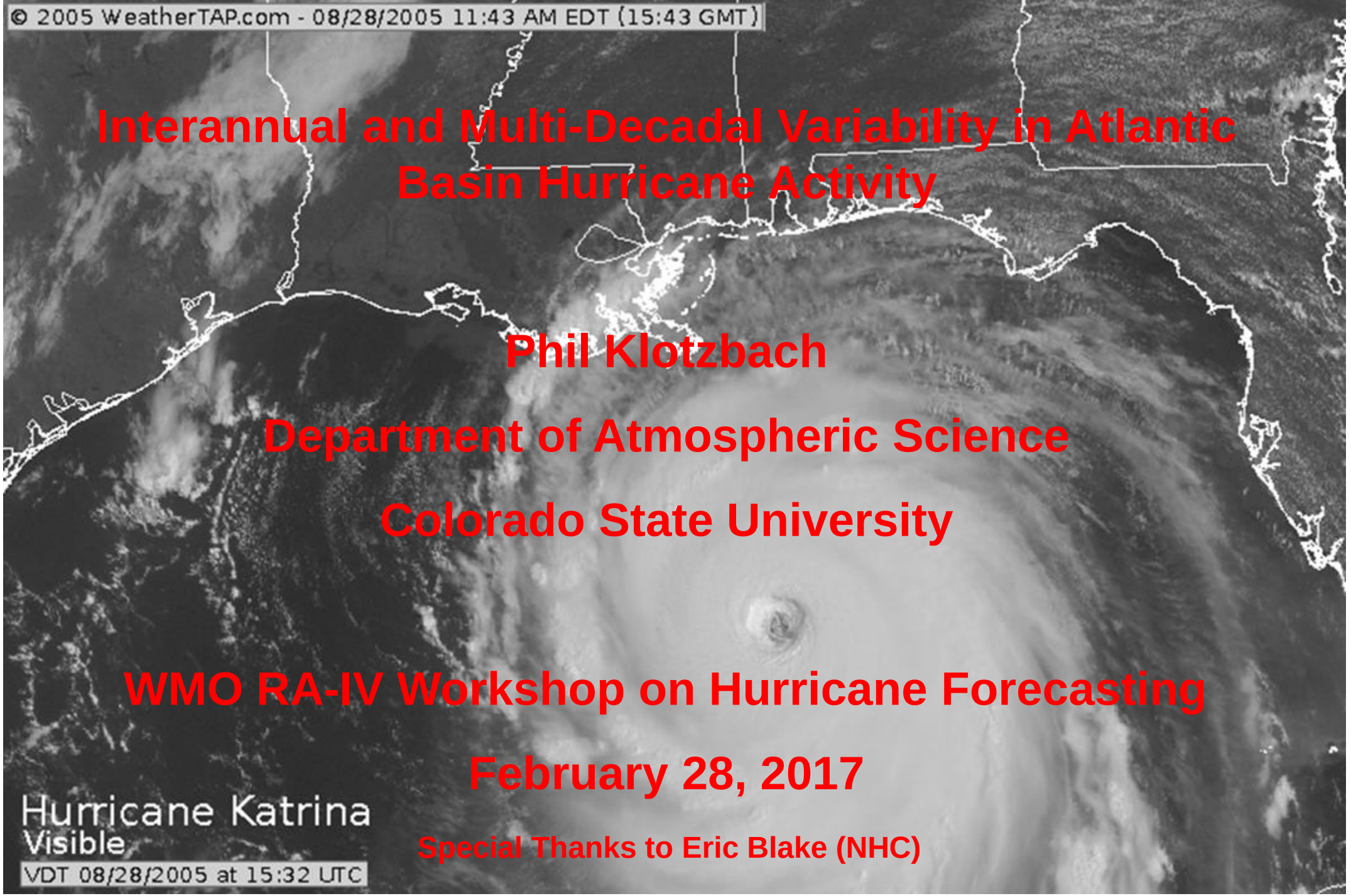


Interannual and Multi-Decadal Variability in Atlantic Basin Hurricane Activity

Phil Klotzbach

Department of Atmospheric Science

Colorado State University

WMO RA-IV Workshop on Hurricane Forecasting

February 28, 2017

Special Thanks to Eric Blake (NHC)

Outline

- Atlantic Basin Seasonal Hurricane Prediction
- Make Your Own Seasonal Hurricane Forecast
- 2017 Atlantic Basin Seasonal Outlook
- Atlantic Basin Multi-Decadal Hurricane Variability

In Memory of Bill Gray (1929-2016)

Seasonal Forecasting is more than this!

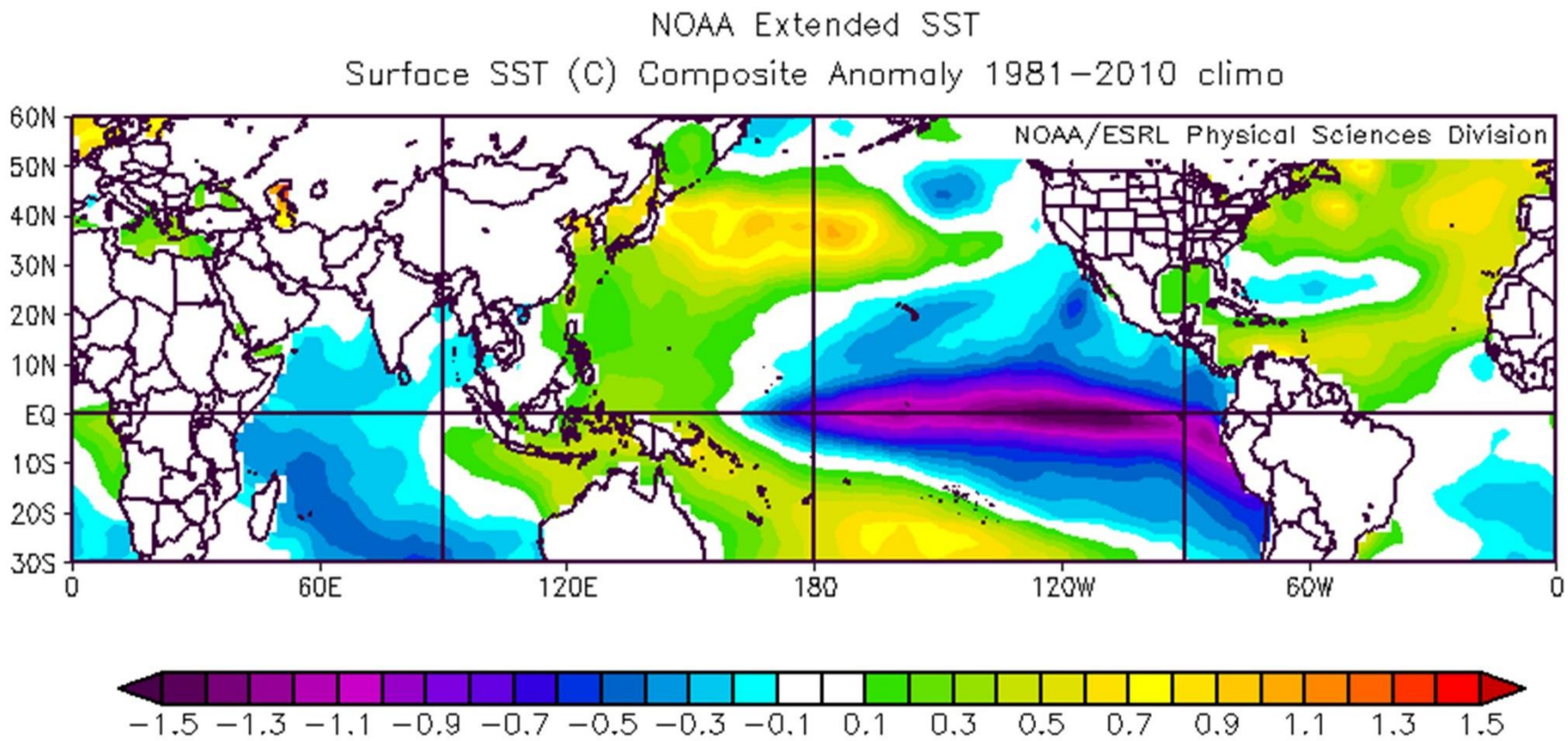
"It's tough to make predictions, especially about the future"

HOWEVER…

"You can see a lot by looking"

Yogi Berra

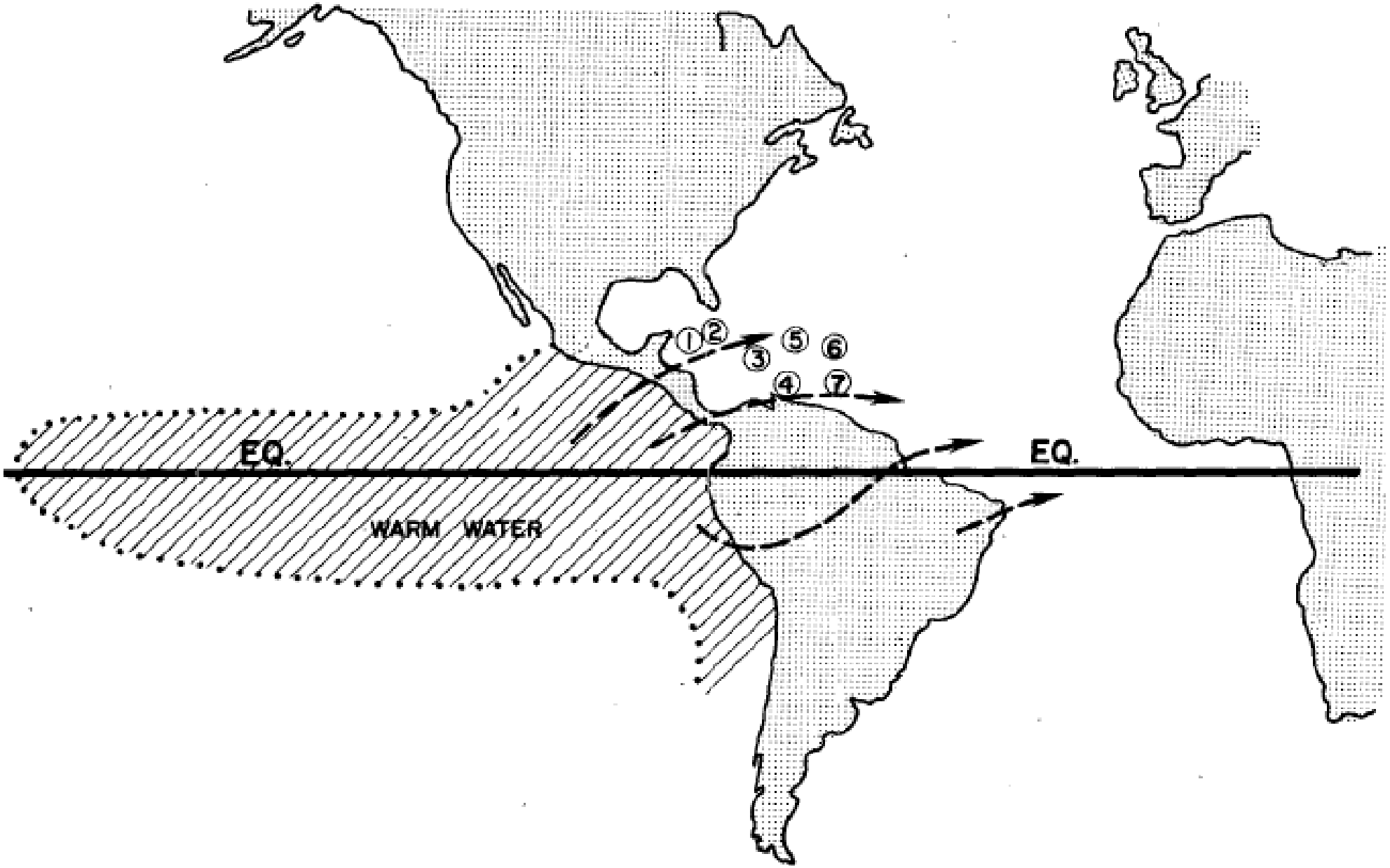
August – October SSTs: Ten Most Active – Ten Least Active Atlantic Hurricane Seasons Since 1950



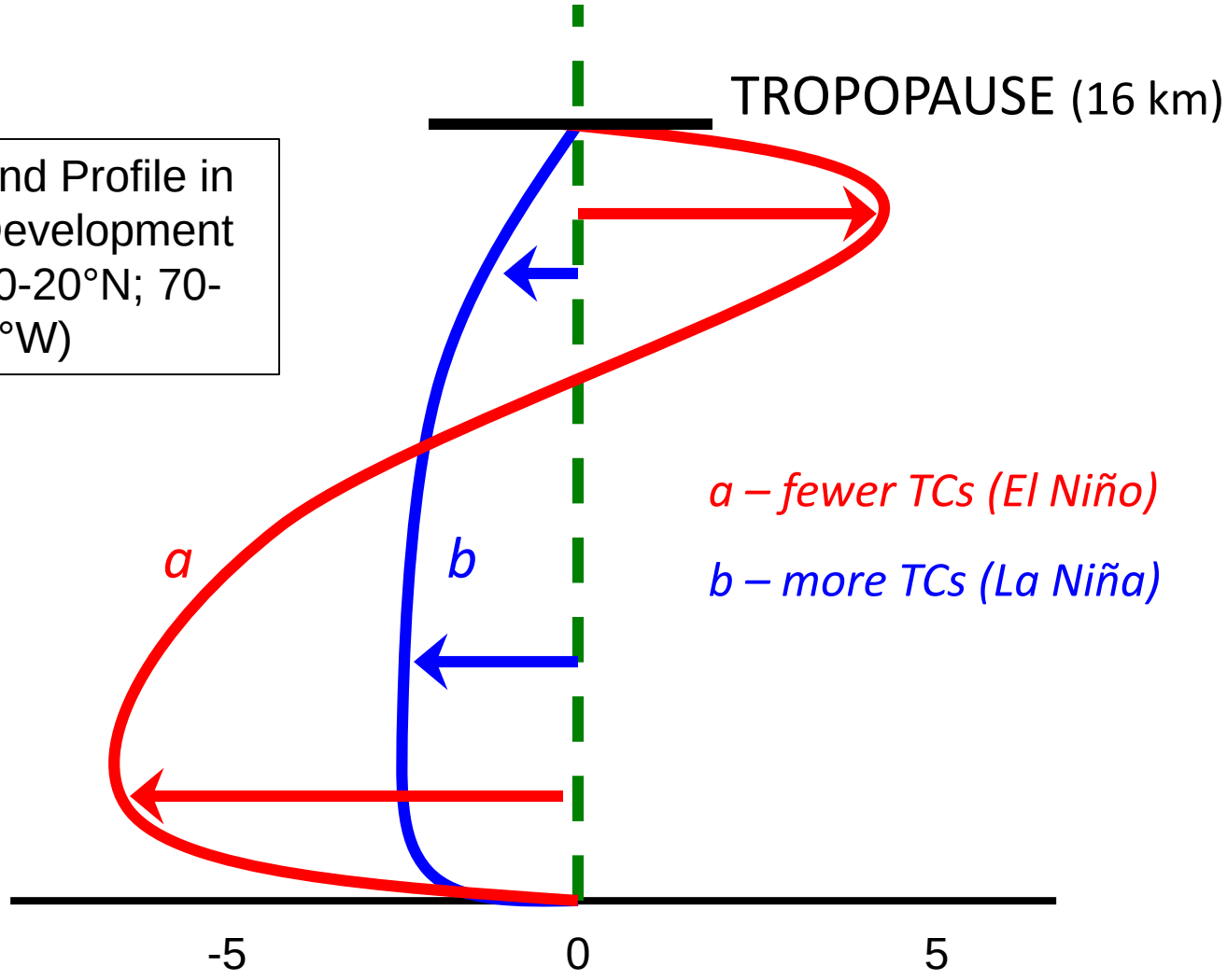
El Niño

- Natural warming of the equatorial waters in the central and eastern Pacific Ocean every 3 to 5 years
- Affects global atmospheric circulation patterns by altering thunderstorm development in the deep tropics
- Moderate or strong events generally cause a reduced Atlantic hurricane season
- Weaker events have little relationship to Atlantic hurricane activity

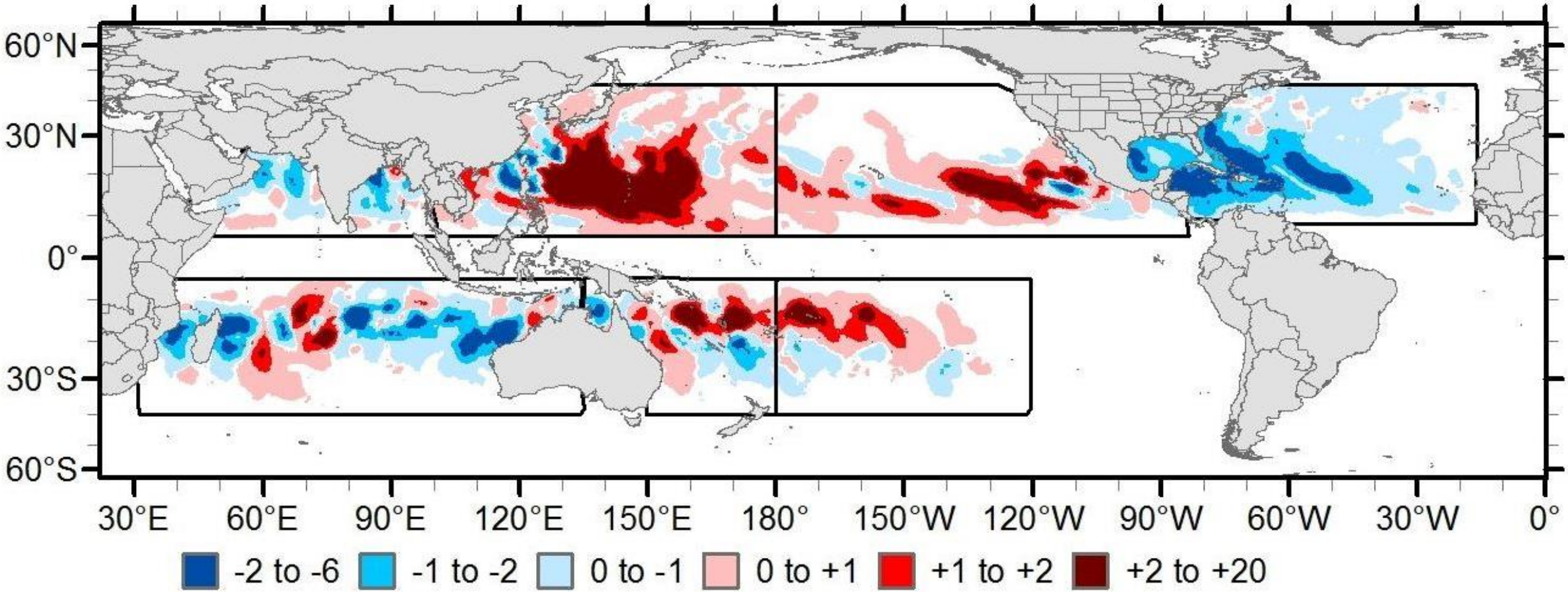
El Niño's Impacts on Upper-Level Wind Flow – From Gray (1984)

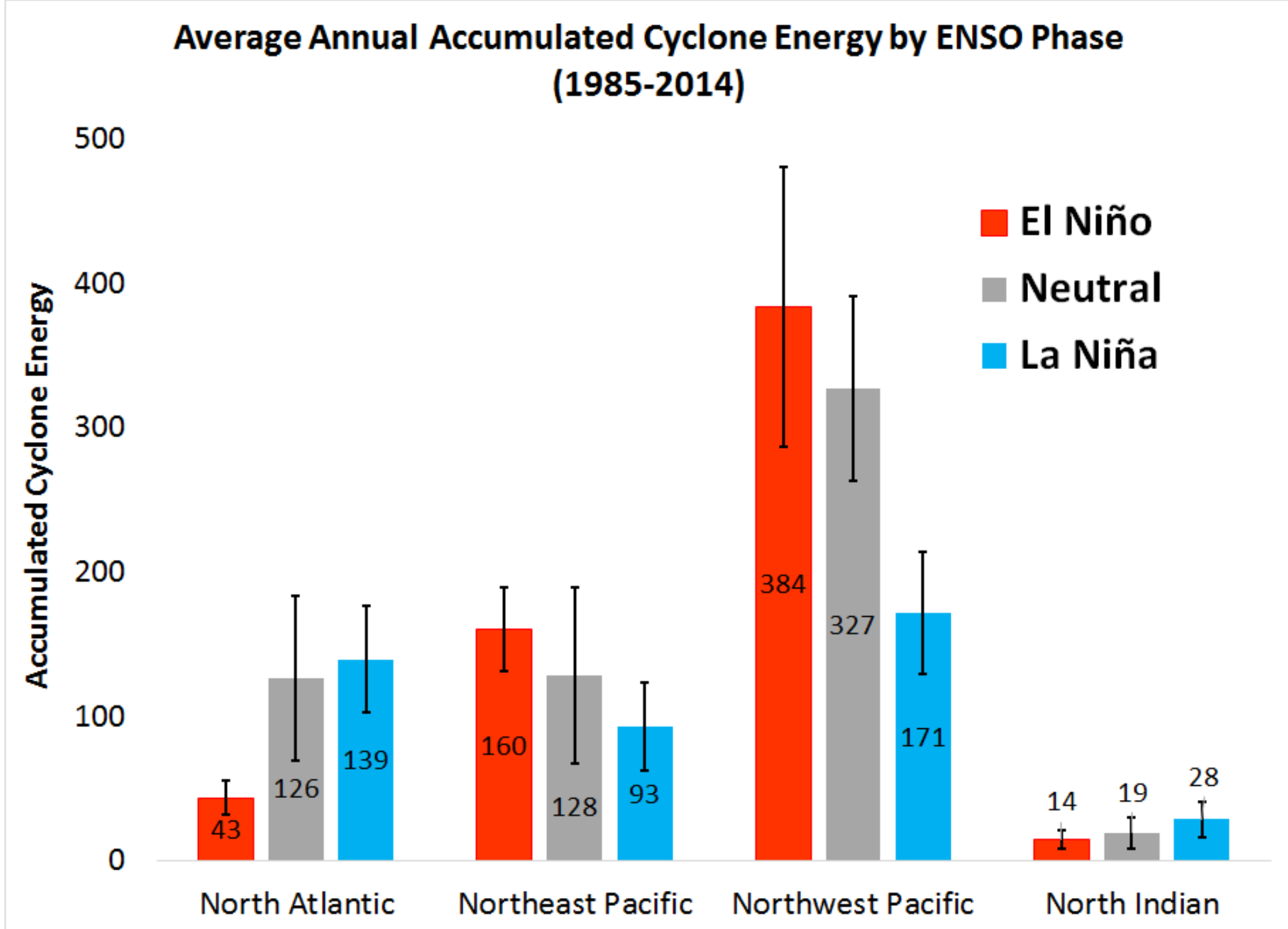


Vertical Wind Profile in the Main Development Region (10-20°N; 70-20°W)



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

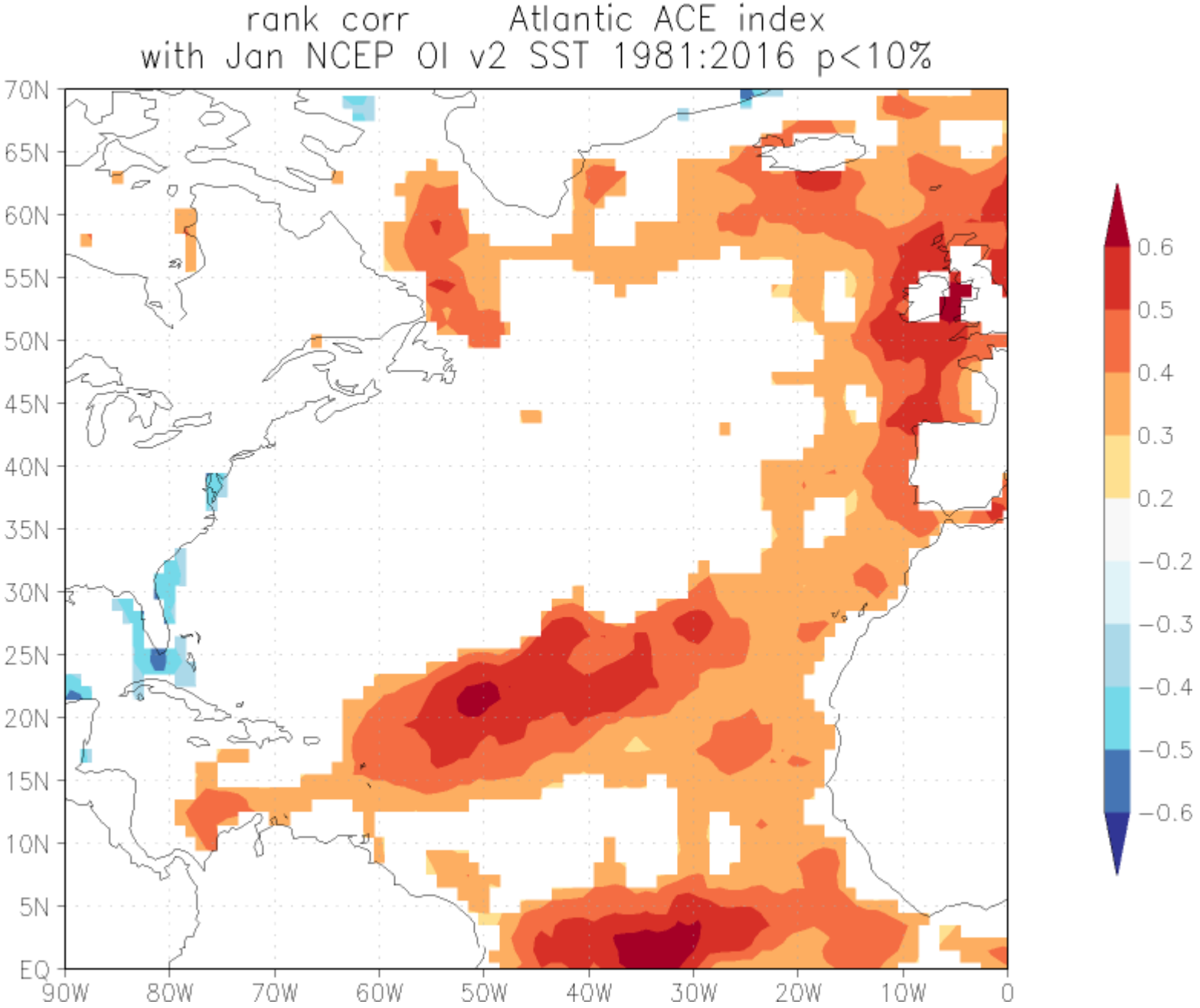



Average Annual Accumulated Cyclone Energy by ENSO Phase
(1985-2014)
Accumulated Cyclone Energy
500
400
300
200
100
0
El Niño
Neutral
La Niña
43
126
139
160
128
93
384
327
171
14
19
28
North Atlantic
Northeast Pacific
Northwest Pacific
North Indian

North Atlantic Sea-Surface Temperatures (SSTs)

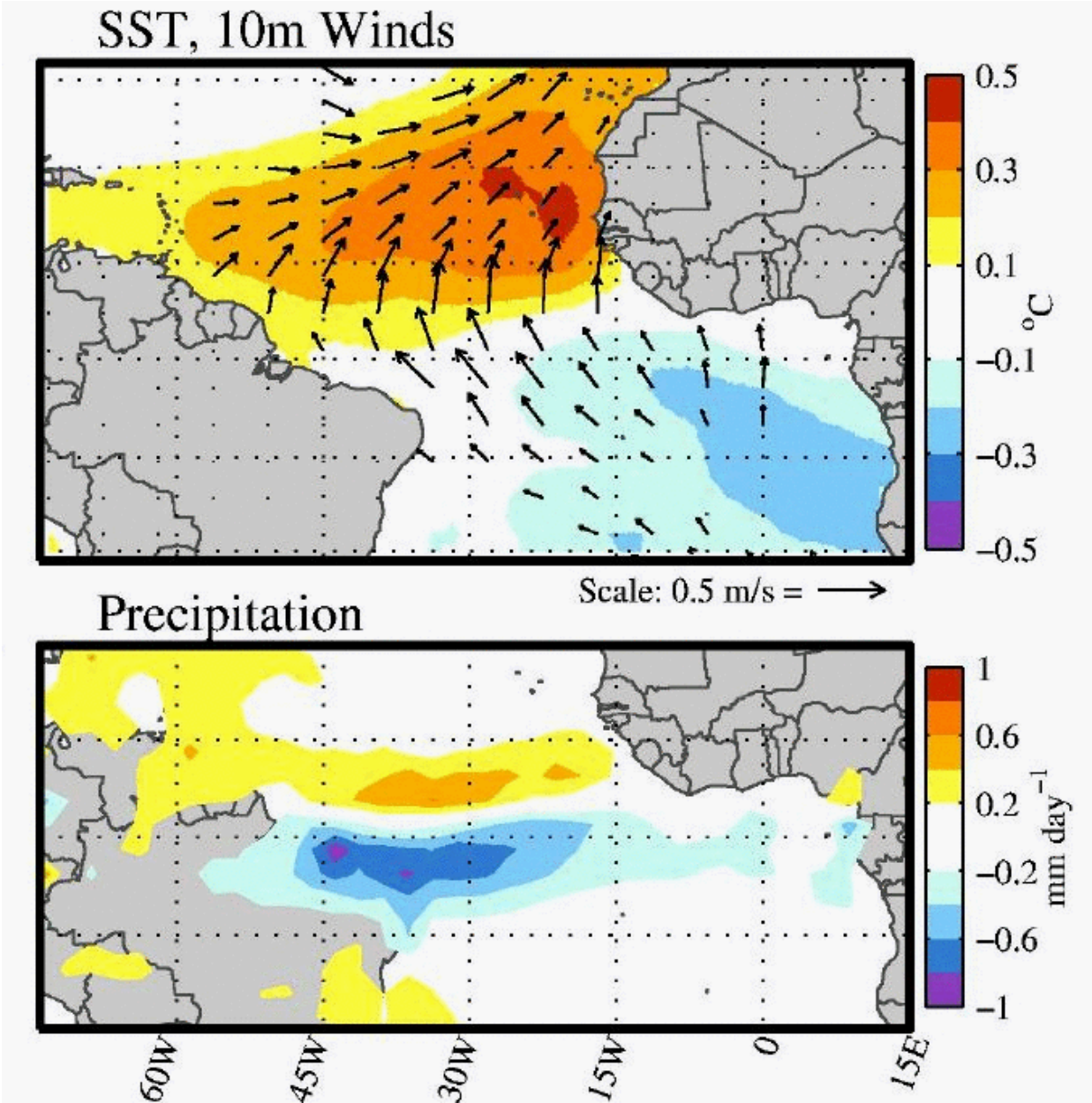
- In the Atlantic basin, warmer waters generally mean a more active hurricane season.
- Relative warmth of Atlantic to global tropics also important.
- Higher SSTs lead to more instability in the boundary layer of the atmosphere.
- Changes in SST gradients modulates regional circulation patterns.
- Atlantic SSTs also atmospheric proxy.
- Cooler waters are linked to higher surface pressures, stronger surface winds (higher shear as a result) and upwelling.

Correlation between Atlantic SST and Atlantic Hurricane Activity

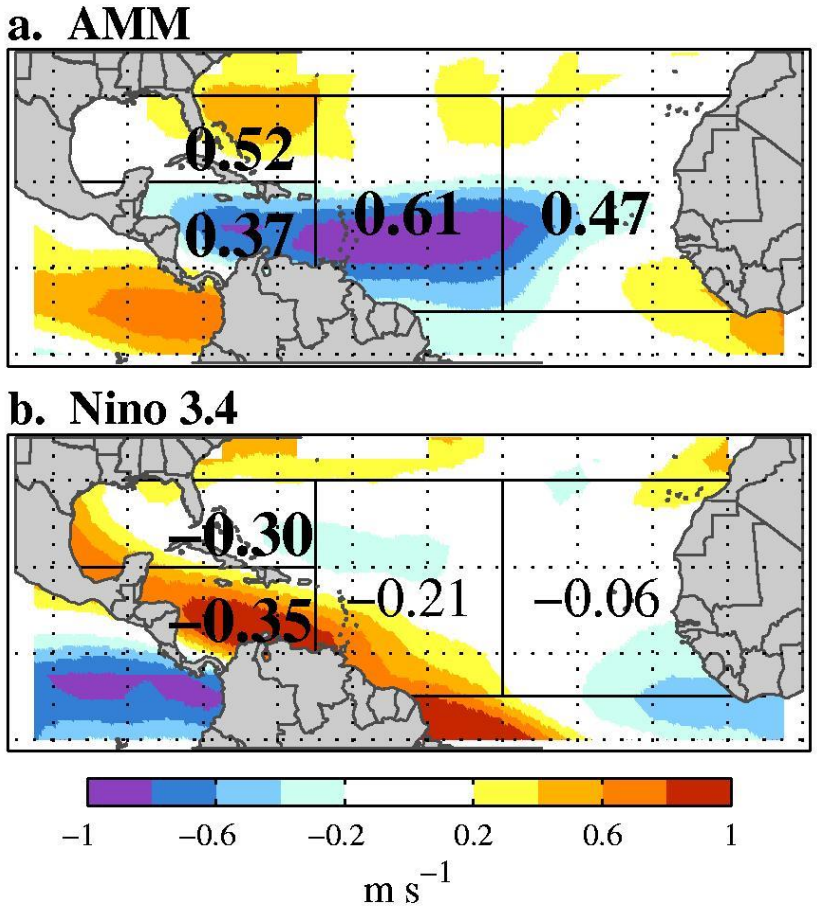


The Atlantic Meridional Mode: SST, wind, and precip anoms

- 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



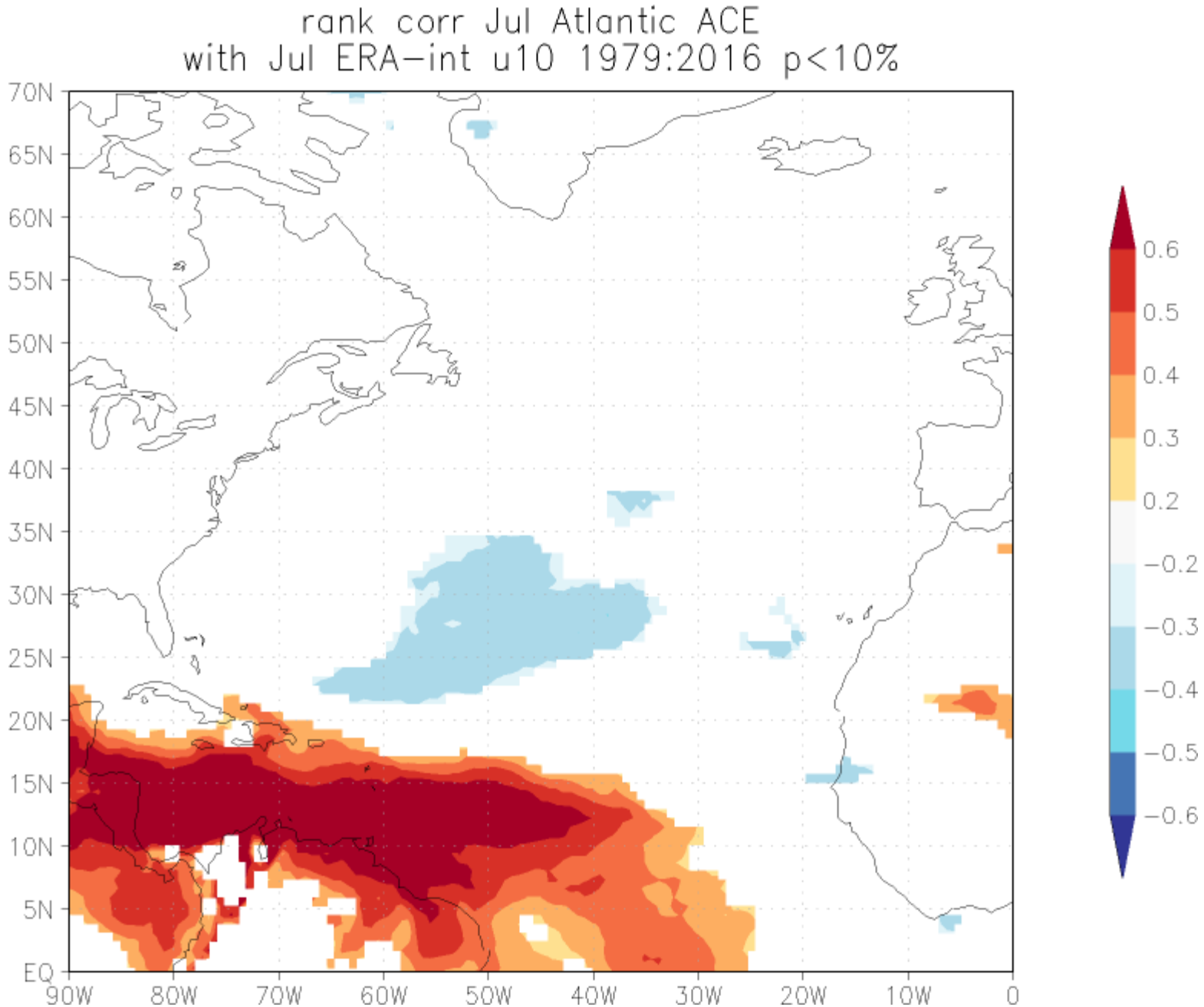
Comparative effects of the AMM (local) and ENSO (remote) on vertical wind shear in the Atlantic



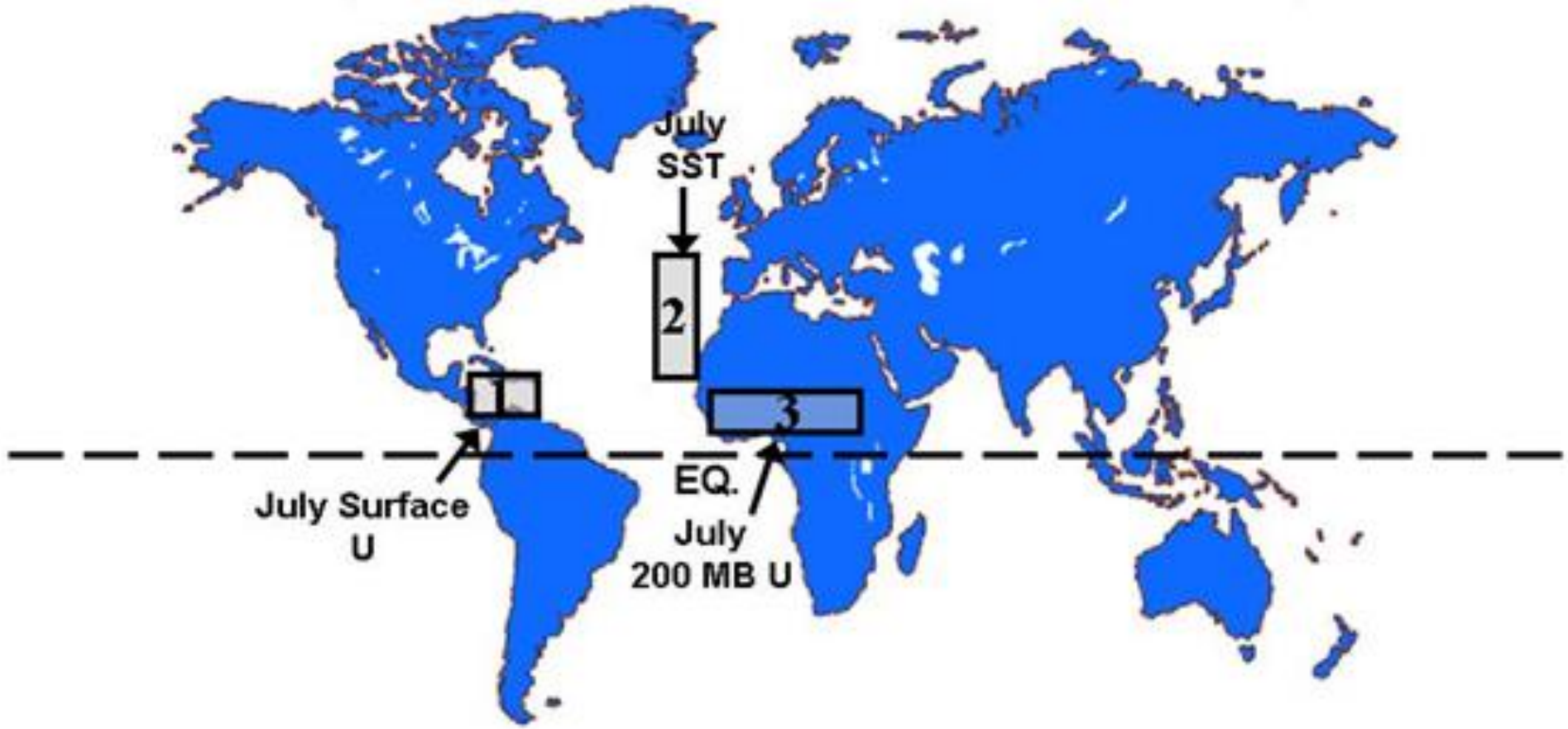
units: m/s per standard deviation

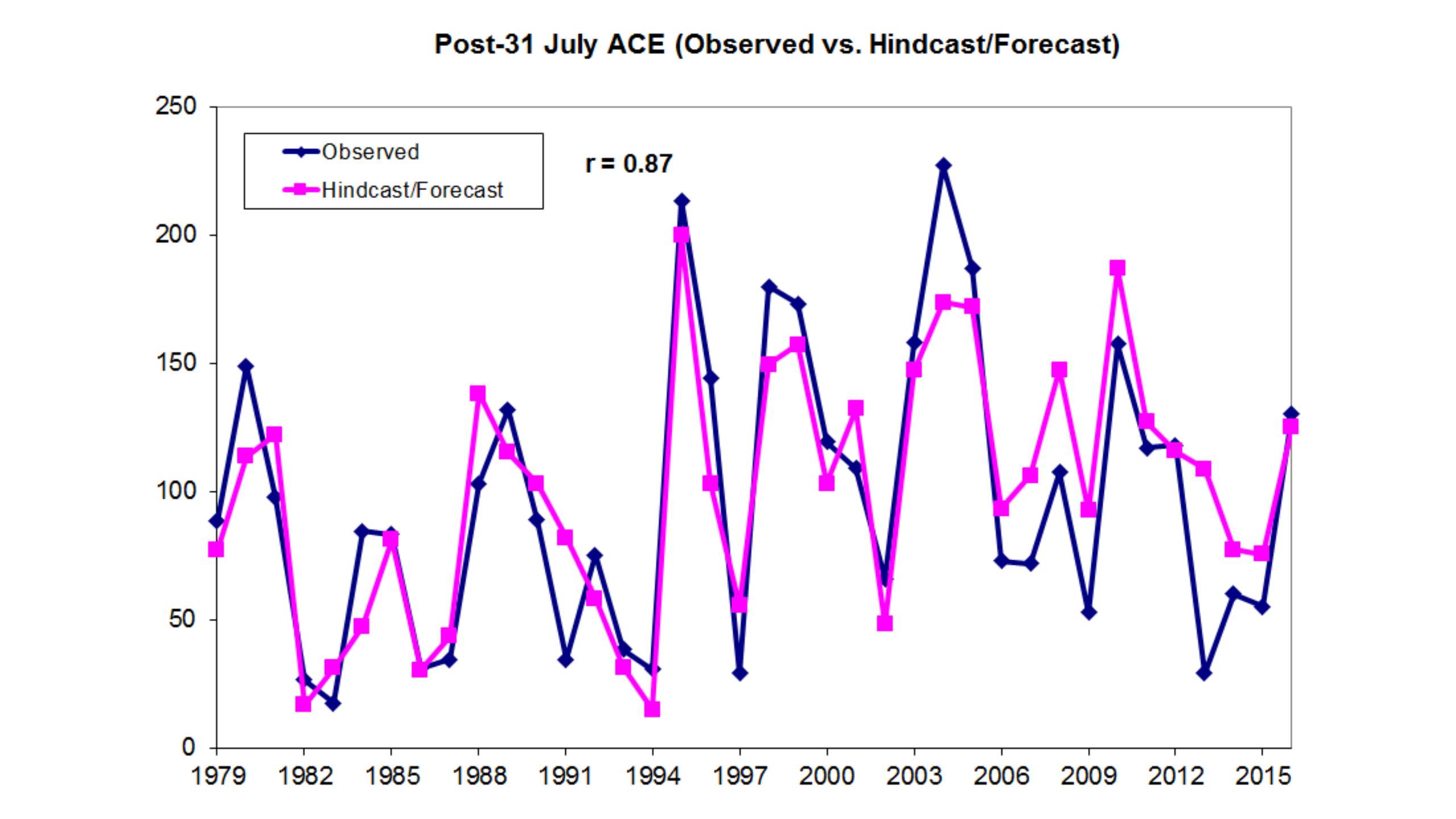
Shear regressed onto AMM and Nino 3.4 indices, and correlations between the indices and storm activity.

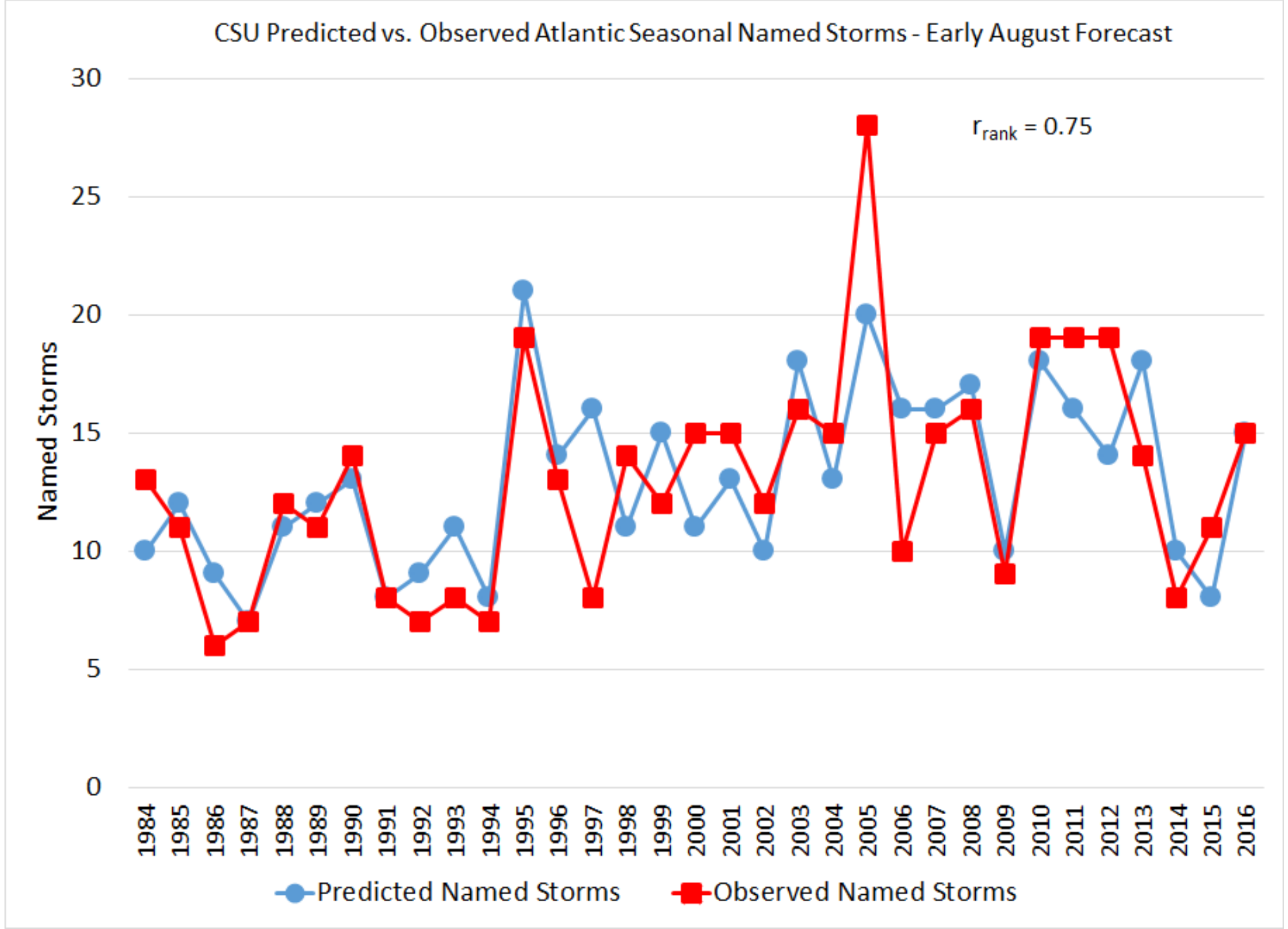
July Low-Level Wind Flow in the Caribbean has Very High Correlation with Atlantic Hurricane Activity

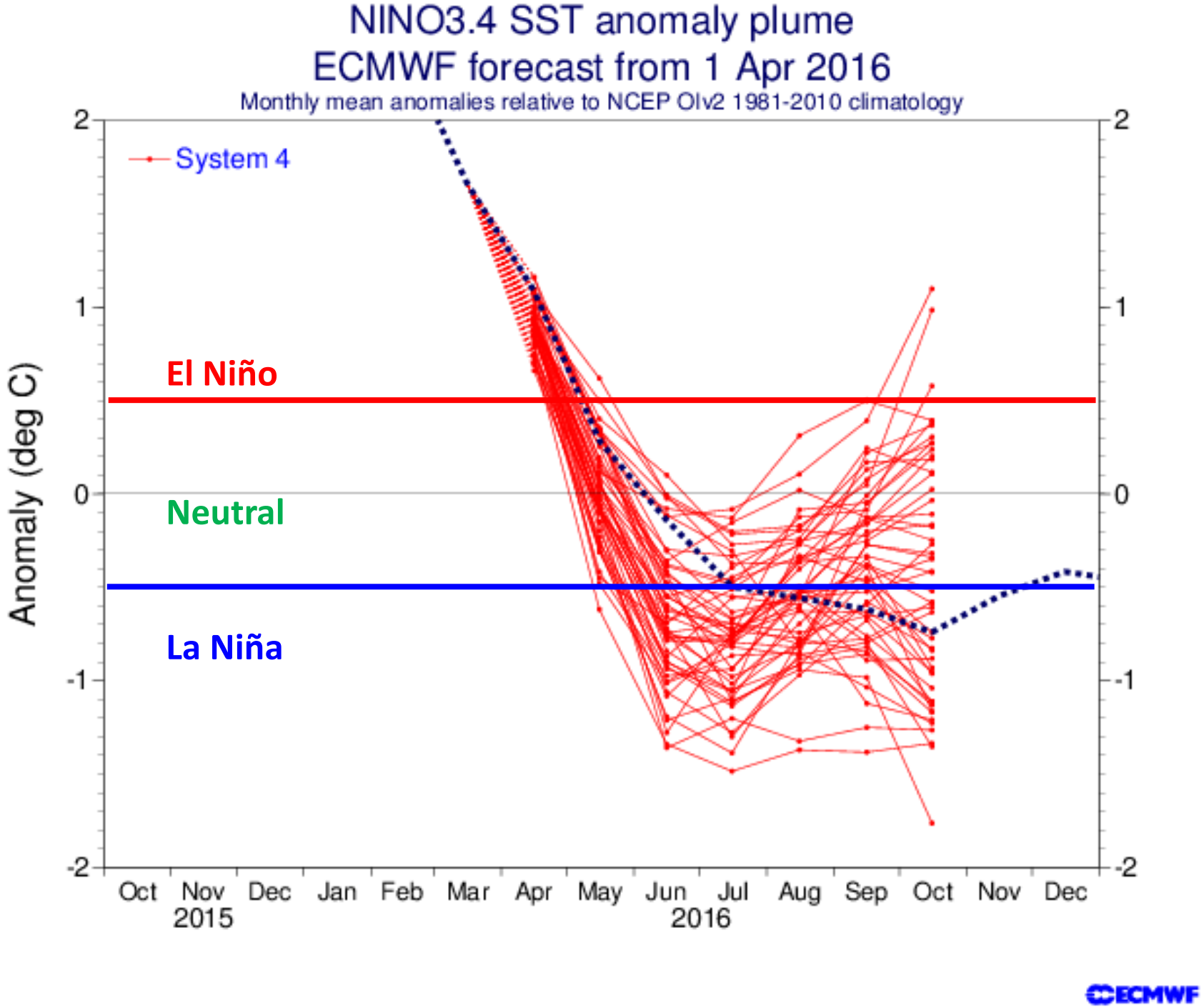


Post-31 July Seasonal Forecast Predictors

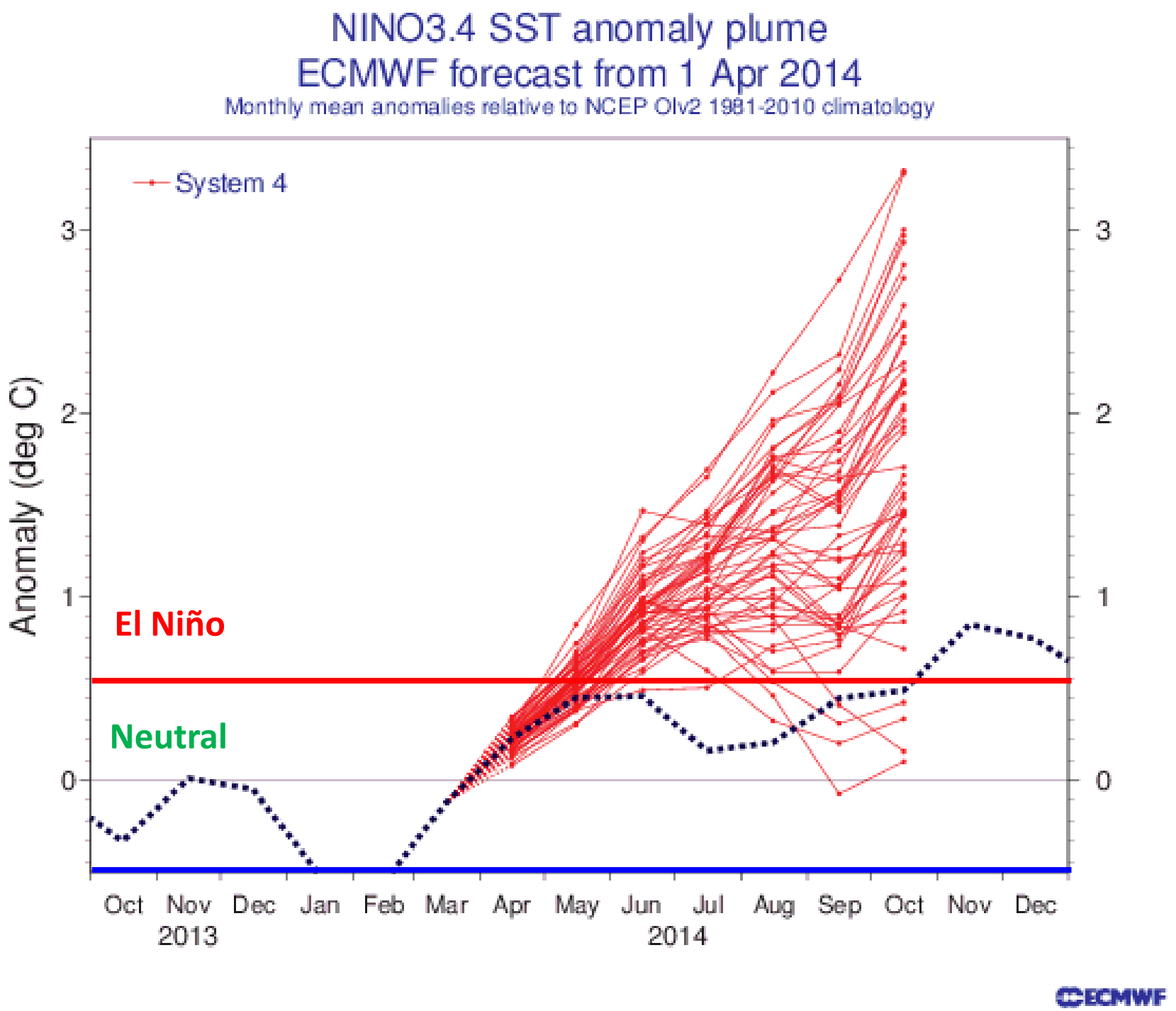


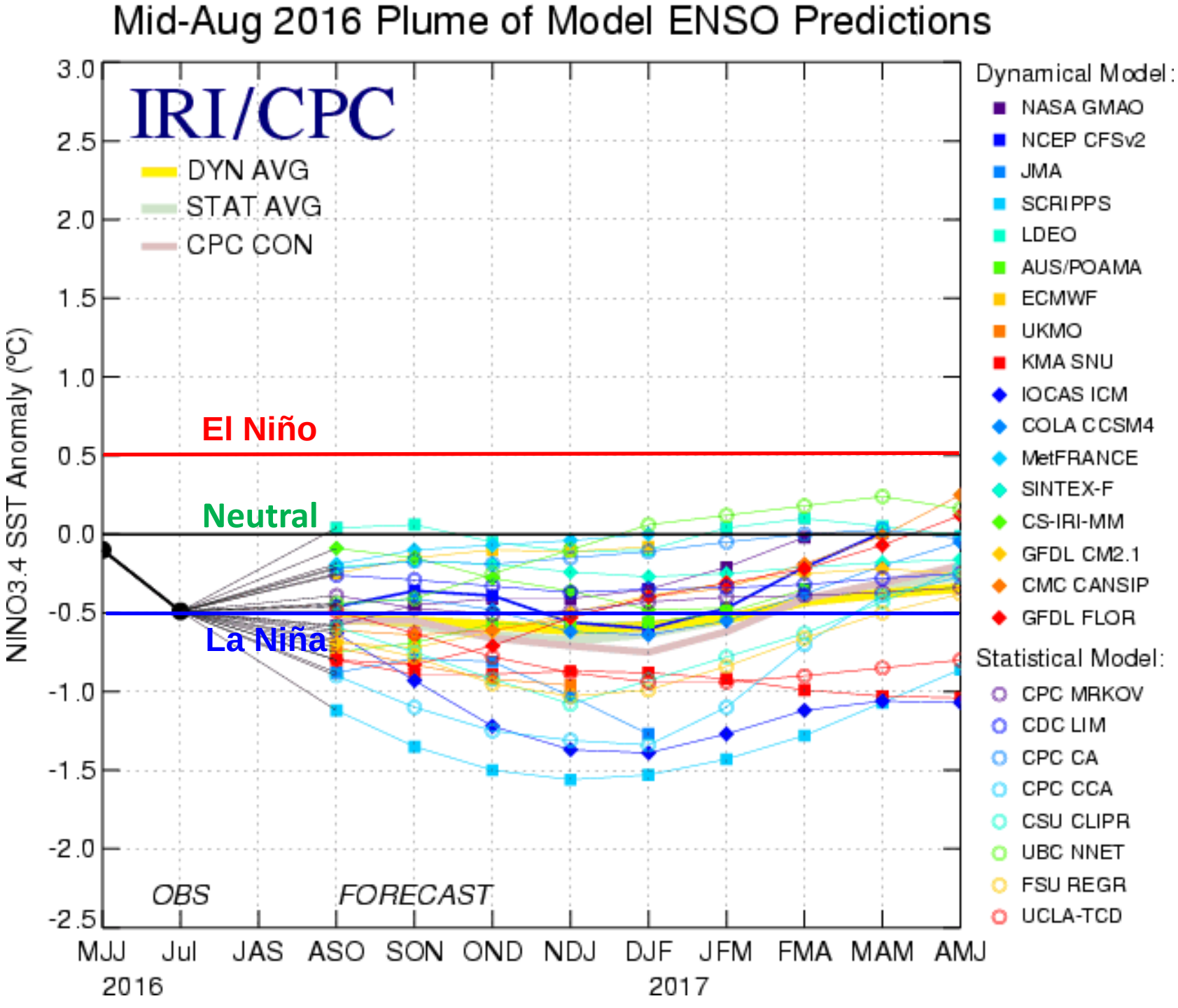

Post-31 July ACE (Observed vs. Hindcast/Forecast)
Observed
Hindcast/Forecast
r = 0.87
250
200
150
100
50
0
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2015

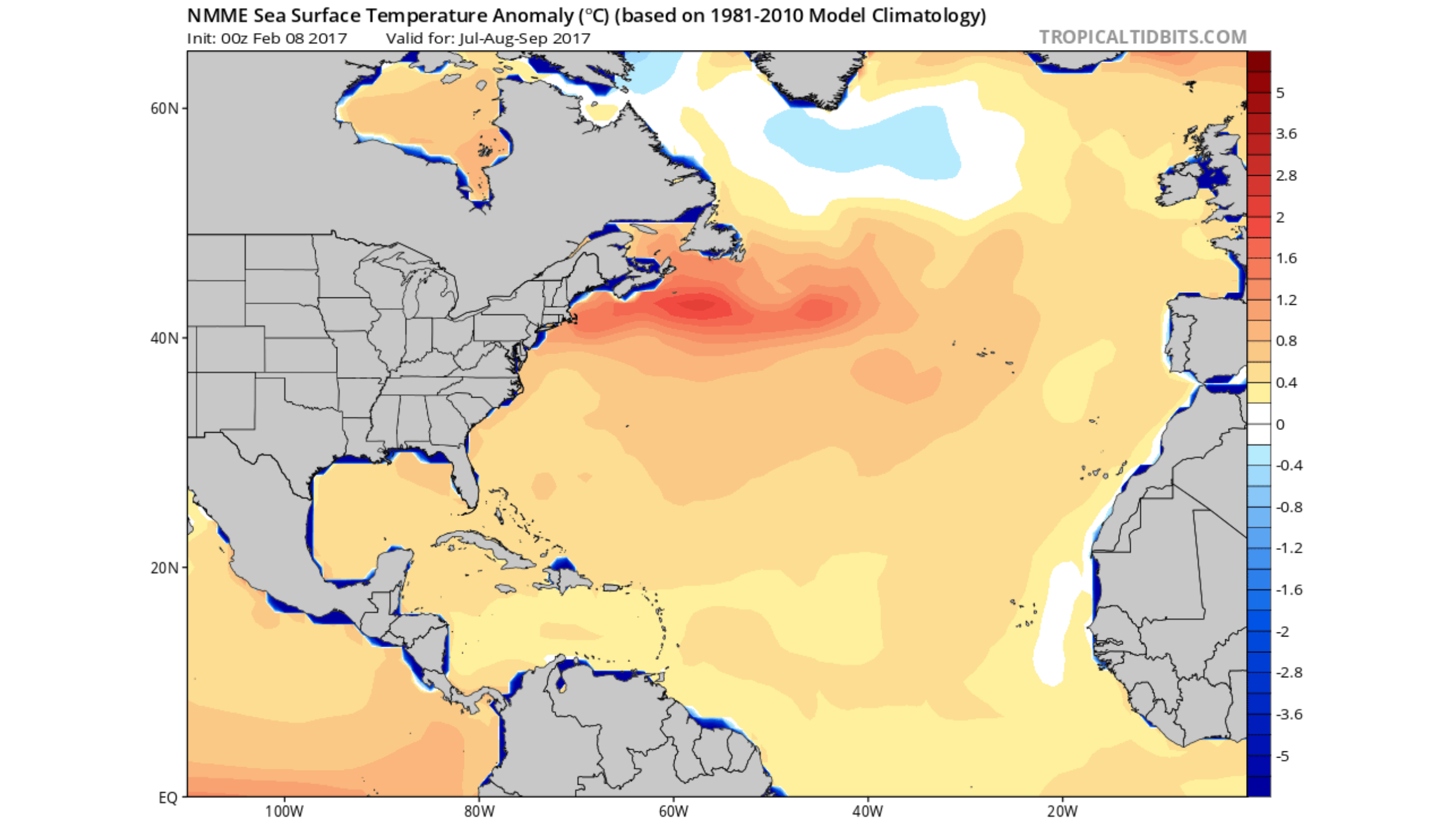

CSU Predicted vs. Observed Atlantic Seasonal Named Storms - Early August Forecast
Named Storms
30
25
20
15
10
5
0
r_{rank} = 0.75
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Predicted Named Storms
Observed Named Storms

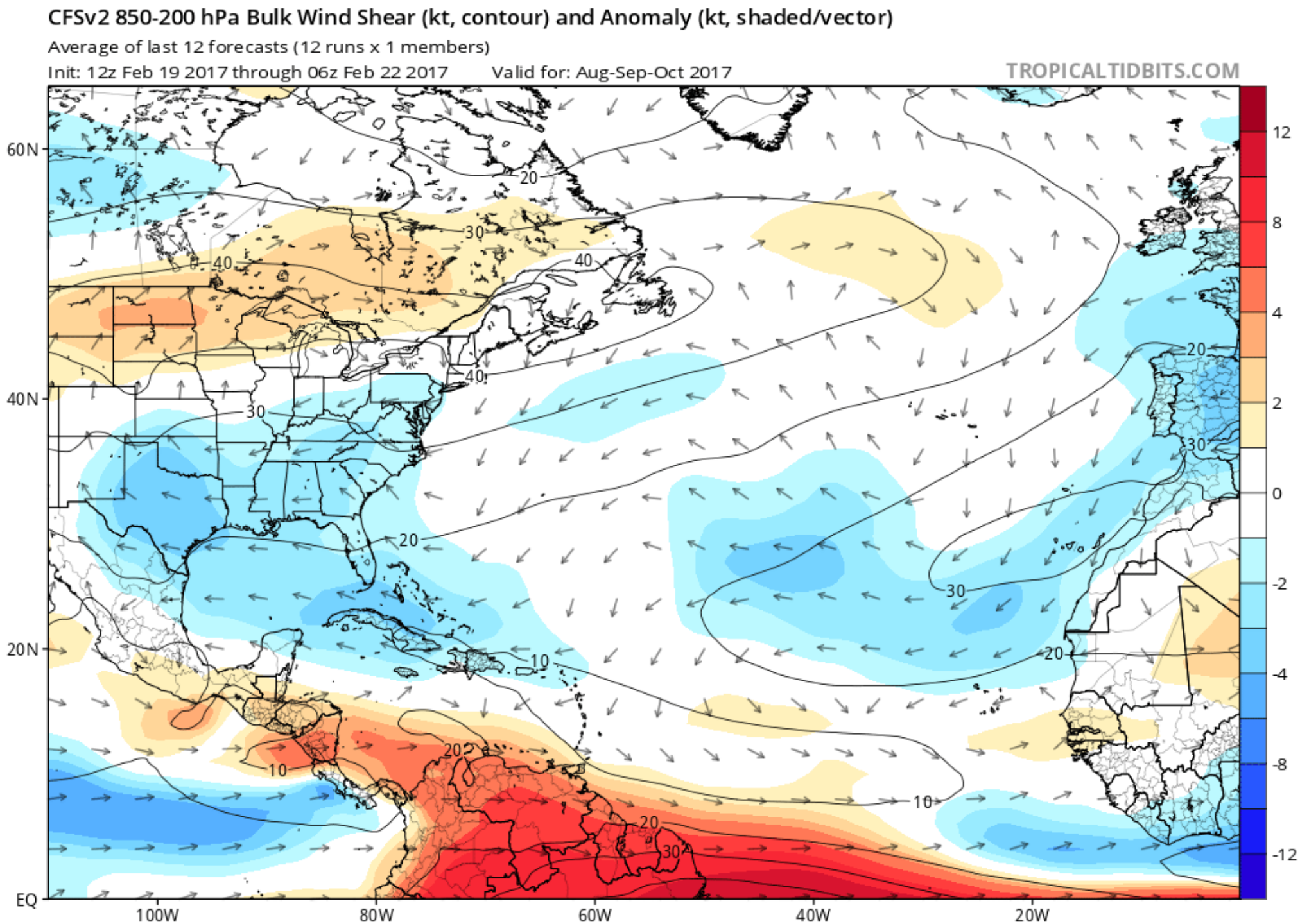

NINO3.4 SST anomaly plume
ECMWF forecast from 1 Apr 2016
Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology
System 4
El Niño
Neutral
La Niña
Anomaly (deg C)
2
1
0
-1
-2
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2015
2016

ECMWF


NINO3.4 SST anomaly plume
ECMWF forecast from 1 Apr 2014
Monthly mean anomalies relative to NCEP Olv2 1981-2010 climatology
System 4
Anomaly (deg C)
3
2
1
0
El Niño
Neutral
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2013
2014
ECMWF


Mid-Aug 2016 Plume of Model ENSO Predictions
IRI/CPC
DYN AVG
STAT AVG
CPC CON
El Niño
Neutral
La Niña
NINO3.4 SST Anomaly (°C)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
OBS
FORECAST
MJJ
Jul
JAS
ASO
SON
OND
NDJ
DJF
JFM
FMA
MAM
AMJ
2016
2017
Dynamical Model:
NASA GMAO
NCEP CFSv2
JMA
SCRIPPS
LDEO
AUS/POAMA
ECMWF
UKMO
KMA SNU
IOCAS ICM
COLA CCSM4
MetFRANCE
SINTEX-F
CS-IRI-MM
GFDL CM2.1
CMC CANSIP
GFDL FLOR
Statistical Model:
CPC MRKOV
CDC LIM
CPC CA
CPC CCA
CSU CLIPR
UBC NNET
FSU REGR
UCLA-TCD


NMME Sea Surface Temperature Anomaly (°C) (based on 1981-2010 Model Climatology)
Init: 00z Feb 08 2017
Valid for: Jul-Aug-Sep 2017
TROPICALTIDBITS.COM
60N
40N
20N
EQ
100W
80W
60W
40W
20W
5
3.6
2.8
2
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
-2
-2.8
-3.6
-5


CFSv2 850-200 hPa Bulk Wind Shear (kt, contour) and Anomaly (kt, shaded/vector)
Average of last 12 forecasts (12 runs x 1 members)
Init: 12z Feb 19 2017 through 06z Feb 22 2017
Valid for: Aug-Sep-Oct 2017
TROPICALTIDBITS.COM
60N
40N
20N
EQ
100W
80W
60W
40W
20W
12
8
4
2
0
-2
-4
-8
-12

CFS version 2

1. An atmosphere at high horizontal resolution (spectral T574, ~27 km) and high vertical resolution (64 sigma-pressure hybrid levels) for the real time analysis
2. An atmosphere of T126L64 for the real time forecasts
3. An interactive ocean with 40 levels in the vertical, to a depth of 4737 m, and horizontal resolution of 0.25 degree at the tropics, tapering to a global resolution of 0.5 degree northwards and southwards of 10N and 10S respectively
4. An interactive 3 layer sea-ice model
5. An interactive land model with 4 soil levels

CFS-based TS, Hurricanes and ACE Index Forecast
Atlantic Basin– May forecast

	Tropical Storms	Hurricanes	ACE Index % of Median
402	14	4	132
403	15	5	131
404	11	2	94
405	11	2	132
406	10	3	72
407	9	3	106
408	15	5	131
409	14	2	84
410	11	4	88
411	13	6	184
412	11	0	77
413	14	7	166
414	16	8	185
415			
416			
417			
418			

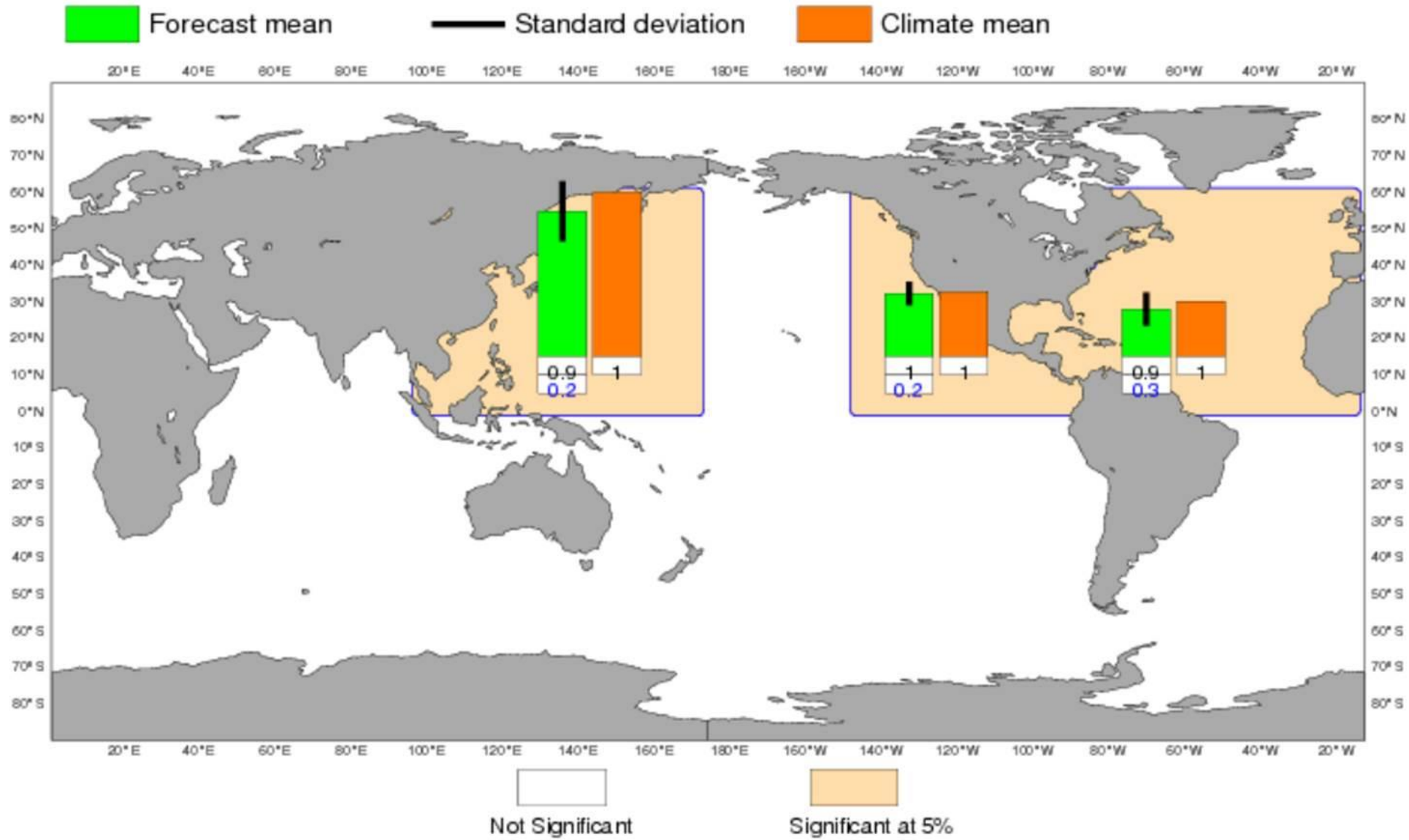
2012
Slightly Above Normal Year

	Tropical Storms	Hurricanes	ACE Index % of Median
Ensemble	**12.6**	**3.9**	**121.6**
Standard Deviation	**2.2**	**2.3**	**39.0**
Range	**10-15**	**2-6**	**83-161**
Model Clim	**10.6**	**3.8**	**85.4**

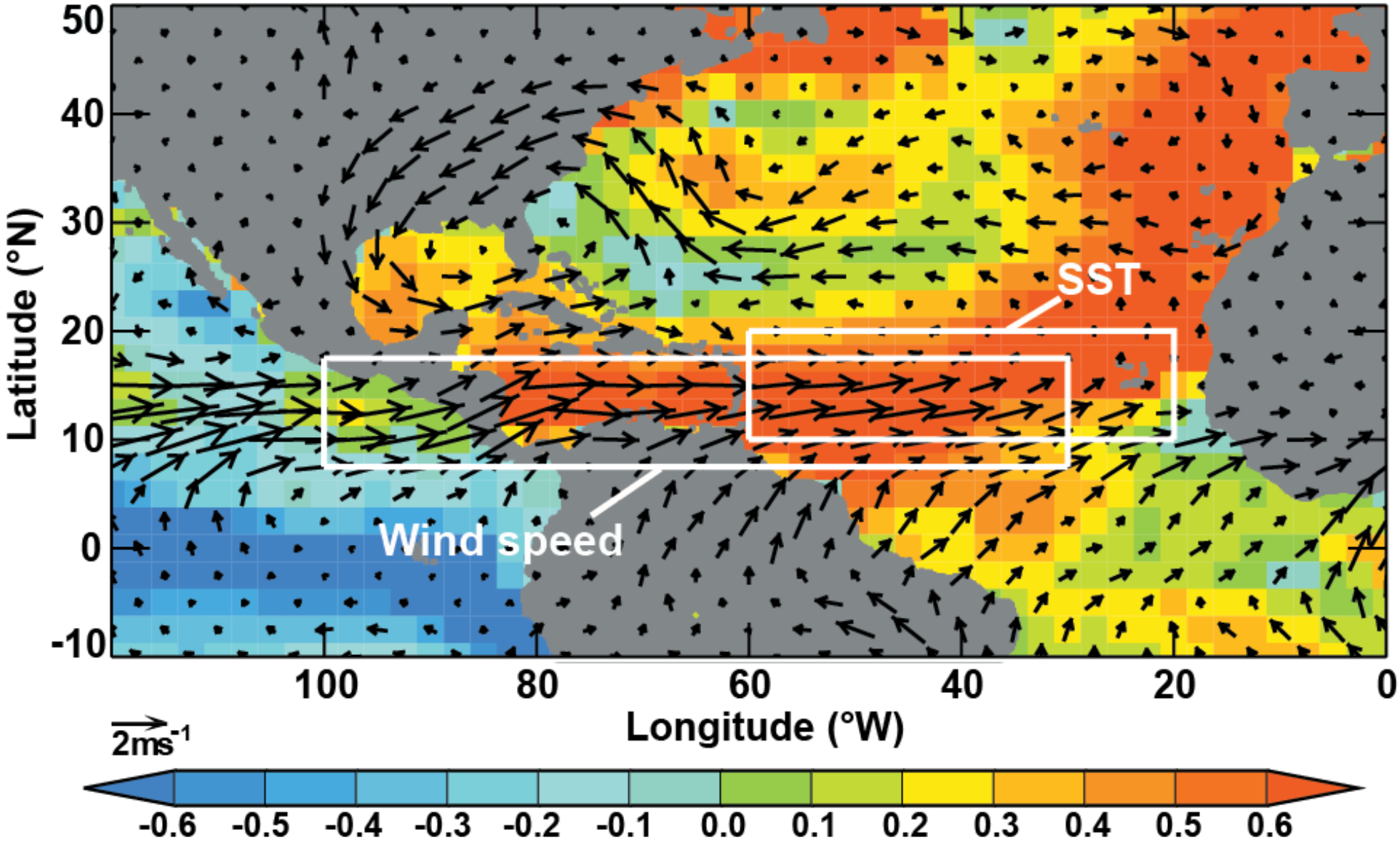
ECMWF Seasonal Forecast
Accumulated Cyclone Energy

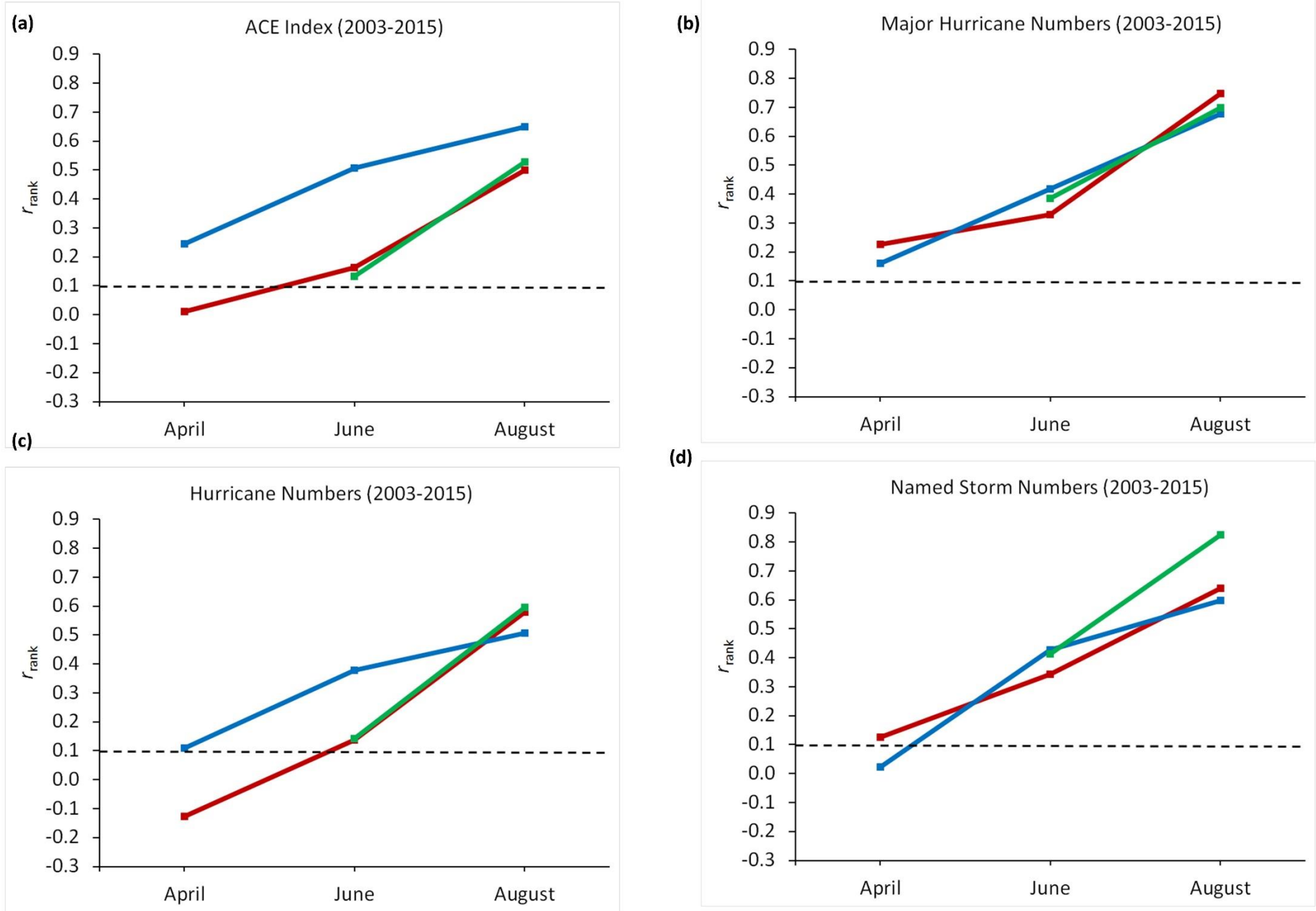
Forecast start reference is 01/05/2016
Ensemble size = 51,climate size =300

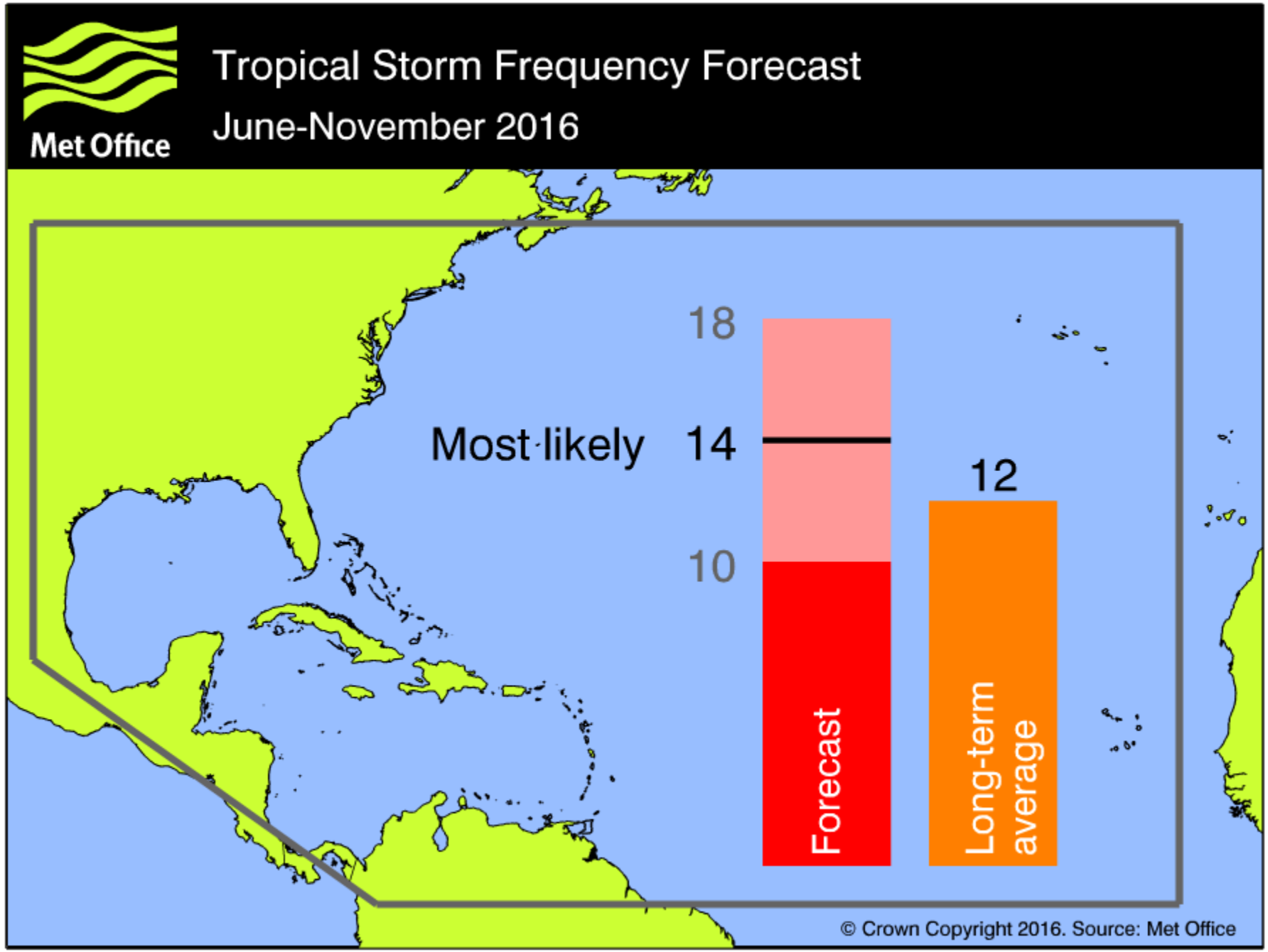
System 4
JJASON 2016
Climate (initial dates) = 1990-2009



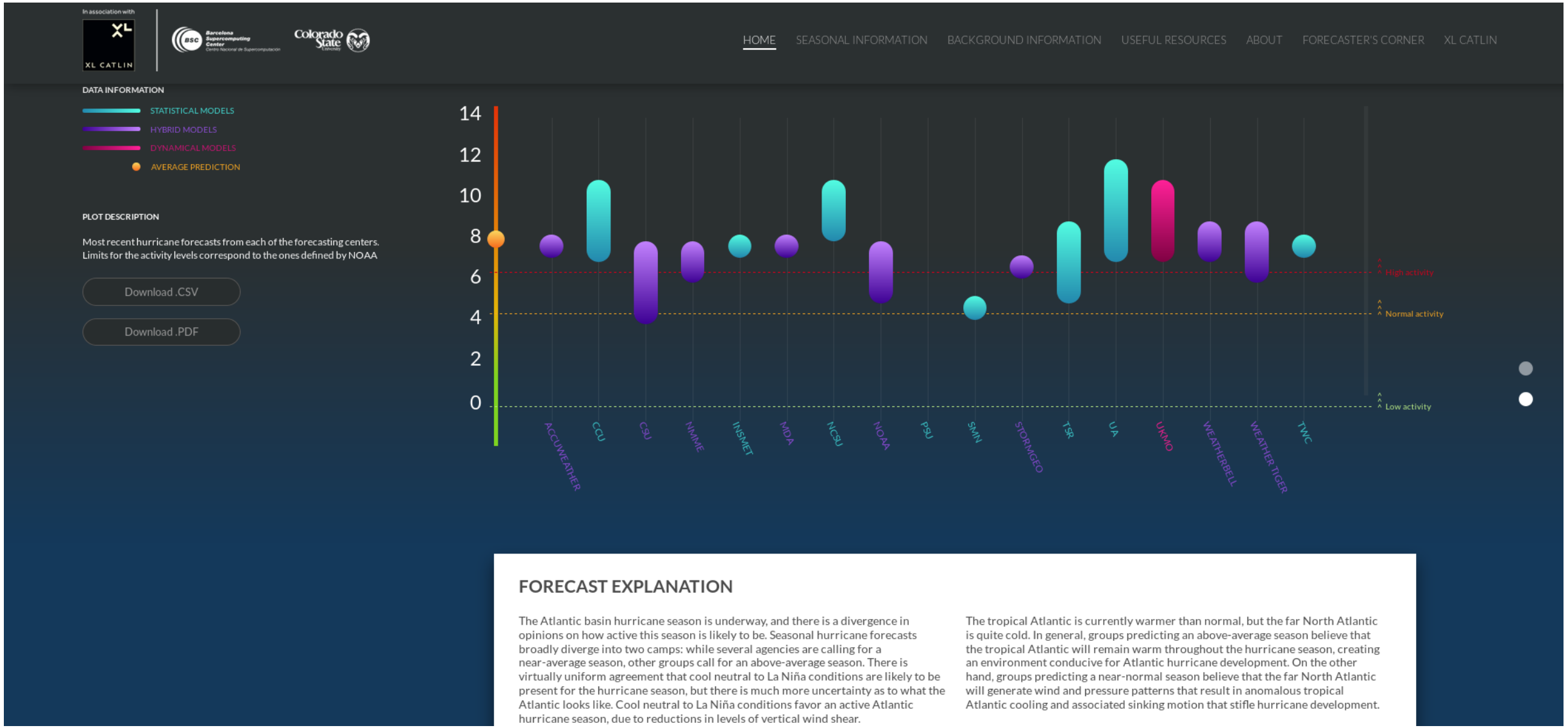
Tropical Storm Risk Seasonal Forecast Predictors




(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


Met Office
Tropical Storm Frequency Forecast
June-November 2016
18
Most likely 14
10
12
Forecast
Long-term average
© Crown Copyright 2016. Source: Met Office

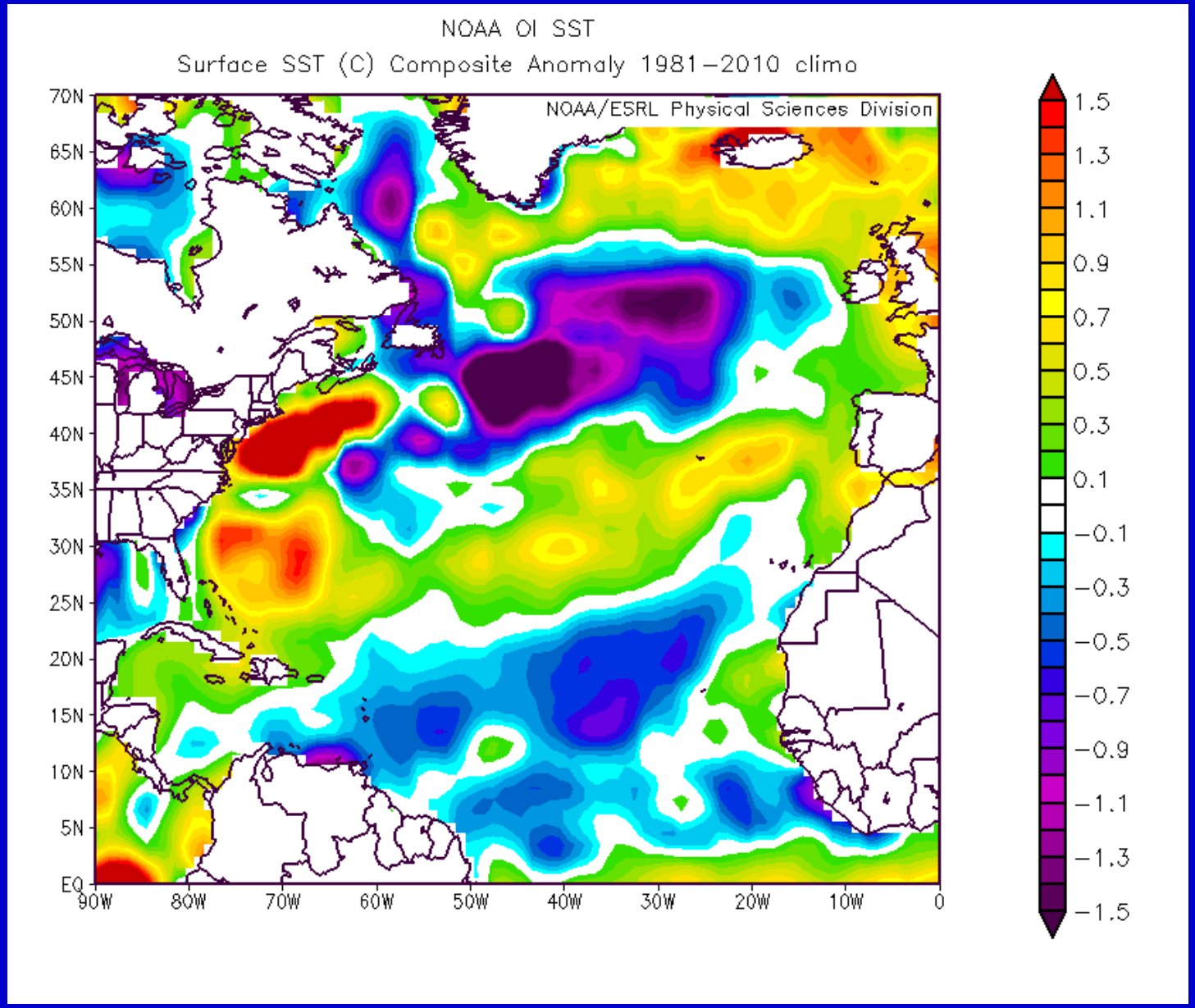
Seasonal Hurricane Forecast Compilation Website – http://www.seasonalhurricanepredictions.org



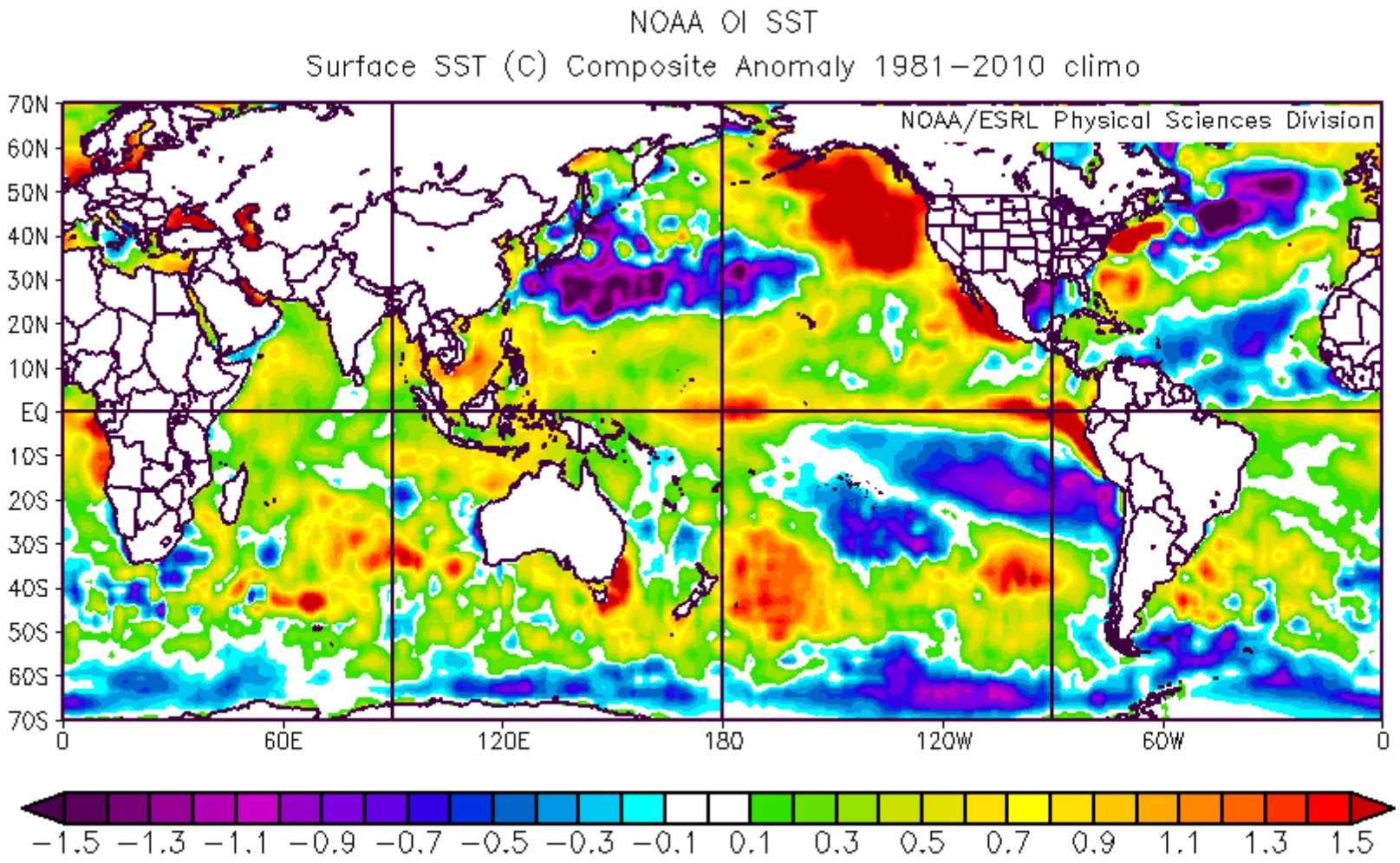
Exercise

- Using what you have been taught about seasonal forecasting, make a seasonal forecast with the atmospheric and oceanic slides in the following slides.
- Please forecast number of tropical storms, hurricanes, major hurricanes and ACE.
- Remember long term averages are 12 TS, 6 H, 3 MH and ACE ~ 100
- What are the expected climate conditions for hurricane season? How will these conditions affect your forecast?

North Atlantic May SSTAs



Global May SSTAs



ENSO Outlook from CPC and Upper Ocean Heat Content Anomalies

EL NIÑO/SOUTHERN OSCILLATION (ENSO) DIAGNOSTIC DISCUSSION

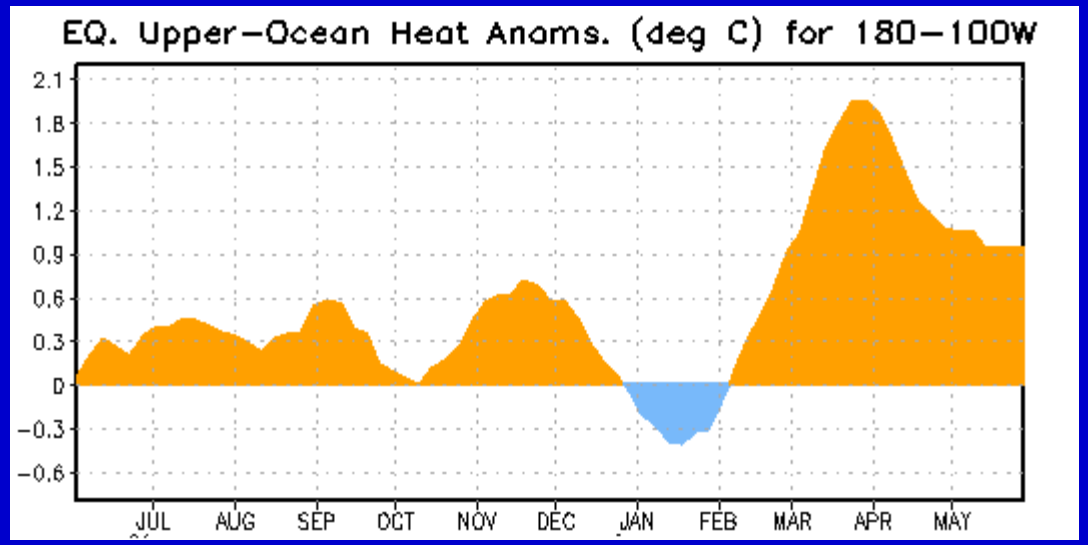
issued by

CLIMATE PREDICTION CENTER/NCEP/NWS
and the International Research Institute for Climate and Society

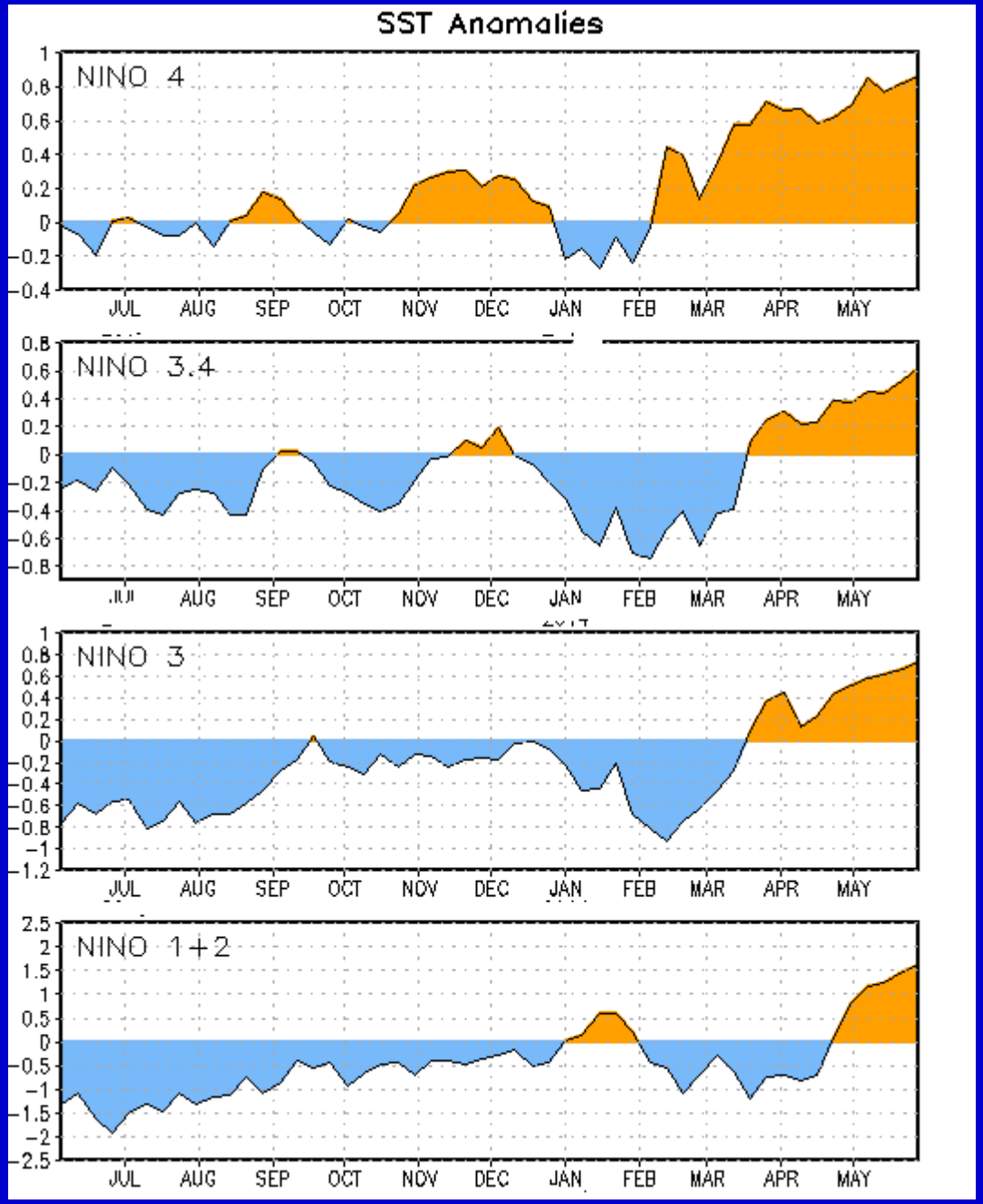
5 June

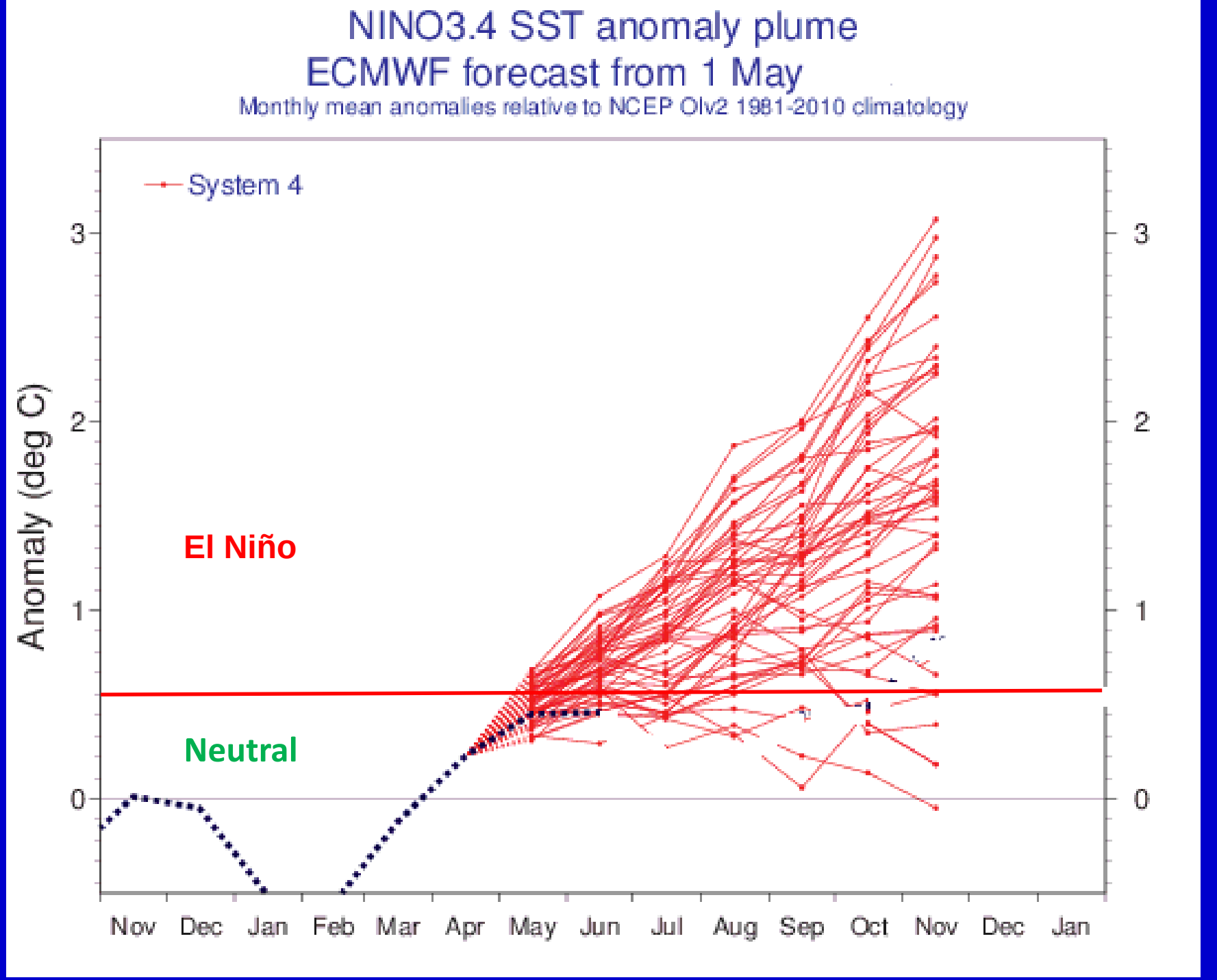
ENSO Alert System Status: El Niño Watch

Synopsis: The chance of El Niño is 70% during the Northern Hemisphere summer and reaches 80% during the fall and winter.



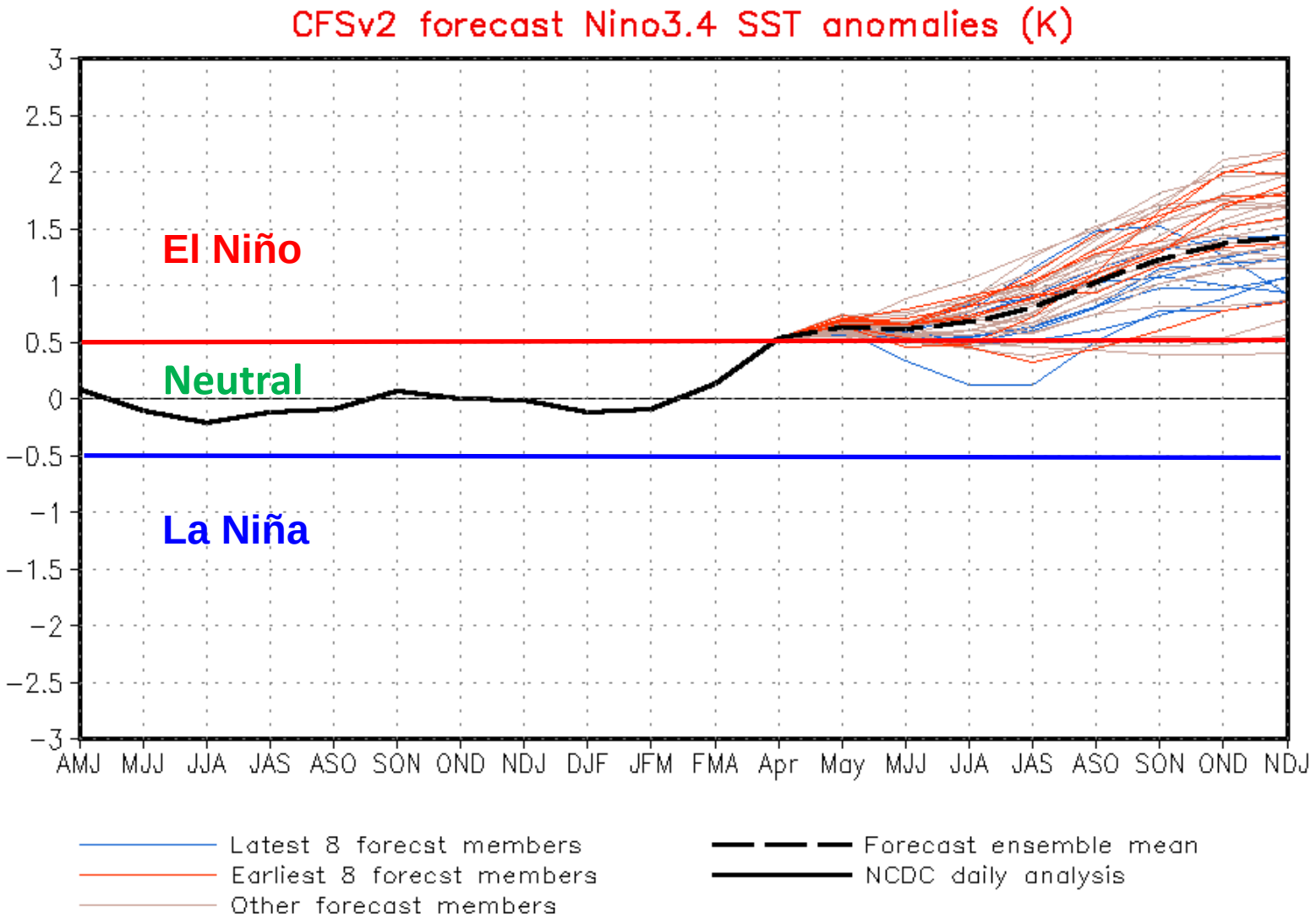
Tropical Pacific SSTA Evolution

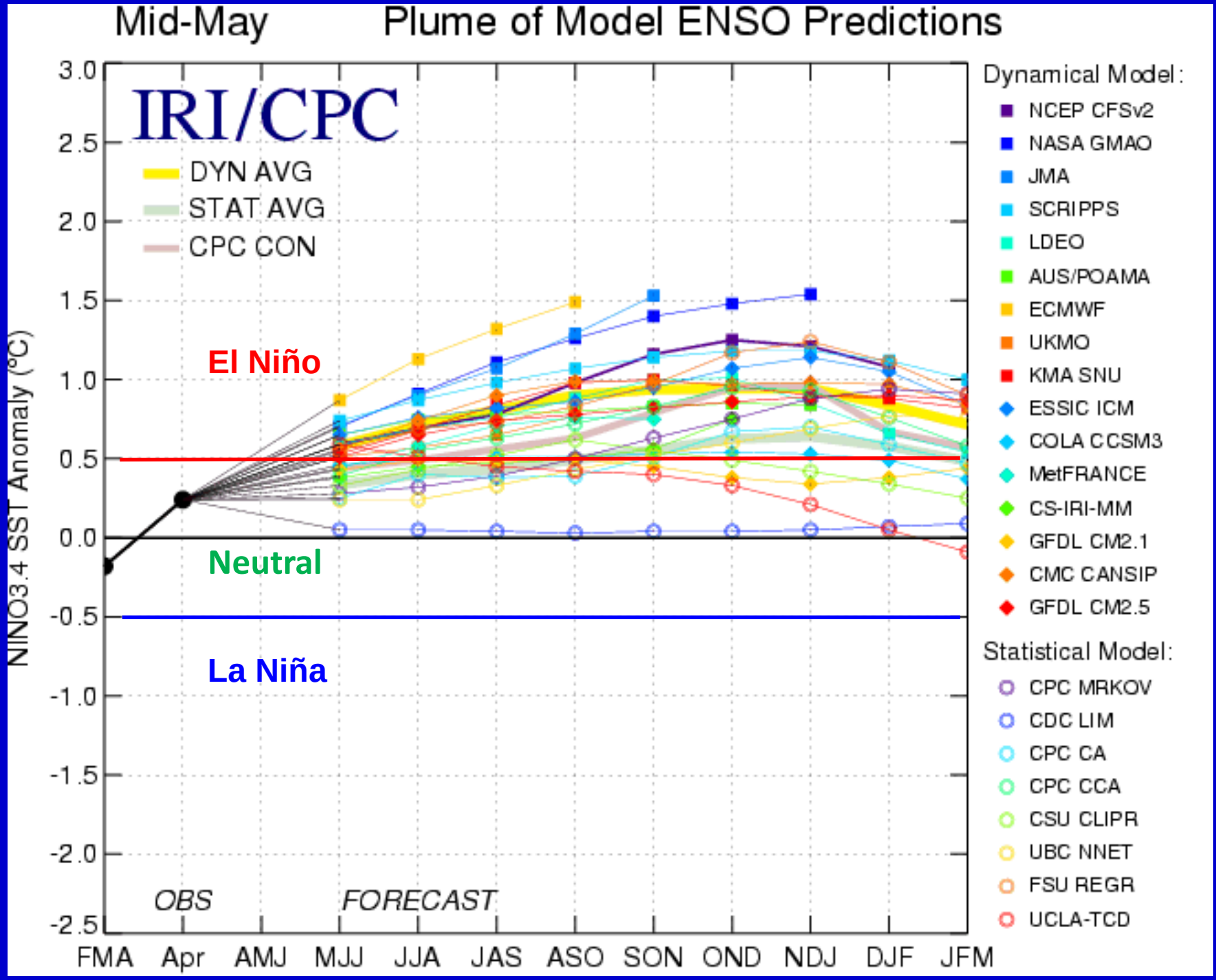



NINO3.4 SST anomaly plume
ECMWF forecast from 1 May
Monthly mean anomalies relative to NCEP Olv2 1981-2010 climatology
System 4
Anomaly (deg C)
3
2
1
0
El Niño
Neutral
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan

NWS/NCEP/CPC

Last update: Mon May 12
Initial conditions: 1May -10May



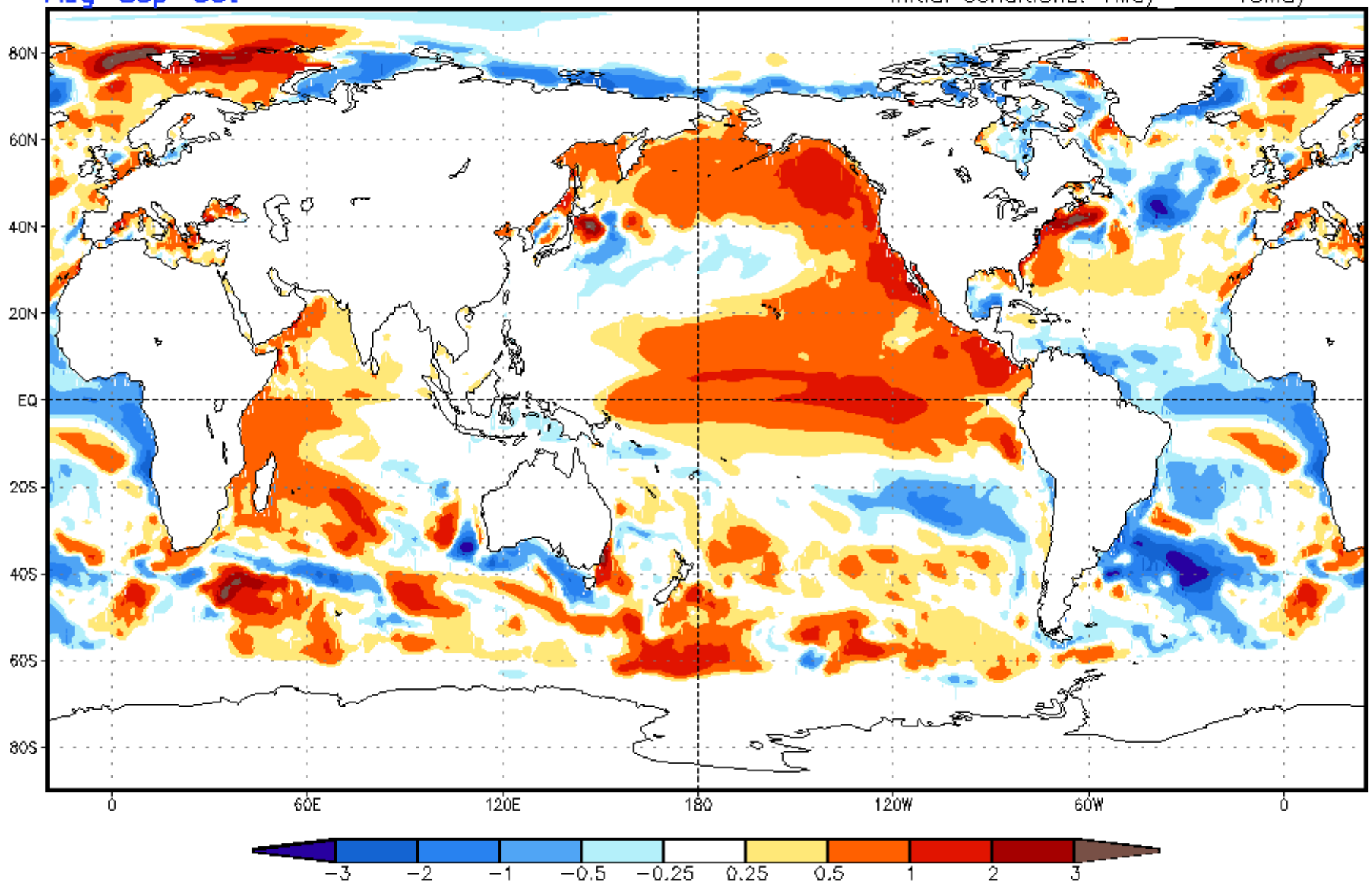

Mid-May
Plume of Model ENSO Predictions
IRI/CPC
DYN AVG
STAT AVG
CPC CON
El Niño
Neutral
La Niña
NINO3.4 SST Anomaly (°C)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
OBS
FORECAST
FMA
Apr
AMJ
MJJ
JJA
JAS
ASO
SON
OND
NDJ
DJF
JFM
Dynamical Model:
NCEP CFSv2
NASA GMAO
JMA
SCRIPPS
LDEO
AUS/POAMA
ECMWF
UKMO
KMA SNU
ESSIC ICM
COLA CCSM3
MetFRANCE
CS-IRI-MM
GFDL CM2.1
CMC CANSIP
GFDL CM2.5
Statistical Model:
CPC MRKOV
CDC LIM
CPC CA
CPC CCA
CSU CLIPR
UBC NNET
FSU REGR
UCLA-TCD

CFSv2 seasonal SST anomalies (K)

NWS/NCEP/CPC

Aug–Sep–Oct

Initial conditions: 1May --10May

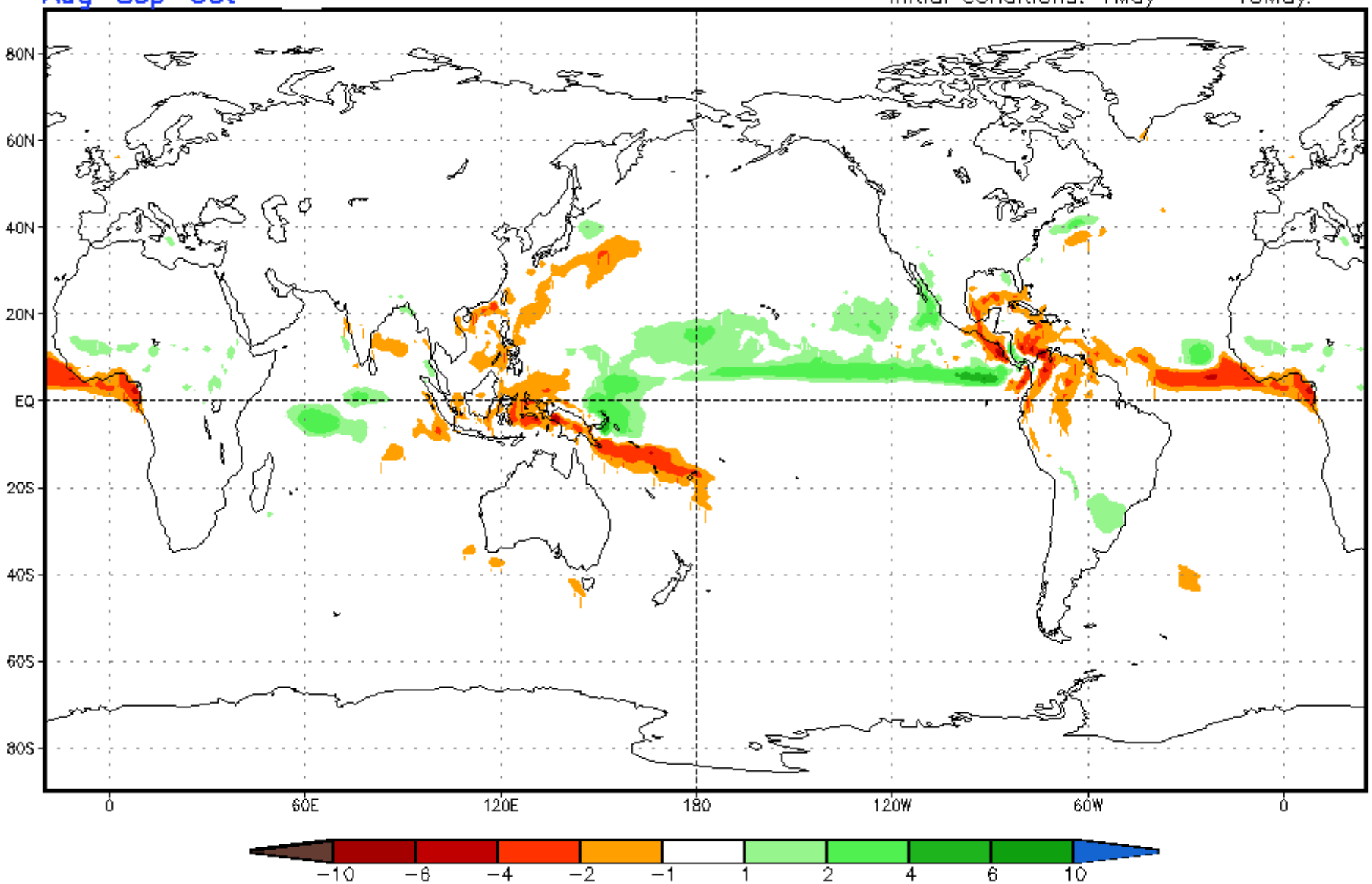


CFSv2 seasonal Prec anomalies (mm/day)

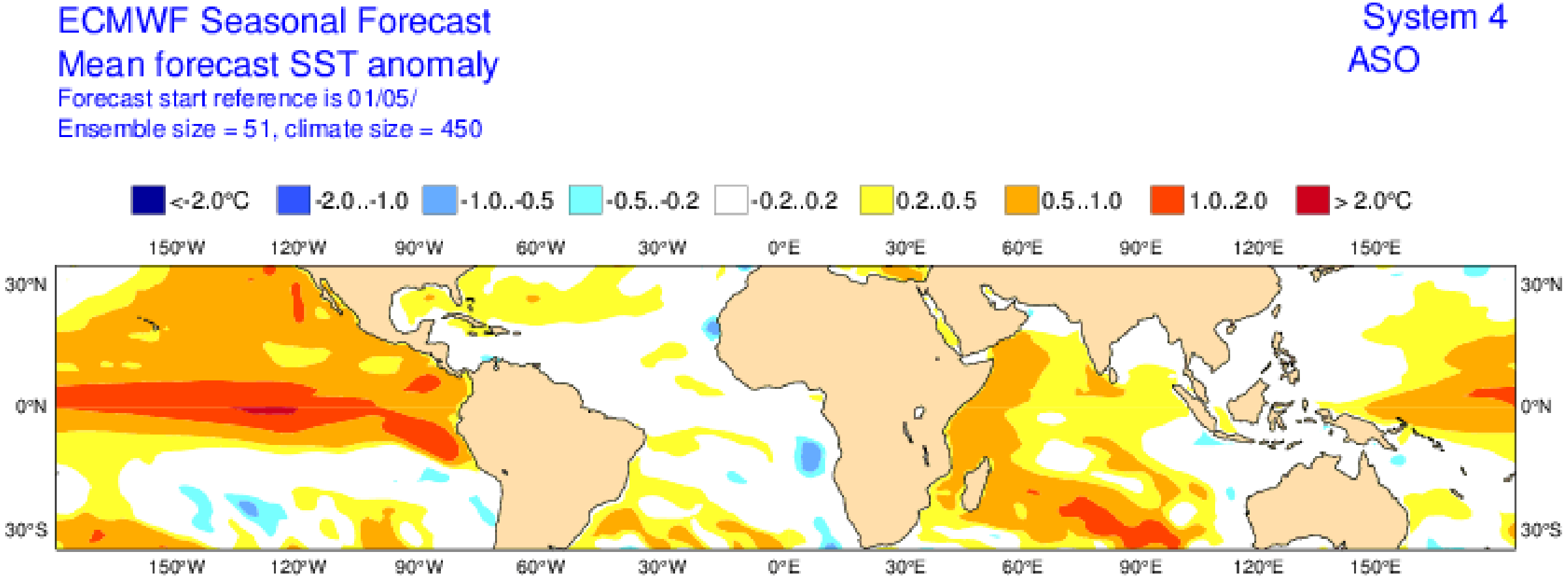
NWS/NCEP/CPC

Aug–Sep–Oct

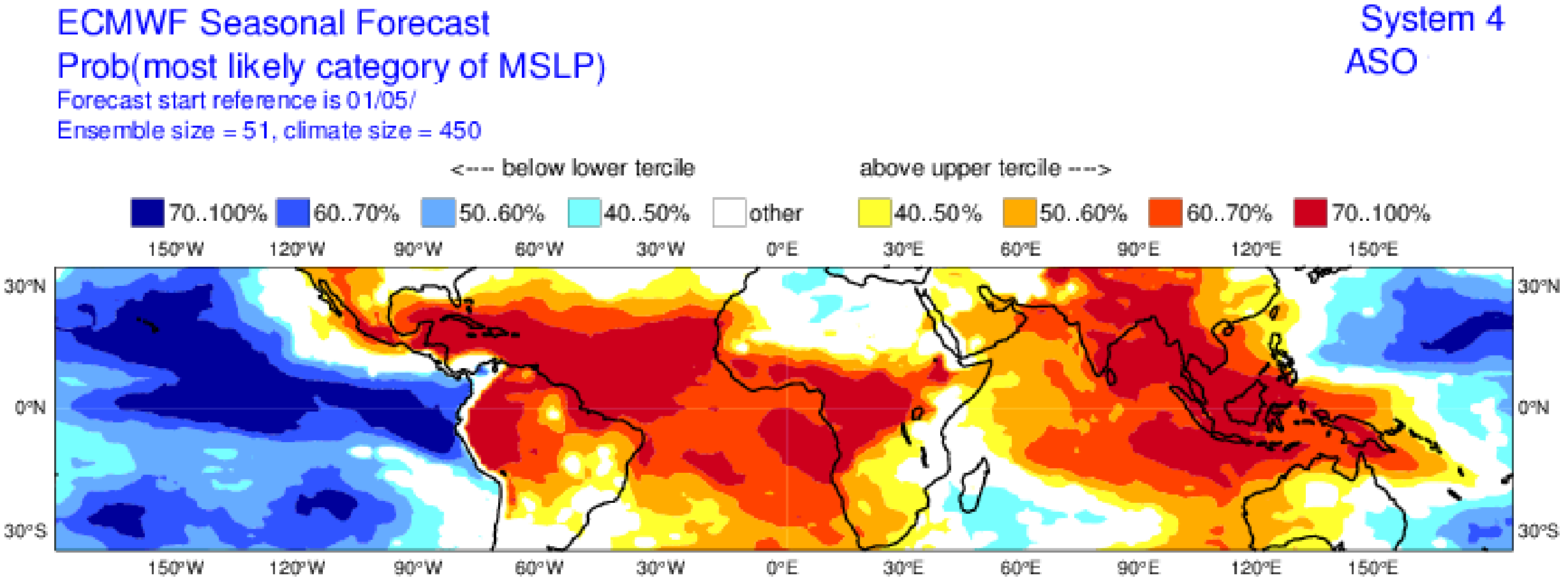
Initial conditions: 1May' –10May.



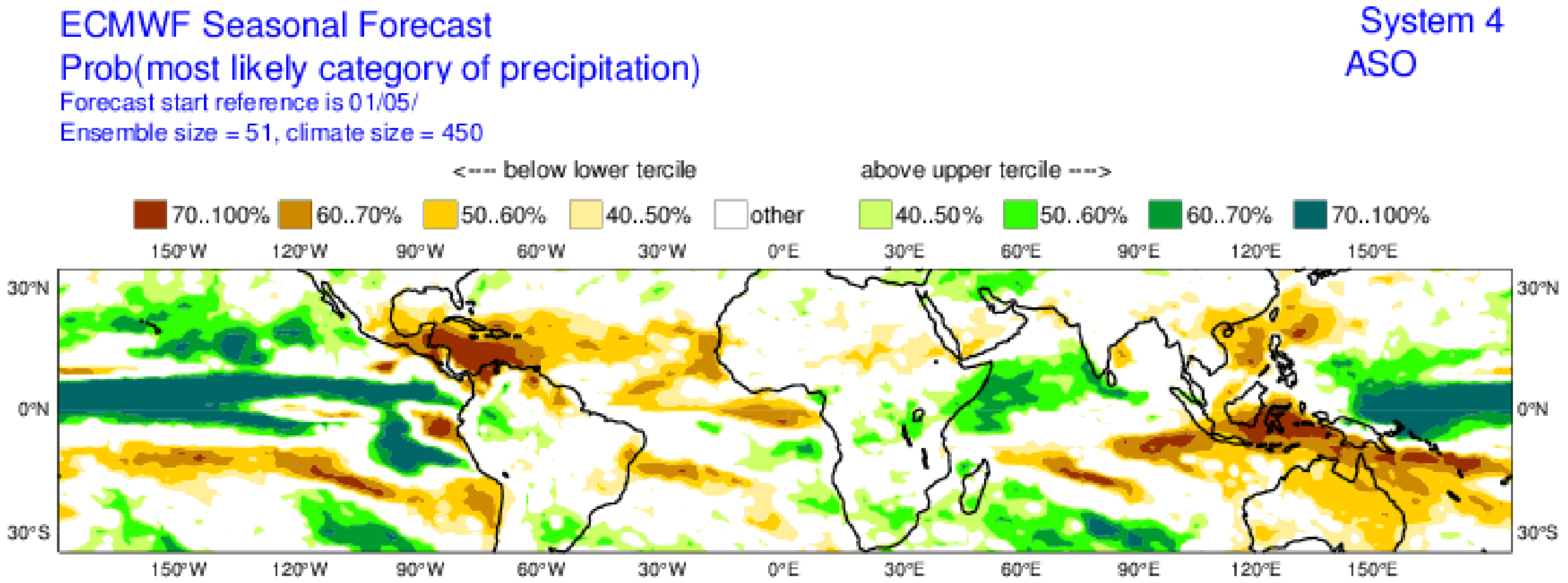
ASO SSTA forecast from ECMWF



ASO SLPA forecast from ECMWF

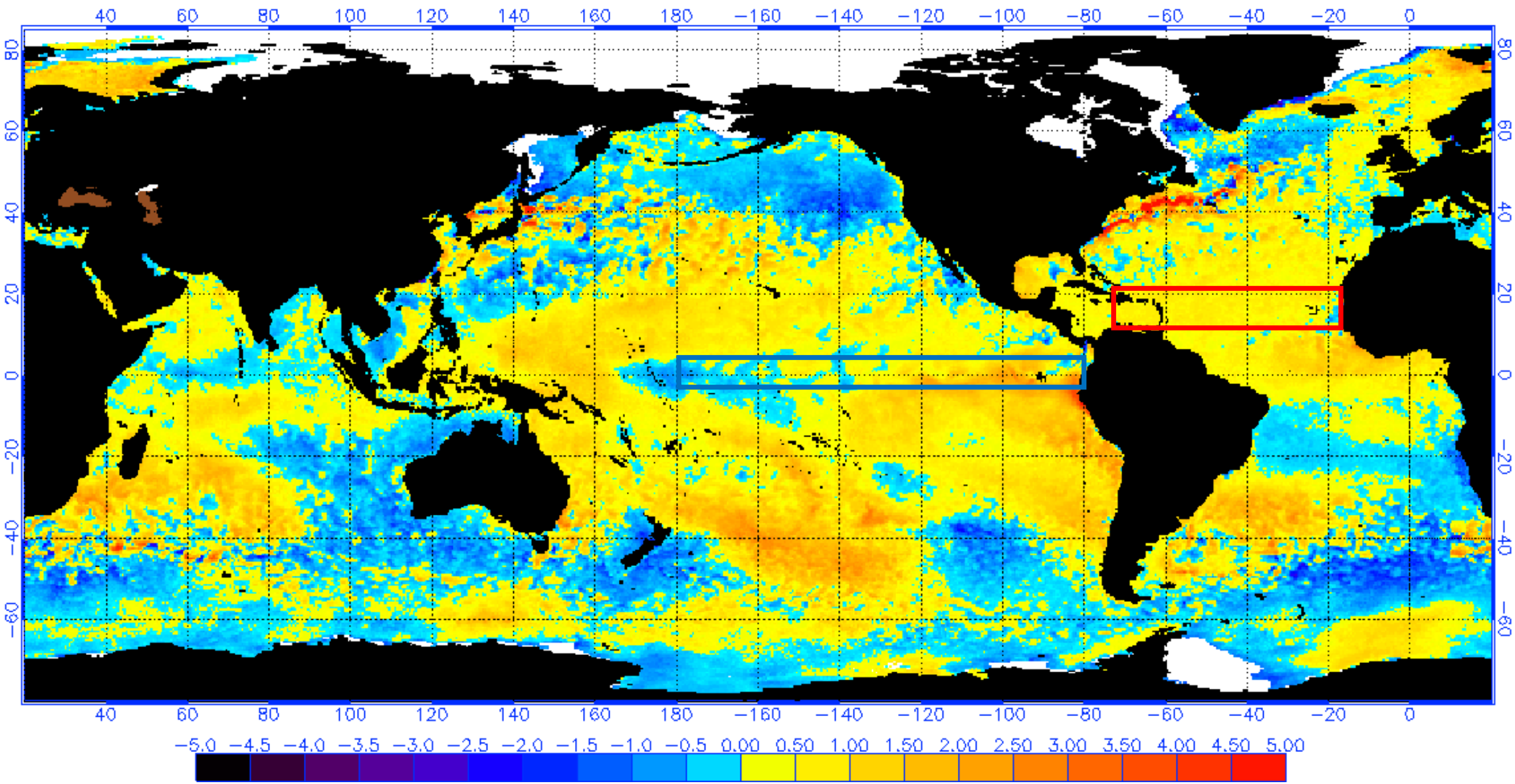


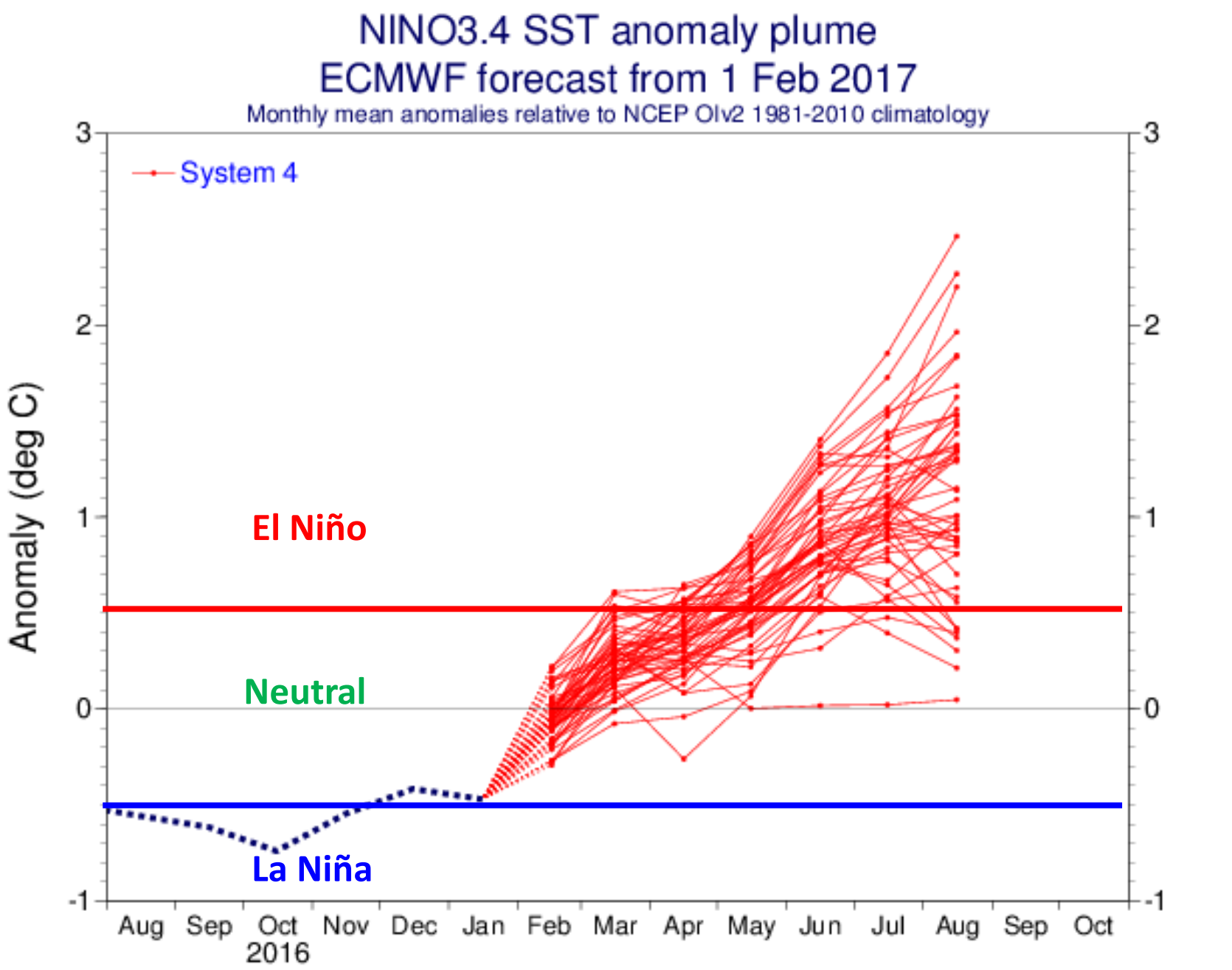
ASO Precipitation Forecast from ECMWF

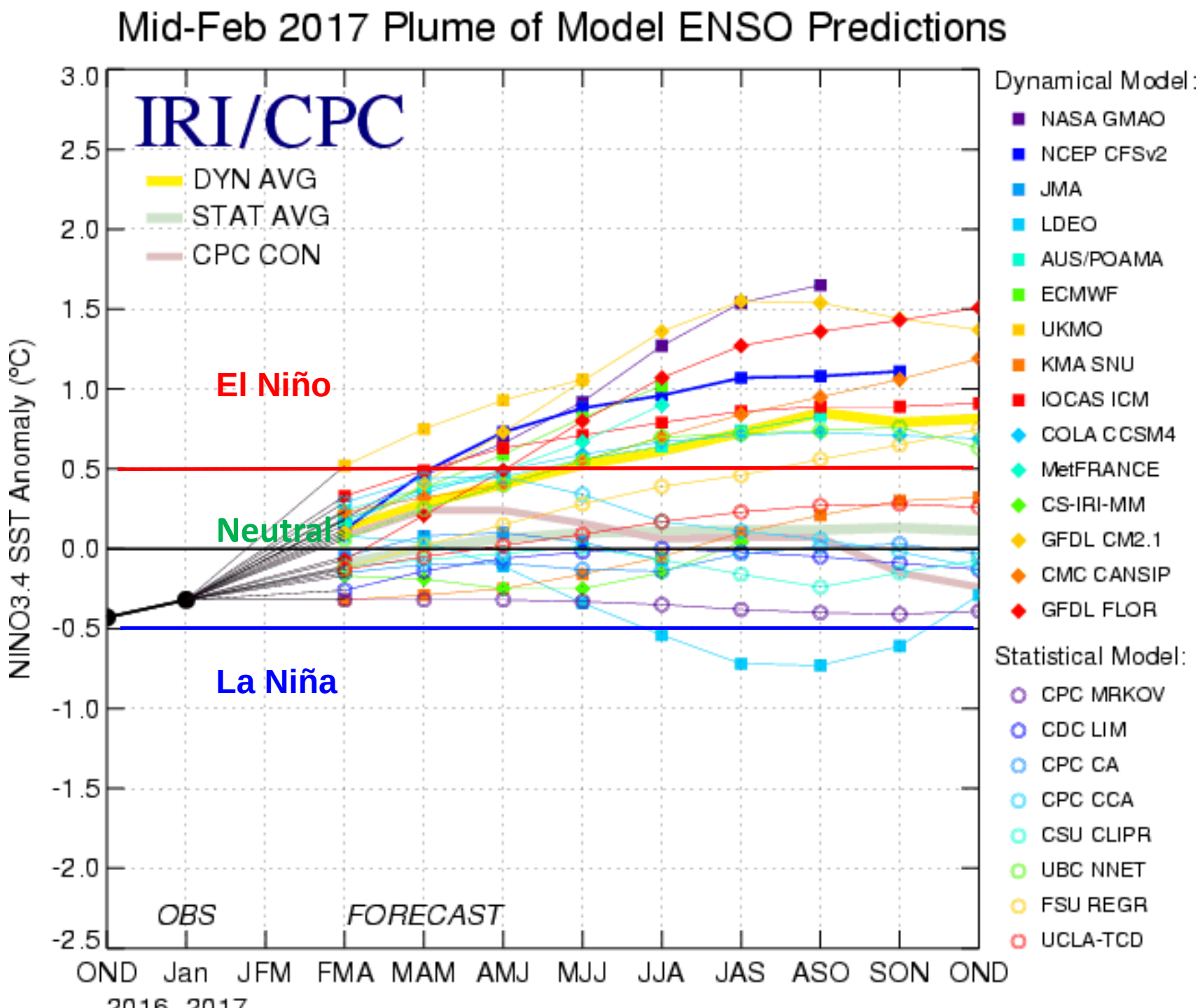


And the Year Being Forecast Is…..

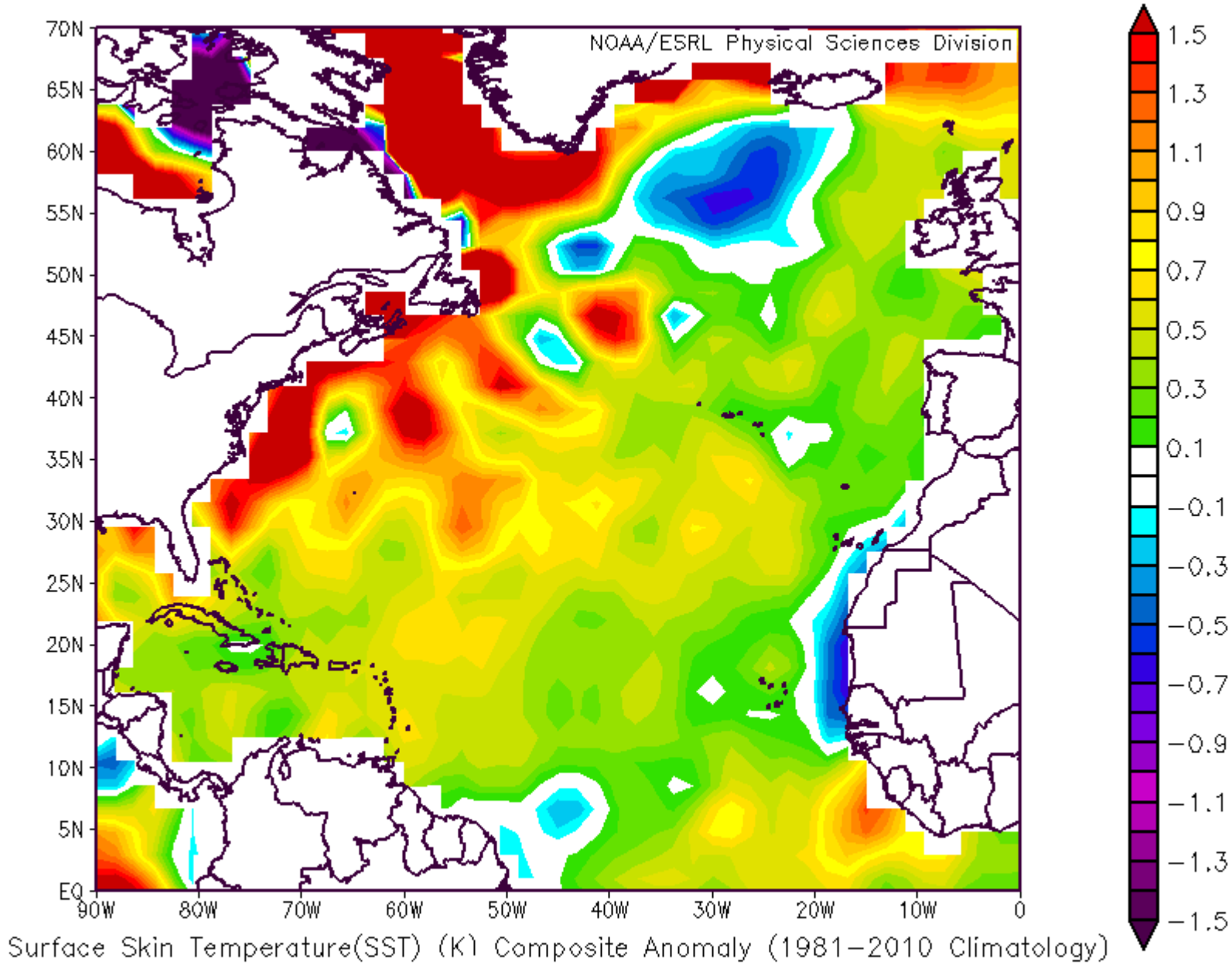
2017 Atlantic Hurricane Season Outlook


NOAA/NESDIS 50 KM GLOBAL ANALYSIS: SST Anomaly (degrees C), 2/20/2017
(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


NINO3.4 SST anomaly plume
ECMWF forecast from 1 Feb 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
Aug
Sep
Oct
2016
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct


Mid-Feb 2017 Plume of Model ENSO Predictions
IRI/CPC
DYN AVG
STAT AVG
CPC CON
El Niño
Neutral
La Niña
NINO3.4 SST Anomaly (°C)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
OBS
FORECAST
OND
Jan
JFM
FMA
MAM
AMJ
MJJ
JJA
JAS
ASO
SON
OND
2016
2017
Dynamical Model:
NASA GMAO
NCEP CFSv2
JMA
LDEO
AUS/POAMA
ECMWF
UKMO
KMA SNU
IOCAS ICM
COLA CCSM4
MetFRANCE
CS-IRI-MM
GFDL CM2.1
CMC CANSIP
GFDL FLOR
Statistical Model:
CPC MRKOV
CDC LIM
CPC CA
CPC CCA
CSU CLIPR
UBC NNET
FSU REGR
UCLA-TCD

Mid February 2017 SST Anomalies

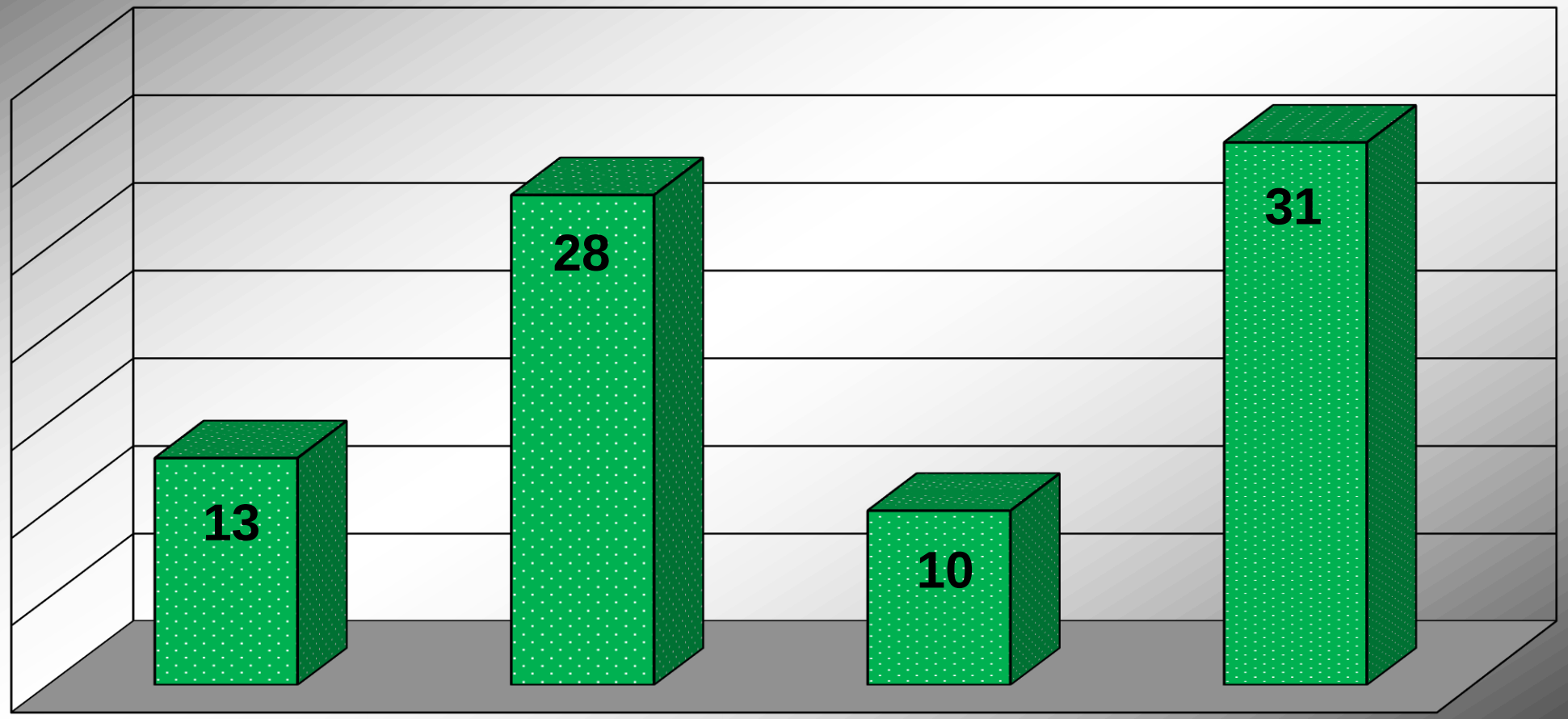


2017
Forecast Schedule

Date	6 April	1 June	3 July	2 Aug
Seasonal Forecast	X	X	X	X

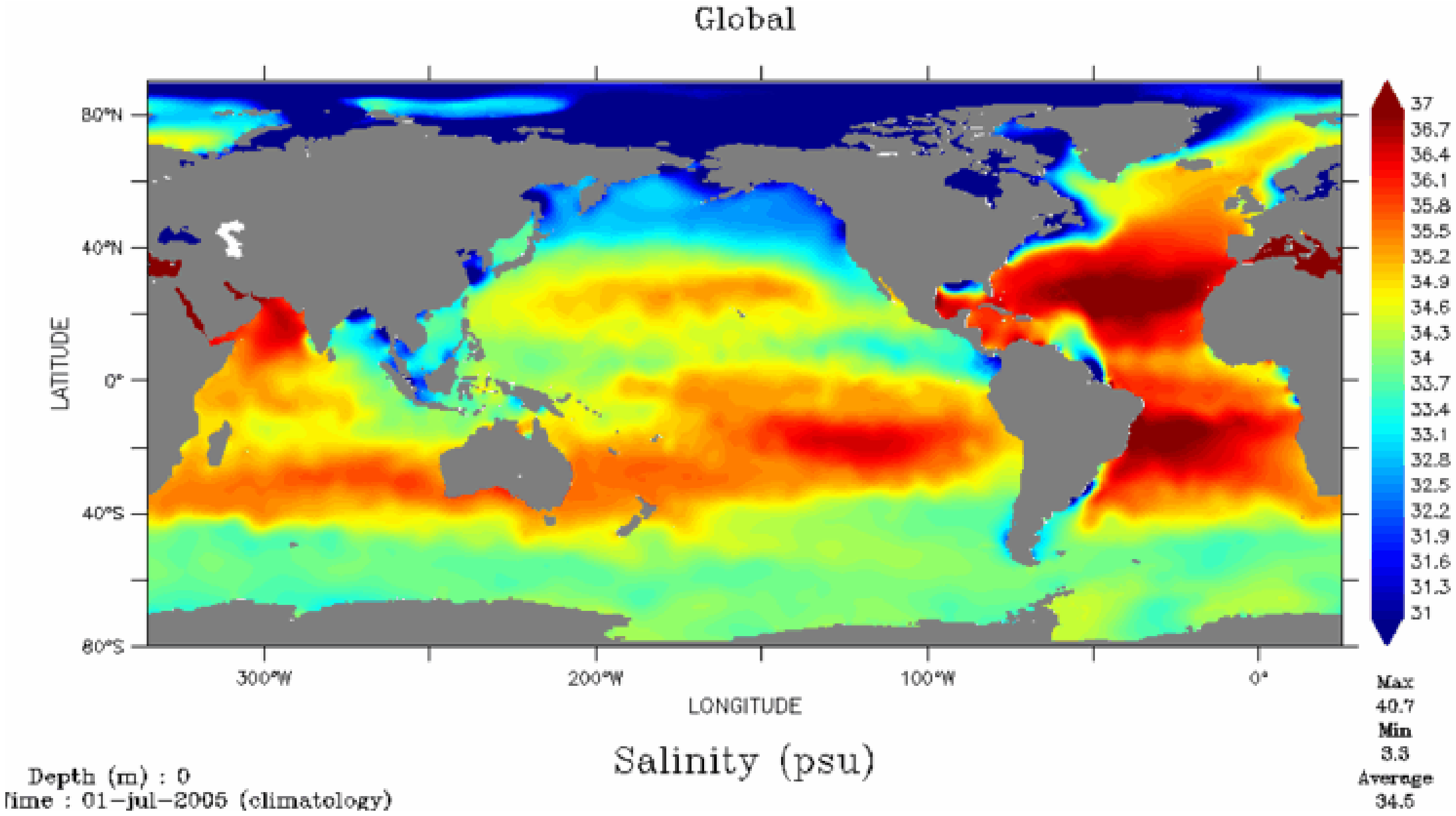
Atlantic Basin Multi-decadal Hurricane Variability

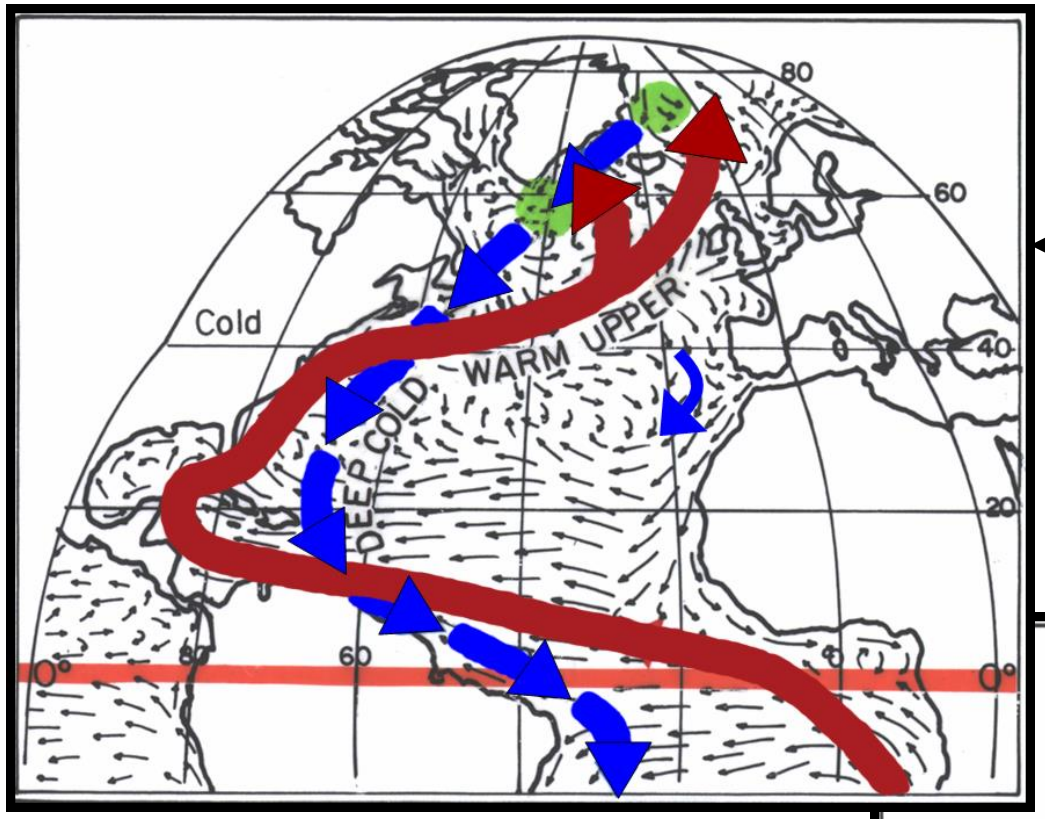
Annual Number of 6 Hour Periods for Cat 3-4-5 Hurricanes



	1900-1925	1926-1969	1970-1994	1995-2016
Cat 3-4-5	13	28	10	31

GLOBAL SURFACE SALINITY





THC *(or AMO)*

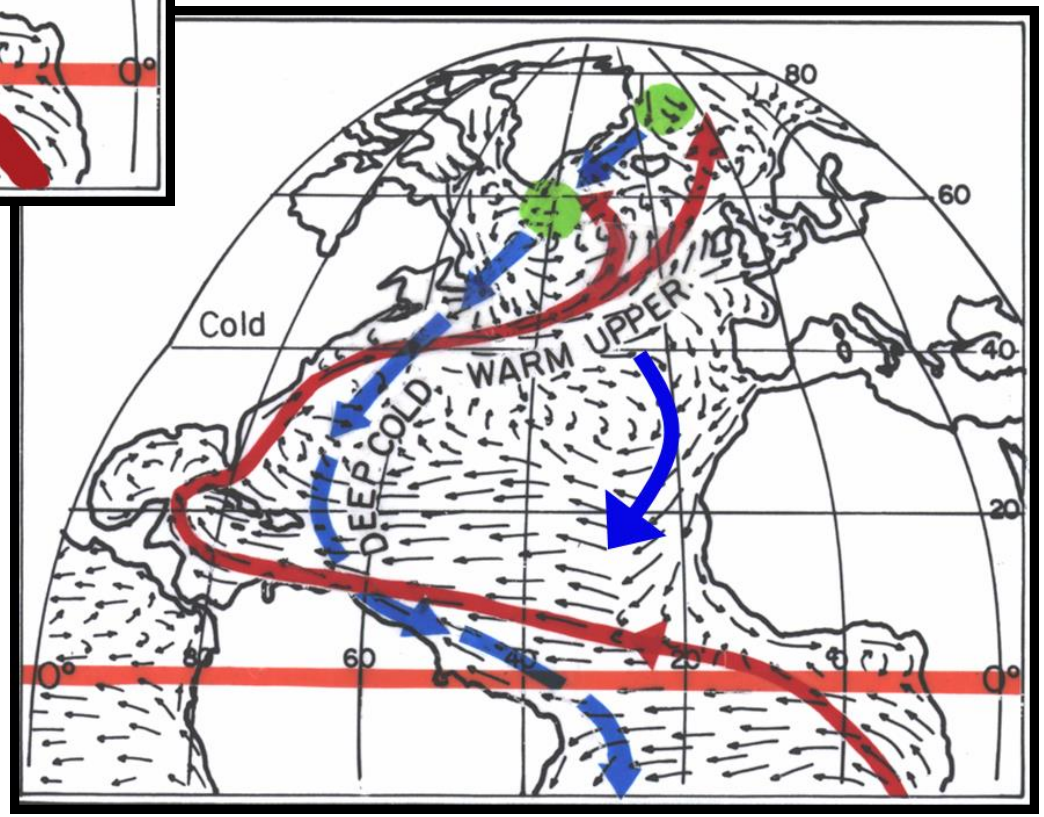
←

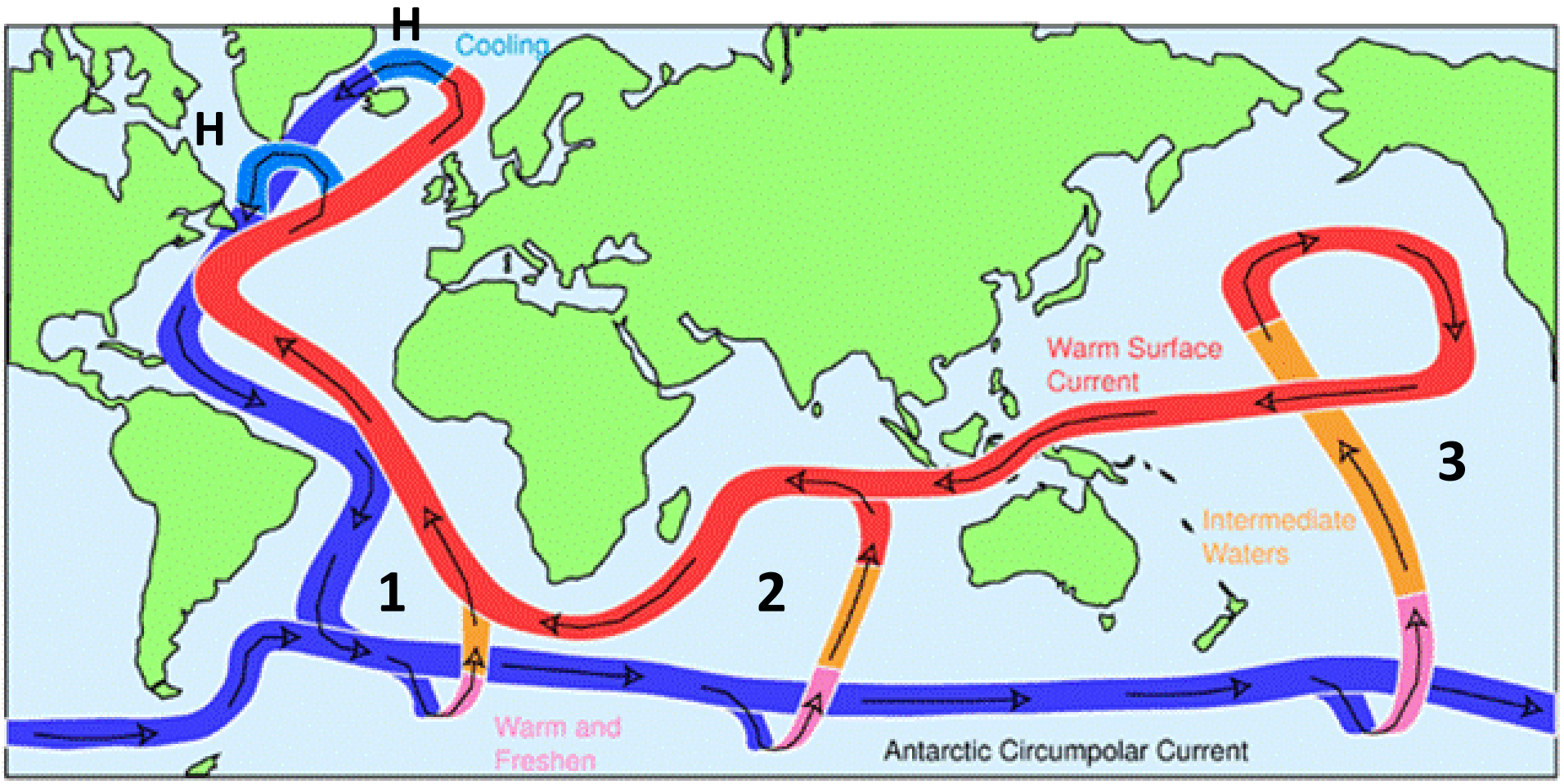
STRONG

THC *(or AMO)*

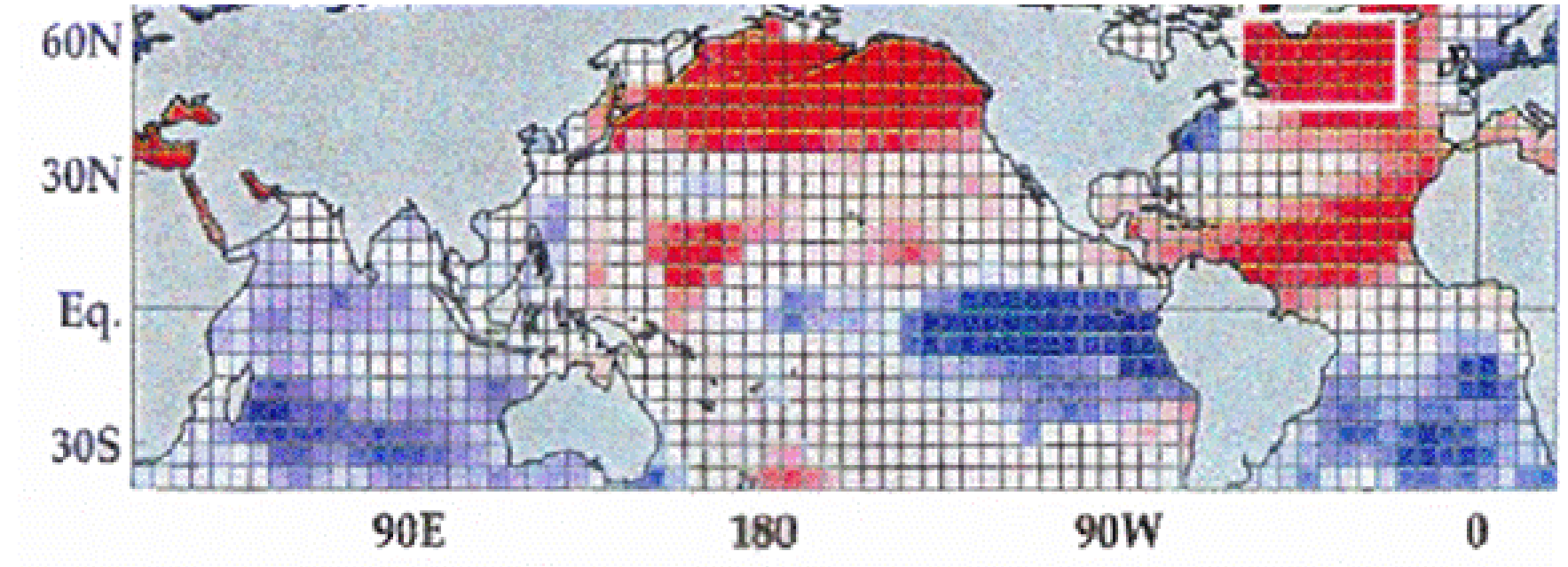
→

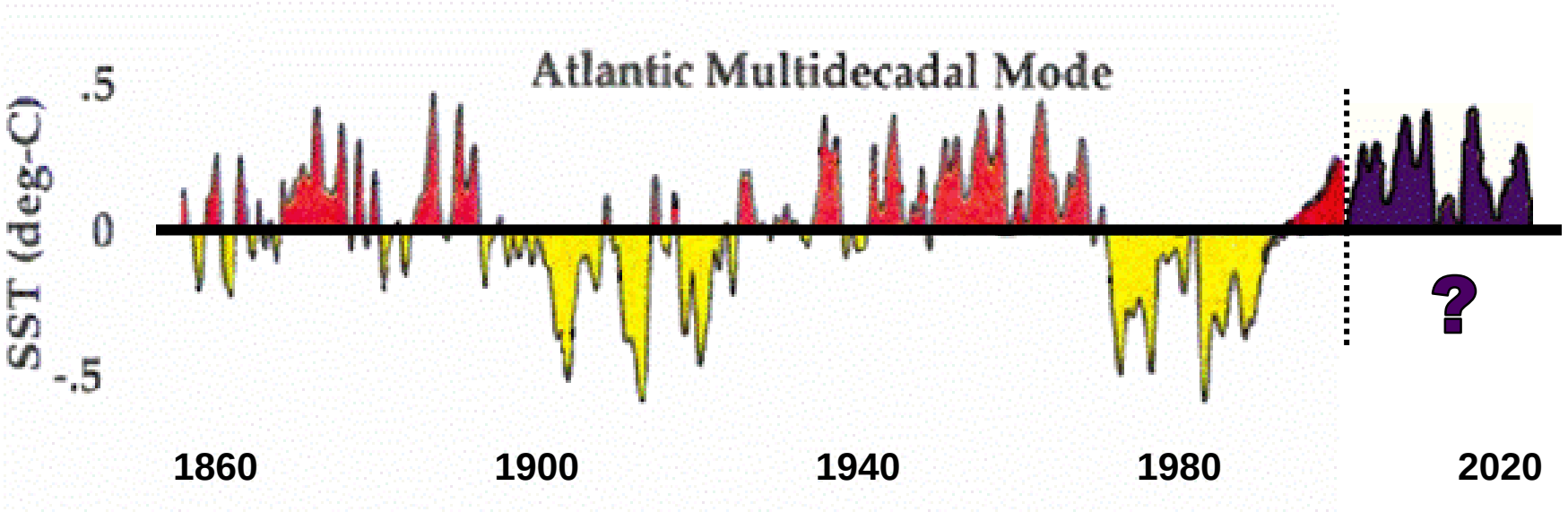
WEAK





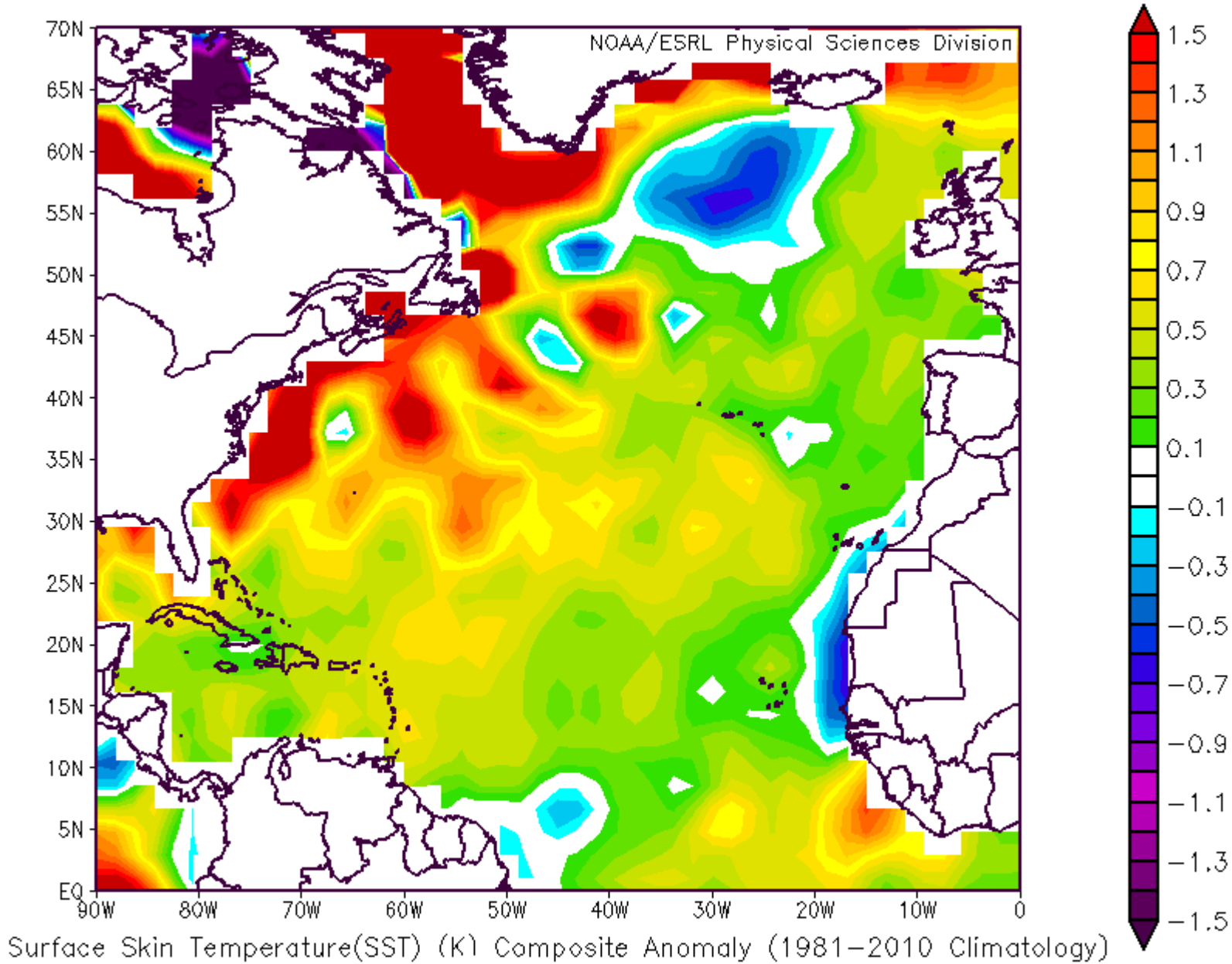
Courtesy of John Marshall (MIT)

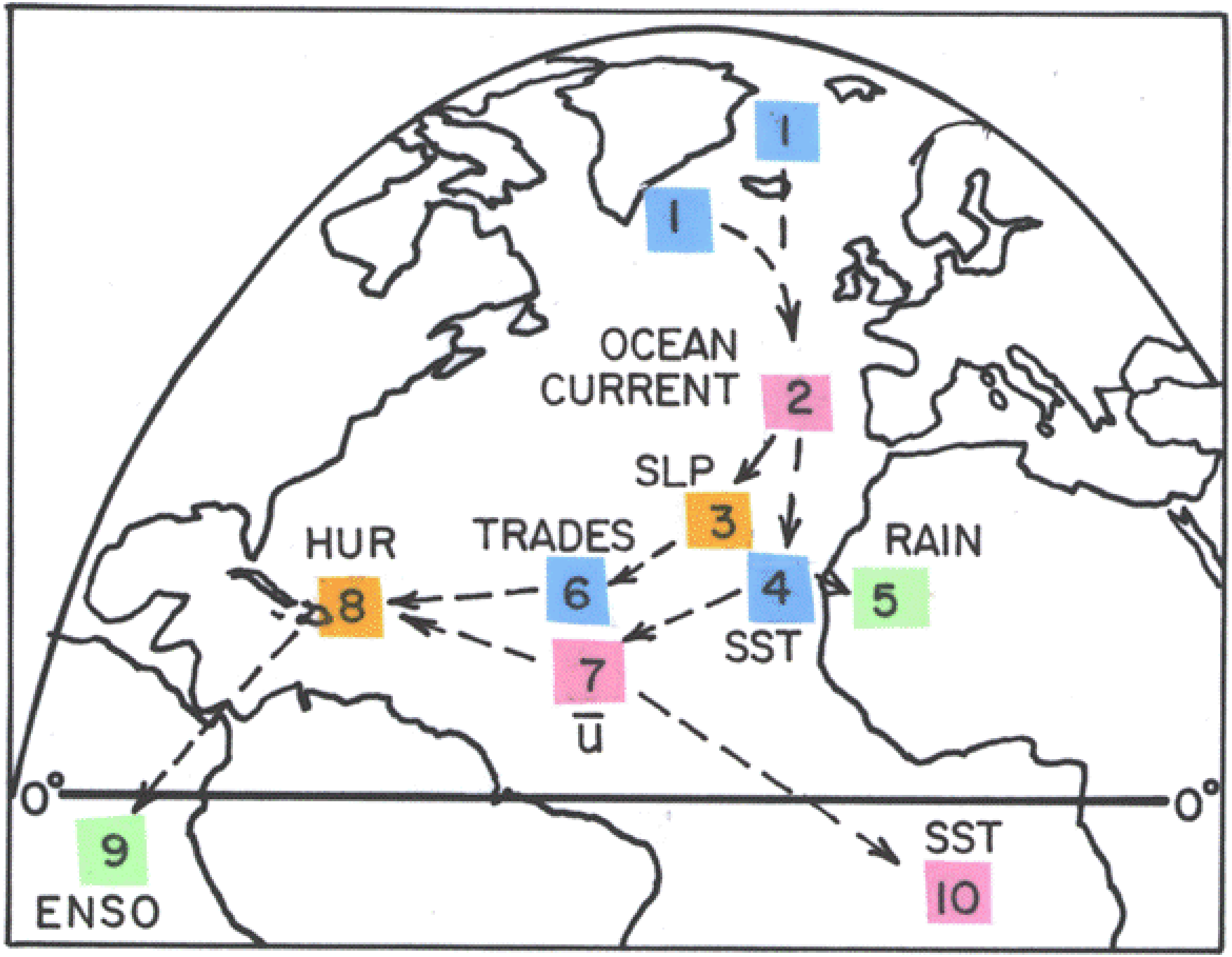


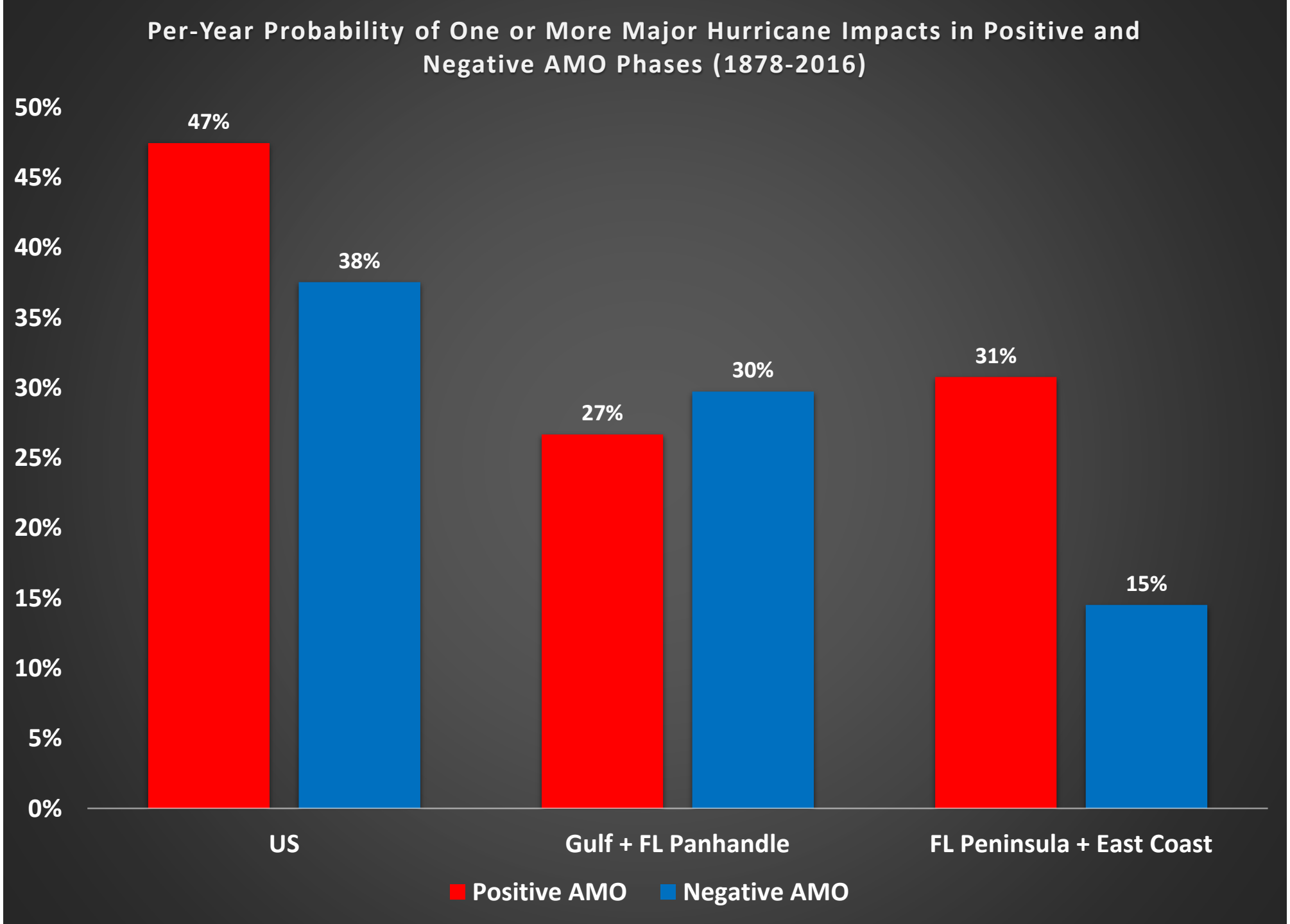


Goldenberg et al. (2001)

Mid February 2017 SST Anomalies




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


Per-Year Probability of One or More Major Hurricane Impacts in Positive and Negative AMO Phases (1878-2016)
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
47%
38%
27%
30%
31%
15%
US
Gulf + FL Panhandle
FL Peninsula + East Coast
Positive AMO
Negative AMO

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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Facebook: CSU Tropical Meteorology Project