SUMMARY OF 2014 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHORS' SEASONAL AND TWO-WEEK FORECASTS

The 2014 Atlantic hurricane season had close to the activity predicted in our seasonal outlooks. We correctly predicted a somewhat below-average season. Strong vertical wind shear and mid-level subsidence combined to suppress activity both in the tropical Atlantic and in the Caribbean. Overall activity in 2014 was approximately 75% of the 1981-2010 median.

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

Kortny Rolston, Colorado State University Media Representative, (970-491-5349) is available to answer various questions about this verification.

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

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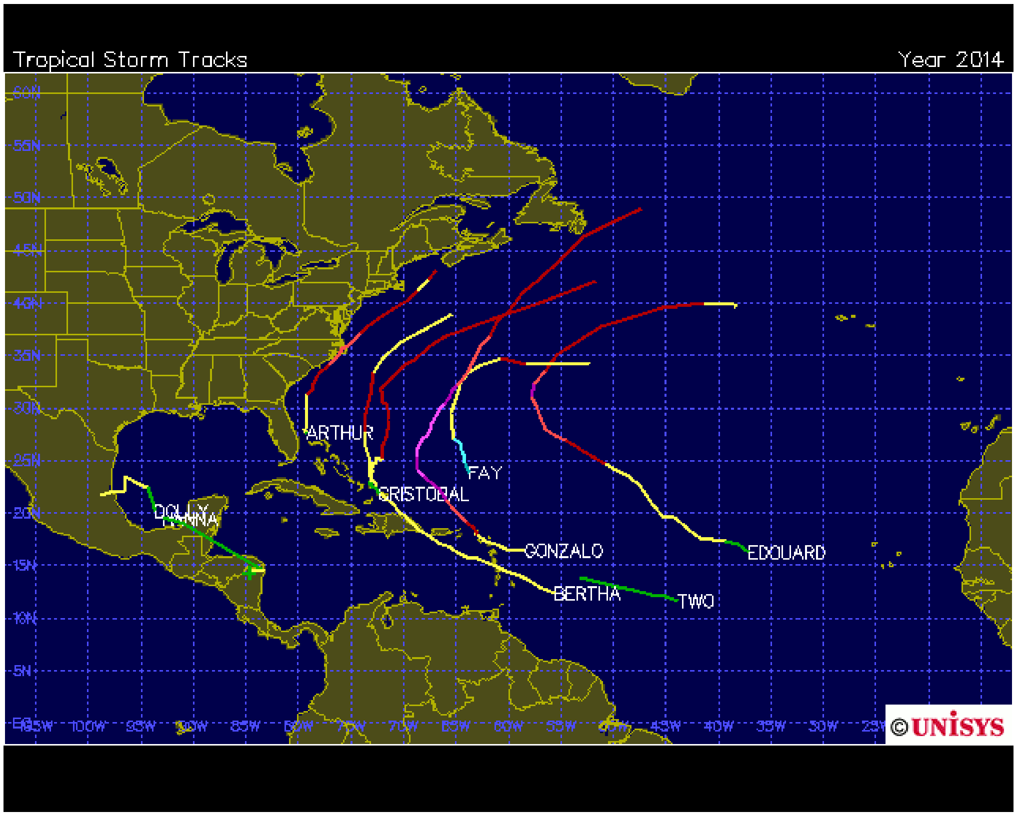
[1] Research Scientist

[2] Professor Emeritus of Atmospheric Science

ATLANTIC BASIN SEASONAL HURRICANE FORECASTS 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	Issue Date 31 July 2014	Observed 2014 Activity	% of 1981-2010 Median
Named Storms (NS) (12.0)	9	10	10	10	8	67%
Named Storm Days (NSD) (60.1)	35	40	40	40	35	58%
Hurricanes (H) (6.5)	3	4	4	4	6	92%
Hurricane Days (HD) (21.3)	12	15	15	15	17.25	81%
Major Hurricanes (MH) (2.0)	1	1	1	1	2	100%
Major Hurricane Days (MHD) (3.9)	2	3	3	3	3.50	90%
Accumulated Cyclone Energy (ACE) (92)	55	65	65	65	66	70%
Net Tropical Cyclone Activity (NTC) (103%)	60	70	70	70	81	79%



Atlantic basin tropical cyclone tracks in 2014. . Figure courtesy of Unisys Weather (http://weather.unisys.com). The purple line indicates a system at major hurricane strength, the red line indicates a system at minor hurricane strength, the yellow line indicates a system at tropical storm strength, the blue line indicates a subtropical system, and the green line indicates a system at tropical depression strength

*Observed activity is through 18Z on November 18, 2014 as calculated from the National Hurricane Center's b-decks. Final season statistics will be included with the December qualitative outlook for 2015 issued on December 11.

ABSTRACT

This report summarizes tropical cyclone (TC) activity which occurred in the Atlantic basin during 2014 and verifies the authors' seasonal Atlantic basin forecasts. Also verified are an October-November Caribbean-only forecast and six two-week Atlantic basin forecasts issued during the peak months of the hurricane season that were primarily based on the phase of the Madden-Julian Oscillation (MJO).

Our first quantitative seasonal forecast for 2014 was issued on 10 April with updates following on 2 June, 1 July and 31 July. These seasonal forecasts also contained estimates of the probability of U.S. and Caribbean hurricane landfall during 2014.

The 2014 hurricane season was relatively quiet. The season was characterized by somewhat below-average named storm numbers, with near-average numbers of both hurricanes and major hurricanes. This year's seasonal forecast was one of our most skillful ones when verified against integrated measures such as Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity.

We issued six consecutive two-week forecasts during the peak months of the Atlantic hurricane season from August-October. These forecasts were primarily based on predicted activity by the global forecast models and the phase of the Madden-Julian Oscillation (MJO). These two-week forecasts generally verified quite well. Our October-November Caribbean basin-only forecast also correctly predicted a slightly below-average end to the season there.

Integrated measures such as Net Tropical Cyclone (NTC) activity and Accumulated Cyclone Energy (ACE) were at somewhat below-average levels. As was the case last year, dry mid-level air and sinking motion prevailed across the Atlantic basin. The tropical Atlantic was also a bit cooler than normal, and vertical wind shear was quite strong across the Caribbean. All of these conditions likely combined to create an unfavorable environment for TC formation and intensification.

We expected weak to moderate El Niño conditions to develop during the peak of the Atlantic hurricane season, while observed ENSO conditions were at warm neutral levels. This over-forecast of ENSO conditions was endemic in virtually all of the numerical model forecasts this year.

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 20-70°N, 40-10°W and sea level pressure from 15-50°N, 60-10°W.

Atlantic Basin – The area including the entire North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico.

El Niño – A 12-18 month period during which anomalously warm sea surface temperatures occur in the eastern half of the equatorial Pacific. Moderate or strong El Niño events occur irregularly, about once every 3-7 years on average.

Hurricane (H) - A tropical cyclone with sustained low-level winds of 74 miles per hour (33 ms^{-1} or 64 knots) or greater.

Hurricane Day (HD) - A measure of hurricane activity, one unit of which occurs as four 6-hour periods during which a tropical cyclone is observed or is estimated to have hurricane-force winds.

Indian Ocean Dipole (IOD) - An irregular oscillation of sea surface temperatures between the western and eastern tropical Indian Ocean. A positive phase of the IOD occurs when the western Indian Ocean is anomalously warm compared with the eastern Indian Ocean.

Madden Julian Oscillation (MJO) – A globally propagating mode of tropical atmospheric intra-seasonal variability. The wave tends to propagate eastward at approximately 5 ms^{-1}, circling the globe in roughly 40-50 days.

Main Development Region (MDR) – An area in the tropical Atlantic where a majority of major hurricanes form, which we define as 7.5-22.5°N, 20-75°W.

Major Hurricane (MH) - A hurricane which reaches a sustained low-level wind of at least 111 mph (96 knots or 50 ms^{-1}) at some point in its lifetime. This constitutes a category 3 or higher on the Saffir/Simpson scale.

Major Hurricane Day (MHD) - Four 6-hour periods during which a hurricane has an intensity of Saffir/Simpson category 3 or higher.

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

Named Storm (NS) - A hurricane, a tropical storm or a sub-tropical storm.

Named Storm Day (NSD) - As in HD but for four 6-hour periods during which a tropical or sub-tropical cyclone is observed (or is estimated) to have attained tropical storm-force winds.

Net Tropical Cyclone (NTC) Activity –Average seasonal percentage mean of NS, NSD, H, HD, MH, MHD. Gives overall indication of Atlantic basin seasonal hurricane activity. The 1950-2000 average value of this parameter is 100.

Saffir/Simpson Hurricane Wind Scale – A measurement scale ranging from 1 to 5 of hurricane wind intensity. One is a weak hurricane; whereas, five is the most intense hurricane.

Southern Oscillation Index (SOI) – A normalized measure of the surface pressure difference between Tahiti and Darwin. Low values typically indicate El Niño conditions.

Sea Surface Temperature – SST

Sea Surface Temperature Anomaly – SSTA

Thermohaline Circulation (THC) – A large-scale circulation in the Atlantic Ocean that is driven by fluctuations in salinity and temperature. When the THC is stronger than normal, the AMO tends to be in its warm (or positive) phase, and more Atlantic hurricanes typically form.

Tropical Cyclone (TC) - A large-scale circular flow occurring within the tropics and subtropics which has its strongest winds at low levels; including hurricanes, tropical storms and other weaker rotating vortices.

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

Tropical Storm (TS) - A tropical cyclone with maximum sustained winds between 39 mph (18 ms^{-1} or 34 knots) and 73 mph (32 ms^{-1} or 63 knots).

Vertical Wind Shear – The difference in horizontal wind between 200 mb (approximately 40000 feet or 12 km) and 850 mb (approximately 5000 feet or 1.6 km).

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

Acknowledgment

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 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 thank Bill Thorson for technical advice and assistance.

1 Preliminary Discussion

1a. Introduction

The year-to-year variability of Atlantic basin hurricane activity is the largest of any of the globe's tropical cyclone basins. Table 1 displays the average of the five most active seasons (as ranked by NTC) compared with the five least active seasons (as ranked by NTC) since 1944. Note how large the ratio differences are between very active versus very inactive seasons, especially for major hurricanes (16.5 to 1) and major hurricane days (63 to 1). Major hurricanes, on a normalized basis, bring about 80-85% of hurricane-related destruction (Pielke et al. 2008).

Table 1: Comparison of the average of the five most active seasons since 1944 compared with the five least active seasons since 1944. The active/inactive ratio is also provided.

	NS	NSD	H	HD	MH	MHD	ACE	NTC
Five Most Active Seasons	17.2	102.9	10.8	52.8	6.6	18.9	231	240
Five Least Active Seasons	6.0	23.2	3.0	6.7	0.4	0.3	31	35
Most Active/Least Active Ratio	2.9	4.4	3.6	7.9	16.5	63.0	7.6	6.9

There has always been and will continue to be much interest in knowing if the coming Atlantic hurricane season is going to be unusually active, very quiet or just average. There was never a way of objectively determining how active the coming Atlantic hurricane season was going to be until the early to mid-1980s when global data sets became more accessible.

The global atmosphere and oceans in combination have stored memory buried within them that can provide clues as to how active the upcoming Atlantic basin hurricane season is likely to be. The benefit of such empirical investigation (or data mining) is such that any precursor relationship that might be found can immediately be utilized without having to have a complete understanding of the physics involved.

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

A cardinal rule we have always followed is to issue no forecast for which we do not have substantial hindcast skill extending back in time for at least 30 years. The NCEP/NCAR reanalysis data sets we now use are available back to 1948. This gives us more than 60 years of hindcast information. We also utilize newer reanalyses that have been developed on the past ~30 years of data (e.g., the ERA-Interim and CFSR Reanalyses). We also have been exploring longer-term reanalysis products such as the 20th Century Reanalysis from the Earth System Research Laboratory.

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

1b. Seasonal Forecast Theory

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

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

In a four-predictor empirical forecast model, the contribution of each predictor to the net forecast skill can only be determined by the separate elimination of each parameter from the full four-predictor model while noting the hindcast skill degradation. When taken from the full set of predictors, one parameter may degrade the forecast skill by 25-30 percent, while another degrades the forecast skill by only 10-15 percent. An individual parameter that, through elimination from the forecast, degrades a forecast by as much as 25-30 percent may, in fact, by itself, show relatively little direct correlation with the predictand. A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 3-4 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmospheric-oceanic system that is highly non-linear. There is a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all these processes interact with each other. Despite the complicated relationships that are involved, all of our statistical models show considerable hindcast skill. We are confident that in applying these skillful hindcasts to future forecasts that appreciable real-time skill will result.

2 Tropical Cyclone Activity for 2014

Figure A and Table 2 summarize Atlantic basin TC activity which occurred in 2014. The season was characterized by below-average activity.

3 Individual 2014 Tropical Cyclone Characteristics

The following is a brief summary of each of the named tropical cyclones in the Atlantic basin for the 2014 season. Figure A shows the tracks of all of this season's tropical cyclones, and Table 2 gives statistics for each of these tropical cyclones. TC statistics were calculated from the National Hurricane Center's b-decks for all TCs. Online entries from Wikipedia (http://www.wikipedia.org) were very helpful in putting together these tropical cyclone summaries.

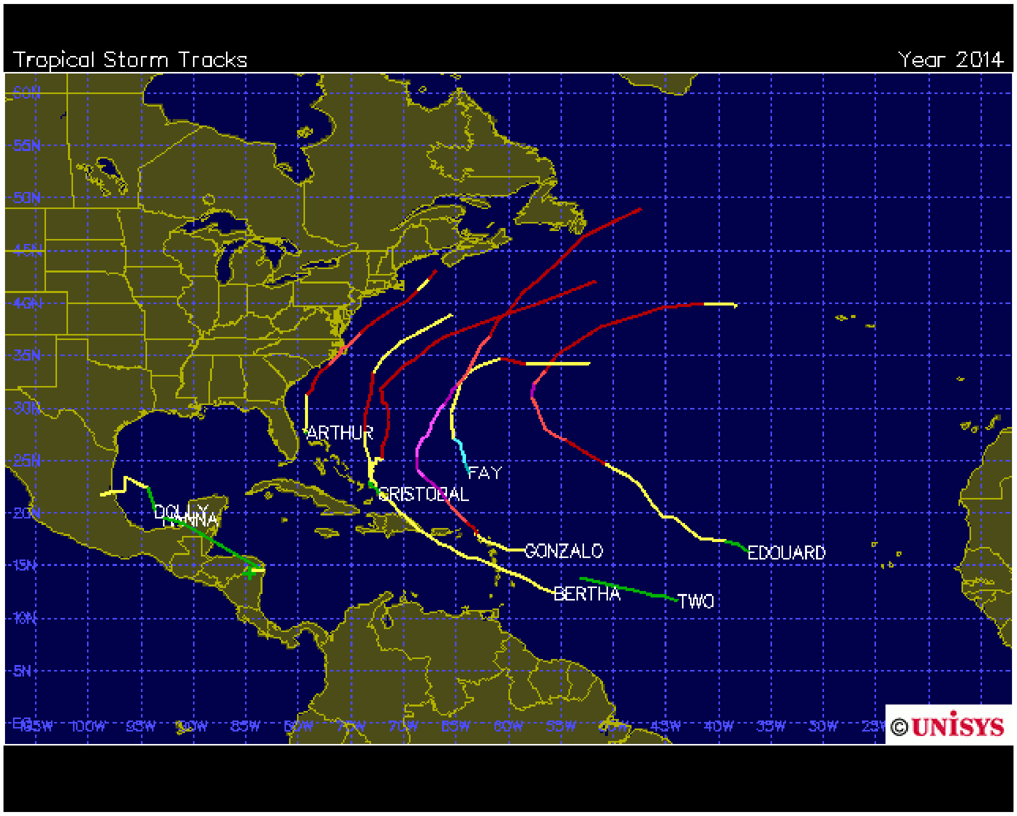


Figure A: Tracks of 2014 Atlantic Basin tropical cyclones. Figure courtesy of Unisys Weather (http://weather.unisys.com). The purple line indicates a system at major hurricane strength, the red line indicates a system at minor hurricane strength, the yellow line indicates a system at tropical storm strength, the blue line indicates a subtropical system, and the green line indicates a system at tropical depression strength

Table 2: Observed 2014 Atlantic basin tropical cyclone activity through November 18.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	MHD	ACE	NTC
H-2	Arthur (1)	July 1 - 5	85 kt/973 mb	4.00	2.00		6.8	7.3
H-1	Bertha (2)	August 1 – 6	70 kt/998 mb	5.50	0.75		5.2	6.9
H-1	Cristobal (3)	August 24 – 29	75 kt/970 mb	5.25	3.50		7.7	8.7
TS	Dolly (4)	September 2 – 3	45 kt/1003 mb	1.50			0.9	2.2
MH-3	Edouard (5)	September 12 – 19	100 kt/954 mb	7.75	4.50	0.25	15.3	18.3
H-1	Fay (6)	October 10 – 13	65 kt/986 mb	3.00	0.25		3.8	5.7
MH-4	Gonzalo (7)	October 12 – 19	125 kt/940 mb	7.25	6.25	3.25	25.6	29.4
TS	Hanna (8)	October 27	35 kt/1005 mb	0.75			0.4	2.0
Totals	8			35.00	17.25	3.50	65.7	80.6

Hurricane Arthur (#1): Arthur formed east of the Bahamas on June 30 (Figure 1). It became a tropical storm the following day as it moved slowly northward. Relatively light vertical wind shear and warm SSTs allowed for steady strengthening, and Arthur became a hurricane on July 3. It continued to intensify as it tracked northeastward across the Outer Banks as a Category 2 storm. It continued its northeastward track and began accelerating as it encountered a trough over the northeastern United States. Arthur became post-tropical on July 5. Minimal damage was reported from the storm in North Carolina, and there were no direct fatalities.

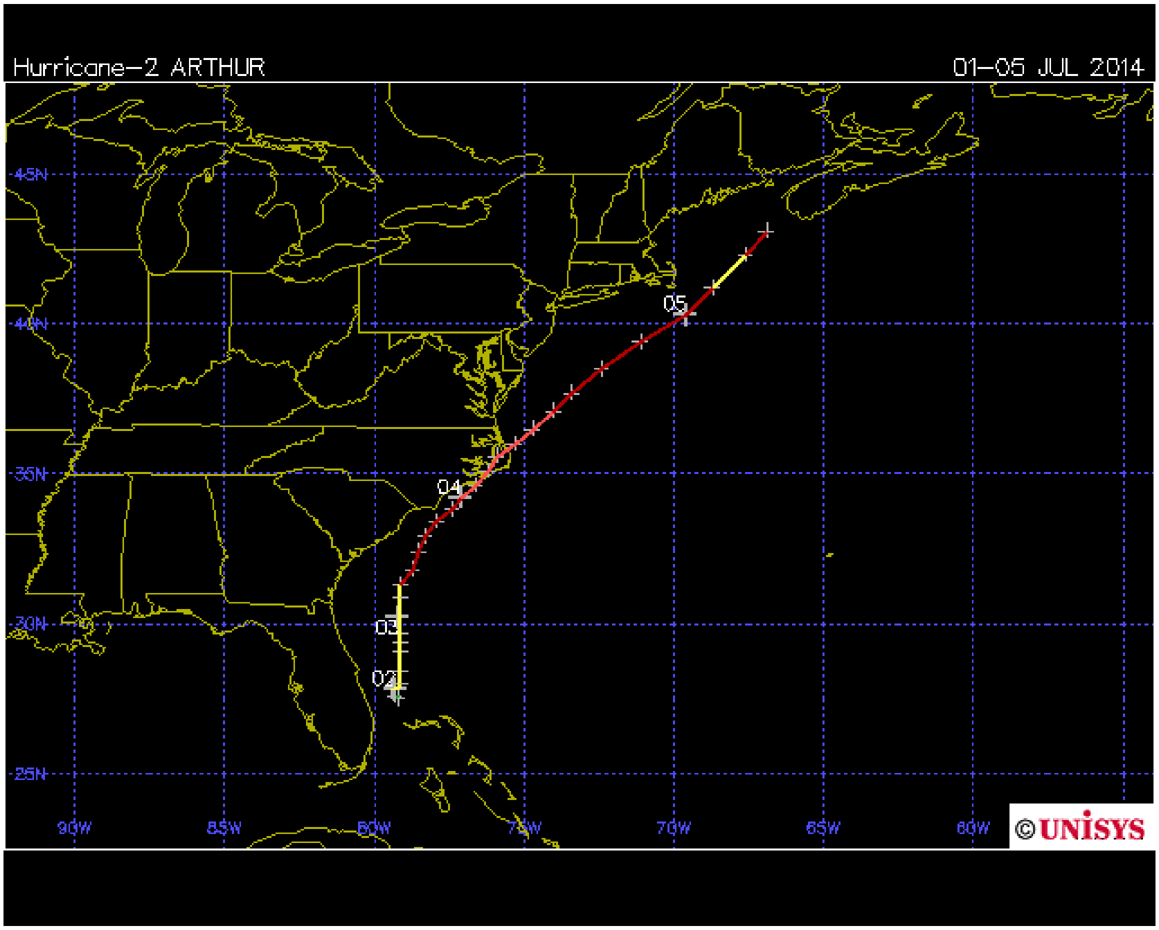


Figure 1: Track of Hurricane Arthur. Figure courtesy of Unisys Weather. The green line indicates a system at tropical depression strength, a yellow line indicates a system at tropical storm strength, while the red line indicates a system at hurricane strength.

Name	NSD	HD	MHD	ACE	NTC
Arthur	4.00	2.00	0.00	6.8	7.3

Hurricane Bertha (#2): Bertha formed east of Barbados on August 1 (Figure 2). Relatively strong southwesterly shear prevented Bertha from strengthening much during the early portion of its lifetime. The shear began to relax on August 3, and it began to strengthen, reaching hurricane intensity on August 4. It weakened back to a tropical storm as it encountered stronger vertical shear. The system accelerated northeastward while interacting with the mid-latitude westerlies and merged with a frontal system on August 6.

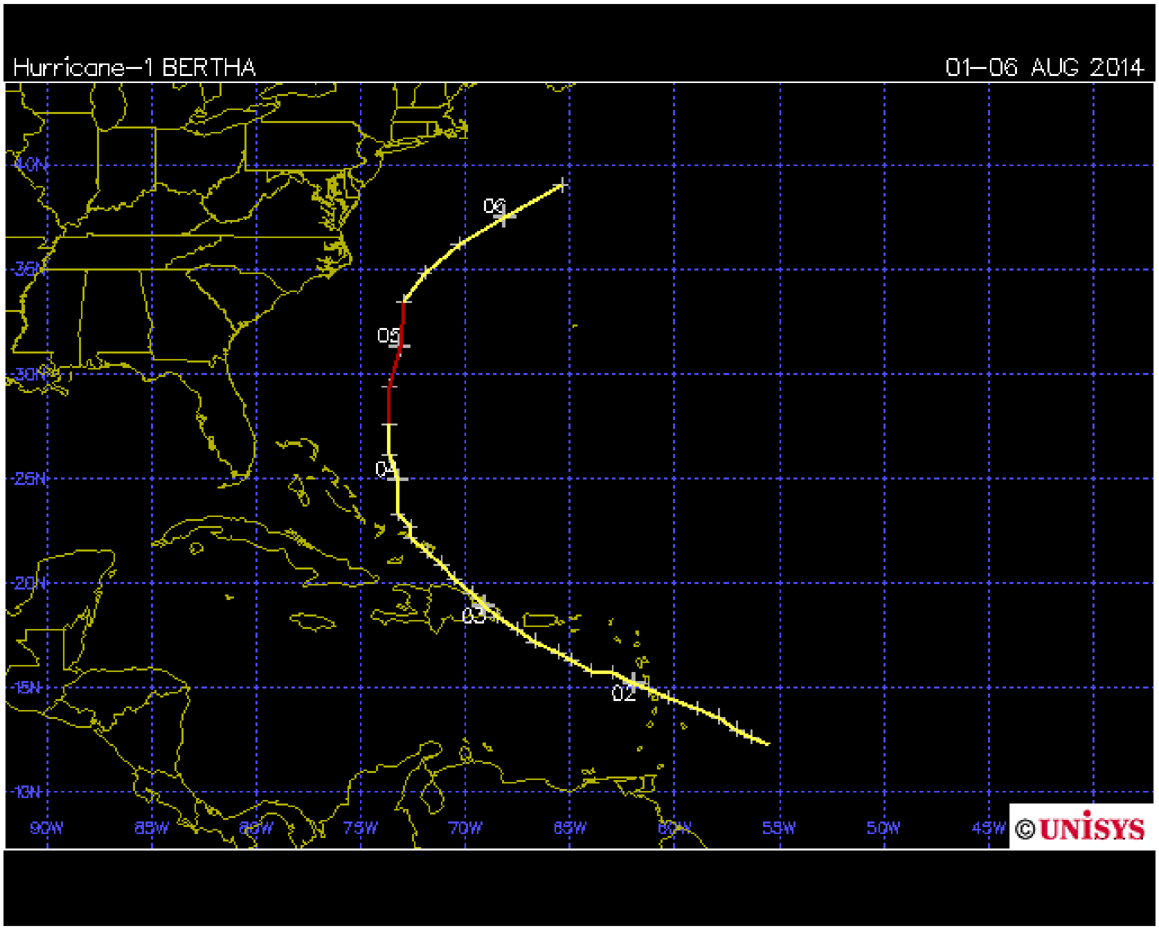


Figure 2: Track of Hurricane Bertha. Figure courtesy of Unisys Weather. The yellow line indicates a system at tropical storm strength, while the red line indicates a system at hurricane strength.

Name	NSD	HD	MHD	ACE	NTC
Bertha	5.50	0.75	0.00	5.2	6.9

<u>Hurricane Cristobal (#3)</u>: Cristobal formed near the southeastern Bahamas on August 23 (Figure 3). It intensified to a tropical storm the following day as it moved slowly northward. Despite encountering fairly strong northerly shear, Cristobal became a hurricane on August 26. It continued to move northward, steered by a subtropical ridge to its southeast and began to encounter the mid-latitude westerlies. Cristobal then rapidly accelerated northeastward and became extra-tropical on August 29.

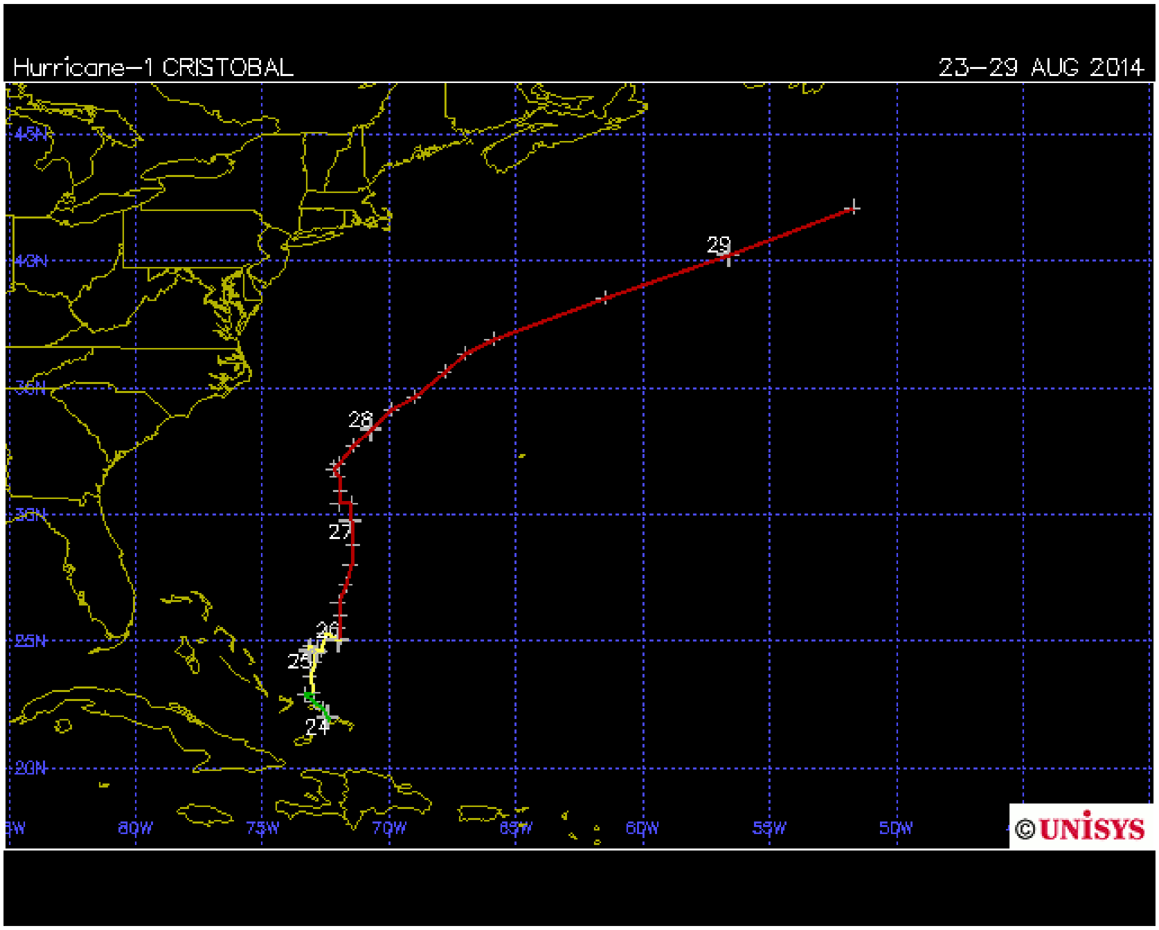


Figure 3: Track of Hurricane Cristobal. Figure courtesy of Unisys Weather. The green line indicates a system at tropical depression strength, a yellow line indicates a system at tropical storm strength, while the red line indicates a system at hurricane strength.

Name	NSD	HD	MHD	ACE	NTC
Cristobal	5.25	3.50	0.00	7.7	8.7

Tropical Storm Dolly (#4): Dolly formed in the Bay of Campeche on September 1 (Figure 4). It became a tropical storm the following day while battling moderate to strong northerly shear. A ridge to the north of Dolly steered the system westward, and it made landfall just south of Tampico early on September 3. It dissipated over the mountains of Mexico the following day. Flooding from Dolly was responsible for one fatality in Mexico.

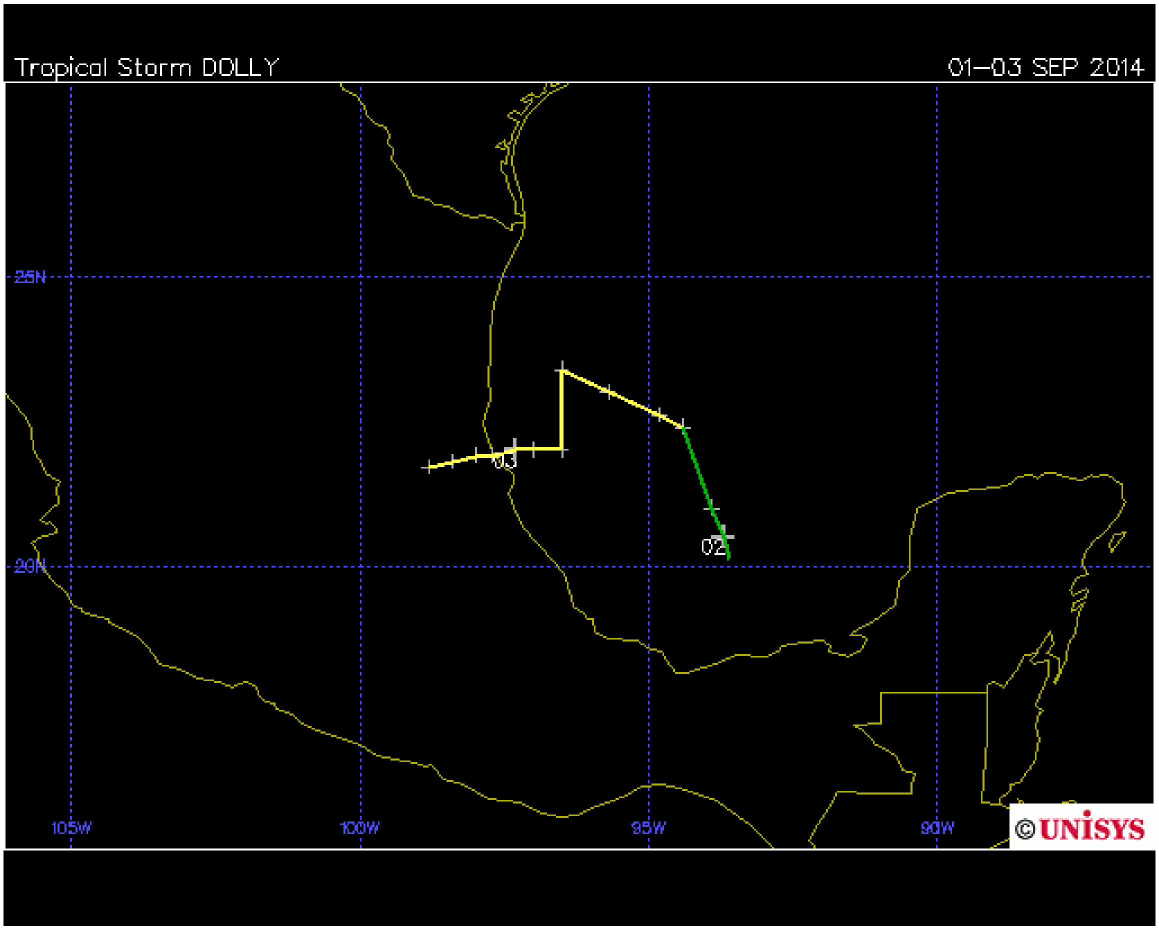


Figure 4: Track of Tropical Storm Dolly. Figure courtesy of Unisys Weather. The yellow line indicates a system at tropical storm strength, while the green line indicates a system at tropical depression strength.

Name	NSD	HD	MHD	ACE	NTC
Dolly	1.50	0.00	0.00	0.9	2.2

Major Hurricane Edouard (#5): Edouard became a tropical depression over the eastern Atlantic on September 11 (Figure 5). It was upgraded to a tropical storm the following day as it moved west-northwest underneath the subtropical ridge. Relatively strong shear prevented rapid strengthening, although Edouard did manage to slowly intensify, becoming a hurricane on September 14. The subtropical ridge north of Edouard weakened and shifted eastward, allowing Edouard to track more towards the north. By September 16, Edouard had reached major hurricane strength, although it did so only briefly before weakening in the face of cooler SSTs and increasing westerly wind shear. It began to accelerate northeastward and weakened to a tropical storm late on September 18. It became post-tropical the following day.

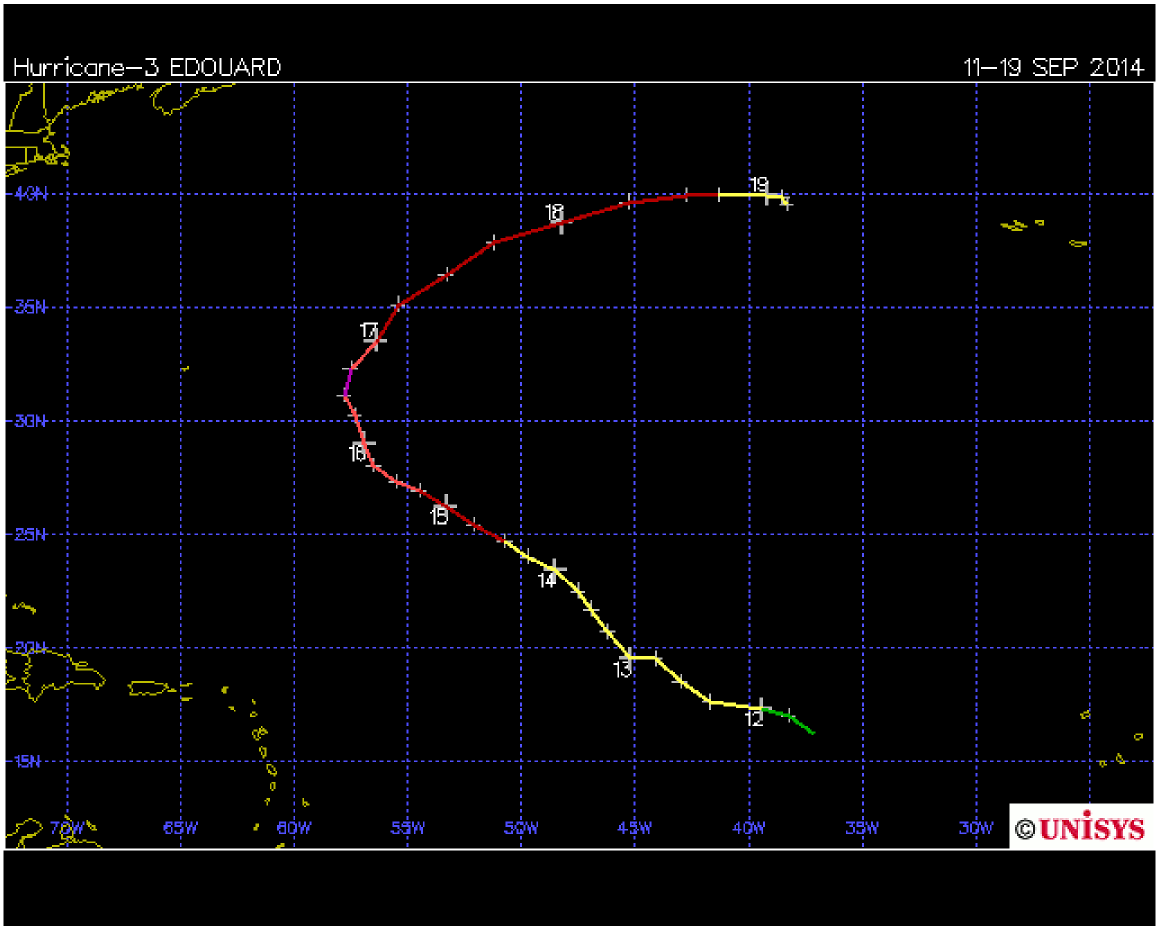


Figure 5: Track of Major Hurricane Edouard. Figure courtesy of Unisys Weather. The purple line indicates a system at major hurricane strength, the red line indicates a system at minor hurricane strength, the yellow line indicates a system at tropical storm strength, while the green line indicates a system at tropical depression strength.

Name	NSD	HD	MHD	ACE	NTC
Edouard	7.75	4.50	0.25	15.3	18.3

Hurricane Fay (#6): Fay formed north of the Leeward Islands on October 10 (Figure 6). It was upgraded to a subtropical storm later that day. It moved towards the west-northwest around the western edge of the subtropical ridge and strengthened as it did so. Despite moderate southwesterly shear, Fay reached hurricane strength as it passed by Bermuda on October 12. It began to weaken soon thereafter as it moved into an area of very strong shear and cooler SSTs. Fay merged with a frontal system later on October 13. Only minor damage on Bermuda was reported from Fay.

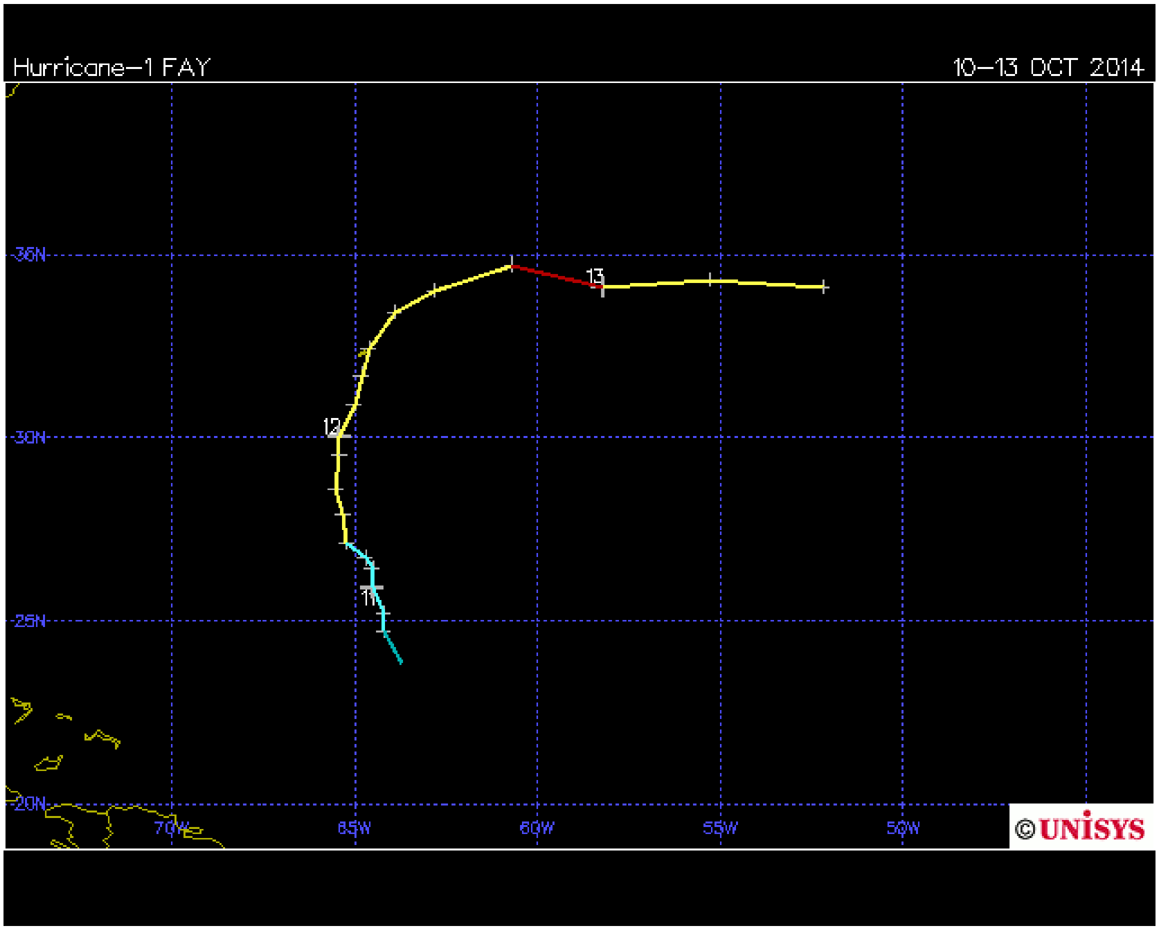


Figure 6: Track of Hurricane Fay. Figure courtesy of Unisys Weather. The red line indicates a system at minor hurricane strength, the yellow line indicates a system at tropical storm strength, while the blue line indicates a subtropical system.

Name	NSD	HD	MHD	ACE	NTC
Fay	3.00	0.25	0.00	3.8	5.7

Major Hurricane Gonzalo (#7): Gonzalo formed from a tropical wave just east of the Leeward Islands on October 12 (Figure 7). It intensified in a favorable environment of low vertical wind shear, ample mid-level moisture and warm SSTs. It became a hurricane later on October 13 and a major hurricane the following day. It did some minor damage to Antigua and Barbuda along with Saint Martin as it passed through the northern Leeward Islands. It soon intensified into a Category 4 hurricane and began to bear down on Bermuda, battering the island with wind gusts of over 100 mph. It began to slowly weaken as it moved northward. Remarkably, even as SSTs cooled dramatically, Gonzalo continued to maintain a warm core structure and was not classified as extratropical until it had reached 50°N on October 19. Its remnants battered the United Kingdom on October 21 with wind gusts exceeding 100 mph. Gonzalo was responsible for four fatalities and did approximately $200-$400 million dollars in damage in Bermuda.

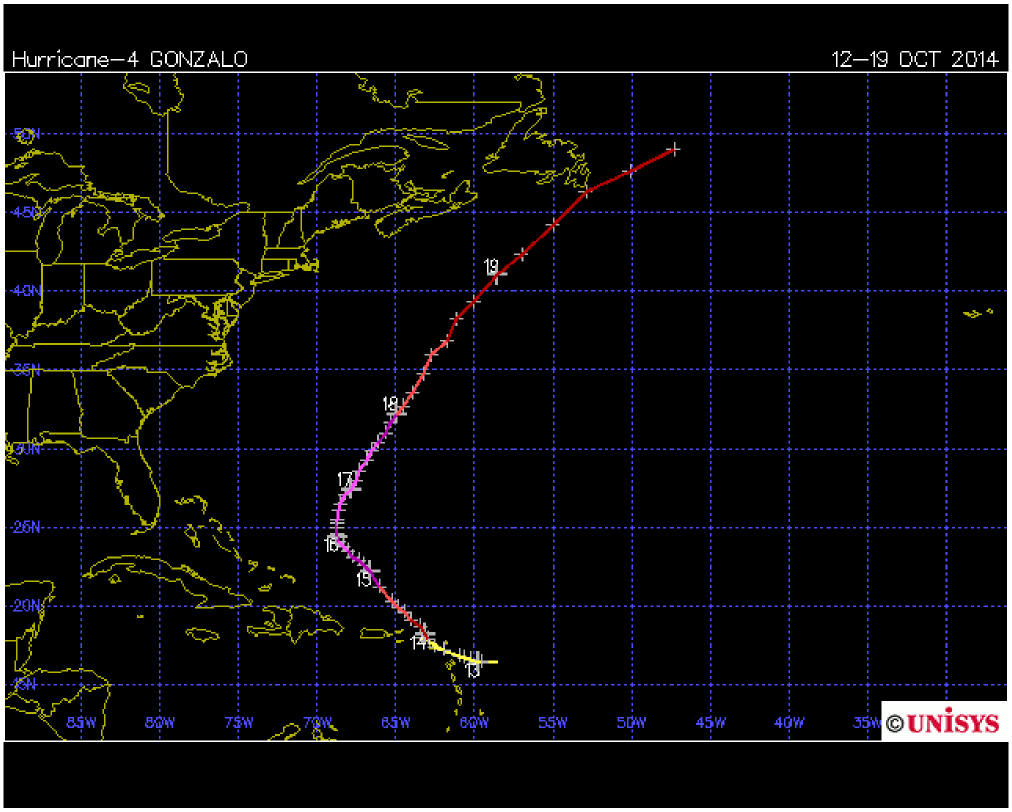


Figure 7: Track of Major Hurricane Gonzalo. Figure courtesy of Unisys Weather. The purple line indicates a system at major hurricane strength, the red line indicates a system at minor hurricane strength, and the yellow line indicates a system at tropical storm strength.

Name	NSD	HD	MHD	ACE	NTC
Gonzalo	7.25	6.25	3.25	25.6	29.4

Tropical Storm Hanna (#8): Hanna originally developed in the Bay of Campeche on October 22 as Tropical Depression Nine. It slowly drifted southeastward and made landfall along the Yucatan Peninsula before it could reach tropical storm strength. After several days transiting Central America, the remnants of Tropical Depression Nine intensified off of the coast of Nicaragua, reaching tropical storm strength on October 27. It moved inland over northeastern Nicaragua later that day and dissipated soon thereafter.

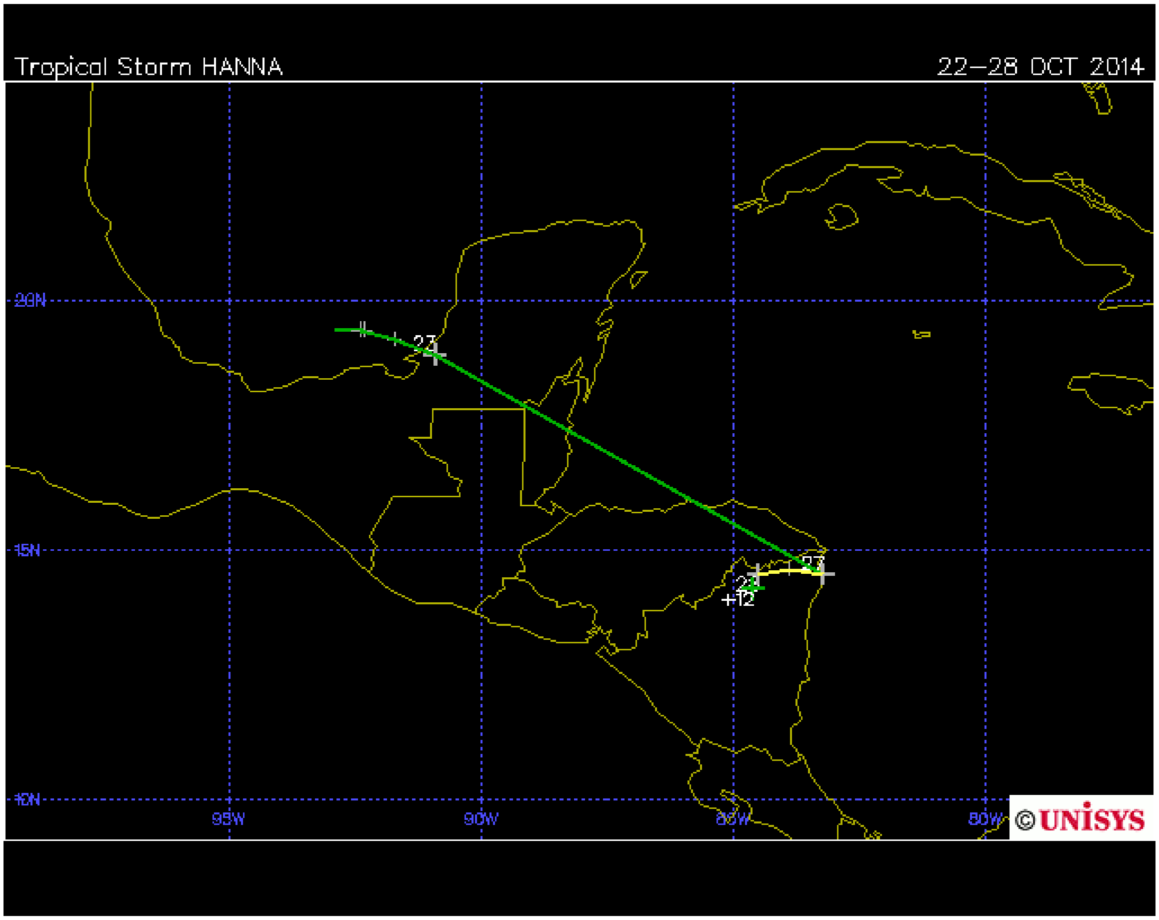


Figure 8: Track of Tropical Storm Hanna. Figure courtesy of Unisys Weather. The yellow line indicates a system at tropical storm strength, while the green line indicates a system at tropical depression strength.

Name	NSD	HD	MHD	ACE	NTC
Hanna	0.75	0.00	0.00	0.4	2.0

U.S. Landfall. Figure 9 shows the track of Hurricane Arthur, which was the only TC to make United States landfall this year. Table 3 summarizes the landfalling statistics for Arthur. Damage and fatality estimates were obtained from Wikipedia.

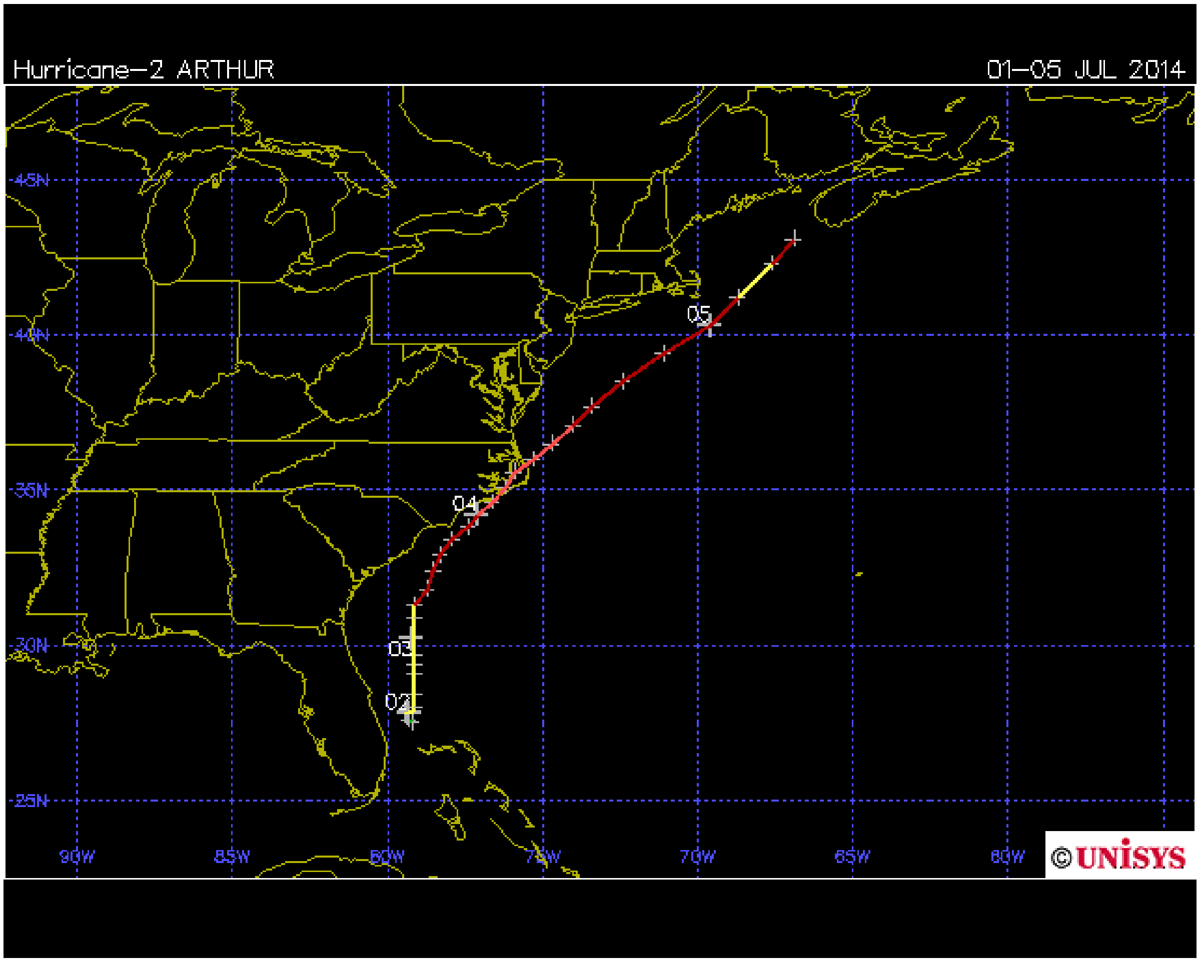


Figure 9: Track of Hurricane Arthur - the only TC to make US landfall this year. The green line indicates a system at tropical depression strength, a yellow line indicates a system at tropical storm strength, while the red line indicates a system at hurricane strength. Figure courtesy of Unisys Weather.

Table 3: Summary of US TC landfall statistics for 2014.

	Landfall Date(s)	Location(s)	Insured Damage (Millions)	Fatalities
Hurricane Arthur	July 4	NC	21	0

4 Special Characteristics of the 2014 Hurricane Season

The 2014 hurricane season had the following special characteristics:

- Eight named storms (NS) occurred during 2014. This is the fewest named storms to occur during a hurricane season since 1997 (8 NS)

- Only two of the eight named storms that formed failed to reach hurricane strength. The last season to have two or fewer named storms fail to reach hurricane strength was 1986 (when 6 NS and 4 H formed)

- 35 named storm days (NSD) occurred during 2014. This is the fewest named storms to occur during a hurricane season since 2009 (30 NSD).

- Gonzalo's maximum intensity was 125 knots. The last 125-knot or greater storm in the Atlantic was Igor (2010).

- Gonzalo was classified as a hurricane at 50.7°N. This is the farthest north that a TC has been classified as a hurricane since Debby in 1982 (50.8°N).

- Arthur was the strongest storm (Category 2 at landfall) to impact the US since Hurricane Ike (also Category 2 at landfall) in 2008.

- No major hurricanes made US landfall in 2014. The last major hurricane to make US landfall was Wilma (2005), so the US has now gone nine years without a major hurricane landfall. The US has never had a nine-year period without a major hurricane landfall, eclipsing the previous record of eight years set from 1861-1868.

- Florida has gone without a hurricane impact since 2005 (nine years). This is the longest consecutive year period on record that Florida has not had a landfall (since 1851). The longest previous record was only five years set from 1980-1984.

- July-September-averaged 200-850-mb vertical wind shear in the Caribbean (10-20°N, 90-60°W) was 11.3 ms^{-1} which was the strongest since 1986 (11.6 ms^{-1}).

- More ACE was accrued during October (30 units) than during August and September combined (29 units). The last time that this happened was 1963.

5 Verification of Individual 2014 Lead Time Forecasts

Table 4 is a comparison of our forecasts for 2014 for four different lead times along with this year's observations. The 2014 Atlantic hurricane season was characterized by somewhat below-average levels of overall basinwide activity.

Table 4: Verification of our 2014 seasonal hurricane predictions.

Forecast Parameter and 1981-2010 Median (in parentheses)	10 April 2014	Update 2 June 2014	Update 1 July 2014	Update 31 July 2014	Observed 2014 Total	% of 1981-2010 Median
Named Storms (NS) (12.0)	9	10	10	10	8	67%
Named Storm Days (NSD) (60.1)	35	40	40	40	35	58%
Hurricanes (H) (6.5)	3	4	4	4	6	92%
Hurricane Days (HD) (21.3)	12	15	15	15	17.25	81%
Major Hurricanes (MH) (2.0)	1	1	1	1	2	100%
Major Hurricane Days (MHD) (3.9)	2	3	3	3	3.50	96%
Accumulated Cyclone Energy (ACE) (92)	55	65	65	65	66	70%
Net Tropical Cyclone Activity (NTC) (103%)	60	70	70	70	81	79%

Table 5 provides the same forecasts, with error bars (based on one standard deviation of absolute errors) as calculated from real-time forecasts from 1995-2013. We typically expect to see two-thirds of our forecasts verify within one standard deviation of observed values, with 95% of forecasts verifying within two standard deviations of observed values. Since July forecasts have only been issued in real-time for one year, we estimate that the July forecast should have errors halfway in between the errors of the June and August forecasts. Since we have only issued ACE forecasts for the past few years, we estimate ACE errors to be the same as NTC errors. This year's seasonal forecasts were generally quite good.

Table 5: Verification of our 2014 seasonal hurricane predictions with error bars (one standard deviation). Predictions that lie within one standard deviation of observations are highlighted in red bold font, while predictions that lie within two standard deviations are highlighted in green bold font. Predictions that are outside of two standard deviations are highlighted in black bold font. In general, we expect that two-thirds of our forecasts should lie within one standard deviation of observations, with 95% of our forecasts lying within two standard deviations of observations. All forecast parameters except for our early April forecast of hurricanes were within one standard deviation of observations, indicating a very successful forecast. Error bars for storms are rounded to the nearest storm. For example, the hurricane prediction in early April would be 0.8-5.2, which with rounding would be 1-5.

Forecast Parameter and 1981-2010 Median (in parentheses)	10 April 2014	Update 2 June 2014	Update 1 July 2014	Update 31 July 2014	Observed 2014 Total
Named Storms (NS) (12.0)	**9** (±3.6)	**10** (±2.9)	**10** (±2.6)	**10** (±2.2)	8
Named Storm Days (NSD) (60.1)	**35** ±(20.1)	**40** (±19.9)	**40** (±18.1)	**40** (±16.2)	35
Hurricanes (H) (6.5)	**3** (±2.2)	**4** (±2.0)	**4** (±1.8)	**4** (±1.7)	6
Hurricane Days (HD) (21.3)	**12** (±11.2)	**15** (±10.7)	**15** (±10.1)	**15** (±9.5)	17.25
Major Hurricanes (MH) (2.0)	**1** (±1.4)	**1** (±1.4)	**1** (±1.2)	**1** (±1.0)	2
Major Hurricane Days (MHD) (3.9)	**2** (±4.0)	**3** (±3.7)	**3** (±3.9)	**3** (±4.1)	3.50
Accumulated Cyclone Energy (ACE) (92)	**55** (±42)	**65** (±40)	**65** (±36)	**65** (±31)	66
Net Tropical Cyclone Activity (NTC) (103%)	**60** (±42)	**70** (±40)	**70** (±36)	**70** (±31)	81

5.1 Preface: Aggregate Verification of our Last Sixteen Yearly Forecasts

Another way to consider the skill of our forecasts is to evaluate whether the forecast for each parameter successfully forecast above- or below-average activity. Table 6 displays how frequently our forecasts have been on the right side of climatology for the past sixteen years. In general, our forecasts are successful at forecasting whether the season will be more or less active than the average season by as early as April. We tend to have improving skill as we get closer in time to the start of the hurricane season.

Table 6: The number of years that our tropical cyclone forecasts issued at various lead times have correctly predicted above- or below-average activity for each predictand over the past sixteen years (1999-2014).

Tropical Cyclone Parameter	**Early April**	**Early June**	**Early August**
NS	13/16	14/16	13/16
NSD	12/16	12/16	12/16
H	12/16	12/16	12/16
HD	10/16	11/16	12/16
MH	11/16	12/16	13/16
MHD	11/16	12/16	12/16
NTC	10/16	11/16	13/16
Total	**79/112 (71%)**	**84/112 (75%)**	**87/112 (78%)**

Of course, there are significant amounts of unexplained variance for a number of the individual parameter forecasts. Even though the skill for some of these parameter forecasts is somewhat low, there is a great curiosity in having some objective measure as to how active the coming hurricane season is likely to be. Therefore, even a forecast that is only modestly skillful is likely of some value. In addition, we have recently redesigned all our statistical forecast methodologies using more rigorous physical and statistical tests which we believe will lead to more accurate forecasts in the future. Despite the large forecast bust last year, in general, our forecasts in recent years have shown significant improvements in skill relative to our earlier predictions. Complete verifications of all seasonal forecasts are available online at http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls. Verifications are currently available for all of our prior seasons from 1984-2013. This spreadsheet will be updated with 2014's values once the National Hurricane Center finishes its post-season analysis of all storms that formed this year.

5.2 Verification of Two-Week Forecasts

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

The metric that we tried to predict with these two-week forecasts is the Accumulated Cyclone Energy (ACE) index, which is defined to be the square of the named storm's maximum wind speeds (in 10^4 knots^2) for each 6-hour period of its existence over the two-week forecast period. These forecasts are too short in length to show significant skill for individual event parameters such as named storms and hurricanes. We issued forecasts for ACE using three categories as defined in Table 7.

Table 7: ACE forecast definition for two-week forecasts.

Parameter	Definition
Above-Average	Greater than 130% of Average ACE for the Two-Week Period
Average	70% - 130% of Average ACE for the Two-Week Period
Below-Average	Less than 70% of Average ACE for the Two-Week Period

Table 8 displays the six two-week forecasts that were issued during the 2014 hurricane season and shows their verification. We correctly predicted five of the six two-week periods, with a significant under-forecast in the final two-week period when both Fay and Gonzalo formed.

Table 8: Two-week forecast verification for 2014. Forecasts that verified in the correct category are highlighted in blue, forecasts that missed by one category are highlighted in green, while forecasts that missed by two categories are highlighted in red.

Forecast Period	Predicted ACE	Observed ACE
7/31 – 8/13	**Average (3-5)**	**5**
8/14 – 8/27	**Below-Average (8 or Less)**	**8**
8/28 – 9/10	**Below–Average (16 or Less)**	**4**
9/11 – 9/24	**Below-Average (18 or Less)**	**15**
9/25 – 10/8	**Below-Average (8 or Less)**	**0**
10/9 – 10/22	**Average (4-8)**	**29**

The MJO was fairly weak and disorganized during 2014, with most of the period from late August through early October spent in the middle of the circle (indicating an amplitude of the MJO of less than one) (Figure 10).

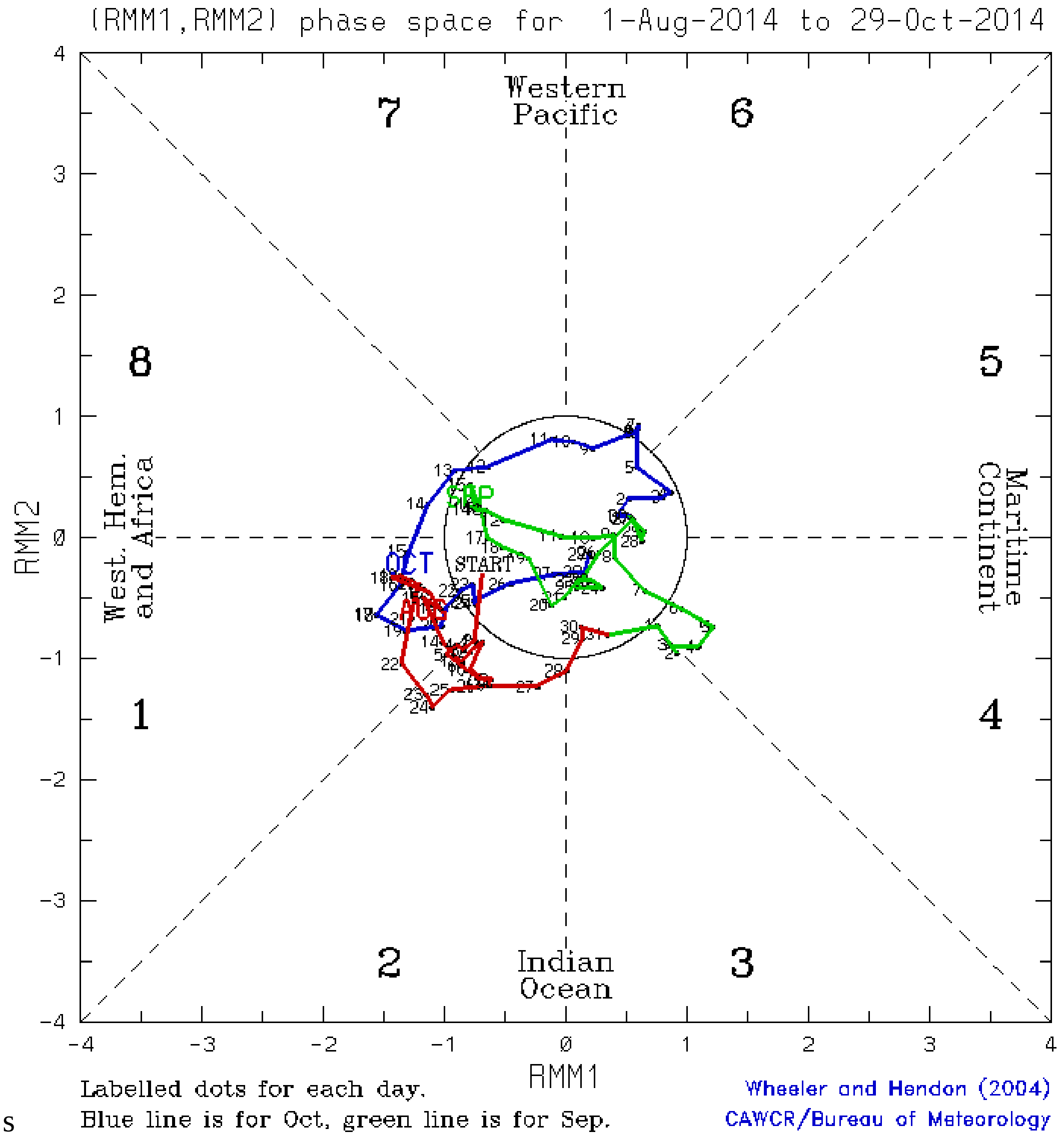


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Figure 10: Propagation of the Madden-Julian Oscillation (MJO) based on the Wheeler-Hendon classification scheme over the period from August 1 to October 29. The MJO was generally weak during the peak months of this year's Atlantic hurricane season. The Maritime Continent refers to Indonesia and the surrounding islands. RMM stands for Real-Time Multivariate MJO. The red line represents August values, the green line represents September values and the blue line represents October values.

5.3 Verification of October-November Caribbean Basin Forecast

Our October-November Caribbean basin forecast for hurricane days and ACE in the Caribbean verified well. This model effectively uses two predictors: 1) the state of ENSO, and 2) the size of the Atlantic Warm Pool. These predictors called for a somewhat below-average end of the season in the Caribbean. Gonzalo generated all of the activity observed in the Caribbean in October-November, which equated to activity at somewhat below-average levels. Table 9 displays the predicted and observed values of hurricane days and ACE for October-November in the Caribbean.

Table 9: Predicted versus observed October-November Caribbean basin hurricane days and ACE.

Forecast Parameter and 1981-2010 Climatology (in parentheses)	Forecast	Observed
Hurricane Days (1.25)	0.5	1
Accumulated Cyclone Energy Index (6.3)	3	3

6 Landfall Probabilities

Every hurricane season, we issue forecasts of the seasonal probability of hurricane landfall along the U.S. coastline as well as the Caribbean. Whereas individual hurricane landfall events cannot be accurately forecast, the net seasonal probability of landfall can be issued using past climatology and this year's forecast in combination. Our landfall probabilities have statistical skill, especially over several-year periods. With the premise that landfall is a function of varying climate conditions, U.S. probabilities have been calculated through a statistical analysis of all U.S. hurricane and named storm landfalls during a 100-year period (1900-1999). Specific landfall probabilities can be given for all tropical cyclone intensity classes for a set of distinct U.S. coastal regions. Net landfall probability is statistically related to overall Atlantic basin Net Tropical Cyclone (NTC) activity. Table 10 gives verifications of our landfall probability estimates for the United States and for the Caribbean in 2014.

Landfall probabilities for the 2014 hurricane season were estimated to be below their long-period averages for all predictions due to the forecasts of a below-average hurricane season. The 2014 hurricane season was quiet from a U.S. landfall perspective, with only one hurricane (Arthur) making U.S. landfall this year. Average U.S. landfalling statistics since 1900 are that 3.5 named storms, 1.8 hurricanes and 0.7 major hurricanes make U.S. landfall per year.

Three tropical cyclones passed through the Caribbean (10-20°N, 60-88°W) during 2014. Both Bertha and Hanna were at tropical storm strength as they tracked through the Caribbean, while Gonzalo reached Category 2 strength while tracking through the area.

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

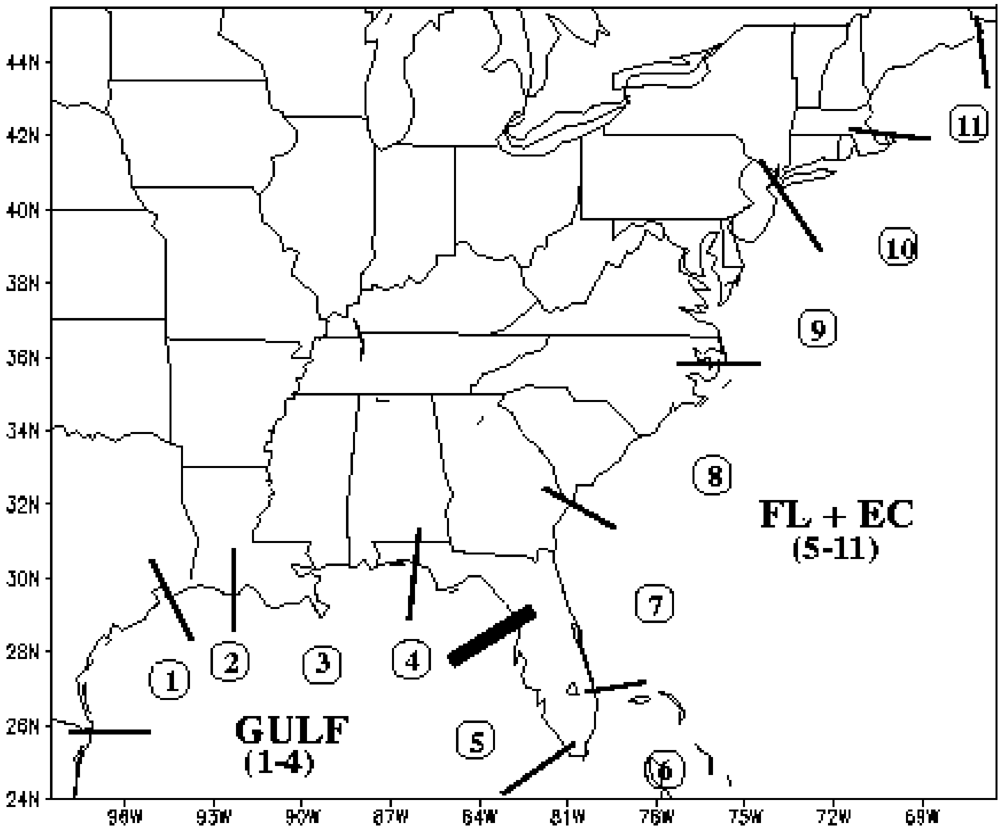


Figure 11: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made. These subdivisions were determined by the historical frequency of landfalling major hurricanes.

Table 10: Estimated forecast probability (percent) of one or more landfalling tropical storms (TS), category 1-2 hurricanes, and category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (Regions 1-4), along the Florida Peninsula and the East Coast (Regions 5-11) and in the Caribbean for 2014 at various lead times. The mean annual percentage of one or more landfalling systems during the 20th century is given in parentheses in the 31 July forecast column. Table (a) is for the entire United States, Table (b) is for the U.S. Gulf Coast, Table (c) is for the Florida Peninsula and the East Coast and Table (d) is for the Caribbean. Early August probabilities are calculated based on storms forming after 1 August.

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

	10 Apr.	2 June	1 July	31 July	Observed Number
TS	61%	67%	67%	64% (80%)	0
HUR (Cat 1-2)	49%	55%	55%	52% (68%)	1
HUR (Cat 3-4-5)	35%	40%	40%	38% (52%)	0
All HUR	67%	73%	73%	70% (84%)	1
Named Storms	87%	91%	91%	89% (97%)	1

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

	10 Apr.	2 June	1 July	31 July	Observed Number
TS	41%	46%	46%	44% (59%)	0
HUR (Cat 1-2)	28%	32%	32%	30% (42%)	0
HUR (Cat 3-4-5)	19%	22%	22%	21% (30%)	0
All HUR	42%	47%	47%	45% (61%)	0
Named Storms	66%	71%	71%	69% (83%)	0

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

	10 Apr.	2 June	1 July	31 July	Observed Number
TS	34%	39%	39%	37% (51%)	0
HUR (Cat 1-2)	29%	33%	33%	31% (45%)	1
HUR (Cat 3-4-5)	20%	23%	23%	21% (31%)	0
All HUR	43%	49%	49%	46% (62%)	1
Named Storms	63%	68%	68%	66% (81%)	1

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

	10 Apr.	2 June	1 July	31 July	Observed Number
TS	64%	70%	70%	67% (82%)	2
HUR (Cat 1-2)	40%	45%	45%	42% (57%)	1
HUR (Cat 3-4-5)	28%	32%	32%	30% (42%)	0
All HUR	56%	62%	62%	59% (75%)	1
Named Storms	85%	89%	89%	87% (96%)	3

7 Summary of Atmospheric/Oceanic Conditions

In this section, we go into detail discussing large-scale conditions that we believe significantly impacted the 2014 Atlantic basin hurricane season in either a favorable or unfavorable manner.

7.1 ENSO

El Niño-Southern Oscillation (ENSO) was poorly predicted by most of the dynamical and statistical model guidance. Our forecast assessment was also too warm compared with observations. In general, most models were predicting a weak to moderate El Niño event, while observed conditions were at warm ENSO-neutral levels. While our ENSO intensity estimate was somewhat too warm, overall conditions in the Atlantic behaved similarly to El Niño in certain respects. Vertical wind shear was much stronger than normal, especially in the Caribbean, and mass subsidence was observed across most of the basin. Here are a few quotes from our various forecasts discussing the current and predicted state of ENSO.

(10 April 2014) –

“The average of the various ECMWF ensemble members is calling for a September Nino 3.4 SST anomaly of approximately 1.2°C. There is a fairly widespread range in the outcomes predicted by the various ensemble members, which indicates the large degree of uncertainty in future ENSO conditions. In general, we put more credence in the ECMWF prediction than in forecasts from the other models, and consequently, we are calling for a stronger El Niño than the median of the forecasts.”

(2 June 2014) –

“Based on the above information, our best estimate is that we will likely transition to warm ENSO conditions for the peak of the Atlantic hurricane season. The buildup of upper ocean heat content in the eastern and central tropical Pacific has continued over the past two months, although at a somewhat slower rate in recent weeks. Trade winds across the central tropical Pacific generally remain somewhat weaker than normal.“

(31 July 2014) –

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

In general, neutral ENSO conditions have persisted across the tropical Pacific for the past twelve months, although SSTs have been significantly warmer than normal in the eastern Pacific for the past few months. Table 11 displays anomalies in the various Nino regions in January, April, July and October 2014, respectively.

Table 11: January anomalies, April anomalies, July anomalies, and October anomalies for the Nino 1+2, Nino 3, Nino 3.4 and Nino 4 regions. SST anomaly differences from January 2014 are in parentheses.

Region	January 2014 Anomaly (ºC)	April 2014 Anomaly (ºC)	July 2014 Anomaly (ºC)	October 2014 Anomaly (ºC)
Nino 1+2	+0.3	-0.4 (-0.7)	+1.4 (+1.1)	+0.8 (+0.5)
Nino 3	-0.4	+0.2 (+0.6)	+0.7 (+1.1)	+0.6 (+1.0)
Nino 3.4	-0.5	+0.2 (+0.7)	+0.2 (+0.7)	+0.4 (+0.9)
Nino 4	-0.2	+0.6 (+0.8)	+0.3 (+0.5)	+0.6 (+0.8)

One of the primary reasons why we anticipated a significant El Niño event this year was due to several strong downwelling Kelvin waves that occurred during the late winter/early spring of 2014 (Figure 12). These Kelvin waves led to a significant increase in upper ocean heat content in the eastern and central tropical Pacific (Figure 13). However, the strong westerly wind bursts that triggered these Kelvin waves subsided significantly after this point, and the upper ocean heat content decreased markedly until late July. Since that point, upper ocean heat content has increased somewhat as the trade winds have slacked somewhat near the International Date Line in recent weeks.

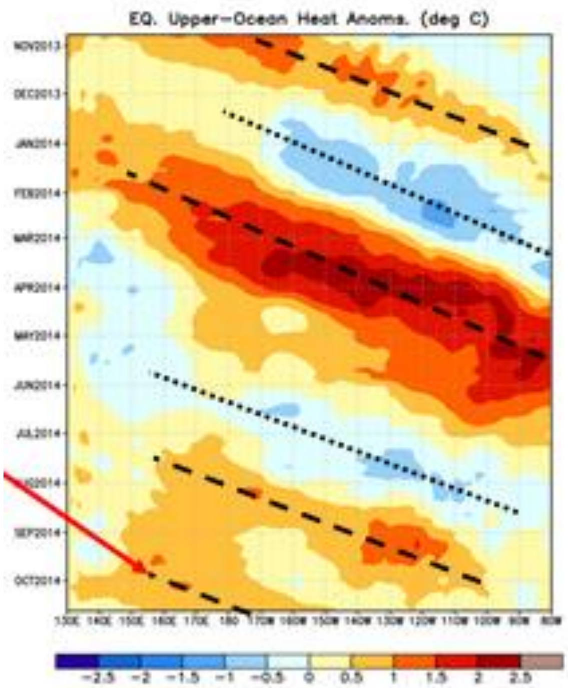


Figure 12: Upper ocean heat content anomalies since November 2013. Dashed lines indicate downwelling (warming) in the leading portion of the Kelvin wave, while the dotted lines indicate upwelling (cooling) in the trailing portion of the Kelvin wave. The red line highlights the current warming Kelvin wave propagating across the tropical Pacific.

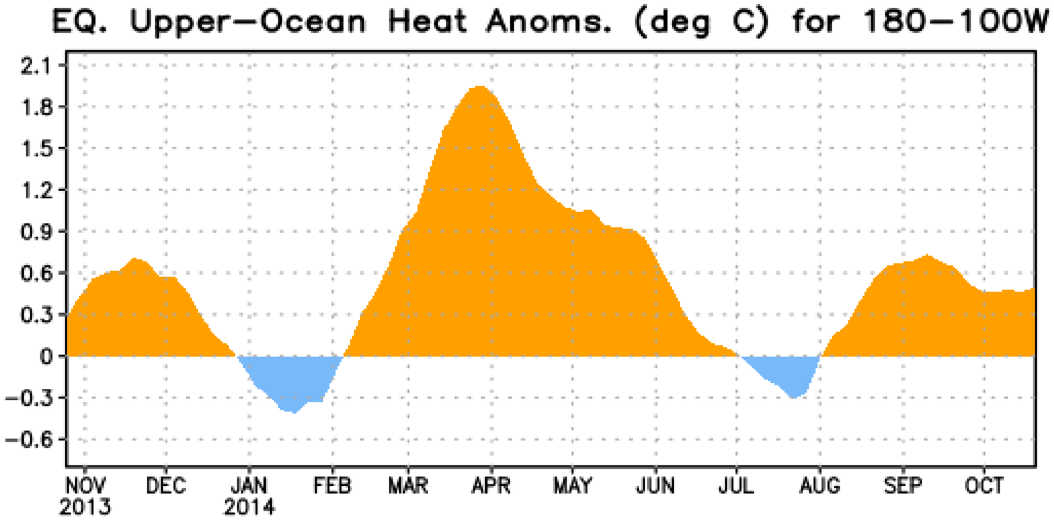


Figure 13: Upper ocean (0-300 meter) heat content anomalies in the eastern and central tropical Pacific from November 2013 – October 2014. Note the large increase in upper ocean heat content from January – March 2014 and the concomitant large decrease until late July.

7.2 Intra-Seasonal Variability

Intra-seasonal (MJO) variability was relatively weak during the peak months of this year's Atlantic hurricane season. Most of the period from late August through early October was spent in the middle of the circle (indicating an amplitude of the MJO of less than one) (Figure 14). Table 12 displays the number of TC formations by MJO phase during the 2014 Atlantic hurricane season. Distinctive differences between MJO phase and TC formations were not observed in 2014. Table 13 displays the normalized values of TC activity by MJO phase from 1974-2007.

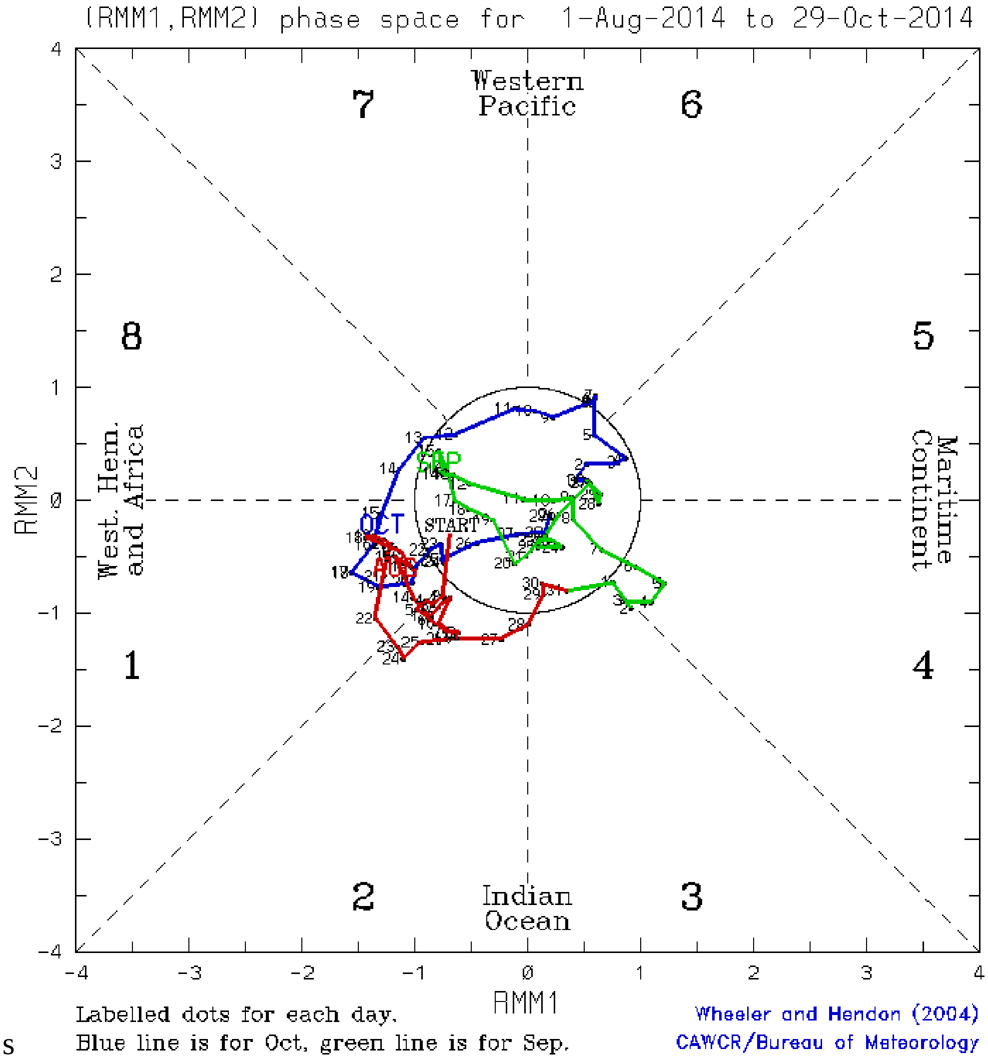


Figure 14: Propagation of the Madden-Julian Oscillation (MJO) based on the Wheeler-Hendon classification scheme over the period from August 1 to October 29. The MJO was generally weak during the peak months of this year's Atlantic hurricane season. The Maritime Continent refers to Indonesia and the surrounding islands. RMM stands for Real-Time Multivariate MJO.

Table 12: TC formations by MJO phase during the 2014 Atlantic hurricane season.

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

Table 13: Normalized values of named storms (NS), named storm days (NSD), hurricanes (H), hurricane days (HD), major hurricanes (MH), major hurricane days (MHD) and Accumulated Cyclone Energy (ACE) generated by all tropical cyclones forming in each phase of the MJO over the period from 1974-2007. Normalized values are calculated by dividing storm activity by the number of days spent in each phase and then multiplying by 100. This basically provides the level of TC activity that would be expected for 100 days given a particular MJO phase.

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

7.3 Atlantic SST

As was the case in 2013, the Atlantic was characterized by significant changes in SST over the course of 2014. The SST pattern observed during March of 2014 was more indicative of a weak THC, with cold anomalies observed in the tropical and North Atlantic and warm anomalies off of the US East Coast (Figure 15).

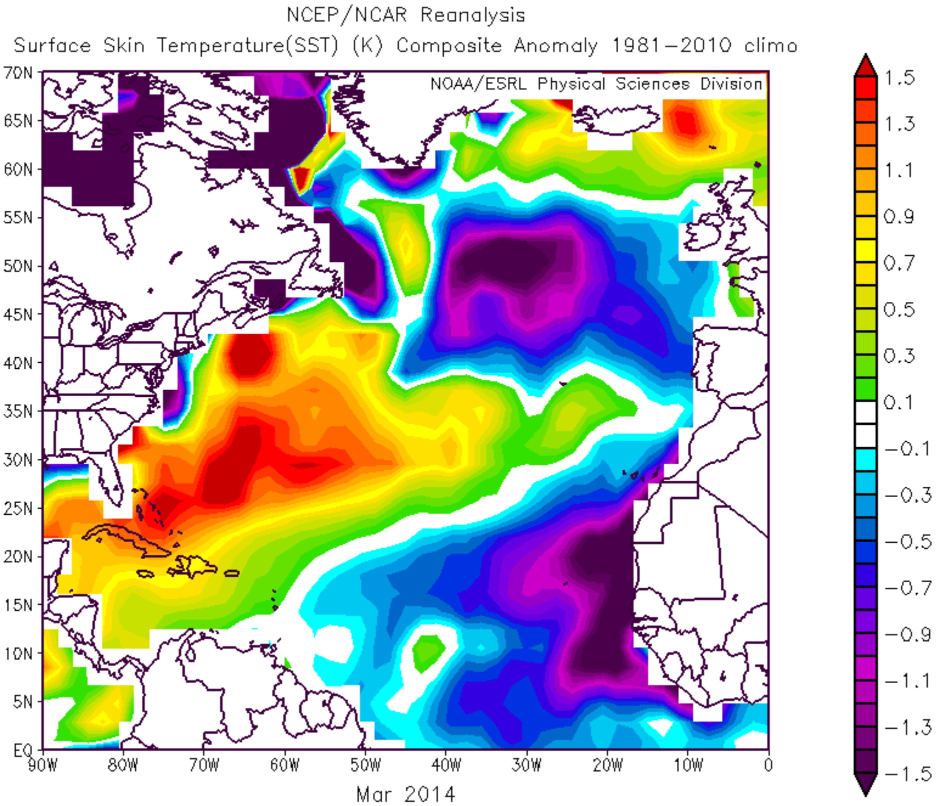


Figure 15: March 2014 SST anomalies across the Atlantic basin. Note the cold anomalies that pervaded both the tropical and far North Atlantic.

However, over the next several months, a negative North Atlantic Oscillation (NAO) developed (Figure 16). A negative NAO is associated with anomalously weak trade winds which reduced mixing and upwelling in the tropical and subtropical Atlantic, causing warming. Figure 17 displays the anomalous SST pattern change that took place across the Atlantic from late March to late June. Note the significant anomalous warming that took place, both in the tropical and far north Atlantic, indicative of a strengthening AMO/THC signal.

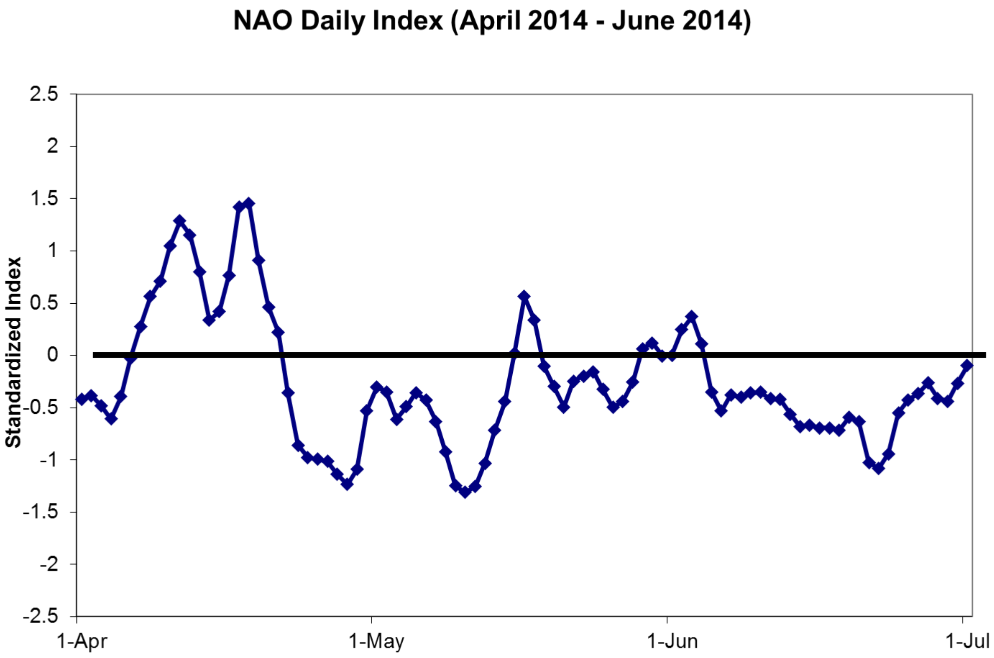


Figure 16: Daily values of the North Atlantic Oscillation (NAO) from April-June 2014. Negative values of the NAO dominated during this three-month period.

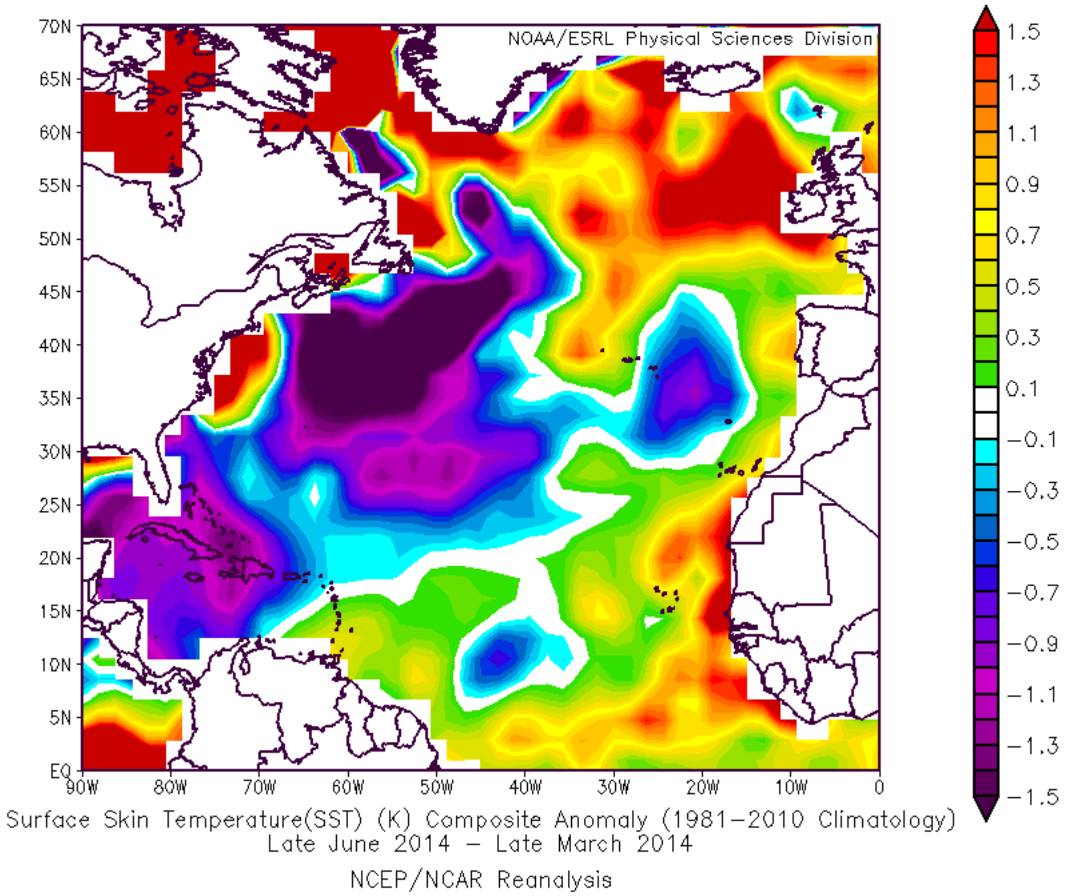


Figure 17: Late June 2014 - late March 2014 anomalous SST change across the Atlantic basin. Note the anomalous warming that occurred in the tropical and especially in the North Atlantic.

Since the end of July, SSTs in the tropical Atlantic have continued to warm (Figure 18). The current SST anomaly pattern is typically one associated with active Atlantic hurricane seasons (Figure 19).

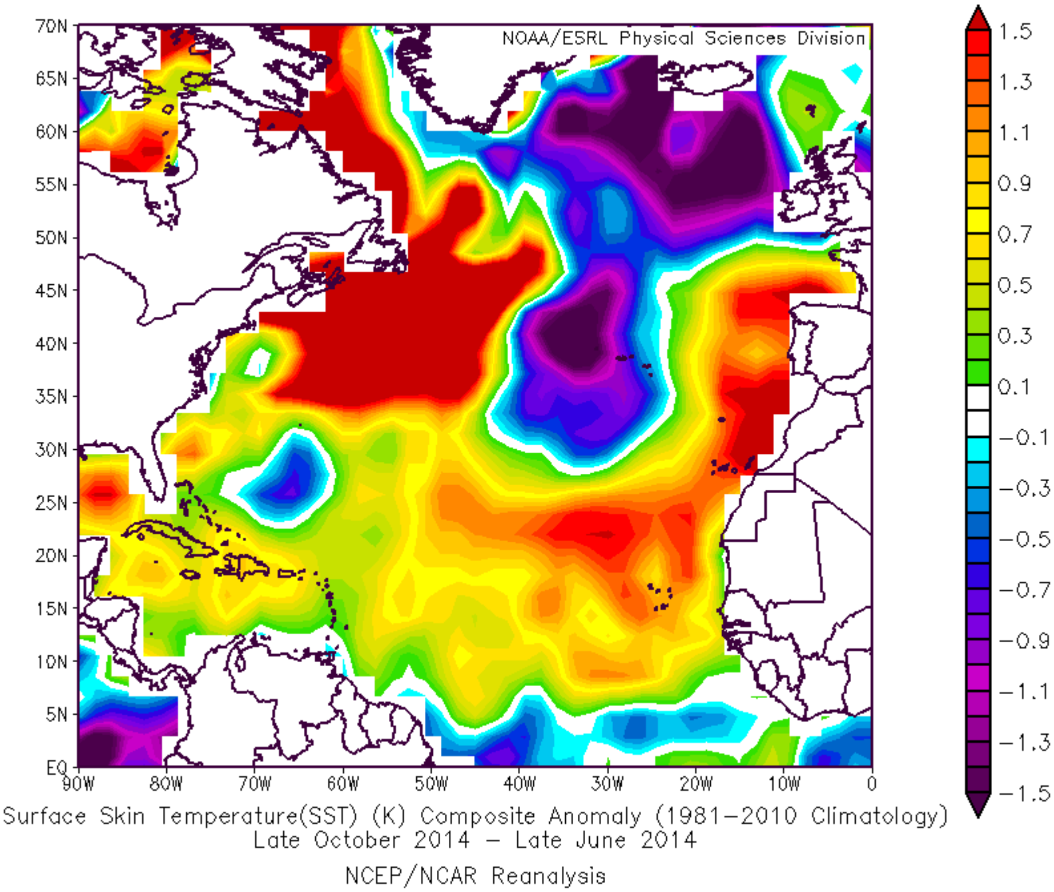
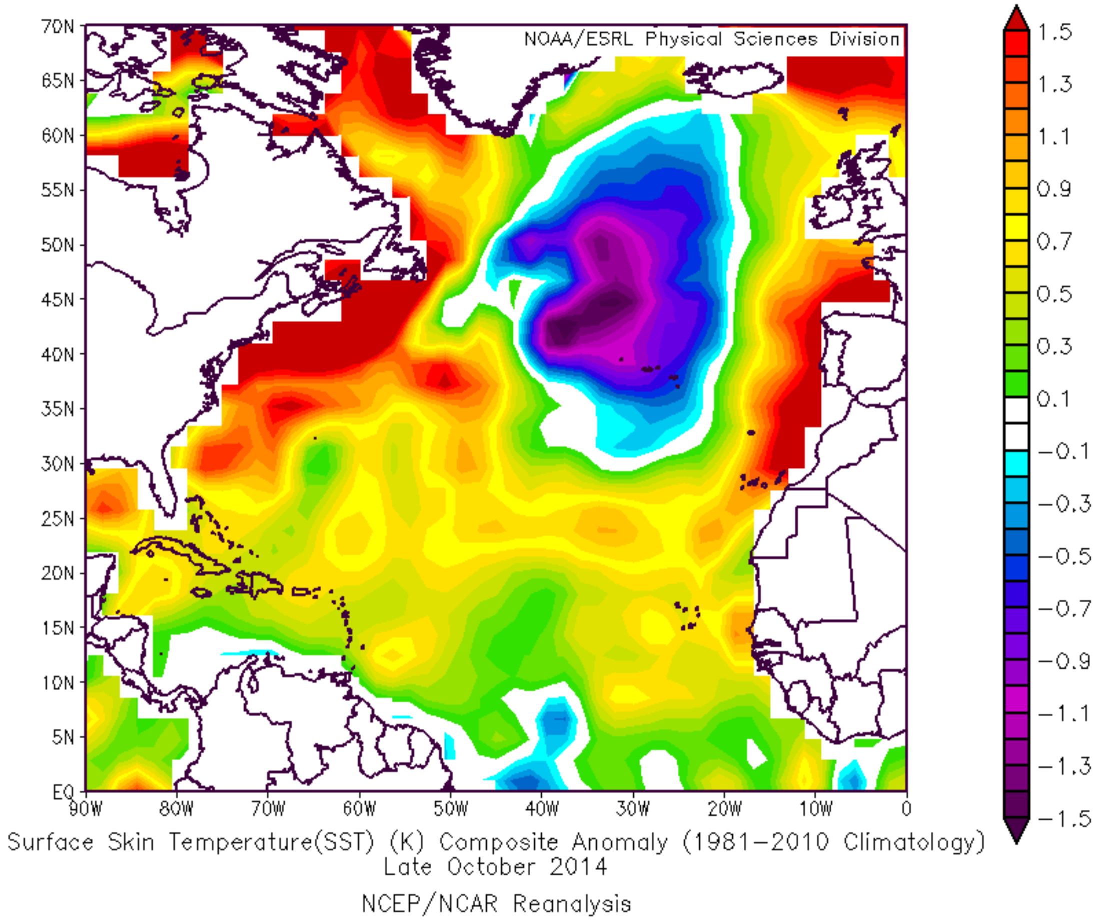


Figure 18: Late October 2014 - late June 2014 anomalous SST change across the Atlantic basin. Most of the basin has continued to experience warming.



Surface Skin Temperature(SST) (K) Composite Anomaly (1981−2010 Climatology)
Late October 2014
NCEP/NCAR Reanalysis

Figure 19: Late October 2014 anomalous SST. Warm anomalies predominate across the basin.

7.4 Tropical Atlantic SLP

Tropical Atlantic sea level pressure values are another important parameter to consider when evaluating likely TC activity in the Atlantic basin. In general, lower sea level pressures across the tropical Atlantic imply increased instability, increased low-level moisture, and conditions that are generally favorable for TC development and intensification. The August-October portion of the 2014 Atlantic hurricane season was characterized by slightly above-normal sea level pressures across the tropical Atlantic and below-normal sea level pressures in the subtropical Atlantic. Figure 20 displays August-October 2014 tropical and sub-tropical sea level pressure anomalies in the North Atlantic.

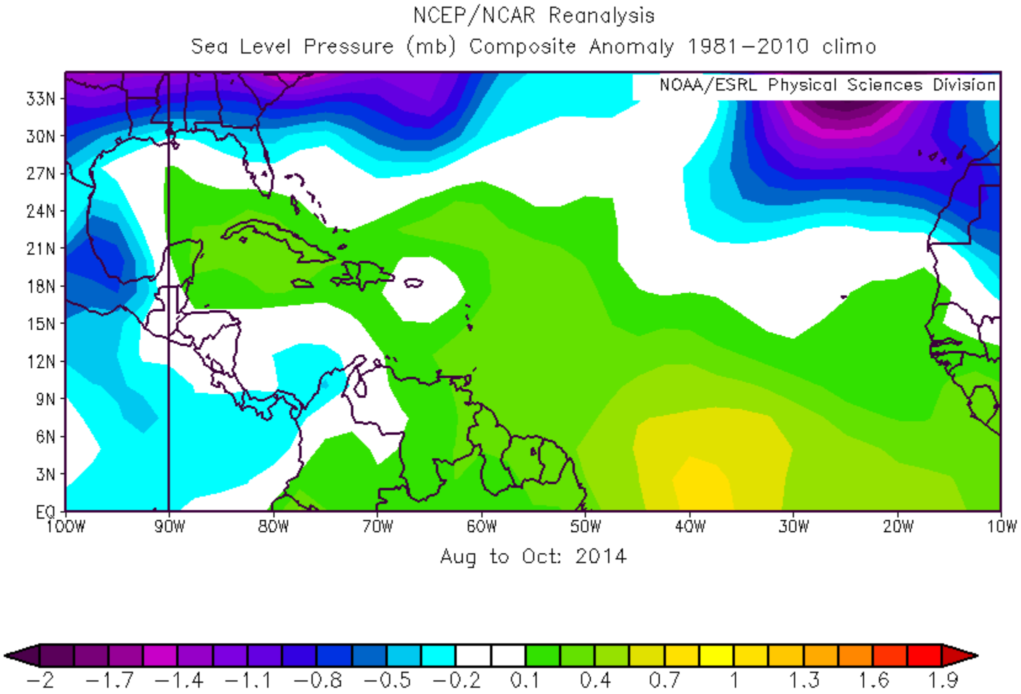


Figure 20: August-October 2014 tropical and sub-tropical North Atlantic sea level pressure anomalies. The August-October portion of the 2014 Atlantic hurricane season was characterized by slightly above-normal sea level pressures across the tropical Atlantic and below-normal sea level pressures in the subtropical Atlantic

7.5 Tropical Atlantic Vertical Wind Shear

Tropical Atlantic vertical wind shear was well above-average across the Caribbean and central tropical Atlantic (highlighted by the black box) during the peak two-month period of the Atlantic hurricane season from mid-August to mid-October (Figure 21). Table 14 displays standardized anomalies of 200-850-mb zonal wind shear for the Caribbean (10-20°N, 88-60°W) and the tropical Atlantic (10-20°N, 60-20°W) for each of three months of the peak of the Atlantic hurricane season from August-October with respect to the 1981-2010 climatology. Vertical shear was approximately average across the tropical Atlantic but was much stronger than normal in the Caribbean, especially during September, when shear was the second strongest on record (only eclipsed by 1972).

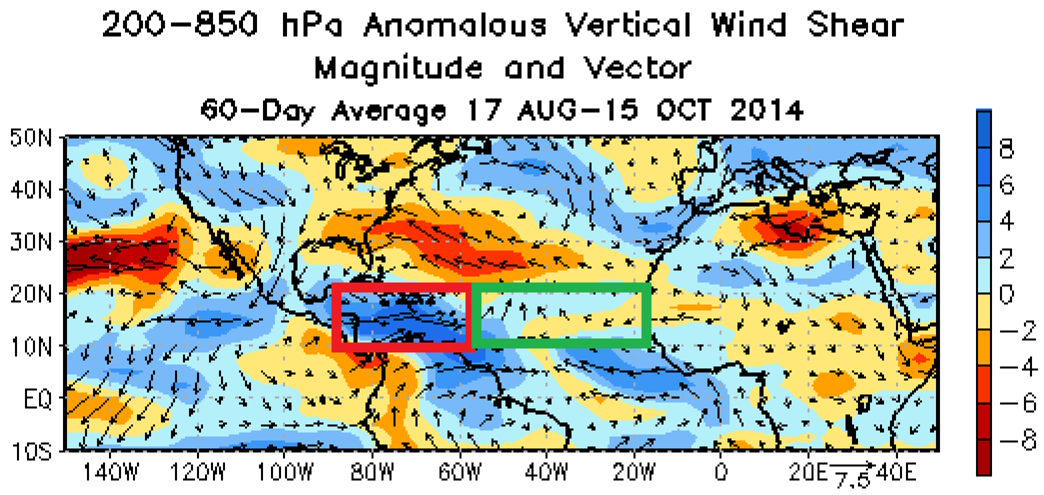


Figure 21: Anomalous vertical wind shear as observed across the Atlantic from August 17 – October 15, 2014. The red box denotes the Caribbean, while the green box denotes the tropical Atlantic.

Table 14: Anomalous vertical shear (in standard deviations) during August, September and October for the Caribbean (10-20°N, 88-60°W) and the tropical Atlantic (10-20°N, 60-20°W), respectively. Red values correspond to the Caribbean basin, demarked by the red box above, while green values correspond to the tropical Atlantic basin, demarked by the green box above.

Region/Month	Standardized Vertical Shear
Caribbean - August	**-0.1 SD**
Caribbean - September	**+2.2 SD**
Caribbean - October	**+1.0 SD**
Tropical Atlantic - August	**-0.7 SD**
Tropical Atlantic - September	**+0.2 SD**
Tropical Atlantic - October	**-0.6 SD**

7.6 Tropical Atlantic Moisture

As was the case last year, the tropical Atlantic was much drier than normal this year. Table 15 displays specific and relative humidity over the Atlantic MDR (defined to be 7.5-22.5°N, 75-20°W) compared with other years from 1979-2012. A ranking of one indicates the driest during the time period. Note the anomalous dryness that occurred throughout the three-month period. It seems like this dry air was an important reason why this season was relatively quiet. We analyze the period from July-September for this analysis, as the likely area for formation typically shifts to the Caribbean in October.

Table 15: Ranking of specific humidity and relative humidity for July 2014, August 2014 and September 2014 at 300-mb, 500-mb and 700-mb across the MDR (7.5-22.5°N, 75-20°W) compared with the 1979-2013 base period. Note that a ranking of one implies the driest conditions observed across the MDR over the period from 1979-2014, while a ranking of 36 would imply the wettest conditions observed across the MDR over the period from 1979-2014.

Specific Humidity

	300-mb	500-mb	700-mb
July 2014	2	1	3
August 2014	2	2	25
September 2014	2	2	11

Relative Humidity

	300-mb	500-mb	700-mb
July 2014	3	1	2
August 2014	2	3	20
September 2014	3	3	4

Figure 22 displays anomalous 500-mb relative humidity during the three-month period from July-September 2014. RH was quite low across the MDR and likely prevented much TC development this year.

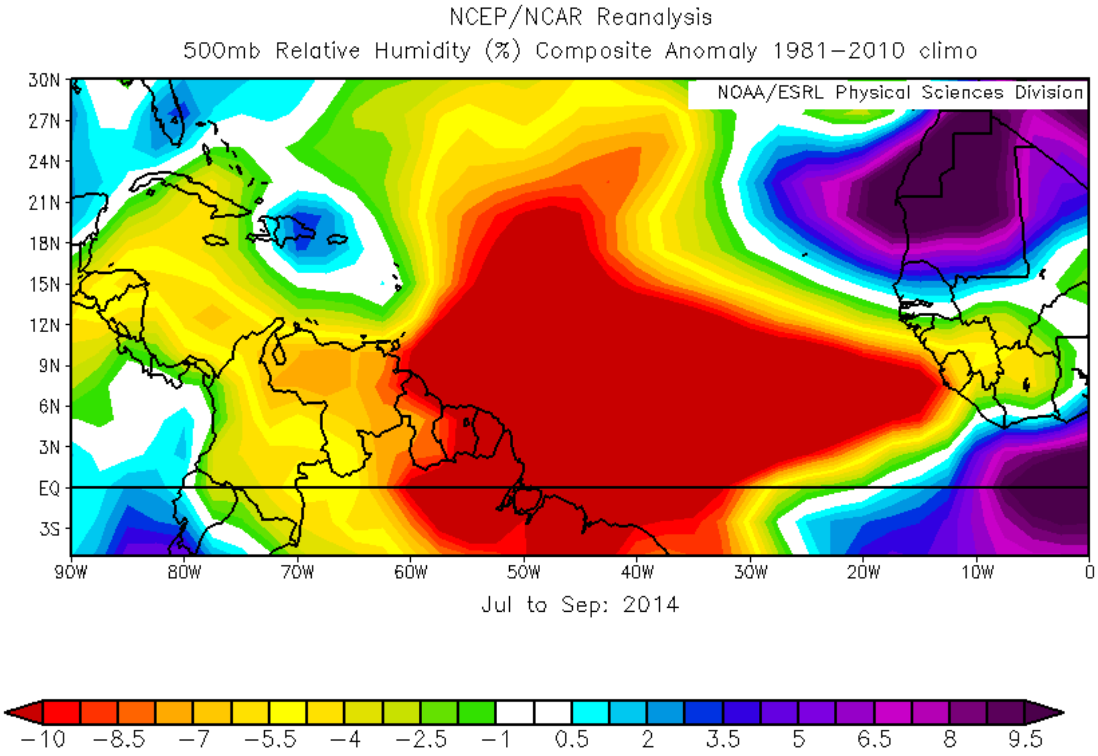


Figure 22: July-September 2014 500-mb RH anomalies. Note the anomalous dryness across the Atlantic MDR this year.

7.7 Tropical Atlantic Subsidence

One way to view the anomalous subsidence that occurred over the tropical Atlantic is to look at upper-level velocity potential anomalies. Positive velocity potential at upper levels indicates upper-level convergence and sinking motion. Figure 23 displays velocity potential anomalies in both the tropical Atlantic and tropical eastern Pacific. Note the strong subsidence present across most of the tropical Atlantic and the concomitant strong rising motion over the tropical eastern Pacific associated with the very active TC season there. Sinking motion over the Atlantic MDR (7.5-22.5°N, 75-20°W) during August-October was the third strongest since 1979, while rising motion over the Northeast Pacific MDR (10-17.5°N, 140-100W) was the second strongest since 1979.

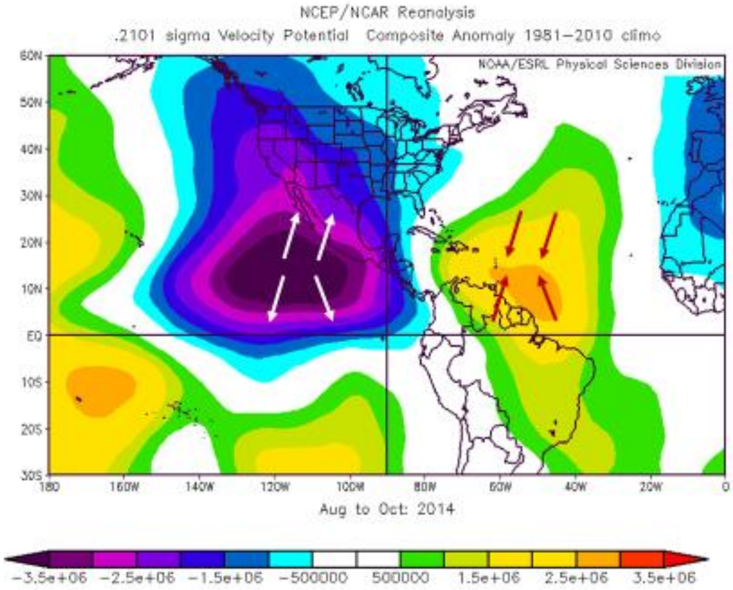


Figure 23: Upper-level velocity potential anomalies in August-October 2014. The white lines show upper-level divergence in the NE Pacific, while the red lines show upper-level convergence in the Atlantic.

7.8 Steering Currents

As has been the case for the past several years, anomalous troughing dominated the United States East Coast this year from the middle of August through the middle of October (Figure 24). The predominant steering flow was such to keep TCs that did form away from the United States mainland. The United States has now gone nine years without a landfalling major hurricane, the longest period on record.

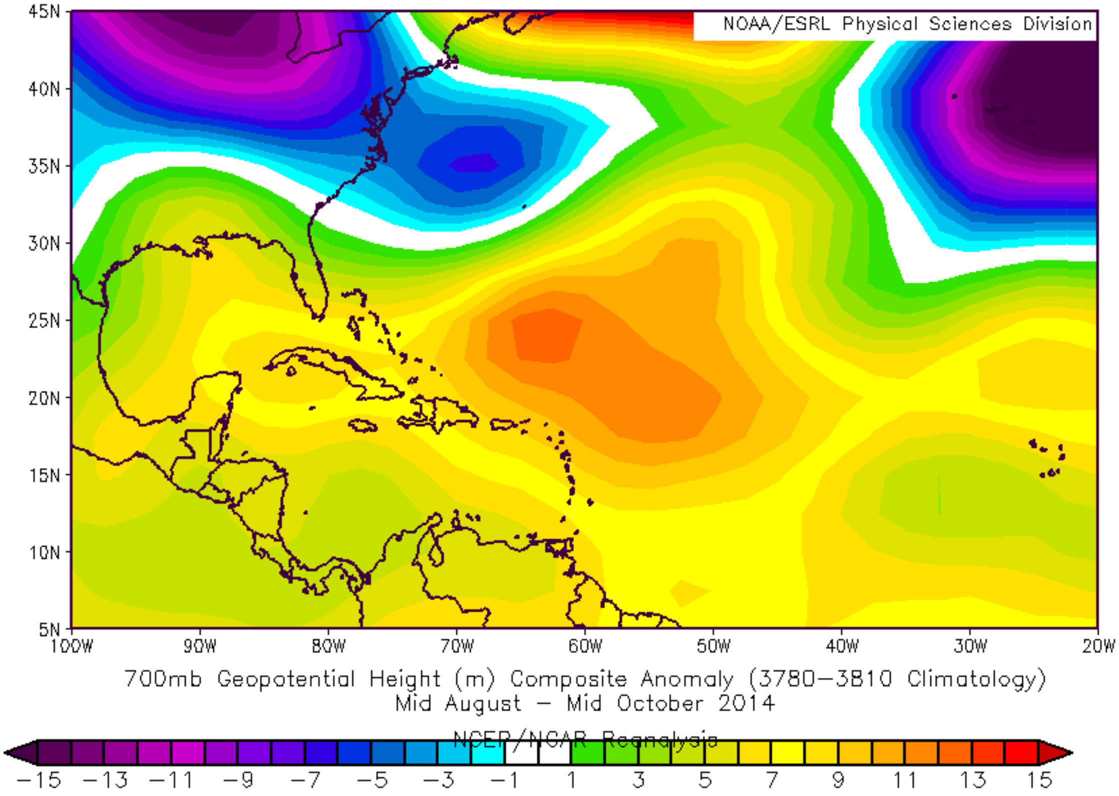


Figure 24: 700-mb height anomalies in the central and western part of the Atlantic from mid-August through mid-October 2014. Anomalous troughing dominated along the East Coast of the United States.

7.9 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 that year. Due to the associated forecast failure with the anomalous THC/AMO changes 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 25). The index is created by weighing the two parameters as follows: 0.6*SST – 0.4*SLP. The index was much more stable this year during the spring months (Figure 26). Note that both 2013 and 2014 had THC proxy values that rebounded significantly during the August-October period. The THC/AMO is currently about one standard deviation stronger than the 1950-2013 average.

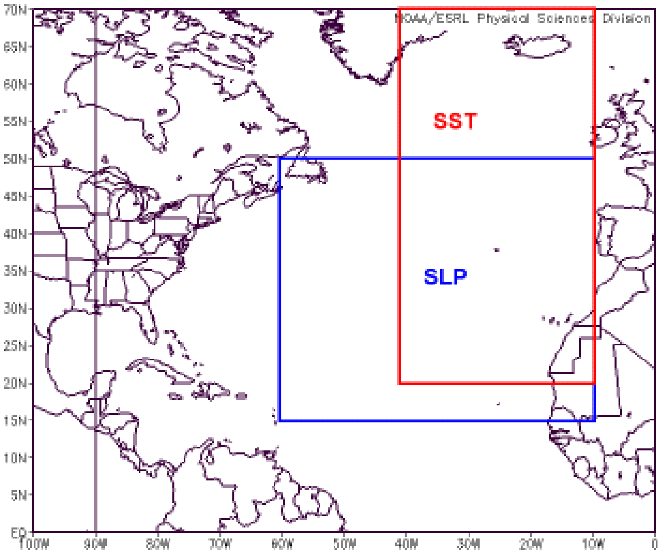


Figure 25: Regions which are utilized for calculation of the new THC/AMO index.

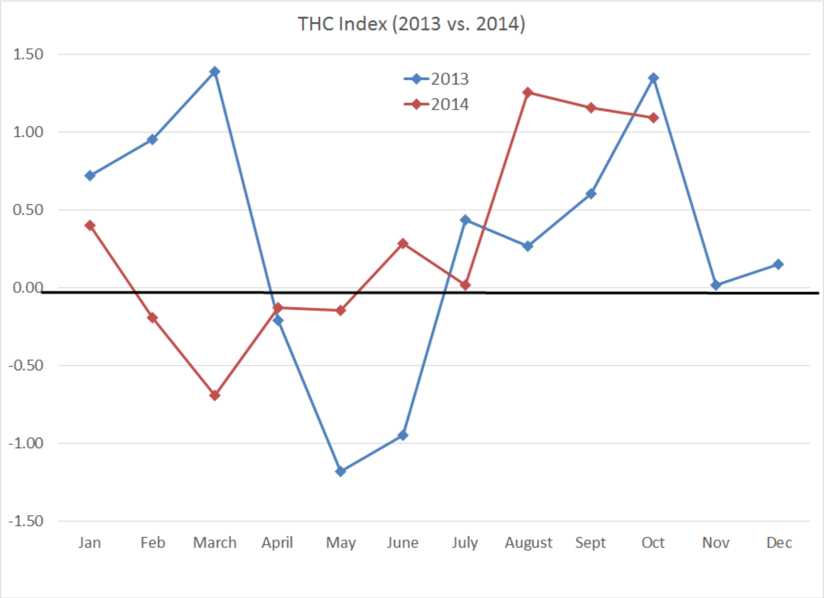


Figure 26: Standardized values of the THC/AMO index by month in 2013 (blue line) and 2014 (red line). Month-to-month changes were much less than 2013 through July. Note that both 2013 and 2014 had THC/AMO values that rebounded significantly to strongly positive during the August-October period. We use THC and AMO interchangeably.

8 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 do not believe that CO_2 increases have caused any significant increases in Atlantic basin or global tropical cyclone frequency or intensity. 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.

9 Forecasts of 2015 Hurricane Activity

We will be issuing our first outlook for the 2015 hurricane season on Thursday, 11 December 2014. This forecast will provide a qualitative outlook for factors likely to impact the 2015 hurricane season. This December forecast will include the dates of all of our updated 2015 forecasts. All of these forecasts will be made available online at: http://hurricane.atmos.colostate.edu/Forecasts.

10 Acknowledgments

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11 Citations and Additional Reading

Alexander, M. A., I. Blade, M. Newman, J. R. Lanzante, N.-C. Lau, and J. D. Scott, 2002: The atmospheric bridge: The influence of ENSO teleconnections on air-sea interaction over the global oceans. *J. Climate*, 15, 2205-2231.

Blake, E. S., 2002: Prediction of August Atlantic basin hurricane activity. Dept. of Atmos. Sci. Paper No. 719, Colo. State Univ., Ft. Collins, CO, 80 pp.

Blake, E. S. and W. M. Gray, 2004: Prediction of August Atlantic basin hurricane activity. *Wea. Forecasting*, 19, 1044-1060.

Chiang, J. C. H. and D. J. Vimont, 2004: Analogous Pacific and Atlantic meridional modes of tropical atmosphere-ocean variability. *J. Climate*, 17, 4143-4158.

DeMaria, M., J. A. Knaff and B. H. Connell, 2001: A tropical cyclone genesis parameter for the tropical Atlantic. *Wea. Forecasting*, 16, 219-233.

Elsner, J. B., G. S. Lehmiller, and T. B. Kimberlain, 1996: Objective classification of Atlantic hurricanes. *J. Climate*, 9, 2880-2889.

Evan, A. T., J. Dunion, J. A. Foley, A. K. Heidinger, and C. S. Velden, 2006: New evidence for a relationship between Atlantic tropical cyclone activity and African dust outbreaks, *Geophys. Res. Lett*, 33, doi:10.1029/2006GL026408.

Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nunez, and W. M. Gray, 2001: The recent increase in Atlantic hurricane activity: Causes and Implications. *Science*, 293, 474-479.

Goldenberg, S. B. and L. J. Shapiro, 1996: Physical mechanisms for the association of El Niño and West African rainfall with Atlantic major hurricane activity. *J. Climate*, 1169-1187.

Gray, W. M., 1984a: Atlantic seasonal hurricane frequency: Part I: El Niño and 30 mb quasi-biennial oscillation influences. *Mon. Wea. Rev.*, 112, 1649-1668.

Gray, W. M., 1984b: Atlantic seasonal hurricane frequency: Part II: Forecasting its variability. *Mon. Wea. Rev.*, 112, 1669-1683.

Gray, W. M., 1990: Strong association between West African rainfall and US landfall of intense hurricanes. *Science*, 249, 1251-1256.

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. Available online at http://tropical.atmos.colostate.edu/Includes/Documents/Publications/gray2011.pdf.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1992: Predicting Atlantic seasonal hurricane activity 6-11 months in advance. *Wea. Forecasting*, 7, 440-455.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1993: Predicting Atlantic basin seasonal tropical cyclone activity by 1 August. *Wea. Forecasting*, 8, 73-86.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1994a: Predicting Atlantic basin seasonal tropical cyclone activity by 1 June. *Wea. Forecasting*, 9, 103-115.

Gray, W. M., J. D. Sheaffer and C. W. Landsea, 1996: Climate trends associated with multi-decadal variability of intense Atlantic hurricane activity. Chapter 2 in "Hurricanes, Climatic Change and

Socioeconomic Impacts: A Current Perspective", H. F. Diaz and R. S. Pulwarty, Eds., Westview Press, 49 pp.

Gray, W. M., 1998: Atlantic ocean influences on multi-decadal variations in El Niño frequency and intensity. Ninth Conference on Interaction of the Sea and Atmosphere, 78th AMS Annual Meeting, 11-16 January, Phoenix, AZ, 5 pp.

Grossmann, I. and P. J. Klotzbach, 2009: A review of North Atlantic modes of natural variability and their driving mechanisms. *J. Geophys. Res.*, 114, D24107, doi:10.1029/2009JD012728.

Henderson-Sellers, A., H. Zhang, G. Berz, K. Emanuel, W. Gray, C. Landsea, G. Holland, J. Lighthill, S-L. Shieh, P. Webster, and K. McGuffie, 1998: Tropical cyclones and global climate change: A post-IPCC assessment. *Bull. Amer. Meteor. Soc.*, 79, 19-38.

Klotzbach, P. J., 2002: Forecasting September Atlantic basin tropical cyclone activity at zero and one-month lead times. Dept. of Atmos. Sci. Paper No. 723, Colo. State Univ., Ft. Collins, CO, 91 pp.

Klotzbach, P. J., 2006: Trends in global tropical cyclone activity over the past twenty years (1986-2005). *Geophys. Res. Lett.*, 33, doi:10.1029/2006GL025881.

Klotzbach, P. J., 2007: Revised prediction of seasonal Atlantic basin tropical cyclone activity from 1 August. *Wea. and Forecasting,* 22, 937-949.

Klotzbach, P. J. and W. M. Gray, 2003: Forecasting September Atlantic basin tropical cyclone activity. *Wea. and Forecasting,* 18, 1109-1128.

Klotzbach, P. J. and W. M. Gray, 2004: Updated 6-11 month prediction of Atlantic basin seasonal hurricane activity. *Wea. and Forecasting,* 19, 917-934.

Klotzbach, P. J. and W. M. Gray, 2006: Causes of the unusually destructive 2004 Atlantic basin hurricane season. *Bull. Amer. Meteor. Soc.,* 87, 1325-1333.

Knaff, J. A., 1997: Implications of summertime sea level pressure anomalies. *J. Climate,* 10, 789-804.

Knaff, J. A., 1998: Predicting summertime Caribbean sea level pressure. *Wea. and Forecasting,* 13, 740-752.

Kossin, J. P., and D. J. Vimont, 2007: A more general framework for understanding Atlantic hurricane variability and trends. *Bull. Amer. Meteor. Soc.,* 88, 1767-1781.

Landsea, C. W., 1991: West African monsoonal rainfall and intense hurricane associations. Dept. of Atmos. Sci. Paper, Colo. State Univ., Ft. Collins, CO, 272 pp.

Landsea, C. W., 1993: A climatology of intense (or major) Atlantic hurricanes. *Mon. Wea. Rev.,* 121, 1703-1713.

Landsea, C. W., 2007: Counting Atlantic tropical cyclones back to 1900. *EOS,* 88, 197, 202.

Landsea, C. W. and W. M. Gray, 1992: The strong association between Western Sahel monsoon rainfall and intense Atlantic hurricanes. *J. Climate,* 5, 435-453.

Landsea, C. W., W. M. Gray, P. W. Mielke, Jr., and K. J. Berry, 1992: Long-term variations of Western Sahelian monsoon rainfall and intense U.S. landfalling hurricanes. *J. Climate,* 5, 1528-1534.

Landsea, C. W., W. M. Gray, K. J. Berry and P. W. Mielke, Jr., 1996: June to September rainfall in the African Sahel: A seasonal forecast for 1996. 4 pp.

Landsea, C. W., N. Nicholls, W.M. Gray, and L.A. Avila, 1996: Downward trends in the frequency of intense Atlantic hurricanes during the past five decades. *Geo. Res. Letters,* 23, 1697-1700.

Landsea, C. W., R. A. Pielke, Jr., A. M. Mestas-Nunez, and J. A. Knaff, 1999: Atlantic basin hurricanes: Indices of climatic changes. *Climatic Changes,* 42, 89-129.

Landsea, C.W. et al., 2005: Atlantic hurricane database re-analysis project. Available online at http://www.aoml.noaa.gov/hrd/data_sub/re_anal.html

Mielke, P. W., K. J. Berry, C. W. Landsea and W. M. Gray, 1996: Artificial skill and validation in meteorological forecasting. *Wea. Forecasting,* 11, 153-169.

Mielke, P. W., K. J. Berry, C. W. Landsea and W. M. Gray, 1997: A single sample estimate of shrinkage in meteorological forecasting. *Wea. Forecasting*, 12, 847-858.

Pielke, Jr. R. A., and C. W. Landsea, 1998: Normalized Atlantic hurricane damage, 1925-1995. *Wea. Forecasting*, 13, 621-631.

Pielke, Jr. R. A., J. Gratz, C. W. Landsea, D. Collins, and R. Masulin, 2008: Normalized hurricane damage in the United States: 1900-2005. *Nat. Haz. Rev.,* 9, 29-42, doi:10.1061/(ASCE)1527-6988(2008)9:1(29).

Powell, M. D., and T. A. Reinhold, 2007: Tropical cyclone destructive potential by integrated kinetic energy. *Bull. Amer. Meteor. Soc., 88,* 513-526.

Rasmusson, E. M. and T. H. Carpenter, 1982: Variations in tropical sea-surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. *Mon. Wea. Rev.*, 110, 354-384.

Seseske, S. A., 2004: Forecasting summer/fall El Niño-Southern Oscillation events at 6-11 month lead times. Dept. of Atmos. Sci. Paper No. 749, Colo. State Univ., Ft. Collins, CO, 104 pp.

Vimont, D. J., and J. P. Kossin, 2007: The Atlantic meridional mode and hurricane activity. *Geophys. Res. Lett.,* 34, L07709, doi:10.1029/2007GL029683.

Wheeler, M. C., and H. H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. *Mon. Wea. Rev.,* 132, 1917-1932.

12 Verification of Previous Forecasts

Table 16: Verification of the authors' early August forecasts of Atlantic named storms and hurricanes between 1984-2014. Observations only include storms that formed after 1 August. Note that these early August forecasts have either exactly verified or forecasted the correct deviation from climatology in 26 of 31 years for named storms and 23 of 31 years for hurricanes. If we predict an above- or below-average season, it tends to be above or below average, even if our exact forecast numbers do not verify.

Year	Predicted NS	Observed NS	Predicted H	Observed H
1984	10	12	7	5
1985	10	9	7	6
1986	7	4	4	3
1987	7	7	4	3
1988	11	12	7	5
1989	9	8	4	7
1990	11	12	6	7
1991	7	7	3	4
1992	8	6	4	4
1993	10	7	6	4
1994	7	6	4	3
1995	16	14	9	10
1996	11	10	7	7
1997	11	3	6	1
1998	10	13	6	10
1999	14	11	9	8
2000	11	14	7	8
2001	12	14	7	9
2002	9	11	4	4
2003	14	12	8	5
2004	13	14	7	9
2005	13	20	8	12
2006	13	7	7	5
2007	13	12	8	6
2008	13	12	7	6
2009	10	9	4	3
2010	16	17	9	11
2011	12	15	9	7
2012	10	15	5	9
2013	14	9	8	2
2014	9	7	3	5
Average	**10.9**	**10.8**	**6.3**	**6.1**
1984-2014 Correlation		**0.59**		**0.51**

Table 17: 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