



# **UNIT 3:**

# **Forecast Uncertainty**

# Unit 3 Objectives



## Unit Objectives

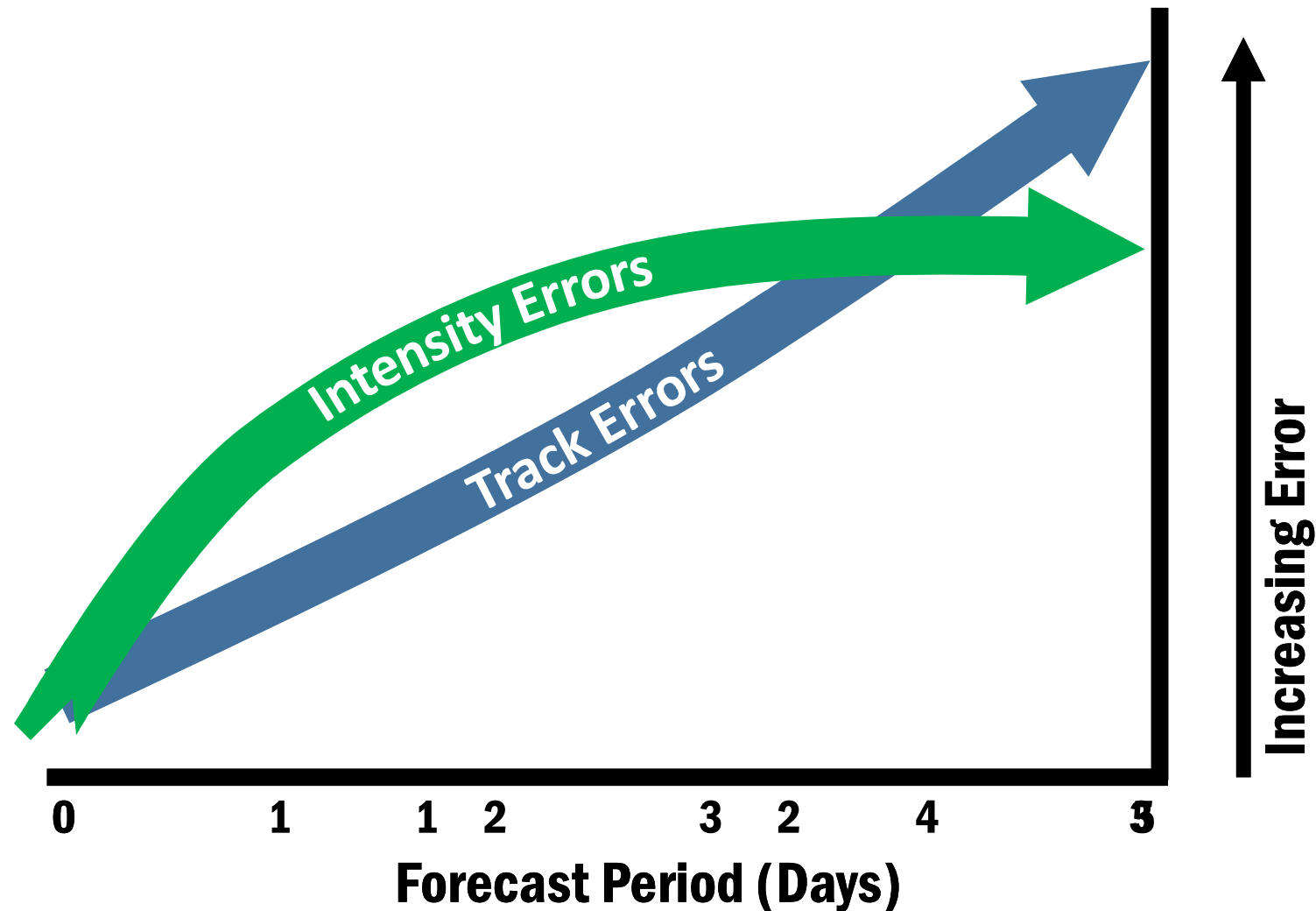
### **At the end of Unit 3, you should be able to:**

- Explain how wind speed probability products are used to predict the chance and timing of hazardous winds.
- Explain uncertainty as it relates to arrival times for TS wind speeds.
- Identify products used to evaluate storm surge risk.
- Identify and discuss coastal surge models.

# Forecast Errors



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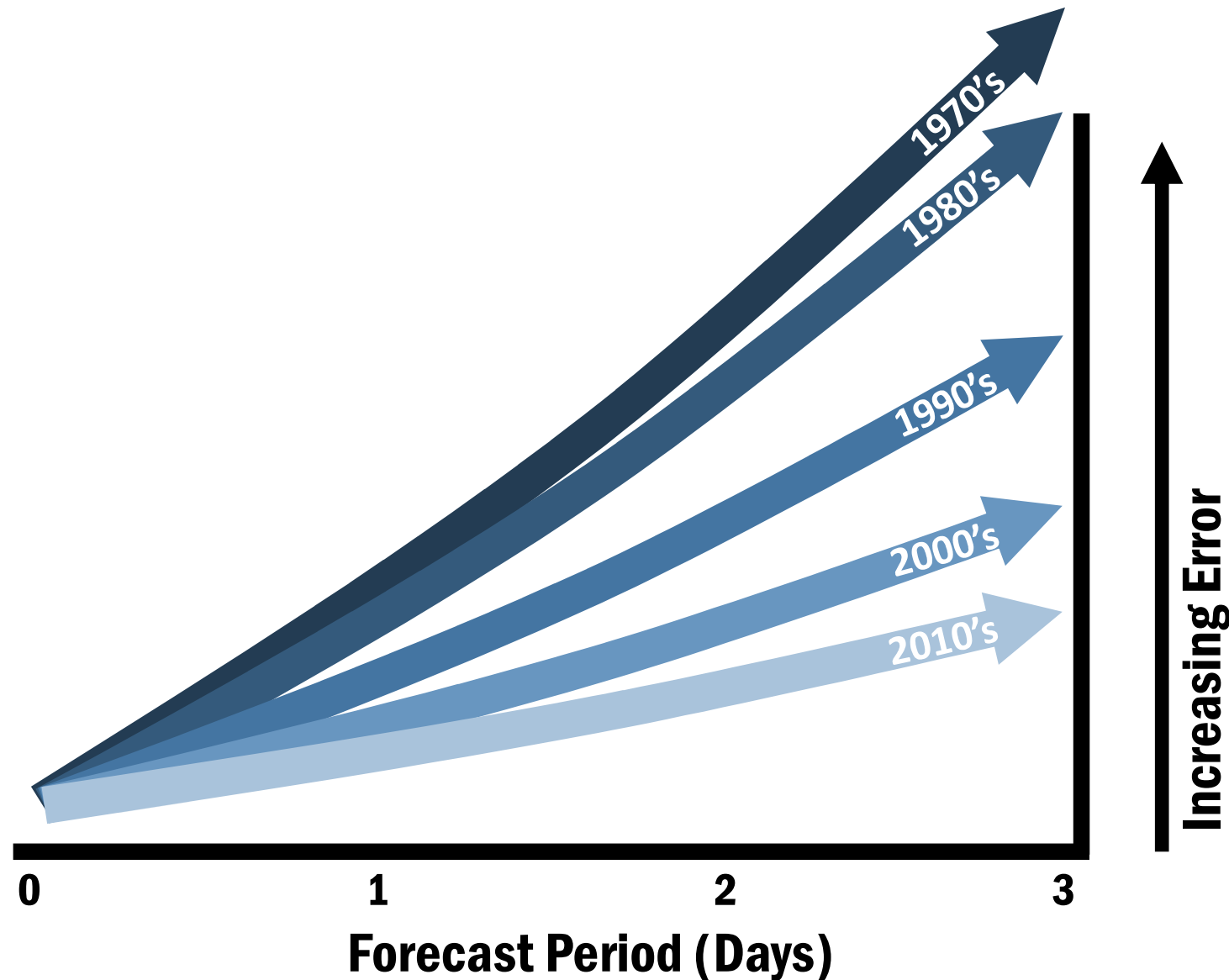


# Improving, But Not Perfect



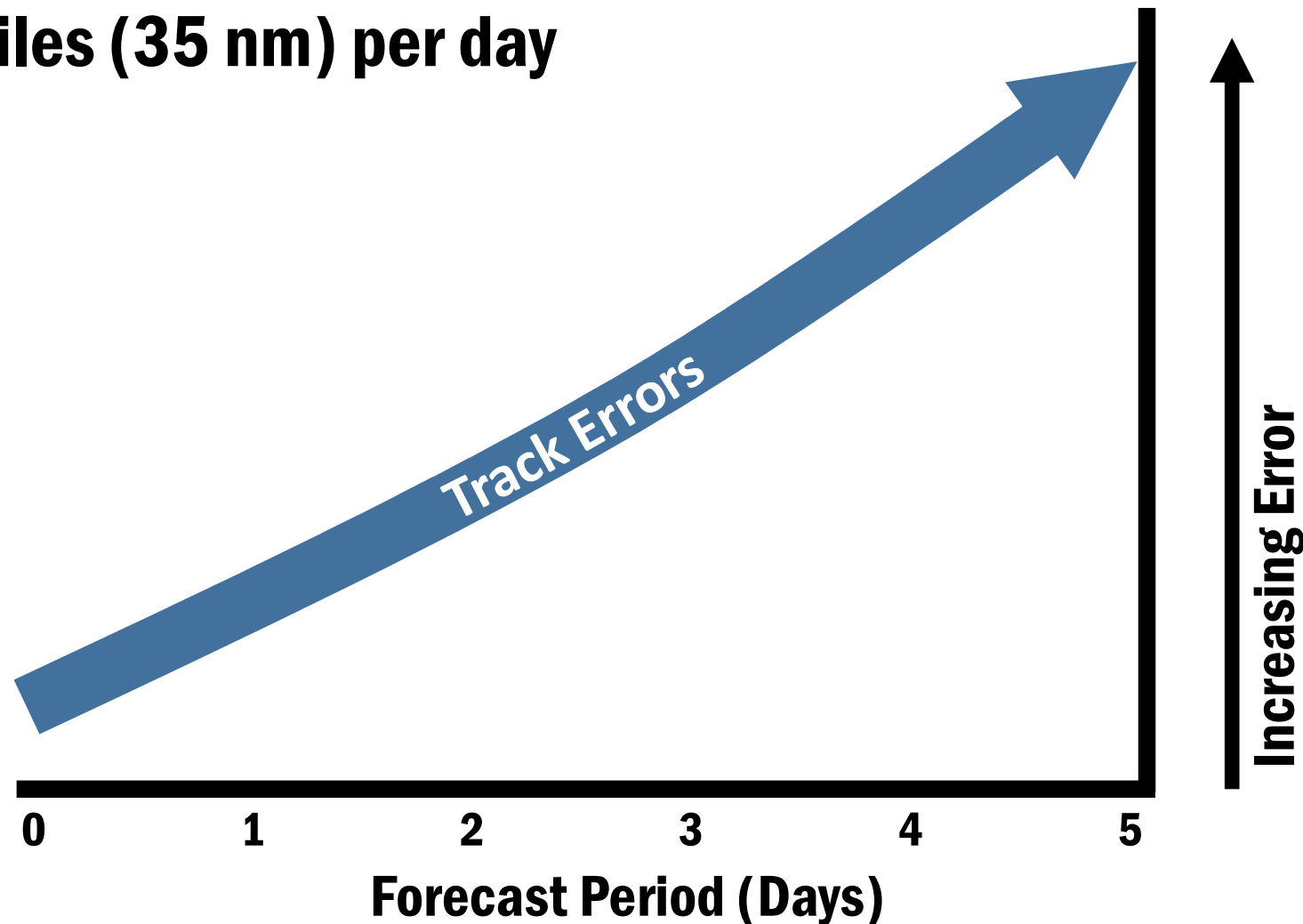
FEMA

## Track Errors



## Track Errors

- **Increase 40 miles (35 nm) per day**



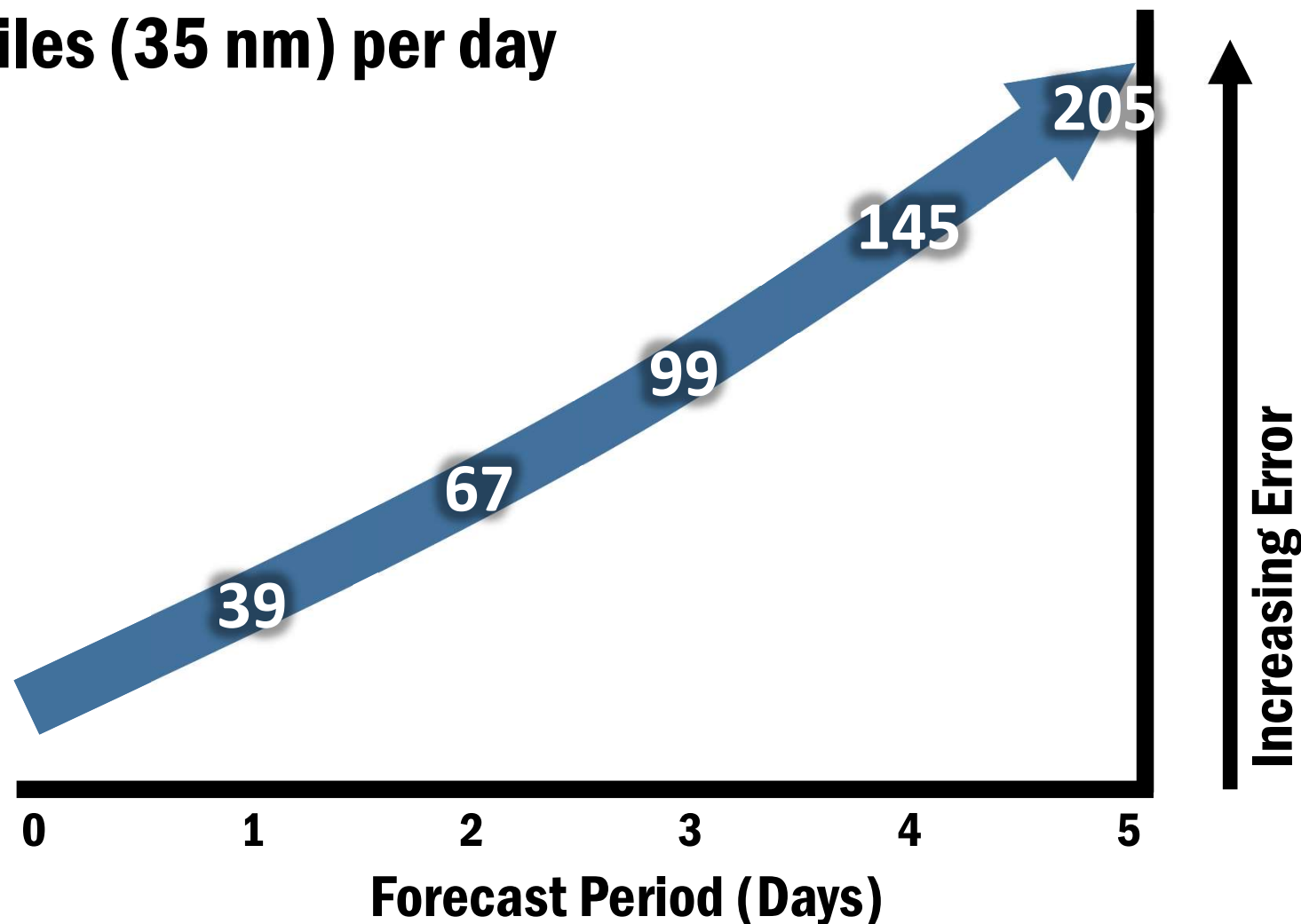
# Forecast Track Errors in Miles



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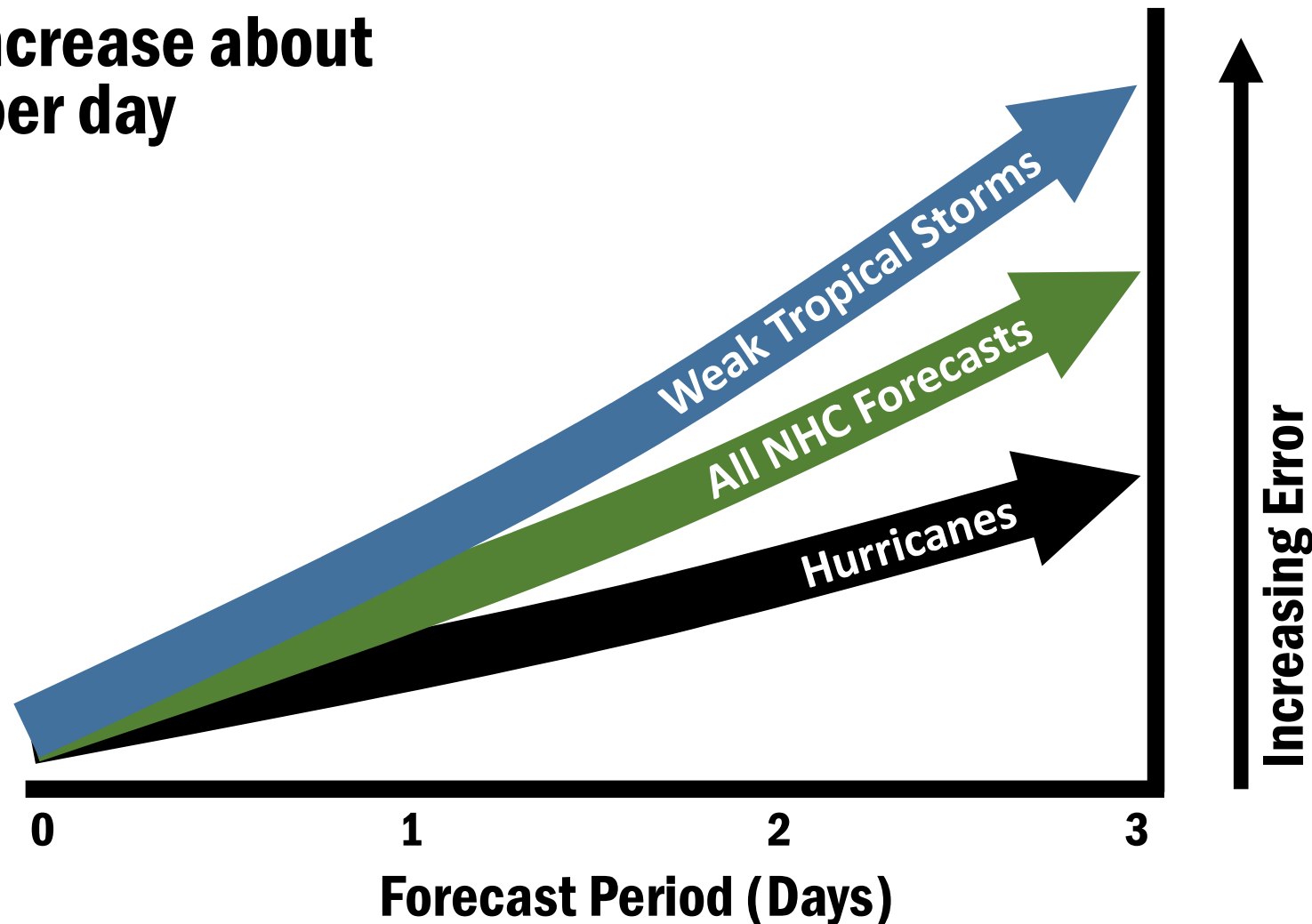
## Track Errors

- Increase 40 miles (35 nm) per day



## Hurricanes

- Track errors increase about 25–30 miles per day

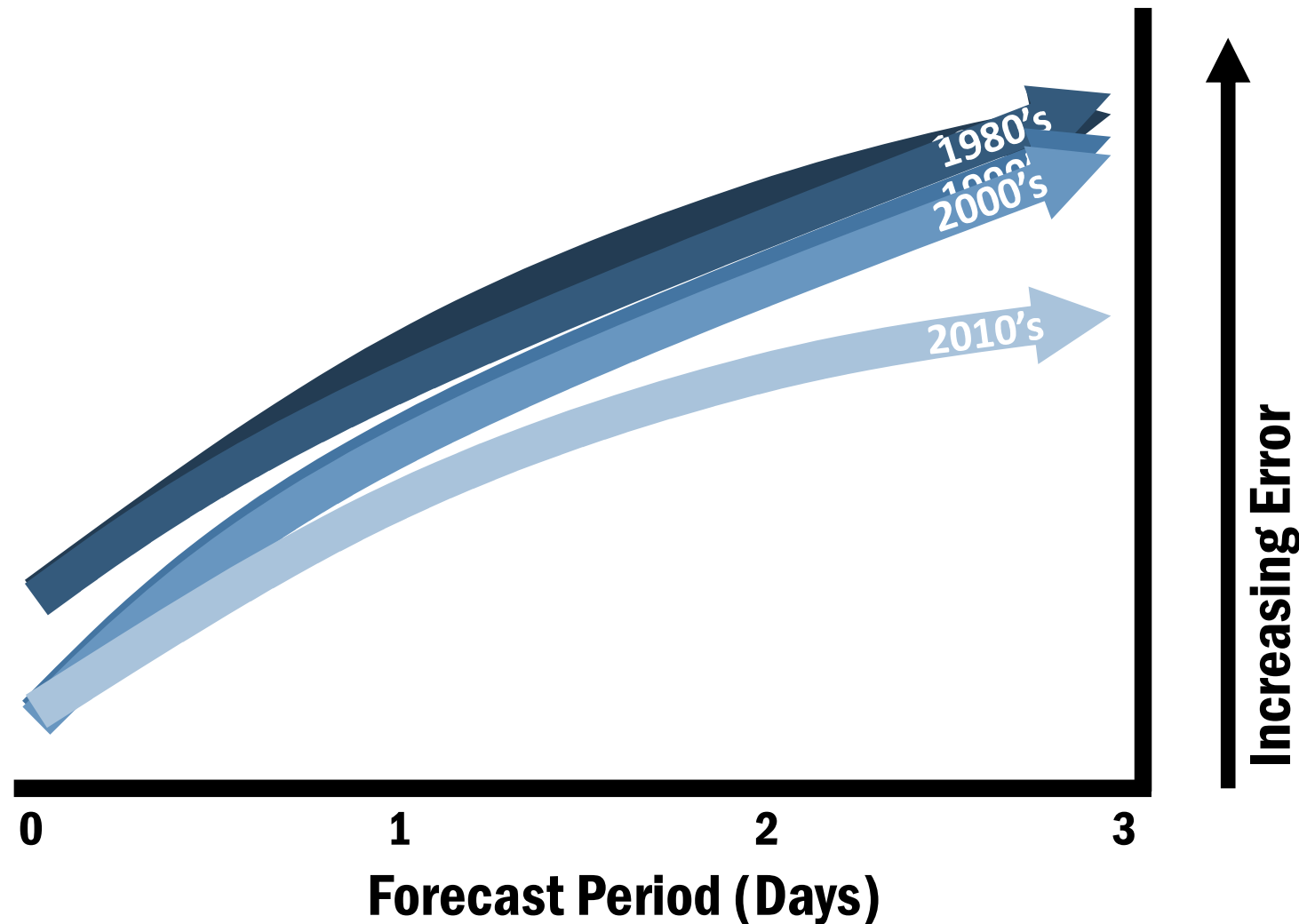


# Finally, Signs of Improvement



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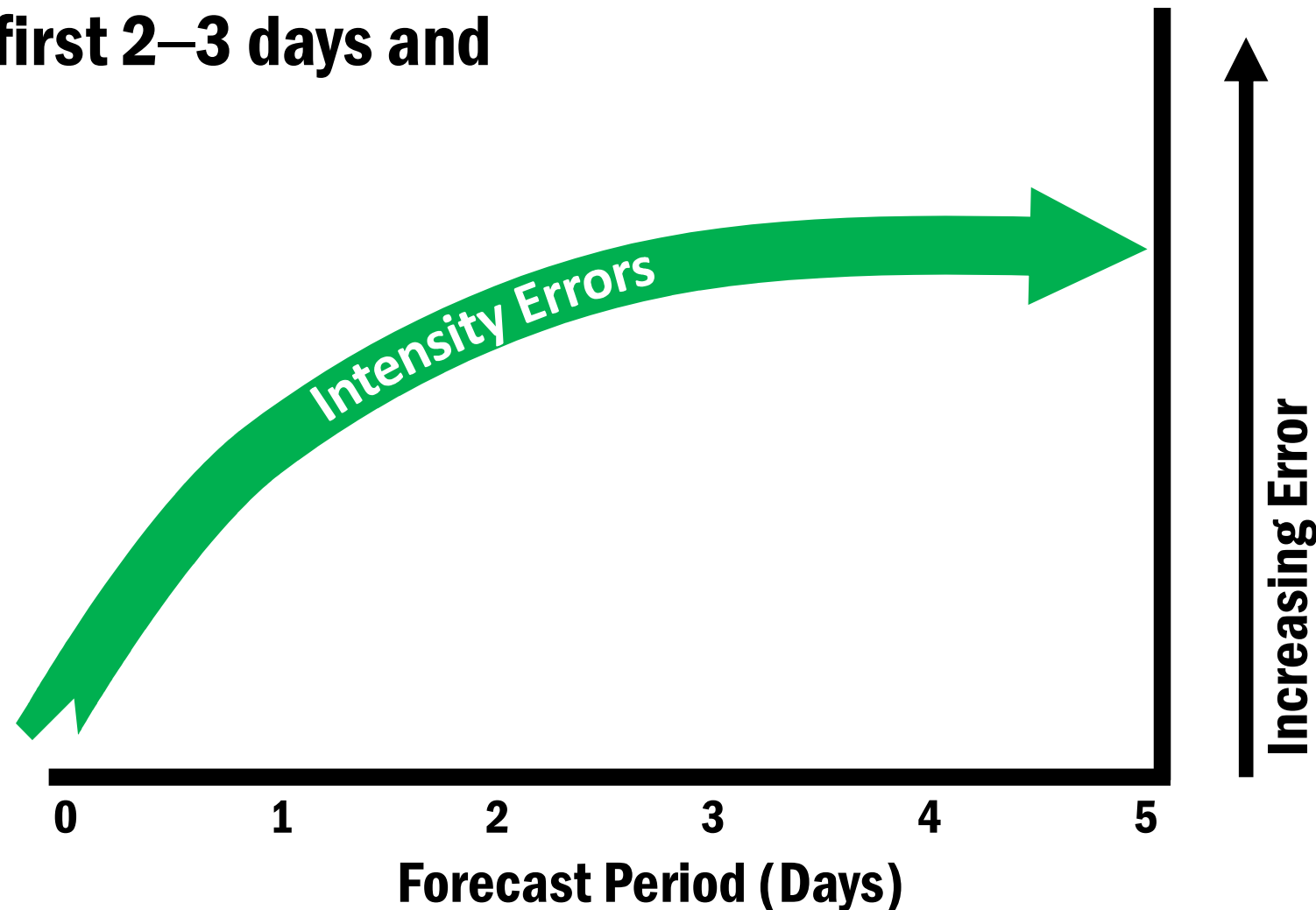
## Forecast Intensity Errors





## Track Errors

- Increase the first 2–3 days and then level off



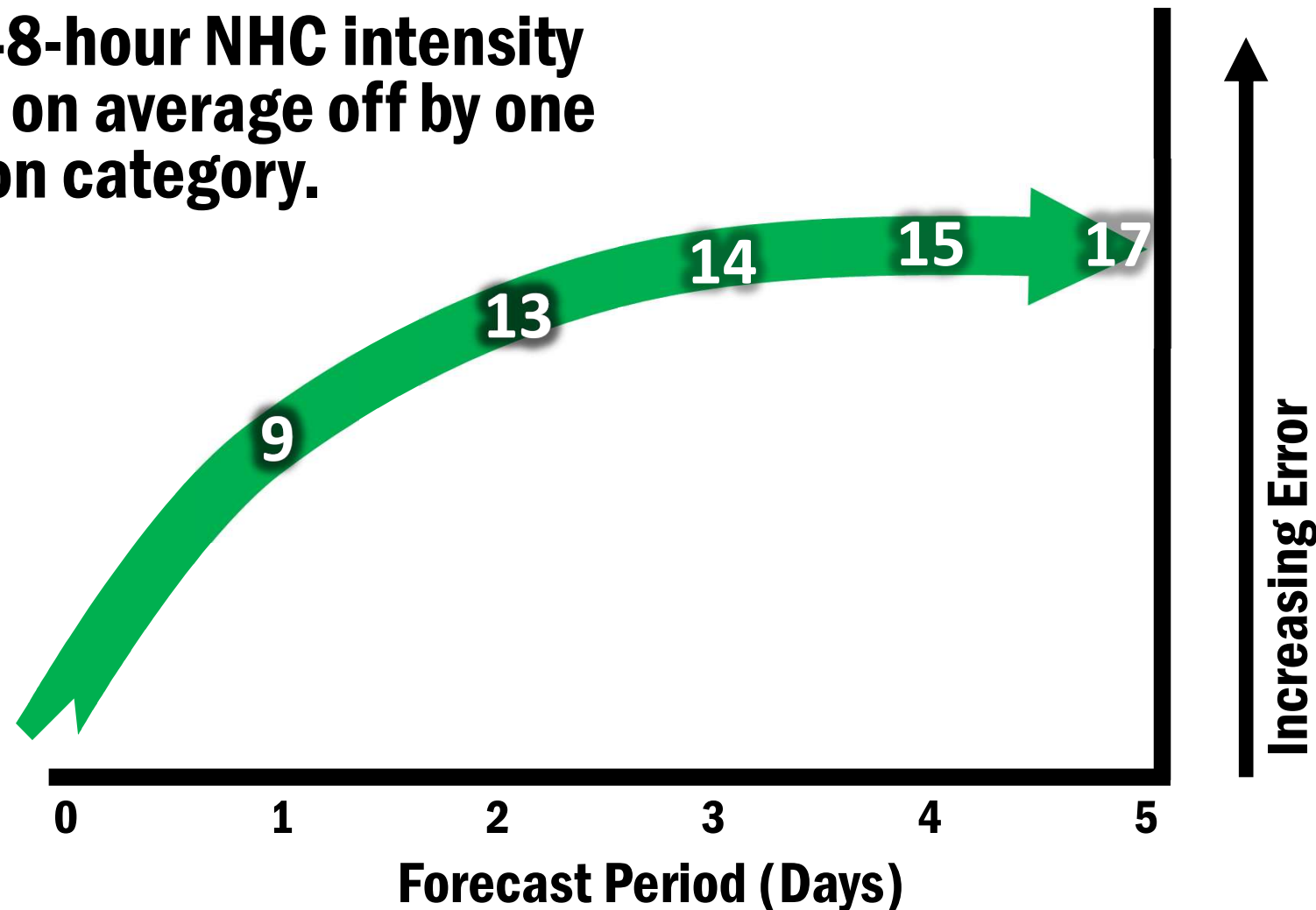
# Intensity Errors in MPH



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## Intensity Errors

- The 24- and 48-hour NHC intensity forecasts are on average off by one Saffir-Simpson category.



# Forecast Intensity Errors: RI



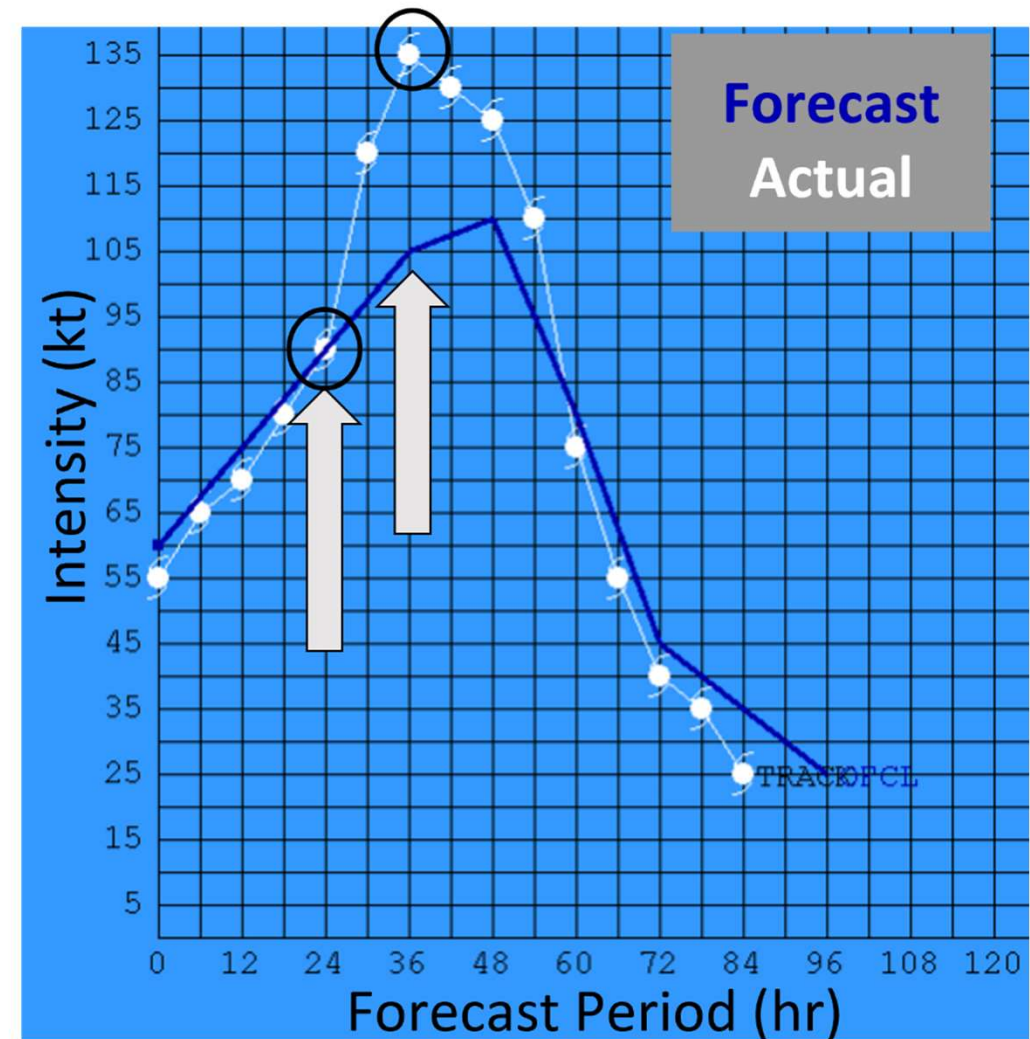
## Rapid Intensification

- A forecast challenge
- Often results in very large errors
- Forecasting the extent and timing of that intensification remains difficult

Example: Iota Advisory 7 (2020)

Initial Intensity: 65 mph  
24h Forecast: 105 mph  
Actual Intensity: 105 mph  
**24h Error: 0 mph**

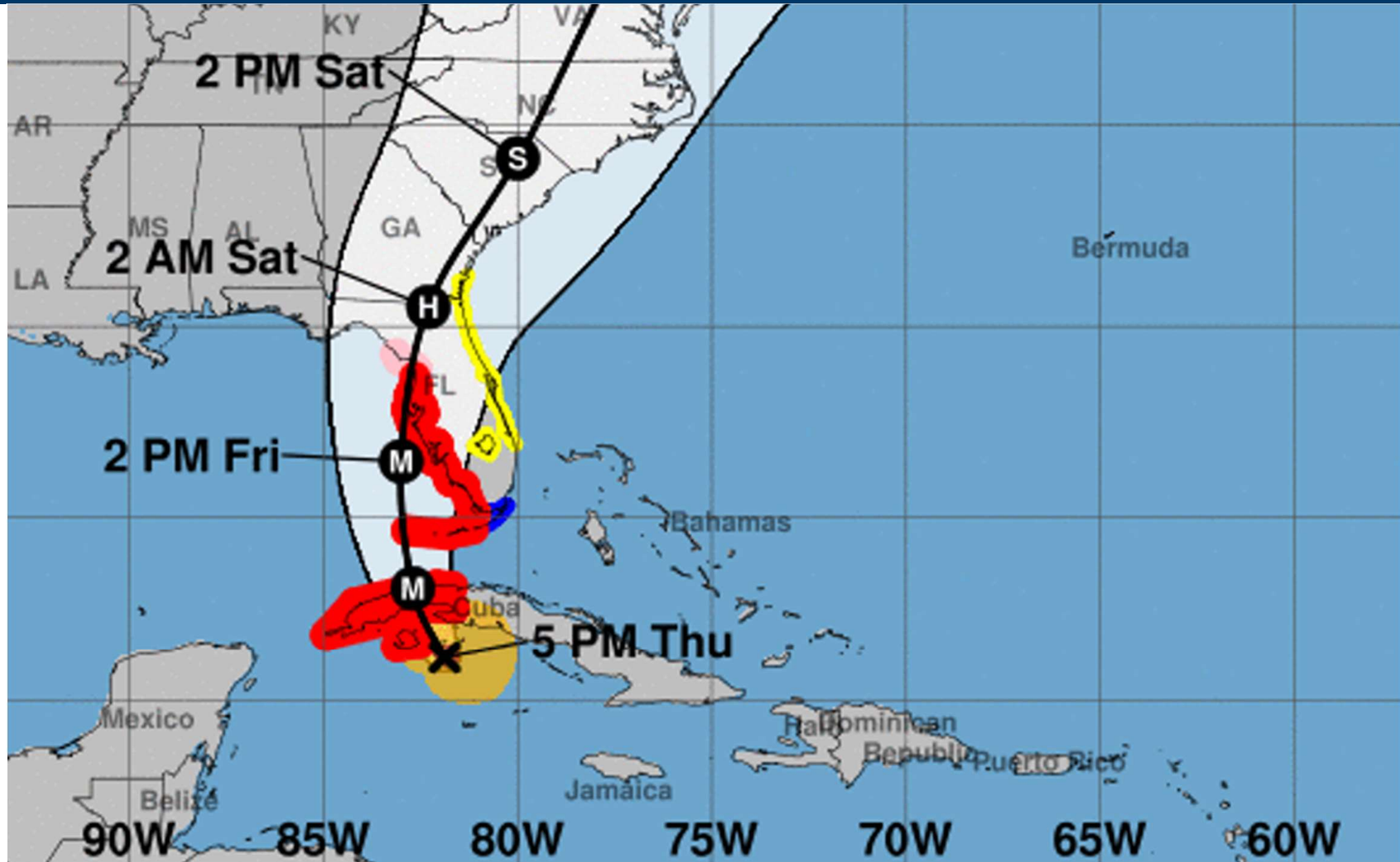
Initial Intensity: 65 mph  
36h Forecast: 120 mph  
Actual Intensity: 155 mph  
**36 h Error: 35 mph**



# Don't Focus on the Skinny Black Line



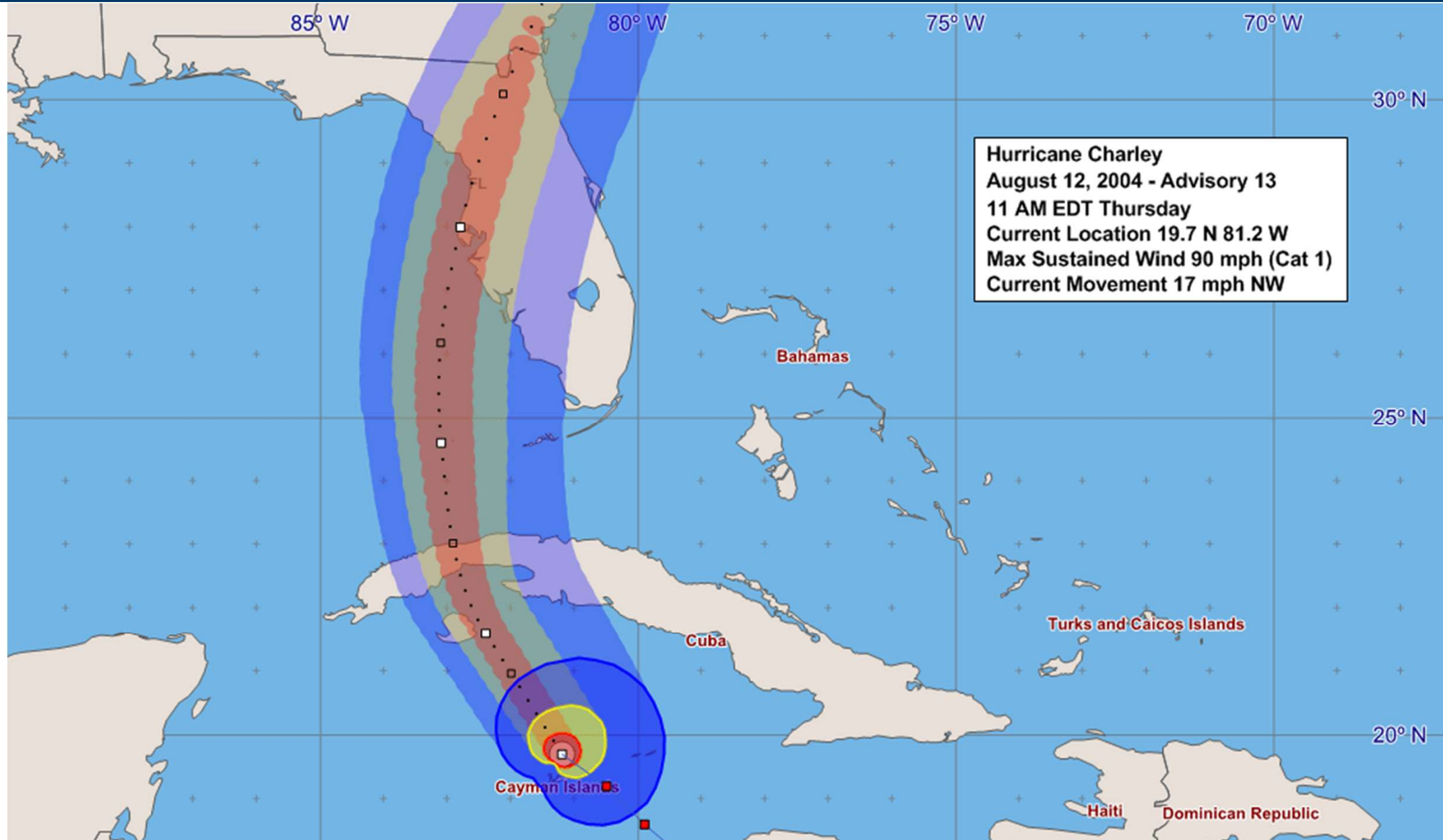
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# Hurricane Charley



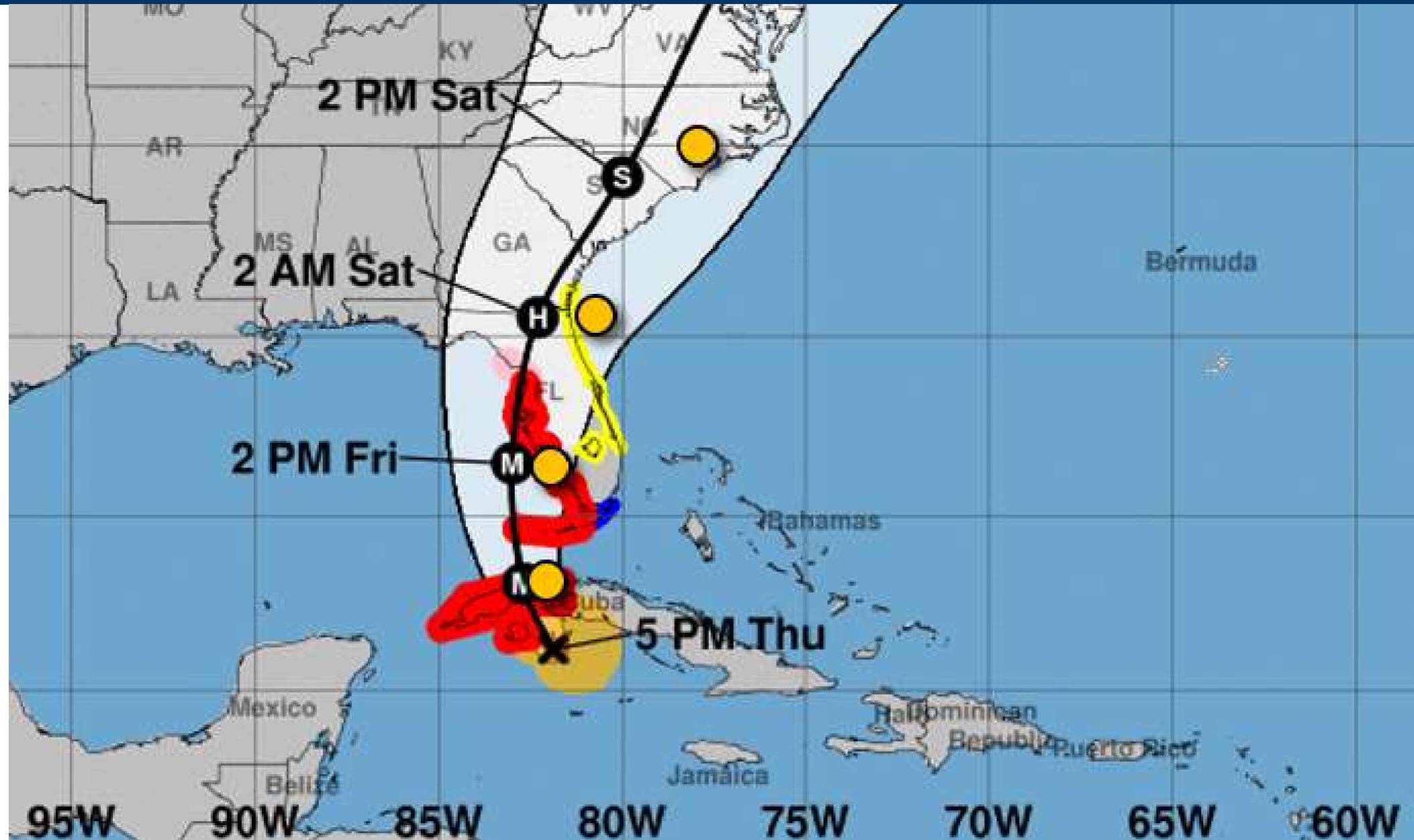
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# Forecast vs. Observed



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# Would Alternate Scenarios Help?



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# Wind Speed Probabilities



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**NATIONAL HURRICANE CENTER**  
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

TROPICAL STORM MICHAEL WIND SPEED PROBABILITIES NUMBER 7  
NWS NATIONAL HURRICANE CENTER MIAMI FL AL142018  
0900 UTC MON OCT 08 2018

--- WIND SPEED PROBABILITIES FOR SELECTED LOCATIONS ---

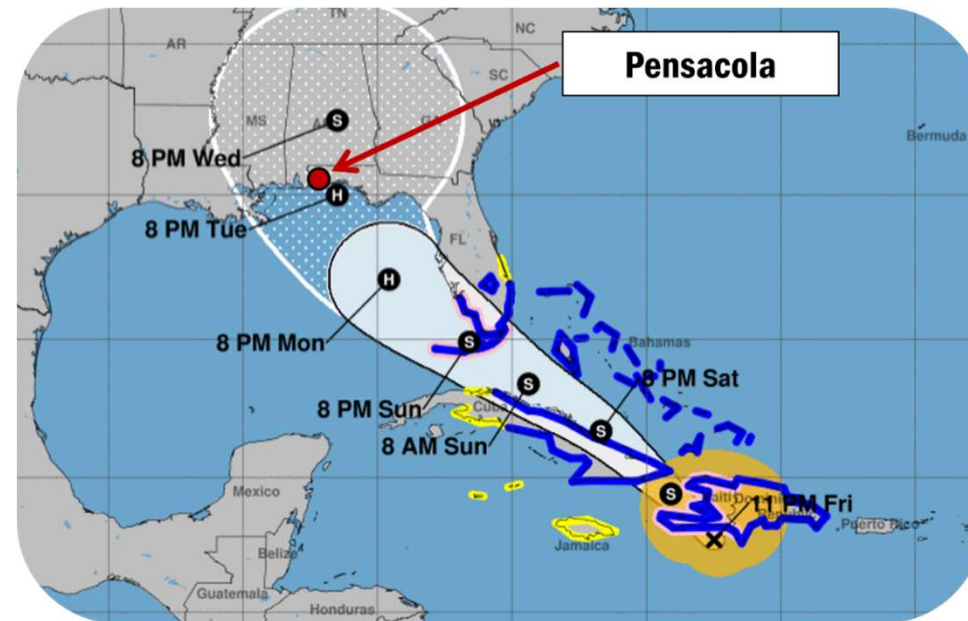
TIME PERIODS	FROM 06Z MON TO 18Z MON	FROM 18Z MON TO 06Z TUE	FROM 06Z TUE TO 18Z TUE	FROM 18Z TUE TO 06Z WED	FROM 06Z WED TO 06Z THU	FROM 06Z THU TO 06Z FRI	FROM 06Z FRI TO 06Z SAT
FORECAST HOUR	(12)	(24)	(36)	(48)	(72)	(96)	(120)
LOCATION	KT						
TALLAHASSEE FL 34	X	X ( X )	1 ( 1 )	6 ( 7 )	68 (75)	6 (81)	X (81)
TALLAHASSEE FL 50	X	X ( X )	X ( X )	1 ( 1 )	41 (42)	6 (48)	X (48)
TALLAHASSEE FL 64	X	X ( X )	X ( X )	X ( X )	20 (20)	4 (24)	X (24)
APALACHICOLA 34	X	X ( X )	5 ( 5 )	29 (34)	57 (91)	1 (92)	X (92)
APALACHICOLA 50	X	X ( X )	X ( X )	6 ( 6 )	59 (65)	2 (67)	X (67)
APALACHICOLA 64	X	X ( X )	X ( X )	1 ( 1 )	39 (40)	1 (41)	X (41)
PANAMA CITY FL 34	X	X ( X )	4 ( 4 )	26 (30)	60 (90)	1 (91)	X (91)
PANAMA CITY FL 50	X	X ( X )	X ( X )	6 ( 6 )	57 (63)	1 (64)	X (64)
PANAMA CITY FL 64	X	X ( X )	X ( X )	1 ( 1 )	37 (38)	X (38)	X (38)





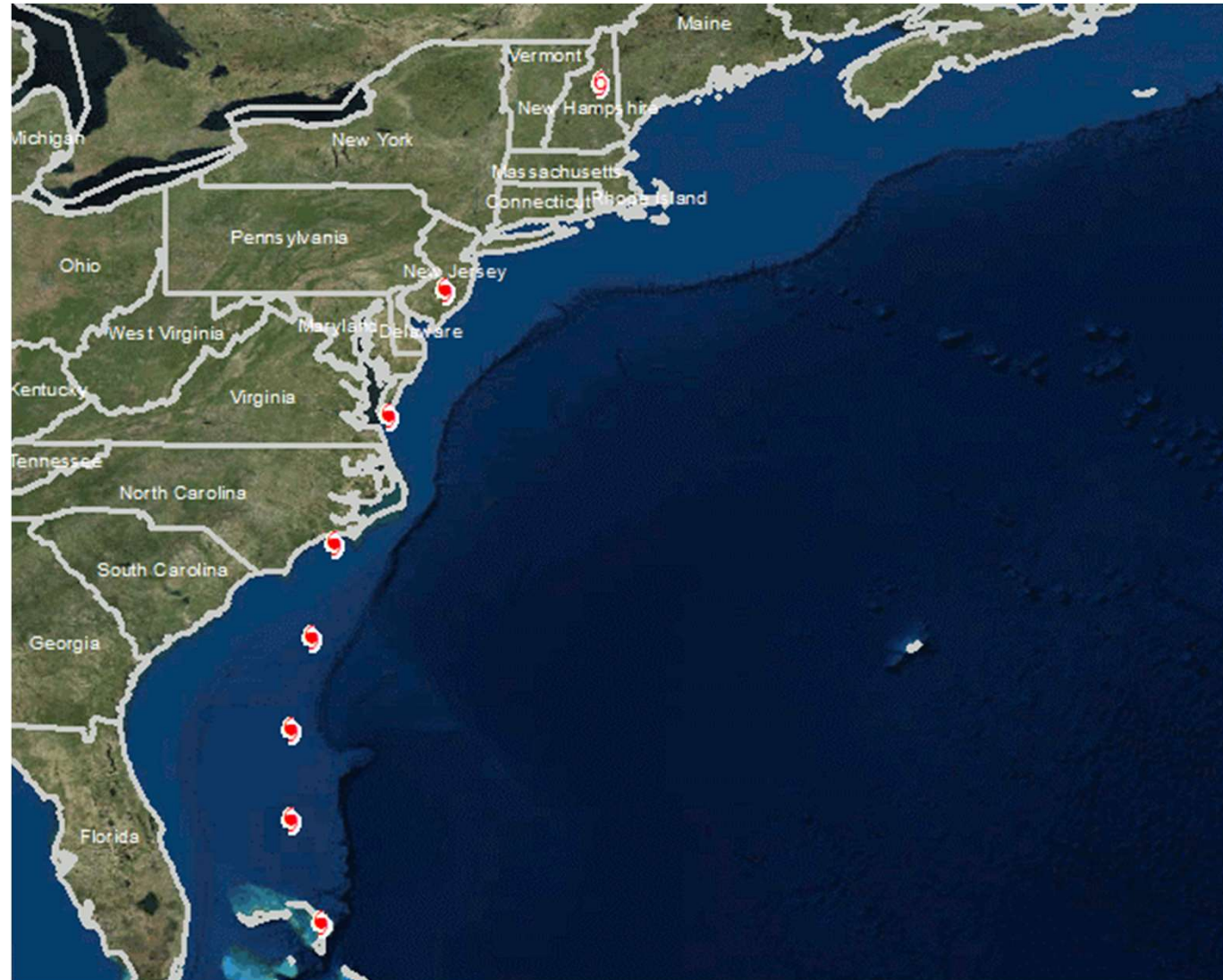
**The chance of hurricane-force winds occurring at Pensacola during the next 5 days is between\_\_\_\_\_.**

- A. 1% to 10%
- B. 10% to 20%
- C. 20% to 30%
- D. 30% to 40%
- E. 40% to 50%



## More Scenarios

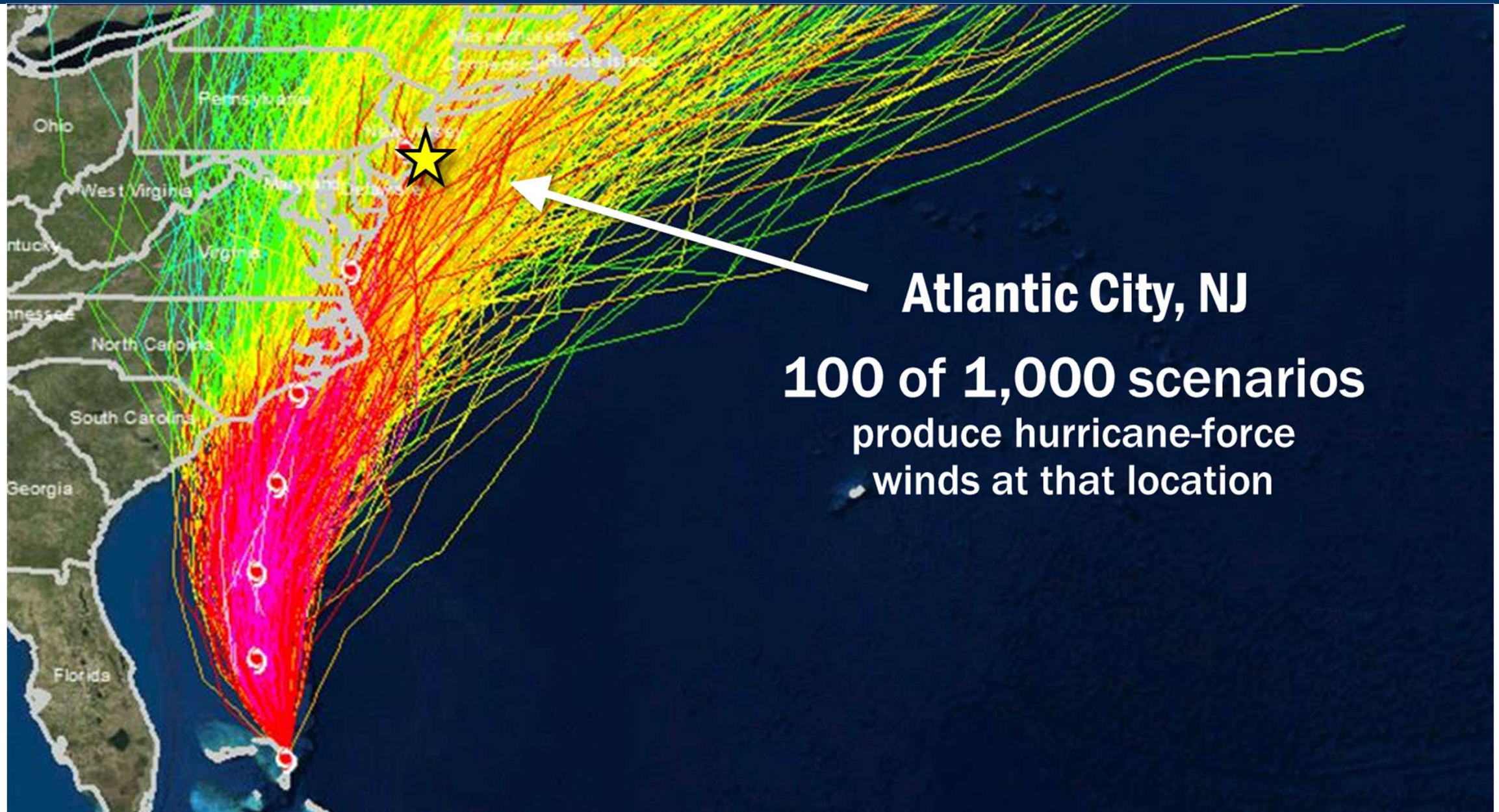
- **1,000 realistic alternate scenarios are generated.**
  - Official NHC forecast
  - Historical track and intensity errors
- **Weakening over land**
- **Track model spread**
  - Forecast track errors are correlated to the spread of the model guidance.



# Generating Probabilities 2



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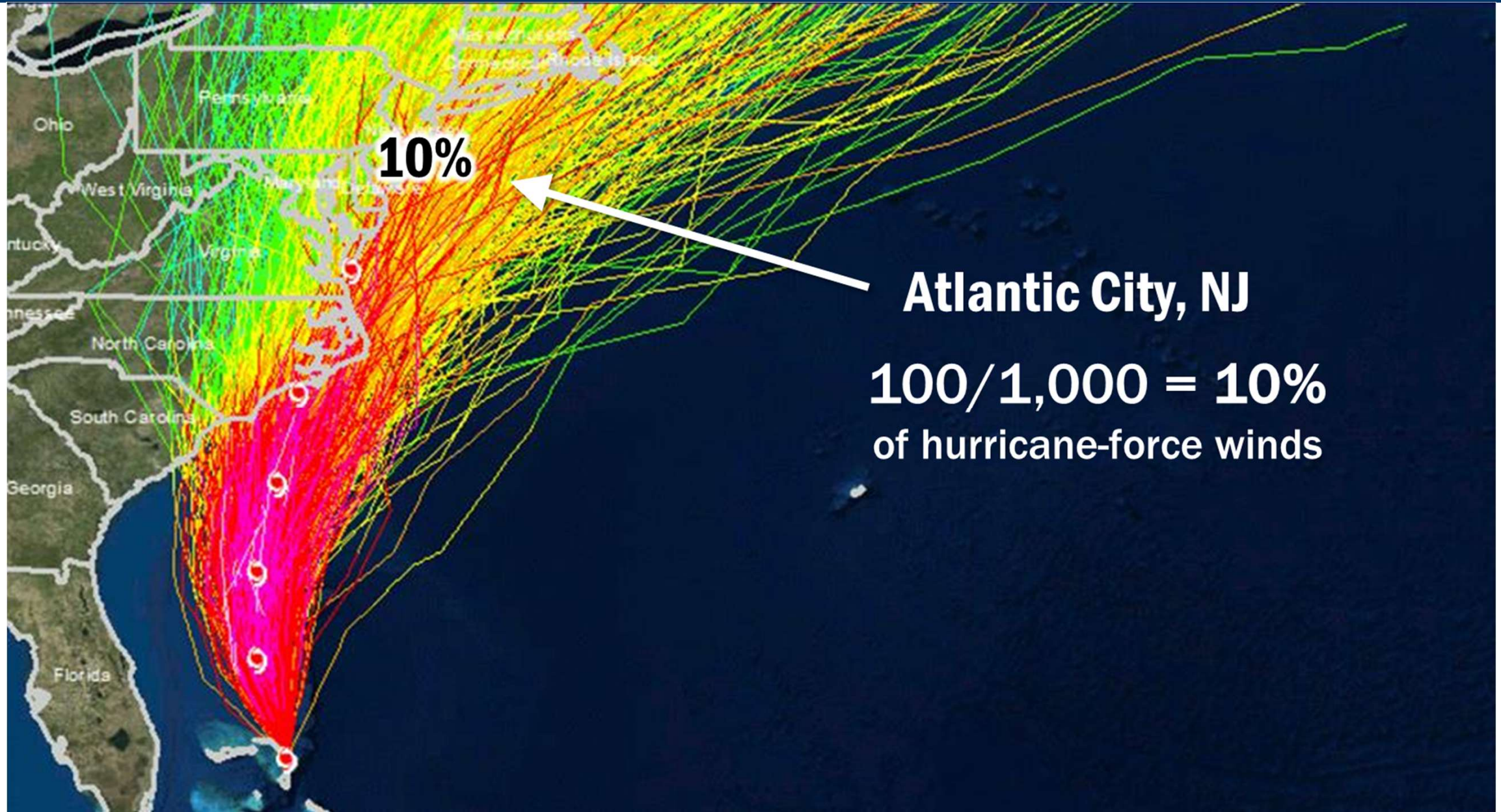
**Atlantic City, NJ**

**100 of 1,000 scenarios  
produce hurricane-force  
winds at that location**

# Generating Probabilities 3



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**10%**

**Atlantic City, NJ**

**100/1,000 = 10%**  
of hurricane-force winds

# What Does 10% Chance Mean?



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# Location-Specific Probabilities 1



NATIONAL HURRICANE CENTER		NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION						
TROPICAL STORM MICHAEL WIND SPEED PROBABILITIES NUMBER 7								
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**Location-Specific Probabilities**

- Tropical-Storm-Force
- 58 mph
- Hurricane-Force

# Location-Specific Probabilities 2



NATIONAL HURRICANE CENTER									
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION									
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**Location-Specific Probabilities**

- Tropical-Storm-Force
- 58 mph
- Hurricane-Force

# Location-Specific Probabilities 3



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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION									
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**Location-Specific Probabilities**

- Tropical-Storm-Force
- 58 mph
- Hurricane-Force



# Onset Probabilities



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LOCATION	KT							
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PANAMA CITY FL 64	X	X ( X )	X ( X )	1 ( 1 )	37 (38)	X (38)	X (38)	

**Onset Probabilities**  
 •Timing information

# Cumulative Probabilities



		NATIONAL HURRICANE CENTER NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION						
TROPICAL STORM MICHAEL WIND SPEED PROBABILITIES NUMBER		7						
NWS NATIONAL HURRICANE CENTER MIAMI FL		AL142018						
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**Cumulative Probabilities**  
 • Total chance through the time period

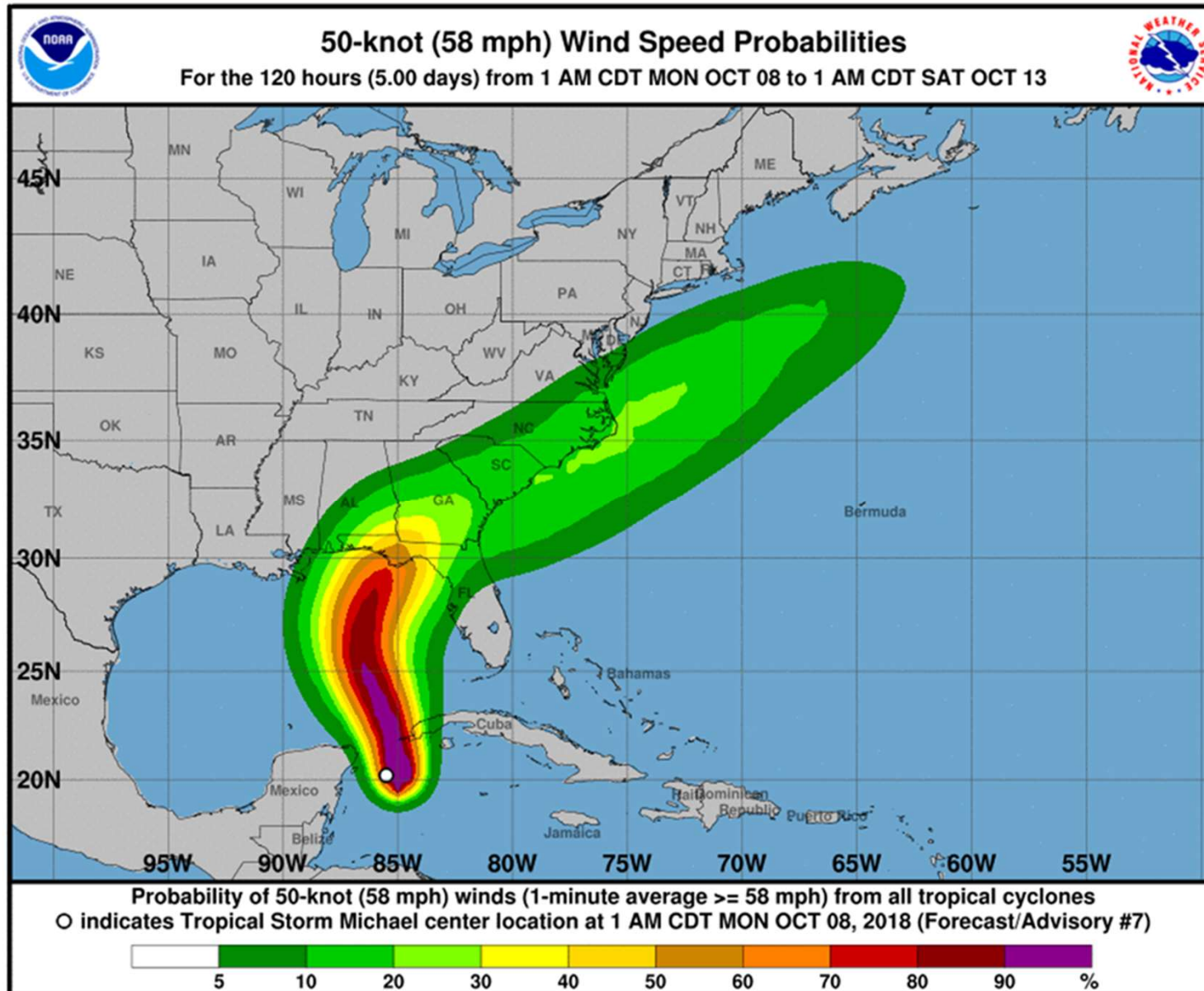
# 5-Day Cumulative Graphic: TS-Force



## Location-Specific Probabilities

- Tropical-Storm-Force
- 58 mph
- Hurricane-Force

# 5-Day Cumulative Graphic: 58 mph



**Location-Specific Probabilities**

- Tropical-Storm-Force
- 58 mph
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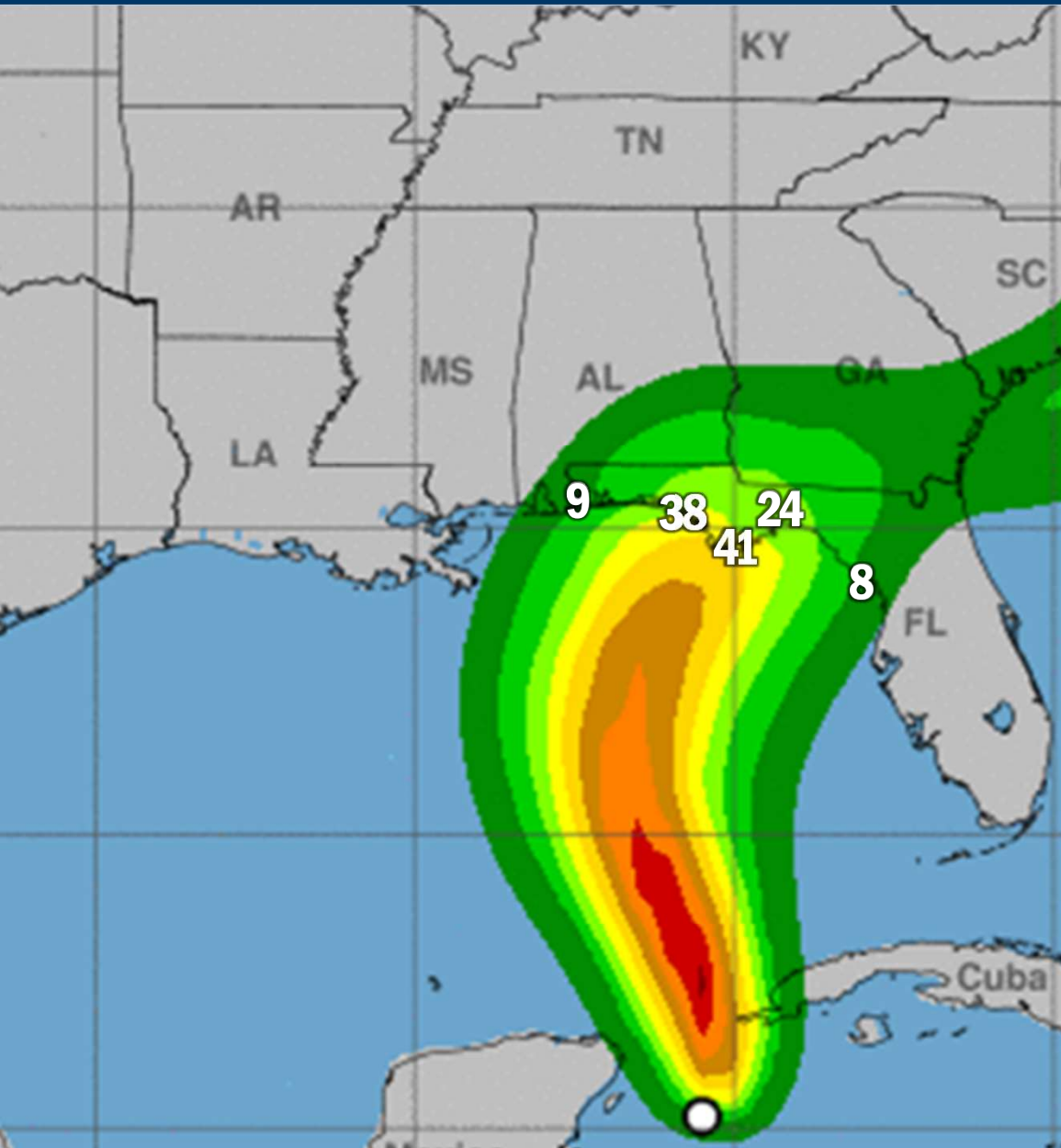
# 5-Day Cumulative Graphic: Hurricane



## Location-Specific Probabilities

- Tropical-Storm-Force
- 58 mph
- Hurricane-Force

# Location-Specific Probabilities 4

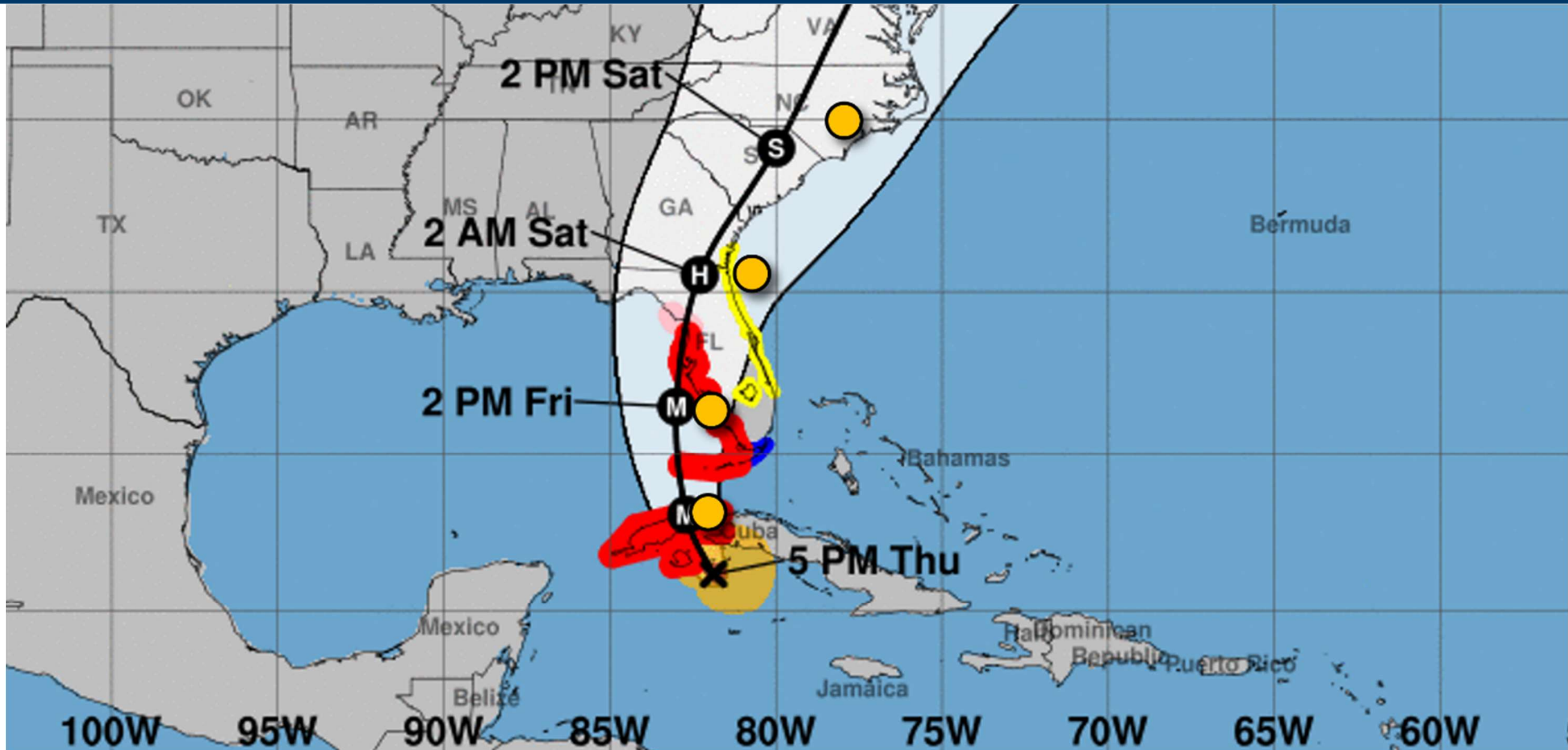


<b>NATIONAL HURRICANE CENTER</b> <small>NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION</small>								
TIME PERIODS	FROM 06Z MON TO 18Z MON	FROM 18Z MON TO 06Z TUE	FROM 06Z TUE TO 18Z TUE	FROM 18Z TUE TO 06Z WED	FROM 06Z WED TO 06Z THU	FROM 06Z THU TO 06Z FRI	FROM 06Z FRI TO 06Z SAT	
FORECAST HOUR	(12)	(24)	(36)	(48)	(72)	(96)	(120)	
LOCATION	KT							
CEDAR KEY FL	34 X	X ( X )	3 ( 3 )	15 ( 18 )	43 ( 61 )	2 ( 63 )	X ( 63 )	
CEDAR KEY FL	50 X	X ( X )	X ( X )	1 ( 1 )	20 ( 21 )	1 ( 22 )	X ( 22 )	
CEDAR KEY FL	64 X	X ( X )	X ( X )	X ( X )	7 ( 7 )	1 ( 8 )	X ( 8 )	
TALLAHASSEE FL	34 X	X ( X )	1 ( 1 )	6 ( 7 )	68 ( 75 )	6 ( 81 )	X ( 81 )	
TALLAHASSEE FL	50 X	X ( X )	X ( X )	1 ( 1 )	41 ( 42 )	6 ( 48 )	X ( 48 )	
TALLAHASSEE FL	64 X	X ( X )	X ( X )	X ( X )	20 ( 20 )	4 ( 24 )	X ( 24 )	
APALACHICOLA	34 X	X ( X )	5 ( 5 )	29 ( 34 )	57 ( 91 )	1 ( 92 )	X ( 92 )	
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APALACHICOLA	64 X	X ( X )	X ( X )	1 ( 1 )	39 ( 40 )	1 ( 41 )	X ( 41 )	
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PANAMA CITY FL	50 X	X ( X )	X ( X )	6 ( 6 )	57 ( 63 )	1 ( 64 )	X ( 64 )	
PANAMA CITY FL	64 X	X ( X )	X ( X )	1 ( 1 )	37 ( 38 )	X ( 38 )	X ( 38 )	
PENSACOLA FL	34 X	X ( X )	1 ( 1 )	8 ( 9 )	43 ( 52 )	2 ( 54 )	X ( 54 )	
PENSACOLA FL	50 X	X ( X )	X ( X )	1 ( 1 )	20 ( 21 )	1 ( 22 )	X ( 22 )	
PENSACOLA FL	64 X	X ( X )	X ( X )	X ( X )	9 ( 9 )	X ( 9 )	X ( 9 )	

# Forecast vs. Observed 2



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# Would Alternate Scenarios Help? 2

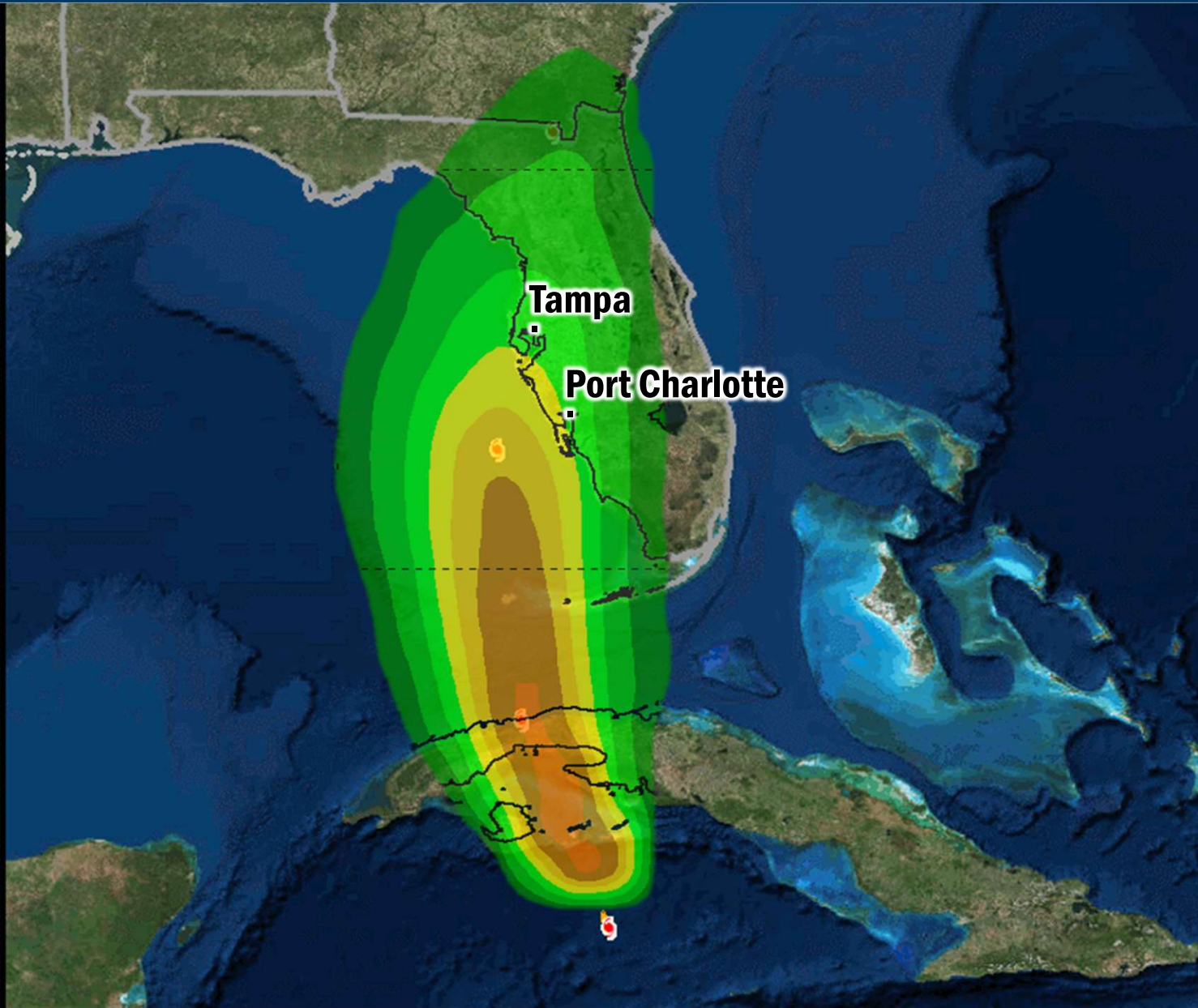


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# Would Alternate Scenarios Help? 3

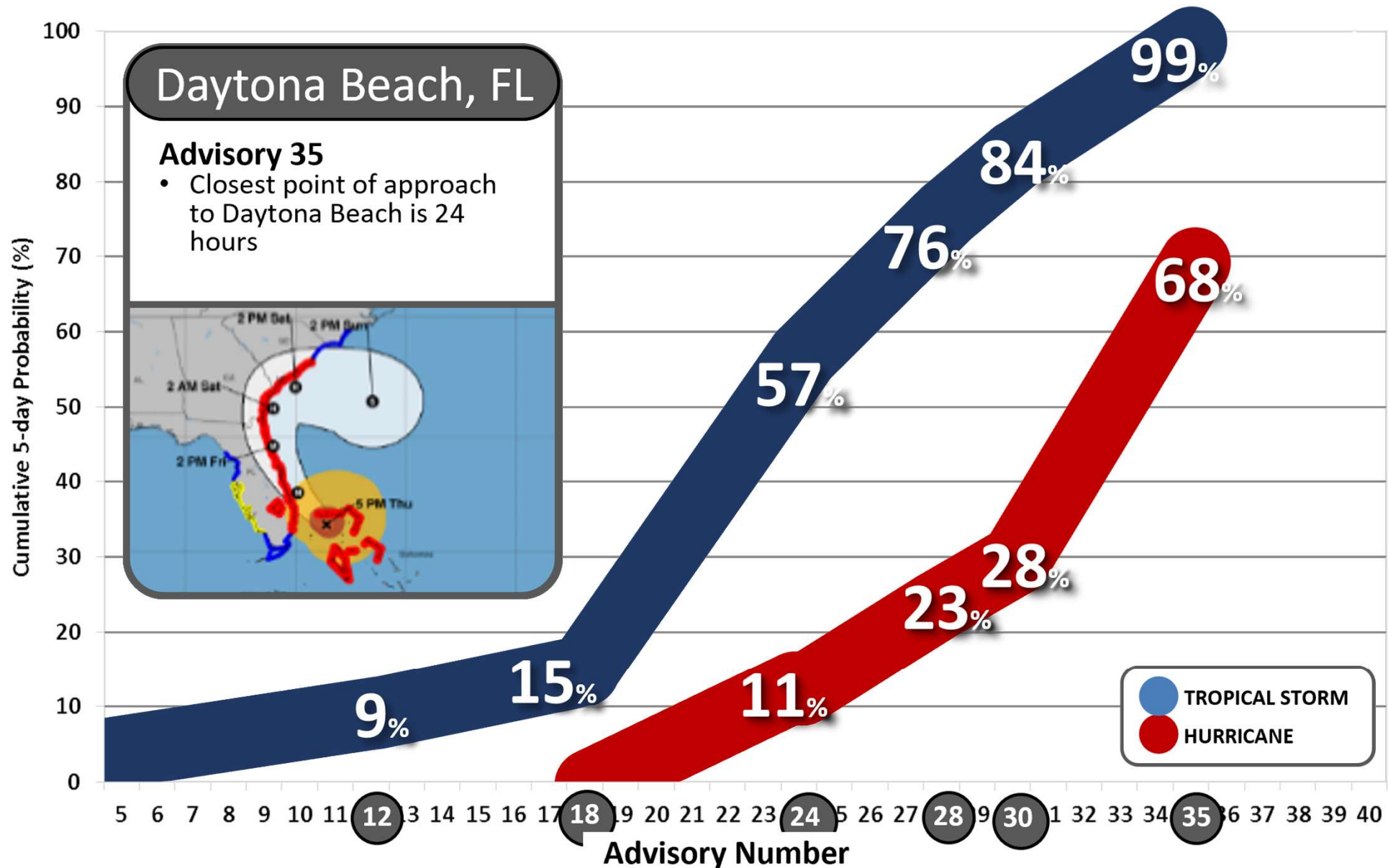


**Chances of hurricane-force winds at Tampa and Port Charlotte are both around 30%**

# Hurricane Matthew (2016)

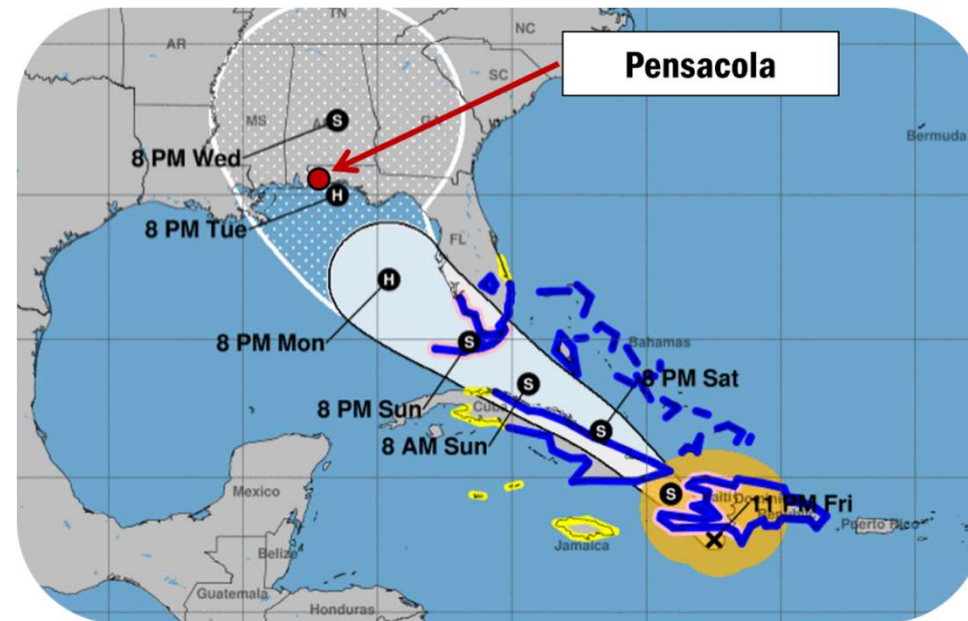


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**The chance of hurricane-force winds occurring at Pensacola during the next 5 days is between\_\_\_\_\_.**

- A. 1% to 10%
- B. 10% to 20%
- C. 20% to 30%
- D. 30% to 40%
- E. 40% to 50%



## Uncertainty in Wind Timing

- **Track**
  - Forward speed, direction of motion, and location of center relative to given location
- **Storm Size**
  - How far will TS winds extend from the center?  
Difficult to forecast and highly variable

### Time of Arrival Graphics

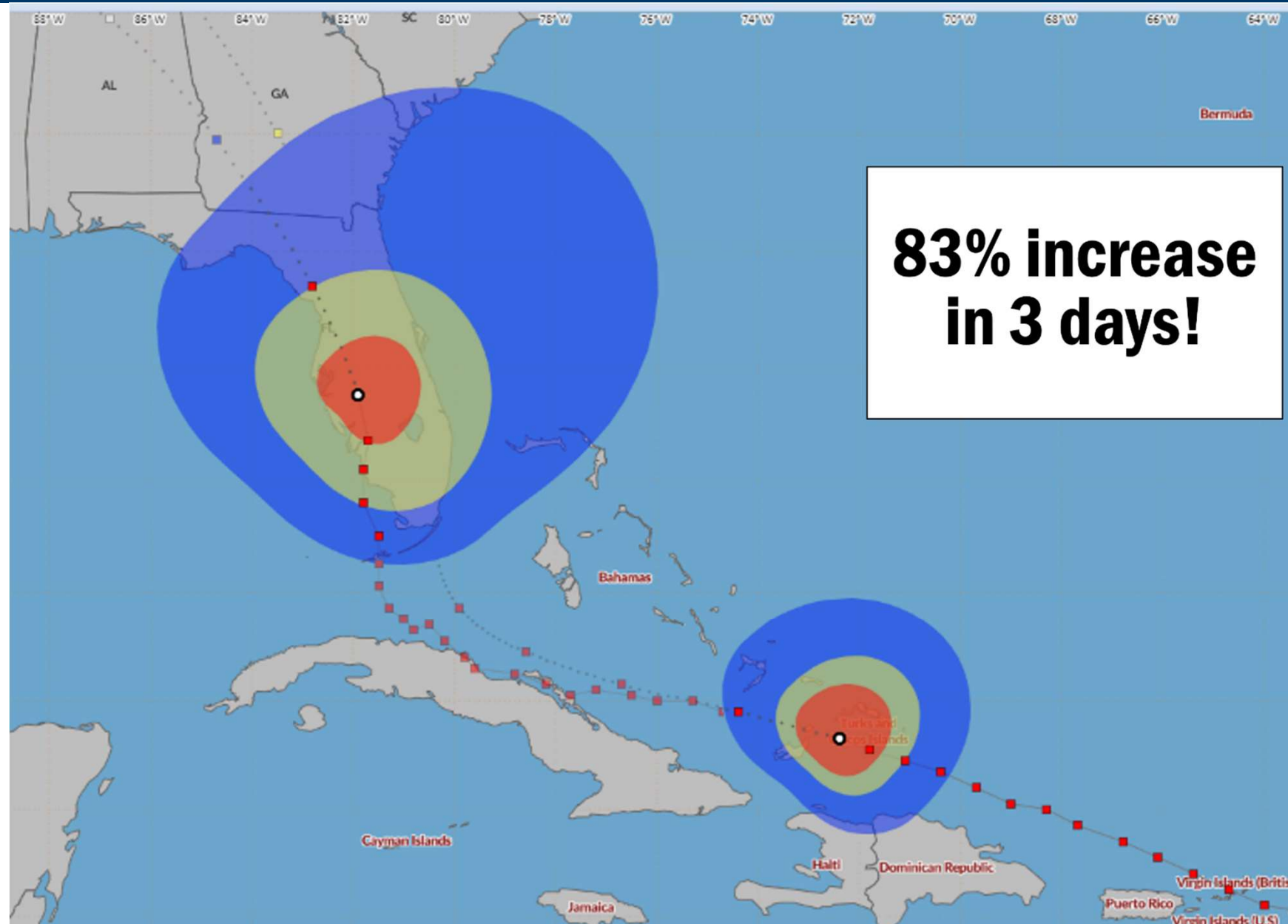
Designed to account for uncertainty in arrival of TS-force winds and provide timing information



# Importance and Causes

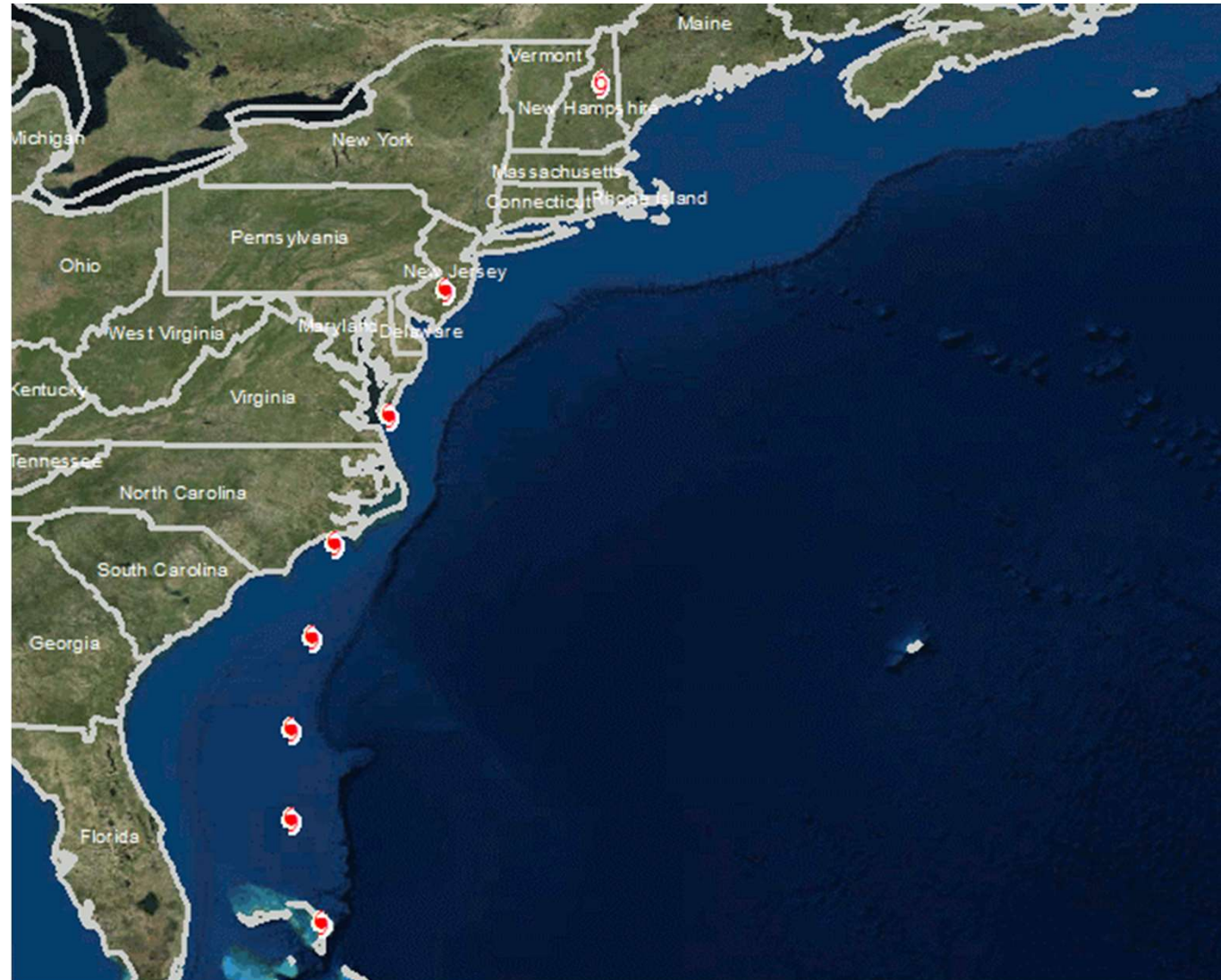


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## More Scenarios

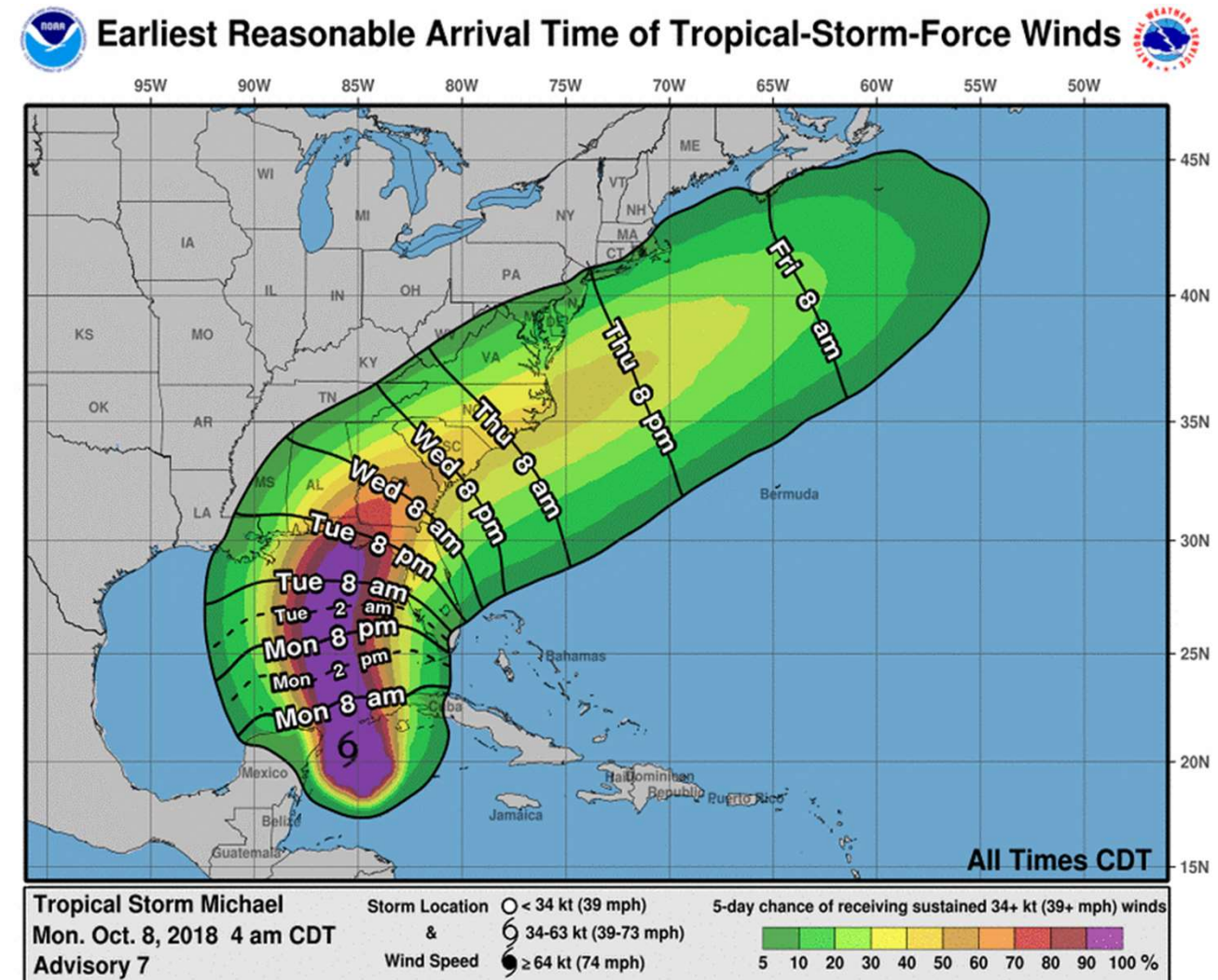
- **1,000 realistic alternate scenarios are generated.**
  - Official NHC forecast and historical errors
  - Weakening over land
  - Track model spread
- **Produces information about:**
  - Chance of wind occurring
  - Probabilistic onset timing



# Earliest Reasonable Onset

## Earliest Reasonable

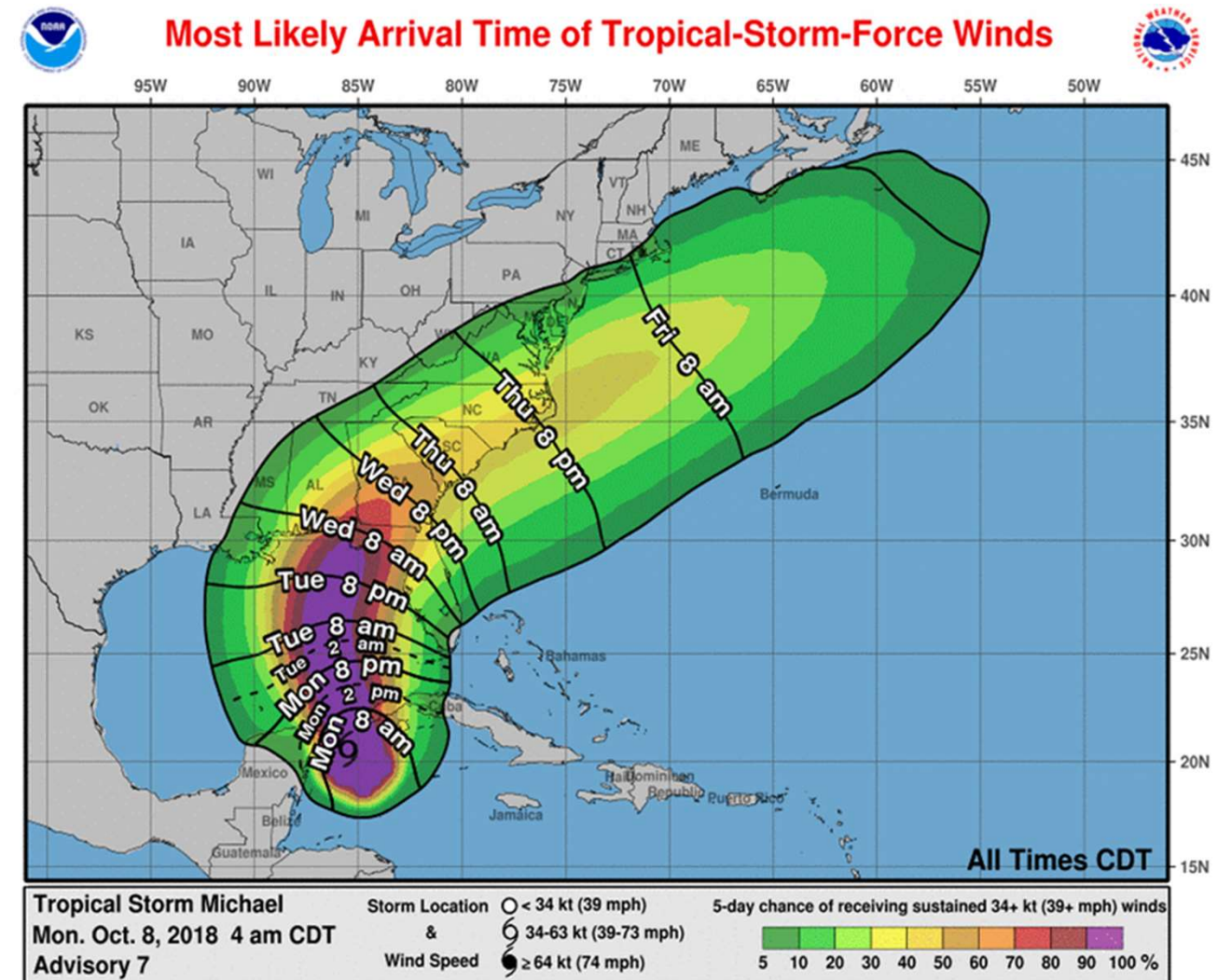
- **10% chance of onset**
  - Most conservative timing
- **Arrival Time of TS winds**
  - Black contours
- **5-day cumulative TS probabilities**
  - Color filled



# Most Likely Onset

## Most Likely

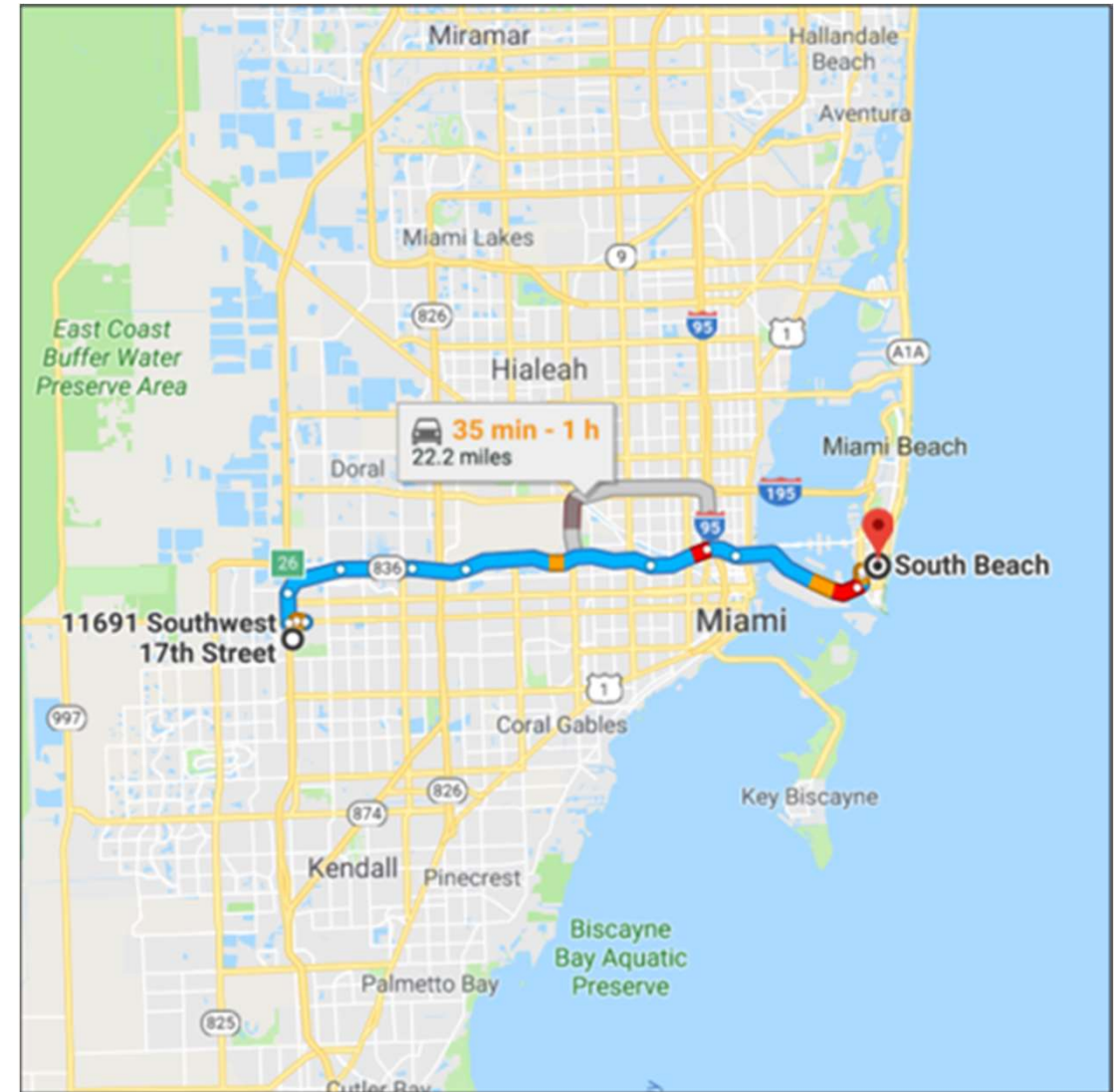
- **50% chance of onset**
  - Equally likely to occur before as after
- **Arrival Time of TS winds**
  - Black contours
- **5-day cumulative TS probabilities**
  - Color filled





## Timing Uncertainty

- **Earliest Reasonable**
  - Absolutely must be there by 5 p.m.
  - Leave by 4:10 p.m. (50 min)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 4:34 p.m. (26 min)
- **Window to leave: 24 min**
  - 4:10 p.m. to 4:34 p.m.

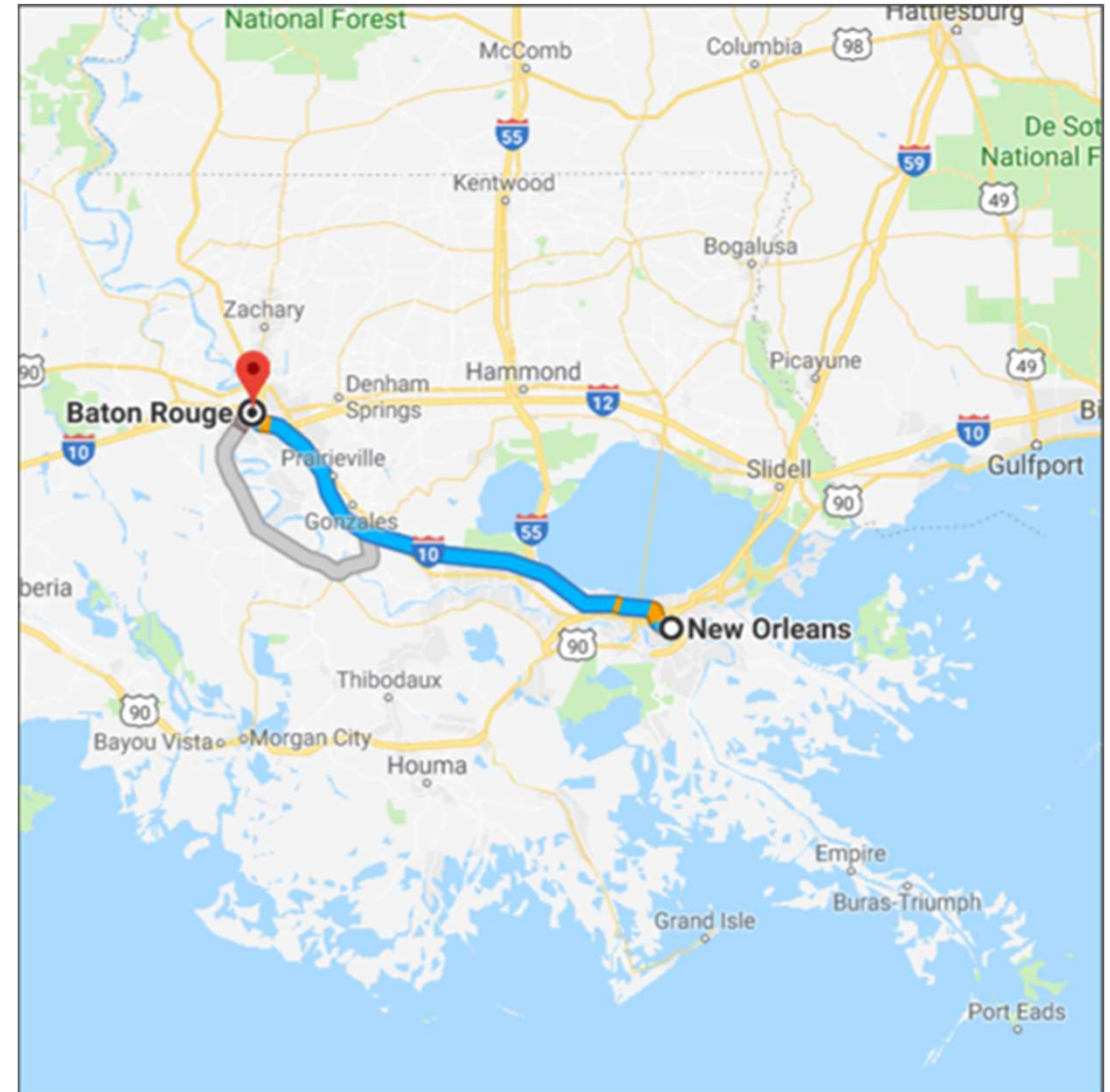


# New Orleans – Baton Rouge



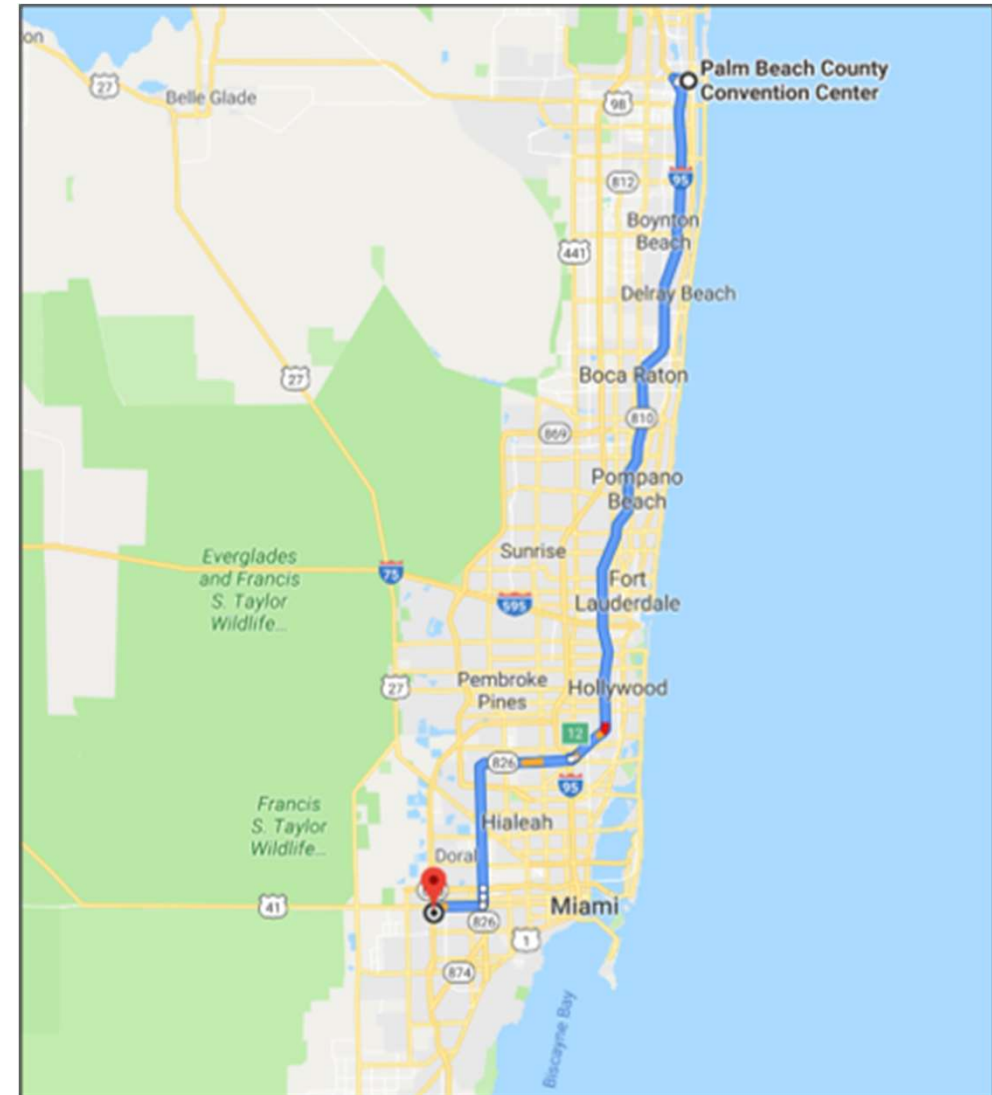
## Timing Uncertainty

- **Earliest Reasonable**
  - Absolutely must be there by 5 p.m.
  - Leave by 4:10 p.m. (50 min)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 4:34 p.m. (26 min)
- **Window to leave: 24 min**
  - 4:10 p.m. to 4:34 p.m.



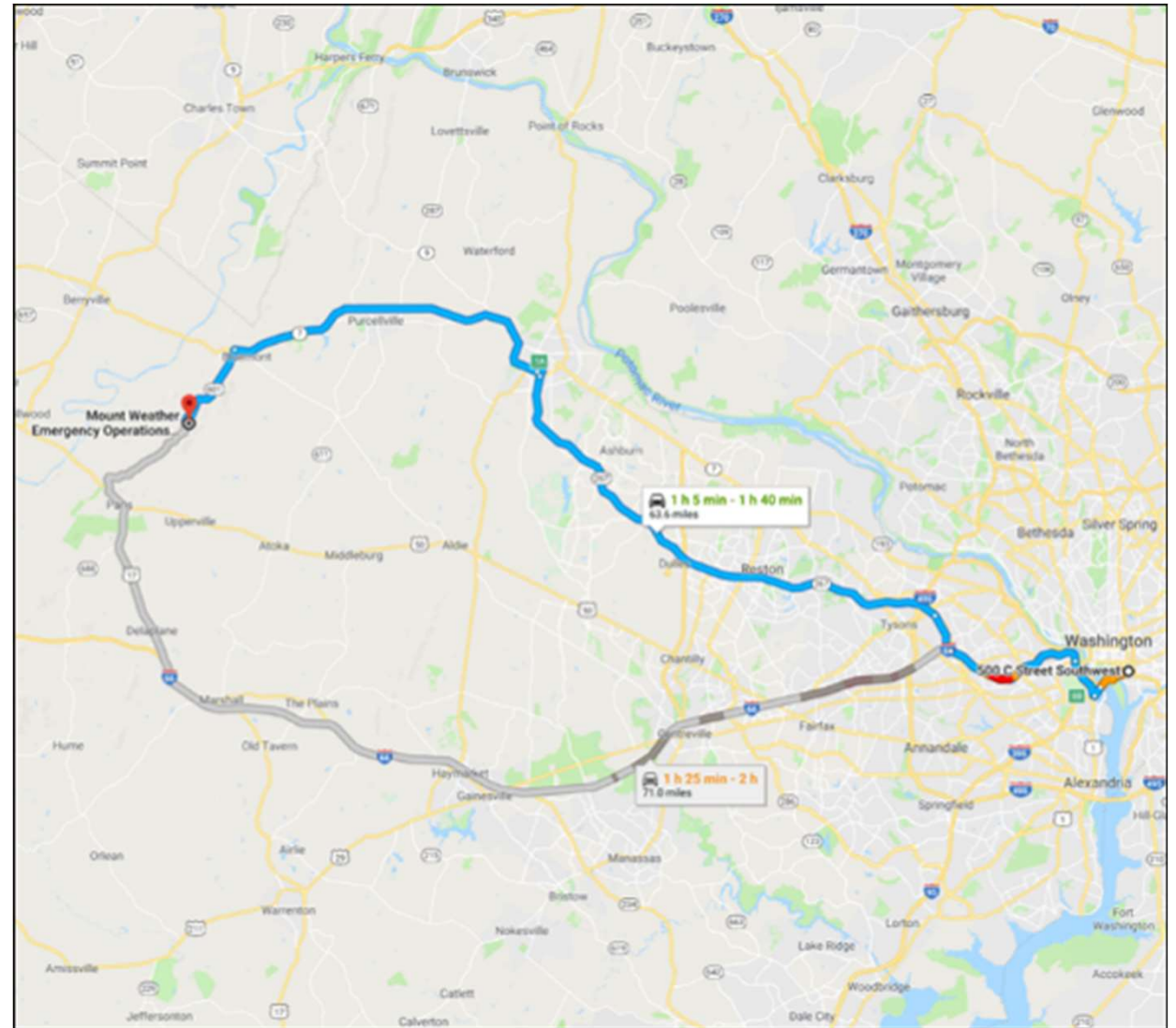
## Timing Uncertainty

- **Earliest Reasonable**
  - Absolutely must be there by 3 p.m.
  - Leave by 1 p.m. (2 hrs)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 1:35 p.m. (1 hr 25 min)
- **Window to leave: 35 min**
  - 1 p.m. to 1:35 p.m.



## Timing Uncertainty

- **Earliest Reasonable**
  - Absolutely must be there by 4 p.m.
  - Leave by 2:20 p.m. (1 h 40 min)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 2:55 p.m. (1 h 5 min)
- **Window to leave: 35 min**
  - 2:20 p.m. to 2:55 p.m.

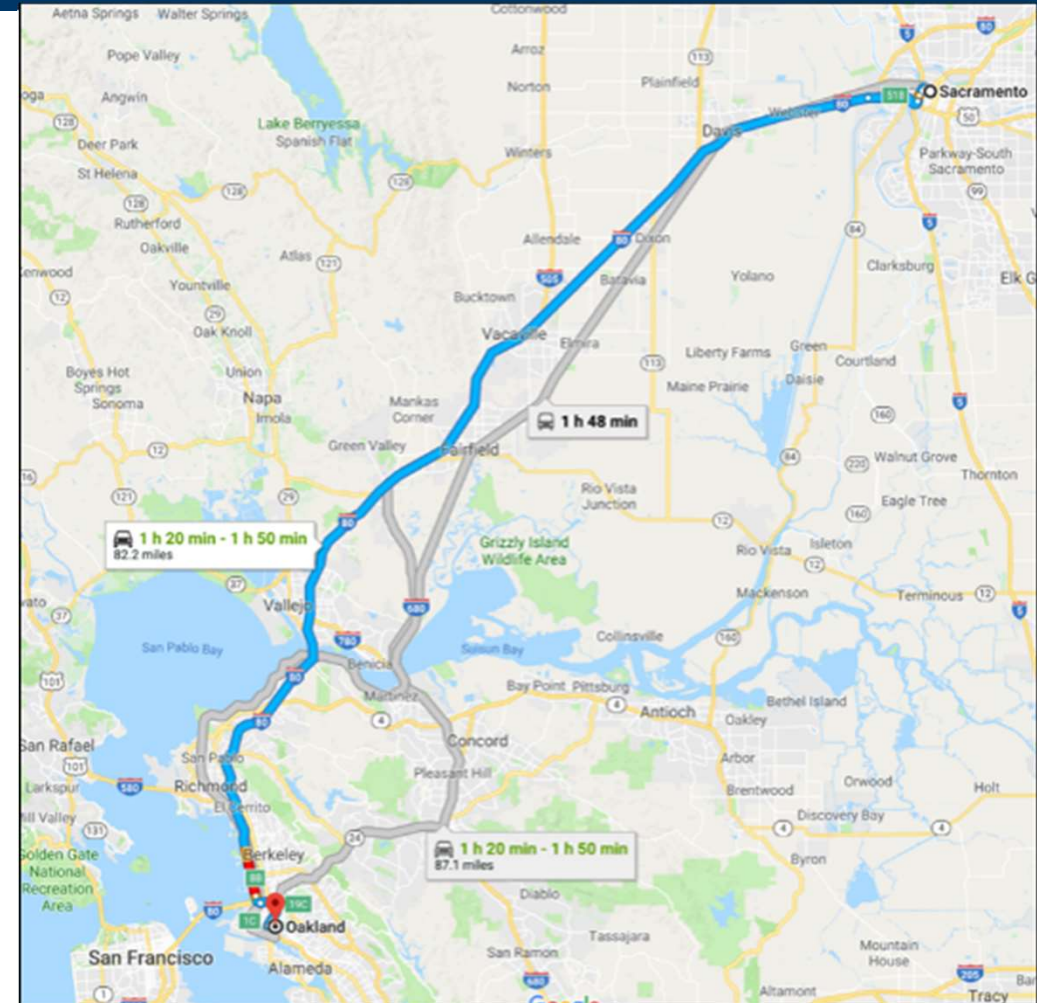


# Sacramento, CA – Oakland, CA



## Timing Uncertainty

- **Earliest Reasonable**
  - Absolutely must be there by 3 p.m.
  - Leave by 1:10 p.m. (1 h 50 min)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 1:40 p.m. (1 h 20 min)
- **Window to leave: 30 min**
  - 1:10 p.m. to 1:40 p.m.



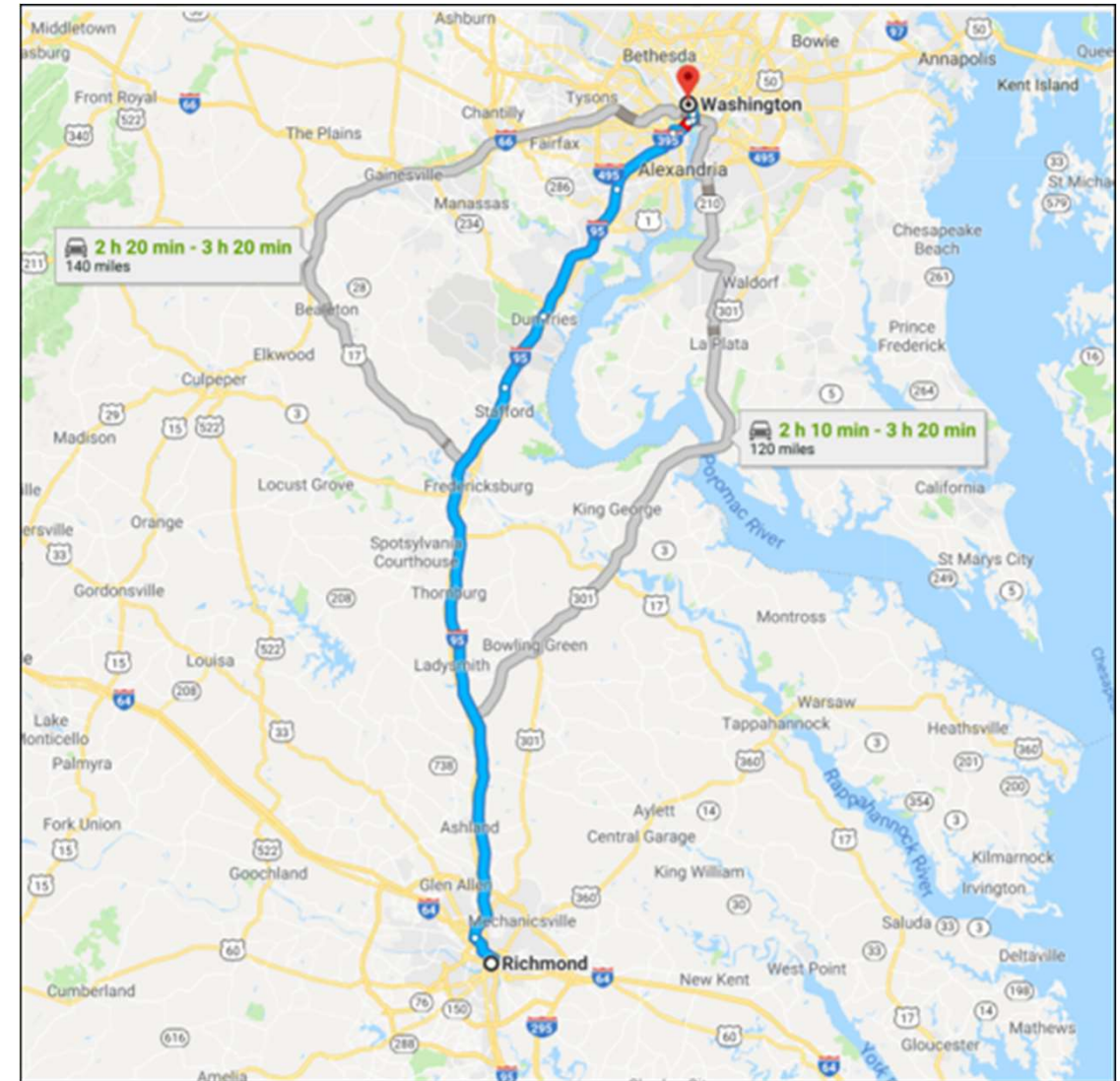
# Richmond, VA – Washington, DC



FEMA

## Timing Uncertainty

- **Earliest Reasonable**
  - Absolutely must be there by 5 p.m.
  - Leave by 1:40 p.m. (3 h 20 min)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 2:44 p.m. (2 h 20 min)
- **Window to leave: 1 h**
  - 1:40 p.m. to 2:40 p.m.



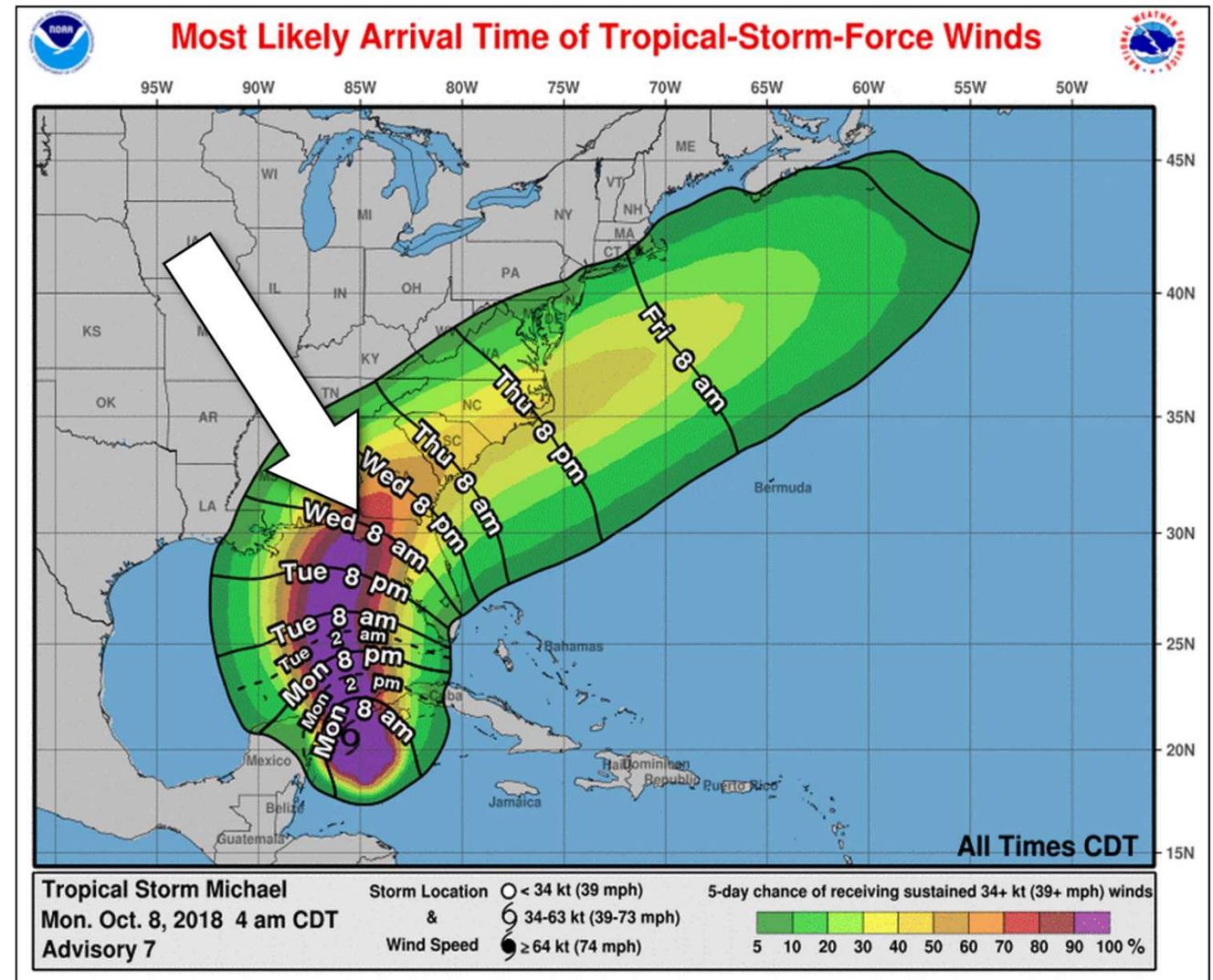
# Hurricane Michael - Tallahassee FL



FEMA

## Timing Uncertainty

- **Earliest Reasonable**
  - 10% chance of onset
  - Most conservative timing
  - Tuesday 8 p.m.
- **Most Likely**
  - 50% chance of onset
  - Equally likely before as after
  - Wednesday 8 a.m.
- **Range of wind arrival: 12 h**
  - Tue 8 p.m. to Wed 8 a.m.



## TOA Product Limitations

- **Storm Size**
  - Unusually large or small storms may not be handled well, especially beyond the first 24–36 hours.
- **Slow Forward Speed**
  - Storms that stall or move slowly can have much earlier onset times than what is conveyed in the official forecast.

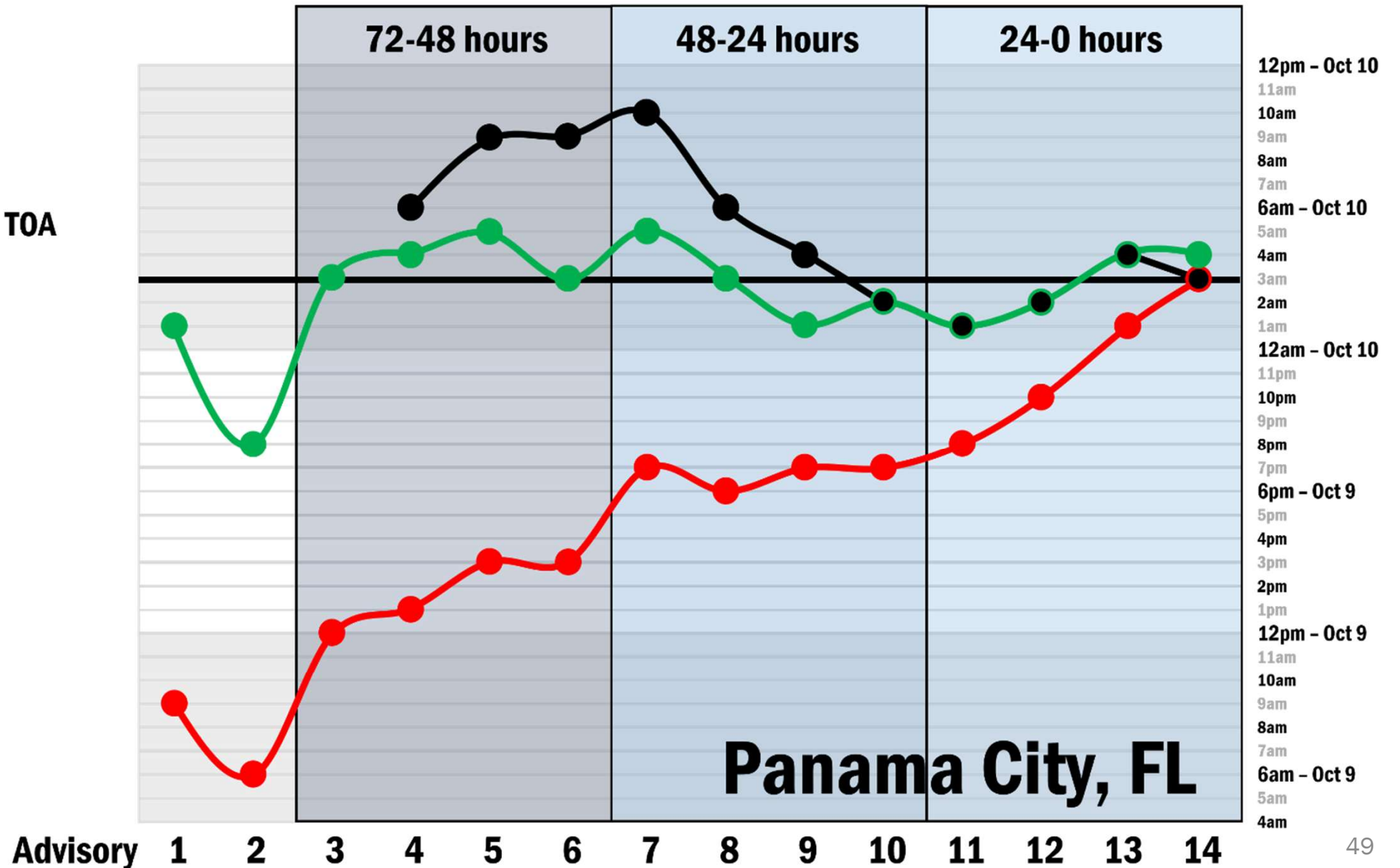


# Hurricane Michael (2018)

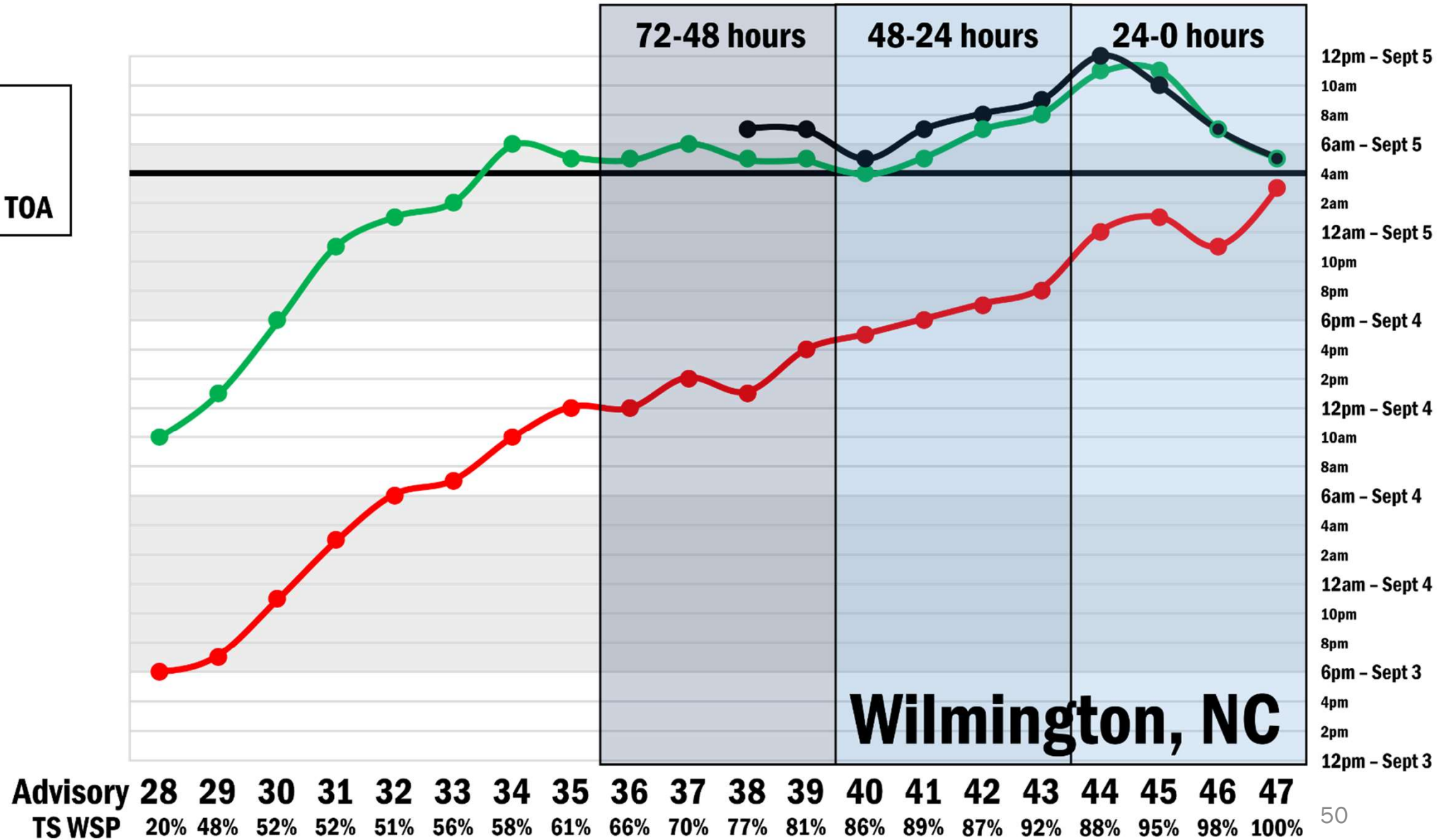
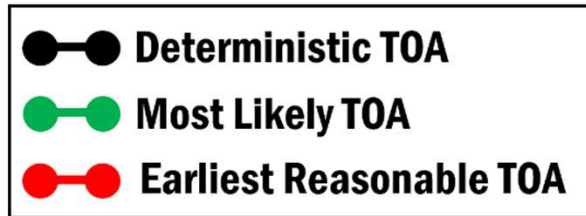


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- Deterministic TOA
- Most Likely TOA
- Earliest Reasonable TOA



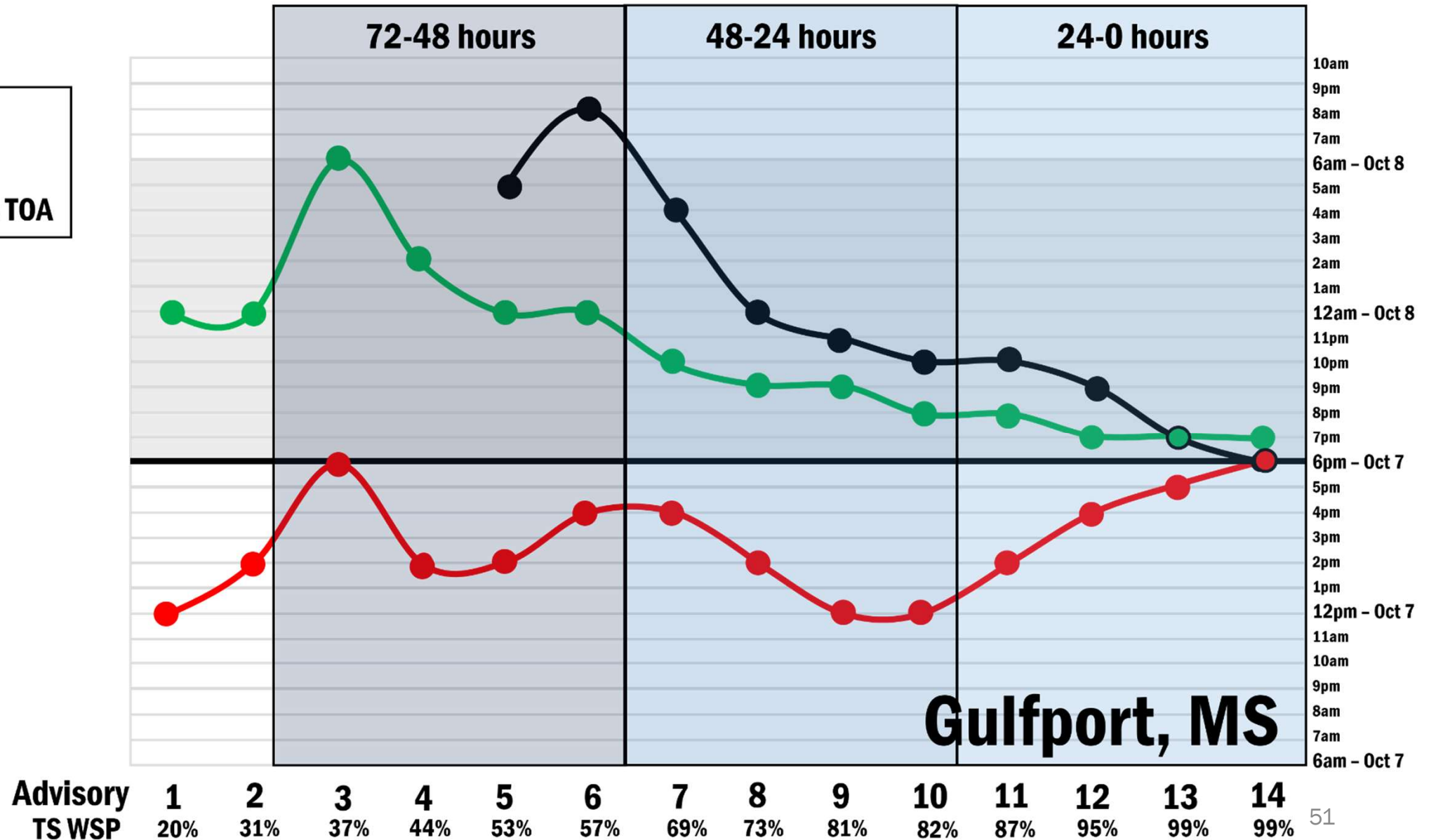
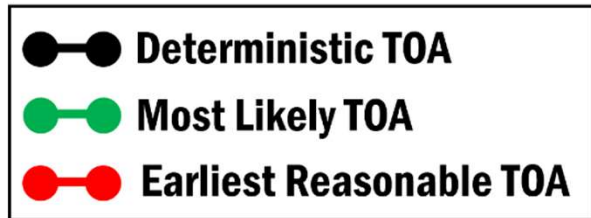
# Hurricane Dorian (2019)



# Hurricane Nate (2017)



FEMA



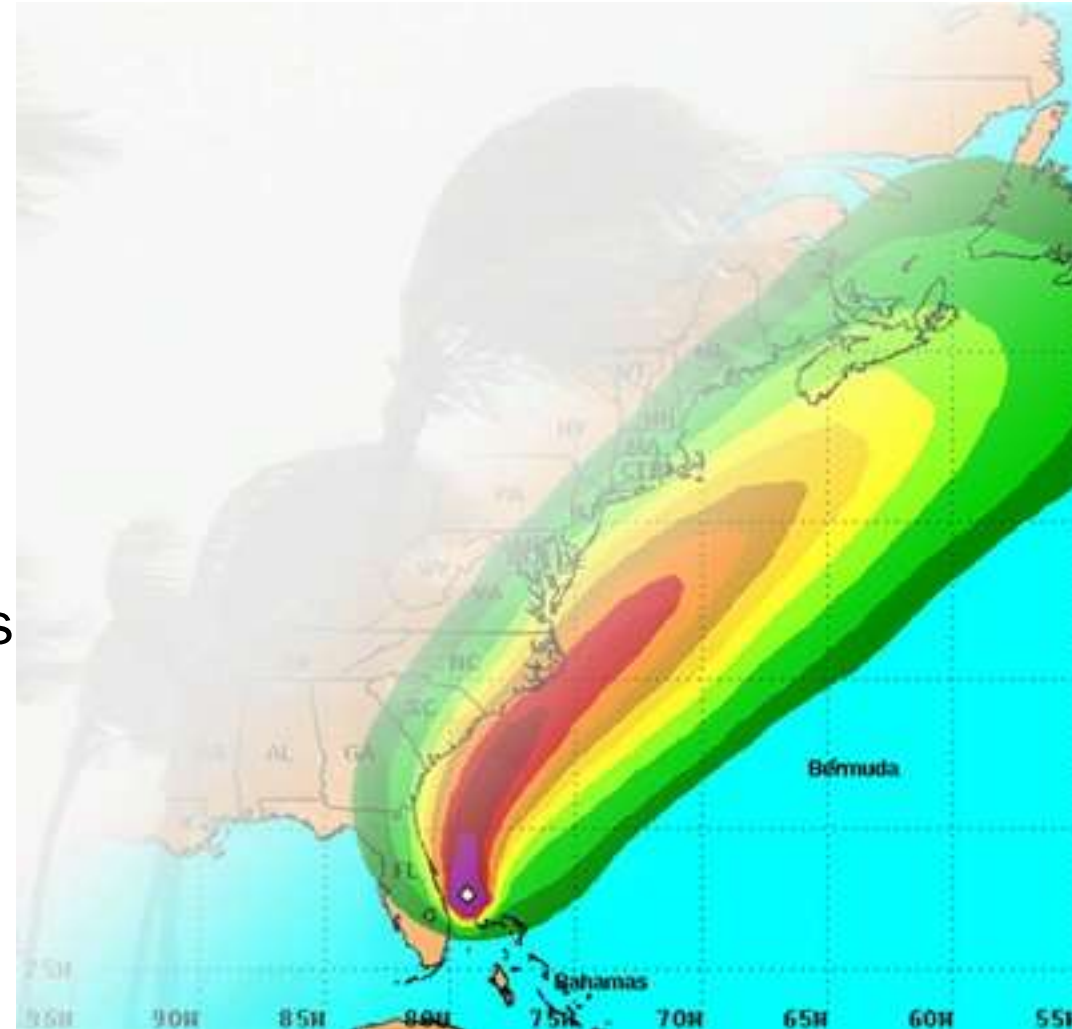
# Summary - Wind Speed Probabilities



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## Summary

- **NHC's forecasts are improving but errors remain.**
  - Error cone is not the cure for the skinny black line.
- **Wind Speed Probabilities.**
  - Likelihood of Tropical Storm and Hurricane Winds
  - Onset timing of wind hazards
- **Incorporates track, intensity, and size uncertainty.**
  - Includes weakening due to land
  - Provides an assessment of wind timing and threat that accounts for NHC forecast errors.



# Unit 3 Objectives Revisited



## Unit Objectives

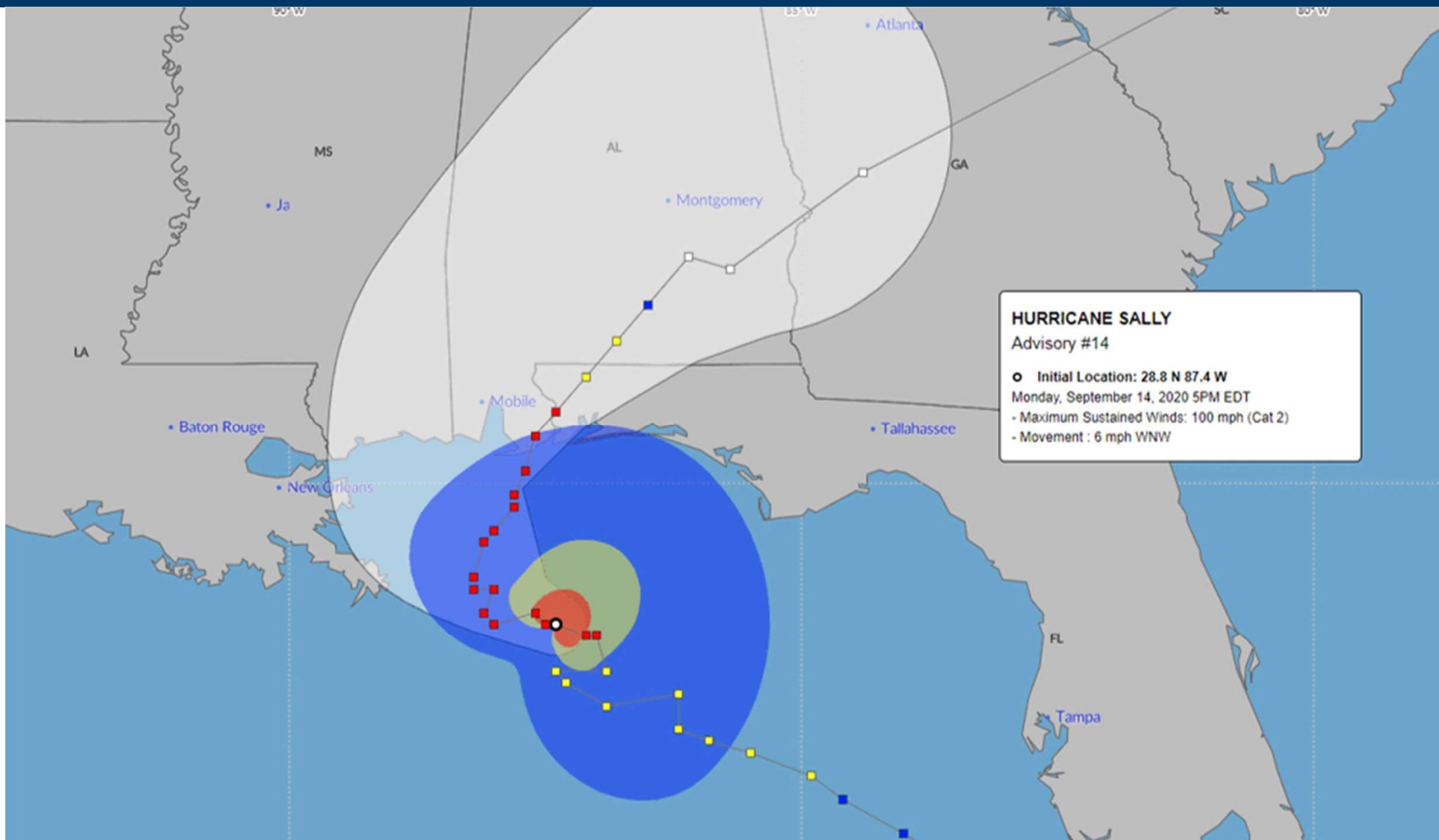
### **At the end of Unit 3, you should be able to:**

- Explain how wind speed probability products are used to predict the chance and timing of hazardous winds.
- Explain uncertainty as it relates to arrival times for TS wind speeds.
- Identify products used to evaluate storm surge risk.
- Identify and discuss coastal surge models.

# Hurricane Sally



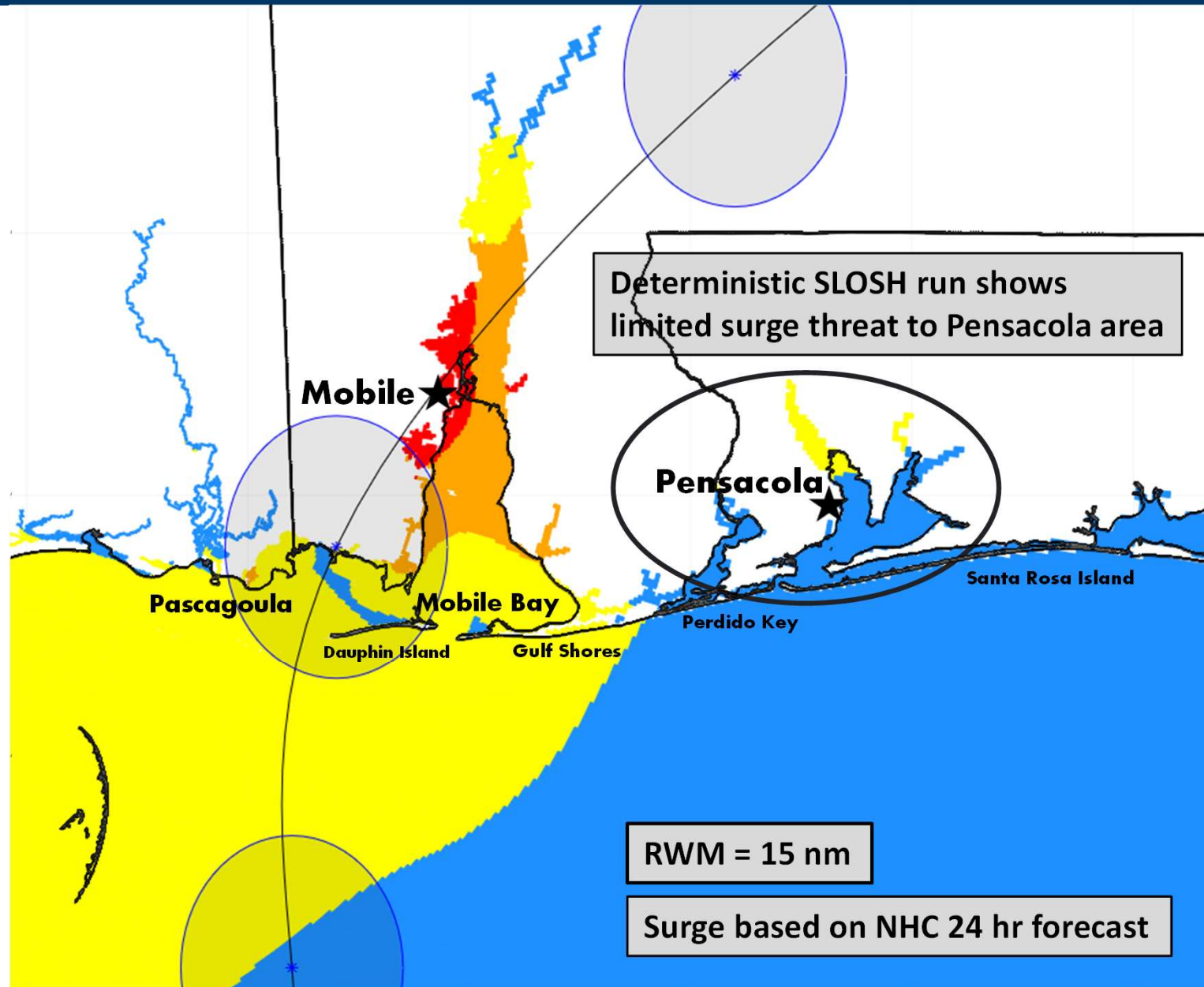
FEMA



# What a Difference a Bay Makes



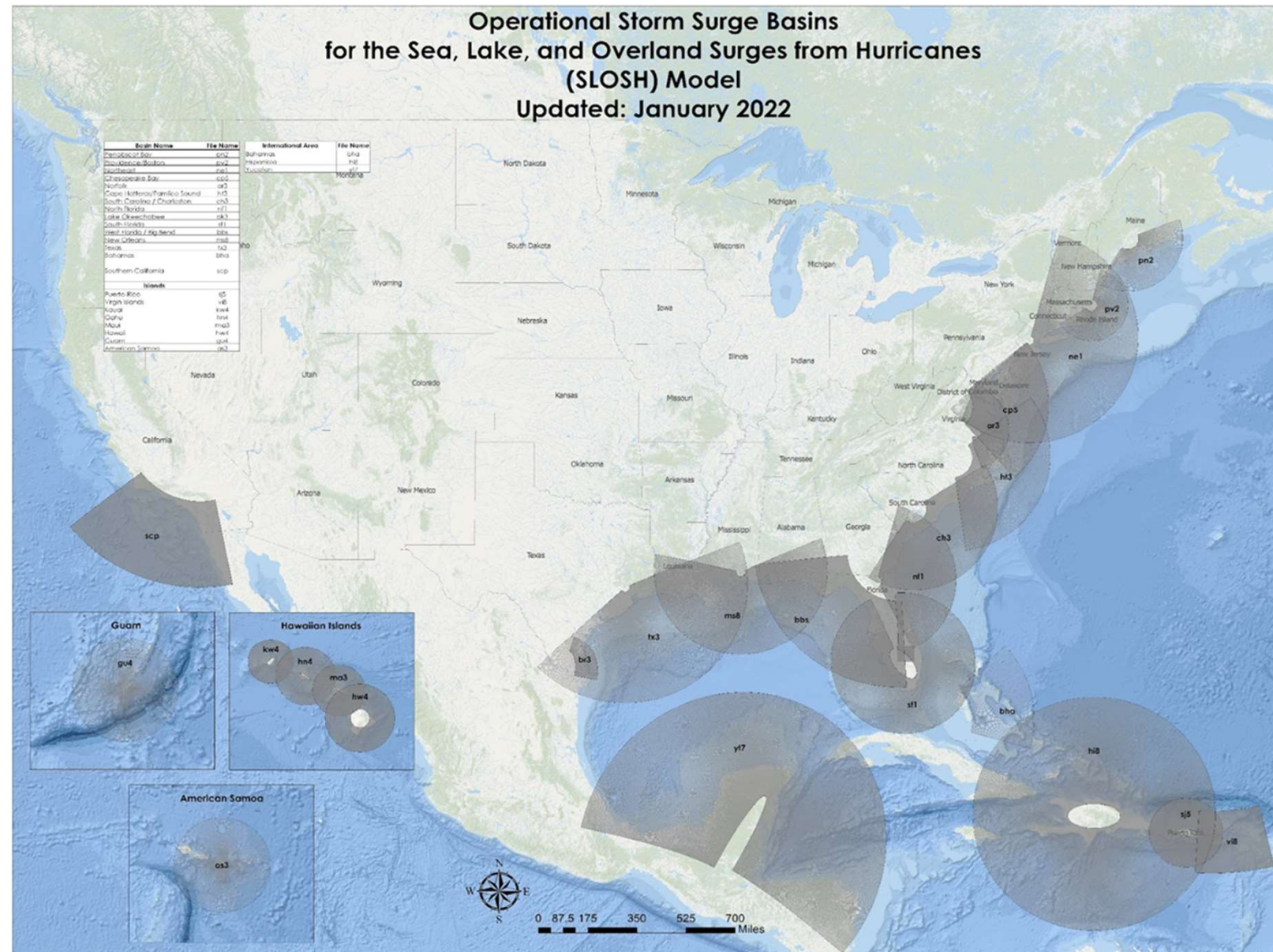
FEMA



# Storm Surge – SLOSH Model

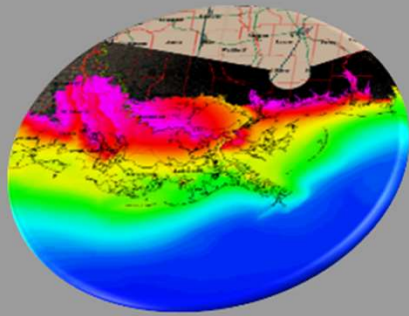
## Sea, Lake, and Overland Surges from Hurricanes

A numerical model used to estimate storm surge heights for historical, hypothetical, or predicted hurricanes

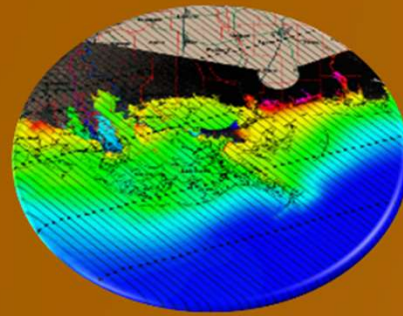




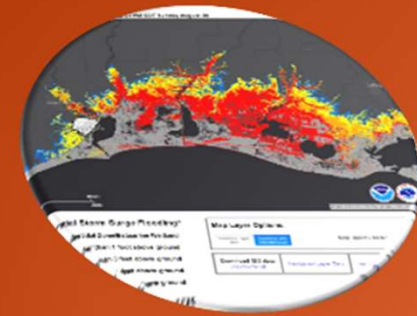
# Storm Surge Risk Tools



*Maximum of the MEOWs  
(MOMs)*



**Maximum Envelopes of  
Water (MEOWs)**



**Probabilistic Storm Surge  
(P-Surge)**  
**Potential Storm Surge  
Flooding Map**  
**Storm Surge Watch/Warning**

**Planning / More Forecast Uncertainty**

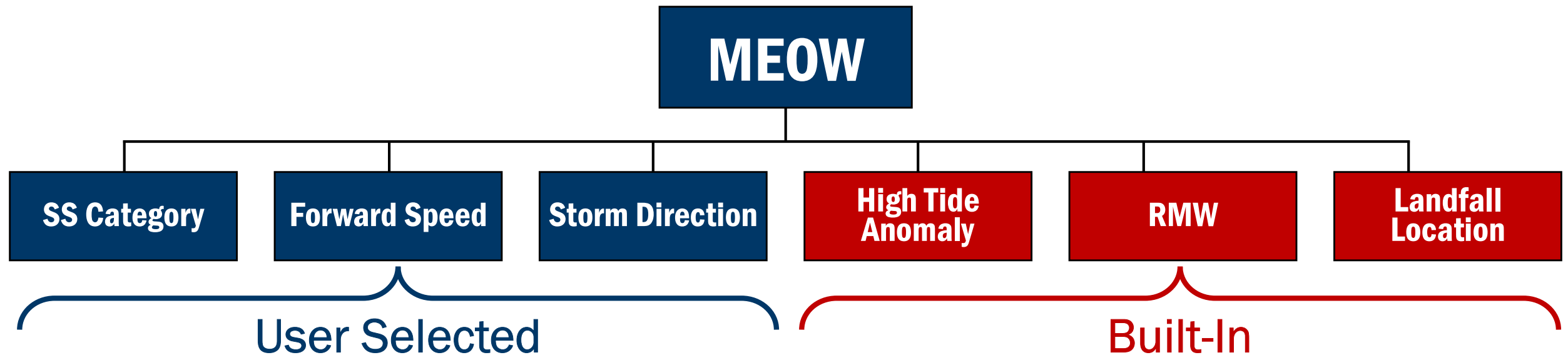
**More Forecast Certainty**

# Maximum Envelope of Water



## MEOWS

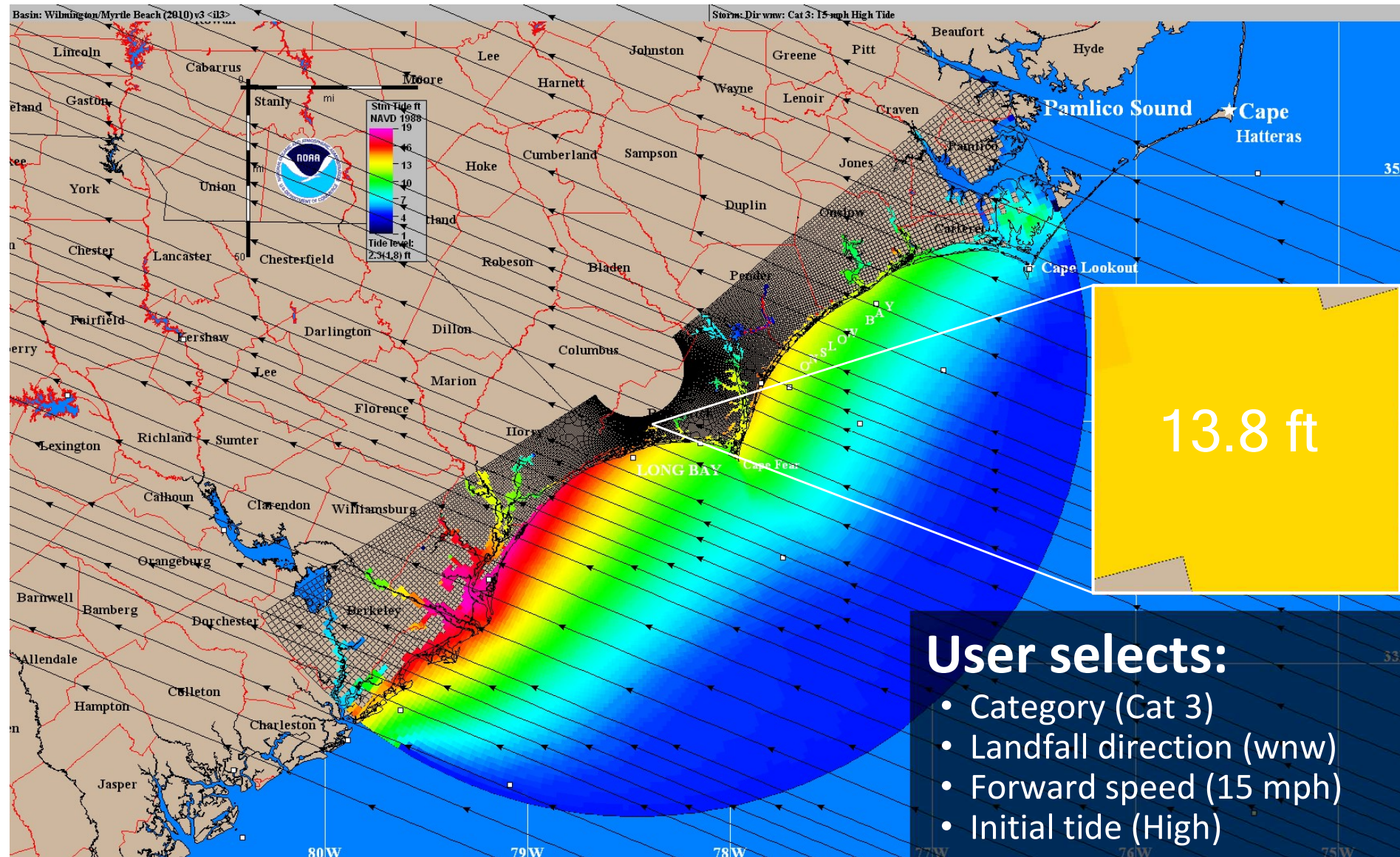
- **Composite of maximum storm surge for a given set of parameters (by basin)**
- **Used as guidance for planning and operations**



# MEOW Example



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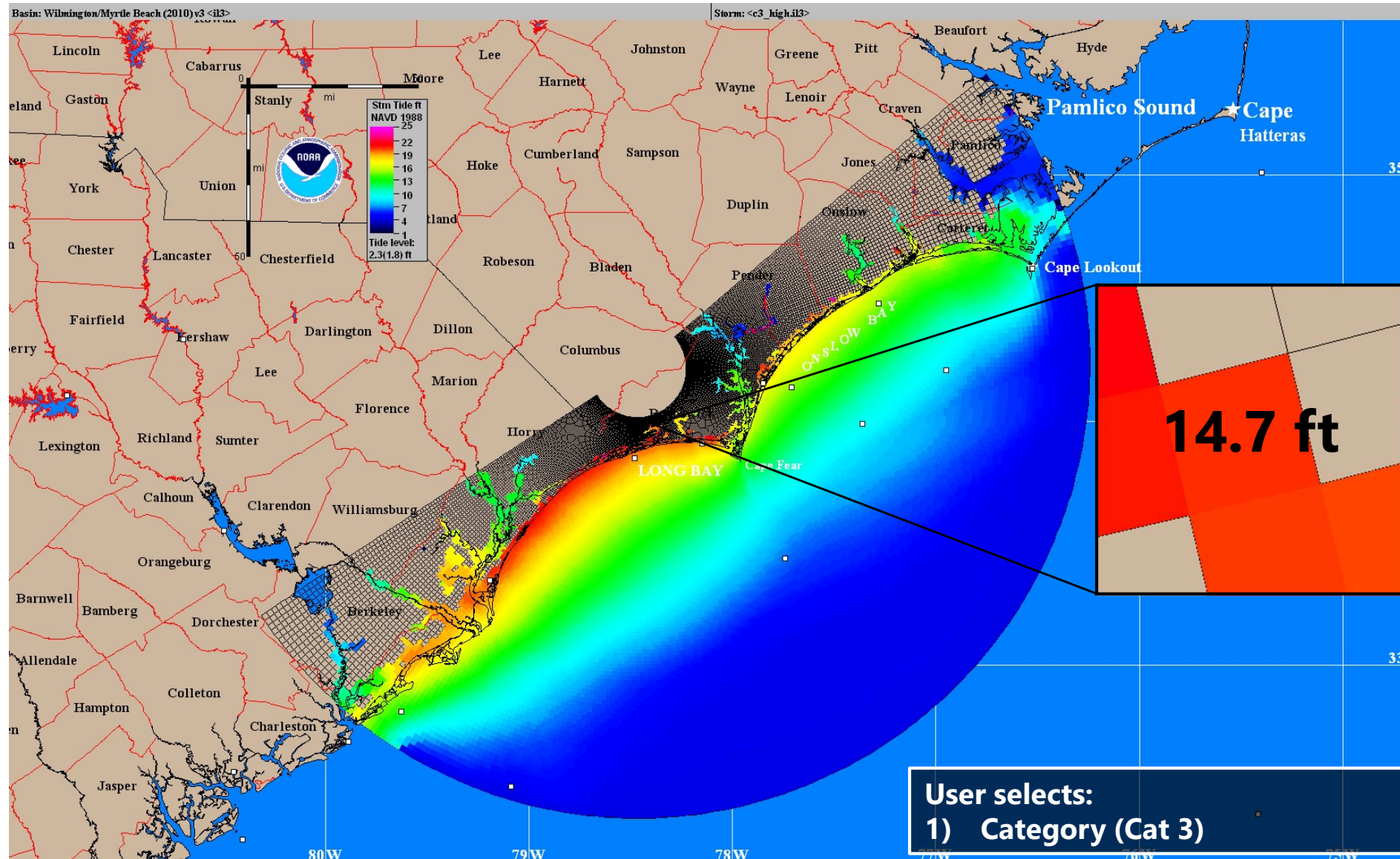
## MOMs

- **Worst-case for a particular category storm**
- **Combination of many scenarios**
  - Forward speed
  - Angle of approach
  - Size (Radius of maximum wind)
  - Initial tide level
- **No single hurricane will produce the regional flooding depicted in a Maximum of Maximums (MOMs)**

# Maximum of Maximums (MOMs) 2



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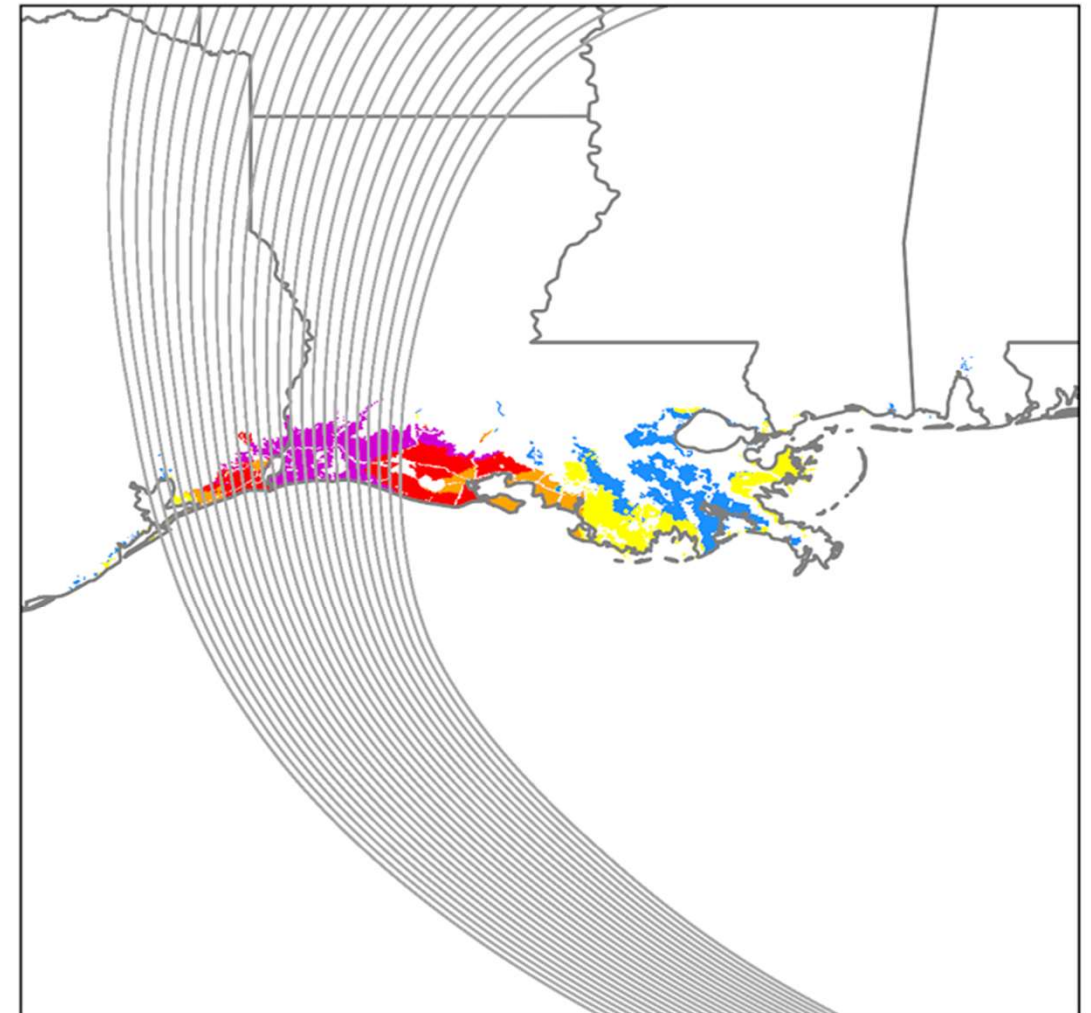


# Probabilistic Storm Surge (P-Surge)



## P-Surge

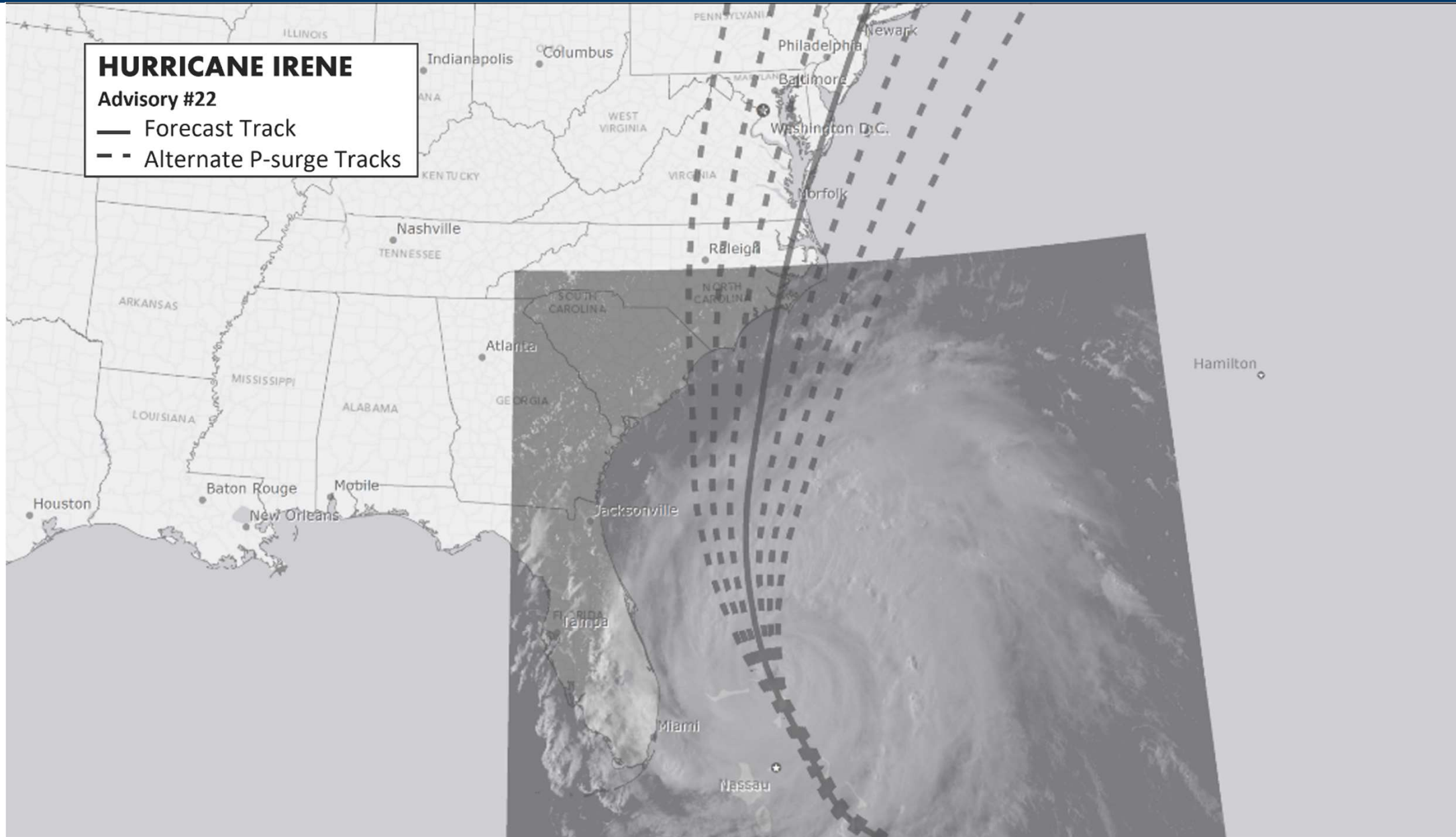
- **Based on NHC official advisory**
  - Uncertainties based on historical errors
- **Accounts for uncertainty in:**
  - Track (landfall location)
  - Forward speed
  - Size (Radius of maximum wind)
  - Intensity
- **Accounts for tide**
- **Heights above ground level**



# Probabilistic Storm Surge



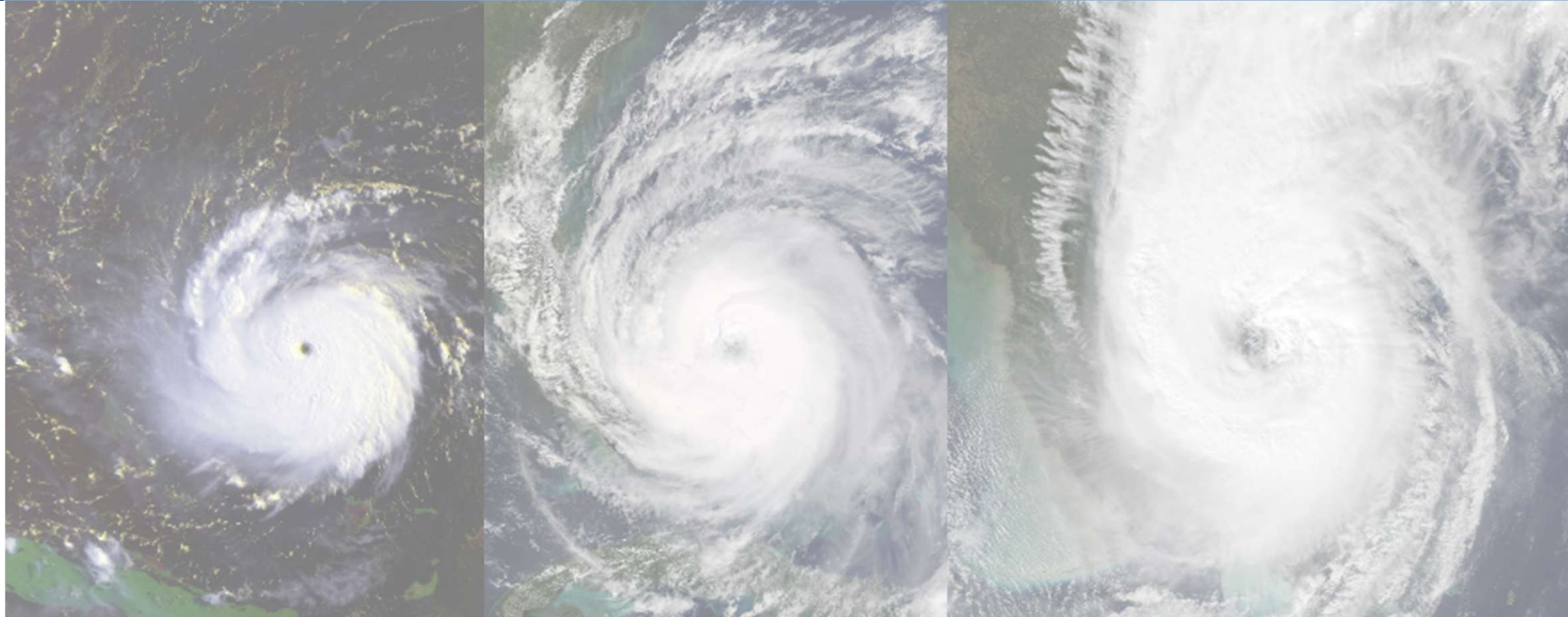
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# Sizes, Intensities, Forward Speeds



FEMA



**Size (RMW):** Small, Medium, Large

**Forward Speed:** Fast, Medium, Slow

**Intensity:** Strong, Medium, Weak



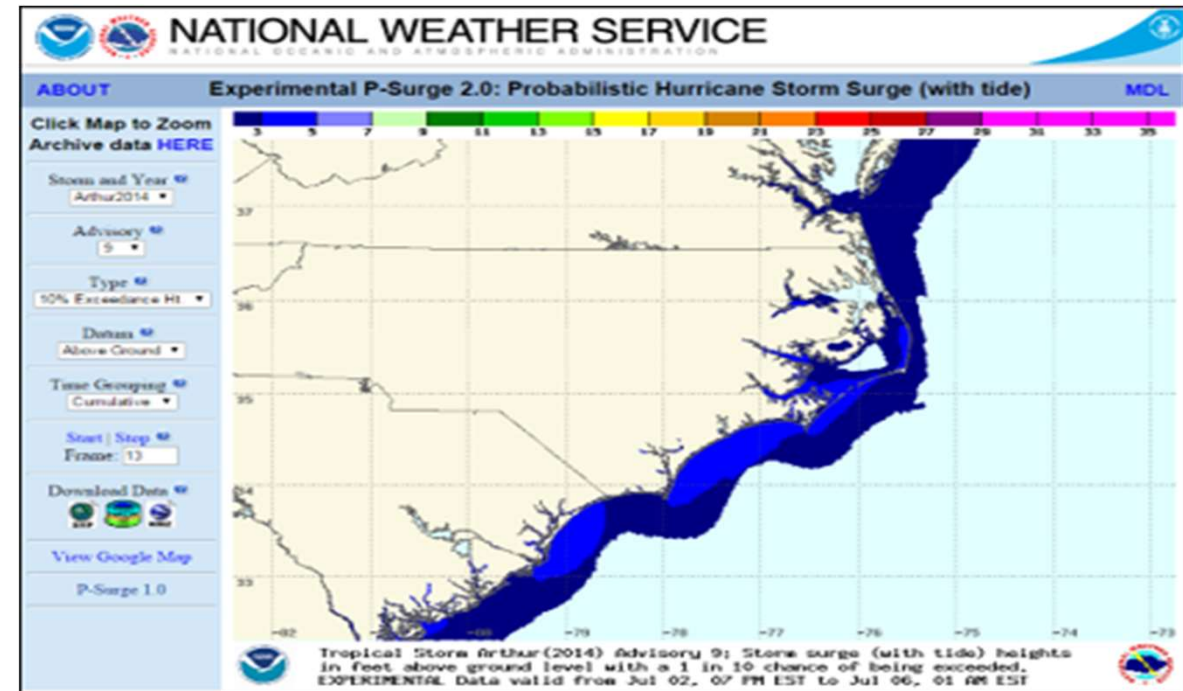
# Web-Based. Timing. Availability.



## P-Surge

- **Typically issued with a Hurricane or Storm Surge Watch/Warning**
  - But can be provided up to 72 hours prior to arrival of TS winds when forecaster confidence is high
- **Available about 1 hour after advisory**

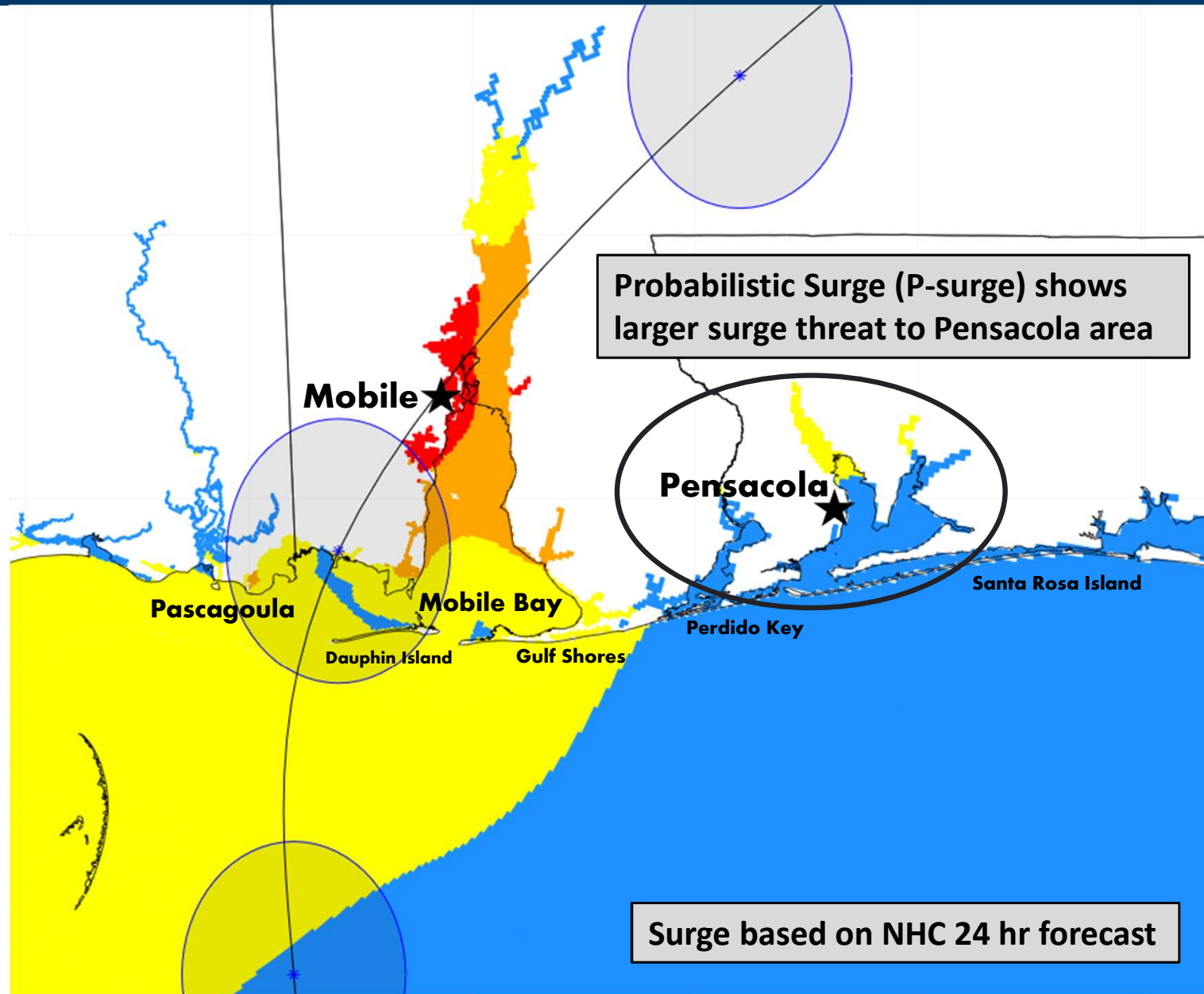
<b>ADV TIME</b>	<b>P-SURGE</b>
• 0500	0600 EDT
• 1100	1200 EDT
• 1700	1800 EDT
• 2300	0000 EDT



# Deterministic vs. Probabilistic



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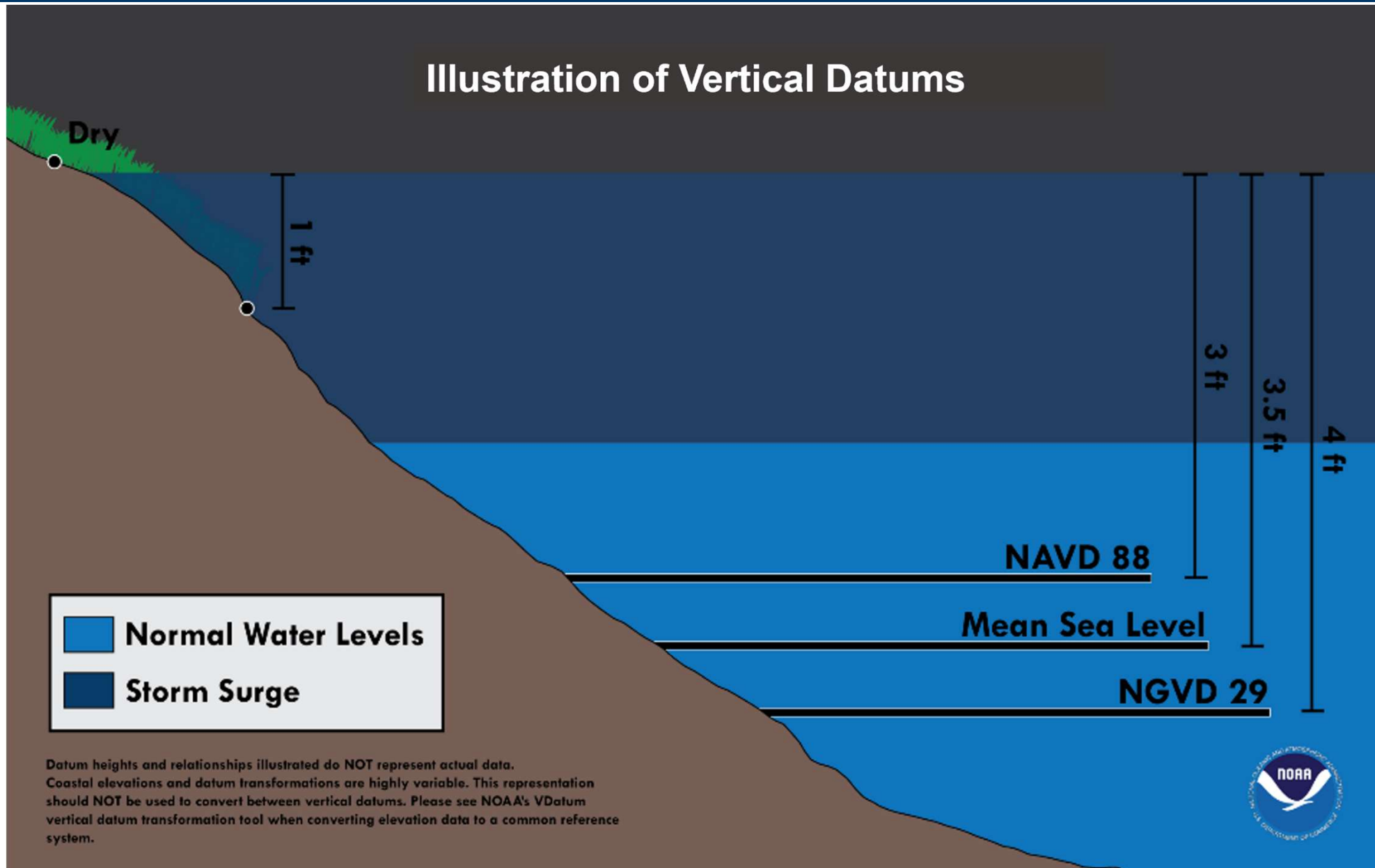
**In general, NHC operational storm surge products provide water levels above which reference level?**

- A. Mean Sea Level (MSL)
- B. Ground Level (AGL)
- C. NAVD88
- D. Normal Tidal Levels

# Vertical Datums



FEMA

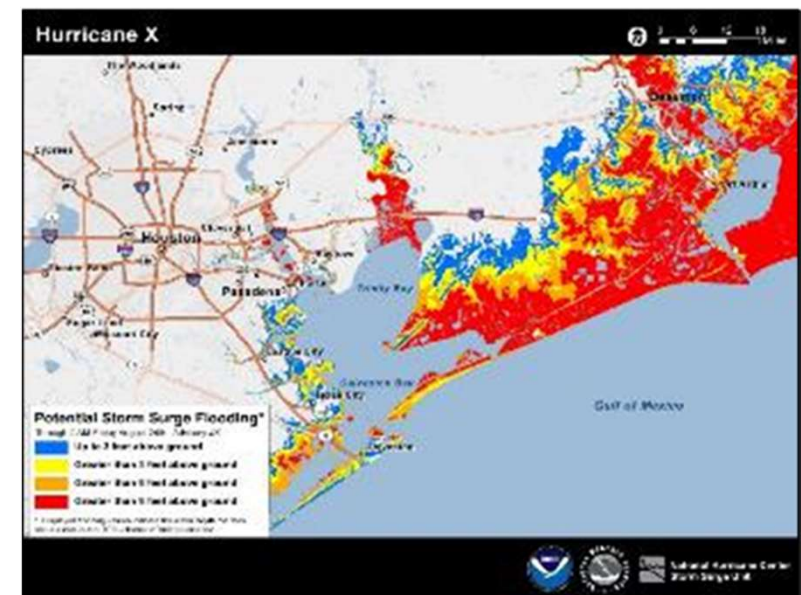


# Potential Storm Surge Flooding Map



## Potential Inundation Map

- **Height above ground that the water could reach**
  - Reasonable worst-case scenario for any individual location
  - Storm surge heights at any individual location have a **10% chance of being exceeded**
- **Not a flooding footprint**
- **Issuance and availability are the same as P-Surge**



# Intertidal/Wetlands

## Tidal (Estuarine) Wetlands

### Estuarine Forested Wetland



Mangroves  
Everglades National Park, Florida

### Estuarine Scrub/Shrub Wetland



Tidal Shrub Swamp  
Virginia

### Estuarine Emergent Wetland



Salt Marsh  
Brigantine, New Jersey

## Non-Tidal (Palustrine) Wetlands

### Palustrine Forested Wetland



Cypress Swamp  
Bayou Corne, Louisiana

### Palustrine Scrub/Shrub Wetland



Short Pocosin  
Pocosin Lakes National Wildlife Refuge, North Carolina

### Palustrine Emergent Wetland

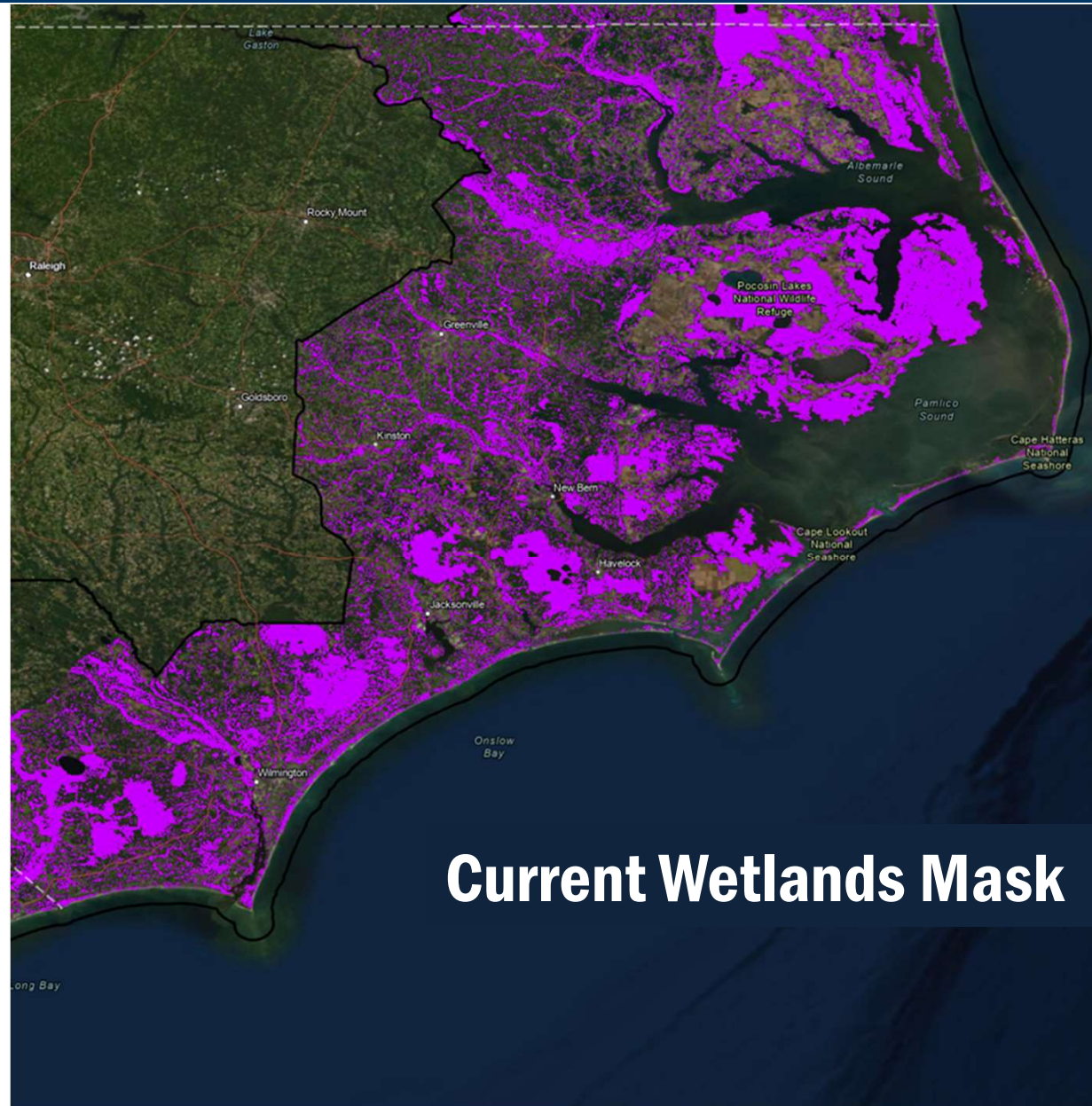


Sawgrass Prairie  
Everglades National Park, Florida

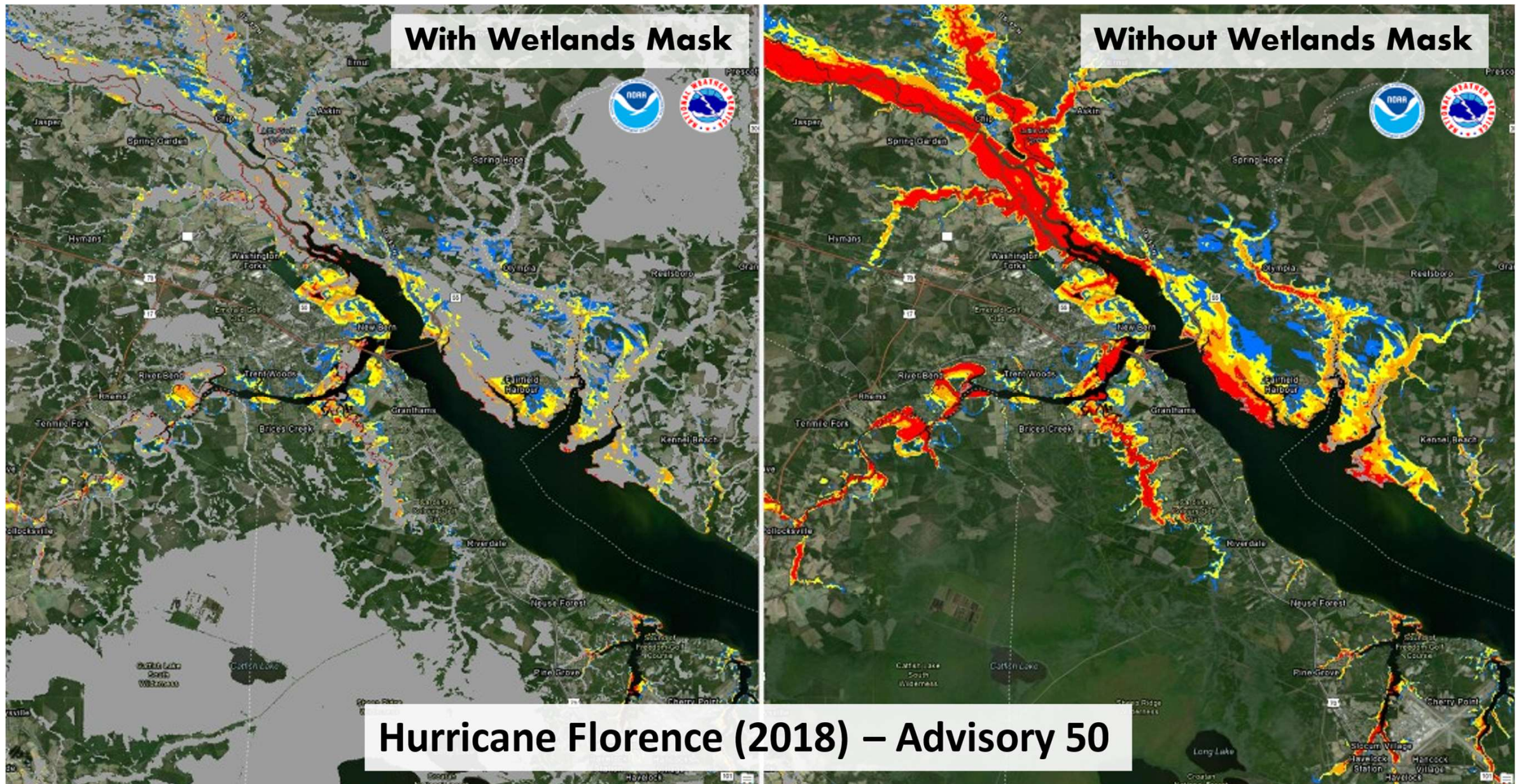
# Intertidal/Wetlands Mask



FEMA



# Intertidal/Wetlands Mask 2



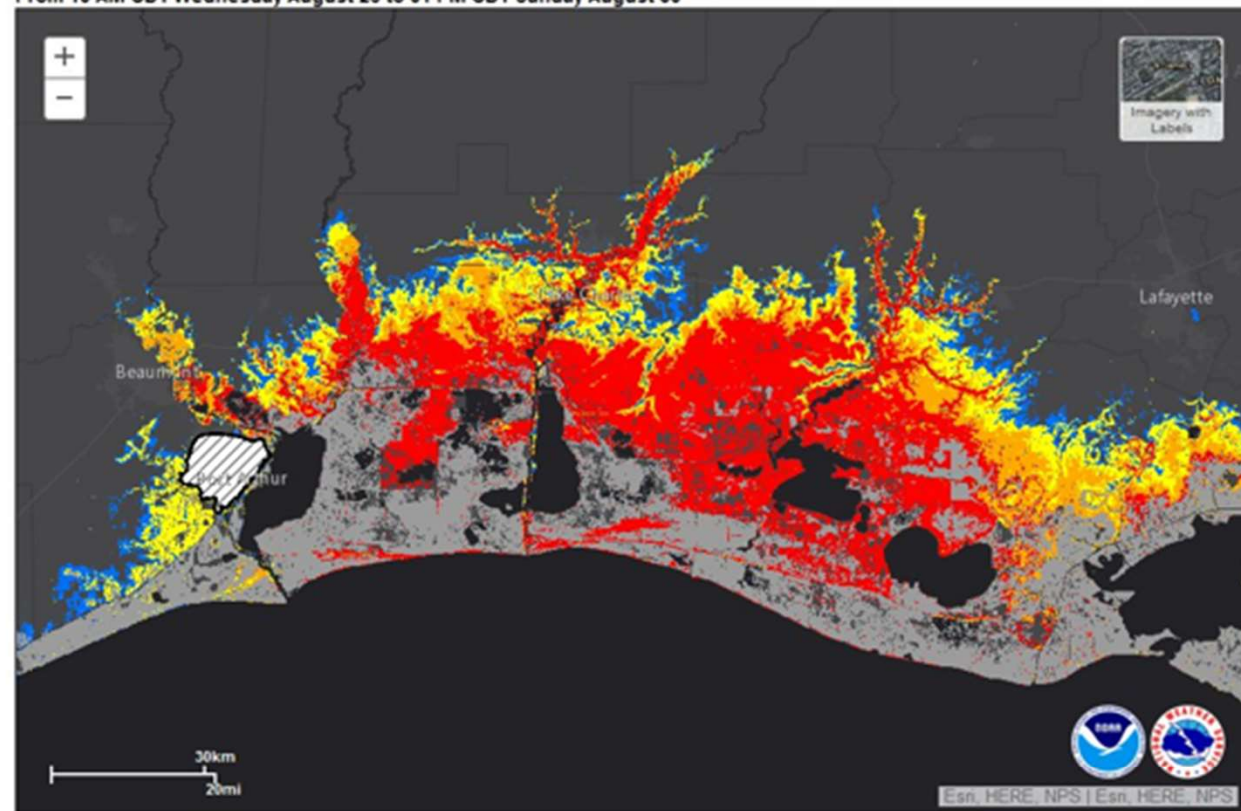


# Messaging P-Surge



FEMA

NHC Potential Storm Surge Flooding Map  
Hurricane LAURA (2020) Advisory 27  
From 10 AM CDT Wednesday August 26 to 01 PM CDT Sunday August 30



## Potential Storm Surge Flooding\*

- Intertidal Zone/Estuarine Wetland
- Greater than 1 foot above ground
- Greater than 3 feet above ground
- Greater than 6 feet above ground
- Greater than 9 feet above ground
- Leveed area
- Consult local officials for flood risk

### Map Layer Options:

Inundation Layer Only
  Inundation with Intertidal Layer
  Map Opacity Slider

## Potential Storm Surge Flooding

The NWS's potential storm surge flooding map indicates the **height** above ground that the **water** could reach.

LAND      COASTLINE      WATER

*"Above Ground Level" describes the water level of the flooding that moves inland due to the combined effect of storm surge and tide.*

**A** Greater than 9 feet above ground

**B** 6-9 feet above ground

**C** 3-6 feet above ground

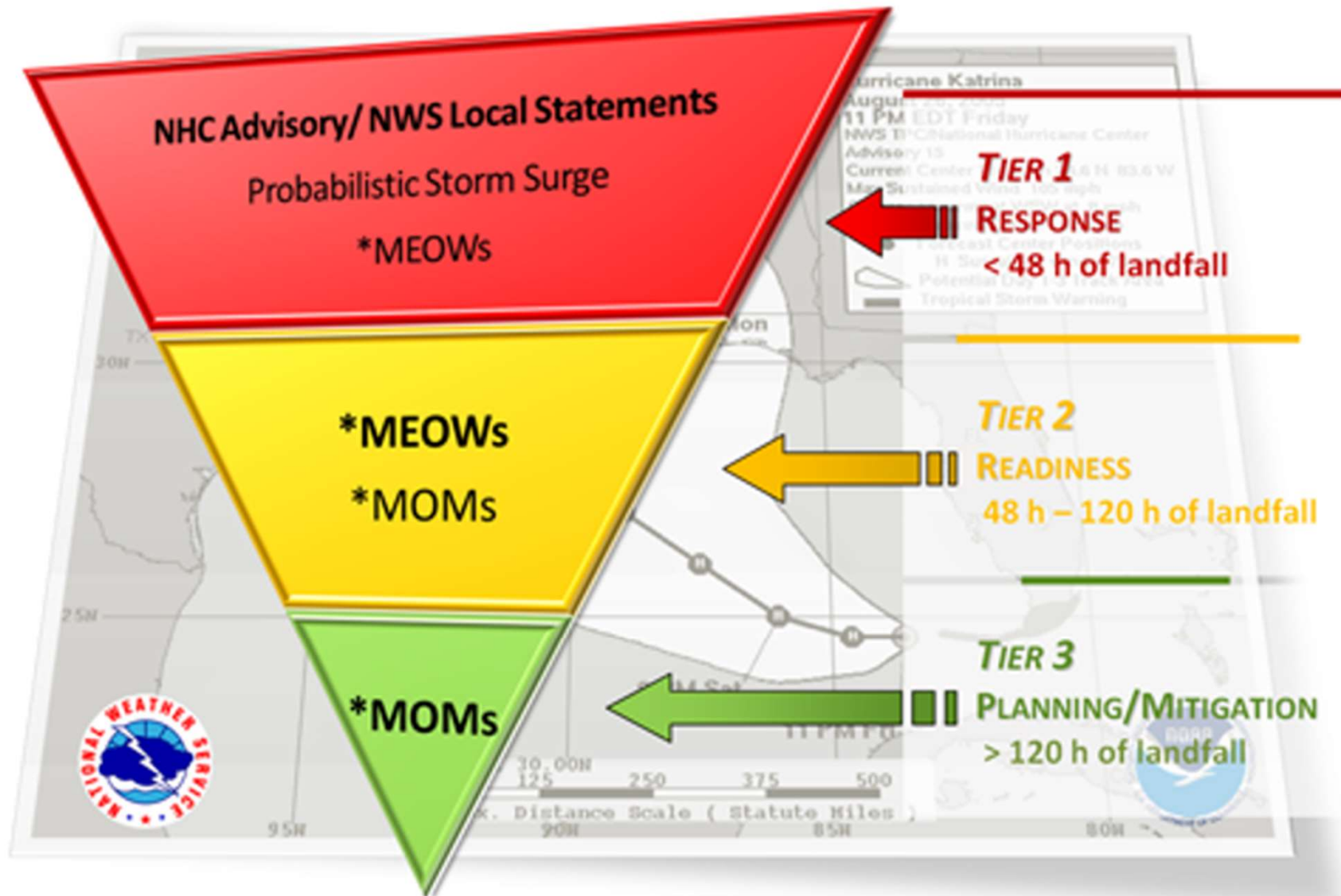
**D** 1-3 feet above ground

weather.gov  
hurricanes.gov

# Decision Support Timeframes



FEMA



# Questions/Comments?



FEMA

