EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2020

We anticipate that the 2020 Atlantic basin hurricane season will have above-normal activity. Current warm neutral ENSO conditions appear likely to transition to cool neutral ENSO or potentially even weak La Niña conditions by this summer/fall. Sea surface temperatures averaged across the tropical Atlantic are somewhat above normal. Our Atlantic Multi-decadal Oscillation index is below its long-term average; however, most of the tropical Atlantic is warmer than normal. We anticipate an 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 2 April 2020)

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

In Memory of William M. Gray[4]

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

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2020

Forecast Parameter and 1981-2010 Average (in parentheses)	Issue Date 2 April 2020
Named Storms (NS) (12.1)	16
Named Storm Days (NSD) (59.4)	80
Hurricanes (H) (6.4)	8
Hurricane Days (HD) (24.2)	35
Major Hurricanes (MH) (2.7)	4
Major Hurricane Days (MHD) (6.2)	9
Accumulated Cyclone Energy (ACE) (106)	150
Net Tropical Cyclone Activity (NTC) (116%)	160

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 - 69% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 45% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 44% (average for last century is 30%)

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

1) 58% (average for last century is 42%)

ABSTRACT

Information obtained through March 2020 indicates that the 2020 Atlantic hurricane season will have activity above the 1981-2010 average. We estimate that 2020 will have about 8 hurricanes (average is 6.4), 16 named storms (average is 12.1), 80 named storm days (average is 59.4), 35 hurricane days (average is 24.2), 4 major (Category 3-4-5) hurricanes (average is 2.7) and 9 major hurricane days (average is 6.2). The probability of U.S. major hurricane landfall is estimated to be about 130 percent of the long-period average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2020 to be approximately 140 percent of their long-term averages.

This forecast is based on a new extended-range early April statistical prediction scheme that was developed using 38 years of past data. Analog predictors are also utilized. We are also including statistical/dynamical models based off data from both the ECMWF SEAS5 model and the Met Office GloSea5 model as two additional forecast guidance tools. We are also including probability of exceedance curves to better quantify the uncertainty in these outlooks.

The current warm neutral ENSO event appears likely to transition to either cool neutral ENSO or weak La Niña during the summer/fall. The tropical Atlantic is warmer than normal, while the subtropical Atlantic is quite warm, and the far North Atlantic is anomalously cool. The anomalously cold sea surface temperatures in the far North Atlantic lead us to believe that the Atlantic Multi-decadal Oscillation is in its negative phase. While a cold far North Atlantic is typically associated with a cold tropical Atlantic, that has not occurred this winter.

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. For the first time this year, we are also presenting probabilities of exceedance for hurricanes and Accumulated Cyclone Energy to give interested readers a better idea of the uncertainty associated with these forecasts.

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 and statistical/dynamical hybrid models show strong evidence on nearly 40 years of data that significant improvement over a climatological forecast can be attained. We would never issue a seasonal hurricane forecast unless we had models developed over a long hindcast period which showed skill. We also now include probabilities of exceedance to provide a visualization of the uncertainty associated with these predictions.

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

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

Acknowledgment

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

We are grateful for support from Interstate Restoration, Ironshore Insurance, and the Insurance Information Institute. 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 would like to acknowledge assistance from Louis-Philippe Caron and the data team at the Barcelona Supercomputing Centre for providing data and insight on the statistical/dynamical models. We have also benefited from meteorological discussions with Carl Schreck, Louis-Philippe Caron, Brian McNoldy, Paul Roundy, Jason Dunion, Peng Xian and Amato Evan over the past few years.

DEFINITIONS AND ACRONYMS

Accumulated Cyclone Energy (ACE) - A measure of a named storm's potential for wind and storm surge destruction defined as the sum of the square of a named storm's maximum wind speed (in 10^4 $knots^2$) for each 6-hour period of its existence. The 1981-2010 average value of this parameter is 106 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.

Standard Deviation (SD) – A measure used to quantify the variation in a dataset.

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 hPa (approximately 40000 feet or 12 km) and 850 hPa (approximately 5000 feet or 1.6 km).

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

1 Introduction

This is the 37th 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 new statistical methodology as well as output from two statistical/dynamical models calculated from the SEAS5 climate model from the European Centre for Medium Range Weather Forecasts (ECMWF) and the GloSea5 model from the UK Met Office. These models show skill on 25-40 years of historical data, depending on the particular forecast technique. We also select analog seasons, based primarily on conditions we anticipate for the peak of the Atlantic hurricane season. Qualitative adjustments are added to accommodate additional processes which may not be explicitly represented by these 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 are 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

We are debuting a new April statistical forecast scheme this year that has been developed over the period from 1982-2019. The model uses the newly-released ECMWF Reanalysis 5 (ERA5) (https://confluence.ecmwf.int/display/CKB/ERA5%3A+data+documentation) as well as NOAA Optimum Interpolation (IO) SST (Reynolds et al. 2002). The ERA5 reanalysis currently extends from 1979 to near-present and will be extended back to 1950 in the upcoming months. A benefit of the ERA5 reanalysis is that it is the first reanalysis from ECMWF that provides updates in near real-time, allowing for the same reanalysis product to be used for both hindcast model development as well as real-time analysis. The NOAA Optimum Interpolation (OI) SST (Reynolds et al. 2002) is available from 1982-present. This new model showed significant skill in cross-validated (e.g., leaving the year out of the developmental model that is being predicted) hindcasts of Accumulated Cyclone Energy (ACE) (r = 0.65) over the period from 1982-2019.

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 1982-2019 hindcast period. All predictors correlate significantly at the 5% level using a two-tailed Student's t-test and assuming that each year represents an individual degree of freedom. Table 2 displays the 2020 observed values for each of the three predictors in the statistical forecast scheme. Table 3 displays the statistical model output for the 2020 hurricane season. Two of the three predictors call for increased Atlantic hurricane activity, while one predictor (200 hPa zonal wind) is near average.

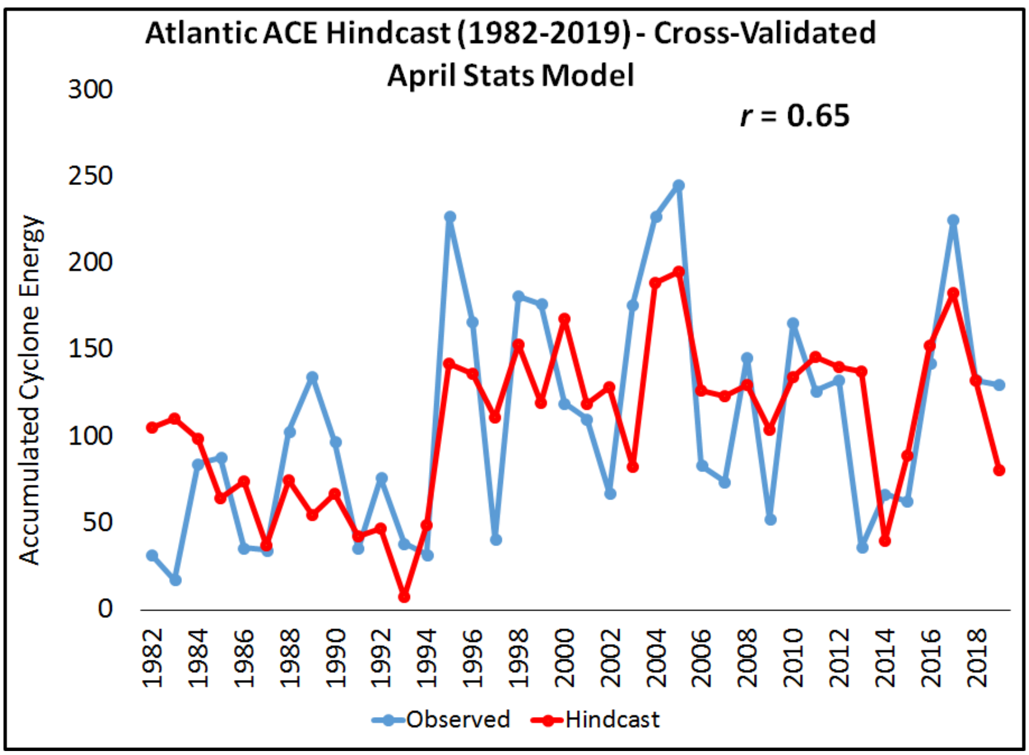

Figure 1: Observed versus early April cross-validated hindcast values of ACE for the statistical model for 1982-2019.

April Forecast Predictors

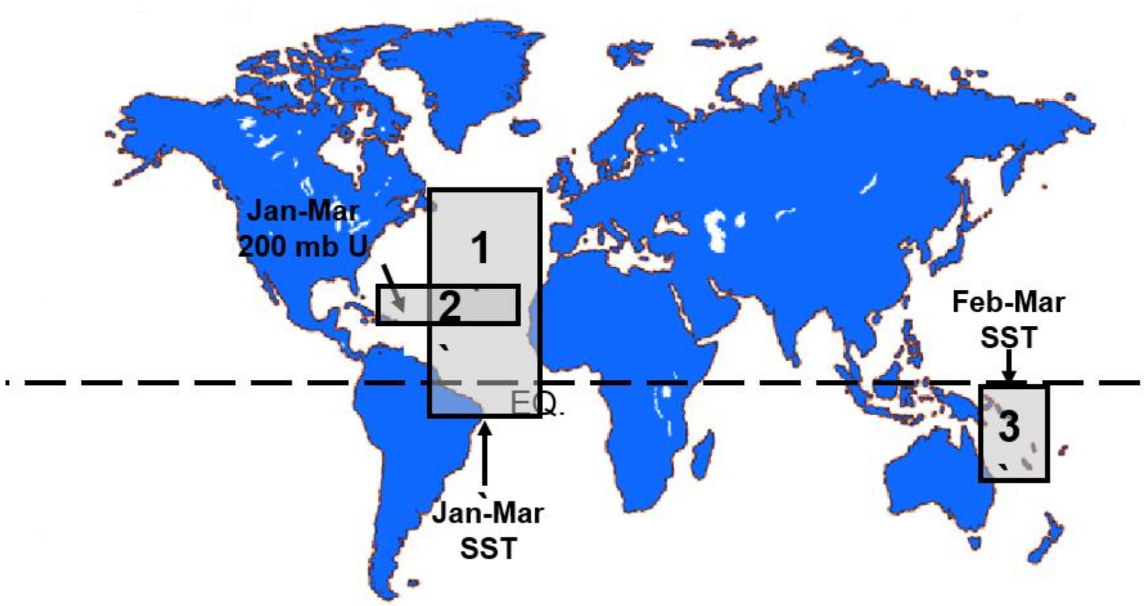

Figure 2: Location of predictors for our early April extended-range statistical prediction for the 2020 hurricane season.

Table 1: Linear correlation between early April predictors and ACE over the period from 1982-2019.

Predictor	Correlation w/ ACE
1) January-March SST (5°S-50°N, 40°W-10°W) (+)	0.54
2) January-March 200 hPa U (17.5°N-27.5°N, 60°W-20°W) (+)	0.46
3) February-March SST (20°S-0°, 145°E-170°E) (-)	0.49

Table 2: Listing of early April 2020 predictors for the 2020 hurricane season. A plus (+) means that positive deviations of the parameter are associated with increased hurricane activity, while a minus (-) means that negative deviations of the parameter are associated with increased hurricane activity. SD stands for standard deviation.

Predictor	2020 Forecast Value	Impact on 2020 TC Activity
1) January-March SST (5°S-50°N, 40°W-10°W) (+)	+2.2 SD	Enhance
2) January-March 200 hPa U (17.5°N-27.5°N, 60°W-20°W) (+)	-0.2 SD	Suppress
3) February-March SST (20°S-0°, 145°E-170°E) (-)	+1.4 SD	Enhance

Table 3: Statistical model output for the 2020 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1981-2010 Average (in parentheses)	Statistical Forecast	Final Forecast
Named Storms (NS) (12.1)	16.3	16
Named Storm Days (NSD) (59.4)	87.6	80
Hurricanes (H) (6.4)	9.1	8
Hurricane Days (HD) (24.2)	38.4	35
Major Hurricanes (MH) (2.7)	4.3	4
Major Hurricane Days (MHD) (6.2)	11.3	9
Accumulated Cyclone Energy (ACE) (106)	169	150
Net Tropical Cyclone Activity (NTC) (116%)	178	160

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.

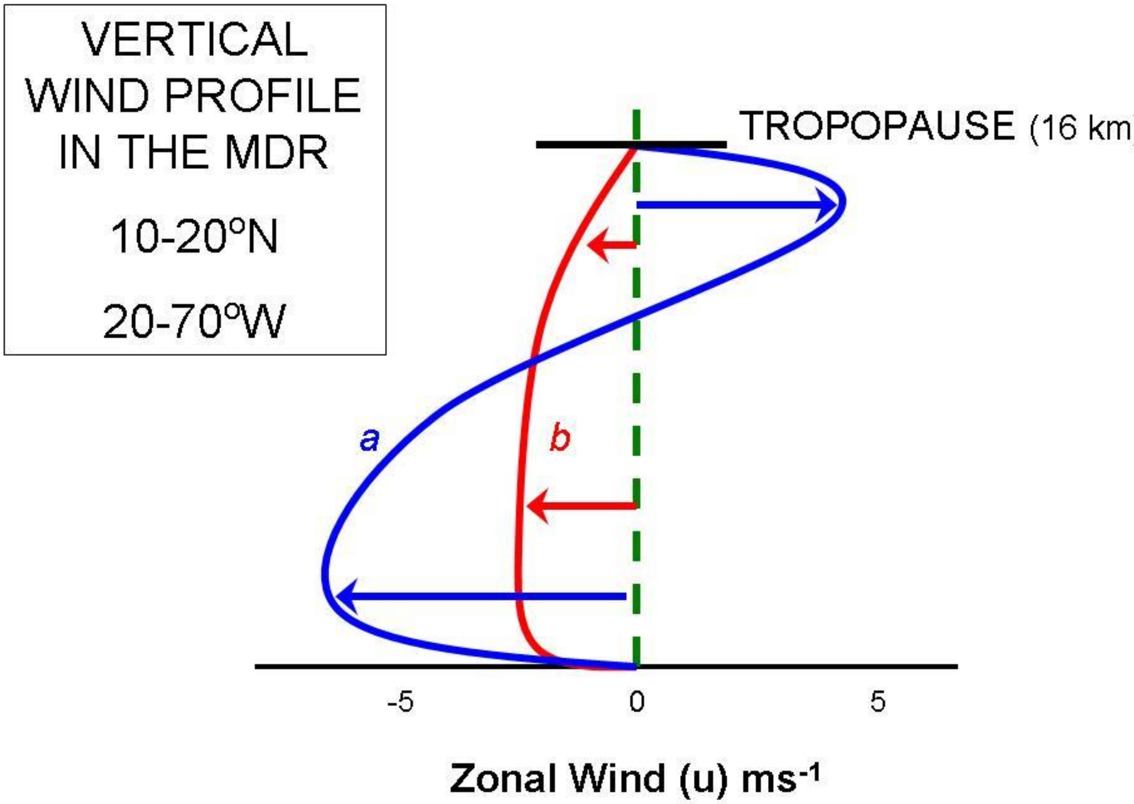

Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.

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 hPa zonal wind, and 850 hPa zonal wind, respectively, during 1982-2019. In general, higher values of SSTs, lower values of SLP, anomalous westerlies at 850 hPa and anomalous easterlies at 200 hPa are associated with active Atlantic basin hurricane seasons. SST correlations are displayed using the NOAA Optimum Interpolation (OI) SST, while atmospheric field correlations are displayed using ERA5.

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

(5°S-50°N, 40°W-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 (r =0.54) with ACE from 1982-2019. Predictor 1 also strongly correlates (r = 0.61) with August-October values of the Atlantic Meridional Mode (AMM) (Kossin and Vimont 2007) over the period from 1982-2019. 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.

<u>Predictor 2. January-March 200 hPa U in the Subtropical North Atlantic (+)</u>

(17.5°N-27.5°N, 60°W-20°W)

Anomalously strong winds at upper-levels in the subtropical North Atlantic are associated with anomalously low pressure in the tropical and subtropical Atlantic during January-March. As has been shown in prior work (Knaff 1997), when the Azores High is weaker than normal, Atlantic trade winds are also weaker than normal. These weaker trades inhibit ocean mixing and upwelling, thereby causing anomalous warming of tropical Atlantic SSTs. These warmer SSTs are then associated with lower-than-normal sea level pressures which can create a self-enhancing feedback that relates to lower pressure, weaker trades and warmer SSTs during the hurricane season (Figure 5) (Knaff 1998). All three of these factors are associated with active hurricane seasons. This predictor is also negatively correlated with tropical central Pacific SSTs during August-October, indicating that La Niña-like conditions are favored during the boreal summer when anomalously strong upper-level winds predominate over the Atlantic during January-March.

<u>Predictor 3. February-March SST in the Coral Sea (+)</u>

(20°S-0°, 145°E-170°E)

Anomalous warmth in the Coral Sea is associated with lower pressure in the western tropical Pacific and higher pressure in the eastern tropical Pacific, thereby driving stronger trade winds across the tropical Pacific that inhibit El Niño development. The development of anomalously high pressure in the eastern tropical Pacific then drives anomalously weak trade winds in the tropical Atlantic, feeding back into both reduced shear and anomalously warm SSTs in the tropical Atlantic by the peak of the Atlantic hurricane season (August-October) (Figure 6).

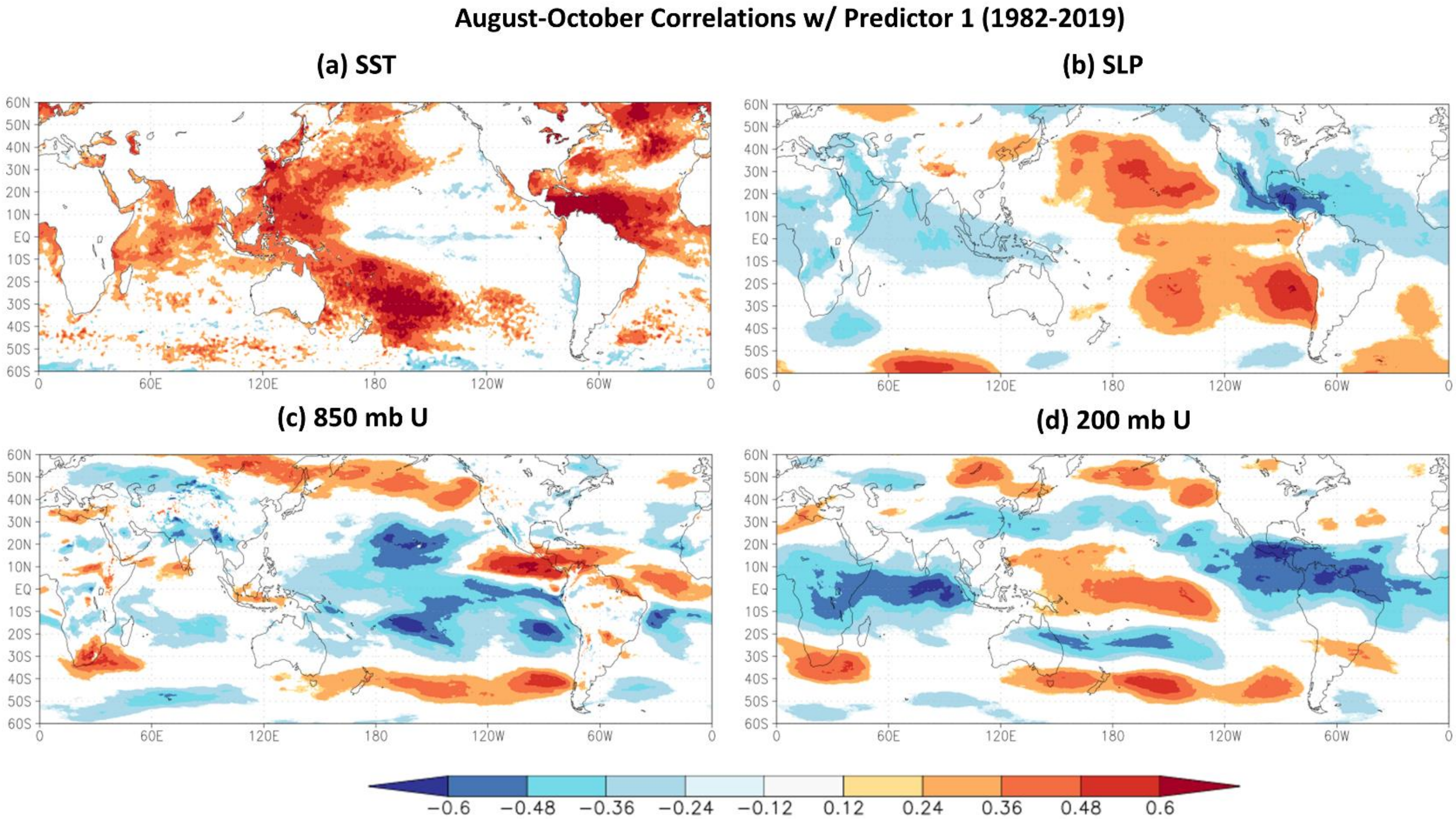

Figure 4: Rank correlations between January-March SST in the tropical and subtropical Atlantic (Predictor 1) and (panel a) August-October sea surface temperature, (panel b) August-October sea level pressure, (panel c) August-October 850 hPa zonal wind and (panel d) August-October 200 hPa zonal wind.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

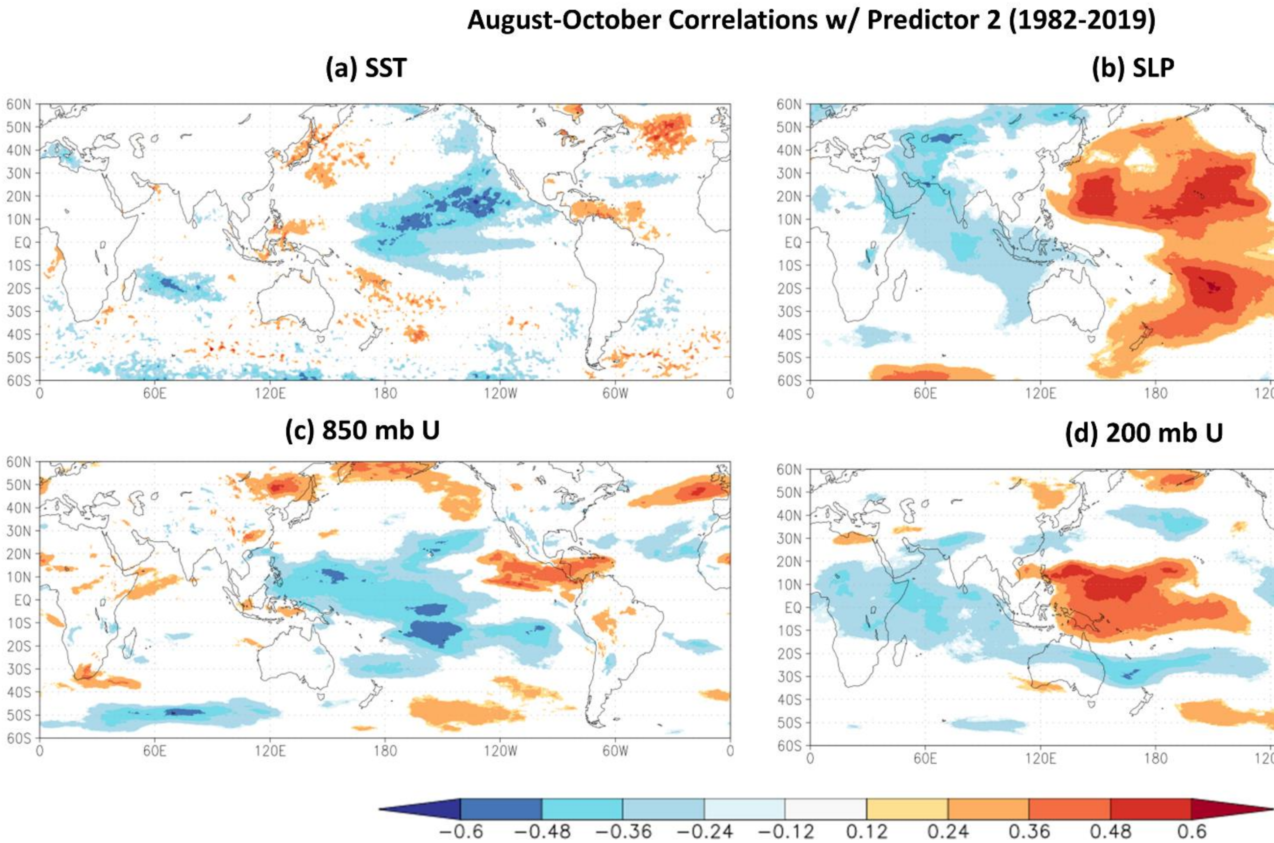

Figure 5: As in Figure 4 but for January-March 200 hPa zonal wind in the subtropical North Atlantic.

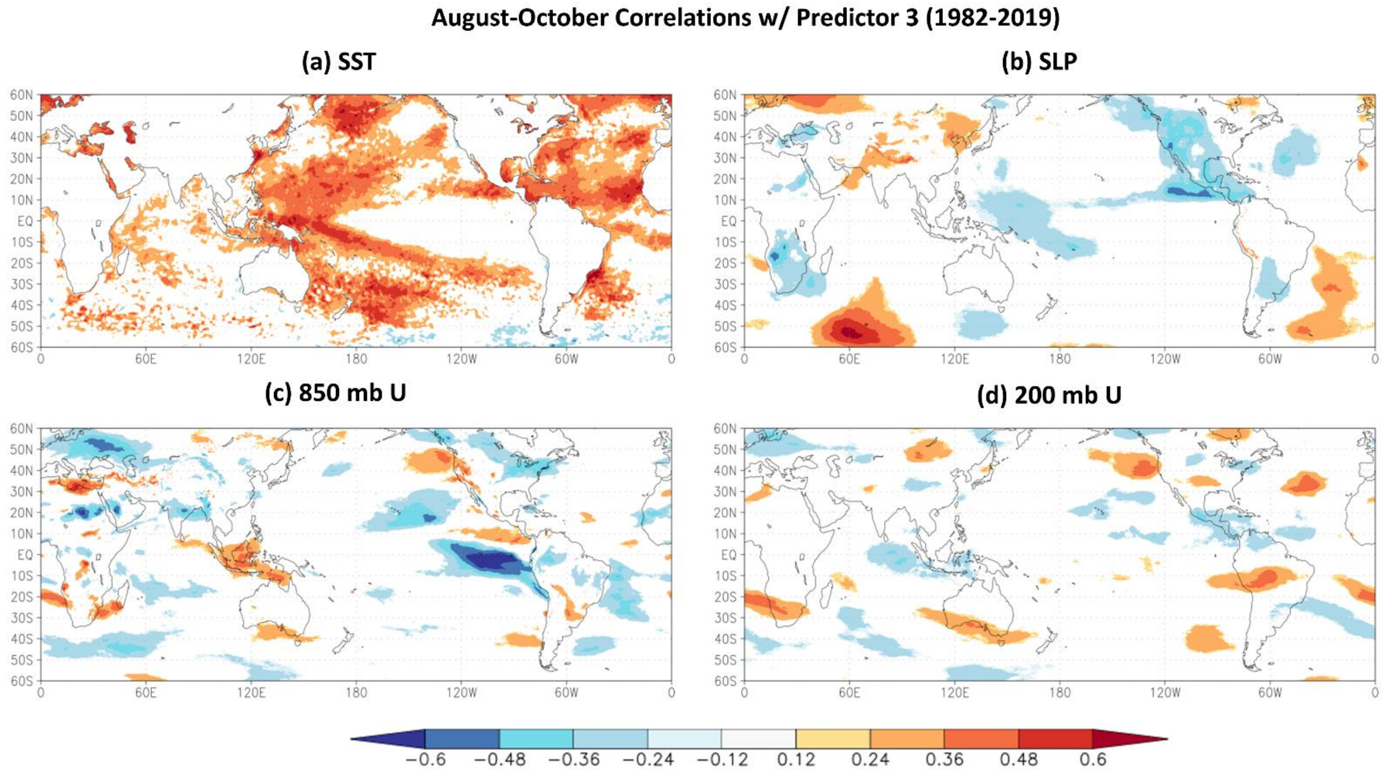

Figure 6: As in Figure 4 but for February-March SST in the Coral Sea.

2.2 April Statistical/Dynamical Forecast Scheme

We developed a new statistical/dynamical hybrid forecast model scheme that we used for the first time in 2019. This model, developed in partnership with Louis-Philippe Caron and the data team at the Barcelona Supercomputing Centre, uses output from the ECMWF SEAS5 model to forecast the input to our early August statistical forecast model. The early August statistical forecast model shows the highest level of skill of any of our statistical models, since it is the model released just before the peak of the Atlantic hurricane season in September. ECMWF SEAS5 is able to forecast the large-scale fields that go into the early August statistical forecast model with considerable skill by March. We then use the forecasts of the individual parameters to forecast ACE for the 2020 season. All other predictands (e.g., named storms, major hurricanes) are calculated based on their historical relationships with ACE. It typically takes about two weeks after the initialization date to obtain SEAS5 output, so the results displayed here are from the model output from the 1 March forecast.

Figure 7 displays the parameters used in our early August statistical model, while Table 4 displays SEAS5's forecasts of these parameters for 2020 from a 1 March initialization date. Two of the three parameters call for above-normal activity, while the trade wind predictor in the Caribbean/tropical Atlantic indicates below-normal activity. However, the trade wind predictor has relatively less weight at the 1 March initialization time than the other two predictors, and consequently, the SEAS5 statistical/dynamical model is calling for a very active season. Figure 8 displays cross-validated hindcasts for SEAS5 forecast of ACE from 1982-2019, while Table 5 presents the forecast from SEAS5 for the 2020 Atlantic hurricane season.

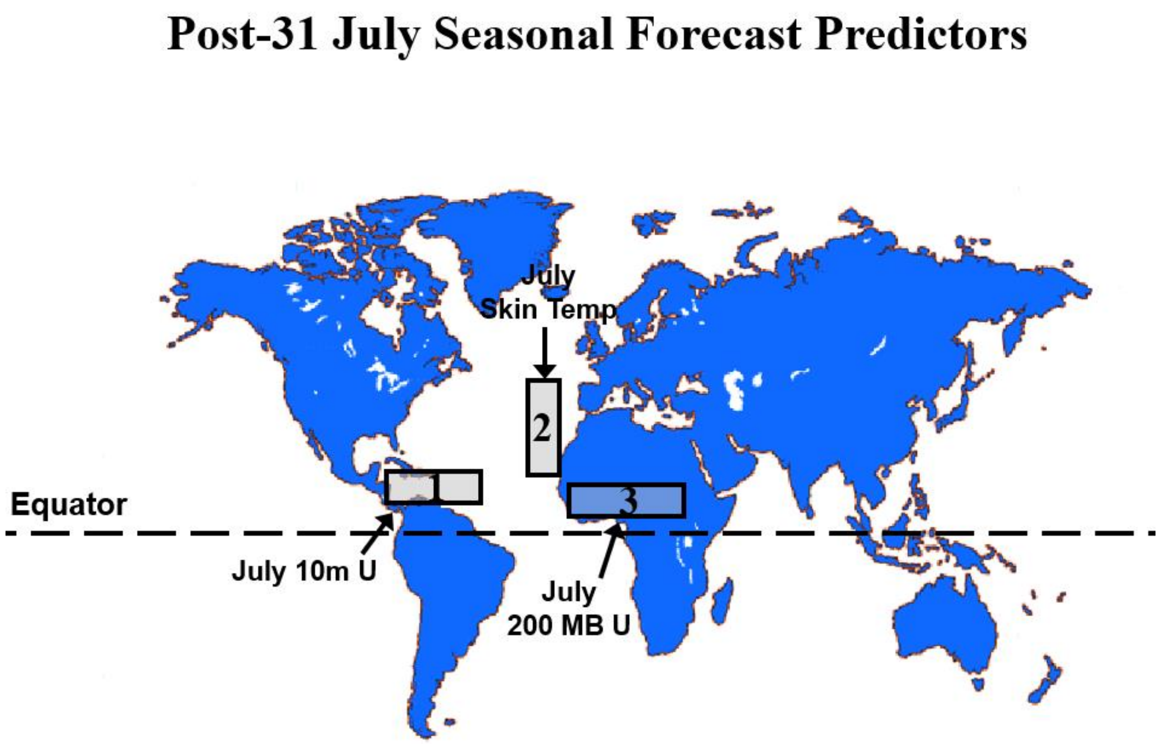

Figure 7: Location of predictors for our early April statistical/dynamical extended-range statistical prediction for the 2020 hurricane season. This forecast uses the ECMWF SEAS5 or GloSea5 models to predict July conditions in the three boxes displayed and uses those predictors to forecast ACE.

Table 4: Listing of predictions of July large-scale conditions from ECMWF SEAS5 output, initialized on 1 March. A plus (+) means that positive deviations of the parameter are associated with increased hurricane activity, while a minus (-) means that negative deviations of the parameter are associated with increased hurricane activity.

Predictor	Values for 2020 Forecast	Effect on 2020 Hurricane Season
1) ECMWF Prediction of July Surface U (10-20°N, 90-40°W) (+)	-0.5 SD	Suppress
2) ECMWF Prediction of July Skin Temperature (20-40°N, 35-15°W) (+)	+1.6 SD	Enhance
3) ECMWF Prediction of July 200 hPa U (5-15°N, 0-40°E) (-)	-0.8 SD	Enhance

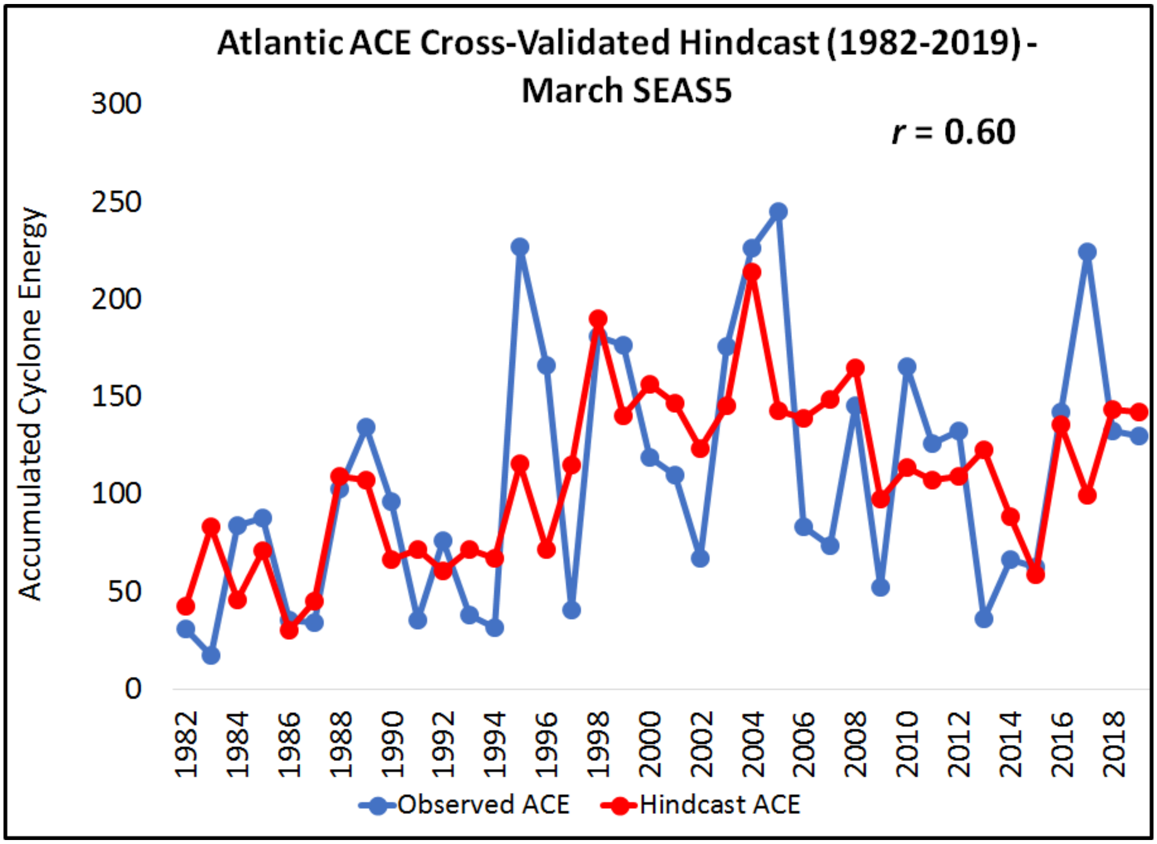

Figure 8: Observed versus early April cross-validated statistical/dynamical hindcast values of ACE for 1982-2019 from SEAS5.

Table 5: Statistical/dynamical model output from SEAS5 for the 2020 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1981-2010 Average (in parentheses)	Statistical/Dynamical Hybrid Forecast	Final Forecast
Named Storms (12.1)	16.9	16
Named Storm Days (59.4)	92.0	80
Hurricanes (6.4)	9.6	8
Hurricane Days (24.2)	41.0	35
Major Hurricanes (2.7)	4.6	4
Major Hurricane Days (6.2)	12.2	9
Accumulated Cyclone Energy Index (106)	180	150
Net Tropical Cyclone Activity (116%)	189	160

By combining the statistical model forecast and the statistical/dynamical model forecast from SEAS5, we can increase the hindcast skill from either model individually. As noted earlier, the statistical model has a cross-validated hindcast with ACE of r = 0.65, while the statistical/dynamical model has a cross-validated hindcast with ACE of r = 0.60. By simply averaging the forecasts from the two models together, we can improve the cross-validated hindcast variance explained to $r = 0.69$ – or nearly half of the variance in ACE (Figure 9).

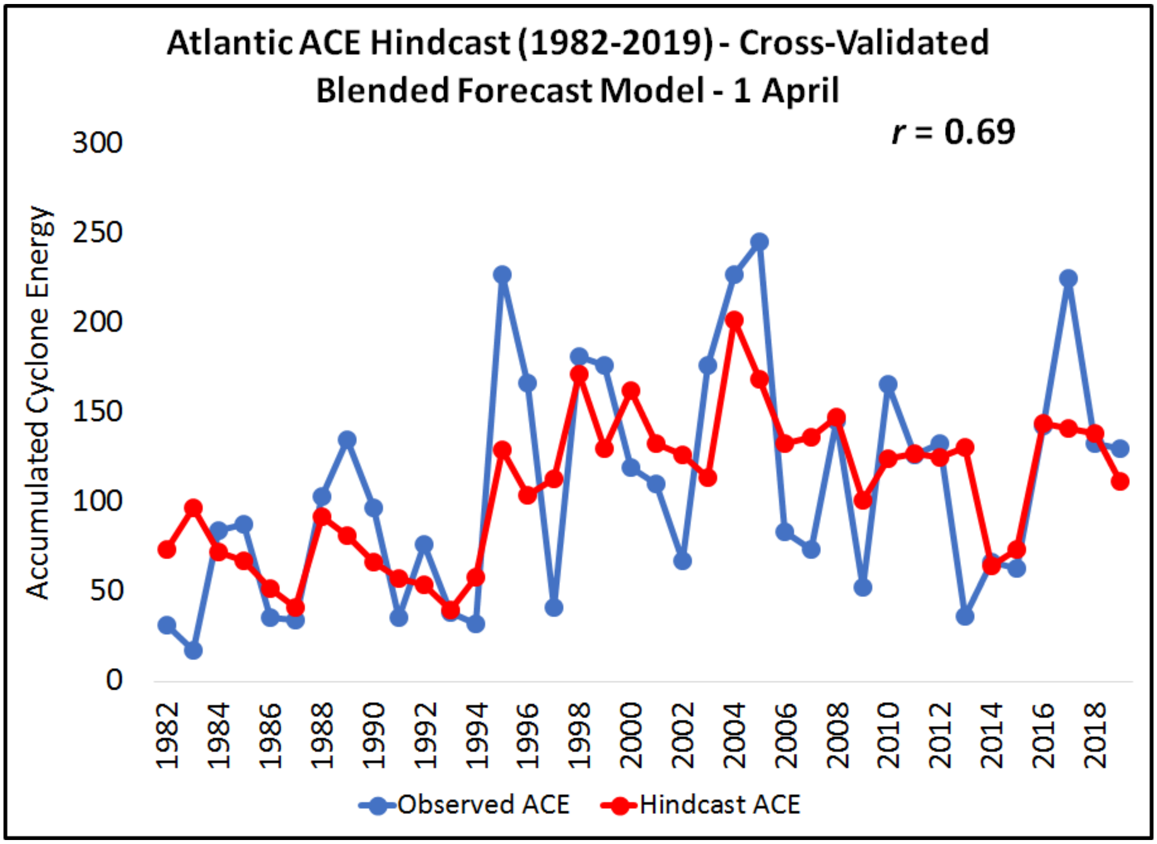

Figure 9: Observed versus early April blended (e.g., statistical and statistical/dynamical) model cross-validated hindcast values of ACE for 1982-2019.

In addition to forecasts from ECMWF SEAS5, we are incorporating a similar forecast from the UK Met Office's GloSea5 model this year. The GloSea5 model shows comparable levels of skill to ECMWF SEAS5 at predicting the large-scale fields going into the early August statistical forecast model based on GloSea5 hindcast data of 1993-2016. For example, Figure 10 displays the correlation between July low-level winds in the tropical Atlantic and Caribbean with both SEAS5 and GloSea5 model forecasts issued at various lead times from 1 March to 1 July.

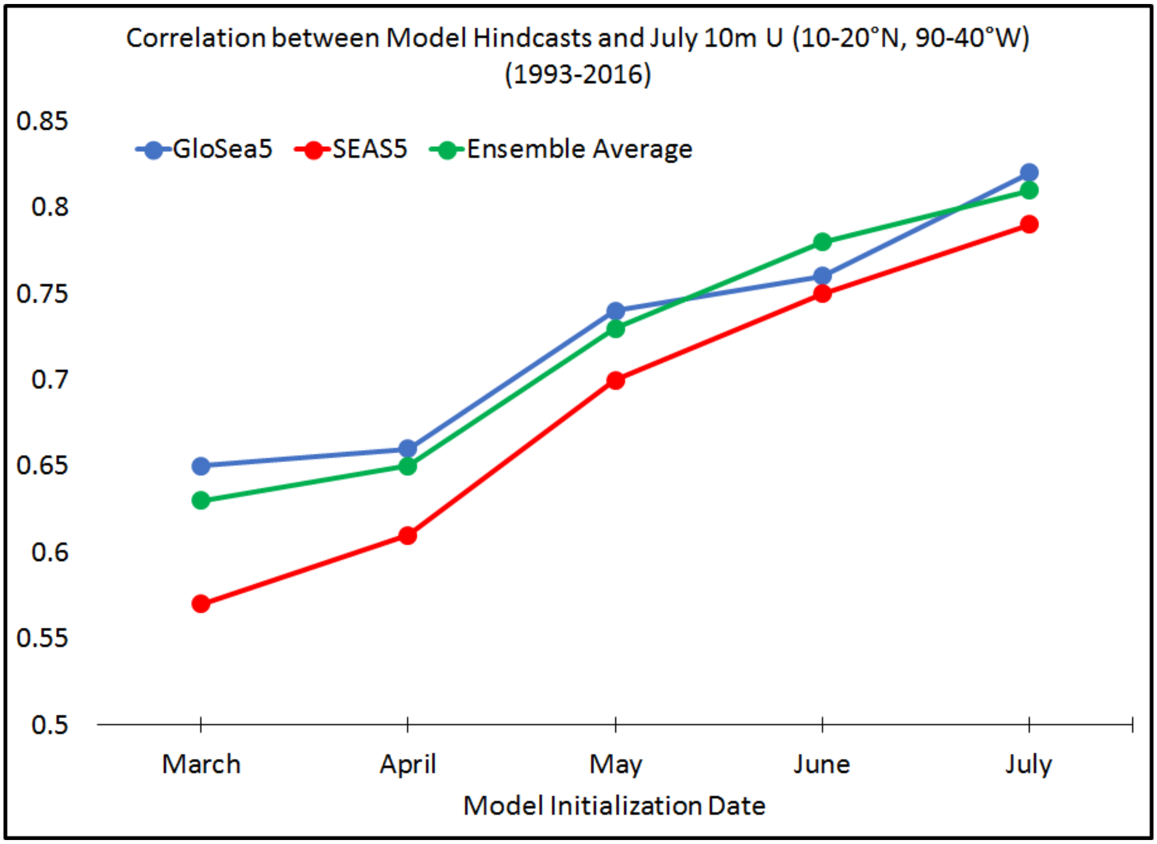

Figure 10: Correlation between model hindcasts issued at various lead times and July low-level wind in the tropical Atlantic and Caribbean based on data from 1993-2016.

The output from the GloSea5 model also calls for an above-average Atlantic hurricane season in 2020. Table 6 displays the forecasts of the three individual parameters comprising the early August statistical/dynamical hybrid forecast, while Table 7 displays the final forecast from the GloSea5 model.

Table 6: Listing of predictions of July large-scale conditions from the Met Office's GloSea5 model output, initialized on 1 March. A plus (+) means that positive deviations of the parameter are associated with increased hurricane activity, while a minus (-) means that negative deviations of the parameter are associated with increased hurricane activity.

Predictor	Values for 2020 Forecast	Effect on 2020 Hurricane Season
1) GloSea5 Prediction of July Surface U (10-20°N, 90-40°W) (+)	-0.3 SD	Suppress
2) GloSea5 Prediction of July Skin Temperature (20-40°N, 35-15°W) (+)	+3.1 SD	Enhance
3) GloSea5 Prediction of July 200 hPa U (5-15°N, 0-40°E) (-)	-0.5 SD	Enhance

Table 7: Statistical/dynamical model output from GloSea5 for the 2020 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1981-2010 Average (in parentheses)	Statistical/Dynamical Hybrid Forecast	Final Forecast
Named Storms (12.1)	14.8	16
Named Storm Days (59.4)	76.3	80
Hurricanes (6.4)	7.9	8
Hurricane Days (24.2)	31.9	35
Major Hurricanes (2.7)	3.5	4
Major Hurricane Days (6.2)	8.9	9
Accumulated Cyclone Energy Index (106)	141	150
Net Tropical Cyclone Activity (116%)	151	160

2.3 April Analog Forecast Scheme

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2020. These years also provide useful clues as to likely levels of activity that the forthcoming 2020 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 2020 conditions and, more importantly, projected August-October 2020 conditions. Table 8 lists our analog selections.

We searched for years that were generally characterized by cool neutral ENSO to weak La Niña conditions during August-October. We selected years that had near- to above-average SSTs in the tropical Atlantic. We anticipate that the 2020 hurricane season will have activity near the average of our five analog years.

Table 8: Analog years for 2020 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
1966	11	64.00	7	41.75	3	8.75	145	140
1980	11	62.25	9	38.25	2	7.25	149	130
1996	13	79.00	9	45.00	6	13.00	166	192
2008	16	88.25	8	30.50	5	7.50	146	162
Average	11.8	65.4	7.4	34.1	3.6	9.0	136	143
2020 Forecast	**16**	**80**	**8**	**35**	**4**	**9**	**150**	**160**

2.4 April Forecast Summary and Final Adjusted Forecast

Table 9 shows our final adjusted early April forecast for the 2020 season which is a combination of our statistical scheme, our two statistical/dynamical schemes, our analog scheme and qualitative adjustments for other factors not explicitly contained in any of these schemes. All four of our schemes call for above-average Atlantic hurricane activity this year. Our forecast is near the average of the four schemes and calls for an above-normal season, due to both anticipated cool ENSO neutral or weak La Niña conditions as well as anomalously warm SSTs in the tropical Atlantic for the peak of the Atlantic hurricane season (August-October).

Table 9: Summary of our early April statistical forecast, our statistical/dynamical forecast, our analog forecast, the average of those four schemes and our adjusted final forecast for the 2020 hurricane season.

Forecast Parameter and 1981-2010 Average (in parentheses)	Statistical Scheme	SEAS5 Scheme	GloSea5 Scheme	Analog Scheme	4-Scheme Average	Adjusted Final Forecast
Named Storms (12.1)	16.3	16.9	14.8	11.8	15.0	16
Named Storm Days (59.4)	87.6	92.0	76.3	65.4	80.3	80
Hurricanes (6.4)	9.1	9.6	7.9	7.4	8.5	8
Hurricane Days (24.2)	38.4	41.0	31.9	34.1	36.4	35
Major Hurricanes (2.7)	4.3	4.6	3.5	3.6	4.0	4
Major Hurricane Days (6.2)	11.3	12.2	8.9	9.0	10.4	9
Accumulated Cyclone Energy Index (106)	169	180	141	136	157	150
Net Tropical Cyclone Activity (116%)	178	189	151	143	165	160

3 Forecast Uncertainty

One of the questions that we are asked regarding our seasonal hurricane predictions is the degree of uncertainty that is involved. This season we are unveiling probability of exceedance curves using the methodology outlined in Saunders et al. (2020). In that paper, we outlined an approach that uses statistical modeling and historical skill of various forecast models to arrive at a probability that particular values for hurricane numbers and ACE would be exceeded. Here we display probability of exceedance curves for hurricanes and ACE (Figures 11 and 12), using the error distributions calculated from both normalized cross-validated statistical as well as the cross-validated statistical/dynamical hindcasts from SEAS5. Hurricane numbers are fit to a Poisson distribution, while ACE is fit to a Weibull distribution. Table 10 displays one standard deviation uncertainty ranges (~68% of all forecasts within this range). This uncertainty estimate is also very similar to the 70% uncertainty range that NOAA provides with its forecasts. We use Poisson distributions for all storm parameters (e.g., named storms, hurricanes and major hurricanes) while we use a Weibull distribution for all integrated parameters except for major hurricane days (e.g., named storm days, ACE, etc.). We use a Laplace distribution for major hurricane days.

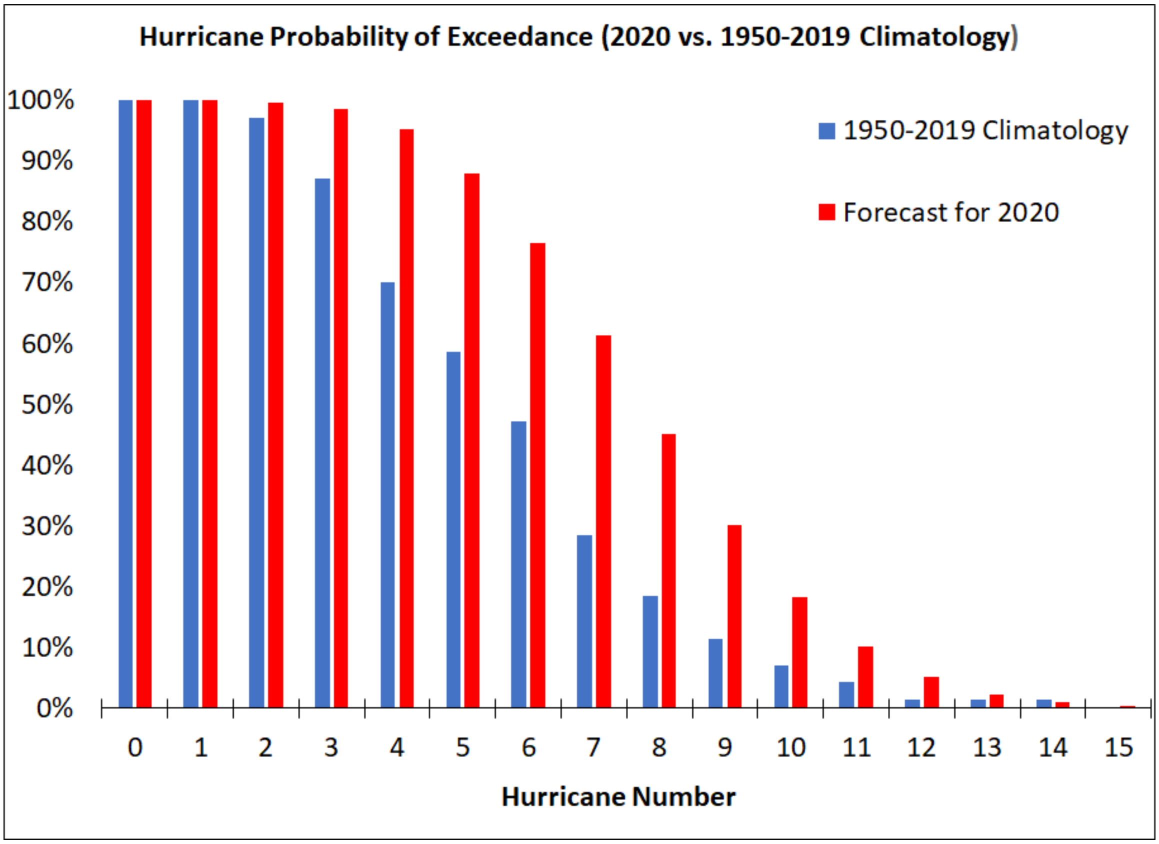

Figure 11: Probability of exceedance plot for hurricane numbers for the 2020 Atlantic hurricane season. The values on the x-axis indicate that the number of hurricanes exceeds that specific number. For example, 97% of Atlantic hurricane seasons from 1950-2019 have had more than two hurricanes.

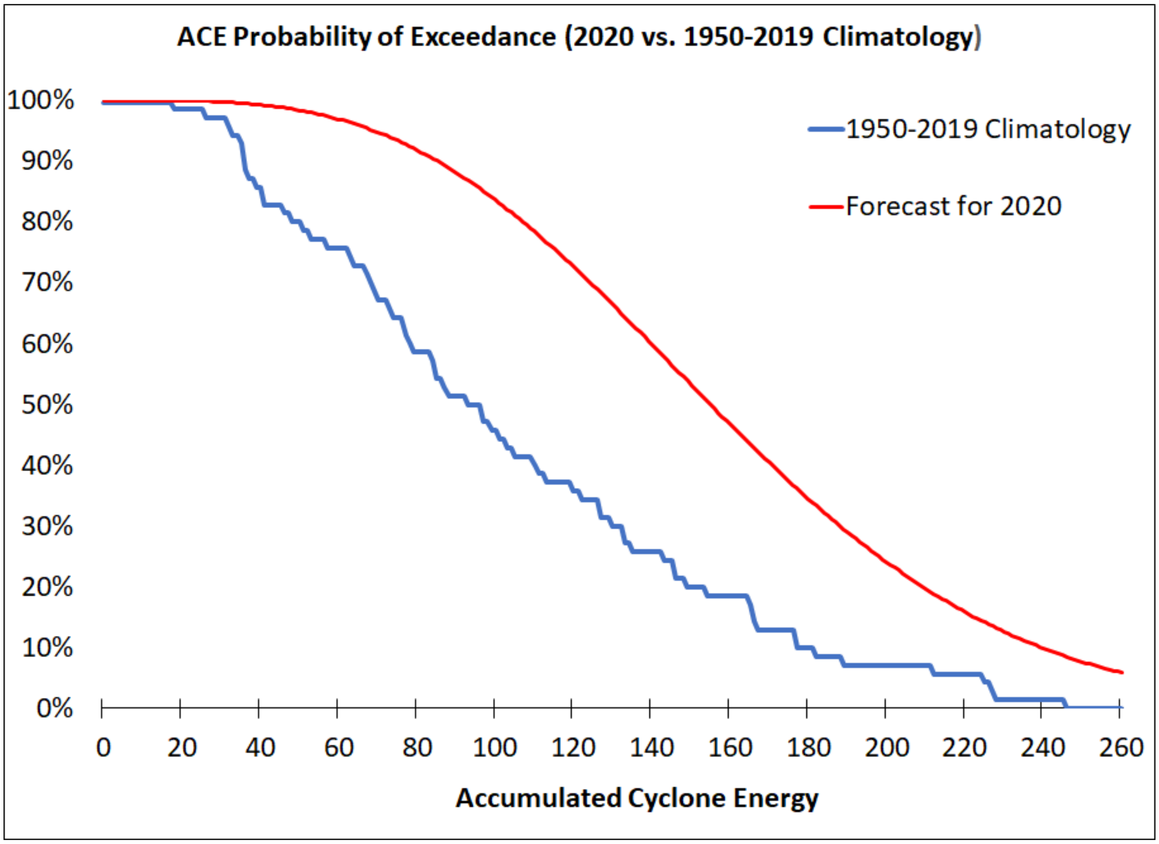

Figure 12: As in Figure 11 but for ACE.

Table 10: Forecast ranges for each parameter. Note that the forecast spread may not be symmetric around the mean value, given the historical distribution of tropical cyclone activity.

Parameter	2020 Forecast	Uncertainty Range (68% of Forecasts Likely to Fall in This Range)
Named Storms (NS)	16	13 – 19
Named Storm Days (NSD)	80	60 – 100
Hurricanes (H)	8	6 – 10
Hurricane Days (HD)	35	23 – 48
Major Hurricanes (MH)	4	3 – 6
Major Hurricane Days (MHD)	9	6 – 13
Accumulated Cyclone Energy (ACE)	150	104 – 201
Net Tropical Cyclone (NTC) Activity	160	115 – 208

4 ENSO

The tropical Pacific has been broadly characterized by warm neutral ENSO conditions since last summer (Figure 13). ENSO events are partially defined by NOAA based on SST anomalies in the Nino 3.4 region, which is defined as 5°S-5°N, 170-120°W. Warm neutral ENSO conditions are defined by anomalies between 0°C – 0.5°C. Over the past several months, SST anomalies have remained nearly stationary. However, we believe that there are signs that the eastern and central tropical Pacific may begin anomalously cooling over the next couple of months.

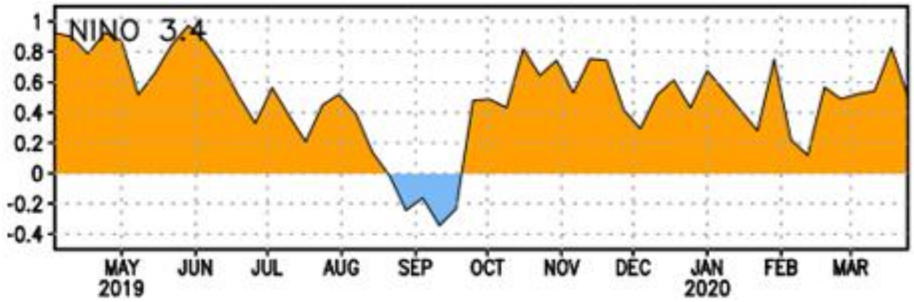

Figure 13: Nino 3.4 SST anomalies from April 2019 through March 2020. Figure courtesy of Climate Prediction Center.

Upper-ocean heat content anomalies in the eastern and central tropical Pacific have been at above-normal levels since last October (Figure 14). These anomalies peaked at 0.8°C in late October, decreased until late November, increased until early January and have persisted around 0.5°C over the past several months.

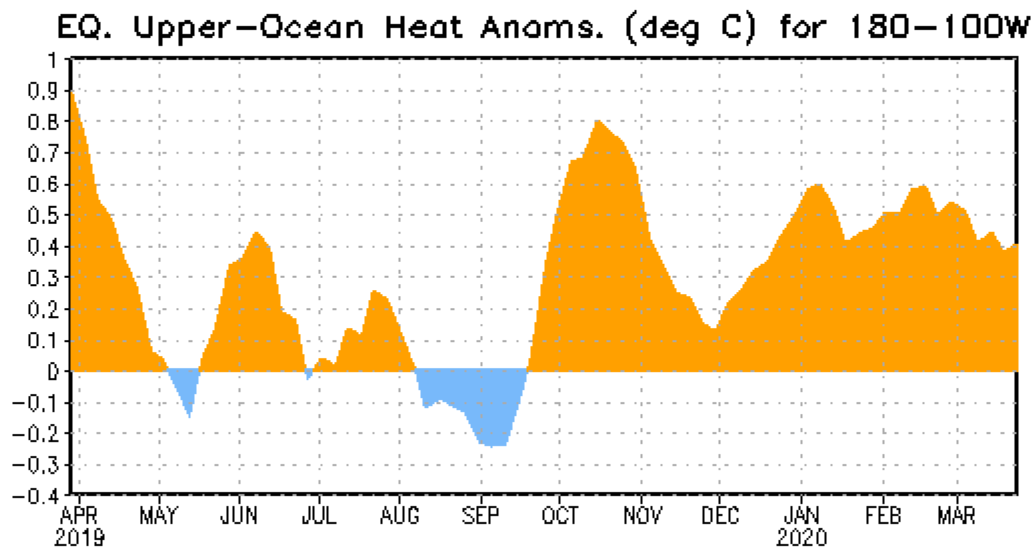

Figure 14: Central and eastern equatorial Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Upper ocean heat content anomalies have generally been around 0.5°C since January 2020.

SSTs are above normal across most of the tropical Pacific right now (Figure 15). Portions of the eastern and central subtropical Pacific are anomalously cool.

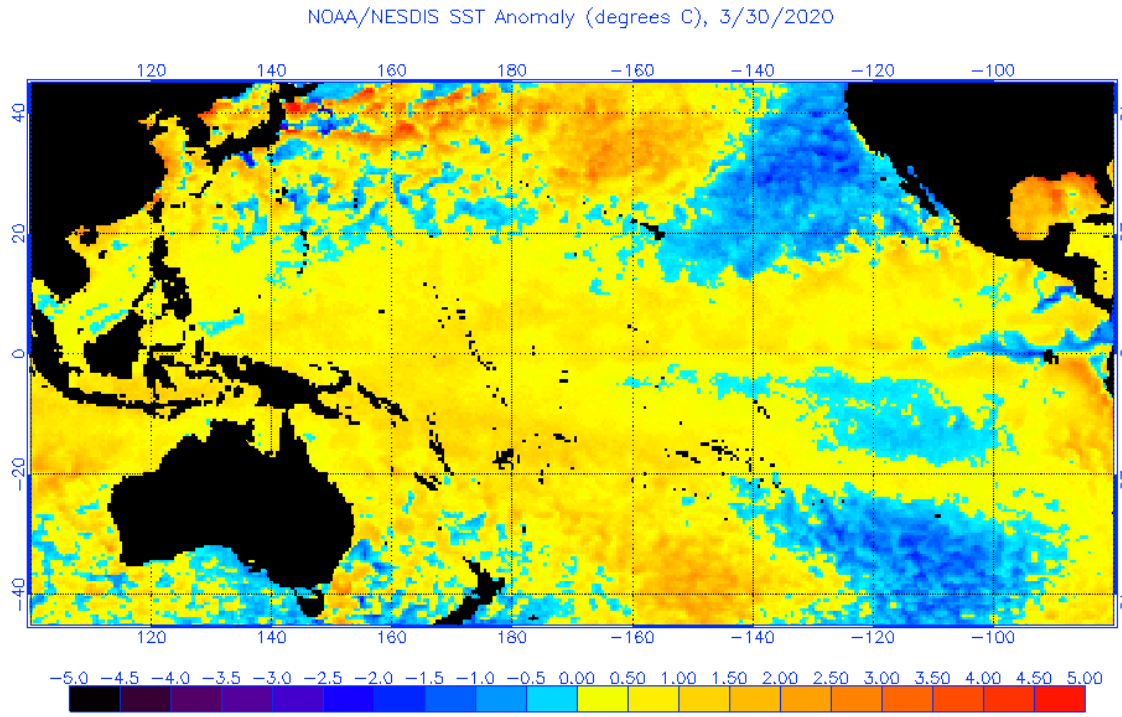

Figure 15: Current SST anomalies across the tropical and subtropical Pacific.

Table 11 displays January and March SST anomalies for several Nino regions. Anomalies have trended slightly upward over the past couple of months across most of the central and eastern tropical Pacific. However, as will be discussed in the next several paragraphs, there are indications that anomalous cooling may begin in the tropical Pacific in the next few weeks.

Table 11: 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	+0.0	+0.6	+0.6
Nino 3	+0.2	+0.3	+0.1
Nino 3.4	+0.5	+0.6	+0.1
Nino 4	+1.0	+1.0	0.0

The tropical Pacific has experienced a couple of downwelling (warming) Kelvin waves (denoted by the long dashed line) since late last fall, with the most recent downwelling Kelvin wave currently nearing South America (Figure 16). These downwelling Kelvin waves are typically triggered by anomalous low-level westerly winds in the tropical Pacific. While it does not happen on every occasion, often downwelling (warming) Kelvin waves are followed by upwelling (cooling) Kelvin waves, as indicated by the short dashed lines in Figure 16.

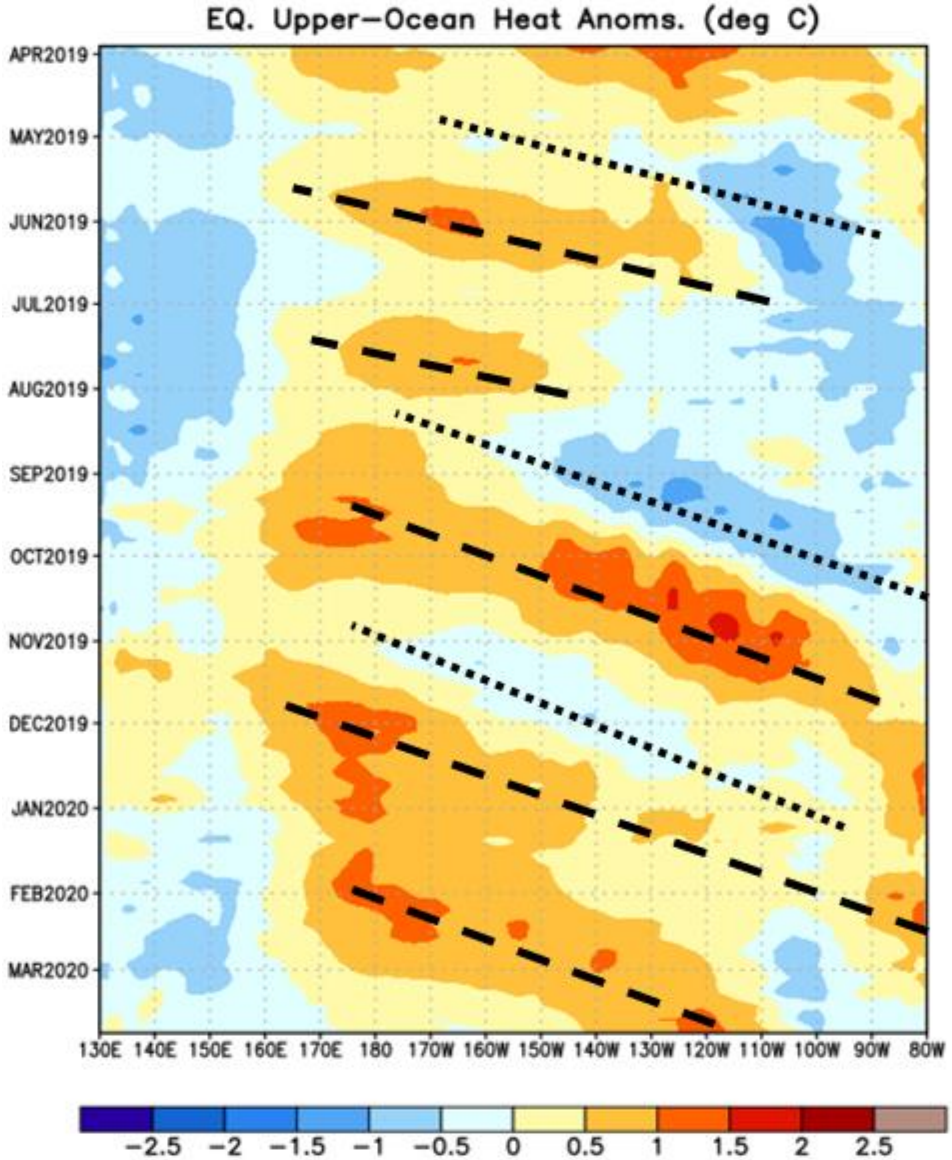

Figure 16: Upper-ocean heat content anomalies in the tropical Pacific since April 2019. Dashed lines indicate downwelling Kelvin waves, while dotted lines indicate upwelling Kelvin waves. Downwelling Kelvin waves result in upper-ocean heat content increases, while upwelling Kelvin waves result in upper-ocean heat content decreases.

Over the next several months, we will be closely monitoring low-level winds over the tropical Pacific. Anomalous easterlies are currently observed across the central tropical Pacific, and the Climate Forecast System (CFS) is forecasting a briefly westerly wind episode followed by near-average wind speeds (Figure 17). Consequently, we believe that there is likely to be some anomalous cooling taking place in the tropical Pacific over the next several weeks. While it remains too early to confidently know what the state of ENSO will be in August through October, we think that the odds of an El Niño event are relatively small.

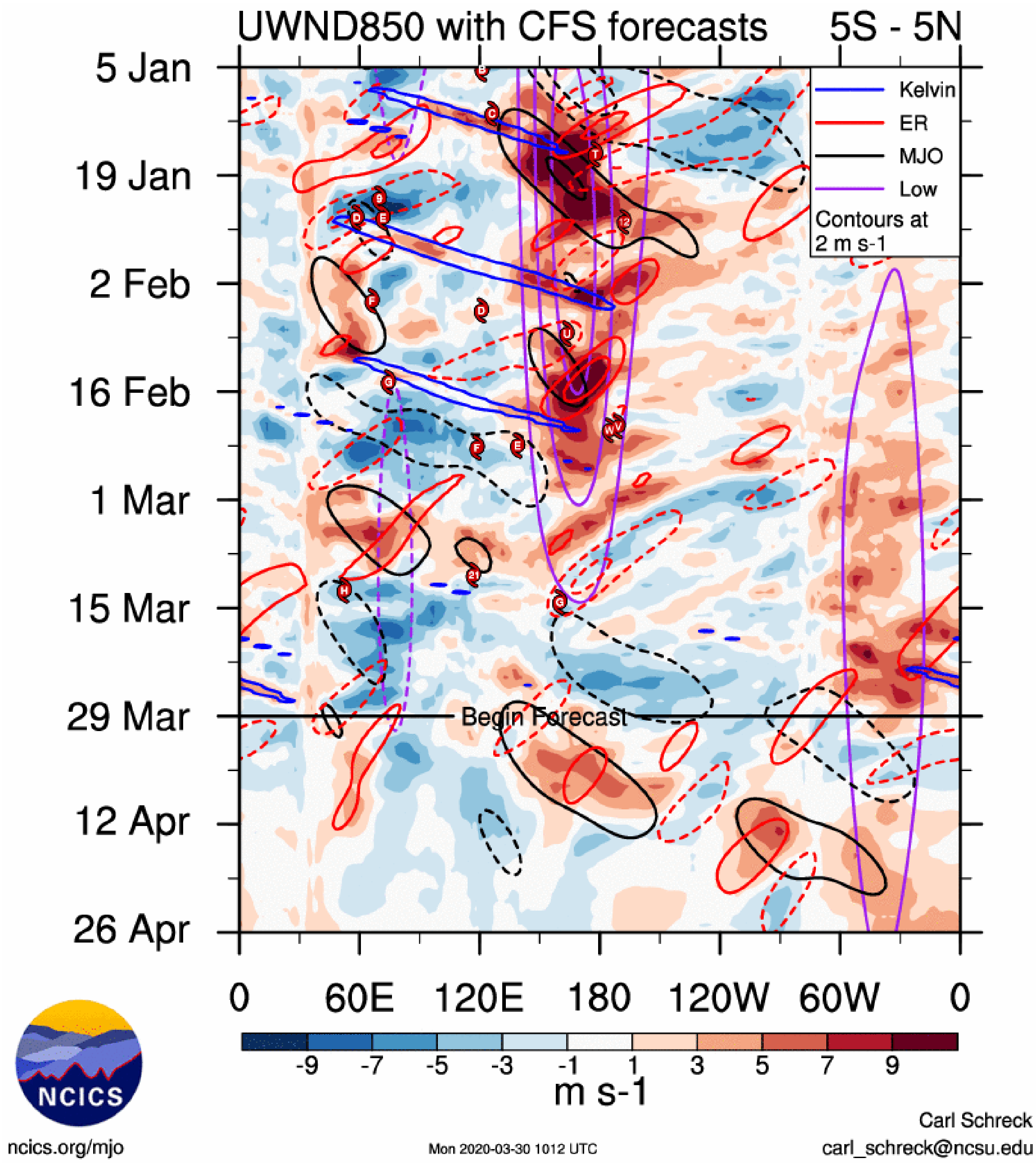

Figure 17: Observed low-level winds across the equatorial region as well as predictions for the next four weeks by the Climate Forecast System. Figure courtesy of Carl Schreck.

There is always considerable uncertainty with the future state of El Niño during the Northern Hemisphere spring. The latest plume of ENSO predictions from several statistical and dynamical models shows a large spread by the peak of the Atlantic hurricane season in August-October (Figure 18). Most models indicate some anomalous cooling between now and the peak of the Atlantic hurricane season, however.

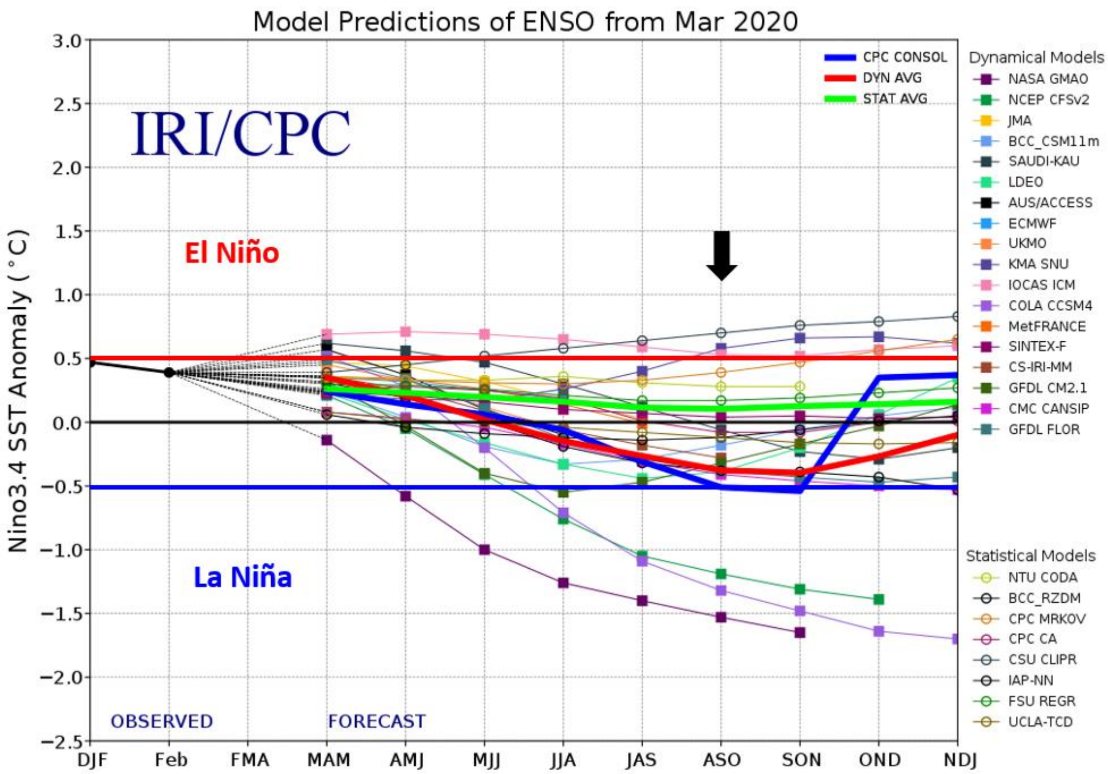

Figure 18: ENSO forecasts from various statistical and dynamical models for the Nino 3.4 SST anomaly based on late February to early March initial conditions. Most models are calling for ENSO neutral conditions for August-October. Figure courtesy of the International Research Institute (IRI).

The latest official forecast from NOAA also indicates that the chances of El Niño are relatively low for August-October. NOAA is currently predicting a 20% chance of El Niño, a 45% chance of ENSO neutral conditions and a 35% chance of La Niña for the peak of the Atlantic hurricane season (Figure 19).

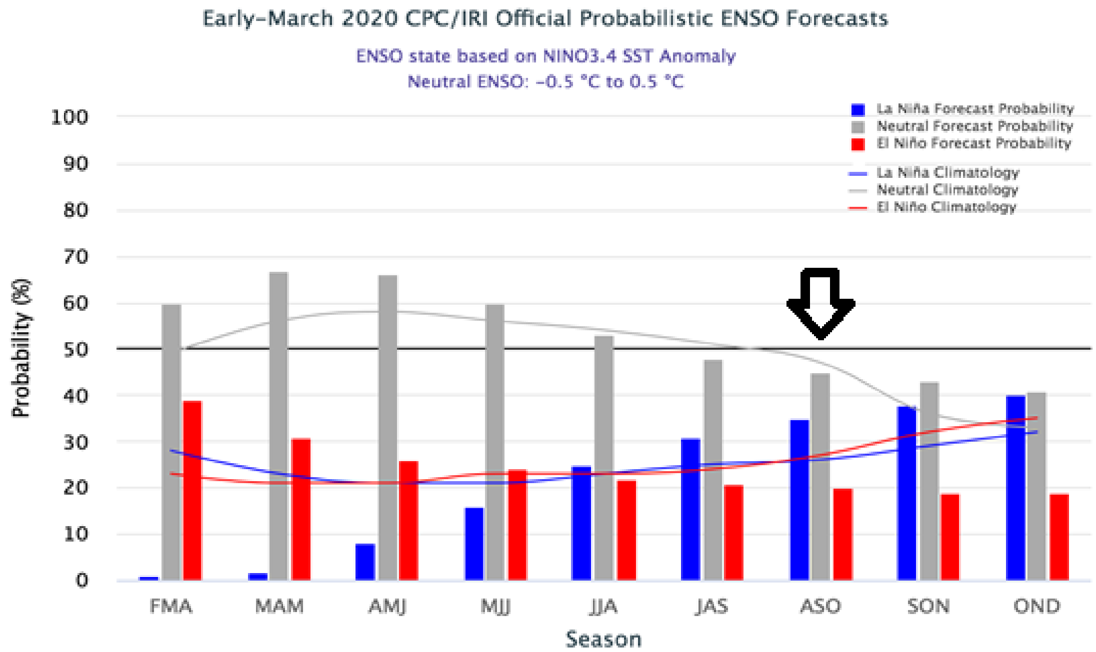

Figure 19: Official NOAA forecast for ENSO.

Based on the above information, our best estimate is that we will likely not have El Niño conditions for the peak of the Atlantic hurricane season. Even if El Niño does not develop, there remains considerable uncertainty as to whether the tropical Pacific will have neutral ENSO conditions or transition towards La Niña. We will have much more to say with our next forecast release on 4 June.

5 Current Atlantic Basin Conditions

The current SST pattern across the North Atlantic basin is characterized by cold SSTs in the far North Atlantic, warm SST anomalies off of the East Coast and across the subtropical Atlantic, near-average SSTs in portions of the subtropical eastern Atlantic and anomalously warm SSTs in the Caribbean and across most of the tropical Atlantic. While the cold SSTs in the far North Atlantic are characteristic of the negative phase of the Atlantic Multi-decadal Oscillation (AMO), the anomalous warmth across most of the tropical Atlantic is not characteristic of a typical negative AMO phase (Figure 20).

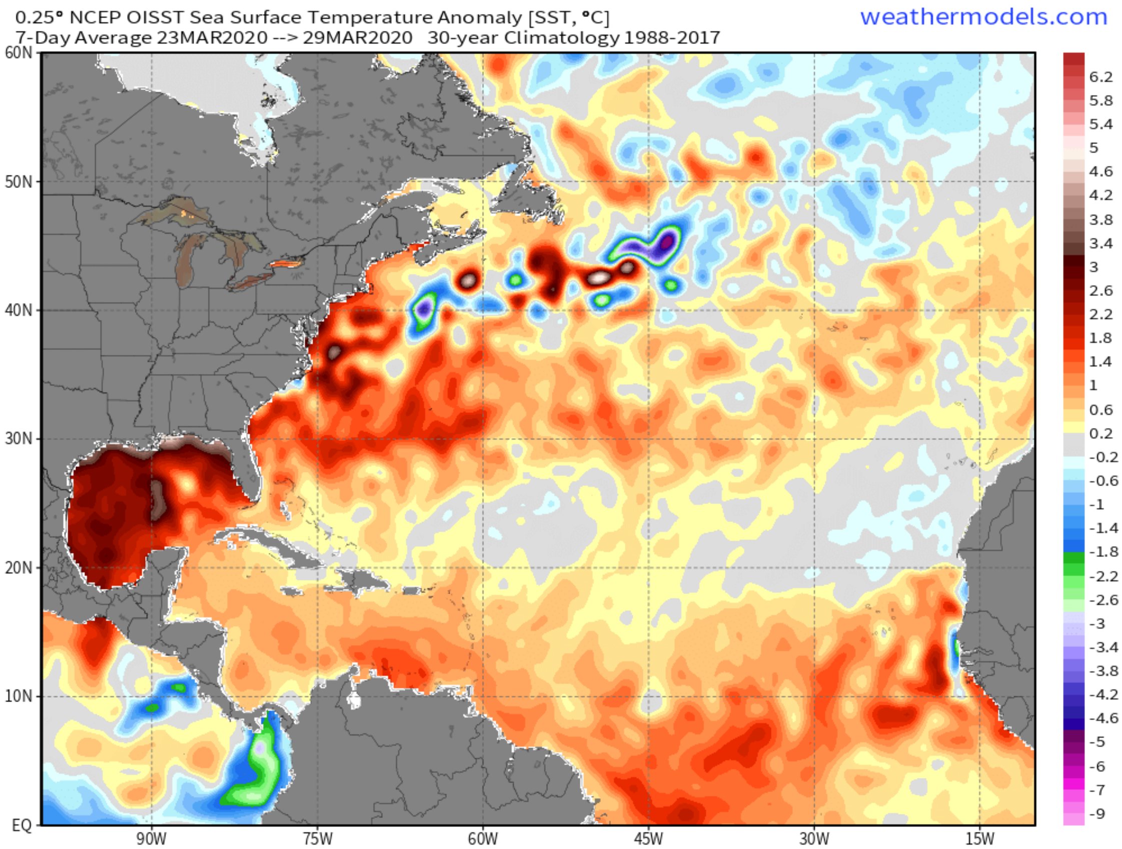

Figure 20: Late March 2020 SST anomaly pattern across the Atlantic Ocean.

The Atlantic had a similar SST pattern in the western Atlantic in late December 2019 (Figure 21). However, the anomalously cool SSTs in the far North Atlantic are stronger now than they were then, while most of the tropical Atlantic has anomalously warmed. In addition, the anomalous cooling off of the west coast of Africa late last year has been replaced by much warmer than normal SSTs. As has been the case the past few winters, we tended to have a positive phase of the North Atlantic Oscillation (NAO) through the winter of 2019/20 (Figure 22), which tends to force a tripole pattern of SSTs characterized by anomalous warmth off of the US East Coast and anomalous cold in the far North Atlantic and in the tropical Atlantic. The strongest pressure anomalies this year have been shifted a bit farther northward than is sometimes the case with positive NAO events, which has prevented significant anomalous cooling of the tropical Atlantic. Overall, the current SST anomaly pattern correlates relatively well with what is typically seen in active Atlantic hurricane seasons (Figure 23). We will be closely monitoring trends in Atlantic SST conditions over the next several months.

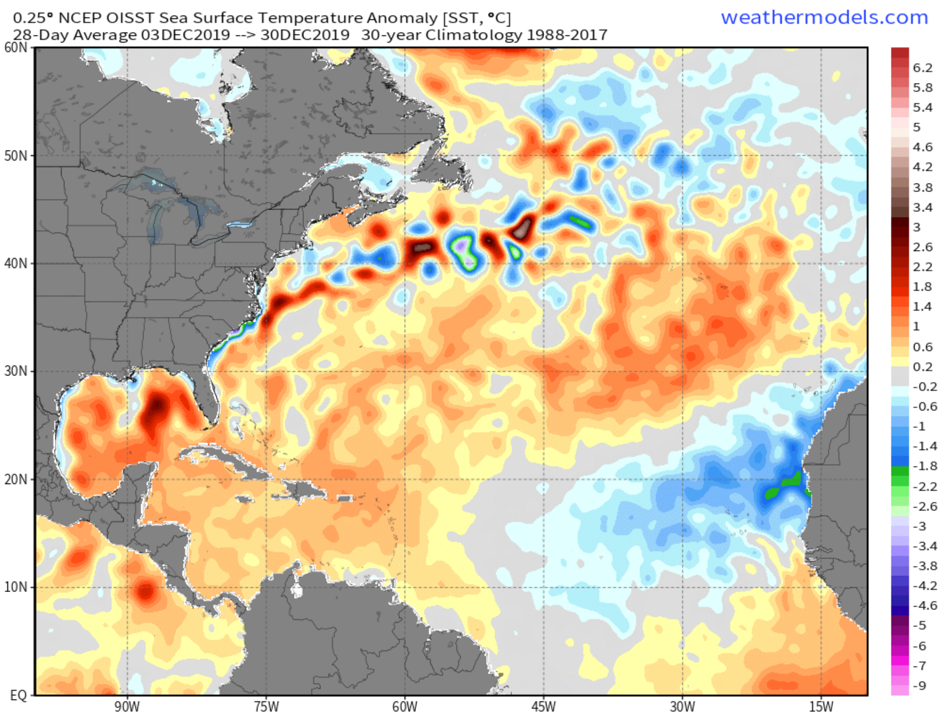

Figure 21: Late December 2019 North Atlantic SST anomalies.

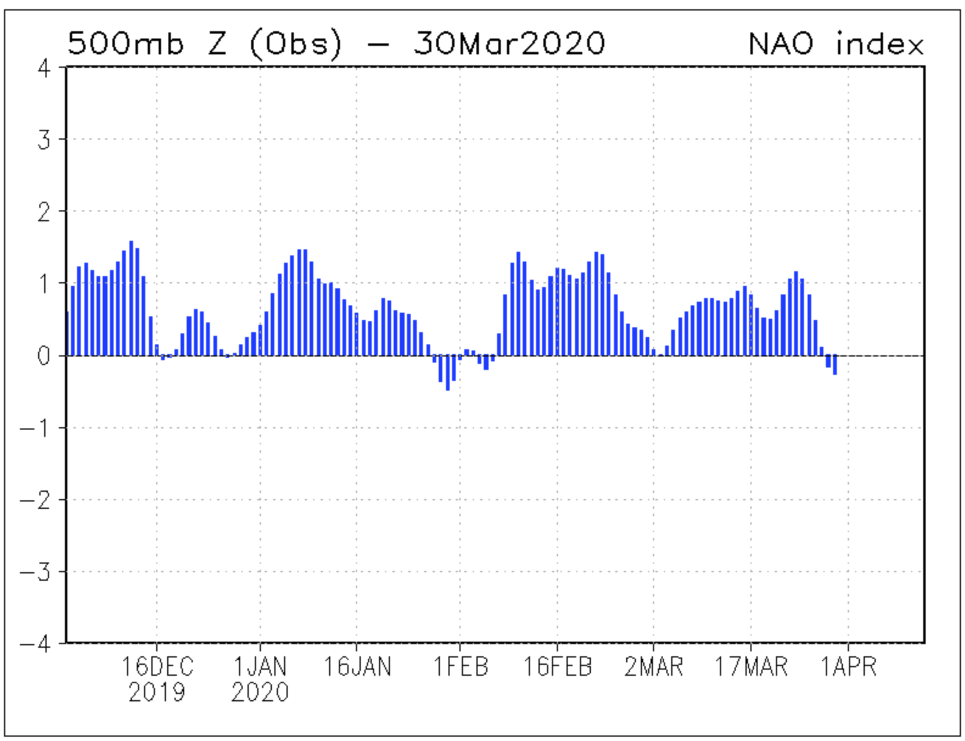

Figure 22: Observed standardized values of the daily NAO since December 2019. The NAO has generally been positive throughout the winter of 2019/20.

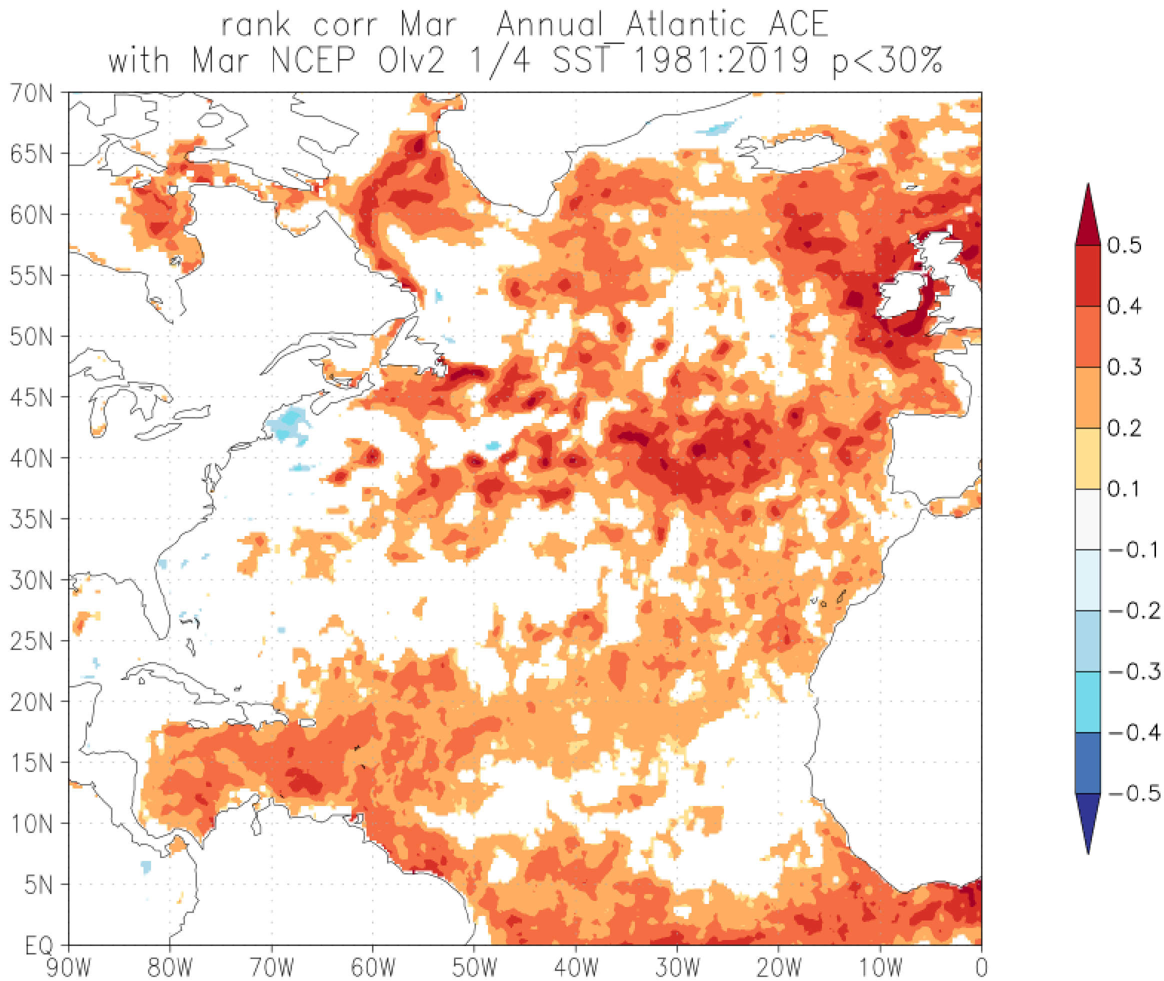

Figure 23: Rank correlation between March North Atlantic SST anomalies and seasonal Atlantic ACE from 1982-2019.

6 Landfall Probabilities for 2020

A significant focus of our 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 to be linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 12). 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 12: 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 13 lists landfall probabilities for the 2020 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 2020 is expected to be above its long-term average of 100, and therefore, landfall probabilities are 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 13: 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 2020. 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)	92% (79%)	84% (68%)	69% (52%)	95% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	76% (59%)	59% (42%)	44% (30%)	77% (60%)	94% (83%)
Florida plus East Coast (Regions 5-11)	67% (50%)	60% (44%)	45% (31%)	78% (61%)	93% (81%)
Caribbean (10-20°N, 60-88°W)	94% (82%)	74% (57%)	58% (42%)	89% (75%)	99% (96%)

7 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, as well as output from dynamical models, indicate that 2020 should have above-normal activity. The big question marks with this season's predictions revolve around what phase ENSO will be, as well as what the configuration of SSTs will look like in the Atlantic Ocean during the peak of the Atlantic hurricane season.

8 Forthcoming Updated Forecasts of 2020 Hurricane Activity

We will be issuing seasonal updates of our 2020 Atlantic basin hurricane forecasts on **Thursday 4 June**, **Tuesday 7 July, and Thursday 6 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 2020 forecasts will be issued in late November 2020. All of these forecasts will be available on our website.

9 Verification of Previous Forecasts

Table 14: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity from 2015-2019.

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

2017	6 April	Update 1 June	Update 5 July	Update 4 August	Obs.
Hurricanes	4	6	8	8	10
Named Storms	11	14	15	16	17
Hurricane Days	16	25	35	35	51.25
Named Storm Days	50	60	70	70	91.25
Major Hurricanes	2	2	3	3	6
Major Hurricane Days	4	5	7	7	19.25
Accumulated Cyclone Energy	75	100	135	135	226
Net Tropical Cyclone Activity	85	110	140	140	231

2018	5 April	Update 31 May	Update 2 July	Update 2 August	Obs.
Hurricanes	7	6	4	5	8
Named Storms	14	14	11	12	15
Hurricane Days	30	20	15	15	26.75
Named Storm Days	70	55	45	53	87.25
Major Hurricanes	3	2	1	1	2
Major Hurricane Days	7	4	2	2	5.00
Accumulated Cyclone Energy	130	90	60	64	129
Net Tropical Cyclone Activity	135	100	70	78	128

2019	4 April	Update 4 June	Update 9 July	Update 5 August	Obs.
Hurricanes	5	6	6	7	6
Named Storms	13	14	14	14	18
Hurricane Days	16	20	20	20	23.25
Named Storm Days	50	55	55	55	68.5
Major Hurricanes	2	2	2	2	3
Major Hurricane Days	4	5	5	5	10
Accumulated Cyclone Energy	80	100	100	105	130
Net Tropical Cyclone Activity	90	105	105	110	142