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

We anticipate that the 2018 Atlantic basin hurricane season will have slightly above-average activity. The current weak La Niña event appears likely to transition to neutral ENSO over the next several months, but at this point, we do not anticipate a significant El Niño event this summer/fall. The western tropical Atlantic is anomalously warm right now, while portions of the eastern tropical Atlantic and far North Atlantic are anomalously cool. Consequently, our Atlantic Multi-decadal Oscillation index is near its long-term average. We anticipate a slightly above-average probability for major hurricanes making landfall along the continental 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 5 April 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
Named Storms (NS) (12.0)	14
Named Storm Days (NSD) (60.1)	70
Hurricanes (H) (6.5)	7
Hurricane Days (HD) (21.3)	30
Major Hurricanes (MH) (2.0)	3
Major Hurricane Days (MHD) (3.9)	7
Accumulated Cyclone Energy (ACE) (92)	130
Net Tropical Cyclone Activity (NTC) (103%)	135

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 - 63% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 39% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 38% (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) 52% (average for last century is 42%)

ABSTRACT

Information obtained through March 2018 indicates that the 2018 Atlantic hurricane season will have activity slightly above the median 1981-2010 season. We estimate that 2018 will have 7 hurricanes (median is 6.5), 14 named storms (median is 12.0), 70 named storm days (median is 60.1), 30 hurricane days (median is 21.3), 3 major (Category 3-4-5) hurricane (median is 2.0) and 7 major hurricane days (median is 3.9). The probability of U.S. major hurricane landfall is estimated to be about 120 percent of the long-period average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2018 to be approximately 135 percent of their long-term averages.

This forecast is based on an extended-range early April statistical prediction scheme that was developed using 29 years of past data. Analog predictors are also utilized. The current weak La Niña event appears likely to transition to neutral ENSO over the next several months, but at this point, we do not anticipate a significant El Niño this summer/fall. The western tropical Atlantic is anomalously warm right now, while portions of the eastern tropical Atlantic and the far North Atlantic are anomalously cool. There is considerably uncertainty as to what the configuration of Atlantic sea surface temperatures will look like for the peak of the Atlantic hurricane season.

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.

The early April forecast is the earliest seasonal forecast issued by Colorado State University and has modest long-term skill when evaluated in hindcast mode. The skill of CSU’s forecast updates increases as the peak of the Atlantic hurricane season approaches.

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 April. 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 April 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 April forecast is based on a statistical methodology derived from 29 years of past data. 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 April Forecast Methodology

2.1 April Statistical Forecast Scheme

Our current April statistical forecast model was built over the period from 1982-2010 to incorporate the most recent and reliable data that is available. It uses a total of four predictors. The Climate Forecast System Reanalysis (CFSR) (Saha et al. 2010) was completed from 1979-2010, and the CFS model's analysis is available from 2011-present to continue this dataset in realtime. The NOAA Optimum Interpolation (OI) SST

(Reynolds et al. 2002) is available from 1982-present. This new model showed significant skill in predicting levels of Accumulated Cyclone Energy (ACE) over the 1982-2010 developmental period. The model correlates with ACE at 0.54 from 1982-2017.

Figure 2 displays the locations of each of our predictors, while Table 1 displays the individual linear correlations between each predictor and ACE over the 1982-2010 hindcast period. All predictors correlate significantly at the 90% level using a two-tailed Student's t-test and assuming that each year represents an individual degree of freedom. Table 2 displays the 2018 observed values for each of the four predictors in the statistical forecast scheme. Table 3 displays the statistical model output for the 2018 hurricane season. Two of the four predictors are favorable for Atlantic hurricane activity, one is neutral, and one (the ECMWF forecast for ENSO) is negative for Atlantic hurricane activity.

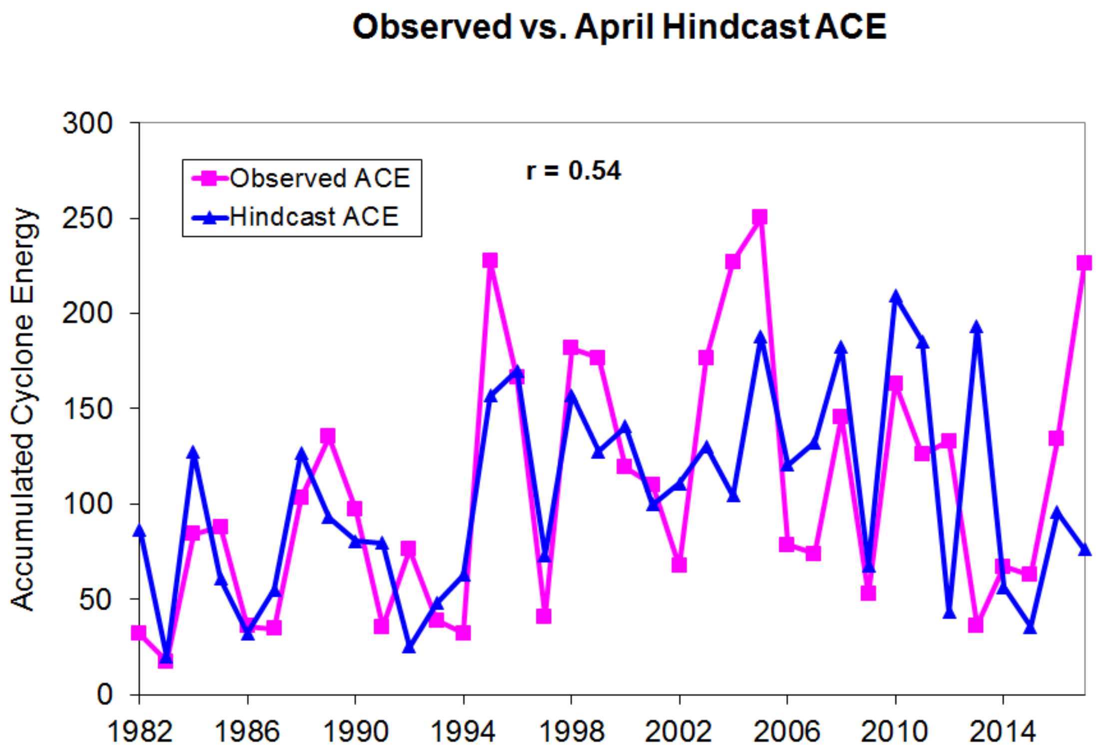

Figure 1: Observed versus early April hindcast values of ACE for 1982-2010 along with real-time forecast values for 2011-2017.

April Forecast Predictors

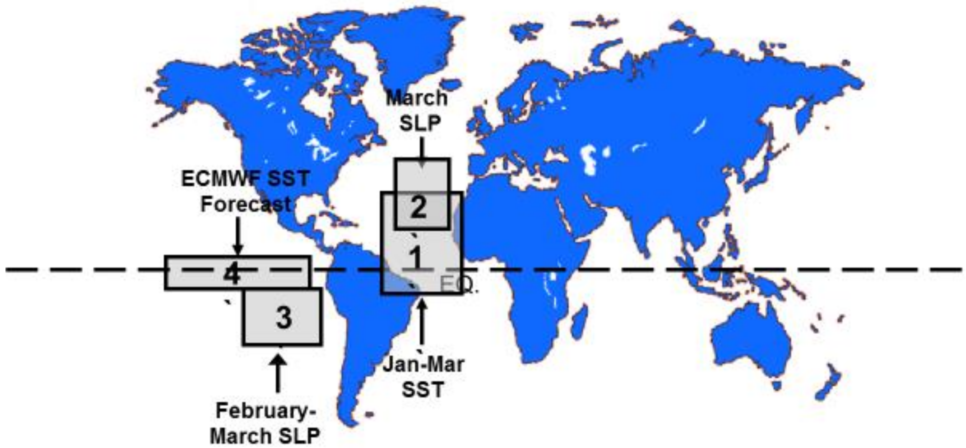

Figure 2: Location of predictors for our early April extended-range statistical prediction for the 2018 hurricane season.

Table 1: Linear correlation between each 1 April predictor and ACE over the period from 1982-2010.

Predictor	Correlation w/ ACE
1) January-March Atlantic SST (5°S-35°N, 10-40°W) (+)	0.56
2) March SLP (20-40°N, 20-35°W) (-)	-0.42
3) February-March SLP (5-20°S, 85-120°W) (+)	0.33
4) ECMWF 1 March SST Forecast for September Nino 3 (5°S-5°N, 90-150°W) (-)	-0.42

Table 2: Listing of 1 April 2018 predictors for the 2018 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity.

Predictor	2018 Forecast Value	Impact on 2018 TC Activity
1) Jan-Mar Atlantic SST (5°S-35°N, 10-40°W) (+)	-0.1 SD	Neutral
2) Mar SLP (20-40°N, 20-35°W) (-)	-0.6 SD	Increase
3) Feb-Mar SLP (5-20°S, 85-120°W) (+)	+0.7 SD	Increase
4) ECMWF 1 Mar SST Forecast for Sep Nino 3 (5°S-5°N, 90-150°W) (-)	+0.9 SD	Decrease

Table 3: Statistical model output for the 2018 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1981-2010 Median (in parentheses)	Statistical Forecast	Final Forecast
Named Storms (12.0)	11.6	14
Named Storm Days (60.1)	59.6	70
Hurricanes (6.5)	6.8	7
Hurricane Days (21.3)	27.7	30
Major Hurricanes (2.0)	3.1	3
Major Hurricane Days (3.9)	7.5	7
Accumulated Cyclone Energy Index (92)	115	130
Net Tropical Cyclone Activity (103%)	125	135

2.2 Physical Associations among Predictors Listed in Table 2

The locations and brief descriptions of the predictors for our early April statistical forecast are now discussed. It should be noted that all predictors correlate with physical features during August through October that are known to be favorable for elevated levels of hurricane activity. These factors are all generally related to August-October vertical wind shear in the Atlantic Main Development Region (MDR) from 10-20°N, 70-20°W as shown in Figure 3.

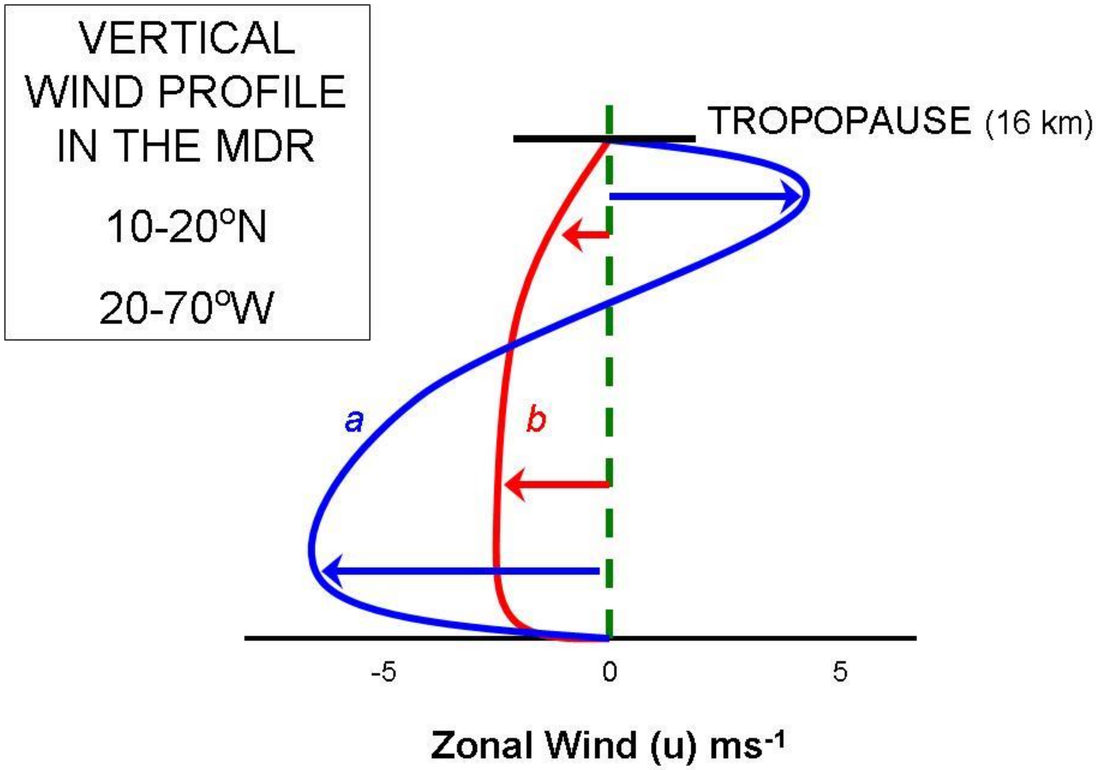

Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.

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 (SLP), 200 mb zonal wind, and 850 mb zonal wind, respectively. In general, higher values of SSTs, lower values of SLP, 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, SLP and 850 mb zonal wind correlations are displayed using the Climate Forecast System Reanalysis (CFSR), while 200 mb zonal wind correlations are displayed using the NCEP/NCAR Reanalysis, as there are questions about the quality of the upper-level wind reanalysis during the 1980s in the CFSR.

<u>Predictor 1. January-March SST in the Tropical and Subtropical Eastern Atlantic (+)</u>

(5°S-35°N, 40-10°W)

Warmer-than-normal SSTs in the tropical and subtropical Atlantic during the January-March time period are associated with a weaker-than-normal subtropical high and reduced trade wind strength during the boreal spring (Knaff 1997). Positive SSTs in January-March 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 (~0.6) 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. March SLP in the Subtropical Atlantic (-)

(20-40°N, 35-20°W)

Our April statistical scheme in the late 1990s used a similar predictor when evaluating the strength of the March Atlantic sub-tropical ridge (Azores High). If the pressure in this area is higher than normal, it correlates strongly with increased Atlantic trade winds. These stronger trades enhance ocean mixing and upwelling, driving cooler tropical Atlantic SSTs. These cooler SSTs are associated with higher-than-normal sea level pressures which can create a self-enhancing feedback that relates to higher pressure, stronger trades and cooler SSTs during the hurricane season (Figure 5) (Knaff 1998). All three of these factors are associated with inactive hurricane seasons.

Predictor 3. February-March SLP in the southeastern tropical Pacific (+)

(5-20°S, 120-85°W)

High pressure in the southeastern tropical Pacific during the months of February-March correlates strongly with a positive Southern Oscillation Index and strong trades blowing across the eastern tropical Pacific. Strong trade winds help prevent eastward propagating Kelvin waves from transporting warmth from the western Pacific warm pool region and triggering El Niño conditions. During the August-October period, positive values of this predictor are associated with weaker trades and lower sea level pressures in the tropical Atlantic and relatively cool SST anomalies in the eastern Pacific (typical of La Niña conditions) (Figure 6). The combination of these features is typically associated with more active hurricane seasons.

Predictor 4. ECMWF 1 March SST Forecast for September Nino 3 (-)

(5°S -5°N, 150-90°W)

The ECMWF seasonal forecast system 4 has shown skill at being able to predict SST anomalies associated with ENSO several months into the future (Stockdale et al. 2011). 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 March forecast date for system 4 correlates with observations at 0.63, which is impressive considering that this forecast goes through the springtime predictability barrier, where fluctuations in ENSO lead to greatly reduced forecast skill. 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 7). System 5, the latest ensemble prediction system recently released by ECMWF, has slightly improved ENSO prediction skill from system 4.

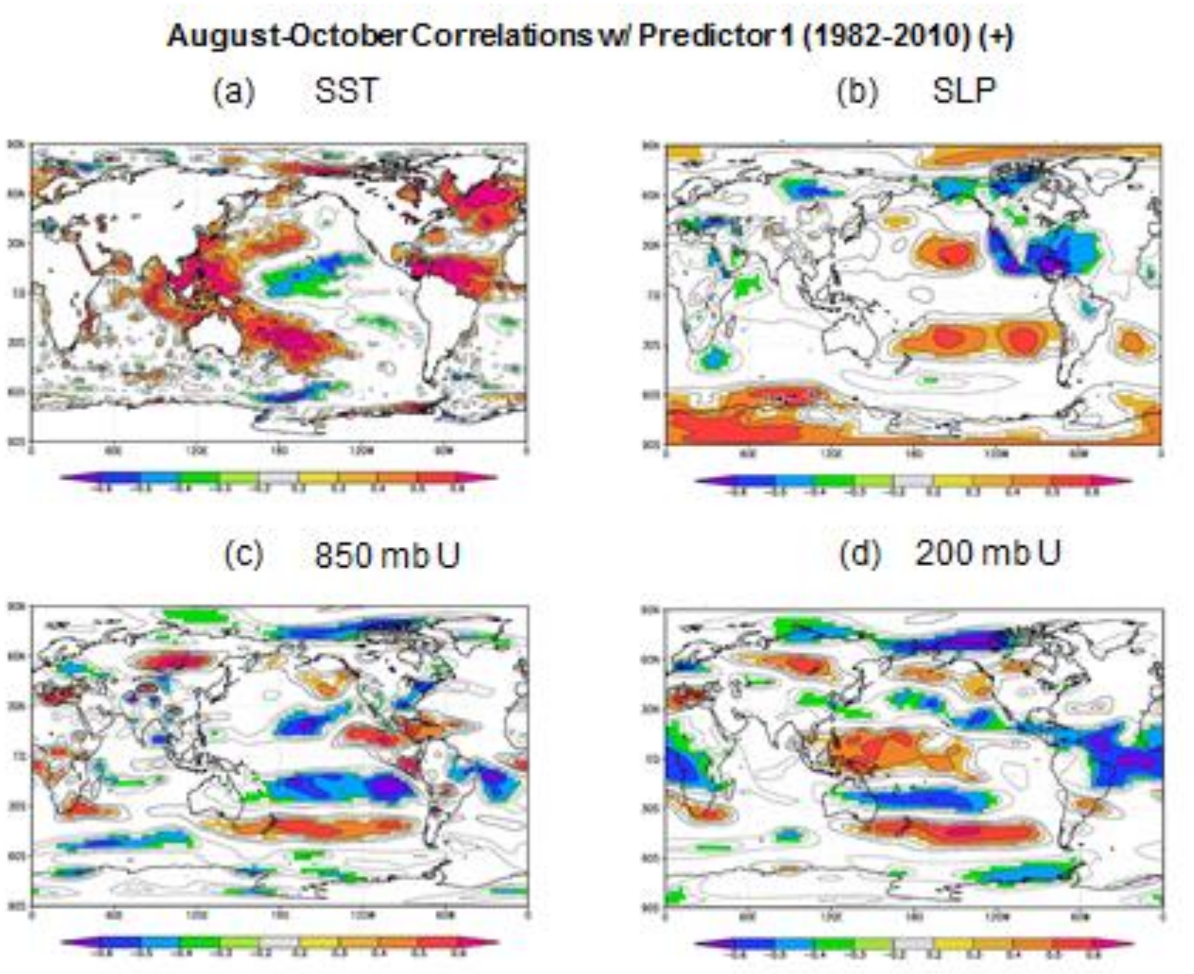

Figure 4: Linear correlations between January-March SST in the tropical and subtropical Atlantic (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d).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

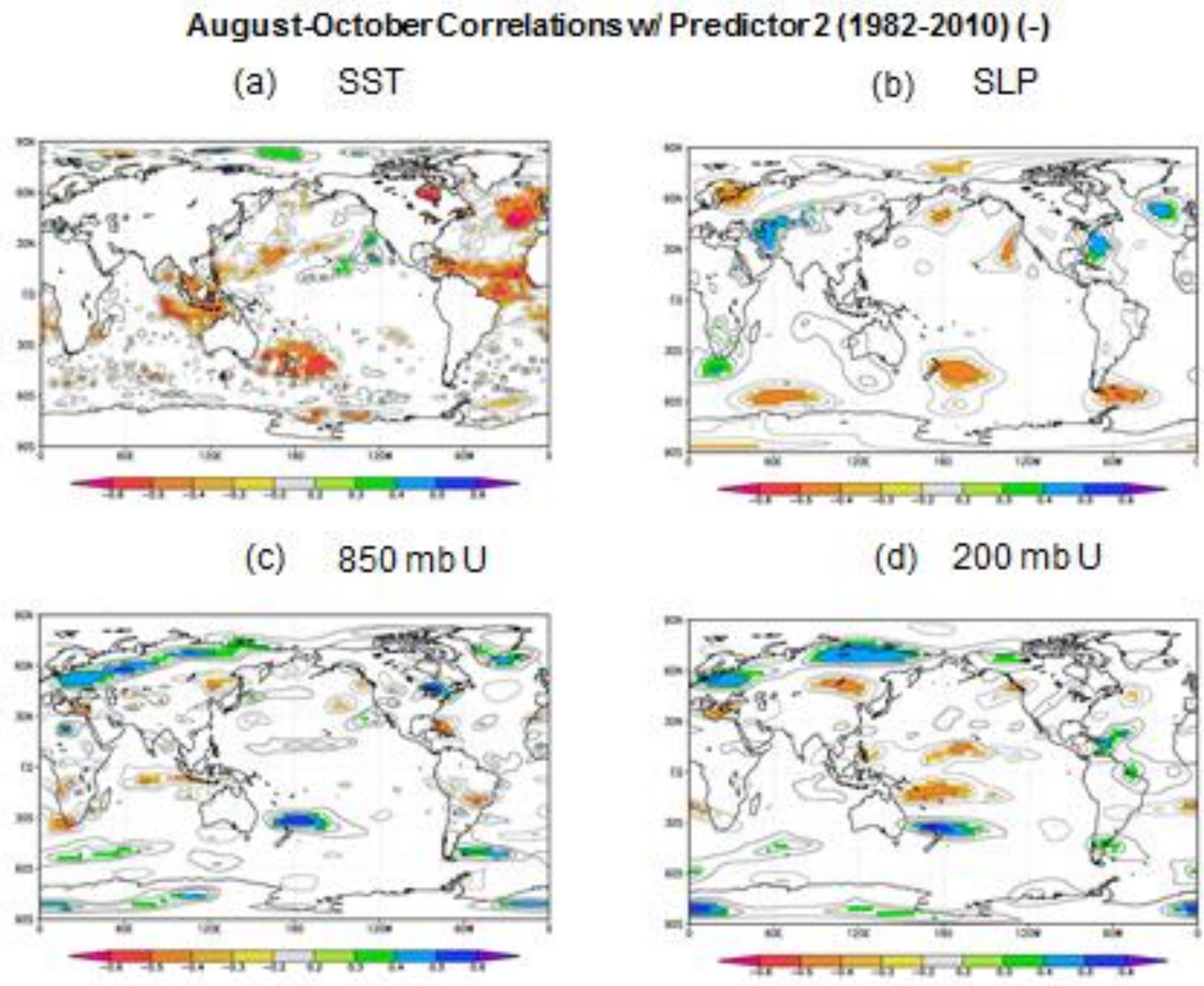

Figure 5: Linear correlations between March SLP in the subtropical Atlantic (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). The predictor's primary impact during the hurricane season appears to be with MDR-averaged SST. **The correlation scale has been reversed (sign changed) to allow for easy comparison of correlations for all four predictors.**

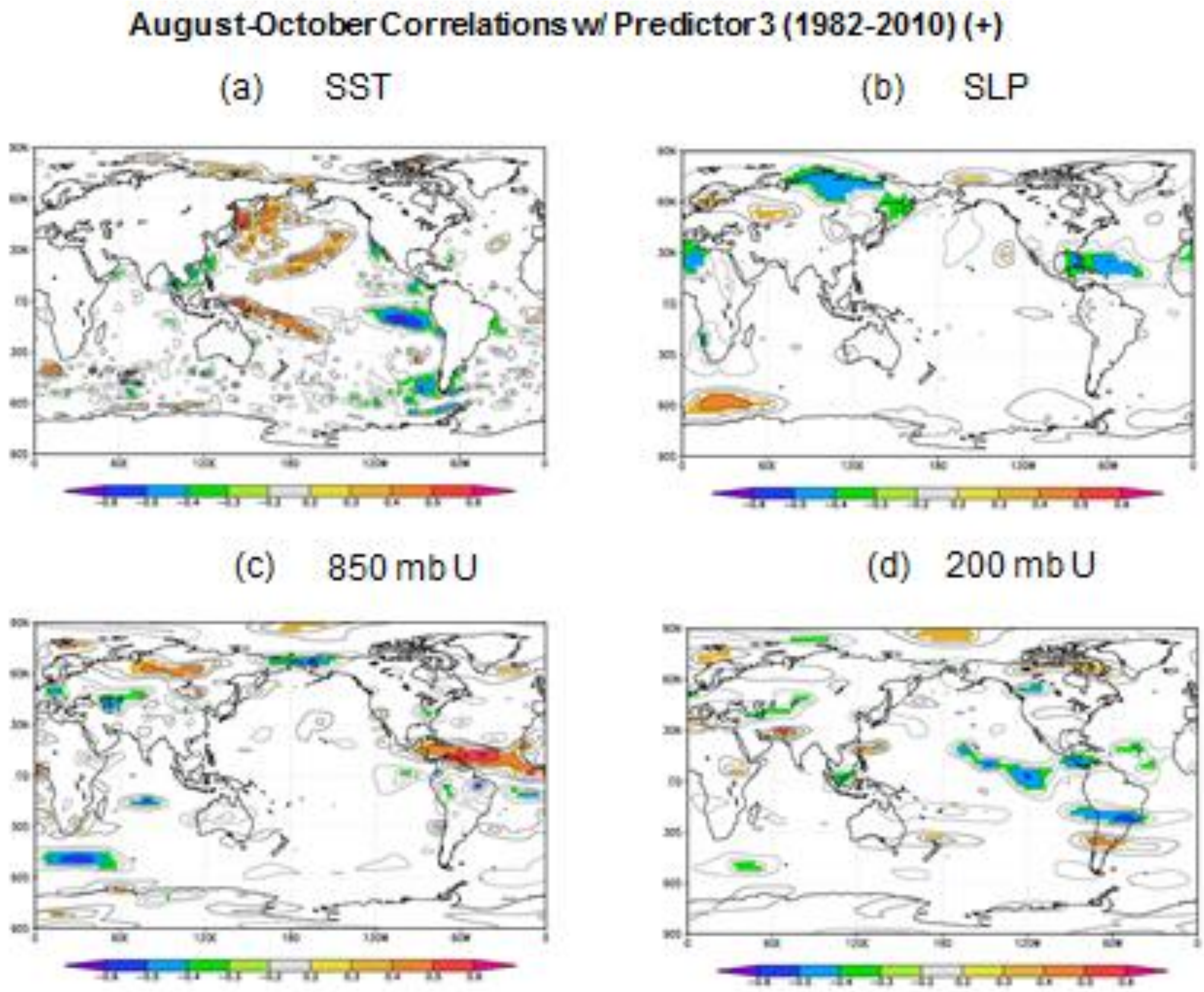

Figure 6: Linear correlations between February-March SLP in the southern tropical Pacific (Predictor 3) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). The predictor's primary impacts appear to be on sea level pressure and trade wind strength across the tropical Atlantic.

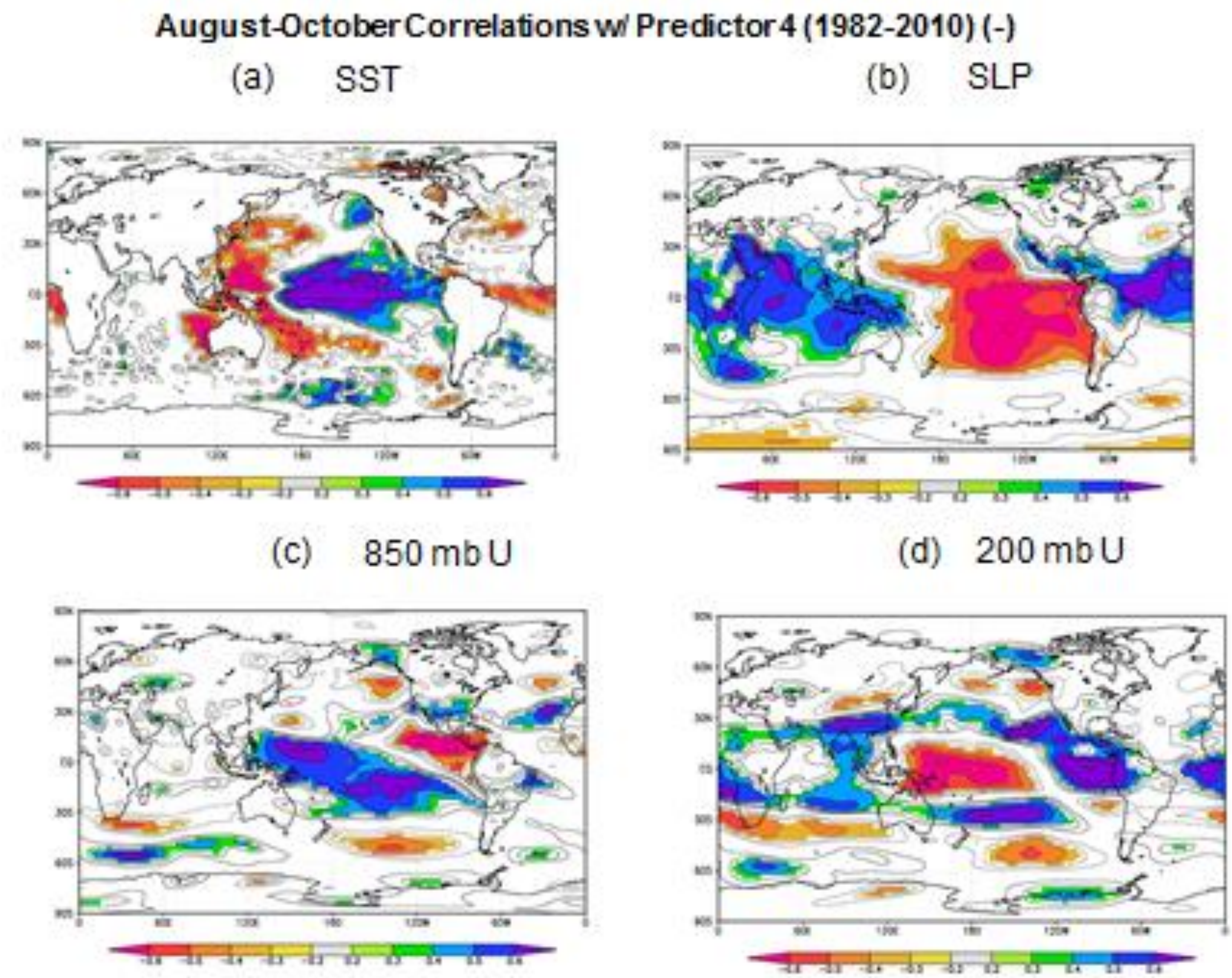

Figure 7: Linear correlations between a 1 March ECMWF SST forecast for September Nino 3 (Predictor 4) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). The predictor correlates very strongly with ENSO as well as vertical shear in the Caribbean. **The correlation scale has been reversed (sign changed) 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. Uncertainty with the April outlook is quite large, given the uncertainty in the state of both ENSO as well as the state of the Atlantic basin SST configuration.

Table 4 provides our early April forecast, 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. Note the rather large uncertainty ranges at this extended lead time. Large changes in the atmosphere-ocean system frequently occur during the spring months and can lead to significant alterations to the seasonal forecast as the peak of the hurricane season approaches. This was certainly evident in last year's early April forecast, where most ENSO models called for El Niño by August-October. August-October ended up with borderline weak La Niña conditions.

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)	3	14	11 – 17
Named Storm Days (NSD)	21	70	49 – 91
Hurricanes (H)	2	7	5 – 9
Hurricane Days (HD)	13	30	17 – 43
Major Hurricanes (MH)	1	3	2 – 4
Major Hurricane Days (MHD)	5	7	2 – 12
Accumulated Cyclone Energy (ACE)	53	130	77 – 183
Net Tropical Cyclone (NTC) Activity	50	135	85 – 185

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 levels of activity that the forthcoming 2018 hurricane season may bring. For this early April 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 February-March 2018 conditions as well as projected August-October 2018 conditions. Table 5 lists our analog selections.

We selected prior hurricane seasons since 1950 which had similar atmospheric-oceanic conditions to those currently being experienced and those that we expect to see this summer and fall. We searched for years that were generally characterized by weak La Niña to weak El Niño conditions during August-October. We selected a variety of tropical and North Atlantic SST anomaly configurations due to the large uncertainty as to what the Atlantic will look like this summer and fall. We anticipate that the 2018 hurricane season will have slightly more activity than the average of our five analog years. We believe that this season should experience slightly above-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
1960	8	33.50	4	15.00	2	8.50	73	90
1967	8	58.00	6	36.25	1	5.75	122	102
1996	13	79.00	9	45.00	6	13.00	166	192
2006	10	58.00	5	21.25	2	2.00	83	87
2011	19	89.75	7	26.00	4	4.50	126	145
Average	11.6	63.7	6.2	28.7	3.0	6.8	114	123
2018 Forecast	**14**	**70**	**7**	**30**	**3**	**7**	**130**	**135**

5 ENSO

The tropical Pacific was characterized by weak La Niña conditions for the second consecutive winter – a phenomenon known as a double-dip La Niña. This was the first time that this has occurred since the winters of 2010 and 2011. Over the past few weeks, however, La Niña conditions have weakened, with the latest official forecast from NOAA indicating a relatively high likelihood of a transition to neutral ENSO conditions over the next couple of months. The Nino 3.4 index (5°S-5°N, 170-120°W) peaked at +0.7°C in late June, indicating borderline weak El Niño conditions (between 0.5°C - 1.0°C) during the early summer of 2017. However, SSTs then anomalously cooled, and by the peak of the Atlantic hurricane season in early September, they had fallen into the cool neutral ENSO category (between -0.5°C and 0°C). Anomalous SST cooling continued through the end of 2017, with recent anomalous SST warming raising the likelihood that weak La Niña (between -1.0°C and -0.5°C) conditions are likely nearing an end.

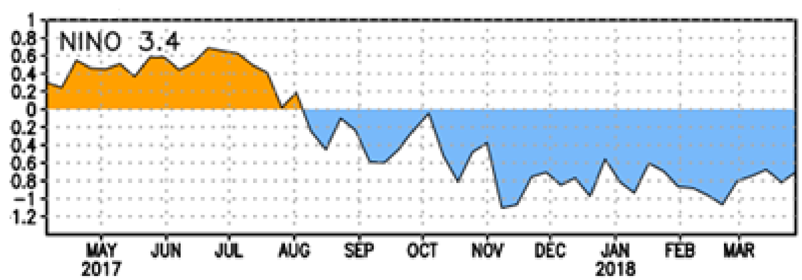

Figure 8: Nino 3.4 SST anomalies from April 2017 through March 2018. Figure courtesy of Climate Prediction Center.

Upper-ocean heat content anomalies in the eastern and central tropical Pacific were at above-normal levels during the spring and early summer of 2017, indicative of the borderline weak El Niño conditions that were present during that time (Figure 9). As would be expected given the transition to weak La Niña conditions in the second half of 2017, upper-ocean heat content anomalies then fell to below normal levels. Upper-ocean heat content anomalies have warmed since November of 2017, likely indicating an imminent transition to neutral ENSO conditions.

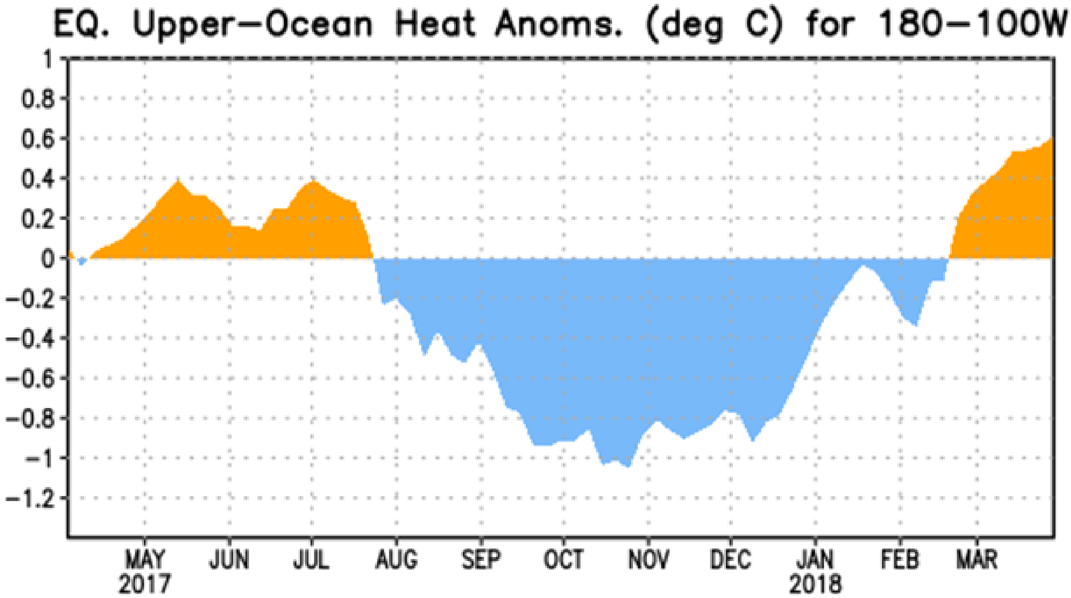

Figure 9: Central and eastern tropical Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Upper ocean heat content anomalies have generally been on an increasing trend since November 2017.

SSTs are generally below normal across the eastern and central tropical Pacific (Figure 10). This is to be expected given the weak La Niña conditions that are present across the basin.

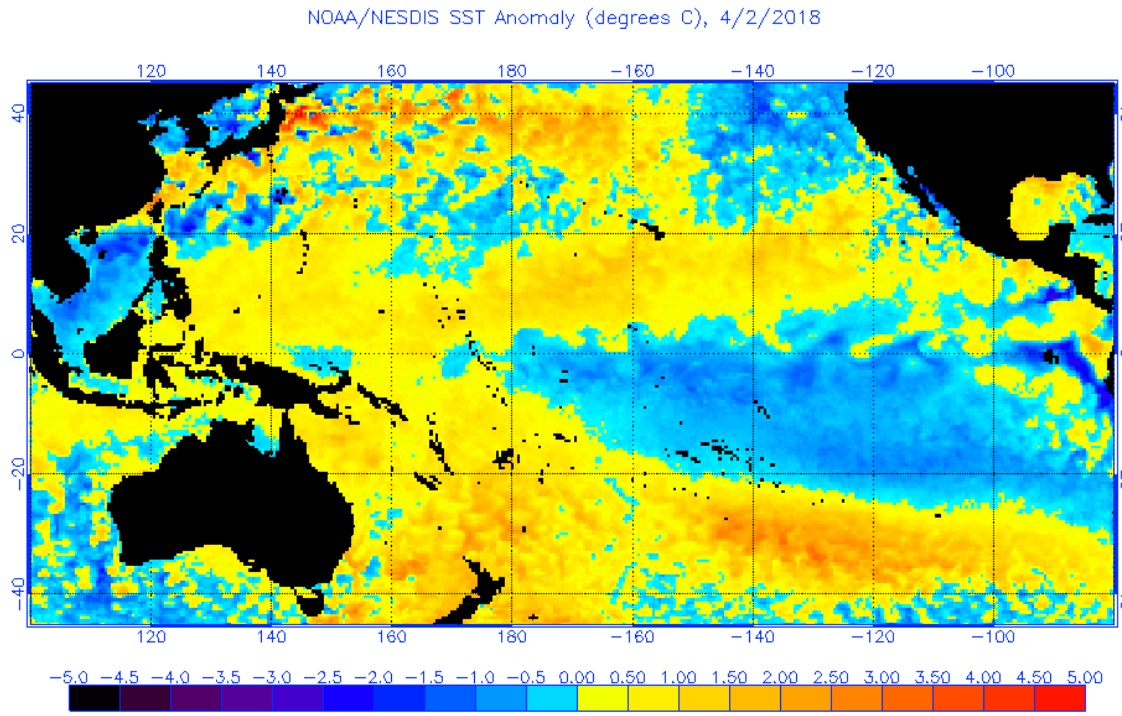

Figure 10: Current SST anomalies across the tropical and subtropical Pacific.

Table 6 displays January and March SST anomalies for several Nino regions. Anomalies have trended slightly upward over the past couple of months across the eastern and central tropical Pacific. These SST trends are in keeping with most of the forecast model guidance (as shown in the next few pages), as well as the official forecast from NOAA that indicates a transition to neutral ENSO conditions is likely in the next couple of months.

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

Region	January SST Anomaly (°C)	March SST Anomaly (°C)	March – January SST Anomaly (°C)
Nino 1+2	-0.8	-0.7	+0.1
Nino 3	-1.1	-0.7	+0.4
Nino 3.4	-0.8	-0.7	+0.1
Nino 4	-0.3	-0.1	+0.2

The tropical Pacific experienced a downwelling (warming) Kelvin wave that temporarily pushed the basin to borderline weak El Niño conditions early last summer (Figure 11). However, we then had a weak upwelling (cooling) Kelvin wave followed by relatively weak Kelvin wave activity through the remainder of the summer/fall, and the tropical Pacific slowly drifted towards weak La Niña conditions. In recent months, we have had much more active Kelvin wave activity, and currently, a downwelling Kelvin wave is moving across the eastern tropical Pacific, potentially indicating a transition to neutral ENSO conditions in the next couple of months.

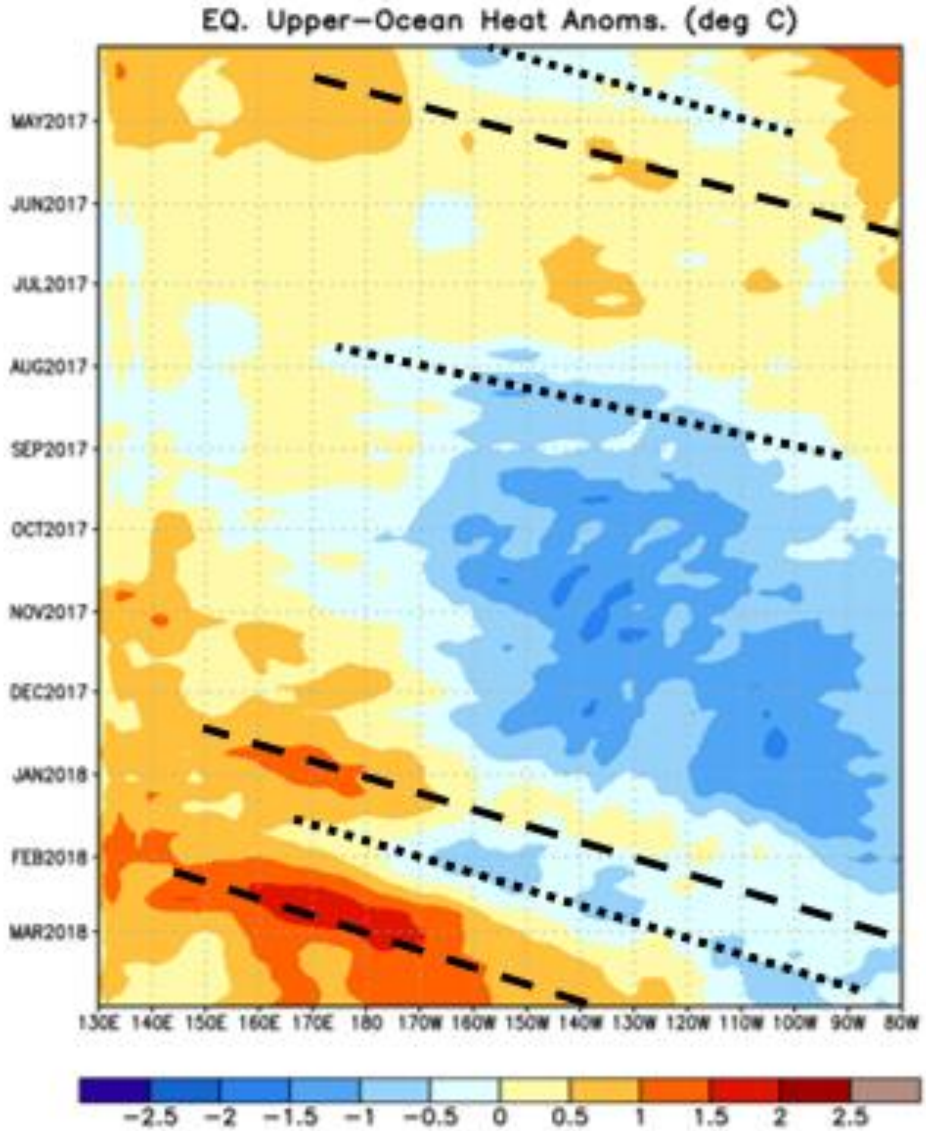

Figure 11: Upper-ocean heat content anomalies in the tropical Pacific since April 2017. Dashed lines indicate downwelling Kelvin waves, while dotted lines indicate upwelling Kelvin waves. Downwelling Kelvin waves result in upper-ocean heat content increases, while upwelling Kelvin waves recent in upper-ocean heat content decreases.

Over the next several months, we will be closely monitoring low-level winds over the tropical Pacific. Typically, when strong low-level westerly anomalies are observed across portions of the western and central tropical Pacific (a phenomenon known as a westerly wind burst), downwelling Kelvin waves are triggered that can cause a transition to El Niño conditions. Anomalous westerlies are currently observed across portions of the western and central Pacific, but these are forecast to weaken over the next couple of weeks (Figure 12). The Madden-Julian Oscillation (MJO), which is an important driver of sub-seasonal variability of lower- and upper-level winds, is predicted to be in phases that typically favor trade wind enhancement over the tropical central Pacific in weeks 3 and 4 (Figure 13).

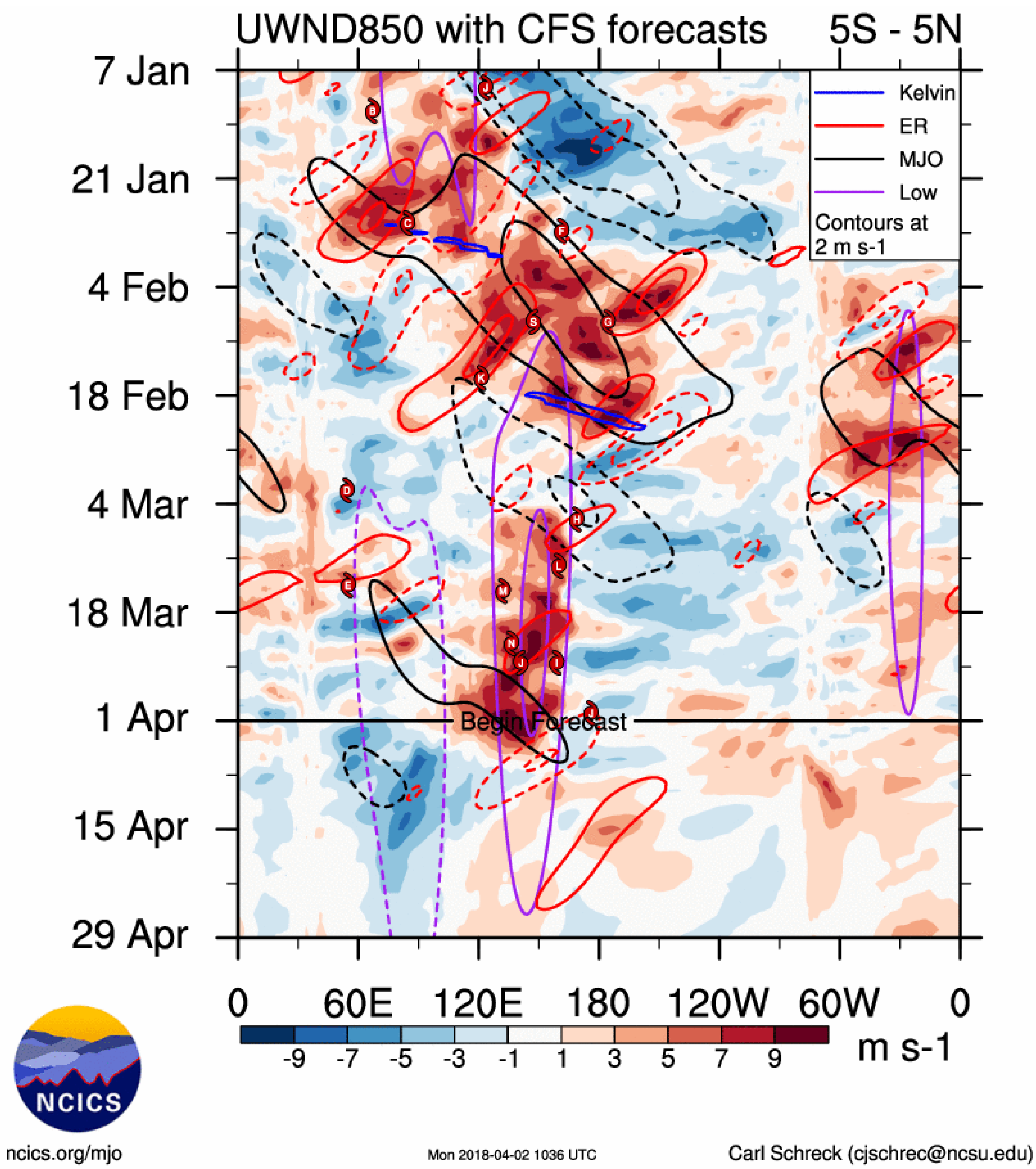

Figure 12: Observed low-level winds across the equatorial region as well as predictions for the next four weeks by the Climate Forecast System. Figure courtesy of Carl Schreck.

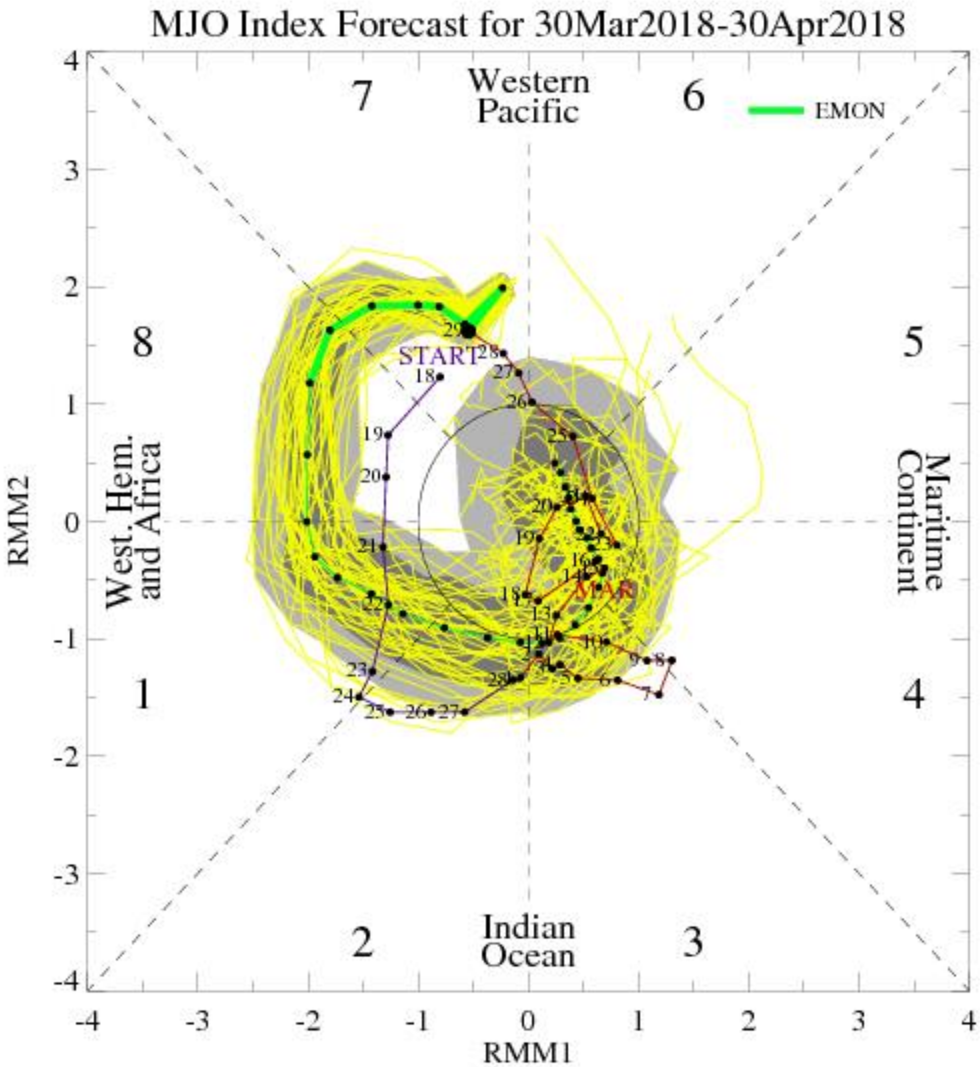

Figure 13: Monthly forecast of the MJO from the ECMWF model. The ECMWF model calls for the MJO to propagate through phases 7 through 3 over the next several weeks, with potential weakening of the MJO later in April.

There is obviously considerable uncertainty with the future state of El Niño. The latest plume of ENSO predictions from a large number of statistical and dynamical models shows a large spread by the peak of the Atlantic hurricane season in August-October (Figure 14). About 1/3 of all forecast models are calling for El Niño conditions by August-October, with the remaining models generally calling for neutral ENSO conditions for this summer/fall.

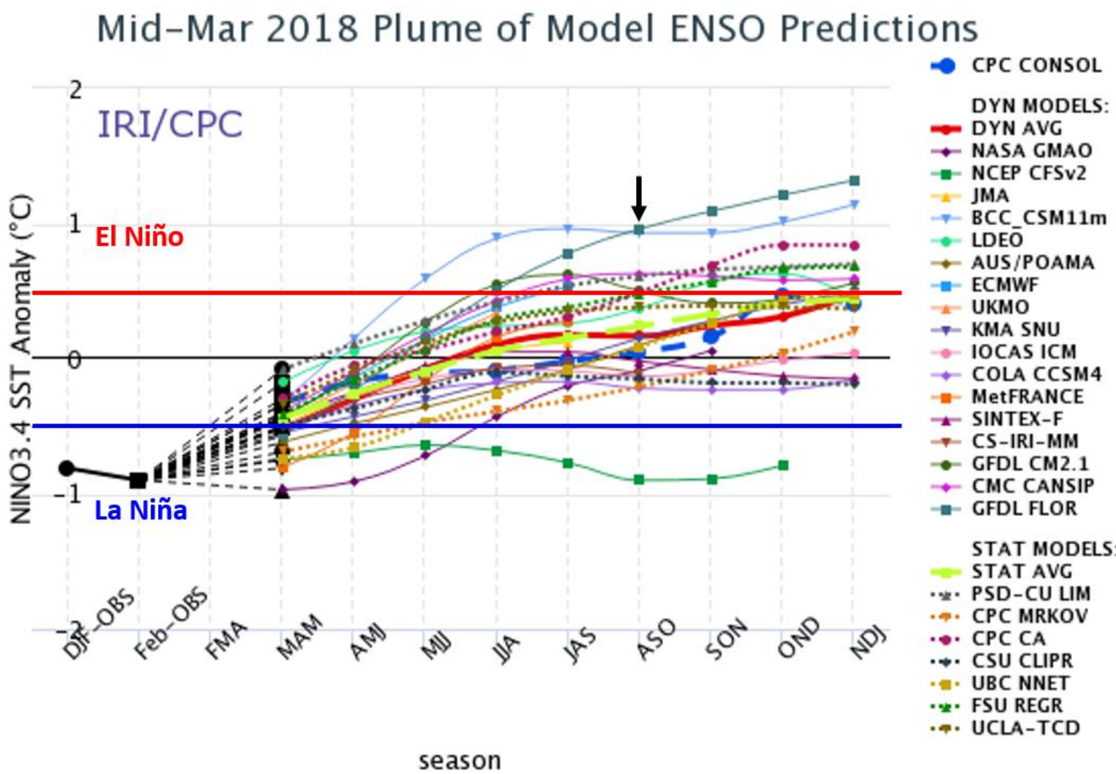

Figure 14: ENSO forecasts from various statistical and dynamical models for the Nino 3.4 SST anomaly based on late February to early March initial conditions. About 1/3 of all forecast models are calling for El Niño conditions by August-October (black arrow), which is the climatological peak of the Atlantic hurricane season. Figure courtesy of the International Research Institute (IRI).

The European Centre for Medium-Range Weather Forecasts (ECMWF) is generally considered to be one of the most skillful models at predicting ENSO. However, even this model has had its fair share of forecast busts, including calling for much warmer ENSO conditions than were experienced last summer/fall. The average of the various ECMWF ensemble members is calling for a September Nino 3.4 SST anomaly of approximately +0.7°C. There is a fairly wide spread for the range of outcomes predicted by the various ensemble members, which indicates the large degree of uncertainty in future ENSO conditions (Figure 15). This is typically what would be expected with a forecast initialized in March, as predicting ENSO is generally most challenging during the Northern Hemisphere spring. A good discussion of the ENSO springtime predictability barrier was published by NOAA a few years ago: https://www.climate.gov/news-features/blogs/enso/spring-predictability-barrier-we%E2%80%99d-rather-be-spring-break

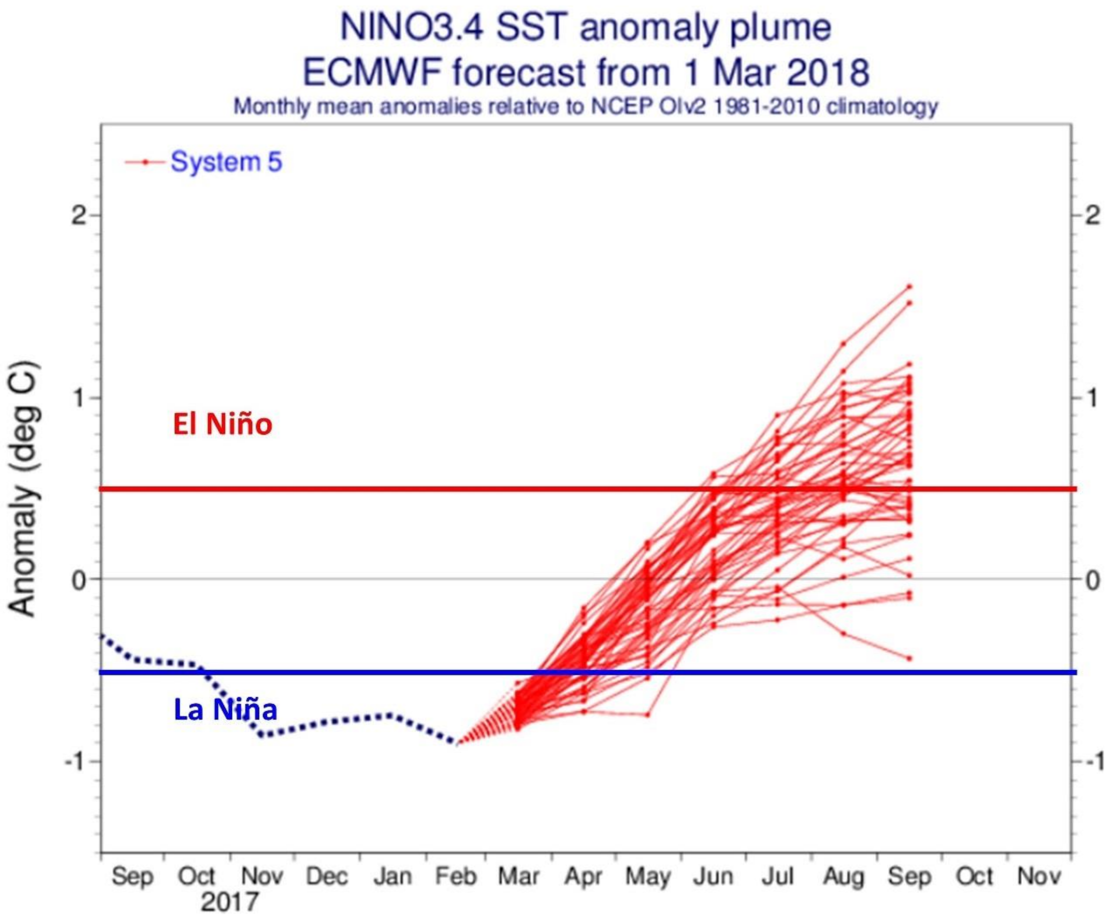

Figure 15: ECMWF ensemble model forecast for the Nino 3.4 region. Slightly more than half of all ensemble members are calling for El Niño conditions by September.

Based on the above information, our best estimate is that we will likely have neutral ENSO conditions by the peak of the Atlantic hurricane season. There remains a need to closely monitor ENSO conditions over the next few months. We believe we will be slightly more confident about ENSO conditions for the upcoming hurricane season by the time of our next forecast on May 31.

6 Current Atlantic Basin Conditions

The current SST pattern across the North Atlantic basin is characterized by relatively cold SSTs in the far North Atlantic, near-normal SSTs in the eastern tropical Atlantic and warm SST anomalies off of the East Coast of the United States. This type of SST pattern is a mixture of signals observed with a positive and negative phase of the Atlantic Multi-decadal Oscillation (AMO) (Figure 16).

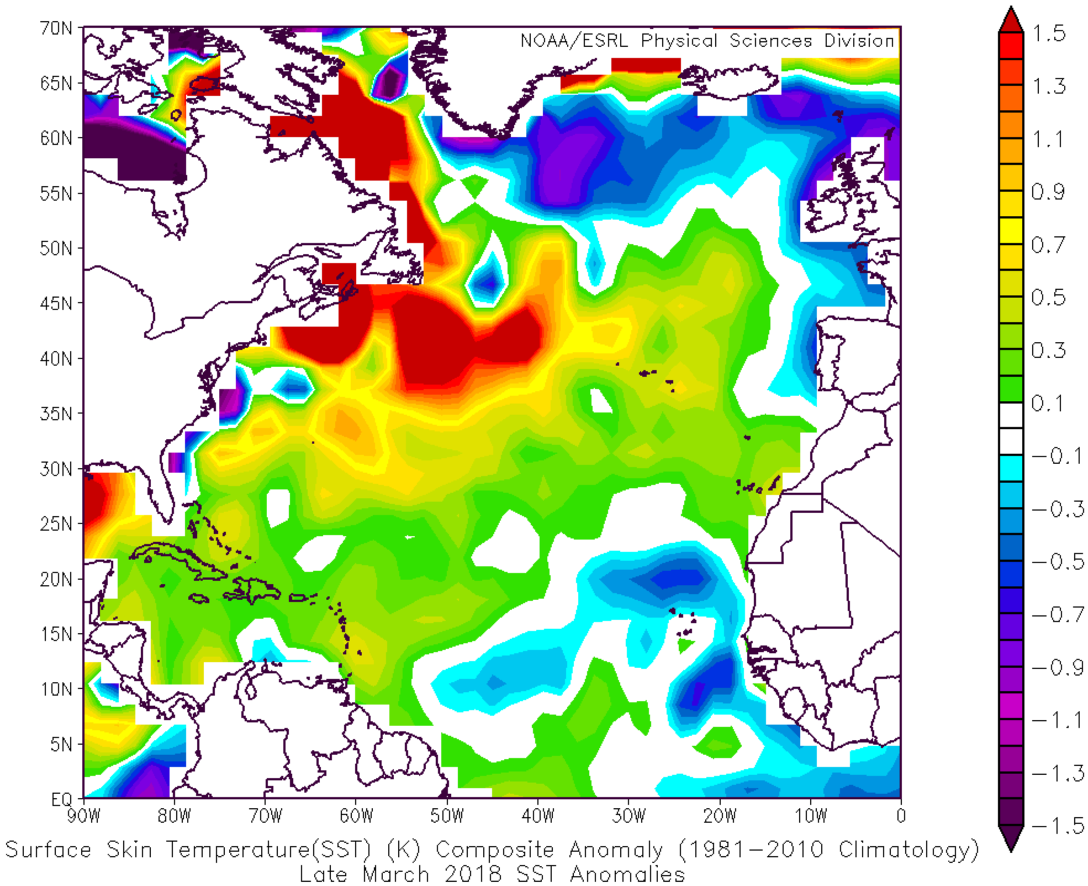

Figure 16: Late March 2018 SST anomaly pattern across the Atlantic Ocean.

The Atlantic was very warm at the end of last year's hurricane season (Figure 17). During the early part of this year, the Atlantic anomalously cooled (Figure 18), due in large part to a strongly positive North Atlantic Oscillation (NAO) (Figure 19) and associated strong trade winds causing increased mixing, upwelling and evaporation. That pattern changed around March 1, where the NAO changed to a predominately negative phase. Slight anomalous warming has occurred across the eastern and central tropical Atlantic over the past month (Figure 20).

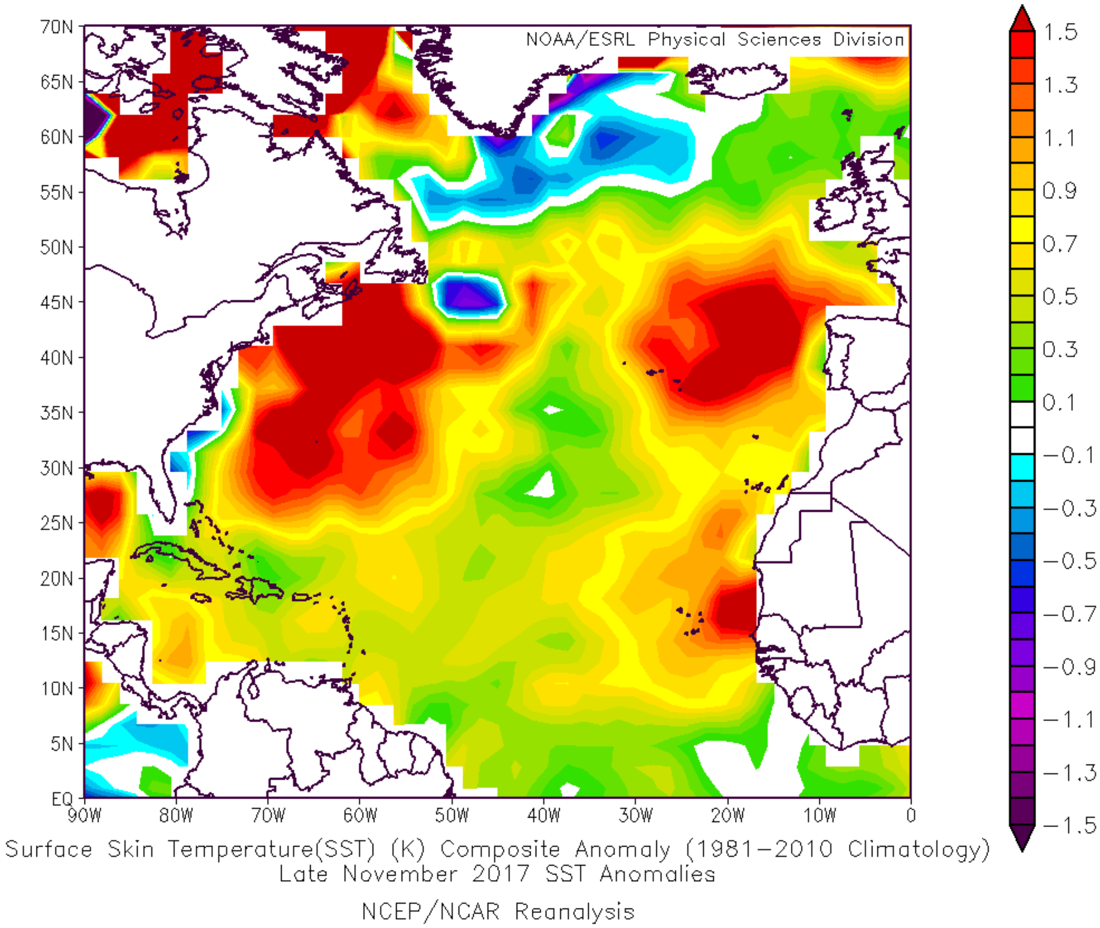

Figure 17: Late November 2017 North Atlantic SST anomalies.

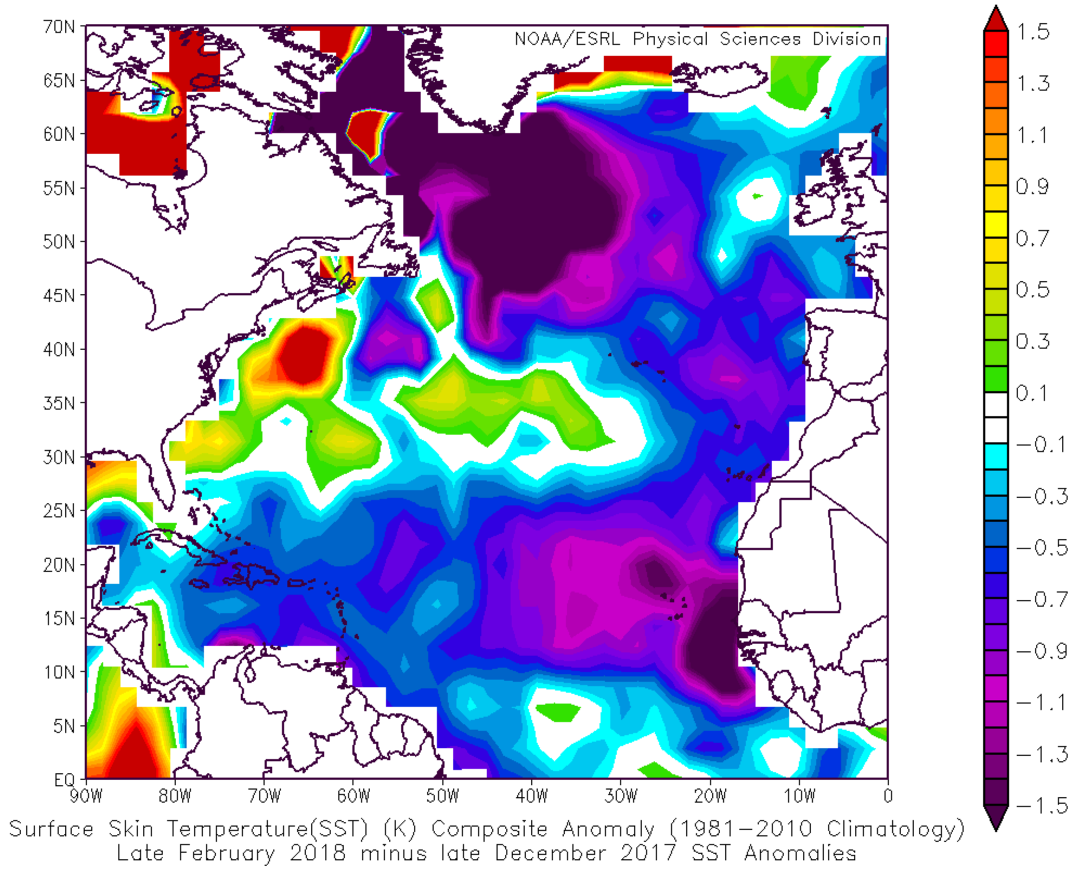

Figure 18: Anomalous SST change from late December 2017 to late February 2018. Anomalous SST cooling occurred across most of the North Atlantic.

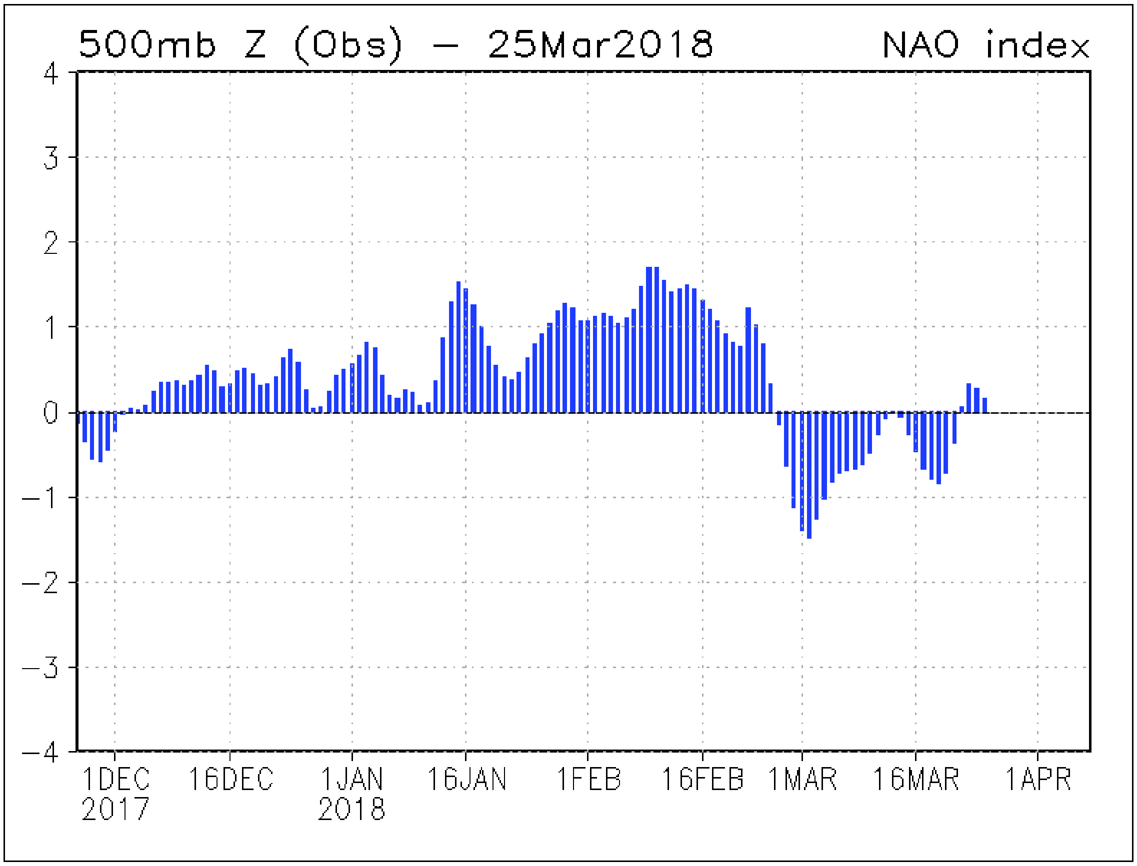

Figure 19: Observed standardized values of the daily NAO since December 2017. The NAO was strongly positive for most of January and February, with a transition to a predominately negative NAO in March 2018.

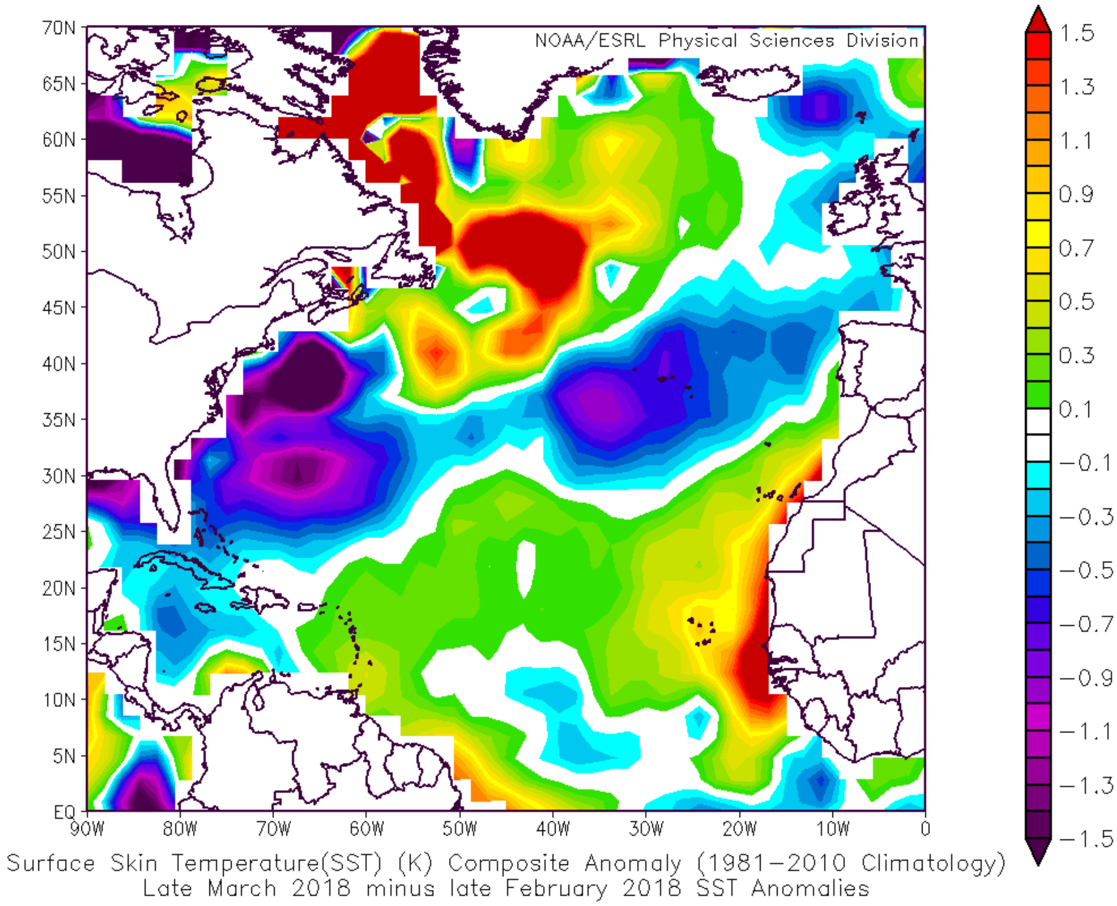

Figure 20: Anomalous SST change from late February to late March 2018. Slight anomalous warming occurred across most of the tropical Atlantic.

There remains considerable uncertainty as to what the tropical Atlantic and the remainder of the North Atlantic will look like for SST anomalies in the summer/fall of 2018. We will continue to closely monitor Atlantic SST conditions over the next several weeks.

7 Adjusted 2018 Forecast

Table 7 shows our final adjusted early April 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 either of these schemes. Both our analog and statistical forecast call for a slightly above-average Atlantic hurricane season this year. We are calling for slightly more activity than either our statistical or analog approach is yielding, given that we think a transition to El Niño is relatively unlikely in the summer/fall of 2018.

Table 7: Summary of our early April 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
Named Storms (12.0)	11.6	11.6	14
Named Storm Days (60.1)	59.6	63.7	70
Hurricanes (6.5)	6.8	6.2	7
Hurricane Days (21.3)	27.7	28.7	30
Major Hurricanes (2.0)	3.1	3.0	3
Major Hurricane Days (3.9)	7.5	6.8	7
Accumulated Cyclone Energy Index (92)	115	114	130
Net Tropical Cyclone Activity (103%)	125	123	135

8 Landfall Probabilities for 2018

A significant focus of our recent research involves efforts to develop forecasts of the probability of hurricane landfall along the continental U.S. coastline and in the Caribbean. Whereas individual hurricane landfall events cannot be accurately 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 1950-2000 climatological 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 landfall 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 NTC activity in 2018 is expected to be slightly above its long-term average of 100, and therefore, landfall probabilities are slightly above their long-term average.

Please 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. The probability of each U.S. coastal state being impacted by hurricanes and major hurricanes is also included. In addition, we include probabilities of named storms, hurricanes and major hurricanes tracking within 50 and 100 miles of various islands and landmasses in the Caribbean and Central America.

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 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)	88% (79%)	78% (68%)	63% (52%)	92% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	70% (59%)	52% (42%)	38% (30%)	71% (60%)	91% (83%)
Florida plus East Coast (Regions 5-11)	61% (50%)	54% (44%)	39% (31%)	72% (61%)	89% (81%)
Caribbean (10-20°N, 60-88°W)	90% (82%)	68% (57%)	52% (42%)	85% (75%)	98% (96%)

9 Summary

An analysis of a variety of different atmosphere and ocean measurements (through March) which are known to have long-period statistical relationships with the upcoming season's Atlantic tropical cyclone activity indicate that 2018 should have slightly above-average activity. The big question marks with this season's predictions are whether a significant El Niño develops, as well as what the configuration of SSTs will look like in the tropical and far North Atlantic Ocean during the peak of the Atlantic hurricane season.

10 Forthcoming Updated Forecasts of 2018 Hurricane Activity

We will be issuing seasonal updates of our 2018 Atlantic basin hurricane forecasts on **Thursday 31 May**, **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	51.25
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