EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2023

We anticipate that the 2023 Atlantic basin hurricane season will have slightly below-average activity. Current neutral ENSO conditions look fairly likely to transition to El Niño this summer/fall. However, there is considerable uncertainty as to how strong an El Niño would be, if it does develop. Sea surface temperatures in the eastern and central Atlantic are much warmer than normal, so if a robust El Niño does not develop, the potential still exists for a busy Atlantic hurricane season. Larger-than-normal uncertainty exists with this outlook. We anticipate a near-average probability for major hurricanes making landfall along the continental United States coastline and in the Caribbean. As is the case with all hurricane seasons, coastal residents are reminded that it only takes one hurricane making landfall to make it an active season for them. They should prepare the same for every season, regardless of how much activity is predicted.

(as of 13 April 2023)

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 forecast. She can be reached at 970-491-1543 or
Jennifer.Dimas@colostate.edu

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

Project Sponsors:

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

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2023

Forecast Parameter and 1991–2020 Average (in parentheses)	Issue Date 13 April 2023
Named Storms (NS) (14.4)	13
Named Storm Days (NSD) (69.4)	55
Hurricanes (H) (7.2)	6
Hurricane Days (HD) (27.0)	25
Major Hurricanes (MH) (3.2)	2
Major Hurricane Days (MHD) (7.4)	5
Accumulated Cyclone Energy (ACE) (123)	100
ACE West of 60°W (73)	55
Net Tropical Cyclone Activity (NTC) (135%)	105

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

1) Entire continental U.S. coastline - 44% (average from 1880–2020 is 43%)

2) U.S. East Coast Including Peninsula Florida (south and east of Cedar Key, Florida)- 22% (average from 1880–2020 is 21%)

3) Gulf Coast from the Florida Panhandle (west and north of Cedar Key, Florida) westward to Brownsville - 28% (average from 1880–2020 is 27%)

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

1) 49% (average from 1880–2020 is 47%)

ABSTRACT

Information obtained through March indicates that the 2023 Atlantic hurricane season will have activity slightly below the 1991–2020 average. We estimate that 2023 will have 13 named storms (average is 14.4), 55 named storm days (average is 69.4), 6 hurricanes (average is 7.2), 25 hurricane days (average is 27.0), 2 major (Category 3-4-5) hurricanes (average is 3.2) and 5 major hurricane days (average is 7.4). The probability of U.S. major hurricane landfall is estimated to be very close to the long-period average. We predict Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2023 to be approximately 80 percent of their long-term averages.

This forecast is based on an extended-range early April 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, the Japan Meteorological Agency and the Centro Euro-Mediterraneo sui Cambiamenti Climatici model as four additional forecast guidance tools. There is a wide range of solutions from our model guidance this year, ranging from a slightly below-average season to a well above-average season.

The tropical Pacific is currently characterized by neutral ENSO conditions. We believe that it is relatively likely that the tropical Pacific will transition to El Niño conditions during this year's hurricane season. However, the intensity of a potential El Niño event is quite uncertain at this time. El Niño typically reduces Atlantic hurricane activity through increases in vertical wind shear. Sea surface temperatures in the eastern and central tropical Atlantic are much warmer than normal, so if a robust El Niño does not develop, the potential for an active Atlantic hurricane season still exists.

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

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

Why issue extended-range forecasts for seasonal hurricane activity?

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

Everyone should realize that it is impossible to precisely predict this season's hurricane activity in early April. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged as regards to the probability of an active or inactive hurricane season for the coming year. Our early April statistical and statistical/dynamical hybrid models show strong evidence on ~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.

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 Louis-Philippe Caron, Dan Chavas, Jason Dunion, Brian McNoldy, Paul Roundy, Carl Schreck, Mike Ventrice 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 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.

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 1991-2020 average value of this parameter is 135.

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 40th year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. This year's April forecast is based on a statistical model as well as output from statistical/dynamical models from the European Centre for Medium-Range Weather Forecasts (ECMWF), the UK Met Office, the Japan Meteorological Agency (JMA) and the Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC). These models show skill at predicting TC activity based on ~25–40 years of historical data. We also select analog seasons, based on currently-observed conditions as well as conditions that 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.

2 April Forecast Methodology

2.1 April Statistical Forecast Scheme

We have slightly modified our April statistical forecast scheme from what has been used during the past few years. The current iteration of the forecast model uses ECMWF Reanalysis 5 (ERA5; Hersbach et al. 2020) for all three parameters. Due to the switch in input sea surface temperature (SST) dataset from NOAA OI SST to ERA5, we now extend the model back to 1979. We redeveloped the model over 1979–2020 and then applied the model to the 2021 and 2022 Atlantic hurricane seasons. The three predictors are similar to what was used in our earlier forecast model, although the regions have changed slightly for our two SST predictors. This model shows 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) ($r = 0.70$) over the period from 1979–2022 (Figure 1).

Figure 2 displays the locations of each predictor, while Table 1 displays the individual linear correlations between each predictor and ACE over the 1979–2022 hindcast/forecast period. All predictors correlate significantly at the 5% level using a two-tailed Student's t-test and assuming that each year represents an individual degree of freedom. Table 2 displays the 2023 observed values for each of the three predictors in the statistical forecast scheme. Table 3 displays the statistical model output for the 2023 hurricane season. The two SST predictors call for an above-average Atlantic hurricane season, while the 200 hPa zonal wind predictor calls for a near-average season. The three predictors in combination call for a well above-average season.

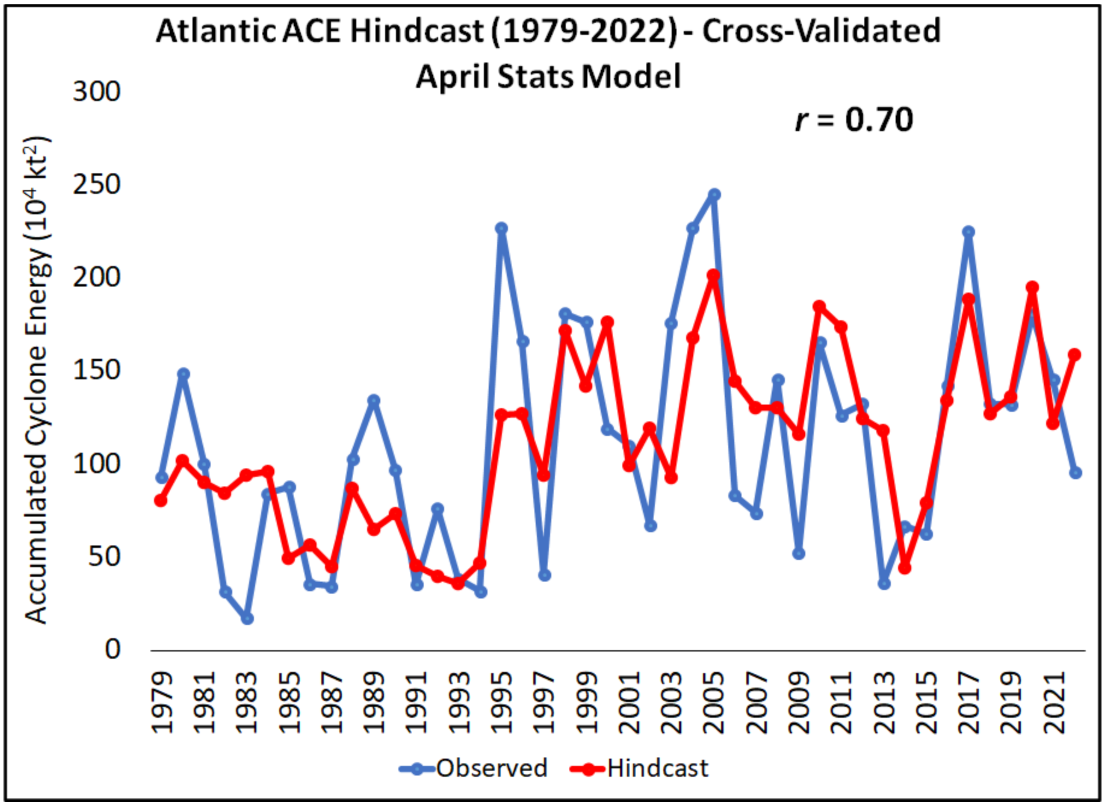


Figure 1: Observed versus early April cross-validated hindcast values of ACE for the statistical model from 1979–2022.

Statistical Model Predictors

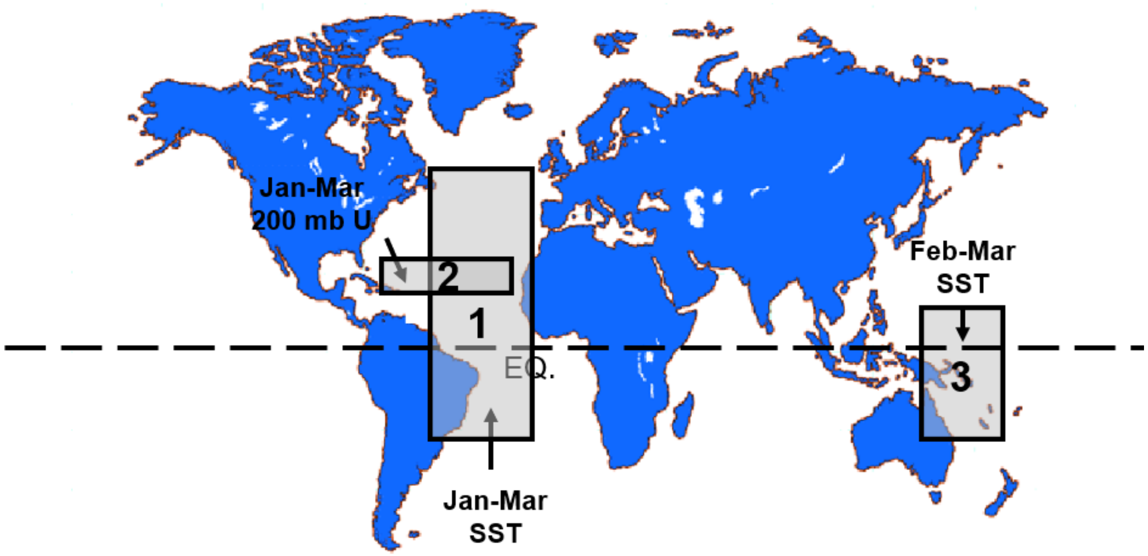


Figure 2: Location of predictors for our early April extended-range statistical prediction for the 2023 hurricane season.

Table 1: Linear correlation between early April predictors and ACE over the period from 1979–2022.

Predictor	Correlation w/ ACE
1) January–March SST (30°S–50°N, 40°W–10°W) (+)	0.56
2) January–March 200 hPa U (17.5°N–27.5°N, 60°W–20°W) (+)	0.42
3) February-March SST (30°S–15°N, 140°E–170°E) (+)	0.51

Table 2: Listing of early April 2023 predictors for the 2023 hurricane season. A plus (+) means that positive deviations of the parameter are associated with increased hurricane activity. SD stands for standard deviation.

Predictor	2023 Forecast Value	Impact on 2023 TC Activity
1) January–March SST (30°S–50°N, 40°W–10°W) (+)	+1.3 SD	Enhance
2) January–March 200 hPa U (17.5°N–27.5°N, 60°W–20°W) (+)	+0.3 SD	Slightly Enhance
3) February-March SST (30°S–15°N, 140°E–170°E) (+)	+0.8 SD	Enhance

Table 3: Statistical model output for the 2023 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)	17.9	13
Named Storm Days (NSD) (69.4)	93.5	55
Hurricanes (H) (7.2)	9.7	6
Hurricane Days (HD) (27.0)	40.1	25
Major Hurricanes (MH) (3.2)	4.7	2
Major Hurricane Days (MHD) (7.4)	12.1	5
Accumulated Cyclone Energy (ACE) (123)	180	100
Net Tropical Cyclone Activity (NTC) (135%)	192	105

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

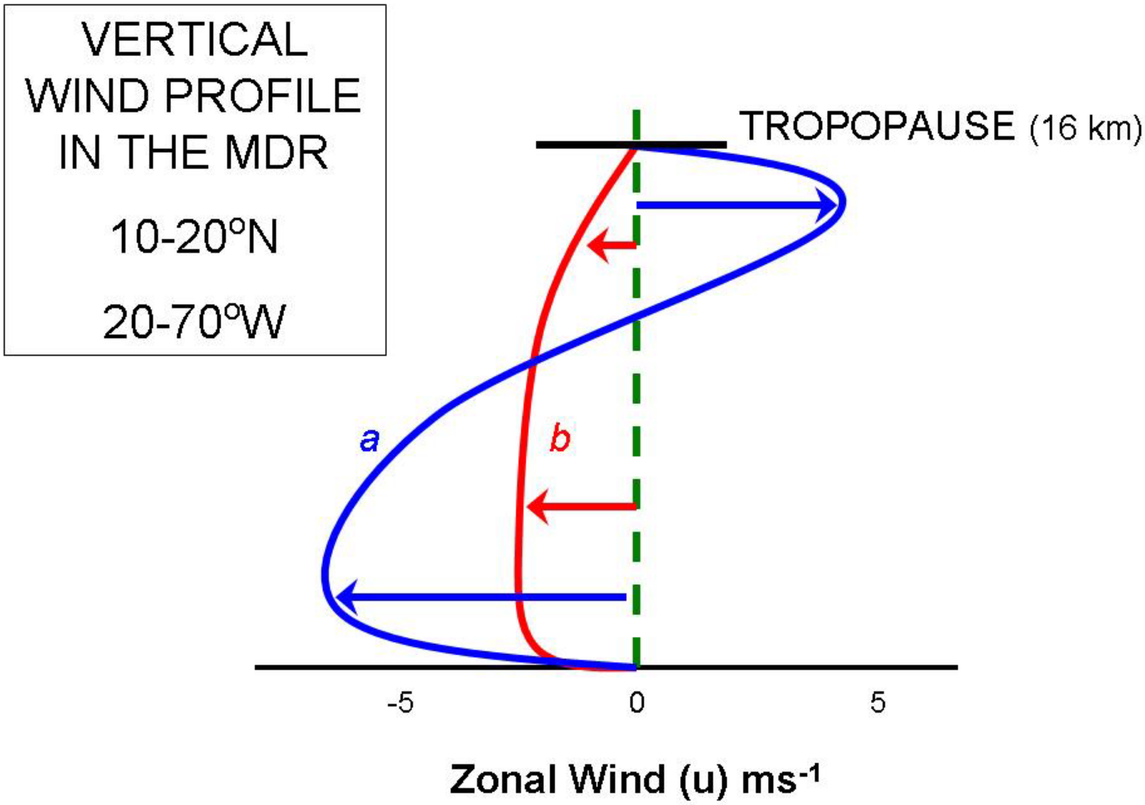


Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.

For each of these predictors, we display a four-panel figure showing linear correlations between values of each predictor and August–October values of SST, sea level pressure (SLP), 200 hPa zonal wind, and 850 hPa zonal wind, respectively, during 1979–2022. In general, higher values of tropical Atlantic SSTs, lower values of tropical Atlantic SLP, anomalous tropical Atlantic westerlies at 850 hPa and anomalous tropical Atlantic easterlies at 200 hPa are associated with active Atlantic basin hurricane seasons. All correlations are displayed using ERA5.

Predictor 1. January–March SST in the tropical and subtropical eastern Atlantic (+)

(30°S–50°N, 40°W–10°W)

Warmer-than-normal SSTs in the tropical and subtropical Atlantic during the January–March time period are associated with a weaker-than-normal subtropical high and reduced trade wind strength during the boreal spring (Knaff 1997). Positive SSTs in January–March are correlated with weaker trade winds and weaker upper tropospheric westerly winds, lower-than-normal sea level pressures and above-normal SSTs in the tropical Atlantic during the following August–October period (Figure 4). All three of these August–October features are commonly associated with active Atlantic basin hurricane seasons, through reductions in vertical wind shear, increased vertical instability and increased mid-tropospheric moisture, respectively. Predictor 1 correlates quite strongly (*r* =0.56) with ACE from 1979–2022. Predictor 1 also strongly correlates (*r* = 0.56) with August–October values of the SST component of the Atlantic Meridional Mode (AMM) (Kossin and Vimont 2007) from 1979–2022. The AMM has been shown to impact Atlantic hurricane activity through alterations in the position and intensity of the Atlantic Inter-Tropical Convergence Zone (ITCZ). Changes in the Atlantic ITCZ bring about changes in tropical Atlantic vertical and horizontal wind shear patterns and in tropical Atlantic SST patterns.

Predictor 2. January–March 200 hPa U in the subtropical North Atlantic (+)

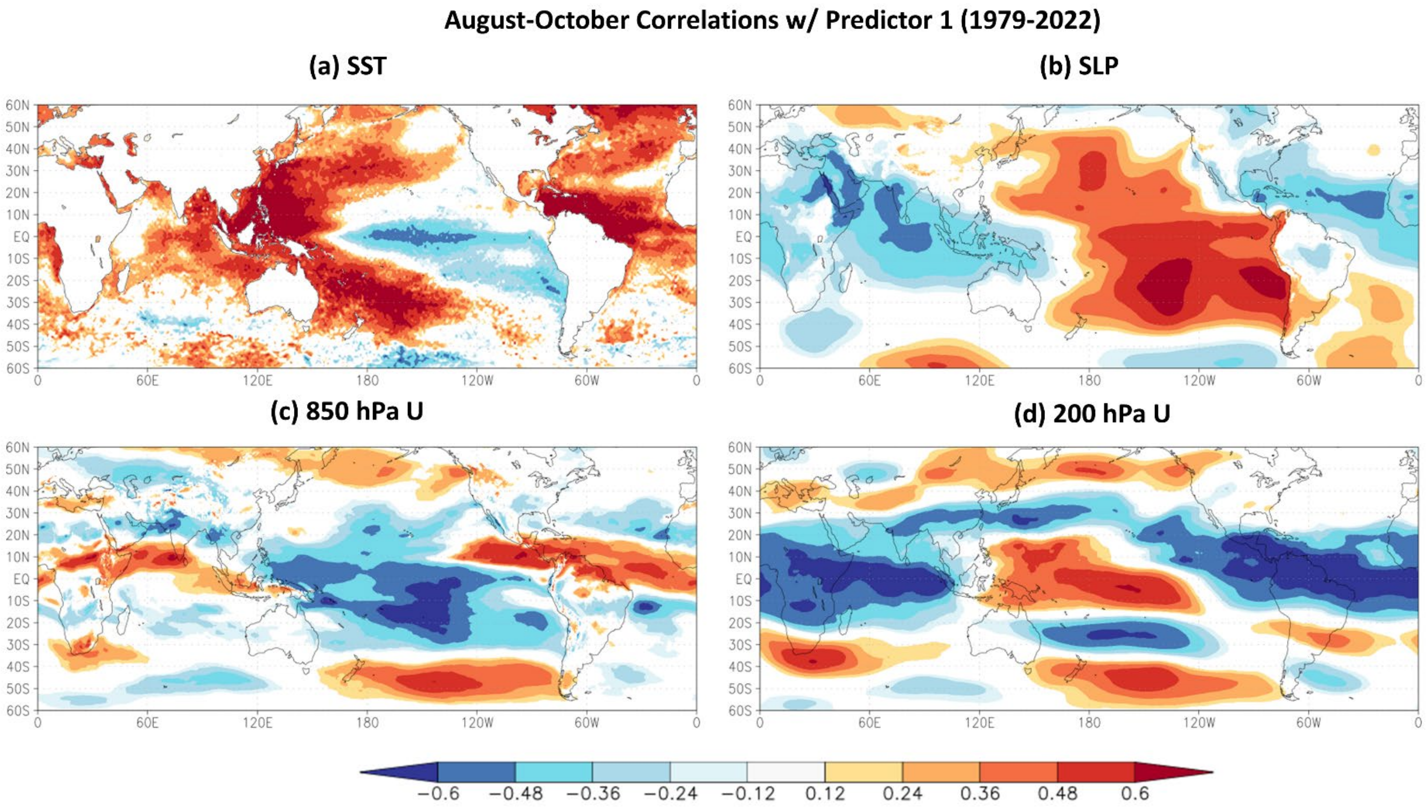
(17.5°N–27.5°N, 60°W–20°W)

Anomalously strong winds at upper-levels in the subtropical North Atlantic are associated with anomalously low pressure in the tropical and subtropical Atlantic during January–March. Stronger-than-normal westerly winds at upper levels in the subtropics are also associated with reduced anticyclonic wavebreaking (and associated reduced vertical wind shear) during the peak of the Atlantic hurricane season (Jones et al. 2023). As has been shown in prior work (Knaff 1997), when the Azores High is weaker than normal, Atlantic trade winds are also weaker than normal. These weaker trades inhibit ocean mixing and upwelling, thereby causing anomalous warming of tropical Atlantic SSTs. These warmer SSTs are then associated with lower-than-normal sea level pressures which can create a self-enhancing feedback that relates to lower pressure, weaker trades and warmer SSTs during the hurricane season (Figure 5) (Knaff 1998). All three of these factors are associated with active hurricane seasons. This predictor is also negatively correlated with tropical central Pacific SSTs during August–October, indicating that La Niña-like conditions are favored during the boreal summer when anomalously strong upper-level winds predominate over the Atlantic during January–March.

Predictor 3. February–March SST in the western tropical/subtropical Pacific (+)

(30°S–15°N, 140°E–170°E)

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



August-October Correlations w/ Predictor 1 (1979-2022)

(a) SST

(b) SLP

(c) 850 hPa U

(d) 200 hPa U

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

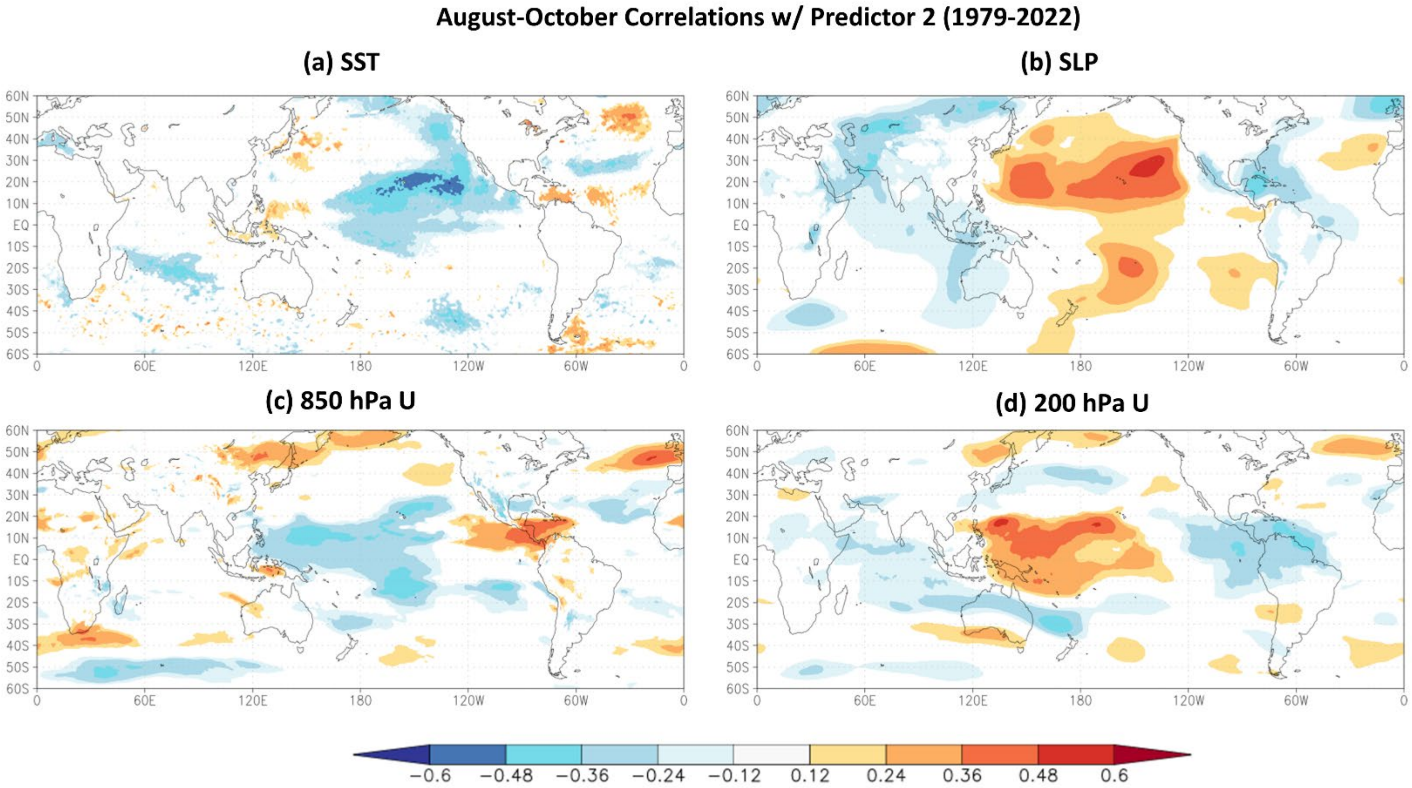


Figure 5: As in Figure 4 but for January–March 200 hPa zonal wind in the subtropical North Atlantic.

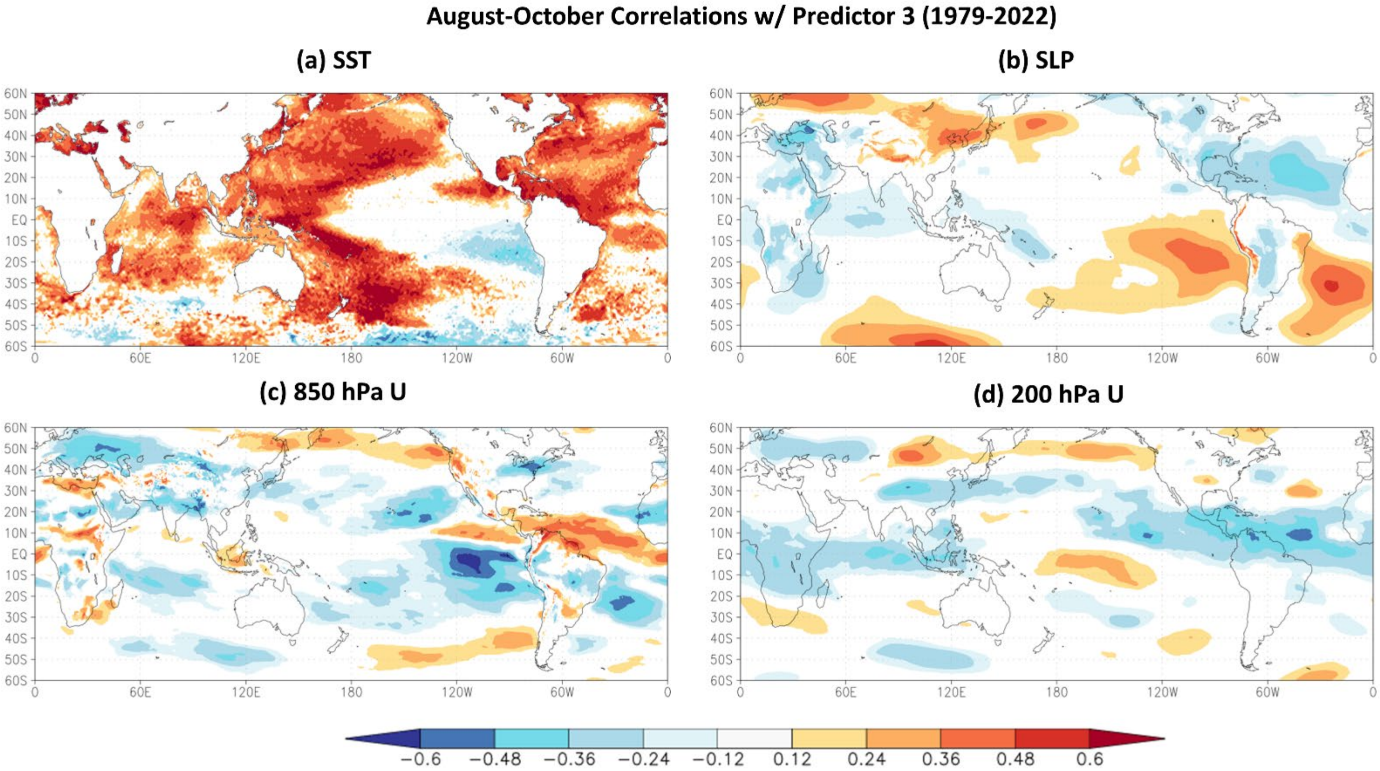


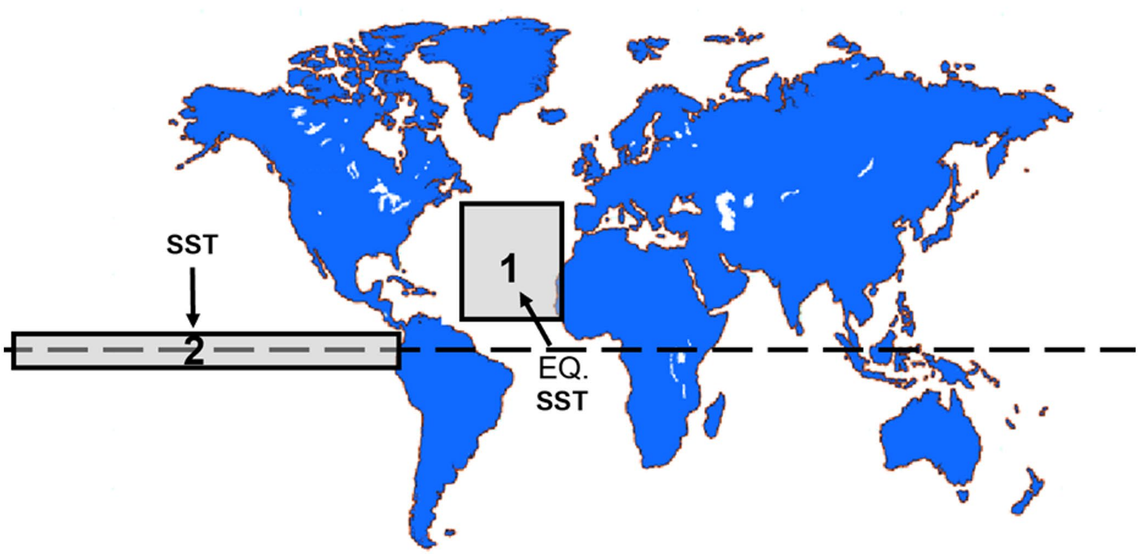
Figure 6: As in Figure 4 but for February–March SST in the western tropical/subtropical Pacific.

2.2 April Statistical/Dynamical Forecast Schemes

We developed a statistical/dynamical hybrid forecast model scheme that we used for the first time in 2019. This model, developed in partnership with Louis-Philippe Caron and the data team at the Barcelona Supercomputing Centre, originally used output from the ECMWF SEAS5 model to forecast the input to our early August statistical forecast model. We have modified our statistical/dynamical model this year and now use four different models, ECMWF, UK Met, JMA and CMCC, to forecast August SSTs (or August-September SSTs for the ECMWF) in the eastern/central equatorial Pacific and in the eastern/central North Atlantic. We then use the forecasts of these individual parameters to forecast ACE for the 2023 season. All other predictands (e.g., named storms, major hurricanes) are calculated based on their historical relationships with ACE. ECMWF climate model output data are now available on the 6th of the month, while all other climate model data are available on the 10th of the month. These model forecasts extend out six months, which is why we examine ECMWF data for August-September while all other models only examine August data. Given the time that it takes to process and run the models, the results displayed here are from the ECMWF model output from a 1 April forecast and are from a 1 March forecast for all other models.

a) ECMWF Statistical/Dynamical Model Forecast

Figure 7 displays the locations of the two forecast parameters, while Table 4 displays ECMWF's forecasts of these parameters for 2023 from a 1 April initialization date. The ECMWF model is predicting the warmest eastern/central North Atlantic on record (since 1981) and also the warmest equatorial eastern/central tropical Pacific on record. Despite the model's forecast for an extremely strong El Niño, the extreme warmth that is predicted for the eastern/central North Atlantic result in a slightly above-average forecast from this model. Figure 8 displays cross-validated hindcasts for ECMWF forecasts of ACE from 1981–2022, while Table 5 presents the forecast from ECMWF for the 2023 Atlantic hurricane season.



Statistical/Dynamical Model Forecast

Figure 7: Location of predictors for our early April statistical/dynamical extended-range statistical prediction for the 2023 hurricane season. This forecast uses dynamical model predictions from ECMWF, the UK Met Office, JMA and CMCC to predict August (or August-September for ECMWF) conditions in the two boxes displayed and uses those predictors to forecast ACE.

Table 4: Listing of predictions of August–September large-scale conditions from ECMWF model output, initialized on 1 April. 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 2023 Forecast	Effect on 2023 Hurricane Season
1) ECMWF Prediction of Aug-Sep SST (10–45°N, 60–20°W) (+)	+3.2 SD	Enhance
2) ECMWF Prediction of Aug-Sep SST (5°S–5°N, 180–90°W) (-)	+2.4 SD	Suppress

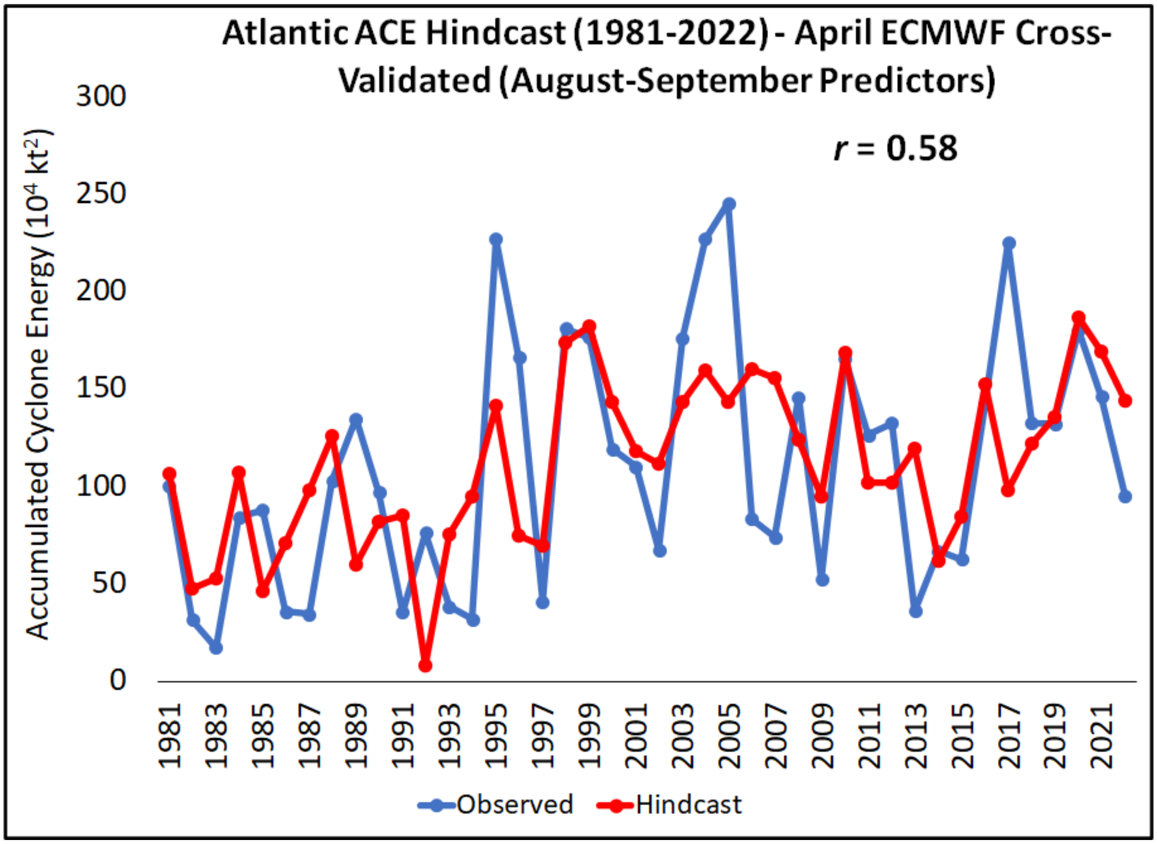


Figure 8: Observed versus cross-validated statistical/dynamical hindcast values of ACE for 1981–2022 from ECMWF.

Table 5: Statistical/dynamical model output from ECMWF for the 2023 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)	15.4	13
Named Storm Days (69.4)	76.3	55
Hurricanes (7.2)	7.9	6
Hurricane Days (27.0)	30.7	25
Major Hurricanes (3.2)	3.6	2
Major Hurricane Days (7.4)	8.7	5
Accumulated Cyclone Energy Index (123)	139	100
Net Tropical Cyclone Activity (135%)	151	105

b) UK Met Office Statistical/Dynamical Model Forecast

Table 6 displays the UK Met Office forecasts of the August parameters for 2023 from a 1 March initialization date. Similar to ECMWF, the UK Met Office is calling for a robust El Niño but also a warm central/eastern North Atlantic. Figure 9 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 2023 Atlantic hurricane season. We note that the UK Met Office, JMA and CPCC have shorter hindcasts available on the Copernicus website (the website where we download our climate model forecasts). The UK Met Office statistical/dynamical model is calling for a less active season than ECMWF, due to a slightly cooler eastern/central North Atlantic and different weighing of the ENSO and Atlantic predictors.

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

Predictor	Values for 2023 Forecast	Effect on 2023 Hurricane Season
1) UK Met Prediction of August SST (10–45°N, 60–20°W) (+)	+2.2 SD	Enhance
2) UK Met Prediction of August SST (5°S–5°N, 180–90°W) (-)	+1.8 SD	Suppress

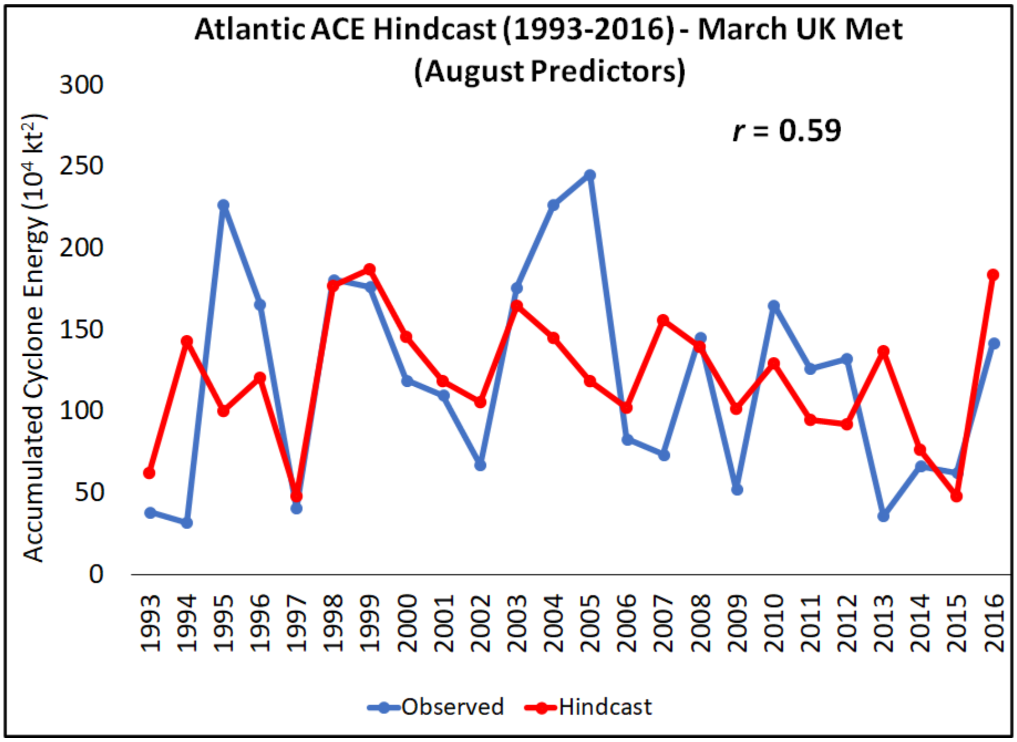


Figure 9: Observed versus statistical/dynamical hindcast values of ACE for 1993–2016 from the UK Met Office.

Table 7: Statistical/dynamical model output from the UK Met Office for the 2023 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)	13.0	13
Named Storm Days (69.4)	59.5	55
Hurricanes (7.2)	6.1	6
Hurricane Days (27.0)	21.6	25
Major Hurricanes (3.2)	2.6	2
Major Hurricane Days (7.4)	5.4	5
Accumulated Cyclone Energy Index (123)	99	100
Net Tropical Cyclone Activity (135%)	111	105

c) JMA Met Office Statistical/Dynamical Model Forecast

Table 8 displays the JMA forecasts of the August parameters for 2023 from a 1 March initialization date. JMA is also calling for a robust El Niño and a warm central/eastern North Atlantic. Figure 10 displays hindcasts for the JMA of ACE from 1993–2020, while Table 9 presents the forecast from the JMA for the 2023 Atlantic hurricane season. The statistical/dynamical model based off of JMA is calling for a near-average 2023 Atlantic hurricane season.

Table 8: Listing of predictions of August large-scale conditions from JMA model output, initialized on 1 March. A plus (+) means that positive deviations of the parameter are associated with increased hurricane activity, while a minus (-) means that negative deviations of the parameter are associated with increased hurricane activity.

Predictor	Values for 2023 Forecast	Effect on 2023 Hurricane Season
1) JMA Prediction of August SST (10–45°N, 60–20°W) (+)	+1.9 SD	Enhance
2) JMA Prediction of August SST (5°S–5°N, 180–90°W) (-)	+1.6 SD	Suppress

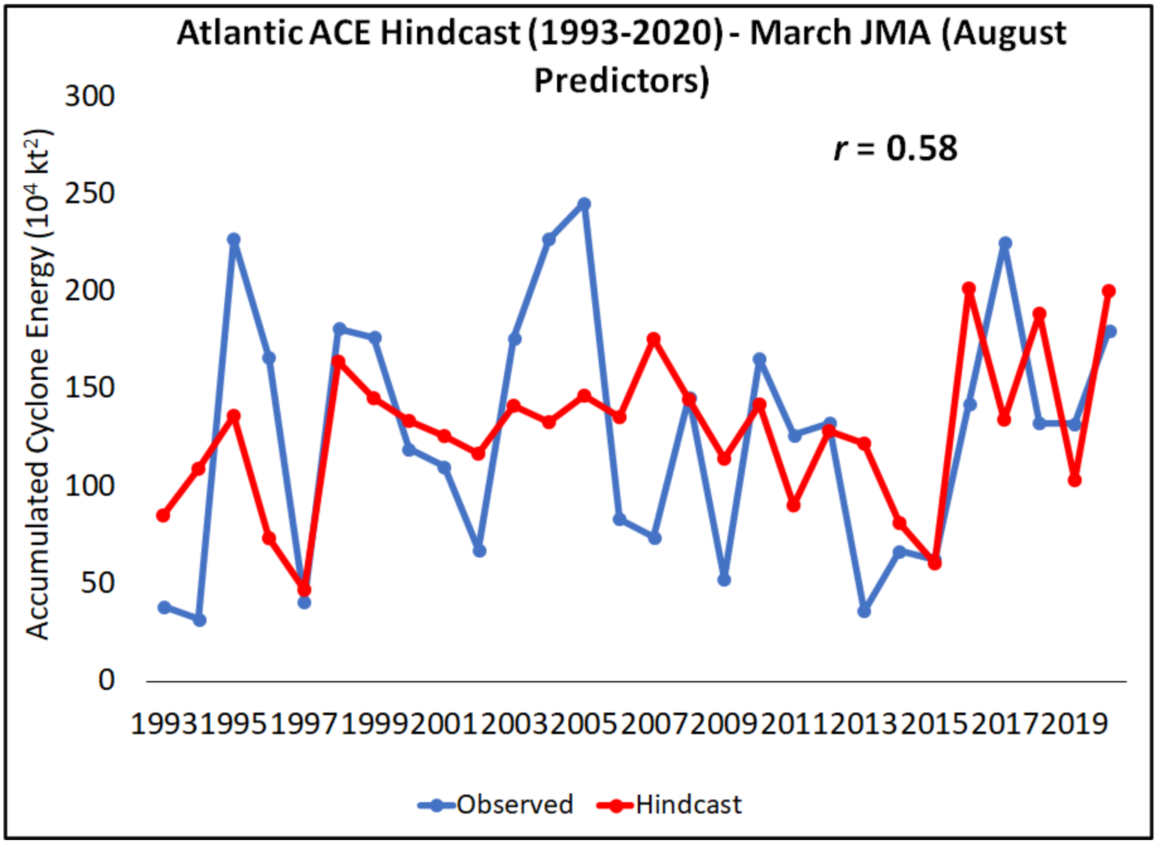


Figure 10: Observed versus statistical/dynamical hindcast values of ACE for 1993–2020 from the JMA.

Table 9: Statistical/dynamical model output from the JMA for the 2023 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)	14.6	13
Named Storm Days (69.4)	70.8	55
Hurricanes (7.2)	7.3	6
Hurricane Days (27.0)	27.8	25
Major Hurricanes (3.2)	3.3	2
Major Hurricane Days (7.4)	7.6	5
Accumulated Cyclone Energy Index (123)	126	100
Net Tropical Cyclone Activity (135%)	138	105

d) CMCC Statistical/Dynamical Model Forecast

Table 10 displays the CMCC forecasts of the August parameters for 2023 from a 1 March initialization date. CMCC is also calling for a robust El Niño and a warm central/eastern North Atlantic. Figure 11 displays hindcasts for the CMCC of ACE from 1993–2016, while Table 11 presents the forecast from the CMCC for the 2023 Atlantic hurricane season. The statistical/dynamical model based off of CMCC is calling for a near-average 2023 Atlantic hurricane season.

Table 10: Listing of predictions of August large-scale conditions from CMCC model output, initialized on 1 March. A plus (+) means that positive deviations of the parameter are associated with increased hurricane activity, while a minus (-) means that negative deviations of the parameter are associated with increased hurricane activity.

Predictor	Values for 2023 Forecast	Effect on 2023 Hurricane Season
1) CMCC Prediction of August SST (10–45°N, 60–20°W) (+)	+1.5 SD	Enhance
2) CMCC Prediction of August SST (5°S–5°N, 180–90°W) (-)	+1.5 SD	Suppress

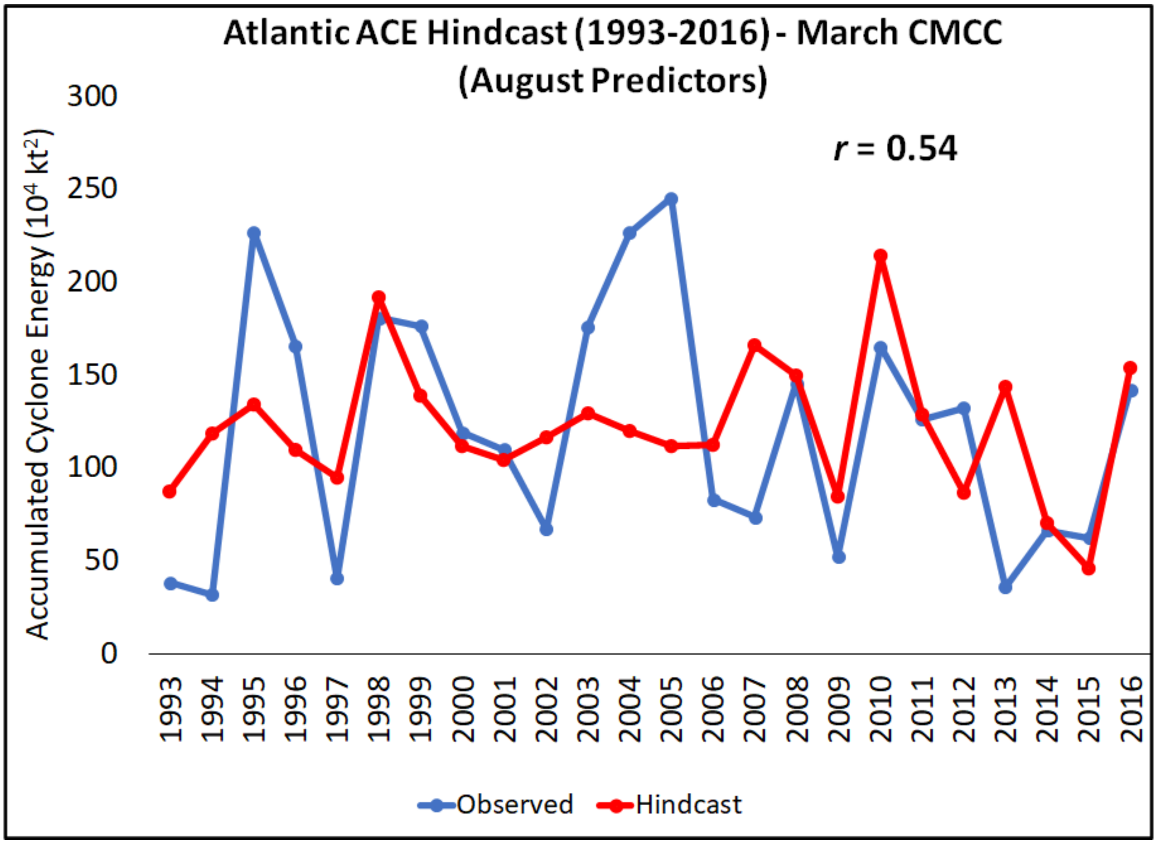


Figure 11: Observed versus statistical/dynamical hindcast values of ACE for 1993–2016 from the CMCC.

Table 11: Statistical/dynamical model output from the CMCC for the 2023 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1991–2020 Average (in parentheses)	CMCC Hybrid Forecast	Final Forecast
Named Storms (14.4)	14.1	13
Named Storm Days (69.4)	67.0	55
Hurricanes (7.2)	6.9	6
Hurricane Days (27.0)	25.7	25
Major Hurricanes (3.2)	3.1	2
Major Hurricane Days (7.4)	6.9	5
Accumulated Cyclone Energy Index (123)	117	100
Net Tropical Cyclone Activity (135%)	129	105

2.3 April Analog Forecast Scheme

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2023. These years also provide useful clues as to likely levels of activity that the forthcoming 2023 hurricane season may bring. For this early April extended range forecast, we determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current March 2023 conditions and, more importantly, projected August–October 2023 conditions. Table 12 lists our analog selections, while Figure 12 shows the composite August–October SST in our seven analog years.

We searched for years that were generally characterized by neutral or La Niña conditions the previous winter and had warm neutral to robust El Niño conditions during the peak of the Atlantic hurricane season (August–October). We also selected years that had near- to above-average SSTs in the tropical Atlantic. We anticipate that the 2023 hurricane season will have activity near the average of our eight analog years.

Table 12: Analog years for 2023 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1969	18	92.25	12	40.25	5	6.50	165.7	181.7
2002	12	57.00	4	10.75	2	3.00	67.4	83.3
2004	15	93.00	9	45.50	6	22.25	226.9	231.6
2006	10	58.00	5	21.25	2	2.00	83.3	86.8
2009	9	30.00	3	12.00	2	3.50	52.6	68.6
2012	19	101.25	10	28.50	2	0.50	132.6	131.2
2014	8	35.00	6	17.75	2	3.75	66.7	81.8
2015	11	43.50	4	12.00	2	4.00	62.7	81.2
Average	12.8	64.4	6.6	22.4	2.6	5.3	105	115
2023 Forecast	**13**	**55**	**6**	**25**	**2**	**5**	**100**	**105**

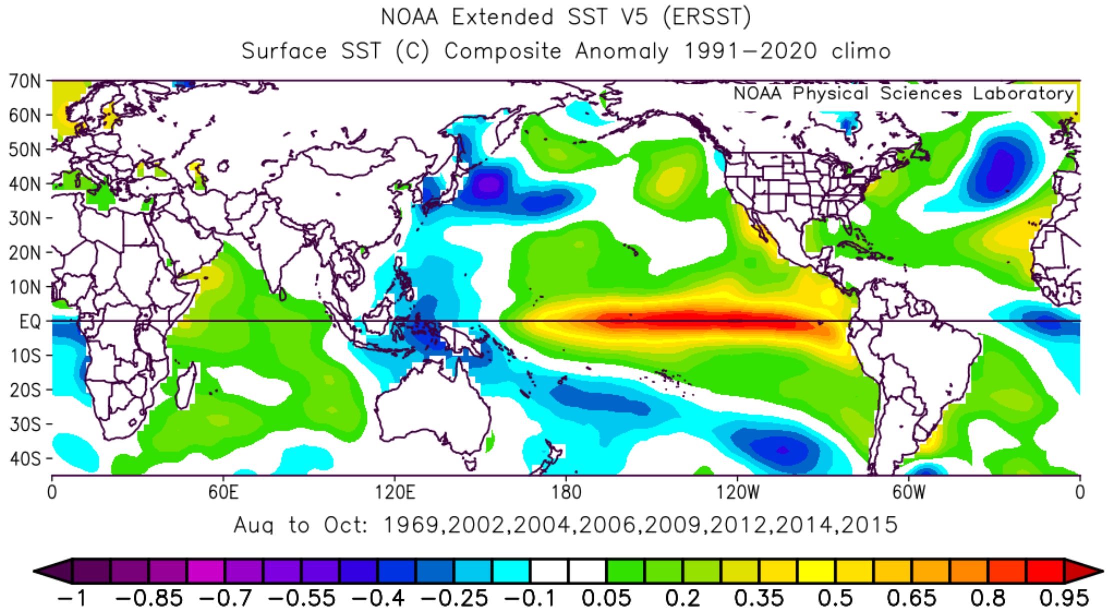


Figure 12: Average August–October SST anomalies in our eight analog years.

2.4 ACE West of 60°W Forecast

For the first time ever, we are explicitly forecasting ACE occurring west of 60°W. While there is a relatively robust relationship between basinwide ACE and North Atlantic landfalling hurricanes (defined as hurricanes making landfall west of 60°W), there is an improved relationship between North Atlantic landfalling hurricanes and ACE west of 60°W (Figures 13 and 14) since 1950.

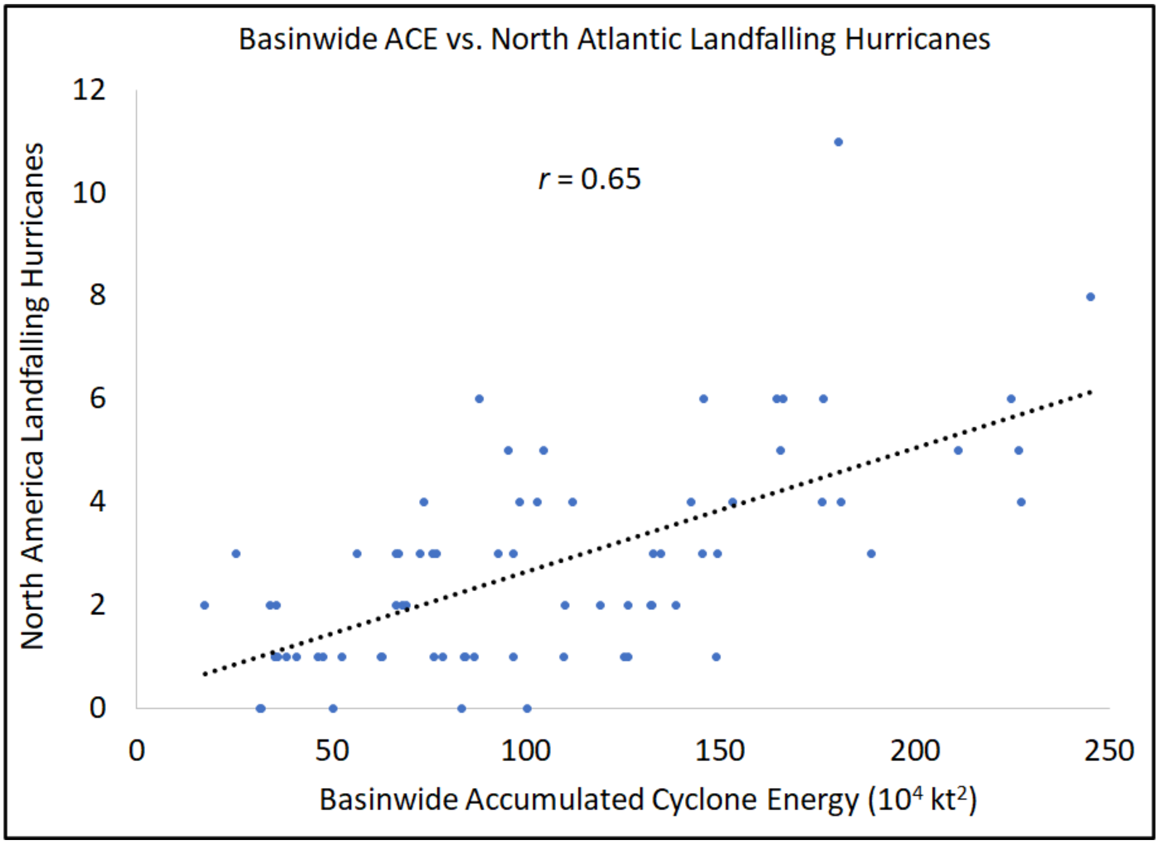


Figure 13: Scatterplot showing relationship between basinwide ACE and North Atlantic landfalling hurricanes.

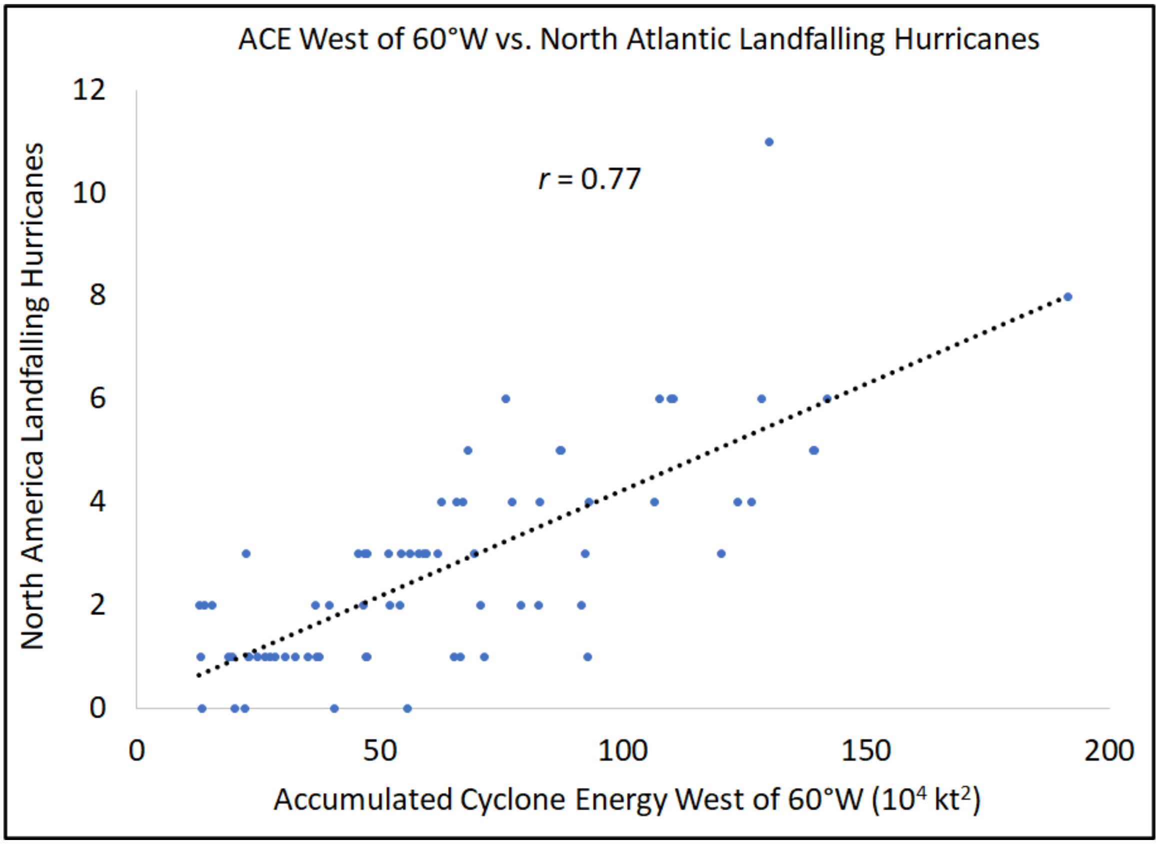


Figure 14: Scatterplot showing relationship between ACE west of 60°W and North Atlantic landfalling hurricanes.

In general, years characterized by El Niño conditions tend to have slightly less ACE west of 60°W than La Niña seasons, likely due to both more conducive conditions in the western Atlantic in La Niña seasons, as well as an increased chance of recurvature for TCs in El Niño seasons (Colbert and Soden 2012). We use data from 1979–2022 and base ENSO classifications on the August–October-averaged Oceanic Nino Index (ONI). Years with an ONI >= 0.5°C are classified as El Niño, years with an ONI <= -0.5°C are classified as La Niña, while all other seasons are classified as neutral ENSO.

We find that 52% of basinwide ACE occurs west of 60°W in El Niño years, while 60% of basinwide ACE occurs west of 60°W in La Niña years. In neutral ENSO years, 59% of basinwide ACE occurs west of 60°W. Given that we are favoring El Niño with this outlook, we are estimating ~55% of basinwide ACE to occur west of 60°W in 2023. More research on additional impact-relevant metrics will be forthcoming in future forecasts.

2.5 April Forecast Summary and Final Adjusted Forecast

Table 13 shows our final adjusted early April forecast for the 2023 season which is a combination of our statistical scheme, our statistical/dynamical schemes, our analog scheme and qualitative adjustments for other factors not explicitly contained in any of these schemes. The various forecast models range from a slightly below-average season to a well above-average season. Our final forecast favors the lower guidance due to an anticipated transition to El Niño for the peak of the 2023 Atlantic hurricane season. As noted earlier, there is larger-than-normal uncertainty associated with this forecast.

Table 13: Summary of our early April statistical forecast, our statistical/dynamical forecasts, our analog forecast, the average of these six schemes and our adjusted final forecast for the 2023 hurricane season.

Forecast Parameter and 1991–2020 Average (in parentheses)	Statistical Scheme	ECMWF Scheme	Met Office Scheme	JMA Scheme	CMCC Scheme	Analog Scheme	6-Scheme Average	Adjusted Final Forecast
Named Storms (14.4)	17.9	15.4	13.0	14.6	14.1	12.8	14.6	13
Named Storm Days (69.4)	93.5	76.3	59.5	70.8	67.0	64.4	71.9	55
Hurricanes (7.2)	9.7	7.9	6.1	7.3	6.9	6.6	7.4	6
Hurricane Days (27.0)	40.1	30.7	21.6	27.8	25.7	22.4	28.1	25
Major Hurricanes (3.2)	4.7	3.6	2.6	3.3	3.1	2.6	3.3	2
Major Hurricane Days (7.4)	12.1	8.7	5.4	7.6	6.9	5.3	7.7	5
Accumulated Cyclone Energy Index (123)	180	139	99	126	117	105	128	100
Net Tropical Cyclone Activity (135%)	192	151	111	138	129	115	139	105

3 Forecast Uncertainty

This season we continue to use probability of exceedance curves as discussed in Saunders et al. (2020) to 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 15 and 16), 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 14 displays one standard deviation uncertainty ranges (~68% of all forecasts within this range). This uncertainty estimate is also very similar to the 70% uncertainty range that NOAA provides with its forecasts. We use Poisson distributions for all storm parameters (e.g., named storms, hurricanes and major hurricanes) while we use a Weibull distribution for all integrated parameters except for major hurricane days (e.g., named storm days, ACE, etc.). We use a Laplace distribution for major hurricane days. As noted earlier, uncertainty is higher than normal with this year's seasonal hurricane forecast.

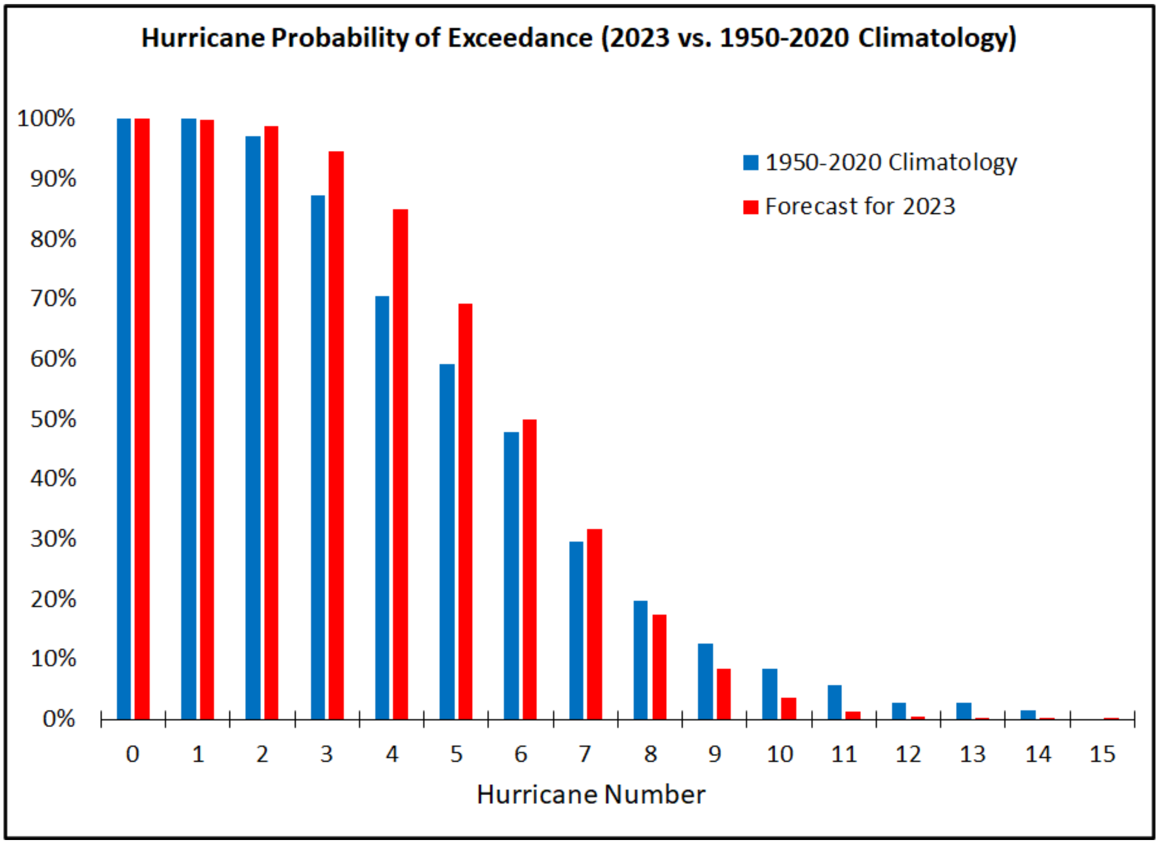


Figure 15: Probability of exceedance plot for hurricane numbers for the 2023 Atlantic hurricane season. The values on the x-axis indicate that the number of hurricanes exceeds that specific number. For example, 97% of Atlantic hurricane seasons from 1950–2020 have had more than two hurricanes.

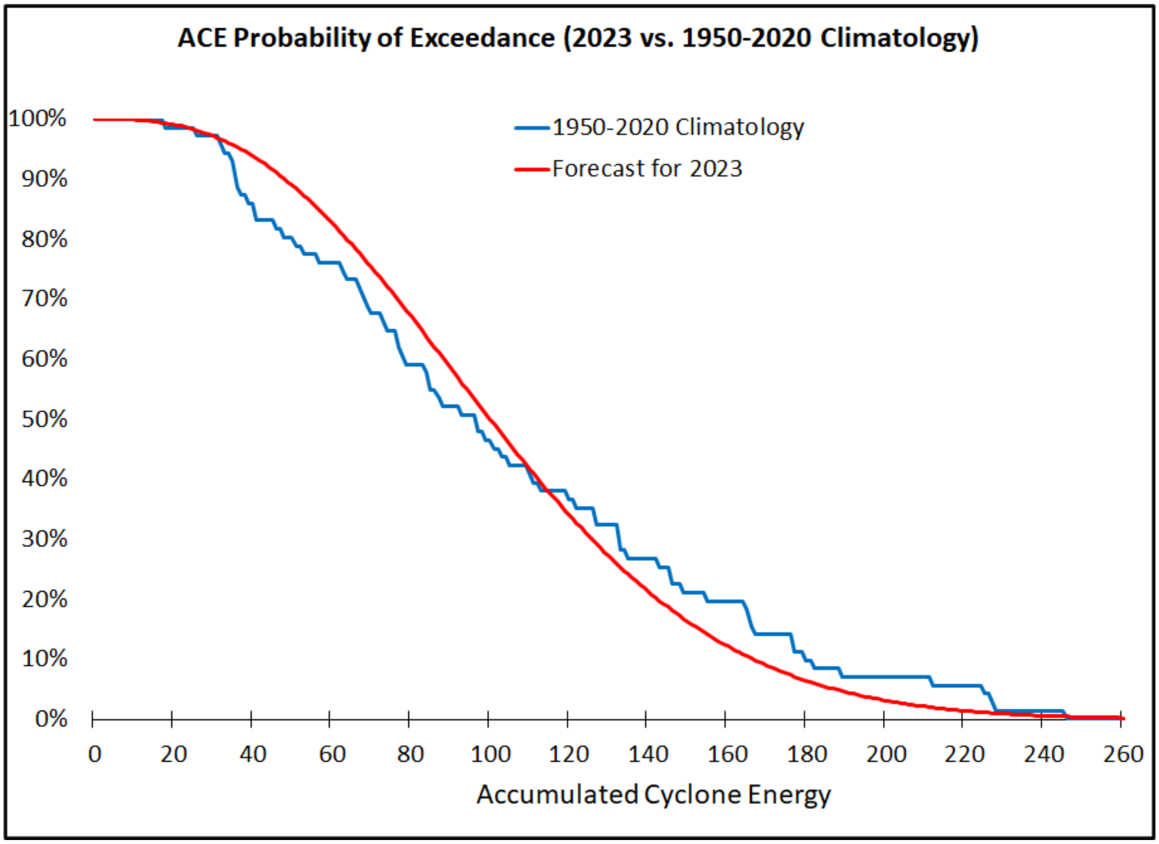


Figure 16: As in Figure 15 but for ACE.

Table 14: 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	2023 Forecast	Uncertainty Range (68% of Forecasts Likely to Fall in This Range)
Named Storms (NS)	13	10 – 16
Named Storm Days (NSD)	55	35 – 78
Hurricanes (H)	6	4 – 8
Hurricane Days (HD)	25	14 – 39
Major Hurricanes (MH)	2	1 – 4
Major Hurricane Days (MHD)	5	1 – 8
Accumulated Cyclone Energy (ACE)	100	57 – 153
ACE West of 60°W	55	28 – 91
Net Tropical Cyclone (NTC) Activity	105	62 – 156

4 ENSO

Over the past several months, the tropical Pacific has transitioned from La Niña to ENSO neutral conditions (Figure 17). 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. Neutral ENSO events are typically defined to be when SST anomalies are between -0.5°C – +0.5°C in the Nino 3.4 region. Over the past couple of months, SST anomalies have increased across the entire tropical Pacific, with strongest anomalous warming taking place in the far eastern tropical Pacific.

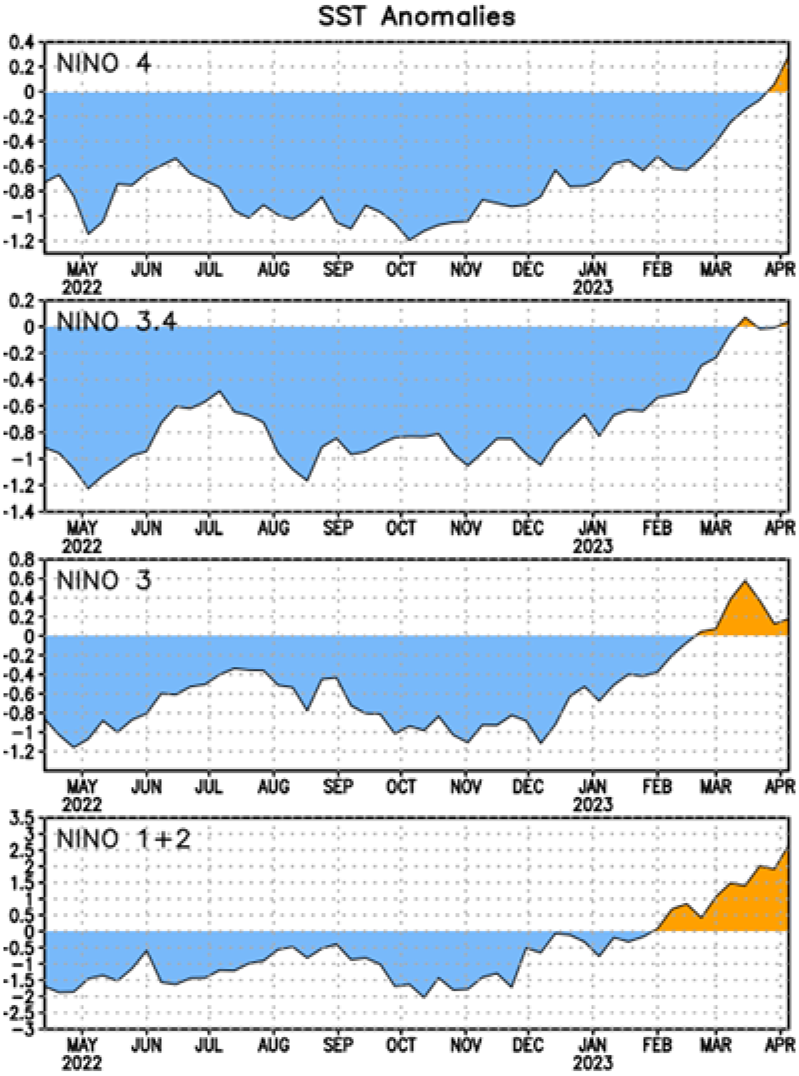


Figure 17: SST anomalies for several ENSO regions over the past year. Figure courtesy of Climate Prediction Center.

Upper-ocean heat content anomalies in the eastern and central tropical Pacific have increased rapidly over the past several weeks (Figure 18). Anomalously strong trade winds that have generally persisted across the eastern and central tropical Pacific for the past couple of years have weakened, allowing for several periods of anomalous westerly winds and associated downwelling oceanic Kelvin waves. These downwelling oceanic Kelvin waves cause anomalous warming in the eastern and central tropical Pacific.

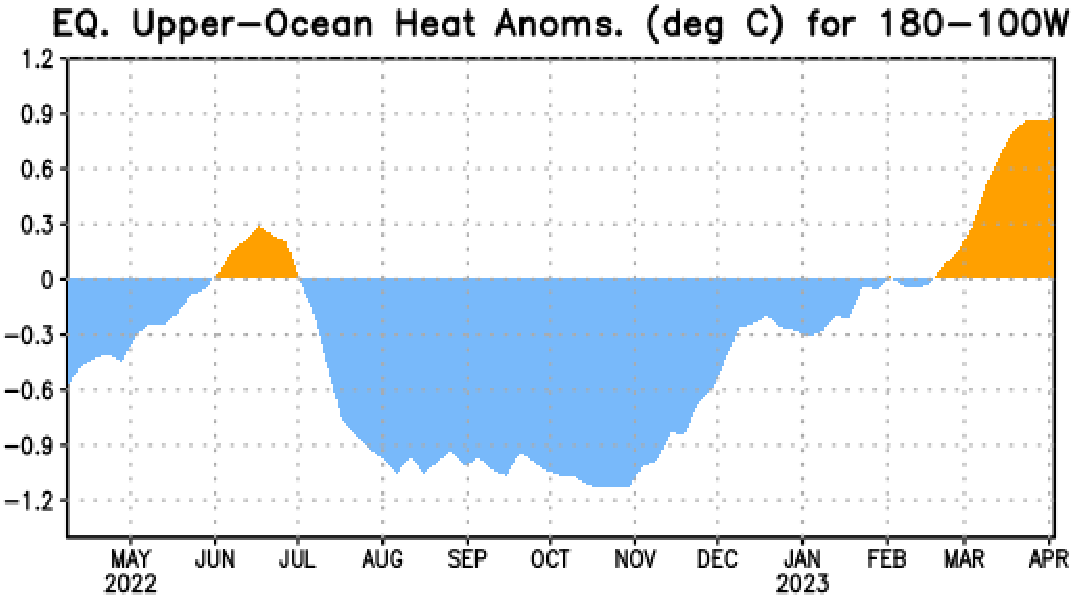


Figure 18: Central and eastern equatorial Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Figure courtesy of Climate Prediction Center.

SSTs are currently above-normal in the eastern equatorial Pacific, while SSTs in the central equatorial Pacific are near-normal (Figure 19). 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) are indicative of a negative phase of the Pacific Decadal Oscillation.

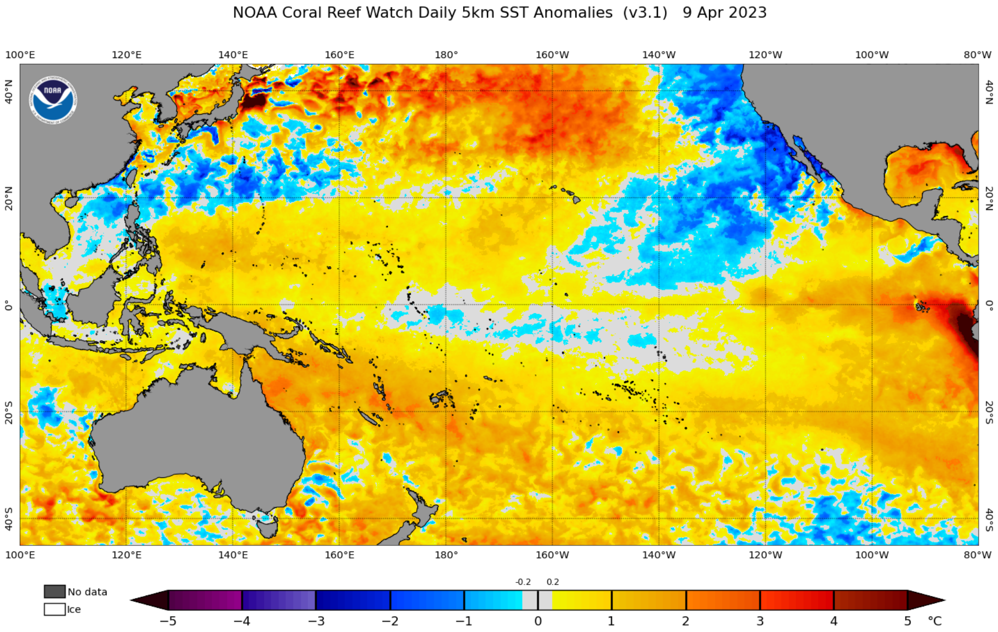


Figure 19: Current SST anomalies across the tropical and subtropical Pacific.

Table 15 displays January and March SST anomalies for several Nino regions. Over the past two months, SST anomalies across the entire eastern and central tropical Pacific have anomalously warmed.

Table 15: January and March SST anomalies for Nino 1+2, Nino 3, Nino 3.4, and Nino 4, respectively. March-January SST anomaly differences are also provided.

Region	January SST Anomaly (°C)	March SST Anomaly (°C)	March – January SST Anomaly (°C)
Nino 1+2	-0.2	+1.5	+1.7
Nino 3	-0.5	+0.4	+0.9
Nino 3.4	-0.7	0.0	+0.7
Nino 4	-0.6	-0.1	+0.5

A downwelling (warming) Kelvin wave, denoted by the long dashed line, is currently transiting eastward from the central to the eastern tropical Pacific (Figure 20). As mentioned earlier, these Kelvin waves are typically triggered by anomalous low-level winds in the tropical Pacific. This most recent downwelling Kelvin wave was likely forced by anomalous low-level westerlies that occurred during early to mid-February (Figure 21). As mentioned earlier, consistent enhanced trade winds across the central equatorial Pacific have weakened over the past few months – a hallmark of a transition from La Niña to neutral ENSO conditions.

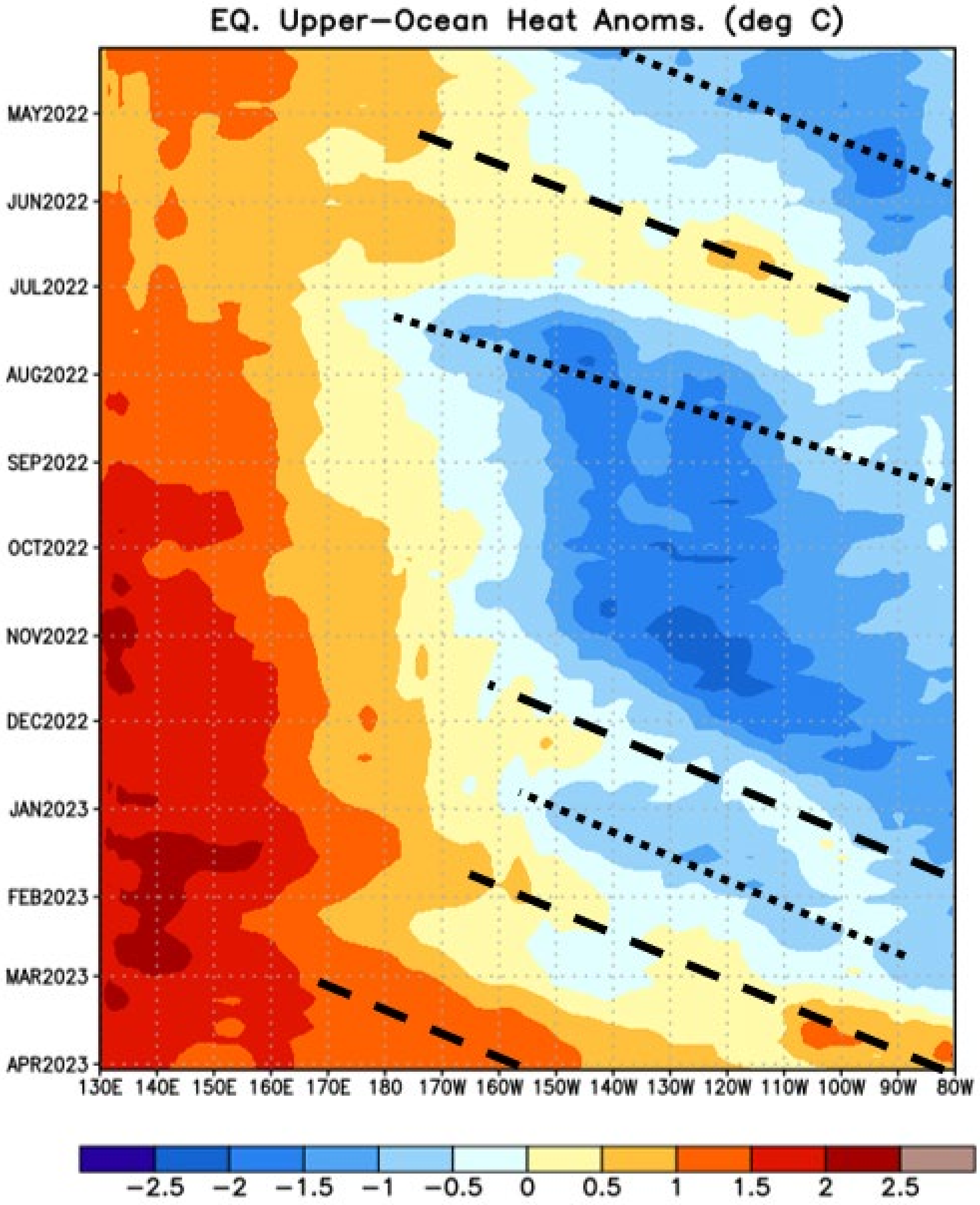


Figure 20: Upper-ocean heat content anomalies in the tropical Pacific since April 2022. Dashed lines indicate downwelling Kelvin waves, while dotted lines indicate upwelling Kelvin waves. Downwelling Kelvin waves result in upper-ocean heat content increases, while upwelling Kelvin waves result in upper-ocean heat content decreases. Figure courtesy of Climate Prediction Center.

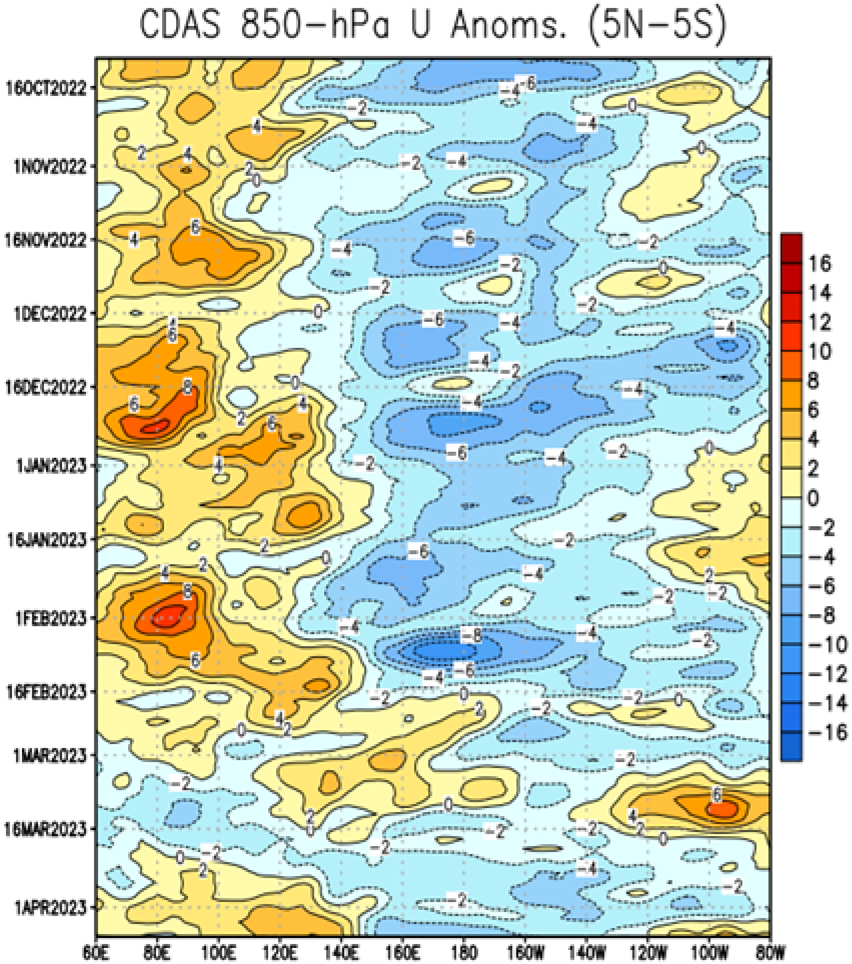


Figure 21: Anomalous equatorial low-level winds spanning from 60°E to 80°W. Figure courtesy of Climate Prediction Center.

Over the next several months, we will be closely monitoring low-level winds over the tropical Pacific. Anomalous low-level westerlies are starting to develop between 120-140°E. In addition low-level westerlies are forecast to span most of the tropical Pacific during mid-April, potentially enhancing a transition towards El Niño (Figure 22).

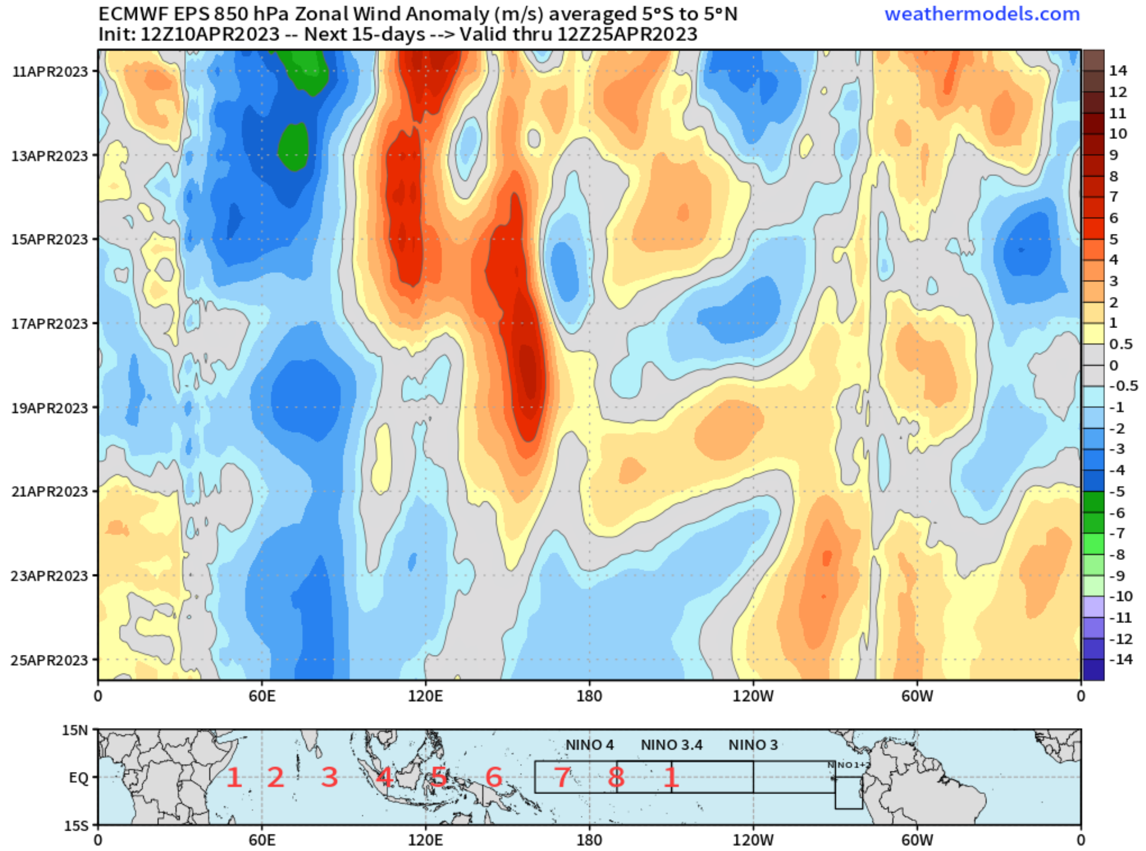


Figure 22: Forecast 850-hPa zonal equatorial winds for the next 15 days. Figure courtesy of weathermodels.com.

There is always considerable uncertainty with the future state of El Niño during the Northern Hemisphere spring. The latest plume of ENSO predictions from several statistical and dynamical models shows considerable spread by the peak of the Atlantic hurricane season in August–October (Figure 23). While there is a large spread, dynamical and statistical models both tend to favor the development of El Niño during the Atlantic hurricane season. Dynamical models are more aggressive with El Niño development than statistical models.

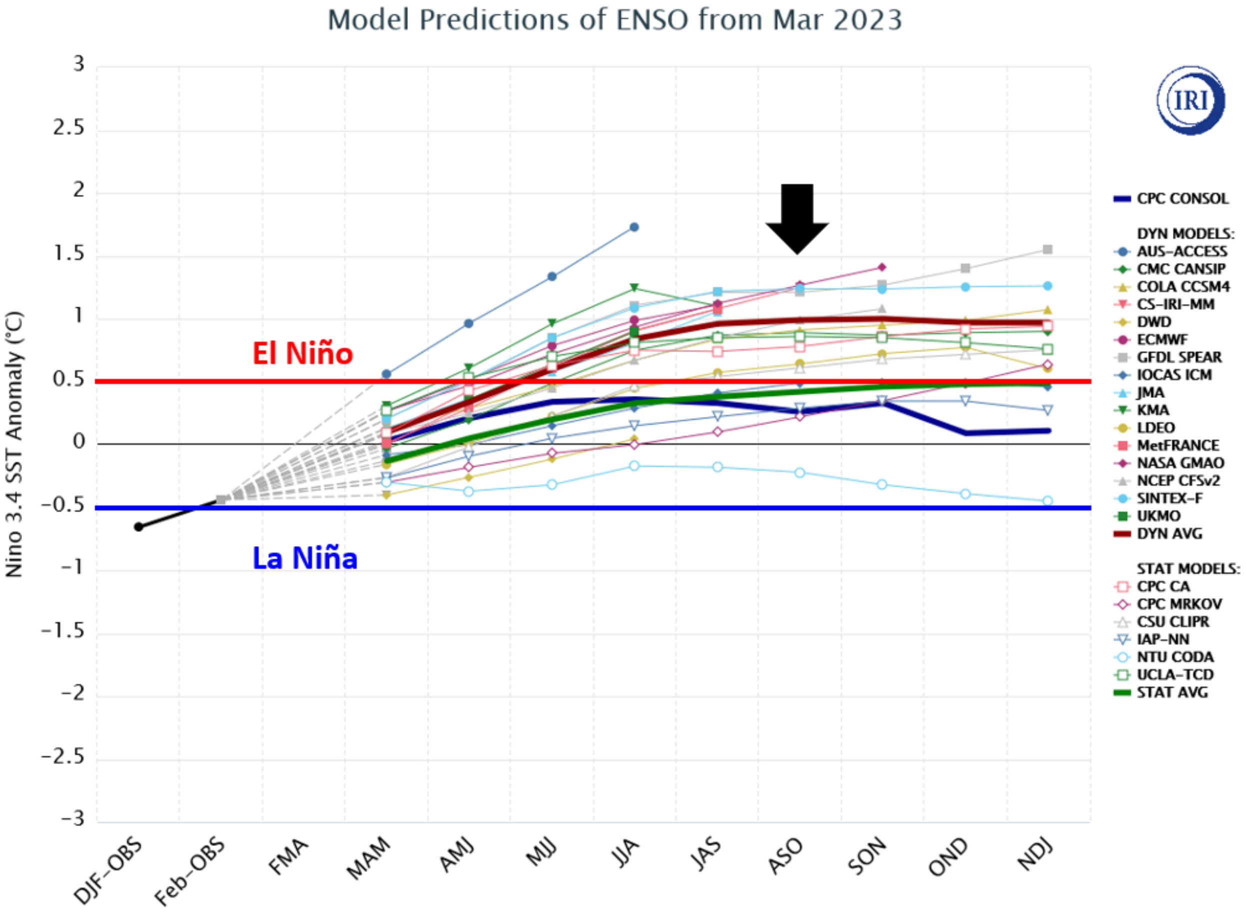


Figure 23: ENSO forecasts from various statistical and dynamical models for Nino 3.4 SST anomalies based on late February to early March initial conditions. All models call for either El Niño or ENSO neutral conditions for August–October. Figure courtesy of the International Research Institute (IRI). The black arrow delineates the peak of the Atlantic hurricane season (August–October).

The latest official forecast from NOAA also favors El Niño for August–October. NOAA is currently predicting a 61% chance of El Niño, a 35% chance of ENSO neutral conditions and a 4% chance of La Niña for the peak of the Atlantic hurricane season (Figure 24).

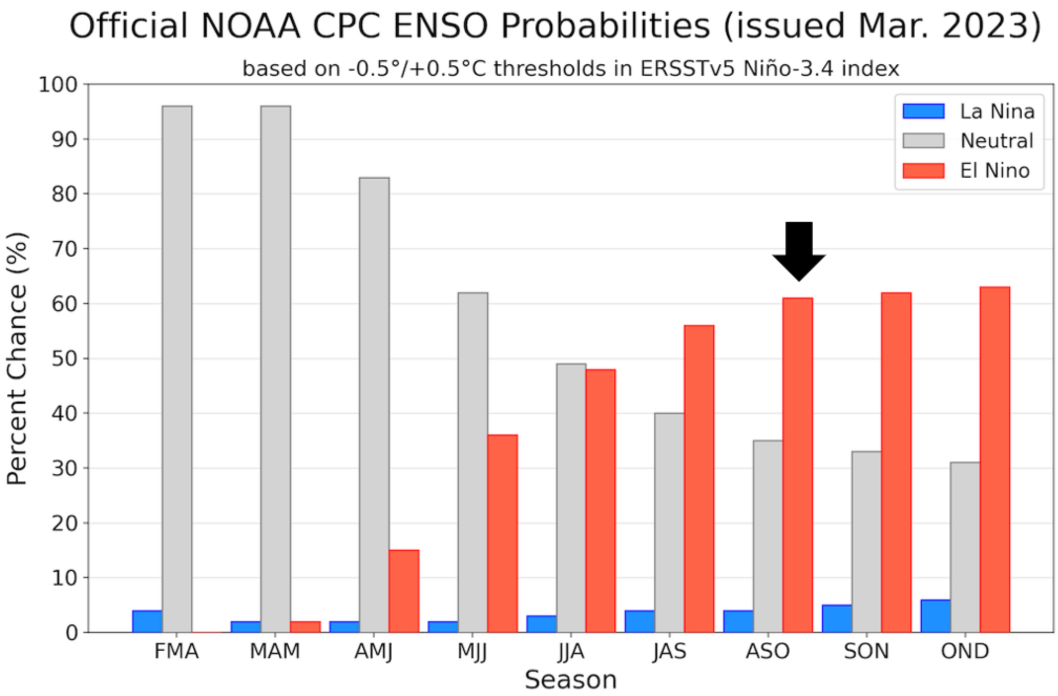


Figure 24: Official probabilistic ENSO forecast from NOAA. The black arrow delineates the peak of the Atlantic hurricane season (August–October).

Based on the above information, our best estimate is that we will have El Niño conditions for the peak of the Atlantic hurricane season. As noted earlier, there remains considerably uncertainty if we transition to El Niño, and if we do, how strong El Niño would get by the peak of the Atlantic hurricane season.

5 Current Atlantic Basin Conditions

Currently, SSTs are well above normal in the eastern tropical and subtropical Atlantic, while they are near normal in the Caribbean (Figure 25). Over the past several weeks, the North Atlantic Oscillation has generally been in its negative phase after being in its positive phase for most of January and February (Figure 26). Associated with this negative phase has been weaker-than-normal trade winds across most of the tropical and subtropical eastern Atlantic (Figure 27). These weaker trades have led to less evaporation and mixing, leading to considerable anomalous warming in the eastern part of the basin. Figure 28 shows the forecast for the next few weeks of low-level winds across the Atlantic. In general, trade winds are forecast to be weaker than average for the next few weeks, indicating potential for continued anomalies warming. Overall, the current SST anomaly pattern correlates relatively well with what is typically seen in active Atlantic hurricane seasons (Figure 29). This anomalous warmth is one of the reasons why our forecast is for just a slightly below-normal season, despite the potential for a robust El Niño.

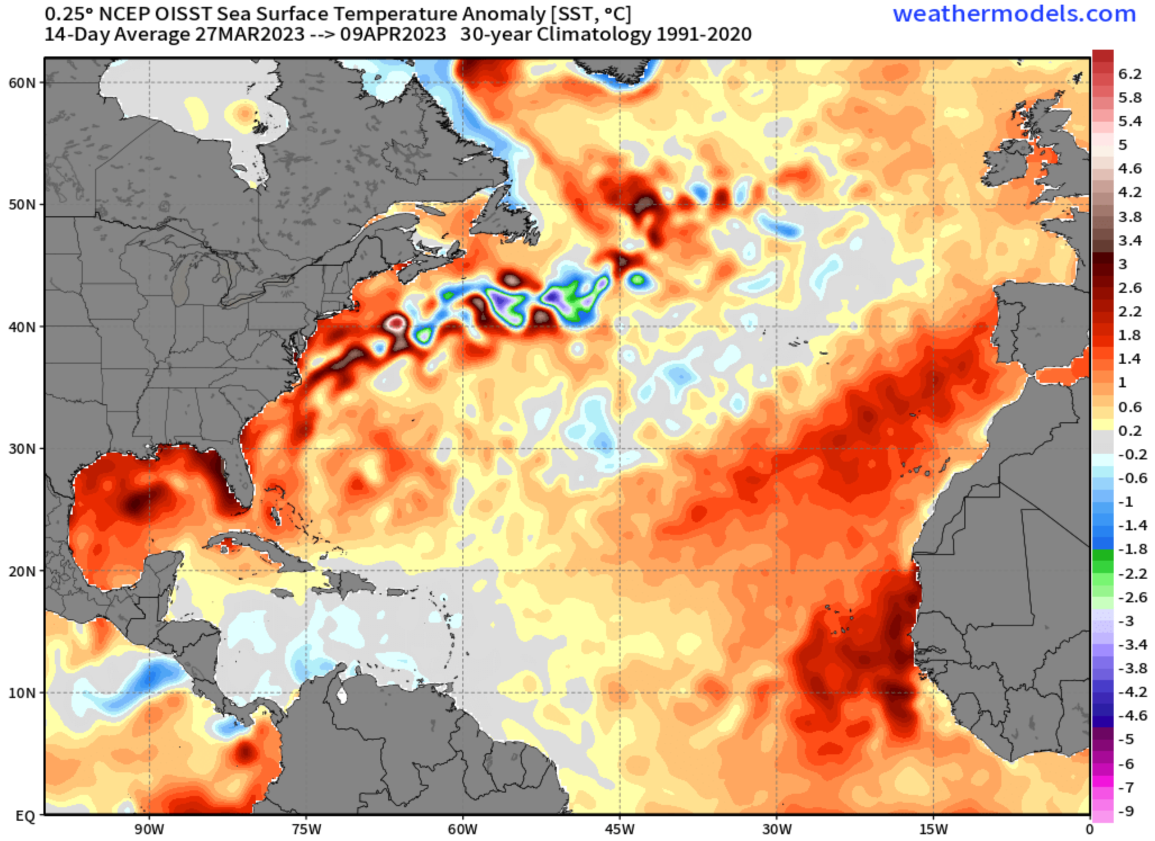


Figure 25: Late March/early April 2023 SST anomaly pattern across the Atlantic Ocean.

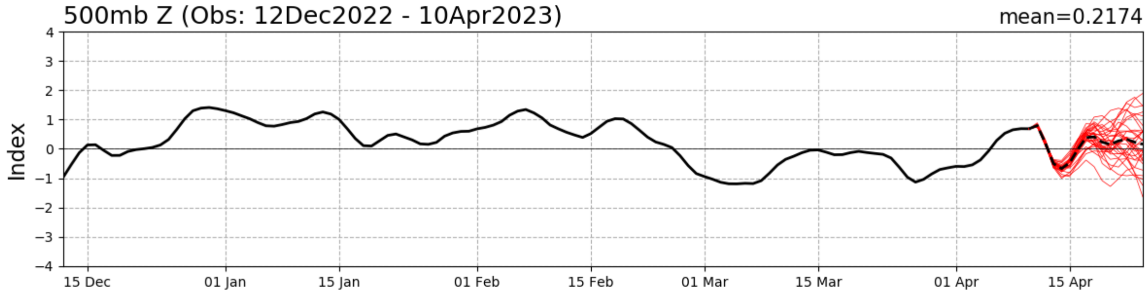


Figure 26: Observed values of the North Atlantic Oscillation since late December and forecasts of the North Atlantic Oscillation from the Global Ensemble Forecast System for the next 15 days.

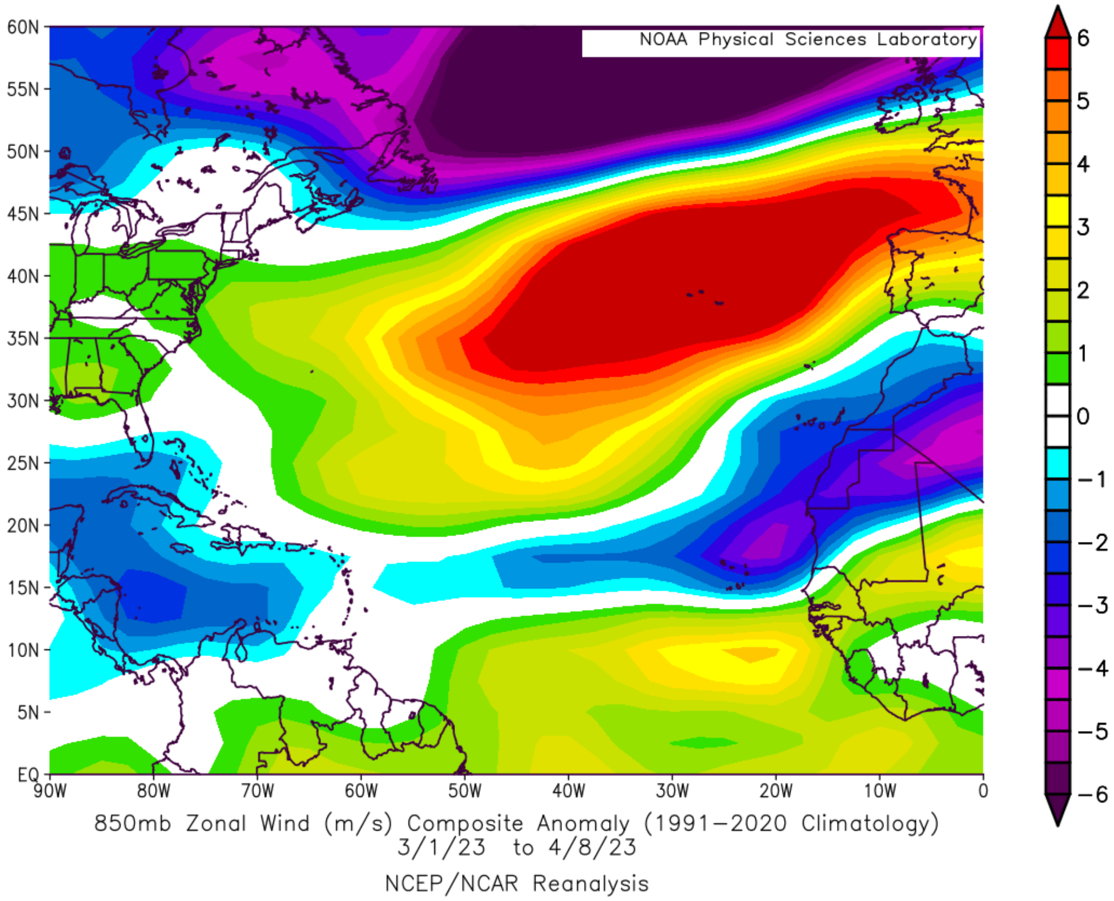


Figure 27: Zonal wind anomalies across the North Atlantic Ocean from March 1, 2023 through April 8, 2023.

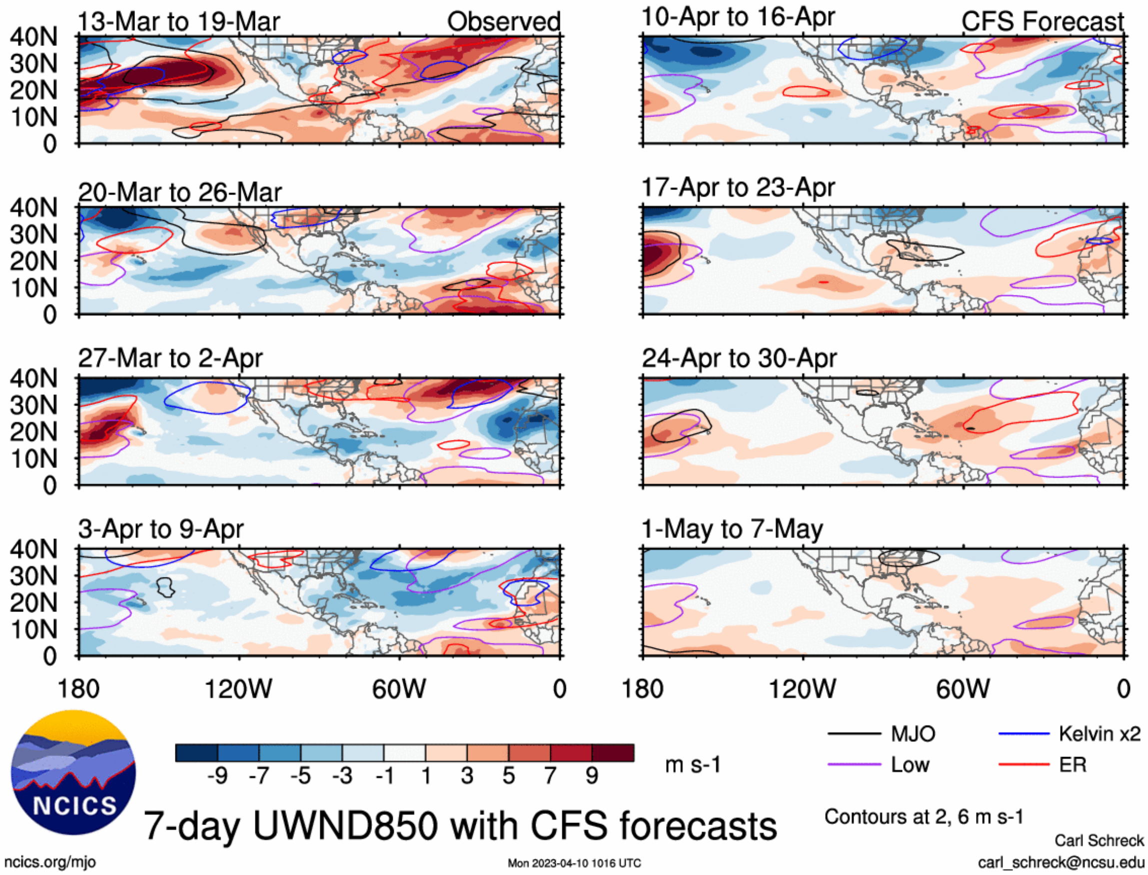


Figure 28: Observed low-level zonal winds across portions of the Western Hemisphere over the past four weeks and predicted low-level zonal winds from the Climate Forecast System for the next four weeks. Figure courtesy of Carl Schreck.

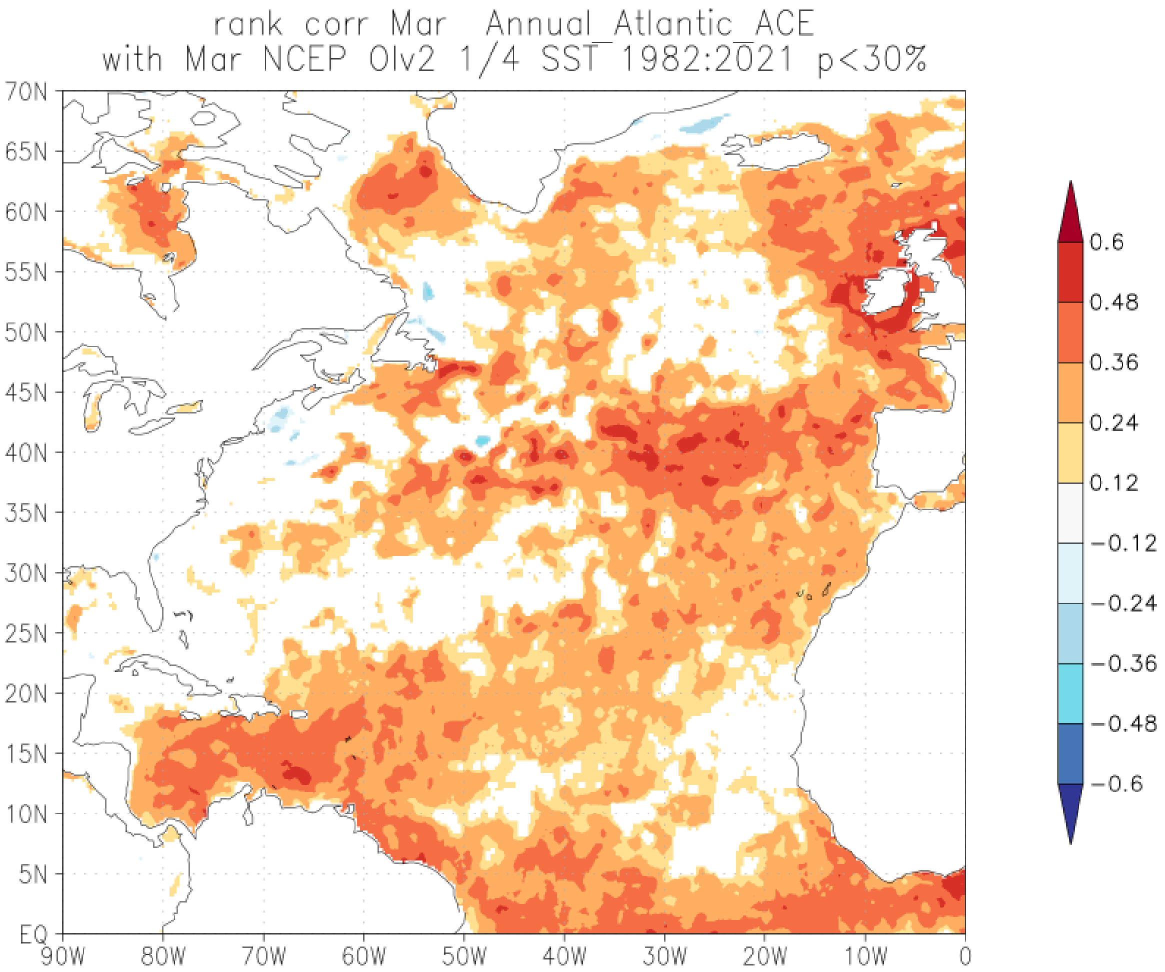


Figure 29: Rank correlations between March sea surface temperatures in the North Atlantic and annual Atlantic ACE from 1982-2021.

6 Tropical Cyclone Impact Probabilities for 2023

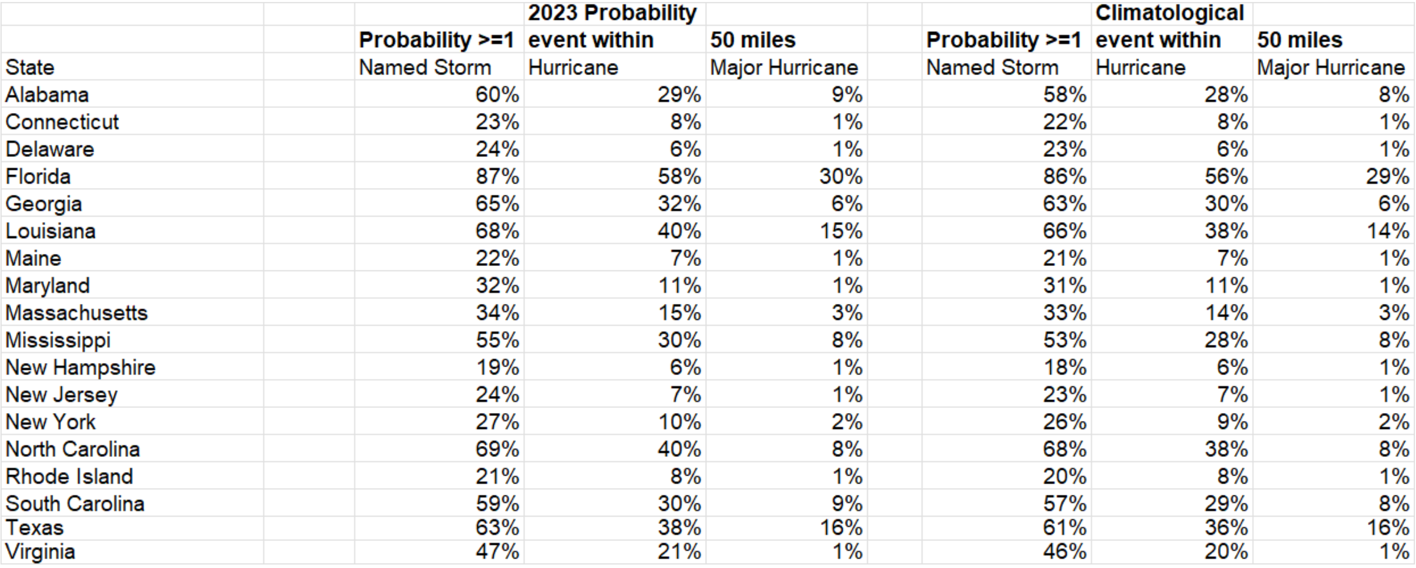
This year, we continue to calculate the impacts of tropical cyclones for each state and county/parish along the Gulf and East Coasts, tropical cyclone-prone provinces of Canada, states in Mexico, islands in the Caribbean and countries in Central America. We have used NOAA's Historical Hurricane Tracks 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 overall Atlantic basin ACE. Long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season is, the greater the probability of hurricane landfalls for various landmasses in the basin.

Table 16 displays the climatological odds of storms tracking within 50 miles of each state along the Gulf and East Coasts along with the odds in 2023. Landfall probabilities are near their long-term averages. Probabilities for other Atlantic basin landmasses are available on our website.

We note that we use a longer climatology (1880–2020) for landfalling statistics than for basinwide statistics, given the relative paucity of landfalls for any particular location. The 1991–2020 average ACE is 123, while the 1880–2020 average ACE is 95. This difference in average ACE for different climatological periods is why basinwide activity is forecast to be slightly below its long-term average while landfall probabilities are near their long-term averages. We note that 1880–2020 average ACE is likely underestimated somewhat due to a less robust observational network prior to the satellite era which began in the mid-1960s.

Table 16: 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 2023, based on the latest CSU seasonal hurricane forecast.



			2023 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
Alabama		60%	29%	9%		58%	28%	8%
Connecticut		23%	8%	1%		22%	8%	1%
Delaware		24%	6%	1%		23%	6%	1%
Florida		87%	58%	30%		86%	56%	29%
Georgia		65%	32%	6%		63%	30%	6%
Louisiana		68%	40%	15%		66%	38%	14%
Maine		22%	7%	1%		21%	7%	1%
Maryland		32%	11%	1%		31%	11%	1%
Massachusetts		34%	15%	3%		33%	14%	3%
Mississippi		55%	30%	8%		53%	28%	8%
New Hampshire		19%	6%	1%		18%	6%	1%
New Jersey		24%	7%	1%		23%	7%	1%
New York		27%	10%	2%		26%	9%	2%
North Carolina		69%	40%	8%		68%	38%	8%
Rhode Island		21%	8%	1%		20%	8%	1%
South Carolina		59%	30%	9%		57%	29%	8%
Texas		63%	38%	16%		61%	36%	16%
Virginia		47%	21%	1%		46%	20%	1%

7 Summary

An analysis of a variety of different atmosphere and ocean measurements (through March) which are known to have long-period statistical relationships with the upcoming season's Atlantic tropical cyclone activity, as well as output from dynamical models, indicate that 2023 will have slightly below-normal activity. The big question marks with this season's predictions revolve around if an El Niño develops, and if so, how strong it will be. Also, does the anomalous warming in the eastern/central tropical Atlantic persist, or do SSTs in this region trend back towards average?

8 Forthcoming Updated Forecasts of 2023 Hurricane Activity

We will be issuing seasonal updates of our 2023 Atlantic basin hurricane forecasts on **Thursday 1 June**, **Thursday 6 July, and Thursday 3 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 2023 forecasts will be issued on **Thursday, 30 November**. All of these forecasts will be available on our website.

9 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 30 displays correlations between observed and predicted Atlantic hurricanes from 1984–2013, from 2014–2022 and from 1984–2022, respectively. Correlation skill has improved at all lead times in recent years, with the most noticeable improvements at longer lead times. While nine 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

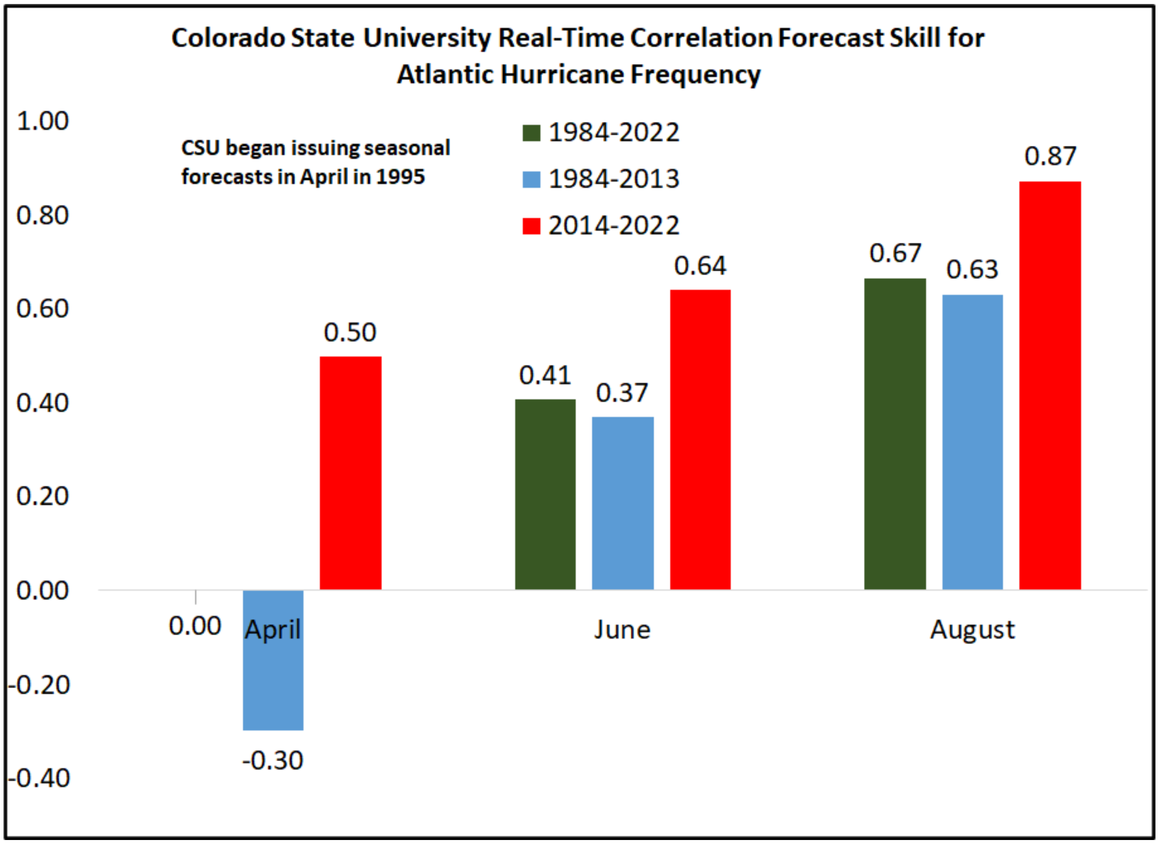


Figure 30: CSU's real-time forecast skill for Atlantic hurricanes using correlation as the skill metric. Correlation skills are displayed for three separate time periods: 1984–2013, 2014–2022 and 1984–2022, respectively.