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

We have decreased our forecast slightly but continue to call for an above-average 2021 Atlantic hurricane season. Sea surface temperatures averaged across the tropical Atlantic are now warmer than normal, while vertical wind shear anomalies averaged over the past 30 days over the Caribbean and tropical Atlantic are slightly weaker than normal. Current cool neutral ENSO conditions are likely to persist (and perhaps even transition to weak La Niña conditions) by the peak of the Atlantic hurricane season. We continue to 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 5 August 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

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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	Issue Date 5 August 2021	Observed Thru 4 August 2021	Remainder of Season Forecast
Named Storms (NS) (14.4)	17	18	20	18*	5	13
Named Storm Days (NSD) (69.4)	80	80	90	80	13.75	66.25
Hurricanes (H) (7.2)	8	8	9	8	1	7
Hurricane Days (HD) (27.0)	35	35	40	35	1.5	33.5
Major Hurricanes (MH) (3.2)	4	4	4	4	0	4
Major Hurricane Days (MHD) (7.4)	9	9	9	9	0	9
Accumulated Cyclone Energy (ACE) (123)	150	150	160	150	13	137
Net Tropical Cyclone Activity (NTC) (135%)	160	160	170	160	17	143

*Total forecast includes Ana, Bill, Claudette, Danny and Elsa which have formed in the Atlantic as of August 4th.

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

1) Entire continental U.S. coastline - 65% (full-season average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 40% (full-season average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 41% (full-season 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 4 AUGUST):

1) 54% (full-season average for last century is 42%)

ABSTRACT

Information obtained through July 2021 indicates that the 2021 Atlantic hurricane season will have slightly above-average activity. The Atlantic has already had 5 named storms and 1 hurricane through August 4. We estimate that 2021 will have an additional 13 named storms (post-31 July average is 11.6), 7 hurricanes (average is 6.5), and 4 major (Category 3-4-5) hurricanes (average is 3.1). The probability of U.S. major hurricane landfall is estimated to be about 125 percent of the long-period full-season average. We predict Atlantic basin Accumulated Cyclone Energy (ACE) to be approximately 120 percent of its long term post-31 July average.

This forecast is based on an extended-range early August statistical prediction scheme that was developed using 39 years of past data. We also include statistical/dynamical model forecasts from the SEAS5 and GloSea6 climate models, which emanate from the European Centre for Medium-Range Weather Forecasts and UK Met Office, respectively. Analog predictors are also utilized.

The tropical Atlantic has anomalously warmed over the past few weeks and is now warmer than normal, while vertical wind shear averaged across the tropical Atlantic and Caribbean over the past 30 days is slightly weaker than normal. Warmer than normal water across the tropical Atlantic provides more fuel for tropical cyclones. Vertical wind shear in July typically has strong persistence, that is, if vertical wind shear is high in July, it is likely to remain elevated during the peak of the season. Both the GloSea6 and SEAS5 climate models predict near-normal vertical wind shear for August-September. Lower vertical wind shear allows hurricanes to better vertically couple and also inhibits entrainment of dry air into the circulation. Sea surface temperatures averaged across the eastern and central tropical Pacific are slightly cooler than average, and it appears likely that there will be either cool neutral ENSO or weak La Niña conditions during the peak of the Atlantic hurricane season. All of these conditions in combination point to an above-average season in 2021, but our statistical model and statistical/dynamical models indicate slightly less activity than was anticipated in early July – hence the slight decrease in the seasonal forecast numbers.

The early August forecast has good long-term skill when evaluated in hindcast mode. The skill of CSU's forecast updates typically increases as the peak of the Atlantic hurricane season approaches. We continue to present probabilities of exceedance for hurricanes and Accumulated Cyclone Energy to give interested readers a better idea of the uncertainty associated with these forecasts.

Starting today and issued every two weeks following (e.g., August 5, August 19, September 2, etc.), we will issue two-week forecasts for Atlantic TC activity during the peak of the Atlantic hurricane season from August-October.

Coastal residents are reminded that it only takes one hurricane making landfall to make it an active season for them, and they need to prepare the same for every season, regardless of how much activity is predicted.

Why issue forecasts for seasonal hurricane activity?

We are frequently asked this question. Our answer is that it is possible to say something about the probability of the coming year's hurricane activity which is superior to climatology. The Atlantic basin has the largest year-to-year variability of any of the global tropical cyclone basins. People are curious to know how active the upcoming season is likely to be, particularly if you can show hindcast skill improvement over climatology for many past years.

Everyone should realize that it is impossible to precisely predict this season's hurricane activity in early August. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged as regards to the probability of an active or inactive hurricane season for the coming year. Our early August statistical 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 considers 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 August 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 August Forecast Methodology

2.1 August Statistical Forecast Scheme

We developed a 1 August statistical seasonal forecast scheme for the prediction of Accumulated Cyclone Energy (ACE) that has been issued operationally since 2012. This model was re-run last year with the latest version of the European Centre for Medium Range Weather Forecasts (ECMWF) Reanalysis product – ERA5. We use the daily NOAA Optimum Interpolation SST version 2 product for the SST predictor. Since the NOAA daily SST product is available since September 1981, this model was developed on Atlantic hurricane seasons from 1982-2020.

The pool of three predictors for the early August statistical forecast scheme is given and defined in Table 2. The location of each of these predictors is shown in Figure 2. Skillful forecasts can be issued for post-31 July ACE based upon cross-validated hindcasts from 1982-2020. When these three predictors are combined, they correlate at 0.82 with observed ACE using cross-validated hindcasts from 1982-2020 (Figure 3). Predictor 1 (Caribbean trade wind strength) and Predictor 3 (tropical Africa upper-level winds) call for near-average activity, while Predictor 2 (Subtropical northeastern Atlantic SST) calls for an above-average remainder of the 2021 Atlantic hurricane season.

Table 2: Listing of 1 August 2021 predictors for this year's hurricane activity. A plus (+) means that positive deviations of the parameter indicate increased hurricane activity this year, and a minus (-) means that positive deviations of the parameter indicate decreased hurricane activity this year.

Predictor	Values for 2021 Forecast	Effect on 2021 Hurricane Season
1) July 10 m U (10-17.5°N, 60-85°W) (+)	+0.4 SD	Slightly Enhance
2) July SST (20-40°N, 15-35°W) (+)	+0.6 SD	Enhance
3) July 200 hPa U (5-15°N, 0-40°E) (-)	+0.3 SD	Slightly Suppress

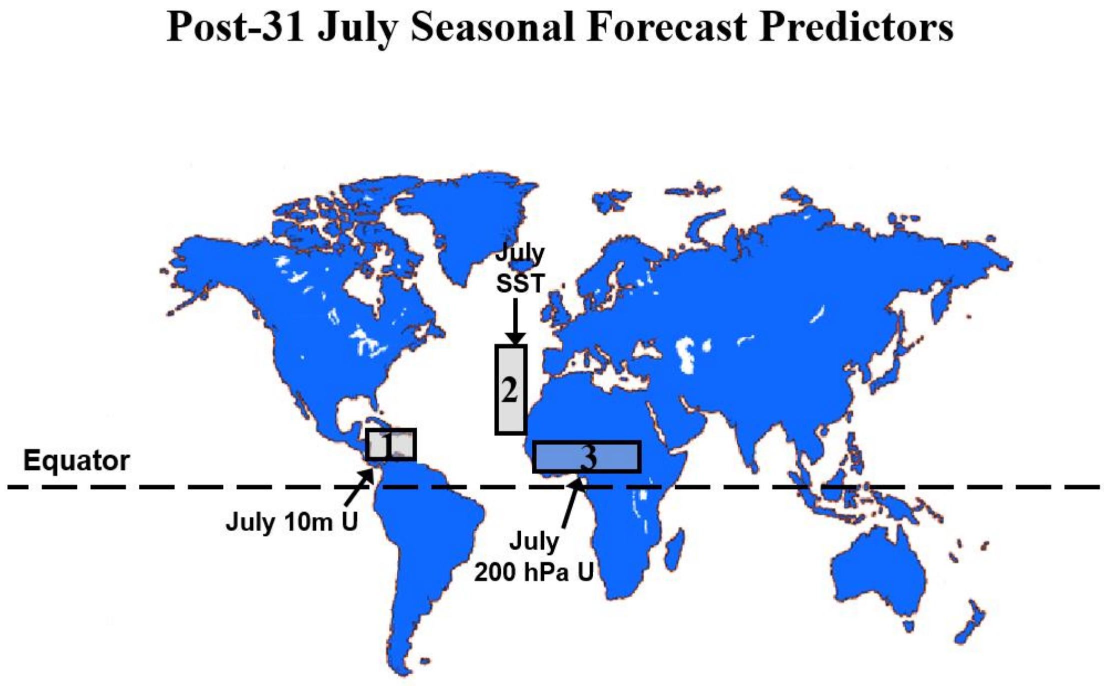

Figure 2: Location of predictors for the post-31 July forecast for the 2021 hurricane season from the statistical model.

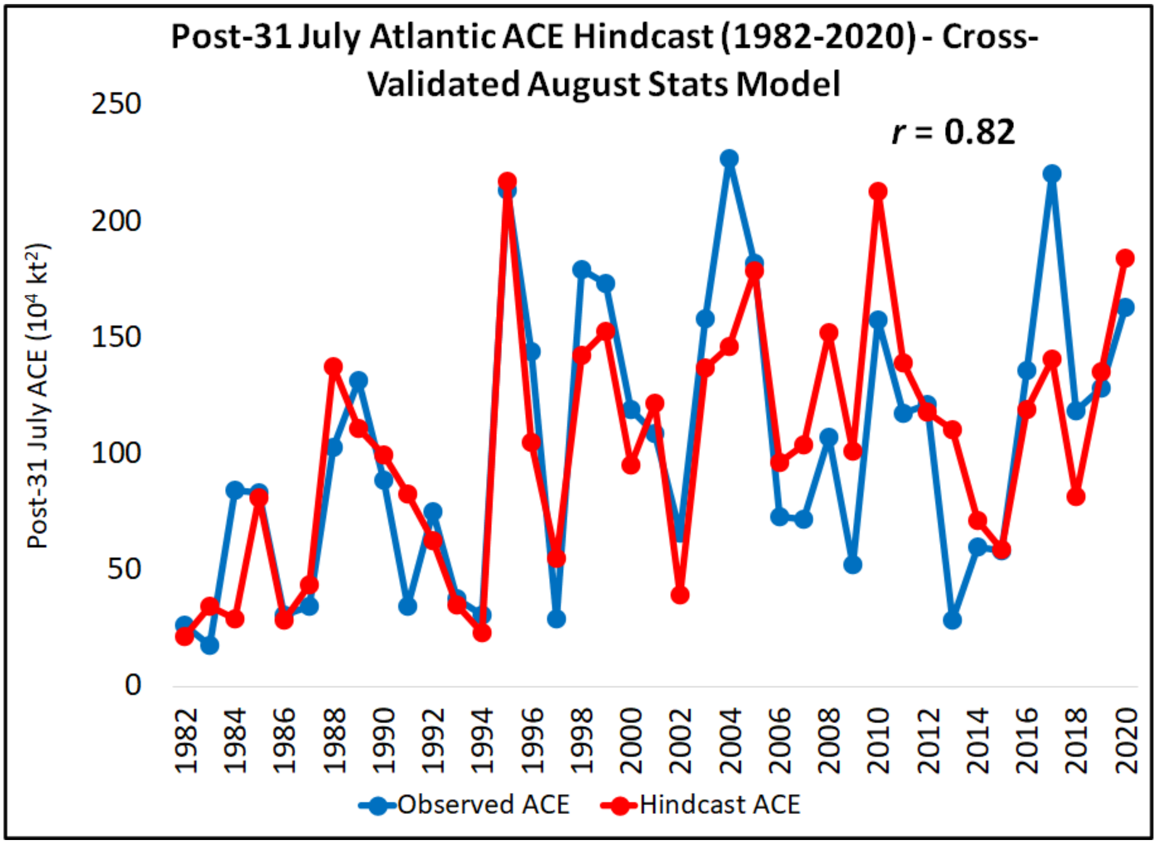

Figure 3: Observed versus hindcast values of post-31 July ACE for 1982-2020 using our current statistical scheme.

Table 3 shows our forecast for the 2021 hurricane season from the statistical model and the comparison of this forecast with the 1991-2020 average. Our statistical forecast is calling for a slightly above-average remainder of the season.

Table 3: Post-31 July statistical forecast for 2021 from the statistical model.

Predictands and Climatology (1991-2020 Post-31 July Average)	Post-31 July Statistical Forecast	Full Season Statistical Forecast (Activity Thru 4 August Added In)
Named Storms (NS) – 11.6	15.1	20.1
Named Storm Days (NSD) – 61.3	74.2	88.0
Hurricanes (H) – 6.5	7.7	8.7
Hurricane Days (HD) – 25.6	29.6	31.1
Major Hurricanes (MH) – 3.1	3.5	3.5
Major Hurricane Days (MHD) – 7.1	8.3	8.3
Accumulated Cyclone Energy (ACE) – 113	134	147
Net Tropical Cyclone Activity (NTC) – 123	146	163

2.2 Physical Associations among Predictors Listed in Table 2

The locations and brief descriptions of the three predictors for our current August statistical forecast are now discussed. It should be noted that all forecast parameters correlate significantly with physical features during August through October that are known to be favorable for elevated levels of TC activity. For each of these predictors, we display a four-panel figure showing rank correlations between values of each predictor and August-October values of SST, sea level pressure (SLP), 850 hPa (~1.5 km altitude) zonal wind (U), and 200 hPa (~12 km altitude) zonal wind (U), respectively.

<u>Predictor 1. July 10 meter U in the Caribbean (+)</u>

(10-17.5°N, 60-85°W)

Low-level trade wind flow has been utilized as a predictor in seasonal forecasting systems for the Atlantic basin (Saunders and Lea 2008). When the trades are weaker-than-normal, SSTs across the tropical Atlantic tend to be elevated, and consequently a larger-than-normal Atlantic Warm Pool (AWP) is typically observed (Wang and Lee 2007) (Figure 4). A larger AWP also correlates with reduced vertical shear across the tropical Atlantic. Weaker trade winds are typically associated with higher pressure in the tropical eastern Pacific (a La Niña signal) and lower pressure in the Caribbean and tropical Atlantic. Both of these conditions generally occur when active hurricane seasons are observed. Predictor 1 also has a strong negative correlation with August-October-averaged 200-850-hPa zonal shear.

<u>Predictor 2. July SST in the Northeastern Subtropical Atlantic (+)</u>

(20°-40°N, 15-35°W)

A similar predictor was utilized in earlier August seasonal forecast models (Klotzbach 2007, Klotzbach 2011). Anomalously warm SSTs in the subtropical North Atlantic are associated with a positive phase of the Atlantic Meridional Mode (AMM), a northward-shifted Intertropical Convergence Zone, and consequently, reduced trade wind strength (Kossin and Vimont 2007). Weaker trade winds are associated with less surface evaporative cooling and less mixing and upwelling. This results in warmer tropical Atlantic SSTs during the August-October period (Figure 5).

<u>Predictor 3. July 200 hPa U over Northern Tropical Africa (-)</u>

(5-15°N, 0-40°E)

Anomalous easterly flow at upper levels over northern tropical Africa provides an environment that is more favorable for easterly wave development into TCs. This anomalous easterly flow tends to persist through August-October, which reduces shear over the Main Development Region (MDR). This predictor also correlates with SLP and SST anomalies over the tropical eastern Pacific that are typically associated with cool ENSO conditions (Figure 6).

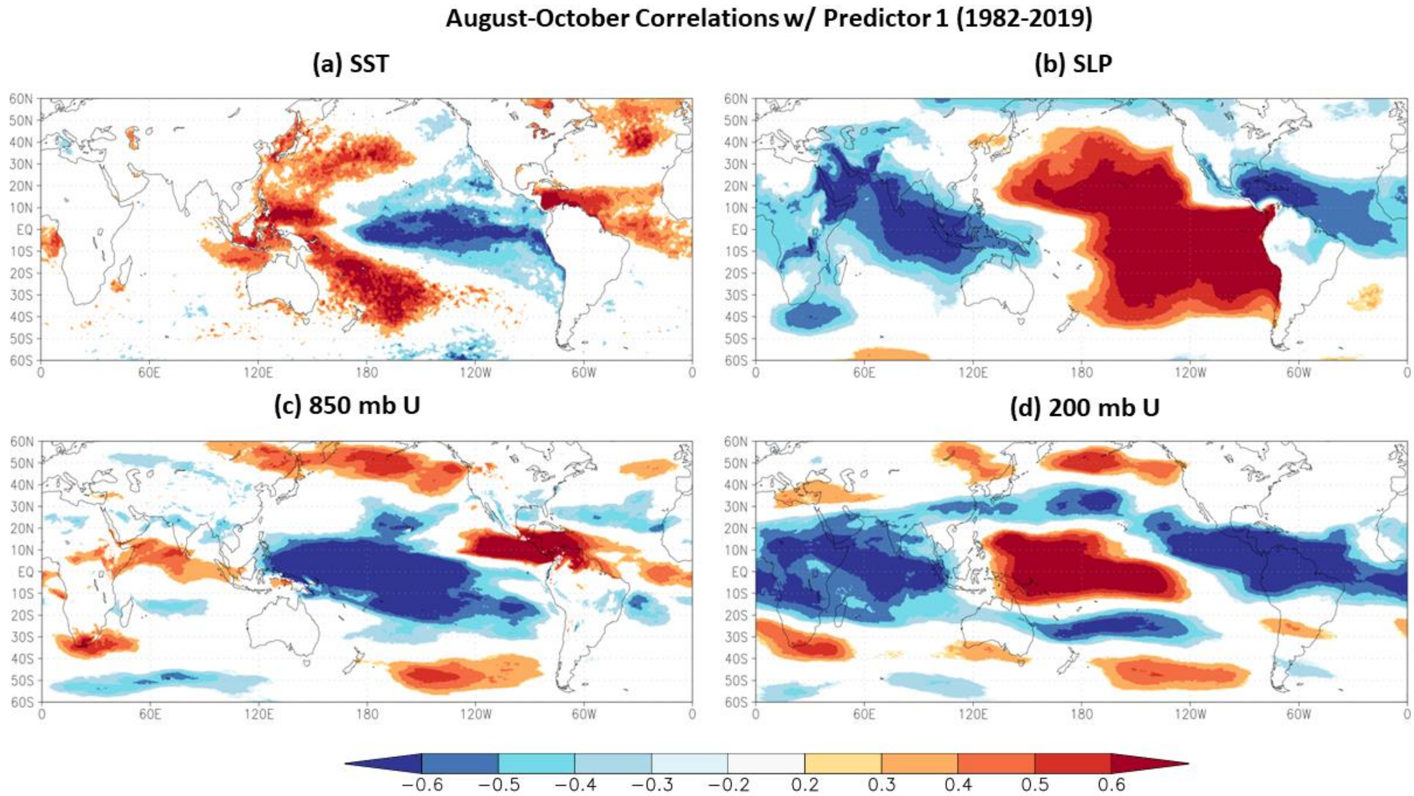

Figure 4: Rank correlations between July 10 meter U in the Caribbean (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 hPa zonal wind (panel c) and August-October 200 hPa zonal wind (panel d) over the period from 1982-2019.

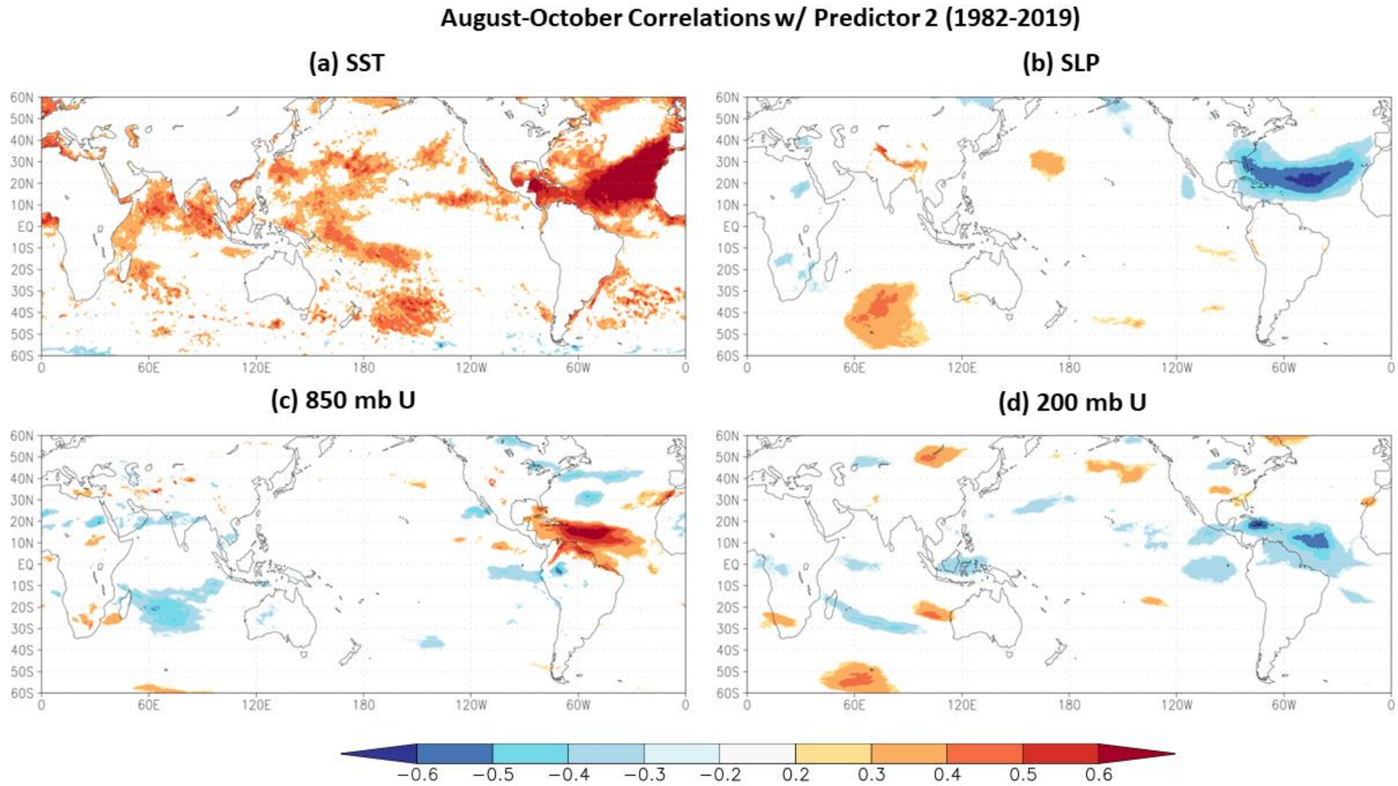

Figure 5: Rank correlations between <u>July sea surface temperature</u> in the subtropical northeastern Atlantic <u>(Predictor 2)</u> and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 hPa zonal wind (panel c) and August-October 200 hPa zonal wind (panel d) over the period from 1982-2019.

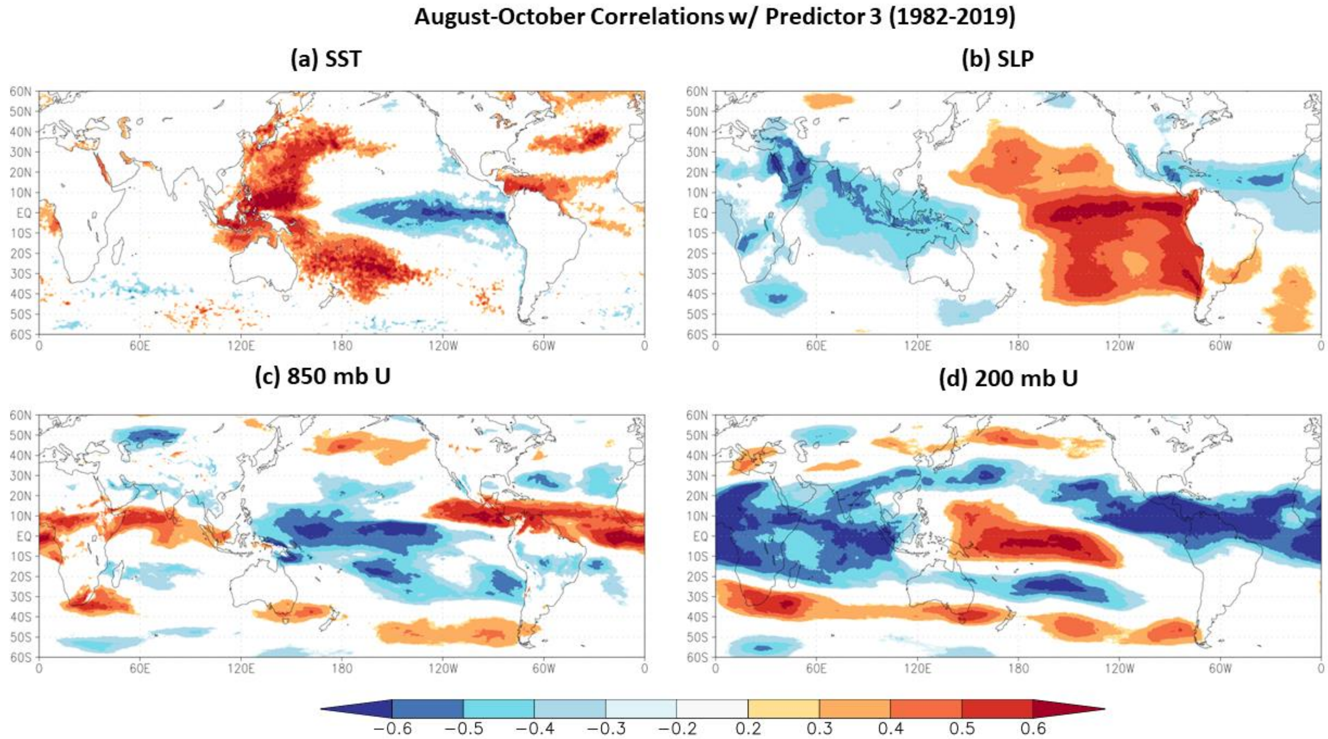

Figure 6: Rank correlations between July 200 hPa zonal wind over tropical north Africa (Predictor 3) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 hPa zonal wind (panel c) and August-October 200 hPa zonal wind (panel d) over the period from 1982-2019. Predictor values have been multiplied by -1 so that the signs of correlations match up with those in Figures 4 and 5.

2.2 August Statistical/Dynamical Forecast Scheme

We have developed a statistical/dynamical forecast model scheme for the early August outlook that we are debuting this year. This model, developed in partnership with Louis-Philippe Caron and the data team at the Barcelona Supercomputing Centre, uses output from the ECMWF SEAS5 and Met Office's GloSea6 models to forecast August-September zonal wind shear and SSTs across the tropical Atlantic and Caribbean (10-20°N, 85-40°W). Lower-than-normal shear and above-normal SSTs in the tropical Atlantic and Caribbean both favor an active Atlantic hurricane season.

Both the SEAS5 and GloSea6 models are able to forecast August-September large-scale fields with considerable skill from an early July initialization. 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 July forecast.

Figure 8 displays the parameters used in our new statistical/dynamical model scheme, while Table 4 displays SEAS5's forecasts of these parameters for 2021 from a 1 July initialization date. SEAS5 is calling for slightly above-normal zonal vertical wind shear and slightly warmer than normal SSTs across the central tropical Atlantic and Caribbean for August-September. We do note, however, that SEAS5 has over-forecast wind shear the past few hurricane seasons, leading to lower-than-observed ACE, both in our statistical/dynamical model as well as in dynamical model forecasts of Atlantic TCs by ECMWF. Figure 9 displays cross-validated hindcasts for SEAS5 forecasts of ACE from 1981-2020, while Table 5 presents the forecast from SEAS5 for the 2021 Atlantic hurricane season. SEAS5 is calling for a near-average rest of the hurricane season.

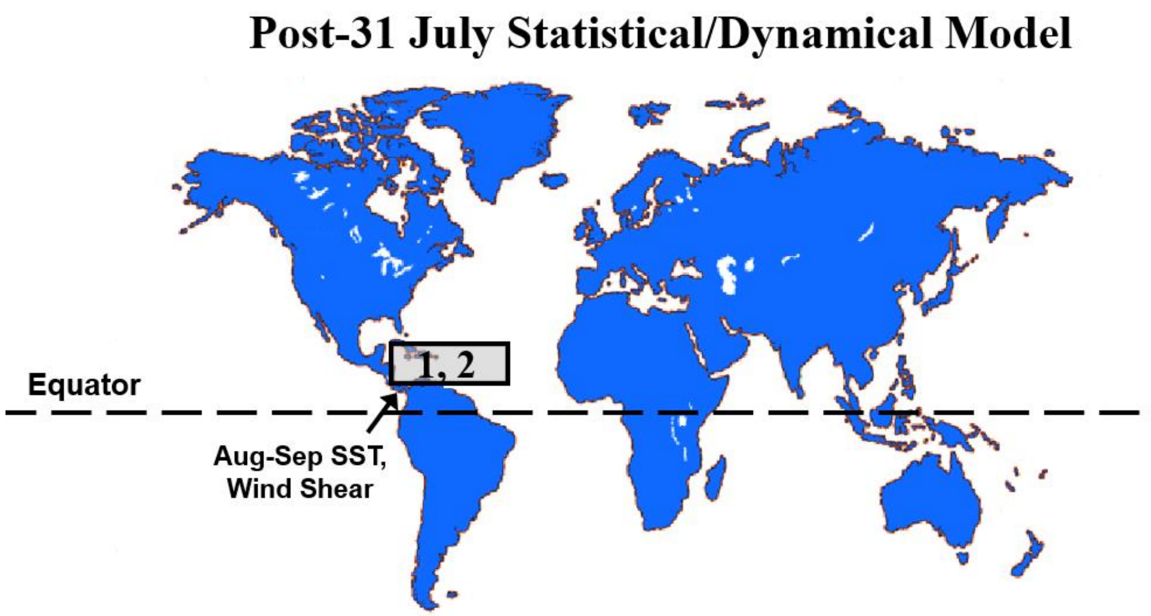

Figure 8: Location of predictors for our early August statistical/dynamical prediction for the 2021 hurricane season. This forecast uses either the ECMWF SEAS5 model or the UK Met Office GloSea6 model to predict August-September SST and zonal wind shear in the box displayed and uses those predictors to forecast ACE.

Table 4: Listing of predictions of August-September large-scale conditions from ECMWF SEAS5 output, initialized on 1 July. 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) SEAS5 Prediction of Aug-Sep Zonal Wind Shear (10-20°N, 85-40°W) (-)	+0.5 SD	Suppress
2) SEAS5 Prediction of Aug-Sep SST (10-20°N, 85-40°W) (+)	+0.3 SD	Enhance

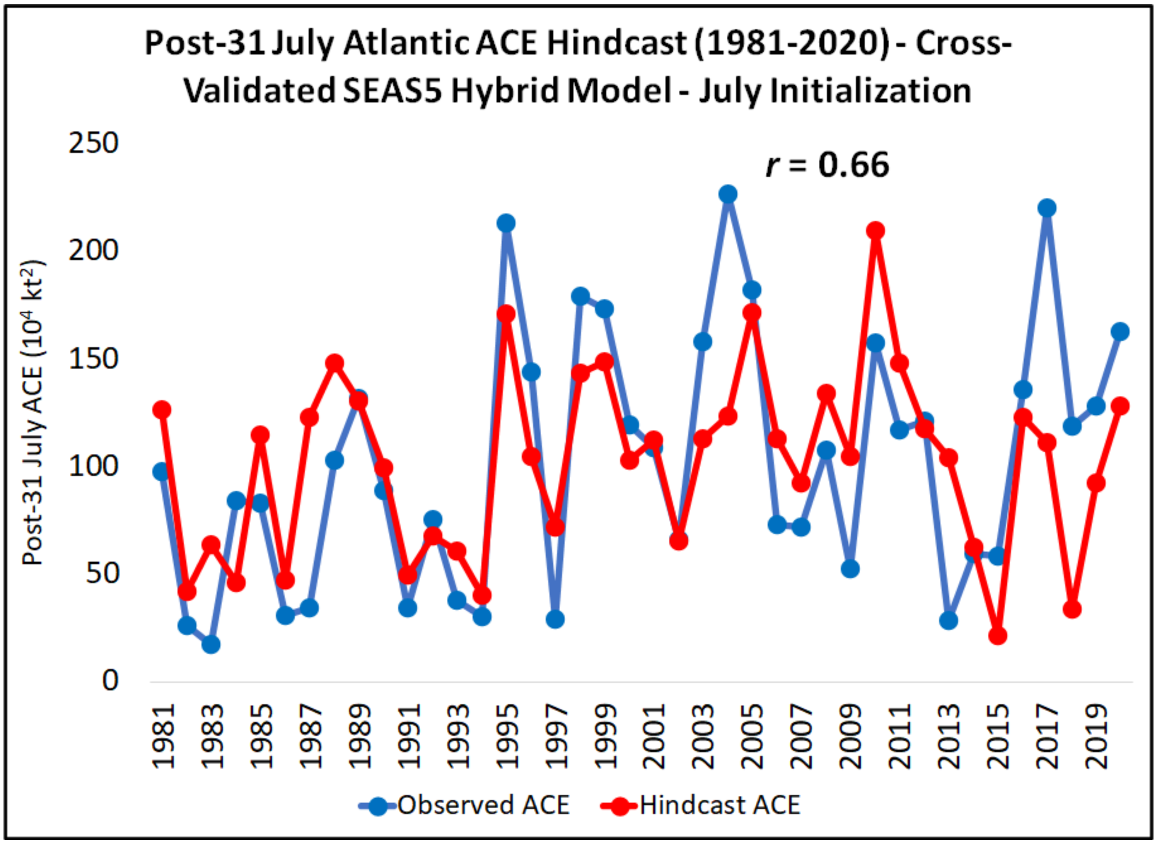

Figure 9: Observed versus early July cross-validated statistical/dynamical hindcast values of ACE for 1981-2020 from SEAS5.

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

Predictands and Climatology (1991-2020 Post-31 July Average)	Post-31 July Statistical/Dynamical Forecast	Full Season Statistical/Dynamical Forecast (Activity Thru 4 August Added In)
Named Storms (NS) – 11.6	13.8	18.8
Named Storm Days (NSD) – 61.3	65.4	79.2
Hurricanes (H) – 6.5	6.7	7.7
Hurricane Days (HD) – 25.6	24.8	26.3
Major Hurricanes (MH) – 3.1	2.9	2.9
Major Hurricane Days (MHD) – 7.1	6.6	6.6
Accumulated Cyclone Energy (ACE) – 113	113	126
Net Tropical Cyclone Activity (NTC) – 123	125	142

As noted earlier, we also developed a statistical/dynamical model forecasting the same large-scale fields and using the GloSea6 model. The GloSea6 model shows comparable levels of skill to SEAS5 at predicting tropical Atlantic and Caribbean August-September zonal wind shear and SST. Figure 10 displays observed versus cross-validated hindcast ACE using the same two predictors as used for the SEAS5 statistical/dynamical forecast model.

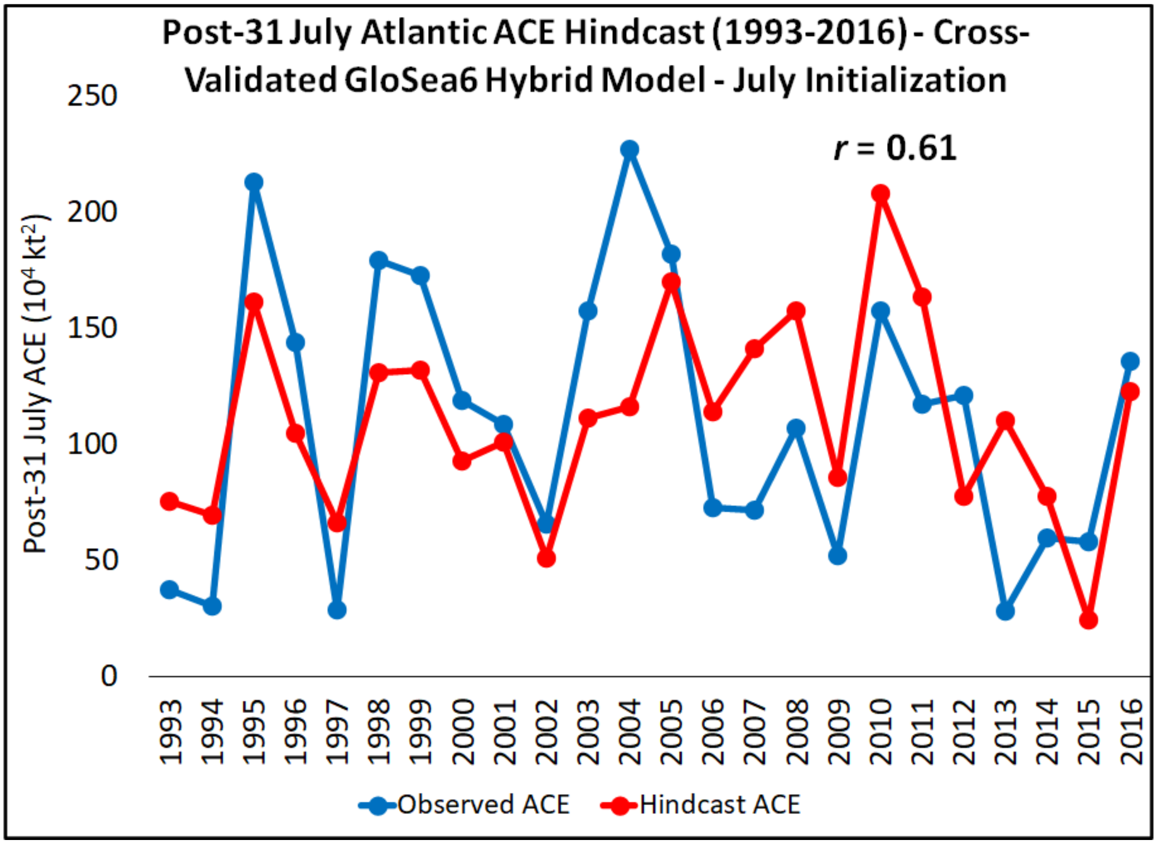

Figure 10: Observed versus June cross-validated statistical/dynamical hindcast values of ACE for 1993-2016 from GloSea6.

The output from the GloSea6 model calls for a slightly above-average remainder of the Atlantic hurricane season in 2021. GloSea6 is predicting near-average vertical wind shear and above-average tropical Atlantic SSTs. Table 6 displays the forecasts of the two 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 August-September large-scale conditions from Met Office GloSea6 output, initialized on 1 July. 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 Aug-Sep Zonal Wind Shear (10-20°N, 85-40°W) (-)	-0.1 SD	Neutral
2) GloSea6 Prediction of Aug-Sep SST (10-20°N, 85-40°W) (+)	+0.8 SD	Enhance

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

Predictands and Climatology (1991-2020 Post-31 July Average)	Post-31 July Statistical/Dynamical Forecast	Full Season Statistical/Dynamical Forecast (Activity Thru 4 August Added In)
Named Storms (NS) – 11.6	14.7	19.7
Named Storm Days (NSD) – 61.3	71.2	85.0
Hurricanes (H) – 6.5	7.4	8.4
Hurricane Days (HD) – 25.6	28.0	29.5
Major Hurricanes (MH) – 3.1	3.3	3.3
Major Hurricane Days (MHD) – 7.1	7.7	7.7
Accumulated Cyclone Energy (ACE) – 113	127	140
Net Tropical Cyclone Activity (NTC) – 123	139	156

2.3 August 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 August forecast, we determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current July 2021 conditions and, more importantly, projected August-October 2021 conditions. Table 4 lists our analog selections.

We searched for years that were generally characterized by cool neutral ENSO to weak La Niña conditions during August-October. These seasons also had relatively warm tropical Atlantic SSTs. We anticipate that the 2021 hurricane season will have activity near the average of our six 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
2016	15	82.25	7	27.75	4	10.25	143	156
2017	17	93.00	10	51.75	6	19.25	225	232
Average	15.8	83.5	8.3	34.4	4.8	9.8	153	170
2021 Forecast	**18**	**80**	**8**	**35**	**4**	**9**	**150**	**160**

2.4 August Forecast Summary and Final Adjusted Forecast

Table 9 shows our final adjusted early August forecast for the 2021 season which is a combination of our statistical scheme, our two statistical/dynamical model schemes, our analog scheme and qualitative adjustments for other factors not explicitly contained in any of these schemes. Most of our model guidance is calling for a slightly above-average remainder of the Atlantic hurricane season. Our forecast is near the average of our model guidance, due to both anticipated cool ENSO-neutral or weak La Niña conditions as well as anticipated anomalously warm SSTs and potentially weaker than normal vertical wind shear in the tropical Atlantic for the peak of the Atlantic hurricane season (August-October).

Table 9: Summary of our early August statistical forecast, our two statistical/dynamical model forecasts, our analog forecast, the average of these schemes and our adjusted final forecast for the 2021 hurricane season. All schemes have TC activity that was observed prior to 5 August included.

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)	20.1	18.8	19.7	15.8	18.6	18
Named Storm Days (69.4)	88.0	79.2	85.0	83.5	83.9	80
Hurricanes (7.2)	8.7	7.7	8.4	8.3	8.3	8
Hurricane Days (27.0)	31.1	26.3	29.5	34.4	30.3	35
Major Hurricanes (3.2)	3.5	2.9	3.3	4.8	3.6	4
Major Hurricane Days (7.4)	8.3	6.6	7.7	9.8	8.1	9
Accumulated Cyclone Energy Index (123)	147	126	140	153	142	150
Net Tropical Cyclone Activity (135%)	163	142	156	170	158	160

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.

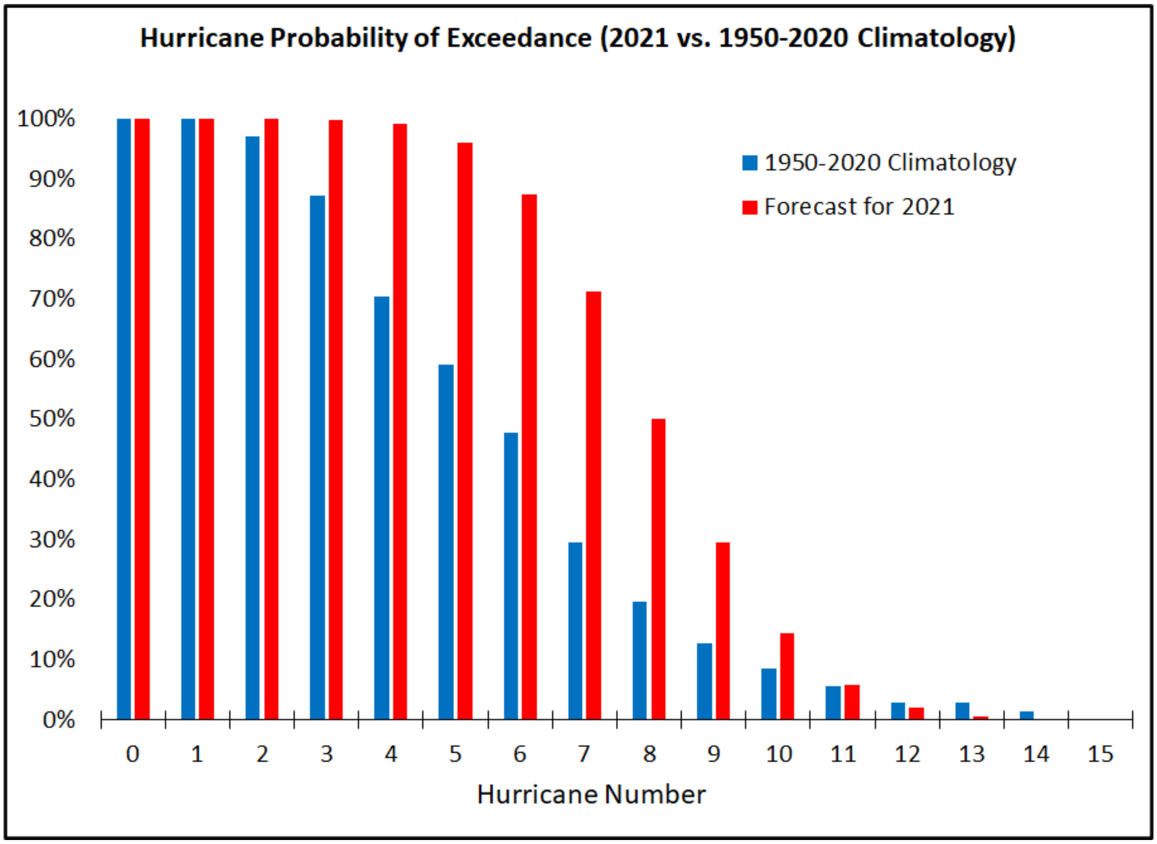

Figure 11: Probability of exceedance plot for hurricane numbers for the 2021 Atlantic hurricane season. The values on the x-axis indicate that the number of hurricanes exceeds that specific number. For example, 97% of Atlantic hurricane seasons from 1950-2020 have had more than two hurricanes.

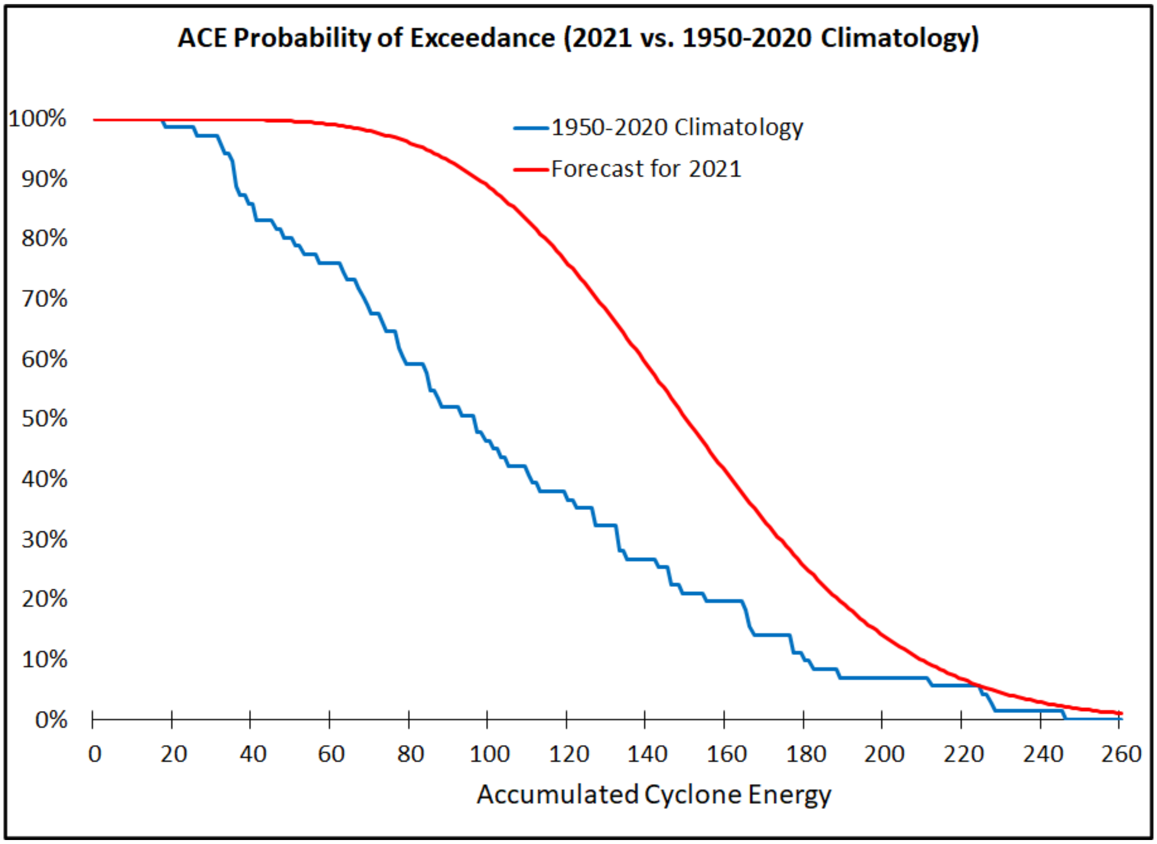

Figure 12: As in Figure 11 but for ACE.

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)	18	15 – 21
Named Storm Days (NSD)	80	61 – 99
Hurricanes (H)	8	6 – 10
Hurricane Days (HD)	35	24 – 47
Major Hurricanes (MH)	4	3 – 5
Major Hurricane Days (MHD)	9	6 – 13
Accumulated Cyclone Energy (ACE)	150	107 – 198
Net Tropical Cyclone (NTC) Activity	160	118 – 205

4 ENSO

The tropical Pacific continues to be characterized by cool neutral ENSO conditions, with SSTs averaging slightly below-normal across most of the central and eastern tropical Pacific, although SST anomalies are somewhat warmer than normal in the far eastern tropical Pacific (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. Cool neutral ENSO conditions are defined by anomalies in the Nino 3.4 region between -0.5°C – 0°C. SST anomalies have generally trended downward in the Nino 3.4 region over the past few weeks (Figure 14), due in part to anomalously strong trade winds across the central tropical Pacific for most of July (Figure 15). Following a brief slackening of the trade winds that is currently ongoing, we anticipate a freshening of the trade winds again, helping to promote additional anomalous cooling across the central and eastern tropical Pacific.

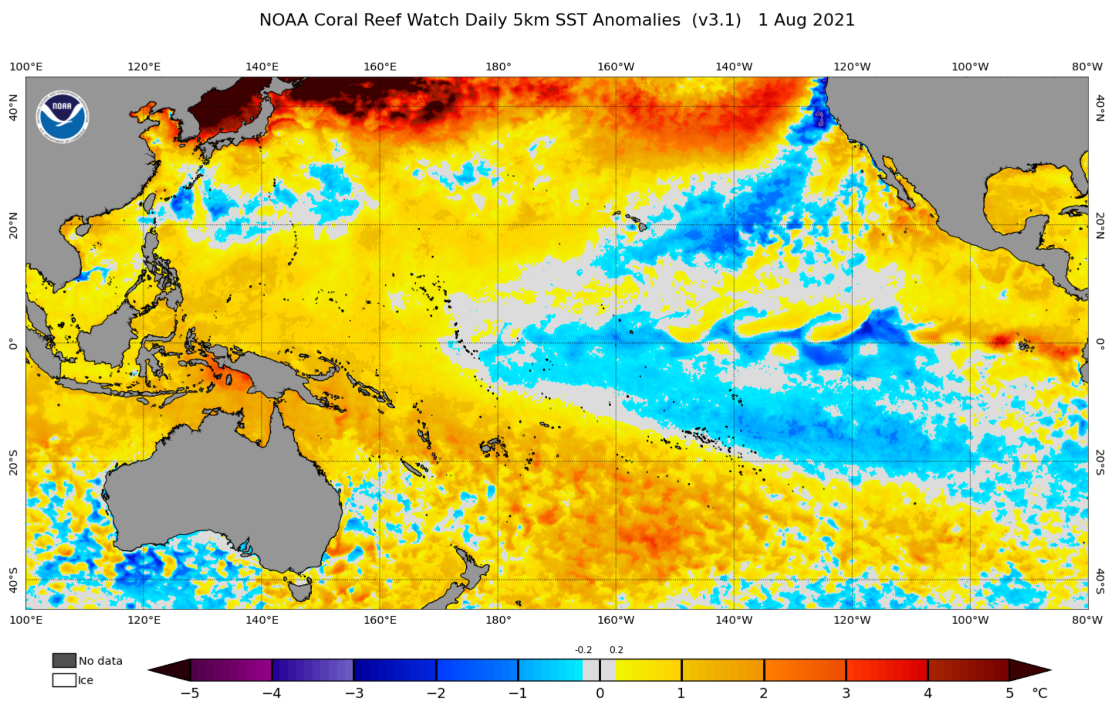

Figure 13: Current SST anomalies across the tropical and subtropical Pacific.

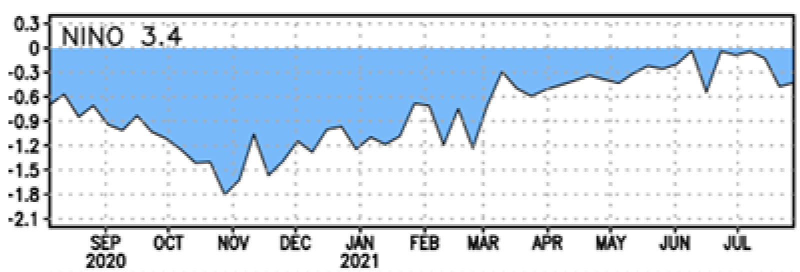

Figure 14: Nino 3.4 SST anomalies from August 2020 through July 2021. Figure courtesy of the Climate Prediction Center.

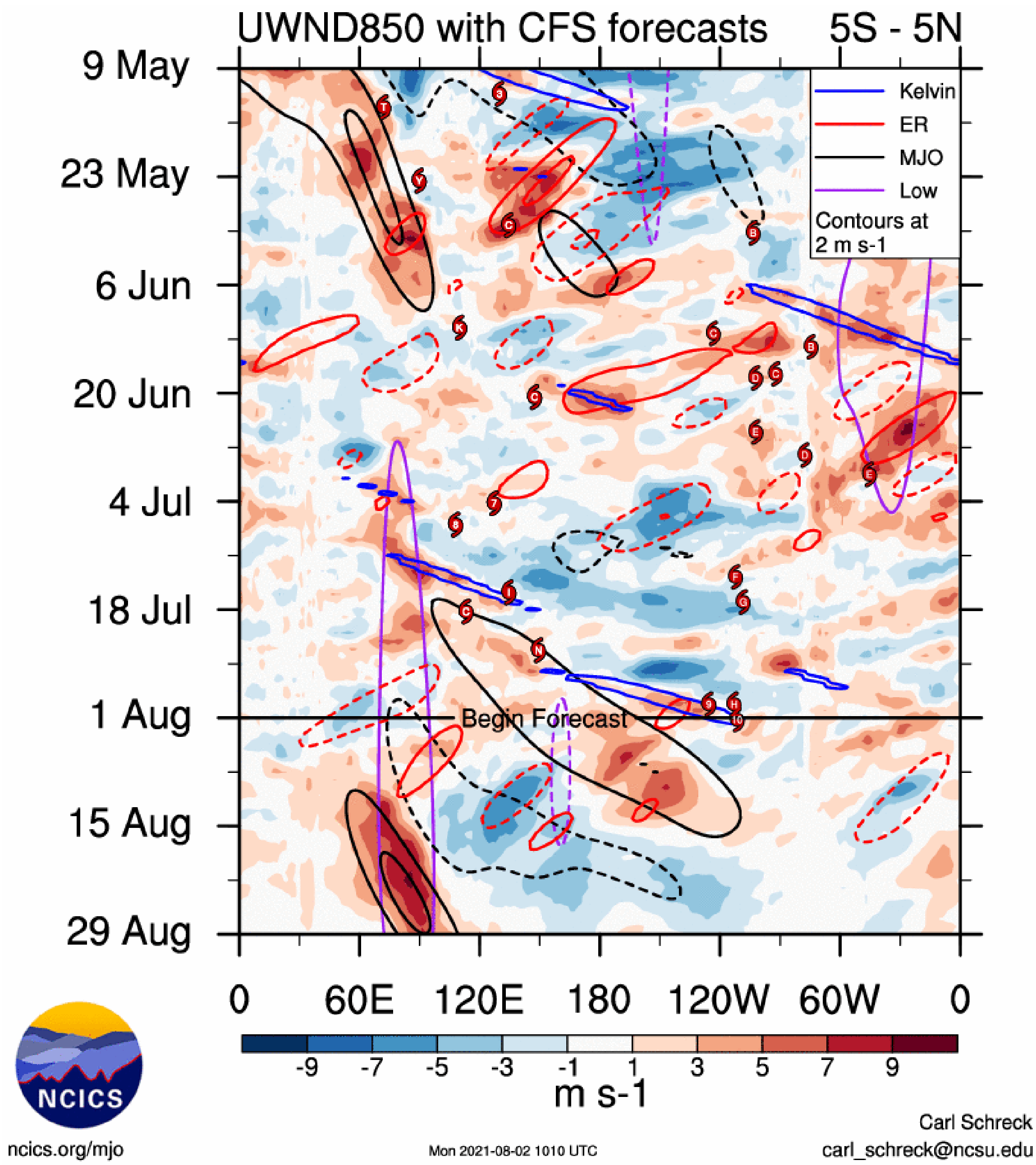

Figure 15: Observed low-level winds across the equatorial region as well as predictions for the next four weeks by the Climate Forecast System. Figure courtesy of Carl Schreck.

Upper-ocean heat content anomalies in the eastern and central tropical Pacific were at below-normal levels through February 2021, increased rapidly until early May, and have since decreased again (Figure 16). As noted in the previous paragraph, the considerable anomalous cooling of the upper-ocean that has occurred over the past few weeks is likely associated with the pronounced trade wind surge.

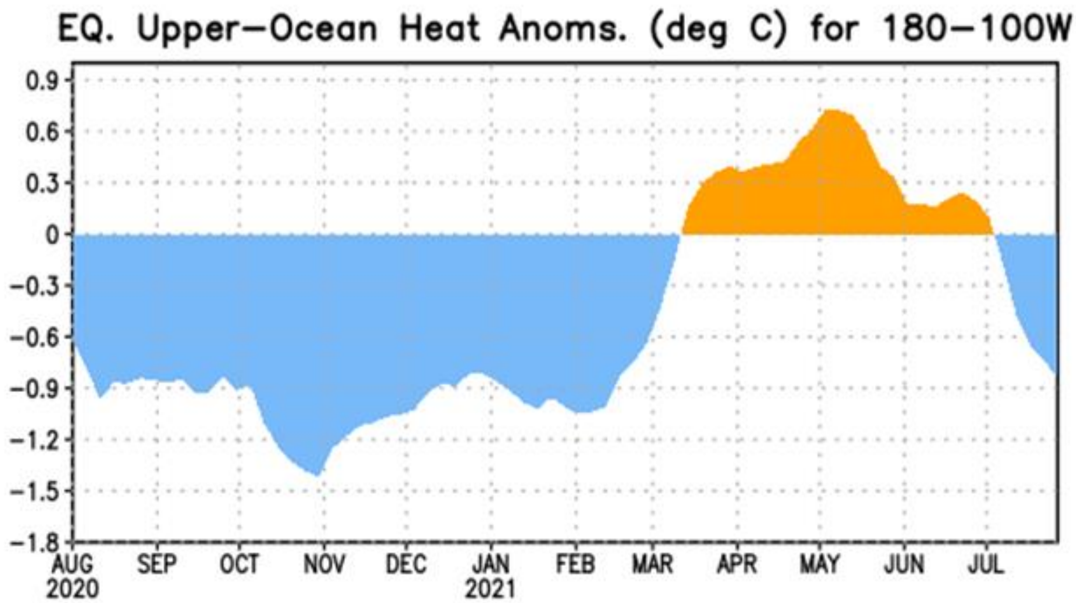

Figure 16: Central and eastern equatorial Pacific upper ocean (0-300 meters) heat content anomalies over the past year.

Table 11 displays June and July SST anomalies for several Nino regions. Anomalies have trended downward slightly except for in the far eastern Pacific (e.g., the Nino 1+2 region).

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

Region	June SST Anomaly (°C)	July SST Anomaly (°C)	July – June SST Anomaly (°C)
Nino 1+2	+0.2	+0.5	+0.3
Nino 3	-0.2	-0.2	0.0
Nino 3.4	-0.2	-0.3	-0.1
Nino 4	-0.1	-0.3	-0.2

The tropical Pacific experienced a downwelling (warming) Kelvin wave (denoted by a dashed line) which reached the coast of South America in mid-June (Figure 17). Since that time, the tropical eastern and central Pacific has generally cooled, due to the trade wind surge that was discussed previously.

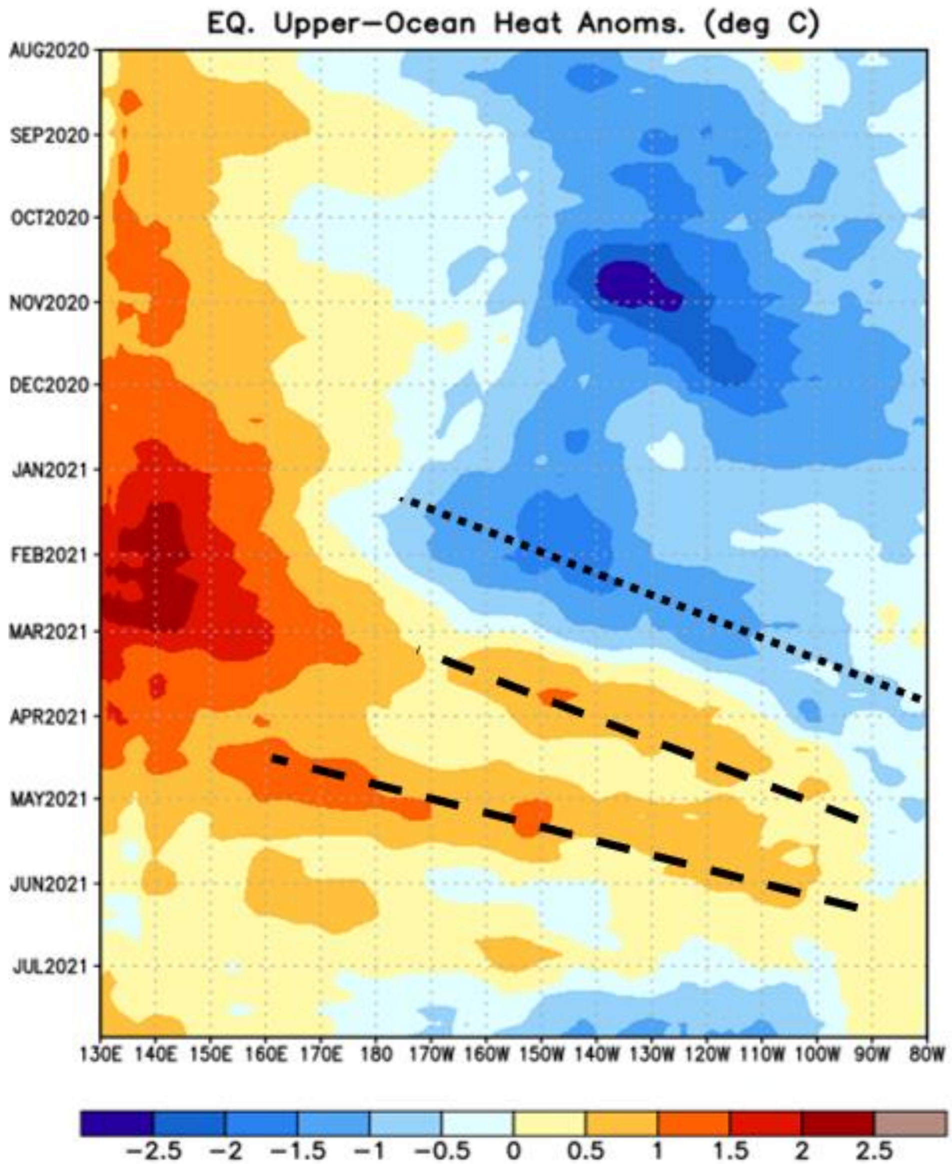

Figure 17: Upper-ocean heat content anomalies in the tropical Pacific since August 2019. Dashed lines indicate downwelling Kelvin waves, while dotted lines indicate upwelling Kelvin waves. Downwelling Kelvin waves result in upper-ocean heat content increases, while upwelling Kelvin waves result in upper-ocean heat content decreases.

We will continue monitoring low-level winds over the tropical Pacific as the peak of the Atlantic hurricane season gets underway. Anomalous easterlies have generally prevailed across the central tropical Pacific for the past few weeks, and as noted earlier, following a brief weakening of the trades that is currently ongoing, the Climate Forecast System (CFS) is forecasting an increase in the trade winds for most of August (Figure 15). Consequently, we believe that we will likely have either cool neutral ENSO or weak La Niña for the peak of the Atlantic hurricane season (August-October).

There is still some uncertainty as to what the exact state of ENSO will be for the peak of the Atlantic hurricane season. The latest plume of ENSO predictions from several statistical and dynamical models shows a continued spread for August-October (Figure 18). Most models are calling for either cool neutral ENSO or weak La Niña conditions for August-October. None of the models in the ENSO plume predict El Niño conditions for August-October.

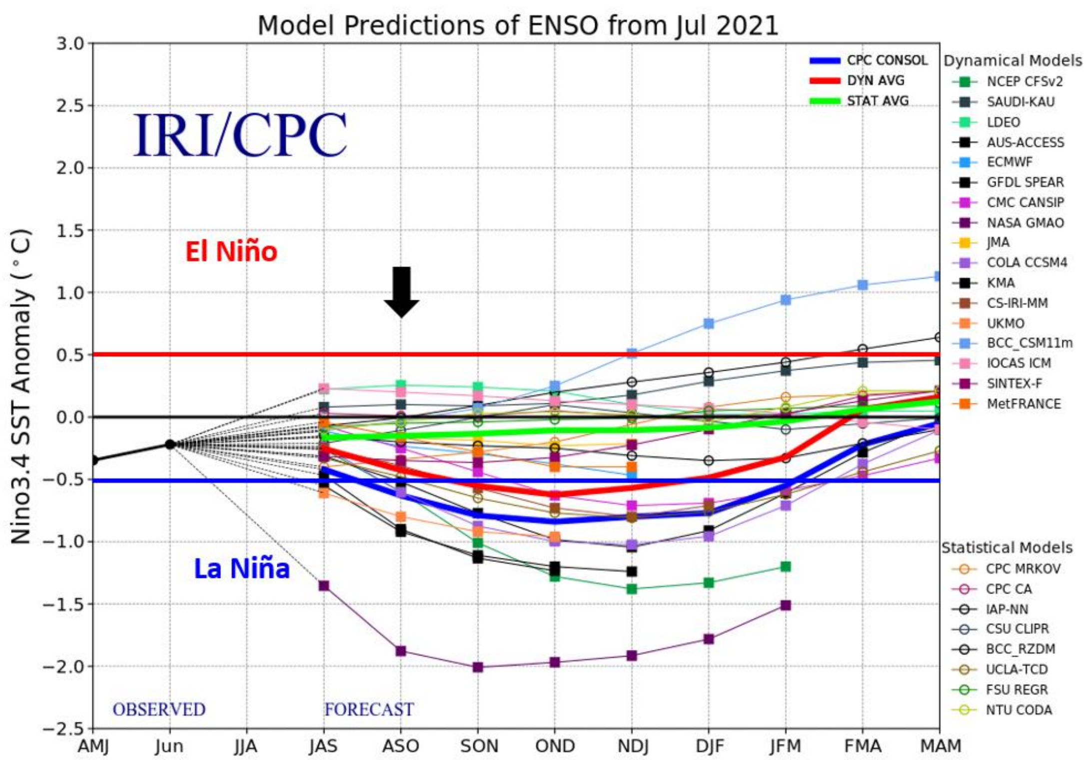

Figure 18: ENSO forecasts from various statistical and dynamical models for the Nino 3.4 SST anomaly based on late June to early July initial conditions. The majority of models are calling for ENSO neutral conditions for August-October. Figure courtesy of the International Research Institute (IRI).

The latest official forecast from NOAA indicates that the chances of El Niño are quite low for August-October. NOAA is currently predicting a 4% chance of El Niño, a 51% chance of ENSO neutral conditions and a 45% chance of La Niña for the peak of the Atlantic hurricane season (Figure 19).

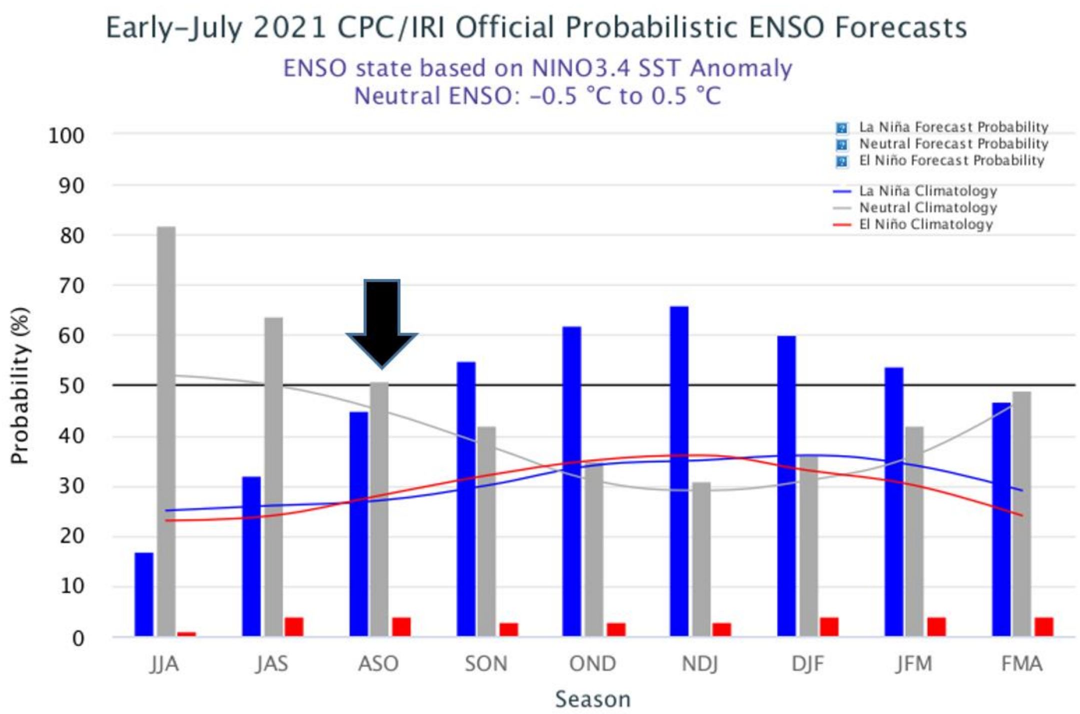

Figure 19: Official NOAA forecast for ENSO.

5 Current Atlantic Basin Conditions

The tropical Atlantic has undergone some anomalous warming over the past month and is now generally warmer than normal (Figure 20). The warm SST anomalies in the tropical Atlantic have continued to grow and expand over the past couple of weeks, due in part to weaker trade winds inhibiting mixing and upwelling of the ocean surface. 14-day-averaged sea surface temperature anomalies in the tropical Atlantic (10-20°N, 60-20°W) are at their 8th highest levels on record (since 1982) through August 1, trailing (in descending order from warmest SSTs) 2010, 2005, 2020, 2017, 2016, 2004 and 2011. All of those hurricane seasons had more ACE than the average 1991-2020 season, and five of those seven seasons were characterized as hyperactive by NOAA (e.g., seasonal ACE >= 160). The current SST anomaly pattern is relatively similar to the historical SST pattern in August that has correlated with active Atlantic hurricane seasons (Figure 21). The current SST pattern is tracking between SSTs typically experienced in above-average Atlantic hurricane seasons and hyperactive seasons of the past ~40 years (Figure 22).

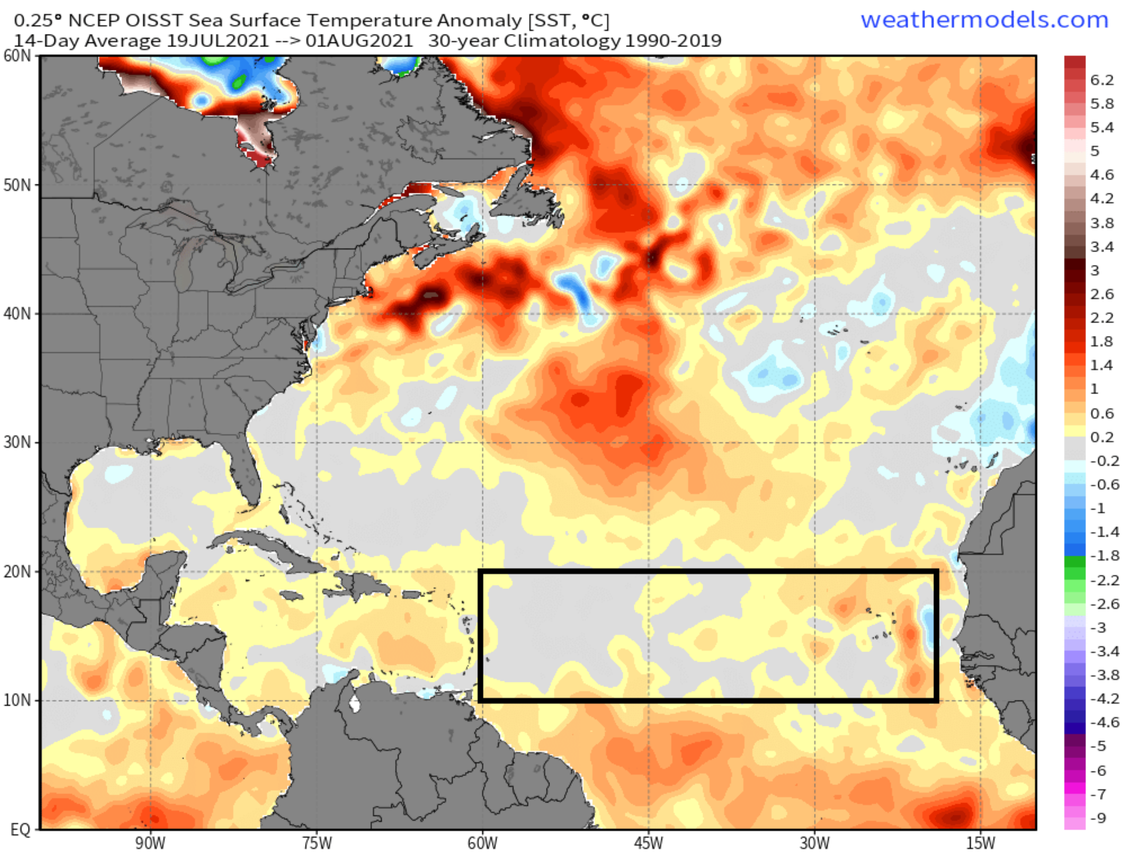

Figure 20: Late July/early August 2021 SST anomaly pattern across the North Atlantic Ocean.

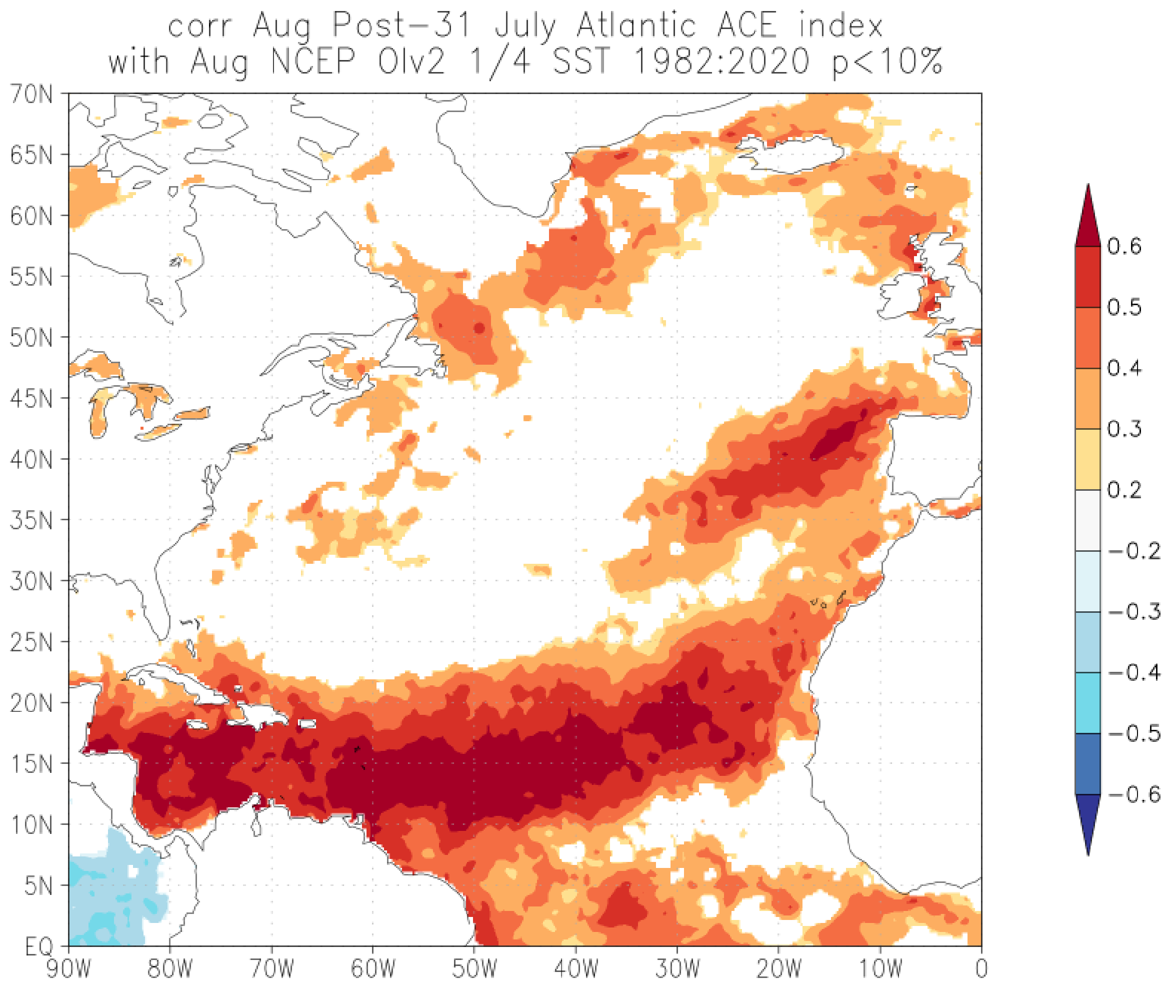

Figure 21: Correlation between August North Atlantic SSTs and post-31 July Atlantic ACE from 1982-2020.

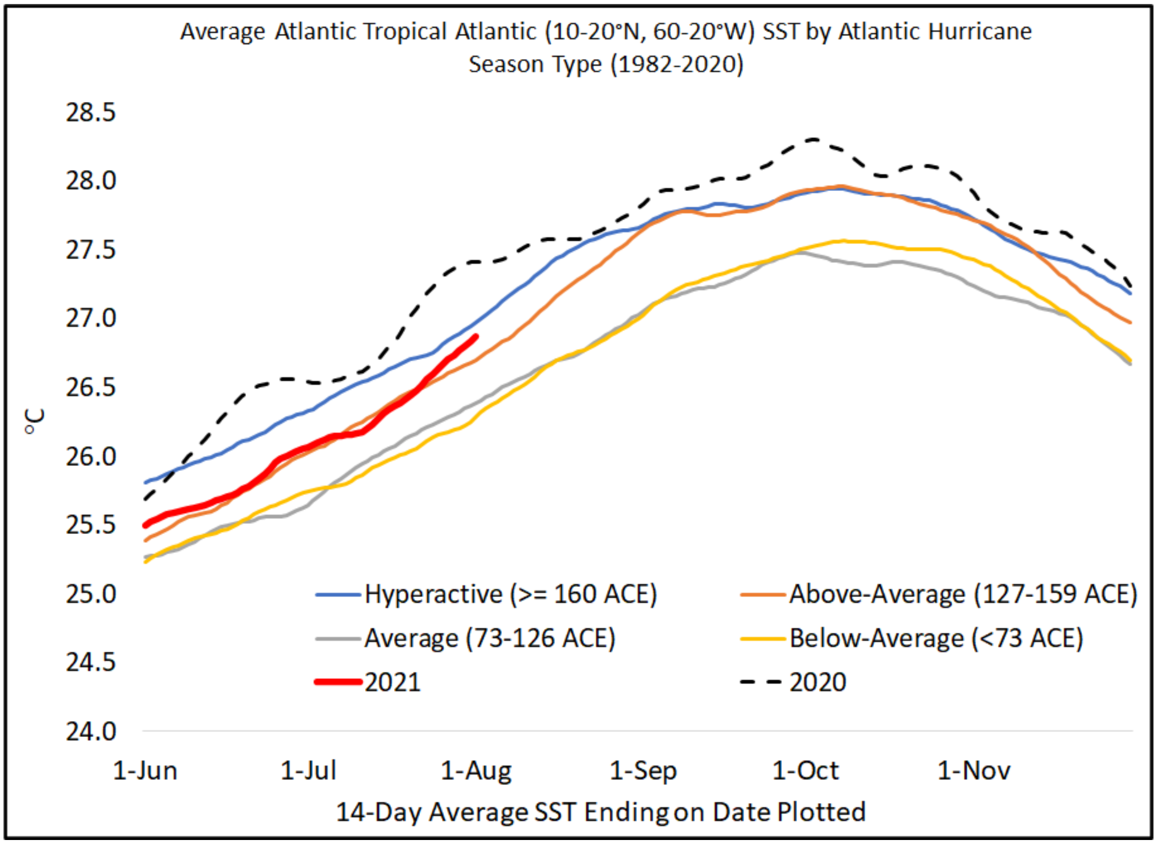

Figure 22: 14-day average SSTs for various Atlantic hurricane season types from 1982-2020 based on the NOAA definition. Also plotted are SSTs for 2021 and 2020 (for comparison). Sea surface temperature anomalies in the tropical Atlantic in 2021 are currently tracking between above-average and hyperactive Atlantic hurricane seasons.

Vertical wind shear was generally below average across most of the tropical Atlantic and Caribbean through the first ten days of July, was elevated across the Caribbean and central Atlantic during the middle of July and since has since dropped back to near (or slightly below normal) levels. Vertical wind shear averaged over the past 30 days has generally been somewhat below normal across the central tropical Atlantic and Caribbean (Figure 23). Current 30-day-averaged zonal wind shear across the central tropical Atlantic and Caribbean (10-20°N, 90-40°W) is the 9th lowest on record since 1982, placing it in the lowest tercile for shear in the past ~40 years. Here our analysis of zonal wind shear uses the ERA5 reanalysis. Current vertical wind shear anomalies are weaker than what is observed in the average above-normal Atlantic hurricane season and above what is observed in the average hyperactive season, indicating activity at levels similar to what we are currently forecasting (e.g., 150 ACE) (Figure 24).

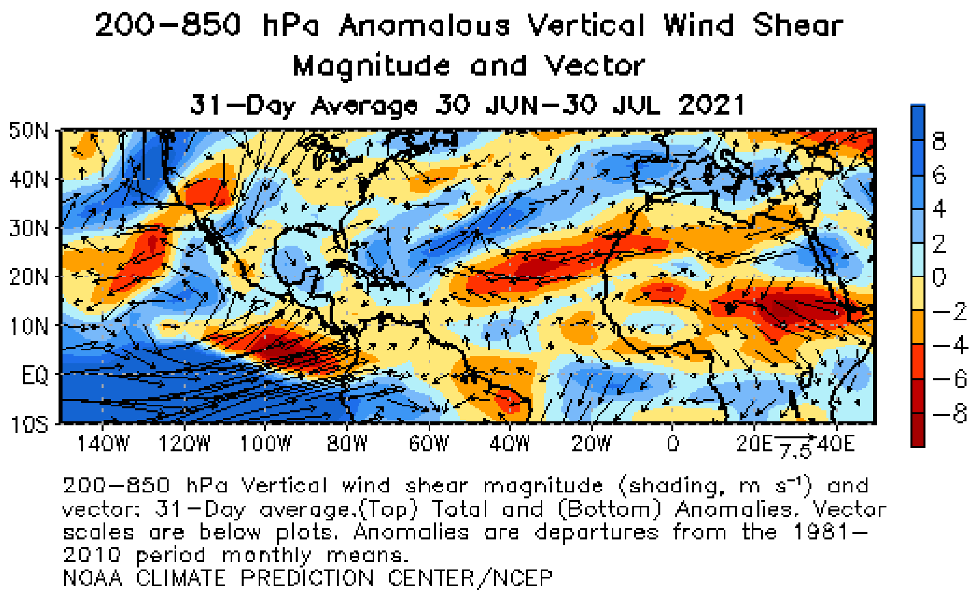

Figure 23: June 30 – July 30, 2021-averaged vertical wind shear across the tropical and subtropical Atlantic differenced from the 1981-2010 climatology.

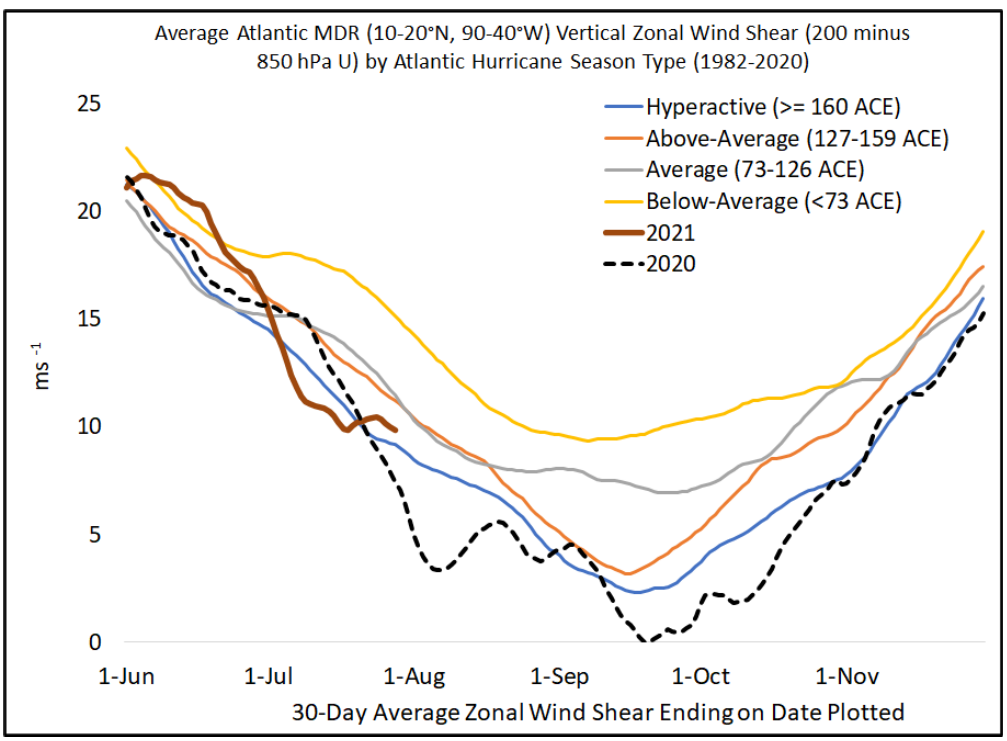

Figure 24: 30-day average zonal wind shear for various Atlantic hurricane season types from 1982-2020 based on the NOAA definition. Also plotted are zonal wind shear for 2021 and 2020 (for comparison). Zonal wind shear in the central tropical Atlantic and Caribbean in 2021 is currently tracking between above-average and hyperactive Atlantic hurricane season types.

Sea level pressure anomalies across the tropical Atlantic (10-20°N, 60-20°W) in July 2021 were slightly above normal (Figure 25). These conditions are in contrast to July 2020, when sea level pressure anomalies across the tropical Atlantic were at their lowest levels on record (since 1948 when the NCEP/NCAR Reanalysis began). Generally, when July sea level pressure anomalies are low, more active Atlantic hurricane seasons are experienced. Lower pressure is typically associated with increased instability, increased mid-level moisture and decreased vertical wind shear. These relatively high sea level pressure anomalies in July 2021 were one reason for the slight decrease in the seasonal forecast.

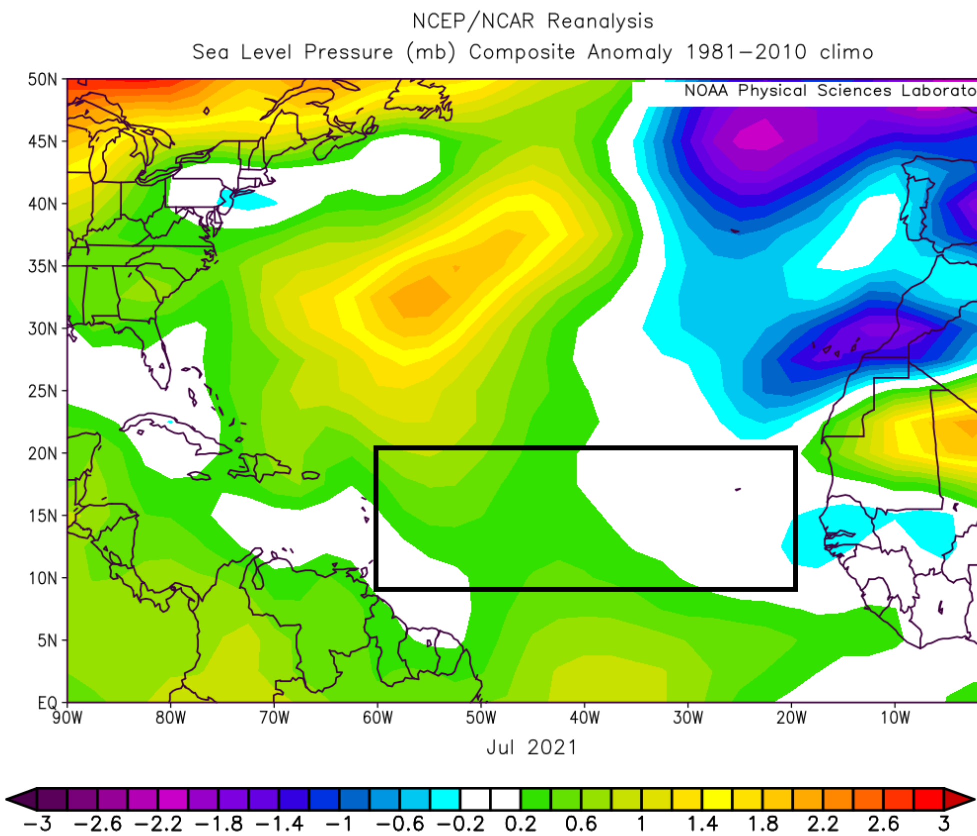

Figure 25: July 2021 sea level pressure anomalies across the tropical and subtropical North Atlantic. The black rectangle highlights the definition of the tropical Atlantic used in the above paragraph.

6 West Africa Conditions

The West African monsoon was relatively active during the early part of July, was suppressed during the middle part of July and has since become more active. Over the past 30 days, vertical motion has averaged near normal over West Africa (Figure 26). The West African monsoon has become reinvigorated in recent days, and the latest forecast from the ECMWF indicates continued increased upward motion over West Africa for the next two weeks (Figure 27).

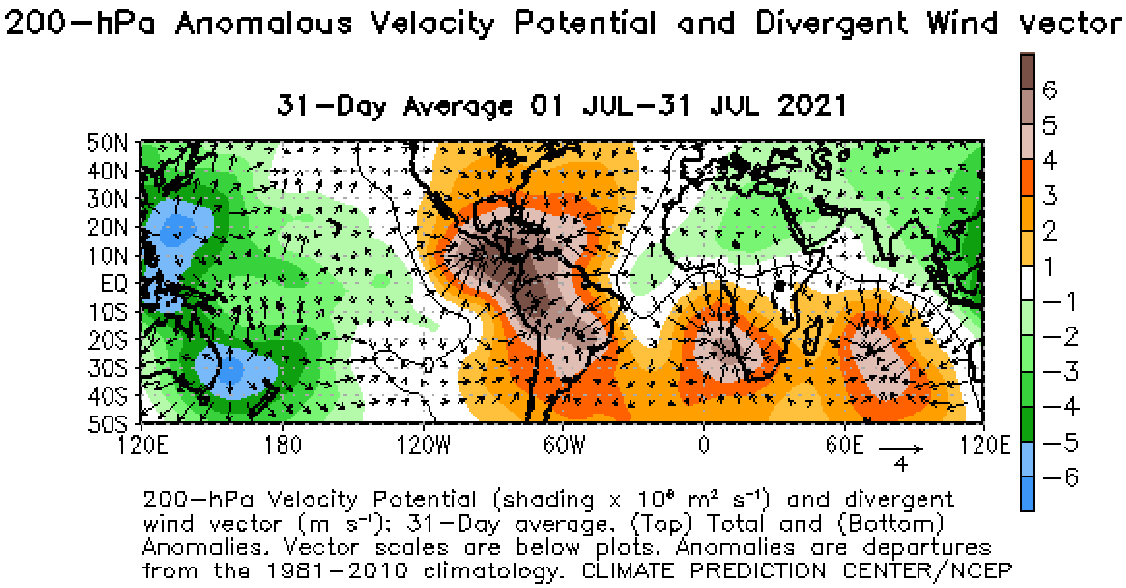

Figure 26: 200 hPa velocity potential anomalies from 50°S – 50°N. Negative velocity potential favors upward vertical motion.

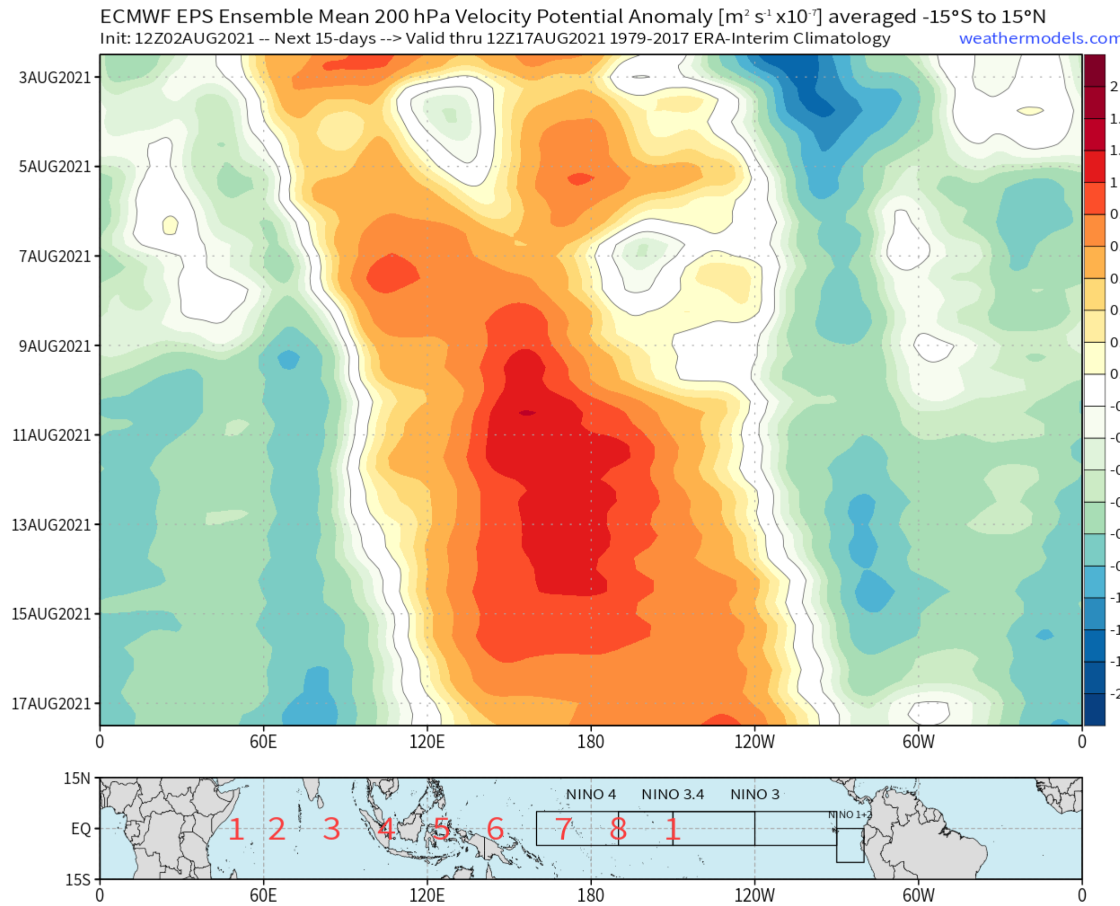

Figure 27: Forecast 200 hPa velocity potential anomalies from ECMWF averaged over the latitude band from 15°S-15°N for the next 15 days.

7 Tropical Cyclone Impact Probabilities for 2021

This year, we are debuting a new methodology for calculating the impacts of tropical cyclones for each state and county/parish along the Gulf and East Coasts, tropical cyclone-prone provinces of Canada, islands in the Caribbean and countries in Central America. We have used NOAA's Historical Hurricane Tracks website and selected all named storms, hurricanes and major hurricanes that have tracked within 50 miles of each landmass from 1880-2020. This approach allows for tropical cyclones that may have made landfall in an immediately adjacent region to be counted for all regions that were in close proximity to the landfall location of the storm. We then fit the observed frequency of storms within 50 miles of each landmass using a Poisson distribution to calculate the climatological odds of one or more events within 50 miles.

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 displays the climatological odds of storms tracking within 50 miles of each state along the Gulf and East Coasts along with the odds for the remainder of 2021. Given that the seasonal forecast is for above-average hurricane activity, the odds of tropical cyclone impacts are also elevated. Probabilities for other Atlantic basin landmasses are available on our website.

Table 13: Probability of >=1 named storm, hurricane and major hurricane tracking within 50 miles of each coastal state from Texas to Maine for the remainder of 2021. Probabilities are provided for both the 1880–2020 climatological average as well as the probability for the remainder of 2021, based on the latest CSU seasonal hurricane forecast.

		2021 Probability				**Climatological**	
	Probability >=1	**event within**	**50 miles**		**Probability >=1**	**event within**	**50 miles**
State	Named Storm	Hurricane	Major Hurricane		Named Storm	Hurricane	Major Hurricane
Texas	74%	48%	22%		61%	36%	16%
Louisiana	78%	50%	20%		66%	38%	14%
Mississippi	66%	38%	11%		53%	28%	8%
Alabama	71%	37%	11%		58%	28%	8%
Florida	94%	69%	39%		86%	56%	29%
Georgia	76%	40%	9%		63%	30%	6%
South Carolina	70%	39%	11%		57%	29%	8%
North Carolina	80%	50%	11%		68%	38%	8%
Virginia	58%	27%	2%		46%	20%	1%
Maryland	41%	15%	1%		31%	11%	1%
Delaware	31%	9%	1%		23%	6%	1%
New Jersey	31%	10%	1%		23%	7%	1%
New York	35%	13%	3%		26%	9%	2%
Connecticut	30%	11%	2%		22%	8%	1%
Rhode Island	28%	11%	2%		20%	8%	1%
Massachusetts	43%	20%	4%		33%	14%	3%
New Hampshire	25%	8%	2%		18%	6%	1%
Maine	29%	10%	2%		21%	7%	1%

8 Summary

An analysis of a variety of different atmosphere and ocean measurements (through July) which are known to have long-period statistical relationships with the upcoming season's Atlantic tropical cyclone activity indicate that the remainder of the 2021 Atlantic hurricane season should be above average. Tropical Atlantic sea surface temperatures are now warmer than normal, while vertical wind shear is slightly lower than normal. We believe that the combination of a relatively warm tropical Atlantic and relatively cool eastern and central tropical Pacific favor an above-average remainder of the Atlantic hurricane season.

9 Forthcoming Updated Forecasts of 2021 Hurricane Activity

We will be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August-October, beginning today, Thursday, August 5 and continuing every other Thursday (August 19, September 2, September 16, etc.). A verification and discussion of all 2021 forecasts will be issued in late November 2021. All of these forecasts will be available online.