EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2021

We have increased our forecast slightly and continue to forecast an above-average 2021 Atlantic basin hurricane season. Current neutral ENSO conditions are anticipated to persist for the next several months. Sea surface temperatures averaged across most of the tropical Atlantic are now near to slightly above normal, and most of the subtropical North Atlantic remains warmer than normal. Elsa's development and intensification into a hurricane in the tropical Atlantic also typically portends an active season. We anticipate an above-normal 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 8 July 2021)

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

Jennifer Dimas, Colorado State University media representative, is coordinating media inquiries into this verification. She can be reached at 970-491-1543 or
Jennifer.Dimas@colostate.edu

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523

Project Sponsors:

EVEX
INSURANCE INFORMATION INSTITUTE
IRONSHORE A Liberty Mutual Company
WEATHERBOY.COM

[1] Research Scientist
[2] Associate Professor
[3] Graduate Research Assistant
[4] Professor Emeritus

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2021

Forecast Parameter and 1991-2020 Average (in parentheses)	Issue Date 8 April 2021	Issue Date 3 June 2021	Issue Date 8 July 2021	Observed Thru 7 July 2021	Remainder of Season Forecast
Named Storms (NS) (14.4)	17	18	20*	5	15
Named Storm Days (NSD) (69.4)	80	80	90	12	78
Hurricanes (H) (7.2)	8	8	9	1	8
Hurricane Days (HD) (27.0)	35	35	40	1.5	38.5
Major Hurricanes (MH) (3.2)	4	4	4	0	4
Major Hurricane Days (MHD) (7.4)	9	9	9	0	9
Accumulated Cyclone Energy (ACE) (123)	150	150	160	12	148
Net Tropical Cyclone Activity (NTC) (135%)	160	160	170	16	154

*Total forecast includes Ana, Bill, Claudette, Danny and Elsa which have formed in the Atlantic as of July 7th.

PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE LANDFALL ON EACH OF THE FOLLOWING COASTAL AREAS (AFTER 7 JULY):

1) Entire continental U.S. coastline - 68% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 43% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 43% (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) (AFTER 7 JULY):

1) 57% (average for last century is 42%)

ABSTRACT

Information obtained through early July 2021 indicates that the 2021 Atlantic hurricane season will have activity above the 1991-2020 average. Ana, Bill, Claudette, Danny and Elsa have already formed as of 7 July. We estimate that the full (e.g., including storms that have already formed) 2021 season will have 9 hurricanes (full-season average is 7.2), 20 named storms (full-season average is 14.4), 90 named storm days (full-season average is 69.4), 40 hurricane days (full-season average is 27.0), 4 major (Category 3-4-5) hurricanes (full-season average is 3.2) and 9 major hurricane days (full-season average is 7.4). The probability of U.S. major hurricane landfall for the remainder of the season is estimated to be about 130 percent of the long-period full-season average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2021 to be approximately 130 percent of their long-term averages.

This forecast is based on an extended-range early July statistical prediction scheme that was developed using 39 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 GloSea6 model as two additional forecast guidance tools. The statistical model, the two statistical/dynamical models and the analog model all call for an above-average Atlantic hurricane season. We also present probabilities of exceedance for hurricanes and Accumulated Cyclone Energy to give interested readers a better idea of the uncertainty associated with these forecasts.

The tropical Pacific is currently characterized by neutral ENSO conditions, and we anticipate that neutral ENSO conditions are the most likely scenario for the peak of this year's Atlantic hurricane season. It appears very unlikely that El Niño conditions will develop over the next few months. El Niño typically reduces Atlantic hurricane activity through increases in vertical wind shear.

The tropical Atlantic currently has near to slightly above-normal sea surface temperatures, while most of the subtropical North Atlantic is warmer than normal. This sea surface temperature configuration is typically associated with more active hurricane seasons. In addition, while early season Atlantic hurricane activity is typically not associated with the remainder of the season's activity, hurricanes in the tropical Atlantic and eastern Caribbean (e.g., Elsa) are typically associated with very active Atlantic hurricane seasons.

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 July forecast has good long-term skill when evaluated in hindcast mode. The hindcast skill of CSU's forecast continues to improve with its early August update.

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 July. 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 July statistical and statistical/dynamical hybrid models show strong evidence on ~25-40 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 improved quantification 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 Ironshore Insurance, the Insurance Information Institute, Weatherboy and Evex. We acknowledge a grant from the G. Unger Vetlesen Foundation for additional financial support.

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 1991-2020 average value of this parameter is 123 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.

ENSO Longitude Index – An index defining ENSO that estimates the average longitude of deep convection associated with the Walker Circulation.

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.

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 38th 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 July forecast is based on a statistical model 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 GloSea6 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. 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 July Forecast Methodology

2.1 July Statistical Forecast Scheme

The July statistical forecast scheme that we are using this year was used for the first time last year and was developed over the period from 1982-2019. The model uses

ECMWF Reanalysis 5 (ERA5) (Hersbach 2020) as well as NOAA Optimum Interpolation (OI) SST (Reynolds et al. 2002). The ERA5 reanalysis currently extends from 1979 to present with a preliminary backward extension to 1950. 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 OISST (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 = 0.79) over the period from 1982-2019 and a real-time forecast in 2020.

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 1982-2020 period. All predictors correlate significantly at the 5% level using a two-tailed Student's t-test and assuming that each year is independent of the prior year (e.g., the correlation between ACE in two consecutive years is very low). Table 2 displays the 2021 observed values for each of the four predictors in the statistical forecast scheme. Table 3 displays the statistical model output for the 2021 hurricane season. Three of the four predictors call for increased Atlantic hurricane activity in 2021.

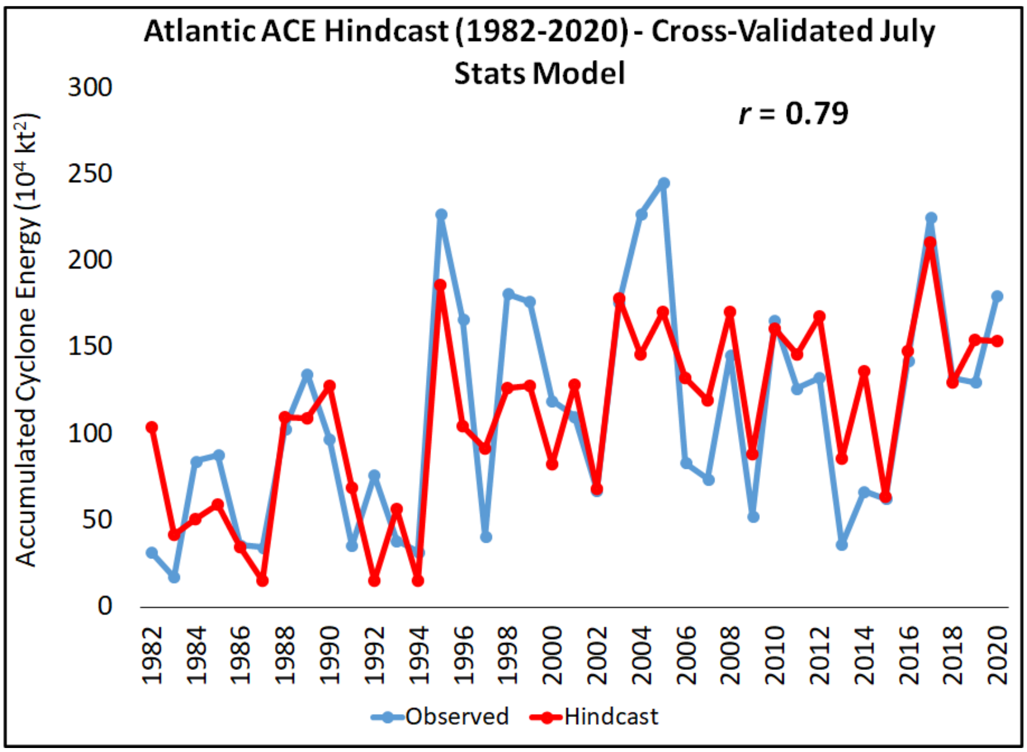

Figure 1: Observed versus early July cross-validated hindcast values of ACE for the statistical model for 1982-2020.

July Forecast Predictors

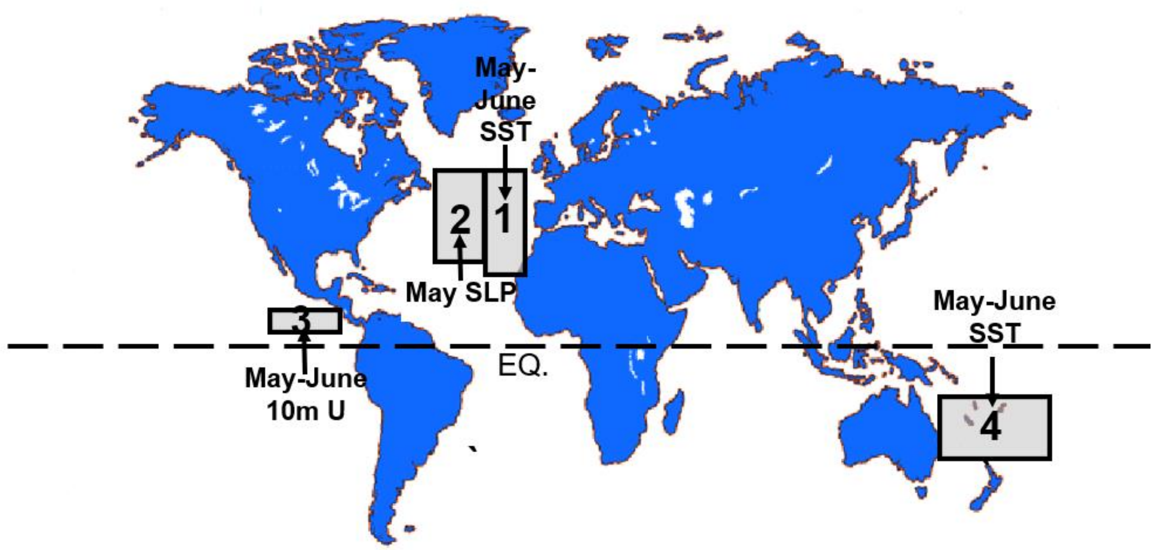

Figure 2: Location of predictors for our early July extended-range statistical prediction for the 2021 hurricane season.

Table 1: Correlations between early July predictors and ACE over the period from 1982-2020.

Predictor	Correlation w/ ACE
1) May-June SST (20°N-50°N, 30°W-15°W) (+)	0.68
2) May-June SLP (25°N-50°N, 50°W-30°W) (-)	-0.45
3) May-June 10m U (5°N-10°N, 120°W-90°W) (-)	0.58
4) May-June SST (35°S-15°S, 155°E-180°E) (+)	0.58

Table 2: Listing of early July 2021 predictors for the 2021 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	2021 Forecast Value	Impact on 2021 TC Activity
1) May-June SST (20°N-50°N, 30°W-15°W) (+)	+0.8 SD	Enhance
2) May-June SLP (25°N-50°N, 50°W-30°W) (-)	+1.6 SD	Suppress
3) May-June 10m U (5°N-10°N, 120°W-90°W) (+)	+1.3 SD	Enhance
4) May-June SST (35°S-15°S, 155°E-180°E) (+)	+0.7 SD	Enhance

Table 3: Statistical model output for the 2021 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1991-2020 Average (in parentheses)	Statistical Forecast	Final Forecast
Named Storms (NS) (14.4)	16.4	20
Named Storm Days (NSD) (69.4)	83.4	90
Hurricanes (H) (7.2)	8.6	9
Hurricane Days (HD) (27.0)	34.6	40
Major Hurricanes (MH) (3.2)	4.1	4
Major Hurricane Days (MHD) (7.4)	10.1	9
Accumulated Cyclone Energy (ACE) (123)	156	160
Net Tropical Cyclone Activity (NTC) (135%)	168	170

The locations and brief descriptions of the predictors for our early July 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, 85-20°W as shown in Figure 3.

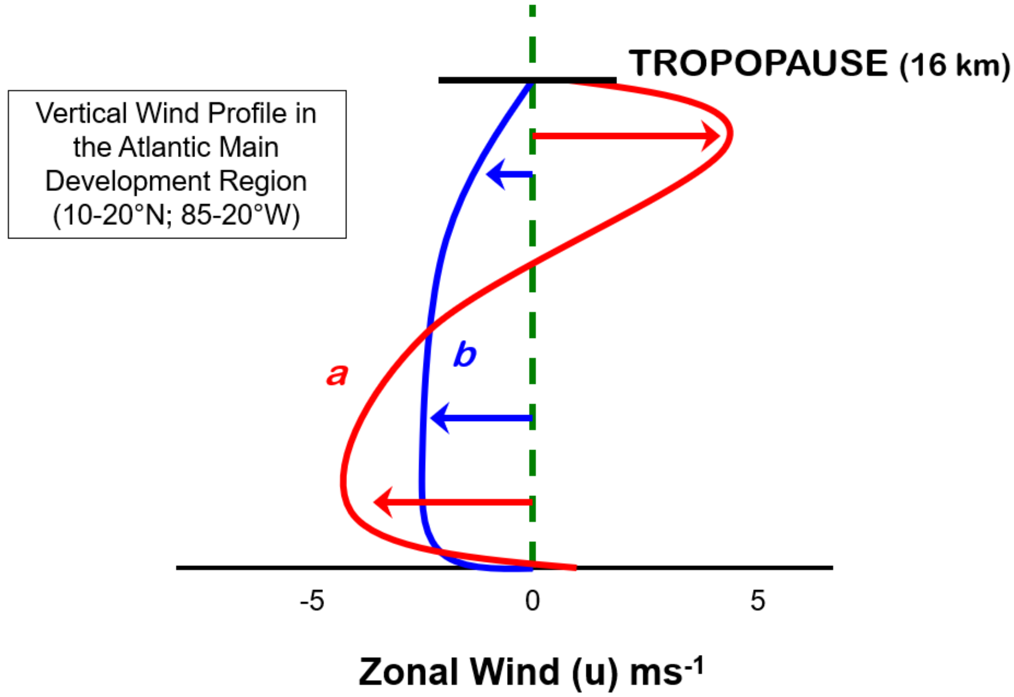

Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.

For each of these predictors, we display a four-panel figure showing rank 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 SST, 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 OISST, while atmospheric field correlations are displayed using ERA5.

<u>Predictor 1. May-June SST in the Subtropical and Mid-latitude eastern North Atlantic (+)</u>

(20°N-50°N, 30°W-15°W)

Warmer-than-normal SSTs in the subtropical and mid-latitude eastern North Atlantic during the May-June time period are typically associated with a weaker-than-normal subtropical high and reduced trade wind strength during the late boreal spring and early boreal summer (Knaff 1997). These warmer-than-normal SSTs in May-June are also correlated with weaker trade winds and weaker upper tropospheric westerly winds, lower-than-normal sea level pressure and above-normal SSTs in the tropical Atlantic during the following August-October period (Figure 4). All four 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* =0.68) with ACE from 1982-2020. Predictor 1 also strongly correlates (*r* = 0.77) with August-October values of the SST component of the Atlantic Meridional Mode (AMM) (Kossin and Vimont 2007) over the period from 1982-2020. 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. May-June SLP in the Subtropical and Mid-Latitude North Atlantic (-)</u>

(25°N-50°N, 50°W-30°W)

Anomalously low pressure in the subtropical and mid-latitude North Atlantic during May and June is associated with weaker trade winds and anomalous warming of the central and eastern tropical Atlantic during the boreal summer. While the anomalous warming signal in the tropical Atlantic SST decays somewhat by the peak of the Atlantic hurricane season (Figure 5), there remains a significant correlation in SST, sea level pressure and vertical wind shear, as evidenced by the anomalous westerlies at 850 hPa and the anomalous easterlies at 200 hPa in the Caribbean and western tropical Atlantic during August-October. Consequently, we observe that when the subtropical and mid-latitude North Atlantic is characterized by lower pressure in May and June, the peak of the Atlantic hurricane season typically has more conducive dynamic and thermodynamic conditions across the Main Development Region.

<u>Predictor 3. May-June 10m U in the eastern tropical Pacific (+)</u>

(5°N-10°N, 120°W-90°W)

Weaker-than-normal low-level winds during May-June in the eastern tropical Pacific are typically associated with a La Niña event and warmer SSTs in the Caribbean and tropical Atlantic. This SST gradient pattern drives higher pressure in the eastern tropical Pacific and lower pressure in the Caribbean and tropical Atlantic. This SST and sea level pressure pattern persists through August-October (Figure 6). The August-October-averaged ENSO Longitude Index correlates with Predictor 3 at -0.52. As would be expected given the negative relationship between Predictor 3 and the ENSO Longitude Index, Predictor 3 also correlates with reduced vertical wind shear during the peak of the Atlantic hurricane season, especially in the Caribbean and western tropical Atlantic, where ENSO typically has its strongest impacts (Figure 6).

<u>Predictor 4. May-June SST in the Tropical and Subtropical Western South Pacific (+)</u>

(35°S-15°S, 155°E-180°E)

Anomalous warmth in the tropical and subtropical western South Pacific is associated with higher-than-normal pressure in the eastern tropical Pacific during the boreal spring and early summer. This anomalous pressure pattern results in a positive Southern Oscillation Index (SOI), both in May-June and in August-October. This positive SOI is typically associated with an anomalously negative ENSO Longitude Index (e.g., westward shifted tropical Pacific convection), as convection is favored in the western tropical Pacific during La Niña conditions. The correlation between the August-October-averaged ENSO Longitude index and Predictor 4 is -0.41 (Figure 7).

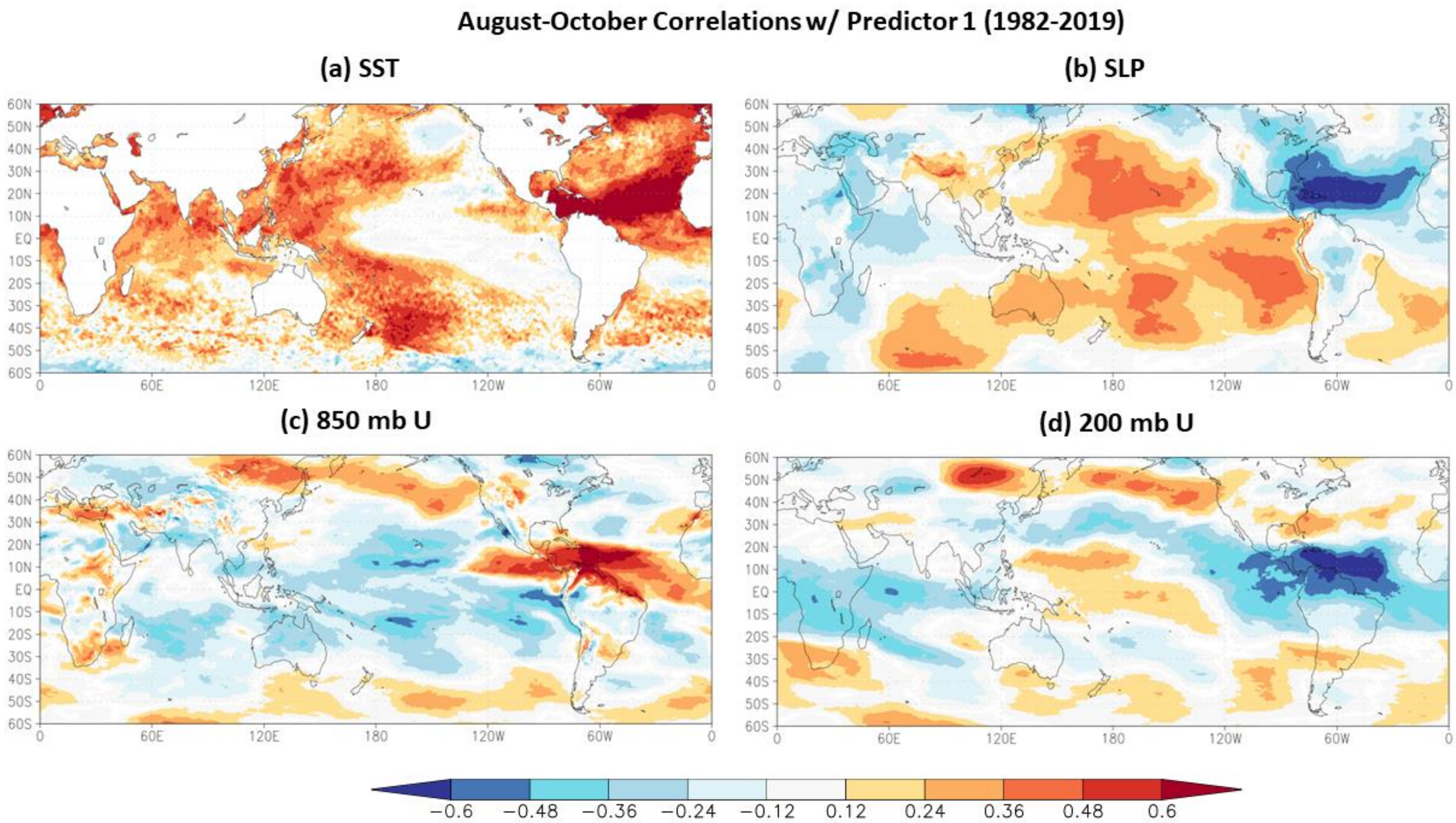

Figure 4: Rank correlations between May-June SST in the subtropical and mid-latitude eastern North Atlantic (Predictor 1) and (panel a) August-October sea surface temperature, (panel b) August-October sea level pressure, (panel c) August-October 850 hPa zonal wind and (panel d) August-October 200 hPa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

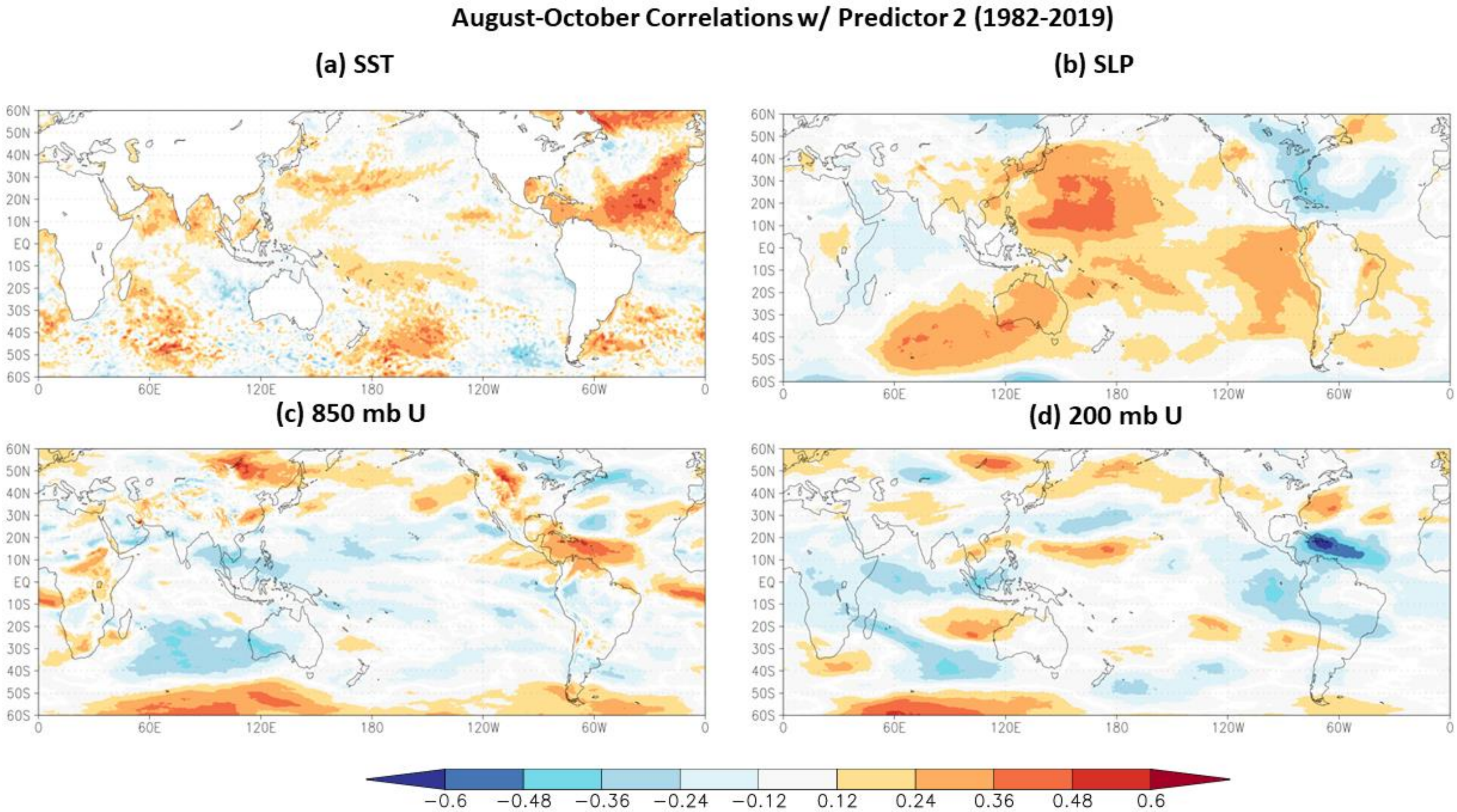

Figure 5: As in Figure 4 but for May-June SLP in the subtropical and mid-latitude North Atlantic. The sign of Predictor 2 has been flipped for easy comparison with Figure 4.

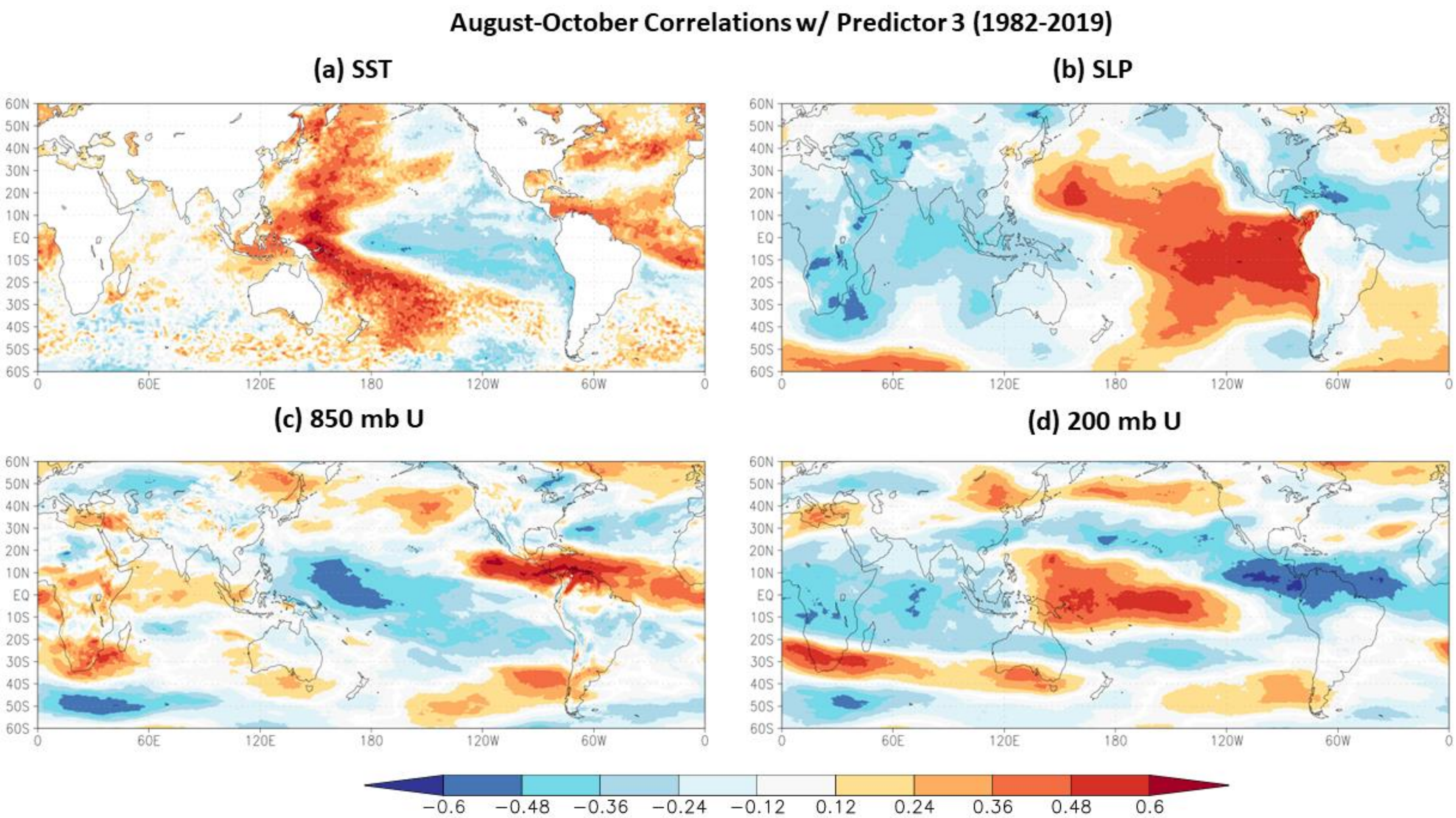

Figure 6: As in Figure 4 but for May-June 10 meter zonal wind in the eastern tropical Pacific Ocean.

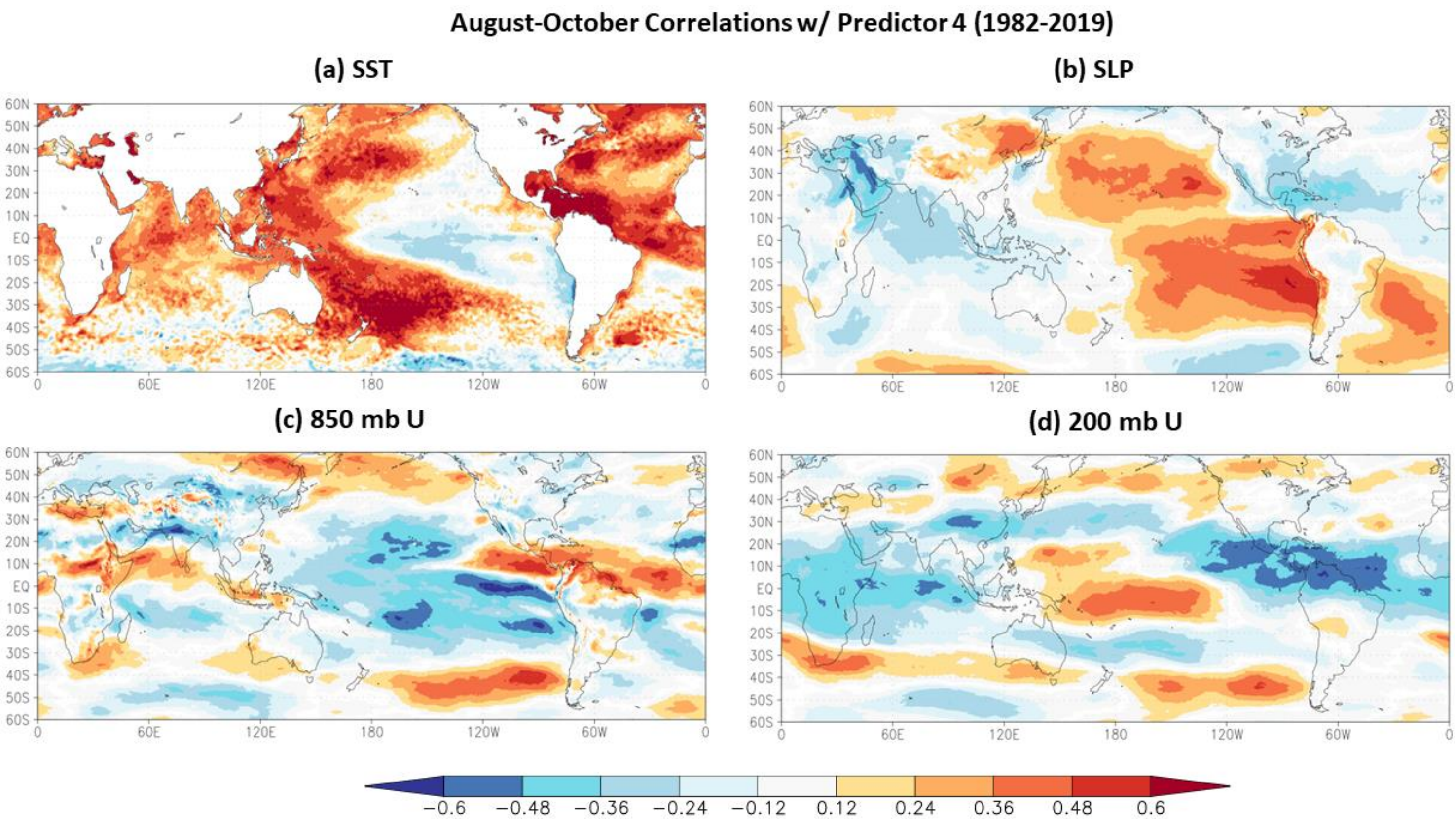

Figure 7: As in Figure 4 but for May-June SST in the tropical and subtropical western South Pacific.

2.2 July 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. Both the ECMWF SEAS5 climate model and the UK Met Office's GloSea6 model are 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 2021 season. All of the 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 the SEAS5 and GloSea6 output, so the results displayed here are from the model output from the 1 June forecast.

Figure 8 displays the parameters used in our early August statistical model, while Table 4 displays SEAS5's forecasts of these parameters for 2021 from a 1 June initialization date. All three parameters call for above-normal activity. Figure 9 displays cross-validated hindcasts for SEAS5 forecast of ACE from 1981-2020, while Table 5 presents the forecast from SEAS5 for the 2021 Atlantic hurricane season.

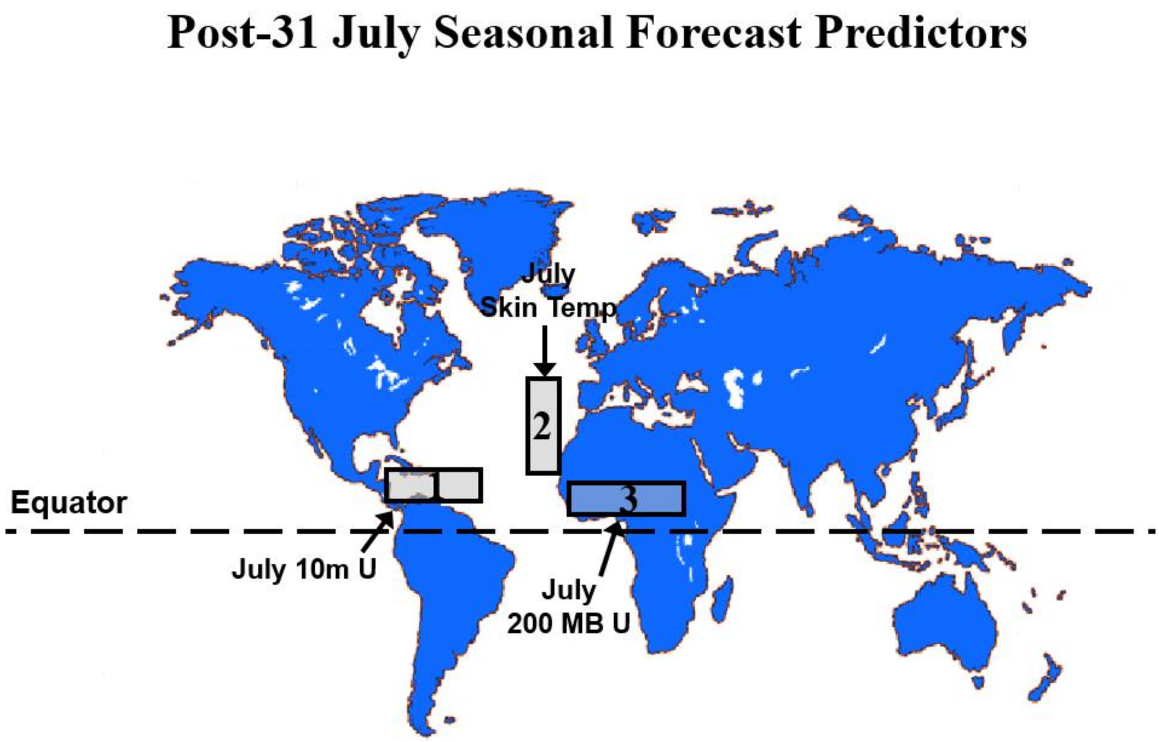

Figure 8: Location of predictors for our early July statistical/dynamical extended-range statistical prediction for the 2021 hurricane season. This forecast uses either the ECMWF SEAS5 model or the UK Met Office GloSea6 model to predict July conditions in the three boxes displayed and uses those predictors to forecast ACE.

Table 4: Listing of predictions of July large-scale conditions from ECMWF SEAS5 output, initialized on 1 June. 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 2021 Forecast	Effect on 2021 Hurricane Season
1) ECMWF Prediction of July Surface U (10-20°N, 90-40°W) (+)	+0.4 SD	Enhance
2) ECMWF Prediction of July Skin Temperature (20-40°N, 35-15°W) (+)	+1.3 SD	Enhance
3) ECMWF Prediction of July 200 hPa U (5-15°N, 0-40°E) (-)	-0.6 SD	Enhance

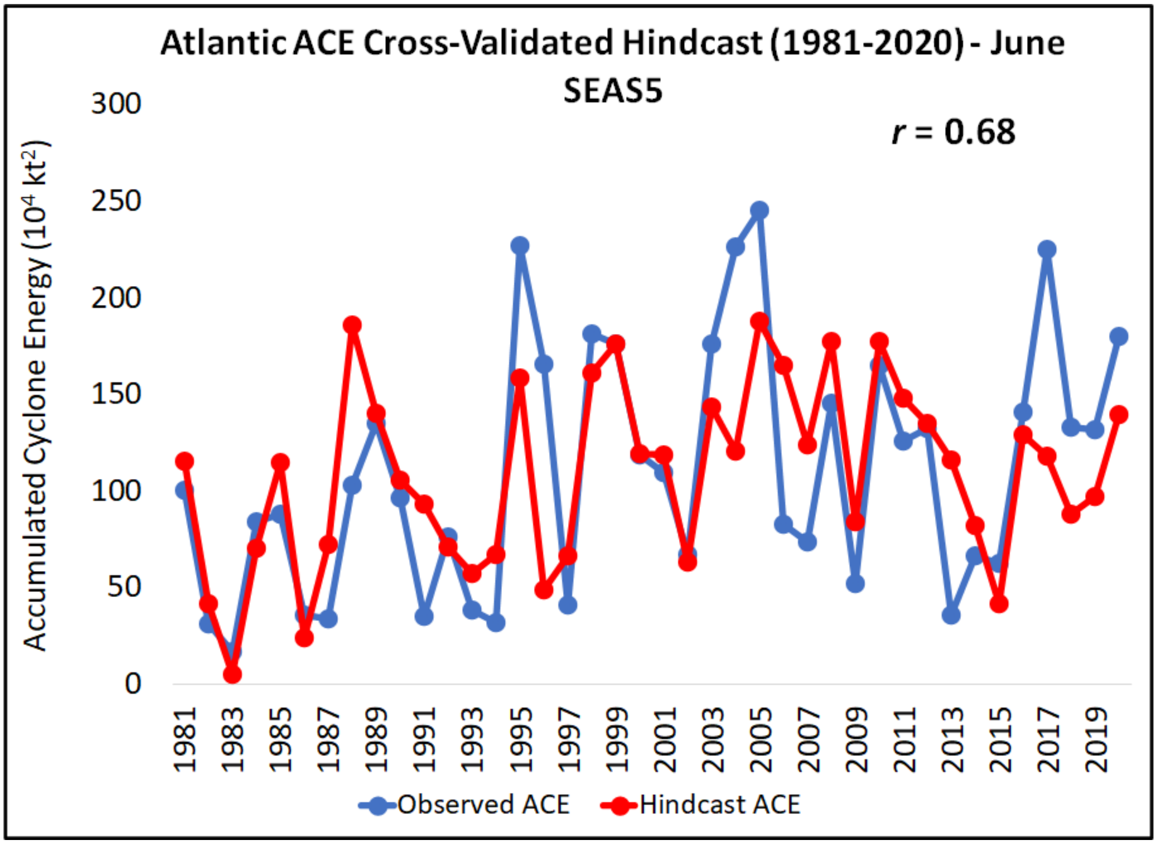

Figure 9: Observed versus early June cross-validated statistical/dynamical hindcast values of ACE for 1981-2020 from SEAS5.

Table 5: Statistical/dynamical model output from SEAS5 for the 2021 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1991-2020 Average (in parentheses)	Statistical/Dynamical Hybrid Forecast	Final Forecast
Named Storms (14.4)	16.7	20
Named Storm Days (69.4)	85.5	90
Hurricanes (7.2)	8.9	9
Hurricane Days (27.0)	35.8	40
Major Hurricanes (3.2)	4.2	4
Major Hurricane Days (7.4)	10.5	9
Accumulated Cyclone Energy Index (123)	161	160
Net Tropical Cyclone Activity (135%)	173	170

In addition to forecasts from ECMWF SEAS5, we continue to also incorporate a similar forecast from the UK Met Office's GloSea6 model this year. The GloSea6 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 GloSea6 hindcast data from 1993-2016. Figure 10 displays observed versus cross-validated hindcast ACE using the same three July predictors as used for the SEAS5 statistical/dynamical forecast model.

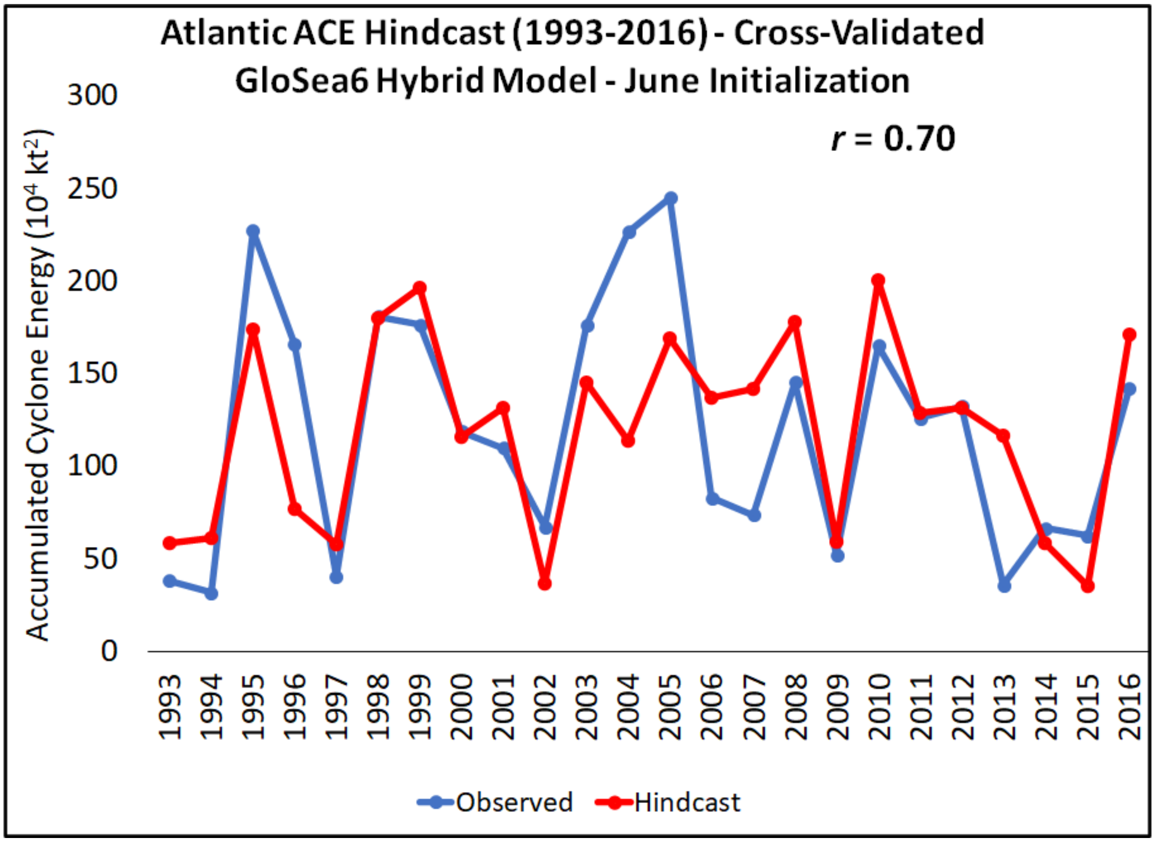

Figure 10: Observed versus June cross-validated statistical/dynamical hindcast values of ACE for 1993-2016 from GloSea6.

The output from the GloSea6 model also calls for a well above-average Atlantic hurricane season in 2021. 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 GloSea6 model.

Table 6: Listing of predictions of July large-scale conditions from the Met Office's GloSea6 model output, initialized on 1 June. 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 2021 Forecast	Effect on 2021 Hurricane Season
1) GloSea6 Prediction of July Surface U (10-20°N, 90-40°W) (+)	+0.2 SD	Enhance
2) GloSea6 Prediction of July SST (20-40°N, 35-15°W) (+)	+1.5 SD	Enhance
3) GloSea6 Prediction of July 200 hPa U (5-15°N, 0-40°E) (-)	-0.5 SD	Enhance

Table 7: Statistical/dynamical model output from GloSea6 for the 2021 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1991-2020 Average (in parentheses)	Statistical/Dynamical Hybrid Forecast	Final Forecast
Named Storms (14.4)	17.6	20
Named Storm Days (69.4)	91.4	90
Hurricanes (7.2)	9.5	9
Hurricane Days (27.0)	39.0	40
Major Hurricanes (3.2)	4.6	4
Major Hurricane Days (7.4)	11.7	9
Accumulated Cyclone Energy Index (123)	175	160
Net Tropical Cyclone Activity (135%)	187	170

2.3 July Analog Forecast Scheme

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2021. These years also provide useful clues as to likely levels of activity that the forthcoming 2021 hurricane season may bring. For this early July 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 June 2021 conditions and, more importantly, projected August-October 2021 conditions. Table 8 lists our analog selections.

We searched for years that were generally characterized by neutral ENSO to weak La Niña conditions during August-October. We selected years that had generally above-average SSTs in the tropical Atlantic. We anticipate that the 2021 hurricane season will have activity near the average of our five analog years.

Table 8: Analog years for 2021 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1996	13	79.00	9	45.00	6	13.00	166	192
2001	15	68.75	9	25.50	4	4.25	110	135
2008	16	88.25	8	30.50	5	7.50	146	162
2011	19	89.75	7	26.00	4	4.50	126	145
2017	17	93.00	10	51.75	6	19.25	225	232
Average	16.0	83.8	8.6	35.8	5	9.7	155	173
2021 Forecast	**20**	**90**	**9**	**40**	**4**	**9**	**160**	**170**

2.4 July Forecast Summary and Final Adjusted Forecast

Table 9 shows our final adjusted early July forecast for the 2021 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 ENSO neutral 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 July statistical forecast, our statistical/dynamical forecast, our analog forecast, the average of those four schemes and our adjusted final forecast for the 2021 hurricane season.

Forecast Parameter and 1991-2020 Average (in parentheses)	Statistical Scheme	SEAS5 Scheme	GloSea6 Scheme	Analog Scheme	4-Scheme Average	Adjusted Final Forecast
Named Storms (14.4)	16.4	16.7	17.6	16.0	16.7	20
Named Storm Days (69.4)	83.4	85.5	91.4	83.8	86.0	90
Hurricanes (7.2)	8.6	8.9	9.5	8.6	8.9	9
Hurricane Days (27.0)	34.6	35.8	39.0	35.8	36.3	40
Major Hurricanes (3.2)	4.1	4.2	4.6	5.0	4.5	4
Major Hurricane Days (7.4)	10.1	10.5	11.7	9.7	10.5	9
Accumulated Cyclone Energy Index (123)	156	161	175	155	162	160
Net Tropical Cyclone Activity (135%)	168	173	187	173	175	170

3 Forecast Uncertainty

This season we continue to use probability of exceedance curves as discussed in Saunders et al. (2020) to better quantify forecast uncertainty. 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 (e.g., named storm days, ACE, etc.) except for major hurricane days We use a Laplace distribution for major hurricane days.

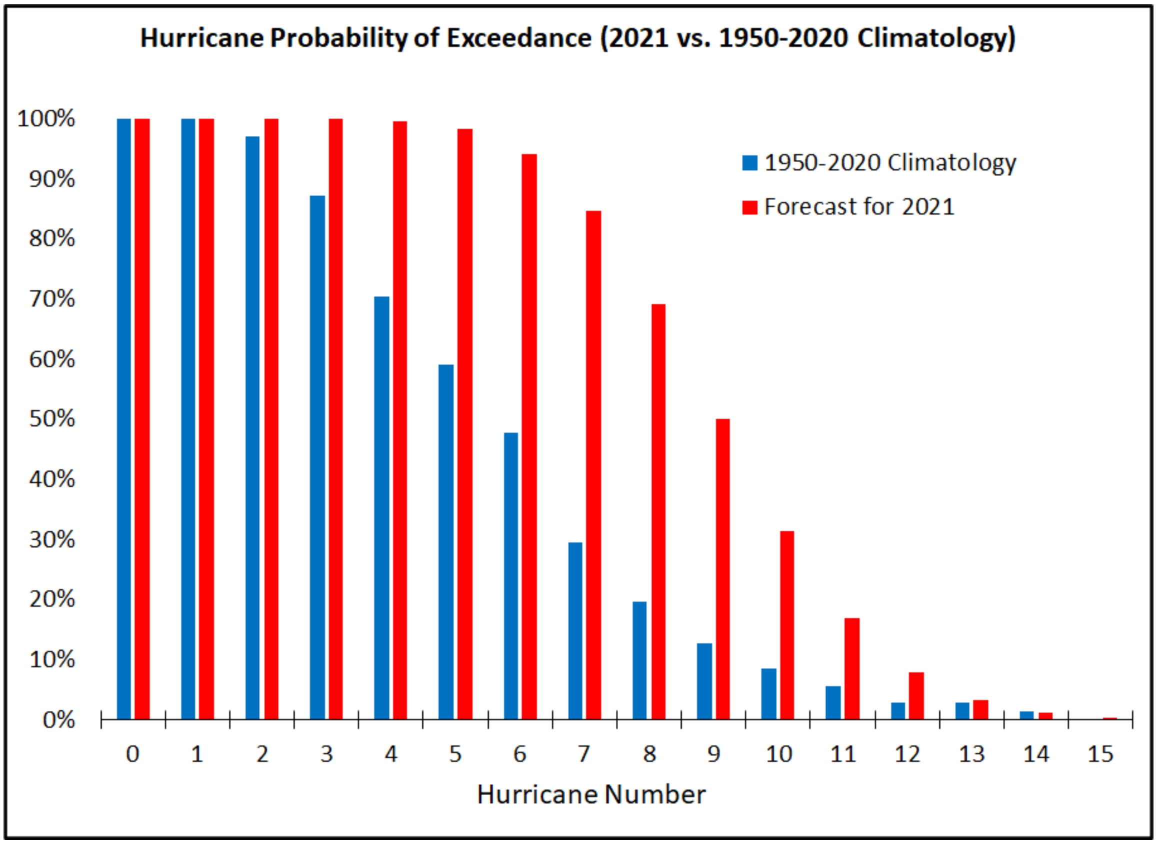

Figure 11: Probability of exceedance plot for hurricane numbers for the 2021 Atlantic hurricane season. The values on the x-axis indicate that the number of hurricanes exceeds that specific number. For example, 97% of Atlantic hurricane seasons from 1950-2020 have had more than two hurricanes.

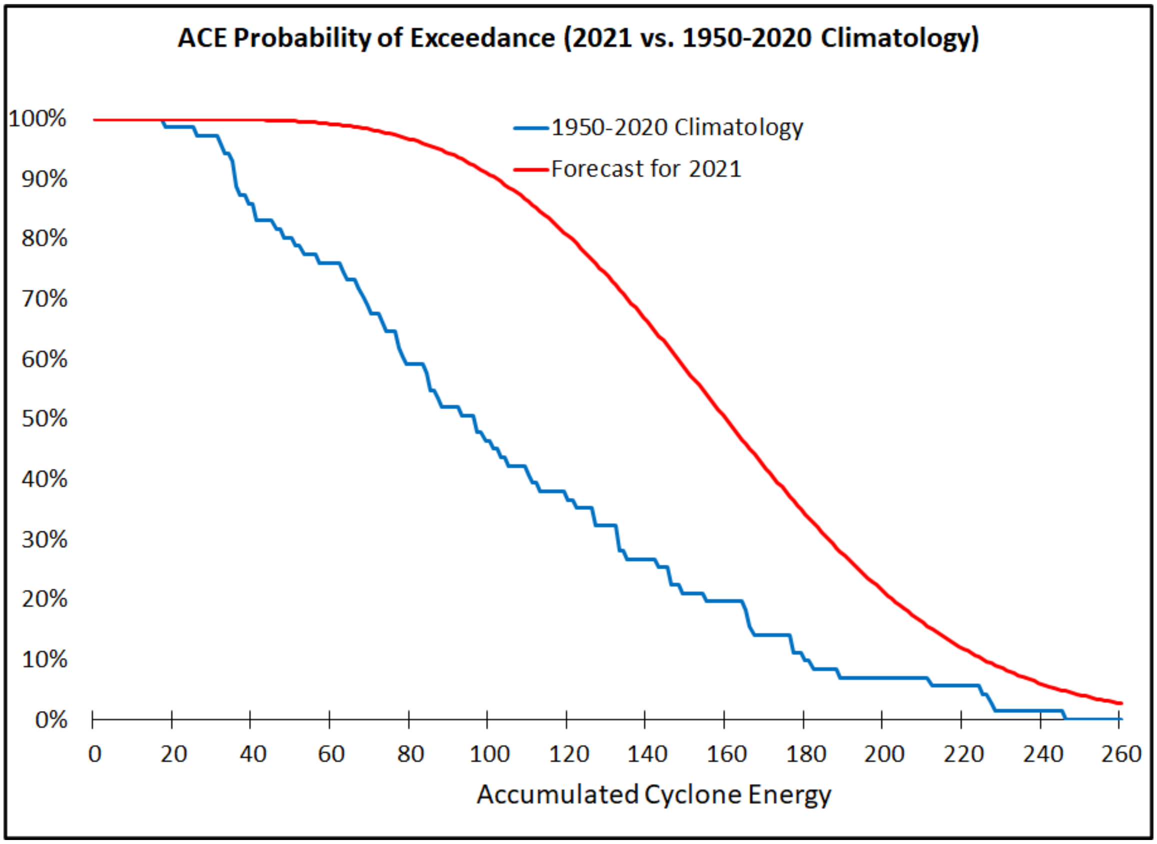

Figure 12: As in Figure 11 but for ACE.

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	2021 Forecast	Uncertainty Range (68% of Forecasts Likely to Fall in This Range)
Named Storms (NS)	20	17 – 23
Named Storm Days (NSD)	90	70 – 111
Hurricanes (H)	9	7 – 11
Hurricane Days (HD)	40	28 – 54
Major Hurricanes (MH)	4	3 – 6
Major Hurricane Days (MHD)	9	6 – 14
Accumulated Cyclone Energy (ACE)	160	112 – 212
Net Tropical Cyclone (NTC) Activity	170	124 – 220

4 ENSO

The tropical Pacific is currently characterized by neutral ENSO conditions, with SST anomalies near their long-term averages across most of the central and eastern tropical Pacific (Figure 13). Over the past couple of months, SST anomalies have generally trended upward in the Nino 3.4 region, with current weekly anomalies near

0°C. The Nino 3.4 region, spanning 5°S-5°N, 170-120°W, is the region that NOAA uses to classify ENSO events.

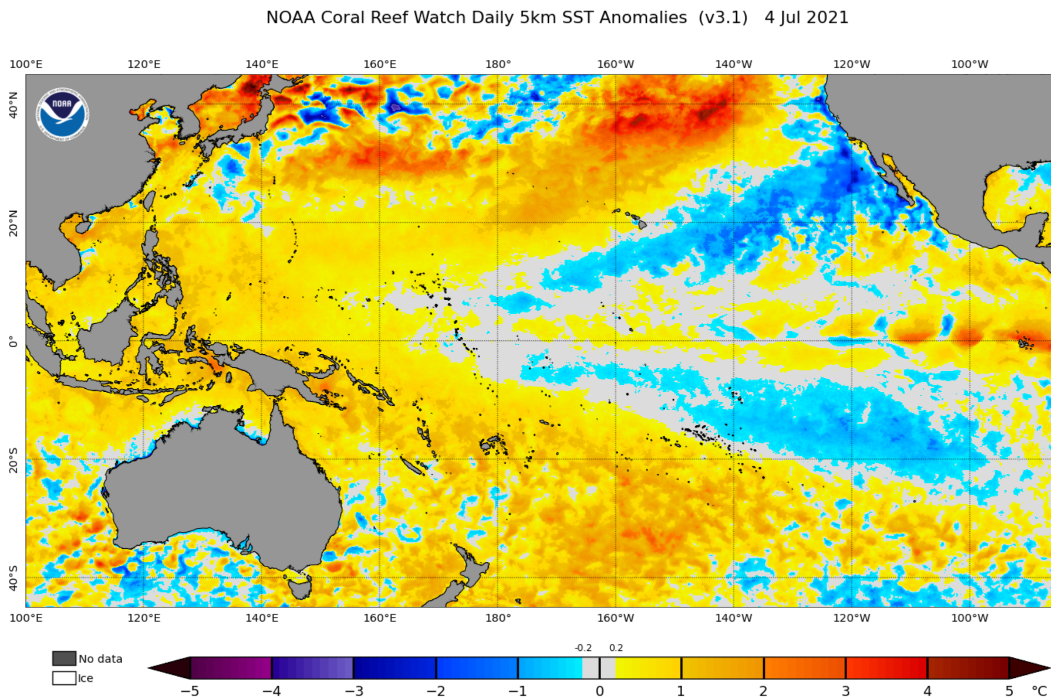

Figure 13: Current SST anomalies across the tropical and subtropical Pacific.

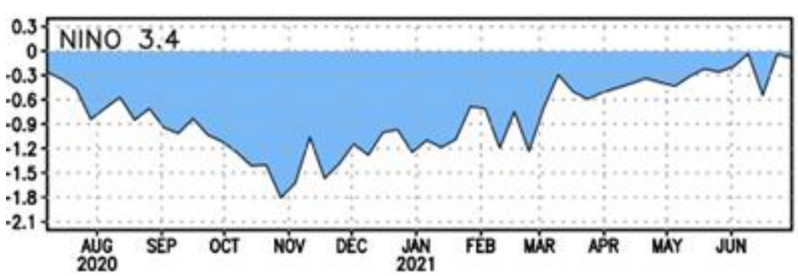

Figure 14: Nino 3.4 SST anomalies from July 2020 through June 2021.   Figure courtesy of Climate Prediction Center.

Upper-ocean heat content anomalies in the eastern and central tropical Pacific generally trended upward from February to May and have since stabilized at near-average levels (Figure 15). The anomalous increase in upper-ocean heat content was associated with the decay of La Niña conditions over the past few months.

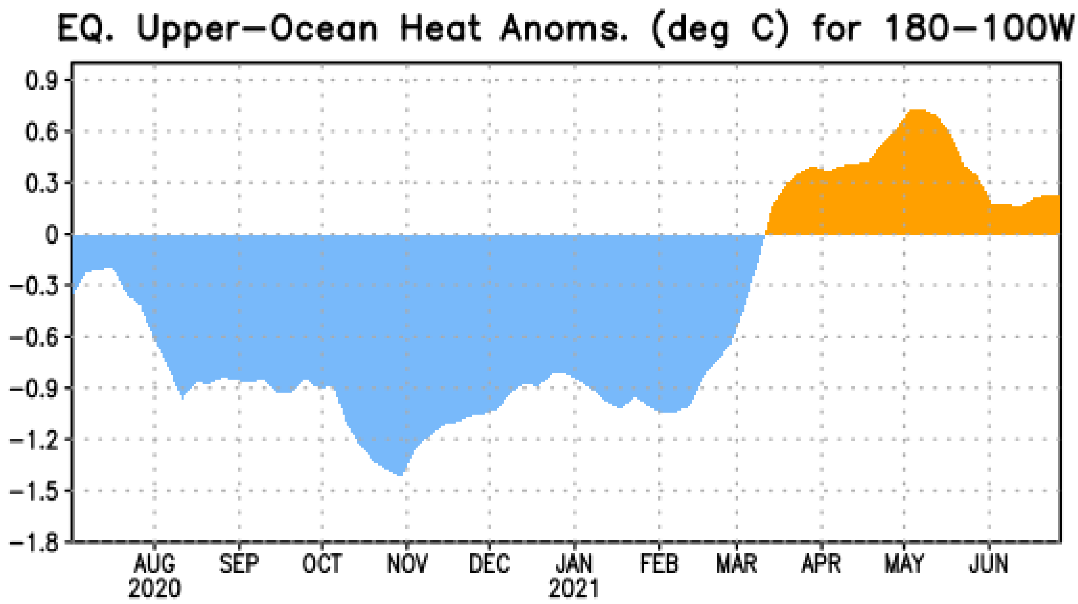

Figure 15: Central and eastern equatorial Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Upper ocean heat content anomalies have dropped precipitously over the past few weeks.

Table 11 displays May and June SST anomalies for several Nino regions. Anomalies have trended upward in the eastern tropical Pacific and have not changed significantly in the central tropical Pacific.

Table 11: May and June SST anomalies for Nino 1+2, Nino 3, Nino 3.4, and Nino 4, respectively. June minus May SST anomaly differences are also provided.

Region	May SST Anomaly (°C)	June SST Anomaly (°C)	June – May SST Anomaly (°C)
Nino 1+2	-0.7	+0.2	+0.9
Nino 3	-0.4	-0.2	+0.2
Nino 3.4	-0.3	-0.2	+0.1
Nino 4	-0.1	-0.1	0.0

The tropical Pacific experienced a downwelling (warming) Kelvin wave (denoted by a dashed line) which reached the coast of South America in June (Figure 16). This anomalous warming was driven by anomalous low-level westerly wind flow which occurred several weeks earlier.

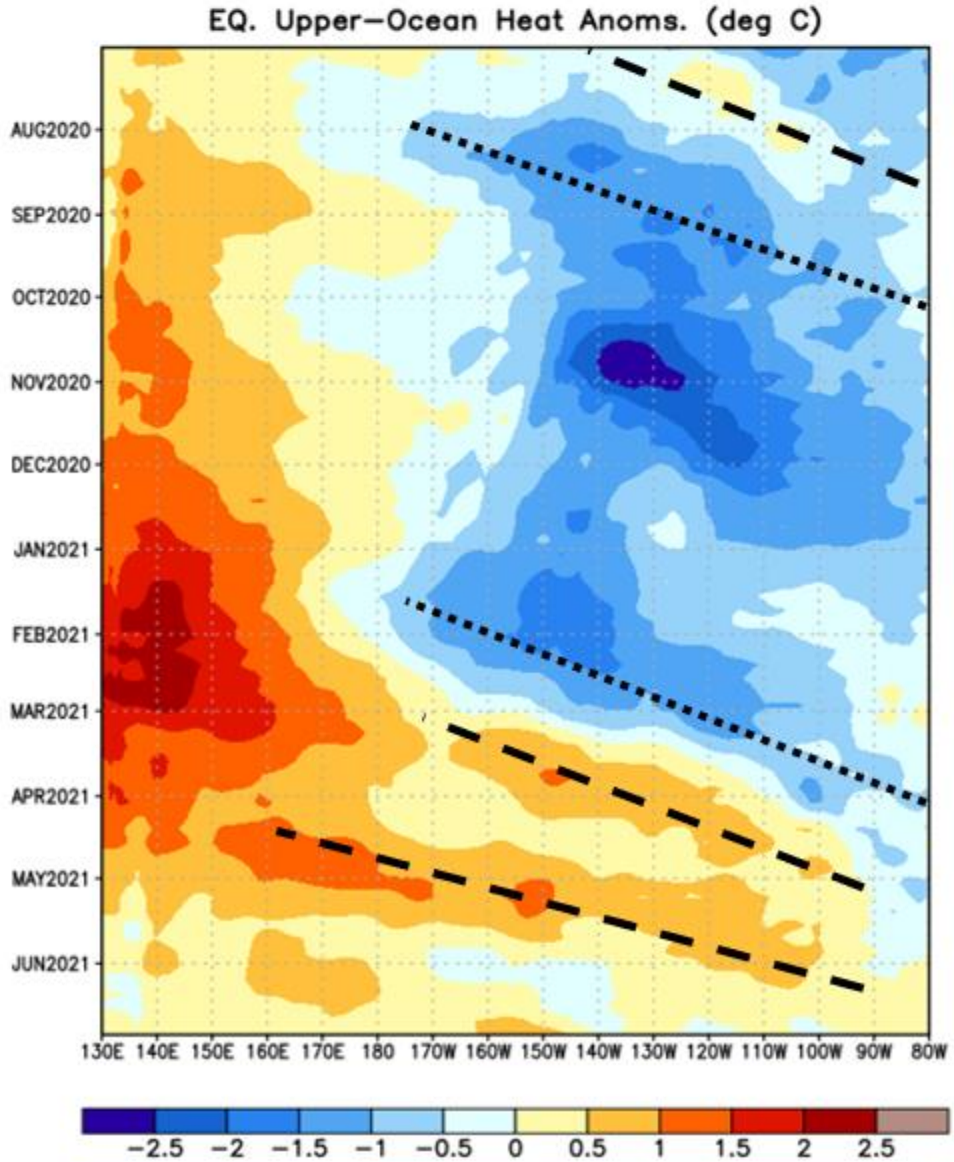

Figure 16: Upper-ocean heat content anomalies in the tropical Pacific since July 2020. Dashed lines indicate downwelling Kelvin waves, while dotted lines indicate upwelling Kelvin waves. Downwelling Kelvin waves result in upper-ocean heat content increases, while upwelling Kelvin waves result in upper-ocean heat content decreases.

We will continue monitoring low-level winds over the tropical Pacific as the peak of the Atlantic hurricane season approaches. Anomalous easterlies have recently developed just west of the International Date Line, and the Climate Forecast System (CFS) is forecasting a continuation of stronger-than-normal trade winds across the central tropical Pacific for the next ten days (Figure 17). These anomalously strong trade winds should suppress anomalous warming of the central and eastern tropical Pacific. At this point, we think that the odds of an El Niño for the peak of the Atlantic hurricane season (August-October) are extremely low.

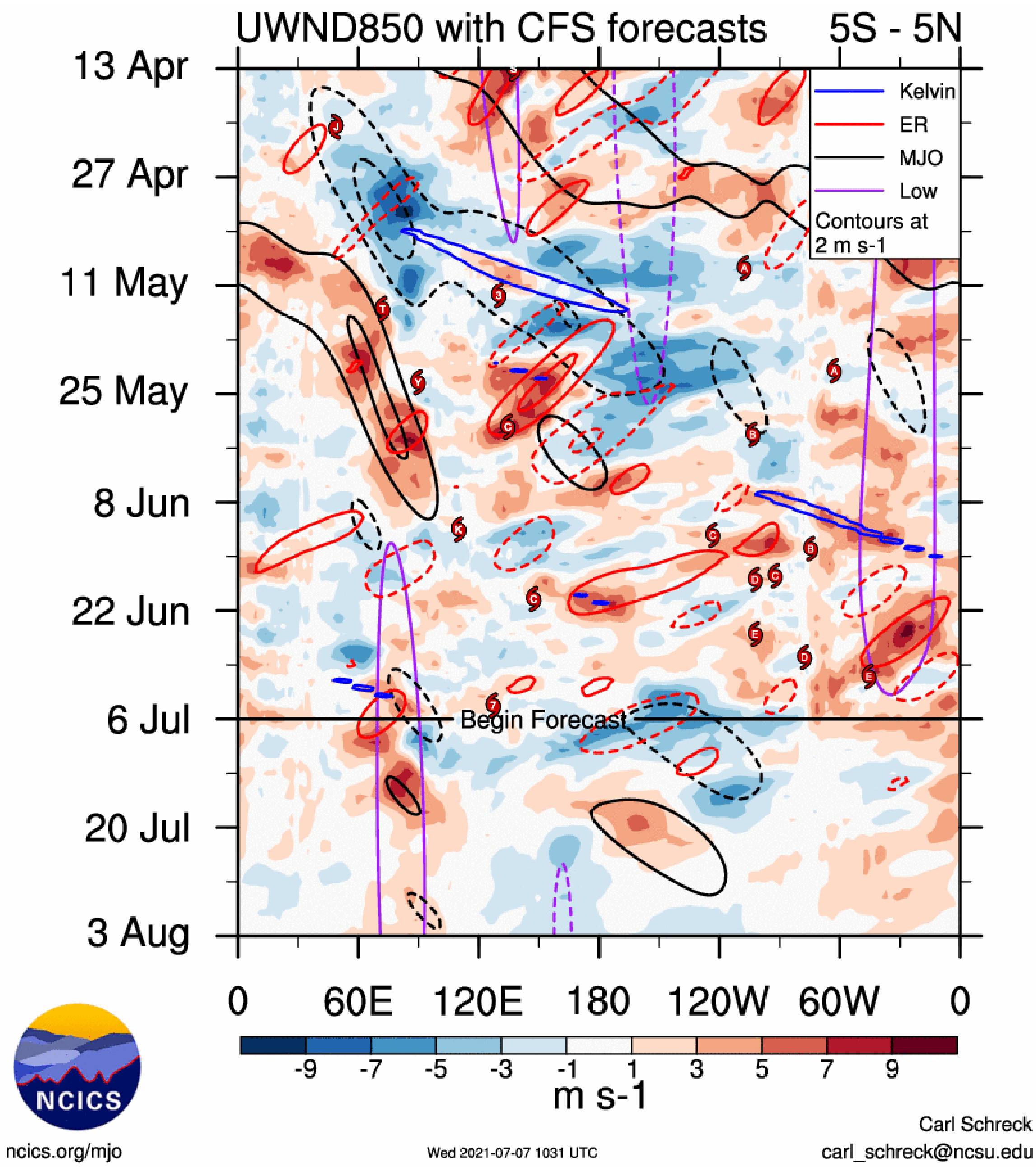

Figure 17: Observed low-level winds across the equatorial region as well as predictions for the next four weeks by the Climate Forecast System. Figure courtesy of Carl Schreck.

There remains some uncertainty with the future state of ENSO for the peak of the Atlantic hurricane season. The latest plume of ENSO predictions from several statistical and dynamical models shows continued spread for August-October (Figure 18), but most models are calling for neutral ENSO conditions for August-October. None of the models in the ENSO prediction plume call for El Niño conditions for August-October.

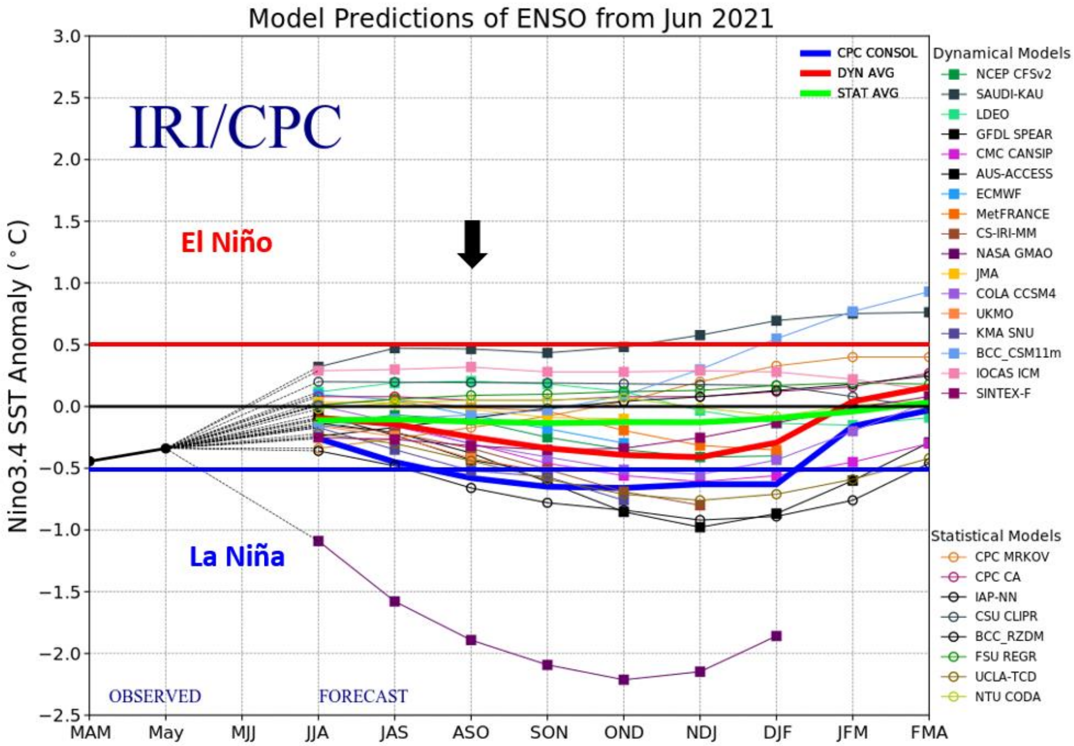

Figure 18: ENSO forecasts from various statistical and dynamical models for the Nino 3.4 SST anomaly based on late May to early June initial conditions. The majority of models are calling for ENSO neutral conditions for August-October. Figure courtesy of the International Research Institute (IRI).

The latest official forecast from NOAA indicates that the chances of El Niño are quite low for August-October. NOAA is currently predicting a 7% chance of El Niño, a 57% chance of ENSO neutral conditions and a 36% chance of La Niña for the peak of the Atlantic hurricane season (Figure 19).

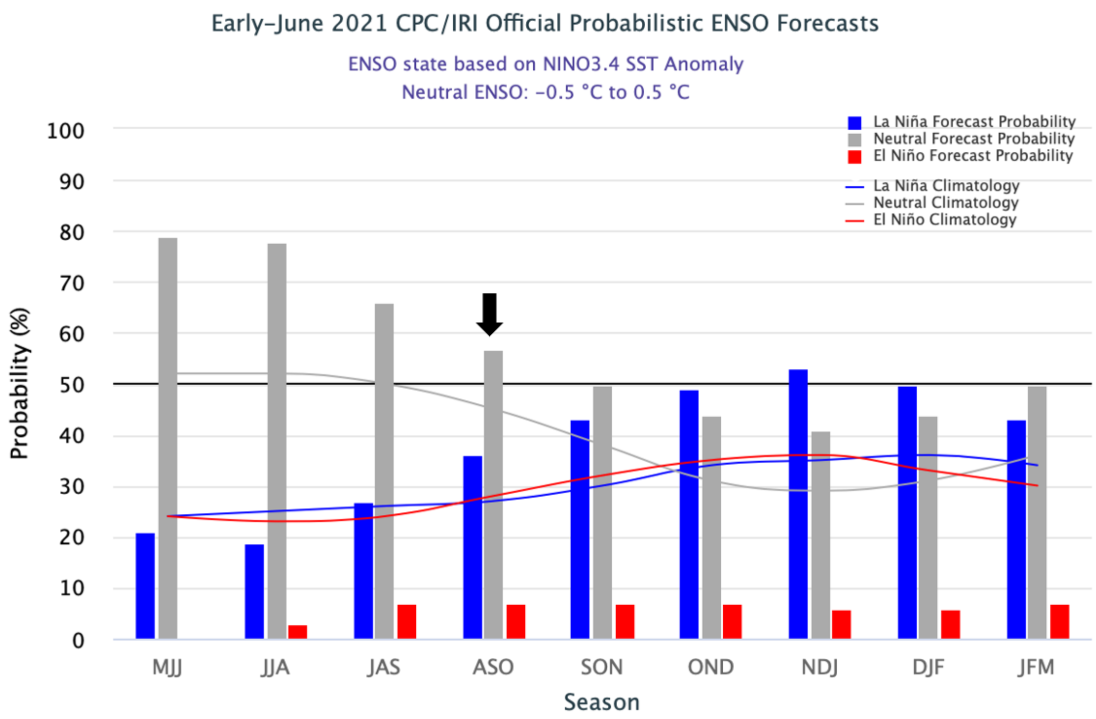

Figure 19: Official NOAA forecast for ENSO.

Based on the above information, our best estimate is that we will likely have neutral ENSO conditions for the peak of the Atlantic hurricane season.

5 Current Atlantic Basin Conditions

Currently, the Caribbean is warmer than normal, while farther east in the tropical Atlantic has near average sea surface temperatures. Sea surface temperatures anomalies in most of the subtropical Atlantic are warmer than normal (Figure 20). The current SST anomaly pattern is somewhat similar to the historical SST pattern in July that has correlated with active Atlantic hurricane seasons (Figure 21).

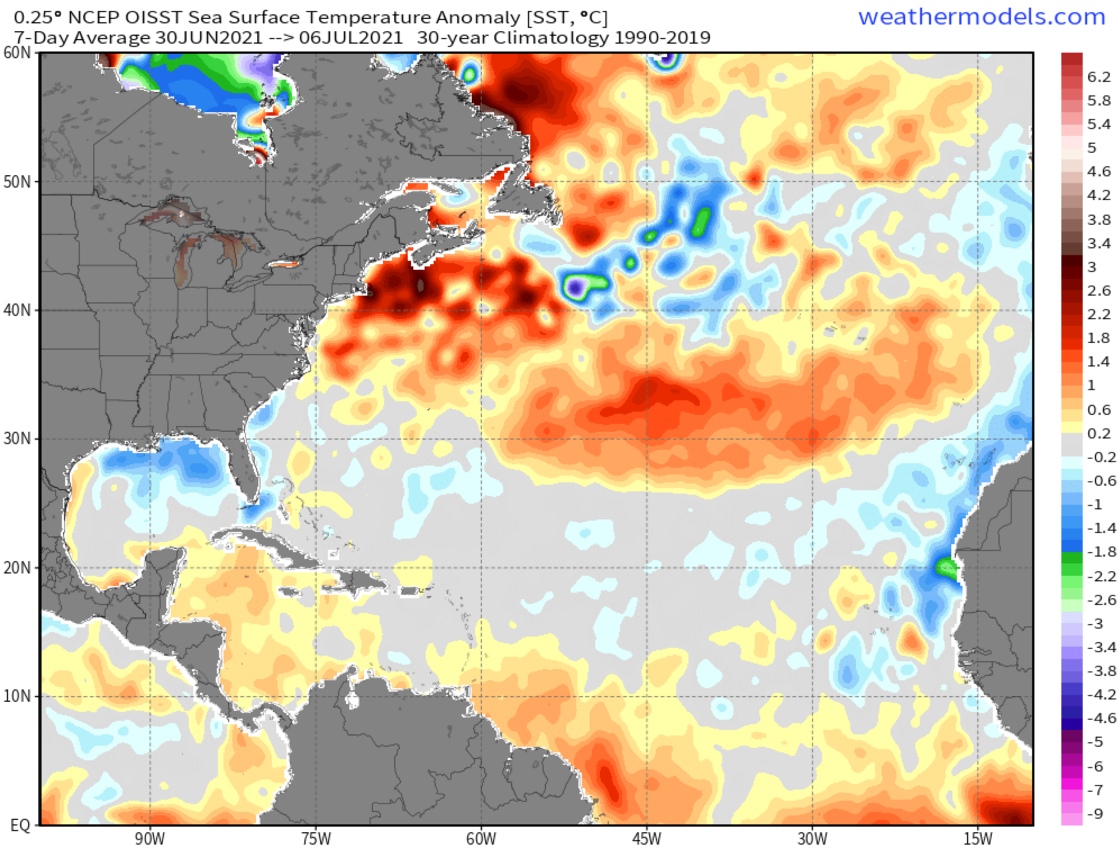

Figure 20: Early July 2021 SST anomaly pattern across the Atlantic Ocean.

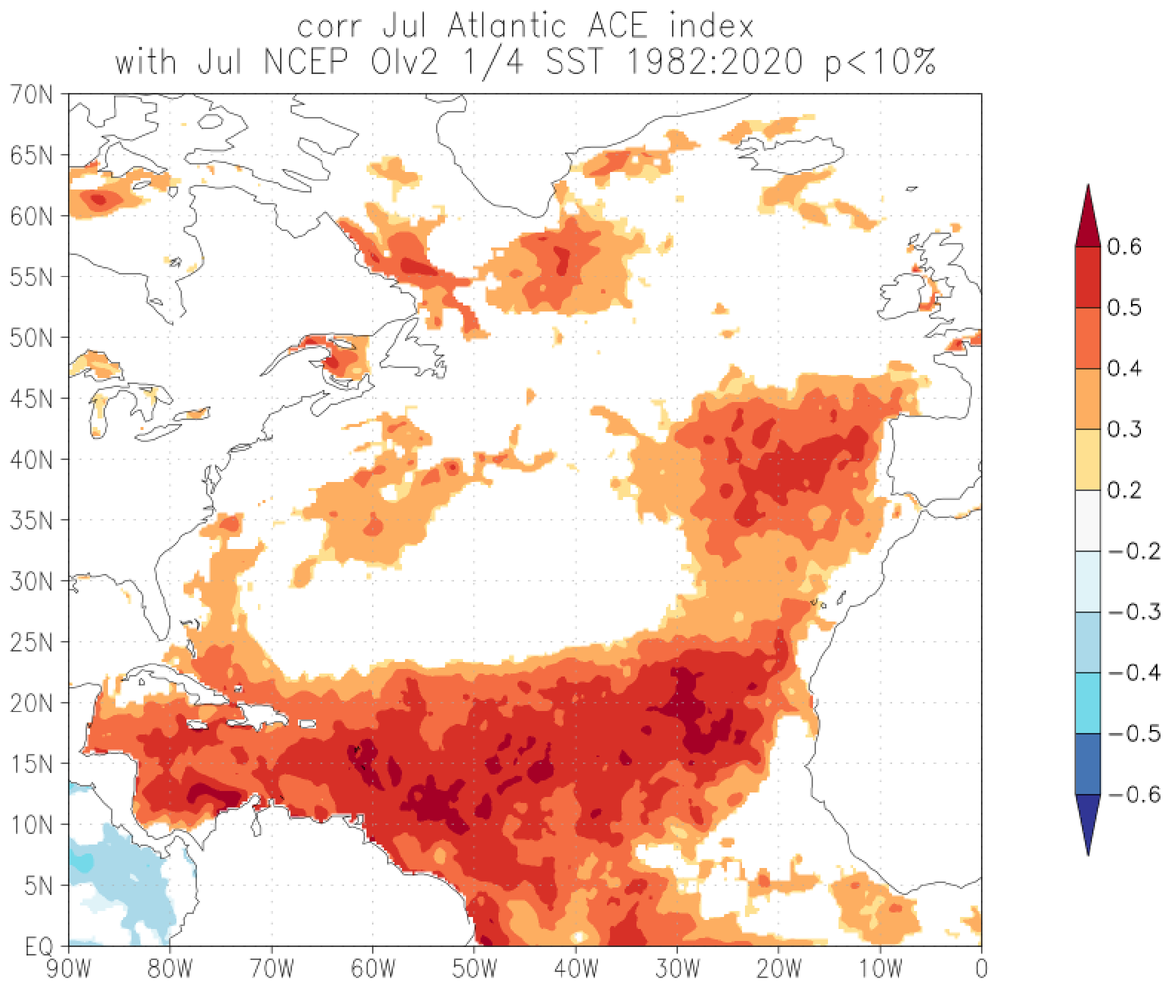

Figure 21: Correlation between July North Atlantic SST anomalies and seasonal Atlantic ACE from 1982-2020.

30-day-averaged vertical wind shear across the tropical Atlantic and Caribbean has been trending downward over the past couple of weeks, with 30-day averages of vertical wind shear currently near the long-term average (Figure 22). However, the correlation between shear and basinwide ACE becomes much stronger in July than it is in June, and this will be something that we monitor closely over the next several weeks.

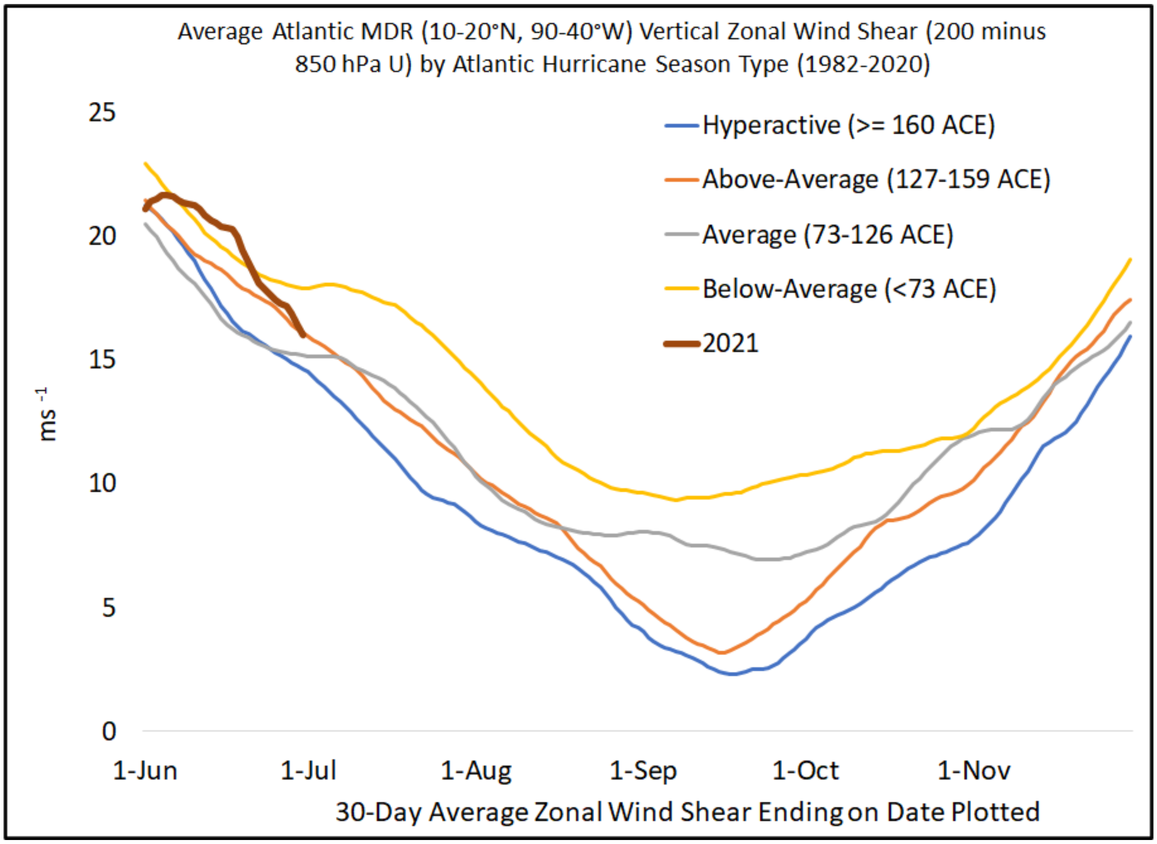

Figure 22: Average vertical zonal wind shear for various Atlantic hurricane season types: 1982-2020. Vertical wind shear in 2021 has strongly trended downward over the past couple of weeks.

6 West Africa Conditions

As was the case in 2020, the West African monsoon has gotten off to a strong start, with pronounced anomalous upward vertical motion across most of tropical Africa over the past 30 days (Figure 23). In addition, precipitation in the Sahel was generally above normal (Figure 24). An active West African monsoon is typically associated with more active Atlantic hurricane seasons.

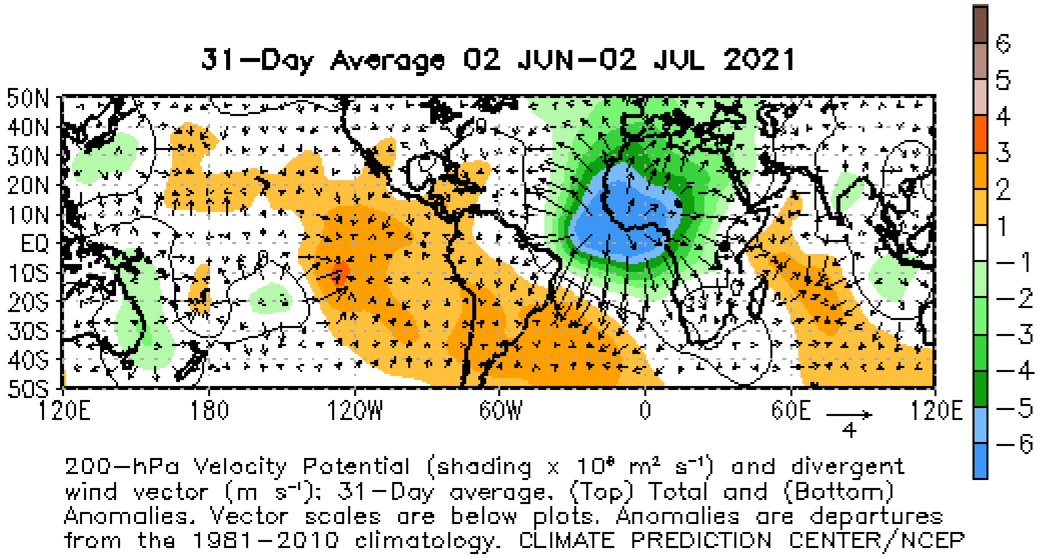

Figure 23: 200 hPa velocity potential anomalies from 50°S – 50°N from 2 June to 2o July 2021. Negative velocity potential favors upward vertical motion.

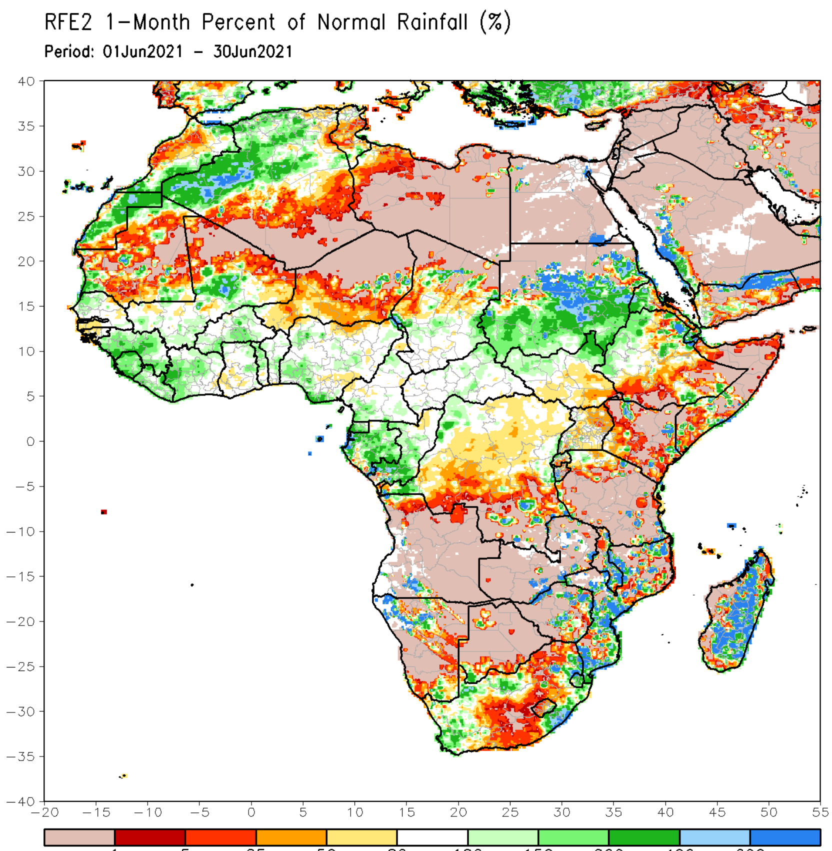

Figure 24: June 2021 rainfall estimates from the African Rainfall Estimation Algorithm, version 2.

7 Hurricane Elsa

In general, early season Atlantic hurricane activity has very little correlation with overall Atlantic hurricane activity. However, when this activity occurs in the tropics (south of 23.5°N), that is typically a harbinger of a very active season. Hurricane Elsa formed in the tropical Atlantic and then tracked into the eastern Caribbean (10-20°N, 75-60°W) at hurricane strength. Since 1900, only six other years have had eastern Caribbean hurricanes prior to 1 August: 1926, 1933, 1961, 1996, 2005 and 2020. All six of those years were classified as hyperactive Atlantic hurricane seasons using the NOAA Atlantic hurricane season definition (>=160 ACE).

8 Forthcoming Updated Forecasts of 2021 Hurricane Activity

We will be issuing a final seasonal update of our 2021 Atlantic basin hurricane forecast on **Thursday, 5 August**. We will also begin issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season on 5 August. A verification and discussion of all 2021 forecasts will be issued in late November 2021. All of these forecasts will be available on our website.