FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2019

We continue to predict a near-normal 2019 Atlantic hurricane season. The forecast number of hurricanes has increased slightly to account for short-lived Hurricane Barry which formed in July. Sea surface temperatures in the tropical Atlantic remain near average. While the odds of a weak El Niño persisting through August-October have decreased, vertical wind shear in the Caribbean remains relatively high. The probability for major hurricanes making landfall along the United States coastline and in the Caribbean remains near its long-term average. 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 5 August 2019)

By Philip J. Klotzbach[1], Michael M. Bell[2], and Jhordanne Jones[3]

In Memory of William M. Gray[4]

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

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2019

Forecast Parameter and 1981-2010 Average (in parentheses)	Issue Date 4 April 2019	Issue Date 4 June 2019	Issue Date 9 July 2019	Observed Activity Thru July 2019	Forecast Activity After 31 July	**Total Seasonal Forecast**
Named Storms (NS) (12.1)	13	14	14	2	12	**14**
Named Storm Days (NSD) (59.4)	50	55	55	4.25	50.75	**55**
Hurricanes (H) (6.4)	5	6	6	1	6	**7**
Hurricane Days (HD) (24.2)	16	20	20	0.25	19.75	**20**
Major Hurricanes (MH) (2.7)	2	2	2	0	2	**2**
Major Hurricane Days (MHD) (6.2)	4	5	5	0	5	**5**
Accumulated Cyclone Energy (ACE) (106)	80	100	100	4	101	**105**
Net Tropical Cyclone Activity (NTC) (116%)	90	105	105	8	102	**110**

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 - 53% (full-season average for last century is 52%)

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

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 31% (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) 43% (full-season average for last century is 42%)

ABSTRACT

Information obtained through July 2019 indicates that the 2019 Atlantic hurricane season will have activity near the average 1981-2010 season. We estimate that the remainder of 2019 will have about 6 hurricanes (post 1-August average is 5.9), 12 named storms (average is 10.2), 50.75 named storm days (average is 53.2), 19.75 hurricane days (average is 22.9), 2 major (Category 3-4-5) hurricanes (average is 2.6) and 5 major hurricane days (average is 5.9). The probability of U.S. major hurricane landfall is estimated to be near its long-period average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2019 to be near their long-term averages for the remainder of the season.

The eastern tropical Atlantic is cooler than normal, while the central tropical Atlantic is slightly warmer than normal. Vertical wind shear across the Caribbean has been slightly stronger than average over the past month. During July, the tropical Atlantic was moister than normal, while the Caribbean was drier than normal. More active Atlantic hurricane seasons are generally characterized by lower shear, more moisture and warmer sea surface temperatures (SSTs), so current conditions in the tropical Atlantic and Caribbean present mixed signals for the remainder of the season. The central tropical Pacific remains much warmer than normal, while the eastern tropical Pacific has anomalously cooled. Regardless of the weakening of El Niño, we believe that the warmth in the central tropical Pacific should continue for the next couple of months, likely preventing upper-level winds from becoming too hurricane favorable in the tropical Atlantic and Caribbean.

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 5, August 19, September 2, 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 model shows strong evidence on 40 years of data that significant improvement over a climatological forecast can be attained. We would never issue a seasonal hurricane forecast unless we had models developed over a long hindcast period which showed skill.

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 and dynamical models which 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, Ironshore Insurance, the Insurance Information Institute 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 (available online at http://www.e-transit.org/hurricane).

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, Louis-Philippe Caron, Brian McNoldy, Paul Roundy, Jason Dunion, 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 36th 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 of 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 2019 Atlantic Basin Named Storm Activity through July

The 2019 Atlantic basin hurricane season has had near-average activity through July. Two named storms (Andrea and Barry) and one hurricane (Barry) have formed. Barry made landfall in south-central Louisiana as a Category 1 hurricane, but thankfully no fatalities, and relatively little damage was reported. Historically, over 90% of all ACE is generated after 1 August. Real-time global tropical cyclone (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 2019 Atlantic basin tropical cyclone activity through July 31. Dates listed are those where TCs had maximum sustained winds of at least 34 knots and are given in UTC time.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	MHD	ACE
TS	Andrea	May 20 – 21	35 kt/1006 mb	0.75			0.4
H-1	Barry	July 11 – 14	65 kt/993 mb	3.50	0.25		3.3
Totals	2			4.25	0.25		3.7

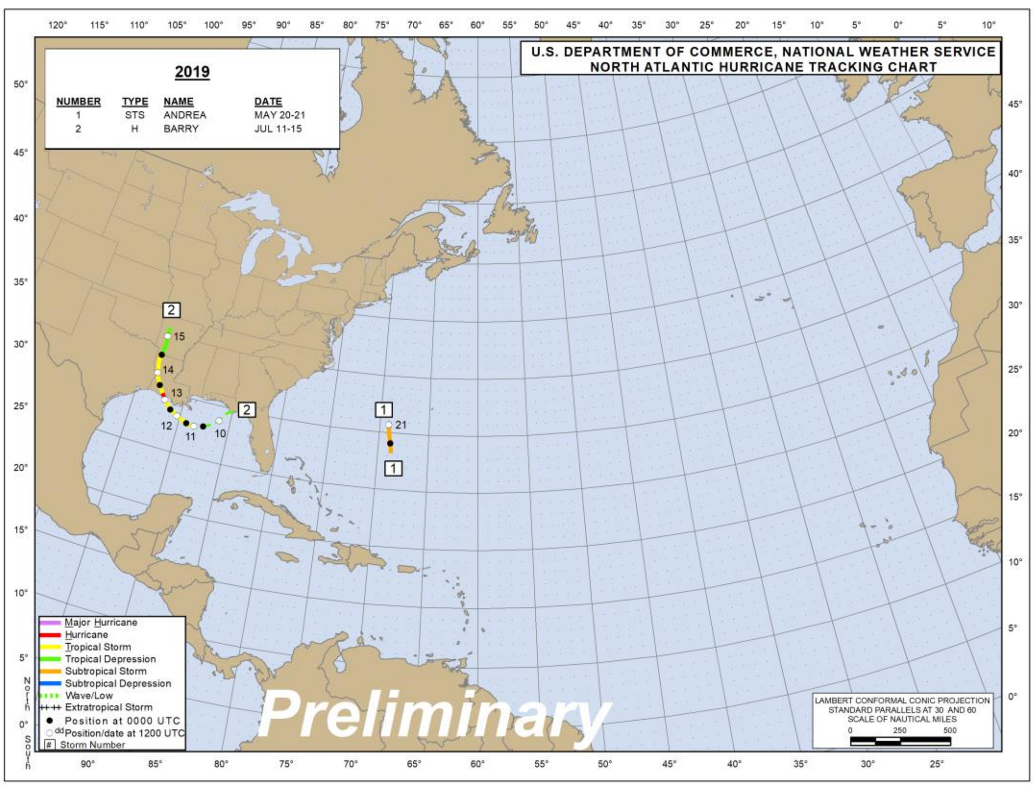

Figure 1: 2019 Atlantic basin TC tracks through July. Figure courtesy of National Hurricane Center.

2 August Forecast Methodology

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 and the Climate Forecast System Reanalysis (CFSR), 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/forecast results over the period from 1979-2018. 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 2019 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 2019 Forecast	Effect on 2019 Hurricane Season
1) July Surface U (10-17.5°N, 60-85°W) (+)	+0.1 SD	Neutral
2) July Surface Temperature (20-40°N, 15-35°W) (+)	+0.9 SD	Enhance
3) July 200 mb U (5-15°N, 0-40°E) (-)	+1.0 SD	Suppress

Post-31 July Seasonal Forecast Predictors

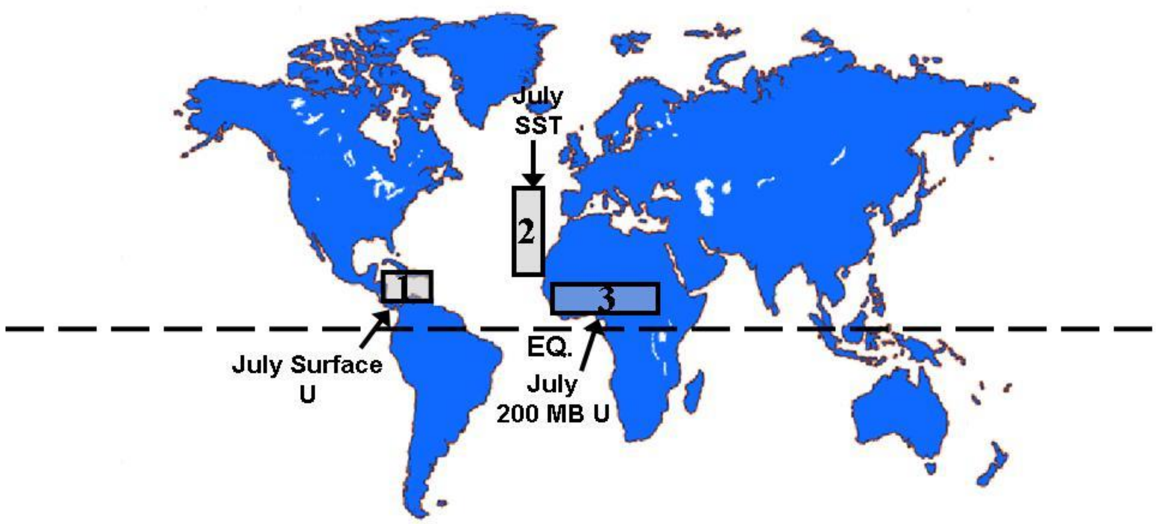

Figure 2: Location of predictors for the post-31 July forecast for the 2019 hurricane season from the statistical model.

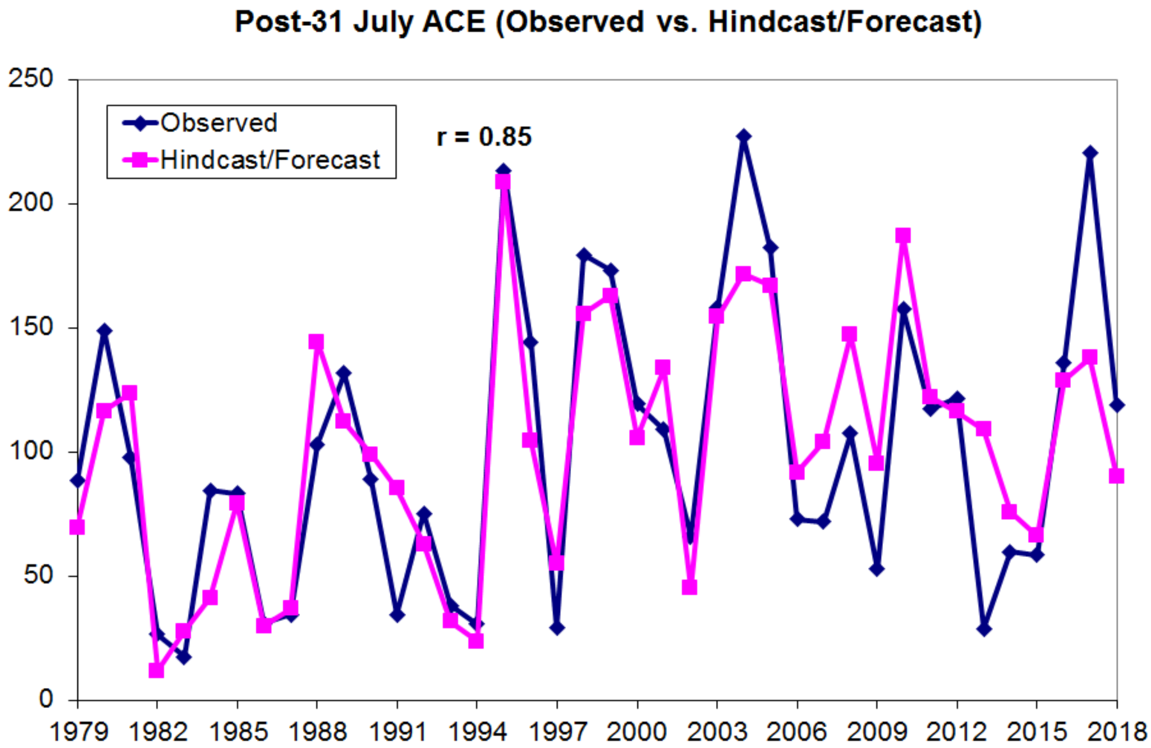

Figure 3: Observed versus hindcast values of post-31 July ACE for 1979-2018 using our current statistical scheme.

Table 3 shows our statistical forecast for the 2019 hurricane season from the new statistical model and the comparison of this forecast with the 1981-2010 average. Our statistical forecast is calling for a near-average remainder of the hurricane season.

Table 3: Post-31 July statistical forecast for 2019 from the statistical model.

Predictands and Climatology (1981-2010 Post-31 July Average)	Statistical Forecast
Named Storms (NS) – 10.2	12.1
Named Storm Days (NSD) – 53.2	60.1
Hurricanes (H) – 5.9	6.2
Hurricane Days (HD) – 22.9	22.7
Major Hurricanes (MH) – 2.6	2.5
Major Hurricane Days (MHD) – 5.9	5.5
Accumulated Cyclone Energy Index (ACE) – 98	101
Net Tropical Cyclone Activity (NTC) – 106	112

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).

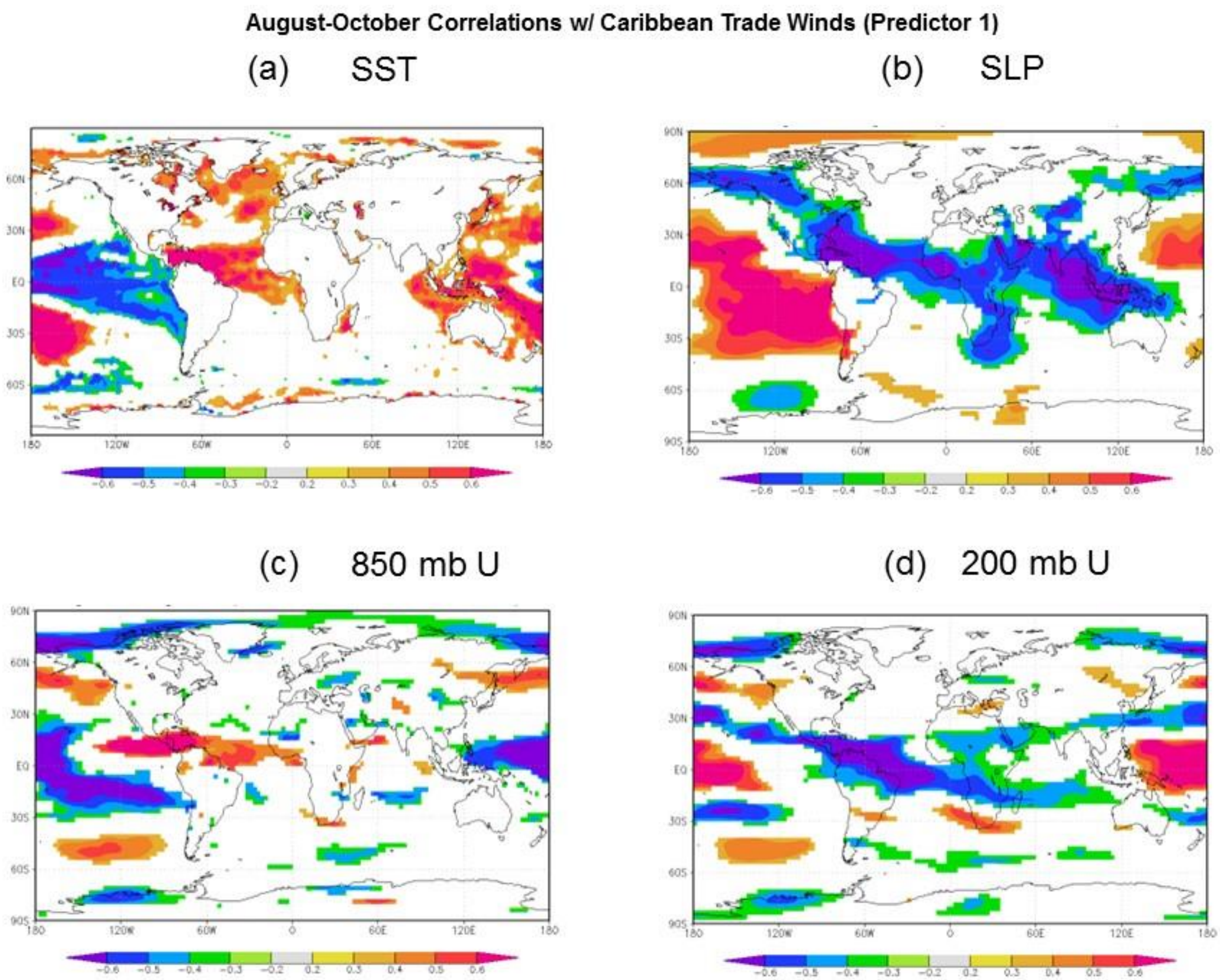

Figure 4: Linear correlations between July Surface U in the Caribbean (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d) over the period from 1979-2011.

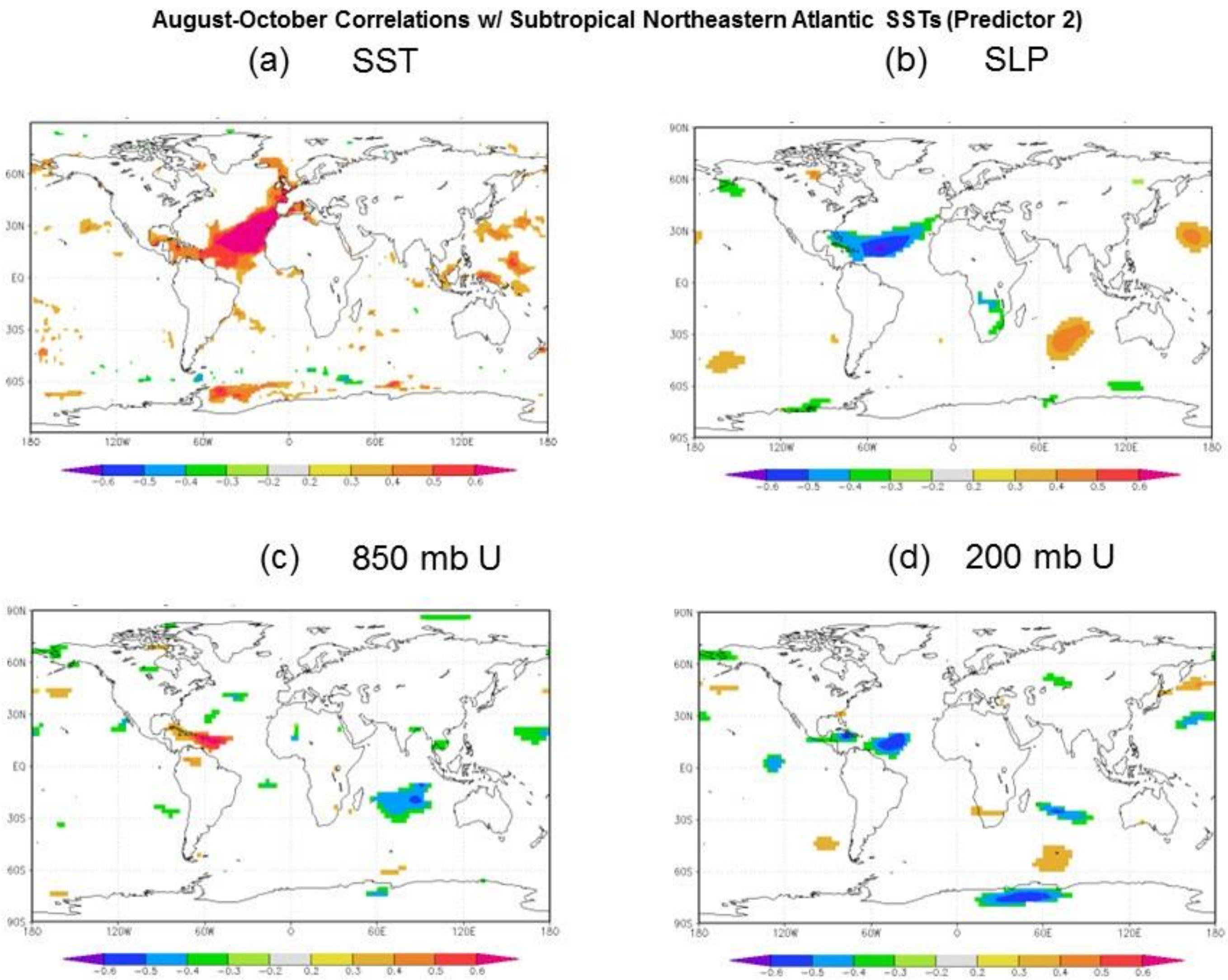

Figure 5: Linear correlations between July Surface Temperature in the Subtropical Northeastern Atlantic (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel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

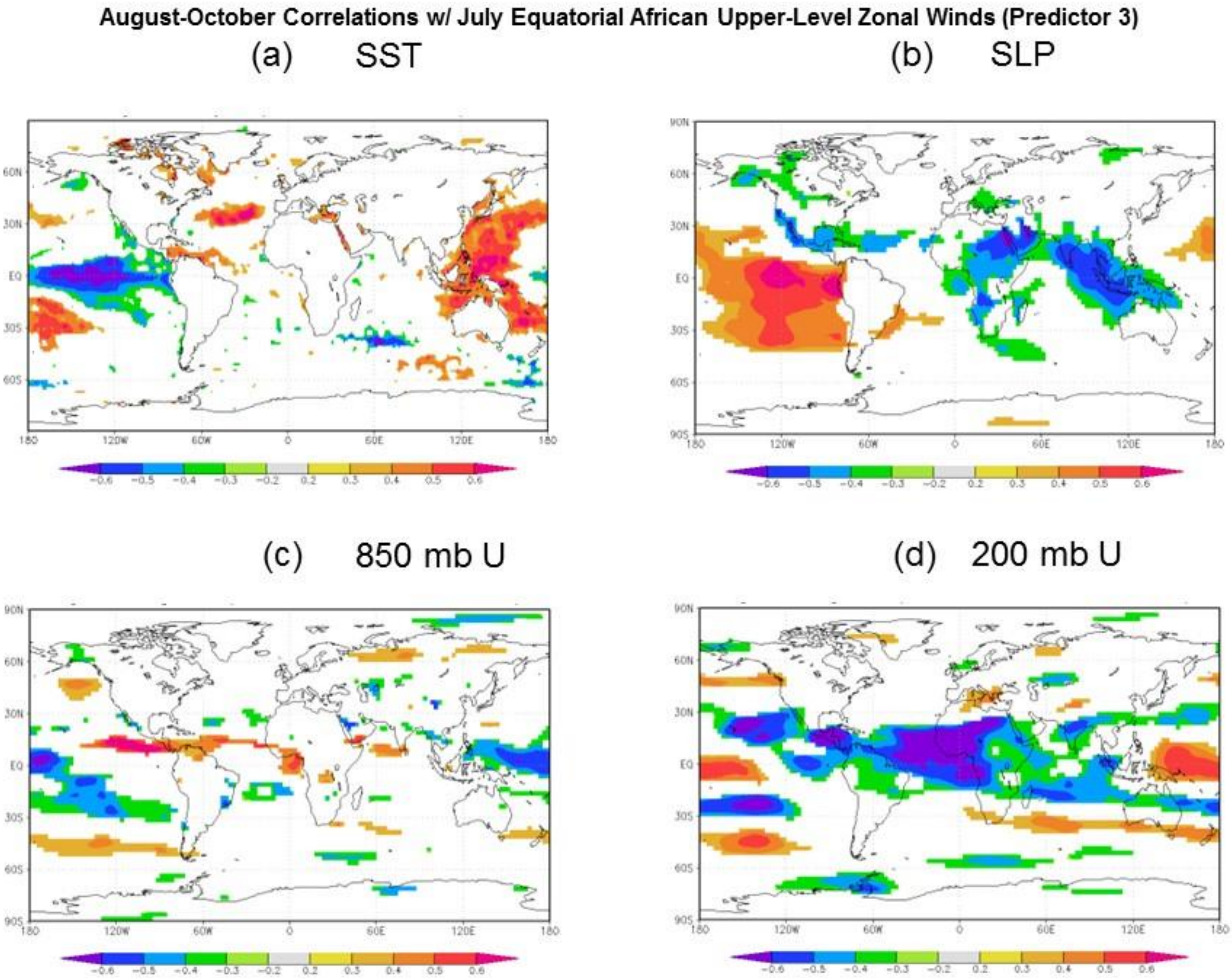

Figure 6: Linear correlations between July 200 MB Zonal Wind over tropical north Africa (Predictor 3) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d) over the period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

2.3 Analog-Based Predictors for 2019 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially like 2019. These years also provide useful clues as to likely trends in activity that the 2019 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 2019 conditions as well as conditions that we anticipate being present during the peak months of the Atlantic hurricane season from August-October. Table 4 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 near average Atlantic MDR SST configurations.

There were four hurricane seasons with characteristics most like what we observed in July 2019. The best analog years that we could find for the 2019 hurricane season were 1990, 1992, 2012 and 2014. We anticipate that 2019 seasonal hurricane activity will have activity near the average of these four analog years. We believe that the remainder of 2019 will have near-average activity in the Atlantic basin.

Table 4: Best analog years for 2019 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1990	14	72.25	8	26.75	1	1.00	97	100
1992	7	40.25	4	16.00	1	3.50	76	67
2012	19	101.25	10	28.50	2	0.50	133	131
2014	8	35.00	6	17.75	2	3.75	67	82
Mean (Full Season)	**12.0**	**62.2**	**7.0**	**22.3**	**1.5**	**2.2**	**93**	**95**
2019 Forecast (Full Season)	**14**	**55**	**7**	**20**	**2**	**5**	**105**	**110**
1981-2010 Average (Full Season)	**12.1**	**59.4**	**6.4**	**24.2**	**2.7**	**6.2**	**106**	**116**

2.4 August Forecast Summary and Final Adjusted Forecast

Table 5 shows our final adjusted early August forecast for the 2019 season which is a combination of our statistical scheme, our analog scheme and qualitative adjustments for other factors not explicitly contained in any of these schemes. Both schemes call for near-average activity. Our forecast is close to the average of these two schemes and also calls for a near-average season, due to what we anticipate will be either warm neutral ENSO or weak El Niño conditions and near-average tropical Atlantic SST conditions for the peak of the Atlantic hurricane season (August-October).

Table 5: Summary of our early August statistical forecast, our analog forecast, the average of those two schemes and our adjusted final forecast for the 2019 hurricane season.

Forecast Parameter and 1981-2010 Average (in parentheses)	Statistical Scheme	Analog Scheme	Average of Two Schemes	Adjusted Final Forecast
Named Storms (12.1)	12.1	12.0	12.1	14
Named Storm Days (59.4)	60.1	62.2	61.2	55
Hurricanes (6.4)	6.2	7.0	6.6	7
Hurricane Days (24.2)	22.7	22.3	22.5	20
Major Hurricanes (2.7)	2.5	1.5	2.0	2
Major Hurricane Days (6.2)	5.5	2.2	3.9	5
Accumulated Cyclone Energy Index (106)	101	93	97	105
Net Tropical Cyclone Activity (116%)	112	95	104	110

3 Forecast Uncertainty

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

Table 6 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 6: Model hindcast error and our post-31 July 2019 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	Post-31 July 2019 Forecast	Post-31 July Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	2	12	10 – 14
Named Storm Days (NSD)	17	50.75	33.75 – 67.75
Hurricanes (H)	2	6	4 – 8
Hurricane Days (HD)	9	19.75	10.75 – 28.75
Major Hurricanes (MH)	1	2	1 – 3
Major Hurricane Days (MHD)	4	5	1 – 9
Accumulated Cyclone Energy (ACE)	36	101	65 – 137
Net Tropical Cyclone (NTC) Activity	34	102	68 – 136

4 ENSO

Weak El Niño conditions currently exist across the tropical Pacific. Table 7 displays May and July SST anomalies for several Nino regions. The central tropical Pacific remains very warm, while the eastern tropical Pacific has anomalously cooled (Table 7). Currently, SST anomalies in the Nino 4 region are at near-record warm levels, while SSTs are near average in the Nino 3 region. This anomalous SST gradient pattern is quite unusual in the historical record, with no close comparable analogs since 1950. In general, when Nino 4 is much warmer than Nino 3, it tends to occur in a La Niña situation.

Table 7: May and July 2019 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	+0.1	-0.2	-0.3
Nino 3	+0.6	+0.1	-0.5
Nino 3.4	+0.8	+0.4	-0.4
Nino 4	+0.7	+0.9	+0.2

There is considerable uncertainty as to whether the weak El Niño that is currently present will persist through October. We note that NOAA typically defines ENSO events by the Nino 3.4 region which has anomalously cooled over the past couple of months (Table 7). Upper ocean heat content anomalies in the eastern and central Pacific have been slightly above average over the past few weeks (Figure 7).

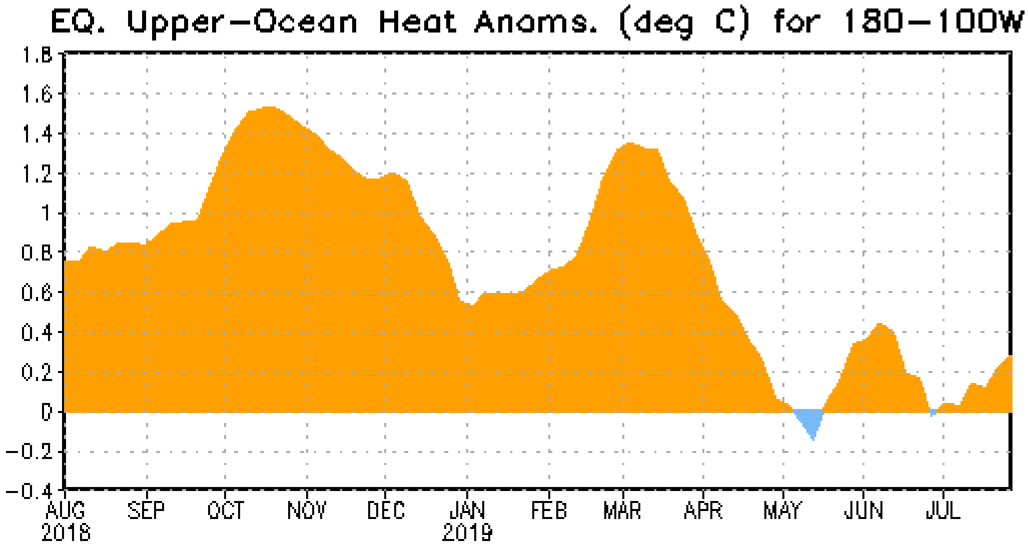

Figure 7: Upper-ocean (0-300 meters depth) heat content anomalies in the eastern and central Pacific since August 2018. Upper ocean heat content decreased rapidly from March to May and has since been near normal, with a weak increasing trend noted over the past several weeks.

While the Nino 3.4 region may cool below the 0.5°C threshold necessary for NOAA to continue its El Niño event definition, we believe that the warm anomalies in the central tropical Pacific are likely to persist. Anomalously westerly winds near the International Date Line over the past few weeks (Figure 8) have led to continued anomalous warming and deepening of the thermocline in the central tropical Pacific (Figure 9). The Climate Forecast System (CFS) is calling for weak low-level westerly wind anomalies to persist near 180° for the next two weeks (Figure 8) which should help these warm SST anomalies to persist. Since overall SSTs are warmer in the central tropical Pacific than in the eastern tropical Pacific, we anticipate that the anomalous warmth near the International Date Line should help focus convection in the central tropical Pacific and thereby increase upper-level westerly winds in the Caribbean. This strengthening of upper-level winds increases vertical wind shear in the Caribbean, since low-level winds in the Caribbean are out of the east. Stronger vertical wind shear is detrimental for hurricane formation and intensification.

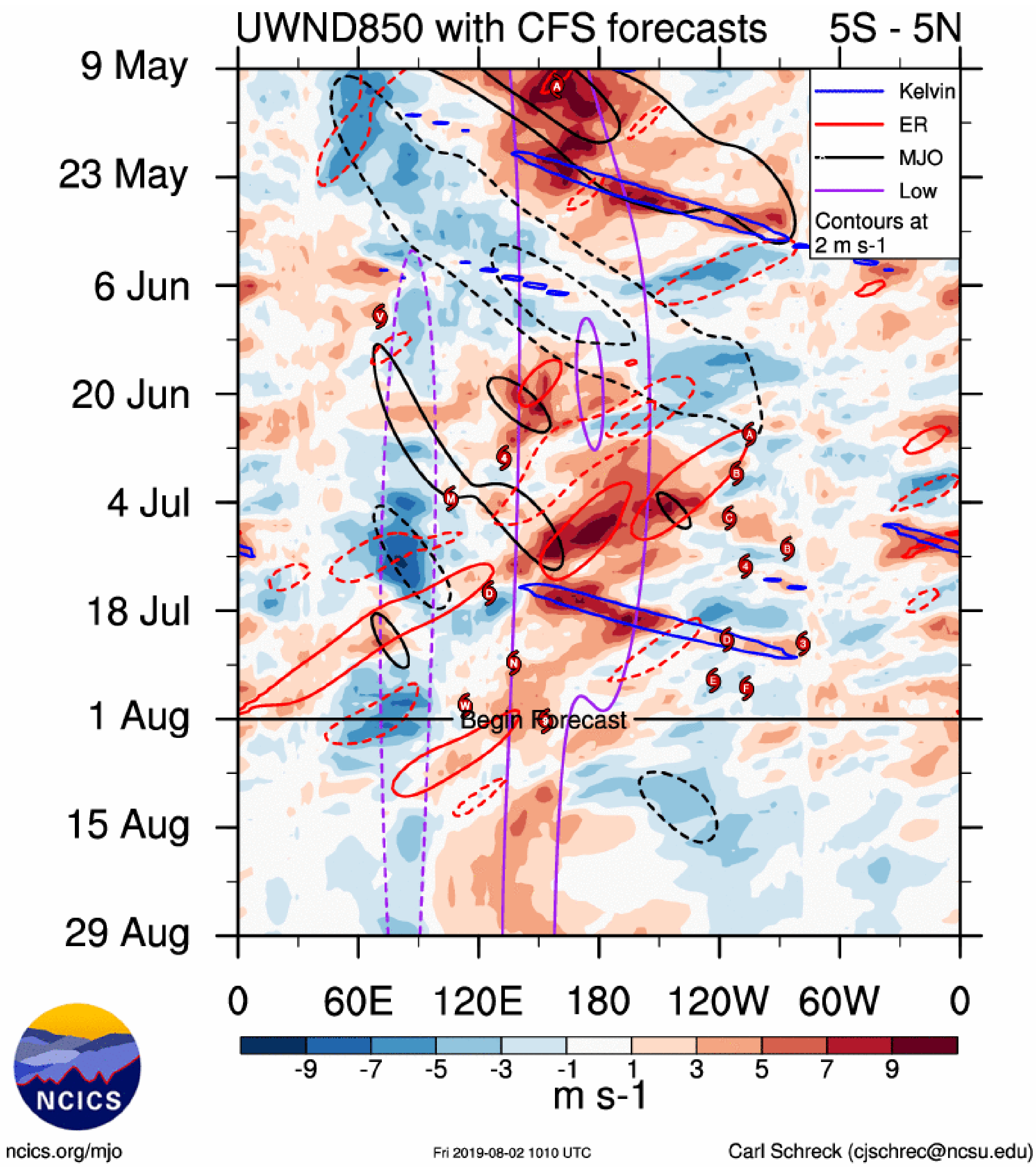

Figure 8: Anomalous 850-mb winds averaged near the equator. Anomalous westerly winds have prevailed near the International Date Line over the past several weeks, helping to promote continued anomalous warmth in the central tropical Pacific. Weak low-level westerly winds are forecast to persist by the Climate Forecast System for the next several weeks in the central tropical Pacific. Figure courtesy of Carl Schreck.

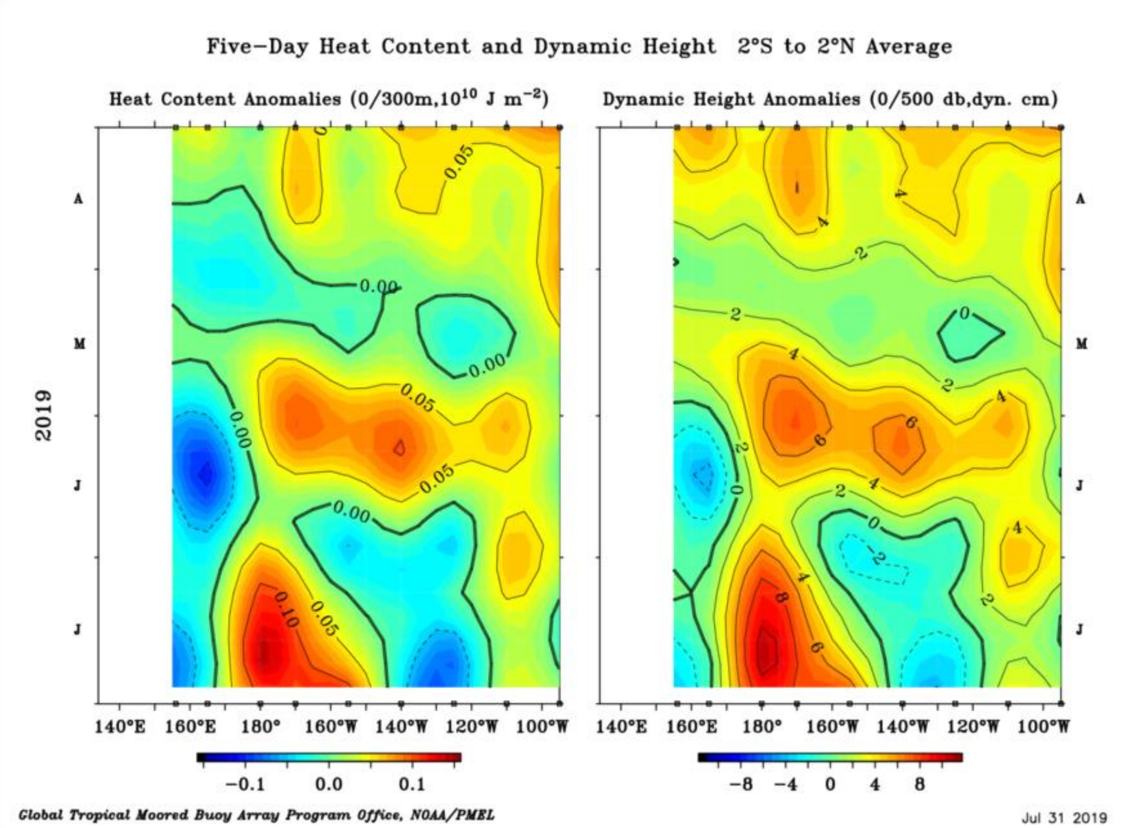

Figure 9: Heat content anomalies (left panel) and dynamic height anomalies (right panel) as analyzed by the Global Tropical Moored Buoy Array Program. Note the increase in both heat content and dynamic height over the past few weeks near 180°. The central tropical Pacific remains very warm, both at the surface and in the upper ~300 meters of the ocean.

The official forecast from the Climate Prediction Center calls for only a ~30% chance that El Niño will persist through the peak of the Atlantic hurricane season from August-October (Figure 10). However, as noted earlier, regardless of whether the Nino 3.4 region persists in meeting the NOAA El Niño threshold of 0.5°C, we believe that the anomalous warmth in the central tropical Pacific will be a slight inhibiting factor for this year's Atlantic hurricane season.

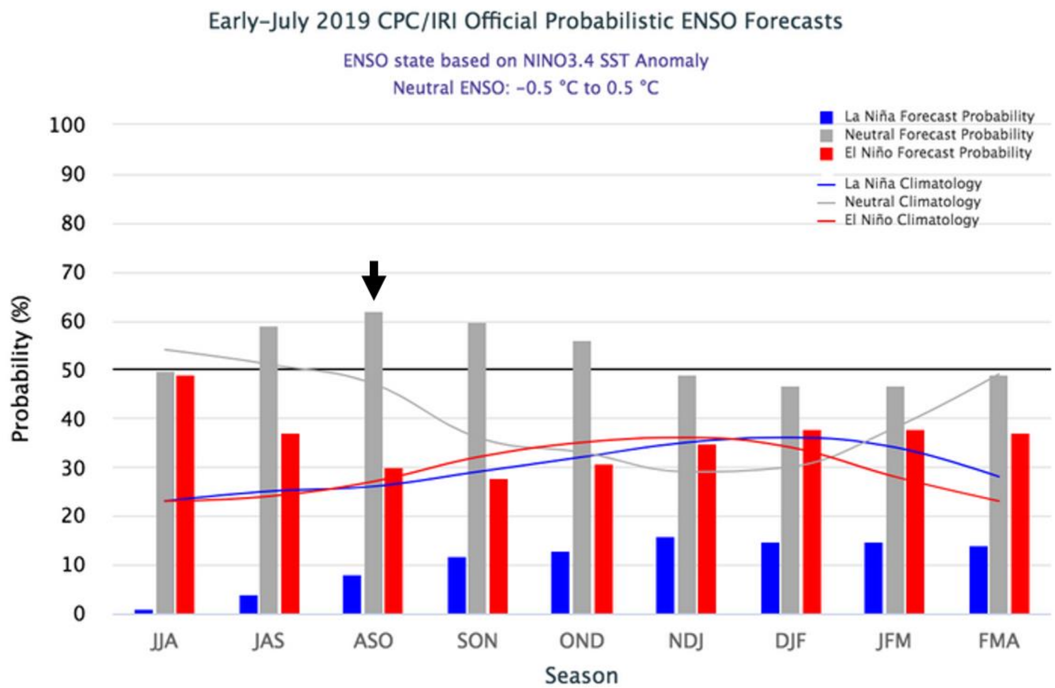

Figure 10: Official ENSO forecast from the Climate Prediction Center. The black arrow represents the peak of the Atlantic hurricane season from August to October.

5 Current Atlantic Basin Conditions

The central tropical Atlantic is slightly warmer than normal, while the eastern tropical Atlantic is colder than normal (Figure 11). As was the case last year, the subtropical Atlantic is much warmer than normal. However, most major hurricane activity develops and intensifies in the deep tropics, where SSTs are closer to their long-term averages. Figure 12 displays the historical correlation map between seasonal ACE and July SSTs. In regions where the historical correlation between ACE and SSTs is the strongest, July 2019 SSTs averaged near normal.

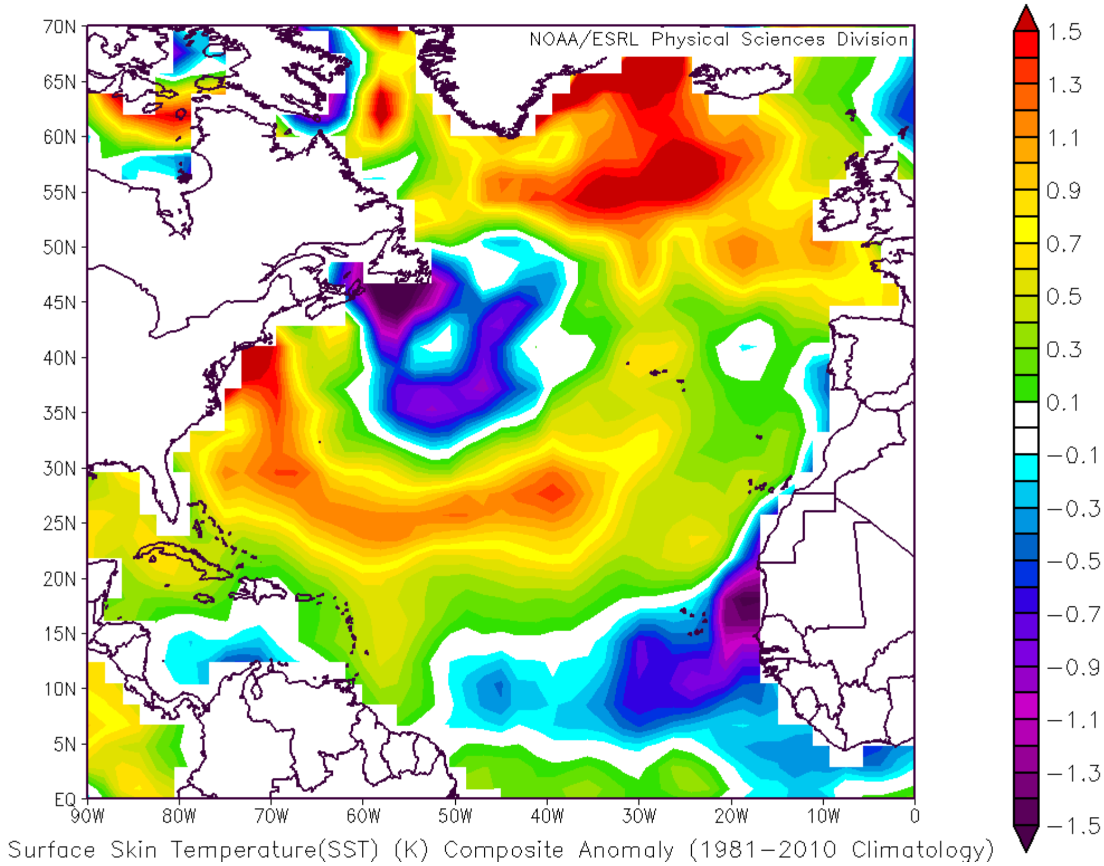

Figure 11: July 2019 SST anomalies.

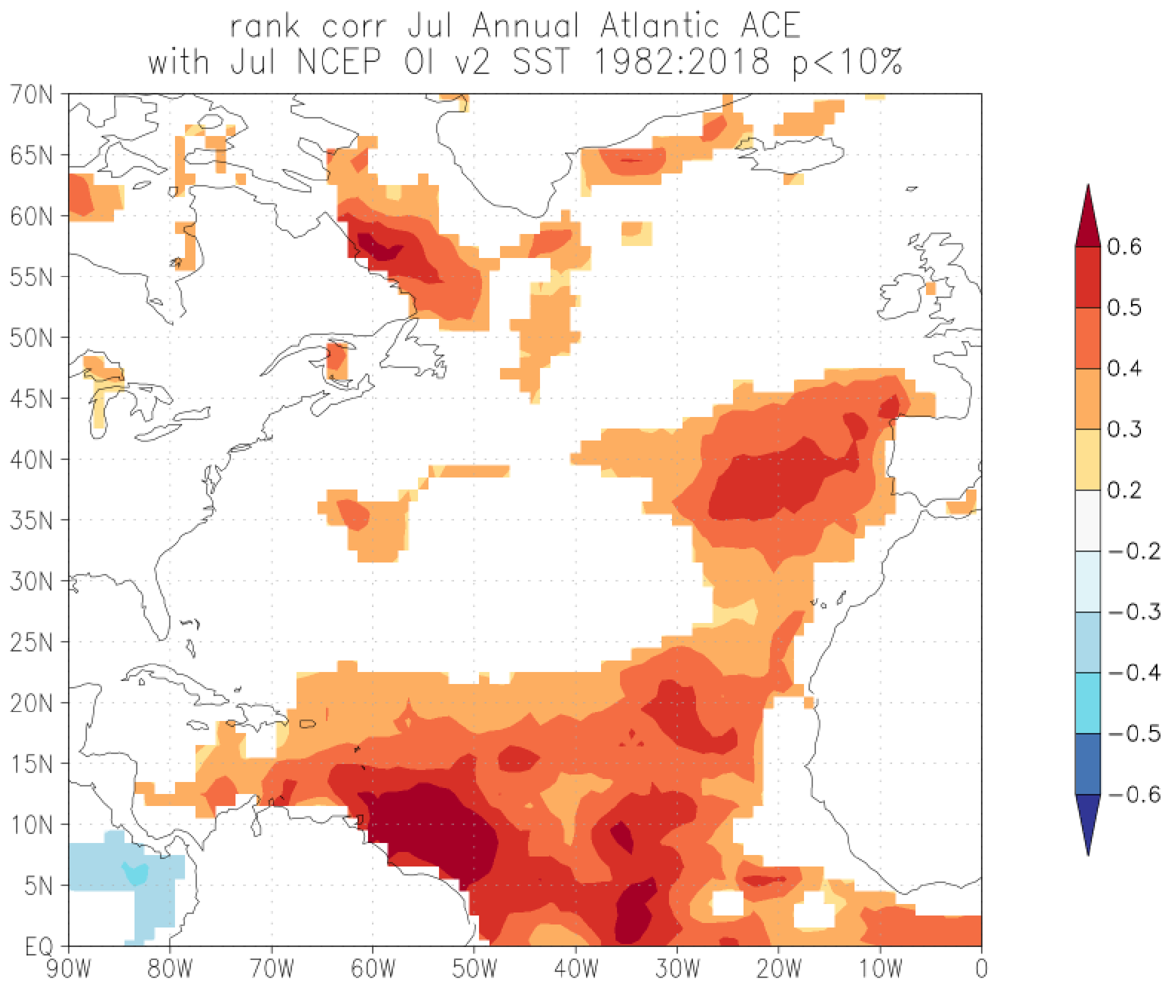

Figure 12: Correlation map between July SSTs and seasonal Atlantic ACE based on data over the period from 1982-2018.

Sea level pressure anomalies over the past month have been near average across most of the tropical Atlantic and below average in the subtropical 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). The July 2019 TUTT looked to be near its long-term average.

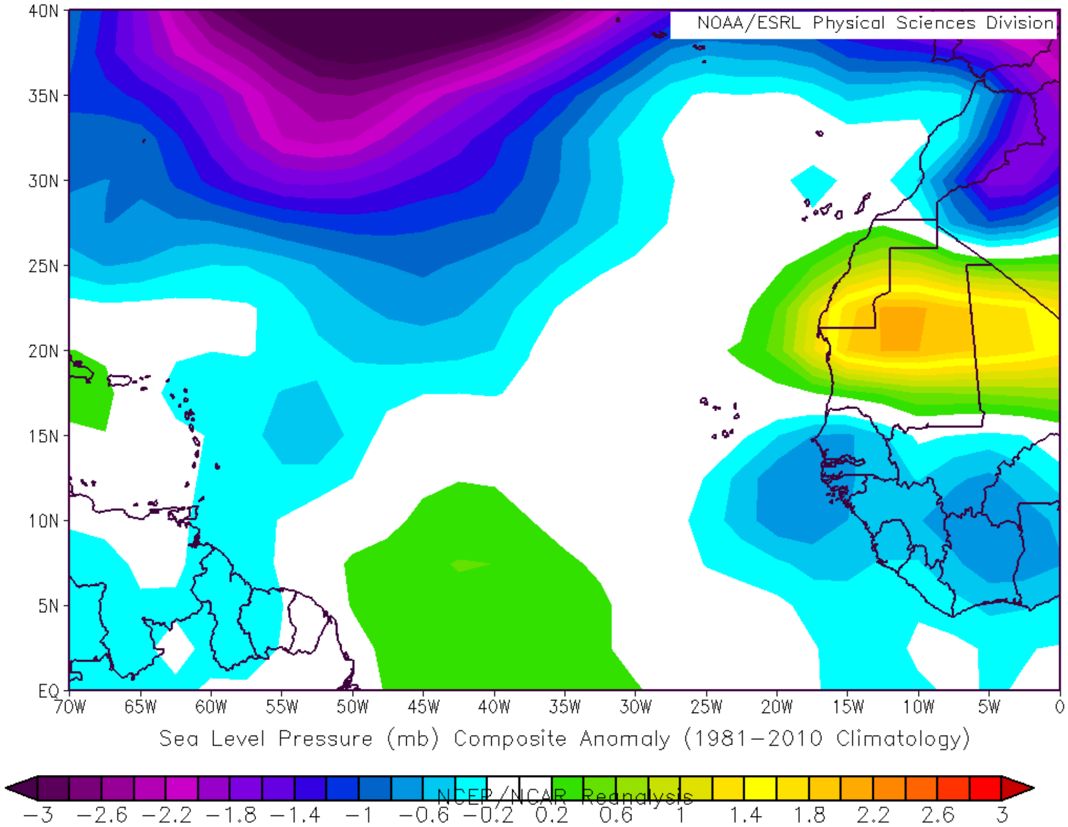

Figure 13: July 2019 Atlantic SLP anomalies. Sea level pressure anomalies have generally been near normal across the tropical Atlantic.

July vertical wind shear has generally been above normal over the Caribbean and below 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.

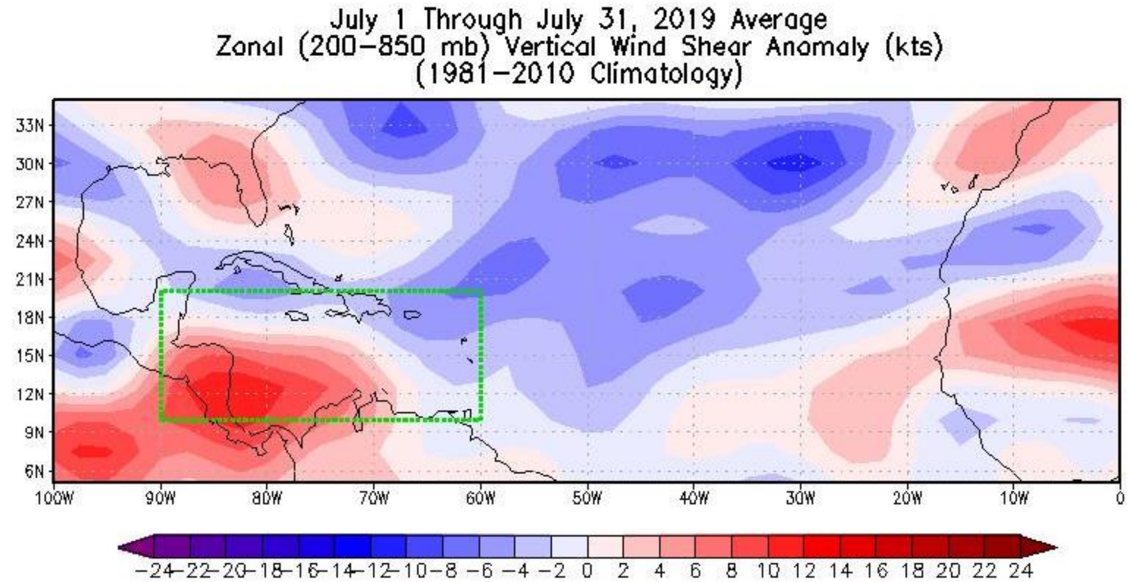

Figure 14: July 2019 averaged 200-850-mb zonal wind anomalies across the tropical Atlantic

The Caribbean has been drier than normal this July, while the eastern and central tropical Atlantic have been moister than normal (Figure 15). The relationship between mid-level moisture and Atlantic ACE is relatively weak, but the correlation is stronger in the Caribbean than farther east in the Atlantic (Figure 16).

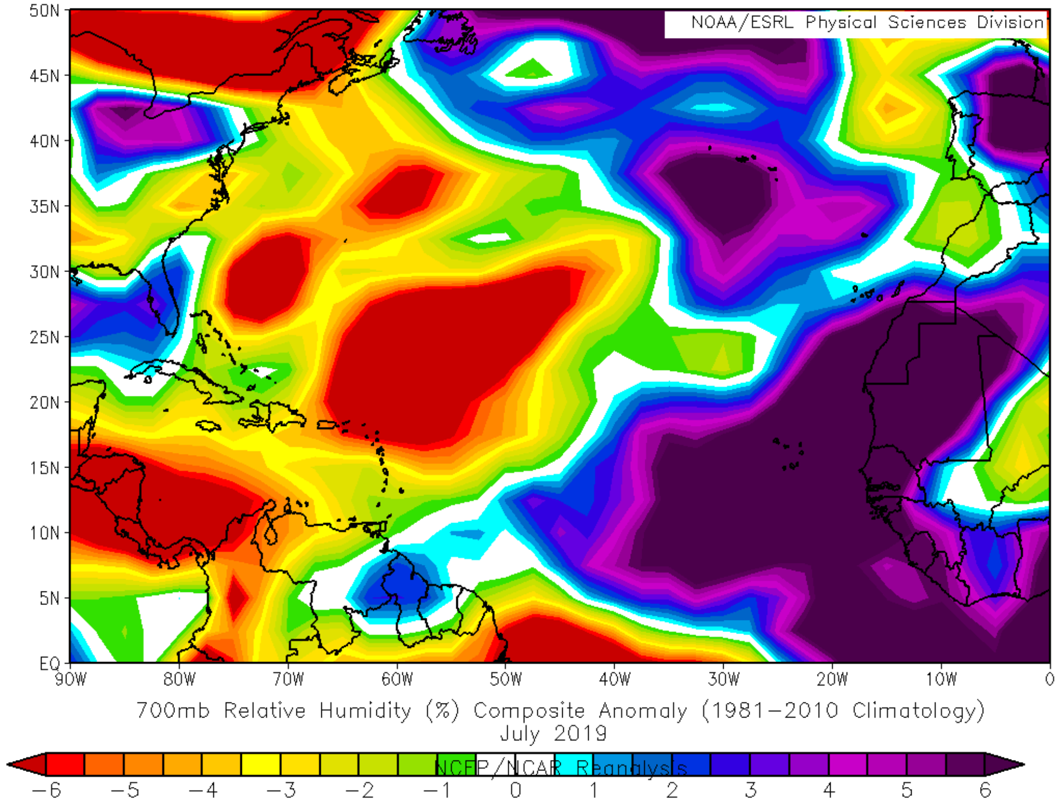

Figure 15: July 2019 700-mb relative humidity anomalies across the tropical Atlantic.

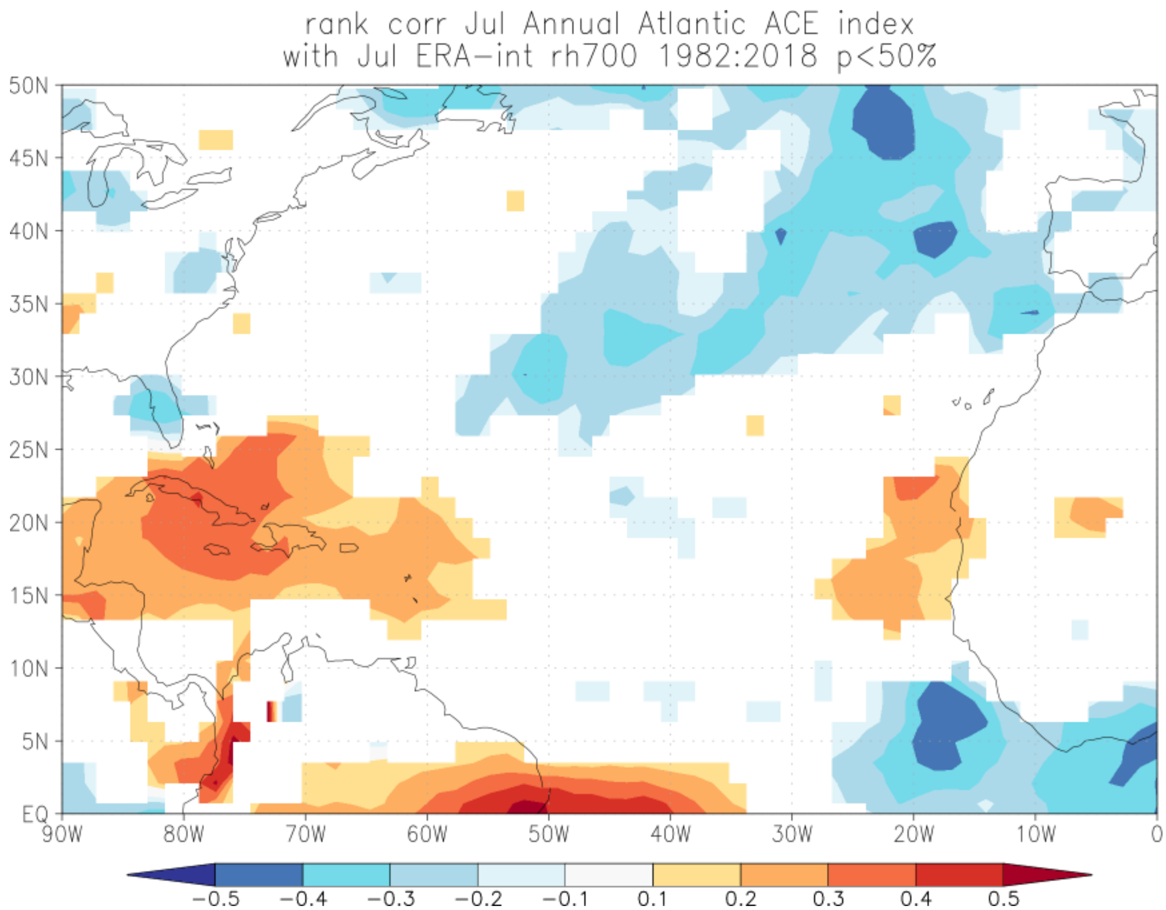

Figure 16: Correlation map between July 700 mb relative humidity and seasonal Atlantic ACE based on data over the period from 1982-2018.

6 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 near normal, favoring a near-normal hurricane season.

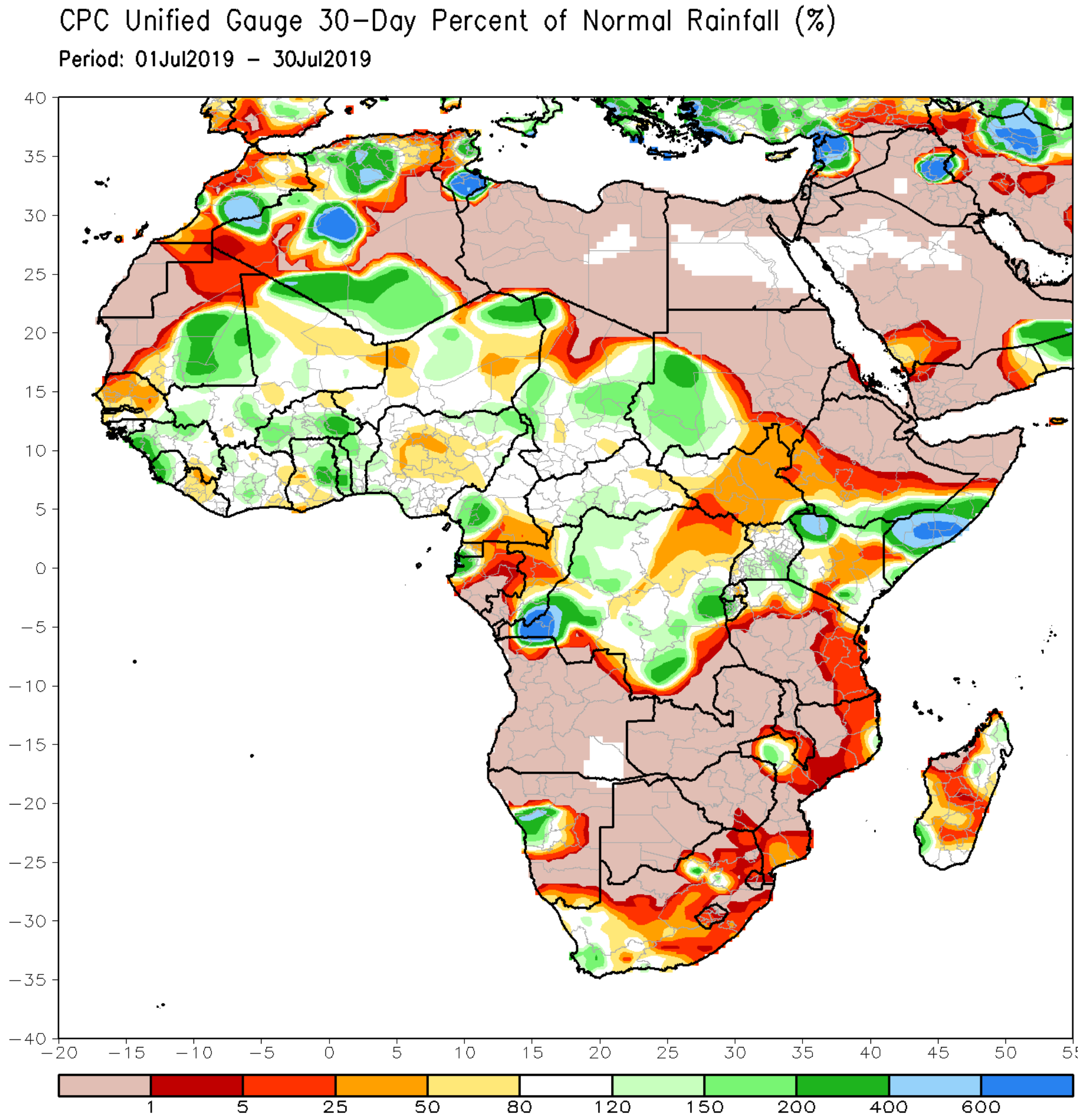

Figure 17: Climate Prediction Center Unified Gauge estimate of percent of normal rainfall from June 30 – July 29, 2019.

7 Landfall Probabilities for 2019

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 2019 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 2019 is expected to be near its long-term average, and therefore, landfall probabilities are near 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 2019 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)	80% (79%)	68% (68%)	53% (52%)	85% (84%)	97% (97%)
Gulf Coast (Regions 1-4)	59% (59%)	43% (42%)	31% (30%)	60% (60%)	84% (83%)
Florida plus East Coast (Regions 5-11)	51% (50%)	45% (44%)	31% (31%)	62% (61%)	81% (81%)
Caribbean (10-20°N, 60-88°W)	83% (82%)	58% (57%)	43% (42%)	76% (75%)	96% (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 Caribbean islands.

8 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 2019 should have near-average hurricane activity. Average SSTs in the tropical Atlantic and the lingering effects of anomalously warm SSTs in the central tropical Pacific will likely lead to a near-normal Atlantic hurricane season.

9 Forthcoming Updated Forecasts of 2019 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, Monday, August 5 and continuing every other Monday (August 19, September 2, September 16, etc.). A verification and discussion of all 2019 forecasts will be issued in late November 2019. All of these forecasts will be available online.

10 Verification of Previous Forecasts

Table 10: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity from 2014-2018.

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	14 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	51.25
Named Storm Days	50	60	70	70	91.25
Major Hurricanes	2	2	3	3	6
Major Hurricane Days	4	5	7	7	19.25
Accumulated Cyclone Energy	75	100	135	135	226
Net Tropical Cyclone Activity	85	110	140	140	231

2018	5 April	Update 31 May	Update 2 July	Update 2 August	Obs.
Hurricanes	7	6	4	5	8
Named Storms	14	14	11	12	15
Hurricane Days	30	20	15	15	27.50
Named Storm Days	70	55	45	53	86.75
Major Hurricanes	3	2	1	1	2
Major Hurricane Days	7	4	2	2	5.25
Accumulated Cyclone Energy	130	90	60	64	133
Net Tropical Cyclone Activity	135	100	70	78	129