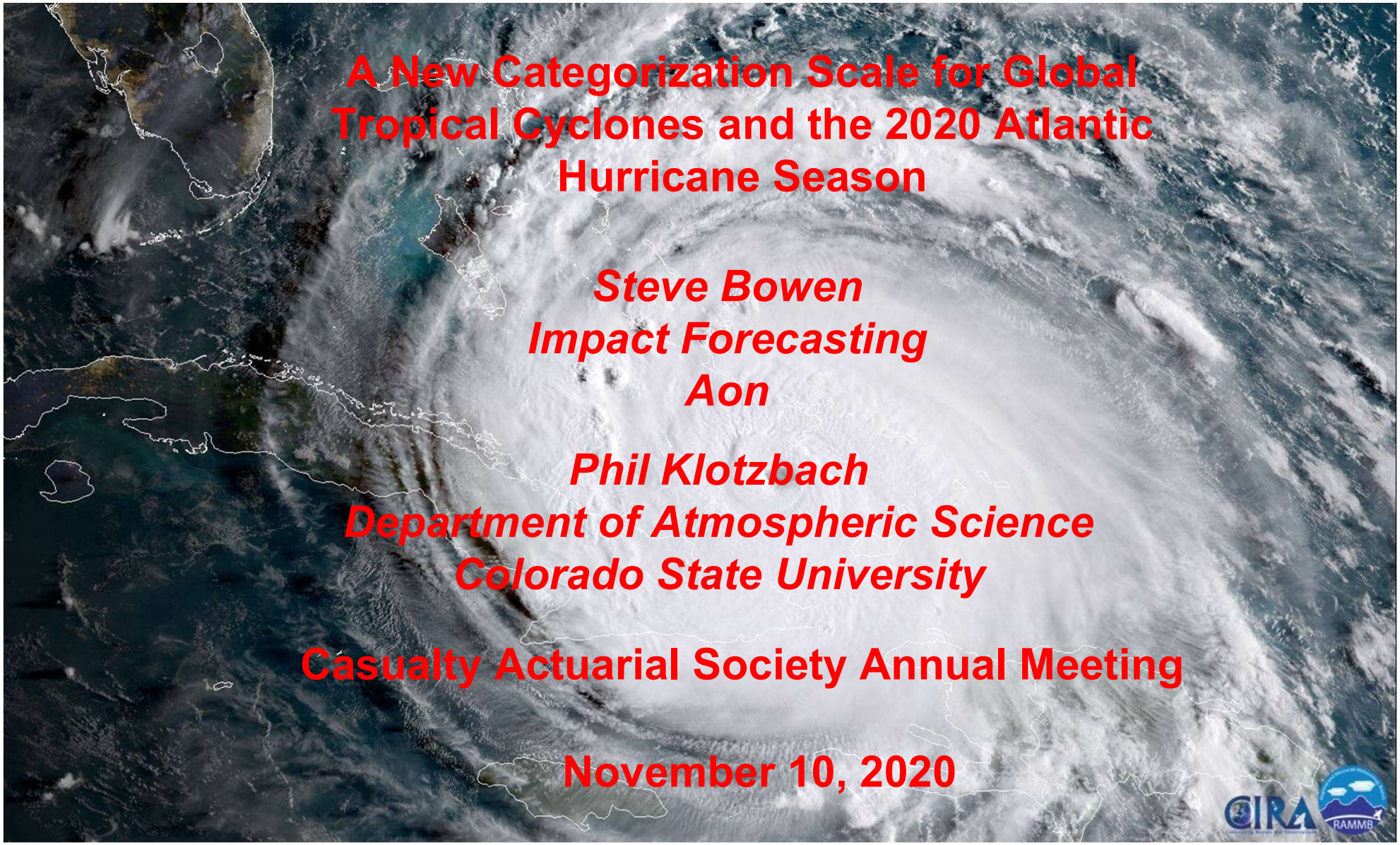

A New Categorization Scale for Global Tropical Cyclones and the 2020 Atlantic Hurricane Season

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Impact Forecasting
Aon

Phil Klotzbach
Department of Atmospheric Science
Colorado State University

Casualty Actuarial Society Annual Meeting

November 10, 2020

Outline

- 2020 Atlantic Hurricane Season Recap
- 2020 Continental US Hurricane Landfalls
- Long-Term Trends in Atlantic Hurricane Activity
- Proposed New Hurricane Categorization Scale

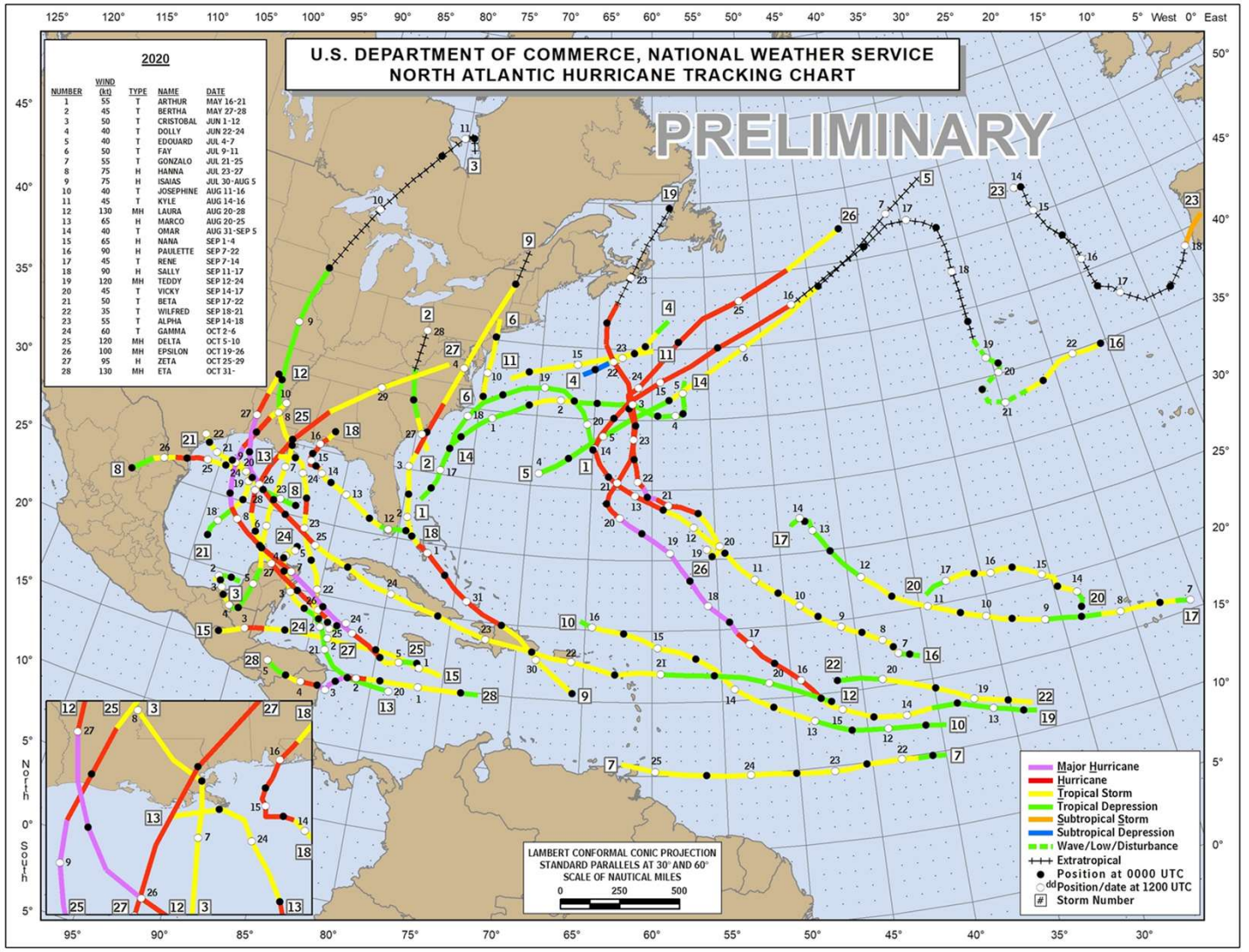
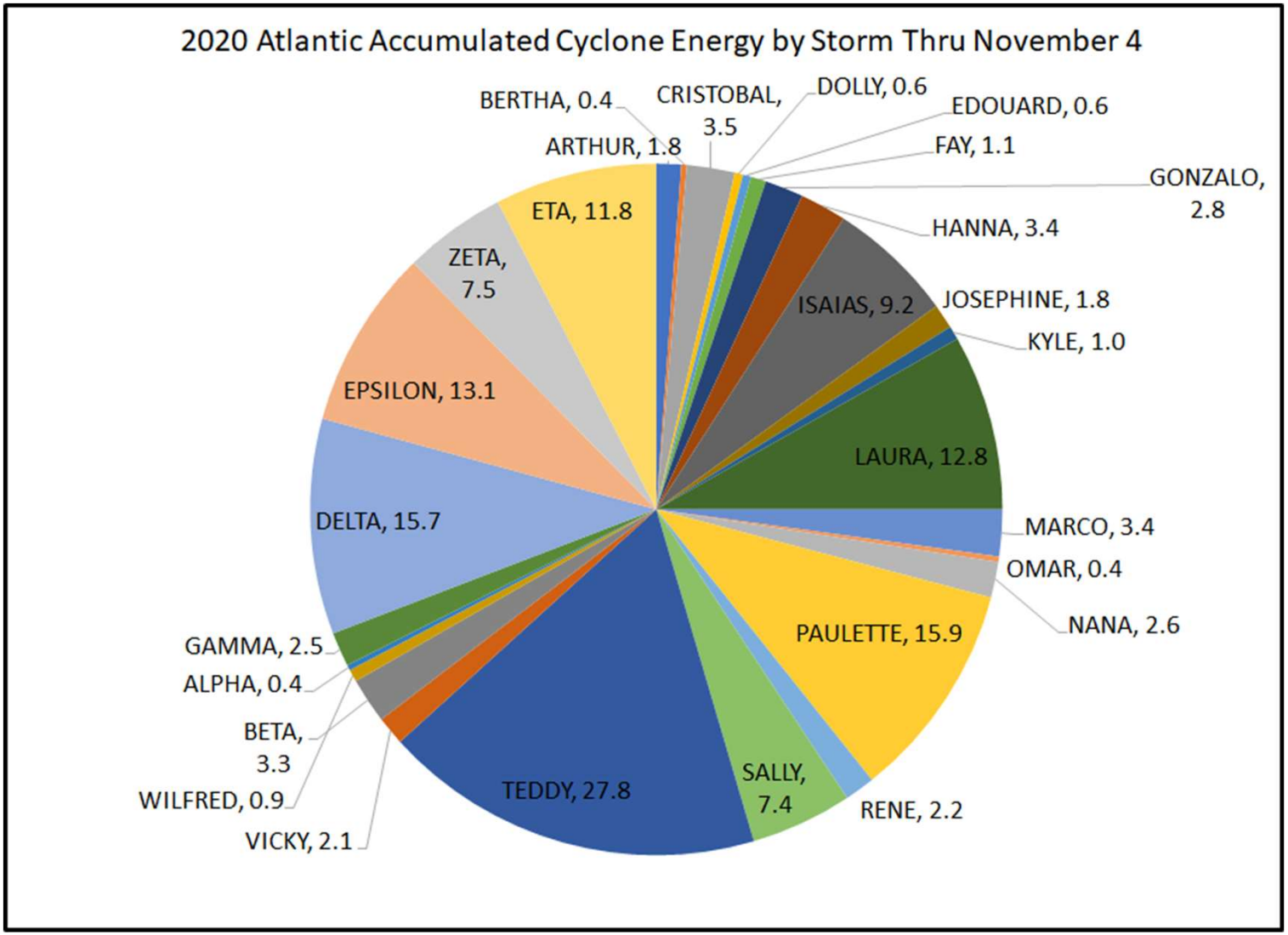


Figure courtesy of Ethan Gibney, NOAA

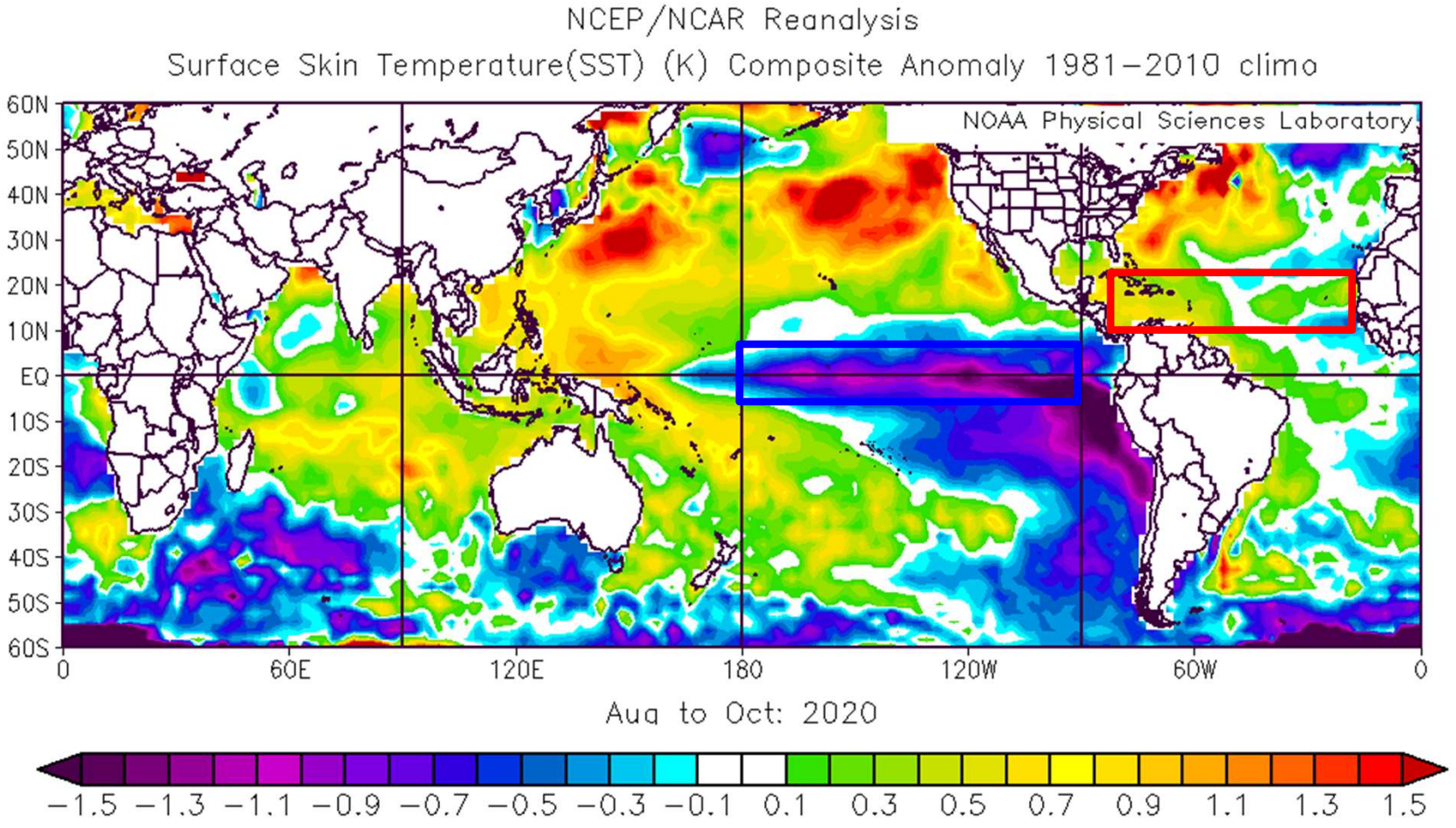
Atlantic Hurricane Activity Through November 4

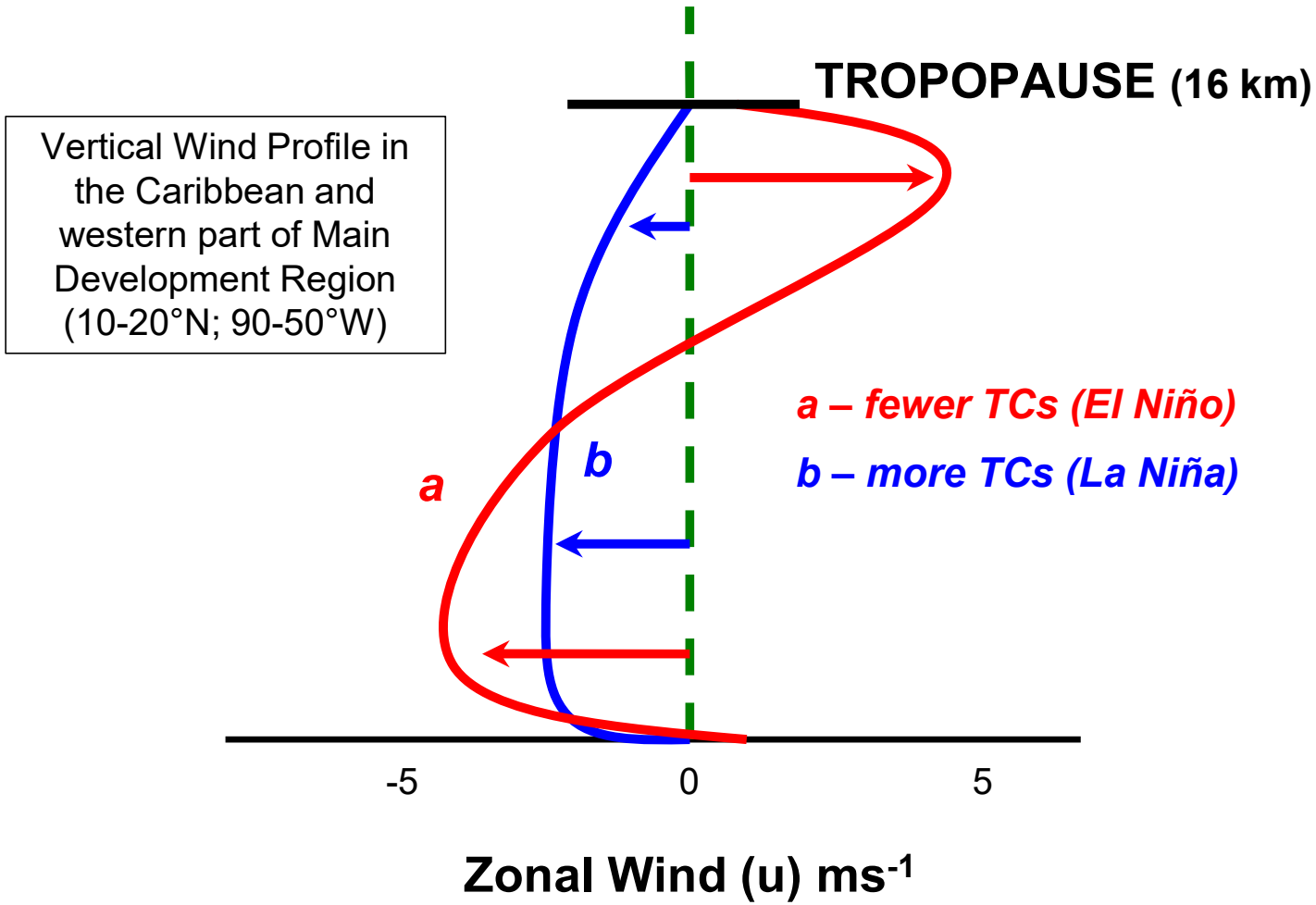
Forecast Parameter	2020 Observed	1981-2010 Average Thru 11/4	2020 % of 1981-2010 Average
Named Storms (NS)	28	11.3	247%
Named Storm Days (NSD)	102	54.8	186%
Hurricanes (H)	12	5.9	203%
Hurricane Days (HD)	32	22.7	141%
Major Hurricanes (MH)	5	2.6	192%
Major Hurricane Days (MHD)	7.50	6.0	125%
Accumulated Cyclone Energy (ACE)	156	99	158%

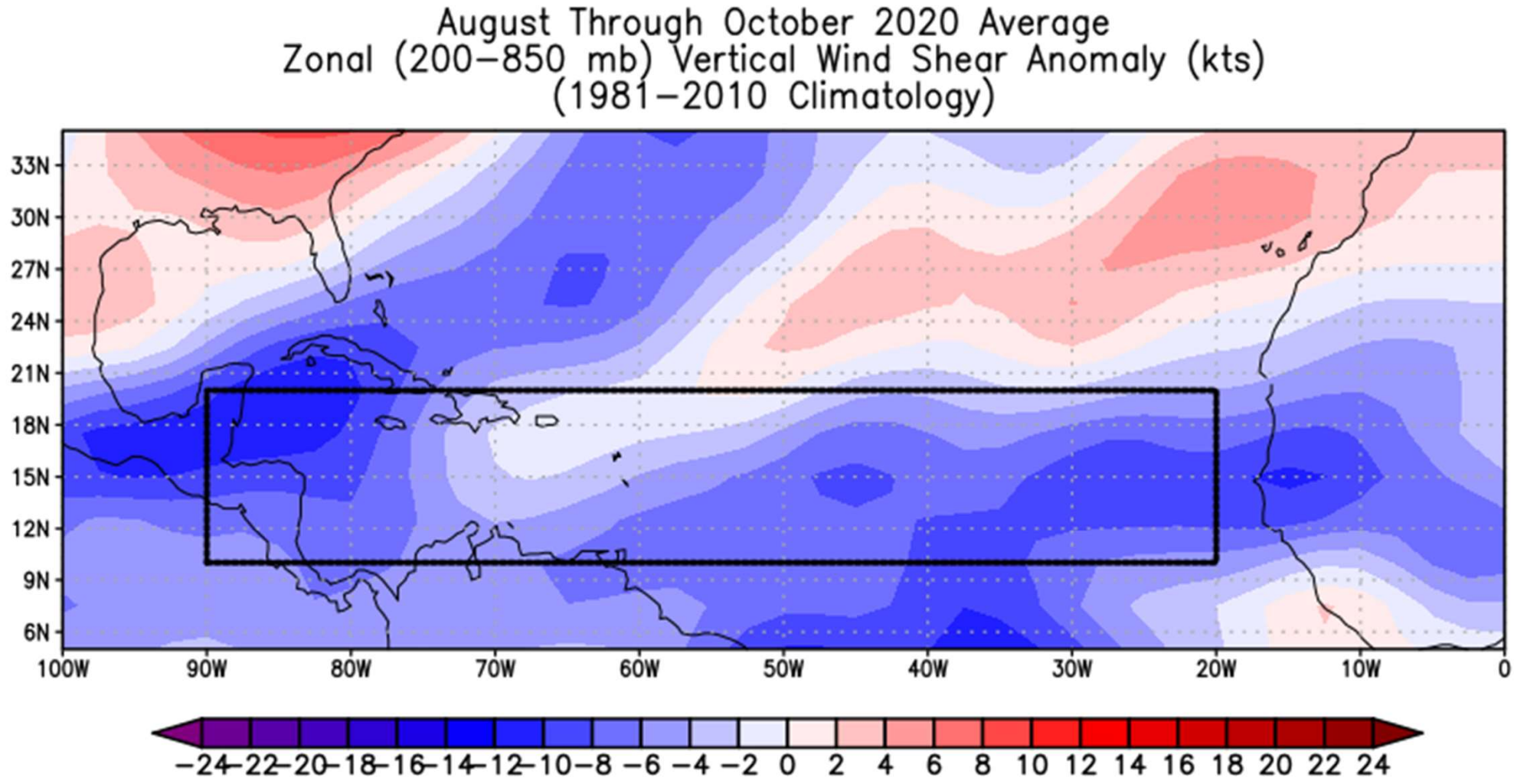
1981-2010 average is current NOAA 30-year climate base period. This 30-year base period will change to 1991-2020 next year.

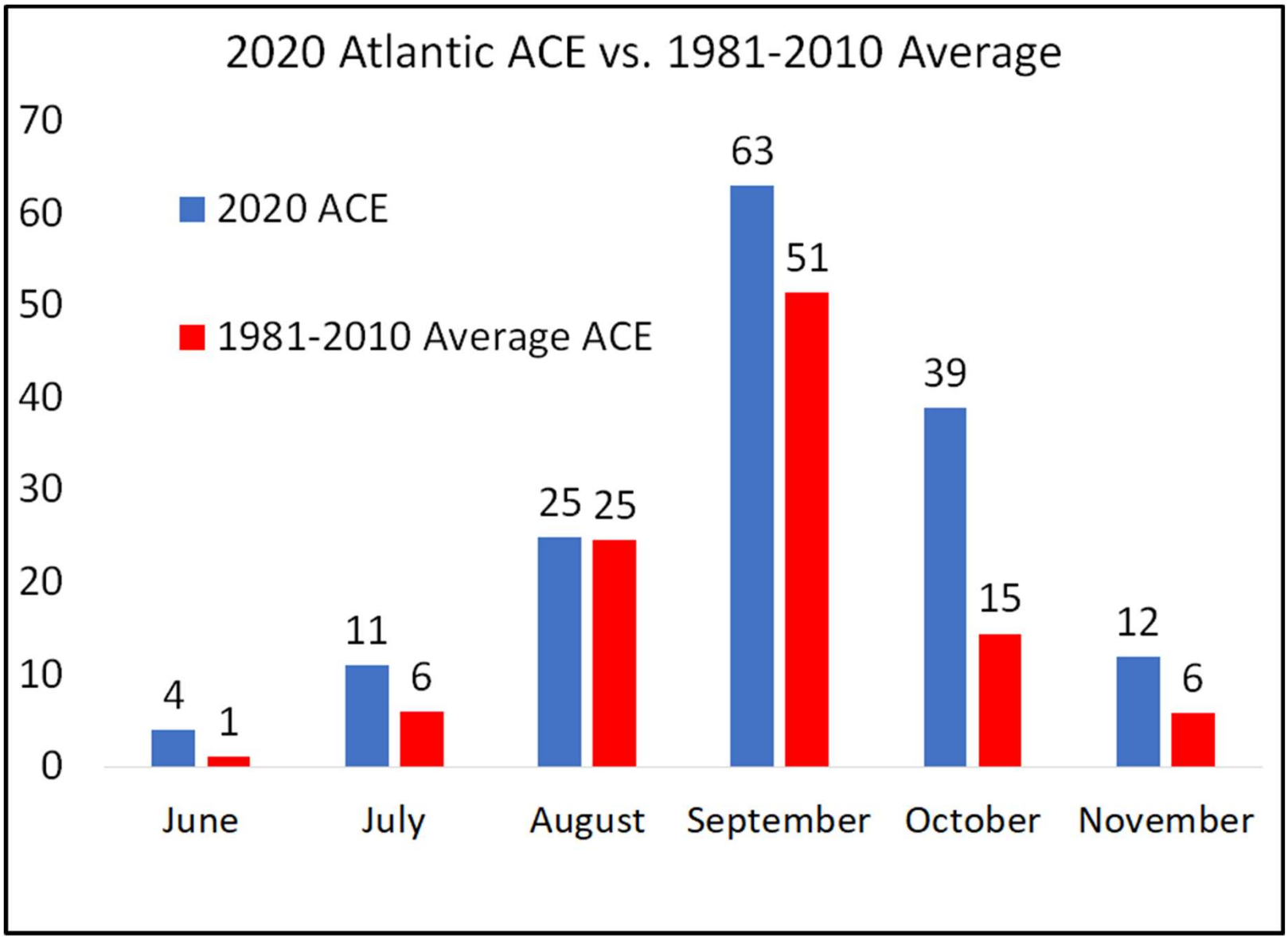

2020 Atlantic Accumulated Cyclone Energy by Storm Thru November 4
BERTHA, 0.4
CRISTOBAL, 3.5
DOLLY, 0.6
EDOUARD, 0.6
ARTHUR, 1.8
FAY, 1.1
GONZALO, 2.8
ETA, 11.8
HANNA, 3.4
ZETA, 7.5
ISAIAS, 9.2
JOSEPHINE, 1.8
KYLE, 1.0
EPSILON, 13.1
LAURA, 12.8
DELTA, 15.7
MARCO, 3.4
OMAR, 0.4
NANA, 2.6
PAULETTE, 15.9
GAMMA, 2.5
ALPHA, 0.4
BETA, 3.3
WILFRED, 0.9
VICKY, 2.1
TEDDY, 27.8
SALLY, 7.4
RENE, 2.2

August-October 2020 Sea Surface Temperature Anomaly

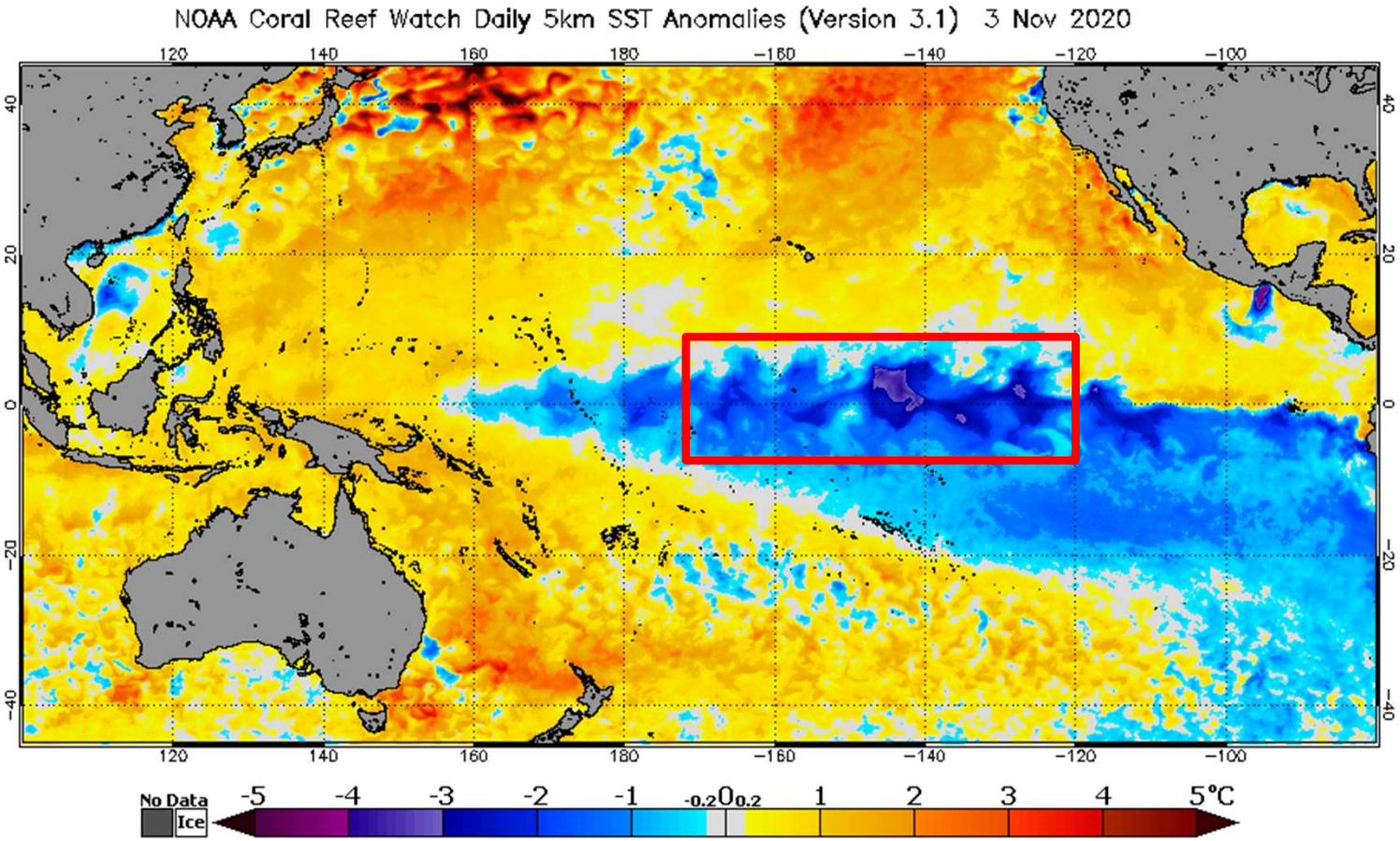


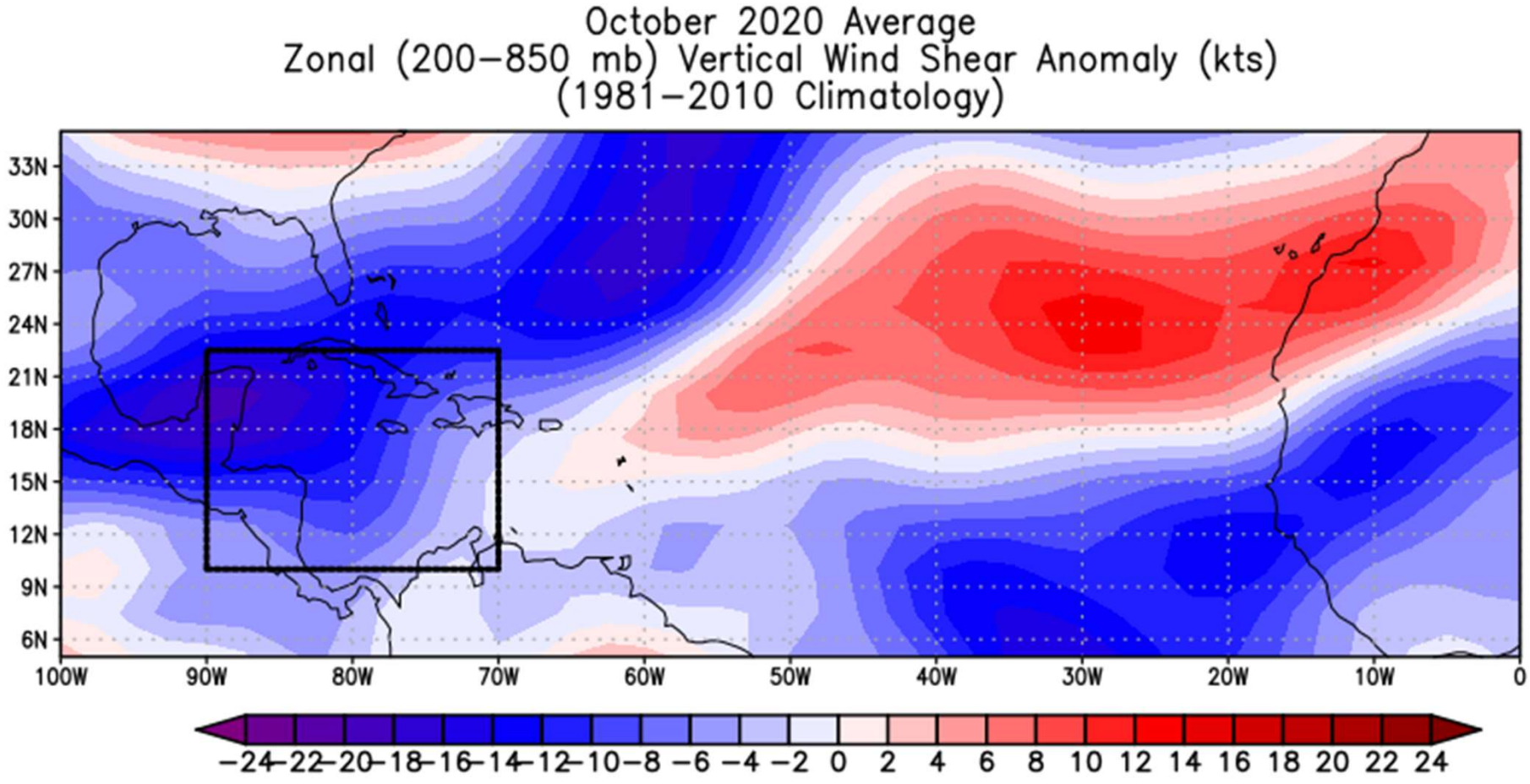

Vertical Wind Profile in the Caribbean and western part of Main Development Region (10-20°N; 90-50°W)
TROPOPAUSE (16 km)
a – fewer TCs (El Niño)
b – more TCs (La Niña)
a
b
-5
0
5
Zonal Wind (u) ms-1

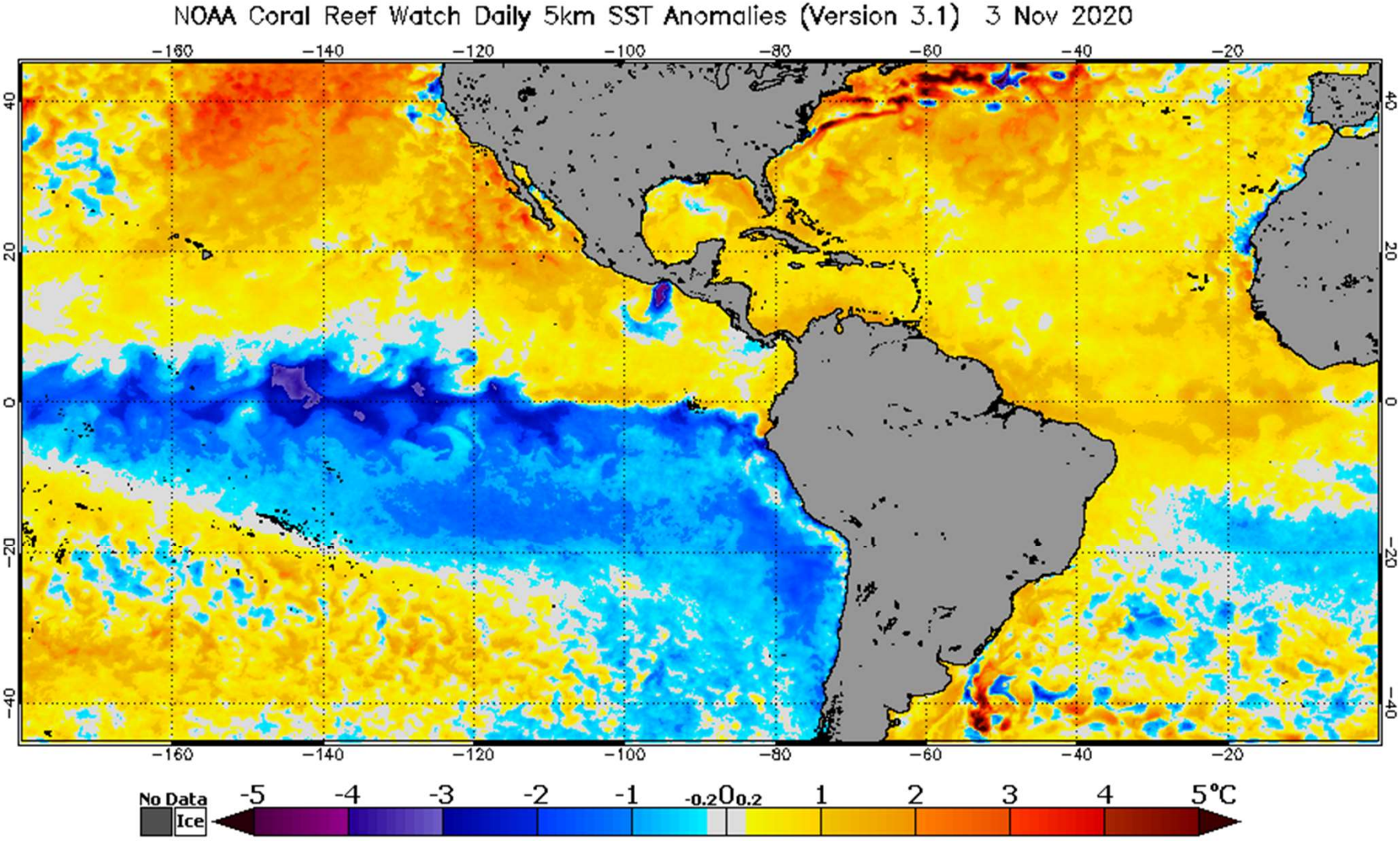

August Through October 2020 Average
Zonal (200–850 mb) Vertical Wind Shear Anomaly (kts)
(1981–2010 Climatology)
33N
30N
27N
24N
21N
18N
15N
12N
9N
6N
100W
90W
80W
70W
60W
50W
40W
30W
20W
10W
0
−24 −22 −20 −18 −16 −14 −12 −10 −8 −6 −4 −2 0 2 4 6 8 10 12 14 16 18 20 22 24


2020 Atlantic ACE vs. 1981-2010 Average
70
60
50
40
30
20
10
0
2020 ACE
1981-2010 Average ACE
4
1
11
6
25
25
63
51
39
15
12
6
June
July
August
September
October
November

La Niña is Here!!!




October 2020 Average
Zonal (200–850 mb) Vertical Wind Shear Anomaly (kts)
(1981–2010 Climatology)
33N
30N
27N
24N
21N
18N
15N
12N
9N
6N
100W
90W
80W
70W
60W
50W
40W
30W
20W
10W
0
−24 −22 −20 −18 −16 −14 −12 −10 −8 −6 −4 −2 0 2 4 6 8 10 12 14 16 18 20 22 24


NOAA Coral Reef Watch Daily 5km SST Anomalies (Version 3.1) 3 Nov 2020
−160
−140
−120
−100
−80
−60
−40
−20
40
20
0
−20
−40
No Data
Ice
-5
-4
-3
-2
-1
-0.2
0
0.2
1
2
3
4
5°C

In Memory of Bill Gray (1929-2016)

Klotzbach, P. J., J. C. L. Chan, P. J. Fitzpatrick, W. M. Frank, C. W. Landsea, and J. L. McBride, 2017: The science of William M. Gray: His contributions to the knowledge of tropical meteorology and tropical cyclones. *Bull. Amer. Meteor. Soc,* **98,** 2311-2336.

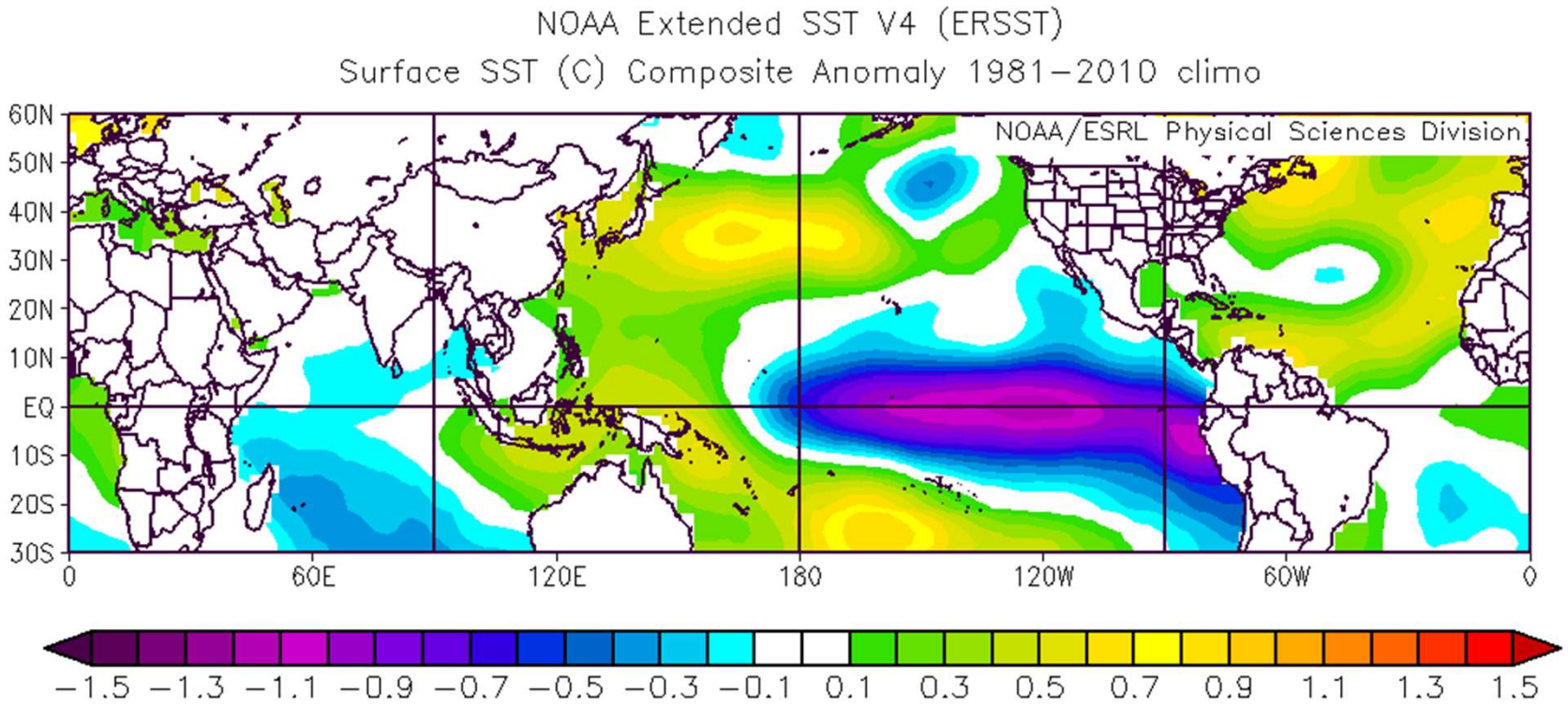
"It's tough to make predictions, especially about the future"

HOWEVER…

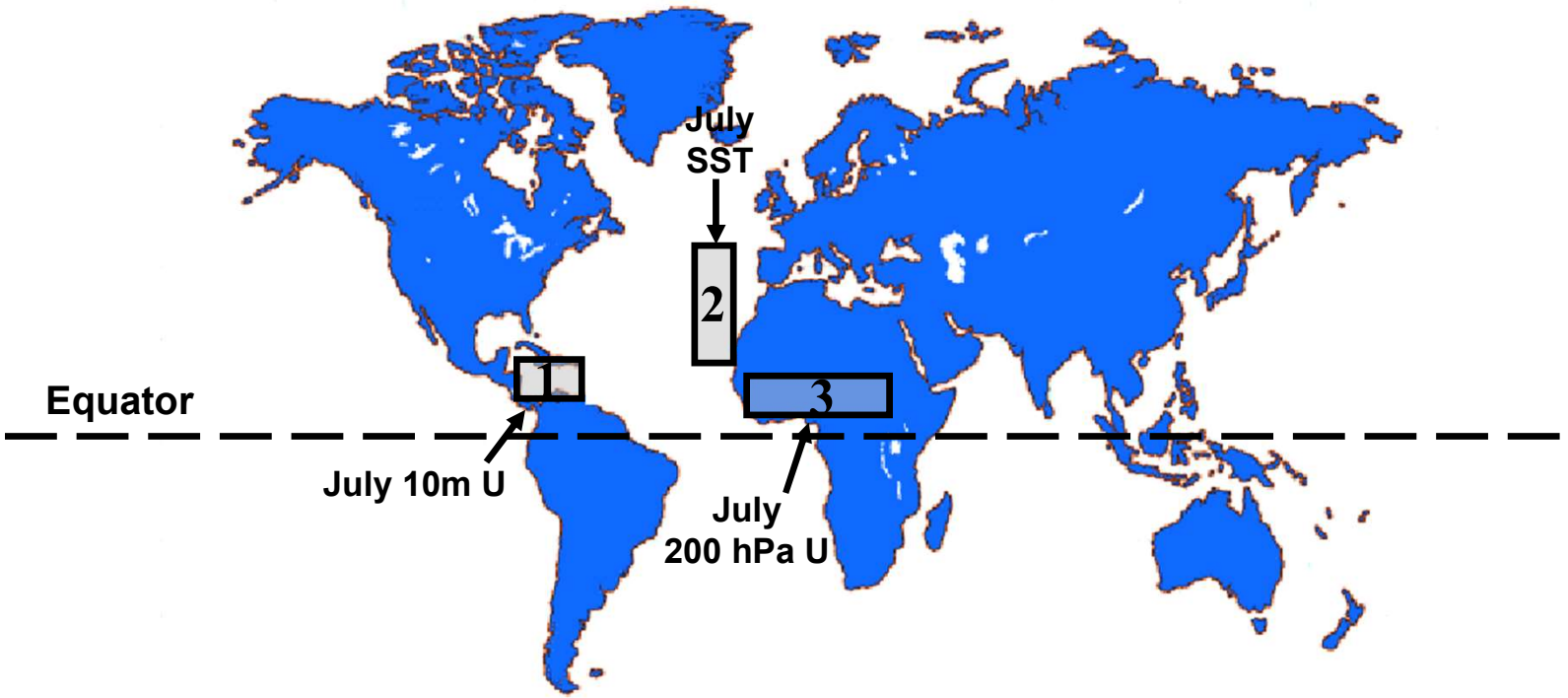
"You can see a lot by looking"

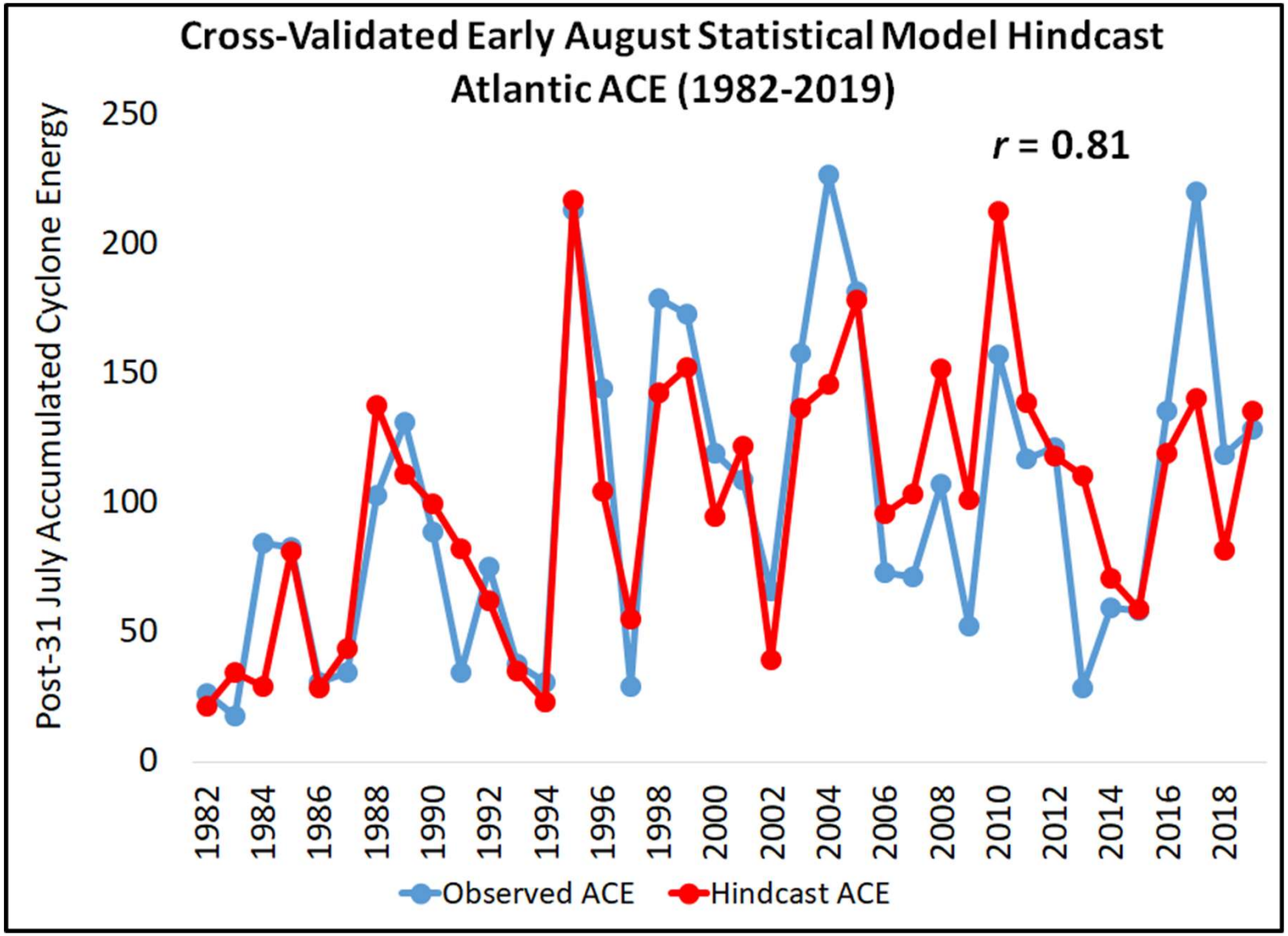
Yogi Berra

August – October SSTs: Ten Most Active minus Ten Least Active Atlantic Hurricane Seasons since 1950



Post-31 July Seasonal Forecast Predictors




Cross-Validated Early August Statistical Model Hindcast
Atlantic ACE (1982-2019)
r = 0.81
Post-31 July Accumulated Cyclone Energy
250
200
150
100
50
0
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Observed ACE
Hindcast ACE

CSU – NOAA: August 2020 Atlantic Hurricane Seasonal Forecast Comparison

Forecast Parameter	CSU Forecast	NOAA Forecast	Observed 2020 Thru 11/4	1981-2010 Avg.
Named Storms (NS)	24 (21-27)	19-25	28	12.1
Hurricanes (H)	12 (10-14)	7-11	12	6.4
Major Hurricanes (MH)	5 (3-7)	3-6	5	2.7
Accumulated Cyclone Energy (ACE)	200 (149-255)	129-212*	156	106

CSU 70% Confidence Intervals Included in Parentheses

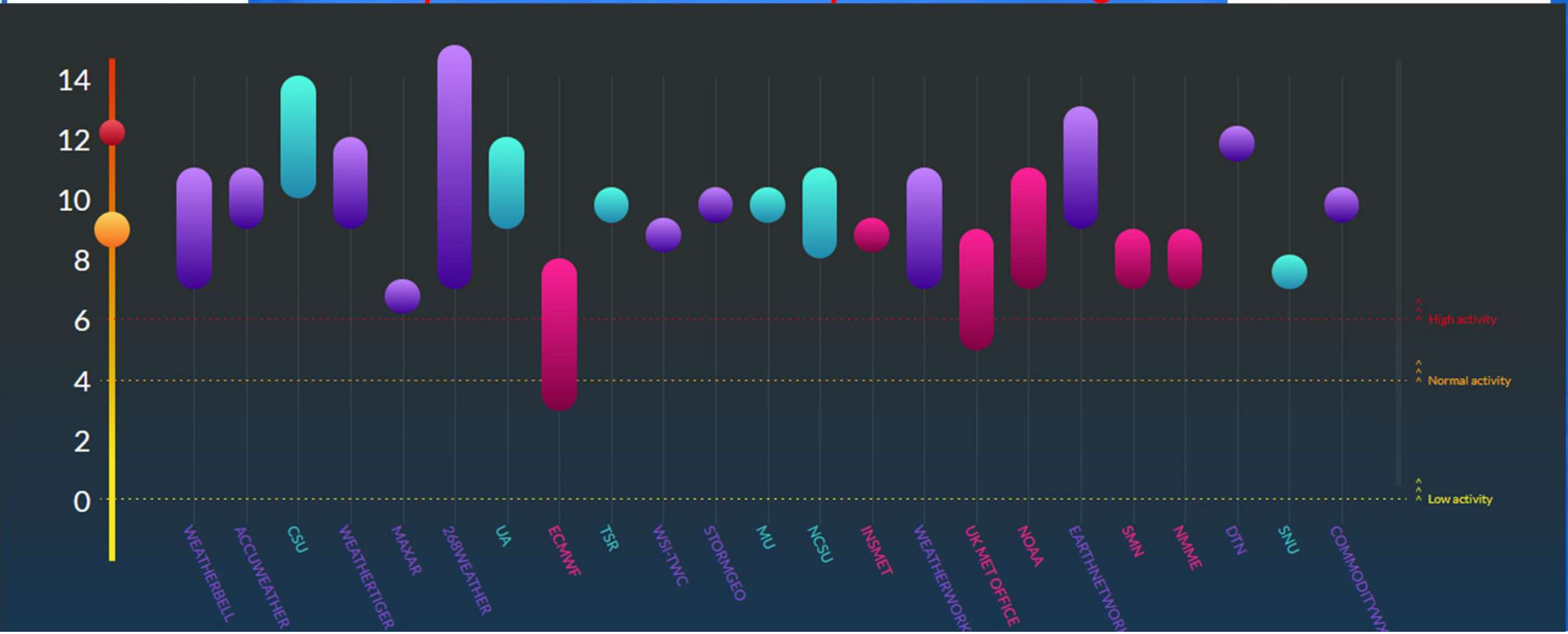
**** Converted NOAA % of Median ACE Forecast to Actual ACE (10^4 kt^2)***

http://www.seasonalhurricanepredictions.org

Contributing Forecast Groups

Seasonal Hurricane Forecast Compilation Website

http://seasonalhurricanepredictions.org



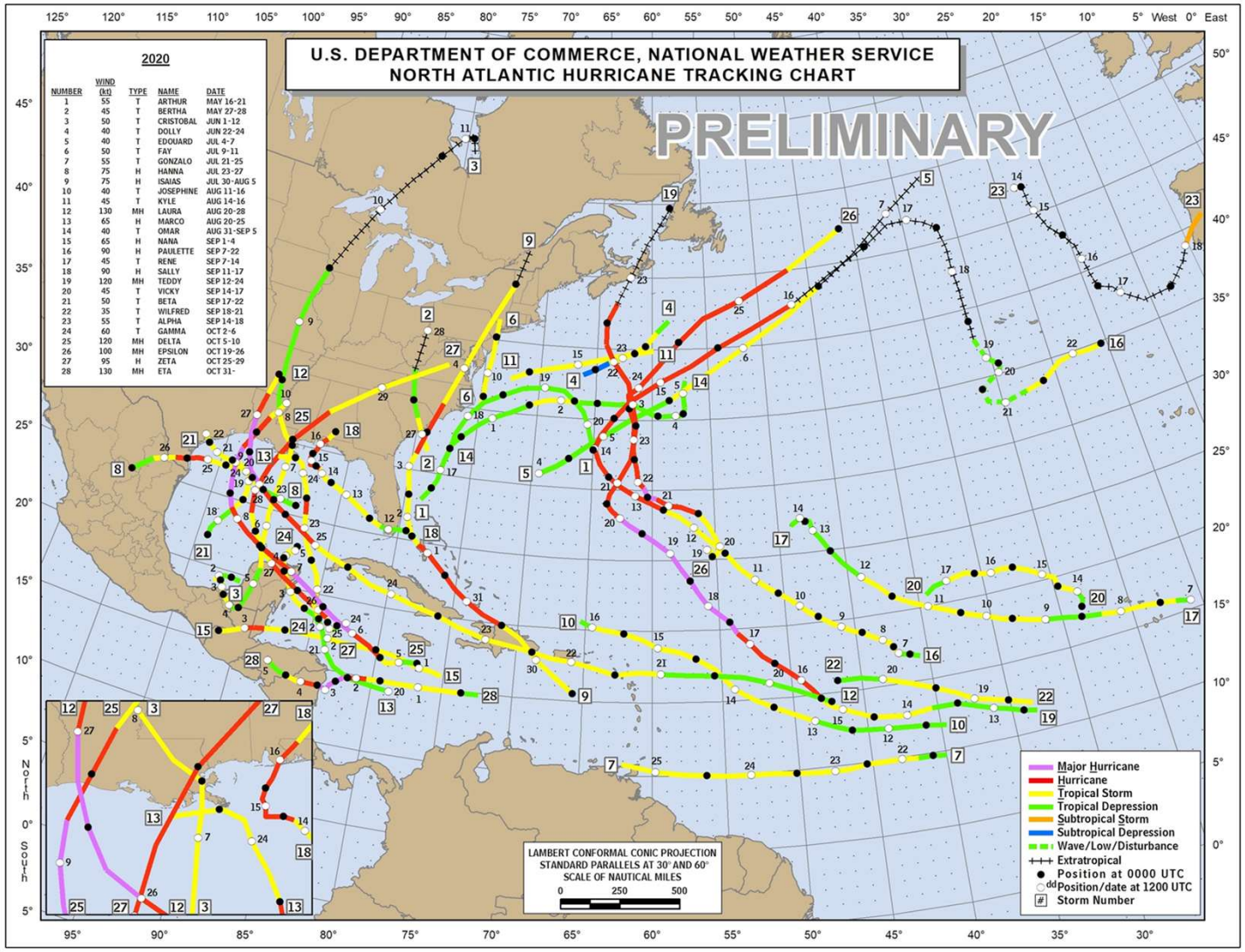
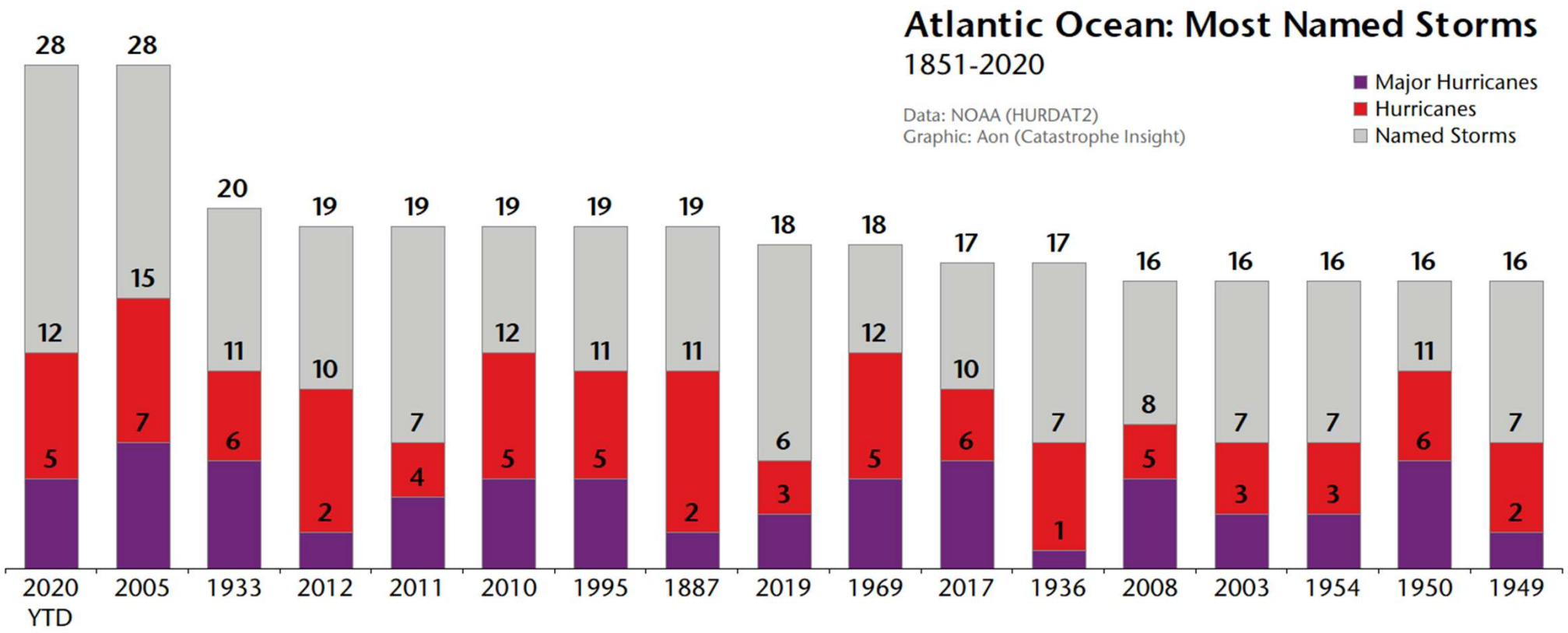


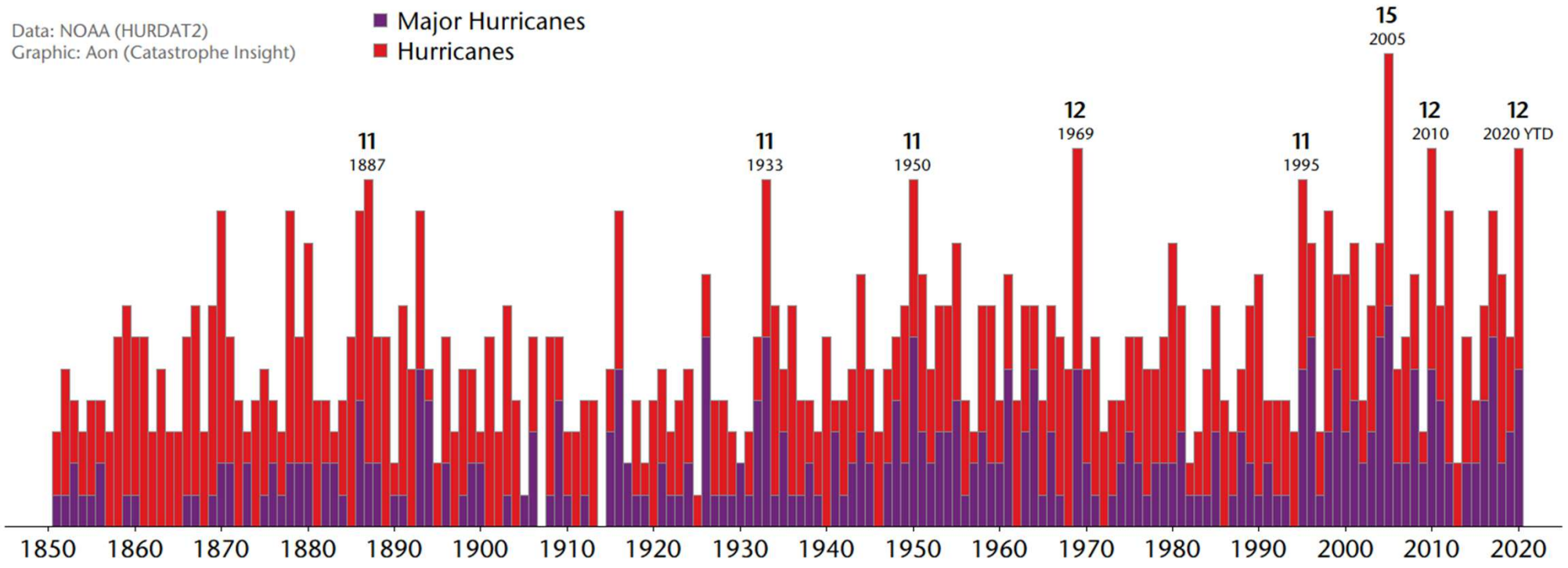
Figure courtesy of Ethan Gibney, NOAA


Atlantic Ocean: Most Named Storms
1851-2020
Data: NOAA (HURDAT2)
Graphic: Aon (Catastrophe Insight)
Major Hurricanes
Hurricanes
Named Storms
28 28 20 19 19 19 19 19 18 18 17 17 16 16 16 16 16
12 15 11 10 7 12 11 11 6 12 10 7 8 7 7 11 7
5 7 6 2 4 5 5 2 3 5 6 1 5 3 3 6 2
2020 YTD
2005
1933
2012
2011
2010
1995
1887
2019
1969
2017
1936
2008
2003
1954
1950
1949

Atlantic Ocean: Most Hurricanes

1851-2020

Data: NOAA (HURDAT2)
Graphic: Aon (Catastrophe Insight)



U.S. Mainland Landfalls 2020 YTD Atlantic Season

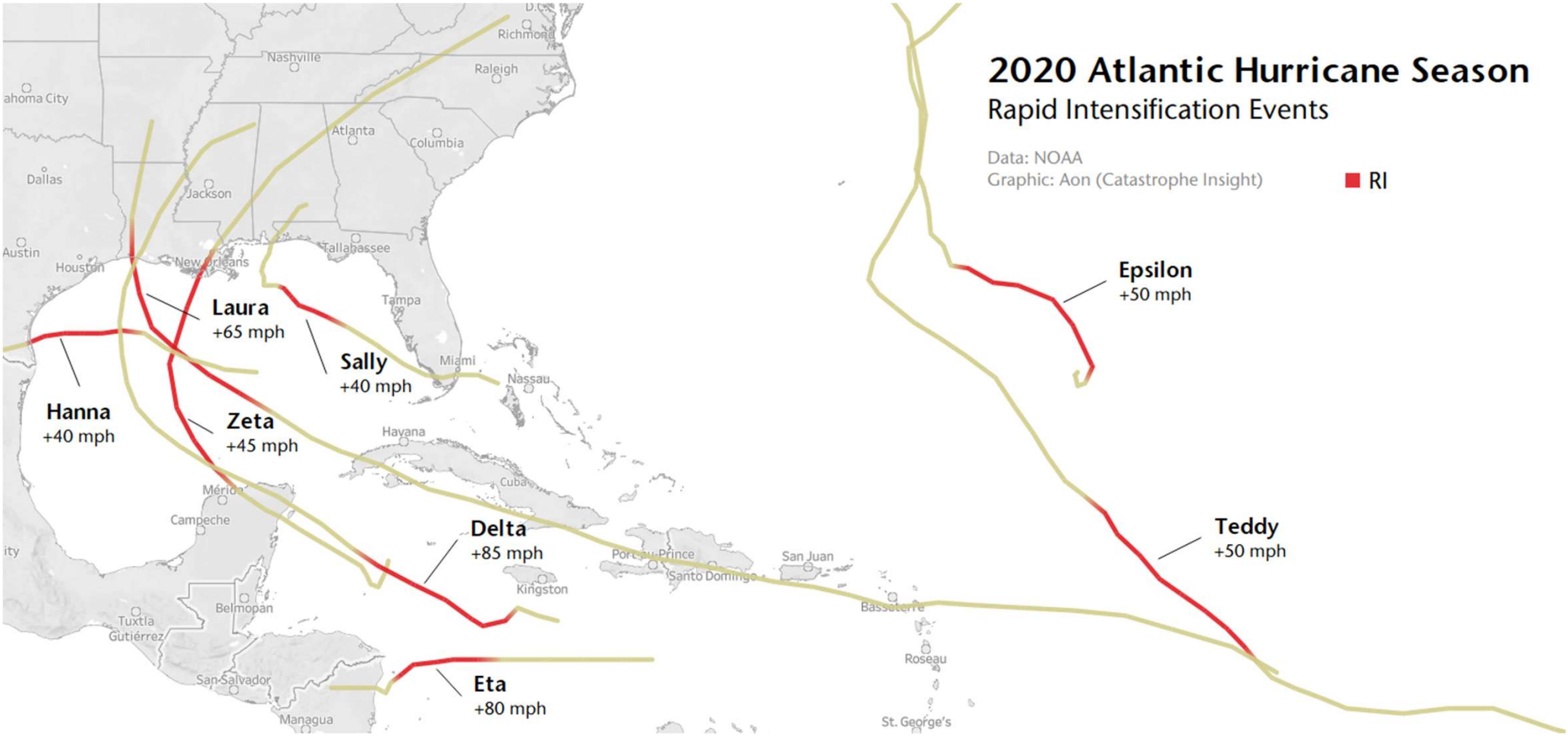
Dates in UTC

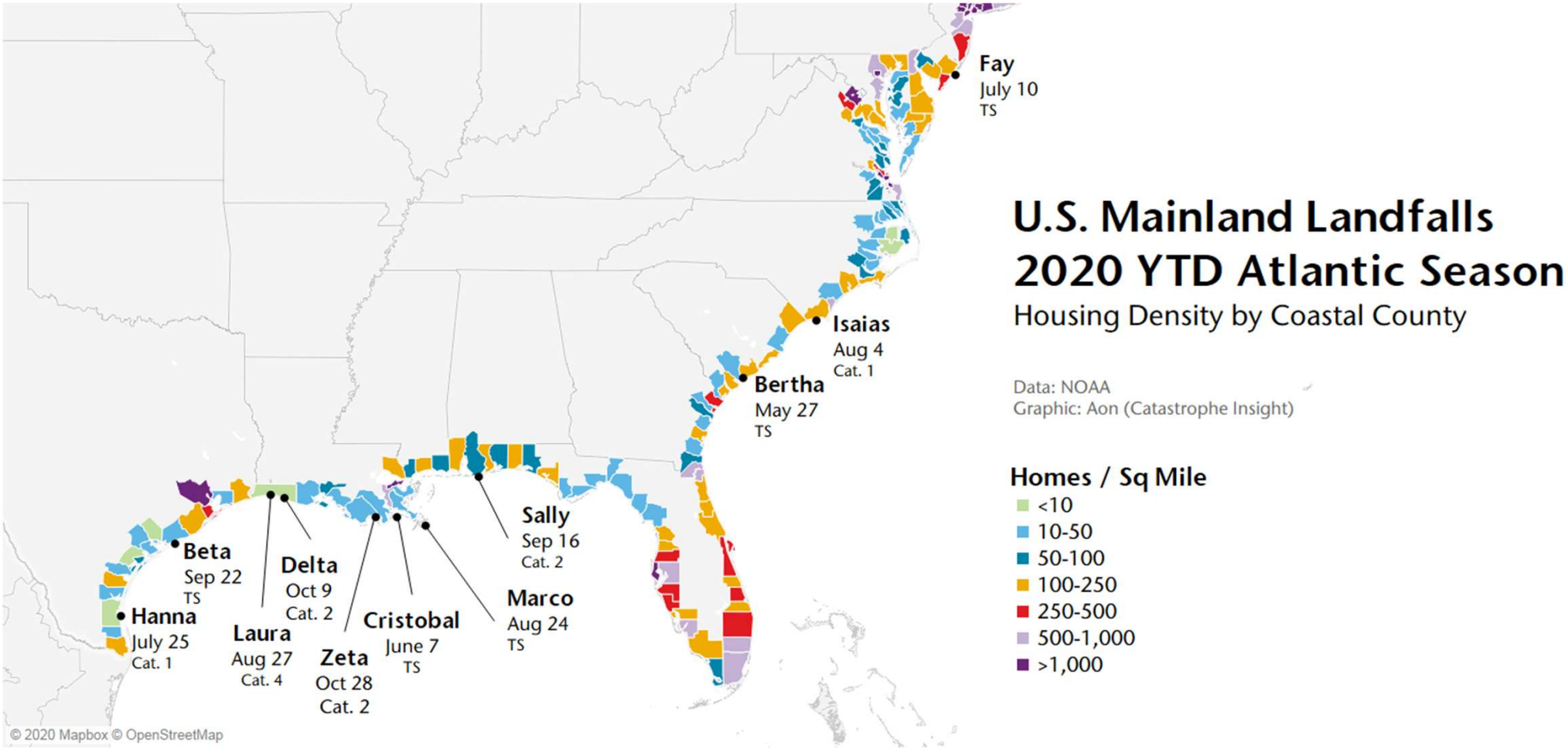
Economic loss estimates subject to change

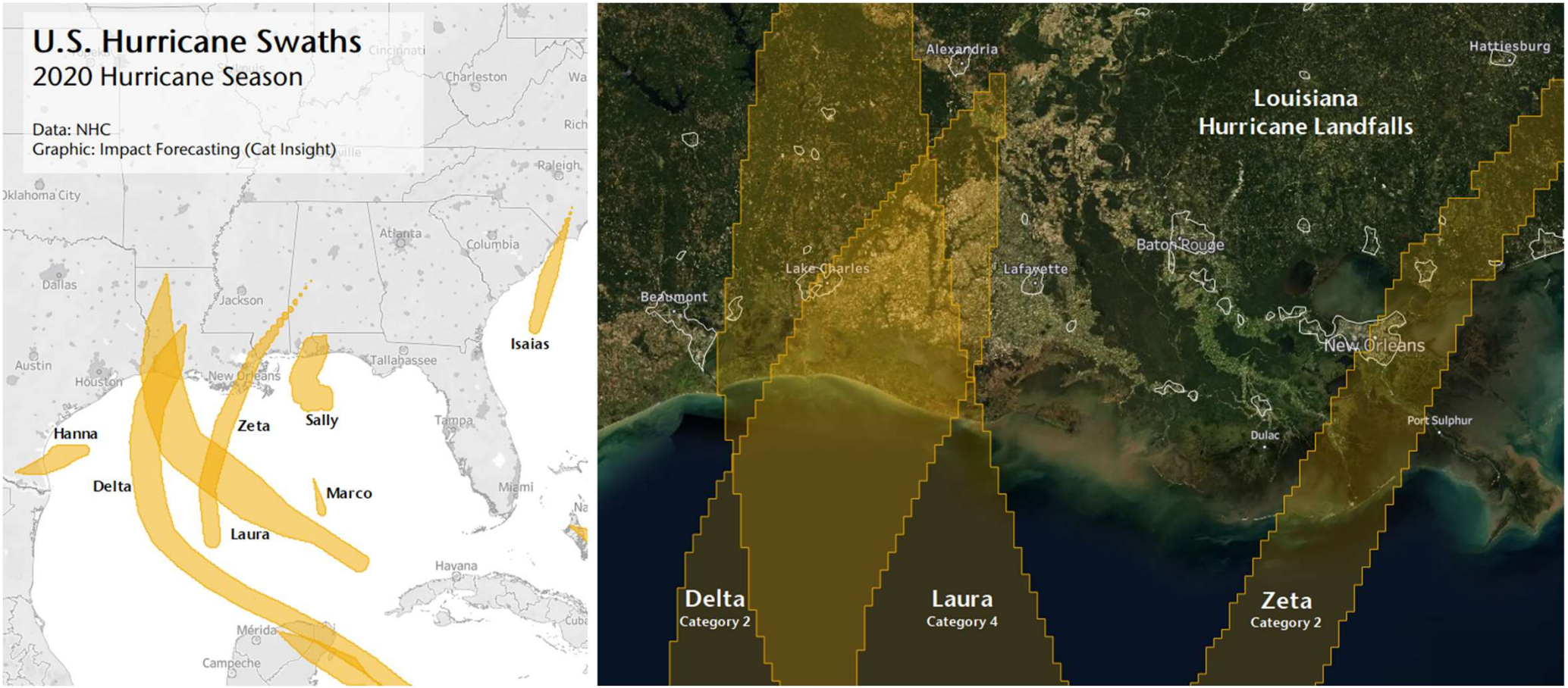
Data: NOAA
Graphic: Aon (Catastrophe Insight)

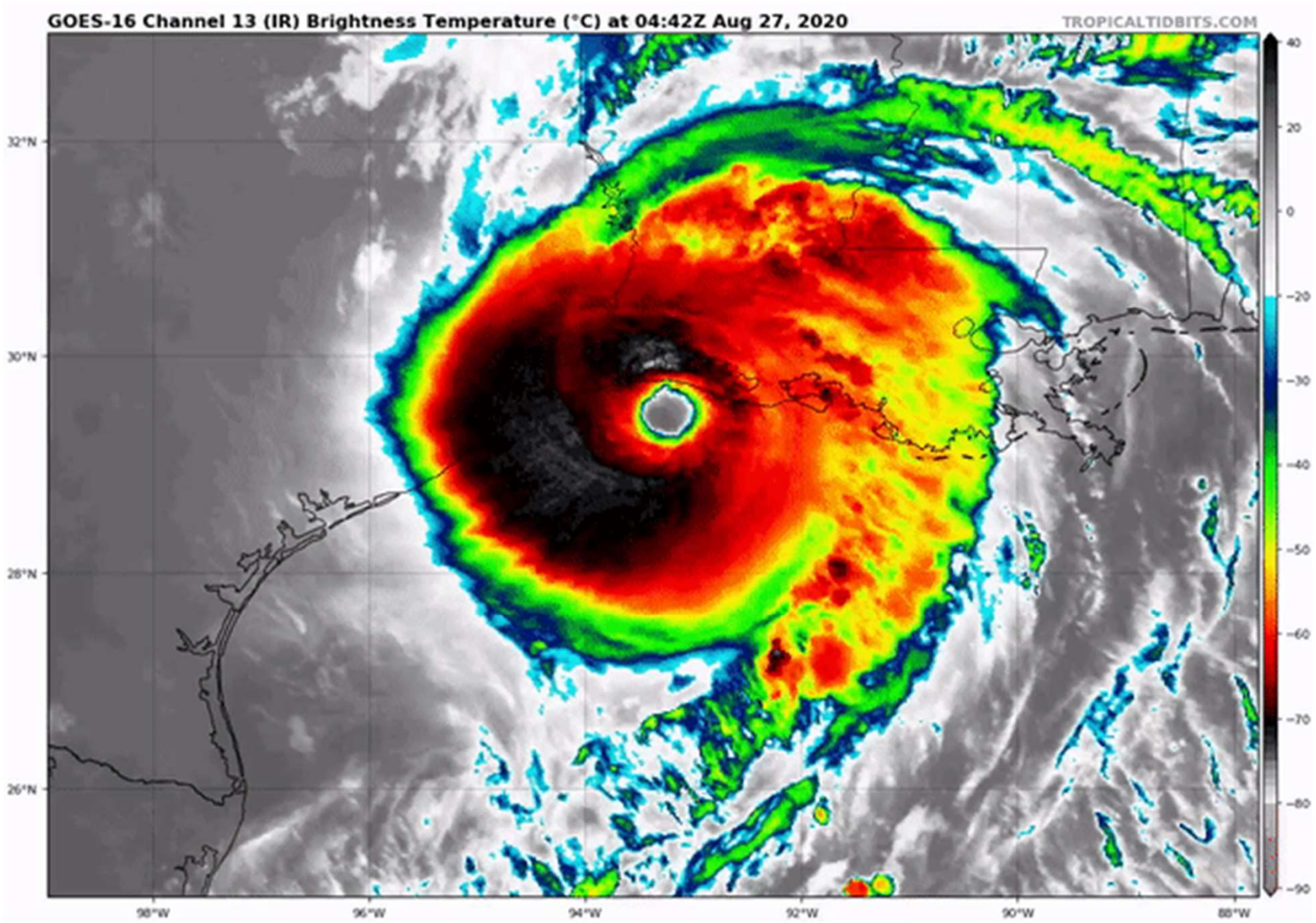
- Category 4
- Category 2
- Category 1
- Tropical Storm

Named Storms	Hurricanes
2020 (11)	2020 (6)
1916 (9)	1985 (6)
2004 (8)	1886 (6)
1985 (8)	2005 (5)
2005 (7)	2004 (5)
2002 (7)	1893 (5)
1998 (7)	
1959 (7)	
1893 (7)	


2020 Atlantic Hurricane Season
Rapid Intensification Events
Data: NOAA
Graphic: Aon (Catastrophe Insight)
RI
Epsilon
+50 mph
Laura
+65 mph
Sally
+40 mph
Hanna
+40 mph
Zeta
+45 mph
Delta
+85 mph
Eta
+80 mph
Teddy
+50 mph
Richmond
Nashville
Raleigh
Atlanta
Columbia
Dallas
Jackson
Austin
Houston
New Orleans
Tallahassee
Tampa
Miami
Nassau
Havana
Cuba
Mérida
Campeche
Kingston
Port-au-Prince
Santo Domingo
San Juan
Belmopan
Tuxtla Gutiérrez
San Salvador
Managua
Roseau
St. George's


Fay
July 10
TS
Isaias
Aug 4
Cat. 1
Bertha
May 27
TS
Sally
Sep 16
Cat. 2
Marco
Aug 24
TS
Cristobal
June 7
TS
Zeta
Oct 28
Cat. 2
Delta
Oct 9
Cat. 2
Laura
Aug 27
Cat. 4
Beta
Sep 22
TS
Hanna
July 25
Cat. 1
© 2020 Mapbox © OpenStreetMap
U.S. Mainland Landfalls
2020 YTD Atlantic Season
Housing Density by Coastal County
Data: NOAA
Graphic: Aon (Catastrophe Insight)
Homes / Sq Mile
<10
10-50
50-100
100-250
250-500
500-1,000
>1,000


U.S. Hurricane Swaths
2020 Hurricane Season
Data: NHC
Graphic: Impact Forecasting (Cat Insight)
Cincinnati
Charleston
Raleigh
Oklahoma City
Atlanta
Columbia
Dallas
Jackson
Austin
Houston
New Orleans
Tallahassee
Tampa
Miami
Havana
Mérida
Campeche
Hanna
Delta
Zeta
Sally
Marco
Laura
Isaias
Louisiana
Hurricane Landfalls
Alexandria
Hattiesburg
Lake Charles
Lafayette
Baton Rouge
Beaumont
New Orleans
Dulac
Port Sulphur
Delta
Category 2
Laura
Category 4
Zeta
Category 2


GOES-16 Channel 13 (IR) Brightness Temperature (°C) at 04:42Z Aug 27, 2020
TROPICALTIDBITS.COM
32°N
30°N
28°N
26°N
98°W
96°W
94°W
92°W
90°W
88°W
40
20
0
−20
−30
−40
−50
−60
−70
−80
−90

Hurricane Laura Notable Facts/Records

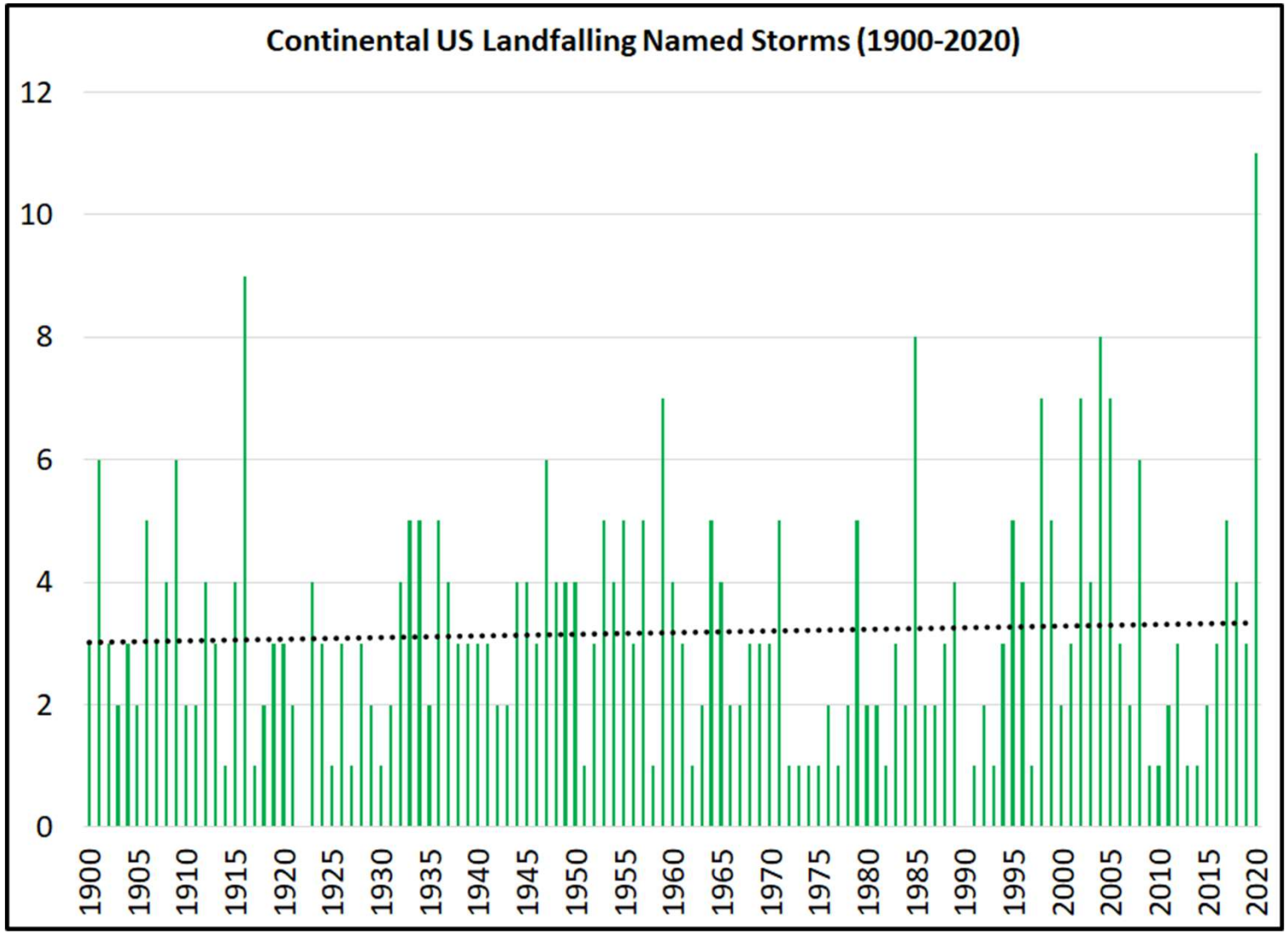
Cameron, Louisiana Landfall: 150 mph, 937 hPa

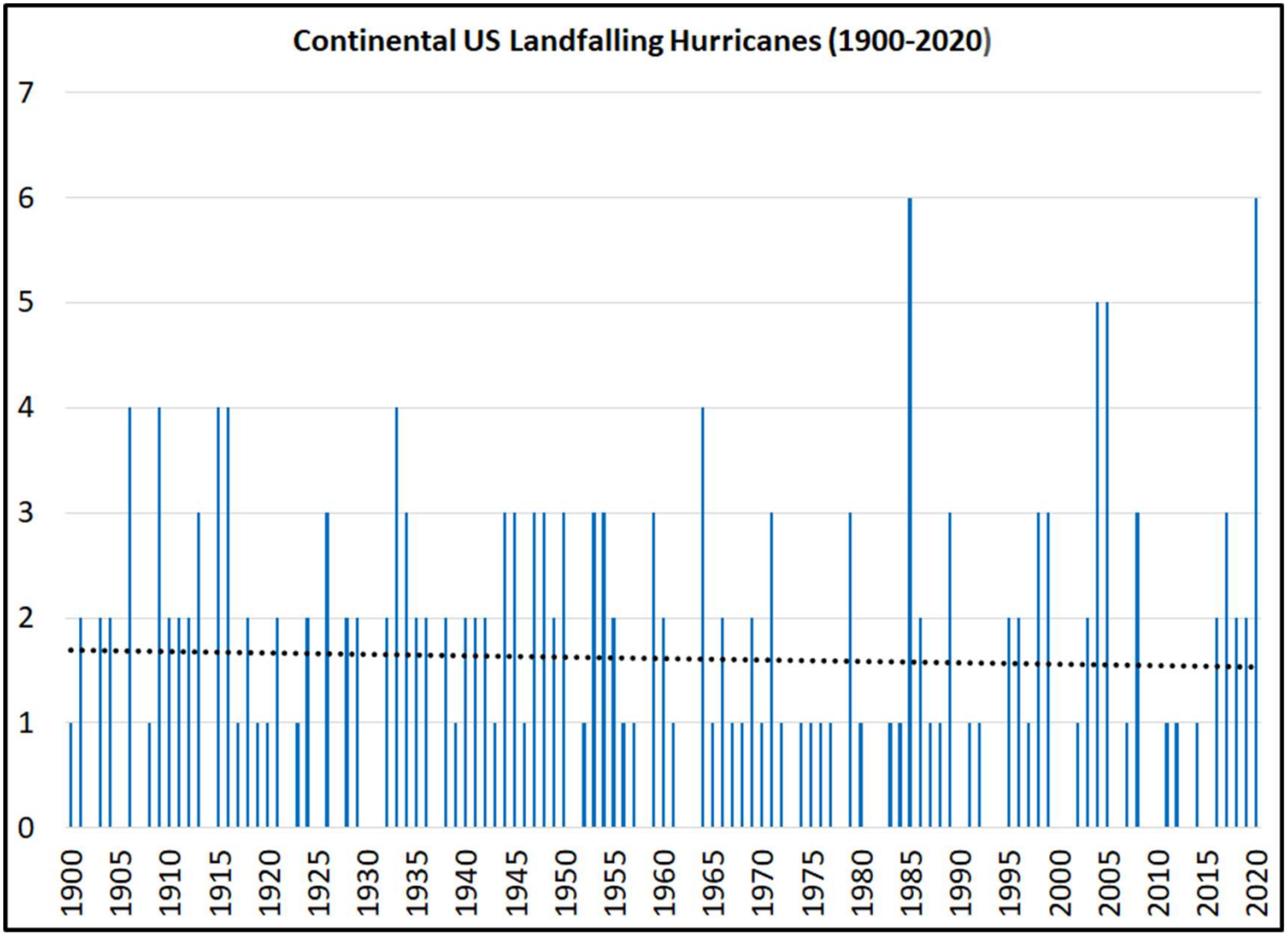
- Tied with Last Island Hurricane of 1856 for strongest hurricane (by maximum sustained wind) on record to make landfall in Louisiana

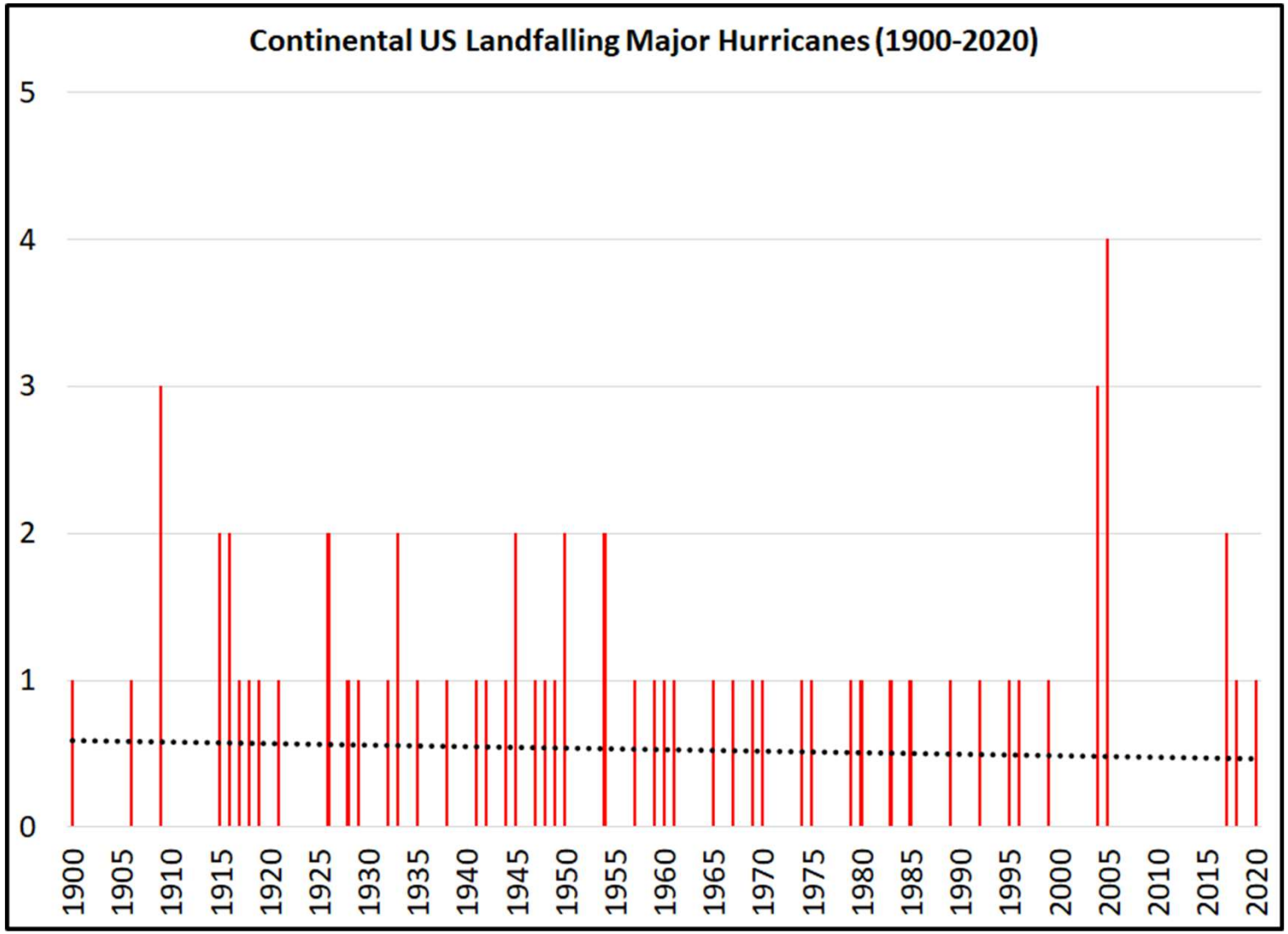
- Tied for 4th strongest hurricane on record to make landfall in Louisiana by pressure – trailing Katrina (2005), Last Island (1856) and Rita (2005)

- 42 fatalities in the United States, 31 fatalities in Haiti, 4 fatalities in Dominican Republic

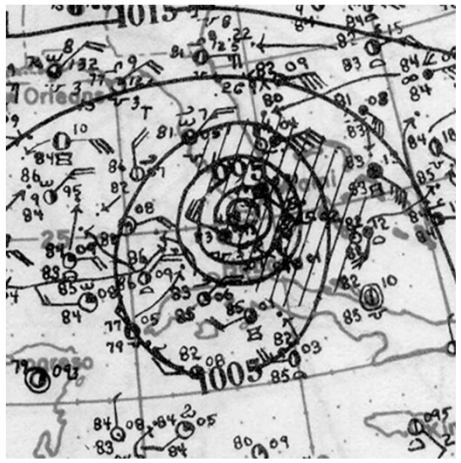
- $14 Billion USD in economic damage in the United States


Continental US Landfalling Named Storms (1900-2020)
12
10
8
6
4
2
0
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


Continental US Landfalling Hurricanes (1900-2020)
7
6
5
4
3
2
1
0
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


Continental US Landfalling Major Hurricanes (1900-2020)
5
4
3
2
1
0
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

1926 Great Miami Hurricane (145 mph winds, 930 hPa) – Category 4



Miami-Dade County Population: ~100,000

Damage: $76,000,000

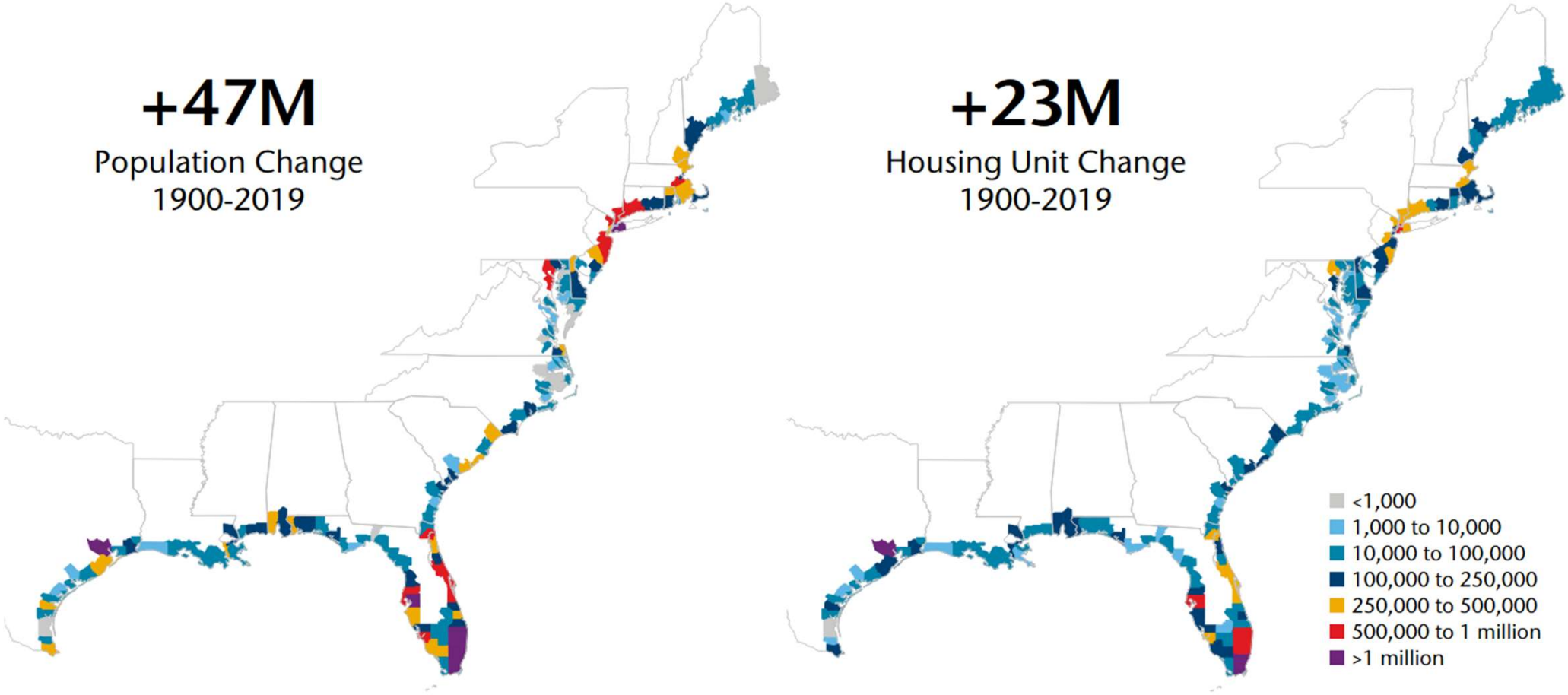
1926

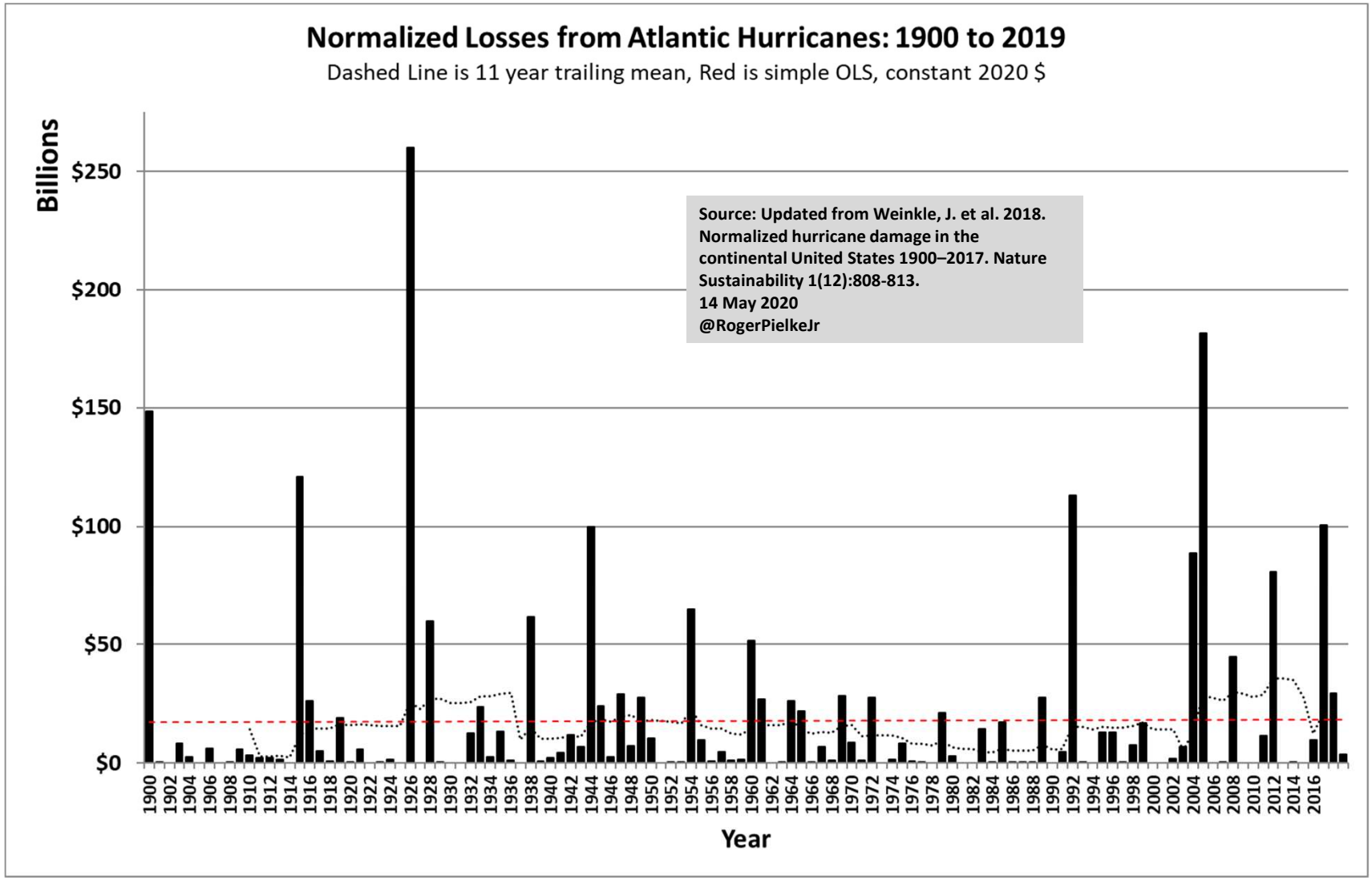
Miami-Dade County Population: ~2.7 Million

Inflation Multiplier: 11.5, Wealth Multiplier: 6.6, South Florida Population Multiplier: 38.8

2020

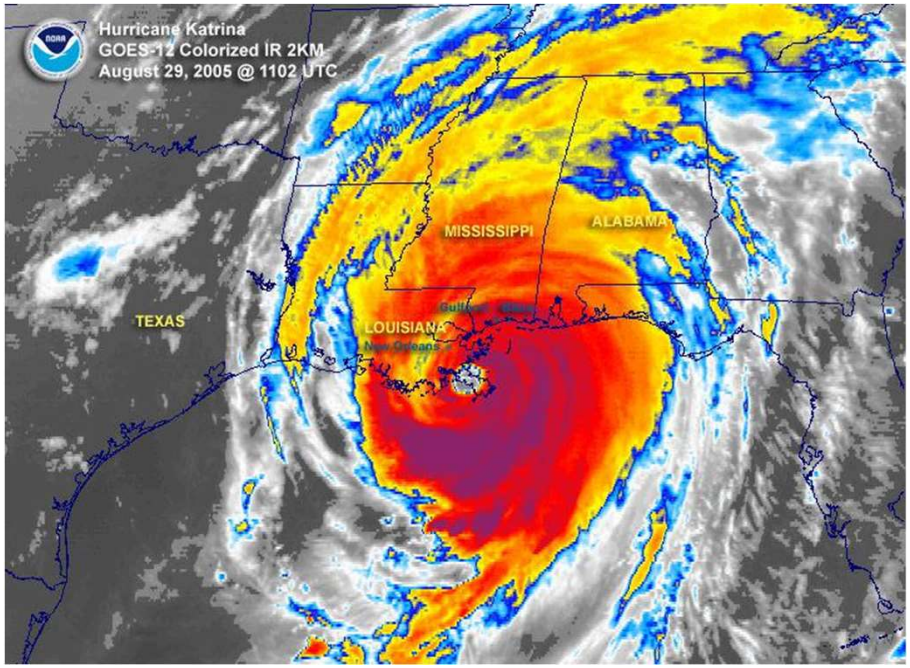
1926 Great Miami Hurricane - >$222 Billion Economic Damage (if it were to occur today)


+47M
Population Change
1900-2019
+23M
Housing Unit Change
1900-2019
<1,000
1,000 to 10,000
10,000 to 100,000
100,000 to 250,000
250,000 to 500,000
500,000 to 1 million
>1 million


Normalized Losses from Atlantic Hurricanes: 1900 to 2019
Dashed Line is 11 year trailing mean, Red is simple OLS, constant 2020 $
Billions
$250
$200
$150
$100
$50
$0
Source: Updated from Weinkle, J. et al. 2018. Normalized hurricane damage in the continental United States 1900–2017. Nature Sustainability 1(12):808-813.
14 May 2020
@RogerPielkeJr
1900 1902 1904 1906 1908 1910 1912 1914 1916 1918 1920 1922 1924 1926 1928 1930 1932 1934 1936 1938 1940 1942 1944 1946 1948 1950 1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016
Year

A Proposed New Hurricane Categorization Scale - What Predicts Damage Better: Wind or Pressure?

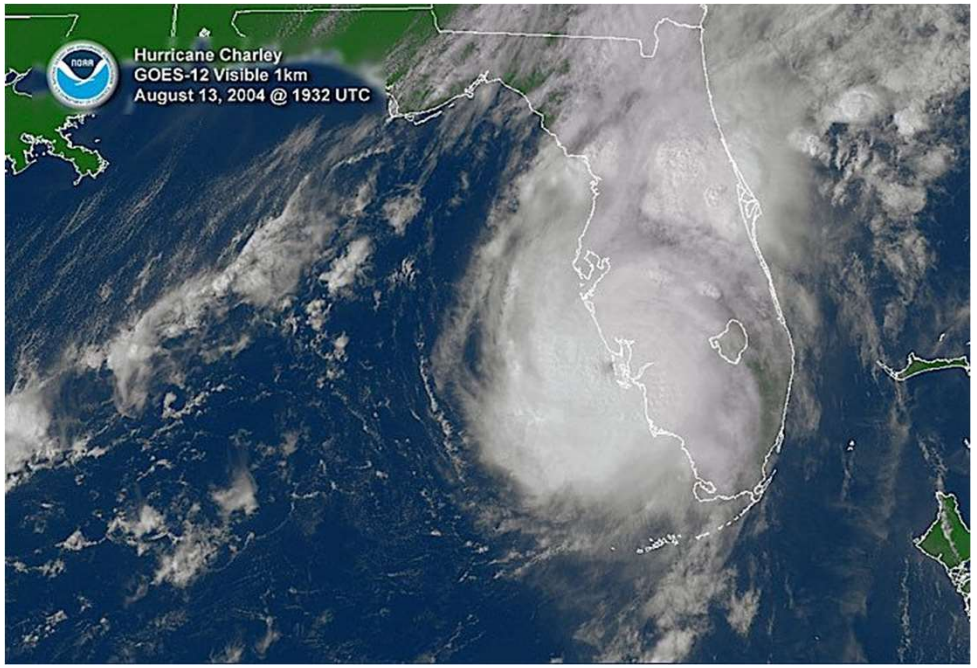
Hurricane Katrina (2005) – Cat. 3
125 mph, 920 hPa



Average 60 mph wind radii: ~105 nm

Maximum Storm Surge: ~28 ft

Hurricane Charley (2004) – Cat. 4
150 mph, 941 hPa



Average 60 mph wind radii: ~35 nm

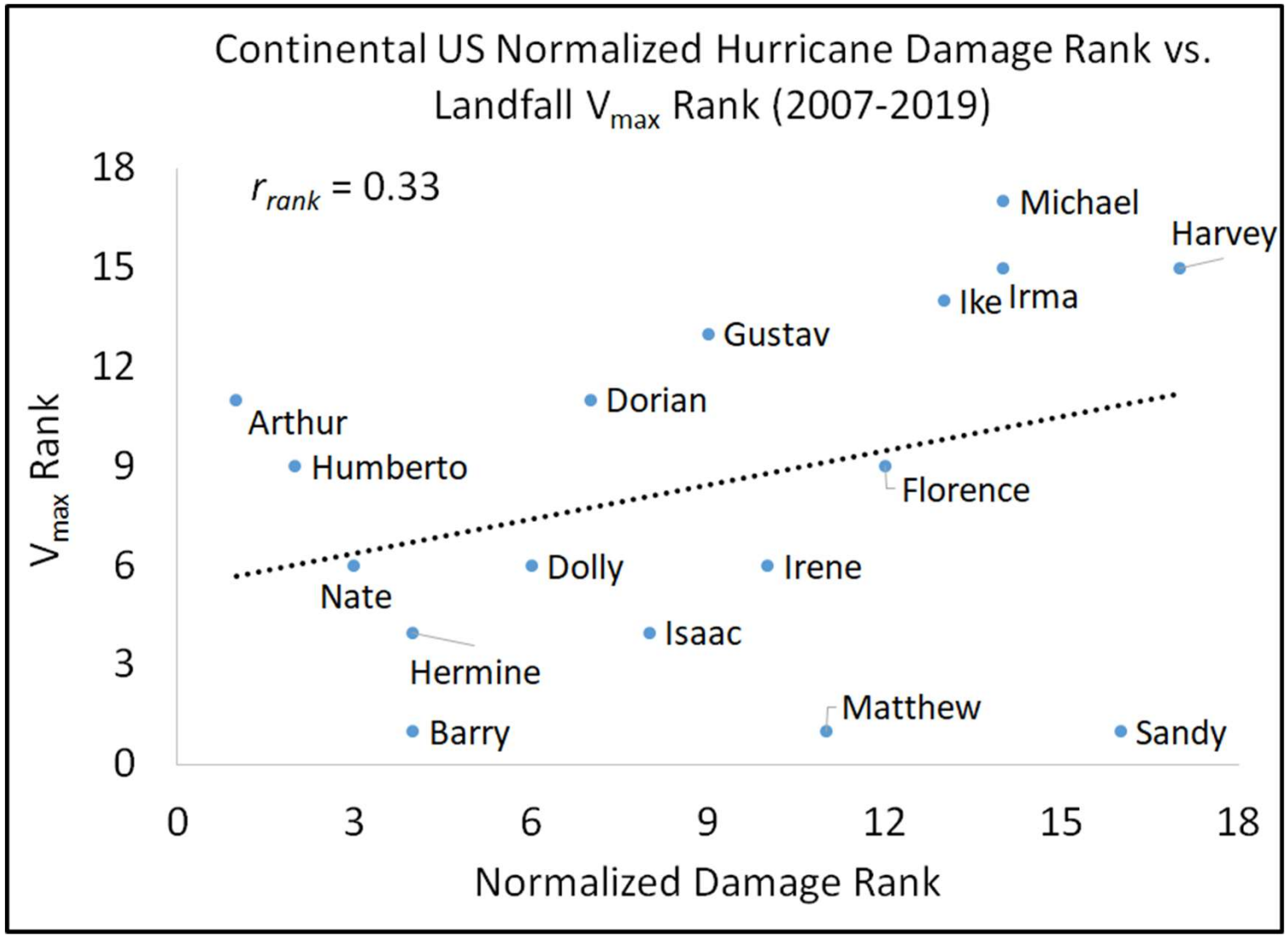
Maximum Storm Surge: ~7 ft

Klotzbach, P. J., M. M. Bell, S. G. Bowen, E. J. Gibney, K. R. Knapp, and C. J. Schreck III, 2020: Surface pressure a more skillful predictor of normalized hurricane damage than maximum sustained wind. *Bull. Amer. Meteor. Soc.,* **101,** E830-E846, doi: 10.1175/BAMS-D-19-0062.1

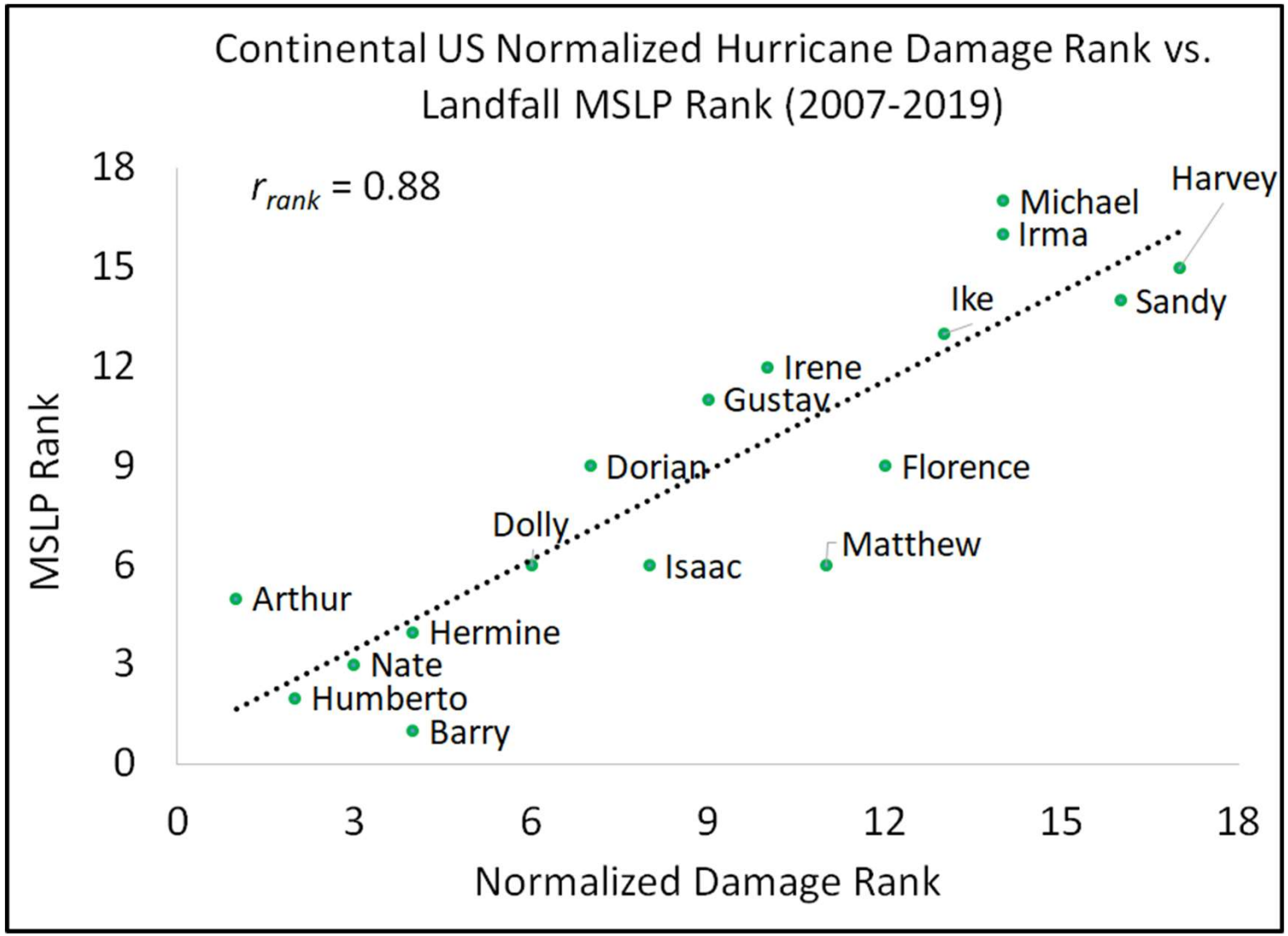
Motivation

- MSLP much easier to measure and has less uncertainty than V_{max} both via aircraft and with surface observations (Landsea and Franklin 2013)
- MSLP is a more robust metric of overall storm intensity (Chavas et al. 2017)
- MSLP a better predictor of damage than V_{max} in global damage survey (Bakkensen and Mendelsohn 2016)

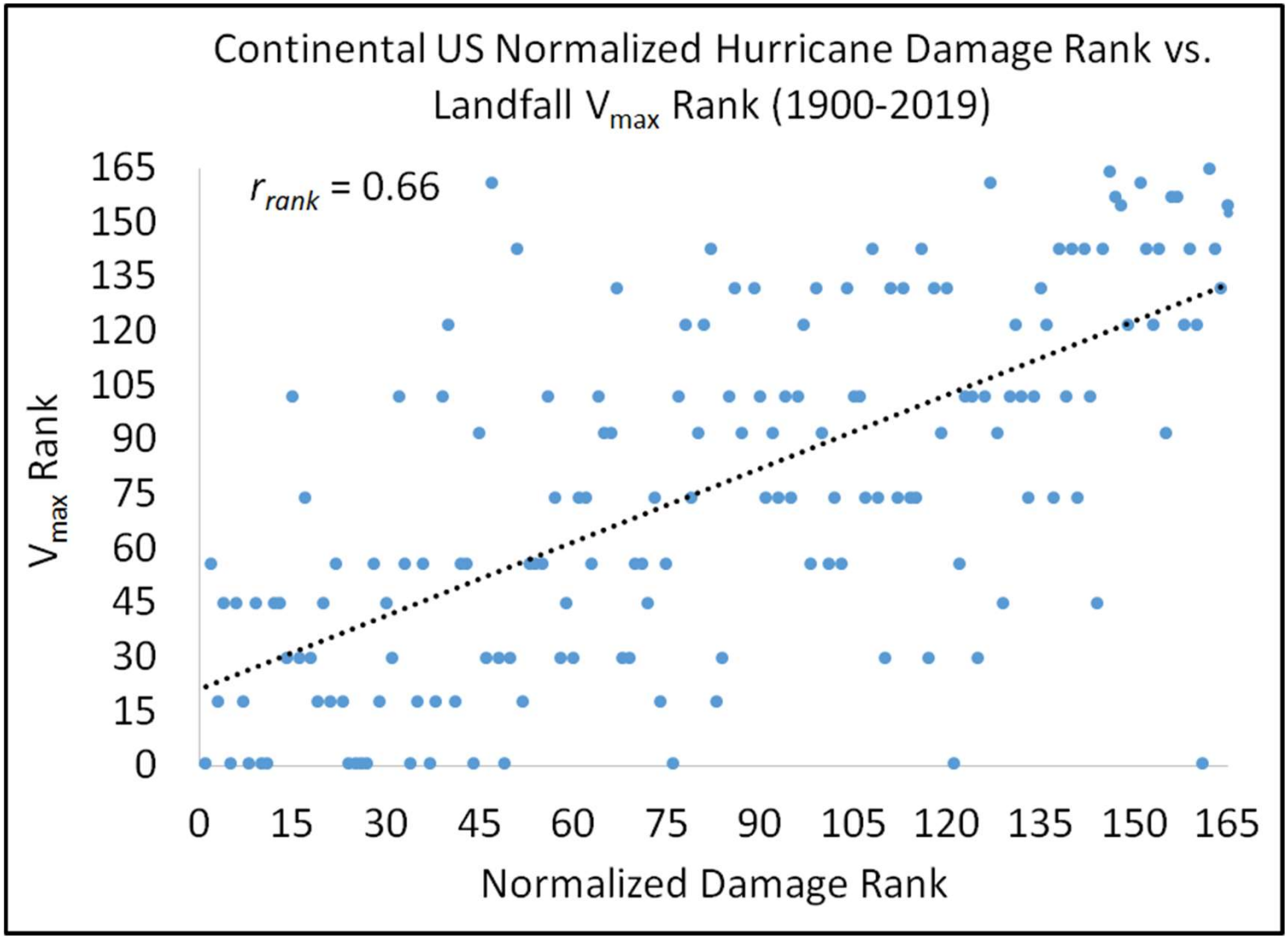
Relationship between V_{max} and Continental US Normalized Hurricane Damage (2007-2019)



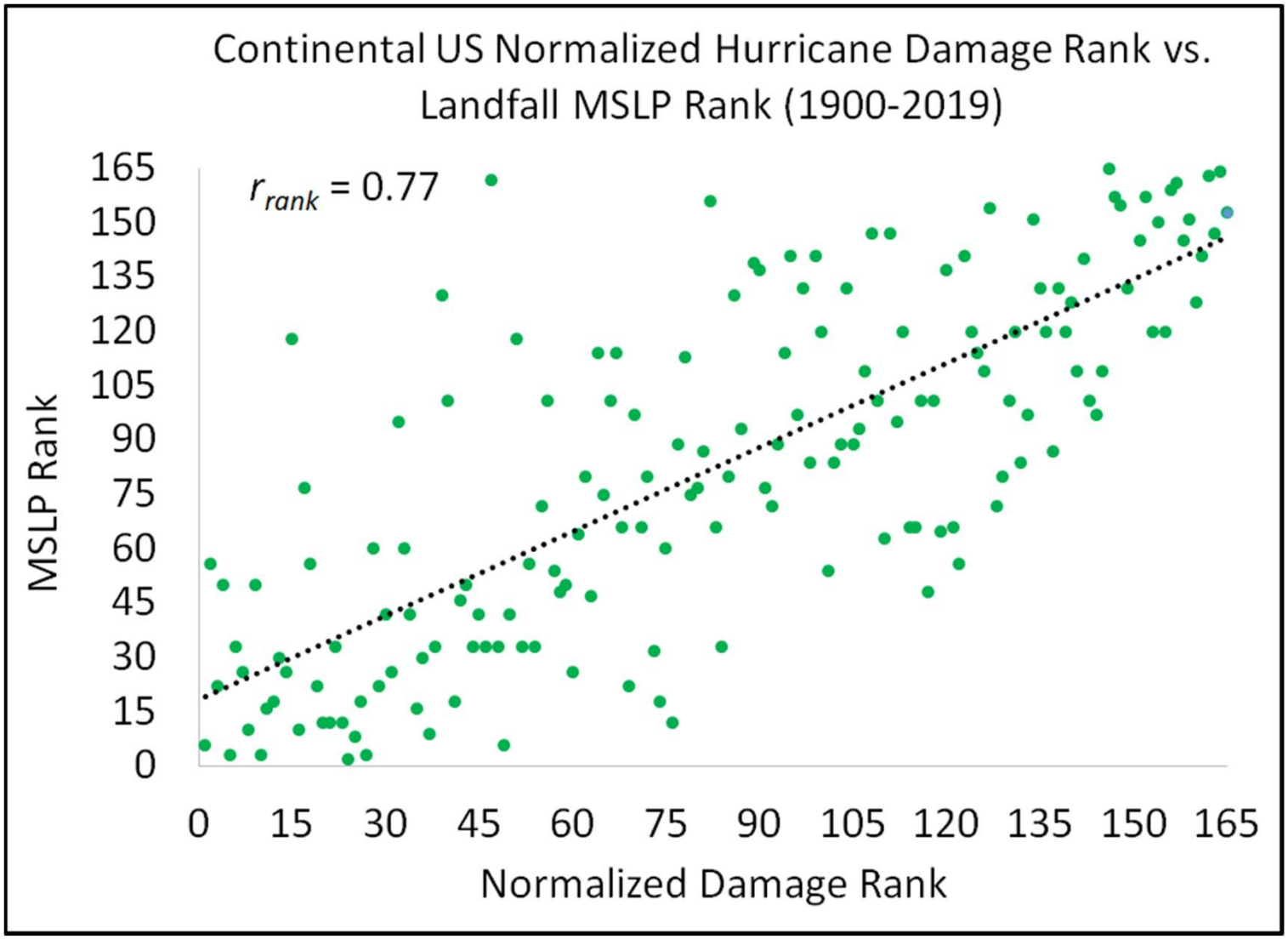
Relationship between MSLP and Continental US Normalized Hurricane Damage (2007-2019)



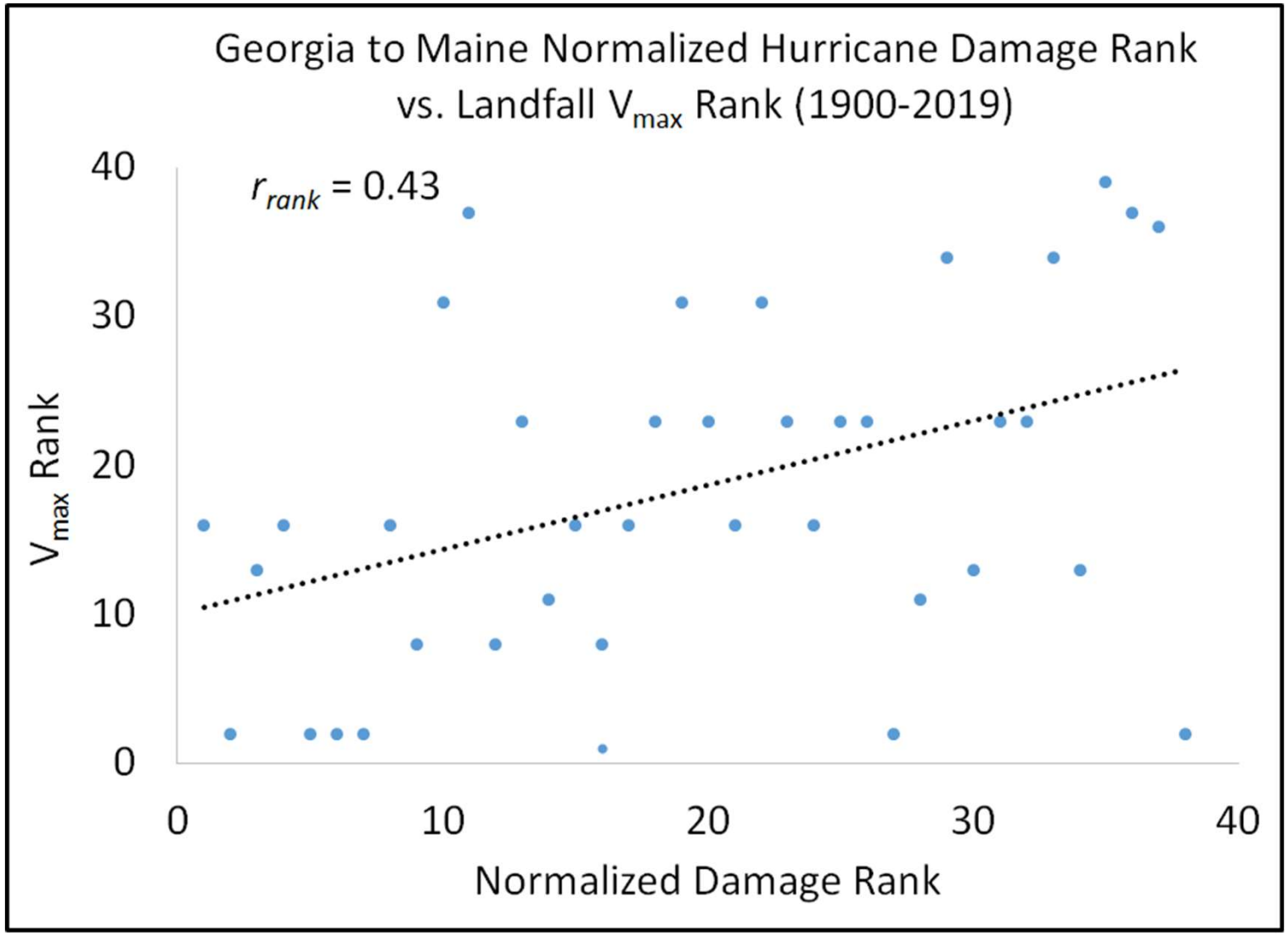
Relationship between V_{max} and Continental US Normalized Hurricane Damage (1900-2019)



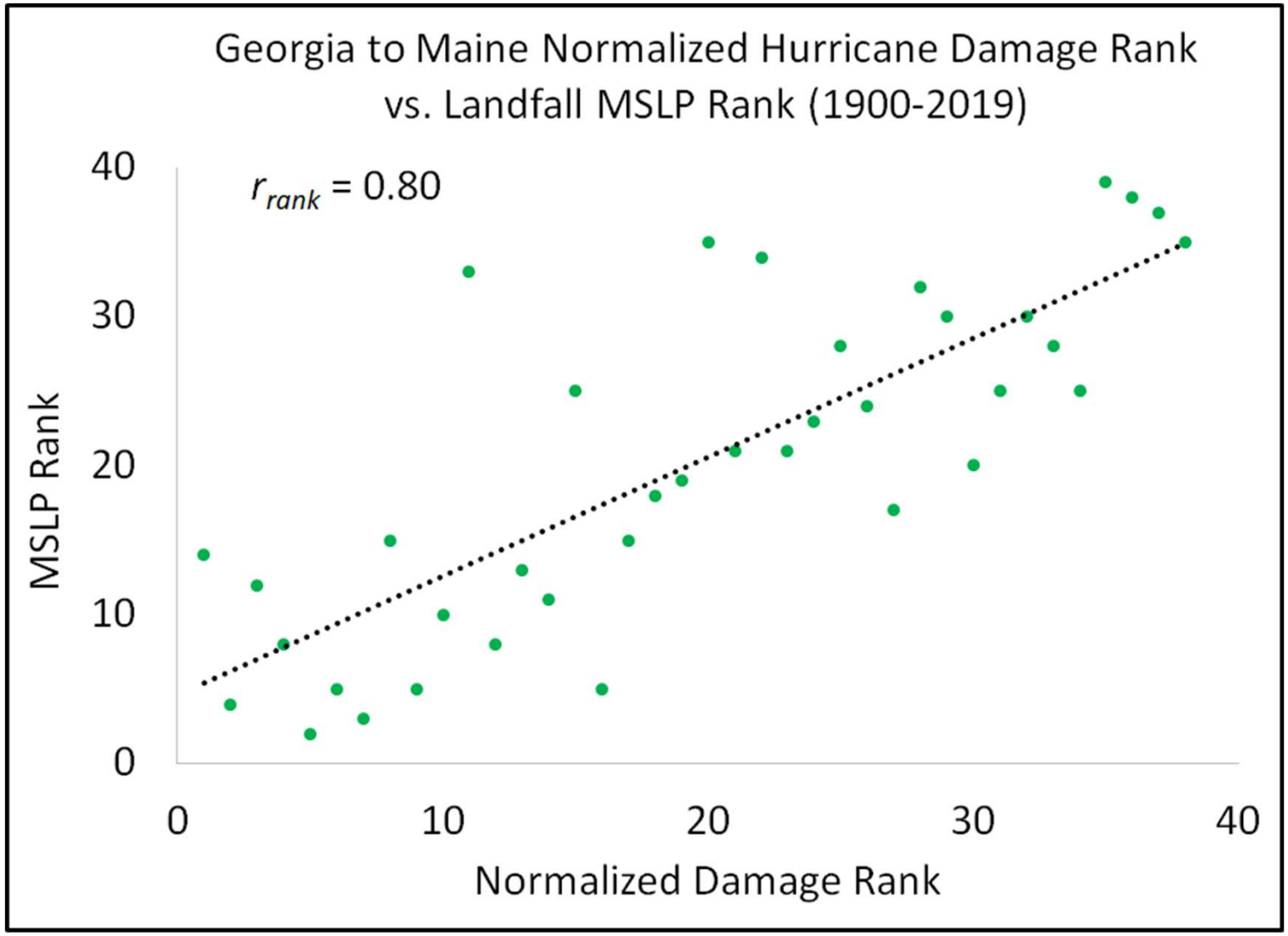
Relationship between MSLP and Continental US Normalized Hurricane Damage (1900-2019)



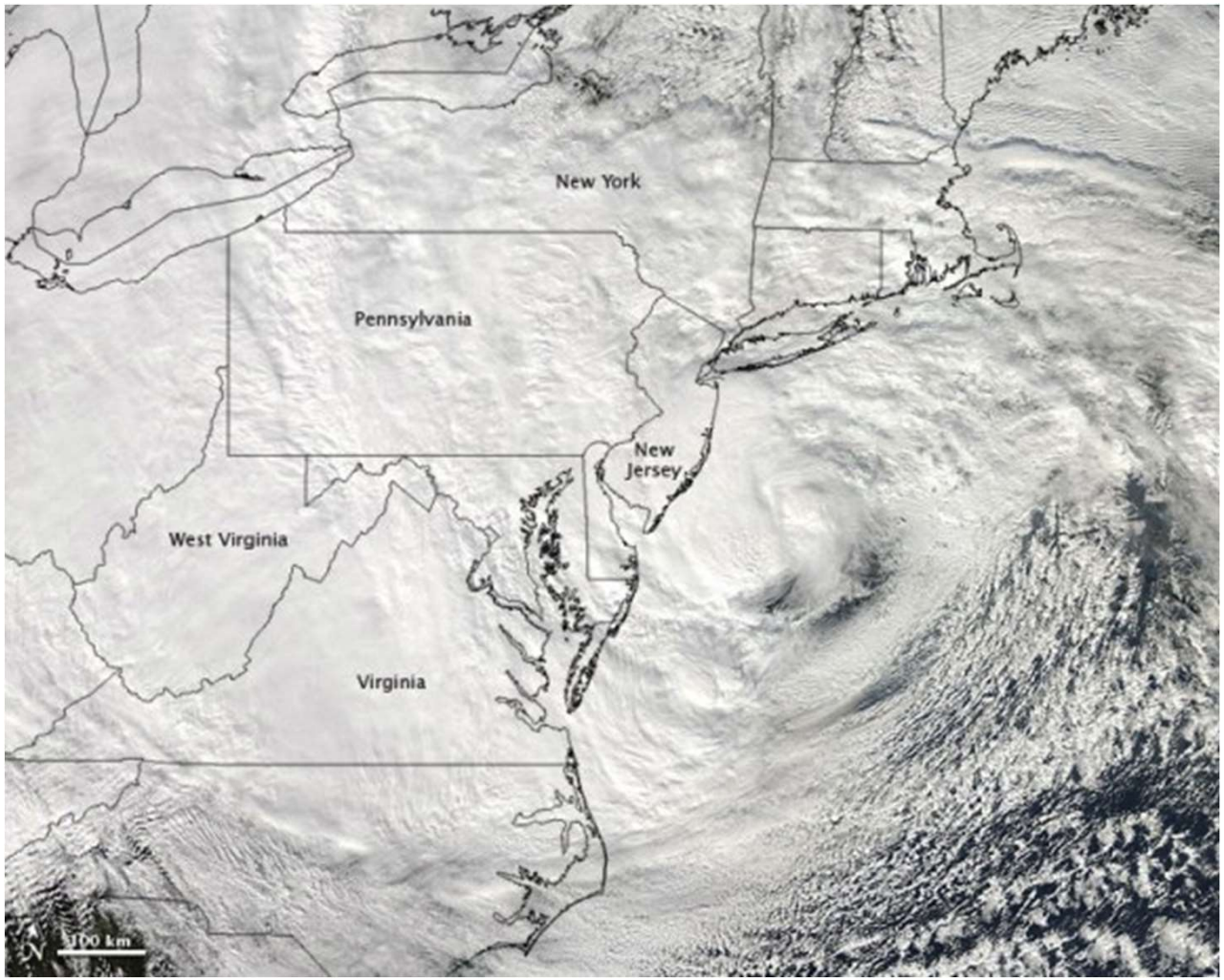
Relationship between V_{max} and GA to ME Normalized Hurricane Damage (1900-2019)



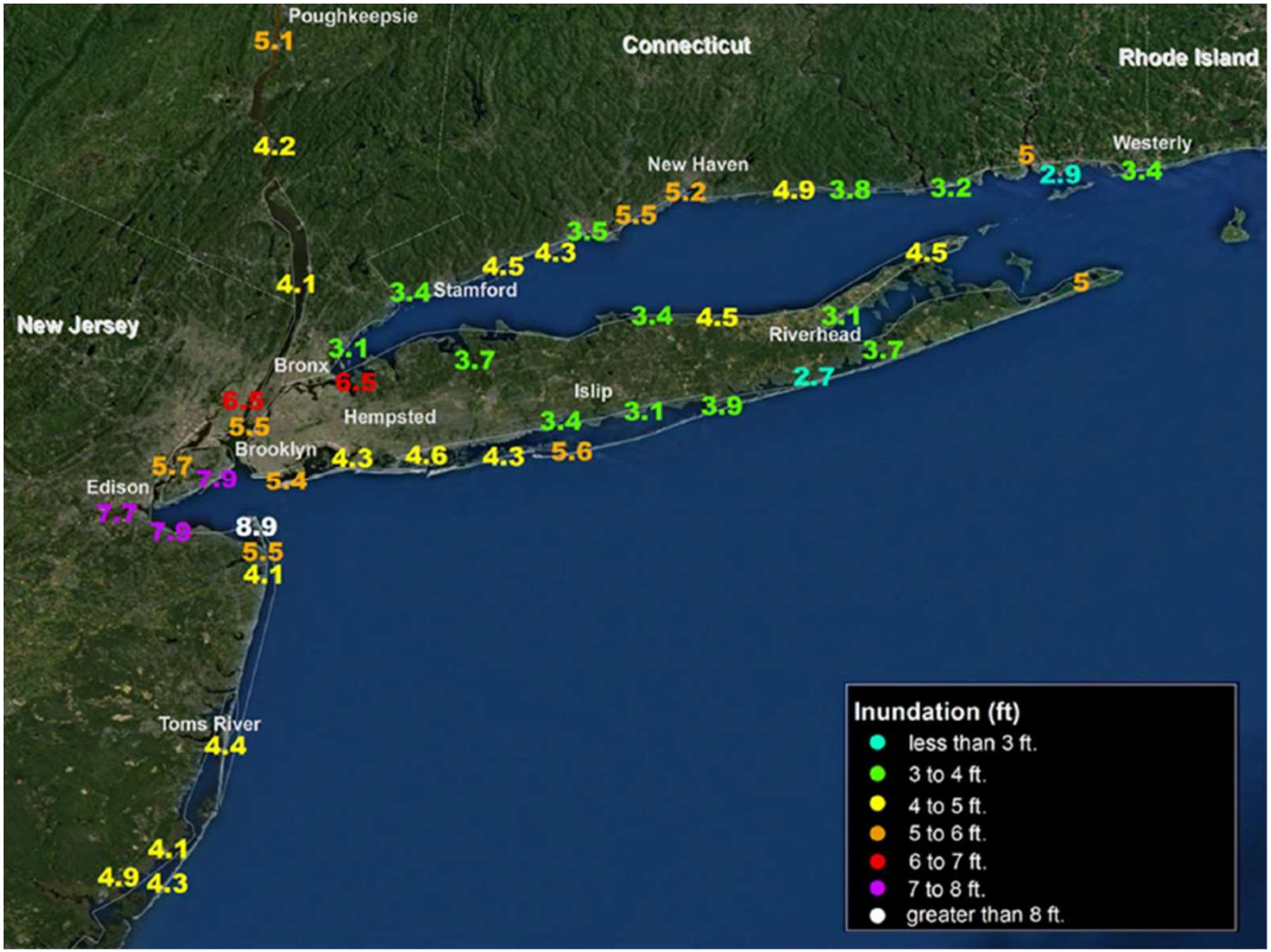
Relationship between MSLP and GA to ME Normalized Hurricane Damage (1900-2019)



Hurricane/Superstorm Sandy: 75 mph winds, 942 hPa MSLP



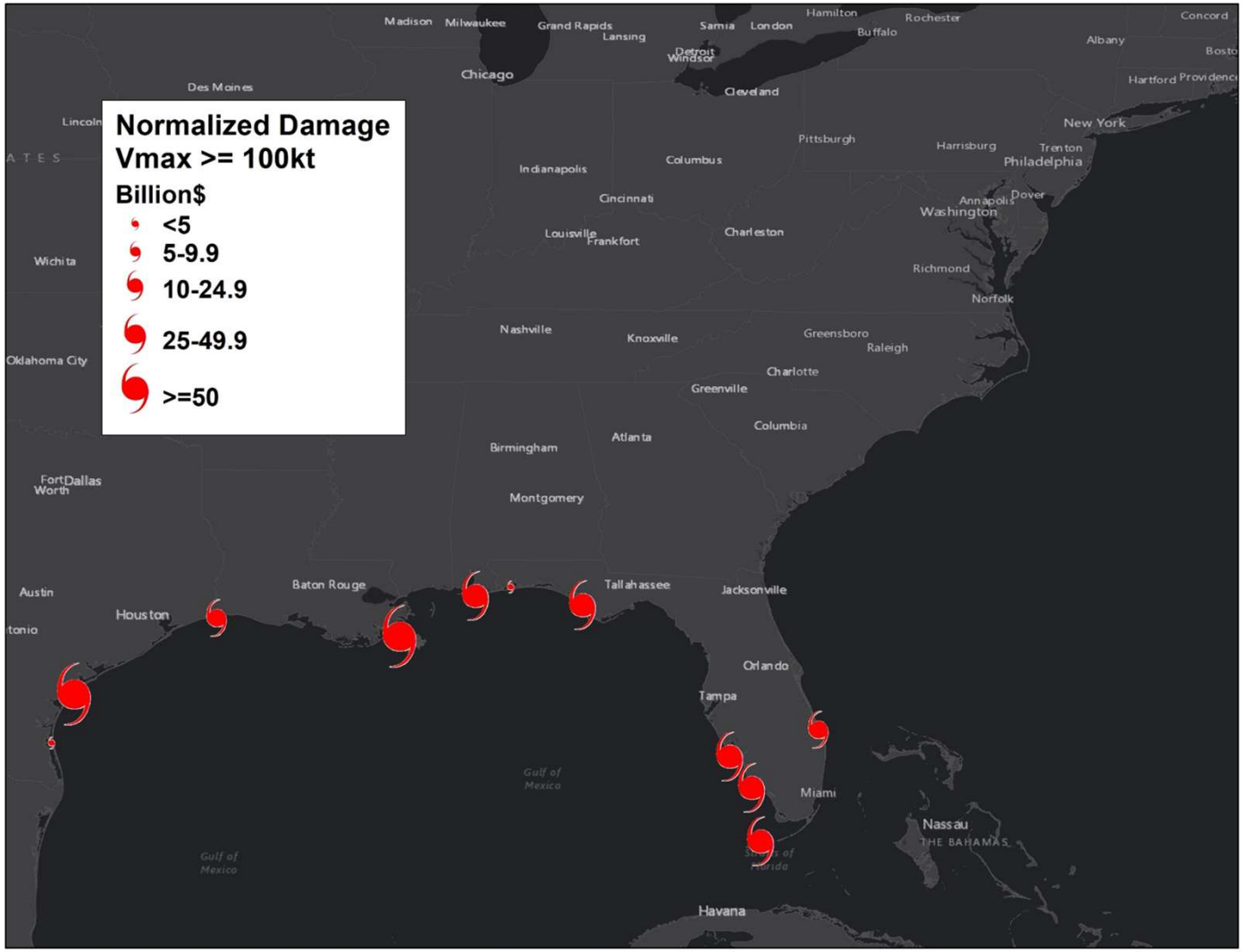
Storm Surge Inundation from Hurricane/Superstorm Sandy (2012)



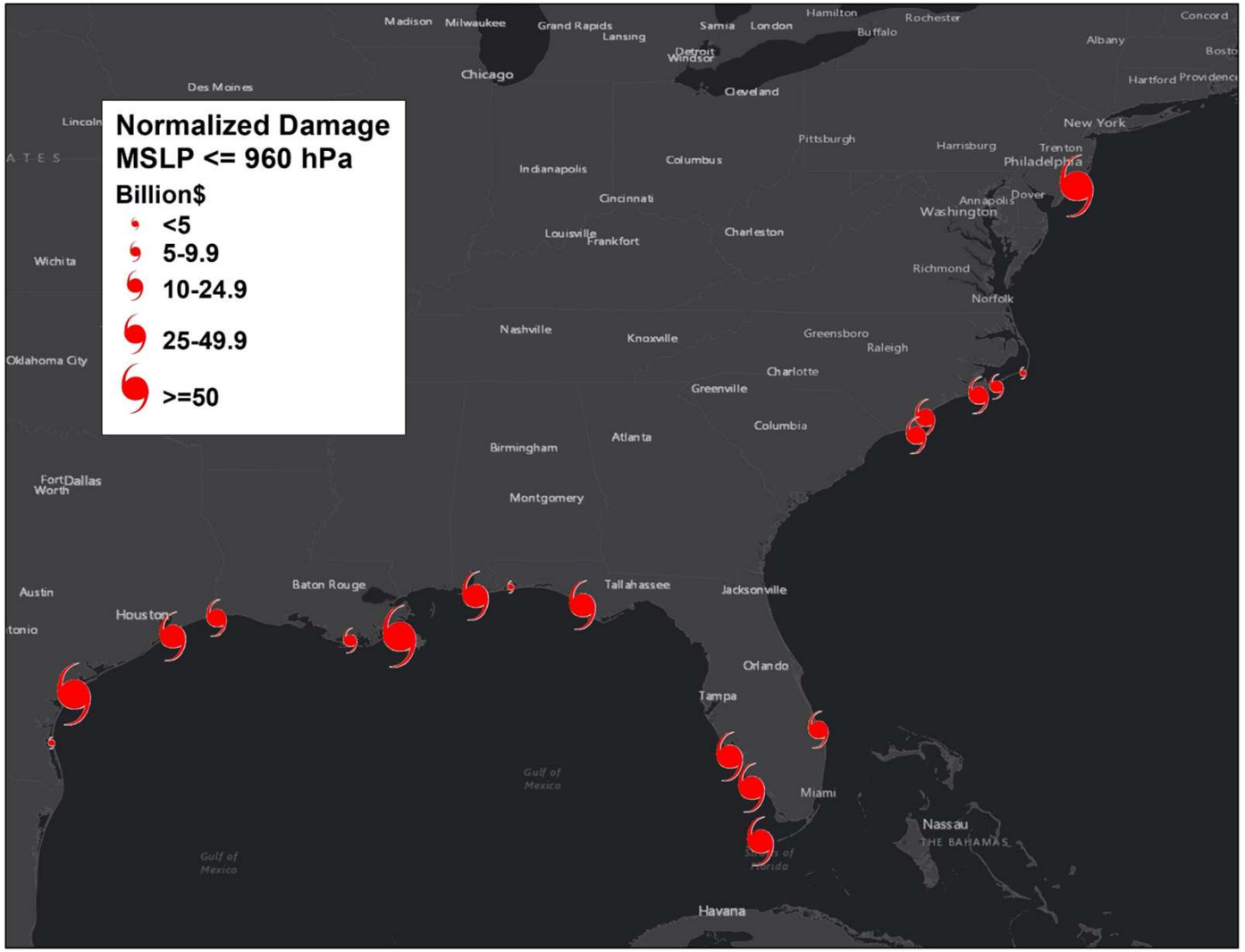
Saffir-Simpson Scale (Includes Proposed MSLP Addition)

Category	V_{max} (kt)	Revised MSLP (hPa)	Original MSLP (hPa)
1	64-82 (52%)	976-990 (55%)	>980 (n/a)
2	83-95 (31%)	961-975 (32%)	965-979 (38%)
3	96-112 (21%)	946-960 (20%)	945-964 (24%)
4	113-136 (13%)	926-945 (12%)	920-944 (12%)
5	>=137 (4%)	<=925 (4%)	<=919 (3%)

CONUS Major Hurricanes Using V_{max} Definition (1999-2019)

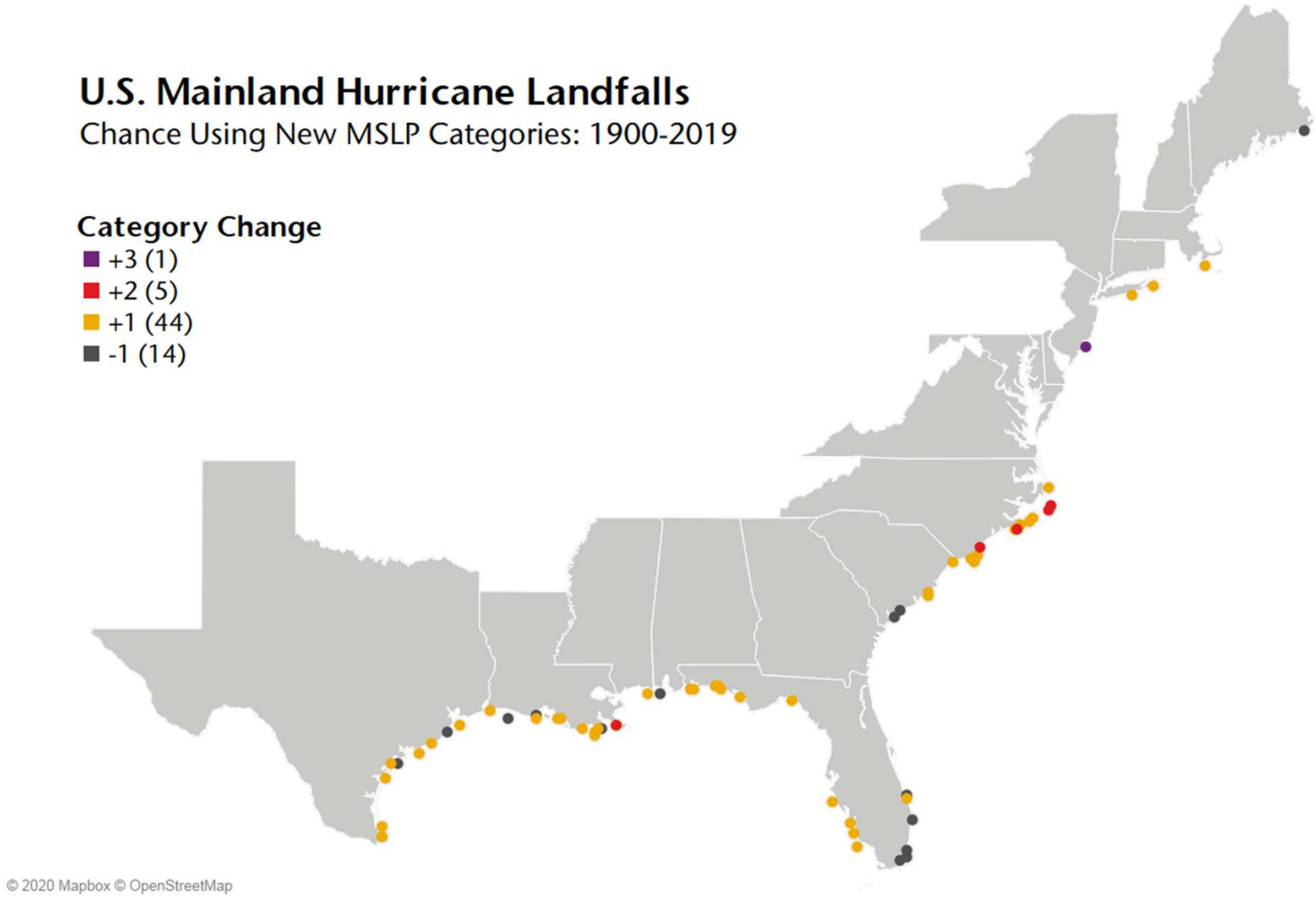


CONUS Major Hurricanes Using MSLP Definition (1999-2019)

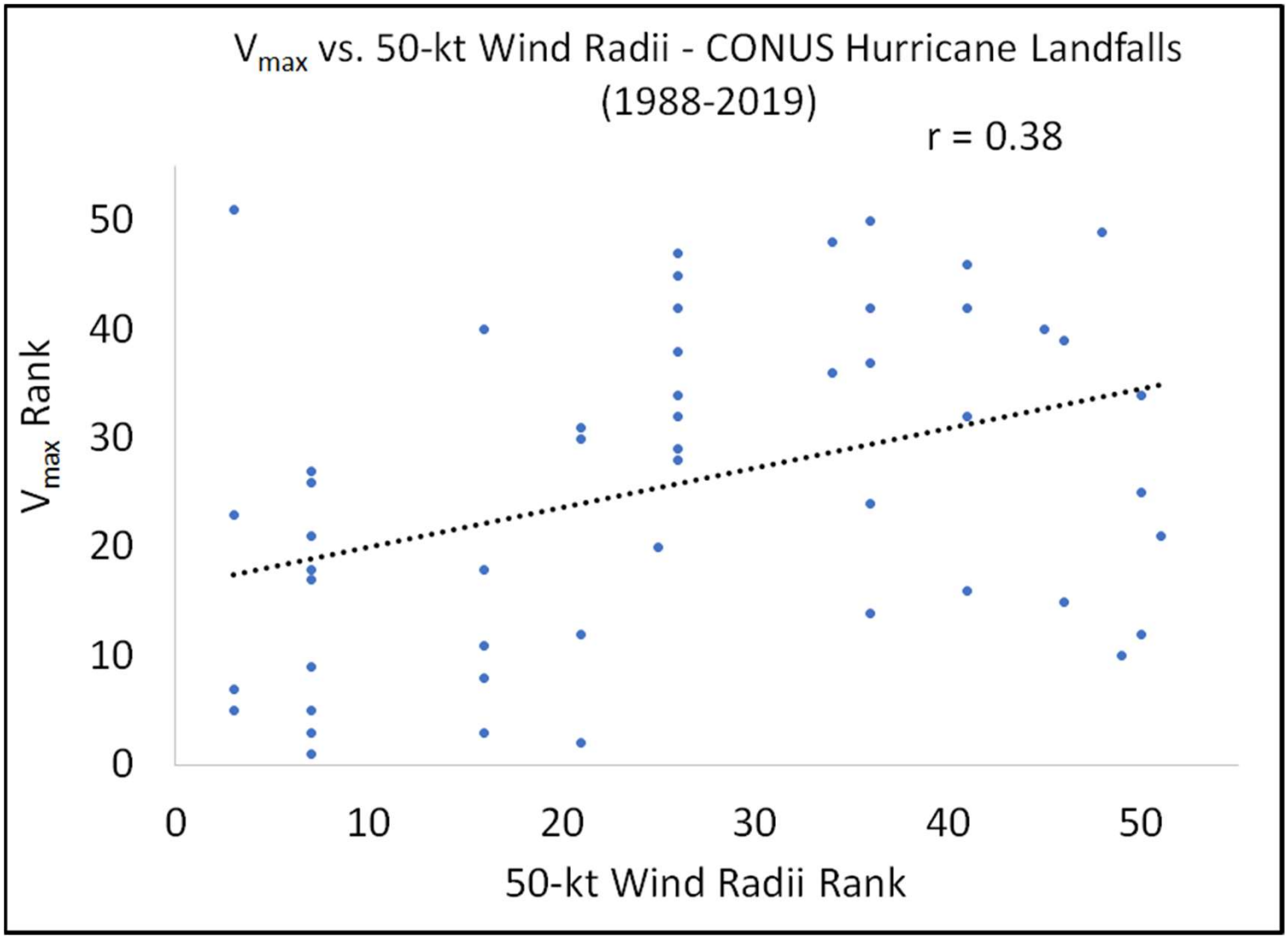


U.S. Mainland Hurricane Landfalls

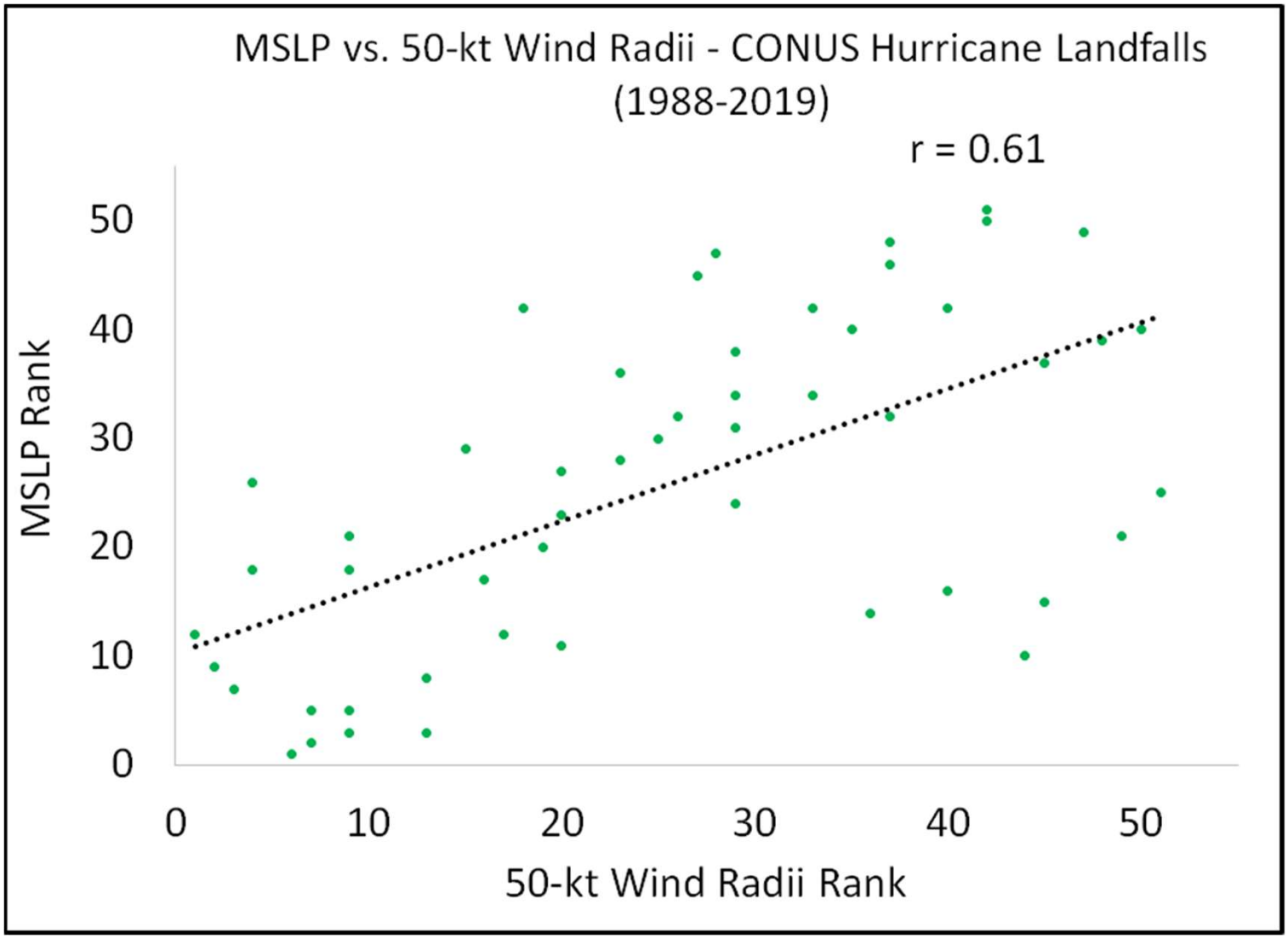
Chance Using New MSLP Categories: 1900-2019



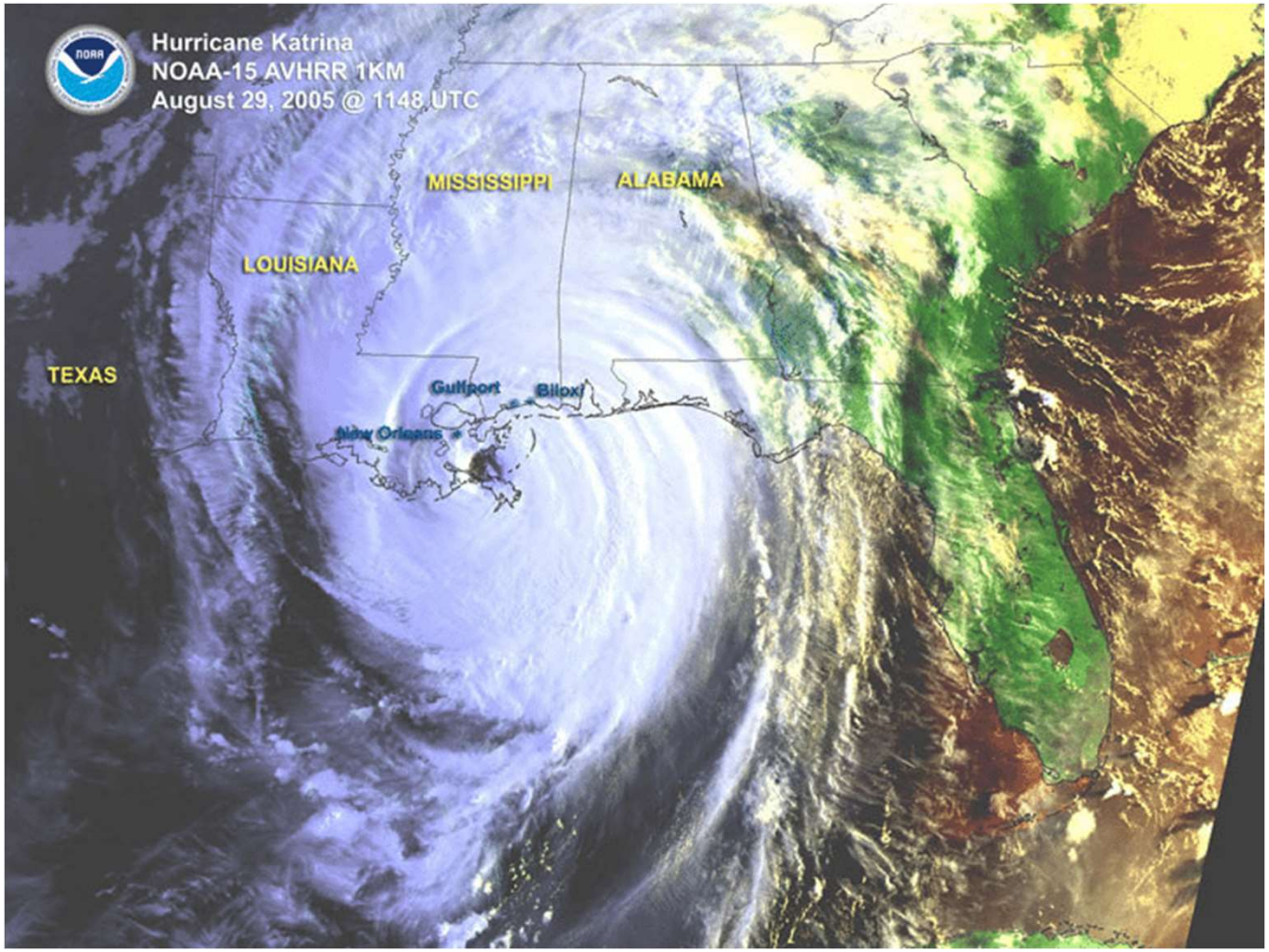
Relationship between V_{max} and 50 kt Wind Radii (1988-2019)



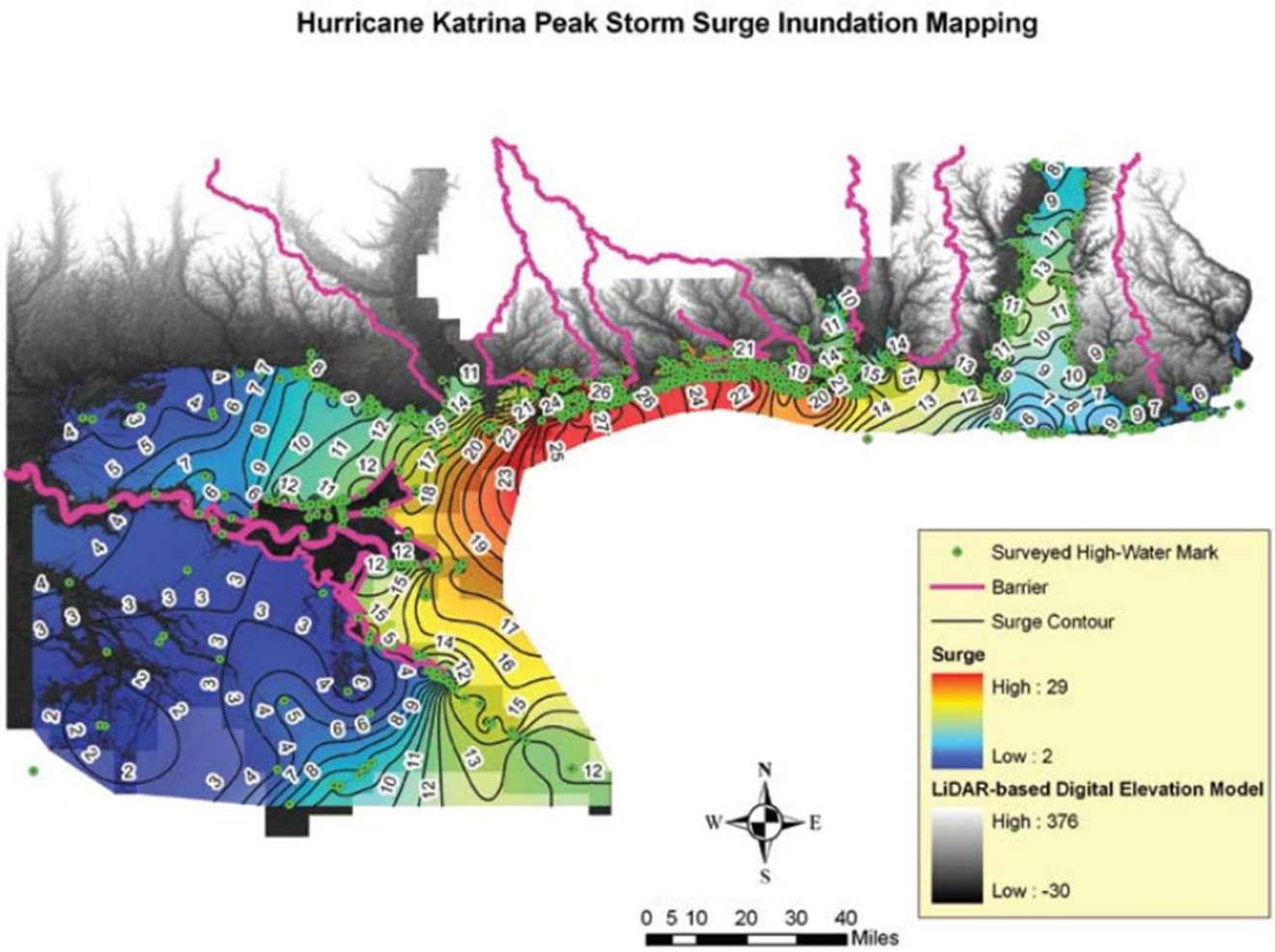
Relationship between MSLP and 50 kt Wind Radii (1988-2019)



Hurricane Katrina: Category 3 by V_{max}, Category 5 by MSLP

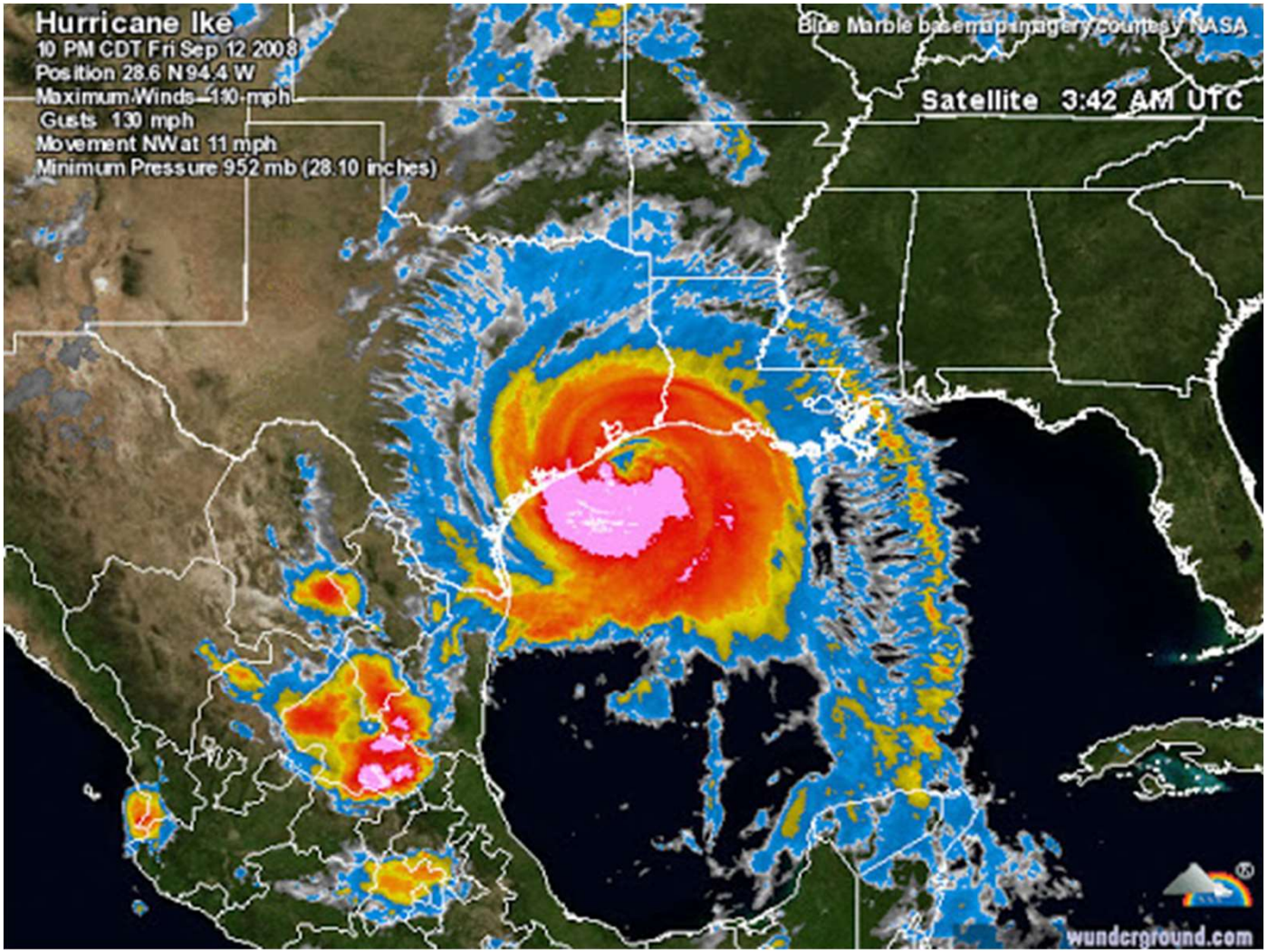


Storm Surge Inundation from Hurricane Katrina (2005)

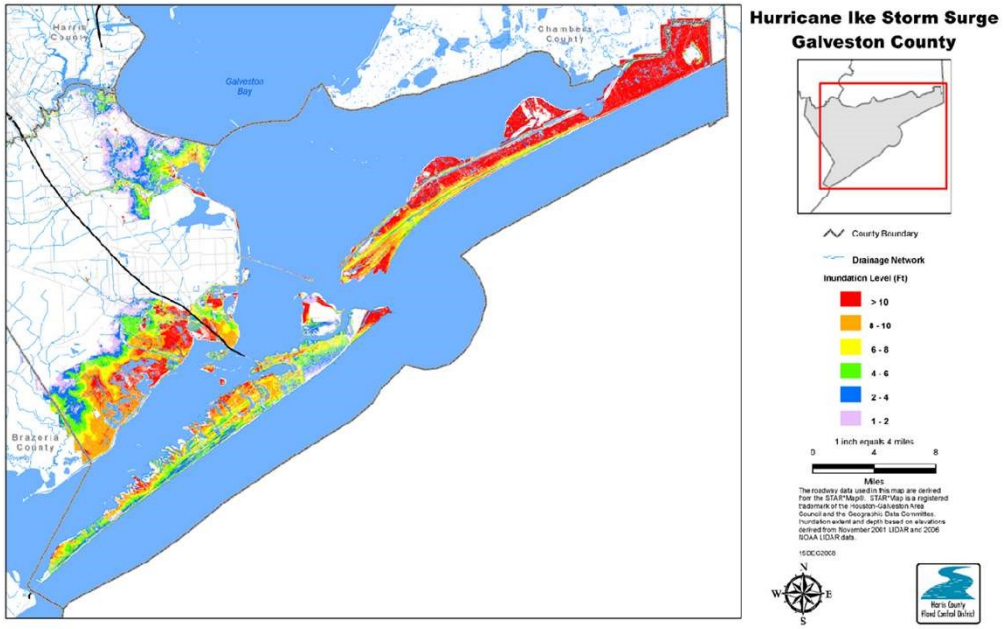


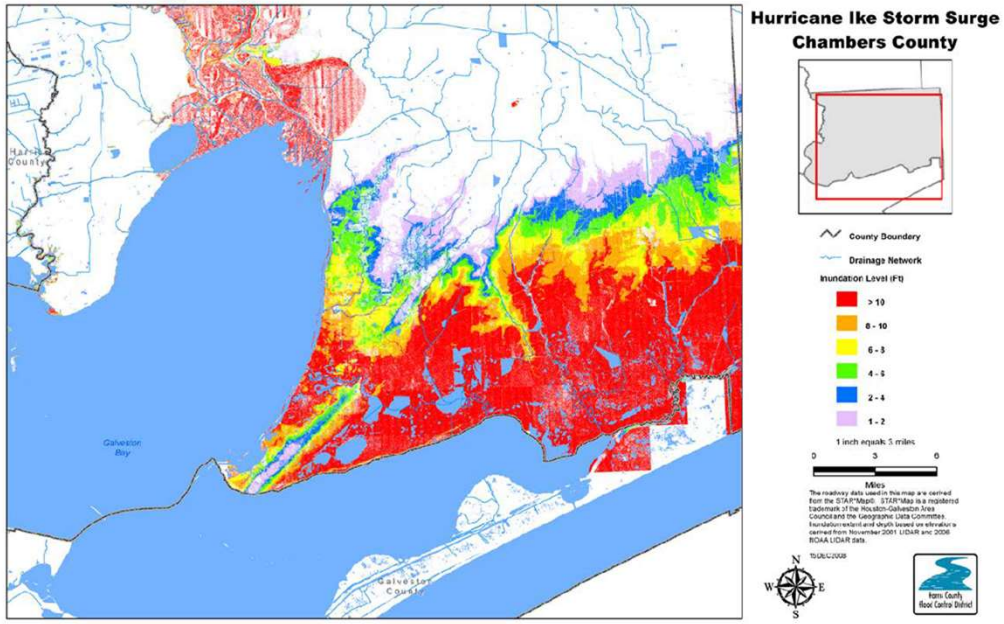
Turnipseed et al. (2007)

Hurricane Ike: Category 2 by V_{max}, Category 3 by MSLP



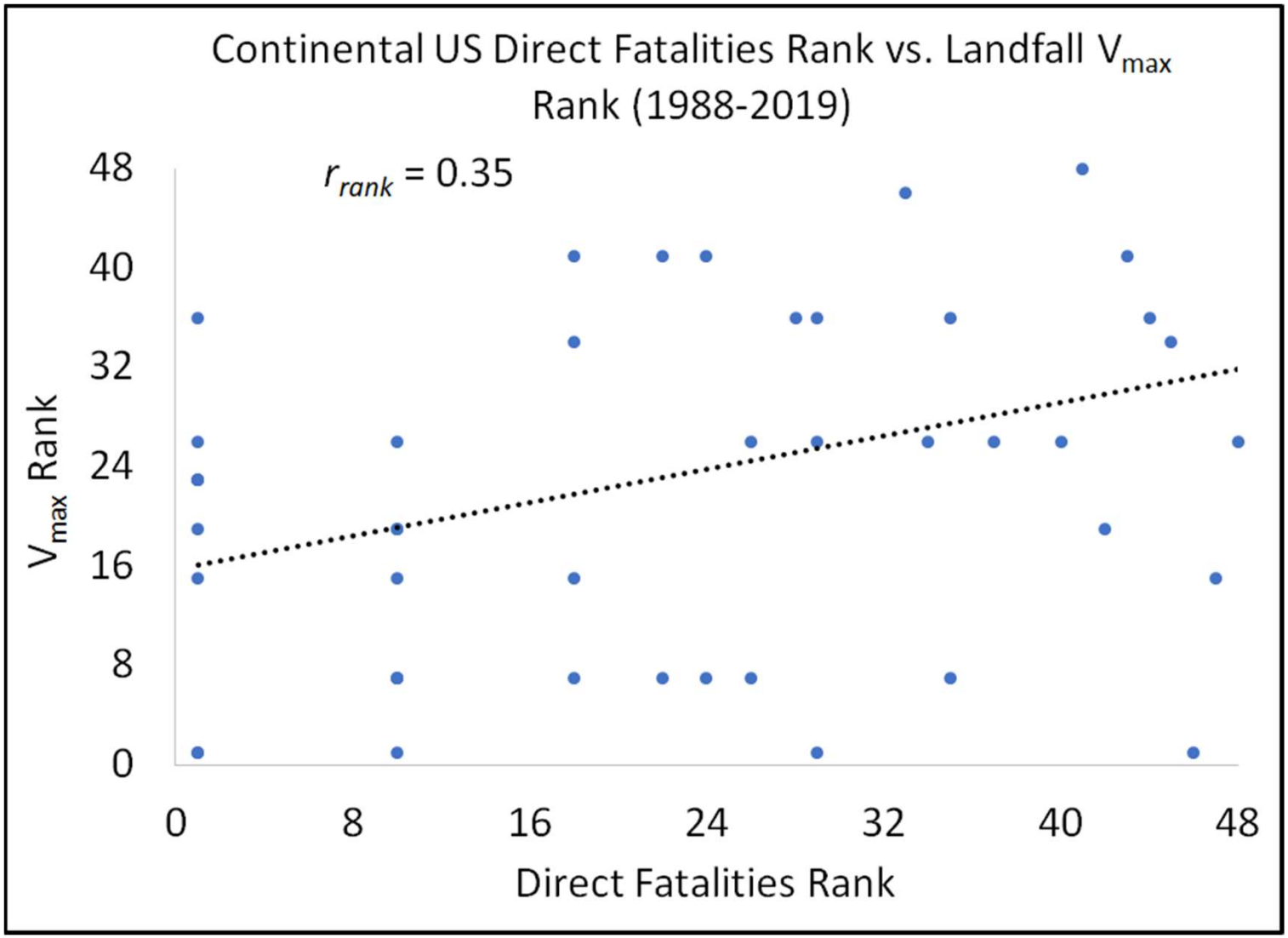
Galveston County Storm Surge from Ike – Areas in Red > 10 ft. of Inundation



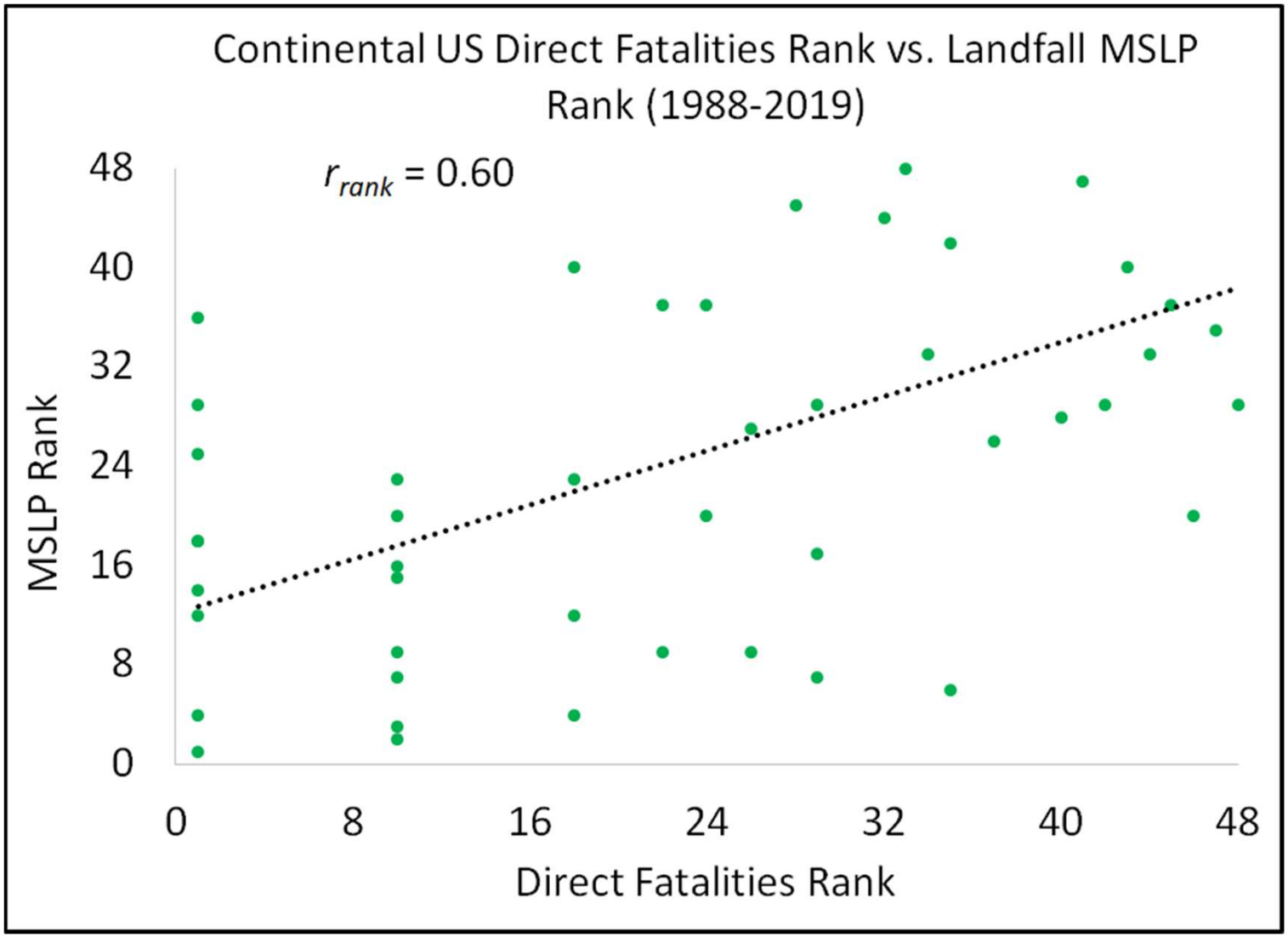


Chambers County Storm Surge from Ike – Areas in Red > 10 ft. of Inundation

Relationship between V_{max} and Fatalities (1988-2019)



Relationship between MSLP and Fatalities (1988-2019)



Summary

- MSLP has a stronger relationship than does V_{max} with normalized continental US hurricane damage since 1900

- MSLP also has a stronger correlation than does Vmax for:
  - *50-kt wind radii*
  - *Fatalities*

Future Work

- Compare MSLP with other recently proposed Saffir-Simpson Scale replacements such as the Hurricane Severity Index and Integrated Kinetic Energy

- Investigate the relationship between rainfall footprint and V_{max}/MSLP

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