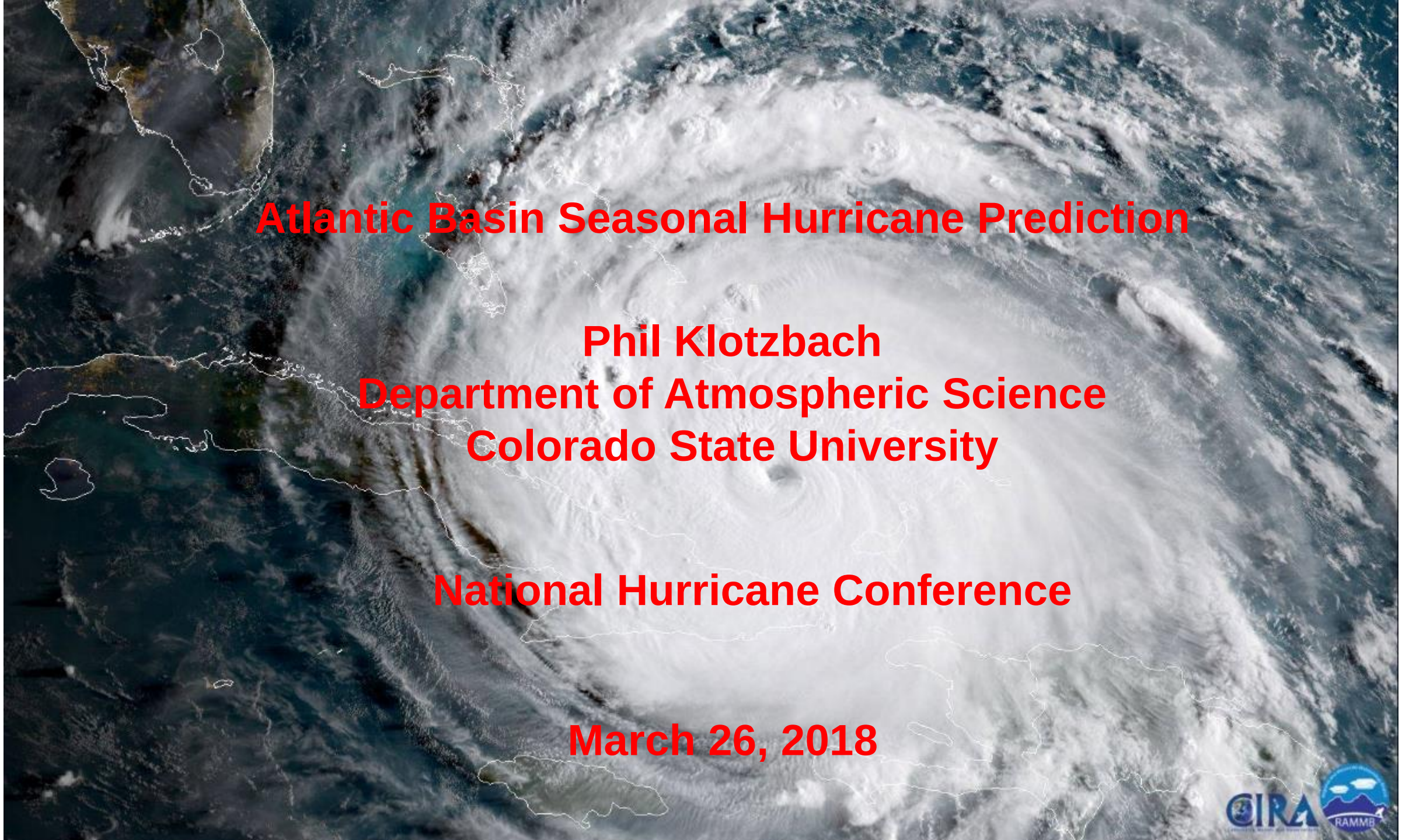


Atlantic Basin Seasonal Hurricane Prediction

Phil Klotzbach
Department of Atmospheric Science
Colorado State University

National Hurricane Conference

March 26, 2018

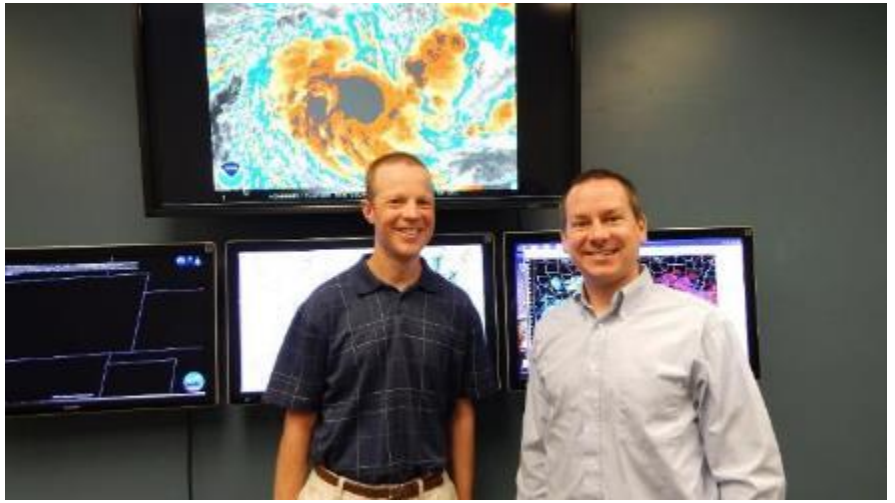
Outline

- Introduction
- Atlantic Basin Multi-Decadal Variability
- Tropical Cyclones and Climate Change
- 2017 Atlantic Basin Seasonal Forecast Verification
- 2018 Atlantic Basin Seasonal Outlook
- New Products

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.

Introducing New Co-Author Michael Bell



- Received M.S. in Atmospheric Science from Colorado State University (2006)
- Received Ph.D. in Meteorology from Naval Postgraduate School (2010)
- Joined faculty at Colorado State University in 2016
- Specializes in study of mesoscale structure of tropical cyclones from genesis to extratropical transition
- Recipient of Presidential Early Career Award

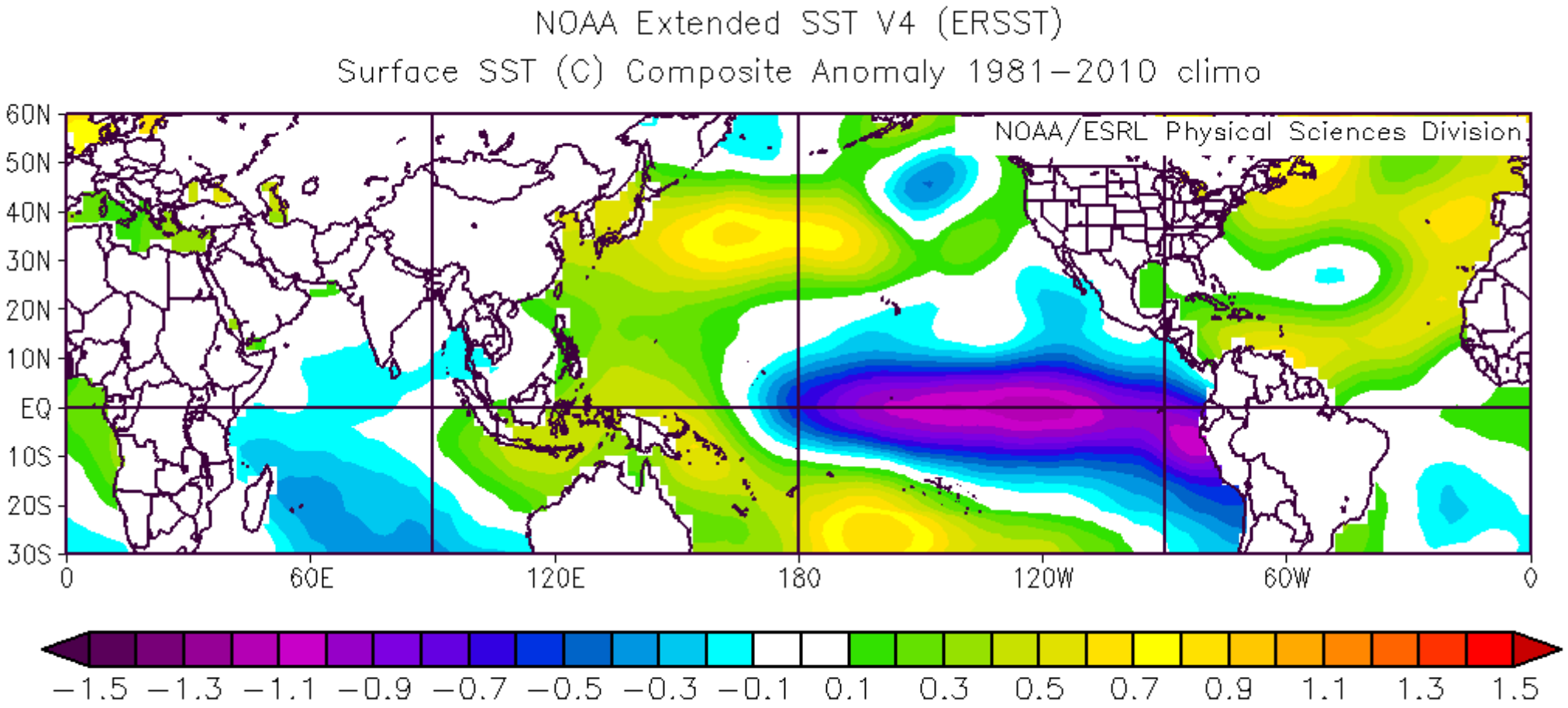
“It's tough to make predictions, especially about the future”

HOWEVER…

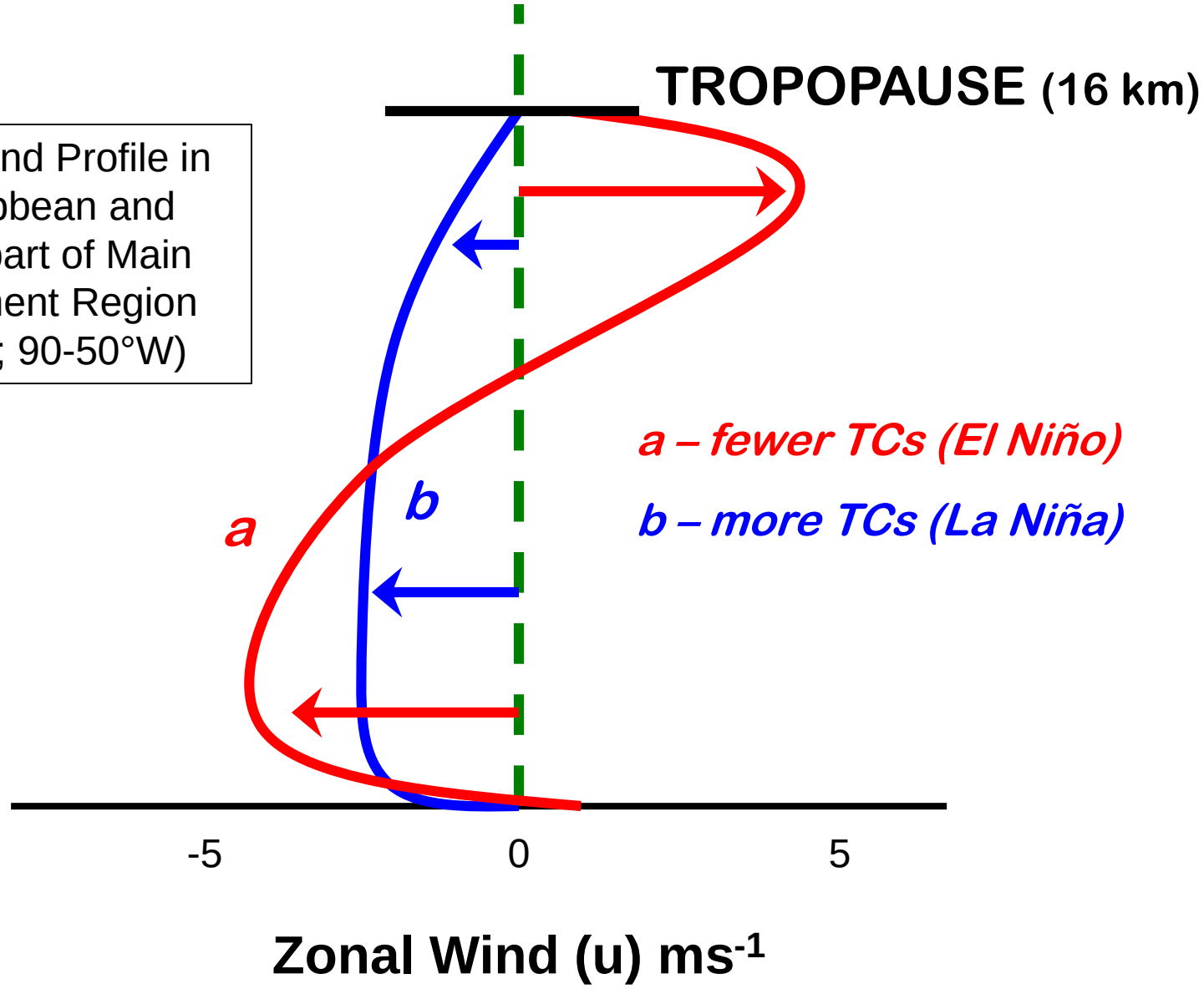
“You can see a lot by looking”

Yogi Berra

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

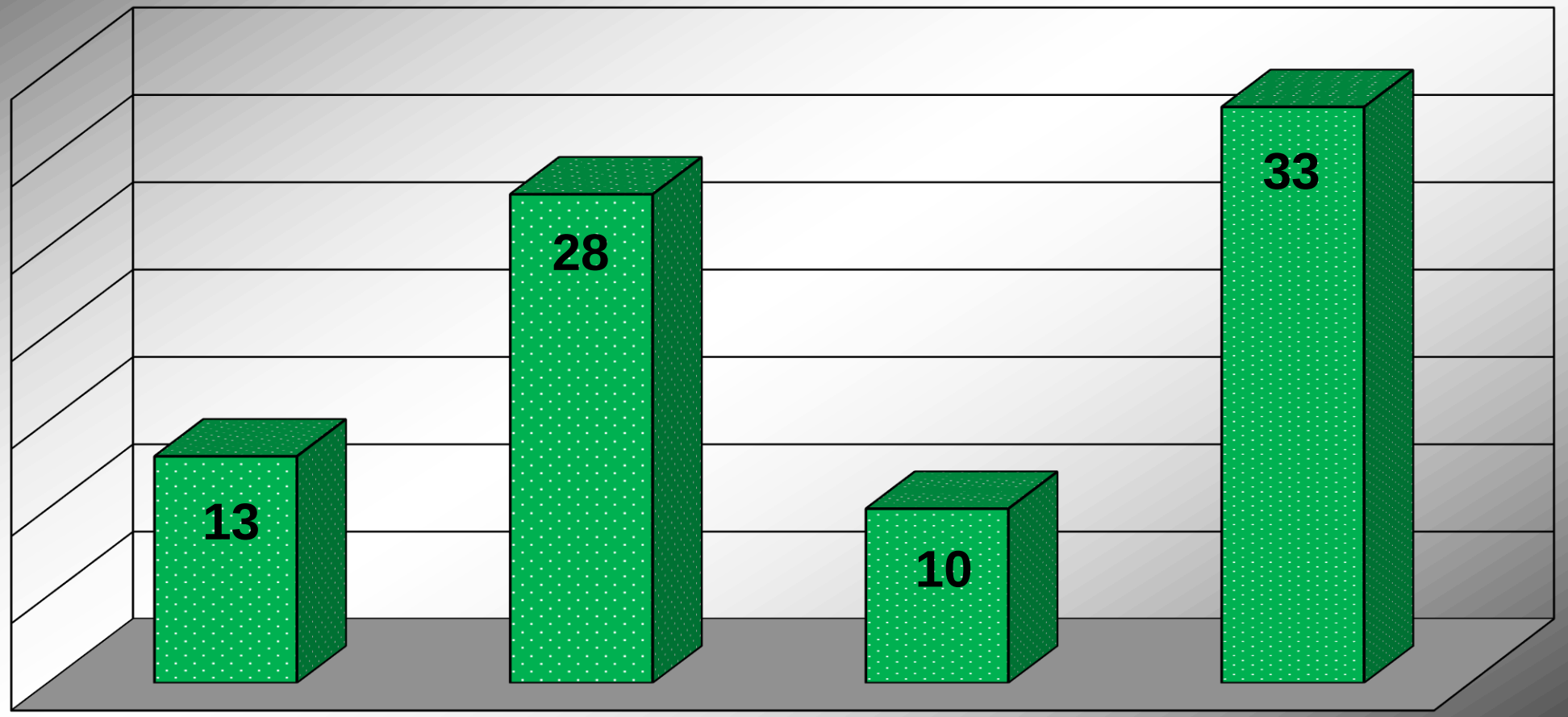


Vertical Wind Profile in the Caribbean and western part of Main Development Region (10-20°N; 90-50°W)



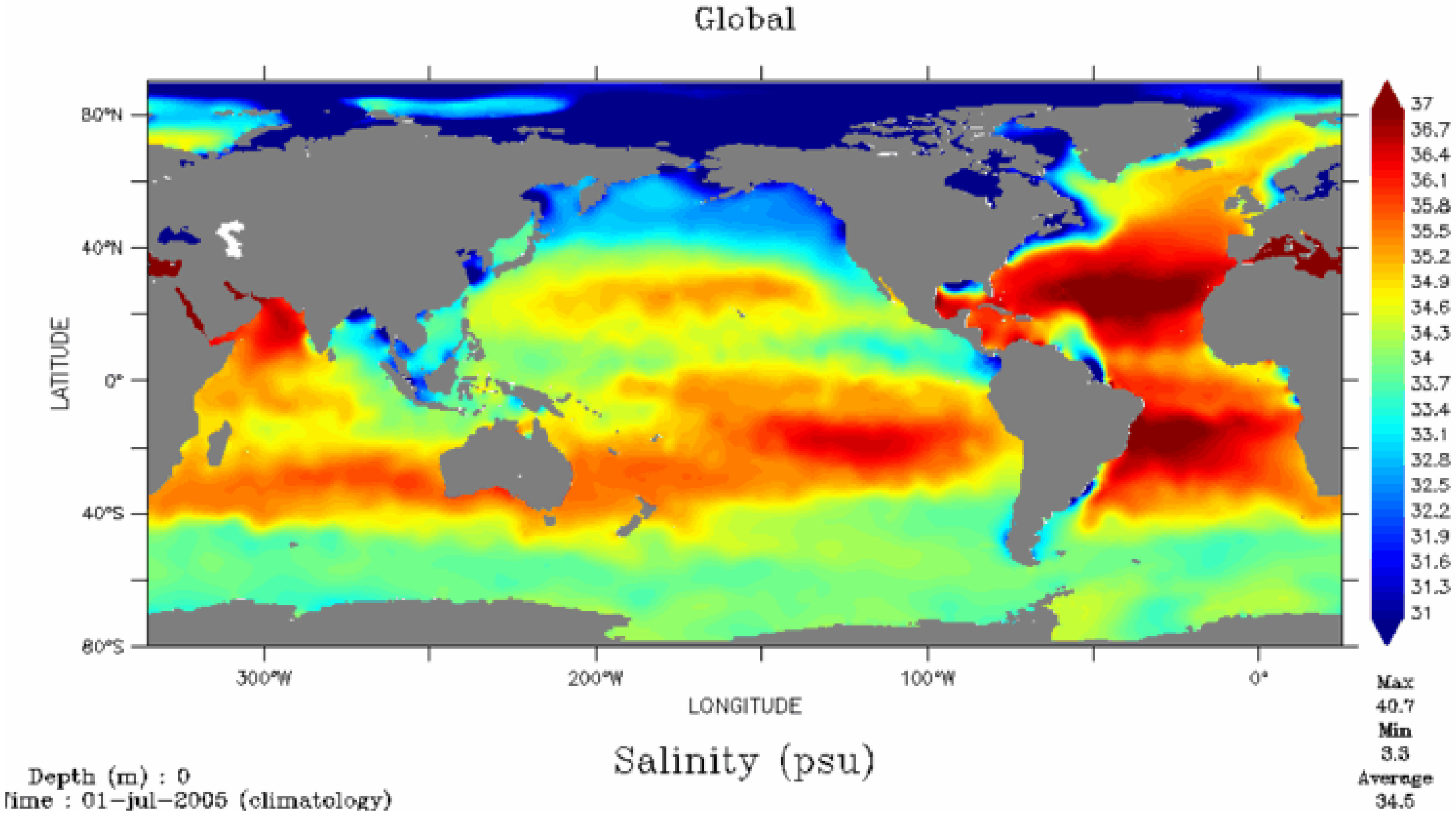
Atlantic Basin Multi-decadal Hurricane Variability

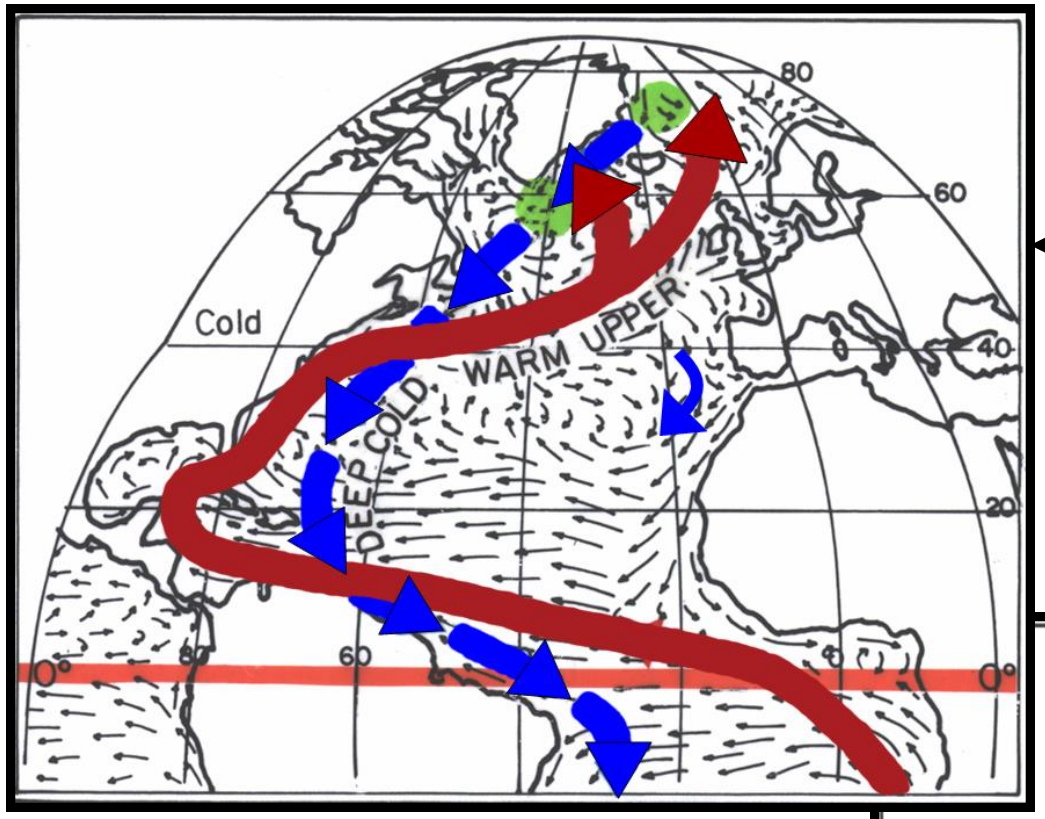
Annual Number of 6 Hour Periods for Cat 3-4-5 Hurricanes



Cat 3-4-5	1900-1925	1926-1969	1970-1994	1995-2017
	13	28	10	33

GLOBAL SURFACE SALINITY





THC *(or AMO)*

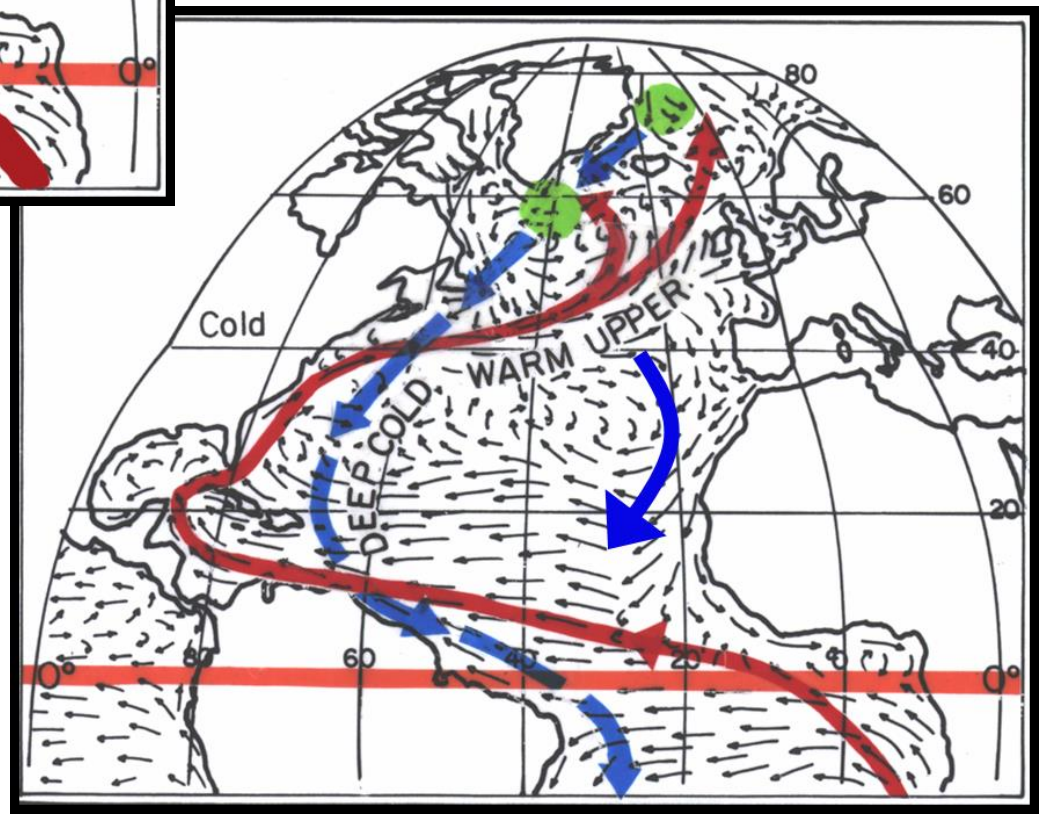
←

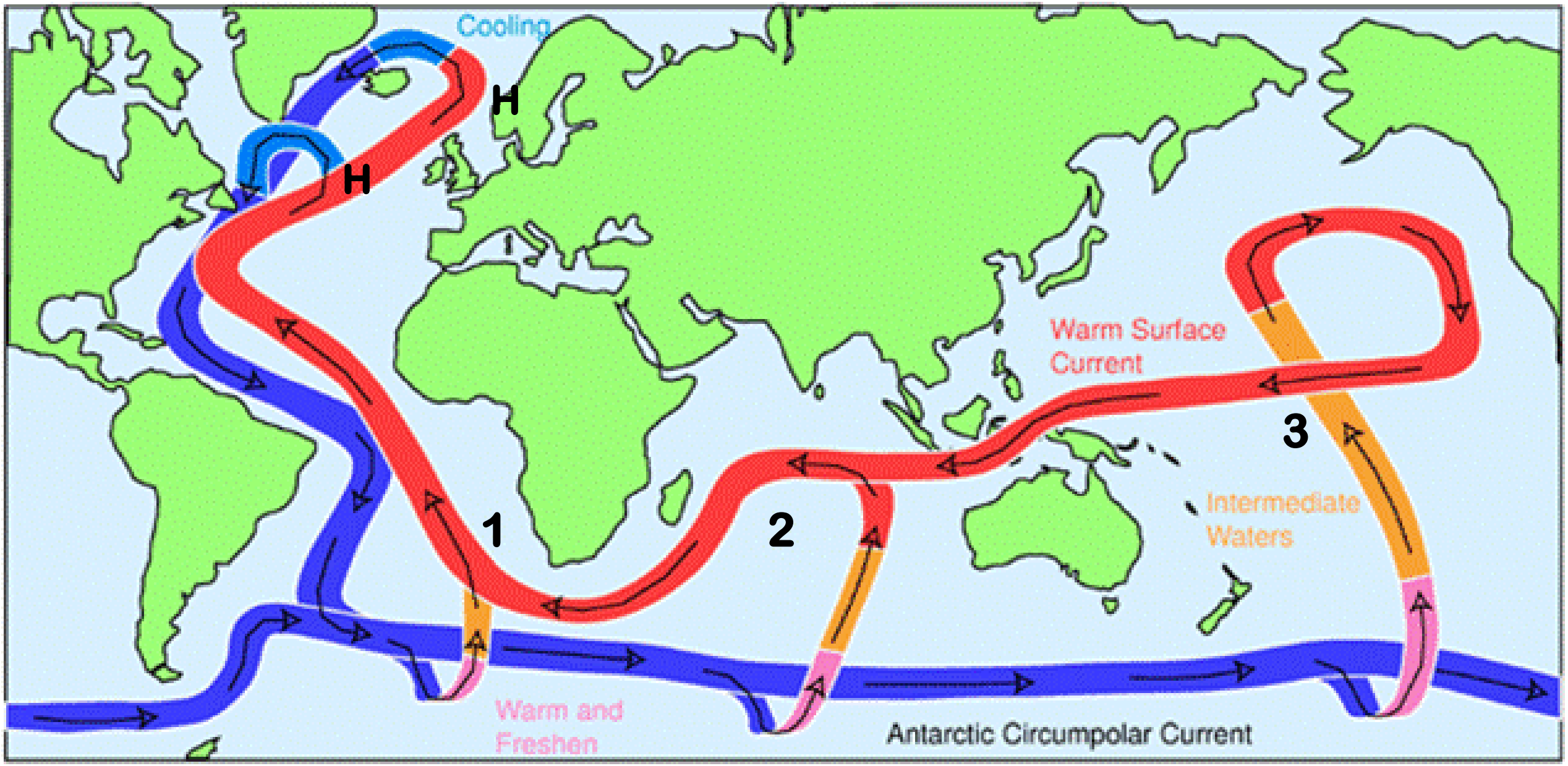
STRONG

THC *(or AMO)*

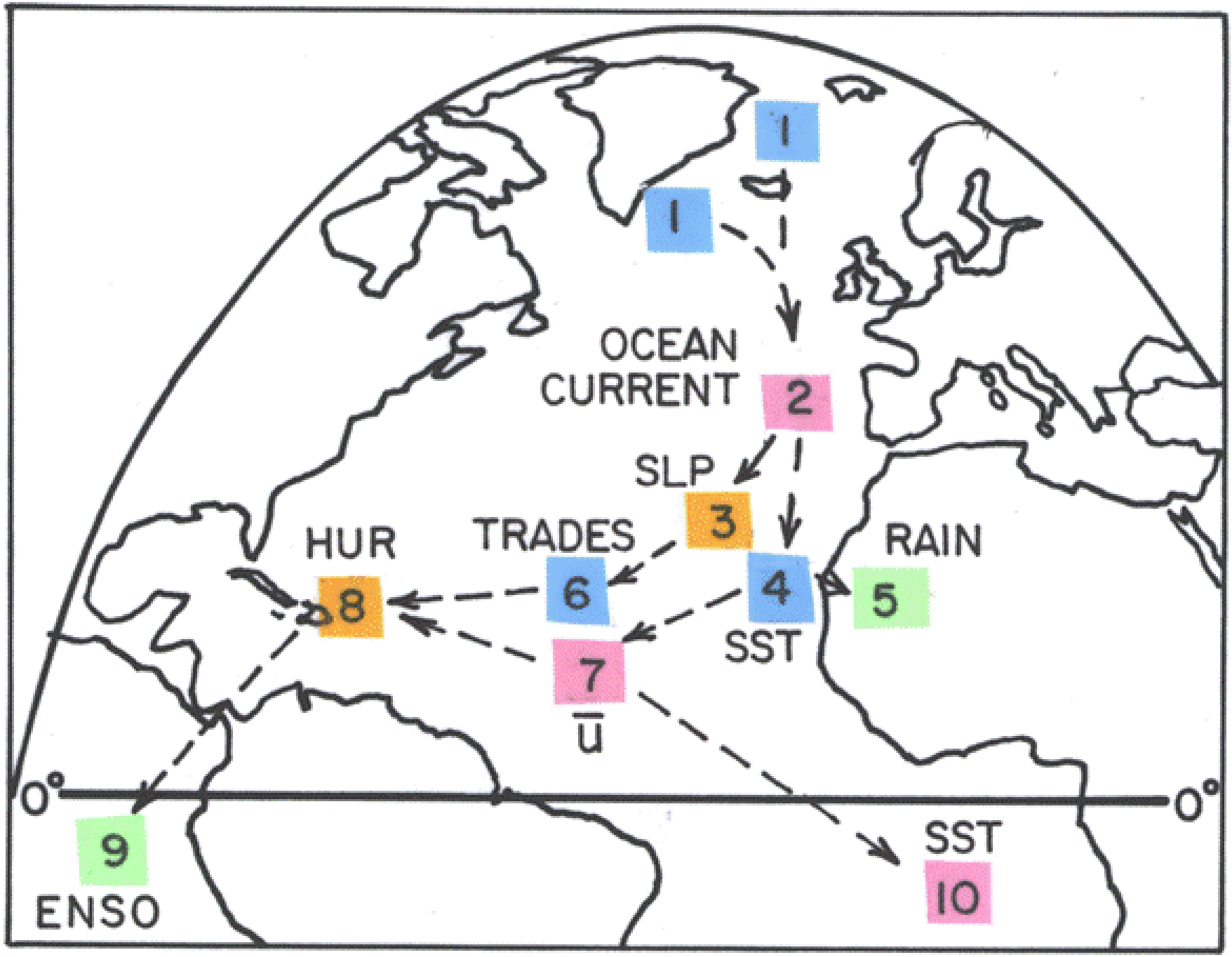
→

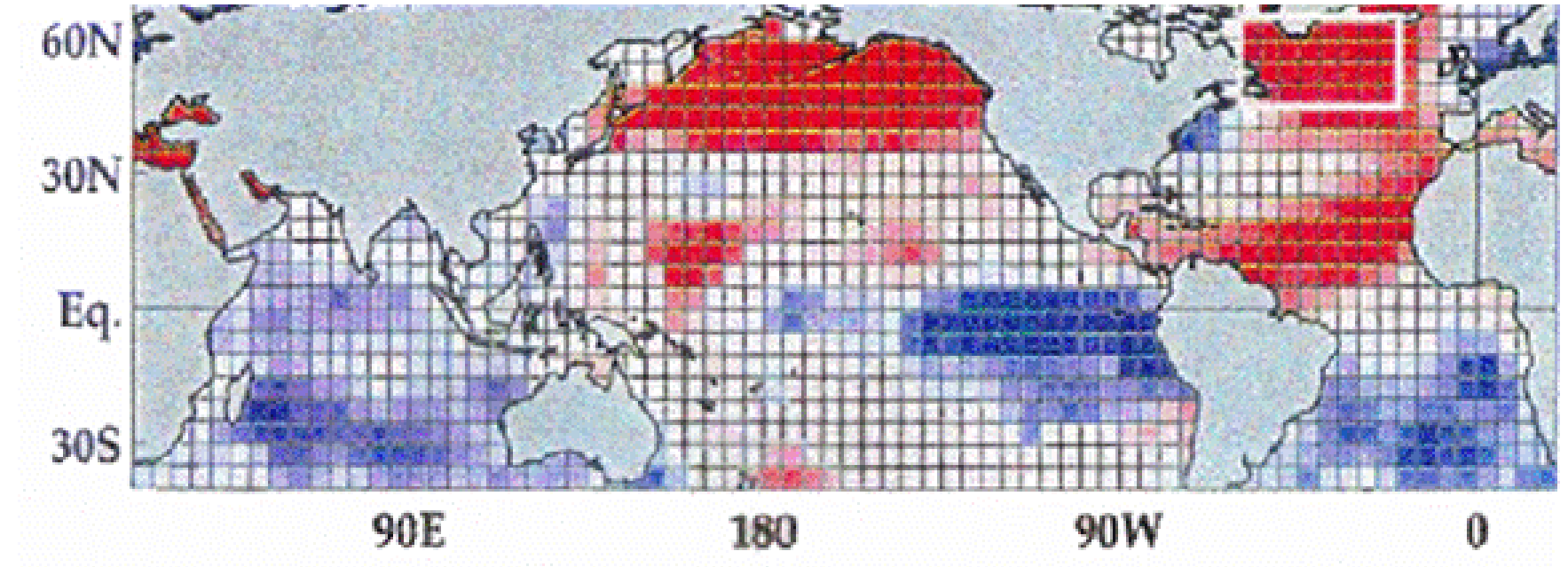
WEAK

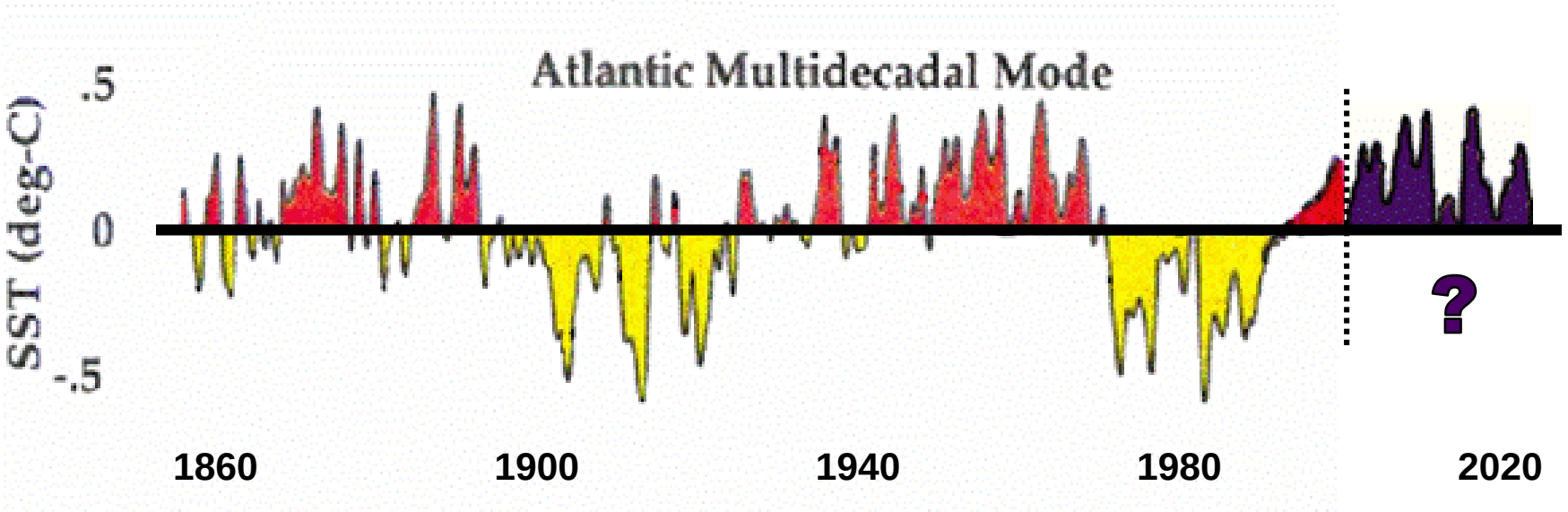




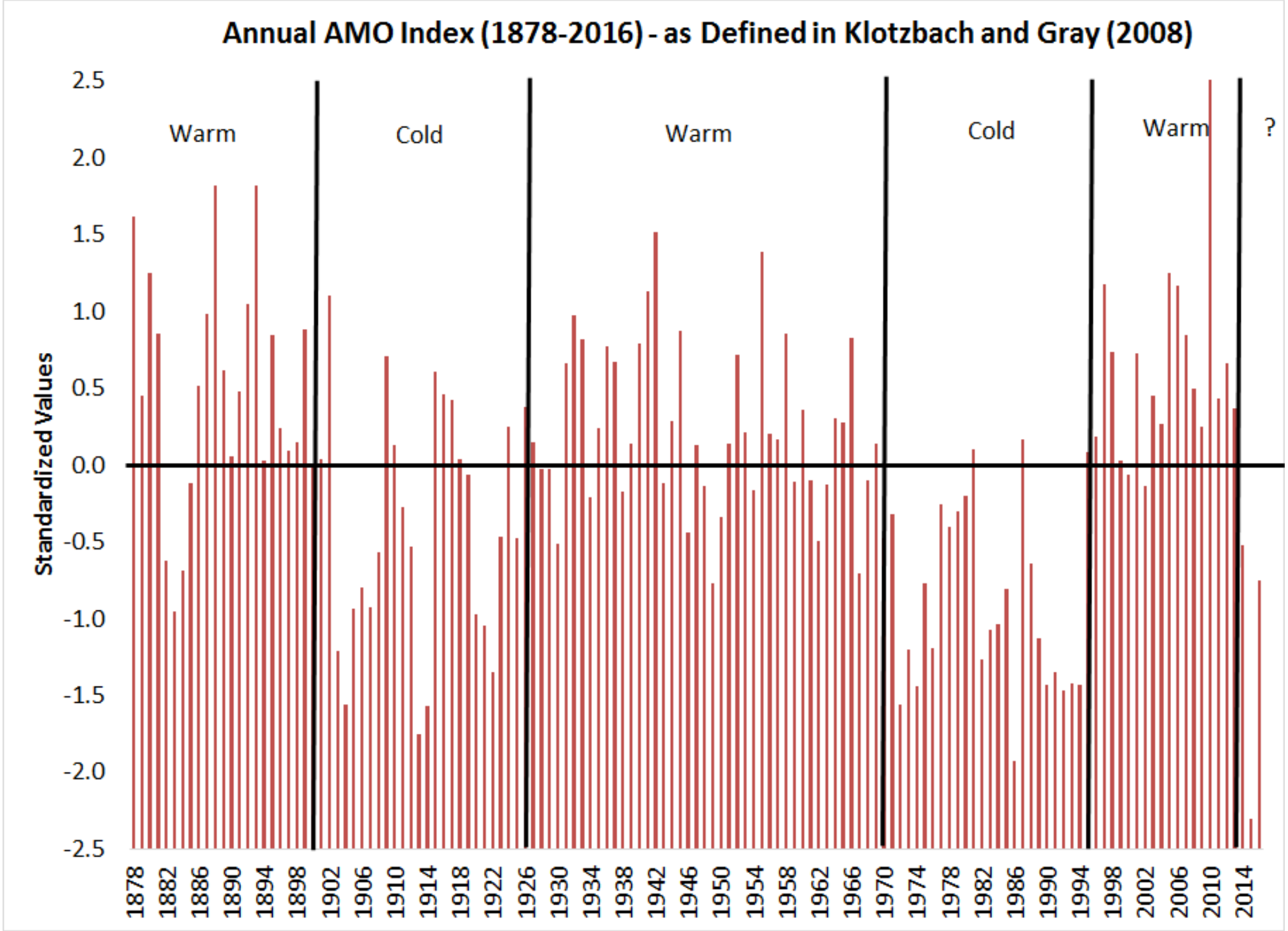
Courtesy of John Marshall (MIT)

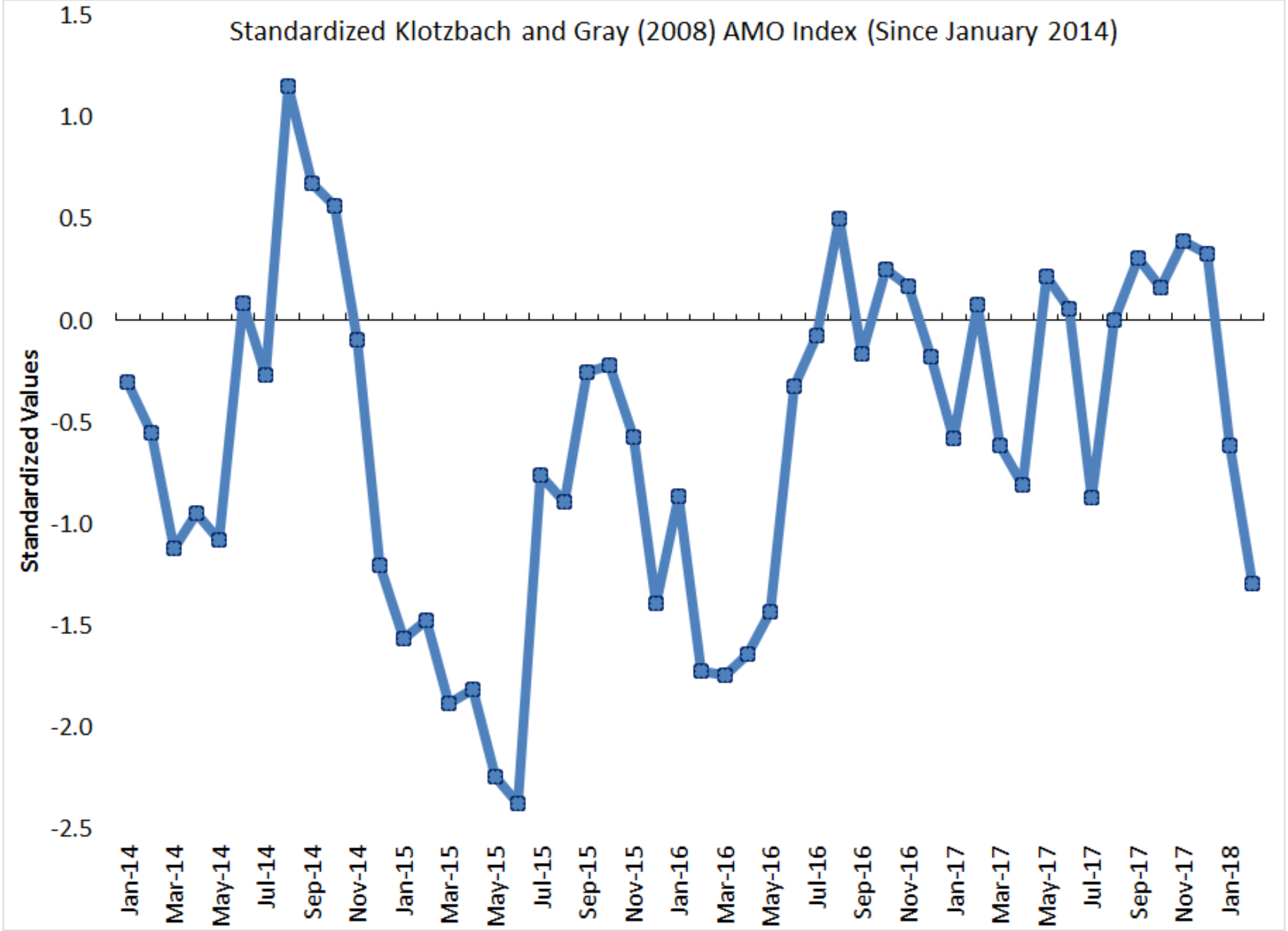

1
1
OCEAN
CURRENT
2
SLP
3
HUR
TRADES
RAIN
8
6
4
5
SST
7
ū
0°
0°
9
ENSO
SST
10



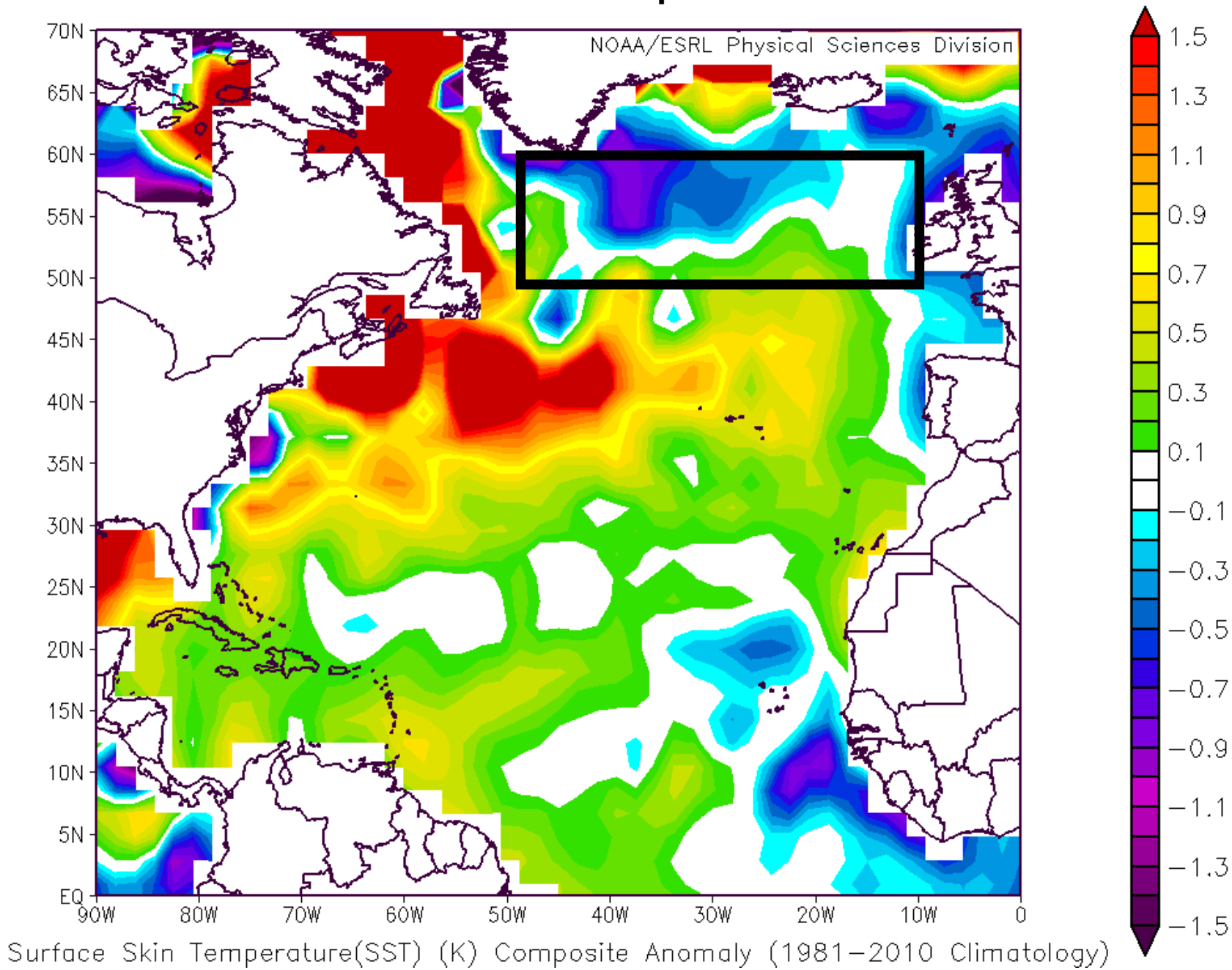


Goldenberg et al. (2001)

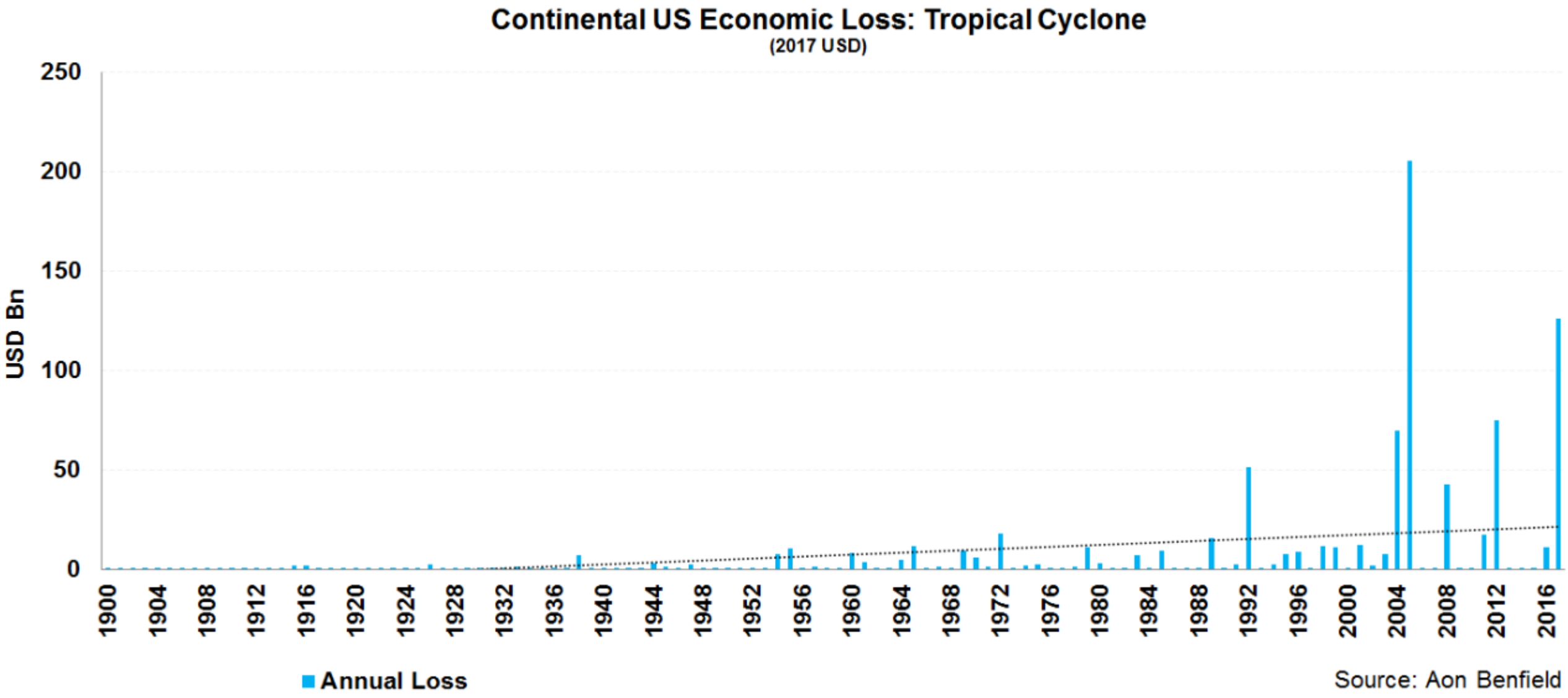

Annual AMO Index (1878-2016) - as Defined in Klotzbach and Gray (2008)
Warm
Cold
Warm
Cold
Warm
?
Standardized Values
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
1878
1882
1886
1890
1894
1898
1902
1906
1910
1914
1918
1922
1926
1930
1934
1938
1942
1946
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006
2010
2014


Standardized Klotzbach and Gray (2008) AMO Index (Since January 2014)
Standardized Values
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
Jan-14
Mar-14
May-14
Jul-14
Sep-14
Nov-14
Jan-15
Mar-15
May-15
Jul-15
Sep-15
Nov-15
Jan-16
Mar-16
May-16
Jul-16
Sep-16
Nov-16
Jan-17
Mar-17
May-17
Jul-17
Sep-17
Nov-17
Jan-18

Current Sea Surface Temperature Anomalies

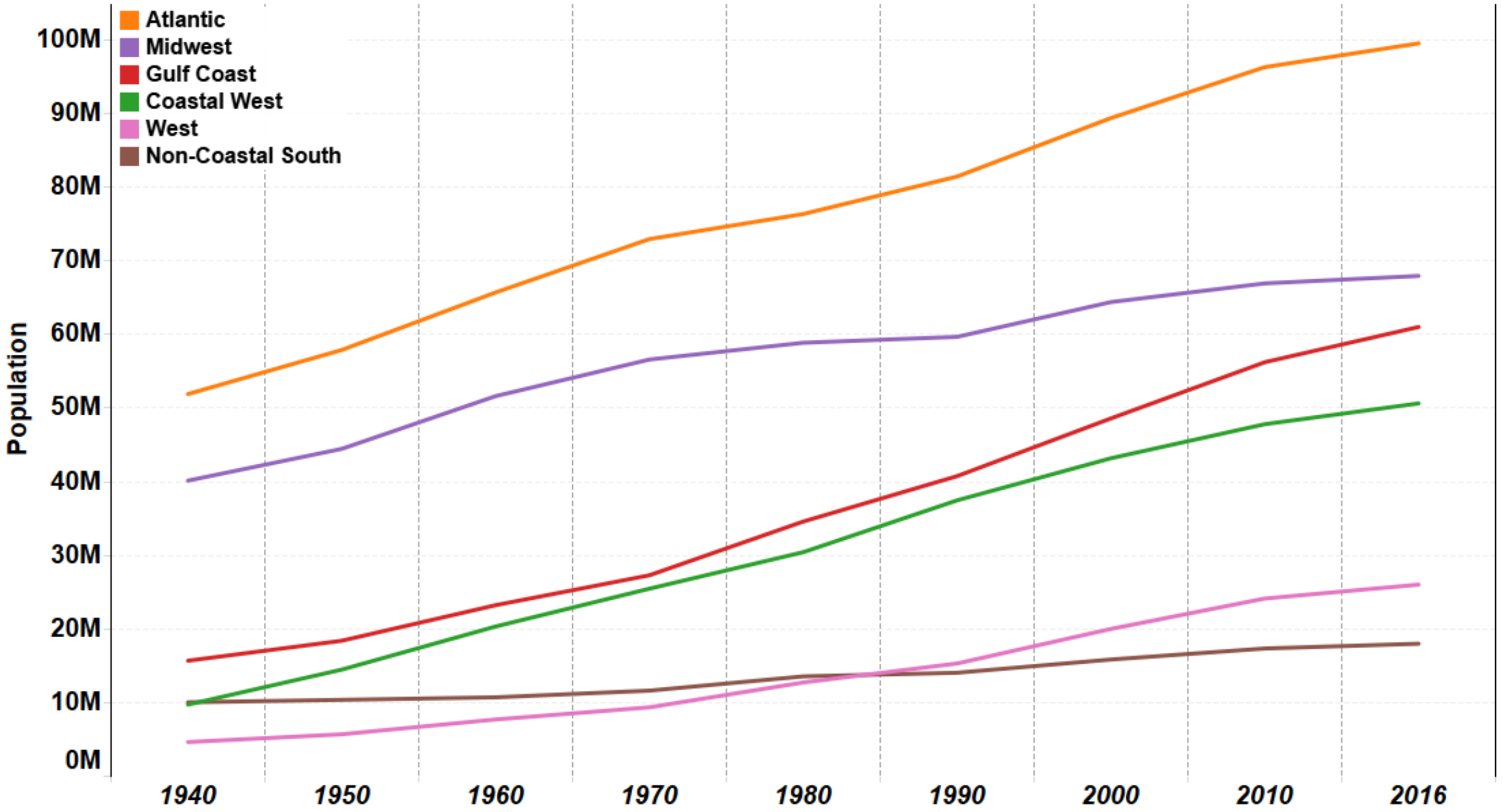


Tropical Cyclones and Climate Change

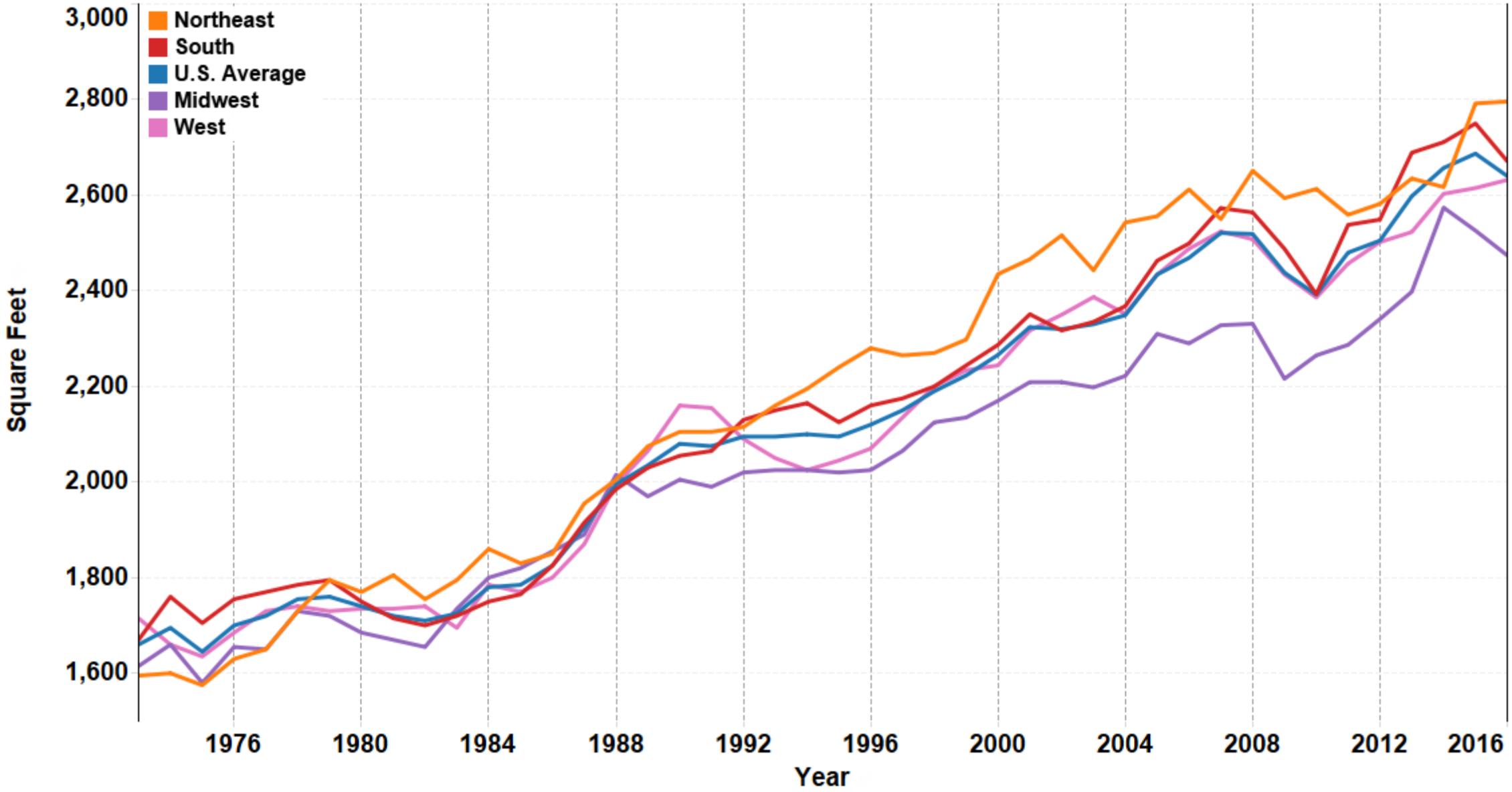


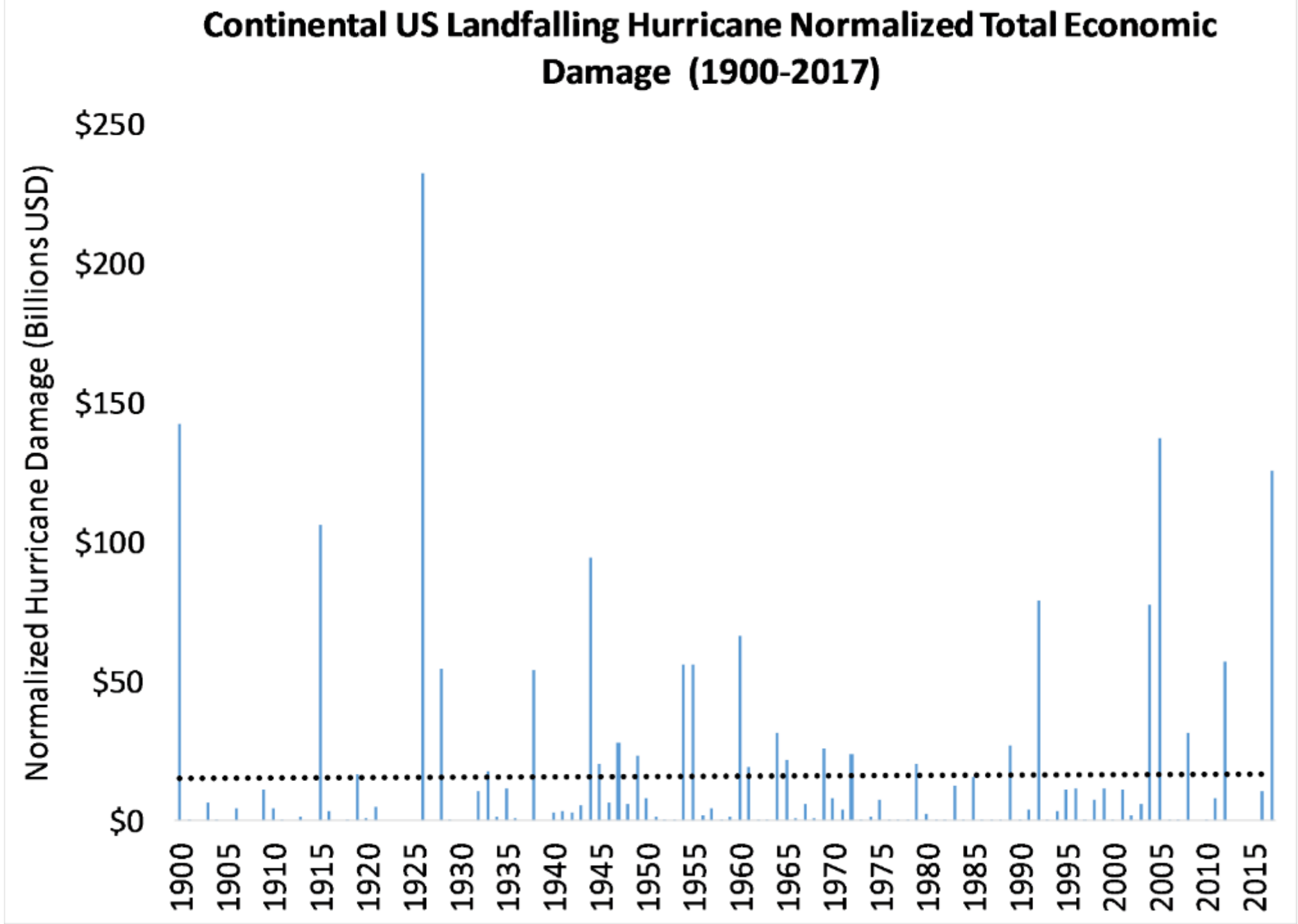
Klotzbach, P. J., S. G. Bowen, R. Pielke Jr., and M. M. Bell, 2018: Continental United States landfall frequency and associated damage: Observations and future risks. *Bull. Amer. Meteor. Soc.*, in press.

US Population by Region



Square Footage of Average Single-Family Home by Region

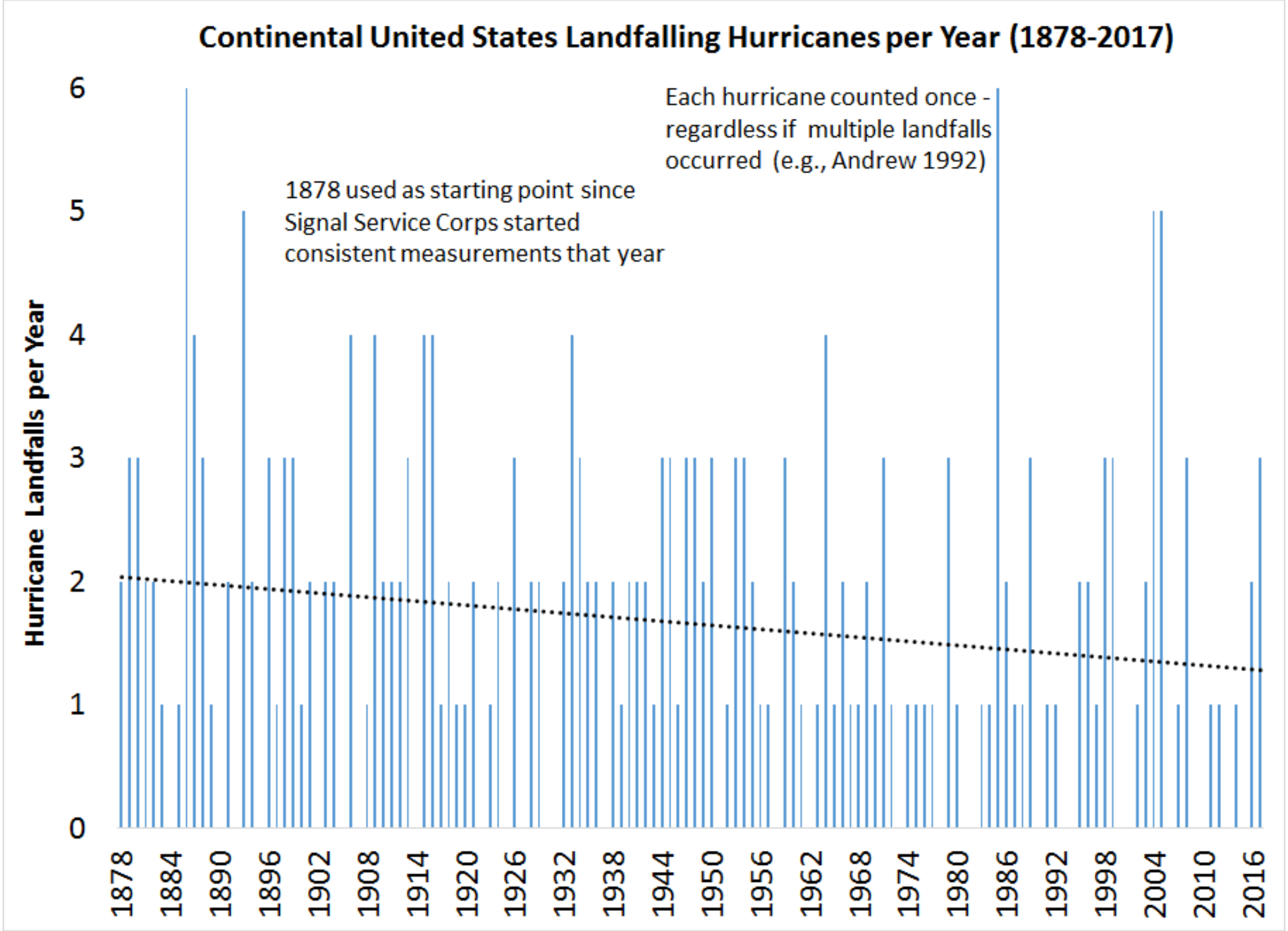


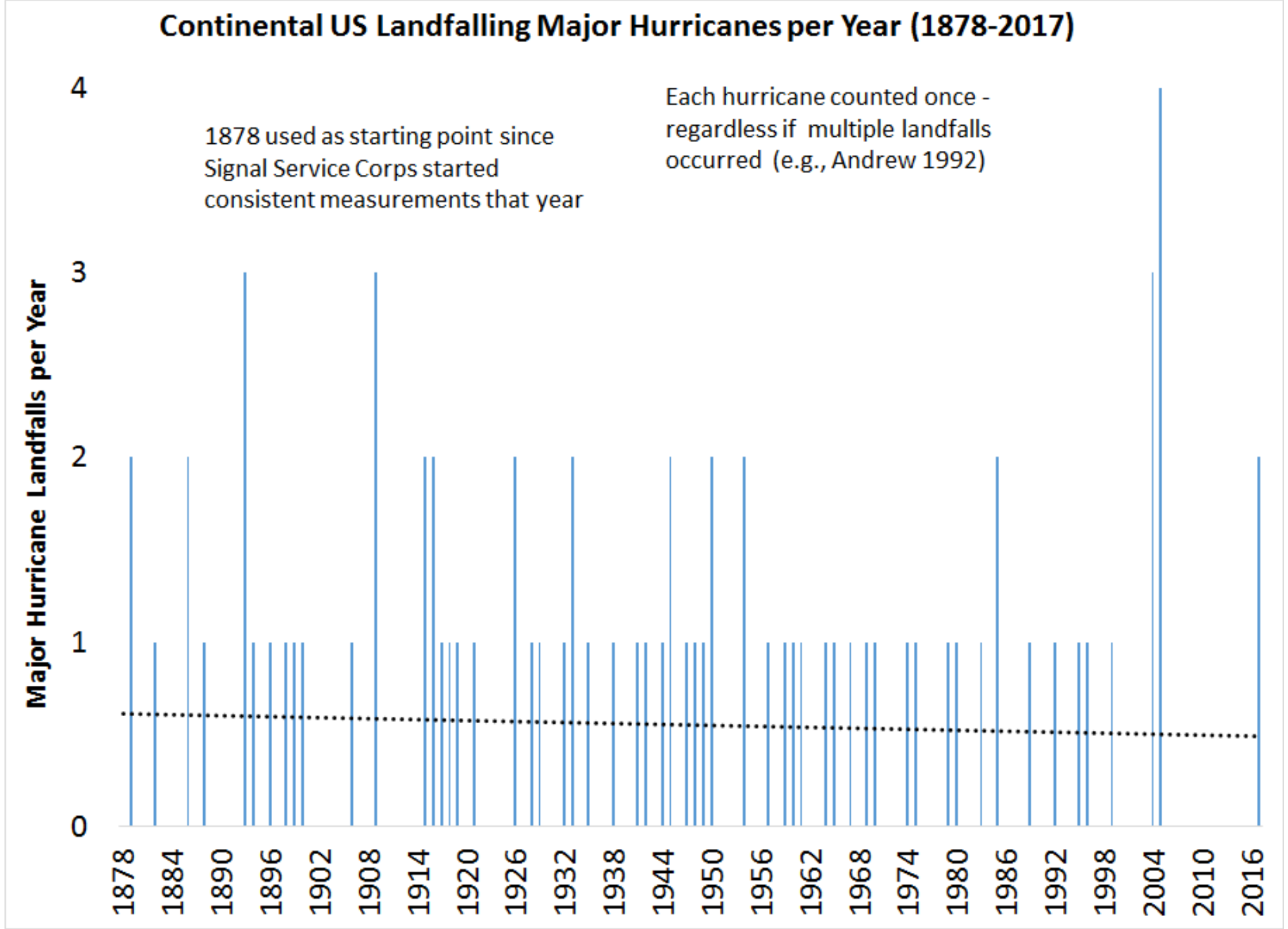

Continental US Landfalling Hurricane Normalized Total Economic Damage (1900-2017)
Normalized Hurricane Damage (Billions USD)
$250
$200
$150
$100
$50
$0
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

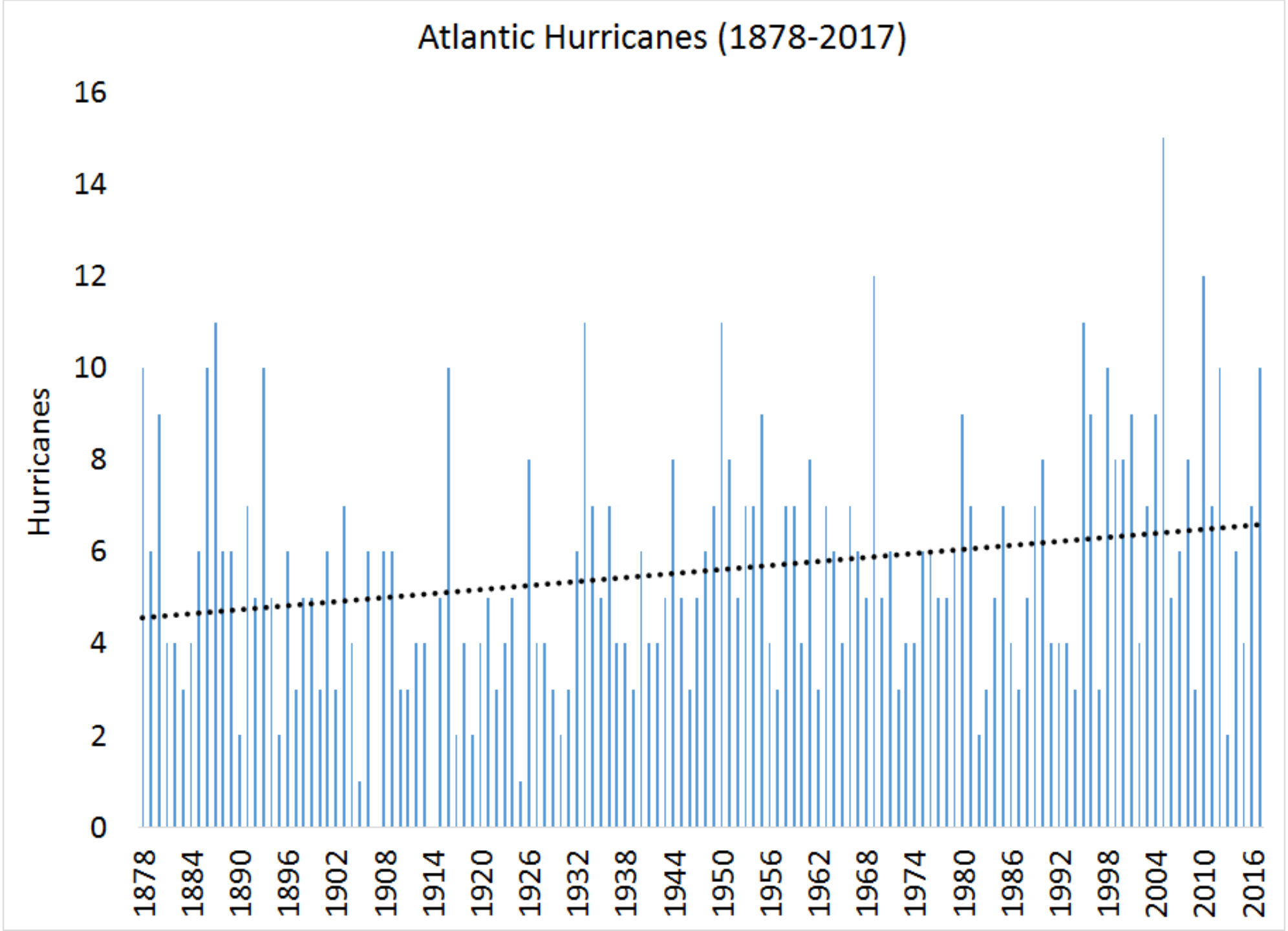
1926 Great Miami Hurricane - >$200 Billion Economic Damage (if it were to occur today)

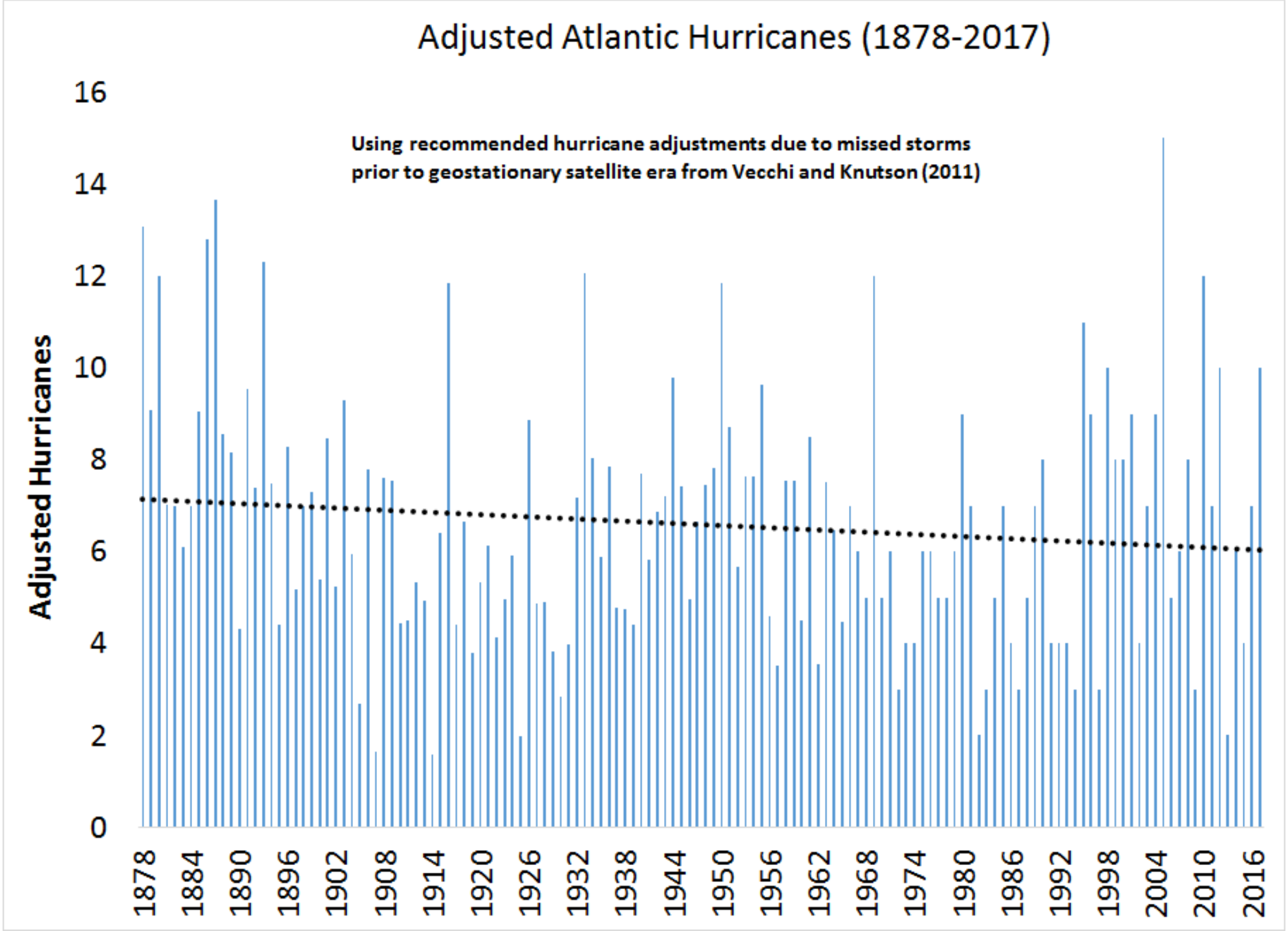
1926

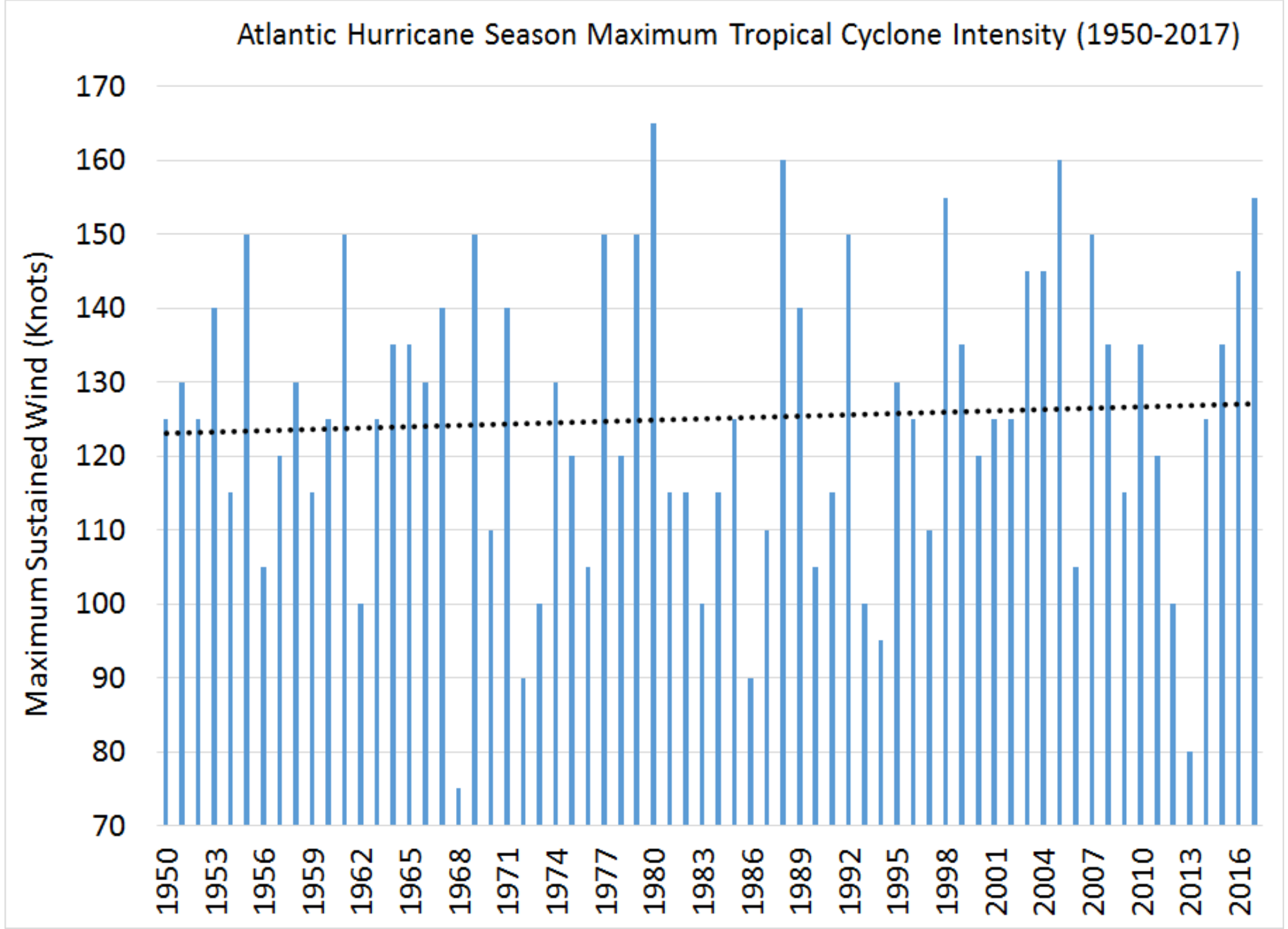
2016


Continental United States Landfalling Hurricanes per Year (1878-2017)
Hurricane Landfalls per Year
0
1
2
3
4
5
6
1878
1884
1890
1896
1902
1908
1914
1920
1926
1932
1938
1944
1950
1956
1962
1968
1974
1980
1986
1992
1998
2004
2010
2016
Each hurricane counted once - regardless if multiple landfalls occurred (e.g., Andrew 1992)
1878 used as starting point since Signal Service Corps started consistent measurements that year


Continental US Landfalling Major Hurricanes per Year (1878-2017)
1878 used as starting point since Signal Service Corps started consistent measurements that year
Each hurricane counted once - regardless if multiple landfalls occurred (e.g., Andrew 1992)
Major Hurricane Landfalls per Year
0
1
2
3
4
1878
1884
1890
1896
1902
1908
1914
1920
1926
1932
1938
1944
1950
1956
1962
1968
1974
1980
1986
1992
1998
2004
2010
2016


Atlantic Hurricanes (1878-2017)
Hurricanes
0
2
4
6
8
10
12
14
16
1878
1884
1890
1896
1902
1908
1914
1920
1926
1932
1938
1944
1950
1956
1962
1968
1974
1980
1986
1992
1998
2004
2010
2016


Adjusted Atlantic Hurricanes (1878-2017)
Using recommended hurricane adjustments due to missed storms
prior to geostationary satellite era from Vecchi and Knutson (2011)
Adjusted Hurricanes
16
14
12
10
8
6
4
2
0
1878
1884
1890
1896
1902
1908
1914
1920
1926
1932
1938
1944
1950
1956
1962
1968
1974
1980
1986
1992
1998
2004
2010
2016


Atlantic Hurricane Season Maximum Tropical Cyclone Intensity (1950-2017)
Maximum Sustained Wind (Knots)
170
160
150
140
130
120
110
100
90
80
70
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016

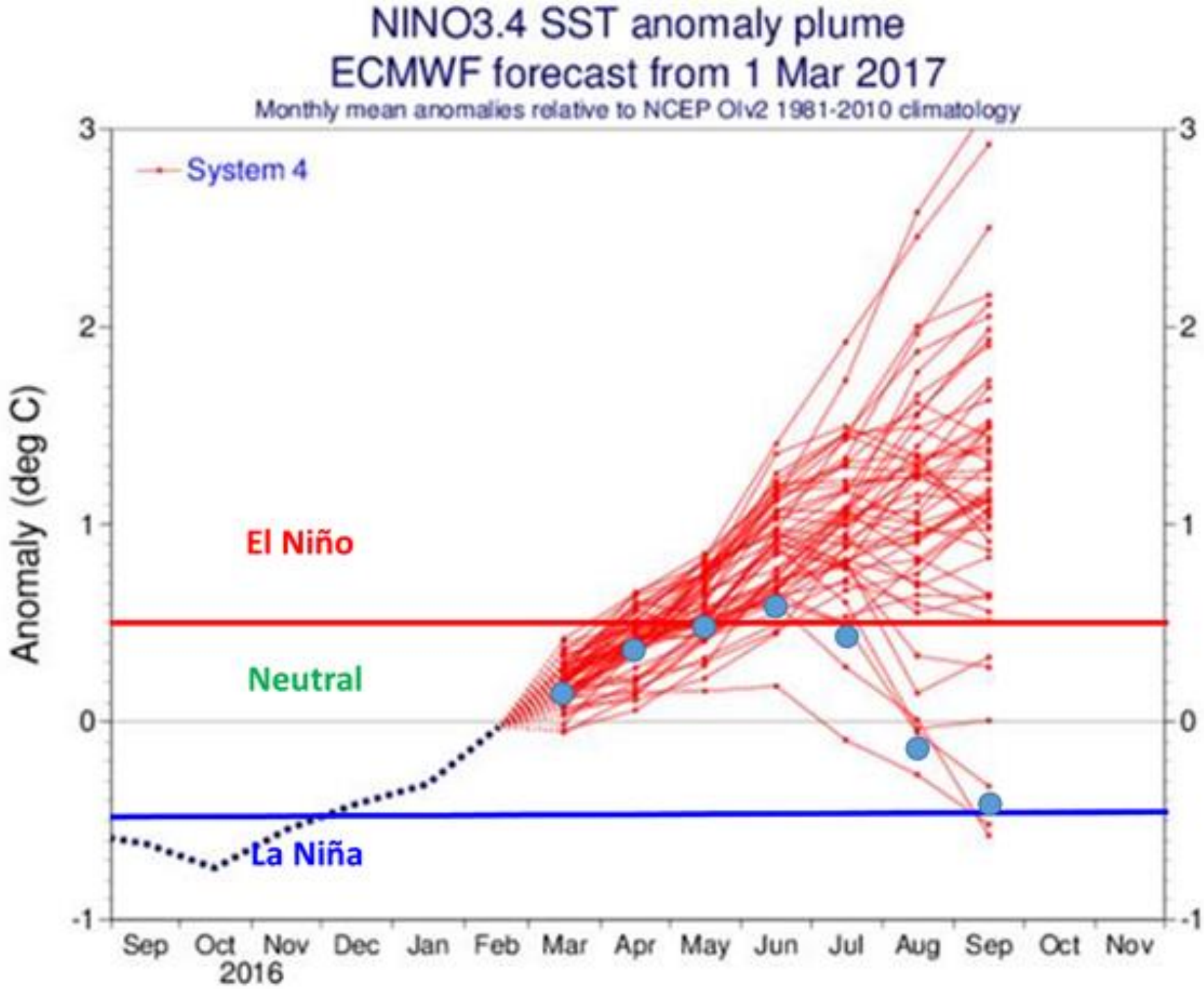
2017 Atlantic Hurricane Season

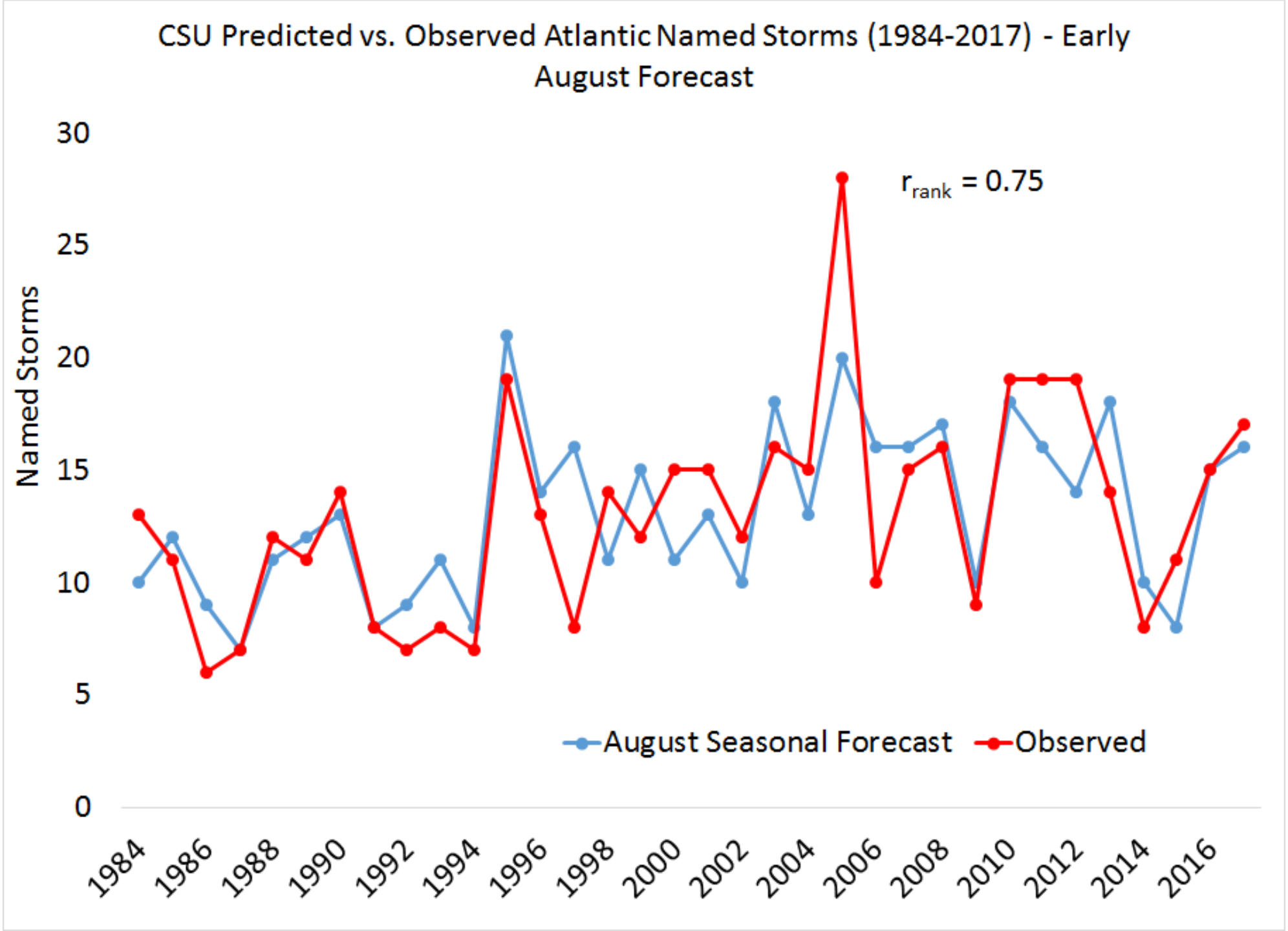
2017 Atlantic Tropical Cyclone Activity

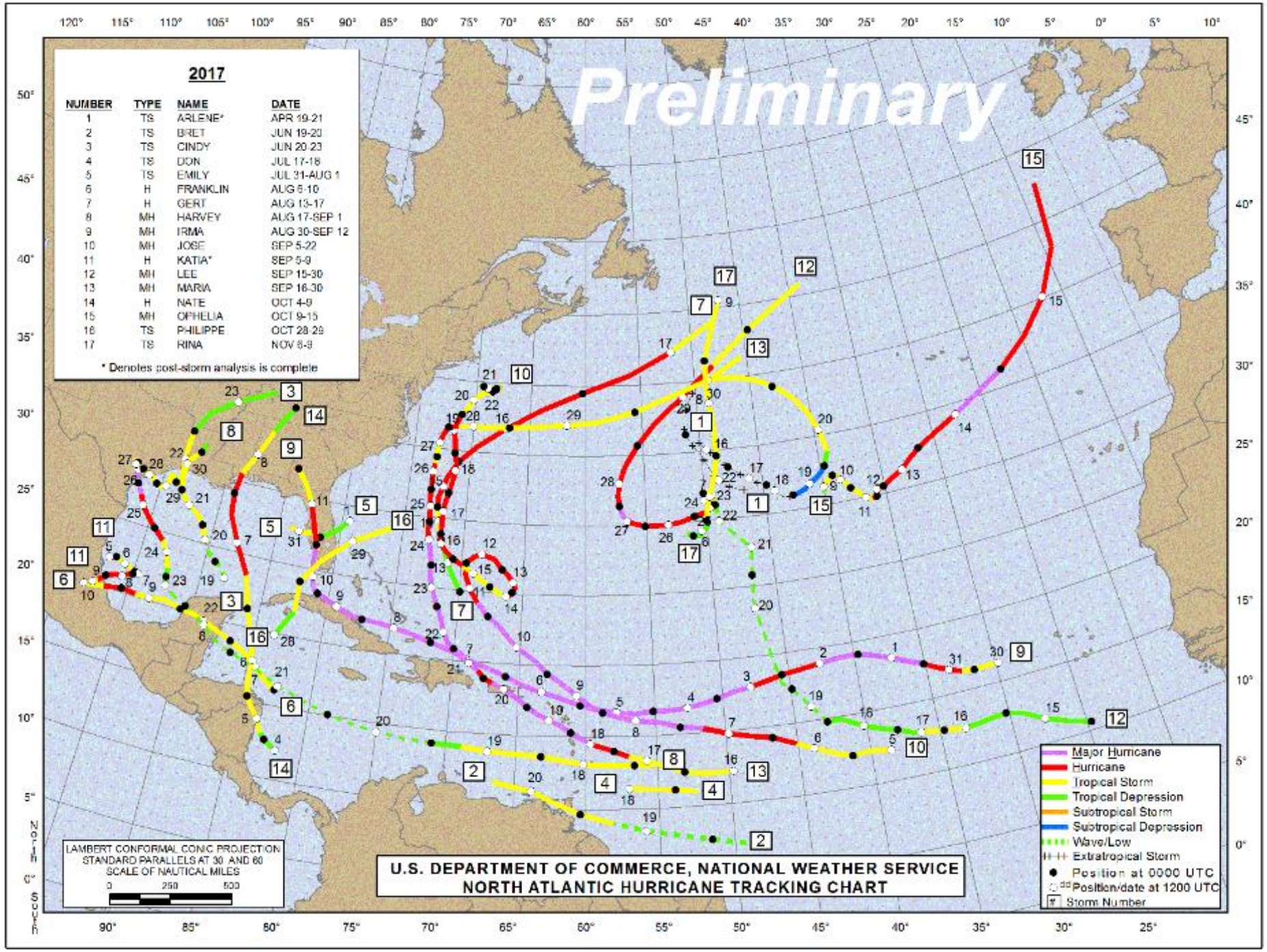
Forecast Parameter	Observed 2017 Atlantic TC Activity	Atlantic Full Season 1981-2010 Median	2017 as Percentage of Full Season Median	2017 All-Time (Since 1851) Full Season Rank	All-Time Record (Year)
Named Storms (NS)	17	12.0	142%	T-9	28 (2005)
Named Storm Days (NSD)	91.25	60.1	152%	11	126.25 (2005)
Hurricanes (H)	10	6.5	154%	T-8	15 (2005)
Hurricane Days (HD)	51.25	21.3	241%	6	61.50 (1893 & 1995)
Major Hurricanes (MH)	6	2.0	300%	T-3	7 (1961 & 2005)
Major Hurricane Days (MHD)	19.25	3.9	494%	6	24.50 (1961)
Accumulated Cyclone Energy (ACE)	226	92	246%	7	259 (1933)

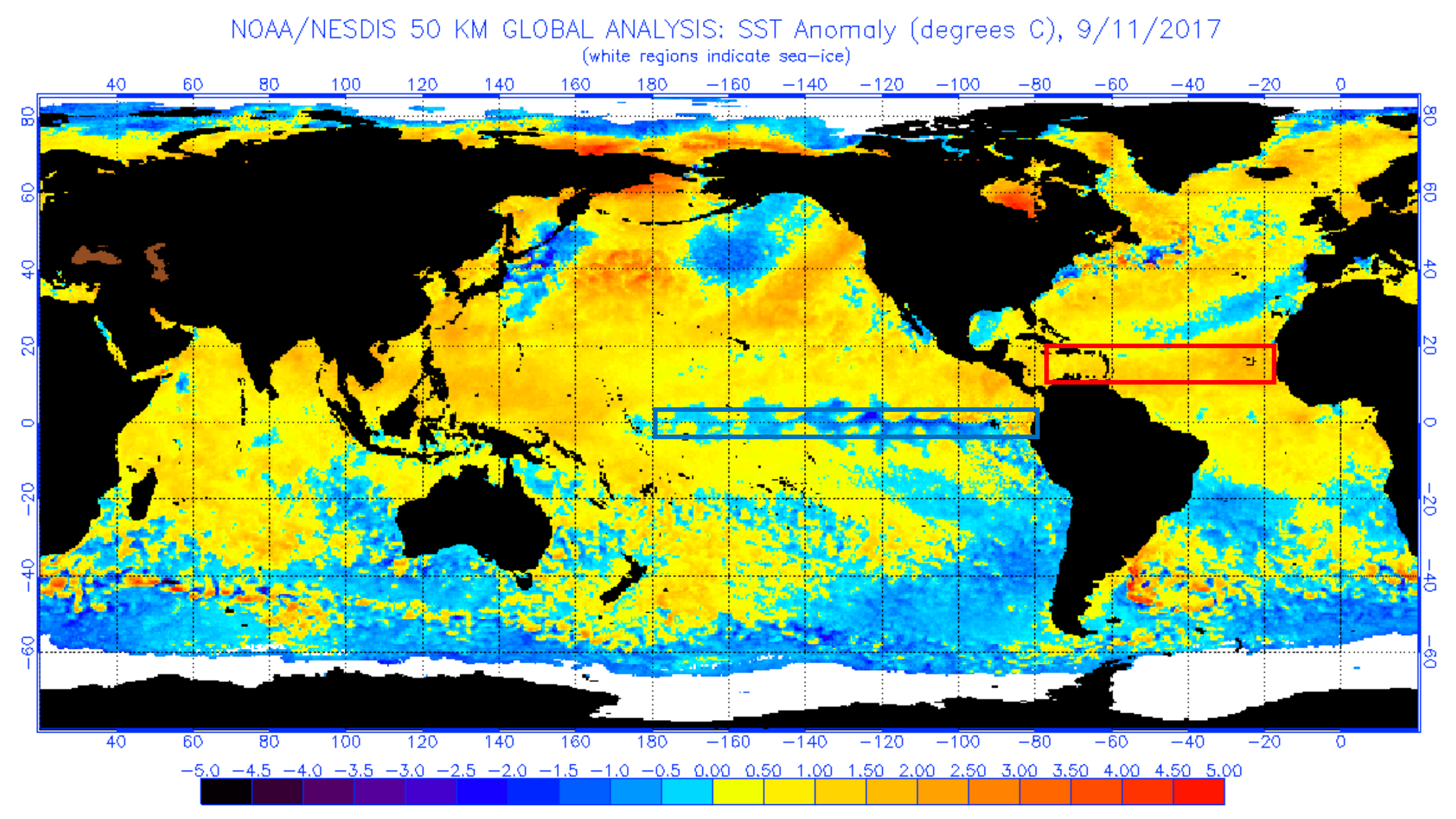
ATLANTIC BASIN SEASONAL HURRICANE FORECASTS FOR 2017

Forecast Parameter and 1981-2010 Median (in parentheses)	6 April 2017	Update 1 June 2017	Update 5 July 2017	Update 4 August 2017	Observed 2017 Total	% of 1981-2010 Median
Named Storms (NS) (12.0)	11	14	15	16	17	142%
Named Storm Days (NSD) (60.1)	50	60	70	70	91.25	152%
Hurricanes (H) (6.5)	4	6	8	8	10	154%
Hurricane Days (HD) (21.3)	16	25	35	35	51.25	241%
Major Hurricanes (MH) (2.0)	2	2	3	3	6	300%
Major Hurricane Days (MHD) (3.9)	4	5	7	7	19.25	494%
Accumulated Cyclone Energy (ACE) (92)	75	100	135	135	226	246%
Net Tropical Cyclone Activity (NTC) (103%)	85	110	140	140	231	224%

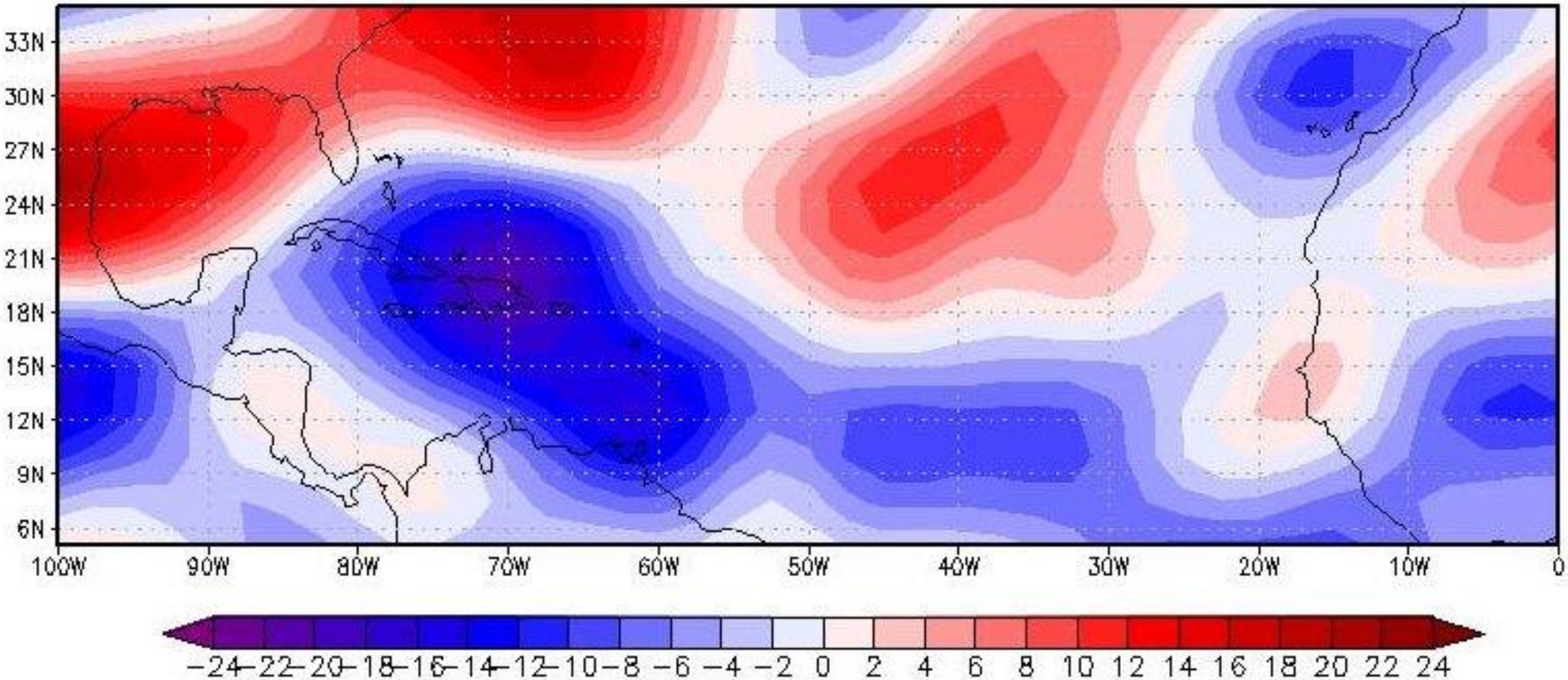

NINO3.4 SST anomaly plume
ECMWF forecast from 1 Mar 2017
Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology
System 4
Anomaly (deg C)
El Niño
Neutral
La Niña
3
2
1
0
-1
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
2016


CSU Predicted vs. Observed Atlantic Named Storms (1984-2017) - Early August Forecast
Named Storms
30
25
20
15
10
5
0
r_{rank} = 0.75
August Seasonal Forecast
Observed
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016

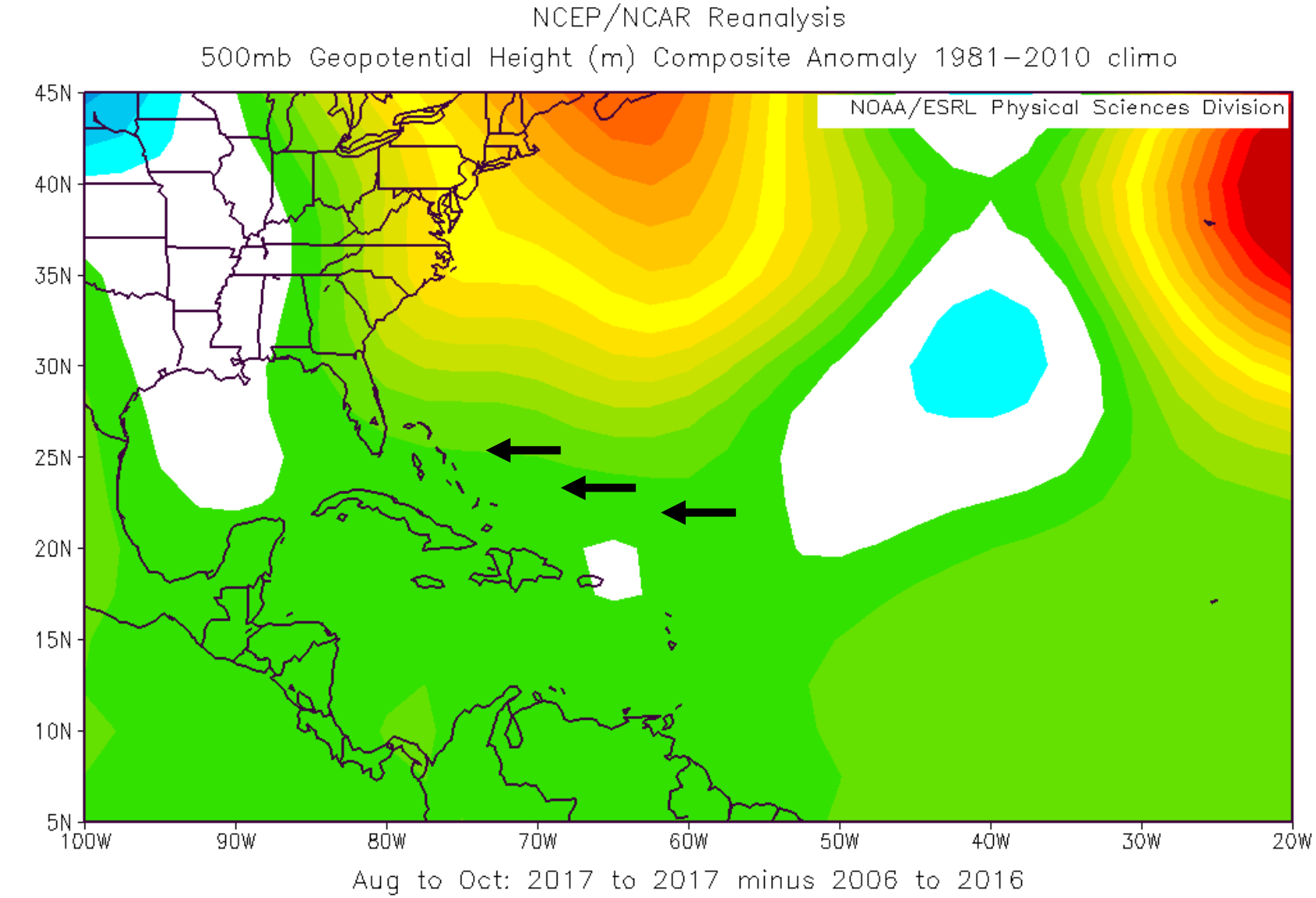

Preliminary
2017
NUMBER TYPE NAME DATE
1 TS ARLENE* APR 19-21
2 TS BRET JUN 19-20
3 TS CINDY JUN 20-23
4 TS DON JUL 17-18
5 TS EMILY JUL 31-AUG 1
6 H FRANKLIN AUG 5-10
7 H GERT AUG 13-17
8 MH HARVEY AUG 17-SEP 1
9 MH IRMA AUG 30-SEP 12
10 MH JOSE SEP 5-22
11 H KATIA* SEP 5-9
12 MH LEE SEP 15-30
13 MH MARIA SEP 16-30
14 H NATE OCT 4-9
15 MH OPHELIA OCT 9-15
16 TS PHILIPPE OCT 28-29
17 TS RINA NOV 8-9
* Denotes post-storm analysis is complete
Major Hurricane
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Wave/Low
Extratropical Storm
Position at 0000 UTC
Position/date at 1200 UTC
Storm Number
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30 AND 60
SCALE OF NAUTICAL MILES
0 250 500
U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART

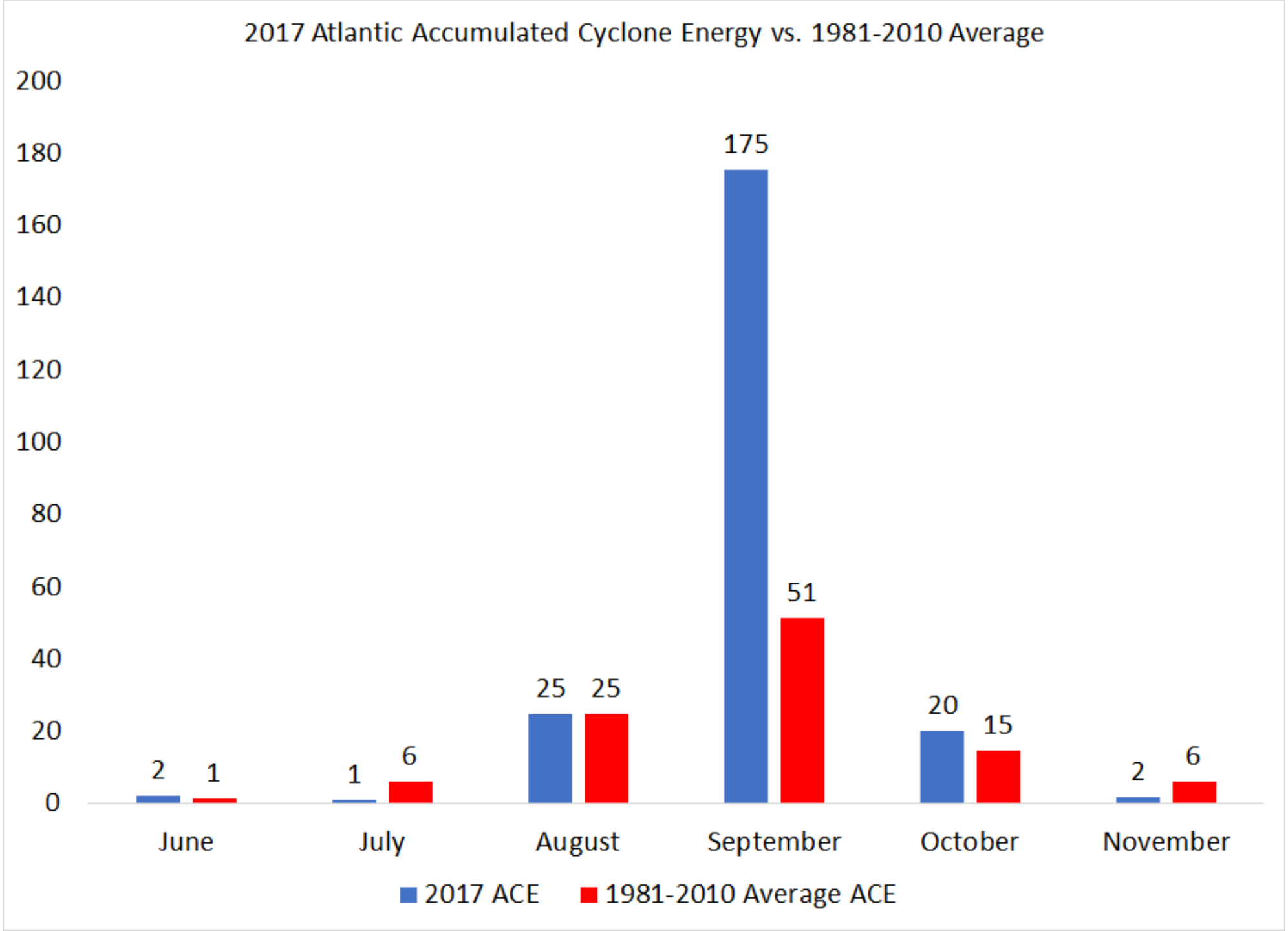

NOAA/NESDIS 50 KM GLOBAL ANALYSIS: SST Anomaly (degrees C), 9/11/2017
(white regions indicate sea-ice)
40 60 80 100 120 140 160 180 -160 -140 -120 -100 -80 -60 -40 -20 0
80 60 40 20 0 -20 -40 -60
-5.0 -4.5 -4.0 -3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00

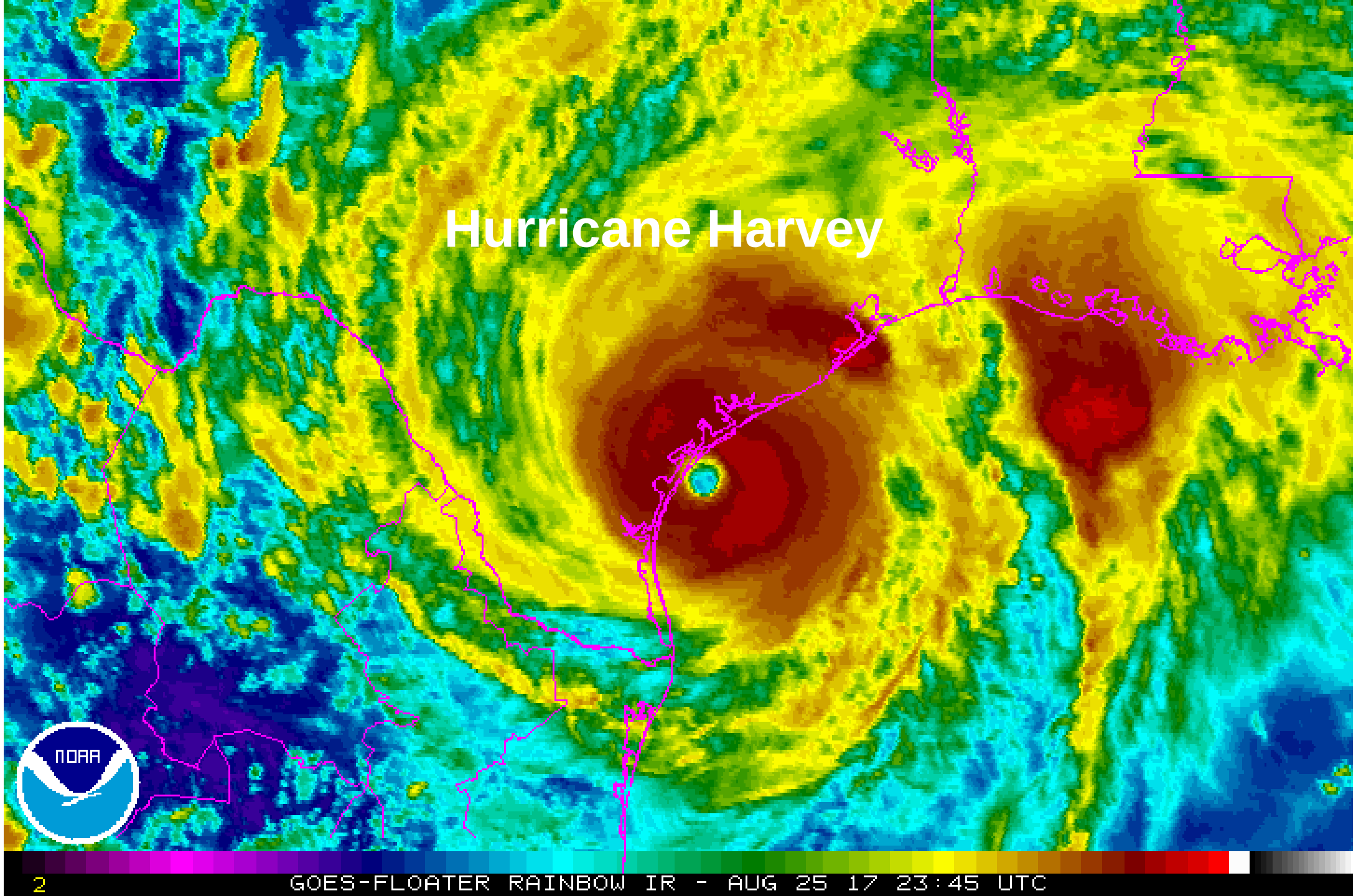
August 27 Through September 25, 2017 Average
Zonal (200-850 mb) Vertical Wind Shear Anomaly (kts)
(1981-2010 Climatology)



August-October 2017 minus August-October (2006 to 2016)



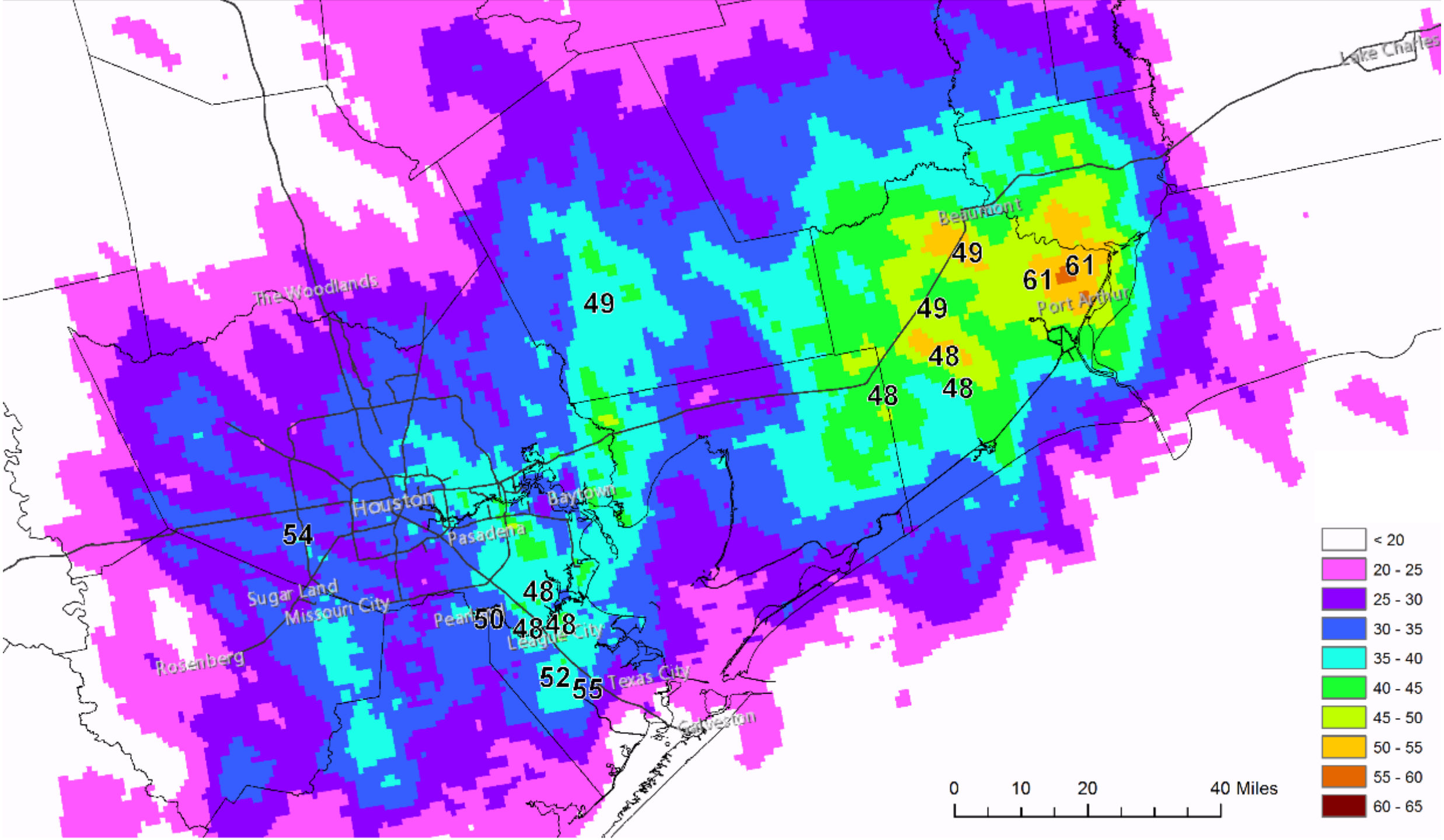

2017 Atlantic Accumulated Cyclone Energy vs. 1981-2010 Average
200
180
160
140
120
100
80
60
40
20
0
2
1
1
6
25
25
175
51
20
15
2
6
June
July
August
September
October
November
2017 ACE
1981-2010 Average ACE

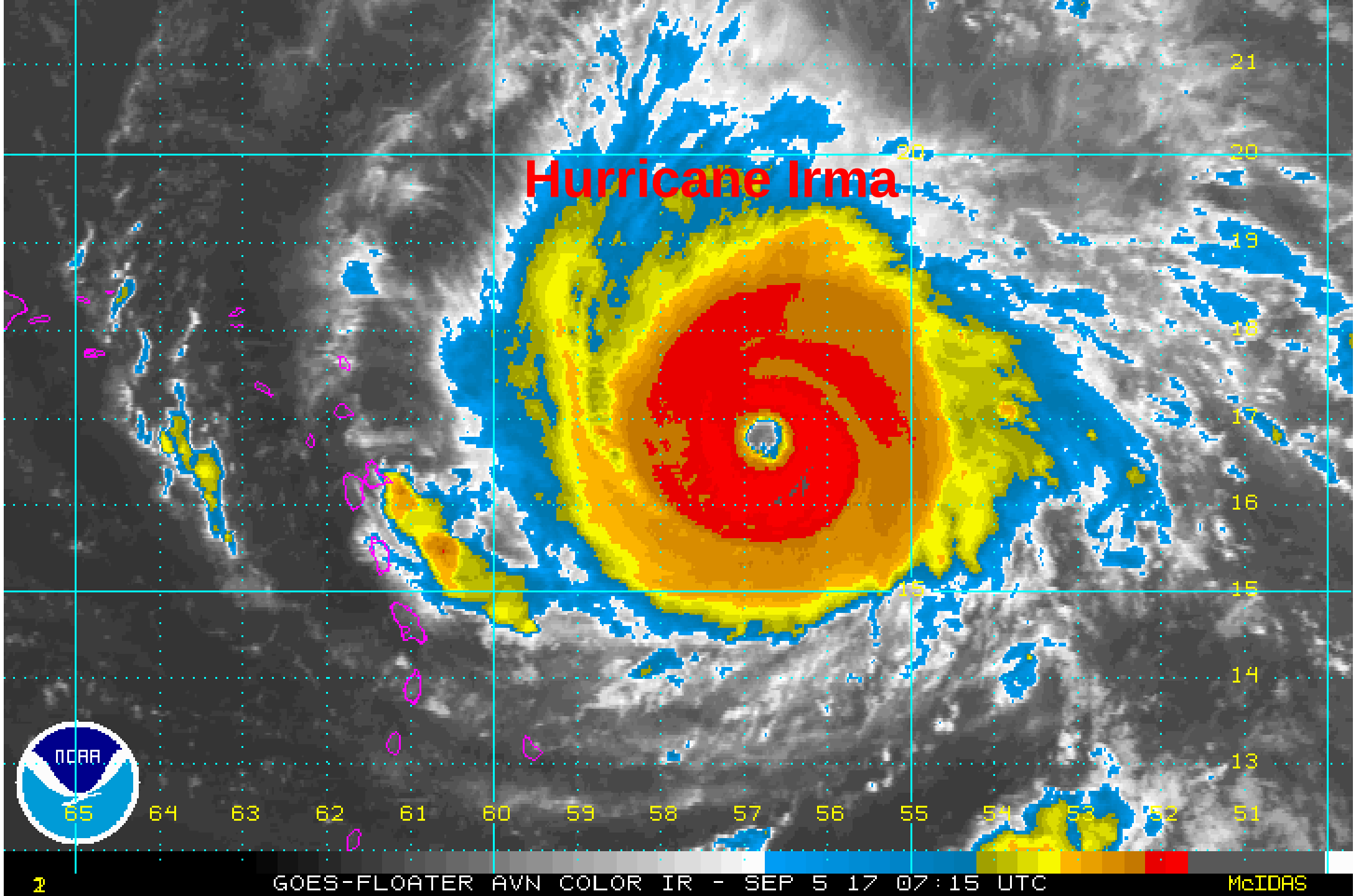

Hurricane Harvey
NOAA
2
GOES-FLOATER RAINBOW IR - AUG 25 17 23:45 UTC

Hurricane Harvey Notable Records

Texas Landfall Intensity: 115 Knots, 938 mb

- $90-$150 Billion USD in economic damage
- First Category 4 hurricane to make landfall in Texas since Carla (1961) and in the United States since Charley (2004)
- Ended the longest-running mainland U.S. landfalling major hurricane drought at 4323 days (Wilma-2005)
- 60.58” rainfall in Nederland, TX – shattering the prior continental and U.S. records for hurricane-related precipitation. Prior record was 48” for continental U.S. (set in Texas with TS Amelia) and 52” for entire U.S. (Hiki-1950)


Lake Charles
Beaumont
Port Arthur
The Woodlands
Houston
Baytown
Pasadena
Sugar Land
Missouri City
Pearland
League City
Texas City
Galveston
Rosenberg
49
49
61
61
49
48
48
48
54
48
50
48
48
52
55
< 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 45
45 - 50
50 - 55
55 - 60
60 - 65
0
10
20
40 Miles


Hurricane Irma
21
20
19
18
17
16
15
14
13
65
64
63
62
61
60
59
58
57
56
55
54
53
52
51
NOAA
1
GOES-FLOATER AVN COLOR IR - SEP 5 17 07:15 UTC
McIDAS

Hurricane Irma Notable Records

Storm Records

- 180 mph max winds – strongest Atlantic storm on record outside of the Gulf of Mexico and Caribbean

- 3.25 days as Cat. 5 hurricane – tied with the Cuba Hurricane of 1932 for longest-lived Atlantic Cat. 5 hurricane on record

- 65.0 Accumulated Cyclone Energy units generated – the second most in the satellite era – trailing Ivan with 70.4 ACE in 2004

Hurricane Irma Notable Records

Landfall Facts

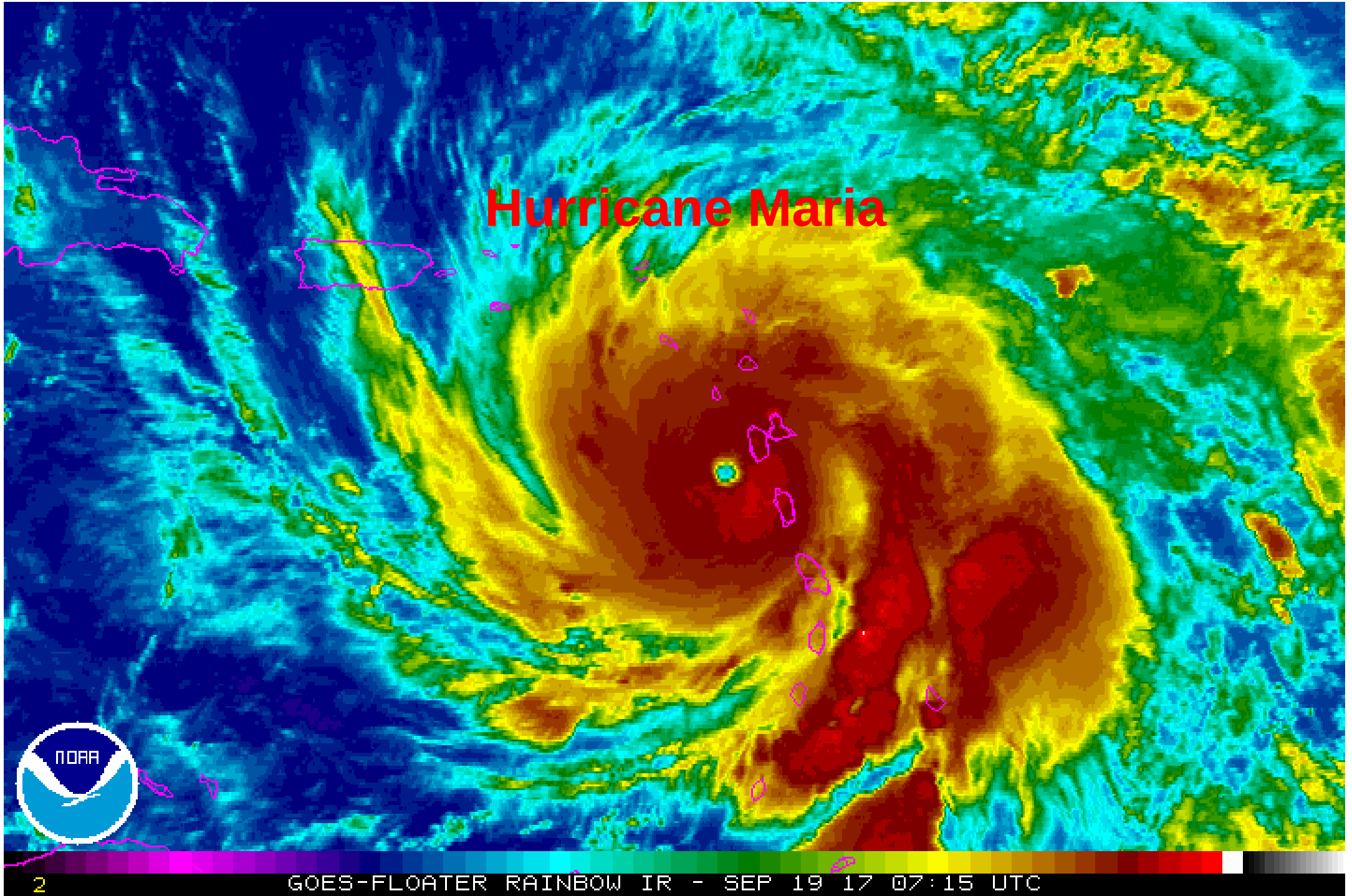
- >$50 Billion USD in economic damage

- Strongest storm (180 mph max winds) on record to impact Leeward Islands – previous strongest were David (1979) & Lake Okeechobee (1928) – 160 mph

- First Category 5 hurricane to make landfall in Cuba since 1924

- Mainland US Landfall: 115 knots, 931 mb – Tied with Carla (1961) for 10th lowest landfall pressure for continental US hurricane on record

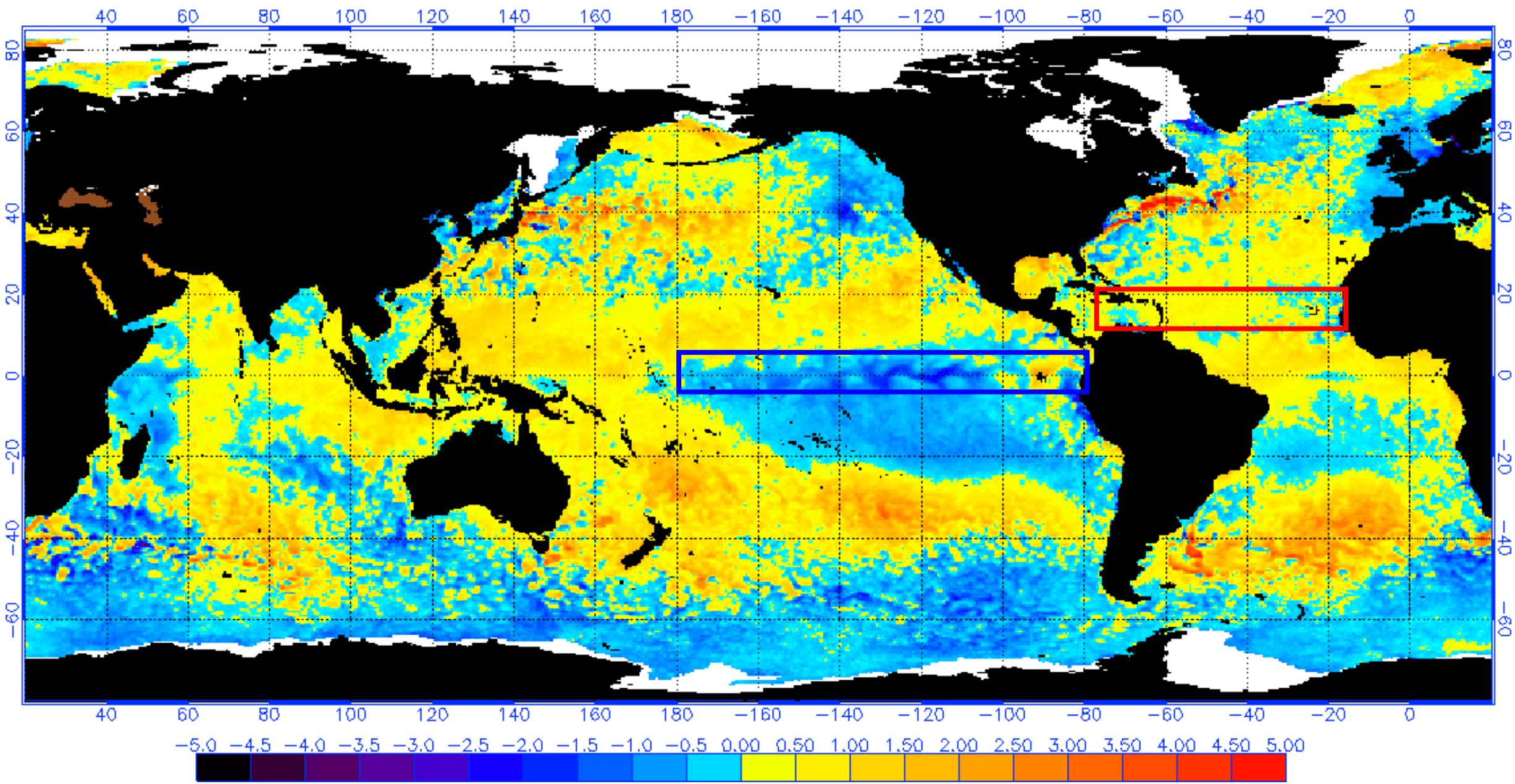
- First time two Category 4 hurricanes (along with Harvey) to make mainland US landfall in same year


Hurricane Maria
NOAA
2
GOES-FLOATER RAINBOW IR - SEP 19 17 07:15 UTC

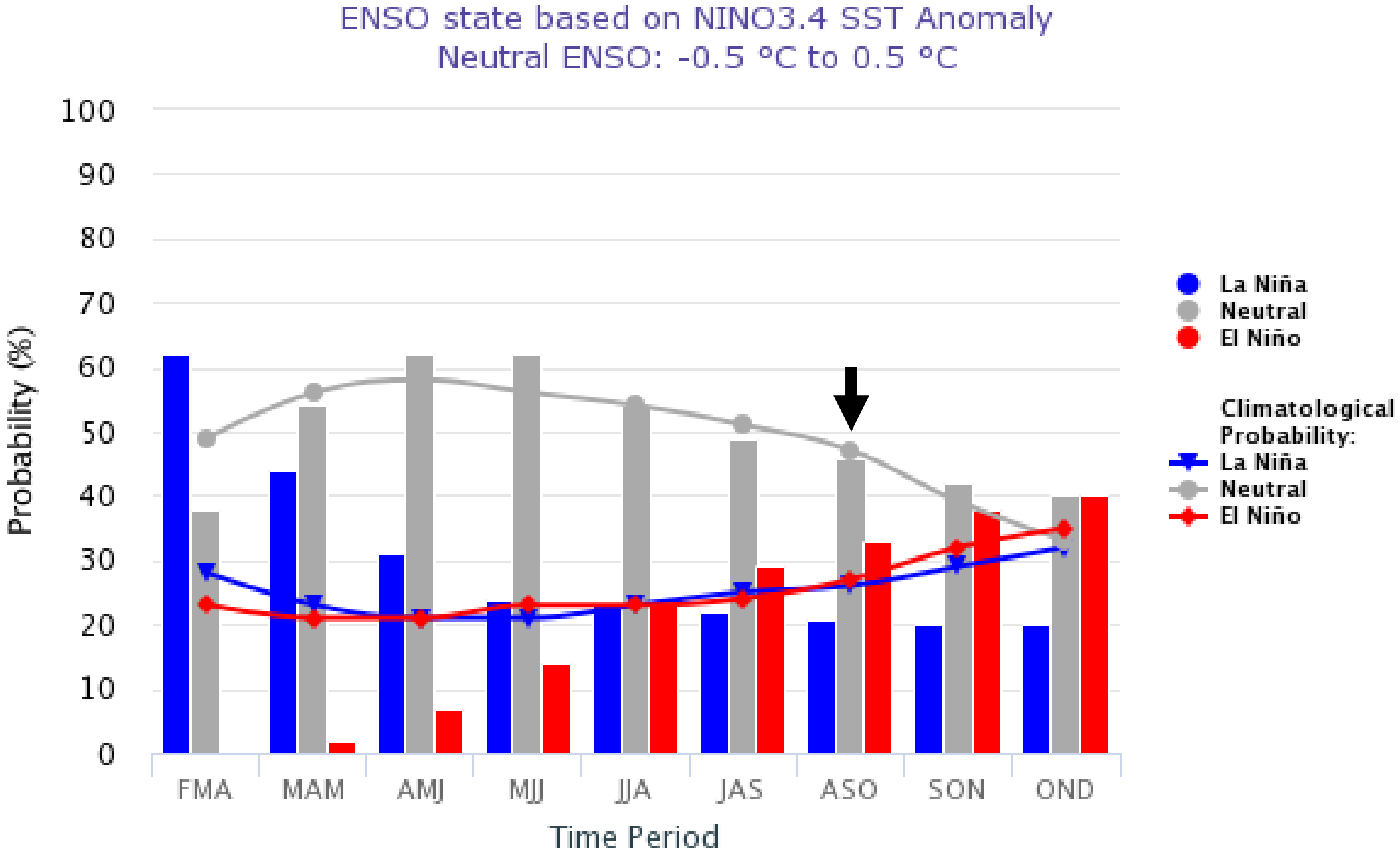
Hurricane Maria Notable Records

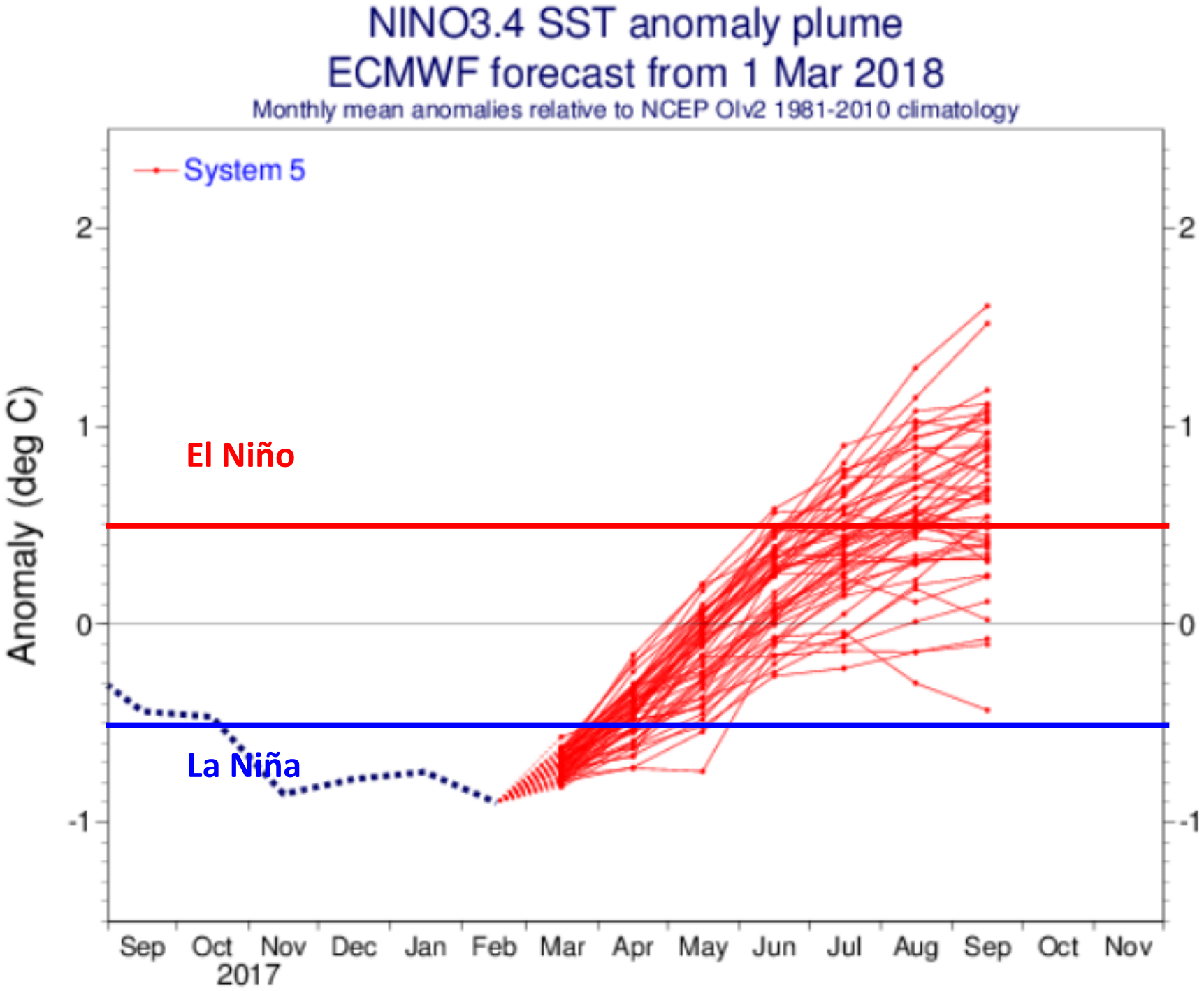
- >60 Billion USD in economic damage
- 908 mb lifetime lowest central pressure – lowest in eastern Caribbean on record
- First Category 5 hurricane to make landfall in Dominica on record
- First Category 4 hurricane to make landfall in Puerto Rico since 1932 (San Ciprian Hurricane)
- Strongest hurricane to make landfall in Puerto Rico since 1928 (San Felipe Segundo Hurricane)

2018 Atlantic Hurricane Season Initial Outlook

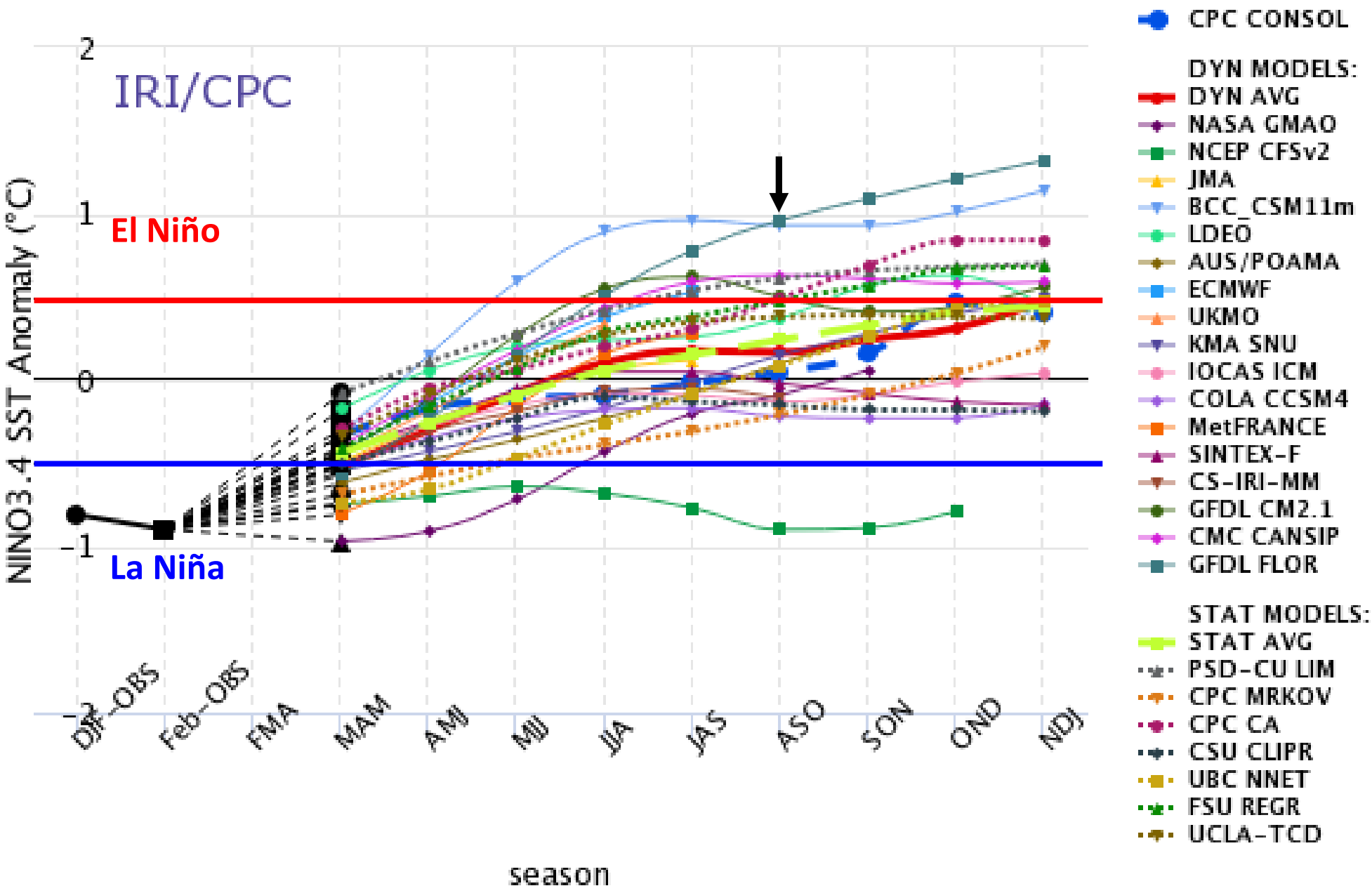

NOAA/NESDIS 50 KM GLOBAL ANALYSIS: SST Anomaly (degrees C), 3/22/2018
(white regions indicate sea-ice)
40 60 80 100 120 140 160 180 −160 −140 −120 −100 −80 −60 −40 −20 0
80 60 40 20 0 −20 −40 −60
−5.0 −4.5 −4.0 −3.5 −3.0 −2.5 −2.0 −1.5 −1.0 −0.5 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00

Early-Mar CPC/IRI Official Probabilistic ENSO Forecasts

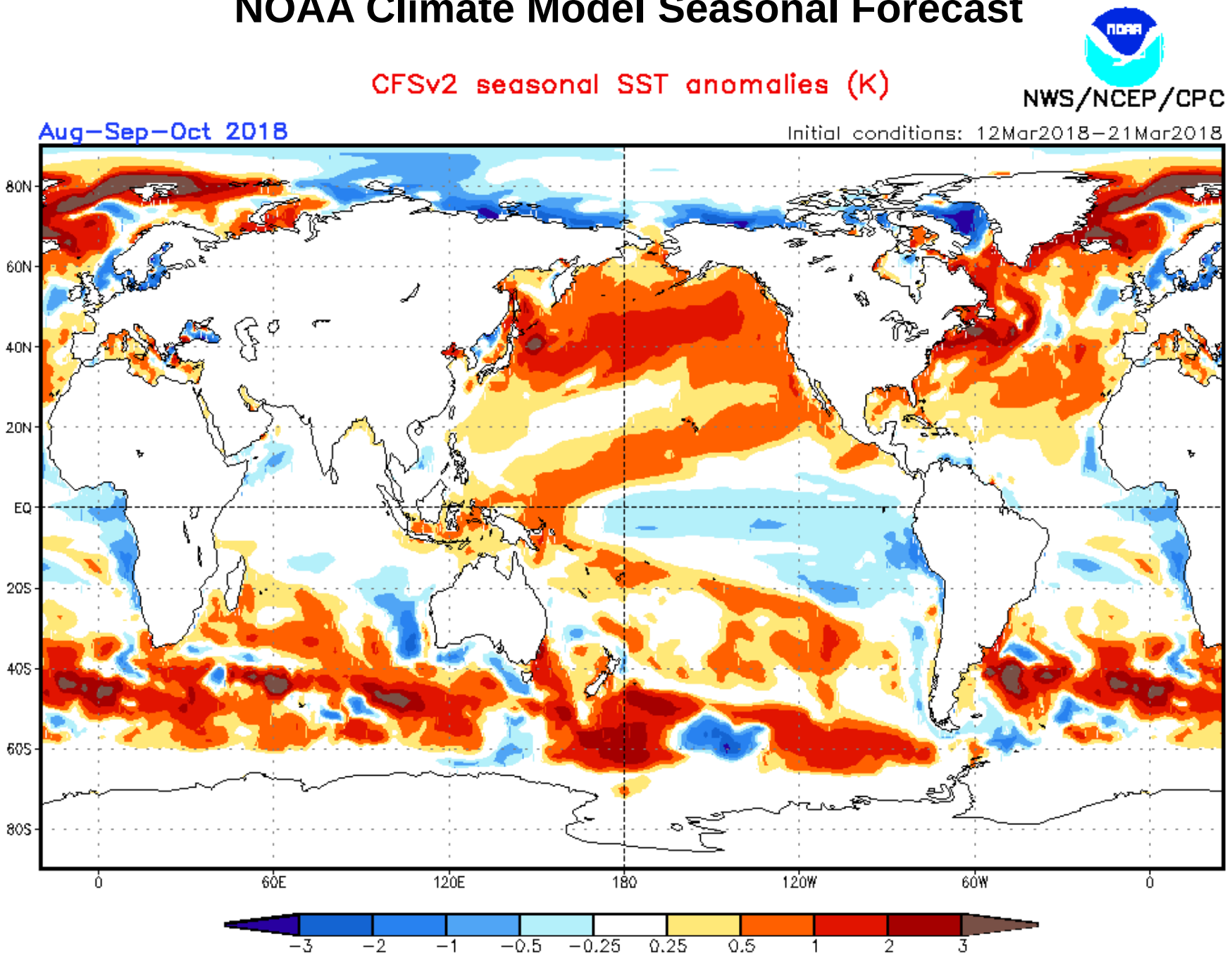



NINO3.4 SST anomaly plume
ECMWF forecast from 1 Mar 2018
Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology
System 5
Anomaly (deg C)
2
1
0
-1
El Niño
La Niña
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
2017

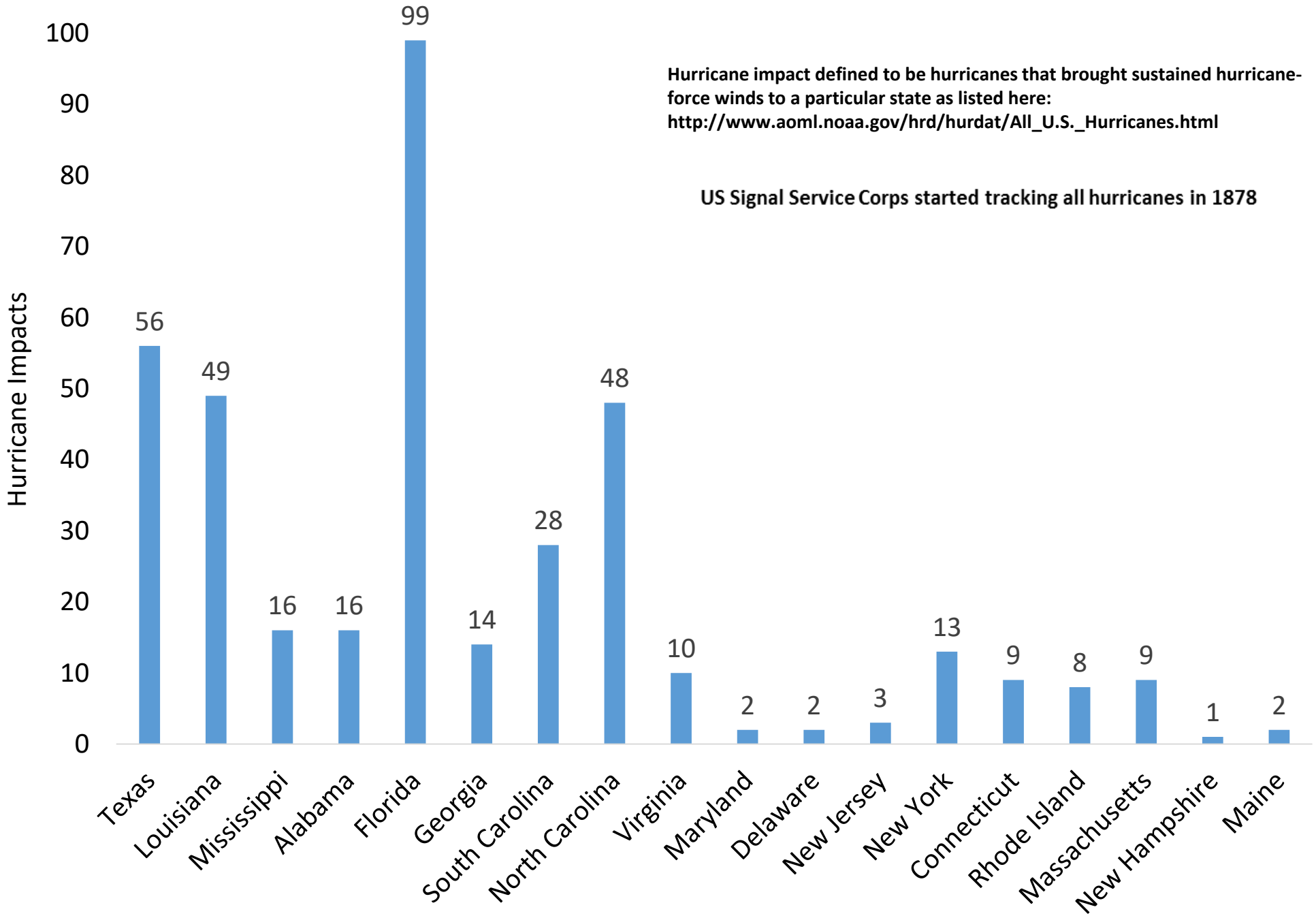
Mid-Mar 2018 Plume of Model ENSO Predictions



NOAA Climate Model Seasonal Forecast

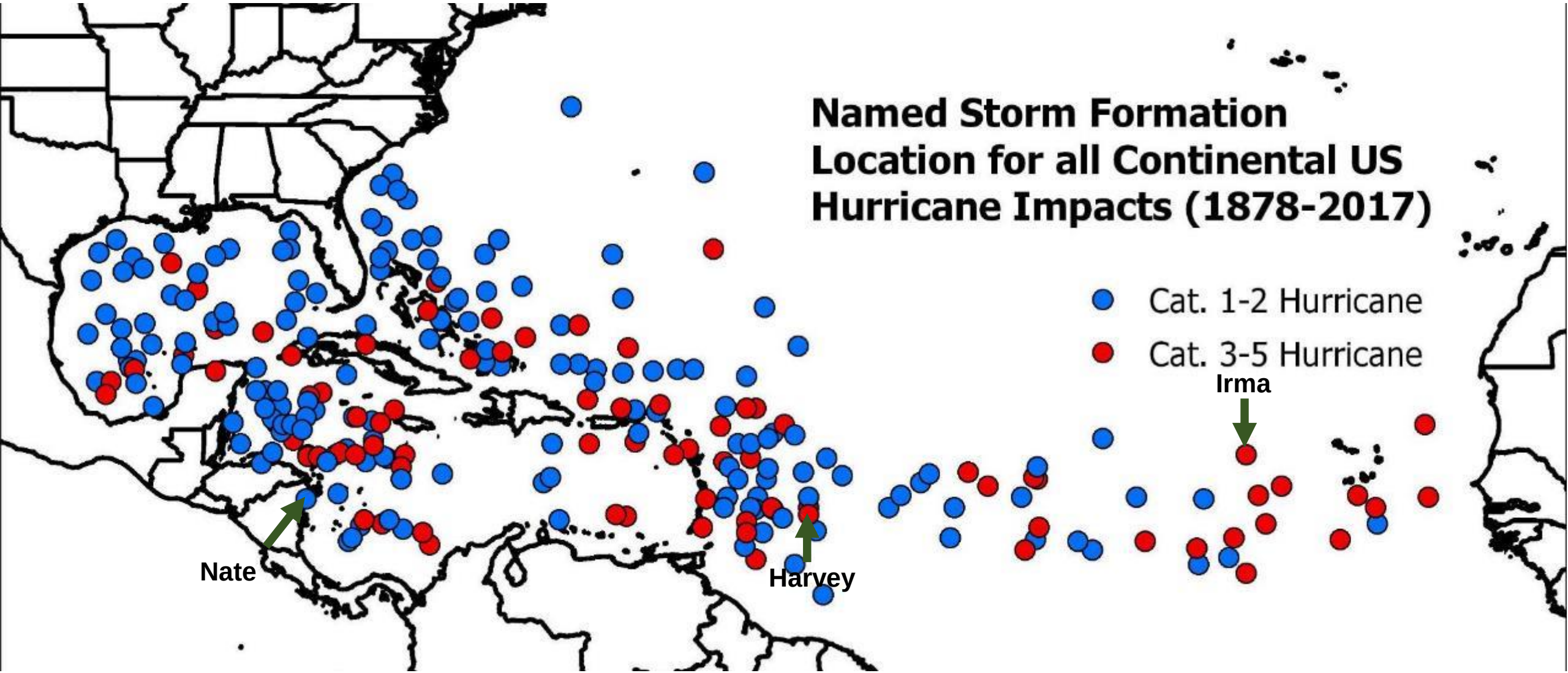


Continental United States Hurricane Impacts by Coastal State (1878-2017)



Hurricane impact defined to be hurricanes that brought sustained hurricane-force winds to a particular state as listed here: http://www.aoml.noaa.gov/hrd/hurdat/All_U.S._Hurricanes.html

US Signal Service Corps started tracking all hurricanes in 1878


Named Storm Formation
Location for all Continental US
Hurricane Impacts (1878-2017)
Cat. 1-2 Hurricane
Cat. 3-5 Hurricane
Irma
Nate
Harvey

2018
Forecast Schedule

Date	5 April	31 May	2 July	2 Aug
Seasonal Forecast	X	X	X	X

New Products

Real-Time Global Tropical Cyclone Statistics Website:

http://tropical.atmos.colostate.edu/Realtime/

Northern Hemisphere Tropical Cyclone Activity for 2017 (2017/2018 for the Southern Hemisphere)

1981-2010 Climatological Activity Through December 14 in Parentheses

Basin	Named Storms	Named Storm Days	Hurricanes	Hurricane Days	Major Hurricanes	Major Hurricane Days	Accumulated Cyclone Energy
North Atlantic	17 (12.0)	91.25 (59.0)	10 (6.4)	51.25 (24.1)	6 (2.7)	19.25 (6.2)	226.0 (105.1)
Northeast Pacific (East of 180°)	18 (16.6)	66.00 (73.2)	9 (8.9)	19.75 (30.0)	4 (4.3)	4.75 (8.9)	98.2 (131.8)
Northwest Pacific (West of 180°)	25 (25.8)	88.50 (134.8)	11 (16.2)	35.75 (66.4)	4 (8.6)	6.00 (23.1)	145.4 (295.7)
North Indian	4 (4.7)	10.75 (13.8)	2 (1.5)	4.00 (3.0)	1 (0.7)	0.25 (1.0)	16.1 (18.5)
Northern Hemisphere	64 (59.1)	256.50 (280.8)	32 (33.0)	110.75 (123.5)	15 (16.3)	30.25 (39.2)	485.7 (551.1)
South Indian (West of 135°E)	1 (3.3)	4.00 (13.3)	0 (1.2)	0.00 (3.8)	0 (0.6)	0.00 (1.3)	2.9 (19.6)
South Pacific (East of 135°E)	0 (1.0)	0.00 (3.5)	0 (0.5)	0.00 (1.3)	0 (0.2)	0.00 (0.4)	0 (6.0)
Southern Hemisphere	1 (4.3)	4.00 (16.8)	0 (1.7)	0.00 (5.1)	0 (0.8)	0.00 (1.7)	2.9 (25.6)

Colorado State University

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

http://www.seasonalhurricanepredictions.org

Contributing Forecast Groups

AccuWeather

COASTAL CAROLINA UNIVERSITY

Colorado State University

INSMET
INSTITUTO DE METEOROLOGIA

MDA
WEATHER SERVICES

NC STATE UNIVERSITY

NMME The North American Multi-Model Ensemble

NOAA

PennState

SMN

StormGeo

Tropical Storm Risk.com

THE UNIVERSITY OF ARIZONA

Met Office

CLIMATE FORECAST APPLICATIONS NETWORK
FAN

WeatherBELL
Analytics LLC

The Weather Company

WEATHER TIGER

WWT

VERI TAS LUX MEA

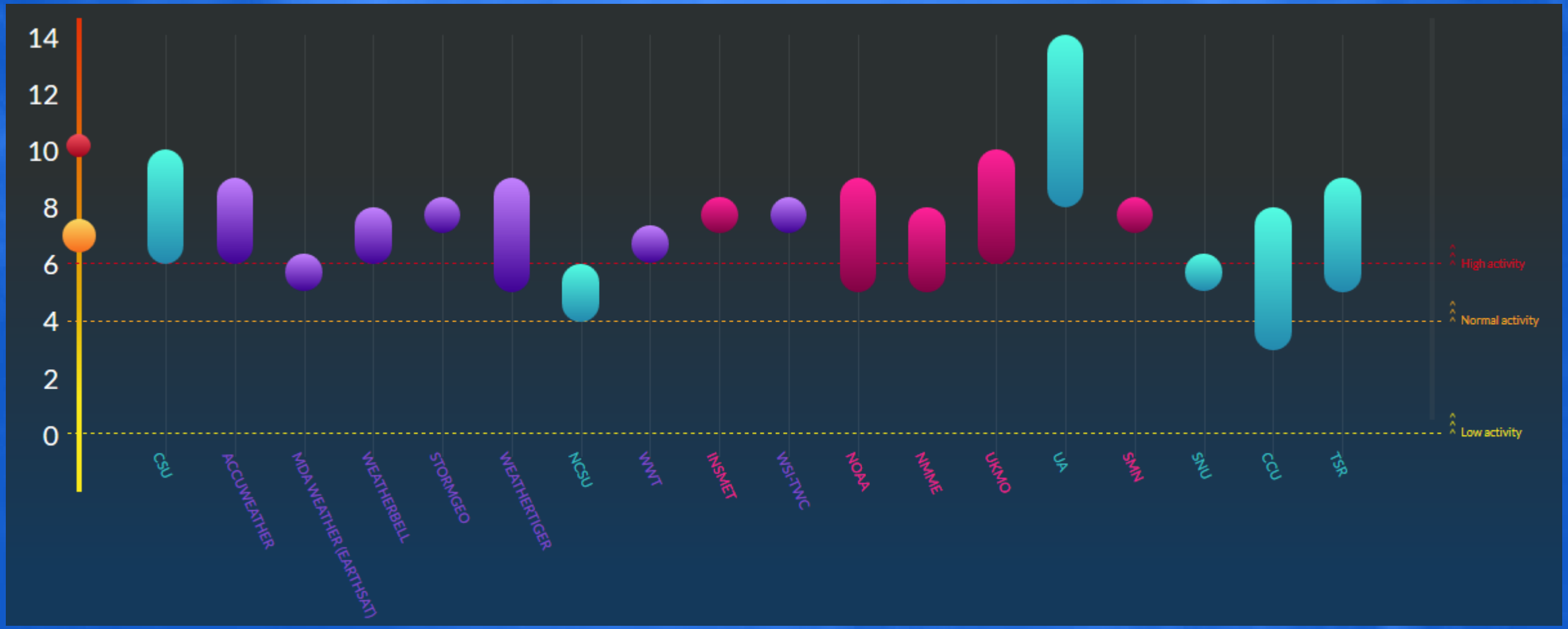
New Products

Colorado State University

Seasonal Hurricane Forecast Compilation Website

http://seasonalhurricanepredictions.org

Barcelona Supercomputing Center
Centro Nacional de Supercomputación



Arago's Admonition:

"Never, no matter what may be the progress of science, will honest scientific men who have regard for their reputations venture to predict the weather."

Contact Info:

Phil Klotzbach

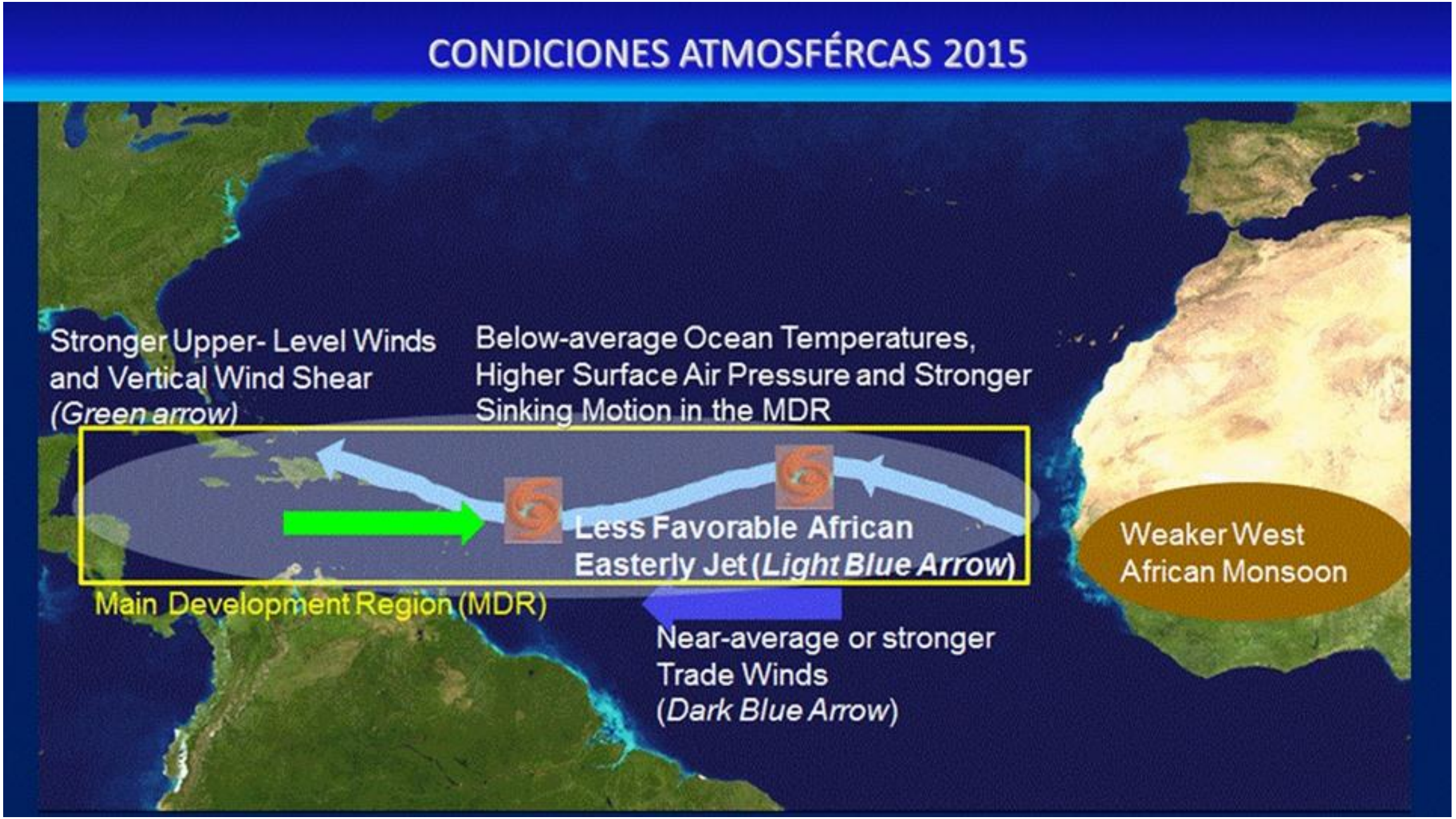
Email: philk@atmos.colostate.edu

Web: http://tropical.colostate.edu

Twitter: @philklotzbach

Facebook: CSU Tropical Meteorology Project

CONDICIONES ATMOSFÉRCAS 2015



PRONÓSTICO TEMPORADA DE CICLONES TROPICALES, ATLANTICO, 2015