SUMMARY OF 2010 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHOR'S SEASONAL AND TWO-WEEK FORECASTS

The 2010 hurricane season had activity at well above-average levels. Our seasonal predictions were quite successful. The United States was very fortunate to have not experienced any landfalling hurricanes this year.

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

This forecast as well as past forecasts and verifications are available via the World Wide Web at http://hurricane.atmos.colostate.edu

Emily Wilmsen, Colorado State University Media Representative, (970-491-6432) is available to answer various questions about this verification.

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As of 10 November 2010*

*Climatologically, about two percent of Net Tropical Cyclone activity occurs after this date

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ATLANTIC BASIN SEASONAL HURRICANE FORECASTS FOR 2010

Forecast Parameter and 1950-2000 Climatology (in parentheses)	9 Dec 2009	Update 7 April 2010	Update 2 June 2010	Update 4 Aug 2010	Observed 2010 Total
Named Storms (NS) (9.6)	11-16	15	18	18	19
Named Storm Days (NSD) (49.1)	51-75	75	90	90	88.25
Hurricanes (H) (5.9)	6-8	8	10	10	12
Hurricane Days (HD) (24.5)	24-39	35	40	40	37.50
Major Hurricanes (MH) (2.3)	3-5	4	5	5	5
Major Hurricane Days (MHD) (5.0)	6-12	10	13	13	11
Accumulated Cyclone Energy (ACE) (96.2)	100-162	150	185	185	163
Net Tropical Cyclone Activity (NTC) (100%)	108-172	160	195	195	195

Note: Any storms forming after November 10 will be discussed with the December forecast for 2011 Atlantic basin seasonal hurricane activity.

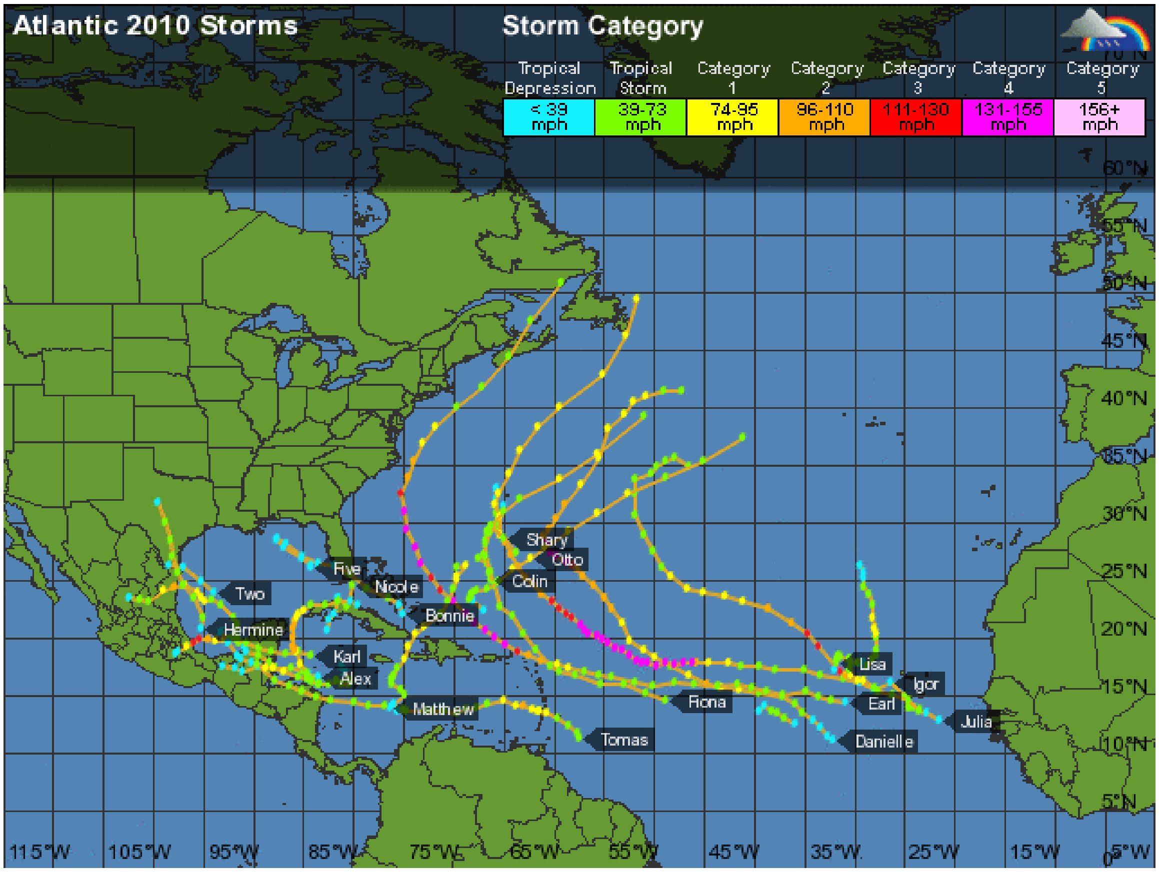


Figure courtesy of Weather Underground (http://www.wunderground.com)

ABSTRACT

This report summarizes tropical cyclone (TC) activity, which occurred in the Atlantic basin during 2010 and verifies the authors' seasonal Atlantic basin forecasts, seasonal Caribbean forecasts and two-week Atlantic basin forecasts of this activity. A forecast was initially issued for the 2010 season on 9 December 2009 with updates on 7 April, 2 June, and 4 August of this year. These seasonal forecasts also contained estimates of the probability of U.S. and Caribbean hurricane landfall during 2010. For the first time this year, seasonal forecasts for Caribbean-only hurricane activity were issued in early June and updated in early August. Our Atlantic basin seasonal hurricane forecasts correctly predicted a very active hurricane season. We somewhat over-predicted activity that occurred in the Caribbean, however.

During the August-October period, we also issued two-week forecasts. These forecasts were primarily based on predicted activity by the global forecast models and the phase of the Madden-Julian Oscillation (MJO). The generally weak nature of the MJO during the August-October period of this year made these forecasts more challenging than in the usual year. However, these two-week forecasts did show modest skill and will be issued again in 2011.

Atlantic basin hurricane activity in 2010 was quite high due to the combination of anomalously warm Atlantic basin sea surface temperatures and a rapidly developing La Niña event. These favorable cyclone-enhancing conditions led to favorable dynamic and thermodynamic conditions for storm formation and intensification. Consequently, nineteen named storms, twelve hurricanes and five major hurricanes formed in 2010. This activity was 198%, 203%, and 217% of the 1950-2000 average for named storms, hurricanes and major hurricanes, respectively.

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.

Atlantic Multi-Decadal Oscillation (AMO) – A mode of natural variability that occurs in the North Atlantic Ocean and evidencing itself in fluctuations in both sea surface temperature and sea level pressure fields. The AMO is likely related to fluctuations in the strength of the 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 approximately 40-50 days.

Main Development Region (MDR) – An area in the tropical Atlantic where a majority of major hurricanes form, defined 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 Scale – A measurement scale ranging from 1 to 5 of hurricane wind and ocean surge 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.

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.

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 (18 ms^{-1} or 34 knots) and 73 (32 ms^{-1} or 63 knots) miles per hour.

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

Notice of Author Changes

By William Gray

The order of the authorship of these forecasts was reversed in 2006 from Gray and Klotzbach to Klotzbach and Gray. After 22 years (1984-2005) of making these forecasts, it was appropriate that I step back and have Phil Klotzbach assume the primary responsibility for our project's seasonal forecasts. Phil has been a member of my research project for the last ten years and was second author on these forecasts from 2001-2005. I have greatly profited and enjoyed our close personal and working relationship.

Phil is now devoting much more time to the improvement of these forecasts than I am. I am now giving more of my efforts to the global warming issue and in synthesizing my projects' many years of hurricane and typhoon studies.

Phil Klotzbach is an outstanding young scientist with a superb academic record. I have been amazed at how far he has come in his knowledge of hurricane prediction since joining my project in 2000. I foresee an outstanding future for him in the hurricane field. He is currently developing new seasonal and two-week forecast innovations that are improving our forecasts. The success of the last three years of seasonal forecasts is an example. Phil was awarded his Ph.D. degree in 2007. He is currently spending most of his time working towards better understanding and improving these Atlantic basin hurricane forecasts.

Acknowledgment

This year's forecasts were funded by private and personal funds. We thank the GeoGraphics Laboratory at Bridgewater State College (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 project members and now colleagues Chris Landsea, John Knaff and Eric Blake. We also thank Professors Paul Mielke and Ken Berry of Colorado State University for much statistical analysis and advice over many years. We also 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 and major hurricane days.

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 much about 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 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 35-40 years. The NCEP/NCAR reanalysis data sets we now use are available back to 1948 which gives us more than 60 years of hindcast information.

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 early forecast schemes 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. All the prediction techniques that were used and discussed with our 2008-2010 forecasts have been revised and improved by the first author over the course of the past three years. 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 momentum 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 2010

Figure A and Table 2 summarize Atlantic basin TC activity which occurred in 2010. A well above-average season was experienced for all TC parameters. See page 4 for acronym definitions.

3 Individual 2010 Tropical Cyclone Characteristics

The following is a brief summary of each of the named tropical cyclones in the Atlantic basin for the 2010 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. Online entries from Wikipedia (http://www.wikipedia.org) were very helpful in putting together these tropical cyclone summaries. One unusual characteristic of the 2010 hurricane season was the copious number of storms that formed in the Main Development Region (MDR) (10-20°N, 20-60°W). Nine named storms formed in this region this year (Colin, Danielle, Earl, Fiona, Gaston, Igor, Julia, Lisa and Tomas). Only 1933 (11 MDR named storm formations) and 1995 (9 MDR named storm formations) have had as many MDR formations during the hurricane season. Tropical cyclones tended to have two clusters of tracks, either developing in the Main Development Region and recurving out to sea (Figure B), or developing in the western Caribbean and tracking westward or northwestward (Figure C).

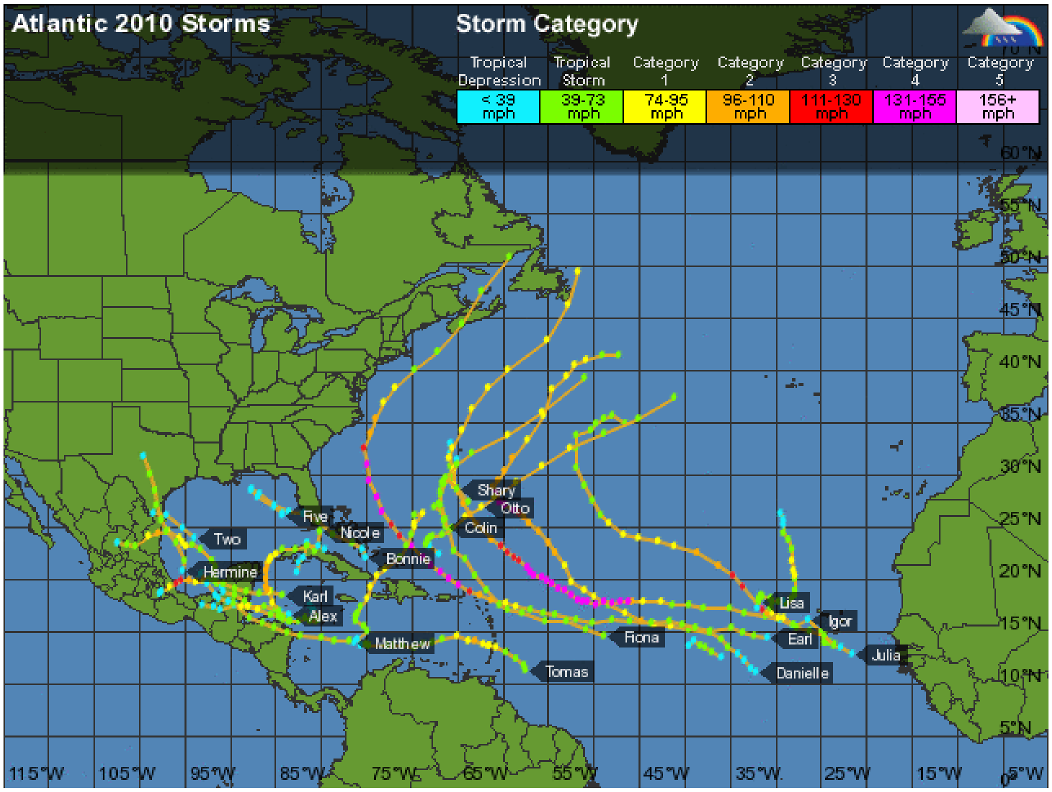


Figure A: Tracks of 2010 Atlantic Basin tropical cyclones. Figure courtesy of Weather Underground (http://www.wunderground.com).

Table 2: Observed 2010 Atlantic basin tropical cyclone activity.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	MHD	ACE	NTC
H-2	Alex (1)	June 26 – July 1	90 kt/947 mb	5.00	1.50		6.7	7.3
TS	Bonnie (2)	July 22 – July 23	35 kt/1006 mb	0.75			0.3	2.0
TS	Colin (3)	August 3, 5 – 9	50 kt/1005 mb	3.25			1.9	2.8
MH-4	Danielle (4)	August 22 – 31	115 kt/942 mb	8.50	6.75	1.00	22.2	22.6
MH-4	Earl (5)	August 25 – September 5	125 kt/928 mb	10.50	5.50	3.50	28.1	30.8
TS	Fiona (6)	August 30 – September 3	50 kt/997 mb	4.25			2.9	3.2
TS	Gaston (7)	September 1 – 2	35 kt/1005 mb	0.75			0.4	2.0
TS	Hermine (8)	September 6 – 7	55 kt/991 mb	1.75			1.3	2.3
MH-4	Igor (9)	September 8 – 21	135 kt/925 mb	12.75	10.00	5.00	42.9	40.4
MH-4	Julia (10)	September 13 – 20	115 kt/950 mb	7.75	3.75	1.00	14.3	20.3
MH-3	Karl (11)	September 14 – 18	105 kt/956 mb	3.25	1.50	0.50	5.8	15.6
H-1	Lisa (12)	September 21 - 26	70 kt/987 mb	4.50	0.50		3.6	6.4
TS	Matthew (13)	September 23 – 25	45 kt/998 mb	2.00			1.4	2.4
TS	Nicole (14)	September 29 - 29	35 kt/996 mb	0.50			0.2	1.9
H-1	Otto (15)	October 6 – 10	75 kt/972 mb	4.00	1.50		5.8	6.9
H-2	Paula (16)	October 11 – 15	85 kt/981 mb	3.50	2.25		6.6	7.3
H-1	Richard (17)	October 21 – 25	80 kt/981 mb	4.00	0.75		4.6	6.4
H-1	Shary (18)	October 29 – 30	65 kt/989 mb	2.00	0.50		2.2	5.6
H-2	Tomas (19)	October 29 – November 7	85 kt/982 mb	8.75	3.00		11.2	9.6
Totals	19			88.25	37.50	11.00	162.7	195.2

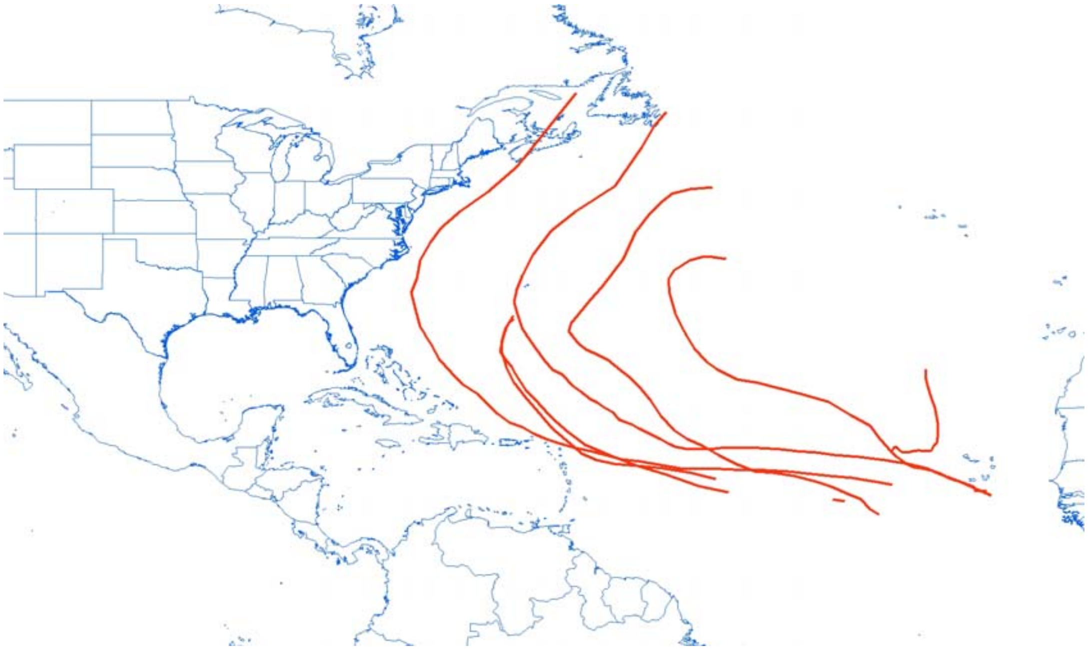


Figure B: Tracks of tropical cyclones that formed in the Main Development Region and recurved (Tropical Storm Colin, Major Hurricane Danielle, Major Hurricane Earl, Tropical Storm Fiona, Tropical Storm Gaston, Major Hurricane Igor, Major Hurricane Julia and Hurricane Lisa).

Figure C: Tracks of tropical cyclones that formed in the western Caribbean (Hurricane Alex, Tropical Storm Hermine, Major Hurricane Karl, Tropical Storm Matthew, Hurricane Paula and Hurricane Richard).

Hurricane Alex (#1): Alex formed in the western Caribbean on June 25 and intensified into a tropical storm early on June 26 (Figure 1). Later on the 26th, Alex made its first landfall in Belize. After briefly weakening to a tropical depression, Alex re-intensified into a tropical storm and then intensified into a hurricane as it tracked through the southern Gulf of Mexico. Alex made landfall approximately 100 miles south of Brownsville, Texas late on June 30 with maximum sustained winds estimated at 90 knots. It dissipated over northern Mexico the following day. Alex was the strongest June hurricane in terms of maximum sustained winds since Alma (1966). It was responsible for approximately two billion dollars in damage in Mexico, and 32 direct fatalities were also associated with the system.

Figure 1: Track of Hurricane Alex. Figure courtesy of Weather Underground.

Tropical Storm Bonnie (#2): Bonnie formed on July 22 while tracking through the southeastern Bahamas (Figure 2). It became a tropical storm later that day. A strong upper-level low to its west imparted large amounts of vertical shear on Bonnie, and the system never strengthened beyond minimal tropical storm status. Bonnie made landfall over Biscayne Bay, Florida, and then weakened to a tropical depression as it moved over south Florida. Strong southeasterly shear decimated Bonnie, and it degenerated into a remnant low before making landfall in southeastern Louisiana. Damage from Bonnie was minimal.

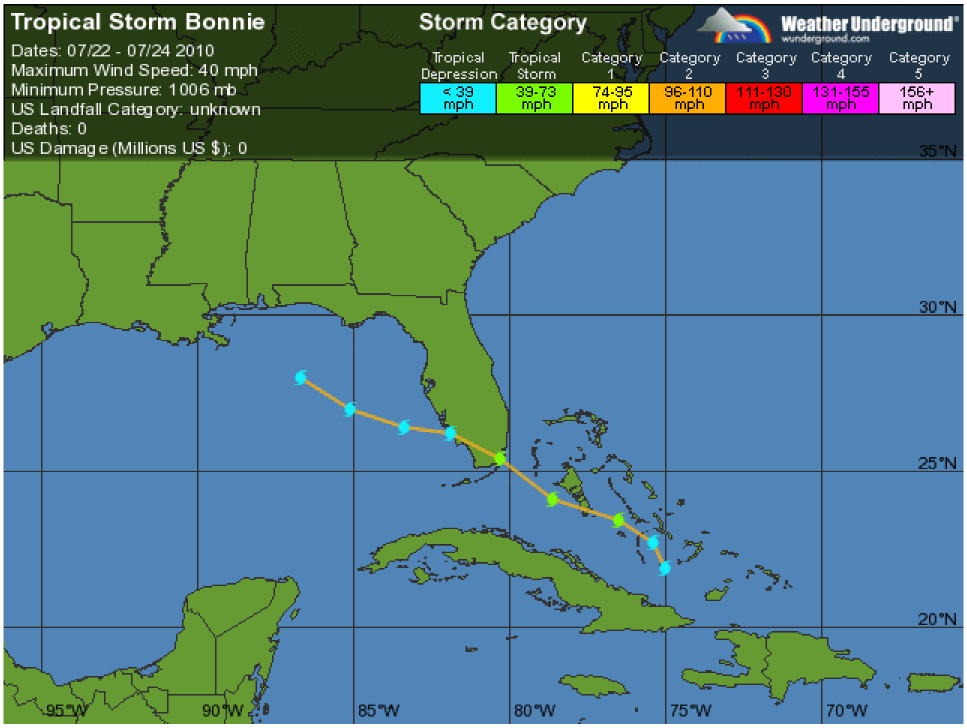


Figure 2: Track of Tropical Storm Bonnie. Figure courtesy of Weather Underground.

<u>Tropical Storm Colin (#3)</u>: Colin formed in the central tropical Atlantic from a tropical wave on August 2 (Figure 3). It moved quickly westward and intensified into a tropical storm on August 3. Strong westerly shear due to an upper-level low caused the system to degenerate into a remnant low late on August 3. By late on August 5, Colin found an area of slightly more favorable conditions, and the system re-intensified into a tropical storm as it tracked northward towards Bermuda. The system began to slow down as the steering currents weakened, and, strong upper-level winds displaced the lower- and upper-level parts of Colin's circulation. Consequently, the system began to weaken. The combination of continued shear and dry air entrainment eventually caused Colin to weaken to a tropical depression on August 8, with the system degenerating into a remnant low later that day.

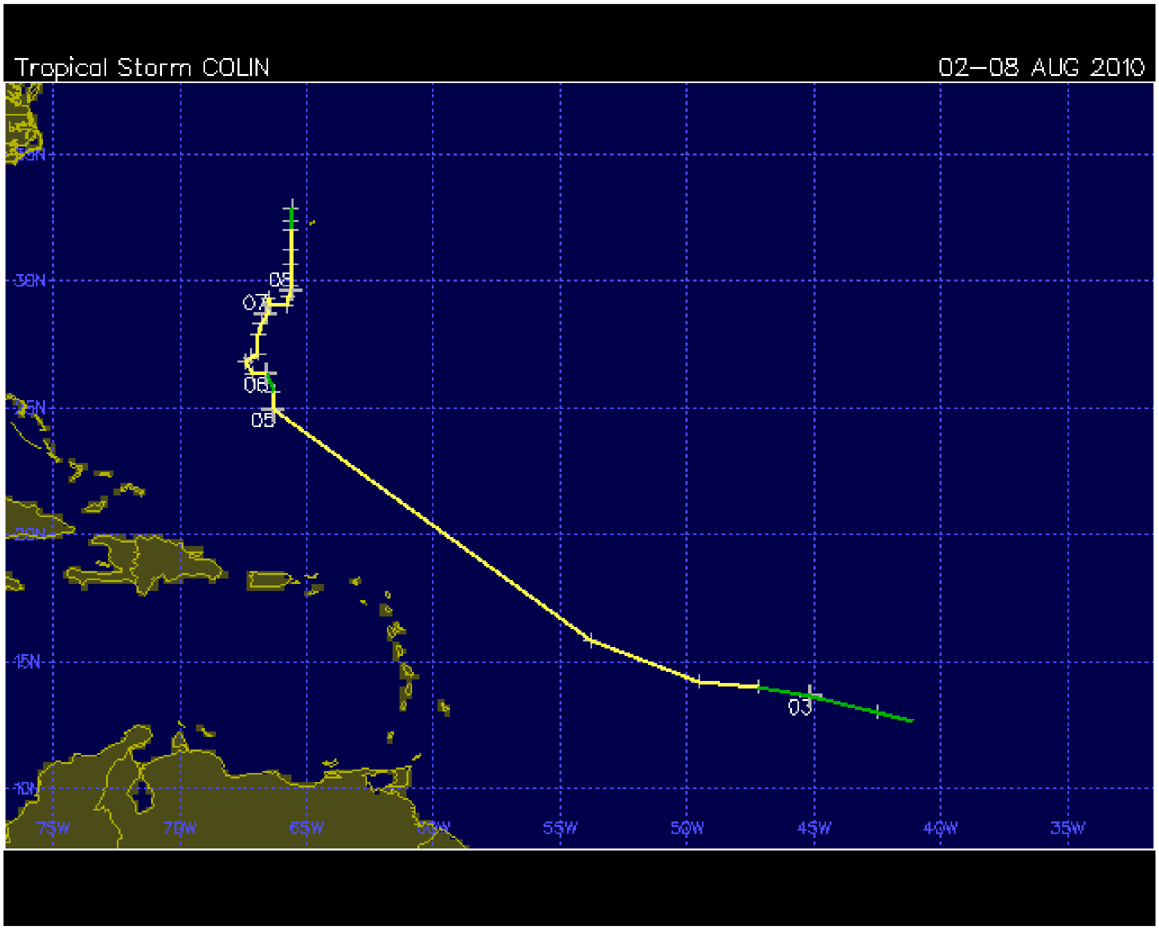


Figure 3: Track of Tropical Storm Colin. Figure courtesy of Unisys Weather. The system was classified as a tropical wave for the portion of the track between August 3 and August 5.

<u>Major Hurricane Danielle (#4):</u> Danielle formed in the eastern tropical Atlantic on August 21 (Figure 4). The system intensified into a tropical storm the following day. Continued strengthening occurred over the next couple of days as the system tracked westward in a moderate easterly shear environment. By August 23, the shear relaxed further, and Danielle intensified into a hurricane, briefly reaching Category 2 status before weakening rapidly due to an infusion of dry air. The system weakened to a tropical storm briefly due to a combination of dry air and westerly shear before regaining hurricane status. An upper-level low to Danielle's northwest caused the system to turn towards the northwest. On August 26, the shear relaxed considerably, and Danielle became the first major hurricane of the 2010 season early on August 27. It reached Category 4 status later that day while tracking around the western portion of the subtropical ridge. By August 28, Danielle began to weaken due to a combination of an eyewall replacement cycle and cooler SSTs. A large trough began to steer Danielle towards the northeast, and the system accelerated. Danielle weakened to a tropical storm on August 30 while undergoing extra-tropical transition and was declared post-tropical early on August 31.

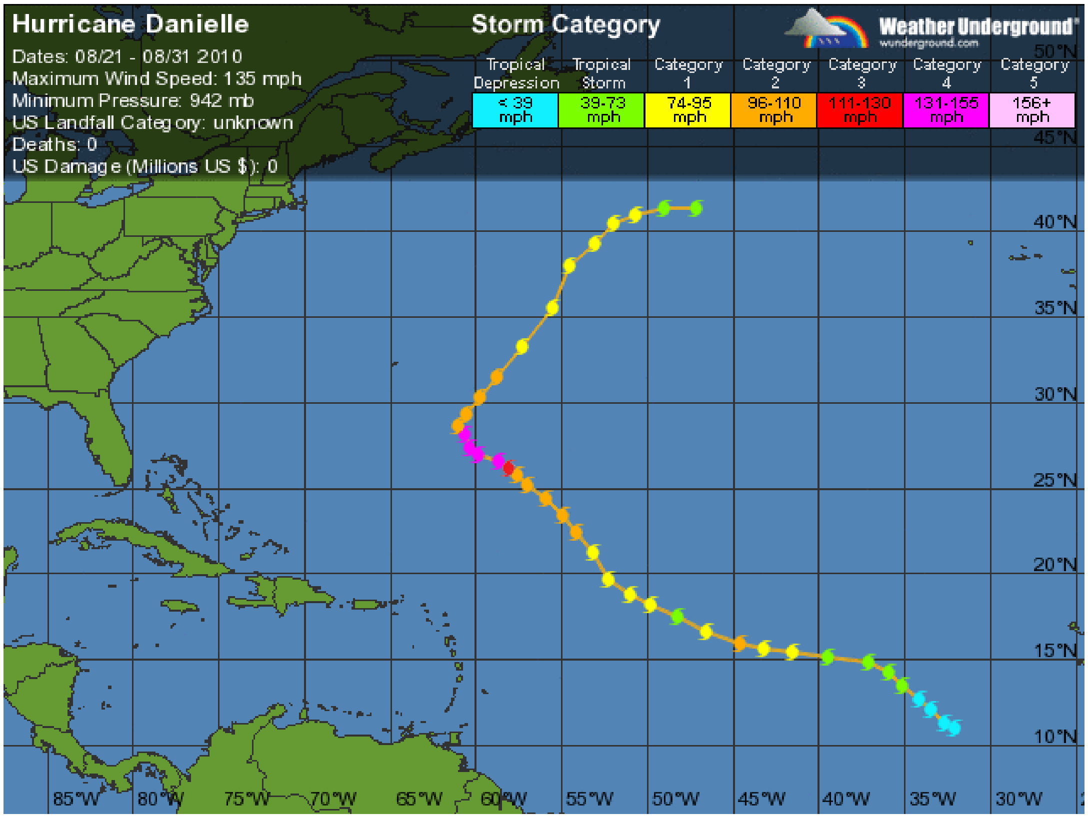


Figure 4: Track of Major Hurricane Danielle. Figure courtesy of Weather Underground.

<u>Major Hurricane Earl (#5)</u>: Earl formed from a tropical wave in the eastern tropical Atlantic on August 25, becoming a tropical storm later that day (Figure 5). The system tracked west-northwestward across the tropical Atlantic and slowly became better organized. By August 29, Earl intensified into a hurricane as it tracked just north of the Leeward Islands. Earl became a major hurricane while passing through the northern Virgin Islands the following day. It reached Category 4 status early on August 31 while beginning to curve towards the northwest along the western portion of the subtropical ridge. Earl went through an eyewall replacement cycle the following day and encountered moderate southwesterly shear. It underwent periods of fluctuations in intensity over the next couple of days but maintained major hurricane status. Earl began to track northward and weaken as it encountered cooler SSTs and stronger shear. The system brushed by the Outer Banks of North Carolina early on September 3 and Nantucket Island, Massachusetts early on September 4, bringing strong winds and some heavy rain to the area. Earl made landfall in Nova Scotia later on September 4 as a strong tropical storm and was declared post-tropical early on September 5. Earl produced some damage in the Leeward Islands from flooding and wind. Damages in the United States and Canada were estimated to be minor. Earl was responsible for four fatalities.

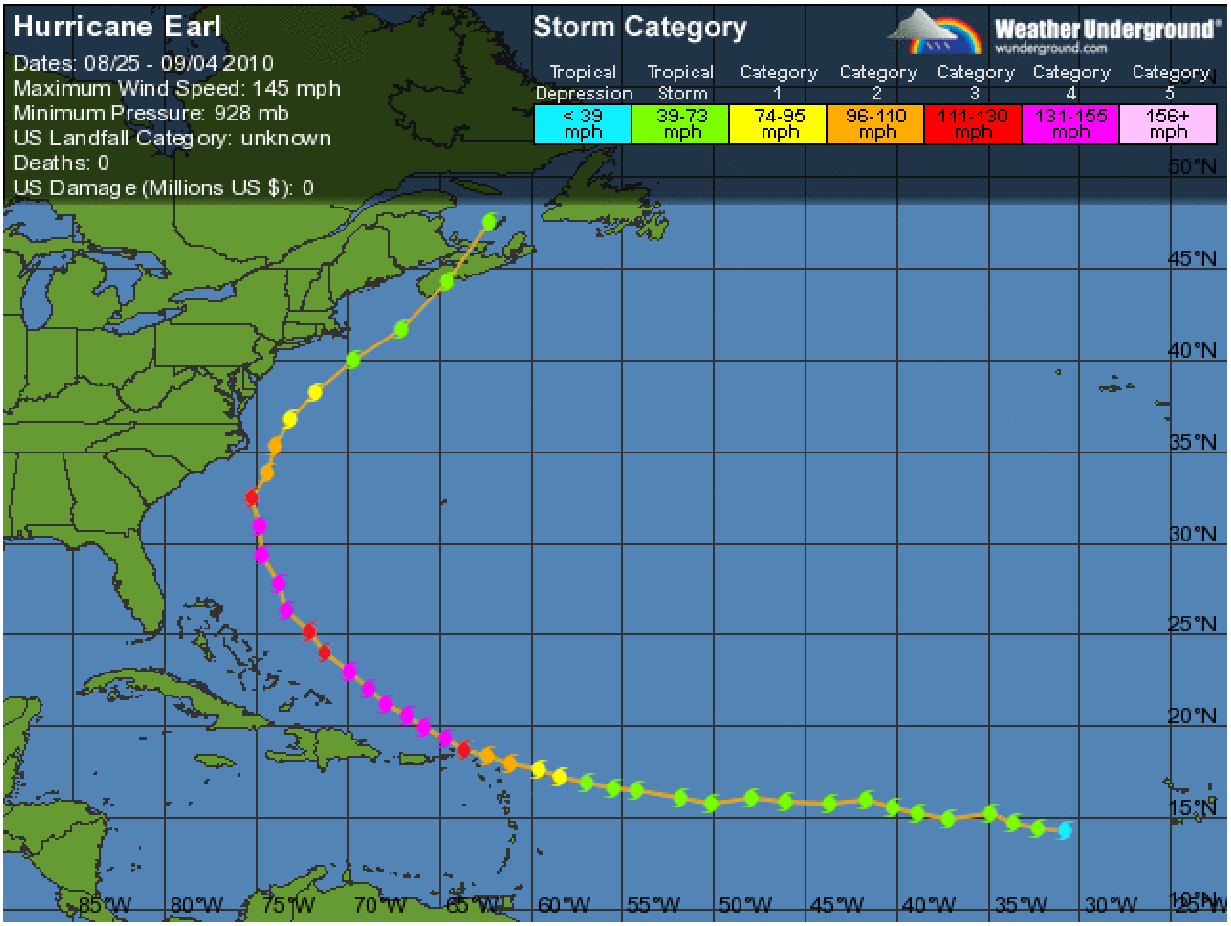


Figure 5: Track of Major Hurricane Earl. Figure courtesy of Weather Underground.

<u>Tropical Storm Fiona (#6)</u>: Fiona developed in the tropical Atlantic while located approximately 900 miles east of the Leeward Islands on August 30 (Figure 6). It moved rapidly westward under a subtropical ridge. It intensified into a 50-knot tropical storm while passing north of the Leeward Islands. The system then weakened due to strong northeasterly shear caused by very large Hurricane Earl. The system began to turn towards the northwest and then north as it was steered between a subtropical ridge and Hurricane Earl. Strong shear from Earl decimated the cyclone, and the system degenerated into a remnant low early on September 4 while located just south of Bermuda. Minimal damage was reported from Fiona.

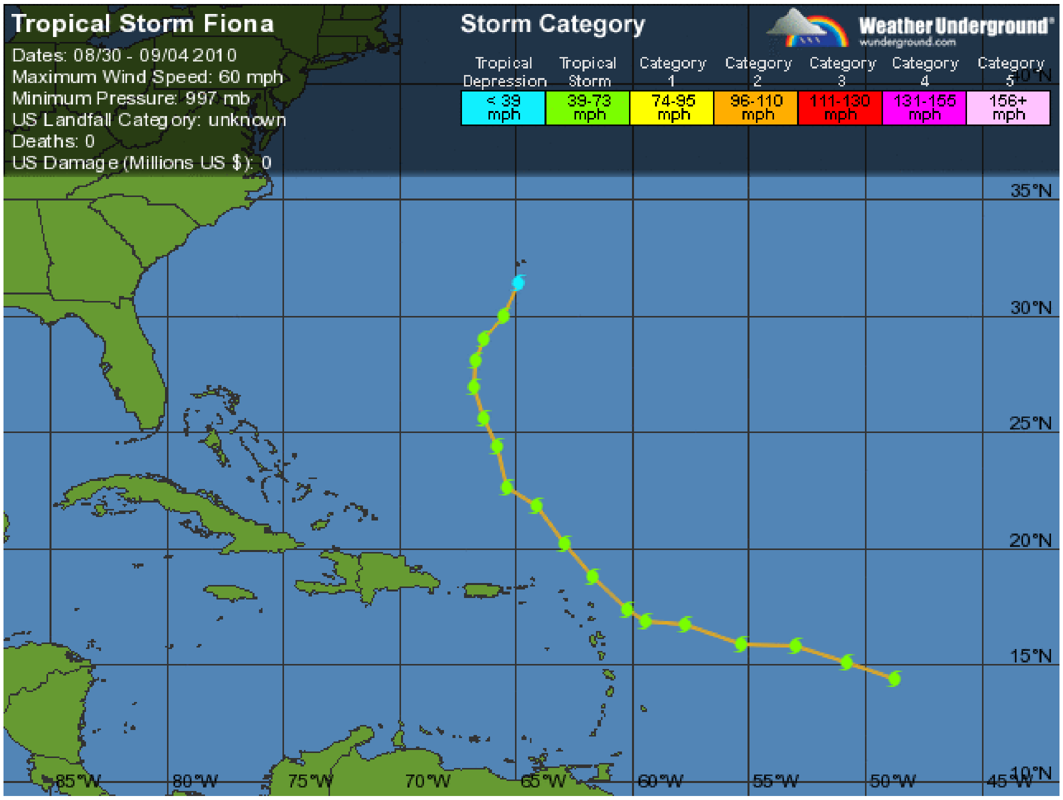


Figure 6: Track of Tropical Storm Fiona. Figure courtesy of Weather Underground.

Tropical Storm Gaston (#7): Gaston formed from a tropical wave while located in the eastern tropical Atlantic on September 1 (Figure 7). It reached tropical storm strength later that day. However, despite being located in an environment of relatively low vertical shear, the system unexpectedly weakened to a tropical depression the following day, probably due to significant dry air entrainment. It was downgraded to a remnant low later on September 2. It was monitored for signs of redevelopment as it continued to track across the tropical Atlantic and Caribbean. Although convective bursts occasionally flared from time to time, the system never regained tropical storm status.

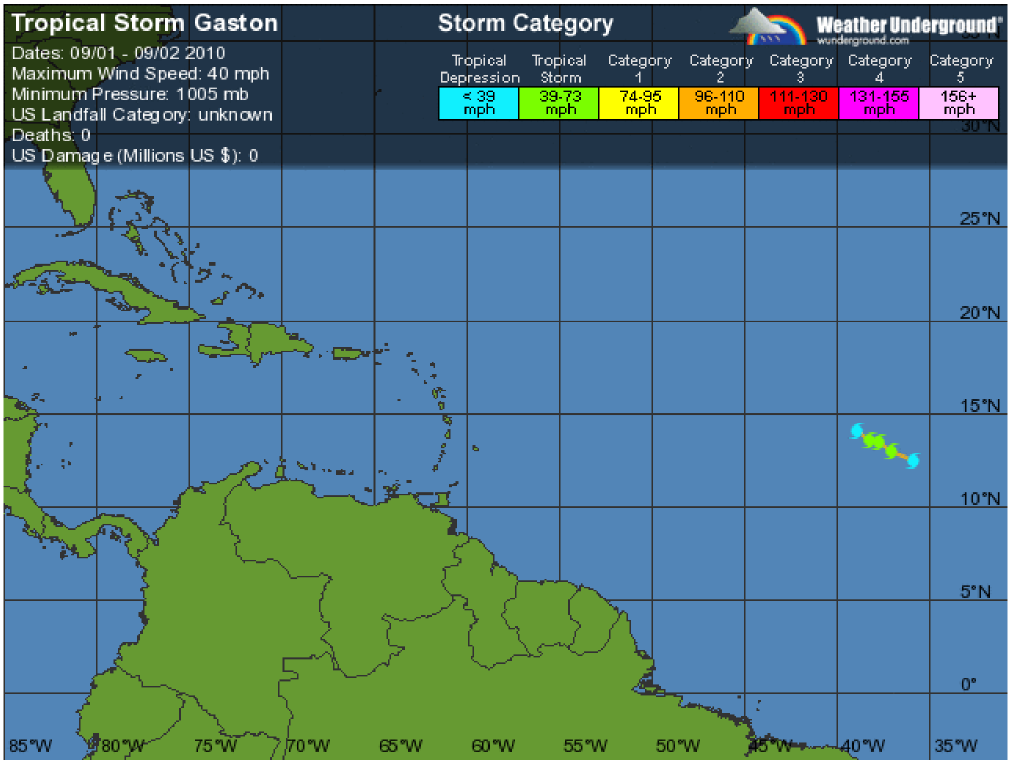


Figure 7: Track of Tropical Storm Gaston. Figure courtesy of Weather Underground.

Tropical Storm Hermine (#8): Hermine formed from a small area of low pressure while located in the southern Bay of Campeche early on September 6 (Figure 8). It was upgraded to a tropical storm later that day as it tracked northward along the western edge of a subtropical ridge. It strengthened in a light wind shear environment, reaching a maximum intensity of 55 knots before making landfall along the northeast coast of Mexico late on September 7. It slowly weakened the following day and was downgraded to a tropical depression. Hermine was responsible for six fatalities and caused approximately $75 million dollars in insured damage in the southern part of Texas.

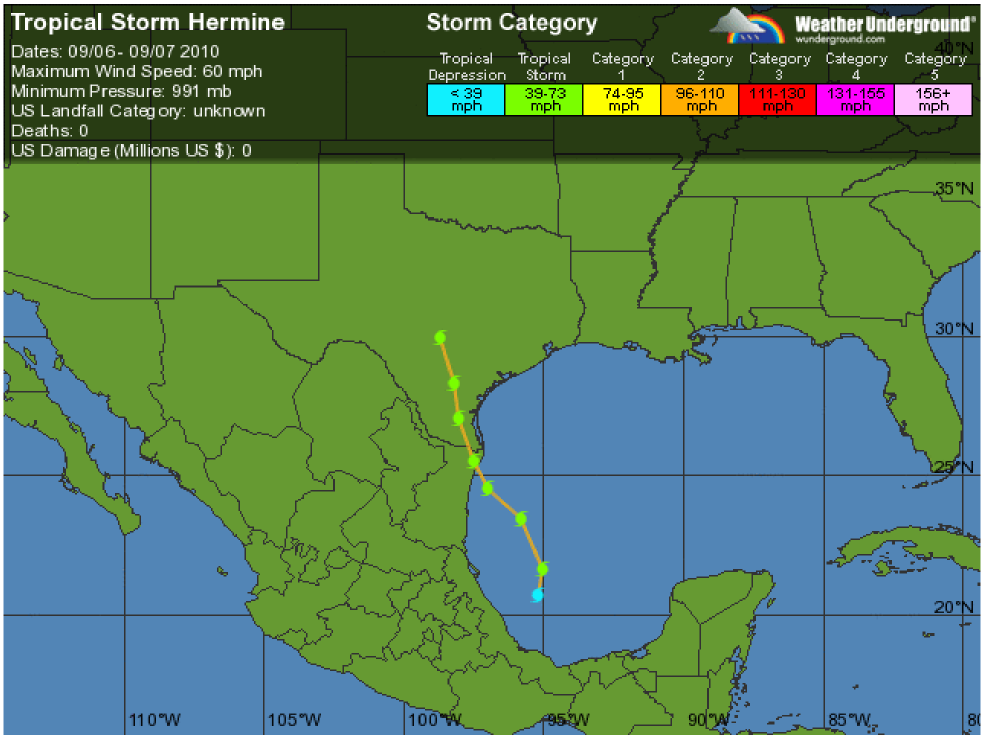


Figure 8: Track of Tropical Storm Hermine. Figure courtesy of Weather Underground.

<u>Major Hurricane Igor (#9)</u>: Igor formed in the far eastern tropical Atlantic on September 8 (Figure 9). It was classified as a tropical storm in its first advisory. Easterly shear prevented strengthening during the early part of Igor's lifespan. It briefly weakened to a tropical depression before regaining tropical storm strength on September 10 as the easterly shear began to weaken. Igor slowly strengthened as the shear continued to weaken, and the system moved westward into warmer SSTs. By early on September 12, Igor was classified as a hurricane. It then underwent a period of rapid intensification, reaching Category 4 status later that day. The system maintained Category 4 status while tracking west-northwest across the tropical Atlantic. A weakness in the subtropical ridge caused Igor to turn northwestward. Relatively strong westerly shear began to impact the hurricane, and it weakened to a Category 3 storm later in the day on September 16. Slightly cooler waters and continued shear caused Igor to weaken to Category 2 status by September 17. Igor weakened further while approaching Bermuda on September 19. However, while the system's central intensity weakened, the size of tropical storm-force and hurricane-force winds expanded outward to a considerable radius, due in large part to eyewall replacement cycles. The center of Igor passed just west of Bermuda early on September 20, bringing hurricane-force winds to the island. Later in the day on September 20, Igor began undergoing extra-tropical transition as it bore down on Newfoundland. The system became classified as a very powerful extra-tropical storm with maximum sustained winds of nearly 70 knots on September 21. Igor caused minimal damage on Bermuda, while significant damage was sustained in Newfoundland, due in large part to flooding from very heavy rains.

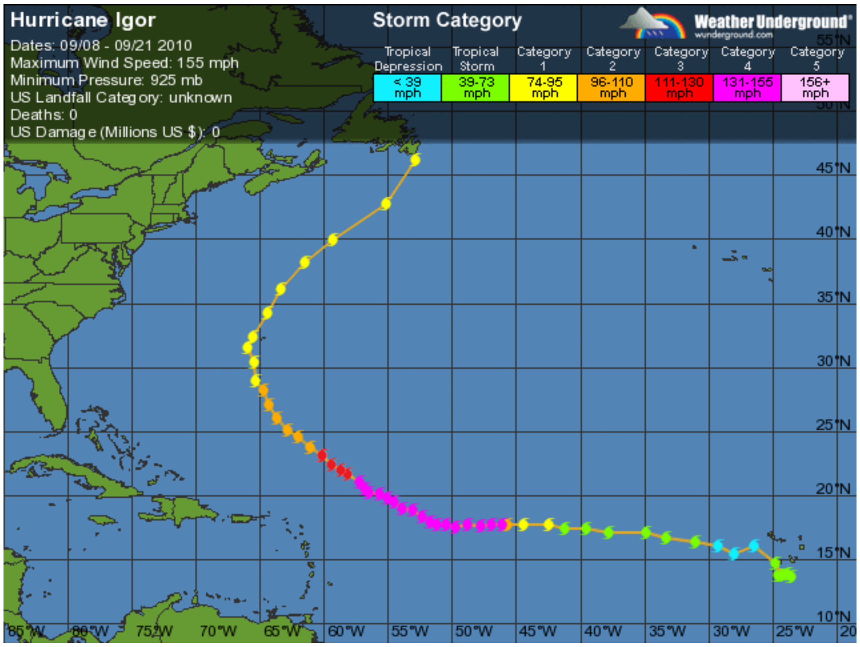


Figure 9: Track of Major Hurricane Igor. Figure courtesy of Weather Underground.

<u>Major Hurricane Julia (#10):</u> Julia formed in the far eastern tropical Atlantic on September 12 (Figure 10). It was upgraded to a tropical storm early on the 13th. Julia began to strengthen later that day as easterly shear weakened. It reached hurricane status on the 14th. By early on the 15th, Julia underwent a period of rapid intensification and strengthened to a Category 4 hurricane. Outflow from Igor along with an upper-level low to its southwest began imparting southerly shear on the system, and it began to slowly weaken. The upper-level low along with a mid-level high to its northeast steered Julia northwestward. The system became more severely impacted by the outflow from Igor which imparted strong northwesterly winds over Julia, causing the system to weaken to a tropical storm early on September 18. The system tenaciously hung on to tropical storm status for a couple more days while battling the outflow of the much larger Igor. However, by September 20, Igor's outflow sheared the convection away from the center of Julia, and it was declared post-tropical as it became embedded within a frontal trough.

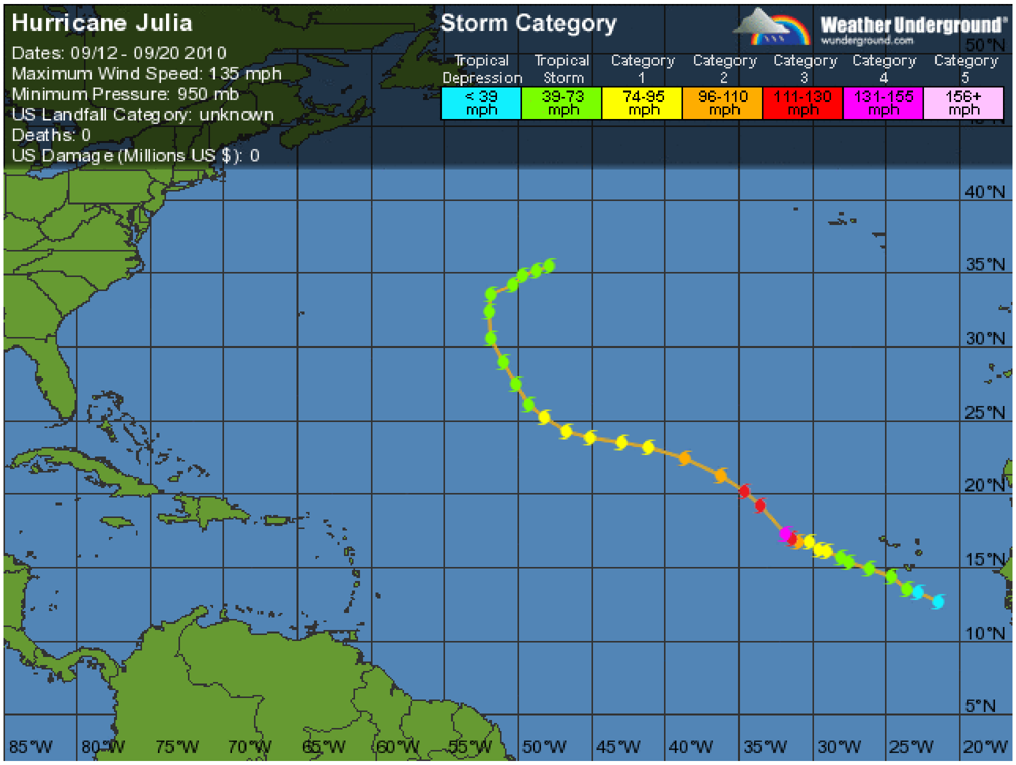


Figure 10: Track of Major Hurricane Julia. Figure courtesy of Weather Underground.

Major Hurricane Karl (#11): Karl formed in the Northwest Caribbean late on September 14 (Figure 11). It strengthened to a 55-knot tropical storm before making landfall along the Yucatan Peninsula the following day. It weakened to a minimal tropical storm while traversing the peninsula, however, it re-strengthened rapidly once it reached the Bay of Campeche. It reached hurricane status on September 16 and then rapidly intensified into a major hurricane by early on September 17. A large ridge over the Gulf of Mexico steered Karl westward, and the system made landfall near Veracruz, Mexico later on September 17 with estimated sustained winds of 100 knots at landfall. Karl rapidly dissipated over the mountains of southern Mexico the following day. Karl was responsible for 16 deaths, and estimated total damage from Karl could approach four billion dollars.

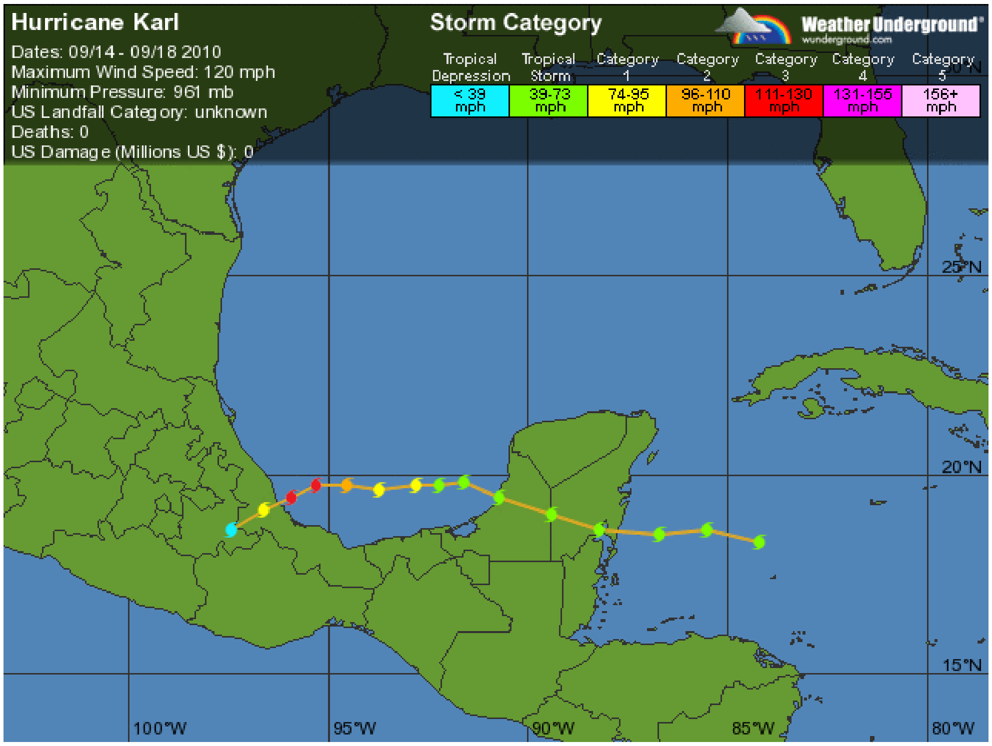


Figure 11: Track of Major Hurricane Karl. Figure courtesy of Weather Underground.

<u>Hurricane Lisa (#12):</u> Lisa developed from an easterly wave in the eastern tropical Atlantic early on September 21 (Figure 12). It was upgraded to a tropical storm shortly thereafter. Lisa intensified slightly while moving very slowly northward. An upper-level low near Lisa imparted westerly shear which weakened Lisa back to a tropical depression on September 23. By late on the 23rd, the shear relaxed, and Lisa began to strengthen. Despite being in an environment of relatively cool SSTs and dry mid levels, Lisa rapidly intensified into a hurricane late on September 24. However, strong westerly shear soon impacted the tropical cyclone, and Lisa weakened to a tropical storm on September 25 while moving northward at a slightly faster forward speed. Shear decimated the storm, with Lisa being downgraded to a tropical depression early on September 26 and a remnant low later that day.

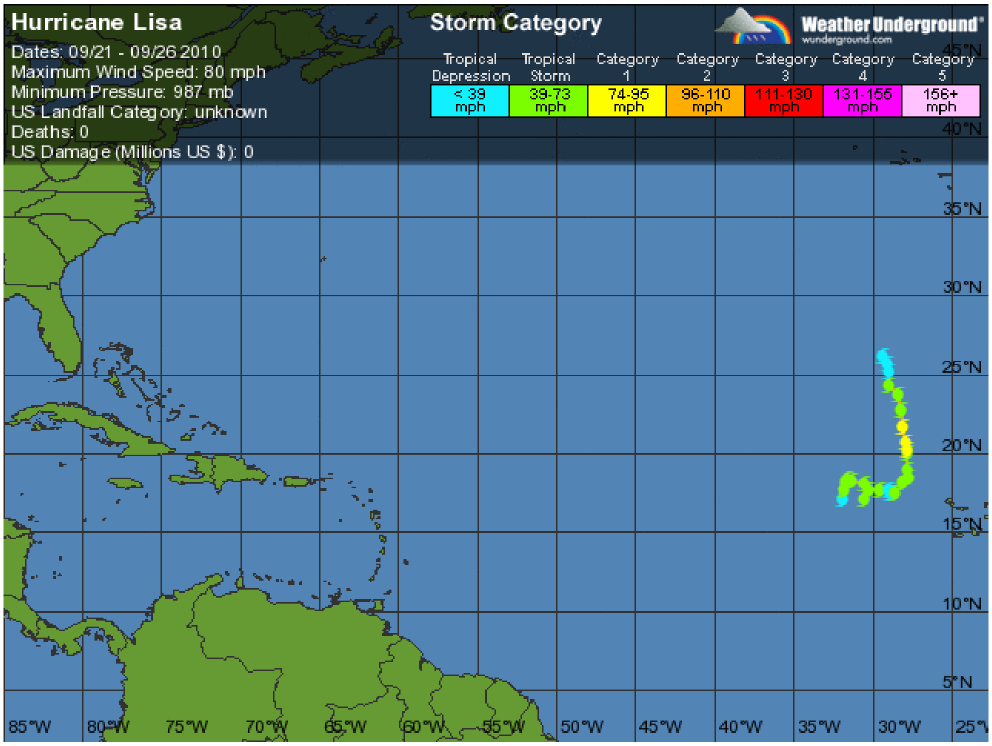


Figure 12: Track of Hurricane Lisa. Figure courtesy of Weather Underground.

Tropical Storm Matthew (#13): Matthew formed in the central Caribbean on September 23 (Figure 13). It was upgraded to a tropical storm a few hours later after aircraft reconnaissance found flight-level winds of 42 knots. A subtropical ridge drove Matthew rapidly westward, and the system strengthened slowly as it approached Central America. Easterly shear prevented much intensification, however, and Matthew made landfall over eastern Nicaragua later in the day on September 24. It slowly weakened over land, dumping copious amounts of rain while doing so. By late on September 25, the system was downgraded to a tropical depression, and it was classified as a remnant low the following day. Flooding from Matthew's precursor low pressure system was responsible for seven deaths in Venezuela.

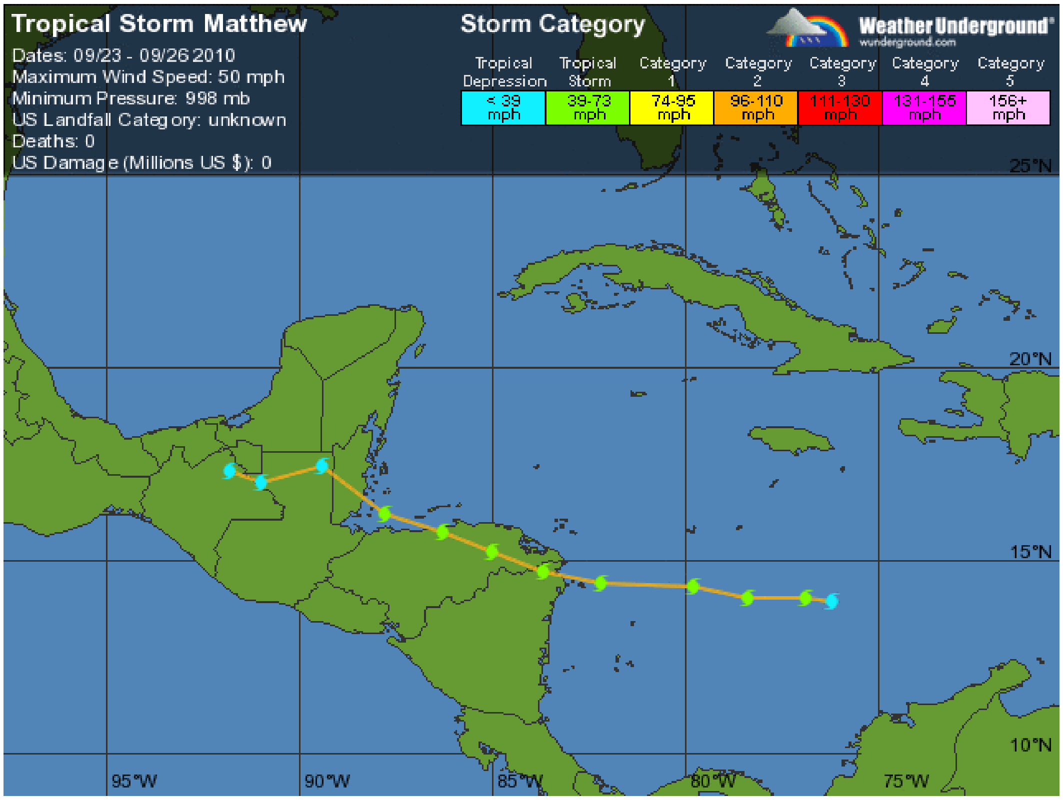


Figure 13: Track of Tropical Storm Matthew. Figure courtesy of Weather Underground.

<u>Tropical Storm Nicole (#14):</u> Nicole formed from a large area of low pressure in the Northwest Caribbean on September 28 (Figure 14). The system was referred to as being more like a monsoon depression typically found in the Northwest Pacific or North Indian Ocean due to its structure and size. The system consolidated slightly and was upgraded to a tropical storm on September 29. However, the circulation became elongated later that day, and Nicole dissipated soon after. Nicole's precursor circulation and remnants dropped copious amounts of rainfall. Jamaica sustained severe flood damage, costing approximately $150 million dollars in damage. Wilmington, North Carolina received over 20 inches of rain from the broad circulation associated with Nicole. Thirteen deaths have been attributed to the tropical cyclone.

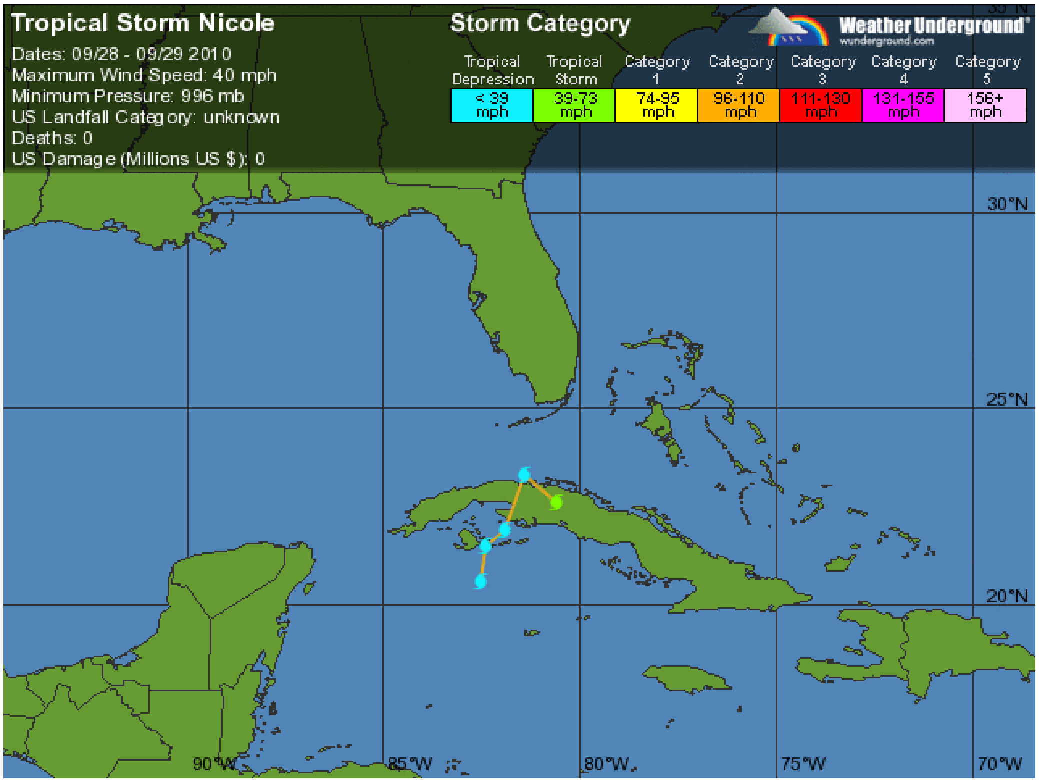


Figure 14: Track of Tropical Storm Nicole. Figure courtesy of Weather Underground.

Hurricane Otto (#15): Otto was originally classified as a subtropical depression on October 6 due to its large radius of maximum winds and proximity to an upper-level low (Figure 15). Aircraft reconnaissance measured tropical storm-force winds later that day, and consequently, Otto was upgraded to a subtropical storm. By later on October 7, Otto separated from the upper-level low and consolidated, becoming a tropical storm. Moderate southwesterly shear relaxed the following day, and Otto became the eighth hurricane of the year later that day. Otto began to move rapidly northeastward as it progressed with the strong southwesterly flow located over the central Atlantic. Otto reached its maximum intensity of 75 knots early on October 9, however, it soon afterwards began to weaken due to increasing southwesterly shear. It was downgraded to a tropical storm on October 10 and became extra-tropical later that day. Otto's precursor dumped large amounts of rain in the Leeward Islands as well as Puerto Rico, causing extensive flooding.

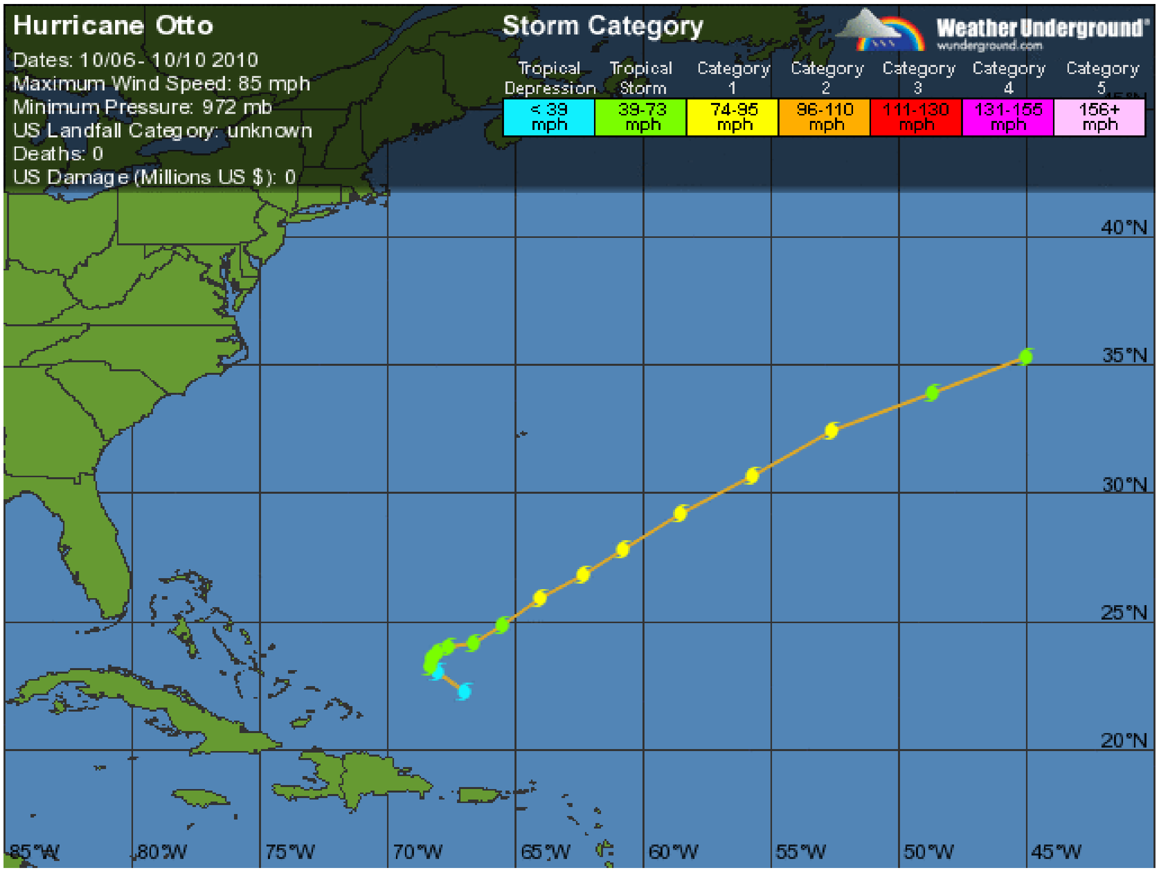


Figure 15: Track of Hurricane Otto. Figure courtesy of Weather Underground.

Hurricane Paula (#16): Paula formed near the coast of Honduras on October 11 (Figure 16). A reconnaissance aircraft measured approximately 50-knot surface winds on its initial flight into the system, and therefore, Paula was classified as a tropical storm at its initial advisory. A ridge over the northwestern Caribbean Sea turned Paula towards the northwest and then north over the next couple of days. Paula was a very small tropical cyclone throughout its lifetime. Paula quickly intensified into a hurricane on October 12 while in an environment of very deep warm waters and relatively light shear, reaching Category 2 status later that day. Strong southwesterly shear as well as dry air began to impinge on the tropical cyclone later that day, and Paula began to weaken. It was downgraded to a tropical storm later on October 14. It made landfall in western Cuba and was downgraded to a tropical depression the following day. It weakened further to a remnant low several hours later. Paula was responsible for minor damage in Honduras and Cuba.

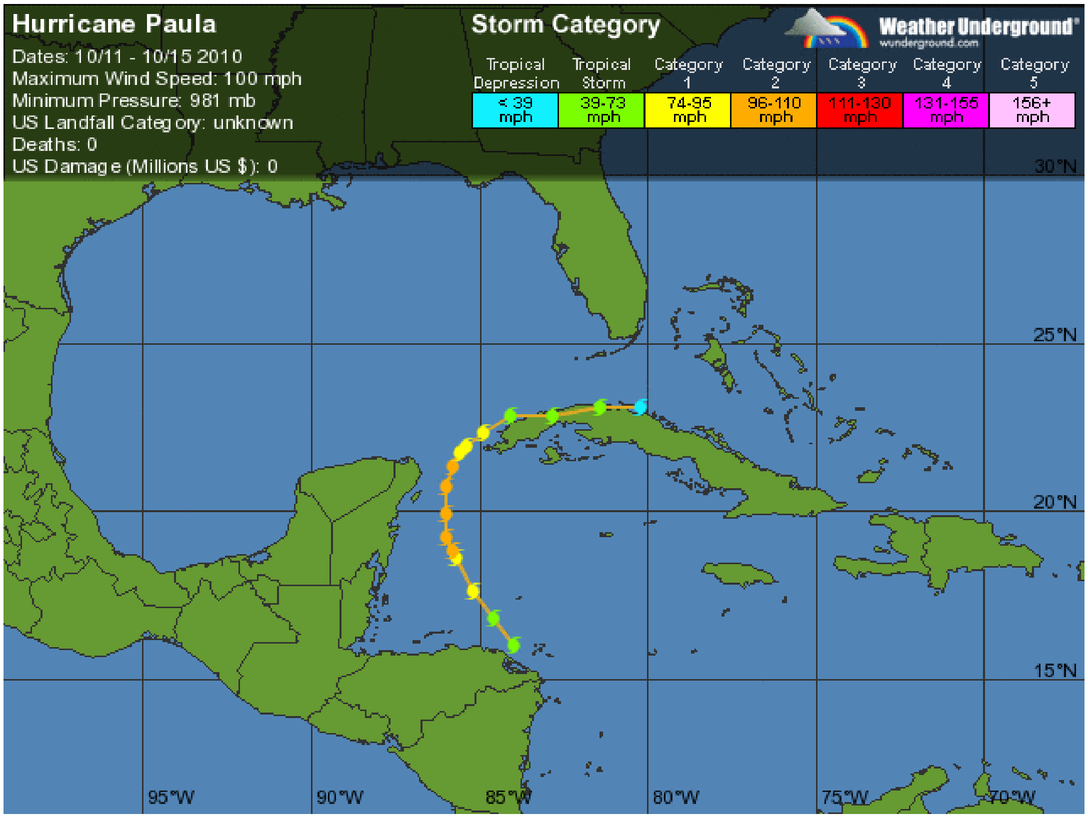


Figure 16: Track of Hurricane Paula. Figure courtesy of Weather Underground.

<u>Hurricane Richard (#17):</u> Richard formed in the northwest Caribbean early on October 21 (Figure 17). It drifted slowly towards the south and intensified into a tropical storm later that day. Moderate wind shear and significant dry air entrainment prevented much strengthening over the next couple of days. By October 23, the shear weakened considerably and Richard began to intensify, reaching hurricane status the following day as it approached the coast of Belize. The system made landfall just south of Belize City early on October 25 with maximum sustained winds at 80 knots. It rapidly weakened to a tropical storm, then a tropical depression later that day. It became a remnant low the following day. Richard was responsible for approximately $18 million dollars worth of damage in Belize, but fortunately, no deaths were reported.

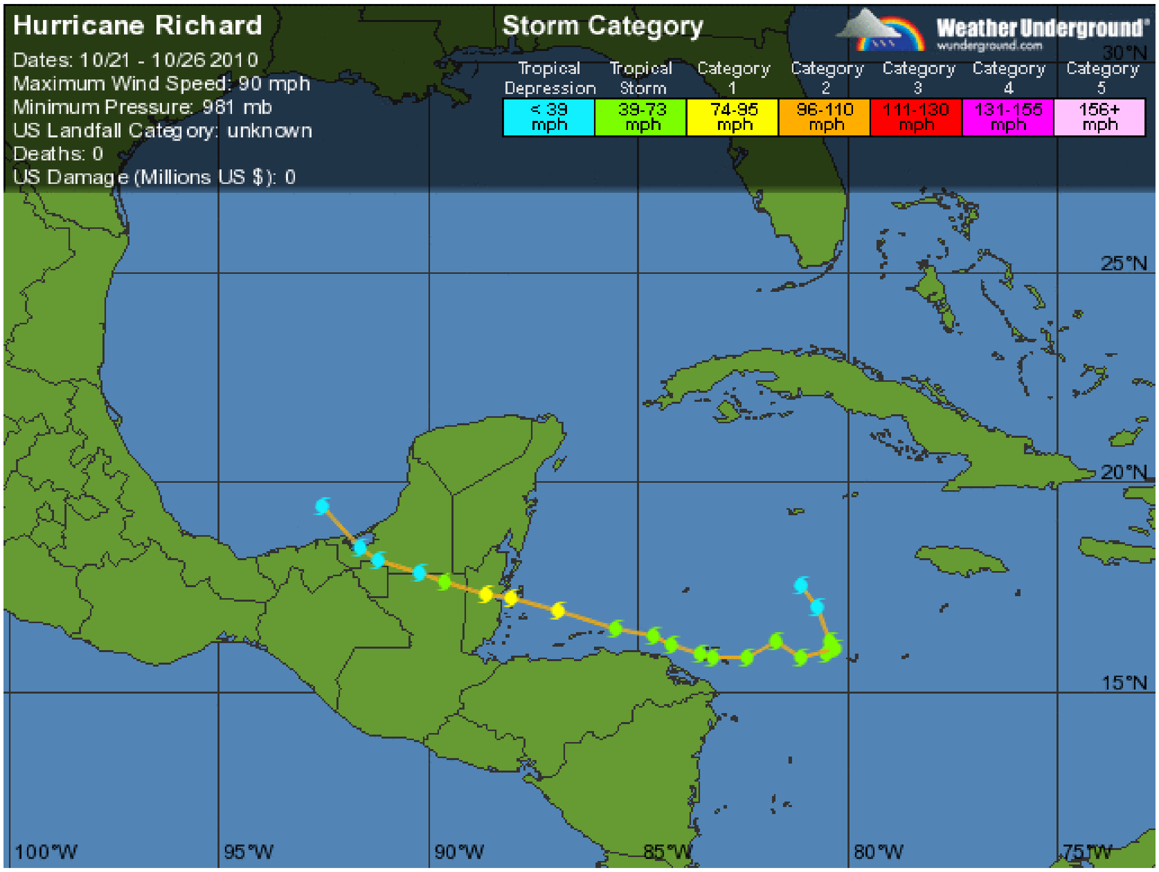


Figure 17: Track of Hurricane Richard. Figure courtesy of Weather Underground.

Hurricane Shary (#18): Shary formed southeast of Bermuda early on October 29 (Figure 18). Despite being in an environment of marginal sea surface temperatures and moderate wind shear, Shary strengthened into a hurricane the following day. The system moved rapidly northeastward and encountered increasing southerly shear and cooler SSTs while doing so. By late on October 30, Shary became extra-tropical as a cold front to its west absorbed the cyclone. Shary threatened Bermuda while moving northeastward, but fortunately, it passed enough to the east of the island to cause no significant impacts there.

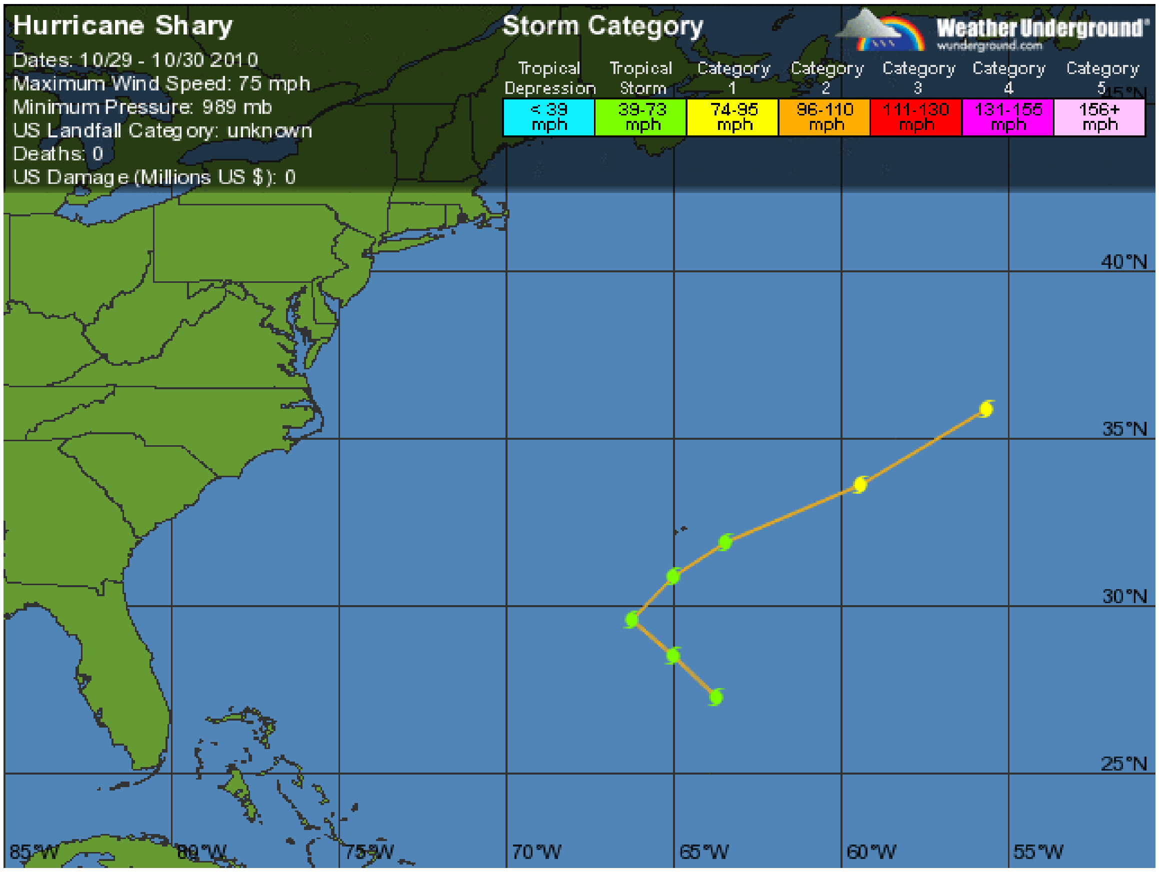


Figure 18: Track of Hurricane Shary. Figure courtesy of Weather Underground.

Hurricane Tomas (#19): Tomas formed east of the Windward Islands late on October 29 (Figure 19). It formed in an environment of low shear, warm SSTs and high mid-level moisture, and consequently, Tomas reached hurricane status the following day while tracking underneath a ridge to its north. While passing across the Windward Islands, Tomas did extensive damage to the islands of Saint Lucia, Saint Vincent and Barbados. It strengthened to a Category 2 storm during this time, however, it soon began to weaken as it encountered dry mid-level air and strong southwesterly shear. It was downgraded to a tropical storm early on November 1 and weakened further throughout the following two days. By November 3, Tomas had weakened to a tropical depression. As it slowly moved westward, it moved into a more favorable environment and re-intensified into a tropical storm the following day. By November 5, Tomas had intensified into a hurricane for the second time and bore down on Jamaica, Cuba and Hispaniola as it began moving northeastward. Fairly strong southerly shear began impacting the storm soon after, and Tomas weakened back to a tropical storm. Tomas surprisingly re-strengthened back into a hurricane late on November 6 before rapidly weakening and transitioning to an extra-tropical low on November 7. Twenty-four direct fatalities have been attributed to Tomas.

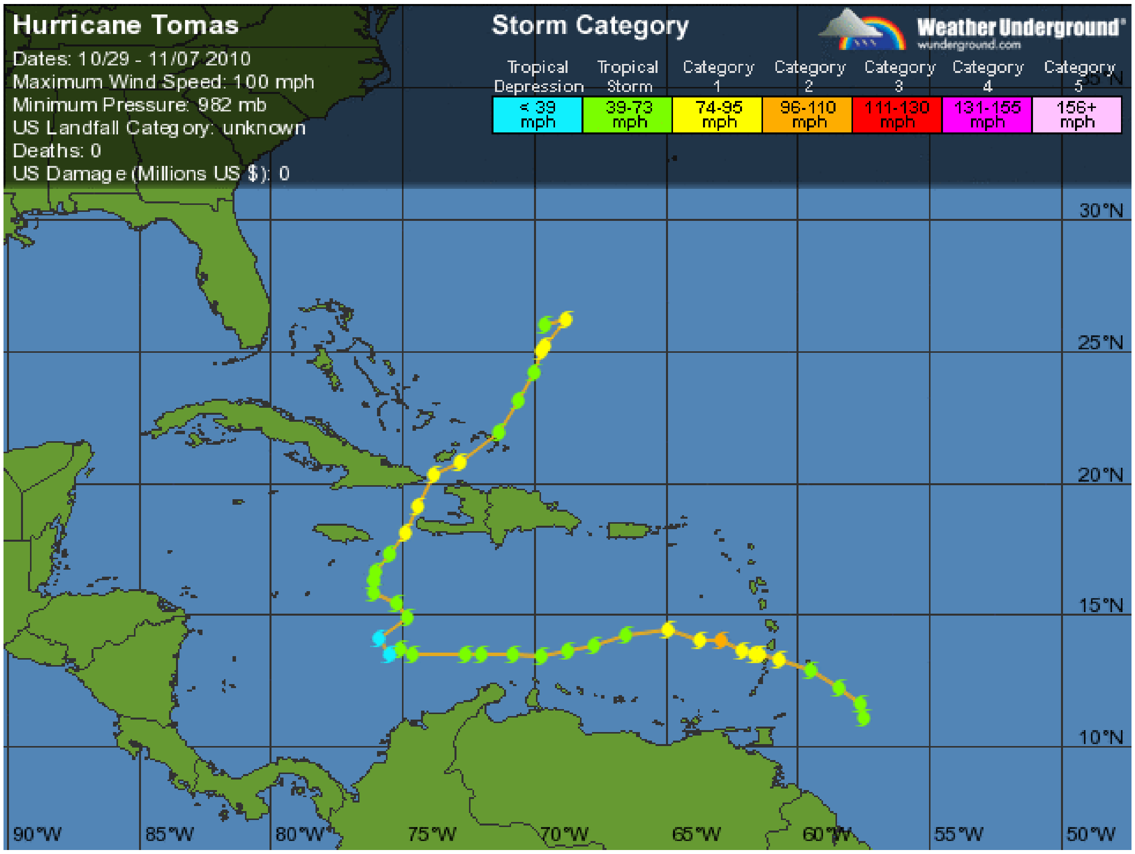


Figure 19: Track of Hurricane Tomas. Figure courtesy of Weather Underground.

U.S. Landfall. Figure 20 shows the track of Tropical Storm Bonnie, which was the only tropical cyclone to make United States landfall this year. Bonnie did very minor damage along the south Florida coast.

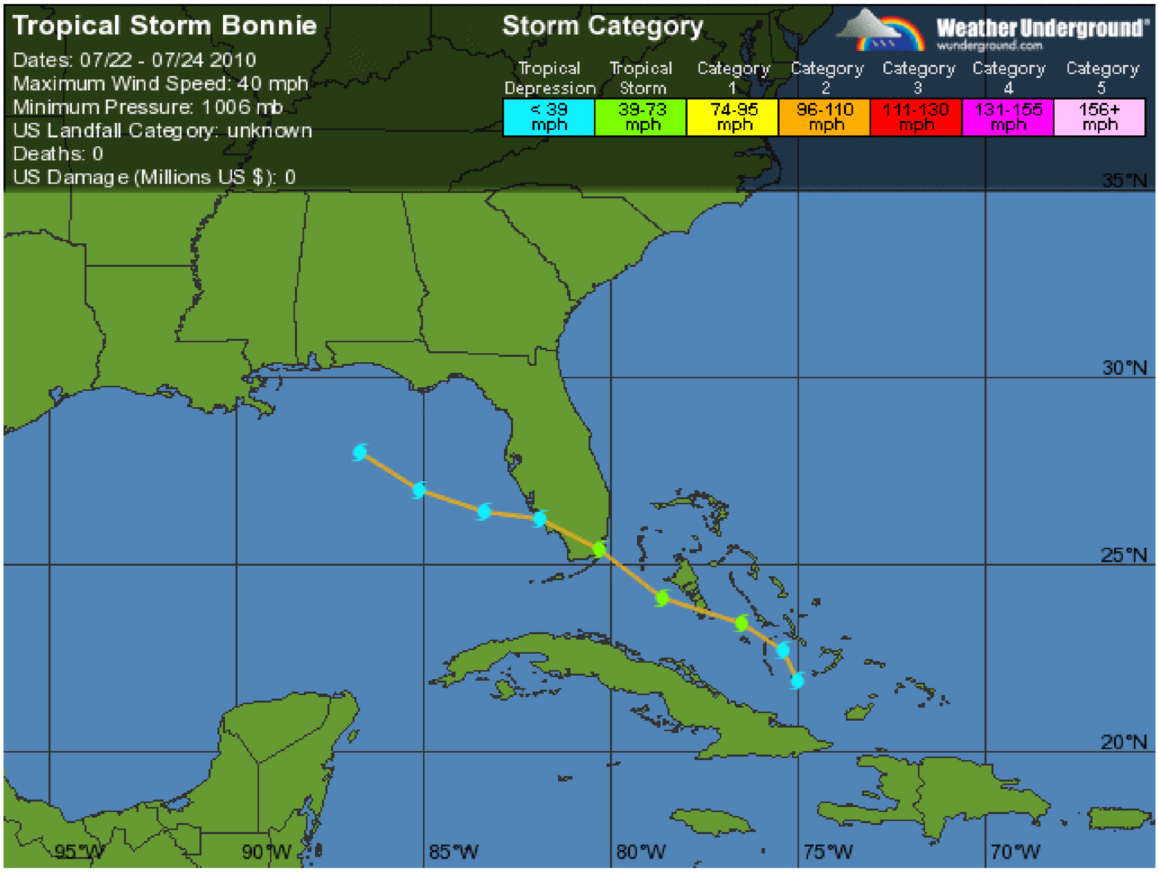


Figure 20: Track of Tropical Storm Bonnie, the only tropical cyclone to make United States landfall this year.

4 Special Characteristics of the 2010 Hurricane Season

The 2010 hurricane season had the following special characteristics:

- Nineteen named storms occurred during 2010. Since 1944, only 1995 (19) and 2005 (28) have had the same or more named storms.

- Nine named storms formed in the Main Development Region this year (Colin, Danielle, Earl, Fiona, Gaston, Igor, Julia, Lisa and Tomas). Only 1933 (11 storms) and 1995 (9 storms) have had as many named storms form in the MDR.

- 88.25 named storm days occurred in 2010. This ties 2010 with 2008 for the 6th most named storm days in a single season since 1944.

- Twelve hurricanes occurred in 2010. Since 1944, only two seasons, 1969 (12) and 2005 (15) have had the same or more hurricanes in a single season.

- 37.50 hurricane days occurred in 2010. This is the most hurricane days observed in a single season since 2005 (when 49.75 hurricane days were recorded).

- 5 major hurricanes formed during the 2010 hurricane season. Since 1944, only seven seasons (1950, 1955, 1961, 1964, 1996, 2004, and 2005) have had more than five major hurricanes form.

- 11 major hurricane days occurred in 2010. This is the 11th most major hurricane days to occur in a single season since 1944.

- The season accrued an ACE of 163. This is the most ACE since 2005 (250) and the 13th most since 1944.

- The season accumulated 195 NTC units. This is the most NTC since 2005 (279) and the 7th highest of the last 66 years.

- No Category 5 hurricanes developed in 2010. This is the third consecutive year with no Category 5 hurricanes. The last time that two or more years occurred in a row with no Category 5 hurricanes was 1999-2002.

- June and July had slightly above-average ACE activity. Seven ACE units were accrued during the two-month period, while the 1950-2000 June-July average was approximately 5 ACE units.

- No named storm days were accrued between August 9 and August 21. The last time that no named storm days occurred between these two dates was 2006.

- August had well above-average ACE activity. 38 ACE units were recorded during the month, which is approximately 165% of the 1950-2000 average. It was the most ACE accrued during the month of August since 2005 when 39 ACE units were accumulated.

- Eleven named storms formed between August 22 and September 29. This is the most named storms to form during this period, breaking the old record of nine named storms set in 1933, 1949, 1984 and 2002.

- September was very active. 102 NTC units were recorded during the month, which is the fourth most of all-time during September, trailing only 2004 (131 NTC), 1926 (138 NTC), and 1961 (146 NTC).

- Five hurricanes formed during the month of October. Only 1870 (six hurricanes) and 1950 (five hurricanes) have had at least five systems reach hurricane strength for the first time during October.

- Hurricane Alex became the most powerful hurricane during the month of June, in terms of maximum sustained winds (90 knots), since Hurricane Alma in 1966 which had estimated maximum sustained winds of 110 knots.

- Hurricane Igor generated 43 ACE units. This is the most ACE units generated by a single storm since Hurricane Ivan (2004) which generated a whopping 70 ACE units.

- Hurricane Julia became the farthest east that a Category 4 hurricane has formed in the MDR, according to the HURDAT database. However, it should be cautioned that the reliability of tropical cyclone statistics, especially in the eastern Atlantic is suspect prior to satellite imagery being readily available in the mid 1960s.

- Igor and Julia both were at Category 4 status on September 15. The only other time that two storms both were at Category 4 status in the Atlantic was on September 15, 1926.

- Igor, Julia and Karl were all at hurricane strength at the same time. This has only occurred in eight years prior to 2010, with the most recent occasion being in 1998.

- Four Category 4 hurricanes (Danielle, Earl, Igor and Julia) formed in the Atlantic between August 27 and September 15 (20 days). This is the shortest time span on record for four Category 4 hurricanes to develop, breaking the old record of 24 days set in 1999.

- Tomas accrued the most named storm days (8.75 NSD) of any storm forming on or after October 29 since Epsilon (2005) accrued 9.25 NSD. Tomas was also the fourth-longest lived post-October 28 tropical cyclone of the last 66 years.

- Only one tropical storm made U.S. landfall this year (Bonnie). We have not had a hurricane landfall since Hurricane Ike in 2008. The last time that we went two years in a row with no hurricane landfalls was 2000-2001.

- Only three tropical storms have made landfall over the past two years. The last time that three or fewer tropical cyclones made landfall in any consecutive two-year period was 1990-1991.

- No hurricanes made landfall along the Florida Peninsula and East Coast. This marks the fifth year in a row with no hurricane landfalls along this portion of the U.S. coastline. This is the first time since reliable U.S. records began in 1878 that no hurricanes have made landfall along the Florida Peninsula and East Coast in a five-year period.

- No hurricanes made landfall along the United States coastline this year. This is the first time in recorded history that as many as twelve hurricanes have occurred in the Atlantic basin without a United States landfall. Every other year with at least ten hurricanes in the Atlantic basin had at least two hurricane landfalls in the United States.

- No major hurricanes made U.S. landfall this year. Following seven major hurricane landfalls in 2004-2005, the U.S. has not witnessed a major hurricane landfall in the past five seasons. The five consecutive years between 1901-1905 and 1910-1914 have been the only other five consecutive year periods with no major U.S. hurricane landfalls.

5 Dearth of U.S. Major Hurricane Landfall in Recent Years (Except 2004-2005)

The United States has been very fortunate during the recent 16-year active period (1995-2010) with regards to major hurricane landfalls. Approximately 80-85 percent of tropical cyclone-related damage is due to major hurricanes, when damage is normalized by population, inflation and wealth per capita (Pielke Jr. and Landsea 1998, Pielke Jr. et al. 2008). The 20th century average is that approximately 30% of all major hurricanes that form in the Atlantic basin make United States landfall. Over the period from 1995-2010, we have had a total of 61 major hurricanes. Of these 61 major hurricanes, only 10 have made United States landfall as major hurricanes (16%), or approximately half of what we would expect given the long-term average. When we exclude the two very active major hurricane landfall years of 2004-2005 (7 major hurricanes making U.S. landfall out of 13 total major hurricanes that formed in the Atlantic basin), only three of the 48 major hurricanes that formed in the Atlantic basin from 1995-2003 and 2006-2010 have made U.S. landfall. This string of good luck can be extended further back into the past. For example, from 1941-1969, we averaged nearly one major hurricane landfall per year (Figure 21), compared with only 0.4 major hurricane landfalls per year from 1970-2010 (excluding 2004-2005) (Figure 22).

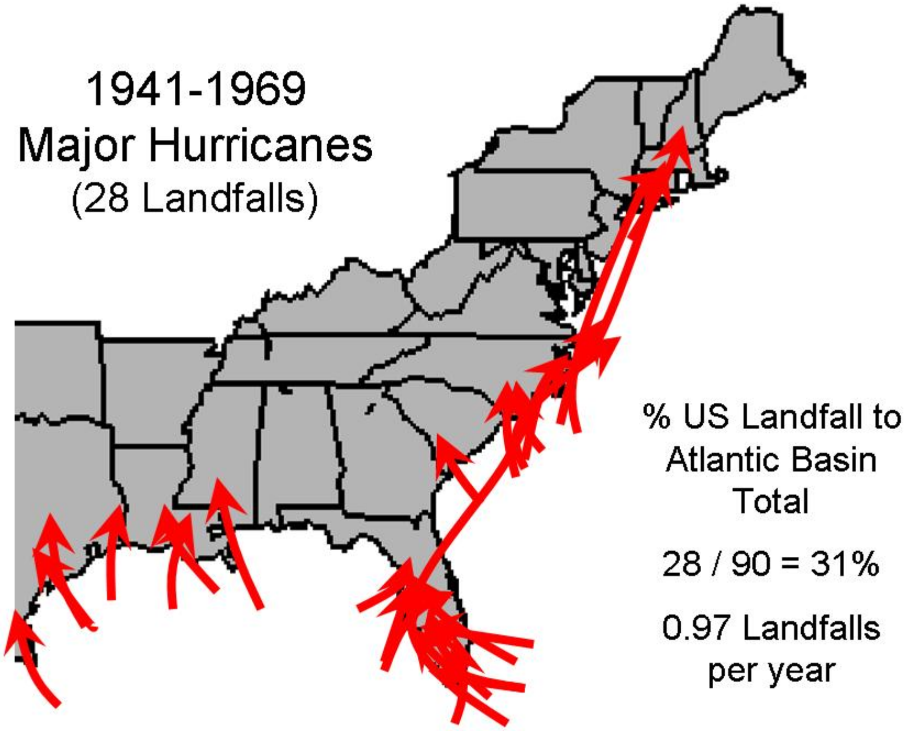


Figure 21: United States major hurricane landfalls from 1941-1969.

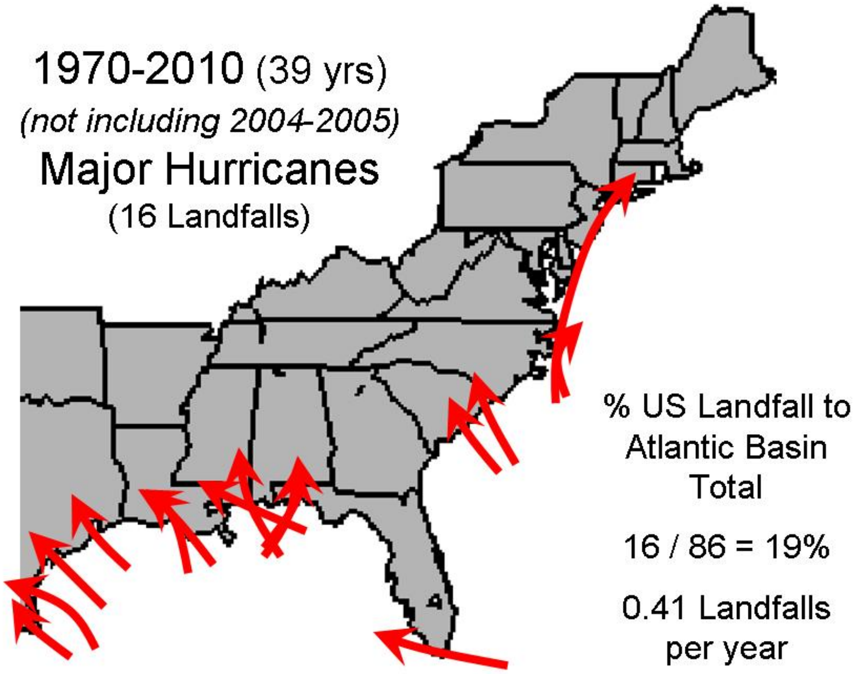


Figure 22: United States major hurricane landfalls from 1970-2010 (excluding 2004-2005).

This string of good luck has been even more remarkable for the Florida Peninsula and the East Coast. From 1995-2010, only four major hurricanes have made landfall along the Florida Peninsula/East Coast of the 61 that formed in the Atlantic basin (7%). The 20th century average is that approximately 18% of all major hurricanes that form in the Atlantic basin make Florida Peninsula/East Coast landfall. There has been a nearly three times reduction in the number of major hurricanes making Florida Peninsula/East Coast landfall during the most recent active period when compared with the 20th century average.

More impressive signals can be seen if one excludes the 2004-2005 hurricane seasons, when three major hurricanes made landfall along the Florida Peninsula and East Coast. From 1941-1969 and 2004-2005, 24 major hurricanes made landfall along the Florida Peninsula/East Coast over 31 years, or 0.77 major hurricane landfalls per year (Figure 23). This compares with the 1970-2010 (excluding 2004-2005) average when only 0.13 major hurricane landfalls per year occurred (or approximately six times fewer landfalls during the more recent period) (Figure 24).

This dearth in United States major hurricane landfalls in more recent years has resulted in much lower damages being sustained along the coastline than would be expected given the heightened amounts of basinwide activity that have been experienced since 1995.

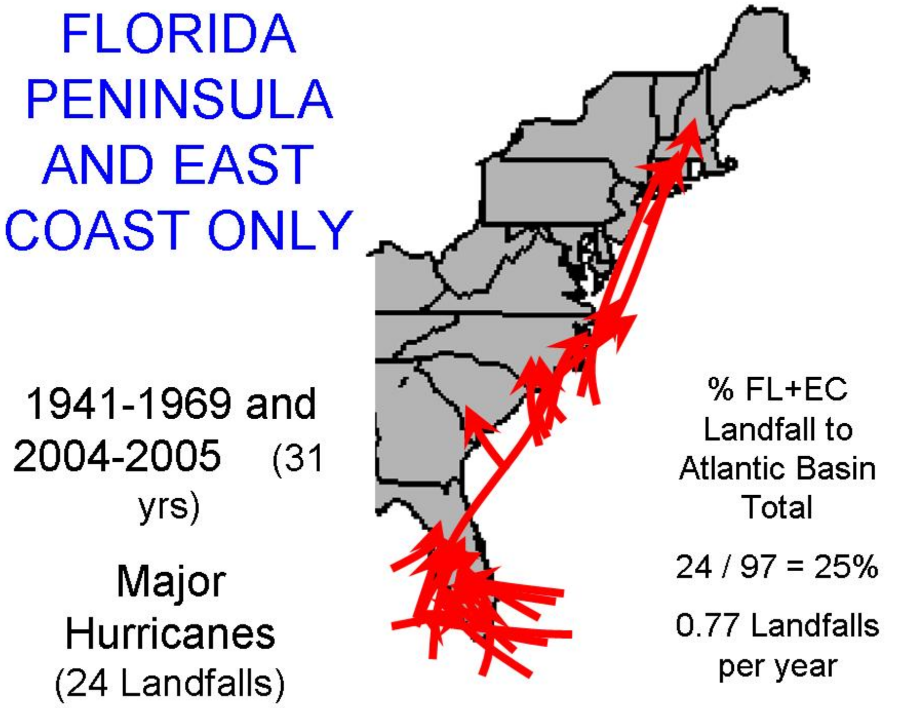


Figure 23: Florida Peninsula and East Coast major hurricane landfalls from 1941-1969 and 2004-2005.

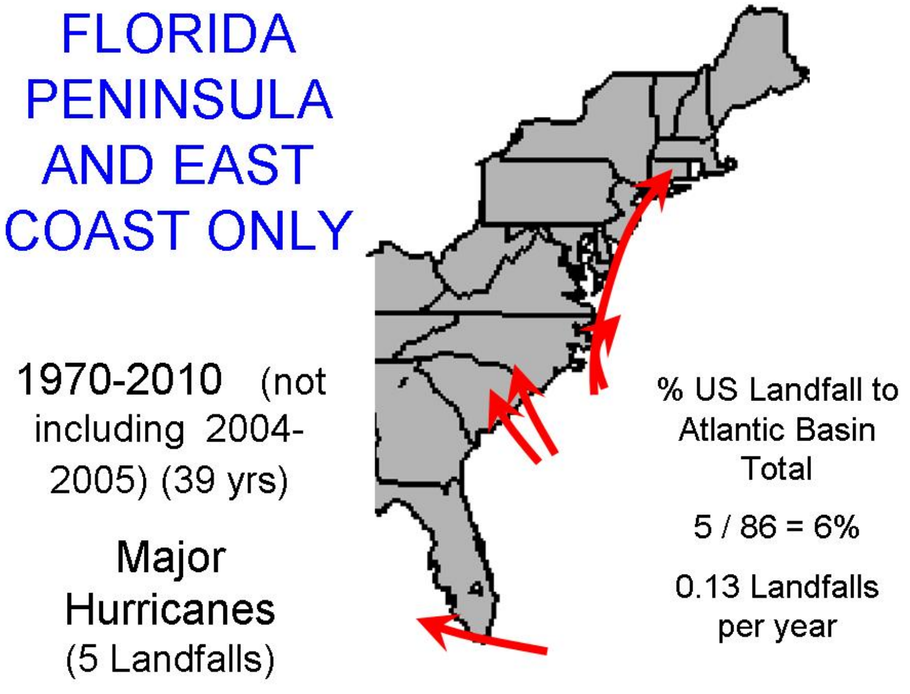


Figure 24: Florida Peninsula and East Coast major hurricane landfalls from 1970-2010 (excluding 2004-2005).

6 Verification of Individual 2010 Lead Time Forecasts

Table 3 is a comparison of our 2010 forecasts for four different lead times along with this year's observations. Our April, June and August forecasts verified quite well, while our December forecast somewhat under-predicted activity. We were not sure if the El Niño event that started in the summer of 2009 would dissipate as rapidly as it did. Our forecasts trended upward as we became more confident that La Niña was likely to develop.

Table 4 provides the same forecasts, with error bars (based on one standard deviation of absolute errors) as calculated from hindcasts over the 1990-2007 period, using equations developed over the 1950-1989 period. 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. All of our June and August forecasts verified within one standard deviation of observed values making this a very successful forecast.

Table 3: Verification of our 2010 seasonal hurricane predictions.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	9 Dec 2009	Update 7 April 2010	Update 2 June 2010	Update 4 Aug 2010	Observed 2010 Total
Named Storms (NS) (9.6)	11-16	15	18	18	19
Named Storm Days (NSD) (49.1)	51-75	75	90	90	88.25
Hurricanes (H) (5.9)	6-8	8	10	10	12
Hurricane Days (HD) (24.5)	24-39	35	40	40	37.50
Intense Hurricanes (IH) (2.3)	3-5	4	5	5	5
Intense Hurricane Days (IHD) (5.0)	6-12	10	13	13	11
Accumulated Cyclone Energy (ACE) (96.2)	100-162	150	185	185	163
Net Tropical Cyclone Activity (NTC) (100%)	108-172	160	195	195	195

Table 4: Verification of our 2010 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. 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. Error bars for storms are rounded to the nearest storm. For example, the hurricane prediction in early April would be 5.8-10.2, which with rounding would be 6-10. We use the midpoint of our December forecast range for verification purposes. All of our June and August forecasts were within one standard deviation of the 2010 observed total, making this a very successful forecast.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	9 Dec 2009	Update 7 April 2010	Update 2 June 2010	Update 4 Aug 2010	Observed 2010 Total
Named Storms (NS) (9.6)	**13.5** (±4.4)	**15** (±4.0)	**18** (±3.8)	**18** (±2.3)	19
Named Storm Days (NSD) (49.1)	**63** (±23.9)	**75** ±(19.4)	**90** (±18.3)	**90** (±17.4)	88.25
Hurricanes (H) (5.9)	**7** (±2.5)	**8** (±2.2)	**10** (±2.1)	**10** (±1.6)	12
Hurricane Days (HD) (24.5)	**31.5** (±12.4)	**35** (±9.5)	**40** (±9.0)	**40** (±8.6)	37.50
Major Hurricanes (MH) (2.3)	**4** (±1.5)	**4** (±1.4)	**5** (±1.2)	**5** (±0.9)	5
Major Hurricane Days (MHD) (5.0)	**9** (±4.7)	**10** (±4.4)	**13** (±4.5)	**13** (±3.5)	11
Accumulated Cyclone Energy (ACE) (96.2)	**131** (±50)	**150** (±39)	**185** (±39)	**185** (±36)	163
Net Tropical Cyclone Activity (NTC) (100%)	**140** (±49)	**160** (±41)	**195** (±37)	**195** (±34)	195

6.1 Preface: Aggregate Verification of our Last Twelve 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 5 displays how frequently our forecasts have been on the right side of climatology for the past twelve 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 December of the previous year. We tend to have improving skill as we get closer in time to the start of the hurricane season.

Table 5: The number of years that our tropical cyclone forecasts issued at various lead times has correctly predicted above- or below-average activity for each predictand over the past twelve years (1999-2010).

Tropical Cyclone Parameter	**Early December**	**Early April**	**Early June**	**Early August**
NS	9/12	10/12	10/12	9/12
NSD	9/12	10/12	10/12	10/12
H	8/12	10/12	10/12	10/12
HD	7/12	8/12	9/12	10/12
MH	7/12	8/12	10/12	10/12
MHD	8/12	9/12	11/12	11/12
NTC	7/12	8/12	9/12	10/12
Total	**55/84 (65%)**	**62/84 (74%)**	**69/84 (82%)**	**70/84 (83%)**

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, especially for the early December lead time, 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 interest. 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. 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 1984-2009.

6.2 Aggregate Verification of our Last Three Years of Forecasts

Following relatively unsuccessful forecasts in 2006 and 2007, we redesigned all of our statistical forecast model guidance prior to the start of the 2008 hurricane season. The combination of these improved forecast models along with improved understanding of how the atmosphere/ocean behaves has led to significantly increased skill over the past three years. Table 6 displays our seasonal forecasts for the 2008-2010 seasons.

Table 6: Forecast verification from 2008-2010

2008	7 Dec. 2007	Update 9 April	Update 3 June	Update 5 August	Obs.
Named Storms	13	15	15	17	16
Named Storm Days	60	80	80	90	88.25
Hurricanes	7	8	8	9	8
Hurricane Days	30	40	40	45	30.50
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.
Named Storms	14	12	11	10	9
Named Storm Days	70	55	50	45	30
Hurricanes	7	6	5	4	3
Hurricane Days	30	25	20	18	12
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	66

2010	9 Dec. 2009	Update 7 April	Update 2 June	Update 4 August	Obs.
Named Storms	11-16	15	18	18	19
Named Storm Days	51-75	75	90	90	88.25
Hurricanes	6-8	8	10	10	12
Hurricane Days	24-39	35	40	40	37.50
Major Hurricanes	3-5	4	5	5	5
Major Hurricane Days	6-12	10	13	13	11.00
Accumulated Cyclone Energy	100-162	150	185	185	163
Net Tropical Cyclone Activity	108-172	160	195	195	195

One way to examine the success of these forecasts is to examine the improvement of these seasonal forecasts from both climatology (1950-2000) as well as the previous five-year mean. For this analysis, we use the mean absolute error skill metric, which is defined as:

Mean Absolute Error = |Forecast – Observation|

Table 7 displays the forecast improvement relative to climatology for each of our eight forecast metrics, while Table 8 displays the forecast improvement relative to the previous five-year mean. Figure 25 represents the same in schematic form for named storms and major hurricanes with respect to climatology.

Table 7: Skill of seasonal forecasts issued in early December, early April, early June and early August **with respect to climatology (1950-2000)** for the past three seasons' worth of forecasts (2008-2010). Skill is defined as improvement in mean absolute error.

	December	April	June	August
Named Storms	18%	51%	76%	82%
Named Storm Days	4%	52%	69%	81%
Hurricanes	10%	37%	64%	64%
Hurricane Days	22%	21%	37%	27%
Major Hurricanes	30%	65%	82%	100%
Major Hurricane Days	30%	60%	60%	40%
Accumulated Cyclone Energy	16%	60%	64%	51%
Net Tropical Cyclone Activity	16%	61%	88%	77%
Average	18%	51%	68%	65%

Table 8: Skill of seasonal forecasts issued in early December, early April, early June and early August with **respect to the previous five-year mean** for the past three seasons' worth of forecasts (2008-2010). Skill is defined as improvement in mean absolute error.

	December	April	June	August
Named Storms	-13%	33%	67%	75%
Named Storm Days	-17%	42%	62%	77%
Hurricanes	6%	34%	62%	62%
Hurricane Days	28%	26%	41%	32%
Major Hurricanes	17%	58%	79%	100%
Major Hurricane Days	58%	76%	76%	64%
Accumulated Cyclone Energy	16%	60%	64%	51%
Net Tropical Cyclone Activity	7%	57%	87%	74%
Average	13%	48%	67%	67%

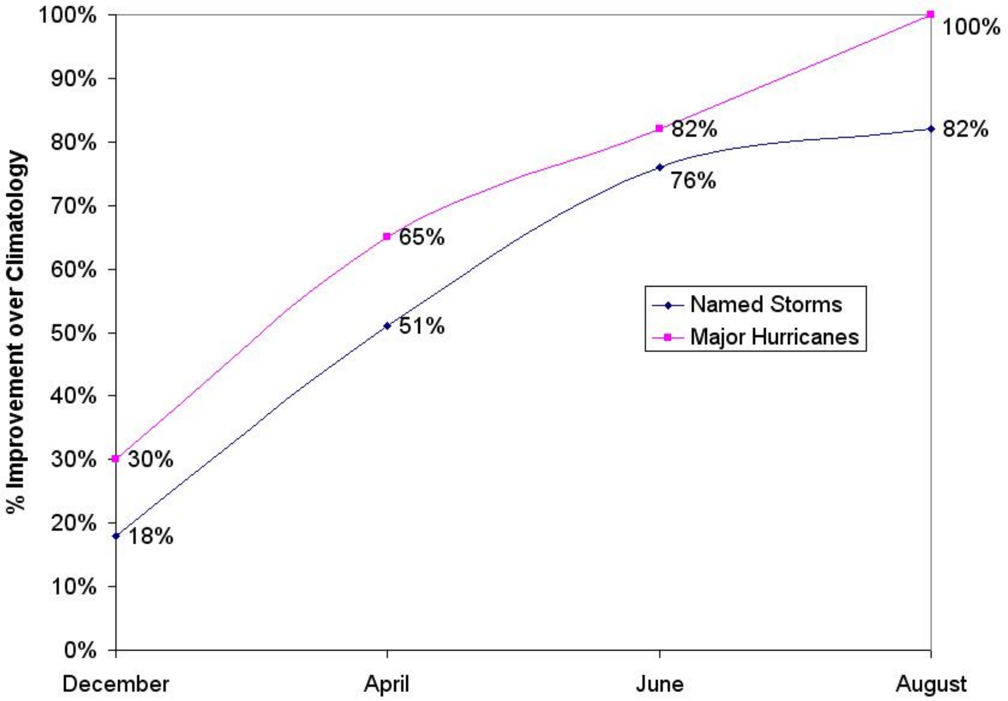


Figure 25: Improvement of the seasonal forecast over climatology for forecasts issued in early December, early April, early June and early August for the three-year period from 2008-2010 for named storms (blue line) and major hurricanes (pink line).

6.3 Verification of Two-Week Forecasts

This is the second 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 were based on a combination of observational and modeling tools. The primary tools that were used for these forecasts were: 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 were judged to be 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 9.

Table 9: 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 10 displays the six two-week forecasts that were issued during the 2010 hurricane season and shows their verification. The first forecast did not verify well. The 2nd, 4th and 6th forecasts verified in the correct category, while the 3rd and 5th forecasts missed by one category.

Table 10: Two-week forecast verification for 2010. 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 Day	Predicted ACE	Observed ACE
8/4/2010	**Above-Average (10 or More)**	**2**
8/18/2010	**Above-Average (19 or More)**	**36**
9/1/2010	**Average (20 – 37)**	**39**
9/15/2010	**Above-Average (29 or More)**	**48**
9/29/2010	**Above-Average (14 or More)**	**8**
10/13/2010	**Average (5 – 9)**	**9**

As was the case last year, one of the primary challenges with the two-week forecasts this year was that we are largely dependent on the MJO for skill, especially during the second week portion of the forecast. Expect for one high-amplitude MJO event that developed in the early part of October, the remainder of the August-October period was characterized by weak MJO activity (Figure 26). We were therefore largely dependent on global model genesis forecasts, storms that existed on the initial forecast date, and the overall favorable seasonal climatic conditions for the skill of these forecasts.

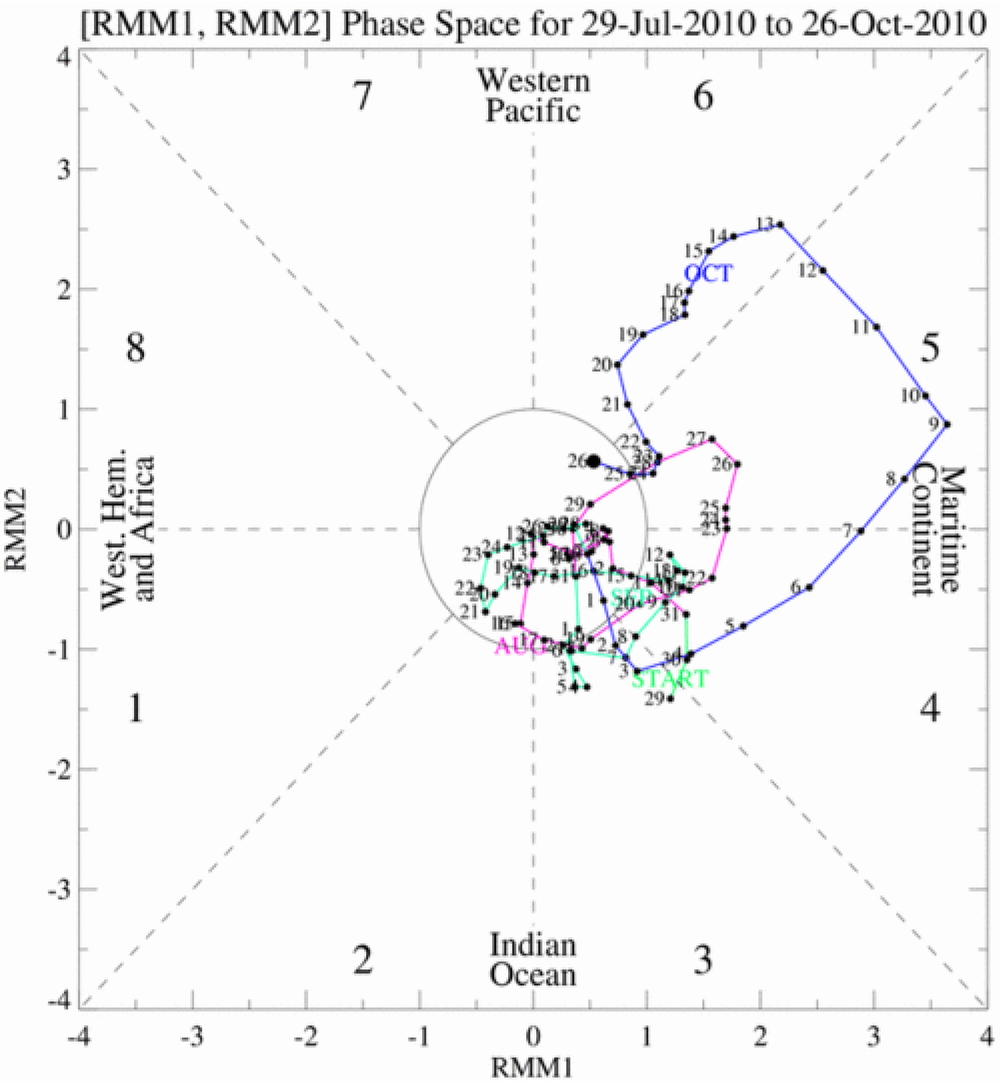


Figure 26: Propagation of the Madden-Julian Oscillation (MJO) based on the Wheeler-Hendon classification scheme over the period from July 29 to October 26. Note that coherent eastward propagation of the MJO during this timeframe was rarely evident and that the magnitude of the MJO was often quite small (e.g., located in the inner circle indicating weak MJO amplitude). The Maritime Continent refers to Indonesia and the surrounding islands.

6.4 Verification of Caribbean Basin Forecasts

This is the first year that we have issued a specific forecast for the Caribbean basin, defined as 10-20°N, 60-88°W (Figure 27). The models that were developed for this Caribbean forecast indicated that approximately 45% of the variance in Accumulated Cyclone Energy (ACE) generated in the Caribbean basin could be explained by the early June forecast, increasing to approximately 50% of the variance by early August.

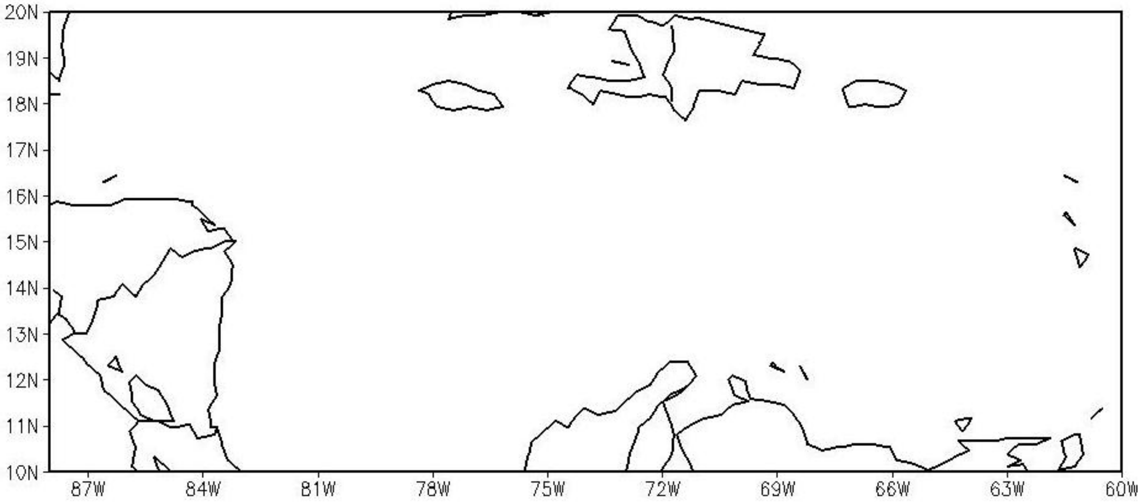


Figure 27: The Caribbean basin as defined for these forecasts.

Real-time forecasts issued in 2010 called for a very active Caribbean. The primary reason why these forecasts called for so much activity was due to anomalously weak trade winds across the region, indicating enhanced pre-existing low-level vorticity across the region as well as the development of a moderate La Niña event. The average annual Caribbean ACE over the period from 1949-2009 was 14, while the early June and early August models predicted an ACE of 58 and 41, respectively. Overall conditions were generally quite favorable for storm formation in the Caribbean, as indicated by the real-time genesis potential produced by the Cooperative Institute for Research in the Atmosphere (CIRA) (Figure 28). Caribbean basin ACE was observed at above-average levels, with 22 ACE units occurring, although not to the magnitude that was predicted in our forecasts. This Caribbean basin model will be refined for the 2011 season.

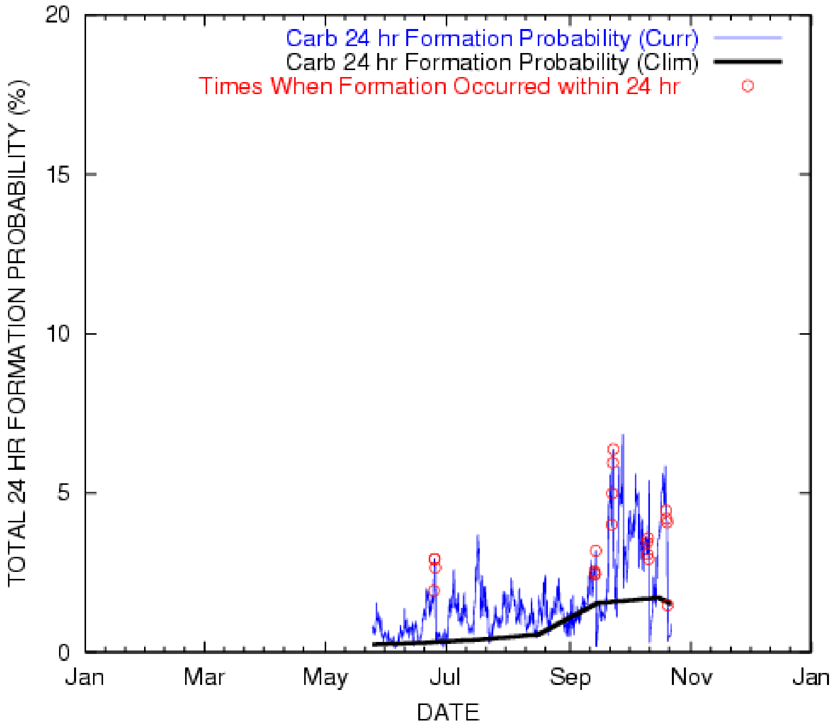


Figure 28: Caribbean real-time genesis parameter. Note that, in general, the 2010 real-time genesis parameter well exceeded climatology. Figure courtesy of CIRA.

7 Landfall Probabilities

7.1 Landfall Probability Verification

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 (relative to climatology) can be forecast with statistical skill. 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 11 gives verifications of our landfall probability estimates for the United States and for the Caribbean in 2010.

Landfall probabilities for the 2010 hurricane season were estimated to be well above their long period averages due to the forecasts of a very active season. The 2010 hurricane season was surprisingly quiet from a U.S. landfall perspective, with only one tropical storm (Bonnie) making U.S. landfall this year. This is the first year in recorded history that twelve hurricanes have formed in the Atlantic basin without a United States landfalling hurricane. All seasons in the historical record that had at least ten hurricanes in the Atlantic basin had at least two hurricanes make United States landfall. Eight tropical cyclones passed through the Caribbean (10-20°N, 60-88°W) during 2010. Alex, Fiona, Karl and Matthew were at tropical-storm strength while tracking through the Caribbean. Richard reached Category 1 strength, Paula and Tomas reached Category 2 hurricane strength and Earl reached Category 4 hurricane strength while in the Caribbean. Since 1944, only 1945, 1996 and 2005 have had eight or more tropical cyclones track through the Caribbean.

Landfall probabilities include specific forecasts of the probability of U.S. landfalling tropical storms (TS) and hurricanes of category 1-2 and 3-4-5 intensity for each of 11 units of the U.S. coastline (Figure 29). 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. Since the website went live on June 1, 2004, the webpage has received nearly one million hits.

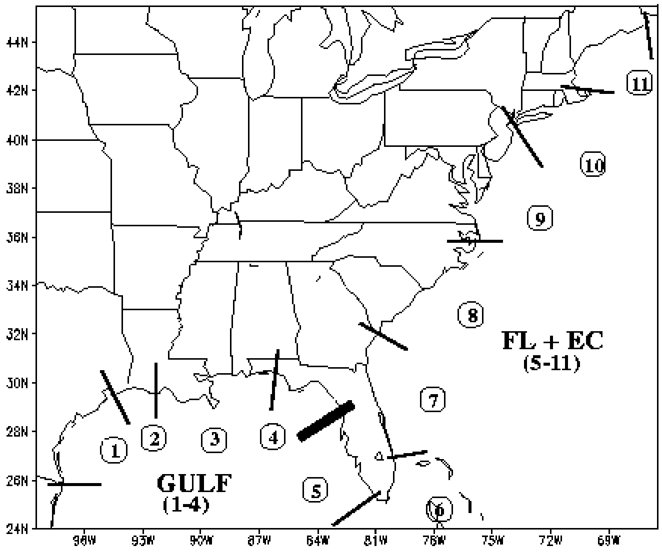


Figure 29: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made. These subdivisions were determined by the historical frequency of landfalling major hurricanes.

Table 11: 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 2010 at various lead times. The mean annual percentage of one or more landfalling systems during the 20th century is given in parentheses in the 4 August forecast column. Table (a) is for the entire United States, Table (b) is for the U.S. Gulf Coast, Table (c) is for the Florida Peninsula and the East Coast and Table (d) is for the Caribbean. Early August probabilities are calculated based on storms forming after 1 August.

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

	Forecast Date				
	9 Dec.	7 Apr.	2 June	4 August	Observed Number
TS	89%	92%	95%	95% (80%)	1
HUR (Cat 1-2)	79%	84%	89%	88% (68%)	0
HUR (Cat 3-4-5)	64%	69%	76%	75% (52%)	0
All HUR	93%	95%	97%	97% (84%)	0
Named Storms	99%	99%	99%	99% (97%)	1

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

	Forecast Date				
	9 Dec.	7 Apr.	2 June	4 August	Observed Number
TS	71%	76%	82%	81% (59%)	0
HUR (Cat 1-2)	54%	59%	66%	64% (42%)	0
HUR (Cat 3-4-5)	40%	44%	50%	49% (30%)	0
All HUR	72%	77%	83%	82% (61%)	0
Named Storms	92%	94%	97%	97% (83%)	0

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

	Forecast Date				
	9 Dec.	7 Apr.	2 June	4 August	Observed Number
TS	62%	67%	74%	73% (51%)	1
HUR (Cat 1-2)	56%	60%	68%	66% (45%)	0
HUR (Cat 3-4-5)	40%	45%	51%	50% (31%)	0
All HUR	74%	78%	84%	83% (62%)	0
Named Storms	90%	93%	96%	96% (81%)	1

(d) Caribbean (10-20°N, 60-88°W)

Forecast Date

	9 Dec.	7 Apr.	2 June	4 August	Observed Number
TS	91%	94%	97%	96% (82%)	4
HUR (Cat 1-2)	69%	74%	81%	79% (57%)	3
HUR (Cat 3-4-5)	54%	58%	65%	64% (42%)	1
All HUR	86%	89%	93%	93% (75%)	4
Named Storms	99%	99%	99%	99% (96%)	8

7.2 Interpretation of Landfall Probabilities

We never intended that our seasonal forecasts be used for individual-year landfall predictions. It is impossible to predict months in advance the mid-latitude flow patterns that dictate U.S. and Caribbean hurricane landfall. We only make predictions of the probability of landfall. Our landfall probability estimates work out very well when we compare 4-5 of our forecasts for active seasons versus 4-5 forecasts for inactive seasons. This is especially the case for landfalling major hurricanes.

High seasonal forecasts of Net Tropical Cyclone activity (NTC) (see Tables 12 and 13) should be interpreted as a higher probability of U.S. or Caribbean landfall but not necessarily that landfall will occur that year. Low seasonal forecasts of NTC do not mean that landfall will not occur but only that its probability is lower than average during that year.

The majority of U.S. landfalling tropical cyclones and Caribbean activity occurs during active Atlantic basin seasons, with below-average Atlantic basin hurricane seasons typically having below-average U.S. and Caribbean hurricane landfall frequency. This is particularly the situation for the Florida Peninsula and the East Coast and the Caribbean.

Table 12 gives observed high to low rankings of NTC for the last 61 (1950-2010) years in association with landfall frequency. Data is broken into numbers of landfalling tropical storms (TS), Cat 1-2 hurricanes (H) and Cat 3-4-5 hurricanes (MH). Note that high NTC years have substantially increased hurricane landfall numbers, particularly for major hurricanes when compared with low NTC years.

The relationship between Atlantic basin NTC and U.S. landfall is especially strong for major hurricane landfall along Peninsula Florida and the East Coast (Regions 5-11). The Gulf Coast landfall – NTC relationship is weaker except for the most active versus least active seasons. The relationship between NTC and Caribbean major hurricane activity is also quite strong.

Table 13 contrasts the observed U.S. landfall and Caribbean activity ratios associated with our high vs. low 1 June NTC hindcast values for the years of 1950-2010. This table also contrasts the upper 10, upper 20 and upper 30 hindcast NTC values vs. the lowest 10, lowest 20 and lowest 30 hindcast NTC values. Note the very high ratio of U.S. and Caribbean landfall differences between the highest and the lowest values of our 1 June NTC hindcasts. These hindcast differences are especially large for major (Cat 3-4-5) hurricanes which on a normalized (coastal population, inflation, wealth per capita) basis cause about 80-85 percent of hurricane-spawned destruction. It is fortunate that our most skillful 1 June NTC hindcasts best differentiate between the most intense and most destructive landfalling hurricanes. Tropical storm landfall frequencies are not nearly as well related to our 1 June hindcast NTC values.

Our 1 June NTC hindcasts work almost as well at specifying the probability of U.S. landfall for the Florida Peninsula and the East Coast (Regions 5-11) as well as the Caribbean as do the NTC observations. U.S. Gulf Coast landfall is less related to either observed or hindcast NTC.

Table 12: Observed landfall of named storms (NS), Cat 1-2 hurricanes (H) and Cat 3-4-5 hurricanes (MH) by high versus low **observed** values of Atlantic basin Net Tropical Cyclone (NTC) activity. Values are separately given for the Gulf Coast, the Florida Peninsula and East Coast, the whole U.S. coastline and the Caribbean for the 61-year period from 1950-2010.

	Gulf Coast (Regions 1-4)			Florida + East Coast (Regions 5-11)			Whole US (Regions 1-11)			Caribbean (10-20°N, 60-88°W)		
NTC Values	***NS***	***H***	***MH***	***NS***	***H***	***MH***	***NS***	***H***	***MH***	***NS***	***H***	***MH***
Top 10 Observed NTC years > 181	20	12	9	31	21	8	51	33	17	51	34	18
Bot 10 Observed NTC years ≤ 52	10	4	1	12	5	1	22	9	2	12	2	1
Top 20 Observed NTC years > 129	39	19	10	41	23	8	80	42	18	92	57	30
Bot 20 Observed NTC years ≤ 83	23	9	4	17	8	3	40	17	7	28	10	4
Top 30 Observed NTC years ≥ 97	53	29	12	64	35	14	117	64	26	126	71	38
Bot 30 Observed NTC years < 97	48	19	8	37	18	7	85	37	15	46	18	7

Table 13: Observed landfall of named storms (NS), Cat 1-2 hurricanes (H) and Cat 3-4-5 hurricanes (MH) based on high versus low 1 June **hindcast** values of Net Tropical Cyclone (NTC) activity for the Gulf Coast, the Florida Peninsula and East Coast, the whole U.S. coastline and the Caribbean for the 61-year period from 1950-2010.

	Gulf Coast (Regions 1-4)			Florida + East Coast (Regions 5-11)			Whole US (Regions 1-11)			Caribbean (10-20°N, 60-88°W)		
NTC Values	***NS***	***H***	***MH***	***NS***	***H***	***MH***	***NS***	***H***	***MH***	***NS***	***H***	***MH***
Top 10 Hindcast NTC years > 181	25	13	7	31	18	7	56	31	14	48	29	20
Bot 10 Hindcast NTC years ≤ 40	13	8	4	10	6	1	23	14	5	15	5	3
Top 20 Hindcast NTC years > 148	42	21	10	48	27	10	90	48	20	85	51	26
Bot 20 Hindcast NTC years ≤ 89	27	15	7	20	9	1	47	24	8	34	13	6
Top 30 Hindcast NTC years ≥ 119	61	29	12	60	35	15	121	64	27	106	65	33
Bot 30 Hindcast NTC years < 118	40	20	8	37	13	3	77	33	11	66	24	13

But more important than our last 27 years of early June forecasts of the numbers of NS and H is the implication of what these forecasts say as to the probability of U.S. and Caribbean landfall. Higher than average 1 June NTC forecasts are associated with a greater frequency of seasonal NS, H and MH landfall events and lower 1 June NTC forecasts are associated with less frequent NS, H and MH landfall events.

Table 14 shows the number of landfalling tropical cyclones which occurred in our 11 most active forecasts when our real time projects' 1 June prediction of the number of hurricanes was 8 or more versus those 11 years when our 1 June prediction of the seasonal number of hurricanes was 6 or less and 1993 (when 7 hurricanes but only 2 major hurricanes were predicted). Notice the nearly 3 to 1 difference in landfall of major hurricanes and the nearly 2 to 1 difference in landfalling Cat 1-2 hurricanes for the entire United States. The ratios for the Caribbean are similar, with a greater than 3 to 1 ratio for Caribbean major hurricanes.

Table 14: Number of U.S. and Caribbean landfalling tropical cyclones in the 11 years when our 1 June forecast was for 8 or more hurricanes versus those 11 years when our 1 June prediction was for 6 or fewer hurricanes and 1993 (when 7 hurricanes but only 2 major hurricanes were predicted).

Forecast H	US NS	US H	US MH	Caribbean NS	Caribbean H	Caribbean MH
≥ 8 (11 years)	57	29	12	50	27	15
≤ 6 & 1993 (11 years)	36	16	5	26	13	4

Our individual season forecasts of the last 27 years have had meaning as regards to the multi-year probability of US and Caribbean landfall, and even stronger statistical relationships are found with our real-time forecasts from 1 August.

8 Summary of 2010 Atmospheric/Oceanic Conditions

In this section, we go into detail discussing large-scale conditions that were present in the atmosphere and in the oceans during the 2010 Atlantic basin hurricane season that caused this season to be so active.

8.1 ENSO

As is usually the case, El Niño-Southern Oscillation (ENSO) presented a challenge with our 2010 seasonal hurricane forecasts. In our early December 2009 forecast for 2010, we believed that it was likely that El Niño would dissipate. Our confidence grew by early April and especially by early June. Consequently, our seasonal forecasts for Atlantic basin hurricane activity increased as we became more confident that El Niño would not be an inhibiting factor. By early August, a moderate La Niña had developed. The following are a couple of quotes from earlier forecasts regarding ENSO this year:

(9 December 2009) –

“We think that the persistence of warm ENSO conditions through next year’s hurricane season is quite unlikely.”

(7 April 2010) –

“Based on this information, we believe that the current moderate El Niño will likely transition to neutral conditions by this summer and early fall… Since we expect El Niño to dissipate over the next few months, we do not expect to see the high levels of vertical shear across the Main Development Region that we experienced last year.“

(2 June 2010) –

“Based on this information, we believe that the transition to neutral conditions will continue for the next couple of months with weak La Niña conditions likely developing thereafter.”

Our definition of weak, moderate and strong La Niña events for the August-October period is based on the August-October-averaged Nino 3.4 index. When this index is between minus 0.5-1.0°C, we define it as a weak La Niña event, when the index is between minus 1.0-1.5°C, we define it as a moderate La Niña event, and when the index is less than minus than 1.5°C, we define it as a strong La Niña event. The August-

October-averaged Nino 3.4 index in 2010 was approximately -1.5°C, or a borderline moderate/strong La Niña event.

A moderate-to-strong El Niño occurred during the winter of 2009/2010, with a rapid transition to neutral conditions occurring during this spring. The transition from El Niño to La Niña was quite rapid. The September - March anomalous cooling in the Nino 3.4 region was the strongest on record back to 1950 (2.7°C cooling), breaking the old record of 2.6°C cooling set in 1998. Table 15 displays temperatures in the various Nino regions as observed in January, April, July and October of this year, respectively. The October – January anomaly is also provided. Note the very rapid cooling that has occurred.

In the Nino 3.4 region, the 3.2°C anomalous cooling from January to October is the third strongest cooling since the Climate Prediction Center's records began in 1950. Only 1998 (3.9°C cooling) and 1983 (3.6°C cooling) had more cooling than was observed in 2010.

Table 15: January anomalies, April anomalies, July anomalies, October anomalies and October-January anomalies in the Nino 1+2, Nino 3, Nino 3.4 and Nino 4 regions.

Region	January Anomaly (ºC)	April Anomaly (ºC)	July Anomaly (ºC)	October Anomaly (ºC)	October – January Anomaly (°C)
Nino 1+2	0.3	0.6	-1.7	-1.9	-2.2
Nino 3	1.0	0.7	-1.0	-1.7	-2.7
Nino 3.4	1.6	0.7	-1.0	-1.6	-3.2
Nino 4	1.4	0.8	-0.5	-1.3	-2.7

One of the primary reasons why we believe that the cooling was as rapid as was observed was due to the persistently strong anomalous trades in the central tropical Pacific during the spring/summer months. These stronger-than-normal trades helped to promote mixing and upwelling and prevented the development of eastward propagating Kelvin waves that tend to warm the eastern and central Pacific. Figure 30 displays the low-level wind anomalies across the tropical Pacific from early April to the middle of October. Easterly anomalies have persisted near the International Date Line for almost the entire six-month period.

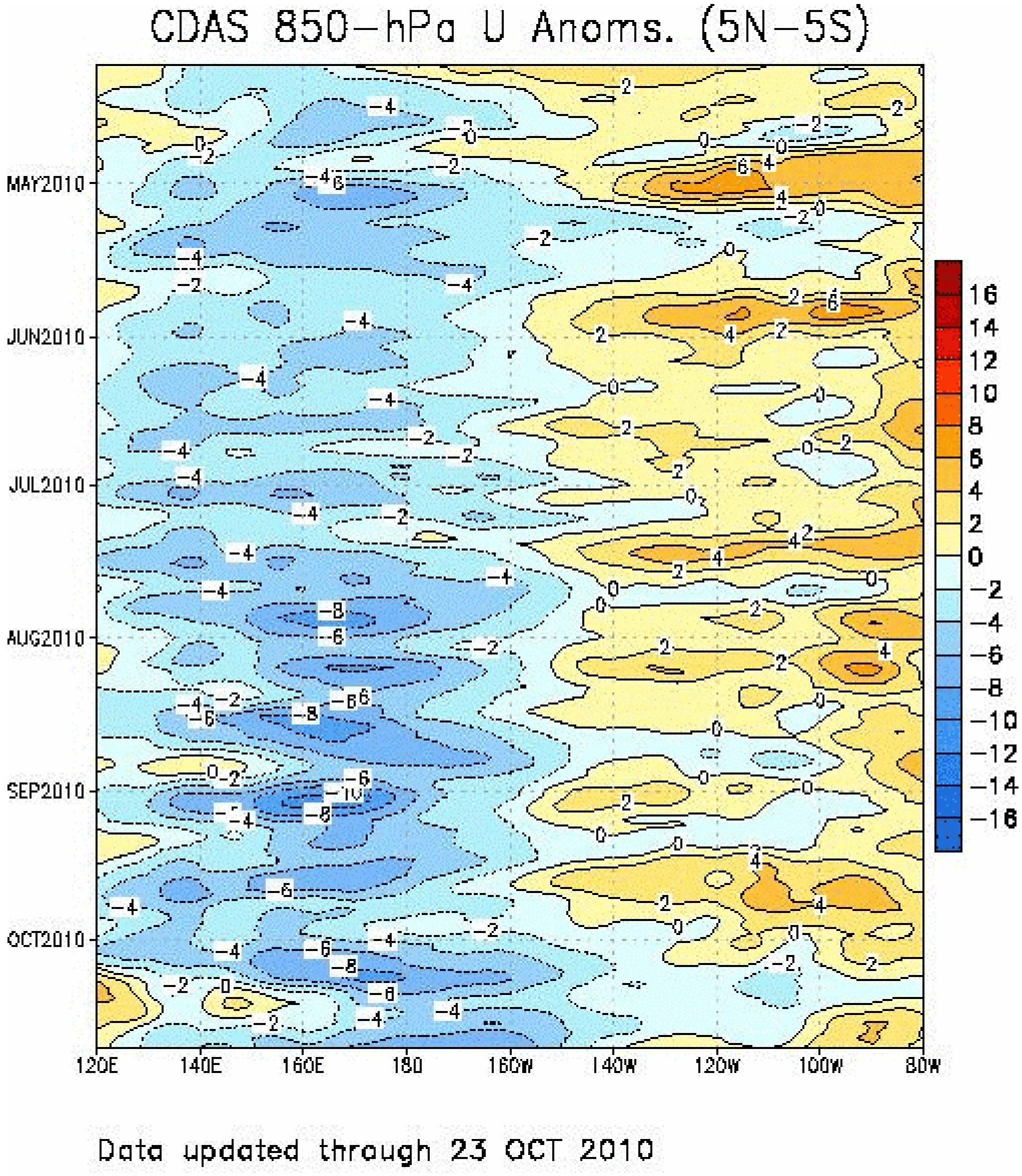


Figure 30: Equatorial wind anomalies in the Indo/Pacific sector. Note the persistence of anomalous easterlies (e.g., stronger trades) near the International Date Line. Figure courtesy of the Climate Prediction Center.

8.2 Intra-Seasonal Variability

Similar to the 2009 hurricane season, the 2010 hurricane season was generally characterized by weak intra-seasonal variability. The only exception in both years was a somewhat heightened MJO during the middle part of October. The MJO was generally of weak amplitude during the peak of the hurricane season in 2010, which allowed for the larger-scale favorable conditions associated with a moderate La Niña and a very warm tropical Atlantic to dominate the signal. In general, both 2007 and 2009 were also characterized by weak intra-seasonal variability as determined by the MJO, while 2008 was associated with considerable intra-seasonal variability (Figure 31).

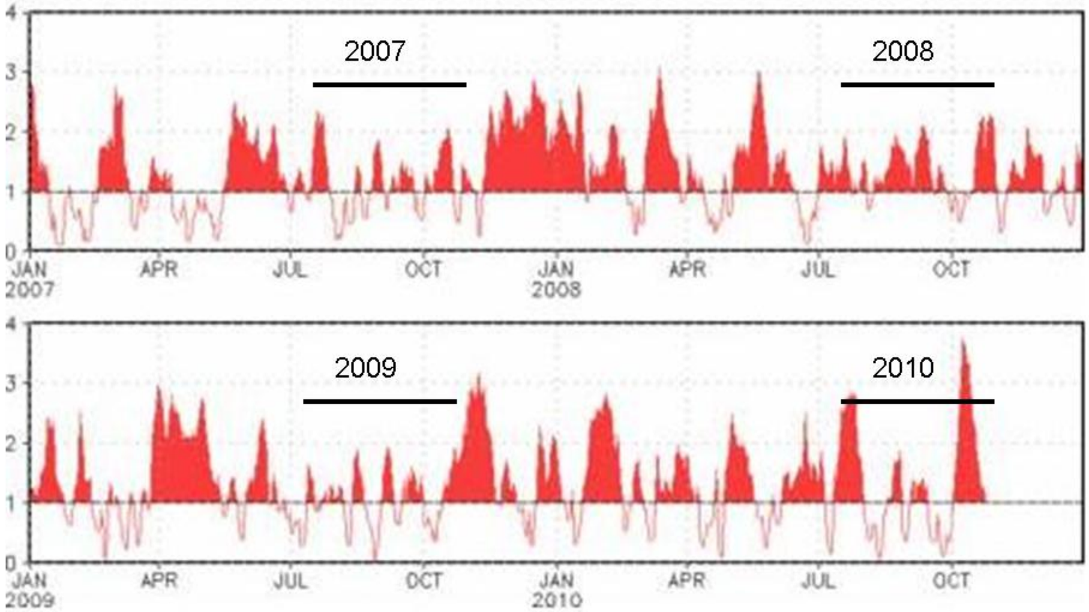


Figure 31: Amplitude of the MJO from January 2007 – October 2010. Lines indicate the climatological peak of the Atlantic basin hurricane season. Note the heightened MJO activity during August-October of 2008 compared with August-October of 2007, 2009 and 2010.

Formation of tropical cyclones in 2010 was fairly well spread out throughout the climatological two-month peak of the hurricane season from approximately August 20 – October 20.

8.3 Tropical Atlantic SST

The tropical Atlantic was characterized by record warmth during the 2010 hurricane season. According to the NCEP/NCAR Reanalysis, SST anomalies averaged over the Main Development Region (MDR) in every month from February-October were at their warmest levels on record, just surpassing levels set in 2005. Significant anomalous warming took place during the winter of 2009/2010, which was likely due to the strongly negative North Atlantic Oscillation and its concomitant reduction in trade wind strength across the MDR (Figure 32). Weaker trades are associated with less mixing and upwelling and therefore contribute to anomalous warming. In addition, enhanced subsidence over the tropical Atlantic occurred during the winter months due to a stronger-than-normal descending branch of the Walker Circulation, typically found with El Niño winters (Figure 33). This enhanced subsidence leads to enhanced incoming solar radiation, which also feeds back to warming the tropical Atlantic. This ENSO-related warming of tropical Atlantic SSTs is termed the atmospheric bridge mechanism (Alexander et al. 2002). Figure 34 displays the August-October-averaged SST anomaly throughout the tropical and subtropical Atlantic.

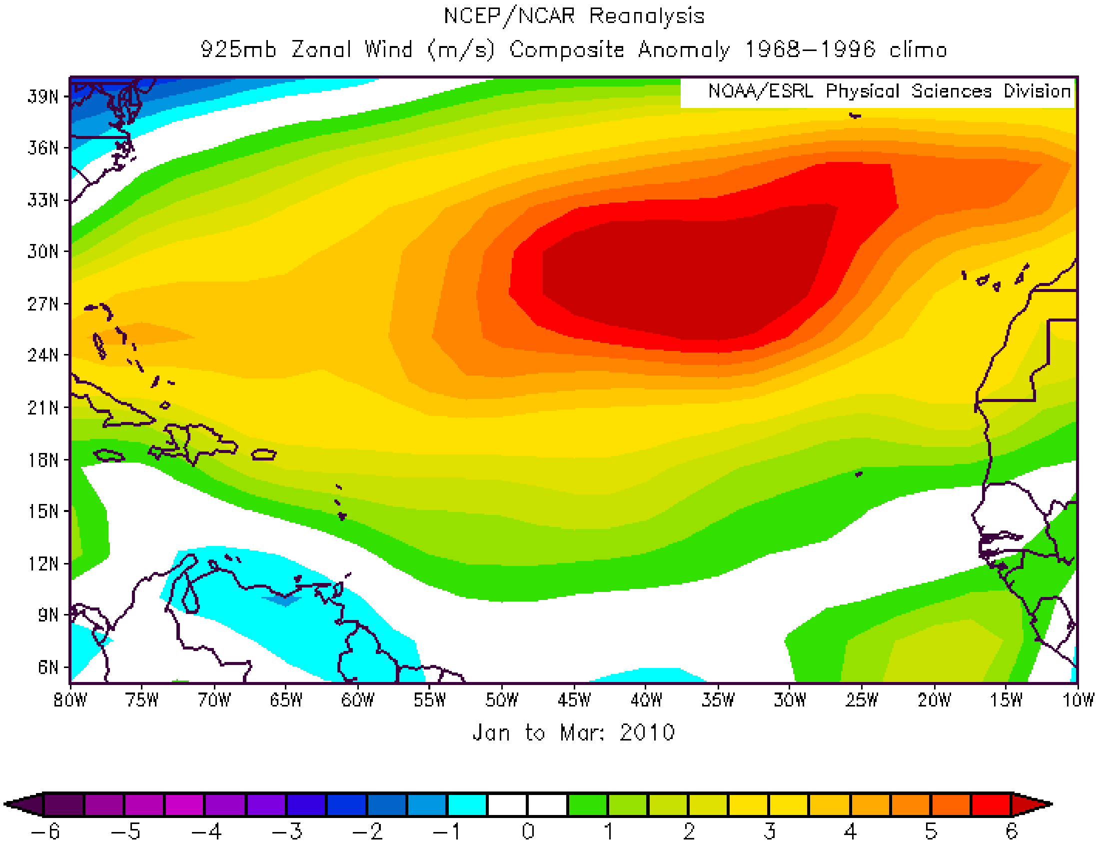


Figure 32: January-March 925 mb zonal wind anomalies across the tropical and subtropical Atlantic. Note the significant westerly anomalies (e.g., weaker trades) throughout most of the Atlantic.

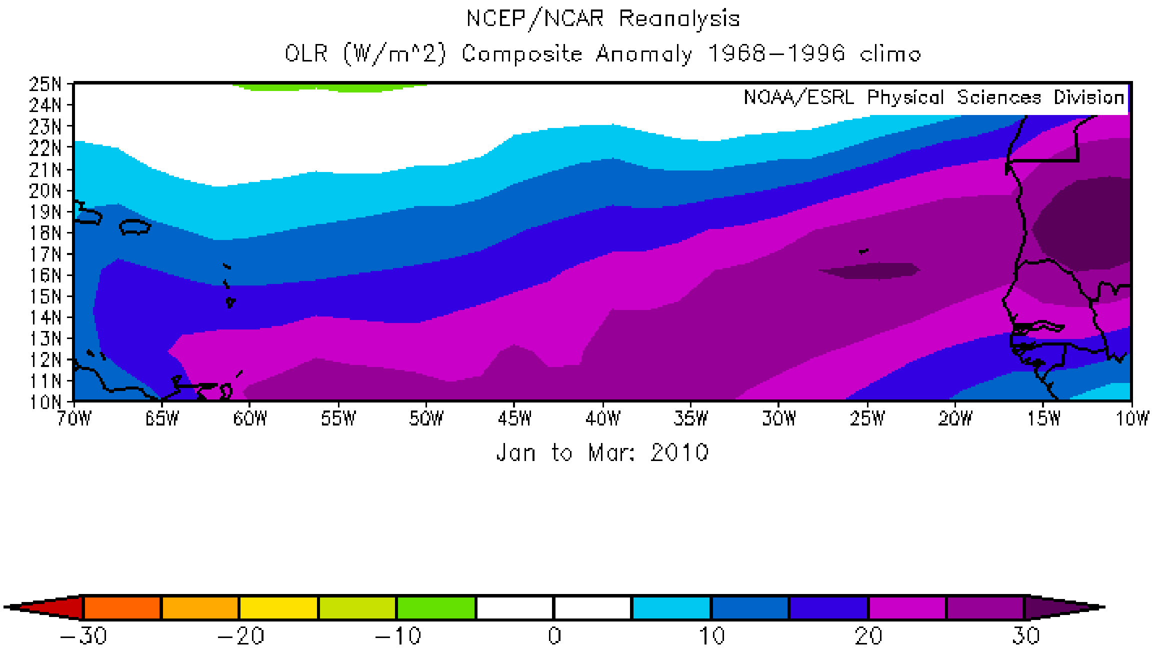


Figure 33: Outgoing longwave radiation (OLR) anomalies from January-March 2010. Note the increased OLR throughout the tropical Atlantic, implying decreased cloudiness, enhanced incoming solar radiation and consequently, a warming of the tropical Atlantic.

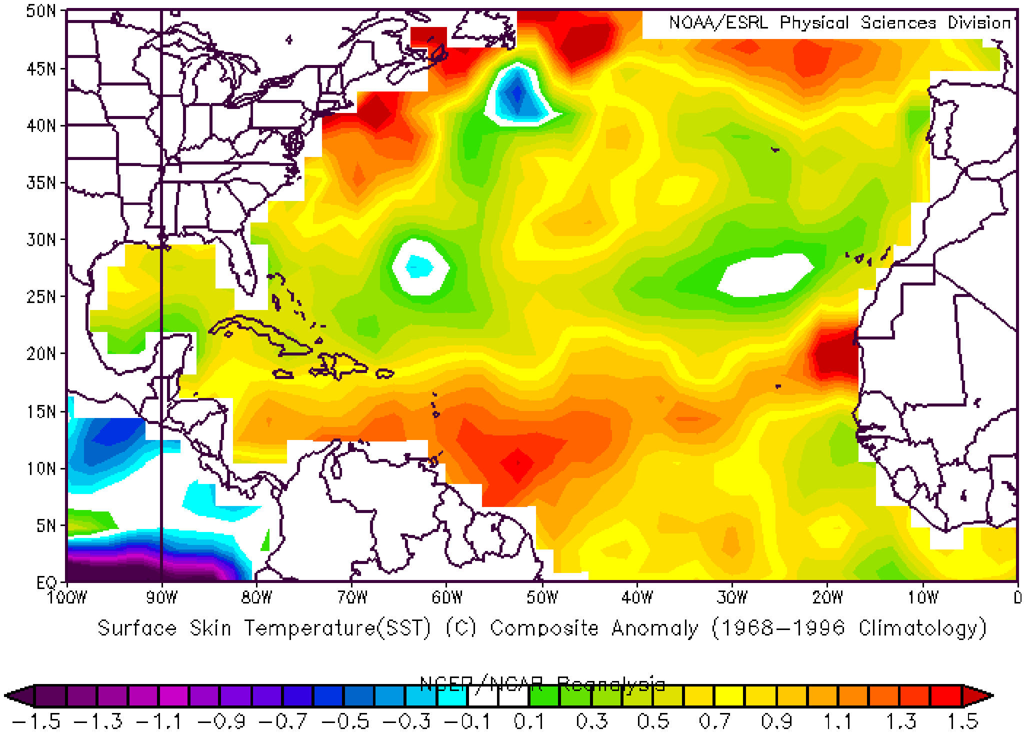


Figure 34: August-October 2010 SST anomaly.

8.4 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 2010 Atlantic hurricane season was characterized by well below-normal sea level pressures. Figure 35 displays August-October 2009 tropical and sub-tropical sea level pressure anomalies in the North Atlantic. Below-average anomalies dominated the basin. Across the Main Development Region (MDR) (10°N-20°N, 20°W-70°W), sea level pressure anomalies were approximately 1.0 mb below the 1995-2009 average. MDR-averaged August-October SLP anomalies in 2010 were some of the lowest on record, trailing only the 1955 season.

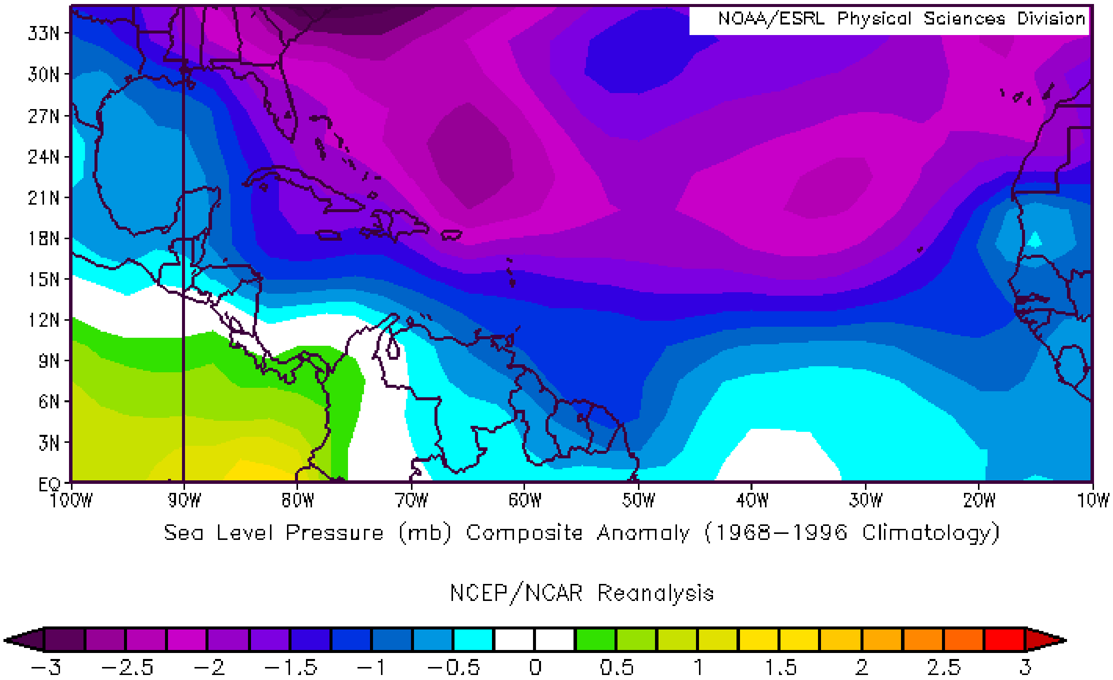
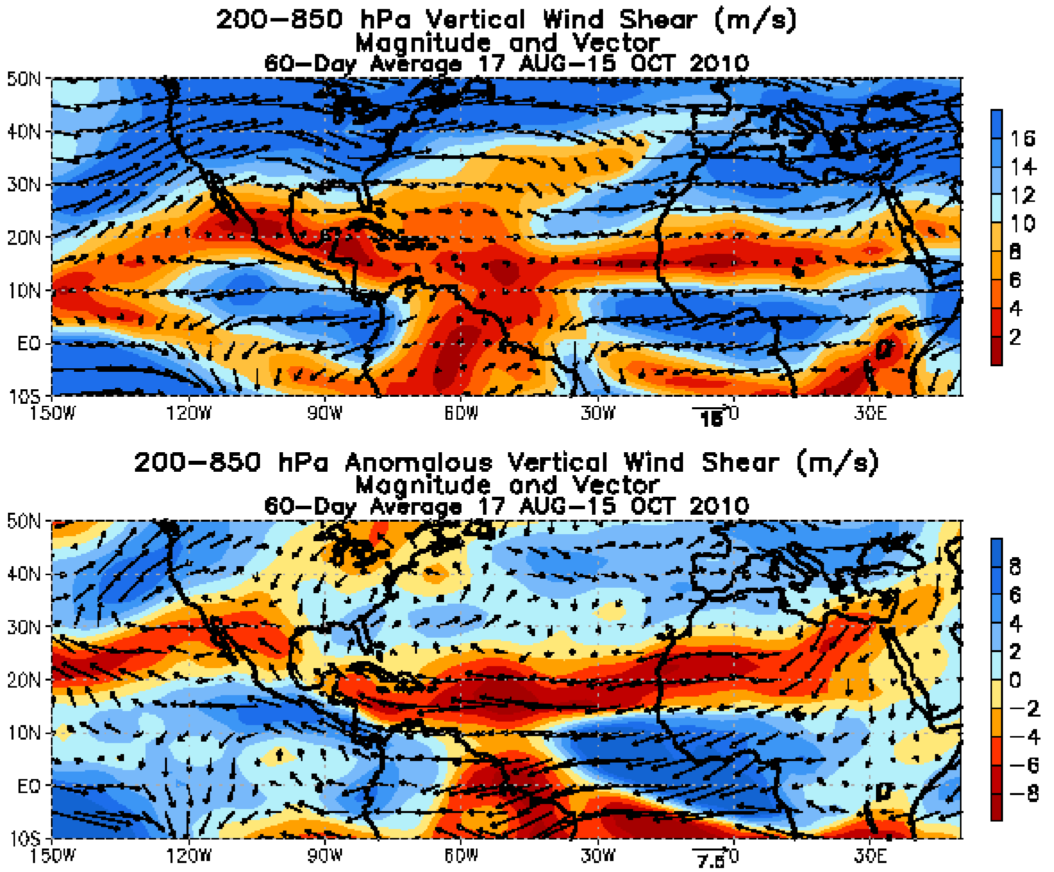


Figure 35: August-October 2010 tropical and sub-tropical North Atlantic sea level pressure anomalies. Sea level pressure anomalies were well below-average across the tropical Atlantic.

8.5 Tropical Atlantic Vertical Wind Shear

Tropical Atlantic vertical wind shear was significantly reduced in 2010 from what was observed in 2009. Over the 60-day period between August 17 and October 15, vertical shear was approximately 5 ms^{-1} below average across both the MDR as well as the Caribbean (Figure 36). Consequently, we saw significant activity occur in the MDR with a near-record number of storms forming in the eastern and central tropical Atlantic.

In addition, eight tropical cyclones had portions of their tracks in the Caribbean. This number of tropical cyclones impacting the Caribbean has only been eclipsed or equaled on three separate occasions since 1944.



CLIMATE PREDICTION CENTER/NCEP

Figure 36: Total and anomalous vertical wind shear as observed across the Atlantic from August 17 – October 15, 2010. Vertical wind shear was significantly below average throughout the tropical Atlantic and Caribbean. The base period was 1971-2000.

8.6 Tropical Atlantic Moisture

One of the factors that likely prevented the 2010 hurricane season from being even more active was the drier-than-normal mid-level air that predominated across the tropical Atlantic. Figure 37 displays anomalous 500-mb relative humidity averaged over the August-October period. The tropical Atlantic was quite dry this year, while the Caribbean tended to be somewhat moister than normal.

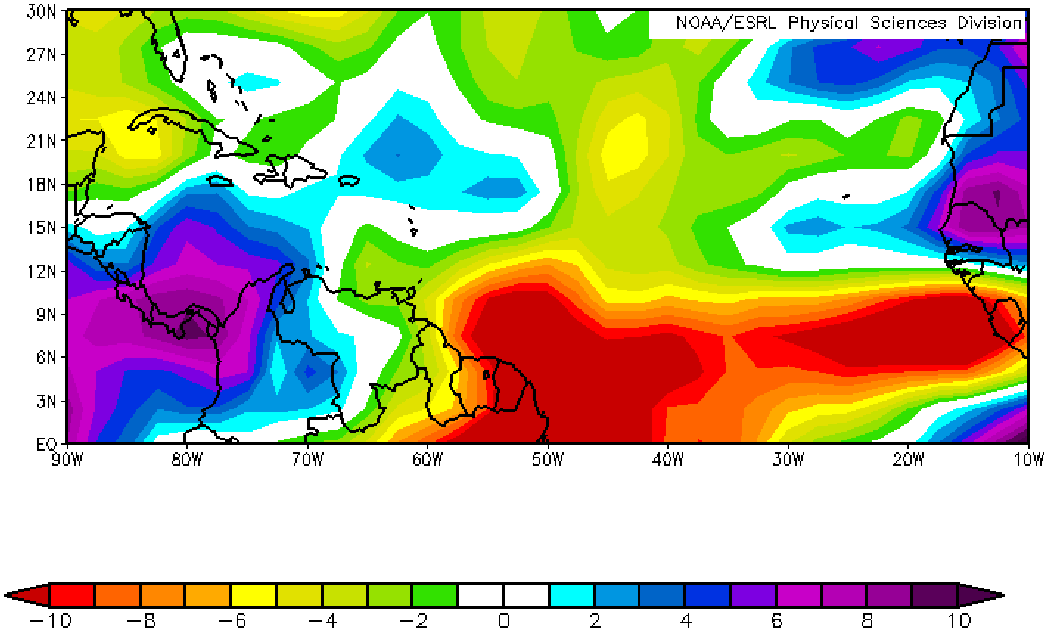


Figure 37: August-October-averaged 500 mb relative humidity anomalies. Note the anomalously dry conditions that prevailed over most of the tropical Atlantic.

Drier middle levels inhibit deep convection, which is evidenced by the warmer-than-normal brightness temperatures over the tropical Atlantic as analyzed by the Cooperative Institute for Research in the Atmosphere (CIRA) (Figure 38). Despite somewhat unfavorable moisture conditions over the tropical Atlantic, the combination of other favorable factors (e.g., reduced shear, increased SSTs, reduced sea level pressures) led to a very active hurricane season.

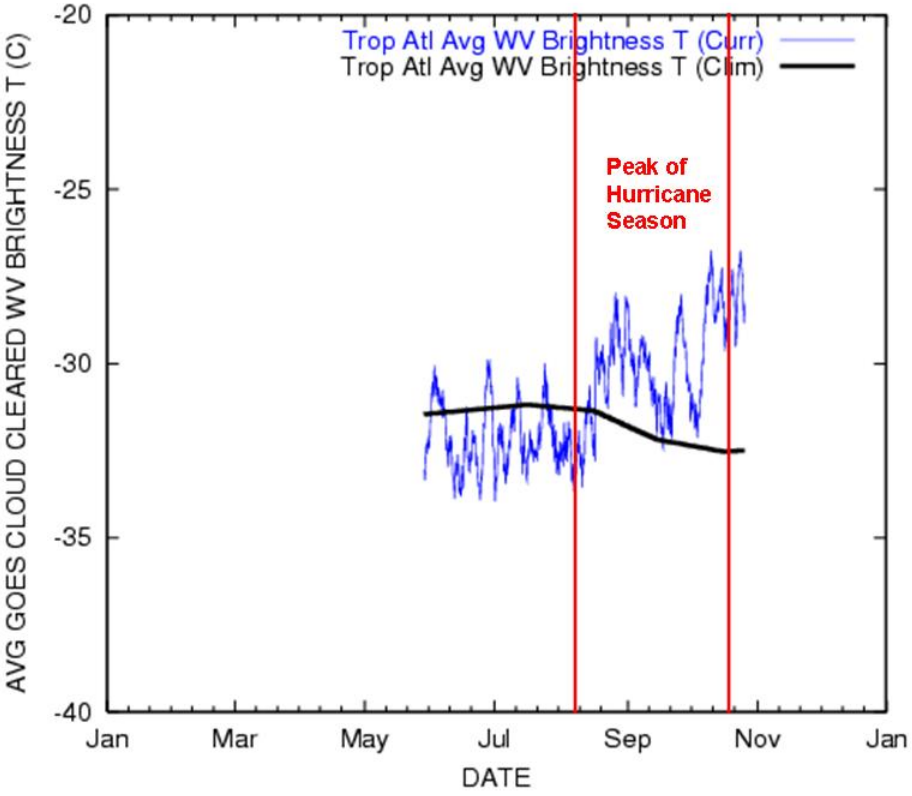


Figure 38: Water vapor brightness temperatures calculated over the tropical Atlantic. In general, brightness temperatures were warmer-than-normal for the peak of the hurricane season, implying dry air and decreased deep convection – an inhibiting factor for tropical cyclones.

8.7 Steering Currents

Several tropical cyclones formed in the eastern tropical Atlantic in 2010 during late August and September and tracked westward. Fortunately, from a United States perspective, these systems recurved to the east of the United States. An analysis of the 700 mb height anomalies during the month of September (Figure 39) provide some evidence for why these storms tracked as observed. Anomalously low heights (e.g., troughing) existed along the East Coast and further east into the tropical Atlantic. This weakness in the subtropical ridge allowed systems moving westward to recurve before impacting the U.S. mainland.

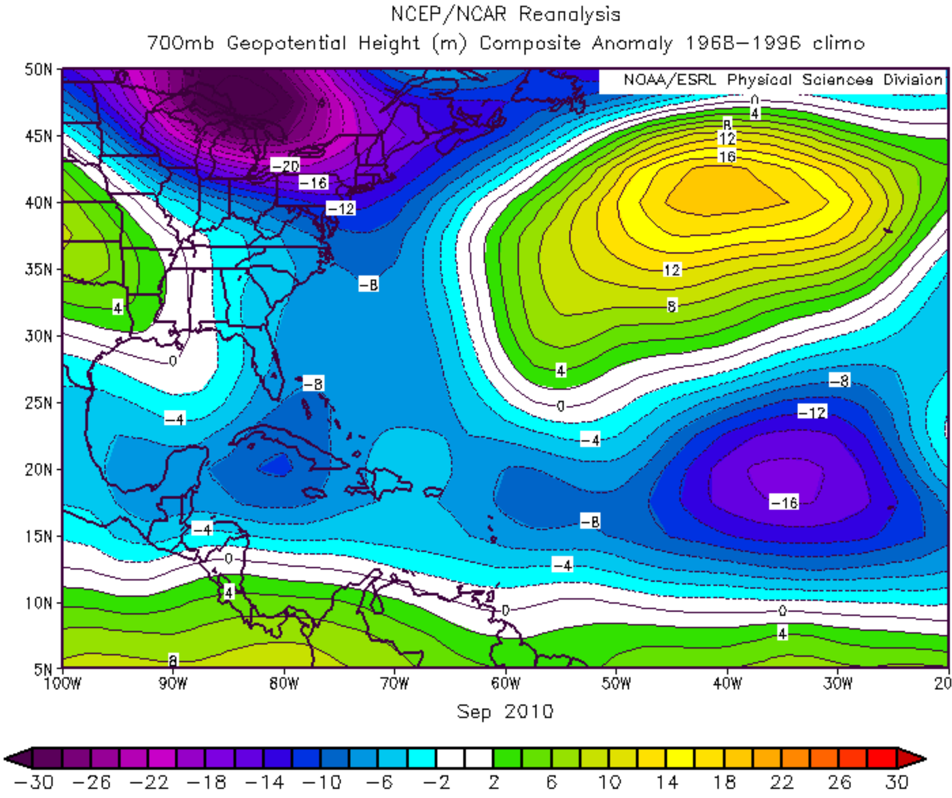


Figure 39: 700 mb height anomalies in the central and western part of the Atlantic in September 2010. Note the lower-than-normal geopotential height anomalies near the United States East Coast.

8.8 Summary

The 2010 Atlantic basin hurricane season was very active. We believe that this very active season was due to a combination of several favorable factors, including record-warm Atlantic basin sea surface temperatures, reduced vertical wind shear (likely driven by the moderate La Niña event in the tropical Pacific) and reduced sea level pressures. We believe that the somewhat unfavorable mid-level conditions (e.g., dry air and subsidence) prevented the season from being even more active than it was. A weakness in the subtropical ridge located near the East Coast helped induce the recurvature of several systems that might otherwise have threatened the U.S. coastline.

9 Has Global Warming Been Responsible for the Recent Large Upswing (Since 1995) in Atlantic Basin Major Hurricanes and U.S. Landfall?

A. BACKGROUND

The U.S. landfall of major hurricanes Dennis, Katrina, Rita and Wilma in 2005 and the four Southeast landfalling hurricanes of 2004 – Charley, Frances, Ivan and Jeanne, raised questions about the possible role that global warming played in those two unusually destructive seasons. In addition, three category 2 hurricanes (Dolly, Gustav and Ike) pummeled the Gulf Coast in 2008 causing considerable devastation. Some researchers have tried to link the rising CO_2 levels with SST increases during the late 20th century and say that this has brought on higher levels of hurricane intensity.

These speculations that hurricane intensity has increased have been given much media attention; however, we believe that they are not valid, given current observational data.

There has, however, been a large increase in Atlantic basin major hurricane activity since 1995 in comparison with the prior 16-year period of 1979-1994 (Figure 40) as well as the prior quarter-century period of 1970-1994. It has been tempting for many who do not have a strong background of hurricane information to jump on this recent increase in major hurricane activity as strong evidence of a human influence on hurricanes. It should be noted, however, that the last 16-year active major hurricane period of 1995-2010 has, however, not been more active than the earlier 16-year period of 1949-1964 when the Atlantic Ocean circulation conditions were similar to what has been observed in the last 16 years. These earlier active conditions occurred even though atmospheric CO_2 amounts were lower during the earlier period.

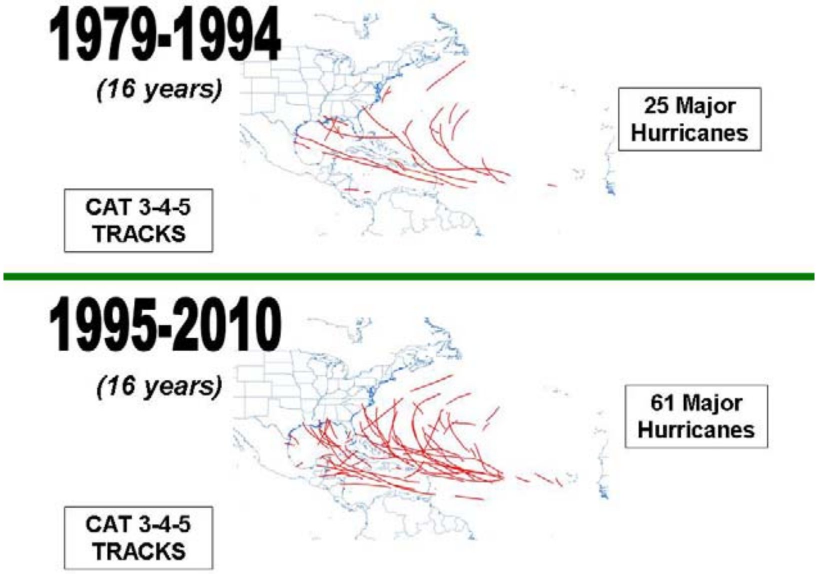


Figure 40: The tracks of major (Category 3-4-5) hurricanes during the 16-year period of 1995-2010 when the Atlantic thermohaline circulation (THC) was strong versus the prior 16-year period of 1979-1994 when the THC was weak. Note that there were approximately 2.5 times as many major hurricanes when the THC was strong as when it was weak.

Table 16 shows how large Atlantic basin hurricane variations are between strong and weak THC periods. Note especially how large the ratio is for major hurricane days (3.7) during strong vs. weak THC periods. Normalized U.S. hurricane damage studies by Pielke and Landsea (1998) show that landfalling major hurricanes account on average for about 80-85 percent of all hurricane-related destruction even though these major hurricanes make up only 20-25 percent of named storms.

Although global surface temperatures increased during the late 20th century, there is no reliable data to indicate increased hurricane frequency or intensity in any of the globe's other tropical cyclone basins since 1979. Global Accumulated Cyclone Energy (ACE) shows significant year-to-year and decadal variability over the past thirty years but no increasing trend (Figure 41). Similarly, Klotzbach (2006) found no significant change in global TC activity during the period from 1986-2005.

Table 16: Comparison of Atlantic annual basin hurricane activity in two 16-year periods when the Atlantic Ocean THC (or AMO) was strong versus an intermediate period (1970-1994) when the THC was weak.

	THC	SST (10-15°N; 70-40°W)	Avg. CO_2 ppm	NS	NSD	H	HD	MH	MHD	ACE	NTC
1949-1964 (16 years)	Strong	27.93	319	10.1	54.1	6.5	29.9	3.8	9.5	121	133
1970-1994 (25 years)	Weak	27.60	345	9.3	41.9	5.0	16.0	1.5	2.5	68	75
1995-2010 (16 years)	Strong	28.02	373	14.6	74.1	7.8	32.0	3.8	9.4	140	153
Annual Ratio Strong/Weak THC		Δ 0.35°C	~ 0	1.3	1.5	1.4	1.9	2.5	3.7	1.9	1.9

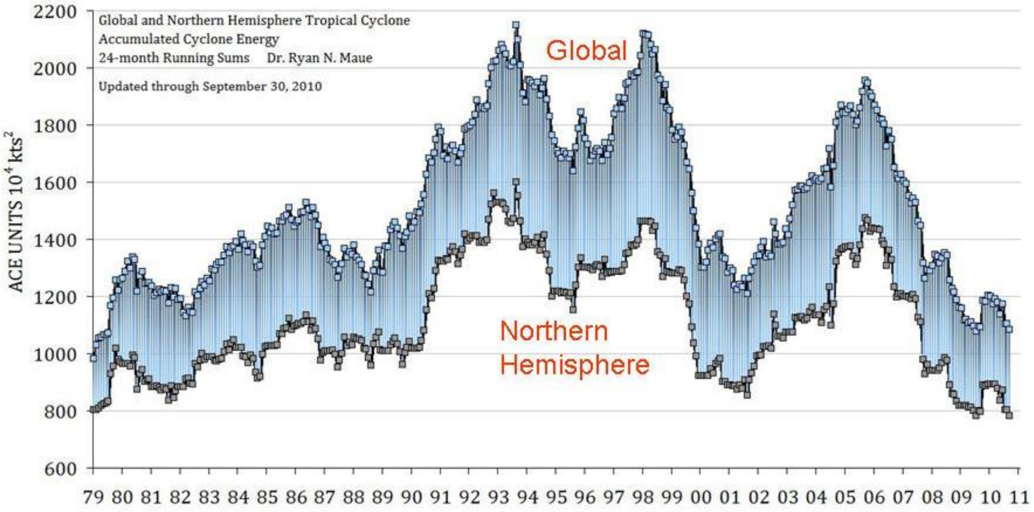


Figure 41: Northern Hemisphere and global Accumulated Cyclone Energy (ACE) over the period from 1979-September 2010. Figure has been adapted from Ryan Maue, Center for Ocean-Atmospheric Prediction Studies, Florida State University.

Causes of the Upswing in Atlantic Major Hurricane Activity since 1995. The Atlantic Ocean has a strong multi-decadal signal in its hurricane activity which is likely due to multi-decadal variations in the strength of the THC (Figure 42). The oceanic and atmospheric response to the THC is often referred to as the Atlantic Multi-decadal Oscillation (AMO). We use the THC and AMO interchangeably throughout the remainder of this discussion. The strength of the THC can never be directly measured, but it can be diagnosed, as we have done, from the magnitude of the sea surface temperature anomaly (SSTA) in the North Atlantic (Figure 43) combined with the sea level pressure anomaly (SLPA) in the Atlantic between the latitude of the equator and 50°N (Klotzbach and Gray 2008).

The THC (or AMO) is strong when there is an above-average poleward advection of warm low-latitude waters to the high latitudes of the North Atlantic. This water can then sink to deep levels when it reaches the far North Atlantic in a process known as deep water formation. The water then moves southward at deep levels in the ocean. The amount of North Atlantic water that sinks is proportional to the water's density which is determined by its salinity content as well as its temperature. Salty water is denser than fresh water especially at water temperatures near freezing. There is a strong association between North Atlantic SSTA and North Atlantic salinity (Figure 44). High salinity implies higher rates of North Atlantic deep water formation (or subsidence) and thus a stronger flow of upper level warm water from lower latitudes as replacement. See the papers by Gray et al. (1999), Goldenberg et al. (2001), and Grossman and Klotzbach (2009) for more discussion.

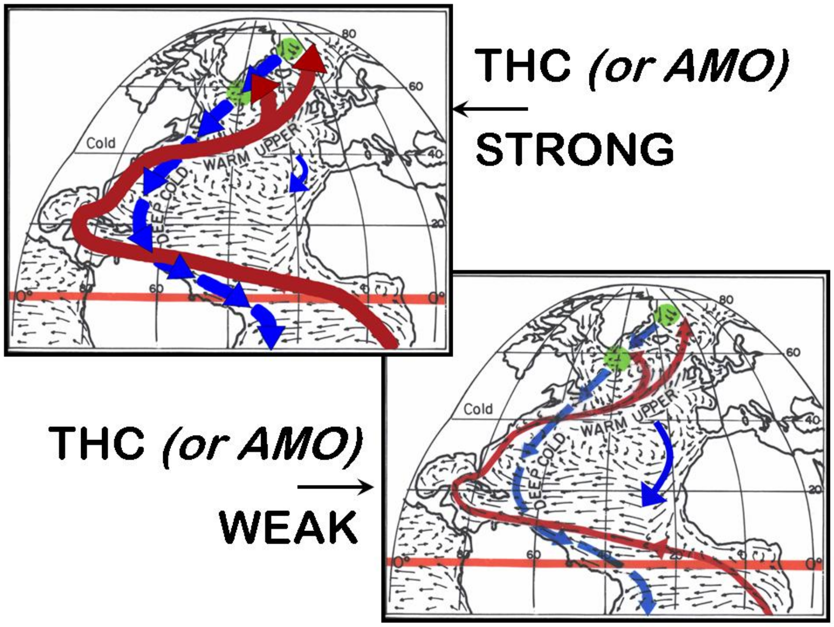


Figure 42: Illustration of strong (top) and weak (bottom) phases of the THC or AMO.

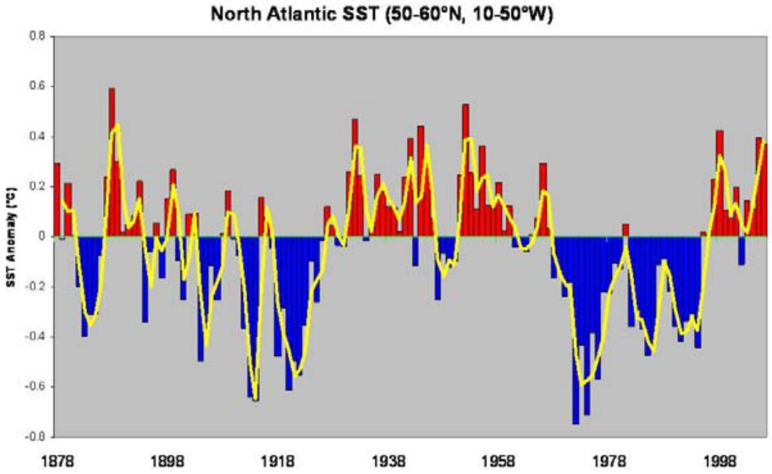


Figure 43: Long-period portrayal (1878-2006) of North Atlantic sea surface temperature anomalies (SSTA). The red (warm) periods are when the THC (or AMO) is stronger than average and the blue periods are when the THC (or AMO) is weaker than average.

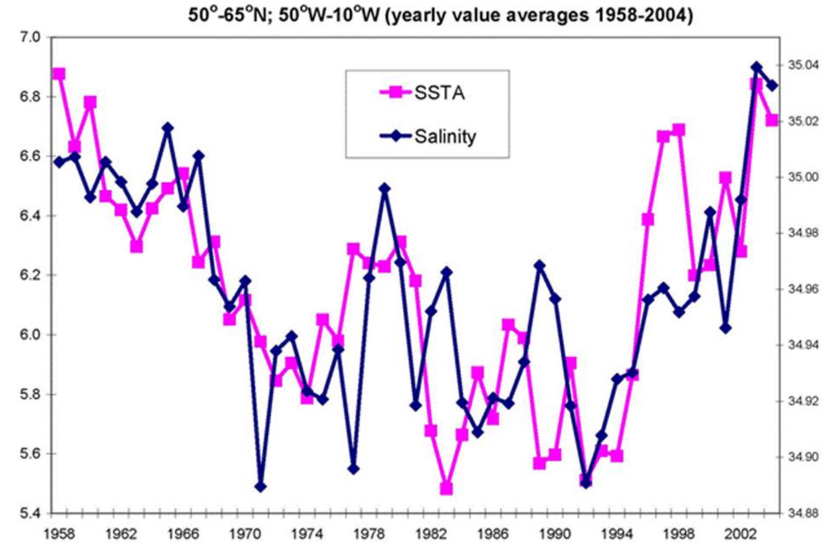


Figure 44: Illustration of the strong association of yearly average North Atlantic SSTA and North Atlantic salinity content between 1958 and 2004.

B. WHY CO_2 INCREASES ARE NOT RESPONSIBLE FOR ATLANTIC SST AND HURRICANE ACTIVITY INCREASES

Theoretical considerations do not support a close relationship between SSTs and hurricane intensity. In a global warming world, the atmosphere's upper air temperatures will warm or cool in unison with longer-period SST changes. Vertical lapse rates will thus not be significantly altered in a somewhat warmer or somewhat cooler tropical oceanic environment. We have no plausible physical reasons for believing that Atlantic hurricane frequency or intensity will significantly change if global or Atlantic Ocean temperatures were to rise by 1-2°C. Without corresponding changes in many other basic features, such as vertical wind shear or mid-level moisture, little or no additional TC activity should occur with SST increases.

Confusing Time Scales of SST Influences. A hurricane passing over a warmer body of water, such as the Gulf Stream, will often undergo some intensification. This is due to the sudden lapse rate increase which the hurricane's inner core experiences when it passes over warmer water. The warmer SSTs cause the hurricane's lower boundary layer temperature and moisture content to rise. While these low level changes are occurring, upper tropospheric conditions are often not altered significantly. These rapidly occurring lower- and upper-level temperature differences cause the inner-core hurricane lapse rates to increase and produce more intense inner-core deep cumulus convection. This typically causes a rapid increase in hurricane intensity. Such observations have led many observers to directly associate SST increases with greater hurricane potential intensity. This is valid reasoning for day-to-day hurricane intensity change associated with hurricanes moving over warmer or colder patches of SST. But such direct reasoning does not hold for conditions occurring in an overall climatologically warmer (or cooler) tropical oceanic environment where broad-scale global and tropical rainfall conditions are not expected to significantly vary. During long-period climate change, temperature and moisture conditions rise at both lower and upper levels. Lapse rates are little affected.

Any warming-induced increase in boundary layer temperature and moisture will be (to prevent significant global rainfall alteration) largely offset by a similar but weaker change through the deep troposphere up to about 10 km height. Upper-tropospheric changes are weaker than boundary layer changes, but they occur through a much deeper layer. These weaker and deeper compensating increases in upper-level temperature and moisture are necessary to balance out the larger increases in temperature and moisture which occur in the boundary layer. Global and tropical rainfall would be altered significantly if broad-scale lapse rates were ever altered to an appreciable degree.

Thus, we cannot automatically assume that with warmer global SSTs that we will necessarily have more intense hurricanes due to lapse-rate alterations. We should not expect that the frequency and/or intensity of major hurricanes will necessarily change as a result of changes in global or individual storm basin SSTs. Historical evidence does not support hurricanes being less intense during the late 19th century and the early part of the 20th century when SSTs were slightly lower.

CO_2 Influence on Hurricane Activity. We have been performing research with the International Satellite Cloud Climatology Project (ISCCP) and the NOAA National Centers for Environmental Prediction (NCEP) Reanalysis data sets. We have used this data to make an annual average of the global tropical (30°N-30°S; 0-360°) energy budget (Figure 45) for the years from 1984-2004. Note that the various surface and top of the atmosphere energy fluxes are very large. For the tropical surface, for instance, there are 637 Wm^{-2} units of downward incoming solar and infrared (IR) energy. This downward energy flux is largely balanced by an upward surface energy flux of 615 Wm^{-2} which is due to upward fluxes from IR radiation, evaporated liquid water, and sensible heat. Similar large energy fluxes are present at the top of the atmosphere and within the troposphere.

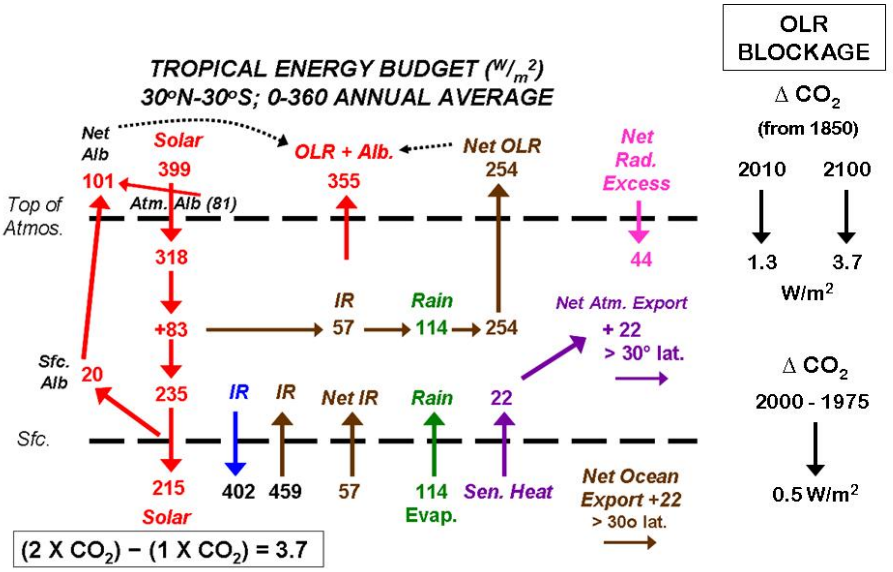


Figure 45: Vertical cross-section of the annual tropical energy budget as determined from a combination of ISCCP and NCEP Reanalysis data over the period from 1984-2004. Abbreviations are **IR** for longwave infrared radiation, **Alb** for albedo and **OLR** for outgoing longwave radiation. The tropics receive an excess of about 44 Wm^{-2} radiation energy which is convected and exported as sensible heat to latitudes poleward of 30°. Estimates are about half (22 Wm^{-2}) of this excess is transported by the atmosphere and the other half is transported by the oceans. Note, on the right, how small an OLR blockage has occurred up to now due to CO$_2$ increases (~ 1.3 Wm^{-2}) and a continued small blockage of 3.7 Wm^{-2} that will occur from a doubling of CO$_2$ by the end of this century.

It has been estimated that a doubling of CO$_2$ (from the pre-industrial period) without any feedback influences would result in a blockage of OLR to space of about 3.7 Wm^{-2}. The currently-measured value of CO$_2$ in the atmosphere is 380 parts per million by volume (ppmv). If we take the background pre-industrial value of CO$_2$ to be 280 ppmv, then by theory we should currently be having (from CO$_2$ increases alone) about (100/280)*3.7 = 1.3 Wm^{-2} less OLR energy flux to space than was occurring in the mid-19th century.

This reduced OLR of 1.3 Wm^{-2} is very small in comparison with most of the other tropical energy budget exchanges. Slight changes in any of these other larger tropical energy budget components could easily negate or reverse this small CO$_2$-induced OLR blockage. For instance, an upper tropospheric warming of about 1°C with no change in moisture would enhance OLR sufficiently that it would balance the reduced OLR influence from a doubling of CO$_2$. Similarly, if there were a reduction of upper level water vapor such that the long wave radiation emission level to space were lowered by about 7 mb (~ 140 m), there would be an enhancement of OLR (with no change of temperature) sufficient to balance the suppression of OLR from a doubling of CO$_2$. The 1.3 Wm^{-2} reduction in OLR we have experienced since the mid-19th century (about one-third of the way to a doubling of CO_2) is very small compared with the overall 399 Wm^{-2} of solar energy impinging on the top of the tropical atmosphere and the mostly compensating 356 Wm^{-2} of OLR and albedo energy going back to space. This 1.3 Wm^{-2} energy gain is much too small to ever allow a determination of its possible influence on TC activity. Any such potential CO_2 influence on TC activity is deeply buried as turbulence within the tropical atmospheres' many other energy components. It is possible that future higher atmospheric CO_2 levels may cause a small influence on global TC activity. But any such potential influence would likely never be able to be detected, given that our current measurement capabilities only allow us to assess TC intensity to within about 5 mph.

C. DISCUSSION

In a global warming or global cooling world, the atmosphere's upper air temperatures will warm or cool in unison with the SSTs. Vertical lapse rates will not be significantly altered. We have no plausible physical reasons for believing that Atlantic hurricane frequency or intensity will change significantly if global ocean temperatures were to continue to rise. For instance, in the quarter-century period from 1945-1969 when the globe was undergoing a weak cooling trend, the Atlantic basin experienced 80 major (Cat 3-4-5) hurricanes and 201 major hurricane days. By contrast, in a similar 25-year period from 1970-1994 when the globe was undergoing a general warming trend, there were only 38 Atlantic major hurricanes (48% as many) and 63 major hurricane days (31% as many) (Figure 46). Atlantic SSTs and hurricane activity do not follow global mean temperature trends.

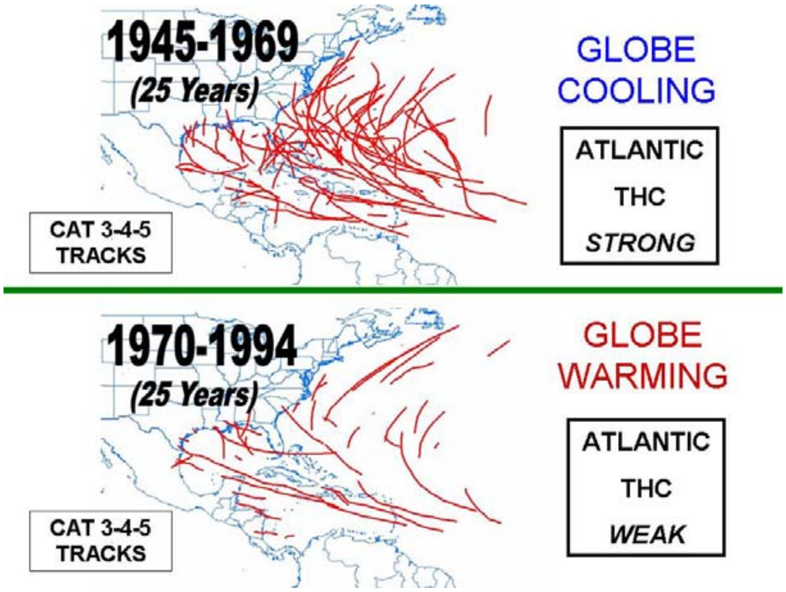


Figure 46: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than in the earlier period. Major Atlantic hurricane activity was only about one-third as frequent during the latter period despite warmer global temperatures.

The most reliable long-period hurricane records we have are the measurements of US landfalling TCs since 1900 (Table 17). Although global mean ocean and Atlantic SSTs have increased by about 0.4°C between two 55-year periods (1901-1955 compared with 1956-2010), the frequency of US landfall numbers actually shows a slight downward trend for the later period. This downward trend is particularly noticeable for the US East Coast and Florida Peninsula where the difference in landfall of major (Category 3-4-5) hurricanes between the 45-year period of 1921-1965 (24 landfall events) and the 45-year period of 1966-2010 (7 landfall events) was especially large (Figure 47). For the entire United States coastline, 39 major hurricanes made landfall during the earlier 45-year period (1921-1965) compared with only 26 major hurricanes for the latter 45-year period (1966-2010). This occurred despite the fact that CO_2 averaged approximately 365 ppm during the latter period compared with 310 ppm during the earlier period.

Table 17: U.S. landfalling tropical cyclones by intensity during two 55-year periods.

YEARS	***Named Storms***	***Hurricanes***	***Major Hurricanes (Cat 3-4-5)***	***Global Temperature Increase***
1901-1955 (55 years)	210	115	44	+0.4°C
1956-2010 (55 years)	180	87	34	

We should not read too much into the four very active hurricane seasons of 2004, 2005, 2008 and 2010. The activity of these years was unusual but well within natural bounds of hurricane variation.

What made the 2004-2005 and 2008 seasons so destructive was not the high frequency of major hurricanes but the high percentage of hurricanes that were steered over the US coastline. The US hurricane landfall events of these years were primarily a result of the favorable upper-air steering currents present during these years.

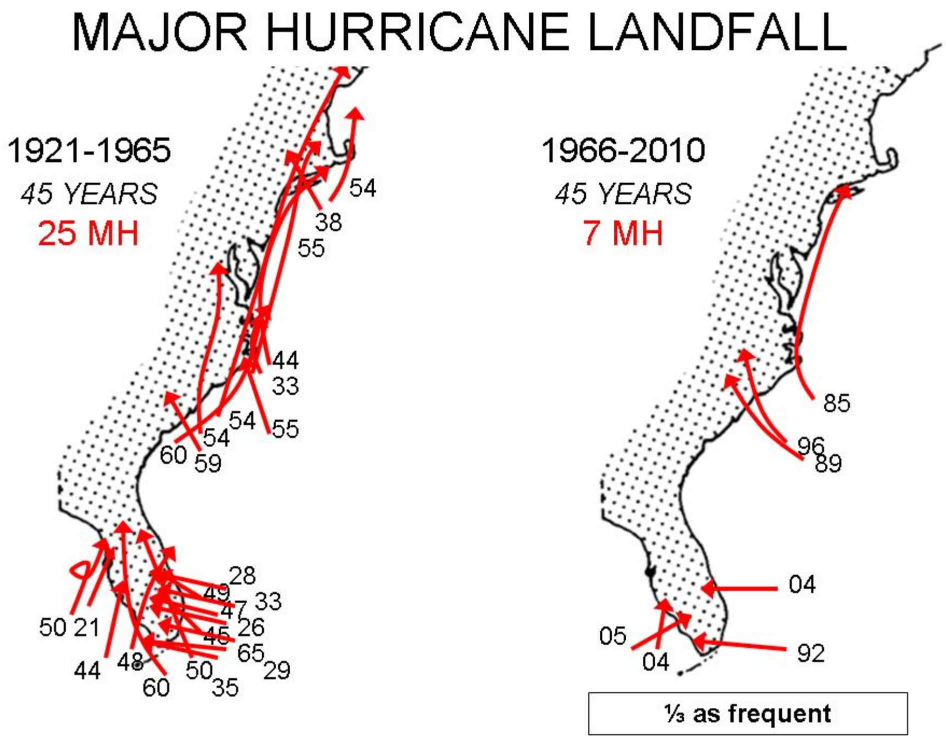


Figure 47: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 45-year period of 1921-1965 versus the most recent 45-year period of 1966-2010.

Although 2005 had a record number of TCs (28 named storms), this should not be taken as an indication of something beyond natural processes. There have been several other years with comparable hurricane activity to 2005. For instance, 1933 had 21 named storms in a year when there was no satellite or aircraft data. Records of 1933 show all 21 named storms had tracks west of 60°W where surface observations were more plentiful. If we eliminate all of the named storms of 2005 whose tracks were entirely east of 60°W and therefore may have been missed given the technology available in 1933, we reduce the 2005 named storm total by seven (to 21) – the same number as was observed to occur in 1933.

Utilizing the National Hurricane Center's best track database of hurricane records back to 1875, six previous seasons had more hurricane days than the 2005 season. These years were 1878, 1893, 1926, 1933, 1950 and 1995. Also, five prior seasons (1893, 1926, 1950, 1961 and 2004) had more major hurricane days. Although the 2005 hurricane season was certainly one of the most active on record, it was not as much of an outlier as many have indicated.

We believe that the Atlantic basin remains in an active hurricane cycle associated with a strong THC. This active cycle is expected to continue for another decade or two at which time we should enter a quieter Atlantic major hurricane period like we experienced during the quarter-century periods of 1970-1994 and 1901-1925. Atlantic hurricanes go through multi-decadal cycles. Cycles in Atlantic major hurricanes have been observationally traced back to the mid-19th century. Changes in the THC (or AMO) have been inferred from Greenland paleo ice-core temperature measurements going back thousand of years. These changes are natural and have nothing to do with human activity.

10 Forecasts of 2011 Hurricane Activity

We will be issuing our first forecast for the 2011 hurricane season on Wednesday, 8 December 2010. This December forecast will include the dates of all of our updated 2011 forecasts. All of these forecasts will be made available online at: http://hurricane.atmos.colostate.edu/Forecasts.

11 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 for this type of forecasting research application from Neil Frank, Robert Sheets, Robert Burpee, Jerry Jarrell, and Max Mayfield, former directors of the National Hurricane Center (NHC) and the current director, Bill Read.

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13 Verification of Previous Forecasts

Table 18: Verification of the authors' early August forecasts of Atlantic named storms and hurricanes between 1984-2010. 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 24 of 27 years for named storms and 21 of 27 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
Average	**11.0**	**10.5**	**6.3**	**6.1**
1984-2010 Correlation		**0.69**		**0.65**

Table 19: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2005-2009. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

2005	3 Dec. 2004	Update 1 April	Update 31 May	Update 5 August	Update 2 Sept.	Update 3 Oct.	Obs.
Hurricanes	6	7	8	10	10	11	14
Named Storms	11	13	15	20	20	20	26
Hurricane Days	25	35	45	55	45	40	48
Named Storm Days	55	65	75	95	95	100	116
Major Hurricanes	3	3	4	6	6	6	7
Major Hurricane Days	6	7	11	18	15	13	16.75
Net Tropical Cyclone Activity	115	135	170	235	220	215	263

2006	6 Dec. 2005	Update 4 April	Update 31 May	Update 3 August	Update 1 Sept.	Update 3 Oct.	Obs.
Hurricanes	9	9	9	7	5	6	5
Named Storms	17	17	17	15	13	11	9
Hurricane Days	45	45	45	35	13	23	20
Named Storm Days	85	85	85	75	50	58	50
Major Hurricanes	5	5	5	3	2	2	2
Major Hurricane Days	13	13	13	8	4	3	3
Net Tropical Cyclone Activity	195	195	195	140	90	95	85

2007	8 Dec. 2006	Update 3 April	Update 31 May	Update 3 Aug	Update 4 Sep	Update 2 Oct	Obs.
Hurricanes	7	9	9	8	7	7	6
Named Storms	14	17	17	15	15	17	15
Hurricane Days	35	40	40	35	35.50	20	11.25
Named Storm Days	70	85	85	75	71.75	53	34.50
Major Hurricanes	3	5	5	4	4	3	2
Major Hurricane Days	8	11	11	10	12.25	8	5.75
Accumulated Cyclone Energy	130	170	170	150	148	100	68
Net Tropical Cyclone Activity	140	185	185	160	162	127	97

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	66