Atlantic Basin Seasonal Hurricane Prediction: Past, Present and Future

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Seasonal Hurricane Forecasting Workshop

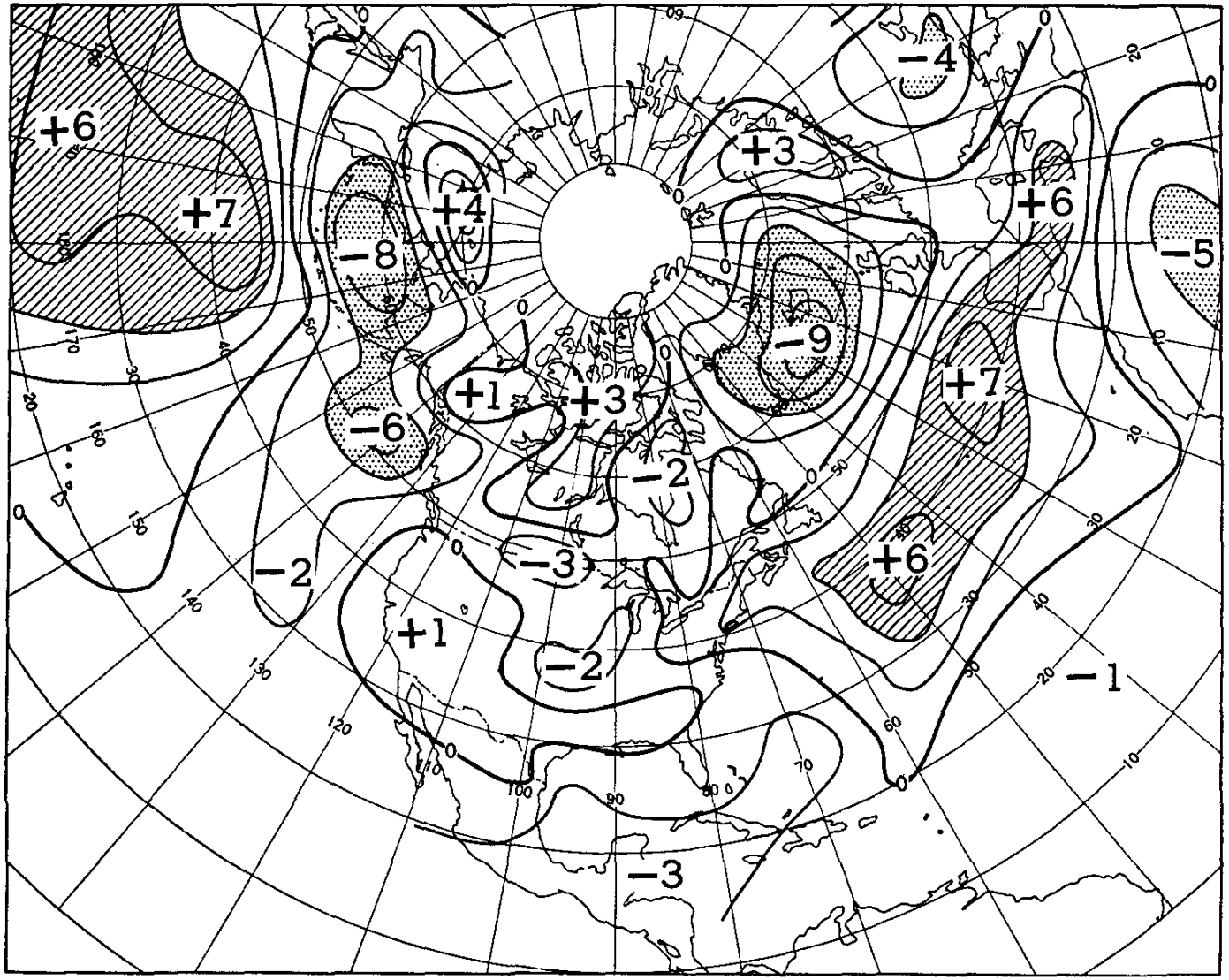
November 2, 2018

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. *Bulletin of the AMS*, **98,** 2311-2336.

Seasonal Forecasting is more than this!

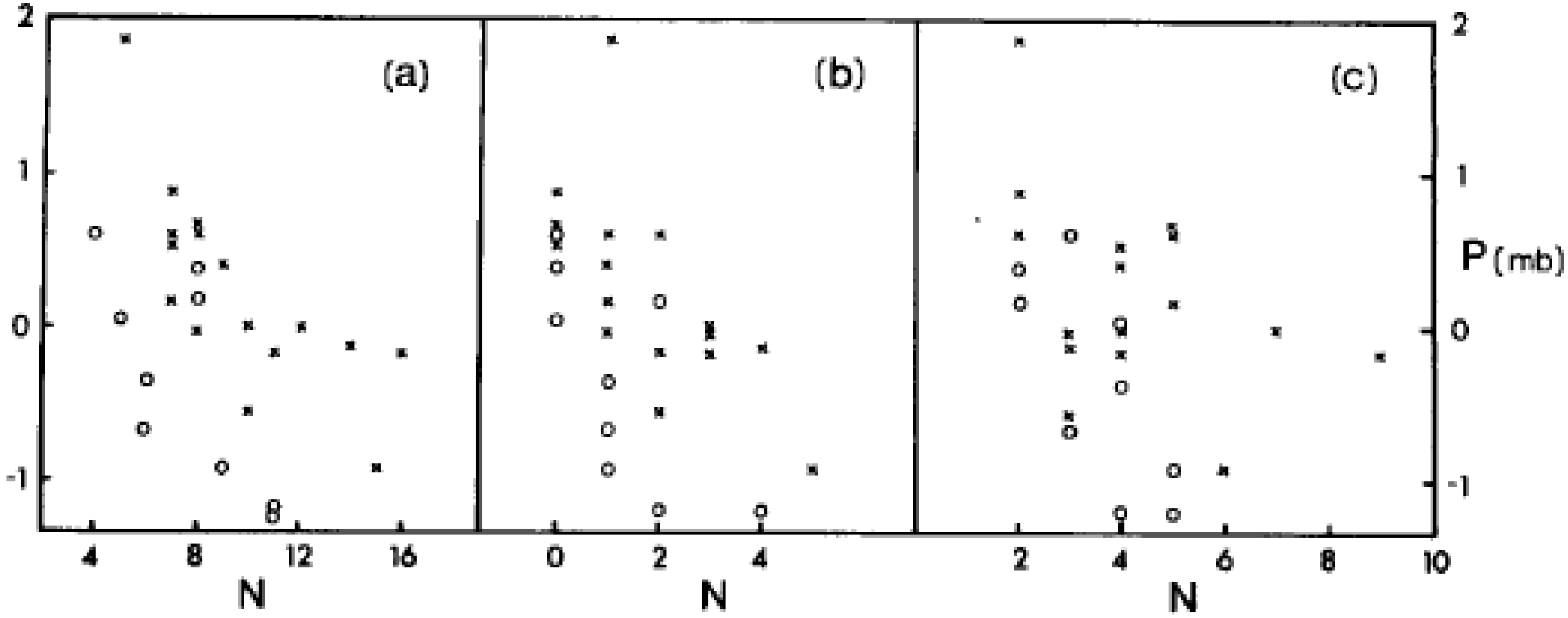
Ballenzweig (1959)



August-October-averaged 700 mb height anomalies in the five most active tropical cyclone seasons: 1933-1955

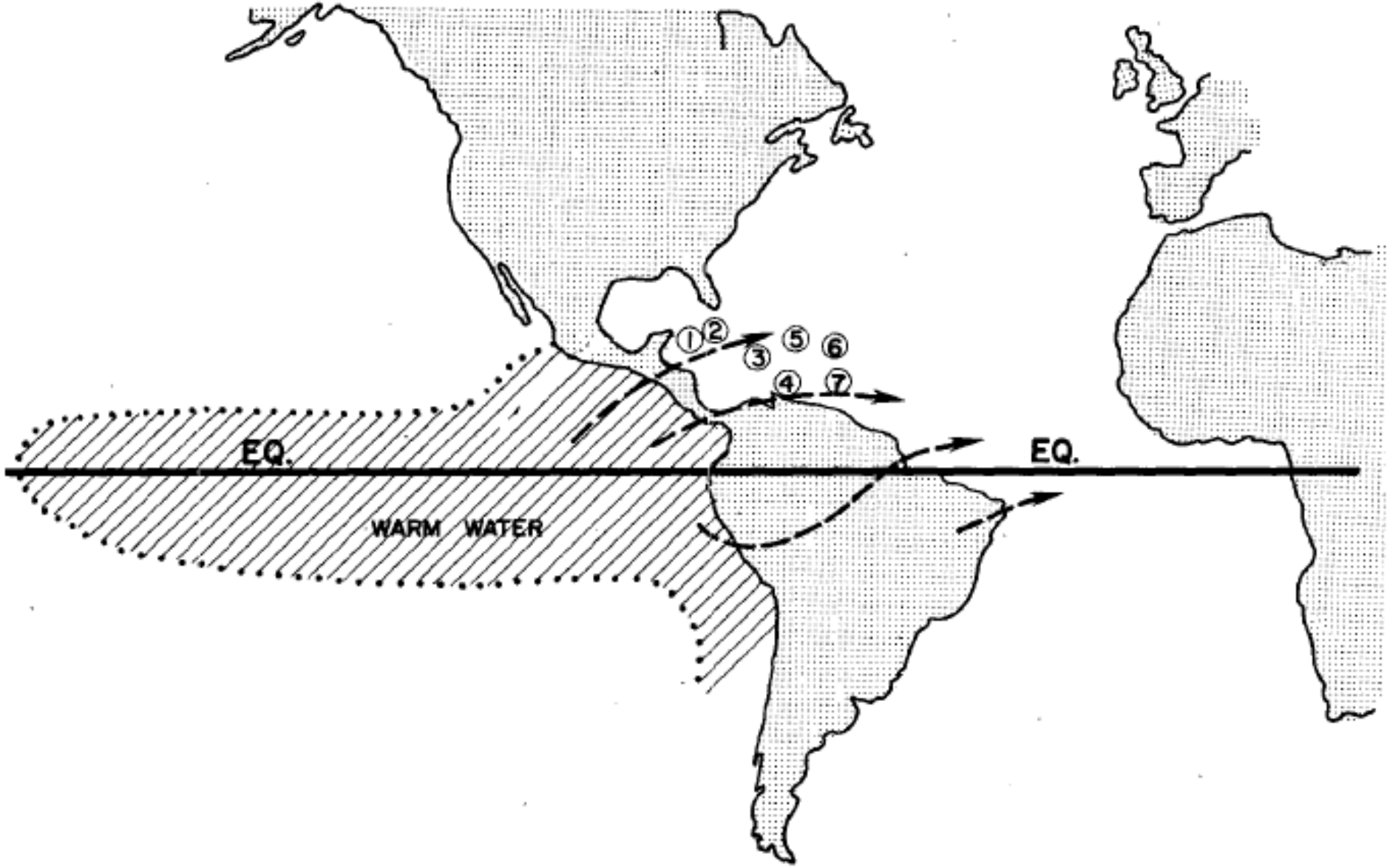
Nicholls (1979)

Positive Southern Oscillation Index (e.g., La Niña) = More Australian Tropical Cyclones



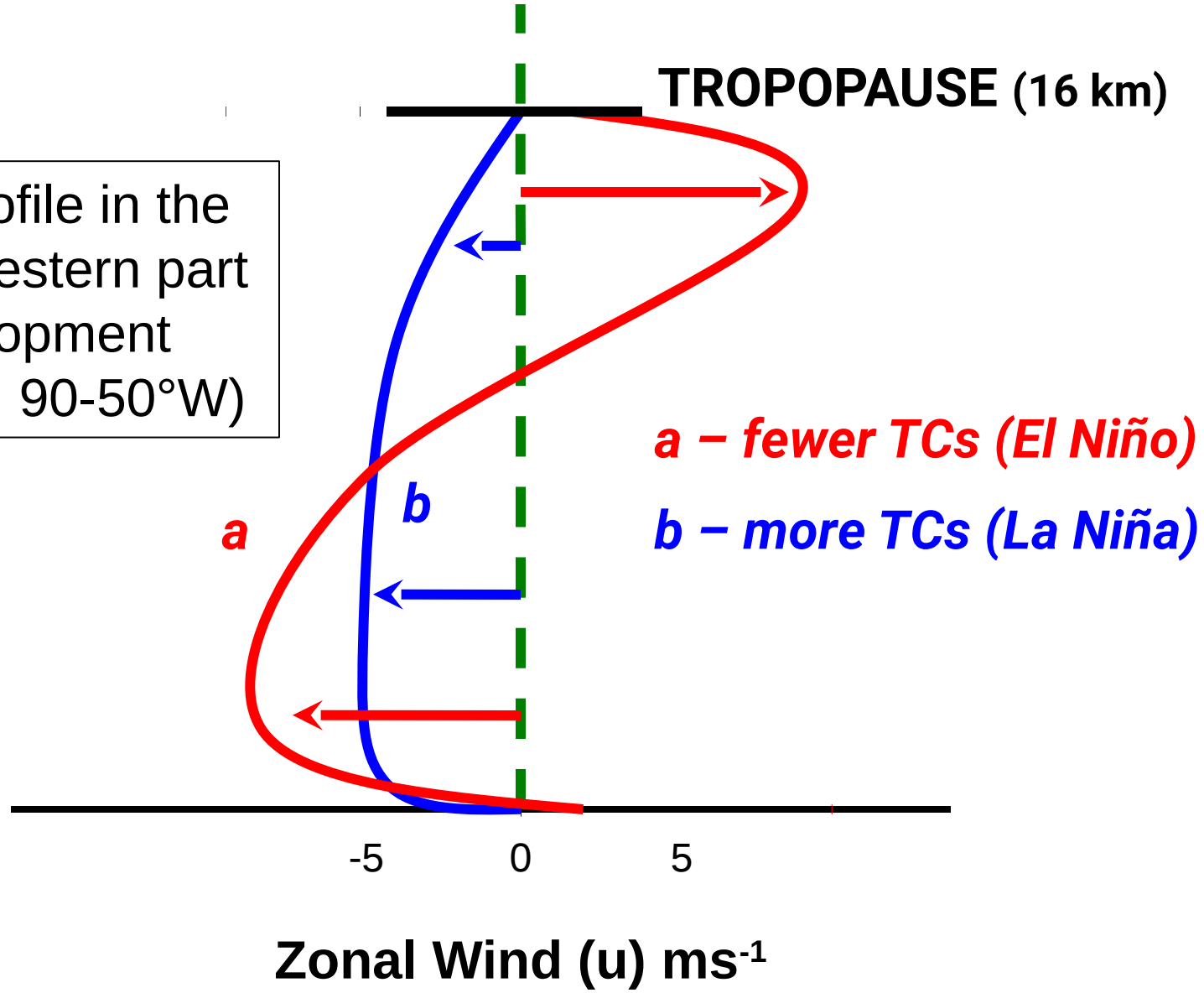
Relationship between Darwin austral winter pressure and tropical cyclone frequency during (a) entire season, (b) October-December and (c) January-February.

Gray (1984)

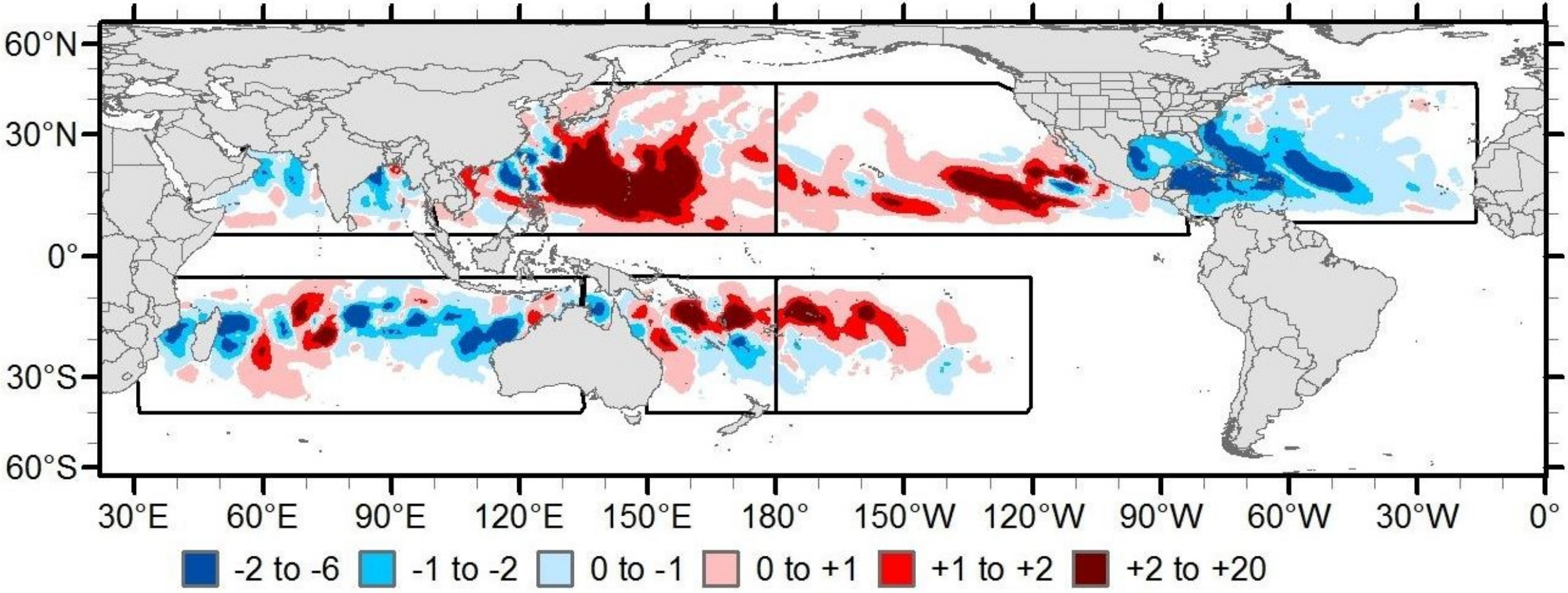


200-hPa zonal wind anomalies associated with El Niño Events – Increased Caribbean Shear

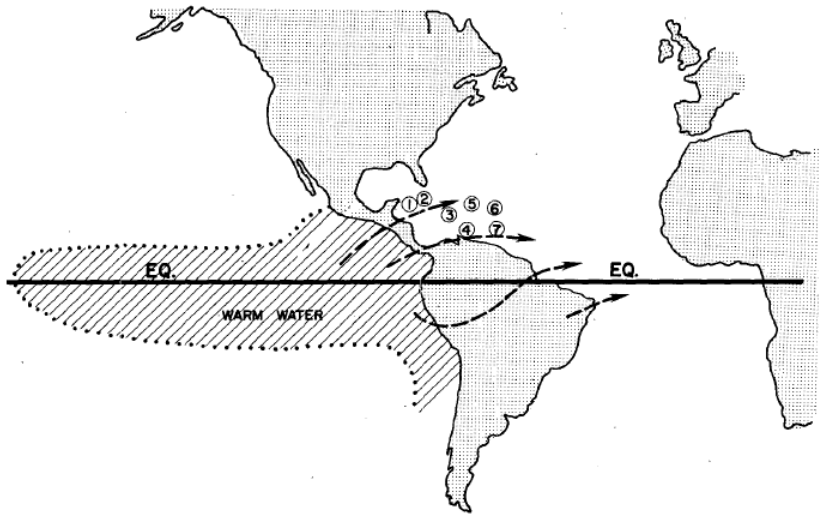
Vertical Wind Profile in the Caribbean and western part of Main Development Region (10-20°N; 90-50°W)



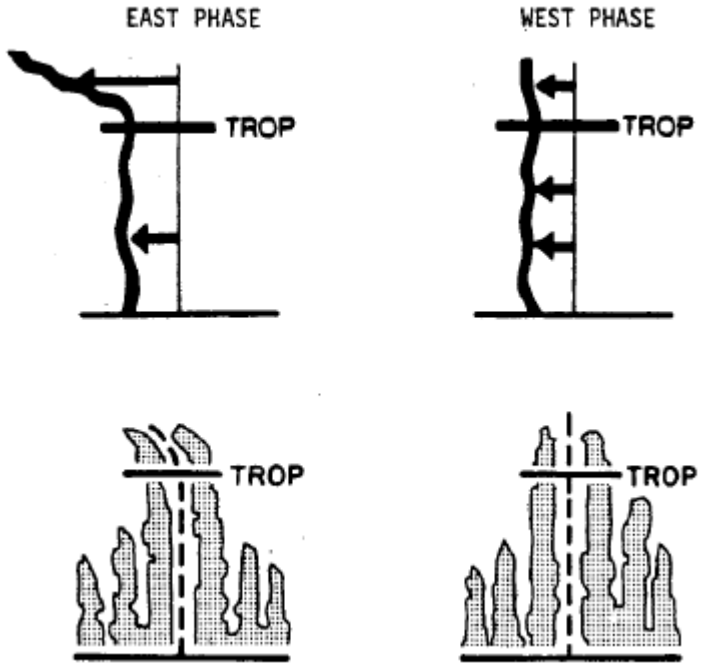
El Niño minus La Niña Accumulated Cyclone Energy Generation (1985-2014)



Original CSU Seasonal Forecast – Gray (1984)



ENSO

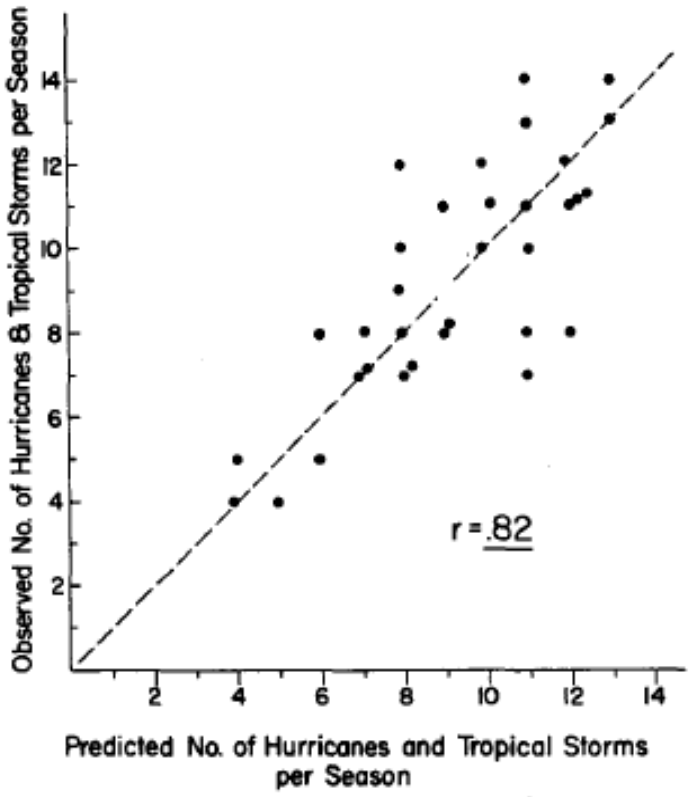


QBO

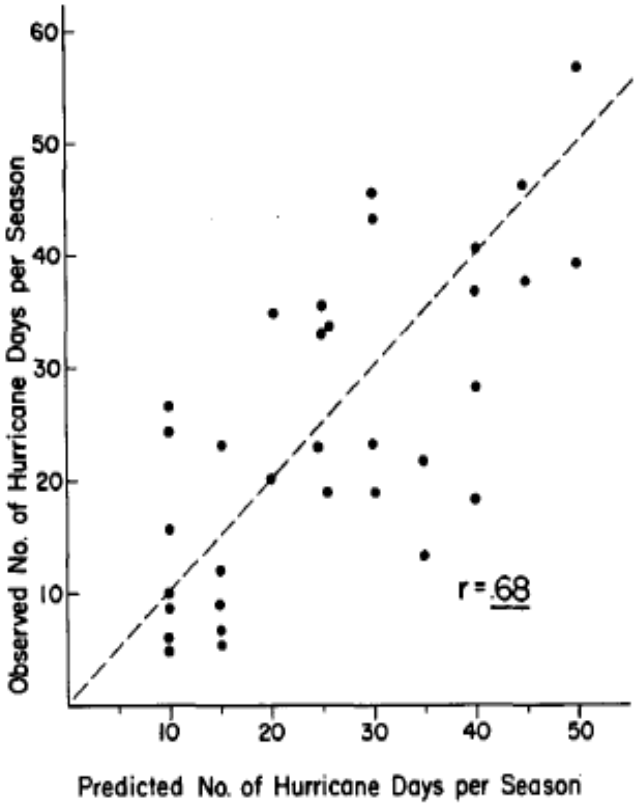
Caribbean SLP

Gray (1984)

Named Storm Skill (r = 0.82)
(1950-1982)



Hurricane Day Skill (r = 0.68)
(1950-1982)



Seasonal Predictors used in early August Forecasts by CSU (late 1990s through early 2000s)

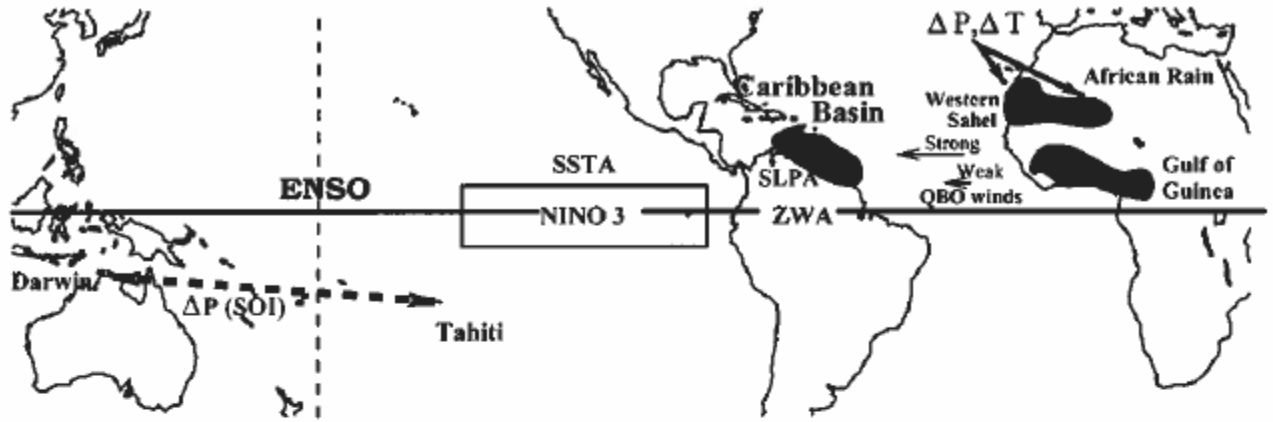


Figure 1: Meteorological parameters used in various prior versions of our early August (Gray et al. 1994a) seasonal forecast.

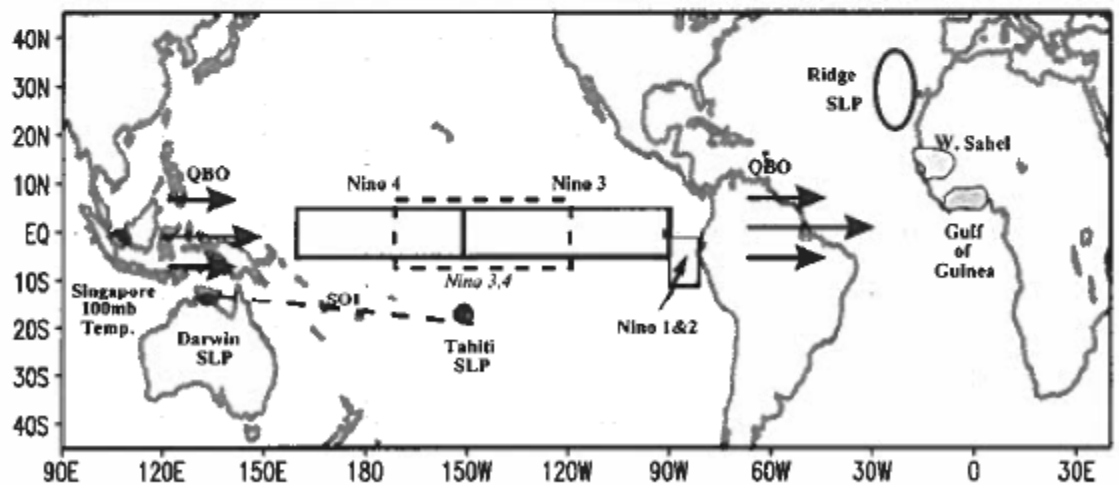


Figure 2: Additional parameters used or consulted in making the actual extended-range forecasts.

TOO MANY PREDICTORS!!

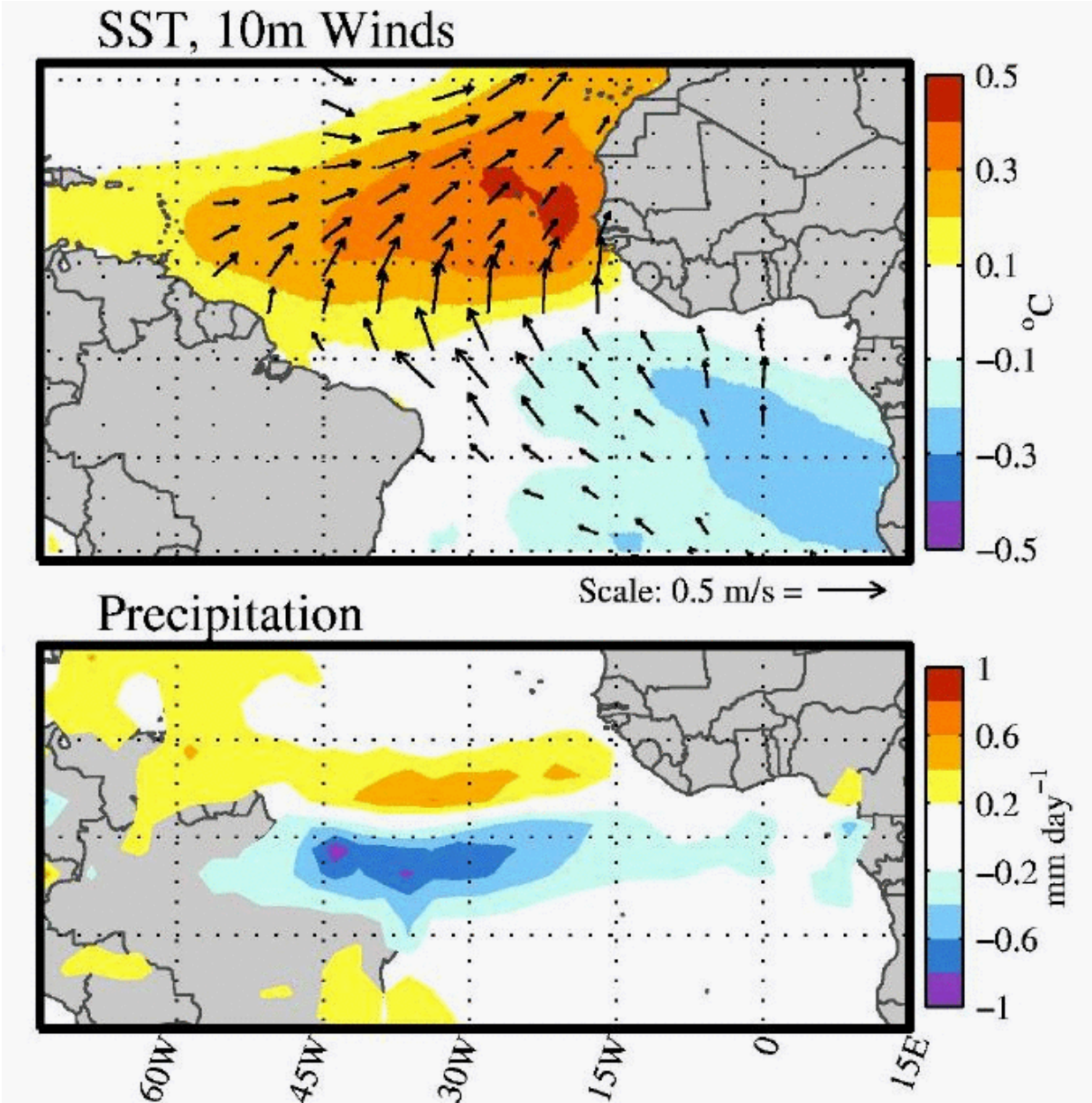
Predictors used in Statistical Model by CSU in August 2000

Table 5: Listing of the pool of predictive parameters and their estimated values for the early August 2000 prediction, based on meteorological data available through July 2001. See Figs. 2 through 4 for the locations of the sources of these predictor data.

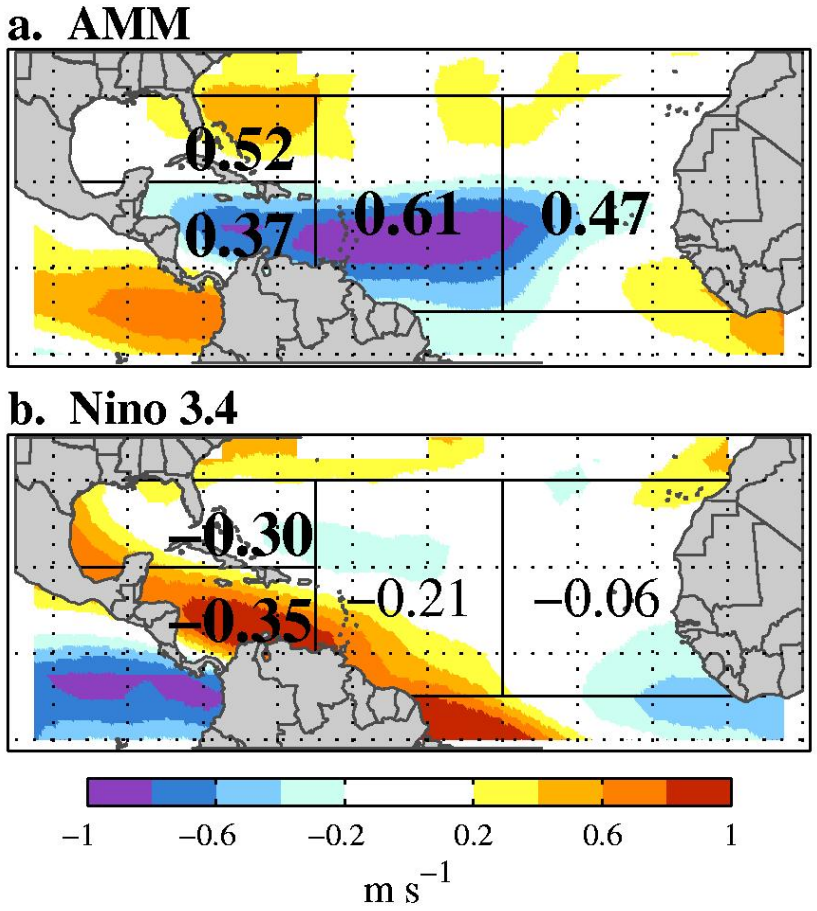
Predictive Parameter	
1 = QBO 50 mb 2-month extrapolation of zonal wind at 12°N to Sept. 2001	$-18\ ms^{-1}$
2 = QBO 30 mb 2-month extrapolation of zonal wind at 14°N to Sept. 2001	$-17\ ms^{-1}$
3 = QBO absolute value of shear between 50 and 30 mb at 8°N to Sept. 2001	$1\ ms^{-1}$
4 = Rgc AN Gulf of Guinea rainfall anomaly (Aug-Nov of 2000)	−0.5 SD
5 = Rws West Sahel rainfall anomaly (June-July 2001)	(assume) 0.0 SD
6 = SST3.4 Nino 3.4 SSTA in June-July 2001	+0.3°C
7 = ZWA June-July 2001 Caribbean basin zonal wind anomaly	+0.2 m/s
8 = SLPA June-July 2001 Caribbean basin sea level pressure anomaly	+0.2 mb
9 = Temp West-East Sahel temperature gradient(Feb-May 2001)	+0.5 SD
10 = NATL North Atlantic SSTA anomaly (50-60°N,10-50°W) (June-July)	+0.75°C
11 = SATL South Atlantic SSTA anomaly (5-18°S,50°W-10°E) (June-July)	+0.2°C
12 = TATL Tropical Atlantic SSTA anomaly (10-22°N,18-50°W) (June-July)	+0.1°C
13 = R-M: Mar Azores surface pressure ridge strength in Mar 2001	−1.60 SD
14 = R-ON: Azores surface pressure ridge strength in Oct-Nov 2000	+1.1 SD
15 = D-SST3.4: Nino 3.4 SSTA for June-July minus April-May 2001	+0.3°C
16 = NSD-S: Named storm days south of 23.5°N and east of 75°W before 1 August	0

The Atlantic Meridional Mode: SST, wind, and precip anoms

- Leading mode of basin-wide ocean-atmosphere interaction between SST and low-level winds
- Amplifies via the **wind-evaporation-SST (WES)** feedback mechanism
- Strongest signal during the spring, but persists into hurricane season



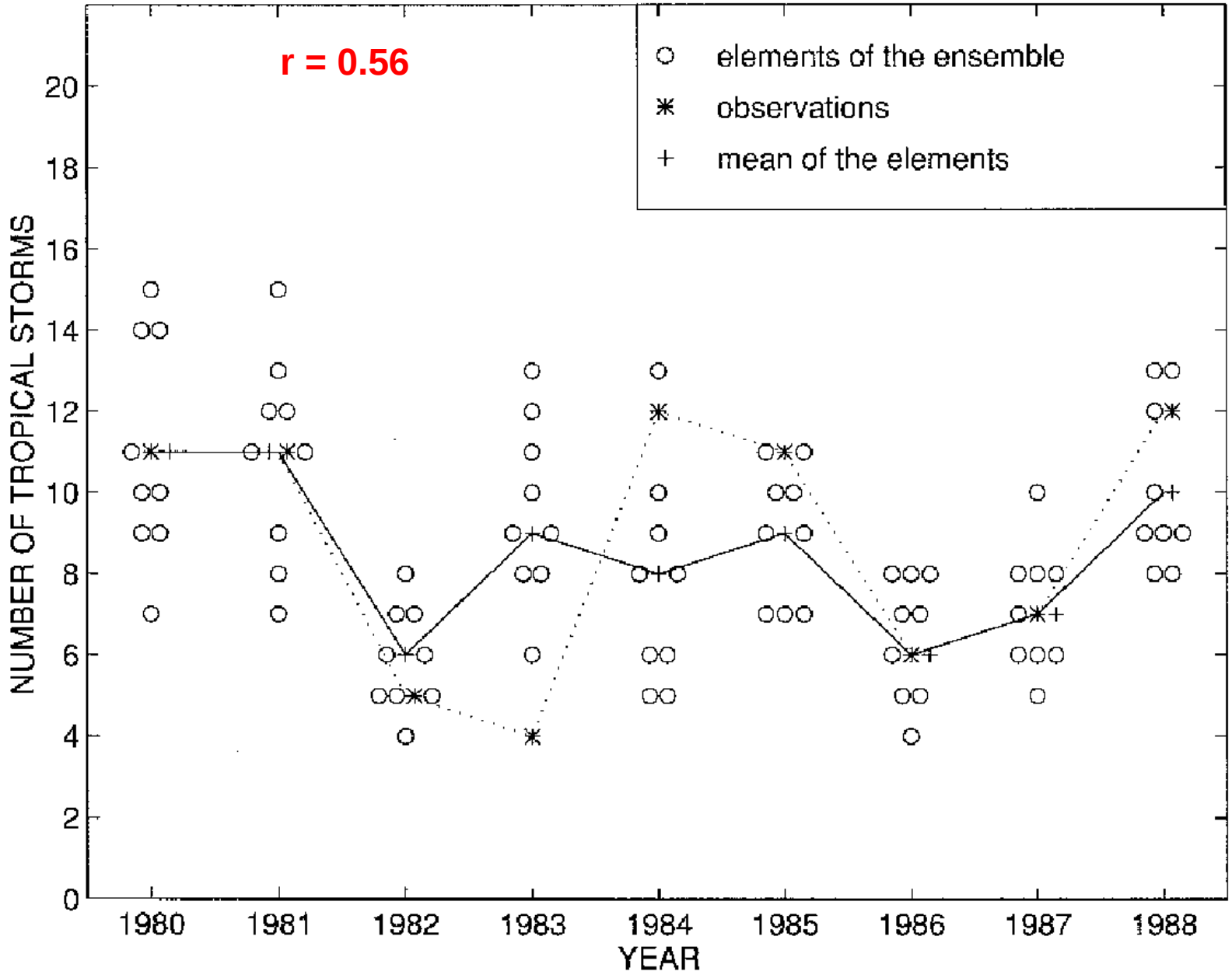
Comparative effects of the AMM (local) and ENSO (remote) on vertical wind shear in the Atlantic



units: m/s per standard deviation

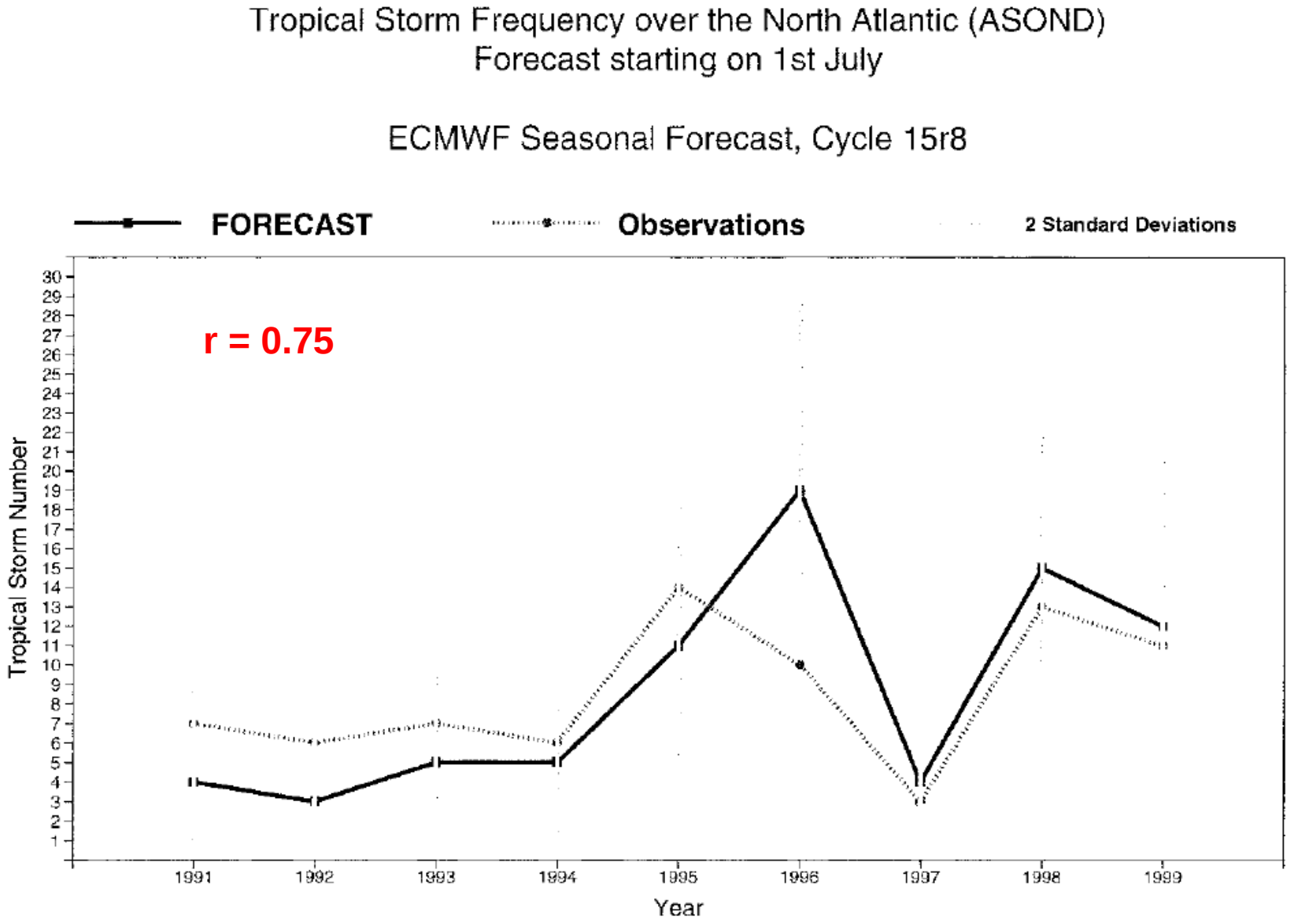
Shear regressed onto AMM and Nino 3.4 indices, and correlations between the indices and storm activity.

ECMWF Hindcasts using Observed SSTs

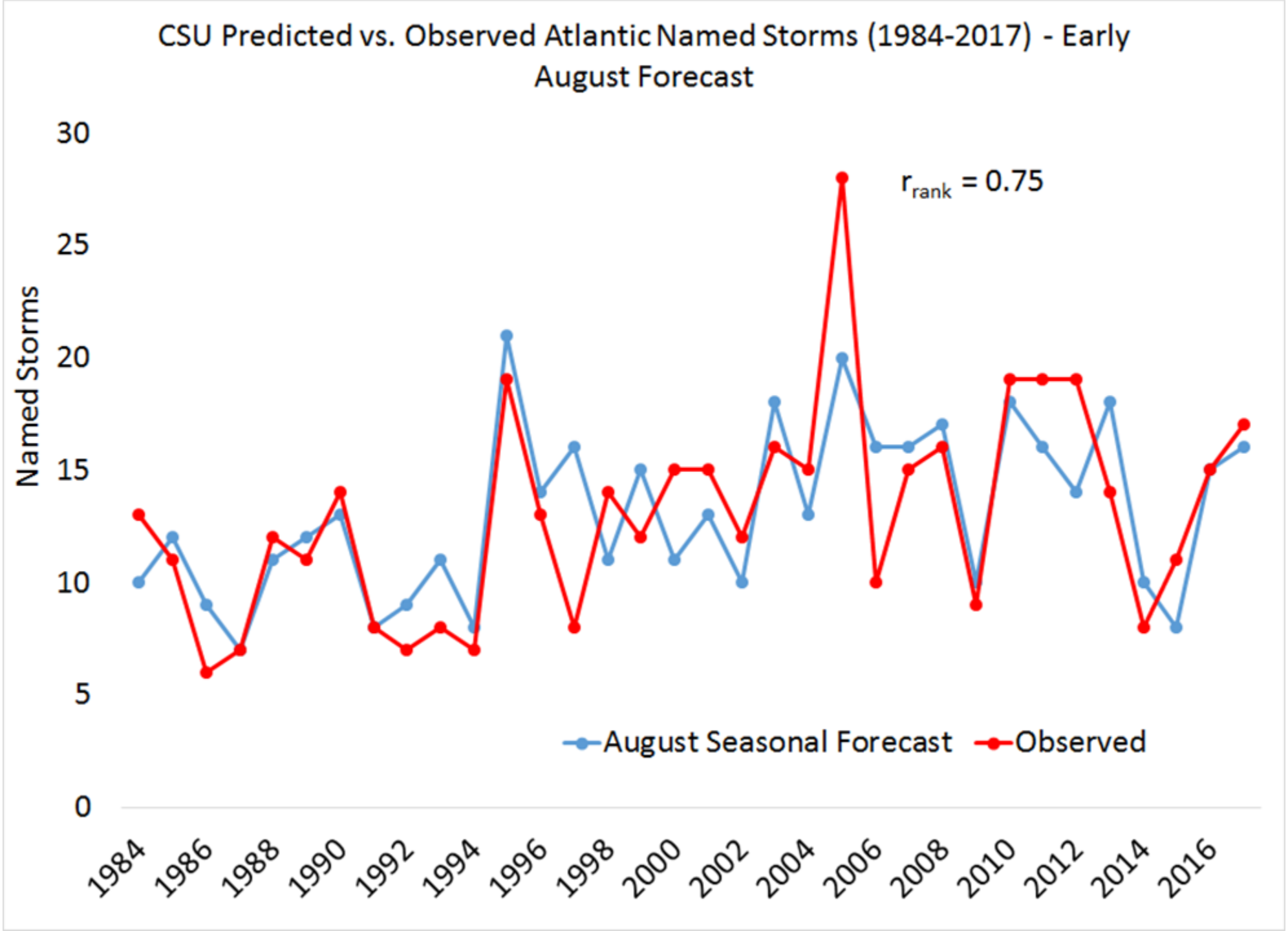


Vitart et al. (1997)

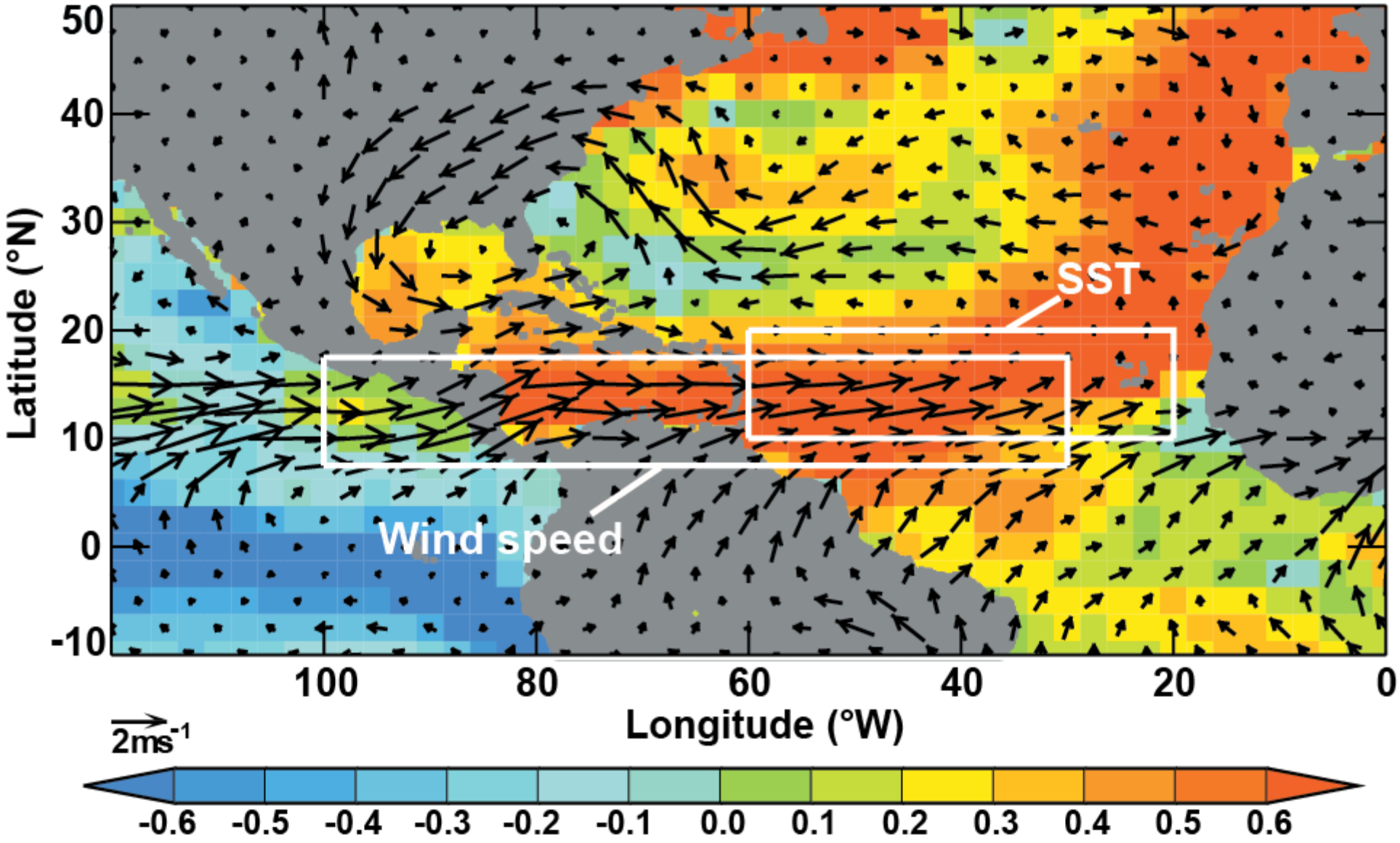
ECMWF Hindcasts using Model Forecast SSTs



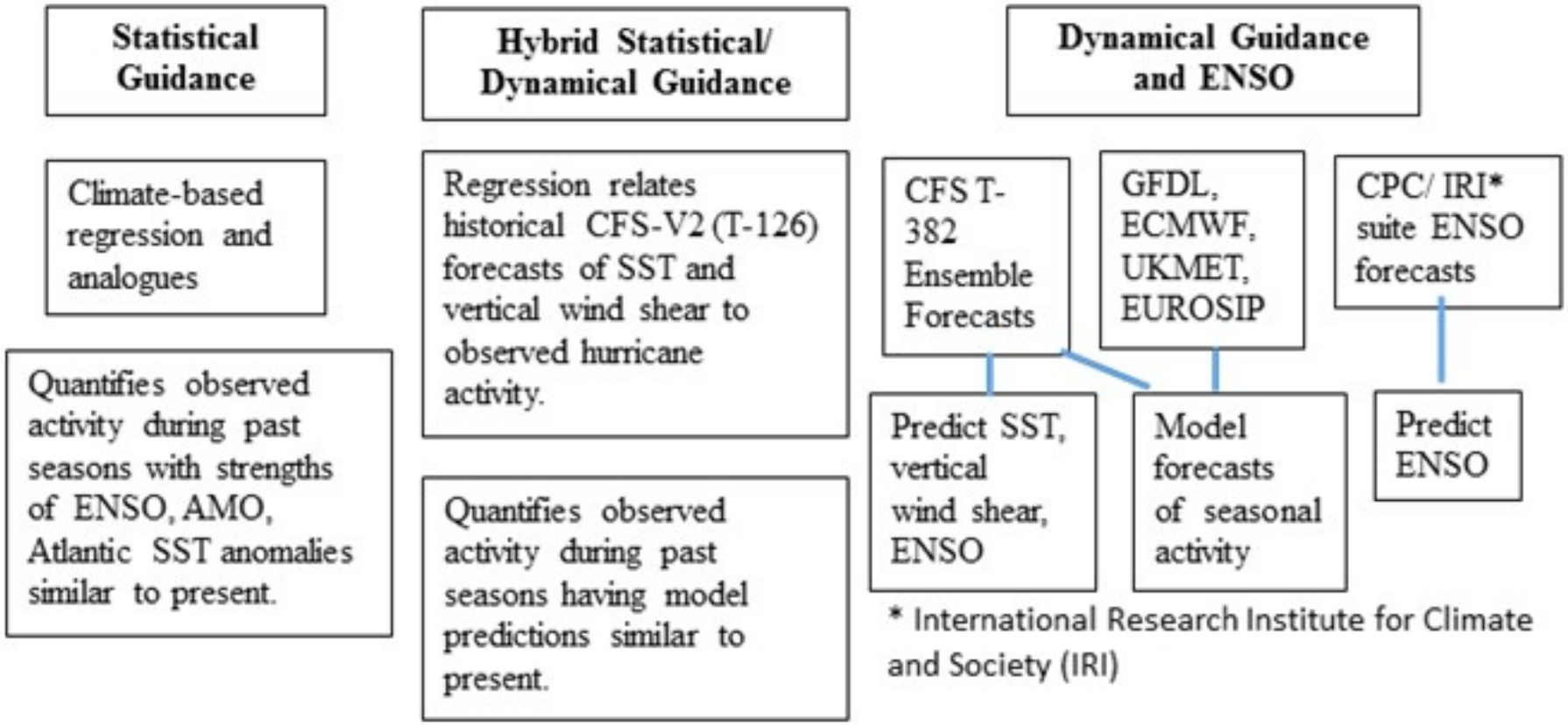
Vitart et al. (2001)


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

Tropical Storm Risk Statistical Prediction Model



NOAA's Atlantic Hurricane Season Outlook Guidance

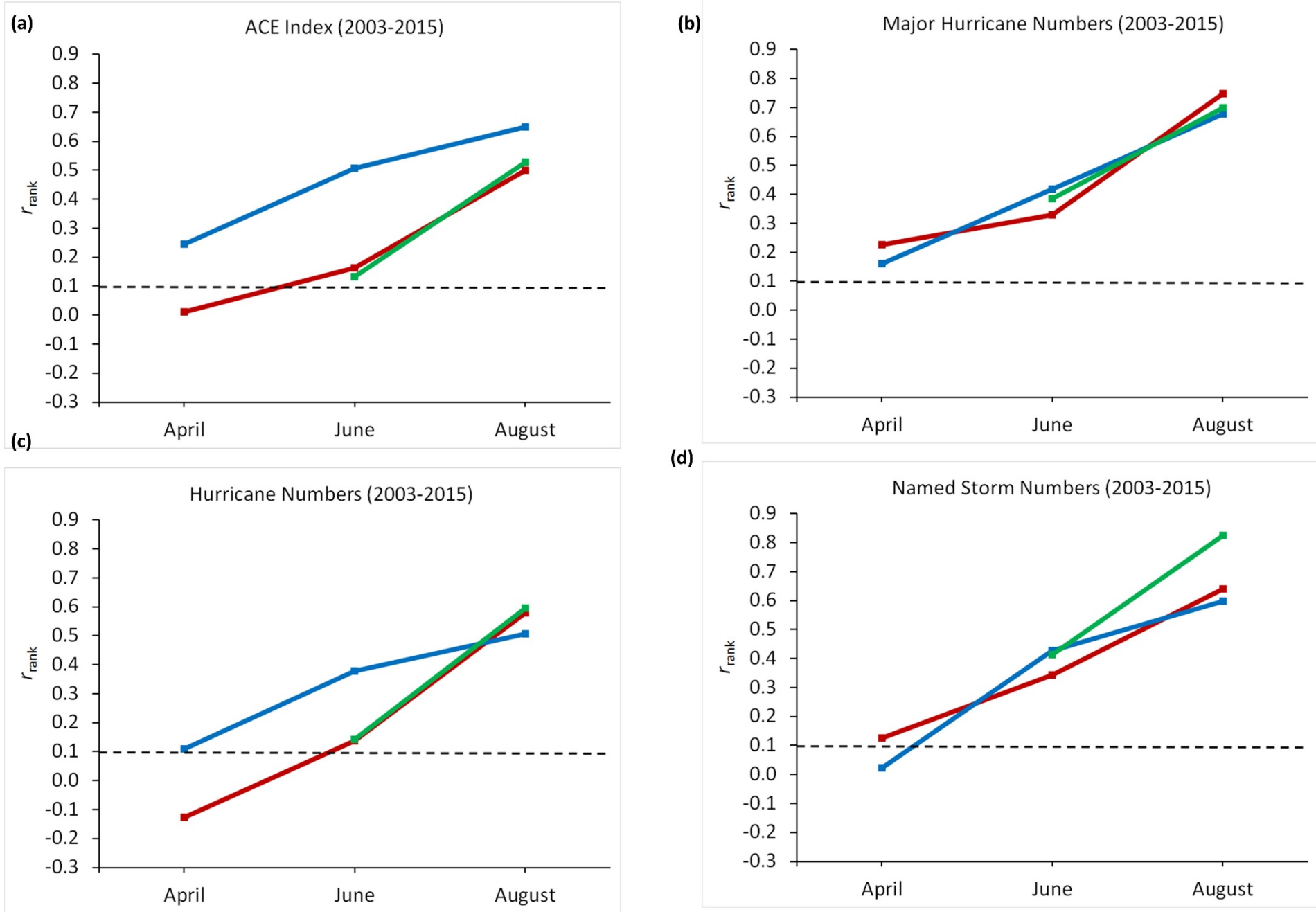


Forecast tool consensus guidance provides 70% probability ranges of activity**

Forecast team members each predict 70% probability ranges of activity.

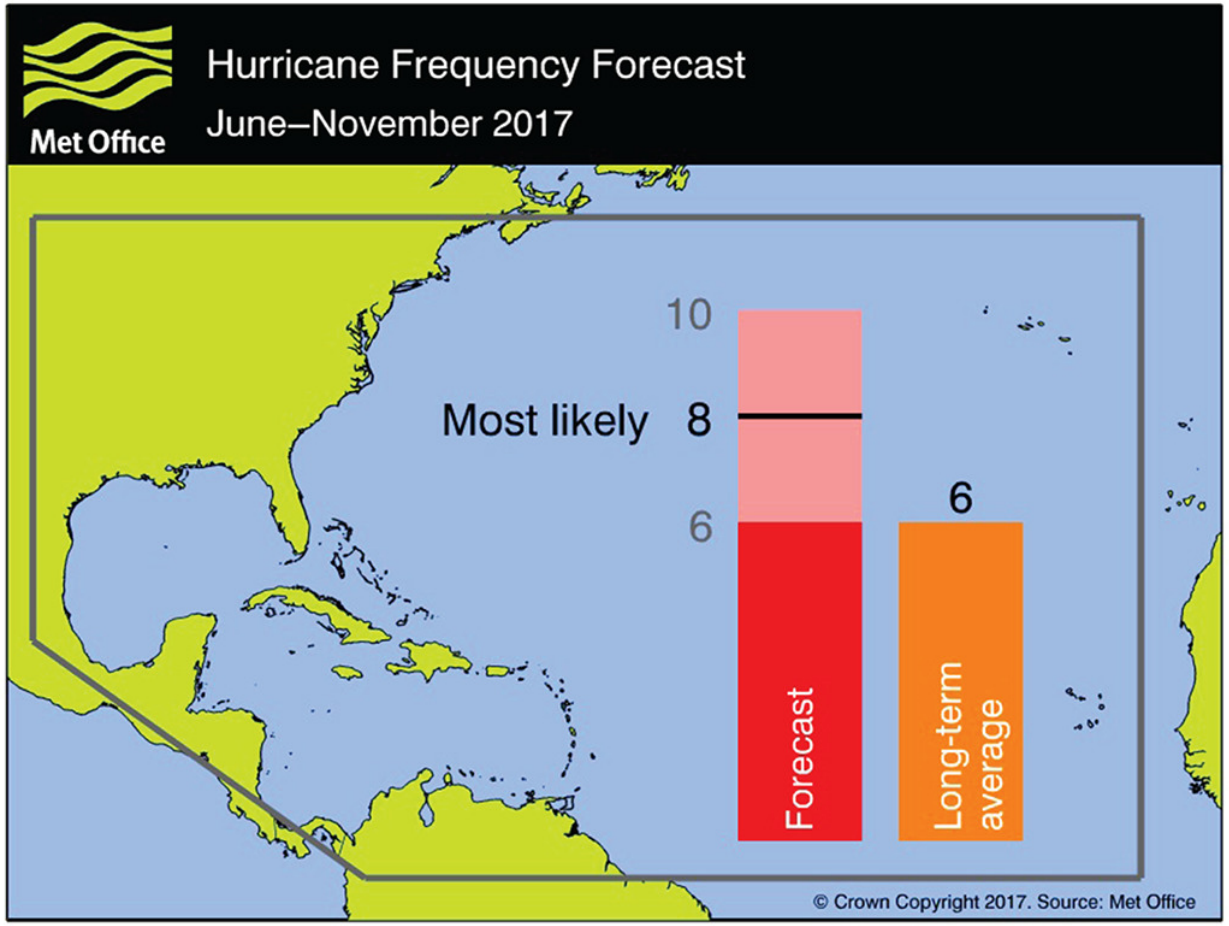
Final outlook is consensus of individual forecaster predicted ranges.

** Prediction parameters include named storms, hurricanes, major hurricanes, ACE, and probabilities for the season being above- near- and below-normal

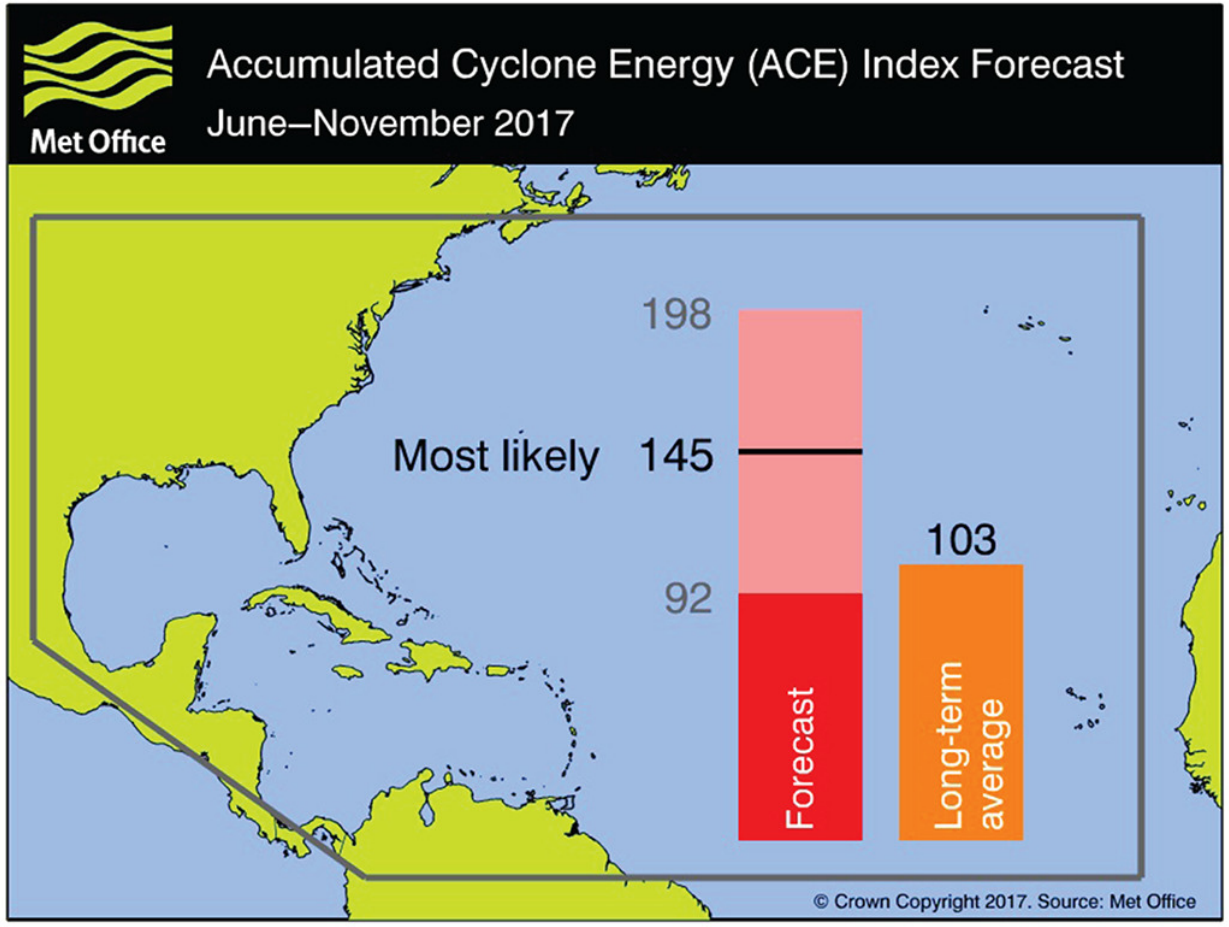

(a)
ACE Index (2003-2015)
(b)
Major Hurricane Numbers (2003-2015)
(c)
Hurricane Numbers (2003-2015)
(d)
Named Storm Numbers (2003-2015)
r rank
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
April
June
August
CSU
TSR
NOAA

Camp et al. (2018)

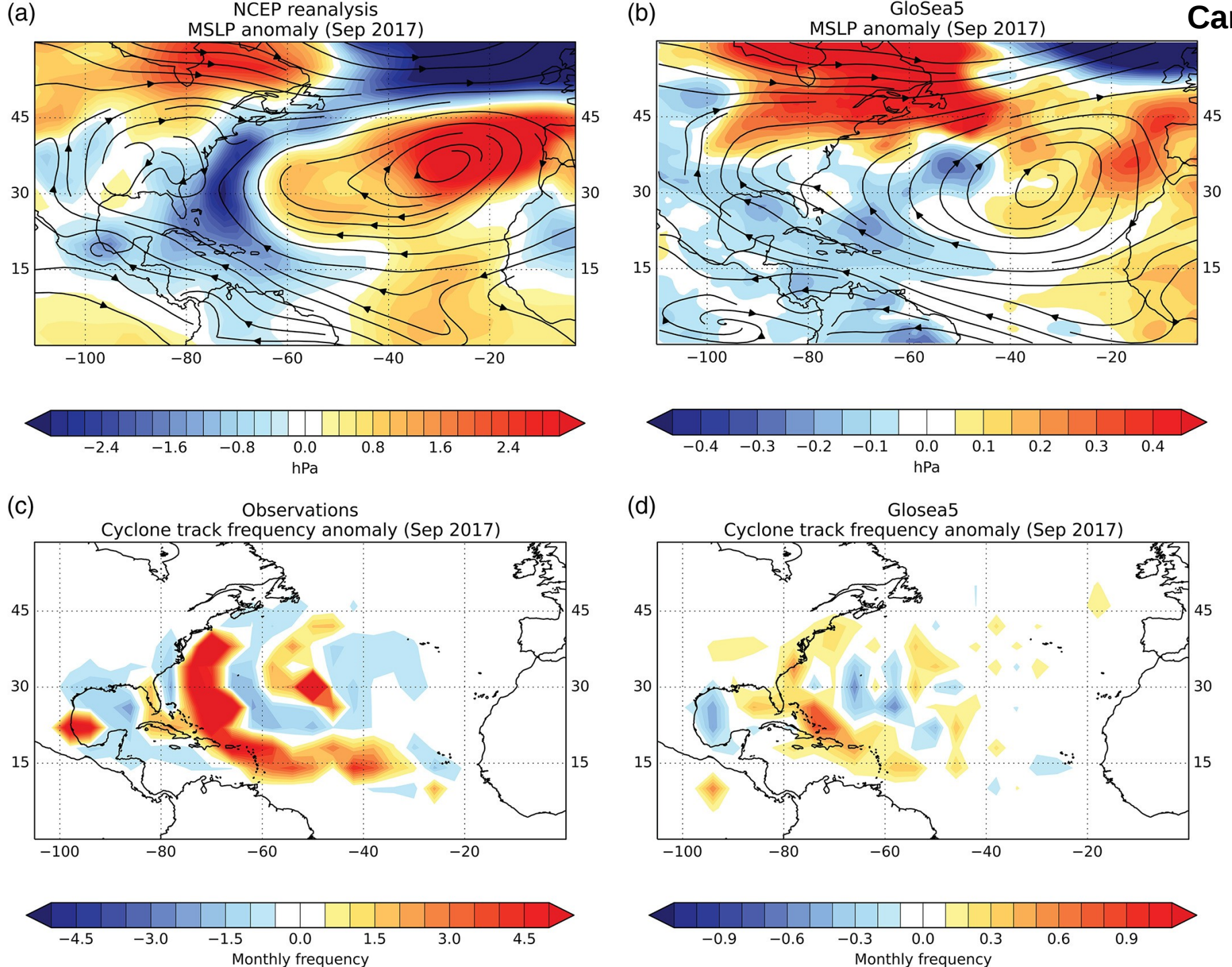
(a)



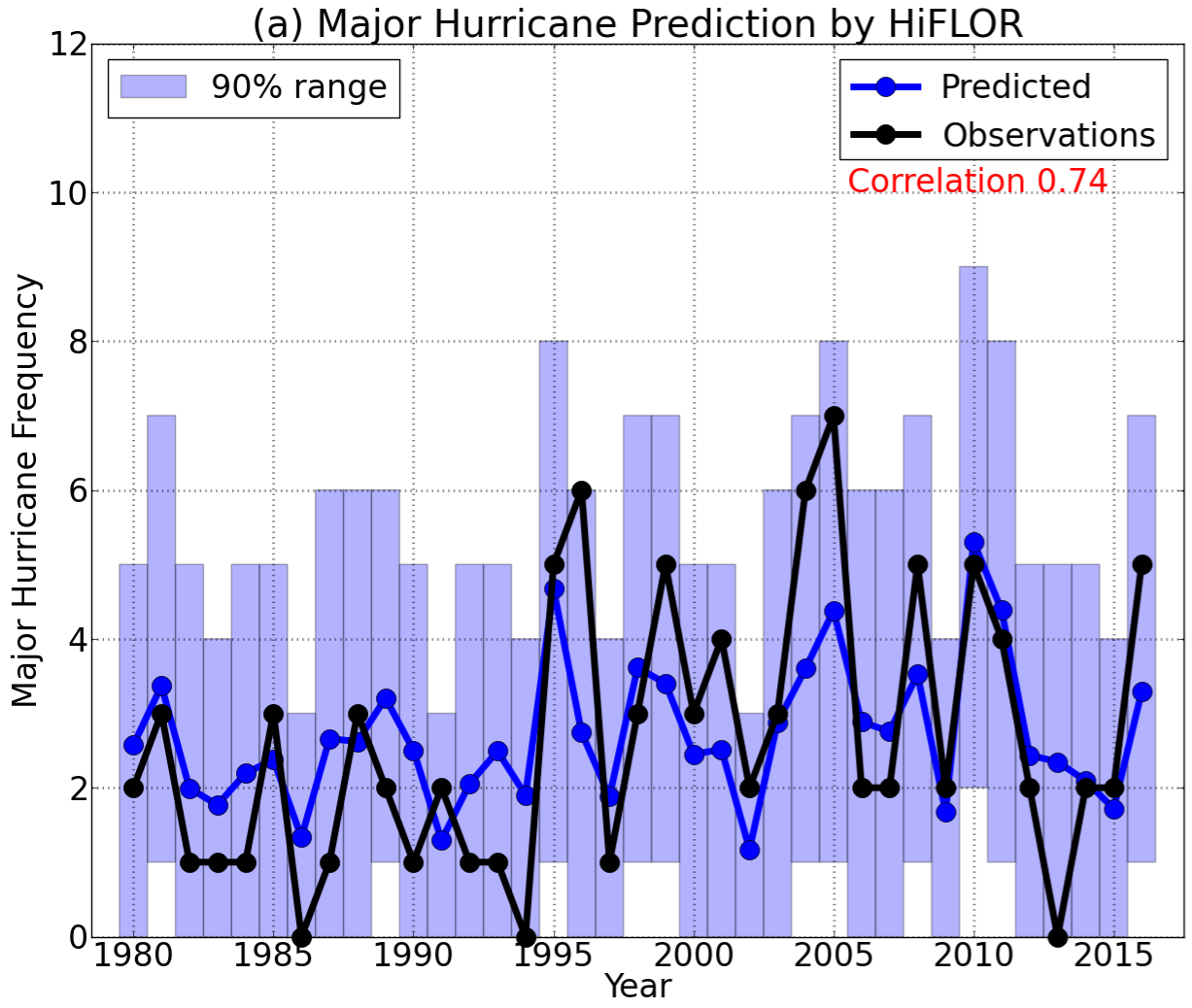
(b)

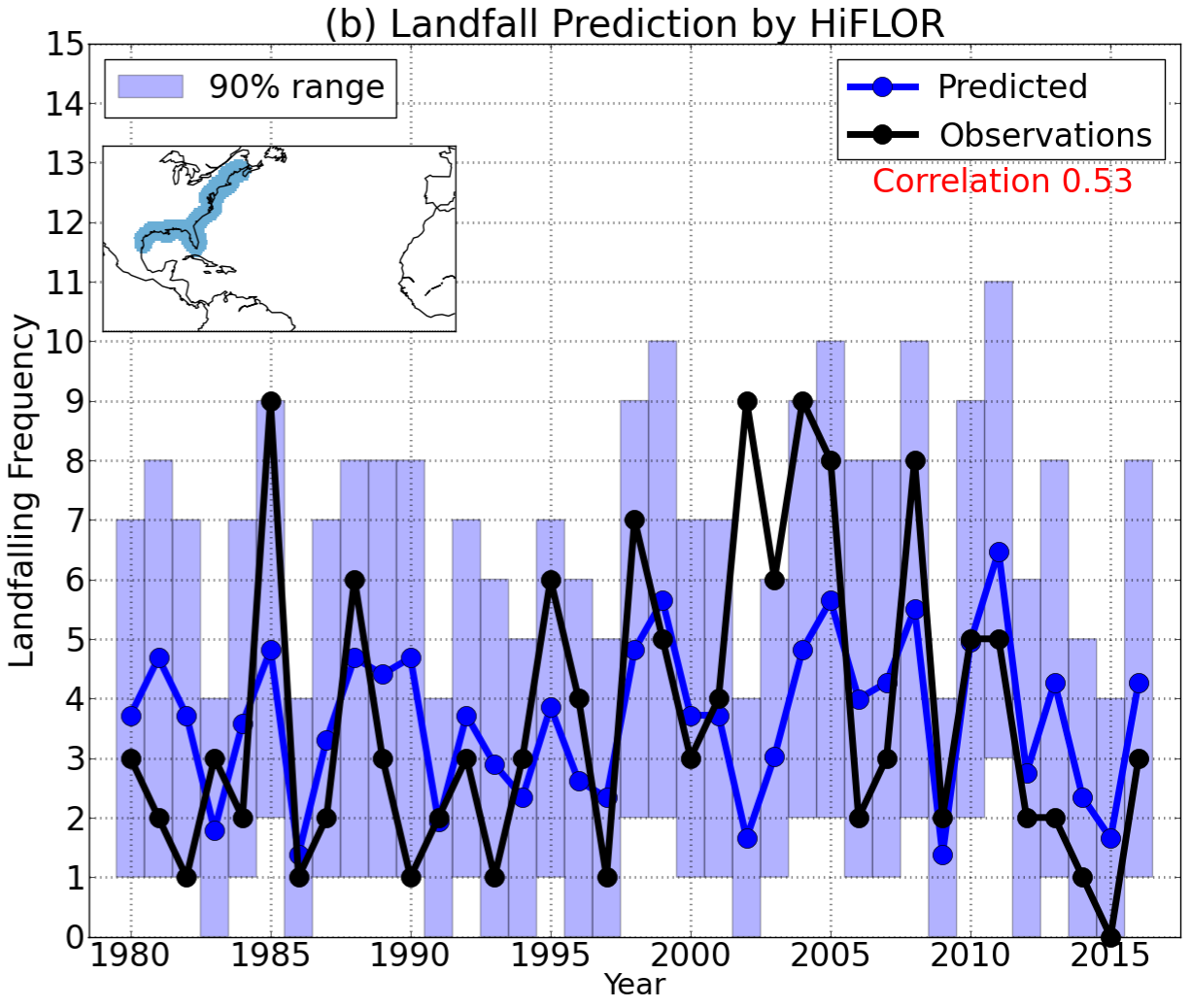


Camp et al. (2018)



HiFLOR Prediction from Geophysical Fluid Dynamics Laboratory

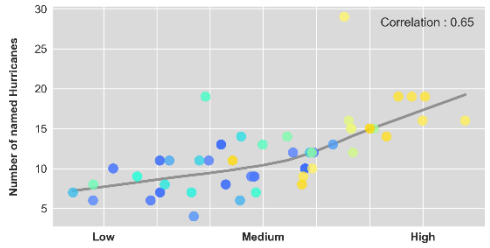




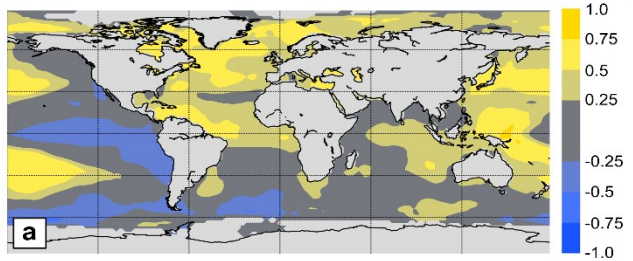
Methodology – From reask

Physical feature selection

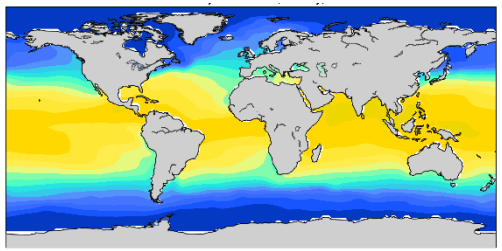
1 – Correlation to number of TC



2 – Correlation with ASO patterns

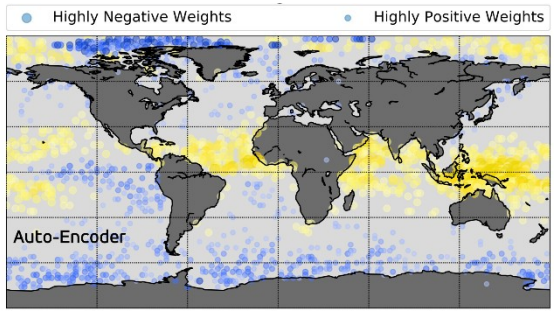


Monthly reanalysis



Dimensionality Reduction

- PCA
- Auto-Encoders



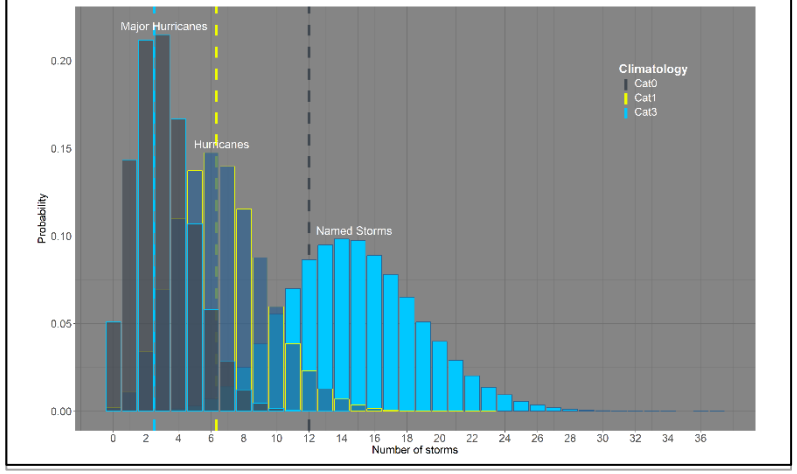
Unsupervised learning

Statistical selection

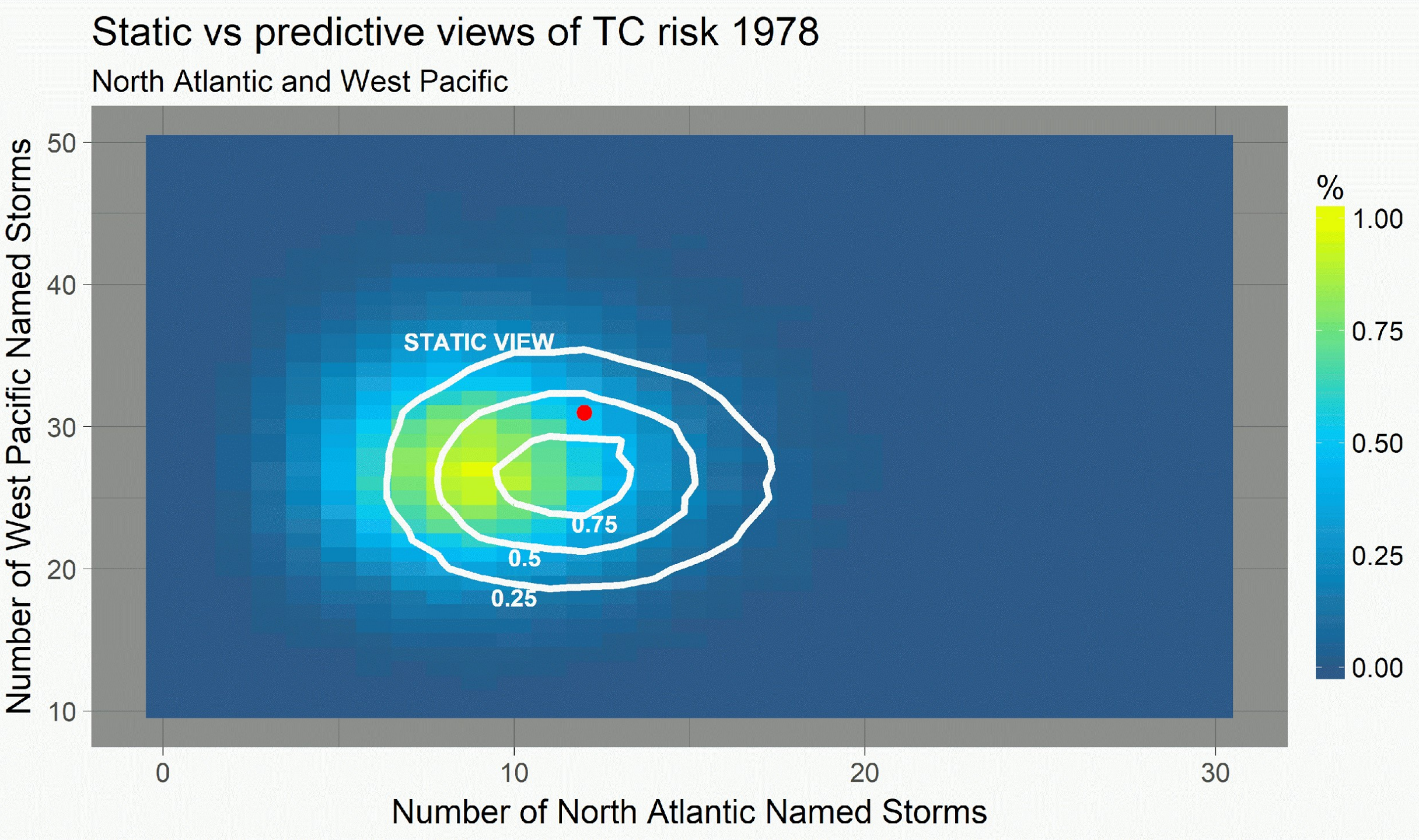
Ensemble of models

~ 10 selected over 10k

Predictive Bayesian model



Supervised learning

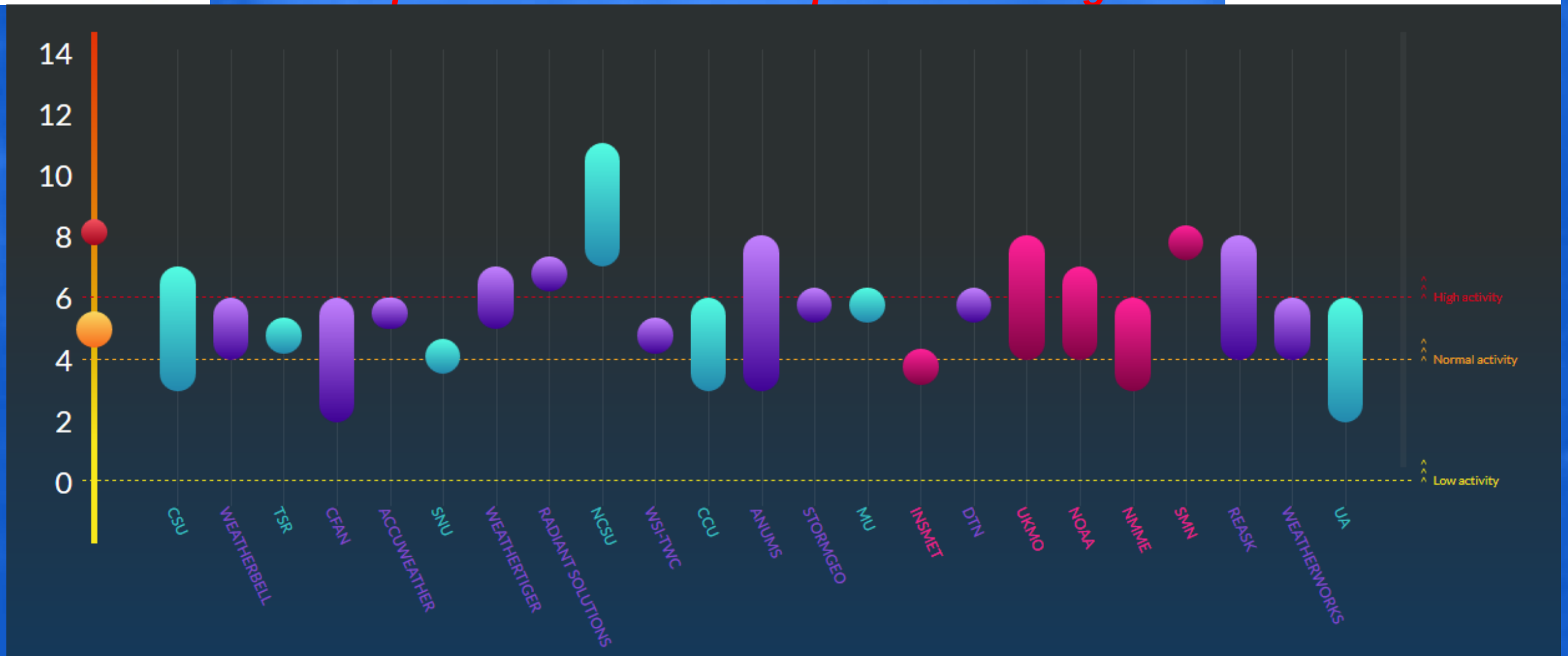

Static vs predictive views of TC risk 1978
North Atlantic and West Pacific
Number of West Pacific Named Storms
50
40
30
20
10
STATIC VIEW
0.75
0.5
0.25
0
10
20
30
Number of North Atlantic Named Storms
%
1.00
0.75
0.50
0.25
0.00

http://www.seasonalhurricanepredictions.org

Contributing Forecast Groups

Seasonal Hurricane Forecast Compilation Website

http://seasonalhurricanepredictions.org



New Product from CSU

Real-Time Global Tropical Cyclone Statistics Website:

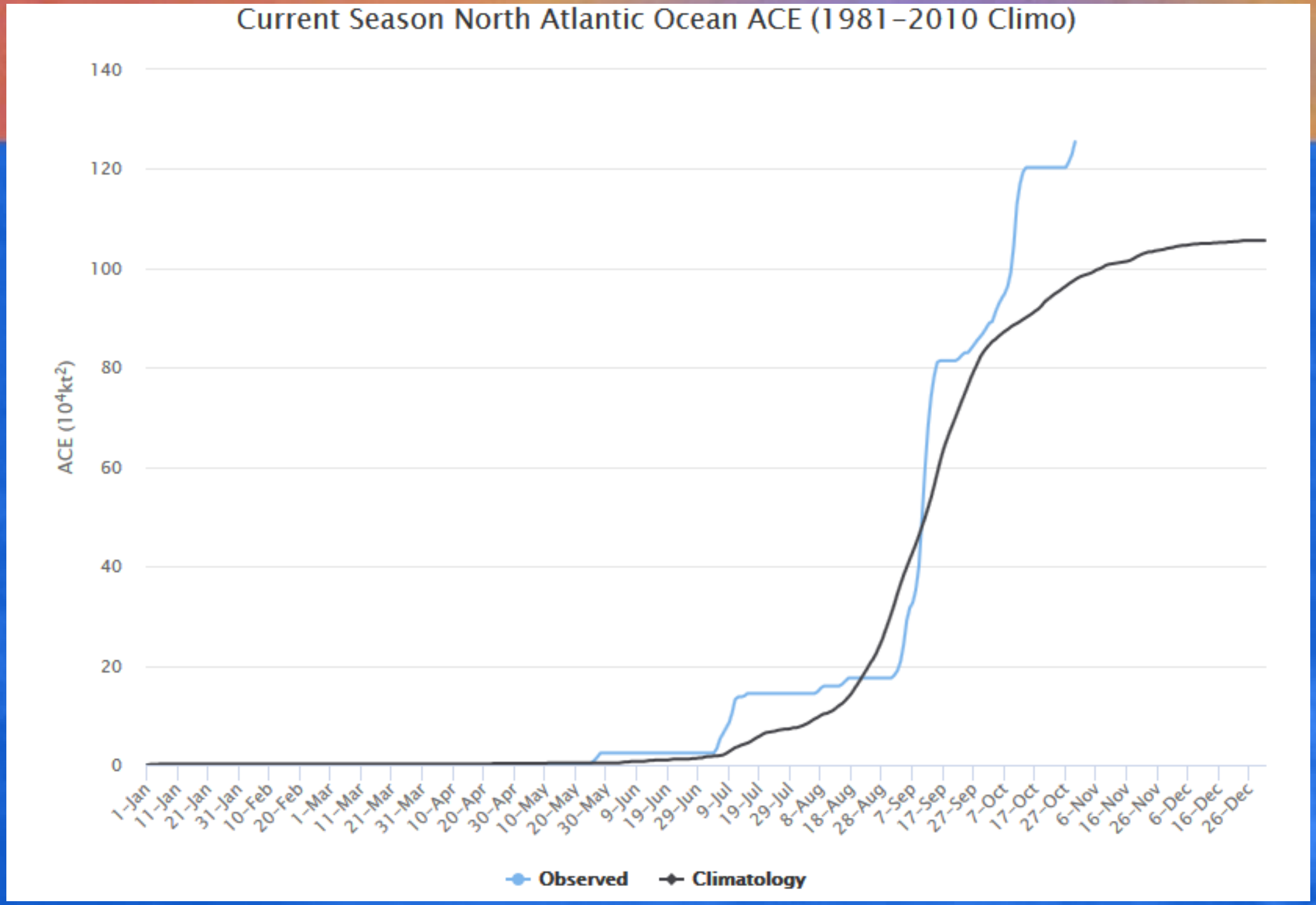
http://tropical.atmos.colostate.edu/Realtime/

Northern Hemisphere Tropical Cyclone Activity for 2018 (2018/2019 for the Southern Hemisphere)

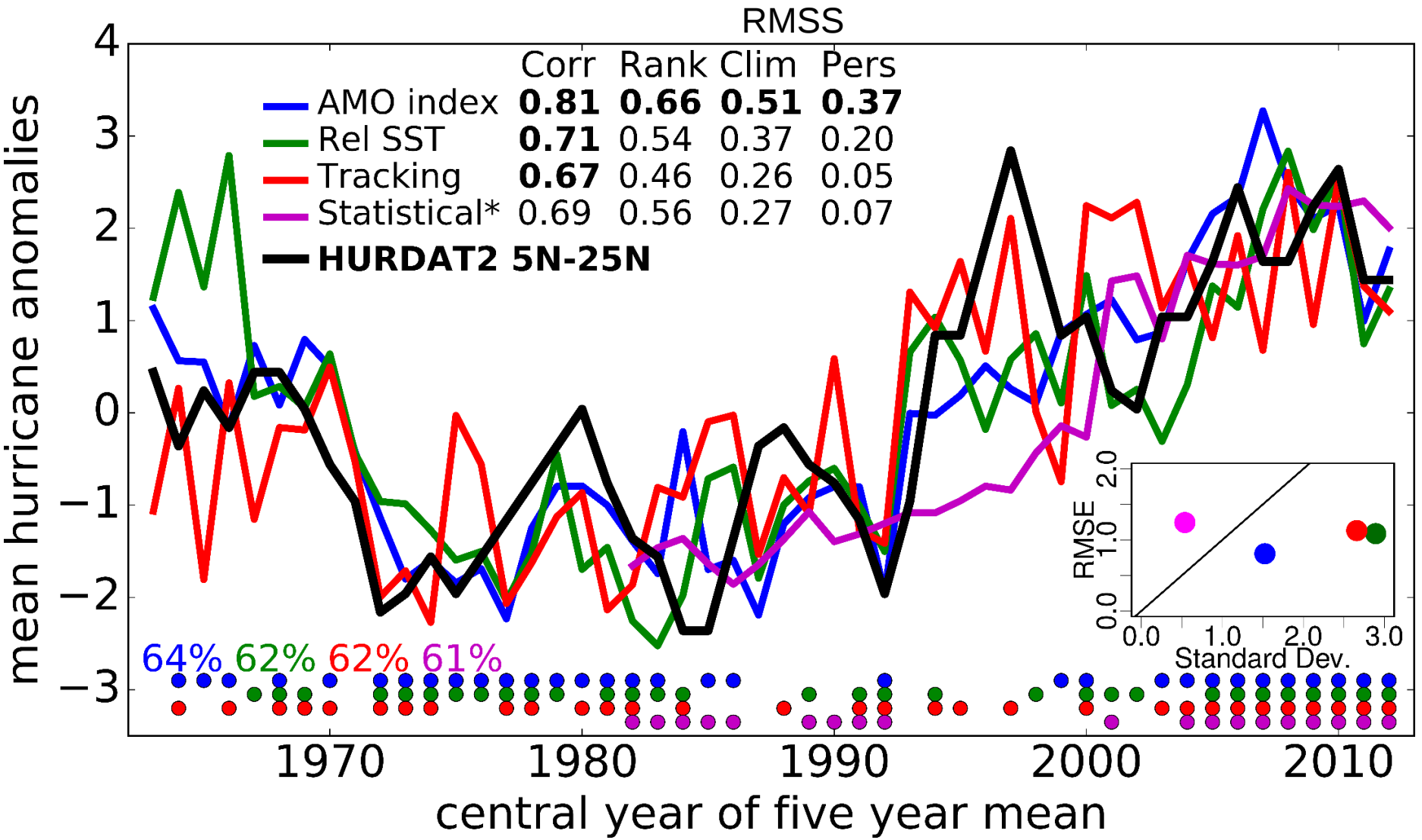
1981-2010 Climatological Activity Through October 30 in Parentheses

Basin	Named Storms	Named Storm Days	Hurricanes	Hurricane Days	Major Hurricanes	Major Hurricane Days	Accumulated Cyclone Energy
North Atlantic	15 (11.1)	86.25 (53.9)	8 (5.8)	25.75 (22.4)	2 (2.5)	5.00 (6.0)	127.0 (97.7)
Northeast Pacific (East of 180°)	22 (16.2)	123.25 (71.5)	13 (8.7)	67.50 (29.5)	10 (4.3)	35.00 (8.9)	313.5 (129.7)
Northwest Pacific (West of 180°)	26 (22.6)	128.50 (116.3)	14 (14.3)	60.25 (56.7)	9 (7.3)	29.00 (19.1)	320.7 (250.3)
North Indian	5 (3.0)	15.75 (8.0)	3 (0.8)	5.75 (1.7)	1 (0.5)	0.50 (0.7)	23.2 (10.6)
Northern Hemisphere	68 (52.9)	353.75 (249.7)	38 (29.6)	159.25 (110.3)	22 (14.6)	69.50 (34.7)	784.4 (488.3)
South Indian (West of 135°E)	1 (1.0)	1.50 (2.6)	0 (0.1)	0.00 (0.3)	0 (0.0)	0.00 (0.0)	0.8 (2.2)
South Pacific (East of 135°E)	1 (0.1)	1.75 (0.3)	0 (0.0)	0.00 (0.1)	0 (0.0)	0.00 (0.0)	0.9 (0.5)
Southern Hemisphere	2 (1.1)	3.25 (2.9)	0 (0.1)	0.00 (0.4)	0 (0.0)	0.00 (0.0)	1.7 (2.7)

Global statistics were last modified: October 30 2018 09:00 MT


Current Season North Atlantic Ocean ACE (1981–2010 Climo)
ACE (10^4kt^2)
140
120
100
80
60
40
20
0
1-Jan
11-Jan
21-Jan
31-Jan
10-Feb
20-Feb
1-Mar
11-Mar
21-Mar
31-Mar
10-Apr
20-Apr
30-Apr
10-May
20-May
30-May
9-Jun
19-Jun
29-Jun
9-Jul
19-Jul
29-Jul
8-Aug
18-Aug
28-Aug
7-Sep
17-Sep
27-Sep
7-Oct
17-Oct
27-Oct
6-Nov
16-Nov
26-Nov
6-Dec
16-Dec
26-Dec
Observed
Climatology

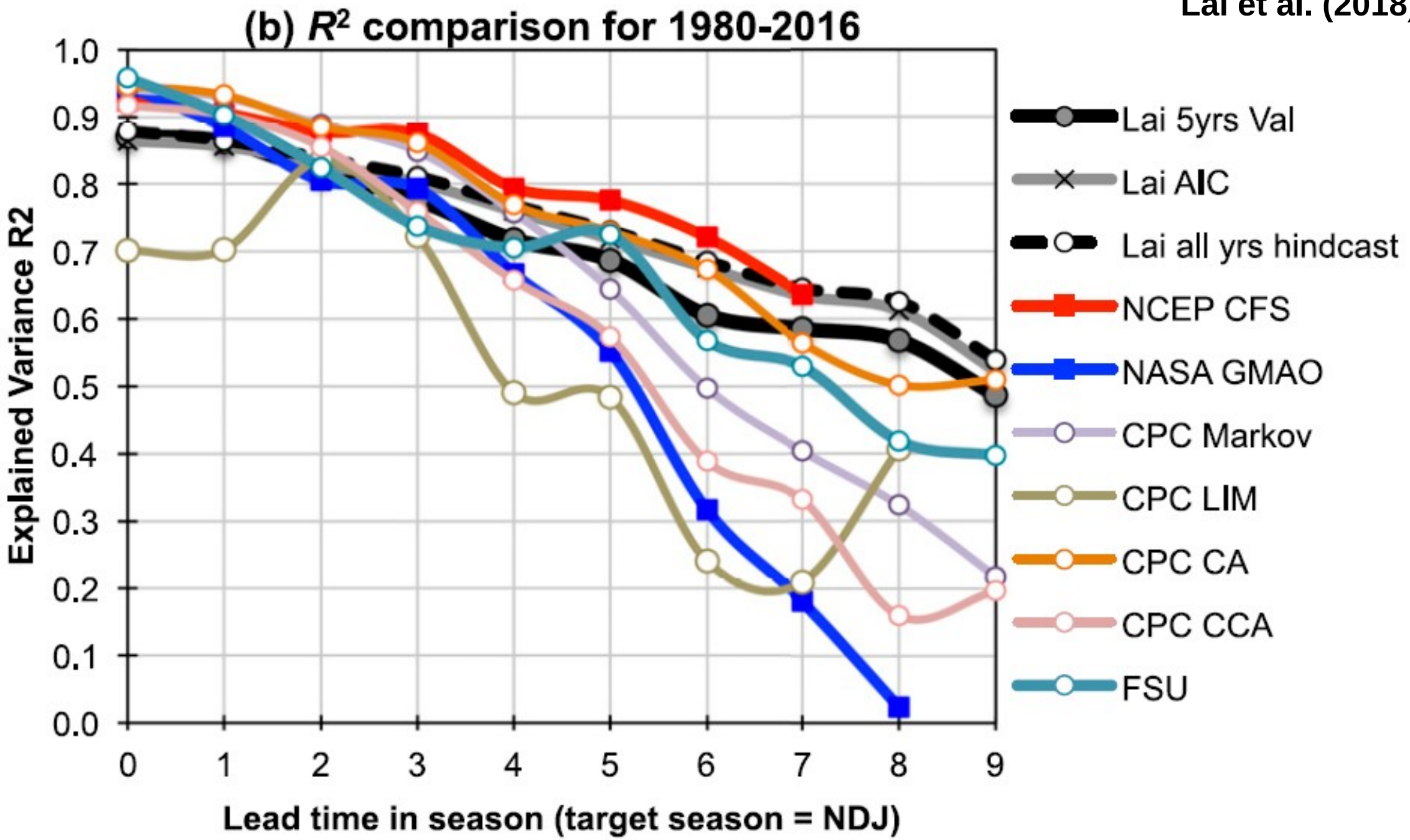
Skill, average year 1-5



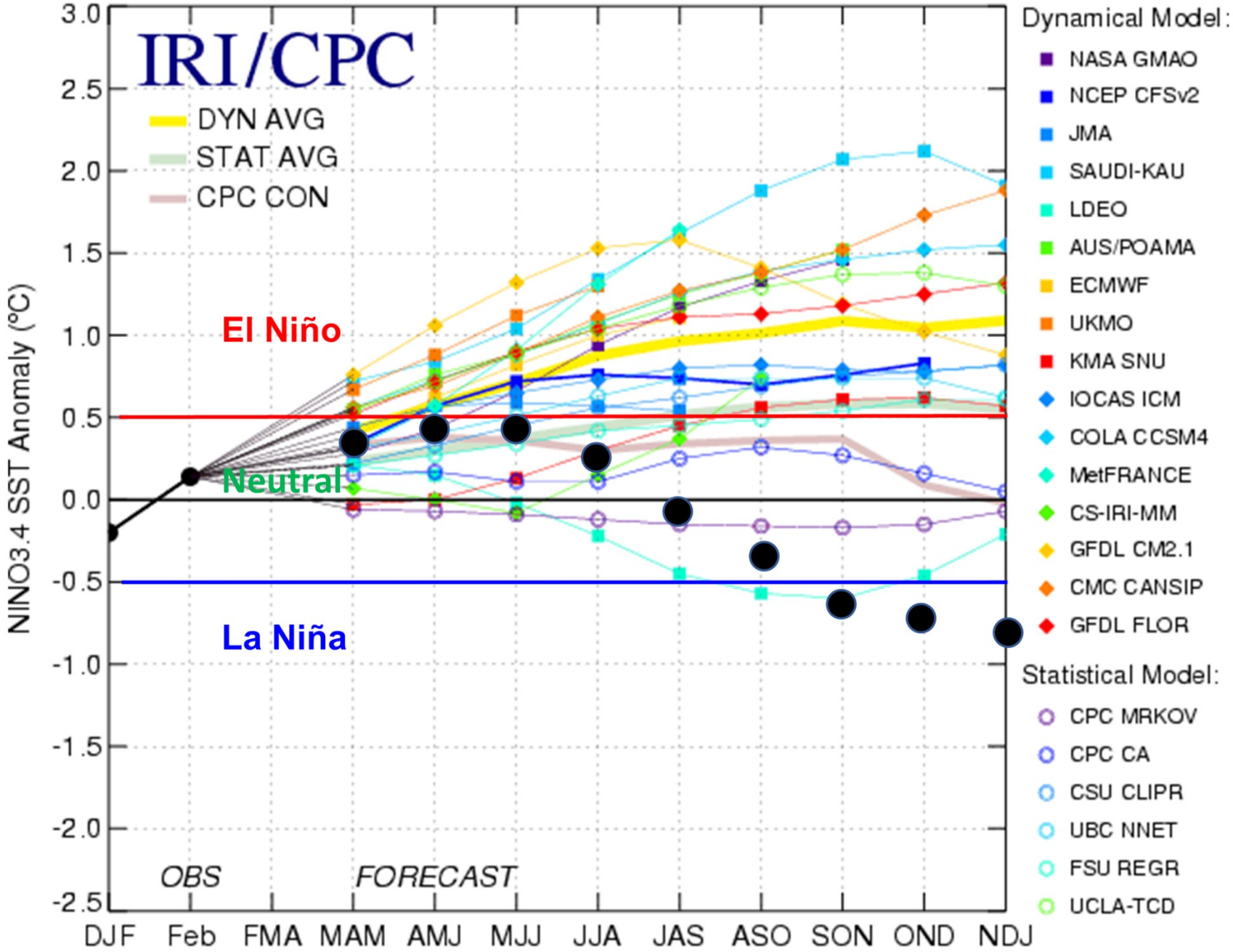
Seasonal Hurricane Forecast Challenges

CSU 1997 Hurricane Forecast Verification Paper – 7 Hurricanes Predicted, 3 Observed

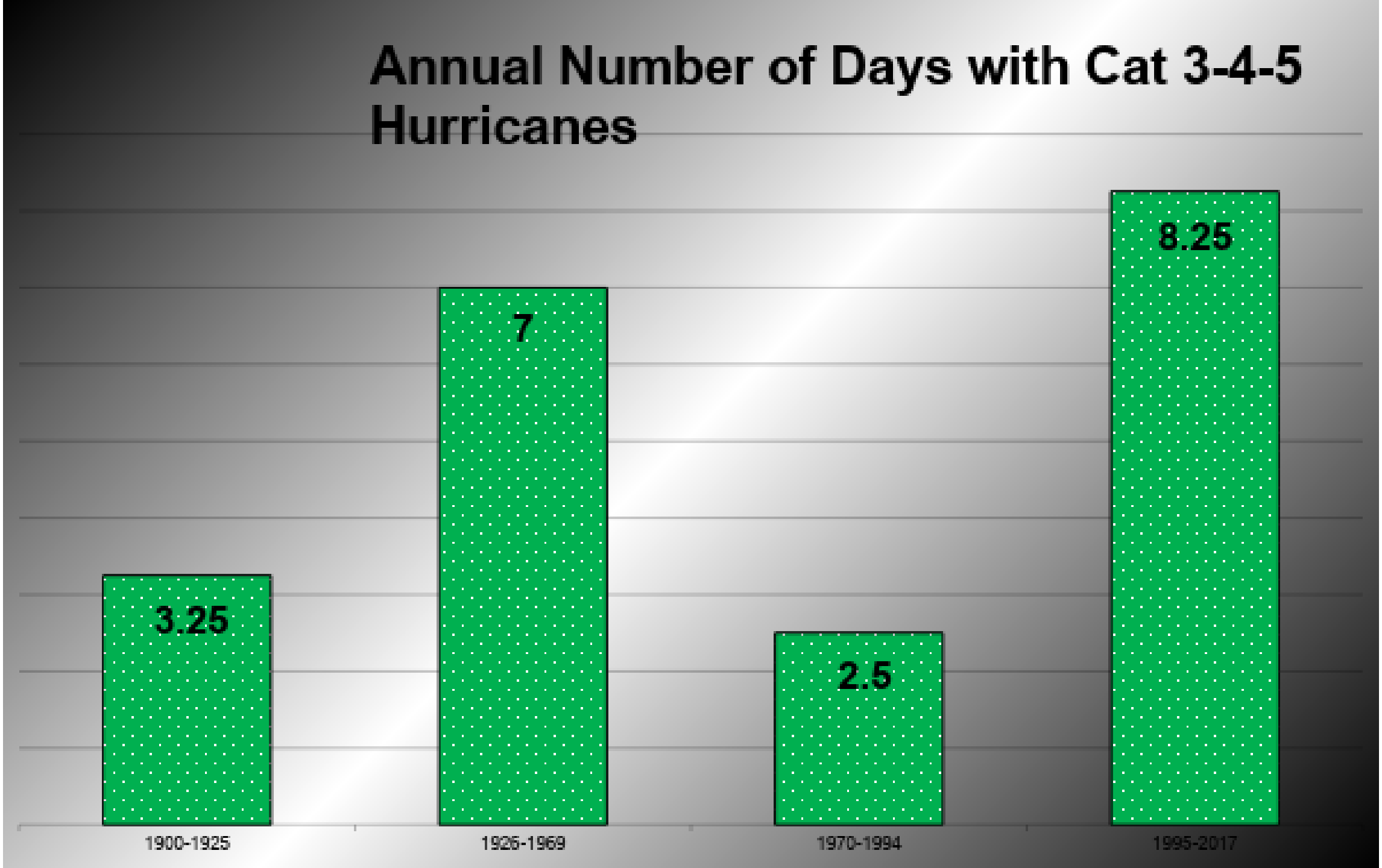
Lai et al. (2018)



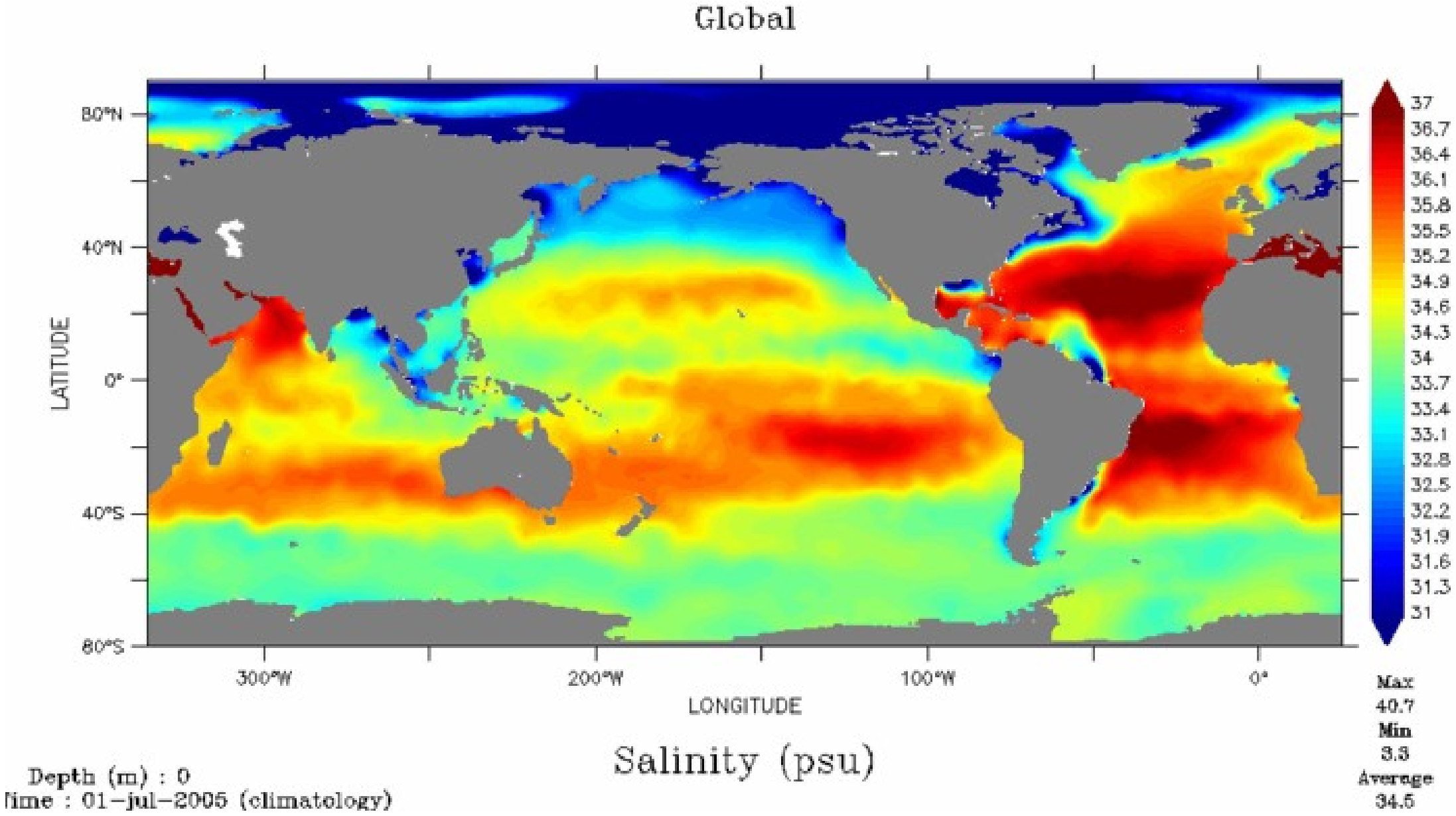
Mid-Mar 2017 Plume of Model ENSO Predictions

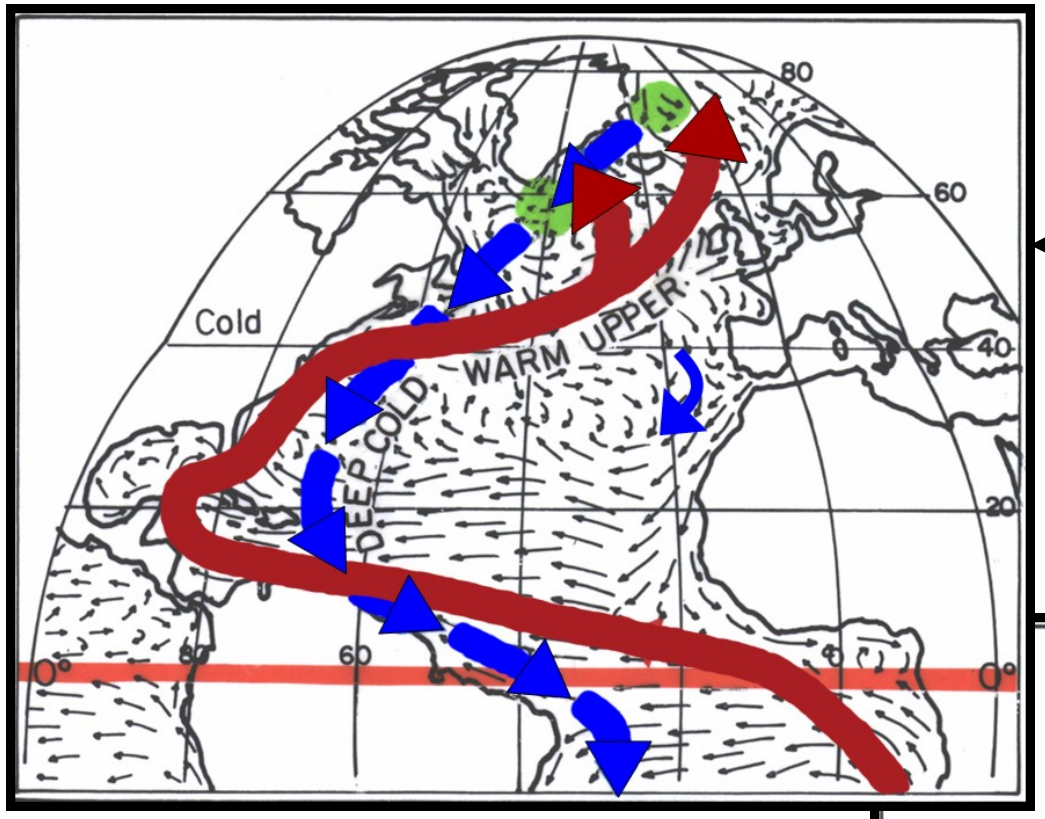


Annual Number of Days with Cat 3-4-5 Hurricanes



GLOBAL SURFACE SALINITY





THC *(or AMO)*

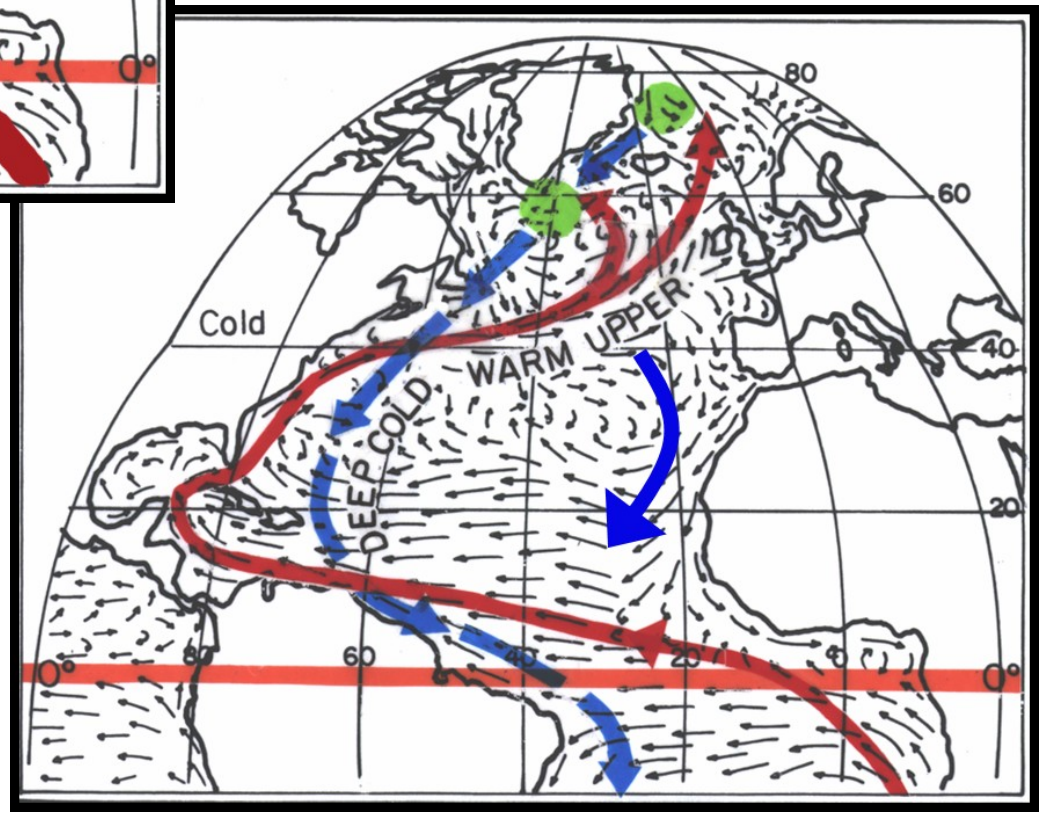
←

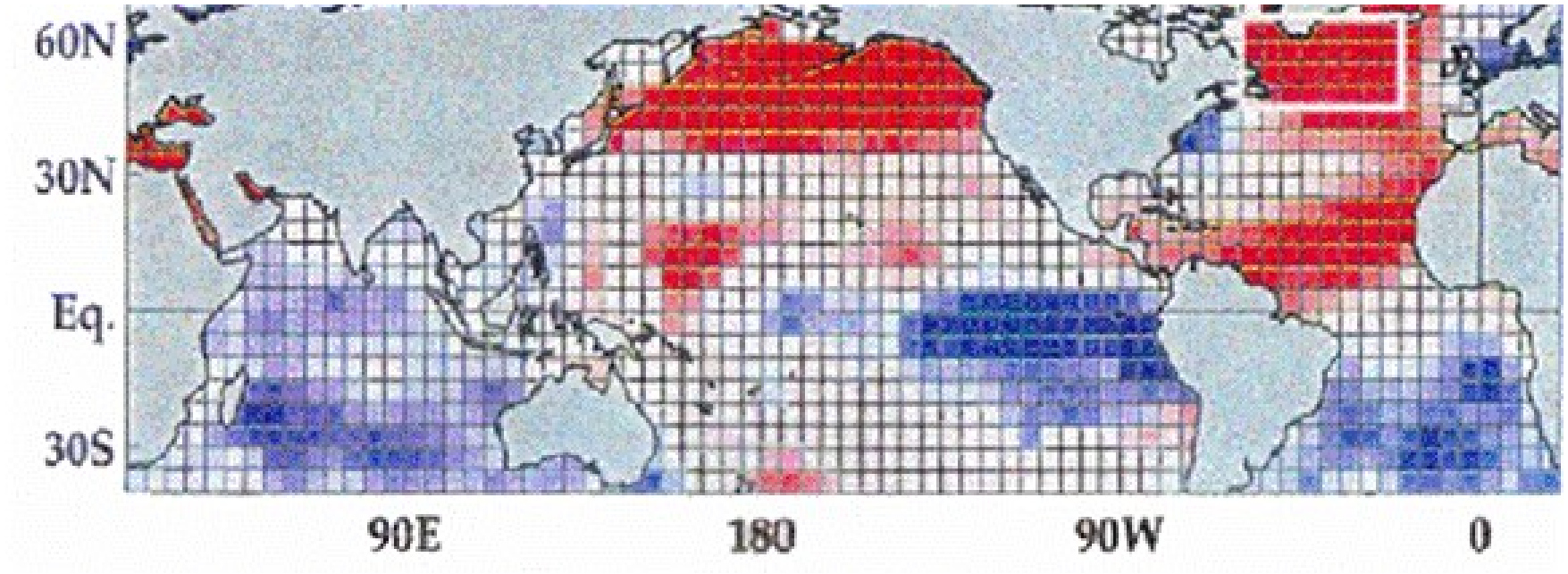
STRONG

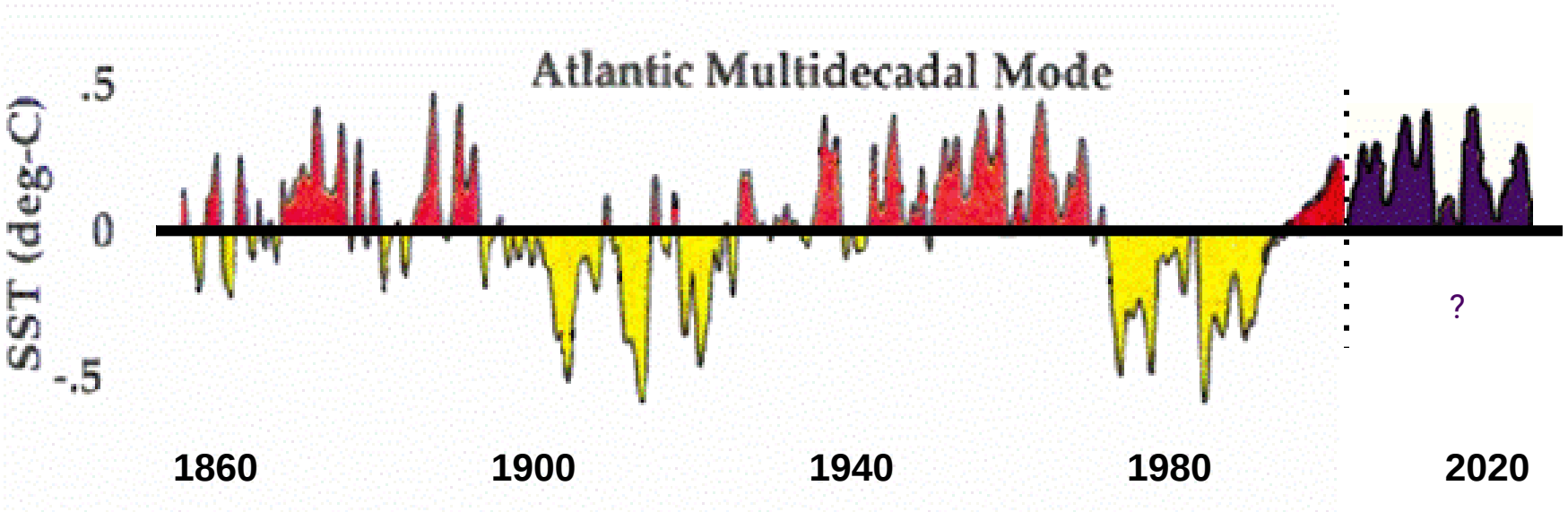
THC *(or AMO)*

→

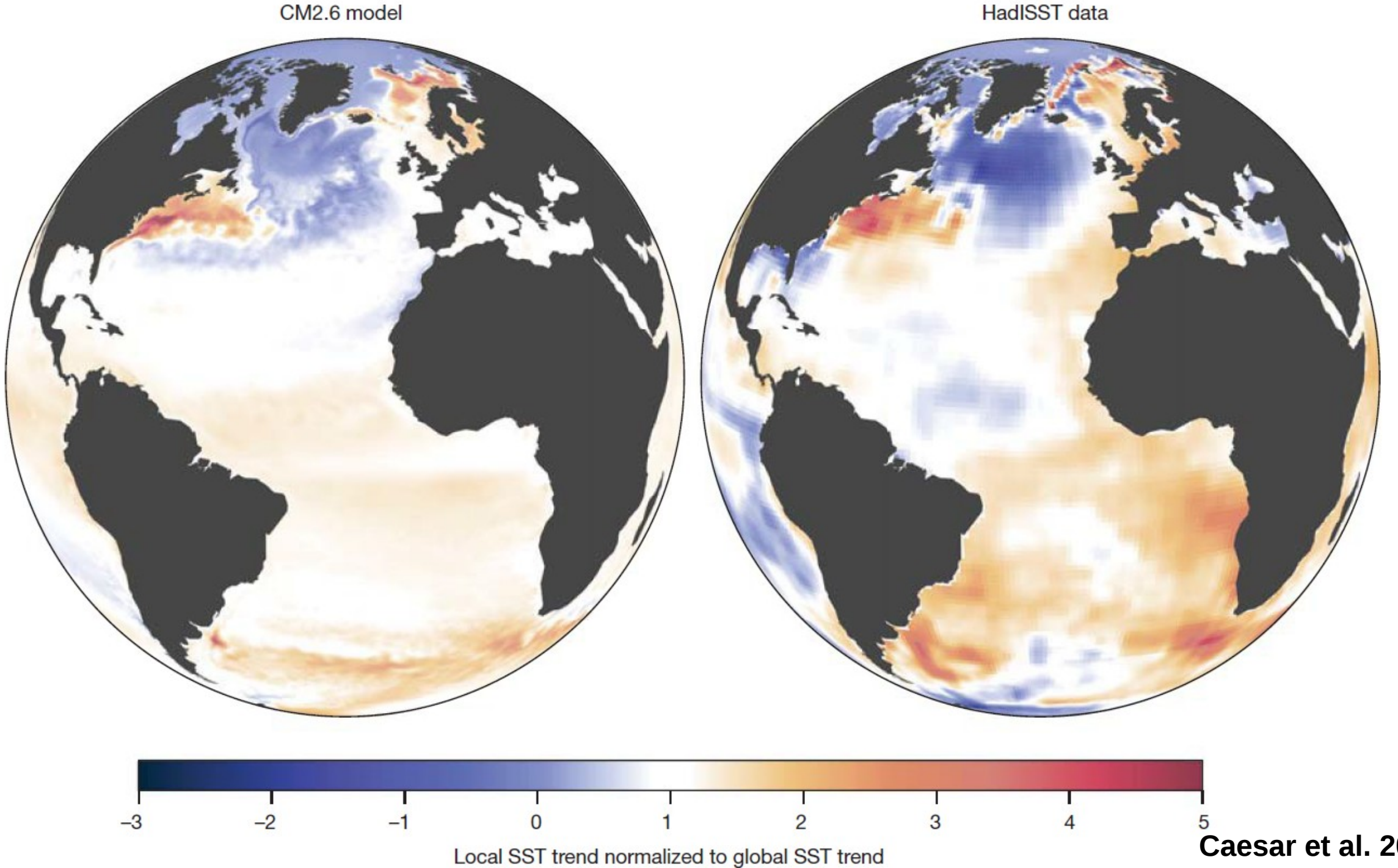
WEAK



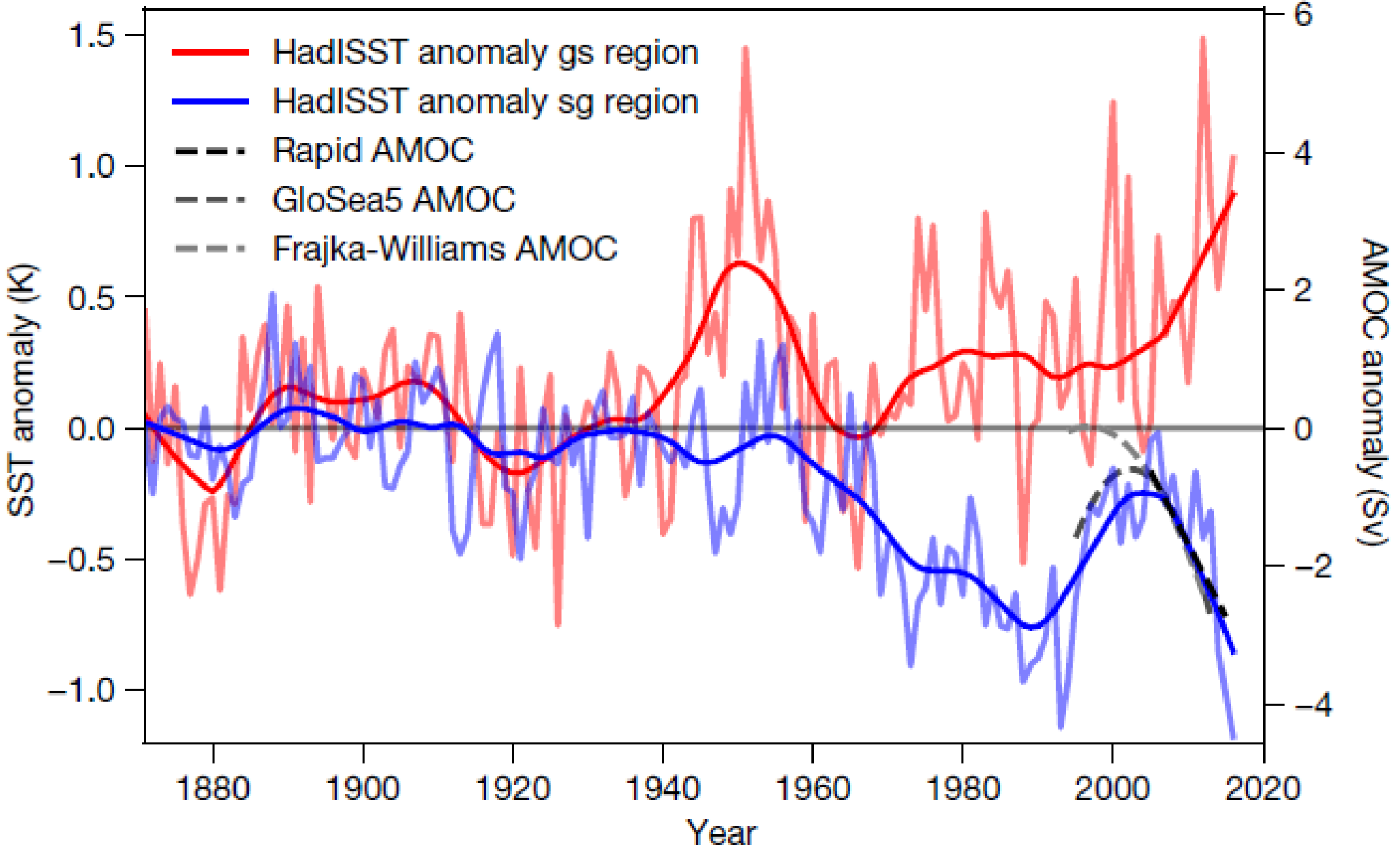


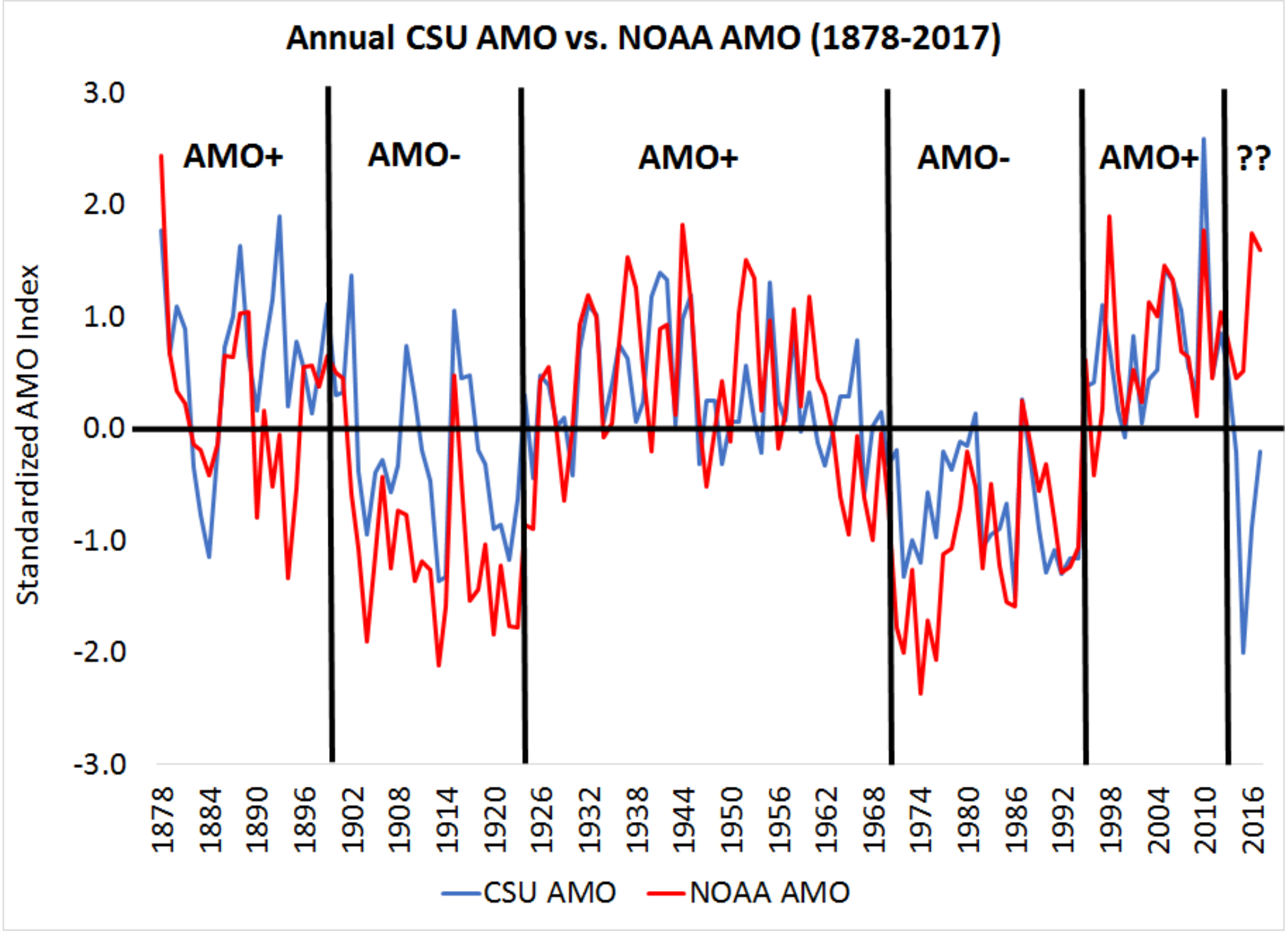


Goldenberg et al. (2001)

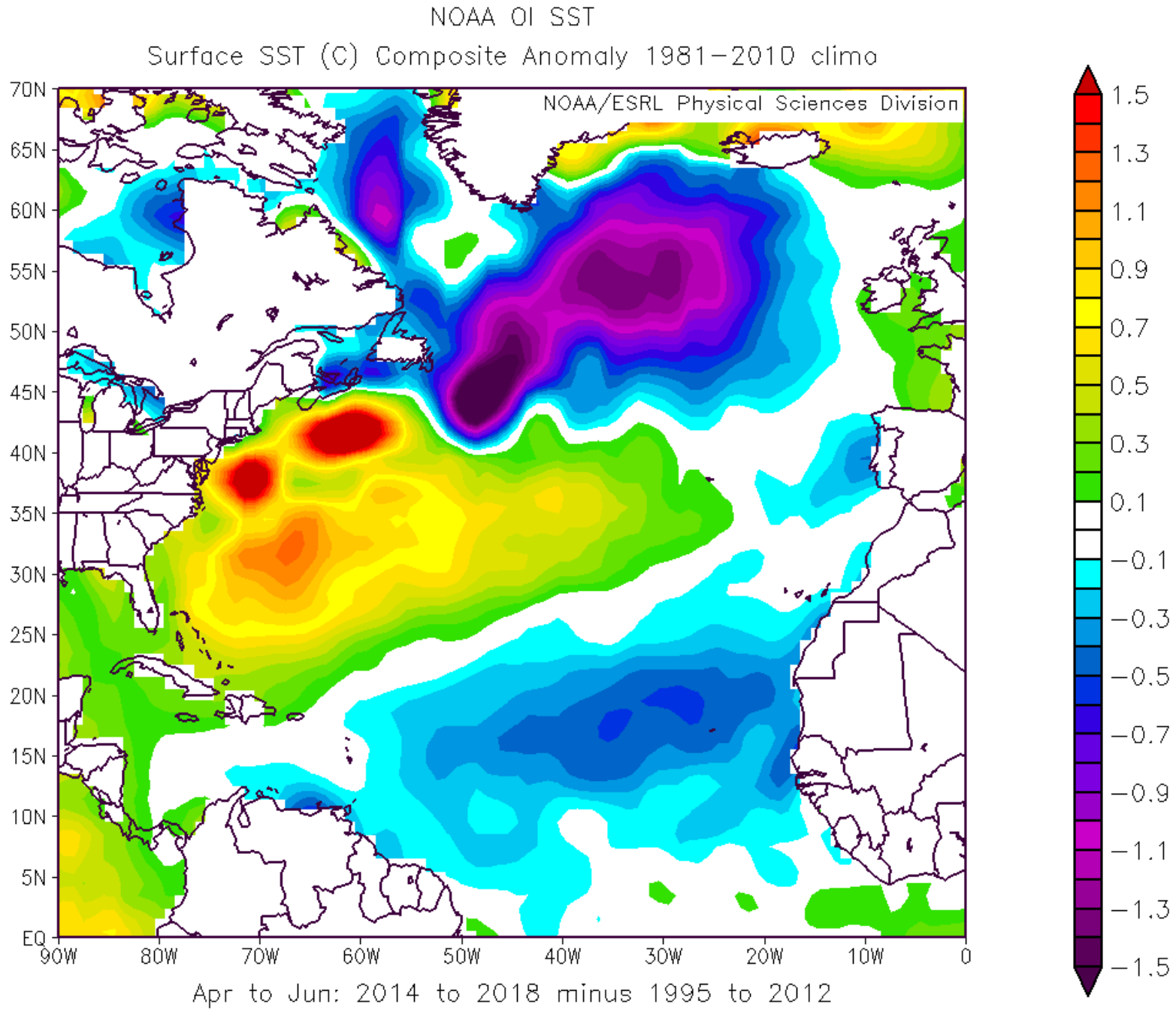


Caesar et al. 2018

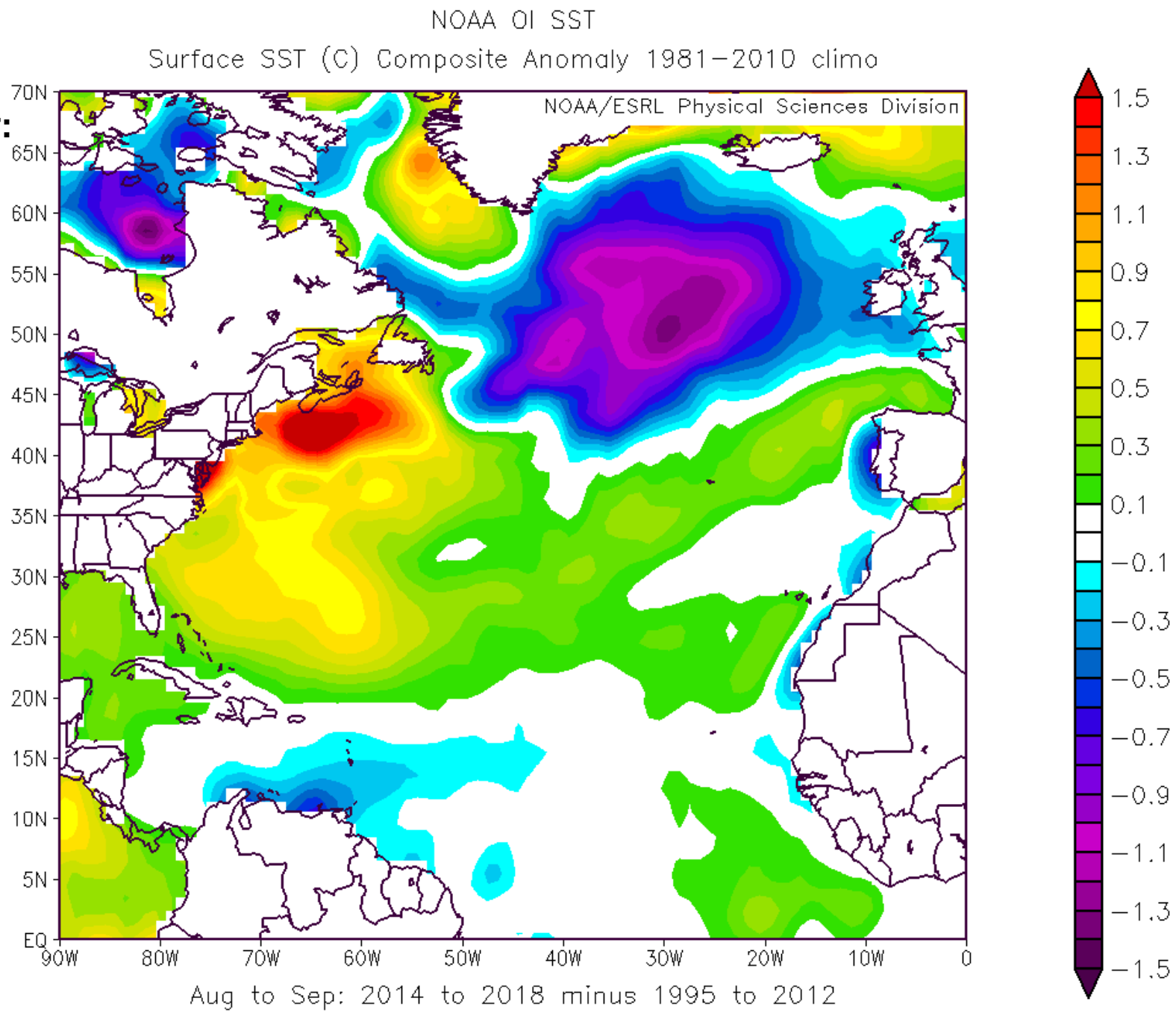

HadISST anomaly gs region
HadISST anomaly sg region
Rapid AMOC
GloSea5 AMOC
Frajka-Williams AMOC
SST anomaly (K)
AMOC anomaly (Sv)
Year
1.5
1.0
0.5
0.0
−0.5
−1.0
6
4
2
0
−2
−4
1880
1900
1920
1940
1960
1980
2000
2020

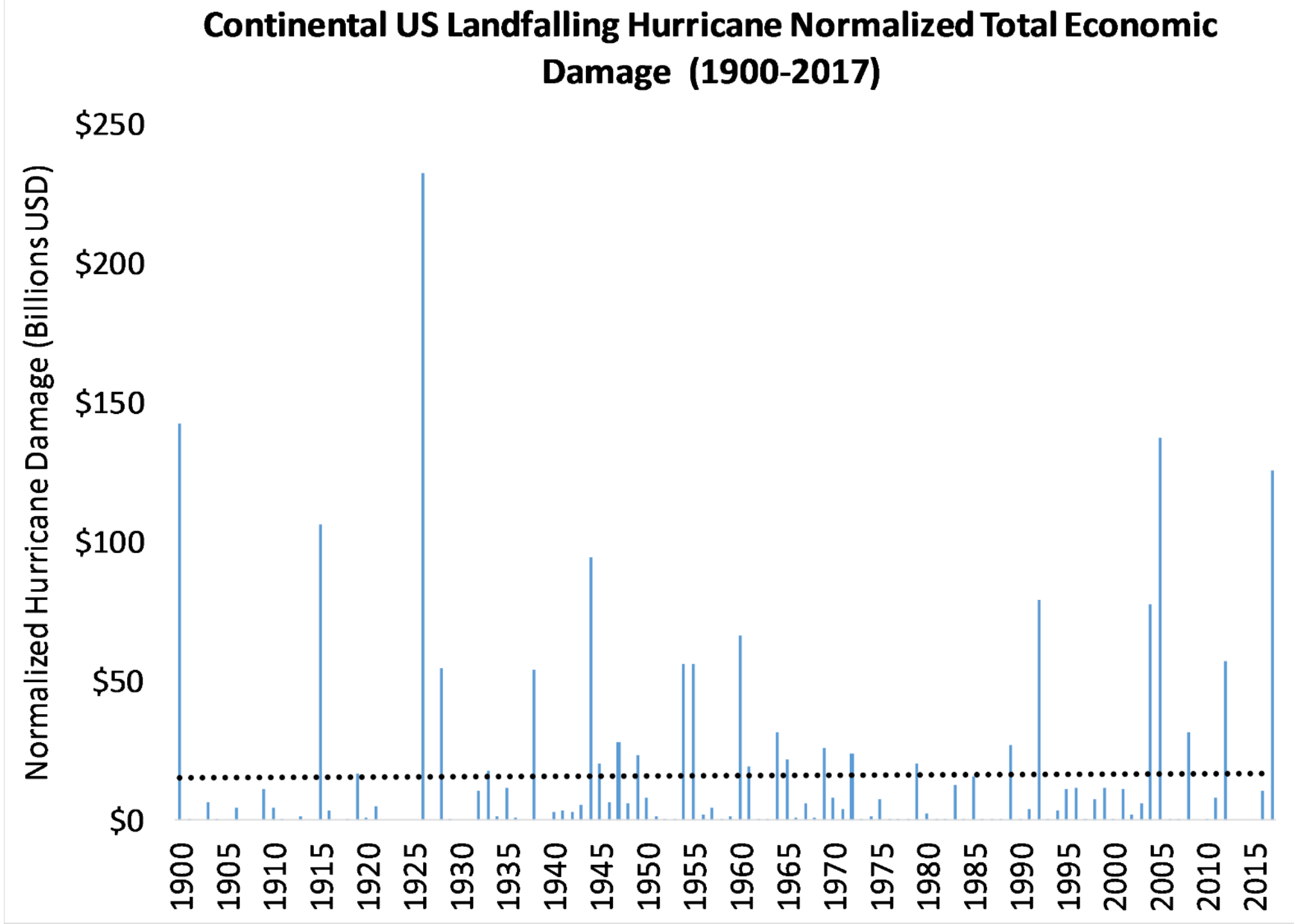

Annual CSU AMO vs. NOAA AMO (1878-2017)
Standardized AMO Index
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
AMO+
AMO-
AMO+
AMO-
AMO+
??
1878
1884
1890
1896
1902
1908
1914
1920
1926
1932
1938
1944
1950
1956
1962
1968
1974
1980
1986
1992
1998
2004
2010
2016
CSU AMO
NOAA AMO

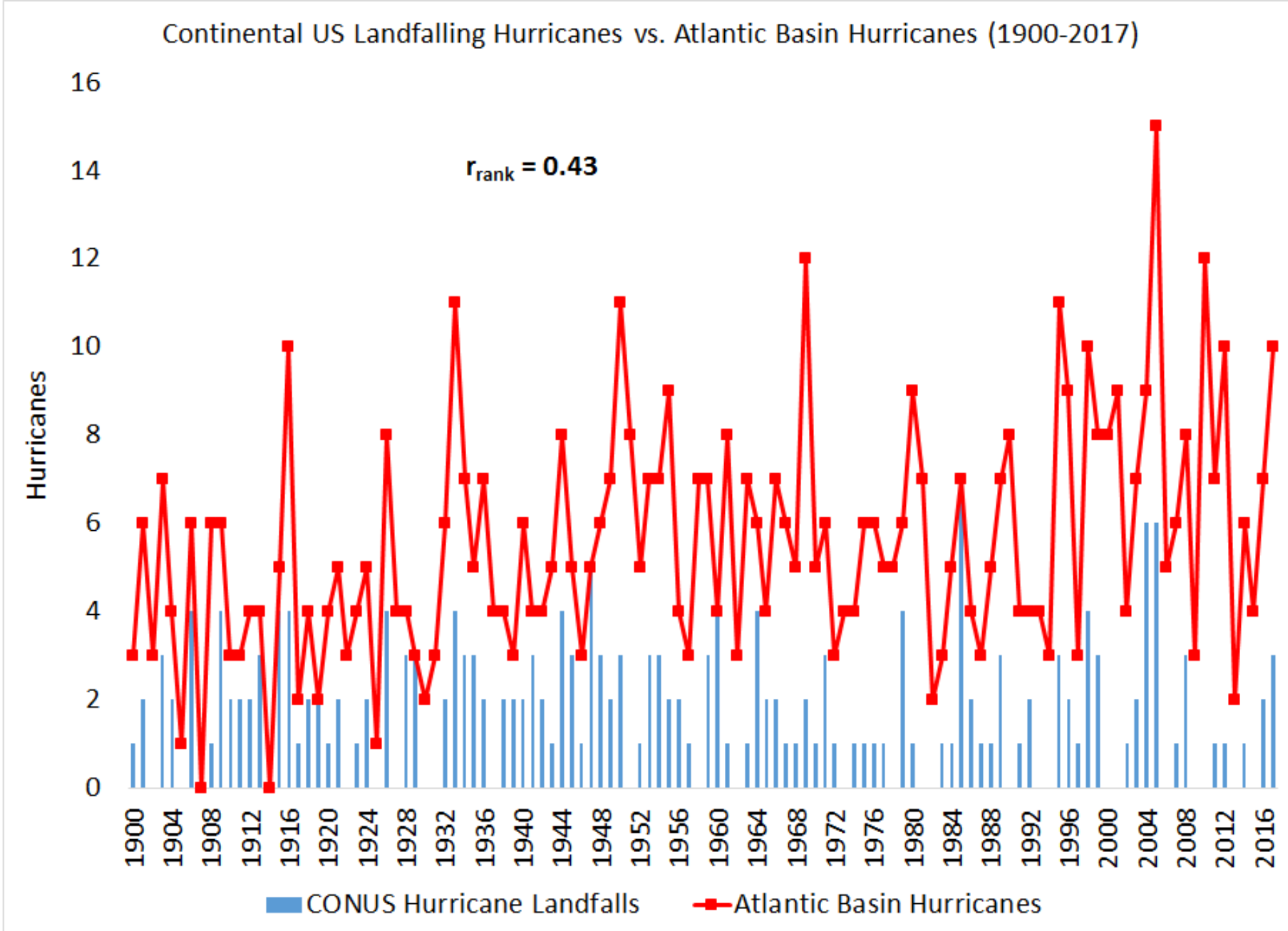
April to June: 2014-2018 minus 1995-2012

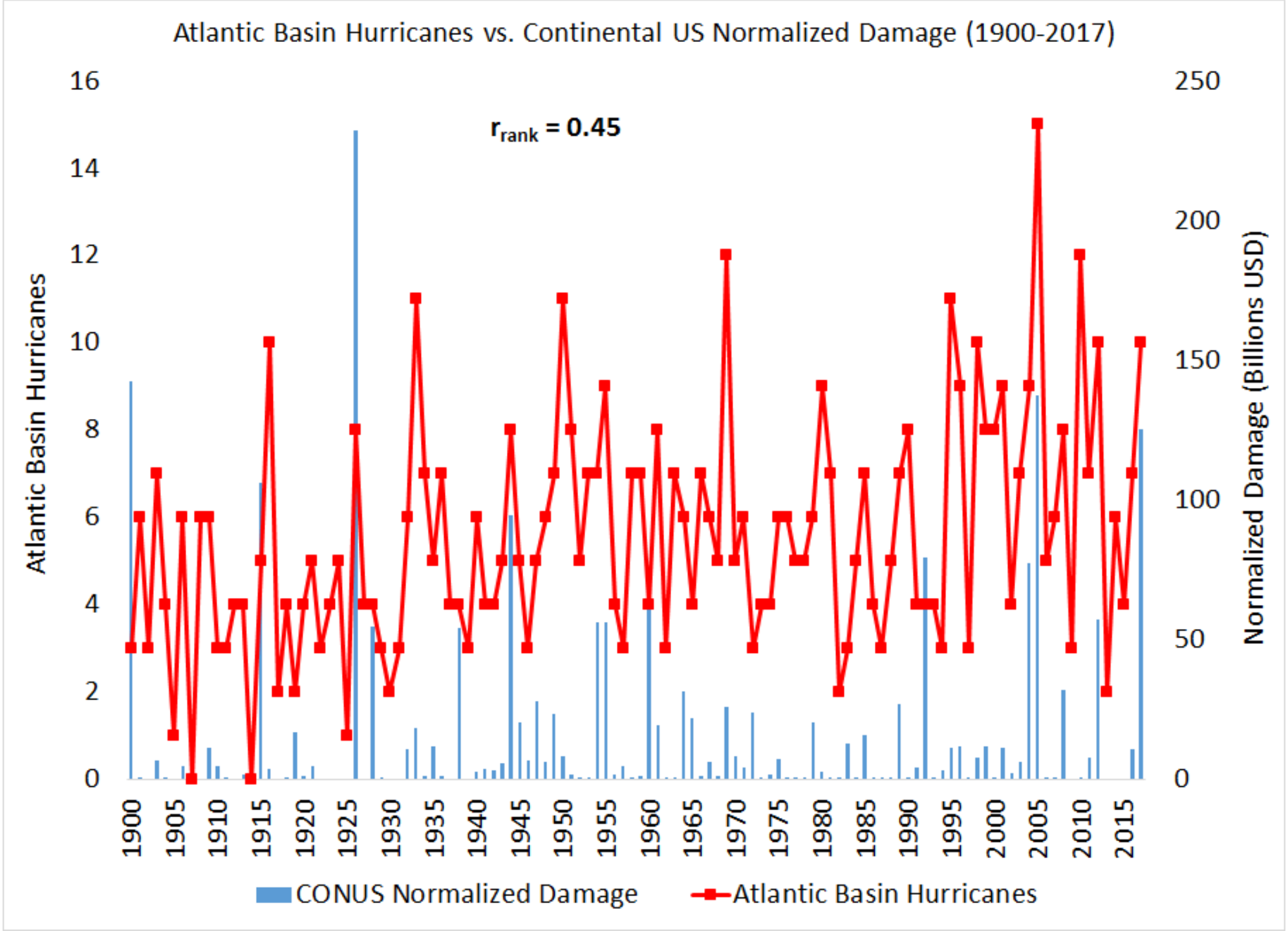


August to September: 2014-2018 minus 1995-2012




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


Continental US Landfalling Hurricanes vs. Atlantic Basin Hurricanes (1900-2017)
r_{rank} = 0.43
Hurricanes
0
2
4
6
8
10
12
14
16
1900
1904
1908
1912
1916
1920
1924
1928
1932
1936
1940
1944
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
CONUS Hurricane Landfalls
Atlantic Basin Hurricanes

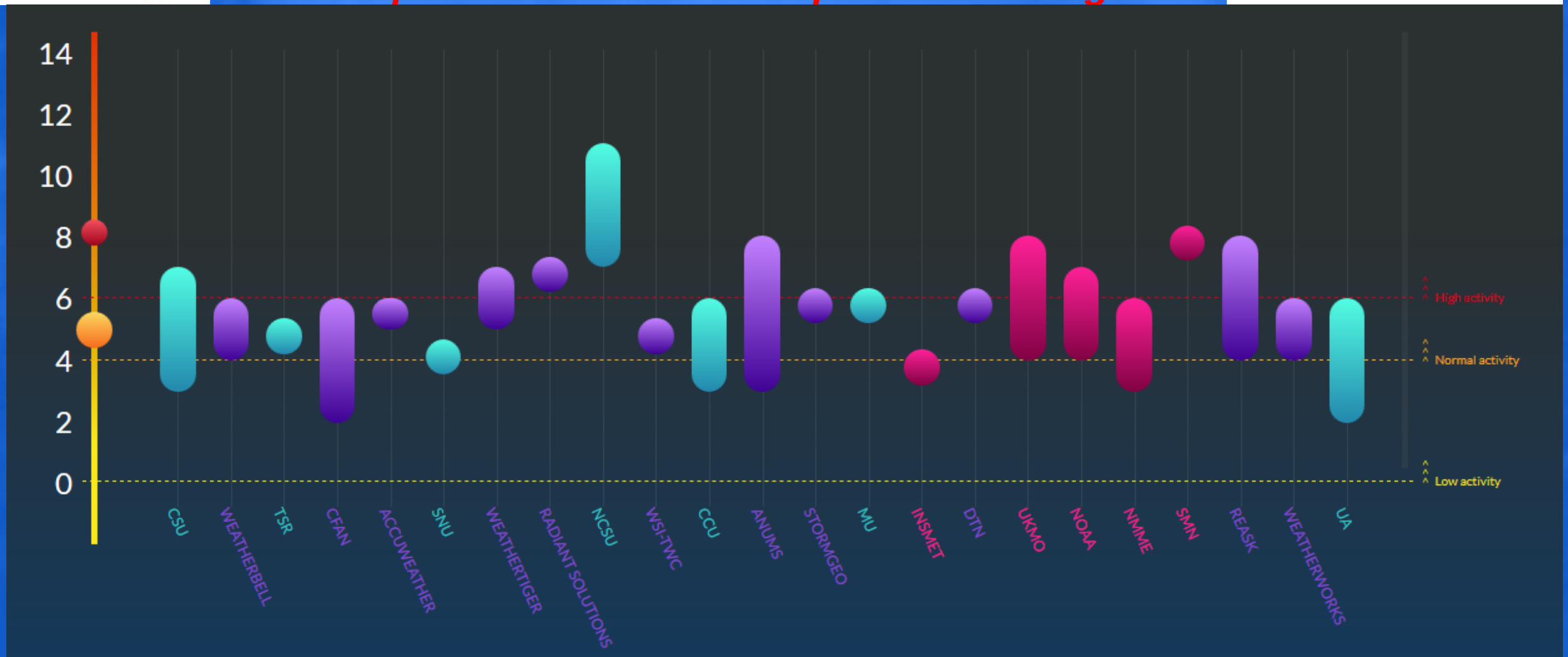

Atlantic Basin Hurricanes vs. Continental US Normalized Damage (1900-2017)
r_{rank} = 0.45
Atlantic Basin Hurricanes
Normalized Damage (Billions USD)
0
2
4
6
8
10
12
14
16
0
50
100
150
200
250
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
CONUS Normalized Damage
Atlantic Basin Hurricanes

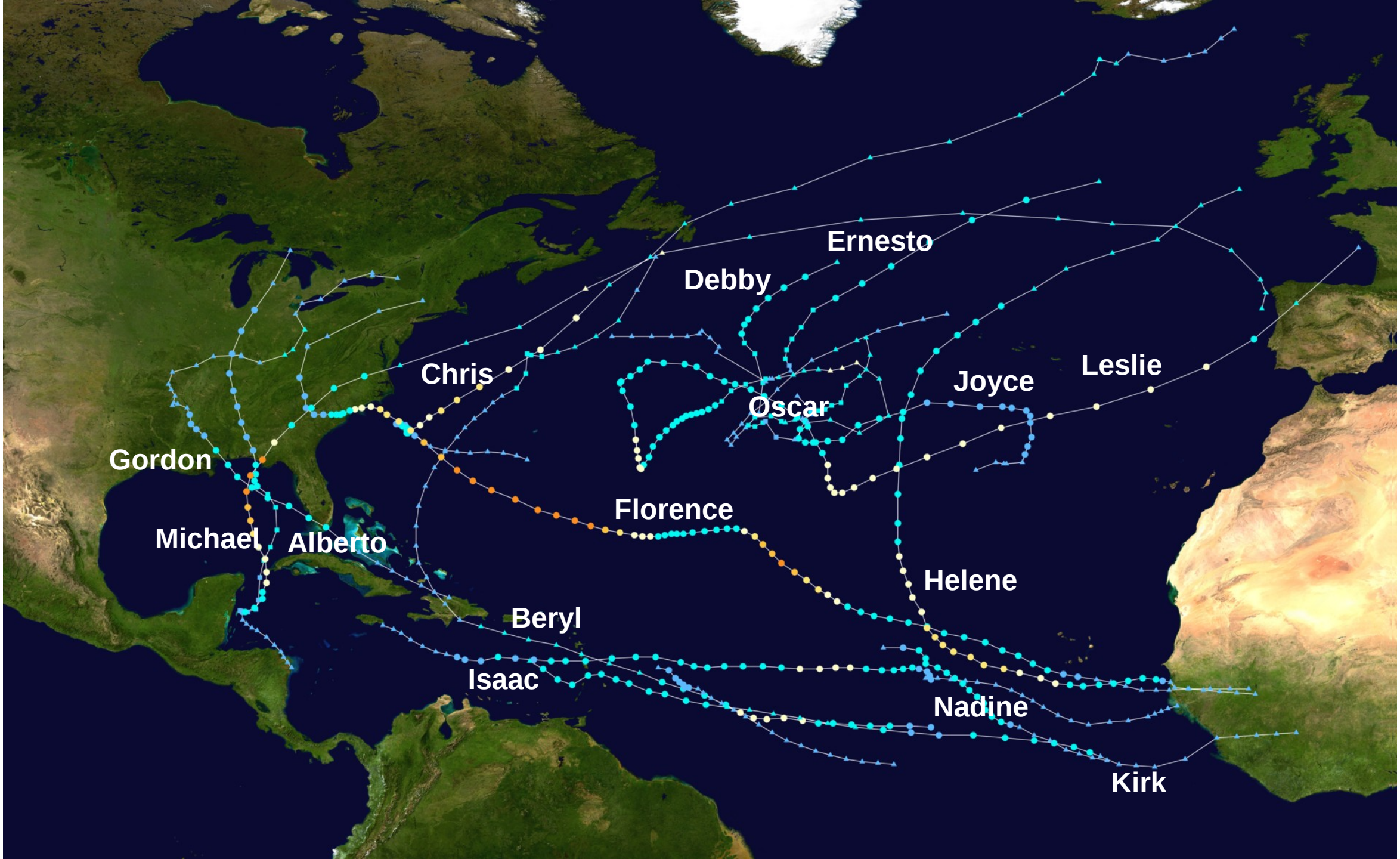
		CSU Forecasts vs. Landfalling Hurricanes (1984-2017)			
		Average	**Average**	**Average**	**Average**
	Years Occurred	Observed Hurricanes	US Landfalling NS	US Landfalling H	US Landfalling MH
June Forecast >= 8 Hurricanes	13	8.1	5.3	2.5	0.9
June Forecast <= 5 Hurricanes	10	4.8	2.4	1.1	0.3
August Forecast >= 8 Hurricanes	12	7.9	4.8	2.4	0.8
August Forecast <= 5 Hurricanes	10	4.2	3.0	1.1	0.3
Observed >= 8 Hurricanes	12	9.8	5.1	2.3	0.8
Observed <= 5 Hurricanes	14	3.8	2.8	0.7	0.1

What Happened in 2018?

Seasonal Hurricane Forecast Compilation Website

http://seasonalhurricanepredictions.org

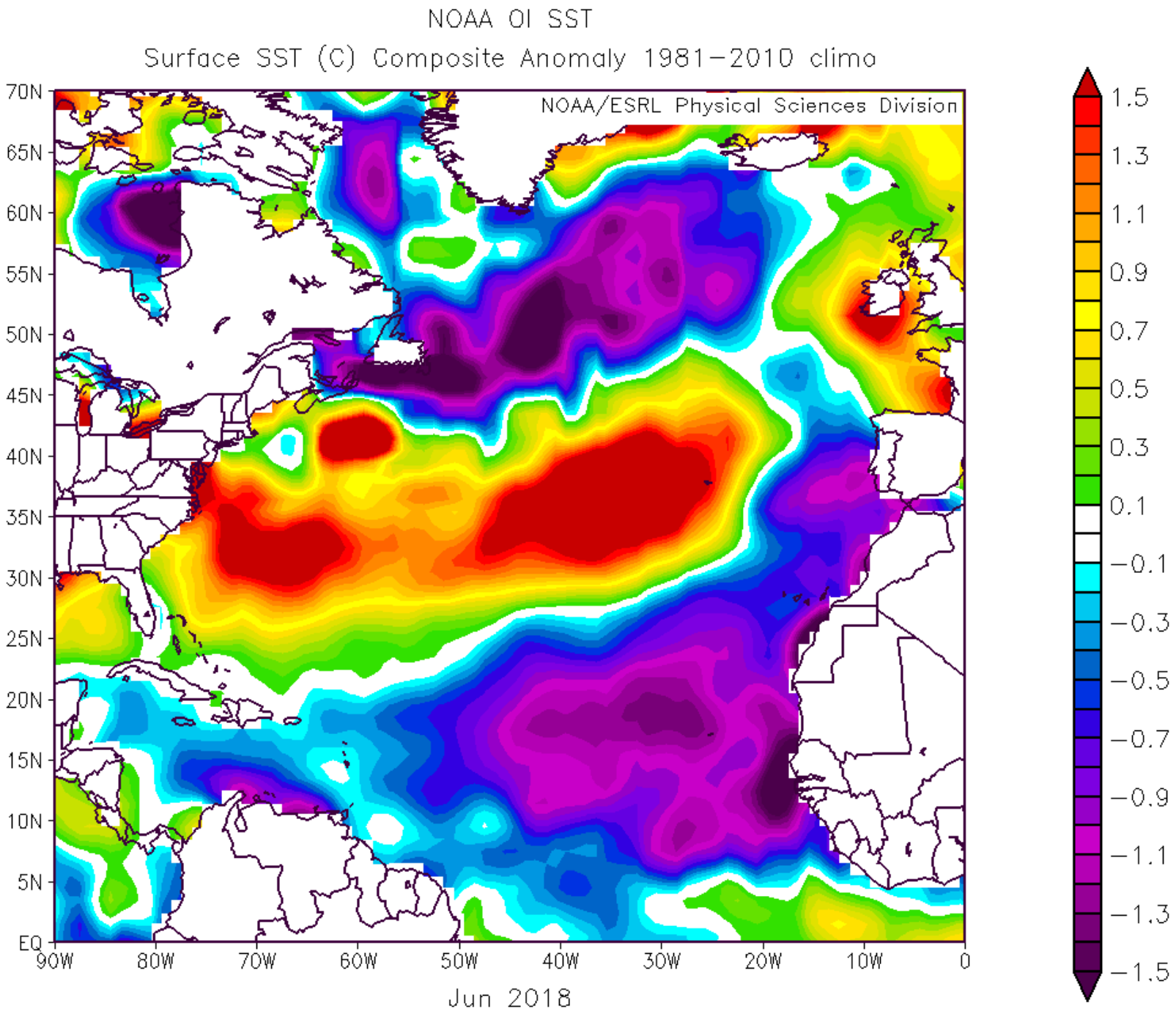



Ernesto
Debby
Chris
Leslie
Joyce
Oscar
Gordon
Florence
Michael
Alberto
Helene
Beryl
Isaac
Nadine
Kirk

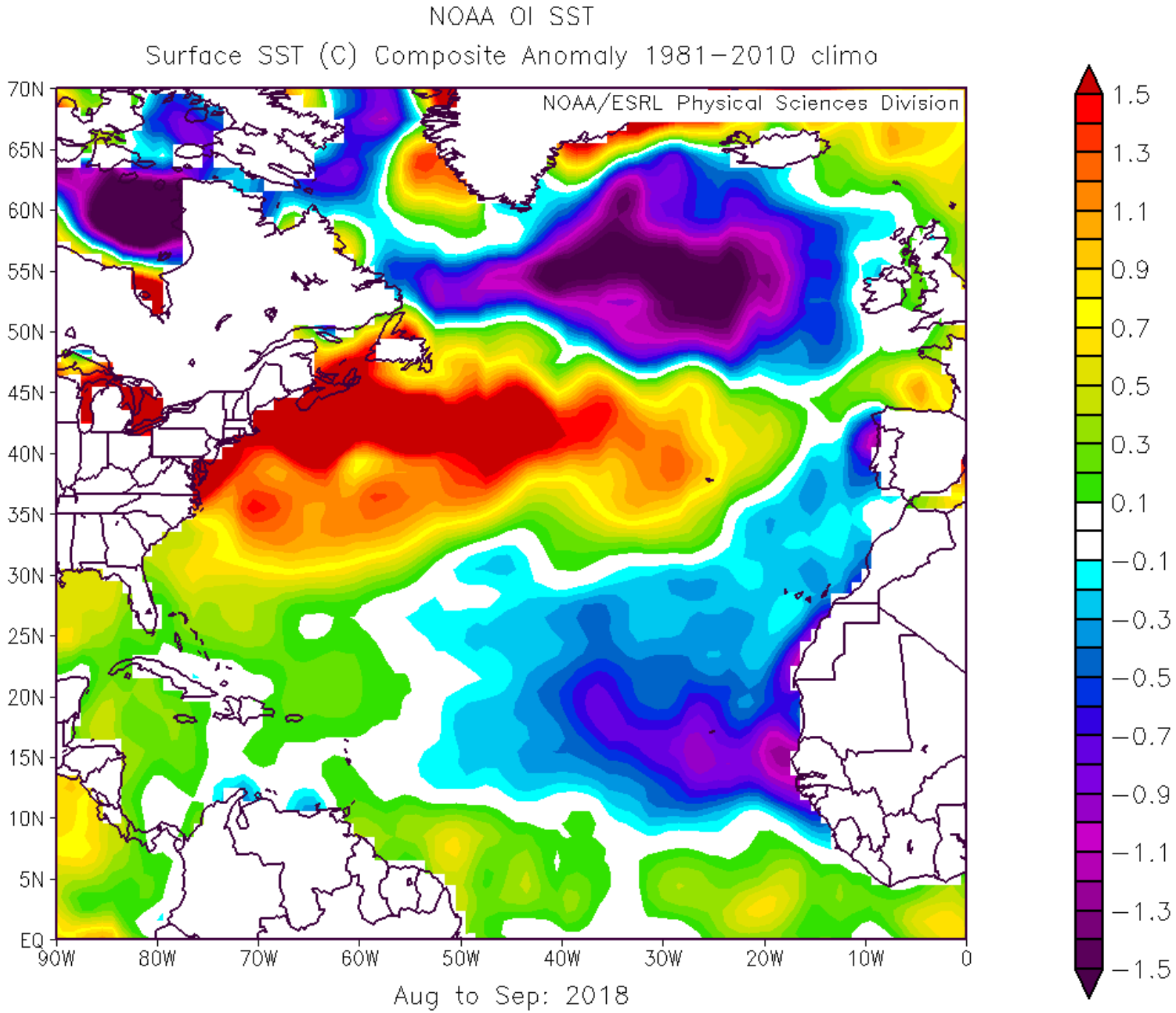
2018 Atlantic TC Activity Thru October 30

Forecast Parameter	Observed 2018 Atlantic TC Activity thru October 30	Atlantic thru October 30 1981-2010 Average	2018 as Percentage of October 30 1981-2010 Average	Atlantic Full Season 1981-2010 Average
Named Storms (NS)	15	11.1	135%	12.1
Named Storm Days (NSD)	87	53.9	161%	59.3
Hurricanes (H)	8	5.8	138%	6.4
Hurricane Days (HD)	26	22.4	116%	24.2
Major Hurricanes (MH)	2	2.5	80%	2.7
Major Hurricane Days (MHD)	5	6.0	83%	6.2
Accumulated Cyclone Energy (ACE)	128	98	131%	106

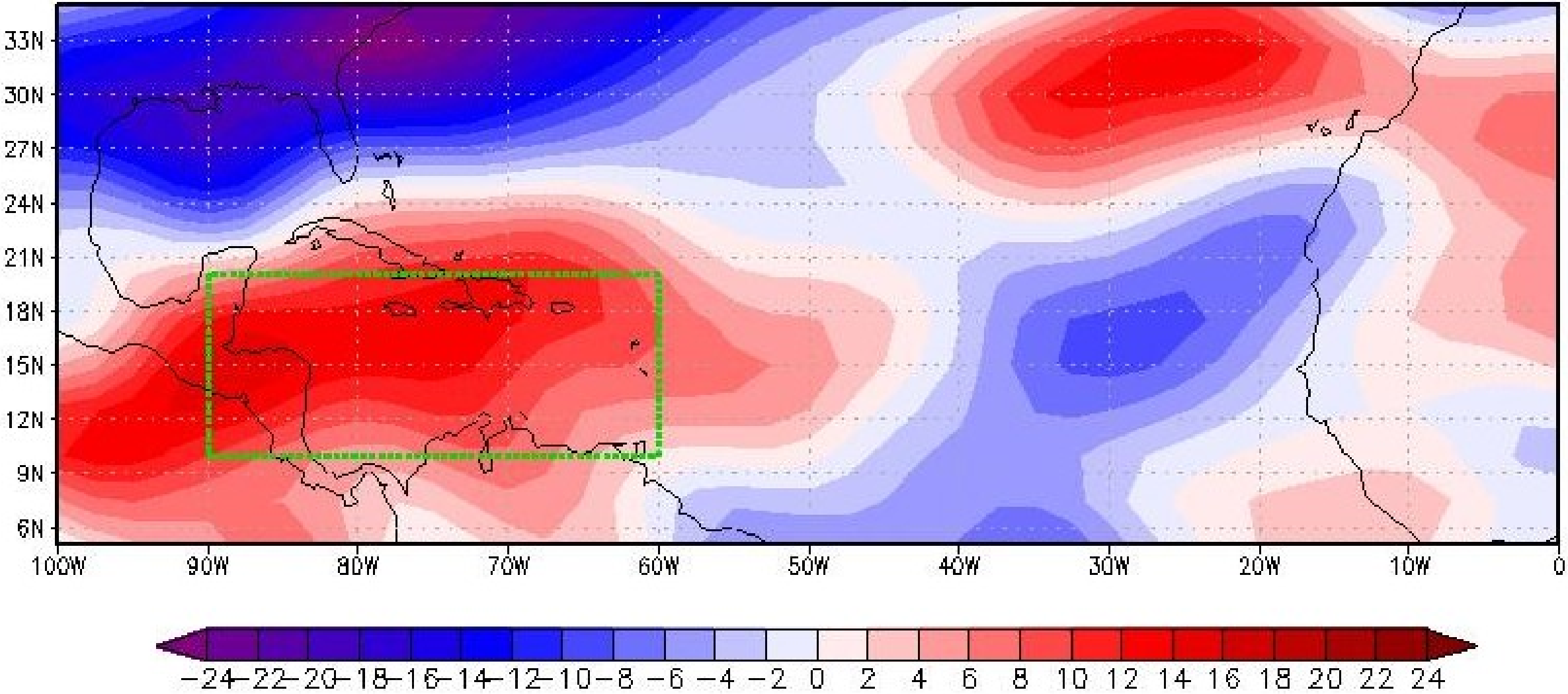
June 2018
SST Anomalies



Aug-Sep 2018
SST Anomalies



August 15 Through October 13, 2018 Average
Zonal (200-850 mb) Vertical Wind Shear Anomaly (kts)
(1981-2010 Climatology)



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."

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