Severe Storm Impacts in the Presence of Hurricane Surge

Philip B. Bedient
Herman Brown Professor of Engineering
Civil and Environmental Engineering
Director, SSPEED Center

Graduate Researchers:
Nick Irza
Courtney Hale
Scope of Work

- Evaluate combined surge/inland flooding impact along the upper-Texas coast
- Concentrate study at the mouth of the Brazos River
- Expand methodology from previous work in Galveston Bay
- Link storm surge and floodplain models together
- Evaluate damages and costs for various scenarios

To inform geomorphology, infrastructure vulnerability, and society development models
Hurricanes in the Gulf Coast

Major Hurricane History
Data from 1949 in the Pacific, from 1851 in the Atlantic

This map shows the tracks of all known North Atlantic and Eastern North Pacific major hurricanes, spanning the period from 1531 to 2007 in the Eastern Pacific, and from 1851-2004 in the Eastern North Pacific. A major hurricane is defined as one of Category 3 or greater in the Saffir-Simpson Hurricane Scale. All Category 1 and 2 hurricanes are represented by yellow tracks, while tracks for major hurricanes are red. The yellow portions of the tracks represent major hurricanes when they were of Category 3 strength or above. The dashed red portions of the tracks represent major hurricanes, dashed in part, as they weakened below Category 3 strength. The solid black lines show the tracks of extratropical transitions, or remnant lows, which occur when hurricanes enter cooler waters and lose their tropical characteristics. The solid black line signifies extratropical transition, or remnant low. The solid blue line represents a tropical cyclone that has transitioned into a remnant low. The solid yellow line represents a hurricane that has transitioned into a remnant low.
Total number of hurricane strikes by counties/parishes/boroughs, 1900-2010


Note: When comparing values for counties/parishes/boroughs, differences in geographical size should be considered.
## Major Gulf Hurricane Landfalls

<table>
<thead>
<tr>
<th>No.</th>
<th>Hurricane</th>
<th>Year</th>
<th>Date of Landfall (UTC)</th>
<th>Time of Landfall (UTC)</th>
<th>U.S. Landfall Location</th>
<th>Saffir-Simpson Category</th>
<th>Min. Central Pressure (mb)</th>
<th>Radius to Maximum Winds (mi)</th>
<th>Max. Sustained Winds (mph)</th>
<th>Max. Storm Surge (ft)</th>
<th>Max. Total Rainfall (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Katrina</td>
<td>2005</td>
<td>Aug, 29</td>
<td>1110</td>
<td>Louisiana</td>
<td>3</td>
<td>920</td>
<td>29 to 35</td>
<td>127</td>
<td>28</td>
<td>14.92</td>
</tr>
<tr>
<td>2</td>
<td>Carla</td>
<td>1961</td>
<td>Sept, 11</td>
<td>0900</td>
<td>Texas</td>
<td>3</td>
<td>931</td>
<td>40</td>
<td>115</td>
<td>18.5</td>
<td>17.48</td>
</tr>
<tr>
<td>3</td>
<td>Rita</td>
<td>2005</td>
<td>Sept, 24</td>
<td>0740</td>
<td>Texas</td>
<td>3</td>
<td>930</td>
<td>35 to 45</td>
<td>115</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>Ivan</td>
<td>2004</td>
<td>Sept, 16</td>
<td>0650</td>
<td>Alabama/Florida</td>
<td>3</td>
<td>943</td>
<td>46 to 58</td>
<td>121</td>
<td>10 to 15</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>Ike</td>
<td>2008</td>
<td>Sept, 13</td>
<td>0700</td>
<td>Texas</td>
<td>2</td>
<td>951</td>
<td>46</td>
<td>109</td>
<td>13</td>
<td>18.9</td>
</tr>
<tr>
<td>6</td>
<td>Gustav</td>
<td>2008</td>
<td>Sept, 1</td>
<td>1500</td>
<td>Louisiana</td>
<td>2</td>
<td>953</td>
<td>-</td>
<td>104</td>
<td>12 to 13</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>Isaac</td>
<td>2012</td>
<td>Aug, 29</td>
<td>0000</td>
<td>Louisiana</td>
<td>1</td>
<td>965</td>
<td>46 to 52</td>
<td>81</td>
<td>11</td>
<td>26.71</td>
</tr>
</tbody>
</table>

Hurricane Katrina had the largest storm surge ever recorded in the U.S.

Hurricane Ike had the heaviest rainfall seen on the Texas coast

*Data is reported for US landfall, extracted from NOAA, USACE, FEMA, and/or peer-reviewed reports*
Mean sea level (MSL), defined datum of sea level.

Storm surge, 5 -25 ft above mean sea level.

The intensity of the cyclone increases the height of waves on top of the surge.
The flat slope of the sea floor near the gulf coast causes storm surge to build up more strongly than in Florida.
Aftermath of Hurricane Ike Storm Surge

Photo courtesy Smiley Pool/Houston Chronicle
How do we model storm surge?

Advanced Circulation (ADCIRC) Storm Surge Model

**Hindcasting**: Historical hurricanes to simulate storm surge
- Evaluate the inundation risk in coastal areas
- High impact – low probability events in an evolving system

**Forecasting**: Estimate maximum surge and extent of inundation for damage estimation
ADCIRC Model of Galveston Bay Response
courtesy of Dr. Clint Dawson, Computational Hydraulics Group, Univ of Texas
Damage Model Methodology

**GIS Damage Model**

**FEMA**
- Effective Flood Insurance Rate Maps
- Manually digitized Base Flood Elevations (BFE)

**County Appraisal District**
- Parcel locations
- Appraised values

**County Municipal Codes**
- Residential slab elevation regulations based off BFE zone

**ADCIRC Model**
- Surge depths for storm scenarios
- LiDAR based Digital Elevation Map

**USACE**
- Residential damage estimate curves
GIS Analysis

- Use LiDAR Digital Elevation Map (DEM)
- Use parcel data from Brazoria County Appraisal District
- Digitize FEMA Flood Insurance Rate Maps (FIRM) and Base Flood Elevations (BFE)
- Generate digital surge levels from simulated hurricane events using ADCIRC
Damage Calculation

Surge Depth at Each Structure

\[ \text{Depth of Water above Slab} = \text{Elev. of Surge} - \text{Slab Elev.} \]
where slab elev. is determined by municipal codes for slab elevation above BFE and local flood zone BFE

Damage($) at Each Parcel

\[ \text{Residential Damage} = \text{Appraised Value} \times \% \text{ structural value}, \]
where % structural value = \( f(\text{Depth of Water above Slab}) \)

Jurisdiction & County-wide Damage

\[ \text{Total Damage} = \sum \text{Residential Damage at Each Parcel} \]
Damage Function

USACE Residential Flood Damage Function

Percent (%) of Structural Value

Depth of Water Above Slab (ft)

- One Story
- Two or More Stories
Single-Family Residential – FEMA Floodzone
Assumptions of Damage Calculation

- Single-family residential structures
- Residential structure at parcel center
- Slab elevations are compliant with FEMA and municipal codes

Yields a conservative damage estimate
Residential Properties affected by Storm Surge

Ike at 35 miles SW of Freeport
Residential Properties affected by Storm Surge
Residential Properties affected by Storm Surge
Residential Properties affected by Storm Surge

Inundated Residential Properties

Inundation:
- 0-2 ft
- 2.4 ft
- 4-6 ft
- 6-10 ft
- 10-14 ft
- 14-18 ft
- 18+ ft
Residential Properties affected by Storm Surge
Residential Properties affected by Storm Surge
Residential Properties affected by Storm Surge
Brazoria County Damage Prediction

Ike @ Brazos

Residential Inundation Levels
Parcel Inundation above Slab
- 0-1 ft
- 1-2 ft
- 2-4 ft
- 4-6 ft
- 6+ ft

Hurricane Track

Source: Center for Spatial Information Science and Engineering, and the FBI National Incident Data Base.
Brazoria County Damage Prediction

Ike @ 35 mi. SW Freeport
## Preliminary Damage Estimates

<table>
<thead>
<tr>
<th></th>
<th>Ike @ Brazos</th>
<th>Ike @ 35 Mi. SW Freeport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazoria County Damage (Millions $)</td>
<td>92.5 - 164.8</td>
<td>127.9 - 226.8</td>
</tr>
</tbody>
</table>

Note: Range is from lower to upper bound damage cost estimate from assumption of all two-story and all one-story homes, respectively.
Galveston County – GLO Study

Galveston County Residential Damage Model:
• Several storm scenarios
• Detailed damage totals for all storm surge events
• Damage estimates by jurisdiction
### Surge Depths at Critical Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Category 2 @ Galveston Island</th>
<th>Category 2 @ San Luis Pass</th>
<th>Category 3 @ Galveston Island</th>
<th>Category 3 @ San Luis Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kemah</td>
<td>10.7</td>
<td>14.7</td>
<td>13.1</td>
<td>18.7</td>
</tr>
<tr>
<td>Texas City Levee</td>
<td>11.7</td>
<td>13.5</td>
<td>14.6</td>
<td>17.4</td>
</tr>
<tr>
<td>Jamaica Beach</td>
<td>10.4</td>
<td>14.7</td>
<td>12.8</td>
<td>17.7</td>
</tr>
<tr>
<td>Galveston</td>
<td>13.9</td>
<td>15.8</td>
<td>16.9</td>
<td>19.3</td>
</tr>
<tr>
<td>Boliver Peninsula</td>
<td>15.9</td>
<td>16.0</td>
<td>19.3</td>
<td>19.6</td>
</tr>
</tbody>
</table>

**Preliminary FEMA Floodplain Maps predict 100-year storm surge of approx. 19 feet at Boliver Roads and 20 feet along West Bayshore.**
# Total Residential Damages

<table>
<thead>
<tr>
<th>Galveston County Damage (Billions $)</th>
<th>Category 2 @ Galveston Island</th>
<th>Category 2 @ San Luis Pass</th>
<th>Category 3 @ Galveston Island</th>
<th>Category 3 @ San Luis Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6 – 0.8</td>
<td>1.1 – 1.7</td>
<td>1.0 – 1.5</td>
<td>2.2 – 3.1</td>
<td></td>
</tr>
</tbody>
</table>
Next Steps

- Expand ADCIRC/flood models to other areas
- Perform damage estimate in cooperation with Brody for other coastal areas
- Expand model framework to account for non-residential properties and differences in structure types (Padgett)
- Predict future damages based off population growth and land use change forecasting (Brody)
• How does predicted sea-level rise and shore erosion affect the coastal floodplain?
• How do anticipated increases in severe storm intensity and frequency affect base flood elevations for this area?
• Do land-use and land-cover change patterns put future residents at risk for storm surge flood damage?