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

We have decreased our forecast and now believe that 2018 will have approximately average activity. While we still do not anticipate a significant El Niño during the 2018 Atlantic hurricane season, most of the North Atlantic has continued to anomalously cool over the past two months. The eastern and central tropical Atlantic is cooler than normal at present. We anticipate a near-average probability for major hurricanes making landfall along the United States coastline and in the Caribbean. 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 31 May 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

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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	Observed Activity Through May 2018	Total Seasonal Forecast (Including Alberto*)
Named Storms (NS) (12.0)	14	13	1	14
Named Storm Days (NSD) (60.1)	70	51.50	3.5	55
Hurricanes (H) (6.5)	7	6	0	6
Hurricane Days (HD) (21.3)	30	20	0	20
Major Hurricanes (MH) (2.0)	3	2	0	2
Major Hurricane Days (MHD) (3.9)	7	4	0	4
Accumulated Cyclone Energy (ACE) (92)	130	88	2	90
Net Tropical Cyclone Activity (NTC) (103%)	135	97	3	100

*Subtropical Storm Alberto formed prior to the official start of the Atlantic hurricane season on June 1.

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

1) Entire continental U.S. coastline – 51% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida – 30% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 29% (average for last century is 30%)

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

1) 41% (average for last century is 42%)

ABSTRACT

Information obtained through May 2018 indicates that the 2018 Atlantic hurricane season will have activity near the median 1981-2010 season. This is a decrease in our forecast from what was predicted in early April.

We estimate that 2018 will have an additional 6 hurricanes (median is 6.5), 13 named storms (median is 12.0), 51.50 named storm days (median is 60.1), 20 hurricane days (median is 21.3), 2 major (Category 3-4-5) hurricanes (median is 2.0) and 4 major hurricane days (median is 3.9). The probability of U.S. major hurricane landfall is estimated to be near the long-period average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2018 to be near their long-term median values.

This forecast is based on an extended-range early June statistical prediction scheme that was developed using 29 years of past data. Analog predictors are also utilized. While we still believe that the odds of a significant El Niño in 2018 are relatively low, most of the tropical Atlantic has anomalously cooled over the past two months. The far North Atlantic remains colder than normal, potentially indicative of a negative phase of the Atlantic Multi-Decadal Oscillation (AMO). Negative phases of the AMO tend to be associated with overall less conducive conditions for Atlantic hurricane activity due to higher tropical Atlantic surface pressures, drier mid-levels of the atmosphere and increased sinking motion.

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 June. 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 June statistical forecast methodology shows strong evidence over 29 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, 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, Brian McNoldy, Art Douglas, Ray Zehr, Mark DeMaria, Todd Kimberlain, Paul Roundy, Jason Dunion 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.

Indian Ocean Dipole (IOD) - An irregular oscillation of sea surface temperatures between the western and eastern tropical Indian Ocean. A positive phase of the IOD occurs when the western Indian Ocean is anomalously warm compared with the eastern Indian Ocean.

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 major hurricanes form, which we define as 7.5-22.5°N, 75-20°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.

Proxy – An approximation or a substitution for a physical process that cannot be directly measured.

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, 57.5-15°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 June forecast is based on a statistical methodology that was developed on 29 years of past data (1982-2010). The forecast model has also shown skill in seasonal ACE forecasts issued from 2011-2017.

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.

2 June Forecast Methodology

2.1 June Statistical Forecast Scheme

Our current June statistical forecast model was built over the period from 1982-2010 to incorporate more recent data where a denser observational network was available. It uses total of four predictors. The Climate Forecast System Reanalysis (CFSR) (Saha et al. 2010) has been completed from 1979-2010, with a continuation of CFS version 2 data through until present, while the NOAA Optimum Interpolation (OI) SST (Reynolds et al. 2002) is available from 1982-present. This 1 June TC forecast model shows significant skill in predicting levels of Accumulated Cyclone Energy (ACE) activity over the 36-year period from 1982-2017. This hindcast model correlates with ACE at 0.74 during this period.

Figure 2 displays the locations of each of our predictors, while Table 1 displays the individual linear correlations between each predictor and ACE from 1982-2017. All predictors correlate significantly at the 95% level using a two-tailed Student's t-test and assuming that each year represents an individual degree of freedom. We are incorporating a dynamical SST forecast from the European Centre for Medium-Range Weather Forecasts (ECMWF). Hindcast data provided by Frederic Vitart indicates that the ECMWF model has significant forecast skill for SSTs across the various Nino regions for September from a 1 May forecast date. We utilize the ECMWF ensemble mean prediction for the following September Nino 3 SSTs. Table 2 displays the 2018 observed values for each of the four predictors in the new statistical forecast scheme. The combination of the four predictors calls for a below-average season. Table 3 displays the statistical model output for the combination of the four predictors for the 2018 Atlantic hurricane season.

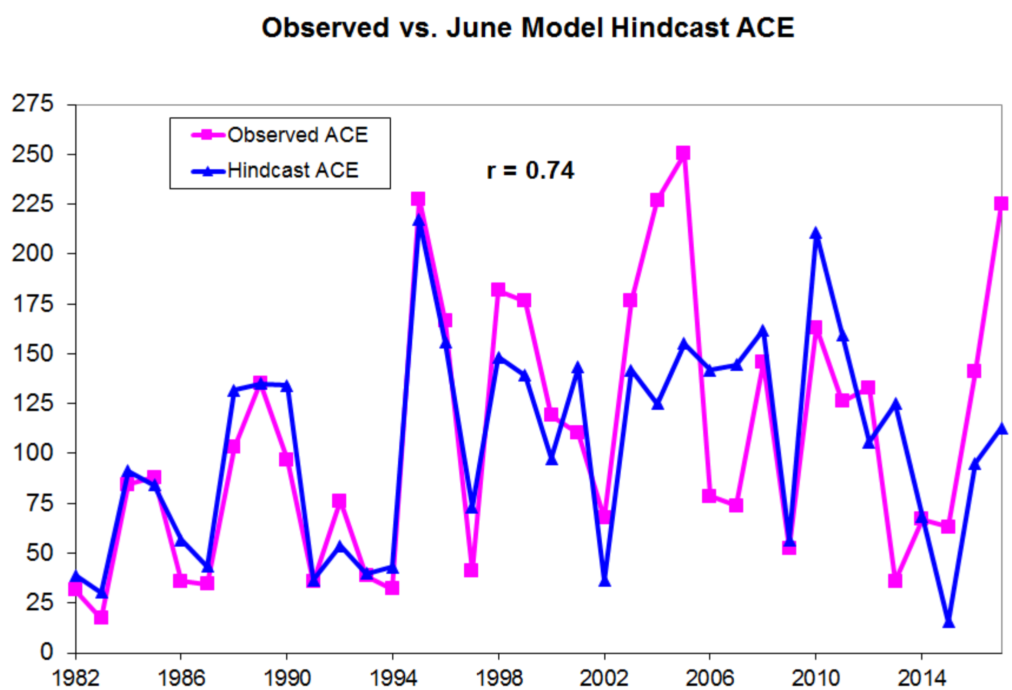

Figure 1: Observed versus early June hindcast values of ACE for 1982-2017. The hindcast model explains approximately 55% of the variance from climatology.

June Forecast Predictors

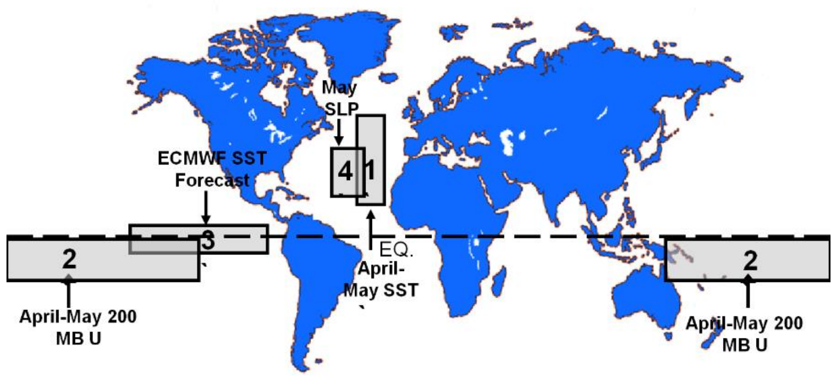

Figure 2: Location of predictors for our early June extended-range statistical prediction for the 2018 hurricane season. Predictor 2 spans both sides of the International Date Line.

Table 1: Linear correlation between each 1 June predictor and ACE from 1982-2017. For more ACE activity, the sign of predictors 1 and 2 should be positive, while the sign of predictors 3 and 4 should be negative.

Predictor	**Correlation w/ ACE**
1) April-May SST (15-55°N, 15-35°W) (+)	0.56
2) April-May 200 MB U (0-15°S, 150°E-120°W) (+)	0.46
3) ECMWF 1 May SST Forecast for September Nino 3 (5°S-5°N, 90-150°W) (-)	-0.42
4) May SLP (20-40°N, 30-50°W) (-)	-0.47

Table 2: Listing of 1 June 2018 predictors for the 2018 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity. The combination of the four predictors calls for a below-average Atlantic hurricane season. SD stands for standard deviations.

Predictor	**2018 Forecast Value**
1) April-May SST (15-55°N, 15-35°W) (+)	-0.9 SD
2) April-May 200 MB U (0-15°S, 150°E-120°W) (+)	+1.3 SD
3) ECMWF 1 May SST Forecast for September Nino 3 (5°S-5°N, 90-150°W) (-)	+0.6 SD
4) May SLP (20-40°N, 30-50°W) (-)	+2.4 SD

Table 3: Statistical model output for the 2018 Atlantic hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	Statistical Forecast
Named Storms (12.0)	9.2
Named Storm Days (60.1)	41.3
Hurricanes (6.5)	4.9
Hurricane Days (21.3)	16.9
Major Hurricanes (2.0)	1.7
Major Hurricane Days (3.9)	3.3
Accumulated Cyclone Energy Index (92)	69
Net Tropical Cyclone Activity (103%)	78

2.2 Physical Associations among Predictors Listed in Table 1

The locations and brief descriptions of the predictors for the early June statistical forecast are now discussed. All of these factors are generally related to August-October vertical wind shear in the Atlantic Main Development Region (MDR) from 10-20°N, 20-70°W as shown in Figure 3.

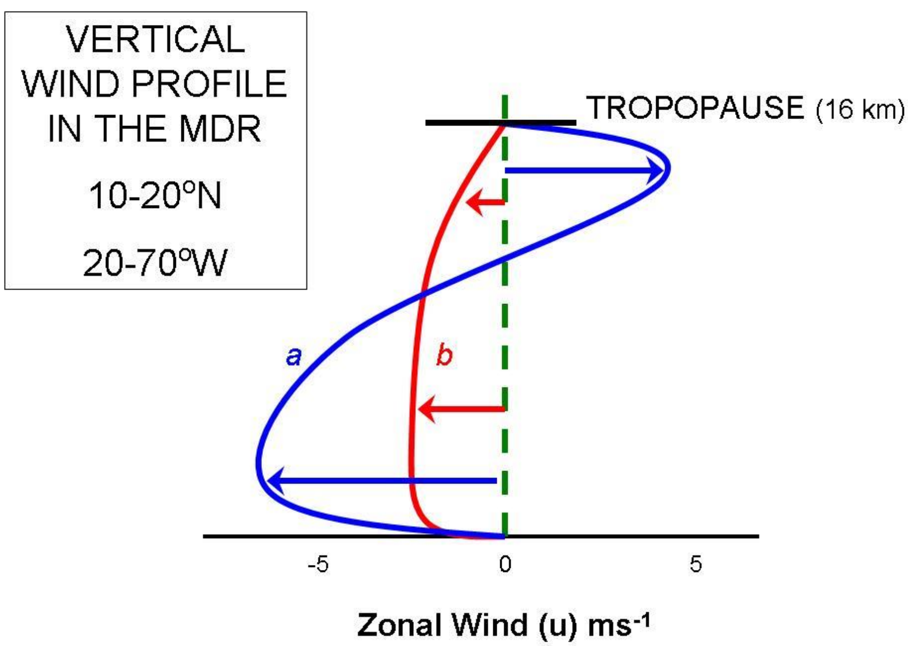

Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of tropospheric vertical wind shear.

For each of these predictors, we display a four-panel figure showing linear correlations between values of each predictor and August-October values of sea surface temperature (SST), sea level pressure, 200 mb zonal wind, and 850 mb zonal wind, respectively. In general, higher values of SSTs, lower values of SLPA, anomalous westerlies at 850 mb and anomalous easterlies at 200 mb are associated with active Atlantic basin hurricane seasons. SST correlations are displayed using the NOAA Optimum Interpolation (OI) SST, while SLP, 850 mb, and 200 mb zonal wind correlations are displayed using the Climate Forecast System Reanalysis (CFSR).

Predictor 1. April-May SST in the Eastern Atlantic (+)

(15-55°N, 15-35°W)

Warmer-than-normal SSTs in the eastern Atlantic during the April-May period are associated with a weaker-than-normal subtropical high and reduced trade wind strength during the boreal spring (Knaff 1997). Positive SST anomalies in April-May are correlated with weaker trade winds and weaker upper tropospheric westerly winds, lower-than-normal sea level pressures and above-normal SSTs in the tropical Atlantic during the following August-October period (Figure 4). All three of these August-October features are commonly associated with active Atlantic basin hurricane seasons, through reductions in vertical wind shear, increased vertical instability and increased mid-tropospheric moisture, respectively. Predictor 1 correlates quite strongly (~0.55) with ACE. Predictor 1 also strongly correlates ($r = 0.65$) with August-October values of the Atlantic Meridional Mode (AMM) (Kossin and Vimont 2007) over the period from 1982-2010. The AMM has been shown to impact Atlantic hurricane activity through alterations in the position and intensity of the Atlantic Inter-Tropical Convergence Zone (ITCZ). Changes in the Atlantic ITCZ bring about changes in tropical Atlantic vertical and horizontal wind shear patterns and in tropical Atlantic SST patterns.

Predictor 2. April-May 200-mb zonal winds in the south-central Tropical Pacific (+)

(0-15°S, 150°E-120°W)

Anomalous upper-level westerly zonal winds in the south-central tropical Pacific are typically associated with ongoing La Niña conditions and a strong Walker Circulation. The spring months are the climatologically favored time for ENSO events to transition from one phase to another (e.g., El Niño to La Niña or vice versa). If the atmosphere is strongly locked into the La Niña phase as evidenced by anomalously strong upper-level westerly winds, the odds of transitioning to an El Niño are reduced. Figure 5 shows that positive values of this predictor are also associated with favorable hurricane formation conditions in the tropical Atlantic, including above-average SSTs and below-average SLPs and zonal wind shear.

Predictor 3. ECMWF 1 May SST Forecast for September Nino 3 (-)

(5°S -5°N, 90-150°W)

The ECMWF seasonal forecast system 3 has shown skill at being able to forecast SST anomalies associated with ENSO several months into the future (Stockdale et al. 2011). ECMWF has since upgraded their seasonal forecast model to system 4. ENSO has been documented in many studies to be one of the primary factors associated with interannual fluctuations in Atlantic basin and U.S. landfalling hurricane activity (Gray 1984, Goldenberg and Shapiro 1996, Bove et al. 1998, Klotzbach 2011), primarily through alterations in vertical wind shear patterns. The ensemble-averaged ENSO forecast for September values of the Nino 3 region from a 1 May issue date correlates with observations at 0.81. When the ECMWF model predicts cool SST anomalies for September, it strongly correlates with observed cool anomalies throughout the tropical Pacific associated with La Niña conditions, as well as reduced vertical wind shear, especially across the Caribbean (Figure 6).

Predictor 4. May SLP in the central Atlantic (-)

(20-40°N, 30-50°W)

Low pressure during the month of May in the central Atlantic is associated with reduced trade wind strength across the tropical Atlantic. This reduced trade wind strength promotes reduced upwelling, mixing and enhances ocean current flow from the south, all of which favor the development or sustenance of warm anomalies in the tropical Atlantic. These warm anomalies tend to persist throughout the peak months of the hurricane season (Figure 7). Also, upper-level easterly anomalies in the Caribbean are associated with low values of this predictor.

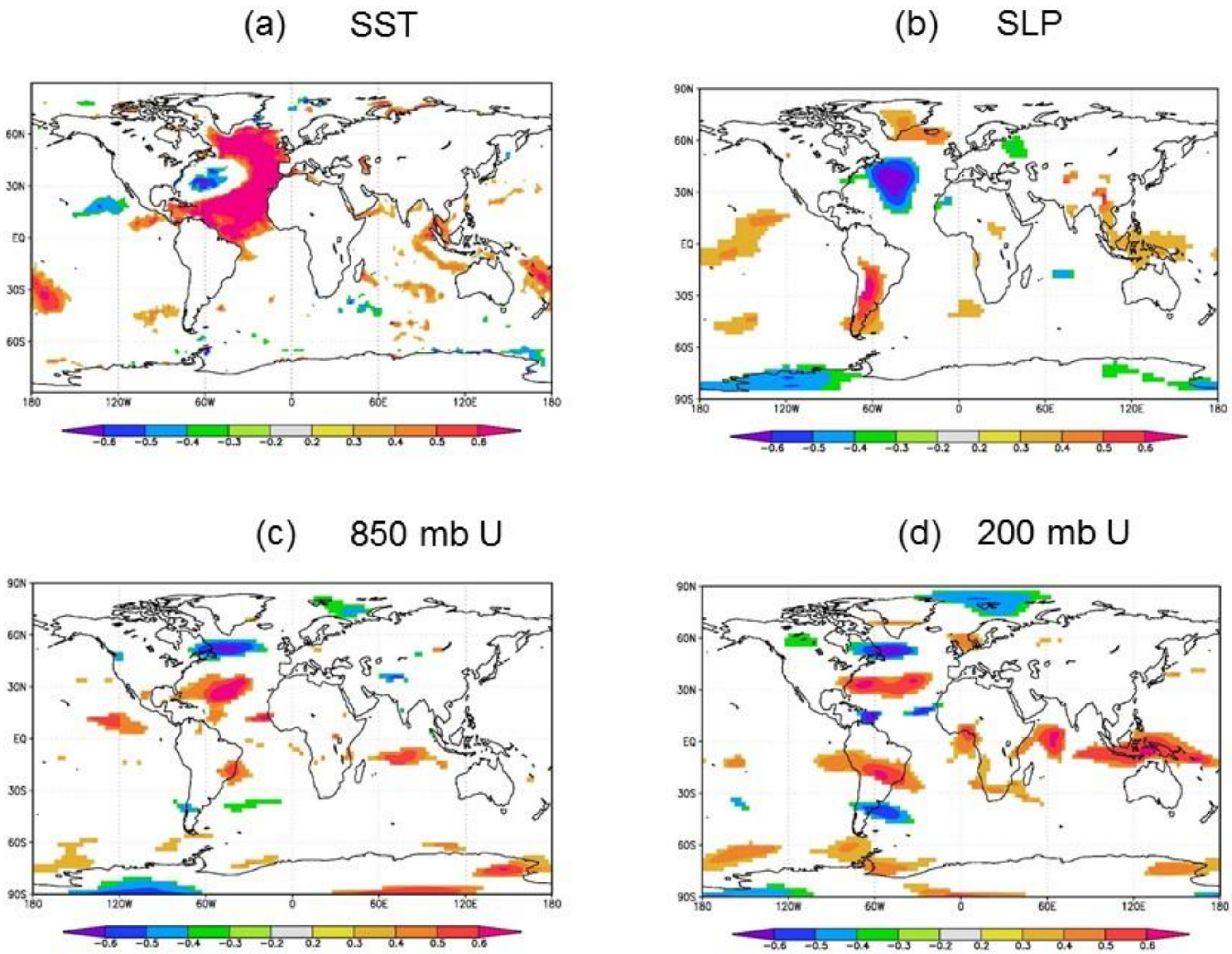

Figure 4: Linear correlations between April-May SST in the eastern Atlantic (Predictor 1) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following August-October 200 mb zonal wind (panel d). All four of these parameter deviations in the tropical Atlantic are known to be favorable for enhanced hurricane activity.

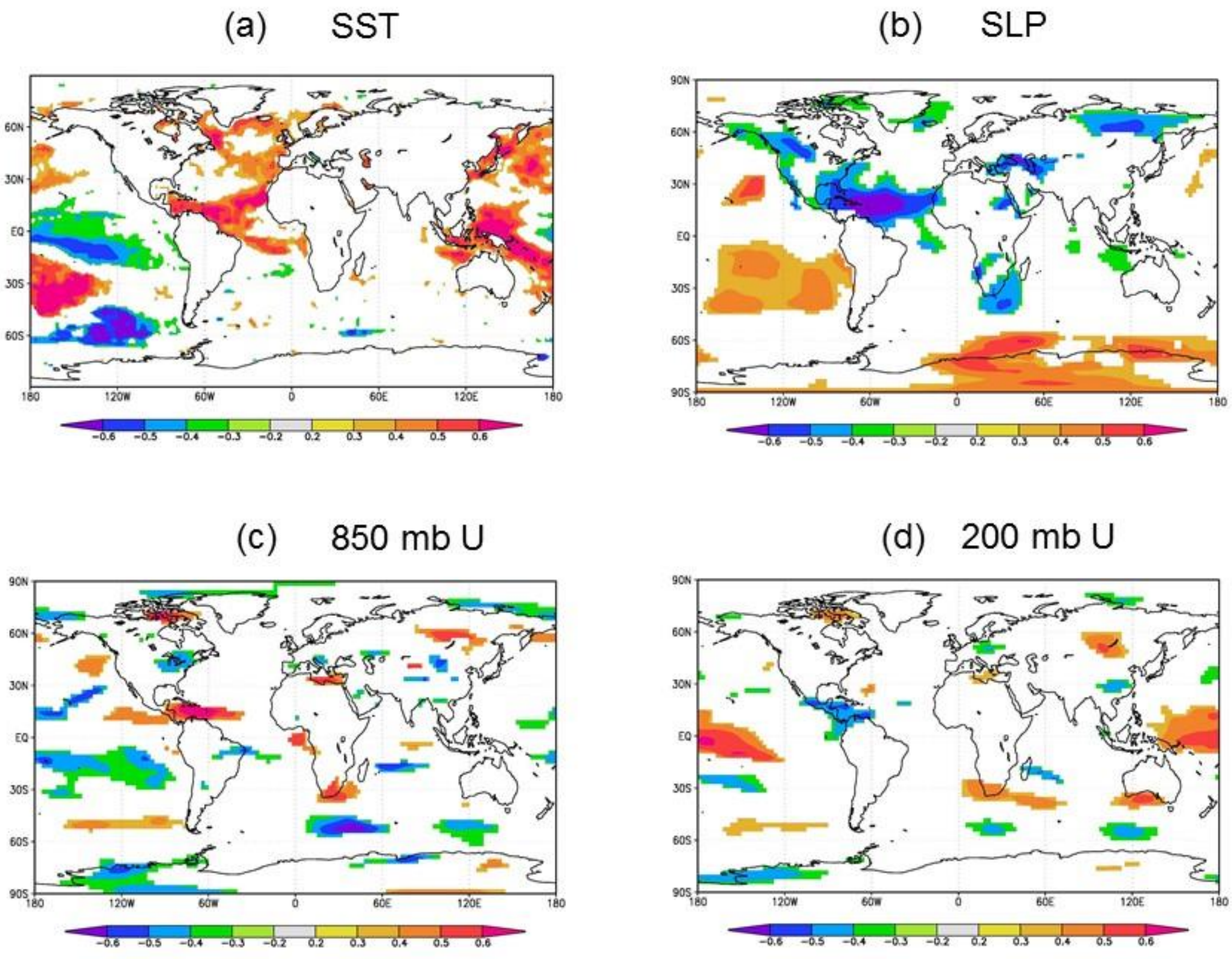

Figure 5: Linear correlations between April-May 200-mb zonal winds in the south-central tropical Pacific (Predictor 2) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following August-October 200 mb zonal wind (panel d). All of these parameter deviations over the tropical Atlantic and tropical Pacific tend to be associated with active hurricane seasons.

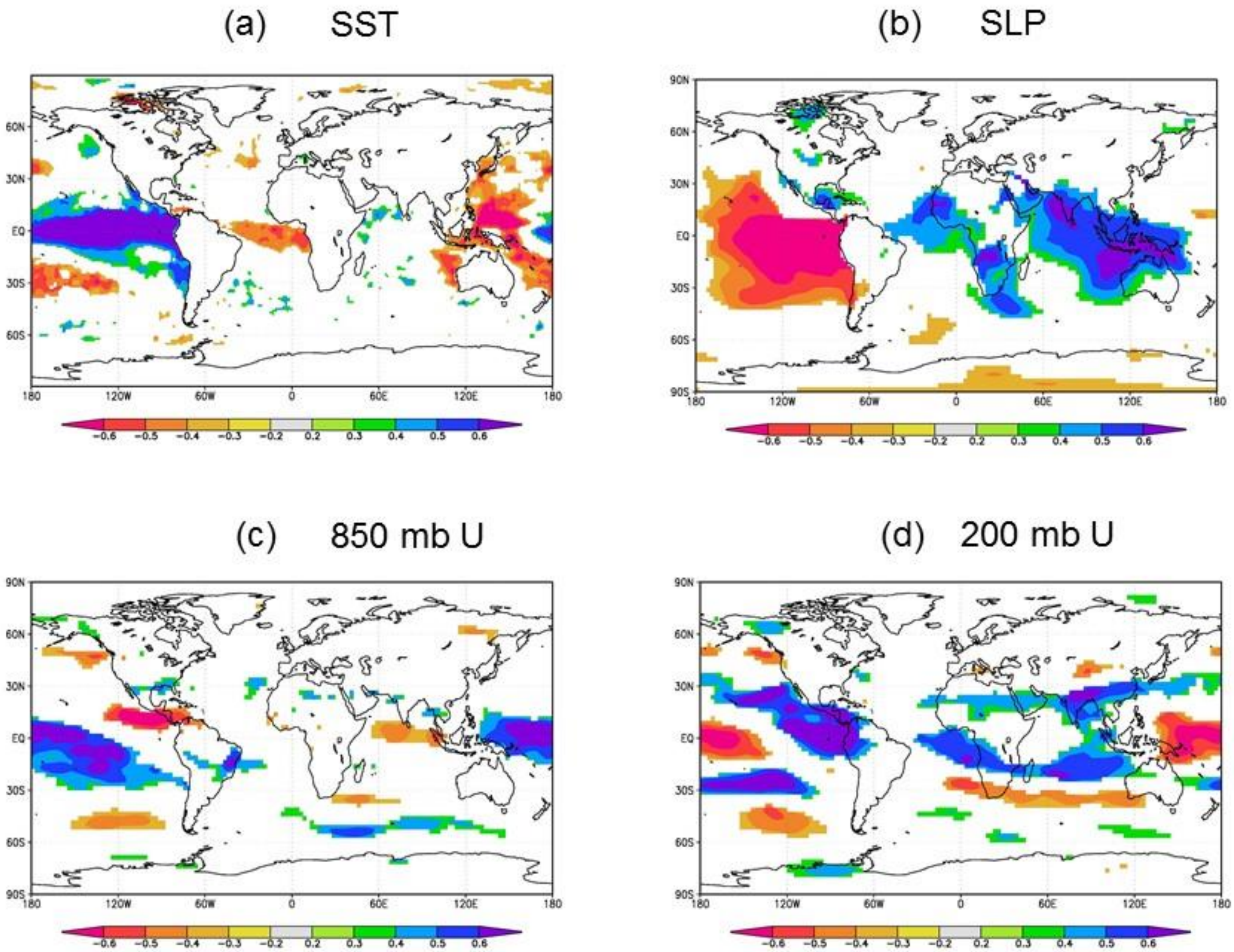

Figure 6: Linear correlations between a 1 May ECMWF SST forecast for September Nino 3 (Predictor 3) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following August-October 200 mb zonal wind (panel d). The predictor correlates very strongly with ENSO as well as vertical shear in the Caribbean. The correlation scale has been flipped to allow for easy comparison of correlations for all four predictors.

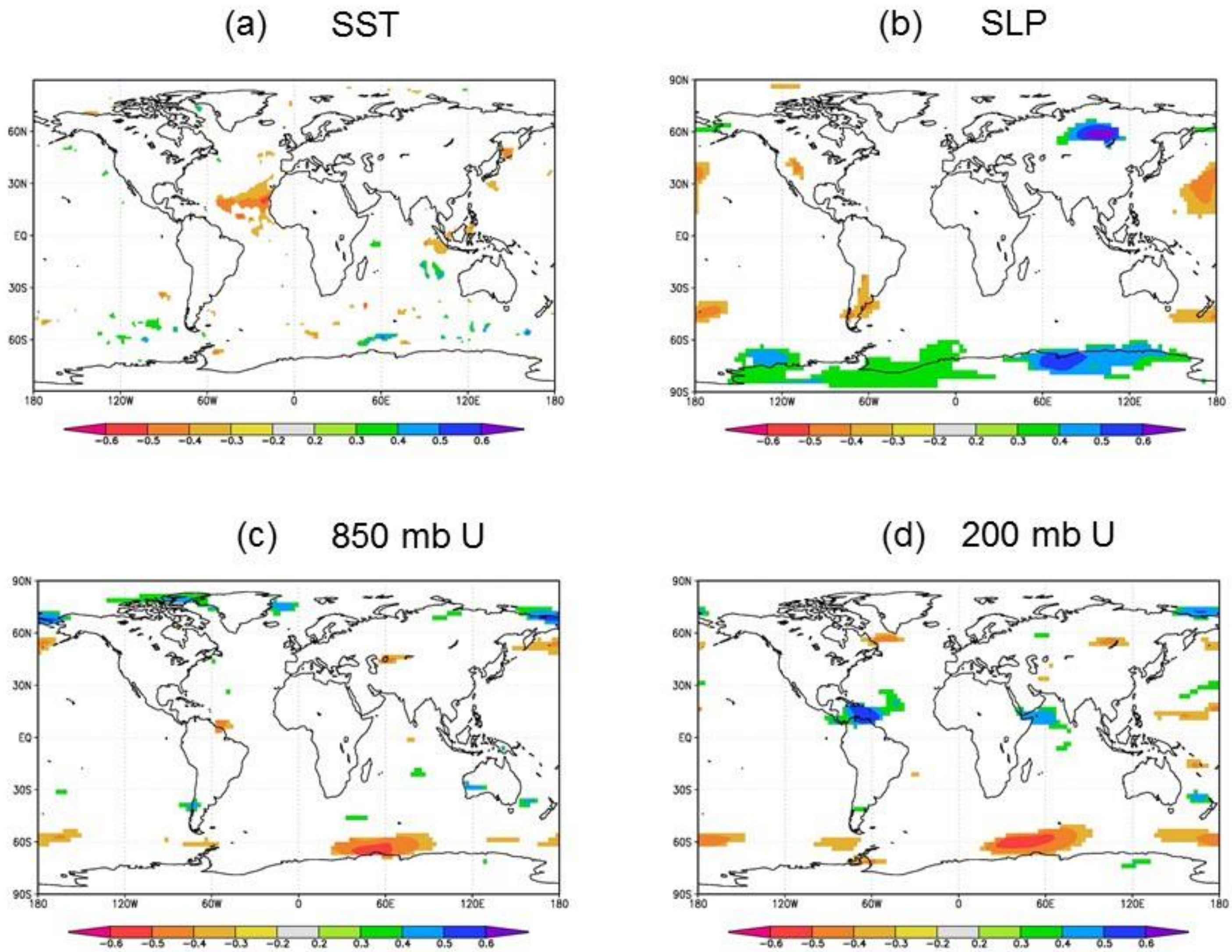

Figure 7: Linear correlations between May sea level pressure in the central Atlantic (Predictor 4) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following August-October 200 mb zonal wind (panel d). The correlation scale has been flipped to allow for easy comparison of correlations for all four predictors.

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 4 provides our early June forecasts, with error bars based on one standard deviation of the 1982-2010 cross-validated hindcast error. 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 2018 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	2018 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	4	14	10 - 18
Named Storm Days (NSD)	21	55	34 – 76
Hurricanes (H)	2	6	4 - 8
Hurricane Days (HD)	10	20	10 – 30
Major Hurricanes (MH)	1	2	1 – 3
Major Hurricane Days (MHD)	4	4	0 – 8
Accumulated Cyclone Energy (ACE)	48	90	42 – 138
Net Tropical Cyclone (NTC) Activity	48	100	52 – 148

4 Analog-Based Predictors for 2018 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2018. These years also provide useful clues as to likely trends in activity that the forthcoming 2018 hurricane season may bring. For this early June extended range forecast, we determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current April-May 2018 conditions as well as predicted conditions for August-October. Table 5 lists our analog selections.

We selected prior hurricane seasons since 1950 which had similar atmospheric-oceanic conditions to those currently being experienced. We searched for years that were generally characterized by warm neutral ENSO and cool to near-average tropical Atlantic SSTs during the peak of the Atlantic hurricane from August-October.

There were four hurricane seasons since 1950 with characteristics most like what we expect to see in August-October of 2018. We anticipate that the 2018 hurricane season will have activity close to the average of our four analog years. We believe that this season should experience near-average activity.

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
1986	6	23.25	4	10.50	0	0.00	36	37
2001	15	69.75	9	25.50	4	4.25	110	135
2012	19	101.25	10	28.50	2	0.50	133	131
2014	8	35.00	6	17.75	2	3.75	67	82
Average	12.0	57.3	7.3	20.6	2.0	2.1	86	96
2018 Forecast	**14**	**55**	**6**	**20**	**2**	**4**	**90**	**100**

5 ENSO

Weak La Niña conditions were present during the winter of 2017/2018. SSTs have anomalous warmed across the central and eastern tropical Pacific over the past several months. Currently, the tropical Pacific is characterized by neutral El Niño-Southern Oscillation (ENSO) (between -0.5°C – 0.5°C SST anomalies) conditions. Upper ocean heat content (top 300 meters) anomalies have been increasing over the past several months, consistent with a transition away from La Niña. (Figure 8).

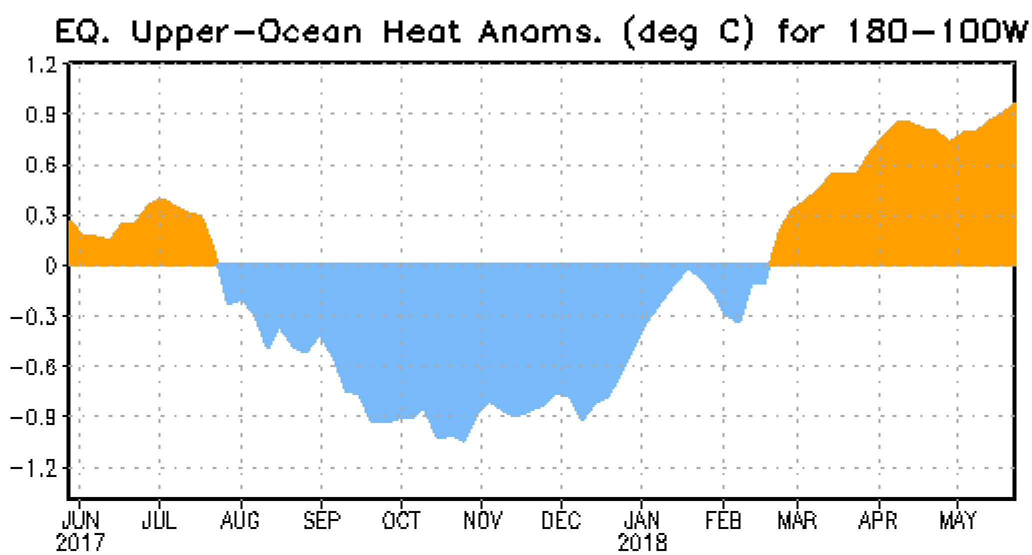

Figure 8: Central and eastern tropical Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Anomalies have generally been on an increasing trend since November.

Currently, SSTs are running near average across most of the eastern and central tropical Pacific. Table 6 displays March and May SST anomalies for several of the Nino regions. The eastern and central tropical Pacific has anomalously warmed over the two-month period (Figure 9). May SST anomalies generally reflect ENSO neutral conditions.

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

Region	March SST Anomaly (°C)	May SST Anomaly (°C)	May – March SST Anomaly (°C)
Nino 1+2	-0.8	-0.6	+0.2
Nino 3	-0.8	-0.2	+0.6
Nino 3.4	-0.7	-0.1	+0.6
Nino 4	-0.1	0.2	+0.3

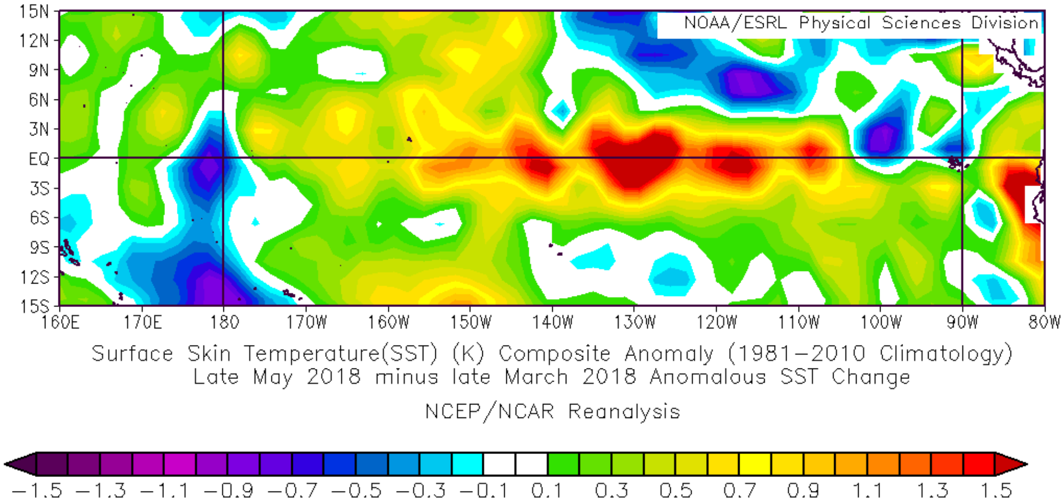

Figure 9: Late May minus late March SST anomaly changes across the tropical Pacific.

There is still considerable uncertainty as to what ENSO conditions will look like during the peak of the Atlantic hurricane season from August-October. The spring months are known for their ENSO predictability barrier. While we are nearing the end of this predictability barrier, considerable changes in ENSO often take place in June and July. Both statistical and dynamical models show improved skill by the end of May for the August-October period when compared with their skill at the end of March. These models show even better skill by the end of June and July. Most of the dynamical model guidance is either calling for warm neutral or weak El Niño conditions by the peak of the Atlantic hurricane season from August to October (Figure 10).

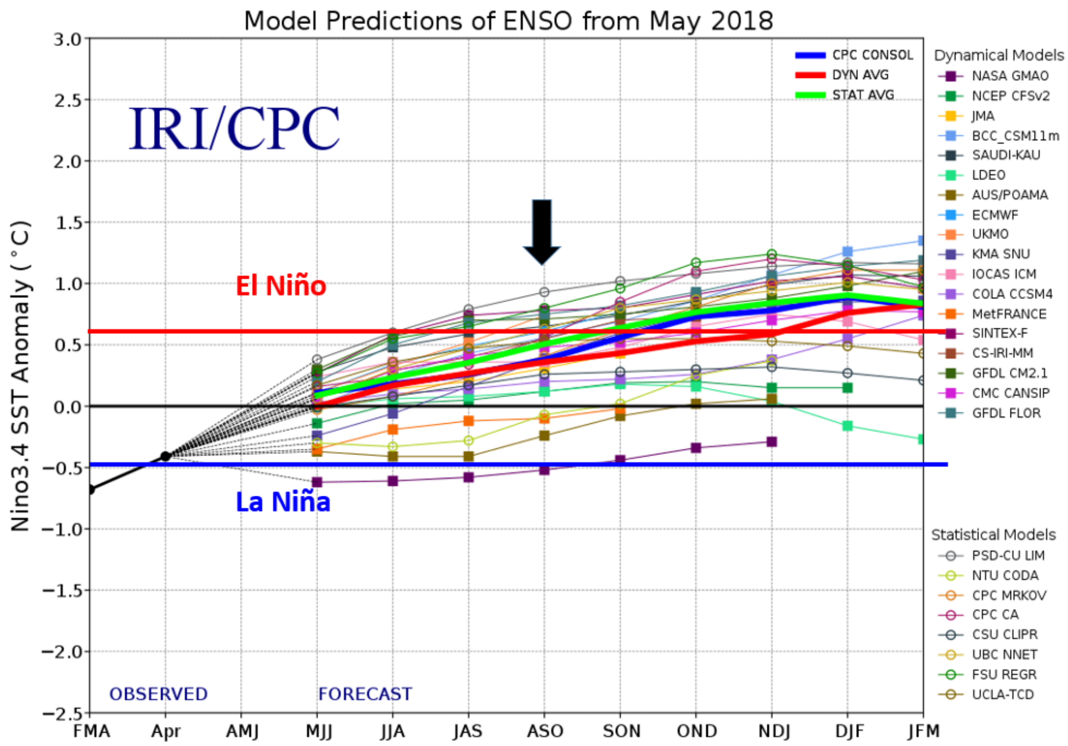

Figure 10: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI). Most dynamical models call for either warm neutral ENSO or weak El Niño conditions over the next several months.

We find that, in general, the European Centre for Medium-Range Weather Forecasts (ECMWF) shows the best prediction skill of the various individual ENSO models. The average of the various ECMWF ensemble members is calling for a September Nino 3.4 SST anomaly of approximately +0.6°C, which would classify as a weak El Niño event. There is a fairly wide spread in the outcomes predicted by the various ensemble members, which indicates the large degree of uncertainty in future ENSO conditions (Figure 11).

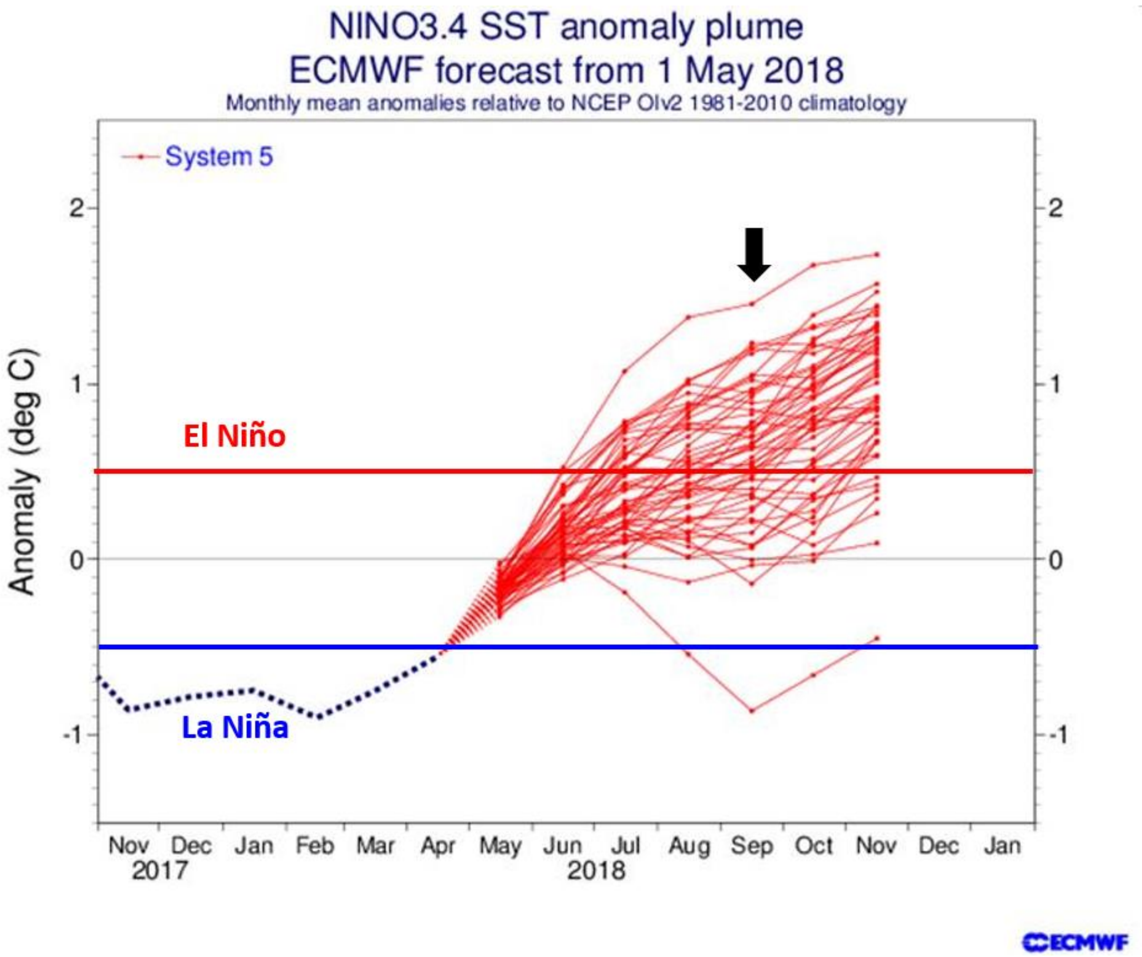

Figure 11: ECMWF ensemble model forecast for the Nino 3.4 region.

Currently, our best estimate is that warm neutral ENSO conditions will be present during the peak of the Atlantic hurricane season from August to October. Several downwelling (warming) Kelvin waves have occurred over the past six months which have triggered anomalous warming across the eastern and central tropical Pacific (Figure 12). However, enhanced trade winds look to dominate the central tropical Pacific over the next couple of weeks (Figure 13), preventing any additional downwelling Kelvin wave generation – at least in the short-term. After that point, the Climate Forecast System (CFS) model is hinting that there may be some weakening of the trade winds associated with the passing of the convectively-enhanced phase of the Madden-Julian Oscillation (MJO); however, uncertainty in MJO propagation more than two weeks into the future is quite large. Consequently, our best estimate is that we will see continued slow anomalous warming in the eastern and central tropical Pacific throughout the Atlantic hurricane season, but we do not anticipate a significant El Niño event by the peak of the season.

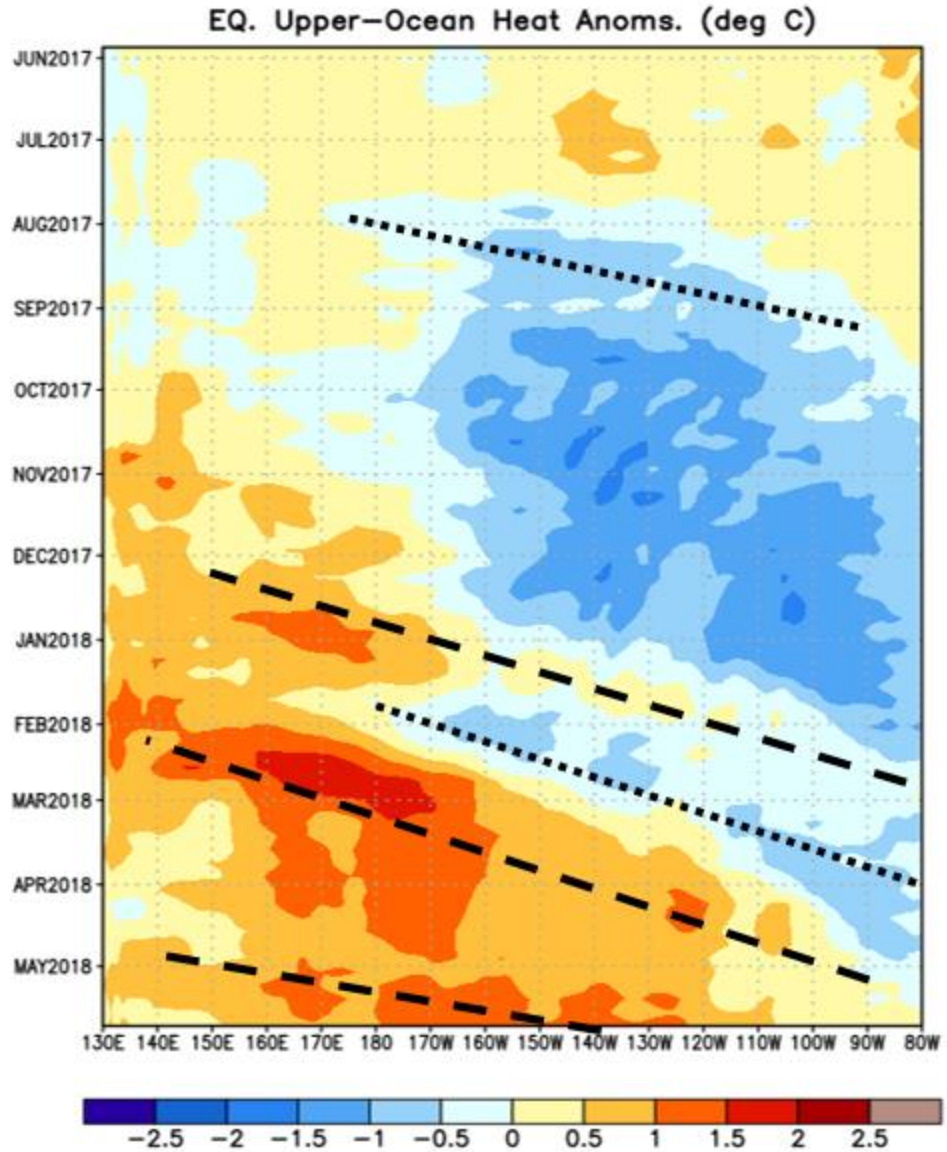

Figure 12: Upper-ocean heat content anomalies across the tropical Pacific. Note that the entire tropical Pacific is presently characterized by slightly above-normal heat content anomalies. Dashed lines represent the warming (downwelling) phase of the Kelvin wave, while the dotted lines represent the cooling (upwelling) phase of the Kelvin wave.

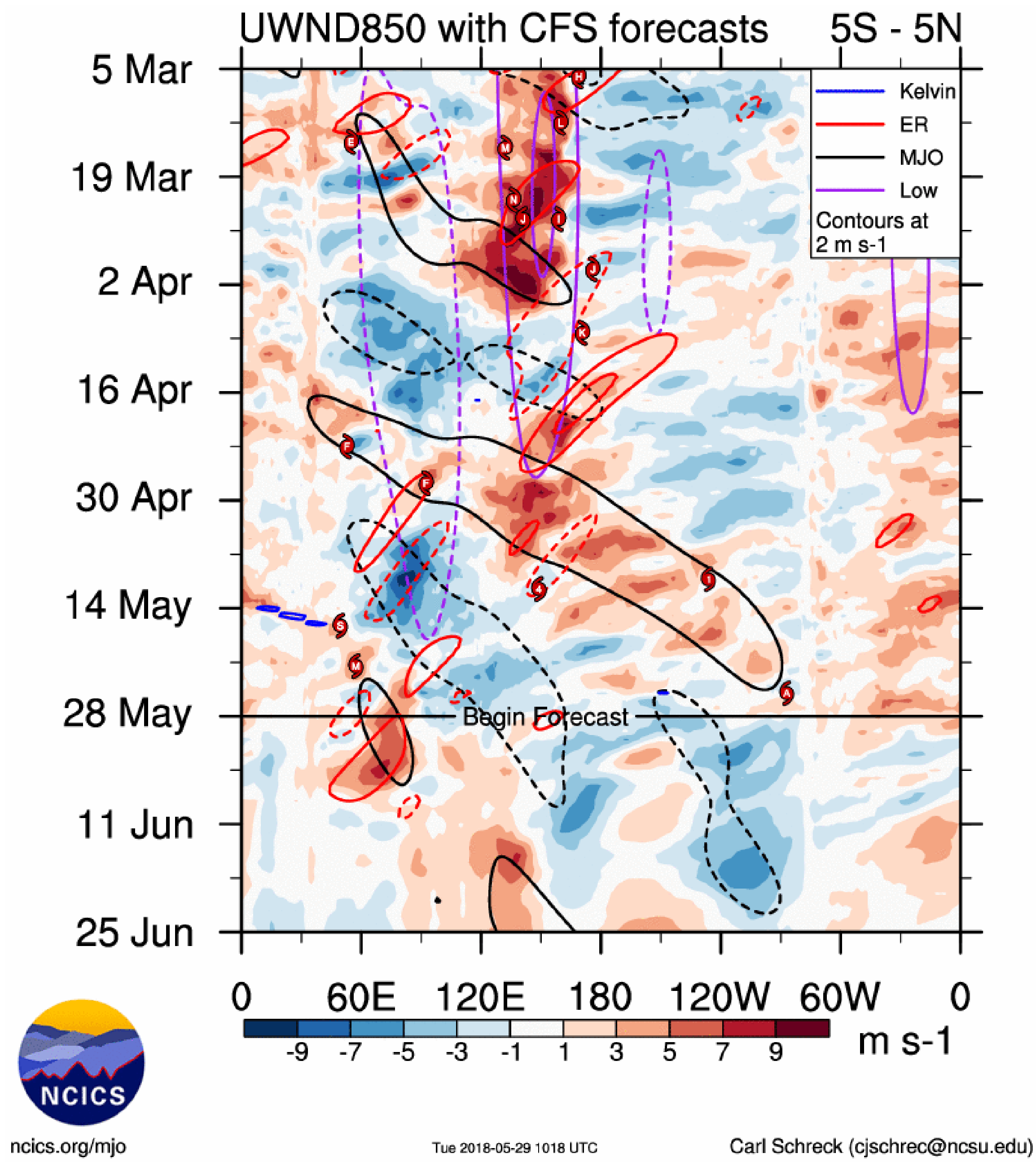

Figure 13: Observed and CFS-predicted low-level winds across the equatorial tropical Pacific.

6 Current Atlantic Basin Conditions

The current SST anomaly pattern across the North Atlantic is not conducive for an active hurricane season (Figure 14). The current SST anomaly pattern features cold anomalies in the far North Atlantic, warm anomalies off of the U.S. East Coast, and cold anomalies in the subtropical eastern Atlantic extending into the tropical Atlantic. In May, positive anomalies in the far North Atlantic, subtropical eastern Atlantic and tropical Atlantic tend to be associated with active Atlantic hurricane seasons (Figure 15).

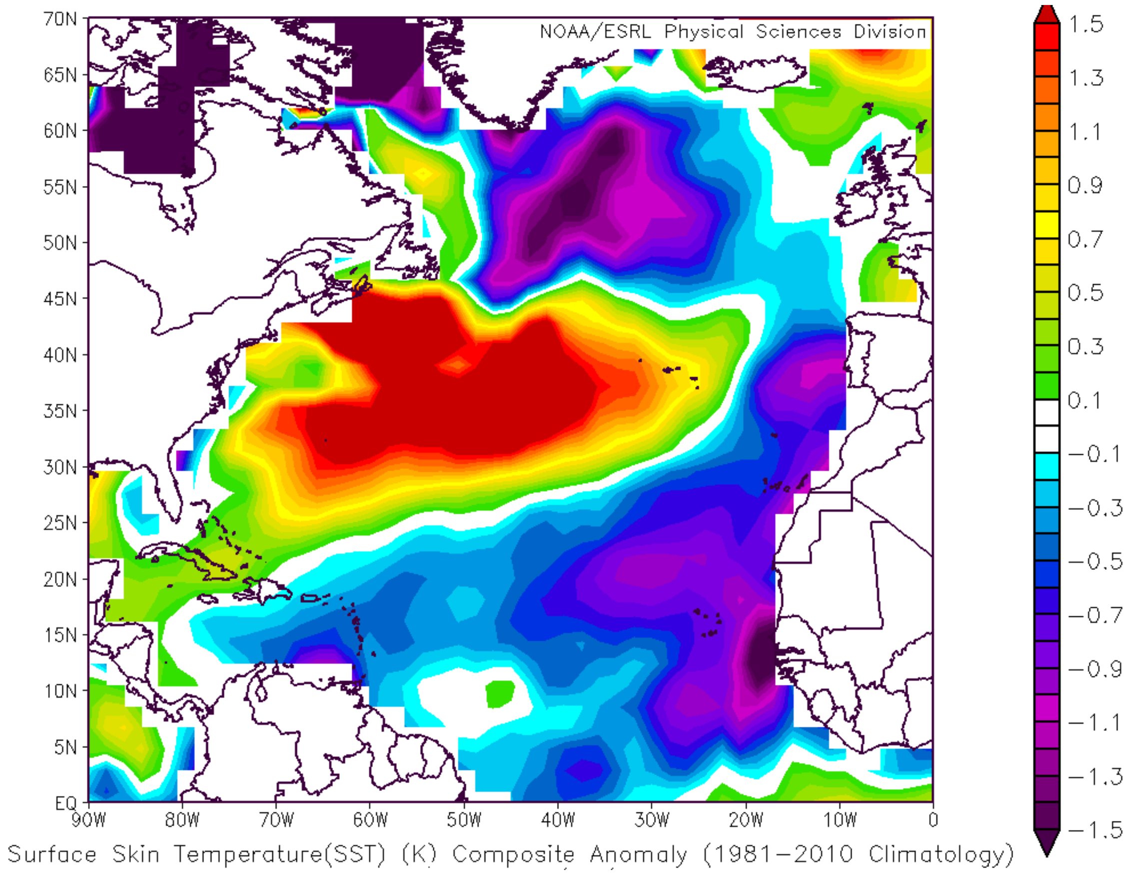

Figure 14: May 1, 2018 to May 27, 2018-averaged SST anomalies across the Atlantic.

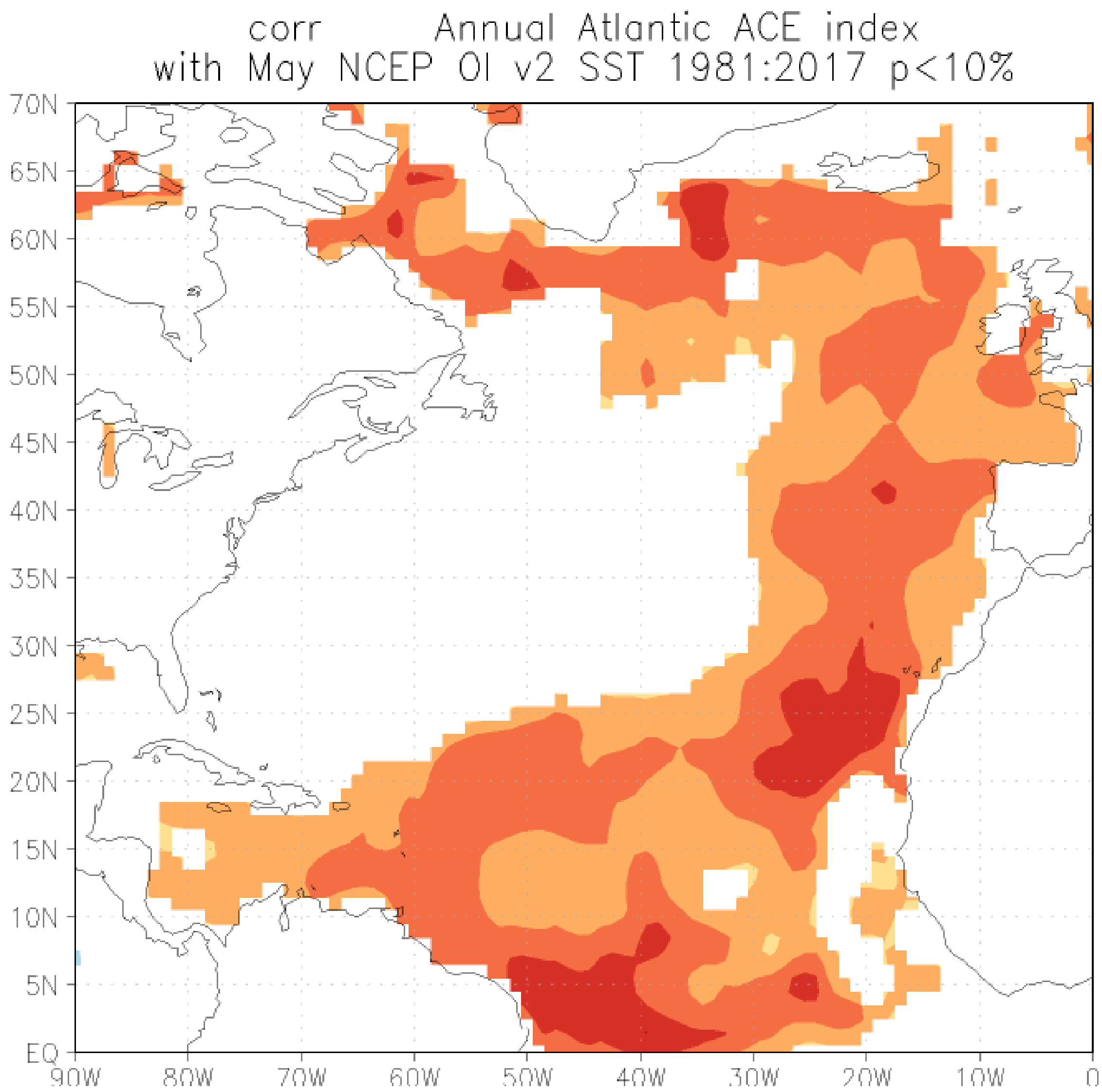

Figure 15: Correlation between seasonal Atlantic ACE and May North Atlantic SSTs over the period from 1981-2017. Note that the strongest correlations are in the far North Atlantic, the subtropical eastern Atlantic and eastern tropical Atlantic.

Over the past two months, SSTs have continued to anomalously warm off of the U.S. East Coast and anomalously cool along the west coast of Africa extending into the tropical Atlantic (Figure 16). Overall, the SST anomaly pattern now is less conducive for an active Atlantic hurricane season than was present in late March. The likely driver of the anomalous SST pattern that we currently observe is the anomalous sea level pressure (SLP) pattern that has been present during April and May (Figure 17). The anomalously strong subtropical high over the eastern and central Atlantic drove anomalous northerly flow (and hence cooling) on its eastern periphery and anomalous southerly flow (and hence warming) on its western periphery over most of the past two months. In addition, a strong subtropical high forces anomalously strong trades which promote cooling over the tropical Atlantic due to enhanced evaporation, mixing and upwelling.

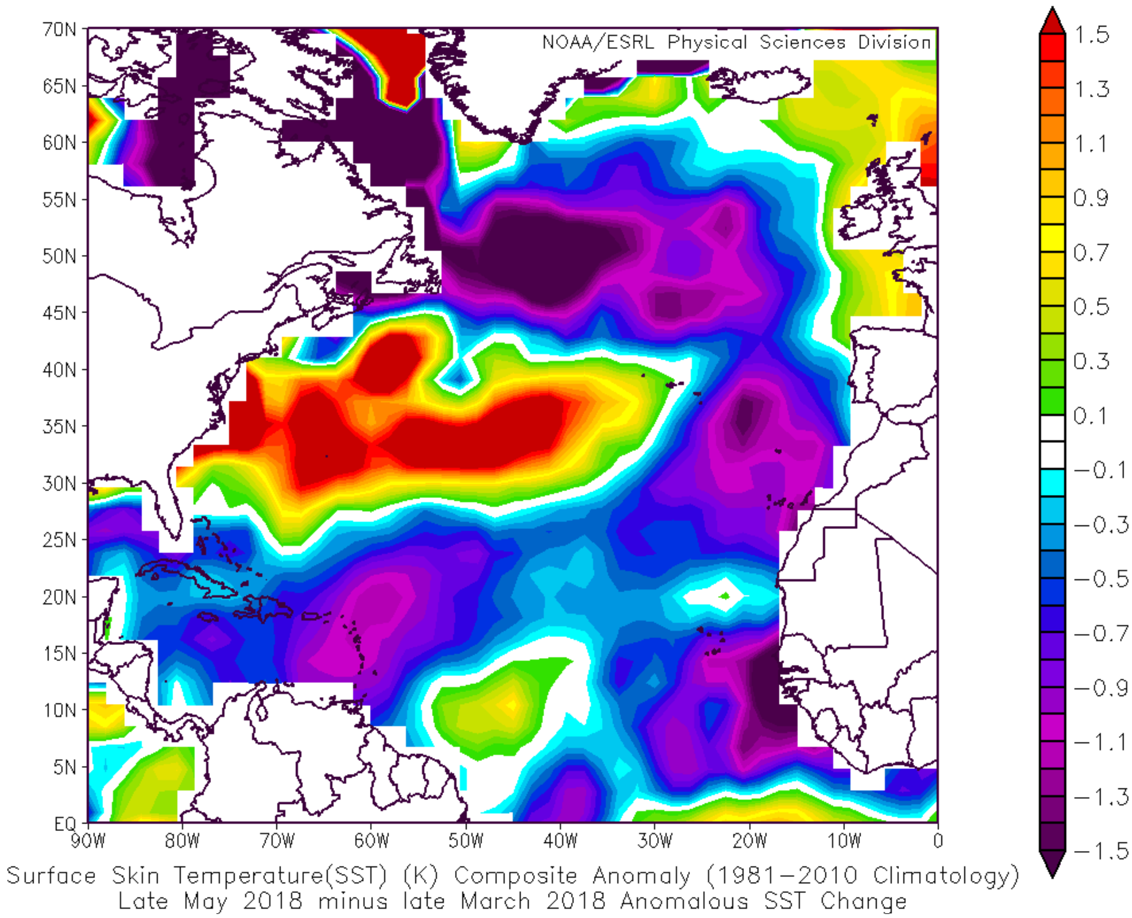

Figure 16: Late May 2018 minus late March 2018 SST anomaly change across the North Atlantic.

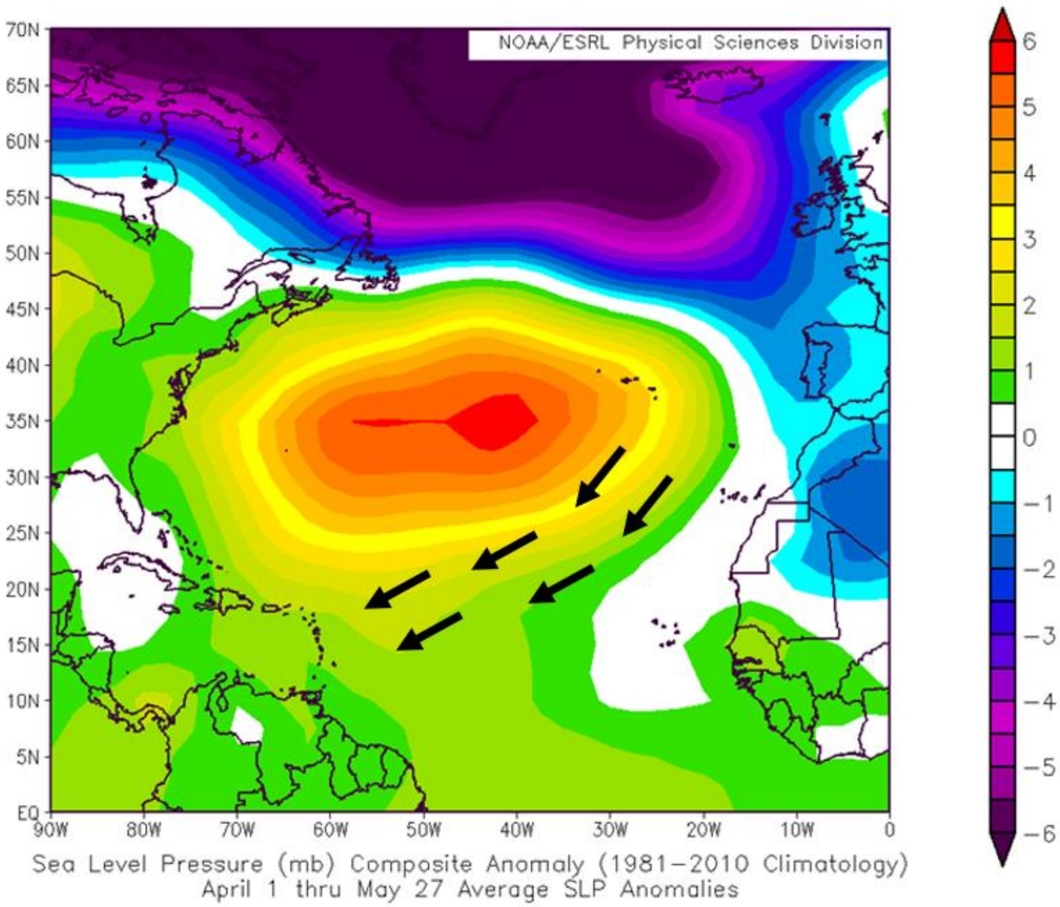

Figure 17: April 1, 2018 to May 27, 2018-averaged SLP anomalies across the North Atlantic.

7 Current THC/AMO Strength

One of the big questions that has been asked over the past several years is whether we have moved out of the active Atlantic hurricane era   This question became even more muddled after the extremely active 2017 North Atlantic hurricane season. 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 18). This index was discussed in detail in Klotzbach and Gray (2008).   The recent weakening of the THC has also been noted in several recent papers including Caesar et al. (2018).

We currently weigh standardized values of the index by using the following formula: 0.6*SST – 0.4*SLP. The AMO has generally been negative since 2014, although the index has typically been more positive during the summer months than during the winter months. Given both the cold SST anomalies in the far North Atlantic and the high SLP anomalies observed in the subtropical Atlantic in May of 2018, we estimate that this month's AMO index will be quite negative.

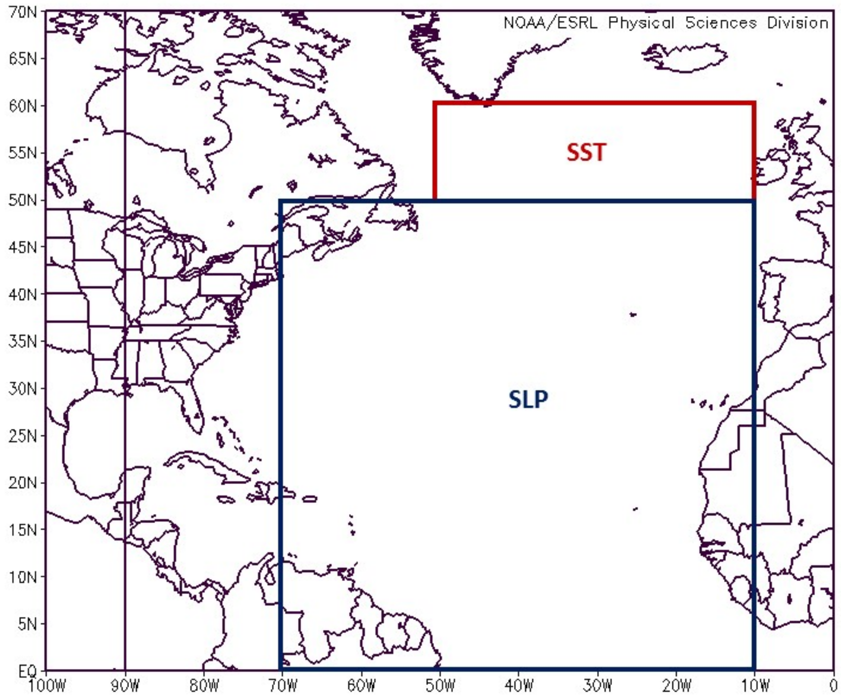

Figure 18: Regions which are utilized for the calculation of our AMO index.

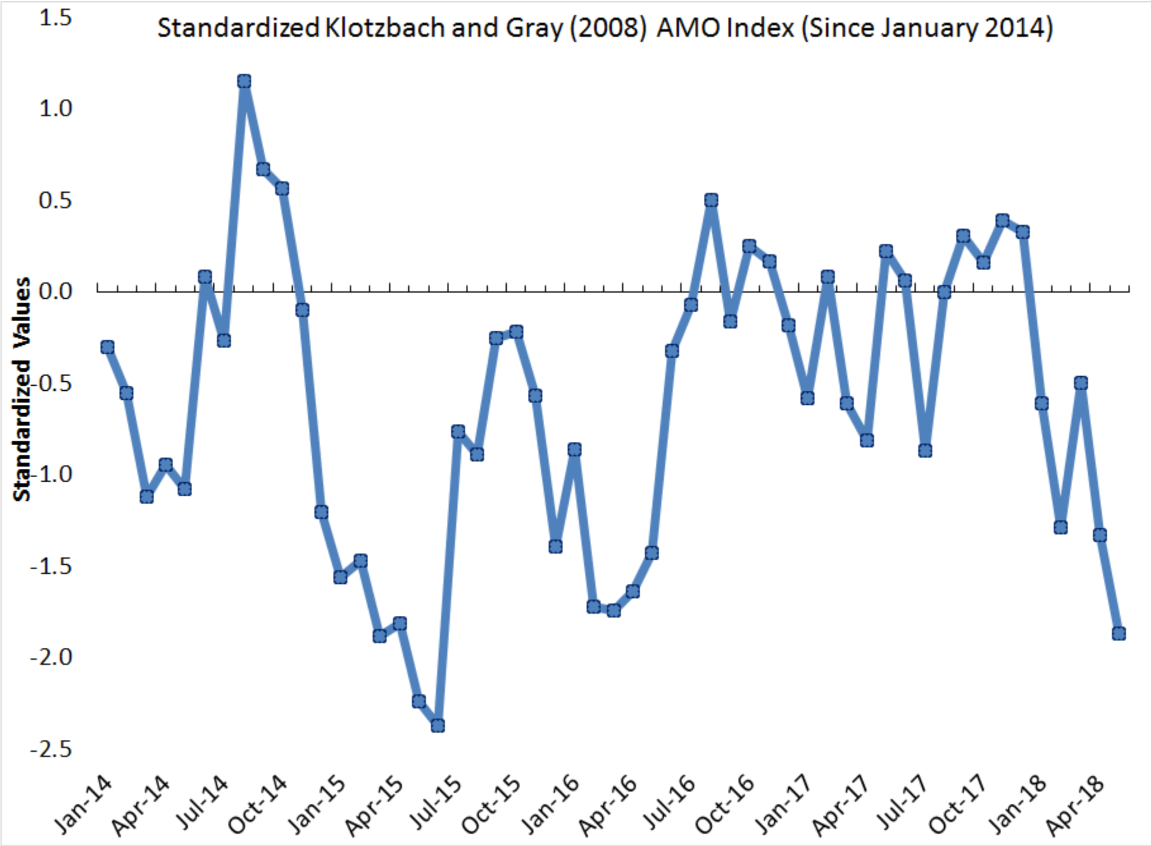

Figure 19: Monthly values of the Klotzbach and Gray (2008) AMO index since January 2014. May 2018's value is estimated with data through May 27. The final May value will be posted online in a couple of days.

8 Adjusted 2018 Forecast

Table 7 shows our final adjusted early June forecast for the 2018 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. Our statistical model is now calling for a below-average season, while our analog scheme calls for near-average activity. We have lowered our seasonal forecast due primarily to anomalous cooling in the tropical Atlantic. If the tropical Atlantic were to remain anomalously cool or if El Niño were to develop unexpectedly, the seasonal forecast would be lowered with our July or August updates. However, if the tropical Atlantic were to anomalously warm and the tropical Pacific were to remain neutral, the seasonal forecast could be increased in future updates.

Table 7: Summary of our early June statistical forecast, our analog forecast and our adjusted final forecast for the 2018 hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	Statistical Scheme	Analog Scheme	Adjusted Final Forecast (Including Alberto)
Named Storms (12.0)	9.2	12.0	14
Named Storm Days (60.1)	41.3	57.3	55
Hurricanes (6.5)	4.9	7.3	6
Hurricane Days (21.3)	16.9	20.6	20
Major Hurricanes (2.0)	1.7	2.0	2
Major Hurricane Days (3.9)	3.3	2.1	4
Accumulated Cyclone Energy Index (92)	69	86	90
Net Tropical Cyclone Activity (103%)	78	96	100

9 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 percentage deviation from average. 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 continental U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula. We also now issue probabilities for various islands and landmasses in the Caribbean and in Central America. Note that Atlantic basin NTC activity in 2018 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 continental U.S. coastline, along the Gulf Coast (Regions 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11) for 2018. 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 last 100 years 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)	78% (79%)	67% (68%)	51% (52%)	84% (84%)	96% (97%)
Gulf Coast (Regions 1-4)	57% (59%)	41% (42%)	29% (30%)	59% (60%)	82% (83%)
Florida plus East Coast (Regions 5-11)	49% (50%)	43% (44%)	30% (31%)	60% (61%)	80% (81%)
Caribbean (10-20°N, 60-88°W)	81% (82%)	56% (57%)	41% (42%)	74% (75%)	95% (96%)

10 Forthcoming Updated Forecasts of 2018 Hurricane Activity

We will be issuing seasonal updates of our 2018 Atlantic basin hurricane forecasts on **Monday 2 July and Thursday 2 August**. We will also be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August-October. A verification and discussion of all 2018 forecasts will be issued in late November 2018. All of these forecasts will be available on our website.

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12 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