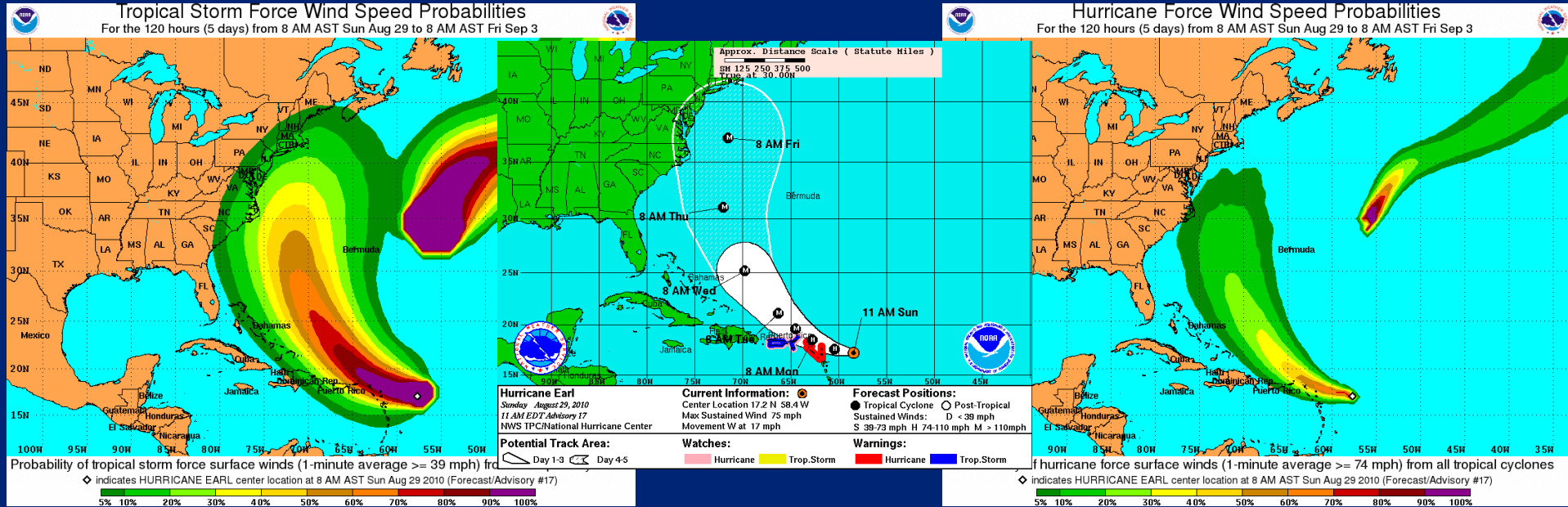
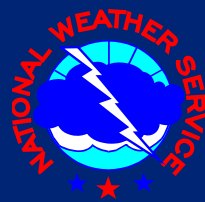




Wind Speed and Intensity Probabilities



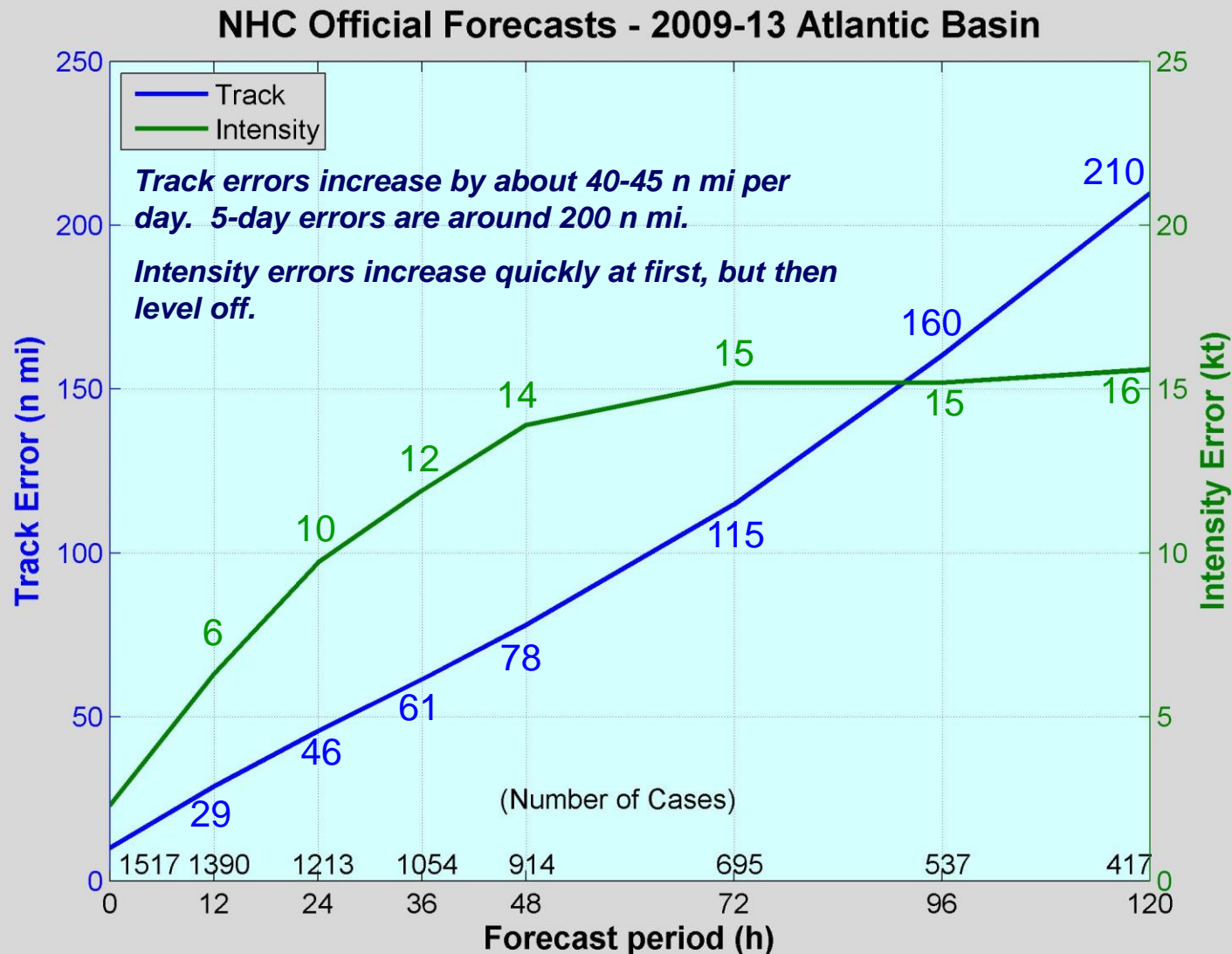
Jack Beven and Colleagues

National Hurricane Center

Florida Governor's Hurricane Conference

11 May 2014

5-Year Mean Atlantic Track Errors



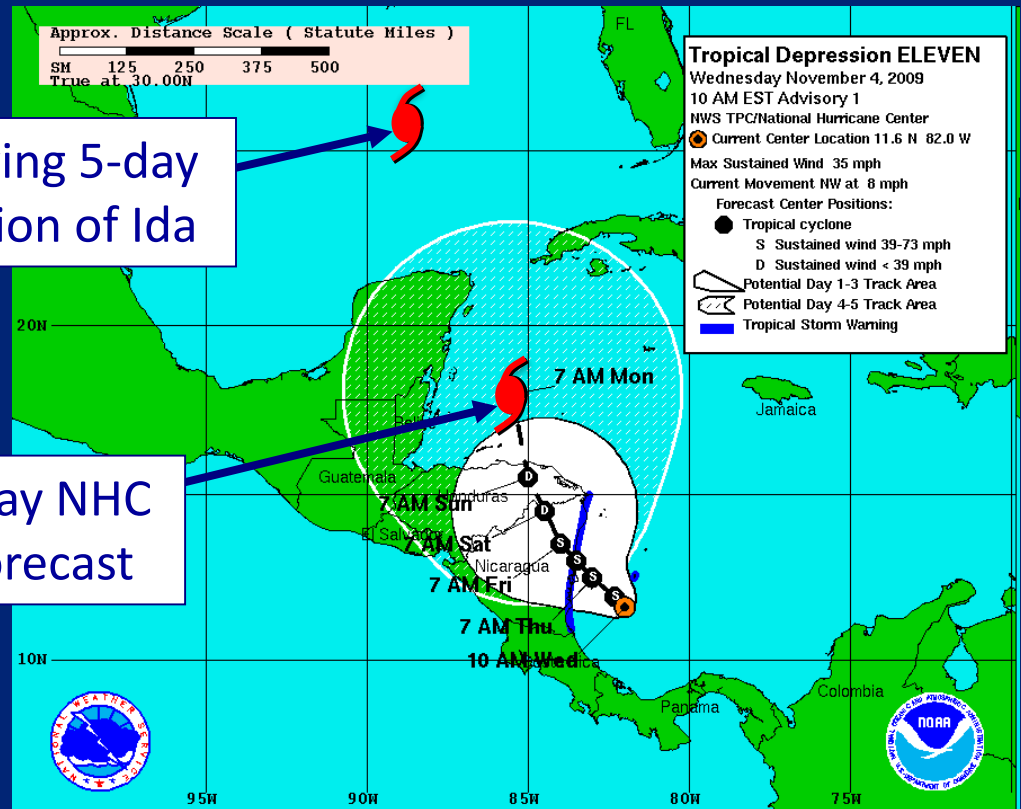
How Can You, as Decision Makers, Deal with Forecast Uncertainty?

TD 11 (later Hurricane Ida)
Advisory Number 1
Issued 10:00 AM EST
4 November 2009

5-day position error
about 600 miles

Verifying 5-day
Position of Ida

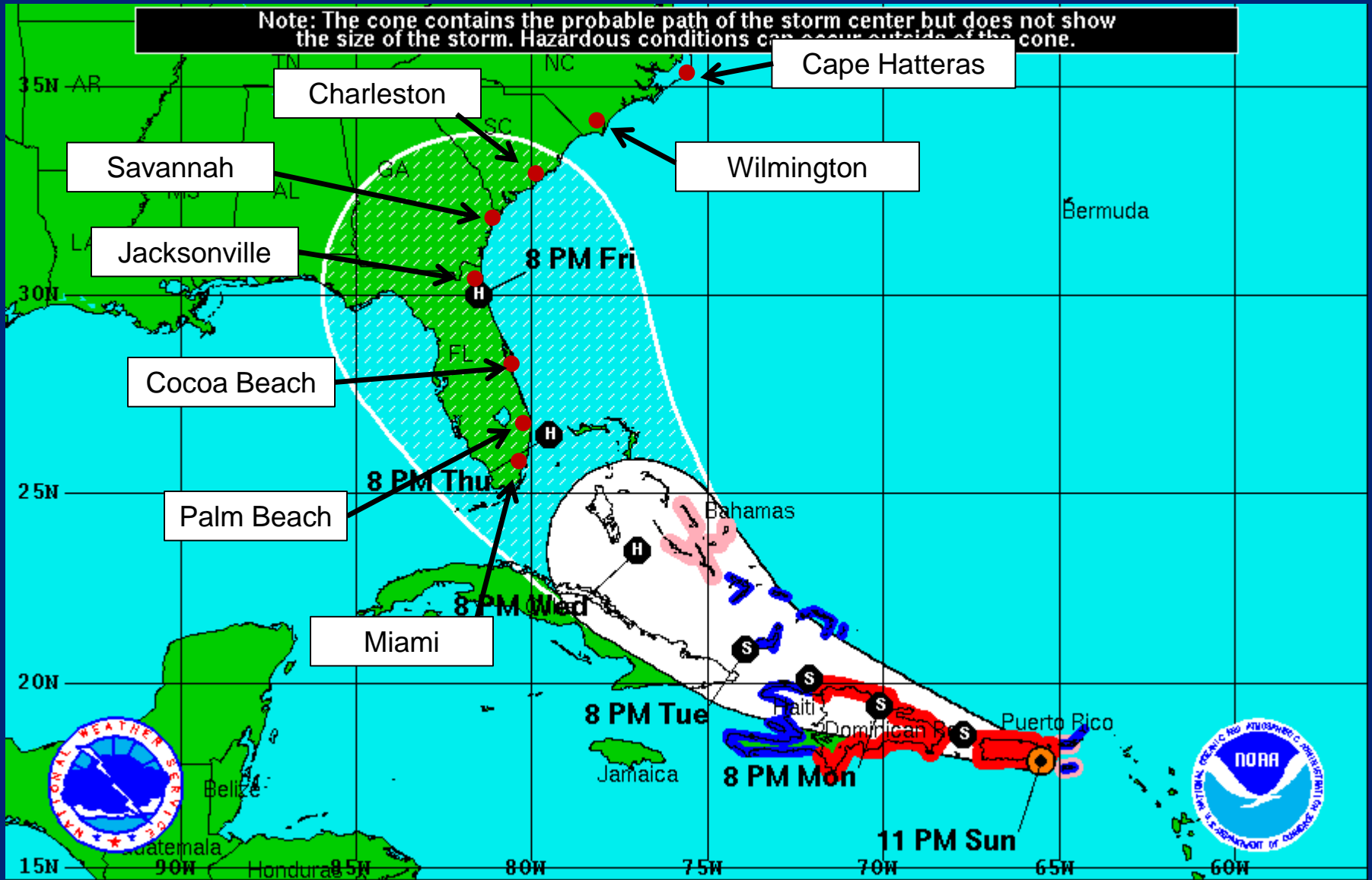
5-day NHC
Forecast



NHC probability products can help

What Are the Chances of Tropical Storm and Hurricane Force Winds at your Location?

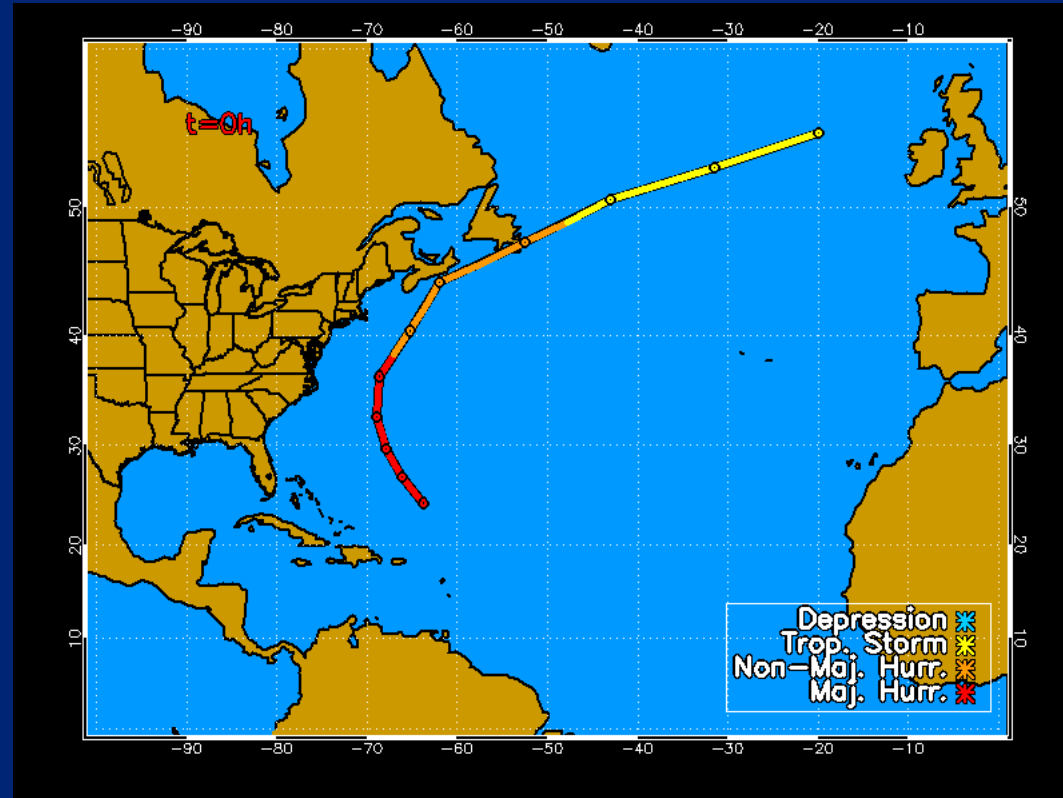
Note: The cone contains the probable path of the storm center but does not show the size of the storm. Hazardous conditions can occur outside of the cone.



Overview of Wind Speed Probability Products

How the Wind Speed Probabilities are Created

- 1,000 realistic alternative scenarios (realizations) are created using
 - Official NHC track and intensity forecasts
 - Historical NHC track and intensity forecast errors
 - Climatology and persistence wind radii model
- Accounts for weakening of storms over land
- Probability of exceeding 34, 50, and 64 kt wind thresholds are computed

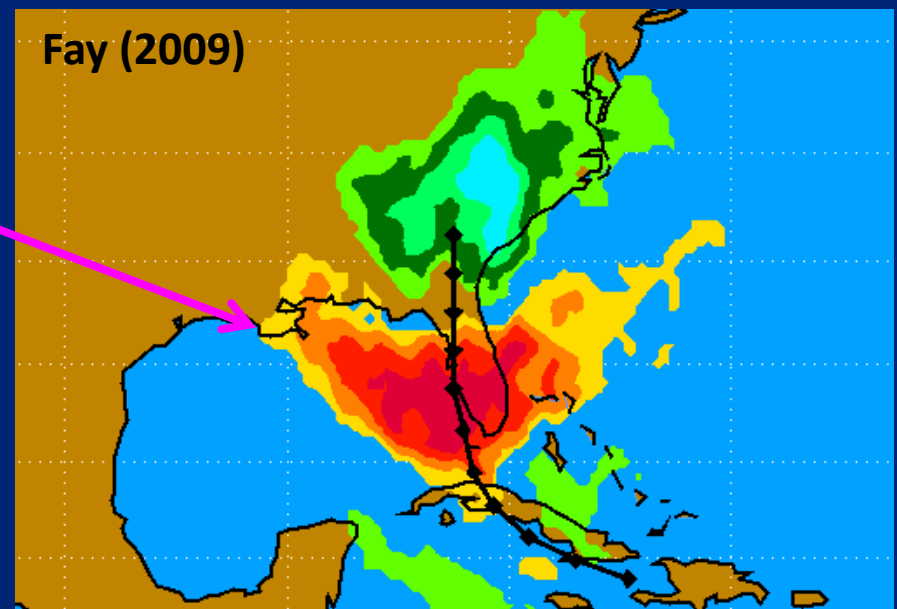
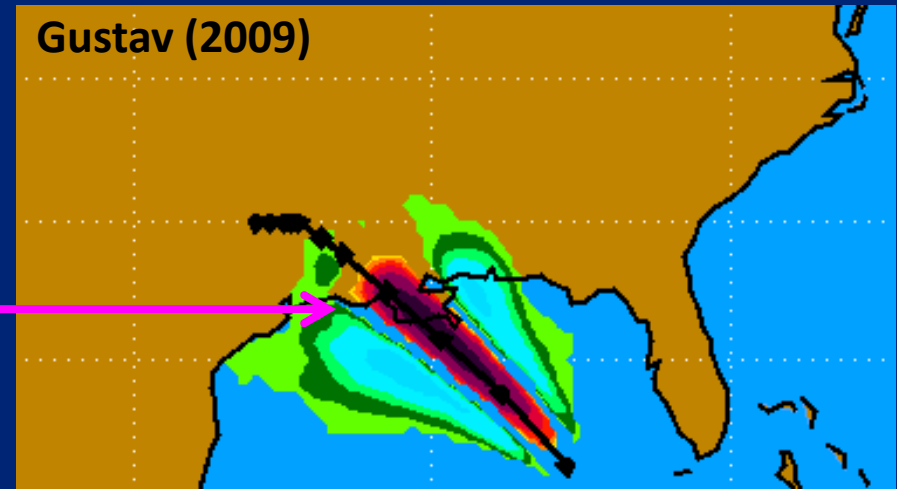


370 of 1,000 realizations bring 34-kt winds to Cape Cod, Massachusetts

$370/1,000 = 0.37 = 37\%$ chance of tropical storm force winds at Cape Cod

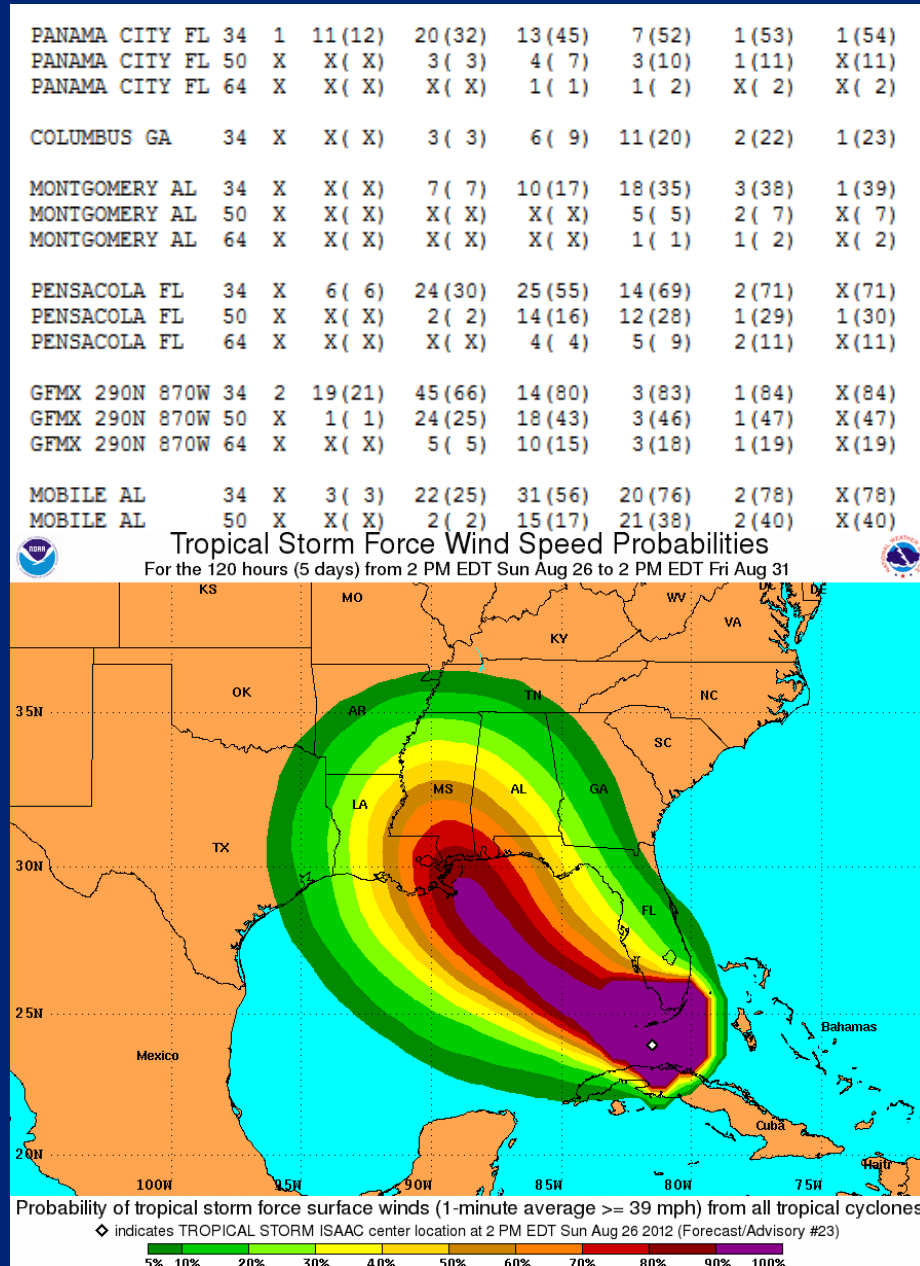
Influence of Track Forecast Uncertainty on Probability Products

- Different historical NHC track forecast errors are sampled depending on how much spread (disagreement) there is in the track model guidance
- If track model spread is small (good model agreement)
 - Probability swath will be narrower with higher probabilities along the official NHC forecast track and lower values along the edges
- If track model spread is large (poor model agreement)
 - Probability swath will be wider, with lower values along the NHC official forecast track and a wider area of low probabilities along the edges



Wind Speed Probabilities

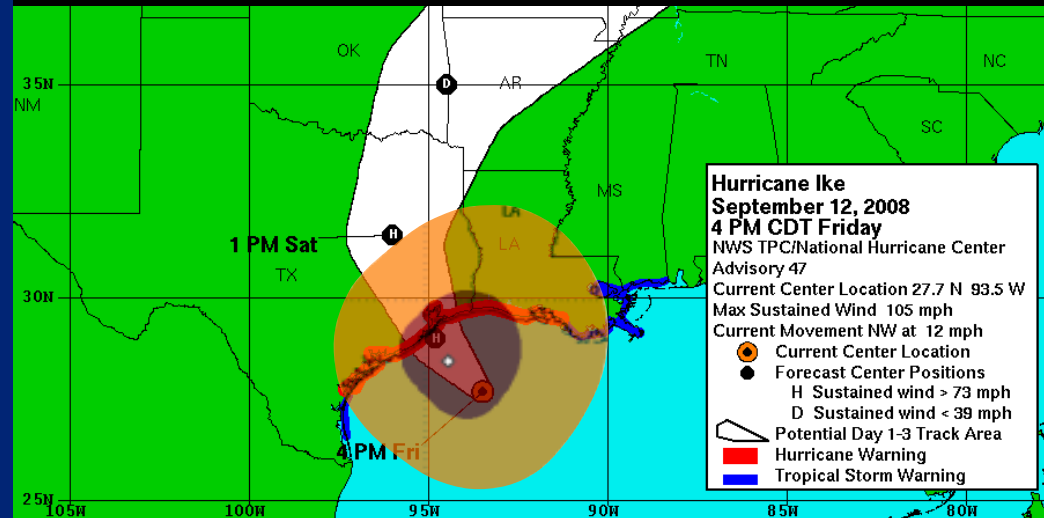
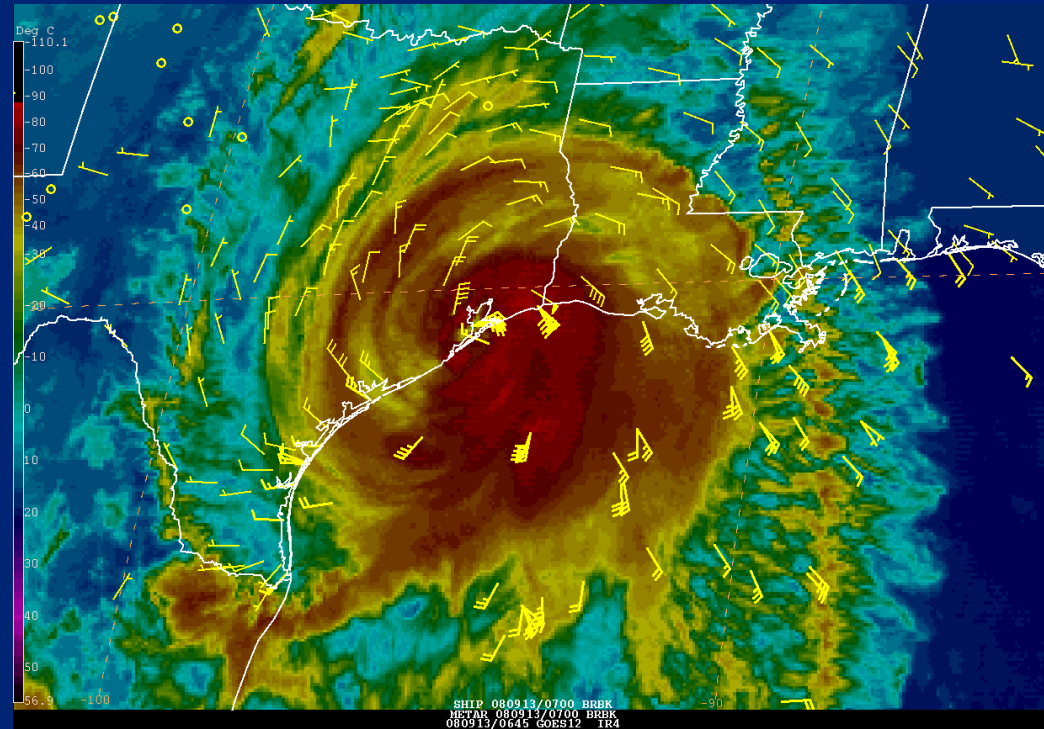
- Depicts location-specific probabilities for 34-kt (tropical-storm-force), 50-kt (58-mph), and 64-kt (hurricane-force) winds
- Text product shows cumulative and onset probabilities for a fixed set of locations
- Graphic shows cumulative probabilities for points over a large domain

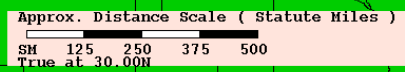


**What the Probabilities Tell
You That the Cone of
Uncertainty Can't**

Impacts Can be Felt Well Outside the Cone

- The cone only displays information about track uncertainty
- It contains no information about specific impacts!
- TC impacts can occur well outside the area enclosed by the cone
 - TC center is expected to move outside the cone about 1/3 of the time
 - Cone narrows near the time of greatest impact due to smaller official track forecast errors

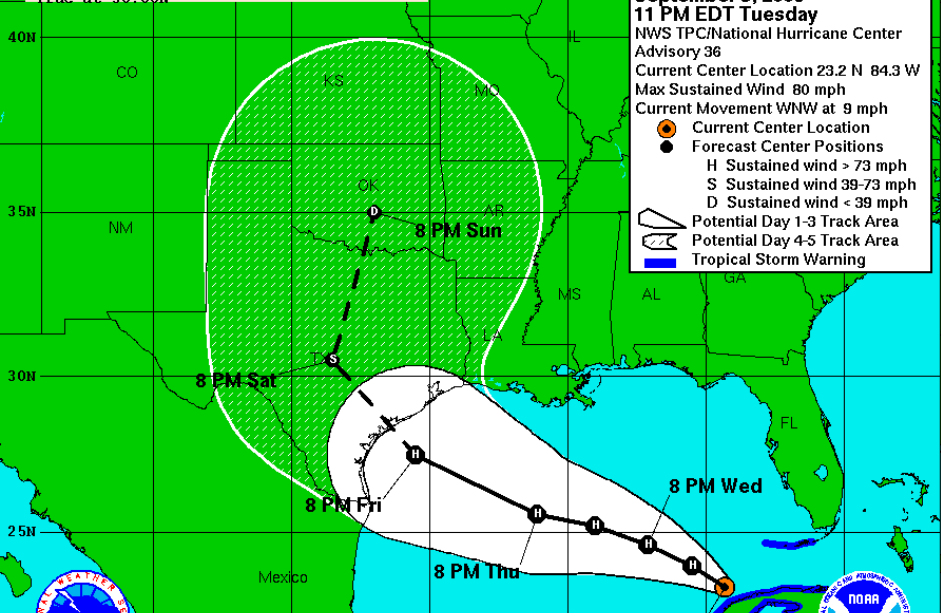




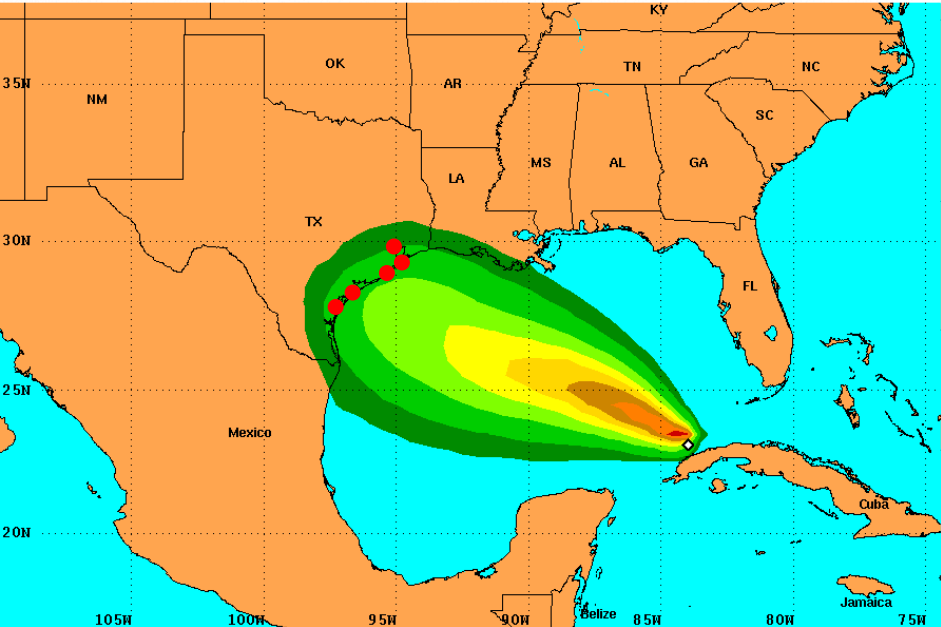
Hurricane Ike
September 9, 2008
11 PM EDT Tuesday
 NWS TPC/National Hurricane Center
 Advisory #36
 Current Center Location 23.2 N 84.3 W
 Max Sustained Wind 80 mph
 Current Movement WNW at 9 mph

- Current Center Location
- Forecast Center Positions
- H Sustained wind > 73 mph
- S Sustained wind 39-73 mph
- D Sustained wind < 39 mph

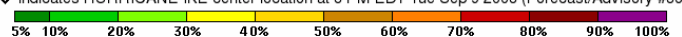
Potential Day 1-3 Track Area
 Potential Day 4-5 Track Area
 Tropical Storm Warning



Hurricane Force Wind Speed Probabilities
 For the 120 hours (5 days) from 8 PM EDT Tue Sep 9 to 8 PM EDT Sun Sep 14



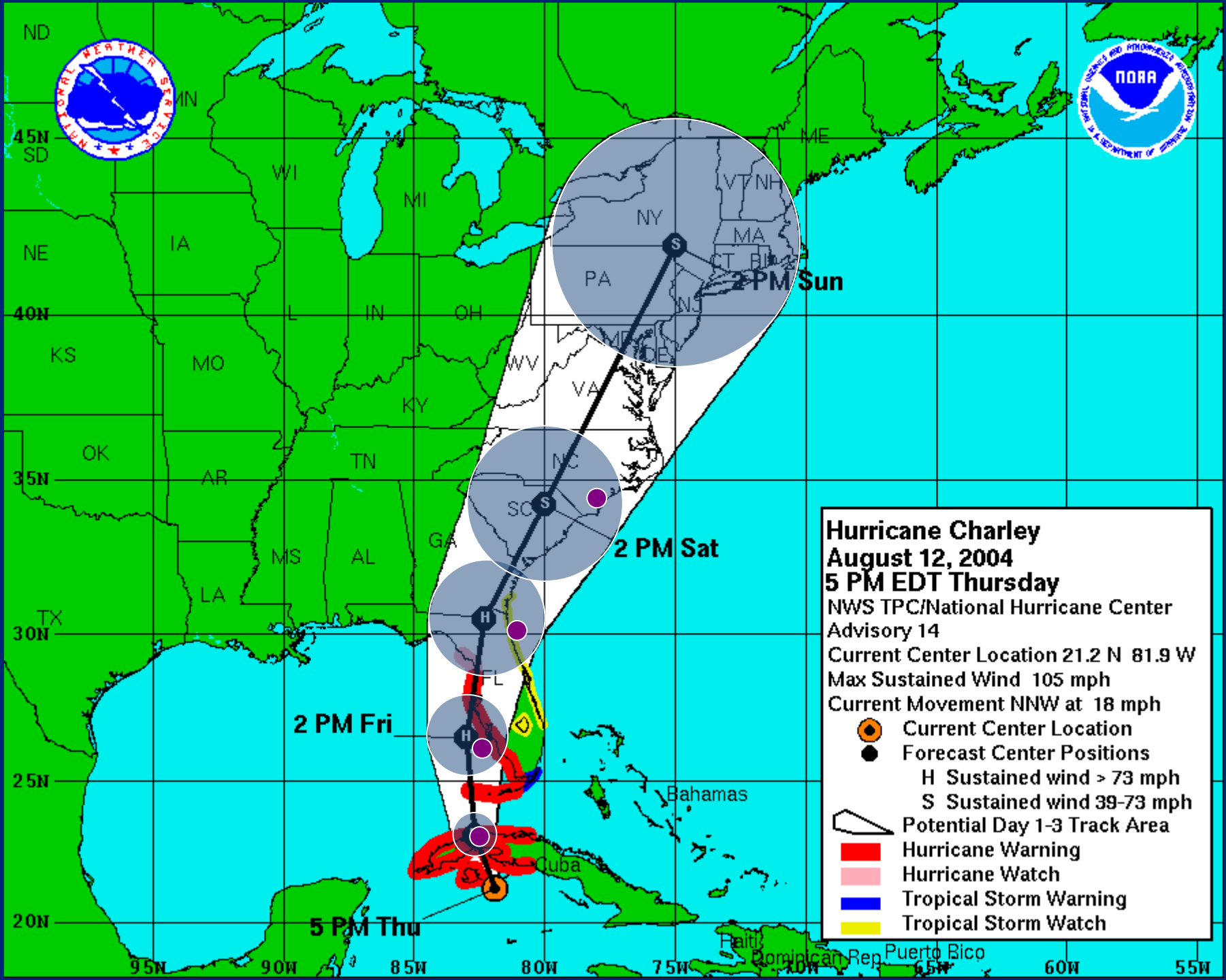
Probability of hurricane force surface winds (1-minute average >= 74 mph) from all tropical cyclones
 ◇ indicates HURRICANE IKE center location at 8 PM EDT Tue Sep 9 2008 (Forecast/Advisory #36)



ZCZC MIAPWSAT4 ALL
 TTAA00 KNHC DDHMMM
 HURRICANE IKE WIND SPEED PROBABILITIES NUMBER 36
 NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL AL092008
 0300 UTC WED SEP 10 2008

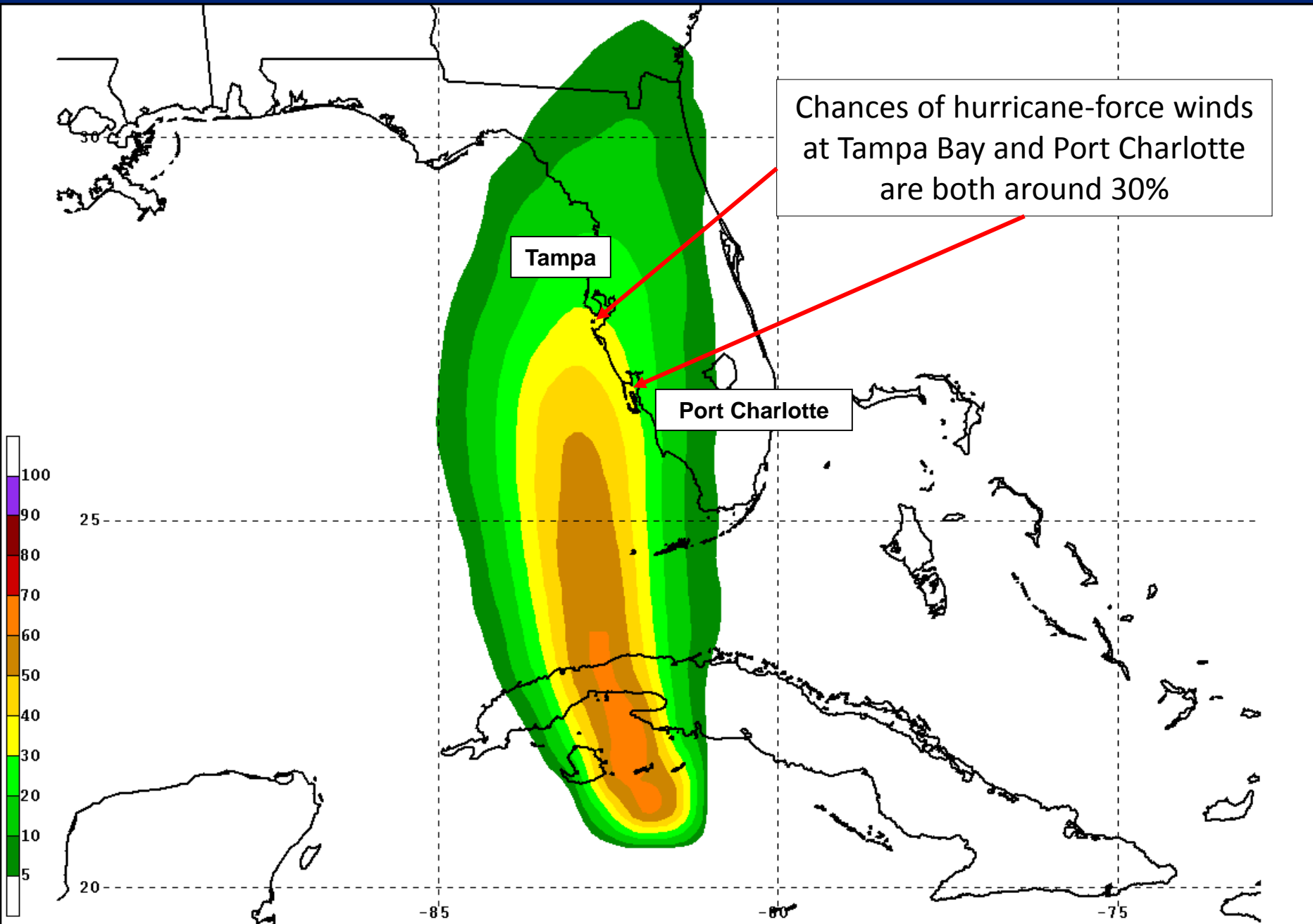
AT 0300Z THE CENTER OF HURRICANE IKE WAS LOCATED NEAR LATITUDE 23.2 NORTH...LONGITUDE 84.3 WEST WITH MAXIMUM SUSTAINED WINDS NEAR 70 KTS ...80 MPH...130 KM/HR.

PORT ARTHUR TX	34	X	X(X)	X(X)	6(6)	32(38)	8(46)	1(47)
PORT ARTHUR TX	50	X	X(X)	X(X)	1(1)	12(13)	5(18)	1(19)
PORT ARTHUR TX	64	X	X(X)	X(X)	X(X)	5(5)	3(8)	X(8)
GALVESTON TX	34	X	X(X)	1(1)	6(7)	38(45)	11(56)	2(58)
GALVESTON TX	50	X	X(X)	X(X)	1(1)	20(21)	7(28)	2(30)
GALVESTON TX	64	X	X(X)	X(X)	X(X)	9(9)	5(14)	X(14)
HOUSTON TX	34	X	X(X)	X(X)	4(4)	33(37)	13(50)	2(52)
HOUSTON TX	50	X	X(X)	X(X)	X(X)	14(14)	8(22)	1(23)
HOUSTON TX	64	X	X(X)	X(X)	X(X)	5(5)	4(9)	1(10)
AUSTIN TX	34	X	X(X)	X(X)	X(X)	17(17)	17(34)	2(36)
AUSTIN TX	50	X	X(X)	X(X)	X(X)	2(2)	6(8)	1(9)
AUSTIN TX	64	X	X(X)	X(X)	X(X)	1(1)	1(2)	X(2)
SAN ANTONIO TX	34	X	X(X)	X(X)	X(X)	16(16)	18(34)	3(37)
SAN ANTONIO TX	50	X	X(X)	X(X)	X(X)	4(4)	7(11)	X(11)
SAN ANTONIO TX	64	X	X(X)	X(X)	X(X)	X(X)	2(2)	X(2)
FREEPORT TX	34	X	X(X)	X(X)	7(7)	40(47)	12(59)	2(61)
FREEPORT TX	50	X	X(X)	X(X)	1(1)	22(23)	10(33)	2(35)
FREEPORT TX	64	X	X(X)	X(X)	X(X)	10(10)	5(15)	1(16)
GFMX 280N 950W	34	X	X(X)	1(1)	13(14)	44(58)	10(68)	2(70)
GFMX 280N 950W	50	X	X(X)	X(X)	3(3)	29(32)	8(40)	3(43)
GFMX 280N 950W	64	X	X(X)	X(X)	1(1)	16(17)	6(23)	2(25)
PORT O CONNOR	34	X	X(X)	X(X)	5(5)	38(43)	16(59)	4(63)
PORT O CONNOR	50	X	X(X)	X(X)	1(1)	19(20)	10(30)	4(34)
PORT O CONNOR	64	X	X(X)	X(X)	X(X)	9(9)	8(17)	1(18)
CORPUS CHRISTI	34	X	X(X)	X(X)	3(3)	29(32)	16(48)	3(51)
CORPUS CHRISTI	50	X	X(X)	X(X)	X(X)	12(12)	10(22)	3(25)
CORPUS CHRISTI	64	X	X(X)	X(X)	X(X)	5(5)	5(10)	1(11)



Hurricane Charley
August 12, 2004
5 PM EDT Thursday
NWS TPC/National Hurricane Center
Advisory 14
Current Center Location 21.2 N 81.9 W
Max Sustained Wind 105 mph
Current Movement NNW at 18 mph

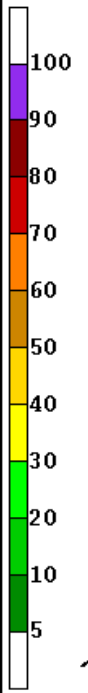
- Current Center Location
- Forecast Center Positions
 - H Sustained wind > 73 mph
 - S Sustained wind 39-73 mph
- ▭ Potential Day 1-3 Track Area
- Hurricane Warning
- Hurricane Watch
- Tropical Storm Warning
- Tropical Storm Watch



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

Tampa

Port Charlotte



HURRICANE CHARLEY 64-KT WIND PROBABILITIES FOR 5 DAYS ENDING 12 UTC 17 AUGUST 2004

Why do Small Probabilities of Extreme Events Matter?

U.S. Hurricane **Watch** and **Warning** Statistics (2000-2008):

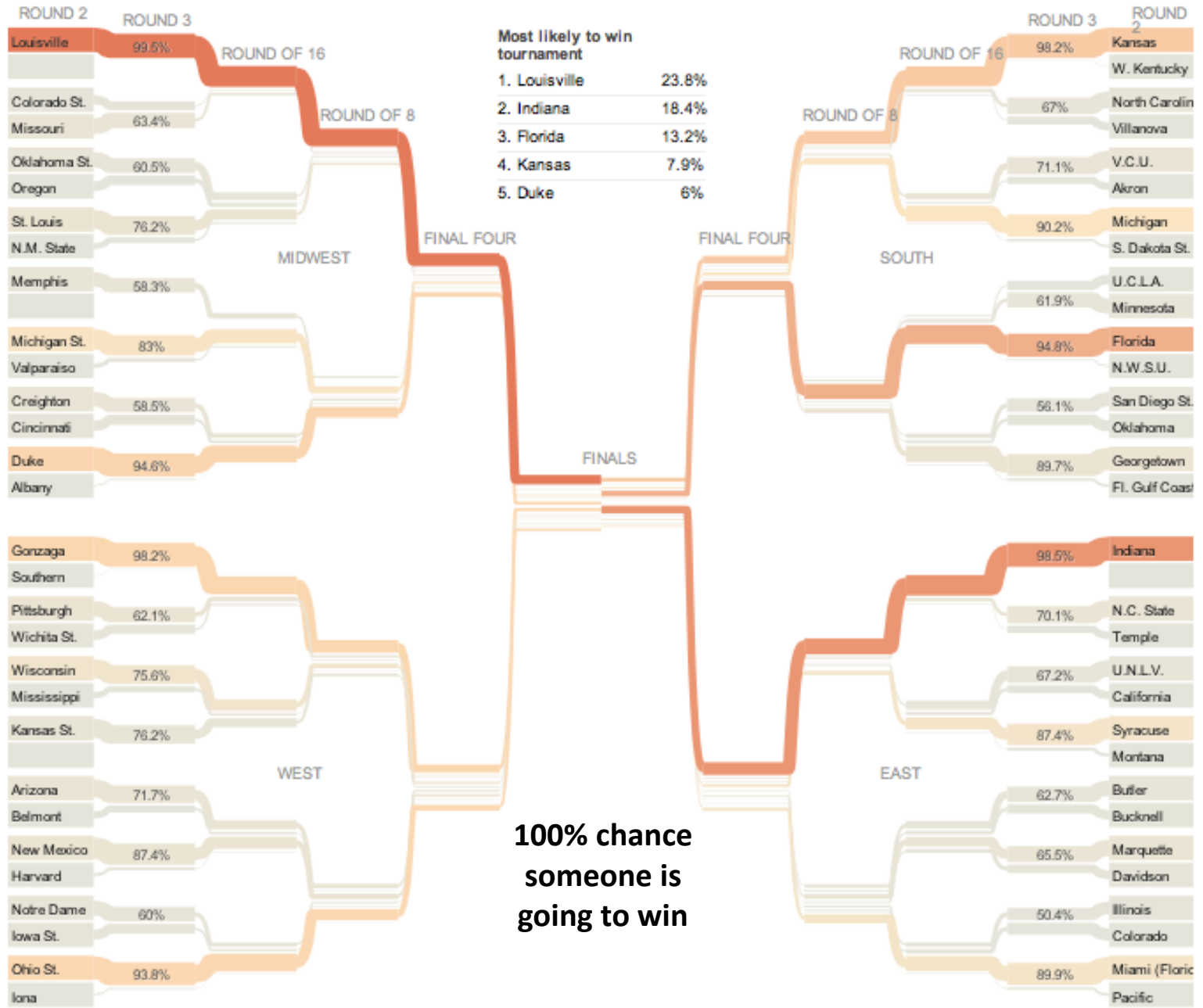
- Average storm-total watch length 477 miles
- Average storm-total length w/ hurricane winds for cases when watch issued 89 miles
- Probability of hurricane winds at point under watch **19%**

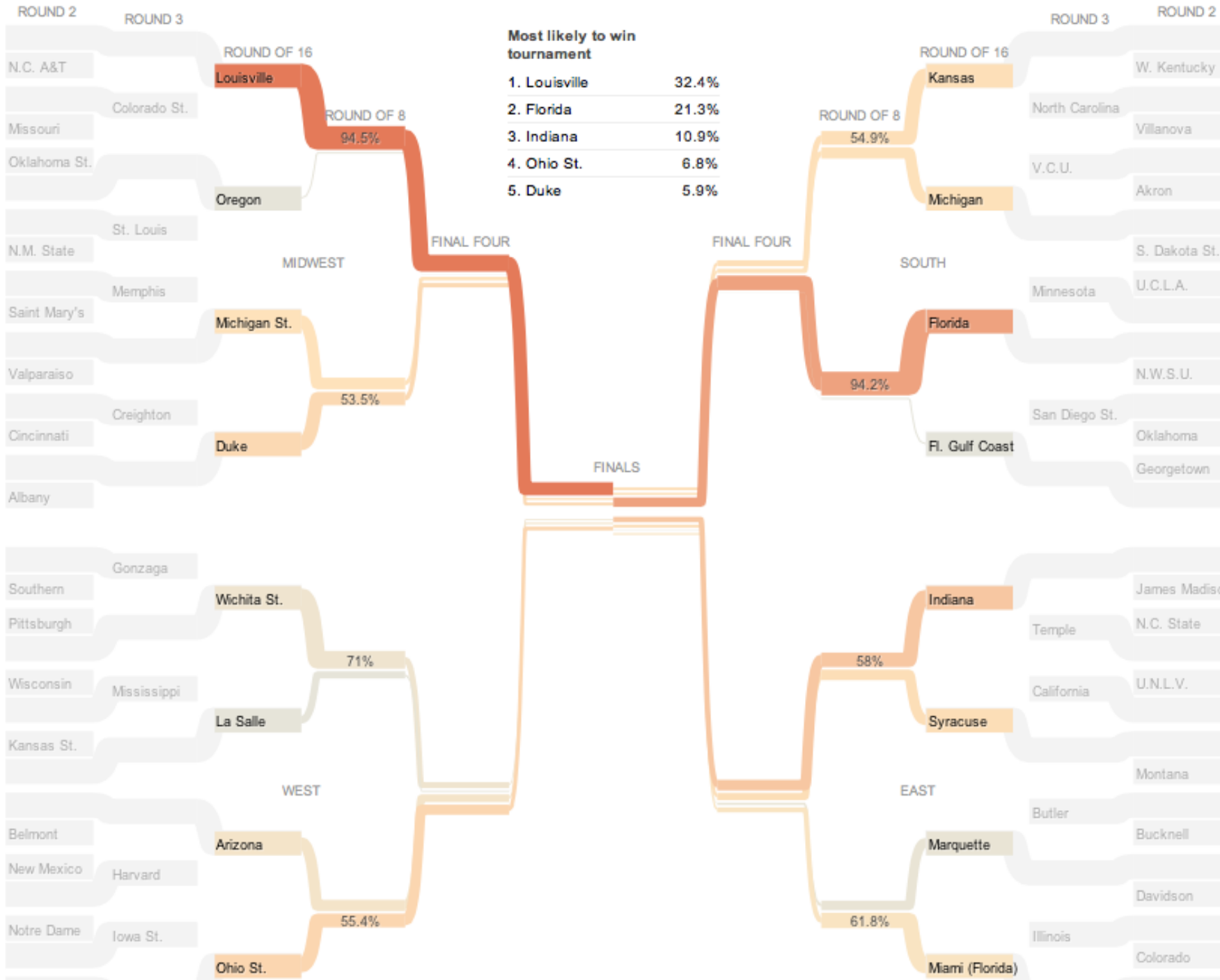
- Average storm-total warning length 403 miles
- Average storm-total length w/ hurricane winds for cases when warning issued 99 miles
- Probability of hurricane winds at warned point **25%**

KEY Height indicates chance of advancing



Color indicates chance to win tournament





Who is going to get hurricane force winds?



5 day forecast

Who is going to get hurricane force winds?



4 day forecast

Who is going to get hurricane force winds?



Who is going to get hurricane force winds?



2 day forecast

Who is going to get hurricane force winds?



1 day forecast

Interpreting the Wind Speed Probability Text Product

Wind Speed Probability Text Product

ZCZC MIAPWSAT4 ALL
TTAA00 KNHC DDHMM

TROPICAL STORM ISAAC WIND SPEED PROBABILITIES NUMBER 23
NWS NATIONAL HURRICANE CENTER MIAMI FL AL092012
2100 UTC SUN AUG 26 2012

AT 2100Z THE CENTER OF TROPICAL STORM ISAAC WAS LOCATED NEAR
LATITUDE 24.2 NORTH...LONGITUDE 82.3 WEST WITH MAXIMUM SUSTAINED
WINDS NEAR 50 KTS...60 MPH...95 KM/H.

Z INDICATES COORDINATED UNIVERSAL TIME (GREENWICH)
ATLANTIC STANDARD TIME (AST)...SUBTRACT 4 HOURS FROM Z TIME
EASTERN DAYLIGHT TIME (EDT)...SUBTRACT 4 HOURS FROM Z TIME
CENTRAL DAYLIGHT TIME (CDT)...SUBTRACT 5 HOURS FROM Z TIME

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

TIME PERIODS	FROM 18Z SUN TO 06Z MON	FROM 06Z MON TO 18Z MON	FROM 18Z MON TO 06Z TUE	FROM 06Z TUE TO 18Z TUE	FROM 18Z TUE TO 18Z WED	FROM 18Z WED TO 18Z THU	FROM 18Z THU TO 18Z FRI
FORECAST HOUR	(12)	(24)	(36)	(48)	(72)	(96)	(120)
LOCATION	KT						
APALACHICOLA	34 3	11(14)	16(30)	9(39)	7(46)	1(47)	X(47)
APALACHICOLA	50 X	X(X)	2(2)	2(4)	1(5)	1(6)	X(6)
APALACHICOLA	64 X	X(X)	X(X)	1(1)	X(1)	X(1)	X(1)
GFMX 290N 850W	34 7	18(25)	17(42)	7(49)	4(53)	1(54)	X(54)
GFMX 290N 850W	50 X	1(1)	3(4)	2(6)	1(7)	X(7)	X(7)
GFMX 290N 850W	64 X	X(X)	X(X)	1(1)	X(1)	X(1)	X(1)
PANAMA CITY FL	34 1	11(12)	20(32)	13(45)	7(52)	1(53)	1(54)
PANAMA CITY FL	50 X	X(X)	3(3)	4(7)	3(10)	1(11)	X(11)
PANAMA CITY FL	64 X	X(X)	X(X)	1(1)	1(2)	X(2)	X(2)
COLUMBUS GA	34 X	X(X)	3(3)	6(9)	11(20)	2(22)	1(23)
MONTGOMERY AL	34 X	X(X)	7(7)	10(17)	18(35)	3(38)	1(39)
MONTGOMERY AL	50 X	X(X)	X(X)	X(X)	5(5)	2(7)	X(7)
MONTGOMERY AL	64 X	X(X)	X(X)	X(X)	1(1)	1(2)	X(2)
PENSACOLA FL	34 X	6(6)	24(30)	25(55)	14(69)	2(71)	X(71)
PENSACOLA FL	50 X	X(X)	2(2)	14(16)	12(28)	1(29)	1(30)
PENSACOLA FL	64 X	X(X)	X(X)	4(4)	5(9)	2(11)	X(11)

Example Interpretation of Output

TIME PERIODS	FROM 18Z FRI TO 06Z SAT	FROM 06Z SAT TO 18Z SAT	FROM 18Z SAT TO 06Z SUN	FROM 06Z SUN TO 18Z SUN	FROM 18Z SUN TO 18Z MON	FROM 18Z MON TO 18Z TUE	FROM 18Z TUE TO 18Z WED
FORECAST HOUR	(12)	(24)	(36)	(48)	(72)	(96)	(120)
LOCATION	KT						
RALEIGH NC	34 X	X(X)	X(X)	2(2)	10(12)	8(20)	10(30)
RALEIGH NC	50 X	X(X)	X(X)	X(X)	2(2)	3(5)	5(10)
RALEIGH NC	64 X	X(X)	X(X)	X(X)	X(X)	2(2)	2(4)
CAPE HATTERAS	34 X	X(X)	X(X)	1(1)	4(5)	3(8)	7(15)
CAPE HATTERAS	50 X	X(X)	X(X)	X(X)	X(X)	1(1)	2(3)
CHARLOTTE NC	34 X	X(X)	X(X)	3(3)	18(21)	12(33)	9(42)
CHARLOTTE NC	50 X	X(X)	X(X)	X(X)	4(4)	6(10)	4(14)
CHARLOTTE NC	64 X	X(X)	X(X)	X(X)	2(2)	2(4)	2(6)

34 kt
probabilities
at Charlotte
NC



What is the chance that winds of tropical storm force (34 kt or greater) will occur at Charlotte NC during the next five days?

Example Interpretation of Output

TIME PERIODS	FROM 18Z FRI TO 06Z SAT	FROM 06Z SAT TO 18Z SAT	FROM 18Z SAT TO 06Z SUN	FROM 06Z SUN TO 18Z SUN	FROM 18Z SUN TO 18Z MON	FROM 18Z MON TO 18Z TUE	FROM 18Z TUE TO 18Z WED
FORECAST HOUR	(12)	(24)	(36)	(48)	(72)	(96)	(120)
LOCATION	KT						
RALEIGH NC	34 X	X(X)	X(X)	2(2)	10(12)	8(20)	10(30)
RALEIGH NC	50 X	X(X)	X(X)	X(X)	2(2)	3(5)	5(10)
RALEIGH NC	64 X	X(X)	X(X)	X(X)	X(X)	2(2)	2(4)
CAPE HATTERAS	34 X	X(X)	X(X)	1(1)	4(5)	3(8)	7(15)
CAPE HATTERAS	50 X	X(X)	X(X)	X(X)	X(X)	1(1)	2(3)
CHARLOTTE NC	34 X	X(X)	X(X)	3(3)	18(21)	12(33)	9(42)
CHARLOTTE NC	50 X	X(X)	X(X)	X(X)	4(4)	6(10)	4(14)
CHARLOTTE NC	64 X	X(X)	X(X)	X(X)	2(2)	2(4)	2(6)

34 kt probabilities at Charlotte NC

What is the chance that winds of tropical storm force (34 kt or greater) will occur at Charlotte NC during the next five days?

42%

Example Interpretation of Output

TIME PERIODS	FROM 18Z FRI TO 06Z SAT	FROM 06Z SAT TO 18Z SAT	FROM 18Z SAT TO 06Z SUN	FROM 06Z SUN TO 18Z SUN	FROM 18Z SUN TO 18Z MON	FROM 18Z MON TO 18Z TUE	FROM 18Z TUE TO 18Z WED
FORECAST HOUR	(12)	(24)	(36)	(48)	(72)	(96)	(120)
LOCATION	KT						
RALEIGH NC	34 X	X(X)	X(X)	2(2)	10(12)	8(20)	10(30)
RALEIGH NC	50 X	X(X)	X(X)	X(X)	2(2)	3(5)	5(10)
RALEIGH NC	64 X	X(X)	X(X)	X(X)	X(X)	2(2)	2(4)
CAPE HATTERAS	34 X	X(X)	X(X)	1(1)	4(5)	3(8)	7(15)
CAPE HATTERAS	50 X	X(X)	X(X)	X(X)	X(X)	1(1)	2(3)
CHARLOTTE NC	34 X	X(X)	X(X)	3(3)	18(21)	12(33)	9(42)
CHARLOTTE NC	50 X	X(X)	X(X)	X(X)	4(4)	6(10)	4(14)
CHARLOTTE NC	64 X	X(X)	X(X)	X(X)	2(2)	2(4)	2(6)

34 kt
probabilities
at Charlotte
NC



What is the chance that winds of tropical storm force (34 kt or greater) will occur at Charlotte NC during the next five days?

42%

When are these winds most likely to start?

Example Interpretation of Output

34 kt
probabilities
at Charlotte
NC

TIME PERIODS	FROM 18Z FRI TO 06Z SAT	FROM 06Z SAT TO 18Z SAT	FROM 18Z SAT TO 06Z SUN	FROM 06Z SUN TO 18Z SUN	FROM 18Z SUN TO 18Z MON	FROM 18Z MON TO 18Z TUE	FROM 18Z TUE TO 18Z WED
FORECAST HOUR	(12)	(24)	(36)	(48)	(72)	(96)	(120)
LOCATION	KT						
RALEIGH NC	34 X	X(X)	X(X)	2(2)	10(12)	8(20)	10(30)
RALEIGH NC	50 X	X(X)	X(X)	X(X)	2(2)	3(5)	5(10)
RALEIGH NC	64 X	X(X)	X(X)	X(X)	X(X)	2(2)	2(4)
CAPE HATTERAS	34 X	X(X)	X(X)	1(1)	4(5)	3(8)	7(15)
CAPE HATTERAS	50 X	X(X)	X(X)	X(X)	X(X)	1(1)	2(3)
CHARLOTTE NC	34 X	X(X)	X(X)	3(3)	18(21)	12(33)	9(12)
CHARLOTTE NC	50 X	X(X)	X(X)	X(X)	4(4)	6(10)	4(14)
CHARLOTTE NC	64 X	X(X)	X(X)	X(X)	2(2)	2(4)	2(6)

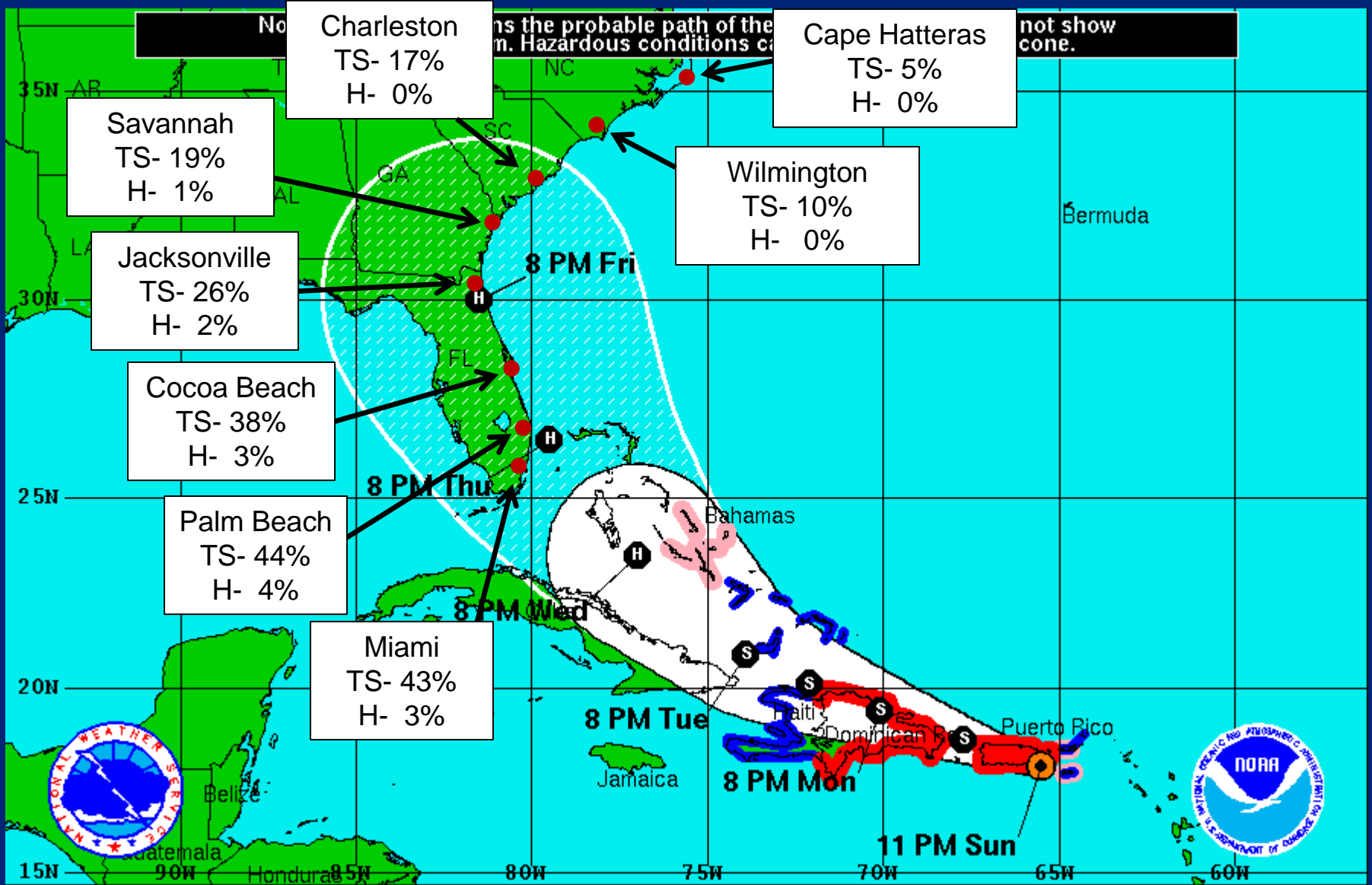
What is the chance that winds of tropical storm force (34 kt or greater) will occur at Charlotte NC during the next five days?

42%

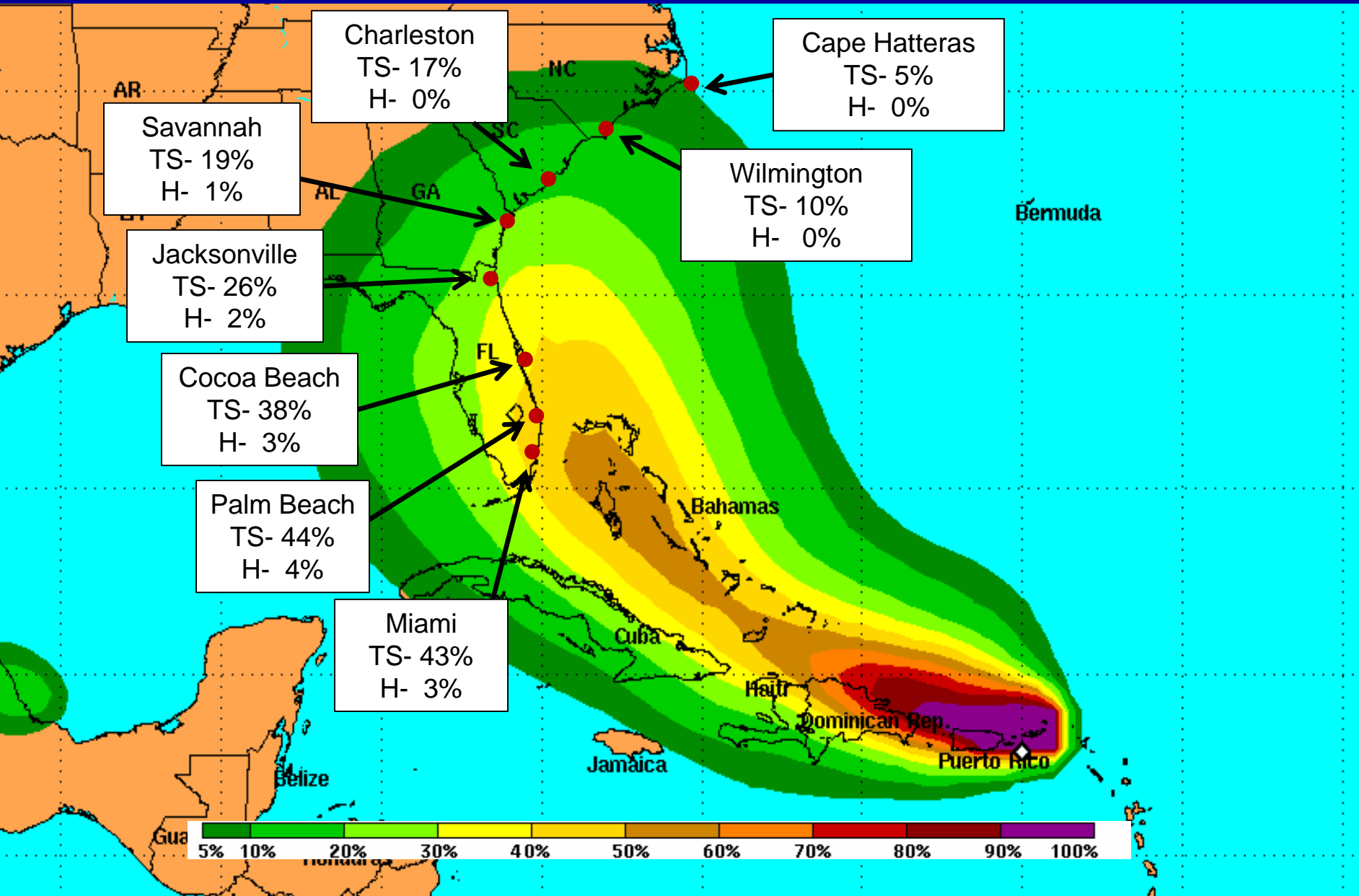
When are these winds most likely to start?

From 18Z Sun to 18Z Mon (18% chance)

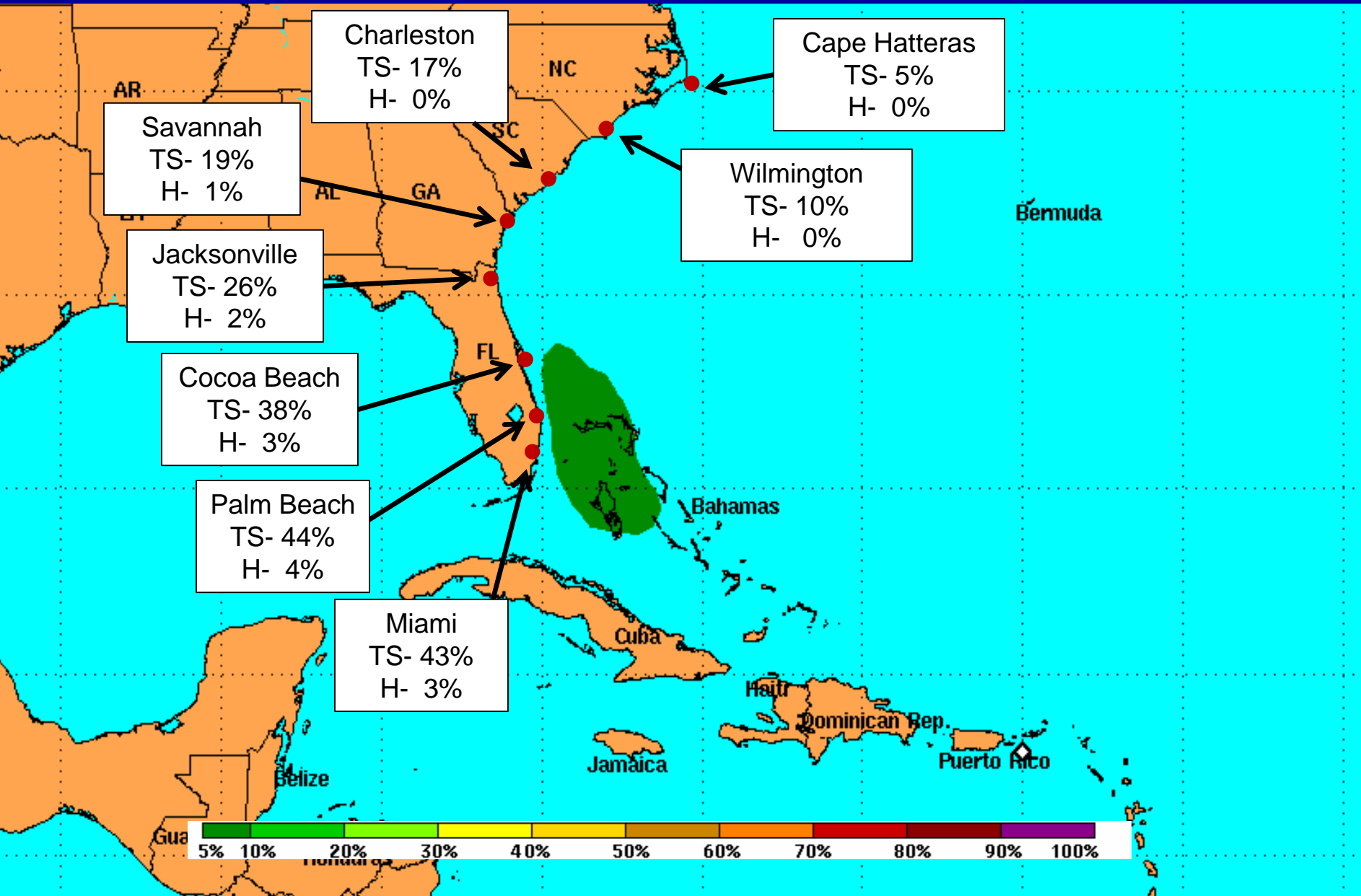
What Are the Chances of Tropical Storm and Hurricane Force Winds at your Location?



What Are the Chances of Tropical Storm and Hurricane Force Winds at your Location?



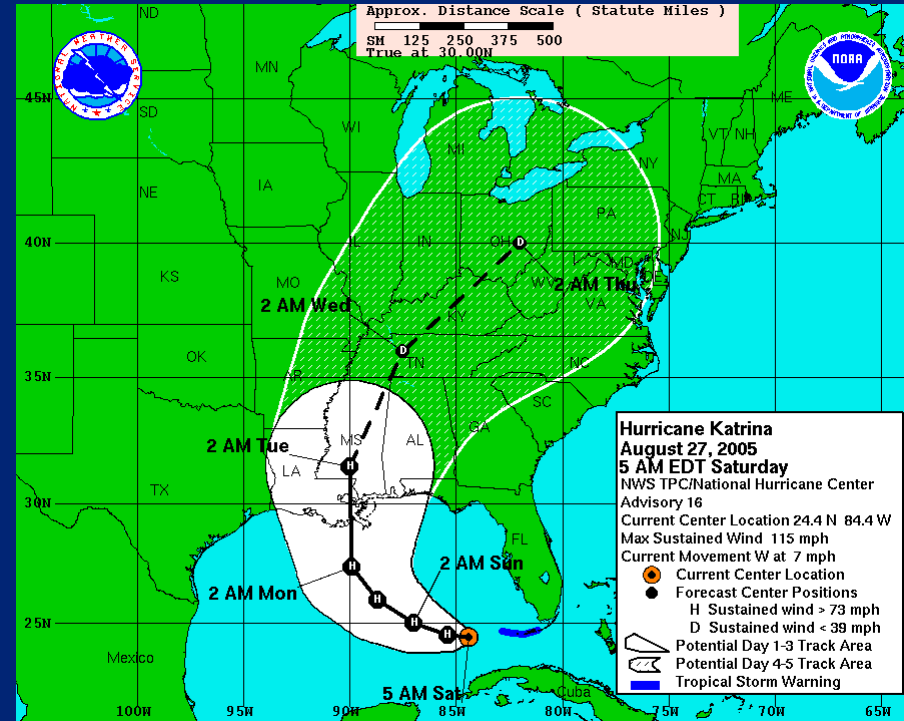
What Are the Chances of Tropical Storm and Hurricane Force Winds at your Location?



Timing Information About Wind Onset

Onset of 34-kt Winds Katrina (2005)

- Onset of 34-kt winds based on deterministic forecast issued with Advisory 16
 - New Orleans, LA – 8/29 (Mon.) 08Z
 - Gulfport, MS – 8/29 (Mon.) 11Z



Wind Speed Probabilities

Katrina (2005) Advisory 16

- - - - WIND SPEED PROBABILITIES FOR SELECTED LOCATIONS - - - -										
		FROM		FROM		FROM		FROM		FROM
TIME		06Z SAT	18Z SAT	06Z SUN	18Z SUN	06Z MON	06Z TUE	06Z WED		
PERIODS		TO	TO	TO	TO	TO	TO	TO		
		18Z SAT	06Z SUN	18Z SUN	06Z MON	06Z TUE	06Z WED	06Z THU		
FORECAST HOUR		(12)	(24)	(36)	(48)	(72)	(96)	(120)		
NEW ORLEANS LA	34 X		1 (1)	9 (10)	28 (38)	34 (72)	5 (77)	X (77)		
GULFPORT MS	34 X		1 (1)	8 (9)	23 (32)	35 (67)	5 (72)	1 (73)		

Wind Speed Probabilities

Katrina (2005) Advisory 16

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

TIME PERIODS	FROM 06Z SAT	FROM 18Z SAT	FROM 06Z SUN	FROM 18Z SUN	FROM 06Z MON	FROM 06Z TUE	FROM 06Z WED
FORECAST HOUR	(12)	(24)	(36)	(48)	(72)	(96)	(120)
NEW ORLEANS LA	34 X	1 (1)	9 (10)	28 (38)	34 (72)	5 (77)	X (77)
GULFPORT MS	34 X	1 (1)	8 (9)	23 (32)	35 (67)	5 (72)	1 (73)

Most likely period of onset of 34-kt winds at New Orleans and Gulfport is between 06Z Monday 8/29 and 06Z Tuesday 8/30

Wind Speed Probabilities

Katrina (2005) Advisory 16

- - - - WIND SPEED PROBABILITIES FOR SELECTED LOCATIONS - - - -										
		FROM		FROM		FROM		FROM		FROM
TIME PERIODS		06Z SAT	18Z SAT	06Z SUN	18Z SUN	06Z MON	06Z TUE	06Z WED	06Z THU	
FORECAST HOUR		(12)	(24)	(36)	(48)	(72)	(96)	(120)		
NEW ORLEANS LA	34 X		1 (1)	9 (10)	28 (38)	34 (72)	5 (77)	X (77)		
GULFPORT MS	34 X		1 (1)	8 (9)	23 (32)	35 (67)	5 (72)	1 (73)		

However, the probability that 34-kt winds will start **prior to** 06Z Monday 8/29 at both New Orleans and Gulfport is nearly as large!


What Actually Happened?

- Onset of 34-kt winds occurred between 00Z and 06Z Monday 8/29 at New Orleans and Gulfport
 - At least **3 hours** earlier than shown by the official forecast at New Orleans
 - At least **5 hours** earlier than shown by the official forecast at Gulfport


Onset Timing Information

- Important information about the onset of wind conditions is contained in the probabilities
- Examine trends from advisory to advisory
 - How are probabilities of onset changing?
 - Are chances of onset nearly equal between two consecutive time periods?

Intensity Probability Table - Eliminated in 2014



Intensity (Maximum Wind Speed) Probability Table
Hurricane Earl Advisory Number 25
11:00 AM AST Aug 31 2010



Wind Range (mph)	Forecast Time						
	12 hour for 8 PM Tue	24 hour for 8 AM Wed	36 hour for 8 PM Wed	48 hour for 8 AM Thu	72 hour for 8 AM Fri	96 hour for 8 AM Sat	120 hour for 8 AM Sun
Dissipated	<1%	<1%	<1%	<1%	1%	6%	15%
Tropical Depression (<39)	<1%	<1%	<1%	<1%	2%	11%	13%
Tropical Storm (39-73)	<1%	<1%	1%	2%	19%	44%	43%
Hurricane (all categories)	99%	99%	99%	98%	78%	39%	30%
-- Category 1 (74-95)	<1%	2%	6%	12%	33%	27%	20%
-- Category 2 (96-110)	3%	7%	17%	24%	24%	8%	7%
-- Category 3 (111-130)	60%	47%	48%	39%	16%	3%	2%
-- Category 4 (131-155)	35%	40%	24%	20%	5%	1%	1%
-- Category 5 (>155)	2%	5%	4%	4%	1%	<1%	<1%
Forecast Maximum Wind	135 mph	140 mph	135 mph	135 mph	115 mph	90 mph	65 mph

- Table provided the chance the storm intensity would fall within the various categories
- Grossly underestimated the likely intensity for storms near landfall
- Eliminated until a suitable replacement can be developed

Summary

- Wind speed probability products help you deal with the uncertainty inherent in forecasting tropical cyclones
- Provide additional information beyond what is available in deterministic forecasts for:
 - Timing of event onset
 - Likelihood of various wind speeds occurring at your location
 - Likelihood of tropical cyclone intensity
- “Low” probabilities of extreme events often warrant action!