INTEGRATING SOCIAL VULNERABILITY AND FLOOD SAFETY MODELING
HURRICANE IKE AND GALVESTON, TEXAS: A CASE STUDY

Image Source: NOAA, 2008
Overview

- Disaster Modeling Framework
- Hurricane Ike and the Galveston experience
- Integrating Social Vulnerability
- Findings and Next Steps
Disaster Modeling Framework

1Adapted from Assaf, 2011.
Objects within the model framework

Flood hazard represented as raster grid (depth and velocity)

Temporally dynamic, evaluated on a time step basis
Objects within the model framework

Buildings, represented as points can be used as shelter, but can collapse if damaged.
Objects within the model framework

Transportation network (nodes and edges) allows population to escape the hazard on foot or using vehicle
Objects within the model framework

People, modeled as individuals or groups
Objects within the model framework

If aware of the hazard, choose to shelter in-place or use transportation network to avoid hazard on foot or in a vehicle.
Fate of objects in the evacuation simulation are determined at each time step.

Safety Criteria for People in Variable Flow Conditions and Typical Modes of Instability in Floods (Source: Cox et al, 2010)
Visualizing the model results

(Source: Map tiles by Stamen Design, 2017)
Modeling the system as a whole allows us to ask new questions about a place

- **Evacuation Planning**
  - Is the evacuation plan effective?
  - How significant is traffic congestion?
  - Is risk affected by time of day or year?
  - Are some groups at greater risk of harm?

- **Scenario-based**
  - Test efficacy of mitigation actions
  - Training (“what if...?”)
  - Communication with managers and public
Research Question: Can the Disaster Simulation Model be refined using Social Vulnerability Data?

- In the U.S., history tells us that roughly a third of the population will not evacuate prior to a hurricane (Weller et al., 2016)

  - Who stays behind?
  - Why do they stay behind?
  - More importantly, where are they located?
Why Galveston?

- History of flooding
- Physically constrained
- Primary data required is publicly availability
What happened in Galveston during Hurricane Ike in 2008?

- Category 2 wind speeds
- **Category 4 storm surge**
- Large wind field – storm surge arrived early
- Storm surge came from the backside of the Island, outflanking the Galveston Seawall.

Source: Harris County Flood Control District (2009)
Preparing the Community Simulation Model: who stayed behind, and where were they?

- Data Uncertainties:
  - Census data is aggregated at block group level, for privacy reasons a one-to-one match with actual population isn’t possible.
  - Data from post-disaster surveys is largely qualitative, difficult to integrate into a GIS framework.
  - Estimates of evacuation compliance vary.
Defining the Population at Risk

- 2010 U.S. Synthesized Population dataset (RTI, 2014)
  - Disaggregated the 2010 Census into individual synthetic households and household members with attributes (sex, age, etc.)
  - Not a one-to-one match, but represents the demographic composition within Census Blocks
  - Useful for agent-based micro-simulation
  - Dasymetric model based on U.S. EPA ICLUS land use data
Data Uncertainty:
Spatial Distribution of Synthetic Population

- ICLUS 90-meter grid resolution is too coarse to map population to individual parcels

(Sources: RTI, 2014 and Esri World Imagery service layer, 2017)
Data Uncertainty: Spatial Distribution of Synthetic Population

- **Assumptions:**
  - Natural breaks can be used to group households by income with similar parcels inside each census block
  - Single family homes given priority, followed by multi-family units
  - Multi-family unit capacity estimated based on square footage estimates

- **Uncertainty:**
  - Parcel data incomplete for multi-family units
  - Large number of vacation rental properties

- **Solution:**
  - Custom Python script
  - Use random function to “shuffle” lists of households and parcels
Data Uncertainty:
Spatial Distribution of Synthetic Population

- Result: households moved to residential parcel centroids

(Sources: Galveston County Central Appraisal District, 2016 and Esri World Imagery service layer, 2017)
Data Uncertainty: Who Stayed Behind?

- Actual spatial distribution of unevacuated PAR cannot truly be known, but Monte Carlo simulation can be used to create an envelope of outcomes.

  - Null hypothesis: select unevacuated population at random
  
  - Alternative hypothesis: stratified sampling based on presence of children in the household will reduce sampling error and improve model predictions.

- Based on sensitivity analysis, assume that 40% of households remain behind (approx. 23,000 people).
### Data Uncertainty: Who Stayed Behind?

#### Sample Description (Weller et al, 2016)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Evacuated (n = 16)</th>
<th>Stayed (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational Level (years)</td>
<td>15.3</td>
<td>14.5</td>
</tr>
<tr>
<td>Age</td>
<td>44.7 (33-63)</td>
<td>48.3 (21-64)</td>
</tr>
<tr>
<td>Length Residency (years)</td>
<td>28.6 (5.5 -61)</td>
<td>26.1 (4-64)</td>
</tr>
<tr>
<td>Own home (%)</td>
<td>80</td>
<td>75</td>
</tr>
<tr>
<td>Windstorm insurance (%)</td>
<td>77</td>
<td>71</td>
</tr>
<tr>
<td>Flood insurance (%)</td>
<td>57</td>
<td>60</td>
</tr>
<tr>
<td>Ethnicity (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>31.3</td>
<td>62.5</td>
</tr>
<tr>
<td>Hispanic</td>
<td>43.8</td>
<td>18.8</td>
</tr>
<tr>
<td>African-American</td>
<td>18.8</td>
<td>12.5</td>
</tr>
<tr>
<td>Nat. American/Pac Islander</td>
<td>6.3</td>
<td>6.3</td>
</tr>
<tr>
<td>Gender (female) (%)</td>
<td>38.8</td>
<td>43.8</td>
</tr>
<tr>
<td>Have Children (%)</td>
<td><strong>56.3</strong></td>
<td><strong>18.8</strong></td>
</tr>
<tr>
<td>Storm damage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>no damage</td>
<td>8%</td>
<td>33%</td>
</tr>
<tr>
<td>minimal damage</td>
<td>38%</td>
<td>8%</td>
</tr>
<tr>
<td>major damage</td>
<td>54%</td>
<td>58%</td>
</tr>
</tbody>
</table>

“...importance of family safety and the evacuation of vulnerable family members (children, elderly, handicapped, and infirm) to a safer place.” (Weller et al., 2016)
Data Uncertainty: Who Stayed Behind?

- Solution:
  - Python scripting
  - CSM scenarios
  - Batch run ESM model
Simulation Results

Null Hypothesis

Actual number of drownings = 5
Results

<table>
<thead>
<tr>
<th>Bins (Number of Fatalities Computed by LSM)</th>
<th>Frequency</th>
<th>Fitted Normal Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0</td>
<td>0 1 2 2 3 4 5 6 7 8 9 10 11 12</td>
<td>0 1.9 3.5 5.8 8.6 11.6 14.1 15.4 15.2 13.4 10.7 7.7 5.0 2.9</td>
</tr>
</tbody>
</table>

Actual number of drownings = 5
Conclusion and Next Steps

- Social vulnerability indicators can be integrated within the CSM framework
- Additional simulations required before drawing conclusions
- Improving the CSM in the future
  - Harmonize census data with disaster
  - Add SV attributes to Synthetic Population dataset
  - Integrate institutional populations
  - Purpose-specific post-disaster surveys
  - Refine cadastral / building inventories
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Questions and Discussion

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References