QUALITATIVE DISCUSSION OF ATLANTIC BASIN SEASONAL HURRICANE ACTIVITY FOR 2019

We provide qualitative discussions of the factors which will determine next year's Atlantic basin hurricane activity with our December outlook. Two big questions with the upcoming hurricane season are what will happen with the current warm ENSO neutral state as well as what trends are likely to occur with the Atlantic Multidecadal Oscillation.

Our first quantitative forecast for 2019 will be issued on Thursday, April 4.

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In Memory of William M. Gray[3]

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

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ABSTRACT

We are providing a qualitative discussion of features likely to impact the 2019 Atlantic basin hurricane season rather than a specific number forecast. This outlook for 2019 will give our assessment of the probability of five potential scenarios for Accumulated Cyclone Energy (ACE).

The current way that we assess the following year's activity in the December outlook is in terms of two primary physical parameters:

1. the strength of the Atlantic Multi-Decadal Oscillation (AMO)

2. the phase of ENSO

The Atlantic had three quiet hurricane seasons from 2013-2015, followed by a slightly above-average season in 2016, near record-breaking levels of activity in 2017 and another slightly above-average season in 2018. This continues the debate as to whether we remain in an active AMO phase (Klotzbach et al. 2015). Another big question for 2019 is how El Niño-Southern Oscillation (ENSO) will trend over the next few months. There is considerable model disagreement as to what the phase of ENSO will look like for the summer and fall of 2019.

For the 2019 hurricane season, we anticipate five possible scenarios with the probability of each as indicated on the next page:

1. AMO becomes very strong in 2019 and no El Niño occurs (resulting in a seasonal average Accumulated Cyclone Energy (ACE) activity of ~ 170) – **10% chance**.
2. AMO is above average and no El Niño occurs (ACE ~ 130) – **25% chance**.
3. AMO is above average and El Niño develops (ACE ~ 80) – **20% chance**.
4. AMO is below average and no El Niño occurs (ACE ~ 80) – **30% chance**.
5. AMO is below average and El Niño develops (ACE ~ 50) – **15% chance**.

Typically, seasons with the above-listed ACE values have TC activity as follows:

170 ACE – 14-17 named storms, 9-11 hurricanes, 4-5 major hurricanes
120 ACE – 12-15 named storms, 6-8 hurricanes, 2-3 major hurricanes
80 ACE – 8-11 named storms, 3-5 hurricanes, 1-2 major hurricanes
50 ACE – 5-7 named storms, 2-3 hurricanes, 0-1 major hurricane

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 in 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 Interstate Restoration, the Insurance Information Institute, Weatherboy and Ironshore Insurance that partially support the release of these predictions. We thank the GeoGraphics Laboratory at Bridgewater State University (MA) for their assistance in developing the United States Landfalling Hurricane Probability Webpage.

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 have also benefited from meteorological discussions with Carl Schreck, Brian McNoldy, Paul Roundy, Jason Dunion, Mike Ventrice, Peng Xian and Amato Evan 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 1950-2000 average value of this parameter is 96 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.

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.

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 40-50 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, 20-75°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.

Multivariate ENSO Index (MEI) – An index defining ENSO that takes into account tropical Pacific sea surface temperatures, sea level pressures, zonal and meridional winds and cloudiness.

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.

Sea Surface Temperature – SST

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 mb (approximately 40000 feet or 12 km) and 850 mb (approximately 5000 feet or 1.6 km).

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

1 Introduction

This is the 36th 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. These forecasts are based on a statistical methodology derived from 30-60 years of past data. Qualitative adjustments are added to accommodate additional processes which may not be explicitly represented by our statistical 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 is 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. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmosphere-ocean system that is highly non-linear. There is a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. 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 some of the climate system's non-linear interactions. Any seasonal or climate forecast scheme must show significant hindcast skill before it is used in real-time forecasts.

2 The Influence of the Atlantic Ocean Thermohaline Circulation (THC) and the Strength of the Atlantic Gyre on Atlantic Hurricane Activity

Over the next few pages, we discuss two large-scale physical features which we know are fundamental for how active the 2019 Atlantic hurricane season is likely to be.

The longer-period SST changes which the Atlantic Ocean experiences are due primarily to variations in the strength of the southwest to northeast upper branch of the THC in the high latitude Atlantic, which are then reflected in changes in the AMO. The THC (which is observed and modeled to vary considerably in strength on multi-decadal timescales) is strong when there is an above-average poleward advection of warm tropical waters to the high latitudes of the Atlantic. This poleward-moving water can then sink to deep levels if it has high enough salinity content. This sinking process is known as North Atlantic Deep Water Formation (NADWF). The deep water then moves southward into the Southern Hemisphere. The amount of North Atlantic water that sinks is roughly proportional to the water's density which at high latitudes, where water temperatures are low, is primarily dependent on salinity content. The strong association between our proxy for the AMO and North Atlantic salinity in the far North Atlantic (50-60°N, 50-10°W) is shown in Figure 1. High salinity implies higher rates of NADWF. When the salinity rates are lower, less NADWF formation occurs. During these periods, the water tends to recirculate and increase the ocean's clockwise circulating gyre motion.

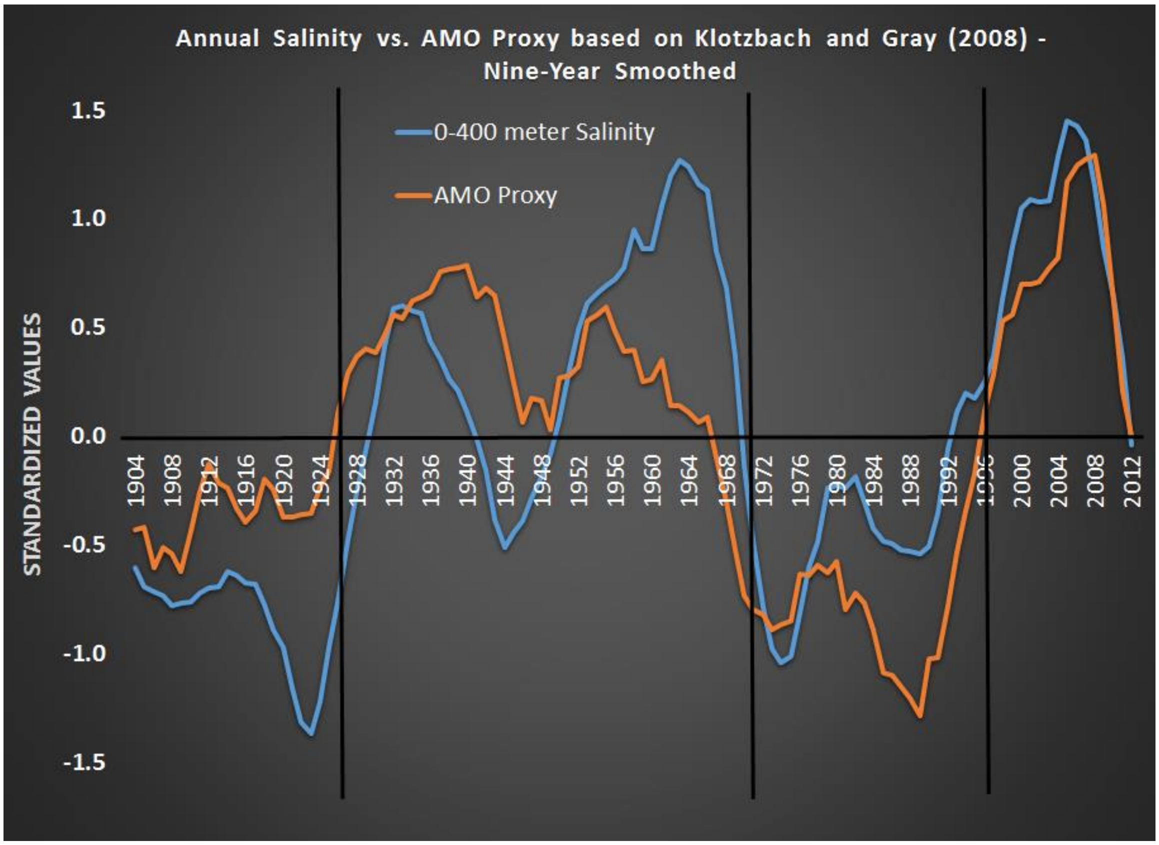

Figure 1: Illustration of the strong association of the AMO with North Atlantic salinity content from 1900-2016.

Through a progression of relationships, the strength of the NADWF and inverse strength of the Atlantic gyre is hypothesized to bring about alterations of the tropospheric vertical wind shear, trade wind strength, SSTs, middle-level water vapor, and other conditions in the Atlantic Main Development Region (MDR – 7.5-22.5°N; 20-75°W). Changes of SST in the MDR are a consequence of a combination of the AMO's influences on a variety of other parameters in the MDR (Figure 2). A stronger than average THC causes more ocean sinking in area 1. This in turn reduces the strength of the Atlantic gyre. There is then a change in the other conditions shown in Figure 2 to bring about more or less favorable parameters in the MDR for TC formation and intensification. This figure illustrates how the changing rate of southward advection of cold water in the east Atlantic (2) brings about alterations of SLP (3), SST (4), and rainfall (5). These changes in turn lead to changes in trade wind strength (6) and 200 mb zonal wind (7). Changes in hurricane activity and especially major hurricane activity follow (8). It is also found that in periods with a strong THC, El Niño frequency and intensity is typically reduced (9) and tropical South Atlantic SSTs are decreased (10).

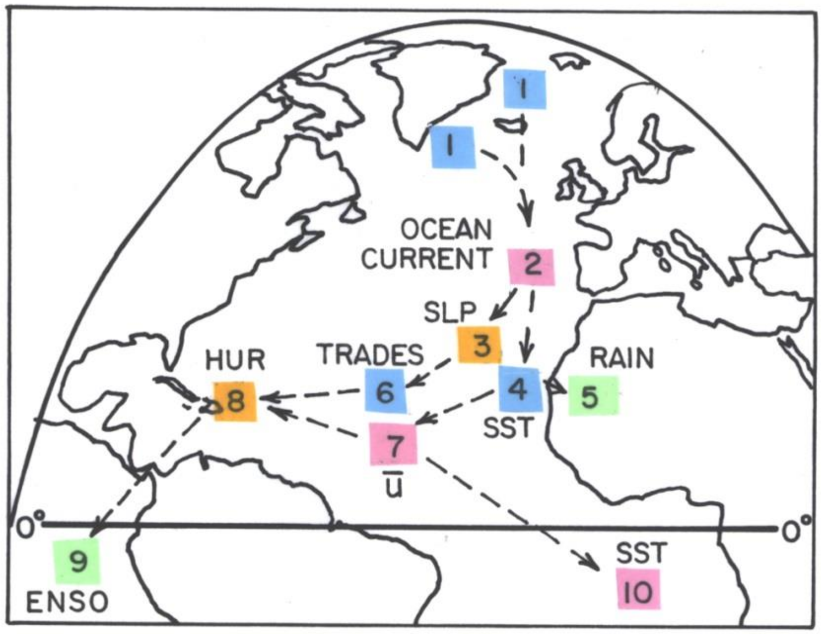

Figure 2: Idealized analysis of how changes in North Atlantic SST and salinity (area 1) lead to progressive ocean current, wind, pressure, SST, vertical shear and rain changes as portrayed in nine areas. It is this complete package of Atlantic/eastern Pacific Ocean/atmosphere parameter changes on multi-decadal time scales which cause large changes in Atlantic major hurricanes on this time scale.

One of the primary physical drivers for active versus inactive Atlantic basin hurricane seasons is the strength of the AMO (Gray et al. 1996, Goldenberg et al. 2001, Klotzbach and Gray 2008). A positive phase of the AMO (or strong phase of the THC) typically leads to 3-5 times more major Atlantic basin hurricane activity than does a negative phase. The typical period of the AMO is about 60 years, with the period length varying between as short as 40-50 years and if 70-80 years. This means that we typically have 25-35 years of above-average Atlantic basin major TC activity and similar length periods with considerably reduced amounts of major TC activity. Recently, we had three quiet Atlantic hurricane seasons in a row (e.g., 2013-2015) which led us to question whether we had moved out of the active era that began in 1995 (Klotzbach et al. 2015). The relatively active 2016 Atlantic hurricane season, the extremely active 2017 Atlantic hurricane season and the slightly above-average 2018 Atlantic hurricane season considerably clouds the current AMO phase issue.

While the AMO typically remains in an above-average or in a below-average state for periods of 25-35 years, there can be monthly, seasonal or longer breaks up to a year or two within these decadal periods when the AMO conditions of features such as SST, salinity, pressure, wind, and moisture become substantially weaker in positive AMO phases or stronger during negative AMO phases.

There is a strong inverse relationship between the strength of the AMO and the strength of the Atlantic gyre (Bermuda-Azores High). This has been well documented in our analysis of various yearly and seasonal gyre and AMO proxy variations. Hurricane activity, particularly the most intense hurricane activity, is much more frequent when the Atlantic Bermuda-Azores gyre circulation system is weak and the Atlantic Ocean THC system is strong. Hurricane activity is generally reduced when the reverse conditions occur. Increased gyre strength acts to bring about cooler air (and reduced moisture) and cooler ocean water advection in the eastern half of the Atlantic. This acts to increase the strength of the trade winds and increase the low latitude (5-20°N) south to north tropospheric temperature gradient and the upper tropospheric westerly winds. These changes are inhibiting factors for hurricane formation and intensification.

We currently monitor a THC proxy that utilizes SST in the region from 50-60°N, 50-10°W and SLP in the region from 0-50°N, 70-10°W (Figure 3). The index is created by weighing the two parameters as follows: 0.6*SST – 0.4*SLP. Our AMO index is currently running at near-normal levels (Figure 4). The tropical Atlantic and far North Atlantic are slightly cooler than normal right now (Figure 5). However, SLP anomalies in November were lower than normal, which is why the AMO index ended up near average.

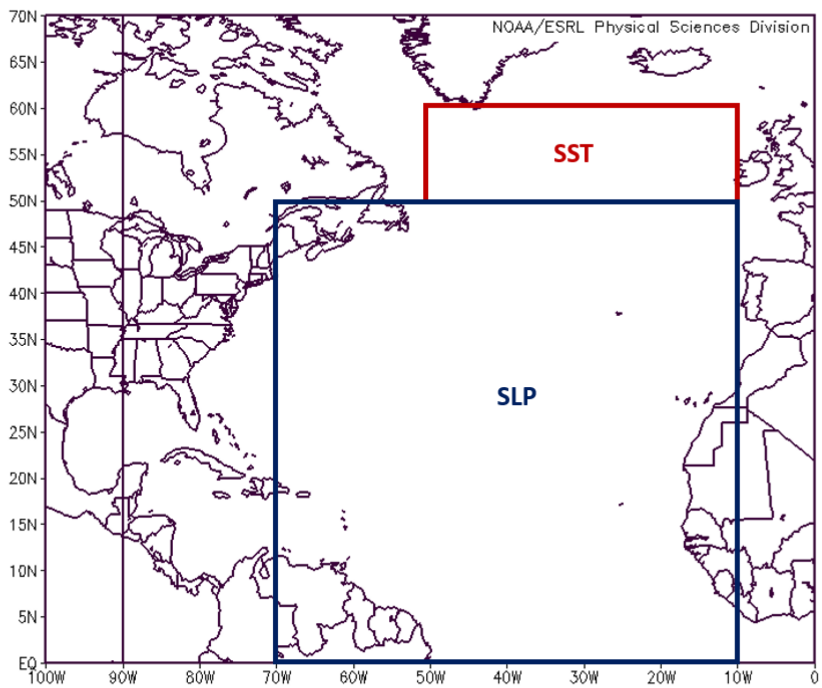

Figure 3: Regions which are utilized for calculation of our THC/AMO index. These regions are as defined in Klotzbach and Gray (2008).

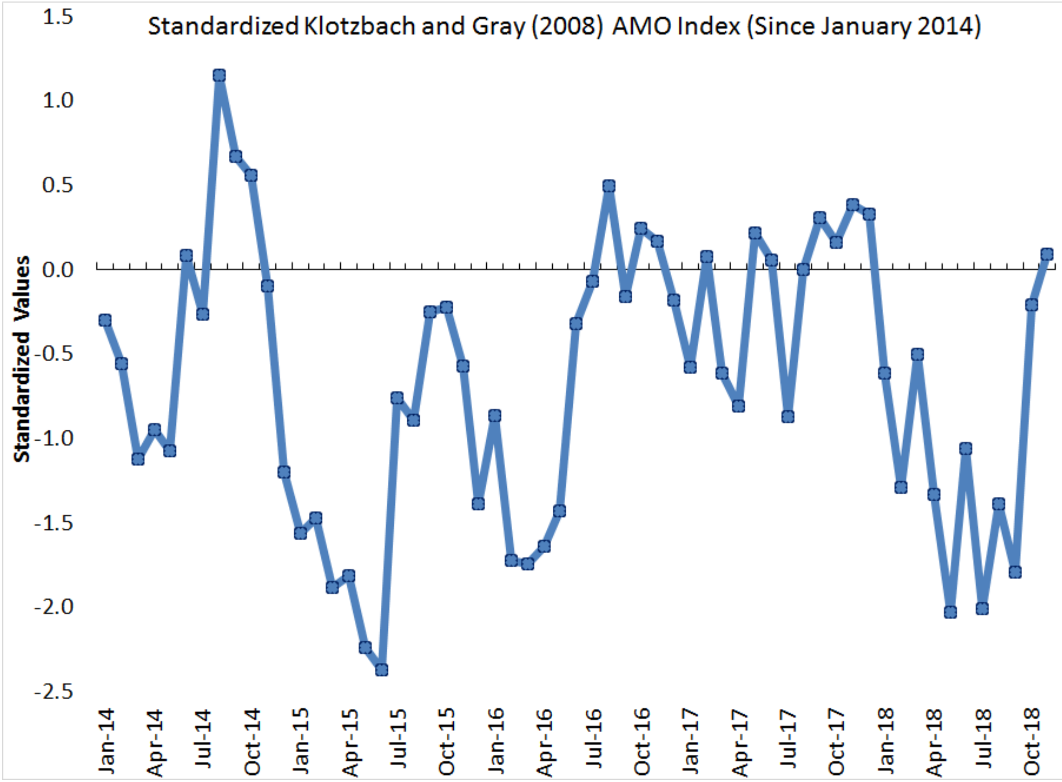

Figure 4: Standardized values of the AMO index by month since January 2014.

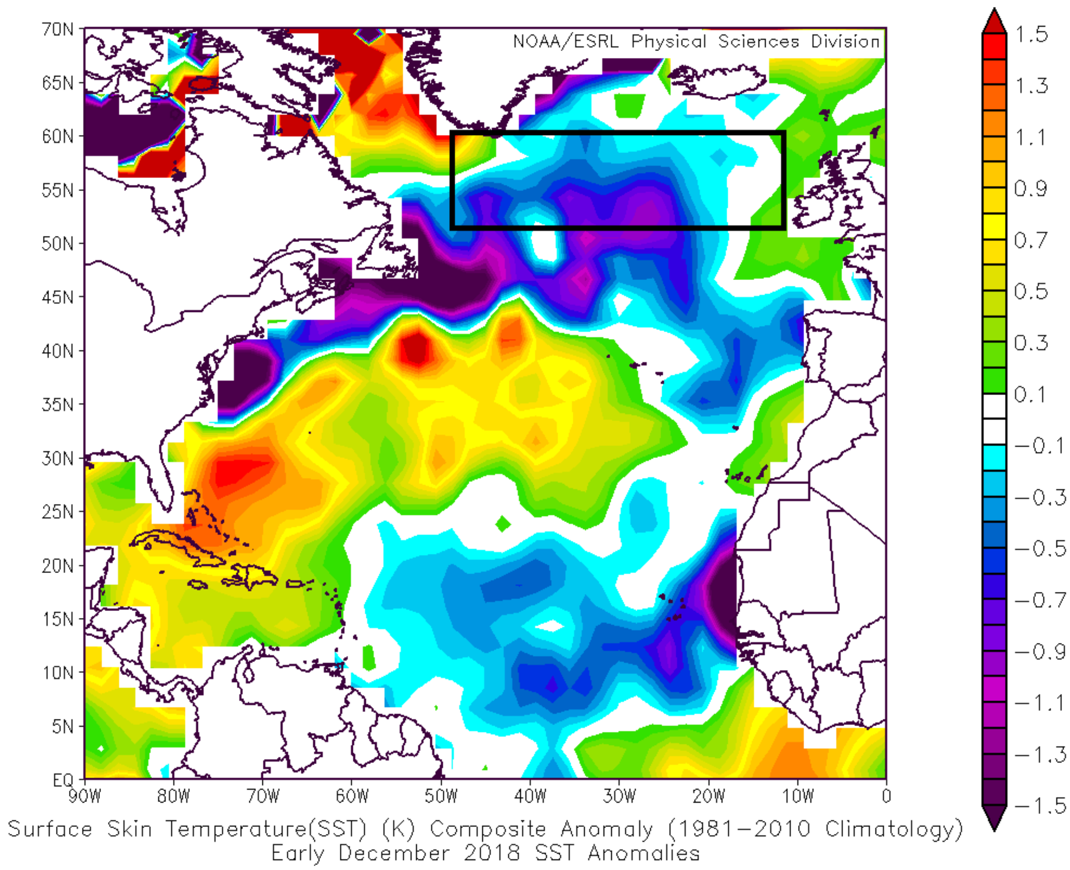

Figure 5: Current SST anomalies across the North Atlantic Ocean. The black box highlights the region where we measure SSTs for our AMO index.

3 ENSO

There are currently warm neutral ENSO conditions in place across the tropical Pacific (Figure 6). While weekly anomalies have reached El Niño levels (e.g., >=0.5°C) in the Nino 3.4 region, these anomalies have not been persistent enough for NOAA to declare an El Niño event yet. However, it appears likely that an El Niño event will develop in the next month or two. One of the important questions for the upcoming hurricane season is what the ENSO state will look like during the peak of the Atlantic hurricane season in 2019. In general, most ENSO forecast models call for a weak to moderate El Niño this winter and next spring, with a split between weak to moderate El Niño and neutral ENSO conditions for next summer (Figure 7). The European Center for Medium-Range Weather Forecasts (ECMWF) model tends to be warmer than many of the other models, with its ensemble average calling for a moderate El Niño event persisting through next spring (Figure 8). The ECMWF model has been shown to be one of the more skillful models at predicting future ENSO conditions. There is considerable uncertainty at this point both at how strong a potential El Niño would become and whether any El Niño that does develop would dissipate by the start of next year's hurricane season.

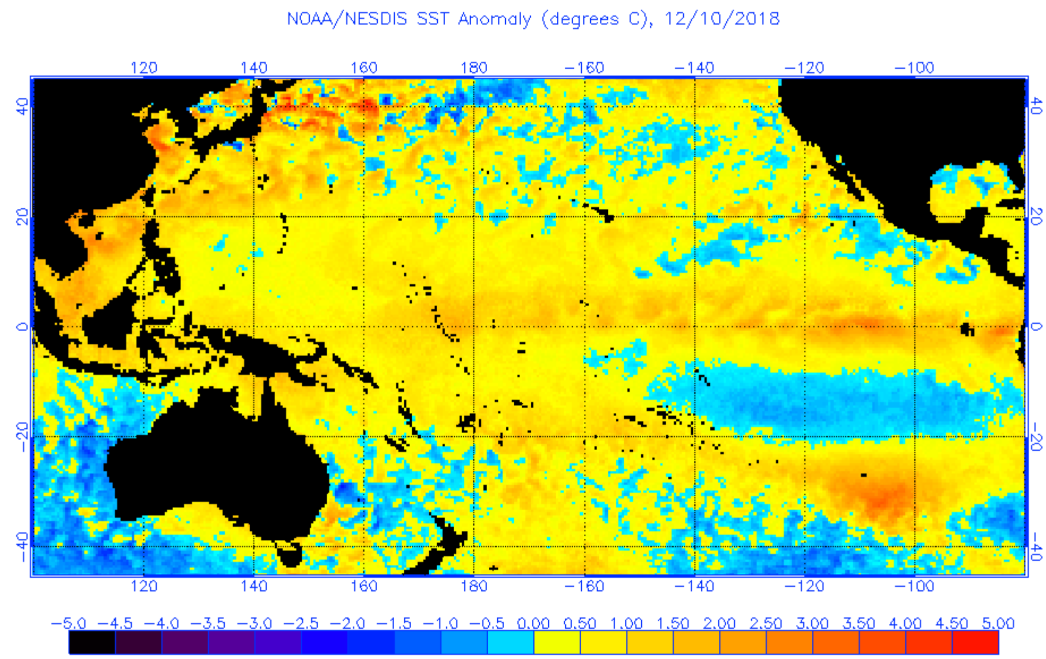

Figure 6: Early December 2018 SST anomalies across the Pacific Ocean. Warm SSTs prevail across the entire tropical Pacific at the present time.

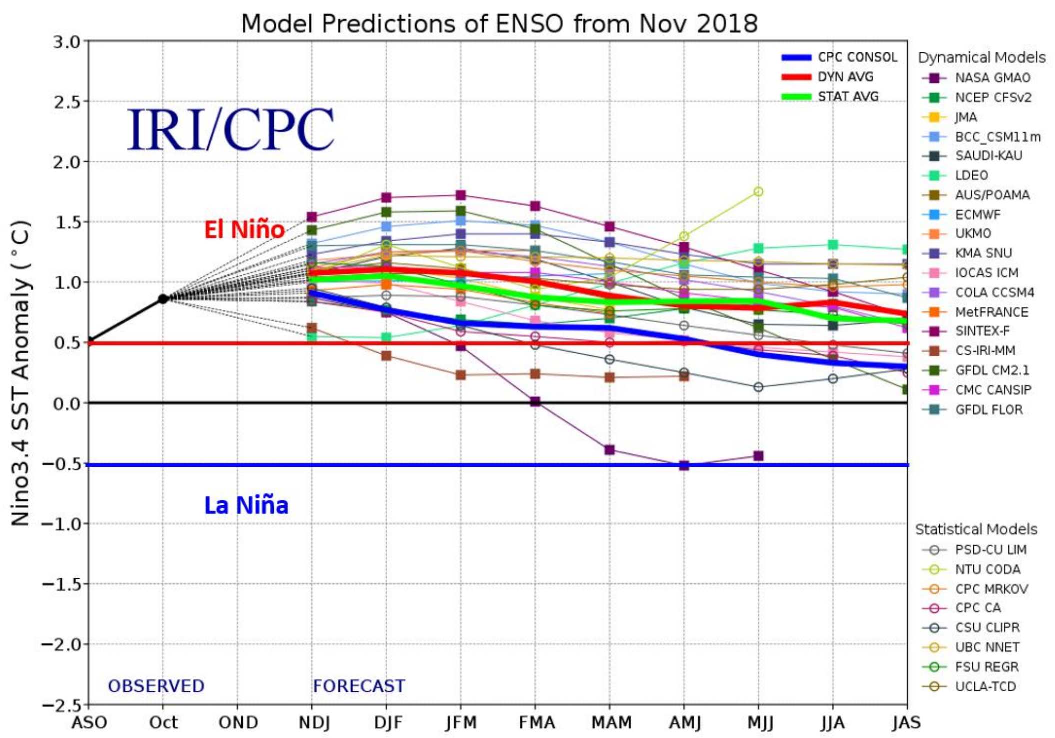

Figure 7: ENSO model prediction plume from mid-November for the next several months. Figure courtesy of the International Research Institute for Climate and Society.

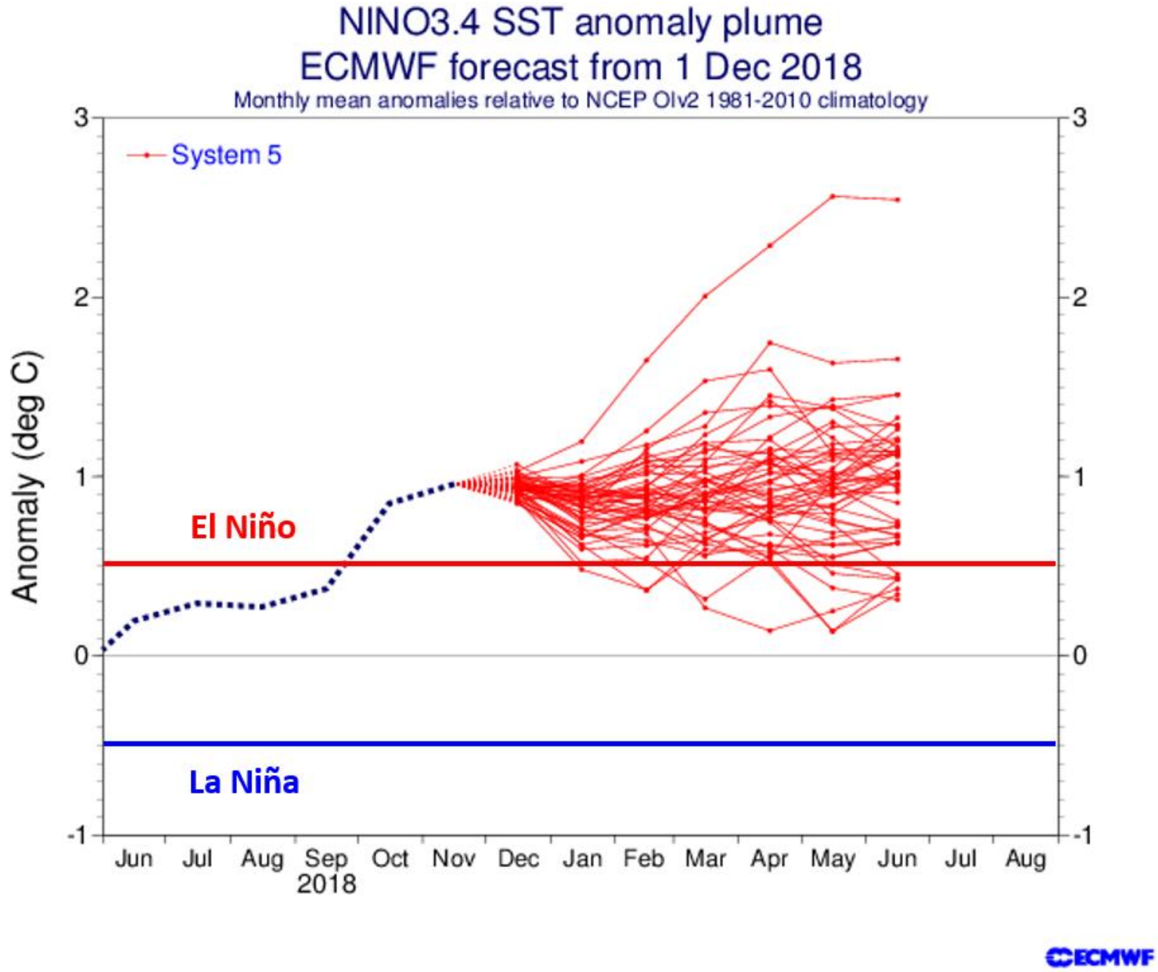

Figure 8: Ensemble ECMWF forecast plume for Nino 3.4 SSTs over the next few months. Most ECMWF ensemble members predict El Niño conditions to persist through next spring.

4 Climatological Landfall Probabilities

A significant focus of our recent research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline and in the Caribbean. While we are not issuing a quantitative forecast in this early outlook, we can still provide interested readers with the climatological probabilities of landfall for various portions of the United States coastline.

Table 1 lists climatological strike probabilities for the hurricane season for different TC categories for the entire U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula. We also issue probabilities for various islands and landmasses in the Caribbean and in Central America.

Table 1: Climatological probability (expressed in percent) of one or more landfalling tropical storms (TS), category 1-2 hurricanes (HUR), category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (Regions 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11). Probabilities of a tropical storm, hurricane and major hurricane tracking into the Caribbean are also provided.

Region	TS	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	Named Storms
Entire U.S. (Regions 1-11)	79%	68%	52%	84%	97%
Gulf Coast (Regions 1-4)	59%	42%	30%	60%	83%
Florida plus East Coast (Regions 5-11)	50%	44%	31%	61%	81%
Caribbean (10-20°N, 60-88°W)	82%	57%	42%	75%	96%

We have also calculated probabilities of each state being impacted by a tropical cyclone, using the impacts database available from the National Hurricane Center. Table 2 displays the climatological probabilities for each state along the United States coastline being impacted by a hurricane and major hurricane, respectively.

Table 2: Climatological probability of each state along the United States coastline being impacted by a hurricane and major hurricane, respectively.

State	**Hurricane**	**Major Hurricane**
Texas	33%	12%
Louisiana	30%	12%
Mississippi	11%	4%
Alabama	16%	3%
Florida	51%	21%
Georgia	11%	1%
South Carolina	17%	4%
North Carolina	28%	8%
Virginia	6%	1%
Maryland	1%	<1%
Delaware	1%	<1%
New Jersey	1%	<1%
New York	8%	3%
Connecticut	7%	2%
Rhode Island	6%	3%
Massachusetts	7%	2%
New Hampshire	1%	<1%
Maine	4%	<1%

The Landfall Probability Website has additional probability information including county-level probabilities for 205 coastal counties from Brownsville, Texas to Eastport, Maine. These probabilities will be updated on Thursday, April 4 with our first quantitative outlook for 2019.

5 Summary

There is always considerable uncertainty as to how much activity an Atlantic hurricane season is going to generate at such a long forecast lead time. We detail in this outlook two key parameters that are critical for determining levels of Atlantic hurricane activity: North Atlantic SSTs and ENSO. Currently, tropical and far North Atlantic SSTs are slightly cooler than normal, but the CSU AMO index is at near average levels due to anomalously low pressure averaged across the North Atlantic. The tropical Pacific is currently characterized by warm neutral ENSO conditions. Most models predict that a weak to moderate El Niño will develop in the next few months. There is considerable uncertainty as to whether any El Niño does develop will persist through next year's hurricane season. We are closely monitoring these conditions and will have additional extensive discussion with our early April outlook.

6 Forthcoming Updated Forecasts of 2019 Hurricane Activity

We will be issuing seasonal outlooks for the 2019 Atlantic basin hurricane season on **Thursday April 4**, **Tuesday June 4, Tuesday July 2, and Tuesday 6 August**. We will also be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August-October. A verification and discussion of all 2019 forecasts will be issued in late November 2019. These forecasts will be available on our project's website.

7 Verification of Previous Forecasts

Table 3: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity from 2014-2018.

2014	10 April	Update 2 June	Update 1 July	Update 31 July	Obs.
Hurricanes	3	4	4	4	6
Named Storms	9	10	10	10	8
Hurricane Days	12	15	15	15	17.75
Named Storm Days	35	40	40	40	35
Major Hurricanes	1	1	1	1	2
Major Hurricane Days	2	3	3	3	3.75
Accumulated Cyclone Energy	55	65	65	65	67
Net Tropical Cyclone Activity	60	70	70	70	82

2015	9 April	Update 1 June	Update 1 July	Update 4 August	Obs.
Hurricanes	3	3	3	2	4
Named Storms	7	8	8	8	11
Hurricane Days	10	10	10	8	11.50
Named Storm Days	30	30	30	25	43.75
Major Hurricanes	1	1	1	1	2
Major Hurricane Days	0.5	0.5	0.5	0.5	4
Accumulated Cyclone Energy	40	40	40	35	60
Net Tropical Cyclone Activity	45	45	45	40	81

2016	14 April	Update 1 June	Update 1 July	Update 4 August	Obs.
Hurricanes	6	6	6	6	7
Named Storms	13	14	15	15	15
Hurricane Days	21	21	21	22	27.75
Named Storm Days	52	53	55	55	81.00
Major Hurricanes	2	2	2	2	4
Major Hurricane Days	4	4	4	5	10.25
Accumulated Cyclone Energy	93	94	95	100	141
Net Tropical Cyclone Activity	101	103	105	110	155

2017	6 April	Update 1 June	Update 5 July	Update 4 August	Obs.
Hurricanes	4	6	8	8	10
Named Storms	11	14	15	16	17
Hurricane Days	16	25	35	35	51.25
Named Storm Days	50	60	70	70	91.25
Major Hurricanes	2	2	3	3	6
Major Hurricane Days	4	5	7	7	19.25
Accumulated Cyclone Energy	75	100	135	135	226
Net Tropical Cyclone Activity	85	110	140	140	231

2018	5 April	Update 31 May	Update 2 July	Update 2 August	Obs.
Hurricanes	7	6	4	5	8
Named Storms	14	14	11	12	15
Hurricane Days	30	20	15	15	26.75
Named Storm Days	70	55	45	53	87.25
Major Hurricanes	3	2	1	1	2
Major Hurricane Days	7	4	2	2	5.00
Accumulated Cyclone Energy	130	90	60	64	129
Net Tropical Cyclone Activity	135	100	70	78	128