EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2025

We anticipate that the 2025 Atlantic basin hurricane season will have above-normal activity. Current La Niña conditions are likely to transition to ENSO neutral conditions in the next couple of months; however, there remains considerable uncertainty as to what the phase of ENSO will be this summer and fall. Sea surface temperatures across the eastern and central Atlantic are generally warmer than normal, but not as warm as they were last year at this time. A warmer-than-normal tropical Atlantic combined with likely ENSO neutral (or potential La Niña) conditions typically provides a more conducive dynamic and thermodynamic environment for hurricane formation and intensification. We anticipate an 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 3 April 2025)

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In Memory of William M. Gray[6]

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2025

Forecast Parameter and 1991–2020 Average (in parentheses)	Issue Date 3 April 2025
Named Storms (NS) (14.4)	17
Named Storm Days (NSD) (69.4)	85
Hurricanes (H) (7.2)	9
Hurricane Days (HD) (27.0)	35
Major Hurricanes (MH) (3.2)	4
Major Hurricane Days (MHD) (7.4)	9
Accumulated Cyclone Energy (ACE) (123)	155
ACE West of 60°W (73)	93
Net Tropical Cyclone Activity (NTC) (135%)	165

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 – 51% (average from 1880–2020 is 43%)

2) U.S. East Coast Including Peninsula Florida (south and east of Cedar Key, Florida) – 26% (average from 1880–2020 is 21%)

3) Gulf Coast from the Florida Panhandle (west and north of Cedar Key, Florida) westward to Brownsville – 33% (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) 56% (average from 1880–2020 is 47%)

ABSTRACT

Information obtained through March indicates that the 2025 Atlantic hurricane season will have activity above the 1991–2020 average. We estimate that 2025 will have 17 named storms (average is 14.4), 85 named storm days (average is 69.4), 9 hurricanes (average is 7.2), 35 hurricane days (average is 27.0), 4 major (Category 3-4-5) hurricanes (average is 3.2) and 9 major hurricane days (average is 7.4). The probability of U.S. and Caribbean major hurricane landfall is estimated to be above its long-period average. We predict Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2025 to be approximately 125 percent of their long-term averages.

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.

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 utilized as well. We are also including statistical/dynamical models based on 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. All of our model guidance is pointing towards an above-normal season.

The tropical Pacific is currently characterized by weak La Niña conditions. These La Niña conditions are likely to transition to neutral ENSO conditions in the next couple of months; however, there is considerable uncertainty as to what the phase of ENSO will be this summer and fall. Sea surface temperatures in the eastern and central tropical Atlantic are warmer than normal, although not as warm as they were last year at this time. A warmer-than-normal Atlantic combined with ENSO neutral (or La Niña) conditions typically favors an active Atlantic hurricane season via dynamic and thermodynamic conditions that are conducive to developing hurricanes (e.g., low vertical wind shear, increased upper ocean heat content).

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 with respect 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 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 that are discussed in this paper highlighting his research legacy. His investments in both time and energy on these forecasts cannot be acknowledged enough.

We are grateful for support from Commodity Weather Group, 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 and Alex DesRosiers, Ph.D. graduates from 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, Lauren Beard, Delián Cólon Burgos, Jen DeHart, Chandler Jenkins, Nick Mesa, Angelie Nieves-Jiménez, Isaac Schluesche and Meghan Stell.

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 (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.

Relative Oceanic Nino Index (RONI) – Three-month running mean of SST anomalies in the Nino 3.4 region (5°S–5°N, 170–120°W) minus tropically-averaged (20°S–20°N) SST anomalies multiplied by a scaling factor.

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.

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 42nd 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 forecast with skill exceeding climatology. Four components are used to produce our April forecast. These components are a statistical regression model, a combined statistical/dynamical model, a selection of analog seasons, and lastly, qualitative adjustments to accommodate additional processes which may not be explicitly represented by these analyses. The statistical/dynamical models are 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). All of these models show skill at predicting TC activity based on ~25–40 years of historical data. 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

Our current April statistical forecast model uses ECMWF Reanalysis 5 (ERA5; Hersbach et al. 2020). This approach was developed on data from 1979–2020, was independently tested on data for 2021 and 2022 and was used for real-time forecasts in 2023–2024. This model shows significant skill in cross-validated hindcasts of Accumulated Cyclone Energy (ACE) ($r = 0.67$) over the period from 1979–2024 (Figure 1). Cross-validation entails that for each year being forecast, the equation is developed on all other years in the hindcast but excluding the year being forecast. So a forecast for 1979 would be based on a hindcast equation developed on 1980–2020, a forecast for 1980 would be based on a hindcast equation developed on 1979 and 1981–2020, etc. The model performed quite well in 2023 but was a significant over-forecast in 2024 due largely to the pronounced lull that occurred during the climatological peak of the 2024 season. We are finalizing a paper discussing the likely drivers of the lull.

Figure 2 displays the locations of each predictor, while Table 1 displays the individual linear correlations between each predictor and ACE over the 1979–2024 hindcast/forecast period. All predictors correlate significantly at the 5% level using a two-tailed Student's t-test, and each year is assumed to represent an individual degree of freedom. Table 2 displays the 2025 observed values for each of the three predictors in the statistical forecast scheme. Standard deviations are given relative to a 1991–2020 base period – the current 30-year NOAA climatological period. Table 3 displays the statistical model output for the 2025 hurricane season. The two SST predictors call for a very active Atlantic hurricane season, while the 200 hPa zonal wind predictor calls for a below-average season. The three predictors in combination call for a somewhat above-normal season.

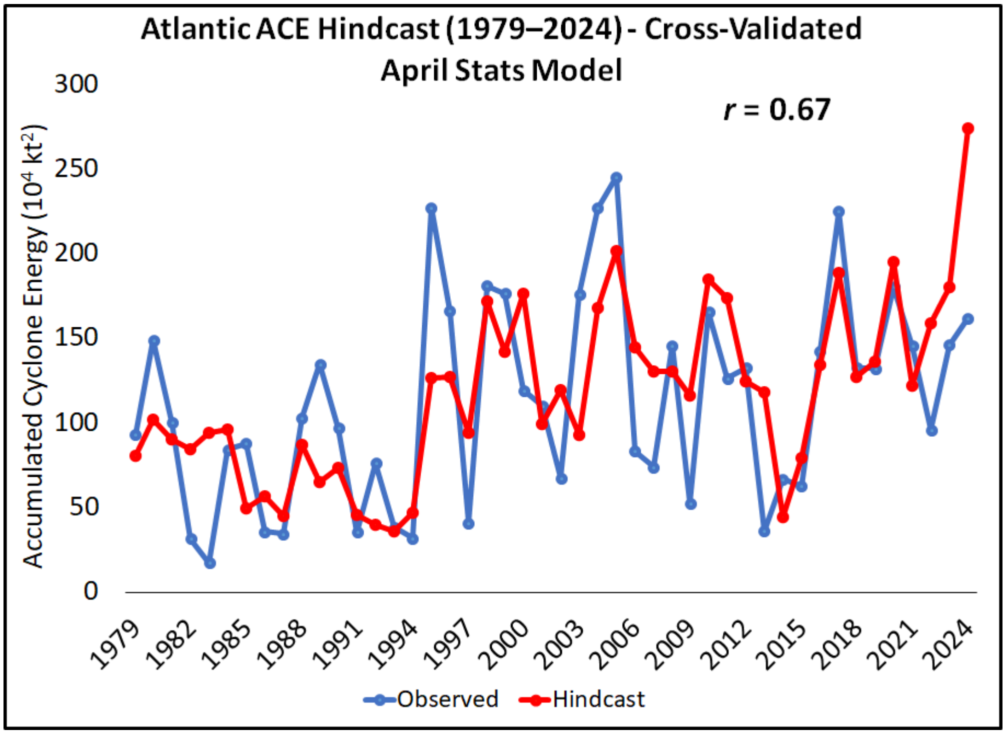

Figure 1: Observed versus early April cross-validated hindcast values of ACE for the statistical model from 1979–2024.

Statistical Model Predictors

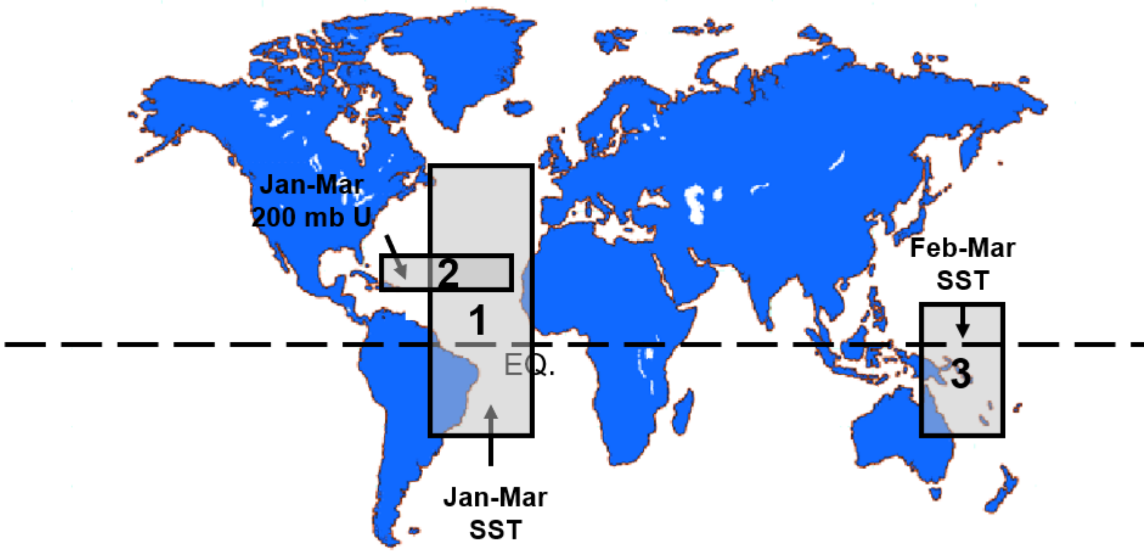

Figure 2: Location of predictors for our early April extended-range statistical prediction for the 2025 hurricane season.

Table 1: Linear correlation between early April predictors and ACE over the period from 1979–2024.

Predictor	Correlation w/ ACE
1) January–March SST (30°S–50°N, 40°W–10°W) (+)	0.53
2) January–March 200 hPa U (17.5°N–27.5°N, 60°W–20°W) (+)	0.43
3) February–March SST (30°S–15°N, 140°E–170°E) (+)	0.53

Table 2: Listing of early April 2025 predictors for the 2025 hurricane season. A plus (+) means that positive deviations of the parameter are associated with increased hurricane activity. SD stands for standard deviation.

Predictor	2025 Forecast Value	Impact on 2025 TC Activity
1) January–March SST (30°S–50°N, 40°W–10°W) (+)	+2.0 SD	Strongly Enhance
2) January–March 200 hPa U (17.5°N–27.5°N, 60°W–20°W) (+)	–1.8 SD	Strongly Suppress
3) February-March SST (30°S–15°N, 140°E–170°E) (+)	+1.4 SD	Strongly Enhance

Table 3: Statistical model output for the 2025 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)	17.6	17
Named Storm Days (NSD) (69.4)	81.3	85
Hurricanes (H) (7.2)	8.4	9
Hurricane Days (HD) (27.0)	33.5	35
Major Hurricanes (MH) (3.2)	3.9	4
Major Hurricane Days (MHD) (7.4)	9.7	9
Accumulated Cyclone Energy (ACE) (123)	151	155
Net Tropical Cyclone Activity (NTC) (135%)	166	165

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 positively 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.

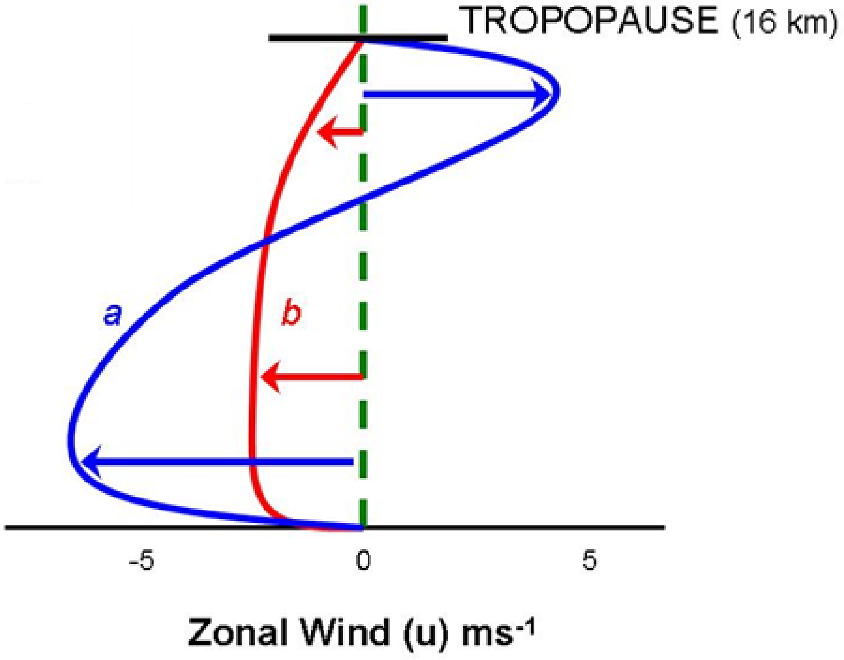

Figure 3: Vertical wind profile in the MDR typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (a) gives an example of increased vertical wind shear and (b) an example of reduced levels of vertical wind shear.

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 January–March are associated with a weaker-than-normal subtropical high and reduced trade wind strength during the boreal spring (Knaff 1997). Anomalously warm 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 (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 =0.53) with ACE from 1979–2024. Predictor 1 also strongly correlates (r = 0.60) with August–October values of the SST component of the Atlantic Meridional Mode (AMM) (Kossin and Vimont 2007) from 1979–2024. 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. 2022). 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).

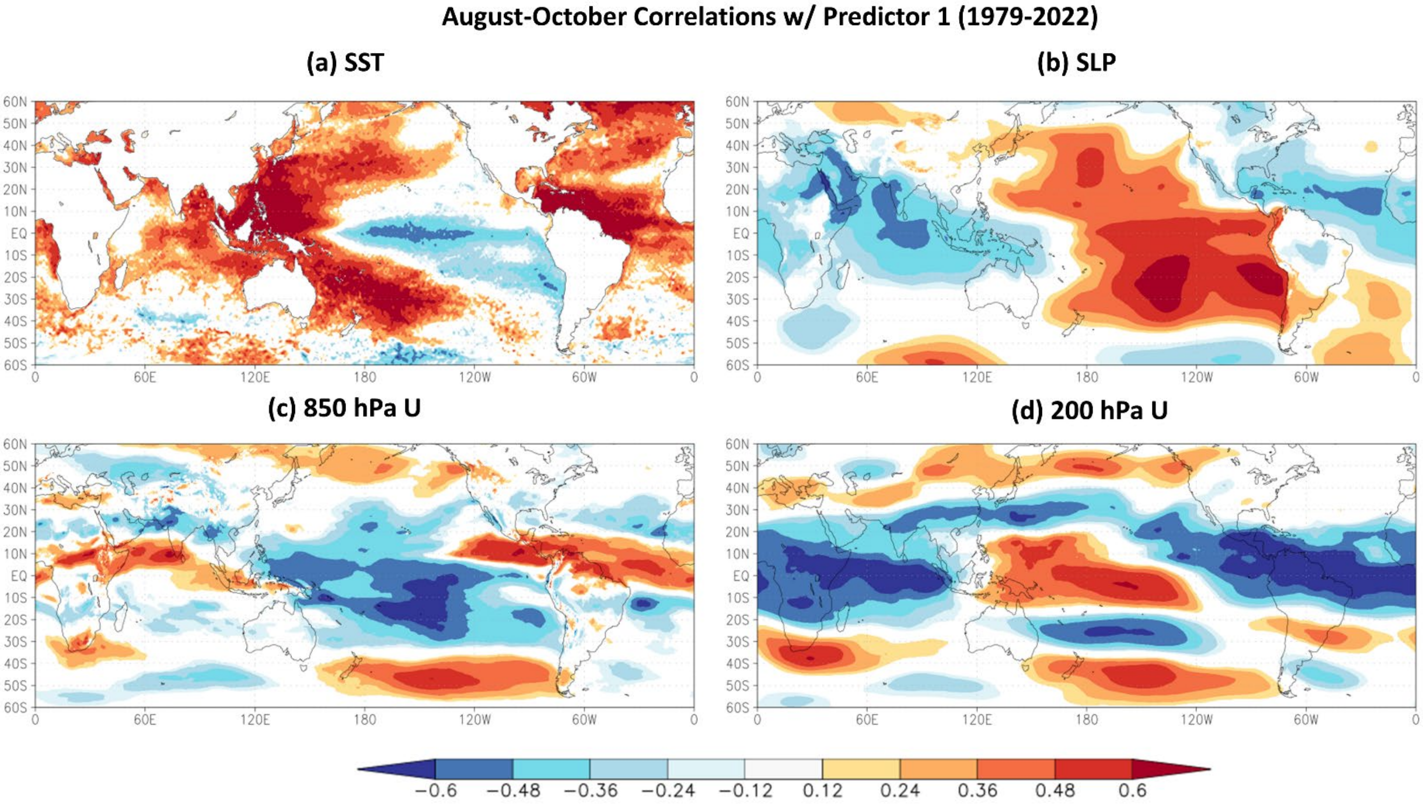

Figure 4: Rank correlations between January–March SST in the tropical and subtropical Atlantic (Predictor 1) and (panel a) August–October sea surface temperature, (panel b) August–October sea level pressure, (panel c) August–October 850 hPa zonal wind and (panel d) August–October 200 hPa zonal wind.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

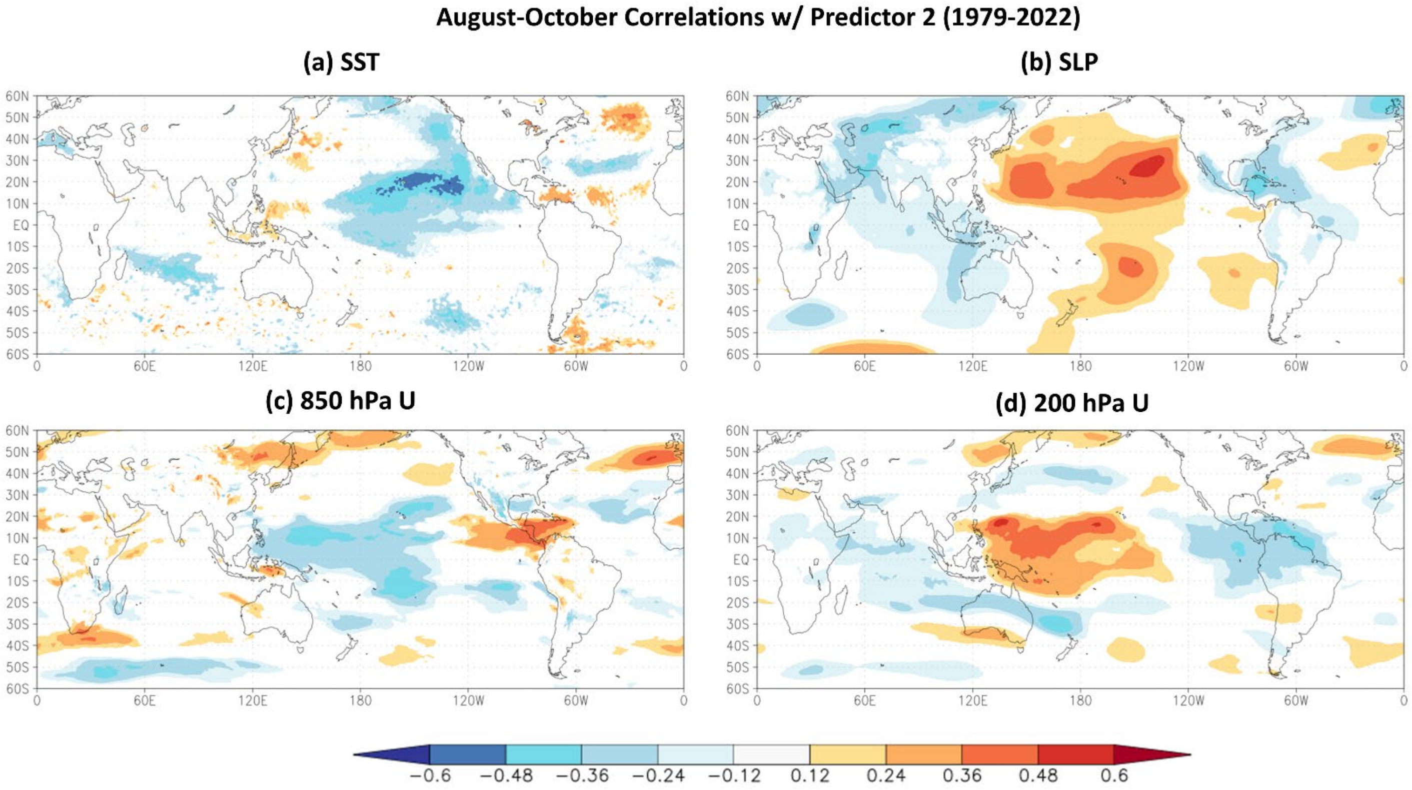

Figure 5: As in Figure 4 but for January–March 200 hPa zonal wind in the subtropical North Atlantic.

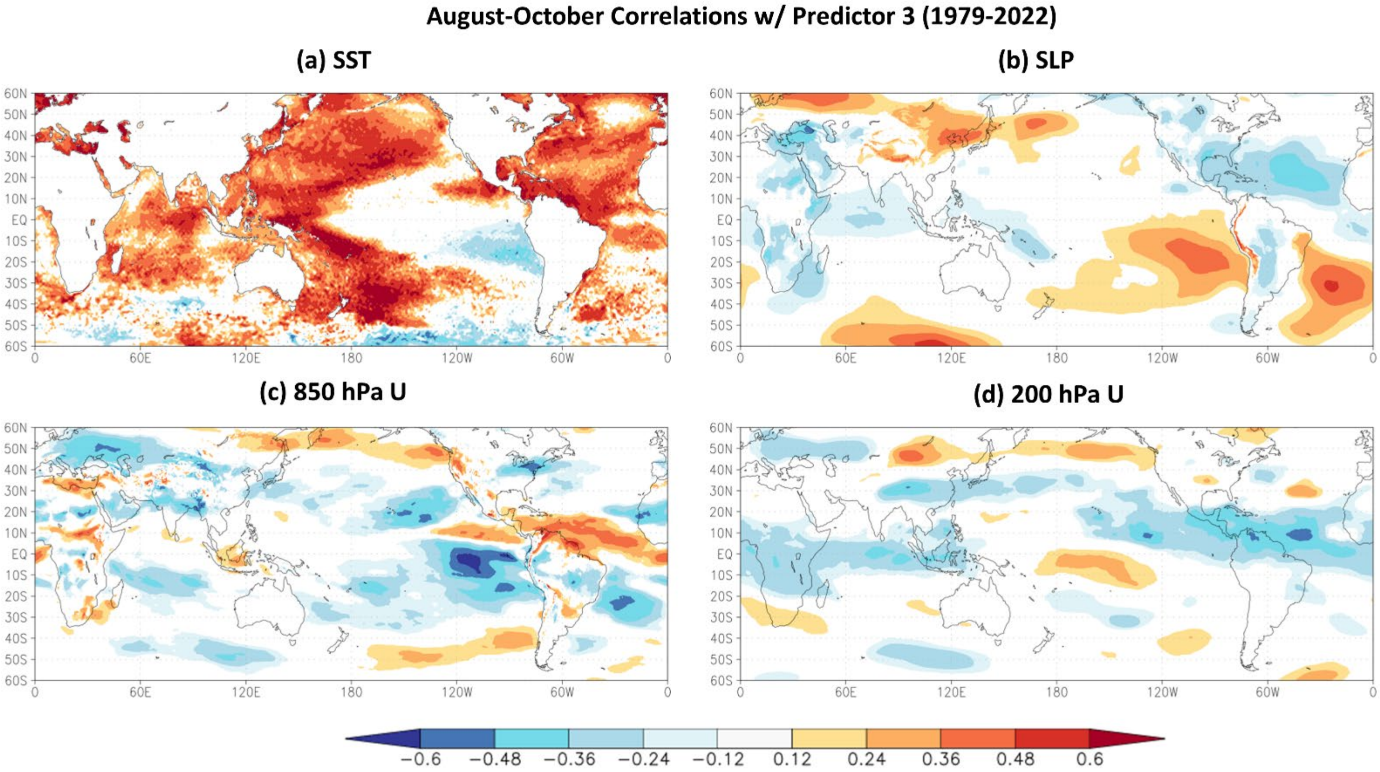

Figure 6: As in Figure 4 but for February–March SST in the western tropical/subtropical Pacific.

2.2 April Statistical/Dynamical Forecast Schemes

a) Statistical/Dynamical Model Predictor Ensemble Mean Output

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 now use four different models, namely, ECMWF, UK Met, JMA and CMCC, to forecast August SSTs in the eastern/central equatorial Pacific and in the eastern/central North Atlantic. We then use the forecasts of these individual models to forecast ACE for the 2025 season. ECMWF hindcasts are available from 1981–2024, while all other models have data available spanning the period from 1993–2016. All other predictands (e.g., named storms, major hurricanes) are calculated based on their historical relationships with ACE. These model forecasts extend out six months, which is why all forecasts here examine August data. All standard deviations are given relative to a 1993–2016 base period – the period for which all four different models have hindcasts.

Figure 7 displays the locations of the two forecast parameters, while Table 4 displays the various statistical/dynamical model forecasts for each of these parameters.

All models are calling for a very warm eastern and central tropical and subtropical Atlantic and neutral ENSO conditions. Table 5 displays the seasonal TC forecast output for the various statistical/dynamical models. These forecasts all call for a hyperactive[3] 2025 season. Figure 8 displays hindcasts for ECMWF forecasts of ACE from 1981–2024, while Figure 9 displays forecasts of ACE from all four statistical/dynamical models from 1993–2016 – the joint period where all four models have hindcasts available.

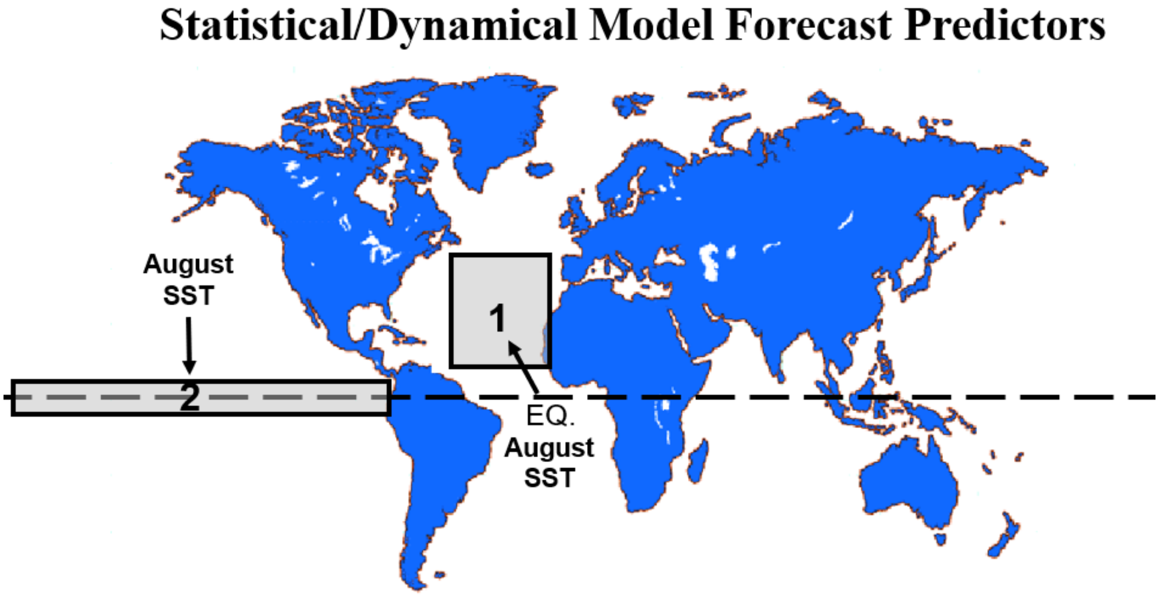

Figure 7: Location of predictors for our early April statistical/dynamical extended-range statistical prediction for the 2025 hurricane season. This forecast uses dynamical model predictions from ECMWF, the UK Met Office, JMA and CMCC to predict August SSTs in the two boxes displayed and then uses those predictors to forecast ACE.

Table 4: Listing of predictions of August large-scale conditions from our statistical/dynamical 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	ECMWF Forecast	UK Met Forecast	JMA Forecast	CMCC Forecast
1) August SST (10–45°N, 60–20°W) (+)	+1.9 SD	+3.0 SD	+2.3 SD	+3.5 SD
2) August SST (5°S–5°N, 180–90°W) (-)	+0.3 SD	0.0 SD	+0.2 SD	+0.1 SD

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[3] NOAA defines a hyperactive Atlantic hurricane season to have an ACE > 159.6 10^4 kt^2 (https://www.cpc.ncep.noaa.gov/products/outlooks/Background.html)

Table 5: Summary of our statistical/dynamical forecasts.

Forecast Parameter and 1991–2020 Average (in parentheses)	ECMWF Scheme	Met Office Scheme	JMA Scheme	CMCC Scheme	Adjusted Final Forecast
Named Storms (14.4)	18.8	18.4	19.0	21.2	17
Named Storm Days (69.4)	89.3	86.8	91.0	105.6	85
Hurricanes (7.2)	9.3	9.0	9.4	11.0	9
Hurricane Days (27.0)	37.8	36.5	38.7	46.7	35
Major Hurricanes (3.2)	4.4	4.3	4.6	5.5	4
Major Hurricane Days (7.4)	11.3	10.8	11.6	14.5	9
Accumulated Cyclone Energy Index (123)	170	164	174	209	155
Net Tropical Cyclone Activity (135%)	185	179	189	223	165

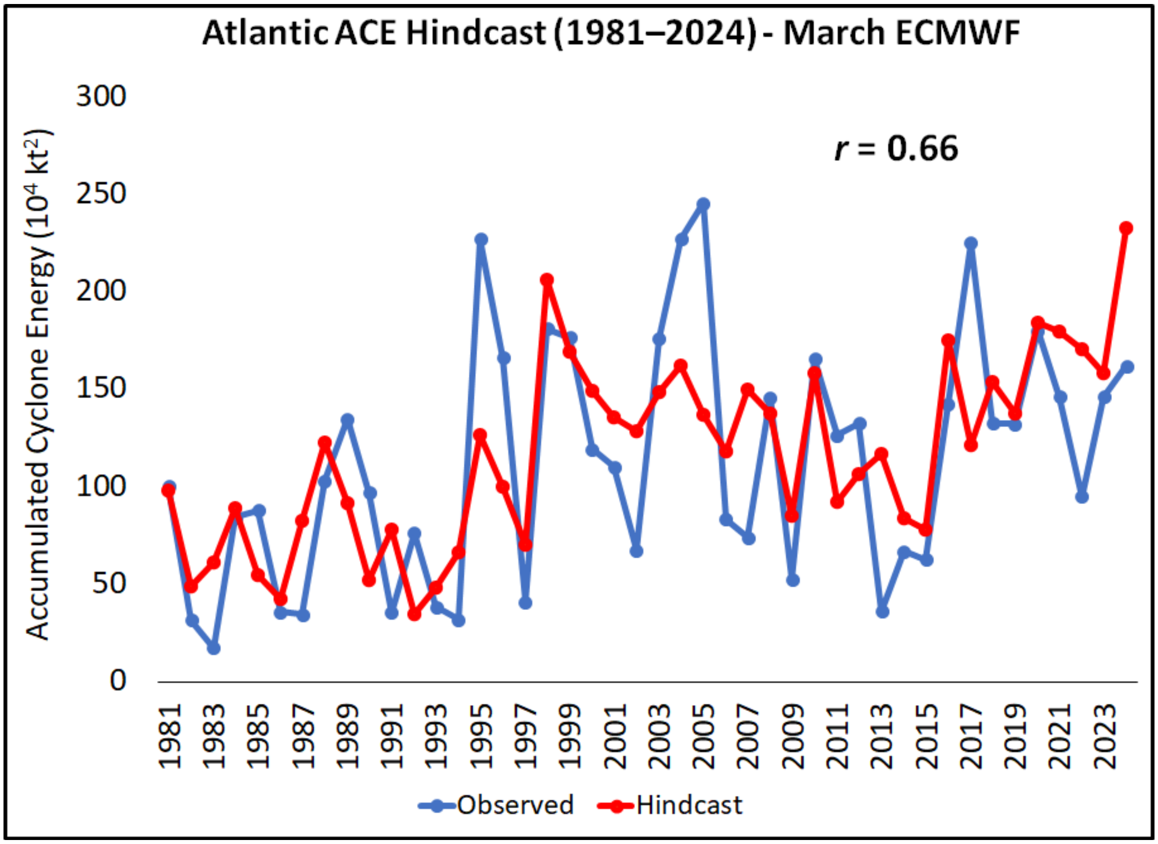

Figure 8: Observed versus statistical/dynamical hindcast values of ACE for 1981–2024 from ECMWF.

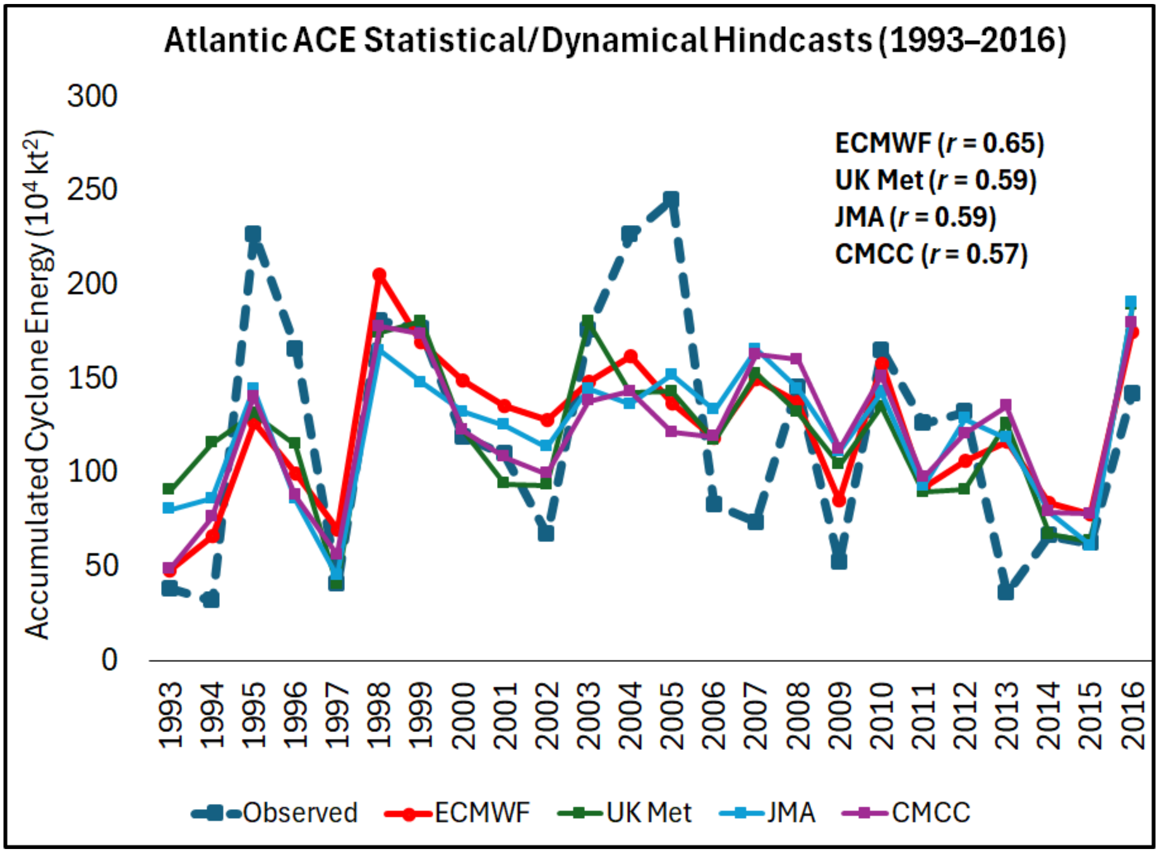

Figure 9: Observed versus statistical/dynamical hindcast values for all four statistical/dynamical models from 1993–2016.

b) *Statistical/Dynamical Model Predictor Ensemble Spread*

For the first time, we now include the ensemble spread of our statistical/dynamical model predictors to clarify what degree of confidence is warranted for each of the dynamical models in the ensemble average forecasts for the two predictors displayed in Table 6. For example, a larger-than-normal standard deviation in the ensemble spread would indicate a lower confidence and hence more uncertain forecast from that particular model for that particular predictor. Consequently in Table 6, lower standard deviations are associated with higher confidence forecasts. All standard deviations are calculated relative to the 1993–2016 period which is available for all four models.

Table 6: Standard deviation of the ensemble spread for the four forecast models (ECMWF, UK Met, JMA and CMCC) for the two predictors that comprise our statistical/dynamical model. A plus (+) means a lower confidence forecast, while a minus (-) means a higher confidence forecast.

Predictor	ECMWF St. Dev.	UK Met St. Dev.	JMA St. Dev.	CMCC St. Dev.
1) August SST (10–45°N, 60–20°W) (+)	+0.5 SD	+1.5 SD	-1.0 SD	+1.8 SD
2) August SST (5°S–5°N, 180–90°W) (-)	-0.5 SD	-0.1 SD	-0.2 SD	-0.3 SD

All models except for JMA have somewhat larger uncertainty with the August Atlantic SST predictor, while all four models are slightly more confident than normal for the tropical Pacific SST predictor. There remains considerable uncertainty with all dynamical model forecasts given the long lead time.

2.3 April Analog Forecast Scheme

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2025. These years also provide useful clues as to likely levels of activity that the forthcoming 2025 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 2025 conditions and, more importantly, projected August–October 2025 conditions. Table 7 lists our analog selections, while Figure 10 shows the composite August–October SST in our six analog years.

We searched for years that were the second year following an El Niño event and had La Niña conditions during the boreal winter of the current year. We also selected years that generally had above-average SSTs in the tropical and subtropical Atlantic. We anticipate that the 2025 hurricane season will have activity near the average of our six analog years for most parameters.

Table 7: Analog years for 2025 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1996	13	79.00	9	45.00	6	13.00	166.2	192.2
1999	12	78.50	8	41.00	5	14.25	176.5	181.7
2006	10	58.00	5	21.25	2	2.00	83.3	86.8
2008	16	88.25	8	30.50	5	7.50	145.7	162.3
2011	19	89.75	7	26.00	4	4.50	126.3	144.9
2017	17	93.00	10	51.75	6	19.25	224.9	232.2
Average	14.5	81.1	7.8	35.9	4.7	10.1	153.8	166.7
2025 Forecast	**17**	**85**	**9**	**35**	**4**	**9**	**155**	**165**

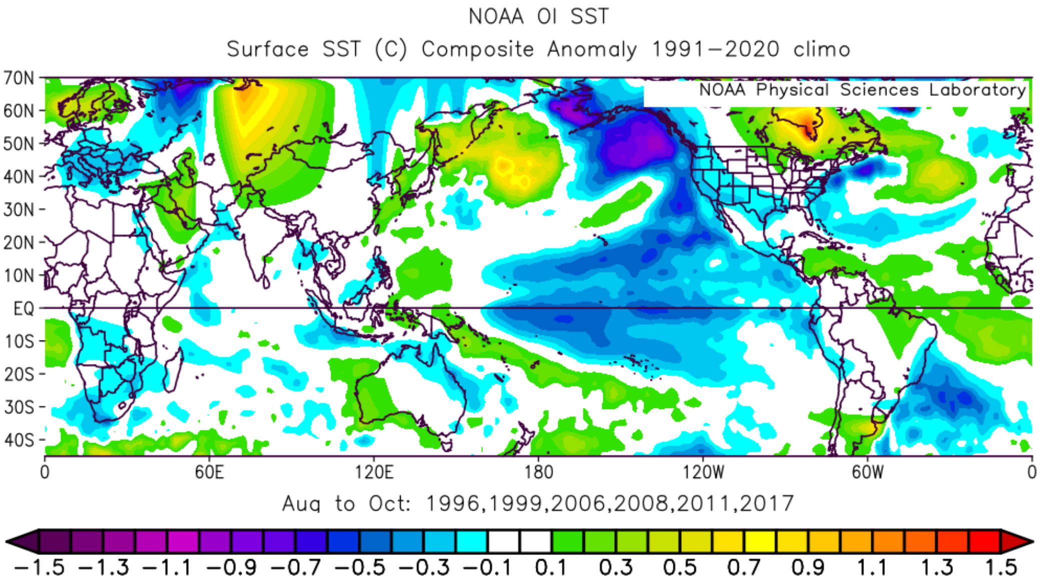

Figure 10: Average August–October SST anomalies in our six analog years.

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 11 and 12) since 1979. In this analysis, we only count one landfall per storm, regardless if the storm made multiple landfalls at hurricane strength (e.g., Irma–2017).

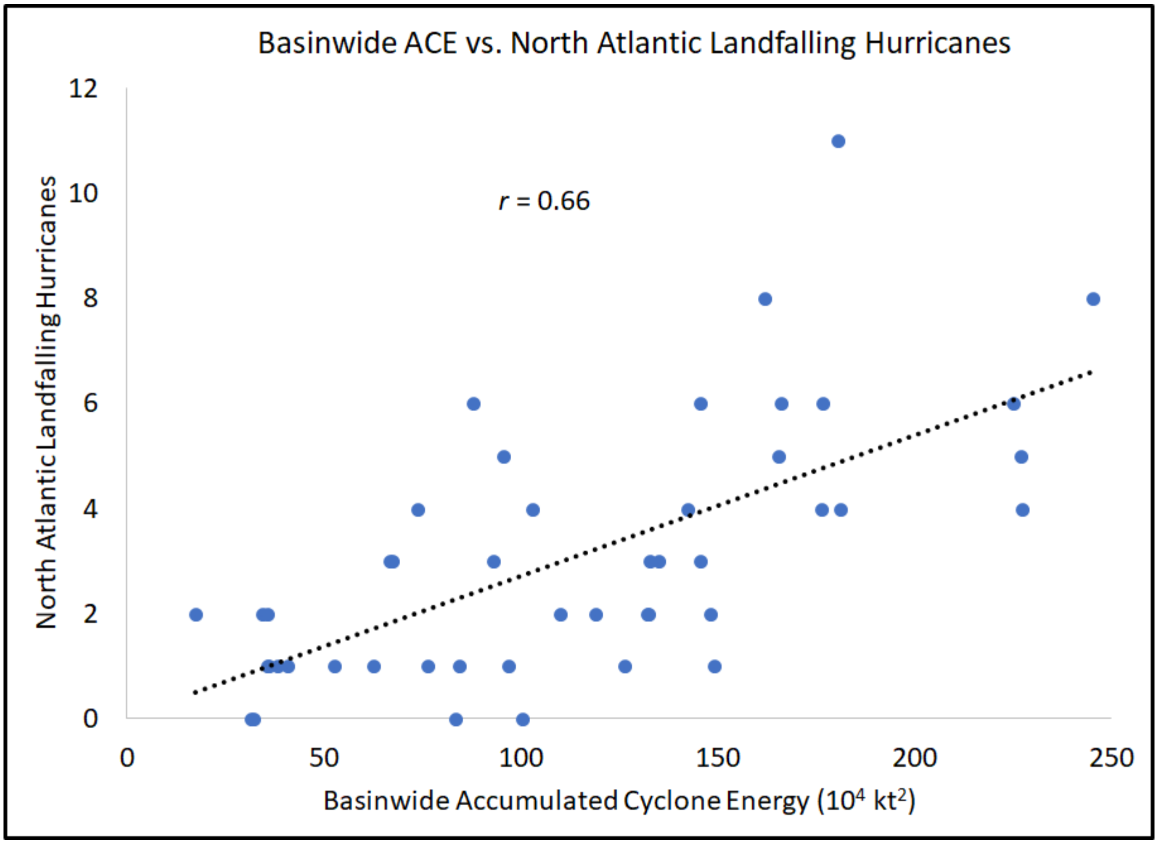

Figure 11: Scatterplot showing relationship between basinwide ACE and North Atlantic landfalling hurricanes.

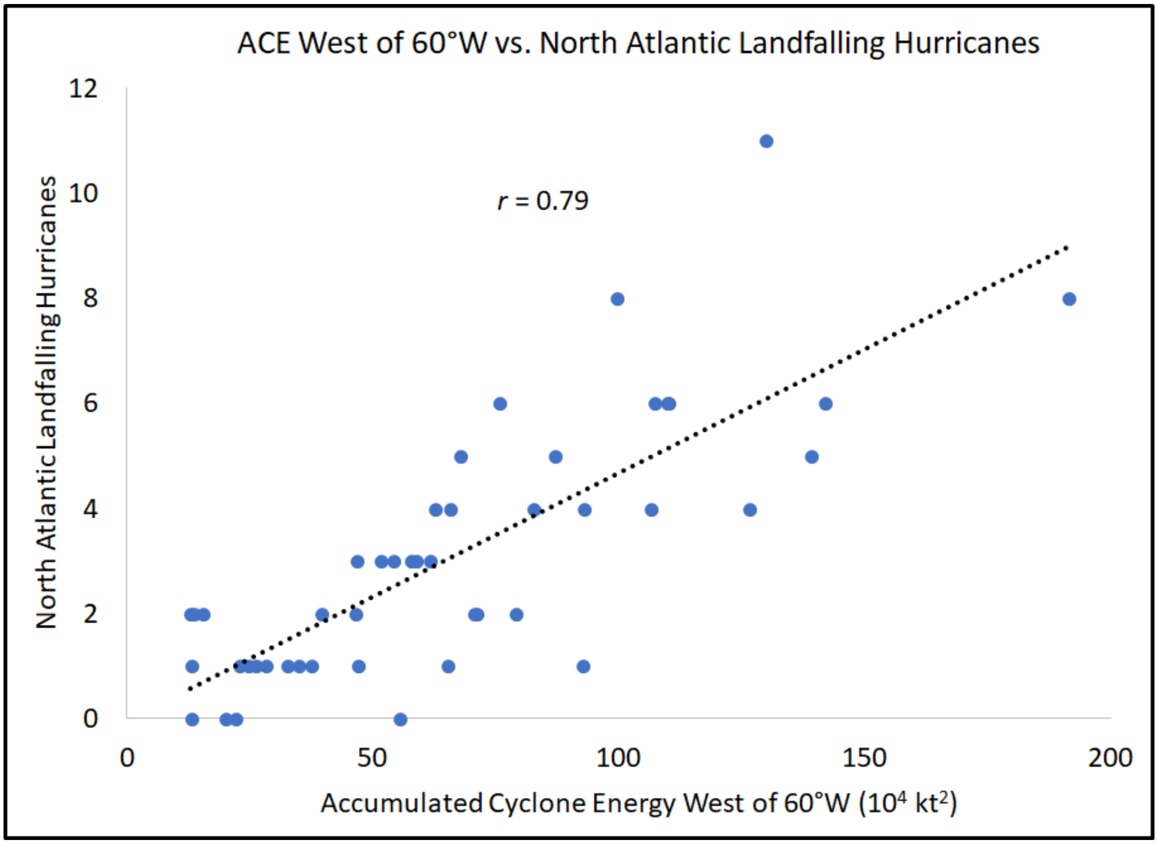

Figure 12: Scatterplot showing relationship between ACE west of 60°W and North Atlantic landfalling hurricanes.

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 and 2024. 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. In 2024, the western Atlantic was much busier for TC formations, and 8 of the 11 hurricanes that formed last year made landfall west of 60°W. 48% and 62% of basinwide ACE occurred west of 60°W in 2023 and 2024, respectively.

We use data from 1979–2024 and base ENSO classifications on the August–October-averaged Relative Oceanic Nino Index (RONI). Years with an RONI >= 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. The RONI index is calculated by differencing SSTs in the Nino 3.4 region (5°S–5°N, 170–120°W) from tropical mean SST (20°S–20°N, 0°–360°) and scaling the time series to match the variability of the observed SST in the Nino 3.4 region.

We find that 54% of basinwide ACE occurs west of 60°W in El Niño years, while 62% of basinwide ACE occurs west of 60°W in La Niña years. In neutral ENSO years, 58% of basinwide ACE occurs west of 60°W. Given that we are expecting cool neutral ENSO conditions with this outlook, we are estimating ~60% of basinwide ACE to occur west of 60°W in 2025.

2.5 April Forecast Summary and Final Adjusted Forecast

Table 8 shows our final adjusted early April forecast for the 2025 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. We favor our statistical and analog guidance over our statistical/dynamical model guidance due to recent anomalous cooling that has occurred across the tropical Atlantic (discussed in section 5). All our forecast model guidance is calling for an above-average season, however, there remains considerable uncertainty with this outlook given uncertainty in the large-scale environmental conditions that will be present during the peak of the upcoming season (August–October).

Table 8: 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 2025 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)	17.6	18.8	18.4	19.0	21.2	14.5	18.3	17
Named Storm Days (69.4)	81.3	89.3	86.8	91.0	105.6	81.1	89.2	85
Hurricanes (7.2)	8.4	9.3	9.0	9.4	11.0	7.8	9.2	9
Hurricane Days (27.0)	33.5	37.8	36.5	38.7	46.7	35.9	38.2	35
Major Hurricanes (3.2)	3.9	4.4	4.3	4.6	5.5	4.7	4.6	4
Major Hurricane Days (7.4)	9.7	11.3	10.8	11.6	14.5	10.1	11.3	9
Accumulated Cyclone Energy Index (123)	151	170	164	174	209	154	170	155
Net Tropical Cyclone Activity (135%)	166	185	179	189	223	167	185	165

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 the particular values of hurricane numbers and ACE would be exceeded. Here we display probability of exceedance curves for hurricanes and ACE (Figures 13 and 14), using the error distributions calculated from both normalized cross-validated statistical as well as the cross-validated statistical/dynamical hindcasts from SEAS5. Hurricane numbers are fit to a Poisson distribution, while ACE is fit to a Weibull distribution. Table 9 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.

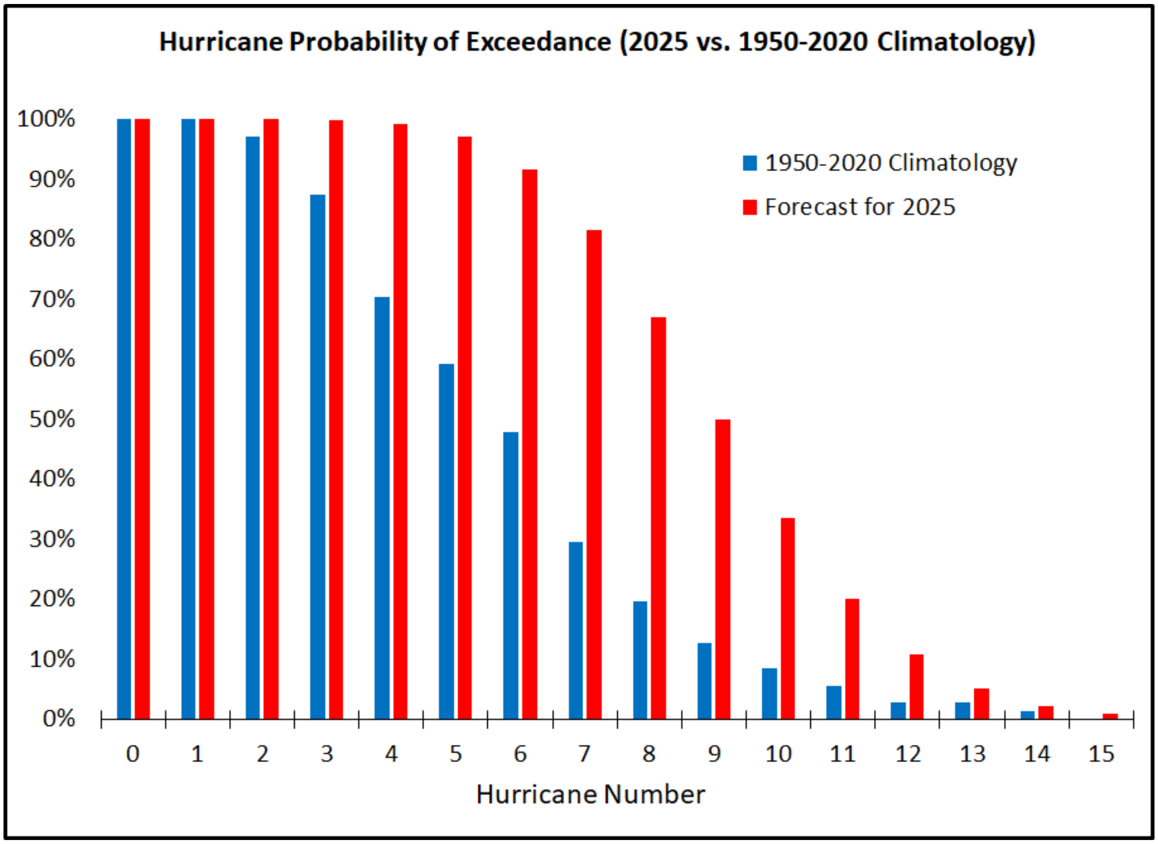

Figure 13: Probability of exceedance plot for hurricane numbers for the 2025 Atlantic hurricane season. The values on the x-axis indicate that the number of hurricanes exceeds that specific number. For example, 97% of Atlantic hurricane seasons from 1950–2020 have had more than two hurricanes.

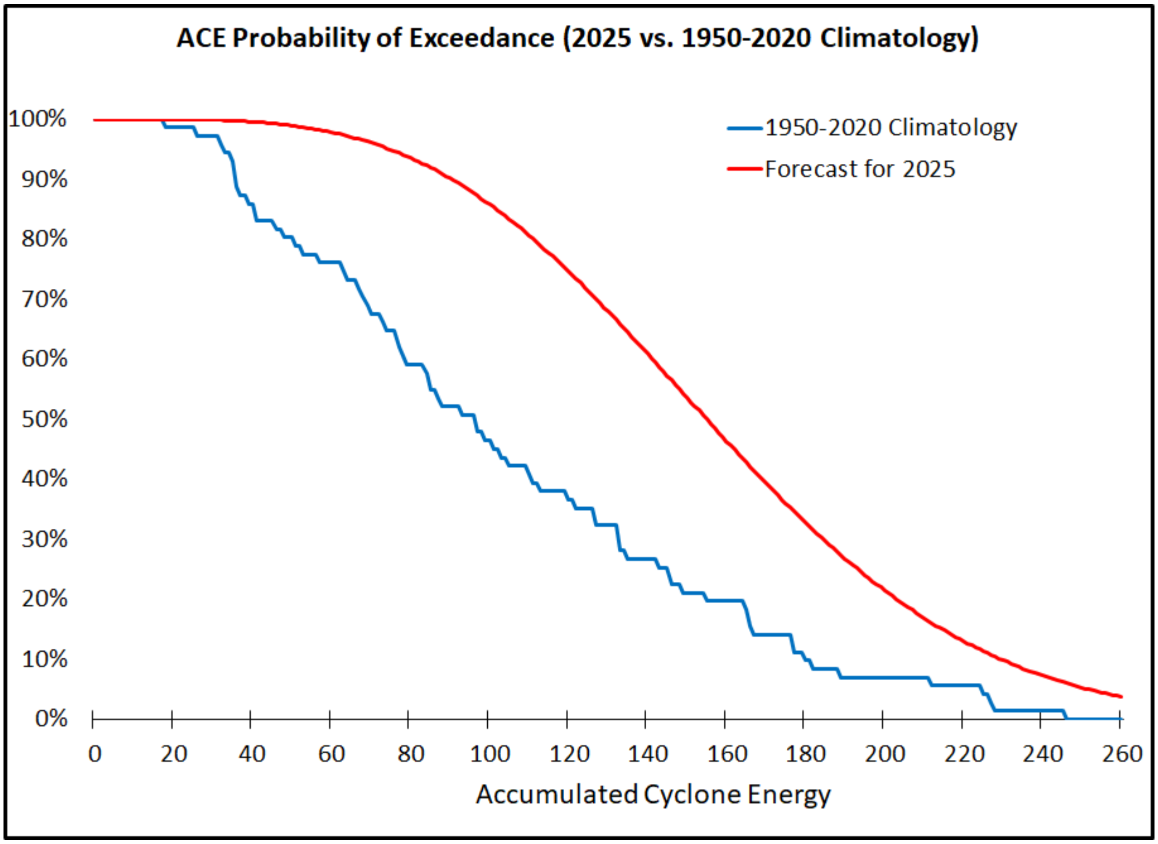

Figure 14: As in Figure 13 but for ACE.

Table 9: 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	2025 Forecast	Uncertainty Range (68% of Forecasts Likely to Fall in This Range)
Named Storms (NS)	17	14 – 20
Named Storm Days (NSD)	85	62 – 109
Hurricanes (H)	9	7 – 12
Hurricane Days (HD)	35	22 – 50
Major Hurricanes (MH)	4	2 – 6
Major Hurricane Days (MHD)	9	6 – 14
Accumulated Cyclone Energy (ACE)	155	102 – 215
ACE West of 60°W	93	57 – 136
Net Tropical Cyclone (NTC) Activity	165	113 – 222

4 ENSO

Over the past several months, La Niña conditions in the tropical Pacific have gradually weakened (Figure 15), with anomalously warm SSTs now predominating in the eastern part of the basin. SST anomalies have increased across the entire tropical Pacific, with the strongest anomalous warming taking place in the far eastern tropical Pacific. Figure 16 displays the locations of the various Nino regions displayed in Figure 15.

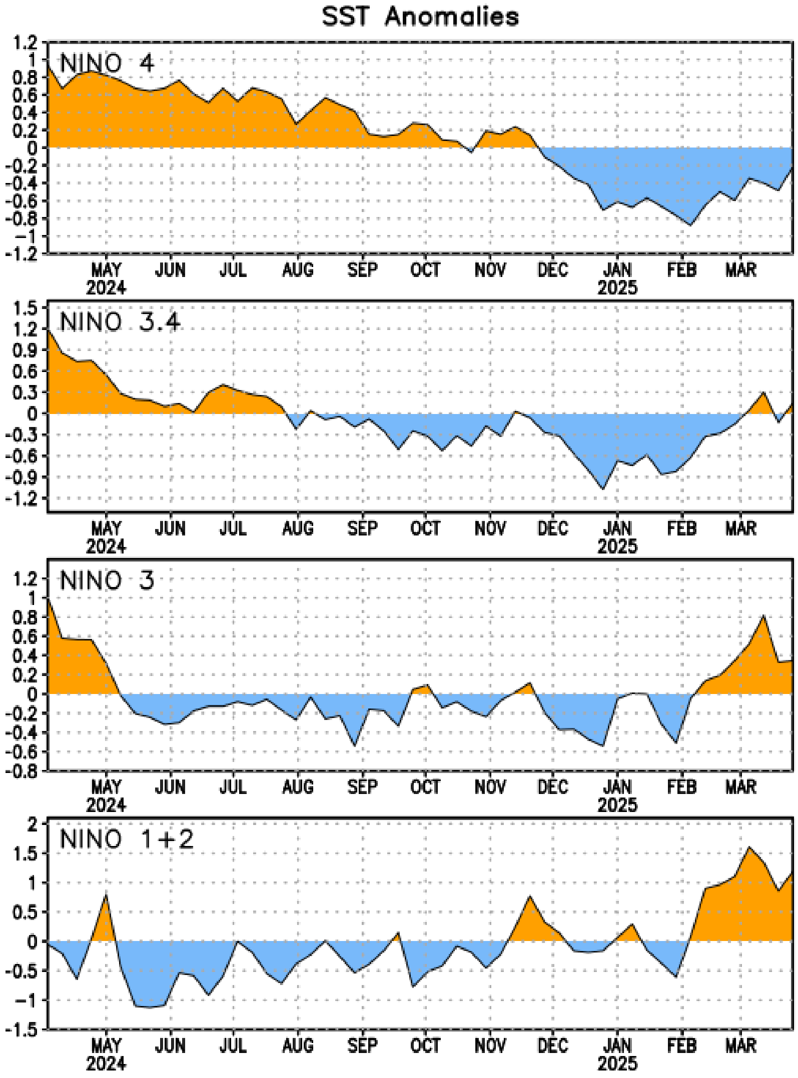

Figure 15: SST anomalies for several ENSO regions over the past year. Figure courtesy of the Climate Prediction Center.

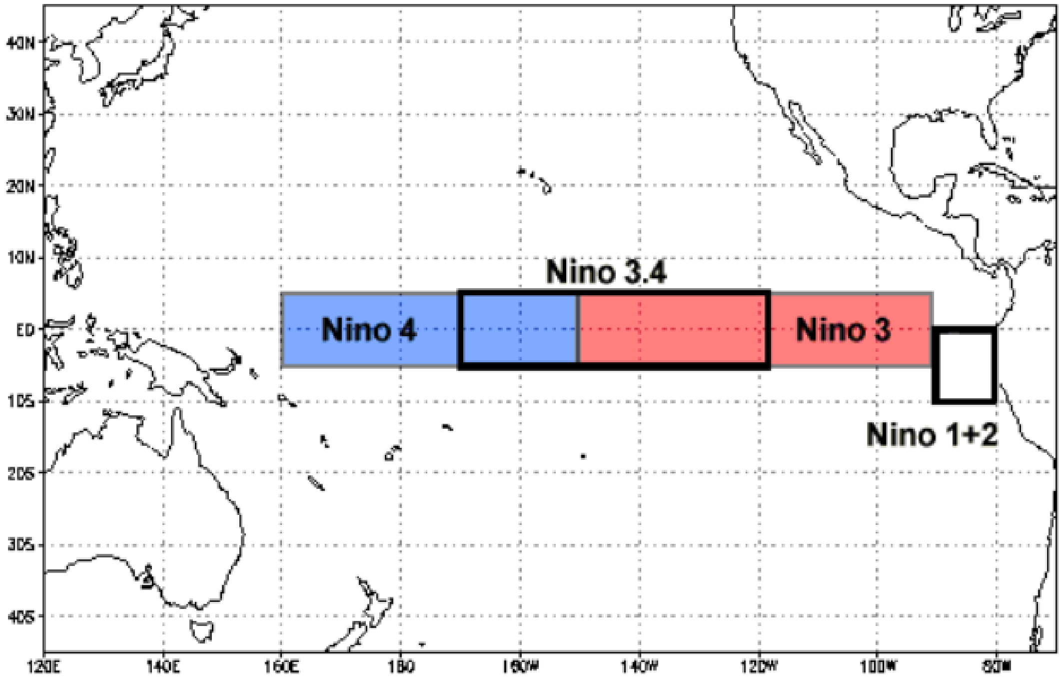

Figure 16: Location of ENSO SST regions used in Figure 15. Figure courtesy of the National Centers for Environmental Information.

Upper-ocean heat content anomalies in the eastern and central tropical Pacific have increased rapidly over the past several weeks but still remain negative when averaged from 180°–100°W (Figure 17). While trade winds in the central tropical Pacific have been much stronger than normal, trade winds farther east in the tropical Pacific have generally been weaker than normal, resulting in above-average SSTs developing in that region due to reduced evaporation and upwelling (Figure 18).

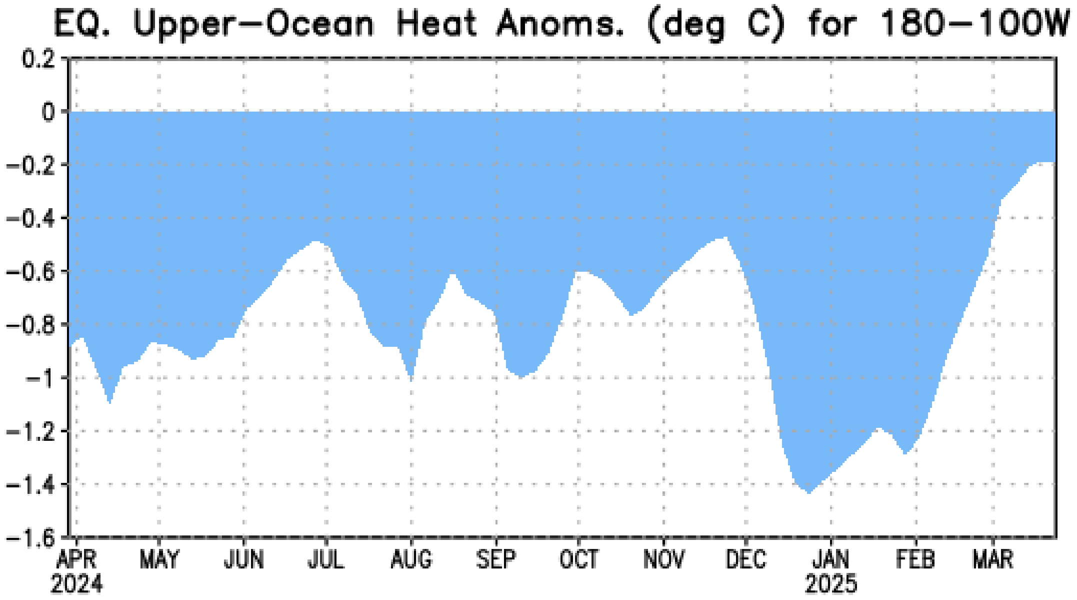

Figure 17: Central and eastern equatorial Pacific upper ocean (0–300 meters) heat content anomalies over the past year. Figure courtesy of Climate Prediction Center.

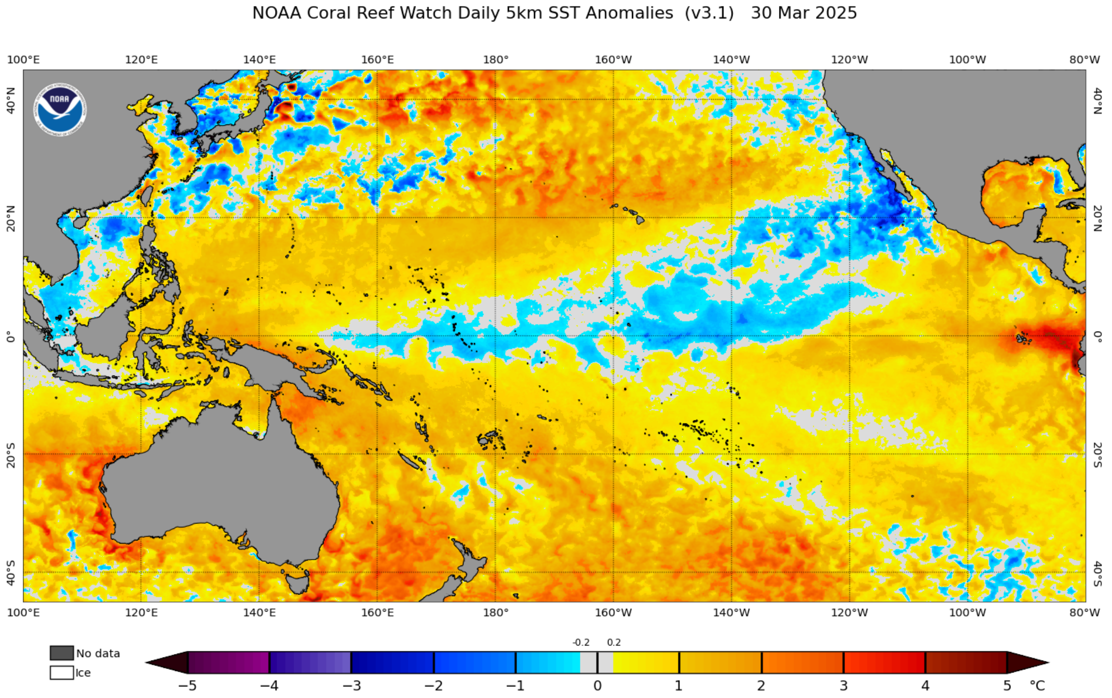

Figure 18: Current SST anomalies across the tropical and subtropical Pacific.

Table 10 displays January and March SST anomalies for several Nino regions. As noted earlier, over the past two months, SST anomalies across the entire eastern and central tropical Pacific have warmed, with the more pronounced warmth taking place in the eastern part of the basin.

Table 10: 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	+1.2	+1.4
Nino 3	-0.2	+0.5	+0.7
Nino 3.4	-0.7	+0.1	+0.8
Nino 4	-0.6	-0.4	+0.2

Following robust upwelling (cooling) oceanic Kelvin wave activity throughout the second half of 2024 and during January of 2025 (Figure 19), oceanic Kelvin wave activity has been relatively weak since that time. The prominent dipole pattern of zonal wind anomalies across the eastern and central tropical Pacific of anomalously strong trades in the central tropical Pacific and weak trades across the eastern tropical Pacific since early February (Figure 20) is the likely primary driver of the anomalous SST dipole pattern that currently exists over the eastern and central tropical Pacific.

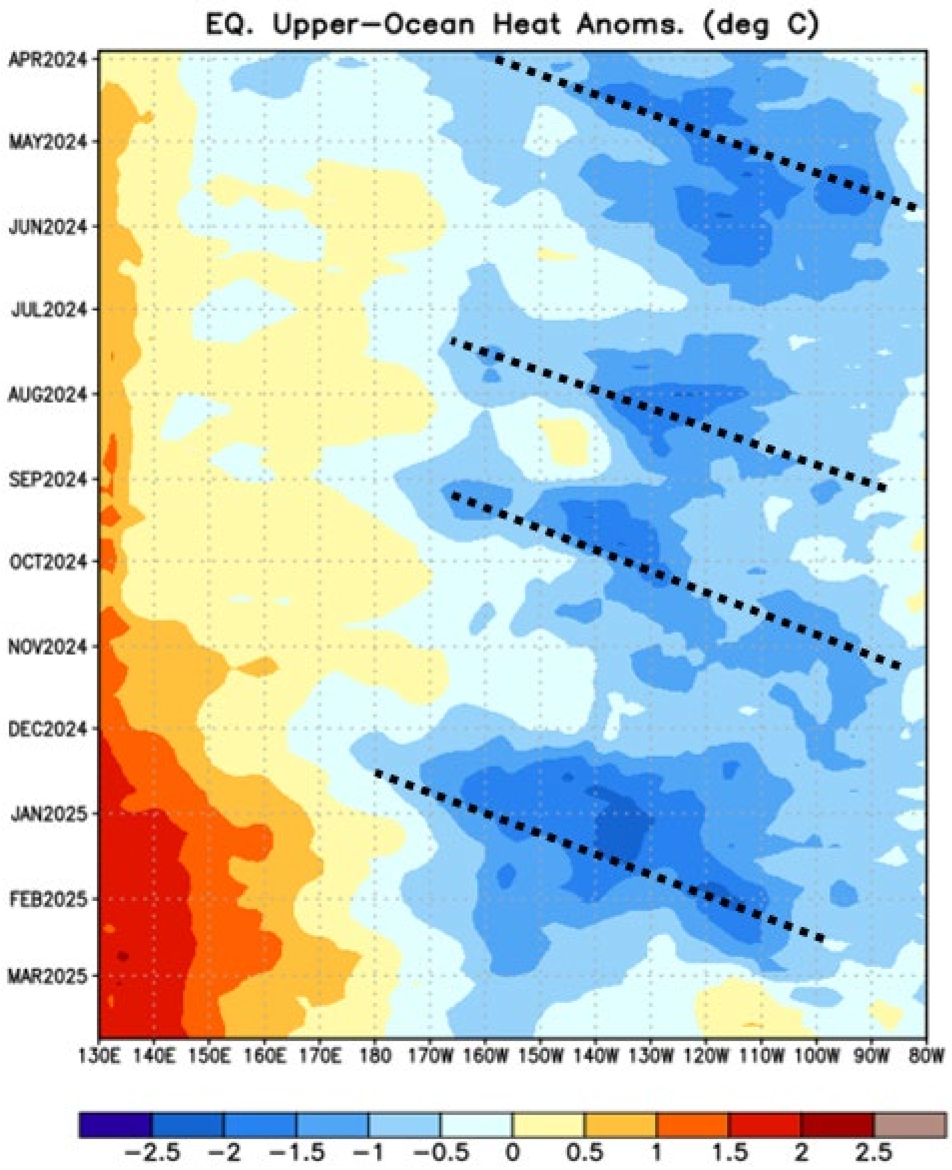

Figure 19: Upper-ocean (0–300 meter) heat content anomalies in the tropical Pacific since April 2024. Long dashed lines indicate downwelling Kelvin waves, while short dashed lines indicate upwelling Kelvin waves. Downwelling Kelvin waves result in upper-ocean heat content increases, while upwelling Kelvin waves result in upper-ocean heat content decreases. Over the past year, no coherent downwelling Kelvin waves have been identified per this analysis from the Climate Prediction Center.

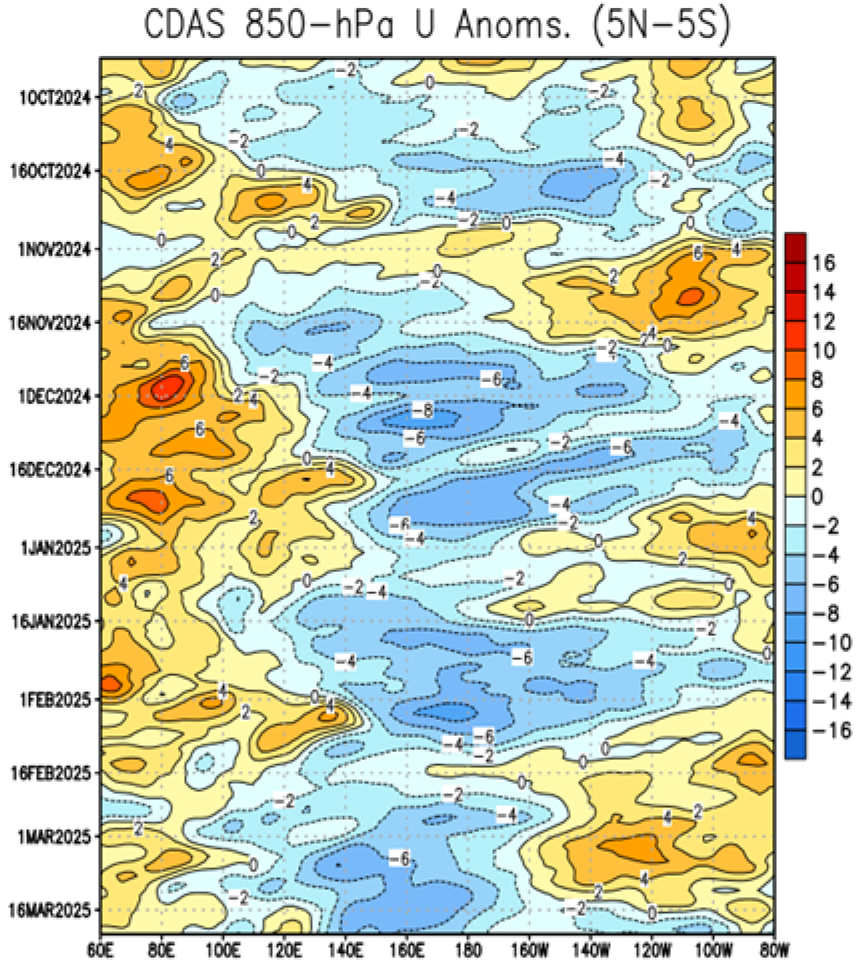

Figure 20: Anomalous equatorial low-level winds spanning from 120°E to 80°W. Figure courtesy of Climate Prediction Center.

The dipole pattern of anomalously strong trades near the International Date Line and anomalous weak trades farther east in the tropical Pacific are forecast to persist by ECMWF for the next several weeks (Figure 21). This low-level wind pattern is likely to contribute to the demise of La Niña, however, we do anticipate that the persistence of strong trades near the International Date Line should inhibit any rapid transition to El Niño this summer.

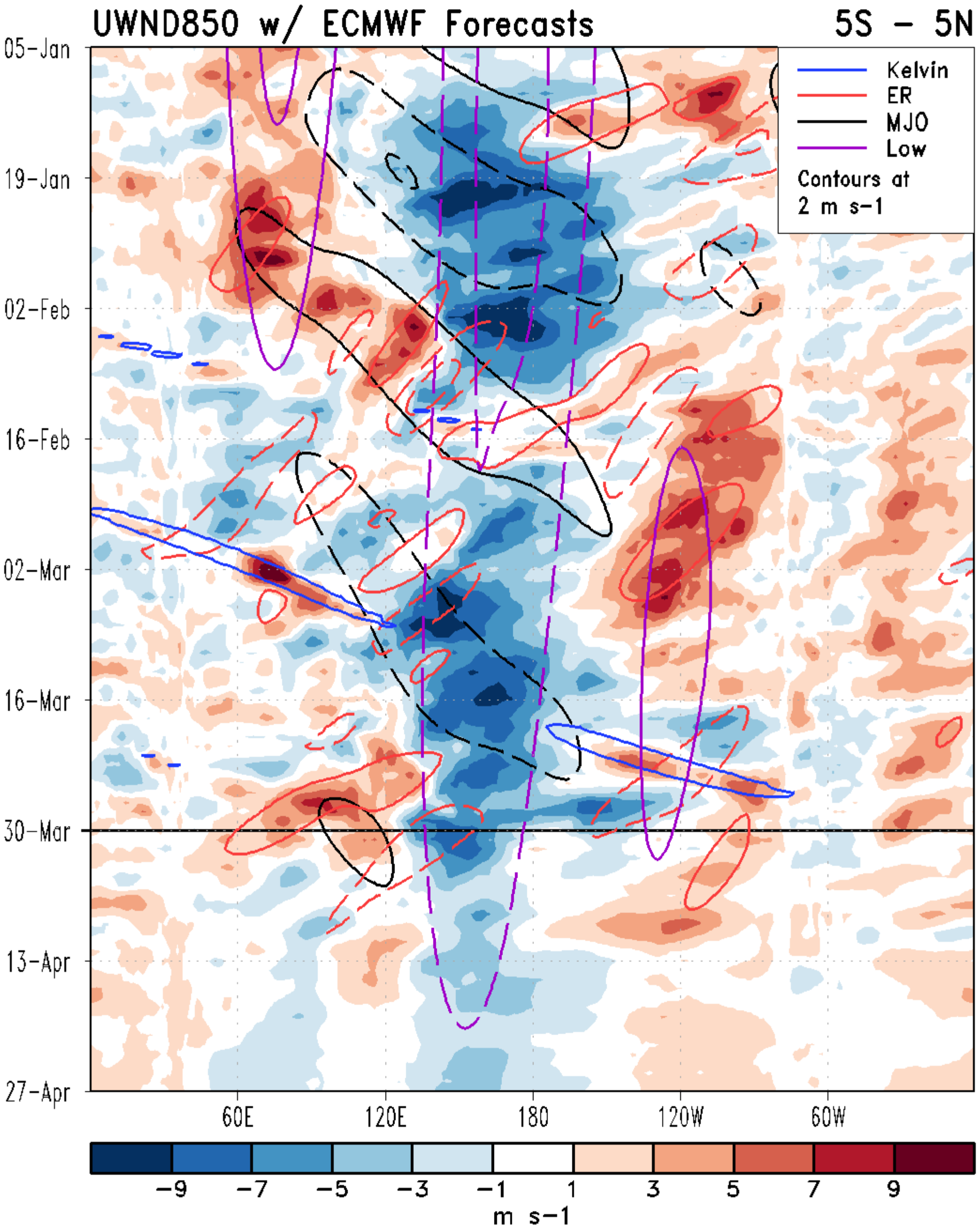

Figure 21: ECMWF forecast 850-hPa zonal equatorial winds for the next 46 days. Figure courtesy of Nick Novella (NOAA/Climate Prediction Center).

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 22). However, most models are either forecasting ENSO neutral or La Niña conditions for the peak of the Atlantic hurricane season.

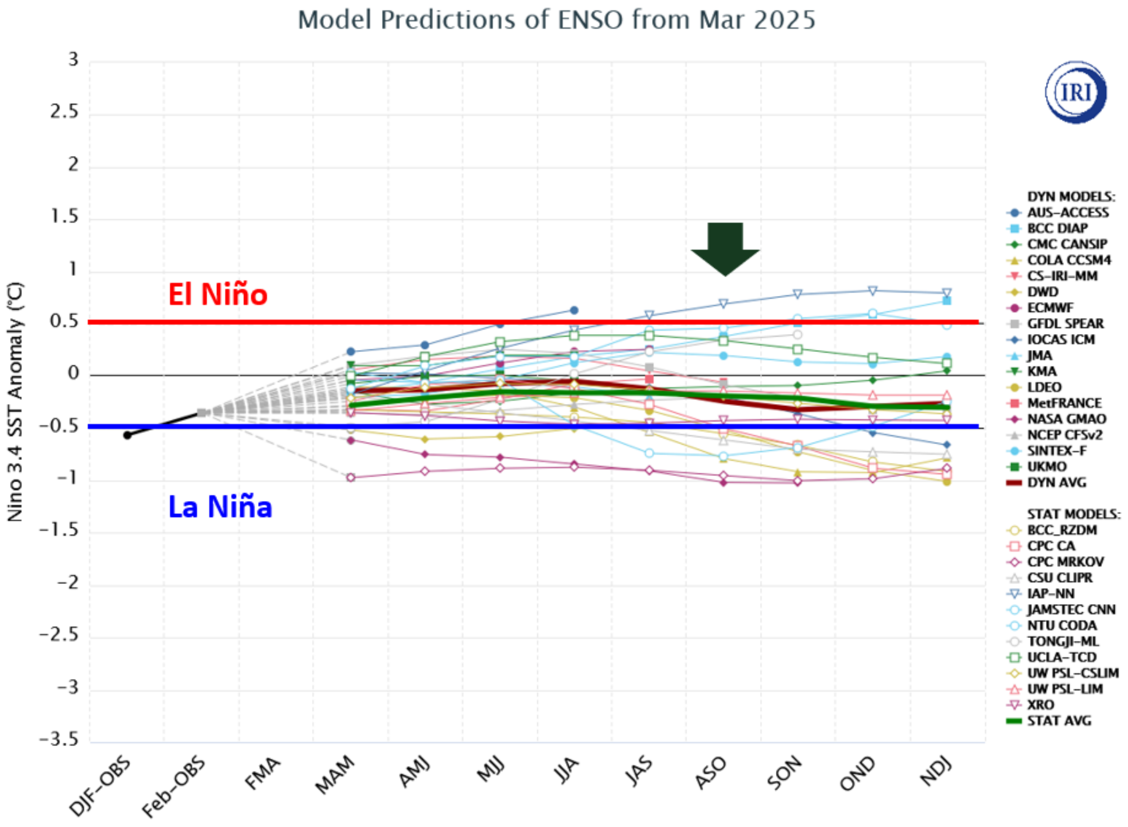

Figure 22: ENSO forecasts from various statistical and dynamical models for Nino 3.4 SST anomalies based on late February to early March initial conditions. Most models call for either ENSO neutral or La Niña conditions for August–October. The black arrow delineates the peak of the Atlantic hurricane season (August–October). Figure courtesy of the International Research Institute (IRI).

The latest official forecast from NOAA somewhat favors ENSO neutral conditions relative to La Niña for August–October, with a much lower chance of El Niño. NOAA is currently predicting a 49% chance of ENSO neutral, a 38% chance of La Niña, and a 13% chance of El Niño for the peak of the Atlantic hurricane season (Figure 23).

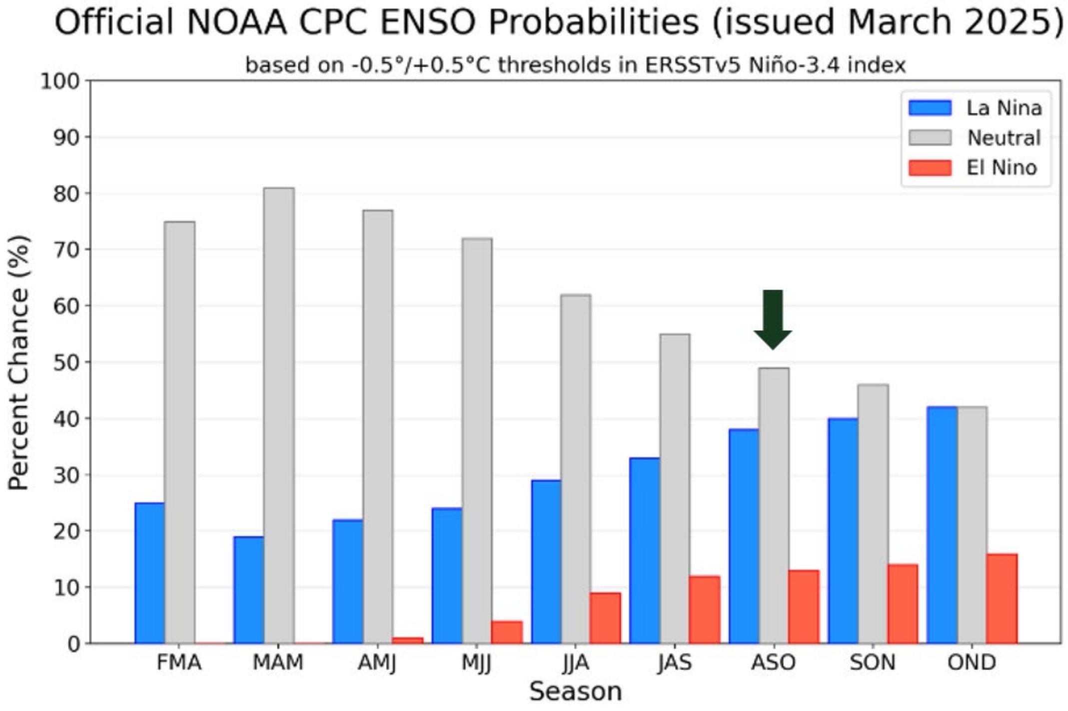

Figure 23: Official probabilistic ENSO forecast from NOAA. The black arrow delineates the peak of the Atlantic hurricane season (August–October).

Based on the above information, our best estimate is that we will have ENSO neutral conditions for the peak of the Atlantic hurricane season, although the possibility of a weak La Niña is also fairly high. While the odds of El Niño are relatively low, if the trade winds in the central tropical Pacific were to weaken considerably, we could still get an El Niño given the considerable warmth that is present in the western Pacific (Figure 18–19).

5 Current Atlantic Basin Conditions

Currently, SSTs are much warmer than normal in the western and central Atlantic as well as the eastern subtropical Atlantic, while they are near to slightly below-normal in the eastern part of the tropical Atlantic (Figure 24). Over the past several weeks, trade winds across the eastern and central tropical Atlantic have been stronger than normal, allowing for considerable reductions in the extremely warm SST anomalies that were present at the beginning of 2025 (Figure 25). Strong trade winds lead to more evaporation and mixing, favoring anomalous cooling. Figure 26 shows the forecast for the next ~4 weeks of low-level winds across the Atlantic. In general, trade winds in the eastern Atlantic are forecast to be somewhat weaker than normal, indicating that the anomalous cooling that has occurred in recent weeks may start to weaken. Overall, the current SST anomaly pattern of enhanced warmth in the eastern subtropical Atlantic and in the Caribbean correlates well with what is typically seen in April before active Atlantic hurricane seasons (Figure 27).

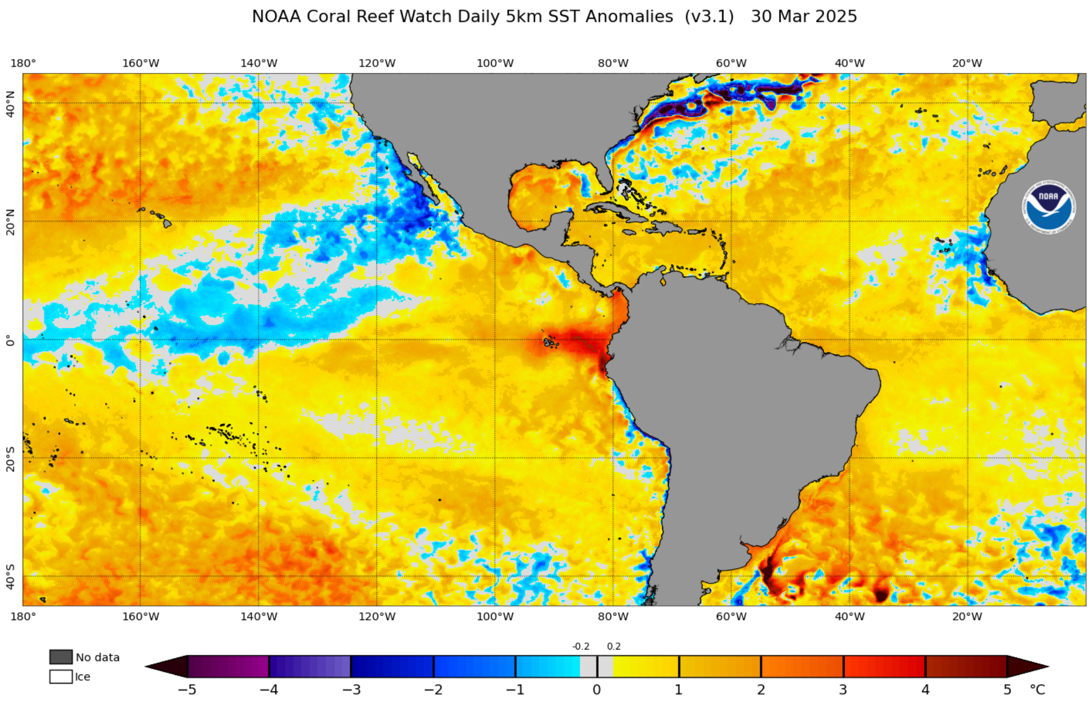

Figure 24: Late March 2025 Western Hemisphere SST anomalies.

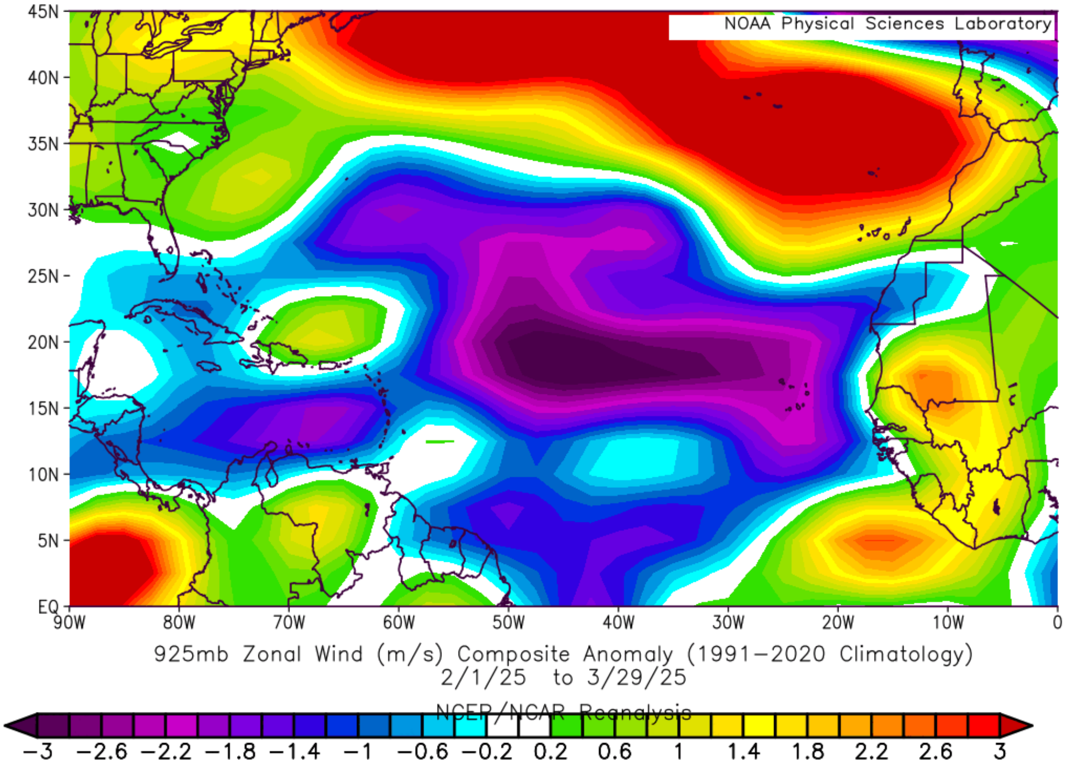

Figure 25: 925 hPa zonal wind anomalies across the North Atlantic Ocean from 1 February through 29 March 2025.

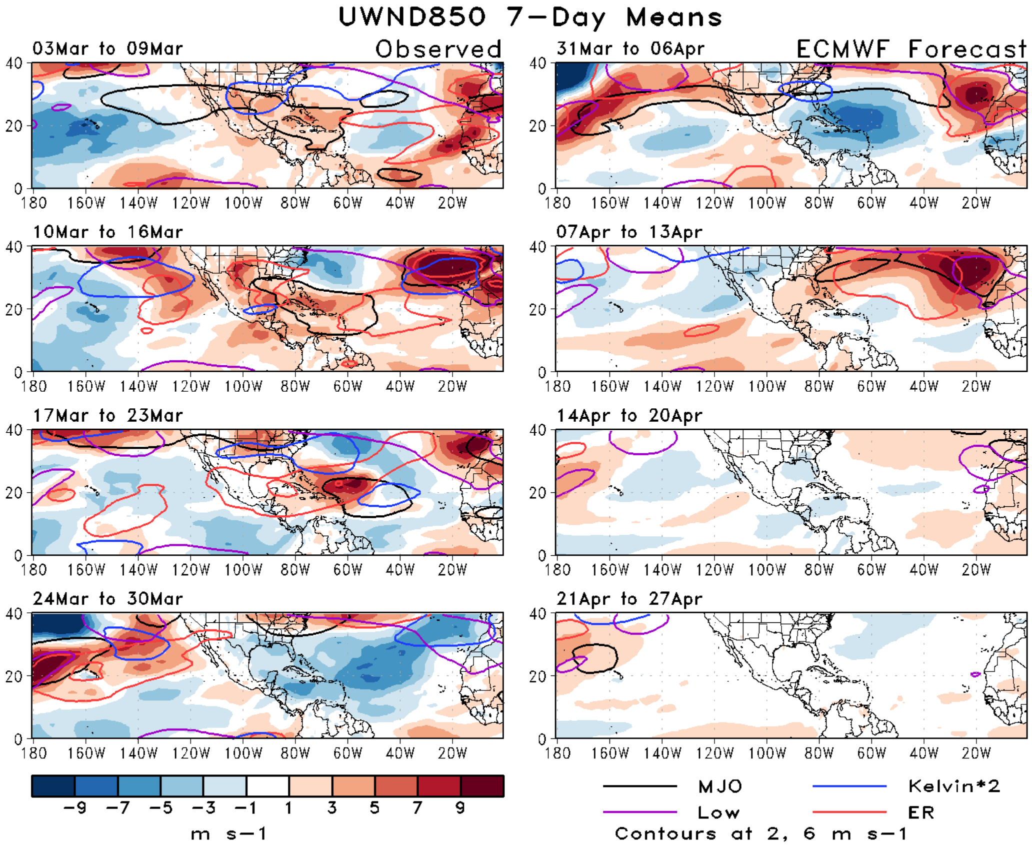

Figure 26: Observed low-level zonal winds across portions of the Western Hemisphere over the past four weeks and predicted low-level zonal winds by ECMWF through 27 April. Figure courtesy of Nick Novella (NOAA/Climate Prediction Center).

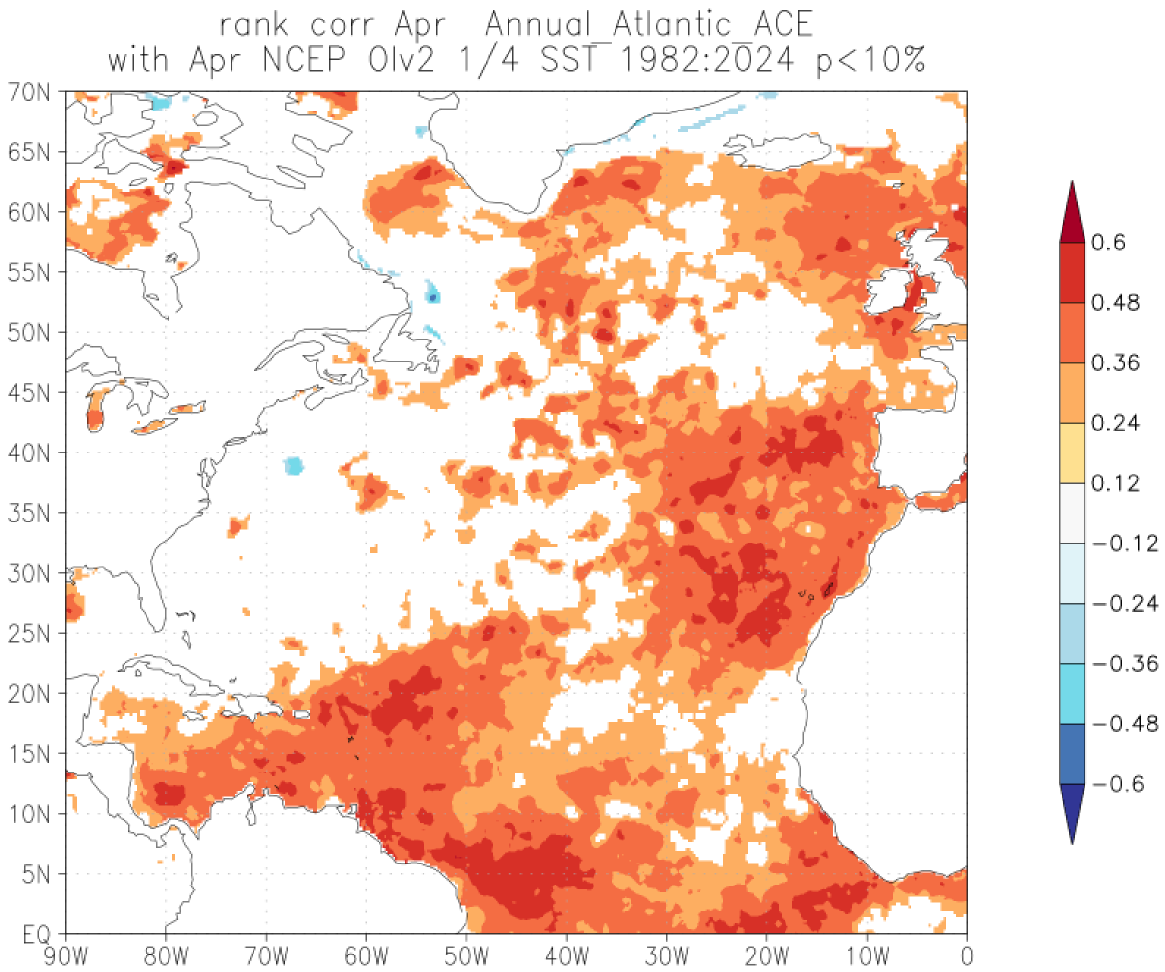

Figure 27: Rank correlations between April sea surface temperatures in the North Atlantic and annual Atlantic ACE from 1982–2024.

6 Tropical Cyclone Impact Probabilities for 2025

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. As was done last year, we adjust 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 17 displays the climatological odds of storms tracking within 50 miles of each state along the Gulf and East Coasts along with the odds in 2025. Landfall probabilities are 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 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 11: 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 2025, based on the latest CSU seasonal hurricane forecast.

		2025 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	67%	34%	10%	58%	28%	8%
Connecticut	27%	9%	2%	22%	8%	1%
Delaware	28%	8%	1%	23%	6%	1%
Florida	92%	65%	35%	86%	56%	29%
Georgia	72%	37%	8%	63%	30%	6%
Louisiana	74%	46%	18%	66%	38%	14%
Maine	26%	9%	2%	21%	7%	1%
Maryland	37%	13%	1%	31%	11%	1%
Massachusetts	40%	18%	4%	33%	14%	3%
Mississippi	62%	35%	9%	53%	28%	8%
New Hampshire	22%	7%	2%	18%	6%	1%
New Jersey	28%	9%	1%	23%	7%	1%
New York	32%	12%	3%	26%	9%	2%
North Carolina	76%	46%	9%	68%	38%	8%
Rhode Island	25%	9%	2%	20%	8%	1%
South Carolina	66%	35%	10%	57%	29%	8%
Texas	70%	44%	19%	61%	36%	16%
Virginia	54%	24%	2%	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 2025 will have above-average activity. The big question marks with this season's predictions are if the anomalous warmth in the eastern subtropical Atlantic and Caribbean persists and expands to the remainder of the Atlantic Main Development Region or begins to weaken. In addition, there is considerable uncertainty as to what phase ENSO will be in for the peak of the 2025 Atlantic hurricane season. While El Niño seems unlikely, the realm of likely possibilities spans anywhere from weak La Niña to warm neutral ENSO conditions.

8 Forthcoming Updated Forecasts of 2025 Hurricane Activity

We will be issuing seasonal updates of our 2025 Atlantic basin hurricane forecasts on **Wednesday 11 June**, **Wednesday 9 July, and Wednesday 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 2025 forecasts will be issued on **Thursday, 20 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 28 displays correlations between observed and predicted Atlantic hurricanes from 1984–2024, from 1984–2013 and from 2014–2024, respectively. Correlation skill has improved at all lead times in recent years, with the most noticeable improvements at longer lead times. While eleven 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

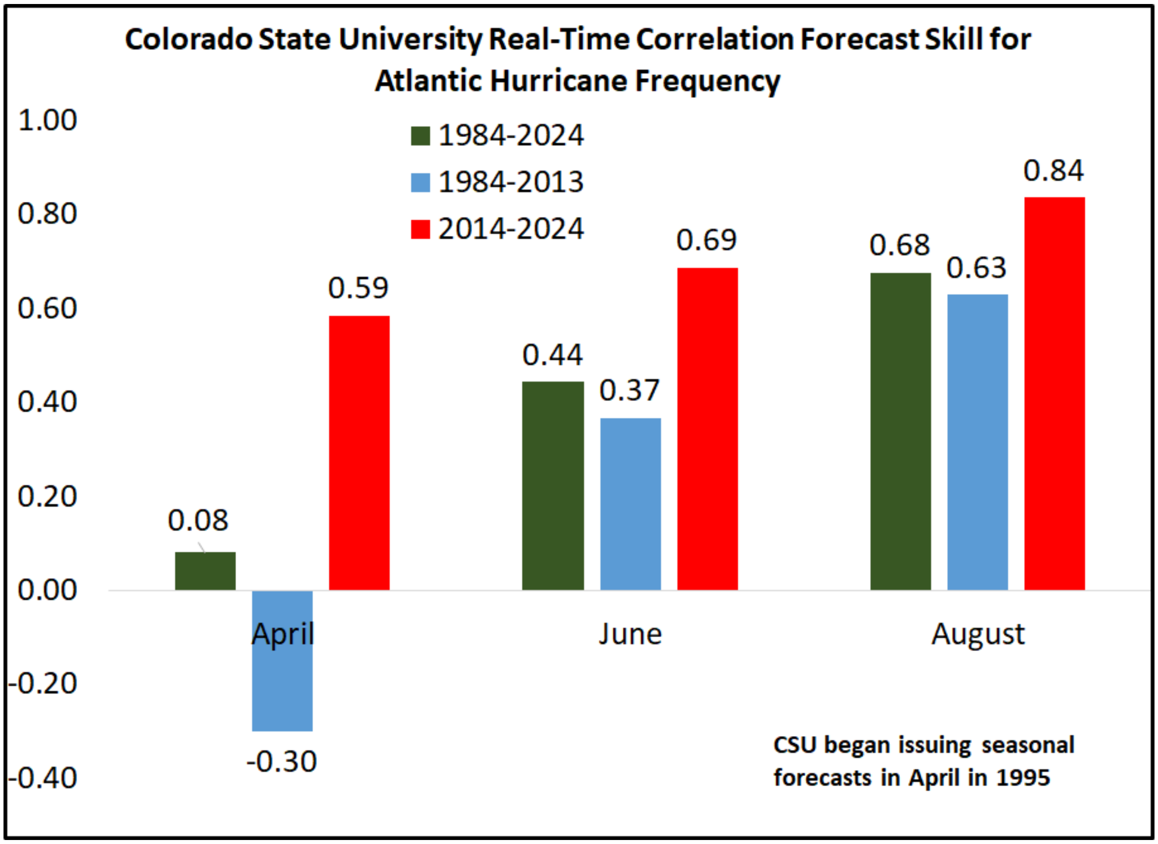

Figure 28: CSU's real-time forecast skill for Atlantic hurricanes using correlation as the skill metric. Correlation skills are displayed for three separate time periods: 1984–2013, 2014–2024 and 1984–2024, respectively.