FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2014

We continue to anticipate a below-average Atlantic hurricane season. While we only expect a weak El Niño to develop this year, conditions in the Atlantic basin appear especially detrimental for hurricane formation. Atlantic Main Development Region sea surface temperatures are cooler than normal, sea level pressures are higher than normal, and vertical wind shear throughout the Atlantic basin has been much stronger than normal. Landfall probabilities for both the United States and Caribbean are below their long-period average values.

(as of 31 July 2014)

By Philip J. Klotzbach[1] and William M. Gray[2]

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

Kate Jeracki, Colorado State University Media Representative, (970-491-2658) is available to answer various questions about this verification.

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2014

Forecast Parameter and 1981-2010 Median (in parentheses)	Issue Date 10 April 2014	Issue Date 2 June 2014	Issue Date 1 July 2014	Observed Activity Through July 2014	Forecast Activity After 31 July	**Total Seasonal Forecast**
Named Storms (NS) (12.0)	9	10	10	1	9	**10**
Named Storm Days (NSD) (60.1)	35	40	40	4	36	**40**
Hurricanes (H) (6.5)	3	4	4	1	3	**4**
Hurricane Days (HD) (21.3)	12	15	15	2	13	**15**
Major Hurricanes (MH) (2.0)	1	1	1	0	1	**1**
Major Hurricane Days (MHD) (3.9)	2	3	3	0	3	**3**
Accumulated Cyclone Energy (ACE) (92)	55	65	65	7	58	**65**
Net Tropical Cyclone Activity (NTC) (103%)	60	70	70	5	65	**70**

POST-31 JULY PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE LANDFALL ON EACH OF THE FOLLOWING UNITED STATES COASTAL AREAS:

1) Entire U.S. coastline - 38% (full-season average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 21% (full-season average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 21% (full-season average for last century is 30%)

POST-31 JULY PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE TRACKING INTO THE CARIBBEAN (10-20°N, 60-88°W)

1) 30% (full-season average for last century is 42%)

POST-31 JULY HURRICANE IMPACT PROBABILITIES FOR 2014 (NUMBERS IN PARENTHESES ARE LONG-PERIOD FULL SEASON AVERAGES)

State	Hurricane	Major Hurricane
Texas	23% (33%)	8% (12%)
Louisiana	21% (30%)	8% (12%)
Mississippi	7% (11%)	3% (4%)
Alabama	10% (16%)	2% (3%)
Florida	37% (51%)	14% (21%)
Georgia	7% (11%)	1% (1%)
South Carolina	12% (17%)	3% (4%)
North Carolina	19% (28%)	5% (8%)
Virginia	4% (6%)	<1% (1%)
Maryland	1% (1%)	<1% (<1%)
Delaware	1% (1%)	<1% (<1%)
New Jersey	1% (1%)	<1% (<1%)
New York	5% (8%)	2% (3%)
Connecticut	5% (7%)	1% (2%)
Rhode Island	4% (6%)	2% (3%)
Massachusetts	5% (7%)	1% (2%)
New Hampshire	1% (1%)	<1% (<1%)
Maine	3% (4%)	<1% (<1%)

POST-31 JULY PROBABILITIES OF HURRICANES AND MAJOR HURRICANES TRACKING WITHIN 100 MILES OF EACH ISLAND OR LANDMASS FOR 2014 (NUMBERS IN PARENTHESES ARE LONG-PERIOD FULL SEASON AVERAGES)

Island/Landmass	Hurricane within 100 Miles	Major Hurricane within 100 Miles
The Bahamas	37% (51%)	21% (30%)
Cuba	38% (52%)	19% (28%)
Haiti	19% (27%)	9% (13%)
Jamaica	17% (25%)	7% (11%)
Mexico (East Coast)	43% (57%)	15% (23%)
Puerto Rico	20% (29%)	9% (13%)
Turks and Caicos	16% (24%)	6% (9%)
US Virgin Islands	21% (30%)	8% (12%)

Please also visit the Landfalling Probability Webpage at http://www.e-transit.org/hurricane for landfall probabilities for 11 U.S. coastal regions and 205 coastal and near-coastal counties from Brownsville, Texas to Eastport, Maine as well as probabilities for every island in the Caribbean. We suggest that all coastal residents visit the Landfall Probability Webpage for their individual location probabilities.

ABSTRACT

Information obtained through July 2014 indicates that the remainder of the 2014 Atlantic hurricane season will be less active than the average 1981-2010 season. We estimate that the remainder of 2014 will have about 3 hurricanes (average is 5.5), 9 named storms (average is 10.5), 36 named storm days (average is 58), 13 hurricane days (average is 21.3), 1 major (Category 3-4-5) hurricane (average is 2.0) and 3 major hurricane days (average is 3.9). The probability of U.S. major hurricane landfall and Caribbean major hurricane activity for the remainder of the 2014 season is estimated to be below its long-period average. We expect the remainder of the Atlantic basin hurricane season to accrue Net Tropical Cyclone (NTC) activity approximately 65 percent of the seasonal average. We have maintained our below-average seasonal forecast, due to anomalous cooling of sea surface temperatures in the tropical and subtropical eastern Atlantic along with high sea level pressures and strong vertical wind shear across the tropical Atlantic.

This forecast was based on a newly-developed extended-range early August statistical prediction scheme developed over the previous 33 years. Analog predictors were also considered.

Warm neutral ENSO conditions are currently present in the tropical Pacific, and we believe that we are likely to experience a weak El Niño during the peak of this year's hurricane season.

Starting today and issued every two weeks following (e.g., July 31, August 14, August 28, etc.), we will issue two-week forecasts for Atlantic TC activity during the peak of the Atlantic hurricane season from August-October. A late-season forecast for the Caribbean basin will be issued on Tuesday, October 1.

Why issue forecasts for seasonal hurricane activity?

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

Everyone should realize that it is impossible to precisely predict this season's hurricane activity in early August. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged as regards to the probability of an active or inactive hurricane season for the coming year. Our new early August statistical forecast methodology shows strong evidence over 33 past years that improvement over climatology can be attained. We utilize this newly-developed model along with an older August statistical models when issuing this year's forecast. **We would never issue a seasonal hurricane forecast unless we had a statistical model constructed over a long hindcast period which showed significant skill over climatology.**

We issue these forecasts to satisfy the curiosity of the general public and to bring attention to the hurricane problem. There is a general interest in knowing what the odds are for an active or inactive season. One must remember that our forecasts are based on the premise that those global oceanic and atmospheric conditions which preceded comparatively active or inactive hurricane seasons in the past provide meaningful information about similar trends in future seasons. This is not always true for individual seasons. It is also important that the reader appreciate that these seasonal forecasts are based on statistical schemes which, owing to their intrinsically probabilistic nature, will fail in some years. Moreover, these forecasts do not specifically predict where within the Atlantic basin these storms will strike. The probability of landfall for any one location along the coast is very low and reflects the fact that, in any one season, most U.S. coastal areas will not feel the effects of a hurricane no matter how active the individual season is.

Acknowledgment

We are grateful for support from Interstate Restoration and Ironshore Insurance that partially support the release of these predictions. The remainder of this year's forecasts are provided by personal funds. 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).

The second author gratefully acknowledges the valuable input to his CSU seasonal forecast research project over many years by former graduate students and now colleagues 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.

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, 10-50°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 tropical cyclones that become major hurricanes form, which we define as 10-20°N, 20-60°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

1 Introduction

This is the 31st year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. This year's August forecast is based on a new statistical methodology derived from 33 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.

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. No one can completely understand the full complexity of the atmosphere-ocean system. But, it is still possible to develop a reliable statistical forecast scheme which incorporates a number of the climate system's non-linear interactions. Any seasonal or climate forecast scheme should show significant hindcast skill before it is used in real-time forecasts.

1.1 2014 Atlantic Basin Activity through July

The 2014 Atlantic basin hurricane season has had approximately average TC activity, based on the ACE index, during June and July.

Arthur formed on July 1 from an area of low pressure off of the east coast of Florida. It developed in a fairly favorable environment of light wind shear and warm sea surface temperatures and intensified into a hurricane on July 3 as it tracked northward. Arthur made landfall along the Outer Banks of North Carolina early on July 4 as a Category 2 hurricane. It began to weaken as it accelerated northward and underwent extratropical transition on July 5. Damage from Arthur was minimal ($14 million dollars according to Wikipedia), and no direct fatalities were attributed to the storm. Arthur was the earliest hurricane on record to impact North Carolina.

Table 1 records observed Atlantic basin TC activity through 31 July, while tracks through 31 July are displayed in Figure 1. All TC activity calculations are based upon data available in the National Hurricane Center's b-decks.

Table 1: Observed 2014 Atlantic basin tropical cyclone activity through July 31.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	MHD	ACE	NTC
H-2	Arthur	July 1 – July 5	85 kt/973 mb	4.00	2.00		6.8	4.5
Totals	1			4.00	2.00		6.8	4.5

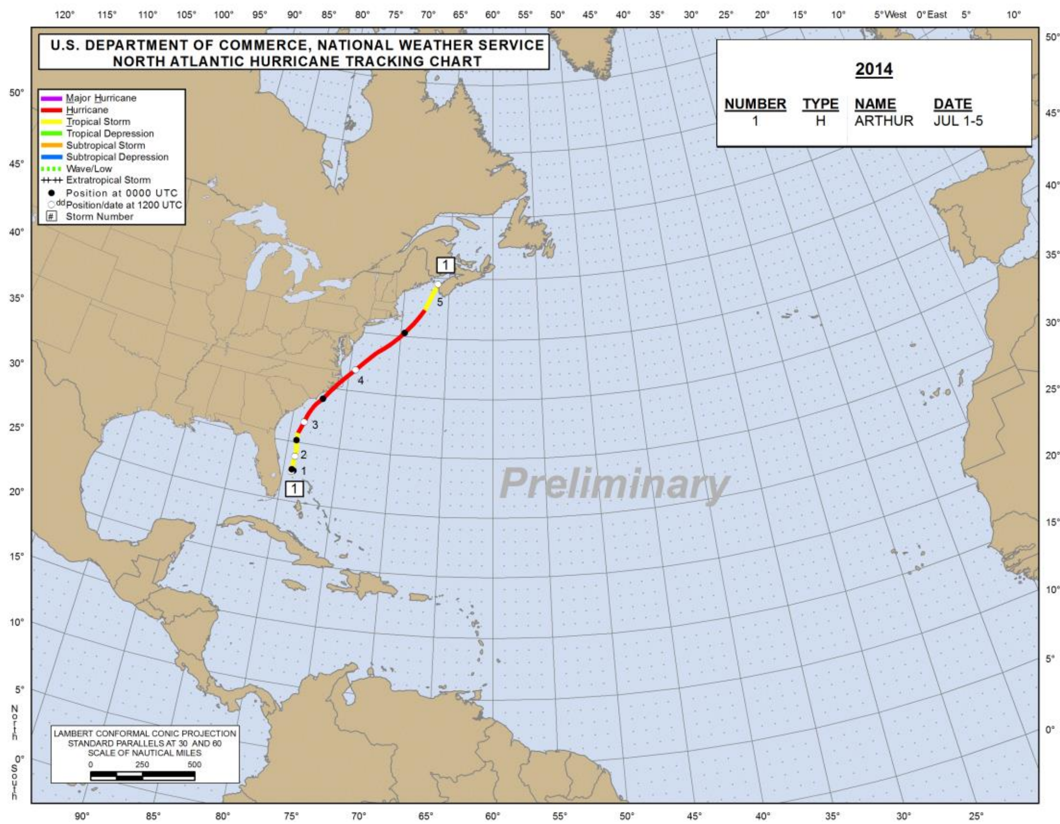

Figure 1: 2014 Atlantic basin hurricane tracks through July. Figure courtesy of the National Hurricane Center (http://www.nhc.noaa.gov). A red lines indicate a TC at hurricane strength, and a yellow lines indicates a TC at named storm strength.

2 Newly-Developed 1 August Forecast Scheme

We developed a new 1 August statistical seasonal forecast scheme for the prediction of Net Tropical Cyclone (NTC) activity two years ago. This model uses a total of three predictors, all of which are selected from the ERA-Interim Reanalysis dataset, which is available from 1979-present. The major components of the forecast scheme are discussed in the next few paragraphs.

The pool of three predictors for this new early August statistical forecast scheme is given and defined in Table 2. The location of each of these predictors is shown in Figure 2. Skillful forecasts can be issued for post-31 July NTC based upon hindcast results over the period from 1979-2011 as well as a real-time forecast in 2012. Like all of our forecasts, the model did not anticipate the below-average 2013 Atlantic hurricane season. When these three predictors are combined, they correlate at 0.88 with observed NTC using a drop-one cross validation approach over the period from 1979-2013 (Figure 3).

Table 2: Listing of 1 August 2014 predictors for this year's hurricane activity using the new statistical model. A plus (+) means that positive deviations of the parameter indicate increased hurricane activity this year, and a minus (-) means that positive deviations of the parameter indicate decreased hurricane activity this year. All three predictors are calling for a below-average hurricane season.

Predictor	Values for 2014 Forecast	Effect on 2014 Hurricane Season
1) July Surface U (10-17.5°N, 60-85°W) (+)	-1.0 SD	Suppress
2) July Surface Temperature (20-40°N, 15-35°W) (+)	-0.1 SD	Slightly Suppress
3) July 200 mb U (5-15°N, 0-40°E) (-)	+1.0 SD	Suppress

Post-31 July Seasonal Forecast Predictors

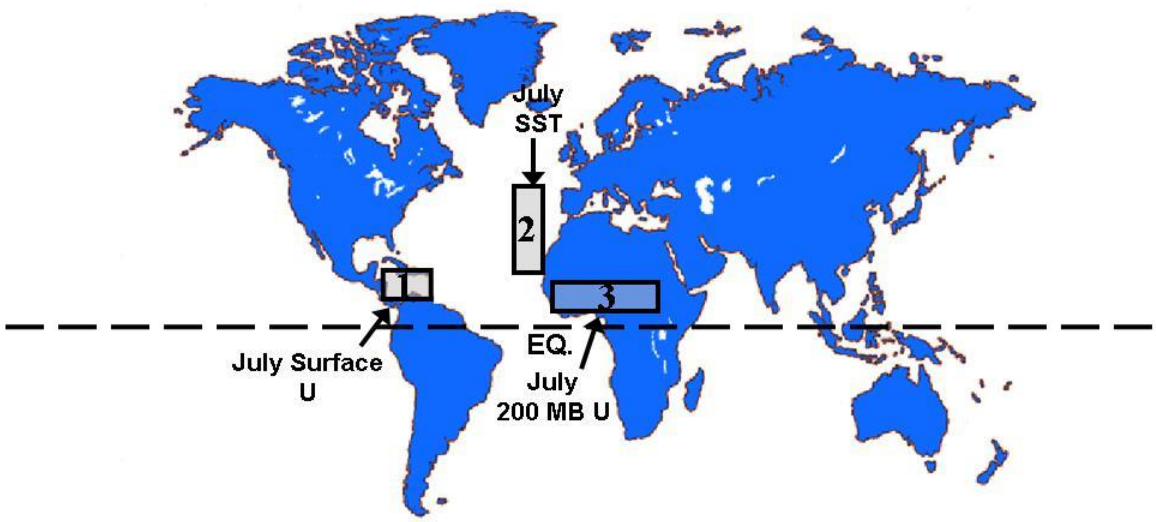

Figure 2: Location of predictors for the post-31 July forecast for the 2014 hurricane season from the new statistical model.

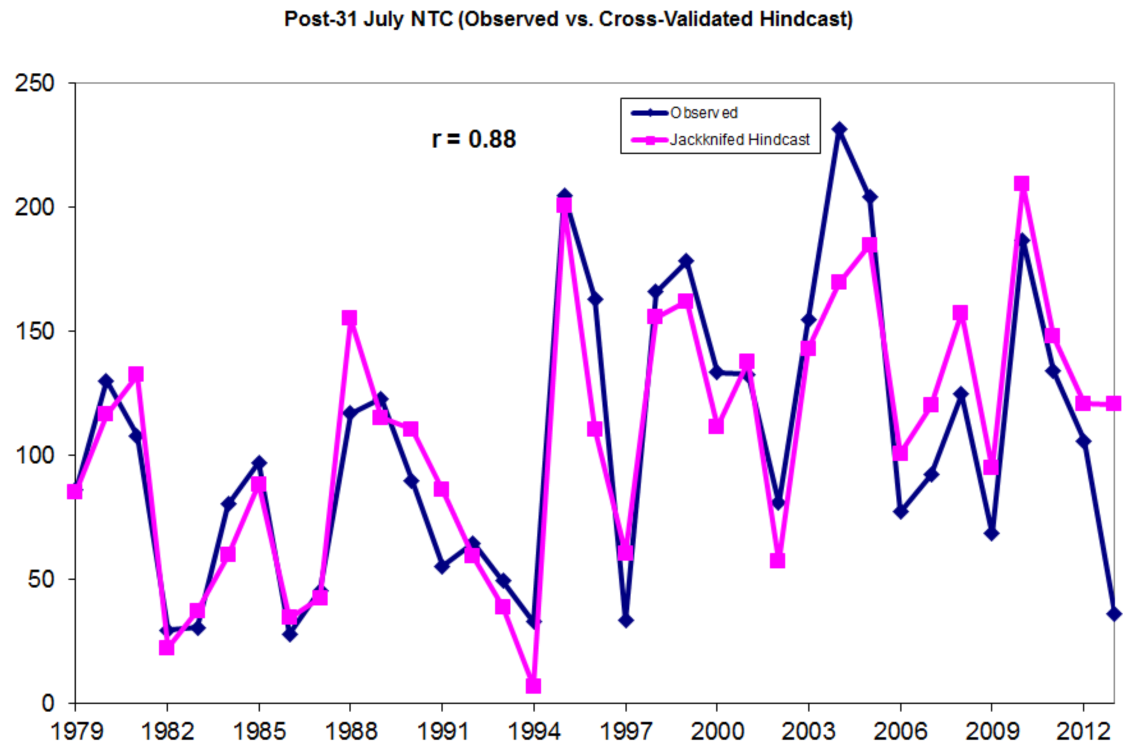

Figure 3: Observed versus hindcast values of post-31 July NTC for 1979-2013 using the new statistical scheme.

Table 3 shows our statistical forecast for the 2014 hurricane season from the new statistical model and the comparison of this forecast with the 1981-2010 median. Our statistical forecast is calling for a quiet remainder of the hurricane season.

Table 3: Post-31 July statistical forecast for 2014 from the new statistical model.

Predictands and Climatology (1981-2010 Post-31 July Median)	Statistical Forecast
Named Storms (NS) – 10.5	7.8
Named Storm Days (NSD) – 58.0	31.1
Hurricanes (H) – 5.5	3.9
Hurricane Days (HD) – 21.3	10.9
Major Hurricanes (MH) – 2.0	0.9
Major Hurricane Days (MHD) – 3.8	1.1
Accumulated Cyclone Energy Index (ACE) – 86	44
Net Tropical Cyclone Activity (NTC) – 95	52

Table 4 displays our early August cross-validated hindcasts for 1979-2011 along with the real-time forecasts in 2012-2013 using the new statistical scheme. Our early August model has correctly predicted above- or below-average post-31 July NTC in 30 out of 35 years (86%). These hindcasts have had a smaller error than climatology in 24 out of 35 years (69%). Our average hindcast errors have been 19 NTC units, compared with 46 NTC units had we used only climatology.

Table 4: Observed versus hindcast post-31 July NTC for 1979-2013 using the new statistical scheme. Average errors for hindcast NTC and climatological NTC predictions are given without respect to sign. Red bold-faced years in the "Hindcast NTC" column are years that we did not go the right way, while red bold-faced years in the "Hindcast improvement over Climatology" column are years that we did not beat climatology. **The hindcast went the right way with regards to an above- or below-average season in 30 out of 35 years (86%), while hindcast improvement over climatology occurred in 24 out of 35 years (69%).**

Year	Observed NTC	Hindcast NTC	Observed minus Hindcast	Observed minus Climatology	Hindcast improvement over Climatology
1979	86	85	1	-9	8
1980	130	117	14	35	22
1981	108	132	-24	13	**-11**
1982	30	22	7	-65	58
1983	31	38	-7	-64	57
1984	80	60	21	-15	**-6**
1985	97	**88**	9	2	**-7**
1986	28	35	-7	-67	60
1987	46	43	3	-49	46
1988	117	155	-38	22	**-16**
1989	123	115	8	28	20
1990	90	**111**	-21	-5	**-16**
1991	55	86	-31	-40	9
1992	65	59	5	-30	25
1993	50	39	11	-45	35
1994	33	7	26	-62	36
1995	205	201	4	110	106
1996	163	111	53	68	16
1997	33	61	-27	-62	34
1998	166	156	10	71	61
1999	178	162	16	83	67
2000	134	112	22	39	17
2001	133	138	-5	38	33
2002	81	57	24	-14	**-10**
2003	155	143	12	60	48
2004	232	170	62	137	75
2005	204	185	19	109	90
2006	77	**101**	-23	-18	**-6**
2007	92	**120**	-28	-3	**-25**
2008	125	158	-33	30	**-3**
2009	69	95	-26	-26	0
2010	187	209	-22	92	69
2011	134	148	-14	39	25
2012	106	121	-15	11	**-4**
2013	36	121	-85	-59	**-26**
Average	**105**	**108**	**|19|**	**|46|**	**+27***

* This shows that we obtain a net (27/46) or 59 percent improvement over the year-to-year variance from climatology.

2.2 Physical Associations among Predictors Listed in Table 2

The locations and brief descriptions of the three predictors for our new August statistical forecast are now discussed. It should be noted that all forecast parameters correlate significantly with physical features during August through October that are known to be favorable for elevated levels of TC activity. For each of these predictors, we display a four-panel figure showing linear correlations between values of each predictor and August-October values of SST, sea level pressure (SLP), 850 mb (~1.5 km altitude) zonal wind (U), and 200 mb (~12 km altitude) zonal wind (U), respectively.

Predictor 1. July Surface U in the Caribbean (+)

(10-17.5°N, 60-85°W)

Low-level trade wind flow has been utilized as a predictor in seasonal forecasting systems for the Atlantic basin (Lea and Saunders 2004). When the trades are weaker-than-normal, SSTs across the tropical Atlantic tend to be elevated, and consequently a larger-than-normal Atlantic Warm Pool (AWP) is typically observed (Wang and Lee 2007) (Figure 4). A larger AWP also correlates with reduced vertical shear across the tropical Atlantic. Weaker trade winds are typically associated with higher pressure in the tropical eastern Pacific (a La Niña signal) and lower pressure in the Caribbean and tropical Atlantic. Both of these conditions generally occur when active hurricane seasons are observed. Predictor 1 also has a strong negative correlation with August-October-averaged 200-850-mb zonal shear.

Predictor 2. July Surface Temperature in the Northeastern Subtropical Atlantic (+)

(20°-40°N, 15-35°W)

A similar predictor was utilized in earlier August seasonal forecast models (Klotzbach 2007, Klotzbach 2011). Anomalously warm SSTs in the subtropical North Atlantic are associated with a positive phase of the Atlantic Meridional Mode (AMM), a northward-shifted Intertropical Convergence Zone, and consequently, reduced trade wind strength (Kossin and Vimont 2007). Weaker trade winds are associated with less surface evaporative cooling and less mixing and upwelling. This results in warmer tropical Atlantic SSTs during the August-October period (Figure 5).

Predictor 3. July 200 mb U over Northern Tropical Africa (-)

(5-15°N, 0-40°E)

Anomalous easterly flow at upper levels over northern tropical Africa provides an environment that is more favorable for easterly wave development into TCs. This anomalous easterly flow tends to persist through August-October, which reduces shear over the Main Development Region (MDR). This predictor also correlates with SLP and SST anomalies over the tropical eastern Pacific that are typically associated with cool ENSO conditions (Figure 6).

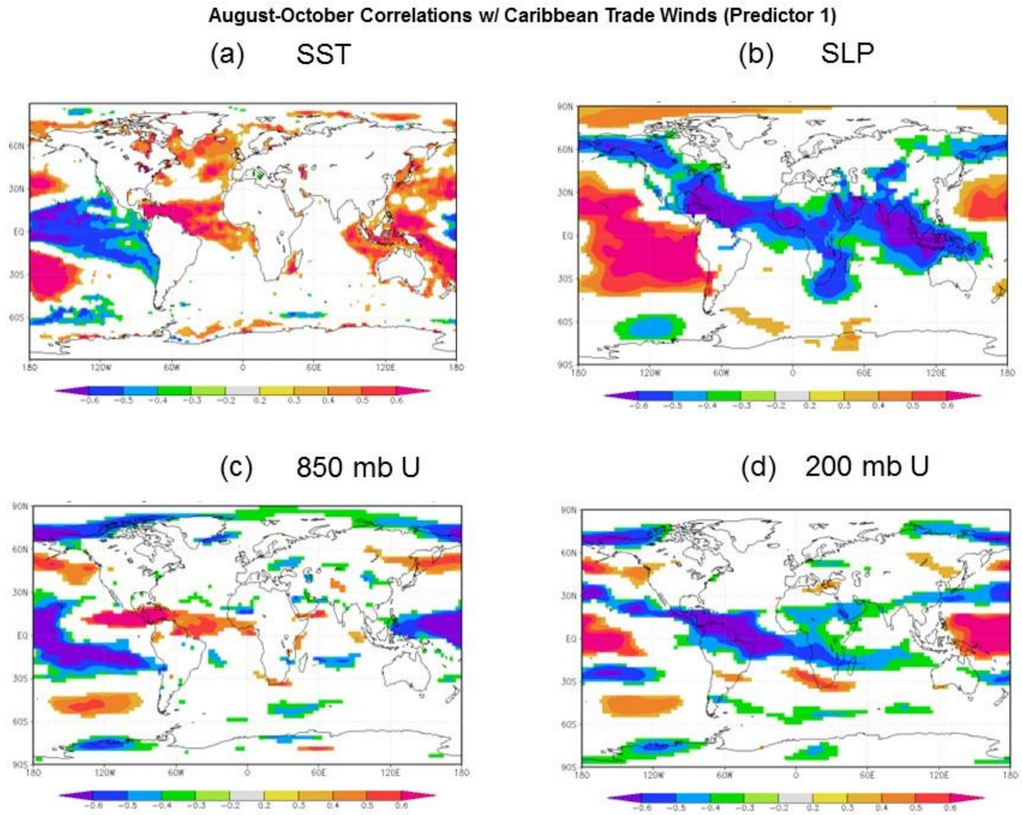

Figure 4: Linear correlations between July Surface U in the Caribbean (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d) over the period from 1979-2011.

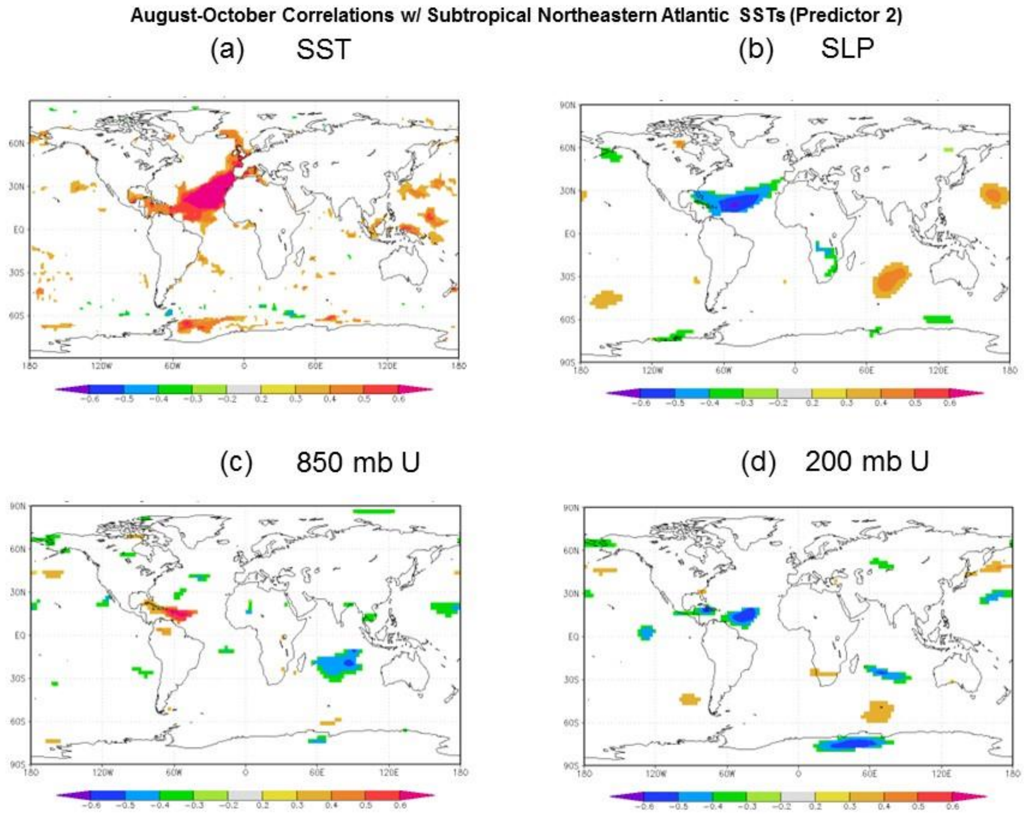

Figure 5: Linear correlations between July Surface Temperature in the Subtropical Northeastern Atlantic (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d) over the period from 1979-2011.

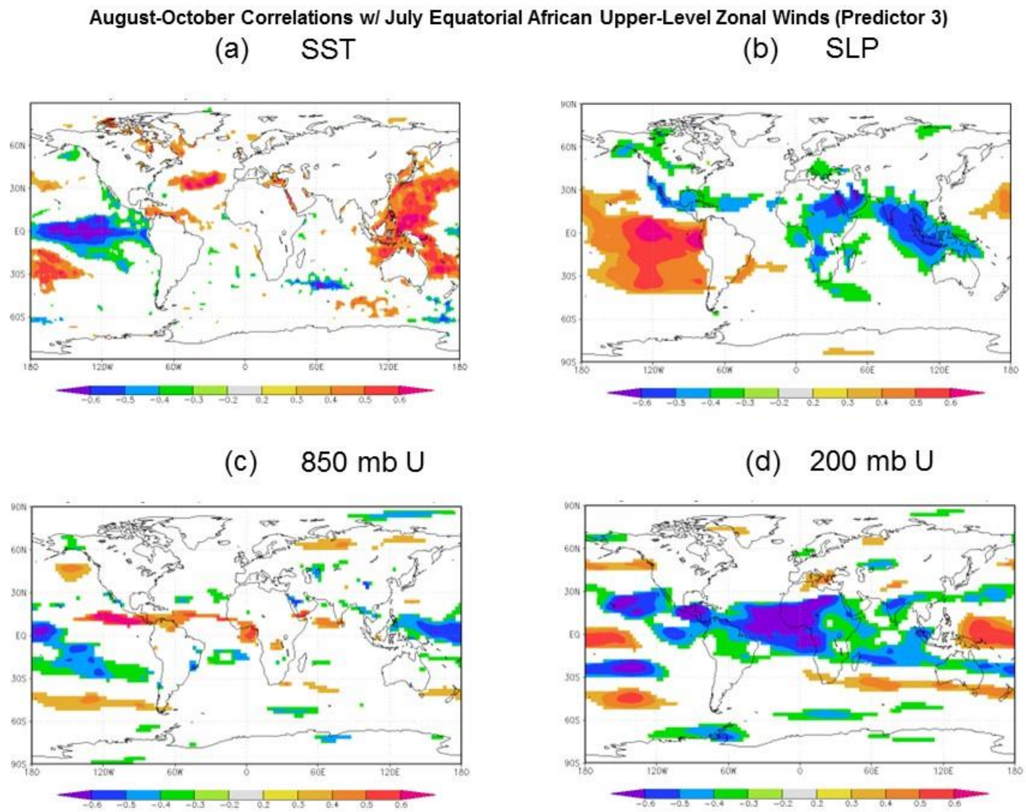

Figure 6: Linear correlations between July 200 MB Zonal Wind over tropical north Africa (Predictor 3) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d) over the period from 1979-2011. The color scale has been reversed so that the correlations match up with those in Figures 4 and 5.

3 Forecast Uncertainty

One of the questions that we are asked regarding our seasonal hurricane predictions is the degree of uncertainty that is involved. Obviously, our predictions are our best estimate, but there is with all forecasts an uncertainty as to how well they will verify.

Table 5 provides our post-31 July forecast, with error bars (based on one standard deviation of absolute errors) as calculated from hindcasts/forecasts of the Klotzbach (2007) scheme over the 1990-2009 period, using equations developed over the 1950-1989 period. We typically expect to see 2/3 of our forecasts verify within one standard deviation of observed values, with 95% of forecasts verifying within two standard deviations of observed values.

Table 5: Model hindcast error and our post-31 July 2014 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	Post-31 July 2014 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	2.3	9	6.7 - 11.3
Named Storm Days (NSD)	17.4	36	18.6 - 53.4
Hurricanes (H)	1.6	3	1.4 - 4.6
Hurricane Days (HD)	8.6	13	4.4 - 21.6
Major Hurricanes (MH)	0.9	1	0.1 - 1.9
Major Hurricane Days (MHD)	3.5	3	0 – 6.5
Accumulated Cyclone Energy (ACE)	36	58	22 – 94
Net Tropical Cyclone (NTC) Activity	34	65	29 - 99

4 Analog-Based Predictors for 2014 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2014. These years also provide useful clues as to likely trends in activity that the 2014 hurricane season may bring. For this early August forecast we determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current June-July 2014 conditions. Table 6 lists the best analog selections from our historical database.

We select prior hurricane seasons since 1950 which have similar atmospheric-oceanic conditions to those currently being experienced. We searched for years that had weak to moderate El Niño conditions along with generally TC-unfavorable tropical Atlantic conditions.

There were five hurricane seasons with characteristics most similar to what we observed in June-July 2014. The best analog years that we could find for the 2014 hurricane season were 1957, 1986, 1993, 2002, and 2009. We anticipate that 2014 seasonal hurricane activity will have activity that is in line with the average of these five analog years. We believe that the remainder of 2014 will have below-average activity in the Atlantic basin.

Table 6: Best analog years for 2014 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1957	8	38.00	3	21.00	2	6.50	84	86
1986	6	23.25	4	10.50	0	0.00	36	37
1993	8	30.00	4	9.50	1	0.75	39	52
2002	12	57.00	4	10.75	2	3.00	67	83
2009	9	30.00	3	12.00	2	3.50	53	69
Mean (Full Season)	**8.6**	**35.7**	**3.6**	**12.8**	**1.4**	**2.8**	**56**	**65**
2014 Forecast (Full Season)	**10**	**40**	**4**	**15**	**1**	**3**	**65**	**70**
1981-2010 Median (Full Season)	**12.0**	**60.1**	**6.5**	**21.3**	**2.0**	**3.9**	**92**	**103**

5 ENSO

Warm neutral ENSO conditions currently persist across the tropical Pacific. SST anomalies are generally slightly above-average across the central tropical Pacific and are much warmer than normal in the eastern tropical Pacific. Table 7 displays July and May SST anomalies for several Nino regions. The eastern tropical Pacific has warmed slightly, while the central Pacific has cooled somewhat since late May.

Table 7: May and July 2014 SST anomalies for Nino 1+2, Nino 3, Nino 3.4, and Nino 4, respectively. July-May SST anomaly differences are also provided.

Region	May SST Anomaly (°C)	July SST Anomaly (°C)	July minus May SST Change (°C)
Nino 1+2	+1.3	+1.4	+0.1
Nino 3	+0.6	+0.7	+0.1
Nino 3.4	+0.5	+0.2	-0.3
Nino 4	+0.8	+0.3	-0.5

It appears that weak El Niño conditions are the most likely scenario for the peak of this year's hurricane season. Earlier, we had anticipated a moderate to strong El Niño event, due to the rapid upper ocean heat content buildup during the spring months (Figure 7). However, over the past few weeks, due to an increase in strength of trade winds and absence of westerly wind bursts (Figure 8), upper ocean heat content has decreased.

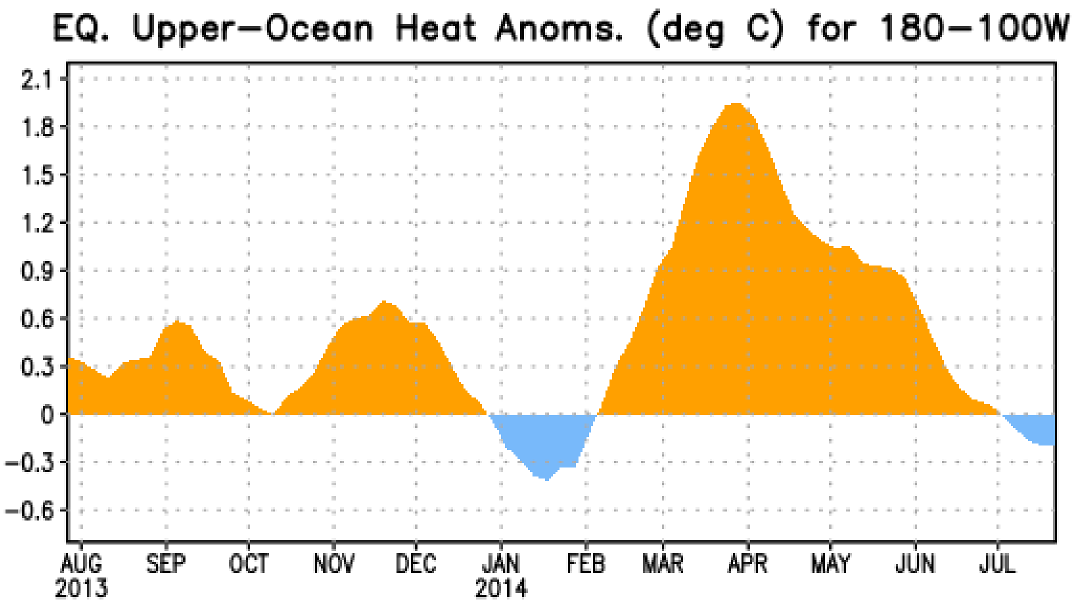

Figure 7: Upper-ocean (0-300 meters depth) heat content anomalies in the eastern and central Pacific since August 2013. Upper ocean heat content increased rapidly through March of 2014 and has recently decreased to near-average levels.

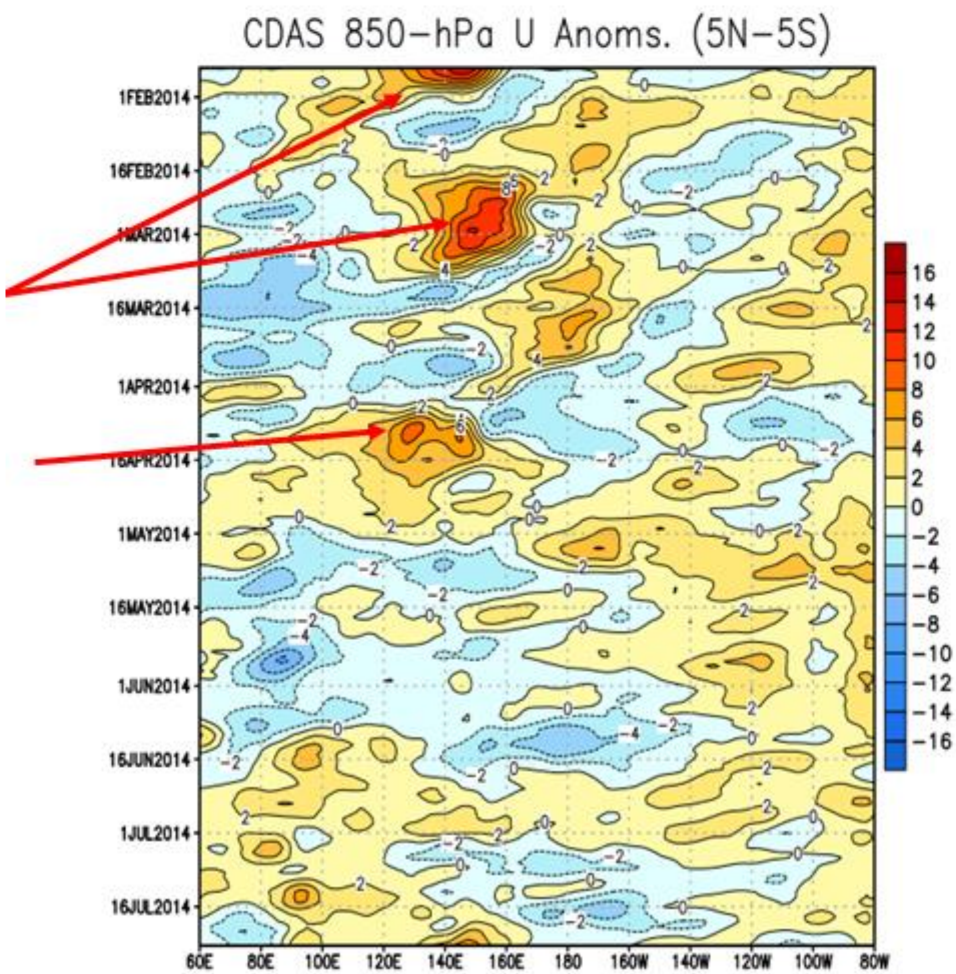

Figure 8: Anomalous 850-mb winds across the tropical Indian and Pacific Oceans from 60°E-80°W. The red lines delineate westerly wind bursts that were experienced during the late winter/early spring of 2014. Note the absence of strong westerly flow near the International Date Line in the past couple of months.

Most dynamical models are calling for weak El Niño conditions for the peak of the Atlantic hurricane season from August-October, while most statistical models are calling for the continuation of warm neutral ENSO conditions. Figure 9 displays the current forecasts issued by various ENSO models.

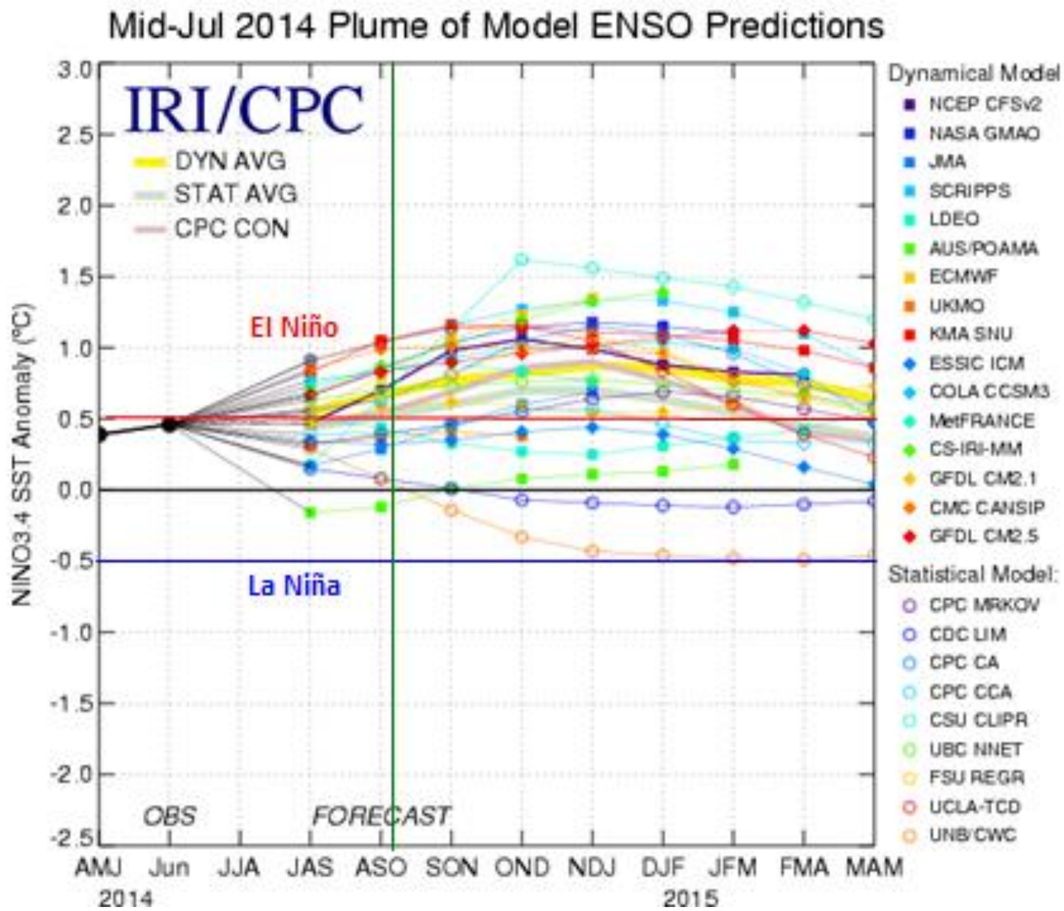

Figure 9: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

As was found with the early June prediction, the European Centre for Medium-Range Weather Forecasts (ECMWF) typically shows the best prediction skill of the various ENSO models. The correlation skill between a 1 July forecast from the ECMWF model and the observed September Nino 3.4 anomaly is 0.89, based on hindcasts/forecasts from 1982-2010, explaining approximately 79% of the variance in Nino 3.4 SST. For reference, the correlation skill of a 1 May forecast from the ECMWF model was 0.82, indicating that approximately 15% additional variance can be explained by shortening the lead time of the forecast from 1 May to 1 July. The ECMWF model has recently been upgraded to system 4, indicating that improved ENSO skill may be possible. The average of the various ECMWF ensemble members is calling for a September Nino 3.4 SST anomaly of approximately 0.8°C (Figure 10).

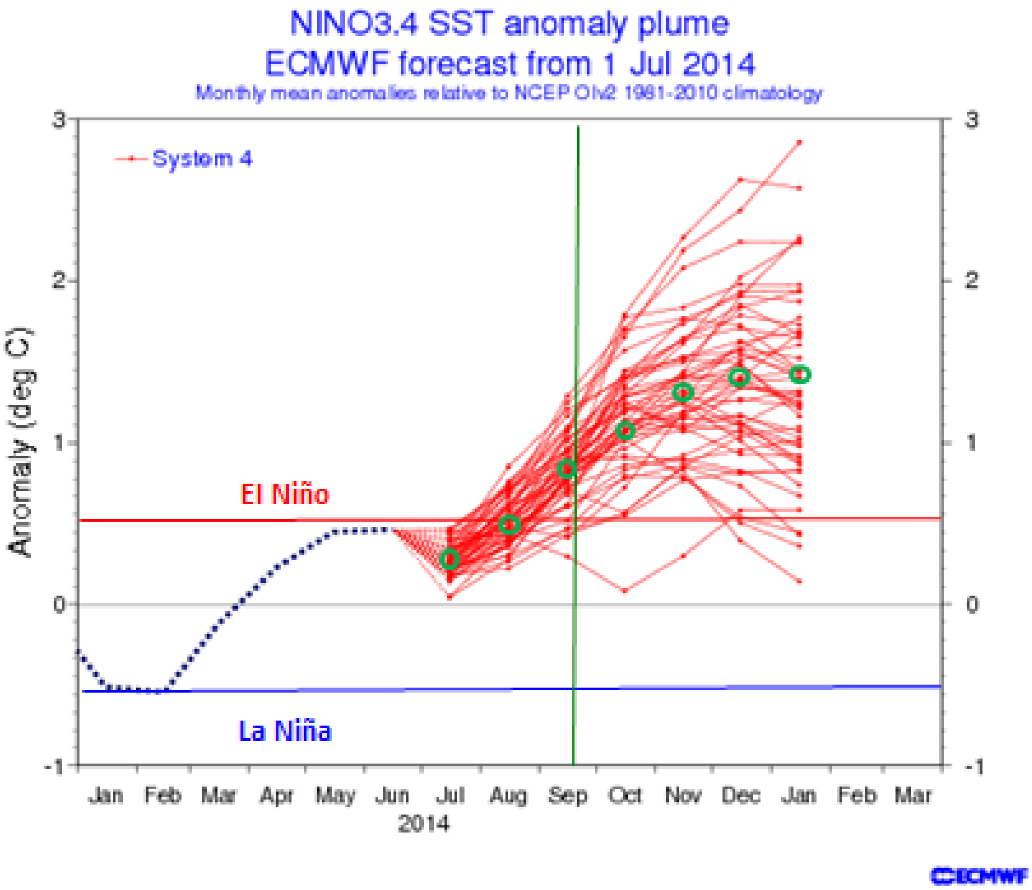

Figure 10: ECMWF ensemble model forecast for the Nino 3.4 region. Most members call for El Niño conditions throughout the August-October period. The green dots represent the approximate average of the ensemble members.

Based on this information, our best estimate is that we will likely have weak El Niño conditions during the August-October period.

6 Current Atlantic Basin Conditions

Conditions in the tropical Atlantic are quite unfavorable at the present time. Figure 11 displays Atlantic basin SST anomalies during the month of July. The Main Development Region (10-20°N, 60-20°W) (MDR) is approximately 0.5°C cooler than normal. SSTs in the MDR are the coldest that they have been during July since 2002 (another relatively quiet Atlantic hurricane season).

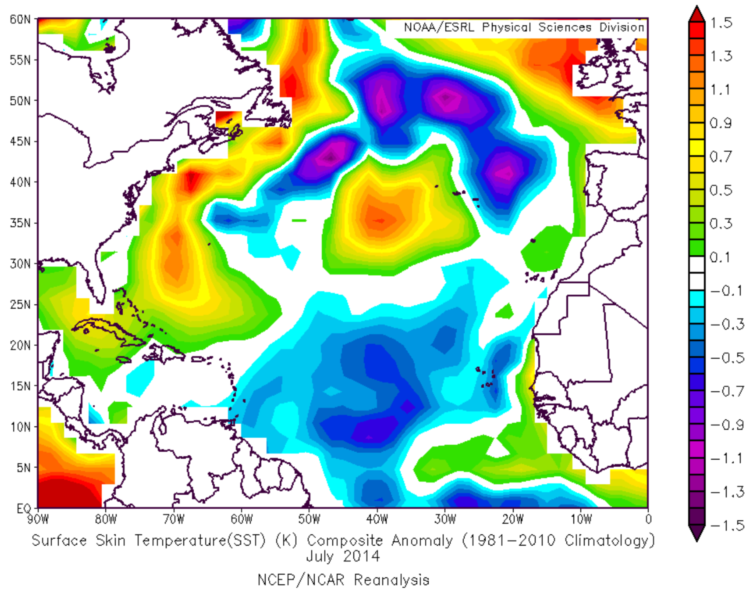

Figure 11: July 2014 SST anomalies. Note the anomalously cool conditions across the tropical eastern and central Atlantic.

Sea level pressure anomalies over the past month have been quite high, implying that the trade winds across the Main Development Region are strong and the Tropical Upper Tropospheric Trough (TUTT) is enhanced (Figure 12). A strong TUTT typically relates to increased vertical wind shear across the tropical Atlantic and Caribbean (Knaff 1997). Sea level pressure anomalies in July 2014 were higher than they have been in any July since 1986.

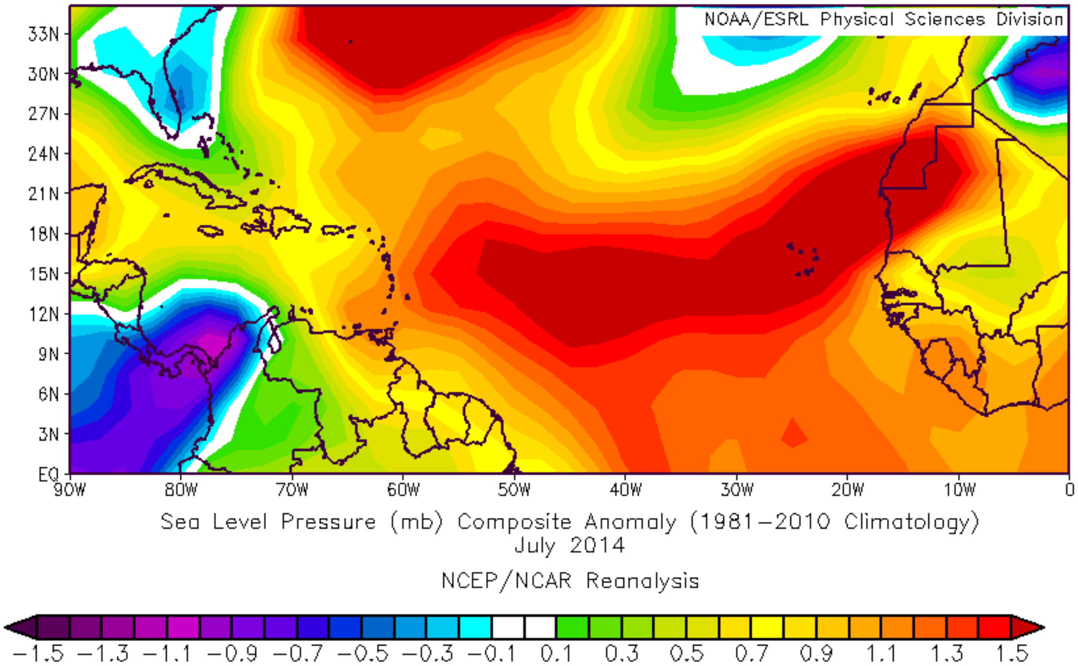

Figure 12: July 2014 Atlantic SLP anomaly. Strongly positive anomalies have predominated across the tropical Atlantic and most of the Caribbean throughout the month.

Vertical wind shear has also been much stronger than normal over the past few weeks. Shear has been strong in the central tropical Atlantic, and even more so across the Caribbean. Vertical shear in July 2014 is close to the strongest ever observed in the Caribbean (records date back to 1948). Figure 13 displays 200-850 mb zonal shear anomalies across the tropical Atlantic and Caribbean.

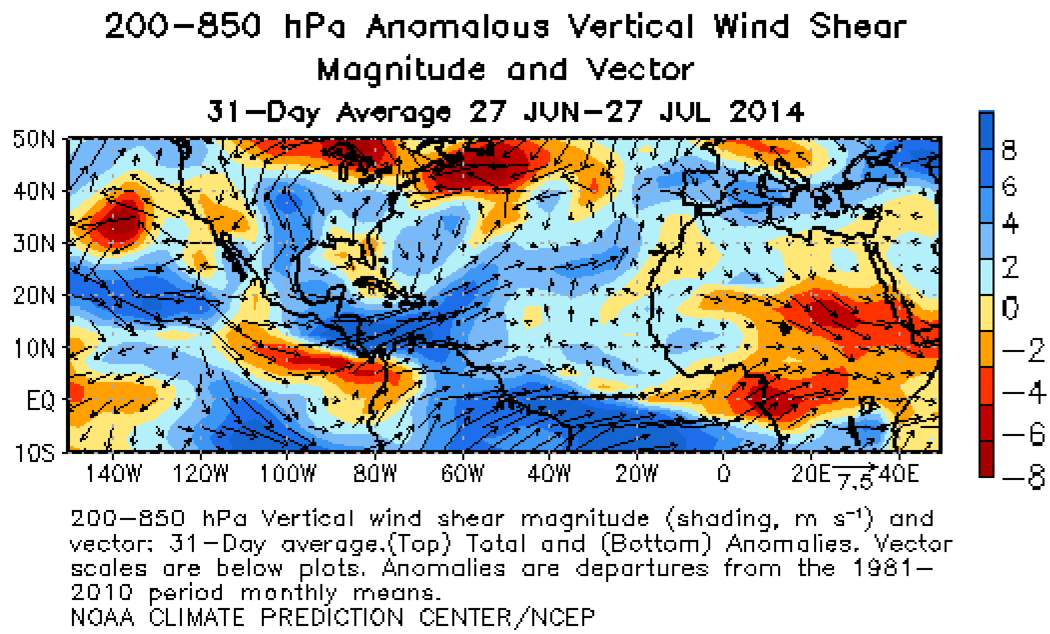

Figure 13: Late June – late July-averaged 2014 200-850-mb zonal wind anomalies across the tropical Atlantic. Note the strongly positive anomalous shear (as evidenced by the dark blue colors) across the Caribbean.

As was the case last year, the tropical Atlantic is much drier than normal this year. While there are issues with the NCEP/NCAR Reanalysis mid-level moisture estimates, it is likely that July 2014 is one of the driest Julys on record. The NCEP/NCAR Reanalysis reports that MDR 600-mb relative humidity in July 2014 is the driest on record by a large margin (Figure 14).

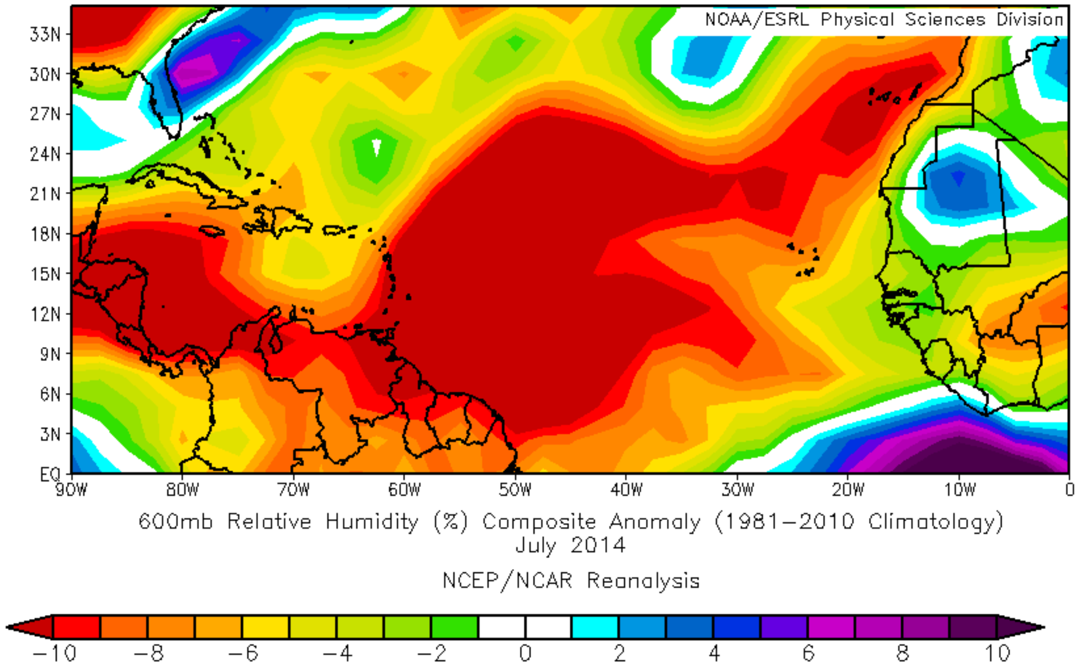

Figure 14: July 2014 600-mb relative humidity anomalies across the tropical Atlantic. Very dry conditions have been observed across the entire region.

According to AOML's Jason Dunion (personal communication), African dust outbreaks have been quite strong this year as well. The Cooperative Research Institute for the Atmosphere (CIRA) monitors real-time conditions for genesis in the tropical Atlantic, and according to their analysis, vertical instability is significantly below normal this year (Figure 15). Positive deviations from the curve displayed below indicate a more unstable atmosphere than normal. In general, the atmosphere has been much more stable than normal since the start of the hurricane season.

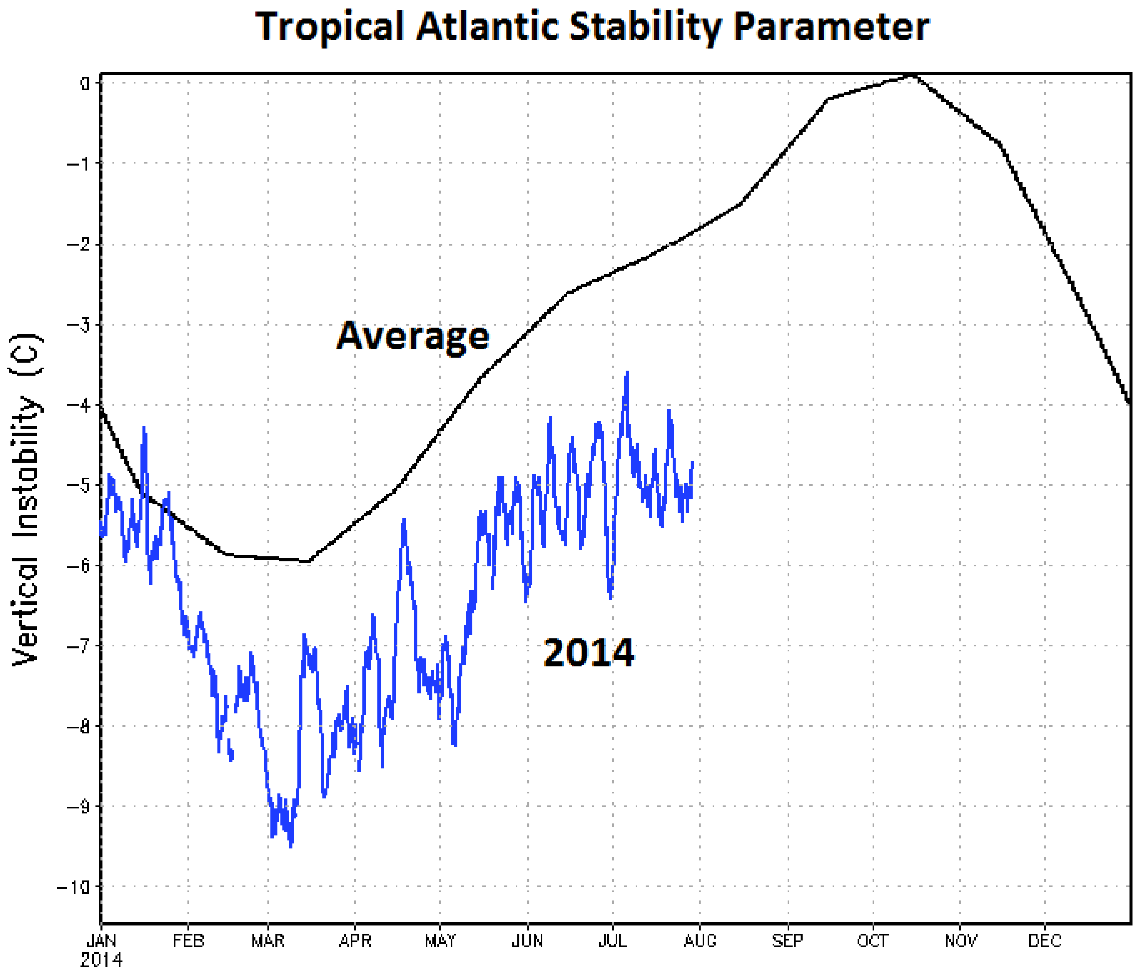

Figure 15: Vertical instability across the tropical Atlantic since January 2014 (blue line). The average season is represented by the black line.

Table 8 summarizes conditions across both the MDR and Caribbean (10-20°N, 90-60°W) for July 2014 in standardized anomaly form from the 1981-2010 average. Several parameters are displayed in the table (including SST, SLP, 850-mb zonal wind, 200-mb zonal wind, 200-850-mb zonal wind shear and 600-mb relative humidity). Note that most parameter deviations in July 2014 are considered unfavorable for hurricane formation/intensification.

Table 8: Standardized anomalies for various large-scale parameters across the MDR and Caribbean for July 2014. The sign of the parameter typically associated with active Atlantic hurricane seasons is indicated in the parameter column. Note that almost all parameters are of a sign to suppress hurricane activity this year. Standardized anomalies are calculated based on the 1981-2010 base period.

Parameter	July 2014 MDR	July 2014 Caribbean
SST (+)	-0.8	+0.2
SLP (-)	+2.3	+0.9
850-mb U (+)	+0.4	-0.2
200-mb U (-)	+0.6	+2.3
200-850-mb U (-)	+0.4	+1.8
600-mb RH (+)	-4.0	-1.7

7 West Africa Conditions

Enhanced rainfall in the Sahel region of West Africa during the June-July time period has been associated with active hurricane seasons (Landsea and Gray 1992). Figure 16 displays a combined satellite/rain gauge estimate, referred to as the African Rainfall Estimation Algorithm Version 2 (RFE 2.0) of percent of normal rainfall over the June-July 2014 time period. In general, it appears that rainfall in the Western Sahel has been near normal during June-July.

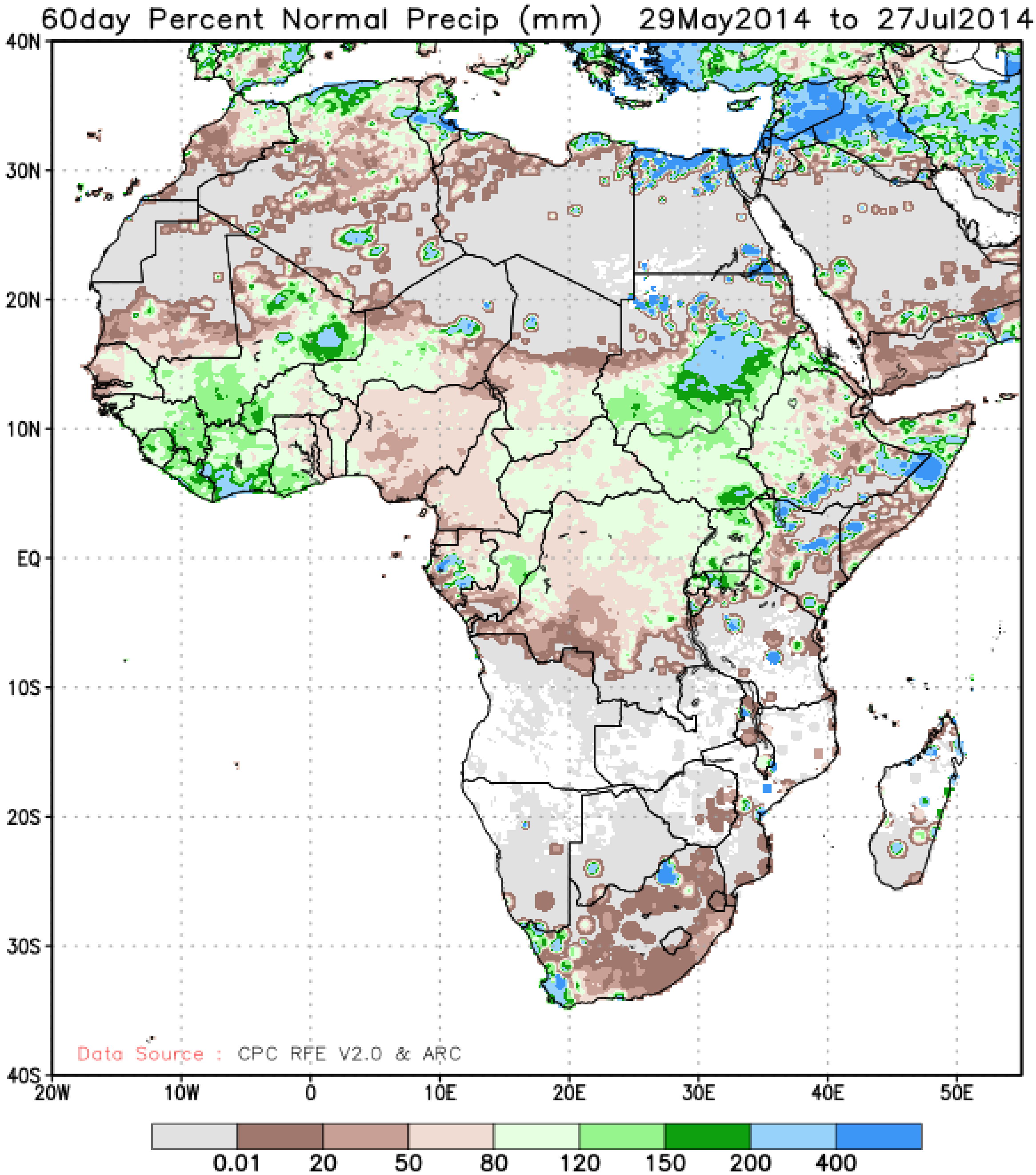

Figure 16: Rainfall Estimation Algorithm Version 2.0 (RFE) estimate of percent of normal rainfall for late May – late July 2014.

8 Atlantic Thermohaline Circulation (THC) Conditions

One of the primary reasons why we believe the 2013 Atlantic hurricane season was so quiet was due to a very strong weakening of the THC/AMO during the spring months of last year. We have created a new index to assess the strength of the THC that is defined as a combination of SST in the region from 20-70°N, 40-10°W and SLP in the region from 15-50°N, 60-10°W (Figure 17). The index is created by weighing the two parameters as follows: 0.6*SST – 0.4*SLP. The index has been much more stable this year and is currently running slightly below average (Figure 18). We do not see any major changes at this point to the THC that would cause us to significantly adjust our forecast.

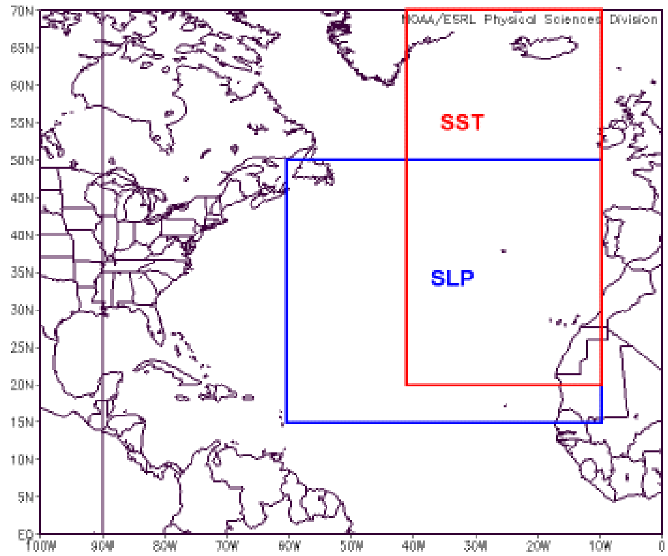

Figure 17: Regions which are utilized for calculation of the new THC/AMO index.

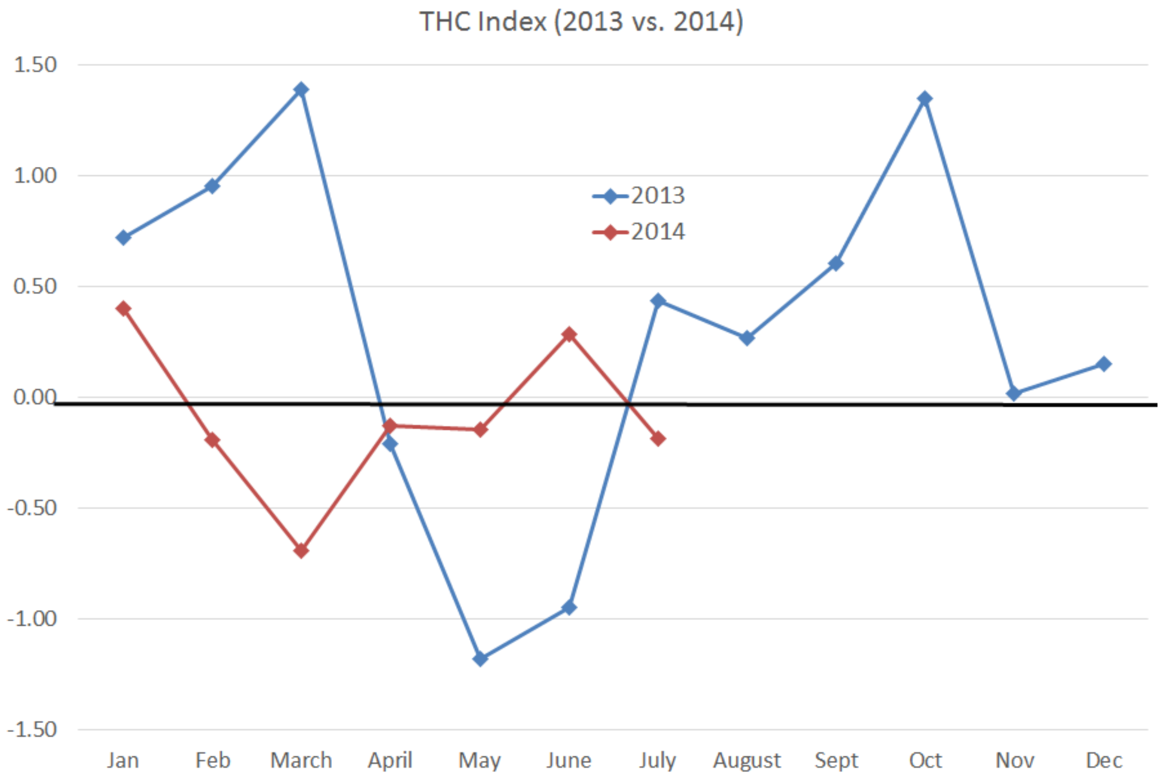

Figure 18: Standardized values of the THC/AMO index by month in 2013 (blue line) and 2014 (red line). Month-to-month changes have been much less in 2014 than they were in 2013.

9 Adjusted 2014 Forecast

Table 9 shows our final adjusted early August forecast for the 2014 season which is a combination of our statistical scheme (with June-July activity added in), our analog forecast and qualitative adjustments for other factors not explicitly contained in any of these schemes. Our statistical forecast, analog forecast and final qualitative outlook are in good agreement that the remainder of the 2014 Atlantic hurricane season should be very quiet.

Table 9: June-July 2014 observed activity, our August full season statistical forecast (with June-July 2014 activity added in), our analog forecast and our adjusted final forecast for the 2014 hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	June-July 2014 Observed Activity	Statistical Scheme	Analog Scheme	Adjusted Final Forecast (Whole Season)
Named Storms (12.0)	1	8.8	8.6	**10**
Named Storm Days (60.1)	4	35.1	35.7	**40**
Hurricanes (6.5)	1	4.9	3.6	**4**
Hurricane Days (21.3)	2	12.9	12.8	**15**
Major Hurricanes (2.0)	0	0.9	1.4	**1**
Major Hurricane Days (3.9)	0	1.1	2.8	**3**
Accumulated Cyclone Energy Index (92)	7	51	56	**65**
Net Tropical Cyclone Activity (103%)	5	57	65	**70**

10 Landfall Probabilities for 2014

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. Whereas individual hurricane landfall events cannot be forecast months in advance, the total seasonal probability of landfall can be forecast with statistical skill. With the observation that landfall is a function of varying climate conditions, a probability specification has been developed through statistical analyses of all U.S. hurricane and named storm landfall events during the 20th century (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 shown linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 10). NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, each expressed as a percentage difference from the long-term average. Long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season is, the greater the probability of U.S. hurricane landfall.

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

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

Table 11 lists strike probabilities for the 2014 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. Note that Atlantic basin post-1 August NTC activity in 2014 is expected to be below its long-term average, and therefore, landfall probabilities are below their long-term average.

Table 11: Estimated 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) for the remainder of the 2014 Atlantic hurricane season. Probabilities of a tropical storm, hurricane and major hurricane tracking into the Caribbean are also provided. The long-term mean annual probability of one or more landfalling systems during the last 100 years is given in parentheses.

Region	TS	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	Named Storms
Entire U.S. (Regions 1-11)	64% (79%)	52% (68%)	38% (52%)	70% (84%)	89% (97%)
Gulf Coast (Regions 1-4)	44% (59%)	30% (42%)	21% (30%)	45% (60%)	69% (83%)
Florida plus East Coast (Regions 5-11)	37% (50%)	31% (44%)	21% (31%)	46% (61%)	66% (81%)
Caribbean (10-20°N, 60-88°W)	67% (82%)	42% (57%)	30% (42%)	59% (75%)	87% (96%)

Please also visit the Landfalling Probability Webpage at http://www.e-transit.org/hurricane for landfall probabilities for 11 U.S. coastal regions and 205 coastal and near-coastal counties from Brownsville, Texas to Eastport, Maine as well as probabilities for every island in the Caribbean. We suggest that all coastal residents visit the Landfall Probability Webpage for their individual location probabilities.

11 Summary

An analysis of a variety of different atmosphere and ocean measurements (through July) which are known to have long-period statistical relationships with the upcoming season's Atlantic tropical cyclone activity indicate that 2014 should be a quiet season. Weak El Niño conditions are likely to combine with unfavorable SST, SLP, mid-level moisture and vertical shear conditions in the tropical Atlantic to significantly reduce activity in 2014 compared with climatology.

12 Can Rising Levels of CO_2 be Associated with the Devastation caused by Hurricane Sandy (2012) along with the Increase in Atlantic Hurricane Activity since 1995?

We have extensively discussed this topic in many previous papers which can be found on our Tropical Meteorology website. For more information on this topic we refer you to the following five references, which can be accessed by clicking on the links below:

Gray, W. M., 2011: Gross errors in the IPCC-AR4 report regarding past and future changes in global tropical cyclone activity. Science and Public Policy Institute, 122 pp.

Gray, W. M., and P. J. Klotzbach, 2011: Have increases in CO_2 contributed to the recent large upswing in Atlantic basin major hurricanes since 1995? Chapter 9 in "Evidence-Based Climate Science", D. Easterbrook, Ed., Elsevier Press, 27 pp.

Gray, W. M., and P. J. Klotzbach, 2012: US Hurricane Damage - Can Rising Levels of CO_2 be Associated with Sandy's Massive Destruction? *Colorado State University Publication*, 23 pp.

W. M. Gray, and P. J. Klotzbach, 2013: Tropical cyclone forecasting. **National Hurricane Conference,** *New Orleans, Louisiana*, March 28, 2013.

W. M. Gray, and P. J. Klotzbach, 2013: Wind destruction from hurricanes. **Windstorm Insurance Conference,** *Orlando, Florida*, January 30, 2013.

13 Forthcoming Updated Forecasts of 2014 Hurricane Activity

We will be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August-October, beginning today, Thursday, July 31 and continuing every other Thursday (August 14, 28, etc.). We will be issuing an October-November Caribbean basin forecast on **Wednesday, 1 October**. A verification and discussion of all 2014 forecasts will be issued in late November 2014. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

14 Acknowledgments

Besides the individuals named on page 6, 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. The second author would further like to acknowledge the encouragement he has received over the last three decades for this type of forecasting research application from Neil Frank, Robert Sheets, Robert Burpee, Jerry Jarrell, Max Mayfield, and Bill Read, former directors of the National Hurricane Center (NHC), and from the current director, Rick Knabb.

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16 Verification of Previous Forecasts

Table 12: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2009-2013. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

2009	10 Dec. 2008	Update 9 April	Update 2 June	Update 4 August	Obs.
Hurricanes	7	6	5	4	3
Named Storms	14	12	11	10	9
Hurricane Days	30	25	20	18	12
Named Storm Days	70	55	50	45	30
Major Hurricanes	3	2	2	2	2
Major Hurricane Days	7	5	4	4	3.50
Accumulated Cyclone Energy	125	100	85	80	53
Net Tropical Cyclone Activity	135	105	90	85	69

2010	9 Dec. 2009	Update 7 April	Update 2 June	Update 4 August	Obs.
Hurricanes	6-8	8	10	10	12
Named Storms	11-16	15	18	18	19
Hurricane Days	24-39	35	40	40	38.50
Named Storm Days	51-75	75	90	90	89.50
Major Hurricanes	3-5	4	5	5	5
Major Hurricane Days	6-12	10	13	13	11
Accumulated Cyclone Energy	100-162	150	185	185	165
Net Tropical Cyclone Activity	108-172	160	195	195	196

2011	8 Dec. 2010	Update 6 April	Update 1 June	Update 3 August	Obs.
Hurricanes	9	9	9	9	7
Named Storms	17	16	16	16	19
Hurricane Days	40	35	35	35	26
Named Storm Days	85	80	80	80	89.75
Major Hurricanes	5	5	5	5	4
Major Hurricane Days	10	10	10	10	4.5
Net Tropical Cyclone Activity	180	175	175	175	145

2012	4 April	Update 1 June	Update 3 August	Obs.
Hurricanes	4	5	6	10
Named Storms	10	13	14	19
Hurricane Days	16	18	20	28.50
Named Storm Days	40	50	52	101
Major Hurricanes	2	2	2	2
Major Hurricane Days	3	4	5	0.50
Accumulated Cyclone Energy	70	80	99	133
Net Tropical Cyclone Activity	75	90	105	131

2013	4 April	Update 1 June	Update 3 August	Obs.
Hurricanes	9	9	8	2
Named Storms	18	18	18	14
Hurricane Days	40	40	35	3.25
Named Storm Days	95	95	84.25	42.25
Major Hurricanes	4	4	3	0
Major Hurricane Days	9	9	7	0
Accumulated Cyclone Energy	165	165	142	36
Net Tropical Cyclone Activity	175	175	150	47