

UNIT 3: Forecast Uncertainty



At the end of this unit, you should be able to:

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

Forecast Errors





Improving, But Not Perfect





NHC 5-Year Averages: Track Errors



Track Errors

• Increase 40 miles per day



Track Errors in Miles



Track Errors

• Increase 40 miles (35nm) per day





All NHC Forecasts

• Track errors increase about 35-40 miles per day



Track Error: Weak TS



Weak Tropical Storms

• Track errors increase about 40-45 miles per day



Track Error: Hurricane



Hurricanes

• Track errors increase about 25 -30 miles per day



Finally, Signs of Improvement





NHC 5-Year Averages: Intensity Errors 🛞



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



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Intensity Errors in Miles

Intensity Errors

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





Intensity Errors: Next 48 Hours



Intensity Errors

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



Forecast Intensity Errors: Rapid Strengthening

RAPID INTENSIFICATION

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

Example: Iota Advisory 7 (2020)

24 h Error:	0 mph	36 h Ei
Actual Intensity:	<u>105 mph</u>	<u>Actual</u>
24h Forecast:	105 mph	36h Fo
Initial Intensity:	65 mph	Initial I

Initial Intensity:	65 mph
36h Forecast:	120 mph
Actual Intensity:	<u>155 mph</u>
36 h Error:	35 mph



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Don't Focus on the Skinny Black Line





Hurricane Charley





Forecast vs. Observed





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Would Alternate Scenarios Help?





Wind Speed Probabilities



NATIONAL HURRICANE CENTER NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION 7 TROPICAL STORM MICHAEL WIND SPEED PROBABILITIES NUMBER AL142018 NWS NATIONAL HURRICANE CENTER MIAMI FL 0900 UTC MON OCT 08 2018 WIND SPEED PROBABILITIES FOR SELECTED LOCATIONS FROM FROM FROM FROM FROM FROM FROM TIME 06Z MON 18Z MON 06Z TUE 18Z TUE 06Z WED 06Z THU 06Z FRI PERIODS ТО ТО ТО ТО ТО ТО ТО 18Z MON 06Z TUE 18Z TUE 06Z WED 06Z THU 06Z FRI 06Z SAT FORECAST HOUR (12)(48) (24) (36) (72)(96) (120)LOCATION KΤ TALLAHASSEE FL 34 X X(X) 6(81) X(81) 1(1)6(7)68 (75) 1(1) TALLAHASSEE FL 50 X X(X) 6(48) X (X) 41(42) X(48) TALLAHASSEE FL 64 X X(X) X(X) X(X) 20(20) X(24) 4 (24) APALACHICOLA X(X) 29(34)57(91)1(92)X(92) 34 X 5(5) X(X) X(X) 6(6) 59(65) 2(67) X(67) APALACHICOLA 50 X X(X) X(X) 1(1)39(40) X(41) APALACHICOLA 64 X 1(41)PANAMA CITY FL 34 X(X) 26(30)60(90) 1(91)X(91) Х 4 (4) PANAMA CITY FL 50 X(X) X(X) 57(63) 1(64) X(64) Х 6(6) X(X) 1(1)37 (38) X(38) X(38) PANAMA CITY FL 64 X X(X)



Wind Speed Probabilities – Question



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 Wind Speed Probabilities



MORE SCENARIOS

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



Generating Wind Speed Probabilities 2 🐼 FEMA

Atlantic City, NJ 100 of 1,000 scenarios North Ca produce hurricane-force outh Caro winds at that location. ≥orai

Generating Wind Speed Probabilities 3 🐼 FEMA



What Does 10% Chance Mean?







Location-Specific Probabilities 1



Location-Specific Probabilities

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



Location-Specific Probabilities 2







Location-Specific Probabilities

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

Location-Specific Probabilities 3



Location-Specific Probabilities

Tropical-Storm-Force

•58 mph

• Hurricane-Force



Onset Probabilities

NATIONAL HURRICANE CENTER							
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							
FRC	M E	ROM	FROM	FROM	FROM	FROM	FROM
TIME 06Z M	ION 182	C MON C	6Z TUE	18Z TUE	06Z WED	06Z THU	06Z FRI
PERIODS TO)	ТО	ТО	ТО	ТО	ТО	ТО
18Z M	10N 062	L TUE 1	L8Z TUE	06Z WED	06Z THU	06Z FRI	06Z SAT
FORECAST HOUR	12)	(24)	(36)	(48)	(72)	(96)	(120)
LOCATION KT							
TALLAHASSEE FL 34	ХΣ	(X)	1(1)	<mark>6(</mark> 7)	<mark>68</mark> (75)	<mark>6</mark> (81)	X(81)
TALLAHASSEE FL 50	ХУ	(X)	X (X)	1(1)	<mark>41</mark> (42)	<mark>6</mark> (48)	<mark>X(</mark> 48)
TALLAHASSEE FL 64	ХУ	(X)	X(X)	X(X)	<mark>20</mark> (20)	<mark>4</mark> (24)	<mark>X (</mark> 24)
	x x	(X)	5 (5)	29(34)	57 (91)	1 (92)	x (92)
APALACHICOLA 50	X X	(\mathbf{x})	$\mathbf{X}(\mathbf{X})$	$\frac{25(31)}{6(6)}$	$\frac{57}{59}(65)$	$\frac{2}{2}(67)$	X(52)
APALACHICOLA 64	X X	(X)	X(X)	$\frac{1}{1}$ (1)	$\frac{39}{39}(40)$	$\frac{1}{1}(41)$	X(41)
			()	- (- /		- (+ - /	
PANAMA CITY FL 34	ХХ	(X)	4 (4)	<mark>26(</mark> 30)	<mark>60</mark> (90)	1(91)	X(91)
PANAMA CITY FL 50	ХΣ	(X)	X (X)	6(6)	57 (63)	1(64)	X(64)
PANAMA CITY FL 64	ХΣ	(X)	X (X)	1(1)	<mark>37</mark> (38)	X(38)	X(38)

Onset Probabilities

•Timing information



Cumulative Probabilities



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Cumulative Probabilities

• Total chance through the time period





Location-specific Probabilities

- Tropical Storm-Force
- 58 mph ("Strong" Tropical Storm)
- Hurricane-Force





Location-specific Probabilities

- Tropical Storm-Force
- 58 mph ("Strong" Tropical Storm)
- Hurricane-Force





Location-specific Probabilities

- Tropical Storm-Force
- 58 mph ("Strong" Tropical Winds)
- Hurricane-Force



NATIONAL HURRICANE CENTER							
TIME C PERIODS 1	FROM 6Z MON TO .8Z 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)
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 <mark>(8)</mark>
TALLAHASSEE FI	34 X	X (X)	1(1)	6(7)	68(75)	6(81)	X (81)
TALLAHASSEE FI	50 X	X (X)	X(X)	1(1)	41(42)	6(48)	X (48)
TALLAHASSEE FI	<mark>64 X</mark>	X (X)	X(X)	X(X)	20(20)	<mark>4(24)</mark>	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 <mark>(41)</mark>
PANAMA CITY FI	34 X	X (X)	4 (4)	26(30)	60(90)	1(91)	X (91)
PANAMA CITY FI	50 X	X (X)	X (X)	6(6)	57(63)	1(64)	X (64)
PANAMA CITY FI	64 X	X (X)	X (X)	1(1)	<mark>37(38</mark>)	X(38)	X <mark>(38)</mark>
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)	<mark>9(9)</mark>	X(9)	x (_9)



Earliest Reasonable Time of Arrival





Time of Arrival of TS Winds

- Earliest Reasonable
- Most Likely

Most Likely Time of Arrival





Time of Arrival of TS Winds

- Earliest Reasonable
- Most Likely

Forecast vs. Observed 2




Would Alternate Scenarios Help? 2





Would Alternate Scenarios Help? 3





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

A Tool to Deal With Uncertainty



HURRICANE IRMA

- Advisory 30 11am EDT
 - 6 September 2017
- 4-day position error 'only' ~100 miles
 - Equal chances of hurricaneforce winds at Marathon and Fort Pierce



Hurricane Matthew (2016)





Question



What is the chance of hurricane force winds occurring at Pensacola during the next 5 days?

- 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



Major sources of 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





How Are Time of Arrival Graphics Generated?

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MORE SCENARIOS

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



Earliest Reasonable Onset of TS Winds



EARLIEST REASONABLE

- 10% chance of onset
 - Most conservative timing
- Arrival time of TS winds
 - Black contours
- 5-day cumulative TS probabilities
 - Color fill



Most Likely Onset of TS Winds



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 fill



New Orleans – Baton Rouge



TIMING UNCERTAINTY

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



Hurricane Michael #7 Tallahassee FL



TIMING UNCERTAINTY

- Earliest Reasonable
 - 10% chance of onset
 - Most conservative timing
 - Tuesday 8pm

Most Likely

- 50% chance of onset
- Equally likely before as after
- Wednesday 8am

Range of wind arrival: 12 h

Tue 8pm – Wed 8am





TOA Product Limitations

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

Hurricane Michael (2018)



Deterministic TOA
 Most Likely TOA
 Earliest Reasonable TOA



Hurricane Dorian (2019)







Hurricane Nate (2017)







Summary - Wind Speed Probabilities



 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



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Coastal Storm Surge forecasts include:

- MEOWs & MOMs
- P-Surge
- Potential Inundation

Hurricane Ivan





Hurricane Ivan – What a Difference A Bay Makes





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 Envelope of Water (MEOW)



MEOWS

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



MEOW Example





Maximum of Maximums (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)

Probabilistic Storm Surge (P-Surge)



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

Probabilistic Storm Surge





Multiple Sizes, Intensities, Forward Speeds





Size (RMW): Small, Medium, Large Forward Speed: Fast, Medium, Slow Intensity: Strong, Medium, Weak

Web-Based. Timing. Availability.



P-SURGE

Available with a Hurricane or Storm Surge Watch/Warning

- 48 hours prior to arrival of TS winds
- Starting in 2021, may be available as early as 60 hours prior to arrival of TS winds when forecaster confidence is high

Approx. 1 hour after advisory

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



Deterministic vs. Probabilistic







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. Norman Tidal Levels

Vertical Datums





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Potential Storm Surge Flooding Map

Height above ground that the water could reach

- Reasonable worst-case scenario for any individual location
- Values have a 10% chance of being exceeded
 Issuance with same criteria as P-Surge
 Available 60+ minutes after the advisory release





P-Surge Flooding Map



Geoprocessing

- Interpolation
- Processing with elevation data
- Smoothing
- Consider shoreline and high tide
- Publish to web





Intertidal/Wetlands





Mangroves Everglades National Park, Florida



Tidal Shrub Swamp Virginia

Short Pocosin

Pocosin Lakes National Wildlife Refuge, North Carolina





Salt Marsh Brigantine, New Jersey



Sawgrass Prairie Everglades National Park, Florida

Cypress Swamp Bayou Corne, Louisiana

Intertidal/Wetlands Mask




Intertidal/Wetlands Mask 2





Messaging P-Surge



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

> Greater than 6 feet above ground Greater than 9 feet above ground

Consult local officials for flood risk

Leveed area





Decision Support Timeframes





Questions/Comments?



