Water Impacts from Recent U.S. Landfalling Tropical Cyclones

Ken Graham
National Hurricane Center
When you close your eyes, what do you see when you think of a hurricane?
Record Setting Rainfall 2017-18

Hurricanes Harvey, Florence, and Lane have each set state records for tropical cyclone rainfall with Harvey’s rainfall of 60+ inches setting the U.S. record.

- **Harvey (2017)** - 60.58 inches (Texas & US Record)
- **Florence (2018)** – 35.93/26.63 inches (North Carolina/South Carolina Record)
- **Lane (2018)** – 52.02 inches (Hawaii Record)
Water is What KILLS!!!

U.S. Tropical Cyclone Fatalities 1963-2012

Water accounts for about 90% of the direct deaths

- Storm Surge: 49%
- Rain: 27%
- Surf: 6%
- Offshore: 6%
- Wind: 8%
- Tornado: 3%
- Other: 1%

Rappaport 2014

Water is What KILLS!!!
Water Continues to Kill

2016 Fatalities: 83% Water Related

2017 Fatalities*: 91% Water Related

2018 Fatalities: 69% Water Related

*excludes Maria due to uncertainty related to causes of direct deaths

Most Inland Flooding – Only 4% Storm Surge Related
Water Continues to Kill

2016-18 Fatalities*

- Water Related: 83%
- Other

Most Inland Flooding – Only 4% Storm Surge Related

*excludes Maria due to uncertainty related to causes of direct deaths
Flood Related Vehicle Fatalities

- During the past three seasons, *more than half* the U.S. tropical cyclone water-related fatalities were vehicle related!
Hurricane Florence

Excellent Forecasts – Yet 16 out of 17 flood related fatalities were in vehicles!
Excessive Rainfall Outlook
Highlights Risk of Flash Flooding

- 54% of High Risk Days have at least 1 fatality or injury
- 73% have at least $1 million in damage
- High Risk Days account for 1/3 of flood fatalities and 4/5 of damage
Storm Surge Forecasting

Most Inland Flooding – Only 4% Storm Surge Related (2017-2018)

*excludes Maria due to uncertainty related to causes of direct deaths
Public Risk Perception Based on Previous Experience

• “My house is elevated, I thought we would be just fine”
• “It’s never flooded here before”
• “They always turn”
• “I thought these floods come once in a 100 years”
• “It’s just a tropical storm”
• “I live a hundred miles from the coast, I didn’t expect this”
• “This didn’t happen last time”
Public Risk Perception Based on Previous Experience

• “I didn’t know it would be this bad, I’ll never stay again”
• “This wasn’t that bad, I’ll never leave again”
• “It was nothing when I looked a few days ago” (anchoring)
What’s Influencing Evacuation Decisions
From Dr. Laura Myers Research

• Past Experience – Wasn’t that bad!
  • Often not to evacuate. What is there wasn’t a last time?

• Track Forecast/Cone – Overly focused on track
  • Impacts far reaching!

• Storm Intensity – “Just a” Category One (TS)
  • Focus on hazards – Cat 1’s - 175 fatalities - $103 billion in damage in U.S. this decade

• Hurricane Warning – Tied to wind
  • Water – storm surge & rainfall historical most deadly
<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Out</td>
<td>Anxious and eager to leave if a hurricane is in the forecast</td>
</tr>
<tr>
<td>21%</td>
<td></td>
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<tr>
<td>Constrained</td>
<td>Aware of risks &amp; willing to evacuate but face barriers</td>
</tr>
<tr>
<td>14%</td>
<td></td>
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<tr>
<td>Optimists</td>
<td>Doubt that a hurricane will occur but willing to evacuate</td>
</tr>
<tr>
<td>16%</td>
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<tr>
<td>Reluctant</td>
<td>Reluctant to evacuate but will leave if ordered to</td>
</tr>
<tr>
<td>27%</td>
<td></td>
</tr>
<tr>
<td>Diehards</td>
<td>Confident they can safely ride out hurricanes at home</td>
</tr>
<tr>
<td>22%</td>
<td></td>
</tr>
</tbody>
</table>

Sandy study by Jennifer Marlon, Yale University
Storm Surge Highly Sensitive to Track! Irma 2017

~50,000 people with 3+ foot surge

~200,000 people with 3+ foot surge
Florence: Structure Matters

Best Track Deterministic

Stronger, Smaller Storm
Michael: Just a Little East
Experience Based Perceptions of Risk

It was just 7 miles in Jackson County from the max estimated rainfall to the minimum estimated rainfall.

Near Gulf Park Estates radar estimated 12.2 inches but just 7 miles to the east radar estimated only 3.5 inches. Yes that is almost 9 inches difference in just “7” miles.
When you close your eyes, what do you see when you think of a hurricane?
“The storm is past me, I’m safe now”
Indirect Fatalities

Longer-Term Impacts

Most frequent factors: cardiovascular, loss of electricity, vehicle accident, and evacuation
Where were the nation’s most powerful hurricanes five days before landfall?

Labor Day, Camille, & Michael did not exist!
Where were the nation’s most powerful hurricanes *three* days before landfall?
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Where were the nation’s most powerful hurricanes *three* days before landfall?

- **Labor Day (1935)**
  - 40 mph

- **Camille**
  - 65 mph
Where were the nation’s most powerful hurricanes *three* days before landfall?
Where were the nation’s most powerful hurricanes three days before landfall?

All tropical storms! All rapidly strengthened!!

Labor Day

Andrew 50 mph

Michael 50 mph

Camille 65 mph
Thinking About Timelines

Hurricane Florence

10 days plus
Thinking About Timelines

Hurricane Michael
3-4 days
Thinking About Timelines

[Map showing verified and forecast positions of a hurricane]
It’s About the Impacts

Since 2010 in the U.S., Category 1 hurricanes*

175 direct deaths
$103 billion

*Irene, Isaac, Sandy, Hermine, Matthew, Nate, Florence
It’s About the Impacts

Hazards Extent Far From the Center!
A Hurricane is Not a Point!
Where to Next Forecast

Hurricane Forecast Improvement Project Goals:

• Reduce forecast (model) guidance errors, including during rapid intensification, by 50%
• Produce 7-day forecast guidance as good as the 5-day forecast guidance
• Improve guidance of pre-formation disturbances, including timing, track, and intensity forecasts, by 20%
• Potential Tropical Cyclone – add marine threat issuance
Track Forecast Success During Florence’s Approach to the U.S.
Some long-range forecasts suggested Florence would re-curve over the central Atlantic.
Potential Tropical Cyclone (PTC) 2017-2018

Even used to issue warnings for the Cabo Verde Islands
Where to Next
Storm Surge

• Storm Surge model improvements
  – Puerto Rico storm surge modeling – 2019 Watch/Warning and Potential Inundation Forecast
  – Southern California (waves too)
  – Higher resolution work
  – Super basin for Florida

• World Meteorological Organization – SLOSH expansion
• Adding waves into the SLOSH model
• Storm Surge real-time storm surge guidance from current 48 hours to 72 hours
Where to Next

Improve hazard guidance and risk communication based on **social and behavioral science** to modernize the tropical cyclone product suite for actionable lead-times for storm surge and all other threats

- **Hurricane Forecast Improvement Project**
  - Web-based survey on economic value of improved forecasts
  - Use study for the Cone of Uncertainty

- **Supplemental**
  - Wait, that forecast changed? – Assess consumption and processing of a changing forecast
  - NHC website – Optimizing tropical cyclone information
  - Minding the Gap – looking at the product suite by evaluating partner needs
  - There’s a Chance of What? – numeracy analysis of forecasters, partners, and the public when it comes to uncertainty products