FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2013

We continue to anticipate an above-average season in 2013, although we have lowered our forecast slightly due to anomalous cooling in the eastern subtropical and tropical Atlantic. We expect an above-average probability of United States and Caribbean major hurricane landfall.

(as of 2 August 2013)

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 or Kate.Jeracki@colostate.edu) is available to answer various questions about this forecast

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523
Email: amie@atmos.colostate.edu

"It's tough to make predictions, especially about the future". Yogi Berra

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[1] Research Scientist
[2] Professor Emeritus of Atmospheric Science

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2013

Forecast Parameter and 1981-2010 Median (in parentheses)	Issue Date 10 April 2013	Issue Date 3 June 2013	Observed Activity Through July 2013	Forecast Activity After 31 July	**Total Seasonal Forecast**
Named Storms (NS) (12.0)	18	18	4	14	**18**
Named Storm Days (NSD) (60.1)	95	95	9.25	75	**84.25**
Hurricanes (H) (6.5)	9	9	0	8	**8**
Hurricane Days (HD) (21.3)	40	40	0	35	**35**
Major Hurricanes (MH) (2.0)	4	4	0	3	**3**
Major Hurricane Days (MHD) (3.9)	9	9	0	7	**7**
Accumulated Cyclone Energy (ACE) (92)	165	165	7	135	**142**
Net Tropical Cyclone Activity (NTC) (103%)	175	175	10	140	**150**

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 - 64% (full-season average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 40% (full-season average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 40% (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) 53% (full-season average for last century is 42%)

POST-31 JULY HURRICANE IMPACT PROBABILITIES FOR 2013 (NUMBERS IN PARENTHESES ARE LONG-PERIOD FULL SEASON AVERAGES)

State	Hurricane	Major Hurricane
Texas	43% (33%)	**16% (12%)**
Louisiana	40% (30%)	**16% (12%)**
Mississippi	14% (11%)	**6% (4%)**
Alabama	21% (16%)	**4% (3%)**
Florida	63% (51%)	**28% (21%)**
Georgia	15% (11%)	**2% (1%)**
South Carolina	23% (17%)	**5% (4%)**
North Carolina	37% (28%)	**10% (8%)**
Virginia	9% (6%)	**1% (1%)**
Maryland	2% (1%)	**<1% (<1%)**
Delaware	2% (1%)	**<1% (<1%)**
New Jersey	2% (1%)	**<1% (<1%)**
New York	10% (8%)	**4% (3%)**
Connecticut	10% (7%)	**3% (2%)**
Rhode Island	8% (6%)	**4% (3%)**
Massachusetts	10% (7%)	**3% (2%)**
New Hampshire	2% (1%)	**<1% (<1%)**
Maine	5% (4%)	**<1% (<1%)**

POST-31 JULY PROBABILITIES OF HURRICANES AND MAJOR HURRICANES TRACKING WITHIN 100 MILES OF EACH ISLAND OR LANDMASS FOR 2013 (NUMBERS IN PARENTHESES ARE LONG-PERIOD FULL SEASON AVERAGES)

Island/Landmass	Hurricane within 100 Miles	Major Hurricane within 100 Miles
Bahamian Islands	64% (51%)	**39% (30%)**
Cuba	64% (52%)	**37% (28%)**
Haiti	36% (27%)	**18% (13%)**
Jamaica	33% (25%)	**15% (11%)**
Mexico (East Coast)	70% (57%)	**30% (23%)**
Puerto Rico	38% (29%)	**18% (13%)**
Turks and Caicos	32% (24%)	**13% (9%)**
US Virgin Islands	39% (30%)	**16% (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 2013 indicates that the remainder of the 2013 Atlantic hurricane season will be more active than the average 1981-2010 season. We estimate that the remainder of 2013 will have about 8 hurricanes (average is 5.5), 14 named storms (average is 10.5), 75 named storm days (average is 58), 35 hurricane days (average is 21.3), 3 major (Category 3-4-5) hurricanes (average is 2.0) and 7 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 2013 season is estimated to be above its long-period average. We expect the remainder of the Atlantic basin hurricane season to accrue Net Tropical Cyclone (NTC) activity approximately 140 percent of the seasonal average. We have decreased our seasonal forecast slightly from early April and early June, due to anomalous cooling of sea surface temperatures in the tropical and subtropical eastern Atlantic.

This forecast was based on a newly-developed extended-range early August statistical prediction scheme developed over the previous 33 years. An earlier statistical model that was utilized for several years has also been consulted. Analog predictors were also considered.

Cool neutral ENSO conditions are currently present in the tropical Pacific, and we believe that these conditions are likely to persist for the remainder of the Atlantic hurricane season. While sea level pressure anomalies across the tropical Atlantic have been relatively low during June and July, sea surface temperatures have anomalously cooled in the eastern tropical and subtropical Atlantic. These cooler SSTs are typically associated with less favorable thermodynamic conditions which we believe could cause slightly less TC activity than expected earlier.

Starting today and issued every two weeks following (e.g., August 16, August 30, 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

This year's forecasts are funded by private and 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 also thank Bill Thorson for his long-period 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 major hurricanes form, which we define as 10-20°N, 20-70°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 30th 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 along with an earlier August forecast scheme. 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 2013 Atlantic Basin Activity through July

The 2013 Atlantic basin hurricane season has had approximately average TC activity, based on the ACE index, during June and July.

<u>Andrea</u> developed on June 5 from an area of low pressure in the eastern Gulf of Mexico. It slowly intensified as it moved northeast and then accelerated northeastward ahead of an upper-level trough. Andrea reached a peak intensity of 55 knots just before making landfall along the Big Bend of Florida late on June 6. It rapidly weakened after

landfall, becoming a post-tropical cyclone on June 7. Andrea's post-tropical remnants were responsible for three fatalities in North Carolina.

Barry formed from an area of low pressure in the northwestern Caribbean Sea on June 17. It drifted across Belize as a tropical depression, nearly being downgraded to a remnant low in the process, before intensifying into a tropical storm when it emerged over the southern Bay of Campeche on June 19. A ridge over the southern Gulf of Mexico steered Barry westward, and it made landfall in the state of Veracruz, Mexico on June 20 with maximum sustained winds near 40 knots at landfall. It rapidly weakened over the course of the day, being downgraded to a tropical depression a few hours after landfall and then a remnant low later that day. Three fatalities in Mexico and Belize have been attributed to Barry.

Chantal developed from an easterly wave in the central tropical Atlantic late on July 7. It moved rapidly westward as it was steered by a strong ridge to its north. Despite its accelerated speed, Chantal intensified slowly over the next day, due to relatively light vertical wind shear. It reached its maximum intensity of 55 knots on July 9. Strong westerly shear soon interacted with the system, and Chantal weakened rapidly. It degenerated into an open wave on July 10. Chantal's remnants caused heavy flooding in Hispaniola and killed one individual in the Dominican Republic.

Dorian formed in the eastern tropical Atlantic from an easterly wave on July 24. The system intensified into a tropical storm later that day as it moved rapidly westward. It reached its maximum intensity of 50 knots the following day while traveling through an area of relatively light shear. By July 26, Dorian began to encounter relatively strong southwesterly shear and drier air and began weakening. A large upper-level trough to the west of Dorian continued to impart strong southwesterly shear over the system, and it degenerated into a tropical wave the following day.

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 2013 Atlantic basin tropical cyclone activity through July 31.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	MHD	ACE	NTC
TS	Andrea	June 5 - June 7	55 kt/992 mb	2.00			1.5	2.4
TS	Barry	June 19 - June 20	40 kt/1003 mb	1.00			0.6	2.1
TS	Chantal	July 8 - July 10	55 kt/1003 mb	2.75			2.1	2.7
TS	Dorian	July 24 - July 27	50 kt/999 mb	3.50			2.6	2.9
Totals	4			9.25			6.8	10.1

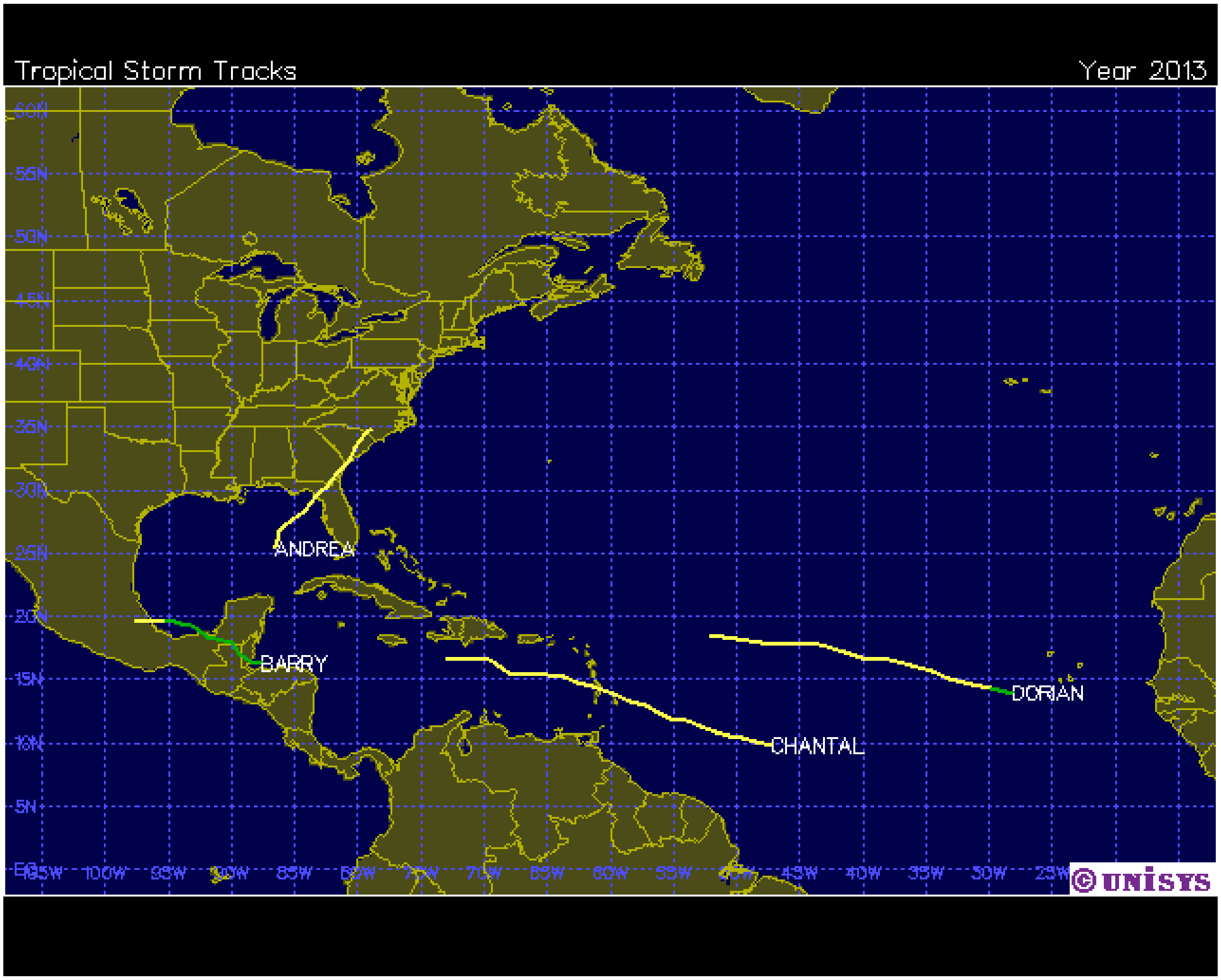


Figure 1: 2013 Atlantic basin hurricane tracks through July. Figure courtesy of Unisys Weather (http://weather.unisys.com). Yellow lines indicate TCs at named storm strength, while green lines indicate TCs at tropical depression strength.

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 last year. 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. When these three predictors are combined, they correlate at 0.91 with observed NTC using a drop-one cross validation approach over the period from 1979-2012 (Figure 3).

Table 2: Listing of 1 August 2013 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. The combination of these three predictors calls for a slightly above-average hurricane season. None of these predictors deviate significantly from their 1981-2010 average values.

Predictor	Values for 2013 Forecast	Effect on 2013 Hurricane Season
1) July Surface U (10-17.5°N, 60-85°W) (+)	+0.4 SD	**Slightly Enhance**
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) (-)	-0.1 SD	Slightly Suppress

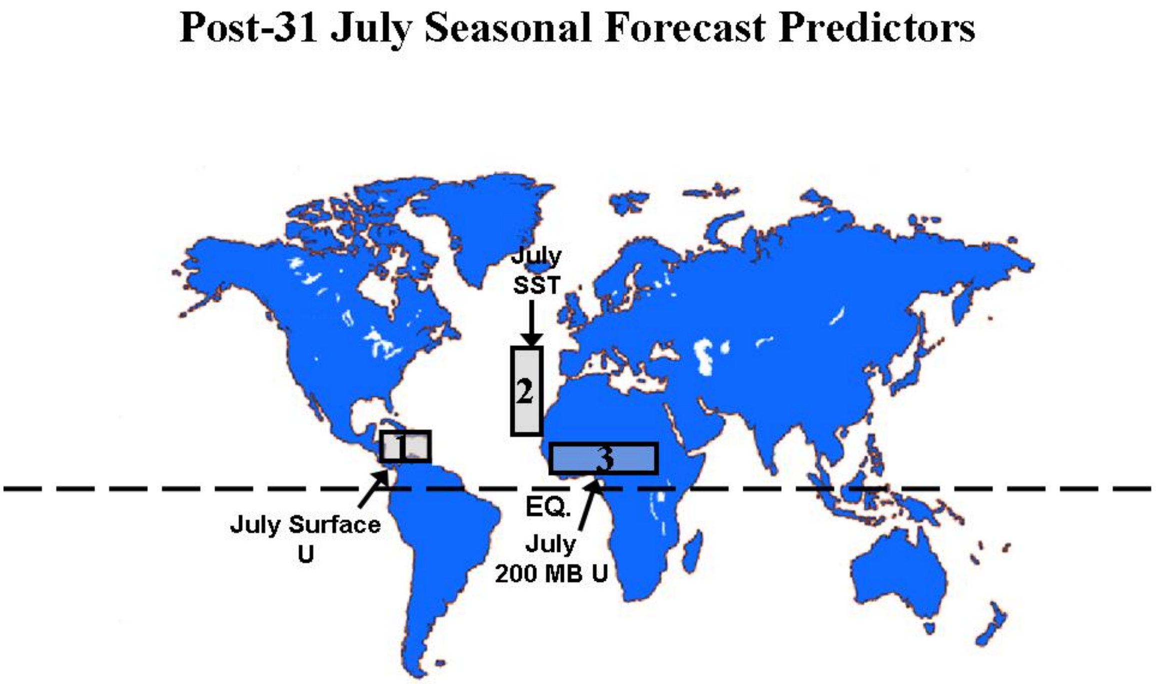


Figure 2: Location of predictors for the post-31 July forecast for the 2013 hurricane season from the new statistical model.

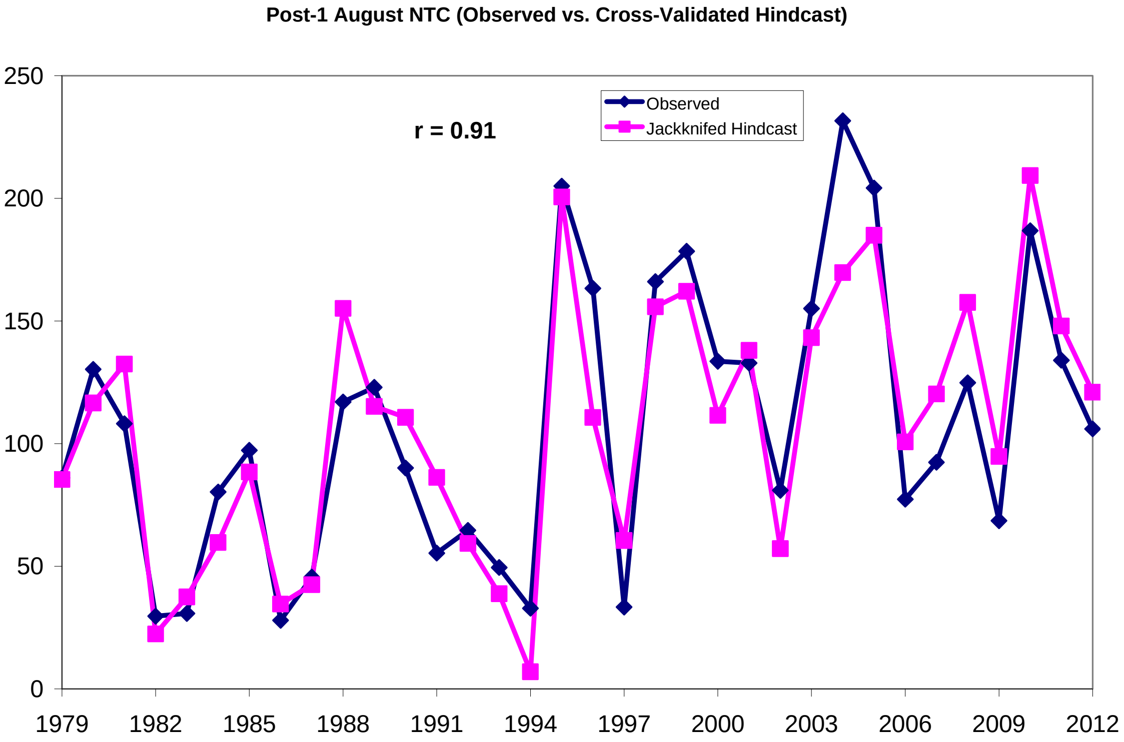


Figure 3: Observed versus hindcast values of post-31 July NTC for 1979-2012 using the new statistical scheme - a very skillful hindcast verification.

Table 3 shows our statistical forecast for the 2013 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 relatively active season this year.

Table 3: Post-31 July statistical forecast for 2013 from the new statistical model.

Predictands and Climatology (1981-2010 Post-31 July Median)	Statistical Forecast
Named Storms (NS) – 10.5	11.5
Named Storm Days (NSD) – 58.0	58.5
Hurricanes (H) – 5.5	6.7
Hurricane Days (HD) – 21.3	27.3
Major Hurricanes (MH) – 2.0	3.0
Major Hurricane Days (MHD) – 3.8	7.3
Accumulated Cyclone Energy Index (ACE) – 86	113
Net Tropical Cyclone Activity (NTC) – 95	123

Table 4 displays our early August cross-validated hindcasts for 1979-2011 along with the real-time forecast in 2012 using the new statistical scheme. Our early August model has correctly predicted above- or below-average post-31 July NTC in 30 out of 34 years (88%). These hindcasts have had a smaller error than climatology in 24 out of 34 years (71%). 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 1979-2012 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 34 years (88%), while hindcast improvement over climatology occurred in 24 out of 34 years (71%).**

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**
Average	**107**	**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 (+)

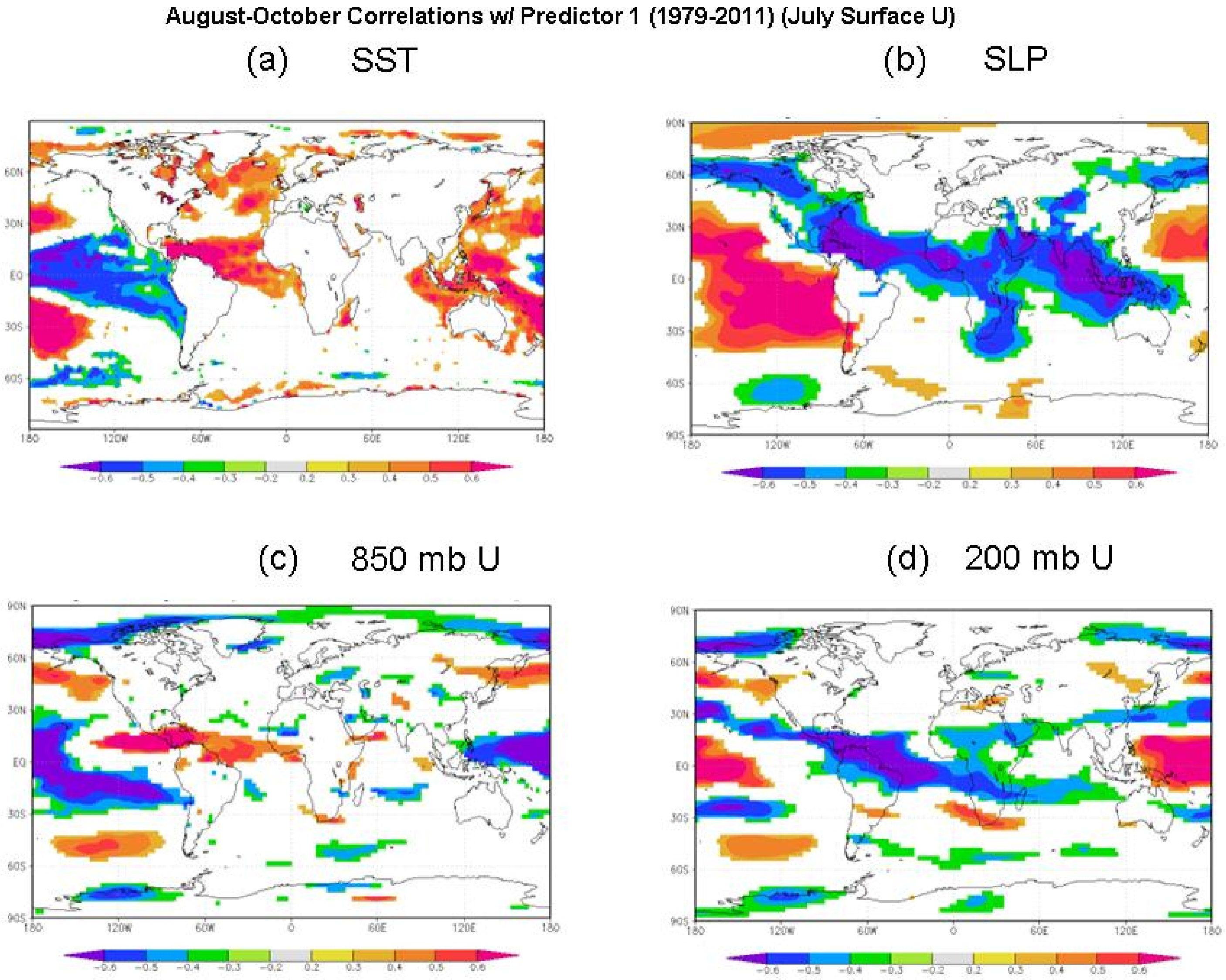
(20°-40°N, 15-35°W)

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).



August-October Correlations w/ Predictor 1 (1979-2011) (July Surface U)

(a) SST

(b) SLP

(c) 850 mb U

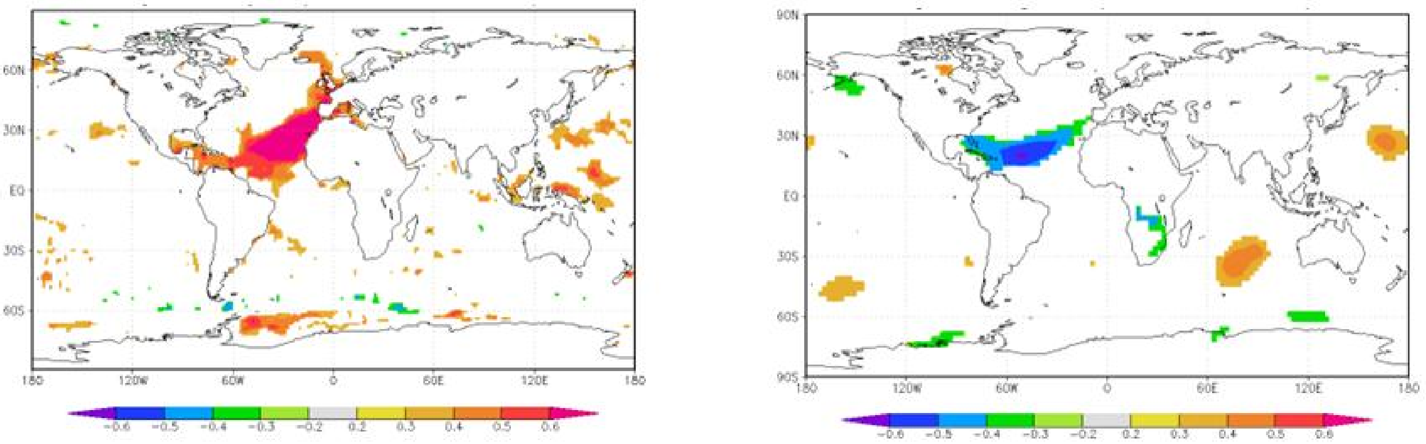
(d) 200 mb U

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).

August-October Correlations w/ Predictor 2 (1979-2011) (July SSTA)

(a) SST

(b) SLP



(c) 850 mb U

(d) 200 mb U

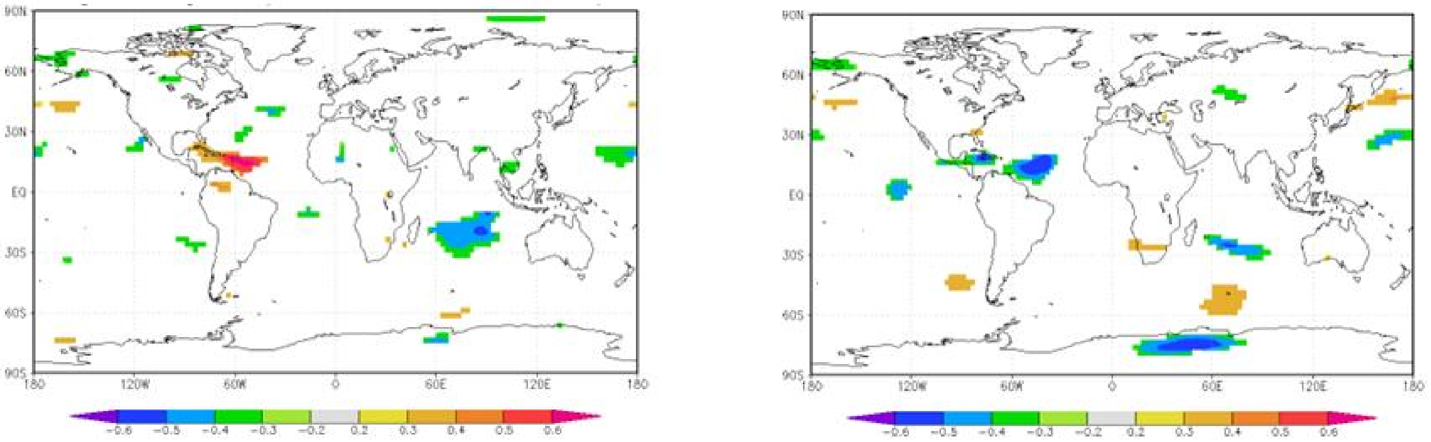


Figure 5: Linear correlations between July Surface Temperature in the Subtropical Northeastern Atlantic (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel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

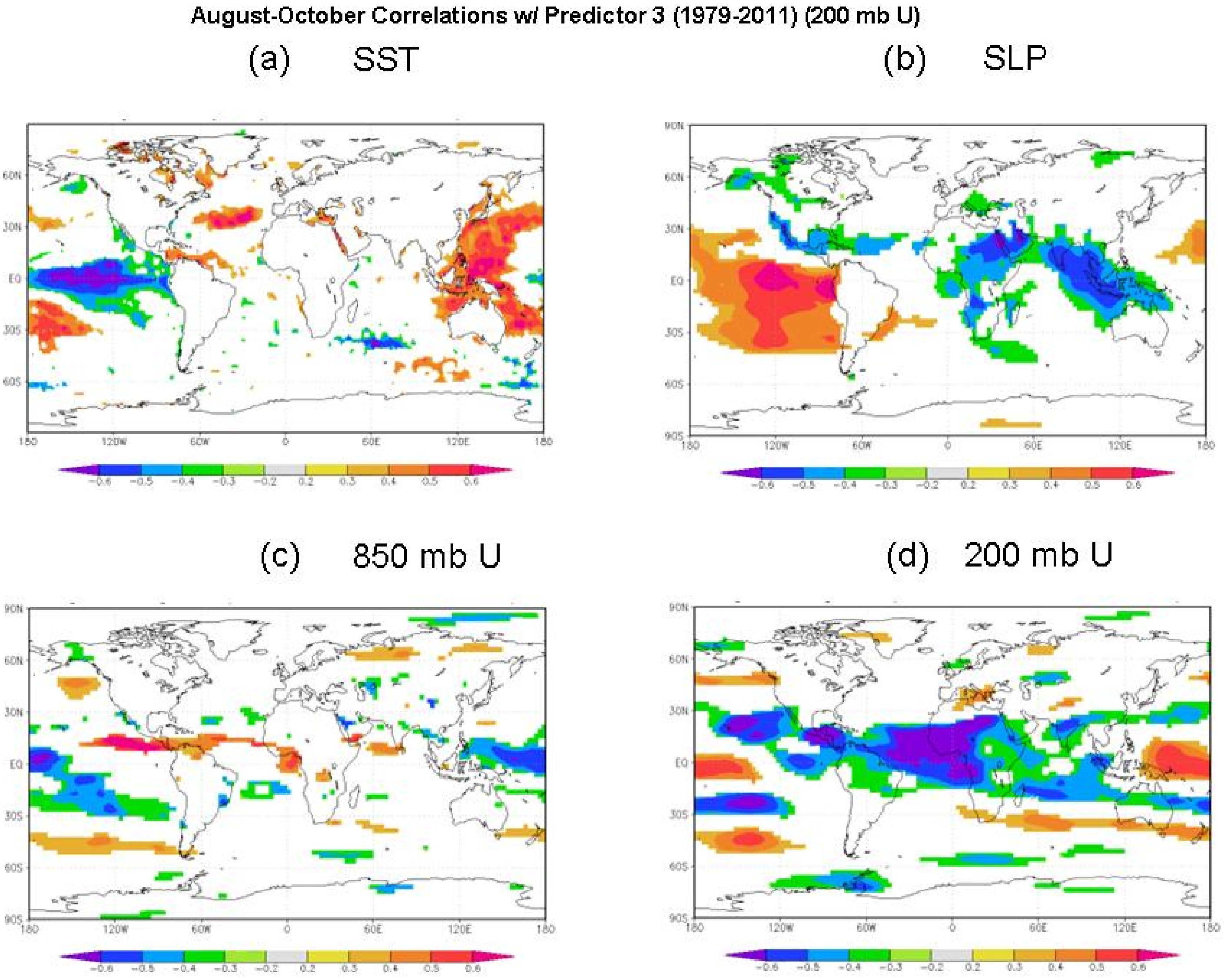


Figure 6: Linear correlations between July 200 MB Zonal Wind over tropical north Africa (Predictor 3) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). The color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

Table 5 summarizes the statistical model output from the new forecast as well as an earlier statistical model discussed in detail in Klotzbach (2007). The newly-developed model calls for a relatively active season, while the Klotzbach (2007) model calls for a very active remainder of the season.

Table 5: Summary of output from the Klotzbach (2007) statistical model for post-31 July tropical cyclone activity as well as the new forecast model (Klotzbach 2012).

Predictands and Climatology (1950-2000 – Post-31 July Average)	Klotzbach (2007)	Klotzbach (2012)
Named Storms (NS) - 10.5	13.2	11.5
Named Storm Days (NSD) – 58.0	71.3	58.5
Hurricanes (H) – 5.5	8.0	6.7
Hurricane Days (HD) – 21.3	34.6	27.3
Major Hurricanes (MH) – 2.0	4.0	3.0
Major Hurricane Days (MHD) – 3.8	10.1	7.3
Accumulated Cyclone Energy Index (ACE) – 86	144	113
Net Tropical Cyclone Activity (NTC) – 95	155	123

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 6 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 6: Model hindcast error and our post-31 July 2013 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	Post-31 July 2013 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	2.3	14	11.7 - 16.3
Named Storm Days (NSD)	17.4	75	57.6 - 92.4
Hurricanes (H)	1.6	8	6.4 - 9.6
Hurricane Days (HD)	8.6	35	26.4 - 43.6
Major Hurricanes (MH)	0.9	3	2.1 - 3.9
Major Hurricane Days (MHD)	3.5	7	3.5 - 10.5
Accumulated Cyclone Energy (ACE)	36	135	99 - 171
Net Tropical Cyclone (NTC) Activity	34	140	106 - 174

4 Analog-Based Predictors for 2013 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2013. These years also provide useful clues as to likely trends in activity that the 2013 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 2013 conditions. Table 7 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 cool neutral ENSO conditions and slightly above-average tropical Atlantic sea surface temperatures.

There were five hurricane seasons with characteristics most similar to what we observed in June-July 2013. The best analog years that we could find for the 2013 hurricane season were 1952, 1966, 1996, 2007, and 2008. We anticipate that 2013 seasonal hurricane activity will have activity that is slightly above the average of these five analog years. <u>We believe that the remainder of 2013 will have above-average activity in the Atlantic basin.</u>

Table 7: Best analog years for 2013 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1952	7	39.75	6	22.75	3	7.00	87	103
1966	11	64.00	7	41.75	3	8.75	145	140
1996	13	79.00	9	45.00	6	13.00	166	192
2007	15	37.75	6	12.25	2	6.00	74	99
2008	16	88.25	8	30.50	5	7.50	146	162
Mean (Full Season)	**12.4**	**61.8**	**7.2**	**30.5**	**3.8**	**8.5**	**124**	**139**
2013 Forecast (Full Season)	**18**	**84.25**	**8**	**35**	**3**	**7**	**140**	**150**
1981-2010 Median (Full Season)	**12.0**	**60.1**	**6.5**	**21.3**	**2.0**	**3.9**	**92**	**103**

5 ENSO

Cool neutral ENSO conditions currently persist across the tropical Pacific. SST anomalies are generally below-average across the central and eastern tropical Pacific. Table 8 displays July and May SST anomalies for several Nino regions. No significant changes in SST have been observed in any of the four Nino regions over the past two months.

Table 8: May and July 2013 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	-1.4	-1.3	+0.1
Nino 3	-0.7	-0.7	0.0
Nino 3.4	-0.3	-0.3	0.0
Nino 4	-0.1	-0.1	0.0

It appears that cool neutral ENSO conditions are the most likely scenario for the peak of this year's hurricane season. While there had been some upper-level ocean warning in the past few weeks, trade winds near the International Date Line have recently reasserted themselves. Consequently, the anomalous warming of upper ocean heat content that has developed in recent weeks has recently begun to level off.

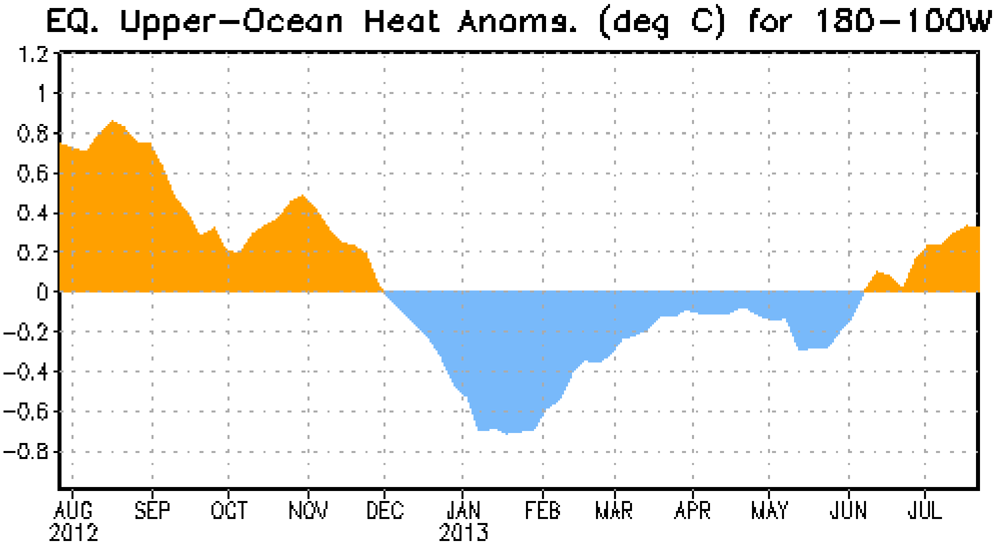


Figure 7: Upper-ocean (0-300 meters depth) heat content anomalies in the eastern and central Pacific since August 2012. There has been an increase in upper ocean heat content anomalies since the middle of May, but this increase has leveled off during the second half of July.

Both dynamical and statistical models are in good agreement that neutral conditions are likely for the peak of the Atlantic hurricane season from August-October. Figure 8 displays the current forecasts issued by various ENSO models. In general, the statistical models are calling for slightly cooler conditions than those predicted by the dynamical models. No statistical or dynamical models call for El Niño development during the August-October period.

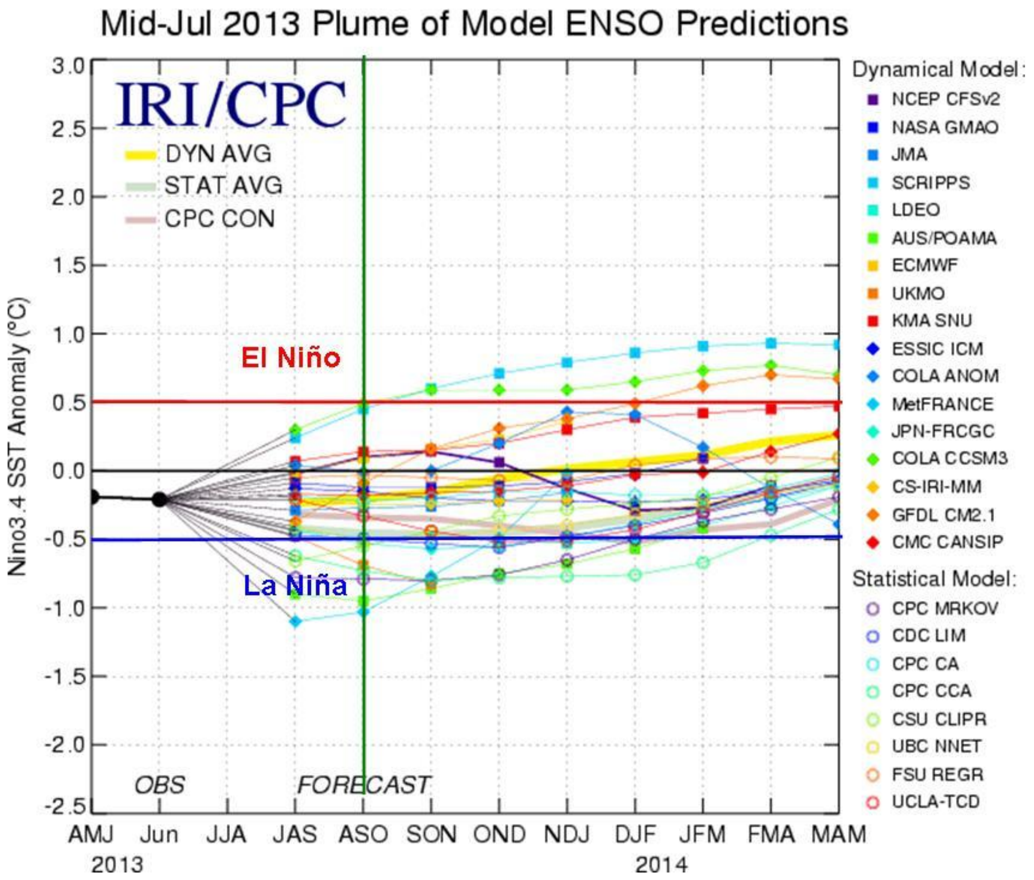


Figure 8: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

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 0.1°C (Figure 9).

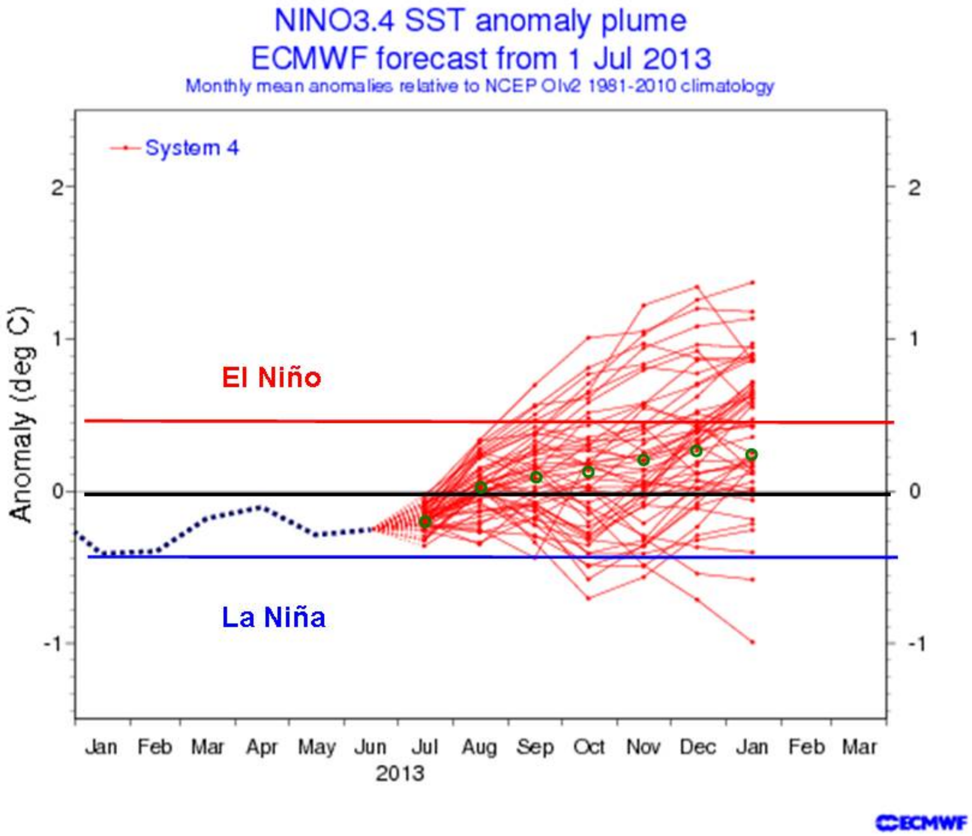


Figure 9: ECMWF ensemble model forecast for the Nino 3.4 region. Most members call for neutral conditions throughout the August-October period. The green dots represent the approximate average of the ensemble members.

Based on this information, our best estimate is that we will likely have cool neutral ENSO conditions during the August-October period. Consequently, we do not anticipate increased vertical wind shear associated with El Niño to be present this year.

6 Current Atlantic Basin Conditions

Conditions in the tropical Atlantic have become somewhat less favorable over the past couple of months. The primary negative factor has been the development and advection of cool SST anomalies from the subtropical northeast Atlantic into the tropical Atlantic. Figure 10 displays the SST change from late May 2013 to late July 2013, with the significant cooling of SSTs in the eastern tropical Atlantic being the most definitive feature.

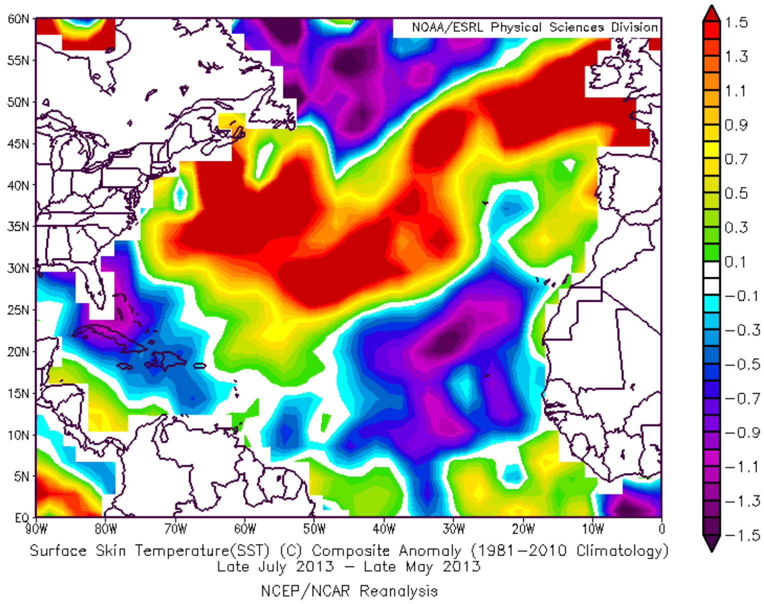


Figure 10: Late July 2013-late May 2013 SST anomaly. Note the anomalous cooling that has taken place across the tropical and subtropical eastern Atlantic. This cooling predominately took place during the month of June.

Despite this cooling, SSTs across the MDR are still somewhat above their climatological averages (Figure 11). In addition, two early season TCs formed in the MDR (Chantal and Dorian). From a climatological perspective, thermodynamics are typically what restricts early season TC development in the MDR, and consequently, the development of Chantal and Dorian indicates that MDR thermodynamics are not particularly unfavorable. Table 9 displays the 10 seasons since 1851 that have had two storms form in the MDR prior to 1 August. All of these years had at least average activity, with many of these seasons being very active.

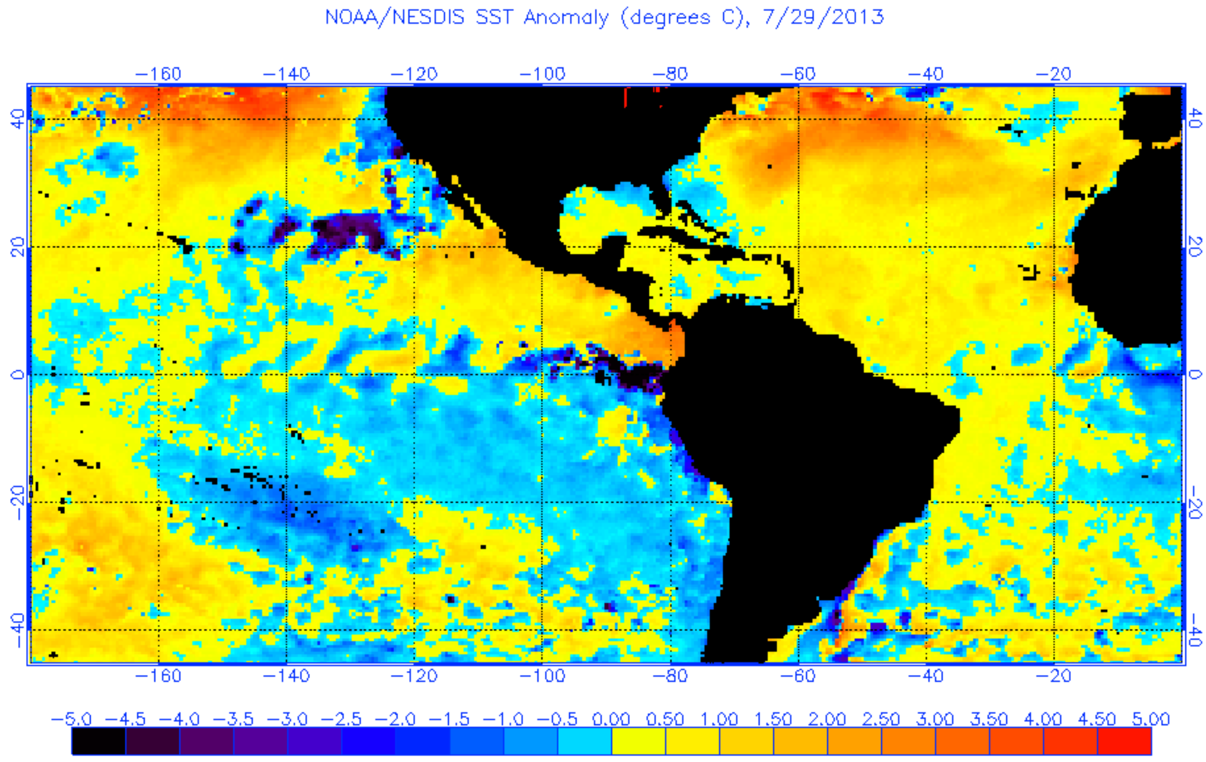


Figure 11: Current SST anomalies as estimated by NOAA/NESDIS. In general, warm anomalies still predominate in the tropical and subtropical Atlantic despite the recent cooling shown in Figure 10.

Table 9: Seasonal TC activity in years where at least two TCs formed in the MDR prior to 1 August.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1887	19	106.25	11	47.00	2	6.75	181	169
1901	13	85.75	6	18.75	0	0.00	99	81
1926	11	86.75	8	58.50	6	22.75	230	230
1933	21	136.00	10	50.25	5	10.50	213	216
1944	11	53.00	7	27.25	3	5.25	96	115
1966	11	64.00	7	41.75	3	8.75	145	140
1979	9	45.75	6	21.75	2	5.75	93	97
1995	19	121.25	11	61.50	5	11.50	227	222
1996	13	79.00	9	45.00	6	13.00	166	192
2005	28	131.50	15	49.75	7	17.50	250	279
Average	15.5	90.9	9.0	42.2	3.9	10.2	170.1	174.0
Median	13.0	86.3	8.5	46.0	4.0	9.6	173.7	180.7

Sea level pressure anomalies over the past month have been quite low, implying that the trade winds across the Main Development Region are weak and the Tropical

Upper Tropospheric Trough (TUTT) is reduced in strength (Figure 12). A weakened TUTT typically relates to reduced vertical wind shear across the tropical Atlantic and Caribbean (Knaff 1997). We do not foresee a strong TUTT formation this season.

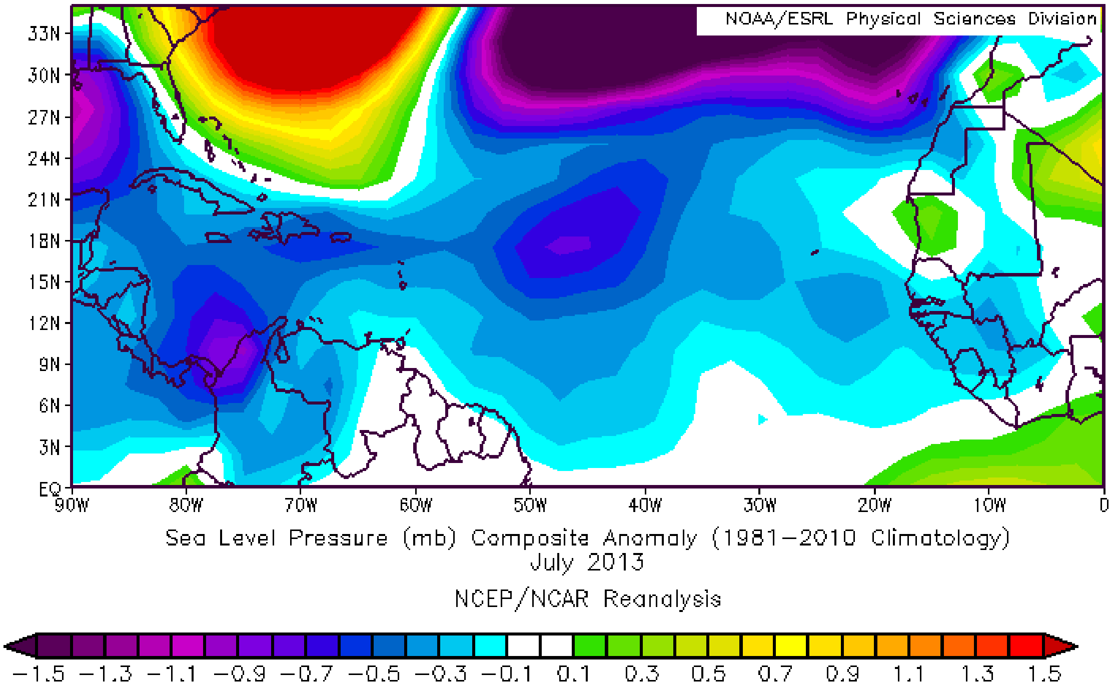


Figure 12: July 2013 Atlantic SLP anomaly. Negative anomalies have predominated across the tropical Atlantic and Caribbean throughout the month.

As was the case last year, the tropical Atlantic atmosphere appears to be somewhat more stable than normal. 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 somewhat limited this year (Figure 13). Positive deviations from the curve displayed below indicate a more unstable atmosphere than normal. In general, the atmosphere has been more stable than normal since the start of the hurricane season.

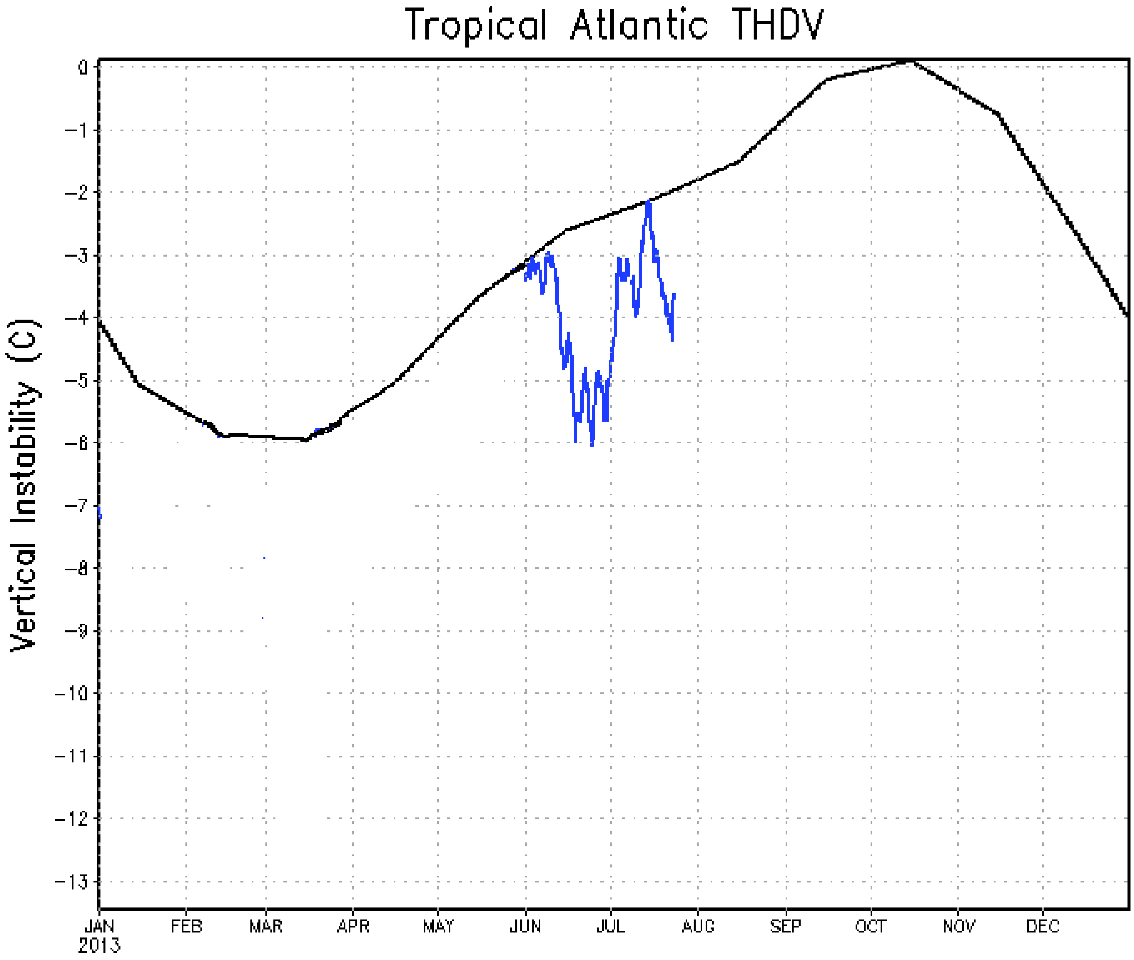


Figure 13: Vertical instability across the tropical Atlantic since the start of the hurricane season. In general, this year's instability has been lower than normal, indicating a relatively stable atmosphere this year.

It is primarily these mixed signals in the tropical Atlantic which are causing us to reduce our forecast slightly.

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 14 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 2013 time period. In general, it appears that rainfall in the Western Sahel has been at near-average levels during June-July.

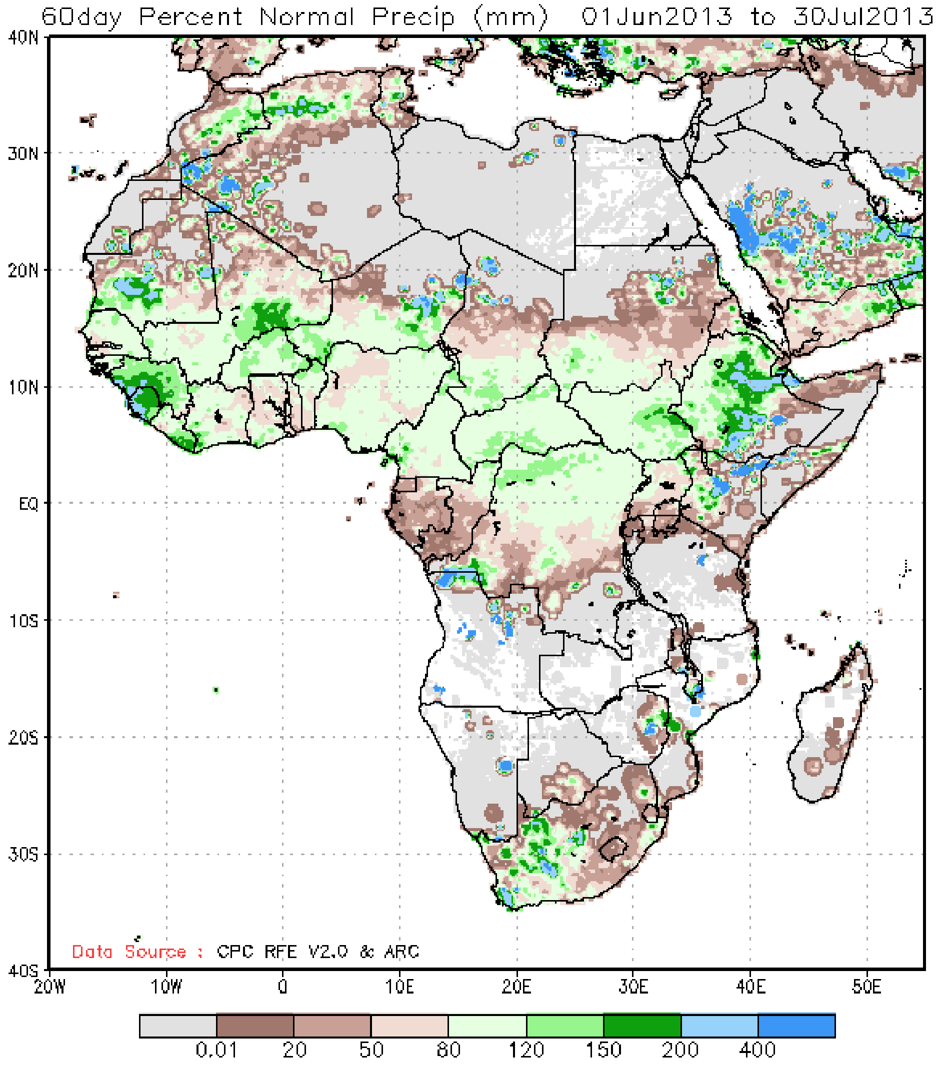


Figure 14: Rainfall Estimation Algorithm Version 2.0 (RFE) estimate of percent of normal rainfall for June-July 2013.

8 Adjusted 2012 Forecast

Table 10 shows our final adjusted early August forecast for the 2013 season which is a combination of our two statistical schemes (with June-July activity added in), our analog forecast and qualitative adjustments for other factors not explicitly contained in any of these schemes. The average of our two statistical forecasts (with June-July activity added in) and our analog forecast call for an above-average season. We thus foresee an above-average amount of TC activity for the remainder of the Atlantic hurricane season.

Table 10: June-July 2013 observed activity, our two early August full season statistical forecasts (with June-July 2013 activity added in), our analog forecast and our adjusted final forecast for the 2013 hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	June-July 2013 Observed Activity	Klotzbach (2007) Statistical Scheme	New Statistical Scheme (2012)	Analog Scheme	Adjusted Final Forecast (Whole Season)
Named Storms (12.0)	4	17.2	15.5	12.4	**18**
Named Storm Days (60.1)	9.25	80.5	67.7	61.8	**84.25**
Hurricanes (6.5)	0	8.0	6.7	7.2	**8**
Hurricane Days (21.3)	0	34.6	27.3	30.5	**35**
Major Hurricanes (2.0)	0	4.0	3.0	3.8	**3**
Major Hurricane Days (3.9)	0	10.1	7.3	8.5	**7**
Accumulated Cyclone Energy Index (92)	7	151	120	124	**142**
Net Tropical Cyclone Activity (103%)	10	165	133	139	**150**

9 Landfall Probabilities for 2013

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 11). 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 11: 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 12 lists strike probabilities for the 2013 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 2013 is expected to be above its long-term average, and therefore, landfall probabilities are above their long-term average.

Table 12: 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 2013 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)	89% (79%)	79% (68%)	64% (52%)	93% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	71% (59%)	54% (42%)	40% (30%)	72% (60%)	92% (83%)
Florida plus East Coast (Regions 5-11)	62% (50%)	56% (44%)	40% (31%)	74% (61%)	90% (81%)
Caribbean (10-20°N, 60-88°W)	91% (82%)	69% (57%)	53% (42%)	86% (75%)	99% (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.

As an example we find that the probability of Florida being hit by a major (Cat 3-4-5) hurricane during the remainder of this year is 28% which is higher than the long-term seasonal climatological average of 21%.

South Florida is much more prone to being impacted by a hurricane on an individual-year basis compared with northeast Florida. For instance, the probability of Miami-Dade County being impacted by hurricane-force wind gusts for the remainder of this year is 16%. For Duval County (Jacksonville metropolitan area) in northeast Florida, the probability of being impacted by hurricane-force wind gusts is only 4%. However, considering a 50-year period, the probability of Duval County experiencing hurricane-force wind gusts is 75%.

For the island of Puerto Rico, the probability of a named storm, hurricane and major hurricane tracking within 50 miles of the island this year is 43%, 21%, and 7%, respectively.

10 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 2013 should be a relatively active season. Cool neutral ENSO conditions should generally provide favorable upper-level winds across the Caribbean and tropical Atlantic. Two early season MDR storms are also indicative that the season should be quite active. The only significant negative factor at this point is the anomalous cooling that has occurred in the eastern tropical and subtropical Atlantic over the past two months. However, this cooling has abated in recent weeks.

11 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. We believe the hypothesized influence of atmospheric CO_2 increases on increased hurricane activity has been exaggerated. For more information on this topic we refer you to the following four references, which can be accessed by clicking on the links below:

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Gray, W. M., and P. J. Klotzbach, 2012: US hurricane damage - Can rising levels of CO2 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.

11 Forthcoming Updated Forecasts of 2013 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, Friday, August 2 and continuing every other Friday (August 16, 30, etc). We will be issuing an October-November Caribbean basin forecast on **Tuesday, 1 October**. A verification and discussion of all 2013 forecasts will be issued in late November 2013. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

12 Acknowledgments

Besides the individuals named on page 5, 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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14 Verification of Previous Forecasts

Table 11: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2008-2012. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

2008	7 Dec. 2007	Update 9 April	Update 3 June	Update 5 August	Obs.
Hurricanes	7	8	8	9	8
Named Storms	13	15	15	17	16
Hurricane Days	30	40	40	45	30.50
Named Storm Days	60	80	80	90	88.25
Major Hurricanes	3	4	4	5	5
Major Hurricane Days	6	9	9	11	7.50
Accumulated Cyclone Energy	115	150	150	175	146
Net Tropical Cyclone Activity	125	160	160	190	162

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