FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2018

We continue to forecast a below-average Atlantic hurricane season. The tropical Atlantic remains cooler than normal, and there is a relatively high potential that a weak El Niño develops in the next several months. The probability for major hurricanes making landfall along the United States coastline and in the Caribbean is below normal due to the forecast for a below-average season. As is the case with all hurricane seasons, coastal residents are reminded that it only takes one hurricane making landfall to make it an active season for them. They should prepare the same for every season, regardless of how much activity is predicted.

(as of 2 August 2018)

By Philip J. Klotzbach[1] and Michael M. Bell[2]

In Memory of William M. Gray[3]

This discussion as well as past forecasts and verifications are available online at http://tropical.colostate.edu

Anne Manning, Colorado State University media representative, is coordinating media inquiries into this forecast. She can be reached at 970-491-7099 or anne.manning@colostate.edu.

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2018

Forecast Parameter and 1981-2010 Median (in parentheses)	Issue Date 5 April 2018	Issue Date 31 May 2018	Issue Date 2 July 2018	Observed Activity Thru July 2018	Forecast Activity After 31 July	**Total Seasonal Forecast**
Named Storms (NS) (12.0)	14	14	11	3	9	**12**
Named Storm Days (NSD) (60.1)	70	55	45	13	40	**53**
Hurricanes (H) (6.5)	7	6	4	2	3	**5**
Hurricane Days (HD) (21.3)	30	20	15	3.25	11.75	**15**
Major Hurricanes (MH) (2.0)	3	2	1	0	1	**1**
Major Hurricane Days (MHD) (3.9)	7	4	2	0	2	**2**
Accumulated Cyclone Energy (ACE) (92)	130	90	60	14	50	**64**
Net Tropical Cyclone Activity (NTC) (103%)	135	100	70	18	60	**78**

POST-31 JULY PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE LANDFALL ON EACH OF THE FOLLOWING UNITED STATES COASTAL AREAS:

1) Entire U.S. coastline - 35% (full-season average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 20% (full-season average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 19% (full-season average for last century is 30%)

POST-31 JULY PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE TRACKING INTO THE CARIBBEAN (10-20°N, 60-88°W)

1) 28% (full-season average for last century is 42%)

ABSTRACT

Information obtained through July 2018 indicates that the 2018 Atlantic hurricane season will have activity below the median 1981-2010 season. We estimate that the remainder of 2018 will have about 3 hurricanes (average is 5.5), 9 named storms (average is 10.5), 40 named storm days (average is 58), 12 hurricane days (average is 21.3), 1 major (Category 3-4-5) hurricane (average is 2.0) and 2 major hurricane days (average is 3.9). The probability of U.S. major hurricane landfall is estimated to be below the long-period average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2018 to be below their long-term averages for the remainder of the season.

The tropical Atlantic remains anomalously cool, and vertical wind shear across the Caribbean has been quite strong over the past month. The tropical Atlantic has also been very dry in July. All these conditions tend to be associated with quieter Atlantic hurricane seasons. There remains uncertainty as to if an El Niño will develop over the next few months. However, regardless if conditions remain in ENSO-neutral territory or anomalously warm to a weak El Niño event, we believe that the hurricane-unfavorable conditions in the Atlantic are likely to persist over the next several months.

This forecast is based on an extended-range early August statistical prediction scheme developed on data from 1979-2011 and issued operationally since 2012. Analog predictors were also considered.

Starting today and issued every two weeks following (e.g., August 2, August 16, August 30, etc.), we will issue two-week forecasts for Atlantic TC activity during the peak of the Atlantic hurricane season from August-October.

Coastal residents are reminded that it only takes one hurricane making landfall to make it an active season for them, and they need to prepare the same for every season, regardless of how much activity is predicted.

Why issue extended-range forecasts for seasonal hurricane activity?

We are frequently asked this question. Our answer is that it is possible to say something about the probability of the coming year's hurricane activity which is superior to climatology. The Atlantic basin has the largest year-to-year variability of any of the global tropical cyclone basins. People are curious to know how active the upcoming season is likely to be, particularly if you can show hindcast skill improvement over climatology for many past years.

Everyone should realize that it is impossible to precisely predict this season's hurricane activity in early August. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged as regards to the probability of an active or inactive hurricane season for the coming year. Our early August statistical forecast methodology shows strong evidence over 39 past years that significant improvement over climatology can be attained. We would never issue a seasonal hurricane forecast unless we had a statistical model developed over a long hindcast period which showed significant skill over climatology.

We issue these forecasts to satisfy the curiosity of the general public and to bring attention to the hurricane problem. There is a general interest in knowing what the odds are for an active or inactive season. One must remember that our forecasts are based on the premise that those global oceanic and atmospheric conditions which preceded comparatively active or inactive hurricane seasons in the past provide meaningful information about similar trends in future seasons.

It is also important that the reader appreciate that these seasonal forecasts are based on statistical schemes which, owing to their intrinsically probabilistic nature, will fail in some years. Moreover, these forecasts do not specifically predict where within the Atlantic basin these storms will strike. The probability of landfall for any one location along the coast is very low and reflects the fact that, in any one season, most U.S. coastal areas will not feel the effects of a hurricane no matter how active the individual season is.

Acknowledgment

These seasonal forecasts were developed by the late Dr. William Gray, who was lead author on these predictions for over 20 years and continued as a co-author until his death in 2016. In addition to pioneering seasonal Atlantic hurricane prediction, he conducted groundbreaking research in a wide variety of other topics including hurricane genesis, hurricane structure and cumulus convection. His investments in both time and energy to these forecasts cannot be acknowledged enough.

We are grateful for support from Interstate Restoration, the Insurance Information Institute, Ironshore Insurance and Weatherboy that partially support the release of these predictions. We acknowledge a grant from the G. Unger Vetlesen Foundation for additional financial support. We thank the GeoGraphics Laboratory at Bridgewater State University (MA) for their assistance in developing the United States Landfalling Hurricane Probability Webpage.

Colorado State University's seasonal hurricane forecasts have benefited greatly from a number of individuals that were former graduate students of William Gray. Among these former project members are Chris Landsea, John Knaff and Eric Blake. We have also benefited from meteorological discussions with Carl Schreck, Brian McNoldy, Paul Roundy, Jason Dunion, Mike Ventrice, Peng Xian and Amato Evan over the past few years.

DEFINITIONS AND ACRONYMS

Accumulated Cyclone Energy (ACE) - A measure of a named storm's potential for wind and storm surge destruction defined as the sum of the square of a named storm's maximum wind speed (in 10^4 $knots^2$) for each 6-hour period of its existence. The 1950-2000 average value of this parameter is 96 for the Atlantic basin.

Atlantic Multi-Decadal Oscillation (AMO) – A mode of natural variability that occurs in the North Atlantic Ocean and evidencing itself in fluctuations in sea surface temperature and sea level pressure fields. The AMO is likely related to fluctuations in the strength of the oceanic thermohaline circulation. Although several definitions of the AMO are currently used in the literature, we define the AMO based on North Atlantic sea surface temperatures from 50-60°N, 50-10°W and sea level pressure from 0-50°N, 70-10°W.

Atlantic Basin – The area including the entire North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico.

El Niño – A 12-18 month period during which anomalously warm sea surface temperatures occur in the eastern half of the equatorial Pacific. Moderate or strong El Niño events occur irregularly, about once every 3-7 years on average.

Hurricane (H) - A tropical cyclone with sustained low-level winds of 74 miles per hour (33 ms^{-1} or 64 knots) or greater.

Hurricane Day (HD) - A measure of hurricane activity, one unit of which occurs as four 6-hour periods during which a tropical cyclone is observed or is estimated to have hurricane-force winds.

Madden Julian Oscillation (MJO) – A globally propagating mode of tropical atmospheric intra-seasonal variability. The wave tends to propagate eastward at approximately 5 ms^{-1}, circling the globe in roughly 30-60 days.

Main Development Region (MDR) – An area in the tropical Atlantic where a majority of tropical cyclones that become major hurricanes form, which we define as 10-20°N, 20-60°W.

Major Hurricane (MH) - A hurricane which reaches a sustained low-level wind of at least 111 mph (96 knots or 50 ms^{-1}) at some point in its lifetime. This constitutes a category 3 or higher on the Saffir/Simpson scale.

Major Hurricane Day (MHD) - Four 6-hour periods during which a hurricane has an intensity of Saffir/Simpson category 3 or higher.

Multivariate ENSO Index (MEI) – An index defining ENSO that takes into account tropical Pacific sea surface temperatures, sea level pressures, zonal and meridional winds and cloudiness.

Named Storm (NS) - A hurricane, a tropical storm or a sub-tropical storm.

Named Storm Day (NSD) - As in HD but for four 6-hour periods during which a tropical or sub-tropical cyclone is observed (or is estimated) to have attained tropical storm-force winds.

Net Tropical Cyclone (NTC) Activity –Average seasonal percentage mean of NS, NSD, H, HD, MH, MHD. Gives overall indication of Atlantic basin seasonal hurricane activity. The 1950-2000 average value of this parameter is 100.

Saffir/Simpson Hurricane Wind Scale – A measurement scale ranging from 1 to 5 of hurricane wind intensity. One is a weak hurricane; whereas, five is the most intense hurricane.

Southern Oscillation Index (SOI) – A normalized measure of the surface pressure difference between Tahiti and Darwin. Low values typically indicate El Niño conditions.

Sea Surface Temperature – SST

Sea Surface Temperature Anomaly – SSTA

Thermohaline Circulation (THC) – A large-scale circulation in the Atlantic Ocean that is driven by fluctuations in salinity and temperature. When the THC is stronger than normal, the AMO tends to be in its warm (or positive) phase, and more Atlantic hurricanes typically form.

Tropical Cyclone (TC) - A large-scale circular flow occurring within the tropics and subtropics which has its strongest winds at low levels; including hurricanes, tropical storms and other weaker rotating vortices.

Tropical North Atlantic (TNA) index – A measure of sea surface temperatures in the area from 5.5-23.5°N, 15-57.5°W.

Tropical Storm (TS) - A tropical cyclone with maximum sustained winds between 39 mph (18 ms^{-1} or 34 knots) and 73 mph (32 ms^{-1} or 63 knots).

Vertical Wind Shear – The difference in horizontal wind between 200 mb (approximately 40000 feet or 12 km) and 850 mb (approximately 5000 feet or 1.6 km).

1 knot = 1.15 miles per hour = 0.515 meters per second

1 Introduction

This is the 35th year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. This year's August forecast is based on a statistical methodology developed on Atlantic hurricane seasons from 1979-2011 and has been utilized operationally since 2012. Qualitative adjustments are added to accommodate additional processes which may not be explicitly represented by our statistical analyses. These evolving forecast techniques are based on a variety of climate-related global and regional predictors previously shown to be related to the forthcoming seasonal Atlantic basin TC activity and landfall probability. We believe that seasonal forecasts must be based on methods that show significant hindcast skill in application to long periods of prior data. It is only through hindcast skill that one can demonstrate that seasonal forecast skill is possible. This is a valid methodology provided that the atmosphere continues to behave in the future as it has in the past.

The best predictors do not necessarily have the best individual correlations with hurricane activity. The best forecast parameters are those that explain the portion of the variance of seasonal hurricane activity that is not associated with the other forecast variables. It is possible for an important hurricane forecast parameter to show little direct relationship to a predictand by itself but to have an important influence when included with a set of 2-3 other predictors.

A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 3-4 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmospheric-oceanic system that is highly non-linear. There is a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all these processes interact with each other. No one can completely understand the full complexity of the atmosphere-ocean system. But, it is still possible to develop a reliable statistical forecast scheme which incorporates a number of the climate system's non-linear interactions. Any seasonal or climate forecast scheme should show significant hindcast skill before it is used in real-time forecasts.

1.1 2018 Atlantic Basin Activity through July

The 2018 Atlantic basin hurricane season has had an above-average number named storms, hurricanes and ACE through the end of July. However, over 90% of all ACE is generated after 1 August. Real-time global TC statistics are available.

Table 1 records observed Atlantic basin TC activity through 31 July, while tracks through 31 July are displayed in Figure 1. All TC activity calculations are based upon data available in the National Hurricane Center's b-decks.

Table 1: Observed 2018 Atlantic basin tropical cyclone activity through July 31. Dates listed are those where TCs had maximum sustained winds of at least 35 knots and are given in UTC time.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	MHD	ACE
TS	Alberto	May 25 - 28	55 kt/990 mb	3.50			2.4
H-1	Beryl	July 5 - 9, 14 - 15	70 kt/994 mb	5.25	1.25		4.9
H-2	Chris	July 8 – 12	90 kt/970 mb	4.25	2.00		7.1
Totals	3			13.00	3.25		14.4

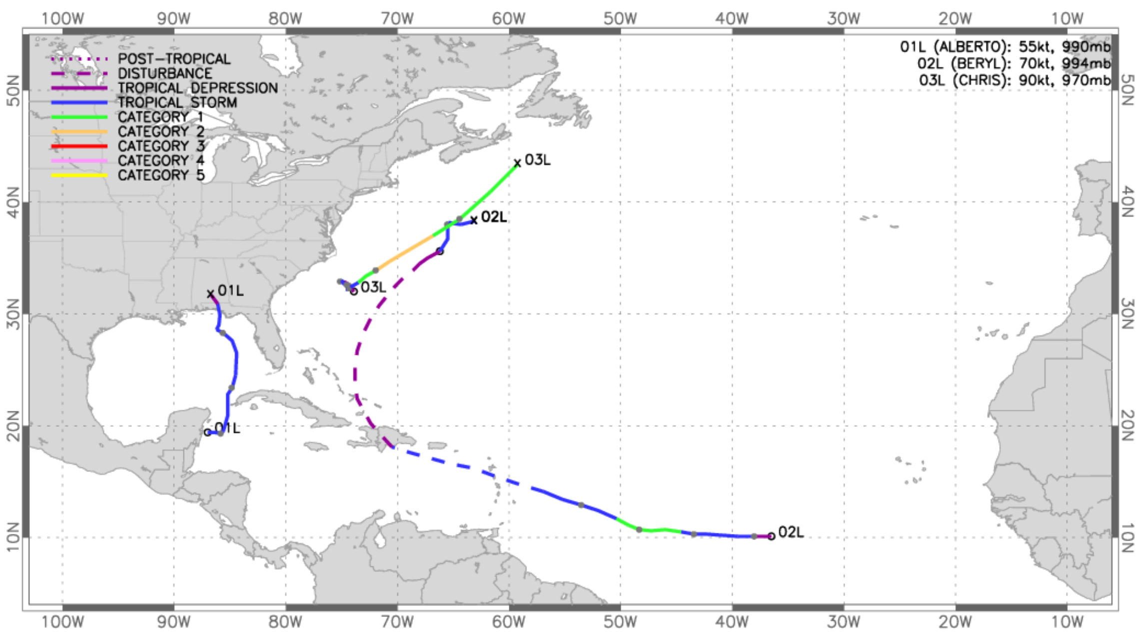

Figure 1: 2018 Atlantic basin hurricane tracks through July. Figure courtesy of Brian McNoldy.

2 1 August Statistical Forecast Scheme

We developed a 1 August statistical seasonal forecast scheme for the prediction of Accumulated Cyclone Energy (ACE) that was developed over the period from 1979-2011 and has been issued operationally since 2012. This model uses three predictors, all of which are selected from the ERA-Interim Reanalysis dataset, which is available from 1979 to near-present. Real-time predictor estimates are done from the NCEP/NCAR Reanalysis, as ERA-Interim Reanalysis products are not available in real time. The major components of the forecast scheme are discussed in the next few paragraphs.

The pool of three predictors for the early August statistical forecast scheme is given and defined in Table 2. The location of each of these predictors is shown in

Figure 2. Skillful forecasts can be issued for post-31 July ACE based upon hindcast results over the period from 1979-2011 as well as real-time forecasts in 2012, and 2014-2017. Like all of our other forecasts, the model did not anticipate the below-average 2013 Atlantic hurricane season. When these three predictors are combined, they correlate at 0.85 with observed ACE using hindcasts/forecasts over the period from 1979-2017 (Figure 3).

Table 2: Listing of 1 August 2018 predictors for this year's hurricane activity. A plus (+) means that positive deviations of the parameter indicate increased hurricane activity this year, and a minus (-) means that positive deviations of the parameter indicate decreased hurricane activity this year.

Predictor	Values for 2018 Forecast	Effect on 2018 Hurricane Season
1) July Surface U (10-17.5°N, 60-85°W) (+)	-1.2 SD	Suppress
2) July Surface Temperature (20-40°N, 15-35°W) (+)	+0.7 SD	Enhance
3) July 200 mb U (5-15°N, 0-40°E) (-)	_+1.5 SD	Suppress

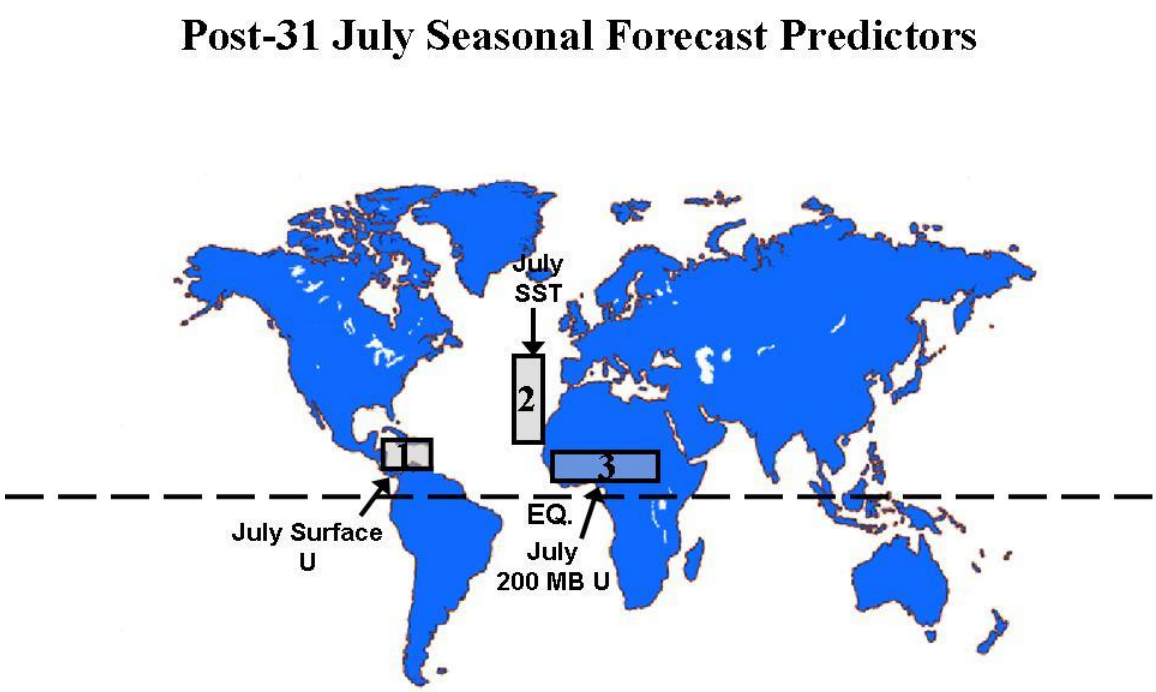

Figure 2: Location of predictors for the post-31 July forecast for the 2018 hurricane season from the statistical model.

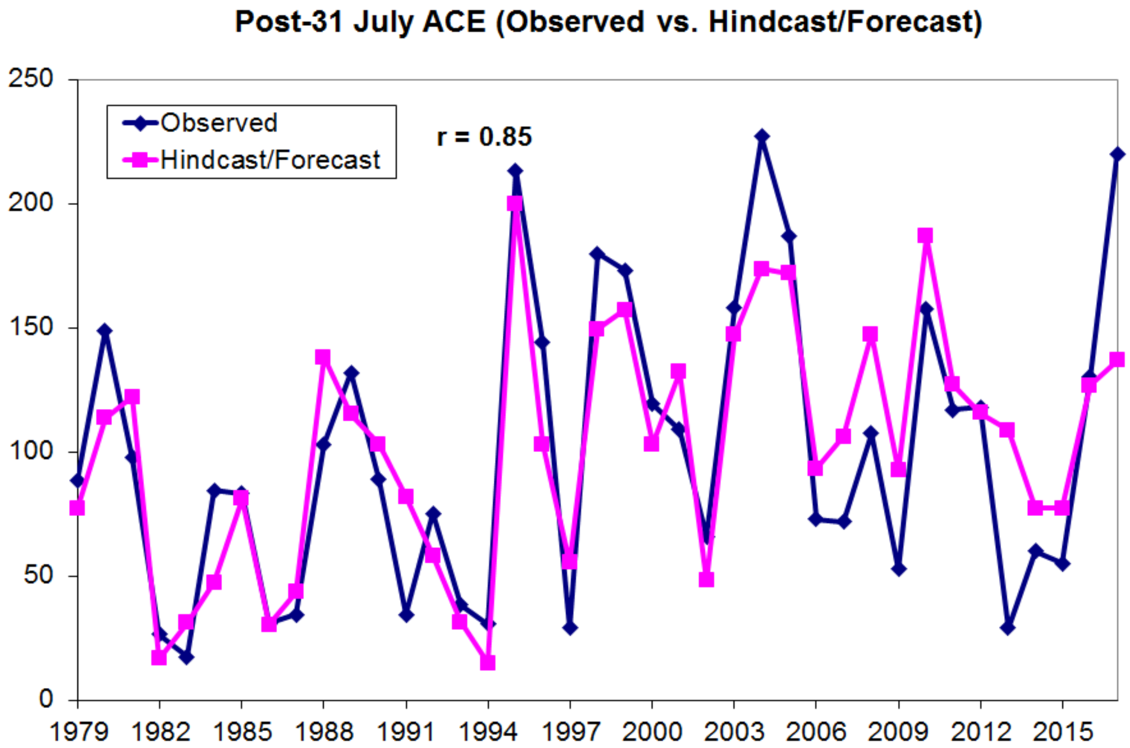

Figure 3: Observed versus hindcast values of post-31 July ACE for 1979-2017 using our current statistical scheme.

Table 3 shows our statistical forecast for the 2018 hurricane season from the new statistical model and the comparison of this forecast with the 1981-2010 median. Our statistical forecast is calling for a below-average hurricane season.

Table 3: Post-31 July statistical forecast for 2018 from the statistical model.

Predictands and Climatology (1981-2010 Post-31 July Median)	Statistical Forecast
Named Storms (NS) – 10.5	8.2
Named Storm Days (NSD) – 58.0	34.3
Hurricanes (H) – 5.5	4.2
Hurricane Days (HD) – 21.3	12.7
Major Hurricanes (MH) – 2.0	1.1
Major Hurricane Days (MHD) – 3.8	1.8
Accumulated Cyclone Energy Index (ACE) – 86	52
Net Tropical Cyclone Activity (NTC) – 95	60

2.2 Physical Associations among Predictors Listed in Table 2

The locations and brief descriptions of the three predictors for our current August statistical forecast are now discussed. It should be noted that all forecast parameters correlate significantly with physical features during August through October that are known to be favorable for elevated levels of TC activity. For each of these predictors, we display a four-panel figure showing linear correlations between values of each predictor and August-October values of SST, sea level pressure (SLP), 850 mb (~1.5 km altitude) zonal wind (U), and 200 mb (~12 km altitude) zonal wind (U), respectively.

Predictor 1. July Surface U in the Caribbean (+)

(10-17.5°N, 60-85°W)

Low-level trade wind flow has been utilized as a predictor in seasonal forecasting systems for the Atlantic basin (Saunders and Lea 2008). When the trades are weaker-than-normal, SSTs across the tropical Atlantic tend to be elevated, and consequently a larger-than-normal Atlantic Warm Pool (AWP) is typically observed (Wang and Lee 2007) (Figure 4). A larger AWP also correlates with reduced vertical shear across the tropical Atlantic. Weaker trade winds are typically associated with higher pressure in the tropical eastern Pacific (a La Niña signal) and lower pressure in the Caribbean and tropical Atlantic. Both of these conditions generally occur when active hurricane seasons are observed. Predictor 1 also has a strong negative correlation with August-October-averaged 200-850-mb zonal shear.

Predictor 2. July Surface Temperature in the Northeastern Subtropical Atlantic (+)

(20°-40°N, 15-35°W)

A similar predictor was utilized in earlier August seasonal forecast models (Klotzbach 2007, Klotzbach 2011). Anomalously warm SSTs in the subtropical North Atlantic are associated with a positive phase of the Atlantic Meridional Mode (AMM), a northward-shifted Intertropical Convergence Zone, and consequently, reduced trade wind strength (Kossin and Vimont 2007). Weaker trade winds are associated with less surface evaporative cooling and less mixing and upwelling. This results in warmer tropical Atlantic SSTs during the August-October period (Figure 5).

Predictor 3. July 200 mb U over Northern Tropical Africa (-)

(5-15°N, 0-40°E)

Anomalous easterly flow at upper levels over northern tropical Africa provides an environment that is more favorable for easterly wave development into TCs. This anomalous easterly flow tends to persist through August-October, which reduces shear over the Main Development Region (MDR). This predictor also correlates with SLP and SST anomalies over the tropical eastern Pacific that are typically associated with cool ENSO conditions (Figure 6).

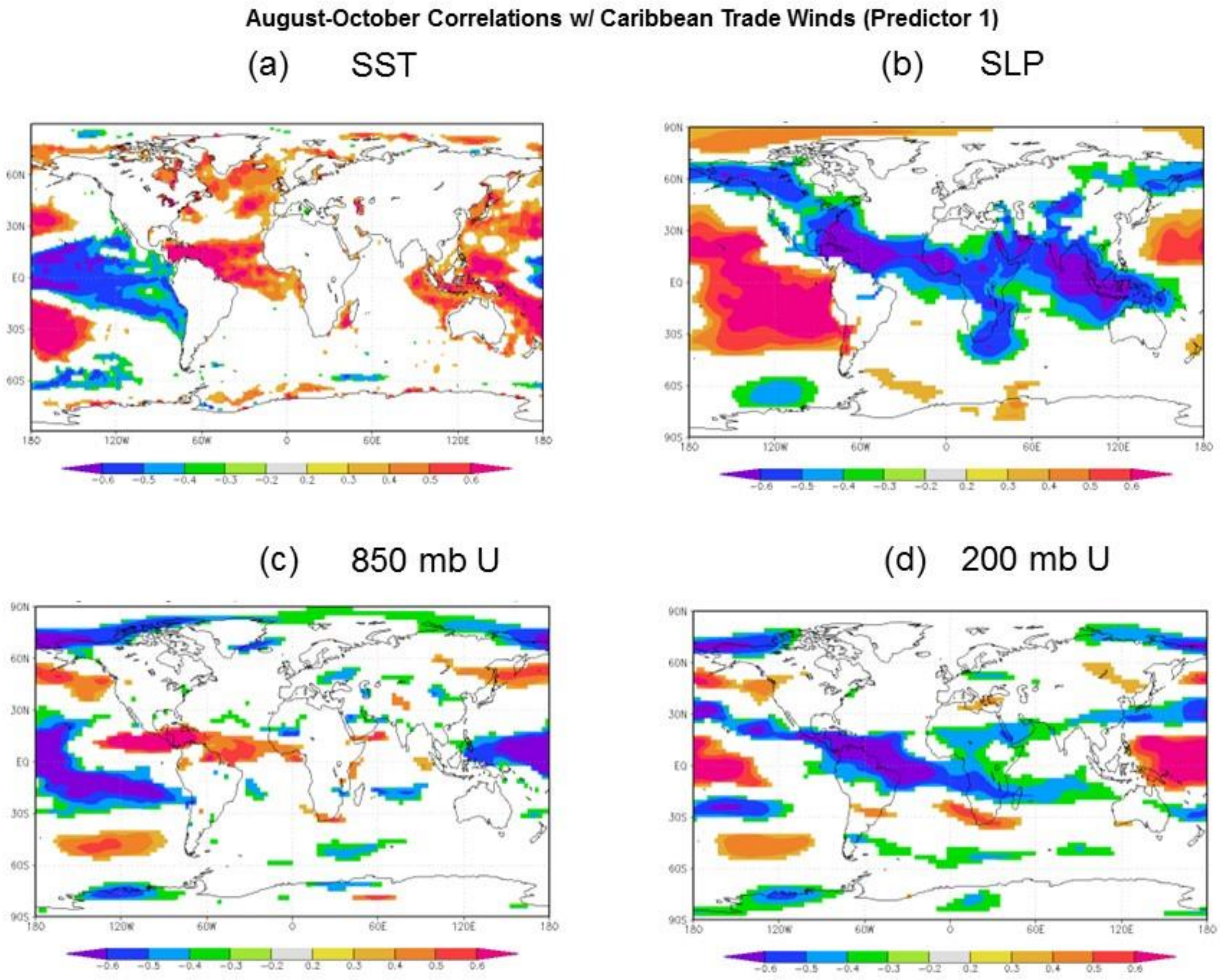

Figure 4: Linear correlations between July Surface U in the Caribbean (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d) over the period from 1979-2011.

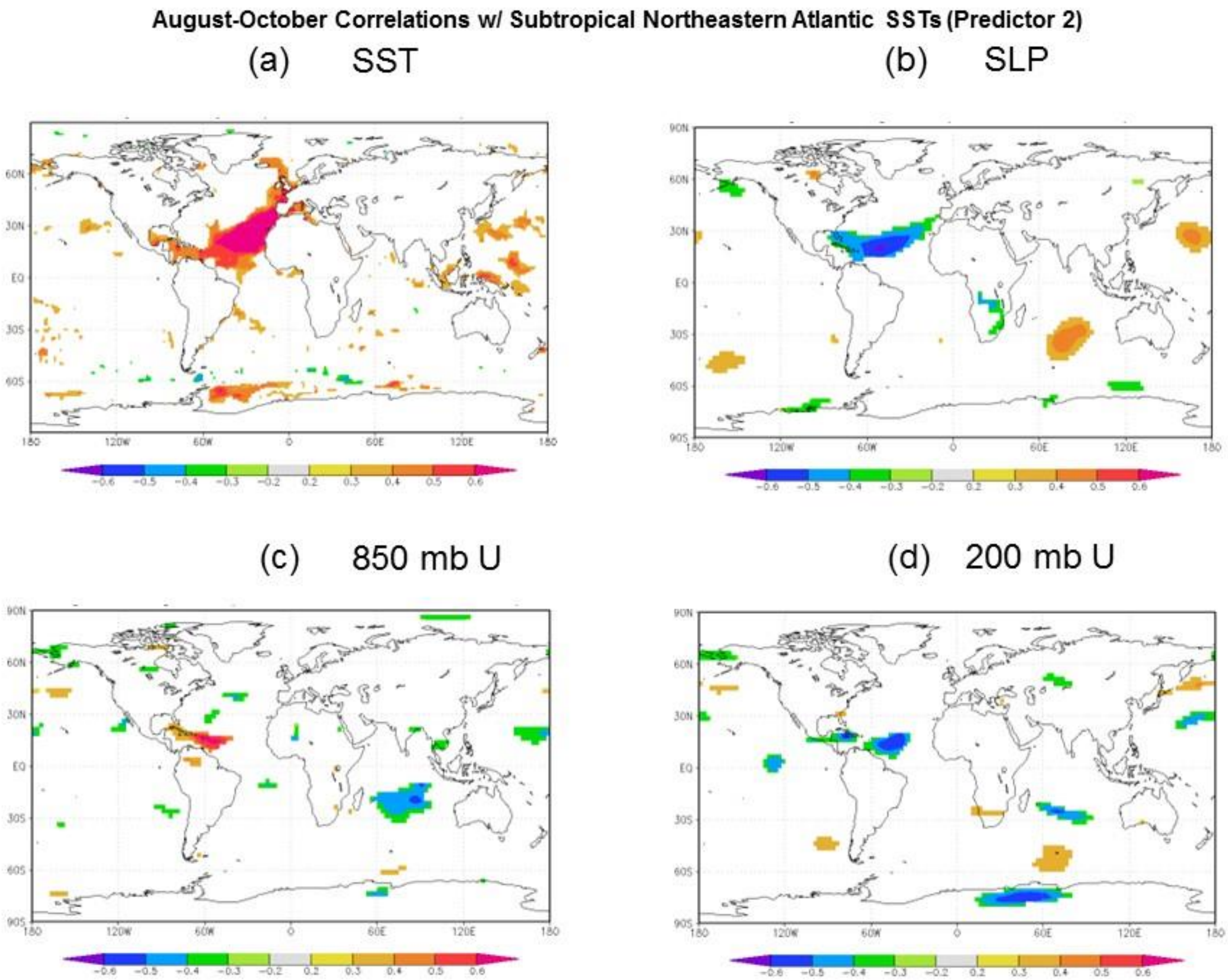

Figure 5: Linear correlations between July Surface Temperature in the Subtropical Northeastern Atlantic (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d) over the period from 1979-2011.

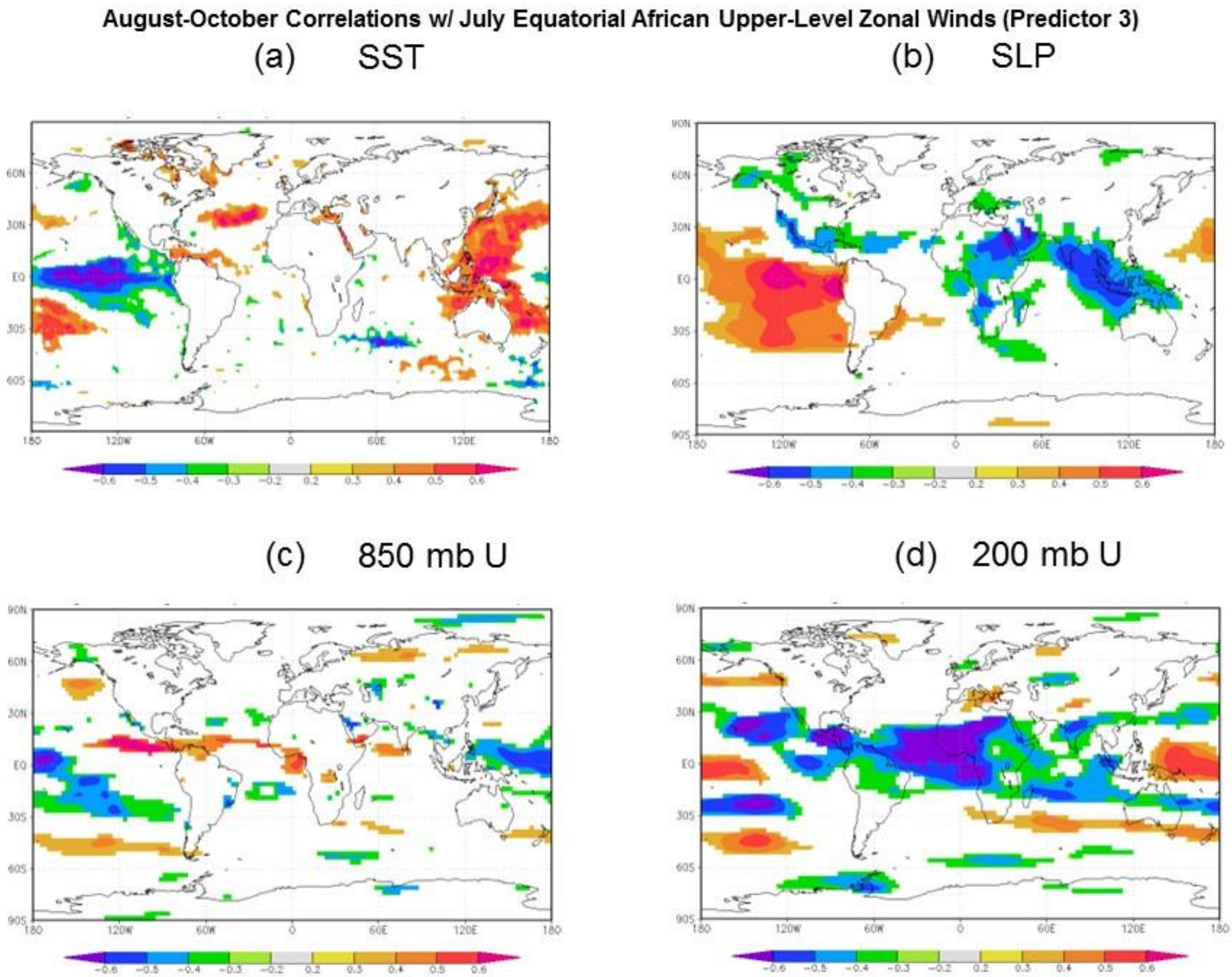

Figure 6: Linear correlations between July 200 MB Zonal Wind over tropical north Africa (Predictor 3) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d) over the period from 1979-2011. The color scale has been reversed so that the correlations match up with those in Figures 4 and 5.

3 Forecast Uncertainty

One of the questions that we are asked regarding our seasonal hurricane predictions is the degree of uncertainty that is involved. Obviously, our predictions are our best estimate, but there is with all forecasts an uncertainty as to how well they will verify.

Table 4 provides our post-31 July forecast, with error bars (based on one standard deviation of absolute errors) as calculated from hindcasts/forecasts of the Klotzbach (2007) scheme over the 1990-2009 period, using equations developed over the 1950-1989 period. We typically expect to see 2/3 of our forecasts verify within one standard deviation of observed values, with 95% of forecasts verifying within two standard deviations of observed values.

Table 4: Model hindcast error and our post-31 July 2018 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	Post-31 July 2018 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	2	9	7 – 11
Named Storm Days (NSD)	17	40	23 – 57
Hurricanes (H)	2	3	1 – 5
Hurricane Days (HD)	9	11.75	2.75 – 20.75
Major Hurricanes (MH)	1	1	0 – 2
Major Hurricane Days (MHD)	4	2	0 – 6
Accumulated Cyclone Energy (ACE)	36	50	14 – 86
Net Tropical Cyclone (NTC) Activity	34	60	26 – 94

4 Analog-Based Predictors for 2018 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially like 2018. These years also provide useful clues as to likely trends in activity that the 2018 hurricane season may bring. For this early August forecast, we determine which of the prior years in our database have distinct trends in key environmental conditions which are like current June-July 2018 conditions as well as conditions that we anticipate being present during the peak months of the Atlantic hurricane season from August-October. Table 5 lists the best analog selections from our historical database.

We select prior hurricane seasons since 1950 which have similar atmospheric-oceanic conditions to those currently being experienced. We searched for years that had generally ENSO neutral to weak El Niño conditions along with anomalously cool Atlantic MDR SST configurations.

There were five hurricane seasons with characteristics most like what we observed in June-July 2018. The best analog years that we could find for the 2018 hurricane season were 1968, 1986, 1993, 1994, and 2002. We anticipate that 2018 seasonal hurricane activity will have activity slightly above the average of these five analog years, due primarily to the enhanced activity that has already occurred in the Atlantic this season. We believe that the remainder of 2018 will have below-average activity in the Atlantic basin.

Table 5: Best analog years for 2018 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1968	8	33.75	5	11.75	0	0.00	45	47
1986	6	23.25	4	10.50	0	0.00	36	37
1993	8	30.00	4	9.50	1	0.75	39	52
1994	7	28.75	3	7.25	0	0.00	32	35
2002	12	57.00	4	10.75	2	3.00	67	83
Mean (Full Season)	**8.2**	**34.6**	**4.0**	**10.0**	**0.6**	**0.8**	**44**	**51**
2018 Forecast (Full Season)	**12**	**53**	**5**	**15**	**1**	**2**	**64**	**78**
1981-2010 Median (Full Season)	**12.0**	**60.1**	**6.5**	**21.3**	**2.0**	**3.9**	**92**	**103**

5 ENSO

Warm neutral ENSO conditions currently exist across the tropical Pacific. Table 6 displays May and July SST anomalies for several Nino regions. The eastern and central tropical Pacific has anomalously warmed over the past two months (Table 6).

Table 6: May and July 2018 SST anomalies for Nino 1+2, Nino 3, Nino 3.4, and Nino 4, respectively. July-May SST anomaly differences are also provided.

Region	May SST Anomaly (°C)	July SST Anomaly (°C)	July minus May SST Change (°C)
Nino 1+2	-0.5	-0.3	+0.2
Nino 3	-0.2	+0.4	+0.6
Nino 3.4	-0.1	+0.3	+0.4
Nino 4	+0.2	+0.3	+0.1

There is considerable uncertainty as to whether a weak El Niño will develop in time for peak of the Atlantic hurricane season from August-October. At this point, the transition to El Niño appears to have briefly stalled. Upper ocean heat content anomalies in the eastern and central Pacific have diminished in the past few weeks (Figure 7).

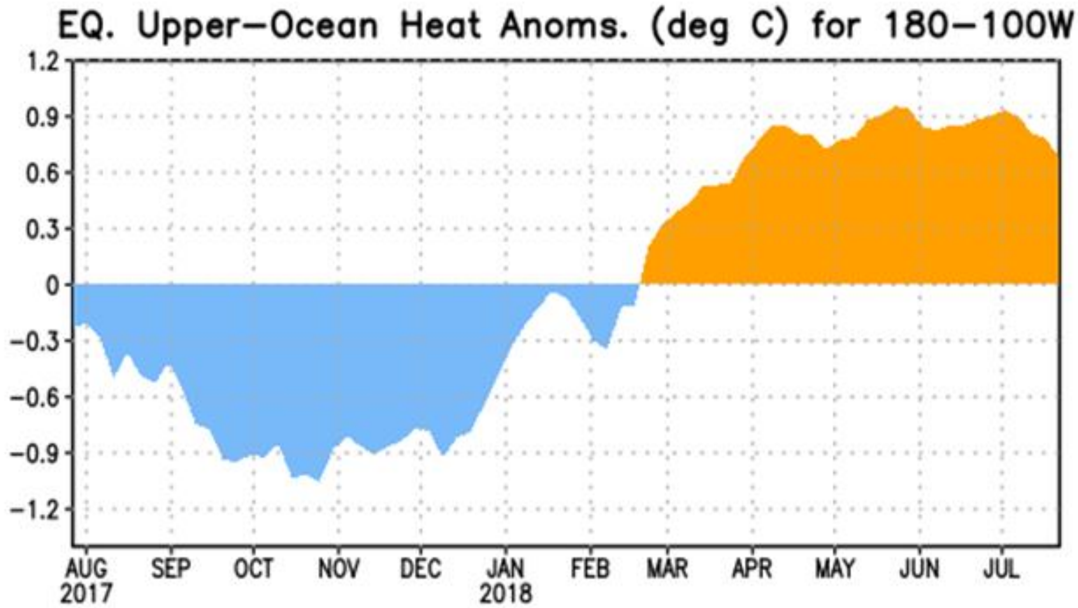

Figure 7: Upper-ocean (0-300 meters depth) heat content anomalies in the eastern and central Pacific since August 2017. Upper ocean heat content increased from November through May and have remained above-average since that time.

However, recent observations as well as forecasts from the Climate Forecast System (CFS) indicate that anomalous low-level westerly winds have developed in the central Pacific and may persist for the next several weeks (Figure 8). If this occurs, it could trigger a downwelling Kelvin wave which would then support additional anomalous warming of the eastern and central Pacific.

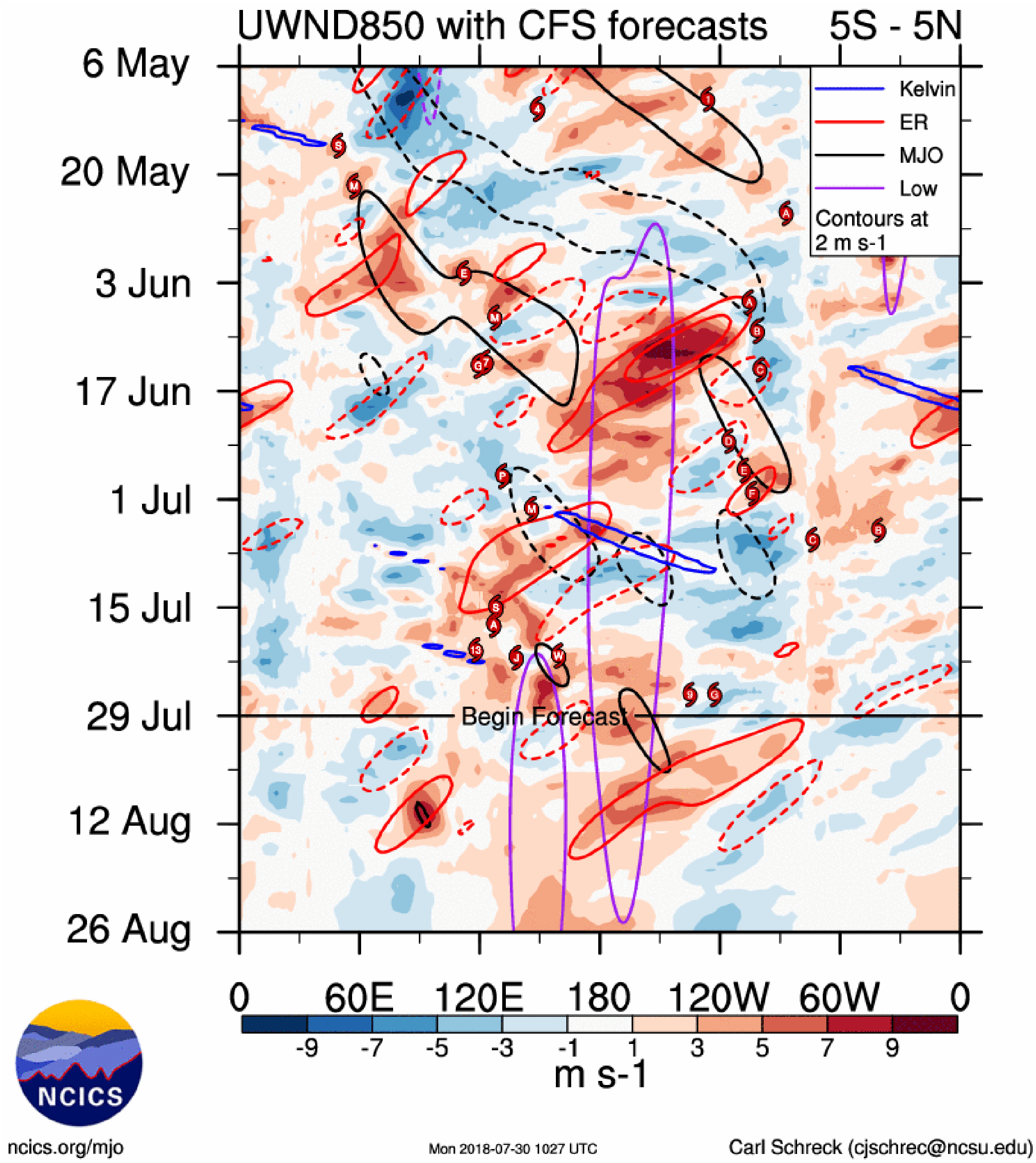

Figure 8: Anomalous 850-mb winds averaged near the equator. Over the past few days, trade winds have weakened in the central Pacific and are forecast to remain weak for the next several weeks by the Climate Forecast System. Figure courtesy of Carl Schreck.

There has been a lack of significant oceanic Kelvin wave activity over the past couple of months (Figure 9). However, there is considerable warmth across the western and central Pacific. If these current westerly winds were to trigger another oceanic Kelvin wave, there could be additional anomalous warming potentially leading to El Niño development.

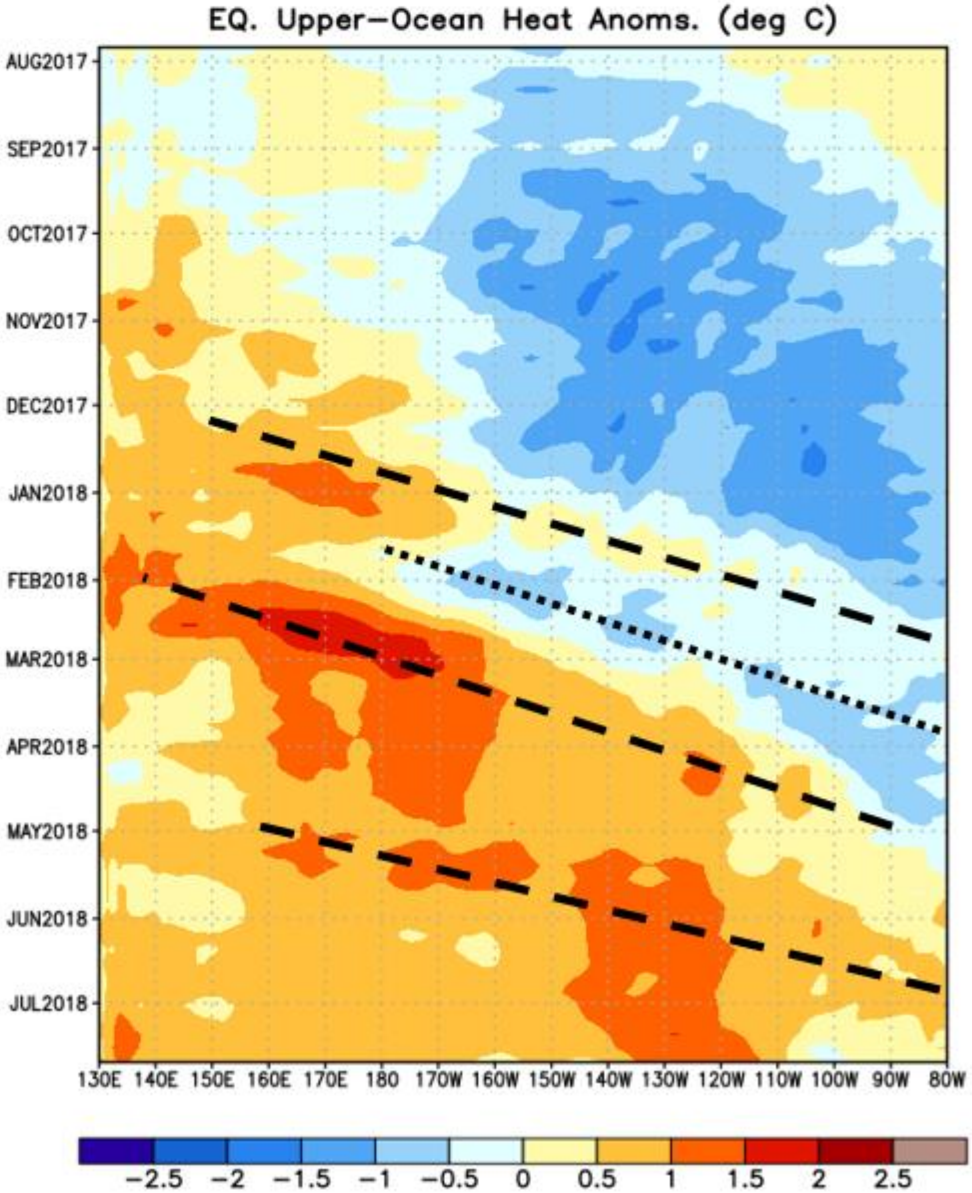

Figure 9: Upper-ocean heat content anomalies across the tropical Pacific. Dashed lines indicate downwelling (warming) Kelvin waves, while dotted lines indicate upwelling (cooling) Kelvin waves. Oceanic Kelvin wave activity appears to have been fairly limited over the past few months. Figure courtesy of the Climate Prediction Center.

The official forecast from the Climate Prediction Center has a ~55% chance that El Niño will develop by the peak of the Atlantic hurricane season from August-October (Figure 10). Whether or not the official El Niño threshold is reached in the next few months, we believe that the Atlantic hurricane season will be below normal due to hurricane-unfavorable conditions in the tropical Atlantic.

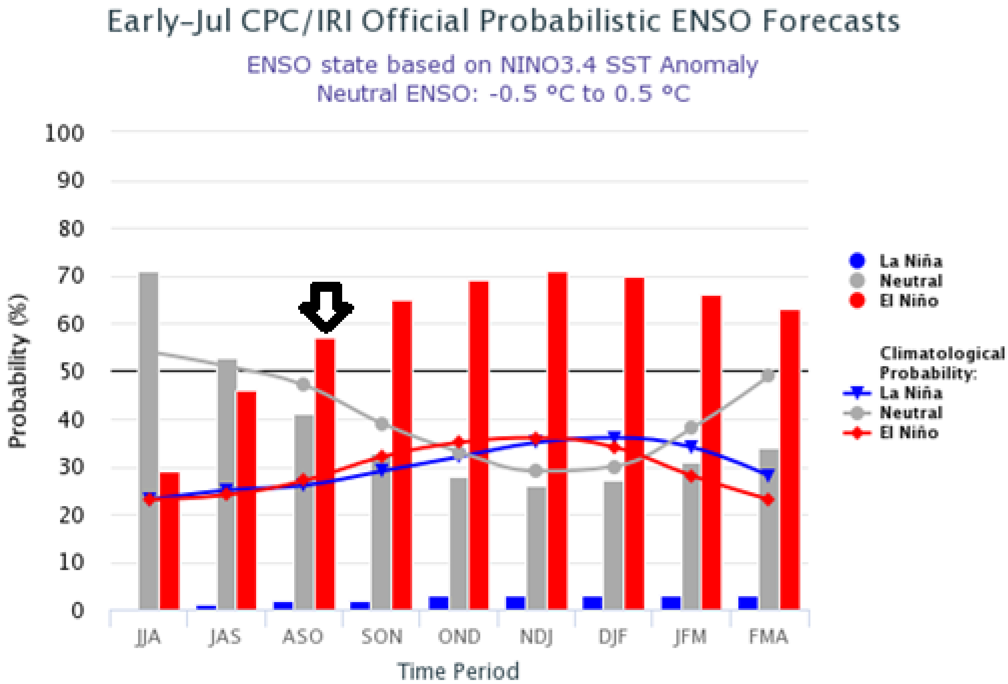

Figure 10: Official ENSO forecast from the Climate Prediction Center. The black arrow represents the peak of the Atlantic hurricane season from August to October.

6 Current Atlantic Basin Conditions

The tropical and far Atlantic are much colder than normal right now. Figure 11 displays SST anomalies observed across the North Atlantic in July. The current SST anomaly pattern strongly resembles a negative Atlantic Multi-Decadal Oscillation (AMO) pattern. A negative AMO pattern is typically characterized by cold anomalies in both the far North Atlantic and the tropical Atlantic. The July 2018 SST pattern generally resembles the July SST pattern associated with inactive Atlantic hurricane seasons (Figure 12). The current 10-day running average of tropical Atlantic (10-20°N, 60-20°W) SSTs are the coldest on record for August 1 (since daily SST data became available from NOAA in late 1981).

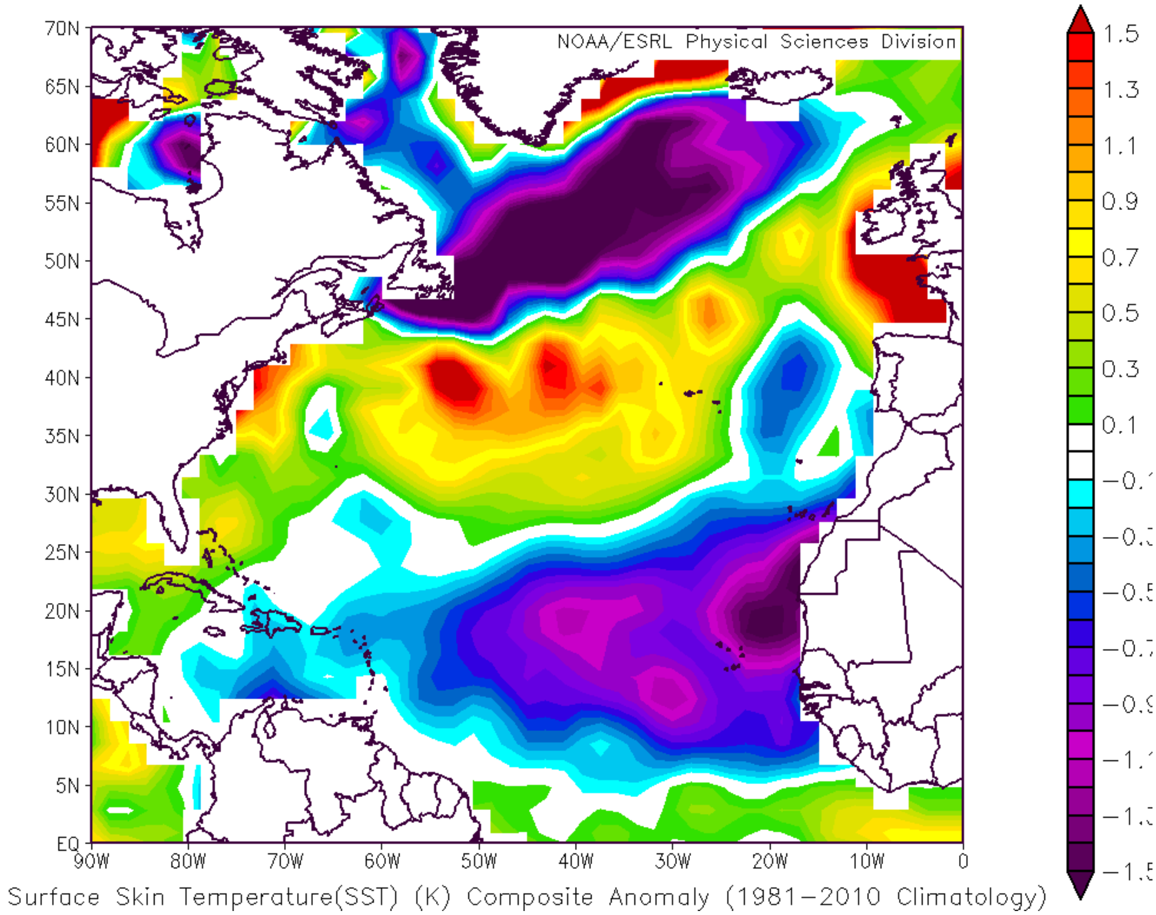

Figure 11: July 2018 SST anomalies.

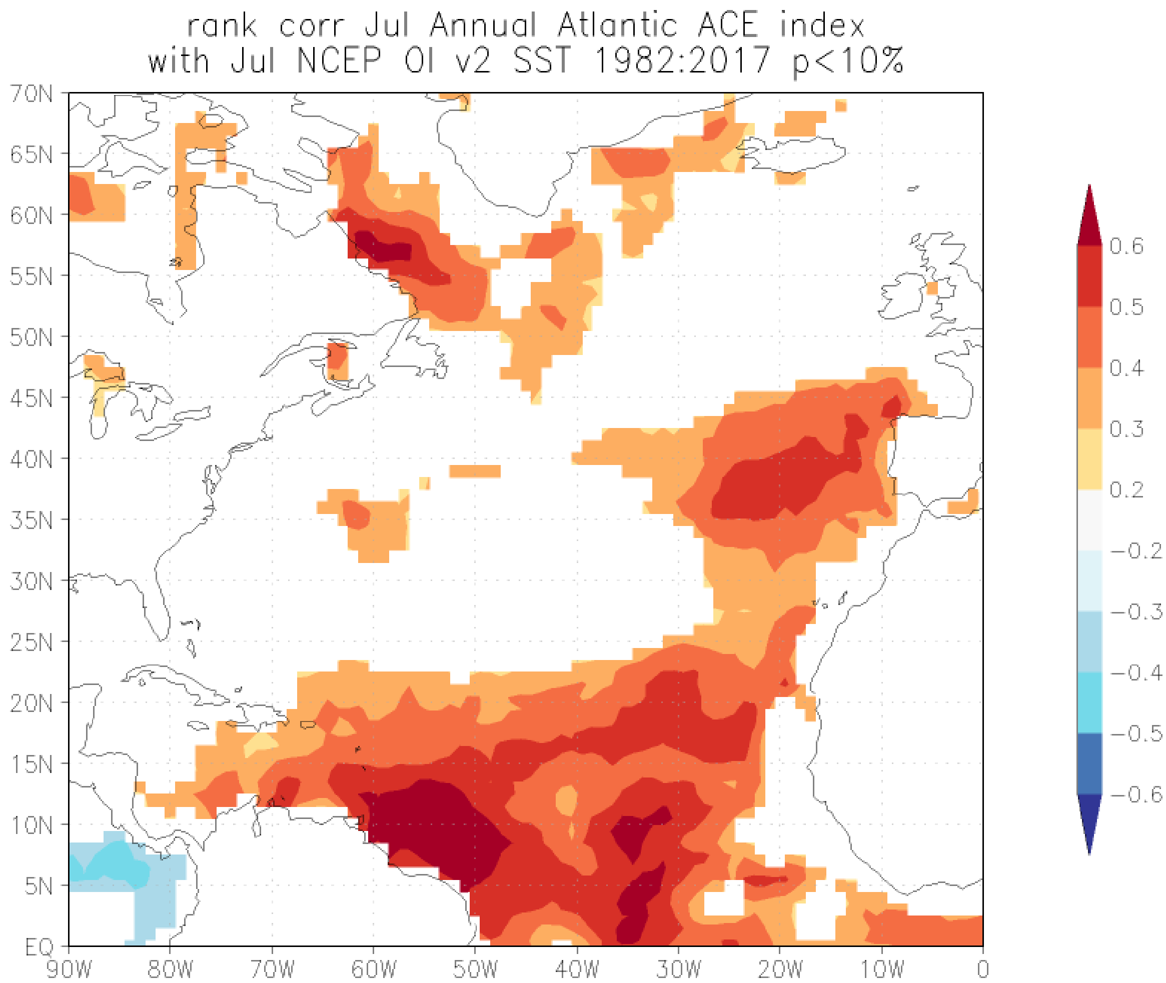

Figure 12: Correlation map between July SSTs and seasonal Atlantic ACE based on data over the period from 1982-2017.

Sea level pressure anomalies over the past month have been above normal across most of the tropical Atlantic. Above-normal sea level pressure anomalies in the tropical Atlantic imply a stronger than normal Tropical Upper Tropospheric Trough (TUTT) (Figure 13). A strong TUTT typically relates to increased vertical wind shear across the tropical Atlantic and Caribbean (Knaff 1997).

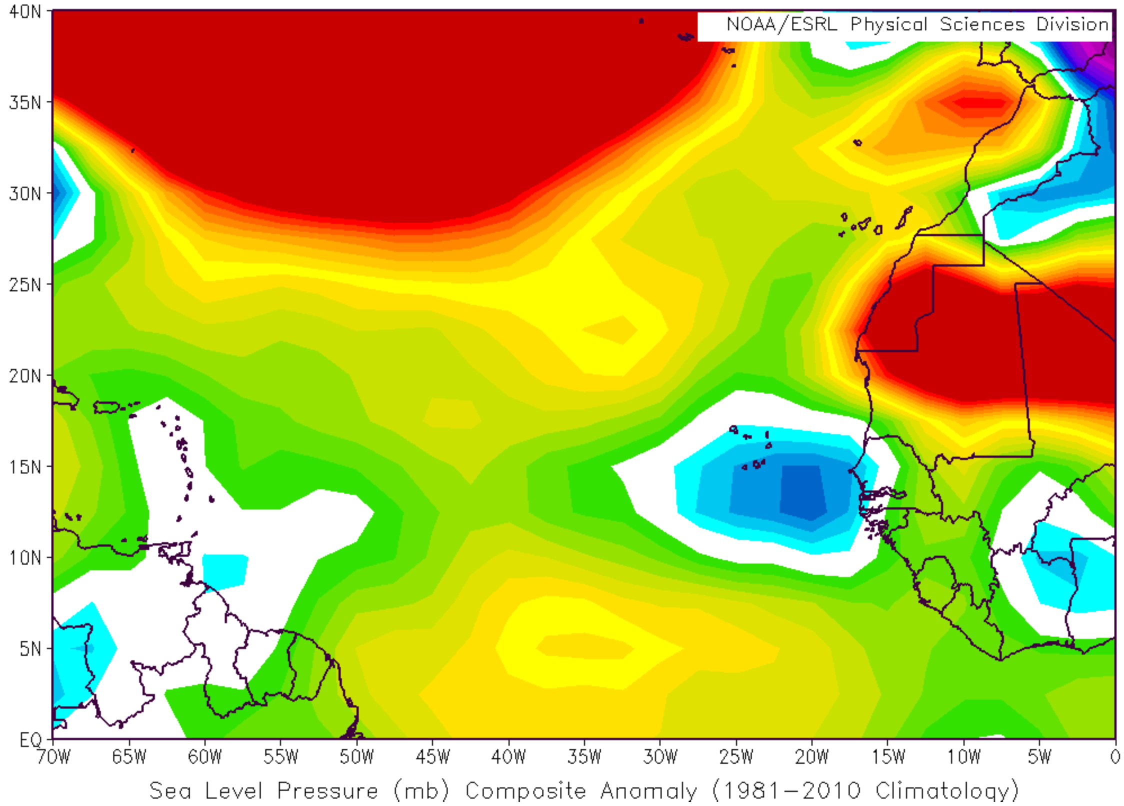

Figure 13: July 2018 Atlantic SLP anomaly. Sea level pressure anomalies have generally been above normal across the tropical Atlantic.

July vertical wind shear has been above normal over the Caribbean and near normal further east in the tropical Atlantic (Figure 14). There is a strong negative correlation between July vertical wind shear in the Caribbean and seasonal Atlantic ACE, that is, stronger vertical wind shear typically correlates with a quieter overall Atlantic hurricane season.

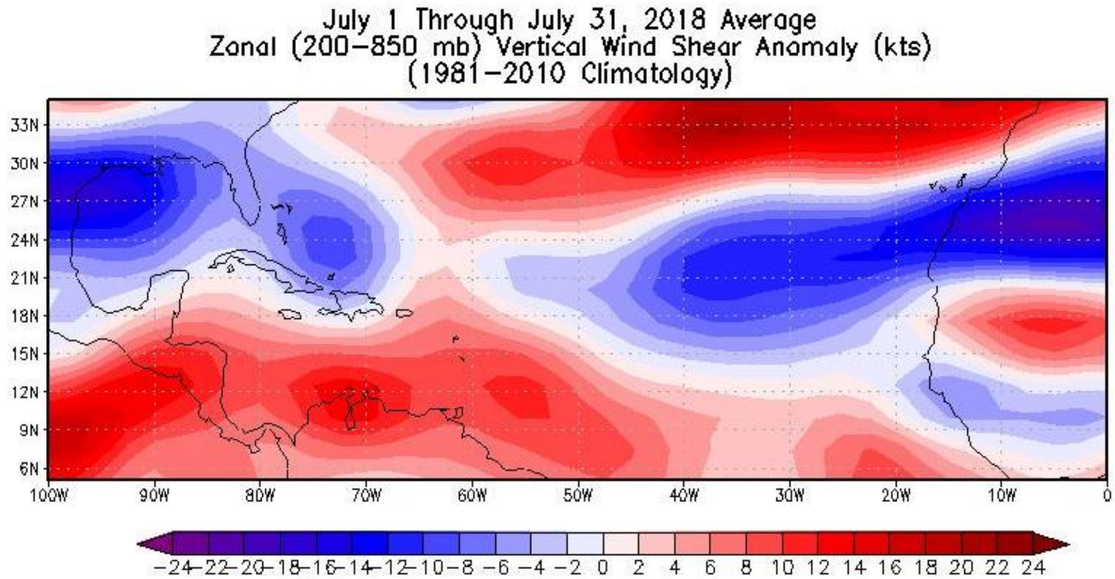

Figure 14: July 2018 averaged 200-850-mb zonal wind anomalies across the tropical Atlantic

The tropical Atlantic has been much drier than normal this July (Figure 15). This has also tended to be the case the past few Julys, but the dryness this July has been stronger and more persistent than in most other recent Julys. Typically, a drier tropical Atlantic is unfavorable for hurricane formation.

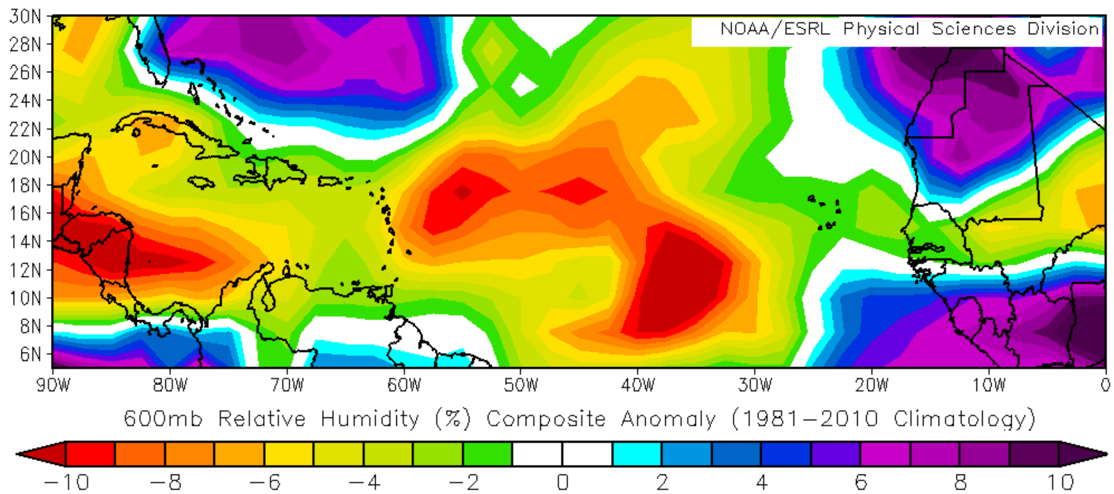

Figure 15: July 2018 600-mb relative humidity anomalies across the tropical Atlantic.

The Cooperative Research Institute for the Atmosphere (CIRA) monitors real-time conditions for genesis in the tropical Atlantic, and according to their analysis, vertical instability has been below normal since the start of the Atlantic hurricane season (Figure 16). Positive deviations from the curve displayed below indicate a more unstable atmosphere than normal. A more stable atmosphere suppresses deep thunderstorm development, which are critical for the formation and maintenance of tropical cyclones.

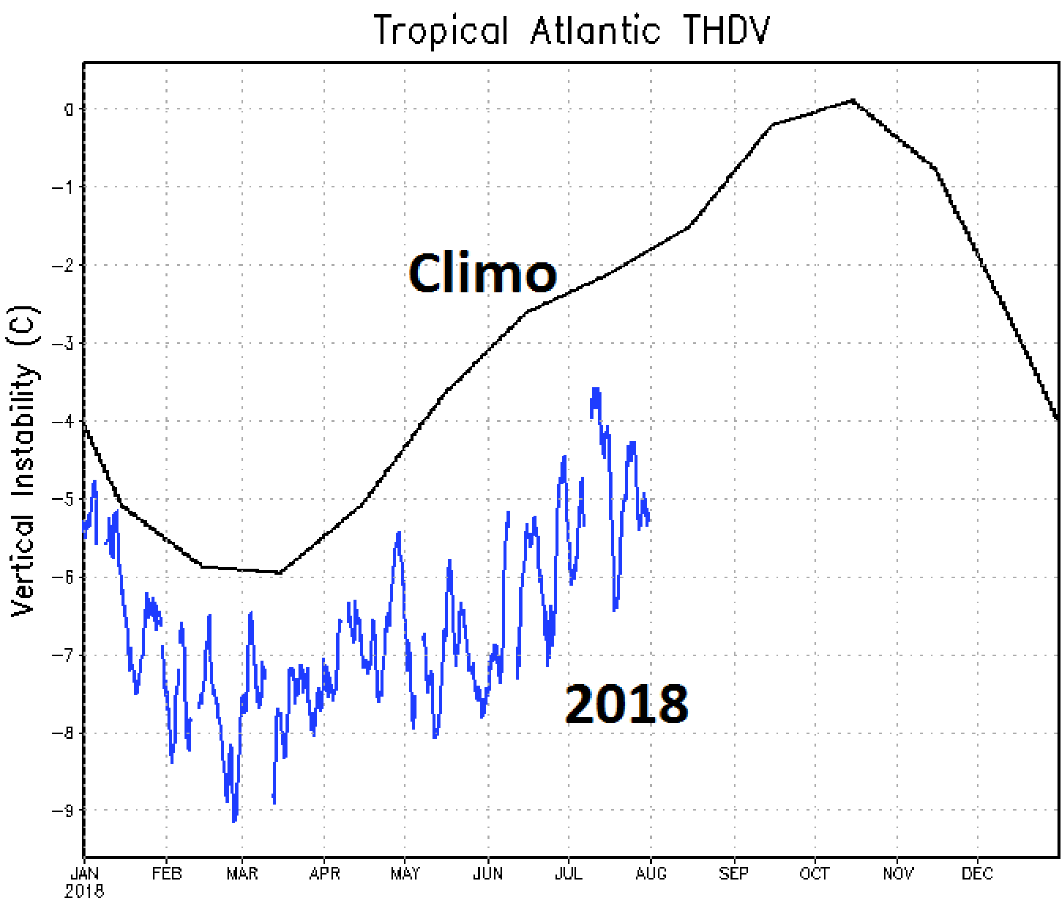

Figure 16: Vertical instability across the tropical Atlantic since January 2018 (blue line). The average season is represented by the black line.

7 West Africa Conditions

Enhanced rainfall in the Sahel region of West Africa during July has been associated with active hurricane seasons (Landsea and Gray 1992). Figure 17 displays rainfall estimates over Africa over the past few weeks. In general, rainfall in the western Sahel has been slightly above normal, which would tend to favor a more active season. However, upper-level winds over most of tropical Africa have been anomalously out of the west over the past several weeks, which is typically correlated with inactive Atlantic hurricane seasons (Figure 18).

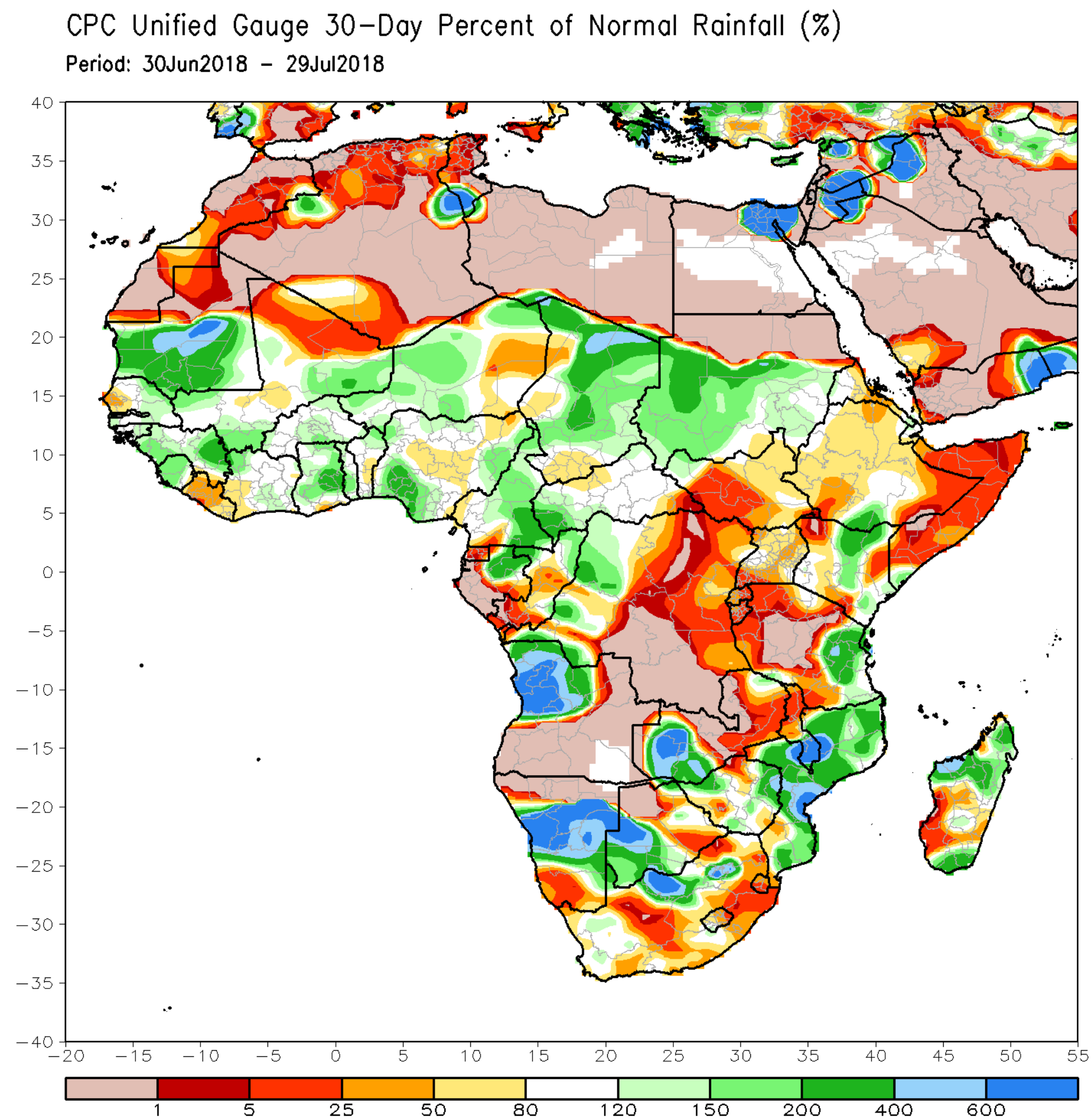

Figure 17: Climate Prediction Center Unified Gauge estimate of percent of normal rainfall from June 30 – July 29, 2018.

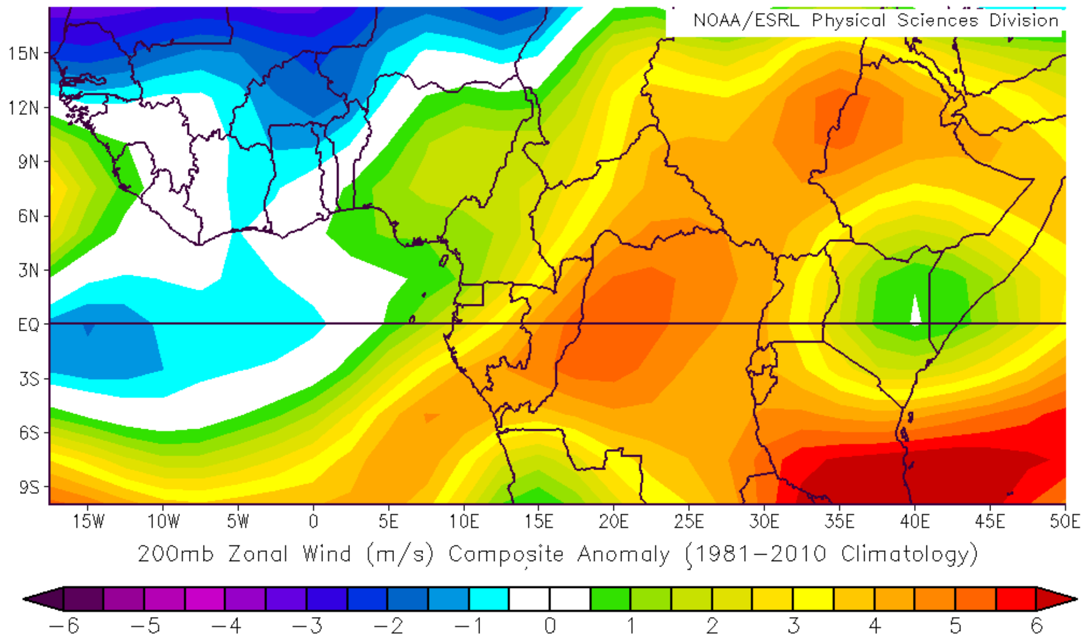

Figure 18: Upper-level wind anomalies over Africa during July.

8 Atlantic Multi-Decadal Oscillation (AMO)/Thermohaline Circulation (THC) Conditions

We currently monitor the strength of the Atlantic Multidecadal Oscillation (AMO) and Atlantic thermohaline circulation (THC) using a combined proxy measure of SST in the region from 50-60°N, 50-10°W and SLP in the region from 0-50°N, 70-10°W (Figure 19). This index was discussed in detail in Klotzbach and Gray (2008).

We currently weigh standardized values of the index by using the following formula: 0.6*SST – 0.4*SLP. While the final AMO value for July 2018 will not be available for a couple of days (due to the lag of availability of NCEP/NCAR Reanalysis data), we anticipate July 2018 to be the lowest July value of the AMO on record (since 1950) (Figure 20).

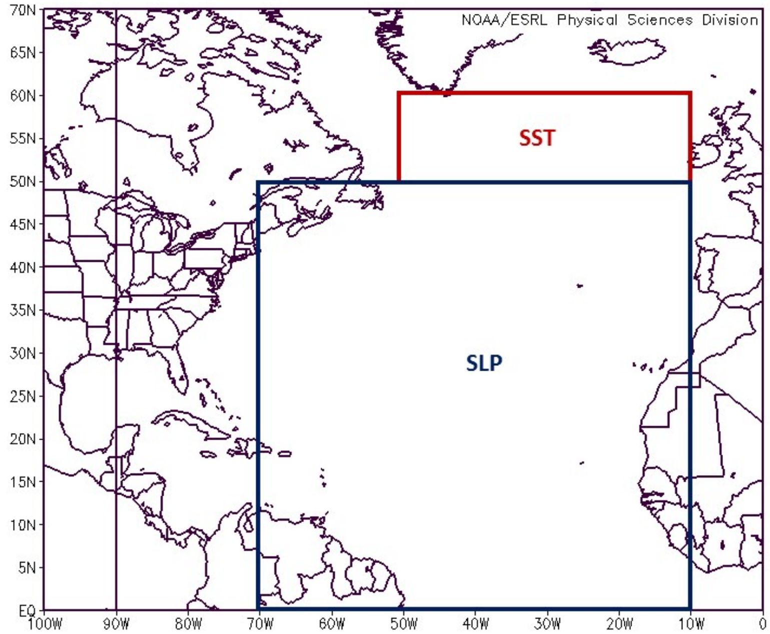

Figure 19: Regions which are utilized for the calculation of our THC/AMO index.

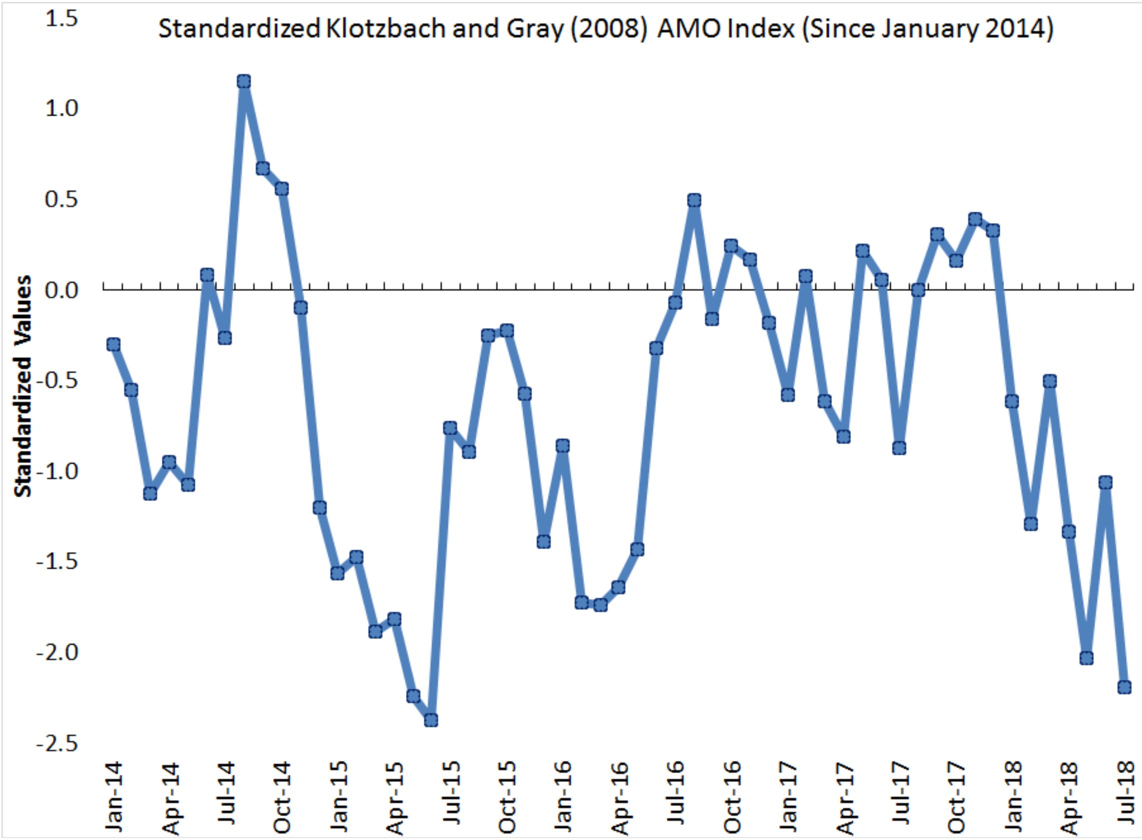

Figure 20: Monthly values of the Klotzbach and Gray (2008) AMO index since January 2014.

9 Adjusted 2018 Forecast

Table 7 shows our final adjusted early August forecast for the 2018 season which is a combination of our statistical scheme (with June-July activity added in), our analog forecast and qualitative adjustments for other factors not explicitly contained in any of these schemes. Our statistical forecast, analog forecast and final qualitative outlook are in good agreement that the remainder of the 2018 Atlantic hurricane season should have below-average TC activity.

Table 7: June-July 2018 observed activity, our August full season statistical forecast (with June-July 2018 activity added in), our analog forecast and our adjusted final forecast for the 2018 hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	Observed 2018 Activity through July	Statistical Scheme (Whole Season)	Analog Scheme (Whole Season)	**Adjusted Final Forecast (Whole Season)**
Named Storms (12.0)	3	11.2	8.2	**12**
Named Storm Days (60.1)	13	47.3	34.6	**53**
Hurricanes (6.5)	2	6.2	4.0	**5**
Hurricane Days (21.3)	3.25	16.0	10.0	**15**
Major Hurricanes (2.0)	0	1.1	0.6	**1**
Major Hurricane Days (3.9)	0	1.8	0.8	**2**
Accumulated Cyclone Energy Index (92)	14	66	44	**64**
Net Tropical Cyclone Activity (103%)	18	78	51	**78**

10 Landfall Probabilities for 2018

A significant focus of our recent research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline and in the Caribbean. Whereas individual hurricane landfall events cannot be forecast months in advance, the total seasonal probability of landfall can be forecast with statistical skill. With the observation that landfall is a function of varying climate conditions, a probability specification has been developed through statistical analyses of all U.S. hurricane and named storm landfall events during the 20th century (1900-1999). Specific landfall probabilities can be given for all tropical cyclone intensity classes for a set of distinct U.S. coastal regions.

Net landfall probability is shown linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 8). NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, each expressed as a percentage difference from the long-term average. Long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season is, the greater the probability of U.S. hurricane landfall.

Table 8: NTC activity in any year consists of the seasonal total of the following six parameters expressed in terms of their long-term averages. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 MH, and 5 MHD would then be the sum of the following ratios: 10/9.6 = 104, 50/49.1 = 102, 6/5.9 = 102, 25/24.5 = 102, 3/2.3 = 130, 5/5.0 = 100, divided by six, yielding an NTC of 107.

	1950-2000 Average	
1)	Named Storms (NS)	9.6
2)	Named Storm Days (NSD)	49.1
3)	Hurricanes (H)	5.9
4)	Hurricane Days (HD)	24.5
5)	Major Hurricanes (MH)	2.3
6)	Major Hurricane Days (MHD)	5.0

Table 9 lists strike probabilities for the 2018 hurricane season for different TC categories for the entire U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula. We also issue probabilities for various islands and landmasses in the Caribbean and in Central America. Note that Atlantic basin post-31 July NTC activity in 2018 is expected to be below its long-term average, and therefore, landfall probabilities are below their long-term average.

Table 9: Estimated probability (expressed in percent) of one or more landfalling tropical storms (TS), category 1-2 hurricanes (HUR), category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (Regions 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11) for the remainder of the 2018 Atlantic hurricane season. Probabilities of a tropical storm, hurricane and major hurricane tracking into the Caribbean are also provided. The long-term mean annual probability of one or more landfalling systems during the 20th century is given in parentheses.

Region	TS	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	Named Storms
Entire U.S. (Regions 1-11)	61% (79%)	49% (68%)	35% (52%)	67% (84%)	87% (97%)
Gulf Coast (Regions 1-4)	41% (59%)	28% (42%)	19% (30%)	42% (60%)	66% (83%)
Florida plus East Coast (Regions 5-11)	34% (50%)	29% (44%)	20% (31%)	43% (61%)	63% (81%)
Caribbean (10-20°N, 60-88°W)	64% (82%)	40% (57%)	28% (42%)	56% (75%)	85% (96%)

Please also visit the Landfalling Probability Webpage for landfall probabilities for 11 U.S. coastal regions and 205 coastal and near-coastal counties from Brownsville, Texas to Eastport, Maine as well as probabilities for every island in the Caribbean.

11 Summary

An analysis of a variety of different atmosphere and ocean measurements (through July) which are known to have long-period statistical relationships with the upcoming season's Atlantic tropical cyclone activity indicate that 2018 should have below-average hurricane activity. A cooler-than-normal tropical Atlantic and the potential for a weak El Niño should generate anomalously hurricane-unfavorable conditions for the peak months of this year's hurricane season.

12 Forthcoming Updated Forecasts of 2018 Hurricane Activity

We will be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August-October, beginning today, Thursday, August 2 and continuing every other Thursday (August 16, August 30, etc.). A verification and discussion of all 2018 forecasts will be issued in late November 2018. All of these forecasts will be available online.

13 Citations and Additional Reading

Alexander, M. A., I. Blade, M. Newman, J. R. Lanzante, N.-C. Lau, and J. D. Scott, 2002: The atmospheric bridge: The influence of ENSO teleconnections on air-sea interaction over the global oceans. *J. Climate*, 15, 2205-2231.

Blake, E. S., 2002: Prediction of August Atlantic basin hurricane activity. Dept. of Atmos. Sci. Paper No. 719, Colo. State Univ., Ft. Collins, CO, 80 pp.

Blake, E. S. and W. M. Gray, 2004: Prediction of August Atlantic basin hurricane activity. *Wea. Forecasting*, 19, 1044-1060.

Chiang, J. C. H. and D. J. Vimont, 2004: Analogous Pacific and Atlantic meridional modes of tropical atmosphere-ocean variability. *J. Climate*, 17, 4143-4158.

DeMaria, M., J. A. Knaff and B. H. Connell, 2001: A tropical cyclone genesis parameter for the tropical Atlantic. *Wea. Forecasting*, 16, 219-233.

Elsner, J. B., G. S. Lehmiller, and T. B. Kimberlain, 1996: Objective classification of Atlantic hurricanes. *J. Climate*, 9, 2880-2889.

Evan, A. T., J. Dunion, J. A. Foley, A. K. Heidinger, and C. S. Velden, 2006: New evidence for a relationship between Atlantic tropical cyclone activity and African dust outbreaks, *Geophys. Res. Lett*, 33, doi:10.1029/2006GL026408.

Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nunez, and W. M. Gray, 2001: The recent increase in Atlantic hurricane activity: Causes and Implications. *Science*, 293, 474-479.

Goldenberg, S. B. and L. J. Shapiro, 1996: Physical mechanisms for the association of El Niño and West African rainfall with Atlantic major hurricane activity. *J. Climate*, 1169-1187.

Gray, W. M., 1984a: Atlantic seasonal hurricane frequency: Part I: El Niño and 30 mb quasi-biennial oscillation influences. *Mon. Wea. Rev.*, 112, 1649-1668.

Gray, W. M., 1984b: Atlantic seasonal hurricane frequency: Part II: Forecasting its variability. *Mon. Wea. Rev.*, 112, 1669-1683.

Gray, W. M., 1990: Strong association between West African rainfall and US landfall of intense hurricanes. *Science*, 249, 1251-1256.

Gray, W. M., and P. J. Klotzbach, 2011: Have increases in CO_2 contributed to the recent large upswing in Atlantic basin major hurricanes since 1995? Chapter 9 in "Evidence-Based Climate Science", D. Easterbrook, Ed., Elsevier Press, 27 pp.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1992: Predicting Atlantic seasonal hurricane activity 6-11 months in advance. *Wea. Forecasting*, 7, 440-455.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1993: Predicting Atlantic basin seasonal tropical cyclone activity by 1 August. *Wea. Forecasting*, 8, 73-86.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1994a: Predicting Atlantic basin seasonal tropical cyclone activity by 1 June. *Wea. Forecasting*, 9, 103-115.

Gray, W. M., J. D. Sheaffer and C. W. Landsea, 1996: Climate trends associated with multi-decadal variability of intense Atlantic hurricane activity. Chapter 2 in "Hurricanes, Climatic Change and

Socioeconomic Impacts: A Current Perspective", H. F. Diaz and R. S. Pulwarty, Eds., Westview Press, 49 pp.

Gray, W. M., 1998: Atlantic ocean influences on multi-decadal variations in El Niño frequency and intensity. Ninth Conference on Interaction of the Sea and Atmosphere, 78th AMS Annual Meeting, 11-16 January, Phoenix, AZ, 5 pp.

Grossmann, I. and P. J. Klotzbach, 2009: A review of North Atlantic modes of natural variability and their driving mechanisms. *J. Geophys. Res.*, 114, D24107, doi:10.1029/2009JD012728.

Henderson-Sellers, A., H. Zhang, G. Berz, K. Emanuel, W. Gray, C. Landsea, G. Holland, J. Lighthill, S-L. Shieh, P. Webster, and K. McGuffie, 1998: Tropical cyclones and global climate change: A post-IPCC assessment. *Bull. Amer. Meteor. Soc.,* 79, 19-38.

Klotzbach, P. J., 2002: Forecasting September Atlantic basin tropical cyclone activity at zero and one-month lead times. Dept. of Atmos. Sci. Paper No. 723, Colo. State Univ., Ft. Collins, CO, 91 pp.

Klotzbach, P. J., 2006: Trends in global tropical cyclone activity over the past twenty years (1986-2005). *Geophys. Res. Lett.*, 33, doi:10.1029/2006GL025881.

Klotzbach, P. J., 2007: Revised prediction of seasonal Atlantic basin tropical cyclone activity from 1 August. *Wea. and Forecasting,* 22, 937-949.

Klotzbach, P. J. and W. M. Gray, 2003: Forecasting September Atlantic basin tropical cyclone activity. *Wea. and Forecasting,* 18, 1109-1128.

Klotzbach, P. J. and W. M. Gray, 2004: Updated 6-11 month prediction of Atlantic basin seasonal hurricane activity. *Wea. and Forecasting,* 19, 917-934.

Klotzbach, P. J. and W. M. Gray, 2006: Causes of the unusually destructive 2004 Atlantic basin hurricane season. *Bull. Amer. Meteor. Soc.,* 87, 1325-1333.

Knaff, J. A., 1997: Implications of summertime sea level pressure anomalies. *J. Climate,* 10, 789-804.

Knaff, J. A., 1998: Predicting summertime Caribbean sea level pressure. *Wea. and Forecasting,* 13, 740-752.

Kossin, J. P., and D. J. Vimont, 2007: A more general framework for understanding Atlantic hurricane variability and trends. *Bull. Amer. Meteor. Soc.,* 88, 1767-1781.

Landsea, C. W., 1991: West African monsoonal rainfall and intense hurricane associations. Dept. of Atmos. Sci. Paper, Colo. State Univ., Ft. Collins, CO, 272 pp.

Landsea, C. W., 1993: A climatology of intense (or major) Atlantic hurricanes. *Mon. Wea. Rev.,* 121, 1703-1713.

Landsea, C. W., 2007: Counting Atlantic tropical cyclones back to 1900. *EOS,* 88, 197, 202.

Landsea, C. W. and W. M. Gray, 1992: The strong association between Western Sahel monsoon rainfall and intense Atlantic hurricanes. *J. Climate,* 5, 435-453.

Landsea, C. W., W. M. Gray, P. W. Mielke, Jr., and K. J. Berry, 1992: Long-term variations of Western Sahelian monsoon rainfall and intense U.S. landfalling hurricanes. *J. Climate,* 5, 1528-1534.

Landsea, C. W., W. M. Gray, K. J. Berry and P. W. Mielke, Jr., 1996: June to September rainfall in the African Sahel: A seasonal forecast for 1996. 4 pp.

Landsea, C. W., N. Nicholls, W.M. Gray, and L.A. Avila, 1996: Downward trends in the frequency of intense Atlantic hurricanes during the past five decades. *Geo. Res. Letters*, 23, 1697-1700.

Landsea, C. W., R. A. Pielke, Jr., A. M. Mestas-Nunez, and J. A. Knaff, 1999: Atlantic basin hurricanes: Indices of climatic changes. *Climatic Changes,* 42, 89-129.

Landsea, C.W. et al., 2005: Atlantic hurricane database re-analysis project. Available online at http://www.aoml.noaa.gov/hrd/data_sub/re_anal.html

Mielke, P. W., K. J. Berry, C. W. Landsea and W. M. Gray, 1996: Artificial skill and validation in meteorological forecasting. *Wea. Forecasting,* 11, 153-169.

Mielke, P. W., K. J. Berry, C. W. Landsea and W. M. Gray, 1997: A single sample estimate of shrinkage in meteorological forecasting. *Wea. Forecasting*, 12, 847-858.

Pielke, Jr. R. A., and C. W. Landsea, 1998: Normalized Atlantic hurricane damage, 1925-1995. *Wea. Forecasting*, 13, 621-631.

Pielke, Jr. R. A., and J. Gratz, C. W. Landsea, D. Collins, and R. Masulin, 2008: Normalized hurricane damage in the United States: 1900-2005. *Nat. Haz. Rev.*, 9, 29-42, doi:10.1061/(ASCE)1527-6988(2008)9:1(29).

Rasmusson, E. M. and T. H. Carpenter, 1982: Variations in tropical sea-surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. *Mon. Wea. Rev.*, 110, 354-384.

Saunders, M. A., and A. S. Lea, 2008: Large contribution of sea surface warming to recent increase in Atlantic hurricane activity. *Nature,* 451, 557-560.

Seseske, S. A., 2004: Forecasting summer/fall El Niño-Southern Oscillation events at 6-11 month lead times. Dept. of Atmos. Sci. Paper No. 749, Colo. State Univ., Ft. Collins, CO, 104 pp.

Vimont, D. J., and J. P. Kossin, 2007: The Atlantic meridional mode and hurricane activity. *Geophys. Res. Lett.,* 34, L07709, doi:10.1029/2007GL029683.

Wheeler, M. C., and H. H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. *Mon. Wea. Rev.*, 132, 1917-1932.

14 Verification of Previous Forecasts

Table 10: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity from 2013-2017.

2013	10 April	Update 3 June	Update 2 August	Obs.
Hurricanes	9	9	8	2
Named Storms	18	18	18	13
Hurricane Days	40	40	35	3.75
Named Storm Days	95	95	84.25	38.50
Major Hurricanes	4	4	3	0
Major Hurricane Days	9	9	7	0
Accumulated Cyclone Energy	165	165	142	33
Net Tropical Cyclone Activity	175	175	150	44

2014	10 April	Update 2 June	Update 1 July	Update 31 July	Obs.
Hurricanes	3	4	4	4	6
Named Storms	9	10	10	10	8
Hurricane Days	12	15	15	15	17.75
Named Storm Days	35	40	40	40	35
Major Hurricanes	1	1	1	1	2
Major Hurricane Days	2	3	3	3	3.75
Accumulated Cyclone Energy	55	65	65	65	67
Net Tropical Cyclone Activity	60	70	70	70	82

2015	9 April	Update 1 June	Update 1 July	Update 4 August	Obs.
Hurricanes	3	3	3	2	4
Named Storms	7	8	8	8	11
Hurricane Days	10	10	10	8	11.50
Named Storm Days	30	30	30	25	43.75
Major Hurricanes	1	1	1	1	2
Major Hurricane Days	0.5	0.5	0.5	0.5	4
Accumulated Cyclone Energy	40	40	40	35	60
Net Tropical Cyclone Activity	45	45	45	40	81

2016	9 April	Update 1 June	Update 1 July	Update 4 August	Obs.
Hurricanes	6	6	6	6	7
Named Storms	13	14	15	15	15
Hurricane Days	21	21	21	22	27.75
Named Storm Days	52	53	55	55	81.00
Major Hurricanes	2	2	2	2	4
Major Hurricane Days	4	4	4	5	10.25
Accumulated Cyclone Energy	93	94	95	100	141
Net Tropical Cyclone Activity	101	103	105	110	155

2017	6 April	Update 1 June	Update 5 July	Update 4 August	Obs.
Hurricanes	4	6	8	8	10
Named Storms	11	14	15	16	17
Hurricane Days	16	25	35	35	51.75
Named Storm Days	50	60	70	70	93.00
Major Hurricanes	2	2	3	3	6
Major Hurricane Days	4	5	7	7	19.25
Accumulated Cyclone Energy	75	100	135	135	225
Net Tropical Cyclone Activity	85	110	140	140	232