# SUMMARY OF 2017 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHORS' SEASONAL AND TWO-WEEK FORECASTS

The 2017 Atlantic hurricane season was an extraordinarily active one, with levels of activity that were higher than were predicted by our seasonal outlooks. While the overall season was very active, what most stood out about 2017 was the record-breaking levels of hurricane activity that occurred during September. Hurricanes Harvey, Irma and Maria were the most notable storms of 2017, leaving paths of death and destruction in their wake.

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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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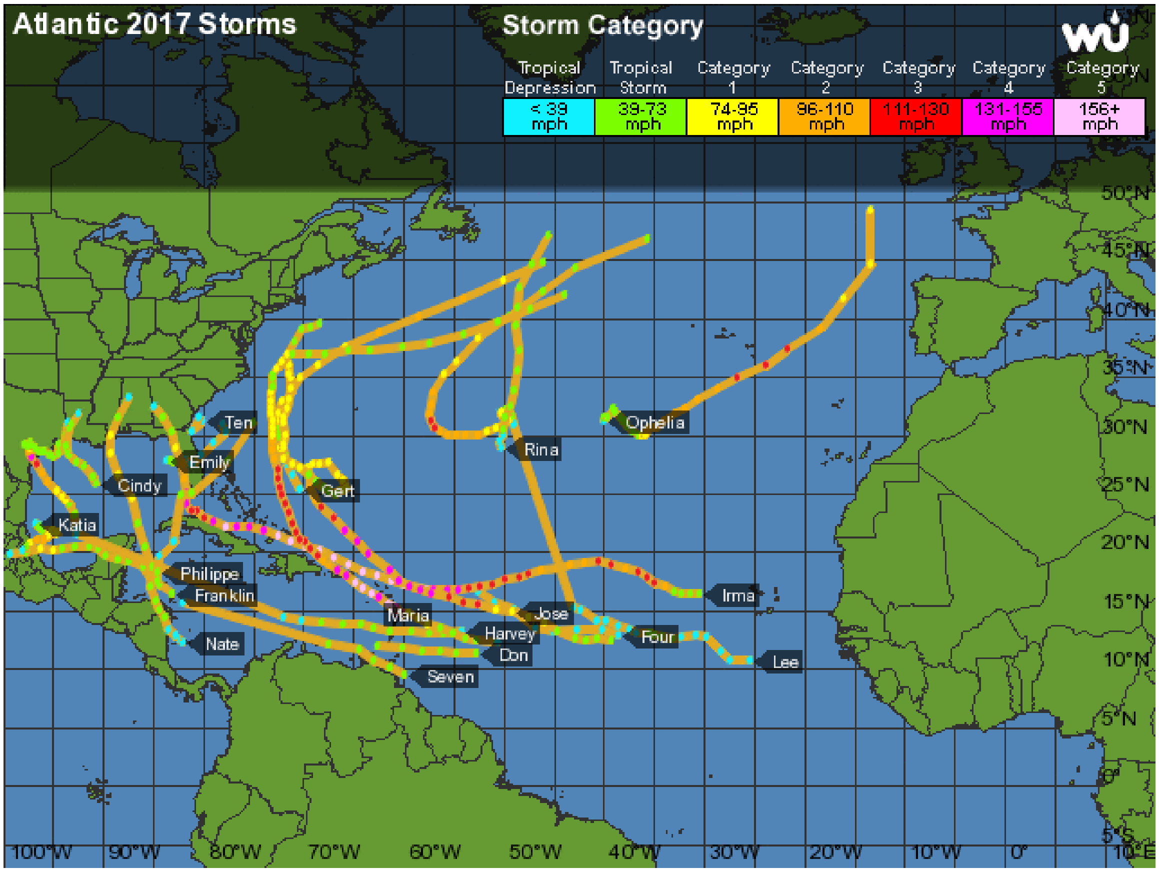
## ATLANTIC BASIN SEASONAL HURRICANE FORECASTS FOR 2017

| Forecast Parameter and 1981-2010 Median (in parentheses) | Issue Date 6 April 2017 | Issue Date 1 June 2017 | Issue Date 5 July 2017 | Issue Date 4 August 2017 | **Observed 2017 Activity** | % of 1981-2010 Median |
|---|---|---|---|---|---|---|
| Named Storms (NS) (12.0) | 11 | 14 | 15 | 16 | **17** | 142% |
| Named Storm Days (NSD) (60.1) | 50 | 60 | 70 | 70 | **91.25** | 152% |
| Hurricanes (H) (6.5) | 4 | 6 | 8 | 8 | **10** | 154% |
| Hurricane Days (HD) (21.3) | 16 | 25 | 35 | 35 | **51.25** | 241% |
| Major Hurricanes (MH) (2.0) | 2 | 2 | 3 | 3 | **6** | 300% |
| Major Hurricane Days (MHD) (3.9) | 4 | 5 | 7 | 7 | **19.25** | 494% |
| Accumulated Cyclone Energy (ACE) (92) | 75 | 100 | 135 | 135 | **226** | 246% |
| Net Tropical Cyclone Activity (NTC) (103%) | 85 | 110 | 140 | 140 | **231** | 224% |



Atlantic basin tropical cyclone tracks in 2017. 17 named storms, 10 hurricanes and 6 major hurricanes occurred. Figure courtesy of Weather Underground.

# ABSTRACT

This report summarizes tropical cyclone (TC) activity which occurred in the Atlantic basin during 2017 and verifies the authors' seasonal Atlantic basin forecasts. Also verified are six two-week Atlantic basin forecasts issued during the peak months of the hurricane season that were based on a combination of current activity, model forecasts and the phase of the Madden-Julian Oscillation (MJO).

The first quantitative seasonal forecast for 2017 was issued on 6 April with updates following on 1 June, 5 July and 4 August. These seasonal forecasts also contained estimates of the probability of U.S. and Caribbean hurricane landfall during 2017.

The 2017 hurricane season was an extremely active one. The season was characterized by well above-average numbers of named storms, hurricanes, major hurricanes as well as duration and integration metrics such as hurricane days and Accumulated Cyclone Energy (ACE). Our initial seasonal forecast issued in April underestimated activity in 2017 by a large margin, due in part to El Niño predictions by many statistical and dynamical models that did not come to fruition. Later seasonal forecasts issued in July and August correctly predicted an above-average season but still considerably underestimated just how active the season was going to be.

Six consecutive two-week forecasts were issued during the peak months of the Atlantic hurricane season from August-October. These forecasts were based on current hurricane activity, predicted activity by global forecast models and the phase of the Madden-Julian Oscillation (MJO). These two-week forecasts generally verified well.

Integrated measures such as Net Tropical Cyclone (NTC) activity and Accumulated Cyclone Energy (ACE) were at top ten levels based on Atlantic hurricane data going back to the mid-19th century. Well above-average sea surface temperatures and reduced levels of vertical wind shear in the tropical Atlantic were two of the primary reasons why such an active season was observed.

While the season was very active, it will be most remembered for several hurricanes that devastated portions of the continental United States as well as islands in the Caribbean and other parts of the tropical Atlantic. Hurricane Harvey brought epic flooding to the Houston metropolitan area, while Irma and Maria both brought devastation to islands throughout the Caribbean and tropical Atlantic. Irma also made landfall in the Florida Keys as a Category 4, pummeling the Keys and bringing considerable damage to mainland Florida as well. The 2017 Atlantic hurricane season was also the first season on record (since 1851) to have two Category 4 hurricanes make continental United States landfall in the same year (Harvey and Irma).

# 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.

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 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 North Atlantic (TNA) index – A measure of sea surface temperatures in the area from 5.5-23.5°N, 15-57.5°W.

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

## 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 last year. 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 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.

# 1 Preliminary Discussion

## 1a. Introduction

The year-to-year variability of Atlantic basin hurricane activity is the largest of any of the globe's tropical cyclone (TC) basins. There has always been and will continue to be much interest in knowing if the coming Atlantic hurricane season is going to be unusually active, very quiet or just average. There was never a way of objectively determining how active the coming Atlantic hurricane season was going to be until the early to mid-1980s when global data sets became more accessible.

Analyzing the available data in the 1980s, it was found that the coming Atlantic seasonal hurricane season did indeed have various precursor signals that extended backward in time from zero to 6-8 months before the start of the season. These precursor signals involved El Niño – Southern Oscillation (ENSO), Atlantic sea surface temperatures (SSTs) and sea level pressures, West African rainfall, the Quasi-Biennial Oscillation (QBO) and a number of other global parameters. Much effort has since been expended by our project's current and former members (along with other research groups) to try to quantitatively maximize the best combination of hurricane precursor signals to give the highest amount of reliable seasonal hindcast skill. We have experimented with a large number of various combinations of precursor variables and now find that our most reliable forecasts utilize a combination of three or four variables.

A cardinal rule that has always been followed is to issue no forecast for which we do not have substantial hindcast skill extending back in time for at least 30 years. The NCEP/NCAR reanalysis data sets now used are available back to 1948 providing 70 years of hindcast information. We also utilize newer reanalyses that have been developed on the past ~35 years of data (e.g., the ERA-Interim and CFSR Reanalyses). We also have been exploring longer-term reanalysis products such as the 20th Century Reanalysis from the Earth System Research Laboratory.

The explorative process to skillful prediction should continue to develop as more data becomes available and as more robust relationships are found. There is no one best forecast scheme that can always be confidently applied. We have learned that precursor relations can change with time and that one must be alert to these changing relationships. For instance, earlier seasonal forecasts relied heavily on the stratospheric QBO and West African rainfall. These precursor signals have not worked in recent years. Because of this, other precursor signals were substituted in their place. As new data and new insights are gathered in the coming years, it is to be expected that our forecast schemes will in future years also need revision. Keeping up with the changing global climate system, using new data signals, and exploring new physical relationships is a full-time job. Success can never be measured by the success of a few real-time forecasts but only by long-period hindcast relationships and sustained demonstration of real-time forecast skill over a decade or more.

## 1b. Seasonal Forecast Theory

A variety of atmosphere-ocean conditions interact with each other to cause year-to-year and month-to-month hurricane variability. The interactive physical linkages between these precursor physical parameters and hurricane variability are complicated and cannot be well elucidated to the satisfaction of the typical forecaster making short range (1-5 days) predictions where changes in the current momentum and pressure fields are the crucial factors. Seasonal forecasts, unfortunately, must deal with the much more complicated interaction of the energy-moisture fields along with the momentum fields.

We find that there is a rather high (50-60 percent) degree of year-to-year hurricane forecast potential if one combines 3-4 semi-independent atmospheric-oceanic parameters together. The best predictors (out of a group of 3-4) do not necessarily have the best individual correlations with hurricane activity. The best forecast parameters are those that explain a portion of the variance of seasonal hurricane activity that is not associated with the other variables. It is possible for an important hurricane forecast parameter to show only a marginally significant correlation with the predictand by itself but to have an important influence when included with a set of 3-4 other predictors.

In a four-predictor empirical forecast model, the contribution of each predictor to the net forecast skill can only be determined by the separate elimination of each parameter from the full four-predictor model while noting the hindcast skill degradation. When taken from the full set of predictors, one parameter may degrade the forecast skill by 25-30 percent, while another degrades the forecast skill by only 10-15 percent. An individual parameter that, through elimination from the forecast, degrades a forecast by as much as 25-30 percent may, in fact, by itself, show relatively little direct correlation with the predictand. 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 is 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 these processes interact with each other. Despite the complicated relationships that are involved, all of our statistical models show considerable hindcast skill. We are confident that in applying these skillful hindcasts to future forecasts that appreciable real-time skill will result.

## 2 Tropical Cyclone Activity for 2017

Figure 1 and Table 1 summarize Atlantic basin TC activity which occurred in 2017. Overall, the season was characterized by well above-average activity. Online entries from Wikipedia are available for in-depth discussions of each TC that occurred in 2017. The National Hurricane Center is also currently in the process of writing up extensive reports on all 2017 tropical cyclones.

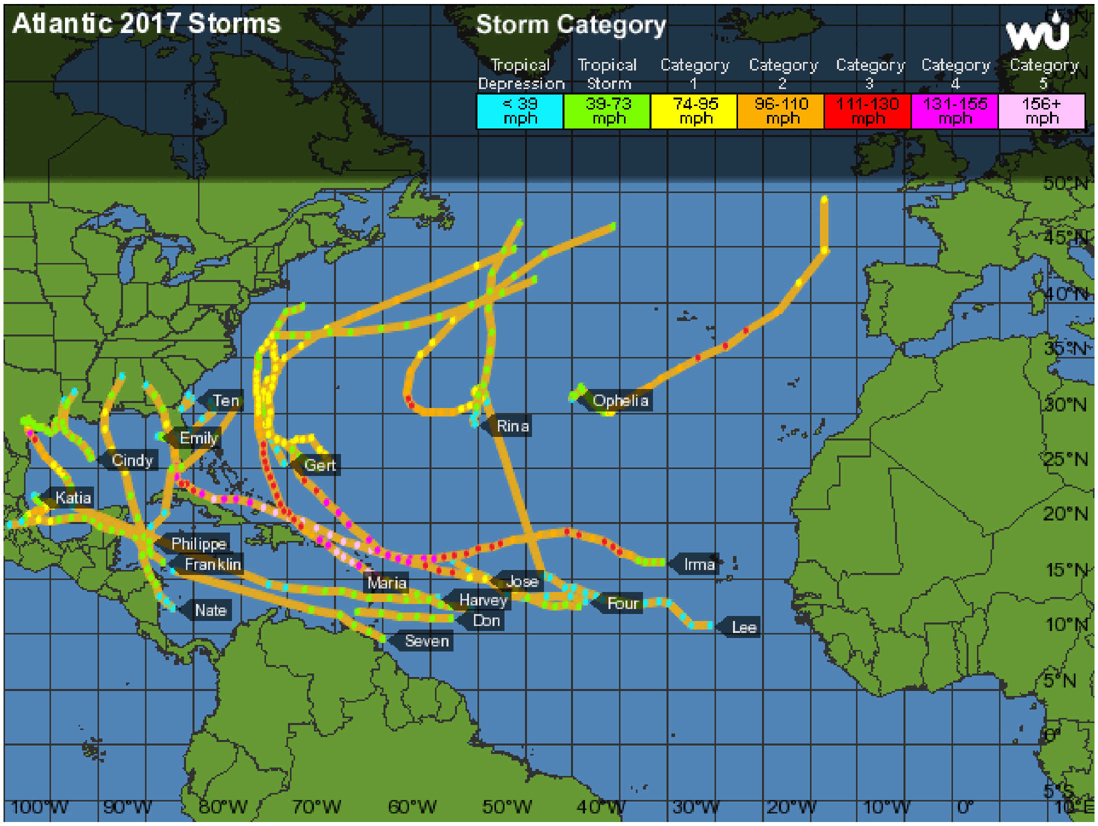
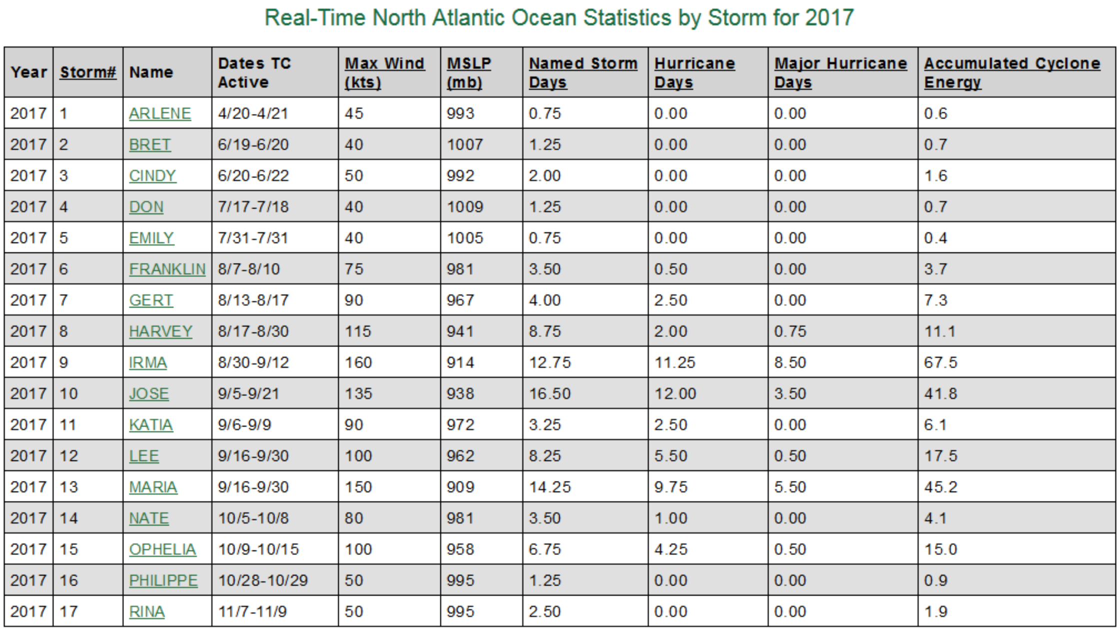


Figure 1: Atlantic basin tropical cyclone tracks in 2017. 17 named storms, 10 hurricanes and 6 major hurricanes occurred. Figure courtesy of Weather Underground.

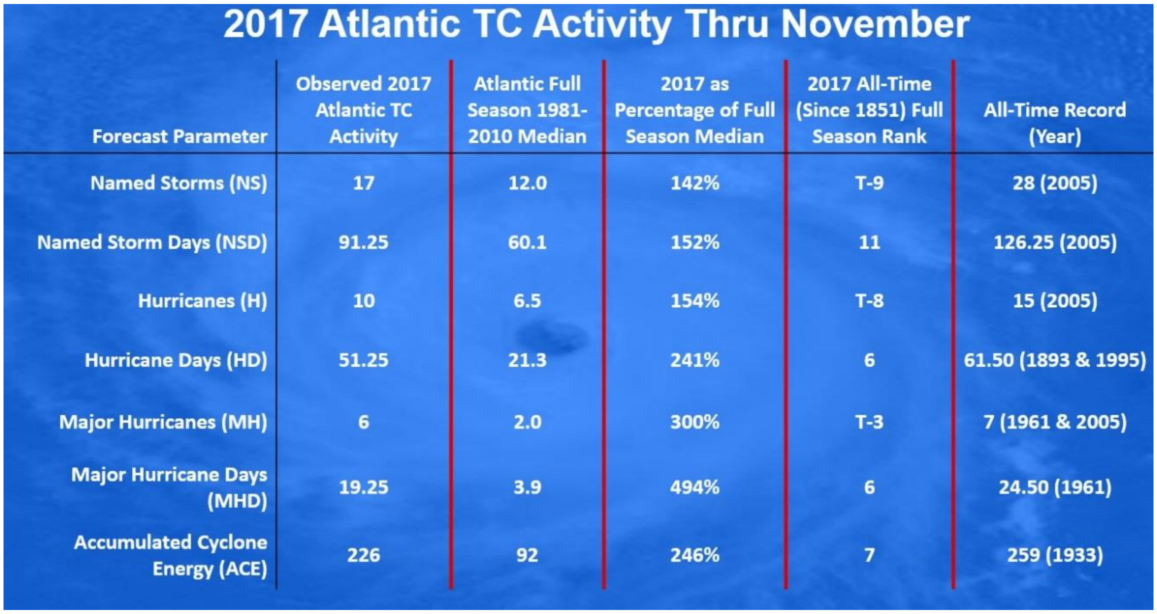

Real-Time North Atlantic Ocean Statistics by Storm for 2017

| Year | Storm# | Name | Dates TC Active | Max Wind (kts) | MSLP (mb) | Named Storm Days | Hurricane Days | Major Hurricane Days | Accumulated Cyclone Energy |
|---|---|---|---|---|---|---|---|---|---|
| 2017 | 1 | ARLENE | 4/20-4/21 | 45 | 993 | 0.75 | 0.00 | 0.00 | 0.6 |
| 2017 | 2 | BRET | 6/19-6/20 | 40 | 1007 | 1.25 | 0.00 | 0.00 | 0.7 |
| 2017 | 3 | CINDY | 6/20-6/22 | 50 | 992 | 2.00 | 0.00 | 0.00 | 1.6 |
| 2017 | 4 | DON | 7/17-7/18 | 40 | 1009 | 1.25 | 0.00 | 0.00 | 0.7 |
| 2017 | 5 | EMILY | 7/31-7/31 | 40 | 1005 | 0.75 | 0.00 | 0.00 | 0.4 |
| 2017 | 6 | FRANKLIN | 8/7-8/10 | 75 | 981 | 3.50 | 0.50 | 0.00 | 3.7 |
| 2017 | 7 | GERT | 8/13-8/17 | 90 | 967 | 4.00 | 2.50 | 0.00 | 7.3 |
| 2017 | 8 | HARVEY | 8/17-8/30 | 115 | 941 | 8.75 | 2.00 | 0.75 | 11.1 |
| 2017 | 9 | IRMA | 8/30-9/12 | 160 | 914 | 12.75 | 11.25 | 8.50 | 67.5 |
| 2017 | 10 | JOSE | 9/5-9/21 | 135 | 938 | 16.50 | 12.00 | 3.50 | 41.8 |
| 2017 | 11 | KATIA | 9/6-9/9 | 90 | 972 | 3.25 | 2.50 | 0.00 | 6.1 |
| 2017 | 12 | LEE | 9/16-9/30 | 100 | 962 | 8.25 | 5.50 | 0.50 | 17.5 |
| 2017 | 13 | MARIA | 9/16-9/30 | 150 | 909 | 14.25 | 9.75 | 5.50 | 45.2 |
| 2017 | 14 | NATE | 10/5-10/8 | 80 | 981 | 3.50 | 1.00 | 0.00 | 4.1 |
| 2017 | 15 | OPHELIA | 10/9-10/15 | 100 | 958 | 6.75 | 4.25 | 0.50 | 15.0 |
| 2017 | 16 | PHILIPPE | 10/28-10/29 | 50 | 995 | 1.25 | 0.00 | 0.00 | 0.9 |
| 2017 | 17 | RINA | 11/7-11/9 | 50 | 995 | 2.50 | 0.00 | 0.00 | 1.9 |

Table 1: Observed 2017 Atlantic basin tropical cyclone activity.

# 3 Special Characteristics of the 2017 Hurricane Season

The 2017 hurricane season set many records, especially during September. Figure 2 displays 2017 hurricane activity and compares it with historical seasons. Note that nearly all seasonal tropical cyclone quantities displayed were at top 10 levels in 2017.



2017 Atlantic TC Activity Thru November

| Forecast Parameter | Observed 2017 Atlantic TC Activity | Atlantic Full Season 1981-2010 Median | 2017 as Percentage of Full Season Median | 2017 All-Time (Since 1851) Full Season Rank | All-Time Record (Year) |
|---|---|---|---|---|---|
| Named Storms (NS) | 17 | 12.0 | 142% | T-9 | 28 (2005) |
| Named Storm Days (NSD) | 91.25 | 60.1 | 152% | 11 | 126.25 (2005) |
| Hurricanes (H) | 10 | 6.5 | 154% | T-8 | 15 (2005) |
| Hurricane Days (HD) | 51.25 | 21.3 | 241% | 6 | 61.50 (1893 & 1995) |
| Major Hurricanes (MH) | 6 | 2.0 | 300% | T-3 | 7 (1961 & 2005) |
| Major Hurricane Days (MHD) | 19.25 | 3.9 | 494% | 6 | 24.50 (1961) |
| Accumulated Cyclone Energy (ACE) | 226 | 92 | 246% | 7 | 259 (1933) |

Figure 2: Atlantic tropical cyclone activity in 2017 and comparisons with historical seasons. "T" in the fifth column indicates that the season was in a tie with other seasons.

Below is a selection of some of the records that were set during the season:

- The Atlantic had a total of 17 named storms, 91.25 named storm days and 10 hurricanes in 2017. Each of these were the most that the Atlantic had in a season since 2012.

- 51.25 hurricane days occurred in 2017 – the most in a season since 1995.

- Six major hurricanes formed in 2017 – the most in a season since 2005.

- 19.25 major hurricane days occurred in 2017 – the most in a season since 2004.

- 226 Accumulated Cyclone Energy units were generated in 2017 – the most in a season since 2005.

- September 2017 broke Atlantic calendar month records for named storm days (53.5), hurricane days (40.25), major hurricane days (18) and Accumulated Cyclone Energy (175).

- September 8, 2017 generated more Accumulated Cyclone Energy than any other Atlantic calendar day on record. Irma, Jose and Katia were responsible for the ACE generated on that day.

- Harvey was the first major hurricane to make continental United States landfall since Wilma in 2005, ending the record-long major hurricane landfall drought at 4323 days.

- Harvey was the first Category 4 hurricane to make landfall in Texas since Carla (1961)

- Harvey lasted 117 hours as a named storm after Texas landfall, shattering the old record for named storm longevity after Texas hurricane landfall set by Fern (1971) at 54 hours.

- Harvey broke the tropical cyclone-generated United States rainfall record. Over 60” of rain fell in Nederland, Texas, breaking the old United States record of 52” in Hawaii set by Hurricane Hiki in 1950.

- Irma’s maximum intensity of 160 knots were the strongest one-minute maximum sustained winds winds recorded by an Atlantic hurricane outside of the Gulf of Mexico and Caribbean on record.

- Irma maintained an intensity of 160 knots for 37 hours – the longest any cyclone around the globe has maintained that intensity on record – breaking old record of 24 hours set by Haiyan (2013).

- 67.5 ACE generated by Irma were the second-most in the satellite era (since 1966) by an Atlantic hurricane – trailing only Ivan (2004) which had 70.4 ACE

- Irma was the strongest hurricane to impact the Leeward Islands (15-19°N, 65-60°W) on record.

- Irma was the first Category 5 hurricane to make landfall in Cuba since 1924.

- Irma was the first Category 4 hurricane to make Florida landfall since Charley in 2004.

- Irma and Harvey marked the first time that two Category 4 hurricanes have made continental United States landfall in the same year.

- The continental United States had three landfalling hurricanes (Harvey, Irma and Nate) for the first time since 2008.

- Irma's Florida Keys' landfall pressure of 929 mb was tied with the Lake Okeechobee Hurricane of 1928 for the 7th lowest on record for a continental US hurricane. More records from Irma are listed here.

- Maria's lowest central pressure of 908 mb was the lowest on record for a hurricane in the eastern Caribbean (<=20°N, 75-60°W)

- Maria intensified 60 knots in 18 hours – only Wilma (2005), Felix (2007) and Ike (2008) have intensified more in 18 hours

- Maria was first Category 5 hurricane on record to make landfall in Dominica

- Maria was the first Category 4 hurricane to make landfall in Puerto Rico since 1932 and the strongest hurricane to make landfall in Puerto Rico since 1928.

- Nate's 12-hour-averaged translation speed of 28 mph was the fastest 12-hour-averaged translation speed in the Gulf of Mexico on record

- Hurricane Ophelia was a major hurricane until it reached 18.3°W – the farthest east an Atlantic TC has been at major hurricane strength on record

# 4 Verification of Individual 2017 Lead Time Forecasts

Table 2 is a comparison of our forecasts for 2017 for four different lead times along with this year's observations. The 2017 Atlantic hurricane season was an extremely active one.

Table 2: Verification of our 2017 seasonal hurricane predictions.

| Forecast Parameter and 1981-2010 Median (in parentheses) | Issue Date 6 April 2017 | Issue Date 1 June 2017 | Issue Date 5 July 2017 | Issue Date 4 August 2017 | **Observed 2017 Activity** | % of 1981-2010 Median |
|---|---|---|---|---|---|---|
| Named Storms (NS) (12.0) | 11 | 14 | 15 | 16 | **17** | 142% |
| Named Storm Days (NSD) (60.1) | 50 | 60 | 70 | 70 | **91.25** | 152% |
| Hurricanes (H) (6.5) | 4 | 6 | 8 | 8 | **10** | 154% |
| Hurricane Days (HD) (21.3) | 16 | 25 | 35 | 35 | **51.25** | 241% |
| Major Hurricanes (MH) (2.0) | 2 | 2 | 3 | 3 | **6** | 300% |
| Major Hurricane Days (MHD) (3.9) | 4 | 5 | 7 | 7 | **19.25** | 494% |
| Accumulated Cyclone Energy (ACE) (92) | 75 | 100 | 135 | 135 | **226** | 246% |
| Net Tropical Cyclone Activity (NTC) (103%) | 85 | 110 | 140 | 140 | **231** | 224% |

Table 3 provides the same forecasts, with error bars (based on one standard deviation of absolute errors) as calculated from real-time forecasts from 1995-2014. We typically expect to see two-thirds of our forecasts verify within one standard deviation of observed values, with 95% of forecasts verifying within two standard deviations of observed values. Since July forecasts have only been issued in real-time for the past few years, we estimate that the July forecast should have errors halfway in between the errors of the June and August forecasts. Since we have only issued ACE forecasts for the past few years, we estimate ACE errors to be the same as NTC errors. This year's seasonal forecasts under-estimated the very active season that was observed.

Table 3: Verification of CSU's 2017 seasonal hurricane predictions with error bars (one standard deviation). Predictions that lie within one standard deviation of observations are highlighted in red bold font, while predictions that lie within two standard deviations are highlighted in green bold font. Predictions that are outside of two standard deviations are highlighted in black bold font. In general, we expect that two-thirds of our forecasts should lie within one standard deviation of observations, with 95% of our forecasts lying within two standard deviations of observations. Only 5 out of 32 (16%) of seasonal forecast parameters were within one standard deviation of observations for the 2017 seasonal forecast. As discussed throughout the text of this season's verification, we significantly underestimated overall levels of hurricane activity that occurred. Error bars for storms are rounded to the nearest storm. For example, the hurricane prediction in early April would be 1.9-6.1, which with rounding would be 2-6.

| Forecast Parameter and 1981-2010 Median (in parentheses) | 6 April 2017 | Update 1 June 2017 | Update 5 July 2017 | Update 4 August 2017 | Observed 2017 Total |
|---|---|---|---|---|---|
| Named Storms (NS) (12.0) | **11** (±3.5) | **14** (±2.9) | **15** (±2.6) | **16** (±2.2) | 17 |
| Named Storm Days (NSD) (60.1) | **50** (±20.7) | **60** (±19.9) | **70** (±18.1) | **70** (±16.3) | 91.25 |
| Hurricanes (H) (6.5) | **4** (±2.1) | **6** (±2.0) | **8** (±1.8) | **8** (±1.7) | 10 |
| Hurricane Days (HD) (21.3) | **16** (±11.1) | **25** (±10.7) | **35** (±10.1) | **35** (±9.5) | 51.25 |
| Major Hurricanes (MH) (2.0) | **2** (±1.3) | **2** (±1.4) | **3** (±1.2) | **3** (±0.9) | 6 |
| Major Hurricane Days (MHD) (3.9) | **4** (±4.0) | **5** (±3.7) | **7** (±3.9) | **7** (±4.1) | 19.25 |
| Accumulated Cyclone Energy (ACE) (92) | **75** (±42) | **100** (±40) | **135** (±36) | **135** (±31) | 226 |
| Net Tropical Cyclone Activity (NTC) (103%) | **85** (±42) | **110** (±40) | **140** (±36) | **140** (±31) | 231 |

## 4.1 Preface: Aggregate Verification of our Last Nineteen Yearly Forecasts

Another way to consider the skill of our forecasts is to evaluate whether the forecast for each parameter successfully forecast above- or below-average activity. Table 4 displays how frequently our forecasts have been on the right side of climatology for the past nineteen years. In general, our forecasts are successful at forecasting whether the season will be more or less active than the average season by as early as April. We tend to have improving skill as we get closer in time to the peak of the hurricane season (August-October).

Table 4: The number of years that our tropical cyclone forecasts issued at various lead times have correctly predicted above- or below-median activity for each predictand over the past eighteen years (1999-2017).

| **Tropical Cyclone Parameter** | **Early April** | **Early June** | **Early August** |
|---|---|---|---|
| **NS** | 15/19 | 17/19 | 16/19 |
| **NSD** | 13/19 | 13/19 | 14/19 |
| **H** | 13/19 | 13/19 | 14/19 |
| **HD** | 11/19 | 13/19 | 15/19 |
| **MH** | 14/19 | 15/19 | 15/19 |
| **MHD** | 13/19 | 14/19 | 15/19 |
| **NTC** | 11/19 | 14/19 | 16/19 |
| **Total** | **90/133 (68%)** | **99/133 (74%)** | **105/133 (79%)** |

Of course, there are significant amounts of unexplained variance for a number of the individual parameter forecasts. Even though the skill for some of these parameter forecasts is somewhat low, there is a great curiosity in having some objective measure as to how active the coming hurricane season is likely to be. Therefore, even a forecast that is only modestly skillful is likely of some value. In addition, we have recently redesigned all of our statistical forecast methodologies using more rigorous physical and statistical tests which we believe will lead to more accurate forecasts in the future. Complete verifications of all seasonal forecasts are available. Verifications are currently available for all of our prior seasons from 1984-2016. These tables will be updated with 2017's values once the National Hurricane Center finishes its post-season analysis of all storms that formed this year.

## 4.2 Verification of Two-Week Forecasts

This is the ninth year that we have issued intraseasonal (e.g. two-week) forecasts of tropical cyclone activity starting in early August. These two-week forecasts are based on a combination of observational and modeling tools. The primary tools that are used for these forecasts are: 1) current storm activity, 2) National Hurricane Center Tropical Weather Outlooks, 3) forecast output from global models, 4) the current and projected state of the Madden-Julian Oscillation (MJO) and 5) the current seasonal forecast.

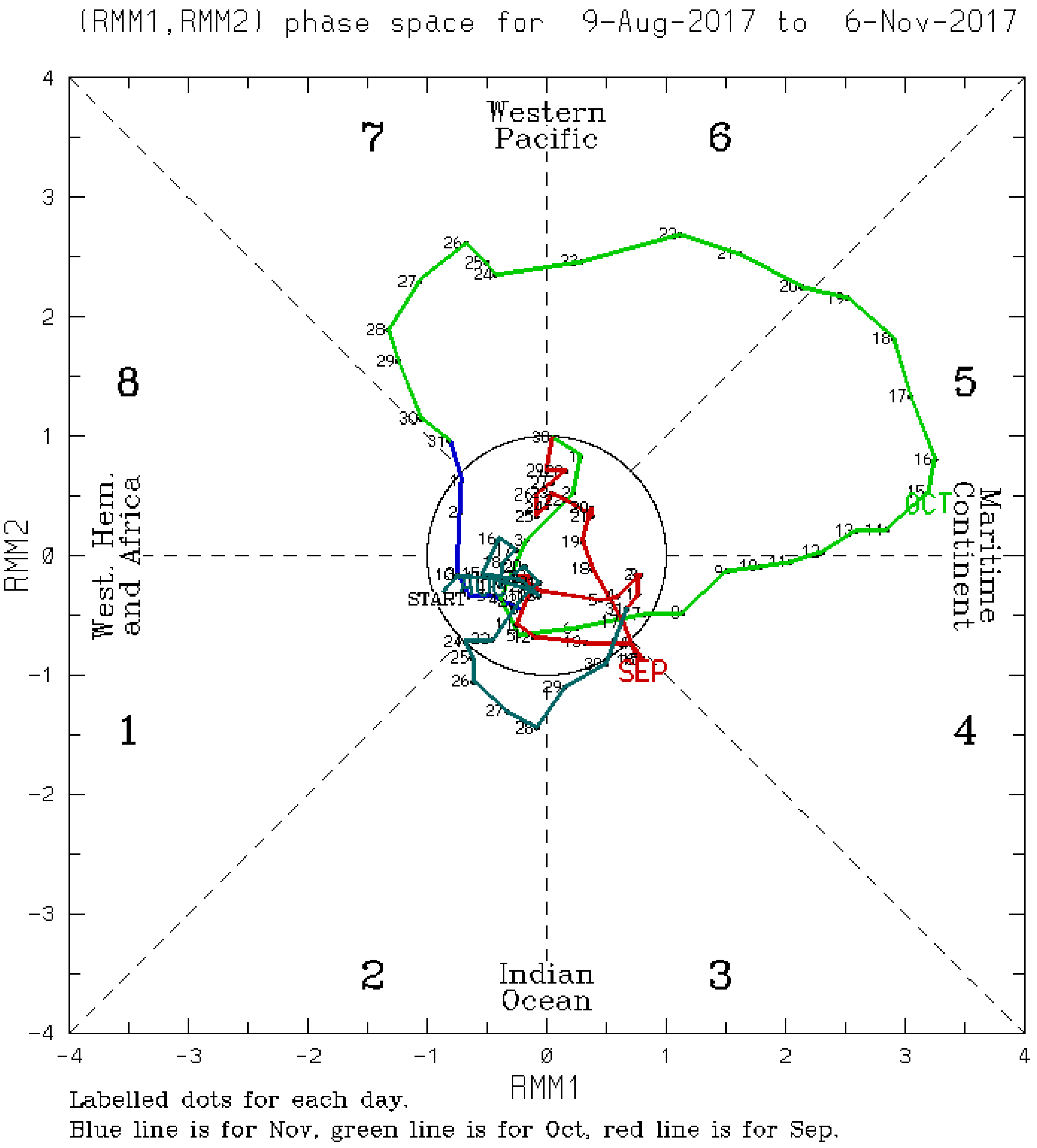
The metric that we tried to predict with these two-week forecasts is the Accumulated Cyclone Energy (ACE) index, which is defined to be the square of the named storm's maximum wind speeds (in $10^4$ $knots^2$) for each 6-hour period of its existence over the two-week forecast period. These forecasts are too short in length to show significant skill for individual event parameters such as named storms and hurricanes.

Our forecast definition of above-normal, normal, and below-normal ACE periods was changed this season to better fit, in our view, the observed historical distributions. Our ACE forecasts are now defined by ranking observed activity in the satellite era (since 1966) and defining above-normal, normal and below-normal two-week periods based on terciles. Since there were 51 years from 1966-2016, each tercile is composed of 17 years. The 17 years with the most active ACE for a two-week period were classified as the upper tercile, the 17 years with the least active ACE for a two-week period were classified as the lower tercile, while the remaining 17 years were classified as the middle tercile.

Table 5 displays the six two-week forecasts that were issued during the 2017 hurricane season and shows their verification. We correctly predicted five of the six two-week periods. In general, the 2017 hurricane season was very active, and consequently we predicted above-average activity throughout the peak of the Atlantic hurricane season. The MJO was fairly weak and disorganized during most of the peak of the Atlantic hurricane season (Figure 3), with an amplification in largely unfavorable phases (MJO phases 4-7) for Atlantic hurricane activity during October. Our over-forecast of activity in late August was primarily due to anticipation of a couple of easterly waves moving off of Africa developing. These storms did not develop.

Table 5: Two-week Atlantic ACE forecast verification for 2017. Forecasts that verified in the correct category are highlighted in blue, forecasts that missed by one category are highlighted in green, while forecasts that missed by two categories are highlighted in red.

| Forecast Period | Predicted ACE | Observed ACE |
|---|---|---|
| **8/4 – 8/17** | **Above-Normal (11 or More)** | **11** |
| **8/18 – 8/31** | **Above-Normal (23 or More)** | **14** |
| **9/1 – 9/14** | **Above-Normal (31 or More)** | **101** |
| **9/15 – 9/28** | **Above-Normal (25 or More)** | **70** |
| **9/29 – 10/12** | **Above-Normal (9 or More)** | **13** |
| **10/13 – 10/26** | **Above-Normal (9 or More)** | **10** |


(RMM1,RMM2) phase space for 9-Aug-2017 to 6-Nov-2017

Labelled dots for each day.
Blue line is for Nov, green line is for Oct, red line is for Sep.

Figure 3: Propagation of the Madden-Julian Oscillation (MJO) based on the Wheeler-Hendon classification scheme over the period from August 9 to November 6. The MJO was generally weak during the peak of the Atlantic hurricane season, with amplification of the signal over the Maritime Continent and the western Pacific in October. The Maritime Continent refers to Indonesia and the surrounding islands. RMM stands for Real-Time Multivariate MJO. Figure courtesy of Bureau of Meteorology.

## 5 Landfall Probabilities

Every hurricane season, we issue forecasts of the seasonal probability of hurricane landfall along the U.S. coastline as well as the Caribbean. Whereas individual hurricane landfall events cannot be accurately forecast, the net seasonal probability of landfall can be issued using past climatology and this year's forecast in combination. Our landfall probabilities have statistical skill, especially over several-year periods. With the premise that landfall is a function of varying climate conditions, U.S. probabilities have been calculated through a statistical analysis of all U.S. hurricane and named storm landfalls during a 100-year period (1900-1999). Specific landfall probabilities can be given for all tropical cyclone intensity classes for a set of distinct U.S. coastal regions. Net landfall probability is statistically related to overall Atlantic basin Net Tropical Cyclone (NTC) activity. Table 6 gives verifications of our landfall probability estimates for the United States and for the Caribbean in 2017.

Landfall probabilities for the 2017 hurricane season were estimated to be above-average for our most recent forecast issued in early August. Obviously, the 2017 Atlantic hurricane season was very active from a landfall perspective with 3 hurricanes (Harvey, Irma and Nate) and 2 major hurricanes hitting the continental United States (Harvey and Irma). In addition, 3 tropical storms also made continental US landfall (Cindy, Emily and Philippe). Average continental U.S. landfalling statistics since 1900 are that 3.5 named storms, 1.8 hurricanes and 0.7 major hurricanes make U.S. landfall per year.

Seven named storms passed through the Caribbean (10-20°N, 60-88°W) during 2017. Both Irma and Maria cut paths of destruction and devastation across portions of the eastern and central Caribbean as they each were at Category 5 strength in the Caribbean. Hurricane Jose reached Category 4 strength in the Caribbean but fortunately did not significantly impact any landmasses. Bret, Franklin, Harvey and Nate were all tropical storms in the Caribbean.

Landfall probabilities include specific forecasts of the probability of U.S. landfalling tropical storms (TS) and hurricanes of category 1-2 and 3-4-5 intensity for each of 11 units of the U.S. coastline (Figure 4). These 11 units are further subdivided into 205 coastal and near-coastal counties. The climatological and current-year probabilities are available online via the Landfalling Hurricane Probability Webpage.

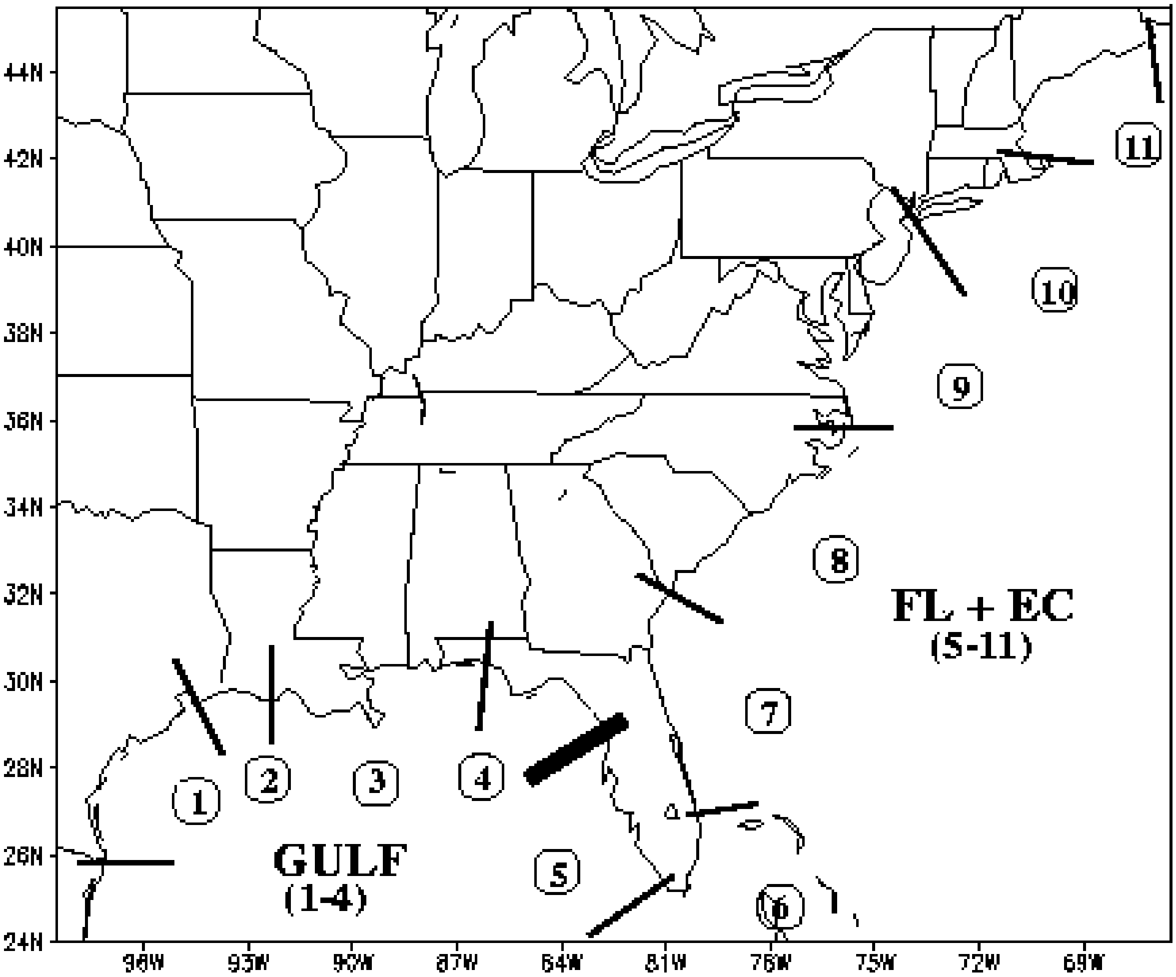


Figure 4: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made. These subdivisions were determined by the historical frequency of landfalling major hurricanes.

Table 6: Estimated forecast probability (percent) of one or more landfalling tropical storms (TS), category 1-2 hurricanes, and category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (Regions 1-4), along the Florida Peninsula and the East Coast (Regions 5-11) and in the Caribbean for 2017 at various lead times. The mean annual percentage of one or more landfalling systems during the 20th century is given in parentheses in the 4 August forecast column. Table (a) is for the entire United States, Table (b) is for the U.S. Gulf Coast, Table (c) is for the Florida Peninsula and the East Coast and Table (d) is for the Caribbean. Early August probabilities are calculated based on storms forming after 1 August.

**(a) The entire U.S. (Regions 1-11)**
**Forecast Date**

| | 6 Apr. | 1 June | 4 August | Observed Number |
|---|---|---|---|---|
| TS | 69% | 82% | 87% (79%) | 3 |
| HUR (Cat 1-2) | 57% | 70% | 77% (68%) | 1 |
| HUR (Cat 3-4-5) | 42% | 55% | 62% (52%) | 2 |
| All HUR | 75% | 87% | 91% (84%) | 3 |
| Named Storms | 92% | 98% | 99% (97%) | 6 |

**(b) The Gulf Coast (Regions 1-4)**
**Forecast Date**

| | 6 Apr. | 1 June | 4 August | Observed Number |
|---|---|---|---|---|
| TS | 48% | 61% | 68% (59%) | 1 |
| HUR (Cat 1-2) | 34% | 45% | 51% (42%) | 1 |
| HUR (Cat 3-4-5) | 24% | 32% | 38% (30%) | 1 |
| All HUR | 49% | 63% | 70% (60%) | 2 |
| Named Storms | 74% | 86% | 90% (83%) | 3 |

**(c) Florida Peninsula Plus the East Coast (Regions 5-11)**
**Forecast Date**

| | 6 Apr. | 1 June | 4 August | Observed Number |
|---|---|---|---|---|
| TS | 41% | 53% | 60% (50%) | 2 |
| HUR (Cat 1-2) | 35% | 47% | 53% (44%) | 0 |
| HUR (Cat 3-4-5) | 24% | 33% | 38% (31%) | 1 |
| All HUR | 51% | 64% | 71% (61%) | 1 |
| Named Storms | 71% | 83% | 88% (81%) | 3 |

**(d) Caribbean (10-20°N, 60-88°W)**
**Forecast Date**

|  | 6 Apr. | 1 June | 4 August | Observed Number |
|---|---|---|---|---|
| TS | 73% | 84% | 90% (82%) | 4 |
| HUR (Cat 1-2) | 47% | 60% | 67% (57%) | 0 |
| HUR (Cat 3-4-5) | 34% | 44% | 51% (42%) | 3 |
| All HUR | 65% | 78% | 84% (75%) | 3 |
| Named Storms | 90% | 97% | 98% (96%) | 7 |

# 7 Summary of Atmospheric/Oceanic Conditions

In this section, we go into detail discussing large-scale conditions that we believe significantly impacted the 2017 Atlantic basin hurricane season.

## 7.1 ENSO

Going into the 2017 Atlantic hurricane season, we anticipated a weak to moderate El Niño event, based largely on dynamical model guidance that was predicting this event. As the season started in early June, we began to realize that neutral ENSO conditions were the most likely scenario for the peak of the hurricane season. The season ended up being characterized by cool neutral ENSO conditions, with NOAA recently declaring that a weak La Niña was underway. Below are some quotes excerpted from our seasonal forecasts issued this year showing how our views on the likelihood of El Niño changed as the peak of the Atlantic hurricane season approached.

**(6 April 2017) –**

**"Based on the above information (e.g., dynamical and statistical model guidance), our best estimate is that we will likely have weak to moderate El Niño conditions by the peak of the Atlantic hurricane season. There remains a need to closely monitor ENSO conditions over the next few months. We believe we will be somewhat more confident about ENSO conditions for the upcoming hurricane season by the time of our next forecast on June 1."**

**(1 June 2017) –**

**"Our confidence that a weak to moderate El Niño will develop has diminished since early April. While upper ocean content heat anomalies have slowly increased over the past several months, the transition towards warm ENSO conditions appears to have been delayed compared with earlier expectations. At this point, we believe that the most realistic scenario for the 2017 Atlantic hurricane season is borderline warm neutral ENSO to weak El Niño conditions."**

**(4 August 2017) –**

**"The official forecast from the Climate Prediction Center indicates that ENSO neutral conditions are the most likely scenario for the peak of the Atlantic**

**hurricane season from August through October. Based on our assessment of both current conditions as well as forecast model output, we are now quite confident that El Niño will not play a significant role in the 2017 Atlantic hurricane season.“**

As mentioned briefly earlier, most of the dynamical and statistical model guidance were much warmer than what was actually observed in the eastern and central tropical Pacific in 2017. These significant over-forecasts are a symptom of a phenomena known as the ENSO springtime predictability barrier, which is the time of year where ENSO forecasts have the least skill. Some of this reduction in skill is due to the fact that this is climatologically when SST gradients are at their weakest, and consequently, the trade winds that blow across the eastern and central tropical Pacific are also at their weakest and subject to more sub-seasonal variability. An excellent discussion that goes into more detail describing the springtime predictability barrier was published a couple of years ago in a NOAA blog.

Figure 5 displays the ECMWF seasonal forecast for Nino 3.4 from March, which is the forecast information that we had available for our early April seasonal forecast. By September, the observed Nino 3.4 value was outside virtually all of its ensemble members. Similarly, Figure 6 displays the CFS seasonal forecasts for Nino 3.4 from early April. The CFS also predicted much warmer SSTs in the eastern and central tropical Pacific than were observed.

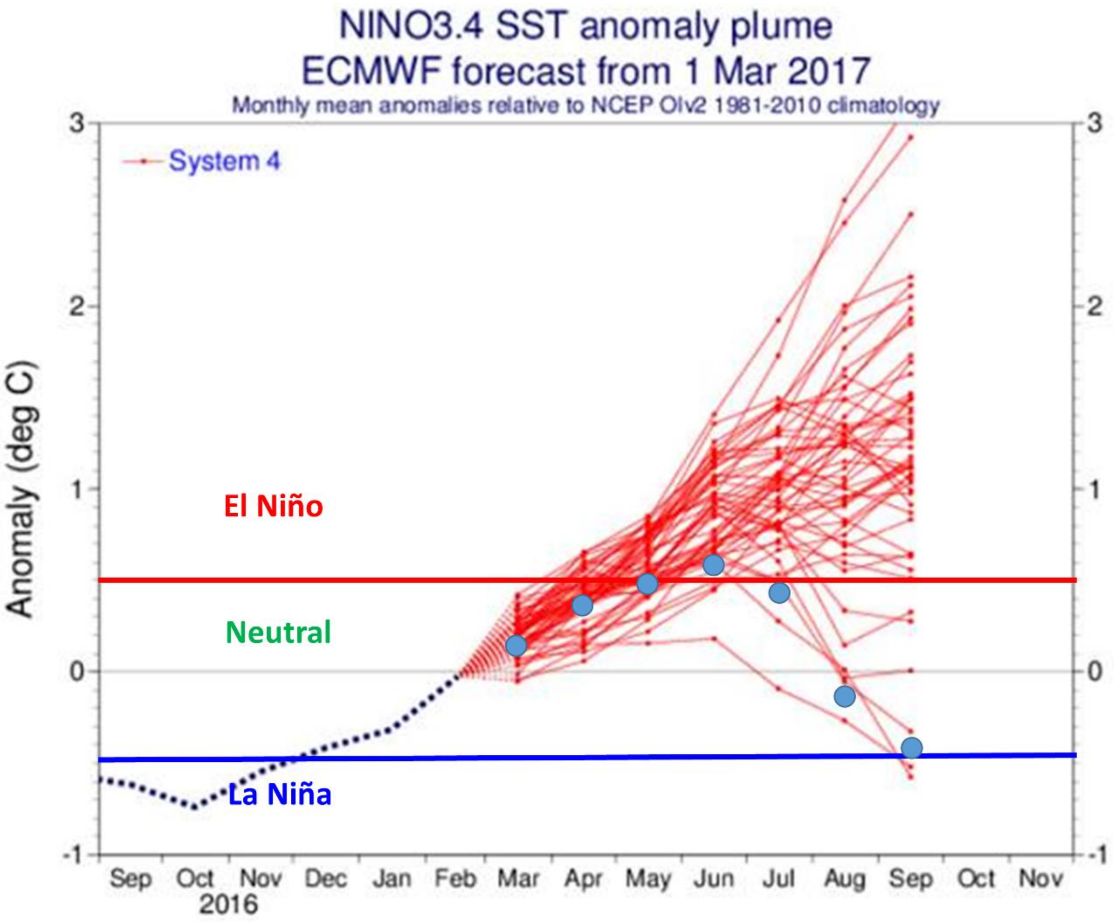


Figure 5: ECMWF ensemble prediction for Nino 3.4 from 1 March – the most recent information that we had available for our early April forecast in 2017. Blue dots represent the observed values.

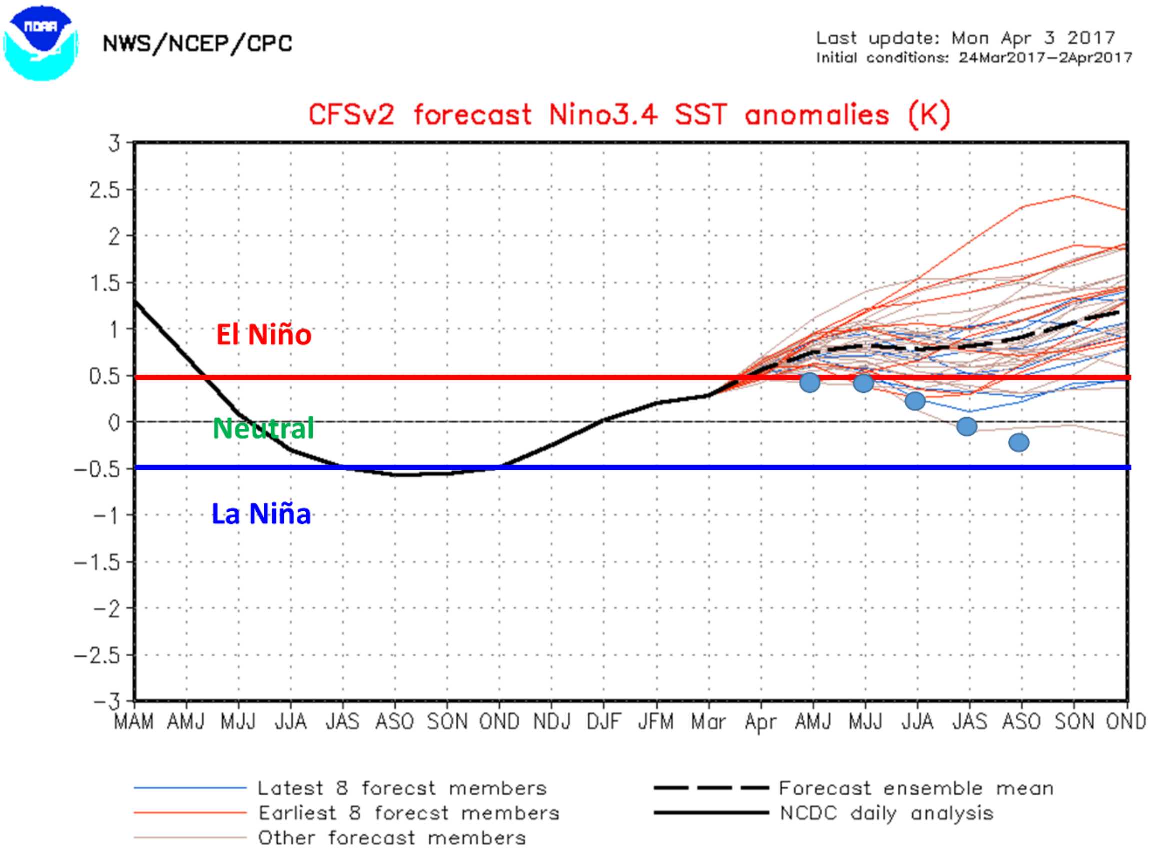


Figure 6: CFS ensemble prediction for Nino 3.4 from early April. Blue dots represent the observed values.

Weak La Niña conditions briefly occurred during the winter of 2016/17, then rapidly warmed to near borderline El Niño conditions during the late spring/early summer of 2017. These warm SST anomalies then rapidly cooled, and during the peak of the Atlantic hurricane season, we had cool neutral ENSO conditions. In early November, NOAA officially declared that we had moved into weak La Niña conditions. Table 7 displays anomalies in the various Nino regions in January, April, July and October 2017, respectively.

Table 7: January anomalies, April anomalies, July anomalies, and October anomalies for the Nino 1+2, Nino 3, Nino 3.4 and Nino 4 regions. SST anomaly differences from January 2017 are in parentheses.

| Region | January 2017 Anomaly (ºC) | April 2017 Anomaly (ºC) | July 2017 Anomaly (ºC) | October 2017 Anomaly (ºC) |
|---|---|---|---|---|
| Nino 1+2 | +1.2 | +0.9 (-0.3) | -0.1 (-1.3) | -1.3 (-2.5) |
| Nino 3 | 0.0 | +0.6 (+0.6) | +0.2 (+0.2) | -0.6 (-0.6) |
| Nino 3.4 | -0.3 | +0.3 (+0.6) | +0.4 (+0.7) | -0.5 (-0.2) |
| Nino 4 | -0.1 | +0.2 (+0.3) | +0.4 (+0.5) | -0.1 (0.0) |

An additional way to visualize the changes in ENSO that occurred over the past several months is to look at upper-ocean heat content anomalies in the eastern and central tropical Pacific (Figure 7). These anomalies were below normal in the early part of the year, warmed to slightly above-normal levels during the middle of the year and have recently cooled back to below-normal levels.

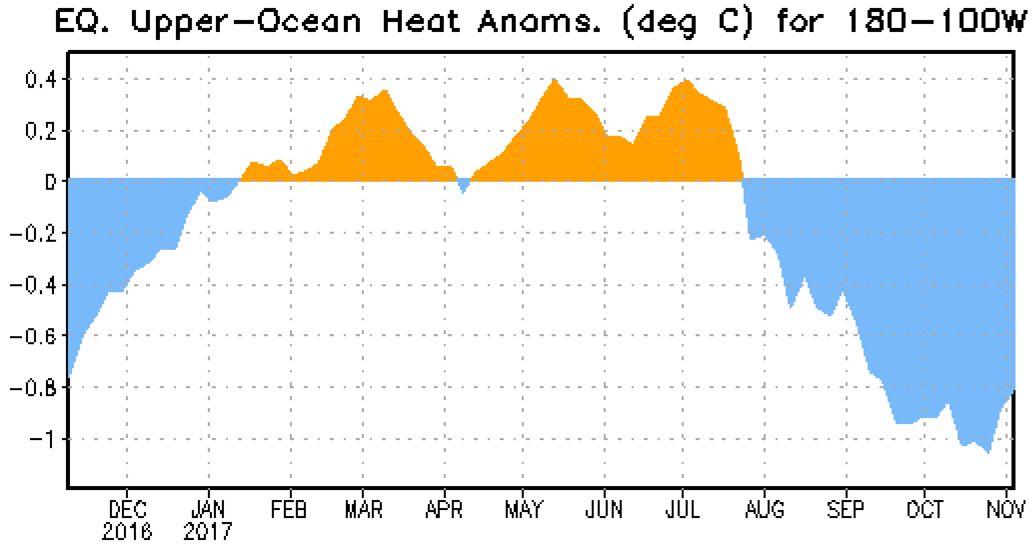


Figure 7: Upper ocean (0-300 meter) heat content anomalies in the eastern and central tropical Pacific from December 2016 – November 2017.

## 7.2 Intra-Seasonal Variability

The MJO was fairly weak and disorganized for most of the peak of the Atlantic hurricane season (Figure 8). The MJO did amplify into phases 4-7 during October. These phases are climatologically associated with less Atlantic hurricane activity (Table 8) due to increased vertical wind shear and are likely one reason why October ended up with only near-average Atlantic hurricane activity despite favorable large-scale conditions (e.g., borderline La Niña and very warm tropical Atlantic and Caribbean SSTs). The 2017 Atlantic hurricane season was, in general, characterized by average activity when broken down by month except for September, which as noted earlier was the most active Atlantic calendar month on record (Figure 9). Table 9 displays the number of storms that were first named in each phase of the MJO over the course of the 2017 Atlantic hurricane season. In general, the relationships that have previously been documented between MJO phase and Atlantic hurricane activity matched up fairly well with what was observed in 2017.

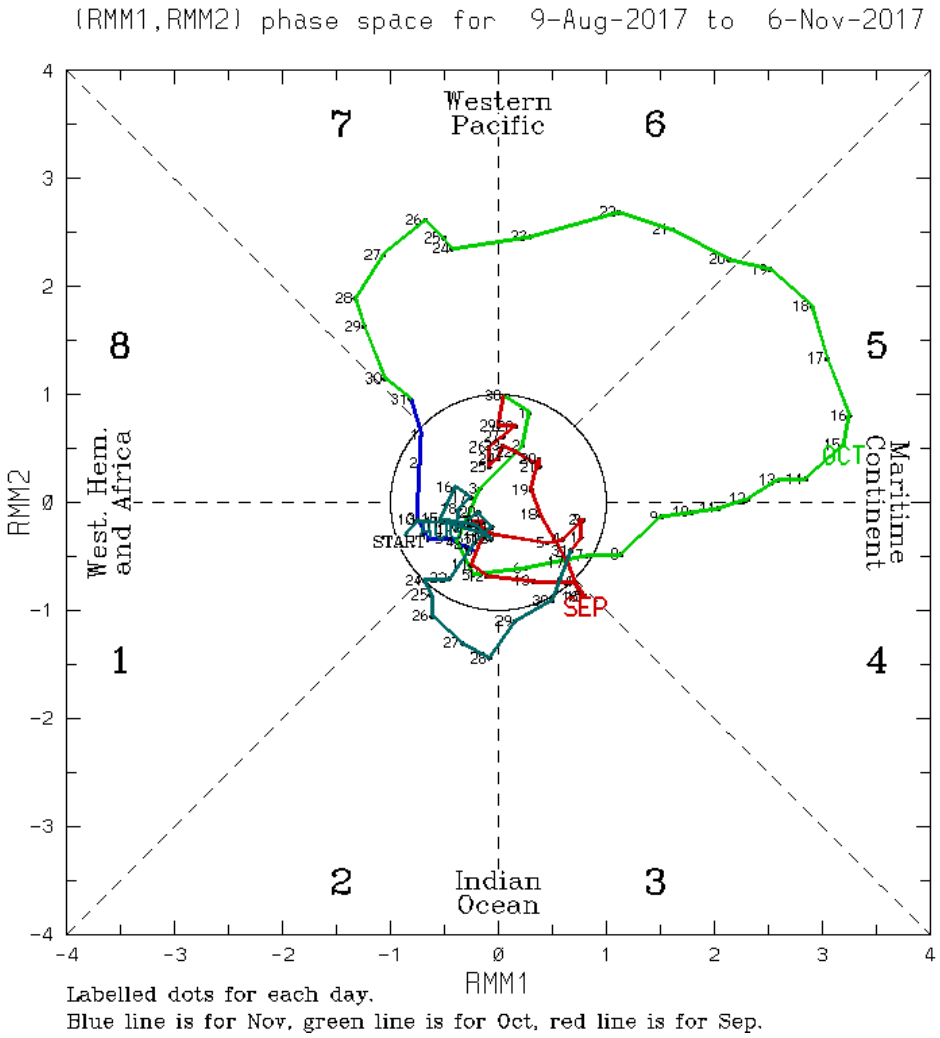


Figure 8: Propagation of the Madden-Julian Oscillation (MJO) based on the Wheeler-Hendon classification scheme over the period from August 9 to November 6. The MJO was generally weak during the peak of the Atlantic hurricane season, with amplification of the signal over the Maritime Continent and the western Pacific in October. The Maritime Continent refers to Indonesia and the surrounding islands. RMM stands for Real-Time Multivariate MJO. Figure courtesy of Bureau of Meteorology.

Table 8: Normalized values of named storms (NS), named storm days (NSD), hurricanes (H), hurricane days (HD), major hurricanes (MH), major hurricane days (MHD) and Accumulated Cyclone Energy (ACE) generated by all tropical cyclones forming in each phase of the MJO over the period from 1974-2007. Normalized values are calculated by dividing storm activity by the number of days spent in each phase and then multiplying by 100. This basically provides the level of TC activity that would be expected for 100 days given a particular MJO phase.

| MJO Phase | NS | NSD | H | HD | MH | MHD | ACE |
|---|---|---|---|---|---|---|---|
| Phase 1 | 6.4 | 35.9 | 3.7 | 17.9 | 1.8 | 5.3 | 76.2 |
| Phase 2 | 7.5 | 43.0 | 5.0 | 18.4 | 2.1 | 4.6 | 76.7 |
| Phase 3 | 6.3 | 30.8 | 3.0 | 14.7 | 1.4 | 2.8 | 56.0 |
| Phase 4 | 5.1 | 25.5 | 3.5 | 12.3 | 1.0 | 2.8 | 49.4 |
| Phase 5 | 5.1 | 22.6 | 2.9 | 9.5 | 1.2 | 2.1 | 40.0 |
| Phase 6 | 5.3 | 24.4 | 3.2 | 7.8 | 0.8 | 1.1 | 35.7 |
| Phase 7 | 3.6 | 18.1 | 1.8 | 7.2 | 1.1 | 2.0 | 33.2 |
| Phase 8 | 6.2 | 27.0 | 3.3 | 10.4 | 0.9 | 2.6 | 46.8 |
| | | | | | | | |
| Phase 1-2 | 7.0 | 39.4 | 4.3 | 18.1 | 1.9 | 4.9 | 76.5 |
| Phase 6-7 | 4.5 | 21.5 | 2.5 | 7.5 | 1.0 | 1.5 | 34.6 |
| | | | | | | | |
| Phase 1-2 / Phase 6-7 | 1.6 | 1.8 | 1.7 | 2.4 | 2.0 | 3.2 | 2.2 |

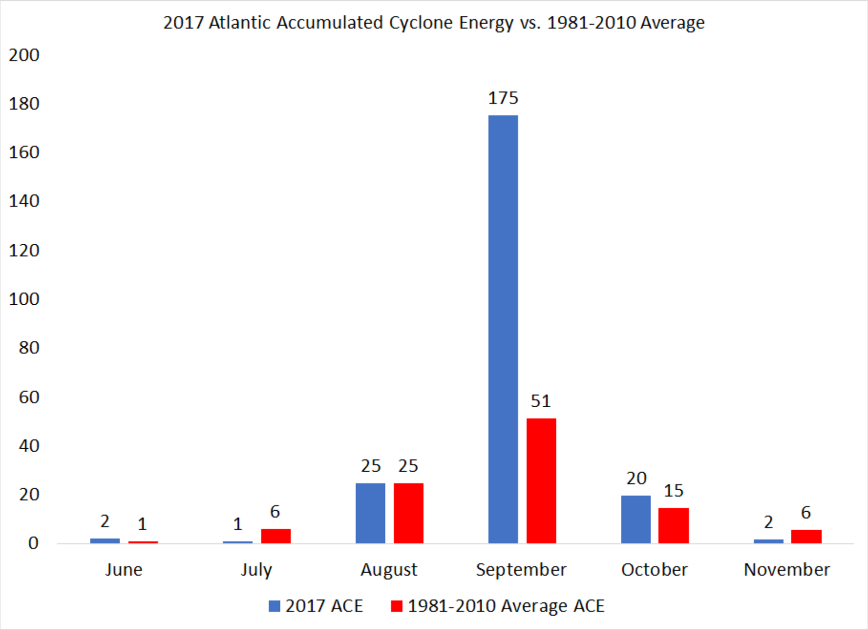


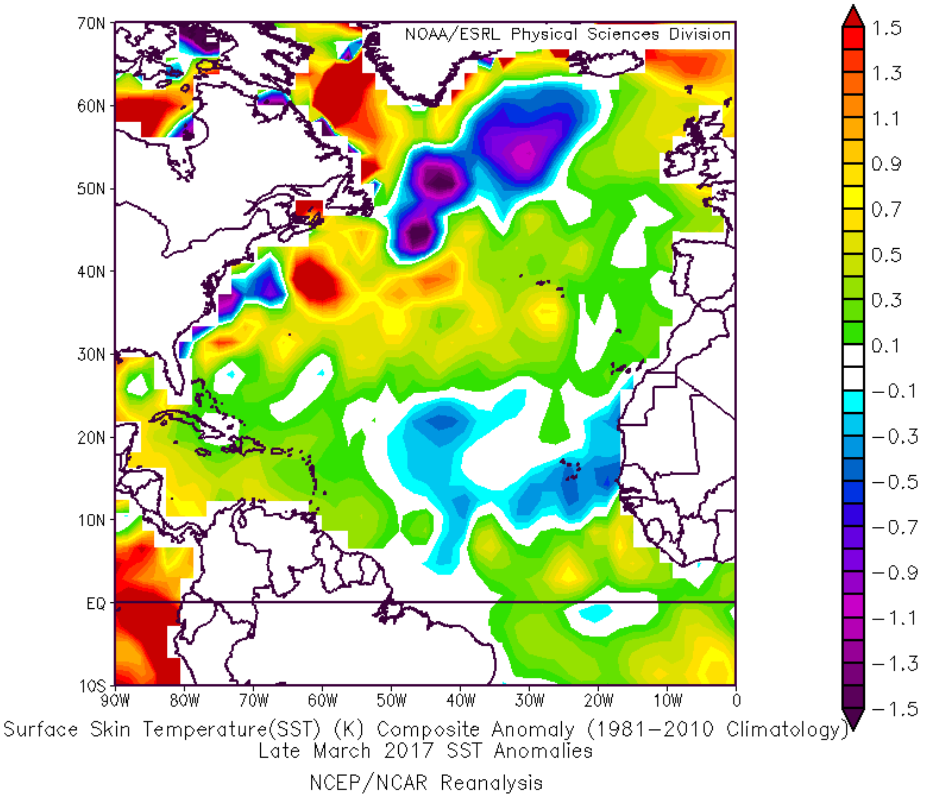
Figure 9: Atlantic Accumulated Cyclone Energy generated by month during the 2017 Atlantic hurricane season. Note that all months were fairly close to near-normal for ACE except for September, which as noted in the text was the most active calendar month on record.

Table 9: TC formations by MJO phase during the 2017 Atlantic hurricane season.

| MJO Phase | TC Formations |
|---|---|
| 1 | 3 |
| 2 | 4 |
| 3 | 4 |
| 4 | 2 |
| 5 | 0 |
| 6 | 0 |
| 7 | 2 |
| 8 | 2 |

## 7.3 Atlantic SST

The other primary reason for the marked under-forecast of the 2017 Atlantic hurricane season, especially with the outlook issued in April, other than the forecast bust of the ENSO models was due to anomalously cool tropical Atlantic SSTs that were observed in the latter part of March/early April. Figure 10 displays late March SST anomalies across the North Atlantic.


NOAA/ESRL Physical Sciences Division

Surface Skin Temperature(SST) (K) Composite Anomaly (1981–2010 Climatology)
Late March 2017 SST Anomalies

NCEP/NCAR Reanalysis

Figure 10: Late March 2017 SST anomaly pattern across the Atlantic Ocean.

During this same time, the far North Atlantic was also quite cold, indicative of a potential negative phase of the AMO. Typically, when the far North Atlantic is colder than normal, the atmosphere responds with a stronger subtropical high that drives stronger trade winds, increased evaporation and upwelling, and consequently anomalous cooling in the tropical Atlantic. This did not occur, however, in 2017. The subtropical high was much weaker than normal during April/May, leading to much weaker trade winds, reduced evaporation and upwelling and considerable anomalous warming (Figure 11).

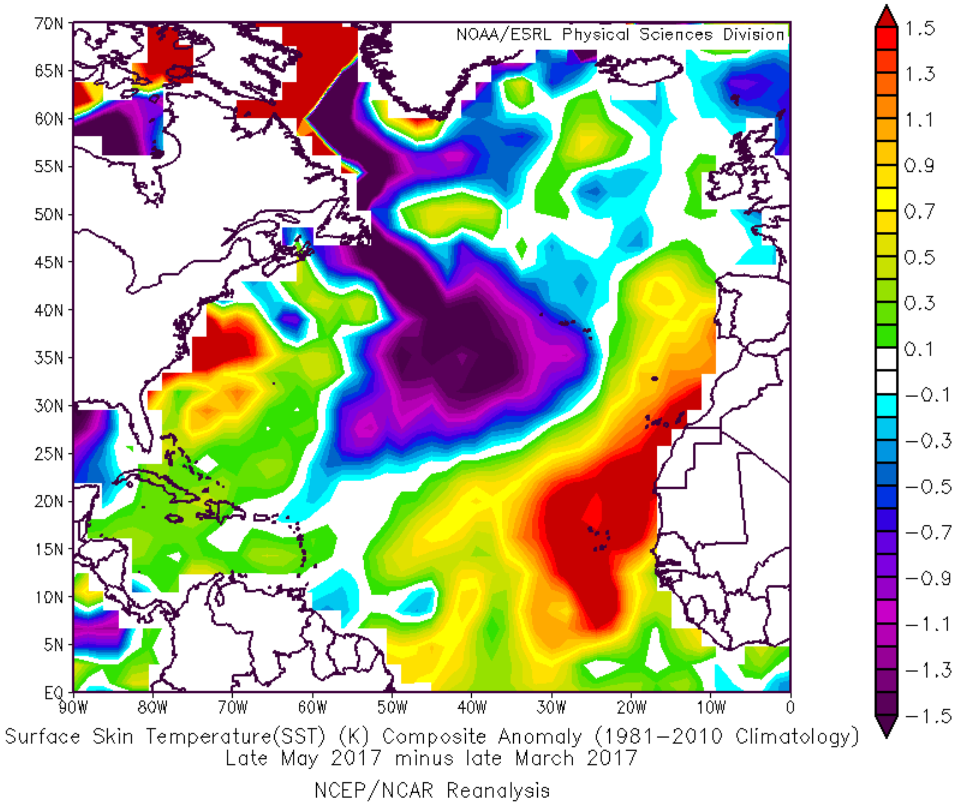


Figure 11: Late May 2017 minus late March 2017 SST anomaly change across the North Atlantic.

These warm SST anomalies persisted throughout the Atlantic hurricane season. During the record-breaking September that occurred, SST anomalies across the Main Development Region (10-20°N, 60-20°W) were at their third warmest values on record using the NOAA OI SST dataset which goes back to 1982. The only Septembers that were warmer were 2005 and 2010 which were also both very active Atlantic hurricane seasons. In addition to warmer SSTs providing more fuel for developing tropical cyclones, these warm SSTs are typically associated with lower sea level pressures, weaker trade winds (and associated reduced vertical wind shear) and increased mid-level moisture.

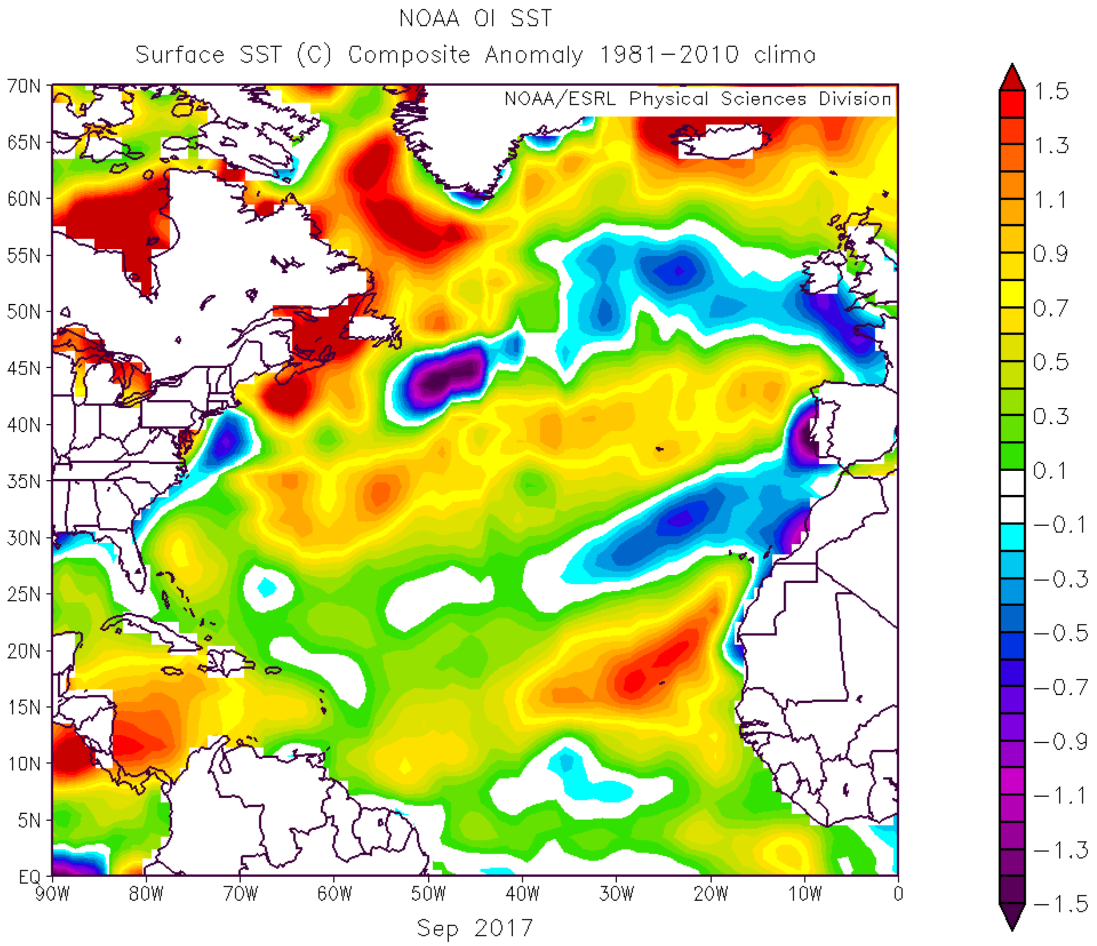


Figure 12: September 2017 SST anomalies.

## 7.4 Tropical Atlantic SLP

Tropical Atlantic sea level pressure values are another important parameter to consider when evaluating likely TC activity in the Atlantic basin. In general, lower sea level pressures across the tropical Atlantic imply increased instability, increased low-level moisture, and conditions that are generally favorable for TC development and intensification. The August-October portion of the 2017 Atlantic hurricane season was characterized by below-normal sea level pressures across the central and western tropical Atlantic (Figure 13). Some of these low pressure anomalies may be due to the tropical cyclones themselves, although the NCEP/NCAR Reanalysis which is used to plot sea level pressure anomalies is at a 2.5° resolution. Consequently, hurricanes are only represented very coarsely.

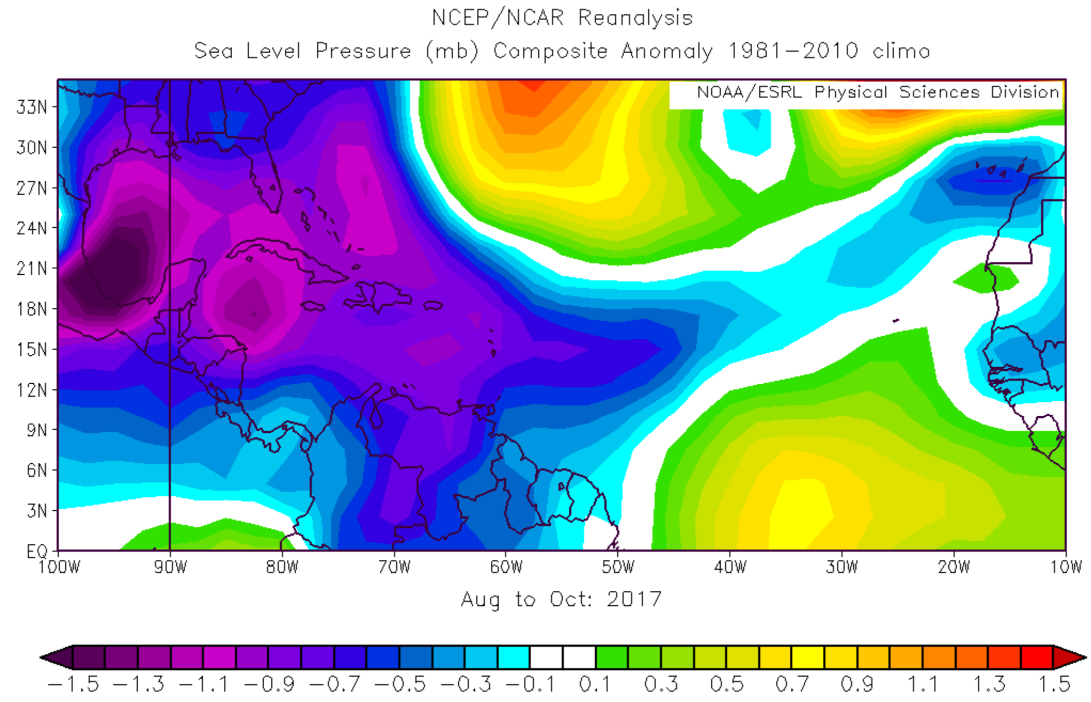


Figure 13: August-October 2017 tropical and sub-tropical North Atlantic sea level pressure anomalies.

## 7.5 Tropical Atlantic Vertical Wind Shear

One of the primary reasons why the 2017 hurricane season was so active was due to the very low values of vertical wind shear that were observed in the central and western Atlantic, especially during the very active portion of the season from late August to late September (Figure 14). A combination of very favorable thermodynamic conditions associated with the anomalously warm SSTs discussed previously and low levels of vertical wind shear allowed for very powerful hurricanes like Irma, Jose and Maria to develop and intensify during the record-shattering September of 2017.

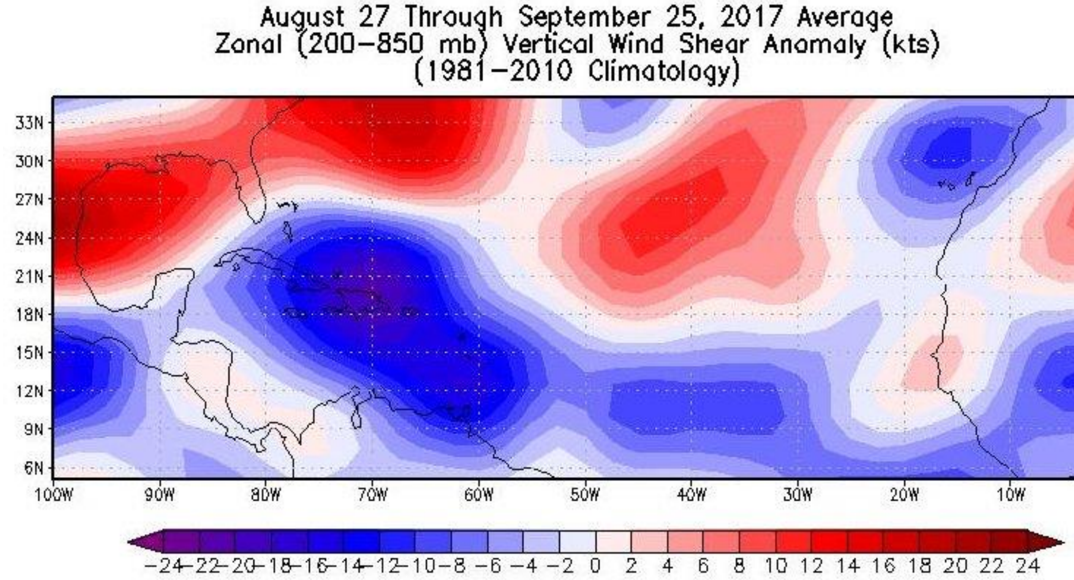


Figure 14: Anomalous vertical wind shear observed across the Atlantic from late August to late September. This period was associated with the most active portion of the 2017 Atlantic hurricane season.

## 7.6 Steering Currents

In addition to the very conducive dynamic and thermodynamic conditions discussed earlier in this verification, the mid-level steering flow in 2017 was quite a bit different than what was observed from 2006 to 2016, when the continental United States was in a major hurricane landfall drought (Figure 15). The subtropical high extended further west in 2017 than in the past decade, driving storms on a westward trajectory and preventing recurvature. Consequently, the 2017 Atlantic hurricane season witnessed storms like Irma and Maria tracking due west (or even south of due west) as they moved across the Atlantic. It was the unfortunate combination of both highly conducive hurricane formation conditions as well as steering currents that prevented recurvature that allowed the 2017 season to be as damaging and devastating as it turned out to be.

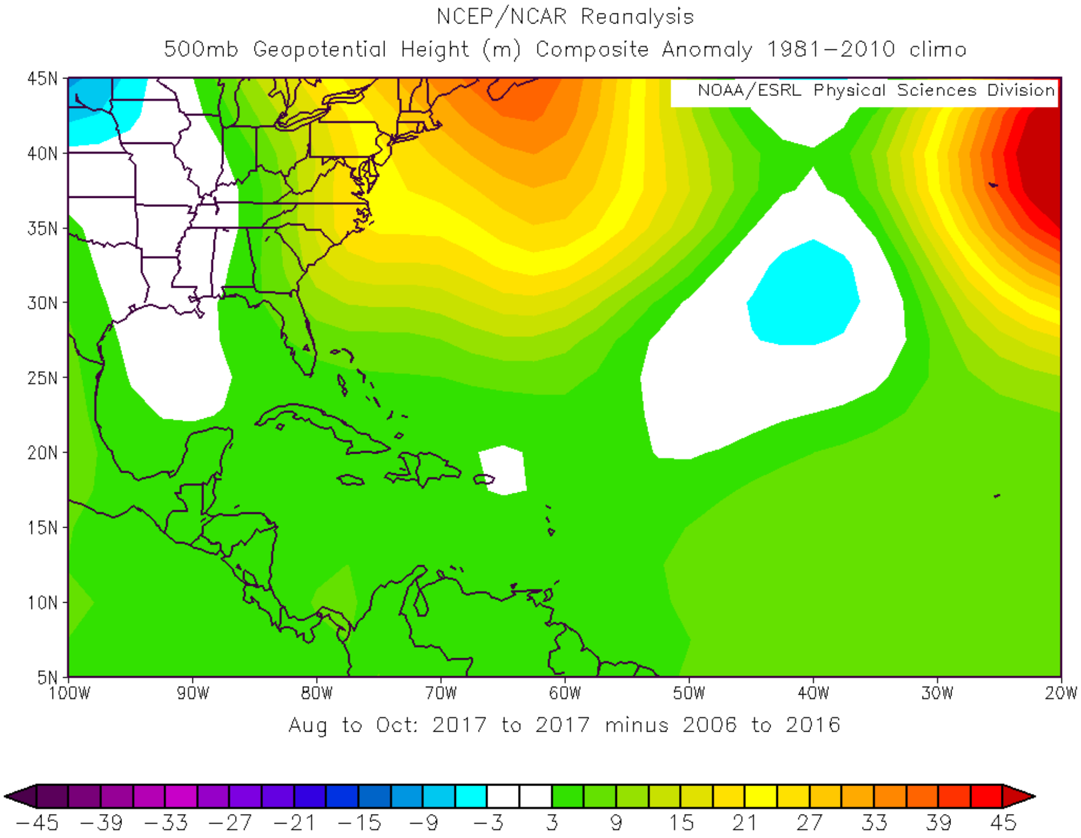


Figure 15: 500-mb height in the central and western part Atlantic from August to October in 2017 differenced from the August-October 2006 to 2016 period.

## 7.7 Atlantic Multi-Decadal Oscillation (AMO) Status

One of the big questions that has been raised in recent years has been: are we moving out of the active era? We recently addressed this in an article published in *Nature Geoscience* (Klotzbach et al. 2015). The 2017 Atlantic hurricane season has added additional intrigue to this question, as we have just experienced one of the most active seasons on record.

We monitor the strength of the AMO in real-time through an index that combines SSTs measured from (50-60°N, 50-10°W) as well as SLPs measured from (0-50°N, 70-10°W) (Figure 16). This index reached very low levels earlier this year (associated with both colder than normal SSTs as well as higher than normal SLPs) (Figure 17). However, the index then rebounded to near or slightly above-normal values during this year's hurricane season. In addition, while far North Atlantic SSTs were near average over the past few months, tropical Atlantic SSTs were much warmer than normal. In a long-term average sense, far North Atlantic SST anomalies and tropical Atlantic SST anomalies tend be of the same sign, contrary to what was observed this year.

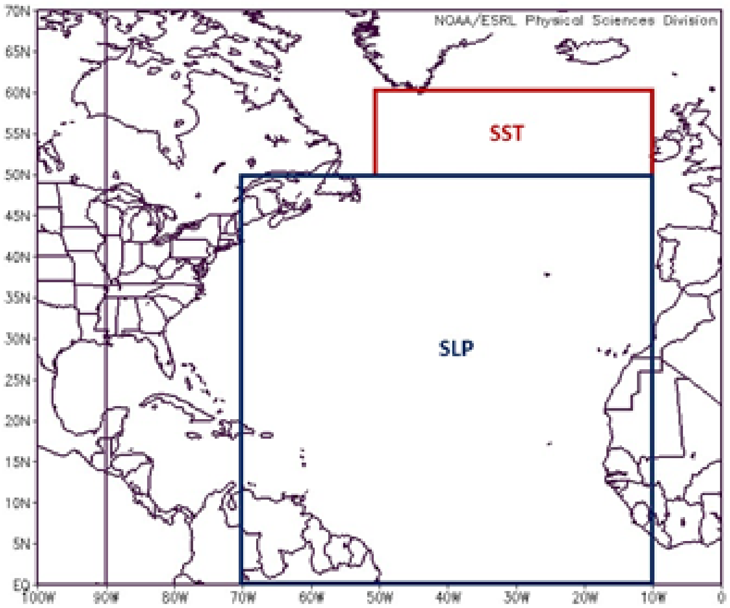


Figure 16: Regions which are utilized for the calculation of our AMO index.

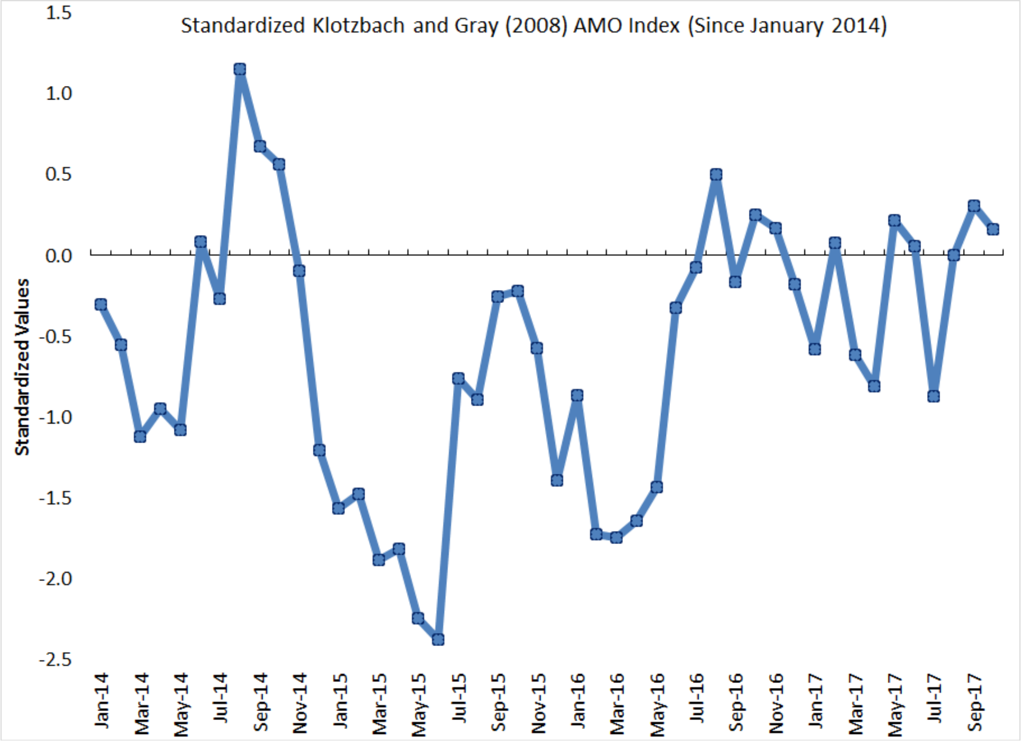


Figure 17: Standardized values of the AMO index by month since January 2014. The index was generally below normal in the early part of 2017 but has since rebounded to near-normal levels.

## 8 Forecasts of 2018 Hurricane Activity

We will be issuing our first outlook for the 2017 hurricane season on Wednesday, 13 December 2017. This forecast will provide a qualitative outlook for factors likely to impact the 2018 hurricane season. This December forecast will include the dates of all of our updated 2018 forecasts. All of these forecasts will be made available online.

## 9 Citations and Additional Reading

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# 10 Verification of Previous Forecasts

Table 10: Verification of the authors' early August forecasts of Atlantic named storms and hurricanes between 1984-2017. Observations only include storms that formed after 1 August. Note that these early August forecasts have either exactly verified or forecasted the correct deviation from climatology in 29 of 34 years for named storms and 26 of 34 years for hurricanes. If we predict an above- or below-average season, it tends to be above or below average, even if our exact forecast numbers do not verify.

| Year | Predicted NS | Observed NS | Predicted H | Observed H |
|---|---|---|---|---|
| 1984 | 10 | 12 | 7 | 5 |
| 1985 | 10 | 9 | 7 | 6 |
| 1986 | 7 | 4 | 4 | 3 |
| 1987 | 7 | 7 | 4 | 3 |
| 1988 | 11 | 12 | 7 | 5 |
| 1989 | 9 | 8 | 4 | 7 |
| 1990 | 11 | 12 | 6 | 7 |
| 1991 | 7 | 7 | 3 | 4 |
| 1992 | 8 | 6 | 4 | 4 |
| 1993 | 10 | 7 | 6 | 4 |
| 1994 | 7 | 6 | 4 | 3 |
| 1995 | 16 | 14 | 9 | 10 |
| 1996 | 11 | 10 | 7 | 7 |
| 1997 | 11 | 3 | 6 | 1 |
| 1998 | 10 | 13 | 6 | 10 |
| 1999 | 14 | 11 | 9 | 8 |
| 2000 | 11 | 14 | 7 | 8 |
| 2001 | 12 | 14 | 7 | 9 |
| 2002 | 9 | 11 | 4 | 4 |
| 2003 | 14 | 12 | 8 | 5 |
| 2004 | 13 | 14 | 7 | 9 |
| 2005 | 13 | 20 | 8 | 12 |
| 2006 | 13 | 7 | 7 | 5 |
| 2007 | 13 | 12 | 8 | 6 |
| 2008 | 13 | 12 | 7 | 6 |
| 2009 | 10 | 9 | 4 | 3 |
| 2010 | 16 | 17 | 9 | 11 |
| 2011 | 12 | 15 | 9 | 7 |
| 2012 | 10 | 15 | 5 | 9 |
| 2013 | 14 | 9 | 8 | 2 |
| 2014 | 9 | 7 | 3 | 5 |
| 2015 | 5 | 8 | 2 | 4 |
| 2016 | 15 | 15 | 6 | 7 |
| 2017 | 11 | 12 | 8 | 10 |
| Average | **10.9** | **10.7** | **6.2** | **6.1** |
| 1984-2016 Rank Correlation | | **0.63** | | **0.55** |

Table 11: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity from 2012-2016.

| | | Update | Update | |
|---|---|---|---|---|
| 2012 | 4 April | 1 June | 3 August | Obs. |
| Hurricanes | 4 | 5 | 6 | 10 |
| Named Storms | 10 | 13 | 14 | 19 |
| Hurricane Days | 16 | 18 | 20 | 26 |
| Named Storm Days | 40 | 50 | 52 | 99.50 |
| Major Hurricanes | 2 | 2 | 2 | 1 |
| Major Hurricane Days | 3 | 4 | 5 | 0.25 |
| Net Tropical Cyclone Activity | 75 | 90 | 105 | 121 |

| | | Update | Update | |
|---|---|---|---|---|
| 2013 | 10 April | 3 June | 2 August | Obs. |
| Hurricanes | 9 | 9 | 8 | 2 |
| Named Storms | 18 | 18 | 18 | 13 |
| Hurricane Days | 40 | 40 | 35 | 3.75 |
| Named Storm Days | 95 | 95 | 84.25 | 38.50 |
| Major Hurricanes | 4 | 4 | 3 | 0 |
| Major Hurricane Days | 9 | 9 | 7 | 0 |
| Accumulated Cyclone Energy | 165 | 165 | 142 | 33 |
| Net Tropical Cyclone Activity | 175 | 175 | 150 | 44 |

| | | Update | Update | Update | |
|---|---|---|---|---|---|
| 2014 | 10 April | 2 June | 1 July | 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 |

| | | Update | Update | Update | |
|---|---|---|---|---|---|
| 2015 | 9 April | 1 June | 1 July | 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 |

| | | Update | Update | Update | |
|---|---|---|---|---|---|
| 2016 | 9 April | 1 June | 1 July | 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 |