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

We anticipate that the 2022 Atlantic basin hurricane season will have above-normal activity. Current weak La Niña conditions look fairly likely to transition to neutral ENSO by this summer/fall, but the odds of a significant El Niño seem unlikely. Sea surface temperatures averaged across the eastern and central tropical Atlantic are currently near average, while Caribbean and subtropical Atlantic sea surface temperatures are warmer than normal. We anticipate an above-average probability for major hurricanes making landfall along the continental United States coastline and in the Caribbean. As is the case with all hurricane seasons, coastal residents are reminded that it only takes one hurricane making landfall to make it an active season for them. They should prepare the same for every season, regardless of how much activity is predicted.

(as of 7 April 2022)

By Philip J. Klotzbach[1] and Michael M. Bell[2]

In Memory of William M. Gray[3]

This discussion as well as past forecasts and verifications are available online at http://tropical.colostate.edu

Jennifer Dimas, Colorado State University media representative, is coordinating media inquiries into this verification. She can be reached at 970-491-1543 or Jennifer.Dimas@colostate.edu

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2022

Forecast Parameter and 1991–2020 Average (in parentheses)	Issue Date 7 April 2022
Named Storms (NS) (14.4)	19
Named Storm Days (NSD) (69.4)	90
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)	160
Net Tropical Cyclone Activity (NTC) (135%)	170

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 - 71% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 47% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 46% (average for last century is 30%)

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

1) 60% (average for last century is 42%)

ABSTRACT

Information obtained through March 2022 indicates that the 2022 Atlantic hurricane season will have activity above the 1991–2020 average. We estimate that 2022 will have 9 hurricanes (average is 7.2), 19 named storms (average is 14.4), 90 named storm days (average is 69.4), 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. major hurricane landfall is estimated to be about 135 percent of the long-period average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2022 to be approximately 130 percent of their long-term averages.

This forecast is based on an extended-range early April statistical prediction scheme that was developed using~40 years of past data. Analog predictors are also utilized. We are also including statistical/dynamical models based off of 25–40 years of past data from the European Centre for Medium Range Weather Forecasts, the UK Met Office and the Japan Meteorological Agency as three additional forecast guidance tools. Our statistical model, our statistical/dynamical models and our analog model all call for an active Atlantic hurricane season in 2022.

The tropical Pacific is currently characterized by weak La Niña conditions. We believe that it is relatively likely that the tropical Pacific will revert to neutral ENSO conditions during this summer, but it seems unlikely that El Niño conditions will occur during this year's hurricane season. El Niño typically reduces Atlantic hurricane activity through increases in vertical wind shear. The eastern and central tropical Atlantic are currently have near average sea surface temperatures, while the Caribbean and most of the subtropical Atlantic are warmer than normal.

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

The early April forecast is the earliest seasonal forecast issued by Colorado State University and has modest long-term skill when evaluated in hindcast mode. The skill of CSU's forecast updates increases as the peak of the Atlantic hurricane season approaches. We also now present probabilities of exceedance for hurricanes and Accumulated Cyclone Energy to give interested readers a better idea of the uncertainty associated with these forecasts.

Why issue extended-range forecasts for seasonal hurricane activity?

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

Everyone should realize that it is impossible to precisely predict this season's hurricane activity in early April. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged as regards to the probability of an active or inactive hurricane season for the coming year. Our early April statistical and statistical/dynamical hybrid models show strong evidence on ~25–40 years of data that significant improvement over a climatological forecast can be attained. We would never issue a seasonal hurricane forecast unless we had models developed over a long hindcast period which showed skill. We also now include probabilities of exceedance to provide a visualization of the uncertainty associated with these predictions.

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

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

Acknowledgment

These seasonal forecasts were developed by the late Dr. William Gray, who was lead author on these predictions for over 20 years and continued as a co-author until his death in 2016. In addition to pioneering seasonal Atlantic hurricane prediction, he conducted groundbreaking research on a wide variety of other topics including hurricane genesis, hurricane structure and cumulus convection. His investments in both time and energy to these forecasts cannot be acknowledged enough.

We are grateful for support from Ironshore Insurance, the Insurance Information Institute, Weatherboy and Evex. We acknowledge a grant from the G. Unger Vetlesen Foundation for additional financial support.

Colorado State University's seasonal hurricane forecasts have benefited greatly from a number of individuals that were former graduate students of William Gray. Among these former project members are Chris Landsea, John Knaff and Eric Blake. We also would like to thank Jhordanne Jones, recent Ph.D. graduate in Michael Bell's research group, for model development and forecast assistance over the past several years.

We thank Louis-Philippe Caron and the data team at the Barcelona Supercomputing Centre for providing data and insight on the statistical/dynamical models. We have also benefited from meteorological discussions with Carl Schreck, Louis-Philippe Caron, Brian McNoldy, Paul Roundy, Jason Dunion, and Peng Xian over the past few years.

DEFINITIONS AND ACRONYMS

Accumulated Cyclone Energy (ACE) - A measure of a named storm's potential for wind and storm surge destruction defined as the sum of the square of a named storm's maximum wind speed (in 10^4 $knots^2$) for each 6-hour period of its existence. The 1991–2020 average value of this parameter is 123 for the Atlantic basin.

Atlantic Multi-Decadal Oscillation (AMO) – A mode of natural variability that occurs in the North Atlantic Ocean and evidencing itself in fluctuations in sea surface temperature and sea level pressure fields. The AMO is likely related to fluctuations in the strength of the oceanic thermohaline circulation. Although several definitions of the AMO are currently used in the literature, we define the AMO based on North Atlantic sea surface temperatures from 50–60°N, 50–10°W and sea level pressure from 0–50°N, 70–10°W.

Atlantic Basin – The area including the entire North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico.

El Niño – A 12-18 month period during which anomalously warm sea surface temperatures occur in the eastern half of the equatorial Pacific. Moderate or strong El Niño events occur irregularly, about once every 3–7 years on average.

ENSO Longitude Index – An index defining ENSO that estimates the average longitude of deep convection associated with the Walker Circulation.

Hurricane (H) - A tropical cyclone with sustained low-level winds of 74 miles per hour (33 ms^{-1} or 64 knots) or greater.

Hurricane Day (HD) - A measure of hurricane activity, one unit of which occurs as four 6-hour periods during which a tropical cyclone is observed or is estimated to have hurricane-force winds.

Indian Ocean Dipole (IOD) - An irregular oscillation of sea surface temperatures between the western and eastern tropical Indian Ocean. A positive phase of the IOD occurs when the western Indian Ocean is anomalously warm compared with the eastern Indian Ocean.

Madden Julian Oscillation (MJO) – A globally propagating mode of tropical atmospheric intra-seasonal variability. The wave tends to propagate eastward at approximately 5 ms^{-1}, circling the globe in roughly 30-60 days.

Main Development Region (MDR) – An area in the tropical Atlantic where a majority of major hurricanes form, which we define as 7.5-22.5°N, 75-20°W.

Major Hurricane (MH) - A hurricane which reaches a sustained low-level wind of at least 111 mph (96 knots or 50 ms^{-1}) at some point in its lifetime. This constitutes a category 3 or higher on the Saffir/Simpson scale.

Major Hurricane Day (MHD) - Four 6-hour periods during which a hurricane has an intensity of Saffir/Simpson category 3 or higher.

Named Storm (NS) - A hurricane, a tropical storm or a sub-tropical storm.

Named Storm Day (NSD) - As in HD but for four 6-hour periods during which a tropical or sub-tropical cyclone is observed (or is estimated) to have attained tropical storm-force winds.

Net Tropical Cyclone (NTC) Activity –Average seasonal percentage mean of NS, NSD, H, HD, MH, MHD. Gives overall indication of Atlantic basin seasonal hurricane activity. The 1950-2000 average value of this parameter is 100.

Saffir/Simpson Hurricane Wind Scale – A measurement scale ranging from 1 to 5 of hurricane wind intensity. One is a weak hurricane; whereas, five is the most intense hurricane.

Southern Oscillation Index (SOI) – A normalized measure of the surface pressure difference between Tahiti and Darwin. Low values typically indicate El Niño conditions.

Standard Deviation (SD) – A measure used to quantify the variation in a dataset.

Sea Surface Temperature Anomaly – SSTA

Thermohaline Circulation (THC) – A large-scale circulation in the Atlantic Ocean that is driven by fluctuations in salinity and temperature. When the THC is stronger than normal, the AMO tends to be in its warm (or positive) phase, and more Atlantic hurricanes typically form.

Tropical Cyclone (TC) - A large-scale circular flow occurring within the tropics and subtropics which has its strongest winds at low levels; including hurricanes, tropical storms and other weaker rotating vortices.

Tropical Storm (TS) - A tropical cyclone with maximum sustained winds between 39 mph (18 ms^{-1} or 34 knots) and 73 mph (32 ms^{-1} or 63 knots).

Vertical Wind Shear – The difference in horizontal wind between 200 hPa (approximately 40000 feet or 12 km) and 850 hPa (approximately 5000 feet or 1.6 km).

1 knot = 1.15 miles per hour = 0.515 meters per second

1 Introduction

This is the 39th year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. This year's April forecast is based on a statistical model as well as output from statistical/dynamical models from the European Centre for Medium Range Weather Forecasts (ECMWF), the UK Met Office and the Japan Meteorological Agency (JMA). These models show skill at predicting TC activity based on ~25–40 years of historical data. We also select analog seasons, based on currently-observed conditions as well as conditions that we anticipate for the peak of the Atlantic hurricane season. Qualitative adjustments are added to accommodate additional processes which may not be explicitly represented by these analyses. These evolving forecast techniques are based on a variety of climate-related global and regional predictors previously shown to be related to the forthcoming seasonal Atlantic basin TC activity and landfall probability. We believe that seasonal forecasts must be based on methods that show significant hindcast skill in application to long periods of prior data. It is only through hindcast skill that one can demonstrate that seasonal forecast skill is possible. This is a valid methodology provided that the atmosphere continues to behave in the future as it has in the past.

The best predictors do not necessarily have the best individual correlations with hurricane activity. The best forecast parameters are those that explain the portion of the variance of seasonal hurricane activity that are not associated with the other forecast variables. It is possible for an important hurricane forecast parameter to show little direct relationship to a predictand by itself but to have an important influence when included with a set of 2–3 other predictors.

A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 3–4 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmospheric-oceanic system that is highly non-linear. There are a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all of these processes interact with each other. No one can completely understand the full complexity of the atmosphere-ocean system. But, it is still possible to develop a reliable statistical forecast scheme which incorporates a number of the climate system's non-linear interactions. Any seasonal or climate forecast scheme should show significant hindcast skill before it is used in real-time forecasts.

2 April Forecast Methodology

2.1 April Statistical Forecast Scheme

We are currently using an April statistical forecast scheme that was developed on data from 1982–2019 and yielded successful real-time forecasts in 2020 and 2021. The model uses the ECMWF Reanalysis 5 (ERA5) (Hersbach et al. 2020) as well as NOAA Optimum Interpolation (OI) sea surface temperature (SST) (Reynolds et al. 2002). The ERA5 reanalysis currently extends from 1979 to present with a preliminary version now extending back to 1950. The ERA5 reanalysis is the first reanalysis from ECMWF that provides updates in real time, allowing for the same reanalysis product to be used for both hindcast model development as well as real-time analysis. The NOAA Optimum Interpolation SST (Reynolds et al. 2002) is available from 1982–present. This new model showed significant skill in cross-validated (e.g., leaving the year out of the developmental model that is being predicted) hindcasts of Accumulated Cyclone Energy (ACE) (r = 0.66) over the period from 1982–2021.

Figure 2 displays the locations of each predictor, while Table 1 displays the individual linear correlations between each predictor and ACE over the 1982–2021 hindcast/forecast period. All predictors correlate significantly at the 5% level using a two-tailed Student's t-test and assuming that each year represents an individual degree of freedom. Table 2 displays the 2022 observed values for each of the three predictors in the statistical forecast scheme. Table 3 displays the statistical model output for the 2022 hurricane season. The two SST predictors call for a very active Atlantic hurricane season, while the 200 hPa zonal wind predictor calls for a slightly below-average season. The three predictors in combination call for an above-average season.

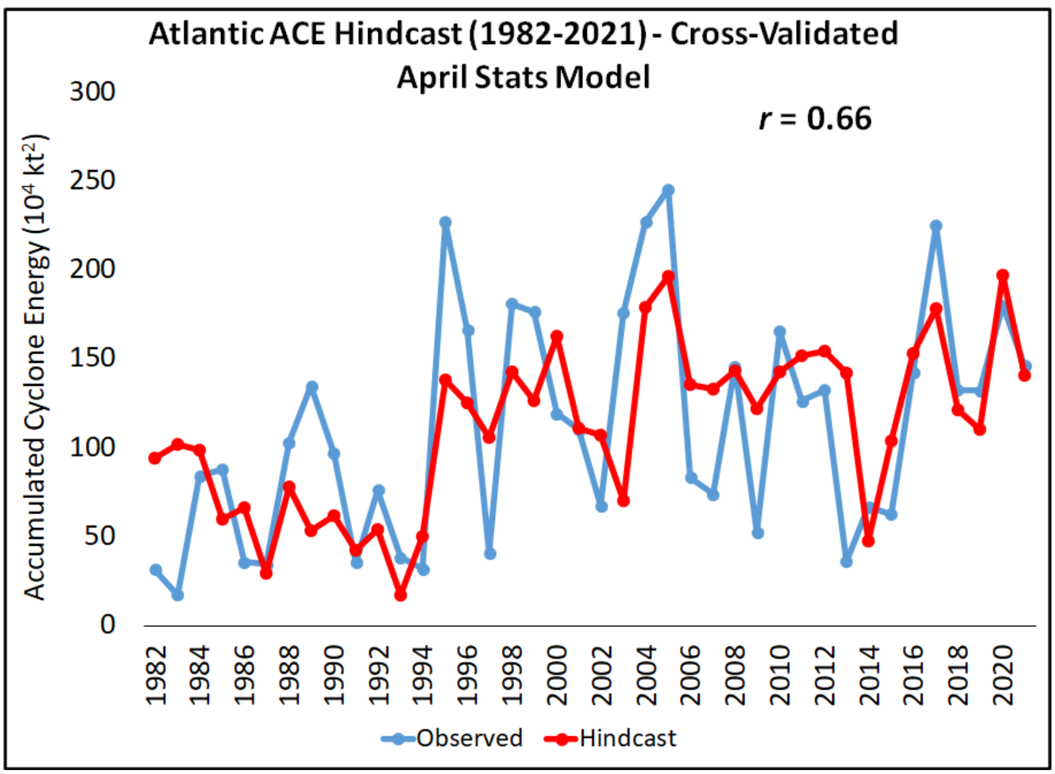

Figure 1: Observed versus early April cross-validated hindcast values of ACE for the statistical model from 1982–2021.

April Forecast Predictors

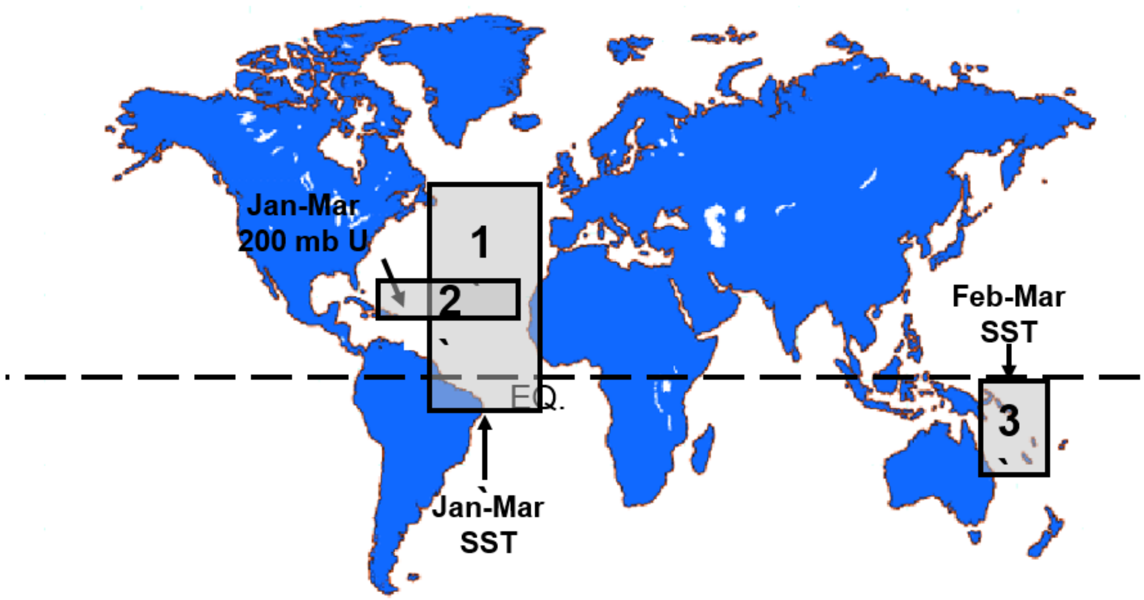

Figure 2: Location of predictors for our early April extended-range statistical prediction for the 2022 hurricane season.

Table 1: Linear correlation between early April predictors and ACE over the period from 1982–2021.

Predictor	Correlation w/ ACE
1) January–March SST (5°S–50°N, 40°W–10°W) (+)	0.57
2) January–March 200 hPa U (17.5°N–27.5°N, 60°W–20°W) (+)	0.44
3) February-March SST (20°S–0°, 145°E–170°E) (+)	0.52

Table 2: Listing of early April 2022 predictors for the 2022 hurricane season. A plus (+) means that positive deviations of the parameter are associated with increased hurricane activity, while a minus (-) means that negative deviations of the parameter are associated with increased hurricane activity. SD stands for standard deviation.

Predictor	2022 Forecast Value	Impact on 2022 TC Activity
1) January–March SST (5°S–50°N, 40°W–10°W) (+)	+1.5 SD	Enhance
2) January–March 200 hPa U (17.5°N–27.5°N, 60°W–20°W) (+)	-0.5 SD	Suppress
3) February-March SST (20°S–0°, 145°E–170°E) (+)	+1.5 SD	Enhance

Table 3: Statistical model output for the 2022 Atlantic hurricane season and the final adjusted forecast.

Forecast Parameter and 1991–2020 Average (in parentheses)	Statistical Forecast	Final Forecast
Named Storms (NS) (14.4)	17.2	19
Named Storm Days (NSD) (69.4)	88.4	90
Hurricanes (H) (7.2)	9.2	9
Hurricane Days (HD) (27.0)	37.4	35
Major Hurricanes (MH) (3.2)	4.4	4
Major Hurricane Days (MHD) (7.4)	11.1	9
Accumulated Cyclone Energy (ACE) (123)	168	160
Net Tropical Cyclone Activity (NTC) (135%)	180	170

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

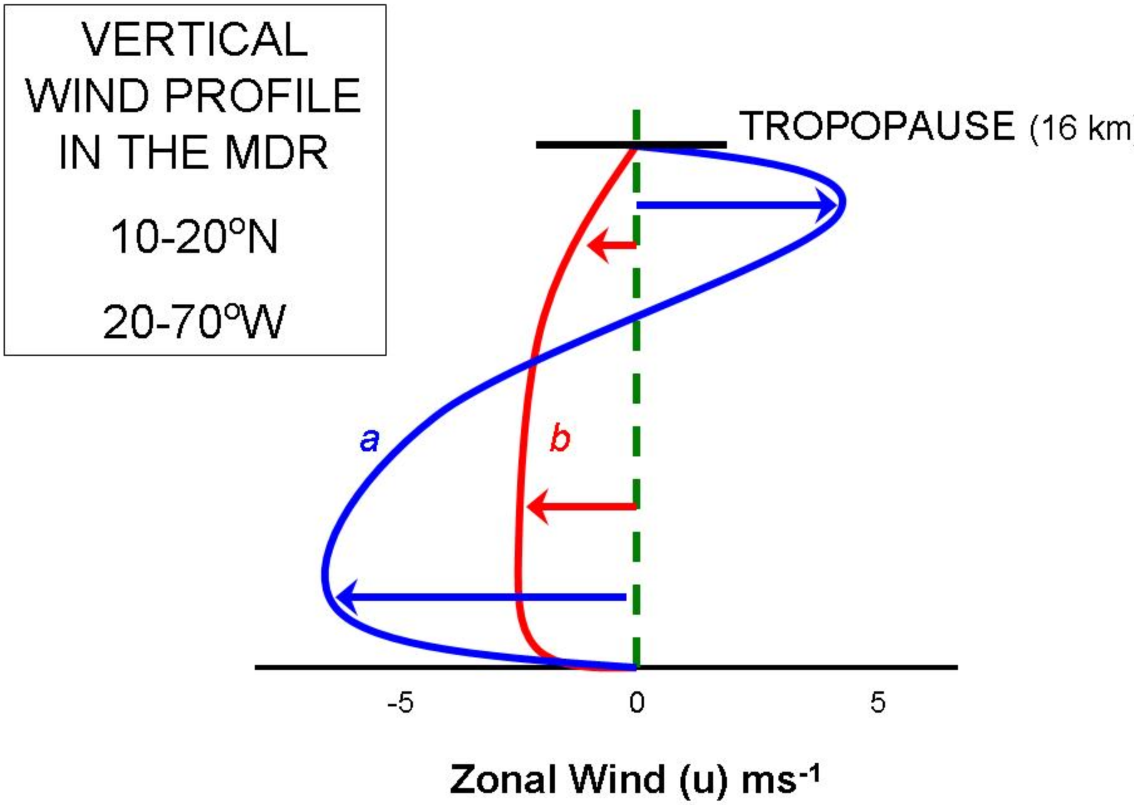

Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.

For each of these predictors, we display a four-panel figure showing linear correlations between values of each predictor and August–October values of SST, sea level pressure (SLP), 200 hPa zonal wind, and 850 hPa zonal wind, respectively, during 1982–2019. In general, higher values of tropical Atlantic SSTs, lower values of tropical Atlantic SLP, and anomalous tropical Atlantic westerlies at 850 hPa and anomalous easterlies at 200 hPa are associated with active Atlantic basin hurricane seasons. SST correlations are displayed using the NOAA Optimum Interpolation SST, while atmospheric field correlations are displayed using ERA5.

Predictor 1. January–March SST in the Tropical and Subtropical Eastern Atlantic (+)

(5°S–50°N, 40°W–10°W)

Warmer-than-normal SSTs in the tropical and subtropical Atlantic during the January–March time period are associated with a weaker-than-normal subtropical high and reduced trade wind strength during the boreal spring (Knaff 1997). Positive SSTs in January–March are correlated with weaker trade winds and weaker upper tropospheric westerly winds, lower-than-normal sea level pressures and above-normal SSTs in the tropical Atlantic during the following August–October period (Figure 4). All three of these August–October features are commonly associated with active Atlantic basin hurricane seasons, through reductions in vertical wind shear, increased vertical instability and increased mid-tropospheric moisture, respectively. Predictor 1 correlates quite strongly (r =0.57) with ACE from 1982–2021. Predictor 1 also strongly correlates (r = 0.57) with August–October values of the SST component of the Atlantic Meridional Mode (AMM) (Kossin and Vimont 2007) from 1982–2021. The AMM has been shown to impact Atlantic hurricane activity through alterations in the position and intensity of the Atlantic Inter-Tropical Convergence Zone (ITCZ). Changes in the Atlantic ITCZ bring about changes in tropical Atlantic vertical and horizontal wind shear patterns and in tropical Atlantic SST patterns.

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 Coral Sea (+)

(20°S–0°, 145°E–170°E)

Anomalous warmth in the Coral Sea 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).

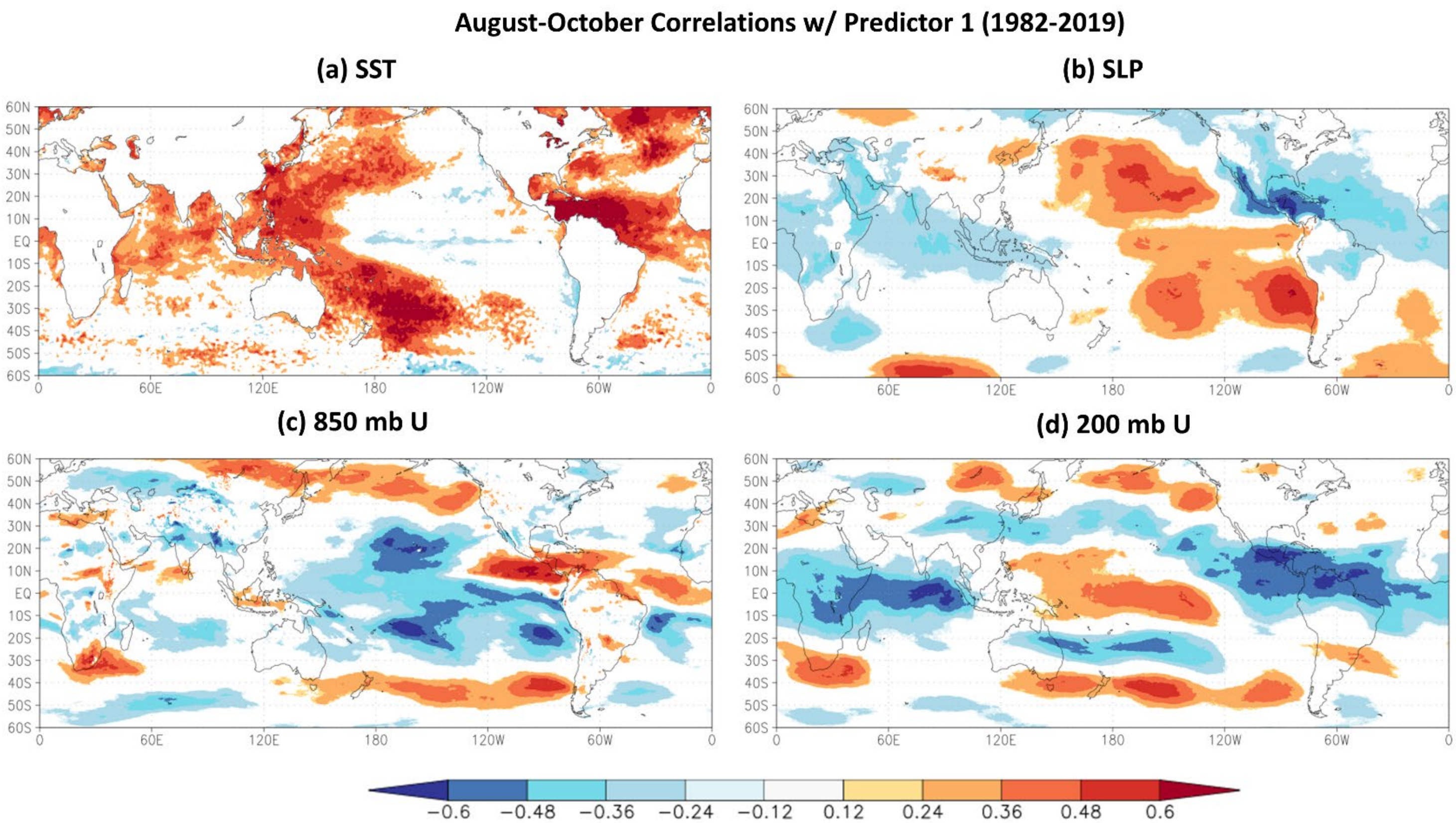

Figure 4: Rank correlations between January–March SST in the tropical and subtropical Atlantic (Predictor 1) and (panel a) August–October sea surface temperature, (panel b) August–October sea level pressure, (panel c) August–October 850 hPa zonal wind and (panel d) August–October 200 hPa zonal wind.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

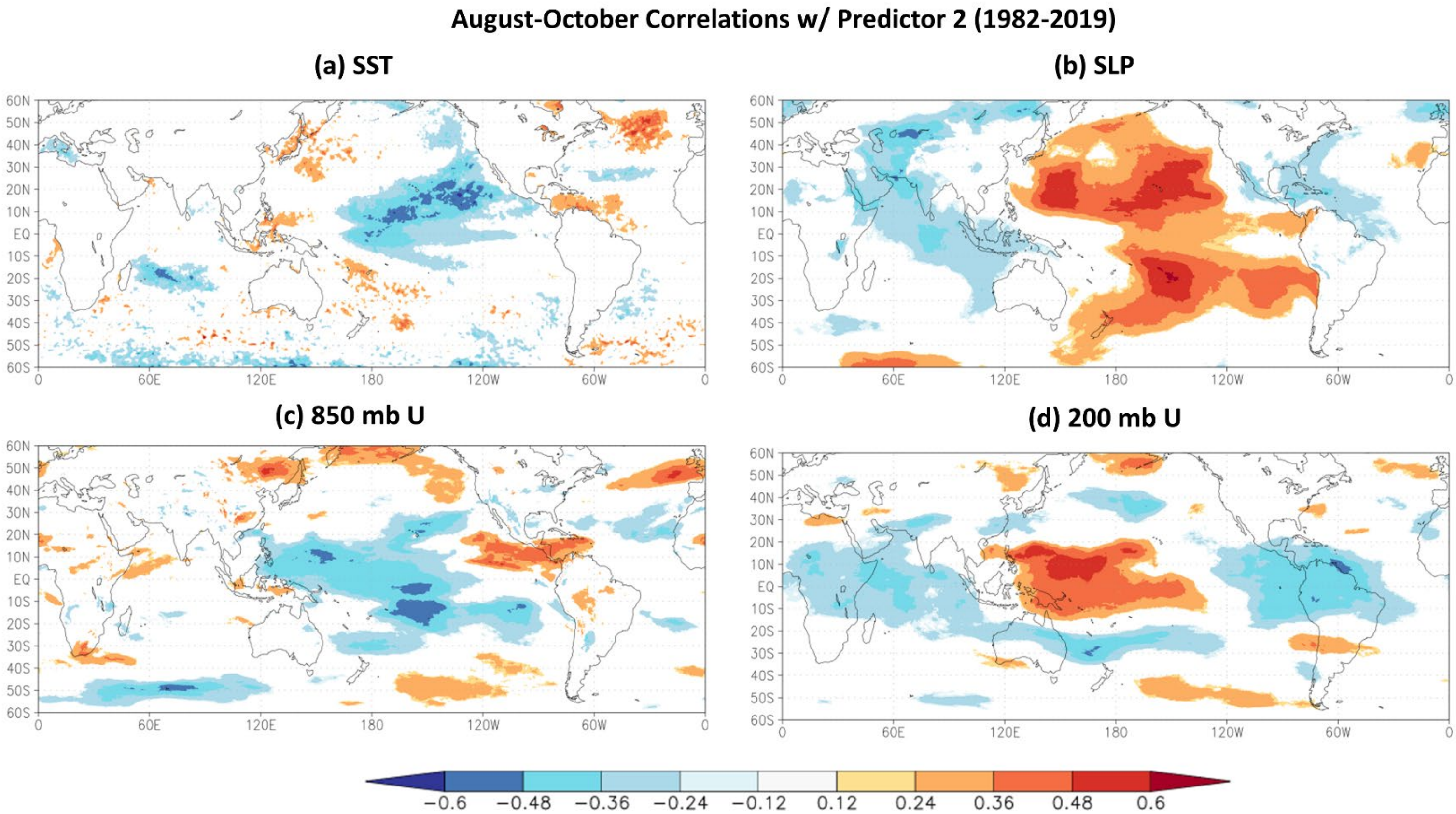

Figure 5: As in Figure 4 but for January–March 200 hPa zonal wind in the subtropical North Atlantic.

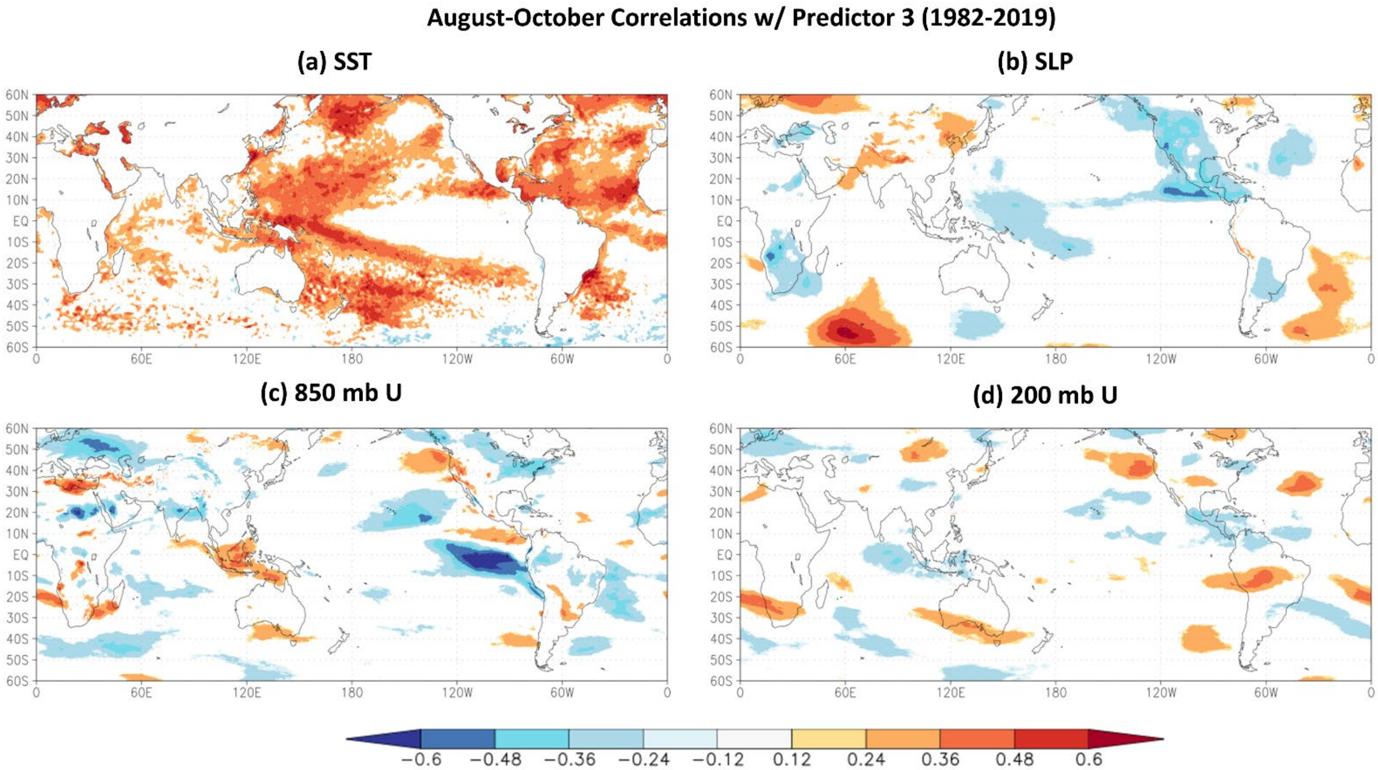

Figure 6: As in Figure 4 but for February–March SST in the Coral Sea.

2.2 April Statistical/Dynamical Forecast Schemes

We developed a statistical/dynamical hybrid forecast model scheme that we used for the first time in 2019. This model, developed in partnership with Louis-Philippe Caron and the data team at the Barcelona Supercomputing Centre, originally used output from the ECMWF SEAS5 model to forecast the input to our early August statistical forecast model. The early August statistical forecast model shows the highest level of skill of any of our statistical models, since it is the model released just before the peak of the Atlantic hurricane season in September. Our statistical/dynamical forecast scheme now uses three separate climate model forecasts from ECMWF, the UK Met Office and JMA to forecast the large-scale fields that go into the early August statistical forecast model. We then use the forecasts of the individual parameters to forecast ACE for the 2022 season. All other predictands (e.g., named storms, major hurricanes) are calculated based on their historical relationships with ACE. It typically takes about two weeks after the initialization date to obtain climate model output, so the results displayed here are from the model output from a 1 March forecast. We have published a paper discussing this scheme in detail using the SEAS5 model (Klotzbach et al. 2020).

a) ECMWF Statistical/Dynamical Model Forecast

Figure 7 displays the parameters used in our early August statistical model, while Table 4 displays ECMWF's forecasts of these parameters for 2022 from a 1 March initialization date. All three parameters call for above-normal activity, with the predictors of subtropical eastern Atlantic surface temperature and upper-level wind over tropical western and central Africa being extremely favorable for an active season. Figure 8 displays cross-validated hindcasts for ECMWF forecasts of ACE from 1981–2021, while Table 5 presents the forecast from ECMWF for the 2022 Atlantic hurricane season.

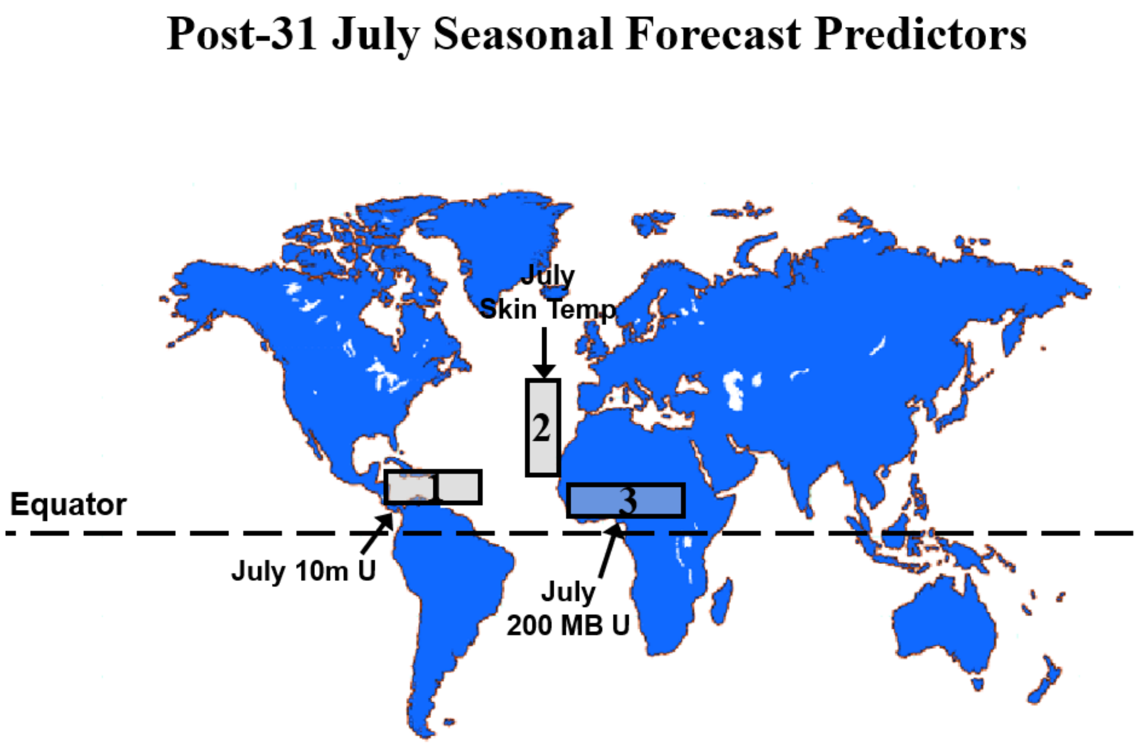

Figure 7: Location of predictors for our early April statistical/dynamical extended-range statistical prediction for the 2022 hurricane season. This forecast uses dynamical model predictions from ECMWF, the UK Met Office or JMA to predict July conditions in the three boxes displayed and uses those predictors to forecast ACE.

Table 4: Listing of predictions of July large-scale conditions from ECMWF model output, initialized on 1 March. A plus (+) means that positive deviations of the parameter are associated with increased hurricane activity, while a minus (-) means that negative deviations of the parameter are associated with increased hurricane activity.

Predictor	Values for 2022 Forecast	Effect on 2022 Hurricane Season
1) ECMWF Prediction of July Surface U (10–20°N, 90–40°W) (+)	+0.6 SD	Enhance
2) ECMWF Prediction of July Skin Temperature (20–40°N, 35–15°W) (+)	+1.3 SD	Enhance
3) ECMWF Prediction of July 200 hPa U (5–15°N, 0–40°E) (-)	-1.3 SD	Enhance

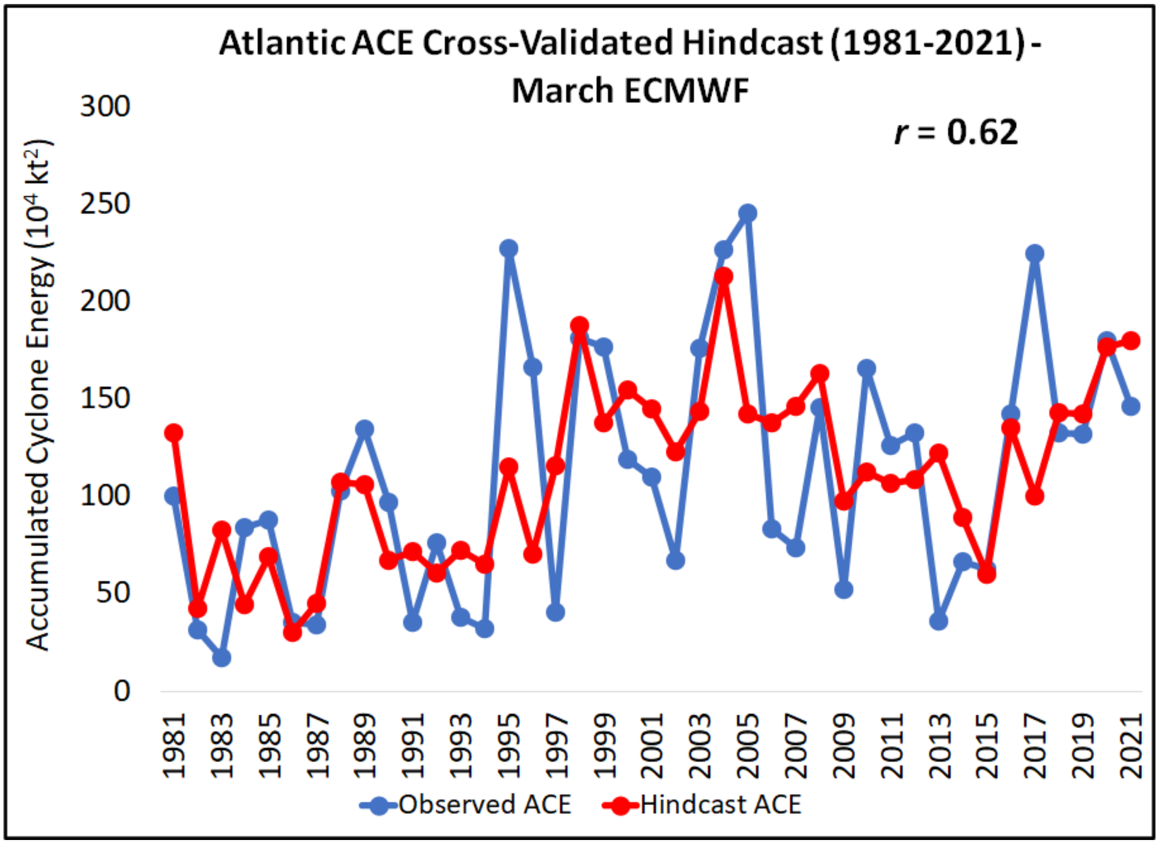

Figure 8: Observed versus cross-validated statistical/dynamical hindcast values of ACE for 1981–2021 from ECMWF.

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

Forecast Parameter and 1991–2020 Average (in parentheses)	ECMWF Hybrid Forecast	Final Forecast
Named Storms (14.4)	17.9	19
Named Storm Days (69.4)	93.5	90
Hurricanes (7.2)	9.7	9
Hurricane Days (27.0)	40.1	35
Major Hurricanes (3.2)	4.7	4
Major Hurricane Days (7.4)	12.1	9
Accumulated Cyclone Energy Index (123)	180	160
Net Tropical Cyclone Activity (135%)	192	170

By combining the statistical model forecast and the statistical/dynamical model forecast from ECMWF, we can increase the hindcast skill from either model individually. As noted earlier, the statistical model has a cross-validated hindcast with ACE of r =

0.66, while the statistical/dynamical model has a cross-validated hindcast with ACE of $r = 0.62$. By simply averaging the forecasts from the two models together, we can improve the cross-validated hindcast variance explained to $r = 0.70$, or ~50% of the variance in ACE (Figure 9).

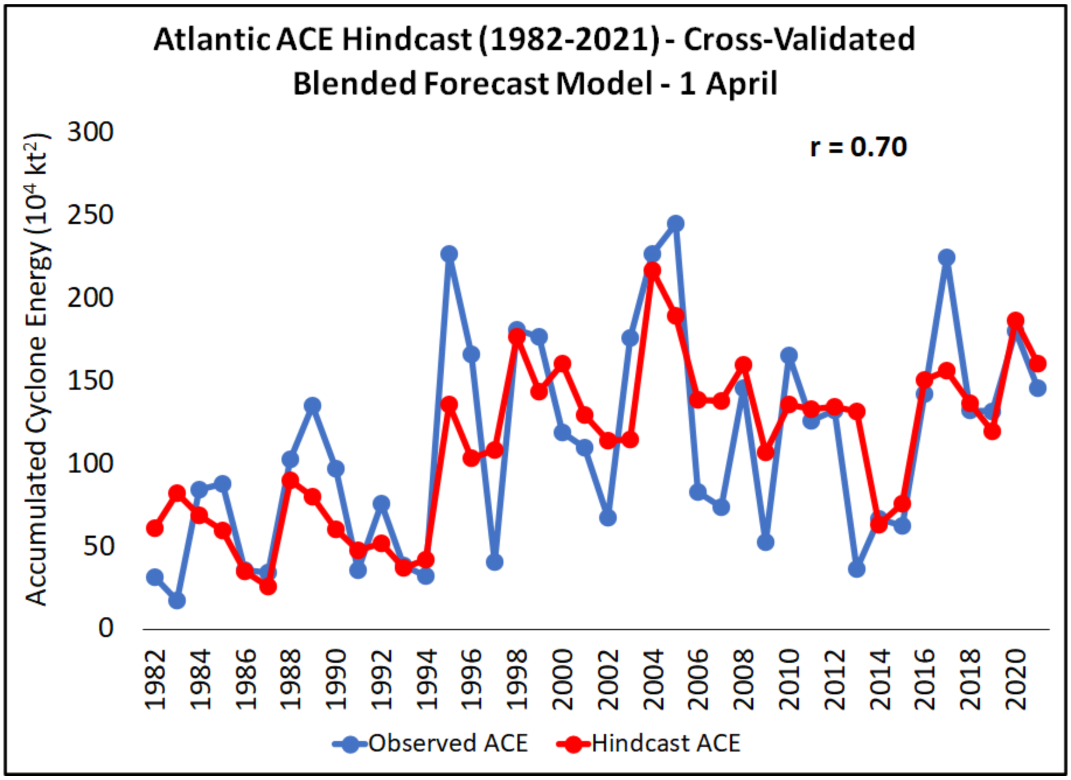

Figure 9: Observed versus early April blended (e.g., statistical and statistical/dynamical) model cross-validated hindcast values of ACE for 1982–2021.

b) UK Met Office Statistical/Dynamical Model Forecast

Table 6 displays the UK Met Office forecasts of the early August parameters for 2022 from a 1 March initialization date. All three parameters call for an above-average season. Figure 10 displays hindcasts for the UK Met Office of ACE from 1993–2016, while Table 7 presents the forecast from the UK Met Office for the 2022 Atlantic hurricane season. We note that both the UK Met Office and JMA forecasts (detailed in the next subsection) only have hindcasts for the 1993–2016 period on the Copernicus website (the website where we download our climate model forecasts), which is why the hindcast period is shorter than what we used for ECMWF.

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

Predictor	Values for 2022 Forecast	Effect on 2022 Hurricane Season
1) Met Office Prediction of July Surface U (10–20°N, 90–40°W) (+)	+0.7 SD	Enhance
2) Met Office Prediction of July Skin Temperature (20–40°N, 35–15°W) (+)	+2.4 SD	Enhance
3) Met Office Prediction of July 200 hPa U (5–15°N, 0–40°E) (-)	-1.2 SD	Enhance

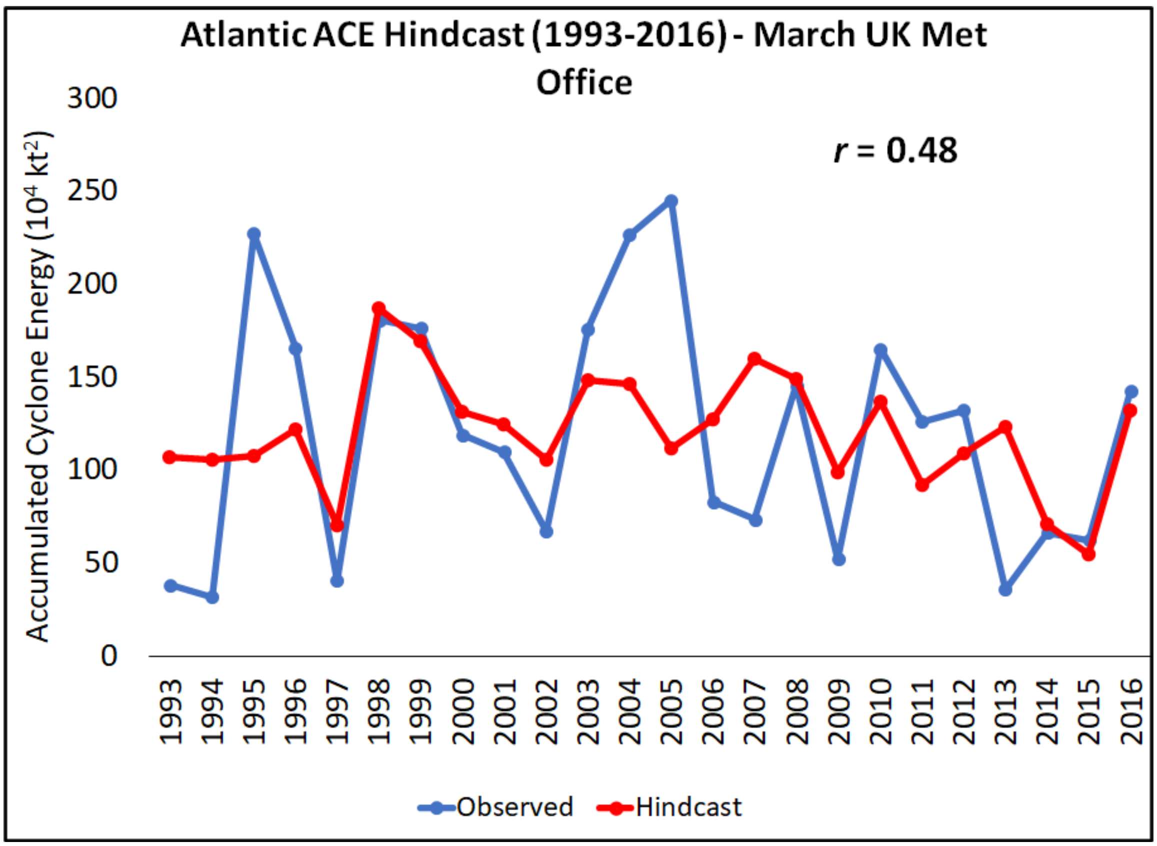

Figure 10: Observed versus statistical/dynamical hindcast values of ACE for 1993–2016 from the UK Met Office.

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

Forecast Parameter and 1991–2020 Average (in parentheses)	Met Office Hybrid Forecast	Final Forecast
Named Storms (14.4)	17.0	19
Named Storm Days (69.4)	87.6	90
Hurricanes (7.2)	9.1	9
Hurricane Days (27.0)	36.9	35
Major Hurricanes (3.2)	4.3	4
Major Hurricane Days (7.4)	11.0	9
Accumulated Cyclone Energy Index (123)	166	160
Net Tropical Cyclone Activity (135%)	178	170

c) JMA Statistical/Dynamical Model Forecast

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

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

Predictor	Values for 2022 Forecast	Effect on 2022 Hurricane Season
1) JMA Prediction of July Surface U (10–20°N, 90–40°W) (+)	+2.0 SD	Enhance
2) JMA Prediction of July Skin Temperature (20–40°N, 35–15°W) (+)	+2.0 SD	Enhance
3) JMA Prediction of July 200 hPa U (5–15°N, 0–40°E) (-)	-0.6 SD	Enhance

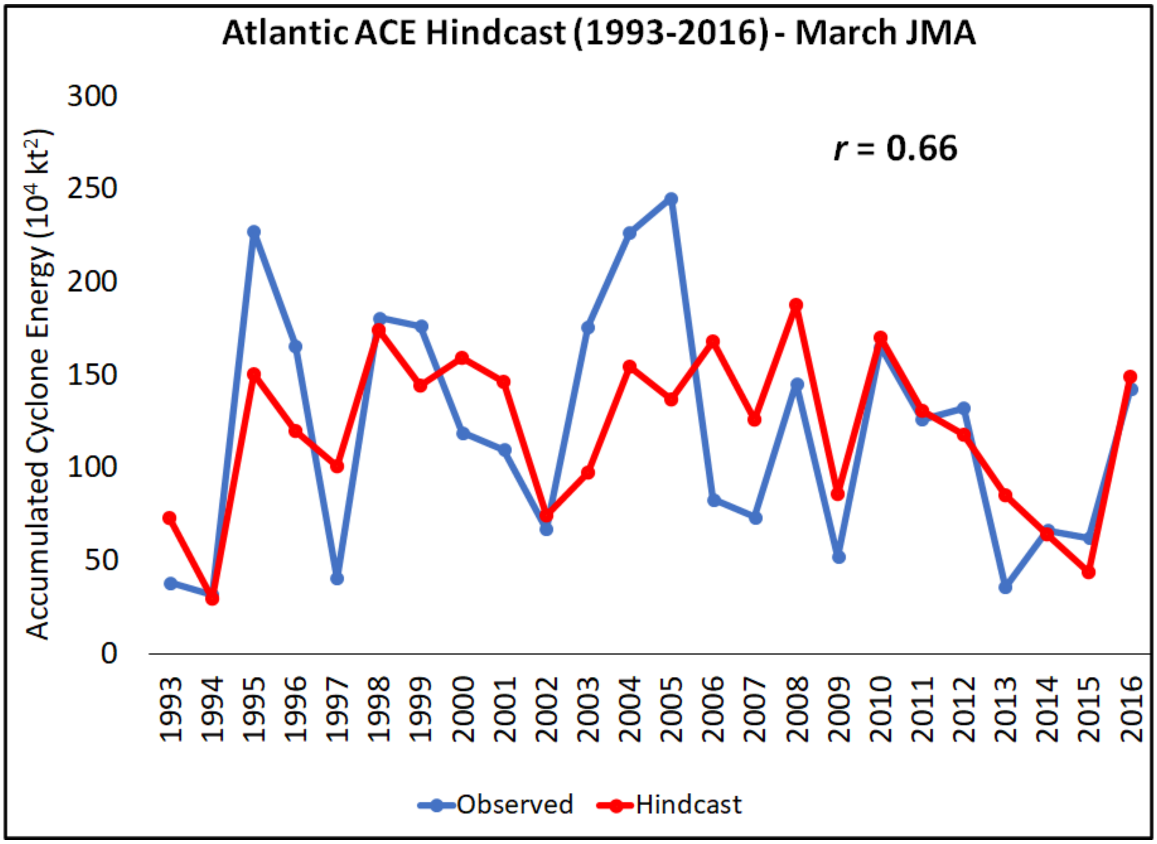

Figure 11: Observed versus statistical/dynamical hindcast values of ACE for 1993–2016 from the JMA.

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

Forecast Parameter and 1991–2020 Average (in parentheses)	JMA Hybrid Forecast	Final Forecast
Named Storms (14.4)	21.0	19
Named Storm Days (69.4)	114.9	90
Hurricanes (7.2)	11.9	9
Hurricane Days (27.0)	51.8	35
Major Hurricanes (3.2)	6.0	4
Major Hurricane Days (7.4)	16.3	9
Accumulated Cyclone Energy Index (123)	231	160
Net Tropical Cyclone Activity (135%)	241	170

2.3 April Analog Forecast Scheme

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2022. These years also provide useful clues as to likely levels of activity that the forthcoming 2022 hurricane season may bring. For this early 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 February-March 2022 conditions and, more importantly, projected August–October 2022 conditions. Table 10 lists our analog selections.

We searched for years that were generally characterized by La Niña conditions the previous winter and had neutral ENSO or weak La Niña conditions during the peak of the Atlantic hurricane season (August–October). We also selected years that had near- to above-average SSTs in the tropical Atlantic. We anticipate that the 2022 hurricane season will have activity somewhat above the average of our six analog years, given the high outlooks issued by our statistical model and our statistical/dynamical models.

Table 10: Analog years for 2022 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1996	13	79.00	9	45.00	6	13.00	166	192
2000	15	71.50	8	32.75	3	5.00	119	134
2001	15	68.75	9	25.50	4	4.25	110	135
2008	16	88.25	8	30.50	5	7.50	146	162
2012	19	101.25	10	28.50	2	0.50	133	131
2021	21	79.00	7	27.50	4	13.75	146	177
Average	16.5	81.3	8.5	31.6	4.0	7.3	137	155
2022 Forecast	**19**	**90**	**9**	**35**	**4**	**9**	**160**	**170**

2.4 April Forecast Summary and Final Adjusted Forecast

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

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

Forecast Parameter and 1991–2020 Average (in parentheses)	Statistical Scheme	ECMWF Scheme	Met Office Scheme	JMA Scheme	Analog Scheme	5-Scheme Average	Adjusted Final Forecast
Named Storms (14.4)	17.2	17.9	17.0	21.0	16.0	17.8	19
Named Storm Days (69.4)	88.4	93.5	87.6	114.9	77.3	92.3	90
Hurricanes (7.2)	9.2	9.7	9.1	11.9	8.2	9.6	9
Hurricane Days (27.0)	37.4	40.1	36.9	51.8	32.3	39.7	35
Major Hurricanes (3.2)	4.4	4.7	4.3	6.0	4.4	4.8	4
Major Hurricane Days (7.4)	11.1	12.1	11.0	16.3	8.7	11.8	9
Accumulated Cyclone Energy Index (123)	168	180	166	231	137	176	160
Net Tropical Cyclone Activity (135%)	180	192	178	243	160	191	170

3 Forecast Uncertainty

This season we continue to use probability of exceedance curves as discussed in Saunders et al. (2020) to quantify forecast uncertainty. In that paper, we outlined an approach that uses statistical modeling and historical skill of various forecast models to arrive at a probability that particular values for hurricane numbers and ACE would be exceeded. Here we display probability of exceedance curves for hurricanes and ACE (Figures 12 and 13), 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 12 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.

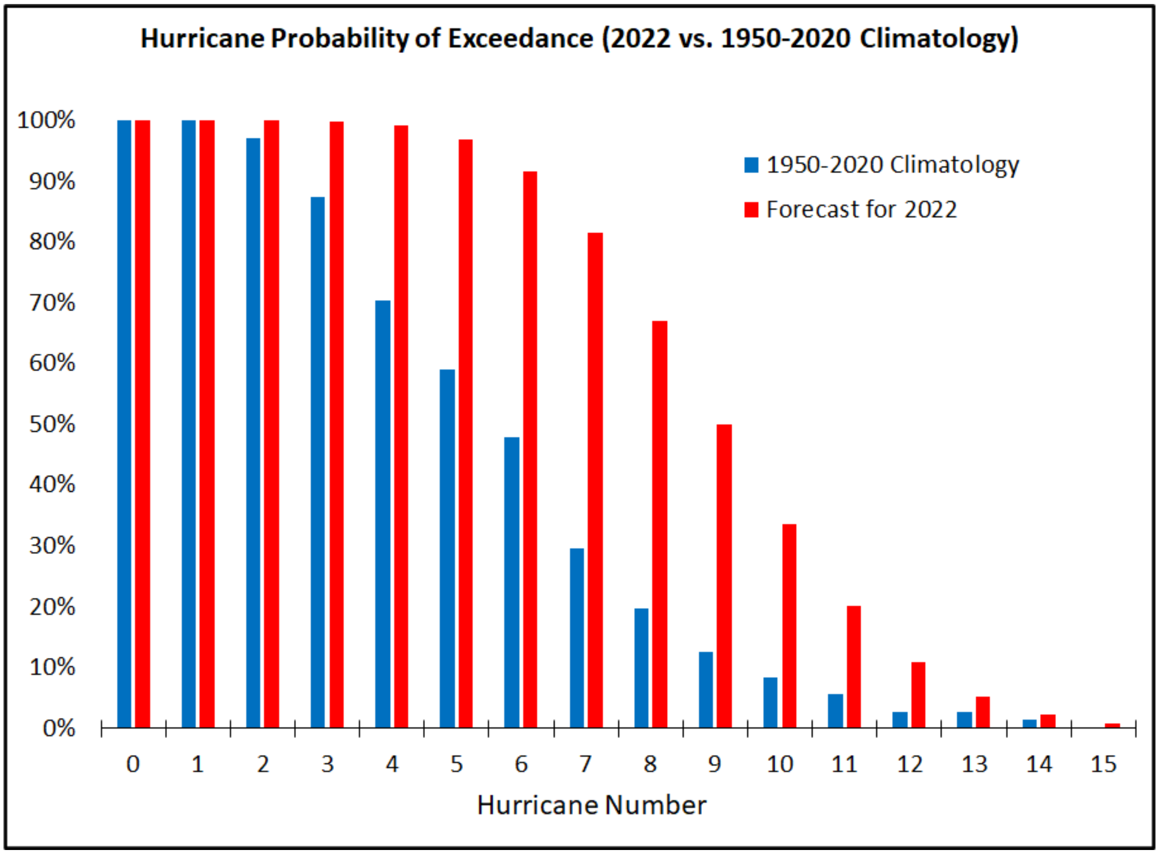

Figure 12: Probability of exceedance plot for hurricane numbers for the 2022 Atlantic hurricane season. The values on the x-axis indicate that the number of hurricanes exceeds that specific number. For example, 97% of Atlantic hurricane seasons from 1950–2020 have had more than two hurricanes.

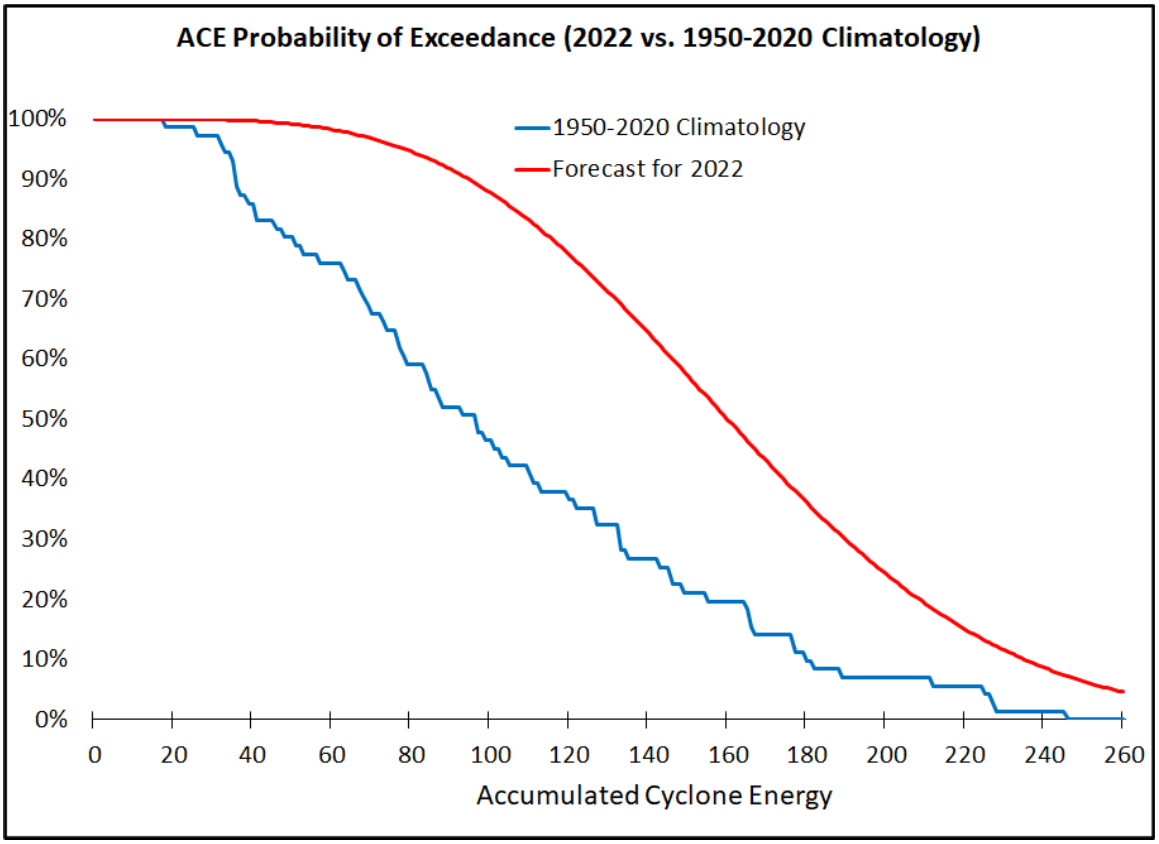

Figure 13: As in Figure 10 but for ACE.

Table 12: Forecast ranges for each parameter. Note that the forecast spread may not be symmetric around the mean value, given the historical distribution of tropical cyclone activity.

Parameter	2022 Forecast	Uncertainty Range (68% of Forecasts Likely to Fall in This Range)
Named Storms (NS)	19	16 – 23
Named Storm Days (NSD)	90	67 – 114
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)	160	106 – 220
Net Tropical Cyclone (NTC) Activity	170	117 – 227

4 ENSO

Over the past several months, the tropical Pacific has been characterized by a weak La Niña event (Figure 14). ENSO events are partially classified by NOAA based on SST anomalies in the Nino 3.4 region, which is defined as 5°S–5°N, 170–120°W. Weak La Niña events are typically defined to be those where SST anomalies are between -0.5°C – -1.0°C. Over the past several weeks, SST anomalies have increased in the eastern tropical Pacific but have decreased in the central tropical Pacific. The overall oceanic/atmospheric pattern still reflects weak La Niña conditions.

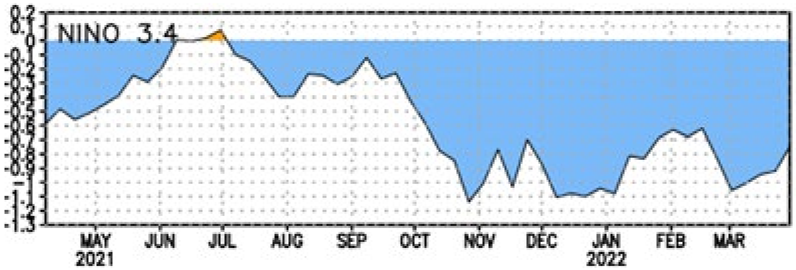

Figure 14: Nino 3.4 SST anomalies from April 2021 through March 2022. Figure courtesy of Climate Prediction Center.

Upper-ocean heat content anomalies in the eastern and central tropical Pacific reached their coldest during the middle part of October and then increased rapidly through early February (Figure 15). Over the past few weeks, these heat content anomalies have generally decreased, likely due to an upwelling Kelvin wave currently transiting the central tropical Pacific. This Kelvin wave will be discussed in more detail later in this section.

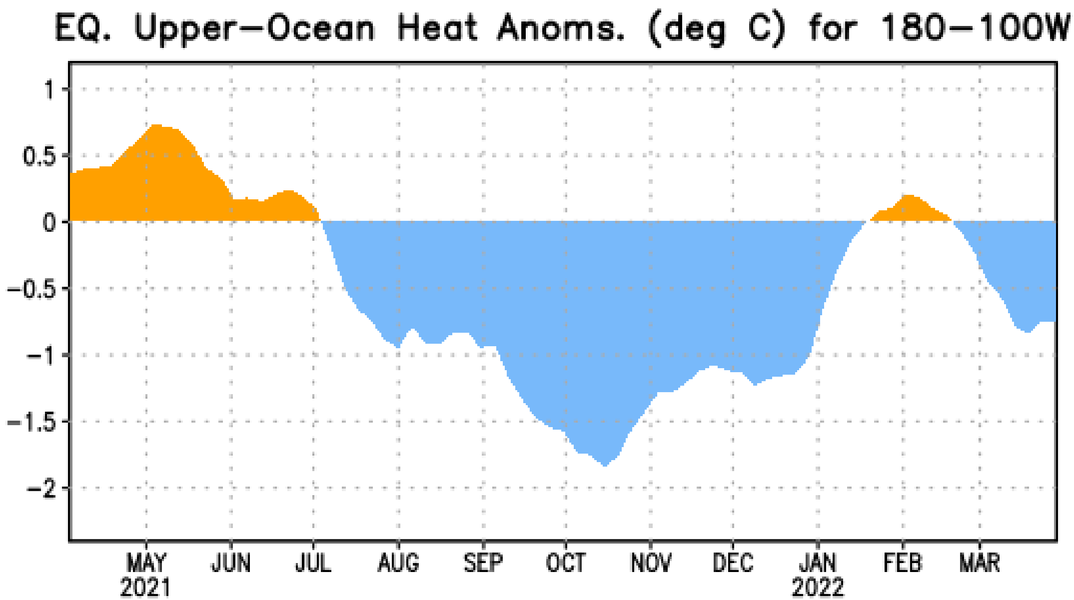

Figure 15: Central and eastern equatorial Pacific upper ocean (0-300 meters) heat content anomalies over the past year.

Below-normal SSTs currently extend across most of the eastern and central equatorial Pacific (Figure 16), although there are warmer than normal SSTs just off of the west coast of Ecuador and Peru. The western North Pacific is warmer than normal, while the current spatial pattern of SSTs in the North Pacific (e.g., warm anomalies across most of the North Pacific and cold anomalies off of the west coast of California) are indicative of a negative phase of the Pacific Decadal Oscillation.

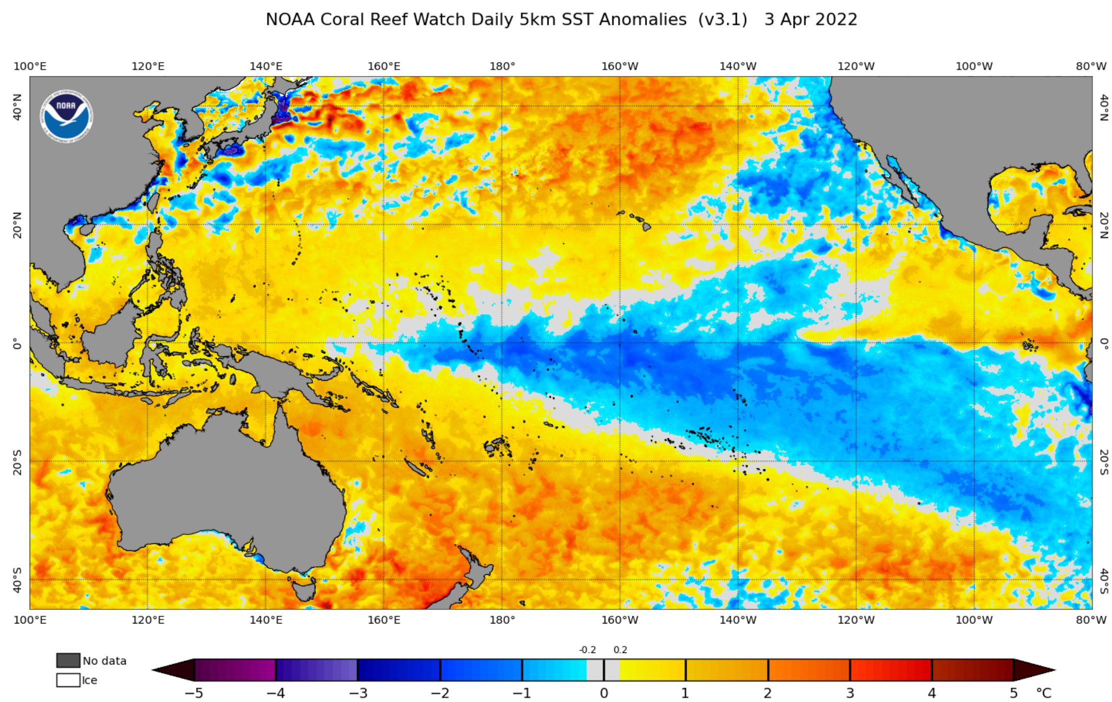

Figure 16: Current SST anomalies across the tropical and subtropical Pacific.

Table 13 displays January and March SST anomalies for several Nino regions. Over the past two months, SST anomalies in the eastern equatorial Pacific have anomalously warmed, while SST anomalies in the central equatorial Pacific remain anomalously cool.

Table 13: 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	-0.7	-0.6	+0.1
Nino 3	-1.2	-0.7	+0.5
Nino 3.4	-1.1	-0.9	+0.2
Nino 4	-0.8	-0.8	0.0

A downwelling (warming) Kelvin wave, denoted by the long dashed line, has nearly transited the entire tropical Pacific and has reached the South American coast. A strong trade wind surge has helped to enhance an upwelling (cooling) Kelvin wave, denoted by the short, dotted line, which is currently located in the east/central Pacific (Figure 17). These Kelvin waves are typically triggered by anomalous low-level winds in the tropical Pacific.

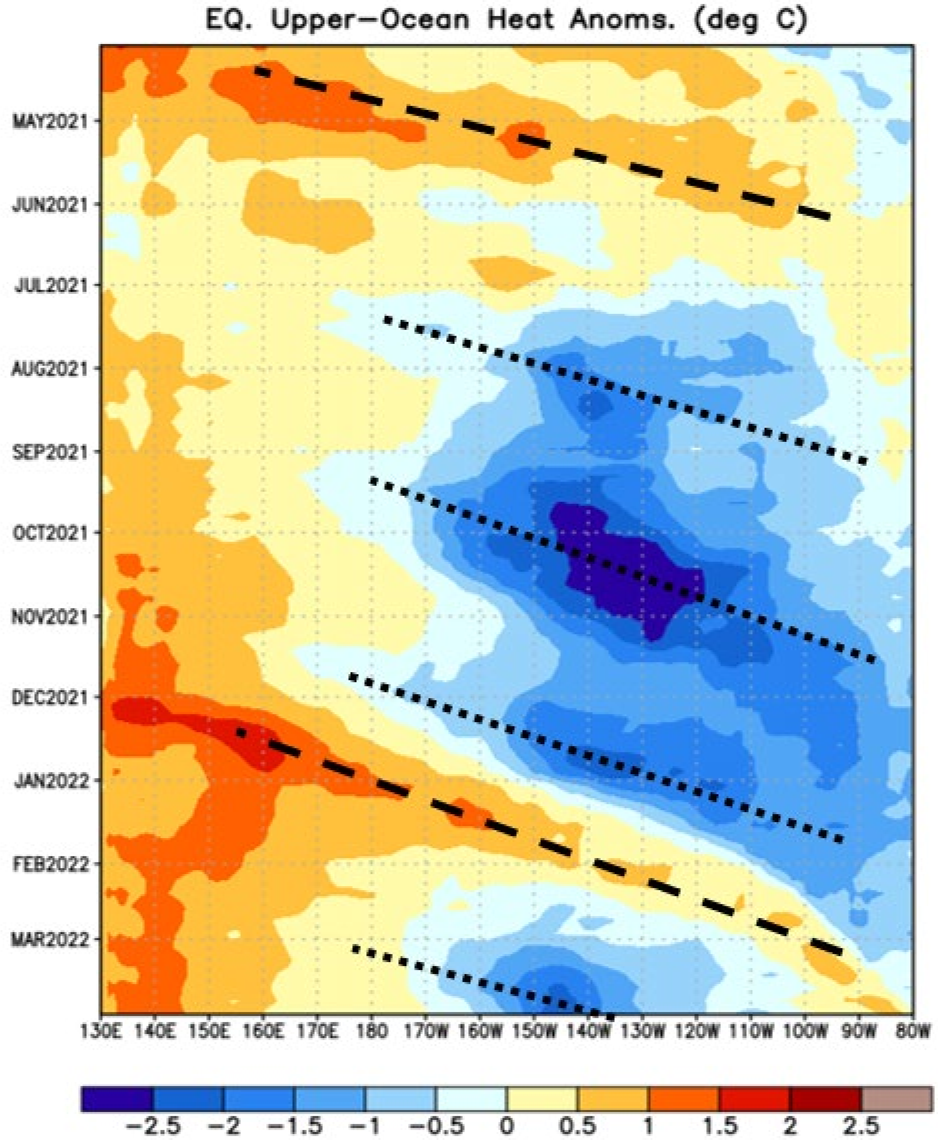

Figure 17: Upper-ocean heat content anomalies in the tropical Pacific since April 2021. Dashed lines indicate downwelling Kelvin waves, while dotted lines indicate upwelling Kelvin waves. Downwelling Kelvin waves result in upper-ocean heat content increases, while upwelling Kelvin waves result in upper-ocean heat content decreases.

Over the next several months, we will be closely monitoring low-level winds over the tropical Pacific. Anomalous easterlies have generally prevailed across the central tropical Pacific over the past few months. There has been a recent relaxation of these trade winds associated with an enhanced convective phase of the Madden-Julian oscillation (Figure 18). These anomalously weak trade winds may increase anomalous SSTs in the short term, but we believe that the odds of a significant El Niño event for the 2022 Atlantic hurricane season are quite small.

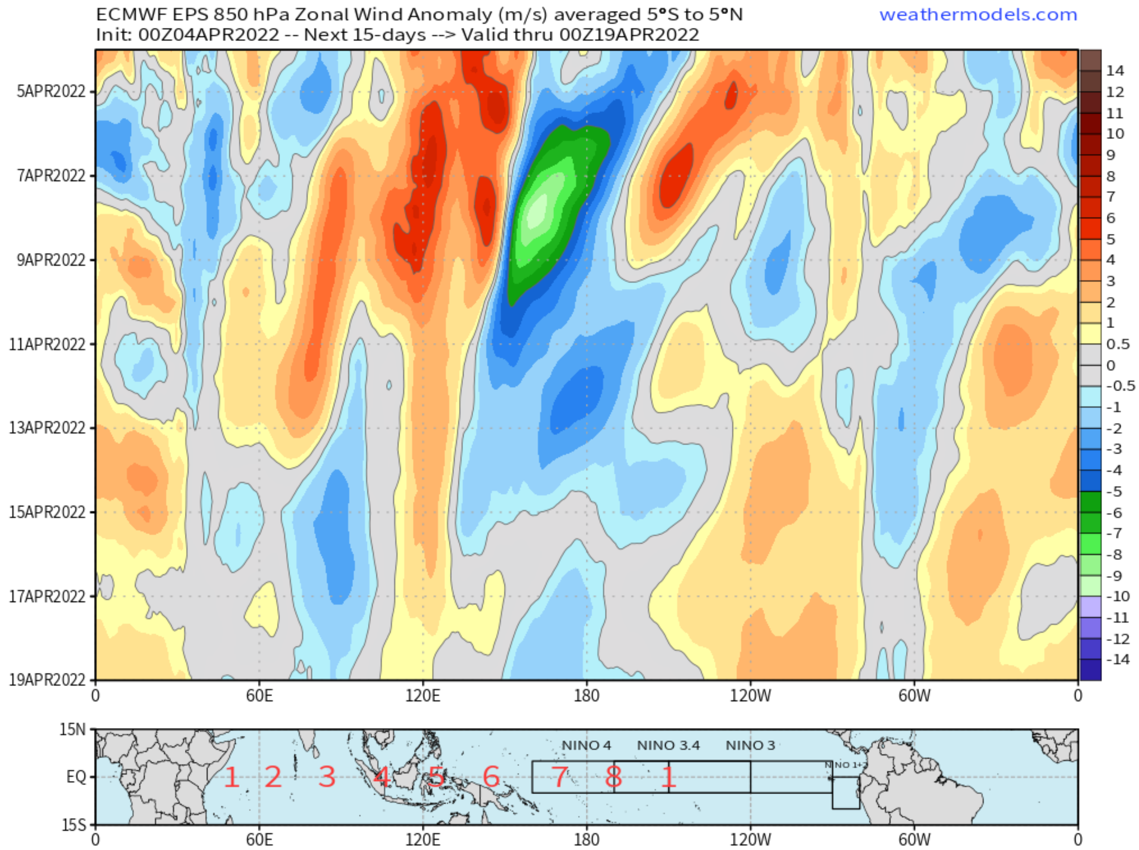

Figure 18: Forecast 850-hPa zonal equatorial winds for the next 15 days. Figure courtesy of weathermodels.com.

There is always considerable uncertainty with the future state of El Niño during the Northern Hemisphere spring. The latest plume of ENSO predictions from several statistical and dynamical models shows considerable spread by the peak of the Atlantic hurricane season in August–October (Figure 19). While there is a large spread, most models call for either La Niña or neutral ENSO conditions for the next several months.

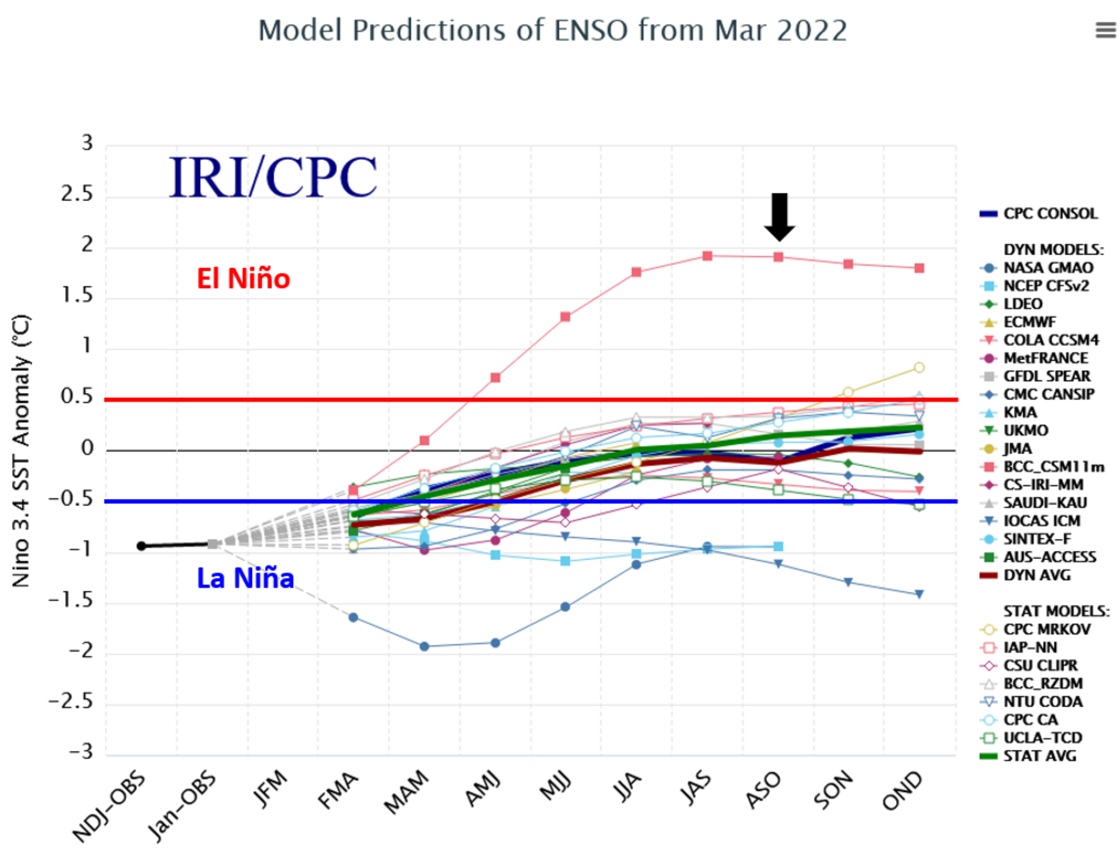

Figure 19: ENSO forecasts from various statistical and dynamical models for Nino 3.4 SST anomalies based on late February to early March initial conditions. Most models are calling for either La Niña or ENSO neutral conditions for August–October. Figure courtesy of the International Research Institute (IRI).

The latest official forecast from NOAA also indicates that the chances of El Niño are quite low for August–October. NOAA is currently predicting a 10% chance of El Niño, a 45% chance of ENSO neutral conditions and a 45% chance of La Niña for the peak of the Atlantic hurricane season (Figure 20).

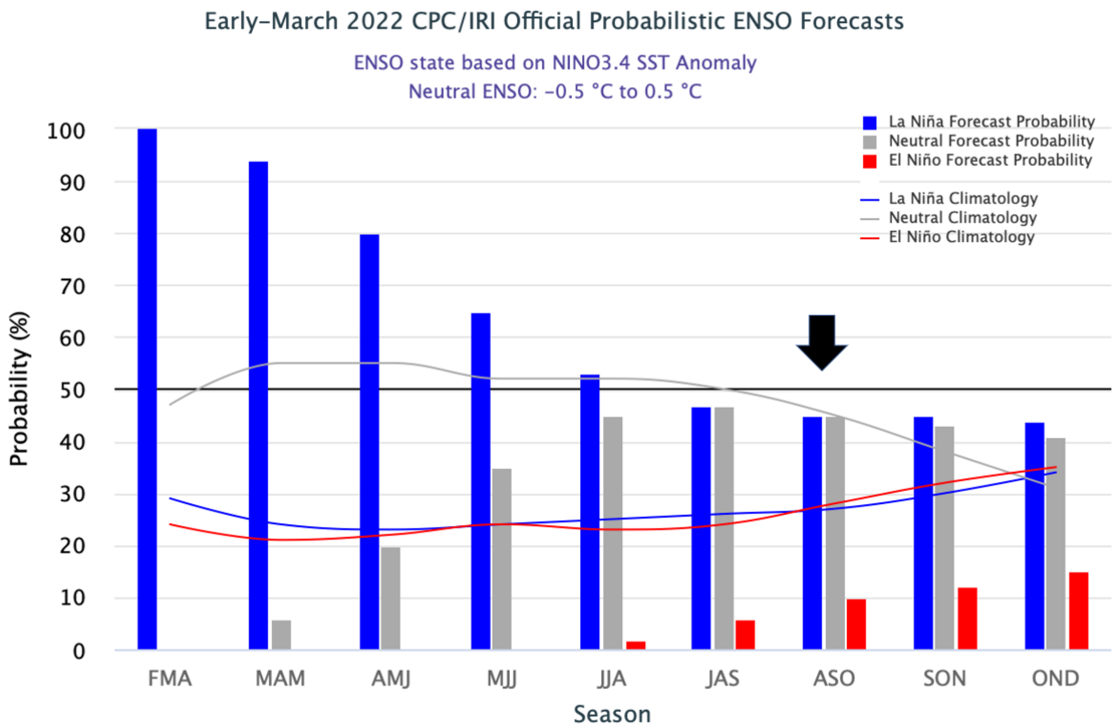

Figure 20: Official NOAA forecast for ENSO.

Based on the above information, our best estimate is that we will likely not have El Niño conditions for the peak of the Atlantic hurricane season. While El Niño seems unlikely, there remains considerable uncertainty as to whether the tropical Pacific will have neutral ENSO conditions or continue to have La Niña conditions. We will have more to say with our next forecast release on 2 June.

5 Current Atlantic Basin Conditions

Currently, SSTs are near to slightly below normal in the tropical Atlantic, while they are well above normal in the Caribbean and in the subtropical North Atlantic (Figure 21). As has generally been the case during most of the past few winters, the North Atlantic Oscillation (NAO) has been positive during most of this winter (Figure 22). A positive NAO tends to force a tripole pattern of SSTs characterized by anomalous warmth off of the US East Coast and anomalous cold in the tropical Atlantic due to stronger-than-normal trade winds. Virtually the entire North Atlantic was much warmer than normal during January (Figure 23), so while the positive NAO has caused considerable anomalous cooling in the tropical Atlantic, overall tropical Atlantic SSTs remain near normal. In addition, Figure 22 shows the upcoming forecast for the NAO for the next 15 days from the Global Ensemble Forecast System, with the trade winds likely to be at more average levels as the NAO has generally trended negative/neutral over the past few weeks. Overall, the current SST anomaly pattern correlates relatively well with what is typically seen in active Atlantic hurricane seasons. Anomalous warmth in the subtropical eastern Atlantic and in the Caribbean in March correlate well with active Atlantic hurricane seasons (Figure 24).

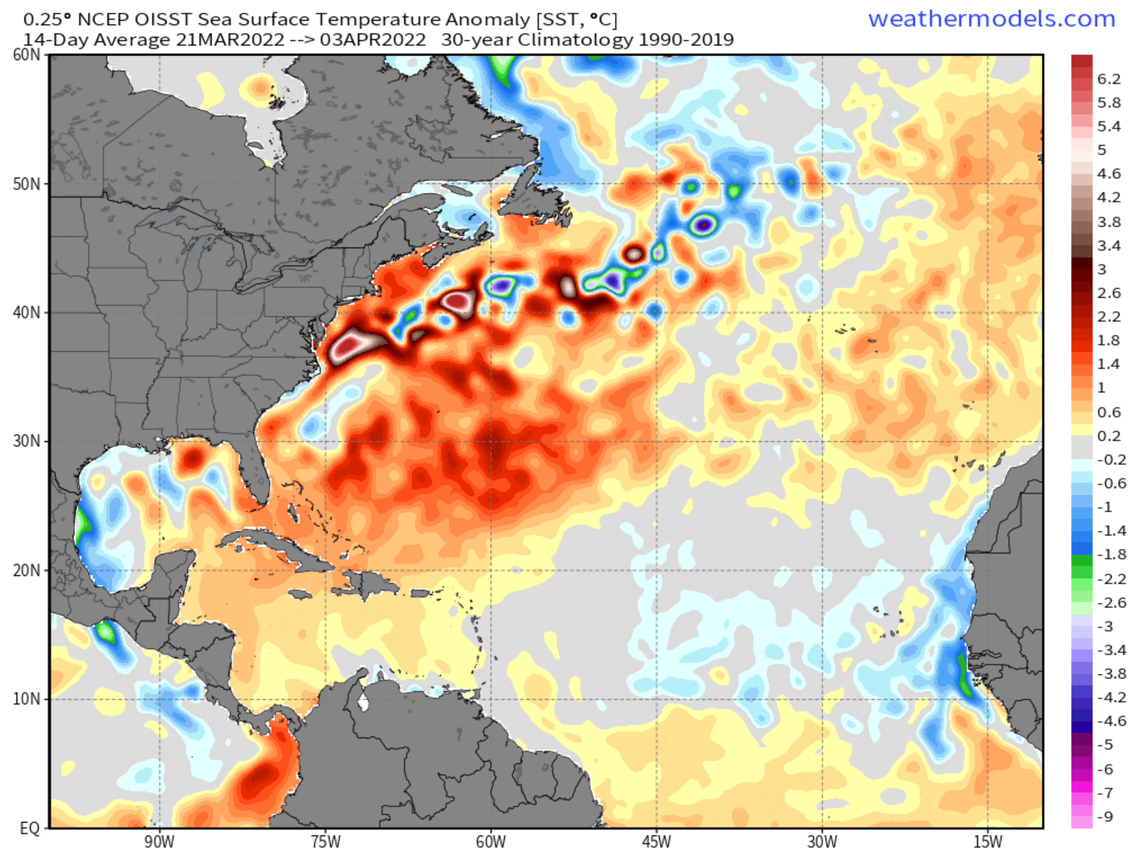

Figure 21: Late March/early April 2022 SST anomaly pattern across the Atlantic Ocean.

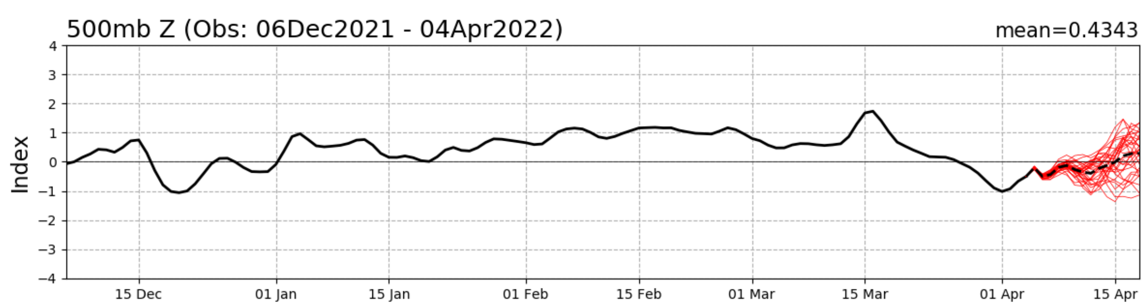

Figure 22: Observed values of the NAO since late December and forecasts of the NAO from the Global Ensemble Forecast System for the next 15 days.

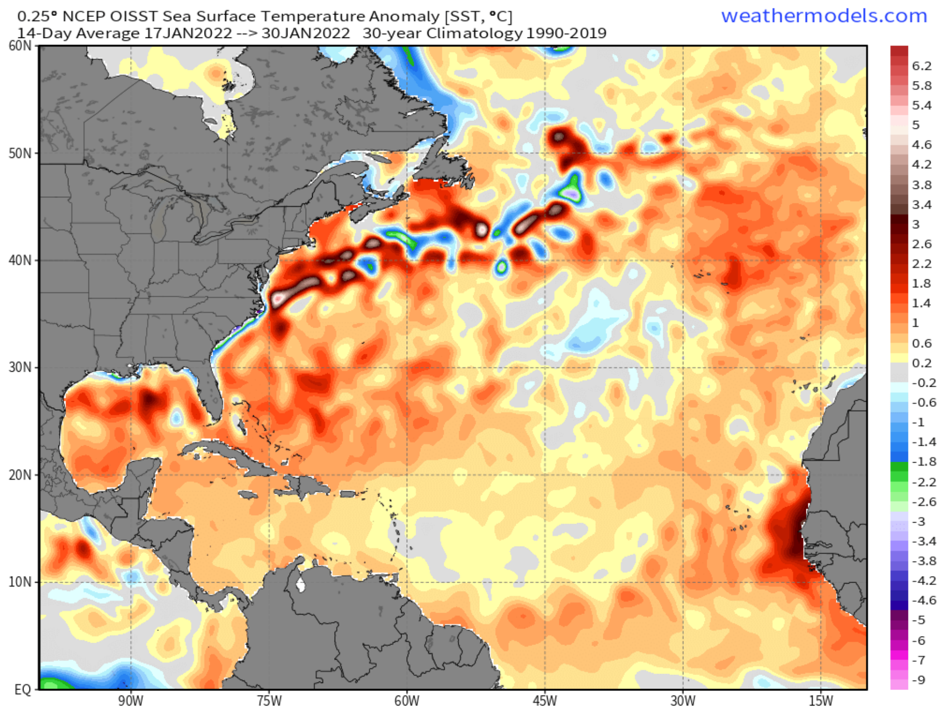

Figure 23: Late January 2022 SST anomaly pattern across the Atlantic Ocean.

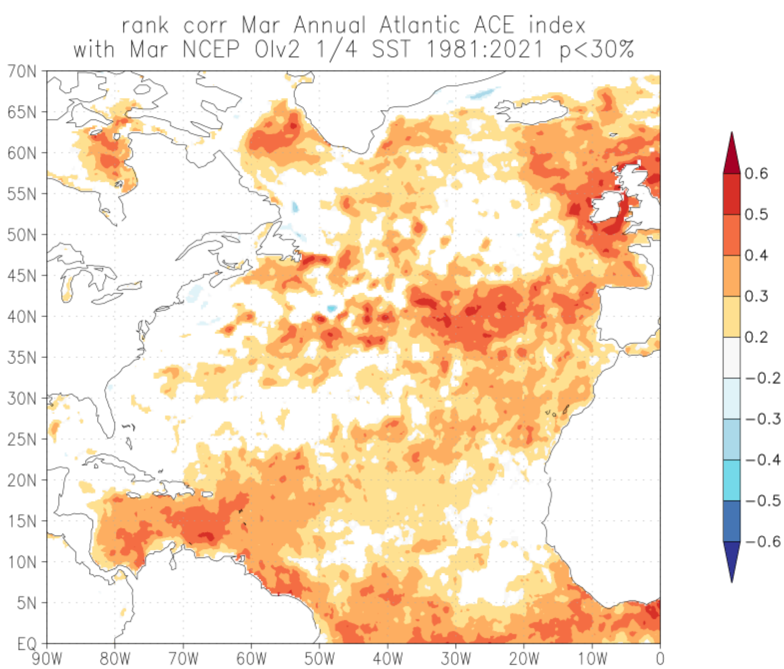

Figure 24: Rank correlation between March North Atlantic SST anomalies and seasonal Atlantic ACE from 1982–2021.

6 Tropical Cyclone Impact Probabilities for 2022

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

Net landfall probability is shown to be linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 14). NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, each expressed as a percentage difference from the 1950–2000 climatological average. Long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season is, the greater the probability of U.S. hurricane landfall.

Table 14: NTC activity in any year consists of the seasonal total of the following six parameters expressed in terms of their long-term averages. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 MH, and 5 MHD would then be the sum of the following ratios: 10/9.6 = 104, 50/49.1 = 102, 6/5.9 = 102, 25/24.5 = 102, 3/2.3 = 130, 5/5.0 = 100, divided by six, yielding an NTC of 107.

	1950–2000 Average	
1)	Named Storms (NS)	9.6
2)	Named Storm Days (NSD)	49.1
3)	Hurricanes (H)	5.9
4)	Hurricane Days (HD)	24.5
5)	Major Hurricanes (MH)	2.3
6)	Major Hurricane Days (MHD)	5.0

Table 15 displays the climatological odds of storms tracking within 50 miles of each state along the Gulf and East Coasts along with the odds in 2022. Given that the seasonal forecast is for above-average hurricane activity, the odds of tropical cyclone impacts are also elevated. Probabilities for other Atlantic basin landmasses are available on our website.

Table 15: Probability of >=1 named storm, hurricane and major hurricane tracking within 50 miles of each coastal state from Texas to Maine. Probabilities are provided for both the 1880–2020 climatological average as well as the probability for 2022, based on the latest CSU seasonal hurricane forecast.

	2022 Probability			Climatological		
	Probability >=1	event within	50 miles	Probability >=1	event within	50 miles
State	Named Storm	Hurricane	Major Hurricane	Named Storm	Hurricane	Major Hurricane
Texas	80%	54%	25%	61%	36%	16%
Louisiana	84%	56%	23%	66%	38%	14%
Mississippi	72%	43%	12%	53%	28%	8%
Alabama	77%	43%	13%	58%	28%	8%
Florida	96%	75%	44%	86%	56%	29%
Georgia	82%	46%	10%	63%	30%	6%
South Carolina	76%	44%	13%	57%	29%	8%
North Carolina	85%	56%	12%	68%	38%	8%
Virginia	65%	31%	2%	46%	20%	1%
Maryland	47%	18%	1%	31%	11%	1%
Delaware	35%	10%	1%	23%	6%	1%
New Jersey	35%	11%	1%	23%	7%	1%
New York	40%	16%	4%	26%	9%	2%
Connecticut	34%	12%	2%	22%	8%	1%
Rhode Island	32%	12%	2%	20%	8%	1%
Massachusetts	49%	23%	5%	33%	14%	3%
New Hampshire	29%	9%	2%	18%	6%	1%
Maine	34%	11%	2%	21%	7%	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 2022 should have above-normal activity. The big question marks with this season's predictions revolve around what phase ENSO will be, as well as what the configuration of SSTs will look like in the Atlantic Ocean during the peak of the Atlantic hurricane season.

8 Forthcoming Updated Forecasts of 2022 Hurricane Activity

We will be issuing seasonal updates of our 2022 Atlantic basin hurricane forecasts on **Thursday 2 June**, **Thursday 7 July, and Thursday 4 August**. We will also be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August–October. A verification and discussion of all 2022 forecasts will be issued in late November 2022. All of these forecasts will be available on our website.

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 25 displays correlations between observed and predicted Atlantic hurricanes from 1984–2013, from 2014–2021 and from 1984–2021, respectively. Correlation skill has improved at all lead times in recent years, with the most noticeable improvements at longer lead times. While eight years is a relatively short sample size, improvements in both modeling and physical understanding should continue to result in future improvements in seasonal Atlantic hurricane forecast skill. More detailed verification statistics are also available at: https://tropical.colostate.edu/archive.html#verification

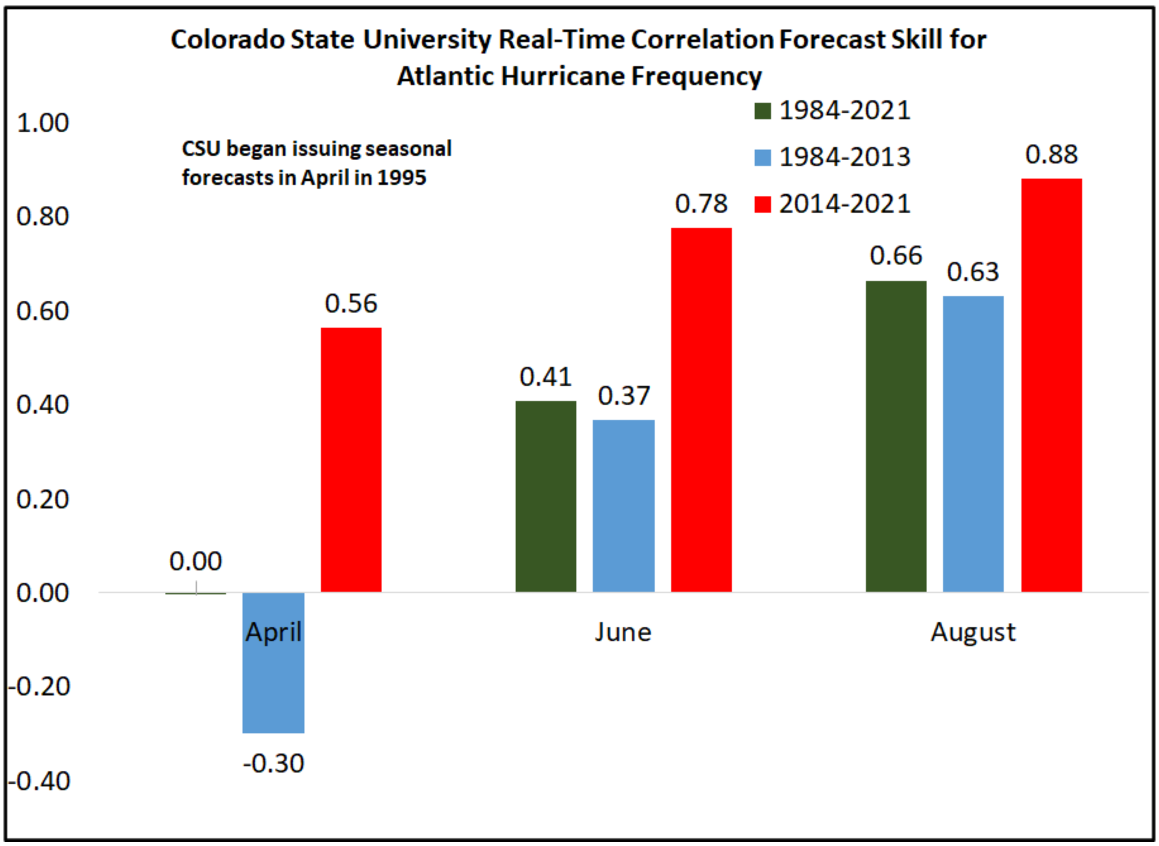

Figure 25: CSU's real-time forecast skill for Atlantic hurricanes using correlation as the skill metric. Correlation skills are displayed for three separate time periods: 1984–2013, 2014–2021 and 1984–2021, respectively.