FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2022

We continue to forecast a well above-average 2022 Atlantic basin hurricane season. We anticipate La Niña to persist throughout the remainder of the hurricane season, given the strong central tropical Pacific trade wind surge that is underway and predicted to persist for the next several weeks. Sea surface temperatures across most of the tropical Atlantic are now above normal. 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 7 July 2022)

By Philip J. Klotzbach[1], Michael M. Bell[2] and Alexander J. DesRosiers[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 2022

Forecast Parameter and 1991-2020 Average (in parentheses)	Issue Date 7 April 2022	Issue Date 2 June 2022	Issue Date 7 July 2022	Observed Thru 6 July 2022	Remainder of Season Forecast
Named Storms (NS) (14.4)	19	20	20*	3	17
Named Storm Days (NSD) (69.4)	90	95	95	3.25	91.75
Hurricanes (H) (7.2)	9	10	10	0	10
Hurricane Days (HD) (27.0)	35	40	40	0	40
Major Hurricanes (MH) (3.2)	4	5	5	0	5
Major Hurricane Days (MHD) (7.4)	9	11	11	0	11
Accumulated Cyclone Energy (ACE) (123)	160	180	180	3	177
Net Tropical Cyclone Activity (NTC) (135%)	170	195	195	6	189

*Total forecast includes Alex, Bonnie and Colin which have formed in the Atlantic as of July 6.

PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE LANDFALL ON EACH OF THE FOLLOWING COASTAL AREAS (AFTER 6 JULY):

1) Entire continental U.S. coastline - 75% (full-season average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 50% (full-season average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 49% (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 6 JULY):

1) 64% (full-season average for last century is 42%)

ABSTRACT

Information obtained through early July 2022 indicates that the 2022 Atlantic hurricane season will have well above the 1991–2020 average activity. Alex, Bonnie and Colin have already formed as of 6 July. We estimate that the full (e.g., including storms that have already formed) 2022 season will have 10 hurricanes (average is 7.2), 20 named storms (average is 14.4), 95 named storm days (average is 69.4), 40 hurricane days (average is 27.0), 5 major (Category 3-4-5) hurricanes (average is 3.2) and 11 major hurricane days (average is 7.4). The probability of U.S. major hurricane landfall for the remainder of the season is estimated to be about 145 percent of the long-period full-season average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2022 to be approximately 145 percent of their long-term averages.

This forecast is based on an extended-range early July statistical prediction scheme that was developed using 40 years of past data. Analog predictors are also utilized. We are also including statistical/dynamical models based off of 25–40 years of past data from the European Centre for Medium Range Weather Forecasts, the UK Met Office and the Japan Meteorological Agency as three additional forecast guidance tools. The statistical model, the three statistical/dynamical models and the analog model all call for a well 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 weak La Niña conditions, and we anticipate that these La Niña conditions are likely to persist given the very strong trade wind surge that is currently underway in the central tropical Pacific. 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.

Most of the tropical Atlantic and Caribbean now has above-normal sea surface temperatures, and the far eastern part of the subtropical North Atlantic is also warmer than normal. The current 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, named storm activity in the Caribbean in July (e.g., Bonnie) is typically associated with above-normal 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 oceanic and atmospheric 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 robust 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 a visualization of the uncertainty associated with these predictions.

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

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

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 on 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, First Onsite and IAA. 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 also would like to thank Jhordanne Jones, recent Ph.D. graduate in Michael Bell's research group, for model development and forecast assistance over the past several years.

We thank 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, and Peng Xian 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.

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 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 39th 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 statistical/dynamical models from the European Centre for Medium Range Weather Forecasts (ECMWF), the UK Met Office and the Japan Meteorological Agency (JMA). These models show skill at predicting TC activity based on ~25–40 years of historical data. 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 complicated atmospheric-oceanic system that is highly non-linear. There is a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all of these processes interact with each other. No one can completely understand the full complexity of the atmosphere-ocean system. But, it is still possible to develop a reliable statistical forecast scheme which incorporates a number of the climate system's non-linear interactions. Any seasonal or climate forecast scheme should show significant hindcast skill before it is used in real-time forecasts.

2 July Forecast Methodology

2.1 July Statistical Forecast Scheme

The July statistical forecast scheme that we are using this year was developed over the period from 1982–2019 and has been used successfully in real-time the past two years. 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 1959 to present. 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 real-time forecasts in 2020–2021 (Figure 1).

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 1982–2021 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 2022 observed values for each of the four predictors in the statistical forecast scheme. Table 3 displays the statistical model output for the 2022 hurricane season. Three of the four predictors call for increased Atlantic hurricane activity in 2022.

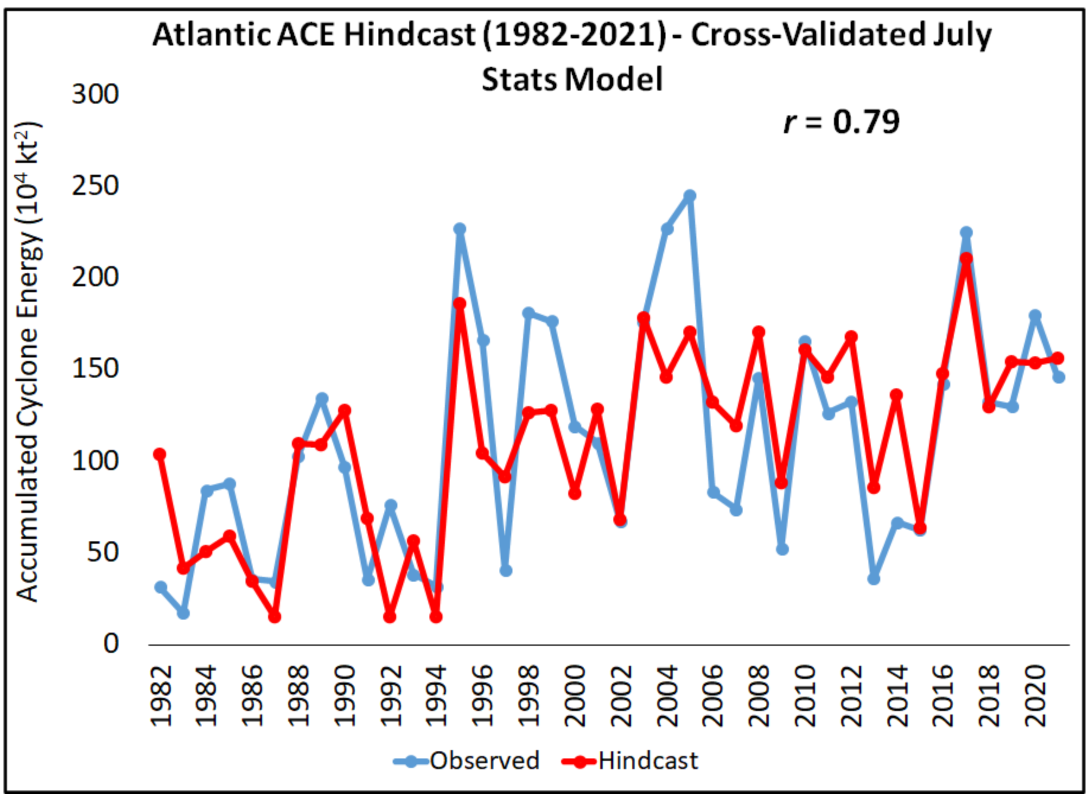

Figure 1: Observed versus early July cross-validated hindcast values of ACE for the statistical model for 1982–2021.

July Forecast Predictors

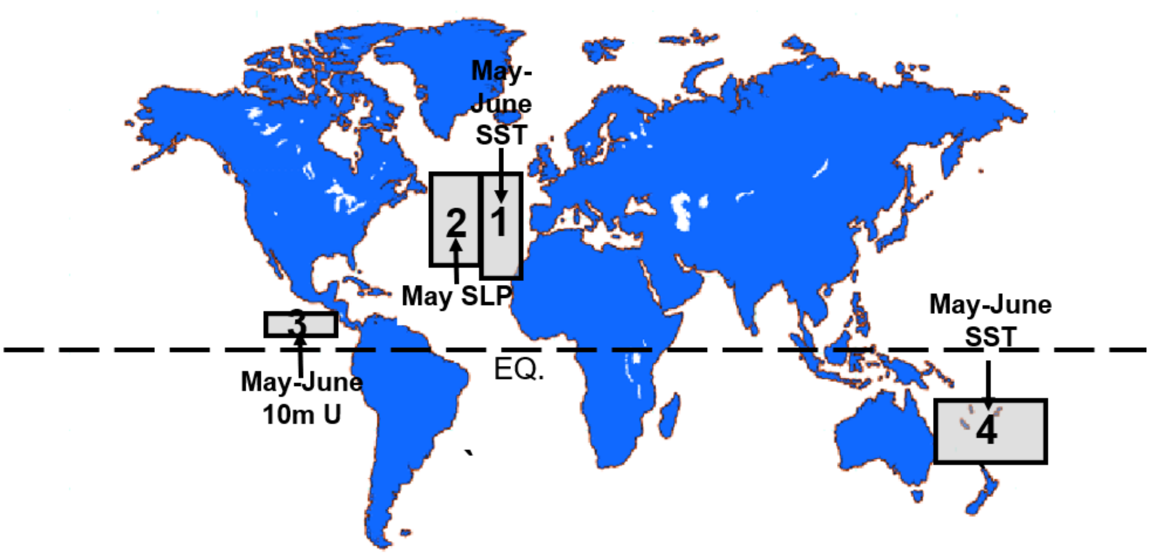

Figure 2: Location of predictors for our early July extended-range statistical prediction for the 2022 hurricane season.

Table 1: Correlations between early July predictors and ACE over the period from 1982–2021.

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) (-)	-0.41
3) May–June 10m U (5°N-10°N, 120°W-90°W) (-)	0.59
4) May–June SST (35°S-15°S, 155°E-180°E) (+)	0.58

Table 2: Listing of early July 2022 predictors for the 2022 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	2022 Forecast Value	Impact on 2022 TC Activity
1) May–June SST (20°N–50°N, 30°W–15°W) (+)	+0.6 SD	Enhance
2) May–June SLP (25°N–50°N, 50°W–30°W) (-)	+0.8 SD	Suppress
3) May–June 10m U (5°N–10°N, 120°W–90°W) (+)	+2.3 SD	Enhance
4) May–June SST (35°S–15°S, 155°E–180°E) (+)	+1.6 SD	Enhance

Table 3: Statistical model output for the 2022 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)	19.0	20
Named Storm Days (NSD) (69.4)	101.4	95
Hurricanes (H) (7.2)	10.5	10
Hurricane Days (HD) (27.0)	44.5	40
Major Hurricanes (MH) (3.2)	5.2	5
Major Hurricane Days (MHD) (7.4)	13.7	11
Accumulated Cyclone Energy (ACE) (123)	199	180
Net Tropical Cyclone Activity (NTC) (135%)	211	195

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.

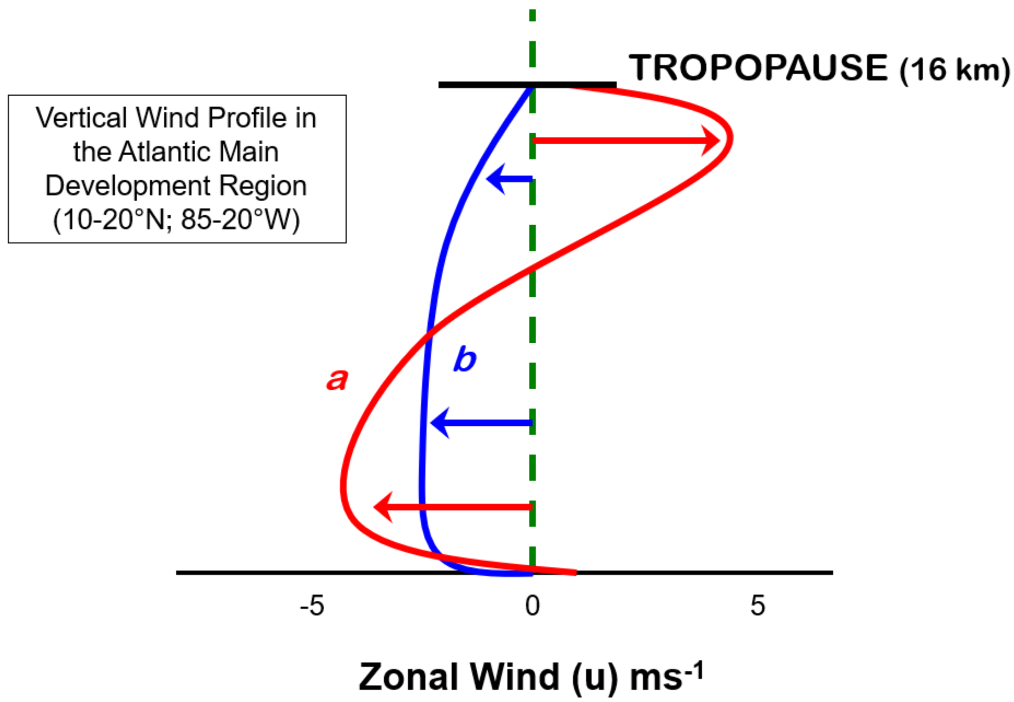

Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.

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.

Predictor 1. May–June SST in the Subtropical and Mid-latitude eastern North Atlantic (+)

(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 1982–2021. Predictor 1 also strongly correlates (r = 0.75) with August–October values of the SST component of the Atlantic Meridional Mode (AMM) (Kossin and Vimont 2007) over the period from 1982–2021. 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 -0.54. 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 -0.42 (Figure 7).

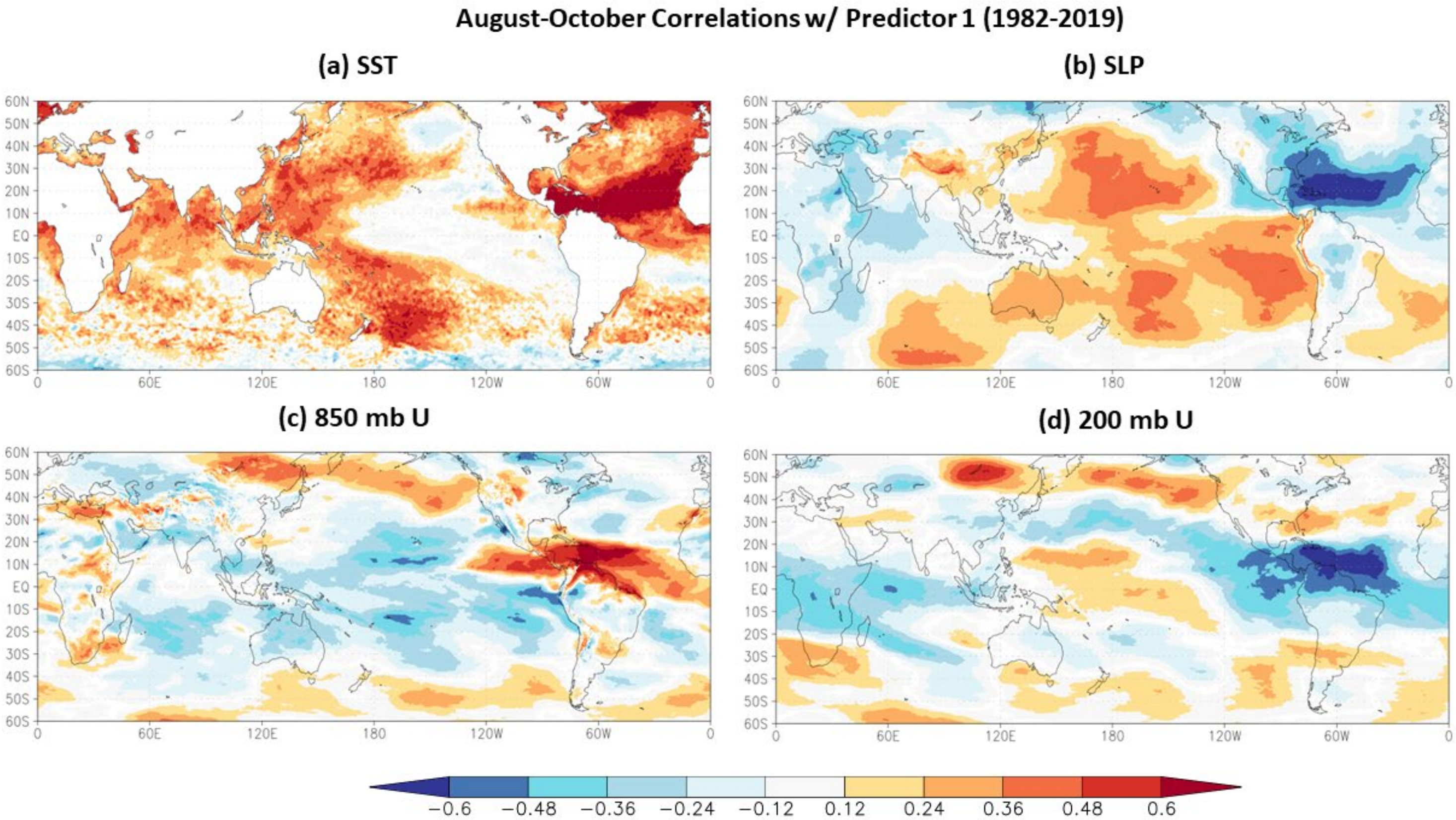

Figure 4: Rank correlations between May–June SST in the subtropical and mid-latitude eastern North Atlantic (Predictor 1) and (panel a) August–October sea surface temperature, (panel b) August–October sea level pressure, (panel c) August–October 850 hPa zonal wind and (panel d) August–October 200 hPa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

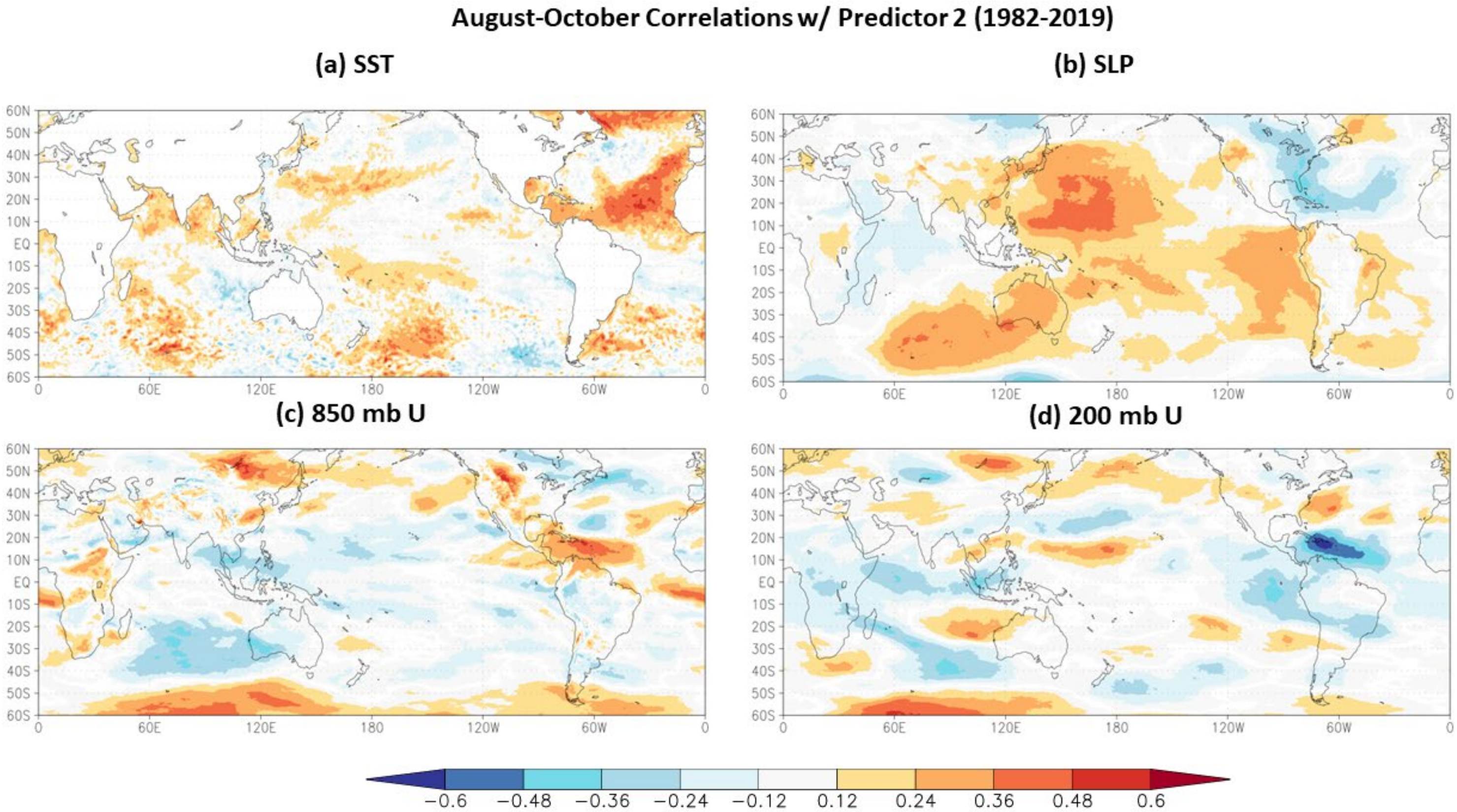

Figure 5: As in Figure 4 but for May–June SLP in the subtropical and mid-latitude North Atlantic. The sign of Predictor 2 has been flipped for easy comparison with Figure 4.

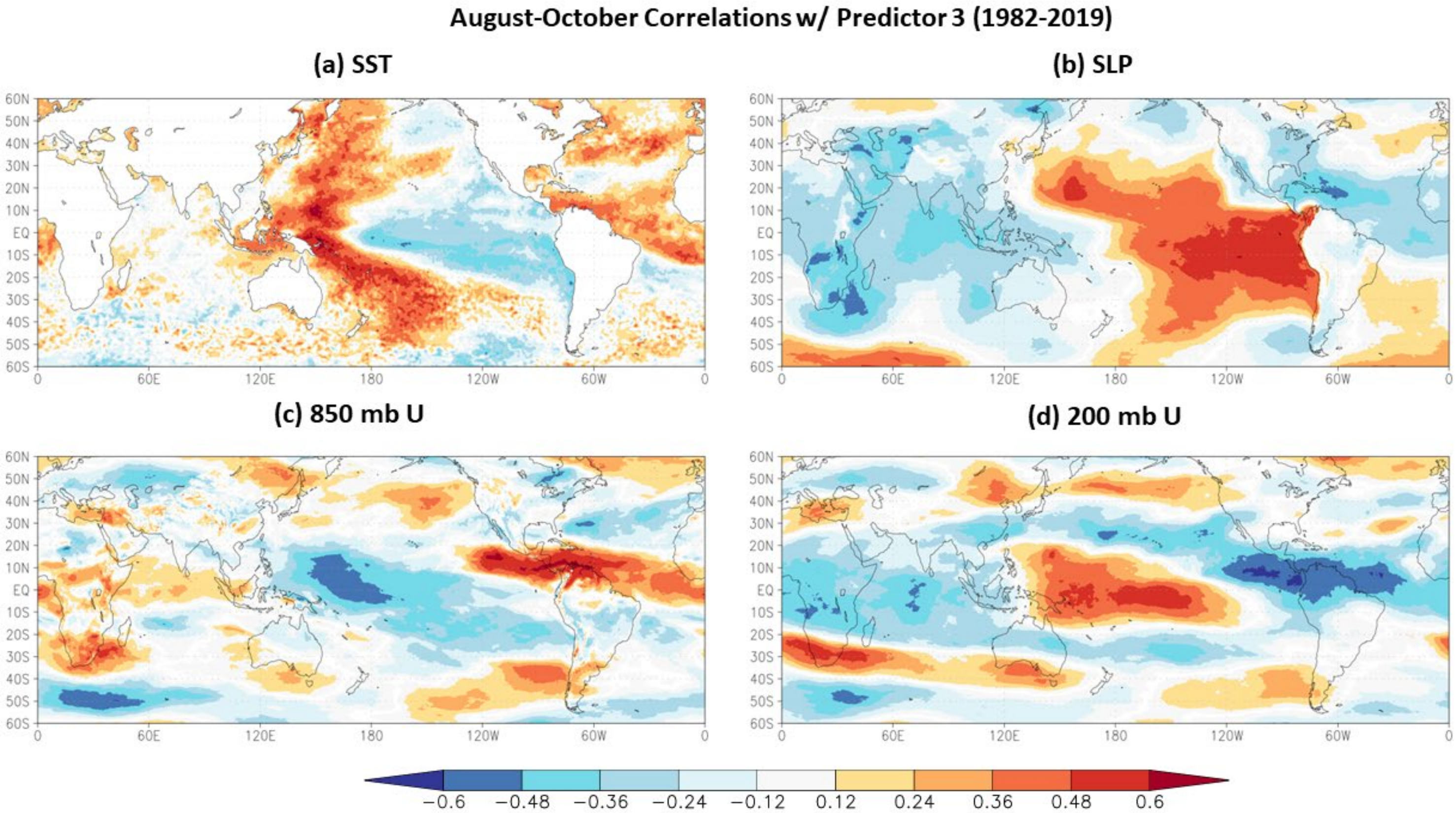

Figure 6: As in Figure 4 but for May–June 10 meter zonal wind in the eastern tropical Pacific Ocean.

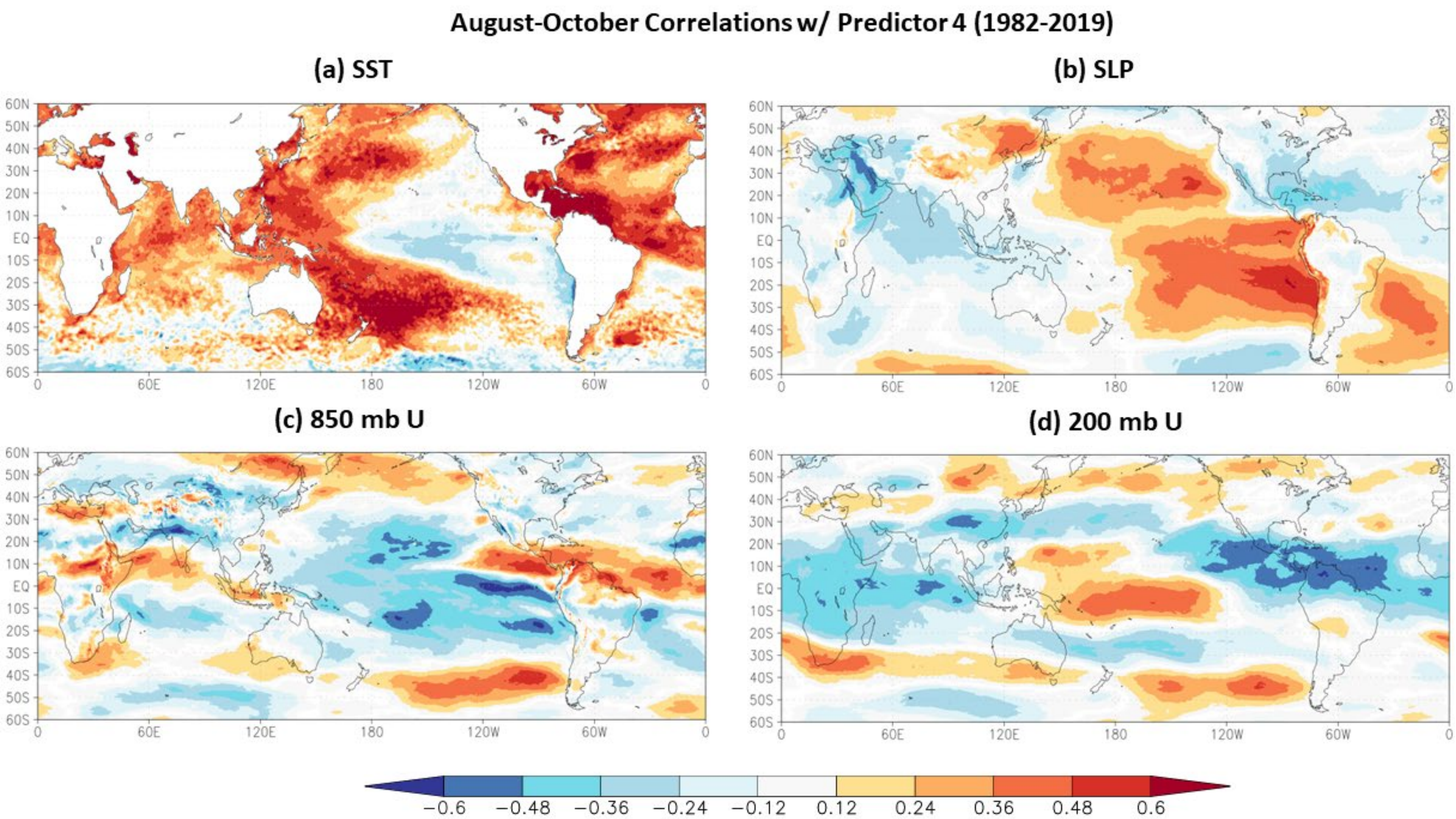

Figure 7: As in Figure 4 but for May–June SST in the tropical and subtropical western South Pacific.

2.2 July Statistical/Dynamical Forecast Scheme

a) ECMWF Statistical/Dynamical Model Forecast

Figure 8 displays the parameters used in our early August statistical model, while Table 4 displays ECMWF's forecasts of these parameters for 2022 from a 1 June initialization date. All three parameters call for above-normal activity, with the upper-level wind over tropical western and central Africa predictor being extremely favorable for an active season. Figure 9 displays cross-validated hindcasts for ECMWF forecasts of ACE from 1981–2021, while Table 5 presents the forecast from ECMWF for the 2022 Atlantic hurricane season. The ECMWF statistical/dynamical model is calling for a very active 2022 Atlantic hurricane season.

Post-31 July Seasonal Forecast Predictors

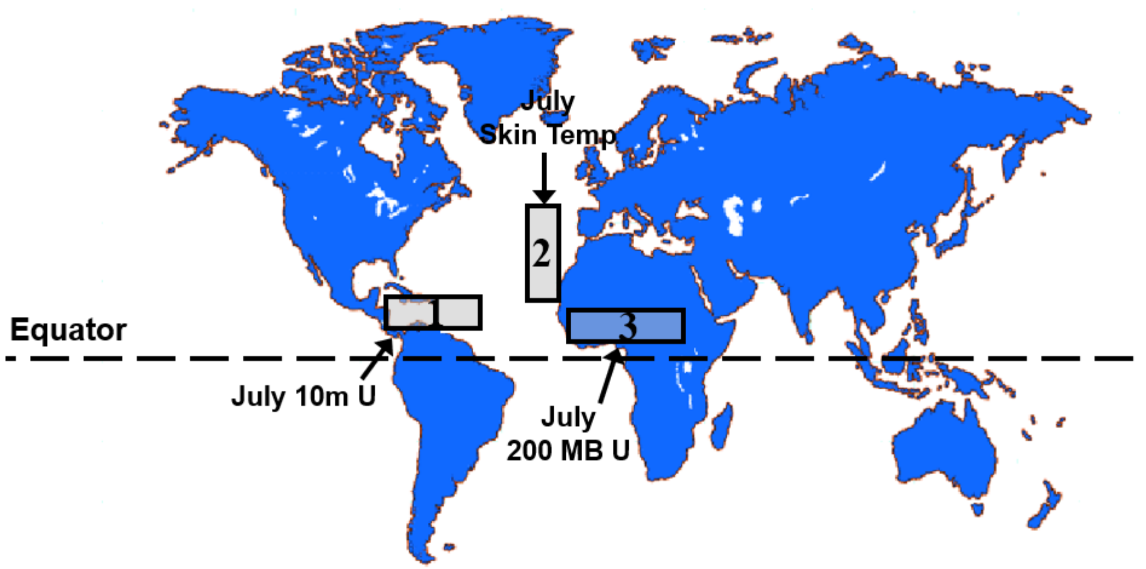

Figure 8: Location of predictors for our early July statistical/dynamical extended-range statistical prediction for the 2022 hurricane season. This forecast uses dynamical model predictions from ECMWF, the UK Met Office and JMA to predict July conditions in the three boxes displayed and uses those predictors to forecast ACE.

Table 4: Listing of predictions of July large-scale conditions from ECMWF 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 2022 Forecast	Effect on 2022 Hurricane Season
1) ECMWF Prediction of July Surface U (10–20°N, 90–40°W) (+)	+0.7 SD	Enhance
2) ECMWF Prediction of July Skin Temperature (20–40°N, 35–15°W) (+)	+0.4 SD	Enhance
3) ECMWF Prediction of July 200 hPa U (5–15°N, 0–40°E) (-)	-1.3 SD	Enhance

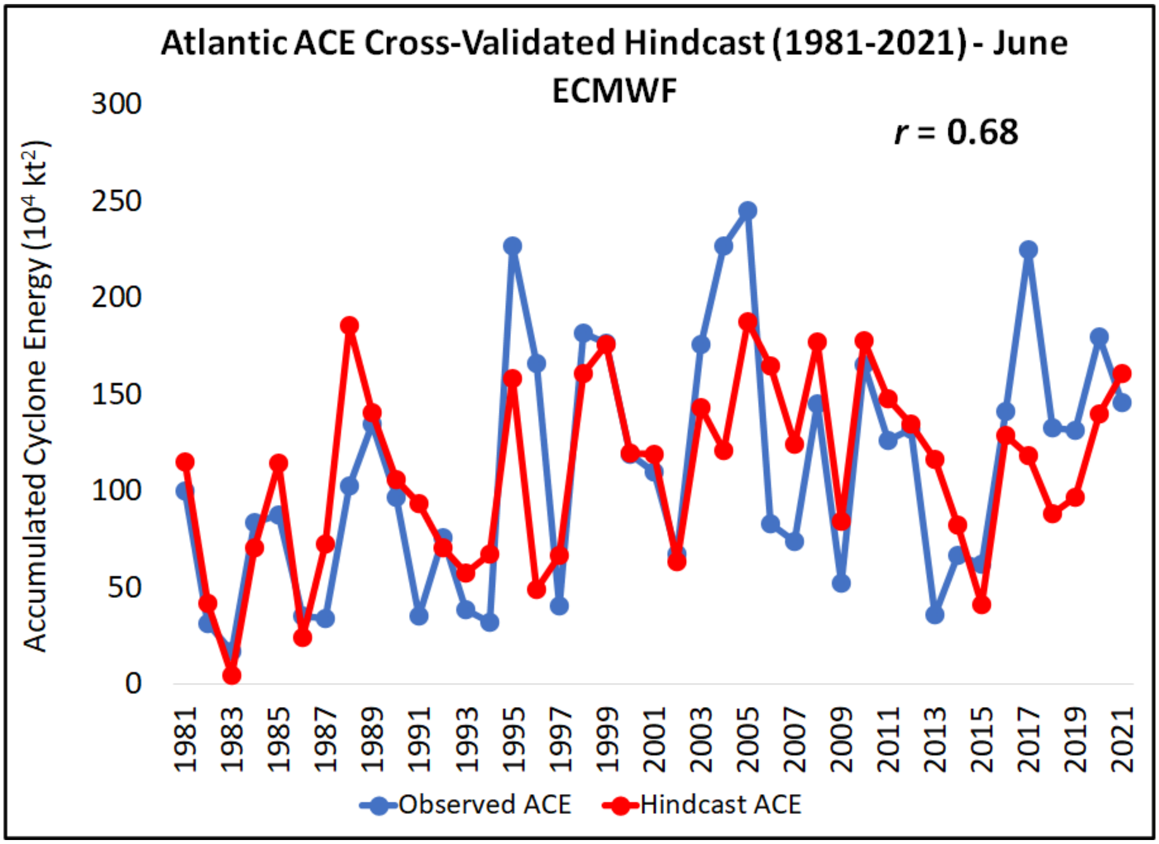

Figure 9: Observed versus cross-validated statistical/dynamical hindcast values of ACE for 1981–2021 from ECMWF.

Table 5: Statistical/dynamical model output from ECMWF for the 2022 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1991–2020 Average (in parentheses)	ECMWF Hybrid Forecast	Final Forecast
Named Storms (14.4)	16.5	20
Named Storm Days (69.4)	83.8	95
Hurricanes (7.2)	8.7	10
Hurricane Days (27.0)	34.9	40
Major Hurricanes (3.2)	4.1	5
Major Hurricane Days (7.4)	10.2	11
Accumulated Cyclone Energy Index (123)	157	180
Net Tropical Cyclone Activity (135%)	169	195

b) UK Met Office Statistical/Dynamical Model Forecast

Table 6 displays the UK Met Office forecasts of the early August parameters for 2022 from a 1 June initialization date. All three parameters call for an above-average season, with the combination of the three predictors calling for a hyperactive season. Figure 10 displays hindcasts for the UK Met Office of ACE from 1993–2016, while

Table 7 presents the forecast from the UK Met Office for the 2022 Atlantic hurricane season. We note that both the UK Met Office and JMA forecasts (detailed in the next subsection) only have hindcasts for the 1993–2016 period on the Copernicus website (the website where we download our climate model forecasts), which is why the hindcast period is shorter than what we used for ECMWF.

Table 6: Listing of predictions of July large-scale conditions from UK Met Office 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 2022 Forecast	Effect on 2022 Hurricane Season
1) Met Office Prediction of July Surface U (10–20°N, 90–40°W) (+)	+1.3 SD	Enhance
2) Met Office Prediction of July Skin Temperature (20–40°N, 35–15°W) (+)	+0.9 SD	Enhance
3) Met Office Prediction of July 200 hPa U (5–15°N, 0–40°E) (-)	-1.7 SD	Enhance

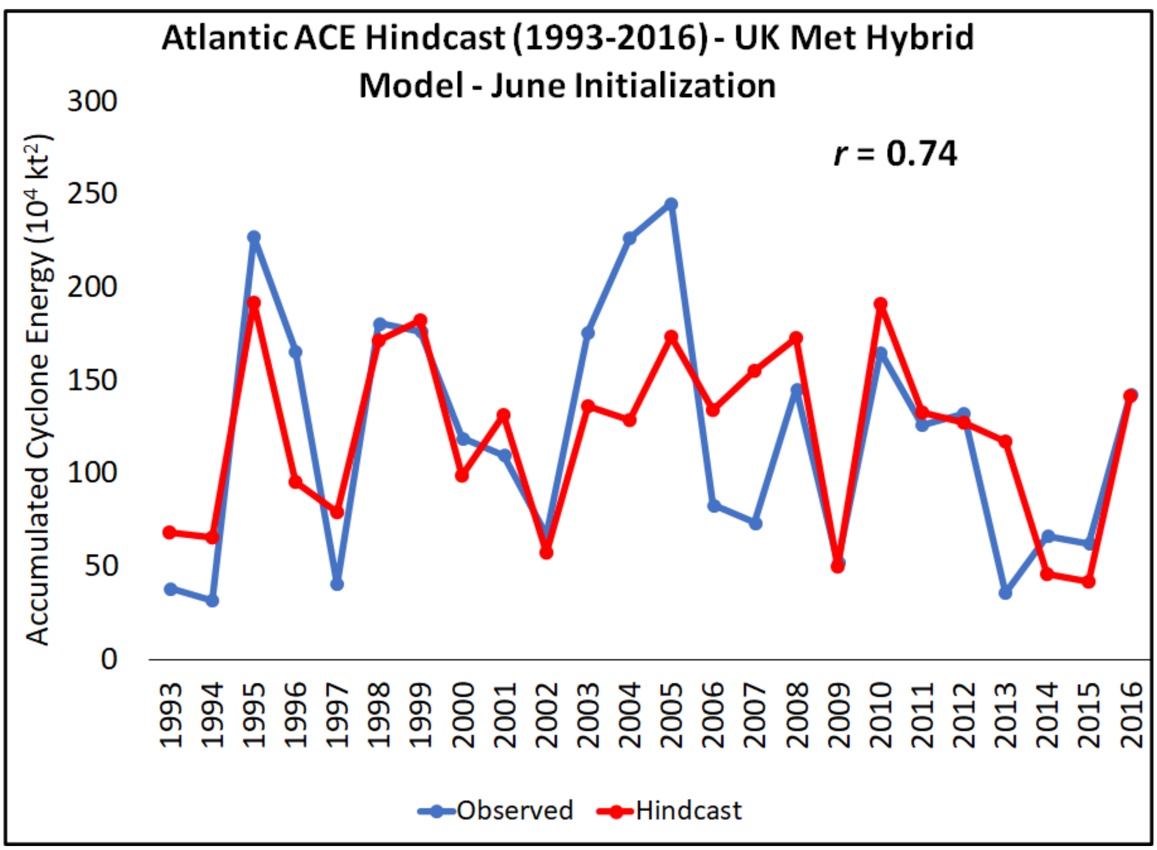

Figure 10: Observed versus statistical/dynamical hindcast values of ACE for 1993–2016 from the UK Met Office.

Table 7: Statistical/dynamical model output from the UK Met Office for the 2022 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1991–2020 Average (in parentheses)	Met Office Hybrid Forecast	Final Forecast
Named Storms (14.4)	19.4	20
Named Storm Days (69.4)	103.5	95
Hurricanes (7.2)	10.7	10
Hurricane Days (27.0)	45.6	40
Major Hurricanes (3.2)	5.3	5
Major Hurricane Days (7.4)	14.1	11
Accumulated Cyclone Energy Index (123)	204	180
Net Tropical Cyclone Activity (135%)	216	195

c) JMA Statistical/Dynamical Model Forecast

Table 8 displays the JMA forecasts of the early August parameters for 2022 from a 1 June initialization date. All three parameters call for an above-average season, with the combination of the three parameters predicting a highly active season. Figure 11 displays hindcasts for the JMA of ACE from 1993–2016, while Table 9 presents the forecast from the JMA for the 2022 Atlantic hurricane season.

Table 8: Listing of predictions of July large-scale conditions from JMA 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 2022 Forecast	Effect on 2022 Hurricane Season
1) JMA Prediction of July Surface U (10–20°N, 90–40°W) (+)	+1.4 SD	Enhance
2) JMA Prediction of July Skin Temperature (20–40°N, 35–15°W) (+)	+0.8 SD	Enhance
3) JMA Prediction of July 200 hPa U (5–15°N, 0–40°E) (-)	-1.0 SD	Enhance

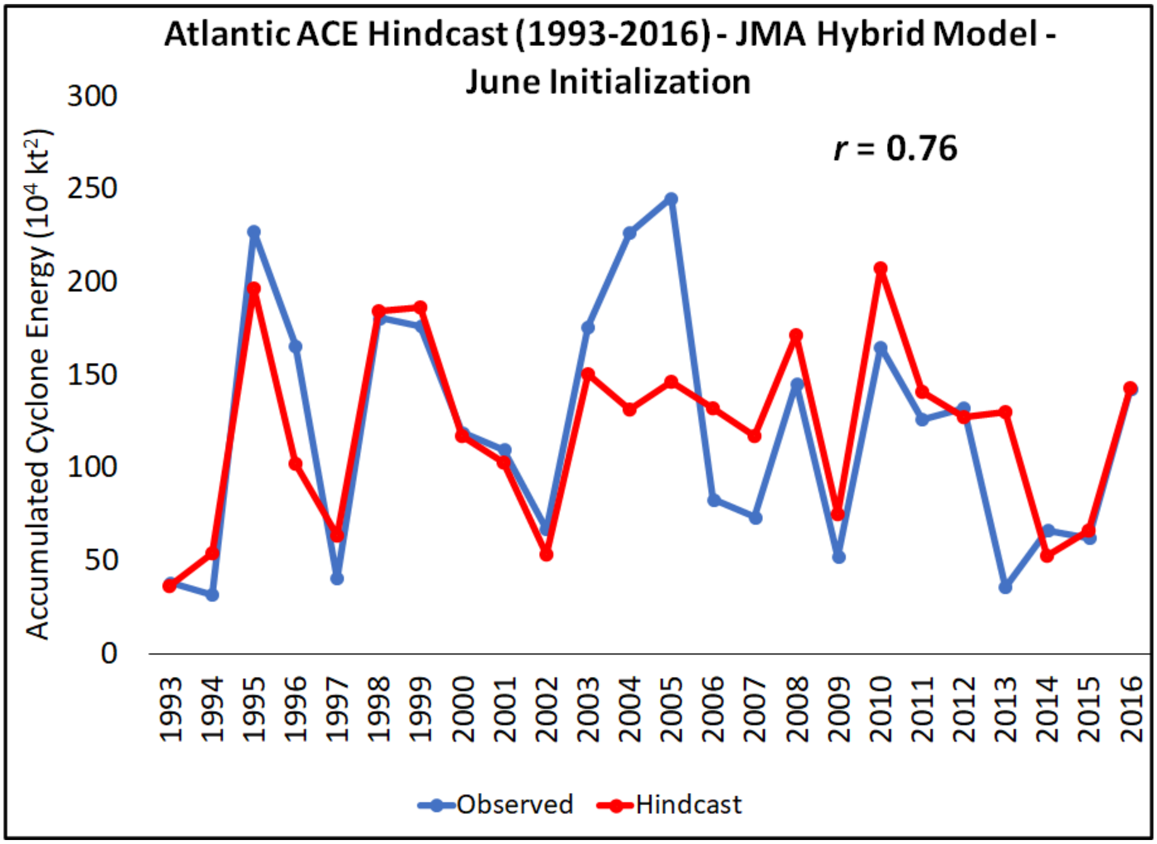

Figure 11: Observed versus statistical/dynamical hindcast values of ACE for 1993–2016 from the JMA.

Table 9: Statistical/dynamical model output from the JMA for the 2022 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1991–2020 Average (in parentheses)	JMA Hybrid Forecast	Final Forecast
Named Storms (14.4)	18.7	20
Named Storm Days (69.4)	99.3	95
Hurricanes (7.2)	10.3	10
Hurricane Days (27.0)	43.3	40
Major Hurricanes (3.2)	5.1	5
Major Hurricane Days (7.4)	13.3	11
Accumulated Cyclone Energy Index (123)	194	180
Net Tropical Cyclone Activity (135%)	206	195

2.3 July Analog Forecast Scheme

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2022. These years also provide useful clues as to likely levels of activity that the forthcoming 2022 hurricane season may bring. For this early July forecast, we determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current June 2022 conditions and, more importantly, projected August–October 2022 conditions. Table 10 lists our analog selections.

We searched for years that were generally characterized by cool neutral ENSO or weak La Niña conditions and warmer than normal North Atlantic SSTs (Figure 12) during the peak of the Atlantic hurricane season. We anticipate that the 2022 hurricane season will have slightly more activity than the average of our six analog years.

Table 10: Analog years for 2022 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
1999	12	78.50	8	41.00	5	14.25	177	182
2000	15	71.50	8	32.75	3	5.00	119	134
2008	16	88.25	8	30.50	5	7.50	146	162
2011	19	89.75	7	26.00	4	4.50	126	145
2021	21	79.75	7	27.75	4	12.75	146	174
Average	16.0	81.1	7.8	33.8	4.5	9.5	147	165
2022 Forecast	**20**	**95**	**10**	**40**	**5**	**11**	**180**	**195**

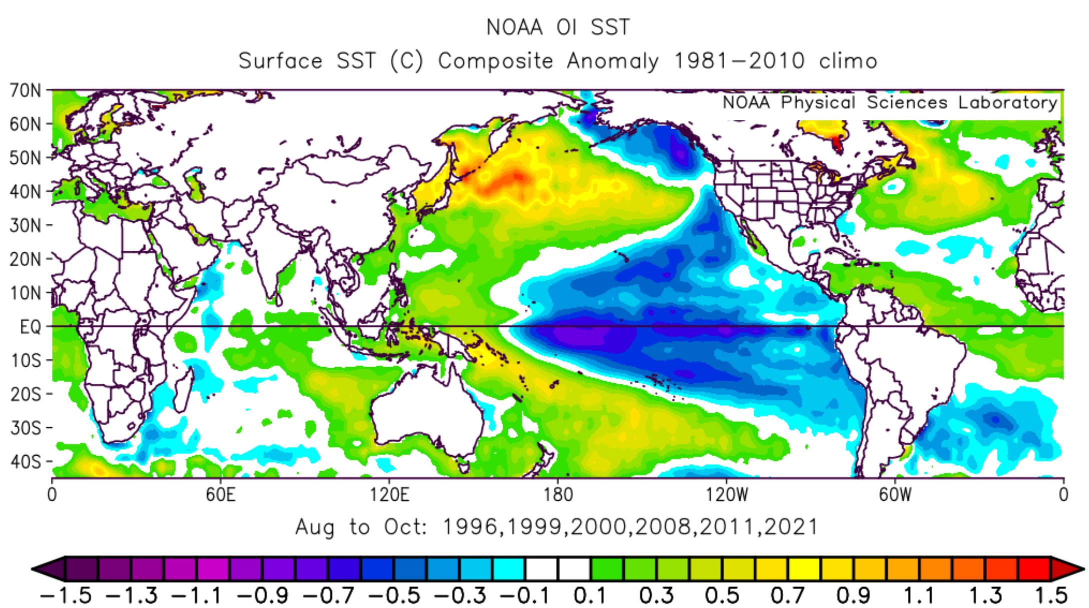

Figure 12: Average August–October SST anomalies in our six analog years.

2.4 July Forecast Summary and Final Adjusted Forecast

Table 11 shows our final adjusted early July forecast for the 2022 season which is a combination of our statistical scheme, our three statistical/dynamical schemes, our analog scheme and qualitative adjustments for other factors not explicitly contained in any of these schemes. All five of our schemes call for above-average Atlantic hurricane activity this year. Our forecast is near the average of the five schemes and calls for a well above-normal season, due to both anticipated La Niña conditions as well as anticipated anomalously warm SSTs in the tropical Atlantic for the peak of the Atlantic hurricane season (August–October).

Table 11: Summary of our early July statistical forecast, our statistical/dynamical forecasts, our analog forecast, the average of these five schemes and our adjusted final forecast for the 2022 hurricane season.

Forecast Parameter and 1991–2020 Average (in parentheses)	Statistical Scheme	ECMWF Scheme	Met Office Scheme	JMA Scheme	Analog Scheme	5-Scheme Average	Adjusted Final Forecast
Named Storms (14.4)	19.0	16.5	19.4	18.7	16.0	17.9	20
Named Storm Days (69.4)	101.4	83.8	103.5	99.3	81.1	93.8	95
Hurricanes (7.2)	10.5	8.7	10.7	10.3	7.8	9.6	10
Hurricane Days (27.0)	44.5	34.9	45.6	43.3	33.8	40.4	40
Major Hurricanes (3.2)	5.2	4.1	5.3	5.1	4.5	4.8	5
Major Hurricane Days (7.4)	13.7	10.2	14.1	13.3	9.5	12.2	11
Accumulated Cyclone Energy Index (123)	199	157	204	194	147	180	180
Net Tropical Cyclone Activity (135%)	211	169	216	206	165	193	195

3 Forecast Uncertainty

One of the questions that we are asked regarding our seasonal hurricane predictions is the degree of uncertainty that is involved. This season we continue to use probability of exceedance curves as discussed in Saunders et al. (2020). In that paper, we outlined an approach that uses statistical modeling and historical skill of various forecast models to arrive at a probability that particular values for hurricane numbers and ACE would be exceeded. Here we display probability of exceedance curves for hurricanes and ACE (Figures 13 and 14), using the error distributions calculated from both normalized cross-validated statistical as well as the cross-validated statistical/dynamical hindcasts from ECMWF. Hurricane numbers are fit to a Poisson distribution, while ACE is fit to a Weibull distribution. Table 12 displays one standard deviation uncertainty ranges (~68% of all forecasts within this range). This uncertainty estimate is also similar to the 70% uncertainty range that NOAA provides with its forecasts. We use a Poisson distribution 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.

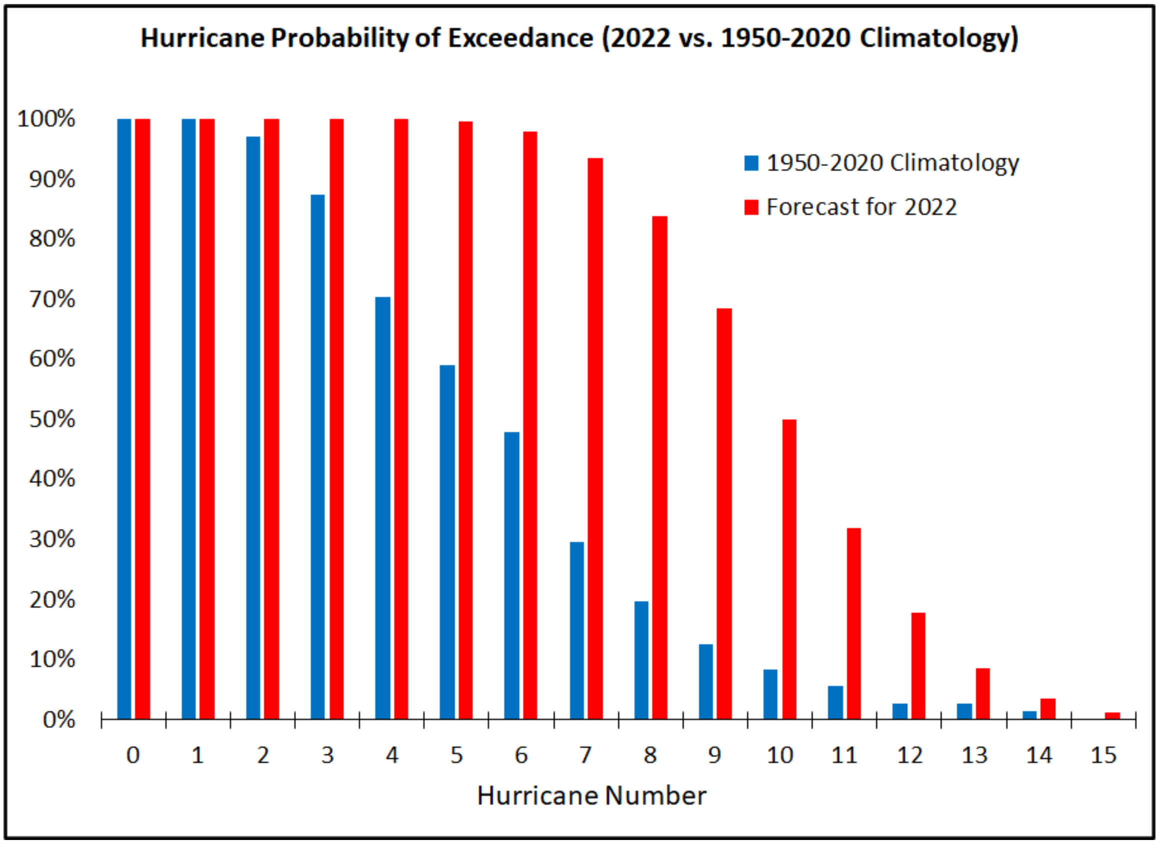

Figure 13: Probability of exceedance plot for hurricane numbers for the 2022 Atlantic hurricane season. The values on the x-axis indicate that the number of hurricanes exceeds that specific number. For example, 97% of Atlantic hurricane seasons from 1950-2020 have had more than two hurricanes.

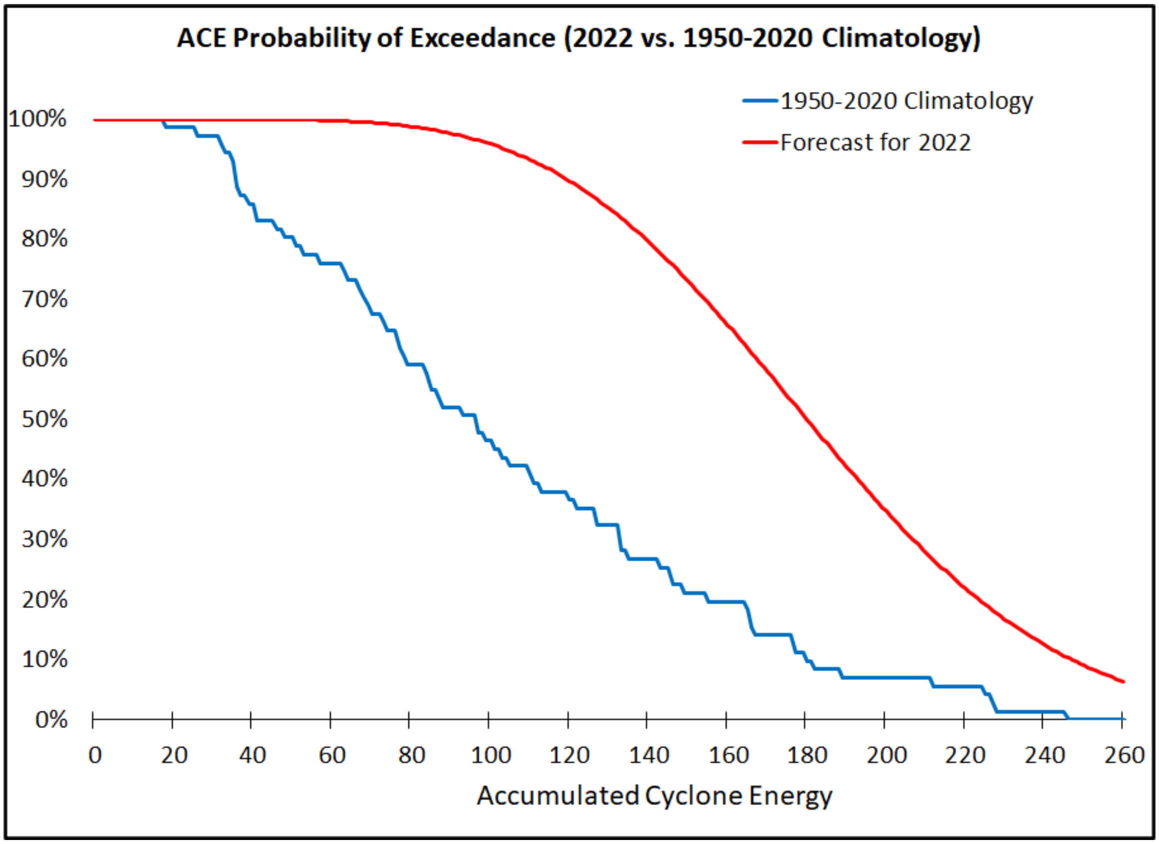

Figure 14: As in Figure 13 but for ACE.

Table 12: 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	2022 Forecast	Uncertainty Range (68% of Forecasts Likely to Fall in This Range)
Named Storms (NS)	20	17 – 23
Named Storm Days (NSD)	95	75 – 116
Hurricanes (H)	10	8 – 12
Hurricane Days (HD)	40	28 – 54
Major Hurricanes (MH)	5	3 – 7
Major Hurricane Days (MHD)	11	7 – 16
Accumulated Cyclone Energy (ACE)	180	130 – 234
Net Tropical Cyclone (NTC) Activity	195	147 – 246

4 ENSO

Over the past several months, the tropical Pacific has been characterized by a weak to moderate La Niña event (Figure 15). ENSO events are partially classified by NOAA based on SST anomalies in the Nino 3.4 region, which is defined as 5°S–5°N, 170–120°W. Weak La Niña events are typically defined to be those where SST anomalies are between -0.5°C – -1.0°C, while moderate La Niña events are when SST anomalies are between -1.0° – -1.5°C. Over the past several weeks, SST anomalies have generally increased across the eastern and central tropical Pacific. The overall oceanic/atmospheric pattern continues to reflect weak La Niña conditions.

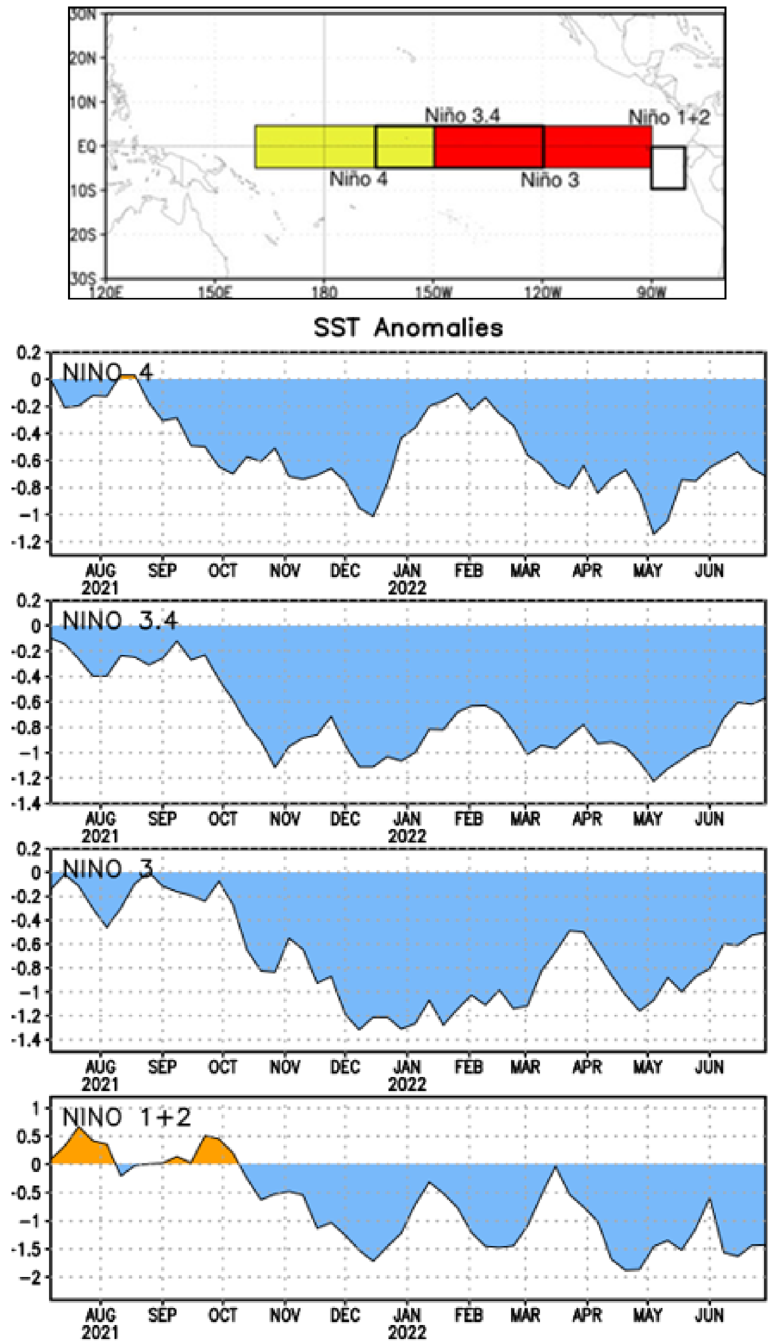

Figure 15: ENSO SST anomalies from July 2021 through June 2022. Figure courtesy of Climate Prediction Center.

Upper-ocean heat content anomalies in the eastern and central tropical Pacific reached their coldest during the middle part of October and then increased rapidly through early February (Figure 16). The heat content anomalies decreased through the middle of March and have since increased and are now at slightly above-normal levels. While typically these above-normal upper-ocean content heat anomalies could signal the imminent demise of La Niña, we discuss later in this section why we think La Niña is likely to persist.

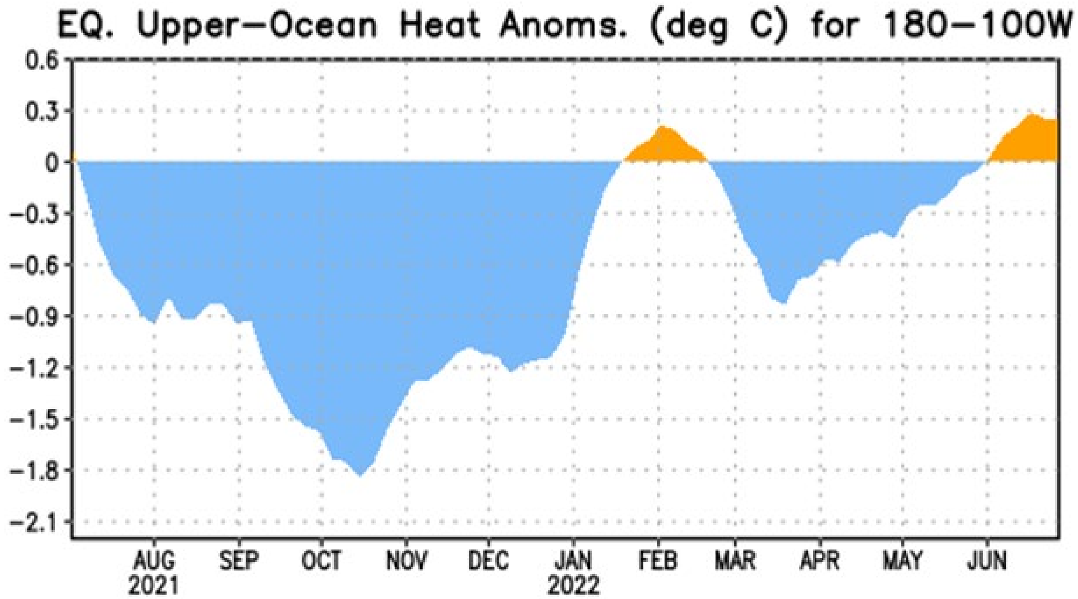

Figure 16: Central and eastern equatorial Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Figure courtesy of Climate Prediction Center.

Below-normal SSTs currently extend across most of the eastern and central equatorial Pacific (Figure 17). The western North Pacific is warmer than normal, while the current spatial pattern of SSTs in the North Pacific (e.g., warm anomalies across most of the North Pacific and cold anomalies off of the west coast of California) continue to be indicative of a negative phase of the Pacific Decadal Oscillation. A negative phase of the Pacific Decadal Oscillation is typically associated with higher pressure in the eastern Pacific, helping to reinforce trade winds blowing across the tropical Pacific. These stronger trades tend to help enhance La Niña and suppress El Niño.

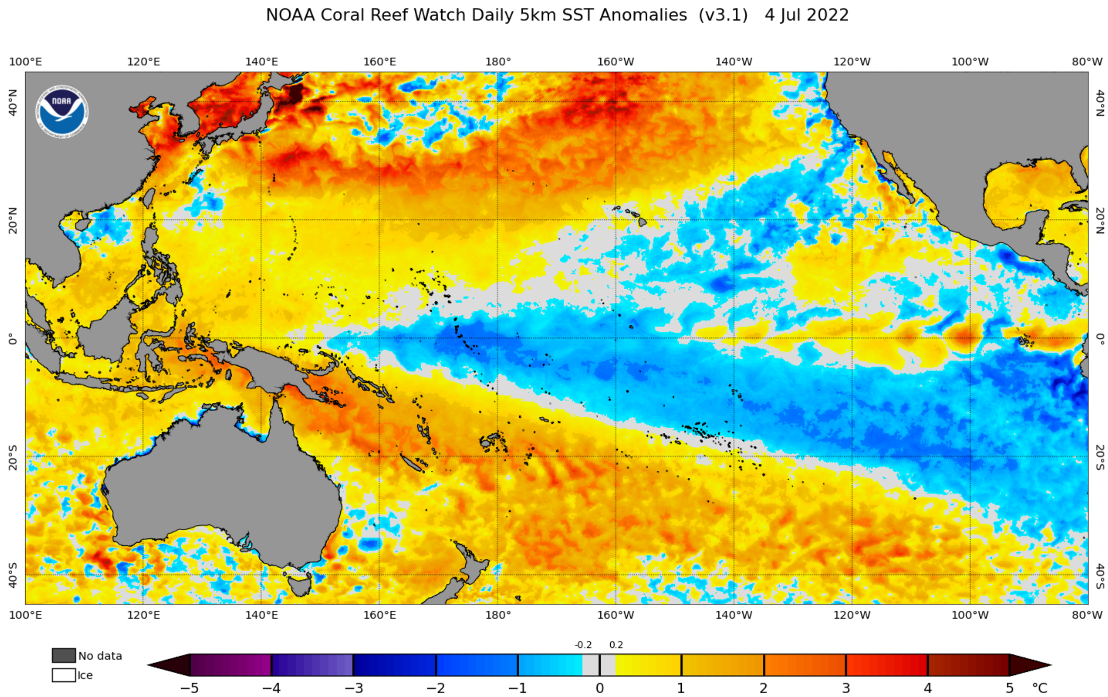

Figure 17: Current SST anomalies across the tropical and subtropical Pacific.

Table 13 displays May and June SST anomalies for several Nino regions. Over the past month, SST anomalies have generally increased across the eastern and central tropical Pacific.

Table 13: 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	-1.4	-1.4	0.0
Nino 3	-0.9	-0.6	+0.3
Nino 3.4	-1.0	-0.7	+0.3
Nino 4	-0.9	-0.6	+0.3

A downwelling (warming) oceanic Kelvin wave, denoted by the dashed line, has transited most of the tropical Pacific since early May (Figure 18). Associated with this oceanic Kelvin wave has been generally increasing SSTs (and ocean heat content) in the eastern and central tropical Pacific.

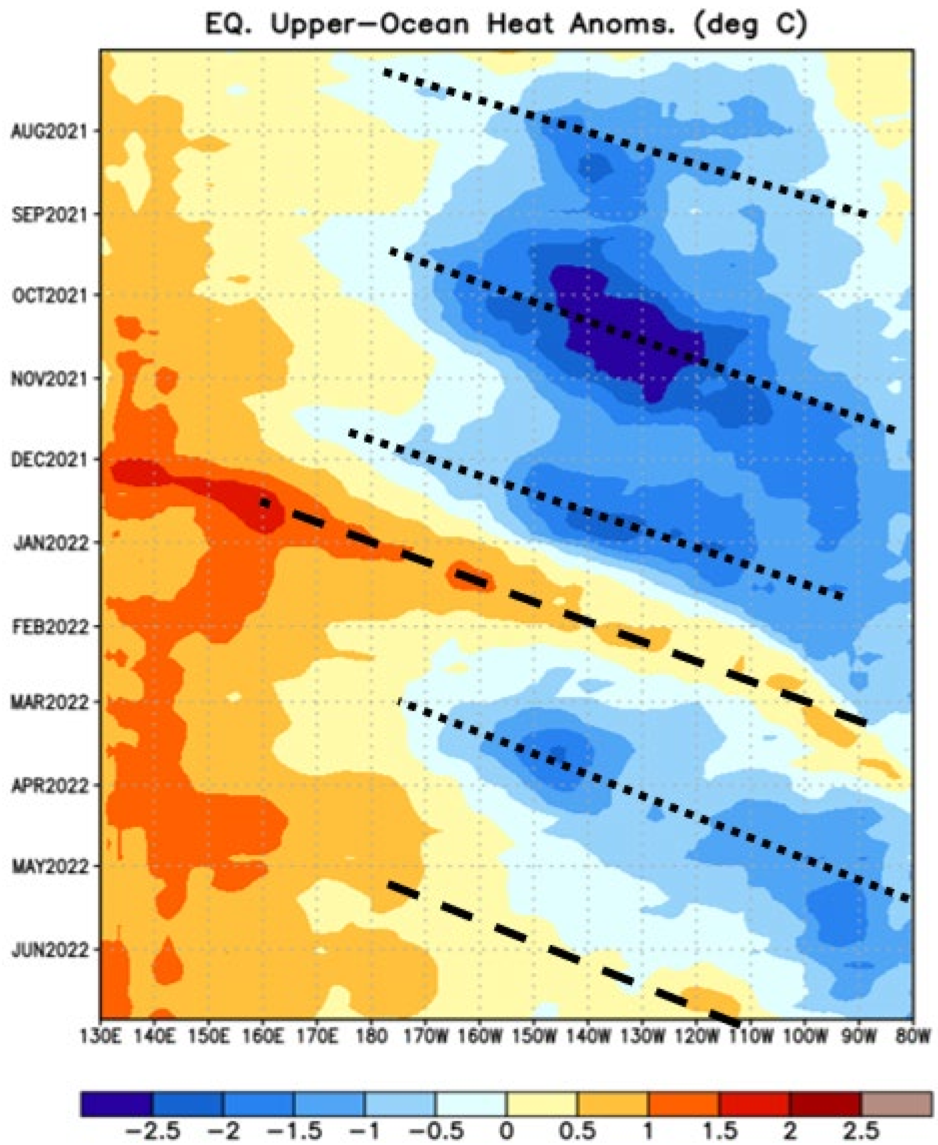

Figure 18: Upper-ocean heat content anomalies in the tropical Pacific since July 2021. Dashed lines indicate downwelling Kelvin waves, while dotted lines indicate upwelling Kelvin waves. Downwelling Kelvin waves result in upper-ocean heat content increases, while upwelling Kelvin waves result in upper-ocean heat content decreases.

Stronger-than-normal trade winds over the central tropical Pacific can trigger upwelling (cooling) oceanic Kelvin waves. These upwelling Kelvin waves then take ~2-3 months to propagate from near the International Date Line to the western coast of South America. Very strong trade winds over the central tropical Pacific have been occurring for the past ~15 days, and the latest forecast from ECMWF calls for continued stronger-than-normal trades for the next 15 days (Figure 19). This persistently strong trade wind surge is likely to cause an upwelling Kelvin wave which we anticipate will help La Niña conditions persist for the remainder of the Atlantic hurricane season. Central Pacific trade winds are also forecast by ECMWF to remain elevated through mid-August (Figure 20), likely helping to persist La Niña conditions.

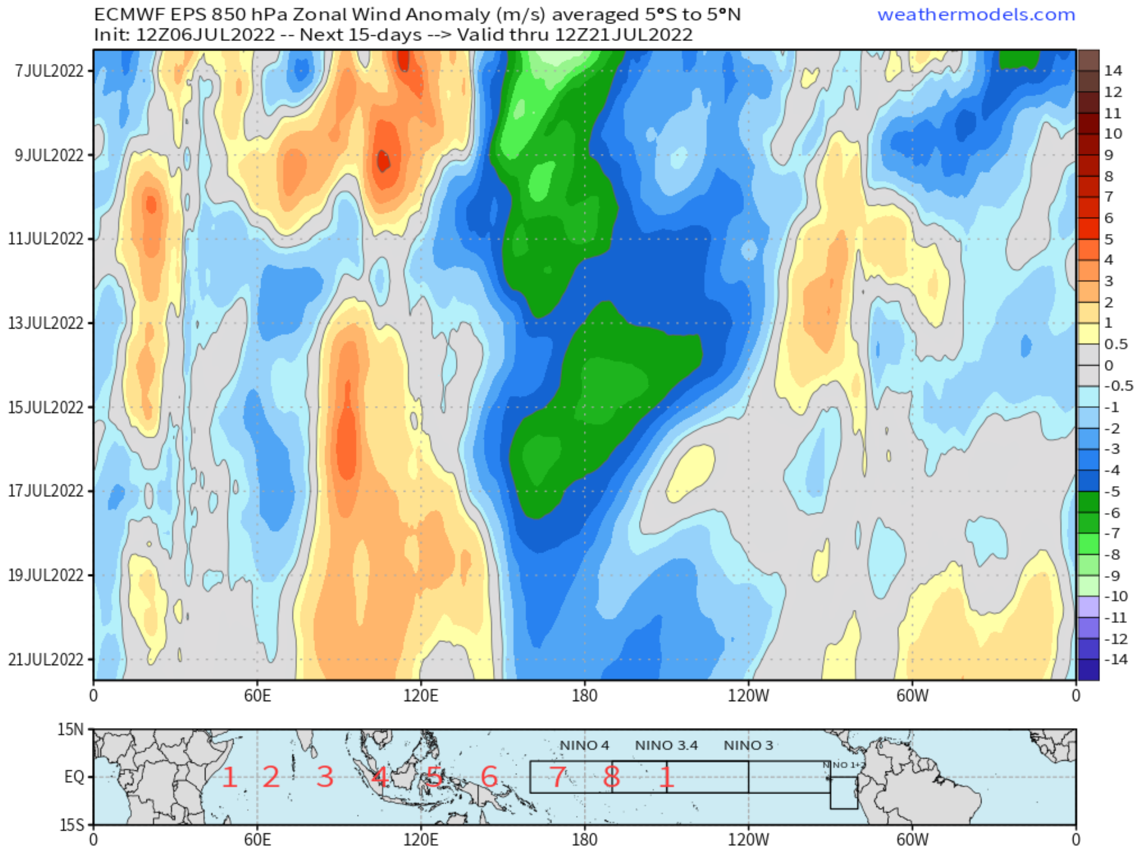

Figure 19: Forecast 850-hPa zonal equatorial winds for the next 15 days. Figure courtesy of weathermodels.com.

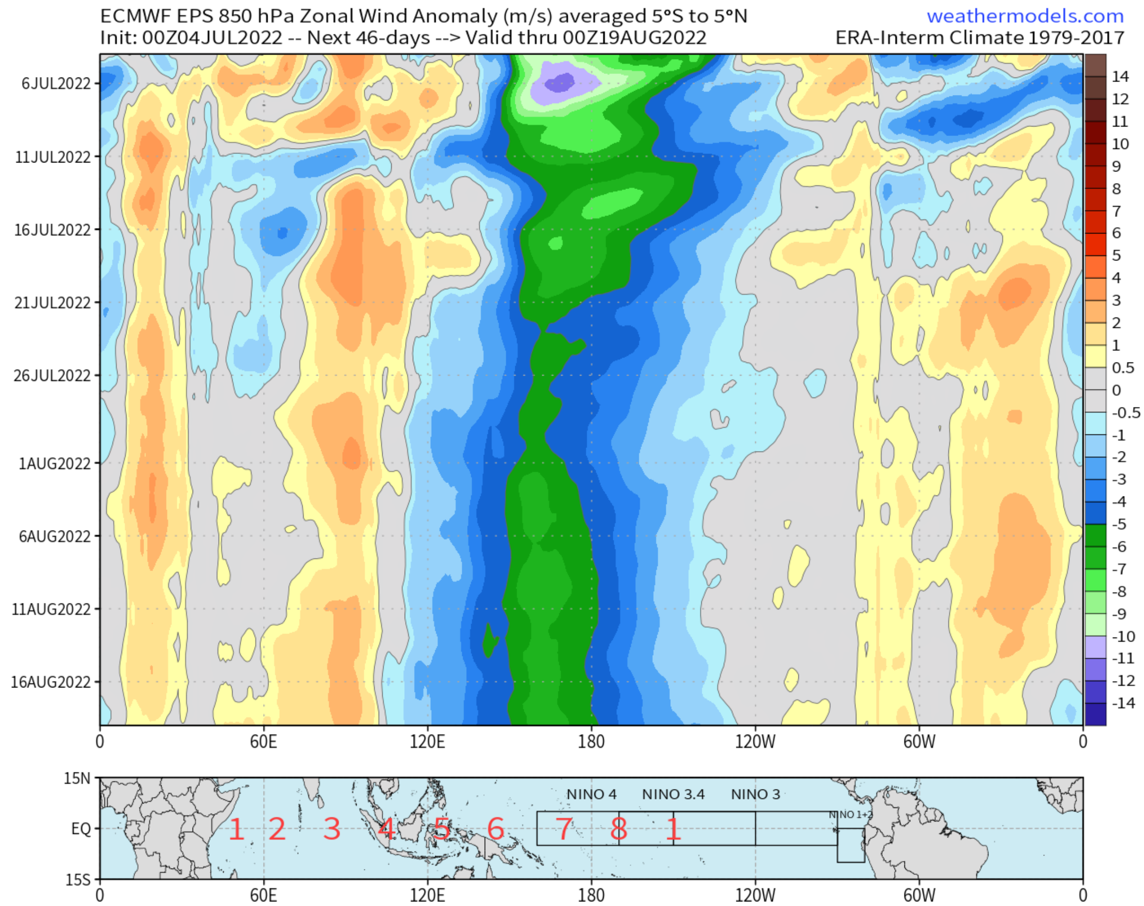

Figure 20: Forecast 850-hPa zonal equatorial winds for the next 46 days. Figure courtesy of weathermodels.com.

The latest plume of ENSO predictions from several statistical and dynamical models shows some spread by the peak of the Atlantic hurricane season in August–October (Figure 21). While there remains some spread, all models call for either La Niña or neutral ENSO conditions for the next several months.

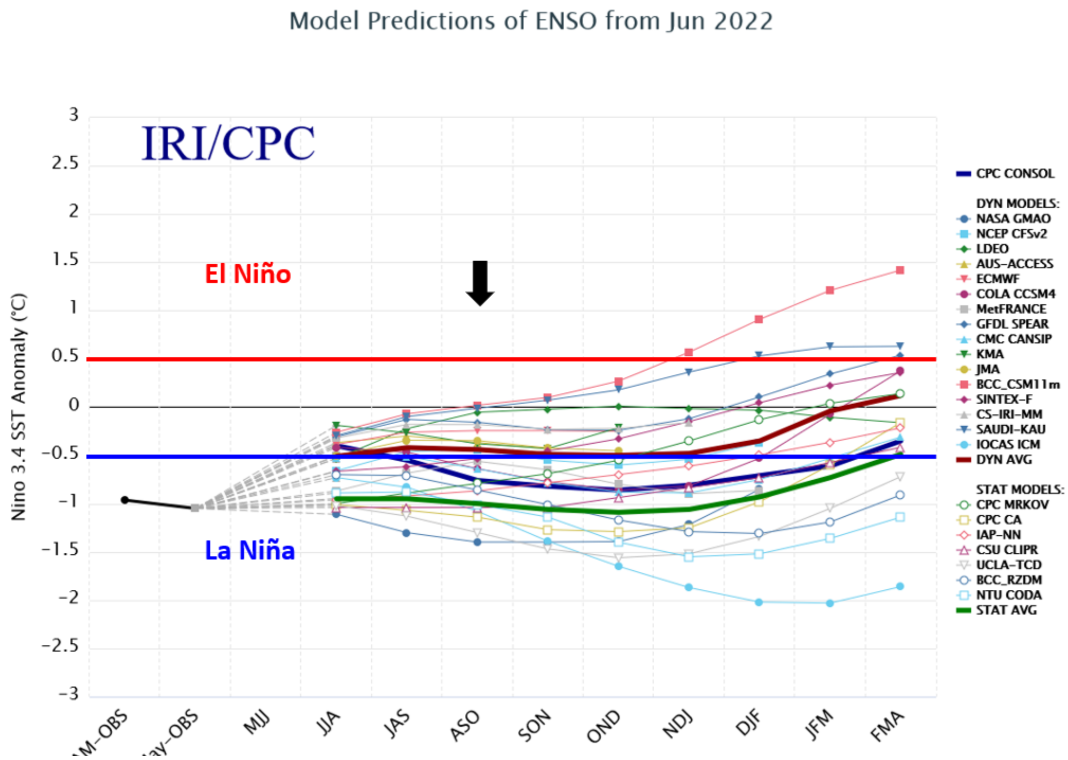

Figure 21: ENSO forecasts from various statistical and dynamical models for Nino 3.4 SST anomalies based on late May to early June initial conditions. All models are calling for either La Niña or ENSO neutral conditions for August–October. Figure courtesy of the International Research Institute (IRI). The black arrow denotes August–October – the peak of the Atlantic hurricane season.

The latest official forecast from NOAA also indicates that the chances of El Niño are quite low for August–October. NOAA is currently predicting a 3% chance of El Niño, a 43% chance of ENSO neutral conditions and a 54% chance of La Niña for the peak of the Atlantic hurricane season (Figure 22).

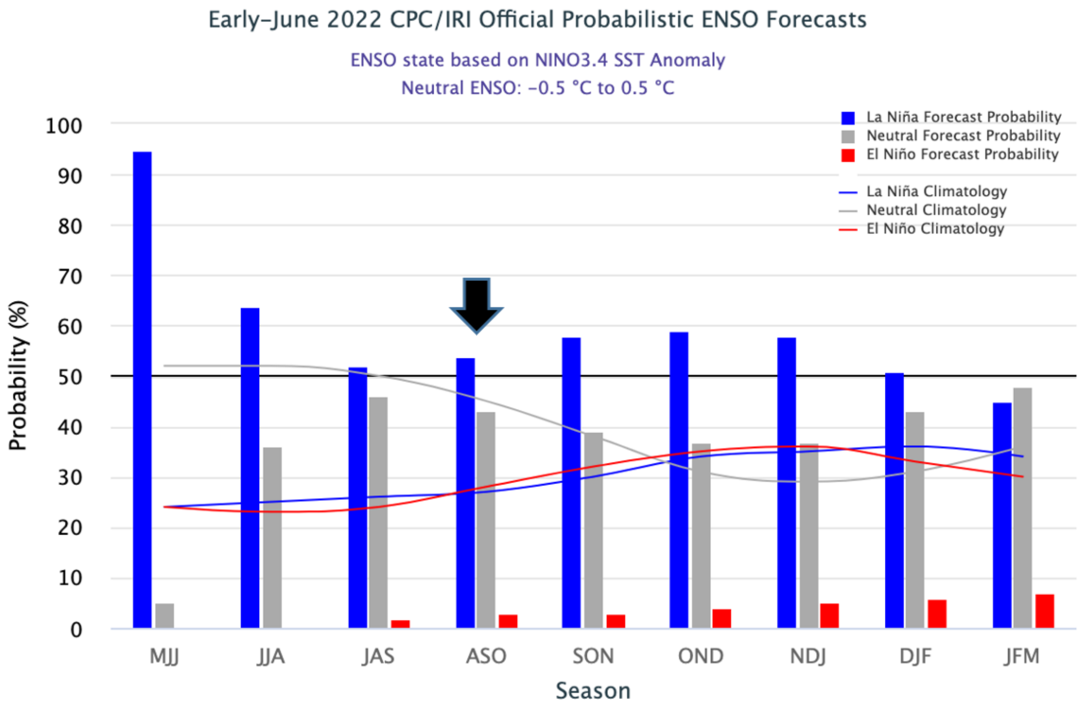

Figure 22: Official NOAA forecast for ENSO. The black arrow denotes August–October – the peak of the Atlantic hurricane season.

Based on the above information, we do not anticipate El Niño conditions for the peak of the Atlantic hurricane season. While El Niño is quite unlikely, there still remains some uncertainty whether La Niña conditions will persist or whether we will revert to neutral ENSO conditions for the peak of the Atlantic hurricane season. While we believe that the current trade wind surge will likely generate a strong upwelling Kelvin wave, we could at least briefly revert to neutral ENSO conditions given the time lag between the current downwelling Kelvin wave and the anticipated upwelling Kelvin wave.

5 Current Atlantic Basin Conditions

Currently, SSTs are above normal across most of the tropical Atlantic and Caribbean and slightly warmer than normal in the far eastern part of the subtropical Atlantic (Figure 23). This type of SST pattern in July is generally correlated with above-average Atlantic hurricane seasons (Figure 24). Parts of the eastern subtropical Atlantic have anomalously cooled over the past few weeks, likely due to stronger-than-normal trades during this time (Figure 25). There has been some anomalous warming in the Caribbean since early June, likely due to the predominately weaker-than-normal trades in this region.

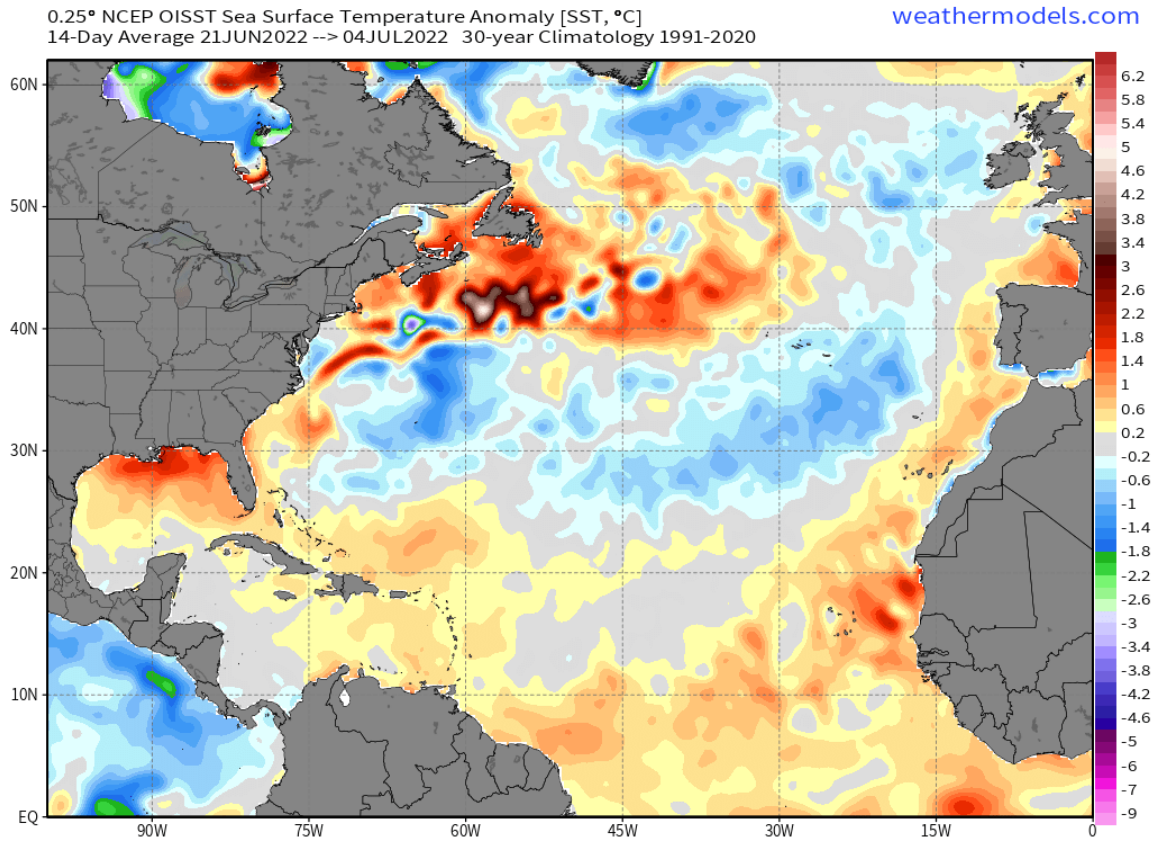

Figure 23: Early July 2022 SST anomaly pattern across the Atlantic Ocean.

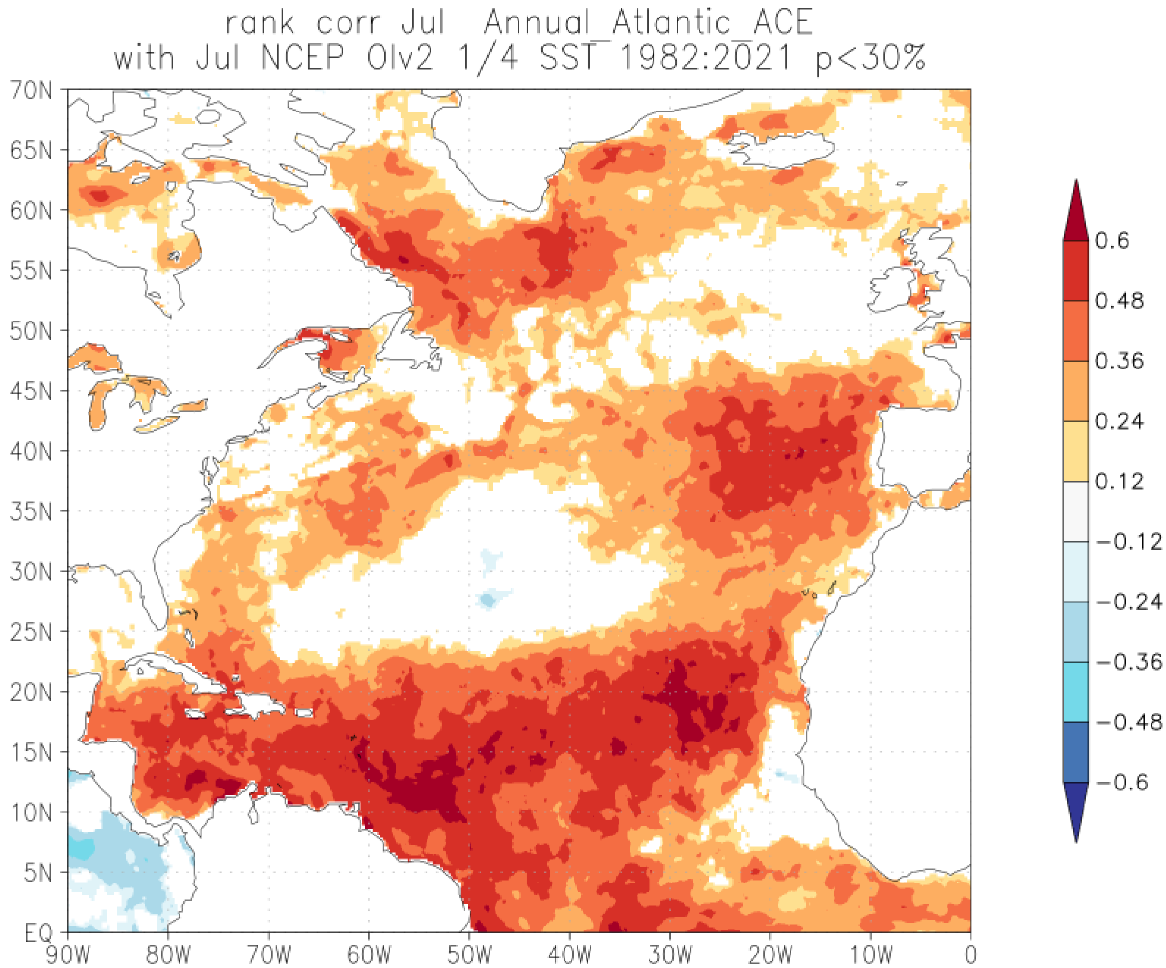

Figure 24: Rank correlation between July North Atlantic SST anomalies and seasonal Atlantic ACE from 1982–2021.

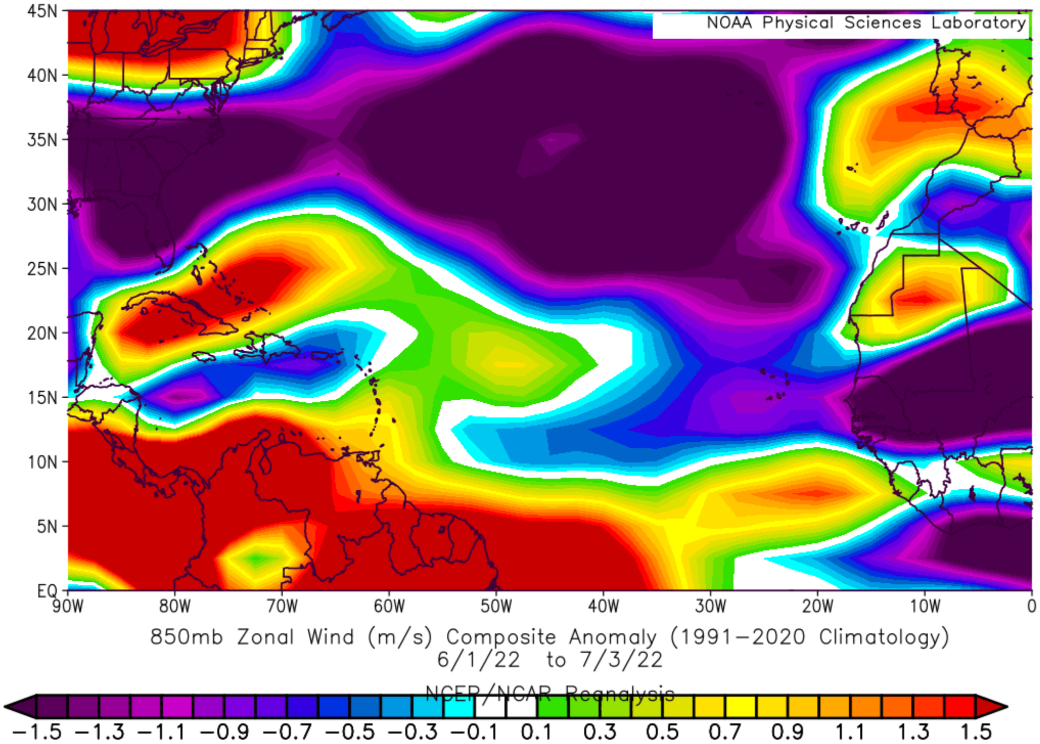

Figure 25: June 1, 2022 through July 3, 2022 averaged 850-hPa zonal wind anomalies across the North Atlantic. In general, low-level trade winds have been weaker than normal (e.g., westerly wind anomalies) across most of the tropical Atlantic over the past two months.

Conditions over the tropical Atlantic look quite unfavorable for hurricane activity over the next couple of weeks with elevated vertical wind shear likely, but towards the end of July, the large-scale circulation looks to get much more favorable, with rising motion projected by ECMWF to persist over Africa and the Indian Ocean and sinking motion over the tropical Pacific (Figure 26). This type of vertical motion pattern is associated with reduced vertical wind shear in the Atlantic.

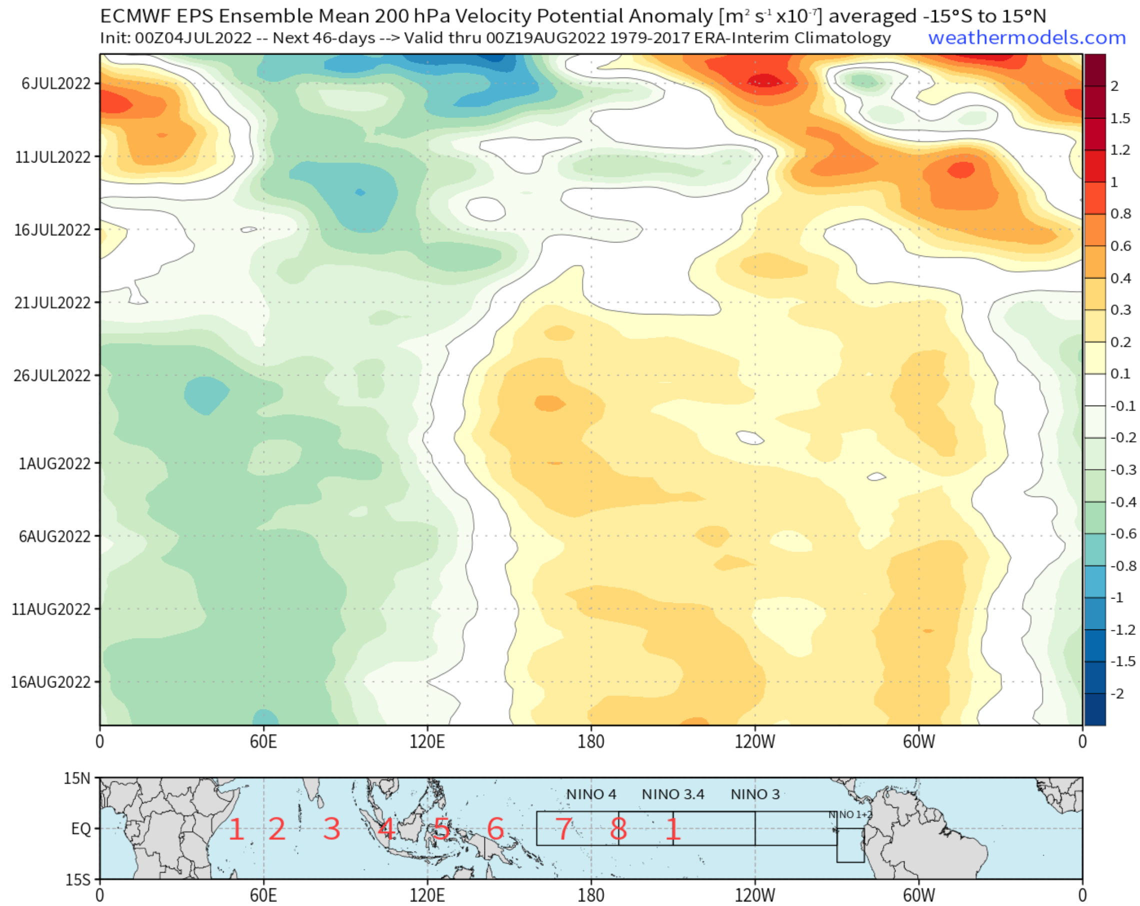

Figure 26: ECMWF forecast upper-level velocity potential anomalies for the next several weeks. Negative velocity potential anomalies (blue colors) at 200 hPa is associated with upper-level divergence. This predicted upper-level divergent outflow pattern over Africa and the Indian Ocean in late July through mid-August would reduce vertical wind shear in the tropical Atlantic.

6 West Africa Conditions

As has been the case the past two years, 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 27). In addition, precipitation in the Sahel was generally above normal (Figure 28). An active West African monsoon is typically associated with more active Atlantic hurricane seasons.

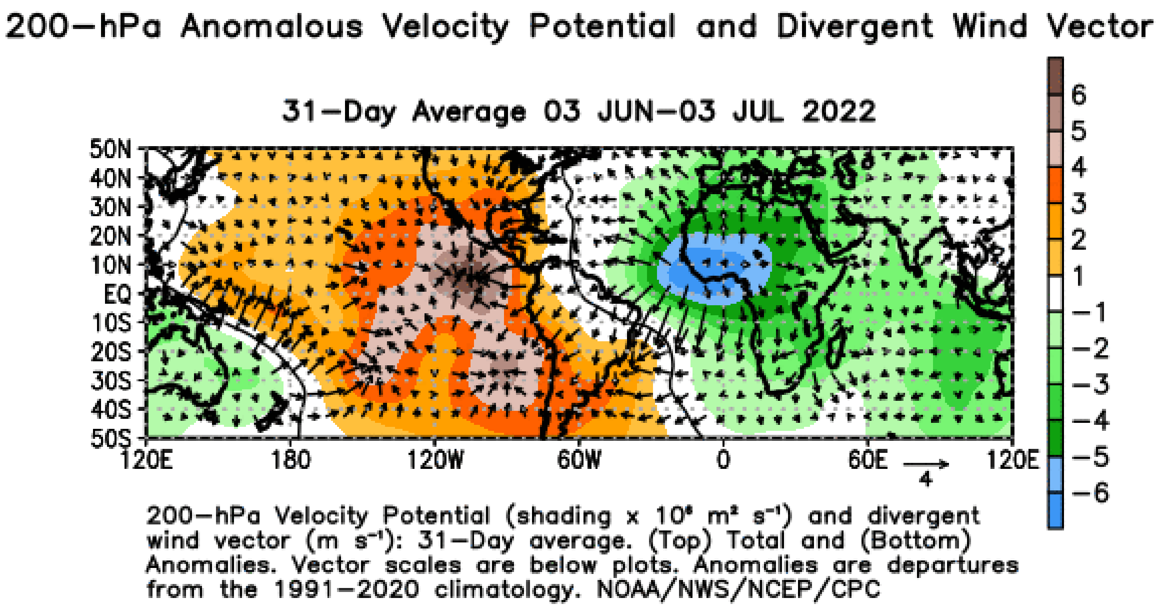

Figure 27: 200 hPa velocity potential anomalies from 50°S – 50°N from 3 June to 3 July 2022. Negative velocity potential favors upward vertical motion.

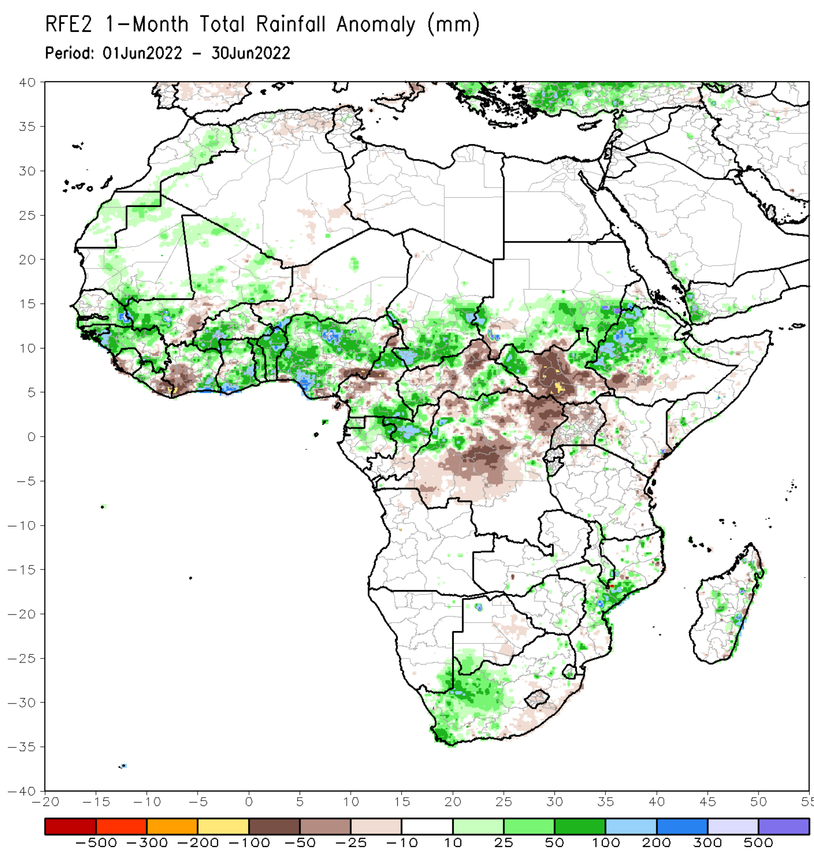

Figure 28: June 2022 rainfall estimates from the African Rainfall Estimation Algorithm, version 2.

7 Tropical Storm Bonnie

In general, early season Atlantic hurricane activity has very little correlation with overall Atlantic hurricane activity. However, when this activity occurs in the Caribbean, it is often a harbinger of a very active season. Bonnie is only the 6^{th} named storm to form in the Caribbean in July since 1950. The other five seasons with July Caribbean named storm formations were: 1961, 1996, 2003, 2005 and 2008. All five seasons had above-normal Atlantic hurricane activity, with all but 2008 meeting the NOAA definition of a hyperactive season.

8 Tropical Cyclone Impact Probabilities for 2022

This year, we continue to calculate the impacts of tropical cyclones for each state and county/parish along the Gulf and East Coasts, tropical cyclone-prone provinces of Canada and states of Mexico, 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 14). 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 14: 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 15 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 2022. 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 15: Probability of >=1 named storm, hurricane and major hurricane tracking within 50 miles of each coastal state from Texas to Maine. Probabilities are provided for both the 1880–2020 climatological average as well as the probability for the remainder of 2022, based on the latest CSU seasonal hurricane forecast.

	2022 Probability event within 50 miles			**Climatological event within 50 miles**		
State	**Probability >=1** Named Storm	Hurricane	Major Hurricane	**Probability >=1** Named Storm	Hurricane	Major Hurricane
Alabama	81%	46%	15%	58%	28%	8%
Connecticut	37%	14%	3%	22%	8%	1%
Delaware	38%	11%	1%	23%	6%	1%
Florida	97%	79%	47%	86%	56%	29%
Georgia	85%	50%	11%	63%	30%	6%
Louisiana	87%	60%	26%	66%	38%	14%
Maine	37%	13%	3%	21%	7%	1%
Maryland	50%	19%	1%	31%	11%	1%
Massachusetts	53%	26%	5%	33%	14%	3%
Mississippi	76%	47%	14%	53%	28%	8%
New Hampshire	31%	10%	3%	18%	6%	1%
New Jersey	38%	13%	1%	23%	7%	1%
New York	44%	17%	4%	26%	9%	2%
North Carolina	88%	60%	14%	68%	38%	8%
Rhode Island	35%	14%	3%	20%	8%	1%
South Carolina	79%	47%	15%	57%	29%	8%
Texas	83%	58%	28%	61%	36%	16%
Virginia	68%	34%	3%	46%	20%	1%

9 Summary

An analysis of a variety of different atmosphere and ocean measurements (through June) which are known to have long-period statistical relationships with the upcoming season's Atlantic tropical cyclone activity, as well as output from dynamical models, indicate that 2022 should have well above-normal activity. The big question marks with this season's predictions continue to revolve around the state of ENSO, as well as what the configuration of Atlantic SSTs will look like during the peak of the Atlantic hurricane season.

10 Forthcoming Updated Forecasts of 2022 Hurricane Activity

We will be issuing a seasonal update of our 2022 Atlantic basin hurricane forecast on **Thursday 4 August**. We will also be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August–October. A verification and discussion of all 2022 forecasts will be issued in late November 2022. All of these forecasts will be available on our website.

11 Verification of Previous Forecasts

CSU's seasonal hurricane forecasts have shown considerable improvement in recent years, likely due to a combination of improved physical understanding, adoption of statistical/dynamical models and more reliable reanalysis products. Figure 29 displays correlations between observed and predicted Atlantic hurricanes from 1984–2013, from 2014–2021 and from 1984–2021, respectively. Correlation skill has improved at all lead times in recent years, with the most noticeable improvements at longer lead times. While eight years is a relatively short sample size, improvements in both modeling and physical understanding should continue to result in future improvements in seasonal Atlantic hurricane forecast skill. More detailed verification statistics are also available at: https://tropical.colostate.edu/archive.html#verification

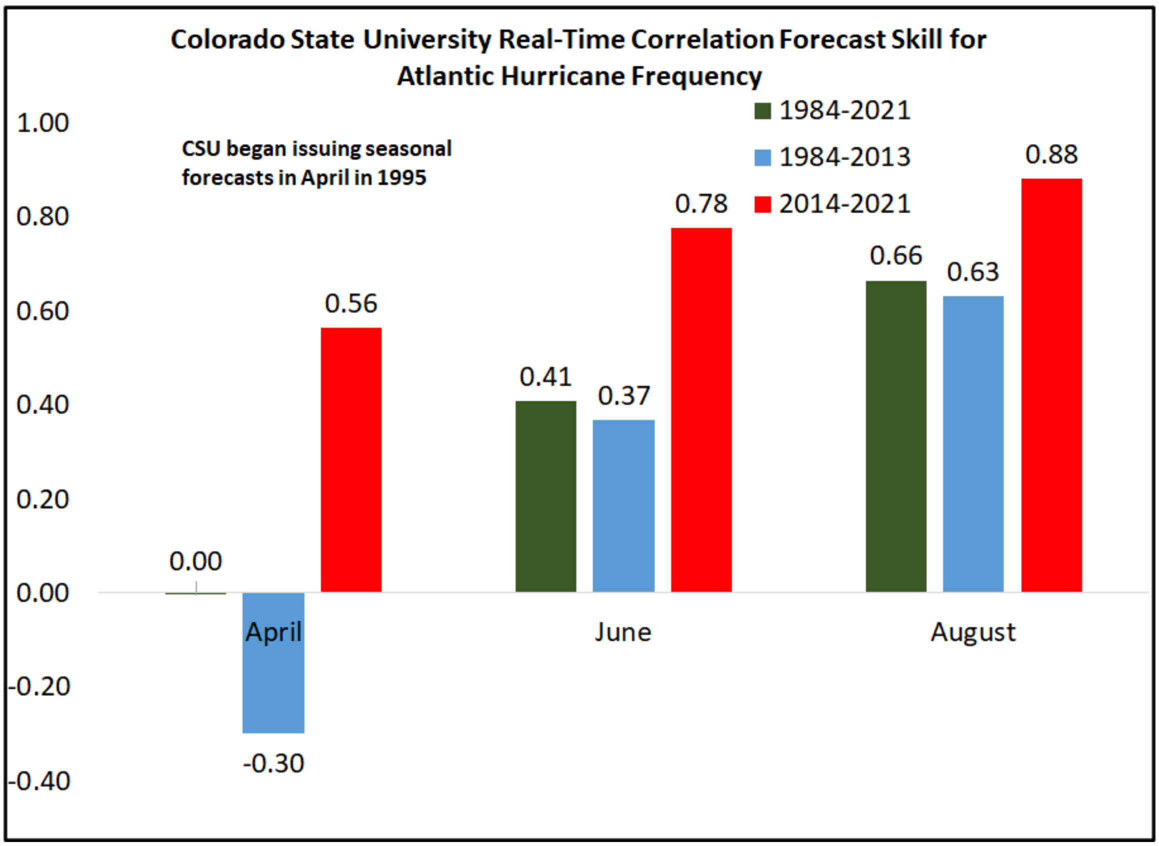

Figure 29: CSU's real-time forecast skill for Atlantic hurricanes using correlation as the skill metric. Correlation skills are displayed for three separate time periods: 1984–2013, 2014–2021 and 1984–2021, respectively.