EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2024

We have maintained our forecast for an extremely active Atlantic hurricane season in 2024. We anticipate that La Niña conditions will develop by the peak of the Atlantic hurricane season, likely resulting in reduced levels of tropical Atlantic vertical wind shear. Sea surface temperatures averaged across the hurricane Main Development Region of the tropical Atlantic and Caribbean remain at record warm levels. Extremely warm sea surface temperatures provide a much more conducive dynamic and thermodynamic environment for hurricane formation and intensification. This forecast is of above-normal confidence for an early June outlook. We anticipate a well above-average probability for major hurricanes making landfall along the continental United States coastline and in the Caribbean. As with all hurricane seasons, coastal residents are reminded that it only takes one hurricane making landfall to make it an active season. Thorough preparations should be made every season, regardless of predicted activity.

(as of 11 June 2024)

By Philip J. Klotzbach[1], Michael M. Bell[2], Alexander J. DesRosiers[3], and Levi Silvers[4]
With Special Assistance from Carl J. Schreck III[5]
In Memory of William M. Gray[6]

Jennifer Dimas, Colorado State University media representative, is coordinating media inquiries in English and Spanish. She can be reached at 970-491-1543 or Jennifer.Dimas@colostate.edu

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

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[1] Senior Research Scientist
[2] Professor
[3] Graduate Research Assistant
[4] Research Scientist
[5] Research Scholar at NC State University
[6] Professor Emeritus

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2024

Forecast Parameter and 1991–2020 Average (in parentheses)	Issue Date 13 April 2024	Issue Date 11 June 2024
Named Storms (14.4)	23	23
Named Storm Days (69.4)	115	115
Hurricanes (7.2)	11	11
Hurricane Days (27.0)	45	45
Major Hurricanes (3.2)	5	5
Major Hurricane Days (7.4)	13	13
Accumulated Cyclone Energy Index (123)	210	210
ACE West of 60°W (73)	125	125
Net Tropical Cyclone Activity (135%)	220	220

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 – 62% (average from 1880–2020 is 43%)

2) U.S. East Coast Including Peninsula Florida (south and east of Cedar Key, Florida) – 34% (average from 1880–2020 is 21%)

3) Gulf Coast from the Florida Panhandle (west and north of Cedar Key, Florida) westward to Brownsville – 42% (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) 66% (average from 1880–2020 is 47%)

ABSTRACT

Information obtained through early June indicates that the 2024 Atlantic hurricane season will have activity well above the 1991–2020 average. We estimate that 2024 will have 23 named storms (average is 14.4), 115 named storm days (average is 69.4), 11 hurricanes (average is 7.2), 45 hurricane days (average is 27.0), 5 major (Category 3-4-5) hurricanes (average is 3.2) and 13 major hurricane days (average is 7.4). The probability of U.S. major hurricane landfall is estimated to be well above its long-period average. We predict Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2024 to be ~170% of their 1991–2020 average. We have maintained the same forecast numbers that we issued with our initial early April prediction.

Coastal residents are reminded that it only takes one hurricane making landfall to make it an active season for them. Thorough preparations should be made for every season, regardless of how much activity is predicted.

We anticipate an imminent transition in the tropical Pacific to neutral ENSO and then likely to La Niña conditions by the peak of the Atlantic hurricane season. La Niña typically increases Atlantic hurricane activity through decreases in vertical wind shear. This year's sea surface temperatures across the tropical Atlantic and Caribbean are much warmer than normal, with temperatures averaged across the Main Development Region currently measuring ~1.4°C above the 1991–2020 average. This warmth favors an active Atlantic hurricane season via dynamic and thermodynamic conditions that are conducive for developing hurricanes.

Our confidence this year is higher than normal for a June forecast based on the strength and persistence of the current hurricane-favorable large-scale environmental conditions. We 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 skill of CSU's forecast updates increases as the peak of the Atlantic hurricane season approaches. Our early June forecast has good long-term skill when evaluated using hindcasts.

In addition to current observations, this forecast is based on an extended-range early June statistical prediction scheme that was developed using ~40 years of past data. Analog predictors are utilized as well. We also include statistical/dynamical models based off 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. This model guidance is unanimously pointing towards a hyperactive season.

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 June. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged with respect to the probability of an active or inactive hurricane season for the coming year. Our early June statistical and statistical/dynamical hybrid models show strong evidence on ~25–45 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 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 Gallagher Re, the Insurance Information Institute, Ironshore Insurance, IAA and Weatherboy. 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 several 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. Thanks also extend to several current members of Michael Bell's research group who have provided valuable comments and feedback throughout the forecast preparation process. These members include: Tyler Barbero, Delián Cólon Burgos, Jen DeHart, Nick Mesa, Angelie Nieves-Jimenez and Isaac Schluesche.

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. ACE is often calculated over a season to reflect overall storm activity that year. 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 (ELI) – 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.

Oceanic Nino Index (ONI) – Three-month running mean of SST anomalies in the Nino 3.4 region (5°S–5°N, 170–120°W) based on centered 30-year base periods.

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) – Observed sea surface temperature differenced from a long-period average, typically 1991–2020.

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 41st 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 June 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 ~25–45 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 less of a relationship to a predictand by itself but to have an important influence when included with a set of 2–3 other predictors.

2 June Forecast Methodology

2.1 June Statistical Forecast Scheme

Our June statistical forecast scheme uses ECMWF Reanalysis 5 data (ERA5; Hersbach et al. 2020). This forecast model was developed over 1979–2020 and then was tested on the 2021 and 2022 Atlantic hurricane seasons (e.g., those years were purposely left out to see how well the model would work at forecasting these omitted years). The model was then used in real-time in 2023. 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 = 0.66) over the period from 1979–2023 (Figure 1).

Figure 2 displays the locations of both predictors, while Table 1 displays the individual linear correlations between each predictor and ACE over the 1979–2023 hindcast/forecast period. Both 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 2024 observed values for both predictors in the statistical forecast scheme. Table 3 displays the statistical model output for the 2024 hurricane season. The eastern Atlantic SST predictor is at its second highest level since 1979 (trailing 2023), while the low-level wind predictor over the central tropical Pacific is slightly stronger than normal, indicative of neutral ENSO conditions. The two predictors in combination call for a hyperactive season, due primarily to the extremely warm eastern Atlantic.

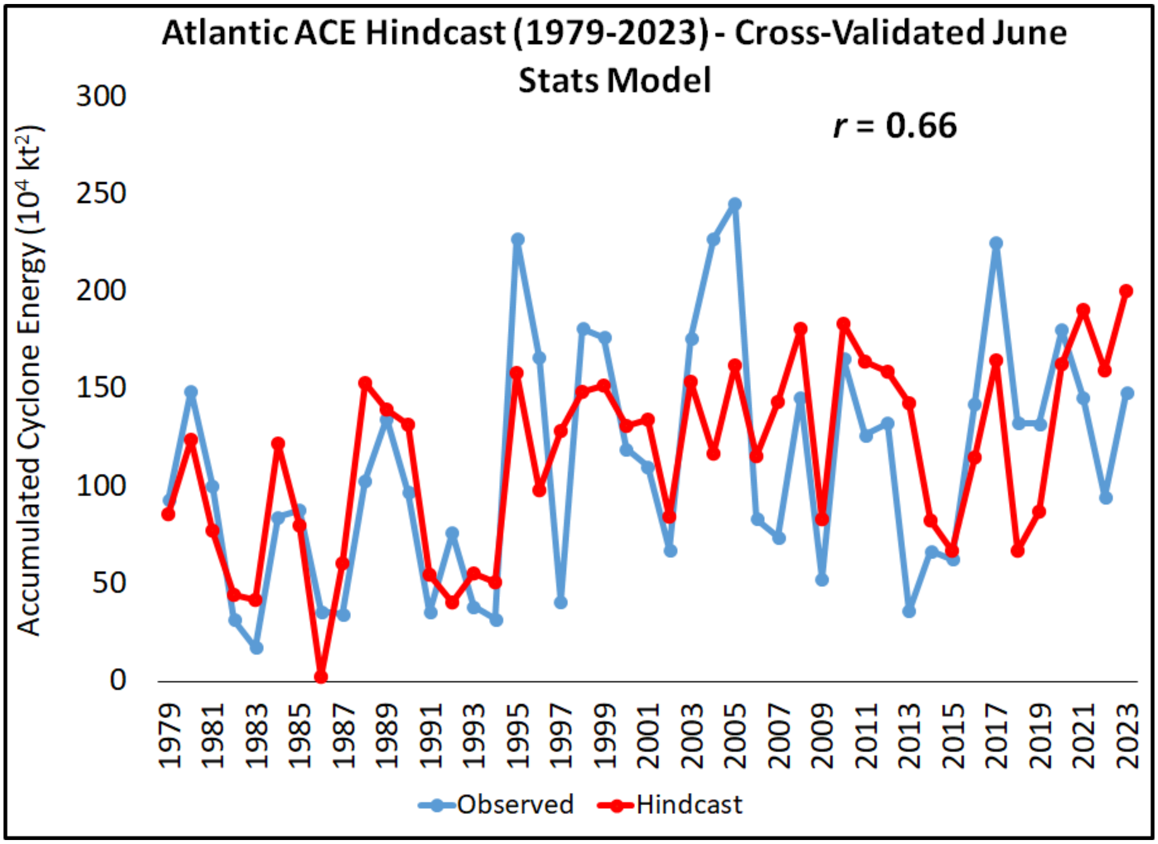

Figure 1: Observed versus early June cross-validated hindcast values of ACE for the statistical model from 1979–2023.

June Forecast Predictors

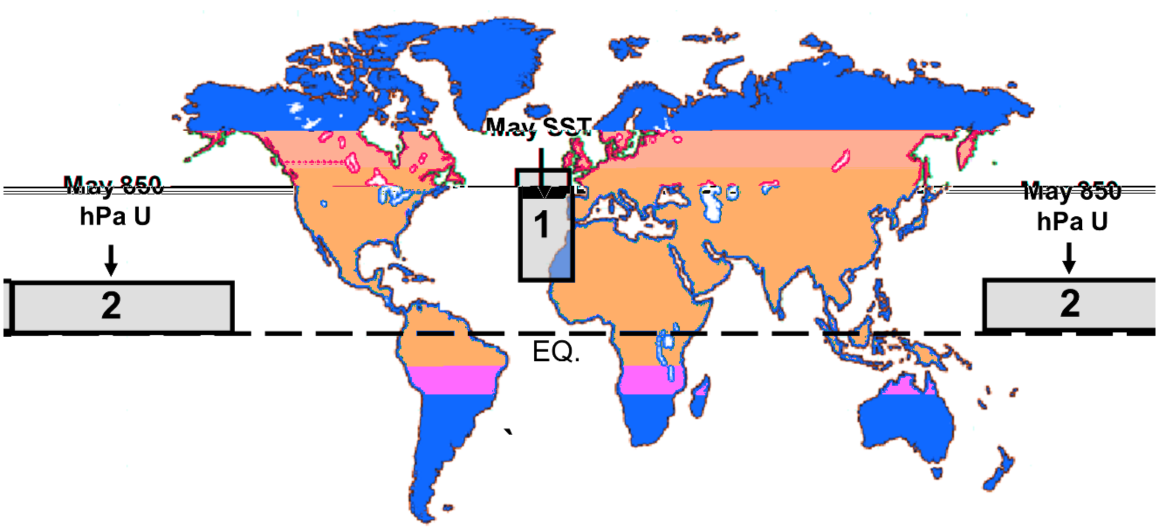

Figure 2: Location of predictors for the early June extended-range statistical prediction for the 2024 hurricane season.

Table 1: Linear correlation between early June predictors and ACE over the period from 1979–2023.

Predictor	Correlation w/ ACE
1) May SST (15°N–50°N, 30°W–10°W) (+)	0.56
2) May 850 hPa U (0°N–20°N, 160°E–140°W) (-)	-0.57

Table 2: Listing of early June 2024 predictors for the 2024 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	2024 Forecast Value	Impact on 2024 TC Activity
1) May SST (15°N–50°N, 30°W–10°W) (+)	+2.3 SD	Strongly Enhance
2) May 850 hPa U (0°N–20°N, 160°E–140°W) (-)	-0.3 SD	Slightly Enhance

Table 3: Statistical model output for the 2024 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)	20.1	23
Named Storm Days (NSD) (69.4)	98.1	115
Hurricanes (H) (7.2)	10.2	11
Hurricane Days (HD) (27.0)	42.6	45
Major Hurricanes (MH) (3.2)	5.0	5
Major Hurricane Days (MHD) (7.4)	13.0	13
Accumulated Cyclone Energy (ACE) (123)	191	210
Net Tropical Cyclone Activity (NTC) (135%)	205	220

The locations and brief descriptions of the predictors for our early June statistical forecast are now discussed. Both 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.

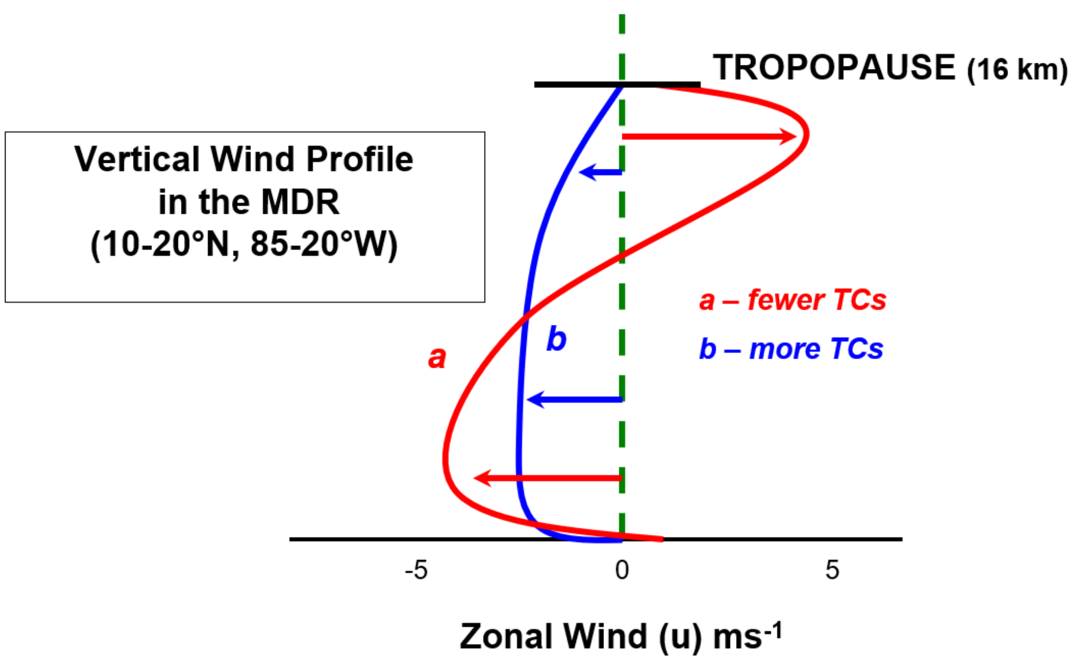

Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.

For each of these predictors, we display a four-panel figure showing rank correlations between values of each predictor and August–October values of SST, sea level pressure (SLP), 200 hPa zonal wind, and 850 hPa zonal wind, respectively, since 1979. 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. May SST in the tropical and subtropical eastern Atlantic (+)

(15°N–50°N, 30°W–10°W)

Warmer-than-normal SSTs in the tropical and subtropical Atlantic during May are associated with a weaker-than-normal subtropical high and reduced trade wind strength during the boreal spring and summer (Knaff 1997). Positive SSTs in May 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 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 1979–2023. Predictor 1 also significantly correlates (r = 0.71) with August–October values of the SST component of the Atlantic Meridional Mode (AMM) (Kossin and Vimont 2007) from 1979–2023. 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. May 850 hPa U in the tropical central Pacific (-)

(0°N–20°N, 160°E–140°W)

Stronger-than-normal low-level winds during May in the central tropical Pacific are associated with enhanced upwelling which drives anomalous cooling in the central and eastern tropical Pacific, inhibiting the development of El Niño conditions. This relationship can be clearly demonstrated by a significant correlation between Predictor 2 with the August–October-averaged Oceanic Nino Index (r = 0.67). Enhanced trade winds in the tropical Pacific favor La Niña, which results in a westward-shifted and stronger Walker Circulation. Associated with this stronger Walker Circulation is anomalous subsidence over the eastern and central tropical Pacific and 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 5).

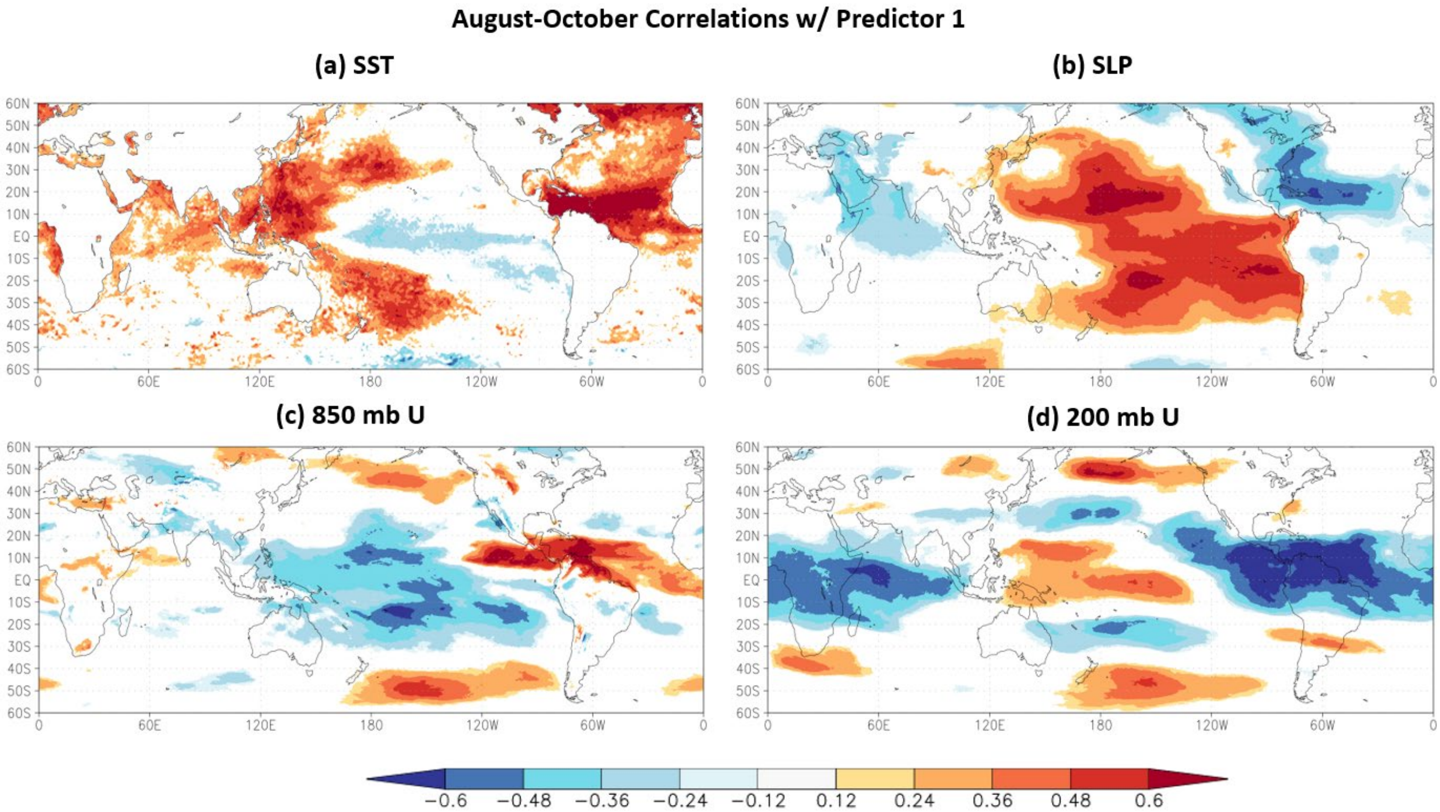

Figure 4: Rank correlations between May SST in the tropical and subtropical Atlantic (Predictor 1) and (panel a) August–October sea surface temperature, (panel b) August–October sea level pressure, (panel c) August–October 850 hPa zonal wind and (panel d) August–October 200 hPa zonal wind. All four of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

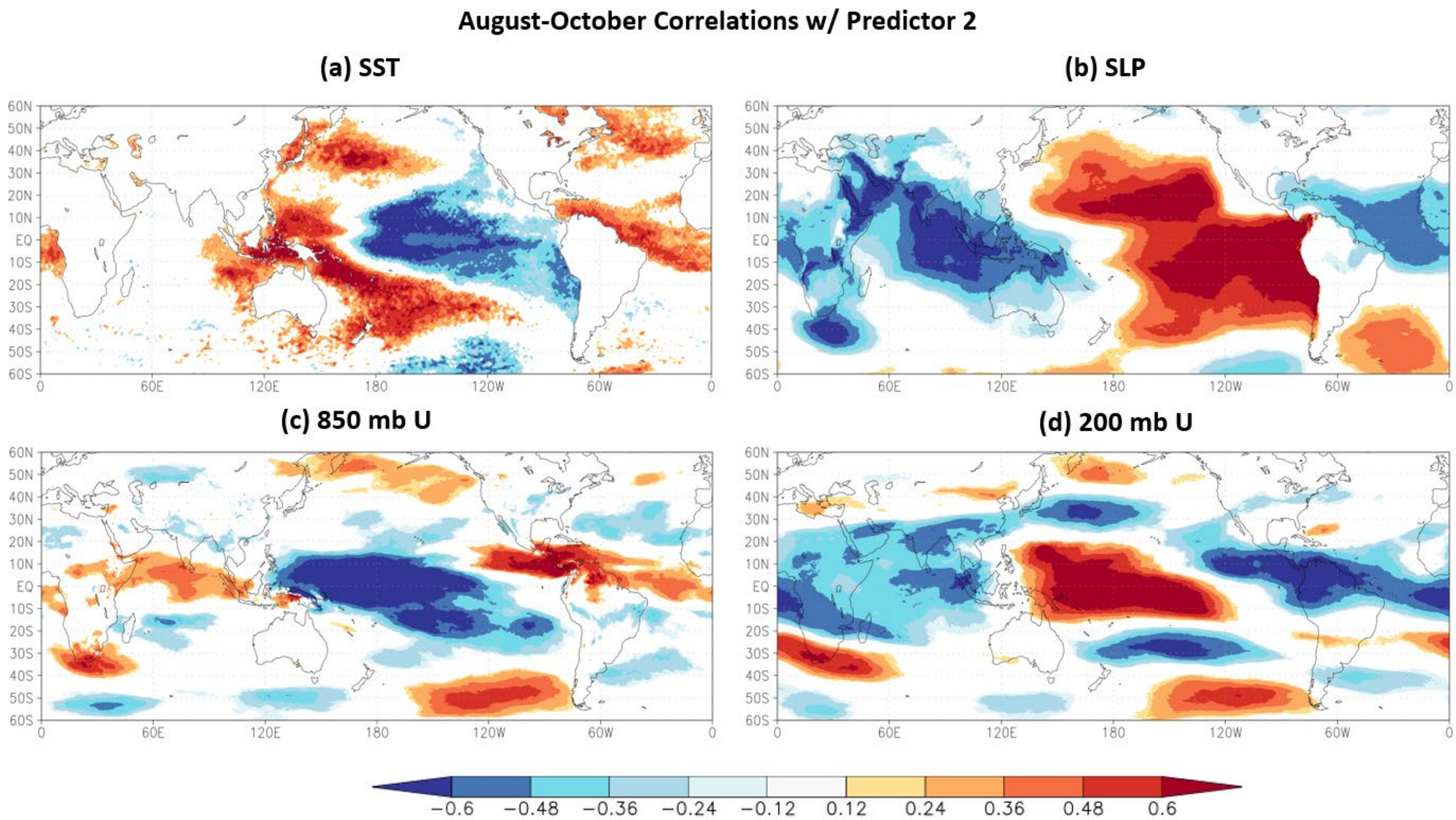

Figure 5: As in Figure 4 but for May 850 hPa zonal wind in the tropical central Pacific. The sign of the predictor has been reversed for ease of comparison with Figure 4.

2.2 June 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 and now use four different models: ECMWF, UK Met, JMA and CMCC. We evaluate model forecasts of August-September SSTs 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 2024 season. All other predictands (e.g., named storms, major hurricanes) are calculated based on their historical relationships with ACE. 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).

Via the Copernicus website, ECMWF climate model output data are available on the 6th of the month, while all other climate model data are available on the 10th of the month. Given the time that it takes to process and run the models, the results displayed here are from the June ECMWF model output and from a May forecast for all other models discussed herein.

a) ECMWF Statistical/Dynamical Model Forecast

Figure 6 displays the locations of the two August–September forecast parameters, while Table 4 displays ECMWF's forecasts of these parameters for 2024 from a 1 June initialization date. The ECMWF model predicts an eastern/central North Atlantic that is tied with 2023 for the warmest on record (since 1981) and a relatively cool tropical eastern/central Pacific. The combination of these two predictors yields a hyperactive forecast of 250 ACE, which is the highest ACE that the 1 June statistical/dynamical model has forecast. Figure 7 displays cross-validated hindcasts of ECMWF hindcasts of ACE from 1981–2023, while Table 5 presents the forecast from ECMWF for the 2024 Atlantic hurricane season.

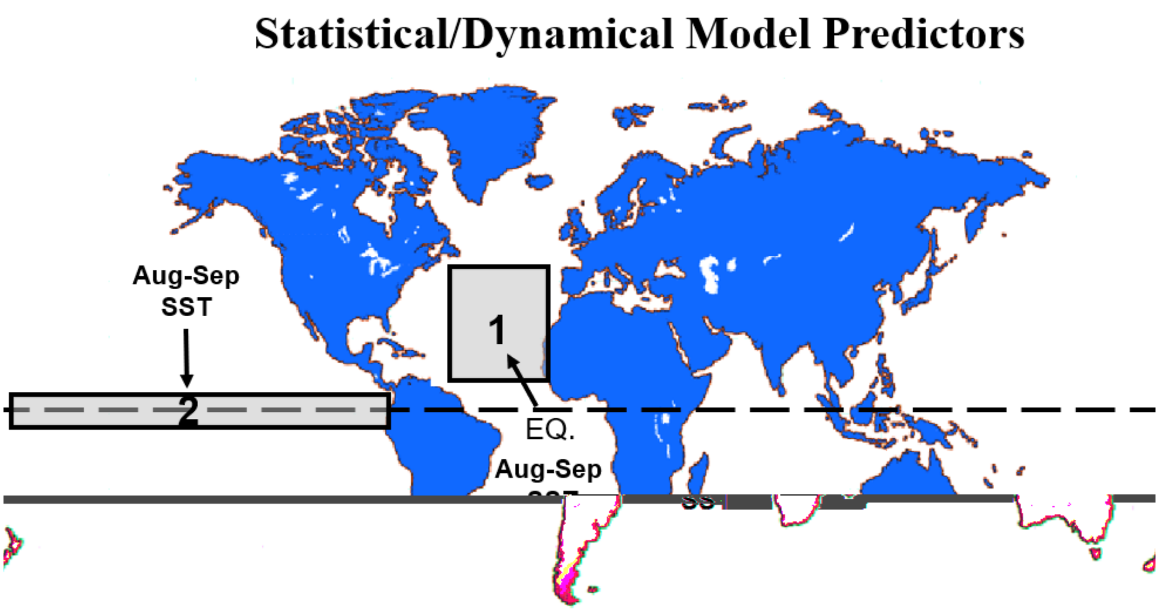

Figure 6: Location of predictors for our statistical/dynamical extended-range statistical prediction for the 2024 hurricane season. This forecast uses dynamical model predictions from ECMWF, the UK Met Office, JMA and CMCC to predict August–September conditions in the two boxes displayed and uses those predictors to forecast ACE.

Table 4: Listing of predictions of August–September large-scale conditions from ECMWF model output, initialized on 1 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 2024 Forecast	Effect on 2024 Hurricane Season
1) ECMWF Prediction of Aug-Sep SST (10–45°N, 60–20°W) (+)	+3.8 SD	Strongly Enhance
2) ECMWF Prediction of Aug-Sep SST (5°S–5°N, 180–90°W) (-)	-0.3 SD	Enhance

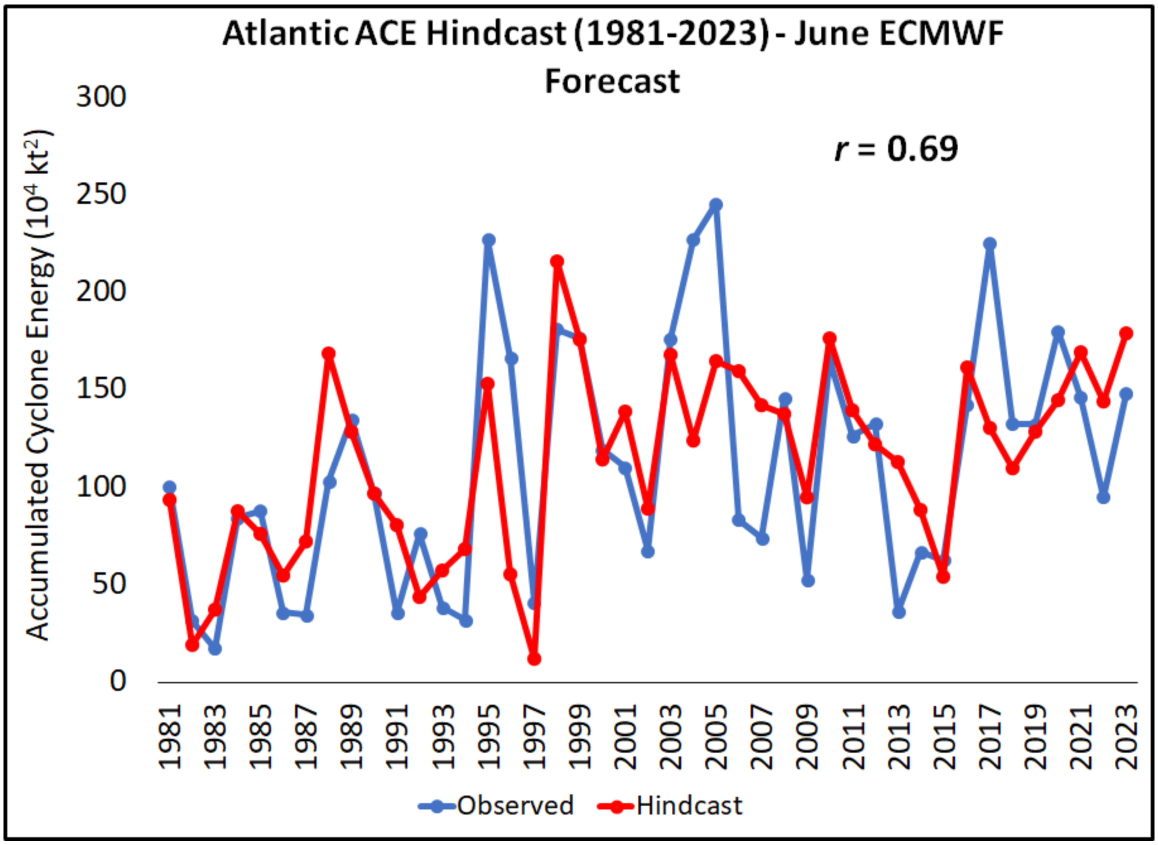

Figure 7: Observed versus cross-validated statistical/dynamical hindcast values of ACE for 1981–2023 from ECMWF.

Table 5: Statistical/dynamical model output from ECMWF for the 2024 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)	23.7	23
Named Storm Days (69.4)	122.8	115
Hurricanes (7.2)	12.8	11
Hurricane Days (27.0)	56.1	45
Major Hurricanes (3.2)	6.5	5
Major Hurricane Days (7.4)	17.9	13
Accumulated Cyclone Energy Index (123)	250	210
Net Tropical Cyclone Activity (135%)	264	220

b) UK Met Office Statistical/Dynamical Model Forecast

Table 6 displays the UK Met Office forecasts of the August–September parameters for 2024 from a 1 May initialization date. The ensemble average of the UK Met Office seasonal forecasts is calling for an extremely warm North Atlantic as well as a La Niña. Figure 8 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 2024 Atlantic hurricane season. Like ECMWF, the Met Office statistical/dynamical model is calling for an extremely active season.

Table 6: Listing of predictions of August–September large-scale conditions from UK Met model output, initialized on 1 May. 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 2024 Forecast	Effect on 2024 Hurricane Season
1) UK Met Prediction of Aug–Sep SST (10–45°N, 60–20°W) (+)	+4.3 SD	Strongly Enhance
2) UK Met Prediction of Aug–Sep SST (5°S–5°N, 180–90°W) (-)	-1.1 SD	Enhance

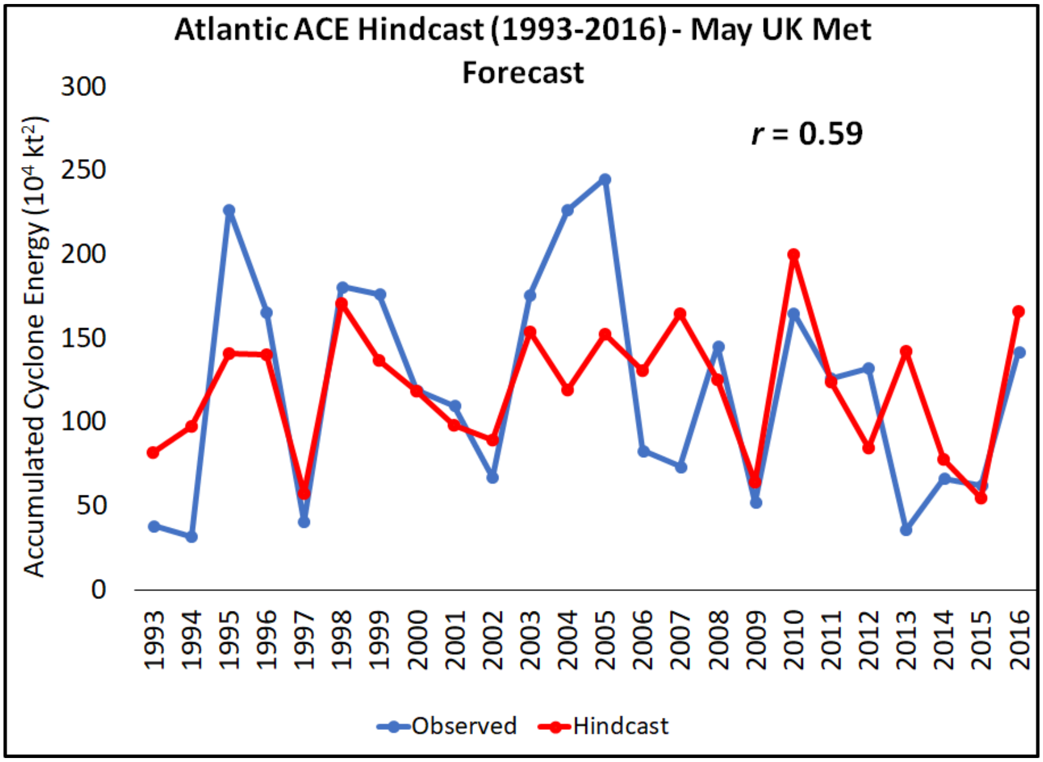

Figure 8: Observed versus statistical/dynamical hindcast values of ACE for 1993–2016 from the UK Met Office.

Table 7: Statistical/dynamical model output from the UK Met Office for the 2024 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)	22.9	23
Named Storm Days (69.4)	117.4	115
Hurricanes (7.2)	12.2	11
Hurricane Days (27.0)	53.1	45
Major Hurricanes (3.2)	6.2	5
Major Hurricane Days (7.4)	16.8	13
Accumulated Cyclone Energy Index (123)	237	210
Net Tropical Cyclone Activity (135%)	251	220

c) JMA Met Office Statistical/Dynamical Model Forecast

Table 8 displays the JMA forecasts of the August–September parameters for 2024 from a 1 May initialization date. The ensemble average of the JMA seasonal forecast is calling for an extremely warm North Atlantic as well as a weak La Niña. Figure 9 displays JMA hindcasts of ACE from 1993–2016, while Table 9 presents the forecast from the JMA for the 2024 Atlantic hurricane season. The statistical/dynamical model based off JMA is calling for the most ACE on record (263) for an individual Atlantic hurricane season.

Table 8: Listing of predictions of August–September large-scale conditions from JMA model output, initialized on 1 May. 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 2024 Forecast	Effect on 2024 Hurricane Season
1) JMA Prediction of Aug-Sep SST (10–45°N, 60–20°W) (+)	+4.2 SD	Strongly Enhance
2) JMA Prediction of Aug-Sep SST (5°S–5°N, 180–90°W) (-)	-0.8 SD	Enhance

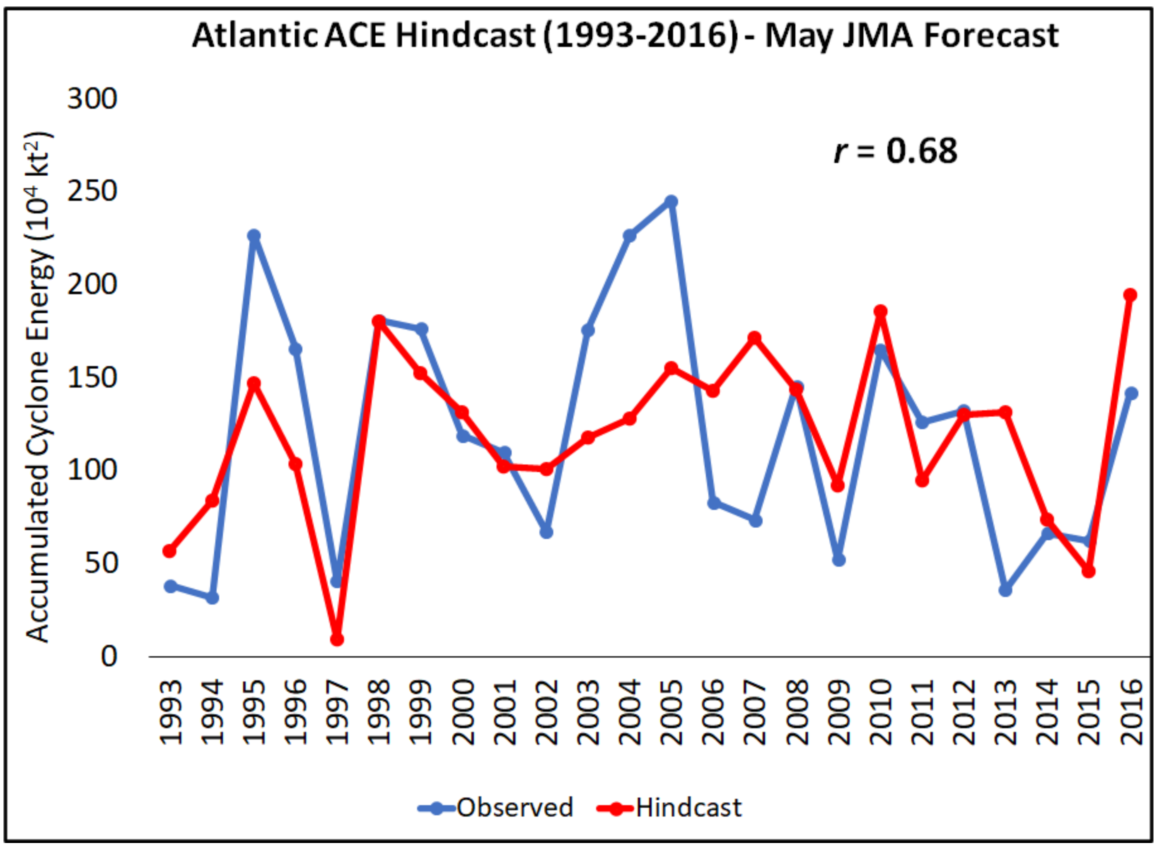

Figure 9: Observed versus statistical/dynamical hindcast values of ACE for 1993–2016 from the JMA.

Table 9: Statistical/dynamical model output from the JMA for the 2024 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)	24.5	23
Named Storm Days (69.4)	128.3	115
Hurricanes (7.2)	13.3	11
Hurricane Days (27.0)	59.1	45
Major Hurricanes (3.2)	6.9	5
Major Hurricane Days (7.4)	19.0	13
Accumulated Cyclone Energy Index (123)	263	210
Net Tropical Cyclone Activity (135%)	277	220

d) CMCC Statistical/Dynamical Model Forecast

Table 10 displays the CMCC forecasts of the August–September parameters for 2024 from a 1 May initialization date. The ensemble average of the CMCC seasonal forecast is calling for an extremely warm North Atlantic as well as cool neutral ENSO/weak La Niña. Figure 10 displays hindcasts for the CMCC of ACE from 1993–2016, while Table 11 presents the forecast from the CMCC for the 2024 Atlantic hurricane season. The statistical/dynamical model based off of CMCC is calling for a hyperactive 2024 Atlantic hurricane season.

Table 10: Listing of predictions of August–September large-scale conditions from CMCC model output, initialized on 1 May. 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 2024 Forecast	Effect on 2024 Hurricane Season
1) CMCC Prediction of Aug-Sep SST (10–45°N, 60–20°W) (+)	+4.5 SD	Strongly Enhance
2) CMCC Prediction of Aug-Sep SST (5°S–5°N, 180–90°W) (-)	-0.6 SD	Enhance

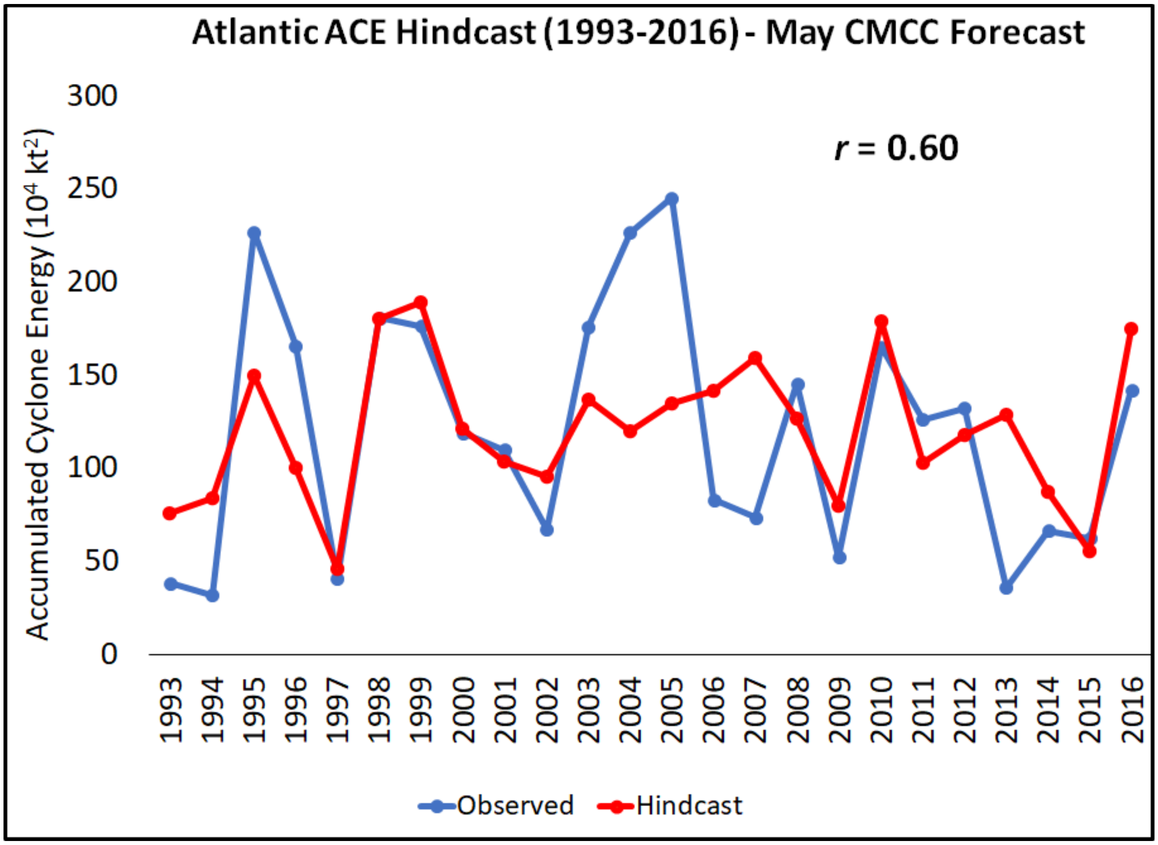

Figure 10: Observed versus statistical/dynamical hindcast values of ACE for 1993–2016 from the CMCC.

Table 11: Statistical/dynamical model output from the CMCC for the 2024 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)	22.7	23
Named Storm Days (69.4)	115.7	115
Hurricanes (7.2)	12.0	11
Hurricane Days (27.0)	52.2	45
Major Hurricanes (3.2)	6.1	5
Major Hurricane Days (7.4)	16.5	13
Accumulated Cyclone Energy Index (123)	233	210
Net Tropical Cyclone Activity (135%)	247	220

2.3 June Analog Forecast Scheme

Certain years in the historical record have global oceanic and atmospheric patterns and trends which resemble 2024. These years also provide useful clues as to likely levels of activity that the forthcoming 2024 hurricane season may bring. For this early June 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 May 2024 conditions and, more importantly, projected August–October 2024 conditions. Table 12 lists our analog selections, while Figure 12 shows the composite August–October SST in our six analog years. Selecting analogs for this season poses an additional challenge in that we have not observed an Atlantic this warm in the historical record without El Niño conditions. Last year had a similarly extremely warm Atlantic but also had a strong El Niño.

We searched for years that were generally characterized by El Niño conditions the previous winter and had La Niña conditions during the peak of the Atlantic hurricane season (August–October). We also selected years that had well above-average SSTs in the tropical Atlantic, although none of these years had SSTs in the tropical Atlantic in May that were as warm as they are now. We anticipate that the 2024 hurricane season will have activity near the average of our six analog years for most parameters. The busy hurricane seasons in all analog years underscore the higher-than-normal confidence in an active 2024 hurricane season. Named storm activity was likely significantly underestimated in 1878 and 1926 given the extremely limited observational network available in those years.

Table 12: Analog years for 2024 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1878	12	90.00	10	50.25	2	10.00	180.9	161.6
1926	11	86.75	8	58.50	6	22.75	229.6	230.3
1998	14	87.25	10	48.50	3	9.50	181.2	168.6
2005	28	126.25	15	49.75	7	17.50	245.3	276.7
2010	19	89.50	12	38.50	5	11.00	165.5	196.4
2020	30	122.75	14	35.25	7	8.25	180.4	235.5
Average	19.0	100.4	11.5	46.8	5.0	13.2	197.1	211.5
2024 Forecast	**23**	**115**	**11**	**45**	**5**	**13**	**210**	**220**

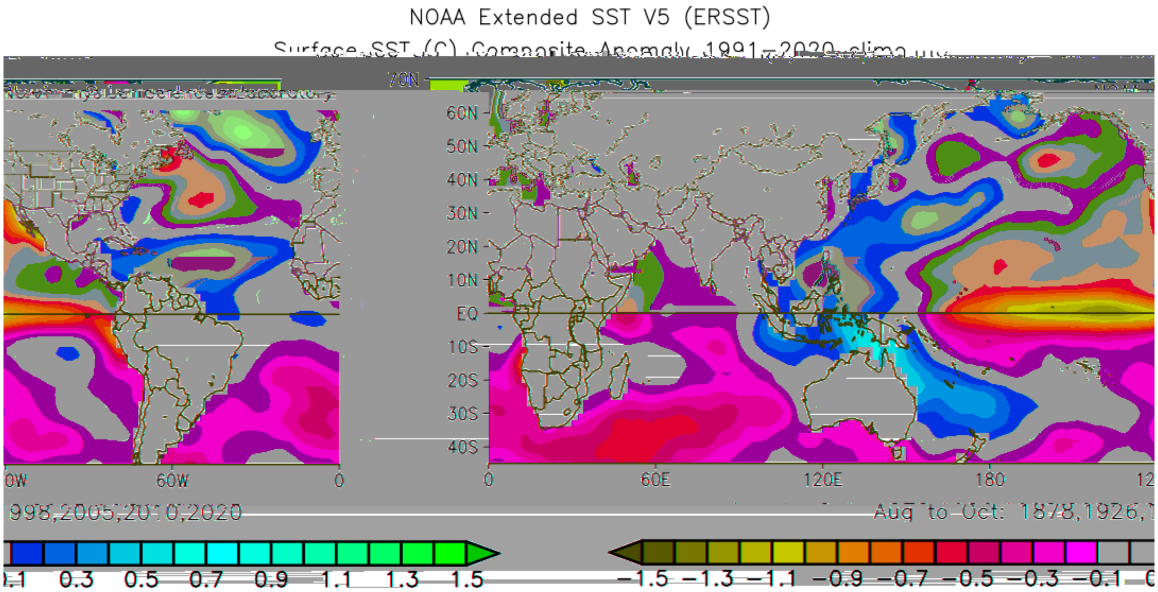

Figure 11: Average August–October SST anomalies in our six analog years.

2.4 ACE West of 60°W Forecast

We now explicitly forecast 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 12 and 13) since 1950.

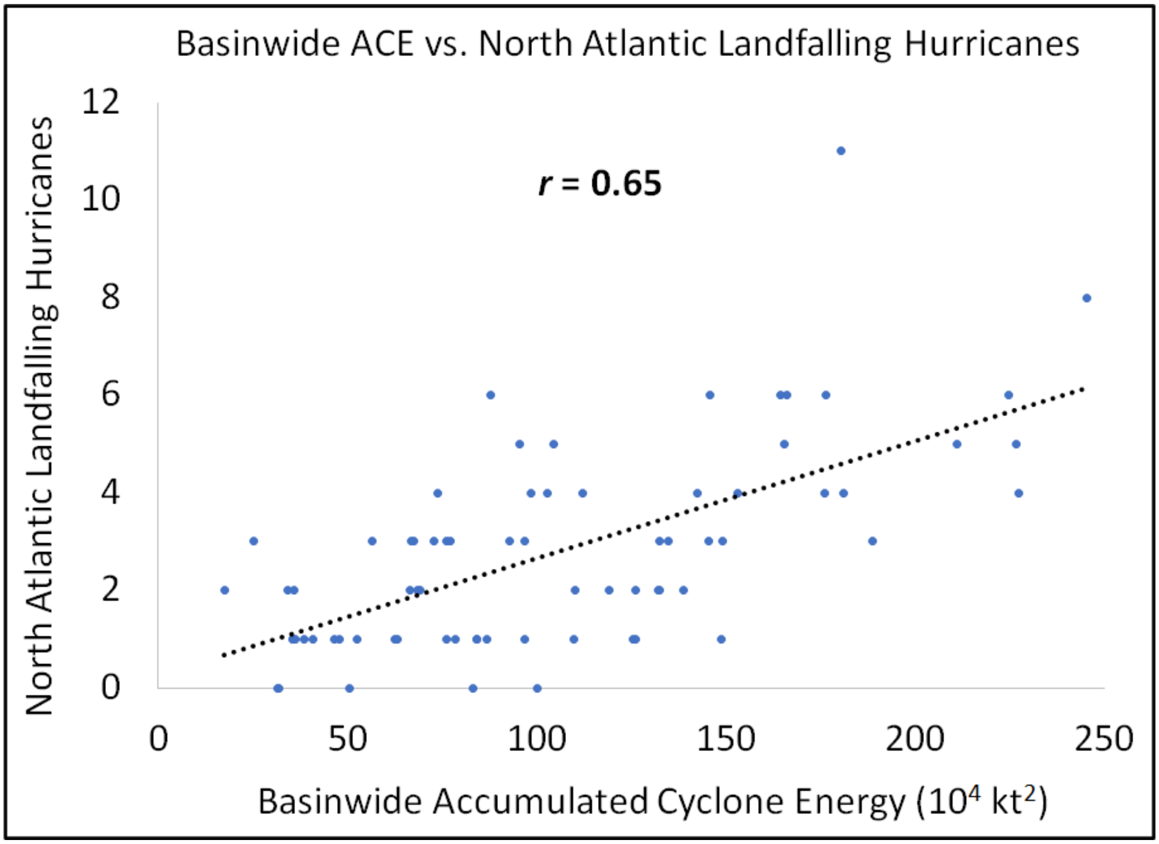

Figure 12: Scatterplot showing relationship between basinwide ACE and North Atlantic landfalling hurricanes.

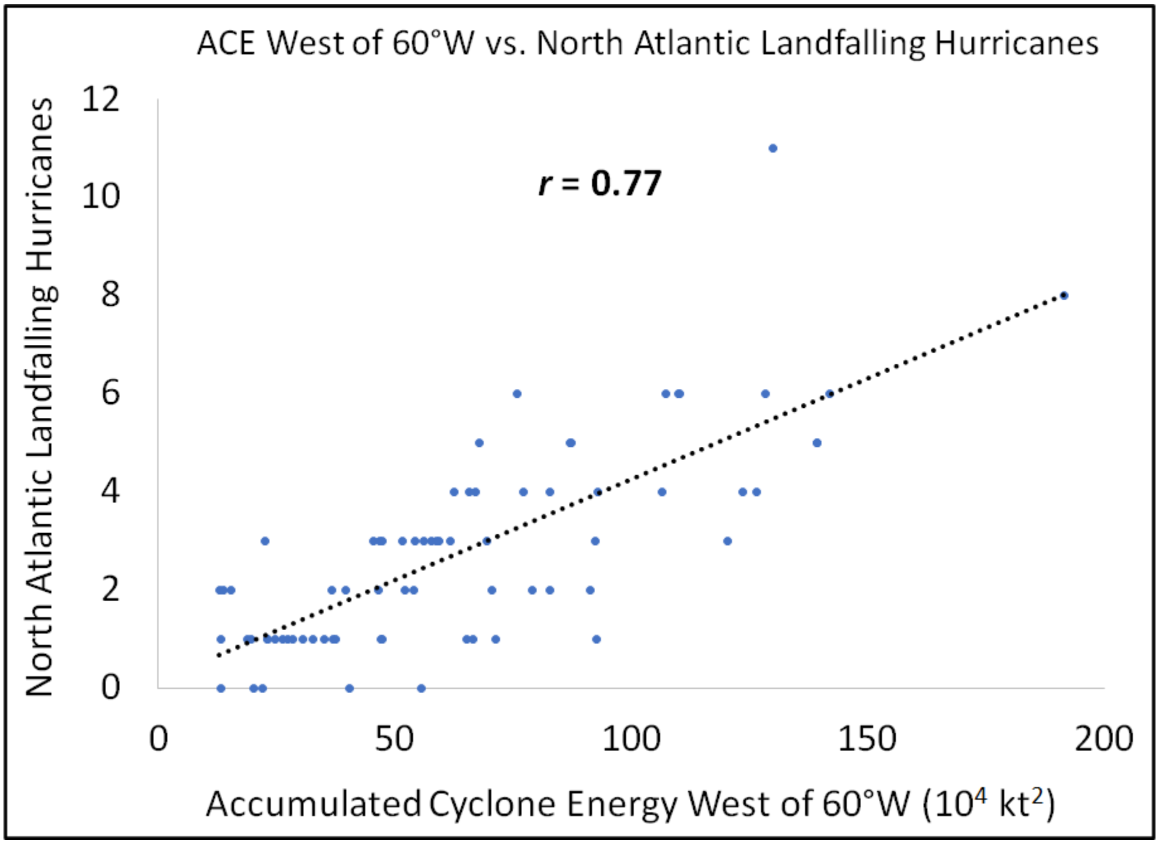

Figure 13: Scatterplot showing relationship between ACE west of 60°W and North Atlantic landfalling hurricanes.

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). This was certainly the case in 2023. A strong El Niño occurred, the subtropical high was quite weak, and many of the TCs that occurred recurved east of 60°W. Caribbean TC activity was also suppressed last year.

We use data from 1979–2023 and base ENSO classifications on the August–October-averaged Oceanic Nino Index (ONI). Years with an ONI >= 0.5°C were classified as El Niño, years with an ONI <= -0.5°C were classified as La Niña, while all other seasons were classified as neutral ENSO.

We find that 51% of basinwide ACE occurred west of 60°W in El Niño years, while 60% of basinwide ACE occurred west of 60°W in La Niña years. In neutral ENSO years, 59% of basinwide ACE occurred west of 60°W. Given that we are favoring La Niña with this outlook, we are estimating ~60% of basinwide ACE to occur west of 60°W in 2024.

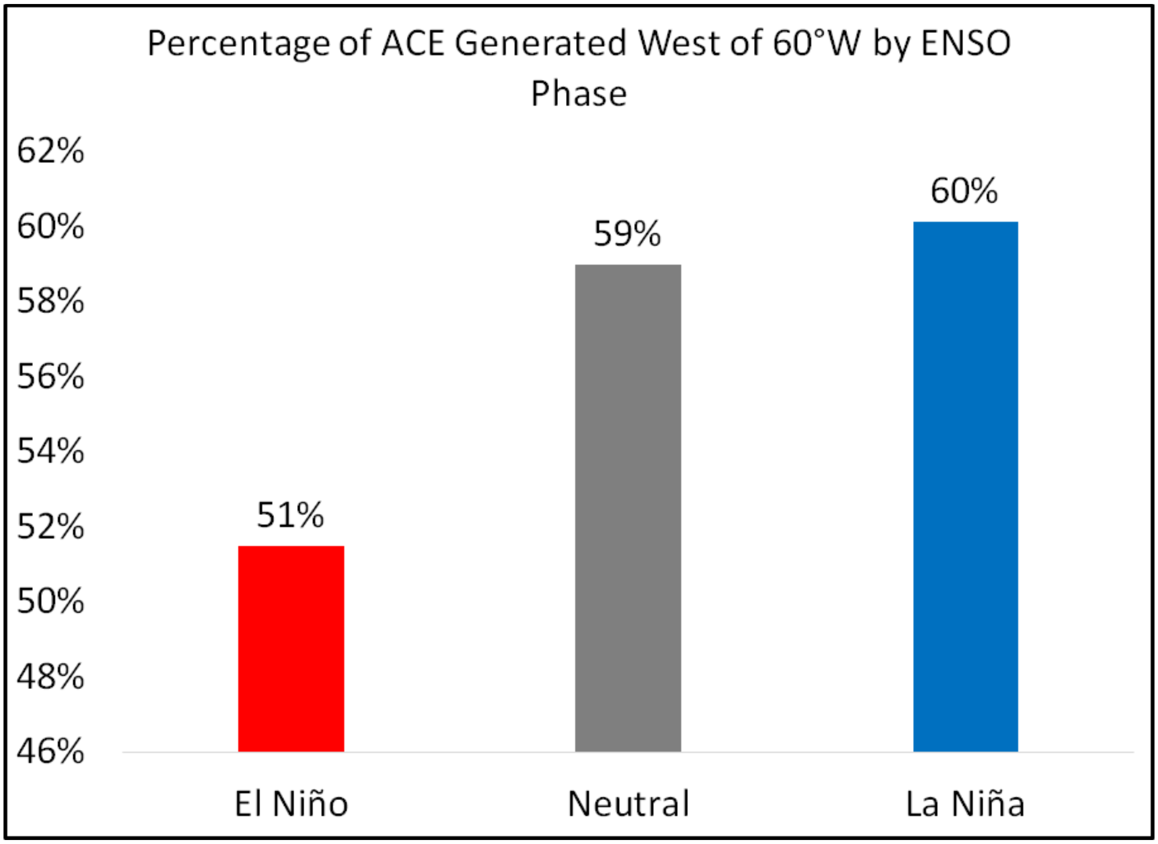

Figure 14: Percentage of ACE generated west of 60°W by ENSO phase.

2.5 June Forecast Summary and Final Adjusted Forecast

Table 13 shows our final adjusted early June forecast for the 2024 season which is a combination of our statistical scheme, statistical/dynamical schemes, and analog scheme as well as qualitative adjustments for other factors not explicitly contained in any of these schemes. All of our forecast model guidance is calling for a hyperactive season. While there remains considerable uncertainty with any seasonal hurricane forecast issued in early June, the confidence in our prediction is higher than normal for an early June outlook. This is our highest hurricane prediction that we have ever issued with our June outlook. Our prior highest June forecast was for ten hurricanes, which we predicted in 2010 (12 hurricanes observed) and 2022 (8 hurricanes observed). CSU began issuing June forecasts in 1984.

Table 13: Summary of our early June statistical forecast, our statistical/dynamical forecasts, our analog forecast, the average of these six schemes and our adjusted final forecast for the 2024 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)	20.1	23.7	22.9	24.5	22.7	19.0	22.2	23
Named Storm Days (69.4)	98.1	122.8	117.4	128.3	115.7	100.4	113.8	115
Hurricanes (7.2)	10.2	12.8	12.2	13.3	12.0	11.5	12.0	11
Hurricane Days (27.0)	42.6	56.1	53.1	59.1	52.2	46.8	51.7	45
Major Hurricanes (3.2)	5.0	6.5	6.2	6.9	6.1	5.0	6.0	5
Major Hurricane Days (7.4)	13.0	17.9	16.8	19.0	16.5	13.2	16.1	13
Accumulated Cyclone Energy Index (123)	191	250	237	263	233	197	229	210
Net Tropical Cyclone Activity (135%)	205	264	251	277	247	212	243	220

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 specific 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, we are more confident than normal for a June forecast given how robust our primary predictors are (e.g., likely La Niña, extremely warm Atlantic sea surface temperatures) for an active Atlantic hurricane season.

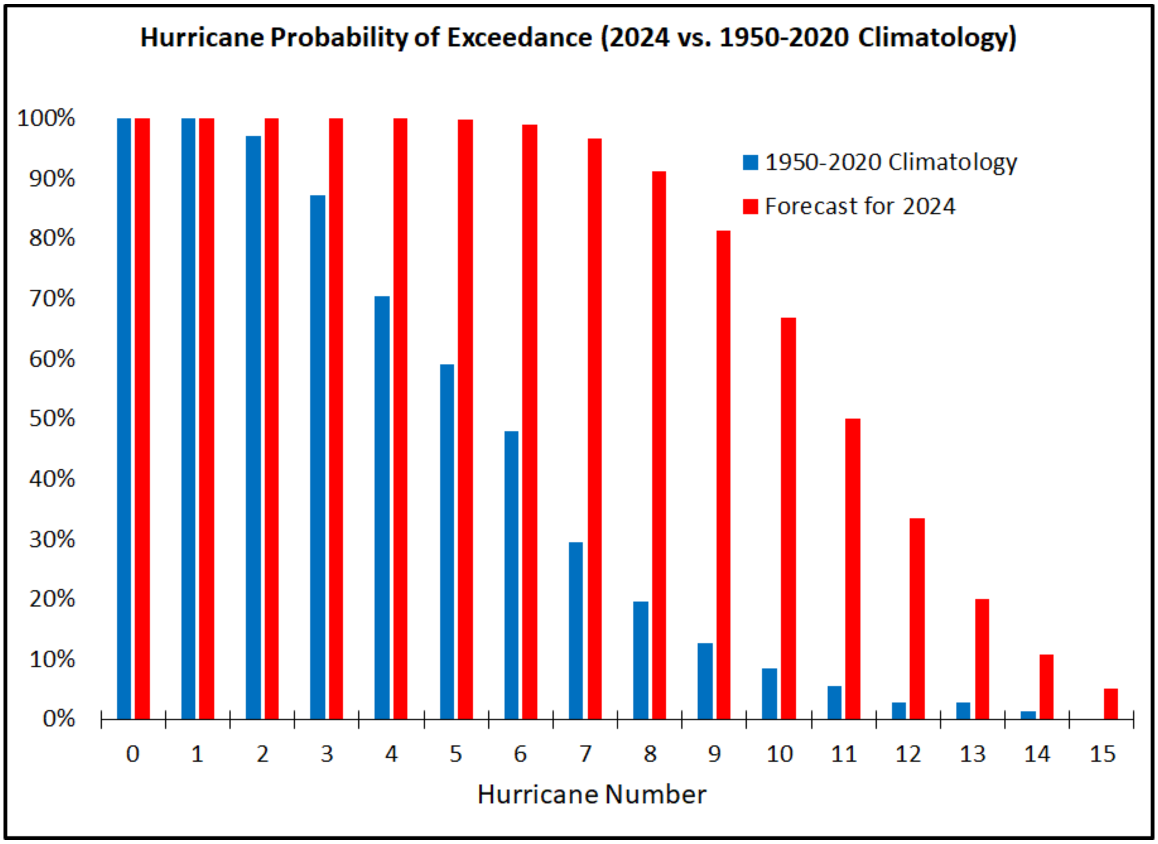

Figure 15: Probability of exceedance plot for hurricane numbers for the 2024 Atlantic hurricane season. The values on the x-axis indicate that the number of hurricanes exceeds that specific number. For example, 97% of Atlantic hurricane seasons from 1950–2020 have had more than two hurricanes.

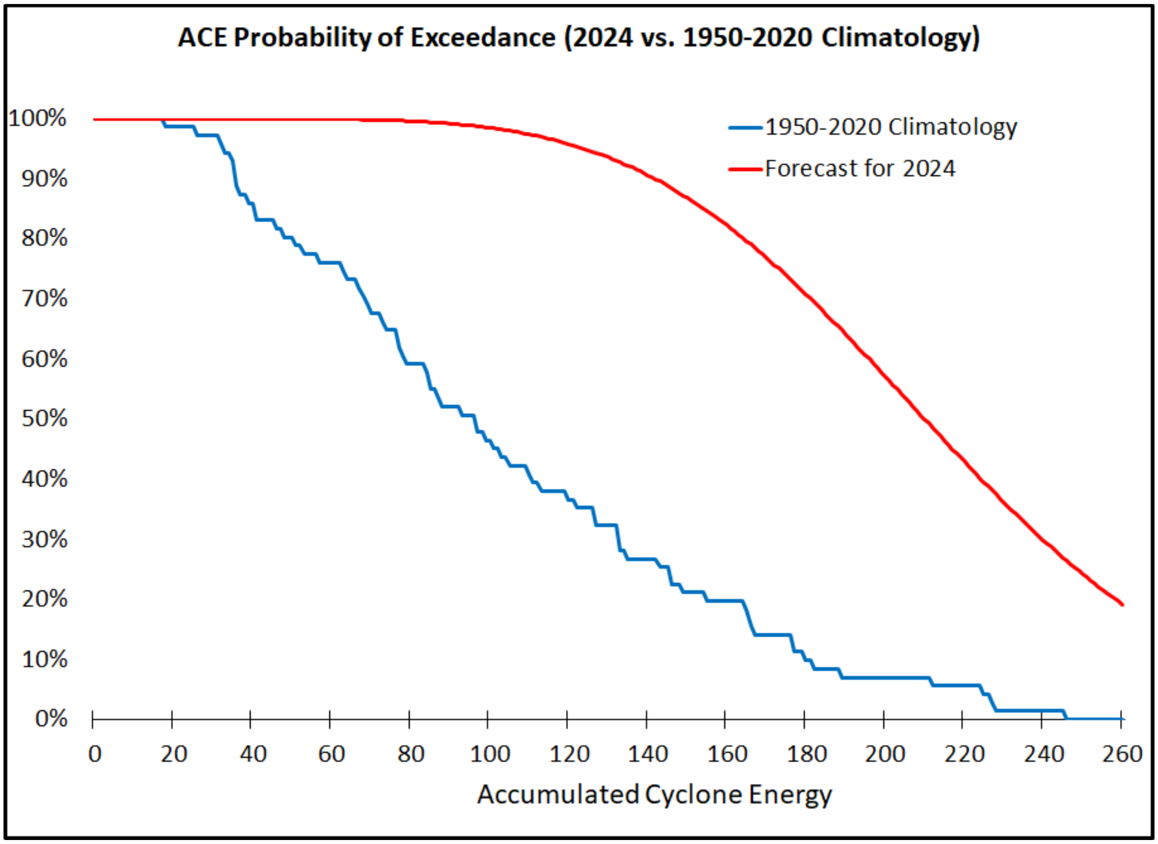

Figure 16: As in Figure 15 but for ACE.

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	2024 Forecast	Uncertainty Range (68% of Forecasts Likely to Fall in This Range)
Named Storms (NS)	23	20 – 27
Named Storm Days (NSD)	115	93 – 130
Hurricanes (H)	11	9 – 14
Hurricane Days (HD)	45	31 – 60
Major Hurricanes (MH)	5	3 – 7
Major Hurricane Days (MHD)	13	8 – 20
Accumulated Cyclone Energy (ACE)	210	154 – 260
ACE West of 60°W	125	86 – 169
Net Tropical Cyclone (NTC) Activity	220	167 – 275

4 ENSO

Over the past couple of months, the tropical Pacific has continued to anomalously cool and is currently characterized by a dissipating El Niño (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. El Niño events are typically defined to be when SST anomalies are >=0.5°C in the Nino 3.4 region. Over the past couple of months, SST anomalies have decreased across most of the tropical Pacific, with weekly SST anomalies in the Nino 3.4 region recently decreasing below the 0.5°C threshold. Figure 18 displays the locations of the various Nino regions displayed in Figure 17.

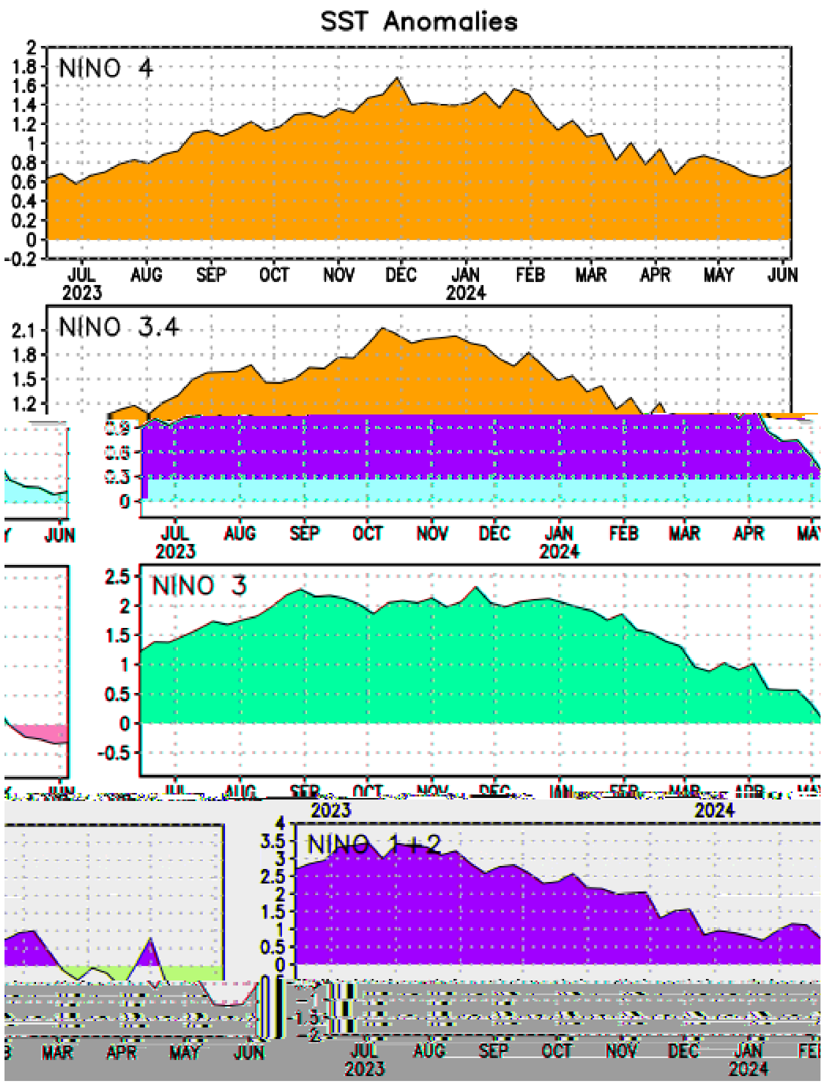

Figure 17: SST anomalies for several ENSO regions over the past year. Figure courtesy of Climate Prediction Center.

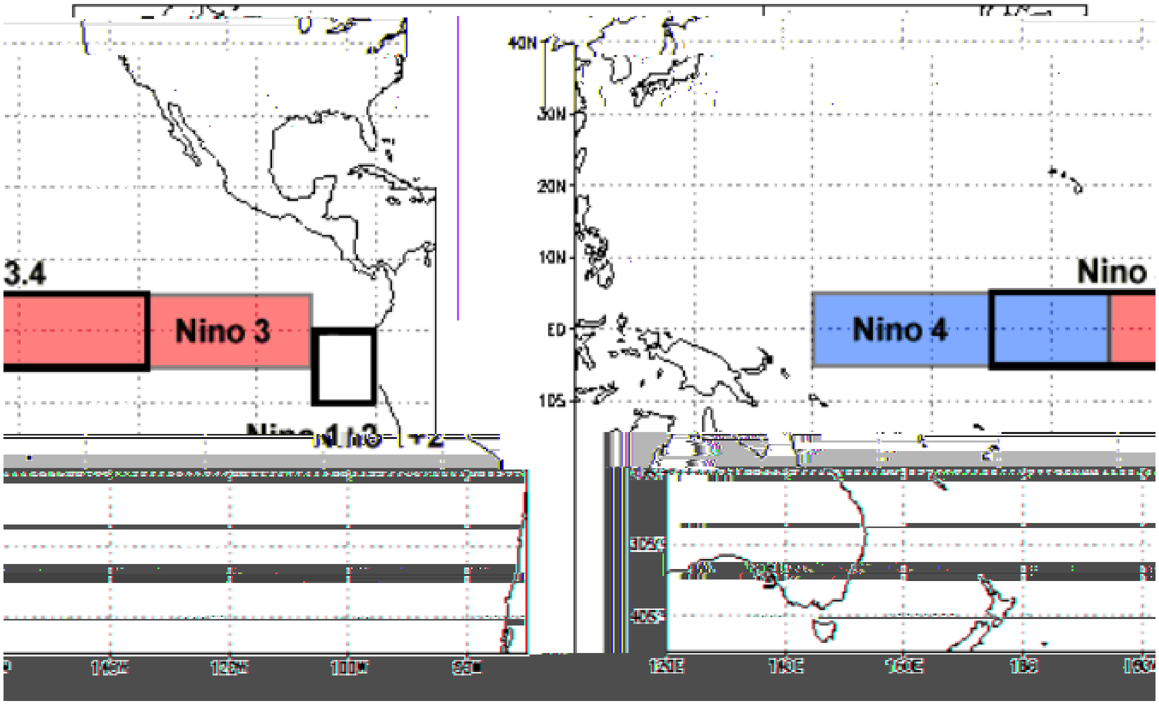

Figure 18: Location of ENSO SST regions used in Figure 17. Figure courtesy of the National Centers for Environmental Information.

Upper-ocean heat content anomalies in the eastern and central tropical Pacific have generally decreased over the past couple of months (Figure 19). Recently, there has been a pronounced trade wind surge in the central tropical Pacific (Figure 20). Despite this trade wind surge, we have not seen any strong signals of an upwelling (e.g., cooling) oceanic Kelvin wave response.

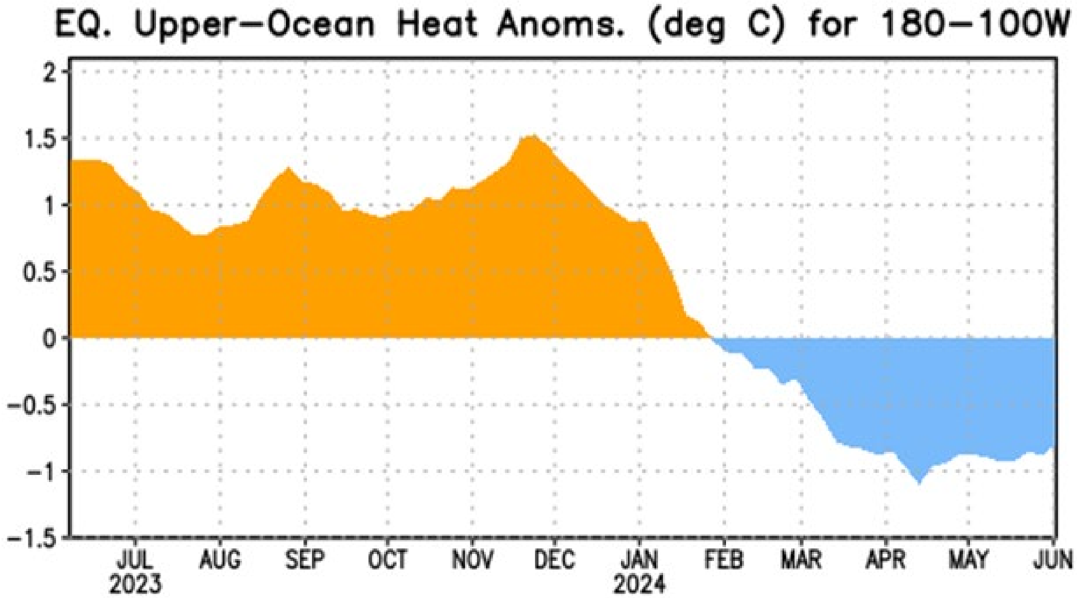

Figure 19: Central and eastern equatorial Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Figure courtesy of Climate Prediction Center.

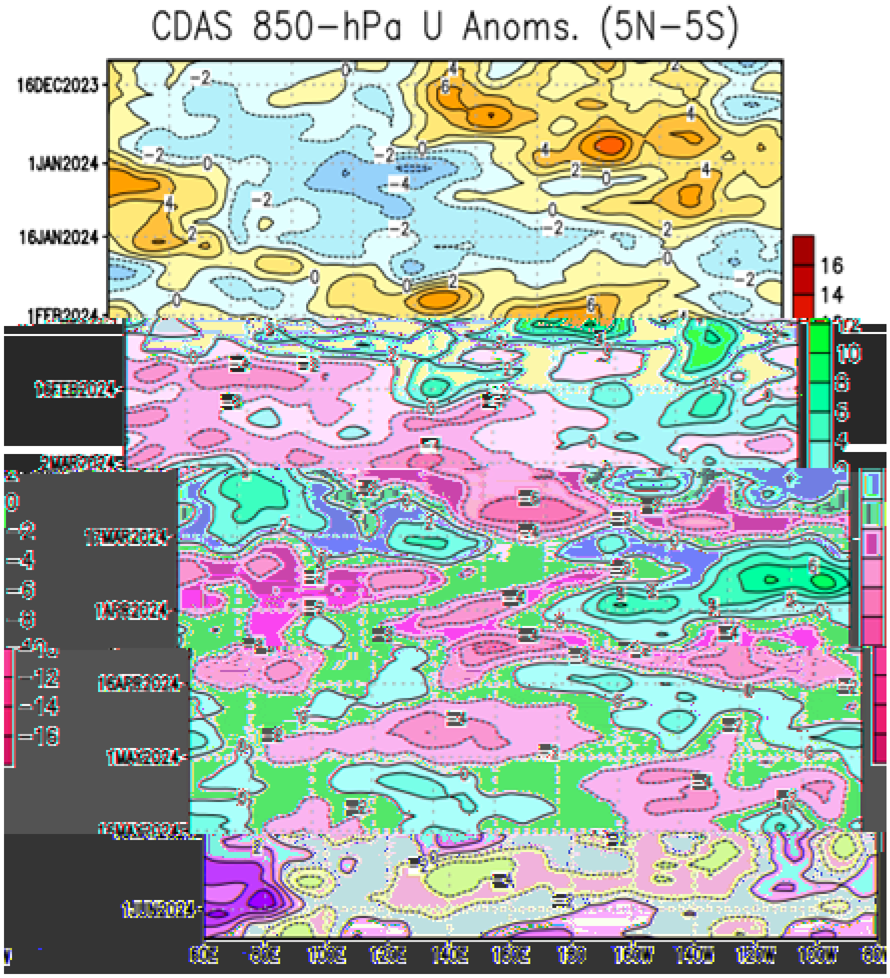

Figure 20: Anomalous equatorial low-level winds spanning from 60°E to 80°W. Figure courtesy of Climate Prediction Center.

SSTs are near average across most of the equatorial Pacific, with below-average SSTs beginning to emerge in parts of the eastern tropical Pacific (Figure 21). The western North Pacific is warmer than normal, while the current spatial pattern of SSTs in the North Pacific (e.g., well above-average SST anomalies across most of the North Pacific and below-average SSTs off the west coast of California) are indicative of a strongly negative phase of the Pacific Decadal Oscillation. The May Pacific Decadal Oscillation index in 2024 was its lowest May value since 1950.

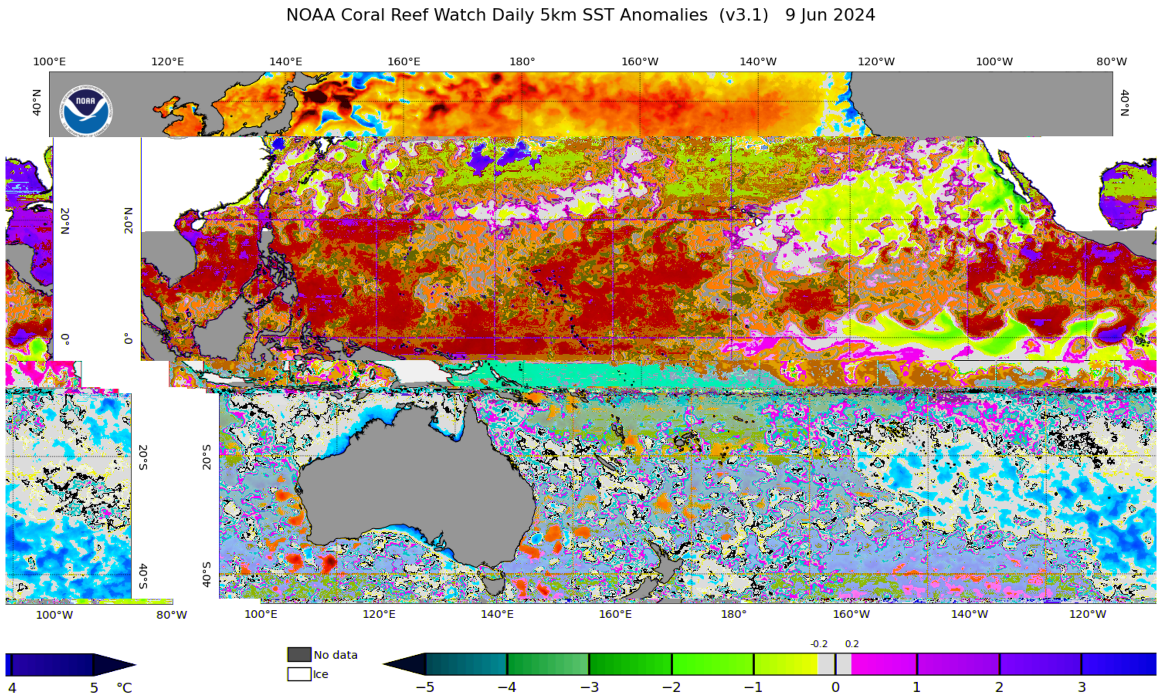

Figure 21: Current SST anomalies across the tropical and subtropical Pacific.

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

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

Region	March SST Anomaly (°C)	May SST Anomaly (°C)	May – March SST Anomaly (°C)
Nino 1+2	+0.3	-0.7	-1.0
Nino 3	+1.0	0.0	-1.0
Nino 3.4	+1.2	+0.3	-0.9
Nino 4	+0.9	+0.7	-0.2

An upwelling (cooling) oceanic Kelvin wave, denoted by the short dashed line, reached the west coast of South America in mid-May after transiting most of the tropical Pacific (Figure 22). In general, upper-ocean heat content anomalies are near average across the central tropical Pacific and below-average in the eastern tropical Pacific.

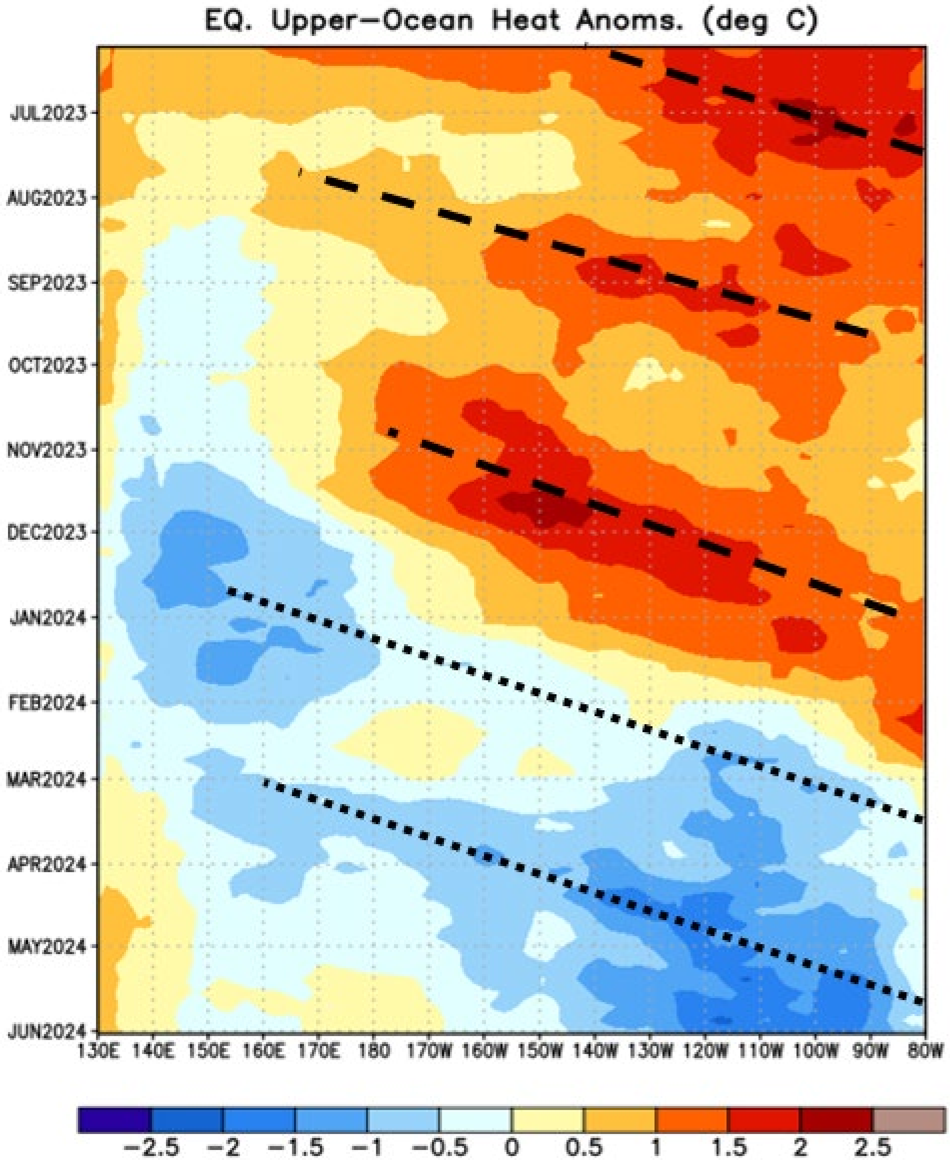

Figure 22: Upper-ocean (0–300 meter) heat content anomalies in the tropical Pacific since June 2023. Long dashed lines indicate downwelling Kelvin waves, while short dashed lines indicate upwelling Kelvin waves. Downwelling Kelvin waves result in upper-ocean heat content increases, while upwelling Kelvin waves result in upper-ocean heat content decreases. Figure courtesy of Climate Prediction Center.

Over the next several months, we will continue to monitor low-level winds over the tropical Pacific. Predominately enhanced low-level easterlies are forecast across the central tropical Pacific for the next few weeks (Figure 23). This is another signal that we are likely headed to La Niña conditions in the next few months.

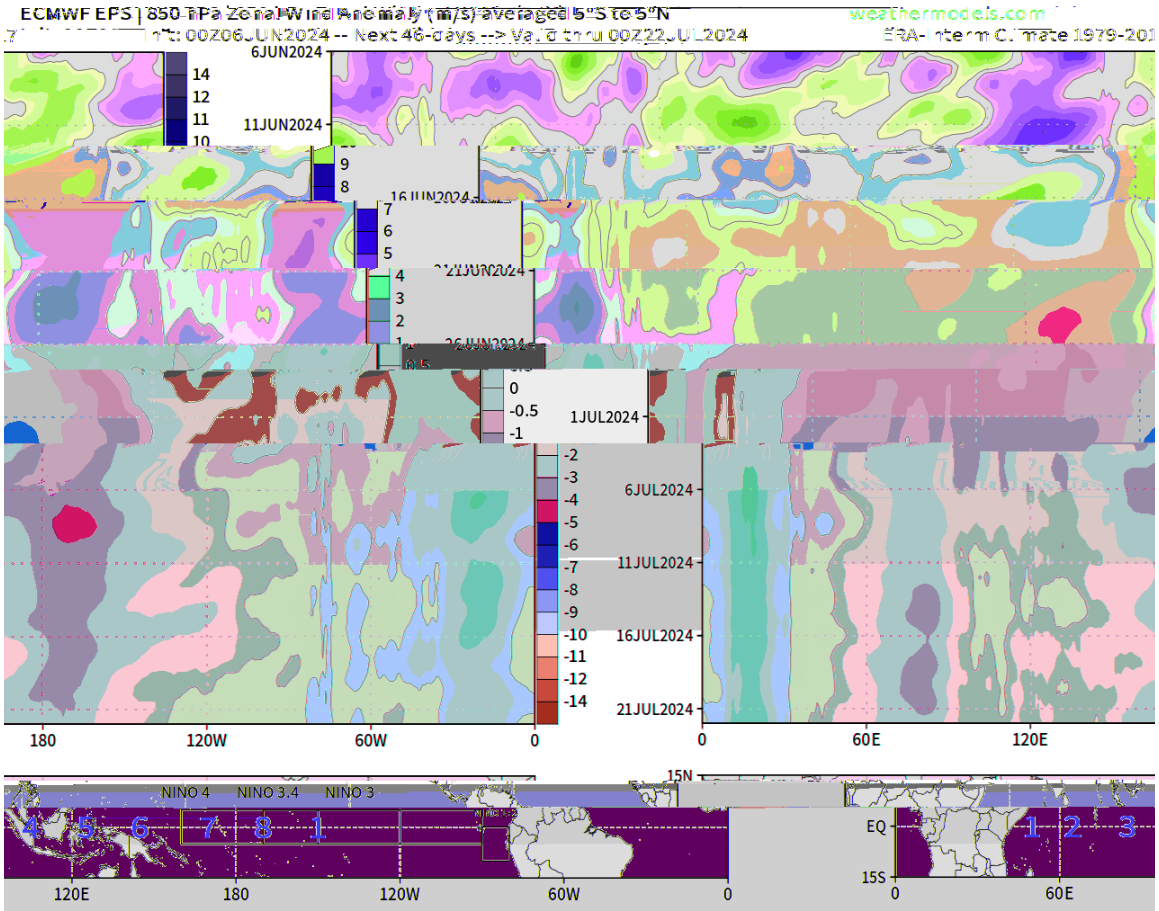

Figure 23: Forecast 850-hPa zonal equatorial winds through late July. Figure courtesy of weathermodels.com.

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 24). However, all models are forecasting El Niño to dissipate, with models split between neutral ENSO and La Niña conditions for the peak of the Atlantic hurricane season.

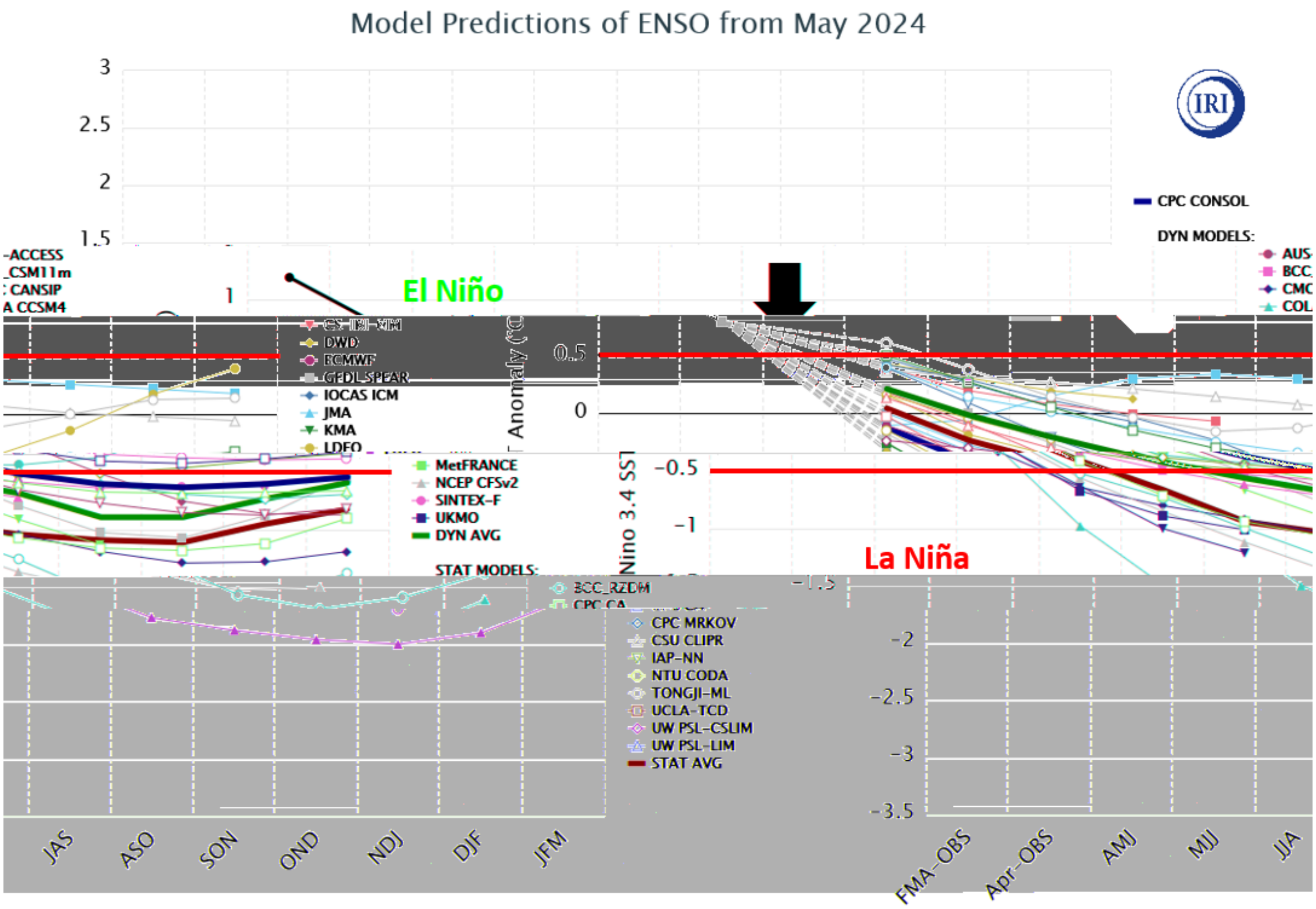

Figure 24: ENSO forecasts from various statistical and dynamical models for Nino 3.4 SST anomalies based on late April to early May initial conditions. All models call for either ENSO neutral or La Niña conditions for August–October. The black arrow delineates the peak of the Atlantic hurricane season (August–October). Figure courtesy of the International Research Institute (IRI).

The latest official forecast from NOAA favors La Niña for August–October. NOAA is currently predicting a 77% chance of La Niña, a 22% chance of ENSO neutral conditions and a 1% chance of El Niño for the peak of the Atlantic hurricane season (Figure 25).

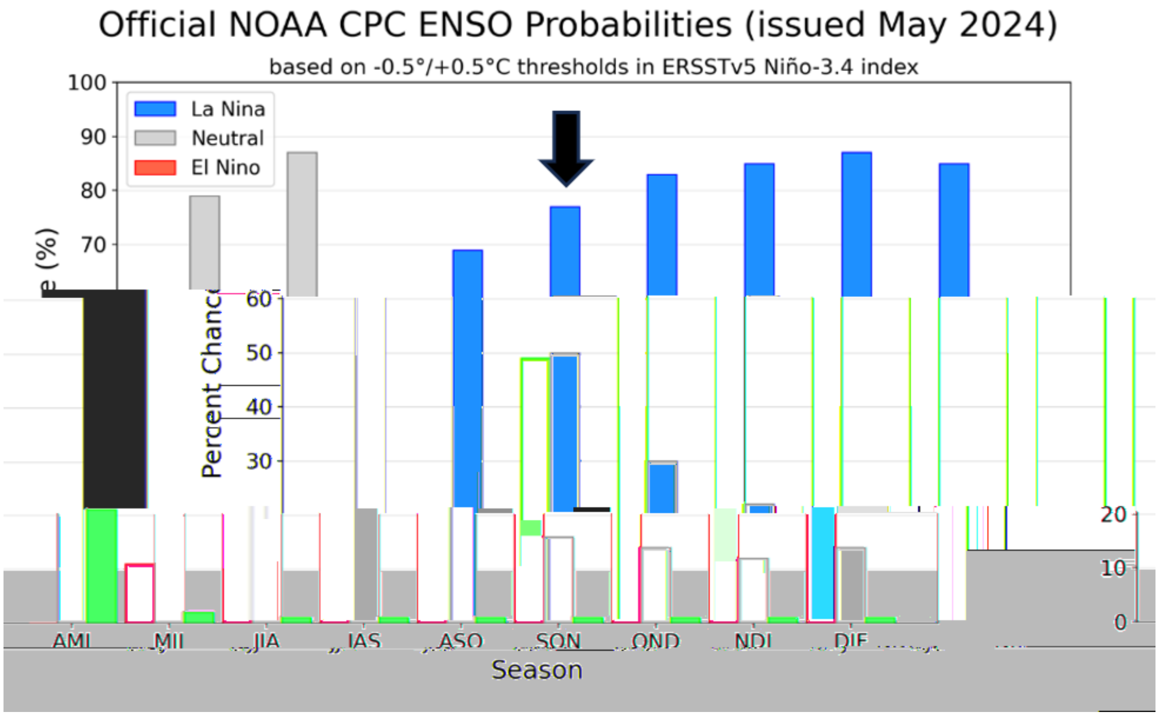

Figure 25: Official probabilistic ENSO forecast from NOAA. The black arrow delineates the peak of the Atlantic hurricane season (August–October).

Based on the above information, our best estimate is that we will have La Niña conditions for the peak of the Atlantic hurricane season. As noted earlier, there remains uncertainty if we transition to La Niña. Even if we do not transition to La Niña, we anticipate cool neutral ENSO conditions. The near-certain removal of the hurricane-unfavorable conditions presented by El Niño provide a likely opportunity for storms that form to capitalize on the strong oceanic heat in the basin regardless of the strength of a potentially developing La Niña.

5 Current Atlantic Basin Conditions

Currently, SSTs are at record warm levels across the Atlantic Main Development Region (10–20ºN, 85–20ºW) (Figure 26). Over the past several months, trade winds across most of the tropical and the eastern subtropical Atlantic have been weaker than normal, helping to reinforce the extremely warm SSTs that have predominated across the Atlantic over the past ~12 months (Figure 27). Weaker trade winds lead to less evaporation and mixing, favoring anomalous warming. Figure 28 shows the forecast for the next four weeks of low-level winds across the Atlantic. In general, trade winds are forecast to be weaker than average, indicating that extremely warm SST anomalies are likely to continue. Overall, the current SST anomaly pattern correlates extremely well with the June SST pattern that is typically seen in active Atlantic hurricane seasons (Figure 29).

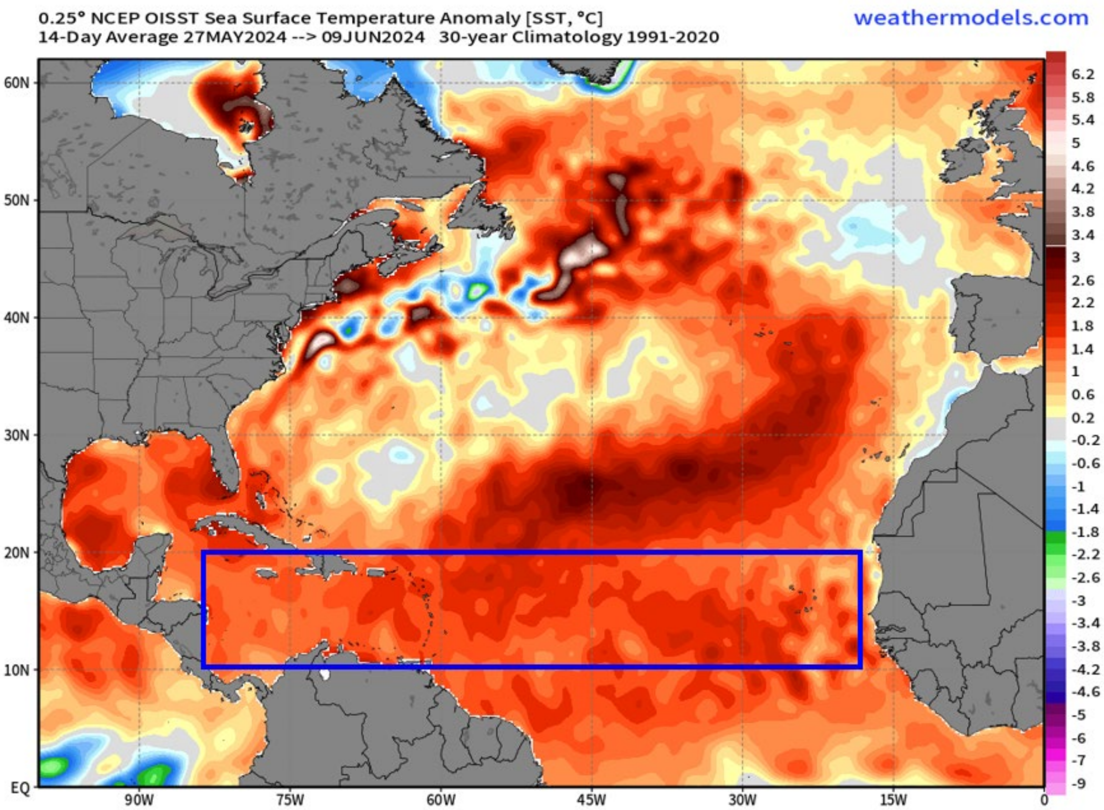

Figure 26: Late May/early June 2024 North Atlantic SST anomalies. The blue rectangle denotes the Atlantic Main Development Region.

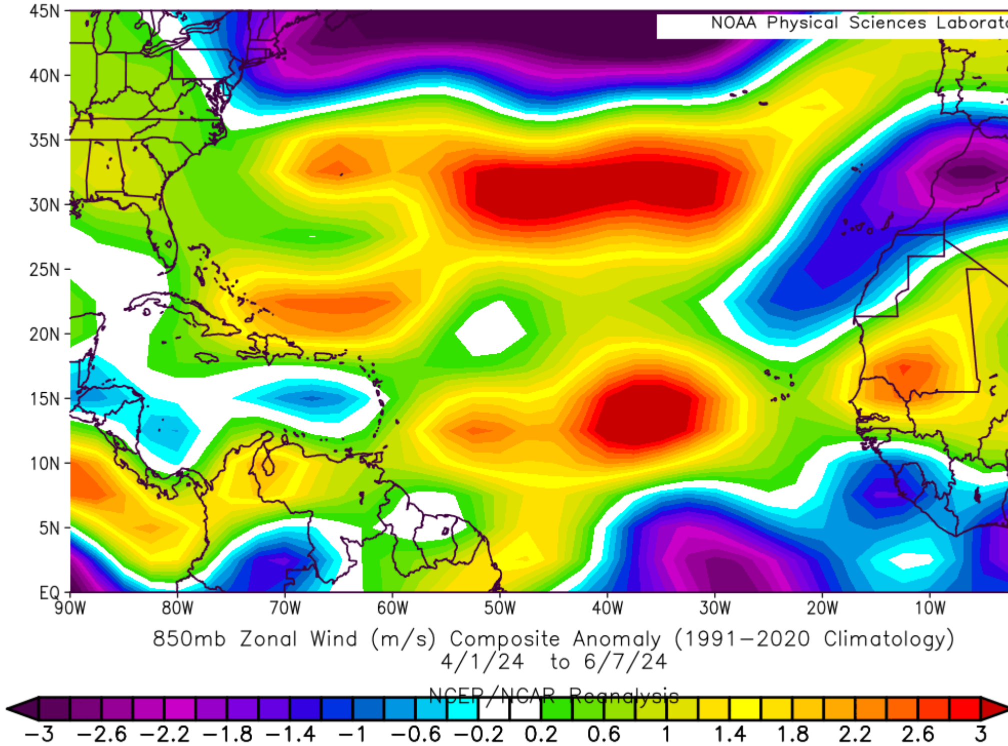

Figure 27: Zonal wind anomalies across the North Atlantic Ocean from April–early June 2024.

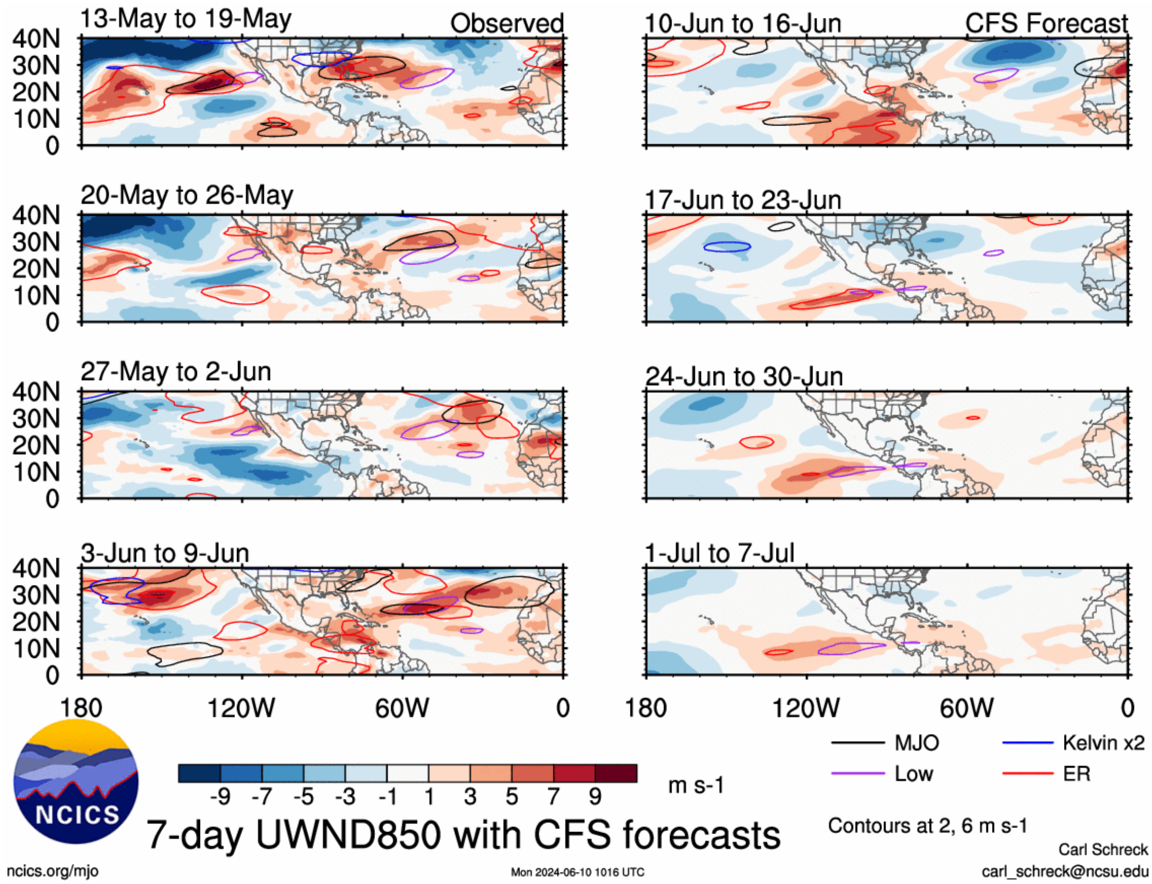

Figure 28: Observed low-level zonal winds across portions of the Western Hemisphere over the past four weeks and predicted low-level zonal winds from the Climate Forecast System through 7 July. Figure courtesy of Carl Schreck.

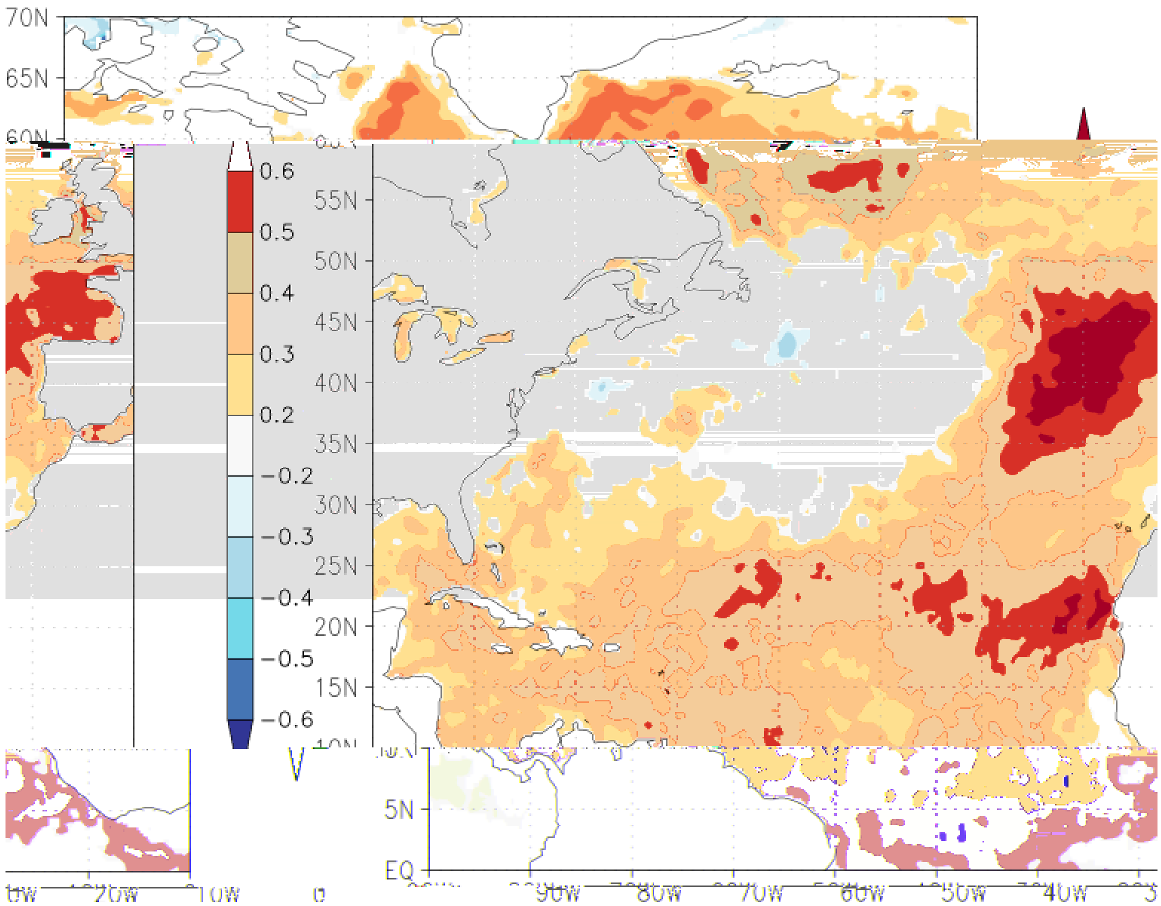

Figure 29: Rank correlations between June sea surface temperatures in the North Atlantic and annual Atlantic ACE from 1982–2023.

6 Tropical Cyclone Impact Probabilities for 2024

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 has been 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. Beginning this year, we are adjusting landfall probabilities based on the ratio of predicted ACE west of 60°W to the average ACE west of 60°W, as almost all landmasses that we are issuing probabilities for are west of 60°W.

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 2024. Landfall probabilities are well above their long-term averages. Probabilities for other Atlantic basin landmasses are available on our website.

Given that landfall rates between 1880–2020 and 1991–2020 are similar for the continental US, we adjust all landfall rates based on a ratio of the forecast ACE relative to the 1991–2020 Atlantic west of 60°W ACE climatology. We prefer to use 1880–2020 for landfall statistics to increase the robustness of the historical landfall dataset. Also, storms near landfall are likely better observed than those farther east in the basin prior to the satellite era (e.g., mid-1960s). Slight differences in ACE west of 60°W between the two periods (73 for 1991–2020 vs. 66 for 1880–2020) are likely mostly due to improved observational technology in the more recent period.

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 2024, based on the latest CSU seasonal hurricane forecast.

		2024 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	78%	43%	14%	58%	28%	8%
Connecticut	35%	13%	2%	22%	8%	1%
Delaware	35%	10%	1%	23%	6%	1%
Florida	96%	75%	44%	86%	56%	29%
Georgia	82%	46%	10%	63%	30%	6%
Louisiana	84%	56%	23%	66%	38%	14%
Maine	34%	11%	2%	21%	7%	1%
Maryland	47%	18%	1%	31%	11%	1%
Massachusetts	49%	23%	5%	33%	14%	3%
Mississippi	72%	43%	13%	53%	28%	8%
New Hampshire	29%	9%	2%	18%	6%	1%
New Jersey	35%	11%	1%	23%	7%	1%
New York	41%	16%	4%	26%	9%	2%
North Carolina	85%	56%	13%	68%	38%	8%
Rhode Island	32%	13%	2%	20%	8%	1%
South Carolina	76%	44%	14%	57%	29%	8%
Texas	80%	54%	25%	61%	36%	16%
Virginia	65%	31%	2%	46%	20%	1%

7 Summary

An analysis of a variety of different atmosphere and ocean measurements (through early 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 2024 will have well above-average activity. The big question marks with this season's prediction are the persistence of the extreme anomalous warmth in the tropical Atlantic, as well as the potential strength of a La Niña, should it develop as forecast.

8 Forthcoming Updated Forecasts of 2024 Hurricane Activity

We will be issuing seasonal updates of our 2024 Atlantic basin hurricane forecasts on **Tuesday 9 July and Tuesday 6 August**. We will also be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August–October. A verification and discussion of all 2024 forecasts will be issued on **Tuesday, 26 November**. All forecasts and verifications are 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 2014–2023 and from 1984–2023 for the June and August forecasts and from 1995–2013, 2014–2023 and from 1995–2023 for the April forecast, respectively. Correlation skill has improved at all lead times in recent years, with the most noticeable improvements at longer lead times. While ten 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:

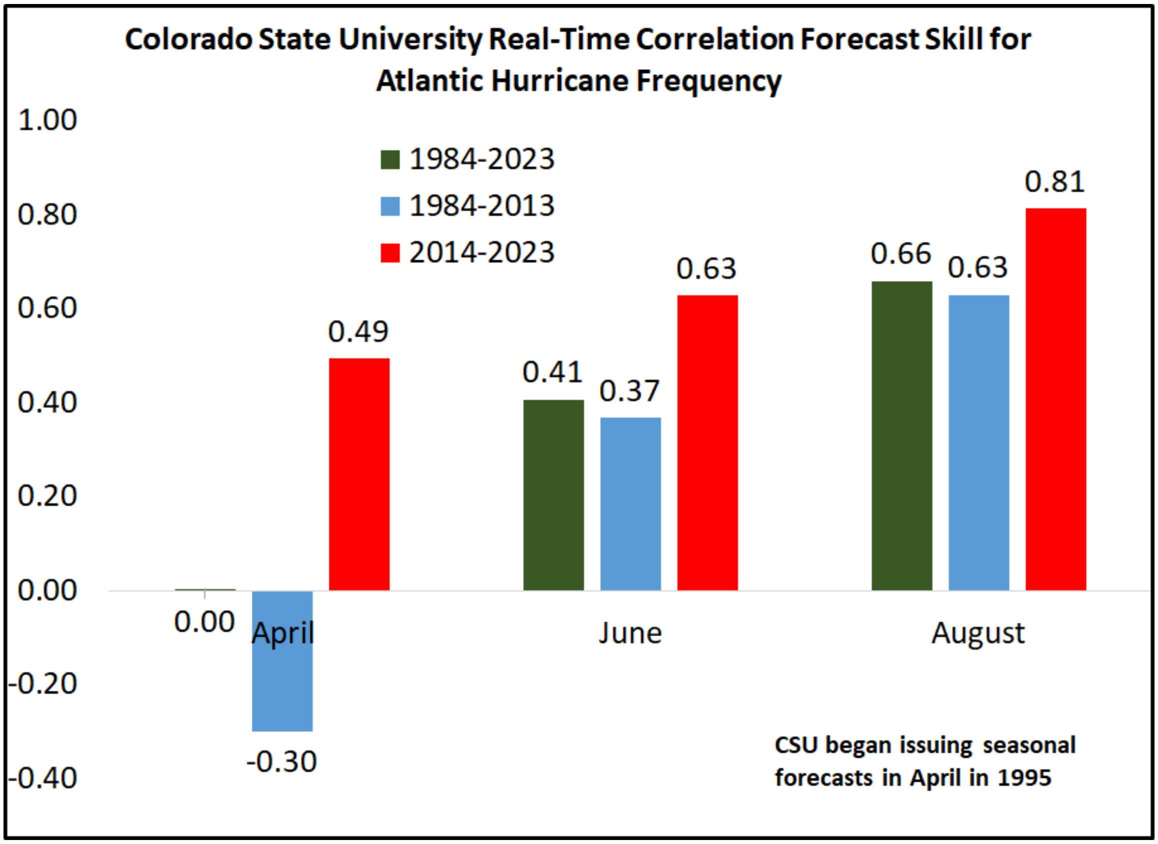

Figure 30: CSU's real-time forecast skill for Atlantic hurricanes using correlation as the skill metric. Correlation skills are displayed for three separate time periods: 1984–2013, 2014–2023 and 1984–2023 for the June and August forecasts and for 1995–2013, 2014–2023 and 1995–2023 for the April forecast.