


Water Impacts from Recent U.S. Landfalling Tropical Cyclones



Ken Graham
National Hurricane Center

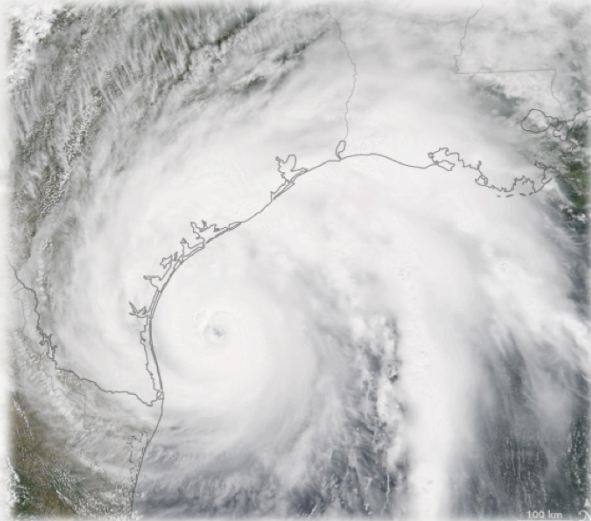




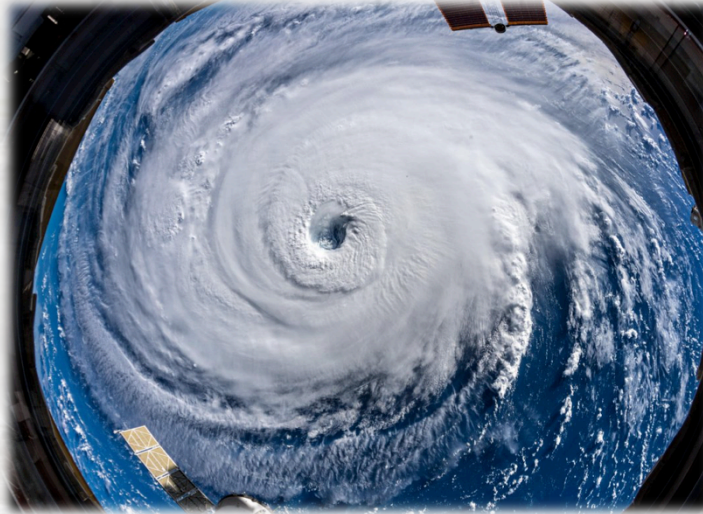
**When you close your
eyes, what do you see
when you think of a
hurricane?**

Record Setting Rainfall 2017-18

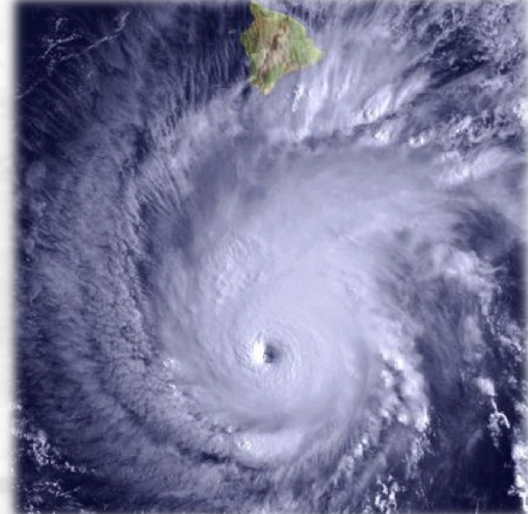
Hurricanes Harvey, Florence, and Lane have each set state records for tropical cyclone rainfall with Harvey's rainfall of 60+ inches setting the U.S. record



**Harvey (2017) - 60.58 inches
Texas & US Record**



**Florence (2018) – 35.93/26.63 inches
North Carolina/South Carolina Record**

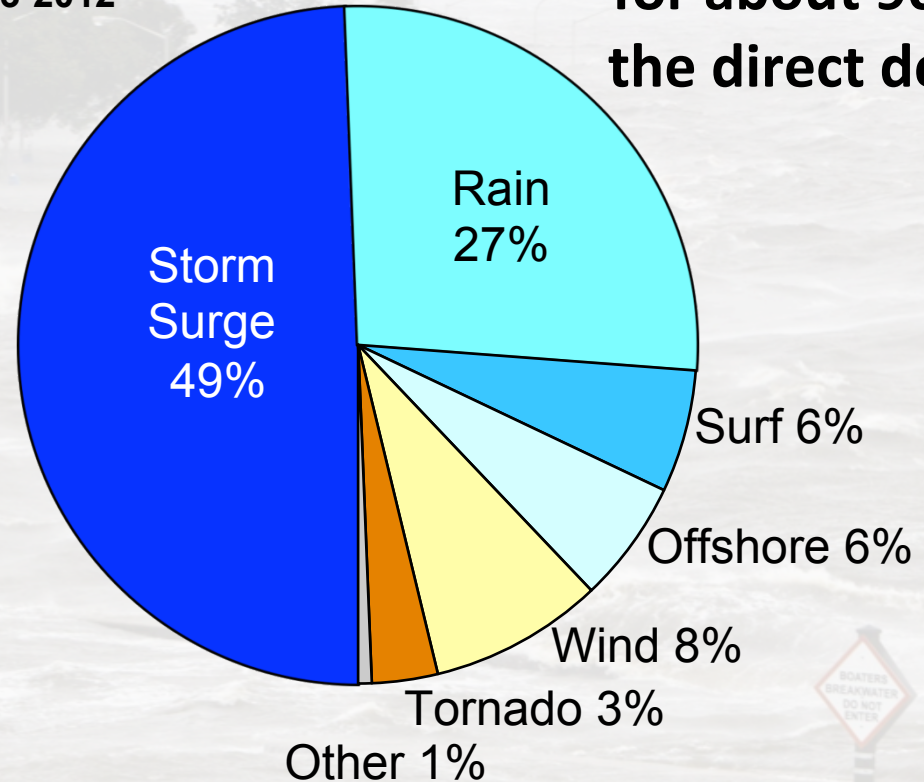


**Lane (2018) – 52.02 inches
Hawaii Record**

Water is What KILLS!!!

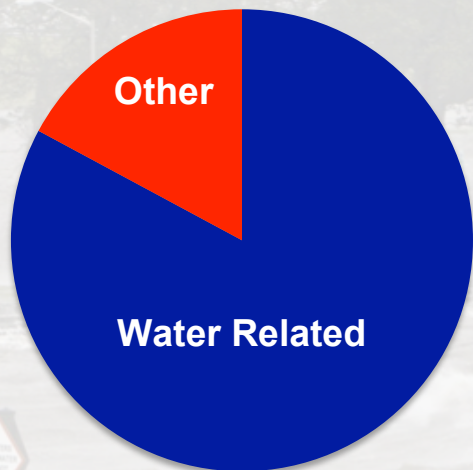
U.S. Tropical Cyclone Fatalities
1963-2012

**Water accounts
for about 90% of
the direct deaths**



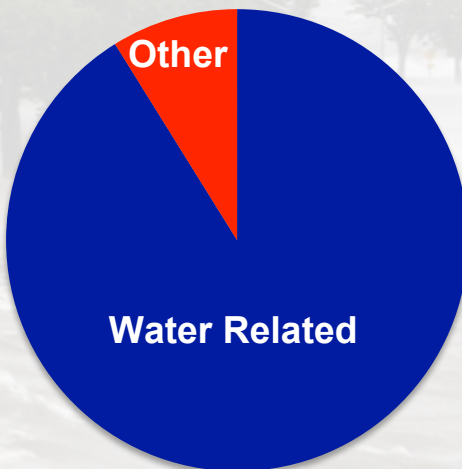
Water Continues to Kill

2016 Fatalities



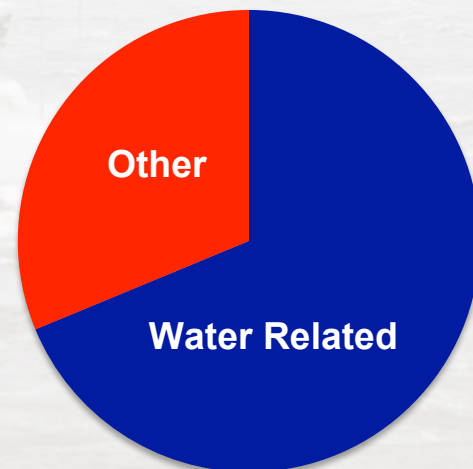
83% Water Related

2017 Fatalities*



91% Water Related

2018 Fatalities



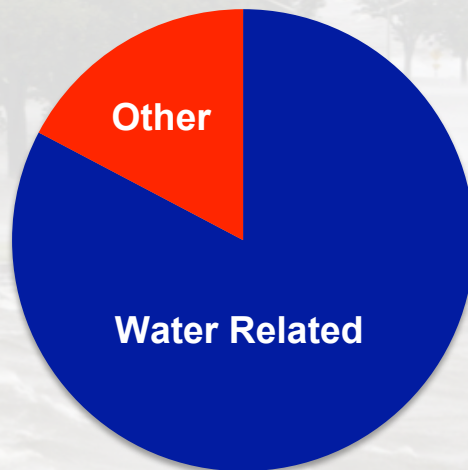
69% Water Related

Most Inland Flooding – Only 4% Storm Surge Related

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

Water Continues to Kill

2016-18 Fatalities*



83% Water Related

Most Inland Flooding – Only 4% Storm Surge Related

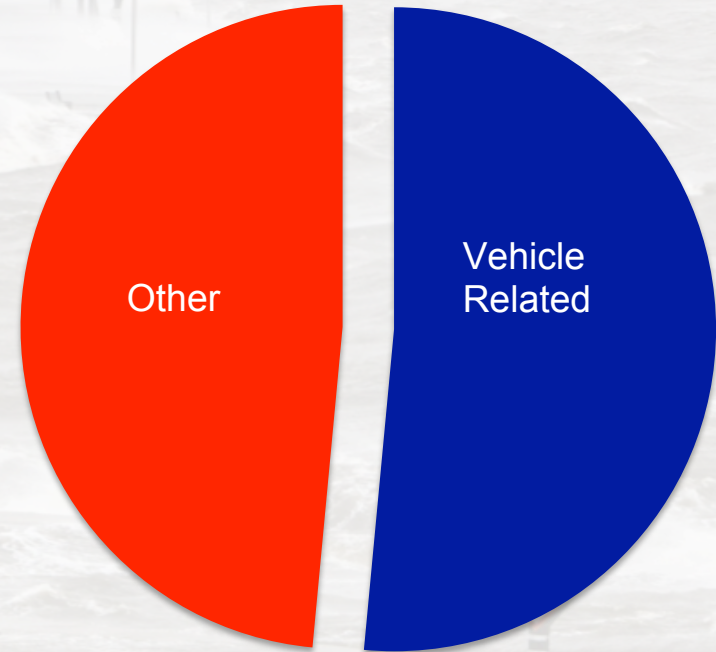
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Flood Related Vehicle Fatalities

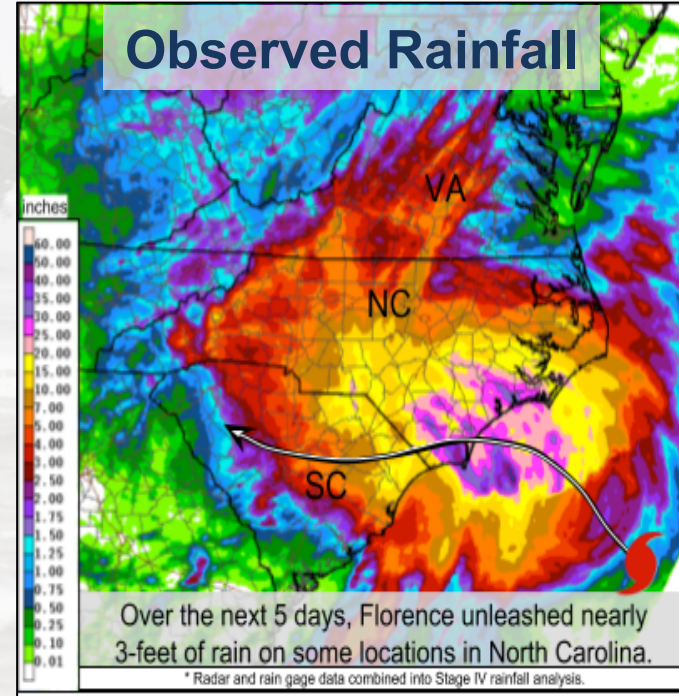
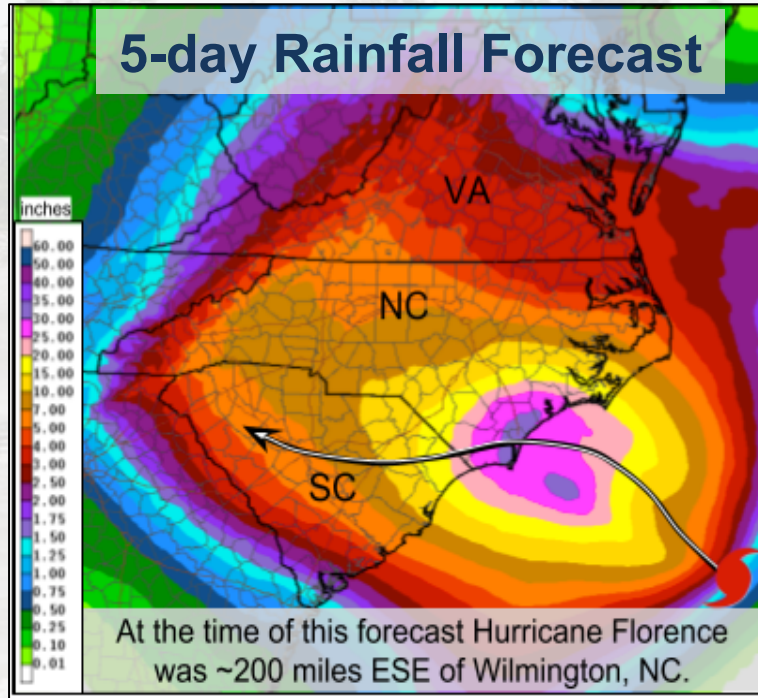
- During the past three seasons, more than half the U.S. tropical cyclone water-related fatalities were vehicle related!



2016-18 U.S. Tropical Cyclone
Water Related Fatalities



Hurricane Florence

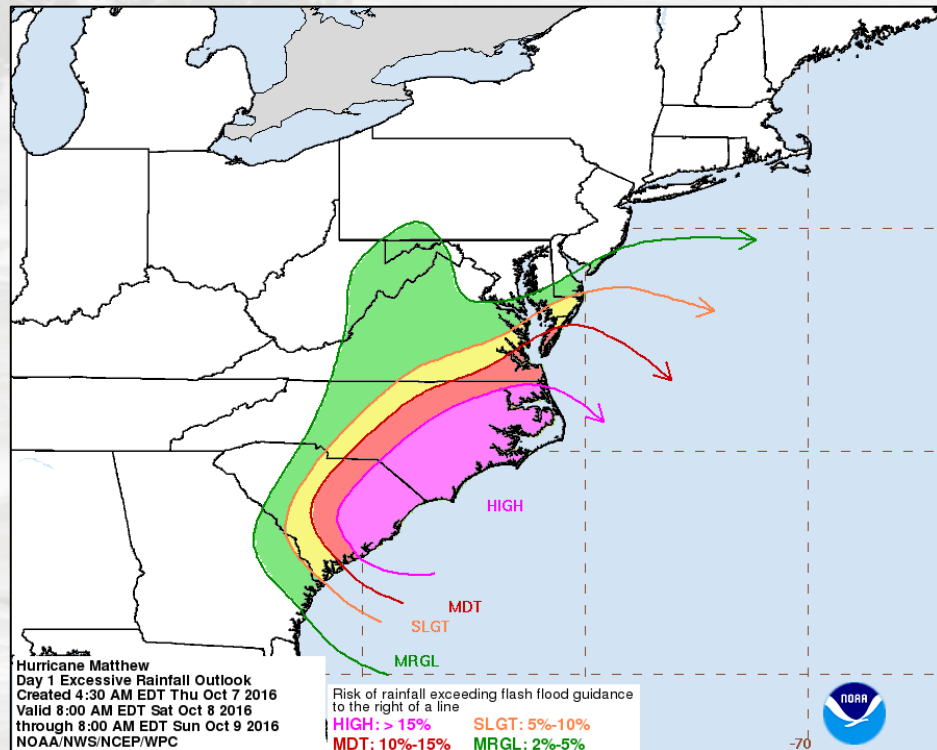


Excellent Forecasts – Yet 16 out of 17 flood related fatalities were in vehicles!

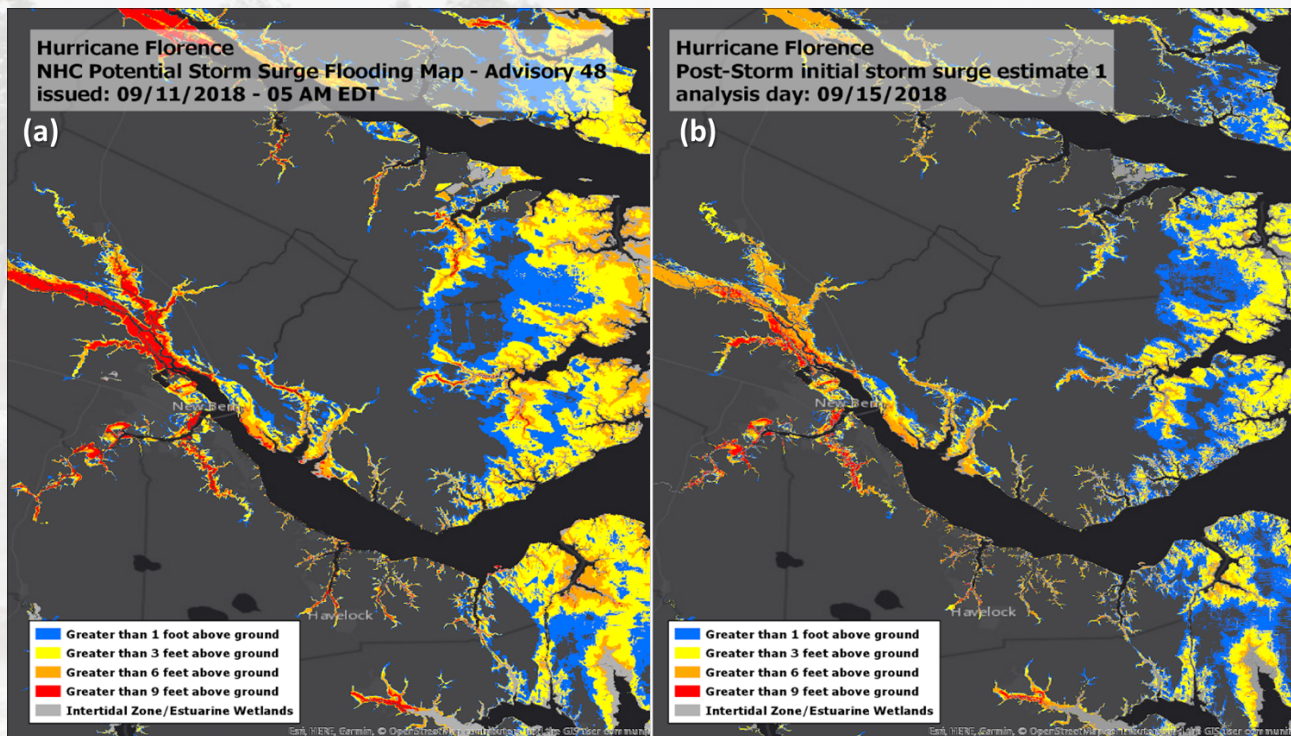
Excessive Rainfall Outlook

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)

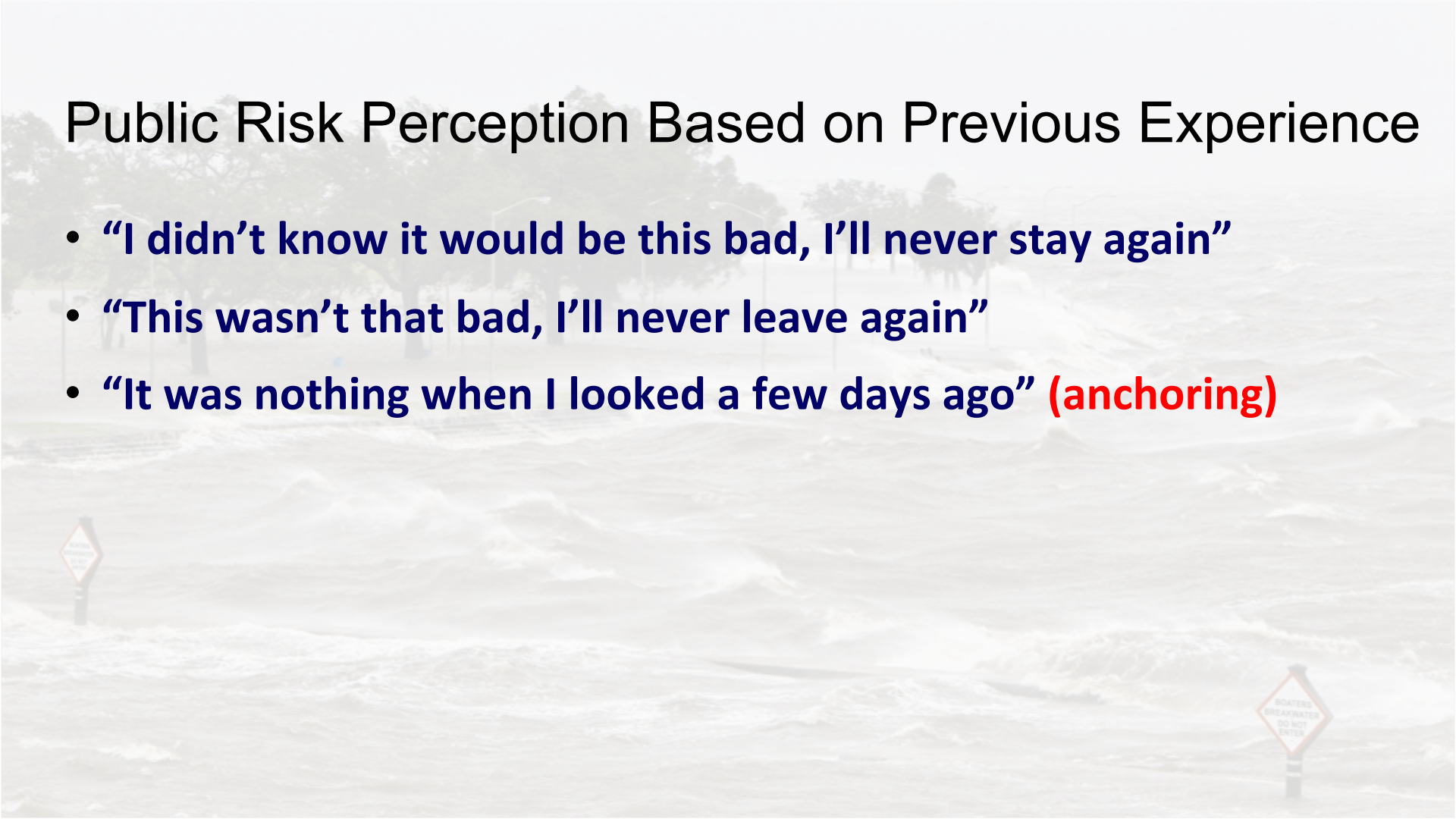
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Public Risk Perception Based on Previous Experience

- **“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



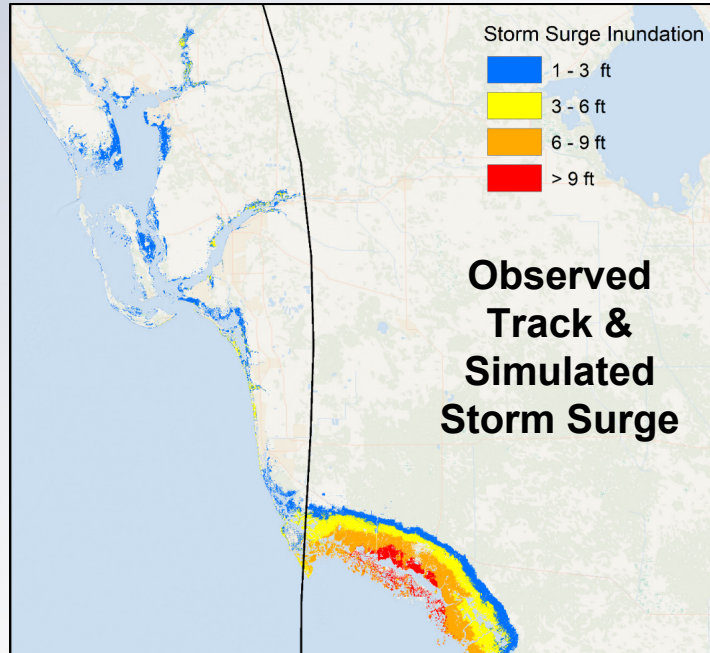
Communicating Risk Challenge

First Out 21%	Anxious and eager to leave if a hurricane is in the forecast
Constrained 14%	Aware of risks & willing to evacuate but face barriers
Optimists 16%	Doubt that a hurricane will occur but willing to evacuate
Reluctant 27%	Reluctant to evacuate but will leave if ordered to
Diehards 22%	Confident they can safely ride out hurricanes at home

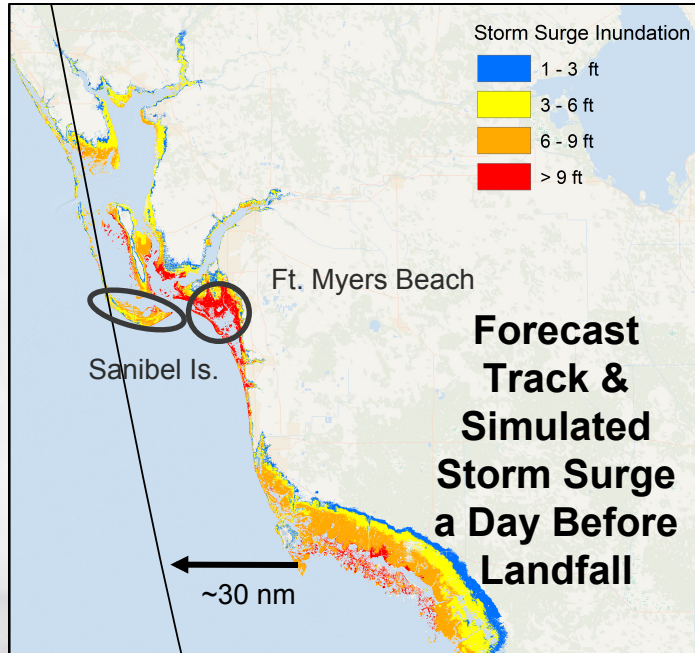
Sandy study by Jennifer Marlon, Yale University

Storm Surge Highly Sensitive to Track!

Irma 2017



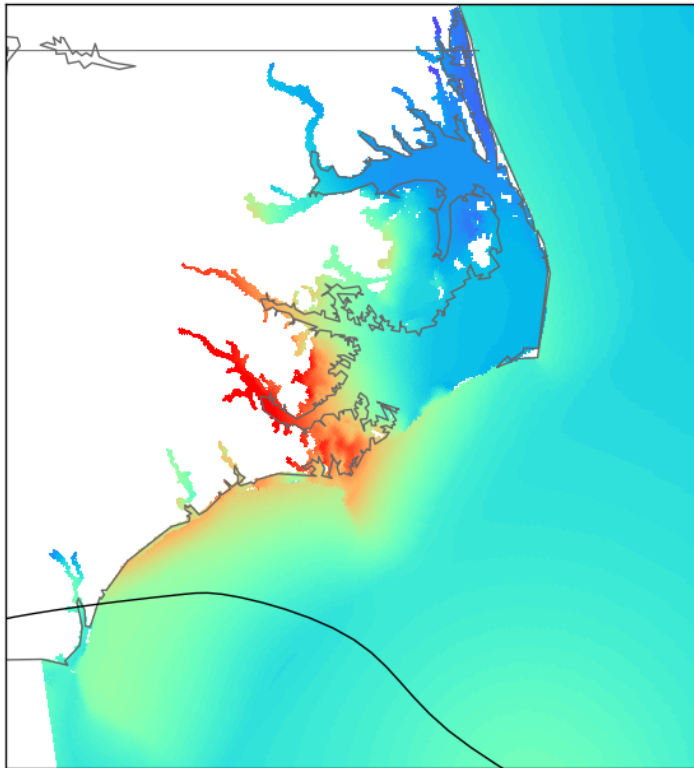
**~50,000 people
with 3+ foot surge**



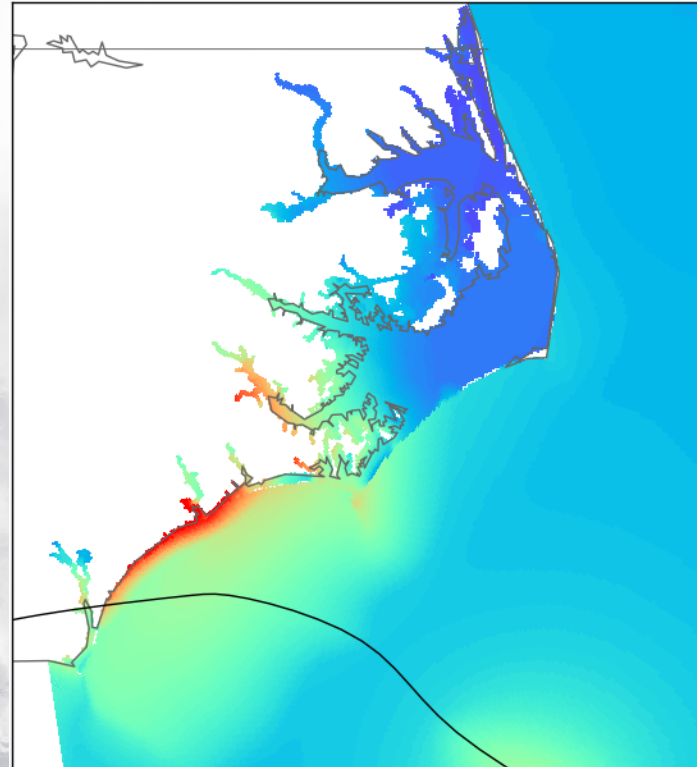
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Florence: Structure Matters

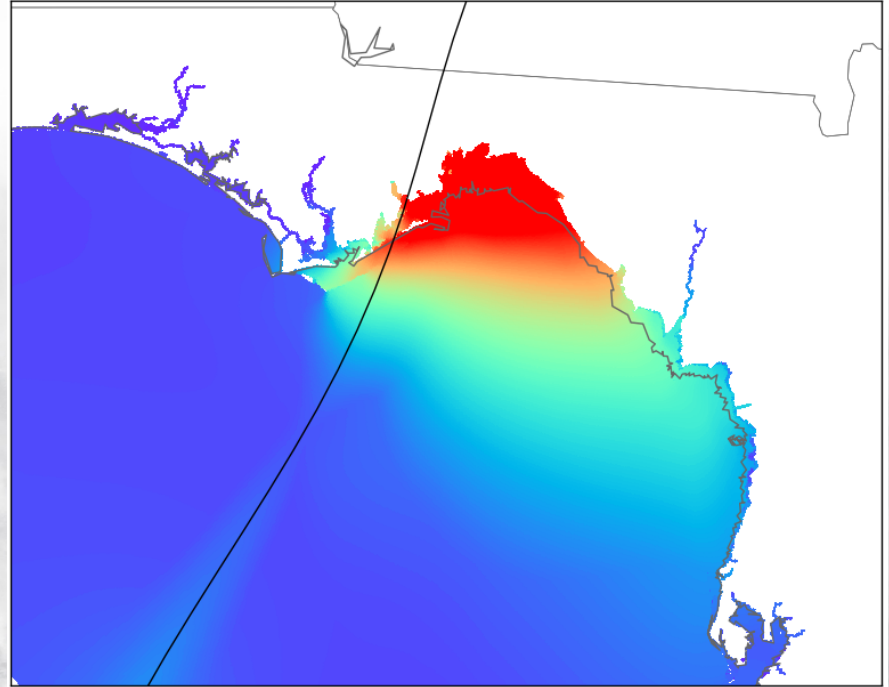
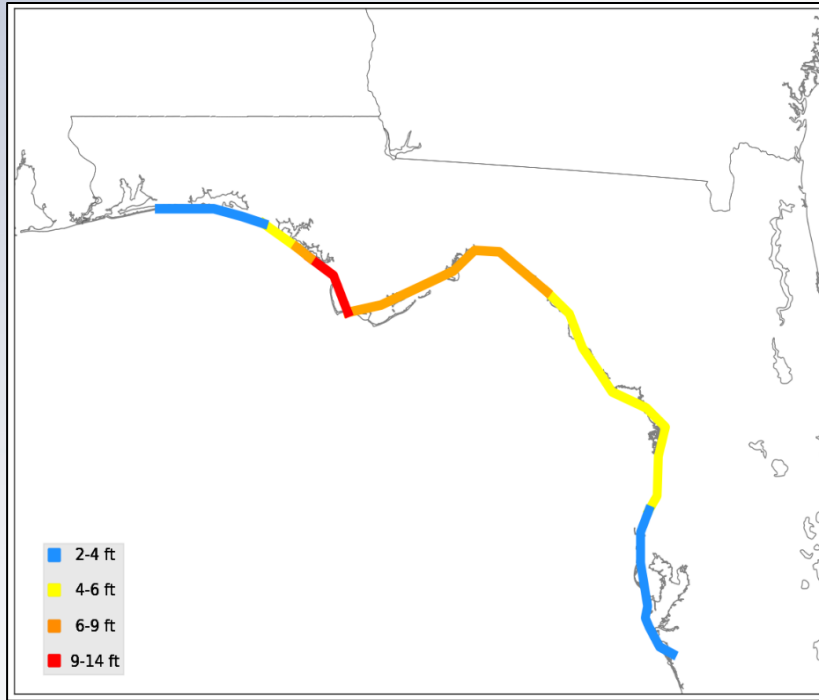
Best Track Deterministic



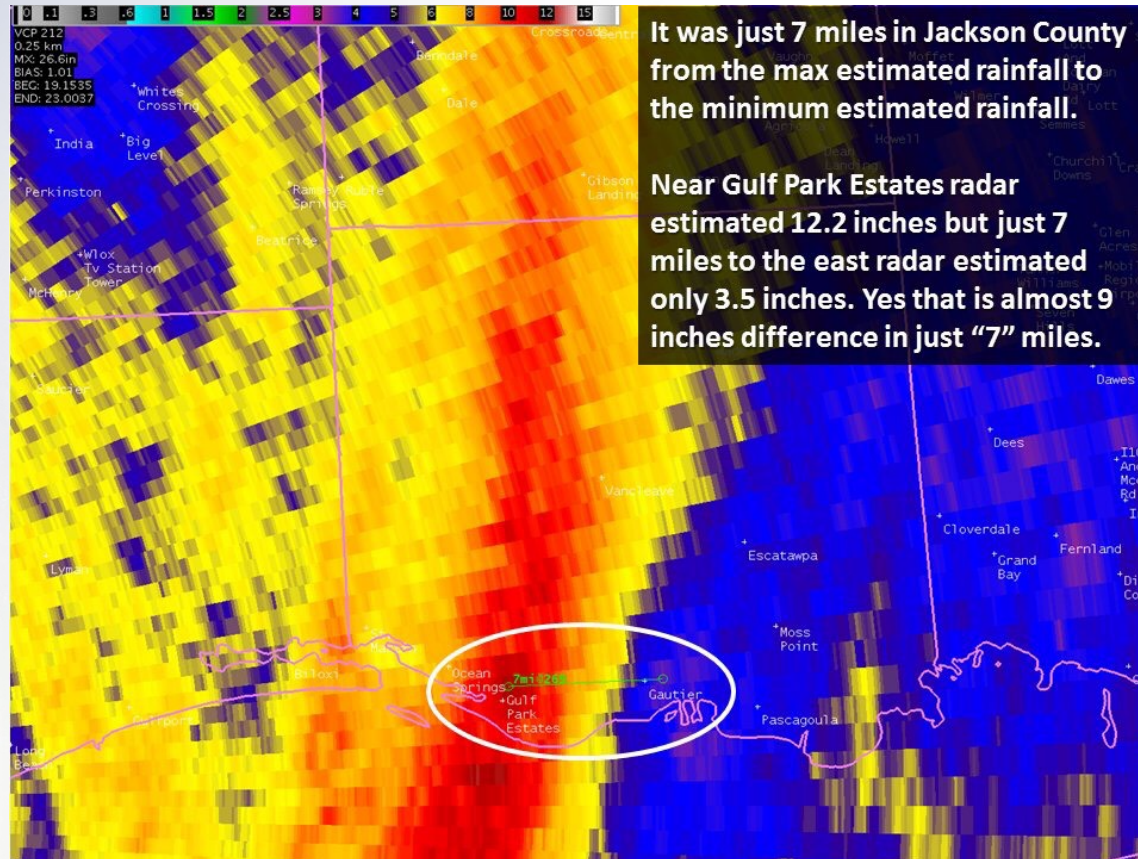
Stronger, Smaller Storm




Michael: Just a Little East



Experience Based Perceptions of Risk





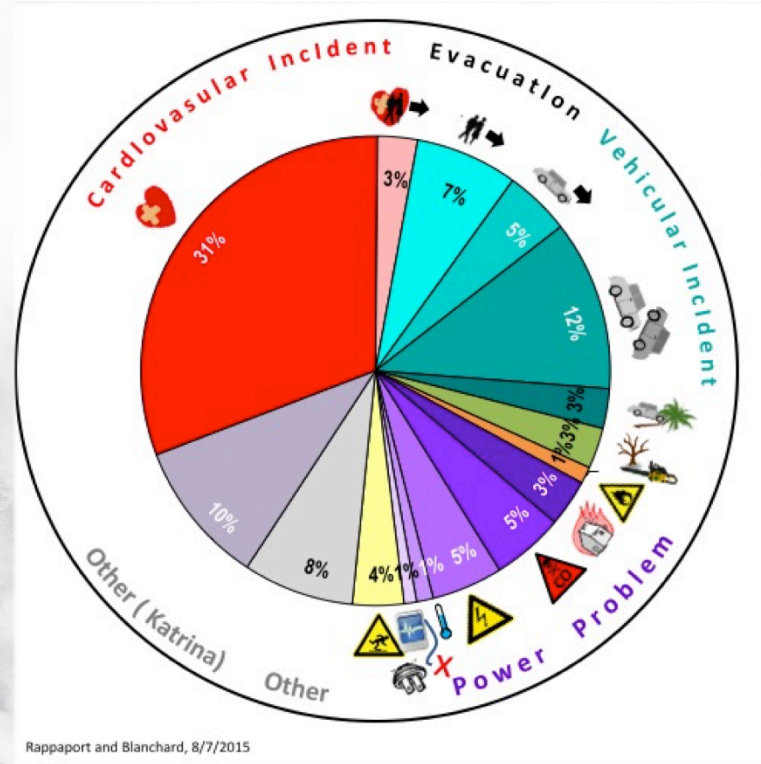
**When you close your
eyes, what do you see
when you think of a
hurricane?**



“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!

Andrew



Where were the nation's most powerful hurricanes three days before landfall?

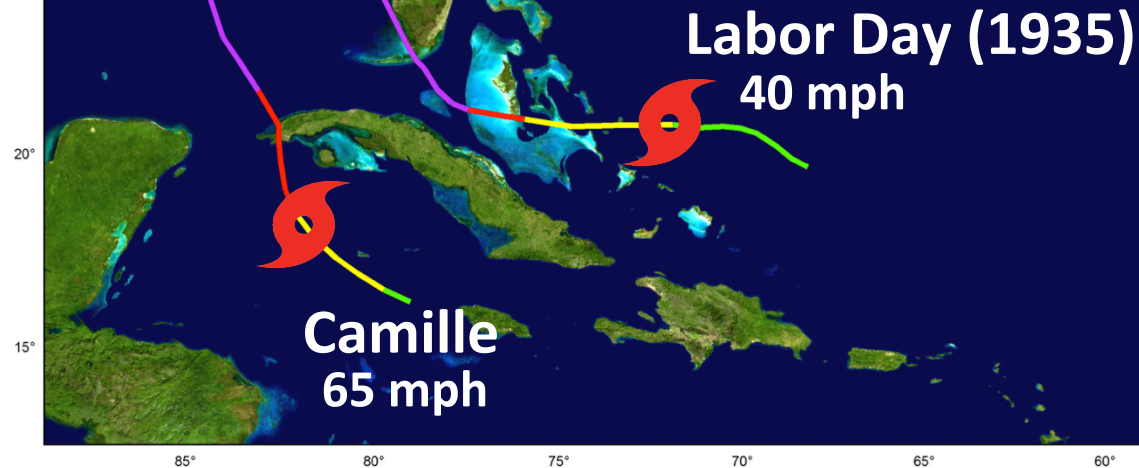


Where were the nation's most powerful hurricanes three days before landfall?

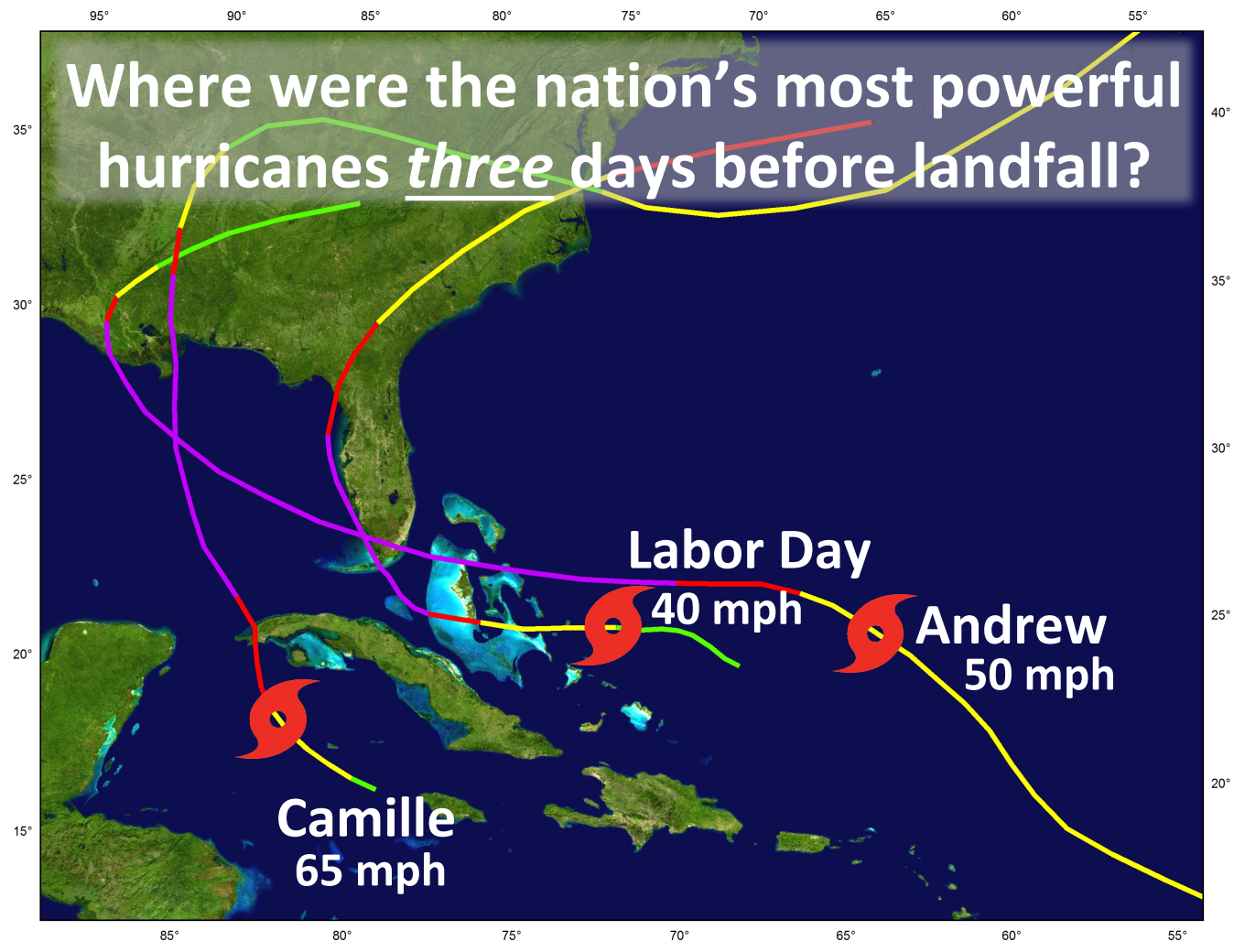
Labor Day
40 mph



Where were the nation's most powerful hurricanes three days before landfall?



Where were the nation's most powerful hurricanes three days before landfall?

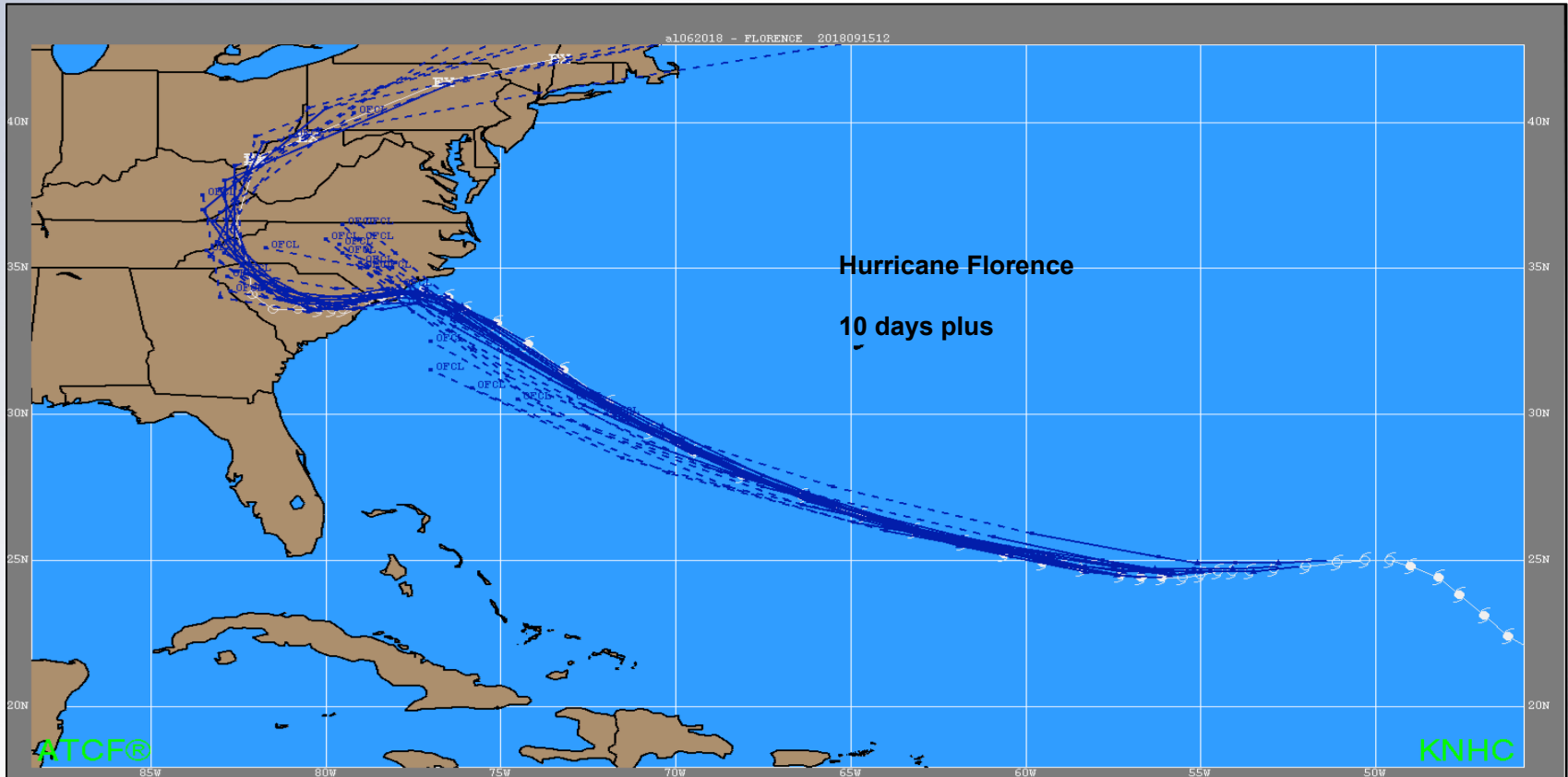


Where were the nation's most powerful hurricanes three days before landfall?

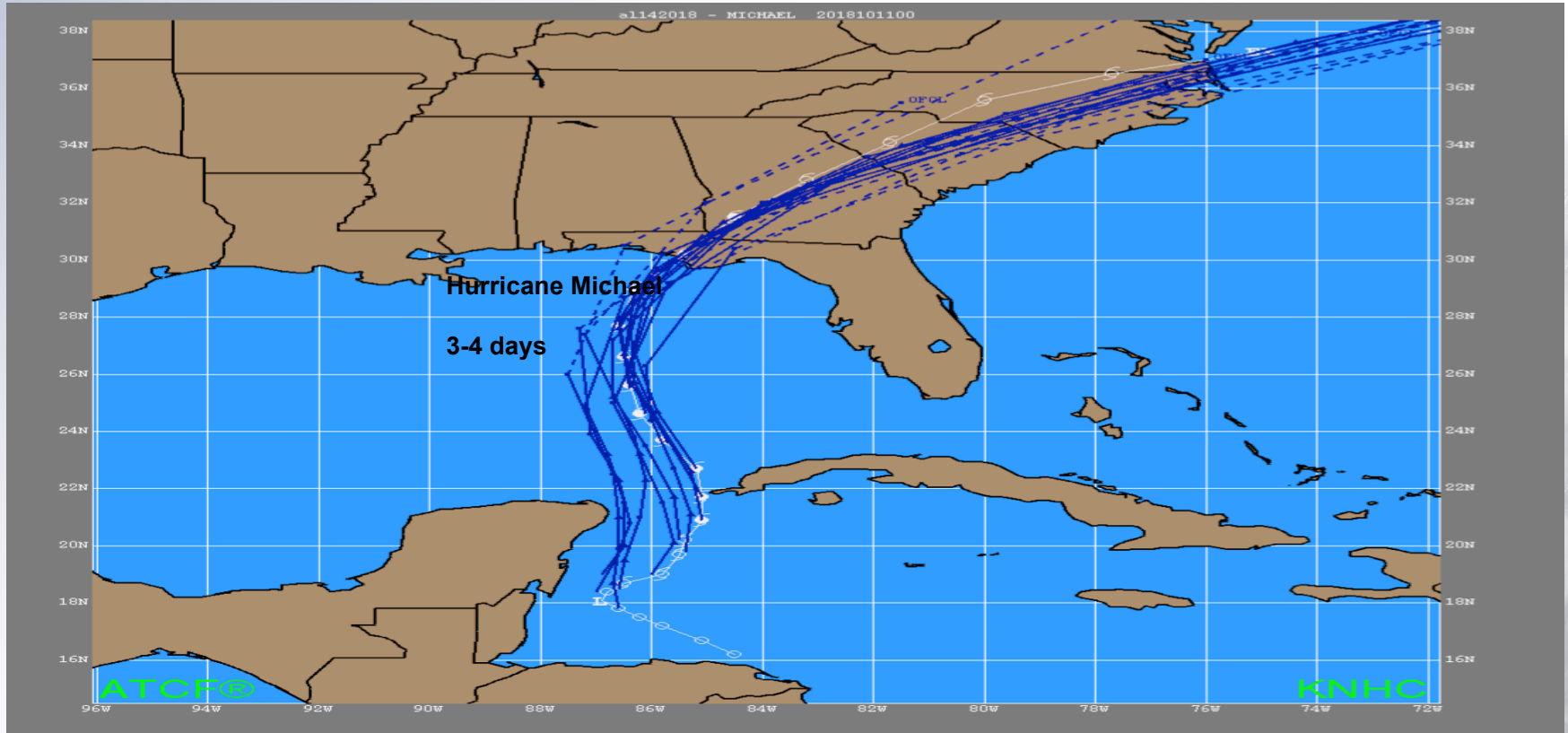
**All tropical storms!
All rapidly strengthened!!**



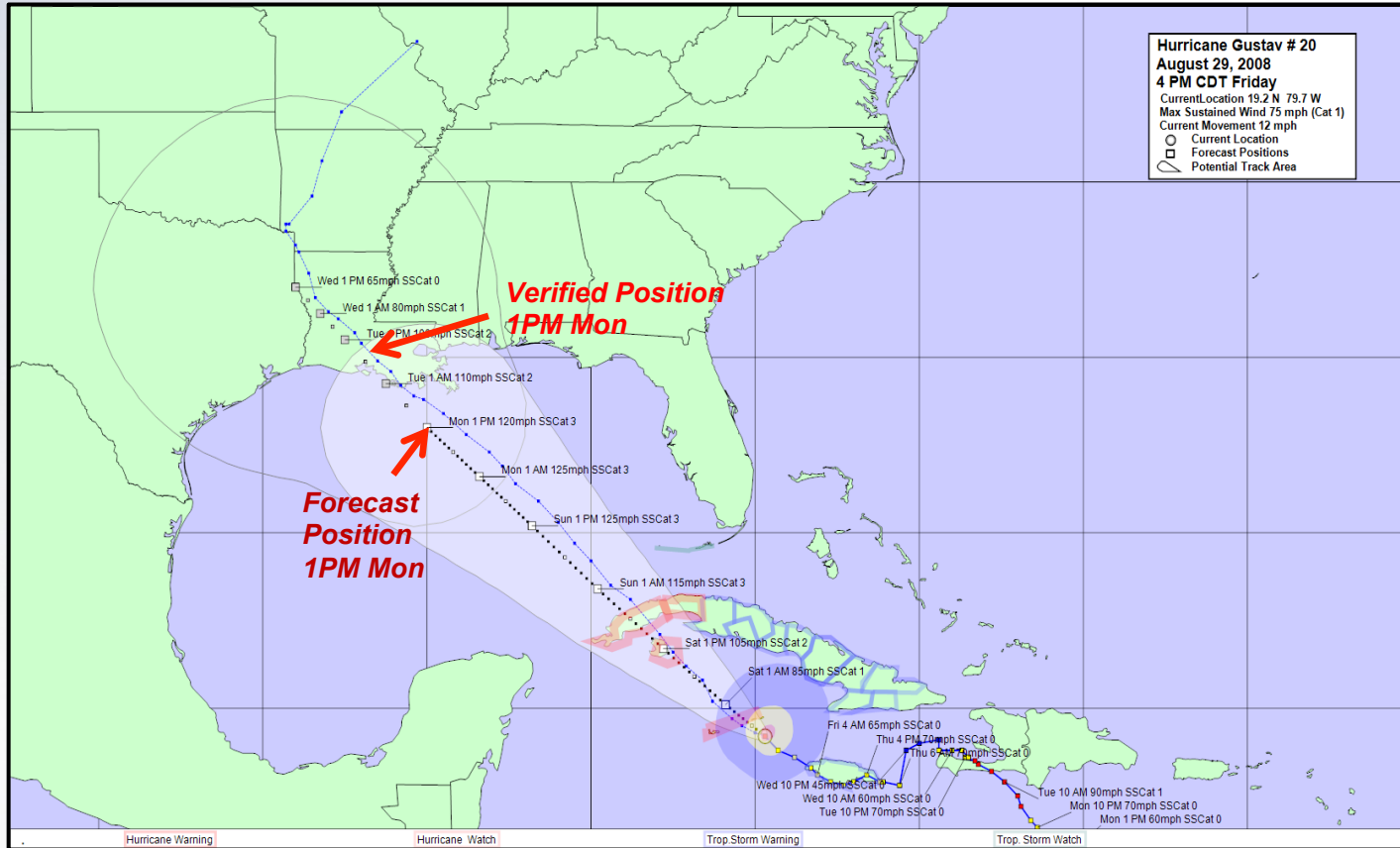
Thinking About Timelines



Thinking About Timelines



Thinking About Timelines



It's About the Impacts



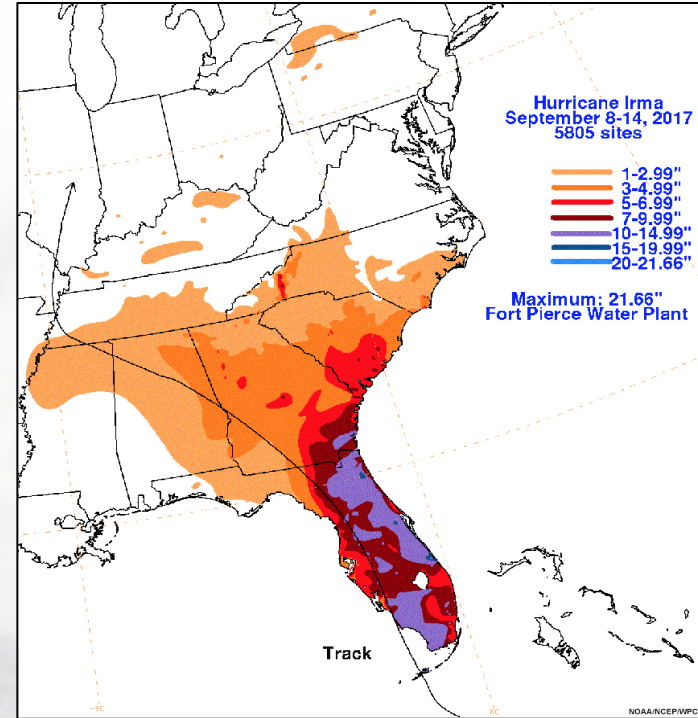
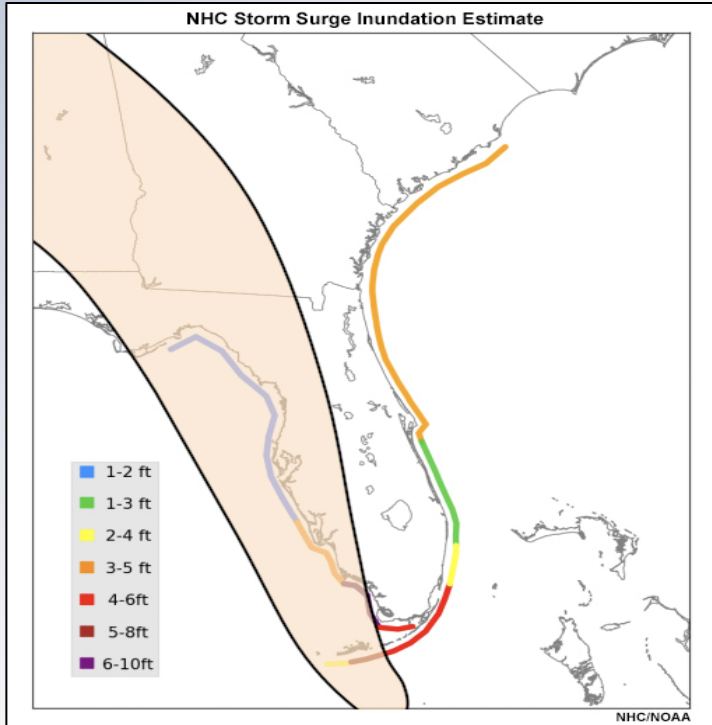
**Since 2010 in the U.S.,
Category 1 hurricanes***

**175 direct deaths
\$103 billion**

***Irene, Isaac, Sandy, Hermine, Matthew, Nate, Florence**



It's About the Impacts

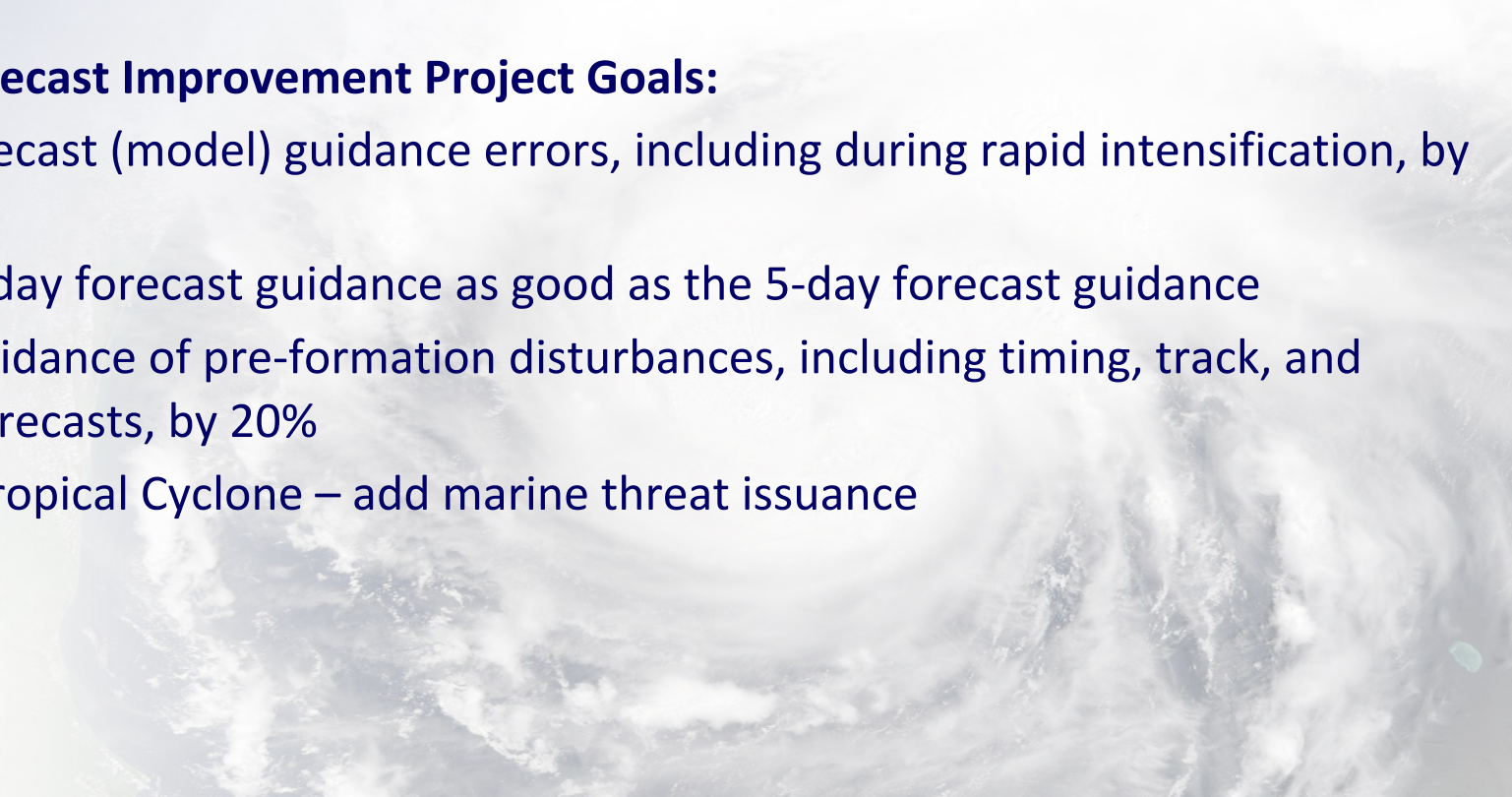


Hazards Extent Far From the Center!
A Hurricane is Not a Point!

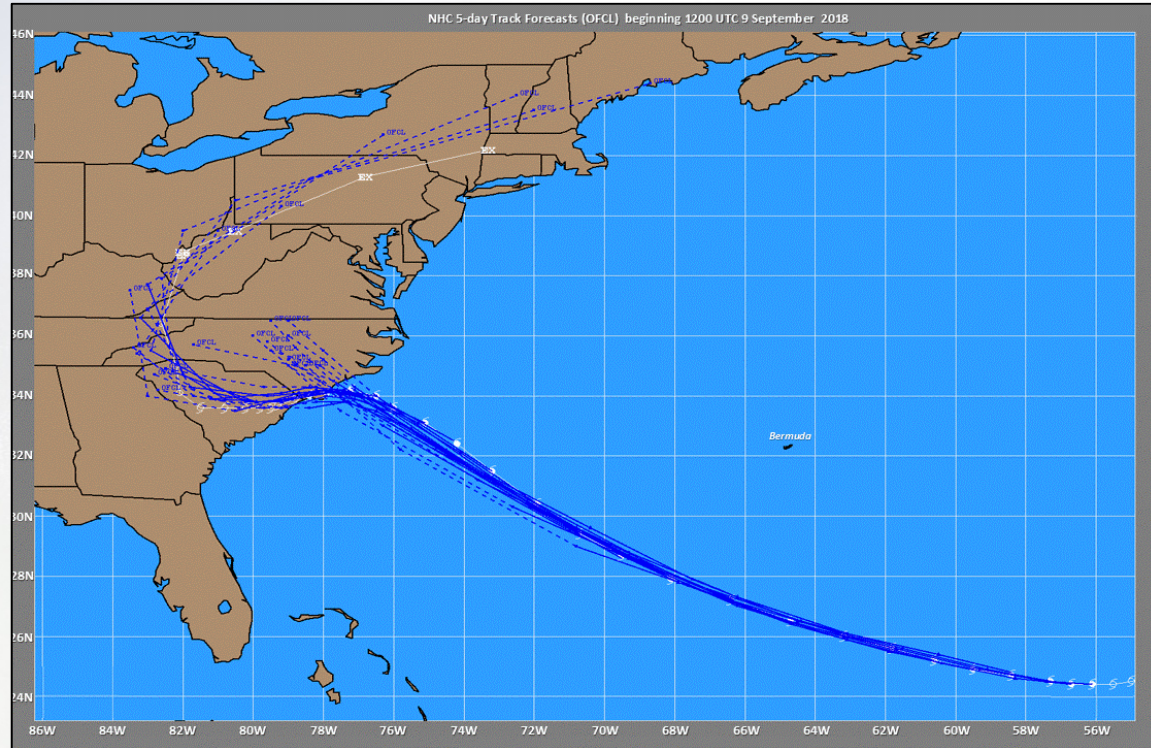


Where to Next Forecast

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
- 

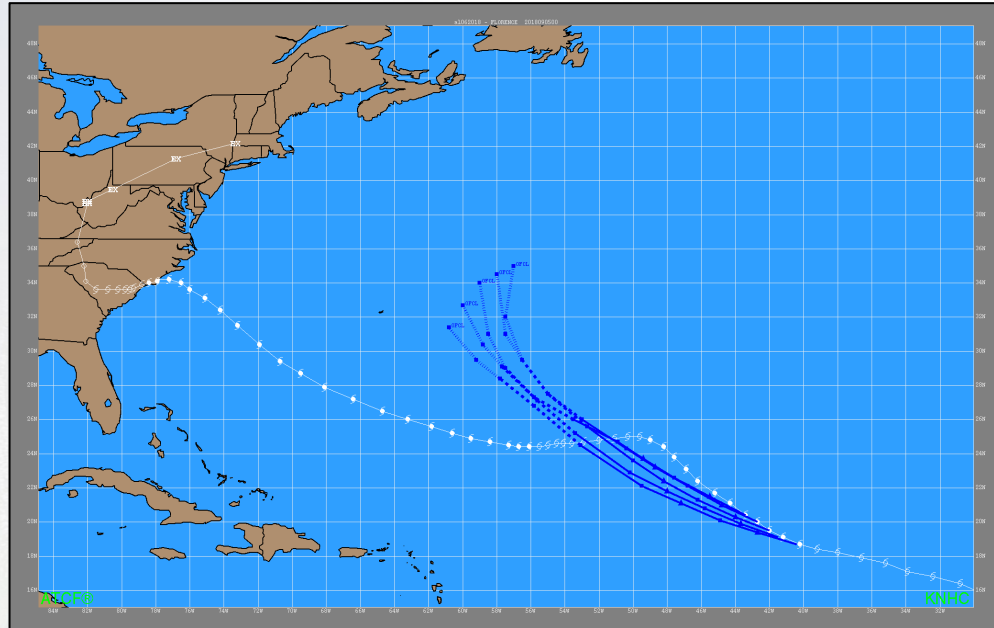
Track Forecast Success During Florence's Approach to the U.S.



Hurricane Florence

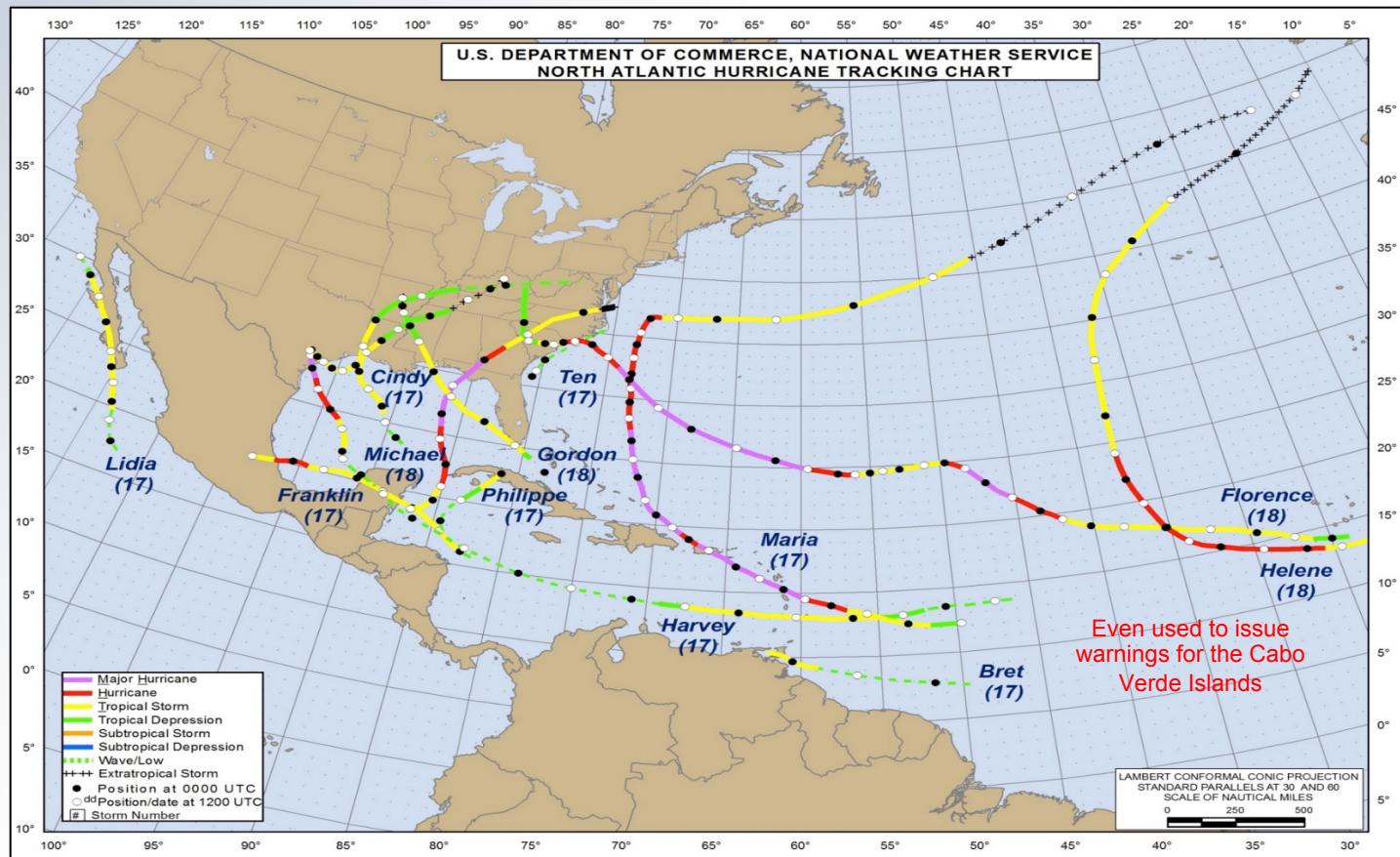
In-house 6- and 7-day Forecasts

NHC Experimental 6- and 7-day forecasts




Some long-range forecasts suggested Florence would re-curve over the central Atlantic

Potential Tropical Cyclone (PTC) 2017-2018





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