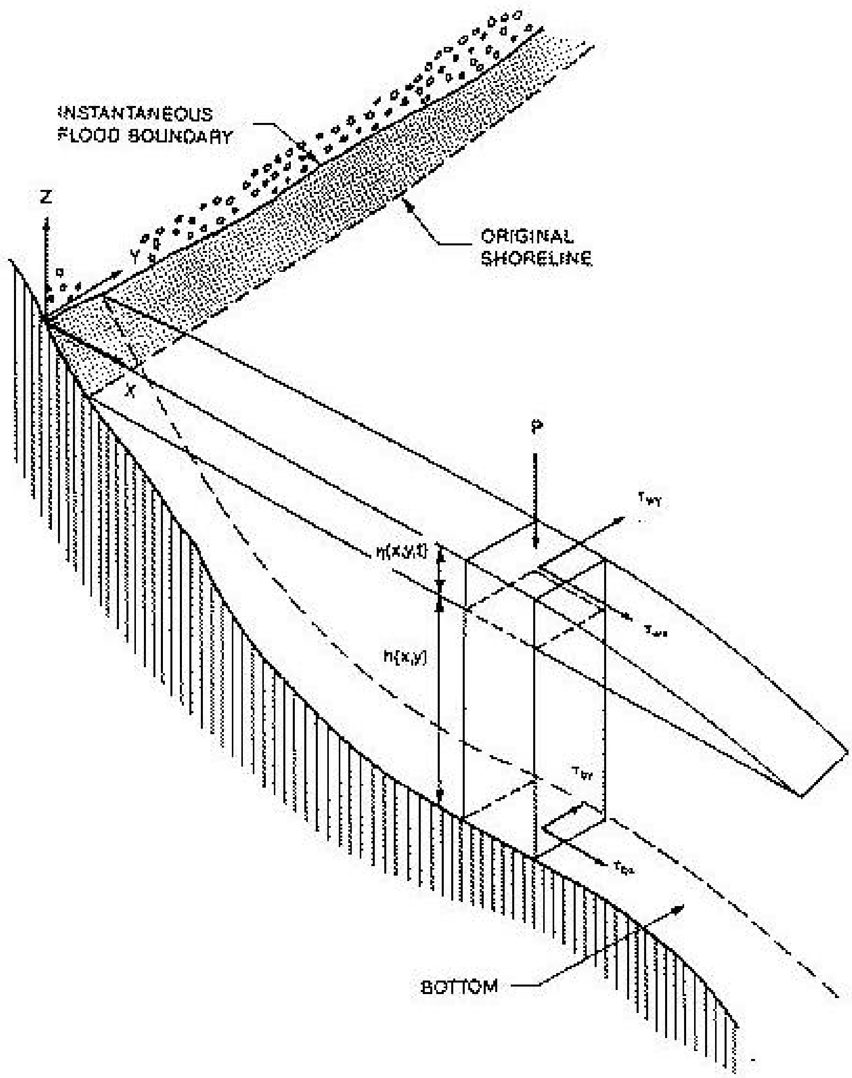


FIGURE 2-1 FORCES ACTING ON AN ELEMENTAL WATER COLUMN

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial \eta}{\partial x} + fv - \frac{\tau_{bx}}{\rho(h+\eta)} + \frac{\tau_{wx}}{\rho(h+\eta)} - \frac{1}{\rho}\frac{\partial p}{\partial x} \quad (2.1)$$

Convective Terms	Hydraulic Gradient	Coriolis Term	Flow Resistance	Wind Stress	Barometric Pressure Gradient

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial \eta}{\partial y} - fu - \frac{\tau_{by}}{\rho(h+\eta)} + \frac{\tau_{wy}}{\rho(h+\eta)} - \frac{1}{\rho}\frac{\partial p}{\partial y} \quad (2.2)$$

The conservation of mass, or continuity equation, is written as follows:

$$\frac{\partial \eta}{\partial t} + \frac{\partial}{\partial x}((h+\eta)u) + \frac{\partial}{\partial y}((h+\eta)v) = 0 \quad (2.3)$$

where

x,y = rectangular Cartesian coordinates

u,v = vertically averaged velocity components in the x- and y-directions, respectively

t = time

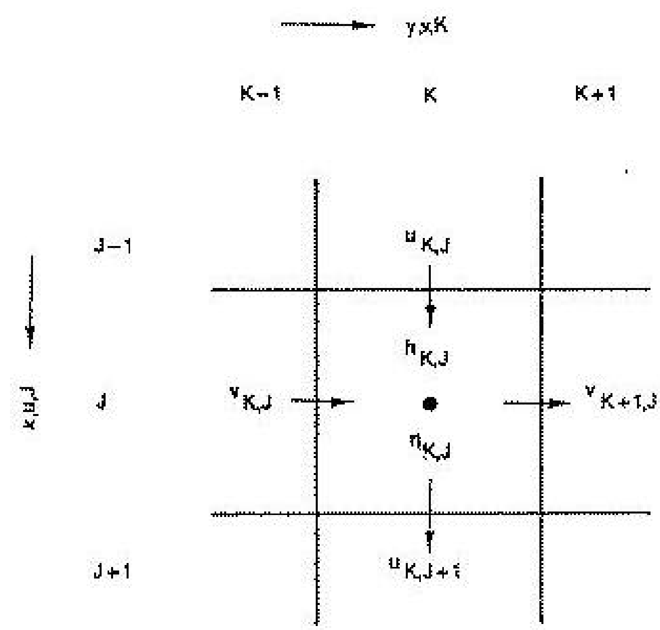


FIGURE 2-3 SPATIAL STAGGERING IN COMPUTATIONAL GRID

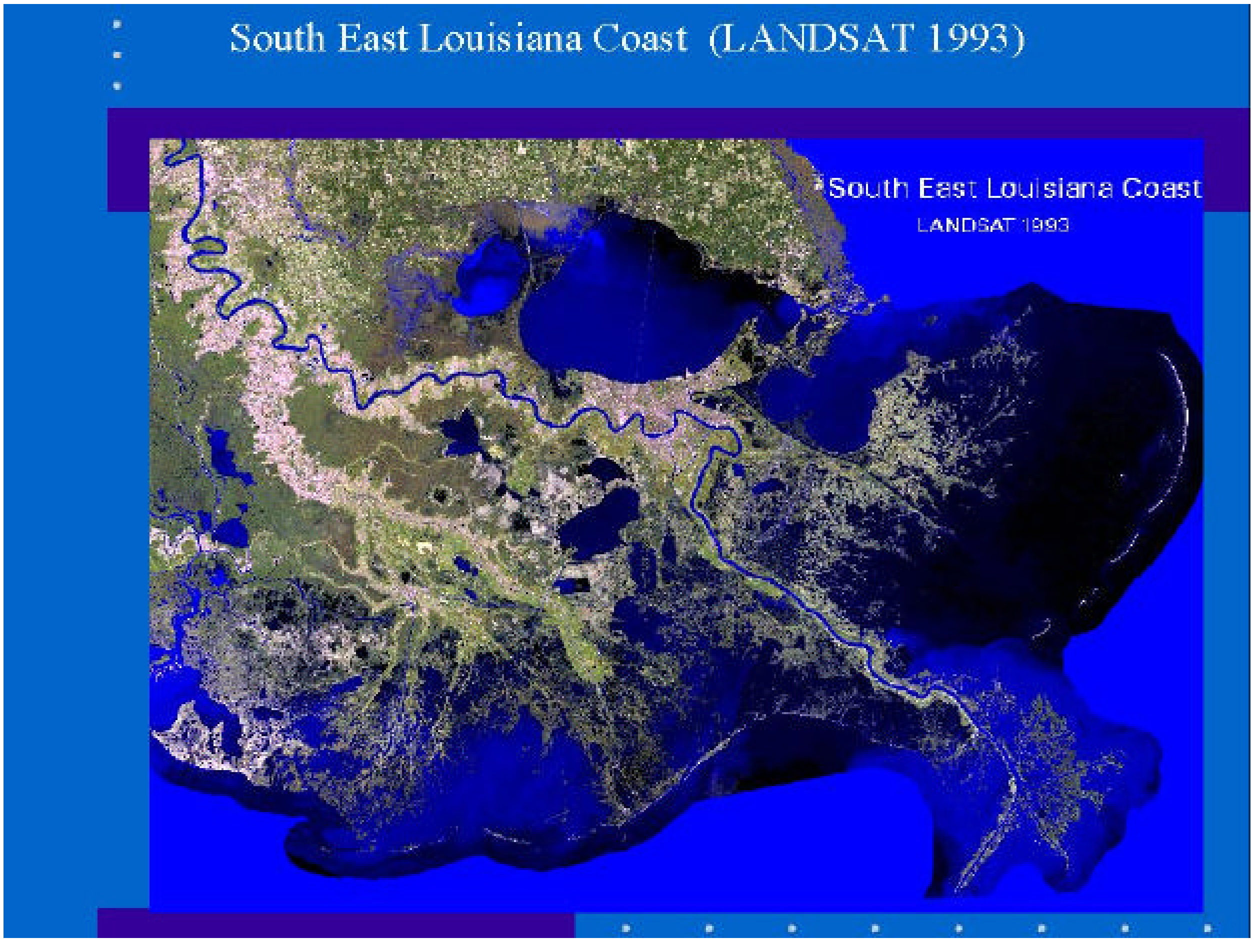

South East Louisiana Coast (LANDSAT 1993)
South East Louisiana Coast
LANDSAT 1993

Figure. 6


City of New Orleans (LANDSAT 1993)
City of New Orleans (LANDSAT 1993)

Figure. 7

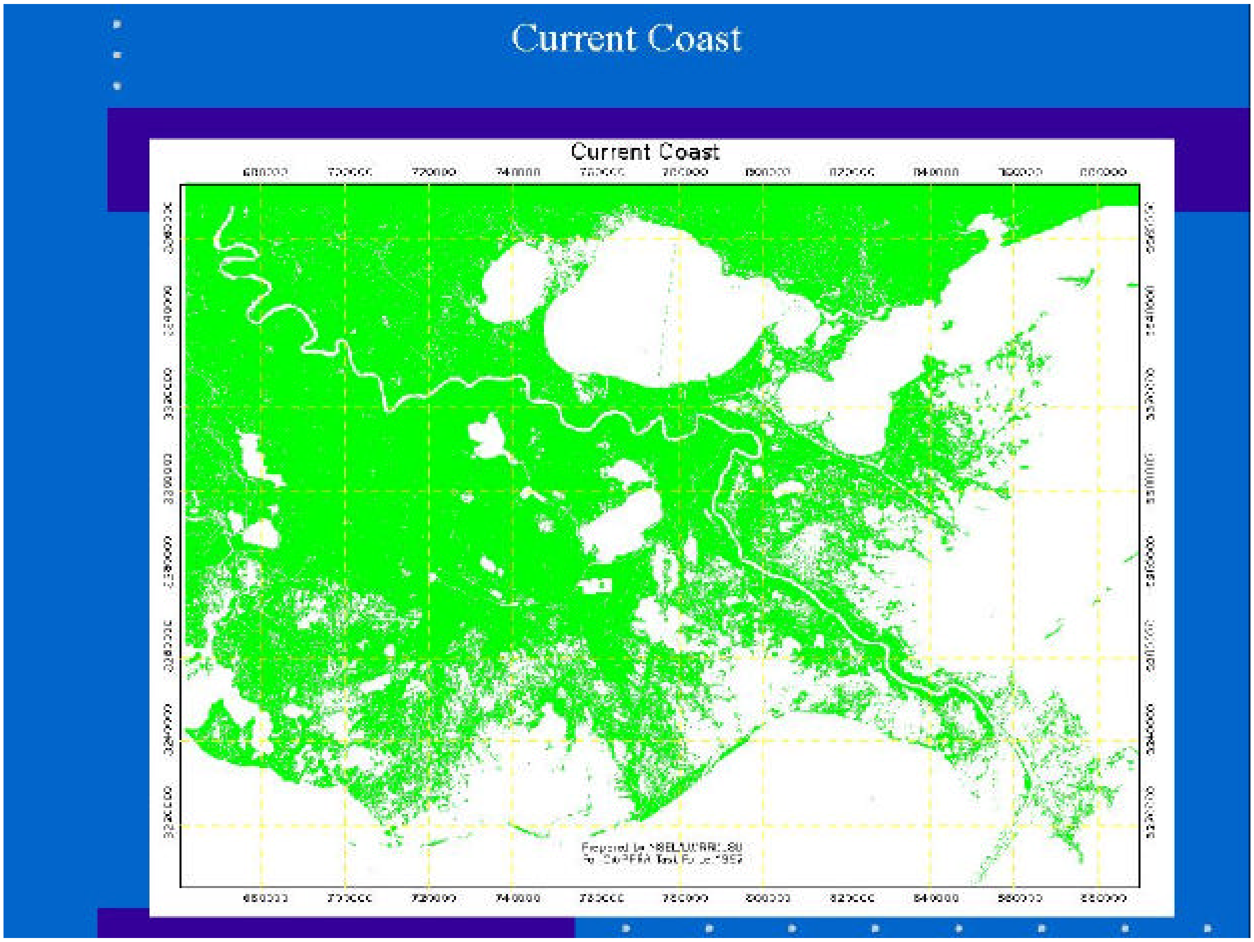
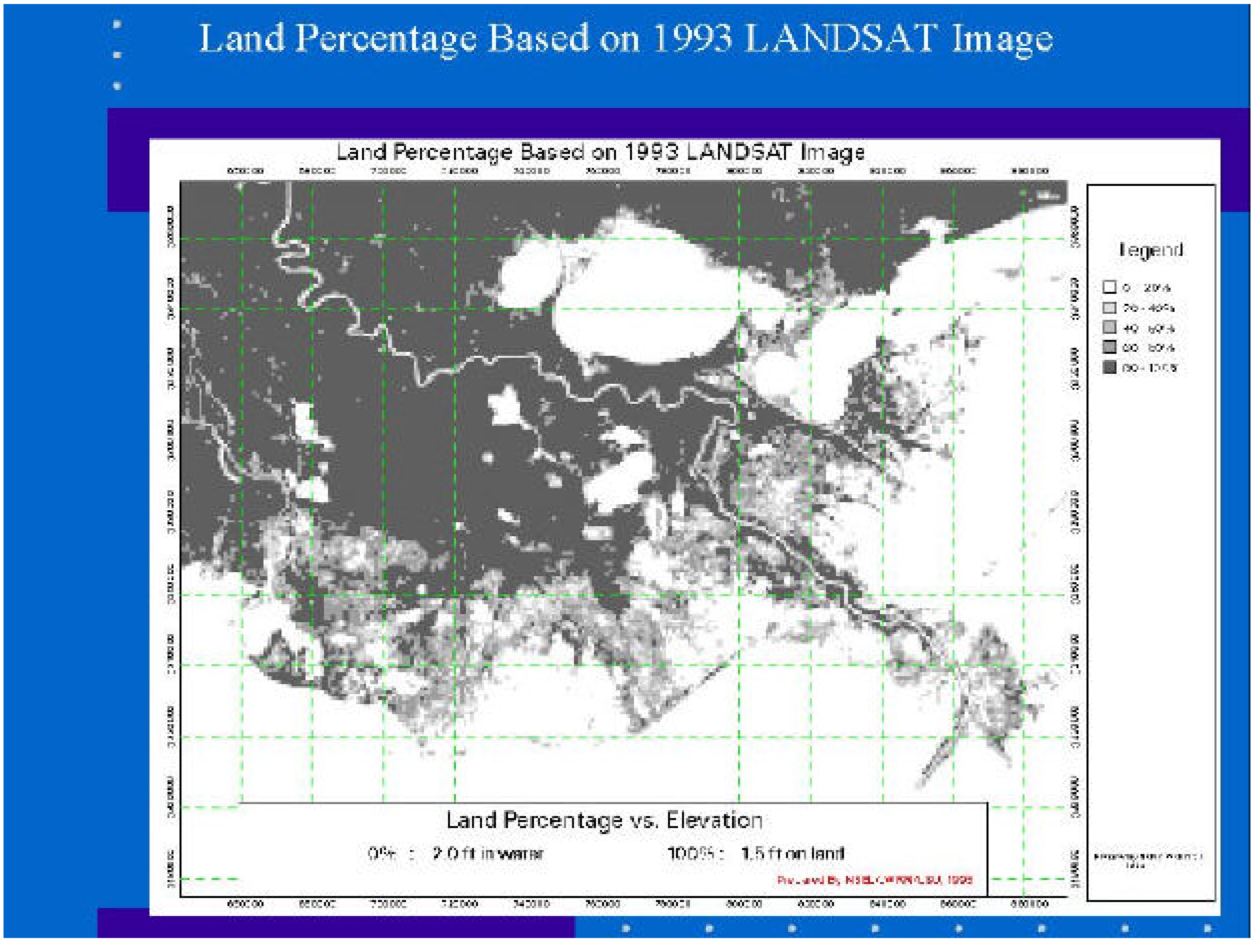


Figure. 8



Land Percentage Based on 1993 LANDSAT Image
Land Percentage Based on 1993 LANDSAT Image
Legend
Land Percentage vs. Elevation
0% : 2.0 ft in water
100% : 1.5 ft on land

Figure. 9

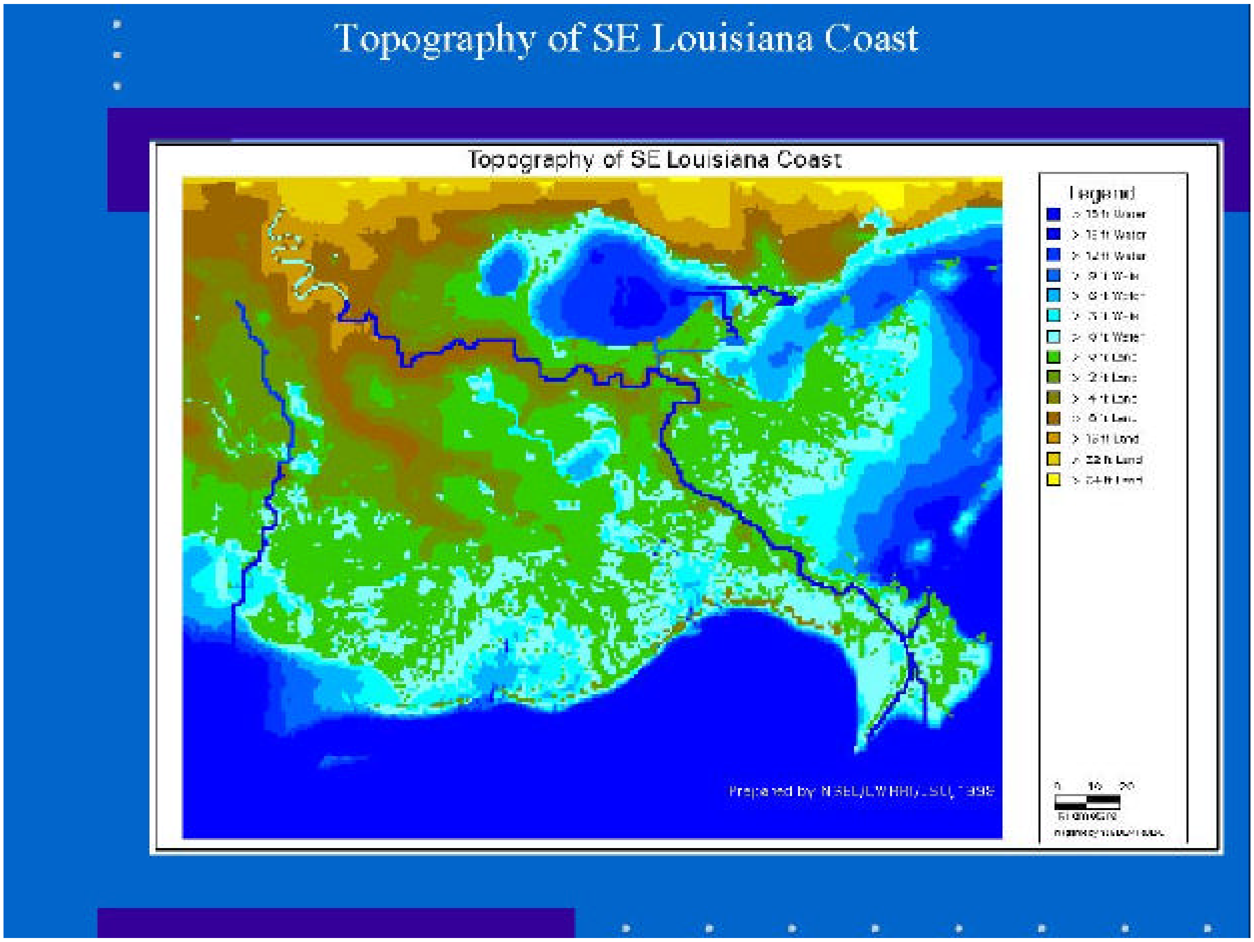

Topography of SE Louisiana Coast
Topography of SE Louisiana Coast
Legend
> 22 ft Land

Figure. 10

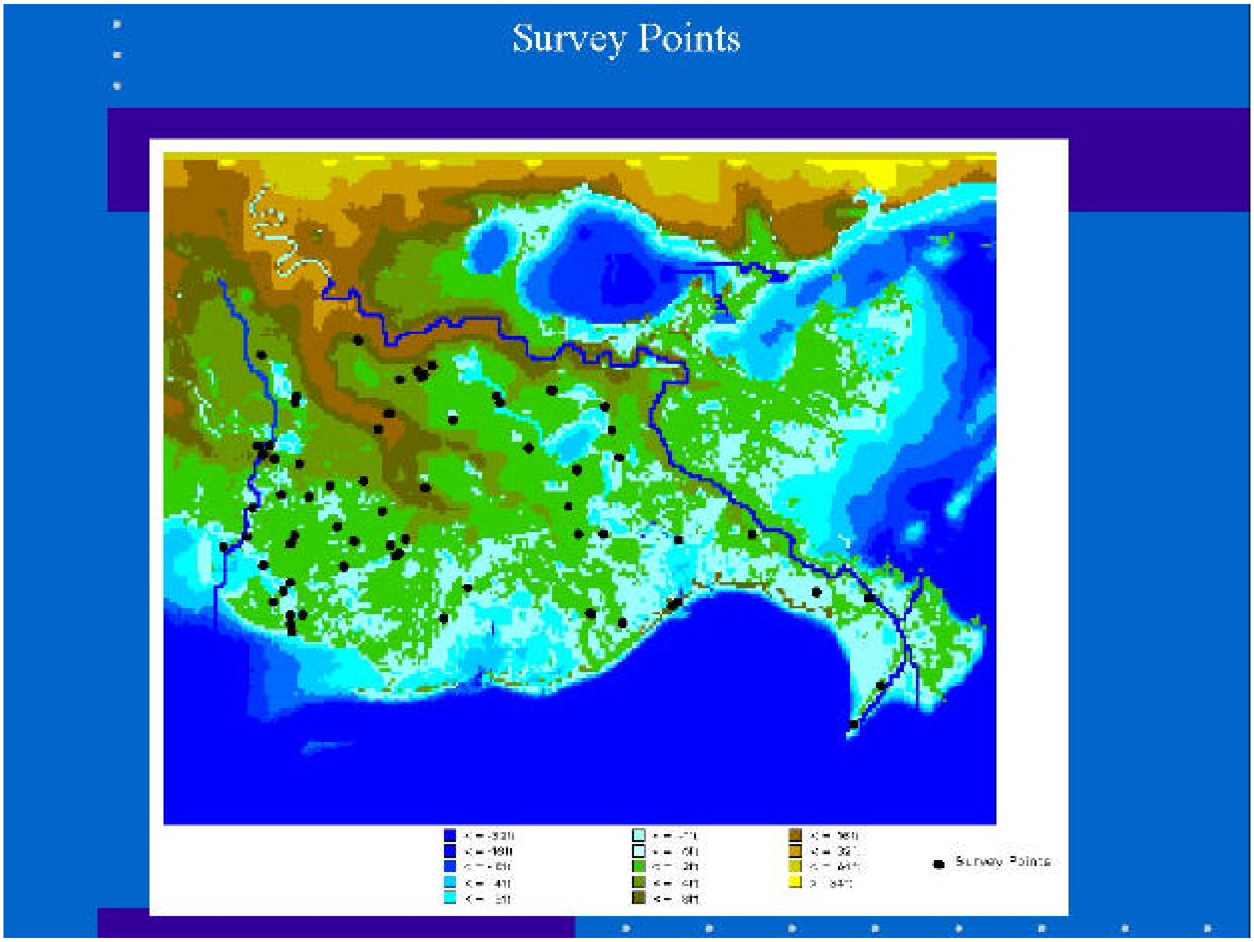


Figure. 11

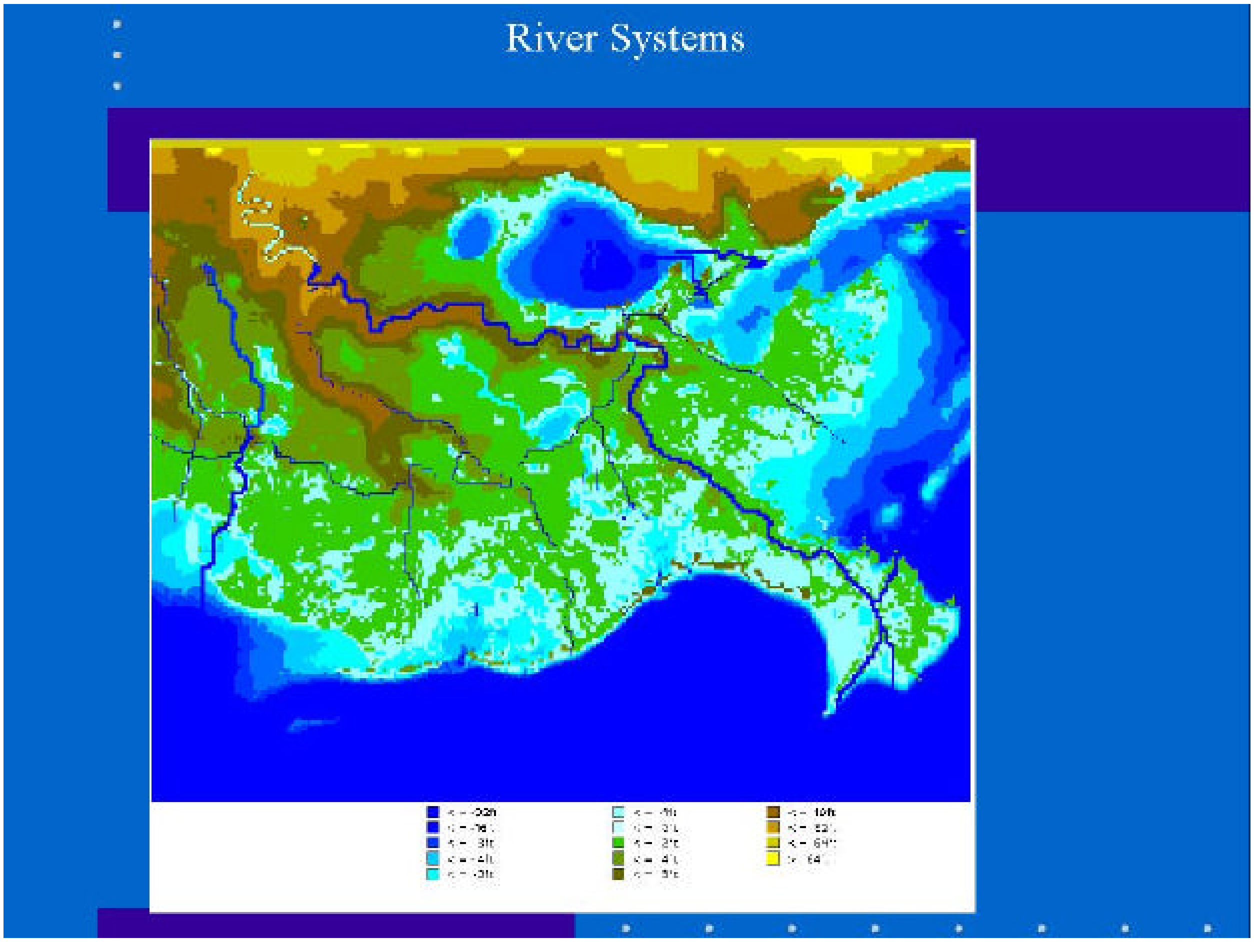


Figure. 12

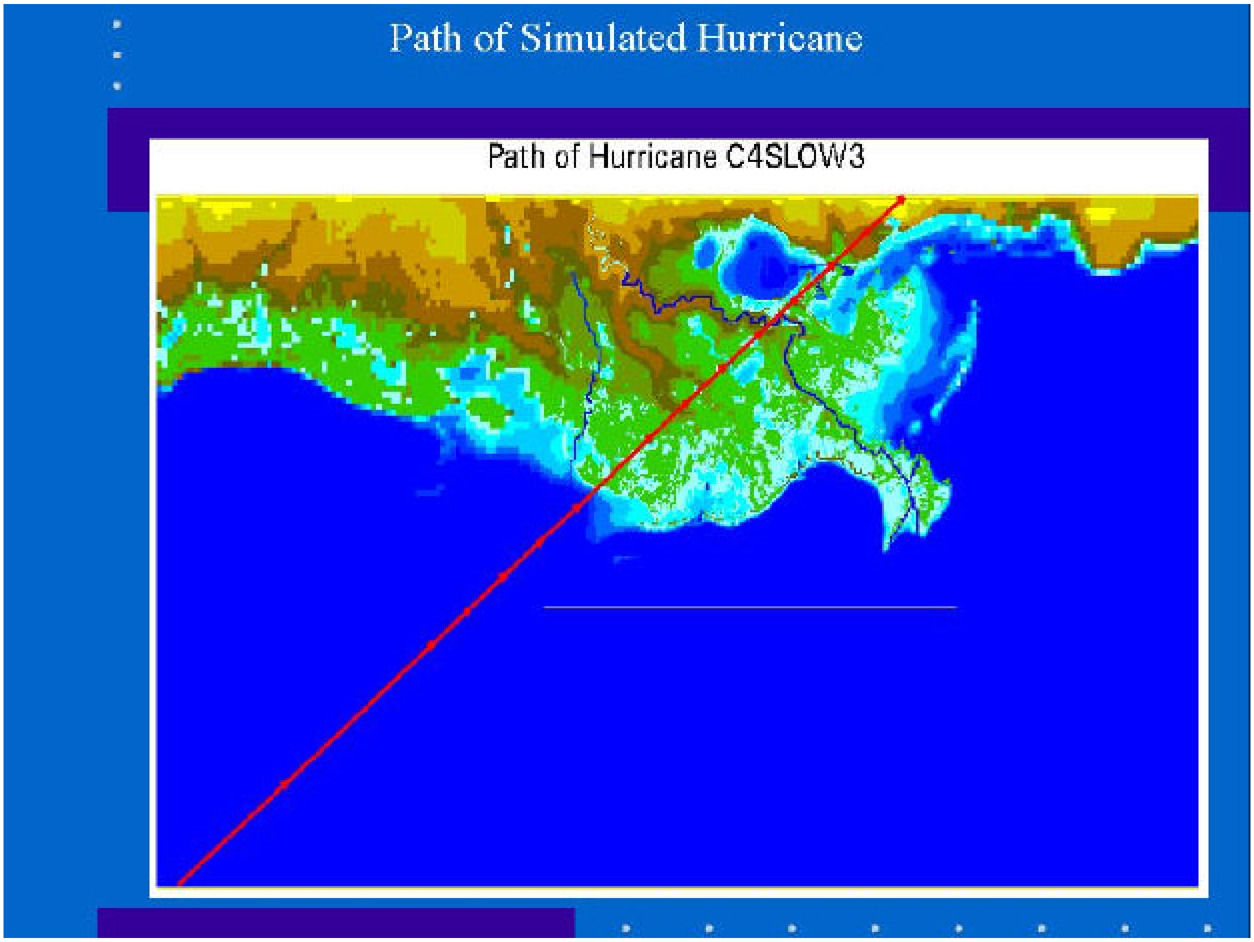
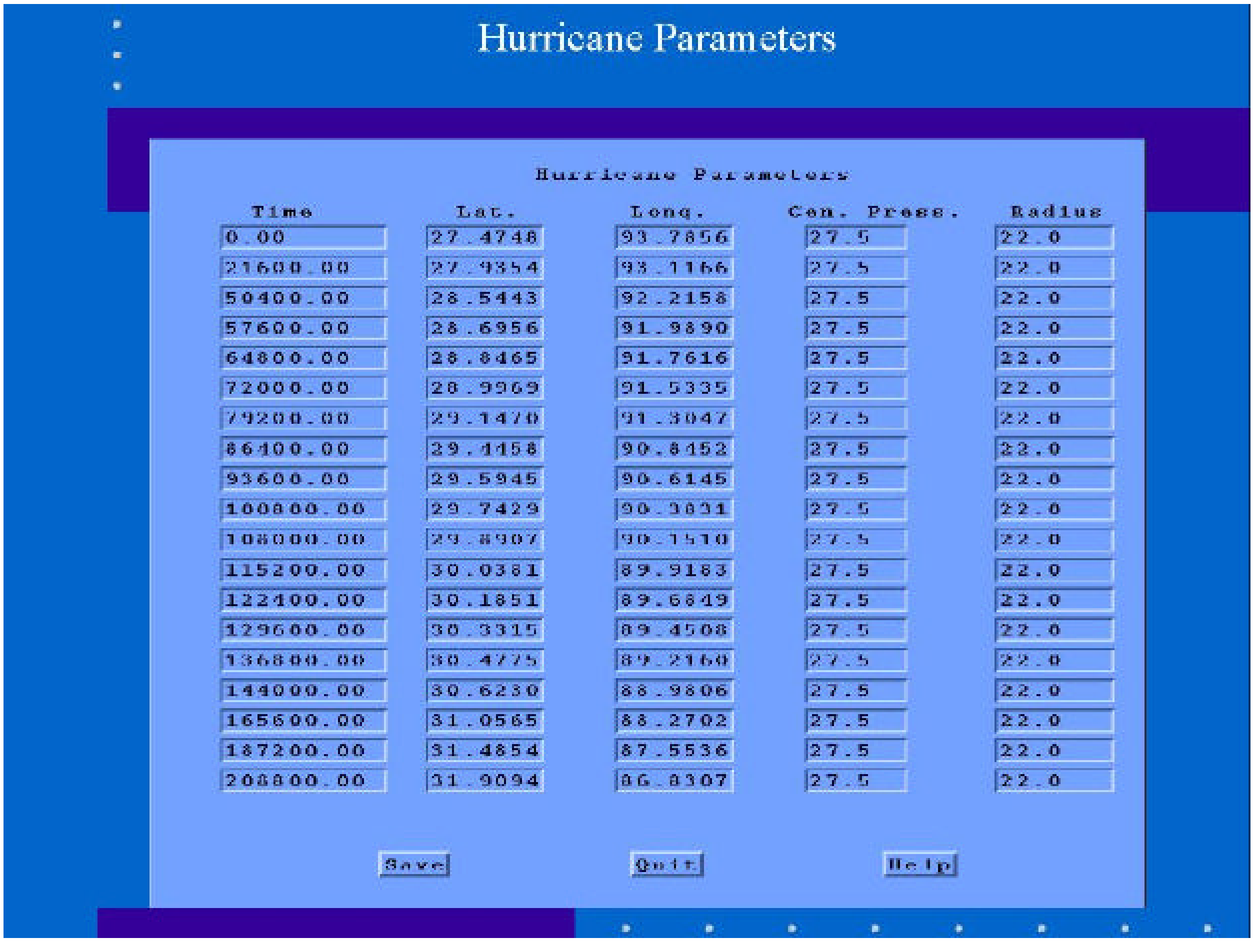


Figure. 13



Hurricane Parameters

Time	Lat.	Long.	Cen. Press.	Radius
0.00	27.4748	93.7856	27.5	22.0
21600.00	27.9354	93.1166	27.5	22.0
50400.00	28.5443	92.2158	27.5	22.0
57600.00	28.6956	91.9890	27.5	22.0
64800.00	28.8465	91.7616	27.5	22.0
72000.00	28.9969	91.5335	27.5	22.0
79200.00	29.1470	91.3047	27.5	22.0
86400.00	29.4458	90.8452	27.5	22.0
93600.00	29.5945	90.6145	27.5	22.0
100800.00	29.7429	90.3831	27.5	22.0
108000.00	29.8907	90.1510	27.5	22.0
115200.00	30.0381	89.9183	27.5	22.0
122400.00	30.1851	89.6849	27.5	22.0
129600.00	30.3315	89.4508	27.5	22.0
136800.00	30.4775	89.2160	27.5	22.0
144000.00	30.6230	88.9806	27.5	22.0
165600.00	31.0565	88.2702	27.5	22.0
187200.00	31.4854	87.5536	27.5	22.0
208800.00	31.9094	86.8307	27.5	22.0

Figure. 14

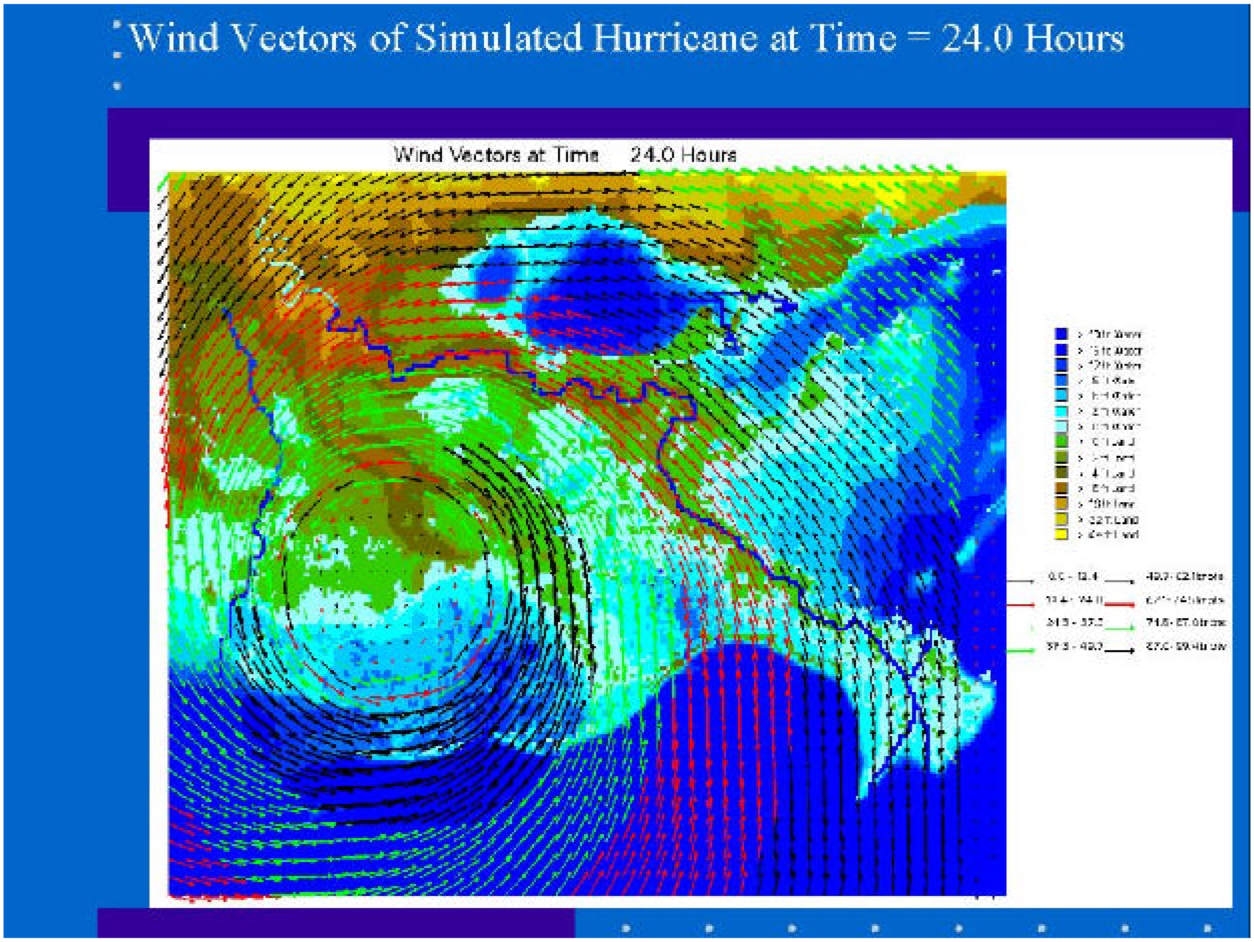

Wind Vectors of Simulated Hurricane at Time = 24.0 Hours
Wind Vectors at Time 24.0 Hours

Figure. 15

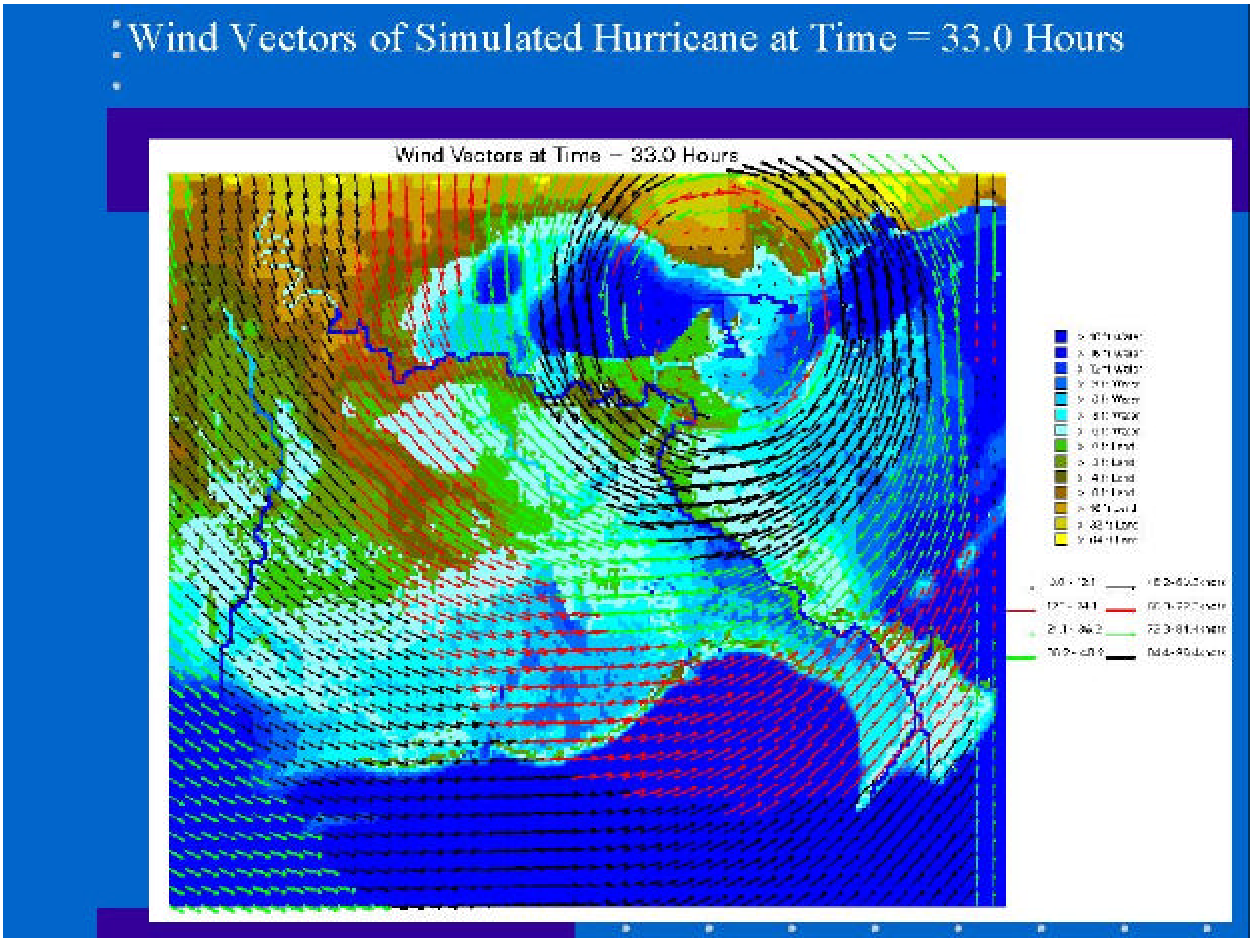

Wind Vectors of Simulated Hurricane at Time = 33.0 Hours
Wind Vectors at Time = 33.0 Hours

Figure. 16

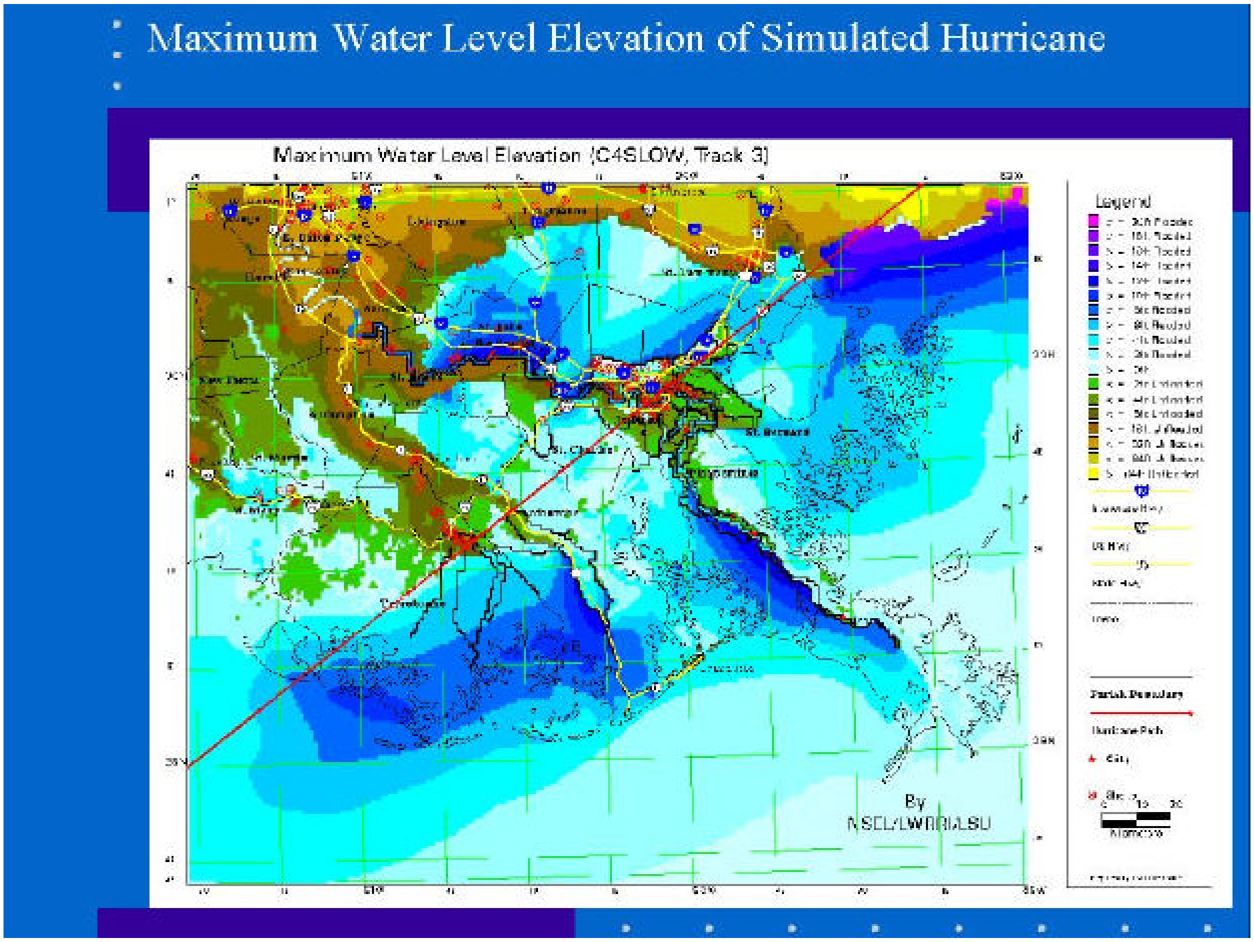

Maximum Water Level Elevation of Simulated Hurricane
Maximum Water Level Elevation (C4SLOW, Track 3)
Legend
By
NSEL/LWRRI/LSU

Figure. 17

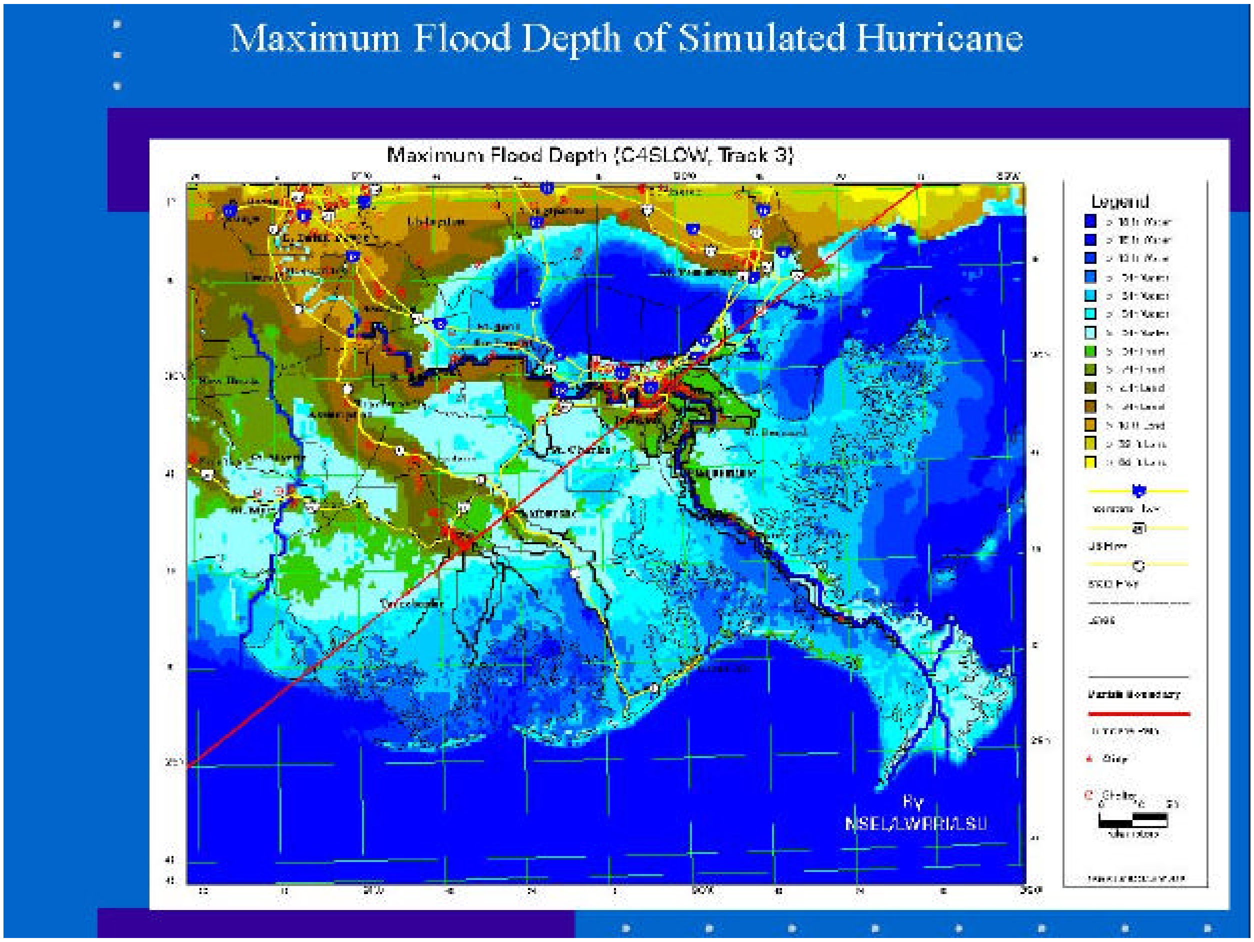

Maximum Flood Depth of Simulated Hurricane
Maximum Flood Depth (C4SLOW, Track 3)
Legend
By
NSEL/LWRRI/LSU

Figure. 18


W. Baton Rouge
E. Baton Rouge
Livingston
Tangipahoa
St. Tammany
Iberville
Ascension
St. John
the Baptist
Orleans
New Iberia
St. James
St. Charles
Assumption
St. Bernard
St. Martin
St. Mary
Lafourche
Terrebonne
Plaquemines
Flood in Southeast Louisiana from a Category 4 Slow Hurricane
(Resolution of Flood Simulation = 1 km)
By NSEL/LWRRI/LSU, 1998

Figure. 19

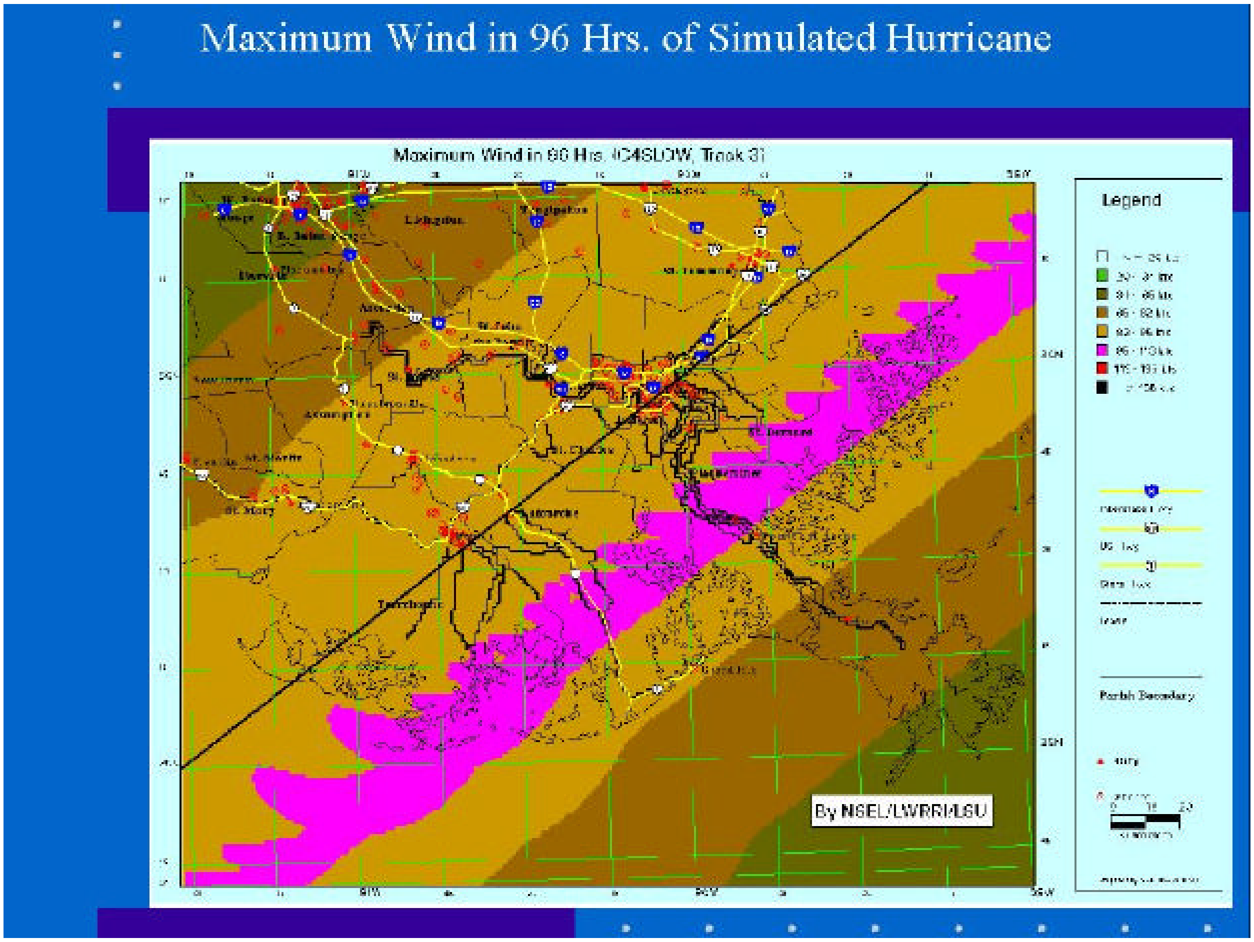

Maximum Wind in 96 Hrs. of Simulated Hurricane
Legend
Parish Boundary
By NSEL/LWRRI/LSU

Figure. 20

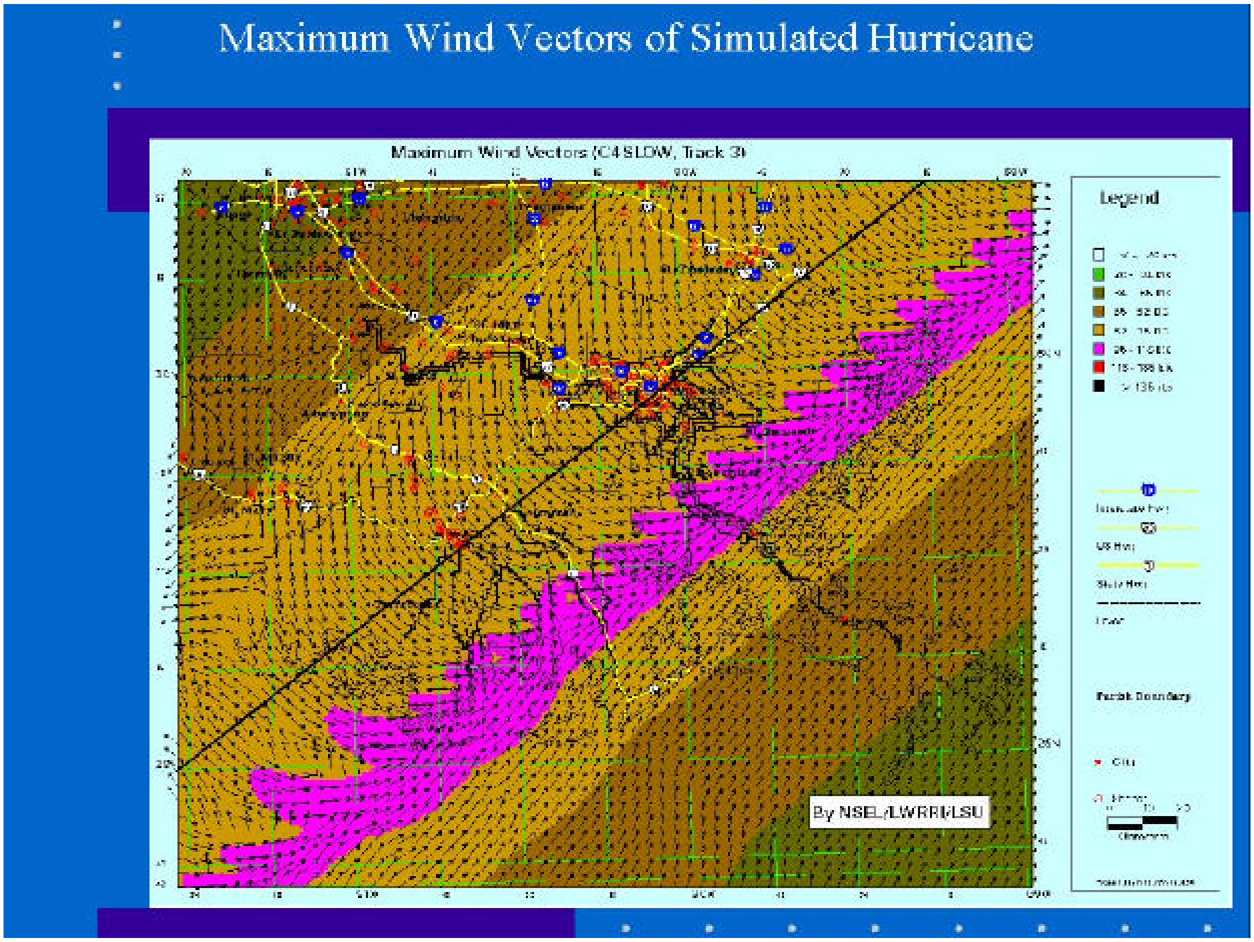

Maximum Wind Vectors of Simulated Hurricane
Maximum Wind Vectors (C4SLOW, Track 3)
Legend
By NSEL/LWRRI/LSU

Figure. 21

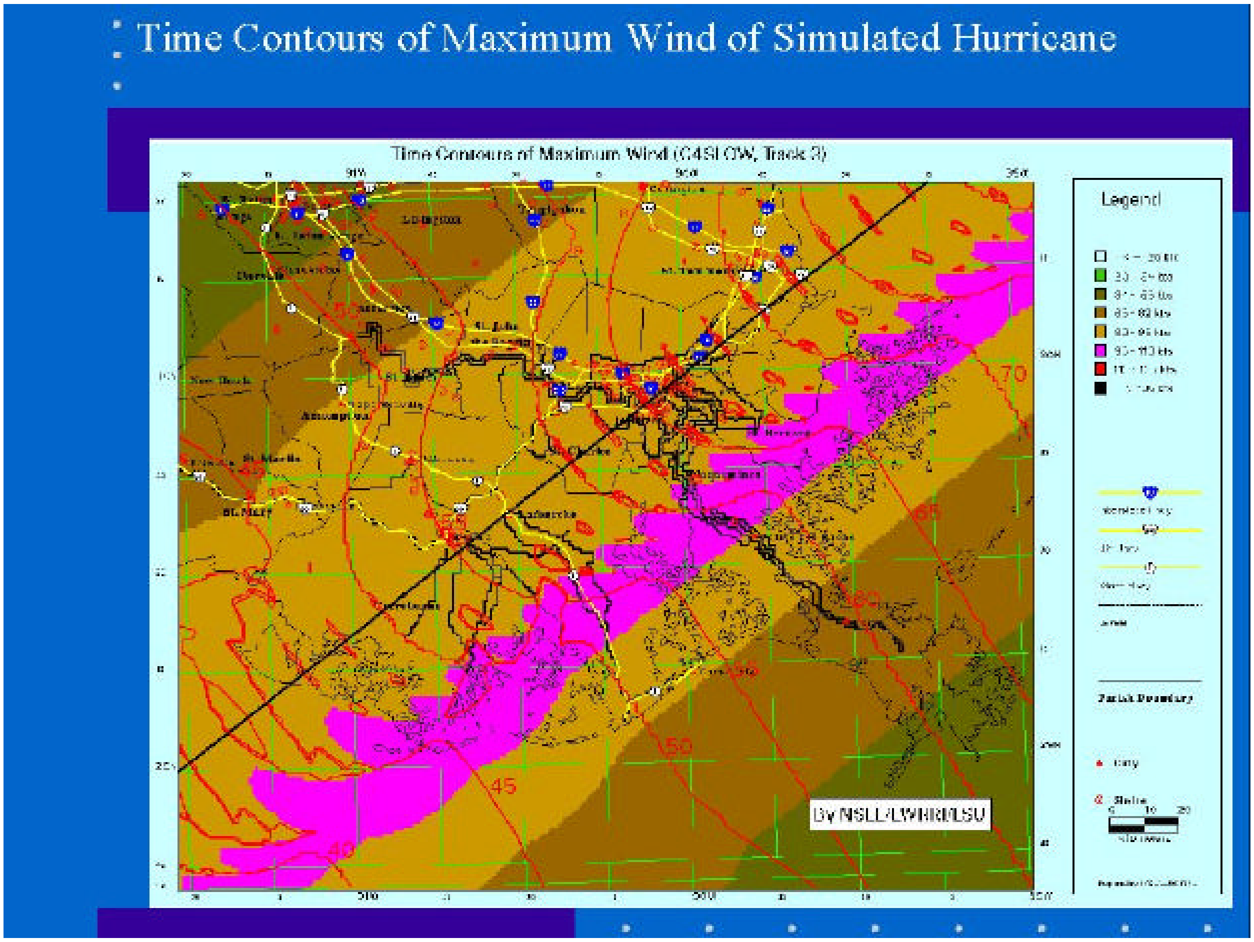

Time Contours of Maximum Wind of Simulated Hurricane
Time Contours of Maximum Wind (C4SLOW, Track 3)
Legend
Parish Boundary
By NSLL/LWRRI/LSU

Figure. 22

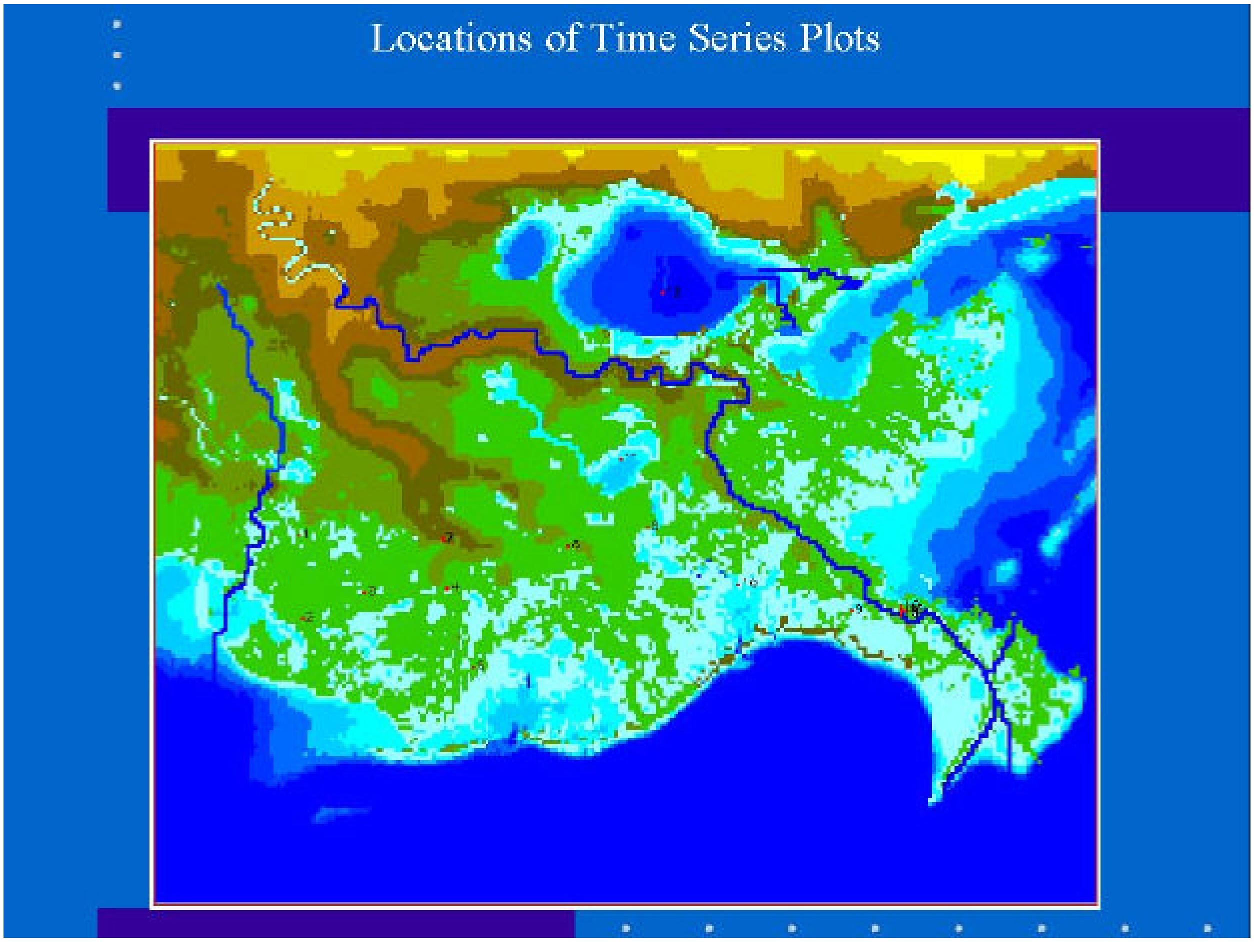
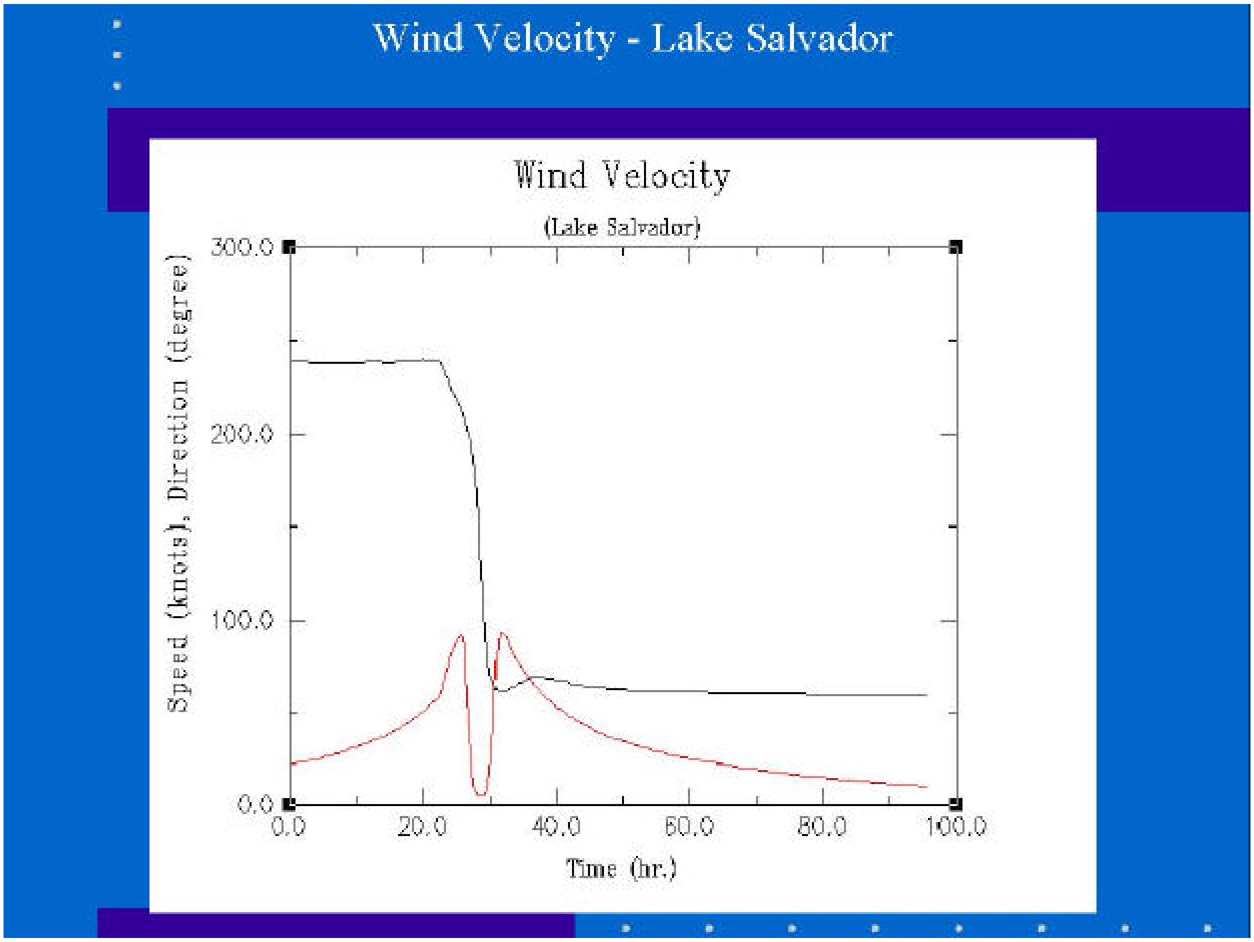


Figure. 23



Wind Velocity - Lake Salvador
Wind Velocity
(Lake Salvador)
Speed (knots), Direction (degree)
300.0
200.0
100.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
Time (hr.)

Figure. 24

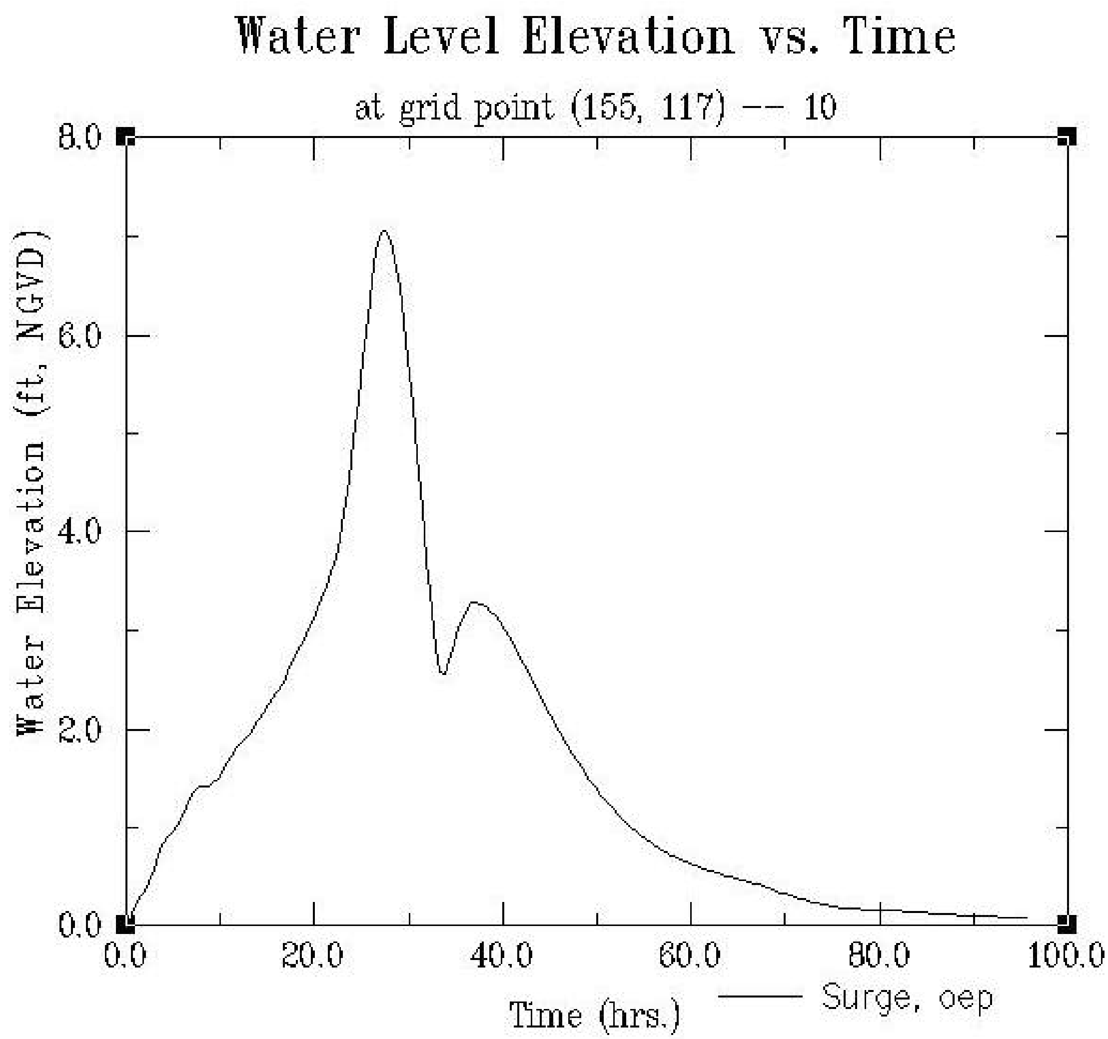

Water Level Elevation vs. Time
at grid point (155, 117) -- 10
Water Elevation (ft, NGVD)
8.0
6.0
4.0
2.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
Time (hrs.)
Surge, oep

Figure. 25

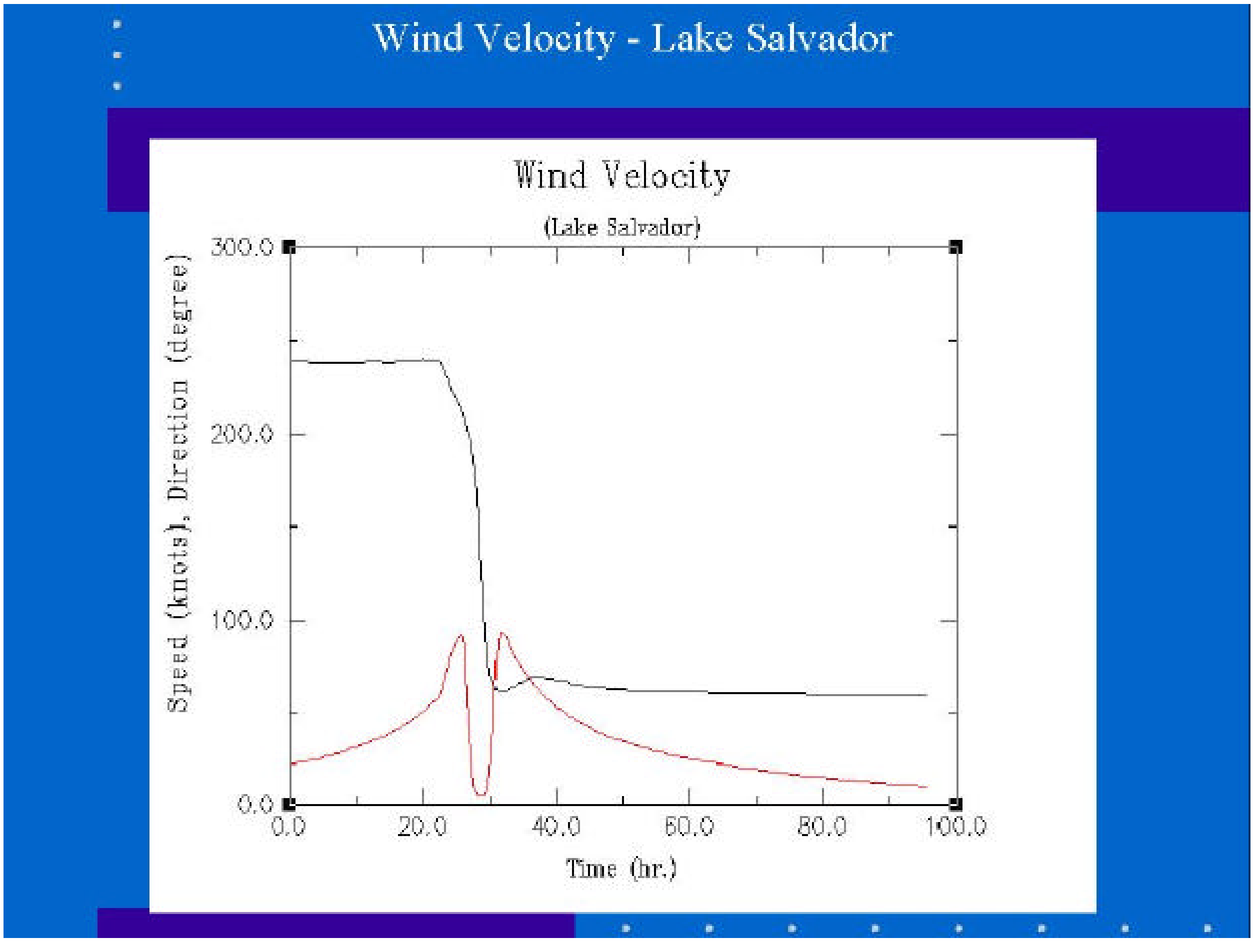

Wind Velocity - Lake Salvador
Wind Velocity
(Lake Salvador)
Speed (knots), Direction (degree)
300.0
200.0
100.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
Time (hr.)

Figure. 26

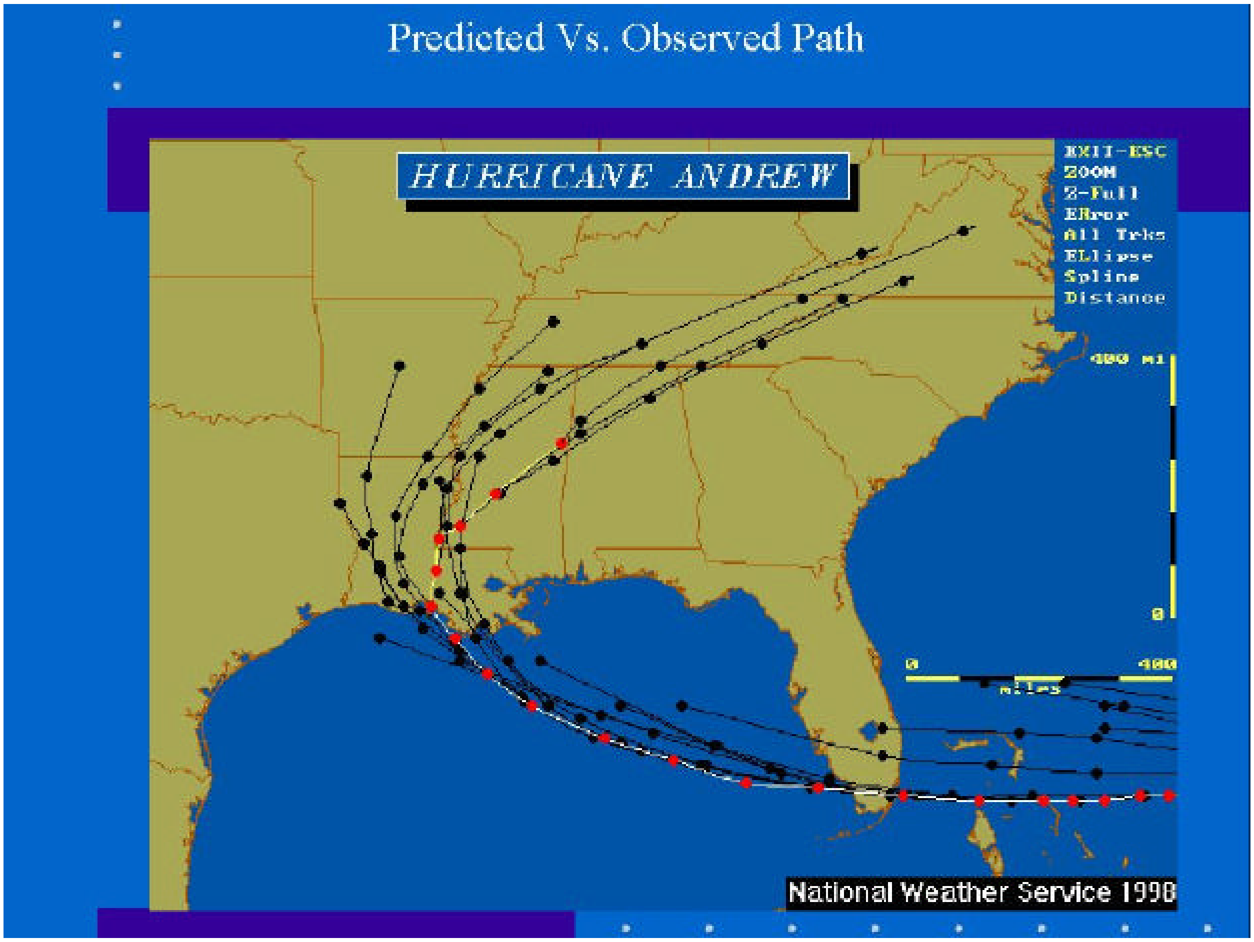

Predicted Vs. Observed Path
HURRICANE ANDREW
EXIT-ESC
ZOOM
Z-Full
ERror
All Trks
ELlipse
Spline
Distance
400 mi
0
0
400
miles
National Weather Service 1998

Figure. 27

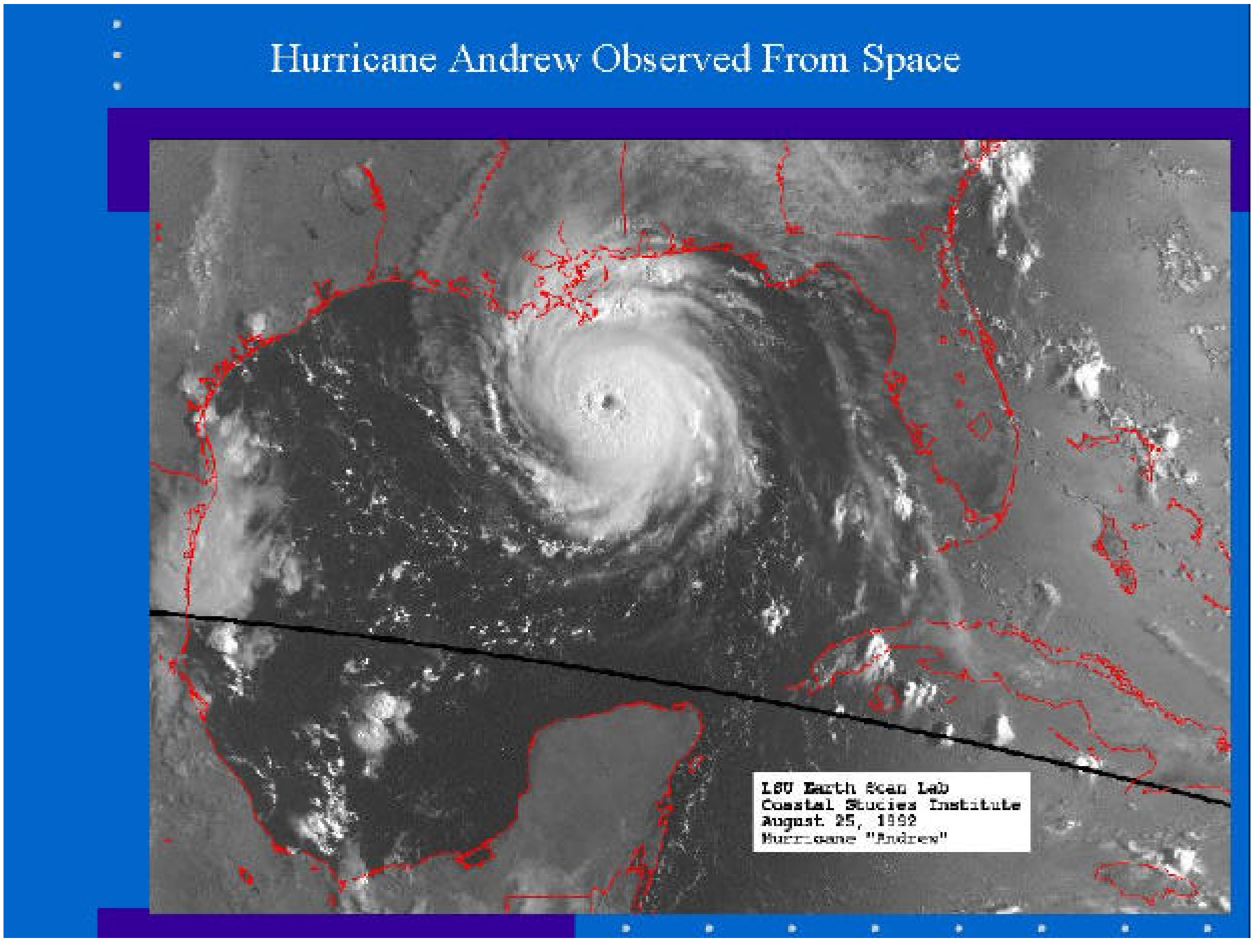

Hurricane Andrew Observed From Space
LSU Earth Scan Lab
Coastal Studies Institute
August 25, 1992
Hurricane "Andrew"

Figure. 28