FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2016

We continue to foresee a near-average 2016 Atlantic hurricane season. ENSO is currently neutral and the potential for a transition to weak La Niña conditions by the peak of the Atlantic hurricane season is possible. While most of the tropical Atlantic and subtropical Atlantic is slightly warmer than normal, the far North Atlantic remains cold, potentially indicative of a negative phase of the Atlantic Multi-Decadal Oscillation. We anticipate a near-average probability for major hurricanes making landfall along the 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 1 July 2016)

By Philip J. Klotzbach[1]

In Memory of William M. Gray[2]

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

Anne Ju Manning, Colorado State University Media Representative, (970-491-7099) is available to answer various questions about this outlook.

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Dr. Bill Gray (1929-2016)

Dr. Gray passed away on April 16, 2016. He pioneered seasonal Atlantic hurricane prediction and conducted groundbreaking research in a wide variety of other topics including hurricane genesis, hurricane structure and cumulus convection. On a personal note, he was an amazing graduate advisor, mentor and friend. He will be greatly missed. I promised him when I saw him a few days before his death that I would give him at least 50 more years of seasonal forecasts. I will do my best to continue his legacy and produce seasonal Atlantic hurricane forecasts for as long as I can! A more in-depth eulogy is available here:

http://tropical.atmos.colostate.edu/Includes/Documents/gray_eulogy.pdf

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2016*

Forecast Parameter and 1981-2010 Median (in parentheses)	Issue Date 14 April 2016	Issue Date 1 June 2016	Issue Date 1 July 2016	Observed Activity Through June 2016	1 July Forecast for Remainder of 2016
Named Storms (NS) (12.0)	13	14	15	4	11
Named Storm Days (NSD) (60.1)	52	53	55	6.50	48.50
Hurricanes (H) (6.5)	6	6	6	1	5
Hurricane Days (HD) (21.3)	21	21	21	1	20
Major Hurricanes (MH) (2.0)	2	2	2	0	2
Major Hurricane Days (MHD) (3.9)	4	4	4	0	4
Accumulated Cyclone Energy (ACE) (92)	93	94	95	6	89
Net Tropical Cyclone Activity (NTC) (103%)	101	103	105	13	92

*Seasonal forecast numbers in the first three forecast columns in the above table include tropical cyclones that formed prior to the date of the forecast release (e.g., Alex, Bonnie, Colin and Danielle)

PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE LANDFALL ON EACH OF THE FOLLOWING COASTAL AREAS:

1) Entire U.S. coastline - 50% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 30% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 29% (average for last century is 30%)

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

1) 40% (average for last century is 42%)

ABSTRACT

Information obtained through July 2016 indicates that the 2016 Atlantic hurricane season will have activity near the median 1981-2010 season. There remains considerable uncertainty with this forecast which we outline in the following paragraphs.

We estimate that 2016 will have an additional 5 hurricanes (median is 6.5), 11 named storms (median is 12.0), 50 named storm days (median is 60.1), 20 hurricane days (median is 21.3), 2 major (Category 3-4-5) hurricane (median is 2.0) and 4 major hurricane days (median is 3.9). The probability of U.S. major hurricane landfall is estimated to be about 95 percent of the long-period average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2016 to be approximately 90 percent of their long-term averages for the remainder of the season.

This forecast is based on an extended-range early July statistical prediction scheme that was developed utilizing 34 years of past data. Analog predictors are also utilized. We anticipate an average Atlantic basin hurricane season. The two primary factors that we think may lead to an average season are the potential development of a weak La Niña and cooler-than-normal far North Atlantic SSTs. La Niña tend to favor an environment more favorable for Atlantic hurricane formation, while cool far North Atlantic SSTs may force higher-than-normal pressures and stronger trades in the tropical Atlantic for the peak of the hurricane season.

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.

Acknowledgment

We are grateful for support from Interstate Restoration, Ironshore Insurance and Macquarie Group that partially support the release of these predictions. We acknowledge a grant from the G. Unger Vetlesen Foundation for additional financial support. We thank the GeoGraphics Laboratory at Bridgewater State University (MA) for their assistance in developing the United States Landfalling Hurricane Probability Webpage (available online at http://www.e-transit.org/hurricane).

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 thank Professors Paul Mielke and Ken Berry of Colorado State University for statistical analysis and guidance over many years. We thank Bill Thorson for technical advice and assistance.

1 Introduction

This is the 33rd year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. We have shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology.

2 July Forecast Methodology

Klotzbach (2014) developed a 1 July seasonal forecast model which was utilized for the first time in real time last year. This 1 July forecast is now based on 34 years of hindcast data since 1982 and maximized 1 July prediction skill over the last 34 years (Figure 1).

The model has been modified since Klotzbach (2014) to substitute daily NOAA Optimum Interpolation (NOAA OI) SST instead of ERA-Interim 2-meter temperature for the East Atlantic predictor. The primary reason why this was done is daily OI SST is available in real-time, while ERA-Interim is not available in real-time. ERA-Interim is generally preferred over the Climate Forecast System Reanalysis (CFSR) for statistical model development, as most geophysical parameters show slightly better correlations with Accumulated Cyclone Energy (ACE) when using ERA-Interim than they do with CFSR. We utilize the CFSR dataset to estimate the real-time values for our 2nd predictor which is surface pressure in the tropical equatorial Pacific. We have replaced the 2nd predictor in the forecast model this year, as sea level pressure anomalies in the tropical Pacific likely have a stronger physical link with Atlantic hurricane activity than do upper-level winds in the tropical Indian Ocean.

Figure 2 displays the locations of our two 1 July predictors, while Table 1 displays the values of each predictor for the 2016 hurricane season. Table 2 displays the combination of the two predictors as model output for the 2016 Atlantic hurricane season. Both predictors are very close to their long-term averages, providing some increased confidence in our forecast for an average Atlantic hurricane season.

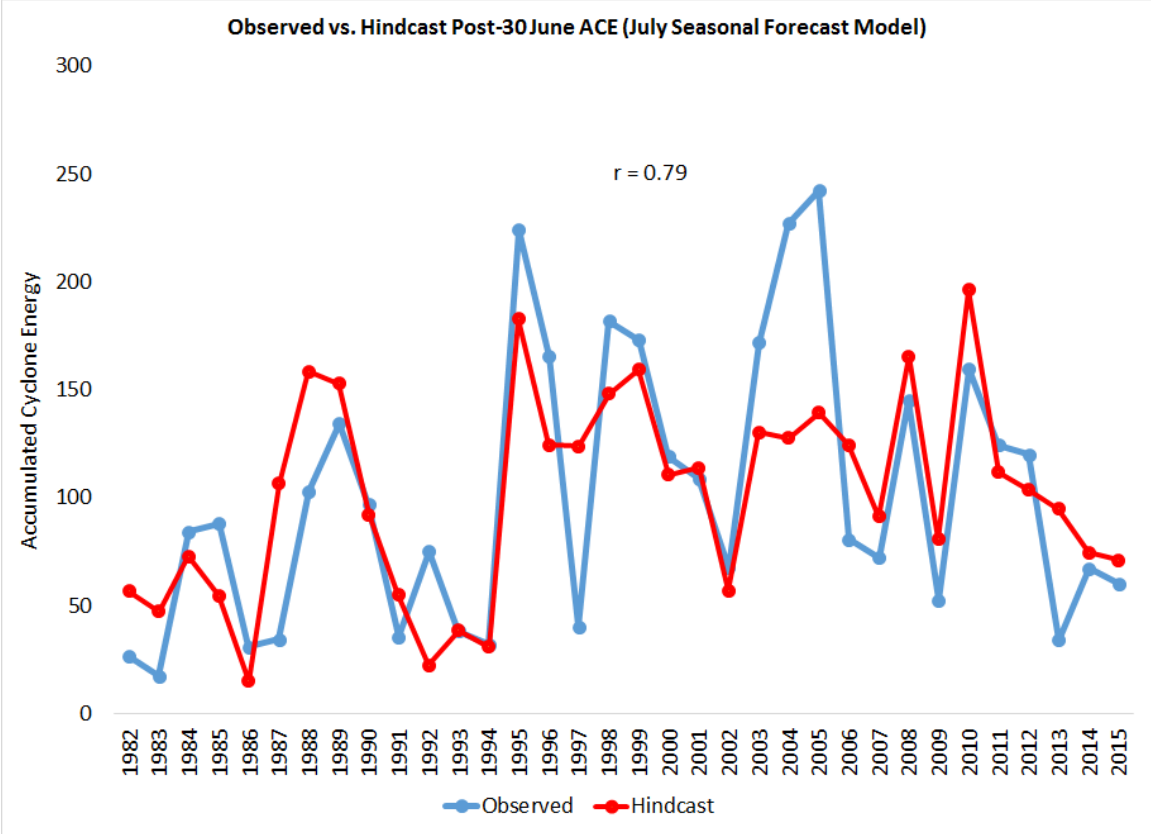

Figure 1: Observed versus early July jackknifed hindcast values of ACE for 1982-2015. The hindcast model explains approximately 60% of the variance from climatology.

July Forecast Predictors

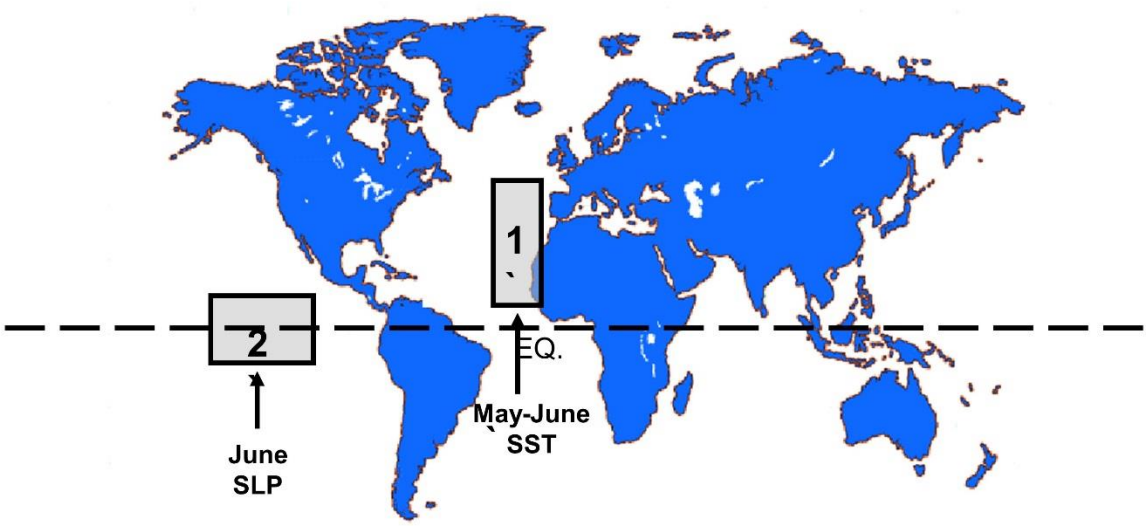

Figure 2: Location of predictors for the early July statistical prediction for the 2016 hurricane season.

Table 1: Listing of 1 July 2016 predictors for the 2016 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity.

Predictor	2016 Forecast Value	Favorable/Unfavorable for TCs
1) May-June SST (10-50°N, 30-10°W) (+)	+0.1 SD	Neutral
2) June SLP (15°S-15°N, 150-110°W) (+)	-0.1 SD	Neutral

Table 2: 1 July statistical model output for the remainder of the 2016 Atlantic hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	Statistical Forecast
Named Storms (12.0)	10.7
Named Storm Days (60.1)	53.0
Hurricanes (6.5)	6.1
Hurricane Days (21.3)	23.8
Major Hurricanes (2.0)	2.6
Major Hurricane Days (3.9)	6.0
Accumulated Cyclone Energy Index (92)	99
Net Tropical Cyclone Activity (103%)	108

3 Analog-Based Predictors for 2016 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2016. These years also provide useful clues as to likely trends in activity that the forthcoming 2016 hurricane season may bring. For this early July extended range forecast, we determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current May-June 2016 conditions as well as what we anticipate to be present during August-October. Table 3 lists our analog selections.

We select prior hurricane seasons since 1950 which have similar atmospheric-oceanic conditions to those currently being experienced. We searched for years that were characterized by cool neutral to weak La Niña conditions and a variety of tropical and North Atlantic SST configurations.

There were six hurricane seasons since 1950 with characteristics most similar to what we expect to see in August-October of 2016. We anticipate that the 2016 hurricane season will have activity near the average of our six analog years. We believe that this season should experience near-average activity.

Table 3: Best analog years for 2016 with the associated full-season hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1959	11	40.00	7	22.00	2	4.25	77	96
1960	7	29.50	4	18.25	2	9.75	88	93
1966	11	64.00	7	41.75	3	8.75	145	140
1977	6	14.75	5	6.75	1	1.00	25	47
1992	7	40.25	4	16.00	1	3.50	76	67
2003	16	81.50	7	32.75	3	16.75	176	175
Average	9.7	45.0	5.7	22.9	2.0	7.3	98	103
2016 Forecast	**15**	**55**	**6**	**21**	**2**	**4**	**95**	**105**

3 ENSO

The slow progression away from El Niño conditions has continued over the past month, with SSTs across most of the tropical eastern and central Pacific now below normal. Upper ocean heat content has been below average for the past several weeks (Figure 3).

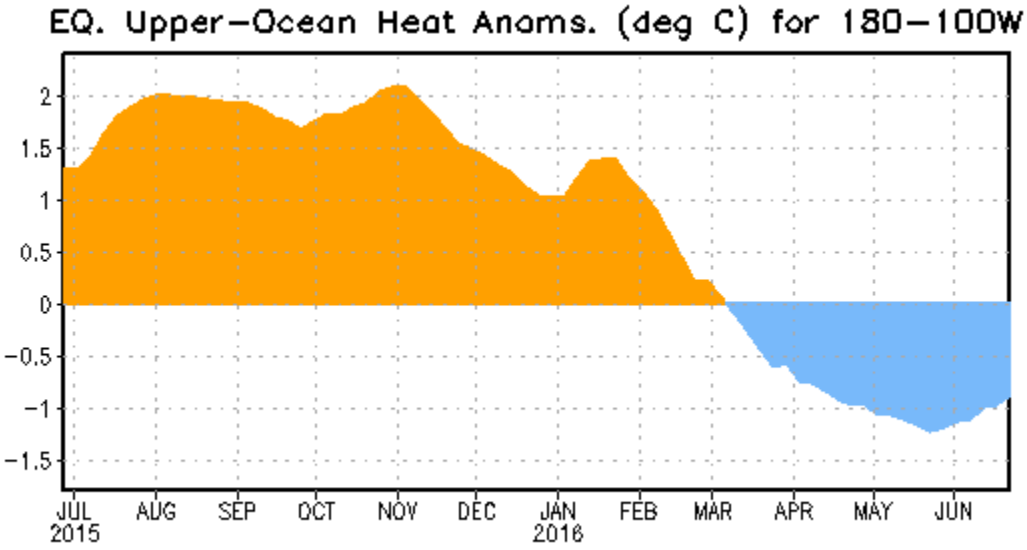

Figure 3: Central and eastern tropical Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Anomalies have been below-normal since early March 2016. Figure courtesy of the Climate Prediction Center.

Currently, SSTs are running near to slightly below average across the eastern tropical Pacific with above-average SSTs persisting in the central tropical Pacific. Table

4 displays the May and June SST anomalies across the tropical Pacific. There has generally been a modest cooling across the tropical eastern and central Pacific over the past month.

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

Region	May SST Anomaly (°C)	June SST Anomaly (°C)	June minus May SST Anomaly (°C)
Nino 1+2	+0.3	+0.2	-0.1
Nino 3	+0.0	-0.1	-0.1
Nino 3.4	+0.3	-0.2	-0.5
Nino 4	+0.6	+0.6	0.0

There is a fairly wide spread amongst the various dynamical and statistical models as to what is likely to occur with ENSO over the next few months, but virtually all models are calling for either cool neutral or weak La Niña conditions. This should create vertical wind shear conditions that are more conducive for hurricane formation in the Caribbean and potentially also the Main Development Region than have been present the past two years (Figure 4).

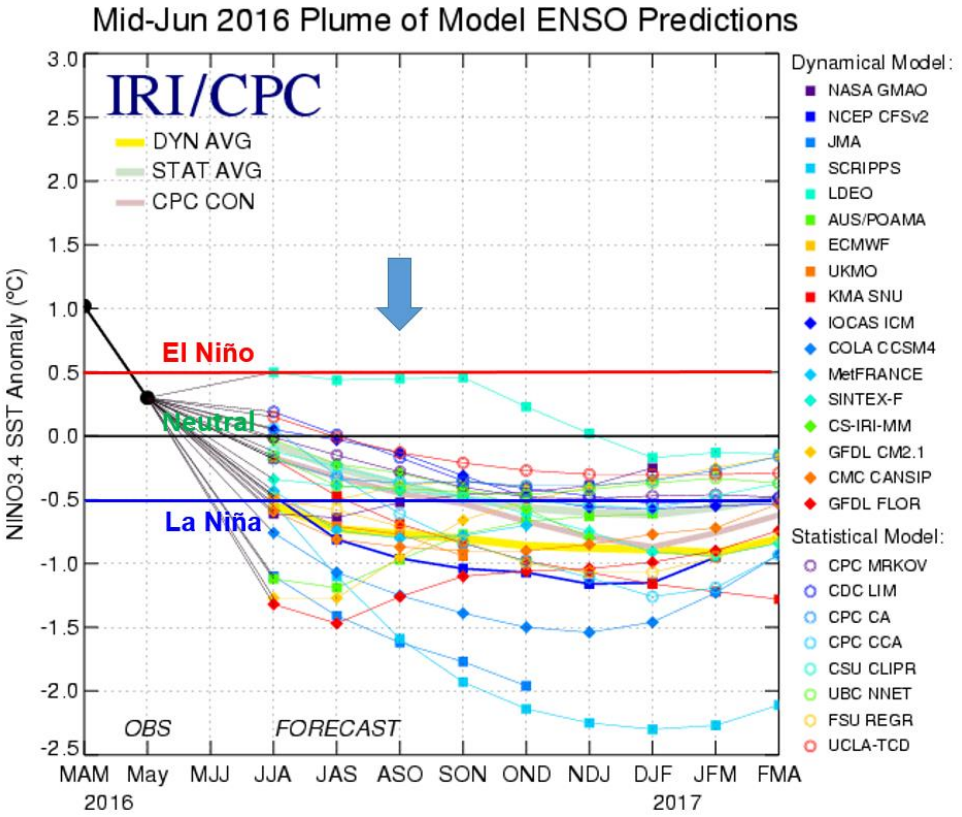

Figure 4: ENSO forecasts from a wide variety of dynamical and statistical models. Figure courtesy of International Research Institute/Climate Prediction Center. The blue arrow highlights the peak of the Atlantic hurricane season (August-October).

Based on the above information, our best estimate is that we will have either cool neutral or weak La Niña conditions in place for the peak of the 2016 Atlantic hurricane season. Additional discussion of ENSO will be included with the 4 August update.

4 Current Atlantic Basin Conditions

The tropical Atlantic currently has slightly warmer-than-normal SSTs, while the far North Atlantic is quite cold (Figure 5). The overall SST pattern across the Atlantic basin somewhat resembles the negative phase of the AMO or weak phase of the thermohaline circulation, but the tropical Atlantic portion of the SST anomaly is warmer than would be expected for a typical negative AMO. However, the signal of a negative AMO looks much clearer when looking at the North Atlantic basin in comparison with global mean SSTs, which are still warmer-than-normal due in large part to the strong El Niño event that just occurred (Figure 6).

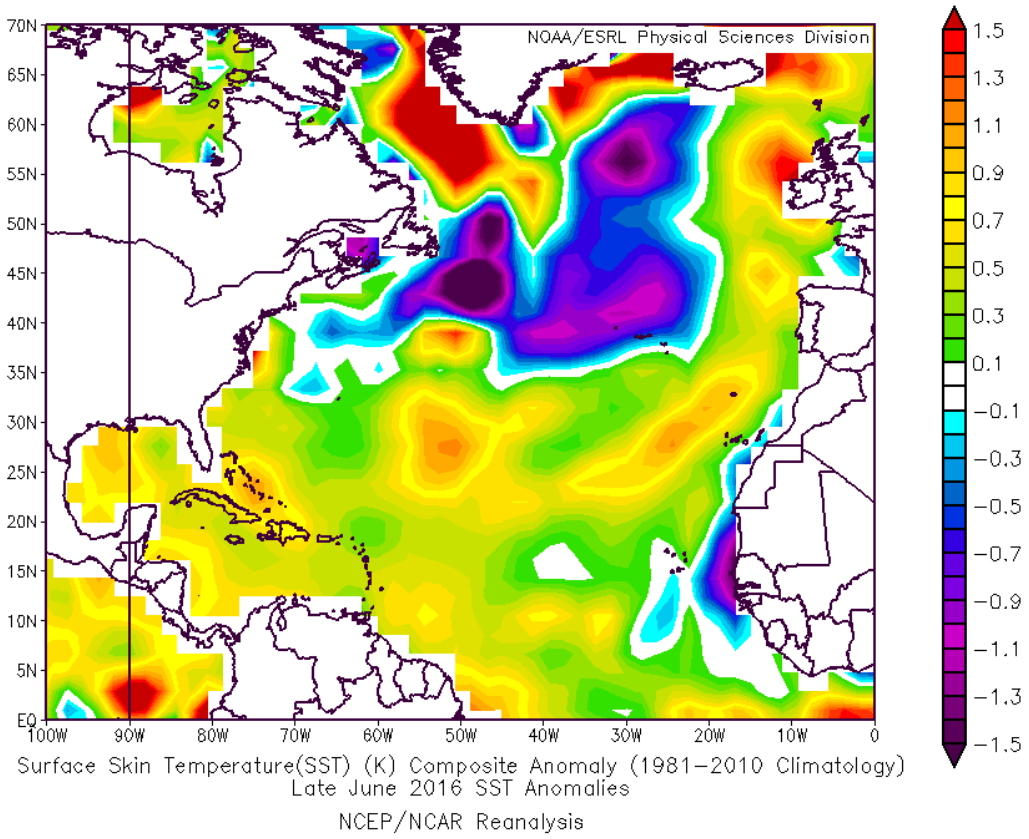

Figure 5: Late June SST anomalies across the Atlantic.

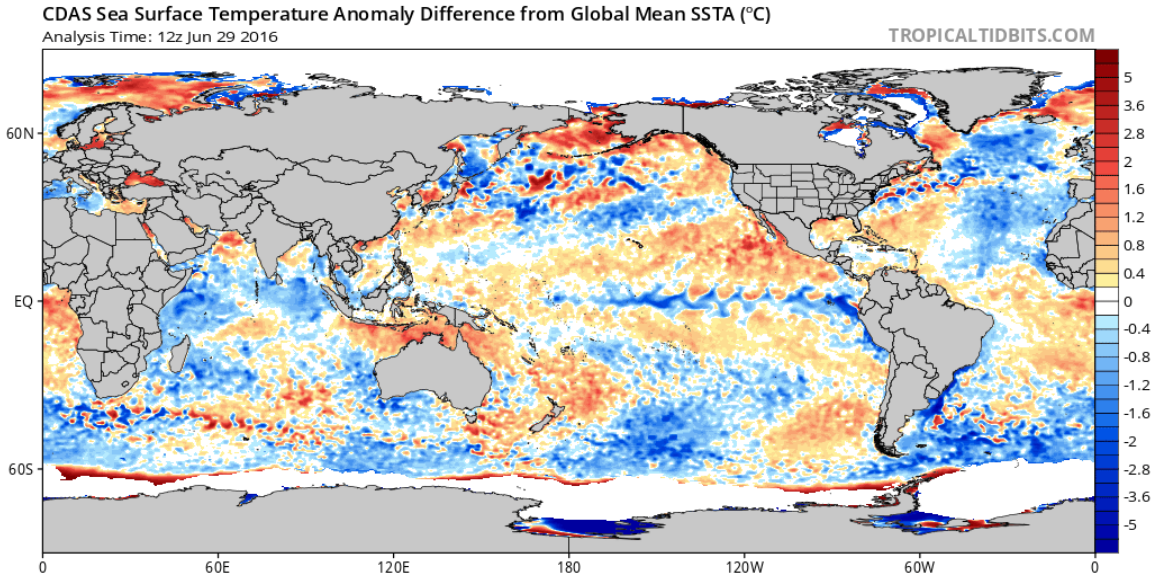

Figure 6: SST anomalies differenced from the current global mean SST anomaly. The cold AMO pattern shows up much more clearly when looking at SSTs from this perspective. Figure courtesy of Tropical Tidbits.

Sea level pressure anomalies have been running well above-average since the beginning of June in the Main Development Region (MDR) (10-20°N, 60-20°W) (Figure 7). While the important of this predictor increases significantly in July compared with June, the persistence of these high anomalies has been impressive over the past few weeks. In addition, the ECMWF model is predicting continued above-average sea level pressure anomalies for the next ten days (Figure 8). The ECMWF is generally calling for above-average sea level pressure for the August-October average as well (Figure 9). It should be cautioned while in general, the ECMWF shows significant skill at seasonal forecasts, their sea level pressure forecasts across the tropical Atlantic have not been particularly skillful over the past few years.

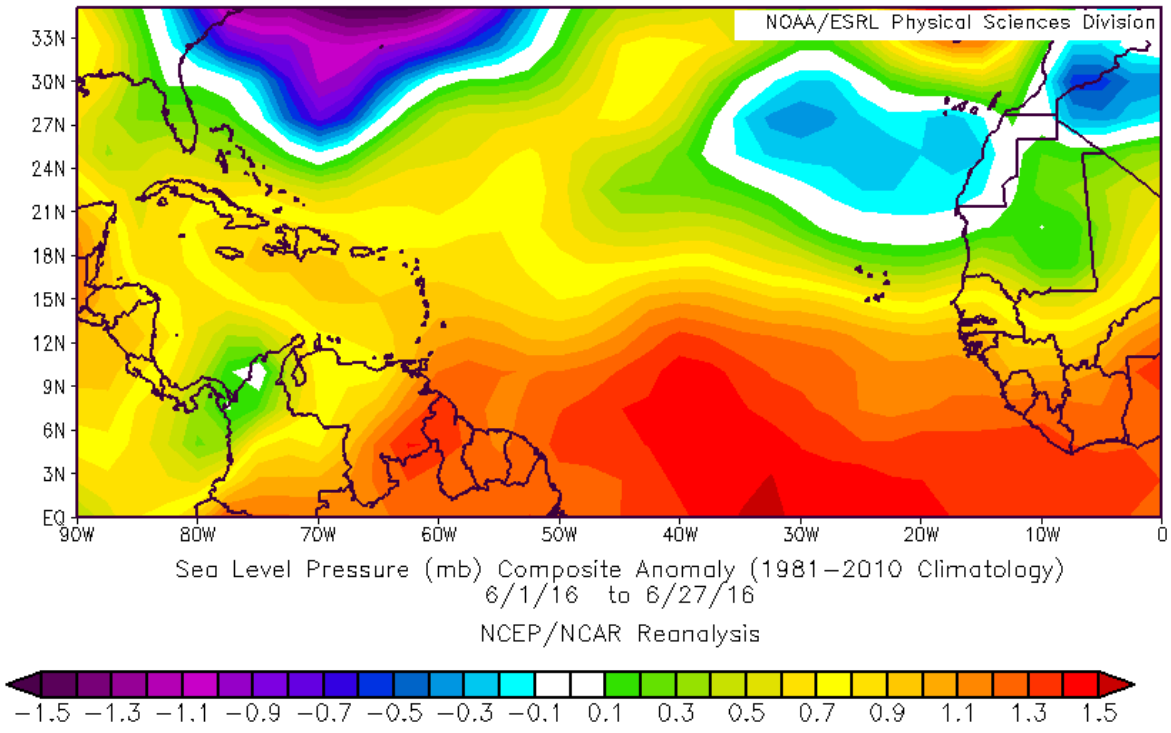

Figure 7: Sea level pressure anomalies across the tropical Atlantic from June 1 – June 27. Sea level pressure anomalies are running well above average this month.

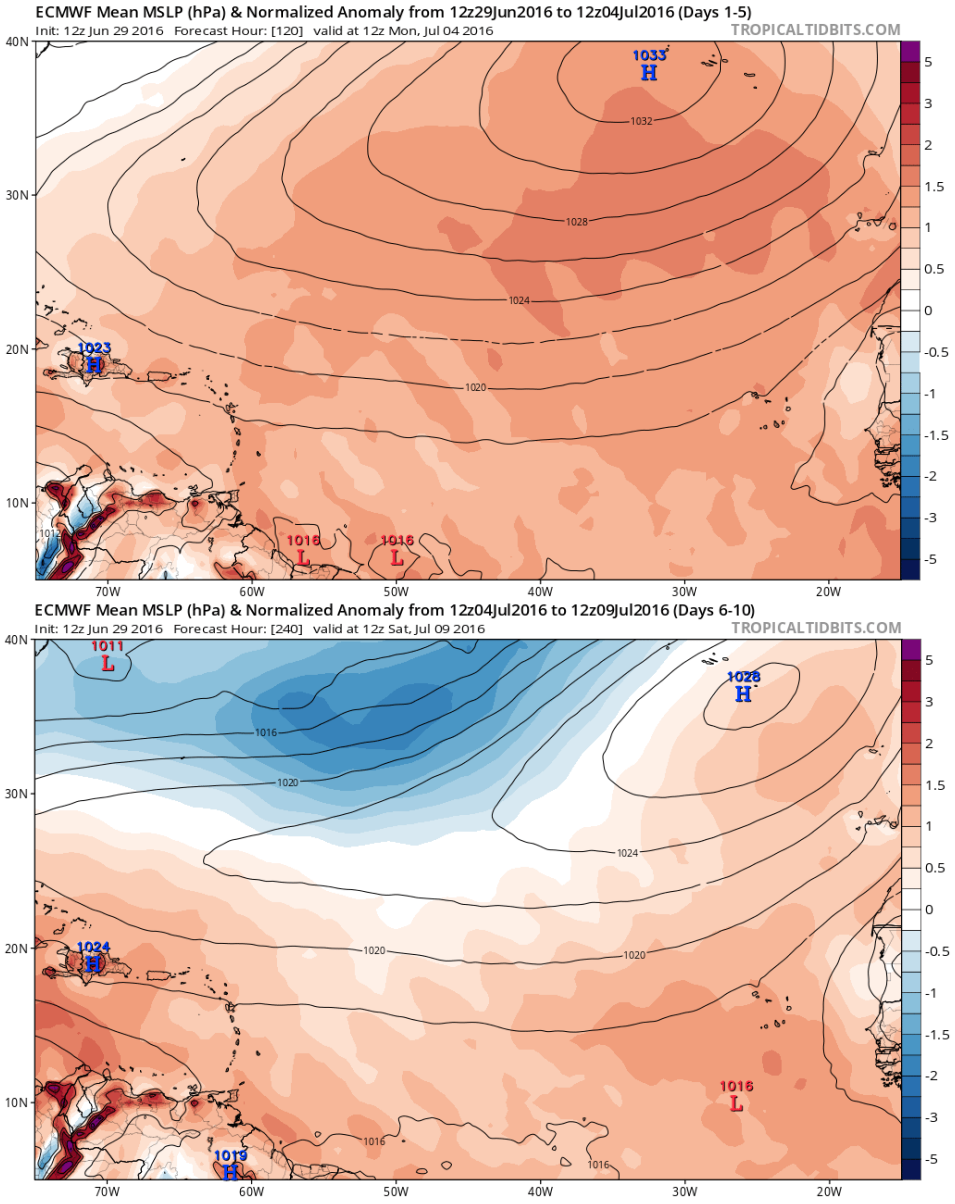

Figure 8: (top panel) Predicted normalized sea level pressure anomalies from the tropical Atlantic from June 29 – July 4, (bottom panel): Predicted normalized sea level pressures for the tropical and subtropical Atlantic from July 4 – 9. Both forecasts are from the ECMWF model.

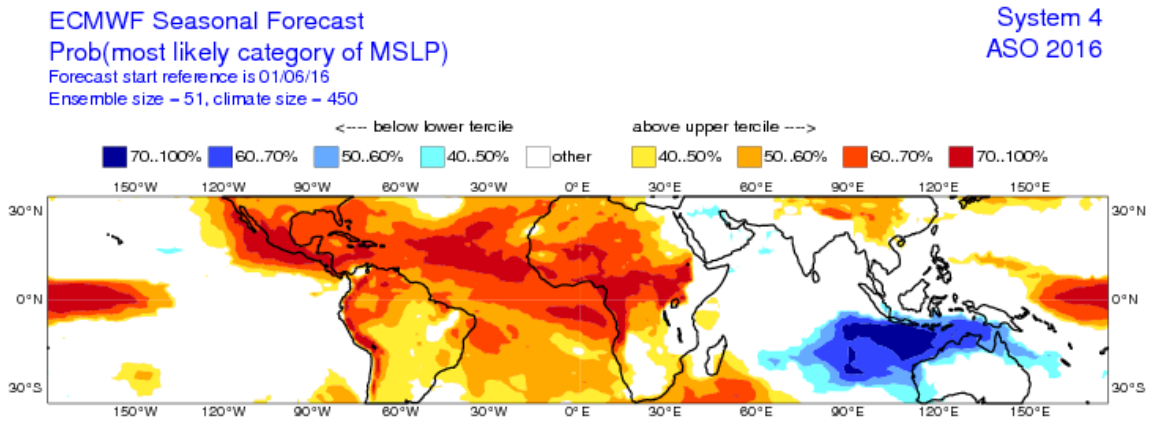

Figure 9: Most likely category of mean sea level pressure anomalies predicted by the ECMWF for the August-October period. The ECMWF is predicting a fairly high likelihood of experiencing above-normal sea level pressure anomalies during the three most active months of the Atlantic hurricane season.

Levels of vertical wind shear across the tropical Atlantic have been somewhat below average while they have been somewhat above average across the Caribbean over the past 30 days (Figure 10). Vertical shear anomalies across the tropical Atlantic and Caribbean are much reduced from their extraordinarily high values that were experienced last year at this time (Figure 11). This reduction in vertical wind shear is likely driven by the fact that El Niño has dissipated.

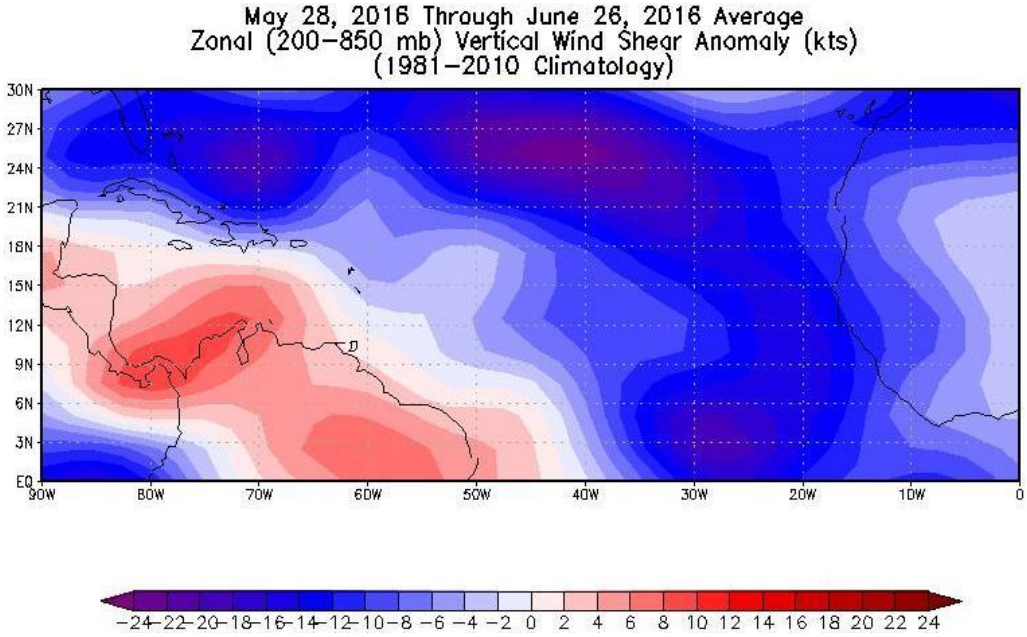

Figure 10: Recent 30-day anomalies of zonal vertical wind shear across the tropical Atlantic and Caribbean differenced from the 1981-2010 climatology.

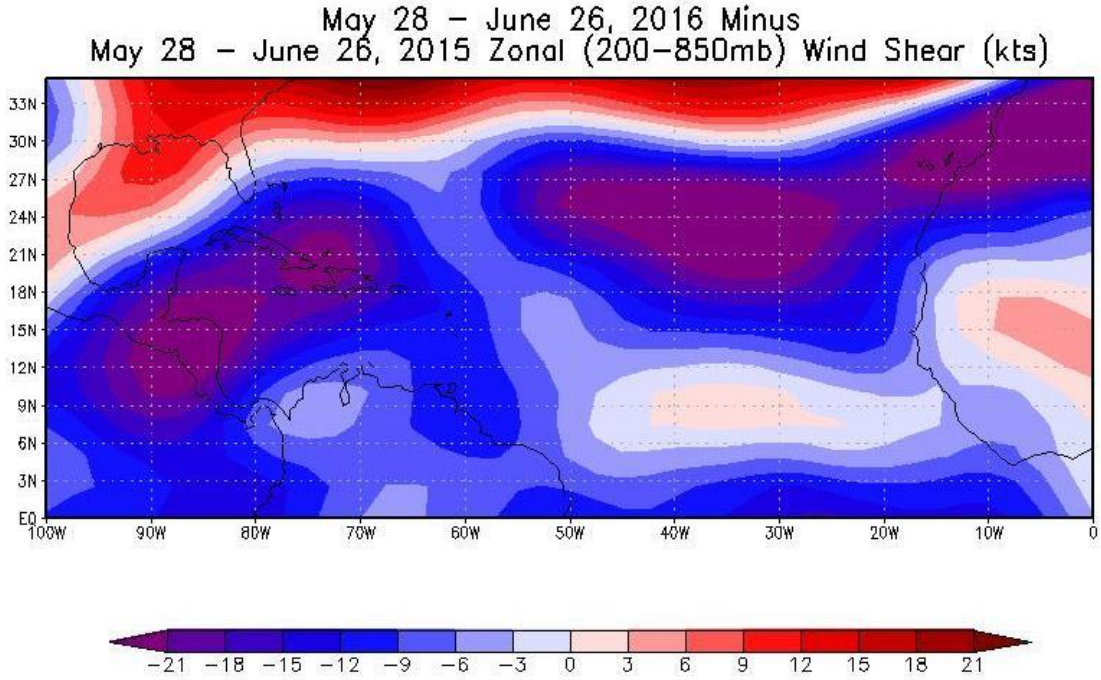

Figure 11: Recent 30-day anomalies of zonal vertical wind shear anomalies across the tropical Atlantic and Caribbean differenced from 2015.

The latest forecast from the CFS model is calling for above-normal vertical wind shear across the MDR during the peak of the Atlantic hurricane season from August-October (Figure 12), with below-normal vertical wind shear predicted for the Gulf of Mexico and Caribbean (Figure 13). While there is obvious uncertainty in seasonal forecasts of vertical wind shear, the anomalous reduction in vertical wind shear across the Caribbean would be typical of what would be expected in a season with cool neutral to weak La Niña conditions.

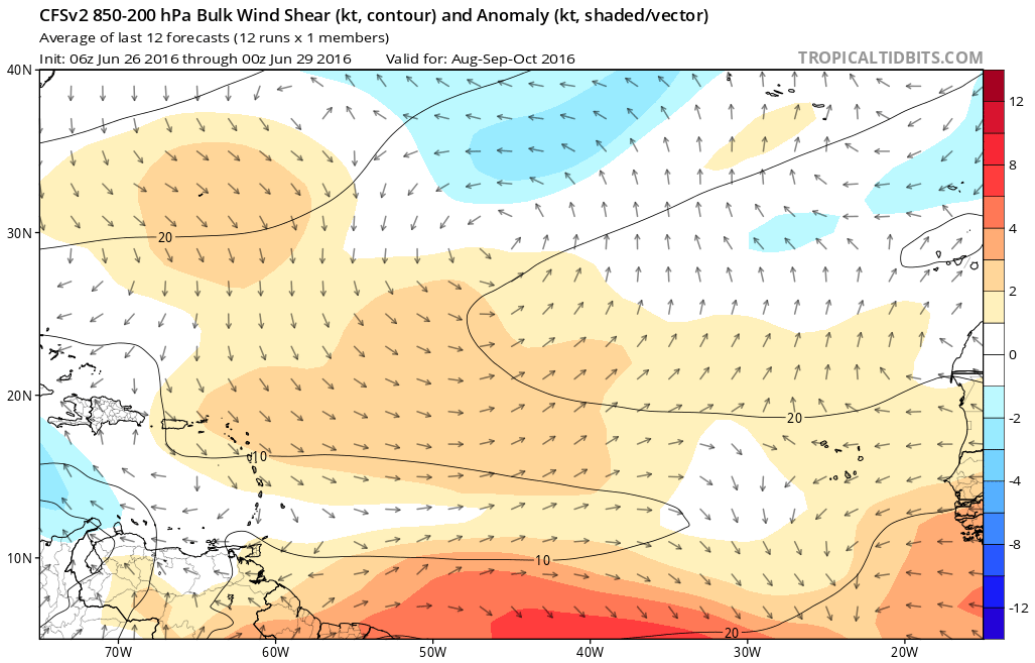

Figure 12: Most recent forecast from the Climate Forecast System for bulk wind shear across the tropical Atlantic for August-October. Slightly above-normal shear is predicted. Figure courtesy of Tropical Tidbits.

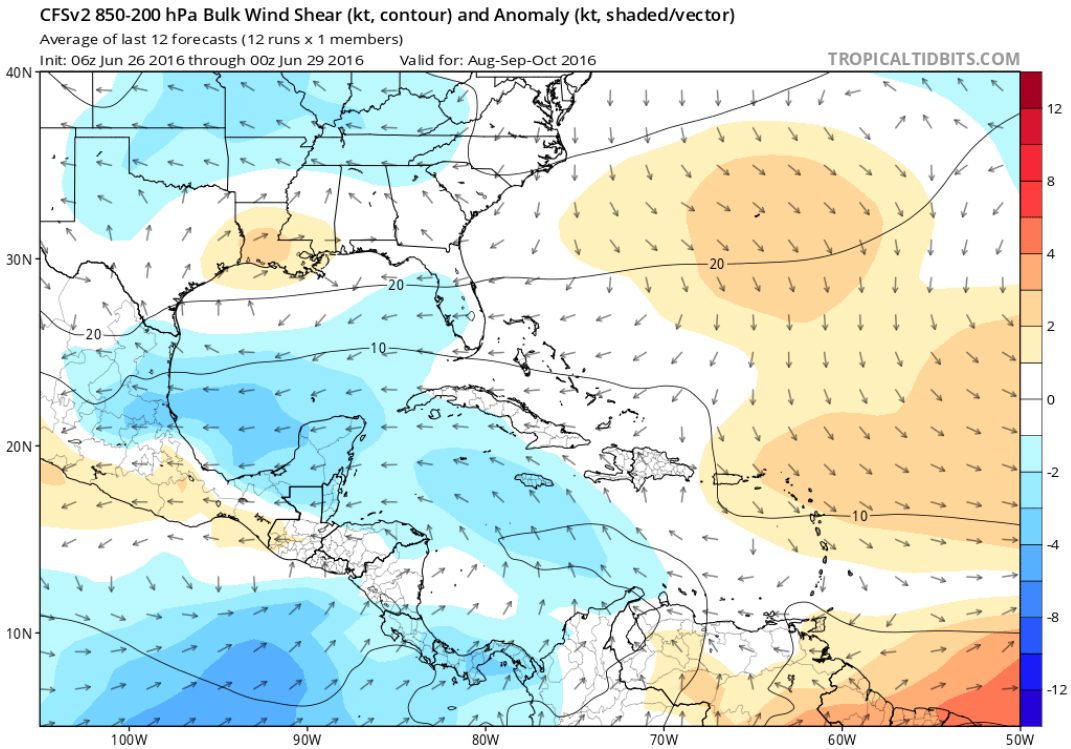

Figure 13: Most recent CFS forecast for bulk wind shear across the wfor August-October. Slightly below-normal shear is predicted. Figure courtesy of Tropical Tidbits.

5 Forthcoming Updated Forecasts of 2016 Hurricane Activity

We will be issuing a final seasonal update of our 2016 Atlantic basin hurricane forecasts on **Thursday, 4 August**. We will also be releasing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August-October. A verification and discussion of all 2016 forecasts will be issued in late November 2016. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

6 Acknowledgments

Besides the individuals named on page 3, there have been a number of other meteorologists that have furnished us with data and given valuable assessments of the current state of global atmospheric and oceanic conditions. These include Brian McNoldy, Art Douglas, Ray Zehr, Mark DeMaria, Todd Kimberlain, Paul Roundy and Amato Evan. In addition, Barbara Brumit and Amie Hedstrom have provided excellent manuscript, graphical and data analysis and assistance over a number of years. We have profited over the years from many in-depth discussions with most of the current and past NHC hurricane forecasters.