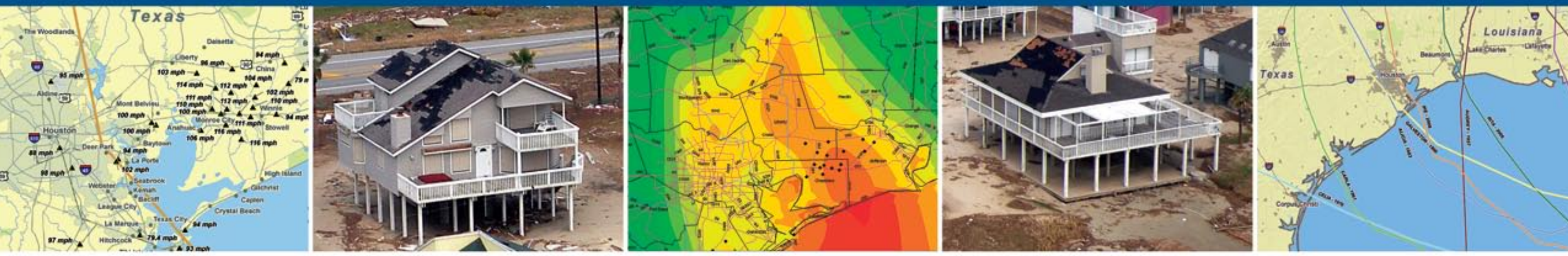
MITIGATION ASSESSMENT TEAM REPORT



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HURRICANE **IKE** IN TEXAS & LOUISIANA

# 1 Introduction

*On October 15, 2008, the Mitigation Division of the Department of Homeland Security's (DHS) Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) to the States of Texas and Louisiana to assess damage caused by the floodwaters and winds of Hurricane Ike. This report presents the MAT's observations, conclusions, and recommendations in response to those field investigations.*

This chapter provides an introduction, a discussion of the event, historical information, and background on the MAT process. Floodplain management regulations and building codes and standards that affect construction in Texas and Louisiana are discussed in Chapter 2. Chapter 3 provides a basic assessment and characterization of the structural and envelope performance of residential buildings, including FEMA-funded mitigation projects in areas affected by Hurricane Ike. Chapter 4 presents damage to, and functional loss of, critical and essential facilities affected by Hurricane Ike. Chapter 5 presents damage to buildings in Houston's Central Building

District. Chapters 6 and 7 present the MAT's conclusions and recommendations, respectively, intended to help guide the reconstruction for hurricane-resistant communities in Texas and Louisiana, and other hurricane-prone regions susceptible to future hurricanes. Chapter 8 presents information on sustainable building practices, which are those practices that promote the longevity of buildings and the ecosystem. Although not generally part of a MAT report, this information is provided because sustainability issues are in the forefront of building responsibly. This information is intended to support the significant reconstruction effort that will follow Hurricane Ike. Over the past few decades, FEMA has provided guidance on hazard-resistance building practices. FEMA highly recommends that designers, architects, and planning officials in hurricane-prone areas refer to these publications. Relevant FEMA publications are provided in Appendix B. In addition, the following appendices are presented herein:

Appendix A: Acknowledgments

Appendix B: References and FEMA Publication List

Appendix C: Acronyms and Glossary of Terms

Appendix D: FEMA Recovery Advisories

- Attachment of Brick Veneer in High-Wind Regions (December, 2005; revised 2009)
- Design and Construction in Coastal A Zones (December, 2005; revised 2009)
- Designing for Flood Levels above the BFE (July, 2006; revised 2009)
- Enclosures and Breakaway Walls
- Erosion, Scour, and Foundation Design
- Minimizing Water Intrusion Through Roof Vents in High-Wind Regions
- Metal Roof Systems in High-Wind Regions
- Siding Installation in High-Wind Regions

Appendix E: FEMA High Water Marks for Hurricane Ike

## 1.1 Hurricane Ike – The Event

Hurricane Ike made landfall over Galveston, TX, on September 13, 2008, at 2:10 a.m. Central Daylight Time (CDT) as a large Category 2 hurricane. Hurricane Ike was the ninth named storm during the 2008 hurricane season and the seventh of the season's storms to hit the U.S. mainland. It was the most significant of the three that hit Texas in 2008 and the second to hit Louisiana in a matter of weeks, with Gustav having hit southwestern Louisiana on September 1, 2008. Hurricane Ike made landfall over Galveston, TX, on September 13, 2008, at 2:10 a.m. as a large Category 2 hurricane. Even though damages were still being tallied as of February 2009, Hurricane Ike is likely to be one of the costliest and most destructive hurricanes in U.S. history; the total damage is estimated to be $21.3 billion, making it the fourth costliest hurricane in history behind Hurricanes Katrina (2005), Andrew (1992), and Wilma (2005) (National Hurricane Center [NHC], 2007).

Although Hurricane Ike was a Category 2 hurricane when it made landfall near Galveston, TX, the large wind field of Hurricane Ike led to storm surge levels more typically associated with a Category 4 hurricane. This disparity is due to the fact that the Saffir-Simpson hurricane scale (Table 1-1), the scale currently used to measure hurricane intensity, is based on typical storm characteristics, and Ike was atypical. Ike was a very large hurricane; tropical-storm-force and hurricane-force winds associated with Ike at the time of its landfall extended approximately 275 miles and 120 miles from the storm center, respectively. A proposed new storm classification system, called the Integrated Kinetic Energy classification (Powell and Reinhold, 2007), would place Ike's storm Surge/Wave Destructive Potential (SDP) as high as a 5.2 (on a scale of 1 to 6) at mid-day on September 11, 2008 (refer to text box for additional information). Figure 1-1 provides a satellite image of Hurricane Ike that illustrates the size of the storm as it approached Galveston, TX.

**Table 1-1. Saffir-Simpson Hurricane Scale Wind Speeds and Pressures**

| Strength | Sustained Wind Speed[1] (mph) | Gust Wind Speed[2] (mph) | Pressure (mb[3]) |
|---|---|---|---|
| Category 1 | 74-95 | 89-116 | >980 |
| Category 2 | 96-110 | 117-134 | 965-979 |
| Category 3 | 111-130 | 135-159 | 945-964 |
| Category 4 | 131-155 | 160-189 | 920-944 |
| Category 5 | >155 | >189 | <920 |

[1] 1-minute sustained over open water [2] 3-second gust over open water [3] mb = millibars

SOURCE: http://www.nhc.noaa.gov/aboutsshs.shtml

## INTEGRATED KINETIC ENERGY

The kinetic energy in a hurricane or any windstorm is proportional to the wind velocity squared. The Integrated Kinetic Energy (IKE) is calculated for a 1-meter deep layer of the storm centered at about a height of 10 meters and can be produced using any appropriate wind field that provides a map of sustained 1-minute winds. The IKE values reported are based on the H*Wind wind field produced by the Hurricane Research Division (HRD) of the National Oceanographic and Atmospheric Administration (NOAA) as an experimental product. The H*Wind wind field is used to produce contours of areas where the wind speeds are greater than tropical storm force, greater than hurricane force, and greater than very strong hurricane force winds ( >123 mph sustained winds). These estimates of IKE for areas experiencing wind speeds above certain thresholds are used to produce an SDP and a Wind Destructive Potential (WDP). The SDP is based on the total IKE for all areas where sustained wind speeds are greater than or equal to tropical storm force. The resulting IKE is expressed in terrajoules and is converted to a decimal value between 0 and 6.

**What it is:**

- A number between 0 and 6 that gives a relative measure of the wind field forcing over the ocean that can lead to high surge and wave damage
- The higher the number, the greater the potential for extensive along-shore inundation and damage from surge and waves
- Independent of bottom slope, coastline shape or properties at risk

**What it is not:**

- An accurate estimate of actual surge levels or damage since these depend on characteristics of the storm throughout its life cycle as it approaches the coast, and local effects including bottom slope, coastline shape, track of the storm, the roughness of the land surface, and property at risk.

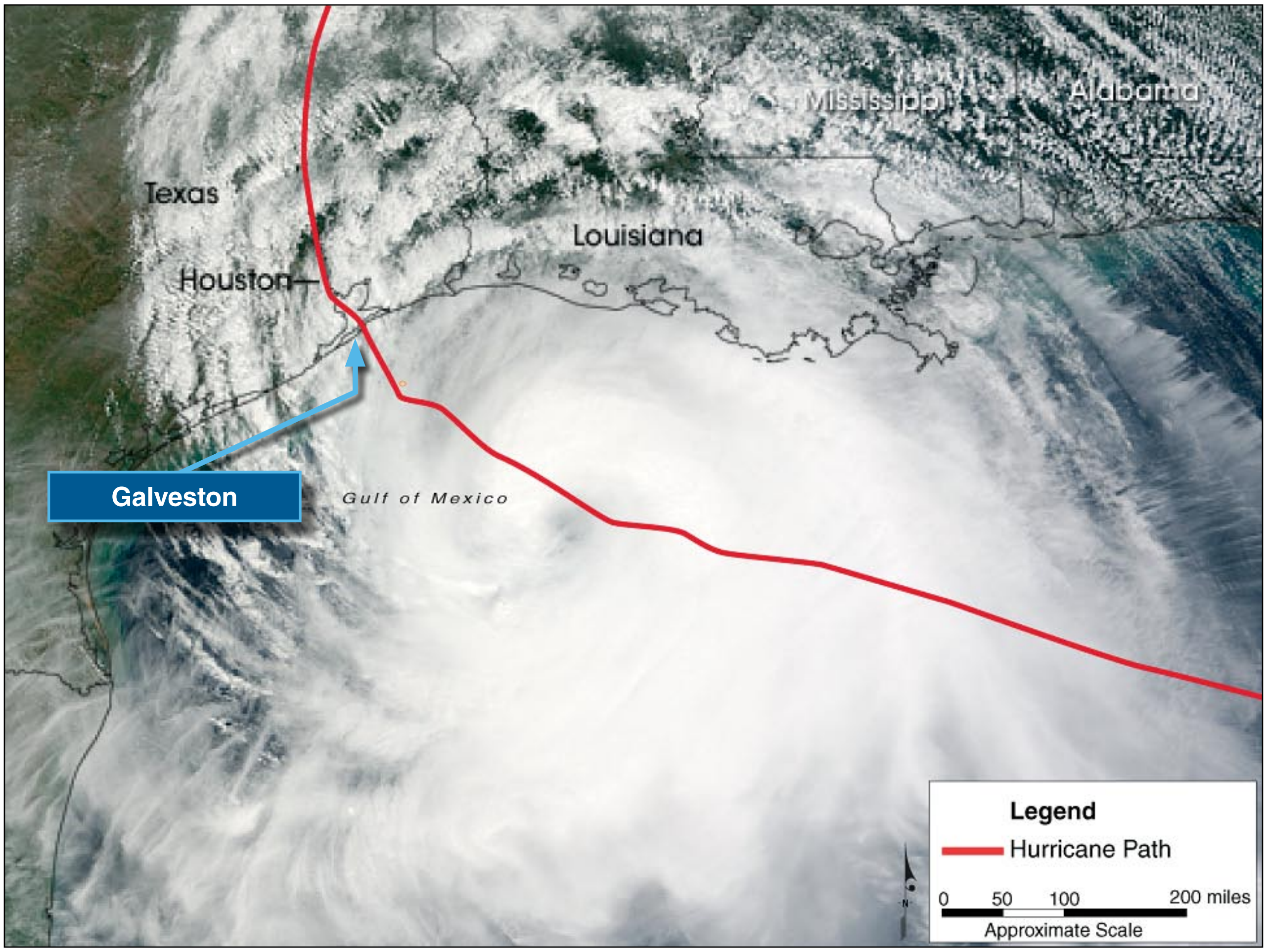



**Figure 1-1. Satellite image of Hurricane Ike as it moved toward Texas and Louisiana**

SOURCE: http://www.srh.noaa.gov/hgx/projects/ike08.htm

The Saffir-Simpson Scale consists of five separate categories. The NHC reserves the term "major hurricane" for hurricanes that reach maximum 1-minute sustained surface winds of at least 111 miles per hour (mph) over open water. Therefore, Category 3, 4, and 5 hurricanes are all considered major hurricanes.

Hurricane Ike's significant storm surge caused damage to a widespread area across the upper Texas and southwestern Louisiana coast. Some of the hardest hit areas include the communities of Crystal Beach, Gilchrist, and High Island on the Bolivar Peninsula, TX (Figure 1-2). Parts of Galveston Island, TX, were also hit hard by the storm surge, although the seawall protected much of the City of Galveston from the direct impact by storm surge and wave action from the Gulf of Mexico. However, the seawall did not protect Galveston from flooding when water rose on the north side of the island from Galveston Bay. In Louisiana, storm surge caused flooding in Lake Charles in Calcasieu Parish, which is 30 miles inland. The storm surge also inundated areas in parts of Cameron, Vermilion, St. Mary, Terrebonne, Lafourche, Iberia, Jefferson, Plaquemines, St. Bernard, Orleans, St. Charles, St. John the Baptist, St. Tammany, Tangipahoa, Livingston, Ascension, and St. James Parishes.

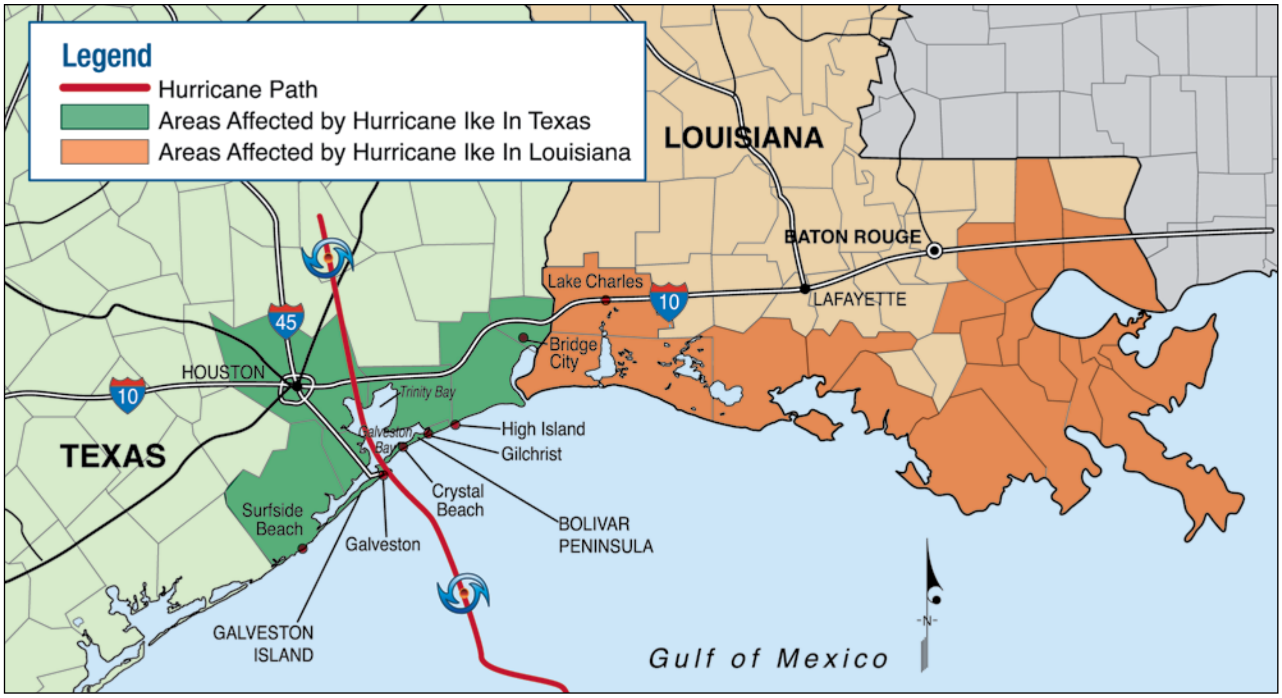



Figure 1-2. Areas affected by Hurricane Ike

Hurricane Ike became extratropical as it moved inland over Arkansas. It continued through the Midwest and into the Ohio Valley, dumping between 6 and 8 inches of rain in parts of Indiana, Illinois, and Missouri (Minnesota Public Radio, 2008). Twenty-nine tornadoes were reported in association with Hurricane Ike. Luckily there were no deaths reported from the tornadoes.

The Tropical Cyclone Report for Hurricane Ike published by the NHC on January 23, 2009 (Berg, 2009) indicated that Hurricane Ike is directly responsible for 103 deaths across Hispaniola, Cuba, and parts of the U.S. Gulf Coast. The report also states that the latest official counts and media reports indicate that 20 people died in Texas, Louisiana, and Arkansas as a direct result of Hurricane Ike, and at least 64 indirect deaths were reported in Texas. According to the Laura Recovery Center,[1] 33 people were still missing in Texas as of February 12, 2009.

### 1.1.1 Summary of Damage and Economic Loss

The combination of surge and high waves were particularly destructive in areas along the Gulf of Mexico coast and parts of the Galveston Bay shoreline, particularly Bolivar Peninsula, TX. Preliminary numbers show that of the 5,900 buildings standing on Bolivar Peninsula before Ike, approximately 3,600 were destroyed, 400 sustained major damage (likely substantially damaged),

1 NWS Houston/Galveston office, http://www.srh.noaa.gov/hgx/projects/ike08/wind_analysis.htm

1,800 sustained some damage but were not substantially damaged, and only 100 were undamaged or sustained only minimal damage (Halff Associates, 2008). Eastern areas of Trinity and Galveston Bays were inundated with floodwaters. In Bridge City, TX, 3,380 of the 3,400 residences in the city were inundated. Flooding also damaged many homes and businesses in the City of Galveston, on west Galveston Island and Follet's Island, in communities surrounding Galveston Bay, and in low-lying southwest Louisiana. Final estimates on the total number of homes and businesses damaged in the affected areas were not available at the time of the publication of this report.

Ports from Corpus Christi to Lake Charles were closed in advance of Ike. Damage to the Ports of Galveston and Houston, as well as debris in Galveston Bay and the Houston Ship Channel, kept those ports closed after the storm for several days, leaving almost 150 tankers, cargo vessels, and container ships waiting offshore. The U.S. Department of Energy said that 14 oil refineries were closed by the storm, as well as two Texas strategic petroleum reserve sites, causing rising gas prices and gas shortages across parts of the United States. In addition, the storm destroyed at least 10 offshore oil rigs and damaged several large pipelines. Before Ike reached the coast, a Cypriot freighter carrying petroleum coke, the 580-foot *Antalina,* lost propulsion about 90 miles southeast of Galveston with its 22-man crew. The U.S. Coast Guard could not rescue the crew during the storm due to the hazardous weather conditions, but the ship rode out the storm without casualties.

In January 2009, the Property Claim Services (PCS) of the Insurance Services Office revised its estimated insured losses to $10.655 billion from its original estimates of $8.1 billion. Based on the revised estimated insured losses, total losses are estimated at $21.3 billion. PCS may increase its estimates again because it is considering including offshore properties in its catastrophe estimates, which it currently does not (Berg, 2009; Hays, 2009).

The Louisiana Economic Development agency reported on September 18, 2008, that "conservative preliminary estimates suggest the total physical damage in Louisiana as a result of Gustav and Ike combined amounts to roughly $8 to $20 billion, including insured and uninsured losses."[2] This amount includes only physical damage and does not include losses due to economic activity; as of the publication of this report, Louisiana Economic Development had not yet estimated that amount for Hurricane Ike alone.

The U.S. Department of Energy estimated that 2.6 million customers lost power in Texas and Louisiana (NHC, 2009). Power outages were also experienced along Ike's path as it moved northward through the United States. Ohio experienced the same level of power interruption as Texas and Louisiana combined, with almost 2.6 million people losing power. The Cincinnati, Columbus, and Dayton areas experienced significant wind damage from the remnants of Hurricane Ike. PCS estimates that the post-tropical remnants of Ike produced $2.3 billion in non-flooding related insured losses—this value equates to approximately $4.7 billion in damages. Insured losses in Ohio alone are estimated at $1.1 billion (Berg, 2009).

2 http://www.ledlouisiana.com/news--multimedia/news-releases/led-releases-hurricane-gustav-and-hurricane-ike-economic-impact-assessment.aspx

### 1.1.2 Timeline and History of Hurricane Ike

According to the NHC, Hurricane Ike originated as a well-defined tropical wave off the coast of West Africa on August 28, 2008. Tropical Storm Ike developed from a tropical depression west of the Cape Verde Islands on September 1, 2008. On September 3, 2008, the tropical storm had intensified and strengthened into a hurricane. Hurricane Ike continued its path west toward the Caribbean. On September 4, Hurricane Ike had strengthened to a Category 4 hurricane on the Saffir-Simpson scale, with maximum sustained winds of 145 mph.[3]

On September 7, Hurricane Ike made landfall over the Turks and Caicos Islands, with the eye of the storm coming directly over Grand Turk Island and over Great Inagua Island in the southeastern Bahamas. The hurricane continued on its westward path and made its first of two landfalls in Cuba as a strong Category 3 hurricane near Cabo Lucrecia. Hurricane Ike emerged over the ocean south of Cuba during September 8. The hurricane moved northwest through the night and made its second landfall in Cuba on Pinar del Rio on September 9. The storm entered the Gulf of Mexico as a Category 2 hurricane and continued its course toward Galveston Island, TX. Hurricane Ike produced tropical force winds over portions of the Florida Keys, but did not make landfall. The path of the hurricane is shown in Figure 1-3.

According to the National Weather Service,[4] the storm continued its track northwest making its way to the Texas coastline. As it made its way across the Gulf of Mexico, a few unique characteristics associated with this storm started to take place. The central pressure slowly fell from 968 millibars (mb) upon entering the Gulf of Mexico to 944 mb by late on September 10. Although the decrease in central pressure generally indicates that the storm is intensifying, Hurricane Ike had unusually low sustained winds of 110 mph at that time. Another unique aspect was the large envelope of winds associated with Hurricane Ike. The hurricane continued to grow in diameter overnight. By 10 a.m. CDT on September 11, aircraft reconnaissance measured Ike's tropical storm wind swath to be approximately 450 miles wide, with a hurricane force wind swath of 180 miles. At that point, the National Oceanic and Atmospheric Administration (NOAA) issued a hurricane warning for the area between Morgan City, LA, and Baffin Bay, TX.

3 NWS Houston/Galveston office, http://www.srh.noaa.gov/hgx/projects/ike08/wind_analysis.htm

4 NWS Forecast Office, Lake Charles, LA, http://www.srh.noaa.gov/lch/ike/ikemain.php


**Figure 1-3. Hurricane Ike storm track**

On September 13 at 2:10 a.m. CDT, Hurricane Ike made landfall as a Category 2 hurricane on Galveston Island, TX, with reported sustained winds of 110 mph. Hurricane Ike made its final landfall at about 4:00 a.m. CDT near Baytown, TX.[5]

Hurricane Ike continued to move in a north and ultimately northeastern direction. By the afternoon of September 13, the hurricane was downgraded to a tropical storm by the NHC; it continued to weaken into a tropical depression before the center reached southwestern Arkansas later that evening. The storm continued its northeastern path, passing near St. Louis, MO, before it merged with a large cold front moving east across central United States. Hurricane Ike spawned a major wind event in the lower and middle Ohio Valley with strong wind gusts reported across parts of Kentucky, Indiana, Ohio, and Pennsylvania. Wind gusts of 75 mph were recorded in Columbus, OH.[6] According to American Society of Civil Engineers (ASCE) 7-05, *Minimum Design Loads for Buildings and Other Structures,* the design wind speed for the Ohio Valley is 90 mph (3-second gust).

5 NWS Houston/Galveston office, http://www.srh.noaa.gov/hgx/projects/ike08/wind_analysis.htm

6 Ibid.

## 1.2 Coastal Flooding

The area affected by Hurricane Ike is a low-lying region susceptible to flooding by hurricane storm surge and freshwater flooding during heavy rain events (e.g., Tropical Storm Allison, 2001). Flood Insurance Studies (FISs) and Flood Insurance Rate Maps (FIRMs) have been prepared for communities in the area since the 1970s and 1980s. A study is currently underway to update coastal flood hazard analysis and maps (the study was already in progress when Hurricane Ike struck).

### 1.2.1 Shoreline Characteristics

The region most directly affected by Hurricane Ike was from Brazoria County, TX, to Plaquemines Parish, LA, and adjacent inland areas. The eastern portion of the affected area, coastal Louisiana, is a low-lying chenier plain—intermittent sand ridges atop Mississippi River delta sediments, cut by tidal channels and embayments fringed with marsh. This plain extends west into eastern Texas, to the salt dome upon which the community of High Island sits. The shoreline from High Island, TX, to Freeport, TX, is composed of barrier islands of varying widths. The region landward of Galveston Island and Bolivar Peninsula is a large estuary known as Galveston Bay.

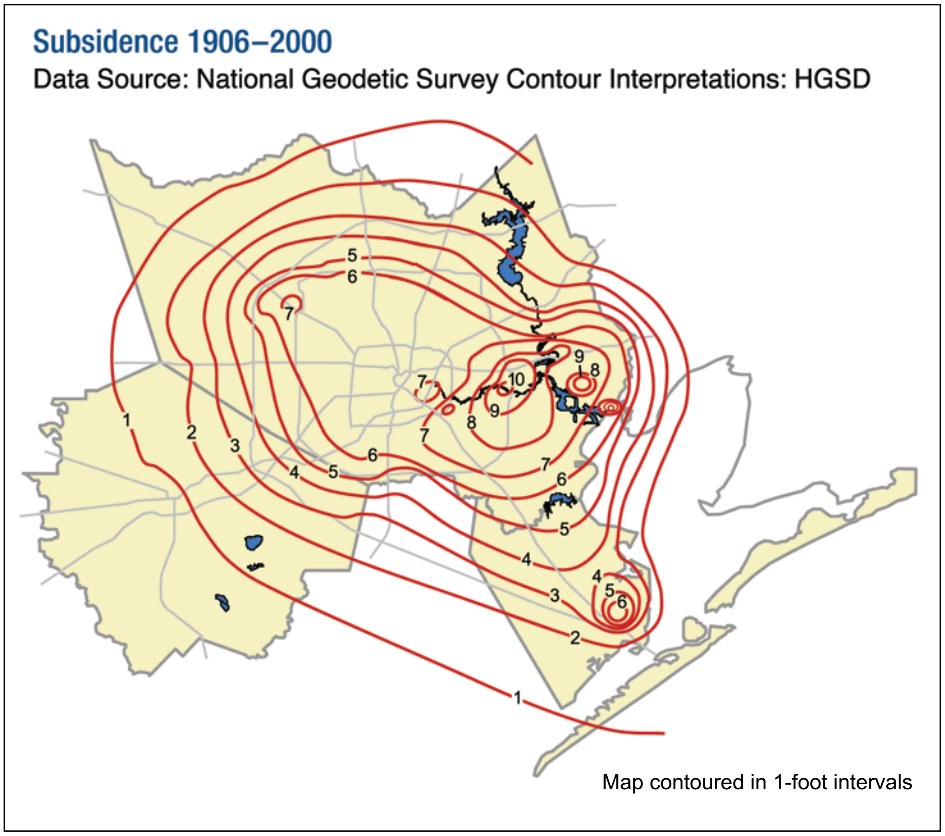
### 1.2.2 Subsidence

One factor that increases the vulnerability of the coastal region to hurricane storm surge is land subsidence—a lowering of the ground surface with respect to a fixed reference elevation. It can occur for a number of reasons, which vary geographically and over time (e.g., extraction of groundwater and hydrocarbon, tilt of underlying geologic strata, compaction of surface sediments, and interruption of natural delta sedimentation processes). Subsidence affects the entire region visited by the Ike MAT, from the Houston-Galveston region to coastal Louisiana. In portions of Texas, subsidence has been measured for over 100 years, and subsidence of several feet has been measured over a wide area; some land areas in Texas have dropped 10 feet in elevation since 1906 (see Figure 1-4). Subsidence rates in coastal Louisiana are also high, reaching 0.8 foot/decade in places.[7] Subsidence also complicates flood hazard mapping and can render some flood hazard maps obsolete before they would otherwise need to be updated.

7 Hurricane Katrina Flood Recovery (Louisiana), Questions and Answers about the Advisory Flood Elevations and the Katrina Recovery Maps. http://www.fema.gov/hazard/flood/recoverydata/katrina/katrina_la_faqs.shtm

Figure 1-4.
Land subsidence in the Houston-Galveston area, 1906–2000 (Harris-Galveston Subsidence District [HGSD], retrieved January 2009)

SOURCE: http://www.hgsubsidence.org/assets/pdfdocuments/HGSD%20Subsidence%20Map%201906-2000.pdf




## 1.2.3 Hurricane Ike High Water Marks

A total of 380 high water marks (HWMs) were surveyed by FEMA in Texas and Louisiana after Hurricane Ike. Figure 1-5 shows the locations of surveyed HWM in Texas, identifies each by type (stillwater, wave height, wave runup ), and provides the elevation (grouped, in feet North American Vertical Datum [NAVD]).[8] Figure 1-6 provides HWM data for Louisiana. Appendix E of the report provides additional FEMA HWM maps and relevant data for Texas and Louisiana.

### IKE FLOOD LEVELS

Although data reviewed by the MAT indicated that the area flooded by Ike exceeded the Effective Special Flood Hazard Area (SFHA), and Ike wave crest levels exceeded the Effective Base Flood Elevations (BFEs) by up to approximately 5 feet in east Texas and southwest Louisiana, Ike flooding should not be considered a rare event. A new flood study begun before Ike will likely show Ike flood levels to be below the new BFEs for much of the affected area.

Based on the preliminary HWM survey data, some areas of southeast Galveston Bay may have been affected by water levels over 20 feet NAVD. The stillwater level is estimated to have been in the range of 17 feet NAVD in areas of Chambers County, TX, and averaged about 15 feet NAVD near the Bolivar Peninsula, TX.

8 For this report, the FEMA and Harris County Flood Control District HWM elevations are in NAVD of 1988, 2001 adjustment. The U.S. Geological Survey (USGS) HWM elevations are in NAVD of 1988.

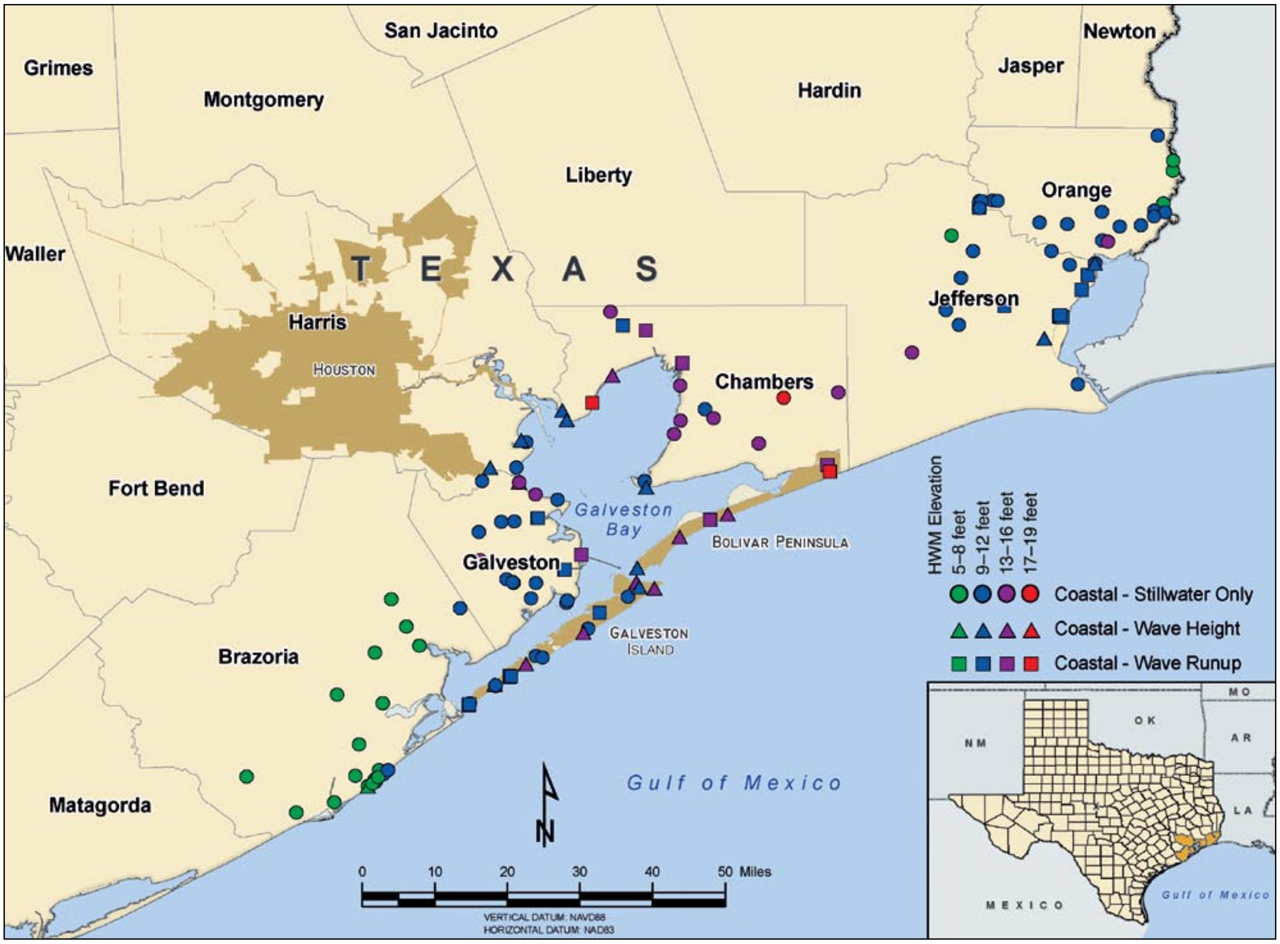



Figure 1-5. FEMA's surveyed locations of Hurricane Ike's HWMs in Texas

Based on preliminary results from the HWM surveys, southwestern areas of Cameron Parish, LA, may have been affected by water levels in the range of 12 feet. The stillwater level is estimated to have reached over 9 feet in the Lake Charles area of Calcasieu Parish.

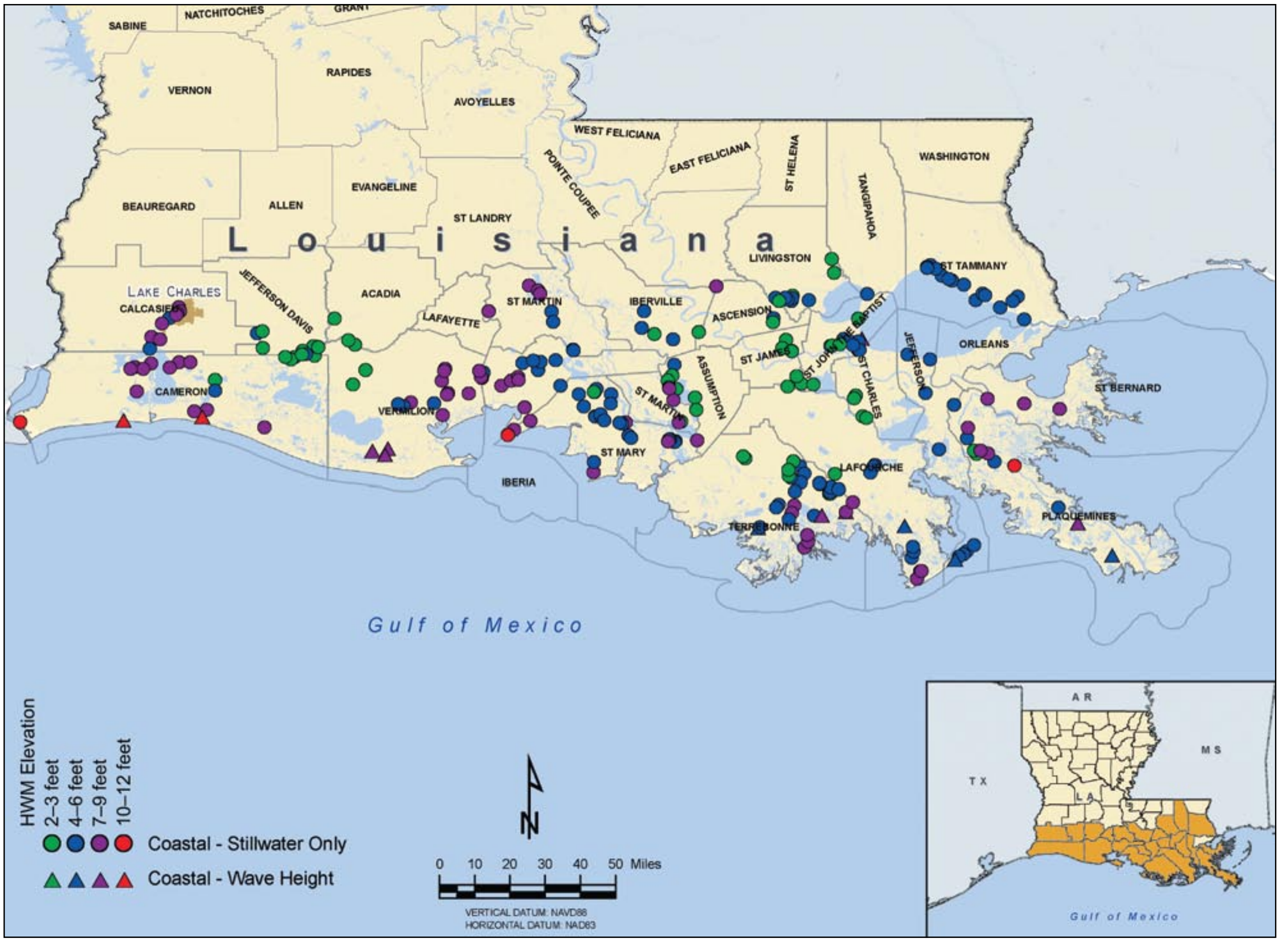



**Figure 1-6. FEMA's surveyed locations of Hurricane Ike's HWMs in Louisiana**

## 1.3 Wind Hazard Analysis and Discussion

Hurricane Ike came ashore along Galveston Island and the Bolivar Peninsula early morning on September 13, 2008, as a Category 2 storm with 1-minute sustained winds of 110 mph, according to the NWS October 5, 2008, report.[9] The NHC Tropical Cyclone Report states that the landfall intensity of 110 mph was determined from three different sources: 1) flight level winds of 120 mph using the standard 90 percent reduction to get the 10-meter, 1-minute average; 2) stepped Frequency Microwave Radiometer (SFMR) on the Hurricane Hunter Aircraft indicating 104 mph; and 3) Weather Surveillance Radar 88 Doppler System radar wind velocities from the NWS Houston/Galveston radar site that measured 130 mph at 6,500 feet above the ground

> Wind speed weather reporting stations include Automated Surface Observing Systems (ASOS), Coastal-Marine Automated Network (C-MAN), and portable meteorological towers deployed by universities or other agencies.

9 NWS Houston/Galveston office, http://www.srh.noaa.gov/hgx/projects/ike08/wind_analysis.htm

(Berg, 2009). Although the NHC Report does not specify where this wind speed was measured, it is likely to have been close to a point over the Gulf southeast of High Island, TX.

On land, reporting Automated Surface Observation System (ASOS) towers nearest the eye of the storm included Houston Hobby Airport and Bush Intercontinental Airport. Houston Hobby reported winds of 75 mph with gusts of 92 mph. Bush Intercontinental did not report hurricane-force winds despite the eye of Hurricane Ike passing reasonably close to the airport. Galveston Scholes Field stopped reporting prior to the passage of the hurricane's eye due to storm surge. Other reporting stations included Coastal Marine (C-MAN) stations located at lighthouses, piers, and offshore navigation platforms.

NOAA's Office of Atmospheric Research (OAR) uses a 1-minute averaging time for reporting sustained winds. The maximum sustained wind referenced in National Hurricane Advisories for tropical storms and hurricanes is the highest 1-minute surface wind occurring within the circulation of the system. The ASOS stations average and report their wind data over a 2-minute period, but no conversion factor is required to change a 2-minute average wind into a 1-minute average wind, since they are virtually the same speed. The "surface" winds are those observed or estimated to occur at the standard meteorological height of 33 feet (10 meters) in an unobstructed exposure (i.e., not blocked by buildings or trees).[10] Refer to the inset for the definition of wind exposure zones.

### DEFINITION OF WIND EXPOSURE ZONES

**Exposure B.** Urban, suburban, wooded areas

**Exposure C.** Open terrain, flat open country, grasslands, all water surfaces in hurricane-prone regions

Normally, gusts are only a few seconds (3 to 5 seconds) of peak wind. Typically, in a hurricane environment, the value of the maximum 3-second gust over a 1-minute period is on the order of 1.3 times (or 30 percent higher than) the 1-minute sustained wind. ASCE 7-05 requires buildings to be designed using 3-second gust wind speeds (ASCE, 2005b).

In addition to aircraft, radar, and official monitoring stations, wind speeds were also obtained from portable land-based anemometers positioned along the storm's path. Portable units included five 10-meter towers operated by the Florida Coastal Monitoring Program (FCMP) and 18 towers (2.25-meter instrumented probes) provided by Texas Tech University (TTU). The highest land-based wind speed recorded by FCMP for Hurricane Ike was 116 mph, 3-second gust, recorded near Sea Breeze, TX, approximately 18 miles east of Anahuac, which is near the northeast corner of Galveston Bay. The highest speed recorded by TTU was also 116 mph, 3-second gust, recorded near Monroe City, which is approximately halfway between Anahuac and Sea Breeze, TX. The map in Figure 1-7 shows all of the stations and portable towers that reported data in Texas during Hurricane Ike. Table 1-2 provides a summary of the notable maximum recorded wind speeds. These data have been converted to 3-second gust wind speeds. Data has been adjusted for a 10-meter instrument elevation and Exposure C.

10 NOAA, "H*Wind Swath Hurricane Ike," http://www.atmo.ttu.edu/TTUHRT/HWindSwath.png


Figure 1-7. Locations of monitoring stations and portable towers that reported data in Texas during Hurricane Ike

Table 1-2. Notable Wind Speeds Recorded in Texas for Hurricane Ike

| Data Collector | Location (Station type) | Wind Speed |
|---|---|---|
| **Official Locations** | FreePort (C-MAN) | 93 mph |
| | Galveston Island east end (C-MAN) | 93 mph |
| | Houston Hobby International Airport (ASOS) | 98 mph |
| | Houston George Bush International Airport (ASOS) | 95 mph |
| **Universities deploying portable meteorological towers at various locations** | LaPorte (FCMP T4) | 102 mph |
| | Winnie (FCMP T5) | 116 mph |
| | Baytown (FCMP T2 & T3) | 110 mph |
| | Beaumont (TTU 108B) | 103 mph |
| | Anahuac (TTU 103A) | 106 mph |
| | Port Bolivar (TTU 110A) | 94 mph |
| | Monroe City (TTU 104B) | 116 mph |

**Note:** Wind speeds provided are 3-second peak gusts measured at 33 feet (10 meters), Exposure C.

### HURRICANE IKE'S WIND SPEEDS RELATIVE TO DESIGN WIND SPEEDS

**Texas.** Though Hurricane Ike's estimated wind speeds were less than design wind speeds given in the 2006 International Building Code (IBC 2006)/ASCE 7-05, the MAT observed widespread wind damage in the areas that were investigated. Most of the wind damage was to building envelopes (primarily roof coverings, rooftop equipment, and wall coverings). A few high-rise buildings in downtown Houston had extensive glazing damage.

Although a very large number of buildings (including residential, commercial, and critical facilities) were damaged, the damage was light to moderate at many of the damaged buildings. Wind damage was most pronounced along the Bolivar Peninsula, the eastern portion of Galveston Island, and areas bordering Galveston Bay.

**Louisiana.** Wind speeds in Louisiana were also less than the design wind speeds given in IBC 2006/ASCE 7-05, and they were much less than those in Texas. Estimated wind speeds ranged from 80 mph near the Texas-Louisiana border to 50 mph in Vermilion Parish. East of Vermilion Parish, estimated wind speeds were less than 50 mph. Although wind damage did occur in Louisiana, it was not as significant as the damage in Texas.

### 1.3.1 H*Wind

As a result of both non-functioning wind-measuring instruments and a lack of instruments in the hurricane's path (ASOS, C-MAN, and portable towers), few wind speed measurements reflect the actual strength of the storm. Thus, damage investigators and weather scientists estimate wind speeds based on a variety of methods, the most reliable being scientifically based wind models. The best known model in the public domain for estimating wind variations is H*Wind from NOAA's Hurricane Research Division (HRD). Based on past experience of comparing modeled estimates with actual recorded wind speeds, the H*Wind model provides reasonably accurate estimates of maximum wind speeds over significant areas impacted by a storm. Contours of the 1-minute sustained wind speeds from H*Wind analysis are shown in Figure 1-8. All wind speeds have been adjusted for a 10-meter instrument height and marine exposure over water or open terrain (Exposure C) over land.

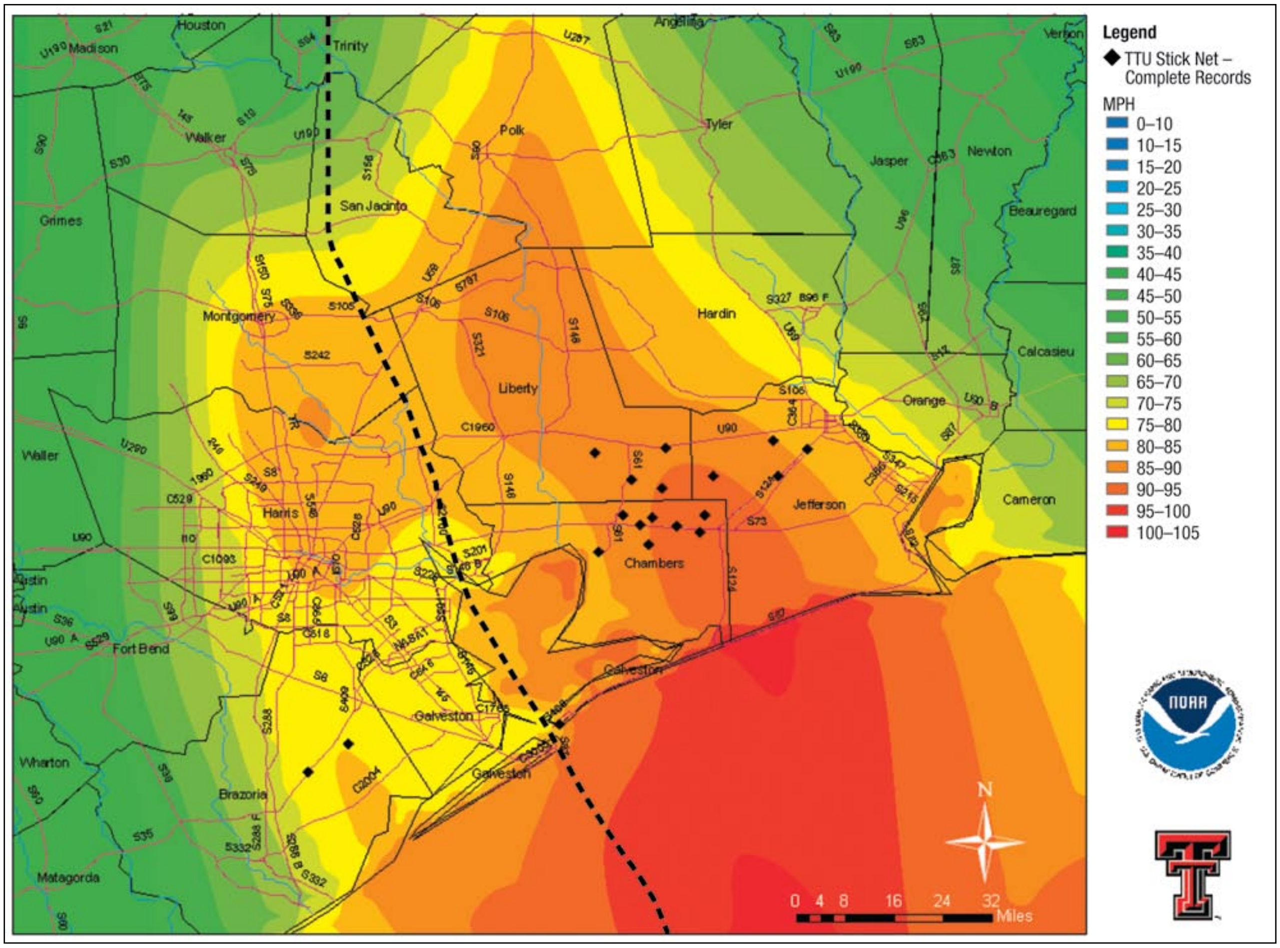



**Figure 1-8.**
**Wind swath contour plot based on H*Wind analysis; wind speeds given in mph with contours of the 1-minute sustained wind speed**
SOURCE: http://www.atmo.ttu.edu/TTUHRT/Ike.htm

## 1.3.2 HAZUS-MH

Another model for estimating wind speeds is FEMA's HAZUS-MH (Hazards United States-Multi-Hazard) loss estimation model, which produces reasonable estimates of maximum speed and lateral distribution of wind. Figure 1-9 is a wind swath contour plot of maximum 3-second gust wind speeds in mph at a height of 33 feet (10 meters) above ground (over land wind speeds are representative of open terrain conditions; over water wind speeds are representative of marine conditions) produced by Hurricane Ike in Texas and Louisiana based on HAZUS-MH wind field methodology and modeled by Applied Research Associates (ARA, 2008). Figure 1-10 portrays the estimated maximum peak gust winds nearest the eye of Hurricane Ike, radius of maximum winds.

The HAZUS-MH model for Hurricane Ike used weather data collected from the five FCMP portable towers, three C-MAN stations, and nine ASOS stations. The locations of these reporting stations are shown in Figures 1-9 and 1-10. The data are weighted and aggregated to develop a plot of the wind fields. The data collected from towers are influenced by ground exposure around the towers, which may differ from tower to tower. Given these conditions, the data from the towers are normalized for exposure and proximity to the storm path. Historically, these data have compared favorably with other modeled data.

Table 1-3 provides a summary of maximum recorded and modeled wind speeds for the sites investigated by the MAT. These data are 3-second gust wind speeds and have been standardized for 10-meter instrument heights and Exposure C. The conversion from Exposure B to Exposure C was made using an equivalent wind pressure calculation equation contained in ASCE 7-05.

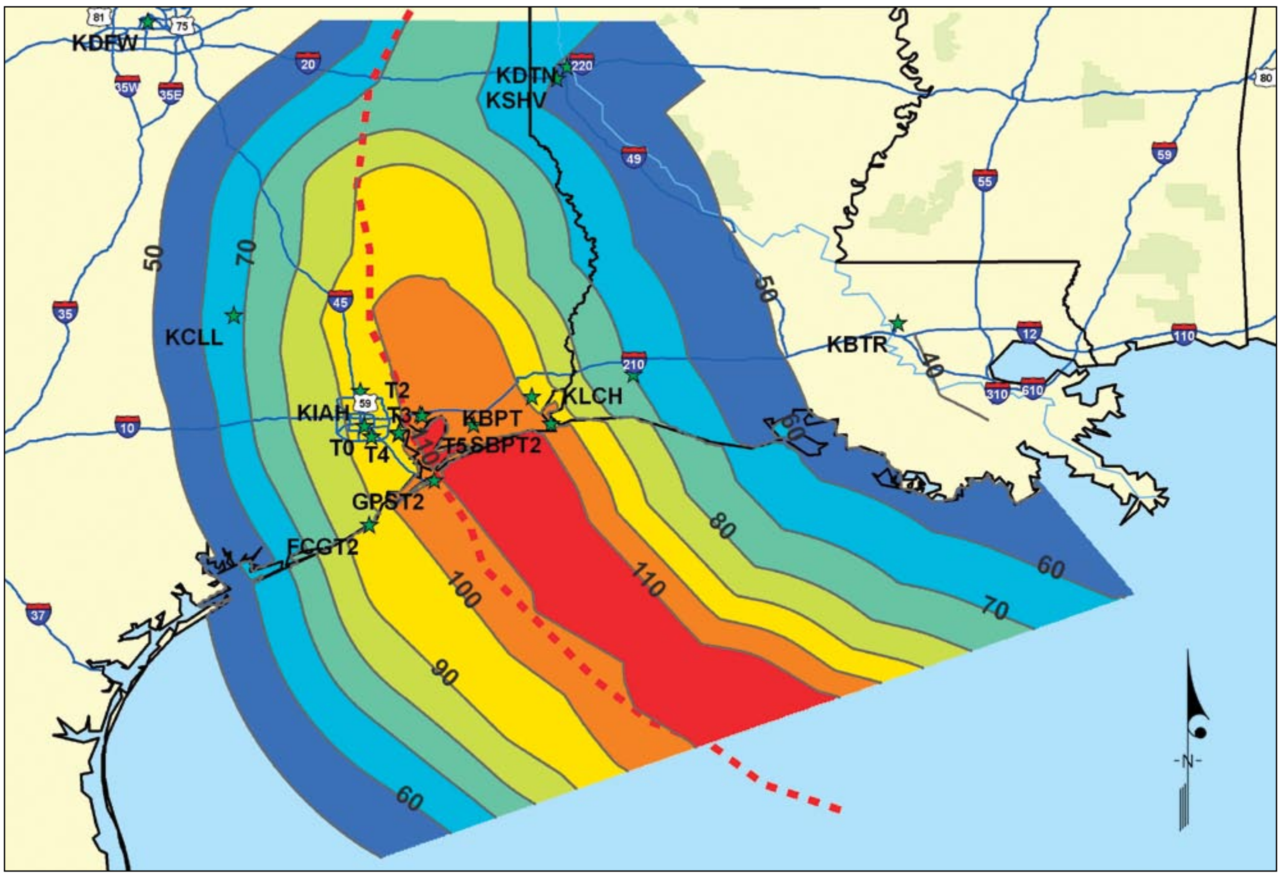



**Figure 1-9.**
**Wind swath contour plot (3-second gust at 10-meter elevation [33 feet above ground level]) at Texas and Louisiana based on HAZUS-MH wind field methodology. Anemometer locations used in model verification are indicated by the stars.**
SOURCE: ARA, 2008

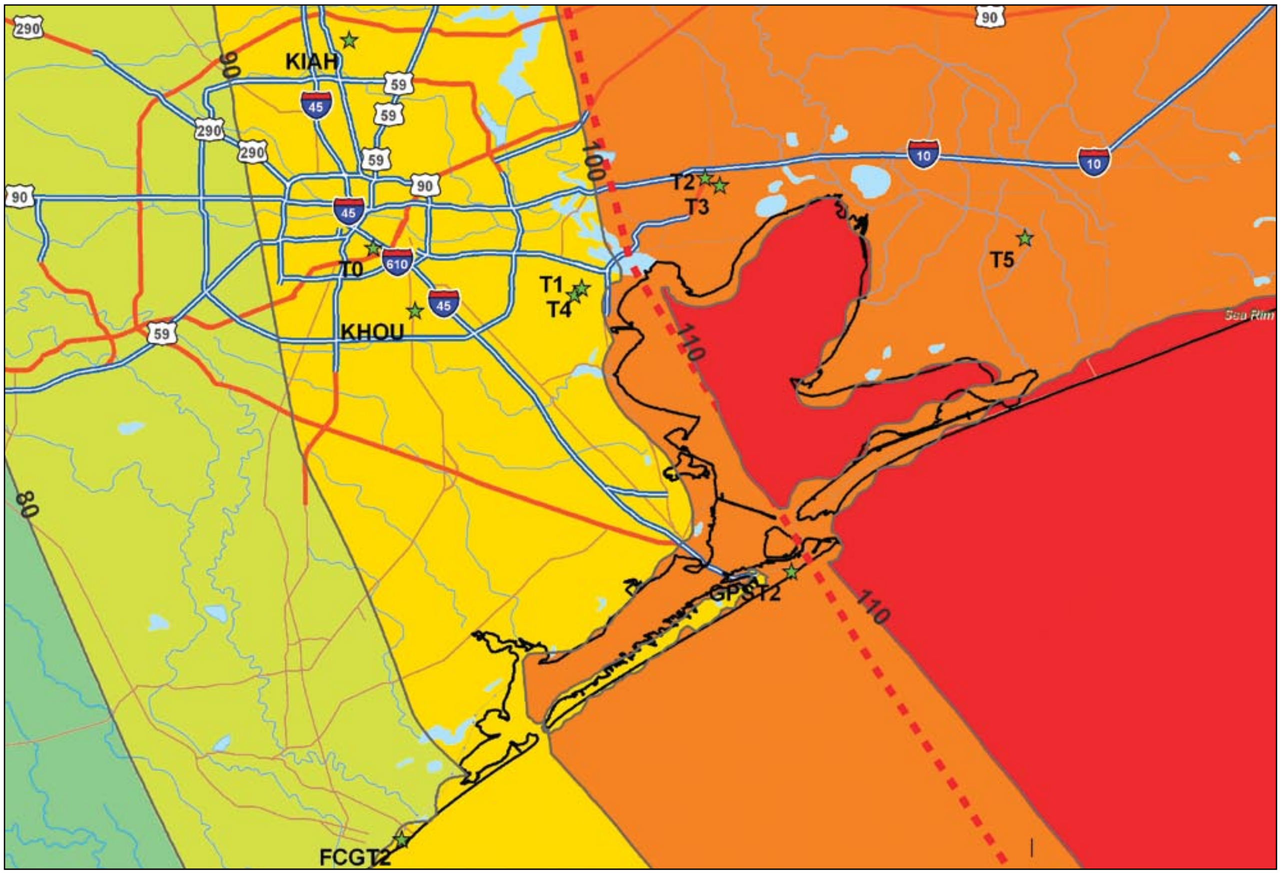



Figure 1-10.
HAZUS-MH-estimated maximum peak gust wind speeds near radius of maximum winds. Stars indicate anemometer locations used in model verification.
SOURCE: ARA, 2008

**Table 1-3.**
**Estimated Maximum 3-Second Gust Wind Speeds for MAT Investigation Sites in Texas Based on Reporting Stations and HAZUS-MH Wind Model**

| Data Source | MAT Investigation Site | 3-Second Gust Speed Estimate for Exposure C (Open Terrain) | 3-Second Gust Speed* Estimate for Exposure B (Suburban Terrain) |
|---|---|---|---|
| Universities deploying portable meteorological towers at various locations | Anahuac | 106 mph | 90 mph |
| | Baytown | 100 mph | 85 mph |
| | Houston (City) | 88 mph | 75 mph |
| | Jamaica Beach | 90–95 mph* | 75–80 mph* |
| | LaPorte | 102 mph | 85 mph |
| | Port Bolivar | 94 mph | 80 mph |
| | Surfside | 90 mph* | 75 mph* |
| | Winnie | 110 mph | 95 mph |
| HAZUS-MH modeled data | Audubon Village** | 110 mph | 95 mph |
| | Beachtown | 108 mph | 93 mph |
| | Crystal Beach** | 110 mph | 95 mph |
| | Deer Park | 95 mph | 80 mph |
| | Galveston (City) | 100–105 mph | 85–90 mph |
| | High Island** | 110 mph | 95 mph |
| | Houston Central Business District | 90–94 mph | 75–80 mph |
| | Port Neches | 90 mph | 75 mph |
| | Texas City | 105 mph | 90 mph |
| | Tiki Island | 103 mph | 88 mph |

* Calculated wind speeds, Exposure B—calculated from wind pressure conversions for components and cladding for buildings with a mean roof height of 33 feet (see ASCE 7-05, Table 6-3)

** Located on Bolivar Peninsula, TX

According to the HRD analysis, much of east Texas felt the brunt of hurricane force winds from the east side of the storm moving through Chambers and Jefferson Counties approximately 2 hours after Ike made landfall. Maximum sustained winds on the east side of the storm were between 92 and 98 mph. Three hours later, at 5:30 a.m. CDT (1030 Universal Time Coordinated [UTC]), Hurricane Ike had continued to push north and begun to weaken. Even though the maximum sustained winds decreased to 80 to 85 mph, hurricane force winds still covered much of Galveston Bay and Chambers County through the southern part of Hurricane Ike (Figure 1-11). Figure 1-11 also shows that Hurricane Ike still had hurricane force winds in the southern part of its core as shown by the red arrows, all of which contributed to the Galveston West Bay surge along the west end of the island and the wind damage noted on the north and western exposures of the building structures, as seen in Figure 1-12. Though the east side of a hurricane produces the highest wind speeds and surge levels, these graphics illustrate that damaging forces exist on the weaker west side of a storm.

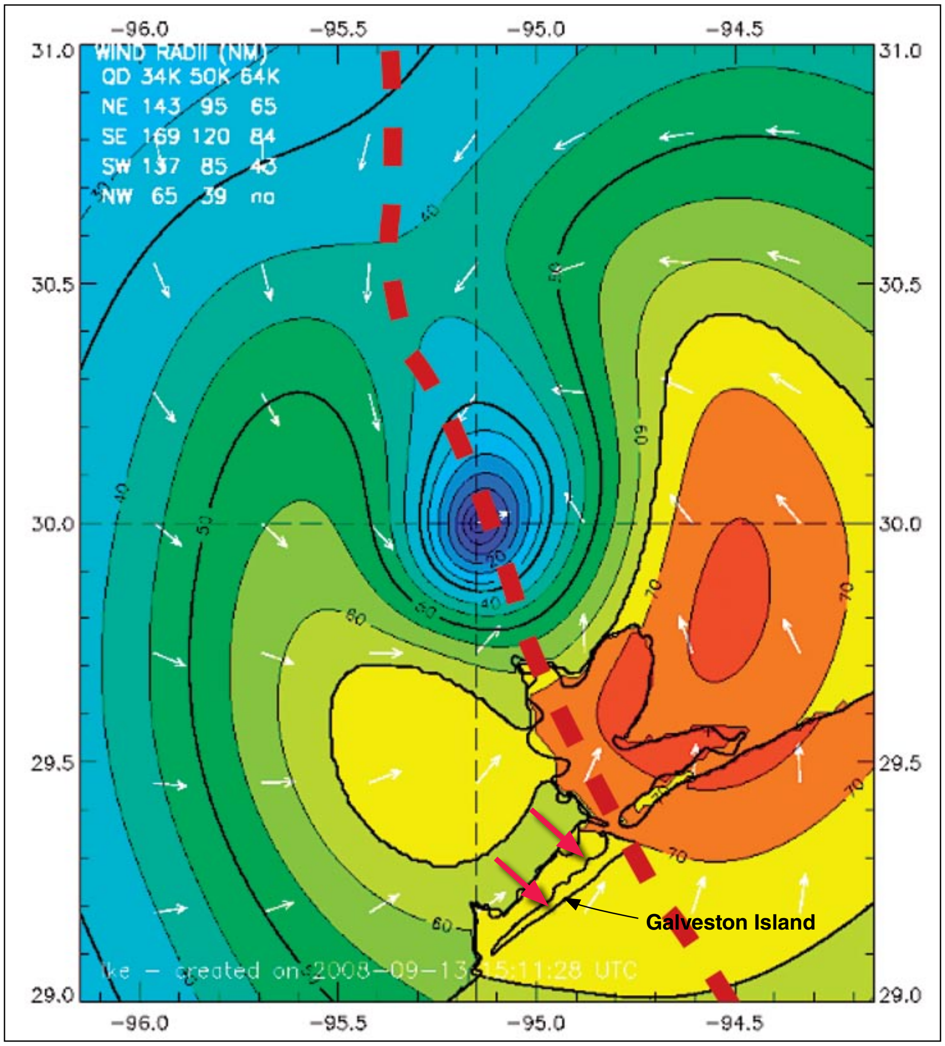



**Figure 1-11.**
**Map showing 1-minute sustained winds 3 hours after Galveston landfall with continued high back bay winds**
SOURCE: NWS, 2008

## Hurricane Ike Tornadoes

According to the NHC Tropical Cyclone Report for Hurricane Ike, a total of 29 tornadoes associated with Hurricane Ike were reported in Arkansas, Florida, Louisiana, and Texas (Berg, 2009). Tornadoes spawned by hurricanes are normally in the lower range of intensity, EF0 or EF1 on the Enhanced Fujita (EF) Scale (65–110 mph); however, they frequently produce significant damage and even deaths. In this instance, no deaths were reported from the tornadoes.


Figure 1-12.
Roofing damage to north and west exposures produced by Hurricane Ike backside winds

## 1.4 Historic Hurricanes

The Texas and Louisiana coastlines have experienced many destructive hurricanes, with Hurricane Katrina being the most notable. The following section describes significant hurricanes that have damaged the Texas-Louisiana coastline beginning with the most recent, Hurricane Rita, and ending with the deadliest hurricane to affect the Galveston area, the Great Galveston Hurricane of 1900 (unless otherwise stated, information from NHC-NOAA).[11] Figure 1-13 shows the paths of the Great Galveston Hurricane and Hurricanes Audrey, Carla, Betsy, Celia, Allen, Alicia, Andrew, Katrina, and Rita. Table 1-4 shows the total estimated damages for each hurricane discussed in this section.

11 http://www.nhc.noaa.gov/HAW2/english/history.shtml and Tropical Cyclone Reports for specific hurricanes found at http://www.nhc.noaa.gov/pastall.shtml#tcr

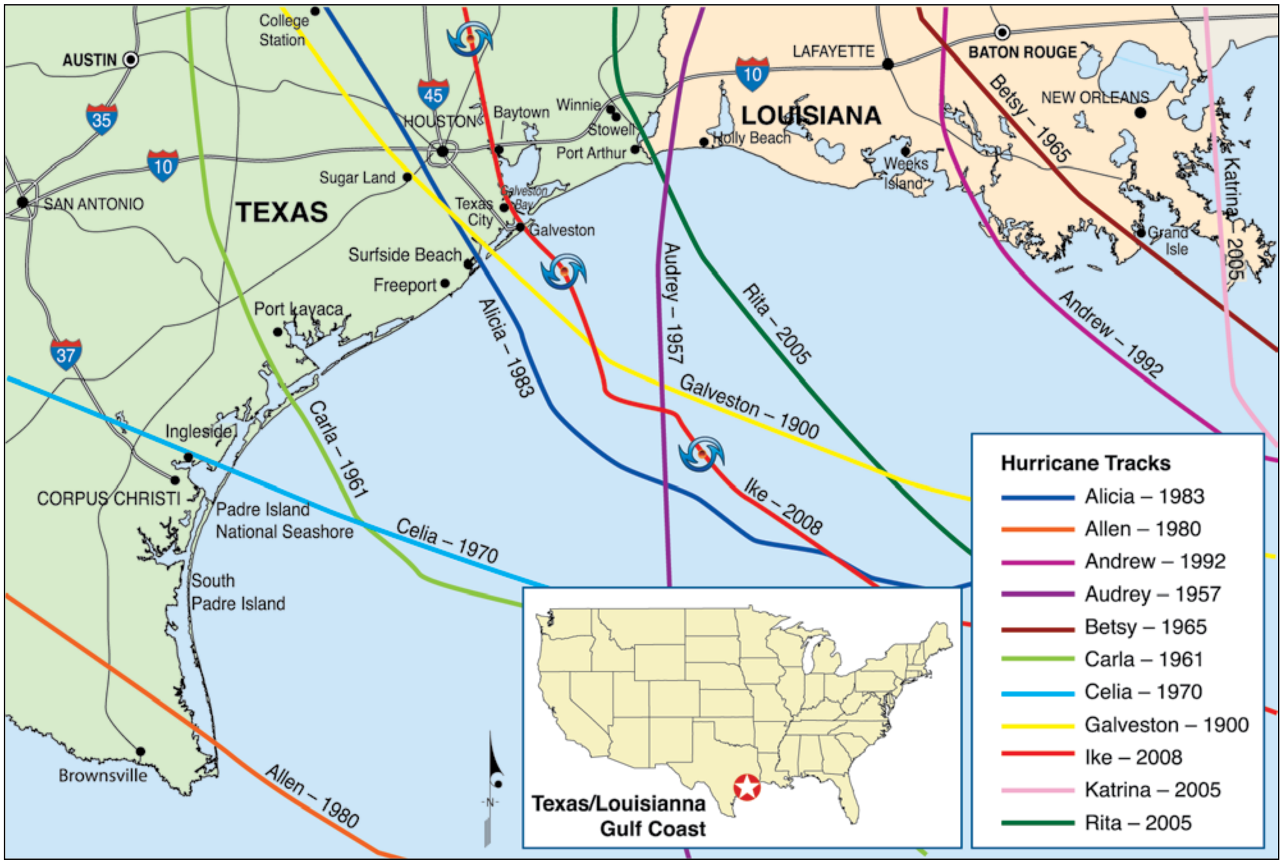



Figure 1-13. Hurricane tracks of significant historic hurricanes in Texas and Louisiana

Table 1-4. Damage Costs of Historic Hurricanes—Original and 2009 Dollars

| Hurricane | Year | Original Cost of Damages ($ Million) | Cost of Damages in 2009 Dollars ($ Million) |
|---|---|---|---|
| Rita[1,2] | 2005 | 16,000 | 18,000 |
| Katrina[1,2] | 2005 | 125,000 | 139,000 |
| Andrew[1,2] | 1992 | 27,000 | 41,000 |
| Alicia[1,2] | 1983 | 3,000 | 6,000 |
| Allen[1] | 1980 | 600 | 1,500 |
| Celia[1] | 1970 | 453 | 2,220 |
| Betsy[1] | 1965 | 1,400 | 8,300 |
| Carla[1] | 1961 | 325 | 2,020 |
| Audrey[1] | 1957 | 147 | 970 |
| Galveston[3] | 1900 | 30 | 770 |

**Notes:**

1 Conversion factor used is from Consumer Price Index Conversion Factors to Convert to 2007 Dollars Table from Oregon State, http://oregonstate.edu/cla/polisci/faculty-research/sahr/cv2007rs.pdf

2 Estimated cost from NOAA paper, Billion Dollar U.S. Disasters, 1980–2008 (January 2009), http://www.ncdc.noaa.gov/img/reports/billion/billionz-2008.pdf

3 Conversion factor used is from Consumer Price Index Conversion Factors 1774 to estimated 2018 to Convert to 2006 Dollars Table from Oregon State, http://oregonstate.edu/cla/polisci/faculty-research/sahr/cv2006.pdf

### Hurricane Rita

Hurricane Rita struck the east side of the Texas-Louisiana border on September 24, 2005, as a Category 3 hurricane with 1-minute sustained winds of 115 mph. It produced storm surges 10 to15 feet above normal tide levels. The storm surge devastated coastal communities in southwestern Louisiana. Coastal areas of southeastern Louisiana were flooded by 4 to 7 feet of storm surge, including some areas that had already been impacted by the surge from Hurricane Katrina about 1 month earlier. Portions of the Florida Keys were inundated from the storm surge as well. Its winds, rain, and tornadoes caused fatalities and damages from eastern Texas to Alabama. A total of seven deaths and $16 billion worth of damage resulted from this storm.

### Hurricane Katrina

Hurricane Katrina, which struck the U.S. coast on August 25, 2005, now ranks as one of the most destructive hurricanes in U.S. history for cost (No. 1), deaths (No. 3), and intensity (No. 3). Hurricane Katrina made its first U.S. landfall near Miami, FL, on August 25. The hurricane moved into the eastern Gulf of Mexico, and over the next 2 days it significantly strengthened to become a Category 5 hurricane. Hurricane Katrina made a second landfall on the Louisiana-Mississippi border as a Category 3 hurricane with 1-minute sustained winds of 127 mph at the Louisiana landfall and 120 mph 1-minute sustained winds at the Mississippi landfall. Storm surge flooding of 25 to 28 feet above normal tide level occurred along portions of the Mississippi coast and storm surge flooding of 10 to 20 feet above normal tide levels occurred along the southeastern Louisiana coast. This resulted in over 1,700 deaths and $125 billion in damages. It is ranked as the costliest hurricane in U.S. history.

### Hurricane Andrew

Hurricane Andrew struck Florida and Louisiana in August 1992. With total damage estimates at $27 billion, Hurricane Andrew is the second costliest hurricane in the United States. It is also ranked as one of the 10 most intense hurricanes in the United States, with a minimum pressure of 922 mb (27.23 inches) (NOAA, 2007). On August 24, Hurricane Andrew made landfall over south Florida as a Category 5 hurricane with peak gusts of 164 mph. The hurricane continued westward into the Gulf of Mexico where it made its second U.S. landfall on August 26 on the central Louisiana coast as a Category 3 hurricane. Andrew produced a storm tide of at least 8 feet and inundated portions of the Louisiana coast. The total death toll was 65 people.

### Hurricane Alicia

Hurricane Alicia, a Category 3 hurricane, struck southwest Galveston Island on August 17, 1983. Alicia had sustained winds over 96 mph with gusts of up to 125 mph along the coast. Hobby Airport at Houston reported 94 mph sustained winds with gusts to 107 mph. Hurricane Alicia is notable because it resulted in extensive glazing damage in high-rise buildings in downtown Houston (for further discussion of the glazing damage, see Chapter 5). Storm surges of 12.1 feet were recorded at Morgan Point along Galveston Bay. It is believed that a total of 17 people lost their lives in this storm.

### Hurricane Allen

Hurricane Allen is one of the top five most intense storms in history. The storm became a hurricane on August 3, 1980, about 120 miles east of Barbados as it made its way westward across the Atlantic. On August 7, 1980, the storm became the strongest hurricane recorded at that time, with sustained winds of 185 mph and higher gusts and a central pressure of 899 mb (26.55 inches). Hurricane Allen made landfall as a Category 3 hurricane near Port Mansfield, TX, on August 10. The highest wind gust reported was from Port Mansfield, registering 138 mph. Storm surges reached 12 feet at Port Mansfield. A total of 34 tornadoes from this hurricane were known to have touched down across south Texas. About 300,000 people were evacuated. Seven died in Texas and 17 in Louisiana, with the majority of the deaths in Louisiana having occurred when a helicopter crashed trying to evacuate people from an offshore platform. Estimated damages in Texas and Louisiana were over $600 million at the time.

### Hurricane Celia

On August 3, 1970, Hurricane Celia made landfall in Texas midway between Corpus Christi and Aransas Pass. Hurricane Celia had strong wind gusts estimated as high as 180 mph that far exceeded the hurricane sustained winds of 130 mph. The hurricane did not produce torrential rains and massive flooding over a large area as storms of this magnitude typically do. The heaviest storm rainfall was in the immediate Corpus Christi area, where 6 to 6.5 inches fell. Rains of 3 to 4 inches or less accompanied the hurricane along its path across south Texas. The major cause of destruction from this storm was from the extreme winds. The final estimate of damage was placed at $453 million. Nine deaths and 466 injuries were a direct result of the storm.

### Hurricane Betsy

Hurricane Betsy was a major hurricane of the 1965 hurricane season tracking through the Bahamas and Florida before making landfall on September 9, 1965, as a Category 3 hurricane at Grand Isle, LA. Hurricane Betsy brought 160 mph gusts and a 16-foot storm surge that flooded the entire island. Winds gusted to 125 mph in New Orleans and a 10-foot storm surge caused major flooding. Winds in most of southeast Louisiana reached 100 mph and, in areas as far inland as Monroe, winds exceeded 60 mph. Offshore oil rigs, public utilities, and commercial boats all suffered severe damage, resulting in approximately $1.4 billion in damage in 1965 dollars. Seventy-six people lost their lives as a direct result of Hurricane Betsy, the first storm to cause $1 billion in damage.

Hurricane Betsy caused surge effects in Lake Pontchartrain that caused a section of the levee to fail, resulting in flooding within New Orleans in the Ninth Ward and in the Chalmette area of St. Bernard Parish. In most low-lying areas of the city, floodwaters reached to the roofs of houses, resulting in drowning deaths of some of those who had sought refuge from the floodwaters in their attics. Water levels receded after approximately 10 days. It is estimated that approximately 164,000 homes were flooded in Louisiana as a result of Hurricane Betsy. A new levee system, both higher and stronger than the former system, was constructed by the U.S. Army Corps of Engineers (USACE) and protected New Orleans from Hurricane Camille's storm surge in 1969.

### Hurricane Carla

Hurricane Carla hit Texas on September 11, 1961. Carla ranks among the top 30 costliest and most intense hurricanes on record (NHC, 2007). A Category 5 hurricane at its peak, it was a Category 4 when it struck Port O'Connor and Port Lavaca, TX. The highest maximum sustained winds for Hurricane Carla were recorded at 175 mph, 1-minute sustained; the hurricane had storm surges of 22 feet. Approximately 250,000 people evacuated Texas. This hurricane also spawned 26 tornadoes through its path. Damages at the time were estimated at $325 million. Because of the large, effective evacuation, there were only 43 deaths due to this hurricane.

### Hurricane Audrey

Hurricane Audrey, a Category 4 hurricane, hit Louisiana and eastern Texas with winds of 145 mph, 1-minute fastest-mile and storm surges of 6 feet on June 27, 1957. The highest surge was measured at 12.4 feet west of Cameron, LA. Two tornadoes in New Orleans and Ardaudville, LA, were reported. Audrey also spawned 23 tornadoes in Mississippi and Alabama. Its destruction continued through the Ohio Valley, Pennsylvania, New York, and Canada with severe rainfall, flooding, and winds of up to 80 mph, 1-minute fastest-mile. Audrey caused approximately 600 casualties and $147 million of damage.

### Great Galveston Hurricane

The deadliest hurricane in U.S. history was the Great Galveston Hurricane that occurred September 7 to 8 in the year 1900. This hurricane claimed approximately 8,000 lives. The population of Galveston in 1900 was approximately 37,000. This hurricane traveled the Caribbean as a tropical storm before making landfall across the southern United States where it hit Florida, Mississippi, Louisiana, and Texas. The hurricane then traveled through central United States and up through the Great Lakes making its way through Canada. The Great Galveston Hurricane was classified as a Category 4 at landfall, with sustained winds of 100 mph and gusts over 125 mph. The minimum central pressure was 931 mb or 27.49 inches of mercury. The monument shown in Figure 1-14 commemorates the Great Galveston Hurricane; plaques around the statue were destroyed by Hurricane Ike.

The storm surge and high water level from the Great Galveston Hurricane washed out the four bridges linking Galveston to the mainland and downed telephone lines, cutting off the island from the mainland. The highest land elevation on Galveston Island in 1900 was 8.7 feet; the storm surge reached 15 feet. The damage to property was about $30 million. The horrific devastation of the hurricane propelled the people of Galveston to find a way to protect themselves against another disaster of this magnitude. Construction of a 17-foot-high seawall began in 1902 to protect 3 miles of oceanfront and raise the city portion of the island by 8 feet. Sand was dredged from Galveston Bay to elevate the island. A memorial to the construction of seawall was erected after construction was completed; the monument was damaged by Hurricane Ike (Figure 1-15).

Figure 1-14.
Plaques near the Great Galveston Hurricane Memorial were destroyed by Ike

## Future Hurricanes

Based on the history of hurricanes in this area, hurricanes of at least the same intensity can be expected to occur in the future. However, subsidence, shoreline retreat, and sea-level rise may increase the damaging effects of future hurricanes in some areas.

Figure 1-15.
The memorial capstone was moved off center by Ike

## 1.5 FEMA Mitigation Assessment Teams

Along with responding to disasters and providing assistance to people and communities affected by disasters, FEMA conducts building performance studies after disasters in order to better understand how natural and manmade events affect the built environment. The intent of the studies is to reduce the number of lives lost to these events and minimize the economic impact on the communities where these events occur. Also, lessons learned are applied to the rebuilding effort after disasters to enhance the disaster-resistance of new construction and building repairs using recommendations provided in the MAT report. The MAT studies the adequacy of current building codes, other construction requirements, and building practices and materials.

Following a Presidentially declared disaster, FEMA determines the potential need to deploy one or more MATs to observe and assess damage to buildings and structures, as caused by wind, rain, and flooding associated with the storm. FEMA bases this need on estimates from preliminary information of the potential type and severity of damage in the affected area(s) and the magnitude of the expected hazards. These teams are deployed only when FEMA believes the findings and recommendations derived from field observations will provide design and construction guidance that will not only improve the disaster resistance of the built environment in the impacted State or region, but will also be of national significance to all disaster-prone regions.

### 1.5.1 Purpose of the MAT

In response to a request for technical support from FEMA's Joint Field Office in Austin, TX, and the Transitional Recovery Office in New Orleans, FEMA's Mitigation Division deployed a MAT to Texas and Louisiana on October 15, 2008, to evaluate both building performance during Hurricane Ike and the adequacy of current building codes, other construction requirements, and building practices and materials. One of the major objectives of the MAT is to provide recommendations that can help reduce future damage from natural disasters.

The flood levels for Hurricane Ike exceeded the current design flood event (i.e., 100-year base flood event) in localized areas in Texas and Louisiana, as illustrated on the FEMA FIRMs. The wind speeds from Hurricane Ike were less than the design speeds prescribed in IBC 2006/ASCE 7-05.

FEMA was interested in the performance of new construction, hurricane-resistant homes on the Bolivar Peninsula, and residential structures and critical facilities that received FEMA mitigation funding, as well as houses in communities requiring freeboard. Of particular interest was the issue of sustainability and how it relates to rebuilding efforts. The MAT was also tasked with evaluating the performance of approximately 40 buildings on Galveston Island that were previously evaluated by TTU.

### 1.5.2 Team Composition

The MAT included FEMA Headquarters and Regional Office engineers and experts, technical consultants, and construction industry experts. Team members from FEMA's database of national experts included structural engineers, architects, wind engineers, civil engineers, and coastal scientists. In addition, there were representatives from the American Institute of Architects (AIA), the American Planning Association (APA), the Institute for Business and Home Safety (IBHS), the International Code Council (ICC), the National Association of Home Builders (NAHB), the Texas Association of Builders, the Vinyl Siding Institute (VSI), and TTU. In response to the unique situation presented by the substantial flooding in both Texas and Louisiana, a separate flood team was deployed for each State.

The MAT received invaluable support from independent Texas and Louisiana home builders and guides that assisted the MAT. They accompanied the MAT through many of the affected areas, providing valuable insights regarding local construction practices.

### 1.5.3 Methodology

Five days after Hurricane Ike struck the Texas/Louisiana Gulf Coasts (September 18 and 19), preliminary field investigations were performed by MAT members to assess overall building damage in limited areas of Texas. This investigation was tasked to observe and record perishable damage data and to locate damaged areas requiring further investigation. This survey included ground surveillance and aerial reconnaissance in the areas shown in Figure 1-16. The initial leg of the aerial reconnaissance focused on downtown Houston to look at window breakage in high-rise buildings (such as the JP Morgan Chase Building) and the Galleria area to observe roof and glazing damage. From the downtown area, the reconnaissance proceeded to the coastal areas starting at Surfside Beach and continuing along the beach side of Galveston Island, across the channel and up the Bolivar Peninsula to High Island. The return leg included observation of the bayside damage of the Bolivar Peninsula, San Leon, Seabrook, and LaPorte.


**Figure 1-16. Flight plan for pre-MAT aerial reconnaissance**

Based on findings from the preliminary field investigation, FEMA decided to deploy the full MAT. Consequently, the MAT was deployed on October 15 for 1 week. The MAT was separated into three teams: a flood team for Texas, a wind team for Texas, and a flood team for Louisiana.

The Texas MATs conducted extensive ground observations from October 16 through October 21, 2008, in the following locations:

- Brazoria County: Surfside Beach
- Galveston County: Galveston Island, Bolivar Peninsula, and cities and towns along Galveston Bay on the mainland
- Harris County, including downtown Houston
- Chambers County
- Orange County

The Louisiana MAT conducted observations from October 15 through October 20, 2008, in the following parishes:

- Calcasieu
- Cameron
- Vermilion
- Iberia
- St. Mary's
- Terrebonne
- Lafourche
- Jefferson

Figure 1-17 provides details on the locations visited by the MAT in Texas and Louisiana.

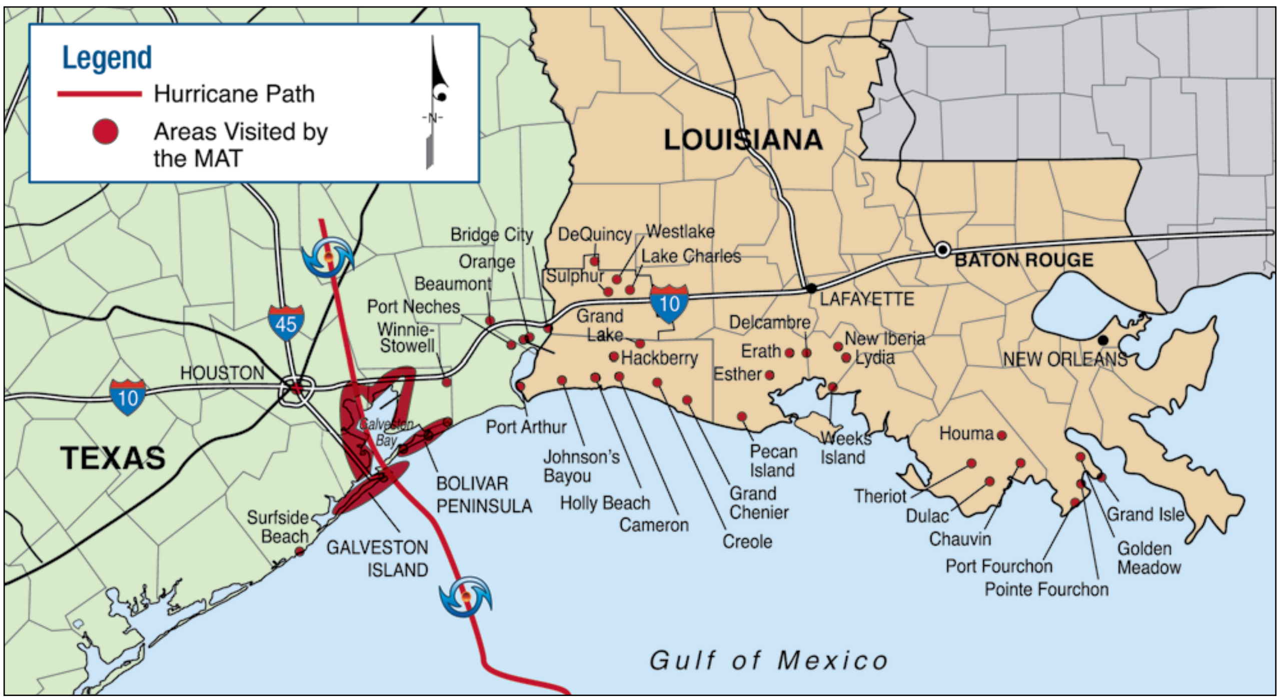



**Figure 1-17. Locations visited by the MAT in Texas and Louisiana**

Damage was observed to single- and multi-family buildings, manufactured housing, commercial buildings, and historic buildings. In addition, critical facilities, such as Emergency Operations Centers (EOCs), fire and police stations, hospitals, nursing homes, and schools were also evaluated in order to document building performance as well as loss of function from Hurricane Ike. Documentation of observations is presented in this report. Photographs and figures are included to illustrate building performance in the wind field and surge areas produced by Hurricane Ike. The conclusions and recommendations of the MAT's findings will assist in minimizing damages from future hurricanes.