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Electronic Database Compiling Bridge Storm Design Parameters

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Cooperative Research Program

TEXAS A&M UNIVERSITY–KINGSVILLE
KINGSVILLE, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
http://users.tamuk.edu/kfgfa00/Wave%20Loads.HTM

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16. Abstract

Several coastal bridges have been destroyed by historic and recent hurricanes. Currently no guidelines exist for the design of bridge superstructures when subjected to the action of waves. Design parameters available for the design of bridge superstructures against storm wave forces are scattered and difficult to interpret. This document provides a synthesis of data found in several historical databases and databases maintained regularly by government organizations and research laboratories.

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ELECTRONIC DATABASE
COMPILING BRIDGE STORM DESIGN PARAMETERS

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I. INTRODUCTION

Several coastal bridges have been destroyed by historic and recent hurricanes. Examples include the bridges on U.S. HW 90 across Biloxi Bay and St. Louis Bay, heavily damaged by hurricane Camille in 1969 (Denson, 1980). More recent examples include the Escambia Bay Bridge damaged by hurricane Ivan in 2004 on the coast of Florida, the bridge on U.S. HW 90 across St. Louis Bay (Miss.), the bridge on U.S. HW 90 across Biloxi Bay (Miss.), and the bridge on I-10 across Lake Pontchartrain in New Orleans (La.), all seriously damaged by hurricane Katrina in 2005.

Currently no guidelines exist for the design of bridge superstructures when subjected to the action of waves. Design parameters available for the design of bridge superstructures against storm wave forces are scattered and difficult to interpret. This document provides a synthesis of data found in several historical databases and databases maintained regularly by government organizations and research laboratories. References are also given about documents containing information about hurricane pressure, radius of maximum winds, frequency of occurrence of hurricanes, and bathymetry of the Gulf of Mexico coast.

II. DATABASE OF BRIDGE DESIGN PARAMETERS

Crucial to any design is the availability of data to be used in the design equations. Due to the fact that meteorological data are difficult to find and sometimes to interpret, this section will provide a compilation of hurricane, wave, and meteorological data obtained from four different data sources. Most of the information has been formatted to condense and facilitate its interpretation. The four main sources of databases are: the Texas Coastal Ocean Observation Network (TCOON) from the Division of Nearshore Research (DNR), the website weatherunderground.com, the National Oceanic and Atmospheric Administration's (NOAA) data buoy center, and NOAA's National Hurricane Center. A brief description and linked references to a world tsunami database are also provided in this chapter. Information contained in this chapter does not necessarily include information on all the parameters needed for the design of bridge superstructures against wave action.

An electronic copy of the compiled database information is provided with this document on a compact disc (CD) containing four folders. One folder is named TCOON and contains a condensed database for 32 weather stations retrieved from the Texas Coastal Ocean Observation Network. Each station folder contains an Excel® file. The Excel file summarizes all the data available at that station, including an overview sheet that describes in a graphical format the availability of each parameter. The overview sheet also indicates the station name, ID, location, and a summary of data on barometric pressure, primary water level, wind speed, and water temperature for each year of data recorded. Separate sheets within the same Excel file list data recorded every hour for four parameters: barometric pressure, primary water level, wind speed, and water temperature.

The CD contains another folder named UNDERGROUND that includes two Excel files: one labeled "Historical Atlantic Coast Data" and another called "Historical

Texas Coast Data." The "Historical Atlantic Coast Data" file contains a summary page showing a plot of the number of events for each year recorded. This Excel file also includes 120 sheets, one for each year of recorded storms from 1886 to 2005. The data contained in each sheet are described in the weather underground database section of this chapter. The second Excel file under the weather underground folder is labeled "Historical Texas Coast Data." This file presents the same information as the Historical Atlantic Coast Data file, except that this file includes only data about hurricanes and tropical storms that have landed on the Texas coast. The summary page of this file includes a plot of storm frequency for the Texas coast by month. Further description of this folder is given under the weatherunderground database of this chapter.

The third folder is named NOAA and contains one Excel file and a folder. The Excel file is labeled "NOAA Historical" and contains historical data retrieved from NOAA's National Hurricane Center. The contents of this file are described further in the NOAA's National Hurricane Center section of this chapter. The folder located under the NOAA folder is labeled "NOAA National Data Buoy Center" and contains weather data retrieved from 12 buoys. The folder includes reports of data for hurricanes Katrina, Rita, and Wilma in Word® document format. The data from the buoy stations are provided in separate folders, each identified by the buoy's ID number. Further information about this database is given in the NOAA's National Data Buoy Center database description of this chapter.

The fourth folder termed TSUNAMI contains copies of two portable document format (PDF) files containing two journal articles that relate to tsunami and tsunami-like waves recorded in the eastern United States and the Caribbean Sea.

TEXAS COASTAL OCEAN OBSERVATION NETWORK

This section includes a description of the type of information available in the Texas Coastal Ocean Observation Network (TCOON). The network is part of the Division of Nearshore Research, and some of the data collected include: water level, wave period and height, temperature, wind speed and direction, barometric pressure, cumulative rainfall, water velocity, and tides.

This database collects data at 32 stations along the Texas coast (TCOON-1, 2005). The data are transmitted to Texas A&M University–Corpus Christi at multiples of six-minute intervals. The data are then processed and stored in real time in a database linked to the worldwide web. TCOON has been in operation since 1988. A description of the database is given next.

Figure 1 shows the location of the 32 active TCOON stations on the Texas coast. The TCOON data query web page shown in Figures 2 and 3 allows the user to retrieve data from the DNR in a variety of formats and combinations (TCOON-2, 2005). The data query page is divided into three sections as shown in Table 1:

Table 1. TCOON main page options

Section	Options
Basic query parameters	Enter desired stations, series, dates, and output format
Graph options	Customize graph layout and construction
ASCII options	Customize ASCII data formatting

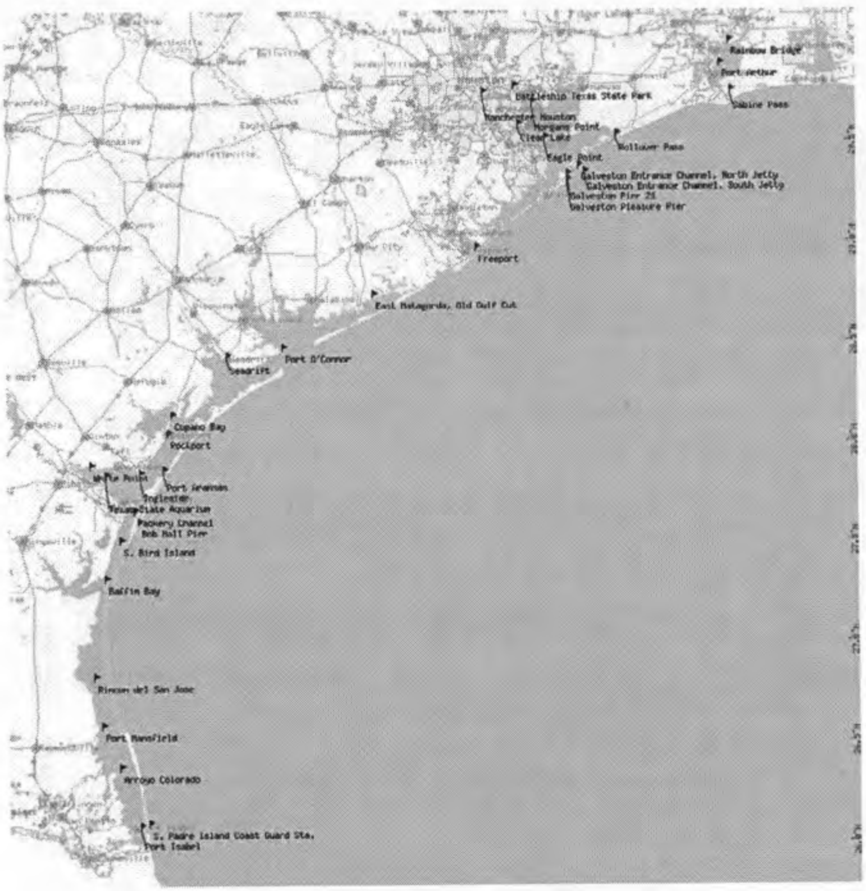

Figure 1. Location of active TCOON stations, source: (TCOON-1, 2005).

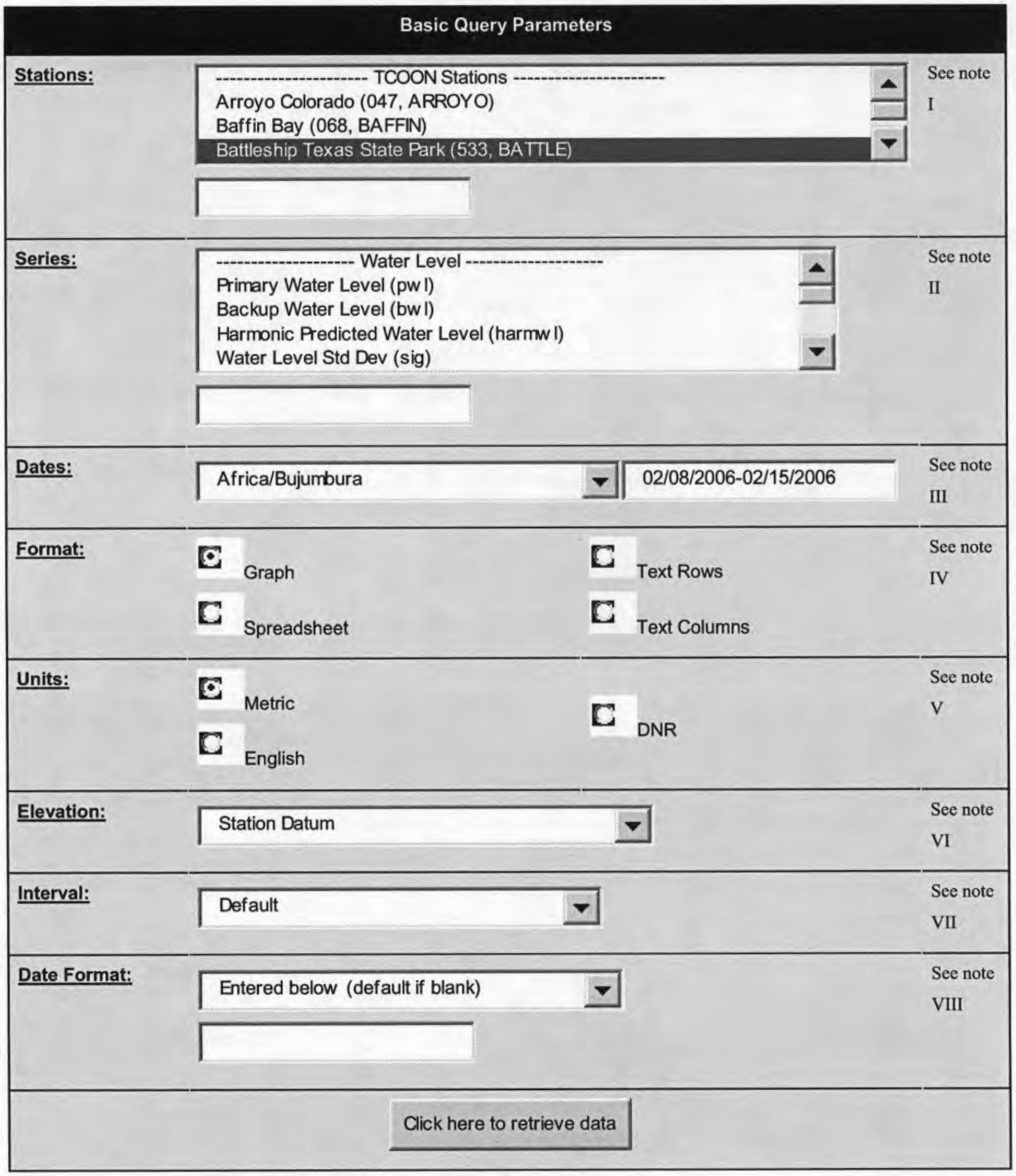

Figure 2. Basic query parameters, source: (TCOON-2, 2005).

(See figure notes on following page.)

NOTES:

I Select the station(s) of interest from the selection box. Stations are grouped by function and listed alphabetically by name within each group. If you already know the identifiers for the station(s) you want, you can enter them directly into the text box. Click for more information on DNR stations and locations.

II Select the data series you would like to view. Note that not all data series are available for all stations. If you already know the abbreviations for the series you want, you can enter them directly into the text box. Click for more information on data series.

III Enter the range of dates for which you want data. In general you can enter dates in the form **mm/dd/yyyy-mm/dd/yyyy**, but other specifications such as **yesterday**, **now**,**-7d**, and **mm/yyyy** also work. Click for more information on date ranges.

IV Select your desired output format. Click for more information on output formats.

V Select your desired output units. **DNR** units indicate the default unit of measurement as stored in the database (always an integer value). Click for more information on units.

VI What do you want vertical elevations (e.g., water level) referenced to? The default is **station datum**, which is an arbitrary zero established at each station. Other elevations may not be available for the station(s) you have requested. Click for more information on elevations.

VII For column-style output, select the time interval to use for each row of output. The value reported on each row is the value recorded at the time indicated on the row.

VIII How do you want dates to be displayed? The default gives reasonable output for most requests, but if you need more control you can either select a predefined format from the top selection box or enter your own strftime specification in the bottom box. Click for more information on date formats.

Graphical Output Parameters		
Title:		Specify an optional title for the graph.
Width:	600	Specify the width of the graph output image.
Height:	400	Specify the height of the graph output image.
Legend Position:	Default, Top, Left, No Legend, Bottom, Right	Specify the position of the legend.
	Click here to retrieve data	

Figure 3. Graphical output parameters, source: (TCOON-2, 2005).

List of TCOON stations

Table 2 shows a list of the 32 active stations in the system. Stations are listed by latitude from north to south. In addition to the active stations there are a total of 162 inactive stations.

Table 2. List of TCOON active stations

No.	Station name	No.	Station name
1	Arroyo Colorado	17	Packery Channel
2	Baffin Bay	18	Port Aransas
3	Battleship Texas State Park	19	Port Arthur
4	Bob Hall Pier	20	Port Isabel
5	Clear Lake	21	Port Mansfield
6	Copano Bay	22	Port O'Connor
7	Eagle Point	23	Rainbow Bridge
8	East Matagorda, Old Gulf Cut	24	Rincon del San Jose
9	Freeport	25	Rockport
10	Galveston Entrance Channel, North Jetty	26	Rollver Pass
11	Galveston Entrance Channel, South Jetty	27	S. Bird Island
12	Galveston Pier 21	28	S. Padre Island Coast Guard Station
13	Galveston Pressure Pier	29	Sabine Pass
14	Ingleside	30	Seadrift
15	Manchester Houston	31	Texas State Aquarium
16	Morgans Point	32	White Point

Basic query parameters

The TCOON database is organized in several groups of data. Each data group will be labeled from A through H for convenience in this report. Group A contains information about the water level, group B about weather, group C about waves, group D relates to water velocity, group E about tides, F regards water quality, group G relates to monthly statistics, and group H about other data. The type of information stored in each data group is described below.

Information available by data group

Table 3 indicates the type of data contained in each data group. Group F collects the following data on water quality: water salinity, conductivity, pH, dissolved oxygen, saturation, turbidity, and water depth. Group H stores data on battery voltage and calibration temperatures A and B. The data collected in Group H give information about the data acquisition system and measurement apparatuses. Since the data contained in groups F and H are irrelevant to this project, they are not listed in Table 3.

Table 3. Data contained in each group

No.	Data	No.	Data
	A - Water level		
1	Primary water level	4	Water level standard deviation
2	Backup water level	5	Water level outliers
3	Harmonic predicted water level	6	Stage height
	B - Weather		
1	Air temperature	6	Barometric pressure
2	Water temperature	7	Cumulative rainfall
3	Wind speed	8	Wind speed B
4	Wind gust	9	Wind gusts B
5	Wind direction	10	Wind direction B
	C - Waves		
1	Significant wave height	6	RDI wave direction
2	Peak wave period	7	RDI maximum wave height
3	RDI significant wave height	8	RDI mean wave period
4	RDI peak wave period	9	Pressure
5	RDI water depth	10	Average water pressure
	D - Water velocity		
1	Velocity X	12	Mid-depth velocity Up
2	Velocity Y	13	Bottom velocity East
3	Velocity Z	14	Bottom velocity North
4	Velocity East	15	Bottom velocity Up
5	Velocity North	16	Signal strength X
6	Velocity Up	17	Signal strength Y
7	Surface velocity East	18	Signal strength Z
8	Surface velocity North	19	ADCP compass heading**
9	Surface velocity Up	20	ACDP sensor tilt
10	Mid-depth velocity East	21	ACDP sensor roll
11	Mid-depth velocity North	22	Percent good
	E - Tides		
1	Higher high water	4	Low water
2	Lower high water	5	Higher low water
3	High water	6	Lower low water
	G - Monthly ststistics		
1	Monthly mean higher high water	7	Monthly great diurnal range
2	Monthly mean high water	8	Monthly mean tide range
3	Monthly mean tide level	9	Monthly DHQ***
4	Monthly mean sea level	10	Monthly DLQ****
5	Monthly mean low water	11	Salinity lower bound
6	Monthly mean lower low water	12	Salinity upper bound

* Relational dimensions instrument (RDI)
** Acoustic Doppler current profiler (ADCP)
*** Diurnal high water inequality (DHQ)
**** Diurnal low water inequality (DLQ)

The following data are also stored at each station regarding elevation: station datum, mean higher high water, mean high water, mean tide level, mean sea level, mean low water, mean lower low water, mean water level, national geodetic vertical datum (1929), North American vertical datum 1988.

An Excel file containing a record of the years in which data are available in all the active TCOON stations is on the CD accompanying this document. The file is labeled "data available at TCOON stations." The Excel spreadsheets include data for all the elements in the TCOON database (all elements in data groups A through H) for each station.

Nomenclature used in the database

Mean higher high water (MHHW)

MHHW is the average height of the higher high waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.

Mean high water (MHW)

MHW is the average height of the high waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. So determined, mean high water in the latter case is the same as mean higher high water.

Mean tide level (MTL)

MTL represents a plane midway between mean high water and mean low water. Not necessarily equal to mean sea level. Also known as half-tide level.

Mean sea level (MSL)

MSL is the average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings. Not necessarily equal to Mean Tide Level. It is also the average water level that would exist in the absence of tides.

Mean low water (MLW)

MLW is the average height of the low waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All low water heights are included in the average where the type of tide is either semidiurnal or mixed. Only lower low water heights are included in the average where the type of tide is diurnal. So determined, mean low water in the latter case is the same as mean lower low water.

Mean lower low water (MLLW)

MLLW is the average height of the lower low waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. Frequently abbreviated to Lower Low Water.

WEATHERUNDERGROUND DATABASE

This section includes a brief description of a database existing on the website weatherunderground (Weatherunderground, 2005). The subdirectory labeled "UNDERGROUND" contains a database of historical hurricanes developed on the Atlantic Ocean and the Gulf of Mexico between 1886 and 2005. This database includes information such as storm name, storm track, and date of occurrence, maximum wind speed, minimum pressure, and number of deaths caused by the storm. This information is presented in two separate files: "Historical Atlantic Coast Data" and "Historical Texas Coast Data."

The Historical Atlantic Coast Data file contains records of tropical storms and hurricanes that landed on the U.S. Atlantic Ocean coast between 1886 and 2005. This file includes plots of storm path and maximum wind speed records for each recorded storm. Data on minimum barometric pressure and number of deaths are also given for some storms. This database summary includes a storm frequency chart that depicts the number of tropical storms and hurricanes that occurred each year.

The Historical Texas Coast Data file includes data on tropical storms and hurricanes that landed on the Texas coast between 1886 and 2005. Plots of storm paths and maximum wind speeds are presented for each event. Charts of storm frequency by year and by month are also given in this file.

NOAA'S NATIONAL DATA BUOY CENTER

The National Data Buoy Center was formed in 1967 with the mission to provide reliable marine data for the National Weather Service (NDBC, 2006). The system has buoys placed around the United States. These buoys measure average wave period, dominant wave period, sea level pressure, significant wave height, sea temperature, peak wind gust, and average wind speed. Each buoy indicates the date it was placed in service. The parameters are available every hour for the years stated in the historical portion of the website. Along with the historical data, the active buoys can provide current wave and weather conditions in real-time weather forecasting in the recent data portion of the records.

This document is accompanied by a CD with a file folder named "NOAA National Data Buoy Center," located under the "NOAA" folder. The NOAA National

Center folder contains a summary of data retrieved from 12 buoys along the Texas coast. Each buoy record was placed in a separate folder labeled with the buoy's ID number. The buoy ID numbers are shown in Figure 4, obtained from NOAA's web page (NDBC, 2006). Each buoy folder contains a word document that describes the information available for that buoy.

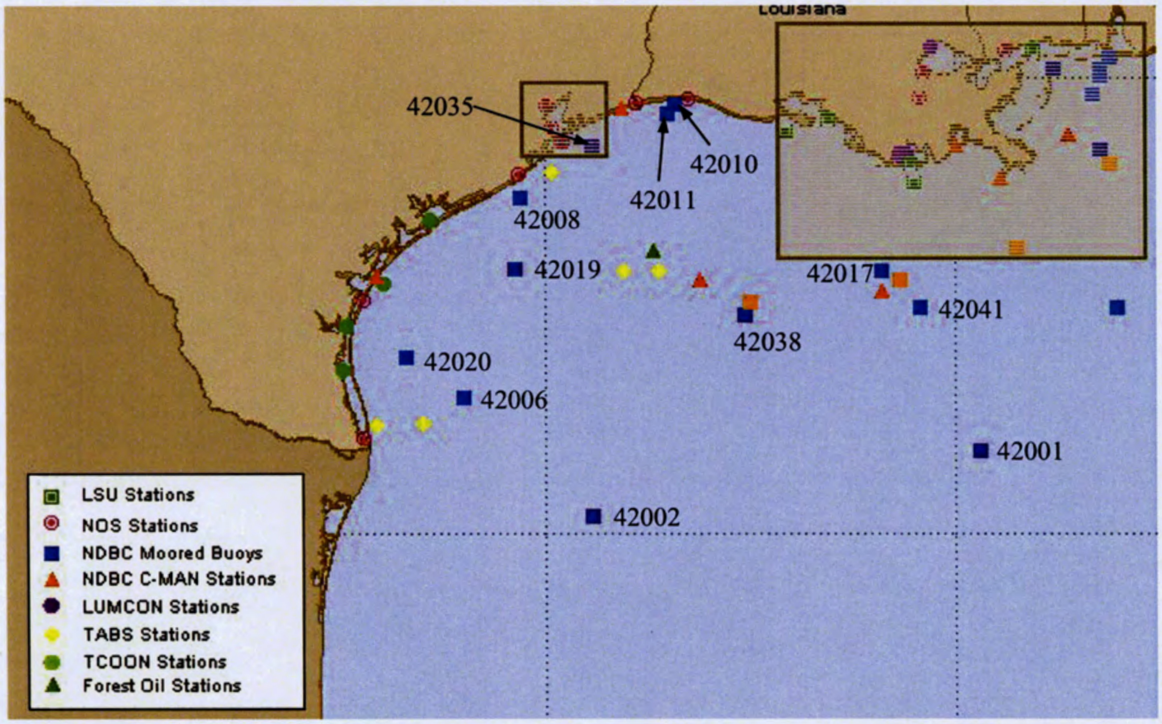

Figure 4. NOAA's buoy location map (only blue squares are buoys), source: (NDBC, 2006).

This database is also accompanied by three reports about hurricanes Katrina, Rita, and Wilma. The reports were produced by the National Data Buoy Center and include recorded storm track, wind speed, sea level pressure, significant wave height, and dominant wave period. These reports are provided in electronic format on a compact disc.

In addition to this database, NOAA's Environmental Buoy Data has compiled buoy information in CD ROMs and they are available for sale (NOAA-8, 2006). The

CD-ROMs contain a historical archive of oceanographic and meteorological data obtained by moored buoys and C-MAN stations operated by the NOAA National Data Buoy Center. The set consists of 7 discs containing data collected by the buoys from the 1970's through December 1977, with online Internet links to updated data, information, and time series plots. Parameters compiled in the database include air sea temperatures, wind and wave data, and other oceanographic and meteorological data. Disk 1 contains data from the upper North Atlantic buoys, disk 2 has data from the mid and lower North Atlantic buoys, disk 3 compiles data from buoys located in the Gulf of Mexico, disk 4 stores buoy data from the Great Lakes, disk 5 compiles data from buoys in the lower Eastern US coast Pacific, disk 6 has data from buoys in the upper Eastern US coast Pacific, and disk 7 stores data from Alaska, Hawaii, and other Pacific buoys.

NOAA'S NATIONAL HURRICANE CENTER

The National Weather Service and the National Oceanic and Atmospheric Administration made available data from the National Hurricane Center through a web page (NOAA-1, 2006). The following information is provided there:

- An archive of hurricane seasons (NOAA-2, 2006).
- A list of the costliest hurricanes without adjustment for inflation (NOAA-3, 2006).
- A list of the costliest hurricanes adjusted for inflation (NOAA-4, 2006).
- A list of the deadliest hurricanes (NOAA-5, 2006).
- A list of the most intense hurricanes (NOAA-6, 2006).
- A file containing a list of hurricanes recorded according to the state where they landed (NOAA-7, 2006).

This section is accompanied by a file containing a summary of NOAA's list of hurricanes recorded by state. The file name "NOAA Historical by State," includes a list of hurricane direct hits on mainland U.S. between 1851 and 2004. The file indicates the under the Excel sheet labeled "Historical by State." The same file contains another sheet labeled "Historical with Pressure-Speed," presenting a chronological list of all hurricanes which affected the continental United States between 1851 and 2005. This file includes information such as minimum central pressure in millibars and maximum wind speed in knots.

WEATHER INFORMATION STUDIES

The U.S. Army Corps of Engineers through the Coastal and Hydraulics laboratory has developed a set of hindcasts of ocean waves (COE, 2006). The laboratory provides a website labeled Wave Information Studies that contains a database of wave hindcast data for the entire U. S. Atlantic and Pacific coasts as well as Puerto Rico, Hawaii, and Alaska (COE-2, 2006). The data are produced by numerical simulation of past wind and wave conditions (hindcasting). Data are available for 91 stations located along the Texas coast. The data for the Gulf of Mexico and Atlantic Ocean can provide plots of wave information between 1980 and 1999. The data provided include: station number, location (latitude and longitude), water depth, significant wave height, peak wave period, overall vector mean wave direction, wind direction, and wind speed. The hindcasting model used is called WISWAVE and is fed using measured wave and wind data from buoys and satellites.

OCEANWEATHER

Oceanweather, Incorporated, is a private company that has applied hindcasting models since 1983 to forecast ocean wind and waves (Oceanweather, 2006). Oceanweather has a forecast center that runs operational global and regional wave models.

WORLD TSUNAMI DATABASE

This section of the document briefly describes two journal articles contained on the accompanying CD in PDF files under the electronic folder labeled TSUNAMI. Lander et al. describe a brief history of tsunamis in the Caribbean Sea (Lander et al., 2002). That journal article contains a description of many events and several tables summarizing the events and wave data. An article by Lockridge describes tsunamis and tsunami-like waves of the eastern United States (Lockridge et al., 2002). That document describes events that occurred since 1668 and describes damage and wave data of the events. The document also summarizes earthquake and tsunami data in tables.

An important world tsunami database is found in the International Tsunami Information Centre (ITIC, 2006). This database contains links to four databases with information for: Mediterranean Sea, Atlantic Ocean, Pacific Ocean, and two world datasets. The databases mentioned in this section typically include the maximum wave height recorded for each tsunami event.

Database for the Mediterranean Sea

The database for the Mediterranean Sea includes tsunami events between 1628 BC and 1999. This database is hosted at the Novosibirsk Tsunami Laboratory in Russia (NTL-1, 2006).

Database for the Atlantic Ocean

The database for the Atlantic Ocean reports tsunami events in the Atlantic region between 60 BC and today (NTL-2, 2006). The Novosibirsk Tsunami Laboratory maintains the web version of the database. The laboratory is part of the Institute of Computational Mathematics and Mathematical Geophysics of the Siberian Division of the Russian Academy of Sciences. The database contains two parts: the first one (event data) contains the basic tsunami parameters on 260 historical tsunami events that occurred in the Atlantic; the second part (run-up data) includes available run-up and tide-gage observations for the region.

Database for the Pacific Ocean

This database includes tsunami events that occurred in the Pacific between 47 BC and today. The Novosibirsk Tsunami Laboratory also maintains this database (NTL-3, 2006). This dataset is divided into three parts: the first one (event data) contains information on nearly 1490 historical events; the second part (run-up data) contains almost 8000 coastal run-up and tide-gage observations of wave heights; the third part (earthquake data) contains a worldwide earthquake catalog with close to 6300 events that occurred since prehistoric times.

NOAA/NGDC World Tsunami Database

This database is presented in two formats by the National Oceanic and Atmospheric Administration and by the National Geophysical Data Center of the U.S. The database is presented in geographic information system (GIS) graphic format (NOAA/NGDC-1, 2006), as well as in text format (NOAA/NGDC-2, 2006).

FEMA – COASTAL CONSTRUCTION MANUAL

Chapter 7 of the *Coastal Construction Manual* by the Federal Emergency Management Agency (FEMA) contains a table of mean return periods for landfall or nearby passage of tropical cyclones (FEMA, 2000). The return periods are reproduced in Table 4.

Table 4. Mean return period for landfall or nearby passage of tropical cyclones (FEMA, 2000)

Area	Mean return period (years)		
	Passage of all tropical cyclones within 50 miles *	Landfall of all hurricanes (Category 1-5) **	Landfall of all major hurricanes (Category 3-5) **
U.S. (Texas to Maine)	-	0.6	1.5
Texas	1.4	2.7	6.5
South	-	7.5	16
Central	-	16	49
North	-	5.7	14
Louisiana	1.6	3.9	8.1
Mississippi	2.7	12	16
Alabama	2.7	9.7	19
Florida	0.8	1.7	4
Northwest	-	4	14
Southwest	-	5.4	11
Southeast	-	3.7	8.8
Northeast	-	11	#
Georgia	2.0	19	#
South Carolina	2.3	6.9	24
North Carolina	1.7	3.9	8.8
Virginia	4.0	24	97
Maryland	4.2	97	#
Delaware	4.7	#	#
New Jersey	4.7	97	#
New York	3.7	11	19
Connecticut	4.2	19	32
Rhode Island	4.2	19	32
Massachusetts	3.7	16	49
New Hampshire	7.8	49	#
Maine	7.2	19	#
Virgin Islands *	2.0	~	~
Puerto Rico *	2.4	8	~
Hawaii *	7.1	~	~
Guam *	1.0	~	~

* Based on National Weather Service (NWS) data for period 1899-1992, from FEMA Hurricane Program, 1994

** For period 1900-1996, from NOAA Technical Memorandum NWS TPC-1, February 1997

\- No intrastate breakdown by FEMA Hurricane Program

\# Number not computed (no storms of specified intensity made landfall during 1900-1996)

~ Island; landfall statistics alone may understate hazard

THE HURRICANE AND ITS IMPACT

Simpson and Riehl presented historical data on hurricane impact on the U.S. coast in their book *The Hurricane and Its Impact* (Simpson and Riehl, 1981). Figure 5 obtained from Appendix D of the book indicates in box *a* the number of years between occurrences of hurricanes (having maximum wind speeds in excess of 75 mph) and in box *b* the number of years between occurrences of severe hurricanes (having maximum wind speeds in excess of 125 mph) for 58 coastal segments along the Gulf and Atlantic coastlines of the U.S.

Table 5 shows data on the number of hurricanes reaching the United States mainland during the period 1886-1970 for each of the 58 coastal segments indicated in Figure 5. Table 6 lists the probability for a hurricane strike in any given year for each of the 58 coastal segments illustrated in Figure 5.

Figure 5. Number of years between occurrences of hurricanes with wind speeds of (*a*) greater than 75 mph and (*b*) wind speeds greater than 125 mph, source: (Simpson and Riehl, 1981).

Table 5. Number of hurricanes landing on the U.S. coast between 1886 and 1970 for each coastal segment illustrated in Figure 5 (Simpson and Riehl, 1981)

Sector	All hurricanes	Great hurricanes	Sector	All hurricanes	Great hurricanes
1	7	2	30	7	4
2	6	4	31	4	0
3	6	3	32	2	0
4	8	3	33	1	0
5	12	3	34	1	0
6	10	3	35	2	1
7	7	3	36	6	1
8	5	1	37	7	0
9	5	0	38	4	0
10	8	0	39	5	2
11	11	2	40	5	2
12	8	3	41	4	0
13	5	1	42	9	2
14	11	0	43	7	3
15	12	0	44	2	1
16	6	0	45	2	0
17	5	0	46	2	0
18	6	0	47	1	0
19	5	0	48	0	0
20	7	0	49	1	0
21	5	1	50	5	0
22	3	2	51	5	1
23	4	1	52	6	1
24	8	2	53	5	0
25	11	3	54	0	0
26	11	2	55	0	0
27	10	4	56	3	0
28	14	6	57	5	0
29	13	6	58	4	0

Note: Hurricane = winds of 75 mph or greater, great hurricane = winds of 125 mph or higher.
Source: Adapted from Simpson and Riehl, 1981.

Table 6. Probability for a hurricane strike in any given year for each coastal segment illustrated in Figure 5 (Simpson and Riehl, 1981)

Sector	All hurricanes (%)	Great hurricanes (%)	Sector	All hurricanes (%)	Great hurricanes (%)
1	8	2	30	8	5
2	7	5	31	5	0
3	7	4	32	2	0
4	9	4	33	1	0
5	14	4	34	1	0
6	12	4	35	2	1
7	8	4	36	7	1
8	6	1	37	8	0
9	6	0	38	5	0
10	9	0	39	6	2
11	13	2	40	6	2
12	9	4	41	5	0
13	6	1	42	11	2
14	13	0	43	8	4
15	14	0	44	2	1
16	7	0	45	2	0
17	6	0	46	2	0
18	7	0	47	1	0
19	6	0	48	0	0
20	8	0	49	1	0
21	6	1	50	6	0
22	4	2	51	6	1
23	5	1	52	7	1
24	9	2	53	6	0
25	13	4	54	0	0
26	13	2	55	0	0
27	12	5	56	4	0
28	16	7	57	6	0
29	15	7	58	5	0

Note: Hurricane = winds of 75 mph or greater, great hurricane = winds of 125 mph or higher.
Source: Adapted from Simpson and Riehl, 1981.

Table 7 shows the expected daily ranges of astronomical tides during hurricane season for the Atlantic and Gulf of Mexico coasts of the U.S.

Table 7. Expected daily ranges of astronomical tides during hurricane season (Simpson and Riehl, 1981)

Location	Monthly mean (M) and extreme (X) values (feet)											
	Jun		Jul		Aug		Sep		Oct		Nov	
	M	X	M	X	M	X	M	X	M	X	M	X
Tampico (Mexico)	1.3	2.6	1.0	2.6	1.0	2.3	1.0	2.0	1.0	2.0	1.3	2.6
Galveston (TX)	1.0	2.0	0.7	2.3	1.0	2.3	1.0	2.0	1.0	2.0	1.0	1.6
Mobile (AL)	1.6	2.6	1.3	2.6	1.3	2.3	1.0	2.0	1.0	2.3	1.3	2.6
St. Marks (FL)	2.3	4.9	2.3	4.9	2.3	4.6	2.3	4.3	2.3	4.6	2.3	4.9
St. Petersburg (FL)	1.6	3.3	1.3	3.3	1.3	3.0	1.3	2.6	1.3	3.0	1.3	3.3
Key West (FL)	1.3	3.0	1.3	3.0	1.3	2.6	1.3	2.3	1.3	2.6	1.3	2.6
Miami (FL)	2.6	3.6	2.6	3.6	2.6	3.6	2.6	3.3	2.6	3.6	2.6	3.6
Mayport (FL)	4.9	6.6	4.6	6.2	4.6	6.2	4.6	5.9	4.6	5.9	4.6	6.6
Savannah (GA)	7.9	10.2	7.5	10.2	7.5	9.8	7.5	9.5	7.5	9.2	7.5	9.5
Charleston (SC)	5.2	7.2	4.9	7.2	4.9	6.9	5.2	6.6	4.9	6.6	5.2	7.2
Wilmington (NC)	3.6	4.6	3.6	4.6	3.6	4.6	3.6	4.6	3.6	4.3	3.6	4.3
Hampton Rds (VA)	2.3	3.9	2.3	3.9	2.3	3.6	2.6	3.3	2.6	3.6	2.6	3.6
Reedy Pt (DE)	5.6	7.5	5.6	7.5	5.2	6.9	5.2	6.6	5.2	6.6	5.2	6.6
Sandy Hook (NJ)	4.9	7.2	4.6	6.9	4.6	6.9	4.6	6.6	4.6	6.6	4.9	6.9
New York (Battery)	4.6	6.9	4.6	6.9	4.6	6.6	4.6	6.2	4.6	6.2	4.6	6.6
Bridgeport (CN)	6.6	9.8	6.6	9.5	6.9	8.9	6.9	8.5	6.6	9.2	6.6	9.5
Newport (RI)	3.6	5.6	3.6	5.6	3.6	5.2	3.6	4.9	3.6	5.2	3.6	5.6
Boston (MA)	9.5	14.1	9.8	13.5	12.8	13.1	9.5	12.1	9.5	12.8	9.5	13.8
Eastport (ME)	17.4	24.6	17.7	24.0	17.7	23.3	17.7	22.3	17.7	23.6	17.7	24.6

HURRICANE CLIMATOLOGY FOR THE ATLANTIC AND GULF COASTS OF THE UNITED STATES

The referenced document by Ho contains information on the following subjects: sources of data, hurricane central pressure data, hurricane radius of maximum winds, hurricane speed and direction of forward motion, source of speed and direction of forward motion data, meteorological parameters and their interrelations, consideration of data samples for statistical tests, joint probability analysis of central pressure and radius of maximum winds, frequency of hurricane and tropical storm occurrences, and selection of hurricane groups for the Gulf, Florida, and Atlantic coasts (Ho et al, 1987).

OTHER DATA

Data on bathymetry of the Texas coast can be found on the National Geophysical Data Center website (NGDC, 2006), where posters, slides sets, and digital data are available for purchase. The Bureau on Economic Geology distributes a map of the bathymetry of the Gulf of Mexico made by Elazar Uchupi (Uchupi, 1967).

III. DATABASE UPDATING PROCESS

This chapter describes the process that can be followed to update the databases presented in the previous chapter. The updating processes are presented in the same order as the databases in the previous chapters, beginning with the TCOON archive, following with the weatherunderground database. This chapter also includes the updating process for data obtained from NOAA's National Data Buoy Center and the data obtained from NOAA's National Hurricane Center.

TEXAS COASTAL OCEAN OBSERVATION NETWORK

To update this database, first go to the TCOON website (TCOON-1, 2005). Then, under the quick links option, choose data query. This brings the page in Figure 2 onto the screen. At this page choose a station, the parameters needed, the dates desired, the spreadsheet format, metric units, and an hourly interval. Then click the designated icon to retrieve the data. The data will save in an Excel file in one vertical column. Select the data in Excel to copy and paste the selection into the format set in the database. Use Excel formulas to find the statistical values desired and place on overview sheet within the stations folder.

WEATHERUNDERGROUND DATABASE

Enter the weather underground web page (Weatherunderground, 2005). On the main page select the "Tropical/Hurricane" tab. Scroll down the hurricane archive portion of the page. On the right side of the page under the heading "Historical Hurricane Statistics," select "View the Entire Hurricane Archive." On this page select the year of interest and this will bring up a map of all the hurricane tracks for that year. Simply copy and paste that data to an Excel file, and then sort the data and plot resulting information in tables. To compile the database with hurricanes and tropical storms landing on the Texas coast, each hurricane has to be accessed through its own link shown under the picture indicating storm paths for any given year. This link depicts each storm's path, as well as an account of every six hours the storm was active. The archive reports changes in category, wind speed, pressure, latitude, and longitude with time.

NOAA'S NATIONAL DATA BUOY CENTER

To update the archive described in the previous chapter, first visit the NOAA National Data Buoy Center website (NDBC, 2006). Then click on the "Historical Data" tab. Choose the western Gulf of Mexico portion of the map by clicking on it. This will bring up only this region. From this new map click on one of the blue squares, labeled with the buoy's ID number. This will open the buoy's pages where historical data may be retrieved. There are constant data in text form or graphical data over an extended period of time in box-whisker plots.

If more recent information of current weather or wave conditions is needed, simply choose the "Recent Data" tab instead of the "Historical Data" tab on the main page of the National Data Buoy Center. This will bring up the same maps, excluding the inactive buoys. The data retrieval is self-explanatory from there. Conditions are available in real time for weather forecasting if needed.

NOAA'S NATIONAL HURRICANE CENTER

Updating the database presented in the previous chapter only requires copying information from the data presented in a table format at the website referenced in the previous chapter, and then pasting it in the Excel file indicated previously.

OTHER DATABASES

Since no data were summarized from the Weather Information Studies, Oceanweather, and the World Tsunami Database listed in the previous chapter, no updating information is necessary. Likewise, no updating process is given for the data collected from the FEMA Coastal Construction Manual, the book *The Hurricane and Its Impact*, NOAA's report *Hurricane Climatology for the Atlantic and Gulf Coasts of the United States*, and the maps of the bathymetry of the Gulf of Mexico, since no updating is required.

REFERENCES

COE, U. S. Army Corps of Engineers, Coastal and Hydraulics Laboratory, http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=ARTICLES;474, 2006.

COE-2, Wave Information Studies, U. S. Army Corps of Engineers, Coastal and Hydraulics Laboratory, http://frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html, 2006.

Denson, K. H., *Wave Forces on Causeway-Type Bridges: Effects of Angle of Wave Incidence and Cross-Section Shape*, Water Resources Research Institute, Mississippi State University, Report MSHD-RD-80-070, 1980.

FEMA, *Coastal Construction Manual*, Third Edition, Federal Emergency Management, CD, Vols. I, II, and III, June 2000.

Ho, F. P., Su, J. M., Hanevich, K. L., Smith, R. J., Richards, F. P., *Hurricane Climatology for the Atlantic and Gulf Coasts of the United States*, NOAA Technical Report NWS 38, Silver Spring, MD, April, 1987.

ITIC, International Tsunami Information Centre, http://ioc3.unesco.org/itic/categories.php?category_no=72, Intergovernmental Oceanographic Commission of UNESCO, Accessed on May 15, 2006.

Lander, J.F., Whiteside, L.S., and Lockridge, P.A., *A Brief History of Tsunamis in the Caribbean Sea*, Science of Tsunami Hazards, The International Journal of The Tsunami Society, Vol. 20, No. 2, pp. 57-94, 2002.

Lockridge, P.A., Whiteside, L.S., and, Lander, J.F., *Tsunami and Tsunami-Like Waves of the Eastern United States*, Science of Tsunami Hazards, The International Journal of The Tsunami Society, Vol. 20, No. 3, pp. 120-157, 2002.

NDBC, http://www.ndbc.noaa.gov/, National Data Buoy Center, National Oceanic and Atmospheric Administration, Accessed on May 15, 2006.

NGDC, http://www.ngdc.noaa.gov/mgg/fliers/00mgg02.html, Poster: Bathymetry of the Northern Gulf of Mexico and Atlantic Coast East of Florida, World Data Center for Marine Geology and Geophysics, Boulder, National Geophysical Data Center, Accessed on July 20, 2006.

NOAA-1, http://www.nhc.noaa.gov/, National Hurricane Center, National Oceanic and Atmospheric Administration, Accessed on May 15, 2006.

NOAA-2, http://www.nhc.noaa.gov/pastall.shtml, Archive of Hurricane Seasons, National Oceanic and Atmospheric Administration, Accessed on May 15, 2006.

NOAA-3, http://www.nhc.noaa.gov/pastcost.shtml?, Costliest Hurricanes Unadjusted for Inflation, National Oceanic and Atmospheric Administration, Accessed on May 15, 2006.

NOAA-4, http://www.nhc.noaa.gov/pastcost2.shtml?, Costliest Hurricanes Adjusted for Inflation, National Oceanic and Atmospheric Administration, Accessed on May 15, 2006.

NOAA-5, http://www.nhc.noaa.gov/gifs/table2.gif, Deadliest Hurricanes, National Oceanic and Atmospheric Administration, Accessed on May 15, 2006.

NOAA-6, http://www.nhc.noaa.gov/pastint.shtml?, Most Intense Hurricanes, National Oceanic and Atmospheric Administration, Accessed on May 15, 2006.

NOAA-7, http://www.nhc.noaa.gov/paststate.shtml?, Hurricanes by State Where they Landed, National Oceanic and Atmospheric Administration, Accessed on May 15, 2006.

NOAA-8, http://ols.nndc.noaa.gov/plolstore/plsql/olstore.prodspecific?prodnum=W00010-CDR-S0002, National Data Centers, U.S. Department of Commerce, Accessed on July 27, 2006.

NOAA/NGDC-1, http://tsun.sscc.ru/htdbmed/, World Tsunami Database in GIS graphic format, National Oceanic and Atmospheric Administration, U.S., Accessed on May 15, 2006.

NOAA/NGDC-2, http://www.ngdc.noaa.gov/seg/hazard/tsevsrch_idb.shtml, World Tsunami Database in text format, National Geophysical Data Center, U.S., Accessed on May 15, 2006.

NTL-1, http://tsun.sscc.ru/htdbmed/, Tsunami Database for the Mediterranean Sea, Novosibirsk Tsunami Laboratory, Russia, Accessed on May 15,2006.

NTL-2, http://tsun.sscc.ru/htdbatl/, Tsunami Database for the Atlantic Ocean, Novosibirsk Tsunami Laboratory, Russia, Accessed on May 15,2006.

NTL-3, http://tsun.sscc.ru/htdbpac/, Tsunami Database for the Pacific Ocean, Novosibirsk Tsunami Laboratory, Russia, Accessed on May 15,2006.

Oceanweather, Inc., http://www.oceanweather.com/forecast/, 2006.

Simpson, R. H. and Riehl, H., *The Hurricane and Its Impact*, Louisiana State University Press, Baton Rouge, 1981.

TCOON-1, *Texas Coastal Ocean Observation Network*, TCOON Page, http://lighthouse.tamucc.edu/TCOON/HomePage, Accessed on December 10, 2005.

TCOON-2, *Texas Coastal Ocean Observation Network*, Data Query Page http://lighthouse.tamucc.edu/pq , Accessed on December 10, 2005.

Uchupi, E., *Bathymetry of the Gulf of Mexico*, Publication GCAGS 403M, Geological Society, Bureau of Economic Geology, 1967.

Weatherunderground, http://www.weatherunderground.com, Accessed on December 1, 2005.