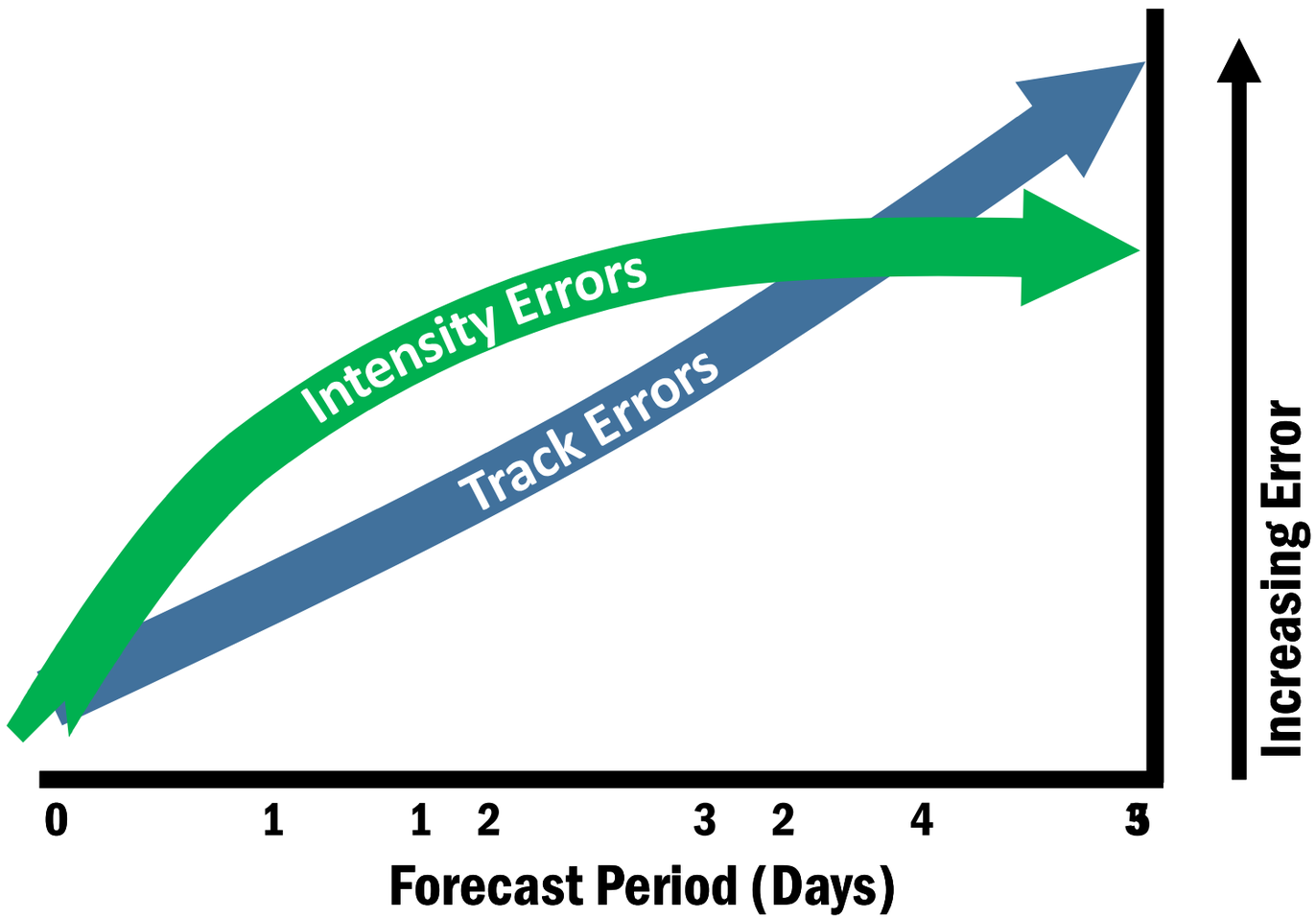
# UNIT 3:
# Forecast Uncertainty

# Unit Objectives

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

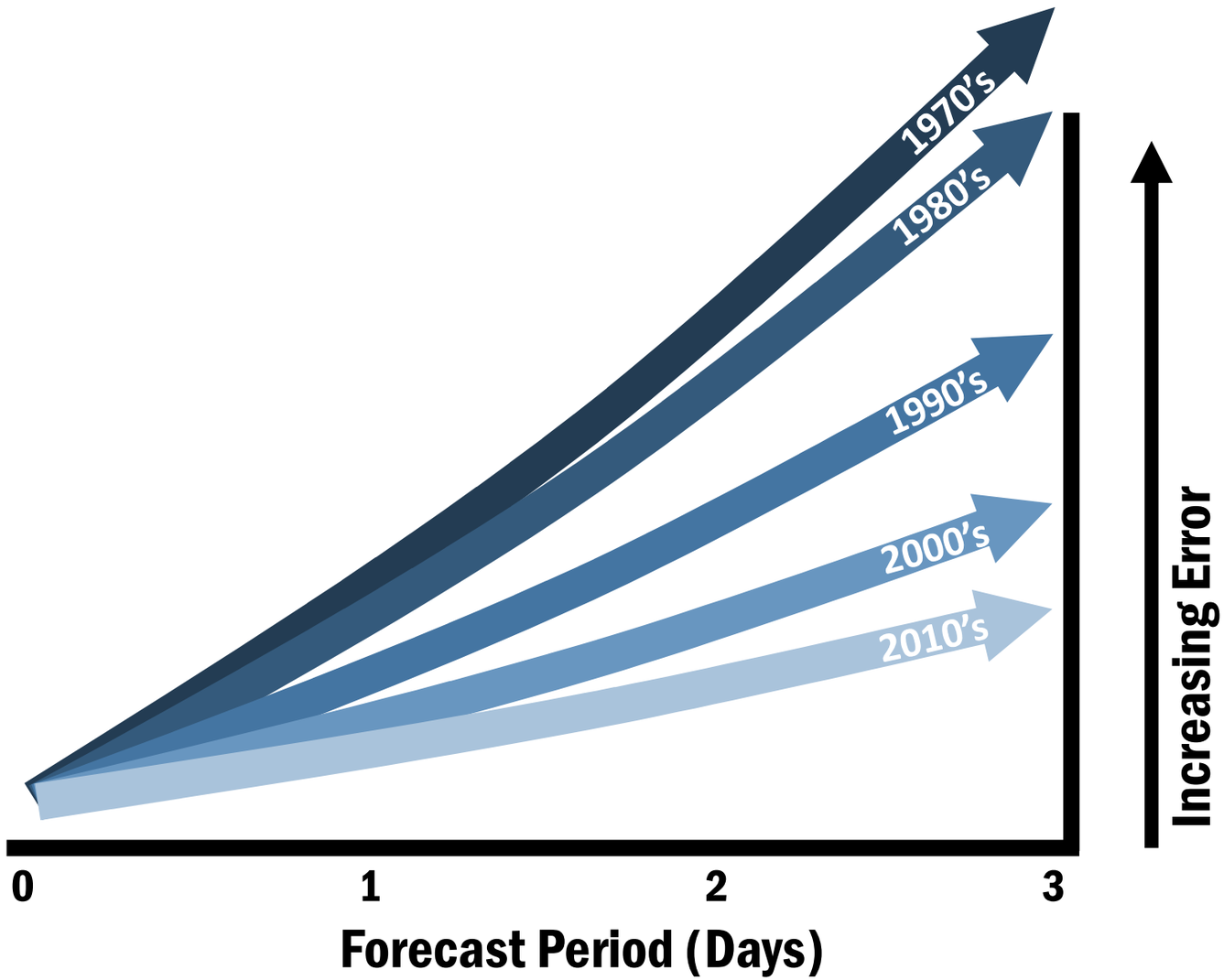
- Explain how wind speed probability products are used to predict the chance and timing of hazardous winds.
- Explain uncertainty as it relates to arrival times for TS wind speeds.
- Identify products used to evaluate storm surge risk.
- Identify and discuss coastal surge models.

# Forecast Errors



# Improving, But Not Perfect

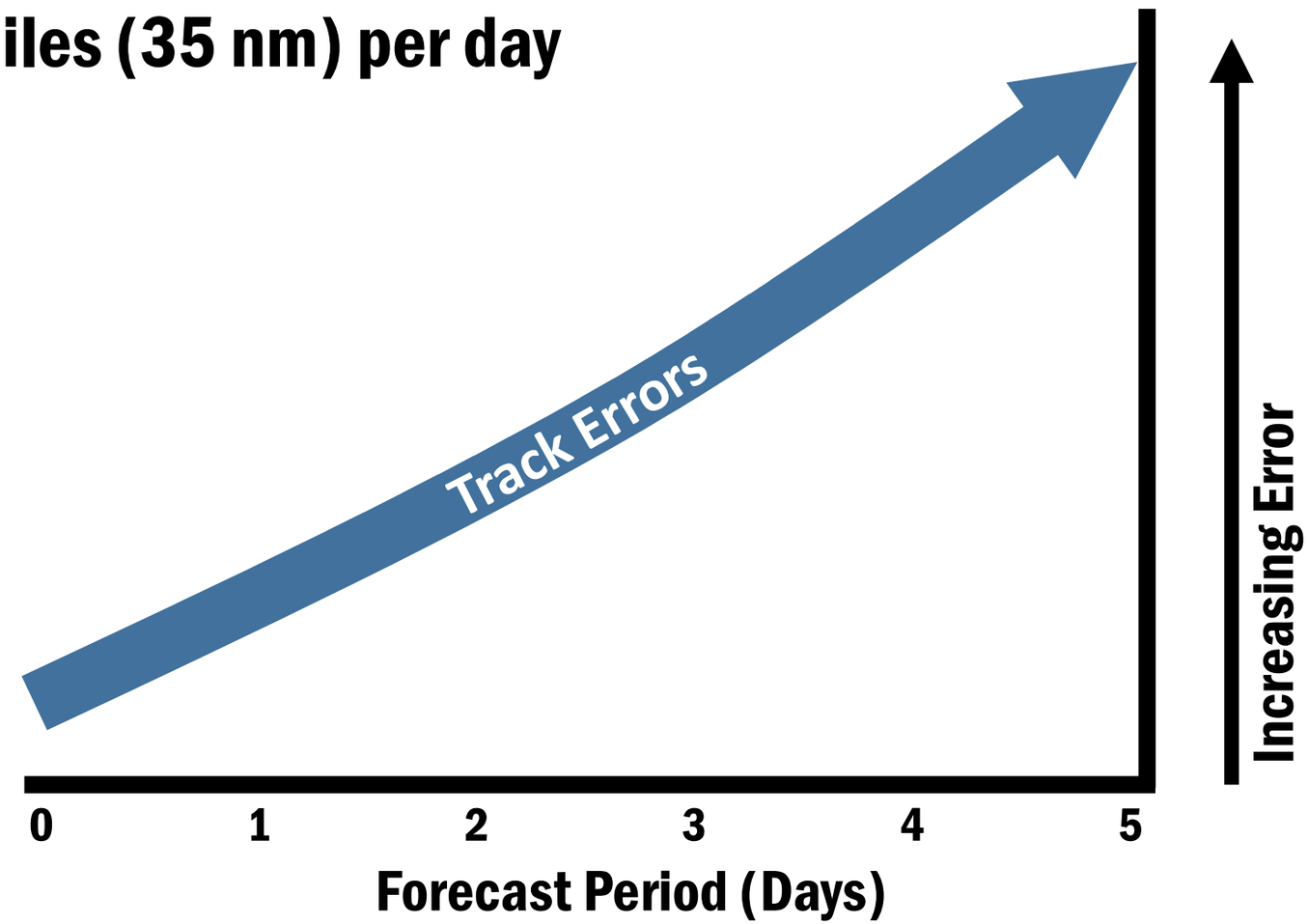
## Track Errors



# Forecast Track Errors

## Track Errors

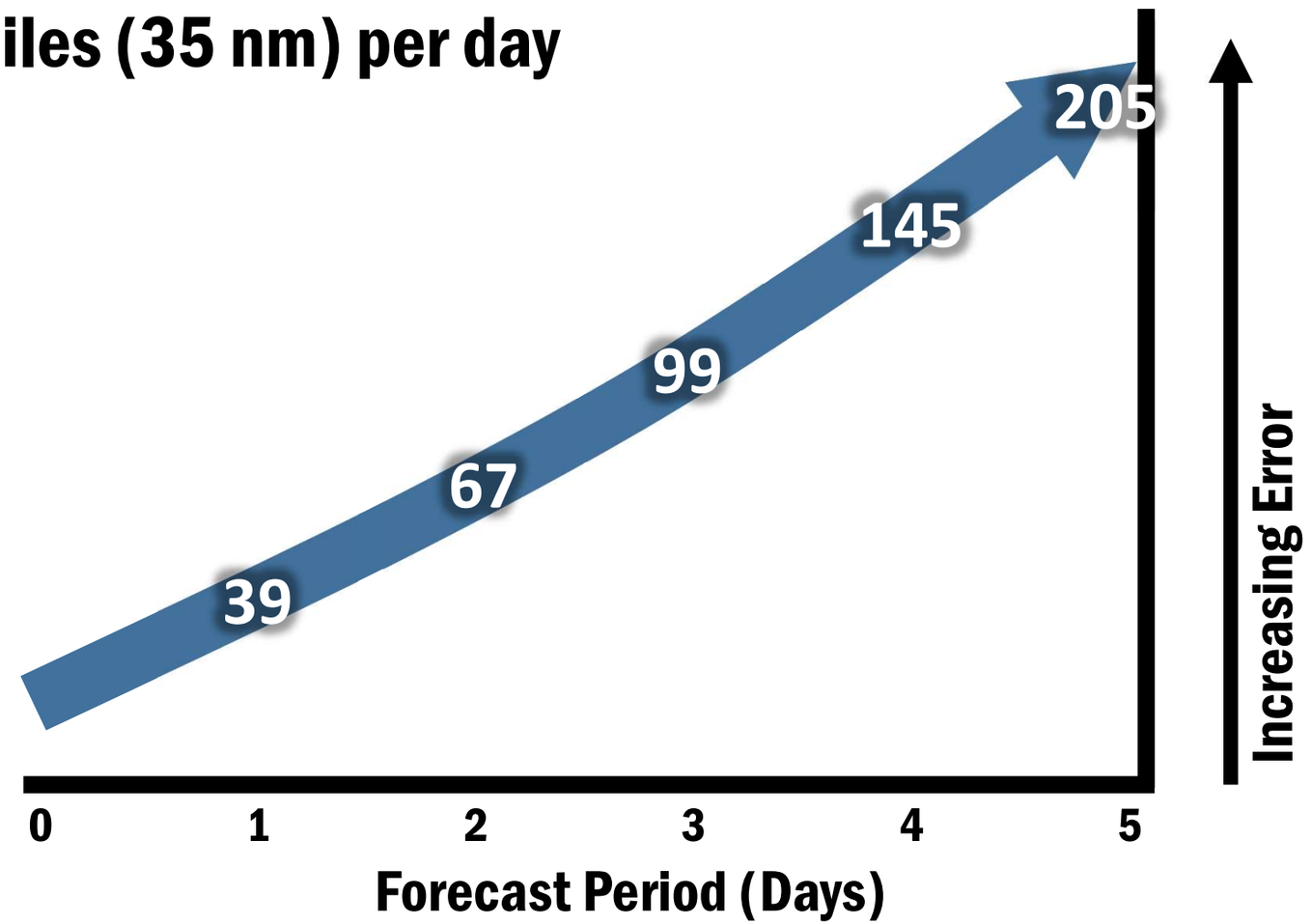
- **Increase 40 miles (35 nm) per day**



# Forecast Track Errors in Miles

## Track Errors

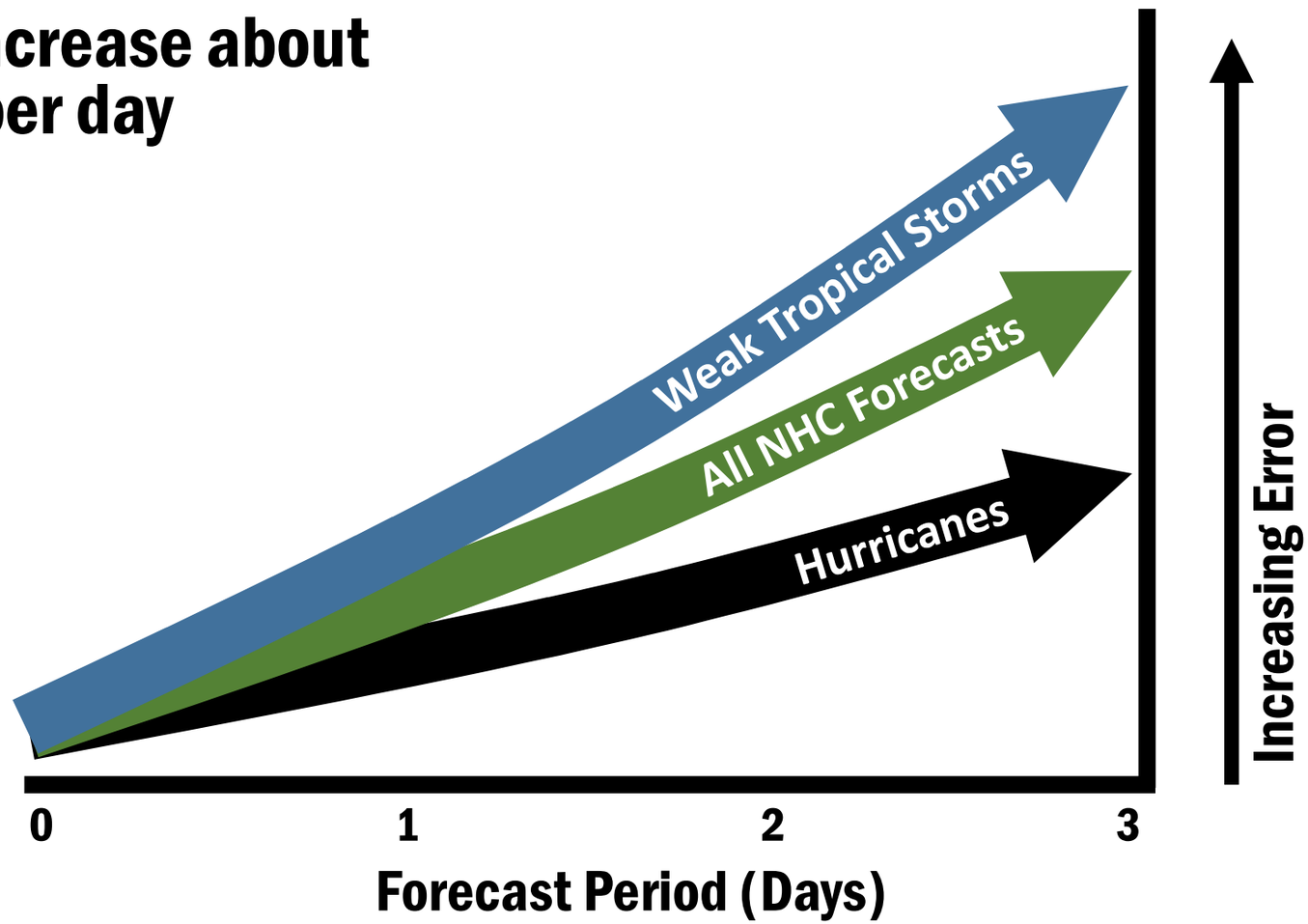
- **Increase 40 miles (35 nm) per day**



# Track Errors Based on Initial Intensity

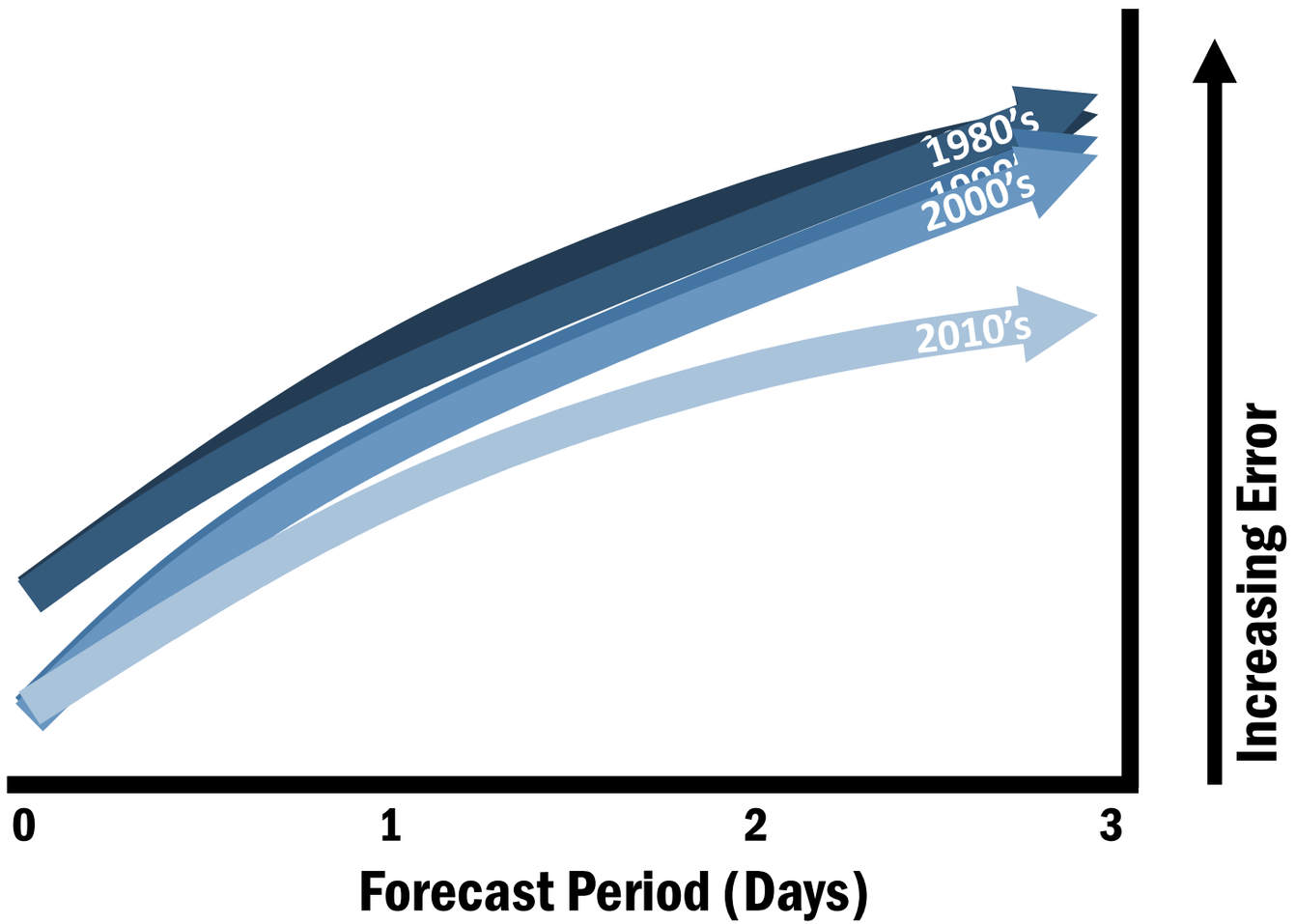
## Hurricanes

- **Track errors increase about 25–30 miles per day**



# Finally, Signs of Improvement

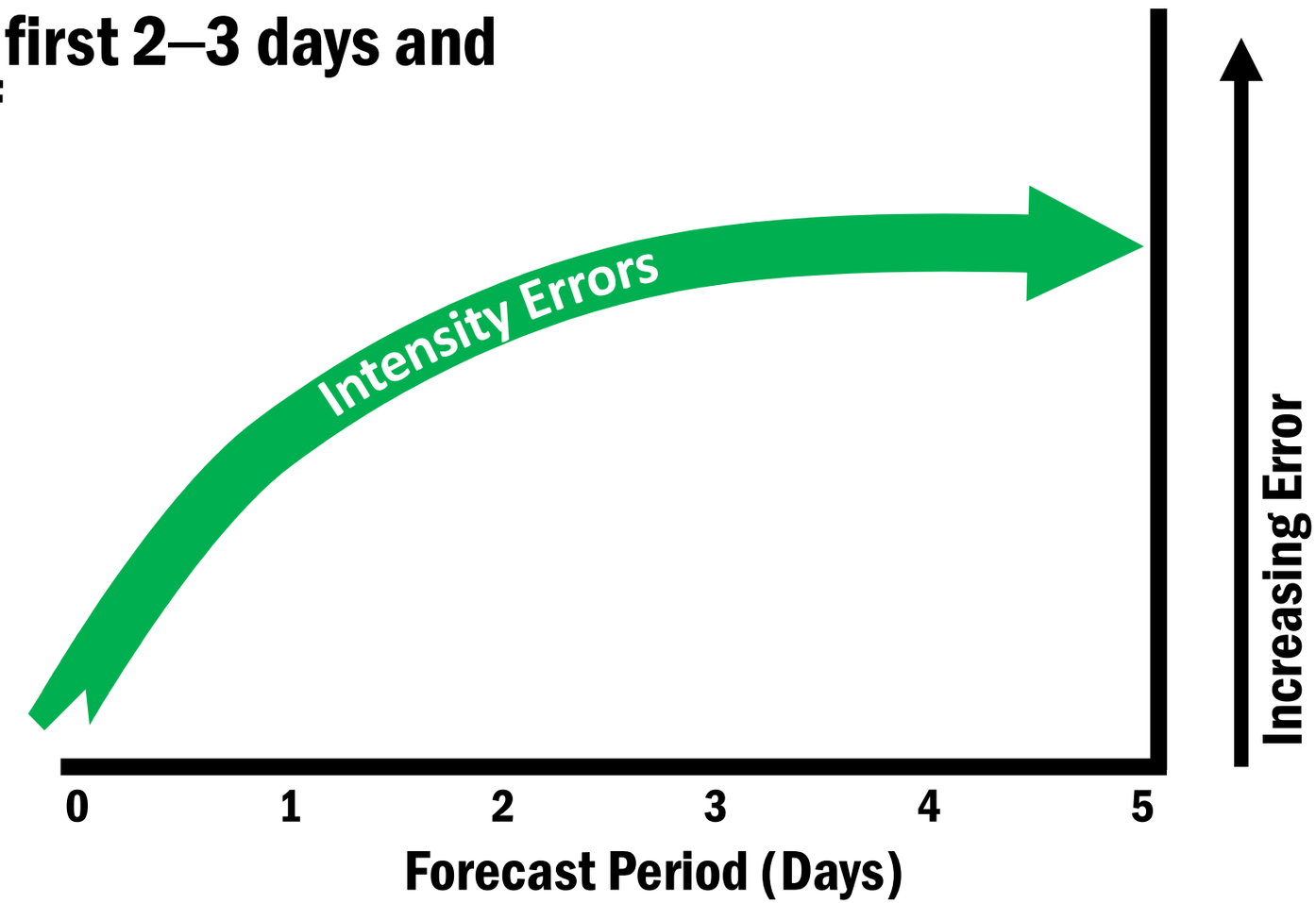
## Forecast Intensity Errors



# Intensity Errors

## Track Errors

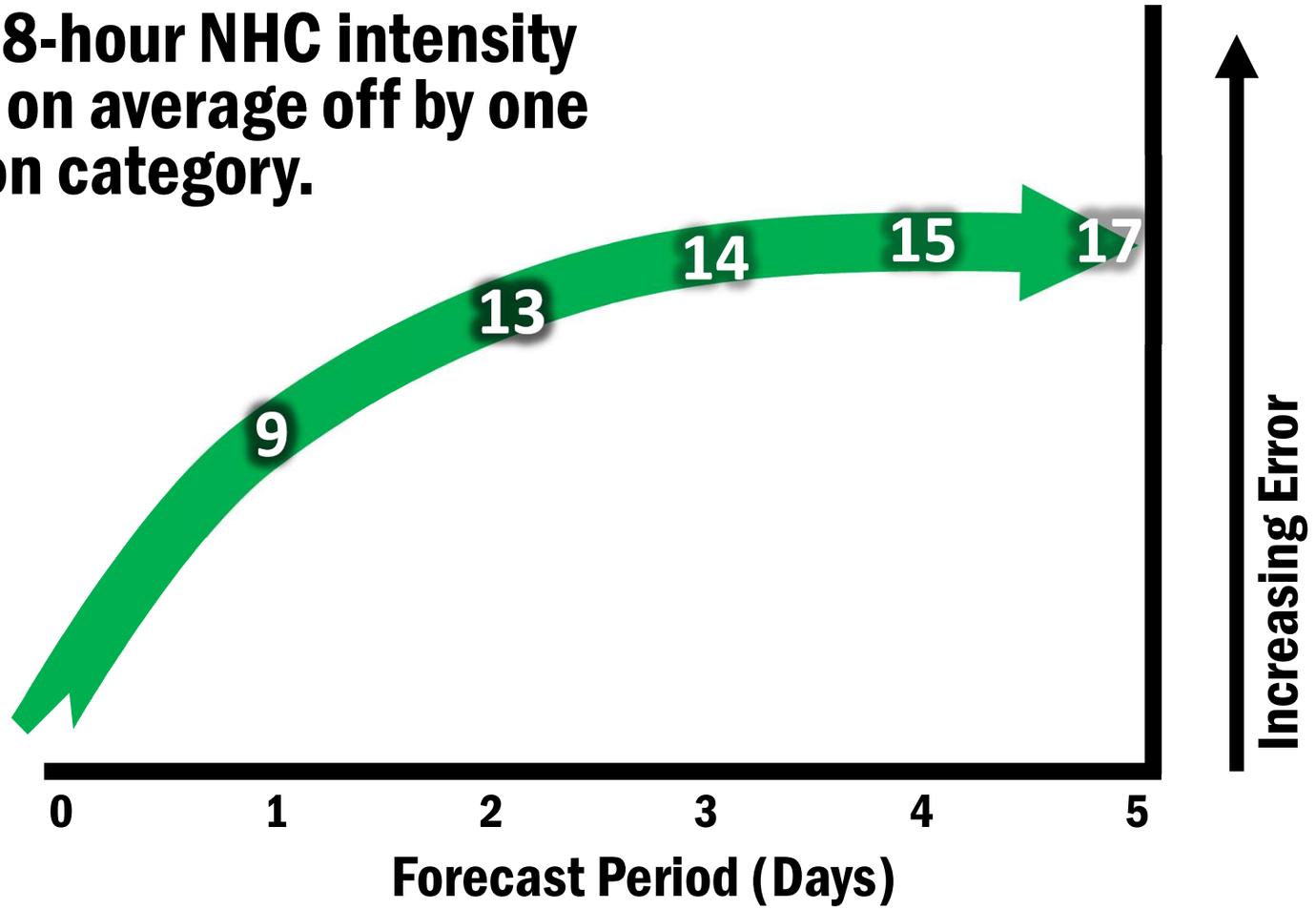
- **Increase the first 2–3 days and then level off**



# Intensity Errors in MPH

## Intensity Errors

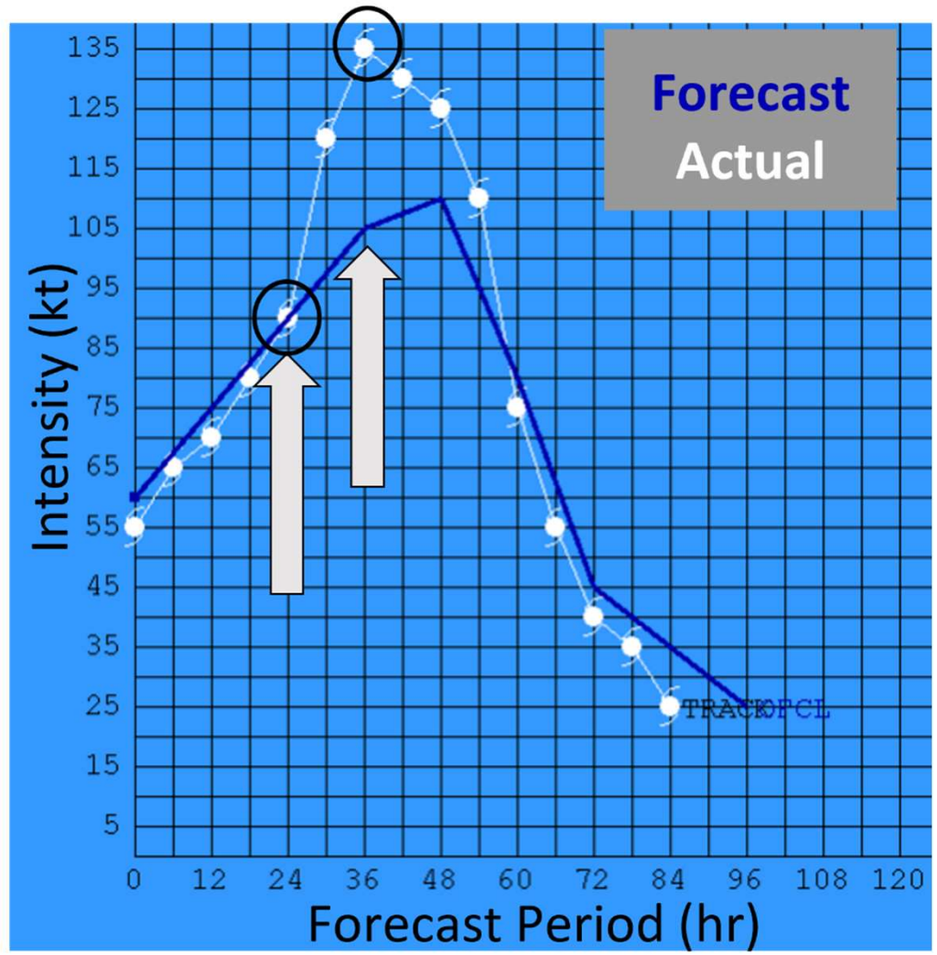
- **The 24- and 48-hour NHC intensity forecasts are on average off by one Saffir-Simpson category.**



# 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**

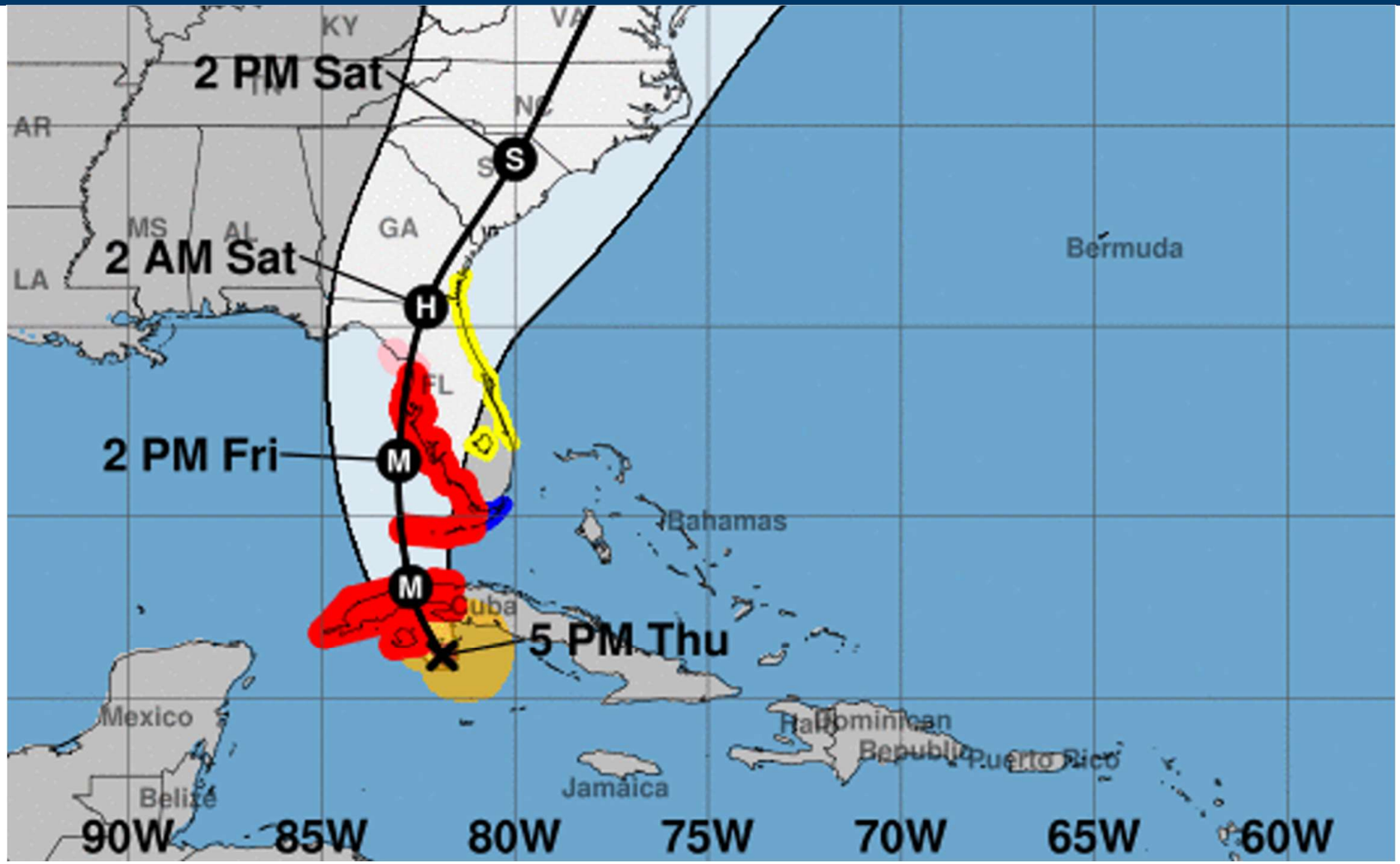



Example: Iota Advisory 7 (2020)

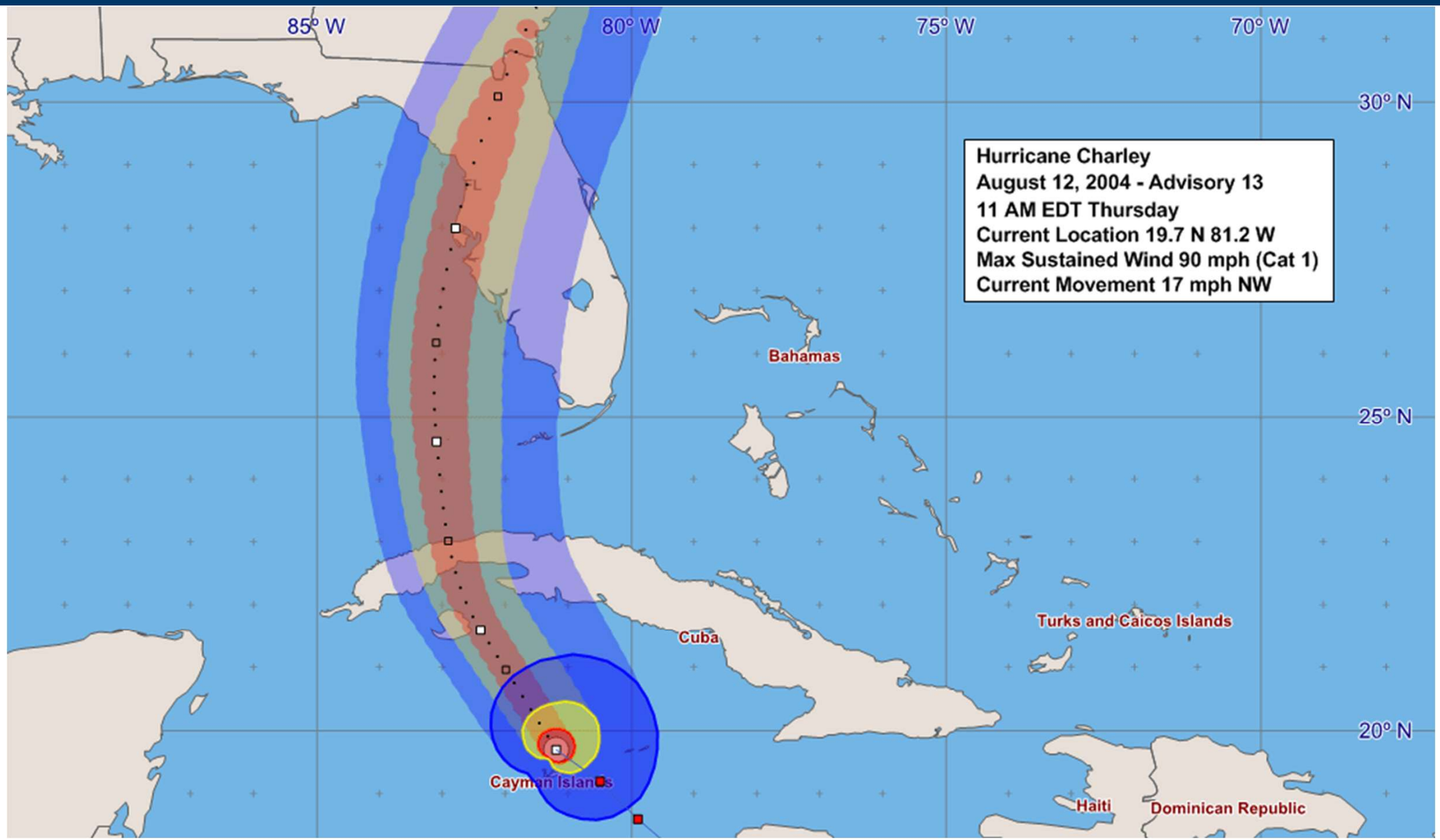
| | |
|---|---|
| Initial Intensity: | 65 mph |
| 24h Forecast: | 105 mph |
| Actual Intensity: | 105 mph |
| **24h Error:** | **0 mph** |

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

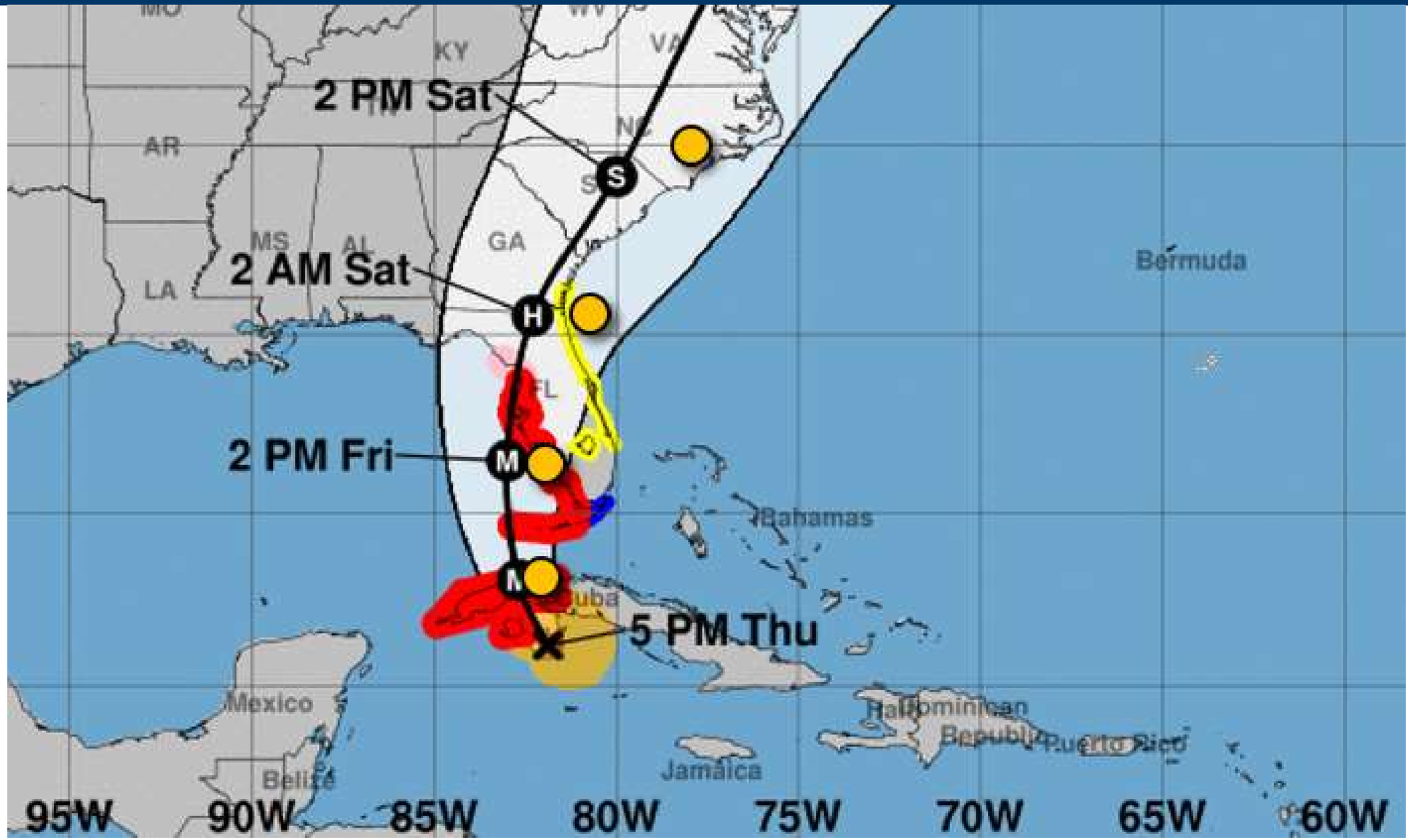
# Don’t Focus on the Skinny Black Line



# Hurricane Charley



# Forecast vs. Observed



# Would Alternate Scenarios Help?

# Wind Speed Probabilities

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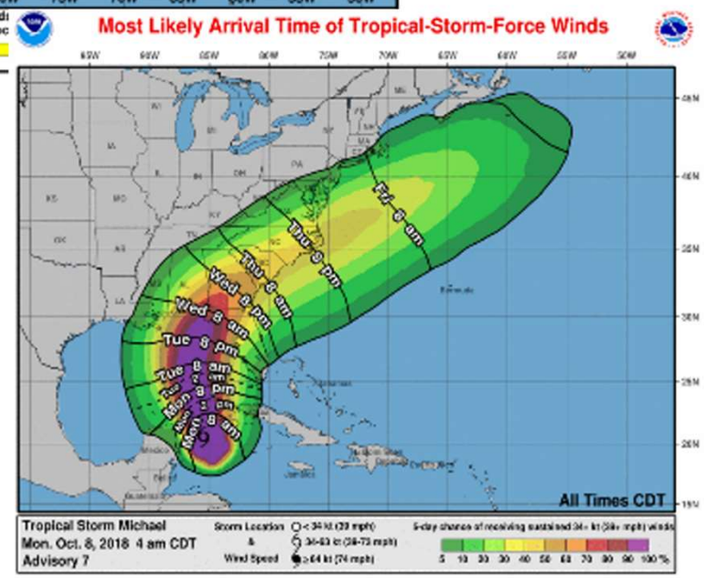
TROPICAL STORM MICHAEL WIND SPEED PROBABILITIES NUMBER 7
NWS NATIONAL HURRICANE CENTER MIAMI FL AL142018
0900 UTC MON OCT 08 2018

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

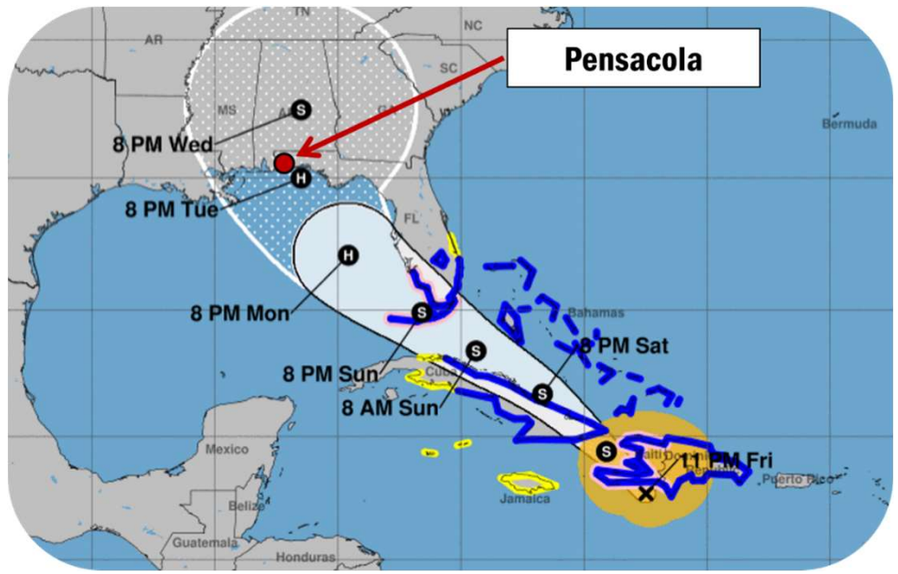
| TIME PERIODS | FROM 06Z MON TO 18Z MON | FROM 18Z MON TO 06Z TUE | FROM 06Z TUE TO 18Z TUE | FROM 18Z TUE TO 06Z WED | FROM 06Z WED TO 06Z THU | FROM 06Z THU TO 06Z FRI | FROM 06Z FRI TO 06Z SAT |
|---|---|---|---|---|---|---|---|
| FORECAST HOUR | (12) | (24) | (36) | (48) | (72) | (96) | (120) |
| 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) |

# WSP – Knowledge Check

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

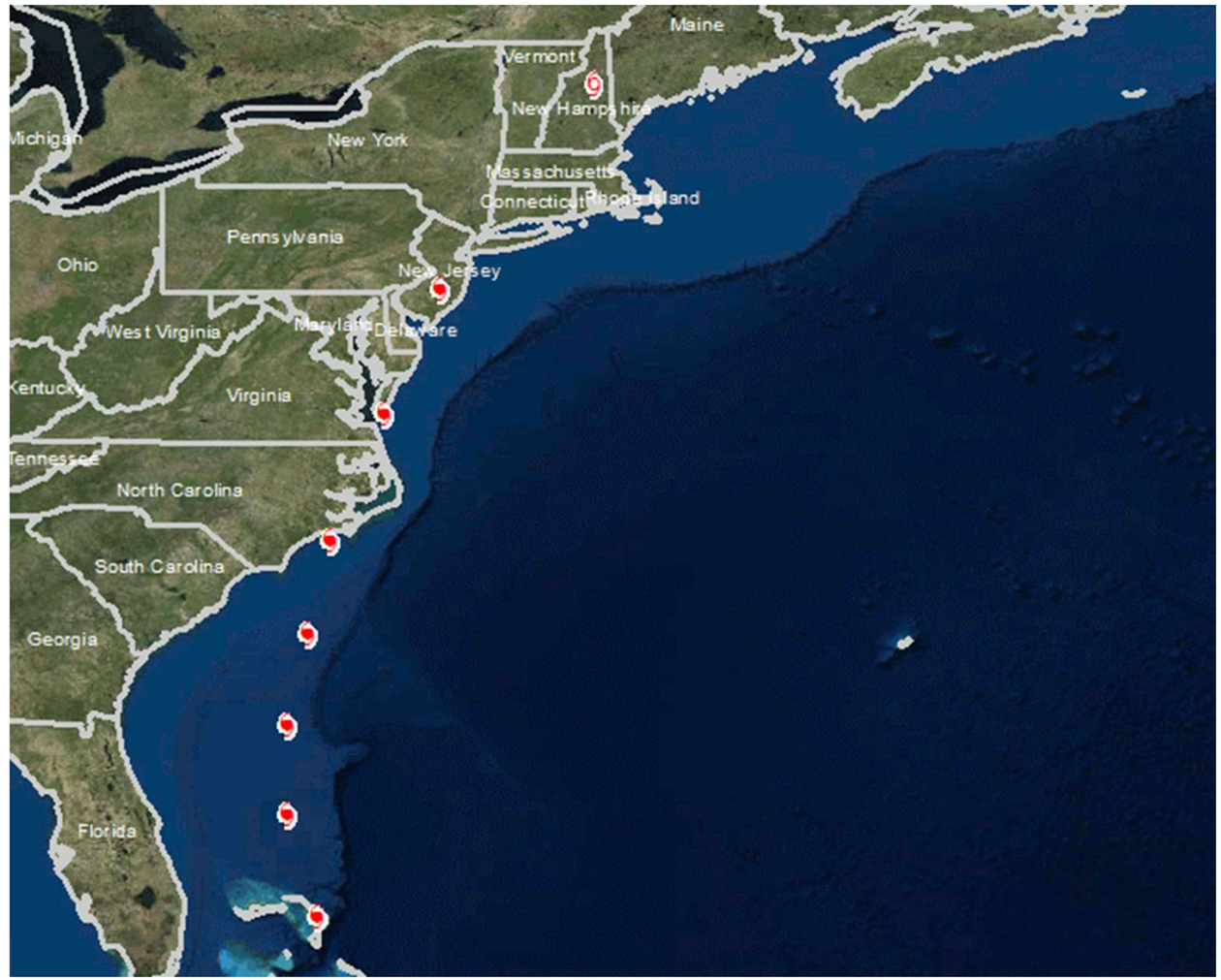
A. 1% to 10%
B. 10% to 20%
C. 20% to 30%
D. 30% to 40%
E. 40% to 50%



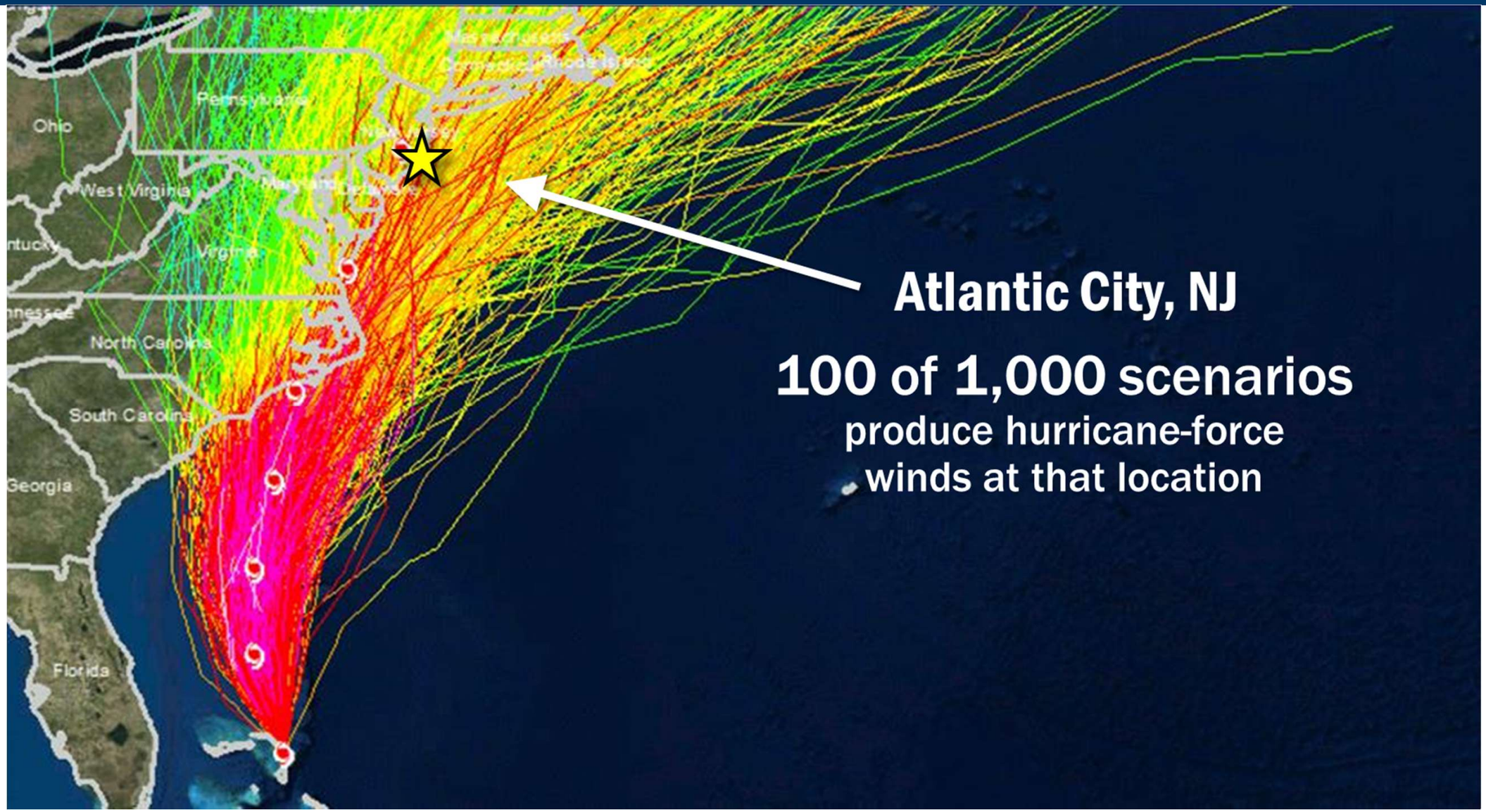
# Generating Probabilities

## More Scenarios

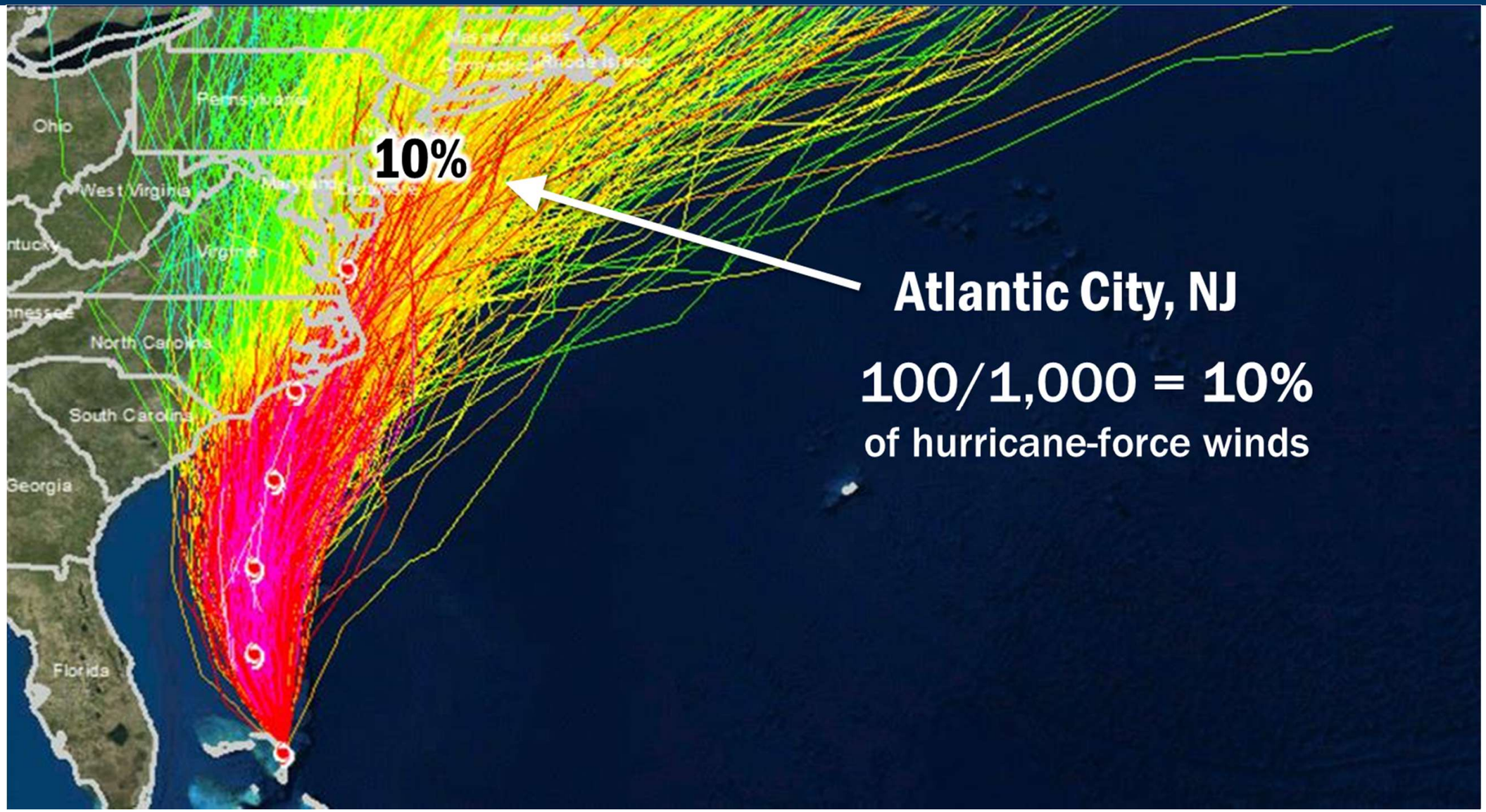
- **1,000 realistic alternate scenarios are generated.**
  - Official NHC forecast
  - Historical track and intensity errors
- **Weakening over land**
- **Track model spread**
  - Forecast track errors are correlated to the spread of the model guidance.



# Generating Probabilities 2



# Generating Probabilities 3



# What Does 10% Chance Mean?

# Location-Specific Probabilities 1

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| 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) |
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| PANAMA CITY FL 64 | X | X( X) | X( X) | 1( 1) | 37(38) | X(38) | X(38) |

**Location-Specific Probabilities**

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

# Location-Specific Probabilities 2

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**Location-Specific Probabilities**

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

# Location-Specific Probabilities 3

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

**Location-Specific Probabilities**

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

# Onset Probabilities

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|---|---|---|---|---|---|---|---|
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| 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) |
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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) |

**Onset Probabilities**

- Timing information

# Cumulative Probabilities

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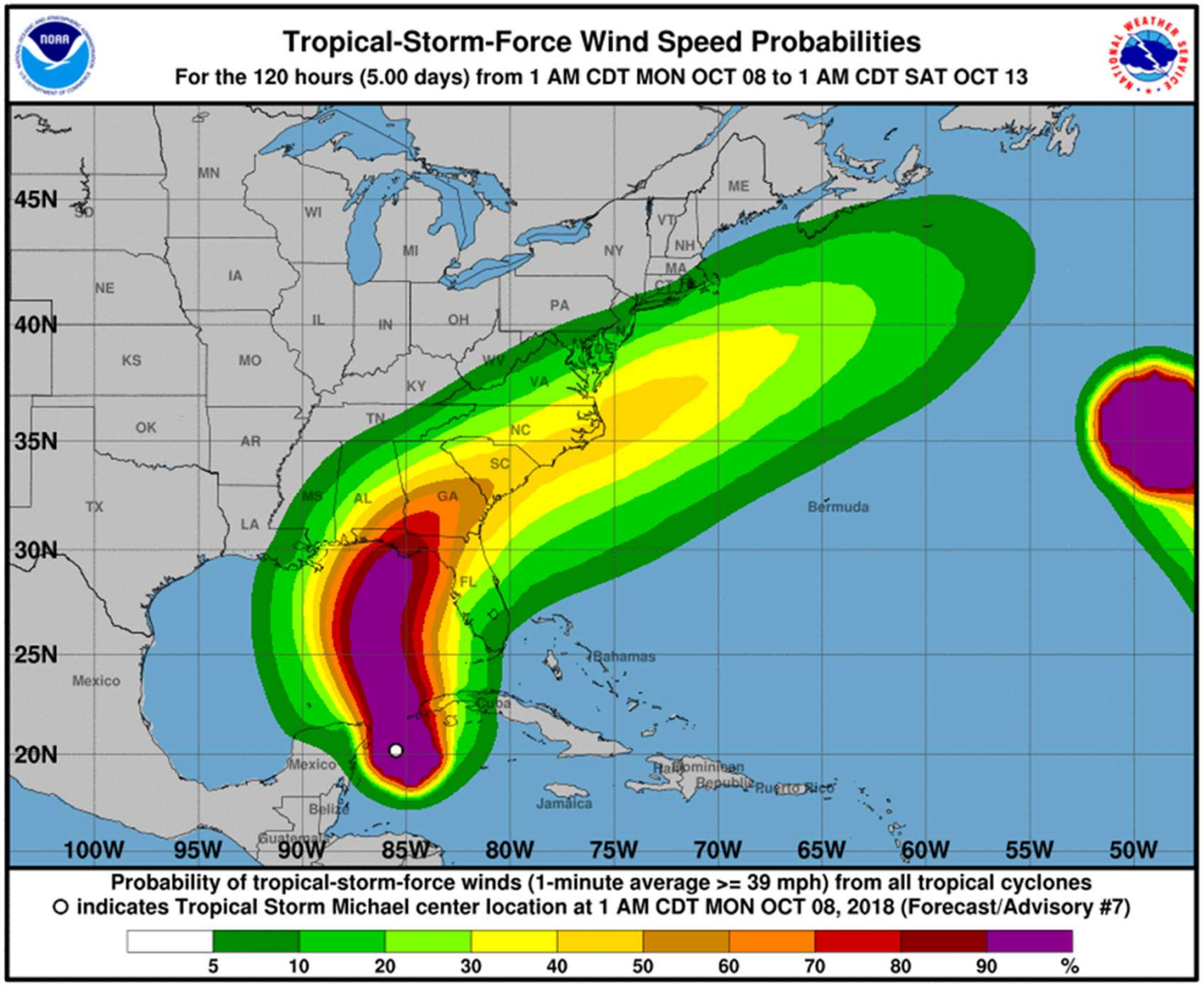
|---|---|---|---|---|---|---|---|---|
| FORECAST HOUR | | (12) | (24) | (36) | (48) | (72) | (96) | (120) |
| LOCATION | KT | | | | | | | |
| TALLAHASSEE FL | 34 | X | X( X) | 1( 1) | 6( 7) | 68(75) | 6(81) | X(81) |
| TALLAHASSEE FL | 50 | X | X( X) | X( X) | 1( 1) | 41(42) | 6(48) | X(48) |
| TALLAHASSEE 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) |

**Cumulative Probabilities**

- Total chance through the time period

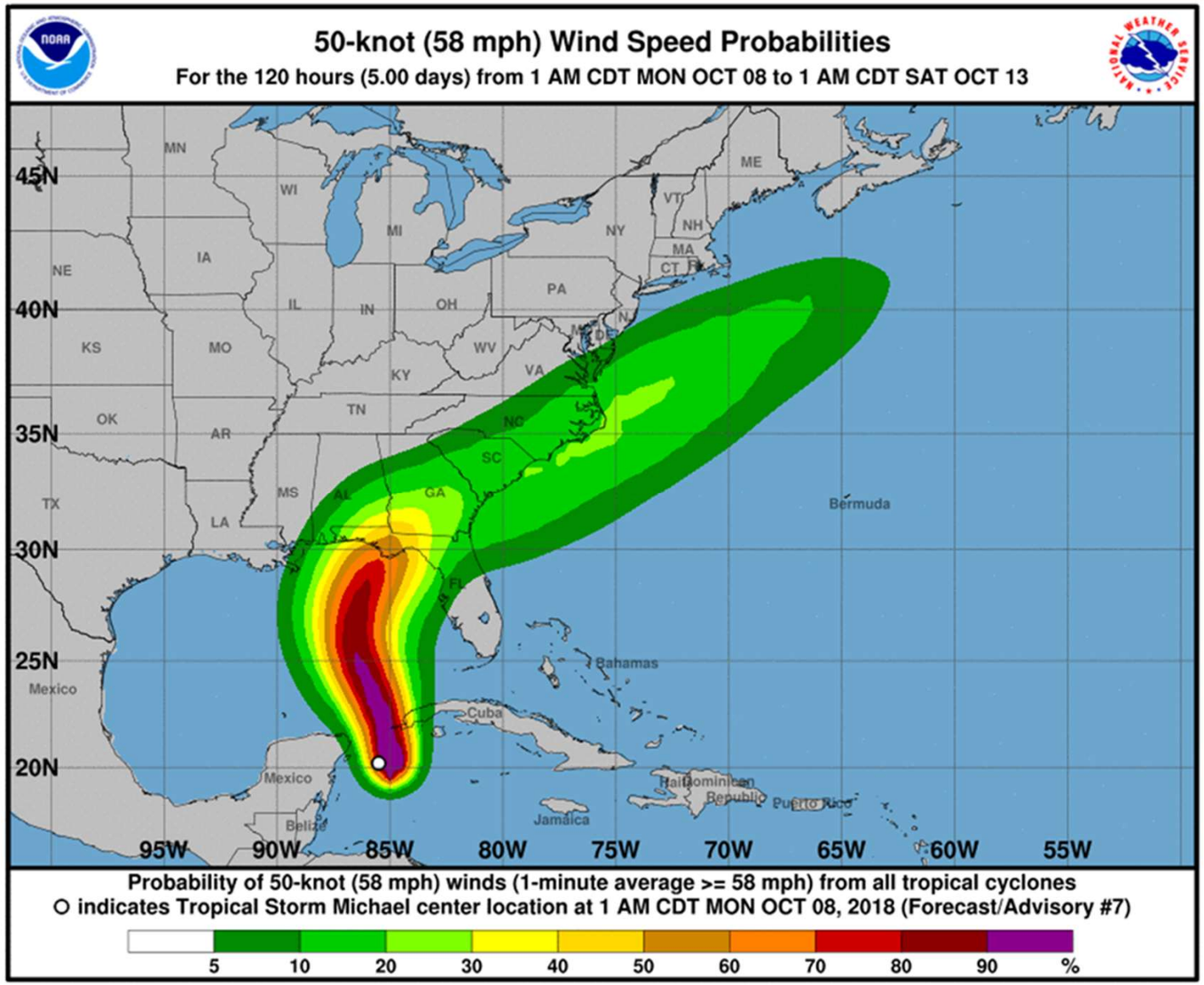
# 5-Day Cumulative Graphic: TS-Force




## Location-Specific Probabilities

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

# 5-Day Cumulative Graphic: 58 mph




## Location-Specific Probabilities

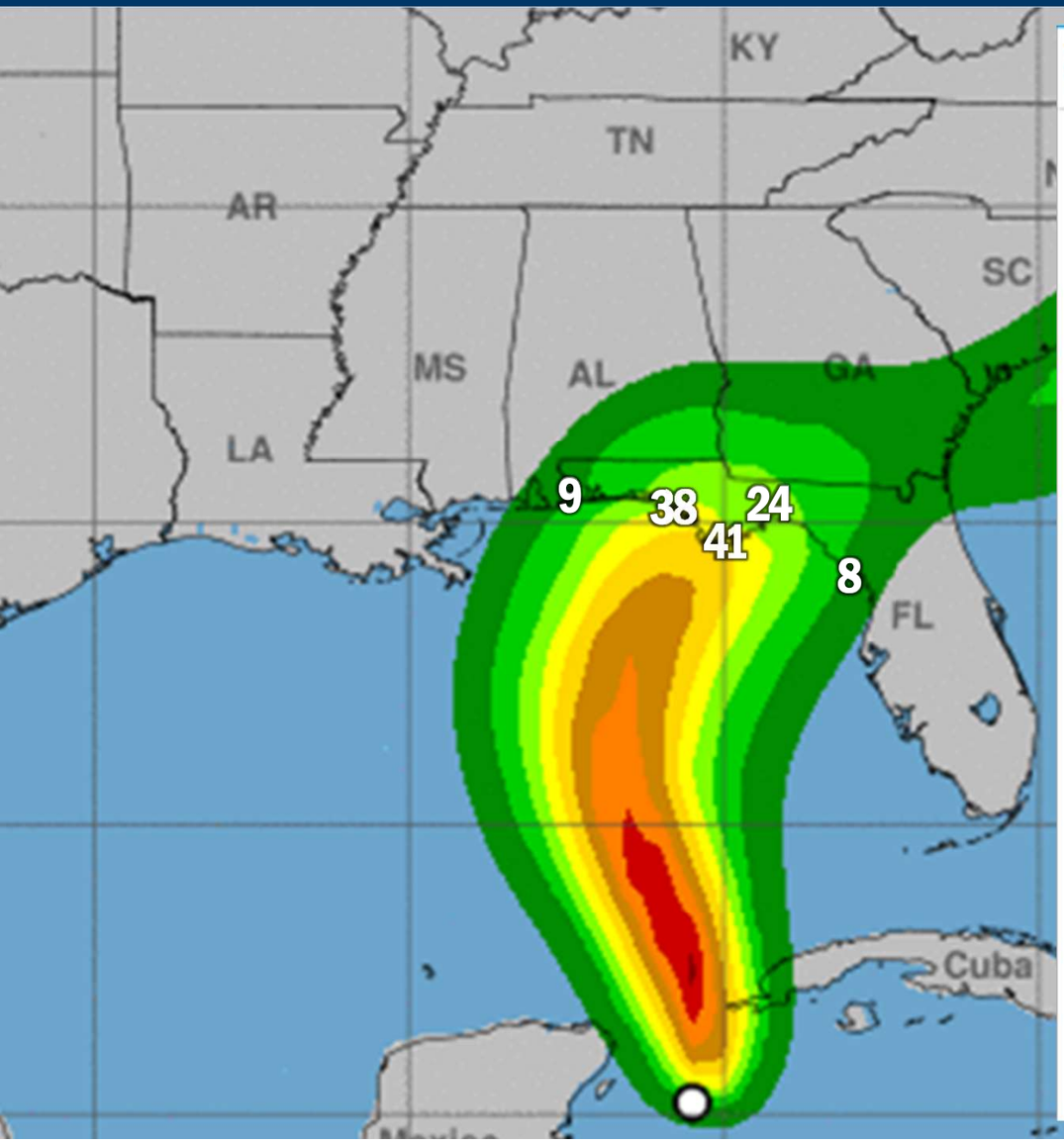
- Tropical-Storm-Force
- 58 mph
- Hurricane-Force

# 5-Day Cumulative Graphic: Hurricane


**Location-Specific Probabilities**

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

# Location-Specific Probabilities 4

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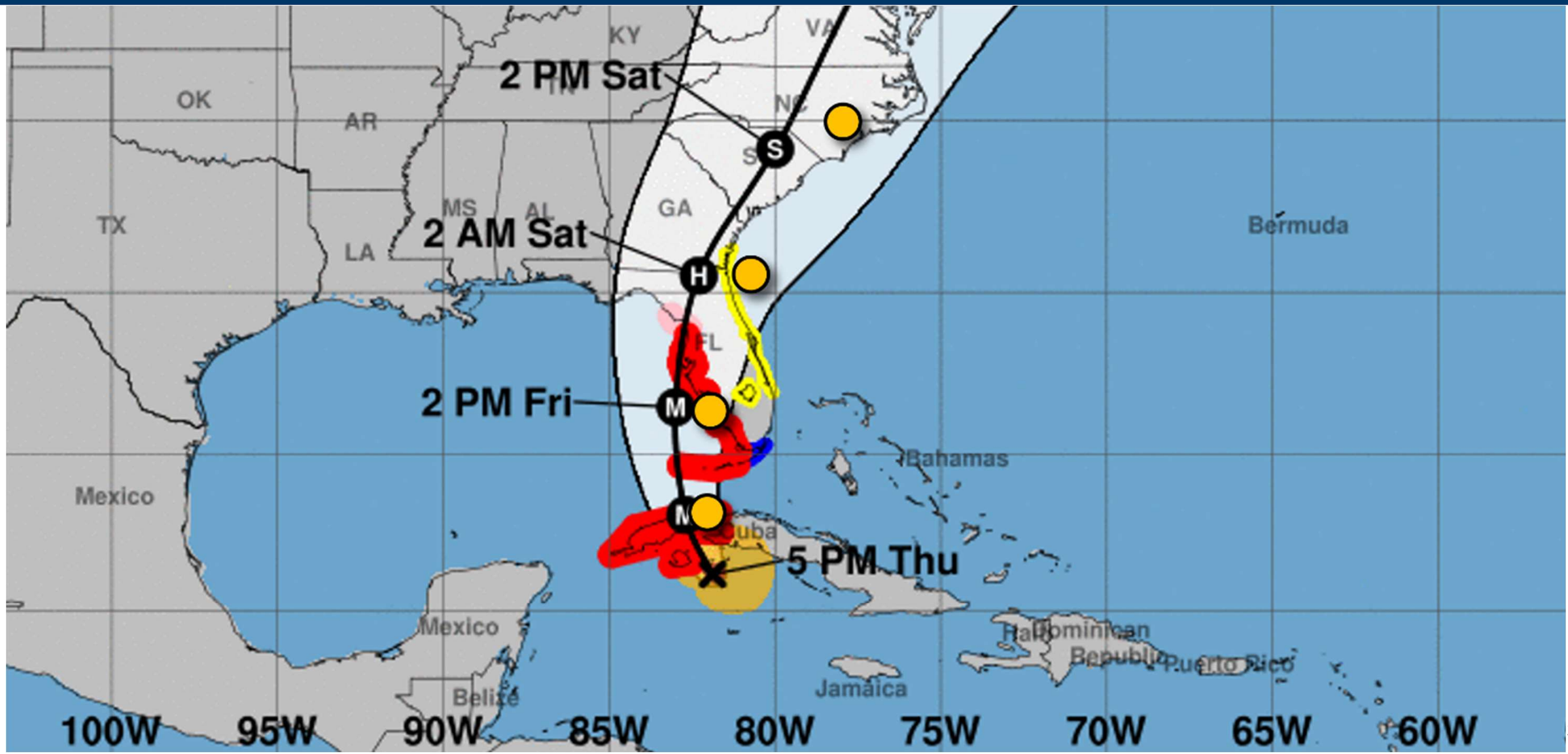
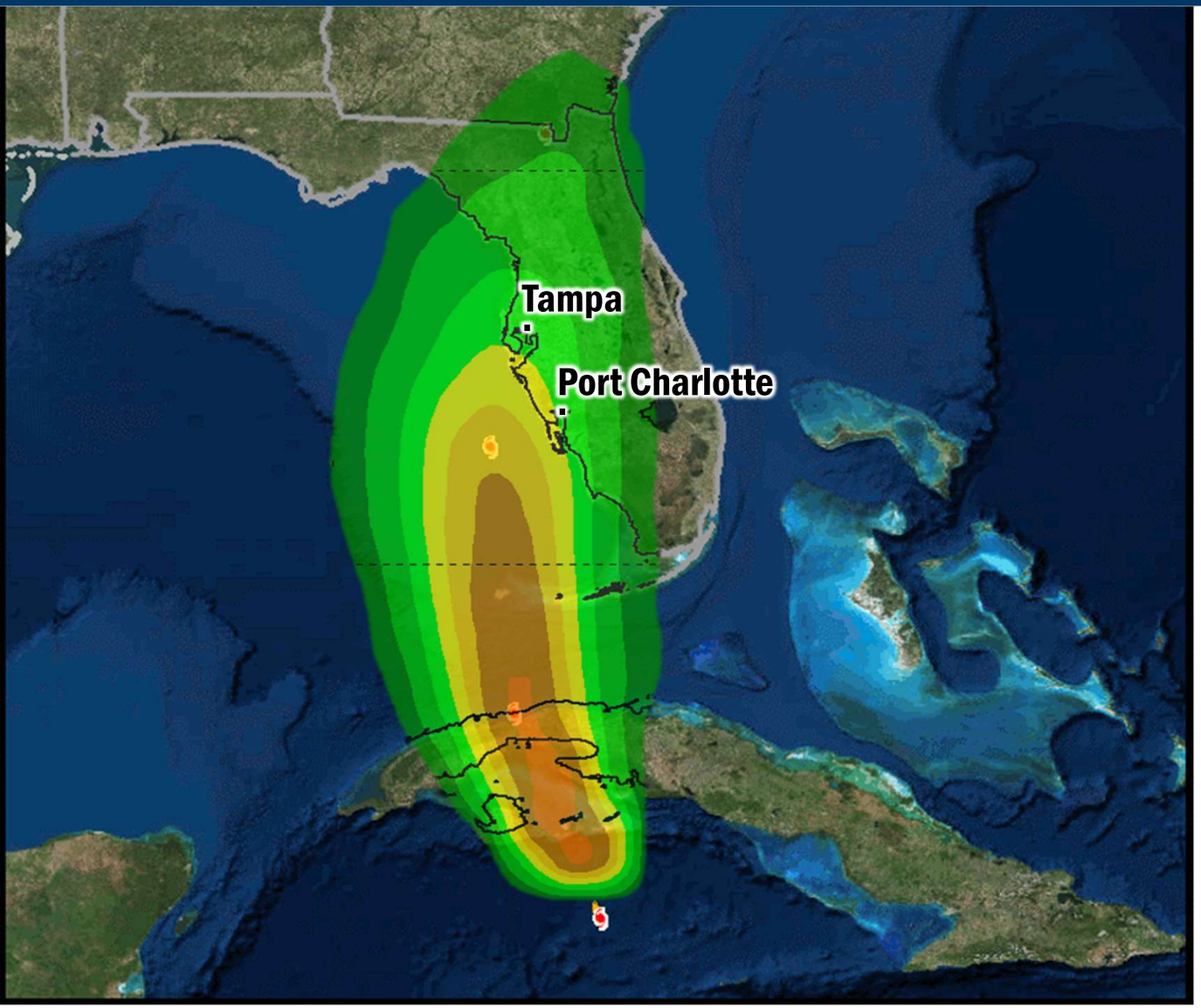
|---|---|---|---|---|---|---|---|---|
| FORECAST HOUR | | (12) | (24) | (36) | (48) | (72) | (96) | (120) |
| LOCATION | KT | | | | | | | |
| CEDAR KEY FL | 34 | X | X( X) | 3( 3) | 15(18) | 43(61) | 2(63) | X(63) |
| CEDAR KEY FL | 50 | X | X( X) | X( X) | 1( 1) | 20(21) | 1(22) | X(22) |
| CEDAR KEY 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) |
| 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) |
| 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



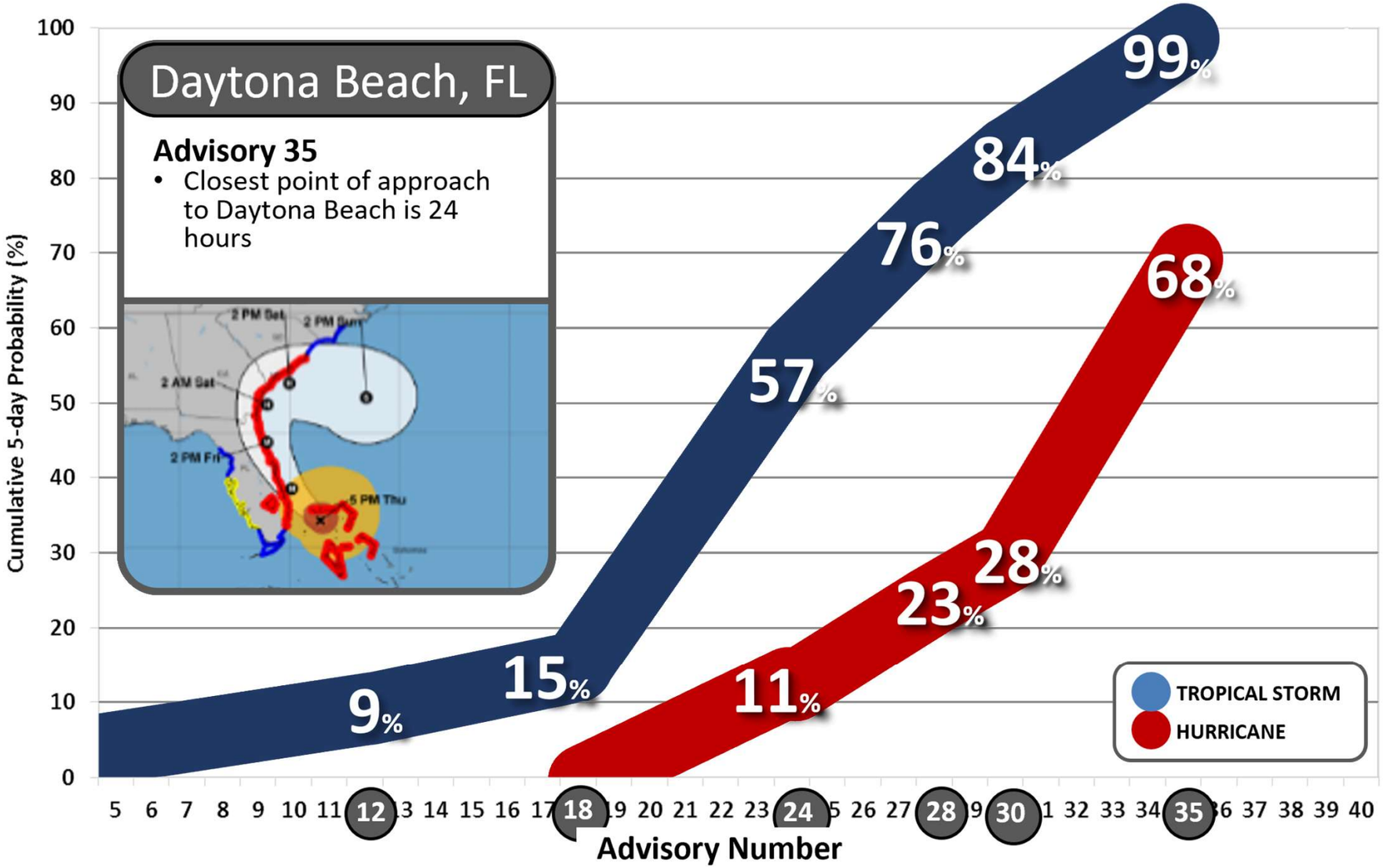
# Would Alternate Scenarios Help? 2

# Would Alternate Scenarios Help? 3




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

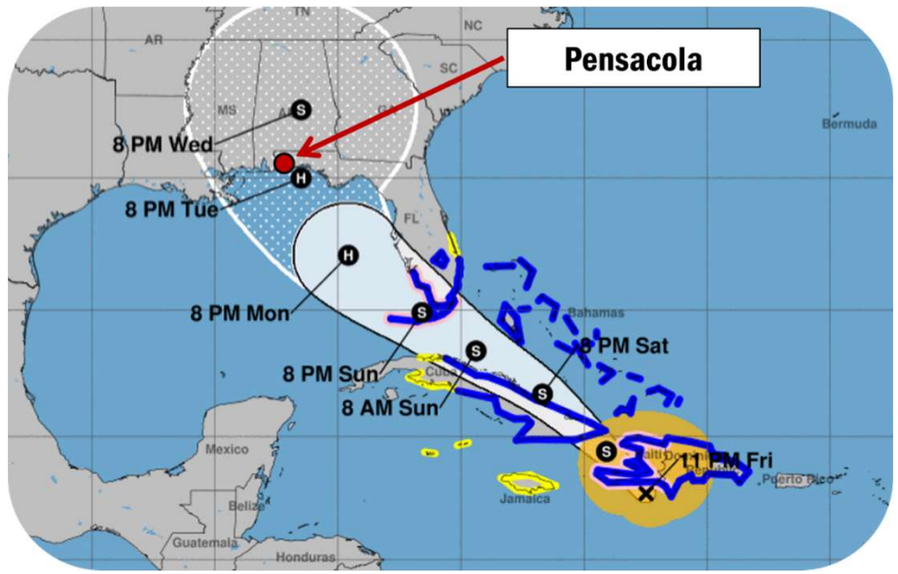
# Hurricane Matthew (2016)



# WSP – Knowledge Check Revisit

**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%



# Wind Timing Importance and Causes

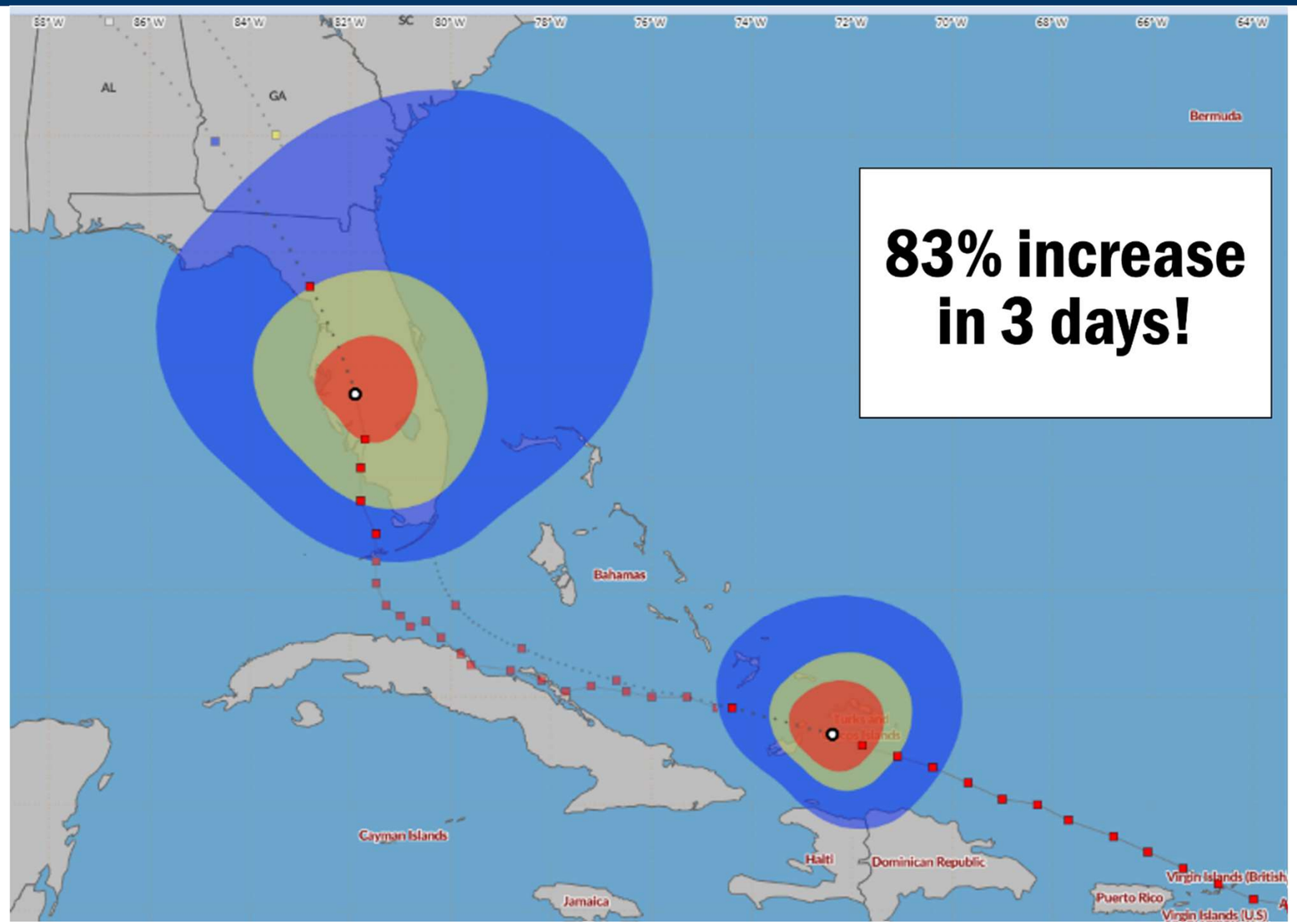
## Uncertainty in Wind Timing

- **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

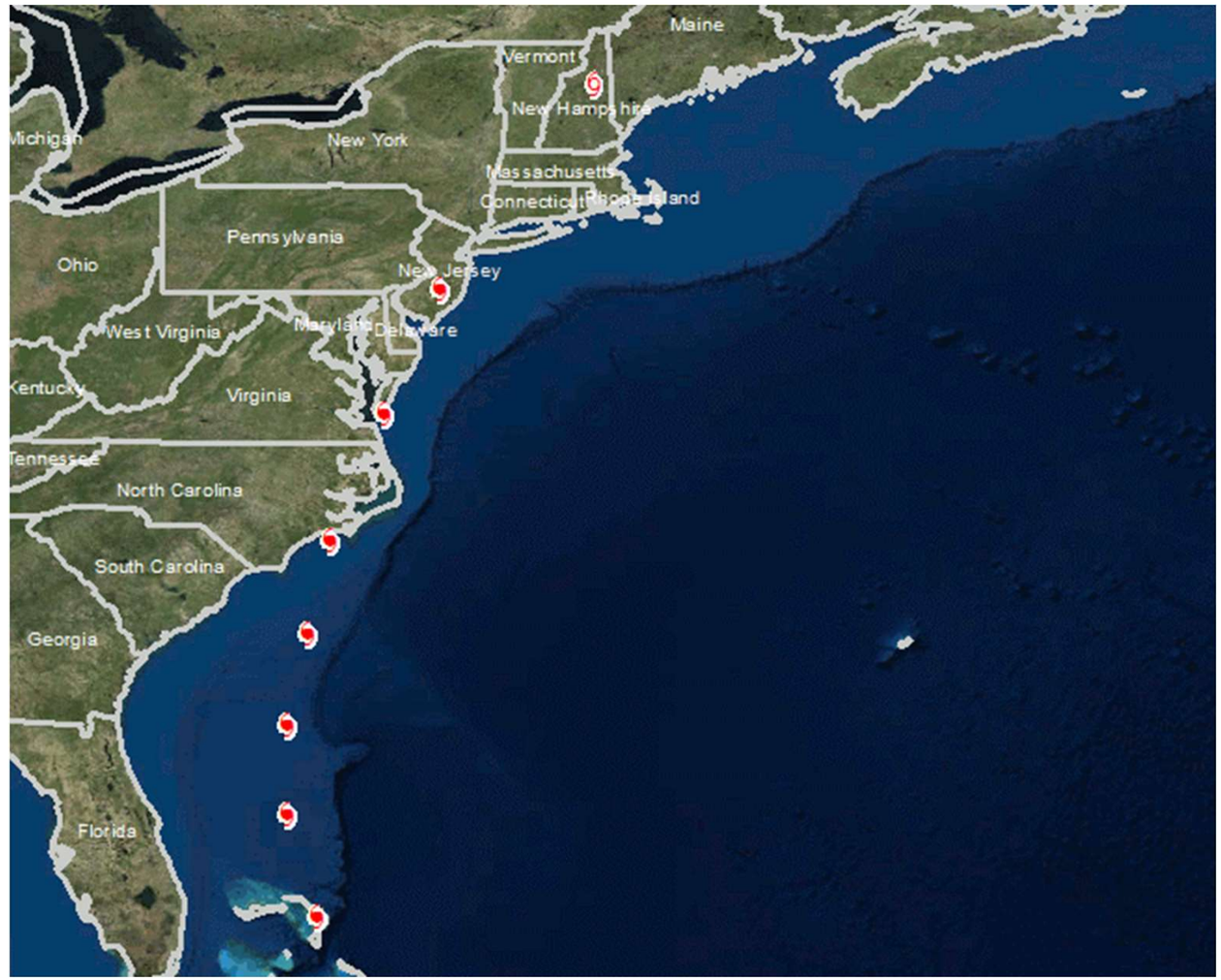


# Generating Time of Arrival Graphics

## More Scenarios

- **1,000 realistic alternate scenarios are generated.**
  - Official NHC forecast and historical errors
  - Weakening over land
  - Track model spread

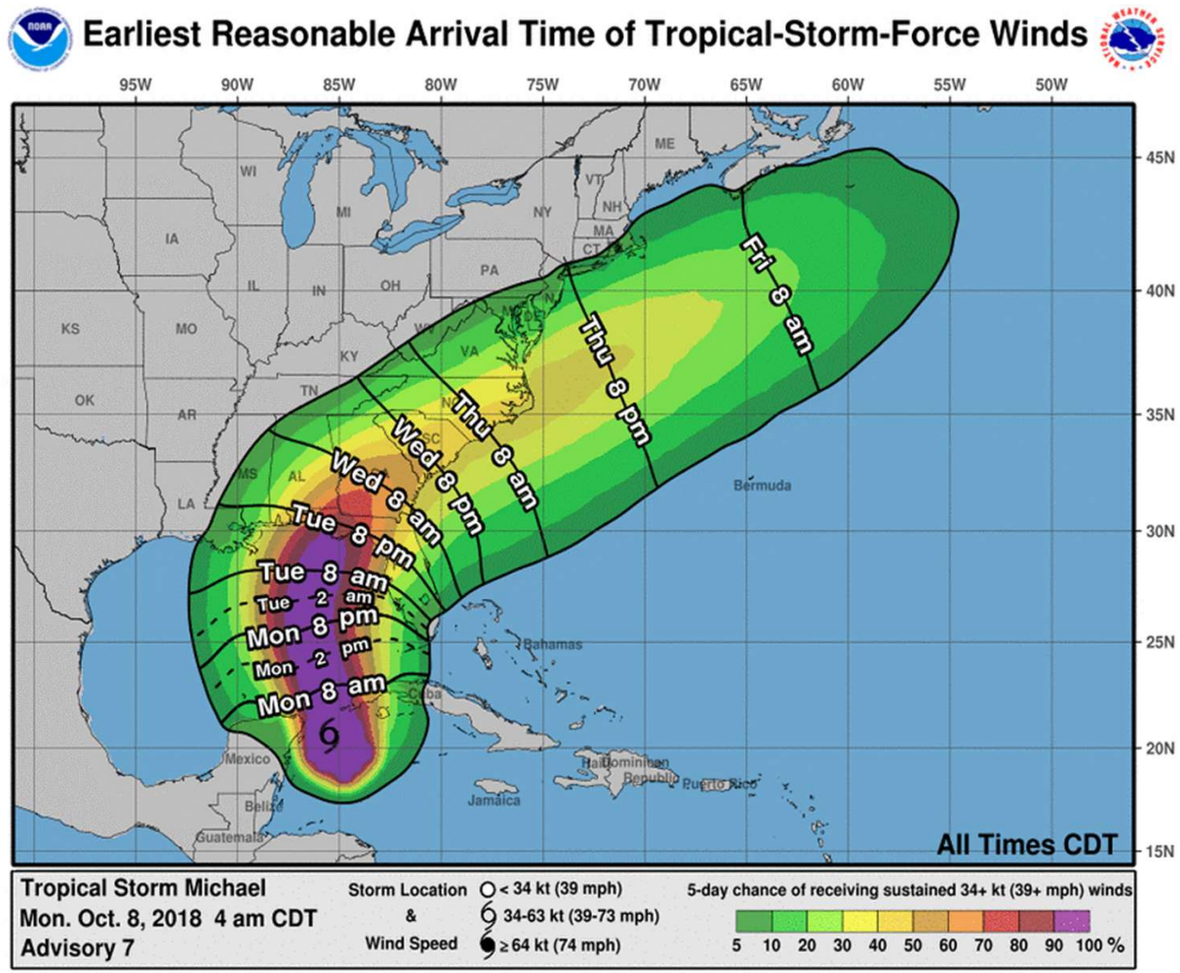
- **Produces information about:**
  - Chance of wind occurring
  - Probabilistic onset timing



# Earliest Reasonable Onset

## Earliest Reasonable

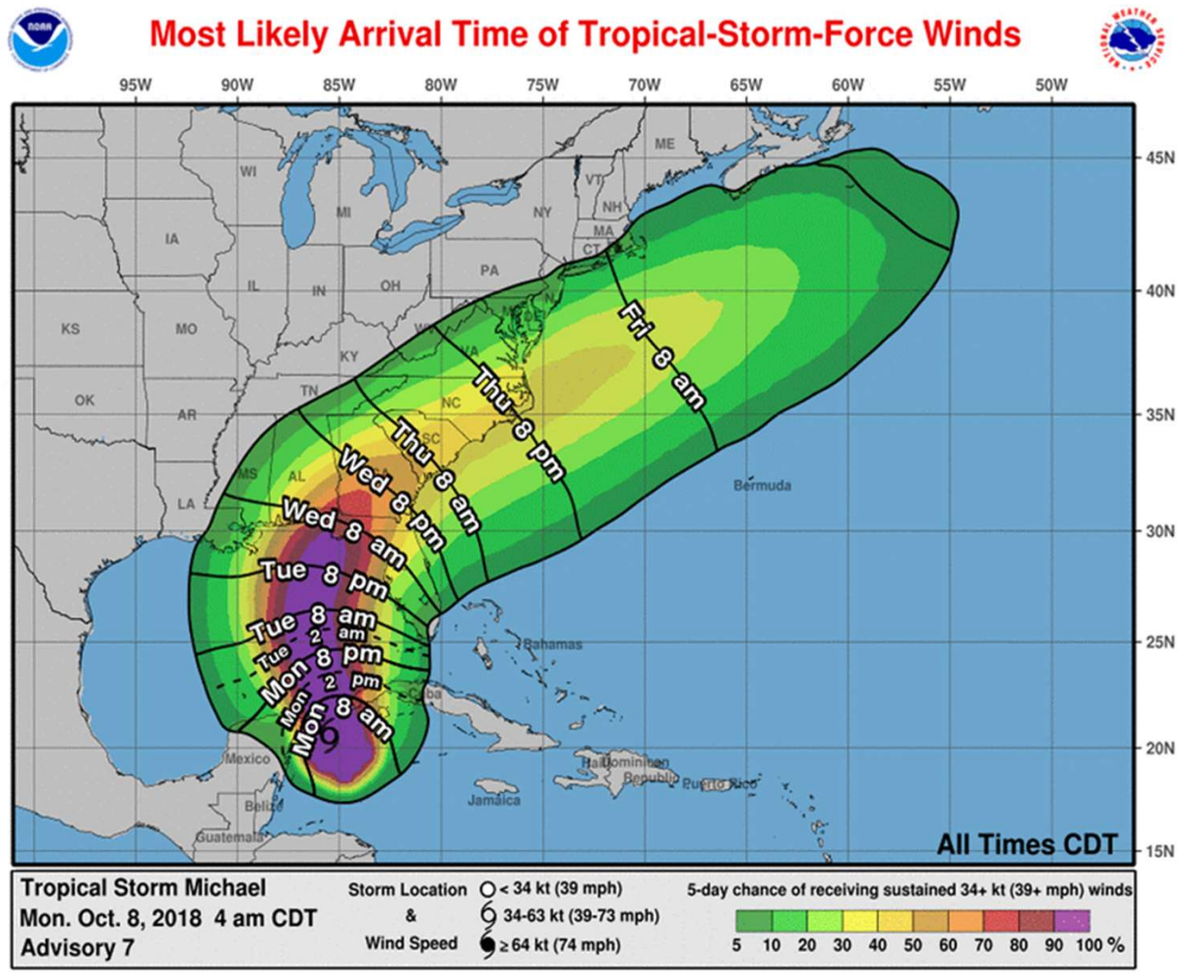
- **10% chance of onset**
  - Most conservative timing
- **Arrival Time of TS winds**
  - Black contours
- **5-day cumulative TS probabilities**
  - Color filled



# Most Likely Onset

## Most Likely

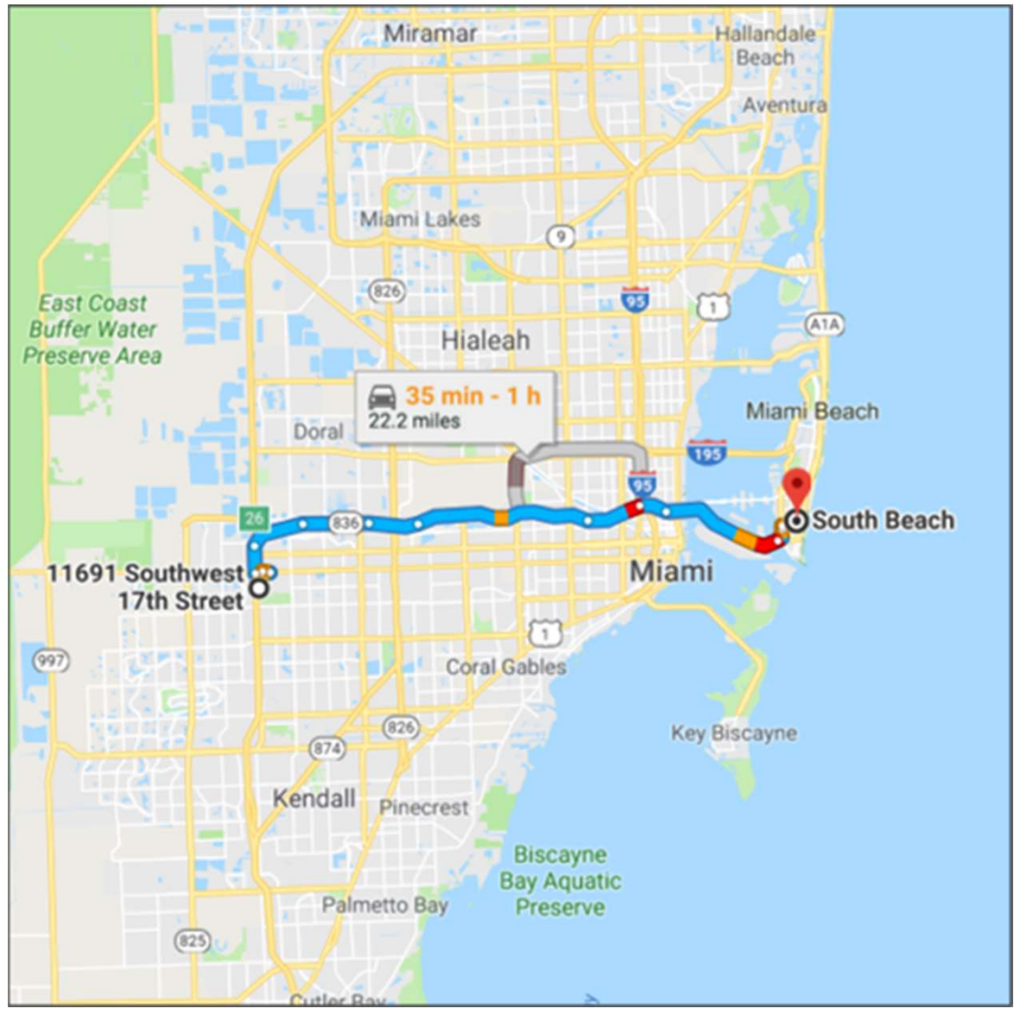
- **50% chance of onset**
  - Equally likely to occur before as after
- **Arrival Time of TS winds**
  - Black contours
- **5-day cumulative TS probabilities**
  - Color filled



# NHC – South Beach

## Timing Uncertainty

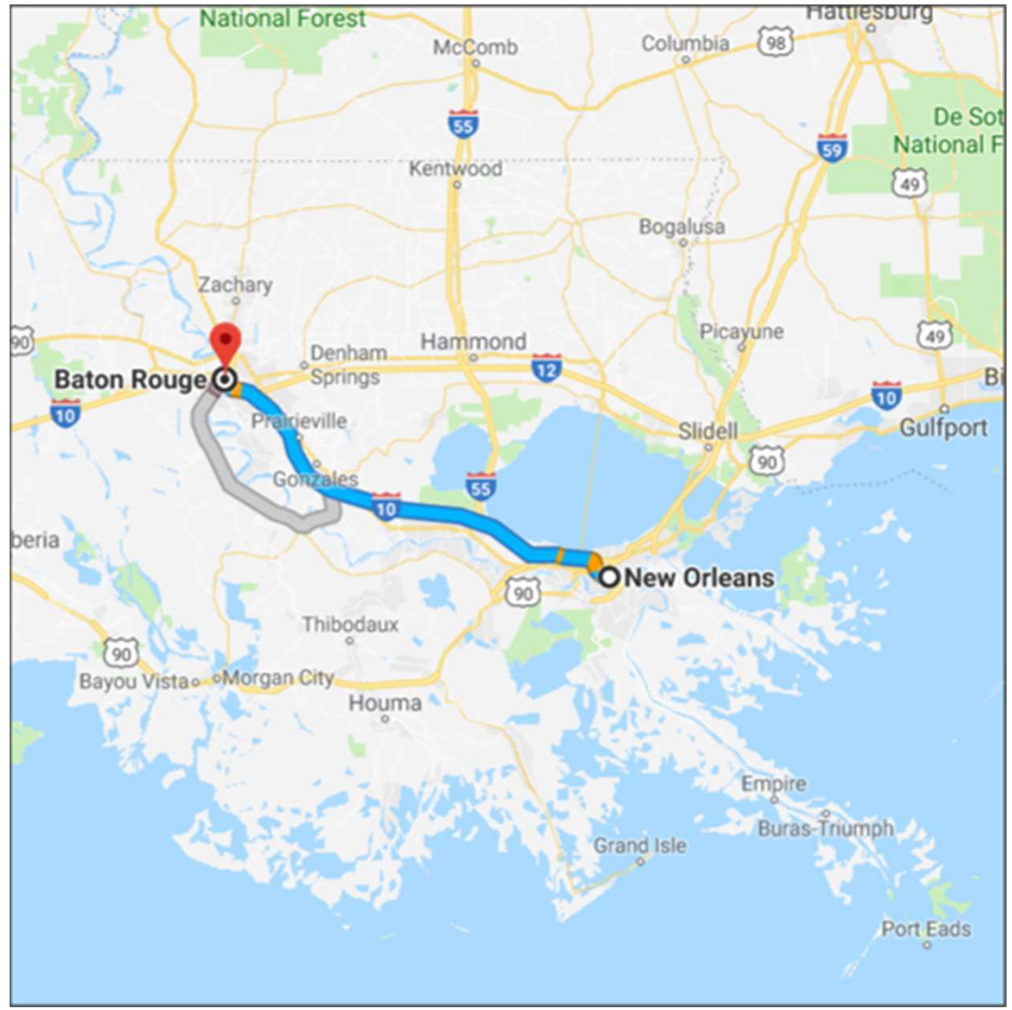
- **Earliest Reasonable**
  - Absolutely must be there by 5 p.m.
  - Leave by 4:10 p.m. (50 min)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 4:34 p.m. (26 min)
- **Window to leave: 24 min**
  - 4:10 p.m. to 4:34 p.m.



# New Orleans – Baton Rouge

## Timing Uncertainty

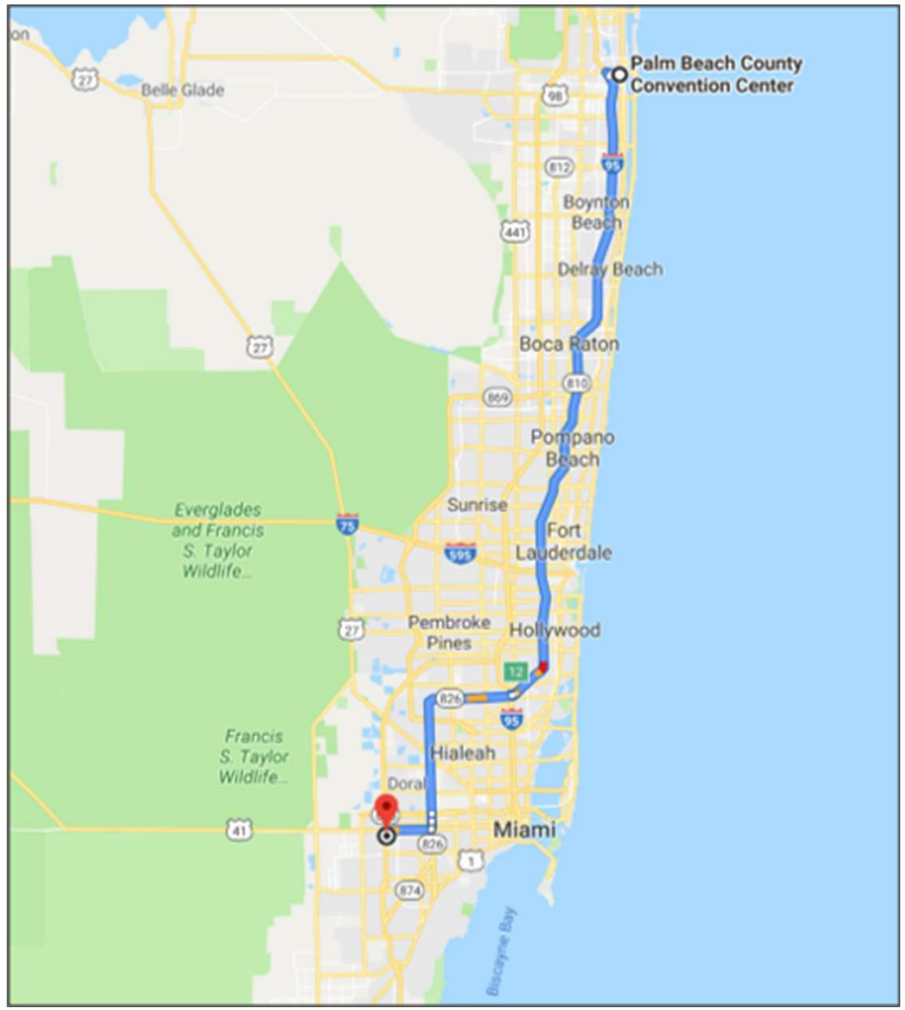
- **Earliest Reasonable**
  - Absolutely must be there by 5 p.m.
  - Leave by 4:10 p.m. (50 min)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 4:34 p.m. (26 min)
- **Window to leave: 24 min**
  - 4:10 p.m. to 4:34 p.m.



# GHC – National Hurricane Center

## Timing Uncertainty

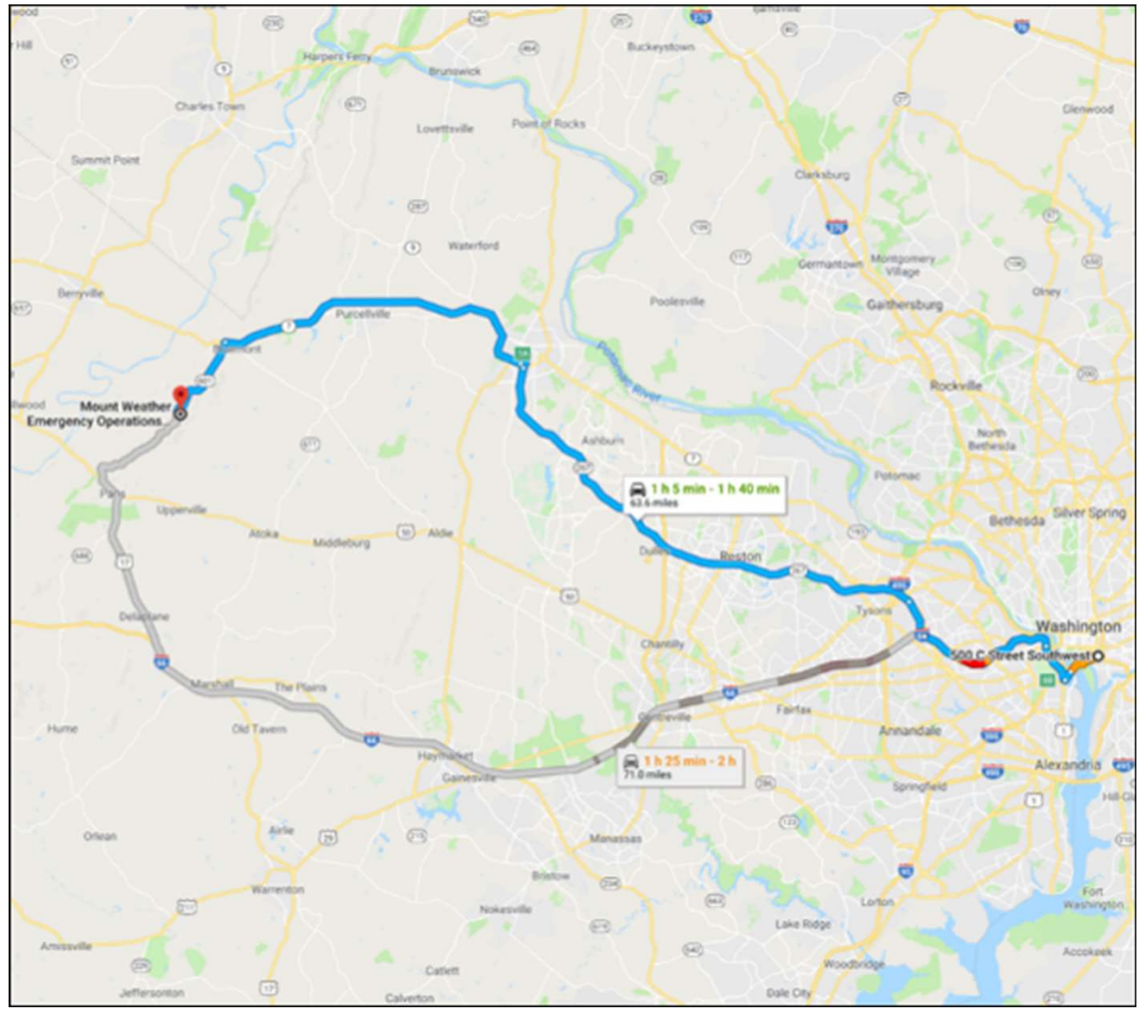
- **Earliest Reasonable**
  - Absolutely must be there by 3 p.m.
  - Leave by 1 p.m. (2 hrs)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 1:35 p.m. (1 hr 25 min)
- **Window to leave: 35 min**
  - 1 p.m. to 1:35 p.m.



# FEMA HQ – Mt. Weather

## Timing Uncertainty

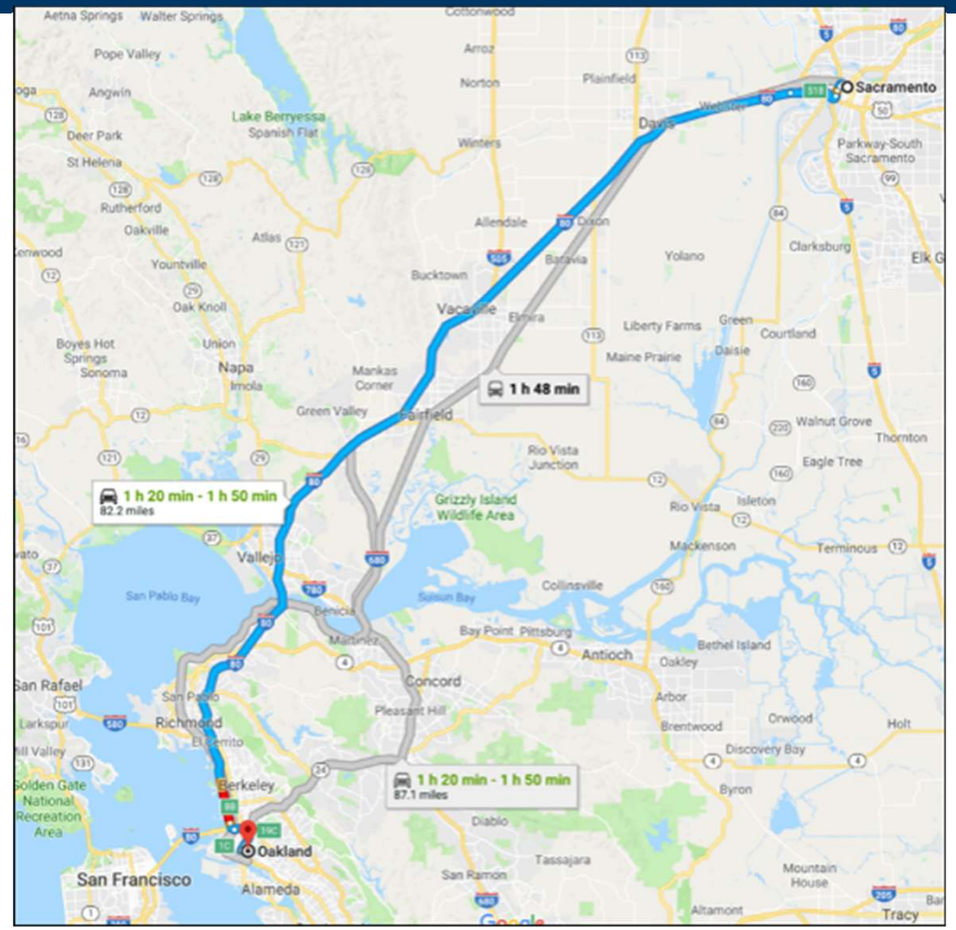
- **Earliest Reasonable**
  - Absolutely must be there by 4 p.m.
  - Leave by 2:20 p.m. (1 h 40 min)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 2:55 p.m. (1 h 5 min)
- **Window to leave: 35 min**
  - 2:20 p.m. to 2:55 p.m.



# Sacramento, CA – Oakland, CA

## Timing Uncertainty

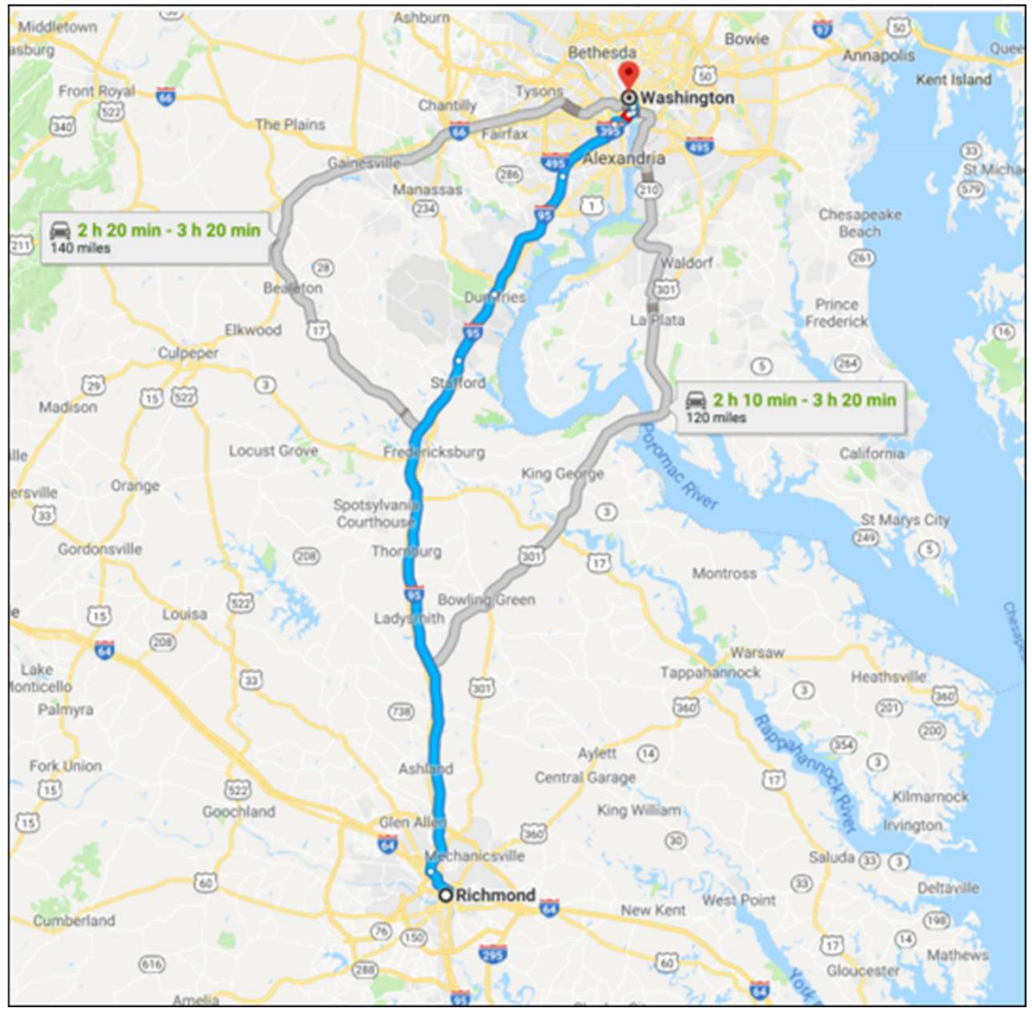
- **Earliest Reasonable**
  - Absolutely must be there by 3 p.m.
  - Leave by 1:10 p.m. (1 h 50 min)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 1:40 p.m. (1 h 20 min)
- **Window to leave: 30 min**
  - 1:10 p.m. to 1:40 p.m.



# Richmond, VA – Washington, DC

## Timing Uncertainty

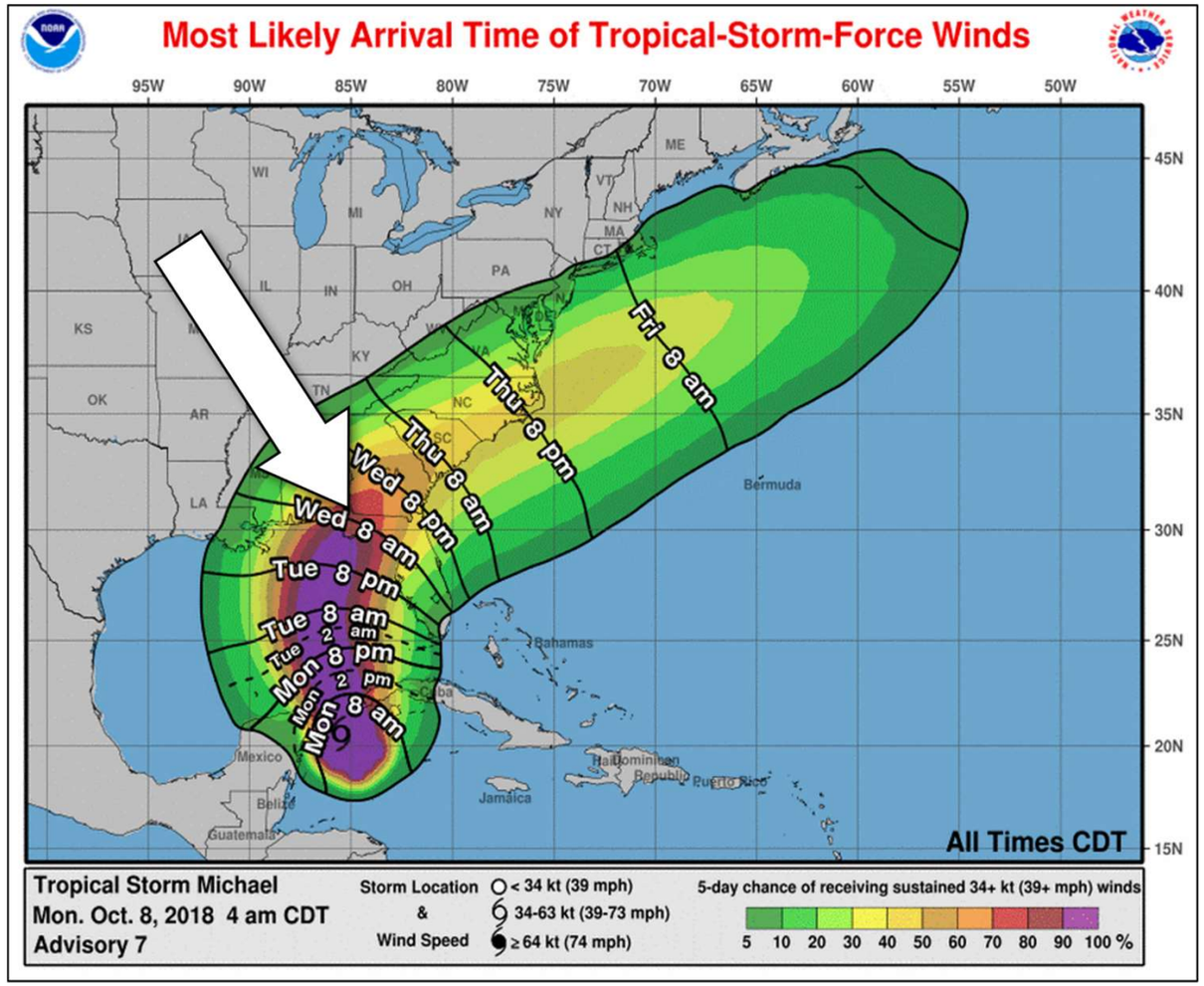
- **Earliest Reasonable**
  - Absolutely must be there by 5 p.m.
  - Leave by 1:40 p.m. (3 h 20 min)
- **Most Likely**
  - Some wiggle room
  - Can afford to be a little late if traffic
  - Leave by 2:44 p.m. (2 h 20 min)
- **Window to leave: 1 h**
  - 1:40 p.m. to 2:40 p.m.



# Hurricane Michael - Tallahassee FL

## 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.



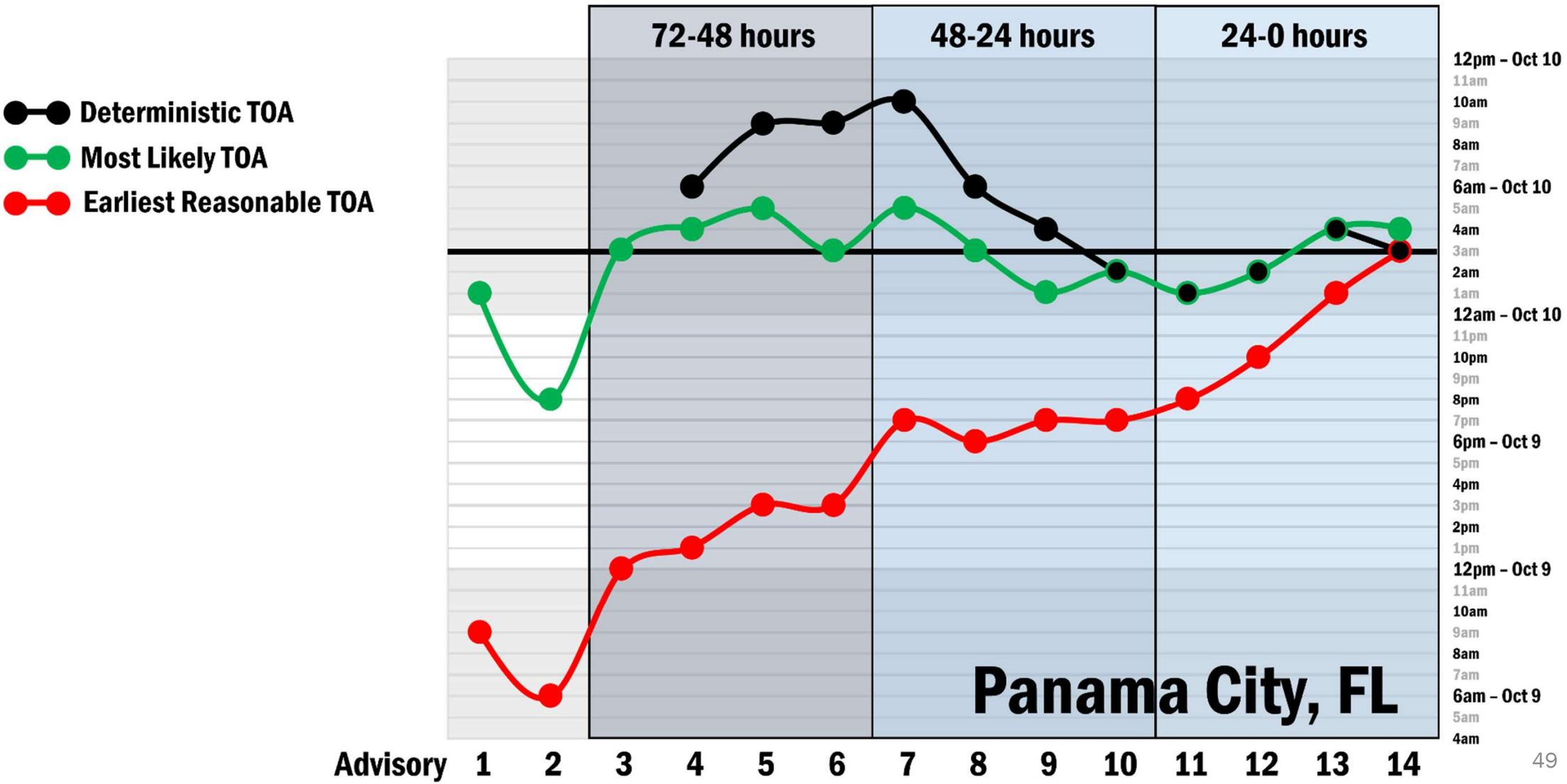
# Wind Timing Uncertainty

## TOA Product Limitations

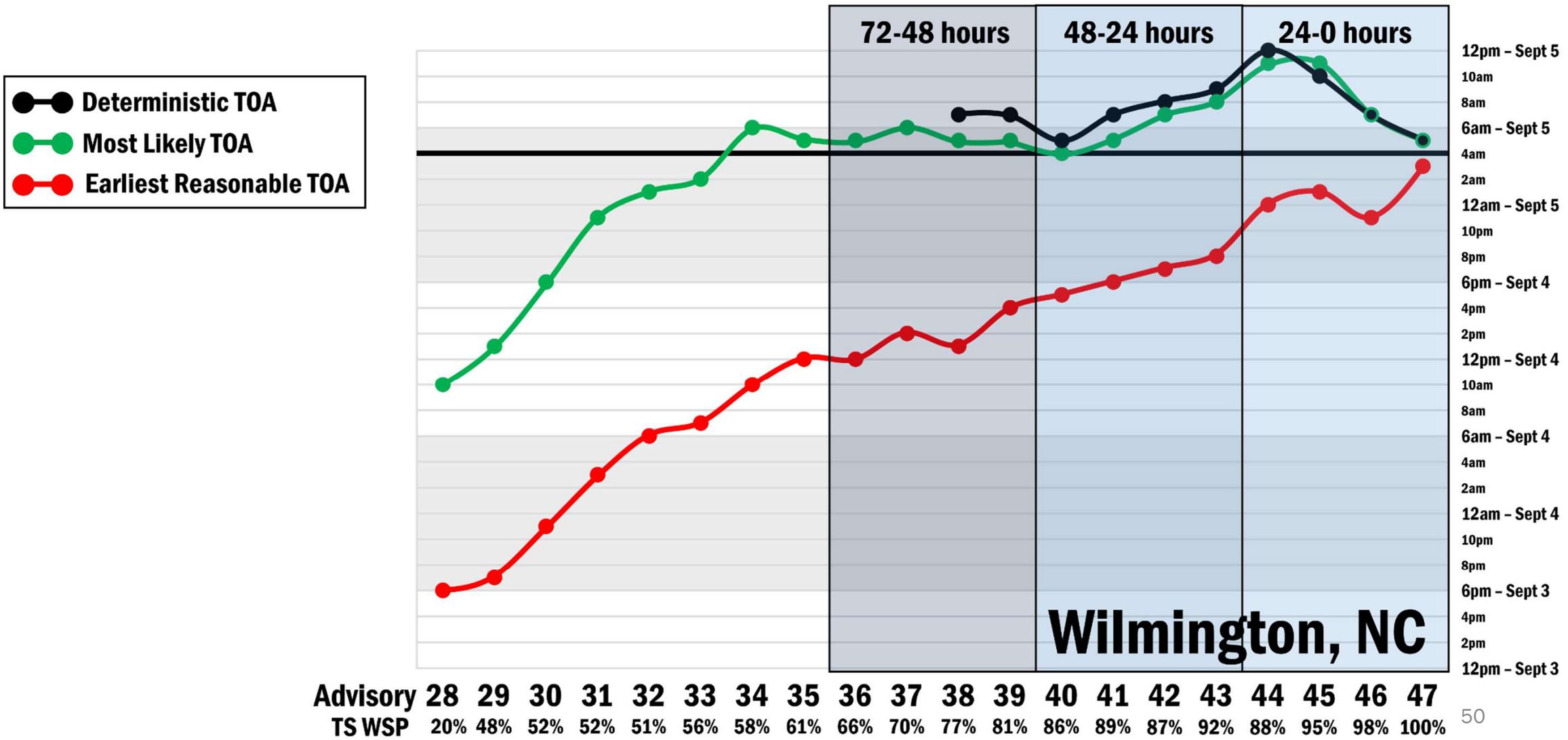
- **Storm Size**
  - Unusually large or small storms may not be handled well, especially beyond the first 24–36 hours.

- **Slow Forward Speed**
  - Storms that stall or move slowly can have much earlier onset times than what is conveyed in the official forecast.

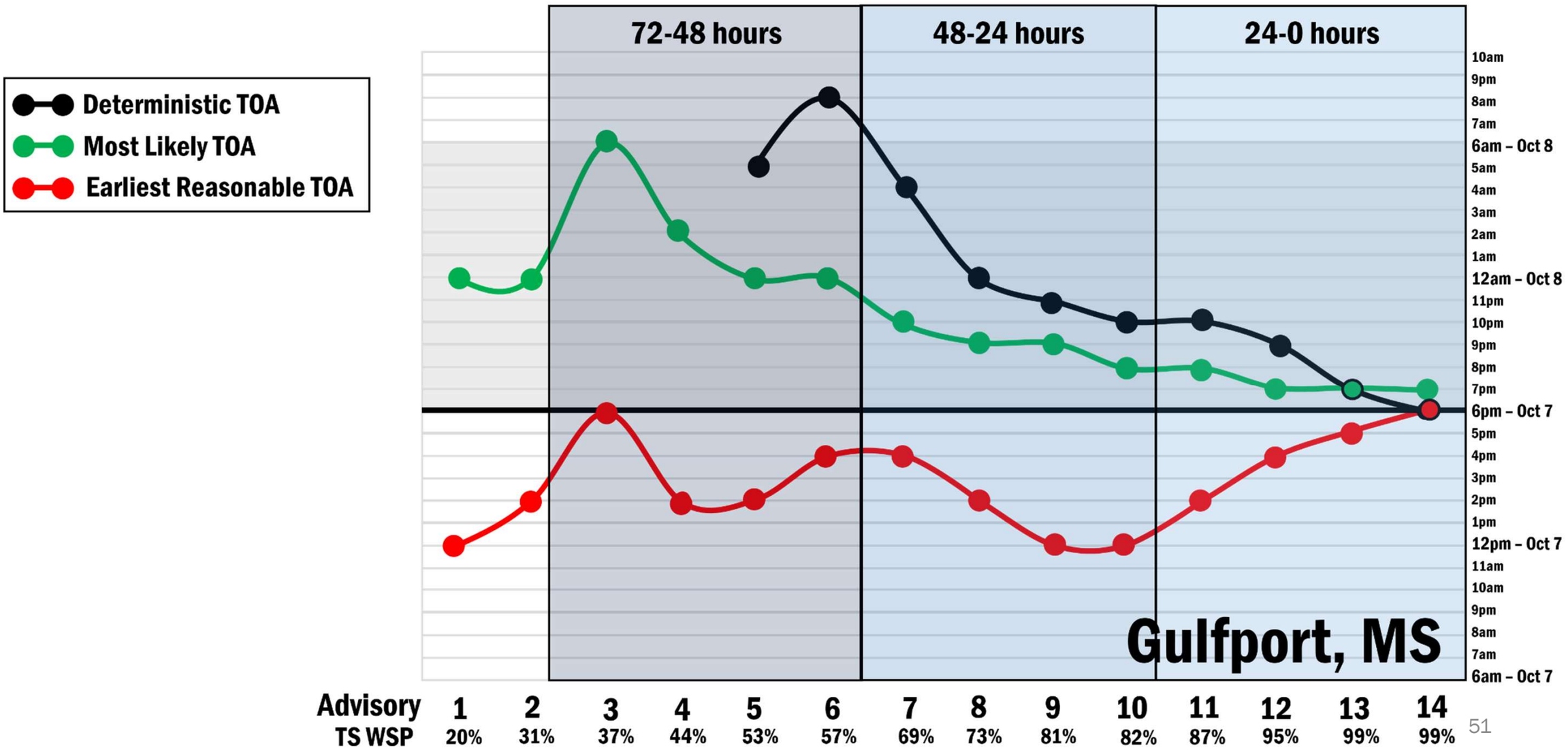
# Hurricane Michael (2018)



# Hurricane Dorian (2019)



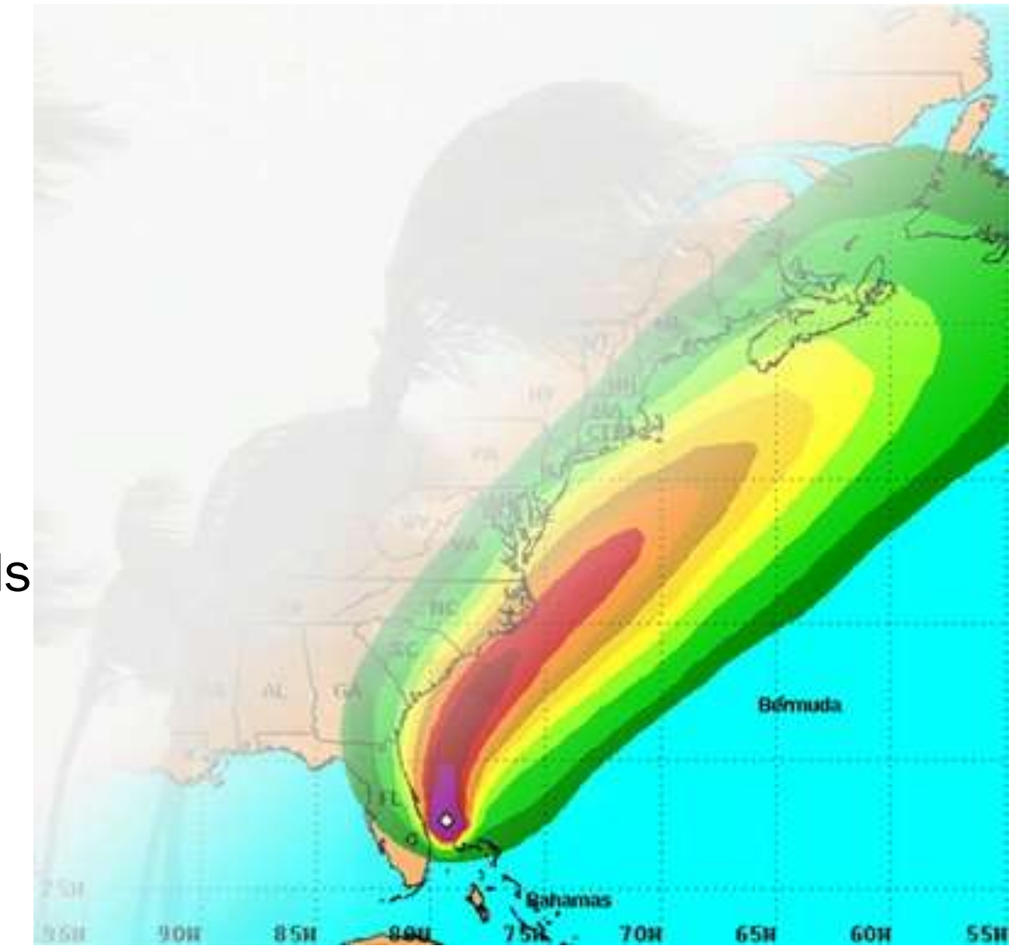
# Hurricane Nate (2017)



# Summary - Wind Speed Probabilities

## 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.



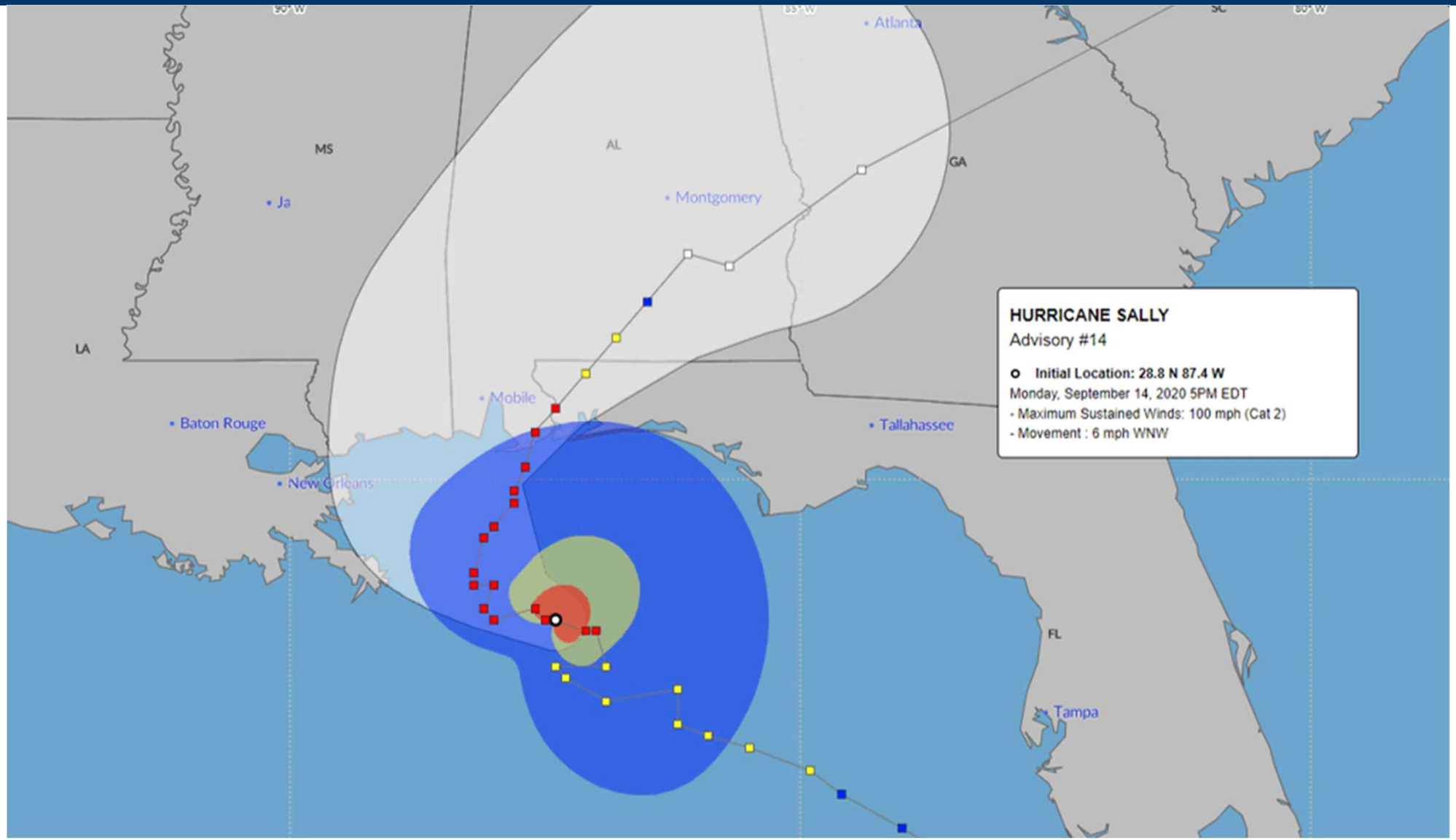
# Unit 3 Objectives Revisited

## Unit Objectives

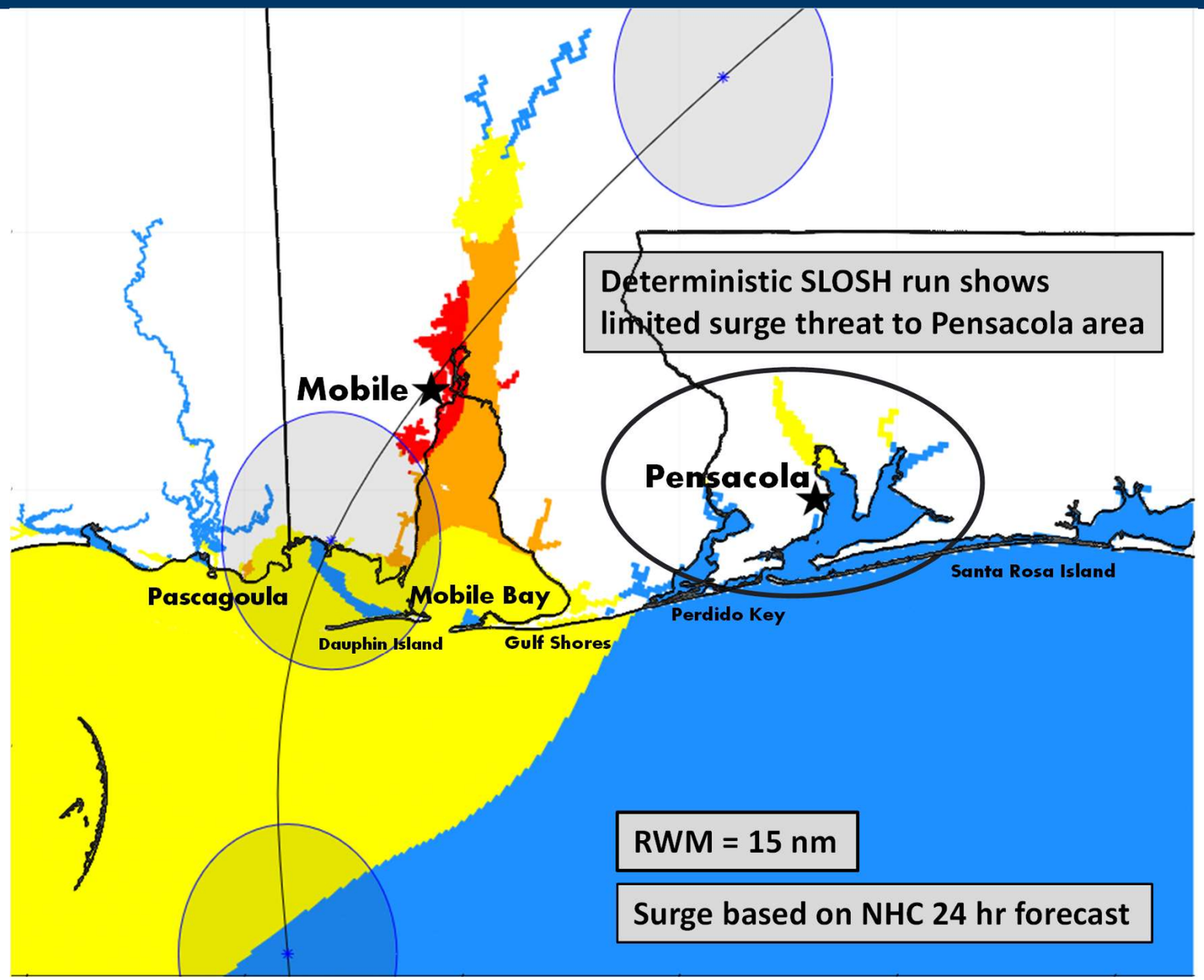
**At the end of Unit 3, you should be able to:**

- 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



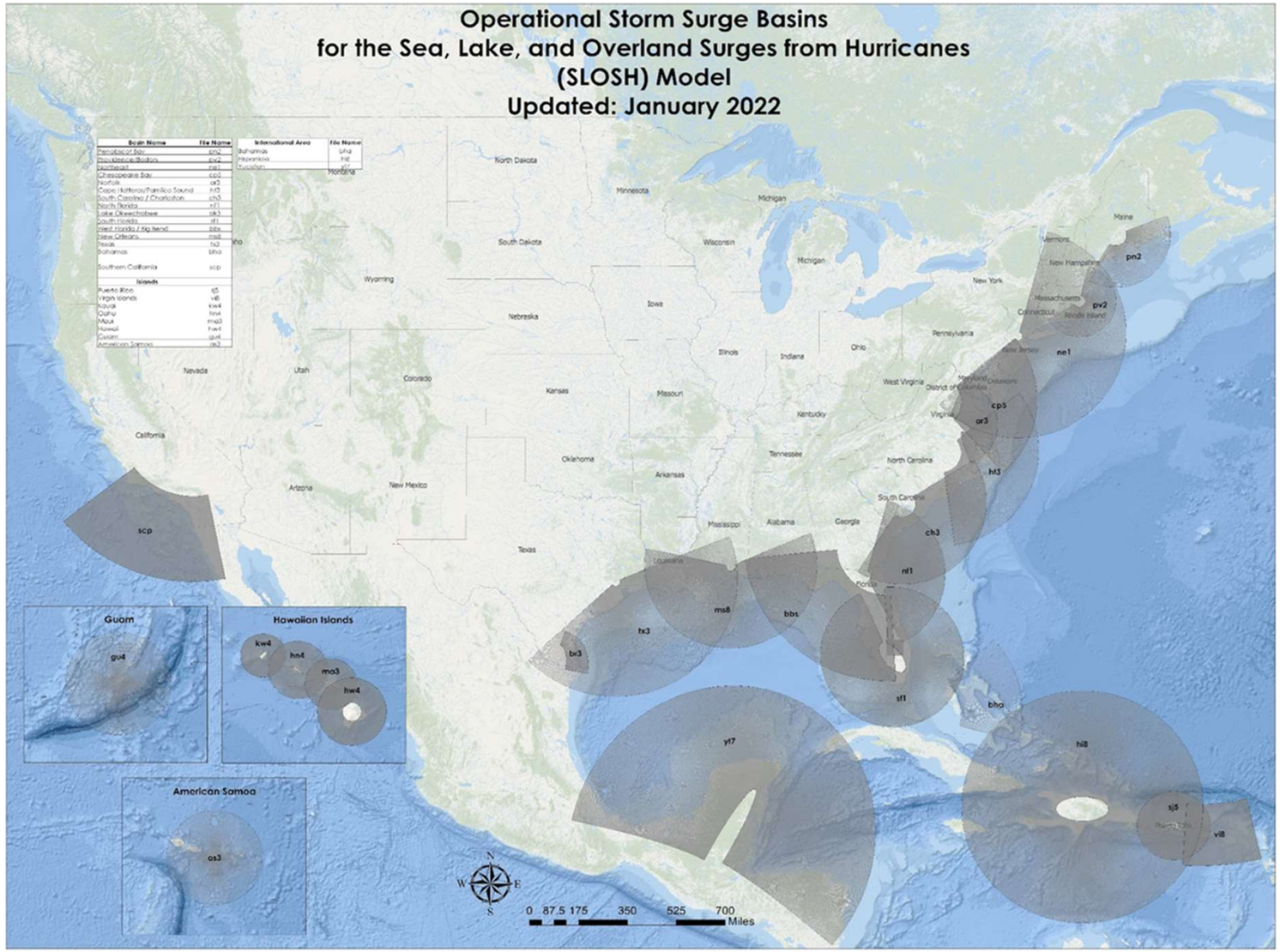
# What a Difference a Bay Makes



# Storm Surge – SLOSH Model

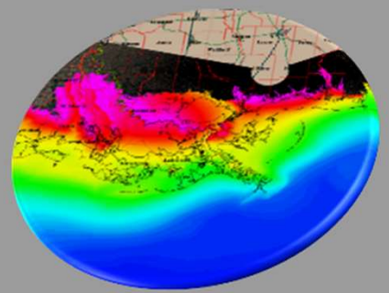
**S**ea,
**L**ake, and
**O**verland
**S**urges from
**H**urricanes

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

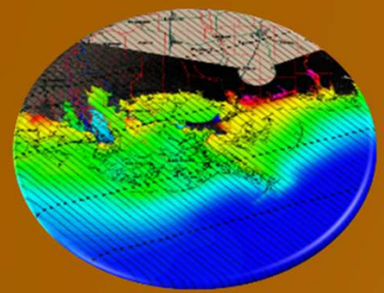


# Storm Surge Risk Tools

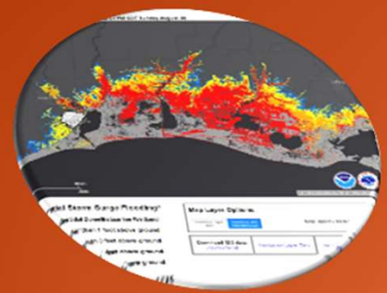
FEMA



*Maximum of the MEOWs (MOMs)*



Maximum Envelopes of Water (MEOWs)



Probabilistic Storm Surge (P-Surge)

Potential Storm Surge Flooding Map

Storm Surge Watch/Warning

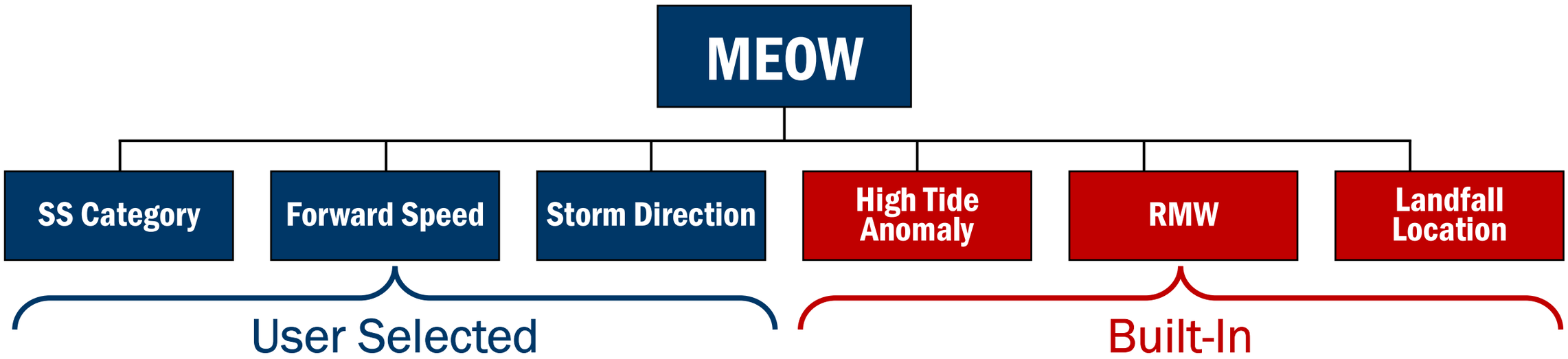
Planning / More Forecast Uncertainty

More Forecast Certainty

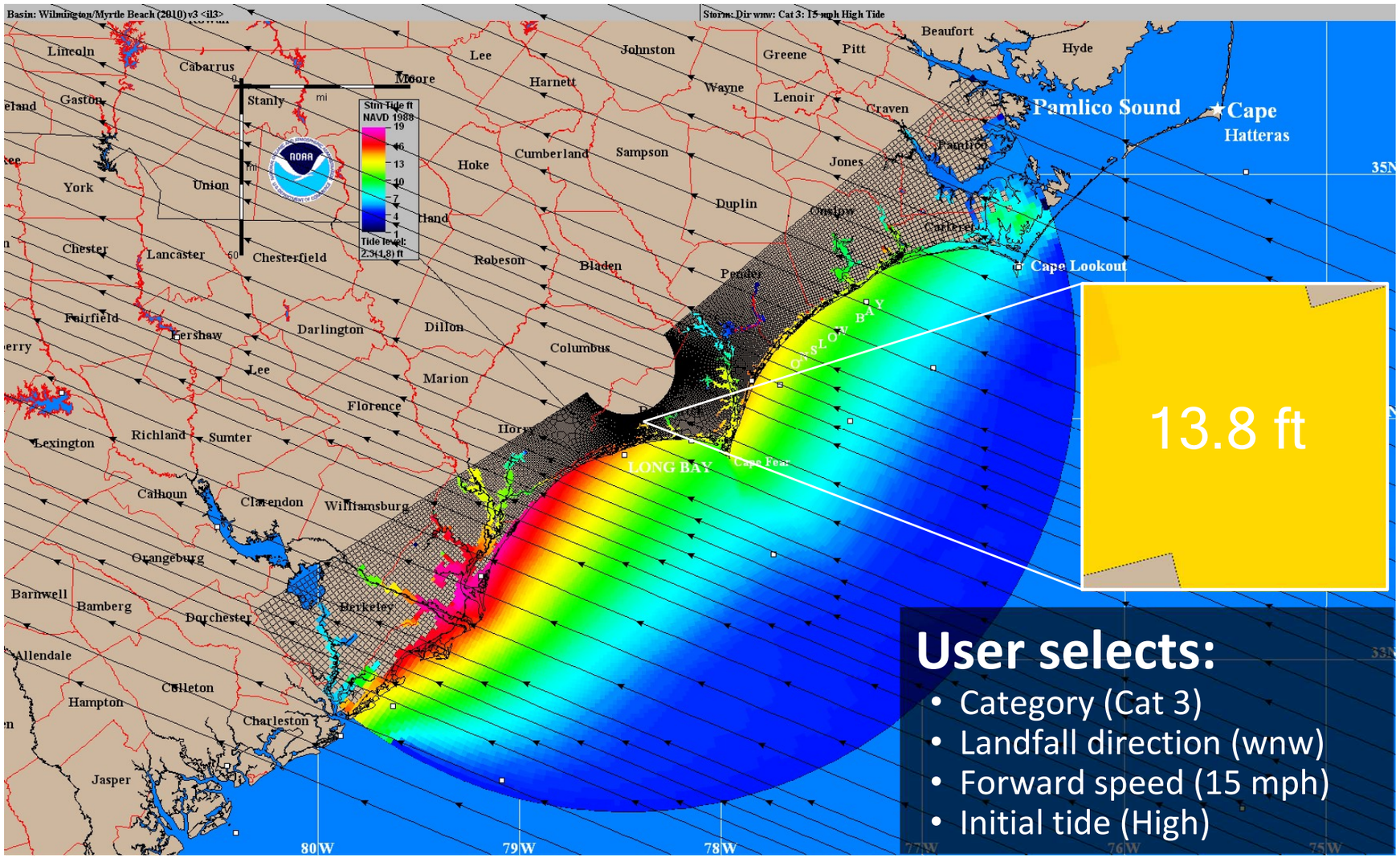
# Maximum Envelope of Water

## MEOWS

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



# MEOW Example

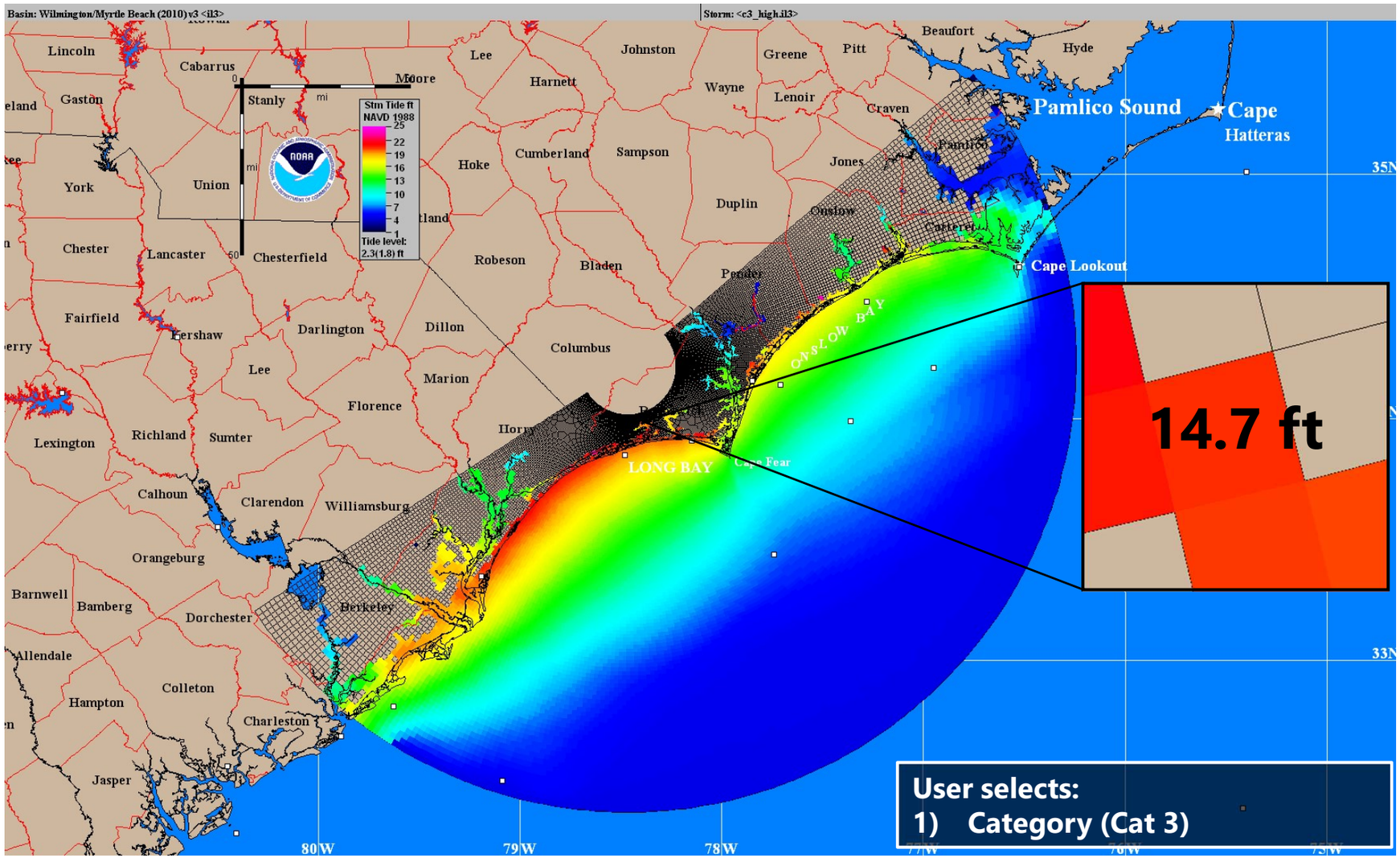


# Maximum of Maximums (MOMs)

## 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)**

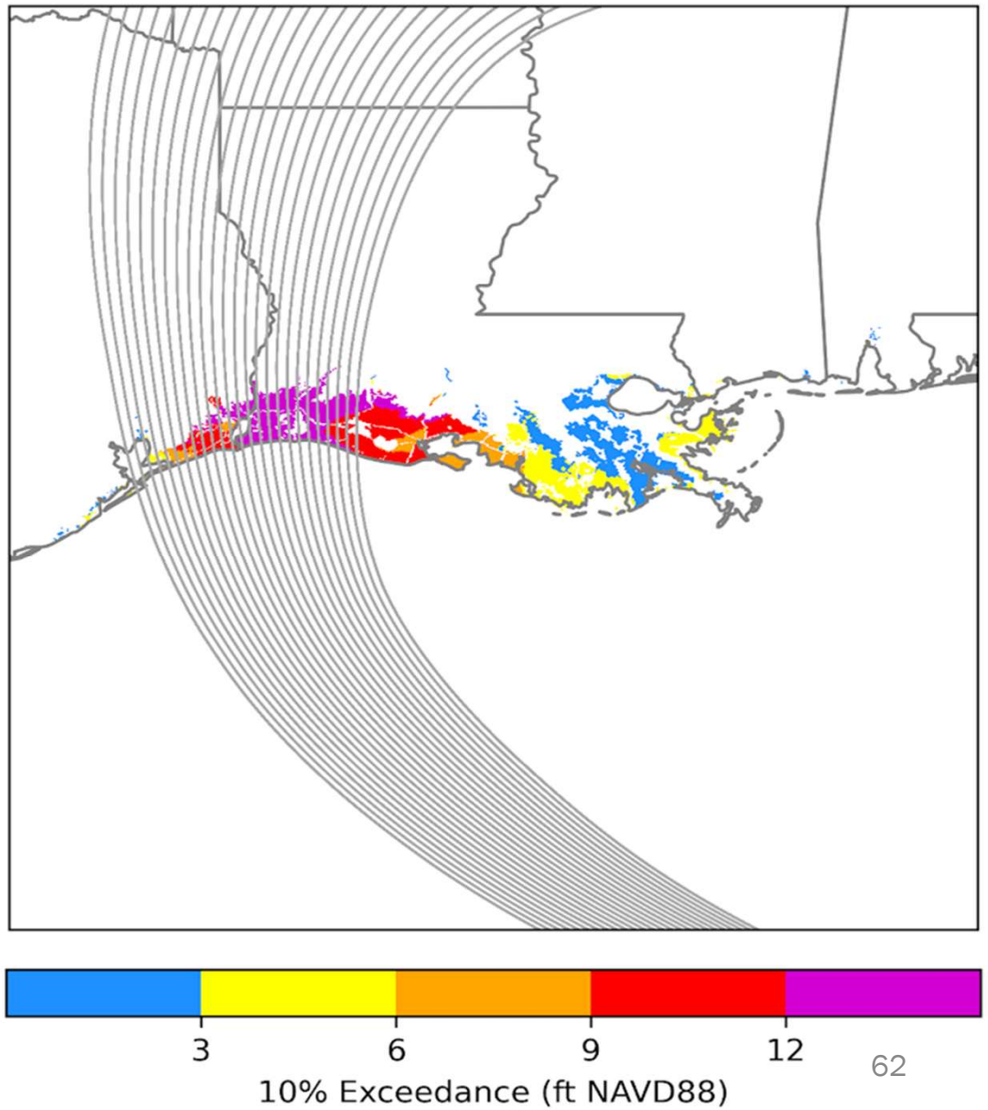
# Maximum of Maximums (MOMs) 2



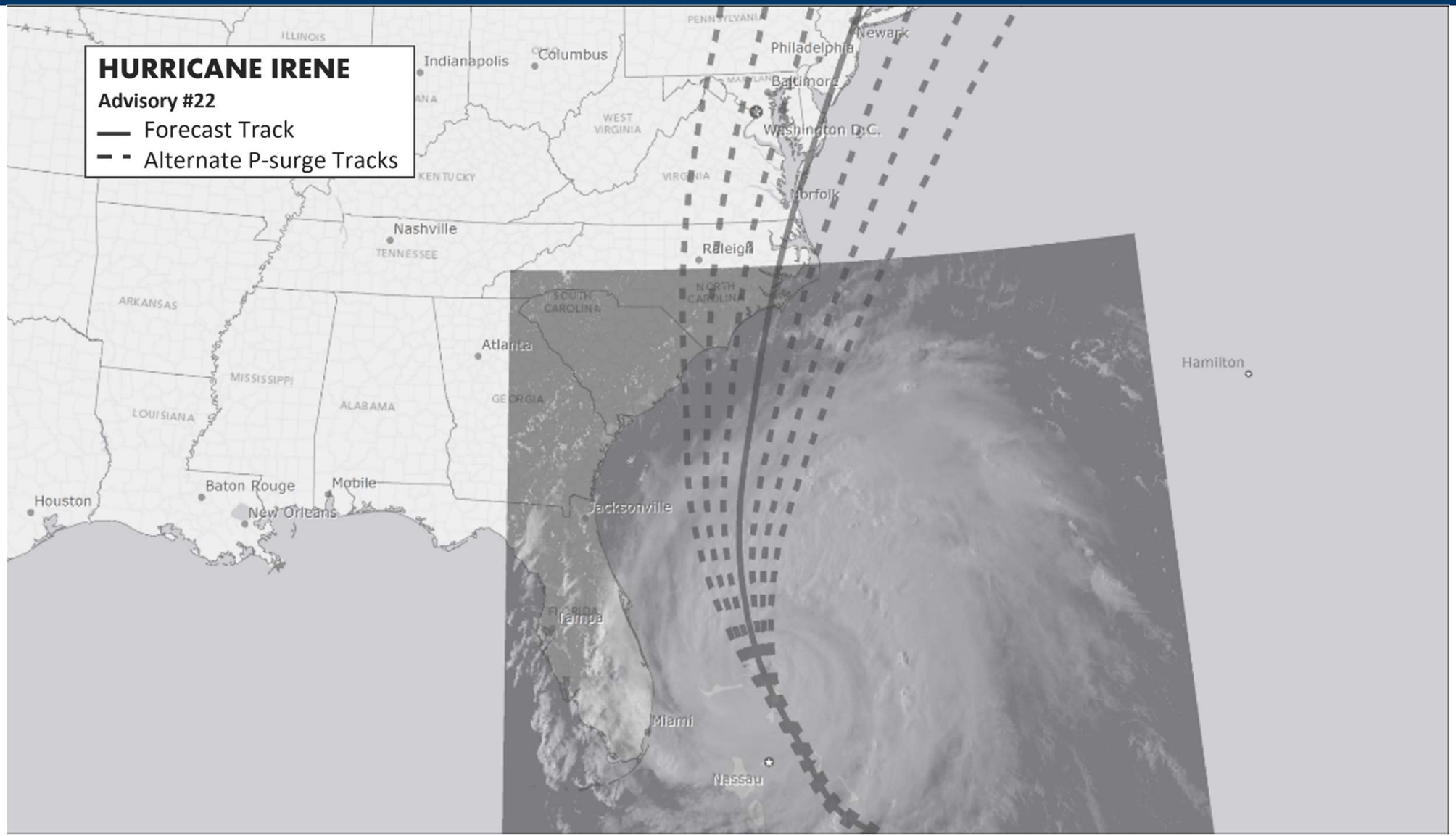
# Probabilistic Storm Surge (P-Surge)

## P-Surge

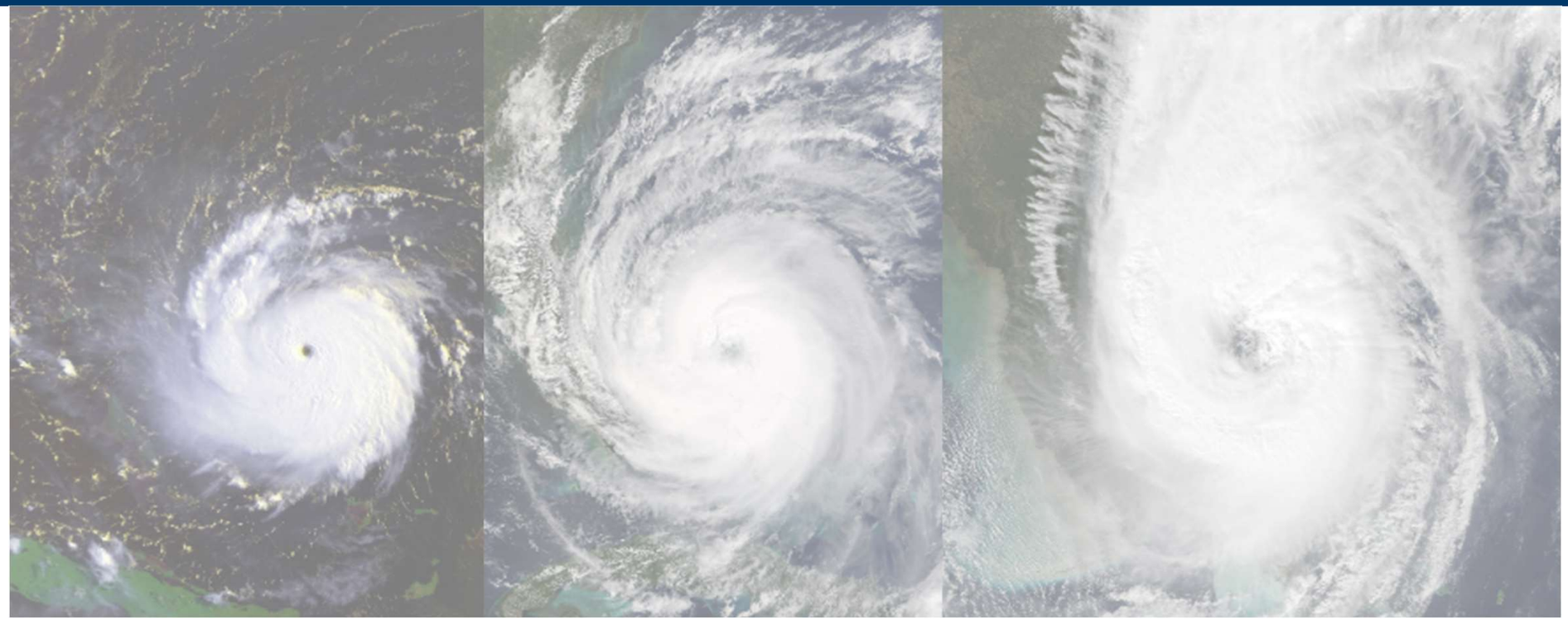
- **Based on NHC official advisory**
  - Uncertainties based on historical errors
- **Accounts for uncertainty in:**
  - Track (landfall location)
  - Forward speed
  - Size (Radius of maximum wind)
  - Intensity
- **Accounts for tide**
- **Heights above ground level**



# Probabilistic Storm Surge



# Sizes, Intensities, Forward Speeds



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

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

**Intensity:** Strong, Medium, Weak

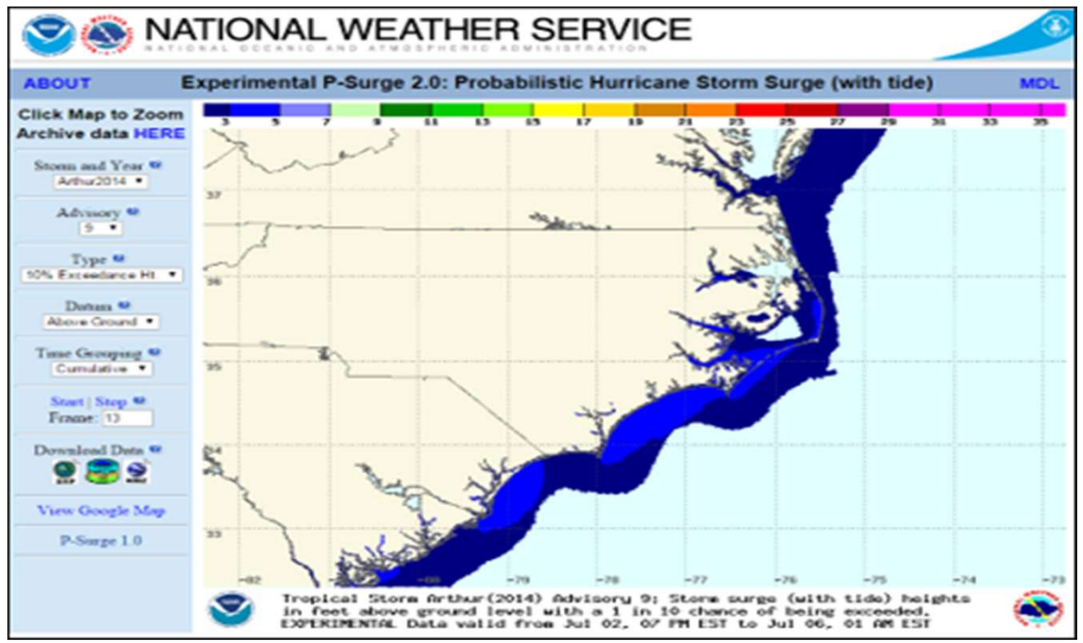
# Web-Based. Timing. Availability.

## P-Surge

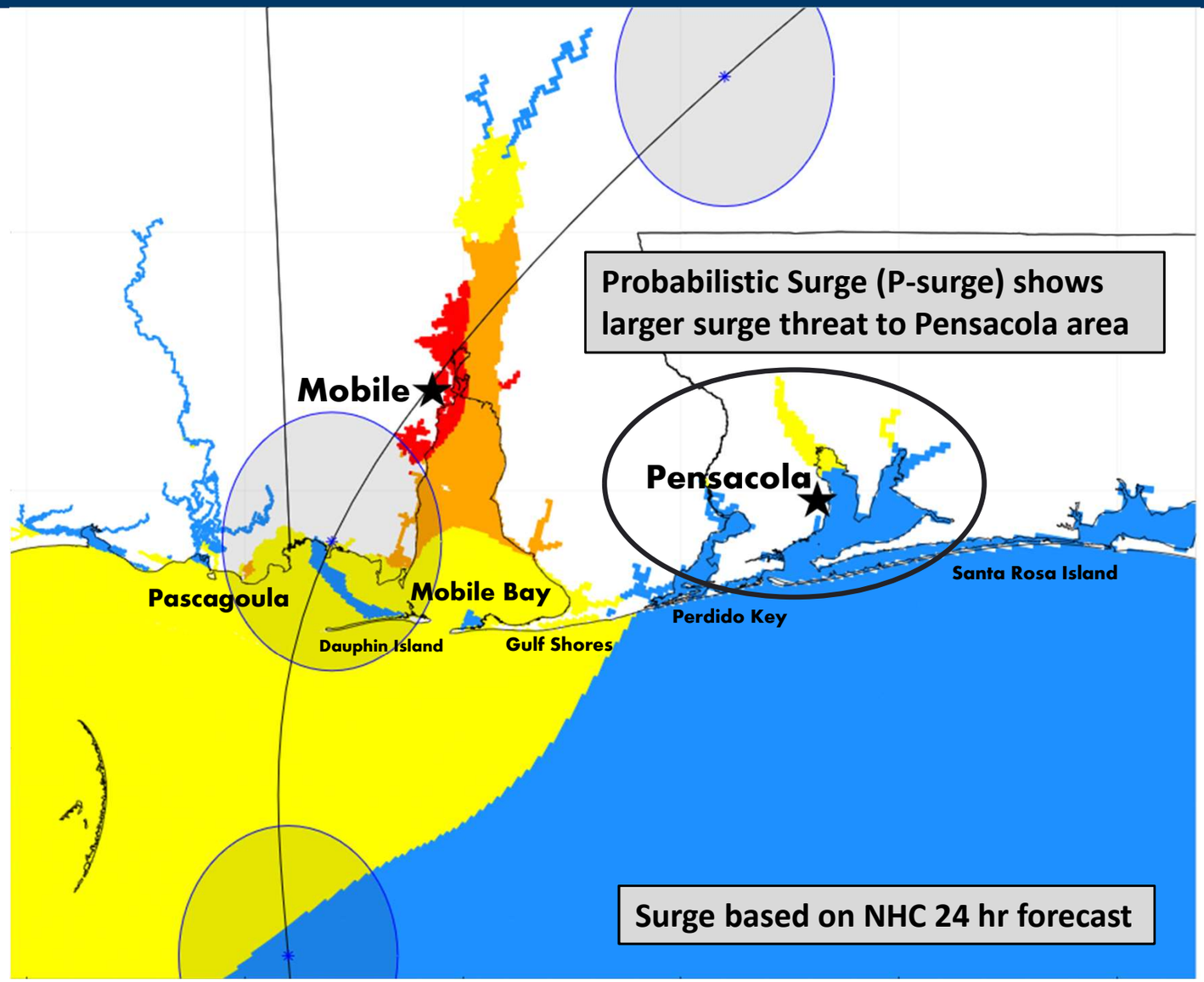
- **Typically issued with a Hurricane or Storm Surge Watch/Warning**
  - But can be provided up to 72 hours prior to arrival of TS winds when forecaster confidence is high

- **Available about 1 hour after advisory**

| ADV TIME | P-SURGE |
|---|---|
| • 0500 | **0600 EDT** |
| • 1100 | **1200 EDT** |
| • 1700 | **1800 EDT** |
| • 2300 | **0000 EDT** |



# Deterministic vs. Probabilistic

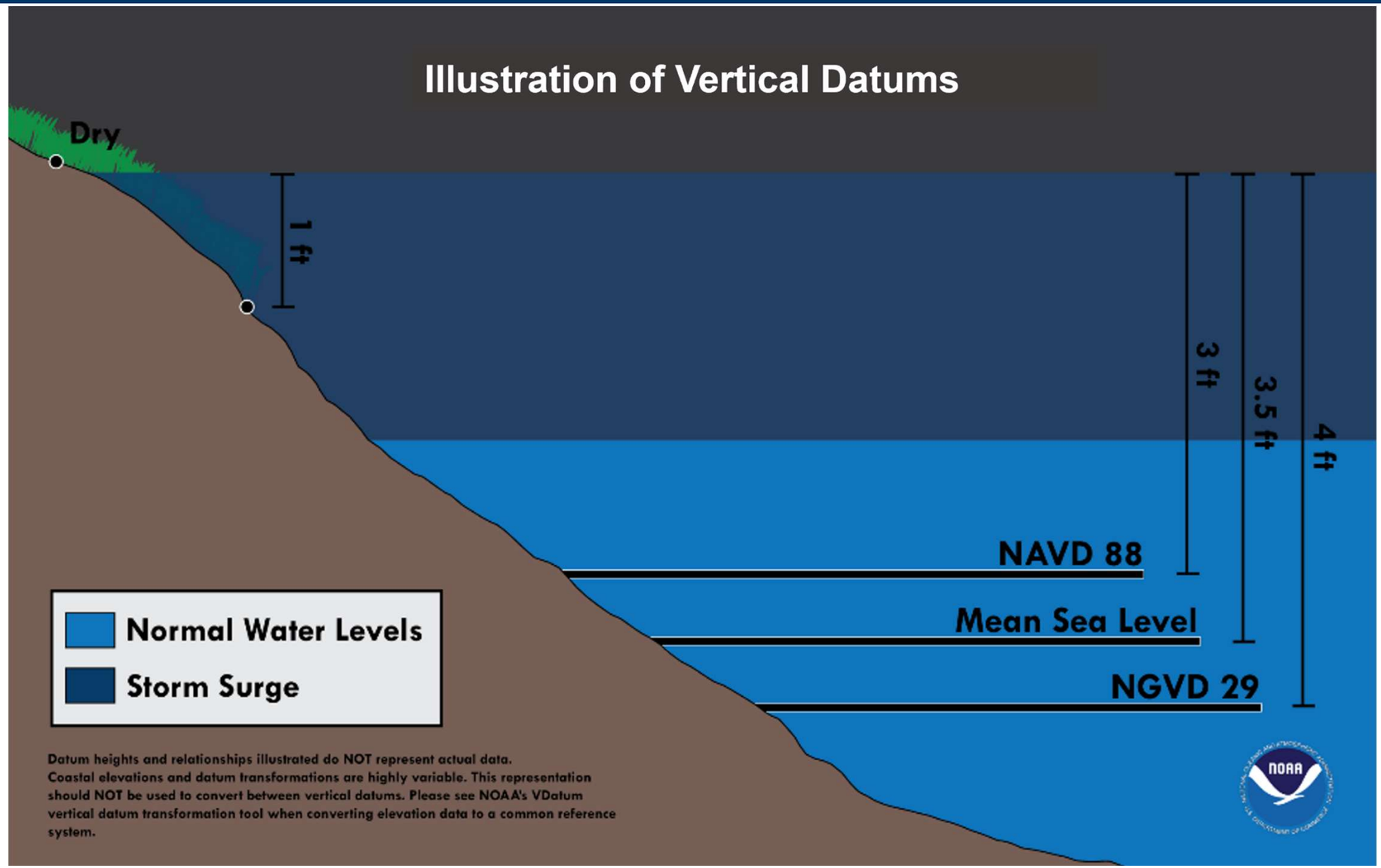


# Vertical Datums – Knowledge Check

**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

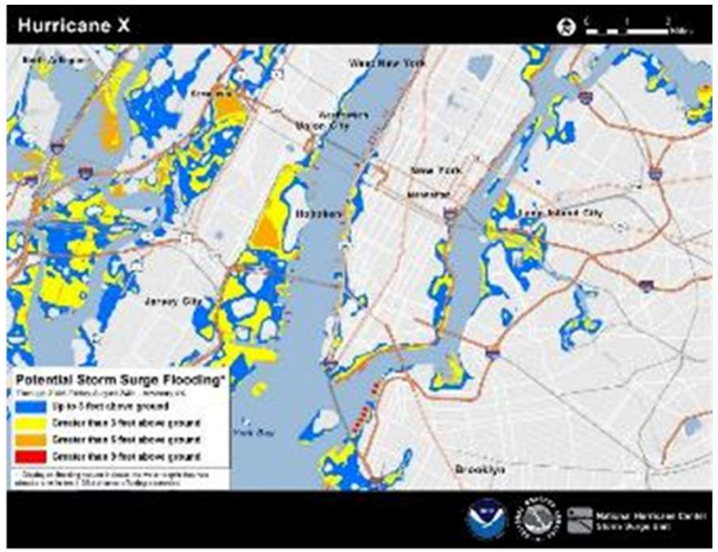
# Vertical Datums

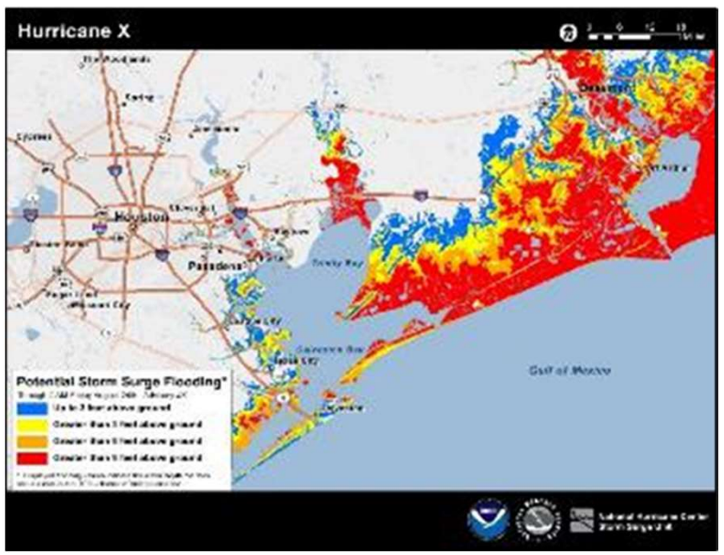


# Potential Storm Surge Flooding Map

## Potential Inundation Map

- **Height above ground that the water <u>could</u> reach**
  - Reasonable worst-cast 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**

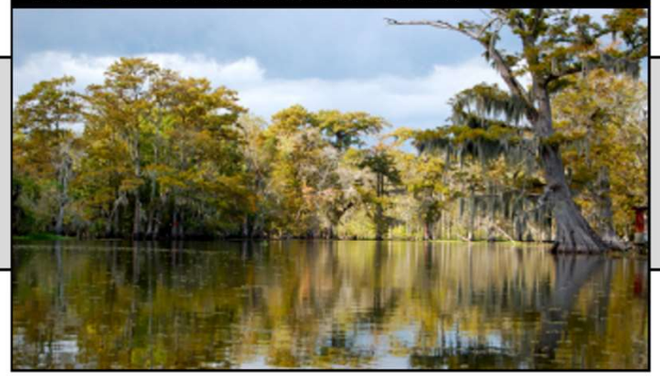
Tidal Shrub Swamp
Virginia

**Estuarine Emergent Wetland**

Salt Marsh
Brigantine, New Jersey

**Non-Tidal (Palustrine) Wetlands**

**Palustrine Forested Wetland**



Cypress Swamp
Bayou Corne, Louisiana

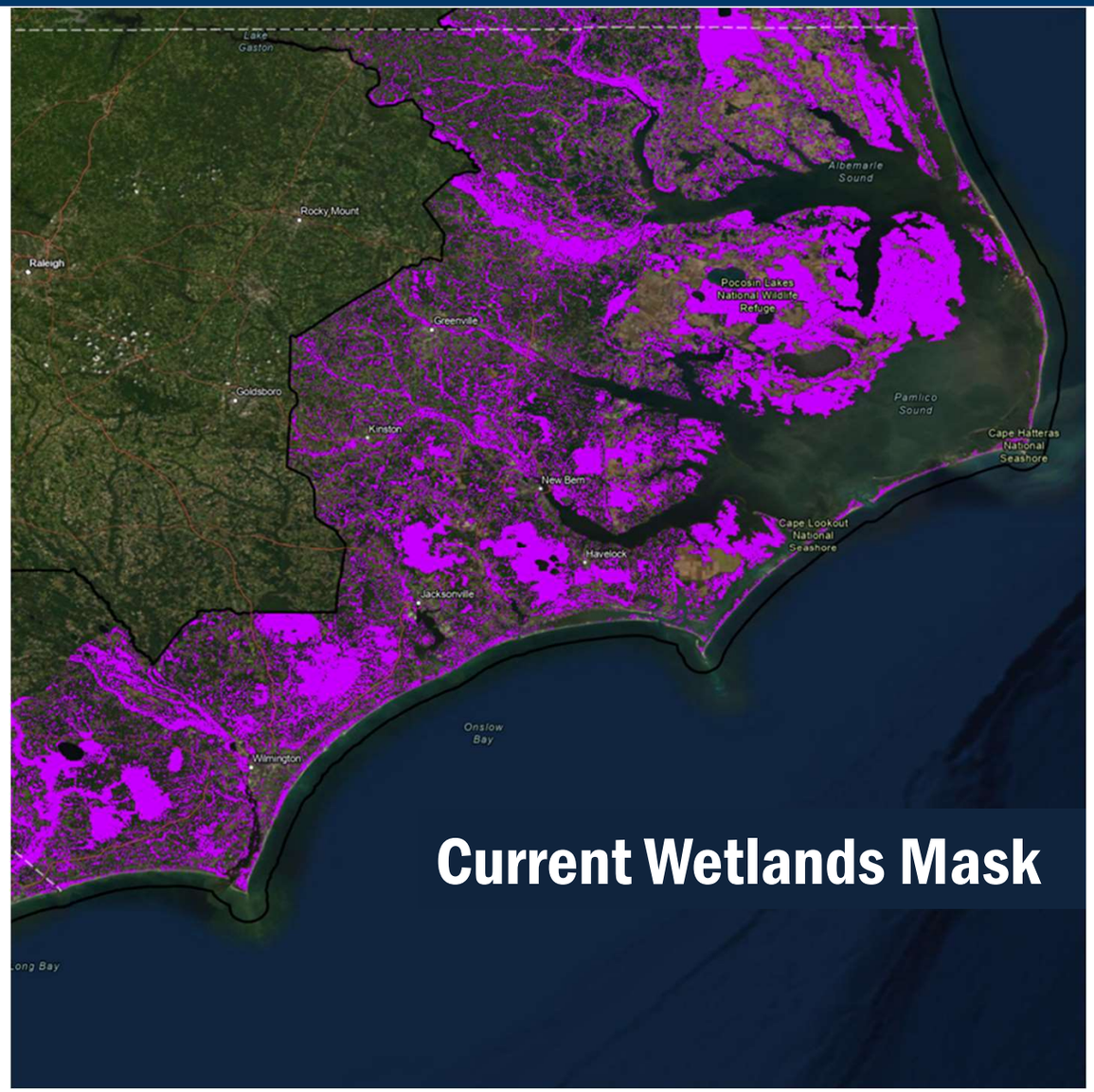
**Palustrine Scrub/Shrub Wetland**

Short Pocosin
Pocosin Lakes National Wildlife Refuge, North Carolina

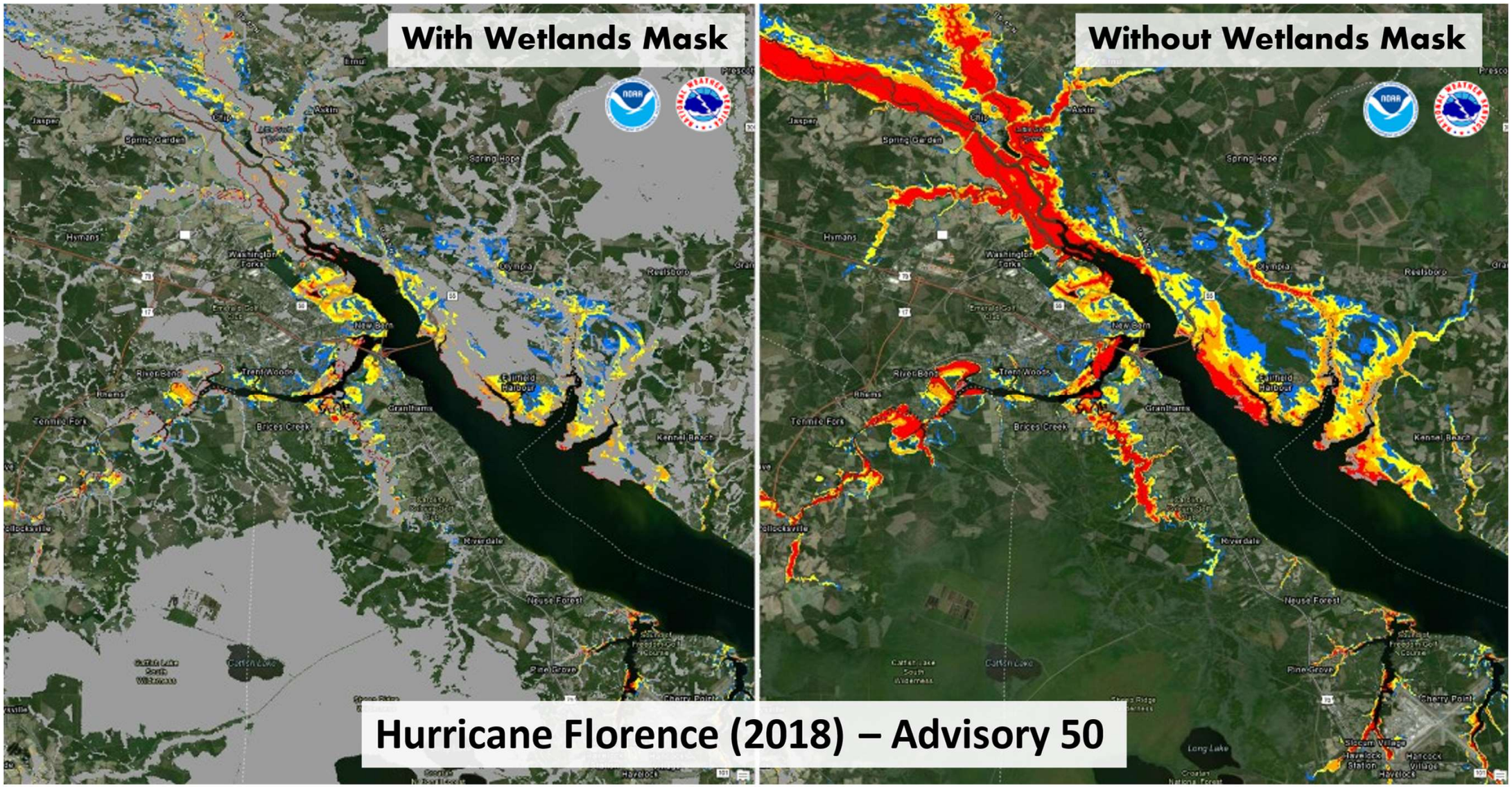
**Palustrine Emergent Wetland**

Sawgrass Prairie
Everglades National Park, Florida

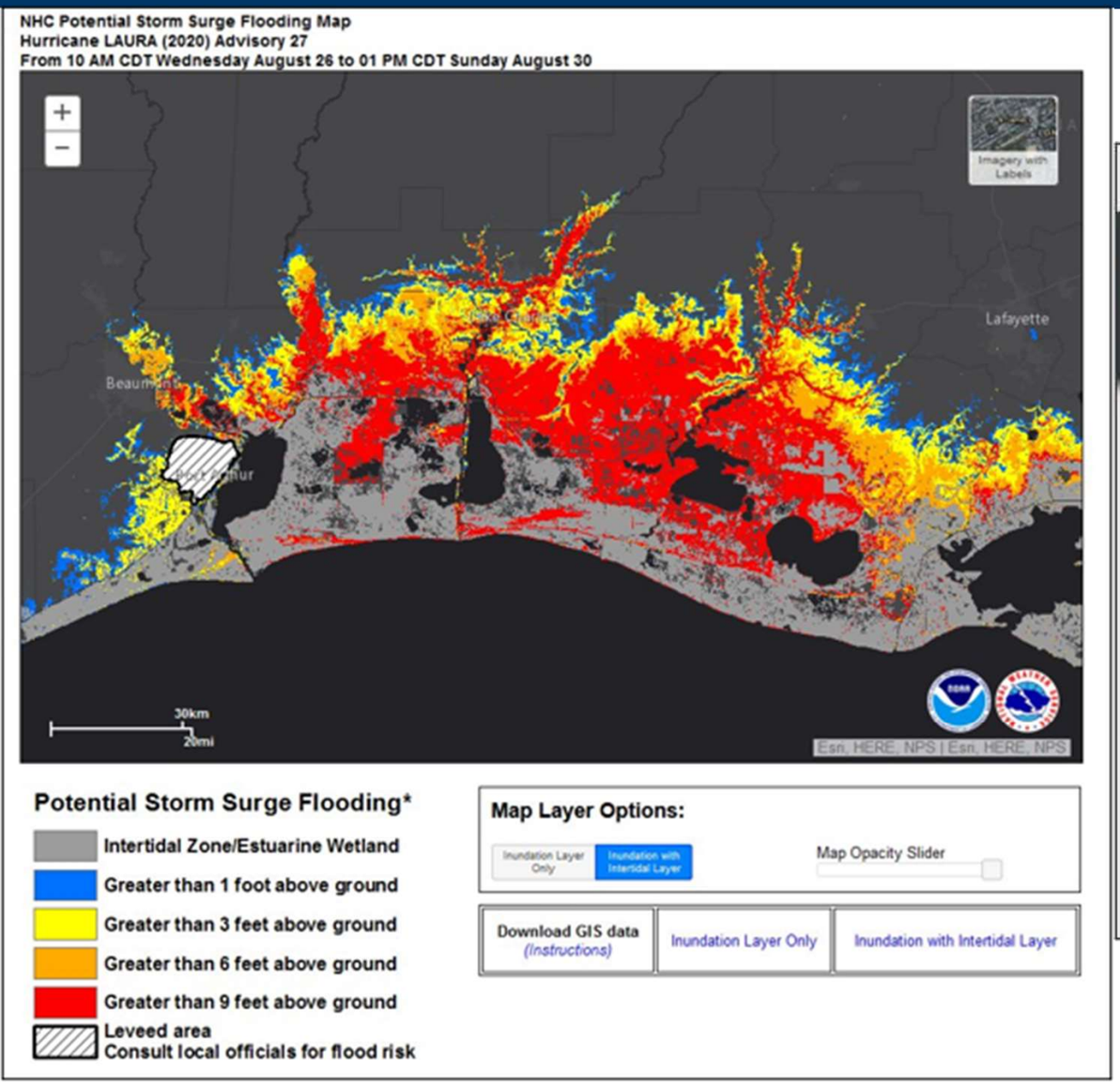
# Intertidal/Wetlands Mask

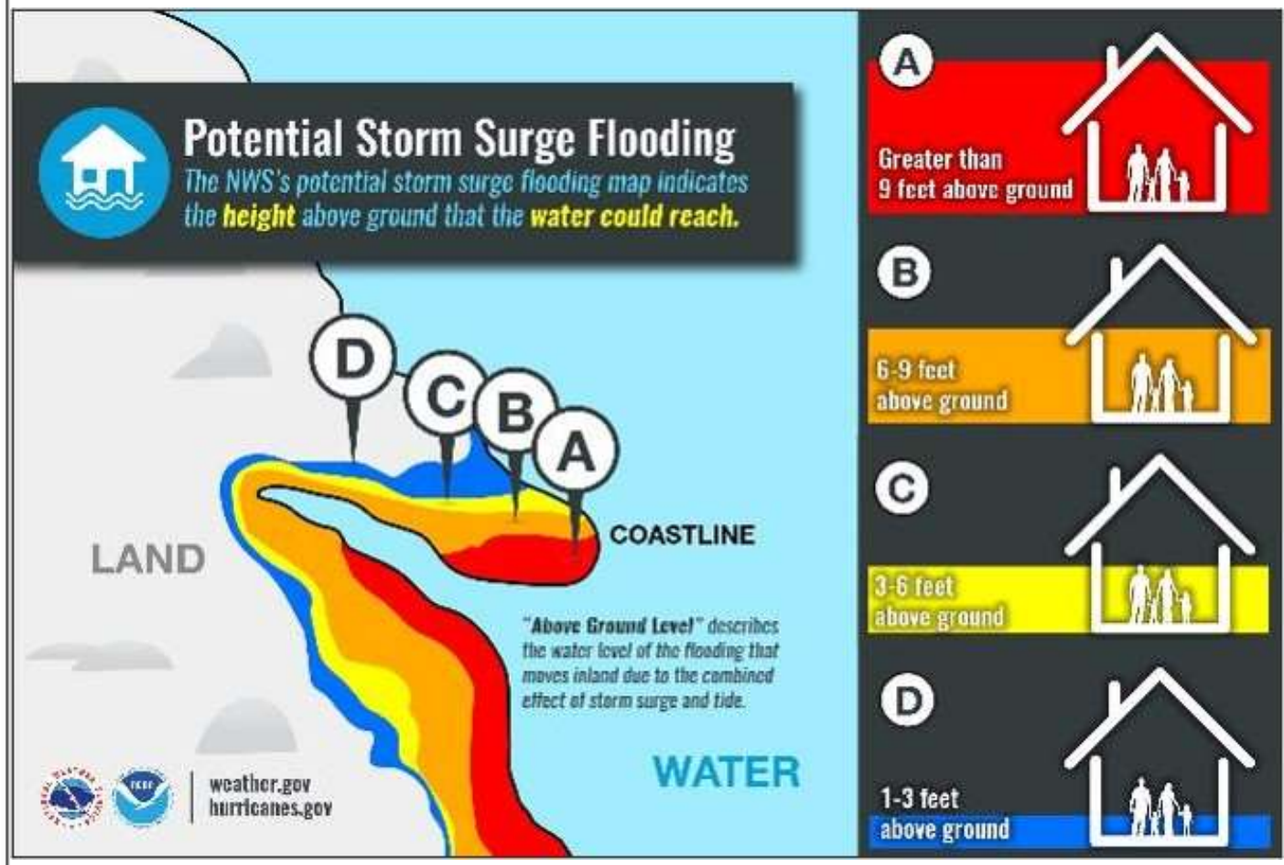


# Intertidal/Wetlands Mask 2

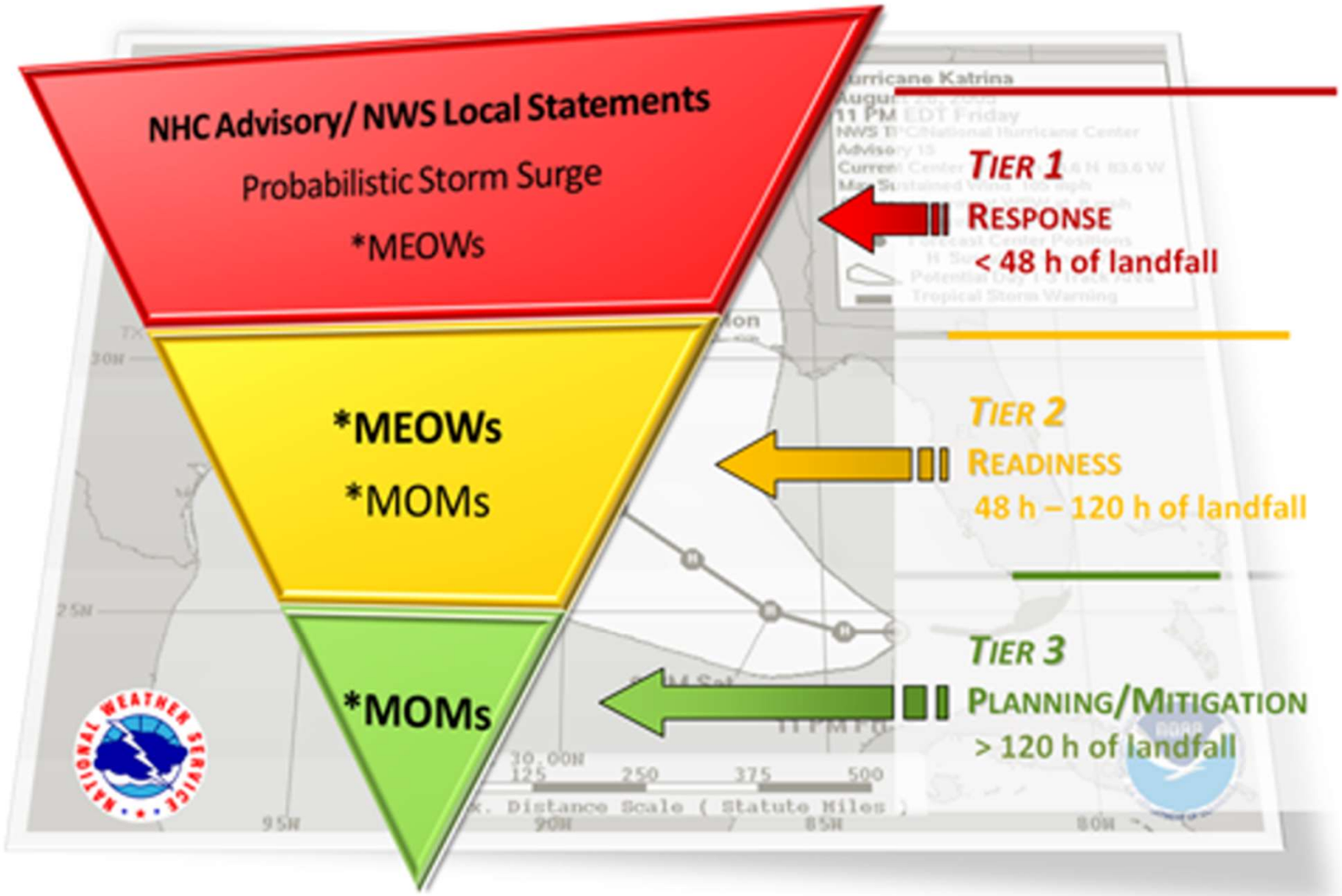


# Messaging P-Surge



# Decision Support Timeframes



# Questions/Comments?